THE OHIO STATE UNIVERSITY

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Annual Report

on

RESEARCH IN ELEMENTARY PARTICLE PHYSICS

prepared under Grant DE-FG02-91ER40690

for period January 1 to October 31, 1992

from

High Energy Physics Group
Department of Physics
The Ohio State University
Columbus, OH 43210

I. HISTORY OF TASK-A RESEARCH ACTIVITIES

The main research interests of the principal investigators of Task A have been the study of weak interaction processes and neutrino physics.

Throughout the late sixties and the early seventies, T.A. Romanowski performed a series of hyperon beta-decay experiments at the ZGS which measured the psudoscalar correlations of particles from the decays of polarized Λ's and Σ^-'s.

During the early seventies, T.Y. Ling was a member of the HPWF collaboration (FNAL-E1A and E310), one of the first neutrino experiments which detected the weak neutral current, observed charmed particle productions through dimuon events and performed early measurements of the proton structure functions with deep inelastic neutrino nucleon interactions.

Prior to joining this task in 1986, L.S. Durkin was involved in BNL-E734, a neutrino experiment which made measurements of the electroweak mixing angle with elastic scatterings of muon-neutrinos (and antineutrinos) on electrons and protons.

From 1978 to 1980, Ling and Romanowski engaged in an experiment at Fermilab (FNAL-E613) to measure the rate and study the properties of prompt neutrinos, neutrinos from the decays of short-lived particles (primarily charmed-mesons and baryons) produced by proton interactions in a beam dump. This experiment measured the inclusive cross section and its A dependence of charmed particle production.

In 1981, Ling and Romanowski jointly initiated an experiment at LAMPF (E645) to search for neutrino oscillations. E645 was officially approved in 1984. The OSU group led the design, construction and operation of this experiment. Data taking took place during three 5-months long running periods from 1987 to 1989. Data analysis, initially led by Durkin shortly after he joined this task, is now being completed. No evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations is observed. Ninety percent confidence level contour ($\delta m^2 < 0.1 eV^2$ for maximum mixing and $sin^2(2\theta) < 1.4 \times 10^{-2}$ for large δm^2) is established.

Motivated by our interest to pursue deep inelastic lepton hadron interactions at higher energy and momentum transfer, this task joined the ZEUS collaboration in 1985. The ZEUS project has been the central focus of our research effort since 1988. Apart from making major technical contributions to the construction of the barrel calorimeter and to the ZEUS trigger system (discussed in detail in the following report), OSU also played a leadership role in the U.S. ZEUS group. T.Y. Ling served as the spokesman for the U.S. group in 1989 and 1990, a period during which the construction phase of the barrel calorimeters began and critical issues in the management and funding of the project had to be confronted.

This task aims to play a significant role in the analysis and the extraction of physics from the ZEUS data. We are anxiously awaiting the turn-on of HERA and we hope to do exciting physics in the coming years.

II. PROGRESS REPORT ON the ZEUS EXPERIMENT

II.1. Introduction

ZEUS is an experiment to study high energy electron-proton collisions at HERA, a new storage ring under construction at DESY in Hamburg, Germany. This ring will generate stable collisions between 30 GeV electrons and 820 GeV protons by late summer of 1992.

The ZEUS collabration consists of physicists from 50 institutions in 10 different countries (CANADA, GERMANY, ISRAEL, ITALY, JAPAN, POLAND, HOLLAND, SPAIN, U.K. and U.S.A.) Ohio State is one of 8 U.S. institutions (OHIO STATE UNIVERSITY, ARGONNE NATIONAL LABORATORY, COLUMBIA UNIVERSITY, UNIVERSITY OF IOWA, LOUISIANA STATE UNIVERSITY, PENN STATE UNIVERSITY, UNIVERSITY OF WISCONSIN, VPI) involved in this collaboration. The Task-A personnel consists of three faculty members (L.S. Durkin, T.Y. Ling and T.A. Romanowski), 3 post doctoral research associates (B. Bylsma, K. McLean, W.N. Murray), two graduate students (R. Seidlein and C.G. Li) and 1 technician(P. Lennous).

With center of mass energy ten times greater and momentum transfer 100 times greater than any previous lepton-hadron experiment, ZEUS provides an excellent opportunity to test, and search for new physics beyond, the *Standard Model.* Neutral current and charged current interactions can be studied with Q^2 up to 40,000 GeV^2. Precise structure function measurements will probe for substructure of the quarks and leptons down to distances of 3×10^{-18} cm. The Q^2 dependence of the Neutral and Charged current interactions allow propagator effects due to new Z's and W's beyond those of the *Standard Model* to be detected up to mass scales of 800 GeV. The longitudinal polarization of the electron (expected to be 84 %) will yield information on the chiralities of the new vector bosons. HERA may also prove to be a rich source of new particles. Searches for leptoquarks, heavy leptons, excited leptons and quarks and SUSY particles (squarks and sleptons) can be carried out to masses of 250 GeV.

II.2. Status of HERA

The installation of the HERA electron ring, consisting of normal conducting magnets and RF cavities, was completed in 1988 and a 5 mA beam was stored and accelerated to 27 GeV in the summer of 1989. The installation of the superconducting proton ring was completed in October of 1990. Following a successful cool-down in December 1990, a proton beam was stored at 40 GeV in the HERA ring for the first time on April, 14 1991. First collisions were established in early November last year between 26 GeV/c electrons and 480 GeV/c protons. By the end of last November HERA was successfully operating in the multibunch mode. With 10 bunches on 10 bunches, a luminosity of $3 \times 10^{28} cm^{-2} s^{-1}$ has been achieved.

The HERA accelerator work was halted in December to allow the moving of the two detectors into their interaction regions. Accelerator work resumed in April this year. On June 13,1992 the multibunch collisions have been reestablished. Ten bunches of 26 GeV/c electrons were collided with ten bunches of 820 GeV protons resulting in a luminosity of $\approx 1.0 \times 10^{29} cm^{-2}s^{-1}$. With this beam ZEUS recorded it's first few physics events (see below).

First polarization studies of the HERA electron beam have proven to be very encouraging. Although polarization has been shown to be very sensitive to both ZEUS and H1 solenoid fields, polarizations of 20 % have been measured.

The electronics for beam control is presently being upgraded. With the new electronics in place, collisions of the designed 220 bunches/species should be available by fall of 1992. With this improvement the design luminosity of $1.5 \times 10^{31} cm^{-1}s^{-1}$ should be reached allowing ZEUS physics analysis to begin in earnest.

II.3. Status of the ZEUS Detector

The ZEUS detector is designed and constructed by an international collaboration of physicists from more than 50 institutions in ten different countries. The layout of the ZEUS detector is shown in Figures 1 and 2.

The inner detector consists of a charged particle spectrometer, and a transition radiation detector (TRD). A solenoid coil with a 2 Tesla magnetic field encloses an axial central tracking device (CTD), and planar forward and backward drift chambers (FTD and RTD). The CTD is a stereo superlayer chamber using 9 superlayers each with 8 sense layers. The cells within each superlayer are rotated 45^o with respect to the radial direction for resolving left-right ambiguities and for rejecting out of time tracks.

Surrounding the inner detector is the high resolution calorimeter. It consists of forward (FCAL), rear (RCAL), and barrel (BCAL) parts and the electromagnetic and hadronic calorimeters are integrated into the same design. The foremost consideration in designing the high resolution calorimeter is to achieve the best energy resolution for both hadronic and electromagnetic showers. Thin depleted uranium plates (3 mm) are used as absorbers and solid polystyrene scintillators are adopted as the readout medium. The depth of the calorimeter are 7, 5, and 4 hadron absorption lengths each for the FCAL, BCAL, and RCAL respectively.

Outside the high resolution calorimeter is a backing calorimeter (FBAC, BBAC, RBAC) constructed with iron plates and proportional drift tubes. The backing calorimeter tags events which have shower debris leaking out of the high resolution calorimeter due to hadronic shower fluctuations. It also serves as a good muon identifier and as the return yoke of the central solenoid.

On the very outside of the detector is located the muon system (FMU, BMU, RMU). The forward muon system is equipped with a separate iron toroidal magnet.

Summarized here is the status of the important components of the ZEUS calorimeter as of June 1992.

- FCAL/BCAL/RCAL - Installed and working(BCAL is discussed in detail below).
- Backing Calorimeter - Installed and working.

- FMU/BMU/RMU - Installed and working.
- VXD - Installed and working.
- CTD - Chamber is physically installed. All R-phi readout electronics installed and working. Three of 7 superlayers Z readout electronics installed and working. The remaining electronics should be installed by December 1992.
- FTD/RTD - Both chambers have been wired. Mounting of preamps is ongoing. Detectors should be in place and working by December 1992.
- Luminosity Monitor - Installed and working.

This summary shows that the detector is almost completed. There are clearly enough components available to fully analyse the first HERA collisions, although the full power of the ZEUS detector will not be realized until December 1992.

II.4. OHIO STATE Contributions to ZEUS

The Barrel Calorimeter

This task, in collaboration with the other U.S. institutions on ZEUS, took on the major responsibility of constructing and instrumenting the high resolution barrel calorimeter (BCAL). As of May 1, 1991 the construction of all 32 modules has been completed.

Ohio State contributions to this effort include:

1. Design and construct the optical readout for the barrel calorimeter. This responsibility includes
   - R/D work for laser cutting of scintillator tiles and wavelength shifters.
   - R/D work for achieving optical uniformity and maximum light yield.
   - Production and optical mapping of all scintillator tiles.
   - Production and optical mapping of all HAC wavelength shifter-light guides.
   - Generation of reflection masks for every HAC tower for the removal of optical nonuniformities.
2. Design, construction and operation of a Co-60 source scanner to monitor the barrel calorimeter response.
3. Construction of a TRD system for electron identification for the the Fermilab test beam.
4. Participation in the beam test and calibration of BCAL modules at Fermilab.
5. Participation in module check out at Argonne and DESY.

6. Supervision of module construction at Jülich, Germany.

The quality of the barrel calorimeter has been proven during the last year using FNAL test beam results. The barrel calorimeter has the designed resolution of $\frac{17\%}{\sqrt{E}}$, and $\frac{35\%}{\sqrt{E}}$ for hadrons. This resolution is in no small part due to our OSU groups care in designing and building the optical components for this calorimeter. Additionally the calorimeter's response to hadrons:electrons has been shown to be compensated 1:1. The calorimeter is in the detector, and has been operating as design for over six months. Physics should confirm this choice of compensating uranium calorimetry.

FAST CLEAR for the ZEUS Trigger System

The other major commitment which this task has undertaken is the design and construction of the Fast Clear for the ZEUS trigger system.

At the HERA design luminosity of $1.5 \times 10^{31} cm^{-2} s^{-1}$, deep inelastic neutral-current and charged current events are expected to occur with a rate of a few Hz. The dominant background for triggering is expected to be caused by beam gas interactions. For a beampipe vacuum of 3×10^{-9} torr, conservative estimates give rates of $\approx$ 400 kHz for this processes, a significant fraction of these will generate activities in the ZEUS detector.

In order to reduce the final trigger rate to the acceptable tape writing rate of less than 10 Hz, the ZEUS trigger system has three levels. The first level is required to reduce the raw rate to 1 kHz, which is made very difficult by high crossing rate (96 ns per crossing) of HERA. Since the typical time for reaching a trigger decision is 5 μs, dead-time consideration forces the first level trigger to be pipelined: every step in the decision making process for a event must be done in less than 96 ns.

The OSU Fast Clear (FC) processor is designed to ensure that the effective first level trigger rate is $\leq$ 1 kHz. This device uses a grid clustering algorithm to associate energy with a particular jet or electron. It is designed to accept events from the first level trigger at a rate of 1-10 kHz. The result of the processor is then used to abort a first level trigger if it decides that the trigger is a clear beam gas interaction. Speed of processing is a primary requirement. The FC system designed at OSU can process and reject a typical beam gas trigger in $\approx 10\mu sec$. This is much faster the one millisecond allowed for the second level trigger decision.

The FAST CLEAR system serves the entire ZEUS calorimeter. This system contains seven separate pc board designs, with a total of 160 boards making up the final system. Work on the FAST CLEAR nears completion. We installed a major portion of the system at ZEUS in November 1991. A completed system is now working successfully at Ohio State. The only holdup in installation is waiting for an interface card being built at Wisconsin to interface the FAST CLEAR with the first level calorimeter trigger. Final installation of the FAST CLEAR should take place in June.

II.5. Analysis of ZEUS Data

In anticipation of the first physics collisions in ZEUS, we have been increasing our analysis capabilities at Ohio State and DESY. One of our research associates (Ken McLean) effectively manages the AMZEUS DEC5000 cluster at DESY. In addition, we have procured and installed four DEC5000 Workstations into the AMZEUS cluster to be used by OSU physicists who are in residence at DESY(Currently two research associates and two students). At Ohio State we have completed the installation of a cpu farm consisting of 24 DEC5000 computers. Software have been developed which allows the ZEUS Geant based Monte Carlo (MOZART) and the ZEUS offline reconstruction program (ZEPHYR) to run on twenty three of these workstation clients streaming the data output to a single tape. Additionally the ZEUS offline analysis has been run on this farm. We are presently using this computer farm to sift through data tapes to select out the first physics interactions from HERA. In the future we plan to use this computing power to both speed up offline analysis as well as Monte Carlo generation when large amounts of ZEUS data become available.

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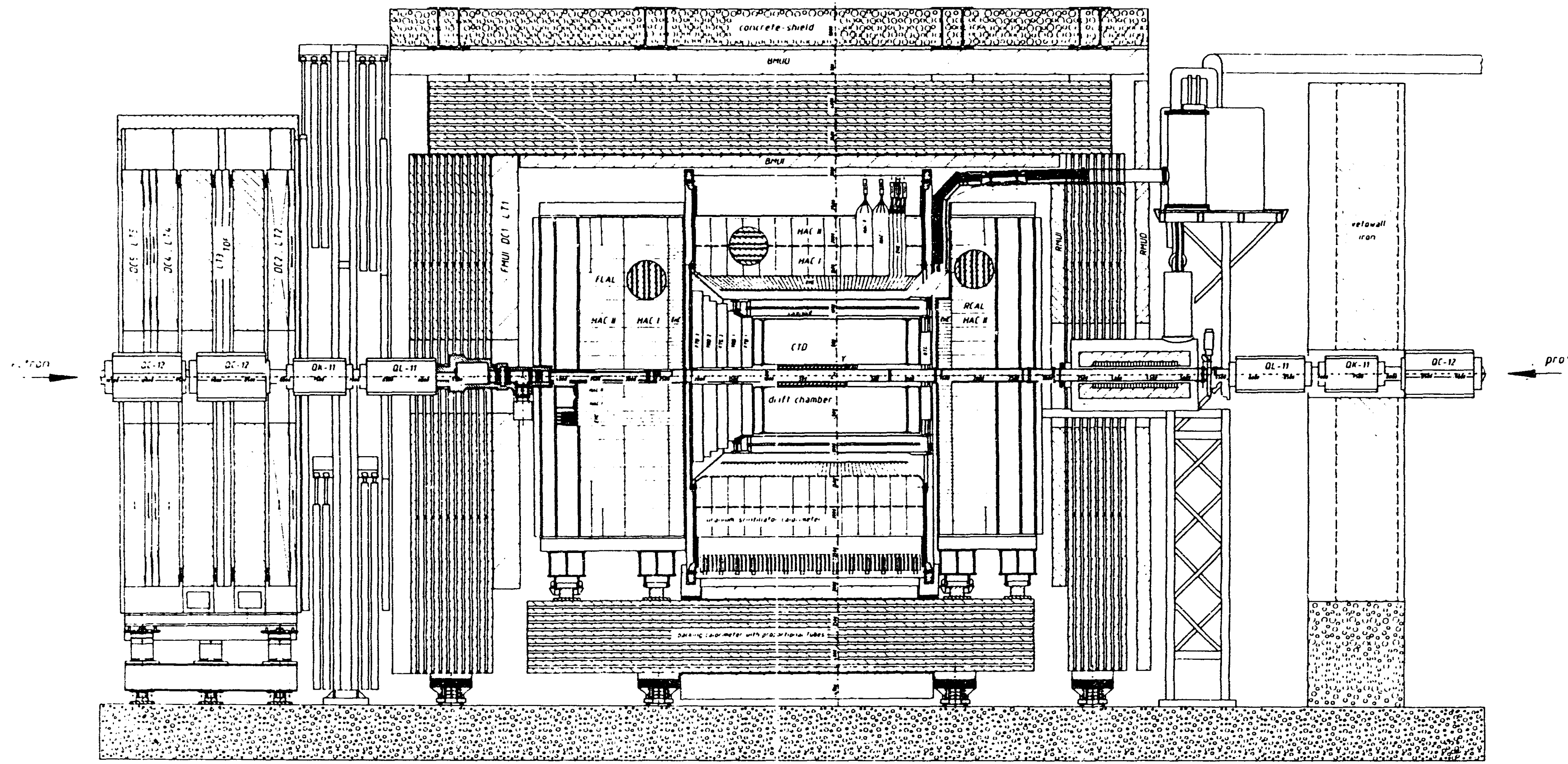

Figure 1
Side view of the ZEUS detector

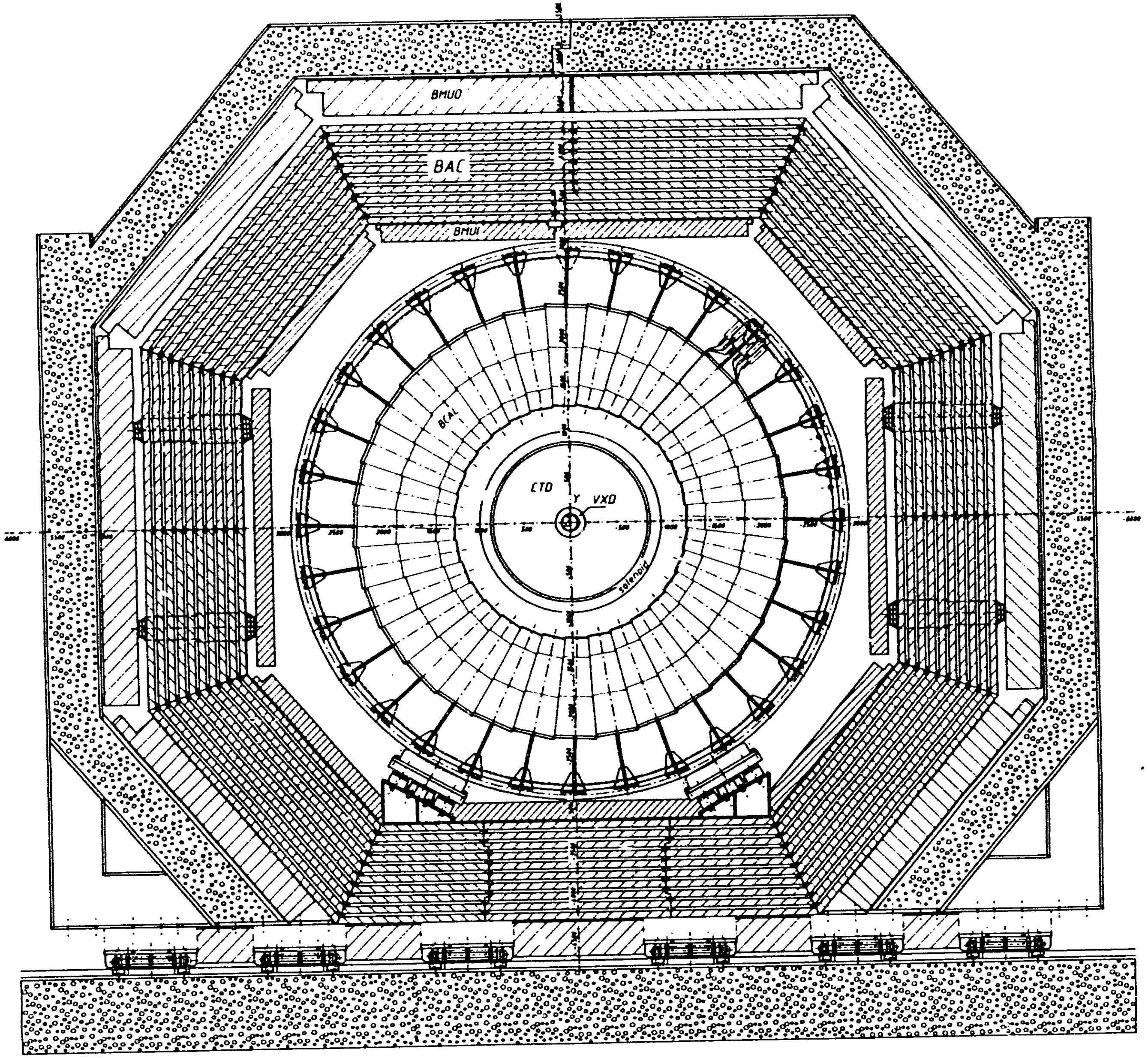

Figure 2
Front View of the ZEUS detector

Progress Report

High Energy Theory

Task B and Task L

INTRODUCTION

The High Energy Theory group at The Ohio State University consists of seven faculty members: G. Kilcup, W. Palmer, S. Pinsky, S. Raby, J. Shigemitsu, K. Tanaka and K. Wilson. We have five post-doctoral research associates, three supported on the DOE grant and two supported with University funds. The post-docs are: G. Anderson, K. Hornbostel, S. Peris, J. Sloan and B. Thacker. We now have two students who have passed their general exams and are working towards their Ph.D. degrees under the supervision of S. Pinsky. Finally, Vladimir Miransky is a visiting professor for the academic year. Two of our post-docs will be leaving. K. Hornbostel has accepted a faculty position at Southern Methodist University in Dallas and he will leave on January 1, 1993. S. Peris has accepted a faculty position at the Universitat Autonoma de Barcelona, Barcelone, Spain and he will leave in September. Beth Thacker, who is funded by the University, has become interested in pursuing a career in physics education research. She is presently spending most of her time in this endeavor with the Discovery Project of Wilson. A new post-doc, Josep Taron, CNRS, Marseille, will arrive in the fall. We plan on hiring a fourth post-doc on the grant next year.

In connection with the light-cone QCD program, we are supporting two long term junior visitors, Stan Glazek and Alex Landau. Stan Glazek is an assistant professor at Warsaw University and will be spending two months at OSU this summer. Alex Landau recently finished his degree at SLAC under the direction of Stan Brodsky and is spending five months at OSU; we are sharing this cost with the nuclear theory group. In addition we are covering all the administrative costs associated with the Light-Cone QCD Workhop that will be held in Telluride, Colorado, August 16–30. We are also providing some direct support to junior people who would not otherwise be able to attend the workshop. Savas Dimopoulos has visited several times in the past year for extended periods. We expect that he will continue to visit next year. Steven Sharpe and Apoorva Patel will be visiting for several weeks this spring. We expect them to visit next year as well. Finally, Manny Paschos, will visit the group next year for the entire fall quarter. He has been selected by the University as a Distinguished University Visiting Professor.

William F. Palmer

1. Overview

I am continuing and broadening my collaboration with G. Kramer at Hamburg on B-mesons physics as a probe of the Standard Model. I am currently on sabbatical leave and am spending approximately 50% of my time in Germany, partially supported by a NATO Collaborative Research Grant. We have recently been joined by T. Mannel (Darmstadt) and E. Paschos (Dortmund). Paschos will visit the Ohio State University for three months in Winter '93 on a Distinguished Visiting Professorship supported fully by The Ohio State University. Much of the conceptualization for this collaboration occurred in 1991 when Kramer was a visitor at Ohio State and I was a visitor in Germany.

With the advent of high statistics B physics, and the proposals of B-factories, much has recently been written on CP violating effects in B decays. Non-leptonic decays offer the best possibility to observing CP violation in the standard model context, and there has been considerable work on this subject but for the most part investigations have concentrated on $B\bar{B}$ mixing as the CP-violating signal. An alternative route is to seek 'direct' CP asymmetries in the angular distributions involving CP-odd amplitudes but no complete analysis has been done. Our initial survey (reference [2]) indicates that these direct asymmetries can be quite reasonably large and will be observable in the next generation of B-meson experiments.

The objective of this collaborative study is to develop a definitive angular correlation analysis for decays of a pseudoscalar into two vectors and apply it to models for such decays. The models must not only estimate the effects of the effective underlying QCD interaction (for example, $b \rightarrow c\bar{c}s$) but also the dynamics associated with quark rearrangements and final state interactions. The analysis should be useful to experimenters seeking the best signals for CP violation in this system and should also contribute to the body of theory concerned with building reliable models for the hadronic matrix elements.

The collaborators are carrying through a detailed analysis of angular correlations and CP-violating signals in weak decays of B-mesons to two vector mesons, for example $B \rightarrow \psi K^*, B \rightarrow \rho K^*$, and $B \rightarrow \omega K^*$. The nonleptonic weak decays of B mesons are very interesting for several reasons. First, CP violation in the B-meson system will eventually give us information about the CP violating phase in the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. Second, nonleptonic weak decays will give additional clues for determining the absolute values of the quark mixing parameters. Last, the dynamics of the nonleptonic weak decays in the framework of the standard model is not yet well understood. One of the problems in calculating the transition amplitudes for nonleptonic weak decays is that one needs to evaluate the hadronic matrix elements of certain four-quark operators which can be done in QCD only with non-perturbative methods. To gain information on the $|V_{ub}/V_{cb}|$ ratio or on the CP violating phase from nonleptonic B decays further progress is required in computing the relevant hadronic matrix elements for these decays.

It is clear that a comprehensive approach to these decays is needed, spanning all channels and all decay parameters: partial decay rates, longitudinal and transverse rates, and the four CP even and CP odd angular coefficients. In the next subsection we review the strategy used in the first survey phase and report some of the conclusions of this study. In the second subsection we discuss our plans for the collaboration in the next year.

2. Progress Report

The usual route to calculating these hadronic matrix elements for B decays is to start from the effective, QCD corrected, Hamiltonian for the $\Delta b = 1$ nonleptonic decays in the six–quark model. The QCD coefficients were calculated by Ponce some years ago for values of the top quark mass and the W-boson mass that are quite different from current data, although the coefficients do not depend sensitively on these inputs. More significantly, this calculation has a numerical error which over estimates the effects of the QCD corrections in c_1 and c_2. We have repeated the calculation (reference [4]) and find the results in substantial agreement with the single case reported by Grinstein and by Buras et al.

Initially we applied this framework for calculating nonleptonic $\bar{B}^o$ and B^- decays into two vector mesons, following earlier work of various authors in particular Bauer, Stech and Wirbel who used current matrix elements obtained from relativistic oscillator wave functions at infinite momentum. In addition to partial decay rates, we calculated the full angular distribution, that is the combined angular correlations of the decay products of V_1 and V_2 as well as the influence of the CP decay amplitude phases on the missing phase. These angular correlations serve as further tests of the combined short distance weak effective Hamiltonian factorization approach together with the BSW current matrix elements. In addition we looked at asymmetries which occur in the decay of the B into two vector mesons which in the absence of unitary phases are signals of CP violation in the b sector. These CP-odd asymmetries can originate only through interference of at least two amplitudes contributing to the same process with different phases coming either from genuine CP violating effects in the CKM matrix or from unitary phases from hadron dynamics. To generate the CP violating effects, in the absence of unitarity phases, we need the full effective weak Hamiltonian including QCD renormalization effects when flavor symmetry breaking (FSB) is considered. The effect of penguins bring in CP phases that allow 'direct' CP effects which occur in both charged and neutral B Decays. The results of this calculation were reported in reference [2].

A different signature for CP violation is obtained when one considers neutral B mesons only. Then it is possible to generate interference via mixing by looking at final states that can occur from B^0 and $\bar{B}^0$ decays. The results of this calculation were also reported in reference [2].

This model can not fit the data on $B \rightarrow K^*\psi$ polarization. In the BSW form factor model, the $K^*\psi$ transverse polarization is relatively high because, while the positive helicity amplitude is small, the negative helicity amplitude is comparable in size to the longitudinal amplitude. These results test the form factor assumptions. Data from ARGUS on the exclusive decay $B \rightarrow K^* + \psi$ indicate that the best fit to angular distributions is $\Gamma_T/\Gamma = 0$ with a confidence level of 95% that this ratio is less than 0.22, whereas the BSW models predict a ratio of 0.43. This prediction depends heavily on the current matrix elements and the factorization assumption but not on the QCD coefficients. The only way to accommodate this result within the factorization approximation is for the second (d-wave) axial vector current form factor to dominate over the first axial vector form factor (s-wave) and the vector form factor. This is in conflict with all quark models including those based on heavy quark symmetries as well as with experiments on corresponding form factors in semileptonic D decays and would indicate failure of the vacuum saturations assumptions or very significant additional contributions from annihilation terms. These results were reported in reference [3].

3. Technical Proposal

In the coming phase of the collaboration, the effort will focus on: (1) an improved or more controlled approach to taking matrix elements of the effective Hamiltonian, (2) improved models for the current matrix elements, (3) an estimate of final state interaction phases, (4) application of these methods to B_s decays.

3.1 Matrix Elements of the Effective Hamiltonian

When taking matrix elements of the effective Hamiltonian one encounters the hadronization problem and there are no easy answers. In the first phase, it was assumed that the amplitudes factorized into hadronic matrix elements of bilinear QCD operators and that OZI forbidden and annihilation terms could be neglected. There is support for these assumptions in $\frac{1}{N}$ analyses with some corroboration from experimental tests. In the second phase we will seek further tests of the factorization hypothesis and attempt to estimate upper limits on the annihilations terms.

There is a related problem in taking hadron matrix elements concerning the color factors which arise in connection with the Fierz reordering. It has been advocated within the framework of the factorization approach that a better approximation is achieved if the reordering color factors are dropped as in a $\frac{1}{N} = \infty$ theory. This seems to be the case for D meson nonleptonic decays. In the first phase survey this appeared also to be the case but the whole issue requires further study and can only be answered by a comprehensive picture of all B decays, nonleptonic and semileptonic, as argued below.

3.2 Models for the Current Matrix Elements

As experiments on polarization and angular correlations improve (e.g., $D \to K^*\rho$, $D \to K^*e\nu$, and $B \to K^*\psi$) there is more opportunity for real tests of models for current matrix elements. Are BSW wave functions reasonable models for these matrix elements? Can heavy quark theory improve these models? Fermilab experiments E691 and E653 are in mild disagreement here as are two lattice calculations The $B \to K^*\psi$ polarization, as earlier remarked can not be fit by the BSW wave functions. Our analysis of $D \to K^*\rho$ angular correlations also suggest that BSW form factors can not fit the data. Clearly much more phenomenological analysis must be done.

We have initiated a study using heavy quark symmetries to estimate applicable B meson rates with a view to improving the BSW form factors. First results of this study will shortly be reported but much phenomenological analysis remains to be done. We are also using experimental data on related rates, including semileptonic ones, together with heavy quark symmetries, to infer some of the current matrix elements needed for our study. Progress in weak interaction tests of the Standard Model relies crucially on knowledge of these hadronic matrix elements. Early results of this study are reported in reference [5].

We are using the results of Yan et al. combining heavy quark symmetries with Chiral Dynamics to calculate the electron spectrum from $B \to D, D + \pi, D^*, D^* + \pi$ final states.

3.3 Estimates of Final State Interaction Phases

Concerning final state interactions and strong phases, our philosophy in the first phase was to show how they could be incorporated if the phases could be calculated but then to present results as if there were no strong phases. While many interesting asymmetries can be unraveled even when there is no knowledge of the strong phases, it is very important to calculate or place limits on them if a comprehensive understanding is to be achieved. Attempts at this difficult calculation have been made along two approaches: (1) absorptive parts of penguin diagrams at the quark level and (2) K- matrix formalism. The first approach has the merits of relative economy of effort if only one can rely on the model as a reasonable estimate of the strong phase. The second approach is very laborious and has its own uncertainties but perhaps can be formulated to give reasonable limits. We are pursuing both approaches.

3.4 Application of these Methods to B_s Decays

As collider experiments yield the first indications of mixing in the $B_s\bar{B}_s$ system, it is timely to calculate CP signals, which could be quite different from the B_u and B_d systems. This work will proceed in parallel with the B_u and B_d effort, stressing (1) an improved model of the effective Hamiltonian, (2) an improved or more controlled approach to taking matrix elements of the effective Hamiltonian, (3) improved models for the current matrix elements, (4) an estimate of final state interaction phases, and (5) continued comprehensive comparison with experimental results as they emerge. Early results in this program are reported in reference [6].

Publications

[1] "Form Factor Analysis and Unitarity Effects in $D \to K^*\ell\nu$," Phys. Lett. B256, 271 (1991) (with G. Kramer, G. Kōpp and G. Schuler).

[2] "Branching Ratios and CP Asymmetries in the Decay $B \to VV$," Phys. Rev. D45, 193 (1992) (with G. Kramer).

[3] "Polarization and CP Asymmetries in the Decays $B \to K^*\psi$, $K^*\omega$, and $K^*\rho$," Phys. Lett. B279, 181 (1992) (with G. Kramer).

[4] "Direct CP Asymmetries in the Decays $B \to VV$ from an Effective Weak Hamiltonian," DESY Report 92-007, January 1992 (with G. Kramer).

[5] "Angular Correlations in the Decays $B \to VV$ using heavy quark Symmetry," DESY Report 92-042.

[6] "The Decay of Strange Bottom into Vector Mesons,"DESY Report 92-043, March 1992 (with G. Kramer).

[7] "Development of Diamond Radiation Detectors for the SSC and LHC," submitted to *Nuclear Instruments and Methods* (1991) (with K.K. Gan, H. Kagan, R. Kass, et al.).

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

"Summary and Concluding Remarks," in *Proceedings of the Diamond Detector Meeting*, The Ohio State University, September 10-11, 1991.

B. Invited Seminars/Colloquia presented

"Angular Correlations and CP Asymmetries in $B \to VV$," Cornell, May, 1991.

"Diamond Detectors for LHC and SSC," DESY, June, 1991.

"Angular Correlations and CP Asymmetries in $B \to VV$," University of Dortmund, June 4, 1992.

Stephen Pinsky

The last of my work on the delta expansion has recently been published [1]. Last year all my research activities have been related to the light-cone field theory project. After the initial work on perturbative QED, which focused on one loop renormalization and Ward identities [2,3], I started working in scattering in the light-cone Tamm-Dancoff approximation. I formulated Compton scattering [4] light-cone Tamm-Dancoff approximation [5] and found that the equations can be solved exactly. I found however that one can not write the scattering amplitude in a Lorentz covariant form and maintain renormalizability in the usual sense. I then turned to a study of relativistic bound states in the Yukawa model in 3+1 dimensions [6,7]. Truncating the Fock space basis at three particles we formulated Tamm-Dancoff integral equation for the wave functions and the masses of the bound states. The equation was found to have two types of divergences. One is a standard mass and wave function renormalization. This renormalization leads a singularity in the equation that relates the bare and renormalized couples and thus prevents one from taking the transverse momentum cutoff to infinity for a fixed renormalized coupling. The other infinity comes from the high transverse momentum behavior of the kernel and requires a new type of renormalization. Finally, I wrote a review paper with co-authors from the competing light-cone research groups spelling out the most important outstanding challenges in light-cone field theory [8].

Publications

[1] "Delta Expansion for Gauge Theory," with C.M. Bender, F. Cooper, M. Moshe, and L. M. Simmons Jr., Phys. Rev. D45, 1248 (1992).

[2] "Perturbative Renormalization of Null-Plan QED," with D. Mustaki, J. Shigemitsu, and K. G. Wilson, Phys. Rev. D43, 3411 (1991).

[3] "Null-Plane QED," Proceedings of the 4th conference of the Intersections between Particle and Nuclear Physics, Tucson, AZ, May 1991, World Scientific.

[4] "The Tamm-Dancoff Method in Gauge Field Theory," Proceedings of Division of Particles and Fields of the APS, Vancouver B.C., Canada, August 18-22, 1991 World Scientific (1991).

[5] "Compton Scattering in the Light-Cone Tamm-Dancoff Approximation," with D. Mustaki, Phys. Rev. D45, (1992).

[6] "Renormalization of Light-Cone Tamm-Dancoff Integral Equations," Proceedings of the 27th Recontre de Moriond, Les Arcs, France, March 22-28, 1992, Editions Frontieres edited by J. Tran Than Van.

[7] "On the Relativistic Bound State Problem in the Light-Front Yukawa Model," with S. Glazek, A. Harindranath, J. Shigemitsu, and K.G. Wilson, submitted to Phys. Rev. D.

[8] "The Challenge of Light-Cone Quantization of Gauge Field Theory," with S.J. Brodsky, G McCartor and H.C. Pauli, to be submitted to Particle World.

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

XXVIIth Recontres de Moriond, March 22–28, 1992 Les Arcs, France.

DPF of the APS Vancouver B.C., Canada, August 18–22, 1991.

1st Conference on Gauge Feild Theory on the Light-Cone, Heidelberg, June 24–28, 1991.

4th Conference on the Intersection between Particle and Nuclear Physics, Tucson, AZ, May 24–29, 1991.

B. Invited Seminars/Colloquia presented

SLAC, April 1992

Argonne National Laboratory, Oct. 1991

Aspen Center for Physics, Aug. 1991

Cornell University, May 1991

SSC National Laboratory, April 1991

Southern Methodist University, April 1991

Other activities

International Advisor Committee on Light-Cone QCD, 1991–present

Organizer, Light-Cone QCD workshop, Aspen Center for Physics, 1991

Organizer, Light-Cone QCD Workshop, Telluride, CO, Aug 16–30, 1992

Scientific Advisory Committee, Light-Cone QCD meeting, Southern Methodist University, May 26, 1992.

Stuart Raby

In the last year, I have been working on supersymmetric model building. Jim Cline and I showed that gravitino decays in the early universe could produce the net baryon number of the universe [1]. Since gravitinos decay just prior to the epoch of nucleosynthesis, it was necessary to re-do the nucleosynthesis calculations with the inclusion of baryogenesis occuring simultaneously. This was redone in paper [2]. We found a lower bound on the gravitino mass of 50 TeV. We also found that in the range of gravitino masses from 50-80 TeV, the effect on the light element abundances was to decrease the Helium abundance below that of the standard model. This result is in fact in better agreement with data. In [3] we reviewed the predictions of supersymmetric grand unified theories, in light of the recent evidence from LEP showing that the measured values of the strong and electroweak couplings agree with the predictions of a minimal supersymmetric GUT. In my most recent work [4,5], we have proposed a new ansatz for fermion mass matrices. With 7 parameters at the GUT scale we can fit the 13 parameters in the quark and lepton masses and mixing angles. We predict the top quark to have a mass of order 180 GeV. In reference [6] we discuss our results in the context of K and B meson physics. I expect to continue working on supersymmetric and technicolor model building in the future.

Publications

[1] "Gravitino Induced Baryogenesis," J. Cline and S. Raby, Phys. Rev. D43, 1781–1787 (1991).

[2] "Gravitino induced Baryogenesis, Primordial Nucleosynthesis, and the Tremaine-Gunn Limit," R.J. Scherrer, J. Cline, S. Raby, and D. Seckel, Phys. Rev. D44, 3760-3766 (1991).

[3] "Unification of Couplings," S. Dimopoulos, S. Raby, and F. Wilczek, Physics Today, 25–33, October (1991).

[4] "A Predictive Framework for Fermion Masses in Supersymmetric Theories," S. Dimopoulos, L.J. Hall, and S. Raby, Phys. Rev. Lett. (1992).

[5] "A Predictive Ansatz for Fermion Mass Matrices in Supersymmetric Grand Unified Theories," S. Dimopoulos, L.J. Hall, and S. Raby, OSU Preprint DOE-ER-01545-567, accepted for publication in Phys. Rev. D (1992).

[6] "Predictions for Neutral K and B Meson Physics," S. Dimopoulos, L.J. Hall, and S. Raby, OSU Preprint OHSTPY-HEP-T-92-003, submitted for publication in Phys. Rev. Lett. (1992).

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

"Gravitino induced Baryogenesis" and "Baryon Number Violation at High T in the Electroweak Theory," Workshop on Electroweak Interactions, Institute for Advanced Study, Princeton, May 1991; Aspen Winter Workshop, January 1992.

"A Predictive Ansatz for Fermion Masses in Supersymmetric GUTs," XXVIIth Rencontres De Moriond, Electroweak Interactions and Unified Theories, March 1992.

B. Invited Seminars/Colloquia presented

"Gravitino induced Baryogenesis," University of Miami seminar, February, 1991; UC Berkeley seminar, February 1991; University of Florida seminar, Gainesville, March 1991.

"Supersymmetry and Grand Unification in the 90s," MIT colloquium, September 1991; UT Arlington colloquium, April 1992.

"A Predictive Ansatz for Fermion Masses in Supersymmetric GUTs," Rutgers seminar, October 1991; UT Austin seminar, January 1992; University of Michigan seminar, February 1992; Los Alamos National Lab, T-8 seminar, April 1992.

"A New Paradigm for Technicolor Model Building," Yale seminar, November 1991; Joint Harvard, MIT, Boston University seminar at BU, November 1991.

"Super-Unification of Force Laws and Matter," talk presented to the Society of Physics Students, University of Rochester, May 1992.

Junko Shigemitsu

Lattice Studies of Yukawa Models

During the past year I have continued working with Sinya Aoki and John Sloan on lattice Yukawa models. This is part of a long term project to understand better couplings, such as the $\lambda\phi^4$ coupling, Yukawa couplings between fermions and scalars and Four-fermion couplings, all three of which are ubiquitous in effective models in particle physics. Under many circumstances these couplings are not asymptotically free, hence in order to avoid pathologies one cannot apply models involving such interactions for arbitrary values of renormalized couplings. Because of the famous triviality phenomenon, there are restrictions on how large renormalized couplings can be, if one wants to extract physics that is insensitive to the cutoff and to the "new physics" beyond it. It is only by carrying out nonperturbative investigations that one can explore the full consequences of the restrictions and make them more quantitative. In reference [4] we showed in a U(1)×U(1) Yukawa model that in an 8 flavor model the renormalized Yukawa coupling can never become larger than ~ 1.5, regardless of how large a bare coupling one might start out with.

We would like to improve on the above first round of calculations and are currently testing more sophisticated methods for investigating spontaneous symmetry breaking and Goldstone bosons on finite lattices. Finite volume chiral perturbation theory could serve as a guide. We are also exploring the possibility of extending the calculations to models that break custodial SU(2) by giving the up- and down-type fermions different Yukawa couplings. This would allow a nonperturbative calculation of $\Delta\rho$. This last project has been motivated by discussions with Santi Peris, who is studying similar issues using large N techniques.

Light Cone Field Theory

Work on developing nonperturbative approaches to relativistic bound state problems utilizing lightcone quantization has continued during the past year. Together with Stan Glazek, Avaroth Harindranath, Steve Pinsky and Kenneth Wilson, I have been involved in a first attempt to understand renormalization of the 2 fermion bound state problem within the Light Front Tamm-Dancoff framework for the 3+1 Yukawa model. The light-cone hamiltonian that we wish to diagonalize, must include several counterterms, many of which are noncovariant, nonlocal and in general involve arbitrary functions of longitudinal momenta. The appearance of such counterterms can be argued for based on power counting, which works very differently on the lightcone compared to in ordinary space-time quantized field theory. Although we were not able to solve for the exact counterterms, we were able to find good approximations to them using perturbation theory and toy models as guides. Due to triviality, in the Yukawa model one should not attempt to take the cutoff all the way to infinity if one wants renormalized couplings to be nonvanishing and to have interesting physics such as bound states. For the range of cutoffs and renormalized couplings allowed by triviality we find that our approximate counterterms can, to a large extent, eliminate cutoff dependence in the low energy spectrum. The experience gained through these studies of the Yukawa model will be indispensable when going on to our next challenge, namely bound state calculations in light-front QCD.

Publications

[1] "Perturbative Renormalization of Null-Plane QED," D. Mustaki, S. Pinsky, J. Shigemitsu, and K. Wilson, Phys. Rev. D43, 3411 (1991).

[2] "Physics Goals of the QCD Teraflop Project," S. Aoki, G. Kilcup, J. Shigemitsu, et al., Int. J. Mod. Phys. C2, 829 (1991).

[3] "Higgs – Yukawa – Chiral Models," J. Shigemitsu, Nucl. Phys. B (Proc. Suppl.) 20, 515 (1991).

[4] "Studies of a U(1)×U(1) Yukawa Model with Staggered Fermions," S. Aoki, J. Shigemitsu, and J. Sloan, Nuclear Physics B372, 361 (1992).

[5] "Boundstate Problem in the Light-Front Tamm-Dancoff: a Numerical Study in 1+1 Dimensions," A. Harindraniath, R. Perry, and J. Shigemitsu, submitted for publication.

[6] "A U(1)×U(1) Yukawa Model with Staggered Fermions," J. Shigemitsu, J. Sloan, and S. Aoki, to appear in the Proceedings of "Lattice 91" .

[7] "On the Relativistic Bound State Problem in the Light-Front Yukawa Model," S. Glazek, A. Harindranath, S. Pinsky, J. Shigemitsu and K. Wilson, to be submitted for publication.

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

"Studies of a U(1)×U(1) Yukawa Model with Staggered Fermions," Presented at the International Symposium on Lattice Field Theory, 'Lattice 91', Tsukuba, Japan, November 1991.

"Going Beyond QCD on the Lattice," Plenary review talk at the Spring Meeting of the Ohio Section/APS , May 1992.

B. Invited Seminars/Colloquia presented

DESY

University of Muenster

Kernforschungsanlage, Juelich

RWTH-Aachen

Max-Planck-Institut, Munich

CERN, Geneva

University of Akron

Stony Brook

Fermilab

Katsumi Tanaka

Various methods of approach to the problem of deriving a scale invariant relation $m = fv$ where m = mass, f = Yukawa coupling constant, and v = vacuum expectation value (or two particle correlation) have been pursued with Miyazawa.

Work continues with Abe and Wilson on LFTD method. It is applied to $\alpha^4 m_e$ terms of positronium. The $\alpha^4 m_e$ factor follows from the box diagrams, but the correct factor $(-\frac{1}{4})$ of $\Delta m = \alpha^4 m_e(-\frac{1}{4})$ for parapositronium (spin singlet), $n = 1$ is elusive. While on research leave at CERN, I am working on the content of papers to be presented at XV International Warsaw Meeting (Kazimierz) and Workshop on QCD Vacuum (Paris).

The renormalization relies on work by Mustaki, Pinsky, Shigemitsu and Wilson, and Yukawa Model on work by Perry, Harindranath and Wilson.

Tanaka was on Research Leave during Spring Quarter 1992.

Mass Renormalization in Light-Front Tamm Dancoff QED [2], O. Abe, K. Tanaka, and K.G. Wilson. **Abstract**: A discussion of mass renormalization in Light-Front Tamm-Dancoff approximation in QED is presented. The covariant mass counter term, that is, one independent of external momenta and free from infrared cut-off parameter, is obtained for an electron by the use of transverse dimensional regularization method. The result coincides with perturbative result. The mass counter term so obtained enables one to obtain a relativistic equation for bound states. The mass counter terms for a hydrogen atom are also considered. We take the nonrelativistic limit and the S-wave energy levels are obtained.

Self-Duality Condition and Critical Potentials [3], C. Cronström, P.P. Srivastava, and K. Tanaka. **Abstract**: It is shown that the self-duality constraint on the scalar field (combined with the equations of motion) by itself leads to the critical forms for the potential that minimizes the energy functional in the Chern-Simons Higgs system. In the case, we have only the Chern-Simons term in the SL(2,R) gauge group one obtains a formalism that yields the equations of motion of variety of non-linear models in two dimensions when the curvature is set equal to zero.

Self-Duality Condition in Chern-Simons Higgs [4], P.P. Srivastava and K. Tanaka. **Abstract**: It is shown that in the Higgs and Chern-Simons-Higgs systems the 'self-duality' constraint on the scalar field (combined with the equations of motion) by itself leads to a general form for the potential. In the limits of the Chern-Simons coefficient $\kappa \to 0$ and $\kappa \to \infty$ one obtains the previous special forms of the potential. In the latter case, it is shown that the quantity $\ln |a|^2$, where a is the bosonic field, satisfies the Liouville equation. The supersymmetric extensions of the theories written in terms of superfields is considered. A 'supersymmetric self-duality' constraint on the matter superfield is proposed which contains the bosonic one and it leads to the specific forms of superpotentials without invoking arguments based on explicit $N = 2$ supersymmetry.

Publications

[1] "Relativistic Bound State Problem," H. Miyazawa and K. Tanaka, Prog. Theor. Phys. 87, (1992).

[2] "Mass Renormalization in Light-Front Tamm Dancoff QED," O. Abe, K. Tanaka, and

K.G. Wilson, submitted for publication.

[3] "Self-Duality Condition and Critical Potentials," C. Cronström, P.P. Srivastava, and K. Tanaka, to appear in Proceedings in honor of E.C.G. Sudarshan, 1991, Austin, Texas.

[4] "Self-Duality Condition in Chern-Simons Higgs," P.P. Srivastava and K. Tanaka, to appear in Classical and Quantum Systems–Foundation of Symmetries, publisher World Scientific.

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

"Self-Duality Conditions," Gulf Conference on High Energy Physics, Gulf Shores, Alabama, January 1–4, 1992.

"Light Method in QED," XV International Warsaw Meeting on Elementary Particle Physics, Kazimierz, Poland, May 25–29, 1992.

"Light Front Tamm Dancoff Method," Workshop on QCD Vacuum Structure, Paris, France, June 1–5, 1992.

B. Invited Seminars/Colloquia presented

1992

Ohio State University: January

CERN: May

University of Warsaw: May

Jagellonian University: May

Fermilab: July

V.A. Miransky

A new approach to the derivation of the low energy effective action based on the formalism of Green's functions of composite operators is developed in field theories with dynamical symmetry breaking [1–3]. The approach is used to derive the effective action of the gauged Nambu-Jona-Lasinio model which provides basic examples for different scenarios of dynamic electroweak symmetry breaking. The spectrum of spinless bound states in the model is described.

A new scenario of electroweak symmetry breaking is suggested [4]. The scenario yields a natural explanation of a large splitting between the masses of t and b quarks and predicts the existence of quark-antiquark resonances in the TeV region. The possibility of accessibility of the resonances at the SSC is established. The enhancement of flavor-changing neutral currents (FCNCs) in B meson physics due to these resonances is described.

In the coming year, I am planning to study the problem of electroweak symmetry breaking and, in particular, to develop dynamical models for the description of the spectrum of quarks and leptons.

Publications

[1] "On the Effective Action in Field Theories with Dynamical Symmetry Breaking," V.P. Gusynin and V.A. Miransky, Mod. Phys. Lett. A6, 2443-2452, (1991).

[2] "Effective Action in the Gauged Nambu-Jona-Lasinio Model," V.P. Gusynin and V.A. Miransky, Sov. Phys. JETP 74, 216-223 (1992).

[3] "On the Generating Functional for Proper Vertices of Local Composite Operators in the Gauged Nambu-Jona-Lasinio Model," V.A. Miransky, Preprint OHSTPY-HEP-T-92-002, 1992.

[4] "Dynamical Generation of Fermion Masses and Quark-Antiquark Resonances in the TeV Region," R.R. Mendel and V.A. Miransky, Phys. Lett. B268, 384-388 (1991).

Invited Presentations (Calendar Year 1991–2)

B. Invited Seminars/Colloquia presented

"The Effective Action in the Gauged Nambu-Jona-Lasinio Model," Yale University seminar, February 1991; SUNY (Stony Brook) seminar, February 1991; University of Illinois at Urbana seminar, March 1991; University of Kansas seminar, March 1991.

"Dynamics of Quark-Antiquark Resonances in the TeV Region," Johns Hopkins University seminar, December 1991; Maryland University seminar, December 1991; University of Delaware seminar, December 1991.

Greg W. Anderson

My most recent publication provided an analytical treatment of the electroweak phase transition and demonstrated that the standard model can be simply augmented in a way which makes electroweak baryogenesis tenable. The thermal rate of anomalous baryon number violation is very sensitive to details of the electroweak phase transition so understanding and characterizing this phase transition is important. Currently I am investigating the effects of large Yukawa couplings on the spectra of supersymmetric grand unified theories and on the details of electroweak symmetry breaking. Supersymmetric theories require two $SU(2)$ Higgs doublets in order to give masses to all known fermions. When the ratio of the vacuum expectation values of these two fields is large, the Yukawa couplings of the bottom quark and the tau lepton make sizable contributions to the renormalization group scaling of many parameters. This effects the details of radiative symmetry breaking in supersymmetry and the values of particle masses. Previous studies of electroweak symmetry breaking in the minimal supersymmetric model have been either incomplete or have failed to satisfy all phenomenological constraints. Recently Stuart Raby, Lawrence Hall, and Savas Dimopoulos provided a predictive framework for fermion masses and mixing angles in SUSY GUTS which favors a large ratio of vacuum expectation values. I am studying the effect of large bottom and tau Yukawa couplings in their framework. This analysis provides an upper limit on $\tan\beta$.

Publications

[1] "The Electroweak Phase Transition and Baryogenesis," with L. Hall, Phys. Rev. D45, 2685-2698 (1992).

Invited Presentations (Calendar Year 1991–2)

A. Invited talks at regional, national and international conferences

"Analytical Treatments of the Electroweak Phase Transition and a Critique of Subcritical Bubbles," Texas Workshop on Electroweak Baryogenesis, Yale University, February 1992.

B. Invited Seminars/Colloquia presented

"The Electroweak Phase Transition," Argonne National Lab., November 1991; Boston University, December 1991.

Kent Hornbotel (arrived 10/91)

Heavy quark bound states such as charmonium and bottomonium provide perhaps the best opportunity for precision tests of QCD and lattice QCD by employing a nonrelativistic effective lagrangian. In Ref. [1], we constructed an improved verison of this lagrangian for use in lattice simulations of heavy quark physics which should reduce systematic errors from all sources to below 10%. These include corrections for relativity, finite lattice spacing, and radiative loops.

Ongoing projects include numerical simulations of heavy quark systems using this action (with G.P. Lepage (Cornell), B. Thacker and J. Sloan (OSU), and C. Davies (Glasgow)); the development of a light-cone version of the Kogut-Susskind hamiltonian lattice as a means for studying confinement and regulation in light-cone quantization; a study of the heavy quark content of light hadrons in 1+1 dimensional QCD using light-cone quantization (with S.J. Brodsky (SLAC)); and developing a consistent light-cone quantization scheme including boundary degrees of freedom (with G. McCartor and D. Robertson (SMU)).

Publications

[1] "Improved Nonrelativistic QCD for Heavy Quark Physics," G.P. Lepage, L. Magnea, C. Nakhleh, U. Magnea and K. Hornbostel, OSU preprint OHSTPY-HEP-T-92-001, (Feb. 1992), submitted to PRD.

Santiago Peris

After my arrival at OSU in September 1991, I continued working on some recent calculations [1,2] of the axial coupling of a constituent quark. These calculations are interesting because they will help explain the long-standing problem of why the ratio of axial-coupling to vector-coupling in the nucleon system turns out to be 1.25; not, but very close to, unity. There is a small discrepancy in the results between the second paper in Ref. [1] and the paper in Ref. [2]. During the Fall of 1991, using dispersion techniques, I recovered my result of Ref. [2] where a loop expansion was used. This has recently appeared as an OSU-preprint (see list of Publications). It now seems that the discrepancy relies on whether one uses the linear sigma model, as I did, or the non-linear sigma model as in Ref. [1]. Work is in progress.

References

[1] S. Weinberg, Phys. Rev. Lett. 65, 1181 (1990); Phys. Rev. Lett. 67, 3473 (1991).

[2] S. Peris, Phys. Lett. B268, 415 (1991).

Publications

[1] "The Adler-Weisberger Sum Rule and the Axial-Vector Coupling of a Constituent Quark," S. Peris, OSU/92-DOE/ER/01545-569, to be published in Phys. Rev. D.

Invited Presentations (Calendar Year 1991–2)

B. Invited Seminars/Colloquia presented

g_A in the Constituent Quark Model," Université de Montréal; McGill's Univ., Montréal, Québec, Canada, October 1991.

John H. Sloan

I am a post-doctoral researcher working on lattice gauge theory. Over the past year, I have mainly been working on two major projects. First, with Junko Shigemitsu and Sinya Aoki (currently at University of Tskuba), I studied a model in which a complex scalar field, with a ϕ^4 interaction, was coupled to staggered lattice fermions through a Yukawa interaction [2]. This model is a toy model for the standard model with the gauge interactions turned off, and is of interest in trying to understand the Higgs mechanism and fermion mass generation in the standard model. The important measurement to make in this model is of Z_π, the wave function renormalization of the Goldstone boson, in the broken symmetry phase. We studied different ways of dealing with the problem of taking into account the finite volume effects present in lattice simulations, and found that there is a large systematic difference between different methods. Without further analytic understanding, this would lead to systematic uncertainties of order 50% in measurements of Z_π. We are currently attempting to apply chiral perturbation theory techniques, in which the finite volume effects are much better controlled, to this problem.

The other project, in collaboration with Dimitri Kusnezov (at Yale) and Aurel Bulgac (at Michigan State), was an attempt to reduce critical slowing down in lattice simulations by adding a small number of additional degrees of freedom to the system which couple globably and mimic a heat bath [3,4]. This algorithm, chaotic molecular dynamics (CMD), was compared to hybrid Monte Carlo (HMC), the algorithm which is currently used in large unquenched QCD simulations, in a simulation of the X-Y model. We showed that, as had been predicted by many groups, the efficiency of the HMC algorithm is very sensitive to the frequency of measurements: if measurements are made too frequently, critical slowing down becomes severe; while if measurements are made too infrequently, the ensemble is undermeasured, leading to a loss of computer time in either case. The CMD algorithm does not suffer from this tuning problem, and we found that it typically performed about as well or slightly better than the best implimentation of HMC. Unfortunately, we have found no tractible way to make CMD exact, i.e. eliminate systematic errors in the ensemble of order δt. Because of this and because the speed-up is only marginal, we are not actively studying this algorithm at this time.

In the coming year, I plan to pursue two avenues of research. First, I will continue my work with Shigemitsu on the Yukawa-Higgs system. As mentioned above, we have been using the insights and results obtained from chiral perturbation theory to improve our measurements of Z_π. I am also planning to begin collaborating with Christine Davies (of Glasgow), Peter Lepage (of Cornell), Kent Hornbostel, and possibly others on a project involving non-relativistic QCD. This will involve measurements of spectra and wave functions for mesons and baryons in which all of the quarks are heavy, such as J/Ψ or bottomonium. We may also, in collaboration with Greg Kilcup, investigate mesons with one heavy and one light quark, such as B or D mesons. This is one of the more exciting areas of lattice gauge theory right now, because systematic errors can be controlled, probably to a level of 10% or better, and because there are many numbers, such as the B meson decay constant f_B, which are needed in order to interprete experimental results in terms of the standard model, while at the same time other results, such as mass splittings, can be checked against experiments.

Publications

[1] "Renormalization Counterterms in Linearized Lattice QED," G. Bodwin, E. Kovacs, and J. Sloan; Phys. Rev. D44, 3924-3930 (1991).

[2] "Studies of a U(1)xU(1) Yukawa Model with Staggered Fermions," S. Aoki, J. Shigemitsu, and J. Sloan; Nucl. Phys. B372, 361 (1992).

[3] "A Test of the Chaotic Molecular Dynamics Algorithm in the XY Model," J. Sloan, D. Kusnezov, and A. Bulgac, Ohio State preprint OSU DOE ER-1545-561, submitted to Phys. Rev. Lett.

[4] D. Kusnezov and J. Sloan, in preparation.

Invited Presentations (Calendar Year 1991)

A. Invited talks at regional, national, and international conferences

"Critical slowing down in Chaotic Molecular Dynamics," Lattice '91 conference, SCRI, Tallahassee, November 1991.

B. Invited Seminars/Colloquia presented

"Speeding Up Molecular Dynamics with Chaos," Argonne National Lab. seminar, September 1991; University of Kentucky seminar, December 1991.

Investigator: **Greg Kilcup**

In the past year I continued research on several areas of lattice gauge theory. In reference [1] we presented the results from a long series of production runs on massively parallel CM-2 computers, looking at the effects of dynamical Wilson quarks on simple hadronic observables. Perhaps the most interesting result was evidence in the matrix element of the scalar density in the proton (the sigma term) sea quarks contribute about the same amount as the valence quarks. In reference [2] I reported the status of our calculations of weak matrix elements. We have been studying the effects of each source of systematic errors in our calculation of B_K, and I presented new results on the effects of dynamical staggered fermions on B_K, as well as on the effects of using improved staggered operators. Reference [3] was a sort of finger exercise, extracting the pion-pion scattering length from finite volume effects. This was a demonstration both that we have a good understanding of finite volume effects, and that the usual current algebra relationships hold when using staggered fermions. In reference [4] we continued our investigations with Wilson fermions, this time using improved smeared sources. This was done on quenched lattices, and is a prelude to continued calculation with dynamical fermions, as in reference [1]. In a related development, we have used the same techniques to calculated the parameter B_K with Wilson fermions, and a preprint is almost ready.

More recently we have begun to work on heavy quarks, and I presented the first results at the April APS meeting. We are computing the parameters f_B and B_B, and anticipate performing a series of calculations to make the same sorts of tests for systematic errors as we have been doing for B_K. Another project which is still underway is the use of improved staggered fermion operators for weak matrix element calculations. This should be finished over the summer. Future projects include another look at the matrix elements of the operators for ϵ'/ϵ, and for the $\Delta I = \frac{1}{2}$ rule. Finally, we hope to be granted access to the new CM-5 installed at LANL, and would anticipate a major set of runs aimed at extracting all the quantities mentioned above, but on even larger (e.g. $64^3 \times 128$) lattices. This would set the new standard for quenched calculations.

Recent Publications

1. "Dynamical Wilson Fermions 2" (with C. Baillie, R. Brickner, R. Gupta, A. Patel and S. Sharpe) *Phys. Rev.* **D44** (1991) 3272.

2. "Weak Interaction Matrix Elements: DPF91 Status Report", proceedings of DPF91, p. 772.

3. "Lattice Calculation of the $I = 2$ Pion Scattering Length", (with S .Sharpe and R. Gupta) submitted to *Phys. Rev.* **D**.

4. "Phenomenology with Wilson Fermions Using Smeared Sources", (with D. Daniel, R. Gupta, A. Patel and S. Sharpe), submitted to *Phys. Rev.* **D**.

Invited Presentations

1. "Phenomenology from Lattice QCD", Aspen Winter Conference, January 1991
2. "Phenomenology from Lattice QCD", Seminar at Argonne National Laboratory, March 1991
3. "The Lattice QCD Grand Challenge", APS meeting on Computational Physics in San Jose, June 1991
4. "Weak Interaction Matrix Elements", DPF 91 meeting in Vancouver BC, August 1991
5. "Numerical Experiments with Quarks and Gluons", colloquium at Univ. of Kentucky, November 1991
6. "New Physics from Lattice QCD: Weak Matrix Elements", APS meeting, Washington DC, April 1992

Part C:

1991-92 PROGRESS REPORT

MEASURING CHARM AND BEAUTY DECAYS VIA HADRONIC PRODUCTION IN A HYBRID EMULSION SPECTROMETER

E653 - FERMILAB

M. Aryal, M. Hansen, A. Nguyen, N. Reay, K. Reibel, R. Sidwell, N. Stanton, N. Witchey, THE OHIO STATE UNIVERSITY; AICHI UNIVERSITY, UNIVERSITY OF CALIFORNIA AT DAVIS, CARNEGIE-MELLON UNIVERSITY, CHONNAM NATIONAL UNIVERSITY, FERMILAB, UNIVERSITY OF GIFU, GYEONG SANG UNIVERSITY, JOENBUG UNIVERSITY, KINKI UNIVERSITY, KOBE UNIVERSITY, KOREA UNIVERSITY, NAGOYA INSTITUTE OF TECHNOLOGY, NAGOYA UNIVERSITY, UNIVERSITY OF OKLAHOMA, OKAYAMA UNIVERSITY, OSAKA CITY UNIVERSITY, SCIENCE EDUCATION CENTER OF OSAKA PREFECTURE, TOHO UNIVERSITY, UTSUNOMIYA UNIVERSITY. YOKOHAMA NATIONAL UNIVERSITY, WONKWANG UNIVERSITY.

Fermilab experiment E653 is studying beauty and charm decays and production properties with a hybrid emulsion spectrometer. Decay candidate events to be scanned in the emulsion were selected from those reconstructed in the spectrometer, which featured 18 silicon microstrip detectors downstream of the emulsion target. A muon trigger enriched the recorded sample of $b\bar{b}$ events and of semimuonic decays of charm. E653 had a shakedown run with 800 GeV protons in 1985, and took a much larger sample of data with 600 GeV π^- in 1987. A total of 9×10^6 triggers, corresponding to 2.5×10^8 emulsion interactions, were recorded in the π^- run.

All results from the 1985 shakedown run have now been published[1, 2, 3, 4] and will not be discussed here. One charm physics result from the 1987 run was published during the past year, and two more have recently been accepted for publication. Two beauty papers are now in the process of collaboration review. Other analysis work now in progress should lead to two to three more papers by the end of 1992, by which time most US work on E653 will end. However, some very interesting long-term emulsion work in Japan, notably on $D_s \to \tau\bar{\nu}_\tau$, will continue and require some US participation.

Decay form factors for $D^+ \to \bar{K}^{*0}\mu^+\nu$

This work has now been published[5]. The decay $D^+ \to \bar{K}^{*0}\mu^+\nu$ is governed by three form factors: A_1 and A_2 (axial vector) and V (vector). Our measured values of the ratios of these form factors at $q^2 = 0$, $A_2(0)/A_1(0) = 0.82^{+0.22}_{-0.23} \pm 0.11$ and $V(0)/A_1(0) = 2.00^{+0.34}_{-0.32} \pm 0.16$, are quite close to quark model predictions. E653 statistical errors are a factor 2 smaller than those of the earlier work[6] of E691, due in large measure to better statistics and better acceptance for the slow lepton. Although the two experiments are not in disagreement, the E653 form factor ratios do not support the E691 suggestion that an anomaly in A_2 is connected to the surprisingly small branching ratio for $D^+ \rightarrow \bar{K}^{*0}\mu^+\nu$, which E653 also finds (see below).

Measurement of the branching ratio for $D^+ \rightarrow \bar{K}^{*0}\mu^+\nu$

This result was recently accepted for publication[7]. E653 has measured this branching ratio by two different methods. The first normalizes to $D^0 \rightarrow K^-\mu^+\nu$, and gives $B(D^+ \rightarrow \bar{K}^{*0}\mu^+\nu) = (3.25 \pm 0.71 \pm 0.75)\%$. From this method we also obtain the direct measurement $\Gamma(D^+ \rightarrow \bar{K}^{*0}\mu^+\nu)/\Gamma(D^0 \rightarrow K^-\mu^+\nu) = 0.43 \pm 0.09 \pm 0.09$. The systematic errror in this method is dominated by the error on the relative cross section for D^0 and D^+ production, which we take from our own measurements of hadronic decay modes[8], and on the world average for $B(K^-\mu^+\nu)$. The second method uses the mode $D^+ \rightarrow K^-\pi^+\pi^+$ for normalization, and yields $B(D^+ \rightarrow \bar{K}^{*0}\mu^+\nu) = (4.18 \pm 0.66 \pm 0.96)\%$. Its accuracy is limited by our statistics in the normalizing $K\pi\pi$ channel, and in the systematics associated with the muonic trigger charm which was the partner of this $K\pi\pi$ decay. After all common statistical and systematic errors have been removed, the ratio of the $D^+ \rightarrow \bar{K}^{*0}\mu^+\nu$ branching fractions determined by the two methods is $1.28 \pm 0.21 \pm 0.28$, indicating consistency. Combining the results of the two methods yields $B(D^+ \rightarrow \bar{K}^{*0}\mu^+\nu) = (3.54 \pm 1.02)\%$. This result is of comparable precision to, and in good agreement with, earlier experiments[9] which find that D's decay to $K^*l\nu$ about half as often as to $Kl\nu$.

Charm meson production by 600 GeV π^- on emulsion

These results were also recently accepted for publication[8]. They are based on 676 electronically-reconstructed D mesons in the modes $D^+ \rightarrow \bar{K}^{*0}\mu^+\nu$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D^0 \rightarrow K^-\mu^+\nu$, $D^0 \rightarrow K^-\pi^+$, and $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$. Fits, for $x_F > 0$, to $d^2\sigma/dx_F dp_T^2 \propto (1 - |x_F|)^n e^{-bp_T^2}$ give $n = 4.25 \pm 0.24 \pm 0.23$, and $b = 0.76 \pm 0.03 \pm 0.03$ $(\mathrm{Gev/c})^{-2}$. The total inclusive D^+ and D^0 cross sections for $x_F > 0$ are respectively $8.64 \pm 0.46 \pm 1.08$ μb/nucleon and $22.15 \pm 1.38 \pm 2.45$ μb/nucleon, where a linear A dependence has been assumed. These results, taken together with earlier NA32 results[10] at a lower energy, indicate that charm mesons are produced with a momentum spectrum that is somewhat stiffer, and total inclusive cross sections that are about a factor of 2 larger, than next-to-leading order QCD predictions[11].

Lifetimes and production properties of charged and neutral beauty particles

Two papers dealing with lifetimes and production properties of charged and neutral beauty hadrons are now under collaboration review. They are based on the 9 $b\bar{b}$ events found in the completed scan of events with muon $p_T > 1.5$ GeV/c; the scan of events with muon $p_T > 0.8$ GeV/c, still in progress, has so far yielded 3 more candidates.

Extensive studies, done mainly at OSU, of sources of background and of possible biases in the search and momentum estimation procedures have convinced us that the expected background is less than 0.3 events, and that systematic errors are small compared to statistical errors. For the 12 neutral decays, which may well contain B_s and Λ_b as well as B_d, we find $\tau_{b^0} = 0.81^{+0.34+0.09}_{-0.22-0.02}$ ps, 1.4 standard deviations below the LEP average of 1.3 ps. Our 6 charged decays include 2 decays longer than 5 ps (Fig. 1). We find $\tau_{b^\pm} = 3.84^{+2.73+1.39}_{-1.36-0.15}$ ps, more than 2 standard deviations above the LEP average. However, semileptonic decay branching ratios from ARGUS and CLEO[12], and also from our own data, do not indicate a significantly larger $b^\pm$ semileptonic branching ratio. It would be very interesting if the $b^\pm$ and b^0 lifetimes are significantly different, while the semileptonic branching ratios are equal.

Other semimuonic charm decays

Work on $\sigma\cdot$BR($D_s \to \phi\mu\nu$), and on extracting the ratio of longitudinal to transverse widths for this decay. will be finished by summer. Results and limits from a search for D semimuonic decay modes other than $K\mu\nu$ and $K^*\mu\nu$ will be collected into a paper on a similar time scale. A new measurement of $\Gamma(D^0 \to K\mu\nu)/\Gamma(D^0 \to \mu X)$, with about 7 times the statistics of our Run 1 result[2], will begin this summer, with anticipated completion by the end of 1992.

$D_s \to \tau\bar{\nu}_\tau$ and other long-term emulsion analyses

The E653 emulsion contingent would like to continue E653 scanning for about three years. They have decided to invest the considerable effort necessary to measure the branching ratio for $D_s \to \tau\bar{\nu}_\tau$, which may be impossible to do in any other experiment. Charged muonic decays (candidates for $\tau \to \mu\nu_\tau\bar{\nu}_\mu$) are first located in the emulsion, and then careful measurements are made along the incoming track looking for the 1-2 mrad $D_s \to \tau$ kink. One excellent candidate (Fig. 2) has so far been found, with an anticipated yield of 10.

The emulsion people will also continue scanning all events with muon $p_T >$ 0.8 GeV/c for beauty, another labor-intensive project. In the course of this scan, and from events tagged by the electronic analyses, 1000-2000 charm pairs will be found; these will be used for production studies.

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[3] K. Kodama, *et al.*, Phys. Lett. B263 (1991) 573.

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[6] J.C. Anjos, *et al.*, Phys. Rev. Lett. 65 (1990) 2630.

[7] K. Kodama, *et al.*, "Measurement of the Branching Ratio for $D^+ \rightarrow \bar{K}^{*0}\mu^+\nu$", to appear in Phys. Lett. B (1992).

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[10] S. Barlag, *et al.*, CERN preprint, CERN-PPE/90-145 (1990).

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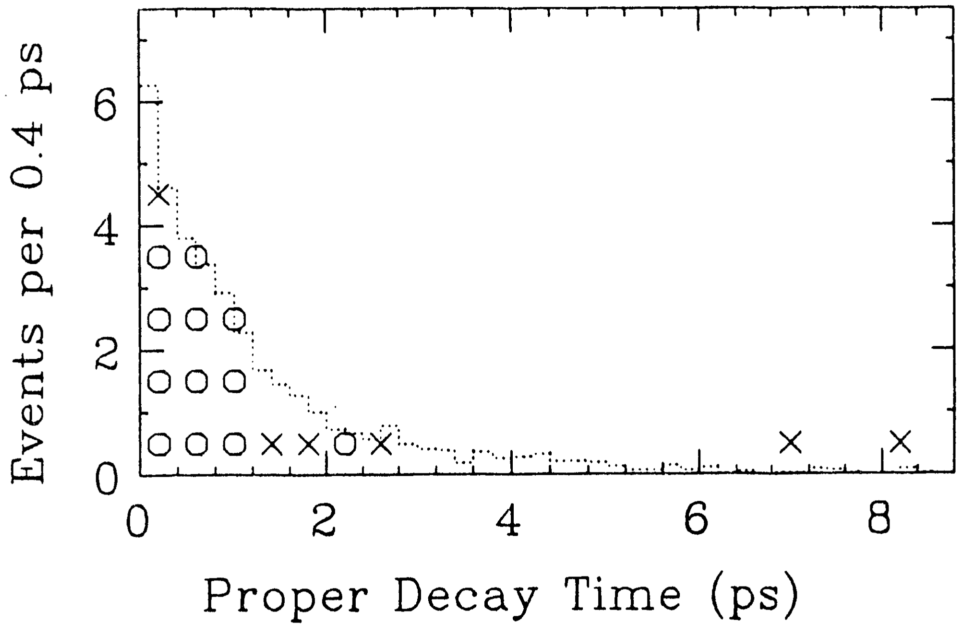

FIG. 1. Histogram of proper decay time for the 12 b^0 decays (circles) and the 6 $b^{\pm}$ decays (X's). The histogram is the expected distribution for a lifetime of 1.3 ps, the average from the LEP experiments.

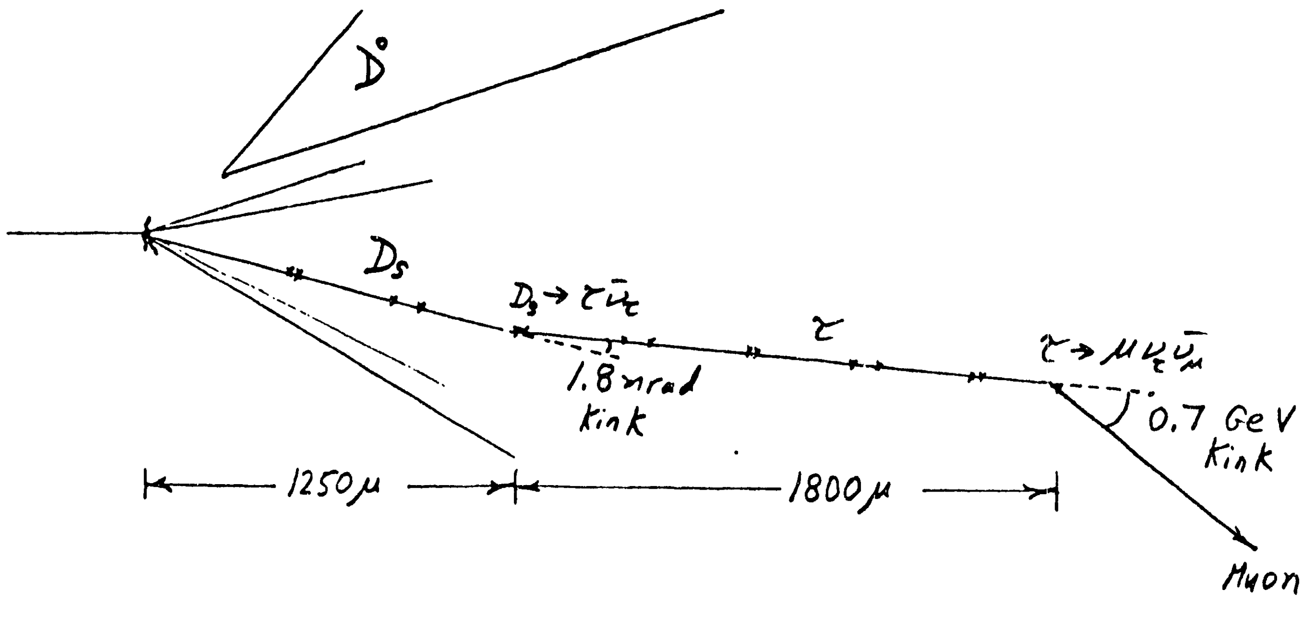

FIG. 2. Sketch of the $D_s \rightarrow \tau\bar{\nu}_\tau$ candidate. All decays occur in emulsion. The x's mark the locations of precision emulsion track measurements to determine the small kink angle.

CONTINUED STUDY OF HEAVY FLAVORS AT TPL

E791 - FERMILAB

D. Granite, M. Hansen, A. Nguyen, B. Palmer, N. Reay, K. Reibel, J. Smith, R. Sidwell, N. Stanton, A. Tripathi, P. Whitney, N. Witchey, THE OHIO STATE UNIVERSITY; CENTRO BRASILEIRO DE PESQUISAS FISICAS, UNIVERSITY OF CALIFORNIA (SANTA CRUZ), UNIVERSITY OF CINCINNATTI, FERMILAB, ILLINOIS INSTITUTE OF TECHNOLOGY, UNIVERSITY OF MISSISSIPPI, PRINCETON UNIVERSITY, TUFTS UNIVERSITY, UNIVERSITY OF WISCONSIN AT MADISON, YALE UNIVERSITY

E791 is a high-statistics heavy quark experiment with excellent sensitivity for rare decays of charm. The old E691 spectrometer (Fig. 1) was operated in a 500 GeV π^- beam with an upgraded silicon vertex detector, contributed in large part by OSU, and a data acquisition system which accepted 10^4 events/sec during the spill. E791 completed a very successful run in January, collecting 20 billion physics triggers on more than 24,000 Exabyte tapes; this is twice as many triggers as originally proposed. The charm yield is conservatively estimated at 300K clean events useful for physics studies.

Workstation farms at OSU and at U. Miss. are now in operation, and have done preliminary analyses on 1% samples of the data. Tuning of reconstruction code will occur over the summer, with the full reconstruction beginning in the fall. The computing power available at that time will be increased by expanding the OSU farm and by use of ACPII farms at Fermilab. The critical issue of whether to use an event filter, which will lose interesting physics and decrease E791's discovery potential, will be decided by the amount of computing which becomes available in 1993.

Physics goals

Charm physics of particular interest to OSU physicists includes the following:

1. A search for flavor-changing neutral currents in modes such as $D^+ \to l^+l^-\pi^+$ which are not helicity-suppressed like l^+l^- modes. We expect to be able to improve on the current limit by nearly two orders of magnitude.

2. Improvement by an order of magnitude in the limits on D^o-$\overline{D^o}$ mixing. Mixing can be distinguished from doubly-suppressed decays both by observation of wrong-sign rate versus proper decay time, and also by the observation of wrong-sign semileptonic decays.

3. Search for new baryonic ground and excited states, including the *ccu* baryon.

4. Investigation of semi-leptonic decay modes, particularly for baryons, and a search for purely leptonic decays in order to determine charm weak coupling constants and polarization.

5. Studies of correlations between associated charm particles which can differentiate between various effects such as the relative contribution to production of simple gluon fusion versus more complicated modes.

E791 also expects to obtain 100 fit beauty decays, and to find even more which are topologically identified. A search for pentaquarks and other exotic states will also be conducted.

OSU contributions to E791

Ohio State has made major contributions to E791 in hardware, computing and software. With four potential thesis students and extensive experience in heavy quark physics, OSU will also play a strong role in analysis.

1. Hardware. OSU provided 6 planes of $(10\ \mathrm{cm})^2$ 50-micron-pitch SMD's, together with precision stands, water cooling and 100 Fastbus cards of electronics. The added tracking redundancy and acceptance of these detectors have proven to be essential. OSU also built and mounted the platinum and carbon foil target.

2. Workstation farm. The OSU workstation farm (discussed in more detail below) now supplies about half of the available computing for E791 analysis, and will continue to do so as more computing power is brought online.

3. Utility computing. OSU provided a VaxStation 3200 with color monitor and dual Exabyte tape drives which is now being used for on-line event displays and database support. An additional UNIX workstation from OSU is used for code development and physics analysis at Fermilab, and is now the main center for distributing nightly updates of the analysis code to the collaboration.

4. Software. OSU people took primary responsibilty for the vertex pattern recognition and fitting software, and for DST organization and software. They also participated in developing the silicon monitoring and readout system and the online event display. We also are helping to debug and improve tracking and momentum algorithms, as well as those for pattern recognition in the calorimeters.

5. Personnel. OSU maintains one research associate full time at Fermilab to work on E791; he was joined during the running period by a second research associate and a technician. Four graduate students are now participating in the analysis, while senior physicists presently are contributing approximately 1.5 full-time-equivalents.

Preliminary data analysis

Work is in progress on algorithms and calibrations for reconstruction. One measure of success is the resolution on primary vertices; Fig. 2 is a plot of the position in z along the beam direction of reconstructed vertices of recorded interactions, and shows the five thin targets (one platinum, four diamond) used in the run. We are also tuning the tracking and vertex finding algorithms, which have been extensively rewritten to take advantage of the larger number of silicon planes in this experiment compared to E769 or E691. Noticeable progress has been made since we started, with the K^0_s yield increasing by 50% during the last 2 months, to about 3000 per million triggers. Calibration of the hadron and electron calorimeters, and of the muon counters, is well-advanced.

Data crunching is underway at two sites: at the U. of Mississippi with 38 DecStations, and at OSU using an average of 30 machines, in two farms. As of June 1, more than 1000 tapes have been run through a preliminary analysis which incorporates most of the detector systems. Events retained are the 10% with 2 or more vertices, and only these events are fully reconstructed. Mean reconstruction times are 270 ms for partially reconstructed events and 650 ms for full reconstruction (which adds stand-alone drift chamber tracking, and analyses of the cerenkov counters, calorimeters and muon hodoscopes). The farm software has been shown to be quite efficient, using 96% of the available cpu time. Work is now in progress to improve the software, which "hangs" ocassionally due to ethernet timeouts. We are encouraged by the facts that software crashes are uncommon compared to past experience, that the event reconstruction time is somewhat faster than expected, and that DEC hardware has been reliable.

Mass spectra based on about 540 tapes ($\approx$440 million triggers) are shown in Fig. 3. Clear signals are seen for $D^0 \rightarrow K\pi$, $D^0 \rightarrow K3\pi$, $D^{*+} \rightarrow D^0\pi$, and for the $D^+ \rightarrow K2\pi$. It is too early to extrapolate the observed signals to final yields, but given plausible gains in tracking and vertexing efficiency we should meet our stated goals.

Computing resources

The computing load for extracting 200,000 charm decays from the expected 2×10^{10} triggers, using the present two-vertex filter will require more than 6000 MIPS-years, where a Vax780 is one MIP. In addition another 1000-1500 MIP-years will be needed for Monte Carlo simulations, and the analysis and compacting of DST tapes. Much of this work is best done in parallel with bulk crunching. If computing resources are adequate, the four graduate students and experienced senior people at OSU should play a strong role in extracting the physics.

An initial 780 MIPS of clustered workstations was installed at OSU in fall, 1991, and another 440 MIPS was installed at Mississippi. These systems together can analyze 1/5 of the total data sample per year. An additional 720 MIPS of computing has been ordered and will be brought online at OSU in late summer, 1992. As was the case for E653, use of students considerably reduces personnel cost during analysis and setup. If OSU and Mississippi are the only sites crunching data, analysis will require more than 3 years. Our Brazilian collaborators will be trying to bring the ACP II system online this summer. This system, now at Fermilab and to be moved to Brazil, could add 800 MIPs. In addition the collaboration is expecting to ask Fermilab for full time use of four 16-node farms. If, in the most optimistic scenario, these latter two efforts are successful, then computing resources would be adequate to filter the data in two years.

With present and projected computing resources, the time per event must be reduced with a filter, which will lose interesting physics and reduce the discovery potential of the experiment. The requirement of a secondary vertex biases heavily against short decays and/or decays where a great deal of information comes from areas removed from the secondary decay vertex. As an example of the first category, most Λ_C charm baryons would be lost, as well as other undiscovered charm baryons which are expected in general to have even shorter lifetimes. Two examples of the latter type of loss would be the decays $D^0 \rightarrow K^0\overline{K^0}$, and $\Lambda_C \rightarrow \Lambda\pi$. Seventeen events from the latter decay have been featured in a recent PRL in an attempt to measure the asymmetry parameter for the Λ_C. We are therefore very much interested in analyzing a sizeable portion of the data with no filter, keeping all multitrack events on the DST's.

Request for additional computing

Complete event reconstruction, in which the results of analyzing every trigger are written to tape, requires another factor of two in computing power. We are therefore requesting an additional \$75K, which will be matched at the 30% level by the University, to purchase 1000 MIPS of computing in FY93. This additional computing would allow us to speed up the filtering of the data by 4 to 6 months, and to analyze an appreciable amount of data with full reconstruction. This additional computing will also make it possible at OSU to do the necessary monte carlo simulations and physics analysis.

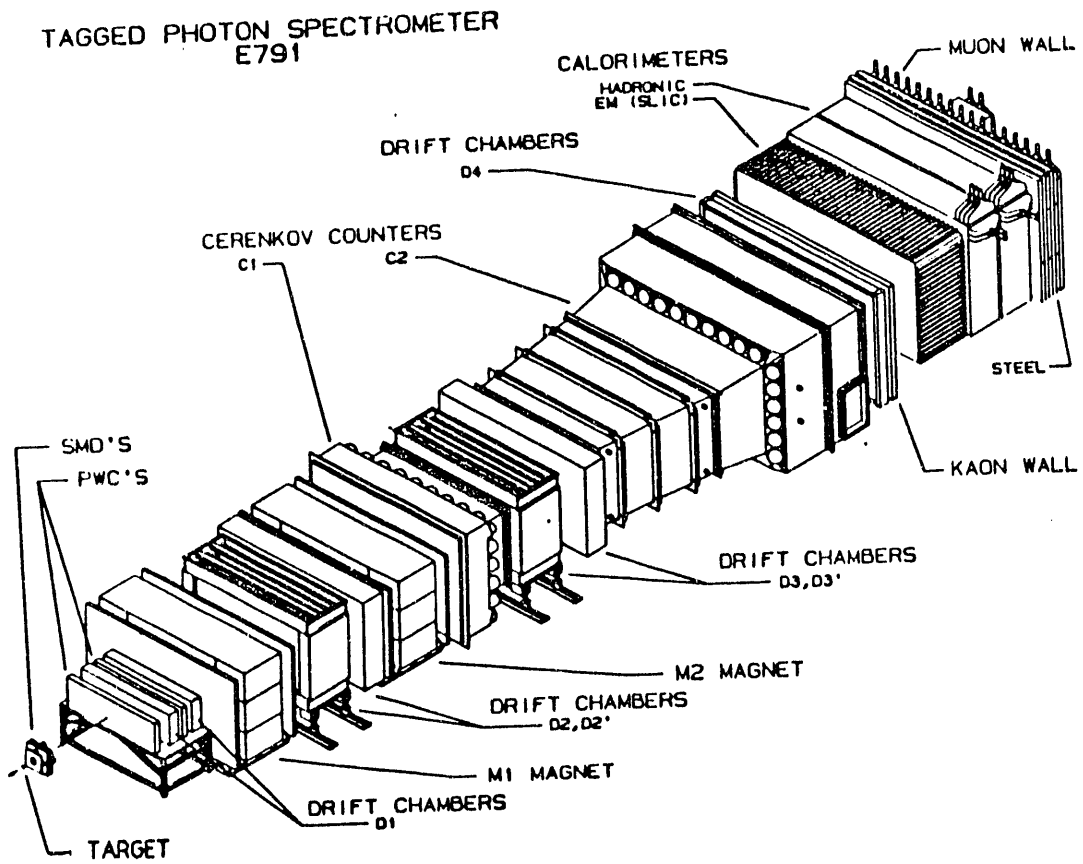

FIG. 1. Isometric view of the E791 spectrometer.

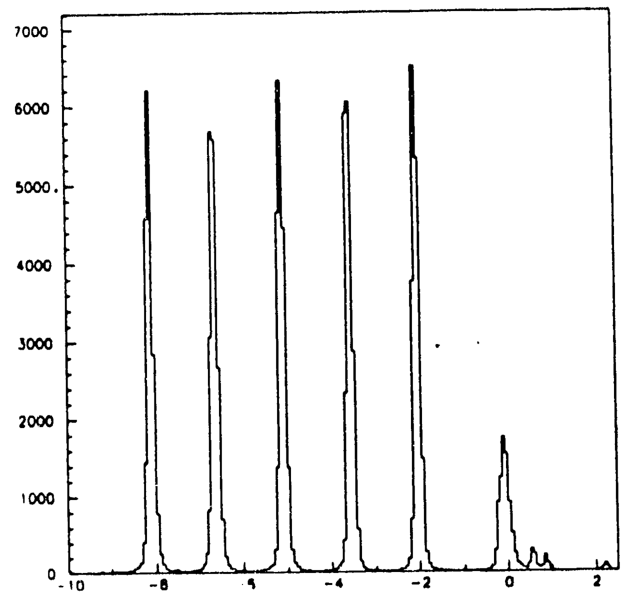

FIG. 2. Z position of reconstructed interactions. The peaks correspond to positions of the five target foils, the trigger counter, and three silicon wafers.

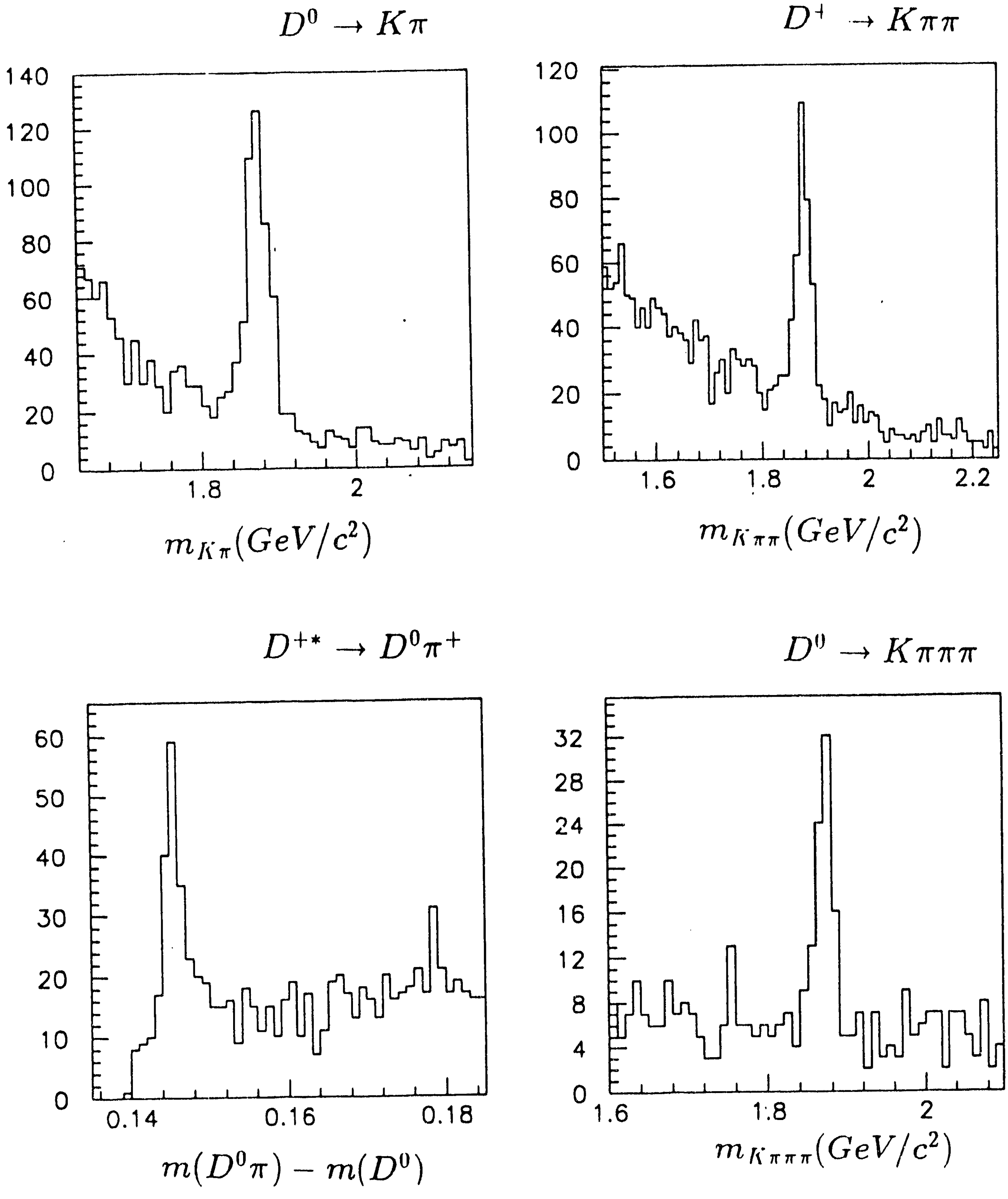

FIG. 3. Charm mass peaks from the preliminary analysis (still in progress). The plots are based on 540 data tapes.

A PRECISION EXPERIMENT TO MEASURE $\nu_\mu \to \nu_\tau$ NEUTRINO OSCILLATIONS

P803 - FERMILAB

D. Granite, M. Hansen, A. Nguyen, B. Palmer, N. Reay, K. Reibel, J. Smith, R. Sidwell, N. Stanton, A. Tripathi, P. Whitney, N. Witchey, THE OHIO STATE UNIVERSITY; AICHI U., U. OF ATHENS, UNIVERSITY OF CALIFORNIA AT DAVIS, FERMILAB, GIFU U., HIROSAKI U., KINKI U., KOBE UNIVERSITY, KOREA A.I.S.T., KOREA U., NAGOYA I.T., NAGOYA UNIVERSITY, OSAKA CITY UNIVERSITY, OSAKA U.C., ROCKEFELLER U., S.E.I.OF OSAKA PREFECTURE. SOAI U., SEOUL N.U., U. SOUTH CAROLINA, TOHO U., TUFTS U., YOKOHAMA N.U., UTSUNOMIYA U.

Rationale for short- and long-baseline experiments

The probability P for neutrino oscillations goes as

$$P_{\nu_a \to \nu_b} = \sin^2(2\theta) \int \sin^2(1.27\delta m^2)\left(\frac{L}{E_\nu}\right) d\left(\frac{L}{E_\nu}\right)$$

with $\delta m^2 = m_a^2 - m_b^2$ in eV^2, the source-to-detector distance L in meters and the neutrino energy E_ν in MeV. Short-baseline measurements made close to the source have the advantage of higher statistics for investigating smaller couplings, while long-baseline experiments at large L can search for oscillations at smaller δm^2. The proposed Fermilab Main Injector Upgrade can provide 120 GeV proton beams (hence neutrinos) with unprecedented intensity, permitting both types of experiments to expand greatly upon previously explored regions of neutrino oscillations.

Interest in oscillations recently has been stimulated by an increasing body of circumstantial evidence: there is an apparent deficit both of ν_e [1], [2], [3] coming from the sun and ν_μ coming from atmospheric cosmic-ray interactions [4], [5], [6]. Theory also plays a role: the "Big Bang" model predicts that approximately 400 neutrinos inhabit every cubic centimeter of the universe; were they to have even a small mass the universe would be closed by gravitational attraction. A see-saw mechanism relating masses of neutrinos to those of associated quarks and/or leptons in the same generation suggests that ν_τ would be the heaviest of known neutrinos and hence is the leading candidate to provide this gravitational attraction [7]. LEP results limiting to three the number of standard neutrinos strengthens this hypothesis [8].

Finally, recent experimental indications of ν_e mixing to a 17 KeV neutrino not suitable for closure [9], [10] provide impetus to the search for $\nu_e \to \nu_\tau$ oscillations.

Goals of P803

The primary goal of P803 is to lower the limits on $\nu_\mu \to \nu_\tau$ oscillation below 10^{-4} in $\sin^2(2\theta)$, smaller than corresponding mixing angles in the quark sector, and to provide incontrovertible evidence should a positive signal exist at 4-5 times this level. Simultaneously, $\nu_e \to \nu_\tau$ mixing would be searched for at a level of 0.005, far below the 3% suggested to explain the 17 KeV neutrino results.

Secondary goals are to measure the Kobayashi-Maskawa matrix element V_{cd} to 2 1/2%, a precision comparable to unitarity estimates [11], to measure "slow rescaling" in neutrino production of charm, to make an experimental determination of higher-order corrections to the QCD theory of deep inelastic neutrino scattering, and of course to serve as a suitable front detector for the long-baseline oscillation efforts.

Present and proposed limits for short-baseline oscillations are given in Figure 1. Present limits are determined by Fermilab experiment E531 [12] and the CERN CDHSW experiment [13]. The sensitivity increase of the new experiment over E531 is due to several factors: higher neutrino flux and target mass, minimizing background by incorporating higher μ detection efficiency and scanning only for single-prong τ decays, and minimizing emulsion analysis time by incorporating automatic techniques developed for Fermilab experiment E653.

If a positive signal is observed for $\nu_e \to \nu_\tau$ or $\nu_\mu \to \nu_\tau$ oscillations, with subsequent production of τ's via charged-current interactions, P803 will be able to determine whether τ candidates have the right mass and lifetime.

Progress in 1991-92

In the past year, P803 has been included in the Fermilab Institutional Plan and has been favorably reviewed by the Fermilab PAC, the URA Board of Trustees, and the Witherell HEPAP subpanel. The Fermilab medium-energy neutrino effort is cited several times in the latter report. Fermilab has set up a committee to review radiation standards with the goal of reducing neutrino-beam costs, has contributed short-baseline/long-baseline R & D money, and has appointed Ray Stefanski as head of the Fermilab side of the Main Injector medium-energy neutrino beam project. Several other Fermilab physicists have expressed interest in joining the project.

Soudan 2 has been selected as the long-baseline site, and SB/LB experimenters have agreed to pool efforts and research. Progress has also been made on extraction from the main injector, and on establishing a beam line pointing to Soudan 2 which has minimal impact on the Fermilab environment.

P803 has made several design improvements, and presently it appears that the D0 plastic-fiber R & D project has goals which coincide with those of P803. This should solve P803's single most uncertain design difficulty.

Other P803 R & D is proceeding, though formal approval awaits the start of Main Injector construction in the Spring of 1993. More discussion on this R & D appears in the Technical Proposal section of this document.

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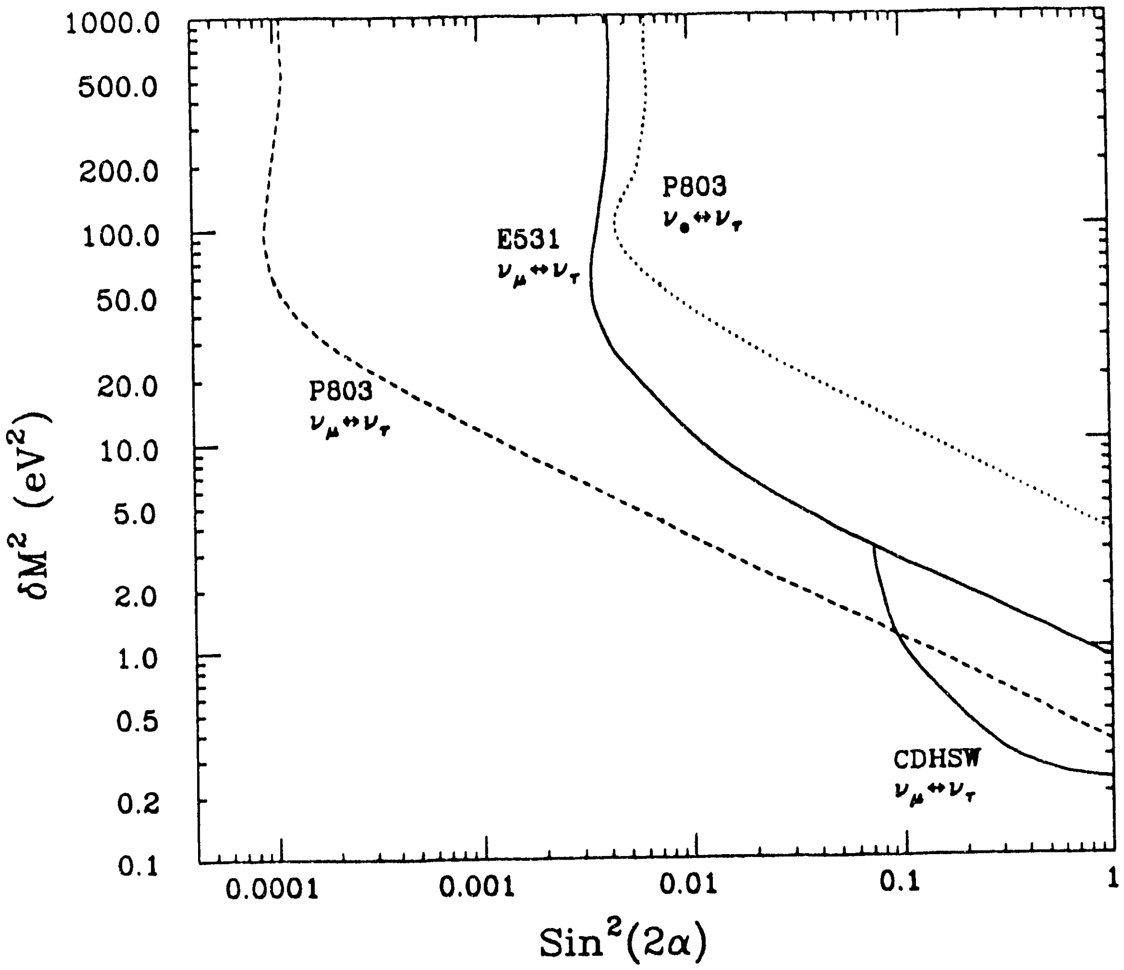

FIG. 1. δM^2 versus $\sin^2(2\alpha)$ plane showing the previous limits for $\nu_\mu \to \nu_\tau$ oscillation superposed on improved limits which could be obtained from P803. The regions to the right of the appropriate curves are excluded at the 90% confidence level.

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2. *Charm Pair Correlations in 800 GeV/c Proton-Emulsion Interactions,* J.M. Dunlea, S.G. Frederiksen, S. Kuramata, B.G. Lundberg, G.A. Oleynik, N.W. Reay, K. Reibel, R.A. Sidwell, and N.R. Stanton, with K. Kodama, *et al.*, Phys. Lett. B263 (1991) 579.

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7. *Measurement of Beauty Hadron Production by 600 GeV/c π^-,* M. Aryal, J.M. Dunlea, S.G. Frederiksen, S. Kuramata, B.G. Lundberg, G.A. Oleynik, N.W. Reay, K. Reibel, R.A. Sidwell, and N.R. Stanton, manuscript under collaboration review.

PRESENTATIONS AND CONFERENCE ACTIVITIES

1. *Neutrino Oscillations*, N.W. Reay, First Annual Spring Conference of the SSC, May, 1991.

2. *Neutrino Oscillations*, N.W. Reay, 1991 Toledo Deep Underground Conference, July-Aug. 1991.

3. Presentation to the Witherell HEPAP Subpanel, N.W. Reay, Winter 1992.

4. *Beauty Pair Production in 600 GeV/c Pion-Emulsion Interactions,* R. A. Sidwell, in Vancouver Meeting: Particles & Fields '91, Vol. I, p.516 (World Scientific, 1991).

5. *A Precision Experiment to Measure ν_μ to ν_τ Neutrino Oscillations,* R.A. Sidwell, Long Baseline Neutrino Oscillations Workshop, Fermilab, Nov. 1991 (to be published).

6. *$B\bar{B}$ Pairs and Charm Semileptonic Decays from Fermilab E653,* N.R. Stanton, at the Third Topical Seminar on Heavy Flavours, San Miniato (Italy) 20 June, 1991 (to be published).

HIGH ENERGY PHYSICS PROPOSAL

THE OHIO STATE UNIVERSITY

TASK D

ELECTRON-POSITRON COLLISIONS

Grant DE-FG02-91ER40690

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1 Electron-Positron Collisions at CLEO II

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Introduction

The CLEO II experiment was designed [1] to perform high precision measurements in the 10 GeV energy region at the Cornell Electron Storage Ring (CESR). The physics of this energy region includes studies of the Υ family of resonances as well as the b quark system. In particular, CLEO II hopes to settle the remaining issues of $b \rightarrow u$, mixing, rare decays, and possibly CP violation. In order to make these experiments a reality CESR was upgraded and has now attained instantaneous luminosities in excess of $\sim 3 \times 10^{32}$ cm^{-2}sec^{-1}. As a result much of the original experimental program planned with CLEO II will be completed in the coming year.

Although the CLEO II upgrade was motivated by B meson physics the final design is also well matched for studies of the properties of charm particles and the τ lepton. Of particular interest to the OSU group is the "τ-paradox" where the inclusive and sum of the exclusive branching ratios do not agree, and the "leptonic branching ratio/τ lifetime" dilemma. As in the case of B physics these issues should be settled in the coming year.

CLEO II Status

In 1989 the CLEO experiment was transformed into the state-of-the-art CLEO II detector. This transformation included the new 3.5 cm radius beryllium beampipe, the new six layer Precision Tracking Layer detector, an upgraded Vertex Detector, an upgraded Drift Chamber, a new Time of Flight System, a new CsI Shower Detector, a new 1.5T superconducting magnet, and a new Muon Detector. The new CLEO II detector is unique in its ability to measure both charged particle momenta and electromagnetic energy with a combined precision better than any previous colliding beam experiment. Data taking with the CLEO II experiment began on schedule in the Fall of 1989.

The initial data run with the CLEO II detector was at the center of mass energy of the

$\Upsilon(3S)$. The approximately 150 pb^{-1} of data collected at this energy were used to debug the many complex detector subsystems in CLEO II in anticipation of a data run at the $\Upsilon(4S)$. After the $\Upsilon(3S)$ run, data were taken at energies above the $\Upsilon(4S)$ and the cross section of $e^+e^- \to B^*B$ was measured. The current physics program is to collect 2000 pb^{-1} of data at the $\Upsilon(4S)$. This program began as of June 1990. With this data it should be possible to reconstruct several thousand B mesons as well as improve the measurements on b mixing and the rate of b→u transitions.

B Physics

The physics goals of the $\Upsilon(3S)$ run include a detailed study of transitions between the $\Upsilon(3S)$ and the $\Upsilon(2S)$ and $\Upsilon(1S)$. These studies have been completed and submitted for publication. In addition the $^1P_1$ and η_b were searched for with this data set. This analysis is now complete and neither of these states were observed.

The physics program at energies above the $\Upsilon(4S)$ includes the measurement of the cross section of $e^+e^- \to B^*B$. This process produces a charge conjugation C=+1 $B\bar{B}$ eigenstate. Unlike the C=−1 eigenstate (e.g. $\Upsilon(4S)$) the time integrated CP asymmetry of a decay such as $B \to \psi K_s$ is not zero. Hence depending on the size of the cross section of $e^+e^- \to B^*B$, this mode may be a useful laboratory to study CP violation in a symmetric e^+e^- collider [2]. Our results from this data set suggest that the cross section for this process will be too low for a symmetric collider unless luminosities in excess of $10^{34}/cm^2$-sec are achieved. This work formed the basis of Mr. Peter Wilson's Ph.D. thesis.

To date 1200 pb^{-1} have been collected on the $\Upsilon(4S)$ and nearby continuum. Over 1000 charged B mesons and 500 neutral B mesons have been reconstructed allowing the first measurement of the B meson semileptonic branching fractions with tagged B^0 and $B^\pm$ events. Figure 1 shows the charged and neutral B mass plots. Preliminary results are:

$$Br(B^0 \to X^- l^+ \nu) = (11.6 \pm 1.5 \pm 2.6)\%$$
$$Br(B^+ \to X^0 l^+ \nu) = (10.0 \pm 1.0 \pm 1.9)\%$$

With the same data sample new searches for exclusive $b \to u$ transitions were performed. These searches included the modes: $B \to \omega l \nu$ and $B \to \rho l \nu$. Both of these reactions should have been observable if recent ARGUS measurements are correct. To date no signal has been observed in either mode.

In addition new measurements of the $B \to \psi X$ branching ratios and polarization in these decays were performed as well as searches for rare B decays from Penguin diagrams or color suppression.

It should be clear from this partial list of CLEO II results that CLEO II has begun to perform high statistics studies of the B meson system. In addition, the high CESR luminosity also make possible studies of charm and tau physics. Much of this analysis was performed by OSU personnel.

Tau Physics

Over the last few years, a discrepancy has appeared between the sum of the exclusive one-charged-particle decay branching ratios and the inclusive one-charged-particle decay branching ratio [3]. Approximately 5-7% of these decays are unaccounted for. This is known as the "τ paradox". Another interesting discrepancy exists between the electronic branching ratio and the τ lifetime. At present measurements of these related quantities are not in complete agreement: the measured τ lifetime implies a larger electronic branching ratio than observed or conversely the measured electronic branching ratio implies a smaller τ lifetime. This is the "electronic branching ratio/τ lifetime" dilemma.

The CLEO II detector is well suited to unravel the τ discrepancies. CLEO II was designed to be a high resolution spectrometer for both charged and neutral particles. In addition, due to upgrades of CESR, CLEO II now routinely attains a daily luminosity of 6-7 pb^{-1}. We have already collected more than 10^6 $\tau^+\tau^-$ events with the new detector, the world's largest sample, and expect to more than double this data set in the coming year.

We have used the CLEO 1.5 data collected previously to measure the τ lifetime. The lifetime is measured by reconstruction of the 3-prong vertex in events with a lepton recoiling against three charged particles. This measurement took advantage of the two precision vertex chambers built by the OSU group. The decay length distribution of the 3-prong decay is shown in Figure 2. A clear excess of events with positive decay length is evident. This distribution yields $\tau_\tau = (3.04 \pm 0.14 \pm 0.07) \times 10^{-13}s$. This lifetime measurement is consistent with current world average measurement of τ_τ and somewhat larger than expected from new measurements of the τ mass and electron branching ratio. This result has been submitted to Physics Letters B for publication and forms the basis of Ms. J. Whitmore's thesis.

As part of the program to study the "τ-paradox", we have measured the τ branching ratios with multiple π^0's in the final state using the CLEO II detector. The branching ratios are measured by using events with two different tags. The events are selected with the requirement that one of the τ's decay into one charged particle with multiple π^0's and the other τ decays into a lepton (e or μ) or three charged pions. The lepton tag has the advantage of low hadronic background; however, the trigger efficiency for such two track events is low and not well understood. The 3-prong tag has much higher trigger efficiency but also has higher background. These two tags have very different systematic errors and provide a powerful consistency check. The results on the branching ratios are:

$$B_{\pi 2\pi^0} = (8.27 \pm 0.15 \pm 0.47)\%$$
$$B_{\pi 3\pi^0} = (1.00 \pm 0.07 \pm 0.11)\%.$$

The first error is statistical and the second is systematic. The measurement of $B_{\pi 3\pi^0}$ represents the first measurement of this branching ratio by fully reconstructing the π^0's. Our precise measurements are lower than the world averages and hence support the existence of the τ paradox. The results have been approved by the CLEO collaboration for submission to PRL.

We have also observed a new decay mode, $\tau^- \to \pi^-\pi^+\pi^-2\pi^0\nu_\tau$. The candidate events for the decay are identified by selecting events with one charged particle recoiling against three charged particles and four photons. Figure 3 shows the invariant mass spectrum of the two photons recoiling against the other two photons reconstructed as an π^0. The signal contains 352 ± 30 events with a hadronic background of 47 ± 16 events. This corresponds to a branching ratio of:

$$B_{3\pi 2\pi^0} = (0.44 \pm 0.04 \pm 0.06)\%.$$

There is no firm theoretical prediction for this branching ratio because the decay proceeds through an axial current. However, we can compare the branching ratio with that of its isospin partner, $\tau^- \to \pi^-\pi^+\pi^-\pi^+\pi^-\nu_\tau$, which has been observed with a branching ratio of $B_{5\pi} = (0.056 \pm 0.016)\%$. The new decay mode is approximately ten times larger! The larger than expected branching ratio may account for the higher branching ratio of $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ observed by other experiments. These experiments are much more sensitive to the feed down from the $2\pi^0$ decay mode because the decay is only identified by counting photons.

We have searched for sub-structure in the $3\pi 2\pi^0$ system. An ω signal has been observed. This is also the first observation of $\tau^- \to \pi^-\omega\pi^0\nu_\tau$. A fit to the signal yields 229 ± 25 events, corresponds to a branching ratio of $B_{\pi\omega\pi^0} = (0.37 \pm 0.04 \pm 0.06)\%$. This unexpected branching ratio also has similar implications for the measurement for the branching ratio of the decay $\tau^- \to \pi^-\omega\nu_\tau$ by other experiments where the feed down is totally ignored. A draft of this paper is now under review by a CLEO committee for submission to PRL.

Work in Progress

This past year the members of the Electron-Positron Collisions Task of the Ohio State University high energy physics group have directed their efforts in four areas: the maintance of CLEO II hardware; the analysis of CLEO I and II data; and the development of new high precision tracking detectors. Our analysis work on CLEO I and II data include studies of two-photon production of charm, $\Upsilon(3S)$ decays, B decays, and the τ lepton. Recent results include a measurement of the BB^* cross section, measurement of the τ lifetime and branching ratio's, observation of new τ decay modes, and a search for the η_b via $\Upsilon(3S)$ transitions.

2 Detector Development

K.K. Gan, H. Kagan, R. Kass, R. Malchow, W. Palmer, C. White, S. Zhao

Tracking Detectors

High quality charged particle tracking is crucial for the success of the physics program at CESR or any facility which reaches luminosities near 10^{33} cm^{-2} sec^{-1} [4]. In any experiment at these facilities the tracking chambers serve as the primary momentum measuring device. As such they must function over a wide range of momenta with high efficiency and cover as large a solid angle as possible. These chambers also serve as a key element in the global particle identification system. Measurement of the specific ionization of the charged particles traversing the chambers can, over a wide range of momenta, identify electrons, pions, kaons, and protons and complement other particle identification techniques. In addition, the reconstruction of secondary vertices from the charged particle trajectories serves as a powerful tool for identifying D^0's, K^0's, Λ's, and γ's. Charged particle tracking also serves as an essential part of the trigger system helping to separate unwanted backgrounds from the interesting physics processes.

Over the past year the OSU group has been leading a Task Force to develop an inner tracking system for the next CESR upgrade, when the luminosity at CESR will reach 10^{33} cm^{-2} sec^{-1}. This upgrade is scheduled to be completed by 1995. The task force involves members from Cornell, Syracuse, UC Santa Barbara, and Canada in addition to OSU. The OSU leadership is based on our expertise with high precision devices and our previous design work on drift chambers for a B factory. The Inner Detector Task Force has been meeting regularly with its goal of a prelimary design of a new inner detector system for CLEO by early 1993.

Gas Microstrip Detectors

The prospect of high luminosity colliders has initiated widespread inquiry into new types of detectors. The physics at high luminosity operation, namely the study of rare processes, requires efficient, intrinsically fast, low mass, large solid angle, high resolution, radiation insensitive equipment. At a B factory, in particular, tracking detectors will play the crucial role in observing CP violation. The Gas Microstrip Detector (GMD) is one new technology that will possibly meet these requirements [5, 6].

The basic idea of a Gaseous Microstrip Detector is to create a multiwire proportional device whose anode to anode distance is comparable with the spatial resolution required. In a conventional Multiwire Proportional Chamber (MWPC) the electrons created in the gas, by the passage of a charged particle, drift to an anode wire under the influence of the applied electric field. The large electric field close to the anode wire produces the gas amplification necessary to obtain an observable signal. The position resolution perpendicular to the anode wire is given by the anode wire spacing divided by $\sqrt{12}$. In a conventional MWPC the anode to anode spacing (usually >2 mm), and hence spatial resolution, is limited by electrostatic instabilities.

Although the first gas microstrip detectors have yielded encourging results they are quite small, have not been applied to any particular experiment, and have been plagued by a loss of gain due to the insulator charging. Our collaboration has designed a large scale detector specifically for use in a colliding beam environment and have a potential solution to the charge-up problem.

We use state-of-the-art printed circuit board techniques to produce the fine strips of the prototype detectors. This technology is very cheap, can be used with a number of substrates, and removes the the constraints of photolithography and glass substrates which presently limit detectors to small sizes (< 10 cm). Devices produced by printed circuit board techniques can extend to areas $\sim 100 \times 100$ cm^2 thus providing highly precise relative spacing of strips over large areas. Our first devices, made on copperized Kapton, have strips 5-25 cm in length. Kapton was chosen as the substrate for its dimensional stability, high resistivity, and insensitivity to radiation. In these prototypes a series of parallel copper strips are placed 25 μm apart on a 50 μm thick Kapton substrate. The anodes are 20 μm wide, typically 1 μm thick and have a pitch of 150 μm. The cathodes are 30 μm wide. The drift region is defined by the drift cathode plane which is an aluminium foil 3-5 mm above the substrate. A back cathode electrode is used to shape the electric field.

The mechanical support for our device is a paper hexcell-based cylinder 6 mm thick wrapped with 25 μm Kapton. The hexcell is strong in one direction (z) and flexible in the other ($r - \phi$) thus allowing it to be formed. Initial measurements have shown that a cylinder constructed from this material is quite strong, easily reproducible, and deflects less than 10 μm. The total material in this cylinder is 0.056% of a radiation length. Thus one could construct a 10 layer detector with less than 1.0% radiation length of material.

We operate the detector at gas gains of $\sim 3 \times 10^3$. Using a typical gas with 30 seed electrons per cm, a 3 mm thick device yields a signal of 30,000 electrons. This is comparable to the signal from a silicon detector. To obtain the desired gain the required anode-to-cathode interstrip voltage is ~ 125 V. We have tested the first prototype and found that all strips can maintain more than twice the required voltage. As in a silicon detector, the noise is determined largely by the capacitance of the device. We have measured a capacitance less than 10 pf for the 25 cm long strips, or < 0.4 pf per cm of strip length. This is quite adequate if we wish to use standard silicon strip electronics (CAMEX, SVX, μ-PLEX, etc). The main problem with these devices is the loss of gain due to charge accumulating on the resistive Kapton substrate. We have investigated other materials (G-10, Mylar, etc.) and found that none of them completely solves the problem.

Our solution to the insulator charged-up problem uses the age old technology of plastic etching. We have developed the techniques to remove the material between strips and still preserve the mechanical integrity of the system. Our first attempts produced excellent results. We hope to produce a working device during the upcoming year.

Diamond Detectors

Experiments at future high energy, high luminosity collider facilities must have the capability to operate in a severe radiation environment and must be able to handle extremely large event rates. No existing detector technology completely fulfills these requirements. Radiation detectors based on diamond are envisaged to have advantages over all existing technologies in their inherent radiation hardness and superior charge collection speed. This technology may make it feasible to construct a detector, at a fraction of the cost of other technologies, with uncompromised tracking and calorimetry, which is also capable of operating in the radiation environment of a high luminosity collider. Our recent studies, for instance, establish the possibility that key components of an SSC, LHC or B-factory detector can be based on diamond technology [7].

Although natural diamond has been considered for use in radiation detectors for over 40 years [8, 9], several shortcomings, primarily high cost and impurities, have prevented its widespread adoption. Within the past ten years, however, a new method of manufacturing diamond by Chemical Vapor Deposition (CVD) [10, 11] has been developed for commercial production of diamond. Recent advances show promise of yielding high quality diamond on an economically feasible scale for large area radiation detectors without the inherent problems associated with natural diamond. We are conducting a series of experiments to explore the novel use of diamond technology in radiation detectors and determine whether this technology can be applied to high energy particle detectors.

The basic principle of the use of diamond as a radiation detector is quite simple. A few hundred volts are applied across a layer of diamond a few hundred microns thick. When a charged particle traverses the diamond, atoms at the crystal lattice sites are ionized, promoting electrons into the conduction band and leaving holes in the valence band. These charges are free to move about the crystal and drift across the layer in response to the applied electric field producing a signal pulse which can be amplified and processed.

We have carried out beam tests of single-crystal natural and polycrystalline CVD diamonds at the Accumulator Ring (AR) test beam at KEK in Japan (5 GeV electrons) and at the M13 beam line at TRIUMF in Canada (100 MeV e's, μ's, and π's). The samples tested at KEK and TRIUMF included natural diamond (D34) and several polycrystalline CVD diamonds. The total number of samples tested was about 50.

The quantity used to characterize the diamond in these tests is the charge collection distance. The observed signal results from induced charge on the electrodes due to the movement of the electrons and holes. Because of impurities and defects, the electrons and holes drift on average some distance, (d), before capture. When this distance is much smaller than the diamond thickness, the observed signal is proportional to the ratio of d to the diamond thickness (t). All samples tested to date have fallen into this category. The collection distance can then be determined by:

$$Q_{meas}/Q_{gen} = d/t$$

Here Q_{gen} is the amount of charge generated by the ionizing radiation and Q_{meas} is the measured charge. The generated charge in diamond has been calculated in two ways: (1) by normalizing the diamond pulse height to the silicon pulse height after correction for solid angle and dE/dx, and (2) using the EGS monte carlo. Both methods agree. In these calculations, we used 13 eV of energy deposit per electron-hole pair produced.

The collection distance is also related to the mobility (μ), carrier lifetime (τ), and applied electric field (E) by:

$$d = v\tau = \mu \mathrm{E} \tau.$$

Figure 4 compares the collection distance for natural diamond and four CVD samples. At electric fields of 25 kV/cm, the natural diamond reaches a collection distance of 50-60 μm and is not saturated. At this electric field the signal to noise (S/N) is approximately 6:1. Extrapolating from this data we expect the natural diamond to reach collection distances of approximately 100 μm (S/N = 10:1) at electric fields of 40 kV/cm. At low electric field, one of the CVD diamonds compares well with natural diamond. This is the region where impurities are expected to dominate. As shown in Fig. 4, at higher fields this CVD sample saturates at a collection distance around 10-15 μm; significantly lower than that of the natural diamond. The onset of this saturation is probably related to imperfections and defects in the CVD sample. This effect is being studied and correlated with CVD production parameters.

In addition to studying the charge collection in natural and CVD diamond, we have begun to look at rate effects. In Fig. 5, we show the normalized pulse height as a function of rate in CVD diamond. No degradation of pulse height was observed up to rates of 10^4 particles/cm^2/sec. This is the first indication that diamond will withstand the large rate environment of the SSC or LHC.

The experiments described above were the first demonstration that CVD diamond can detect charged particle minimum ionizing radiation and handle large rates. During the next year CVD diamond grown to our specifications will be produced which should yield collection distances which are 3-5 times larger than that described above. Indeed we have already measured small samples with these qualities. We are presently producing ten 3cm $\times$ 3cm pieces of CVD diamond for use in a prototype calorimeter. This prototype should be constructed and tested at KEK during the coming year.

3 Personnel

The personnel presently associated with this task include 3 Faculty, 4 Research Associates, and 5 Ph.D. students. Three of the Ph.D. students listed in our last report have graduated taking postdoctoral positions listed below:

Individual	Position at OSU	Present Position
Mark Frautschi	Graduate Student	Post Doc - University of New Mexico
Peter Wilson	Graduate Student	Fermi Fellow - University of Chicago
Julie Whitmore	Graduate Student	Post Doc - Fermilab

Since its inception in 1981, the Electron-Positron Collisions task has attracted some of the best faculty, postdocs and students. This is evidenced by the fact that each of its faculty members have been honored with a national award. Professor K. K. Gan is our most recent honoree attaining two national awards in 1991. In 1992 one of our recent graduates (P. Wilson) received a Fermi Fellowship at the University of Chicago and Professor R. Kass was promoted to Full Professor. Listed below are the recent awards and promotions and dates of reception.

Award	Individual	Year
SSC National Fellowship Award	K.K. Gan	1991
DOE Outstanding Junior Investigator Award	K.K. Gan	1991
Promotion to Full Professor	R. Kass	1992
Fermi Fellowship - University of Chicago	P. Wilson	1992

4 Presentations and Publications

Invited Talks

1. "Charm and Tau Physics from CLEO", XXV Rencontre de Moriond, Les Arcs, France (R. Malchow, Mar. 1991).
2. "Tau Physics at a B-factory", Workshop on Physics and Detectors for KEK Asymmetric B-Factory, KEK, Tsukuba, Japan (K.K. Gan, Apr. 1991).
3. "Charm Particle Decay", IV International Symposium on Heavy Flavor Physics, Orsay, France (R. Kass, June 1991)
4. "Diamond-Based Detectors for the SSC", The Vancouver Meeting - Particles and Fields 91, Vancouver, B.C. Canada (H. Kagan, Aug. 1991).

Colloquia and Seminars

1.	H. Kagan	University of Minnesota	Mar. 1991.
2.	R. Kass	Carnegie Mellon University	Apr. 1991.
3.	R. Kass	University of California, Santa Cruz	Jun. 1991.
4.	H. Kagan	University of Colorado, Boulder	Sept. 1991.
4.	K.K. Gan	Cornell University	Oct. 1991.
5.	H. Kagan	Harvard University	Dec. 1991.
6.	H. Kagan	Cornell University	Jan. 1992.

Publications

1. "Exclusive and Inclusive Semileptonic Decays of B Mesons to D Mesons", Phys. Rev. **D43**, 651 (1991), (R. Fulton, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, F. Morrow, J. Whitmore, P. Wilson *et al.*).

2. "Study of $\pi^+\pi^-$ Transitions from the Υ(3S) and a Search for the h_b", Phys. Rev. **D43**, 1448 (1991), (R. Fulton, P. Haas, M. Hempstead, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, F. Morrow, J. Whitmore, P. Wilson with I.C. Brock *et al.*).

3. "Study of D^0 Decays into Final States with a π^0 or η", Phys. Rev. **D43**, 2836 (1991), (R. Fulton, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, F. Morrow, J. Whitmore, P. Wilson with K. Kinoshita *et al.*).

4. "Inclusive Production of the Charmed Baryon Λ_c^+ from e^+e^- Annihilations at $\sqrt{s} = 10$ GeV", Phys. Rev. **D43**, 3599 (1991), (R. Fulton, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, F. Morrow, J. Whitmore, P. Wilson with P. Avery *et al.*).

5. "Study of Continuum D^{*+} Spin Alignment", Phys. Rev. **D44**, 593 (1991), (G. Crawford, R. Fulton, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with Y. Kubota *et al.*).

6. "The AMY Inner Tracking Chamber", Nucl. Inst. and Meth. **A307**, 52 (1991), (M. Frautschi, D.R. Johnson, H. Kagan, R. Kass, C.G. Trahern *et al.*).

7. "Measurement of the Inclusive B^* Cross Section Above the Υ(4S)", Phys. Rev. Lett. **67**, 1692 (1991), (G. Crawford, R. Fulton, K.K. Gan. T. Jensen, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with D.S. Akerib *et al.*).

8. "Inclusive χ(2P) Production in Υ(3S) Decay", Phys. Rev. Lett. **67**, 1696 (1991), (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with R. Morrison *et al.*).

9. "Inclusive and Exclusive Decays of *B* Mesons to Final States Including Charm and Charmonium Mesons", Phys. Rev. **D45**, 21 (1992), (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with D. Bortoletto *et al.*).

10. "D_s^+ Decays to $\eta\rho^+$, $\eta'\rho^+$, and $\phi\rho^+$", Phys. Rev. Lett. **68**, 1279 (1992), (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, D.R. Johnson, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with P. Avery *et al.*).

11. "Measurements of Semileptonic Branching Fractions of *B* Mesons at the Υ(4S) Resonance", Phys. Rev. **D45**, 2212 (1992), (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with S. Henderson *et al.*).

12. "Two Body D_s^+ Decays to $\eta\pi^+$, $\eta'\pi^+$, $\eta\rho^+$, $\eta'\rho^+$, and $\phi\rho^+$", Phys. Rev. **D45**, 3965 (1992), (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with M. Daoudi *et al.*).

13. "Electronic Branching Ratio of the τ Lepton", Phys. Rev. **D45**, 3976 (1992), (G. Crawford, R. Fulton, K.K. Gan, H. Kagan, R. Kass, J. Lee, R. Malchow, F. Morrow, M. Sung, J. Whitmore, P. Wilson with R. Ammar *et al.*).

14. "Development of Diamond Radiation Detectors for the SSC and LHC", Nucl. Instr. and Meth. **A315**, 39 (1992) (K.K. Gan, H. Kagan, R. Kass, R. Malchow, F. Morrow with M. Franklin *et al.*).

15. "The CLEO II Detector", Nucl. Instr. and Meth. **A320**, 66 (1992) (G. Crawford, R. Fulton, K.K. Gan, T. Jensen, H. Kagan, R. Kass, R. Malchow, F. Morrow, J. Whitmore, P. Wilson with Y. Kubota *et al.*).

5 Technical Proposal

The CLEO II experiment is presently taking data at the $\Upsilon(4S)$ and is expected to continue in this mode until at least 2 fb^{-1} of data are collected at this energy. Although CESR continues to deliver record luminosities (peak luminosities > $2.6x10^{32}/cm^2$-sec and integrated luminosity $\sim$10 pb^{-1}/day) the data run is not expected to end until 1994. This Task is committed, over the next 2 years, to operating the detector elements we constructed, developing and maintaining the software for these devices, and analyzing the enormous data sample presently being accumulated. The detector related software projects underway include calibration and diagnostics for the Vertex Detector and Precision Tracking Layer detector (Lee, Malchow, Morrow, Sung), calibration and monitoring the CsI calorimeter (Lee, Crawford). The physics analysis projects include the measurement of the τ lifetime (Whitmore, Sung, White), measurement of τ branching fractions (Crawford, Daubenmier), analysis of $\Upsilon(3S)$ decays (Malchow, Morrow), two photon production of charm (Fulton), and search for exclusive rare B decays (Malchow, Morrow). This full program places large demands on our present personnel and travel budgets. In addition, Professor Gan's departmental start-up package is complete and so Dr. C. White will move from departmental support to the DOE grant. Dr. F. Morrow will be leaving and he has been replaced by Dr. D. Fujino. We also anticipate the continued support of 5-6 graduate students on the DOE contract throughout the next two year period. This will provide the manpower necessary to maintain our strong position in CLEO and extract physics results from the new data. The attached budgets reflect the total personnel level and activity described above.

The CLEO II experiment is accumulating data at a rate that presently saturates all of our computer analysis capabilities at OSU and Cornell. For example, the CPU time necessary to generate the very large of samples Monte Carlo events required for physics analysis plays a large role in determining the rate at which physics results can be published. As the luminosity of CESR is expected to increase by a factor of 2 in the next year or so, this bottleneck is only expected to get worse. We are currently planning computer upgrades that will allow us to analyze the data and generate Monte Carlo samples in a rapid and timely fashion. In all likelihood any such upgrade will involve the use of UNIX and VMS based machines. The newly announced DEC ALPHA upgrade will give us the ability to go in either direction. This upgrade is necessary for the bulk processing of Monte Carlo and certain CPU intensive software packages (e.g. charged track reconstruction) where raw CPU power is the primary concern rather than IO and user-friendliness. Our present computing resources at OSU consist of about 75 MIPs in the form of a nine VMS based workstations. In the next year we propose to upgrade every workstation with ALPHA chips to enhance our present CPU power. Our budget request for $100K spread in FY93 addresses this computer upgrade plan.

Over the next year we will continue our research and development program on charged particle tracking devices. There is still the possibilty of going ahead with the construction of a new main drift chamber for the CLEO II experiment. Our program also emphasizes the design and construction of smaller high resolution tracking devices ($< 30\mu$) with three dimensional readout. We are also prototyping Gas Microstip detectors. Depending on the results from the prototypes these detectors may play a role in either an upgrade of CLEO II or in a b Factory detector.

On the longer time scale, we are involved in a research and development program aimed at producing diamond based ionization detectors for the SSC. This research is carried out as members of the DIAMAS collaboration (SSC-EOI0009). The results of this research could lead to the first truely viable technology for high luminosity hadron colliders. Recent results from this program include the first observation of minimum ionizing charged particles using CVD diamond radiation detectors. We plan on building on this success by fabricating, using CVD diamond, a prototype electromagnetic calorimeter (1992), a prototype hadron calorimeter (1993), and a prototype high resolution tracking device (1994). These prototypes will be evaluated at various test beam facilities (Fermilab, KEK, TRIUMF).

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Figure Captions

1. Mass Plots for charged and neutral B candidates

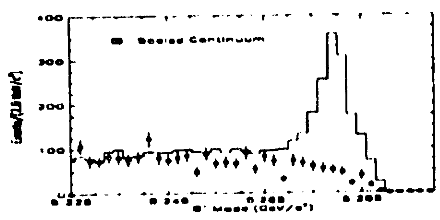
2. The distribution of proper flight distances from the CLEO experiment. Also shown is the Monte Carlo prediction for a proper flight distance of 90.5 μm.

3. The invariant mass spectrum of the two photons recoiling against an π^0 candidate for τ decay candidates with one charged particle and four photons. The histogram shows the Monte Carlo expectation together with the hadronic background (dashed).

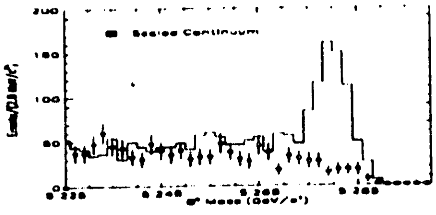
4. Collection distances in natural and CVD diamonds.

5. Pulse height as a function of rate in CVD diamond. The pulse heights are normalized to 1.0 for the lowest rate point.

Figures



B^+ mass distributions for data taken at the $\Upsilon(4S)$ resonance and below



B^0 mass distributions for data taken at the $\Upsilon(4S)$ resonance and below

Figure 1

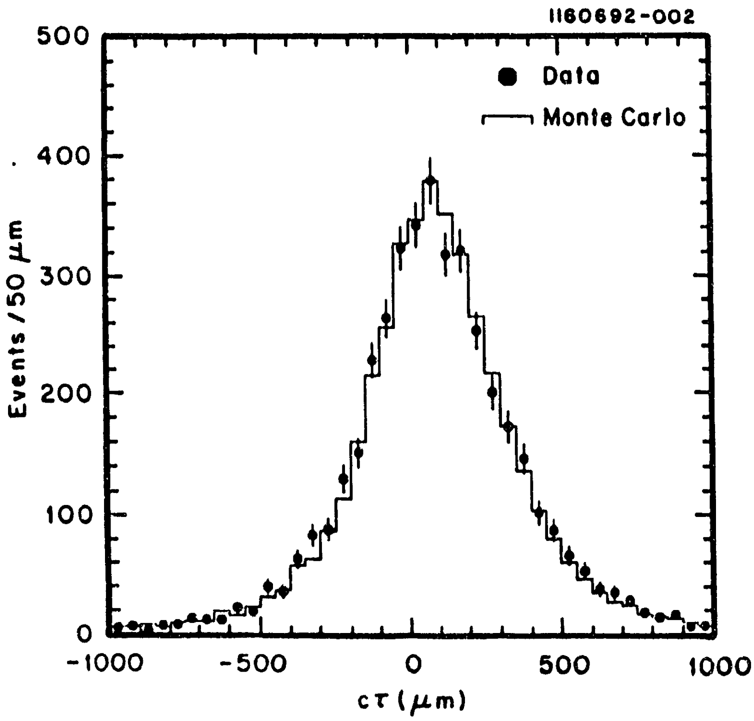


Figure 2

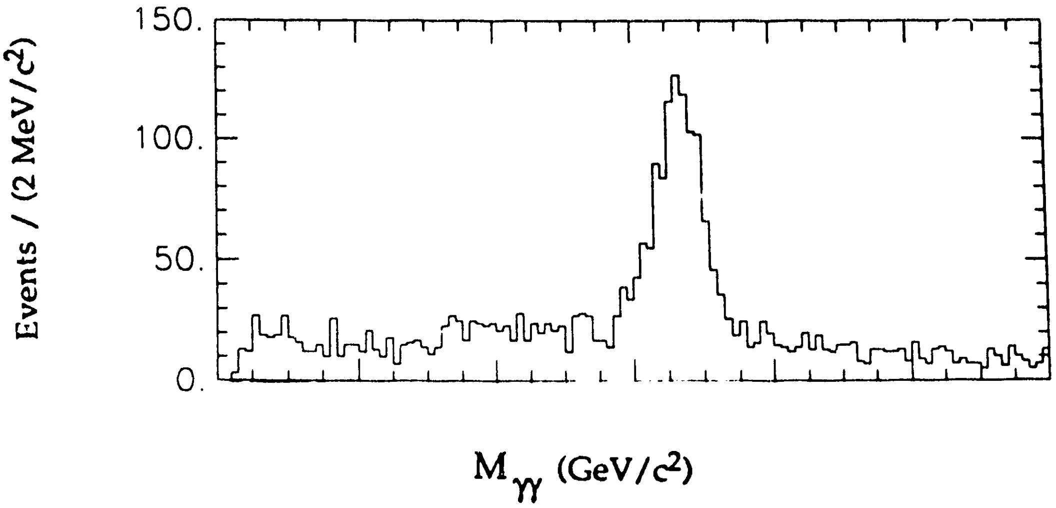


Figure 3

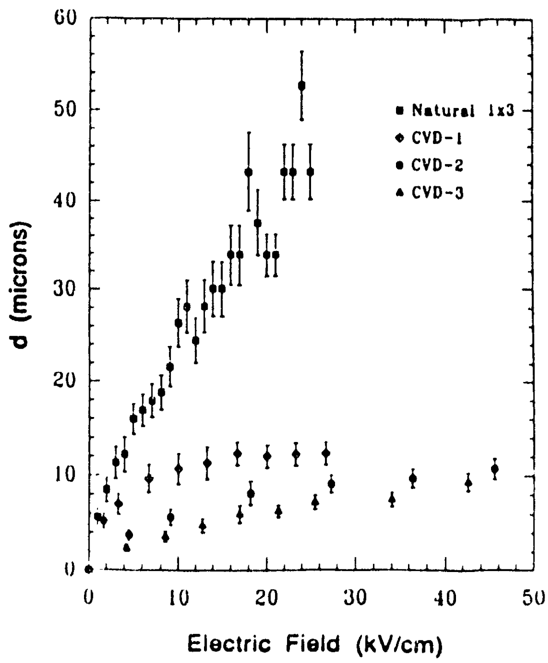
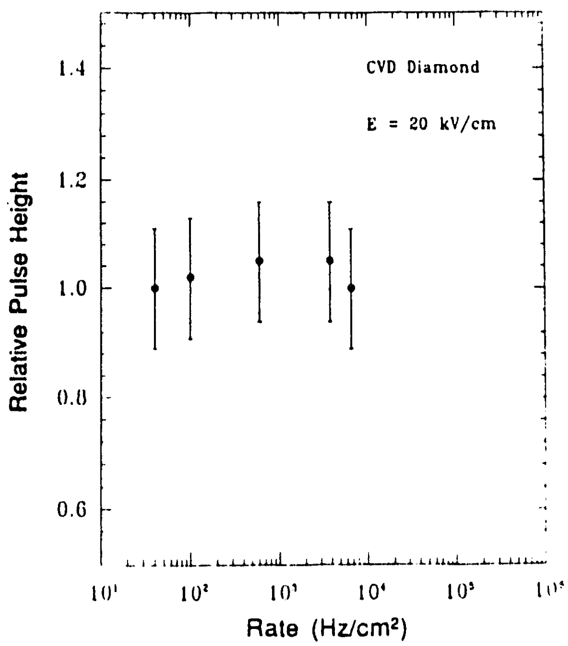


Figure 4



CVD Diamond
E = 20 kV/cm
Relative Pulse Height
1.4
1.2
1.0
0.8
0.6
Rate (Hz/cm²)

Figure 5

ASTROPHYSICS AND COSMOLOGY

TASK K

1. INTRODUCTION

As high energy physics moves beyond the standard model into the SSC era, astroparticle physics will play an increasingly valuable role in testing and constraining new models of elementary particle physics. In a very short period of time the Ohio State Astroparticle Physics Group (R.J. Scherrer, G. Steigman, T.P. Walker) has emerged as one of the preeminent groups in this important area of interdisciplinary research. The history and evolution of this group (Task K) is detailed in our 1991 Proposal. Here we review the work we have done and are doing in the time frame since the submission of that document (May 1991). Among the personnel highlights, we mention here that our previous postdoc, A. van Dalen, left in September 1991 and he is currently a postdoctoral fellow in Japan at the National Observatory in Tokyo. Also, Steigman's student, Ho Shik Kang, will be presenting and defending his Ph.D. thesis in May 1992. Ho Shik has received a postdoctoral research position with the High Energy Physics research group at the University of Pennsylvania. In Fall 1991 our group welcomed Masahiro Kawasaki from Tokyo as our new postdoctoral associate. Masahiro's work is described in the following.

Our group has received a great deal of recognition this year. The "News and Views" section of Nature discussed articles by Robert Scherrer (Aug. 1, 1991) and Terry Walker (Feb. 20, 1992). Gary Steigman was elected a Fellow of the American Physical Society for "pioneering work in the study of the Early Universe, which led to the interdisciplinary field of particle-cosmology". Steigman also received a 1992 Distinguished Scholar Award from The Ohio State University.

2. GARY STEIGMAN

Steigman's research continues the theme of utilizing the Universe — and the astrophysical objects it contains — as a laboratory for probing particle physics. Exploding stars, the early Universe and, the large scale structure of the Universe provide the crucial probes.

In Dr. Walker's section the work of Seckel, Steigman and Walker [1] exploring the sensitivity of current and proposed Water Cerenkov Detectors as probes of neutrino masses is described. The value of this study has been its analysis of the requirements for future detectors if they are to probe "interesting" ranges for neutrino masses.

Particle physics theories beyond the standard model offer candidates for the dark matter in the Universe. The nature of the dark matter is crucial for determining the origin and evolution of structure in the Universe. In the past, observations of large scale structure have led some to argue against neutrino masses in the range of several tens of eV. In Dr. Scherrer's section the work of Gratsias, Scherrer and Steigman [2] on "seeds" and "hot" dark matter is described.

Primordial Nucleosynthesis and the probes it provides for particle physics and cosmology is, by far, the dominant theme in Steigman's research. In this area Dr. Steigman has been very active this past year. In "Primordial Nucleosynthesis Redux" [3], Walker et al. have performed a state of the art comparison between BBN predictions and astronomical observations to constrain the number of "equivalent light neutrinos" ($\Delta N_\nu \leq 0.3$) and to bound the universal density of nucleons. The latter bound demonstrates that most of the baryons in the Universe are "dark" and strongly hints that most of the mass in the Universe is non-baryonic. The former constraint ($\Delta N_\nu \leq 0.3$) leads to significant bounds on (or, even eliminates!) theories beyond the standard model. For example, in work recently completed and submitted for publication [4,5], Bertolini and Steigman [4] and Steigman [5] have used this constraint to eliminate many particle physics models which attempt to incorporate a 17 keV neutrino.

A strongly first order quark-hadron transition could have resulted in a Universe whose baryon density was very inhomogeneous at the epoch of nucleosynthesis. The observed abundances of the light elements provide a probe of such processes. Steigman and Walker [6] have noted that Cosmic Ray Nucleosynthesis during the early Galaxy could have produced the observed abundances of Be and B while maintaining consistency between the observed Li and the predictions of "standard" (i.e., homogeneous) BBN. This offers a probe of the nature of the quark-hadron transition which may possibly be explored at various heavy ion accelerators.

The origin of the baryon asymmetry of the Universe is an important — and hotly debated — topic of current activity in high energy physics. Almost nothing is known of the lepton asymmetry of the Universe. Kang and Steigman [7] have explored the cosmological constraints on the lepton asymmetry ("neutrino degeneracy") and have shown that any such asymmetry must be small and will not permit a Universe with a critical density of baryons.

Finally, Mr. Kang's thesis research will be a valuable contribution to astroparticle physics. He is studying the evolution of weakly interacting, unstable particles in the early Universe. This work will impact virtually all studies where the Universe is used to provide constraints on "new physics." In particular, Mr. Kang will combine the existing accelerator data on the τ-neutrino with various cosmological arguments to constrain the mass and lifetime of ν_τ.

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Cosmological Constraints on Neutrino Degeneracy, H.S. Kang and G. Steigman, Nucl. Phys. B372, 494 (1992).

PREPRINTS/SUBMITTED 1991–1992

Cosmic Ray Nucleosynthesis in the Early Galaxy, G. Steigman (OSU-TA-20/91).

Seeded Hot Dark Matter Models with Inflation, J. Gratsias, R.J. Scherrer, G. Steigman and J.V. Villumsen (OSU-TA-1/92) Ap. J. Submitted.

Big Bang Nucleosynthesis Constraints on Light Scalars and the 17 keV Neutrino Hypothesis, S. Bertolini and G. Steigman (OSU-TA-2/92) Nucl. Phys. B. Submitted.

Galactic Evolution of D and ^3He, G. Steigman and M. Tosi (OSU-TA-3/92) Ap. J. Submitted.

Big Bang Nucleosynthesis Constraints on New Physics, G. Steigman (OSU-TA-5/92) To appear in the Proceedings of TAUP91 (Toledo, Spain; September 1991; eds. A. Morales, J. Morales & J.A. Villar; Elsevier).

INVITED TALKS/COLLOQUIA MAY 1991 – MAY 1992

Big Bang Nucleosynthesis Tests the Standard Models of Particle Physics and Cosmology, Max Planck Institut fur Physik Colloquium, Munich, Germany, May 14, 1991.

Big Bang Nucleosynthesis Tests the Standard Models of Particle Physics and Cosmology, Physics Department Colloquium, University of Bern, Bern, Switzerland, May 24, 1991.

Big Bang Nucleosynthesis Tests the Standard Models of Particle Physics and Cosmology, CERN Colloquium, Geneva, Switzerland, May 28, 1991.

Big Bang Nucleosynthesis Tests the Standard Models of Particle Physics and Cosmology, SISSA Colloquium, Trieste, Italy, May 22, 1991.

Particle Physics and Cosmology, Joint Physics Colloquium, University of Munich and Technical University Munich, Munich, Germany, June 3, 1991.

Big Bang Nucleosynthesis Constrains the Standard Models of Cosmology and Particle Physics, Seminar, Dipartimento di Fisica, Universita di Padova (Italy), July 9, 1991.

The Astro-Particle Physics Connection: The Universe as a High Energy Physics Laboratory, CERN Summer Student Lecture Program, Geneva, Switzerland, August 6, 1991.

Big Bang Nucleosynthesis: The Primordial Reactor Probes Particle Physics and Cosmology, CERN Summer Student Lecture Program, Geneva, Switzerland, August 7, 1991.

Cosmic Ray Nucleosynthesis in Population II Environments, Caltech Centennial Year Nuclear Astrophysics Symposium, Caltech, Pasadena, CA, August 14, 1991.

Primordial Nucleosynthesis Tests the Standard Models of Particle Physics and Cosmology, TAUP 91, Toledo, Spain, September 9, 1991.

Seeds, Hot Dark Matter, and Inflation, Invited Talk at The Many Aspects of Neutrino Physics Workshop, Fermilab, 14–17 November 1991.

Big Bang Nucleosynthesis Constraints on Light Scalars, Invited Talk at The Many Aspects of Neutrino Physics Workshop, Fermilab, 14–17 November 1991.

Cosmic Connections, Shapley Lecture of the American Astronomical Society, Wake Forest University, February 13, 1992.

The Primordial Nuclear Reactor, Physics Department Colloquium, Wake Forest University, February 13, 1992.

Cosmic Connections, Colloquium, Winston-Salem University, February 14, 1992.

Big Bang Nucleosynthesis, Society of Physics Students Physics Seminar, Wittenberg University, February 27, 1992.

Chair, Light Elements Session, National Academy of Sciences Colloquium on Physical Cosmology, Irvine, CA, 27–28 March 1992.

Primordial Nucleosynthesis Tests the Standard Models of Cosmology and Particle Physics, Physics Department Colloquium, University of Toledo, Toledo, OH, 14 April 1992.

Primordial Nucleosynthesis Tests the Standard Models of Cosmology and Particle Physics, Physics Department Colloquium, The Ohio State University, Columbus, OH, 21 April 1992.

Primordial Nucleosynthesis Tests the Standard Models of Cosmology and Particle Physics, Physics Department Colloquium, University of Kentucky, Lexington, KY, 24 April 1992.

Primordial Nucleosynthesis Tests the Standard Models of Cosmology and Particle Physics, Invited Talk, Ohio Section Meeting of the American Physical Society, Cincinnati, OH, 8–9 May 1992.

3. ROBERT SCHERRER

Much of my work over the past year has involved a study of cosmological constraints on particle physics models. With J. Cline, S. Raby, and D. Seckel (Bartol), I investigated a model for primordial nucleosynthesis in which the baryons are produced relatively late by the decay of gravitinos.[5] We were able to constrain the allowed mass for the gravitino in this model, but more importantly, we were able to show that, for certain mass ranges, the helium production is actually smaller than in the standard model, while the neutrino mass needed to provide the dark matter is sufficiently increased that the Tremaine-Gunn bound can be evaded. The latter effect may provide a testable prediction for the model. I also completed, with a graduate student (J. Gratsias) and David Spergel (Princeton) a study of constraints on a decaying particle which produces only neutrinos and other weakly-interacting decay products in the course of its decay.[1] We showed that these neutrinos can scatter off of background antineutrinos to produce electron-positron pairs, which can fission light elements. Decay modes of this type are usually described as "invisible", but our work allowed constraints to be placed on such decays. This is particularly interesting in light of the possible observation of a 17 keV neutrino; such a neutrino can be consistent with standard cosmological models only if it has such an "invisible" decay mode. I have been working with a graduate student (Andrew deLaix) to extend these results by examining other thermalization mechanisms for the neutrinos. Andrew has written a computer code to calculate the relative importance of the various thermalization mechanisms, and we hope to complete the project this summer. Our results should allow us to place tighter constraints on invisible particle decays. With David Spergel, I have just completed a study of astrophysical constraints on spatial and temporal variations of the Fermi coupling constant, using supernova light curves and primordial nucleosynthesis; this work will be submitted to Physical Review D within the next few weeks.[10]

I have continued to investigate models in which neutrinos with masses in the eV range form the dark matter of the universe. My original paper on these seeded hot dark matter models (with J. Villumsen, Ohio State Department of Astronomy, and E. Bertschinger, MIT) indicated that these models produced a distribution of galaxies in good agreement with the observations. Thus, neutrinos with masses in the eV range could provide the dark matter, eliminating the need for exotic new particles to fill this role. Because of the important implications of this model for theories of massive neutrinos, I have been exploring it in more detail. A graduate student (Matt Beaky), Villumsen, and I have examined the topology of the surfaces of constant density in this model.[7] We discovered that on small scales, the matter develops a cellular structure. This is quite different from the results of the standard cold dark matter model, and it should provide a means of distinguishing our model observationally from the cold dark matter model. Villumsen, Gary Steigman, Gratsias, and I have investigated a variant of the seeded hot dark matter in which the seed perturbations are combined with perturbations from inflation.[9] We have derived results for the streaming velocities and microwave anisotropies expected in this model. Our results indicate that the addition of inflation to the seeded hot dark matter model is probably necessary to provide microwave fluctuations in agreement with the recent COBE results. Villumsen, Gratsias, and I are presently developing a numerical simulation of this model.

A large number of recent particle physics models predict the existence of non-Gaussian "seed" perturbations in the early universe; an example is the global texture model. Bertschinger and I have developed a formalism to deal with the statistical properties of such models. We were able to derive analytic results for the density fields produced in such models.[4] I have extended this work to examine velocity fields generated in both seed models and "local" non-Gaussian fields which might be generated in certain inflationary models.[8] I was able to show that the velocity field in non-Gaussian models can actually be nearly Gaussian. I plan to investigate, in collaboraton with R. Schaefer (Bartol), the microwave anisotropies produced in non-Gaussian models. This work is of obvious importance given the recent discovery of microwave anistropies by COBE.

PUBLICATIONS

1] Indirect photofission of light elements from high-energy neutrinos in the early universe, John Gratsias, Robert J. Scherrer, and David N. Spergel, Physics Letters B, **262**, 298 (1991).

2] A quantitative measure of phase correlations in density fields, Robert J. Scherrer, Adrian L. Melott, and Sergei F. Shandarin, The Astrophysical Journal, **377**, 29 (1991).

3] Reviving massive neutrinos for large-scale structure, Robert J. Scherrer, In "Primordial Nucleosynthesis and Evolution of Early Universe", Eds. K. Sato and J. Audouze, Kluwer (1991).

4] Statistics of primordial density perturbations from discrete seed masses, Robert J. Scherrer and Edmund Bertschinger, The Astrophysical Journal, **381**, 349 (1991).

5] Gravitino-induced baryogenesis, primordial nucleosynthesis, and the Tremaine-Gunn limit, Robert J. Scherrer, James Cline, Stuart Raby, and D. Seckel, Physical Review D, **44**, 3760 (1991).

6] Cosmological explosions from cold dark matter perturbations, Robert J. Scherrer, The Astrophysical Journal, **384**, 391 (1992).

7] Topology of large-scale structure in seeded hot dark matter models, Matthew M. Beaky, Robert J. Scherrer, and Jens V. Villumsen, The Astrophysical Journal, **387**, 443 (1992).

8] Linear velocity fields in non-Gaussian models for large-scale structure, Robert J. Scherrer, The Astrophysical Journal, in press.

9] Seeded hot dark matter models with inflation, John Gratsias, Robert J. Scherrer, Gary Steigman, and Jens V. Villumsen, The Astrophysical Journal, submitted.

10] How constant is the Fermi coupling constant? Robert J. Scherrer and David N. Spergel, in preparation.

INVITED PRESENTATIONS

"Non-Gaussian Models for Large-Scale Structure", seminar, Bartol Research Institute, Dec. 1991.

"Velocity Fields in some Non-Gaussian Models for Large-Scale Structure", seminar, Fermilab, Mar. 1992.

"Velocity Fields in some Non-Gaussian Models for Large-Scale Structure", seminar, Washington University, Mar. 1992.

"Velocity Fields in some Non-Gaussian Models for Large-Scale Structure", seminar, University of Missouri, St. Louis, Mar. 1992.

"Non-Gaussian Models for Large-Scale Structure", colloquium, Department of Astronomy, Ohio State University, Apr. 1992.

"The New COBE Results: The Third Most Important Discovery in the History of Cosmology", colloquium, Department of Physics, Ohio State University, Apr. 1992.

4. TERRY WALKER

In the last year I have continued work that uses astrophysical and cosmological arenas to probe neutrino physics. With J. Cline (former OSU postdoc), I completed an analysis of the cosmological and astrophysical constraints on 17 keV neutrinos [1]. If the 17 keV neutrino continues to exist, these constraints are crucial to the construction of any model which hopes to incorporate it. D. Seckel (Bartol), G. Steigman , and I completed work which examined the feasibility of measuring a cosmologically interesting ($\sim$ 20 eV) neutrino mass from the next supernova [2] - masses below 75 eV are not likely to be accessible. Also finished, with K. Olive (Minnesota), D. Schramm (Chicago), and D. Thomas (Minnesota) was a project that examined bounds on neutrino degeneracy from primordial nucleosynthesis[3] - on the grounds of concordance between predicted and observed light element abundances, $\Omega_B = 1$ cosmologies can be made viable with an anomolously large neutrino degeneracy.

I also continued work which studies the production of primordial elements. The success of big bang nucleosynthesis (BBN) is critical to the standard big bang model as well as to its value as a delicate probe of particle physics beyond the standard model. G. Steigman, D. Schramm, K. Olive , H-S. Kang and I have re-examined the predictions of the BBN and their agreement with observation[4] - there is good agreement between prediction and observation provided: (1) the baryon-to-photon ratio, η, lies in the range $2.8 \leq 10^{10}\eta \leq 4.0$ (which corresponds to baryons comprising $\sim$5% of an $\Omega = 1$ Universe) and (2) the number of additional degrees of freedom (beyond the standard model) is less than 0.3 of a massless neutrino, in excellent agreement with collider results. With K. Olive and G. Steigman, I completed a detailed analysis of the upper bound to the primordial abundance of helium which, when coupled with the predictions of BBN, is the crucial test of the standard hot big bang model as well as the single observational measurement necessary for constraining physics beyond the standard model[5] - the upper bound from our analysis is consistent with the lower bound coming from the BBN predictions. Lastly, Steigman and I have proposed a mechanism which explains the observed abundance of Be in the Pop. II halo stars believed to contain primordial lithium[6]. Our mechanism, cosmic ray spallation in the early Galaxy, accounted for the observed Be while not making too much lithium and predicted an observable abundance of B (which was recently seen by the Hubble Space Telescope).

In the coming year I plan to complete several on-going projects related to neutrino physics. With my student , P. Kernan, I will complete the analysis of MSW neutrino oscillations in the presence of a sterile neutrino as a solution to the solar neutrino problem. These results are relevant to the SNO detector and are timely in light of the above mentioned work on 17 keV neutrinos which seems to indicate that a 17 keV neutrino requires ν_μ to be too heavy to participate in solar neutrino oscillations. I will also finish up work with K. Freese (Michigan) on cosmological constraints on the neutrino magnetic moment. In addition, I will continue work on 17 keV neutrino if it survives till summer. Lastly, Kernan and I are examining the effects of finite temperature corrections to the weak rates on the BBN production of helium. The goal is to determine in a systematic way how accurately we can predict the yield of primordial helium.

PUBLICATIONS

(1). Constraints on 17 keV Neutrinos (with J. Cline), *Phys. Rev. Lett.***68**, 270(1992).
(2). Neutrino Masses from Galactic Supernova and Large Water Cerenkov Detectors (with D. Seckel and G. Steigman), *Nucl. Phys.***B366**, 233(1991).
(3). Neutrino Degeneracy and Primordial Nucleosynthesis (with K.A. Olive, D.N. Schramm, and D. Thomas), *Phys. Lett.***B 265**, 239(1991).

(4). Big-Bang Nucleosynthesis Redux (with G. Steigman, D.N. Schramm, K.A. Olive, and H-S Kang, *Astrophys. J.* **376**, 51(1991).
(5). The Primordial Abundance of ^{4}He and the Standard Model of Big Bang Nucleosynthesis (with K.A. Olive and G. Steigman) *Astrophys. J.Lett.* **3 80**, L1(1991).
(6). Production of Li, Be, and B in the Early Galaxy (with G. Steigman), *Astrophys. J.Lett.* **385**, L13(1992).
(7). 4 Lectures on the Standard Model of Cosmology, to appear in *Proceedings of the ICTP Summer School in High Energy Physics and Cosmology* (Trieste - World Scientific)(1991).
(8). The 17 keV Neutrino in Cosmology and Astrophysics, to appear in *Proceedings of the ICTP Workshop on Phenomenology in High Energy Physics and Cosmology* (Trieste - World Scientific)(1991).

INVITED PRESENTATIONS

-ICTP Summer School on Particle Physics and Cosmology ("4 Lectures on the Standard Model of Cosmology" - July, 1991 Trieste, ITALY)
-ICTP Workshop on High Energy Physics (Review Talk - "The 17 keV Neutrino in Cosmology and Astrophysics" - July, 1991 Trieste, ITALY)
-1991 TAUP Conference (Review Talk - "Cosmological and Astrophysical Constraints on a 17 keV Neutrino" - September, 1991 Toledo, SPAIN)
-Fermilab Workshop on The Many Aspects of Neutrino Physics ("Big Bang Nucleosynthesis and a 17 keV Neutrino" - November, 1991 Batavia, IL)
-University of Michigan High Energy Physics Seminar ("17 keV Neutrinos in Astrophysics and Cosmology" - October, 1991 Ann Arbor, Michigan)
-Oberlin College Physics and Astronomy Colloquium ("The Problem With Solar Neutrinos" - October, 1991 Oberlin, Ohio)

5. MASAHIRO KAWASAKI

(1) Reheating of the Universe

The period from $z \simeq 1000$ to $z \simeq 5$ is the least known in the thermal history of the universe. The recent observations of the COBE satellite place a strong constraint on the thermal history in this period. We, therefore, investigated observational constraints on reheating of the universe between redshift $z = 1000$ and $z = 3$[1]. It was found that for some parameter range the reheating is consistent with all observations including the recent COBE experiment. This result can be applied to various energy sources like black holes or decaying particles.

(2) SUSY Dark Matter

The lightest neutralino is one of the promising candidates for the dark matter in the universe. We calculated the relic abundance of the lightest neutralino in the scheme of the grand unified theories coupled to N=1 supergravity[2]. It was found that the lightest neutralino with mass below 1TeV can be dark matter and its abundance can amount to the critical density which is required by the inflationary universe.

(3) Early Decaying Neutrino

We studied the cosmological effects of massive neutrino which decays into invisible particles before the primordial nucleosynthesis epoch. The inverse decay process plays an important role in this case. The numerical code was developed to solve the Boltzmann equation including the invese decay process. We are going to apply this to nucleosynthesis and get the constraint on the lifetime and the mass of τ-neutrino.

PUBLICATIONS

[1] "Observational Constraints on Reheating", M. Fukugita and M. Kawasaki, preprint YITP/K-947 (1991).
[2] "The Relic Abundance of the Neutralino in the Grand Unified Theories Coupled to N=1 Supergravity", M. Kawasaki and S. Mizuta, preprint OSU-TA-4/92 (1992).

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