

**Center for Theoretical Underground Physics and Related Areas –
CETUP*2015 Summer Program**
June 16th – July 18th, 2015
Lead/Deadwood, South Dakota
&
**XIth International Conference on Interconnections between
Particle Physics and Cosmology - PPC 2015**
June 29th – July 3rd, 2015
Deadwood, South Dakota

**Department of Energy, Office of Science, High Energy Physics
Final Technical Report
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Award Period: June 14, 2015 to November 30, 2015

CETUP*2015 & PPC2015 ACCOMPLISHMANTS

Overview

For last five years Center for Theoretical Underground Physics and Related Areas (CETUP*) serves as a collaboration point for scientists from around the world interested in theoretical and experimental aspects of underground science. The mission of CETUP* is to promote an organized research in physics, astrophysics, geoscience, geomicrobiology and other fields related to the underground science and provide a stimulating environment for creative thinking and open communication between researchers of varying ages and nationalities in dynamic atmosphere of intense scientific interactions. Scientists invited to participate in the program will not only provide theoretical support to the underground science, but they will also examine core questions of the 21st century including: What is dark matter? How well do we know the neutrino parameters?, How have neutrinos shaped the evolution of the universe?, How were the heavy elements made?, What are the fundamental underlying symmetries of the Universe? Is there a Grand Unified Theory of the Universe? How do supernovae explode?

Studies of Neutrino Physics and Dark Matter are of high interest to particle and nuclear physicists, astrophysicists and cosmologists. Ongoing and proposed Neutrino and Dark Matter experiments are expected to unveil the answers to fundamental questions about the Universe. This year summer program was focused exactly on these subjects bringing together experts in dark matter, neutrino physics, particle physics, nuclear physics and astrophysics and cosmology.

CETUP*2015 consisted of 5 week long program (June 14 – July 18, 2015) covering various theoretical and experimental aspects in these research areas. The two week long session on Dark Matter physics (June 14 – June 26) was followed by two week long program on Neutrino physics (July 6 – July 18). The international conference entitled IXth International Conference on Interconnection Between Particle Physics and Cosmology (PPC) was hosted at CETUP* in the time between the Dark Matter and Neutrino workshops (June 29 – July 3) covering the subjects of dark matter, dark energy, neutrino physics, gravitational waves, collider physics and many others. PPC brought about 90 national and international participants. Started at Texas A&M University in 2007, PPC travelled to many places which include Geneva (Switzerland), Turin (Italy), Seoul (South Korea) and Leon (Mexico) over last few years.

The objectives of CETUP*2015 and PPC2015 were to analyze the connection between dark matter and particle physics models, discuss the connections among dark matter, grand unification models and recent neutrino results and predictions for possible experiments.

Dark Matter session brought together researchers across all fields of theoretical and experimental dark matter particle physics and astrophysics. During two week long session the scientists discussed new data from cosmological, astronomical, and particle physics probes, examined possible strategies for utilizing the entire wealth of data sets to elucidate the connection between dark matter and particle physics models, reviewed existing models for the nature of the dark matter particle, and discussed future search strategies for dark matter. The talks addressed major theoretical models, current experimental and astrophysical data and the upcoming experiments.

Neutrino Physics session was focused on one of the hottest areas in physics currently with a wealth of new experimental data available and forthcoming. Research in this area has a strong bearing on nuclear physics, particle physics, astrophysics and cosmology. CETUP* 2015 coordinated a very unique session on neutrino physics which consisted of two parallel programs with particle physics and nuclear physics/astrophysics emphasis: Session on Nuclear and neutrino physics inputs for astrophysical simulations of the formation of heavy elements and session on Neutrino physics in particle physics and astrophysics.

The subjects selected during both Neutrino Physics and Dark Matter sessions represented the forefront of research topics in particle and nuclear physics, for example: recent precise measurements of all the neutrino mixing angles (that necessitate a theoretical roadmap for future experiments) or understanding of the nature of dark matter (that allows us to comprehend the composition of the cosmos better). All the covered topics are considered as a base for new physics beyond the Standard Model of particle physics.

Five program objectives for CETUP2015 and PPC2015 were:

1. **Interconnection:** (i) Analyze the connection between dark matter and particle physics models and reevaluate strategies for searches of dark matter particles; (ii) Discuss the connections among dark matter, grand unification models and recent neutrino results and predictions for future experiments; (iii) Explore the connection between particle physics and models of baryogenesis and inflation.
2. **Understanding Neutrino Sector:** (i) Assess, study and compare models to understand the measured neutrino oscillation parameters, in particular the observed large values of the neutrino mixing angles; (ii) Develop a theoretical understanding towards testing the three-neutrino oscillation paradigm by over-constraining parameters; (iii) Identify strategies to measure remaining neutrino parameters, especially the CP-violating phase, mass hierarchy, and absolute values of neutrino masses;
3. **Neutrino Astrophysics:** (i) Identify best path forward to integrate experimental and theoretical advances in neutrino/nuclear data into astrophysical models; (ii) Understand the origin of very high energy astrophysics neutrinos, (iii) Determine crucial neutrino and nuclear inputs for simulations of heavy element synthesis; (iv) Quantify the impact of neutrino and nuclear data uncertainties on galactic chemical evolution predictions, (v) Understand supernova dynamics including collective neutrino oscillations.
4. **Exchange:** Provide a stimulating venue for exchange of scientific ideas among experts in dark matter, neutrino physics, particle physics, nuclear physics and astrophysics
5. **Outreach:** Connect with venues for public education outreach to communicate the importance of dark matter, neutrino research, and support of investment in science education

This year the CETUP* program combined with the PPC conference was attended by a truly international group of over 150 prominent physicists from around the world, including theorists and experimentalists. The physicists represented 23 different countries, 27 US states and 97 different universities, research laboratories and institutions – see below for details.

During the PPC conference 57 scientific talks during the plenary session, 2 summary talks and 20 talks during the parallel session were presented and now archived on the PPC website <http://research.dsu.edu/ppc/agenda.aspx> for worldwide research use. During CETUP* Dark Matter

session 30 scientific talks were presented and 10 extended discussions were led by experts in the Dark Matter field. During the Neutrino Physics sessions 35 talks and 14 discussions were conducted including both particle physics and astrophysics as well nuclear physics point of view - <http://research.dsu.edu/cetup/agenda.aspx>. Total 144 talks were given and 24 discussions lead by experts in the respective field were conducted during summer program 2015.

Organization

Time and location:

Five week long CETUP*2015 summer program took place on June 15 – July 17, 2015 in Lead/Deadwood, SD. The two week long session on Dark Matter physics was followed by two week long program on Neutrino Physics. The IXth International Conference on Interconnections between Particle Physics and Cosmology was hosted in the time between these two sessions covering from both theoretical and experimental aspects of dark matter, dark energy, direct and indirect detection, neutrino physics, collider physics and many others. The Neutrino session consisted of two parallel programs with particle physics and nuclear physics/astrophysics emphasis: session on Nuclear and neutrino physics inputs for astrophysical simulations of the formation of heavy elements, and session on Neutrino physics in particle physics and astrophysics.

The CETUP* attendees were provided by Deadwood-Lead Middle School with a spacious office space, access to the meeting rooms, break room, fax and copy machine, as well as high speed wireless internet connection. The PPC conference took place at the Lodge of Deadwood conference center.

Speakers/Talks:

CETUP*'s scientific program involved 3 to 4 one hour-long talks a day on the current status of dark matter and neutrino theory and experiments. The talks were followed by questions and discussion sessions. The format of this program accommodated separate discussion sessions where the outstanding issues of the disciplines were explored. The selected speakers were very active senior and junior members of the community in order to make the discussions informative and productive. During the PPC conference experts from theory and experiment community gathered together to cover topics related to Dark Matter, Direct and Indirect Detection, Dark Energy, Neutrino Masses and Oscillations, Inflation, Baryogenesis, Large Scale Structure, Higgs Boson Physics, Collider Physics and many others. The list of speakers and talks given during CETUP*2015 is available at <http://research.dsu.edu/cetup/2015.aspx>. Talks given during PPC conference are available at <http://research.dsu.edu/ppc/agenda.aspx>.

CETUP* 2015 Organizing Committee:

Rouzbeh Allahverdi – University of New Mexico, Albuquerque, NM

Baha Balantekin – University of Wisconsin, Madison, WI

Babu Kaladi – Oklahoma University, Stillwater, OK

Jason Kumar – University of Hawaii, Honolulu, HI

Farinaldo Queiroz – University of California, Santa Cruz, CA

Louie Strigari - Texas A&M University, College Station, TX
Rebecca Surman – University of Notre Dame, Notre Dame, IN
Barbara Szczerbinska – Dakota State University, Madison, SD

PPC 2015 Local Organizing Committee:

Barbara Szczerbinska – Dakota State University, Madison, SD
Kaladi Babu – Oklahoma State University, Stillwater, OK
Rouzbeh Allahverdi – University of New Mexico, Albuquerque, NM
Bhaskar Dutta - Texas A&M University, College Station, TX
Teruki Kamon - Texas A&M University, College Station, TX

PPC 2015 International Program Advisory Committee:

Ben Allanach (Cambridge)
Vernon Barger (Wisconsin)
V.A. Bednyakov (JINR)
Wim de Boer (Karlsruhe)
Tiziano Camporesi (CERN)
Dave Charlton(CERN)
David Cline (UCLA)
Johnathan Ellis (CERN)
JoAnne Hewett (SLAC)
Ian Hinchliffe (LBL)
Gordon Kane (Michigan)
Dmitri I. Kazakov (JINR, Dubna)
Robert Kirshner (Harvard)
Tomio Kobayashi (Tokyo)
Pran Nath (NEU)
Mihoko Nojiri (KEK)
Frank Paige (BNL)
Saul Perlmutter (LBNL)
Michael Peskin (SLAC)
Adam Riess (Johns Hopkins)
Graham Ross (Oxford)
Miguel Sabido (U. Guanajuato)
Paul Shapiro (UT Austin)
Melvyn Shochet (Chicago)
George F. Smoot (UC Berkeley)
David Spergel (Princeton)
Paris Sphicas (CERN & Athens U.)
S.C.C. Ting (MIT)
Steven Weinberg (UT Austin)

Financial support:

Supporting organizations:

- Black Hills Vision
- City of Deadwood
- Dakota Sciences
- Dakota State University
- Department of Energy
- John T. Vucurevich Foundation
- Lead-Deadwood School District
- Lodge of Deadwood
- National Science Foundation
- South Dakota Board of Regents
- South Dakota Science and Technology Authority

The support provided by DOE was used to cover lodging for graduate students and postdocs: Asher Berlin (University of Chicago - grad student), Tatha Ghosh (TAMU - grad student), Bibhushan Shakya (University of Michigan - postdoc), Wei Xue (MIT - postdoc), Jiang-Hao Yu (Texas University - postdoc), Sean Fraser (UC Riverside - grad student), Saki Khan (Oklahoma State University - grad student), Jiajun Liao (University of Hawaii - postdoc), Matt Mumtower (University of Notre Dame - postdoc), Farheen Naqvi (NSCL - postdoc), Stylianos Nikas (Central Michigan University - grad student), Shaikh Saad (Oklahoma State University - grad student), Vasja Susic (IPT - grad student), Warren Wright (Penn State University - grad student), Yue Zhang (Caltech - postdoc)

Education and Outreach

Attendees of CETUP* participated in educational outreach programs conducted during the five week time period:

- On June 19th the participants of Dark Matter session met with 10 students participating in Davis-Bahcall summer program (high school graduates and college freshmen). The students discussed different aspects of Dark Matter physics, different career paths available for students interested in science and mathematics. The scientists share their personal stories on selecting physics as a career path as well as provided students with multiple advises on how to be successful in college. This more than hour long overview of neutrino knowledge ended with very rich Q&A session.
- On June 21th five participants of Dark Matter session met with 32 Native American students participating in the summer program organized by the Indian University of North America at Crazy Horse Monument. The talk given by Brooks Thomas from Reed College on Dark Matter detection was followed by extended Q&A session during which scientists discussed the cutting edge subjects discussed during CETUP*, what it takes to be a scientist, different STEM carrier paths. The discussion between students and scientists was continued during the informal lunch.
- During the Neutrino Physics session (July 8th) the scientists met with the students and teachers attending QuarkNet program for Q&A session that followed a talk by Baha Balantekin from the University of Wisconsin – Madison

- Neutrino Day – July 11th – scientists attending Neutrino Physics session participated in different activities, talks and interacted with general public attending the Neutrino day event at Sanford Lab
- On July 15th scientists from the Neutrino Physics program will accompany Dr. Rebecca Surman from Notre Dame University at Black Hills State University where Rebecca will give an open to the public talk on *Astrophysical alchemy: creating the heaviest elements in the galaxy's biggest explosions*”. The talk was followed by Q&A session with CETUP* physicists on neutrino physics.

Summary

Summer programs at CETUP*2015 combined with the PPC conference was attended by a truly international group of over 150 prominent physicists from around the world, including theorists and experimentalists. The physicists represented 23 different countries and 97 different universities, research laboratories and institutions – see below for details. Among US based scientists there were 27 different US states represented (Arizona, California, Florida, Hawaii, Illinois, Indiana, Kansas, Massachusetts, Maryland, Michigan, Minnesota, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Wisconsin).

During the PPC conference 57 scientific talks during the plenary session, 2 summary talks and 20 talks during the parallel session were presented and now archived on the PPC website <http://research.dsu.edu/ppc/agenda.aspx> for worldwide research use.

During CETUP* Dark Matter session 30 scientific talks were presented and 10 extended discussions were led by experts in the Dark Matter field. During the Neutrino Physics sessions 35 talks and 14 discussions were conducted including both particle physics and astrophysics as well nuclear physics point of view - <http://research.dsu.edu/cetup/agenda.aspx>.

Total 144 talks were given and 24 discussions lead by experts in the respective field were conducted during summer program 2015.

During CETUP* 2015 28 preprints were already published based on the collaborations established during CETUP* (June 15, 2015 – January 20, 2016). The list of authors and titles is included in Appendix A. More detailed information including an abstract is included on the CETUP* website - <http://research.dsu.edu/cetup/preprints.aspx?cetupYear=2015>.

The proceedings from CETUP*2015 and PPC2015 are in preparation and will be submitted for publication to American Institute of Physics.

CETUP*2015 PRODUCTS:

CETUP* 2015 – list of preprints submitted (June 15, 2015 – January 20, 2016)

1. Incoherent Pion Production in Neutrino - Deuteron Reactions, Jia-Jun Wu, T. Sato and T.-S. H. Lee - CETUP2015-001
2. Pion Production in High-Energy Neutrino Reactions with Nuclei, Ulrich Mosel - CETUP2015-002
3. Dirac-Fermionic Dark Matter in $U(1)_X$ Models, Alexandre Alves, Asher Berlin, Stefano Profumo, Farinaldo S. Queiroz - CETUP2015-004
4. Distinguishing LSP archetypes via gluino pair production at LHC13, Baris Altunkaynak, Howard Baer, Vernon Barger and Peisi Huang - CETUP2015-005
5. Distinguishing Neutrino Mass Hierarchies using Dark Matter Annihilation Signals at IceCube, Rouzbeh Allahverdi, Bhaskar Dutta, Dilip Kumar Ghosh, Bradley Knockel, Ipsita Saha - CETUP2015-006
6. G221 Interpretations on the Diboson and W Excesses, Yu Gao, Tathagata Ghosh, Kuver Sinha, Jiang-Hao Yu - CETUP2015-007
7. Electro-Weak Dark Matter: non-perturbative effect confronting indirect detections, Eung Jin Chun, Jong-Chul Park - CETUP2015-008
8. PeV Neutrinos and a 3.5 keV X-Ray Line from a PeV Scale Supersymmetric Neutrino Sector, Samuel B. Roland, Bibhushan Shakya, James D. Wells - CETUP2015-009
9. Distinguishing Standard Model Extensions using Monotop Chirality at the LHC, Rouzbeh Allahverdi, Mykhailo Dalchenko, Bhaskar Dutta, Yu Gao, Teruki Kamon - CETUP2015-011
10. Enhancement of new physics signal sensitivity with mistagged charm quarks, Doojin Kim and Myeonghun Park - CETUP2015-012
11. ATLAS Diboson Excesses Demystified in Effective Field Theory Approach, Doojin Kim, Kyoungchul Kong, Hyun Min Lee, and Seongchan Park - CETUP2015-013
12. A Minimal Non-Supersymmetric SO(10) Model: Gauge coupling unification, Proton decay and Fermion masses, K. S. Babu, S. Khan - CETUP2015-014
13. Energy peak: back to the Galactic Center GeV gamma-ray excess, Doojin Kim and Jong-Chul Park - CETUP2015-015
14. Searches for Dark Matter at the LHC: A Multivariate Analysis in the Mono- Z Channel, Alexandre Alves, Kuver Sinha - CETUP2015-016
15. Vector Dark Matter at the LHC, Jason Kumar, Danny Marfatia and David Yaylali - CETUP2015-017
16. Dark Matter and Global Symmetries, Yann Mambrini, Stefano Profumo, Farinaldo S. Queiroz - CETUP2015-018
17. An alternative interpretation for cosmic ray peaks, Doojin Kim and Jong-Chul Park - CETUP2015-019
18. Dark Matter Searches for Monoenergetic Neutrinos Arising from Stopped Meson Decay in the Sun, Carsten Rott, Seongjin In, Jason Kumar and David Yaylali - CETUP2015-020
19. Beyond the CMSSM without an Accelerator: Proton Decay and Direct Dark Matter Detection, John Ellis, Jason L. Evans, Feng Luo, Natsumi Nagata, Keith A. Olive, and Pearl Sandick - CETUP2015-021
20. Stringent Dilepton Bounds on Left-Right Models using LHC data, Sudhanwa Patra, Farinaldo S. Queiroz, Werner Rodejohann - CETUP2015-022

21. Dark Matter Complementarity and the Z' Portal, Alexandre Alves, Asher Berlin, Stefano Profumo, Farinaldo S. Queiroz - CETUP2015-023
22. Interpreting the CMS l+l-jjE/T Excess with a Leptoquark Model, Ben Allanach, Alexandre Alves, Farinaldo S. Queiroz, Kuver Sinha, Alessandro Strumia - CETUP2015-024
23. New Limits on the Dark Matter Lifetime from Dwarf Spheroidal Galaxies using Fermi-LAT, Matthew G. Baring, Tathagata Ghosh, Farinaldo S. Queiroz, Kuver Sinha - CETUP2015-025
24. Disambiguating Seesaw Models using Invariant Mass Variables at Hadron Colliders, Bhupal Dev, Doojin Kim and Rabindra Mohapatra - CETUP2015-026
25. The CTA aims at the Inert Doublet Model, Farinaldo S. Queiroz, Carlos E. Yaguna - CETUP2015-027
26. Z^{\prime} models for the LHCb and $g-2$ muon anomalies, Ben Allanach, Farinaldo S. Queiroz, Alessandro Strumia, Sichun Sun - CETUP2015-028
27. Randomness in the Dark Sector: Emergent Mass Spectra and Dynamical Dark-Matter Ensembles, Keith R. Dienes, Jacob Fennick, Jason Kumar and Brooks Thomas – CETUP2015-029
28. The impact of baryons on the direct detection of dark matter, Chris Kelso, Christopher Savage, Monica Valluri, Katherine Freese, Gregory S. Stinson, Jeremy Bailin – CETUP2015 – 030
29. Neutrino-Nucleus Interactions at the LBNF Near Detector – Ulrich Mosel (arxiv: 1501.03160)

CETUP*2015/PPC2015 conference proceedings are in preparation to be published by American Institute of Physics

CETUP* 2015 and PPC 2015 PARTICIPANTS:

Dark Matter session: June 14 – June 26, 2015

Rouzbeh Allahverdi	University of New Mexico	USA
Howard Baer	University of Oklahoma	USA
Asher Berlin	University of Chicago	USA
Joseph Bramante	University of Notre Dame	USA
Keith Dienes	University of Arizona/ NSF	USA
Bhaskar Dutta	Texas A&M University	USA
Yu Gao	University of Texas A&M	USA
Tathagata Ghosh	Texas A&M University	USA
Paulo Gondolo	University of Utah	USA
Fabio Iocco	ICTP-SAIFR & IFT-UNESP	Brazil
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Chris Kelso	University of North Florida	USA
Doojin Kim	University of Florida	USA

Pyungwon Ko	KIAS	South Korea
K.C. Kong	University of Kansas	USA
Jason Kumar	University of Hawaii	USA
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Tim Linden	University of Chicago	USA
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Simona Murgia	UC Irvine	USA
Jong-Chul Park	Sungkyunkwan University	South Korea
Seongchan Park	Sungkyunkwan University and Korean Institute for Advanced Study	South Korea
Carsten Rott	Sunghyunkwan University	South Korea
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Brooks Thomas	Reed College	USA
Yuhsin Tsai	UC Davis	USA
Mei-Yu Wang	Texas A&M University	USA
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Jianghao Yu	University of Texas at Austin	USA

Neutrino Physics session: July 6 – July 17, 2015

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Borut Bajc	J. Stefan Institute	Slovenia
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**IXth International Conference on Interconnections Between particle Physics and Cosmology,
June 29 – July 3, 2015**

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Pilar	Coloma	Fermilab	USA
Andre	de Gouvea	Northwestern University	USA
Pasquale	Di Bari	University of Southampton	United Kingdom
Keith	Dienes	University of Arizona / NSF	USA
Zelimir	Djurcic	Argonne National Laboratory	USA
Bhaskar	Dutta	Texas A&M University	USA
Lisa	Everett	University of Wisconsin-Madison	USA
Kacie	Fodness	Dakota State University	USA
Chee Sheng	Fong	University of Sao Paulo	Brazil
Raymond	Frey	University of Oregon	USA
Alexander	Friedland	SLAC National Accelerator Lab	USA
George	Fuller	University of California, San Diego	USA
Christopher	Grant	University of California, Davis	USA
José-Marie	Griffiths	Dakota State University	USA
Jan	Hamann	University of Sydney	Australia
Jaret	Heise	SURF	USA
Kurt	Hinterbichler	Perimeter Institute	Canada
Shunsaku	Horiuchi	Virginia Tech	USA
Felice	Iazzi	Politecnico di Torino	Italy
Fabio	Iocco	ICTP-SAIFR & IFT-UNESP	Brazil
Benjamin	Jones	Dakota State University	USA
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Pyungwon	Ko	KIAS	South Korea
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Jiaming	Zheng	University of Minnesota, Twin Cities	USA
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