FINAL REPORT

for

DOE Award DE-FG02-04ER41291

from

December 1, 2009 to May 31, 2013

received from

The U.S. Department of Energy

for

The University of Hawaii

Honolulu, Hawaii 96822

RESEARCH IN HIGH ENERGY PHYSICS

Submitted August 30, 2013

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High Energy Physics at the University of Hawaii:

Final Report

Abstract

Here we present a final report for the DOE award for the University of Hawaii High Energy Physics Group (UHHEPG) for the period from December 1, 2009 to May 31, 2013 (including a period of no-cost extension). The high energy physics (HEP) group at the University of Hawaii (UH) has been engaged in experiments at the intensity frontier studying flavor physics (Task A: Belle, Belle-II and Task B: BES) and neutrinos (Task C: SuperK, LBNE, Double Chooz, DarkSide, and neutrino R&D). On the energy frontier, new types of pixel detectors were developed for upgrades of the ATLAS experiment at the LHC (Task D). On the cosmic frontier, there were investigations of ultra high-energy neutrino astrophysics and the highest energy cosmic rays using special radio detection techniques (Task E: AMBER, ANITA R&D) and results of the analysis of ANITA data. In addition, we have developed new types of sophisticated and cutting edge instrumentation based on novel "oscilloscope on a chip" electronics (Task F). Theoretical physics research (Task G) is phenomenologically oriented and has studied experimental consequences of existing and proposed new theories relevant to the energy, cosmic and intensity frontiers. The senior investigators for proposal were T. E. Browder (Task A), F. A. Harris (Task B), P. Gorham (Task E), J. Kumar (Task G), J. Maricic (Task C), J. G. Learned (Task C), S. Pakvasa (Task G), S. Parker (Task D), S. Matsuno (Task C), X. Tata (Task G) and G. S. Varner (Tasks F, A, E).

Introduction

The Hawaii high energy physics group consists of three University-supported theoretical faculty (Kumar, Pakvasa and Tata) and eight University-supported experimental faculty: Browder, Harris, Gorham, Learned, Maricic, Matsuno, Vahsen and Varner.[19] Sven Vahsen originally from LBNL was hired in 2010 as a replacement for Stephen Olsen, who retired in July 2009. Jelena Maricic was hired in 2012 and began as an assistant professor on August 1, 2012. Senior researcher Parker (ATLAS Silicon R+D) was supported by DOE funds along with one associate researcher, one Research Associate, eight graduate students, and eight postdoctoral fellows in training working on various projects. Parker will retire after the conclusion of this grant and his own most recent supplemental award. In addition, there were seven non-compensated affiliate faculty in the physics department associated with the high energy physics group: Tom Domback, Art McDonald (experimental particle physics), Steve Dye (geoneutrinos), Bob Morse and Sam Ting (cosmic rays), Sho Ohnuma (accelerator physics) and Walt Simmons (theory).

We have benefited from our proximity to world-class experimental facilities in Asia, such as the Super-K & KamLAND underground neutrino detectors and the SuperKEKB/BelleII B-factory in Japan, and the BEPC-II/*BES-III* facility in Beijing, China. Our experimental work is collaborative and we have had important impact on these activities: Harris has been co-spokesperson of BES since 1998; Gorham is the innovator and spokesperson of ANITA, which has two data taking runs in Antartica, and has initiated a radio-detection extension of AUGER called AMBER; Browder is spokesperson of the Belle-II experiment and has previously served as co-spokesperson of Belle and chair of the the Belle executive board; Varner is the leader of Belle-II particle identification and a level II manager on Belle II. His "oscilloscope on a chip" ASIC (Application Specific Integrated Circuit) is the foundation of ANITA, Belle II as well as many other neutrino and astroparticle projects. Learned and Matsuno have initiated a number of initiatives for measuring reactor neutrinos and using scintillation light for neutrino detection. Vahsen, who is funded by a separate DOE grant (# 002443-00002) and by Homeland Security, is the initiator of the D^3 dark matter experiment and leader of the BEASTII background commissioning detector for SuperKEKB/Belle II. Maricic is initiator of CeLand (a new experiment to investigate sterile neutrinos), and is a leader on neutrino calibration on double Chooz and calibration for future dark matter and neutrino projects. She received a DOE Early Career Research Program (ECRP) in 2013 and previously received an OJI (Outstanding Junior Investigator) award and an NSF career grant.

The theoretical research has close overlap and synergy with the experimental program and concentrates on phenomenological analyses of quarks, neutrinos, dark matter, tests of the standard model, and search strategies for new physics. Assistant professor Jason Kumar received an NSF early career award for his research on non-standard forms of dark matter. Professor Tata is a world leader in supersymmetry research, maintains the ISAJET simulation and is the author of a graduate level textbook used worldwide on supersymmetry. Professor Pakvasa is one of the world's leading authorities of neutrinos and heavy quarks. In addition to 340 publications, he recently received an Alexander von Humboldt Research Award. He will retire at the conclusion of this grant (Sept 2013). Pakvasa has been replaced by Professor Danny Marfatia.

During the period of this award, four DOE-supported graduate students completed Phd degrees. These are Joseph Bramante in theory and Kurtis Nishimura, Himansu Sahoo and Jamal Rorie on the Belle experimental task.

The HEP group has permanent laboratory facilities in Watanabe Hall, Krauss Hall and the Physical Sciences Building on the UH Manoa Campus. The University of Hawaii applied the off-campus overhead rate (20.6%) to all HEP activities except administration (subject to a 36.7% rate). Postdoctoral fellows in training are free of overhead. However, essential support services such as grant administration, travel administration, compliance, computing (including support, hardware and software) and engineering are expected to be provided by the external DOE umbrella grant. These support services are now distributed appropriately across the tasks in the Hawaii HEP grant, in contrast to previous years.

Ibaraki (50% DOE supported) & Zi (100% DOE) provide computing and networking for all of the DOE HEP projects. They maintain and upgrade the hardware and software for an assortment of computers, workstations and 44-node and 30-node PC farms, which are connected by Ethernet and linked to the mainland via the university's fiber-optic T1 lines. Marc Rosen (partly DOE supported) provides mechanical support for the iTOP and BEAST II tasks on Belle II. A university supported junior electrical engineer, Matt Andrew, provides electronics for the DOE supported Belle II, radio detection and neutrino tasks in addition to his work for other NASA and NSF projects in physics. A large number of undergraduate students from physics and electrical engineering provide low cost technical help for the electronics effort that covers many of the DOE experimental and R&D projects in the IDL electronics lab.

We are the major user of the physics department's machine shop, which has two full-time, university-supported machinists. We also maintain close contact with our department's free electron laser group and with astronomers, astrophysicists and cosmologists at the UH Institute for Astronomy and geophysicists at SOEST.

The Belle and Belle II Experiments

Drs. M. Barrett, T.E. Browder, I. Jaegle, B. Kirby, M.D. Jones,J. Li, R. Mussa, K. Nishimura, H. Sahoo, C.P. Shen, G.S. Varner, B. Macek,L. Ruckman, S.E. Vahsen, J. Yamaoka, Mssrs. M. Andrew, D. Darby, M. Hedges, C. Lim, J. Rorie, M. Rosen, I. Seong, X. Shi, Ms. R. Caplett and G. Jung

(Browder and Varner are the co-principal investigators of this task; Browder, Vahsen and Varner are the UH physics faculty members associated with this task. Vahsen is funded by a separate DOE grant for Belle II commissioning detector work was *not* supported by this grant. Mussa is a faculty member from Torino INFN in Italy who was on sabbatical for one year (2012) at UH.)

University of Hawaii scope on Belle and Belle-II

The University of Hawaii group on Belle and Belle-II is active in physics analysis of the Belle (~ 1 ab^{-1}) dataset and is the lead US institute in the construction of the iTOP detector for high momentum particle identification in Belle-II at SuperKEKB.

The existing experiment and accelerator complex, Belle and KEKB, were shut down in the summer of 2010. Belle was rolled out of the interaction region in December 2010. To exploit fully and mine the giant data samples accumulated by Belle and the wide range of physics and discovery potential that are available, Belle initiated the "intense analysis phase". At Hawaii we remained active in a variety of analyses. Work included a search for a low mass Higgs in $\Upsilon(1S)$ decay and a search for a dark photon as well as measurement of inclusive rare hadronic B decays. Work that remains in progress includes study of the $B \to K\pi\pi^0$ Dalitz plot and measurement of forward-backwards asymmetry in $B \to K^*\ell^-\ell^+$.

The SuperKEKB accelerator and Belle II experiment have been approved and funded. (For Belle II, in contrast to earlier high energy physics projects in Japan, approximately half of the cost will be provided by outside collaboratoring countries. These countries will also build many of the detector subsystems e.g. the iTOP for the US, the pixel detectors from Germany, the endcap PID from Slovenia and the endcap KLM from Russia.)

At KEK construction of the SuperKEKB accelerator and Belle II detector is now underway. The damping ring tunnel has been completed, the new LER ring vacuum chamber is in hand, new magnets for the LER have been installed and the central drift chamber stringing is 2/3 completed. The new machine is designed to integrate 50 ab^{-1} and have a peak luminosity of $8 \times 10^{35}/\mathrm{cm}^2/\mathrm{sec}$. So far, there have been fifteen open general meetings of the very international Belle II experimental collaboration. The overall schedule is very tight with first beam in the first quarter of 2015, detector construction completed in 2015 and physics running in 2016.

Since the PS (proton synchotron) and Fuji test beamlines at KEK in Japan are no longer operational and JPARC has no test beam facility, we have conducted beam tests at CERN and Fermilab. We plan to establish a cosmic ray test facility and receiving area for quartz bars at KEK in Fuji Hall in the summer of 2013. A cosmic ray commissioning campaign was carried out with a version of the readout ASIC (Application Specific Integrated Circuit) used in the iTOP i.e. the so-called IRS3B. A beam test to verify the system integration and preproduction electronics prototypes took place at the LEPS experimental region at the SR light source in Hyogo perfecture in Japan in 2013. More beam tests at SLAC or other facilities are expected at a later date.

To participate at an adequate level in the final intense phase of analysis and Belle II construction required frequent travel to KEK by Browder in his role as executive board chair and US Belle II spokesperson and by Varner for Belle-II hardware development and construction as well as by the Hawaii/Belle/Belle-II faculty, postdocs and students for beam tests and prototype development.

In the US, testing campaigns for Belle II detector prototypes at test beams and with cosmic rays were initially supported in 2011-2012 through a USA (University Service Account) at PNNL. This arrangement was later modified to reduce overhead.

In collaboration with the other US Belle-II groups and PNNL, we have prepared a proposal and a detailed WBS (Work Breakdown Structure) for the construction of the Belle-II particle identification detector, upgrade of the muon system and a background commissioning detector. This includes acquiring the quartz detectors and construction of the readout electronics. Nagoya and KEK are responsible for the photodetectors. Hawaii is responsible for the iTOP and KLM readout electronics, iTOP software and detector testing as well as the background commissioning detector. Cincinnati is responsible for quartz optics and specifications. PNNL does Belle II project management. The US Belle II project has passed the CD-0, CD-1 milestones during the period of this award and will undergo a CD-2/3 review in April 2014.

UH-Belle Personnel

Browder was co-spokesperson for Belle (serving the maximum of three terms or six years allowed by the Belle constitution). His final term ended in April 2012. He also served for several years as chair of the Belle executive board (EB), US spokesperson for Belle II and the US university representative on the EB for the Belle-II collabration. In July 2013, he was elected as spokesperson of the Belle II collaboration.

Varner is the leader of the Belle barrel particle identification system and high speed electronics. He is also the Hawaii representative on both the Belle and Belle II institutional boards. Varner originally initiated and made a detailed proposal for a new barrel region particle identification detector for Belle II (the i-TOP, which is an acronoym for imaging TOP). Varner is now the level II manager of the readout electronics for the iTOP and KLM upgrade in the US Belle II proposal. He was a high profile leader in the Belle II proposal and in the CD approval process for US Belle II. The "oscilloscope on a chip" electronics that Varner and his team have developed for the readout of the TOP/iTOP particle identification detector and the readout of other detector subsystems such as the KLM) play a critical role in Belle II. This has been noted by various external review committees in 2012 including the BPAC reviews at KEK, the director's review at PNNL, and the CDR (Conceptual Design Report) review at KEK, who have highlighted the risks associated with the heavy responsibilities of the University of Hawaii in the US Belle II effort.

Sven Vahsen from LBNL was hired as an assistant professor to replace Olsen who retired and moved to a faculty position at Seoul National University in Korea. Vahsen moved to Hawaii in July 2010. He and his Belle group (postdocs Jaegle, Yamaoka and graduate student Seong as well as undergraduates) are currently funded by an NSF/Homeland security grant for TPC detector development, the residual of his university start up package and by a single investigator DOE grant awarded during the 2011 comparative review cycle for his work on the Belle II background commissioning detector. Vahsen is the level II manager in the US for the Belle-II background commissioning detector (BEAST II). Members of the Vahsen group are very active in Belle data analysis using the 1 ab^{-1} dataset. We note that the original BEAST experiment at KEKB was built and led by the Hawaii group (Browder et al) in 1998-1999.

Roberto Mussa, who is associate professor at the University of Torino, had a productive sabbatical year at Hawaii during the academic year 2011-2012. He is convenor of the Belle $\Upsilon(nS)$ (where $n = 1, 2, 3$) physics group and has stimulated activity in this area while at Hawaii. Peters is an associate dean of Natural Sciences in the university but continued his Belle paper refereeing work during the period of the award. He did not receive any DOE support from this award.

In Fall 2010 we hired Matthew Barrett, originally from UK groups at CMS and BaBar, as a postdoctoral scholar. Barrett is now a leader of the iTOP software effort and convenes the software meetings. Barrett replaces postdoctoral scholar Li Jin, who took a research professor position in the Brain Korea (BK) program at Seoul National University in July 2010.

Dr Michael Jones is a leader of software for the Belle II beam tests of detector prototypes. His experience with the Belle time-of-flight system and DAQ allowed us to maintain 100 picosecond resolution in the time of flight system under full battle conditions for a decade. The demands for iTOP time calibration in Belle II are equally challenging. Some details of his work are described below. Both Jones and Barrett work closely with Browder and Varner.

Both Himansu Sahoo and Kurtis Nishimura completed their doctoral dissertations on Belle data analyses with Browder. Nishimura has been a postdoc supported by the LAPPD project and with Varner plays a major role in the commissioning and development of Belle electronics for the iTOP detector. Nishimura is currently a staff electrical engineer at SLAC National Accelerator laboratory and is interviewing for faculty jobs. Sahoo has left Hawaii for a postdoctoral position on NOVA at Argonne National Lab.

Postdoctoral scholar Chengping Shen, who was employed by the BES experiment but continued intense Belle analysis (publishing a series of Physical Review papers at Hawaii), took an assistant professor position at Nagoya University for several years. He now has a permanent faculty position and is Belle II group leader at Beihang University in China.

Mechanical engineering provided by Marc Rosen plays an important role in both the design and construction of the particle identification system as well as for integration of Belle-II detector subsystems; in addition to designing the iTOP/TOP structure, Rosen has built components of the iTOP beam test at Fermilab and is designing the structure for iTOP cosmic rays test at Fuji Hall at KEK. He is currently grappling with thermal issues in the iTOP readout module. Rosen also is designing the BEASTII background commissioning experiment, which is part of Vahsen's grant.

Matt Andrew is a university supported junior electrical engineer, who has played a critical role in the design and fabrication of the iTOP readout module in addition to providing support for DOE, NASA, NSF and homeland security projects in the department of Physics. In the past year, he was indispenable in the succesful summer 2013 LEPS beam test at Harima, Japan, which demonstrated 100 ps resolution for the iTOP particle identification detector.

Rorie is a graduate student who has completed a Belle thesis on a search for low mass charged Higgs in radiative $\Upsilon(1S)$ decay via $A_0 \to \tau^+\tau^-$. He is now searching for a postdoctoral position.

Hedges is a new graduate student working with Browder and Vahsen on background issues for Belle II. Browder has taken on a new graduate student, Shawn Dubey, who has passed the qualifier exam for the next DOE award period.

Darby, Lim, Shi, Caplett and Jung are undergraduates who do part-time technical work and electronics assembly of Belle II readout electronics modules under the supervision of Varner and Andrew.

Current Status

In June 2009, KEKB broke the world luminosity record and achieved a luminosity of 2.11×10^{34} /cm^2/sec using its special superconducting crab cavities. This record is more than a factor of two higher than the original design luminosity of KEKB. In addition to the instantaneous luminosity record, KEKB holds the world integrated luminosity record. The KEKB collider is the first accelerator to provide more than one inverse atto-barn of data. The experience developed in this effort as well as the KEKB hardware and tunnel provides the foundation for the SuperKEKB project, which plans to integrate 50 ab^{-1}.

Belle integrated 1025 fb^{-1} before completing operation in July 2010. Most of the data were recorded on the $\Upsilon(4S)$ resonance and used to study the physics of B mesons. However, Belle also took special runs at other center of mass energies and accumulated three unique data samples at the 5S, 2S and 1S resonances. About 121 fb^{-1} of data was recorded on the $\Upsilon(5S)$ resonance in order to study B_s mesons and measure modes that are not accessible at hadron colliders. In 2010, the collaboration decided to initiate the "intense analysis phase", a period during which all of the final Belle datasets are extensively analysed and mined for physics results. The intense analysis phase continues in 2013 with the Belle experiment expected to publish at a rate of $\sim$ 30 journal papers a year for the next few years. Many of the results obtained during this intense analysis phase are included in the upcoming joint Belle-BaBar Physics of the B Factories book (edited by A. Bevan, B. Golob, S. Prell and B. Yabsley).

The final Belle data sample has been reprocessed with much improved tracking software. After completion of the data reprocessing, Belle entered the "Intense Analysis Phase". The final and world's most precise measurement of $\sin(2\phi_1)$ (a.k.a. $\sin(2\beta)$) has been completed. In addition, Belle published the first model independent measurement of the CKM angle ϕ_3 (a.k.a. γ) and the world's first evidence for the highly suppressed Atwood-Dunietz-Soni mode, $B^\pm \to DK^\pm, D \to K^+\pi^-$. In 2013, Belle completed final measurements of CPV in $B \to \pi^+\pi^-$ and a study of $B \to \rho^0\rho^0$. Other Belle physics highlights include a series of dramatic surprises from measurements using Belle's unique $\Upsilon(5S)$ data sample. This includes results on new B_s CP eigenstate decay modes. Belle reported observation of $B_s \to J/\psi f_0(980)$, the first evidence for $B_s \to J/\psi f_0(1370)$ and discoveries of the h_b, $\eta_b(2S)$ and charged bottomonium-like states. In 2013, Belle and BESIII both reported the existence of a new charged charmonium-like state. This cannot be a simple meson but must contain at least 4-quarks.

Using its full reprocessed dataset with 772×10^6 $B\bar{B}$ pairs, Belle increased the statistics of its sample of eigenstate decay modes such as $B \to J/\psi K_S$ by over 50% since its last published measurement with a sample of 535×10^6 $B\bar{B}$ pairs.

The resolution function and systematic error has also been improved. Former Hawaii postdoctoral fellow Himansu Sahoo provided the sample of $B \to \psi(2S)K_S$ for this result. The final measurement is

$$sin(2\phi_1) = 0.668 \pm 0.023 \pm 0.013.$$

The time dependent CP asymmetry is shown in Fig. 1.

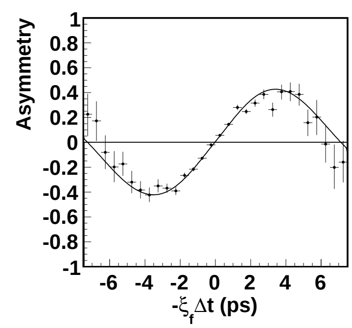

FIG. 1: The time dependent CP asymmetry for all CP eigenstates used in Belle's final measurement of $\sin(2\phi_1)$

Although hadron colliders produce large quantities of B_s mesons, the topics described above require good detection of photons and π^0 mesons and hence cannot be accessed easily at hadron machines. Final results on the CP eigenstate $B_s \to J/\psi\eta'$ were published in 2011. The first signals for $B_s \to J/\psi f_0(980)$ and $B_s \to J/\psi f_0(1370)$, CP eigenstates that do not require angular analysis, were reported. These measurements (work by former Hawaii postdoc Li Jin and Browder) are of great interest to hadron colliders. The Belle PRL was submitted 10 days after the LHCb paper on $B_s \to J/\psi f_0(980)$ and was published as J. Li et al. (Belle collaboration), Phys. Rev. Lett. 106, 121802 (2011).

The resonances below $B\bar{B}$ pair threshold have also been explored. A special 3 fb^{-1} run with a modified trigger configuration was also taken on the $\Upsilon(3S)$ in 2006 to search for dark matter from the $\Upsilon(1S)$. The experimental signature was $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ with the $\Upsilon(1S)$ decaying to invisible particles. In the last two weeks of June 2008, a special 5 fb^{-1} run was taken on the $\Upsilon(1S)$ resonance. This run was difficult for KEKB because of the large change in energy from nominal operation. This run provided the world's largest data sample on the $\Upsilon(1S)$ (~ 5 times larger than the CLEO dataset and at an energy below the range where PEP-II could operate). At the end of 2008, a sample of 7 fb^{-1} was taken on the $\Upsilon(2S)$ resonance. A larger sample was recorded in the fall of 2009. Belle now has a total of 24 fb^{-1} on the $\Upsilon(2S)$ resonance. The Belle 2S sample is the largest sample on this resonance (approximately 50% larger than the corresponding BaBar sample). The unique 1S and 2S data samples were used to study strong interaction physics (visiting professor Mussa) and to search for a non-SM light Higgs (the thesis of Jamal Rorie and Varner).

Physics Publications

Publications during the award are listed in the Belle bibliography. Browder founded the Belle publication council (PC). Browder as spokesperson of Belle for six years was responsible for the final rewriting of all Belle papers (the current total is 398). He served as chair of the executive board, member of publication council and continues to be responsible for assignment of internal referees for all Belle publications.

A subset of recent publications and results are reviewed below. measurement of inclusive rare hadronic B decays (Nishimura, Browder) was completed and published as a PRL. A search for a low mass Higgs in $\Upsilon(1S)$ decay (Rorie, Varner) has been completed. Igal Jaegle's search for a dark sector photon is nearly finished. A study of the $B \to K\pi\pi^0$ Dalitz plot (Barrett, Browder), and measurement of forward-backwards asymmetry in $B \to K^*\ell^-\ell^+$ (Yamaoka) is in progress.

Time-Dependent CP-Violating Asymmetries

Himansu Sahoo and Browder analyzed the time-dependent CP asymmetry in $B \to \psi^{'} K_S$. Using the Belle data sample of 657×10^6 $B\bar{B}$ pairs, they obtained the world's most precise measurement of the effective value of $\sin 2\phi_1$ (a.k.a $\sin(2\beta)$) in this mode, $\sin(2\phi_1) = 0.72 \pm 0.09 \pm 0.03$. The result was published in Phys. Rev. D Rapid Communications. Sahoo also analysed time-dependent asymmetries in $B \to \psi(2S)K_S$ for the final measurements with the full Belle data sample. The results were published in Phys Rev. Lett.

Former postdoc Jin Li and Browder examined the decay mode $B \to K_S\pi^+\pi^-\gamma$ to determine whether it can be used for time-dependent CP violation analysis. Clear signals are visible in the beam-constrained mass distribution. The $B \to K_S\rho^0\gamma$ component may be used to detect the presence of right-handed currents due to new physics. At present the only mode that has been used to search for this type of new physics is $B \to K^{*0}\gamma$. This mode must be reconstructed as $K_S\pi^0\gamma$ and the K_S vertex must be measured inside the silicon vertex detector system. In contrast, the mode used by Li has a prompt two charged pion vertex that can be detected efficiently.

To use this mode for CP violation, the fraction of $K_S\rho\gamma$ in the $B \to K_S\pi^+\pi^-\gamma$ final state must be known. The flavor specific state $B \to K^{*+}\pi^-\gamma$ will dilute any potential CP asymmetry. The final state in the ρ mass region is dominated by $B \to K_S\rho^0\gamma$. Li finds that the time-dependent CP violating parameter $S_{K_S\rho\gamma} = 0.11 \pm 0.33(stat)^{+0.05}_{-0.09}(syst)$, consistent with no right-handed weak currents.

A second class of modes can also be used to search for right-handed weak currents without K_S vertexing. The most promising example is $B \to \phi K_S\gamma$ in which the time dependent CP asymmetry is measured from the charged kaons in the $\phi \to K^+K^-$ decay. Results for $B \to \phi K_S\gamma$ and the control sample $B \to \phi K^+\gamma$ were shown by Sahoo and Browder[1]. The ΔE and M_{bc} distributions for these rare modes using 657 million $B\bar{B}$ pairs are shown in Fig. 2. The time distribution for the $B^\pm \to \phi K^0\gamma$ data control sample has been fitted and CP violation parameters have been determined. The results show that this mode can indeed be used at Super B factories and LHCb for the study of right-handed currents from NP. The measurements of $B^\pm \to \phi K\gamma$ final states are described in a Belle paper with Sahoo and Browder as first authors published in Phys. Rev. D rapid communications.

Inclusive Analysis of Rare B Decays

Kurtis Nishimura and Browder analyzed the inclusive decay $B \to \eta X_s$. This decay has never previously been observed and would complement the results on the anomalous inclusive process $B \to \eta^{'} X_s$ by former student Kirika Uchida (previously at Bonn on ATLAS and now at Imperial College on CMS) as well as measurements of $B \to \eta^{'} X_s$ by BaBar and CLEO. Comparison of the rates and X_s mass distributions would help determine whether the $\eta^{'}$ anomaly (a special two-gluon coupling of the $\eta^{'}$) or

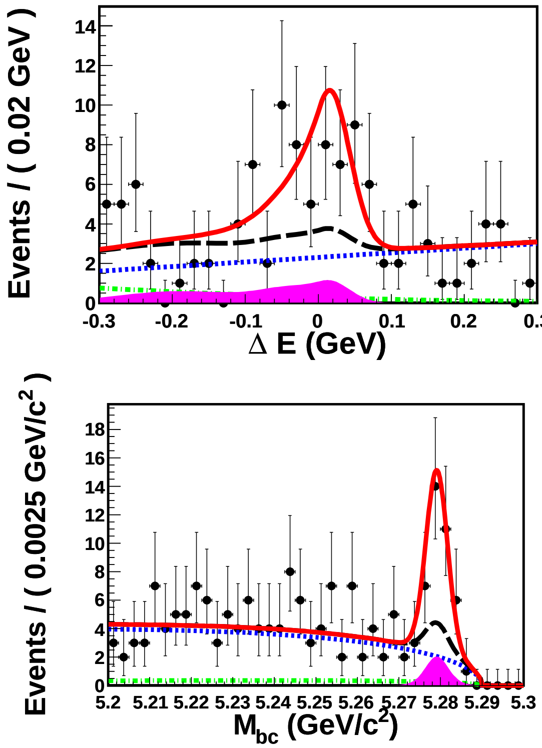

FIG. 2: Data distributions of (a) M_B for $B \to \phi K_S \gamma$ (a) ΔE for $B \to \phi K_S \gamma$. This decay mode can be used to search for right-handed weak currents as in $B \to K_S \rho^0 \gamma$ or $B \to K^{*0} \gamma$. The weak vertex is measured from the $\phi \to K^+ K^-$ decay. Note again in this case, K_S vertexing is not required.

new physics plays a role.

After extensive MC studies, unblinding of partial datasets and checks, the full data sample was unblinded. A signal from $B \to K^* \eta$ is clearly visible along with a higher mass excess. We also carried out the first search for direct CP violation in this inclusive process. These results were published in PRL with Nishimura and Browder as first authors[2].

$\Upsilon(1S)$ running and search for the light Higgs

Jamal Rorie and Varner played an important role in planning and carrying out the dedicated $\Upsilon(1S)$ and $\Upsilon(2S)$ runs. Rorie was in close daily contact with the KEKB machine group, participated in the energy scan to locate the $\Upsilon(1S)$ peak and reported regularly at the KEKB daily accelerator meetings. He and Varner are now using this 1S data sample to search for light non-standard model Higgs. This search is motivated by the possibility that there is a Higgs, H, near 100 GeV that eluded previous LEP limits. The H decays predominantly to pairs of lighter Higgses, $a_0 a_0$, where the a_0 then goes to $\tau^+\tau^-$. At Belle, we search for $\Upsilon(1S) \to \gamma a_0$, $a_0 \to \tau^+\tau^-$. The search is sensitive to light Higgs, a_0's, with masses below 10 GeV.

The $\Upsilon(1S)$ (as well as the $\Upsilon(5S)$ dataset in which the h_b state is observed) dataset may be used to confirm the existence of the η_b particle recently found by BaBar. In the $\Upsilon(2S)$ and $\Upsilon(1S)$ data samples, one expects to observe monochromatic photon lines from the $\Upsilon(nS) \to \gamma \eta_b$ radiative transitions. Shen recently published and was first author for a search for radiative $\Upsilon(1S)$ decays to charmonium and charmonium-like states such as $\Upsilon(1S) \to \gamma X(3872)$. So far no signals are found. Shen also extended and published his search for radiative decays into charmonium using the $\Upsilon(2S)$ sample.

B Decay Modes for Charmonium Spectroscopy

The $b \to c\bar{c}s$ transition is a strong decay channel for b quarks. Consequently about 15% of all B meson decay final states contain a $c\bar{c}$ pair. These frequently combine to form a final-state charmonium (or charmonium-like) meson state. Emeritus professor Olsen and his collaborators showed that the kinematic constraints of B decay allow one to experimentally isolate new charmonium-like resonances, some of which are candidates for exotic states (4-quark states or hybrid charmonium).

The detailed analysis of B decay modes with charmonium in the large Belle data sample has yielded many surprises. While at Hawaii Olsen discovered the $X(3872)$ particle in $B \to K(J/\psi \pi^+\pi^-)$ and the $Y(3940)$ in $B \to K(\omega J/\psi)$. This catalyzed a great deal of experimental activity and theoretical interest. The discovery of the X(3872) was the first in a series of observations of new and unexpected charmonium-like states.

Our former postdoc Chengping Shen (now professor at Beihang University) found evidence of a new charmonium-like state in $\gamma\gamma \to J/\psi \phi$[5] while at Hawaii. However, he also searched for the CDF state in $J/\psi \phi$ at 4140 MeV but was unable to confirm it. His work on this new state was published as a first author PRL.

Belle II

The ultimate luminosity for the KEK Super-B design is $8 \times 10^{35}/\mathrm{cm}^2/\mathrm{sec}$. This will allow the integration of a 50 ab^{-1} data sample that is needed to cover the full range of new physics searches and possibilities. Browder was a long time proponent of the super-B factory path at KEK where it is viewed as a natural follow-up to the very successful KEKB/Belle program. His activities in his area include the organization of the Belle II collaboration structure, meetings and workshops as well as the preparation of review articles on the physics of the super-B factories [10], [11]. The Hawaii group (Browder, Varner and Vahsen) is playing a high-profile role in the Belle II experiment at the KEK Super B factory facility, similar to the role of the Hawaii group during the last decade at Belle.

The Belle II detector must handle much higher data rates and, also, a 20-fold increase in machine-related backgrounds that are associated with Touschek scattering from the nanometer beam sizes; these will present occupancy challenges for the vertex detection, inner tracking and particle id systems.

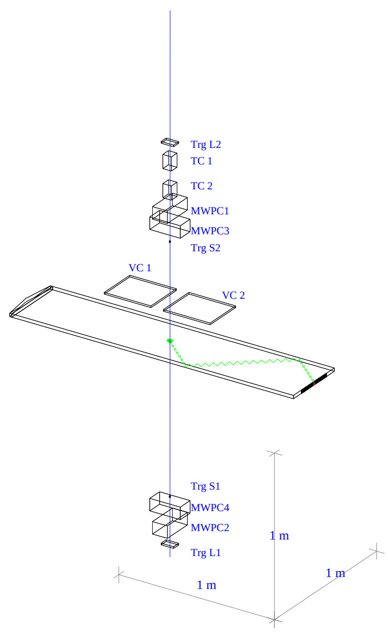

FIG. 3: A GEANT4 simulation of an iTOP counter in a CERN test beam by Barrett. Internal reflection of some photons as well as the incident track are visible. Trigger counters (TC), veto counters (VC) and multiwire proportional chambers (MWPC) are also shown.

Particle identification in the original Belle detector was based on aerogel Cherenkov detectors readout by fine mesh phototubes in the active volume of the detector and time of flight (TOF) scintillators. The aerogel Cerenkov devices provided kaon/pion separation in the momentum range up to 4 GeV while the TOF was used to separate pions and kaons in the momentum up to 1.5 GeV. The information from the TOF and aerogel was combined with dE/dx measurements from the central drift chamber (CDC) to augment particle id, especially in the relativistic rise region. The University of Hawaii group assembled the TOF counters and then was responsible for the reconstruction and calibration throughout the entire Belle run. Varner developed the time stretcher circuit for the TOF readout as well as the trigger electronics.

For Belle II, particle identification will instead be based on internally reflected Cherenkov light in quartz bars. This technique, originally developed by B. Ratcliff et al. for the BaBar DIRC detector, has been modified to be consistent with the space constraints of the Belle structure as well as the constraints of the SuperKEKB background environment. Therefore Varner and Browder with Barrett, Jones, Rosen and Nishimura have simulated and evaluated a compact quartz Cherenkov device that provides both excellent photon timing and modest imaging resolution – thus designated the imaging Time-Of-Propagation (iTOP) detector[17].

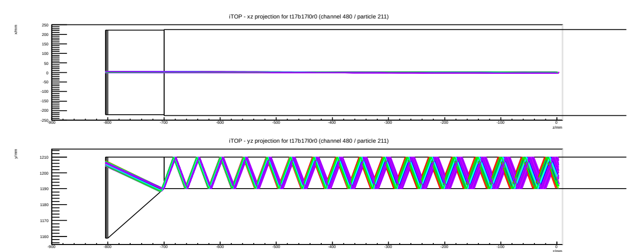

FIG. 4: Pions in the iTOP particle identification detector from a GEANT4 simulation by Matthew Barrett. Cherenkov light is produced in the quartz bar and is transmitted by total internal reflection to a standoff block. The image and arrival times are recorded by pixelated photon detectors. The top figure shows the x-z view while the bottom figure is the y-z view. The colors show the effect of dispersion.

The new detector also takes advantage of important technological developments in pixelated fast photon detectors and Varner's "oscilloscope on a chip" ASIC. This detector will require precise timing and waveform sampling to achieve its reolution goals. Varner is the leader of the Belle-II particle identification system and coordinates Belle II hardware work.

We have now finished the R& D prototype phase and starting construction of Belle II at the KEK super-B factory[14]. Construction of the Belle II barrel PID and electronics ("oscilloscope on chips") for the iTOP and KLM subsystems is the focus of the group and is a major component of the US contribution to Belle-II.

The iTOP system has been fully simulated in GEANT4. This MC simulation was written and launched by Nishimura, who now focuses on electronics, and was taken over by Barrett. It should be noted that in addition to pixelated photon detectors, timing resolution at or below the 100 ps level (with jitter in the T_0 signal below 40 ps) is required for acceptable high momentum particle identification performance. An example is shown in Fig. 5), from a GEANT simulation by Barrett showing the number

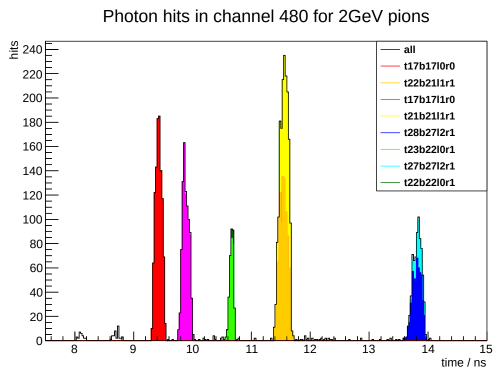

FIG. 5: The time distribution of non-reflected photons in one channel of the iTOP from Matthew Barrett. The peaks are classified by the number of bounces and surfaces in the bar that are hit.

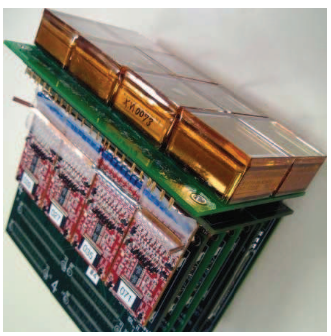

FIG. 6: Compact readout module for the iTOP electronics. This module includes the custom "oscilloscope on a chip" ASIC designed by Varner. The pixelated MCP-PMT photosensors are on the right.

of bounces and time distribution of the prompt photons from 2 GeV pions.

The compact space allowed for the iTOP also poses difficult mechanical engineering challenges. Rosen is designing the support structure, electronics housings and cooling for the barrel particle identification system as well providing CAD and FEA (see Fig. 7) for overall detector subsystem integration.

A series of beam tests, cosmic ray tests and bench tests of the entire iTOP detector chain is now in progress. An example of the beam test geometry with a single event simulated in GEANT4 by Matt Barrett is shown in Fig. 3 In 2010, a beam test with a focussing mirror and Okamoto quartz bar was carried out at CERN. After finding and correcting a major problem with the channel map missed by the University of Nagoya postdocs and students, Jones was able to measure the time resolutions for this beam test. The results are shown below.

In December 2011 a beam test with a Zygo and Okamoto bar, expansion wedge, focussing mirror, University of Hawaii oscilloscope on a chip readout electronics was carried out at FNAL. This was

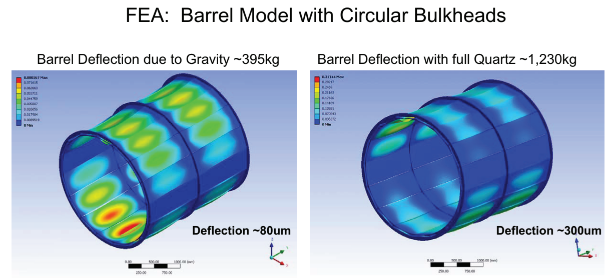

FIG. 7: Finite element analysis of a proposed support structure for the iTOP particle identification detector in Belle II by engineer Rosen.

the first time that all components were integrated. An example of waveforms from the FNAL test are shown in Fig. 8. Future work will be devoted to using DSP's (digital signal processors) to distinguish the signal waveforms from Cerenkov photons from cross-talk and electronics noise as well as reduce the large data volume.

In May 2013, cosmic ray and laser tests were carried out at Fuji Hall at KEK with the same bar used at FNAL and a prism. In June 2013, a beam test was carried out with the improved IRS3B "oscilloscope on a chip" electronics at the LEPS experiment at the SPRING-8 light source in Harima Science City, Japan. Although there were problems with optical coupling, time resolutions of 100 ps were obtained with beam data. These resolutions are consistent with laser bench test measurements at Hawaii.

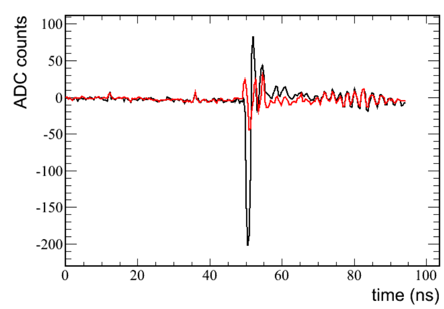

FIG. 8: An example of waveforms from the Dec 2011 Fermilab beam test from analysis by Nishimura. A waveform digitized by Varner's IRS2 ASIC from a Cherenkov photon (black) and a waveform from a channel with cross-talk (red) are shown. Fast DSP processing will be used to distinguish these two classes of pulses in the iTOP detector.

In Belle Jones played a leading role in maintaining the calibration of the TOF (time of flight) system and monitoring the data quality (both in the TOF and in the Belle DAQ). He is well known at KEK for discovering many subtle problems e.g. even and odd numbered events from the two EVENT building processor farms are systematically different. In Belle II he has been a leader in the effort to understand the CERN beam test data for the Okamato prototype bar and focussing mirror. An example of his work is shown in 9. After correcting the Nagoya channel map, he finds that the timing resolution is slightly worse than expected from the GEANT3 based Monte Carlo simulation but still acceptable for good iTOP PID performance. Jones and Barrett also carried out simulation and software work for the FNAL beam test, which included a combination of a Zygo bar and an Okamoto bar, final SL-10 photosensors and Hawaii readout electronics.

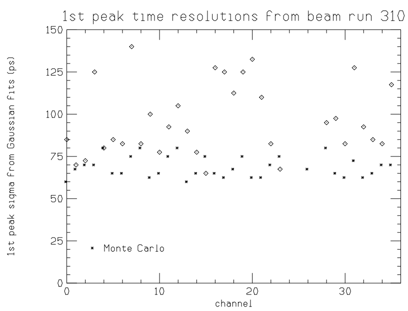

FIG. 9: Comparison of iTOP timing resolutions for runs at the Dec 2010 CERN beamtest with Monte Carlo (squares) from M. Jones. This prototype used constant fraction discriminator electronics and had no expansion wedge.

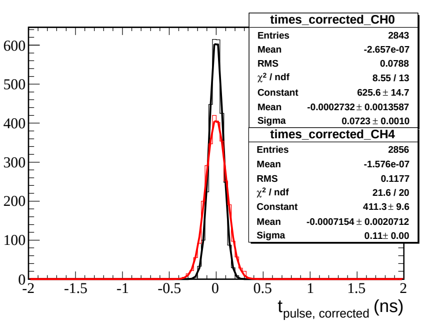

FIG. 10: Bench test results from Nishimura for iTOP timing resolution with an MCP-PMT, laser source, and the UH readout module. Timing resolutions vary betwen 70-110 ps depending on the size of the laser pulse.

Timing studies in Belle I data carried out by Jones using dimuon events and the TOF detector system have found a nearly linear variation of about 20 ps over the 5120 buckets in the beam train. After removing this dependence, there remains a small timing correlation between the two muons in dimuon events. This correlation corresponds to less than 10 ps in quadrature with other contributions to resolution and could be due to overall jitter in the event time determination. Jones' results on these subtle timing effects were reported in a JINST publication[14]. This is a small effect for the present system but will need to be monitored carefully in Belle II, which requires a T_0 jitter of 50 ps or less.

Nishimura and Varner conducted a series of bench tests to verify time resolution and electronics performance. With a pulser input, the electronics resolution is 50 ps under ideal temperature conditions. With a laser source, resolutions between 70-110 ps can be obtained as shown in Fig. 10. Here the range in timing resolution depends on the size of the laser pulse signal. A timing resolution of 100 ps is acceptable for barrel particle identification performance.

Appendices: Biographical Sketches, Publications, Bibliography & References Cited

Biographical Sketch

Thomas E. Browder
Professor
Physics Department

Citizenship: American.
Present Address: University of Hawaii at Manoa, Honolulu, HI, 96822
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E-mail: teb@phys.hawaii.edu

Education:

University of California (Santa Barbara)	- PhD. Physics (1988)
University of Chicago	- B.S. Physics (1982)

Positions Held:

Professor, University of Hawaii (August 2003-present)
Executive Board chair, Belle experiment (April 2012-present)
Co-spokesperson, Belle experiment (April 2004-April 2012)
Associate Professor, University of Hawaii (August 1999-August 2003).
Analysis Coordinator, BELLE experiment (August 1998-2004).
Assistant Professor, University of Hawaii (January 1994-August 1999).
Analysis Coordinator, CLEO experiment (August 1993-August 1994).
Research Associate, Cornell University (September 1989 - December 1993).
Research Associate, SLAC (September 1988 to September 1989).
Research Associate, UCSB (1998)

Awards and Honors:

• Fellow of the American Physical Society	2004 Particles & Fields
• Natural Sciences Faculty Performance Award	2000 University of Hawaii
• Monbusho Fellowship	2000 KEK Laboratory, Japan
• Monbusho Fellowship	1998 KEK Laboratory, Japan
• Regents Scholar	1982 University of California
• Bachelor of Science with Honors	1982 University of Chicago
• Phi Beta Kappa	1981 University of Chicago

Thesis:

- A Study of $D^0 - \overline{D^0}$ Mixing.
  PhD, University of California at Santa Barbara, 1988.

Teaching experience:

Supervision of Graduate Students at Hawaii (B. Casey, F. Fang, Y. Li, S. Swain Y.H.Zheng, N. Kent, K. Uchida, H. Sahoo, K. Nishimura, M. Hedges)
Advanced Lab (Physics 480L, 481L)
General Physics (Physics 151, 170, 272, 274L), Theoretical Mechanics (310, 311)

Selected Publications

Precise Measurement of the CP violation parameter $\sin(2\phi_1)$ in $B^0 \to c\bar{c}K^0$ Decays, I. Adachi *et al.*, Phys. Rev. Lett. 108, 171802 (2012).

Observation of radiative $B^0 \to \phi K \gamma$ Decays and Measurements of their CP Violation, H. Sahoo, T.E. Browder *et al.* (Belle Collab.), Phys. Rev. D RC 84, 071101 (2011).

First Measurement of Inclusive $B \to \eta X$ Decays, K. Nishimura, T.E. Browder *et al.* (Belle Collab.), Phys. Rev. Lett. 105, 191803 (2010).

First Observations of $B_s \to J/\psi\eta$ and $B_s \to J/\psi\eta^{'}$, J. Li *et al.* (Belle Collab.), Phys. Rev. Lett. 108, 181808 (2012).

Observation of $B_s \to J/\psi f_0$ and Evidence for $B_s \to J/\psi f_0(1370)$, J. Li *et al.* (Belle Collab.), Phys. Rev. Lett. 106, 121802 (2011).

T.E. Browder, T. Gershon, D. Pirjol, A. Soni and J. Zupan New Physics at a Super Flavor Factory *Reviews of Modern Physics, vol 81, 2009*

T.E. Browder, M. Cuichini, T. Gershon, M. Hazumi, T. Hurth, Y. Okada and M. Stocchi, On the Physics Case for a Super Flavor Factory *JHEP 0802: 110 (2008)*

H. Sahoo, T. E. Browder et al. (Belle collaboration), Measurement of time-dependent CP violation in $B^0 \to \psi(2S)K_S$ decays *Phys Rev D 77, 091103 (2008)*

Conflicts of Interest: I have collaborated for over a decade with members of the Belle collaboration. I was a founding member and first foreign spokesperson for the Belle II collaboration. Michael Witherell (UCSB) and Rollin Morrison (UCSB) were graduate Phd Advisors. My Phd students at the University of Hawaii are listed on the previous page.

Curriculum Vitae

Name: Michael D. Jones
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Research specialization: experimental high energy physics, Belle II project

Education:

Northwestern Univ.,	B. A. in Physics	1968
Univ. of Chicago,	Ph. D. in Physics	1974

Positions held:

Associate researcher in the Univ. of Hawaii High Energy Physics Group and member of Graduate Faculty	1985-present
Assistant researcher in the Univ. of Hawaii High Energy Physics Group	1976-1985
Part-time lecturer in Rutgers College	1975-1976
Post-doctoral research associate in the Rutgers Univ. Bubble Chamber Physics Group	1973-1976

Teaching:

Physics 100 -	Fall 2007
Physics 100 -	Spring 2008
Physics 100 -	Fall 2008
Physics 100 -	Spring 2009
Physics 100 -	Fall 2009
Physics 100 -	Fall 2010
Physics 100 -	Spring 2011

Contracts and grants:
Current: UH High Energy Physics Group principal investigator for the Hawaii QuarkNet project since 2005

Recent publications:

1. H. Kichimi et al., 2010 JINST 5 P03011, March 2010.

Service work to department, university, state, or profession:

1. helped establish the Vincent Z. Peterson Scholarship for UH Manoa undergraduate physics majors in 2009
2. helped coordinate Physics & Astronomy participation in the Manoa Experience 2008-2011
3. UH Manoa Faculty Senate Committee on Research 2006-2008
4. helped organize Physics Olympics competition 2001-2012
5. helped organize Physics & Astronomy Dept. Open House 2002-2012

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Education:

Boston University:	B.S. in Electrical Engineering, 1989
Boston University:	M.A. in Experimental Physics, 1995
University of Hawaii:	Ph.D. in Experimental Physics, 1999

Professional Employment:

2010-present	Associate Professor of Physics, University of Hawaii
2005-2010	Assistant Professor of Physics, University of Hawaii
2002-2005	Director, Instrumentation Development Laboratory, University of Hawaii
2000-2002	Senior Scientist, AOptix Technologies Campbell, California (silicon valley)
1998-2000	EE/Physicist, University of Hawaii, University of Hawaii
1997-1998	Visiting Researcher CMS Exp., CERN & L.I.P. Portugal, based at CERN
1995-1997	Research Associate, University of Hawaii
1992-1995	Senior Electrical Engineer/Physicist, Boston University & SSC Lab.
1989-1992	Research Associate, Boston University

Selected Recent Publications :

1. **G. Varner** and L. Ruckman, "Sub-10ps Monolithic and Low-power Photodetector Readout," *Nucl. Instr. Meth.* **A601** (2009) 438-445.
2. H. Hoedlmoser, **G. Varner** and M. Cooney, "Hexagonal pixel detector with time encoded binary readout," *Nucl. Instr. Meth.* **A599** (2009) 152-160.
3. J. Benitez, D.W.G.S. Leith, G. Mazaheri, B.N. Ratcliff, J. Schwiening, J. Vavra, L. Ruckman and **G. Varner**, "Status of the Fast Focusing DIRC (fDIRC)," *Nucl. Instr. Meth*. **A595** (2008) 104-107.
4. **G. Varner**, L. Ruckman and A. Wong, "The First version Buffered Large Analog Bandwidth (BLAB1) ASIC for high luminosity collider and extensive radio neutrino detectors," *Nucl. Instr. Meth.* **A591** (2008) 534-545.
5. **G.S. Varner**, L.L. Ruckman, P.W. Gorham, J.W. Nam, R.J. Nichol, J. Cao, M. Wilcox, "Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," *Nucl. Instr. Meth.* **A583** (2007) 447-460.

Synergistic Activities :

1. Large-area, pico-second timing detector development [Argonne, Univ. Chicago, Univ. Hawaii, SLAC collaboration]
2. Coded-aperature imager for beam bunch diagnostics at a high intensity electron storage ring [Cornell Univ., KEK and Univ. Hawaii collaboration]
3. Fast Focusing Direct Internal Reflected Cherenkov (DIRC) detector development for Particle Identification at a Super B factory in Italy [Univ. Cincinnati, Univ. Hawaii and SLAC collaboration]

4. Imaging Time Of Propagation detector development for Particle Identification at a Super B factory in Japan [Univ. Cincinnati, Univ. Hawaii, KEK, Nagoya Univ. collaboration]

Collaborators & Other Affiliations:

Belle Pixel Upgrade

- Hiro Aihara *Univ. of Tokyo (Japan)*, Herbert Hoedlmoser, Tom Browder, Li Jin, James Kennedy, Marc Rosen, Larry Ruckman, Himansu Sahoo *Univ. of Hawaii*, Masashi Hazumi, Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*, Andrezj Bozek, Henryk Palka H. Niewondiczanski *Institute of Nuclear Physics (Poland)*, and Samo Stanic and *Nova Gorica Poly (Slovenia)*

International Linear Collider MAPS Pixel

- Steven Worm *Rutherford Appleton Laboratory (U.K.)*, Marc Winter *LEPSI, Strassbourg (France)* and Ray Yarema Fermi *National Accelerator Laboratory*

Silicon on Insulator Pixel Detectors

- Yasuo Arai and Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*and Hiro Ikeda *JAXA (Japan)*

Thin, Rad-hard, and fast-timing Pixel Detectors

- Chris Kenney *Molecular Biology Consortium/Stanford Univ.* and Sherwood Parker *Univ. of Hawaii and Lawrence Berkeley Lab.*

Giga-sample per second, GHZ analog bandwidth waveform acquisition

- Stefan Ritt *Paul Scherrer Institute (Switzerland)*

1ps Timing Resolution Detector Development

- Henry Frisch, Jean-Francois Genat, Fukun Tang *University of Chicago*

Next generation large Photomultiplier Readout

- John Anderson, Karen Byrum, Gary Drake, Ed May, Harry Weerts *Argonne National Laboratory*

Common Pipelined High-speed Data Acquisition and Storage

- Tadeo Higuchi and Manobu Tanaka *KEK High Energy Physics Laboratory (Japan)*

Imaging Hard X-ray Compton Polarimeter pixel detector

- Hiroyasu Tajima *Kavli Institute/SLAC National Accelerator Laboratory*

Belle Particle Identification Detector Upgrade

- Toru Iijima, Kenji Inami *Nagoya University (Japan)*, Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman *Univ. of Hawaii*, Alan Schwartz, Kay Kinoshita *Univ. of Cincinnati*

Super-B Particle Identification Detector Upgrade

- Peter Krizan, Samo Korpar *J. Stefan Institute (Slovenia)*, Kurtis Nishimura, Larry Ruckman *Univ. of Hawaii*, Jerry Vavra, Blair Ratcliff *SLAC National Accelerator Laboratory*

Graduate advisor Stephen Olsen, Seoul National University (Korea)

5 graduate students advised, 4 postdoctoral candidates sponsored

[1] "Observation of radiative $B^0 \to \phi K \gamma$ Decays and Measurements of their CP Violation", H. Sahoo, T.E. Browder *et al.* (Belle Collab.), arXiv:1104.5590 [hep-ex], Phys. Rev. D RC 84, 071101 (2011).
[2] "First Measurement of Inclusive $B \to \eta X$ Decays", K. Nishimura, T.E. Browder *et al.* (Belle Collab.), Phys. Rev. Lett. 105, 191803 (2010).
[3] "Observation of $B_s \to J/\psi f_0$ and Evidence for $B_s \to J/\psi f_0(1370)$", J. Li *et al.* (Belle Collab.), Phys. Rev. Lett. 106, 121802 (2011).
[4] "Observation of $B_s \to J/\psi \eta$ and Search for $B_s \to J/\psi \eta'$", I. Adachi *et al.* (Belle Collab.), BELLE-CONF-0902, arXiv: 0912.1434.
[5] "Evidence for a new resonance and search for the $Y(4140)$ in $\gamma\gamma \to \phi J/\psi$", C. P. Shen *et al.* (Belle Collab.), Phys. Rev. Lett. 104, 112004 (2010).
[6] "Search for charmonium and charmonium-like states in $\Upsilon(1S)$ radiative decays", C. P. Shen *et al.* (Belle Collab), Phys. Rev. D 82, 051504(R) (2010).
[7] "Observation of the $\phi(1680)$ and the $Y(2175)$ in $e^+e^- \to \phi\pi^+\pi^-$", C. P. Shen *et al.* (Belle Collab.), Phys. Rev. D. 80, 031101 (2009).
[8] "Time-dependent CP Asymmetries in $B^0 \to K_S^0 \rho\gamma$ Decays", J. Li *et al.* (Belle Collab.), arXiv: 0806.1980, Phys. Rev. Lett. 101, 251601 (2008).
[9] "Measurements of time-dependent CP violation in $B^0 \to \psi(2S) K_S$ decays", H. Sahoo, T.E. Browder *et. al* (Belle Collab.), Phys. Rev. D. R77, 091103 (2008), arXiv: 0708.1790.
[10] "New Physics at a Super Flavor Factory", T. E. Browder, T. Gershon, D. Pirjol, A. Soni and J. Zupan, arXiv:0802.3201, published in Reviews of Modern Physics, vol 81, 2009.
[11] "On the Physics Case of a Super Flavor Factory", T. E. Browder, M. Ciuchini, T. Gershon, M. Hazumi, T. Hurth, Y. Okada and A. Stocchi, arXiv:0710.3799, published as JHEP 0802:110, 2008.
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[13] L. Ruckman, G. Varner, K. Nishimura, "Development of an Imaging time-of-propagation (iTOP) prototype detector," Nucl. Instr. Meth. **A623** (2010) 365.
[14] H. Kichimi *et al.* (Belle Collaboration), "KEKB Beam Collision Stability at the Picosecond Timing and Micron Position Resolution as observed with the Belle Detector," JINST **5** (2010) P03011.
[15] G. Varner *et al.*, "The Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," Nucl. Instr. Meth. **A583** (2007) 447.
[16] G.S. Varner, L.L. Ruckman, J. Schwiening and J. Vavra, "Compact, low-power and precision timing photodetector readout," Proc. of Science, **PD07:026** (2008).
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[18] J. Benitez *et al.*, "Status of the Fast Focusing DIRC (fDIRC)," Nucl. Instrum. Meth. A **595**, 104 (2008).
[19] Learned and Matsuno have 11-month University positions and receive no salary support from the DOE grant.

Other recent Belle publications

1. S.Uehara, Y. Watanabe, H. Nakazawa *et al.* (Belle Collaboration), "Measurement of the $\gamma\gamma^* \to \pi^0$ transition form factor at Belle," submitted to Physical Review D, [arXiv:1205.3249 [hep-ex]].
2. C. P. Shen, C. Z. Yuan, T. Iijima et al. (Belle collaboration), "First observation of exclusive $Y(1S)$ and $Y(2S)$ decay into light hadrons," submitted to Physical Review Letters, [arXiv:1205.1246 [hep-ex]].
3. K. Negishi et al. (Belle collaboration), "Search for the decay $B^0 \to DK^{*0}$, followed by $D \to K^-\pi^+$" submitted to Physical Review D(RC), [arXiv:1205.0422 [hep-ex]].
4. H. Aihara et al. (Belle collaboration), "First Measurement with a Model-independent Dalitz Plot Analysis of $\to DK, D \to K_S\pi^+\pi^-$ Decay," submitted to Physical Review D, [arXiv:1204.6561 [hep-ex]].
5. M. Rohrken et al. (Belle collaboration), "Measurements of Branching Fractions and Time-dependent CP Violating Asymmetries in $B^0 \to D^{(*)\pm}D^{*\mp}$ Decays," to appear in Physical Review D(RC), [arXiv:1203.6647 [hep-ex]]
6. B. R. Ko, E. Won et al. (Belle collaboration), "Evidence for CP Violation in the Decay $D^+ \to K_s^0\pi^+$," submitted to Physical Review Letters, arXiv:1203.6409 [hep-ex]].
7. M.-C. Chang, Y.-C. Duh, J.-Y. Lin et al. (Belle collaboration), "Measurement of $B^0 \to J/\psi\eta'$ and Constraint on the $\eta - \eta'$ Mixing Angle," published in Physical Review D85, 091102(R) (2012), [arXiv:1203.3399 [hep-ex]].
8. T. Higuchi, K. Sumisawa et al. (Belle collaboration), "Search for Time-Dependent CPT Violation in Hadronic and Semileptonic B Decays" published in PRD 85, 071105(R) (2012), [arXiv:1203.0930 [hep-ex]].
9. C. P. Shen, C. Z. Yuan, T. Iijima et al. (Belle collaboration), "Search for double charmonium decays of the P-wave spin-triplet bottomonium states" published in Physical Review D85, 071102(R) (2012), [arXiv:1203.0368 [hep-ex]].
10. Z. Q. Liu, C. P. Shen, C. Z. Yuan, T. Iijima et al. (Belle collaboration), "Observation of new resonant structures in $\gamma\gamma \to \omega\phi, \phi\phi$ and $\omega\omega$", to appear in Physical Review Letters, [arXiv:1202.5632 [hep-ex]].
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Invited talks for Task A

1. Browder reviewed results on charmonium, bottomonium and exotic states at the inagaural meeting of Rencontres de Vietnam in Quy Nhon, Vietnam (August 2013).

2. Browder reviewed the Belle II physics program at the Argonne Intensity Frontier Meeting (May 2013) and at Snowmass on the Mississippi (July 2013).

3. Browder gave a lecture at the SLAC summer institute on Future e^+e^- flavor factories in July 2013

4. Browder reviewed the Belle II detector and SuperKEKB at Flavor Physics and CP Violation Conference (FPCP) in Maale Hachmisha, Israel in May 2011.

5. Browder reviewed the Intensity Frontier and Super B factories at a conference on the synergy of the luminosity and energy frontiers at the Tata Institute in Mumbai, India in January 2011.

6. Varner presented the Belle-II Detector at the Technology in Particle Physics (TIPP) in Chicago, June 2011.

7. Varner reviewed the Belle-II experiment at SuperKEKB at the Particles And Nuclei International Conference (PANIC11) at MIT in Boston, Massachusetts in July 2011.

8. Jaegle will give a talk on Dark Photon Searches at Belle at the DARK2012 conference in October 2012, in Frascati, Italy.

9. Jaegle will give a talk on Dark Photon Searches at Belle at the QCD Montpellier conference in July 2012 in Montpellier, France.

10. Nishimura gave a talk on SuperKEKB/Belle II status and plans at the CIPANP 2012 conference in May, 2012 at St. Petersburg, Florida.

11. Nishimura gave a talk on New Physics for Charm and Mixing at Belle II at the CHARM2012 conference in May 2012 in Honolulu, HI.

12. Nishimura gave the Continuum Suppression tutorial at the Belle Analysis School, Feb. 2011 at KEK in Tsukuba, Japan.

13. Nishimura gave a talk on the iTOP particle identification counter for Belle II at the Technology in Particle Physics (TIPP) in Chicago, June 2011.

14. Nishimura gave a talk on the Physics Prospects of SuperKEKB/Belle II at the Lake Louise Winter Institute at Lake Louise, Canada in February 2011.

15. Rorie gave a talk on the light Higgs Search with $\Upsilon(1S)$ data at the European Physical Meeting in Grenoble, France, July 2011.

16. Sahoo reviewed ϕ_1/β angle measurements (Belle/BaBar) at Flavor Physics and CP Violation Conference (FPCP) in Maale Hachmisha, Israel in May 2011.

17. Sahoo gave a review talk on measurements of CP violation in B decay at Belle at the DPF meeting at Brown University in Providence, Rhode Island, August 2011.

18. R. Mussa will review new results on resonances at Belle in the Montpellier QCD conference in July 2012 in Montpellier, France.

19. R.Mussa gave a seminar on Bottomonium Physics at B-factories at the University of Torino, in April 2011.

20. R.Mussa reviewed results on radiative transitions at B factories at the Photon 2011 Conference in Spa (Belgium) in May 2011.

The BES Experiment

Drs. F.A. Harris, J.B. Jiao, M. Kornicer, Q. Liu, M. Pelizaeus, C.P. Shen, T. Luo, and G. Varner; and Mr. J. W. Park

(Harris is principal investigator for this task)

Introduction

The design luminosity of the two-ring Beijing Electron Positron Collider II (BEPCII) is 1 $\times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 100 times that of BEPC and 15 times the highest luminosity achieved at CESRc at Cornell. In early 2013 at an energy of 3.77 GeV, BEPCII reached a peak luminosity at 7.1×10^{32} cm^{-2} s^{-1}, 71% of design and a world record in this energy region. The Beijing Spectrometer III (BESIII) is a state-of-the-art detector, with a helium-based drift chamber, a Time-of-flight (TOF) system with sub-100 ps time resolution, a CsI(Tl) crystal electromagnetic calorimeter, and a Resistive Plate Chamber muon detector that uses the flux-return iron of a 1.0 Tesla superconducting magnet. More detail on BEPCII and BESIII can be found in Ref. [1].

Since starting operation in 2009, BESIII has accumulated a wide variety of data sets for different physics objectives. In 2009, it accumulated 106 M events at the ψ' resonance and 225 M events at the J/ψ resonance. In 2010 and 2011, it accumulated about 2.9 fb^{-1} of $\psi(3770)$ data, a sample that is ideal to study charm physics, including precision studies of D mesons and $D\bar{D}$ mixing, since the $\psi(3770)$ decays into a pair of quantum-correlated D mesons. In 2012, one week was used for J/ψ, ψ', and τ threshold scans in preparation for a full τ mass run in the future. Afterwards 0.3 B (billion) events were accumulated at the ψ' and 1 B at the J/ψ, both of which are world records. In 2013, over 2 fb^{-1} was collected at 4.26 GeV and 0.5 fb^{-1} at 4360 GeV to study the exotic $Y(4260)$ and $Y(4360)$ states. These are the highest energies at which BEPCII has operated, and it performed very well and collected the world's largest such samples.

University of Hawaii-BES Personnel

Post-docs Liu and Shen were Post-docs with our group from 2007 to 2011. Liu is now at UCAS, the Graduate School of the Chinese Academy of Science in Beijing, and Shen has just accepted a Professorship at Beihang University in Beijing. In September 2011, Postdocs Tao Luo from the Institute of High Energy Physics (IHEP) in Beijing and Mihajlo Kornicer from the University of Indiana joined our group. Luo had just finished his thesis on $\chi_{cJ} \to \gamma\gamma$ on BESIII, and Kornicer had been doing partial wave analysis on $\chi_{cJ} \to \eta(\eta')\pi\pi$ on CLEOc and is extending his analysis to the larger BESIII sample.

We have been happy to have visitors join us. Dr. Marc Pelizaeus from Bochum University in Germany was with our group from Sept. 2010 until July 31, 2012. He had received a grant from the German government to work with the Hawaii group for a period of two years. Dr. Cong Geng from the University of Science and Technology (USTC) in China visited from November 1, 2012 to March 31, 2013, and Dr. Jianbin Jiao is visiting for one year starting from Dec. 1 2012 under a grant from the Chinese Academy of Science.

A new addition in August 2012 is graduate assistant Jeong-Wan Park, who has worked on BESIII analysis in Korea at Seoul National University with Steve Olsen and comes highly recommended.

Scope of Hawaii Participation in BES

Hawaii joined the BES collaboration in 1993 and since then has had a strong impact on the BES program. It is the leading US group on BESIII. Harris has been co-spokesman of BESII since 1998 and is currently co-spokesman for BESIII representing groups from outside of China. Hawaii's main hardware responsibility in BESIII was a laser/fiber-optic monitoring system for the TOF counters. The system, which is described in detail in Ref. [2], was installed into the BESIII detector in spring 2008 as part the TOF system. Hawaii post-doc Liu supervised the installation at IHEP, and provided the online and offline software for the TOF monitoring system.

More recently, Hawaii has been collaborating on the implementation of a Compton back-scattered photon beam energy measurement system to measure precisely the energies of the electron and positron beams at BEPCII for high-precision mass measurements for the τ-lepton and D mesons. More detail may be found in Section .

Hawaii Paper Contributions

Recent BES publications are listed in the Appendix. Papers **[P1]** (*Observation of the charged κ in $J/\psi \to K^*(892)^{\mp} K_s \pi^{\pm}$, $K^*(892)^{\mp} \to K_s \pi^{\mp}$ at BESII*) and **[P7]** (*Study of χ_{cJ} radiative decays into* *a vector meson*) were major refereeing and paper writing efforts for Harris. Harris who was a referee on the number of J/ψ events in the 2009 J/ψ run contributed a section to paper **[P2]** (*Measurement of the Matrix Element for the Decay* $\eta' \to \eta\pi^+\pi^-$) on this subject, so this paper was referenced by all other J/ψ papers until recently when **[P26]** (*Determination of the number of* J/ψ *events with* J/ψ *inclusive decays*) was accepted by Chinese Physics. Harris was also the author for paper **[P6]** (*Charmonium in China: BEPCII/BESIII*), **[P17]** (*Recent Results from BESIII*), and a main author for **[P12]** (*The beam energy measurement system for the Beijing electron-positron collider*). Shen was the first author for papers **[P2]** (*Measurement of the Matrix Element for the Decay* $\eta' \to \eta\pi^+\pi^-$), **[P10]** (*Search for CP and P violating pseudo-scalar decays into* $\pi\pi$), and **[P14]** (*Higher-order multipole amplitude measurement in* $\psi(2S) \to \gamma\chi_{c2}$). Liu performed the analysis of η_c candidates decaying to $K^0_S K^\pm\pi^\mp$, which is a very clean η_c decay channel and an important part of **[P19]** (*Measurements of the mass and width of the* η_c *using* $\psi' \to \gamma\eta_c$). Pelizaeus was co-author of paper **[P5]** (*First Observation of the Decays* $\chi_{cJ} \to \pi^0\pi^0\pi^0\pi^0$).

Hawaii members participate in many BES analyses through the referee process and in paper rewriting. Since Harris as co-spokesman must approve all papers before submission, he is involved in the final editing of most papers.

Hawaii Analyses

η_c mass and width

Liu analyzed $\psi(2S) \to \gamma K^+K^-\pi^0$ and $\psi(2S) \to \gamma K^0_S K^\pm\pi^\mp$, where very strong signals for η_c, χ_{cJ}, and light hadron production are seen. The decays of the η_c were not as well understood as other charmonium decays, and even their masses and widths were poorly determined [3]. CLEOc found intriguing line shape discrepancies in both the $\psi^{'} \to \gamma\eta_c$ and $J/\psi \to \gamma\eta_c$ channels [4] and pointed out that these might explain the differences in masses measured in charmonium decays and those measured in $\gamma\gamma$ and $p\bar{p}$ production.

Fig. 11 shows Liu's $K^0_S K^\pm\pi^\mp$ mass distribution in the η_c mass region where a beautiful η_c is seen. Liu's results have been combined in **[P19]** with many other η_c decay channels to do a global fit for the mass and width of the η_c. The fit for the first time incorporates interference between the signal, $\psi' \to \gamma\eta_c$, and a non-resonant background to successfully describe the very asymmetric line shape of the η_c. The global fit yields a mass and width of $(2984.3 \pm 0.6 \pm 0.6)$ MeV/c^2 and $(32.0 \pm 1.2 \pm 1.0)$ MeV/c^2, respectively. The mass and width agree

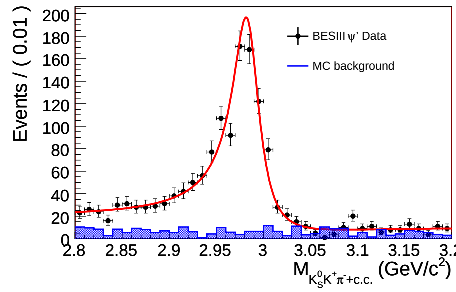

FIG. 11: Invariant mass distribution of $K^0_S K^\pm\pi^\mp$ in the η_c mass region. The points with error bars are data, the solid histogram is the normalized Monte-Carlo simulated background. The red curve is the fit including interference with the non-resonant background, indicated by the very asymmetric nature of the peak.

better with those coming from $\gamma\gamma$ and $p\bar{p}$ production, so maybe this long standing discrepancy is finally understood. In the 2013 compilation of the η_c mass by the Particle Data Group, the earlier $\psi' \to \gamma\eta_c$ results are no longer used while new BESIII results are used, and the new mass is 2983.7 ± 0.7 MeV/c^2, compared to 2012 when it was 2981 ± 1.1 MeV/c^2.

χ_{cJ} decays

$\chi_{c1} \to \eta\pi\pi$ *and* $\eta'\pi\pi$

χ_{cJ} decays provide a clean environment to study various aspects of the production of light mesons and their interactions. In particular, the χ_{c1} decays to three pseudoscalar-mesons (PPP), $\chi_{c1} \to \eta\pi\pi$ and $\chi_{c1} \to \eta'\pi\pi$, are suitable to search for exotic $\eta\pi$ and $\eta'\pi$ states, states with J^{PC} forbidden in the quark model. Characteristic to these decays is that the only S-wave configuration between a bachelor pion and the $\eta\pi$ or $\eta'\pi$ can be achieved only if the $\eta^{(\prime)}\pi$ system has exotic $J^{PC} = 1^{-+}$. These χ_{c1} decays are also useful for studying 0^{++} isoscalars, which are puzzling because their over-population cannot be accommodated by the quark model. The relatively well-known quark content of the η and η' can be used to learn about different flavors of the $\pi\pi$ system recoiling against the octet (η) and singlet (η') state[17]. Very clean χ_{cJ} signals can be selected from the ψ(2S) $\to \gamma\chi_{cJ}$ decays, by tagging a photon with the energy associated with the radiative transition (J=0,1,2).

Before joining UH, Kornicer performed amplitude analyses of ψ(2S) $\to \gamma\chi_{c1}$; $\chi_{c1} \to \eta\pi^+\pi^-$ and ψ(2S) $\to \gamma\chi_{c1}$; $\chi_{c1} \to \eta'\pi^+\pi^-$, using CLEO-c data at Indiana University. An important result from this analysis is evidence for an $\eta'\pi$ amplitude with exotic $J^{PC} = 1^{-+}$, consistent with the $\pi_1(1600)$ state. The $\pi_1(1600)$ was previously reported only in experiments with pion beams. In addition, the analysis yielded the first direct observation of $a_0(980) \to \eta'\pi$ decays. These results were presented at the PANIC-2011 conference and published in Ref. [5].

Techniques developed for amplitude analyses of the CLEO data are currently being employed for analyzing the much larger BESIII data set, which provides an opportunity to further understand two-body structures observed in the $\chi_{c1} \to PPP$ decays. The top plots in Figs. 12 and 13 show the invariant mass distributions of the χ_{cJ} candidates from $\psi(2\mathrm{S}) \to \gamma\eta\pi^+\pi^-$ and $\psi(2\mathrm{S}) \to \gamma\eta'\pi^+\pi^-$ decays, respectively, obtained using 106M BESIII ψ' events. The arrows indicate χ_{c1} candidates, for which corresponding Dalitz plots and Dalitz-projections are shown in the three bottom plots of Figs. 12 and 13. Solid histograms lines in Dalitz-projections represent results from preliminary amplitude analyses. Using $\approx 95\%$ ($\approx 45\%$) of all η (η') decay modes, the statistics surpass the CLEO data sample by a factor of ≈ 3 (2).

Preliminary analysis of the $\eta'\pi^+\pi^-$ data confirms that the observed $\eta'\pi$ P-wave structure around 1.7 GeV/c^2 is significant. The statistics of the CLEO-c data did not allow to rule-out other, non-resonant, explanations for the $\eta'\pi$ P-wave amplitude. The much larger data set expected from BESIII in the future will be used to examine the resonant nature of this structure, and constrain other reported $\pi_1(1600)$ decay modes $\pi_1(1600) \to b_1(1235)\pi$ and $\pi_1(1600) \to f_1(1285)\pi$.

Preliminary results also confirm that $a_0(980) \to \eta\pi$ decays dominate the $\eta\pi^+\pi^-$ data, where a prominent $a_0(980) \to \eta\pi$ peak is evident in the bottom middle plot of Fig 12. Previous analysis of CLEO-c data used the Flatte formula to parameterize the $a_0(980) \to \eta^{(\prime)}\pi$ decays, which takes into account dispersion relation only in the first order approximation. Our current effort is to fully incorporate dispersion effects into the analysis, which should help in distinguishing between various hypotheses of the $a_0(980)$ nature, i.e. if it is a meson-meson or tetraquark $q\bar{q}$ system [6]. In addition, the larger BESIII statistics should enable more precise studies of the difference between the $\pi\pi$ spectra in the η versus η' environment, especially in the region of the $f_0(980)$, where KK loops might dominate the $\pi\pi$ S-wave. The $\chi_{c1} \to \eta\pi^0\pi^0$ and $\chi_{c1} \to \eta'\pi^0\pi^0$ decays have not been measured so far. Kornicer plans to include these two decay modes into the analysis, which will improve the statistics and at the same time serve as an important cross-check of the systematics involved in the analysis.

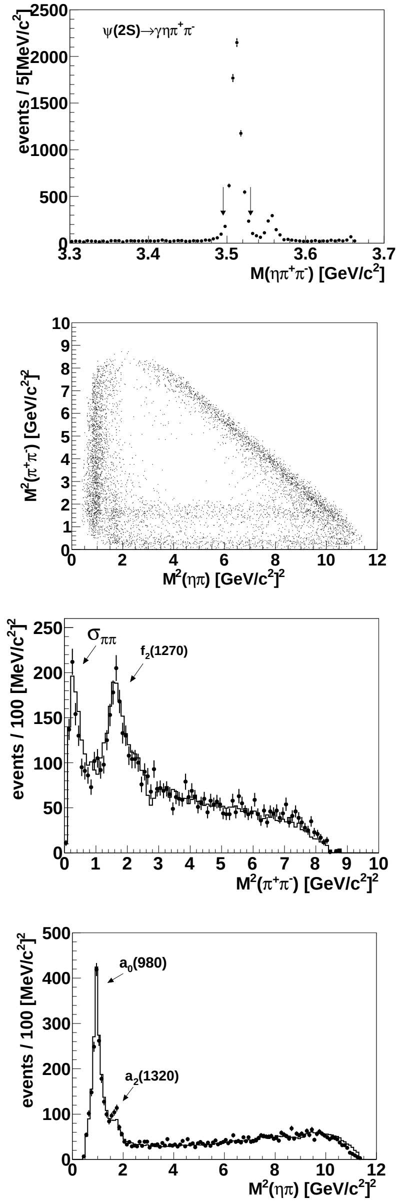

FIG. 12: Invariant mass distribution of the $\eta\pi^+\pi^-$ (top) candidates from the radiative $\psi(2\mathrm{S}) \to \gamma\eta^{(\prime)}\pi^+\pi^-$ decays. The Dalitz plot and two projections, shown by three bottom plots, correspond to selected χ_{c1} decays, indicated by the arrows on the top plot.

$\chi_{c0,2} \to \gamma\gamma$

Charmonium physics is in the boundary domain between perturbative and nonperturbative QCD. Notably, the two-photon decays of P-wave charmonia are helpful for better understanding the nature of interquark forces and decay mechanisms [7]. In particular, the decays of $\chi_{c0,2} \to \gamma\gamma$ offer the closest parallel between quantum electrodynamics (QED) and QCD, being completely analogous to the decays of the corresponding triplet states of positronium. At lowest order, for both positronium and charmonium the ratio of the two-photon decays

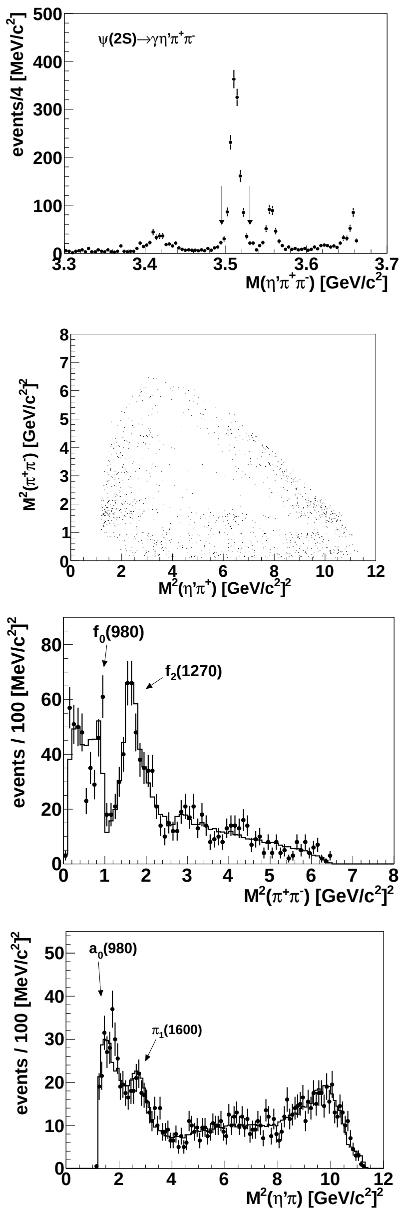

FIG. 13: The same as Fig. 12 in the case of the radiative $\psi(2\mathrm{S}) \to \gamma\eta^{(\prime)}\pi^+\pi^-$ decays.

$\mathcal{R}_{th}^{(0)} \equiv \frac{\Gamma(^3P_2\to\gamma\gamma)}{\Gamma(^3P_0\to\gamma\gamma)} = 4/15 \approx 0.27$ [8]. Any discrepancy from this simple lowest order prediction can arise due to QCD radiative corrections and relativistic corrections, and the measurement of $\mathcal{R}$ provides useful information on these effects. The predictions for the ratio $\mathcal{R} \equiv \frac{\Gamma_{\gamma\gamma}(\chi_{c2})}{\Gamma_{\gamma\gamma}(\chi_{c0})}$ cover a wide range of values between 0.09 and 0.36 [9, 10].

In the analysis by Luo, $(1.06\pm0.04)\times10^8$ ψ' events accumulated in the BESIII experiment are used to study $\psi' \to \gamma_1\chi_{c0,2}$, $\chi_{c0,2} \to \gamma_2\gamma_3$ and measure the two-photon decay widths, $\Gamma_{\gamma\gamma}(\chi_{c0})$ and $\Gamma_{\gamma\gamma}(\chi_{c2})$,

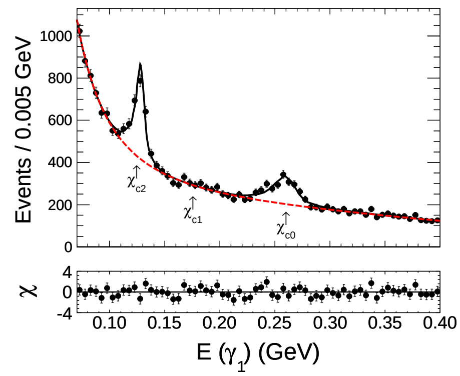

FIG. 14: Upper plot: the fitted E_{γ_1} spectrum for the ψ' data sample. The expected positions of E_{γ_1} from χ_{c0}, χ_{c1}, χ_{c2} are indicated by arrows. Lower plot: the number of standard deviations, χ, of data points from the fitted curves.

which are determined to be $\Gamma_{\gamma\gamma}(\chi_{c0}) = (2.33\pm0.30)$ keV/c^2 and $\Gamma_{\gamma\gamma}(\chi_{c2}) = (0.63\pm0.08)$ keV/c^2. The ratio $\mathcal{R}$ is determined with good control of systematic uncertainties, many of which cancel in the ratio of the two simultaneous measurements; our experimental result is $\mathcal{R} = 0.27\pm0.04$. The energy spectrum of the radiated photons is shown in Fig. 14, where enhancements due to the χ_{c0} and χ_{c2} over substantial backgrounds are clear. The ratio of the helicity-zero component relative to helicity-two component of χ_{c2} is also reported for the first time to be $f_{0/2} = \frac{\Gamma^{\lambda=0}_{\gamma\gamma}(\chi_{c2})}{\Gamma^{\lambda=2}_{\gamma\gamma}(\chi_{c2})} = 0.00\pm0.03$. This analysis **[P23]** was published in Physical Review D **85**, 112008 (2012).

Precision beam energy measurement at BEPCII

We have been collaborating with groups from the Budker Institute of Nuclear Physics (BINP) and IHEP on the first upgrade of the BEPCII/BESIII complex: a system to determine the beam energies with high precision using back-scattered Compton photons from both of the circulating beams in BEPCII. This method has been demonstrated at BESSY-I, BESSY-II, VEPP-4M, and VEPP-3 storage rings at Novosibirsk.

Precise knowledge of the energy of each beam is crucial for many interesting and fundamental measurements, especially the measurement of the τ mass, m_τ, a fundamental parameter of the Standard Model. While the e and μ masses are known with precisions of $\delta m/m$ of $\sim 10^{-8}$, the current world-average value for m_τ is 1776.82 ± 0.16 MeV/c^2 [3], a precision of only $\sim 10^{-4}$. A precise m_τ measurement tests lepton universality, and BESIII provides an opportunity to improve the precision of m_τ and to help provide the most stringent test of lepton universality.

For the m_τ measurement, statistics are not an issue. At BESIII, one week of data taking time leads to a statistical uncertainty of less than 50 keV/c^2. Critical are the systematic errors, and among these the most important source of uncertainty is that of the beam energy.

To measure the beam energy, laser light is injected into BEPCII and made to collide head-on with a beam; the energies of the backscattered photons are precisely measured with a high purity Germanium detector (HPGe) with excellent energy resolution. The maximal energy of the scattered photons is determined from the abrupt Compton edge in the energy spectrum. For a monochromatic laser beam of 0.12 eV photons, the energies of the scattered photons are in the 1 − 10 MeV range, an energy region that can be accurately calibrated using radioactive γ-sources.

The installation of the beam energy measurement system (BEMS) is complete. The coherent laser system, composed of an Agilent DC power supply, Lytron Chiller, and coherent laser and supplied by Hawaii, is installed and operational. In Nov. 2010, a few day scan of the ψ' was completed with BESIII in order to test and calibrate the BEMS. Two separate scans were done with a total of 12 energy points. The energies at each point were determined by the BEMS, the cross section ($\sigma(e^+e^- \to \psi' \to hadrons)$) was determined from the number of hadronic events, and the luminosity at each point was determined using both Bhabha events and $e^+e^- \to \gamma\gamma$. The difference between the fitted ψ' mass and the Particle Data Group ψ' value [3] determines that the systematic error of the beam energy determination of the scan is better than 50 keV, consistent with design. The result was published in **[P12]** (*The beam energy measurement system for the BEPCII collider*).

Preliminary τ-scan:

In December 2011, a preliminary τ mass scan was carried out with scans of the τ threshold region, as well as J/ψ and ψ' scans. The machine performance was not optimal, so the final τ scan will take place in the future. However, this made a good dry run, allowing us to test the system. In Hawaii, Harris and postdocs Luo and Kornicer carried out the analysis, with Luo selecting τ candidates and fitting the τ threshold points, Kornicer selecting hadrons and fitting the J/ψ and ψ' resonances as a function of the center of mass energy to determine the beam widths and energy offsets of the two peaks, and Harris determining luminosities at all scan points using Bhabha scattering and two photon production ($e^+ + e^- \to \gamma\gamma$).

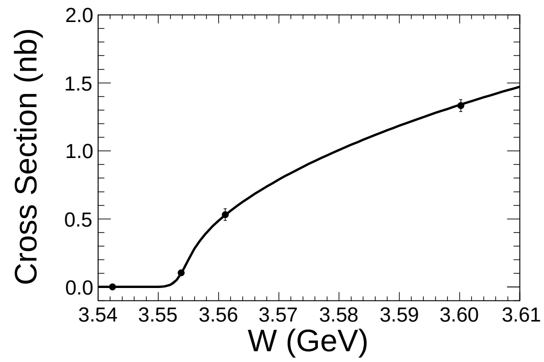

FIG. 15: The center-of-mass energy dependence of the $\tau^+\tau^-$ cross section resulting from the likelihood fit (curve), compared to the efficiency-corrected data. This figure is from a preliminary analysis of Dr. Liu.

An integrated luminosity of $\approx 24.0\ pb^{-1}$ was accumulated at four energy points near the energy threshold of $e^+e^- \to \tau^+\tau^-$ production. In order to reduce the statistical error in the mass of the τ lepton, the analysis incorporates 13 two-prong $\tau^+\tau^-$ final states, which are ee, $e\mu$, $e\pi$, ek, $\mu\mu$, $\mu\pi$, μk, πk, $\pi\pi$, kk, $e\rho$, $\mu\rho$ and $\pi\rho$. For the first ten decay channels, there are two charged tracks and no photons; for the $X\rho$ (for $X = e$, μ or π), the ρ candidate is reconstructed with $\pi^\pm\pi^0$, so there are also two charged tracks and an additional two photons.

An unbinned maximum likelihood (ML) fit is performed to the data to estimate the τ mass. From the ML fit, we obtain the preliminary τ mass, $m_\tau = 1776.91 \pm 0.12$ MeV/c^2, where the error is the statistical uncertainty. The systematical uncertainty analysis has been done, resulting in a final preliminary mass of $m_\tau = 1776.91 \pm 0.12^{+0.09}_{-0.12}$ MeV/c^2. Combining the statistical and systematical uncertainties, we obtain the τ mass: $m_\tau = 1776.91^{+0.15}_{-0.17}$ MeV. The τ mass from PDG2012 is $m_\tau = 1776.82 \pm 0.16$ [3]. The new BESIII τ mass measurement from the preliminary τ scan has comparable precision to the world average, indicating that our final τ scan will be able to improve the precision of the τ mass. The efficiency-corrected cross-section data as a function of corrected beam energy and the curve which results from the likelihood fit are shown in Fig. 15; they agree with each other very well. The analysis memo for the τ mass measurement at BESIII is being refereed.

BESIII does XYZ physics

Many new states, called XYZ states, have been found since the discovery of the $X(3872)$ by the Belle collaboration in 2003 [11]. These states were never predicted by quark antiquark potential models, and

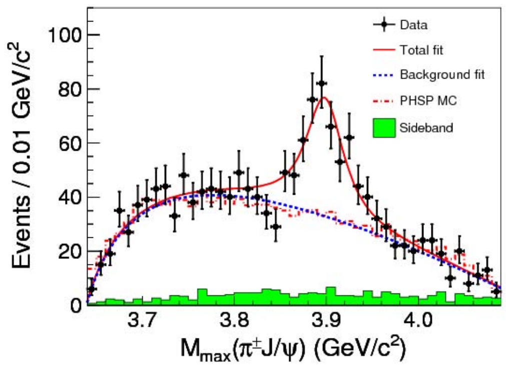

FIG. 16: Fit to the $\pi^{\pm}J/\psi$ mass distribution. Dots with error bars are data; the red solid curve shows the total fit, and the blue dotted curve the background from the fit; the red dot-dashed histogram shows the result of phase space Monte Carlo simulation; and the green shaded histogram shows the normalized J/ψ sideband events.

their discoveries have sparked much theoretical interest. An example is the $Y(4260)$ discovered by the BaBar experiment in the initial state radiation (ISR) process $e^+e^- \to \gamma_{ISR}\pi^+\pi^-J/\psi$ [12]. Its nature remains a mystery, since it does not have a place in the quark model of charmonium [13], and even though it is above $D\bar{D}$ threshold, it prefers to decay to $\pi^+\pi^-J/\psi$ [14].

In December of 2012, BESIII began running at a center of mass energy of 4260 GeV in order to study the $Y(4260)$. After running for 30 days, a sample of 525 pb^{-1} was accumulated, and clear signals of $\pi^+\pi^-J/\psi$ with $J/\psi \to e^+e^-$ (595 events) and $J/\psi \to \mu^+\mu^-$ (882 events) were seen. The Born cross section of $(62.9 \pm 1.9 \pm 3.7)$ pb is consistent with $Y(4260)$ production. Most interesting, a structure was seen in the $\pi^{\pm}J/\psi$ spectrum, dubbed the $Z_c(3900)^{\pm}$. Since it decays into charmonium and has charge, it is a candidate for a state composed of four quarks. Its mass and width are measured to be $(3899.0 \pm 3.6 \pm 4.9)$ MeV/c^2 and $(46 \pm 10 \pm 20)$ MeV, respectively. The fit to the $\pi^{\pm}J/\psi$ mass distribution is shown in Fig. 16. The results were published in **[P47]** (*Observation of a charged charmoniumlike structure in* $e^+e^- \to \pi^+\pi^-J/\psi$ *at* $\sqrt{s} = 4.26$ *GeV*) and were confirmed by the Belle collaboration [15] and an analysis of CLEOc data [16]. This is the first confirmed charged Z state.

BESIII continued running and accumulated a total of 2 fb^{-1} at the $Y(4260)$ and another 500 pb^{-1} at the $Y(4360)$. At the Lepton Photon meeting in July 2013, BESIII reported results on $Y(4260) \to \pi^+\pi^-h_c$ and $Y(4260) \to D^{*+}D^{*0}\pi^-$, where more new Z states are seen. BESIII has jumped head first into the world of XYZ physics.

In Hawaii, Harris and Park are looking for peaks in $Y(4260) \to$ inclusive γ decays. Tao is looking for decays to γ exclusive states.

Summary

The BESIII/BEPCII facility provides unique opportunities for investigations of a variety of important physics subjects. The past US participation in this program has been important both scientifically and politically: the interest of U.S. researchers in the BES physics program has increased its visibility in China and this has helped IHEP maintain its level of support for this effort. The Hawaii group has a substantial and beneficial impact on the BESIII/BEPCII program. We provide much of the leadership for the experiment. Most importantly, we are producing many interesting scientific results.

Appendices: Biographical Sketches, Publications, Bibliography and References Cited

Biographical Sketch

Frederick Allan Harris

Education:

University of Michigan	Eng. Physics	B.S.E. 1963 (Tau Beta Pi)
University of Michigan	Physics	M.S. 1965
University of Michigan	Physics	Ph.D 1970

Research and Professional Experience:

8/86 - present	Professor	University of Hawaii
8/78 - 7/86	Associate Professor	University of Hawaii
7/76 - 7/78	Associate Physicist	University of Hawaii
3/70 - 6/76	Assistant Physicist	University of Hawaii

Publications

1. M. Ablikim *et al.* (BESIII Collaboration), *Spin-Parity Analysis of $p\bar{p}$ Mass Threshold Structure in J/ψ and ψ' Radiative Decays*, Phys. Rev. Lett. **108**, 112003 (2012) [arXiv:1112.0942 [hep-ex]].

2. M. Ablikim *et al.* (BESIII Collaboration), *First observation of $\eta(1405)$ decays into $f_0(980)\pi^0$*, Phys. Rev. Lett. **108**, 182001 (2012) [arXiv:1201.2737 [hep-ex]].

3. M. Ablikim *et al.* (BESIII Collaboration), *Observation of χ_{c1} decays into vector meson pairs $\phi\phi$, $\omega\omega$, and $\omega\phi$*, Phys. Rev. Lett. **107**, 092001 (2011) [arXiv:1104.5068 [hep-ex]].

4. M. Ablikim *et al.* (BES III Collaboration), *"Study of $a_0(980)--f_0(980)$ mixing*, Phys. Rev. D **83**, 032003 (2011) [arXiv:1012.5131 [hep-ex]].

5. M. Ablikim *et al.* (BESIII Collaboration), *"Confirmation of the $X(1835)$ and observation of the resonances $X(2120)$ and $X(2370)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$*, Phys. Rev. Lett. **106**, 072002 (2011) [arXiv:1012.3510 [hep-ex]].

6. M. Ablikim *et al.* (BES III Collaboration), *Study of χ_{cJ} radiative decays into a vector meson*, Phys. Rev. **D 83**, 112005 (2011) [arXiv:1103.5564 [hep-ex]].

7. E. V. Abakumova *et al.*, *The beam energy measurement system for the Beijing electron-positron collider*, Nucl. Instrum. Meth. A **659**, 21 (2011) [arXiv:1109.5771 [physics.acc-ph]].

8. M. Ablikim *et al.* (BES III Collaboration), *Measurement of the Matrix Element for the Decay $\eta' \to \eta\pi^+\pi^-$*, Phys. Rev. D **83**, 012003 (2011) [arXiv:1012.1117 [hep-ex]].

9. M. Ablikim *et al.* (BES III Collaboration), *Higher-order multipole amplitude measurement in $\psi(2S) \to \gamma\chi_{c2}$*, Phys. Rev. D **84**, 092006 (2011) [arXiv:1110.1742 [hep-ex]].

10. M. Ablikim *et al.* (The BESIII Collaboration), *"Measurements of $h_c(^1P_1)$ in ψ' Decays*, Phys. Rev. Lett. **104**, 132002 (2010) [arXiv:1002.0501 [hep-ex]].

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F. A. Harris, Kendall Hunt Publishing Co., ISBN 978-0-7575-6855-8.
Published “General Physics Laboratory II, Electricity & Magnetism, Optics”,
F. A. Harris, Kendall Hunt Publishing Co., ISBN 978-7575-6863-3.
Royalties from these books are used to benefit our lower division labs.

Synergistic Activities:

BESII CO-SPOKESMAN (US side)	1998 - present
BESIII CO-SPOKESMAN (outside China)	2006 - present
Co-chair of CHARM2012	Honolulu, Hawaii, May 14 - 17, 2012

Collaborators and Co-Editors:
BESII and BESIII Collaborations

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Mike Longo, University of Michigan, Ann Arbor, MI 4810
Byron Roe, University of Michigan, Ann Arbor, MI 4810

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Education:

Boston University:	B.S. in Electrical Engineering, 1989
Boston University:	M.A. in Experimental Physics, 1995
University of Hawaii:	Ph.D. in Experimental Physics, 1999

Professional Employment:

2010-present	Associate Professor of Physics, University of Hawaii
2005-2010	Assistant Professor of Physics, University of Hawaii
2002-2005	Director, Instrumentation Development Laboratory, University of Hawaii
2000-2002	Senior Scientist, AOptix Technologies Campbell, California (silicon valley)
1998-2000	EE/Physicist, University of Hawaii, University of Hawaii
1997-1998	Visiting Researcher CMS Exp., CERN & L.I.P. Portugal, based at CERN
1995-1997	Research Associate, University of Hawaii
1992-1995	Senior Electrical Engineer/Physicist, Boston University & SSC Lab.
1989-1992	Research Associate, Boston University

Selected Recent Publications :

1. **G. Varner** and L. Ruckman, "Sub-10ps Monolithic and Low-power Photodetector Readout," *Nucl. Instr. Meth.* **A601** (2009) 438-445.
2. H. Hoedlmoser, **G. Varner** and M. Cooney, "Hexagonal pixel detector with time encoded binary readout," *Nucl. Instr. Meth.* **A599** (2009) 152-160.
3. J. Benitez, D.W.G.S. Leith, G. Mazaheri, B.N. Ratcliff, J. Schwiening, J. Vavra, L. Ruckman and **G. Varner**, "Status of the Fast Focusing DIRC (fDIRC)," *Nucl. Instr. Meth*. **A595** (2008) 104-107.
4. **G. Varner**, L. Ruckman and A. Wong, "The First version Buffered Large Analog Bandwidth (BLAB1) ASIC for high luminosity collider and extensive radio neutrino detectors," *Nucl. Instr. Meth.* **A591** (2008) 534-545.
5. **G.S. Varner**, L.L. Ruckman, P.W. Gorham, J.W. Nam, R.J. Nichol, J. Cao, M. Wilcox, "Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," *Nucl. Instr. Meth.* **A583** (2007) 447-460.

Synergistic Activities :

1. Large-area, pico-second timing detector development [Argonne, Univ. Chicago, Univ. Hawaii, SLAC collaboration]
2. Coded-aperature imager for beam bunch diagnostics at a high intensity electron storage ring [Cornell Univ., KEK and Univ. Hawaii collaboration]
3. Fast Focusing Direct Internal Reflected Cherenkov (DIRC) detector development for Particle Identification at a Super B factory in Italy [Univ. Cincinnati, Univ. Hawaii and SLAC collaboration]

4. Imaging Time Of Propagation detector development for Particle Identification at a Super B factory in Japan [Univ. Cincinnati, Univ. Hawaii, KEK, Nagoya Univ. collaboration]

Collaborators & Other Affiliations:

Belle Pixel Upgrade

- Hiro Aihara *Univ. of Tokyo (Japan)*, Herbert Hoedlmoser, Tom Browder, Li Jin, James Kennedy, Marc Rosen, Larry Ruckman, Himansu Sahoo *Univ. of Hawaii*, Masashi Hazumi, Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*, Andrezj Bozek, Henryk Palka H. Niewondiczanski *Institute of Nuclear Physics (Poland)*, and Samo Stanic and *Nova Gorica Poly (Slovenia)*

International Linear Collider MAPS Pixel

- Steven Worm *Rutherford Appleton Laboratory (U.K.)*, Marc Winter *LEPSI, Strassbourg (France)* and Ray Yarema Fermi *National Accelerator Laboratory*

Silicon on Insulator Pixel Detectors

- Yasuo Arai and Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*and Hiro Ikeda *JAXA (Japan)*

Thin, Rad-hard, and fast-timing Pixel Detectors

- Chris Kenney *Molecular Biology Consortium/Stanford Univ.* and Sherwood Parker *Univ. of Hawaii and Lawrence Berkeley Lab.*

Giga-sample per second, GHZ analog bandwidth waveform acquisition

- Stefan Ritt *Paul Scherrer Institute (Switzerland)*

1ps Timing Resolution Detector Development

- Henry Frisch, Jean-Francois Genat, Fukun Tang *University of Chicago*

Next generation large Photomultiplier Readout

- John Anderson, Karen Byrum, Gary Drake, Ed May, Harry Weerts *Argonne National Laboratory*

Common Pipelined High-speed Data Acquisition and Storage

- Tadeo Higuchi and Manobu Tanaka *KEK High Energy Physics Laboratory (Japan)*

Imaging Hard X-ray Compton Polarimeter pixel detector

- Hiroyasu Tajima *Kavli Institute/SLAC National Accelerator Laboratory*

Belle Particle Identification Detector Upgrade

- Toru Iijima, Kenji Inami *Nagoya University (Japan)*, Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman *Univ. of Hawaii*, Alan Schwartz, Kay Kinoshita *Univ. of Cincinnati*

Super-B Particle Identification Detector Upgrade

- Peter Krizan, Samo Korpar *J. Stefan Institute (Slovenia)*, Kurtis Nishimura, Larry Ruckman *Univ. of Hawaii*, Jerry Vavra, Blair Ratcliff *SLAC National Accelerator Laboratory*

Graduate advisor Stephen Olsen, Seoul National University (Korea)

5 graduate students advised, 4 postdoctoral candidates sponsored

Recent Talks

1. F. A. Harris, "Recent Results from BESIII", invited talk at XLIX International Winter Meeting on Nuclear Physics, Bormio, Italy, Jan. 24 - 28, 2011
2. F. A. Harris, "Recent Results from BESIII", invited talk at SLAC Experimental Seminar, April 3, 2012
3. F. A. Harris, "Charmonium Spectroscopy and the $Z_c^{\pm}(3900)$", invited talk at Workshop on Tau-Charm at High Luminosities, Island of Elba, Italy, May 27 - 31, 2013
4. C. P. Shen, "Recent Results from Belle and BESIII", Summer School, Osaka University, Aug. 9 - 12, 2011
5. M. Pelizaeus, "QCD Studies in the Charm Region", Spring Meeting of the German Physical Society, Muenster (Germany), March 2011
6. M. Pelizaeus, "Recent Results from BESIII", GHP 2011, Anaheim, CA (USA), May 2011
7. M. Pelizaeus, "Study of $J/\psi \to \gamma\phi\phi$", BESIII Physics & Software Workshop, Beijing (China), September 2011
8. M. Pelizaeus, "Studies of the $\phi\phi$ System in Charmonium Decays at BESIII", Seminar Experimental Hadron Physics, Ruhr-Universitaet Bochum, December 2011
9. M. Pelizaeus, "Charm Physics at PANDA", Charm 2012, Honolulu (USA), May 2012

Recent BES Publications:

P1. M. Ablikim *et al.* (BES Collab.), "Observation of charged κ in $J/\psi \to K^*(892)^{\mp} K_s \pi^{\pm}$, $K^*(892)^{\mp} \to K_s\pi^{\mp}$ at BESII," Physics Letters B **698**, 183 (2011)

P2. M. Ablikim *et al.* (BES Collab.), "Measurement of the Matrix Element for the Decay $\eta' \to \eta\pi^+\pi^-$," Physical Review D **83**, 012003 (2011)

P3. M. Ablikim *et al.* (BES Collab.), "Study of $a_0^0(980) - f_0(980)$ mixing," Physical Review D **83**, 032003 (2011)

P4. M. Ablikim *et al.* (BES Collab.), "Confirmation of the $X(1835)$ and observation of the resonances $X(2120)$ and $X(2370)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$," Physical Review Letters **106**, 072002 (2011)

P5. M. Ablikim *et al.* (BES Collab.), "First Observation of the Decays $\chi_{cJ} \to \pi^0\pi^0\pi^0\pi^0$," Physical Review D **83**, 012006 (2011)

P6. F. A. Harris (BES Collaboration), "Charmonium in China: BEPCII/BESIII," Int. J. Mod. Phys. A **26**, 347 (2011)

P7. M. Ablikim *et al.* (BES Collab.), "Study of χ_{cJ} radiative decays into a vector meson," Physical Review D **83**, 112005 (2011)

P8. M. Ablikim *et al.* (BES Collab.), "Observation of χ_{cJ} decays into vector meson pairs, $\phi\phi$, $\omega\omega$, and $\omega\phi$," Physical Review Letters **107**, 092001 (2011)

P9. M. Ablikim *et al.* (BES Collab.), "Observation of χ_{cJ} decays into $p\bar{p}K^+K^-$," Physical Review D **83**, 112009 (2011)

P10. M. Ablikim *et al.* (BES Collab.), "Search for CP and P violating pseudoscalar decays into $\pi\pi$," Physical Review D **84**, 032006 (2011)

P11. M. Ablikim *et al.* (BES Collab.), "$\eta\pi^+\pi^-$ Resonant Structure around 1.8 GeV/c^2 and $\eta(1405)$ in $J/\psi \to \omega\eta\pi^+\pi^-$," Physical Review Letters **107**, 182001 (2011)

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P13. M. Ablikim *et al.* (BES Collab.), "Search for η_c' decays into vector meson pairs," Physical Review D **84**, 091102 (2011)

P14. M. Ablikim *et al.* (BES Collab.), "Higher-order multipole amplitude measurement in $\psi(2S) \to \gamma\chi_{c2}$," Physical Review D **84**, 092006 (2011)

P15. M. Ablikim *et al.* (BES Collab.), "Search for a light Higgs-like boson A^0 in J/ψ radiative decays," Physical Review D **85**, 092012 (2012)

P16. M. Ablikim *et al.* (BES Collab.), "Spin-Parity Analysis of $p\bar{p}$ Mass Threshold Structure in J/ψ and ψ' Radiative Decays," Physical Review Letters **108**, 112003 (2012)

P17. F. A. Harris [BESIII Collaboration], "Recent results from BESIII," PoS BORMIO **2011**, 044 (2011)

P18. M. Ablikim *et al.* (BES Collab.), "Precision measurement of the branching fractions of J/$\psi \to \pi^+\pi^-\pi^0$ and $\psi' \to \pi^+\pi^-\pi^0$," Physics Letters B **710**, 594 (2012)

P19. M. Ablikim *et al.* (BES Collab.), "Measurements of the mass and width of the η_c using $\psi' \to \gamma\eta_c$," Physical Review Letters **108**, 222002 (2012)

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P22. M. Ablikim *et al.* (BES Collab.), "Study of $J/\psi \to p\overline{p}$ and $J/\psi \to n\overline{n}$," Physical Review D **86**, 032014 (2012)

P23. M. Ablikim *et al.* (BES Collab.), "Two-photon widths of the $\chi_{c0,2}$ states and helicity analysis for $\chi_{c2} \to \gamma\gamma$," Physical Review D **85**, 112008 (2012)

P24. M. Ablikim *et al.* (BES Collab.), "First observation of the M1 transition $\psi(3686) \to \gamma\eta_c(2S)$," Physical Review Letters **109**, 042003 (2012)

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P26. M. Ablikim *et al.* (BES Collab.), "Determination of the number of J/ψ events with $J/\psi \to$ *inclusive* decays," Chinese Physics C **36**, 915 (2012)

P27. M. Ablikim *et al.* (BES Collab.), "Observation of two new N^* resonances in $J/\psi \to p\overline{p}\pi^0$," Physical Review Letters **110**, 022001 (2013)

P28. M. Ablikim *et al.* (BES Collab.), "Evidence for $\eta_c \to \gamma\gamma$ and Measurement of $J/\psi \to 3\gamma$," Physical Review D **87**, 032003 (2013)

P29. M. Ablikim *et al.* (BES Collab.), "Observation of $e^+e^- \to \eta J/\psi$ at center-of-mass energy of 4.009 GeV," Physical Review D **86**, 071101 (2012)

P30. M. Ablikim *et al.* (BES Collab.), "Experimental study of ψ' decays to $K^+K^-\pi^0 and K^+K^-\eta$," Physical Review D **86**, 072011 (2012)

P31. M. Ablikim *et al.* (BES Collab.), "Observation of χ_{cJ} Decays to $\Lambda\overline{\Lambda}\pi^+\pi^-$," Physical Review D **86**, 052004 (2012)

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P34. M. Achasov *et al.*, "A scenario for high accuracy tau mass measurement at BEPC-II," Chinese Physics C **36**, 573 (2012)

P33. M. Ablikim *et al.* (BES Collab.), "Search for η and η' Invisible Decays in $J/\psi \to \phi\eta$ and $\phi\eta'$," Physical Review D **87**, 012009 (2013)

P34. M. Ablikim *et al.* (BES Collab.), "Study of $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$ via η_c exclusive decays," Physical Review D **86**, 092009 (2012)

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Neutrino Physics Task C

Faculty: *J.G.Learned, S. Matsuno, J. Maricic, G. Varner*
Students: *S. Dubey, S. Li, R. Meyhandan, J. Murillo, M. Sakai, S.Smith*

Introduction

Three faculty members Jelena Maricic (JM), John Learned (JGL) and Shige Matsuno (SM) lead the neutrino and dark matter research group supported by the Department of Energy HEPG grant. Jelena Maricic is a new faculty member that joined the group in August 2012. During the last 3 year reported period, the grant supported graduate students and postdocs that worked on various projects described below.

In the area of neutrino physics the group is sharing their effort between running experiments SuperK (PI JGL), KamLAND (PI JGL) and Double Chooz (PI JM) and active R&D on coming neutrino experiments LBNE (PI SM) and mTC (PI JGL), CeLAND(PI JM)/reactor short baseline sterile neutrino search (PI JGL). Through these experimental projects, the group has dedicated their effort to investigation of open questions in neutrino physics: exploration of neutrino oscillations with reactor, solar and atmospheric neutrinos; the reactor antineutrino anomaly (RAA); mass hierarchy and the δ_{CP} violation phase with accelerator neutrinos. Large neutrino experiments have a leading role in one of the most important, long unanswered questions today: the search for nucleon decay and a number of particle astrophysics questions.

In the area of dark matter searches, we build upon our extensive experience with low energy neutrino detectors, understanding of backgrounds, calibrations and analysis techniques used for rare signal searches. We approach the challenge of indirect dark matter detection using the existing neutrino detectors KamLAND (KL) and SuperK, suitable for low mass dark matter detection. The complementarity of detector designs (water Cerenkov and liquid scintillator) will enable us to place robust limits on the dark matter interaction cross-section and ensure credibility of a potential dark matter candidate detection claim. We tackle the problem of the direct search for WIMPs with the DarkSide detector (PI JM) that is in the final stages of construction and, for which we engage in the calibration effort for commissioning and detector operation.

SuperK experiment

We report on the work that our group has done toward indirect detection of Dark Matter particles. We performed detailed calculations of expected dark matter signatures, pushing the search for lower energy indirect WIMP detection in several experiment, in particular SuperK and KamLAND. Low mass WIMPs of around 10 GeV have become increasingly interesting after the recent CDMS claims.

Or group has participated in the SuperK experiment since its inception and carried a strong role in the important discovery of neutrino oscillations and the follow on work over the last few years. We take regular shifts annually at SuperK, attend collaboration meetings, serve on paper committees, and maintain a strong involvement in the atmospheric neutrino and muon analysis groups. We shall focus herein on our recent efforts at UH in pursuing low mass dark matter detection.

DM indirect detection signatures

Convincing evidence for the existence of Dark Matter has been obtained from a wide variety of astronomical data, implying that Dark Matter represents a major component of the Universe. However, everything else about it, including the nature of Dark Matter is still unknown. A leading candidate explanation is that Dark Matter is composed of Weakly Interacting Massive Particles (WIMPs) created in the early universe, gravitationally clustered with standard baryonic matter.

One way to detect WIMPs comes about from the annihilation of the putative particles as they gravitationally concentrate after elastic scattering from matter, in the galaxy center, some sort of clusters, the sun and even in the earth. If they behave as Majorana particles as favored by many models, they will reach an equilibrium density, with capture rate equal to annihilation rate. The annihilation channel(s) depend upon the model, and range from “leptophilic” (direct neutrino pair production) to production of heavy particles with a cascade of decays, all of which include neutrinos. SUSY standard models tend to favor hundred GeV masses, but limits and hints from various experiments show a trend to lower WIMP masses, perhaps in the ~ 10 GeV range.

DM signature in the neutrino detectors

One of the key experimental approaches to the detection of dark matter is through indirect experiments, namely neutrino detectors. In some region of elevated dark matter density (for example, the core of the Sun or the Earth, or the galactic center), dark matter particles annihilate with each other to produce Standard Model particles, which can be detected with experiments on earth, such as SuperK.

These stable particles could be produced directly through dark matter annihilation (i.e, through the process $\chi\chi \to p\bar{p}, e^+e^-, \gamma\gamma, \nu\bar{\nu}$). Another possibility is that dark matter particles annihilate to some other Standard Model particles, which in turn decay by showering off the stable particles listed above. Either scenario has interesting distinguishing features.

The advantage of indirect production of stable SM particles is that it is universal; SM particles produced through DM annihilation will shower off at least some set of p, e, γ, ν (often all of them) as they decay. The direct annihilation of dark matter particles to stable SM particles will, on the other hand, be suppressed by the branching fraction to that particular final state (which may be quite small). The advantage of direct production of stable SM states, however, is that the SM particle is produced with an energy equal to the dark matter mass. This can potentially result in a sharp peak in the energy spectrum, as opposed to the broad spectrum expected of indirect production.

One of the main theoretical candidates for dark matter has been neutralino WIMPs, and some search strategies and analysis have been optimized with this in mind. However, a series of dark matter experiments has presented hints of data that might suggest a relatively light dark matter candidate[5, 8]. A unifying feature of these hints is that they are not easily explained by neutralino WIMPs. On the other hand, a variety of theoretical models has also arisen in recent years that can provide reasonable dark matter candidates which are not neutralino WIMPs, and which may have a wide range of masses and couplings [9]. It is thus worthwhile to revisit some of the underexplored regions of dark matter parameter space.

A study of direct annihilation to neutrinos must necessarily be focused on the low dark matter mass range, specifically $m_X \approx 4$ - 10 GeV. For smaller dark matter mass, dark matter evaporation becomes significant[7], and it is difficult to obtain significant bounds on the dark matter-nucleon scattering cross-section. For masses larger than 10 GeV, bounds on the dark matter nucleon spin-independent scattering cross-section from direct detection experiments (shown in Figure 17) are already so restrictive that it appears unlikely that significant improvement can arise from neutrino experiments.

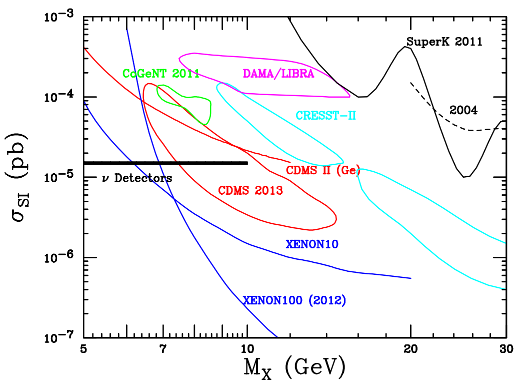

FIG. 17: Bounds on spin-independent scattering as a function of dark matter mass m_X. Favored regions with 90% CL shown for DAMA (magenta), CoGeNT (green), CRESST (cyan), and CDMS (red). Previous Super-K analysis done in 2004 (black dashed) and 2011[3] (black solid) looking at dark matter annihilation in the Earth used high-energy events only, cutting off sensitivity in this low mass region. The "ν Detectors" line (thick black) indicates the estimated sensitivity for indirect detection in this region as calculated in [4].

Figure 17 shows previous searches performed at Super-K, which focused on dark matter masses above 10 GeV [3]. These searches made use of upward through-going muon data sample, which necessarily restricts the search to higher dark matter masses.

To probe the lower mass range, Ms. Smith has begun to analyze the fully contained muon and electron events. Super-K stands to set a very competitive limit on the spin-independent scattering cross section in the low-mass region[4].

Using the DarkSUSY and WimpSim[10, 11] software packages, plus our own calculations, we (Smith, Sakai, Kumar and Learned) have calculated the expected neutrino flux from annihilations in the Sun and Earth[1]. Numerical simulations were run on the Hawaii Open Supercomputing Center (HOSC) computing cluster.

These neutrino spectra (an example of which is

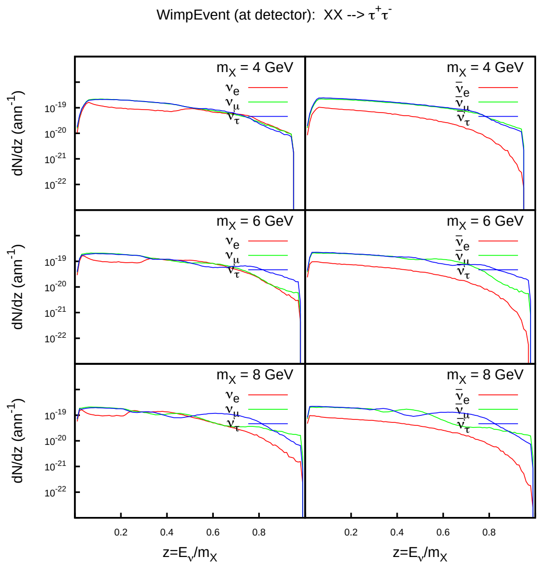

FIG. 18: Neutrino spectra (left panels) and anti-neutrino spectra (right panels) at the detector for dark matter annihilation to the $\tau^+\tau^-$ channel. The spectra for $\nu_e(\bar{\nu}_e)$, $\nu_\mu(\bar{\nu}_\mu)$, and $\nu_\tau(\bar{\nu}_\tau)$ are shown in red, green, and blue, respectively. Spectra are shown for $m_X = 4, 6, 8\ GeV$.

shown in figure 18) were then used to generate a Monte Carlo data set simulating the SuperK detector response. Using existing atmospheric Monte Carlo, events are selected by matching incoming neutrino energy and direction to our dark matter induced neutrino signal. This method allows us to take advantage of all energy and particle types, whereas previous searches at SuperK were limited to the through-going muon sample only, and generally sensitive to greater masses.

The resulting distributions are now being fitted to existing data which will set limits on dark matter annihilations in the Earth. It may be noted that the earth as a source of DM annihilations may be somewhat better than previously thought. This work is nearly complete, and Ms. Smith intends to graduate this Fall.

Dark Matter detection in KamLAND

At the outset we should mention that UH continues as a collaborator in KamLAND both in exploring the ability to reconstruct higher energy (GeV) interactions in liquid scintillator as we discuss below, and through our plan for the CeLAND plan to search for sterile neutrinos, as discussed in Section 2 below. We continue however as previously as collaborators in the ongoing KamLAND work, though we are not part of the KamLAND double beta search KamLAND Zen). We do take shifts and carry on regular collaborator duties.

There has been a plethora of recent efforts to employ neutrino detectors in the search for indirect signatures of the existence of dark matter. The usual technique is to find an excess of neutrino events that point toward a known gravitational well existing at the center of some large celestial body that gravitationally attracts dark matter particles. Particles get gravitationally trapped and may eventually collide, annihilating to standard model particles, including neutrinos. The most common celestial bodies include stars such as our own Sun [3] or even the Earth. These searches have been previously done using water Cerenkov detectors like Super-Kamiokande [3], but have not been attempted with scintillation detectors. This is partly due to the tradition that scintillation detectors have been effectively utilized to detect very low energy neutrinos such as those originating from the Earth and nuclear reactors. This is also partly due to the fact that scintillation detectors have never been used to image particle tracks, let alone discern their direction of travel, and do particle identification on an event by event basis.

In this progress report, we illustrate a new algorithm based on our suggestions of three years ago for the possibility of such reconstruction via time inversion methods (running the Fermat surface backwards) and its application to KamLAND data taken from the Tokai-to-Kamioka (T2K) neutrino beam and from cosmic rays. We show a preliminary result on reconstructed particle directionality and particle identification.

Particle Directionality in High Energy Events

Figure 19 shows a couple of typical 1 GeV e^+ particles, supposedly from a neutrino of similar energies undergoing inverse-beta decay, being simulated with the KamLAND Geant4 simulation and being reconstructed with this new algorithm. As one can see there is fairly good agreement between the actual direction that the particle track traversed in and the reconstructed track directions. The degree of agreement is shown in fig. 20 and it is good to a few degrees. Sometimes the direction of the muons were mis-reconstructed going in the opposite direction from what was simulated if the muon tracks were near the edge of the detector. Efforts are underway to reduce the degeneracy in the reconstruction and improve resolution.

When the tracks were reconstructed with this algorithm, there seemed to be biases in the reconstruction track position. These biases occur frequently when the particle tracks are located near or at the edge of the detector fiducial volume. This is not surprising because these position reconstruction biases are also observed in other algorithms developed by

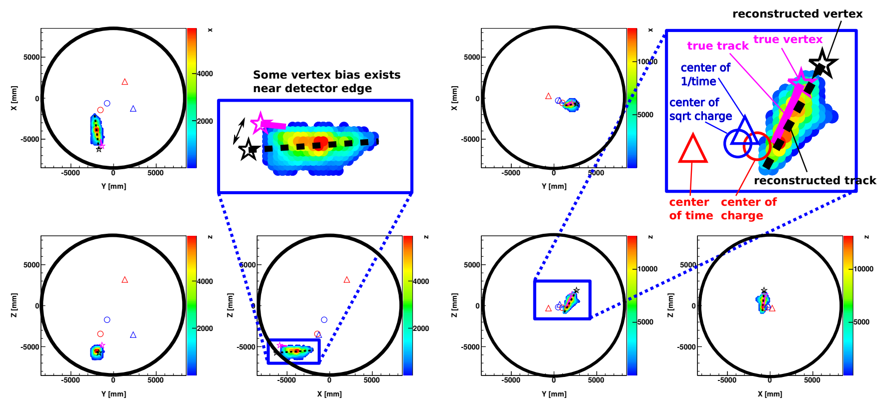

FIG. 19: Two sample reconstructed 1 GeV e^+ events in the KamLAND Geant4 simulation. Both set of three plots are an unfolded box view of the relative photon emission probability (depicted by the colored axes) projected onto the x, y, z planes. The X, Y, Z axes in units of mm correspond to actual physical location inside the KamLAND detector. The pink and black colored markers correspond to simulated and reconstructed particle tracks respectively. The star marker corresponds to the start of the track. The direction and length of the lines represent the direction and the magnitude of the distance traversed by the particle track before coming to a complete stop. The red circle and triangle represent the center of charge and time, respectively. The blue circle and triangle represent the center of the square root of charge and inverse of time, respectively. The vector pointing from the center of the inverse of time to the center of the square root of charge was used to break the degeneracy involved with the direction of the fitted track after the angle and length were derived.

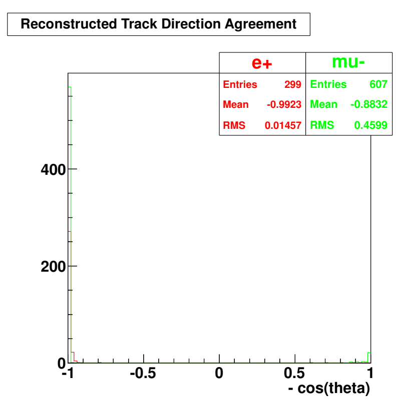

FIG. 20: A histogram showing the agreement between the direction of the reconstructed particle track direction with respect to that of what was simulated using the KamLAND Geant4 simulation. There is excellent agreement up to a few degrees for both lepton flavors of e^+ and μ^-. There is a slight degeneracy in which the μ^- particle was mistakenly reconstructed to be traveling in the opposite direction from what was simulated. This misreconstruction is most likely to occur when it is difficult to distinguish the timing between the start and end of the track such as the case for example when the particle track is near or even outside of the edge of the KamLAND detector balloon.

others for inverse beta decay. These biases are usually corrected by including a constant radial factor to the reconstructed position and we will most likely eventually also have to do the same. These bias corrections were intentionally left out of this report in order to show the raw performance of the algorithm for demonstrative purposes.

An additional reconstruction feature to note is that often, the length of the reconstructed particle track is very different from the length that the simulated particle traversed. This is due to the fact that this algorithm assigns high figure of merit values to positions in the detector that have a high probability of photon emission. This may or may not coincide with the actual path that the particle traversed. For example, in the case of a muon track, the points of photon emission coincide with the actual path that the muon traverses. However, in the case of a 1 GeV positron shower event, the positron only travels a certain distance before immediately annihilating with an electron in the medium and producing other ionizing particles such as gammas and other charged particles. This amounts to a more extended region where scintillation light is produced, and the algorithm fits this entire area.

Particle Identification in High Energy Events

An algorithm was also employed to identify and discriminate between simulated electron and muon leptons. This is important to be able to distinguish between electron and muon type neutrinos events. A fit was done to the calculate the width and length of the particle tracks. An ellipticity ratio e was defined as $e = \frac{(b-a)}{b}$, where a and b are the length and width of the image of the reconstructed track respectively.

Figure 21 shows a histogram plotting the ellipăticity e with respect to lepton flavors e^+ and μ^-. A 3m radius cut was placed on the ending point of the tracks for this plot. This was necessary to obtain a sufficient separation of the two distributions. A skew Gaussian was fitted to both distributions and a discriminant threshold value of $e = -1.6$ was obtained. This 1 GeV 3m radius cut is $\sim 9.8\%$ efficient. We are currently in the midst of looking for alternative discriminating features to be able to include more of the fiducial volume during particle identification.

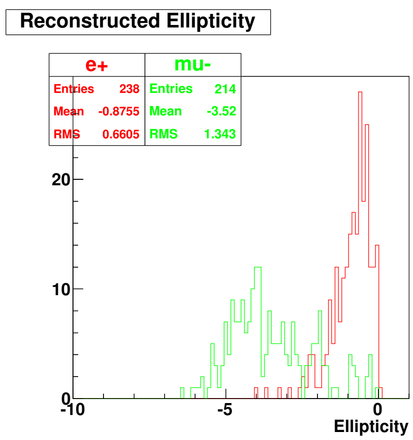

FIG. 21: A histogram showing the discrimination power between lepton flavors of e^+ and μ^- for simulated events. A 3m cut to the end point of fully contained particle tracks was used. The ellipticity of the reconstructed track image was fitted using the ellipticity formula $= \frac{(b-a)}{b}$, where a and b are the length and width of the image of the reconstructed track respectively. ellipticity $= -1.6$ is the crossing point between the two fitted skew Gaussians. This value is used as the threshold for discrimination.

T2K Events

An analysis was done on recent data taken from the Tokai-to-Kamioka (T2K) muon neutrino beam line shot from the J-PARC facility in Tsukuba, Japan. Although this beam line is mainly intended for Super-Kamiokande, KamLAND is also within the beam profile so that it is able to observe neutrino events from neutrinos in this beam using beam spill information provided by J-PARC.

KamLAND observed 3 fully contained T2K neutrino events out of a total of 14. Fig. 22, 23, 24 shows images of these three fully contained T2K events using this technique. As one can see, the reconstructed images are not as simple in structure as were the simulated events. This is most likely due to the fact that there is not just a single lepton to image, but there are a number of other particles also involved in the events, such as recoiling protons.

Figure 25 shows how well the reconstructed T2K events point back toward the J-PARC facility where the neutrinos originate. With 14 events in total, the statistics are not good enough to obtain a decisive conclusion on how well the algorithm is employed. However, the results are consistent with the known direction of J-PARC.

Figure 26 shows the single fully contained T2K event that survived the 3 m radius cut that was needed to apply the particle identification criteria. This single event was identified as being an e-like event.

The Double Chooz experiment

Jelena Maricic has been involved in the Double Chooz (DC) experiment from 2006 at Drexel University. She was responsible for selection, refurbishment and encapsulation of 200 8 inch PMTs for the DC Inner Veto (IV), followed by the development of the articulated arm, optical finder and glovebox extension needed for the full volume calibration of the two detectors.

During the last year, DC collaboration published four papers. The Double Chooz collaboration published the first nearly 3 σ non-zero θ_{13} measurement in the November 2011 [12], that was followed by the updated result in June 2012 [13]. The Double Chooz experiment is the first reactor antineutrino experiment that has fit both rate and energy spectrum shape to determine θ_{13} and has achieved good agreement with the rate only fit. The oscillation signature due to disappearance of electron antineutrinos has a well defined expected spectral distortion, so rate+spectrum shape fit is an important confirmation of the reliability of measurement. Such analysis demonstrated that Double Chooz has an excellent understanding of the detectors energy response and also verified the accuracy of the Double Chooz Monte Carlo simulation.

The non-zero value of θ_{13} completed the measurement of the neutrino oscillation angles and masses in the three-neutrino mixing matrix and demonstrated how vastly different it appears to be compared to the mixing in the quark sector, opening the questions of understanding the difference between quark and lepton mixing features. The main value of the θ_{13} neutrino mixing angle comes from its inseparable association with the CP-violation phase. A large value of θ_{13} significantly improves prospects for measuring the value of the CP-violation phase, that is the goal of LBNE project of which we are a part.

In its first year of running, Double Chooz acquired more than a week of reactor-off data providing experimental validation of the background predictions.

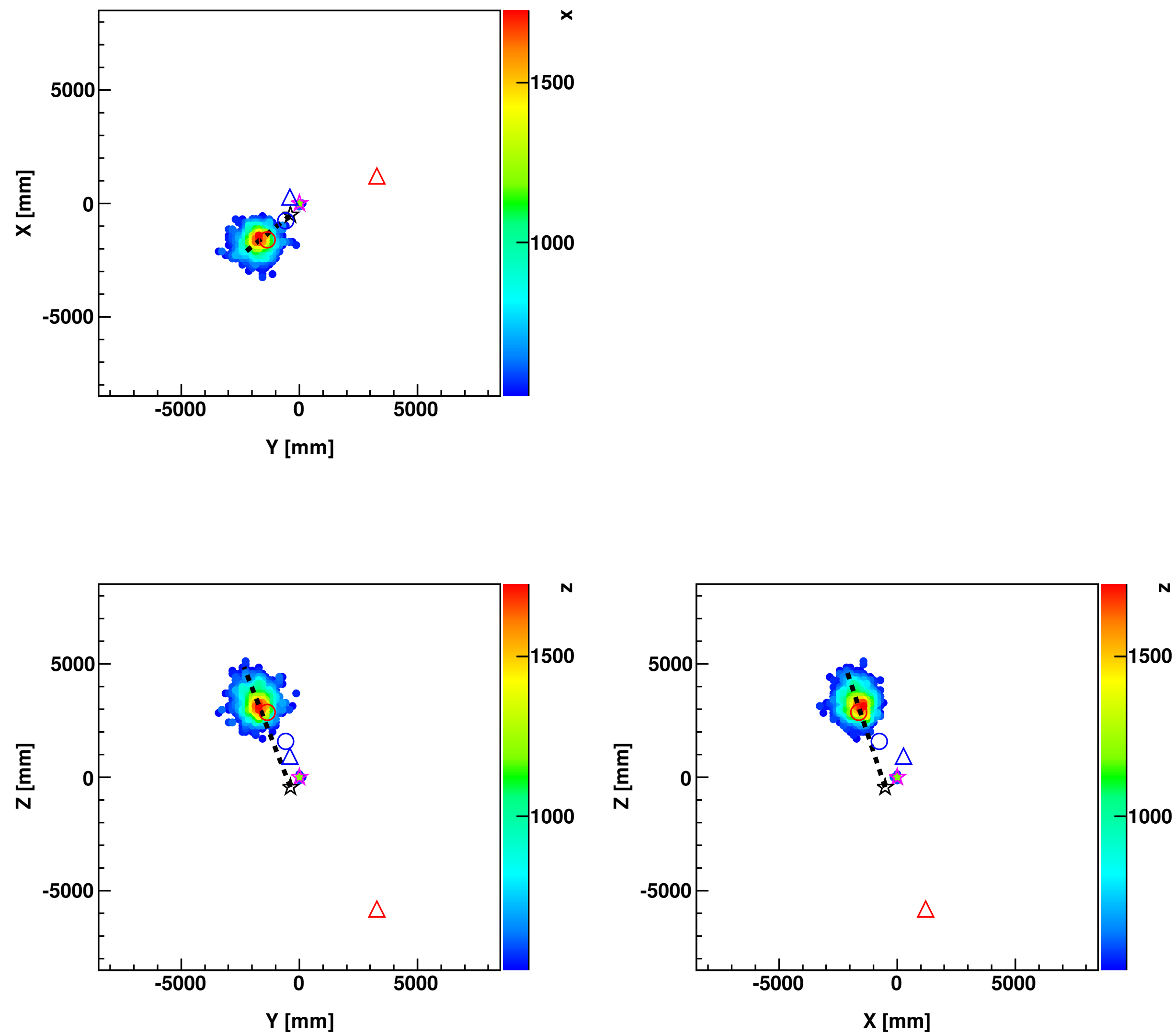

FIG. 22: First of three fully contained T2K events captured in the KamLAND detector. Visible energy of 76 MeV. The black star indicates the start of the fitted track. The dotted black line indicates the length and direction that fitted track traversed. The other red and blue markers show the same parameters as was explained in the case for simulated events. The red circle and triangle represent the center of charge and time, respectively. The blue circle and triangle represent the center of the square root of charge and inverse of time, respectively. The vector pointing from the center of the inverse of time to the center of the square root of charge was used to break the degeneracy involved with the direction of the fitted track after the angle and length were derived from the figure of merit image. The track images are not simple as in the case of simulated events. There is structure in the track shapes leading one to believe that the image is showing different tracks from a variety of daughter particles from the neutrino interactions.

Namely when both reactor cores of the Chooz Nuclear Power Station are brought down for maintenance we obtained an accurate background measurement with reactor-off data. Last fall the Double Chooz collaboration published the background measurement with ”reactor-off” data, which is unique among reactor θ_{13} neutrino experiments [14] confirming our calculation and additionally reinforcing the θ_{13} measurement.

Our latest result includes measurement of θ_{13} using inverse beta decay reaction with delayed coincidence capture on hydrogen instead of gadolinium, confirming the previously measured value [15].

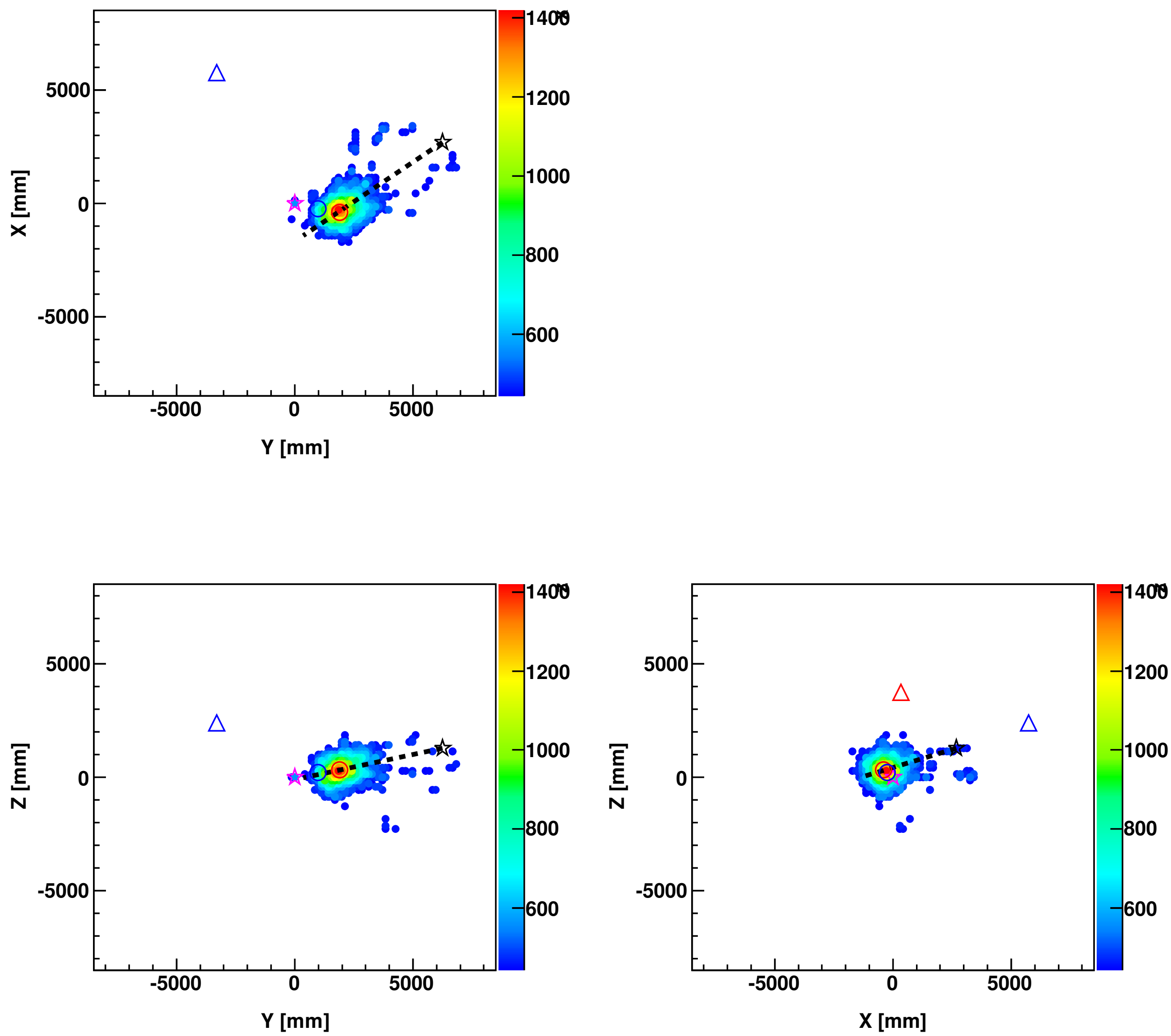

FIG. 23: Second of three fully contained T2K events captured in the KamLAND detector. Visible energy of 131 MeV.

This result uses a different data set, and has different systematics, giving a convincing confirmation of the analysis of data set acquired with neutron captures on gadolinium. Double Chooz was also able to perform the first test of Lorentz Violation with a reactor-based antineutrino experiment and place new limits on a class of theoretical models proposing Lorentz violation, published last fall [16].

In summary, over the course of last year the Double Chooz collaboration provided robust cross-checks and understanding of the neutrino mixing angle θ_{13} and the Double Chooz detector. These results were obtained with Double Chooz far detector alone and therefore lack the precision obtained by the other two reactor experiment Daya Bay and RENO. However, the near detector will begin data taking by late spring 2014, so we expect to obtain a high precision measurement of θ_{13} as well. The Hawaii group coordinates the energy reconstruction and energy estimation for the Double Chooz data analysis.

Analysis effort on the energy reconstruction is well coordinated with our hardware responsibility of the full volume calibration of the Double Chooz detector. Full volume calibration of the DC detectors is

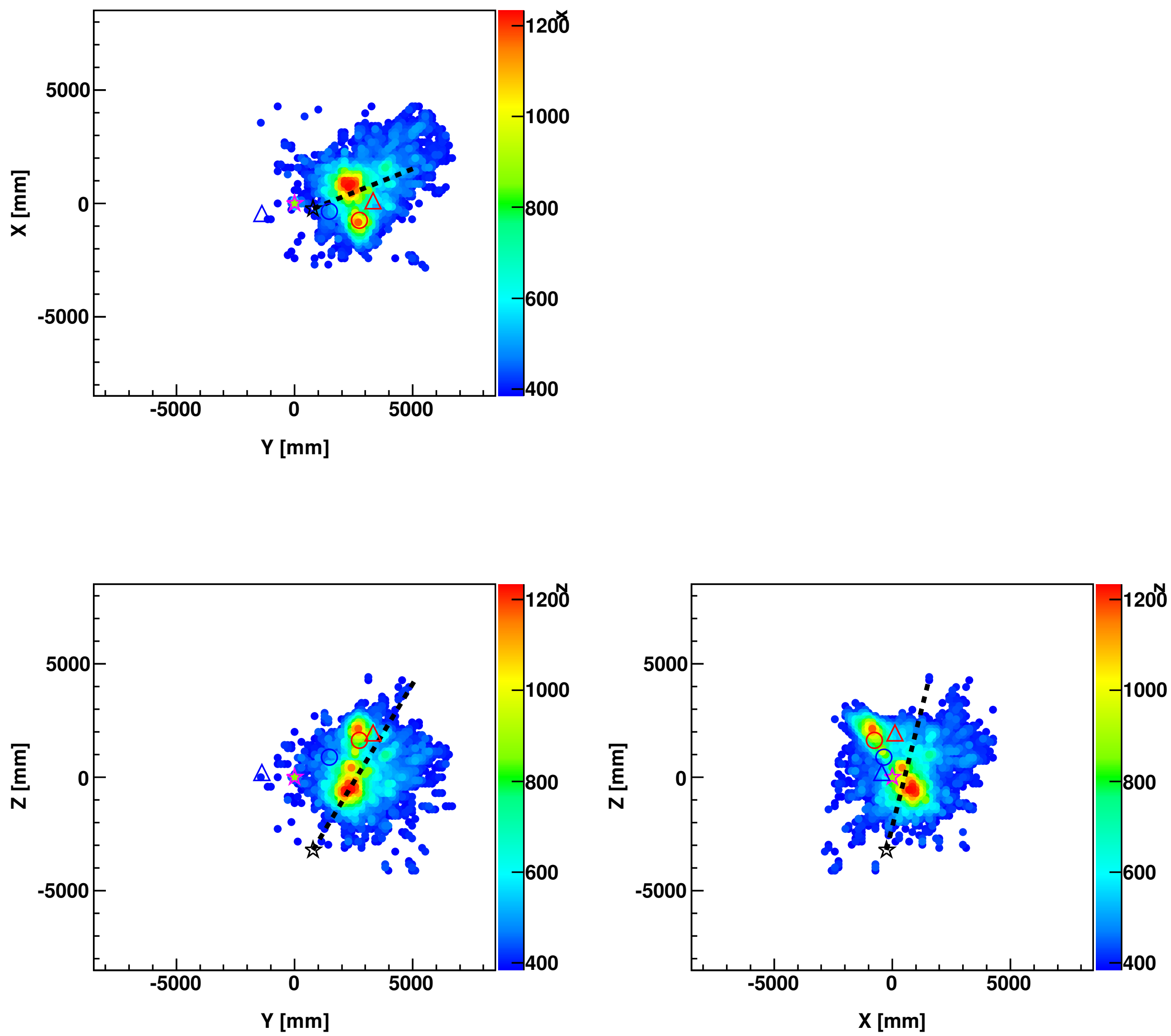

FIG. 24: Third of three fully contained T2K events captured in the KamLAND detector. Visible energy of 363 MeV.

essential for measuring spatial non-uniformities of the energy reconstruction for the accurate spectral response of neutrinos and measuring neutron detection efficiency. A large fraction of time last year was spent on the final testing, installation and commissioning of the articulated robotic arm (ARA), the device used for the full volume calibration. The ARA design and construction is supported by an NSF CAREER grant, however operating funds for travel and personnel (partial support) and modest equipment funds were funded by DOE. This effort will continue for the production of the pin radioactive source holder. Testing of the ARA took place at Argonne National Laboratory (ANL) where the ARA was originally designed and built. At ANL we have access to a high bay building, 35 ton overhead crane, high platform and local machine shop, which are integral to ARA testing. Figure 28 and 27 show testing set-up on an 8 m high bay platform and mock-up of the DC detector chimney for insertion tests. A total of 6 two-week long testing campaigns have been conducted from September 2012 to April 2013. We performed various tests with ARA in order to validate its reliability, precision, safety of operation and test potential failure modes. In July 2013, the ARA was installed in the Double Chooz far detector and tested to operate well as expected. The ARA was placed in the glove box extension (GBE)

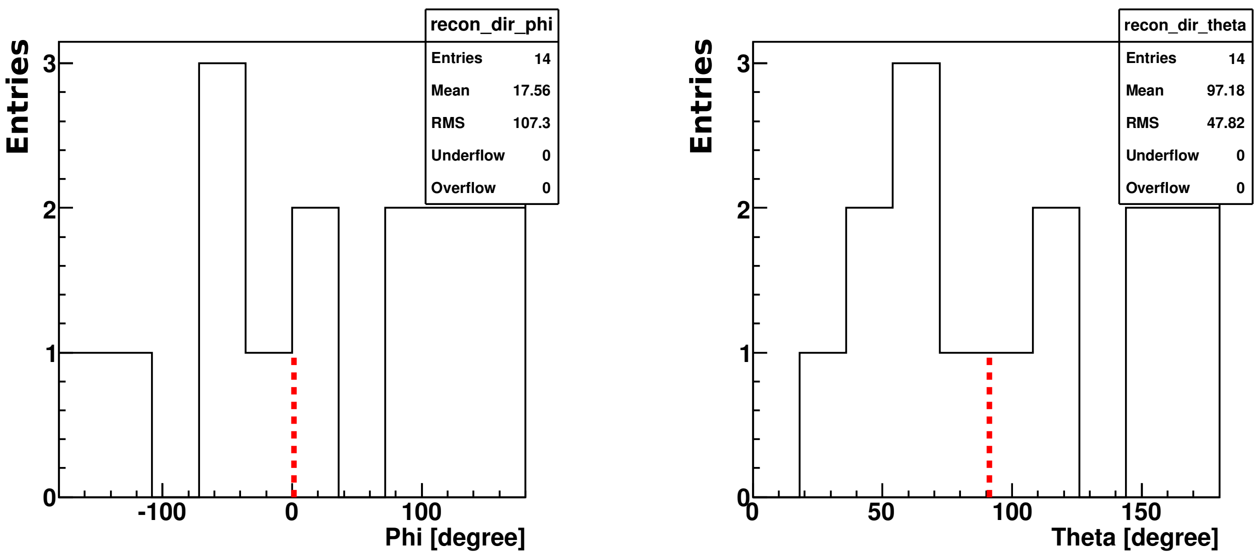

FIG. 25: Histograms showing the fitted Φ and Θ angles of the direction of the 14 events from the T2K neutrino beam. The red dotted lines indicate the direction toward the geographical location of the particle accelerator at J-PARC from which the beam originates. Its values are $\phi_{\text{J-PARC}} = 1.5^0$ and $\theta_{\text{J-PARC}} = 91.3^0$. The reconstructed values are $\phi_{\text{reconstructed}} = 17.6^0 \pm 107.3^0$ and $\theta_{\text{reconstructed}} = 97.2^0 \pm 47.8^0$.

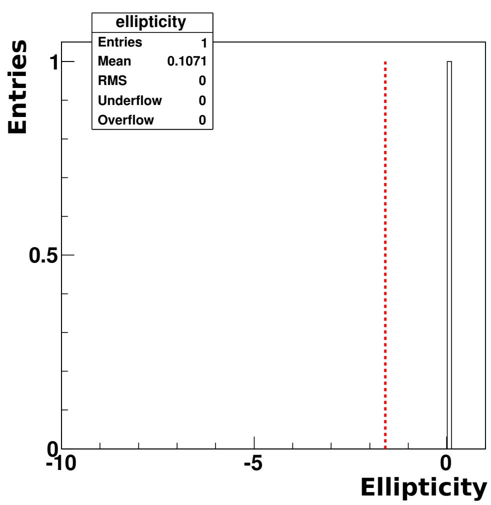

FIG. 26: Histogram showing the reconstructed ellipticity for the single T2K neutrino beam event that passed the 3 m radius fiducial volume cut. The e-like, μ-like event discriminating threshold derived to be -1.6 from simulations is indicated by the red dotted line. Any value greater than this line is defined as an e-like event.

that was built around it. The GBE encloses the AA and is supposed to provide oxygen free environment. While we managed to obtain a low level of oxygen of about 10-20 ppm, it was not possible to pressurize the GBE as expected due to higher than expected level of leaks. The UC Davis group that built the GBE will be going on-site in October 2013 to fix the problem with the GBE so that the AA be safely deployed in the far detector.

Liquid displacement tests

We tested the rate at which the arm displaces liquid under deployment circumstances. This is a very important question for us, since the acrylic chimney of the far detector cannot tolerate more than 3 cm of difference between different liquids. Level differences are maintained by the so-called XTOS system, the limitations of which we were aware based on the previous laser ball deployments. This question is also important to anticipate the maximum safe speed of telescoping inside the detector. For this test, we lowered the ARA into a tube of oil 10 cm in diameter and about 6 feet in height to measure the displacement. The tube diameter is very close to the DC chimney diameter of 9 cm. The tests were performed using three different Lexan ARM segments, the 350 mm, the 650 mm, and the 1050 mm segment. The three tests all showed steady, even liquid displacement at speeds ranging from 10 mm/s to 30 mm/s. We collected displacement data for the 10 mm/s case, with the results given in Table 29.

The rates listed are the average rates, which are higher for the larger segments since the segments are solid rods. Once the solid segment is fully immersed, the rates of liquid displacement level out, as seen in the graph in Fig. 30.

According to the test results shown above, the telescoping sections displace much less liquid than the Lexan articulation arms. The telescope is stable and drains quickly at tested deployment speeds from 1mm/s to 30 mm/s. The conclusion was that the ARA can be deployed at a safe speed that will

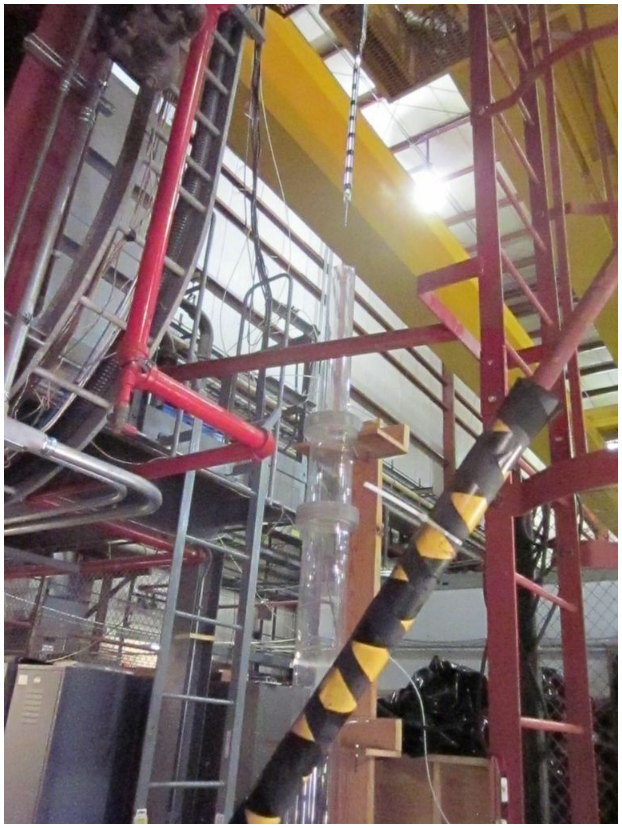

FIG. 27: ARA hanging from the high bay platform above the chimney mock-up.

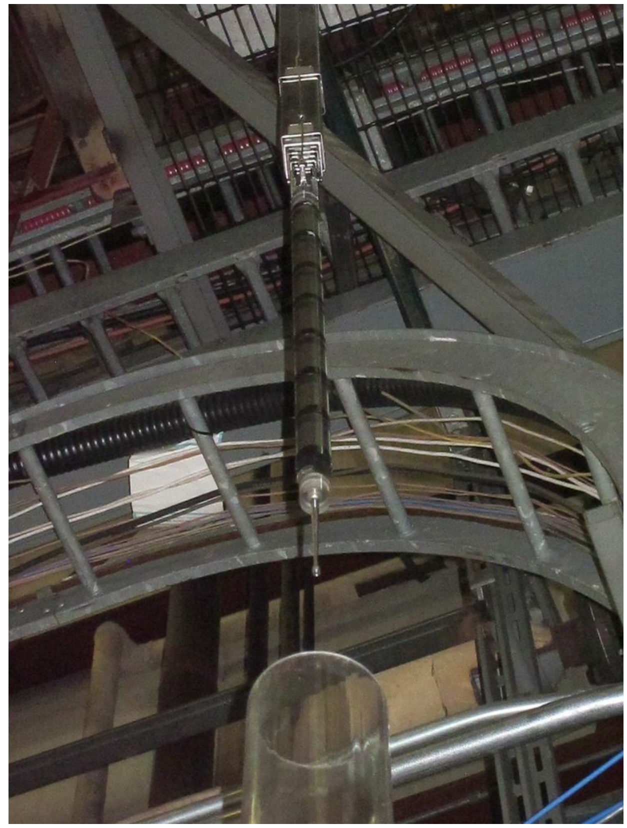

FIG. 28: Close-up of the ARA above the chimney mock-up.

not the endanger acrylic vessel of the DC detector. The final decision about the deployment speed of telescope will be made based on the observed NT differential pressure variations observed during the ARA commissioning phase.

Size	350 mm	650 mm	850 mm	1000 mm	1050 mm
Offset	3 mm forward, 0 mm right	3.5 mm forward, 1.5 mm right	5 mm forward, 1.5 mm right	6 mm forward, 4 mm right	6mm forward, 4 mm right
Pressure	40 psi (stainless nut)	65 psi (stainless nut)	60 psi (lexan nut)	75 psi (lexan nut)	75 psi (lexan nut)

FIG. 29: Table displacement rates for various arm segments at 10 mm/s deployment speed.

Cable breaking strength tests

One of the critical risks is breaking of the cable that holds the telescoping assembly together. The cables used are rated for 500 lb breaking strength which is about 10 times more than the weight of the ARA telescope hanging on the cable. We also conducted tests to verify the breaking strength of the cable and stainless steel sleeves used to make the loops and terminate the cable. The tests confirmed that the breaking strength of the cable is roughly around 500 lbs. or more, which led us to the conclusion that the cable has a sufficiently high safety factor.

Positioning precision tests

Accuracy of z-telescoping as well as ϕ positioning was tested. Due to a change from uncoated to Teflon coated stranded stainless steel cable we observed a 1-2 mm shift in z-positioning at each telescoping segment. The behavior was repeatable over many cycles. The cause of this behavior is change of the amount of weight that is supported by the cable as the telescope extends. With each additional extended segment, the extended segments hang on a previous segment, and one less segment weight is supported by the cable. As a result the cable contracts. The process reverses during the retraction process. Figure 31 shows the shifts in the position measured with a laser ranger. Since the shifts are reproducible they will be taken into account during

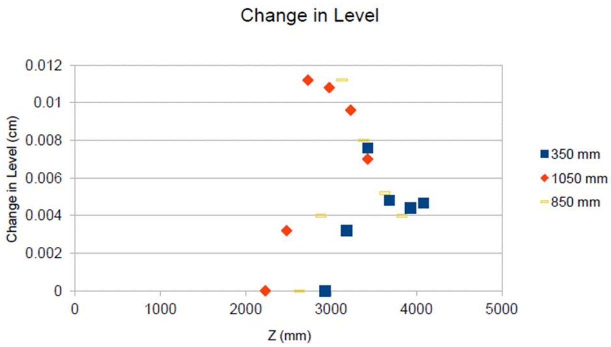

FIG. 30: Table displacement rates for various arm segments at 10 mm/s deployment speed. Displacement of the liquid increases as long as the solid ARM segments are being immersed, while it drops abruptly after that. The reason is that the telescoping segments are hollow and liquid can go in, so they displace very little volume.

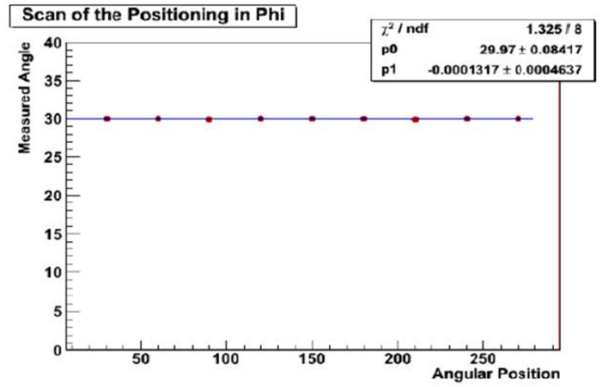

FIG. 32: Z position of the telescope measured with the laser ranger. Step like shifts occur between telescoping segment transitions.

deployment and will not incur additional positioning uncertainty.

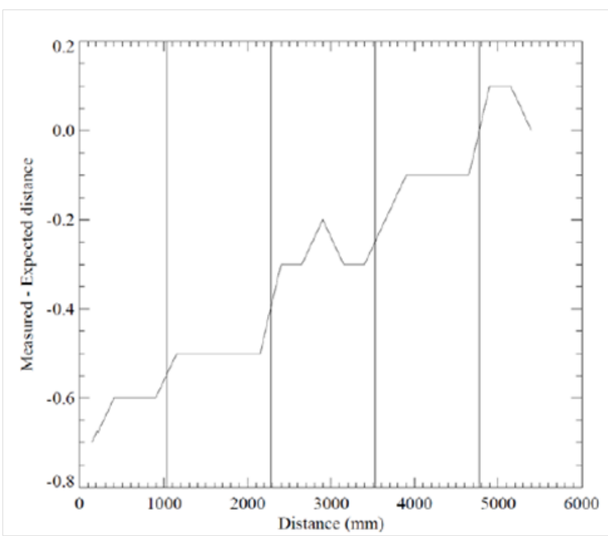

FIG. 31: Z position of the telescope measured with the laser ranger. Step like shifts happen between telescoping segment transitions.

Azimuthal positioning tests were conducted using triangulation. The Φ motor was rotated for a full 360° and assumed the original position with precision better than 0.1°. The ϕ motor positioning test results are shown in the Fig 32.

Choice of articulation segments

A lot of time was spent on the choice of articulation segments, so called articulation arms. They must hang completely vertically while deploying in the chimney due to its very small diameter, and be pulled to horizontal position once they reach the detector. They must sink, but must not be too heavy, since the closeness of the articulation cable to the pivot point, requires a large tension force on the cable to reach sufficient torque. The original design of the articulation segments were hollow Lexan tubes due to their lightness. However, numerous tests with a barrel of mineral oil of a similar density 0.825 g/cm^3 compared to DC scintillator whose density is 0.804 g/cm^3, showed that it is very difficult to ensure verticality of the hollow tubes during deployment. Several thicknesses and tube diameters were machined, mounted on ARA and tested in the mineral oil. In the end, we chose solid Lexan segments, since they were guaranteed to sink and the tension provided by the motion of the pneumatic piston that shortens the articulation cable to provide tension, was not too high. This solution also simplified fabrication and concerns regarding the choice of glue and tightness of the glue joints. A series of tests have been conducted in mineral oil bath to select appropriate pressure for the articulation piston. Insufficient amount pressure leads to the failure to articulate, and too much pressure shortens the whole telescope by about 0.5-1 cm. We also observed a forward shift in the radial direction as a consequence of articulation, which was calibrated by measuring the offsets in the mineral oil bath. Table 33 shows the range of pressures and offsets needed for different articulation segments that bring the source to different radial positions inside the detector.

Clean assembly of the ARA

In January 2013, the ARA was disassembled and sent out for cleaning and electro-polishing of all metal parts. After electro-polishing all metal parts were cleaned in an ultrasonic bath with Citranox

Size	350 mm	650 mm	850 mm	1000 mm	1050 mm
Offset	3 mm forward, 0 mm right	3.5 mm forward, 1.5 mm right	5 mm forward, 1.5 mm right	6 mm forward, 4 mm right	6mm forward, 4 mm right
Pressure	40 psi (stainless nut)	65 psi (stainless nut)	60 psi (lexan nut)	75 psi (lexan nut)	75 psi (lexan nut)

FIG. 33: Measurement of ϕ motion shows excellent precision and accuracy and no additional significant uncertainty is expected from the phi positioning motor.

and rinsed with DI water. All non-metallic parts were cleaned using the same procedure, and carefully baked in a specially constructed baking oven, under nitrogen atmosphere to avoid any contamination with water. Lexan is known to be hydroscopic, while the Double Chooz scintillator deteriorates quickly if it comes in contact with water. Therefore, great care was taken to carefully clean and dry the assembly parts. Figures 34 and 35 show the ARA during assembly and once it was finished inside the ISO 6 level clean room. Once assembled, the AA was tested on the forklift in April 2013 as can be seen in Fig. 36, after which it was packed in a specially built wooden crate and shipped to the detector site at Chooz, France.

FIG. 34: Clean assembly of the ARA inside the ISO 6 clean room. The ANL technician Frank Skrzecz helping with assembly.

Installation of the ARA in the Double Chooz far detector

The ARA arrived at Chooz without major problems. There were minor issues with the customs, which delayed arrival for about two weeks, but there was no damage during transport. The preparation began with installation of a clean tent extension, since the current clean tent could not accommodate the glovebox extension nor the ARA. After the clean tent extension was installed and sealed and the cleanliness level inside the clean tent was around ISO 6, we proceeded with ARA installation. Fig. 37 shows the ARA placed on the top of the glovebox prior to installation of the GBE.

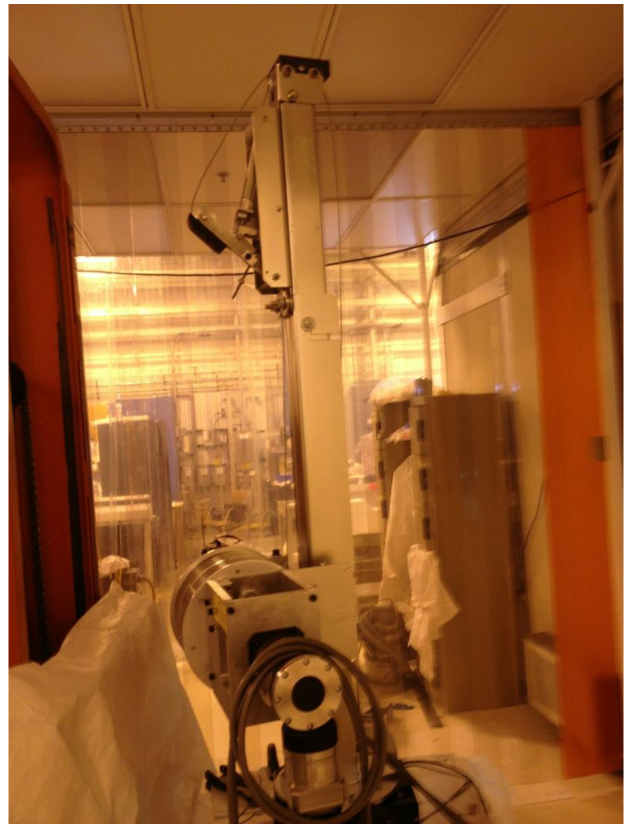

FIG. 35: The ARA after being assembled inside the clean room.

After that, glovebox extension was built as shown in Fig. 38 a number of tests were conducted including using the gloves on the GBE to reach parts of the ARA in case of any problems. Fig. 39 shows the inside of the GBE with the ARA in it and glove access. The ARA was successfully commissioned and its motion was without problems. During the tests we discovered that the DAQ crashes if the motors are operating so we had to come up with software fixes that allow turning off the motors between positions. There was a concern about a pressure increase inside the GBE and consequently the detector in case of a piston nitrogen hose burst. So we reduced the nitrogen flow with a flow restrictor and measured the rate at which the pressure inside the GB+GBE was increasing. The measurements showed about 30 seconds reaction time. Due to great sensitivity of the detector to pressure changes limited to just 2 mbar, we also tested effects of glove insertion in the GBE and speed at which it can be safely done, which resulted in an estimate of about 15-20 minutes in order

FIG. 36: The ARA completely wrapped to avoid any dust contamination, lifted on the forklift and moving inside a specially assembled long plastic sock that allowed 3-4 meters or telescoping motion.

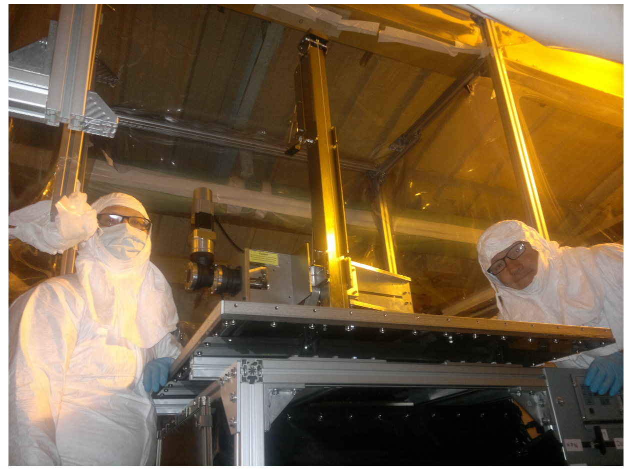

FIG. 37: Student Edward Damon and technician Frank Skrzecz after placing the ARA on top of the glovebox.

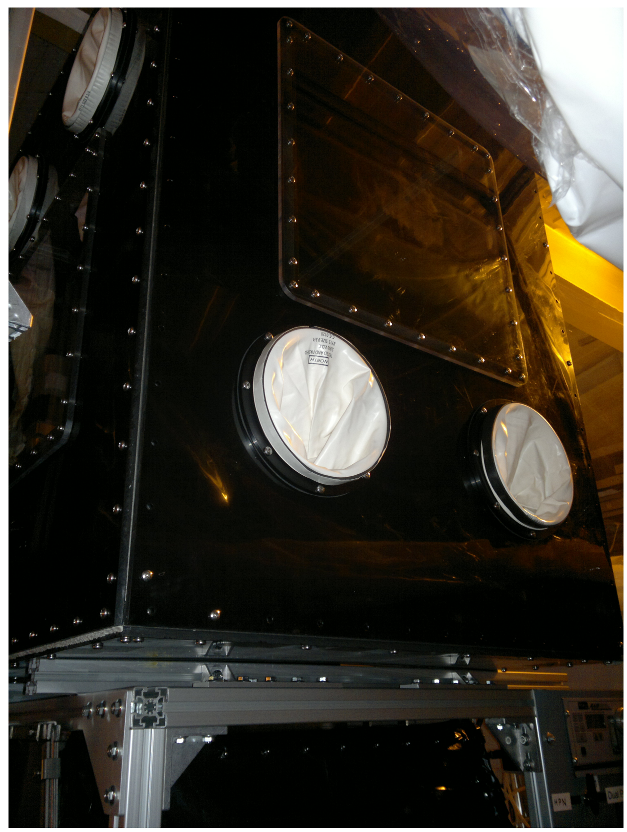

FIG. 38: The GBE closed after installation of the ARA inside.

to avoid large pressure variations.

One issue that we encountered was difficulty to precisely level the ARA, which requires some design changes in the GBE. Pressurization tests of the GBE showed that it could not hold required pressure level of 0.5 mbar at the low nitrogen flow rate. A great deal of time (10 working days at least) was spent in order to identify the source of leaks and along the way we discovered that the acrylic pan that holds the ARA ϕ motor in place unglued along one seam, providing a large source of leak. So we used a lot of caulk to seal the gaps and holes and managed to get the oxygen level to 10-20 ppm after purging the GB+GBE overnight, which is below 50 ppm limit imposed for the scintillator. However, the GBE could not hold pressure as expected, so it was decided to postpone deployment after this problem is solved. UC Davis group members that originally built the GBE will travel on site in October to replace the pan and pressurize the GBE and solve the leveling problem so that ARA is ready for deployment and full volume detector calibration later in the Fall. This schedule coordinates well with the final electronics upgrades of the far detector. So the calibration will take place with the far detector in its final configuration.

FIG. 39: Student Edward Damon using gloves on the GBE to access the top parts of the ARA.

Sterile Neutrino Search

The UH is involved in two methods of searching for sterile neutrinos. We describe below out involvement in the short baseline experiment at a nuclear reactor for, which the collaboration is still in the formation process. Further we describe our involvement in the CeLAND experiment, which aims to employ a radioactive Cerium source brought to the KamLAND detector.

IBD and Background Simulations

We have been studying the detection of reactor neutrinos near the earth's surface, and have participated with others in the invention of a new type of detector which we call the miniTimeCube which aims at using very good timing (in the picosecond range) for precise registration of IBD events from reactors as well as rejection of backgrounds.

In any short baseline (that is near a source reactor) neutrino experiment searching for sterile neutrinos, it becomes extremely important to be able to identify and reject the various backgrounds associated with being near a reactor and worse being near to the Earth's surface. After conquering the reactor associated backgrounds, the most dominant problem are the cosmic ray muons and the numerous isotopes and neutrons that they produce when they undergo electromagnetic showers either inside the detector volume or with the surrounding environment material. Some of these isotopes that are created have long half-lives and can mimic the two-hit inverse beta-decay signature that is relied upon to identify neutrino events.

Some common cosmogenic background isotopes are listed in table I. Of immediate interest among these isotopes are ^{8}He ($\tau = 171.7ms$, $Q = 10.7$ MeV) and ^{9}Li ($\tau = 257.2ms$, $Q = 13.6$ MeV). These isotopes both decay through production of β^- and daughter nuclei exhibiting neutron-unstable excited states. Due to the relatively long half-life and emission of a stray neutron, these isotopes are difficult to reject through simple proximity and timing cuts.[21]. The high muon rate at the earth's surface precludes simply ignoring any events within about a second of a muon traversal.

In our studies we would like to search for other characteristics that may be useful for tagging these particular dangerous isotopes, such as relative light output as compared to cosmic ray muon events that do not produce ^{8}He nor ^{9}Li, or the spatial distribution of the production vertices with respect to the muon trajectory.

A simulation of 10,000 mono-energetic cosmic ray muons incident normal to the top face of a $10m \times 10m \times 10m$ cubic block of generic scintillator material was generated using the Geant4 simulation software package [22].

Figure 40 shows the production vertices of various isotopes and decay products that were created inside the scintillator cube. A clear line through the middle where the muons passed through can be seen along with the general "bunching" of production points that surround this line. This plot shows that the cosmogenic background particles were clearly induced by the muons and exhibits a lateral scale of order of a meter.

Figure 41 shows the tally count of all cosmogenic background products produced from the simulation excluding γ, e^-, and e^+ particles. The rare isotopes that all have a yield of $\sim 10^{-7}(\mu.g/cm^2)^{-1}$ were only counted once out of 10,000 muon events, so their values are not very precise. More statistics a definitely needed to obtain a more accurate measurement of the yield rates of these isotopes, but this is what our current computing power allows. Table II shows the main decay daughters that will become background neutrino inverse-beta decay measurements. A rough comparison can be made between these numbers and those from studies done on data and simulations by the Borexino group [21], and there fairly good agreement within an order of magnitude. In order to obtain better statistics and make a more definitive comparison, we are currently in the process of upgrading our facility computing power to be able to accommodate these needs.

When we have sufficient computing power, we hope to start analyzing in more detail the events that produce ^{8}He and ^{9}Li, by simulating all the γ and scintillating photons that would be detected by photomultiplier tubes in a real experiment. This will help us in searching for features of these special events that we could use to be able to start tagging and rejecting such events on an event by event basis.

Cosmogenic Isotopes	Lifetime	Q-Value [MeV]	Decay Type
^{12}**N**	15.9 ms	17.3	β^-
^{12}**B**	29.1 ms	13.4	β^+
^{8}**He**	171.7 ms	10.7	β^-
^{9}**Li**	257.2 ms	13.6	β^-
^{8}**B**	1.11 s	18.0	β^+
^{6}**He**	1.16 s	3.51	β^-
^{8}**Li**	1.21 s	16.0	β^-
^{9}**C**	182.5 ms	16.5	β^+
^{11}**Be**	19.9 s	11.5	β^-
^{10}**C**	27.8 s	3.65	β^+
^{11}**C**	29.4 min	1.98	β^+

TABLE I: Common isotopes produced by cosmic ray muons and their characteristic lifetimes and decay signatures [21].

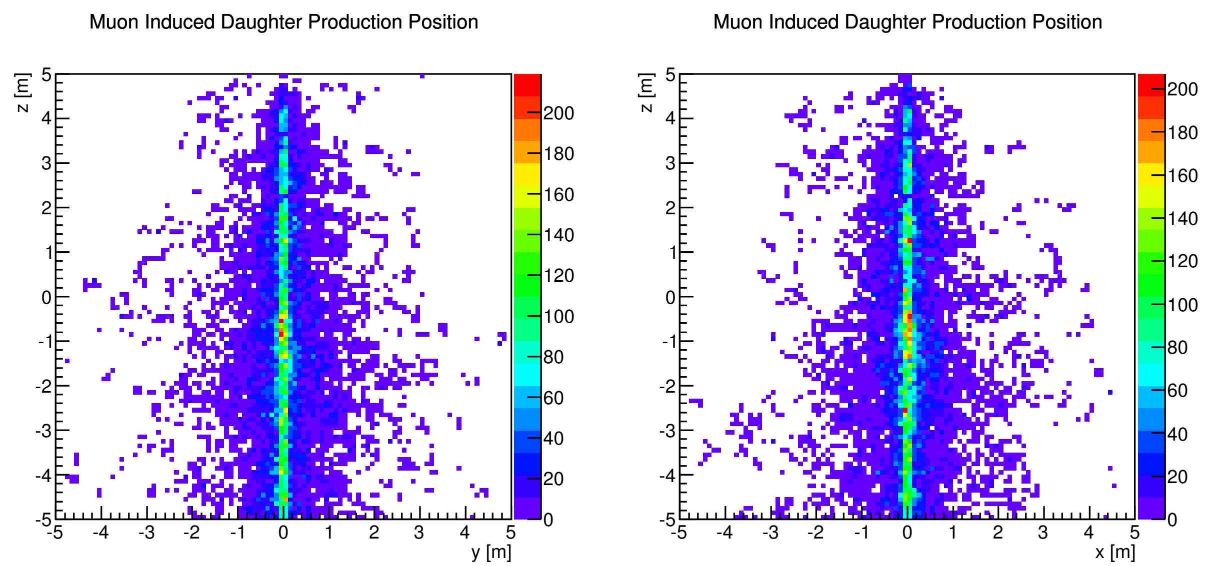

FIG. 40: Scatter plots showing the production position coordinates of isotopes produced from 10,000 mono-energetic 283 GeV μ^- in a 10 × 10 × 10 meter cube of plastic scintillator. The positions surround the general shape of the μ^- track signifying that the events were induced by the particle.

CeLAND

The CeLAND project has been funded by the Department of Energy ECRP program as of July 1st, 2013. CeLAND will search for the sterile neutrinos mixing with electron flavor neutrinos at a very short baseline of a few meters. This project nicely complements design efforts for the short oscillation reactor measurements that we are already part of. The original motivation for this search came from the Double Chooz experiment.

In preparation for the precision measurement of θ_{13}, a detailed calculation of the expected reactor anti-neutrino spectrum from reactor fission rates was carried out by two independent groups [17], [18], with the goal of reducing the associated reactor $\bar{\nu}_e$ flux systematic error. The calculation tracked and accounted for all the beta decay branches from ^{238}U, ^{235}U, ^{239}Pu and ^{241}Pu (more than 10,000 in total). As an unexpected, but an intriguing outcome of this calculation, deviation from expectations at the 6% level was observed in all earlier short baseline reactor anti-neutrino experiments at nearly 3σ C.L. [17]. This has become known as the reactor anti-neutrino anomaly (RAA) and is consistent for all earlier reactor $\bar{\nu}_e$ experiments with baseline longer than 15 m. Part of the RAA may be associated with the uncertainties in the higher order corrections to the allowed fission fragments beta decay spectra, which

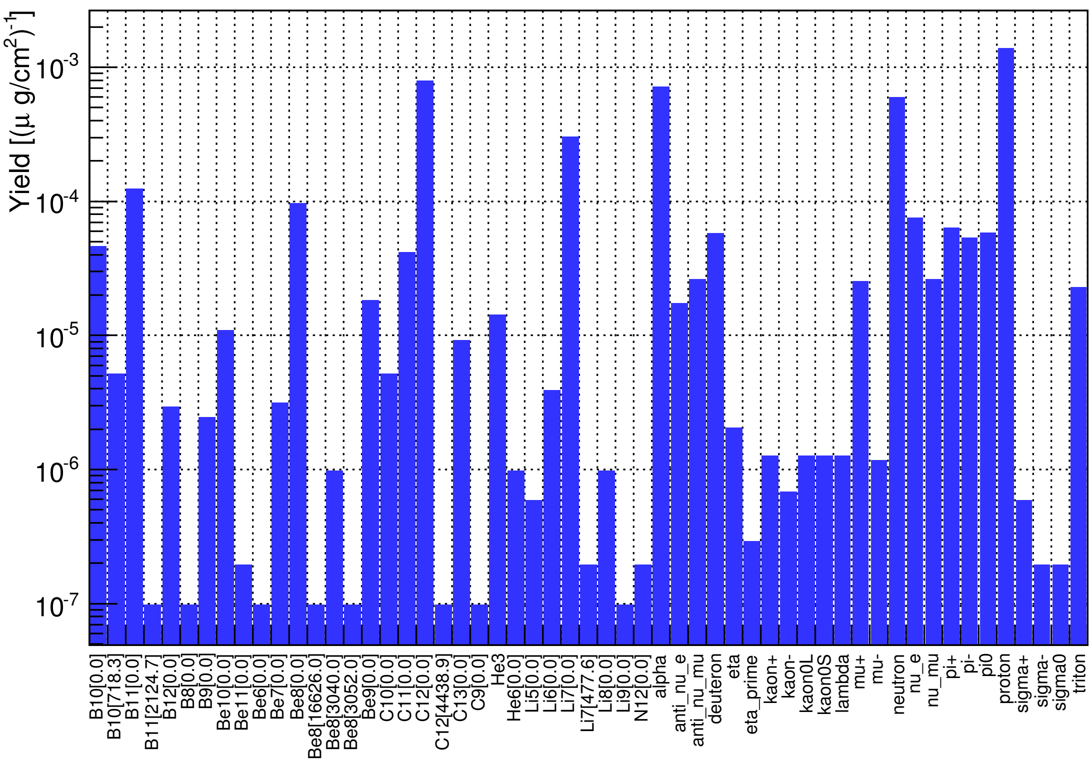

FIG. 41: A bar graph showing the tally count of all daughter products produced from mono-energetic cosmic muons with energies of 283 GeV. The number enclosed in square brackets after the isotope symbol along the x-axis signifies the excitation energy in units of eV of the particular isotope immediately after production.

Isotopes	Yield $[10^{-7}(\mu\text{g/cm}^2)^{-1}]$
^{12}**N**	1.959
^{12}**B**	29.380
^{8}**He**	not observed
^{9}**Li**	0.979
^{8}**B**	0.979
^{6}**He**	9.793
^{8}**Li**	9.793
^{9}**C**	0.979
^{11}**Be**	1.959
^{10}**C**	51.905
^{11}**C**	420.134
Neutrons	Yield $[10^{-4}(\mu\text{g/cm}^2)^{-1}]$
	6.007

TABLE II: This table shows a tally of cosmogenic isotopes of interest extracted from fig. 41. The units were arranged for comparison with results from studies done on data and simulations by the Borexino group [21]. There is agreement within an order of magnitude between these numbers and those obtained by the Borexino group. More simulation runs are planned to increase statistics.

are used to determine the $\bar{\nu}_e$ spectra. However, it appears very unlikely that these effects can account for all of the RAA. A dramatic possible explanation is the existence of a new heavy neutrino flavor with Δ m$^2{}_{new} \geq 1$ eV^2 mixing with reactor $\bar{\nu}_e$, thus very short oscillation length, potentially providing an exciting avenue into substantial physics beyond Standard Model.

The CeLAND project will address the RAA in a complementary manner by deploying a 50 kCi ^{144}Ce $\bar{\nu}_e$ source in KamLAND, a 1 kton liquid scintillator detector. Figure 42 shows the location of the cerium inside the KamLAND outer detector. The goal of the experiment is to unambiguously test the RAA by observing an $\bar{\nu}_e$ disappearance at a short baseline. This measurement will be completely free of any reactor $\bar{\nu}_e$ flux calculation uncertainties that may have influenced the RAA deficit, since it does not utilize reactor $\bar{\nu}_e$'s.

The UH group will model the necessary tungsten shield for the deployment of Cerium source in the KamLAND outer detector. Besides electron antineutrinos, cerium is a copious source of $\beta's$ and $\gamma's$ that we need to shield against. It is a dangerous source of radiation that requires a very significant tungsten shielding. The work on this has been started. We are in the process of selecting a suitable shipping option for this extremely high radioactivity source from its production site at the Mayak reprocessing plant in Russia to the detector site in Japan.

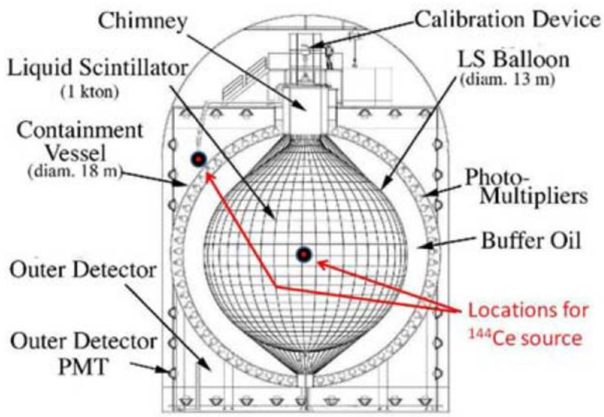

FIG. 42: While inserting the cerium source in the center of the KamLAND inner detector would provide the highest statistics, the source will be deployed in the outer detector since this option significantly simplifies deployment and increases safety of such operation.

DarkSide

The DarkSide experiment is designed to directly search for signatures of dark matter WIMPs in the dual argon Time Projection Chamber. Although not directly funded by this grant (funded from the PI's start-up fund), it is an important contribution to the field of dark matter searches. The UH group has built the first calibration device for the commissioning of the DarkSide TPC. Two students and a postdoc spent several weeks on site at Gran Sasso underground lab participating in the calibration with radioactive sources and seeing first data from the DarkSide TPC. The first radioactive source deployment system has not been liquid tightened and was used for the commissioning of the TPC in air. The second deployment system compatible with the liquid scintillator was built in the summer of 2013, and will be used to calibrate the TPC and the neutron veto around the TPC in the Fall of 2013. DarkSide will start data taking at the end of September 2013.

LBNE

At the time the UH group joined LBNE, active R&D was pursued for both Water Cerenkov and liquid argon detector option. Based on a previous group's experience in IMB and SuperK, work on the water Cerenkov detector R&D was more relevant. After the selection of the liquid argon option, the group began work on the photon detection system.

LBNE – LAr

Since the end of 2012, we have built a test-stand to evaluate performance of the photon detectors for the photon detection system in the LBNE Liquid argon time projection chamber (LAr TPC). Specifically, we have started investigation of the suitability of silicon photo-multipliers for the photon detection system to be used in the LBNE far detector. This system is very important for the underground option when the search for the nucleon decay and detection of supernovae neutrinos from our galaxy becomes possible.

However, even a 10 kton surface detector with minimal shielding will have a very large muon rate and very high associated backgrounds, due to long drift times of a few ms (some estimates show more than a billion muons will pass through detector during the drift times associated with beam spills in a single year). An effective photon detection system will be very important in tagging cosmic ray muons.

The photo-detectors in LBNE will be attached to the end of the light guides embedded in the TPC's anode planes. While the light guides are being developed by our collaborator Stuart Mufson at Indiana University, we have started building a test facility at the University of Hawaii to evaluate and characterize the performance of SiPMs from different manufacturers under cryogenic conditions. There are a large number of SiPM manufacturers (ENSL, Hamamatsu, Voxtel, Zecotek Photonics, Amplication Technologies, STMicroelectronics etc.) so it is important to choose the most suitable candidate device for the photon detection system to maximizing its performance at the lowest price achievable. So far we have acquired SiPMs from AdvanSiD, SenSL, Hamamatsu and CPTA. Originally we purchased SenSL M series SiPMs, but in March 2013 SenSL developed a new B series that has better characteristics. One serious concern with SiPMs from all manufacturers is that they have not been designed for cryogenic temperatures. While they have been shown to work, we also observed some failures, after testing the SiPMs in liquid nitrogen. So far, we have compared the following characteristics of SiPMs: gain as a function of voltage, their linearity and dark rates in cryogenic conditions.

The best characteristics in terms of low dark rate, excellent gain and consistency between gain and applied bias voltage have been obtained for the SenSL B series SiPM. Fig. 43 shows the measured dark rate of this SiPM. We are in the process of debugging the setup for the single photon measurement, where we

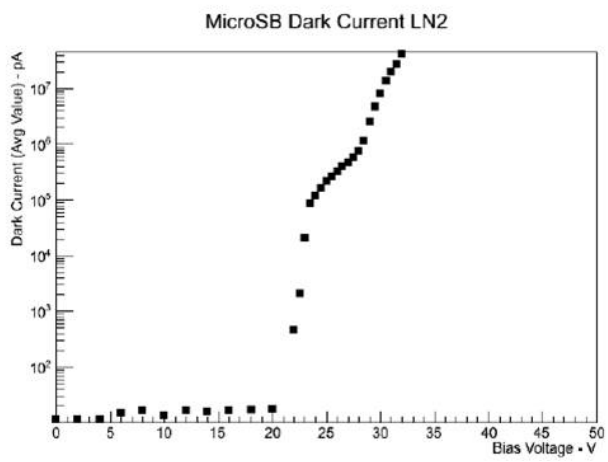

FIG. 43: Measurement of the SenSL B series SiPM dark current obtained with a pico ammeter. The dark rate decreases dramatically at liquid nitrogen temperatures compared to room temperature values, enabling their possible use for the photon detection system.

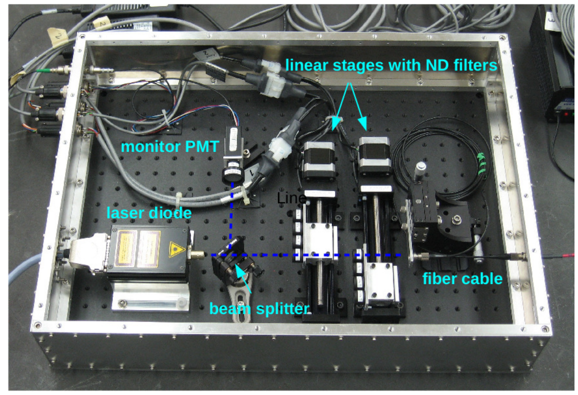

FIG. 44: A laser light source developed for WCD of the LBNE. Laser light (dashed line) passes horizontally in this picture from the laser diode module, through 2 ND filter sets on computer controlled movable stages, before coupled into an optical fiber cable. The laser light is monitored with a PMT after a partially reflective mirror in front of the laser module.

have some electronic noise issue. We are in the process of preparing a variable wavelength laser for the spectral response measurement of SiPMs. In addition, we plan to measure their timing response. At the same time we have been in close contact with SenSL representatives and consulting about packaging that is more suitable for operation at liquid argon temperatures.

LBNE – WCD

Since UH group officially joined the LBNE Collaboration in Fall 2009, we have become integrated into that project. We have taken responsibilities in calibration tasks of a Water Cerenkov detector (WCD), which was one of the candidates for the LBNE far detector then, and worked on designing the calibration system. The liquid Argon (LAr) time projection chamber (TPC) became the detector of choice for the LBNE far detector in early 2012. Even after this decision, the tasks on the WCD continued until summer of that year to finish up on-going works including the WCD part of conceptional design report (CDR) document.

The design of WCD as a LBNE far detector is summarized in volume 4 of the LBNE CDR document [19]. We were in charge mainly of in detector PMT calibration and contributed heavily in the calibration section of this document, while providing comments for other sections.

As an initial part of our WCD calibration effort, we built the laser light source shown in fig-44. This was to be used on determining angular uniformity of the laser light diffusing balls for WCD calibration system. The necessary funds, except for a laser diode module (purchased by the mTC project fund), was provided through the LBNE WCD calibration group. It consists of a pulsed diode laser module (400nm wave length, 30 ps pulse width, 15 pJ per pulse energy), a PMT to monitor laser light, 2 sets of neutral density (ND) filters on computer controlled linear stages, and an optical fiber cable in which the laser light is injected. The system can inject up to $\sim 10^7$ photons into the fiber cable and can adjust the light intensity up to 5 orders of magnitude.

After the completion of the light source in late 2011, it had been used for various purposes, including that of calibrating the mTC detector. Currently it is used for testing light sensors to detect a prompt light signal of LBNE LAr detector described in LBNE – LAr.

New Initiatives

Although we are not explicitly funded by DOE to pursue new initiatives, we of necessity have been looking towards the important new projects on the horizon. These include (already discussed) the short baseline sterile neutrino initiatives, HyperK as a follow-on to SuperK, particularly in light of our long experience with large water Cerenkov detectors, in the guise of HyperK, future large liquid scintillation detectors particularly those involved in detection of geo-neutrinos and of long range reactor monitoring, and the current JUNO proposal by the former Daya Bay Chinese group. We have a special interest in the latter, which aims at using techniques we invented to determine the neutrino mass hierarchy. Much of this will simply have to play out with time and the prospects for US funding.

We have investigated the possibility and potential of HyperK[20], planned in Japan. We have been attending HyperK open meetings, which had been held in IPMU, University of Tokyo several times already. Our works on LBNE WCD, including calibration system design and light collector simulation were presented in the meetings. Following the request of the HyperK calibration working group, one of us (SM) reported an investigation of adopting the Super-Kamiokande outer detector calibration system to HyperK at the latest HK open meeting[20].

An activity on a shorter time scale is the evolving plan to attempt a definitive and unique reactor based search for sterile neutrinos in the US, as mentioned earlier. We expect to participate in a modest collaboration with a proposal going in to DOE in the Fall of 2013 for this project.

Appendices: Biographical Sketches, Publications, Bibliography & References Cited

Curriculum Vitae for **John Gregory Learned**, Department of Physics and Astronomy, University of Hawaii, Manoa, 2505 Correa Road, Honolulu, HI 96822 USA; *phone:* 01-(808)-956-2964; *fax:* 01-(808)-956-2930; *web:* **http://www.phys.hawaii.edu/~jgl**; *email:* **jgl@phys.hawaii.edu**; *skype*: jglearned

Education:

B.A. Columbia College (Physics).	1961
M.S. University of Pennsylvania (Physics)	1963
PhD. University of Washington (Physics)	1968

Positions held:

1961-62	Design Engineer/Rocket Test Conductor, General Dynamics/Astronautics.
1963-65	Design Engineer, The Boeing Co./Aerospace
1965-66	Teaching Asst., University of Washington
1966-68	Research Assistant, University of Washington
1968-73	Research Associate, University of Wisconsin
1973-76	Assistant Scientist, University of Wisconsin
1976-77	Visiting Associate Physicist, UC Irvine
1977-79	Visiting Associate Professor, UC Irvine
1980-83	Visiting Associate Professor, University of Hawaii
1983-88	Associate Professor, University of Hawaii
1988-Present	Professor, University of Hawaii

Experience: Forty years researching particle physics and astrophysics, at accelerators and from deep mines to mountain tops. Prior to graduate school was engineer in aerospace industry, with specialization in communications systems, antenna design and cryptography. Physics career has been centered on neutrino studies; a founder of neutrino astronomy. Co-founded, designed and operated several generations of large under-earth neutrino detectors, most recently the Super-Kamiokande experiment which discovered neutrino oscillations and mass. Continue to make contributions to particle astrophysics and neutrino astronomy, and involved in several new research initiatives in neutrino studies. *For more detail see* http://www.phys.hawaii.edu/~jgl, also for list of graduate students, recent lectures, classes taught, and research projects.

Awards: The Rossi Prize, co-recipient 1988; The Asahi Prize, co-recipient 1998; UH Regents Medal for Excellence in Research 1999; ARCS Scientist of the Year Award 2007

Selected publications: The following list presents 10 publications included in the High Energy Physics Archive at Stanford, SPIRES (http://www.slac.stanford.edu/spires). The first five are ordered by number of citations. A computer generated citation analysis from SPIRES follows. This compilation misses some popular publications and papers in other disciplines, but these are an insignificant number. The list has "live" citations so the individual papers may be viewed with full author lists by clicking on the links.

Citation analysis (as of 25 May 2012)	*All papers*	*Published only*
Renowned papers (500+ cites)	**17**	**17**
Famous papers (250-499 cites)	10	10
Very well-known papers (100-249)	27	26
Total eligible papers analyzed	228	180
Total number of citations	28,791	28,239
Average citations per paper	126.3	156.9
h-index	67	66

Ten Publications (first six listed by descending citation index):

Y. Fukuda et al., **EVIDENCE FOR OSCILLATION OF ATMOSPHERIC NEUTRINOS.**
Phys.Rev.Lett.81:1562-1567,1998. [HEP-EX 9807003]
Cited 3742 times in the HEP (SPIRES-SLAC) database. [Full entry]

K. Eguchi et al., **FIRST RESULTS FROM KAMLAND: EVIDENCE FOR REACTOR ANTI-NEUTRINO DISAPPEARANCE**. *Phys.Rev.Lett.90:021802,2003. [HEP-EX 0212021]*
Cited 1903 times in the HEP (SPIRES-SLAC) database. [Full entry]

S. Fukuda *et al.*, **SOLAR B-8 AND HEP NEUTRINO MEASUREMENTS FROM 1258 DAYS OF SUPER-KAMIOKANDE DATA.** *Phys.Rev.Lett.86:5651-5655,2001. [HEP-EX 0103032]*
Cited 1059 times in the HEP (SPIRES-SLAC) database. [Full entry]

T. Araki et al., **MEASUREMENT OF NEUTRINO OSCILLATION WITH KAMLAND: EVIDENCE OF SPECTRAL DISTORTION.** *Phys.Rev.Lett.94:081801,2005. [HEP-EX 0406035]*
Cited 949 times in the HEP (SPIRES-SLAC) database. [Full entry]

M.H. Ahn *et al*., **INDICATIONS OF NEUTRINO OSCILLATION IN A 250 KM LONG BASELINE EXPERIMENT.** *Phys.Rev.Lett.90:041801,2003. [HEP-EX 0212007]*
Cited 934 times in the HEP (SPIRES-SLAC) database. [Full entry]

R.M. Bionta et al., **OBSERVATION OF A NEUTRINO BURST IN COINCIDENCE WITH SUPERNOVA SN 1987A IN THE LARGE MAGELLANIC CLOUD.**
Phys.Rev.Lett.58:1494,1987.
Cited 920 times in the HEP (SPIRES-SLAC) database. [Full entry]

William F. McDonough, John G. Learned, Stephen T. Dye. **The many uses of electron antineutrinos**, *Phys.Today 65N3 (March 2012) 46-51.*

LENA Collaboration (Michael Wurm et al.). **The next-generation liquid-scintillator neutrino observatory LENA**, *Astropart.Phys. 35 (2012) 685-732. arXiv:1104.5620*

Jason Kumar, John G. Learned, Michinari Sakai, Stefanie Smith.Dark **Matter Detection With Electron Neutrinos in Liquid Scintillation Detectors**,
arXiv:1103.3270[hep-ph].Phys.Rev. D84 (2011) 036007.

John G. Learned **High Energy Neutrino Physics with Liquid Scintillation Detectors.**
arXiv:0902.4009 [hep-ex] Feb. 2009

List of all authors: It is not possible to list all the authors in the 2 page space allocated in the FOA instructions: these papers are all from collaborations of about 100-200 physicists. Learned has made significant contributions to all listed. John Learned is or has recently been a member of the Super-Kamiokande, KamLAND, K2K, ANITA, LBNE, and LENA large neutrino collaborations. For purposes of the identification of potential conflicts of interest or bias in selection of reviewers, it is simply not possible to list here all recent co-authors and collaborators.

List of recent post-docs and students: Jelena Maricic, PhD 2005, Drexel U.; Mavourneen Wilcox, MS 2007, Oceanit Research; Peter Grach, MS 2008, KSBE Schools; Peter Papai, PhD 2011, Current PhD students: Stephanie Smith, Michinari Sakai, Joshua Murillo and Slava Li. Misha Batygov, post doc 2009, SNO Lab, Gene Guillian, post doc 2007, Roosevelt School. He is at present a member of 12 doctoral thesis committees.

Synergistic activities: Aside from usual professorial duties at the University of Hawaii, John Learned serves on various committees and boards. The only relevant commitment (outside of Collaboration Councils) is the Scientific Standing Committee of the large European KM3NET, which aims to build a large neutrino detector in the Mediterranean.

Biographical Sketches for Jelena Maricic

(a) Professional Preparation

University of Belgrade, Belgrade, Serbia; B.S., Physics; 1998

University of Hawaii at Manoa, HI; M.S., Physics; 2003

University of Hawaii at Manoa, HI; Ph.D., Physics; 2005

University of Hawaii at Manoa, HI, P.D., Physics; 2005 - 2006

(b) Appointments:

August 2012: Assistant Professor, University of Hawaii at Manoa, Honolulu, HI

2006-August 2012: Assistant Professor, Drexel University, Philadelphia, PA

2005-2006: Post-doctoral Researcher, University of Hawaii at Manoa, Honolulu, HI

2000-2005: Research Assistant, University of Hawaii at Manoa, Honolulu, HI

1999-2000: Teaching Assistant, University of Hawaii, Honolulu, HI

1998-1999: Research Assistant, University of Belgrade, Belgrade, Serbia

(c) Publications

- Double Chooz Collaboration,
  Indication for the disappearance of reactor electron antineutrinos in the Double Chooz experiment, Phys. Rev. Let. 108, 131801 (2012)
- LBNE Collaboration,
  The Long Baseline Neutrino Experiment (LBNE) Water Cherenkov Detector (WCD) Conceptual Design Report (CDR), *arXiv:1204.2295*
- KamLAND Collaboration,
  A study of extraterrestrial antineutrino sources with the kamland detector, *arXiv:1105.3516v1*, submitted to Astrophys. J (2012)
- LBNE Collaboration,
  The 2010 Interim Report of the Long-Baseline Neutrino Experiment Collaboration Physocs Working Group, *arXiv:1110.6249*
- KamLAND Collaboration,
  Experimental Investigation of Geologically Produced Anti-neutrinos with KamLAND, *Nature 436, 499-503, (2005)*
- KamLAND Collaboration,
  First Results from KamLAND: Evidence for Reactor Antineutrino Disappearance, *Phys. Rev. Lett. 90, 021802 (2003)*

(d) Synergic Activities

- Mentoring undergraduates:
  - Independent research for undergraduates: Rory McGurthy (2007), Kathori Apoorv (2008), Alex Bolesta (2009-2010), Ryan Wasson (2009), Warren Kushner (2009) and two coop students David Gurmai and Othman Rafiki (2010), coop student Ryan Wasson (2011), Jacob Zettlemoyer (2010, 2012), Jeremy Gaison (2011).
  - Sponsored and prepared 2 undergraduate physics students Carlos Bahamondes and James Monahan for a five-month long coop in Germany at the University of Tuebingen, where they tested and encapsulated all PMTs for the GERDA experiment, and then almost all PMTs for the Double Chooz's Inner Veto (far and near) detector during spring and summer 2008. As part of the coop they participated in the Double Chooz collaboration meeting in Givet, France, where Carlos Bahamondes presented their work in front of the collaboration.
- Presentations for undergraduate, high school and pre-school students:
  - Workshop leader for "Expanding Your Horizons" science workshop for Middle School Girls, Swartmore College, March 2010, March 2011
  - Workshop leader for "Career day" with Girl Scouts at Newtown, PA, March 2011
  - "*Probing the Earth with Neutrinos*", for talented high school student, Technical College, Cacak, Serbia, December 2009
  - "*Neutrinos and Why do We care?*", Adolf Reichwein Schule (high school), Langen, Germany, July 2010
  - "*Science Adventure: Exploding Volcano, Balloons and Flying Pepper*", Place to Grow (pre-school), Turnersville, NJ, August 2009

(e) Colaborators and Other Affiliations

- KamLAND Collaboration since the year 2000.
- Double Chooz Collaboration since 2006.
- Long Baseline DUSEL collaboration since 2008.
- Dark Side Collaboration since 2012.
- **Graduate and Postdoctoral Advisors**:
  - Ph.D. Advisor: John. G. Learned, University of Hawaii at Manoa
  - Postdoctoral Advisor: John G. Learned, University of Hawaii at Manoa
- **Graduate students and Postdoctoral Researchers**:
  - Erica Smith, Nicholas Ridella, Matthew Thiesse, Edward Damon, Erica Caden (Co-supervisor), at Drexel
  - Shawn Dubey, Erin Edkins, Brianne Hackett (at University of Hawaii)
  - Stefano Perasso, Karim Zbiri, postdoctoral researchers

Shigenobu Matsuno

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- Education

University of Tokyo, *PhD in Physics,* March 1982
Dissertation; *"Cosmic Ray Muon Spectrum and Charge Ratio up to 20TeV/c at 89° Zenith Angle."*
Kobe University, *Master of Science,* March 1978
Nagoya University, *Bachelor of Science,* March 1976

- Professional Experience

Associate Researcher: *University of Hawaii, Manoa* 2000 – Present
Assistant Researcher: *University of Hawaii, Manoa* 1991 – 2000
Assistant Research Physicist: *University of California, Irvine* 1988 – 1991
Postdoctoral Research Associate: *University of Hawaii, Manoa* 1985 – 1988
Research Associate: *Inst. for Cosmic Ray Research, Univ. of Tokyo* 1982 – 1985

- Selected publications

Publications closely related to proposed project

K2K collaboration: "Measurement of Neutrino Oscillation by the K2K Experiment", Phys. Rev. D74 (2006) 072003
KamLAND collaboration; "Precision Measurement of Neutrino Oscillation Parameters with KamLAND", Phys. Rev. Lett. 100 (2008) 221803
Super-Kamiokande collaboration: "Search for Matter-Dependent Atmospheric Neutrino Oscillations in Super-Kamiokande", Phys. Rev. D 77 (2008) 052001
Super-Kamiokande collaboration; "Three flavor neutrino oscillation analysis of atmospheric neutrinos in Super-Kamiokande", Phys. Rev. D74 (2006) 032002

Other significant publications

ANITA collaboration: "Ultra-Relativistic Magnetic Monopole Search with the ANITA-II Balloon-borne Radio Interferometer.", Phys. Rev. D83 (2011) 023513
ANITA collaboration: "Observational Constraints on the Ultra-high Energy Cosmic Neutrino Flux from the Second Flight of the ANITA Experiment.", Phys. Rev. D82 (2010) 022004
KamLAND collaboration; "Experimental investigation of geologically produced antineutrino with KamLAND", Nature 436 (2005) 499
K2K collaboration; "Measurement of inclusive π^0 production in the Charged-Current Interactions of Neutrinos in a 1.3-GeV wide band beam.", Phys. Rev. D83 (2011) 054023

K2K collaboration; "Experimental study of the atmospheric neutrino backgrounds for proton decay to positron and neutral pion searches in water Cherenkov detectors.",
Phys. Rev. D77 (2008) 032003

Super-Kamiokande collaboration: "An Indirect Search for WIMPs in the Sun using 3109.6days of upward-going muons in Super-Kamiokande", Astroph. J. L12 (2011) 736
Super-Kamiokande collaboration; "Observation of the Anisotropy of 10 TeV Primary Cosmic Ray Nuclei Flux with the Super-Kamiokande-I Detector", Phys. Rev. D75 (2007) 062003

- Synergistic activities Co-convener of up-going muon analysis group, Super-Kamiokande collaboration (1996-2001)
Optical Module development coordinator. DUMAND project (1991-4)

- Collaborations ANITA collaboration: *see http://www.phys.hawaii.edu/˜anita/web/index.htm*
KamLAND collaboration: *see url: http://www.awa.tohoku.ac.jp/kamlande/*
K2K collaboration: *see urlhttp://neutrino.kek.jp/*
LBNE collaboration:
Super-Kamiokande collaboration: *see http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html*
Postdoctoral advisers: Prof. Takashi Kitamura (ICRR, U. Tokyo) and Prof. Vince Z Peterson (U. Hawaii, Manoa)

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Education:

Boston University:	B.S. in Electrical Engineering, 1989
Boston University:	M.A. in Experimental Physics, 1995
University of Hawaii:	Ph.D. in Experimental Physics, 1999

Professional Employment:

2010-present	Associate Professor of Physics, University of Hawaii
2005-2010	Assistant Professor of Physics, University of Hawaii
2002-2005	Director, Instrumentation Development Laboratory, University of Hawaii
2000-2002	Senior Scientist, AOptix Technologies Campbell, California (silicon valley)
1998-2000	EE/Physicist, University of Hawaii, University of Hawaii
1997-1998	Visiting Researcher CMS Exp., CERN & L.I.P. Portugal, based at CERN
1995-1997	Research Associate, University of Hawaii
1992-1995	Senior Electrical Engineer/Physicist, Boston University & SSC Lab.
1989-1992	Research Associate, Boston University

Selected Recent Publications :

1. **G. Varner** and L. Ruckman, "Sub-10ps Monolithic and Low-power Photodetector Readout," *Nucl. Instr. Meth.* **A601** (2009) 438-445.
2. H. Hoedlmoser, **G. Varner** and M. Cooney, "Hexagonal pixel detector with time encoded binary readout," *Nucl. Instr. Meth.* **A599** (2009) 152-160.
3. J. Benitez, D.W.G.S. Leith, G. Mazaheri, B.N. Ratcliff, J. Schwiening, J. Vavra, L. Ruckman and **G. Varner**, "Status of the Fast Focusing DIRC (fDIRC)," *Nucl. Instr. Meth*. **A595** (2008) 104-107.
4. **G. Varner**, L. Ruckman and A. Wong, "The First version Buffered Large Analog Bandwidth (BLAB1) ASIC for high luminosity collider and extensive radio neutrino detectors," *Nucl. Instr. Meth.* **A591** (2008) 534-545.
5. **G.S. Varner**, L.L. Ruckman, P.W. Gorham, J.W. Nam, R.J. Nichol, J. Cao, M. Wilcox, "Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," *Nucl. Instr. Meth.* **A583** (2007) 447-460.

Synergistic Activities :

1. Large-area, pico-second timing detector development [Argonne, Univ. Chicago, Univ. Hawaii, SLAC collaboration]
2. Coded-aperature imager for beam bunch diagnostics at a high intensity electron storage ring [Cornell Univ., KEK and Univ. Hawaii collaboration]
3. Fast Focusing Direct Internal Reflected Cherenkov (DIRC) detector development for Particle Identification at a Super B factory in Italy [Univ. Cincinnati, Univ. Hawaii and SLAC collaboration]

4. Imaging Time Of Propagation detector development for Particle Identification at a Super B factory in Japan [Univ. Cincinnati, Univ. Hawaii, KEK, Nagoya Univ. collaboration]

Collaborators & Other Affiliations:

Belle Pixel Upgrade

- Hiro Aihara *Univ. of Tokyo (Japan)*, Herbert Hoedlmoser, Tom Browder, Li Jin, James Kennedy, Marc Rosen, Larry Ruckman, Himansu Sahoo *Univ. of Hawaii*, Masashi Hazumi, Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*, Andrezj Bozek, Henryk Palka H. Niewondiczanski *Institute of Nuclear Physics (Poland)*, and Samo Stanic and *Nova Gorica Poly (Slovenia)*

International Linear Collider MAPS Pixel

- Steven Worm *Rutherford Appleton Laboratory (U.K.)*, Marc Winter *LEPSI, Strassbourg (France)* and Ray Yarema Fermi *National Accelerator Laboratory*

Silicon on Insulator Pixel Detectors

- Yasuo Arai and Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*and Hiro Ikeda *JAXA (Japan)*

Thin, Rad-hard, and fast-timing Pixel Detectors

- Chris Kenney *Molecular Biology Consortium/Stanford Univ.* and Sherwood Parker *Univ. of Hawaii and Lawrence Berkeley Lab.*

Giga-sample per second, GHZ analog bandwidth waveform acquisition

- Stefan Ritt *Paul Scherrer Institute (Switzerland)*

1ps Timing Resolution Detector Development

- Henry Frisch, Jean-Francois Genat, Fukun Tang *University of Chicago*

Next generation large Photomultiplier Readout

- John Anderson, Karen Byrum, Gary Drake, Ed May, Harry Weerts *Argonne National Laboratory*

Common Pipelined High-speed Data Acquisition and Storage

- Tadeo Higuchi and Manobu Tanaka *KEK High Energy Physics Laboratory (Japan)*

Imaging Hard X-ray Compton Polarimeter pixel detector

- Hiroyasu Tajima *Kavli Institute/SLAC National Accelerator Laboratory*

Belle Particle Identification Detector Upgrade

- Toru Iijima, Kenji Inami *Nagoya University (Japan)*, Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman *Univ. of Hawaii*, Alan Schwartz, Kay Kinoshita *Univ. of Cincinnati*

Super-B Particle Identification Detector Upgrade

- Peter Krizan, Samo Korpar *J. Stefan Institute (Slovenia)*, Kurtis Nishimura, Larry Ruckman *Univ. of Hawaii*, Jerry Vavra, Blair Ratcliff *SLAC National Accelerator Laboratory*

Graduate advisor Stephen Olsen, Seoul National University (Korea)

5 graduate students advised, 4 postdoctoral candidates sponsored

[1] J. Kumar, J.G. Learned, K. Richardson, and S. Smith, *Tools for Studying Low-Mass Dark Matter at Neutrino Detectors*, arXiv:1024.5120.

[2] J. Kumar, J.G. Learned, M. Sakai, and S. Smith, *Dark Matter Detection With Electron Neutrinos in Liquid Scintillation Detectors.*, Phys. Rev D 84, 036007 (2011).

[3] T. Tanaka *et al.* (Super-K collab.), *An Indirect Search for WIMPs in the Sun using 3109.6 days of upward-going muons in Super-Kamiokande*, Arxiv:1108.3384, Astrophys. J. 742, 78 (2011).

[4] J. Kumar, J.G. Learned, and S. Smith, *Light Dark Matter Detection Prospects at Neutrino Experiments*, Phys. Rev. D. 80, 113002 (2009).

[5] O. Adriani *et al.*, (PAMELA collab.) *An anomalous positron abundance in cosmic rays with energies 1.5-100 GeV* arXiv: 0810.4995, Nature 458, 607 (2009).

[6] J. L. Feng, J. Kumar, J.G. Learned, and L. E. Strigari, *Testing the Dark Matter Interpretation of the DAMA/LIBRA Result with Super-Kamiokande*, arXiv:0808.4151; JCAP 0901, 032 (2009).

[7] D. Hooper, F. Petriello, K.M. Zurek, and M. Kamionkowski, *The New DAMA Dark-Matter Window and Energetic-Neutrino Searches*, Phys. Rev. D 79, 015010 (2009).

[8] R. Bernabei *et al.* (DAMA/LIBRA collab.), *First results from DAMA/LIBRA and the combined results with DAMA/NaI*, arXiv:0804.2741, Eur. Phys. J C56, 333 (2008).

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[12] Y. Abe et al., Phys. Rev. Lett. 108, 131801 (2012).

[13] Y. Abe et al., Phys. Rev. D 86 052008 (2012)

[14] Y. Abe et al., Phys. Rev. D 87, 011102(R) (2013)

[15] Y. Abe et al., Physics Letters B Volume 723, Issues 13, 10 June 2013, Pages 6670

[16] Y. Abe et al. Phys. Rev. D 86, 112009 (2012)

[17] G. Mention, M. Fechner, Th. Lasserre, Th. A. Mueller, D. Lhuillier, M. Cribier, A. Letourneau, Phys. Rev. D 83, 073006 (2011)

[18] P. Huber, Phys. Rev. C 84, 024617 (2011)

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[20] 3rd HyperK open meeting, June 2013, `http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=23`

[21] Borexino collaboration, Cosmogenic Backgrounds in Borexino at 3800 m Water-Equivalent Depth*, arXiv:1304.7381v2*

[22] Geant4 collaboration, Geant4 - A Simulation Toolkit*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Vol. 506, Issue 3, 1 July 2003, Pages 250-300*

R&D on 3D Silicon sensors for ATLAS upgrades

S. I. Parker

Introduction

The invention in 1957 of the planar method by Hoerni, its employment in p-n particle detectors by Madden and Gibbon in 1962, the development of microstrip detectors in 1981 by Hyams et al., Parker's role in the 128 channel NMOS Microplex readout chip in 1984, its use in the first silicon microstrip vertex detector at the SLC collider, and of the CMOS readout chips that followed several years later, provided the necessary equipment for the first generation of silicon vertex detectors at LEP and the Tevatron. The use of CCD pixel vertex detectors, pioneered by Damerell, and followed by PIN diodes bump bonded to a CMOS readout chip provided the next step for the LHC detectors.

Now, with the sLHC upgrade, and Parker has prepared for simultaneous running at the energy and intensity frontiers. New techniques in silicon tracking will be needed. 3D silicon sensors are one element, but as developed so far, may not be enough despite their extreme radiation hardness. After a summary of their properties, we will cover two proposed additions.

3D sensors (see Fig. 45) use standard PIN diodes, but with the electrodes forming a three-dimensional array penetrating part or all the way through the silicon, rather than being confined to the surfaces, as was the case prior to their development. Their electrodes can have many different shapes, can be placed close together, and can form the physical edges. Such "active edges", long tracks and short collection distances can give them:

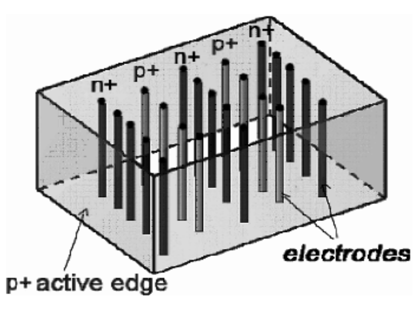

FIG. 45: Schematic diagram of a 3D active edge sensor.

1. low full-depletion bias voltages
2. negligible border dead areas
3. extreme radiation hardness with signal efficiencies of 50% or higher for $2 \times 10^{16} p/cm^2$
4. extreme speed, and
5. With both electrode types reaching both surfaces, metal lines can join one type to form a strip detector for a fast trigger or used to subdivide pixels to help in untangling tracks from closely adjacent vertices.

Figure 46 shows a schematic diagram of such a sensor using cylindrical electrodes. (The FBK sensors use the surface field oxide as an etch stop.) Trench or wall electrodes will be better for high-speed applications. With a suitable RC network fabricated on one surface, strip signals from the bias electrodes could even be read out by a separate part of the pixel ASIC. The reference section has a full list of our 3D publications. Collaboration with FBK in Trento and CNM, Barcelona has been fruitful. These two labs have developed a different form of 3D sensor as shown in Figure 46. It takes fewer fabrication steps, but does not have active edges and is insensitive to tracks aligned with, and passing through the electrodes. Effective high-efficiency is restored with a 15^0 tilt to the particle direction.

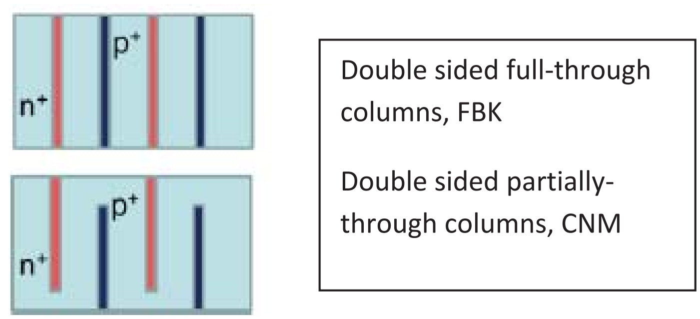

FIG. 46: Double sided columns, no support wafer used in fabrication

Proposed uses in ATLAS

3D sensors have a number of applications, including several in high energy physics and others in photon science. This proposal, however, will concentrate on those proposed for the ATLAS experiment at the Large Hadron Collider:

1. The present ATLAS inner pixel layer (called the "B layer" due to its importance in identifying B mesons) is not expected to last until the planned inner detector replacement prior to the start of the Super LHC (sLHC). A smaller

beam pipe with an additional layer of pixel detectors that can be inserted inside the present detector, the Insertable B Layer (IBL) is under construction. Thanks to the R& D efforts of Parker 3D sensors have been chosen for the forward and backward 25% of the IBL that will be placed inside of the present pixel detector. The entire IBL will have smaller pixels and a readout chip, the FEI-4 that is both more capable at high rates and with $130\mu m$, rather than $250\mu m$ technology, even more radiation hard. The central 75% will use planar technology silicon sensors that will need, as radiation damage sets in, bias voltages up to 1,000 V (about five times that needed for 3D) and consequently have large heat loads. Even so it would have been very difficult for them to collect charge from the far surface, which is necessary in tracking particles that traverse the end sensors at a slope of just 10%. 3D sensors have demonstrated the necessary radiation hardness for this task. FBK and CNM have already fabricated twice the number of sensors needed for the 3D 25%, thus allowing for bump bonding and other fabrication yields.

2. Because of their radiation hardness and active edges, the FP420 (forward protons at $\pm 420m$) collaboration has chosen 3D as their baseline position sensor. Detector systems have been proposed to both ATLAS and CMS. ATLAS already had a group working on detectors to be located at $\pm 220m$, and for the purposes of ATLAS, the two groups have merged. Special Hamburg beam pipes with pockets for tracking and timing detectors that can shift laterally between injection and running positions will be installed; the groups are scrambling to put in test detectors. Three comments [A - C] follow the relevant section below from the Letter of Intent for the Phase-I Upgrade:

   "Concerning the choice of the sensor type, the AFP is closely watching the decision process of the IBL (Insertable B Layer) upgrade project and is willing to follow its decision because it has a very similar time schedule and main requirements (see above). The IBL considered two options of the silicon sensors, namely the 3D and planar slim-edge n-in-n. Recently, the Panel for the choice of the IBL sensor type concluded that both technologies satisfied the IBL performance requirements [A]. For the AFP detectors, the 3D option has clear advantages in providing very short inactive edges (of the order of $\sim 200mm$) [B], high radiation tolerance [C] and low bias voltage. Therefore the 3D technology is considered as the baseline for the 2013-2014 installation (see Section 5.6) and the planar slim-edge n-in-n as the backup one."

   [A] Planar sensors with maximum radiation damage will have difficulty satisfying the IBL performance requirements in the 25% of the IBL closest to the ends.

   [B] The Stanford-SINTEF active edge sensors (Fig 45) have inactive regions of a few microns at most. For example, Fig. 13 of shows a sensor width from beam of $3.203 \pm 0.004mm$ with an expectation (drawn) of 3.195 mm, a lower edge σ of (4.3 ± 4.1) microns, and an upper edge σ of 9.7 ± 3.0 microns with some of this due to the beam telescope accuracy. A new development, covered in section may allow the fabrication of active edges in the FBK process as well.

   [C] High radiation tolerance may not be enough. If the beams downstream from ATLAS are similar to those in CMS, a form of radiation damage failure, not previously described in the literature, could cause even 3D sensors to fail. This problem and a solution are described in section .

3. Finally, 3D sensors designed for extreme radiation hardness might be used for the inner pixel layers of the sLHC detector. Induced-signal dual readout in the z direction could help untangle nearby events.

Electrode Efficiency

Calculations in the initial paper indicated the electrodes could be efficient despite the low fields and short recombination lifetimes in polycrystalline silicon, but it was still something of a surprise to see the complete absence of a low-side tail in the lines in the pulse-height distributions from a ^{241}Am source, indicating all x-rays gave either full or zero size pulses. This is shown in Fig. 7. The variation of counting rates when a sensor is scanned across the microbeam at the LBL Advanced Light Source (ALS) with spreading from the beam profile removed shows completely flat bottoms 5 and 11 microns wide for N and P electrodes, not what would be expected from a short lifetime in polycrystalline silicon.

The reduced efficiency inside the electrodes might be due to the original unavailability of non-oxygen containing dopant gases, resulting in possible thin layers of SiO_2 that could block the collection of charge carriers. Diborane and phosphine are now available and have been used in the last fabrication run. It is planned to use x-rays from a cadmium source passed through collimators fabricated from powdered tungsten and epoxy using a mold made from a silicon wafer with etched columns. The signals will be examined using low-noise amplifiers.

Speed

Reference covers the high speed capabilities of 3D sensors. They can have short collection distances and ionization from δ rays arrive nearly simultaneously with that from the rest of the track, rather than randomly during the middle of the pulse where they would distort the pulse shape as they do with planar sensors.

The data was taken using an un-collimated ^{90}Sr source at a bias of half the maximum safe voltage, with 20 sensors ganged together, and run at room temperature. Fitting pulse shapes gave, in Fig. 18 a noise limited timing error range between 30 and 180 ps for the largest to smallest pulses. With a lower source capacitance from un-ganging, the signal height should at least double and the amplifier speed will also double. Reducing the temperatures from +20 to -28 C would increase drift velocities by factors of 1.3 to 1.5, depending on the electric field value, and will also increase circuit speed. Since the noise is Gaussian to at least, and probably more than three orders of magnitude, increasing the number of layers will also increase the timing resolution. For at least some applications, the needed silicon area is not large, and 9 layers, which would improve timing by a factor of three, could reasonably be used. Other systematic factors will enter as timing is improved, but a time resolution of 30 ps or less seems reasonable.

Active Edges

Fig. 47 shows the fabrication of an active edge sensor. The support wafer (which will eventually have to be removed) is needed to hold the devices together when the trenches are etched. A new development in deep reactive ion etchers - the ability to make trenches with a 90 to 1 depth to width ratio, well beyond the 20 - 30 to one that we had at the start of 3D development, may allow active edges to be fabricated in the FBK sensors of Fig. 46. Fig. 48 shows such trenches.

Hole depth to diameter ratios are usually half those of trenches due to the need to remove etching products from a narrow volume. If 45 to 1 can be realized for the expected wafer thickness of 230 microns, the hole diameters would be about 5 microns. It would then be possible to line the edge with a series of such holes as shown in Fig. 49 for a part of one edge (not to scale; the holes have diameters of about 5 microns and are separated by 7.5 microns. A dicing etch or saw cut, just to the right of the holes is done after deposition of under-bump metal.

The company making the etcher has offered to do sample etches using wafers supplied by us with our lithography. If successful, this would provide more than enough sensors for the forward AFP installation.

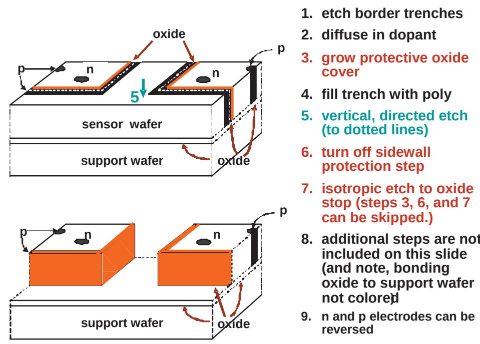

FIG. 47: Fabrication of an active edge sensor using a support wafer.

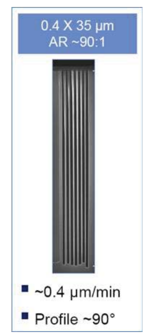

FIG. 48: 90:1 depth to width ratio etched trenches

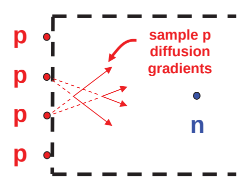

FIG. 49: Active edge side of one pixel (outlined by black —line) showing p diffusion gradients, which will combine to produce an approximately horizontal E field.

A New Form of Radiation Damage Failure

It is well known that depletion voltages increase with irradiation due to the space charge from bulk radiation damage. It is also the case that breakdown voltages can increase due to the more uniform distribution of such bulk and surface charges. The AFP detector will use the large 2 cm FEI-4 readout chip which is not only very radiation hard, but large enough so one readout circuit-sensor combination can completely cover, for any single plane, the

horizontal dist. (mm)		1	3	5	7	9	11	13	15	17	19	21	23
vertical dist. (mm)													
24		4	5	4	3	6	6	6	6	8	18	29	24
		4	6	3	6	6	10	6	13	16	34	34	35
20		4	5	6	8	12	7	9	15	17	37	16	31
		3	7	8	7	12	32	18	19	13	15	15	16
		7	5	8	15	17	19	32	38	19	24	18	13
		9	50	14	40	26	22	28	24	15	16	15	27
		18	14	28	22	51	38	50	40	31	18	52	45
10		20	20	34	55	58	38	24	22	24	22	28	26
		14	33	18	42	45	50	31	43	57	51	40	54
		14	61	31	38	65	74	70	60	38	33	34	37
		26	58	81	122	110	68	53	35	38	38	50	53
		22	61	145	222	223	255	97	88	112	68	171	842
0		11	21	77	204	303	519	201	203	930	**1310**	**2000**	**4750**
		19	43	125	328	256	226	119	56	128	83	180	865
		33	49	60	150	86	69	40	33	35	36	39	60
		20	34	50	103	77	50	37	38	25	31	25	28
		11	36	52	59	35	28	49	48	34	39	23	17
-10		19	13	47	53	48	26	45	39	24	29	19	26
		15	17	84	72	48	50	53	43	23	24	17	29
		16	11	23	21	31	47	71	78	35	43	18	13
		8	7	12	19	16	34	53	35	37	19	21	15
		5	8	6	8	15	37	24	29	25	36	14	20
-20		4	9	8	8	7	8	16	16	10	18	12	38
		4	5	10	11	6	6	6	20	14	26	24	34
-24		7	4	5	3	4	4	4	7	7	10	10	16
horizontal dist. (mm)		1	3	5	7	9	11	13	15	17	19	21	23

FIG. 50: Calculated flux ($cm^{-2}x^{-1}$) of charged hadrons as a function of position at a luminosity of $10^{33}cm^{-2}s^{-1}$ for the TOTEM detector RP4h. The flux is divided by 10^4 then rounded to nearest integer. The horizontal and vertical distances to the center of each pixel are given along the edges. The beam center line is 2.1 mm to the right of the right edge of the pixel with 47.5 million counts.

area of interest. This simplifies what otherwise could be a real mess, but leads into a trap. The area of interest must be very close to the LHC circulating beams and the forward protons are very forward, intensively irradiating a small region of the sensor. Figure 50 shows the distribution downstream from CMS. Detailed calculations for ATLAS are underway. If the results are at all similar to these, bias voltages adequate to deplete the heavily irradiated part of the sensor will most likely cause breakdown elsewhere. Details showing depletion and breakdown can be seen.

There is a solution, also given: in:Line the regions with interior active edges in a regular pattern that isolates heavily irradiated sections. These edges, which must be made from trenches, are separated with etched trenches filled with TEOS - tetraethooxysilane - $Si(OC_2H_5)_4$ making a triple wall: p active edge - TEOS -p active edge of the adjacent section. The TEOS deposition makes a conformal coating, filling the trench, and has a completely adequate dielectric strength. Fig.51 shows a schematic diagram of an interior junction in such a sensor. The regions will be provided with separate bias voltage lines as needed. Some special precautions may be needed along the outside borders and are covered in the paper. The active edges of section are suitable for locations with approximately uniform irradiation such as the innermost barrel pixel layers. This may not be the case for endcap pixel layers, which for high irradiation levels, may develop similar problems.

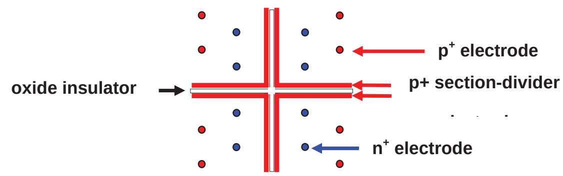

FIG. 51: Triple wall, bias voltage isolating structure.

Conclusions

The past year has seen increased cooperation between the four processing labs. 3D sensors first proposed by S. Parker are set to be used in two places in ATLAS - the IBL and as test devices in the Hamburg beam pipes which pose special challenges at high irradiation levels. A number of new structures should be fabricated including the triple wall, multi-bias voltage sensors and double-sided active edge sensors. One generic development, fast timing, also developed by Parker has well known improvement steps that can be taken in the future. Sensors fabricated with non-oxygen containing dopant gases, diborane and phosphine have been fabricated and are to be tested for charge collection efficiency of ionization created within the electrodes.

Appendices: Biographical Sketch & Publications

Biographical Sketch

Parker, Sherwood I. physicist

U. of Illinois, Urbana-Champaign	BS	1953	physics
U. of California, Berkeley	MA	1955	physics
U. of California, Berkeley	PhD	1959	physics

PROFESSIONAL EXPERIENCE:

1951-52 Summers, Naxon, Lincolnwood, Il, machine tool operator
1953 Summer, General Electric, Syracuse, NY, physicist
1953-55 Teaching Assistant, U. of Calif., Berkeley, physics
1954 Summer, Radiation Lab, machinist
1955-59 Research Associate, Radiation Lab, U. of Calif., Berkeley
1959-64 Instructor, Assistant Professor, U. of Chicago, Chicago
1964-71 Assistant Professor, U. of Calif., Berkeley
1971- Physicist, U. of Hawaii

MEMBERSHIPS:

Fellow, American Physical Society
Life Member, Institute of Electrical and Elecctronics Engineers
1997-2000 Member, NIH Biomedical Imaging Technologies Study Section SSS-7
2003 Member, NIH Biomedical Imaging Technologies Study Section ZRG1

PATENTS:

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7. Sherwood Parker, Cinzia Da Via, Mario Deile, Thor-Erik Hansen, Jasmine Hasi, Christopher Kenney, Angela Kok, Stephen Watts, Dual Readout, "3D Direct / Induced-Signals Pixel Systems", *Nucl. Instr. Meth* **A594** (2008) 332.

8. C. Da Viá, E. Bolle, K. Einsweiler, M. Garcia-Sciveres, J. Hasi, C. Kenney, V. Linhart, Sherwood Parker, S. Pospisil, O. Rohne, T. Slavicek, S. Watts, N. Wermes, "3D Active Edge Silicon Sensors with Different Electrode Configurations: Radiation Hardness and Noise Performance", submitted for publication.

9 S. Parker, A. Kok, C. Kenney, P. Jarron, J. Hasi, M. Despeisse, C. Da Via, and G. Anelli, "Increased Speed: 3D Silicon Sensors; Fast Current Amplifiers", *IEEE Trans. Nucl. Sci.*, **58** (2011) 404.

10. S. Parker, N.V. Mokhov , I.L. Rakhno , I.S. Tropin , Cinzia DaVia , S. Seidel , M. Hoeferkamp , J. Metcalfe , Rui Wang, C. Kenney, J. Hasi, P. Grenier, "Proposed triple-wall, voltage-isolating electrodes for multiple-bias-voltage 3D sensors", to be published in *Nucl. Instr. Meth*

(For a more complete list of 3D publications to get a list of current collaborators, see the reference list in the proposal, selecting those of which I am an author.)

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1. S. Parker, A. Kok, C. Kenney, P. Jarron, J. Hasi, M. Despeisse, C. Da Via, and G. Anelli, "Increased Speed: 3D Silicon Sensors; Fast Current Amplifiers", *IEEE Trans. Nucl. Sci.*, **58** (2011) 404.

2. S. Parker, N.V. Mokhov , I.L. Rakhno , I.S. Tropin , Cinzia DaVia , S. Seidel , M. Hoeferkamp , J. Metcalfe , Rui Wang, C. Kenney, J. Hasi, P. Grenier, "Proposed triple-wall, voltage-isolating electrodes for multiple-bias-voltage 3D sensors", *to be published in Nucl. Instr. Meth*

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6. Sherwood Parker, N.V.Mokhov, I.L.Rakhno, I.S.Tropin, Cinzia DaVia, S.Seidel, M. Hoeferkamp, J.Metcalfe, Rui Wang, Christopher Kenney, Jasmine Hasi, Philippe Grenier, "Proposed triple-wall,voltage-isolating electrodes for multiple-bias-voltage 3D sensors", Nuclear Instruments and Methods in Physics Research **A685** (2012) 98103.

7. Cinzia Da Via, Maurizio Boscardin, Gian-Franco Dalla Betta, Giovanni Darbo, Celeste Fleta, Claudia Gemme, Philippe Grenier, Sebastian Grinstein, Thor-Erik Hansen, Jasmine Hasi, Chris Kenney, Angela Kok, Sherwood Parker, Giulio Pellegrini, Elisa Vianello, "3D silicon sensors: Design, large area production and quality assurance for the ATLAS IBL pixel detector upgrade, 3D silicon sensors: Design, large area production and quality assurance for the ATLAS IBL pixel detector upgrade", Nuclear Instruments and Methods in Physics Research **A694** (2012) 321330.

Radio Detection of High-Energy Particles Progress Report 2013

Faculty: *P. W. Gorham (task PI, gorham@phys.hawaii.edu), S. Matsuno, G. Varner*
Postdoctoral Fellows: *B. Fox, H. Schoorlemmer* **Students:** *B. Hill, T. Nelson, B. Rotter*

ANITA Synopsis

This progress report covers the third year of a four year program which will lead at the end of next year to the third flight of the Antarctic Impulsive Transient Antenna (ANITA) payload. In two successful flights in 2006/2007 and 2009/2010 ANITA has demonstrated a leading role as the most sensitive ultra-high energy neutrino telescope in the world. Although the overall exposure time for long-duration balllon flights does not match the overall exposure of ground-based observatories, ANITA has still established the best world limits on fluxes of astrophysical neutrinos in the 10^{18-21} eV range. This energy interval is encompasses the range where cosmogenic neutrinos, which are produced from the interaction of the highest energy cosmic rays with the cosmic microwave background radiation, are expected to dominate the flux.

ANITA's first two flights tested a range of plausible models for cosmogenic neutrinos, and has set strong and physically compelling constraints on several of them. Thus ANITA has been successful in its original stated goals: to either detect the cosmogenic neutrinos, or constrain their fluxes at a level which challenges current theory for their production. In addition, the pulse- interferometric radio imaging methodology developed for ANITA is a unique contribution to the field of radio science [44], and direct measurements of the Antarctic radio albedo are an important contribution to radio measurements in the field of glaciology [45].

In fact, results from ANITA have exceeded expectations due to the serendipitous observation of radio emission from ultra-high energy cosmic rays (UHECR), observed primarily in reflection off the Antarctic ice sheets. This result, which appeared in a blind analysis of the ANITA data, was unexpected but is now well understood in hindsight, and fortunately poses no background to neutrino detection. Rather it complements the neutrino search by validating its sensitivity with a naturally arising signal that shares many characteristics with the expected neutrino signal, expect that its radio emission is polarized in a completely orthogonal direction. This fortuitous detection of over 20 UHECR events (combining data from both the ANITA-1 and ANITA-2 flights) provides the highest energy sample of such events ever observed via radio emission, and has in one leap now exceeded the energy reach of a wide range of ground-based experiments that have been working on such detections for the last decade.

The third flight for ANITA, here denoted ANITA-3, will now extend ANITA's neutrino sensitivity by a factor of three or more, while at the same time greatly enhancing ANITA's UHECR detection capability, leading to a conservative expectation of several hundred UHECR events detected in a 30-day Long-duration balloon flight. In addition, we have in the last year identified a new area of sensitivity for ANITA observations: radio signatures of potential dark matter candidates can be observed within ANITA's range of detectability, and in some cases, ANITA's observations provide unique sensitivity to certain types of events [46].

Our third year of effort for ANITA-3 has centered on beginning the build of the flight hardware, which includes a completely new trigger and waveform digitization system. Because of the long development cycle for these completely new subsystems, we have extended our efforts to include several additional steps to the development of these systems, including builds of engineering models and proto-flight models where appropriate, prior to full production. In some cases where the development cycle was mature enough, we have begun full flight production of subsystems. In several cases where potential very long leads were possible, we have accelerated procurements to buy down any risk that vendors could not deliver in time.

As of last year, ANITA was scheduled to fly in the 2013/2014 Antarctic season. However, due to several factors, and with careful deliberation and coordination with our NASA discipline scientist Dr. W. V. Jones, and with Dr. Papitashvili of the NSF polar programs, we have deferred our flight until the following season. ANITA is now scheduled to fly as the only primary LDB science payload for the 2014/1025 season. Thus our schedule of deliveries and development has been modified appropriately, and this progress report reflects those changes.

Trigger, Digitizer, Data acquisition subsystems

Early this year we began extensive testing of the two Application Specific Integrated Circuits (ASICs) designed and built for the ANITA-3: The Realtime Interferometer Trigger Correlator (RITC), version 2, and the Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR), version 4B. Since that time an intensive effort of testing of the two ASICs has been ongoing as part of the final flight engineering prior to production of these crucial systems. The *trigger* is that portion of the system which determines that there is a radio pulse of interest present at the terminals of the antenna, thus alerting the waveform digitizers to save data. The digitizers are normally buffering data in a round-robin fashion that overwrites itself every microsecond or so, and thus the trigger subsystem must respond within a few tens of nanoseconds to ensure rapid digitization of events of interest.

The RITC-based trigger requires that the RITC, which is a realtime 3-bit digitizer/correlator, must have adequate fidelity and phase response to coherently sum the waveforms of several antennas in a single azimuthal ϕ-sector of the payload. Testing to determine whether adequate fidelity is achieved in the current version of the RITC is ongoing. As an alternative we have also developed a new tunnel-diode-based trigger system, building on the successful ANITA-2 trigger, and this is now in final production stages, and will provide substantial improvement compared to ANITA-2 should the RITC testing indicate that its correlator functionality does not meet its design specifications.

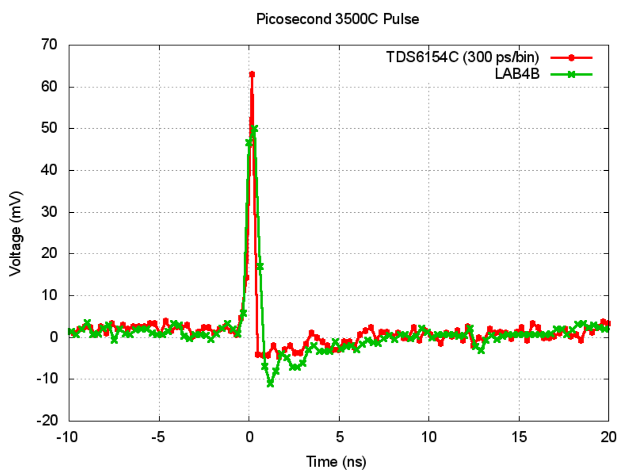

FIG. 52: *Example of a very fast pulse digitized with the LAB4B ASIC (green), and the reference pulse as digitized by a high-bandwidth oscilloscope, re-sampled to a rate close to that of the 3.2 Gs/s LAB4.*

The very successful development of the LABRADOR3 ASIC at Hawaii was one of the enabling technologies that led to the low-power operation of ANITA1 and ANITA2 in flight, an essential function because photovoltaic power generation at float altitudes is very restrictive for the deployment of power-hungry RF digitizers. The LABRADOR4 has now taken this technology to a new generation, and our initial prototype ASIC was successful in initially deploying the improvements, including a much longer record length (from 256 samples to 1024 samples) as well as new sample-stabilization circuitry and better analog-to-digital conversion techniques.

As noted above, the flight version of the LAB chip, denoted the LAB4B, has now undergone months of acceptance testing and results are excellent, with the new ASIC providing significantly improved capability compared to the previous LAB3. Fig. 52 shows an example of a very-fast pulse, (60 ps risetime and about 120 ps falltime) as digitized by both a 15 GHz oscilloscope (red) and the LAB4B (green). The intrinsic bandwidth of the pulse is about 1.2GHz, and the LAB4B provides an excellent response to the pulse, except at the voltage peak where the undershoot compared to the scope indicates its more limited bandwidth. Direct bandwidth measurements for the chip show improvement compared to the LAB3, with the 3dB bandwidth increasing from 650 MHz to about 800 MHz, and a 6 dB bandwidth (factor of 0.5 in peak voltage) of well over 1 GHz.

Ultra-high Energy Cosmic Ray Radio Emission

ANITA-3 will measure several hundred UHECR air showers, and these data will provide a unique data ensemble that will greatly complement ongoing ground-based measurements of UHECRs. NASA/JPL is already considering a Small Explorers Mission, called Synoptic Wideband Orbital Radio Detector (SWORD) for the detection and mapping of UHECRs above 10^{20} eV, where currently very limited data exists. ANITA-3's results will thus have immediate impact on NASA's SMEX program.

To ensure that these data are calibrated to the highest possible accuracy, we have undertaken in 2013 an extensive simulation program to estimate the radio emission parameters of the expected UHECR radio events for ANITA-3, based on ANITA-1 and ANITA-2 data, and also on new simulation codes that have been developed by ANITA collaborators.

In late 2013 and early 2013 we were fortunate to have a long-term visit by Prof. Enrique Zas, Univ. of Santiago de Compostela (Spain). Zas is one of the world experts in both UHECR and radio theory, and has been a pioneer in developing sophisticated simulation codes to estimate UHECR parameters. As a result of his visit, Dr. Harm Schoorlemmer has now implemented a full-scale radio simulation of the UHECR radio events for ANITA, and we have made tremendous progress in this critical science topic for ANITA-3.

Fig. 53 shows an example of the radio emission field-strength angular spectrum for one example event with the new simulation, in this case at 10^{18} eV, and a zenith angle of 60°. Both the full-band spectrum and the spectra in individual sub-frequency bands are shown in the panel on the right. A new result that has come out of these simulations is that this emission forms a narrow cone-beam, about a degree wide in angle, in a manner analogous

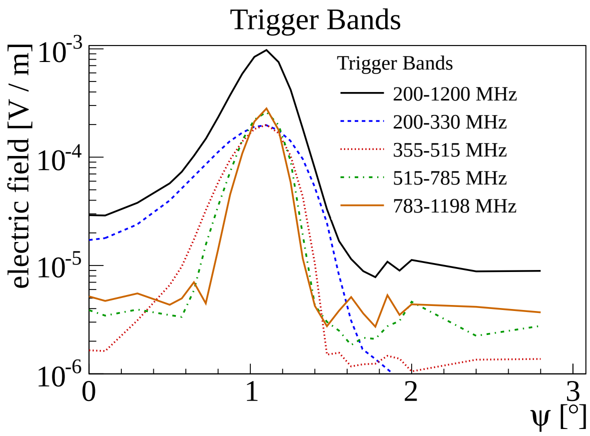

FIG. 53: *Angular spectrum of UHECR signals, log-scale, with subband frequency response shown.*

to Cherenkov radiation, although the emission arises from the geosynchrotron process.

ANITA results on UHECRs, along with the significant progress on the theoretical and simulation front, have led to new developments of possible space-based radio detection methods, and a recent payload concept designed by ANITA collaborators is under consideration as a NASA Small Explorer mission [47].

ANITA Summary

Our third of ANITA-3 payload development has gained momentum and we will carry this into the fourth year with an excellent outlook for a flight that will meet and exceed its science goals. 2013 has seen extensive testing of our new ASICs, the beginning of our flight hardware production program, great progress in the data acquisition and software processing, including the GPU-based processor, and substantial improvements in our theoretical understanding of UHECR radio emission. As of early this year all ANITA-3 antennas were in hand and in storage awaiting the flight preparations in Palestine at the CSBF facility, along with a large fraction of the other flight hardware, including RF cables.We have begun a process of close coordination with CSBF on the payload development for flight, and this will continue through our flight integration into next year. We look forward to the fourth year and its culmination in our third ANITA flight with high hopes and expectations.

FIG. 54: *AMBER installation at Coihueco, Argentina as of March 2013; the bronze mesh screen for reducing thermal noise is evident.*

AMBER

The AMBER project completed two years of initial data taking this year, with some current downtime due to a failed cooling fan within the data acquisition. Because of the difficulty of access to the system, this has caused several months of downtime since May of this year, and we are now in the process of getting replacement parts shipped to Argentina to repair this. However, data analysis is continuing, and several significant calibration improvements were made over the last year, including a much better focal plane mapping to sky coordinates, something that had been problematic in the original installation. This is challenging for a transit system which is designed for fixed pointing in the sky, because the sensitivity of the dish is such that only a relatively small number of radio sources are adequate for precise calibration. However, this has now been completed with accuracy of a fraction of a degree, more than adequate for the several-degree beam size of the current system.

AMBER installation status.

The AMBER installation, except for the recent fan failure, has performed extremely well given the challenging environmental conditions at the site, including very high winds at times. In March of this year, routine maintenance was done to repair some of the bronze ground-screen, but overall the system has been very robust.

Figure 54(top) shows a photograph taken in May of 2013 of the AMBER installation at the Coihueco Fluorescence Detector site near Malargue, Argentina. On the left the off-axis 2.4 m parabolic dish, with an optical axis pointing up at 30°elevation angle, is seen to the left of center, with a bronze mesh screen surrounding its lower half, and also the pad region, to suppress the ground thermal radia-

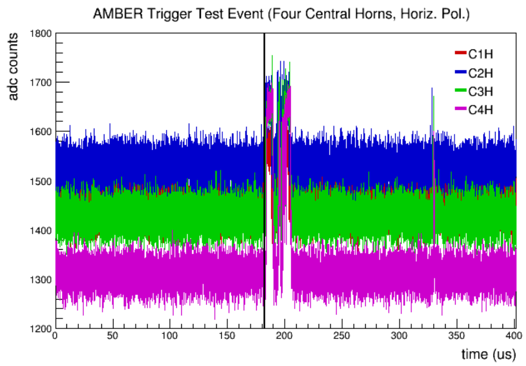

FIG. 55: *Timing experiment for AMBER system, showing that the pulse is synchronized with the trigger window.*

tion, which otherwise reduces the sensitivity of the system.

Data acquisition and analysis.

Analysis of the synchronization of the AMBER time window to the Auger event geometries is critical to detection of potential coincident events, and in late 2011 we discovered several errors that led to incorrect timing for our saved 100-150 μs windows, as well as a GPS incremental offset that was not previously accounted for. Because of the potential for other unforeseen errors of this type, we arranged for two different timing calibration experiments, which were completed by mid-year 2012. These experiments used external GHz signal pulses, along with detectors at several Auger surface detector tanks to produce an artificial coincident trigger in both the surface detector and in AMBER. Updated analysis of these data along with the new geometric constraints from better focal-plane calibration have now yielded excellent precision on the temporal and spatial coordinates for AMBER, and an example of one of the final timing experiment, overlaying the different signals, is shown in Fig. 55. This has required that we perform re-analysis of earlier data to confirm that nothing was missed, and these analyses are ongoing.

GHz detections of air showers

AMBER's pathfinding efforts have motivated several other searches for GHz air shower emission, and in both cases these groups were able to mobilize detector systems much faster than AMBER due to their associations with existing air shower installations, Auger and the Kaskade-GRANDE array in Germany. As originally reported in March 2012, these two groups have detected GHz emission by two different MBR searches independent of AMBER, although all of the detections to date have been by our Auger collaborators. In the first detection, a single-feed system co-located at one of the Auger surface detector tanks was used to observe a strong microwave pulse at 4 GHz that was generated by a 10^{19} eV air shower seen nearly head-on by the system. In the second detection, the *Cosmic Ray Observation via Microwave Emission* (CROME) instrument observed a dozen extensive air showers, also at around 4 GHz, with a single-dish system adjacent to the Kaskade-GRANDE air shower array in Germany. This measurement was based on a system quite similar to AMBER, but the geometry again constrained the showers to be observed very close to the air shower axis, which does not yet confirm that showers may be observed in the GHz regime with larger off-axis angles, a desirable feature for measurement of shower longitudinal distribution.

More recently as of June 2013, these two experiments have accumulated larger livetime under conditions of high efficiency. The most significant outcome of these efforts is from the CROME group, which in June reported the cumulative detection of more than 30 extensive air showers in the 3-4 GHz band [48]. Because of the constrained geometry, these GHz events are again detected very close to the shower axis, and may indicate a mix of different emission mechanisms. However, regardless of exact mechanism, these results now provide clear and compelling evidence that radio emission from air showers extends more than an order of magnitude in frequency above where most efforts have been concentrated in the last decade, and this is a direct outcome of our AMBER efforts to direct the attention of investigators to this possibility.

AMBER Plans and Milestones.

We are in the process of preparing two hardware augmentations to improve AMBER's GHz air shower sensitivity within the next 6 months, We plan to modify the current focal-plane feed array to dedicate all 28 channels C-band (3.4-4.2 GHz), since this is where the two detections to date have been made. At the same time, we will improve the sampling density of the feed array so that it will be more close packed and thus more efficient. A CAD model of the new camera is shown in Fig. 56.

We also plan to install improved low-noise block downconverters from Norsat, Inc., with better noise figure and stability, to improve our thermal noise floor. The new camera hardware is now complete, and is being prepared for final assembly and shipping.

We also plan to deploy a 0.5m annular extension to our existing radio dish. This has been designed

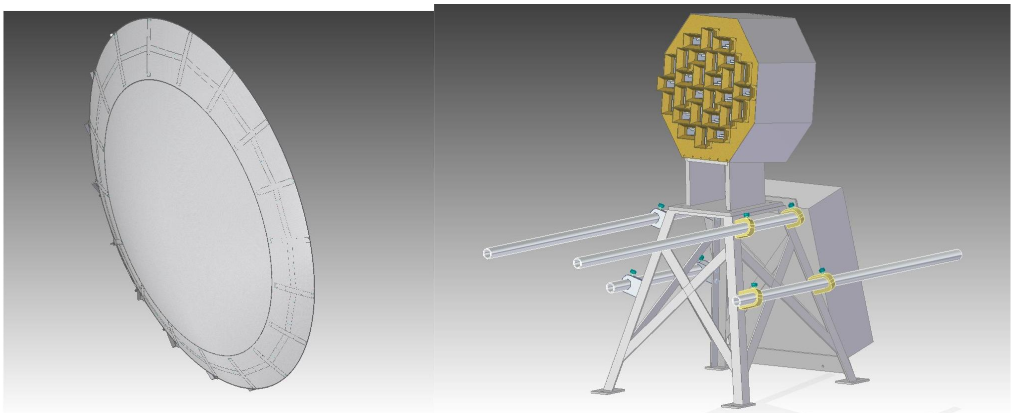

FIG. 56: *Left: The planned AMBER dish extension. The original dish diameter appears as the inner circle. Right: CAD model of the new AMBER camera, with a larger field of view and better sampling.*

and will be bolted to the exterior of the rim of our current dish to give nearly a factor of two increase in total collecting area, taking the dish diameter from 2.4 to 3.4 meters, as shown in Fig. 56. This modification will bring AMBER's sensitivity up to a level much closer to that of several other installations that are coming into operation both in Auger and other cosmic ray observatories. The dish upgrade design has been developed in CAD and is currently in the queue for final fabrication of the panels and extensions.

With these two improvements combined we anticipate a quite substantial increase in our overall sensitivity, a factor of order two or more in threshold, and an improvement of a factor of three or more in sampling efficiency.

Appendix: Biographical Sketches

Peter W. Gorham
Curriculum Vita, May 2012

Professional Preparation:

B.A., English Literature, 1980, University of California at Irvine, Department of English.
B.S., Physics, 1980, University of California at Irvine, Department of Physics.
M.S., Physics, 1983, University of Hawaii at Manoa, Department of Physics & Astronomy
Ph.D., Physics, 1986, University of Hawaii at Manoa, Department of Physics & Astronomy

Appointments:

Professor of Physics, Univ. of Hawaii at Manoa Dept. of Physics & Astronomy, 2005 to present.
Associate Professor of Physics, UH at Manoa Dept. of Physics & Astronomy August 2001 to July 2005.
Senior Member of the Technical Staff, Jet Propulsion Laboratory, California Institute of Technology, 1996-2001.
Functional appointments included:
Instrument Architect, Stellar imaging subsystem, NASA *Starlight Mission*
Project element manager, *StarLight Mission* Focal-Plane Detector System
Research Professor in Physics, UH Manoa Dept. of Physics & Astronomy, (1991-1996)
Senior Research Fellow in Physics, California Institute of Technology (1989-1991).
Postdoctoral Fellow in Physics, California Institute of Technology (1987-1989).

Synergistic Activities:

1. Principal Investigator, *ExaVolt Antenna (EVA) Mission*. NASA Science Mission Directorate funded, approx. $1.2M over 3 years, to pursue technology development for a next-generation suborbital ultra-high energy particle astrophysics detector utilizing novel balloon-embedded optics.
2. Principal Investigator, *Antarctic Impulsive Transient Antenna (ANITA).* NASA Science Mission Directorate funded (ANITA-I $8.1M total). New application of Long-duration Antarctic Ballooning to detect ultra-high energy neutrinos, 2003-2007. ANITA-II flight in 2008-2009 Antarctic season ($4.2M total) yielded UHE cosmic ray detection as well. ANITA-III ($4.5M) funded for flight in 2013. Has provided research and field training to more than 35 students and postdocs.
3. Principal Investigator, *Air-shower Microwave Bremsstrahlung Radiometer (AMBER).* Dept. of Energy, ~$100K/yr ongoing as part of High Energy Physics DOE combined grant. Develop microwave air-shower detector augmentation for the Pierre Auger Ultra-High Energy Cosmic-ray Observatory.
4. Co-Principal Investigator: *Askaryan Radio Array (ARA)*, National Science Foundation, Office of Polar Programs (UH component approx. $350K over 3 years). Pilot project to develop instrumentation and deploy a large-scale under-ice neutrino detector at the South Pole.
5. Co-discoverer (with D. Saltzberg) in first observation of Askaryan effect in the SLAC T460 Experiment: *Characterization of the Askaryan Effect for PeV to EeV Showers*, completed in June 2001. Enabled new methodology for observations of high energy particles.
6. 2004 JPL/NASA Tech Brief award, for NPO-30276, *The StarLight Space Interferometer,* involved invention of a new methodology applied to space interferometry. This development also won the 1999 JPL Director's Award for Exceptional Technical Excellence in the development of a novel dual-spacecraft interferometer design for the Deep Space Three Project ($2000 cash prize).
7. 2002 U.S. Department of Energy *Outstanding Junior Investigator Award* ($100K/yr since 2002) for research in *Radio Detection of High Energy Particles*. Applications of the newly discovered Askaryan effect toward detection of cosmogenic neutrinos.
8. Chair and editor, SPIE 2002 Kona Conference on *Particle Astrophysics Instrumentation;* Co-chair (with D. Saltzberg) of 2000 UCLA conference on *Radio Detection of High Energy Particles* (RADHEP 2000). These two conferences set the experimental foundation for revived interest in radio detection of high energy particles on many fronts.

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- Education

University of Tokyo, *PhD in Physics,* March 1982
Dissertation; *"Cosmic Ray Muon Spectrum and Charge Ratio up to 20TeV/c at 89° Zenith Angle."*
Kobe University, *Master of Science,* March 1978
Nagoya University, *Bachelor of Science,* March 1976

- Professional Experience

Associate Researcher: *University of Hawaii, Manoa* 2000 – Present
Assistant Researcher: *University of Hawaii, Manoa* 1991 – 2000
Assistant Research Physicist: *University of California, Irvine* 1988 – 1991
Postdoctoral Research Associate: *University of Hawaii, Manoa* 1985 – 1988
Research Associate: *Inst. for Cosmic Ray Research, Univ. of Tokyo* 1982 – 1985

- Selected publications

Publications closely related to proposed project

K2K collaboration: "Measurement of Neutrino Oscillation by the K2K Experiment", Phys. Rev. D74 (2006) 072003
KamLAND collaboration; "Precision Measurement of Neutrino Oscillation Parameters with KamLAND", Phys. Rev. Lett. 100 (2008) 221803
Super-Kamiokande collaboration: "Search for Matter-Dependent Atmospheric Neutrino Oscillations in Super-Kamiokande", Phys. Rev. D 77 (2008) 052001
Super-Kamiokande collaboration; "Three flavor neutrino oscillation analysis of atmospheric neutrinos in Super-Kamiokande", Phys. Rev. D74 (2006) 032002

Other significant publications

ANITA collaboration: "Ultra-Relativistic Magnetic Monopole Search with the ANITA-II Balloon-borne Radio Interferometer.", Phys. Rev. D83 (2011) 023513
ANITA collaboration: "Observational Constraints on the Ultra-high Energy Cosmic Neutrino Flux from the Second Flight of the ANITA Experiment.", Phys. Rev. D82 (2010) 022004
KamLAND collaboration; "Experimental investigation of geologically produced antineutrino with KamLAND", Nature 436 (2005) 499
K2K collaboration; "Measurement of inclusive π^0 production in the Charged-Current Interactions of Neutrinos in a 1.3-GeV wide band beam.", Phys. Rev. D83 (2011) 054023

K2K collaboration; "Experimental study of the atmospheric neutrino backgrounds for proton decay to positron and neutral pion searches in water Cherenkov detectors.", Phys. Rev. D77 (2008) 032003

Super-Kamiokande collaboration: "An Indirect Search for WIMPs in the Sun using 3109.6days of upward-going muons in Super-Kamiokande", Astroph. J. L12 (2011) 736
Super-Kamiokande collaboration; "Observation of the Anisotropy of 10 TeV Primary Cosmic Ray Nuclei Flux with the Super-Kamiokande-I Detector", Phys. Rev. D75 (2007) 062003

- Synergistic activities Co-convener of up-going muon analysis group, Super-Kamiokande collaboration (1996-2001)
Optical Module development coordinator. DUMAND project (1991-4)

- Collaborations ANITA collaboration: *see http://www.phys.hawaii.edu/˜anita/web/index.htm*
KamLAND collaboration: *see url: http://www.awa.tohoku.ac.jp/kamlande/*
K2K collaboration: *see urlhttp://neutrino.kek.jp/*
LBNE collaboration:
Super-Kamiokande collaboration: *see http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html*
Postdoctoral advisers: Prof. Takashi Kitamura (ICRR, U. Tokyo) and Prof. Vince Z Peterson (U. Hawaii, Manoa)

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Education:

Boston University:	B.S. in Electrical Engineering, 1989
Boston University:	M.A. in Experimental Physics, 1995
University of Hawaii:	Ph.D. in Experimental Physics, 1999

Professional Employment:

2010-present	Associate Professor of Physics, University of Hawaii
2005-2010	Assistant Professor of Physics, University of Hawaii
2002-2005	Director, Instrumentation Development Laboratory, University of Hawaii
2000-2002	Senior Scientist, AOptix Technologies Campbell, California (silicon valley)
1998-2000	EE/Physicist, University of Hawaii, University of Hawaii
1997-1998	Visiting Researcher CMS Exp., CERN & L.I.P. Portugal, based at CERN
1995-1997	Research Associate, University of Hawaii
1992-1995	Senior Electrical Engineer/Physicist, Boston University & SSC Lab.
1989-1992	Research Associate, Boston University

Selected Recent Publications :

1. **G. Varner** and L. Ruckman, "Sub-10ps Monolithic and Low-power Photodetector Readout," *Nucl. Instr. Meth.* **A601** (2009) 438-445.
2. H. Hoedlmoser, **G. Varner** and M. Cooney, "Hexagonal pixel detector with time encoded binary readout," *Nucl. Instr. Meth.* **A599** (2009) 152-160.
3. J. Benitez, D.W.G.S. Leith, G. Mazaheri, B.N. Ratcliff, J. Schwiening, J. Vavra, L. Ruckman and **G. Varner**, "Status of the Fast Focusing DIRC (fDIRC)," *Nucl. Instr. Meth*. **A595** (2008) 104-107.
4. **G. Varner**, L. Ruckman and A. Wong, "The First version Buffered Large Analog Bandwidth (BLAB1) ASIC for high luminosity collider and extensive radio neutrino detectors," *Nucl. Instr. Meth.* **A591** (2008) 534-545.
5. **G.S. Varner**, L.L. Ruckman, P.W. Gorham, J.W. Nam, R.J. Nichol, J. Cao, M. Wilcox, "Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," *Nucl. Instr. Meth.* **A583** (2007) 447-460.

Synergistic Activities :

1. Large-area, pico-second timing detector development [Argonne, Univ. Chicago, Univ. Hawaii, SLAC collaboration]
2. Coded-aperature imager for beam bunch diagnostics at a high intensity electron storage ring [Cornell Univ., KEK and Univ. Hawaii collaboration]
3. Fast Focusing Direct Internal Reflected Cherenkov (DIRC) detector development for Particle Identification at a Super B factory in Italy [Univ. Cincinnati, Univ. Hawaii and SLAC collaboration]

4. Imaging Time Of Propagation detector development for Particle Identification at a Super B factory in Japan [Univ. Cincinnati, Univ. Hawaii, KEK, Nagoya Univ. collaboration]

Collaborators & Other Affiliations:

Belle Pixel Upgrade

- Hiro Aihara *Univ. of Tokyo (Japan)*, Herbert Hoedlmoser, Tom Browder, Li Jin, James Kennedy, Marc Rosen, Larry Ruckman, Himansu Sahoo *Univ. of Hawaii*, Masashi Hazumi, Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*, Andrezj Bozek, Henryk Palka H. Niewondiczanski *Institute of Nuclear Physics (Poland)*, and Samo Stanic and *Nova Gorica Poly (Slovenia)*

International Linear Collider MAPS Pixel

- Steven Worm *Rutherford Appleton Laboratory (U.K.)*, Marc Winter *LEPSI, Strassbourg (France)* and Ray Yarema Fermi *National Accelerator Laboratory*

Silicon on Insulator Pixel Detectors

- Yasuo Arai and Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*and Hiro Ikeda *JAXA (Japan)*

Thin, Rad-hard, and fast-timing Pixel Detectors

- Chris Kenney *Molecular Biology Consortium/Stanford Univ.* and Sherwood Parker *Univ. of Hawaii and Lawrence Berkeley Lab.*

Giga-sample per second, GHZ analog bandwidth waveform acquisition

- Stefan Ritt *Paul Scherrer Institute (Switzerland)*

1ps Timing Resolution Detector Development

- Henry Frisch, Jean-Francois Genat, Fukun Tang *University of Chicago*

Next generation large Photomultiplier Readout

- John Anderson, Karen Byrum, Gary Drake, Ed May, Harry Weerts *Argonne National Laboratory*

Common Pipelined High-speed Data Acquisition and Storage

- Tadeo Higuchi and Manobu Tanaka *KEK High Energy Physics Laboratory (Japan)*

Imaging Hard X-ray Compton Polarimeter pixel detector

- Hiroyasu Tajima *Kavli Institute/SLAC National Accelerator Laboratory*

Belle Particle Identification Detector Upgrade

- Toru Iijima, Kenji Inami *Nagoya University (Japan)*, Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman *Univ. of Hawaii*, Alan Schwartz, Kay Kinoshita *Univ. of Cincinnati*

Super-B Particle Identification Detector Upgrade

- Peter Krizan, Samo Korpar *J. Stefan Institute (Slovenia)*, Kurtis Nishimura, Larry Ruckman *Univ. of Hawaii*, Jerry Vavra, Blair Ratcliff *SLAC National Accelerator Laboratory*

Graduate advisor Stephen Olsen, Seoul National University (Korea)

5 graduate students advised, 4 postdoctoral candidates sponsored

Detector R&D Scope and Personnel

Drs. S. Butsyk, Z. Cao, L. Macchiarulo, K. Nishimura, G. Varner and Messers M. Andrew, M. Cooney, H. Cumming, D. Darby, X. Gao, C. Lim, J. Malin, M. Rosen, X. Shi, A. Wong and Misses R. Caplett, G. Jung, C. Honniball and C. Yee

This task is an evolution of what had largely been funded incrementally through the previous Advanced Detector Research program awards [1][2][3]. While the overal funding of this task has been modest, it has been enabling to leverage existing personnel interest and capabilities toward the exploration of a number of next-generation detector operating principles and corresponding/integrated readout instrumentation.

Recent results for the fast focusing DIRC prototype [4][5], next-generation atmospheric Chereknov telescope [6][7], and advanced transient waveform digitization techniques [8] have been extremely valuable training grounds for the young engineers, postdoctoral fellows and students.

For example, previous work by postdoctoral fellow Nishimura and former student Ruckman on the fast focusing DIRC was a key factor in their being hired as staff members in the electronics group at the SLAC National Accelerator Laboratory. The coordinating nexus of these subtasks has been the Instrumentation Development Laboratory ("ID-Lab"), created by Varner to support such detector development initiatives. A recent photograph of a subset of the participants is shown in Fig. 57.

Funding for this task is currently modest, though does provide crucial support for coordinating the studies of project non-specific activies, as well as participation in conferences to report these results.

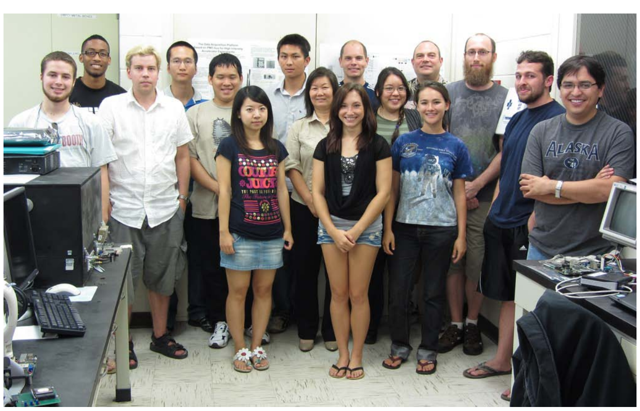

FIG. 57: Recent photograph of a subset of ID-Lab members.

Overview

Future discoveries at the energy, cosmic and intensity frontiers require large, finely segmented detector volumes. The grand themes of this Task are addressing fundamental detector issues:

- channel cost (density)
- signal speed
- information bandwidth
- radiation hardness
- low power operation
- form-factor, interconnect and high-speed data acquisition

the improvements of which are essential enabling tools toward realizing the scientific objectives of future resource-limited experiments.

Progress on these various activies are documented in the citations noted below, as well as lists of presentations at workshops and conferences, a compilation of which is included in a separate Appendix.

Fine Spatial Resolution

Research toward a CMOS-based fast sampling device for an upgraded "super" flavor-factory detector has been the doctoral disseration work of Cooney. While much of that effort has been targeted toward the particular vertexing needs of a detector operating at 10 GeV center-of-mass energy and very high hit rates, much of the architecture is more general. Aspects of the continuous, space-time encoded sampling are directly applicable to a future vertex detector requiring very low-occupancies, such as that of a high energy lepton collider vertex detector.

Cooney and Varner have continued to study implementations of the concept outlined in a detailed design study [9] for an enhanced version of space-time encoding of hits that extends the simple technique studied in earlier Continuous Acquisition Pixel (CAP) prototypes. Fig. 58 illustrates this basic scheme, wherein multiple output paths are used to resolve spatial ambiguities related to continuous readout of hit data that is not time-stamped.

Fig. 59 illustrates a Monte Carlo of the above array, where actual hits are embedded in a background of out of time hits. During continuous readout,

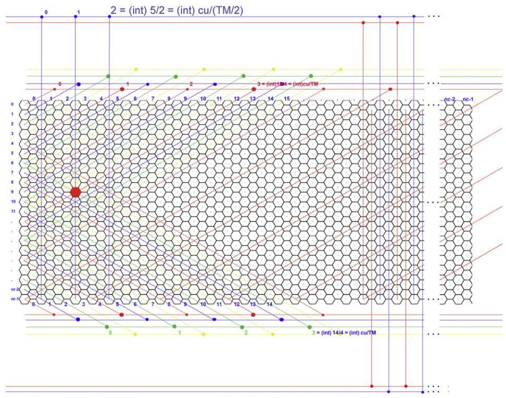

FIG. 58: An improved space-time encoding for continuous readout. Using correlations between multiple readout pathways, unique hit positions are determined for a given trigger time, significantly reducing background hit occupancy.

without using space-time encoding, there are hit-correlation ambiguities in either space or time. Requiring hit coincidences between the multiple paths, at a time constrained to the bunch collision time for a given global detector trigger latency, significantly reduces accidental hits. Further reduction is obtained by making the periphery transfers more parallel, quantified as the Transfer Multiplicity (TM). Increasing the number of these lines reduces the transit time of hits off-chip, as well as providing unique output lines, within groups of the TM modularity.

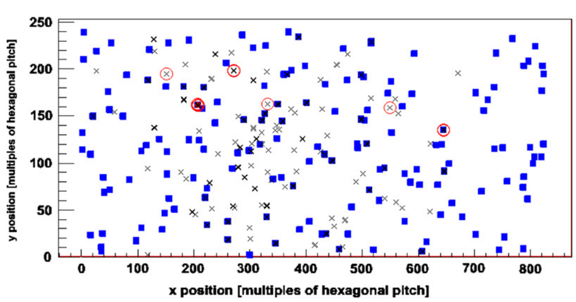

FIG. 59: Monte Carlo simulation used to evaluate the efficacy of Transfer line Multiplicity (TM) in reducing background hits.

In this way the number of such fake hits is significantly reduced, and this general trend is seen for severe (MHz/cm^2 hits) background conditions as plotted in Fig. 60. Many different silicon prototype implementations of this architecture have been studied and reported. A latest version SOI prototype (CAP12) has been fabricated and will be the final device reported in Cooney's dissertation.

A number of potentially fertile directions have been identified for further improving the occupancy and robustness of such thin vertexer devices, and these will be pursued as future resources permit.

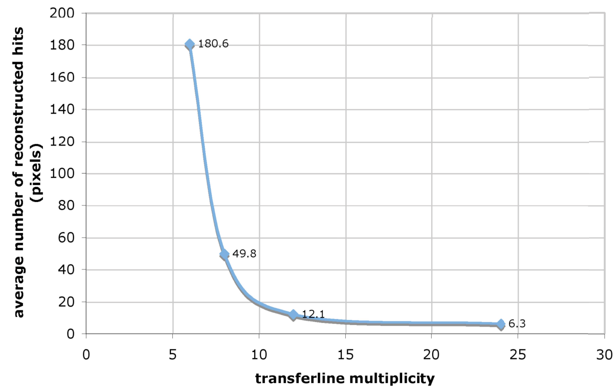

FIG. 60: Reduction in the average number of hit candidates as a function of Transfer line Multiplicity (TM).

High Precision Timing

In the last few years Varner with Andrew, Nishimura and Wong have developed a readout system for future single-photon, high-precision timing devices as part of a DOE ADR award [11][12][13]. This is based upon a deeper sample-depth evolution of the LABRADOR ASIC [19], designated the Buffered LABRADOR (BLAB) [20]. A test of this readout was performed with the focusing DIRC prototype detector at SLAC (T-492) in test beam. Based upon the success of those few-channel tests, a second ADR supported the deployment of a full complement of 448 channels on the f-DIRC prototype, a photograph of which is seen in Fig. 61. The readout ASICs reside within a circuit-board stack that sits directly behind the 64-channel photodetectors, providing a highly compact readout geometry. All control and readout is via Giga-bit fiber-optic connections.

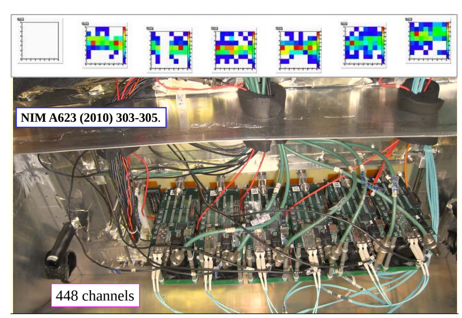

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FIG. 61: Photograph of the highly-integrated readout modules directly mounted to the 64-anode photodetectors at the imaging plane of the SLAC focusing DIRC detector prototype.

Results of those two years of system-level tests are in preparation, where excellent Cherenkov ring angular resolutions have been obtained. A third ADR has supported extension to a much larger readout array in a compact image plane, and will be reported later. In parallel with demonstrating the performance of a large readout array, careful study of the attainable performance [18] for these devices on the test bench has continued. Using MCP-PMT signals, a time difference was measured for signals recorded with two BLAB ASICs to be about 6.4ps [21] as plotted in Fig. 62. In the limit in which the errors are uncorrelated between the two readout channels, a timing resolution below 5ps is obtained.

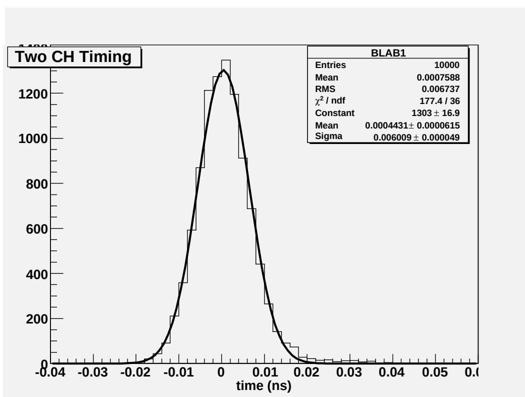

FIG. 62: Measured PMT pulse time difference between a pair of PMT signals recorded with a pair of BLAB1 ASICs.

Our ongoing program continues to study the limits of timing resolution that can be realized with Switched Capacitor Array sampling in inexpensive CMOS processes [15]. Scaling to systems with many thousands of channels, while maintaining excellent timing performance, is also an important direction for this research. Moreover, providing means to auto-calibrate and reduce calibration constants that need to be generated and maintained, is an important direction for future studies.

Precision 3D Silicon Space-Time

Excellent spatial resolution has been demonstrated for so-called 3D silicon detectors, originally pioneered by Parker and Kenney. Fabrication of electrodes through the sensor bulk permits the depletion of the detector with only a few volts of detector bias. Possible applications of this are using timing to improve the spatial resolution for such a detector. Turning the concept around, we intend to study the use of such a detector as an intermediate "timing layer". Time differences between signals on the collection electrodes are used to interpolate the spatial impact position, while the mean time can be used to provide a **time zero** for the particle identification system, independent of the bunch collision time. To realize such a silicon timing detector, integration of fast electronics discussed above with 3D technology is proposed. Studies of such a hybrid detector are envisioned to be the subject of a future ADR proposal.

Large Format Photodetectors

The technological revolution that replaced the bulky Cathode Ray Tube with a wide variety of thin, reduced-cost display technologies, has yet to be realized for photosensors. Such a low-cost, robust and flexible photon detector, capable of efficient single photon measurement with good spatial and temporal resolution, would have numerous scientific, medical and industrial applications. To address the significant technological challenges of realizing such a disruptive technology, the Large Area Picosecond Photo-Detector (LAPPD) collaboration was formed, and has been strongly supported by the Department of Energy. This group leverages the inter-disciplinary capabilities and facilities at Argonne National Laboratory, the Berkeley Space Sciences Laboratory (SSL), electronics expertise at the Universities of Chicago and Hawaii, and close work with industrial partners to extend the known technologies. Advances in theory-inspired design and in-situ photocathode characterization during growth, Atomic Layer Deposition (ALD) for revolutionizing micro-channel plate fabrication, and compact, wave-form sampling CMOS ASIC readout of micro striplines are key tools toward realizing a viable LAPPD device.

From the project inception Varner has been involved in the leadership as a convenor of the electronics group, as well as chair of the internal (god-parent) review committee for the Photocathode development effort. Excellent progress has been made in the last three years on all of the fronts identified, as was summarized by Varner in an invited talk on the LAPPD project at the April 2012 APS meeting.

The development work in Hawaii has focussed on high-performance integrated time and charge readout [16]. Nishimura has been supported by this project and brings experience gained with the subtleties of calibrating such high-speed CMOS sampler ASICs to the project.

Another major initiative was the development of the Chicago-Hawaii ASIC, Multi-Purpose (CHAMP) chip. This test device served as a platform for evaluating and optimizing a number of circuit structures used in the PSEC series of ASICs that are the baseline LAPPD readout device. Fig. 63 summarizes the ASIC design and important results. Perhaps as important as the design itself was the training of 7 students in the art of the design and fab-

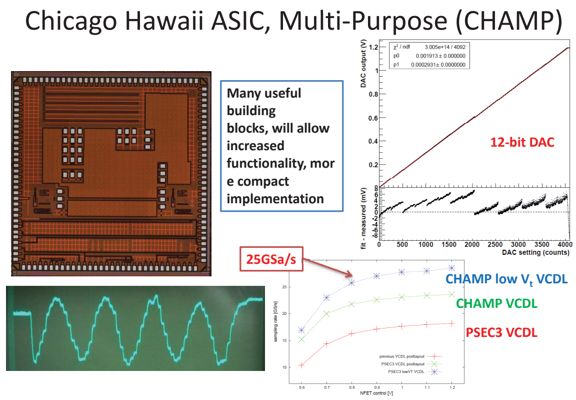

FIG. 63: Die photograph and some of the more important test results for the CHAMP ASIC.

rication a complex, mixed-signal design in the IBM 130nm CMOS process.

Of particular note is the demonstrated ability to perform sampling in excess of 20 Giga-samples/second. Cooney and Nishimura presented many of these results at the TIPP 2011 Conference, and the refereed articles will soon appear in a special edition of NIM A.

Work continues on the commissioning of an integrated readout electronics module, as shown in Fig. 64. The baseline design uses the PSEC4 ASIC, which offers impressive sampling speed, though limited buffer depth for certain applications. The electronics has been designed in a highly modular form and a variant of the front-end ("analog") card is being designed to employ deeper-sampling ASICs developed in Hawaii. Having a portfolio of ASIC choices permits the readout to be optimized to a specific application.

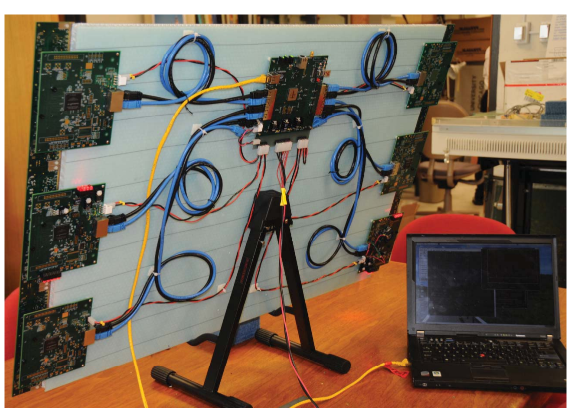

FIG. 64: Photograph of integrated electronics on the back of the LAPPD full module assembly.

High-rate Imaging Instrumentation

Applications at the forefront of high resolution space-time imaging demand higher speed signal processing than that currently available. In conjunction with the Space Sciences laboratory at the University of California at Berkeley, Cumming, Cooney and Varner will be developing next generation Charge Sensitive Amplifiers for integration with a next-generation sampling ASIC that will be optimized for fast digitization and real-time signal processing. This NASA supported project builds on a number of signal processing themes common to next-generation extensions to the waveform sampling technology that is at the heart of the Hawaii Detector R&D effort. A photograph of the first generation CSA ASIC and corresponding evaluation board are shown in Fig. 65.

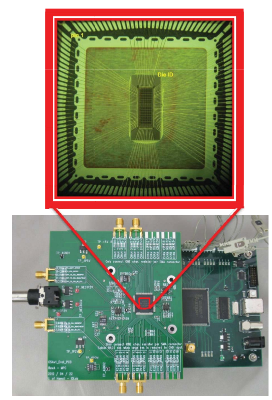

FIG. 65: Die photograph (top) and evaluation board (bottom) for a first prototype Charge Sensitive Amplifier in the IBM 130nm CMOS process.

Tera-ton Detector instrumentation

In order to achieve a canonical 1000 km^3-sr needed for observing a statistically significant number of GZK neutrino events [22], an array of radio stations instrumenting a radio transparent target volume has been proposed. The data logging and triggering issues for such an extended array have been studied in the context of a Salt Dome Shower Array concept [23]. Similarly, an ice surface array prototype station has been constructed, based upon experience integrating our radio sampling instrumentation within the IceCube infrastructure [24]. Experience with operation of these prototypes has guided the design of next-generation low-cost, high reliability radio detection stations. One of the biggest limitations of existing Switched Capacitor Array (SCA) sampling ASICs has been the rather limited storage depth for radio-frequency signals. To address this limitation, a "2 stage transfer" scheme has been adopted, wherein the sampling depth is kept short, to allow for GHz analog bandwidth, while allowing for very large storage depths, by transferring the samples into a larger matrix of stored samples. This concept is illustrated in Fig. 66 and first evaluated on the Ice Radio Sampler (IRS) ASIC. These prototype developments have subsequently evolved and have enabled the transition into formal radio detection projects, the fruits of the initial results recently being reported [25–27].

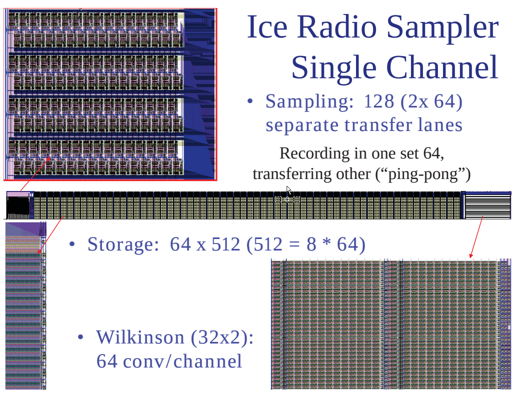

FIG. 66: Overview of a single channel of "2 stage" sampling that allows for GHz analog bandwidth recording while extending the sampling array to 32k storage cell depth.

Beamline Diagnostics

Utilizing fast sampling instrumentation, Varner has been working with beamline diagnostics experts at KEK and Cornell to develop an x-ray Monitor [28] to permit turn-by-turn precision bunch imaging, a valuable tool for diagnosing instabilities in very low-emittance lepton storage rings. A first integrated prototype x-ray sensor and Sampler for Transients of the Uniformly Redundant Mask (STURM) readout was tested in an x-ray beamline at the KEK Photon Factory in March 2009. A photo of the test set-up is seen Fig. 67, where an InGaAs array records x-ray pulses that are separated by about 2ns. Subsequently, measurement of a low-emittance beam was performed [29], validating the experimental approach and further motivating development toward a highly-integrated monitoring system.

Fig. 68 demonstrates the ability to capture the ∼250ps risetime of the x-ray pulse observed with the InGaAs linear-array detector. For each triggered readout, 8 samples are recorded, separated by 100ps. To allow a fine scan, an RF trombone delay was used to offset the signal in 5ps steps. Event-to-event fluctuations in the signal amplitude required some averaging and result in the scatter observed. Nevertheless, the risetime (starting at 800ps) is clearly seen and matches that recorded with a 10GHz analog bandwidth digital oscilloscope.

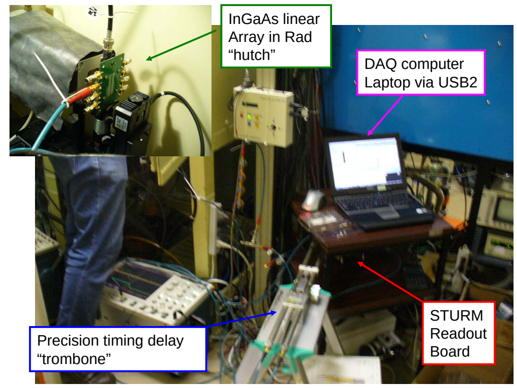

FIG. 67: Photograph of the cramped quarters of the KEK Photon Factory beamline where the STURM prototpe was used to record x-ray signals observed by an InGaAs array (inset at right top).

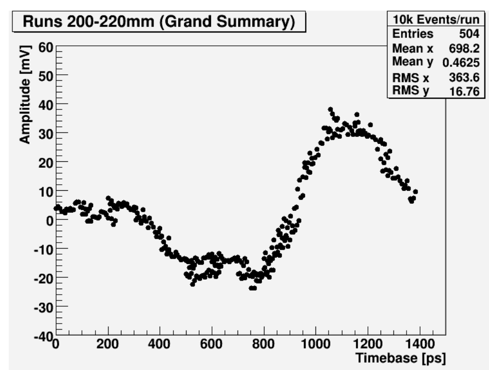

FIG. 68: Cumulative recorded results for 8 samples, separated by 100ps, stitched together with 5ps offset steps.

Visiting Finnish students have completed a highly-integrated readout module design and this will serve as a demonstrator for high-speed x-ray imaging.

In the next stages, Malin will commission a fast, 64-element linear array with upgraded 8-channel STURM2 ASIC, photographs of which are presented in Fig. 69.

Time Encoded Differential Absorption (TEDA)

An example of the synergistic development between various projects, the push to extend the temporal resolution of the x-ray beam size monitor is directly relevant to a novel concept for the detection of special nuclear materials, the concept sketch of

FIG. 69: Die photographs of the Sampler of Transients for the Uniformly Redundant Mask (STURM) ASIC.

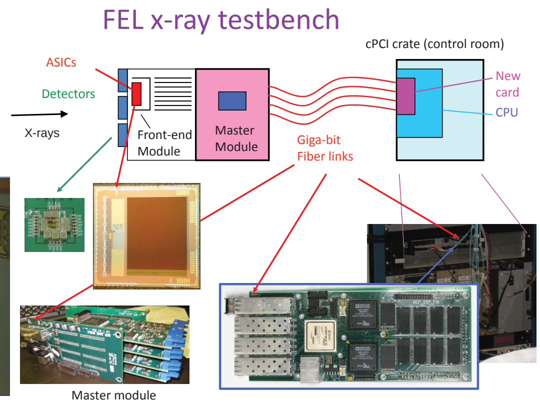

FIG. 71: Development testbed of the Hawaii Free Electron Laser facility, capable of producing high-intensity, pico-second duration characterization pulses.

which is illustrated in Fig. 70. In this Department of Homeland Security funded inititiative, multi-colored x-rays (gamma-rays) are used to differentially probe the spectral dependence of nuclear cross-sections.

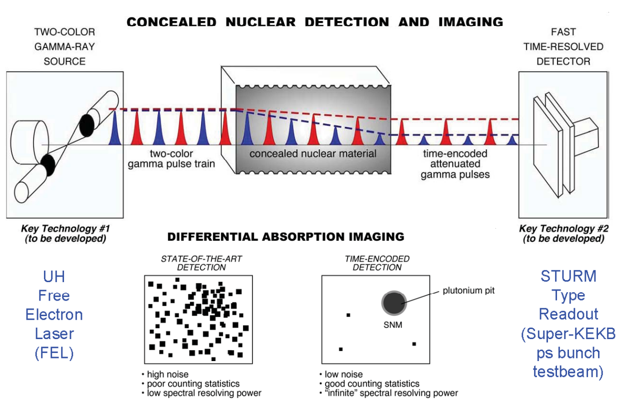

FIG. 70: Illustration of the Time-Encoded Differential Absorption technique, wherein unique Hawaii capabilities in x-ray production and detection provide a novel means of improved materials identification.

Fine spatial and temporal resolution significantly improves image contast and provides sensitivity distinct from simple density characterization of an integral view through a column of material (such as the scan of a shipping container).

This project takes advantage of a unique resource – the Hawaii Free Electron Laser. The ability to generate tunable, intense x-ray pulses of picosecond duration is an extremely valuable tool for the characterization of a number of the sensors, readout electronics, and high-throughput processing electronics described in earlier topics of this Task. An illustration of how this serves as such a test bench is provided in Fig. 71.

Cherenkov Telescope Array (CTA)

As noted at the outset, the small projects that comprise this Task are generally underfunded. In order to evaluate various detector and readout concepts, it has been necessary to align a given exploration direction with future project (speculative) R&D. An example is prototyping of a readout ASIC for the Belle II muon system upgrade. Many microseconds of storage of transient signals at Gigasample per second rates on high channel count, inexpensive readout of dense photo-sensor arrays is a key enabling technology toward an atmospheric gamma ray telescope to supercede existing Cherenkov telescopes such as HESS, MAGIC, and VERITAS.

Specifically, the TeV Array Readout with GSa/s sampling and Event Trigger (TARGET) ASIC [30] has grown out of a concept demonstrator for AGIS, which was a pre-cursor study to what has now become the Cherenkov Telescope Array (CTA) project [31]. TARGET is now one of the many competing options for CTA readout, and currently the only SCA-based CMOS ASIC capable of storage for a full-array trigger maximum latency. Even if not finally adopted by CTA, the development resources provided by SLAC and Nagoya University have enabled the first generations of development of this technology and Belle II and future experiments will benefit from this shared R&D.

Other Efforts

A number of smaller projects are ongoing that represent upgrades to existing major projects or prototype initiatives.

- **HanoHano** – PMT high voltage base, FPGA-based trigger and digitizer [32], and fiber-optic data collection system. First generation system developed with visiting engineering students from Finland.

- **Polarized Gamma Observatory** – Varner with Cooney have developed two generations of pipelined readout, upon which the production PoGO-lite balloon payload flight [33] electronics, to be re-flown from Sweden in summer 2012, is based.

- **Astro-H Prototype** – Varner with Cooney have fabricated an SOI prototype [34] of a silicon pixel tracker for next generation x-ray (multiple Compton scattering) telescope.

Appendices: Biographical Sketch, Publications, Bibliography & References Cited

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2005-2010	Assistant Professor of Physics, University of Hawaii
2002-2005	Director, Instrumentation Development Laboratory, University of Hawaii
2000-2002	Senior Scientist, AOptix Technologies Campbell, California (silicon valley)
1998-2000	EE/Physicist, University of Hawaii, University of Hawaii
1997-1998	Visiting Researcher CMS Exp., CERN & L.I.P. Portugal, based at CERN
1995-1997	Research Associate, University of Hawaii
1992-1995	Senior Electrical Engineer/Physicist, Boston University & SSC Lab.
1989-1992	Research Associate, Boston University

Selected Recent Publications :

1. **G. Varner** and L. Ruckman, "Sub-10ps Monolithic and Low-power Photodetector Readout," *Nucl. Instr. Meth.* **A601** (2009) 438-445.
2. H. Hoedlmoser, **G. Varner** and M. Cooney, "Hexagonal pixel detector with time encoded binary readout," *Nucl. Instr. Meth.* **A599** (2009) 152-160.
3. J. Benitez, D.W.G.S. Leith, G. Mazaheri, B.N. Ratcliff, J. Schwiening, J. Vavra, L. Ruckman and **G. Varner**, "Status of the Fast Focusing DIRC (fDIRC)," *Nucl. Instr. Meth.* **A595** (2008) 104-107.
4. **G. Varner**, L. Ruckman and A. Wong, "The First version Buffered Large Analog Bandwidth (BLAB1) ASIC for high luminosity collider and extensive radio neutrino detectors," *Nucl. Instr. Meth.* **A591** (2008) 534-545.
5. **G.S. Varner**, L.L. Ruckman, P.W. Gorham, J.W. Nam, R.J. Nichol, J. Cao, M. Wilcox, "Large Analog Bandwidth Recorder And Digitizer with Ordered Readout (LABRADOR) ASIC," *Nucl. Instr. Meth.* **A583** (2007) 447-460.

Synergistic Activities :

1. Large-area, pico-second timing detector development [Argonne, Univ. Chicago, Univ. Hawaii, SLAC collaboration]
2. Coded-aperature imager for beam bunch diagnostics at a high intensity electron storage ring [Cornell Univ., KEK and Univ. Hawaii collaboration]
3. Fast Focusing Direct Internal Reflected Cherenkov (DIRC) detector development for Particle Identification at a Super B factory in Italy [Univ. Cincinnati, Univ. Hawaii and SLAC collaboration]

4. Imaging Time Of Propagation detector development for Particle Identification at a Super B factory in Japan [Univ. Cincinnati, Univ. Hawaii, KEK, Nagoya Univ. collaboration]

Collaborators & Other Affiliations:

Belle Pixel Upgrade

- Hiro Aihara *Univ. of Tokyo (Japan)*, Herbert Hoedlmoser, Tom Browder, Li Jin, James Kennedy, Marc Rosen, Larry Ruckman, Himansu Sahoo *Univ. of Hawaii*, Masashi Hazumi, Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*, Andrezj Bozek, Henryk Palka H. Niewondiczanski *Institute of Nuclear Physics (Poland)*, and Samo Stanic and *Nova Gorica Poly (Slovenia)*

International Linear Collider MAPS Pixel

- Steven Worm *Rutherford Appleton Laboratory (U.K.)*, Marc Winter *LEPSI, Strassbourg (France)* and Ray Yarema Fermi *National Accelerator Laboratory*

Silicon on Insulator Pixel Detectors

- Yasuo Arai and Toru Tsuboyama *KEK High Energy Physics Laboratory (Japan)*and Hiro Ikeda *JAXA (Japan)*

Thin, Rad-hard, and fast-timing Pixel Detectors

- Chris Kenney *Molecular Biology Consortium/Stanford Univ.* and Sherwood Parker *Univ. of Hawaii and Lawrence Berkeley Lab.*

Giga-sample per second, GHZ analog bandwidth waveform acquisition

- Stefan Ritt *Paul Scherrer Institute (Switzerland)*

1ps Timing Resolution Detector Development

- Henry Frisch, Jean-Francois Genat, Fukun Tang *University of Chicago*

Next generation large Photomultiplier Readout

- John Anderson, Karen Byrum, Gary Drake, Ed May, Harry Weerts *Argonne National Laboratory*

Common Pipelined High-speed Data Acquisition and Storage

- Tadeo Higuchi and Manobu Tanaka *KEK High Energy Physics Laboratory (Japan)*

Imaging Hard X-ray Compton Polarimeter pixel detector

- Hiroyasu Tajima *Kavli Institute/SLAC National Accelerator Laboratory*

Belle Particle Identification Detector Upgrade

- Toru Iijima, Kenji Inami *Nagoya University (Japan)*, Tom Browder, James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman *Univ. of Hawaii*, Alan Schwartz, Kay Kinoshita *Univ. of Cincinnati*

Super-B Particle Identification Detector Upgrade

- Peter Krizan, Samo Korpar *J. Stefan Institute (Slovenia)*, Kurtis Nishimura, Larry Ruckman *Univ. of Hawaii*, Jerry Vavra, Blair Ratcliff *SLAC National Accelerator Laboratory*

Graduate advisor Stephen Olsen, Seoul National University (Korea)

5 graduate students advised, 4 postdoctoral candidates sponsored

Recent Detector R&D papers

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[1] DE-FG02-06ER41424 (PI Gary Varner)
[2] DE-FG02-08ER41571 (PI Gary Varner)
[3] DE-SC0004815 (PI Gary Varner)
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Theoretical Particle Physics Research

Drs. J. Kumar, D. Marfatia, A. Mustafayev, R. Nevzorov, S. Pakvasa, W. Simmons, X. Tata, B. Thomas and Messrs. J. Bramante, K. Fukushima, R. Kadala, P. Stengel and D. Yaylali

Overview

The Hawaii theory group currently consists of faculty members, Kumar, Marfatia (who starts after completion of this award), Pakvasa, and Tata, affiliate faculty member Simmons, post-doctoral researchers Mustafayev and Thomas, and graduate students Bramante, Fukushima, Stengel and Yaylali. Pakvasa will retire after completion of this award.

The research of the theory group is largely phenomenological in character and covers the energy, cosmic and intensity frontiers. The main theme is to identify new physics that addresses interesting questions in particle physics and cosmology that are beyond the scope of the Standard Model, and then to delineate strategies to confront the Standard Model and these new physics extensions via experimental tests at high-energy and/or high-luminosity colliders as well as at non-accelerator experimental facilities. Kumar has pushed the possibility that the positive signals of the DAMA/LIBRA, CoGeNT and CRESST experiments are due to light (few GeV) dark matter, has been spearheading an effort to incisively probe WIMPless dark matter scenarios that he has proposed, is exploring observational implications of inflationary cosmology, and is studying several aspects of collider phenomenology at the LHC. Pakvasa's activities have centered around neutrino physics and astrophysics, as well as flavor physics, including mixing, CP violation and rare decays of heavy-flavor systems. Tata's main focus has been on the search for new physics with emphasis upon weak scale supersymmetry, at high-energy colliders, through precision measurements and via dark matter searches. Guided by the absence of a signal at the LHC, he has begun to explore the implications of the concept of naturalness in the context of supersymmetry for on-going and future experiments. The different research directions have considerable overlap as well as a common goal. This results in healthy interactions among the theorists and experimentalists in Hawaii as well as colleagues elsewhere.

A big change is that Pakvasa will retire in Aug. 2013 after 46 years in the high energy physics group. Even in retirement, he expects to come in regularly to the Department and continue his research activities. His remarkable commitment and ability to do so may be gauged by the fact that he was awarded the prestigious research award by the Alexander von Humboldt award to enable him to collaborate with Prof. H. Päs (Dortmund) and colleagues in Germany after completing his final semester of teaching. We anticipate that he will continue to be fully engaged in the research activities of the group.

The University, recognizing the importance of the research of the Hawaii Theory Group allowed us to carry out a search during Pakvasa's final year in Hawaii. We are happy that we have been able to recruit Prof. Danny Marfatia to join our group starting August 2013. Marfatia is a recognized authority on neutrino physics with a wide range of interests including dark matter physics and topics in physics beyond the Standard Model. His interests overlap strongly with those Hawaii theory faculty, and he has already begun collaborating with Kumar as well as with Hawaii students. We look forward to fruitful interactions with him.

Over the years we have built a group of researchers that strongly interact with one another and with the experimentalists in Hawaii and elsewhere. While the faculty members each have their individual research directions, they have regular scientific interactions that occasionally lead them to collaborate. It is our goal to provide the postdocs a nurturing environment where they can interact with and collaborate with the faculty and students in the group. While junior postdocs are more likely to work closely with Hawaii faculty members, senior postdocs ultimately develop independent research programs and extended collaborations. This is a win-win situation for all sides. The postdocs gain from interactions and discussions with their senior colleagues who, along with the students, benefit from new ideas that are brought in to the group. The research of the group described here as well as the historical record includes all manners of interactions: where postdocs have joined in research initiated by the Hawaii faculty as well as the other way around.

Theory group students and postdocs are currently involved in a variety of projects. Hawaii post-doc Nevzorov explored E_6 supersymmetric unification. Together with Pakvasa and others, he examined the phenomenology of the extended Higgs sector of a relic-density-consistent E_6 GUT model. He also completed an examination of an exact discrete symmetry that simultaneously ameliorates the flavor and proton decay problems endemic to these models. Former postdoc Hundi, student Kadala who graduated a year back and Tata completed their study of a bottom-up strategy for gleaning information about neutralino properties from LHC data in as model-independent a way as possible. They found that in favorable situations (these case studies are now excluded by non-observation of a signal at the LHC) that it would be possible to extract the parameters M_1, M_2 and μ of the neutralino mass matrix from LHC data in a truly bottom-up manner and without recourse to constrained models. Hawaii postdoc Brooks Thomas and Keith Dienes (Arizona and NSF) have developed a novel scenario that they dubbed dynamical dark matter in which the dark matter is comprised of a large number of particles with masses and lifetimes that naturally match the observed relic density. Kumar and students Bramante and Stengel have joined them in the exploration of its phenomenological consequences, including the recent data from AMS. Student Fukushima, Kumar and Pearl Sandick (Utah) completed a study of the detection prospects for WIMPless dark matter, assuming it to be a Majorana fermion. UH students Bramante and Yaylali, together with Hundi, Kumar and A. Rajaraman (Irvine) have completed an investigation of the prospects for probing (at the LHC) the structure of multi-gauge boson couplings that arises in a class of models where hidden sector gauge bosons couple to both gluons and to electroweak gauge bosons. Bramante, Thomas and Kumar have examined the prospects for the discovery of gluinos under the assumption these decay via $\tilde{g} \to t\tilde{t}$. Kumar and Bramante examined contributions of higher order non-linearities to logrithmic corrections to local non-Gaussianity in the CMB in inflationary scenarios. Azar Mustafayev who joined the group in August 2012 has mainly been working with Tata on natural SUSY models in light of the discovery of a 125 GeV Higgs boson. They have also identified a novel same-sign W production signal which could lead to the discovery of gauginos in small μ models at LHC14.

In other personnel changes, former post-doc Srikanth Hundi who assumed a post-doc position in the Indian Association for the Cultivation of Science in Kolkata upon completing his postdoc in Hawaii has just obtained a faculty position at IIT Kharagpur in India. Roman Nevzorov who spent a year at Moscow State upon completion of his Hawaii postdoc is moving to the University of Adeleide. He has been replaced by Mustafayev. Brooks Thomas will leave Hawaii in Aug. 2013 to take up a post-doctoral position at Carleton University. He is not being replaced. Tata's student Kadala who graduated in AY 2011-12 has a teaching position at Hawaii Pacific University and Kapiolani Community College. Kumar's student Bramante who graduated this summer will take up a post-doc position at Notre Dame. Yaylali will graduate next year, and Fukushima likely in the following year. Student Patrick Stengel has joined the Theory Group, and nearly completed a project with Kumar, and has expressed interest in working with Tata on collider signals in natural SUSY. Students Bret Papopolus-Meredith and Elan Stophnitzky have expressed interest in joining the theory group.

The Hawaii theory group has traditionally been very prudent, usually taking on only one or two students (who show clear promise) at a time into the group. The present situation is unusual by historical standards and represents an opportunity provided by the unexpected availability of excellent students with interest in theory. To realize this opportunity we have had to judiciously combine our DOE grant with the last of Kumar's start-up funds together with Marfatia's upcoming start up and TA support from the Department. This use of various resources for high energy theory research in Hawaii provides excellent value for every DoE HEP dollar to the Hawaii Theory Group.

A list of the entire group's scientific publications and conference talks that covers the funding period of this grant appears after the final report.

Neutrino Physics

The properties of neutrinos, such as their masses, mixings, magnetic moments, *etc.* are extremely important in several ways. These are fundamental parameters, they play an important role in astrophysics and cosmology, and they tell us about what may be beyond the Standard Model (SM). Apart from direct laboratory measurements of masses from β-decay end-point measurements, the other technique for obtaining information on neutrino properties is the study of neutrino propagation and flavor conversion over long distances via neutrino mixing and oscillations. It continues to be an aim of the Hawaii theory group (and especially Pakvasa) to devise means to deduce neutrinos properties from various neutrino experiments, to propose new experiments, and to construct models for neutrino masses and mixings.

Pakvasa has been an active participant in the Hanohano collaboration and in the similar but larger European project LENA. He is a co-author of the white paper/proposal for LENA. Pakvasa was also a participant and a co-author of the white paper on sterile neutrinos. Both these items may be found in the publication list at the end of this chapter.

It has been thought for a long time that high energy neutrinos from astrophysical sources such as AGNs (active galactic nuclei) and GRBs (gamma ray bursters) are produced in beam dumps when protons or photons collide with matter and produce pions. The neutrinos that come from $\pi \to \mu$ decays have a characteristic flavor mix of $\nu_e/\nu_\mu/\nu_\tau \approx 1/2/0$. For large L/E and the known values of Δm^2, the neutrino oscillations average out and the large mixings will convert the flavor ratio into $\nu_e/\nu_\mu/\nu_\tau \approx 1/1/1$. This is a canonical result known for a long time (first discussed in the paper by Learned and Pakvasa: Astropart. Phys. **3**, 267 (1995)). Deviations from this universal flavor mix would be very interesting, since these would serve as a probe of a variety of new phenomena, both in neutrino physics and in astrophysics. In a series of papers, Pakvasa and collaborators developed scenarios that can be tested in deviations of the neutrino flavor mix from the canonical 1/1/1. A detailed review of this whole subject was given by Pakvasa in "Neutrino Flavor Goniometry by High Energy Astrophysical Beams," arXiv:0803.1701 [hep-ph] and more recently in arXiv:1004.5413. He reviewed the subject in two invited presentations last year, at the NUSKY meeting in Trieste in June, and at the INFO-11 meeting in Santa Fe in July. Very recently, the IceCube collaboration released the first data on the observation of very high energy neutrino events in the IceCube detector.The most striking results are the two shower events at 1 and 2 PeV which can be due to ν_e's, together with the lack of ν_μ events: see M. Aartsen *et al.* Phys. Rev. Lett. **111**, 021103 (2013). Pakvasa, in collaboration with A. Joshipura (PRL, Ahmedabad) and S. Mohanty (PRL, Almedabad) wrote a paper offering possible explanations of the paucity of muon events. Their explanations, published in Phys. Rev. Lett., are based on the possibility of the two heavier neutrinos having lifetimes such that they decayed before their arrival on earth, and on the possibility that neutrinos are pseudo-Dirac particles (as envisioned by Wolfenstein, Pontecorvo and others as early as 1981). In a separate study that has also appeared in Phys. Rev. D, Pakvasa, Learned and Barger (Wisconsin) speculated that the two PeV events may be identified with the production of the Glashow resonance initiated by ν_e collisions.

Pakvasa, with W. Rodejohann (Heidelberg) and T. Weiler (Vanderbilt) initiated a study and analysis of the deviations of the neutrino mixing matrix from the simple and empirically successful form of tri-bimaximal matrix. The initial analysis was to simply write a unitary parameterization of the deviations, which was named "triminimal". This enabled writing many expressions for survival/conversion probabilities in a compact form, especially when expanded to second order in the small parameters. (Phys. Rev. Lett., **100**, 111801 (2008)). There are continuing efforts to find physical significance and theoretical understanding of this form of the matrix. In view of the recent results from Daya Bay and RENO experiments which indicate that θ_{13} is somewhat "high', namely of order 10 degrees, it is worthwhile to revisit the issues of CP violation and the mass hierarchy of neutrino masses. Pakvasa and collaborators are revising the studies of capabilities of HANOHANO, especially with respect to the hierarchy question and also plan to study the impact on CP violation searches with this value of θ_{13}.

Future plans involve a study of models for neutrino mass matrix, with further possibilities of a unified description of the fermion masses and mixings, for both quarks and leptons. This is of course very ambitious. Many attempts exist and it is a very active area of investigation. However, Pakvasa is encouraged by the fact that many ideas on which he had worked on in the period 1979-1984, such as discrete non-Abelian family symmetries for the fermion mass matrix, are making their appearance once more *e.g.* the permutation symmetry S_4 and its subgroups. With H. Sugawara, he is studying a novel implementation of discrete family symmetries such as S_3 and S_4 with a view to predict fermion mass matrices.

Sterile Neutrinos with New BSM interactions: Recently sterile neutrinos with beyond the standard model interactions leading to matter effect resonant oscillations has been invoked in analyses of the LSND/MiniBoone discrepancy, indirect dark matter detection from solar dark matter annihilation, and the MINOS muon neutrino-antineutrino anomaly. In a paper motivated by the now defunct OPERA result, Hawaii student Bramante considered a class of sterile neutrinos, which couple to a neutral vector boson singlet of mass $\sim 10^2$ GeV with a strength that would produce observable neutral-current events at long baseline experiments. Such sterile neutrinos evade constraints from traditional neutral-current event studies. Bramante is currently using the data from MINOS and K2K to constrain such these sterile neutrinos and explore the discovery potential for these at the NOvA experiment, whose planned charged vs. neutral-current event selection efficiency make it uniquely suited for this purpose. He will then modify his archive submission (arXiv:1110.4871), including subsequent developments at OPERA, and submit it to Physical Review D.

Heavy Quark and Flavor Physics

There are several aspects to the study of quark flavor physics. One is to devise tests of the Standard Model and/or deduce its parameters (such as KM angles and phase); another is to devise tests of various proposals for new physics beyond the standard model; a third is to speculate about the origin of masses and mixings (*i.e.* model building).

CP violation and mixing in the $D^0 - \overline{D}^0$ system are of great interest as probes of new physics. In the SM, the short distance contribution to Δm_D is known to be extremely small, of order 10^{-17} GeV. At one time, it was thought that there could be long distance enhancement by several orders of magnitudes. Now, there is some rethinking about this. The CP violating phase is also expected to be very small. Specifically, the phase ϕ in mixing which is given by $\tan^{-1}(ImM_{12}/ReM_{12})$ is approximately 10^{-3} when ReM_{12} is taken from the current measurements of

x_D (in the Standard Model).

Although it is possible that the bulk of the observed mass mixing and comes from new physics, without further observables it is impossible to either establish this or to identify the specific new physics that is responsible. One possibility is the study of rare D decay modes such as $D^0 \to \mu^+\mu^-$. Each new physics scenario that can account for the observed mixing (value of x) makes a specific and distinct prediction for a branching ratio such as for $D^0 \to \mu^+\mu^-$. Pakvasa and collaborators pursued this in some detail. They found that in certain models of new physics, the same combination of couplings appears in the amplitudes of both $D^0 - \overline{D}^0$ mixing as well as in a rare decay mode such as $D^0 \to \mu^+\mu^-$. If the new physics dominates and is responsible for the observed mixing, then a very simple and direct correlation exists between the two magnitudes; in fact the rate for $D^0 \to \mu^+\mu^-$ is completely fixed by the observed mixing. An observation of $D^0 \to \mu^+\mu^-$ in excess of the minuscule rate expected in the Standard Model would identify the specific New Physics contributing to the mixing. Thus this decay mode can act as a diagnostic.

Another possible diagnostic is the phase ϕ in $D^0 - \overline{D}^0$ mixing. This is given approximately by $\phi = \tan^{-1}(ImM_{12}/ReM_{12})$. With ReM_{12} fixed by the observed value of x, an SM estimate yields $\phi \approx 10^{-3}$ or about 0.06^0. If x is due to new physics, ϕ can reach values as high as 45^0. The current bound is about $|\phi| < 25^0$ at 90% C.L. A measurement of ϕ can confirm the new physics origin of mixing in the D system as well as pinpoint the specific mechanism at work. Different new physics scenarios predict different values for the phase, and so a measurement of the phase can also discriminate between New Physics models.

Direct CP violation in rate asymmetries is yet another useful probe of new physics. In SM direct CP violation is expected only in singly CKM suppressed modes such as $D \to K\overline{K}, \rho\pi$ *etc.* at a level of about 10^{-3}. New physics (NP) can lead to CP-violating asymmetries in Cabibbo-allowed and Double-Cabibbo suppressed modes at similar levels.

All the above are plans for the future and are under active investigation by Golowich, Hewett, Pakvasa and Petrov, now with the addition of Gagik Yeghiyan.

In the meantime the topic of $B_s \to \mu^+\mu^-$ decays is timely because of on-going work at LHCb and future e^+e^- Super B-factories that has markedly improved the old branching fraction bound $\mathcal{B}^{(\rm expt)}(B_s \to \mu^+\mu^-) < 4.7 \times 10^{-8}$, and has now reached the Standard Model expectation of 3.2×10^{-9}. This two-body final state in which both particles are charged will have a relative advantage over many other rare modes and should be limited only by integrated luminosity. Theoretically, the B_s system has already been suggested as an area of interest for NP. The hope for $B_s \to \mu^+\mu^-$ is that effects of NP will be comparable to the Standard Model (SM) prediction.

Pakvasa's strategy is very similar to his recent study in which he and his collaborators pointed out that in some NP models the $D^0 - \bar{D}^0$ mixing and $D^0 \to \mu^+\mu^-$ decay amplitudes have a common dependence on the NP parameters. If so, one can predict the $D^0 \to \mu^+\mu^-$ branching fraction in terms of the observed ΔM_D provided that much or all of the mixing is attributed to NP. This is a viable possibility for D^0 mixing because the Standard Model signal has large theoretical uncertainties and because many NP models can produce the observed mixing.

For ΔM_{B_s} the situation is very different. In his updated analysis, Pakvasa and collaborators show that

$$|\Delta M_{B_s}^{(\rm NP)}/\Delta M_{B_s}^{(\rm SM)}| \leq 2 \times 10^{-4},$$

reflecting the fact that the SM prediction agrees very well with the experimental value of ΔM_{B_s}. In view of this, the SM expression for ΔM_{B_s} will be given at NLO, whereas only LO results will be used for NP models. At any rate, in those NP models where mixing and $B_s \to \mu^+\mu^-$ arise from a common set of parameters, the severe constraint on any NP signal to B_s mixing places strong bounds on $\mathcal{B}_{B_s\to\mu^+\mu^-}$. In fact, the constraint is so strong that for most NP models the predicted $B_s \to \mu^+\mu^-$ branching fraction lies well below the SM prediction.

Since the long distance estimate for the branching fraction $B_s \to \mu^+\mu^-$ in the SM is negligible, only the short distance contribution needs to be considered. Using the NLO SM formula for $\Delta M_{B_s}^{(SM)}$ as as input to the short-distance-dominated $B_s \to \mu^+\mu^-$ transition, one arrives at

$$\mathcal{B}^{(\rm SM)}_{B_s\to\mu^+\mu^-} = \Delta M_{B_s}\ \tau_{B_s} \frac{3G_{\rm F}^2 M_{\rm W}^2 m_\mu^2}{4\hat{\eta}_{B_s} B_{B_s}\pi^3} \left[1 - 4\frac{m_\mu^2}{M_{B_s}^2}\right]^{1/2} \frac{Y^2(\bar{x}_t))}{S_0(\bar{x}_t)}$$

where $Y(\bar{x}_t)$ is another Inami-Lin function. Expressing $\mathcal{B}^{(\rm SM)}_{B_s\to\mu^+\mu^-}$ in this manner serves to remove some of the inherent model dependence. Numerical evaluation gives

$$\mathcal{B}^{(\rm SM)}_{B_s\to\mu^+\mu^-} \simeq 3.2 \times 10^{-9} \quad .$$

This study on constraints on NP contributions to $B_s \to \mu^+\mu^-$ was conducted with E. Golowich, J. Hewett, A. Petrov and G. Yeghiyan and published in Phys. Rev. D; and is ongoing with a future study of a large class of MSSM models led by JoAnne Hewett; and further studies of CP violation in the mixing in BSM.

Recently, an anomalously large direct CP violating signal has been seen in the difference between the rate asymmetry in $D^0 \to \pi\pi$ and $D^0 \to KK$. This was both unexpected as well as difficult to understand in SM. A lot of theoretical attention is being directed towards this anomaly. Both SM uncertainties as well as potentially large BSM contributions are being studied extensively by a large number of authors. The more recent data from LHCb shows the signal to be rather weak compared to the original claim. It is now not clear whether there is any need for new physics to account for the data

Led by Rahul Sinha (Chennai), Pakvasa and N. Deshpande (Oregon), in a paper submitted to Physical Review Letters, carried out a novel analysis of the decay mode $D \to K^*\pi$ via the Dalitz plot of the final state $K\pi\pi$. It was shown there that it is possible to extract the symmetric and antisymmetric parts of the amplitude from a detailed study of the Dalitz plot provided sufficient statistics are available. It is the possible to remove the remaining ambiguity in the $D \to K\pi\pi$ amplitudes and extract the CP violating phase. In a subsequent follow-up work it is expected that BELLE colleagues will join and apply this idea to data from Belle (T. Browder *et al.*). Pakvasa, Sinha, Deshpande and others are completing a study on the extension of the above idea to modes such as $B \to D\overline{D}P$, where P denotes a pseudoscalar boson. Here, the Bose symmetry can be used to identify an unambiguous signal for the direct CP violation in the decay modes of D.

The DØ collaboration has recently reported evidence for an anomalous like-sign dimuon charge asymmetry. Additional sources of CP violation in the $B_s^0 - \overline{B}_s^0$ system from new physics, which can in principle affect both the mass splitting ΔM_B between the mass eigenstates of the system, and the difference $\Delta\Gamma_B$ between their decay widths, offer one possible explanation for this anomaly. Motivated in part by these considerations, Thomas and S. Su (Arizona) are studying the contributions to ΔM_B and $\Delta\Gamma_B$ that arise in a number of beyond-the-standard-model contexts.

Supersymmetry, Dark Matter and LHC Phenomenology

The Large Hadron Collider has accumulated an integrated luminosity in excess of 5 fb^{-1} at 7 TeV and just over 20 fb^{-1} at 8 TeV. It is scheduled to commence operations at 12-14 TeV. This is an exciting time for Tata who, together with his collaborators, has evolved a program of study of the experimental implications of weak scale supersymmetry, which he regards as the most promising extension of the Standard Model. The codes that they have developed, as well as the strategies that they have suggested, have been extensively used by the DØ and CDF collaborations at the Tevatron in their search for supersymmetric particles, by the ATLAS and CMS collaborations at the CERN LHC, and for projections of the capabilities of a future linear electron-positron collider such as the ILC. Tata has helped develop techniques for the discovery of supersymmetry at colliders and at dark matter search facilities. He has also contributed ideas regarding how one might go about elucidating the nature of any new physics that might be discovered. A long term goal of the Hawaii SUSY effort is to study the extent to which it will be possible to use data from both the LHC as well as from DM search experiments to elucidate the mechanism by which superpartners of SM particles obtain SUSY-breaking masses and couplings.

While Tata has been closely following LHC results, he was cautious about drawing conclusions prematurely from what he regarded as not-yet-conclusive data. This changed with last summer's announcement of a signal for a 125-126 GeV Higgs boson, and he has been examining the implications of this mass for supersymmetric models. The non-observation of a supersymmetry signal to date and the ensuing bounds on gluinos and (first generation) squarks, however, suggest to him that the underlying framework – assuming that weak scale supersymmetry is realized in nature – differs qualitatively from the much-studied mSUGRA/CMSSM framework that has been the focus of many SUSY analyses. Indeed, motivated by the data, Tata along with Mustafayev and other collaborators have sharpened their earlier studies of the so-called effective supersymmetry models and have begun to explore the phenomenology of what they have dubbed dubbed "radiative natural supersymmetry".

The Hawaii SUSY program includes studies of supersymmetry at colliders, studies of SUSY dark matter and strategies for its detection, together with studies of how supersymmetry might show itself in precision measurements of properties of Standard Model particles. Along with H. Baer (Oklahoma), F. Paige (BNL) and S. Protopopescu (BNL), Tata co-authored and aids in the maintenance of the SUSY routines in the SUSY event and spectrum generator ISAJET.

In a series of papers over the last several years, Tata and his collaborators have examined robust implications of the measured relic density of cold dark matter (CDM) for the LHC and dark matter searches, assuming only that the thermal stable neutralino relic forms a significant component of the CDM. Non-observation of a signal at CDMS and XENON100 at the $\sim 10^{-8}$ pb level has begun to constrain an entire class of SUSY models where the observed CDM density is obtained by tempering the higgsino content of the neutralino LSP, as first noted in 2006 by Baer, Mustafayev, Park and Tata (and rediscovered by others years ago). He has been watching the Pamela, FERMI-LAT data and recent AMS02 data that clarifies that there is indeed a signal in positrons (which could, however, be of astrophysical origin). He awaits AMS data on anti-protons and AMS02 and GAPS data on $\overline{D}$. Given the potentially enormous implications, Tata feels this stronger evidence is necessary to make real claims.

During the last two years, Tata's research has focussed mostly on the LHC. He and his collaborators updated earlier projections on the range of gluino and squark masses that will be explored before the LHC shuts down for an upgrade to allow operation at its design energy. Tata along with his collaborators has suggested novel signals for supersymmetry that had been overlooked up to now. Finally, motivated by the absence of any signal in the current LHC data, Tata, Mustafayev and others have elucidated the natural supersymmetry framework. They have argued that the smallness of $|\mu|$ ismore basic to naturalness than the lightness of the top-squark. They have spent much of last year clarifying and exploring the observable consequences of naturalness in supersymmetry.

ISAJET

H. Baer, F. Paige, S. Protopopescu and Tata have developed, and are maintaining, the ISAJET program to simulate production of sparticles and SUSY Higgs bosons at pp, $p\bar{p}$ and also e^+e^- colliders with longitudinal beam polarization and initial state radiation effects included. ISAJET has many popular models hard-wired for easy simulation, and has been used by the CDF and DØ collaborations at Fermilab, by the ATLAS and CMS collaborations at the LHC as well as by theorists and experimentalists for the generation of the SUSY spectrum and SUSY events at various collider facilities including the ILC.

ISASUSY is a subroutine of ISAJET that, for any input set of the Minimal Supersymmetric Model (MSSM) parameters, computes the branching ratios for the decays of various sparticles. ISASUSY interfaces with ISAJET where sparticle pair production is calculated. ISAJET thus allows for a simulation of SUSY, including all the complex cascade decay patterns of SUSY particles and provides experimentalists a powerful tool for their analyses. ISAJET includes the evaluation of sparticle mass parameters by renormalization group evolution starting with a variety of boundary conditions, and allows for easy simulation of an ever-increasing number of models, many of which are hard-wired in for ease of use. A feature unique to ISAJET is that, in the course of renormalization group evolution, it decouples each particle at its mass scale from the various β-functions, thereby allowing for a more precise evolution of various parameters. This is especially important for computations in models involving multiple scales that are gaining importance as we will see below.

Supersymmetric processes included in ISAJET are: the production of gluinos and squarks, the production of a squark or gluino in association with a chargino or neutralino, the production of chargino and neutralino pairs, slepton pair production, and the production of top squarks at pp and $\bar{p}p$ colliders. ISAJET also includes the production of SUSY Higgs bosons (with radiative corrections to their masses and couplings, as given by the effective potential method), either singly, in pairs, or in association with gauge bosons at hadron colliders. All $2 \to 2$ sparticle-pair production processes that can occur at e^+e^- colliders have also been incorporated into ISAJET, allowing for longitudinal polarization of the electron and/or positron beams, initial state radiation (via an electron structure function) and beamstrahlung. This allows the incorporation of cascade decays in studies of the prospects for supersymmetry at future linear colliders.

ISAJET also includes the effects of b and τ Yukawa couplings (these couplings are proportional to $1/\cos\beta$) on the masses as well as couplings involving bottom squarks and stau leptons. These effects are particularly important if the parameter $\tan\beta$ is large. The effects of Yukawa couplings on sparticle masses can be especially important if they result in new two body decay channels of the gluinos, charginos and neutralinos. However, these effects are also important when these sparticles only decay into three body final states because of the enhancement of the b-squark and τ-slepton propagator when these sparticles are light. Complete decay matrix elements in the simulation of gluino, chargino and neutralino three-body decays are also been included.

ISAJET is continually evolving. Aside from the inclusion of new promising models as they appear, ISAJET now includes the tool kit "ISATOOLS" that allows the user to evaluate phenomenologically relevant quantities such as $B(b \to s\gamma), B(B_s \to \ell^+\ell^-)$, $g_\mu - 2$, $\Omega_{\widetilde{Z}_1}h^2$, $\sigma(\widetilde{Z}_1 p/n)$ and most recently, $B^+ \to \tau^+\nu_\tau$ decay mediated by the charged Higgs boson. An improved treatment of sparticle thresholds has been recently incorporated, and Les Houches Accord files for a variety of models (earlier, it was just mSUGRA) have been enabled. In ISAJET v7.81 that was released just over a year back, A. Box (a former Hawaii student), Baer and Tata have incorporated their program that solves the two-loop renormalization group equations of the minimal supersymmetric Standard Model, including *complex* hadron flavor-violating mass and coupling parameters. This allows a systematic examination of flavor-violation associated with sfermion mass matrices and trilinear scalar couplings. SUSY models generically also include large number of potential CP-violating parameters. Tata's former student Box created a code to solve the two-loop renormalization group equations (RGEs) of the MSSM that includes all quark flavor violating masses and couplings, for arbitrary boundary conditions at the high scale. This code, which has now been included in v. 7.81, recently updated to v. 7.83, of ISAJET, also allows the user to let various parameters assume complex values. This provides a tool that allows a detailed examination of various possible flavor structures and CP-violating parameters and explore their phenomenological implications using event generators. They expect to ultimately extend their earlier analysis to include lepton flavor-violation in the same general manner. This is more complicated than for quarks because it entails introducing singlet neutrino superfields and their SUSY-conserving and SUSY-breaking interactions. They have completed their derivation of the RGEs, allowing as before, for sparticle threshold effects, and are working to complete the code to find numerical solutions of the expanded RGE system.

Supersymmetry at the LHC

Early Reach of the LHC: In a paper published in JHEP three years ago, H. Baer, V. Barger (Wisconsin), A. Lessa (Oklahoma, now at São Paulo) and Tata had projected the LHC7 discovery reach for a range of integrated luminosities up to 2 fb^{-1} and showed that gluinos with masses up to 1.1 TeV (600 GeV) would be probed with an integrated luminosity ~ 1 fb^{-1} if $m_{\tilde{q}} \sim m_{\tilde{g}}$ (if squarks are heavy). As is well known, the LHC surpassed all expectations and accumulated an integrated luminosity of 5 fb^{-1} in 2011 and accumulated 25 fb^{-1} would be before the shutdown for an energy upgrade. These authors to update their earlier results and make projections for an integrated luminosities ranging from 5-30 fb^{-1}. Their results, which appeared as a Rapid Communication in Physical Review **D**, imply that gluinos with a mass up to 1.6 TeV will be discoverable if $m_{\tilde{q}} \sim m_{\tilde{g}}$ and up to 1.1 TeV if squarks are heavy.

Measuring Neutralino Properties: Continuing the program to explore strategies to identify new physics signals at the LHC, and further, to devise ways for unraveling what this new physics might be, Hawaii student Kadala (who graduated in Fall 2011), Hawaii postdoc Hundi (who moved to IACS, Kolkata, India) and Tata examined the dilepton mass distribution from neutralino decay with an eye to what this tells us about the neutralino sector without recourse to a detailed model. They showed that this distribution peaks closer to the end point of the dilepton spectrum if the parent and daughter neutralinos have the same signs for their eigenvalues, and peaks substantially inward in the other case. In an effort to identify whether the shapes of the mass distributions serves to distinguish whether the light neutralino decays proceed via the Z- or slepton-mediated amplitudes, as expected for higgsino-like or gaugino-like neutralinos, respectively, they found that even though the analytic forms of the distributions look very different for the two cases, these reduce to the same form when the decay mediators of the decay are heavy relative to the neutralino mass gap!

They also analyzed the possibility that the data might show two distinct dilepton mass edges from the decay of neutralinos $\widetilde{Z}_2$ and $\widetilde{Z}_3$, which is possible if μ is not very large compared to M_1. For a case study chosen to be beyond the range of the Fermilab Tevatron, they found that with an integrated luminosity of just over 10 fb^{-1} data from LHC14 had the potential not only to distinguish between slepton and Z-mediated decays, but also to determine, in favorable cases, the values of μ, M_1 and M_2 as well as $m_{\tilde{\ell}}$ with a precision of $\sim 5-20\%$. Unfortunately, the case studies that they performed were soon excluded by data from the LHC. For this reason they decided not to publish a journal article. Their results, along with details of the analysis, are available in Kadala's doctoral dissertation (arXiv:1205.1267).

A New SUSY signature at LHC7: Data from LHC8 already appears to exclude gluinos and first generation squarks up to 1.5 TeV if these are appoximately degenerate, and gluinos up to 1 TeV if squarks are heavy. These limits apply only to first generation squarks, that are much more copiously produced at the LHC than their second/third generation cousins. Bounds on second and third generation squark masses are much weaker because these cannot be produced by collisions of the "valence quarks" in a proton. This led Tata and his collaborators to consider the possibility that just third generation squarks are at the TeV scale, with other squarks, in the multi-TeV range. Such a spectrum has other desirable features described in Sec. . Assuming gaugino mass unification (and large $|\mu|$, the cross-section for $\widetilde{W}_1\widetilde{Z}_2$ production at LHC7 (LHC14) exceeds that for gluino pair production if $m_{\tilde{g}} > 500$ GeV (1000 GeV), the natural question to ask then is whether it will be possible to detect the signal from electroweak $\widetilde{W}_1\widetilde{Z}_2$ production at LHC7.

Motivated by the fact that $\widetilde{W}_1\widetilde{Z}_2$ could well be the most copious of the sparticle production at LHC8, Tata along with Baer, V. Barger, S. Kraml (Grenoble), Lessa and student W. Sreethawong (then at Oklahoma) re-examined the signal from $\widetilde{W}_1\widetilde{Z}_2$ production for the case that $\widetilde{W}_1 \to W\widetilde{Z}_1$ and $\widetilde{Z}_2 \to Z\widetilde{Z}_1$. Topologically the signal is indistinguishable from WZ production, but has additional $E_T^{\rm miss}$ from the two LSPs in the event. They showed that requiring a large transverse mass $M_T(\ell, E_T^{\rm miss})$ between the one lepton that does not make up the Z and the missing transverse energy suffices to beat down the background, leaving a 5σ signal. This signal is observable at LHC7 (and hence slightly more readily at LHC8) up to the value of $m_{\widetilde{Z}_2}$ where the decay $\widetilde{Z}_2 \to \widetilde{Z}_1 h$ (which dynamically dominates the $\widetilde{Z}_2 \to Z\widetilde{Z}_1$ decay if it is not kinematically suppressed) turns on, assuming an integrated luminosity of 20-30 fb^{-1}. Their findings have been published in JHEP. Unfortunately, the LHC8 data show no evidence of a signal in the trilepto channel.

Novel signals at LHC14: It is well known that the trilepton signal just discussed is lost if $\widetilde{Z}_2 \to h\widetilde{Z}_1$ is kinematically allowed, since this decay then dominates. Indeed this Higgs decay of the neutralino had been referred to as the "spoiler mode" in the literature, and it was generally assumed that backgrounds from QCD and from $t\bar{t}$ production would overwhelm the $b\bar{b}\ell + E_T^{\rm miss}$ signal. Baer, Barger, Lessa, Sreethawong and Tata nevertheless identified a set of cuts by which it may be possible to identify the SUSY signal above Standard Model backgrounds from $t\bar{t}$, Wh and $b\bar{b}W$ production at LHC14. It appears that with an integrated luminosity of 100 fb^{-1}, this signal is observable at the 3-6σ level over most of the mass range. With several hundred fb^{-1} to 1 ab^{-1} of data, it should be possible to see the signal for chargino and neutralino masses up to $\sim$ 800 GeV. While in models with gaugino mass unification the reach in this channel is roughly similar to the reach via the canonical gluino search, in more general models this may well be the discovery channel. A paper reporting these results has appeared in Phys. Rev. **D**.

Light higgsinos are motivated by considerations of naturalness as discussed in Sec. . In such models, wino pair production with subsequent decays of winos to W bosons via $pp \to (\widetilde{W}_2 \to W^\pm \widetilde{W}_1) + (\widetilde{Z}_4 \to W^\pm \widetilde{Z}_{1,2} + X)$ leads to hadronically quiet same sign W-pair events because the decay products of the higgsino-like $\widetilde{Z}_2$ and $\widetilde{W}_1$ tend to be soft. In a paper that has just appeared in Phys. Rev. Lett. Tata and Mustafayev, in collaboration with Baer, Barger, Huang (Wisconsin), Mickelson (Oklahoma) and Sreethawong, showed that this channel can probe winos up to 550 (800) GeV for an integrated luminosity of 100 (1000) fb^{-1}. In models with gaugino mass unification (and small $|\mu|$) the LHC14 reach in this channel is comparable to that via the canonical gluino search for an integrated luminosity of 100 fb^{-1}, and exceeds the gluino reach for higher integrated luminosities.

Very high luminosity LHC: Motivated by the considerations of the Europen Strategy for Particle Physics group, Tata in collaboration with Baer, Barger and Lessa extended their earlier investigations of the examination of the LHC14 reach to integrated luminosities up to 3 ab^{-1}. For 300 (3000) fb^{-1}, they found a reach of 3.2 (3.6) TeV if $m_{\tilde{q}} \sim m_{\tilde{g}}$ with corresponding numbers for the gluino reach of 1.8 (2.3) TeV for very heavy squarks. In this latter case, wino pair production offers a potential higher reach via the Wh channel discussed above, if gaugino mass unification is assumed. Their findings have appeared in Phys. Rev. **D**.

Natural Supersymmetry

Motivated by the lack of a signal at the LHC, Tata, in collaboration with Baer, Barger and student P. Huang (Wisconsin), was motivated to re-visit the constraints on SUSY models from the requirement that SUSY breaking not lead to large fine-tuning. In particular, they looked again at the well-known electroweak symmetry breaking condition that determines M_Z in terms of other model parameters,

$$\frac{1}{2}M_Z^2 = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u)\tan^2\beta}{(\tan^2\beta - 1)} - \mu^2 \,. \tag{1}$$

Here Σ_u and Σ_d arise from radiative corrections, and mainly get contributions from third generation quark-squark loops through superpotential Yukawa couplings, of which the top Yukawa frequently dominates. Naturalness is then the requirement that the terms all be of the same order of magnitude so that the equation can be satisfied without invoking unduly large cancellations. How much cancellation is allowed is clearly subjective, but Tata feels that a cancellation of one order of magnitude is perfectly sensible; this would bound each term in the equation above to be smaller than $\sim$(200 GeV)^2. This, in turn, means that top squarks whose mass enters through Σ_u cannot be arbitrarily heavy: $m_{\tilde{t}_i} \lesssim$ 1.5 TeV if each term is bounded by the 200 GeV scale as just stated. An interesting observation is that the gluino cannot be arbitrarily heavy, since top-gluino loops would then make $m_{\tilde{t}}$ very large. These authors then found that $m_{\tilde{g}} \lesssim 3m_{\tilde{t}} \lesssim 4.5$ TeV. They introduced a high scale parameter space with independent mass parameters for the first/second and third generation sfermions, a unified gaugino mass and A-parameter, and allowed for arbitrary values of $\tan\beta$, μ and m_A and identified ranges of these parameters that lead to a SUSY spectrum of the type discussed above. In a paper published in JHEP, they did a broad brush examination of the resulting phenomenology at the LHC, the ILC and for SUSY dark matter. While they find that there are parameter ranges for which SUSY might be readily discoverable, it is possible that there are other parameter ranges where supersymmetry might be very difficult to find at the LHC. The smallness of μ almost guarantees discovery at a TeV electron-positron linear collider *provided it is possible to extract the chargino signal from two-photon backgrounds* for the small chargino-neutralino mass gap. Indeed, early studies indicate that this may be possible: see H.Baer *et al.* JHEP **0402** (2004) 007, and JHEP **0406** (2004) 061.

They were joined by Mustafayev in a series of papers last year that quantified and sharpened the notion of Natural SUSY. In a paper published in Phys. Rev. Lett. they showed that it was possible to find solutions with $m_h \sim 125$ GeV, where each of the terms in (1) (normalized to $\frac{1}{2}M_Z^2$) is smaller than $\Delta_{\rm EW}$ chosen to be smaller than 10 (30), corresponding to no more than 10% (3%) fine-tuning. These solutions are obtained for a large, negative high scale A-parameter which simultaneously reduces $\Delta_{\rm EW}$ while yielding the observed value of m_h.

The quantity $\Delta_{\rm EW}$, which is essentually determined by the SUSY spectrum, is not a genuine fine-tuning measure as it is independent of the high scale origin of the MSSM parameters. This was made explicit in follow-up papers where a true fine-tuning measure was defined by writing $m^2_{H_{u,d}}$ and μ in (1) as $m^2_{H_{u,d}} = m^2_{H_{u,d}}(\Lambda) + \delta m^2_{H_{u,d}}$, $\mu = \mu(\Lambda) + \delta\mu$ in terms of their values at the high scale Λ, and defining a fine-tuning measure $\Delta_{\rm HS}$ in an analogous manner to how we defined $\Delta_{\rm EW}$. The large logarithms that lead to the largest fine-tuning in generic SUSY models appear in $\delta m^2_{H_{u,d}}$. Since we implicitly allow cancellations between, say $m^2_{H_{u,d}}(\Lambda)$ and $\delta m^2_{H_{u,d}}$ when we combine these in (1), we see $\Delta_{\rm EW} \leq \Delta_{\rm HS}$ so that $\Delta_{\rm EW}$ *is a bound* on the fine-tuning. A large value of $\Delta_{\rm EW}$ necessarily implies any theory with the particular SUSY spectrum is fine-tuned. In a paper published in Phys. Rev. **D**, this was argued to be the case for the spectrum of mSUGRA; the fine-tuning was worse than 1%. In a follow-up paper to be published in Phys. Rev. **D**, parameter regions of the NUHM2 model with small values of $\Delta_{\rm EW}$ were identified, and the phenomenlogy examined. While this does not imply that the fine-tuning in the NUHM2 model is small, it leaves open the possibility that a theory with a qualitatively similar spectrum and a small fine-tuning may one day be found.

String Phenomenology with Strong Moduli Stabilization

Mustafayev is also working on aspects of phenomenology of string theory/supergravity models. In collaboration with E. Dudas (CERN, Ecole Polytechnique and Paris-Sud), A. Linde (Stanford), Y. Mambrini (Paris-Sud) and K. A. Olive (Minnesota) Mustafayev studied an interesting interplay between string theory models with moduli stabilization, inflationary cosmology, phenomenological models of supergravity and the mass of the Higgs boson. These authors studied string theory models with strongly stabilized moduli that provide natural solutions to several cosmological problems, and also lead to a clear separation in scales in which the effects of string moduli can be tested in low energy experiments.

Mustafayev and his collaborators found that models of strong moduli stabilization lead to a very specific low energy spectrum resembling that of split supersymmetry with scalars in the mass range 30 – 1000 TeV. Smaller masses give too light a chargino, while higher masses result in too large a wino relic density as well as too heavy Higgs masses. Indeed the LEP limit on chargino mass immediately gives $m_h \geq 125$ GeV and $m_{\tilde{g}} \gtrsim 1$ TeV. Furthermore, the upper limit on the gravitino mass from the limit on the wino relic density also constraints Higgs mass from above. Thus, there is just a narrow window where all current experimental results are satisfied. While direct detection of wino dark matter will be difficult in this model, detecting gamma rays from wino annihilations may indicate the realization of models of this type. Their findings are reported in Eur. Phys. J. **C**.

NMSSM Higgs near 125 GeV

Motivated by the LHC indications of a SM-like Higgs boson recently presented by the ATLAS and CMS Collaborations, Nevzorov, S. King (Southampton) and M. Muhlleitner (Karlsruhe) considered the Next-to-Minimal Supersymmetric Standard Model (NMSSM) with a SM-like Higgs boson near 125 GeV. In order to satisfy naturalness requirements they assumed that stops and gluinos have masses below 1 TeV. They were careful to ensure that the chosen values of the singlet superpotential couplings do not become non-perturbative below the grand unification scale. They also examined how these couplings limits may be extended by two-loop effects when the NMSSM is augmented by additional matter multiplets. In a paper published in Nucl. Phys. **B**, Nevzorov and his collaborators proposed four sets of benchmark points corresponding to the SM-like Higgs boson being the lightest or the second lightest Higgs state in the NMSSM or the NMSSM-with-extra-matter. With the aid of these benchmark points they discussed how the NMSSM Higgs boson near 125 GeV may be distinguished from the SM Higgs boson in future LHC searches.

Exceptional supersymmetric unification

In a series of papers, Nevzorov led the Hawaii effort on the investigation of E_6-inspired SUSY models. The low–energy spectrum of the $\rm E_6$SSM that Nevzorov examined together with Pakvasa, J. Hall

(Southampton), King, and M. Sher (William and Mary) involves three families of Higgs–like doublets, three families of exotic quarks and three SM singlets that carry $U(1)_N$ charges. One family of the Higgs–like doublets and one SM singlet develop *vevs* breaking gauge symmetry. The fermionic and bosonic components of other Higgs–like and singlet superfields form inert neutralino and chargino states and inert Higgs states, respectively. The two lightest inert neutralinos tend to be the two lightest SUSY particles. The model can account for the dark matter relic abundance if the lightest inert neutralino has mass close to half the Z mass. In this case the usual SM-like Higgs boson decays more than 95% of the time into inert neutralinos. In a detailed study of the non-standard Higgs particle decays within the E_6SSM that is published in Phys. Rev. **D**, they argued that in this case the decays of the lightest Higgs boson into $l^+l^- + X$, where the leptons come from the decay of the NLSP, might play an essential role in the Higgs searches. Their scenario also predicts other light inert chargino and neutralino states below 200 GeV, and an LSP direct detection cross-section on the edge of observability of XENON100. These authors are continuing their study novel Higgs decays within the E_6SSM.

As in any other SUSY model the gauge symmetry in the E_6SSM does not automatically forbid lepton and baryon number violating operators that result in rapid proton decay. Moreover, exotic particles in the E_6 inspired SUSY models give rise to new Yukawa interactions that induce unacceptably large off–diagonal flavor transitions. Nevzorov, examined an E_6 inspired $G_{\rm SM} \times U(1)^2$ SUSY-GUT models in which an *exact* discrete symmetry simultaneously forbids non–diagonal flavor transitions as well as rapid proton decay. He explored both cosmological as well as collider implications of this model. Five–dimensional and six–dimensional orbifold GUT models may provide explicit realizations of such scenarios. Kumar and Tata participated in the initial stages of this work which has appeared in Phys. Rev. **D**.

In a paper published in the Physical Review D, Nevzorov, S. King, S. Moretti (Southampton), D. Miller (Glasgow) and P. Athron (Dresden) studied the LHC Signatures associated with the Z' boson and exotic quarks within the constrained version of the E_6SSM. They demonstrated that exotic states always give a substantial contribution to the Z' width and argued that the Z' boson and exotic quarks might be discovered with the first LHC data. Nevzorov and Pakvasa are in the process of completing a paper on the study of the invisible decay modes of the Higgs boson in a class of E_6-inspired SUSY modles. Specifically, they identify the range of branching ratios for invisible modes expected in these models.

Other Beyond Standard Model Phenomena at the LHC

Hidden sector gauge bosons

Kumar has also worked on aspects of LHC phenomenology. In previous work, Kumar, together with A. Rajaraman (Irvine) and J. Wells (CERN) studied the collider detection prospects for models where hidden sector gauge bosons coupled to Standard Model gauge bosons via trilinear vertices. These would be the dominant couplings in the case where the particles mediating hidden sector-Standard Model interactions are heavy, and are charged under non-Abelian Standard Model gauge groups. In this previous work, they for simplicity considered the case where the hidden sector Z' coupled only to Standard Model $SU(2)$ gauge bosons. But even there they noted the possibility that the Z' may couple to $SU(3)$ gauge bosons as well.

For hadron colliders, the ideal channel for detecting these Z's would be production through trilinear couplings to gluons, with decay through trilinear couplings to electroweak gauge bosons. Kumar and Rajaraman, along with Hundi, and current UH graduate students David Yaylali and Joe Bramante, have performed a detailed study of LHC prospects for probing these models, in the case where the Z' is a pseudovector. If $m_{Z'} = 1$ TeV, then gluon couplings allow the LHC to probe an effective coupling operator scale roughly 10 times larger than that which could be probed via only electroweak couplings. This work has been published in Physical Review **D**.

Kumar, Rajaraman and Yaylali have completed a follow-up LHC analysis of the prospects for determining the spin of a resonance with these trilinear couplings to Standard Model gauge bosons. They found specific signatures (such as extra jets, and certain forbidden decay channels) which would allow one to distinguish spin-0 and spin-1 resonances. This work has been published in Physical Review **D**.

Top quarks plus $E_T^{\rm miss}$ signals

Kumar, Bramante and UH postdoc Brooks Thomas have been motivated by earlier work of Kumar to consider LHC detection prospects for general models of new physics where new particles are produced and decay to top quarks and invisible particles. Kumar's previous work with J. Alwall (NTU, Fermilab), J. Feng and S. Su considered the production of new fermionic $SU(3)$ triplets decaying to tops, as motivated by WIMPless models of dark matter (this will be described later). Kumar, Bramante and Thomas focussed on the limit of MSSM parameter space where the only superpartners accessible at the LHC are the gluino, lightest stop, and the LSP. This provides a toy model for a larger class of new physics models with top-rich decays. This follow-on work has shown that the earlier $SU(3)$-triplet analysis actually teaches a more general lesson: if new particles decay mostly to top quarks and missing energy, then an effective search strategy is to focus (perhaps counterintuitively) on the purely hadronic channel. The signal is a large number of jets and missing E_T, where the lepton veto removes much of the Standard Model background with missing E_T arising from neutrinos. Indeed, for these models, this search strategy is more effective than more standard strategies focussed on leptonic decays or b-tagging of events. This work has appeared in Phys. Rev. **D**.

Exotic color resonances

Kumar and Thomas (along with Rajaraman) recently considered the possibility of LHC searches for heavy resonances transforming in a variety of $SU(3)$ representations. The point is that, for the pair-production of new $SU(3)$-charged particles from a parton-level gg or $q\bar{q}$ initial state, the production cross-section and number of final state jets are largely determined by the spin and $SU(3)$ representation of the new particles. As a result, searches for multi-jet resonances can be rephrased as bounds on the masses of exotics in a variety of $SU(3)$ representations. As an example of this type of analysis, they considered a CMS search for R-parity-violating gluinos decaying to a three jets. They showed that this search could be rephrased as a bound on new particles in several $SU(3)$ representations which are constrained by $SU(3)$ and angular momentum conservation to decay to three jets. Moreover, CMS found a small excess in events consistent with a resonance at 375 GeV. Kumar, Rajaraman and Thomas showed that the number of events in this excess would also be consistent with the production of either a scalar **15**, a scalar **24**, or a fermionic **10**. In fact the production cross-section of a scalar **15** would be a better fit to the number of excess events than an R-parity-violating gluino. This small excess has since gone away, but this work was not really focussed on this anomaly. Rather, this analysis was intended as a prototype for a general analysis of multi-jet resonances in terms of new QCD coupled particles transforming in generic $SU(3)$ representation. This work has been published in Physical Review **D**.

Same-sign trilepton from exotic quarks at the LHC

The "simplified-model" approach to collider phenomenology, in which unusual event topologies are realized from a minimal field Lagrangian, is a useful technique for studying such event topologies. In this vein, Thomas and T. Okui (Florida State) have explored the collider phenomenology of a simplified model which leads to final states involving three leptons, all of the same sign, additional jets, and $\not{E}_T$. This model includes two scalar diquarks transforming as either triplets or sextets under $SU(3)$ color, and a heavy Z' with flavor-off-diagonal couplings to right-handed up-type quarks. Their results appear in a study made at the SLAC Workshop on Topologies for Early LHC Searches.

Dark Matter

Observational evidence indicates that $\sim 80\%$ of the matter in universe is dark matter, but the nature and properties of this dark matter are still elusive. The study of dark matter is a central question at the cosmic frontier of theoretical high-energy physics, and a central topic of both Kumar and Thomas' research program.

WIMPless Dark Matter

In 2008, Kumar and Jonathan Feng (UC Irvine) proposed a dark matter framework known as *WIMPless dark matter*. In this framework, the dark matter is a hidden sector particle whose mass lies at the soft supersymmetry-breaking scale of the hidden sector. In many scenarios for supersymmetry-breaking (such as GMSB and AMSB), the soft SUSY-breaking scale and the gauge-coupling are connected by the relation $m_{soft} \propto g^2$. Since the annihilation cross-section is determined by the ratio $\sigma_A v \propto g^4/m^2$, it is determined by the parameters of the SUSY-breaking sector. In fact, if the the same SUSY-breaking sector generates soft terms in both the hidden and MSSM sectors, then we find $g_X^4/m_X^2 \sim g_{weak}^4/m_{weak}^2$. This dark matter candidate then exhibits the "WIMPless Miracle"; the WIMPless dark matter candidate will naturally have an annihilation cross-section given by $\langle\sigma_A v\rangle \sim 1\,\mathrm{pb}$, and thus have about the right relic density to explain cosmological dark matter, despite having a wide range of possible masses and couplings (unrelated to electroweak physics).

Kumar has since been involved in several projects aimed at novel tests of the WIMPless scenario. Many such tests are possible if WIMPless dark matter is coupled to Standard Model matter. One possibility Kumar has studied is a Yukawa coupling between a WIMPless dark matter supermultiplet X (the WIMPless candidate can be either the scalar or fermion), a Standard Model matter supermultiplet, and an exotic 4th generation supermultiplet.

Kumar, along with Barger, Danny Marfatia (Kansas), Sandick, Enrico Sessolo (Kansas) and UH graduate student Keita Fukushima considered a model where a Majorana fermion WIMPless dark matter candidate coupled to Standard Model quarks through u-channel exchange of a 4th generation squark. They showed that, in this case, spin-independent (SI) scattering arises entirely from squark-mixing or velocity-dependent terms. If these terms are not too large (as will be the case in a significant fraction of the WIMPless model parameter space), then dark matter-nucleon scattering is largely spin-dependent (SD). This is potentially very interesting from the point of view of observation. Because experimental sensitivity to σ_{SI} is so much greater than to σ_{SD}, almost all models of dark matter are expected to be discovered first through SI-scattering. But Majorana fermion WIMPless dark matter is an example of a model for which spin-dependent detection searches provided the best discovery prospects. IceCube/DeepCore is expected to announce its analysis of 180 days of data soon, providing the leading sensitivity to dark matter with SD-scattering. Especially for the case where dark matter annihilates to superpartners, the DeepCore extension can significantly enhance the sensitivity of IceCube. Despite some contrary claims in the literature, Kumar's work has shown that there exist a class of well-motivated dark matter models for which IceCube/DeepCore may be a discovery experiment. This work has been published in the form of two articles in Physical Review **D**.

An alternative method of probing the WIMPless scenarios is through collider searches at the LHC. The strategy is to search for the QCD pair-production of the exotic 4th generation quarks (denoted as T' and B'), which then decay to the Standard Model quarks and the WIMPless candidate (i.e., missing $\not{E}_T$). Kumar studied these prospects in two papers with Johan Alwall (Fermilab), Jonathan Feng (Irvine) and Shufang Su (Arizona), which were published in Physical Review **D**. They focussed on models where the dominant coupling of WIMPless dark matter to Standard Model matter was to 3rd generation Standard Model quarks. They first considered the production process $pp \to T'\bar{T}' \to tX\bar{t}X$, where X is a scalar. They found an effective search strategy for such models based on events with a large number of jets, plus missing transverse energy. They found very good prospects for the Tevatron (with $2-20\,\mathrm{fb}^{-1}$ of data) and a 10 TeV LHC run (with $300\,\mathrm{pb}^{-1}$ of data) to exclude or discover evidence for much of the available parameter space for WIMPless dark matter coupled to tops. For the actual 7 TeV LHC run, an equivalent sensitivity was found to be achievable with $1\,\mathrm{fb}^{-1}$ of data. This work has motivated subsequent analyses of data by the CDF and ATLAS collaborations, which have borne out these claims.

They followed up this work with a study of the complementary process, $pp \to B'\bar{B}' \to bX\bar{b}X$. Here, the most effective search strategy focusses on the signal of b-jets plus missing transverse energy, and LHC detection prospects are even better. But since this is a general search strategy, there are other dark matter models that can potentially be identified by this search, such as little Higgs or universal extra dimensions models. Kumar and Bhaskar Dutta (Texas A&M) have recently constructed a model of asymmetric dark matter which can potentially be detected though the LHC B' search described above. Their model is based on earlier work, where they proposed a mechanism of baryogenesis called *hidden sector baryogenesis*. In this scenario, exotic heavy quarks are coupled to a hidden sector gauge group, and sphalerons of the hidden sector generate a non-zero baryon asymmetry (much like electroweak baryogenesis). The heavy quarks then decay to Standard Model quarks plus a dark matter candidate whose number density is related to the baryon number density. In this model the mass of the dark matter candidates, as well as the bottom, charm and tau are set by the symmetry-breaking scale of a group $U(1)_{T3R}$, which breaks at a scale $\mathcal{O}(10\,\mathrm{GeV})$. As a result, the dark matter candidate mass is of the same order as the b, c and τ, and it has about the right relic density to explain cosmological observations. Moreover, the exotic down-type quark can potentially be produced at the LHC, decaying to b-quarks and dark matter. Evidence for this model can thus be potentially found with the search described above.

Constraining dark matter interactions from lepton dipole moments

Kumar and Fukushima have just completed a study (begun in January 2013) regarding the connection between dark matter annihilation and corrections to the magnetic and electric dipole moments of charged leptons. They considered a simplified model in which scalar dark matter annihilates to electrons or muons through t-channel exchange of a heavy mediator. This simplified model can be realized in many specific dark matter models, including examples of WIMPless and leptophilic dark matter. They found that loop diagrams involving dark matter generate corrections to the electron an muon dipole moments, and that current constraints on these dipoles strongly constrain the dark matter annihilation cross section. In particular, the cross section for annihilation to electrons (through t-channel exchange) must be unobservably small, while annihilation to muons could be observed only if the dominant interactions were CP-violating. This work will soon be submitted to Physical Review **D**.

Isospin-Violating Dark Matter

Recently, there has been intense interest in the possibility of dark matter with a relatively low mass ($\sim 5-20$ GeV), driven by recent data from the DAMA, CoGeNT and CRESST experiments. There has been much confusion, however, since the DAMA and CoGeNT signals would naively seem to suggest different dark matter-nucleon scattering cross-sections, and exclusion bounds from the CDMS and XENON10/100 experiments seems to be in tension with these positive signals. Kumar is involved in developing new models for dark matter particles which can potentially explain the data from these experiments, and in determining ways in which these models can be tested with other experiments.

The direct detection experiments that have probed low-mass dark matter seek to measure the recoil of nuclei after they are scattered against by dark matter. However, all of these experiments utilize different nuclei, such as sodium, silicon, germanium, and xenon. The standard assumption has been that dark matter interacts with protons in the same way as neutrons, implying that the response of one material to dark matter interactions can be easily determined from another. Kumar and his collaborators, Feng, Marfatia and David Sanford (Irvine) have investigated the possibility of *isospin-violating dark matter* (IVDM), wherein the dark matter interacts differently with protons and neutrons. They have found that if the proton and neutron interactions destructively interfere, then the data from DAMA and CoGeNT can be brought into agreement. Moreover, the bounds from the XENON10 and XENON100 experiments are also consistent with this interpretation. The fact that xenon has several significant isotopes is crucial to this analysis; it implies that no choice of destructive interference can completely suppress the sensitivity of xenon-based experiments. This work was published in Physics Letters B in 2011, and has received considerable attention, including more than 100 citations. They have recently completed an updated study, including the effects of surface area contamination on the CoGeNT region of interest, more recent bounds from XENON100, and new data from CDMS silicon detector which also potentially hint at low-mass dark matter. They found that IVDM models with destructive interference can achieve marginal consistency between the data from CoGeNT, CDMS-Si and XENON100. Further improvements in the sensitivity of xenon-based detectors to low-energy recoils may be sufficient to probe these models and quantify the relative strength of coupling to protons and neutrons. This work was published in Physical Review **D**.

It may well be that IVDM is only a piece of the puzzle needed to explain the experimental low-mass data. However, but given the confusing status of this data, it is vital to develop new techniques for studying low-mass IVDM, particularly using methods which do not suffer from the difficulties of direct detection experiments at the limit of low recoil energy. Kumar has done considerable work on this subject. Together with Sanford and Louie Strigari (Stanford), he has recently shown that Fermi-LAT gamma-ray data from dwarf spheroidal galaxies can tightly constrain many models of IVDM. The gamma-ray spectrum arising from low-mass dark matter annihilation was simulated using the computing cluster at HOSC. The gamma-ray data tightly constrain IVDM with destructive interference between proton and neutron couplings (as needed to reconcile the DAMA and CoGeNT data with XENON10/100) because such models necessarily have enhanced coupling to up and down quarks. This yields an enhanced annihilation rate, and a larger gamma-ray signal. As a result, one can conclude that if the tension between the DAMA, CoGeNT and XENON10/100 data is alleviated by isospin-violating interactions, then dark matter annihilation must be either p-wave suppressed, or proceed through a low-mass mediator. This work was published in Physical Review **D** as a Rapid Communication.

One sees that IVDM can be tested with a variety of detection strategies, including direct detection, indirect detection, and collider searches. Each is sensitive to different types of dark matter-nucleon couplings. This has led Kumar and Marfatia to broader research program: to incorporate direct searches (where the isospin-invaraince/violation and spin/velocity dependence/independence of scattering can potentially be determined), indirect searches (where s/p-wave annihilation can be discriminated) and colliders (where flavor and the jet energy distribution can be measured) to determine the dark matter-nucleon interaction structure. Kumar and Marfatia have recently completed the first step in this program – a systematic analysis of matrix elements relevant for dark matter scattering and annihilation. This analysis includes several results which deviate from standard lore in dark matter physics. This work has been published in Physical Review **D**.

It is important to emphasize that, although IVDM can have significant impact on interpretations of the low-mass dark matter data, it is relevant for interpreting any signal of dark matter. Unless dark matter is an MSSM LSP, there is really no reason to assume that dark matter interactions are isospin-invariant. In a paper published in Physics Letters B, Kumar, Marfatia and Yu Gao (Oregon) considered the impact of isospin-violating interactions on the sensitivity of IceCube/DeepCore, as compared to XENON100, CDMS, and upcoming direct detection experiments such as XENON1T and CLEAN. They found that, due to the large number of solar elements with small numbers of neutrons, IceCube/DeepCore can have a sensitivity to some IVDM models which exceeds not only the sensitivity of current direct detection experiments, but even rivals next-generation experiments such as CLEAN and XENON1T. The IceCube/DeepCore analysis of 180 days of data should be released very soon, so Kumar's work will have a timely impact on the interpretation of IceCube's results.

Dark Matter Searches at Neutrino Detectors

Kumar has studied neutrino-based dark matter searches in detail with members of the UH neutrino group. This strategy is based on searches for the neutrino flux arising from the annihilation of dark matter which has been gravitationally captured after scattering off solar nuclei. This has proved to be a very fruitful field. Neutrino-based searches at water Cerenkov detectors can be much more sensitive to low-mass dark matter than many direct detection experiments, as they are easily sensitive to the neutrinos produced by the annihilation of $\mathcal{O}$(10 GeV) dark matter. In addition, when the sun is in equilibrium (as is the case for many models of dark matter), the annihilation rate is one-half of the dark matter capture rate. This implies that the neutrino flux arising from dark matter annihilation is determined by the dark matter-nucleus scattering cross-section, allowing neutrino-based searches to probe dark matter scattering without some of the uncertainties which plague other indirect detection strategies. Moreover, neutrino-based searches can have enhanced sensitivity to dark matter models with non-standard interactions. In 2008, Kumar and Learned (along with Feng and Strigari) showed that an analysis of fully-contained muon data already taken by Super-Kamiokande could potentially probe many of the dark matter models proposed as explanations for the low-mass direct detection data. Based on this result (published in JCAP), UH graduate student Stefanie Smith will perform the actual Super-K data analysis.

Learned has pointed out that liquid scintillator-based neutrino detectors can also be used for searches for neutrinos arising from dark matter annihilation in the sun. The direction of the charged-lepton produced in the detector (by a charged-current interaction) can be reconstructed from the timing of the first photons to reach the various photomultiplier tubes. Moreover, the charged lepton flavor can be determined with very good accuracy from the light and timing information. This has opened up a new avenue for dark matter searches, which the UH group has exploited.

Kumar and Learned, and Hawaii students Michinari Sakai and Smith, showed that neutrino-based dark matter searches have an enhanced sensitivity (relative to most direct detection experiments) to IVDM models that potentially explain the low-mass data. The reason is because of the prevalence of low-neutron atoms (such as hydrogen) in the sun, from which IVDM could scatter without suffering from destructive interference. They have shown that a one kT liquid scintillation detector with a 2135 live-day dataset (roughly the exposure of KamLAND) could potentially probe such IVDM models. This analysis relied on a search for $\nu_e/\bar{\nu}_e$ arising from dark matter annihilation, which has the advantage of a smaller atmospheric neutrino background than the more common $\nu_\mu/\bar{\nu}_\mu$ search strategy. This work was published in Physical Review **D**, and Sakai will be working on the actual dark matter analysis of KamLAND's data.

Subsequently, Kumar, Learned and Smith, along with Katherine Richardson (New Mexico), have performed a detailed study of dark matter capture rates and annihilation spectra for low-mass dark matter (current numerical packages only have tables for $m_X \geq 10$ GeV). They also included the possibility of isospin-violating, long-range, or inelastic dark matter interactions (all of which have been studied in the context of the low-mass data) in determining the capture rate. The computationally-intensive neutrino spectra were simulated using HOSC. They have found that neutrino detectors have an enhanced sensitivity to dark matter with long-range interactions with nuclei, as compared to direct detection experiments. This enhancement occurs because the differential scattering cross-section scales inversely with the momentum transfer; for scattering off light elements, like hydrogen, the momentum transfer is small, implying a much-enhanced dark matter capture rate. With its current dataset, KamLAND's sensitivity to 10 GeV dark matter with long-range interactions could be a factor of $\sim$ 100 greater than that available from the current CDMS dataset. LBNE (with a 51 kT liquid argon target) could achieve the same sensitivity with a mere $\sim$ 17 days of data. They have also found that neutrino-based searches can be sensitive to models of inelastic dark matter which cannot be probed with Earth-based direct detection experiments. The reason is that dark matter which scatters of solar nuclei will have a large kinetic energy due to gravitational infall, permitting scattering processes that would be kinematically inaccessible for Earth-based detectors. Low-mass inelastic dark matter models with mass splittings as large as $\sim$ 50 keV can be probed with neutrino-based dark matter searches. This work has been published in Physical Review **D**.

Kumar and Fukushima, along with Gao and Marfatia, studied the impact of annihilation to 3-

body final states on neutrino-based search sensitivity (published in Physical Review **D**). It is well-known that the $XX \to f\bar{f}$ annihilation cross-section of Majorana-fermion dark matter can be chirality-suppressed, allowing the three-body annihilation cross-section $XX \to f\bar{f}V$ (where V is an electroweak gauge boson) to dominate for heavy dark matter. The effect of this channel on the dark matter annihilation photon spectrum has been well-studied. Kumar and his collaborators quantified the effect of 3-body annihilation channels on the neutrino spectrum, and on the sensitivity of neutrino detectors to annihilating dark matter.

Astrophysical Constraints on Asymmetric Dark Matter

Dark matter searches at neutrino detectors search for the products which result when dark matter annihilates in any region where it has accumulated due to gravitational capture. But if the dark matter annihilation cross section is very suppressed, then dark matter may continue to accumulate at the center of a dense body, eventually forming a black hole. Among the densest stellar bodies, capable of capturing dark matter at the largest rate, are neutron stars. The observation of old neutron stars (which have not been consumed by black holes) has thus been used to constrain the dark matter-neutron scattering cross section for the case of bosonic asymmetric dark matter. In such analyses, it is usually assumed that the asymmetric dark matter is both non-self-interacting and non-annihilating. In fact, it is not necessary for either to be the case. In particular, even asymmetric dark matter can annihilate if the stabilizing symmetry is a parity. Fukushima, Kumar and Bramante recently considered the effect of such annihilation or self-interaction on bounds on bosonic asymmetric dark matter. They found that even an extremely small repulsive self-interaction term or a very small annihilation cross section (smaller than what could be observed at near future experiments) would completely eliminate any bounds on asymmetric dark matter from neutron star observations. This work, published in Physical Review **D**, was the first to indicate this severe limitation on the applicability of neutron star constraints on asymmetric dark matter.

The Fermi-LAT Gamma Ray Line

There has been much recent excitement regarding possible evidence from Fermi-LAT for a 130 GeV gamma-ray line from the Galactic center, which may potentially arise from dark matter annihilation. However, aside from the question of whether this line results from a statistical fluctuation or systematic uncertainty in the detector response, there is an additional theoretical question: how can dark matter models produce such a strong line signal from a one-loop process without producing a (thus unobserved) continuum gamma-ray signal from tree-level annihilation processes? Though this particular data anomaly may well go away, gamma-ray line signatures are nevertheless considered a "smoking gun" for dark matter annihilation, and are thus deserving of study in a more general context. Kumar and Pearl Sandick have recently studied the possibility of dark matter annihilation dominantly in the $\chi\chi \to \gamma\gamma$ channel in the context of the MSSM. They found that in models with a bino-like lightest neutralino, heavy squarks, light sleptons and negligible sfermion mixing, it is possible for dark matter to annihilate dominantly to two photons (even if one accounts for three-body annihilation channels). However, in such models it is difficult to reproduce the magnitude of the gamma-ray line signal observed from the Galactic center. More general models of new physics with a similar matter content, but larger couplings, may be able to produce a much larger signal, however. This work has been published in Physical Review **D**.

Dirac Neutralinos

Kumar has also recently completed work with Matt Buckley and Dan Hooper (Fermilab) on the phenomenology of Dirac neutralinos. In supersymmetric models with unbroken R-symmetry, the neutralinos are forbidden from receiving Majorana masses because they have non-zero R-charge. If the matter content is suitable, however, they can receive Dirac masses. Dirac neutralino dark matter has many interesting phenomenological features which are not seen in more standard Majorana neutralinos. In particular, can exhibit spin-independent scattering with nuclei through either Z-exchange or squark-exchange; bounds from direct detection experiments thus require the dark matter to be almost entirely bino-like and requires the squarks to be very heavy (unless the dark matter is very light). But the Dirac neutralino annihilation cross section is neither velocity- nor chirality-suppressed; if the sleptons are light enough, the annihilation cross section can be large enough to yield the correct relic density. Moreover, this scenario can yield observable signatures at current and near-future indirect detection experiments.

Kumar is continuing work with his collaborators on less-explored regions of the MSSM (and simple extensions thereof) which can potentially explain the dark matter relic density while evading recent tight constraints from the LHC and dark matter direct detection experiments. Current focusses include models with non-universal scalar masses and non-standard squark-mixing.

Dynamical Dark Matter

Recently, Thomas and collaborator K. R. Dienes (Arizona and NSF) have proposed an alternative framework for dark-matter physics called Dynamical Dark Matter (DDM). In this framework, the dark sector consists not of one (or merely a few) stable dark-matter particles, but rather of an *ensemble* consisting of a vast number of constituent particles ϕ_i whose collective properties transcend those normally associated with more traditional dark-matter candidates. For example, dark matter stability is not a requirement in the DDM framework; instead, the decay widths Γ_i of the ϕ_i are balanced against their abundances Ω_i in order that the ensemble as a whole satisfies applicable constraints on dark-matter decays. Moreover, in the DDM framework, cosmological quantities such as $\Omega_{\rm CDM}$ experience non-trivial time-dependences beyond those associated with the expansion of the universe.

One natural realization of the DDM framework occurs in theories with large extra spacetime dimensions, where the constituents of the dark-matter ensemble are the KK excitations ϕ_n of some bulk scalar ϕ. The mass-squared matrix $\mathcal{M}^2_{mn}$ of the ϕ_n in such a theory can include not only diagonal KK-mass contributions, but also off-diagonal brane-mass contributions, which give rise to non-trivial mixing among the ϕ_n. This mixing leads to a suppression of the decay widths Γ_i of the lighter mass-eigenstates ϕ_i. Moreover, this effect also suppresses the relic-abundances of the heavier ϕ_i from misalignment production and thereby yields the desired balancing between Γ_i and Ω_i when this production mechanism dominates. Thomas and Dienes have developed an explicit DDM model in which the bulk scalar is an axion, and have shown that this model is capable of reproducing the observed value of $\Omega_{\rm CDM}$ while at the same time satisfying all relevant constraints.

DDM models may give rise to unusual signature patters at colliders, at dark-matter direct-detection experiments, and at a host of experiments which search for indirect signals of dark matter. Thomas, Dienes and S. Su (Arizona) have been investigating a number of techniques for distinguishing between DDM ensembles and traditional dark-matter candidates at colliders. One such technique involves the identification of distinctive features in the invariant-mass distributions of the SM particles produced alongside the constituent particles in the DDM ensemble by the decays of some additional, heavy field ψ in the theory. Thomas, Dienes, and S. Su have demonstrated that even in the simplest case in which these ψ decay directly to a pair of quarks or gluons (which appear in a collider detector as hadronic jets) and one of the ϕ_i, it is possible in a wide variety of situations to distinguish between a DDM ensemble and a traditional dark-matter candidate at the 5σ significance level on the basis of the resulting dijet invariant-mass distribution within the first 30 fb^{-1} of integrated luminosity at the LHC.

Thomas, Dienes, and Kumar have examined the potential for detecting a DDM ensemble via the scattering of its constituent particles off atomic nuclei, and for differentiating between such a dark-matter candidate and more traditional dark-matter candidates on the basis of the nuclear-recoil-energy spectra observed at direct-detection experiments. Even in cases in which elastic-scattering processes of the form $\phi_i N \to \phi_i N$ (where N denotes the nucleus in question) dominate, Thomas, Dienes, and Kumar have demonstrated that characteristic features in the these spectra could serve to distinguish between these two classes of scenarios. In addition, inelastic scattering processes of the form $\phi_i N \to \phi_j N$, with $i \neq j$ are a natural possibility within the DDM framework, and can have important implications for direct detection for mass splittings $|m_j - m_i| \lesssim \mathcal{O}(100\text{ keV})$.

A number of indirect methods may also be used to detect and distinguish a DDM ensemble from other, more traditional dark-matter candidates. For example Thomas, Dienes, and Kumar have shown that DDM ensembles are able to reproduce the positron excess observed by AMS02 and a number of other experiments due to the natural softening of the $e^{\pm}$ injection spectra which occurs when the dark-matter abundance is partitioned among a large number of constituent particles with a broad spectrum of masses. Moreover, they demonstrated that such ensembles yield a concrete and prediction for the positron fraction at higher energies — no abrupt downturn, but rather a plateau or gradual decline — which is difficult to realize in other dark-matter models of the positron excess.

Clearly, DDM is a fertile, new area of investigation, and Thomas and his collaborators are continuing their investigations along these lines.

Cosmology

Inflationary Cosmology

Inflation is perhaps the most well-studied paradigm for early cosmology. Kumar and his collaborators, Louis Leblond (Perimeter) and Arvind Rajaraman (Irvine) have studied the effect on correlation functions in inflating spacetimes of non-linearities in the dependence of the scalar curvature perturbation upon the fundamental fields. They have shown that ambiguities in the definition of the Feynman propagator in an eternally inflating spacetime can resolve apparent infra-red divergences in the computation of correlation functions. They have also shown that these non-linearities can, in simple effective models, contribute to non-Gaussianities in the curvature spectrum which can be probed by the Planck satellite. This work has been published in Phys. Rev. **D** and in JCAP.

Kumar and Bramante have recently studied the contribution of higher order non-linearities to logarithmic corrections to local non-Gaussianity. It is commonly reported in the literature that local non-Gaussianity parameters τ_{NL} and f_{NL} must obey the constraint $\tau_{NL} \geq [(6/5)f_{NL}]^2$. Kumar and Bramante showed that, for some regions of momentum-space, this relation can be violated (indeed, τ_{NL} may even be negative). New data from Planck and other observatories are expected to constrain f_{NL} and τ_{NL} with unprecedented accuracy, with the hope of discovering non-Gaussianity in the CMB and testing the above constraint. This work (published in **JCAP**) on the range of validity of this constraint has a timely connection to observational cosmology.

They have just completed a follow-up paper, with Sarah Shandera and Elliot Nelson (both at Penn State). This paper focusses on further elucidating the relationship between the scale-dependence of non-Gaussianity and the contribution of super-Hubble modes. The power spectrum of super-Hubble modes contributes to the average curvature within the observable patch, resulting in a new source of cosmic variance which can rescale the observable spectral index and non-Gaussianity. As a result, a fundamental theory which yields significant non-Gaussianity or running of the curvature power spectrum can still be consistent with current bounds from the Planck satellite, due to these inherent cosmic variance limitations on such bounds. Kumar and his collaborators have quantified the connection between this type of cosmic variance and the presence of super-Hubble curvature perturbations.

Cosmological Constant

In $N = 1$ supergravity supersymmetric and non-supersymmetric Minkowski vacua originating in the hidden sector can be degenerate. In the supersymmetric phase in flat Minkowski space non-perturbative supersymmetry breakdown may take place in the observable sector, inducing a non-zero and positive vacuum energy density. Assuming that such a supersymmetric phase and the phase in which we live are degenerate, Nevzorov, C. Froggatt (Glasgow) and H. B. Nielsen (Copenhagen), in a paper published in Int. J. Mod. Phys. A, estimated the value of the cosmological constant. They found that the observed value of the dark energy density can be reproduced in a split-SUSY scenario with gauginos at the TeV scale and scalars at 10^{10} GeV.

Talks and other activities of Theory Group since last review

Pakvasa gave a talk about Raju Raghavan at a memorial meeting devoted to Raghavan held at VPI in Oct. 2012. He also gave a talk on galactic communications with neutrinos and SETI at the VPI colloquium during his trip. He gave a public lecture on the discovery of the Higgs boson at the Rotary Club in Baroda, India in Dec. 2012. He attended the MEDEX workshop on neutrinoless double beta decay, and presented a talk on psuedo-Dirac neutrinos and neutrinoless double beta decay in June 2013. He gave talks on the flavour mix and fluxes of high energy astrophysical neutrinos at the University fo Dresden (June 2013) and at the Max Planck Institute (July 2013). He will be attending the Lomonosov Conference in Moscow in Aug. 2013 where he plans to give a similar talk.

Kumar presented invited talks at the *Aspects of Inflation* workshop (Texas A&M University, Apr. 2011), at the *Dark Matter: Its Origins, Models and Detection* mini-workshop (University of New Mexico, May 2011), at SLAC (Nov. 2012), at TeVPA 2012 (Mumbai, India, Dec. 2012), at the University of Utah (Mar. 2013), at the APS April Meeting (Denver, CO, Apr. 2013), at the *Light Dark Matter: Asymmetric, Thermal and Non-thermal Dark Matter and its Detection Workshop* (University of Michgian, Apr. 2013), and at the *Identifying and Characterizing Dark Matter Via Multiple Probes Conference* (KITP, May 2013). He also presented talks at the 2011 Phenomenology Symposium (University of Wisconsin, May 2011), the *non-Gaussianity: Observations Confront Theory* workshop (University of Michigan, May 2011), CosPA 2011 (Beijing, China, Oct. 2011), at the University of California, Irvine, at the Indian Institute of Science (Dec. 2012), and at SnowDARK 2013 (Snowbird, Utah, Mar. 2013). He has been invited to give pre-SUSY lectures on dark matter prior to SUSY 2012 to be held in Beijing, and has been invited to speak about dark matter at the US/China Kavli Frontiers of Science workshop at UC Irvine in Oct. 2012. He is a co-convenor of the particle astrophysics and cosmology session at ICHEP in Melbourne as well as at SUSY 2012. He organized the *Closing in on Dark Matter* 2013 Aspen Winter Conference at the Aspen Center for Physics, and the CETUP* 2013 Dark Matter Workshop.

Tata presented invited pedagogical lectures at the pre-SUSY meeting in Chicago (Aug. 2011), and presented a talk at the SUSY 2011 at Fermilab (Aug. 2011). He was invited to present a talk on Supersymmetry and Dark Matter at the LHC at the KIAS Phenomenology Workshop in Seoul (Nov. 2011) and at the GCOE 2011 Winter School at Nagoya (Dec. 2011). He also gave a talk at COSPA 2011 in Beijing (Oct. 2011). He presented invited pre-SUSY lectures prior to SUSY 2012 in Beijing, along with talk on natural SUSY at both SUSY 2012 and at PHENO 2012. He presented three pedagogical lectures on Dark Matter and Particle Physics at the Sangam@HRI workshop at the Harish Chandra Institute, Allahabad, India (March 2013). He was one of four Panelists at the Kavli Institute Snowmass on the Pacific Workshop (May 2013) where he also gave a physics talk on naturalness. He also presented an outreach talk aimed at non-physics majors at Chaminade University (Mar. 2012), a colloquium at the U. of Kansas (Apr. 2012) and technical seminars at KEK and Kansas. He presented He served on the NSF review panel for Theory and Cosmology (Mar. 2012), was on the advisory committees for PHENO 2012 and SUSY 2013. He is also a co-convenor of the SUSY Phenomenology as well as the Precision SUSY and SUSY Models sessions at SUSY 2013.

Nevzorov presented invited plenary and parallel talks at the XIX International Workshop on High Energy Physics and Quantum Field Theory (QFTHEP 2010, September 2010). He also presented talks at the 35th International Conference on High Energy Physics in Paris (ICHEP-2010, July 2010), 2011 Meeting of the Division of Particles and Fields of the American Physical Society in Providence (DPF 2011, August 2011) and 19th International Conference on Supersymmetry and Unification of Fundamental Interactions in Fermilab (SUSY11, August - September 2011).

Thomas was an invited participant in the "Hunting for Dark Matter: Building a Cross-Disciplinary, Multi-Pronged Approach" workshop at the Kavli Institute for Theoretical Physics (Santa Barbara, May - June 2013) and presented talks at the 2012 Phenomenology Symposium (Madison, May 2012), the 2012 Anacapa Society Meeting (St. Paul, 2012), the University of Melbourne LHC Theory Workshop (Melbourne, July 2012), the 36th International Conference on High Energy Physics (Melbourne, July 2012), the CETUP* 2012 Dark Matter, Neutrino Physics, and Unification Workshop (Lead, South Dakota, 2012), the 20th International Conference on Supersymmetry and the Unification of Fundamental Interactions (Beijing, August 2012), the Nanjing-Karlstad Theory Workshop (Nanjing, August 2012), the 2013 Phenomenology Symposium (Pittsburgh, May 2013), the "Beyond the Standard Model after the first run of the LHC" workshop at the Galileo Galilei Institute (Florence, June 2013), the CETUP* 2013 Dark Matter Workshop (Lead, July 2013), and the 7th International Conference on Interconnections between Particle Physics and Cosmology (Deadwood, July 2013). He also gave seminars at Shanghai Jiao Tong University (Shanghai, August 2013), the University of Hawaii (Honolulu, March 2013), Carleton University (Ottawa, May 2013) and the Scuola Normale (Pisa, July 2013) and gave colloquia at the University of Hawaii (Honolulu, March 2013) and at Colorado College (Colorado Springs, May 2013) .

Mustafayev presented a talk on the same-sign diboson signal from gaugino production at the LHC in SUSY models with low μ at PHENO 2013, at the University of Pittsburgh.

Appendices: Biographical Sketches & Publications

Biographical Sketch of Jason Kumar

Education and Training

Undergraduate Inst.	Caltech	Physics/Mathematics	B.S./honors, 1995
Graduate Inst.	Stanford University	Physics	PhD, 2000
Post-doctoral Inst.	UC San Diego	Theoretical Physics	2000-2003
Post-doctoral Inst.	University of Michigan	Theoretical Physics	2003-2005
Post-doctoral Inst.	Texas A&M University	Theoretical Physics	2005-2007

Research and Professional Experience

- Assistant Professor, University of Hawaii at Manoa, 2008-present
- Assistant Project Scientist, University of California, Irvine, 2007-2008

Publications

- J. Kumar, D. Sanford and L. E. Strigari, “New Constraints on Isospin-Violating Dark Matter,” Phys. Rev. D **85**, 081301(R) (2012), 6 pages, arXiv:1112.4849 [astro-ph.CO]. DOI: 10.1103/PhysRevD.85.081301
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Synergistic Activities

- Participation in University of Hawaii's QuarkNet program, providing outreach to high school teachers
- Co-convenor of sessions at ICHEP2012 and SUSY2012
- Lecturer at PreSUSY2012
- Speaker at the US/China Kavli Frontiers of Science 2012 meeting in Irvine, CA

Collaborators

Dr. Johan Alwall (Fermilab), Mr. Joseph Bramante (University of Hawaii), Prof. Vernon Barger (University of Wisconsin), Prof. Bhaskar Dutta (Texas A&M Univ.), Prof. Jonathan Feng (University of California, Irvine), Mr. Keita Fukushima (University of Hawaii), Dr. Yu Gao (University of Oregon), Dr. Srikanth Hundi (Indian Association for the Cultivation of Science), Prof. John Learned (University of Hawaii), Dr. Louis Leblond (Perimeter Institute), Prof. Danny Marfatia (University of Kansas), Mr. Elliot Nelson (Penn State), Dr. Roman Nevzorov (University of Hawaii), Prof. Arvind Rajaraman (University of California, Irvine), Ms. Katie Richardson (University of New Mexico), Prof. Pearl Sandick (University of Utah), Mr. Michanari Sakai (University of Hawaii), Mr. David Sanford (University of California, Irvine), Dr. Enrico Sessolo (Soltan Institute for Nuclear Studies), Prof. Sarah Shandera (Penn State), Ms. Stefanie Smith (University of Hawaii), Mr. Pat Stengel (University of Hawaii), Dr. Louis E. Strigari (Stanford University), Prof. Shufang Su (University of Arizona), Prof. Xerxes Tata (University of Hawaii), Dr. Brooks Thomas (University of Hawaii), Mr. David Yaylali (University of Hawaii),

Graduate Advisor: Professor Leonard Susskind, Stanford University

Post-doctoral Sponsors:

- Professor Michael Duff, Imperial College
- Professor Ergin Sezgin, Texas A&M University
- Professor Jonathan Feng, University of California, Irvine

Graduate Students: Mr. Joseph Bramante, Mr. Keita Fukushima, Mr. Pat Stengel, Mr. David Yaylali

Post-doctoral Advisees: Dr. Srikanth Hundi, Dr. Roman Nevzorov, Dr. Brooks Thomas

BIOGRAPHICAL SKETCH

SANDIP PAKVASA
Professor of Physics
Department of Physics and Astronomy
University of Hawaii
Honolulu, HI 96822 USA

Citizenship: USA

Education:

B. Sc. (Physics & Mathematics)	M.S.University of Baroda	1954
M. Sc. Physics	M.S.University of Baroda	1957
Ph. D.	Purdue University	1966

Experience:

Professor of Physics	University of Hawaii	1974-
Associate Professor	University of Hawaii	1970-1974
Assistant Professor	University of Hawaii	1968-1970
Associate Physicist	University of Hawaii	1967-1968
Research Associate	Syracuse University	1965-1967
Visiting Professor	University of Wisconsin	1978
Visiting Professor	KEK	2002, 1989
Visiting Professor	TIFR	1983
McMinn Lecturer/visiting professor	Vanderbilt University	1996
Ramanathan Professor	Physical Research Laboratory Ahmedabad, India	2009
Platinum Jubilee Lecturer, Bangalore Association for Advancement of Science,		March 2009

Elected to Fellowship of American Physical Society	1976
Awarded JSPS Fellowship	1981, 1985
Awarded University of Hawaii Regents Medal for Excellence in Research	2009

Selected Publications:

1. Nonstandard Higgs Decays and Dark Metter in the E6SSM, Phys. Rev. D83, 075013(2011), with R. Nevzorov et al.
2. Neutrino Flavor Detection at Neutrino Telescopes and Its Uses, arXiv:1004.5412.
3. Implications of D0-D0_bar Mixing for New Physics, Phys. Rev. D 76, 095009 (2007), with E, Golowich et al.
4. Determination of neutrino mass hierarchy and theta (13) with a remote detector of reactor antineutrinos, Phys. Rev. D78, 071302(2008), with S. Dye et al.
5. Pseudo-Dirac Neutrinos: A challenge for neutrino telescopes, Phys. Rev. Lett., 92, 01101(2004), with J. Beacom et al.
6. CP Violation in Six Quark Model, Phys. Rev. D14, 305(1976), with H. Sugawara.

7. Neutrino Decay as an explanation of Atmospheric Neutrino Observations., Phys.Rev. Lett., 82, 2640(1999), with V. Barger et al.
8. Bimaximal mixing of three neutrinos, Phys. Lett. B437, 107(1998), with V. Barger et al.
9. Neutrino Mass and Mixing implied by Underground deficit of low-energy Muon-neutrino events, Phys. Lett. B207, 79(1988), with J. Learned, T. Weiler.
10. Muon and Electron Number Nonconservation in a V-A Six Quark Model, Phys. Rev. Lett. 38, 937 (1977), with B. W. Lee, H. Sugawara and R. Shrock.

Synergistic Activities:
Serve on the Internationsl Advisory Committees for
ICHEP (Melbourne) 2012, ISLEPHI-Lepton-Photon Symposium (Mumbai)2011,
Local Org. Comm.(Honolulu) CHARM 2012
Convener for Parallel Sessions in several Conferences ICHEP (Osaka) 2000,
ICHEP (Singapore)1990... etc.

Graduate Student supervised recently: A. Acker.

Recent Postdoctoral Associate: H. Paes.

Recent Collaborators: E, Golowich, A, Petrov, D. Marfatia, T. Weiler,
J. Hewett, H. Paes, R. Nevzorov, M. Batygov, S. Dye, J. G. Learned,
M. Sher, S. F. King, X-G, He, W. Rodejohann, R. Sinha, N. Deshpande,
A. Zee, R. S. Hundi, S. Matsuno, G. Varner, N. Sinha, R. Svoboda,J. Dent.
Members of the KamLAND collaboration, Members of the LENA collaboration,
co-authors of the White Paper on Light Sterile Neutrinos.

Member of Experimental Collaborations:
KamLAND Collaboration: http://www.awa.tohoku.ac.jp/KamLAND/
(during 1999 to 2009)

Hanohano Collaboration: http://www.phys.hawaii.edu/~sdye/hanohano.html

INO Collaboration: http://www.ino.tifr.res.in/ino/collaboration.php

LENA Collaboration: http://www.e15.physik.tu-muenchen.de/research_and_projects/lena/

VITA

Xerxes Ramyar TATA

EDUCATION

Bachelor of Science	Bombay University, India	1974
Master of Science	Indian Institute of Technology Bombay, India	1976
Ph.D.	University of Texas at Austin	1981

EXPERIENCE

Professor	University of Hawaii at Manoa	1994-present
Associate Professor	University of Hawaii at Manoa	1988-1994
Visiting Scientist	KEK, Japan	Sept. 1987-Feb. 1988
Assistant Scientist	University of Wisconsin at Madison	1986-1988
Research Associate	University of Oregon at Eugene	1985-1986
Scientific Associate	CERN, Geneva, Switzerland	1984-1985
Research Scientist	University of Texas at Austin	1984
Research Associate	University of Oregon at Eugene	1983-1984
Lecturer in Physics	University of Texas at Austin	1981-1982
Research Associate	University of Texas at Austin	1981-1983

FELLOWSHIPS

Fellow, American Physical Society (2001)

National Panels

NSF Review Panel for Theoretical Physics and Cosmology, National Science Foundation, Arlington, Virginia (March 27-30, 2012).

SCIENTIFIC SERVICE ACTIVITIES

1. Co-leader, Supersymmetry Subgroup for 1994-95 DPF Long Term Planning Study.
2. Lecturer at 1995 Theoretical Advanced Study Institute, Boulder, Colarado.
3. Co-convenor, SUSY Session at International Workshop on Physics and Experiment at Linear Colliders, Morioka-Appi, 1995.
4. Co-convenor, SUSY Working Group at Snowmass 1996.
5. Lecturer at the IX Jorge Swieca Summer School, Campos do Jordão, Brazil, 1997.
6. Lecturer at the KIAS School for Particle Physics, Seoul, S. Korea, 2001.
7. Lecturer at the International Workshop/School on Frontiers of High Energy Physics, Beijing, China (July, 2004).
8. Lecturer at the SLAC Summer Institute, SLAC, Menlo Park, U.S.A. (August, 2004).
9. Lecturer at the 20th Spring School on Particles and Fields, Taipei, Taiwan (April, 2007).
10. Supersymmetry: Two Pedagogical Lectures, Pre-SUSY 2011, University of Chicago, Chicago, IL (Aug. 2011).

SELECTED PUBLICATIONS

TEXT BOOK

1. H. Baer and X. Tata, Weak Scale Supersymmetry: From Superfields to Scattering Events, Cambridge University Press (May 2006).

Publications of the Theory Group

We list publications of the theory group since the external review three and a alf years back, including papers that were listed as submitted for publication but which have since been published.

Publications in refereed journals

1. K. Fukushima and J. Kumar, Dipole Moment Bounds on Dark Matter Annihilation, arXiv:1307.7120 [hep-ph], submitted to *Phys. Rev.* **D**.
2. J. Bramante, J. Kumar, E. Nelson and S. Shandera, Cosmic Variance of the Spectral Index from Mode Coupling, arXiv:1307.5083 [astro-ph.CO], submitted to *JCAP*.
3. M. R. Buckley, D. Hooper and J. Kumar, Phenomenology of Dirac Neutralino Dark Matter, arXiv:1307.3561 [hep-ph], submitted to *Phys. Rev.* **D**.
4. K. R. Dienes, J. Kumar and B. Thomas, Dynamical Dark Matter and the Positron Excess in Light of AMS, arXiv:1306.2959 [hep-ph], submitted to *Phys. Rev.* **D**.
5. J. Kumar and D. Marfatia, Matrix element analyses of dark matter scattering and annihilation, *Phys. Rev* **D88**, 014035 (2013), arXiv:1305.1611 [hep-ph].
6. J. L. Feng, J. Kumar and D. Sanford, Xenophobic Dark Matter, *Phys. Rev* **D88**, 015021 (2013), arXiv:1306.2315 [hep-ph].
7. J. Kumar and P. Sandick, Gamma Rays from Bino-like Dark Matter in the MSSM, *Phys. Rev.* **D87**, 123534 (2013), [arXiv:1303.2384 [hep-ph]].
8. J. Bramante, K. Fukushima and J. Kumar, Constraints on Bosonic Dark Matter From Observations of Old Neutron Stars, *Phys. Rev.* **D87**, 055012 (2013), [arXiv:1301.0036 [hep-ph]].
   doi: 10.1103/PhysRevD.87.055012
9. J. Kumar, A. Rajaraman and D. Yaylali, Spin Determination for Fermiophobic Bosons, *Phys. Rev.* **D86**, 115019 (2012), [arXiv:1209.5432 [hep-ph]].
10. K. Fukushima, Y. Gao, J. Kumar and D. Marfatia, Bremsstrahlung signatures of dark matter annihilation in the Sun, *Phys. Rev.* **D86**, 076014 (2012), arXiv:1208.1010 [hep-ph].
11. K. R. Dienes, J. Kumar and B. Thomas, Direct Detection of Dynamical Dark Matter, *Phys. Rev.* **D86**, 055016 (2012), arXiv:1208.0336 [hep-ph].
    doi: 10.1103/PhysRevD.86.055016
12. J. Kumar, J. G. Learned, K. Richardson and S. Smith, Tools for Studying Low-Mass Dark Matter at Neutrino Detectors, *Phys. Rev.* **D86**, 073002 (2012), arXiv:1204.5120 [hep-ph].
13. J. Kumar, D. Sanford and L. E. Strigari, New Constraints on Isospin-Violating Dark Matter, *Phys. Rev.* **D85**, 081301(R) (2012), arXiv:1112.4849 [astro-ph.CO].
14. J. Bramante, J. Kumar, B. Thomas, Large Jet Multiplicities and New Physics at the LHC, *Phys. Rev.* **D86**, 015014 (2012) arXiv:1109.6014 [hep-ph].
15. J. Kumar, A. Rajaraman, B. Thomas, Higher Representations and Multi-Jet Resonances at the LHC, *Phys. Rev.* **D84**, 115005 (2011), [arXiv:1108.3333 [hep-ph]].
16. Y. Gao, J. Kumar, D. Marfatia, Isospin-Violating Dark Matter in the Sun, *Phys. Lett.* **B704**, 534 (2011) [arXiv:1108.0518 [hep-ph]].
17. J. Bramante, J. Kumar, Local Scale-Dependent Non-Gaussian Curvature Perturbations at Cubic Order, *JCAP* **1109**, 036 (2011), [arXiv:1107.5362 [astro-ph.CO]].
18. J. Alwall, J. L. Feng, J. Kumar, S. Su, B's with Direct Decays: Tevatron and LHC Discovery Prospects in the $b\bar{b}$ Channel, *Phys. Rev.* **D84**, 074010 (2011), [arXiv:1107.2919 [hep-ph]].

19. J. Bramante, R. S. Hundi, J. Kumar, A. Rajaraman, D. Yaylali, Collider Searches for Fermiophobic Gauge Bosons, *Phys. Rev.* **D84**, 115018 (2011), [arXiv:1106.3819 [hep-ph]].

20. K. Fukushima, J. Kumar, P. Sandick, Detection Prospects for Majorana Fermion WIMPless Dark Matter, *Phys. Rev.* **D84**, 014020 (2011), [arXiv:1103.5068 [hep-ph]].

21. J. Kumar, J. G. Learned, M. Sakai, S. Smith, Dark Matter Detection With Electron Neutrinos in Liquid Scintillation Detectors, *Phys. Rev.* **D84**, 036007 (2011), [arXiv:1103.3270 [hep-ph]].

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23. B. Dutta, J. Kumar, Asymmetric Dark Matter from Hidden Sector Baryogenesis, *Phys. Lett.* **B699**, 364-367 (2011), arXiv:1012.1341 [hep-ph].

24. V. Barger, J. Kumar, D. Marfatia and E. M. Sessolo, Fermion WIMPless Dark Matter at DeepCore and IceCube, *Phys. Rev.* **D81**, 115010 (2010), [arXiv:1004.4573 [hep-ph]].

25. J. Kumar, L. Leblond and A. Rajaraman, Constructing Infrared Finite Propagators in Inflating Space-time, *Phys. Rev.* **D82**, 023525 (2010), [arXiv:1002.4214 [hep-th]].

26. J. Alwall, J. L. Feng, J. Kumar and S. Su, Dark Matter-Motivated Searches for Exotic 4th Generation Quarks in Tevatron and Early LHC Data, *Phys. Rev.* **D81**, 114027 (2010), [arXiv:1002.3366 [hep-ph]].

27. J. Kumar, L. Leblond and A. Rajaraman, Scale Dependent Local Non-Gaussianity from Loops, *JCAP* **1004**, 024 (2010), [arXiv:0909.2040 [astro-ph.CO]].

28. J. Kumar, J. G. Learned and S. Smith, Light Dark Matter Detection Prospects at Neutrino Experiments, *Phys. Rev.* **D80**, 113002 (2009), [arXiv:0908.1768 [hep-ph]].

29. Exotic Higgs decays in E_6 inspired SUSY Models, R. Nevzorov and S. Pakvasa, arXiv:1205.5967 [hep-ph], submitted to *Phys. Rev.* **D**.

30. Explanation for the lower flux of high energy astrophysical muon neutrinos, S. Pakvasa, A. Joshipura, S. Mohanty, *Phys. Rev. Lett.* **110**, 171802 (2013), arXiv:1209.5630 [hep-ph].

31. IceCube PeV events initiated by electron anti-neutrinos at the Glashow resonance, V. Barger, J. Learned, S. Pakvasa, *Phys. Rev.* **D87**, 037302 (2013), arXiv:1207.4571 [astro-ph].

32. Pseudo-Dirac neutrinos via mirror world and depletion of UHE neutrinos, A. Joshipura, S. Mohanty and S. Pakvasa, arXiv:1307.5712, submitted to *Phys. Rev.* **D**.

33. J. G. Learned, R-P. Kudritzki, S. Pakvasa and A. Zee, The Cepheid Galactic Internet, *Contemporary Physics*, **53**, 112 (2012).

34. D. Marfatia, H. Paes, S. Pakvasa and T. J. Weiler, "A Model of Superluminal Neutrinos," *Phys. Lett.* **B707**, (2012).

35. KamLAND Collaboration, (S. Abe. S. Pakvasa et al). Measurement of the 8B Solar Neutrino Flux with the KamLAND Liquid Scintillator Detector, *Phys. Rev.* **C84**, 035804(2011).

36. R. Sinha, N. G. Deshpande, S Pakvasa and C. Sharma, Determination of Weak Amplitudes using Bose Symmetry and Dalitz Plots, *Phys. Rev. Lett.* **107**, 271801(2011).

37. E. Golowich, J. Hewett, S. Pakvasa, A. Petrov and G. Yeghiyan, Relating B_s Mixing and $B_s \to \mu^+\mu^-$ with New Physics, *Phys. Rev.* **D83**, 114017(2011).

38. J. P. Hall, S. F. King, R. Nevzorov, S. Pakvasa and M. Sher, Non-standard Higgs Decays in the E6SSM, *Phys. Rev.* **D83**, 075013 (2011).

39. E. Golowich, J. Hewett, S. Pakvasa and A. Petrov, Relating D^0-anti-D^0 Mixing and $D^0 \to$ l+l with New Physics, *Phys. Rev.* **D79**, 114030 (2009).

40. J. G. Learned, S. Pakvasa and A. Zee, Galactic Neutrino Communication, *Phys. Lett.* **B671**, 15(2009).

41. J. Bramante, Sterile neutrino production through a matter effect enhancement at long baselines, *Int. J. Mod. Phys.* **A28**, 1350067 (2013).

42. H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev, W. Sreethawong and X. Tata, Same Sign Diboson Signature from Supersymmetry Models with Light Higgsinos at the LHC, arXiv:1302.5816 [hep-ph], *Phys. Rev. Lett.* **110**, 151801 (2013)

43. H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata, Radiative Natural Supersymmetry: Reconciling Electroweak Fine-tuning and the Higgs Boson Mass, *Phys. Rev.* **D87**, 115028 (2013).

44. H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata, Post-LHC7 Fine-tuning in the mSUGRA/CMSSM model witha 125 GeV Higgs Boson, arXiv:1210.3019 [hep-ph], *Phys. Rev.* **D** (in press).

45. H. Baer, V. Barger, P. Huang, A. Lessa and X. Tata, Discovery Potential for SUSY at a High Luminosity Upgrade of LHC14, *Phys. Rev.* **D86**, 117701(R) (2012).

46. H. Baer, V. Barger, P. Huang, A. Mustafayev and X. Tata, Radiative Natural SUSY with a 125 GeV Higgs Boson, *Phys. Rev. Lett.* **109**, 161802 (2012).

47. H. Baer, V. Barger, P. Huang and X. Tata, Natural Supersymmetry: LHC, dark matter and ILC searches, *J. High Energy Phys.* **1205**, 109 (2012).

48. H. Baer, V. Barger, S. Kraml, A. Lessa, W. Sreethawong and X. Tata, WZ plus missing-E_T signal from gaugino pair production at LHC7, *J. High Energy Phys.* **1203**, 092 (2012), arXiv:1201.5382 [hep-ph].

49. H. Baer, V. Barger, A. Lessa, W. Sreethawong and X. Tata, Wh plus missing-E_T signal from gaugino pair production at LHC, *Phys. Rev. D* **85** (2012) 055022, arXiv:1201.2949 [hep-ph].

50. H. Baer, V. Barger, A. Lessa and X. Tata, LHC discovery potential for supersymmetry with $\sqrt{s} = 7$ TeV and 5-30 fb^{-1}, *Phys. Rev. D* **85** (2012) 051701 (R), arXiv:1112.3044 [hep-ph].

51. H. Baer, V. Barger, A. Lessa and X. Tata, Capability of the LHC to discover SUSY with $\sqrt{s} = 7$ TeV and 1 fb^{-1}, *J. High Energy Phys.* **1006**, 102 (2010), arXiv:1004.3594 [hep-ph].

52. H. Baer, S. Kraml, A. Lessa, S. Sekmen and X. Tata, Effective Supersymmetry at the LHC, *J. High Energy Phys.* **1010**, 018 (2010), arXiv:1007:3897 [hep-ph].

53. V. Barger, Y. Gao and X. Tata, Determining the Squark Mass at the LHC, *Phys. Rev.* **D83**, 095013 (2011), arXiv:1103:018 [hep-ph].

54. H. Baer, V. Barger, A. Lessa and X. Tata, Supersymmetry discovery potential of the LHC at $\sqrt{s} = 10$ and 14 TeV without and with missing E_T, *J. High Energy Phys.* **0909**, 063 (2009), [arXiv:1007:3897 [hep-ph]].

55. R.S. Hundi, S. Pakvasa and X.Tata, Addressing the $\mu - b_\mu$ and proton lifetime problems and active neutrino masses in a $U(1)'$-extended supergravity model, *Phys. Rev.* **D79**, 095011 (2009), arXiv:0903.1631 [hep-ph].

56. H. Baer, E. Park and X. Tata, Collider, direct and indirect detection of supersymmetric dark matter, *New J. Phys.* **11**, 105024 (2009), arXiv:0903.0555 [hep-ph].

57. X. Miao, S. Su and B. Thomas, Trilepton Signals in the Inert Doublet Model, *Phys. Rev.* **D82**, 035009 (2010) [arXiv:1005.0090 [hep-ph]].

58. K. R. Dienes and B. Thomas, Dynamical Dark Matter: I. Theoretical Overview, *Phys. Rev.* **D85**, 083523 (2012), arXiv:1106.4546 [hep-ph].

59. K. R. Dienes and B. Thomas, Dynamical Dark Matter: II. An Explicit Model, *Phys. Rev.* **D85**, 083524 (2012), arXiv:1107.0721 [hep-ph].

60. K. R. Dienes and B. Thomas, Phenomenological Constraints on Axion Models of Dynamical Dark Matter, *Phys. Rev.* **D86**, 055013 (2012). arXiv:1203.1923 [hep-ph].

61. K. R. Dienes, S. Su and B. Thomas, Distinguishing Dynamical Dark Matter at the LHC, *Phys. Rev.* **D86**, 054008 (2012), arXiv:1204.4183 [hep-ph].

62. R. Nevzorov, E_6-inspired SUSY Models with Exact Custodial Symmetry, *Phys. Rev.* **D87**, 015029 (2013), arXiv:1205.5967 [hep-ph].

63. P. Athron, S. F. King, D. J. Miller, S. Moretti and R. Nevzorov, LHC Signatures of the Constrained Exceptional Supersymmetric Standard Model, *Phys. Rev.* **D84**, 055006 (2011) arXiv:1102.4363 [hep-ph].

64. E. Dudas, A. Linde, Y. Mambrini, A. Mustfayev, and K. A. Olive, Strong moduli stabilization and phenomenology, *Eur.Phys.J.* **C73**, 226, (2013), arXiv:1209.0499 [hep-ph].

65. C. Froggatt, R. Nevzorov and H. B. Nielsen, Dark Energy density in models with Split Supersymmetry and degenerate vacua, arXiv:1103.2146 [hep-ph], *Int. J. Mod. Phys.* **A** (in press).

66. S. F. King, M. Muhlleitner and R. Nevzorov, NMSSM Higgs Benchmarks Near 125 GeV, *Nucl. Phys. B* **860**, 207 (2012) arXiv:1201.2671 [hep-ph].

Additional Technical Reports

1. T. Akiri *et al.* [LBNE Collaboration], "The 2010 Interim Report of the Long-Baseline Neutrino Experiment Collaboration Physics Working Groups," arXiv:1110.6249 [hep-ex].

2. K. N. Abazajian, S. Pakvasa *et al.* "Light Sterile Neutrinos: A White Paper," arXiv:1204.5379 [hep-ph].

3. LENA Collaboration(M. Wurm, S. Pakvasa et al.), "The next generation liquid-scintillator neutrino observatory LENA," arXiv:1104.5620 [astro-ph].

4. D. Alves *et al.*, "Simplified Models for LHC New Physics Searches," arXiv:1105.2838 [hep-ph].

5. R. H. K. Kadala, "PhD Thesis - Topics in SUSY Phenomenology at the LHC," arXiv:1205.1267 [hep-ph].

6. L. S. Kisslinger and S. Pakvasa, "Active and Sterile Neutrino Emission and SN1987A Pulsar Velocity," [arXiv:0906.4117]

Conference Publications

1. S. Pakvasa, The Importance of Flavor, NuSky, *International Workshop on Cosmic Rays and Cosmic Neutrinos:'Looking at the Neutrino Sky'*, Triete, June 20-24, 2011; to be published in the proceedings.

2. S. Pakvasa, Galactic neutrino communication and SETI, *International Symposium on Symmetries in Subatomic Physics* Taipei, 2-5 Jan. 2010, Nucl Phys. **A844**, 244C(2010).

3. S. Pakvasa, Neutrino Flavor Detection at Neutrino Telescopes and its Uses,, *International Conference on Neutrino Physics in the LHC Era*, Luxor, Egypt, 15-19 Nov. 2009, arXiv:1004.5413.

4. S. Pakvasa, 50 Years of V-A (Living Dangerously), *Seven Science Quests Symposium in Honor of Prof. George Sudarshan's 75th Birthday*, Austin, Texas, 6-7 Nov. 2006, J. Phys. Conf.Ser. **196**, 012005(2009).

5. J. Kumar, Probing Isospin-Violating Dark Matter, arXiv:1201.0217 [hep-ph], proceedings of the Symposium on Cosmology and Particle Astrophysics (CosPA2011). (refereed)

6. J. Kumar, WIMPless Dark Matter: Models and Signatures, arXiv:1012.0078 [hep-ph], 4 pages, proceedings of the 35th International Conference of High Energy Physics - ICHEP2010, July 22-28, 2010, Paris France.

7. J. Kumar, New Signatures of WIMPless Dark Matter, arXiv:1011.2993 [hep-ph], 6 pages, proceedings of "Identification of Dark Matter 2010," July 26-30, 2010, Montpellier, France. (refereed)

8. J. L. Feng and J. Kumar, WIMPless Dark Matter, arXiv:0909.2877 [hep-ph], AIP Conf. Proc. 1200, pp. 1059-1062; doi:10.1063/1.3327538 (4 pages), proceedings of SUSY09: 17th International Conference on Supersymmetry and the Unification of Fundamental Interactions.

9. J. Kumar, From DAMA/LIBRA To Super-Kamiokande, arXiv:0903.1700 [hep-ph], proceedings of the Seventh International Heidelberg Conference on Dark Matter in Astro and Particle Physics.

10. X.Tata, Supersymmetry, dark matter and the LHC, *Proc. 17th International Conference on Supersymmetry and the Unification of Fundamental Interactions*, Boston, Ma. (June 2009), AIP Conf. Proc. 1200, 145 (2010).

11. H. Baer, V. Barger, A. Lessa and X. Tata, SUSY Discovery Potential of LHC14 with 0.3-3 ab^{-1}; A Snowmass Whitepaper, arXiv:1306.5243 [hep-ph], submitted to the proceedings of Snowmass 2013.

12. H. Baer, V. Barger, A. Mickelson and X. Tata, Snowmass Whitepaper: Exploring Natural SUSY via Direct and Indirect Detection of Higgsino-like WIMPS, arXiv:1306.4183 [hep-ph], submitted to the proceedings of Snowmass 2013.

13. H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev, W. Sreethawong and X. Tata, Leaving No Stone Unturned in the Hunt for SUSY Naturalness: A Snowmass Whitepaper, arXiv:1306.3148 [hep-ph], submitted to the proceedings of Snowmass 2013.

14. H. Baer, V. Barger, P. Huang, D. Mickelson, A. Mustafayev and X. Tata, Naturalness, Supersymmetry and Light Higgsinos: A Snowmass Whitepaper, arXiv:1306.2926 [hep-ph], submitted to the proceedings of Snowmass 2013.

15. P. Nath, B. Nelson, X. Tata *et al.* The Hunt for new physics at the Large Hadron Collider, Summary Document, Pre-SUSY 2009, arXiv:1001.2693 [hep-ph] *Nucl. Phys. Proc. Suppl.* **200-202**, 185 (2010).

16. H. Baer and X. Tata, Dark matter and the LHC, Physics at the Large Hadron Collider, *Indian National Science Academy Platimum Jubilee Special Issue*, A. Datta, B. Mukhopadhyaya and A. Raychaudhari, Editors (Springer 2009).

17. K. R. Dienes and B. Thomas, Dynamical dark matter: A new framework for dark-matter physics, CETUP 2012, *AIP Conf. Proc.* **1534**, 57 (2012).

18. K. R. Dienes and B. Thomas, Dynamical Dark Matter: An explicit model, *Proc. ICHEP 2012* (to appear).

19. K. R. Dienes and B. Thomas, Dynamical Dark Matter: A Theoretical Overview, *Proc. ICHEP 2012* (to appear).

20. C. Froggatt, R. Nevzorov and H. B. Nielsen, Dark Energy density in Split SUSY models inspired by degenerate vacua, PoS *ICHEP2010* (2010) 442 [arXiv:1012.5121 [hep-ph]].

21. J. P. Hall, S. F. King, R. Nevzorov, S. Pakvasa and M. Sher, Nonstandard Higgs decays in the E_6SSM, PoS *QFTHEP2010* (2010) 069 [arXiv:1012.5365 [hep-ph]].

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