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RESEARCH ON ELEMENTARY PARTICLE PHYSICS

Annual Progress Report

for Period November 1, 1992–October 31, 1993

Principal Investigator: L. E. Holloway

University of Illinois at Urbana-Champaign
Department of Physics
Loomis Laboratory of Physics
1110 West Green Street
Urbana, Illinois

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ABSTRACT

This report describes the activities of the University of Illinois Experimental High Energy Physics Group. The physicists in the University of Illinois High Energy Physics Group are engaged in a wide variety of experiments at current and future accelerator laboratories. These include:

- 1) The CDF experiment at the Fermilab Tevatron $\bar{p}p$ collider.
- 2) Design and developmental work for the SDC group at SSCL.
- 3) Experiments at the wide band photon beam at Fermilab.
- 4) e^+e^- experiments, the Mark III and SLD at SLAC and CLEO at Cornell.
- 5) CP violation experiments at Fermilab.
- 6) The HiRes cosmic ray experiment at Dugway Proving Grounds, Utah.
- 7) Computational facilities.
- 8) Electronics systems development.

Many of the University of Illinois physicists collaborate on several experiments with different colleagues and outside groups in order to make up teams that will allow them to study the physics in which they are interested. In this sense, and in the sharing of common equipment and facilities, the University of Illinois physicists constitute one large group.

COLLIDING BEAM STUDIES AT FERMILAB

D. Errede, S. Errede, L. Holloway, D. Kardelis, R. Keup, T. LeCompte, T. Liss, C. Luchini, A. Martin, V. Simaitis, R. Swartz, M. Vondracek, T. Westhusing, in collaboration with physicists of the Collider Detector Group

OVERVIEW

The Collider Detector at Fermilab (CDF) is a multipurpose detector used in studying proton anti-proton collisions at the Fermilab Tevatron Collider. The center of mass energy of the $p\bar{p}$ system is 1.8 TeV.

The Illinois group has primary responsibility for the central muon, the central drift tubes, and the central muon upgrade systems, their associated readout and trigger electronics, offline calibration and analysis software. The Illinois group is currently participating in run Ia of the Tevatron collider. To date almost 20 inverse picobarns of data have been collected, a factor of 5 over the last run. We are finishing several analyses using the data acquired in the 1988-1989 collider.

THE CENTRAL MUON SYSTEM

The purpose of this system is to provide precise position measurements of muons which penetrate the central electromagnetic and hadron calorimeters and to provide a signal suitable for triggering on potentially interesting events containing muons. One hundred forty four modules containing a total of 2304 drift channels were fabricated, tested, and installed into the CDF. The performance of the central muon chambers during the 1989 CDF run was excellent and has continued in the present run Ia.

THE CENTRAL DRIFT TUBE ARRAY

An array of 2016 drift tubes organized in three close-packed layers surrounding the central tracking chamber has been designed, fabricated and installed in CDF. The purposes of this detector component are to aid in offline track reconstruction, by providing 3D information at a radius of 1.4m, and to augment the ultimate offline momentum resolution by 10% (important for high-PT tracks).

Each element of the CDT array consists of a thin-walled cold-drawn stainless steel tube 12.7 mm in diameter x 3.0 long, operated in the limited streamer mode. The electronics readout is identical to that of the central muon chambers. Both drift timing and charge division are measured. Calibration of the array is achieved via Fe55 sources embedded at the ends of each tube and with collision data. The Z-resolution from charge division is measured to be 0.1% L.

The CDT array has continued to operate successfully during the Tevatron run Ia.

THE CDF MUON UPGRADE

In collaboration with Harvard University and The University of Tsukuba we have built an upgrade to the CDF muon detection system. The upgrade consists of two parts, the Central Upgrade and the Central Extension. The Central Extension extends the muon coverage out to zenith angles of 45 degrees with respect to both the proton and anti-proton directions (the present Central Muon system covers out to 56 degrees) giving us an approximately 40% increase in acceptance for $W \rightarrow \mu\nu$ events and approximately a factor of two increase in acceptance for high mass dimuons from all sources, including top production. The Central Upgrade, which built at the University of Illinois, consists of adding an additional 60cm of steel behind the current Central Muon system followed by a second set of muon chambers. This additional absorber and second set of muon

chambers will reduce the hadronic contamination of the muon signal by a factor of 20. This allows us to keep trigger thresholds constant as the luminosity of the Tevatron increases over the next several runs. In addition, there is a significant impact on the offline analysis of muons where the background from non-interacting hadrons is virtually indistinguishable from a true muon signal. The level of this background is directly related to the sensitivity to rare physics processes involving muons.

The Central Upgrade consists of 858 21 foot long drift chambers each 1 inch by 6 inches in cross section. The chambers will be arrayed in 4 half-cell staggered layers outside the additional steel and will provide a track segment to be matched to the track segment in the inner muon chambers. The total area covered by the Central Upgrade is over 2000 square feet.

The Central Upgrade which was originally approved, and which is currently operating, leaves some holes in the ϕ coverage, primarily between the magnet return yoke pieces on the top and bottom of the detector. When we first proposed the upgrade those areas were "off limits" because of cabling to the central calorimeter and cooling air for the calorimeter electronics. The muon upgrade has now taken on an increased importance within the collaboration because people have begun to realize the impressive physics potential of a fully upgraded muon system, and because of the ever increasing luminosity goals of the Tevatron which necessitates further reductions in the trigger cross section. We are now working on a design for filling these previously "off limits" gaps and have just begun construction of additional chambers to complete the coverage for the scheduled 1993 run.

The implementation of the muon upgrade for the CDF detector will have a profound impact on both the quality and the type of physics done at CDF. In conjunction with the silicon vertex detector, which is now operational, CDF has a

powerful detector with which to do heavy flavor physics. The upgraded muon system allows us to trigger on dimuons with transverse momenta as low as 1.8 GeV/c and on inclusive single muons with transverse momentum above 6 GeV/c. Together with an offline displaced vertex cut, we are able to extract rather clean b samples from both the single and dimuon triggers. Physics goals for the current run include measurement of the B_s mass through the decay $B_s \rightarrow \psi\phi, \phi \rightarrow K^+K^-$. The ratio of the production cross sections B_s/B_d which, together with a measurement of the combined mixing of B_d and B_s , will allow an extraction of the mixing rate for B_s alone (note that e^+e^- mixing results at the $\Upsilon(4s)$ measure B_d mixing alone), rare decay modes of B_s , lifetime measurements of B_s etc. Certainly one must not forget that the enhanced muon system together with the silicon vertex detector also gives us an excellent handle for finding the top quark should its mass be accessible at the Tevatron. Since the standard model top quark (which we now know to be heavier than 90 GeV) decays to a W and a b quark, we can tag these decays by looking for a high transverse momentum muon and a displaced vertex from the b decay. For all of these topics and more, we are increasing our acceptance with the upgraded muon system and at the same time improving our efficiency for identifying the events with the vertex detector.

The construction of the CDF muon upgrade chambers which began in late 1989 was completed in mid-1991. In early 1991, while we were still building chambers at the University of Illinois, we began installation of the chambers at CDF. The installation of the chambers occurred in stages and was completed in March of 1992. In addition to this, a large portion of the muon trigger electronics was built here at Illinois and this was installed and tested in November and December of 1991.

At the present time we are extremely busy taking and analyzing data from the new chambers. In the data taken so far, the performance of our new chambers has been excellent. We are anticipating an exciting run at the Tevatron Collider.

PHYSICS RESULTS

The physics results from the 1989 data arising from central muon triggers are significant. Thus far, we have a data sample of six hundred $W \rightarrow \mu\nu$ candidates, 150 $Z \rightarrow \mu^+\mu^-$ candidates, several thousand low-mass dimuons, a strong signal for $J/\psi \rightarrow \mu^+\mu^-$ is observed as well as upsilon production in 1.8 TeV collisions via T and $T' \rightarrow \mu^+\mu^-$. The low-mass Drell-Yan muon pairs are of interest for small- x physics; like-sign and opposite-sign di-leptons contain information relevant to $B\bar{B}$ mixing. In addition, we are also searching for evidence of the top quark, via their semi-leptonic decays. The CDF lower bound on the mass of the top quark at the present stage of the analysis is 108 GeV/c².

The analysis of the data is proceeding well. Attention is focused on the physics signals associated with muons and electrons in the central region. Among the topics being studied by Illinois PhD students are:

- 1) $W\gamma$ and $Z\gamma$ Production at $\sqrt{s} = 1.8$ TeV.
(Chris Luchini. Work in progress.)
- 2) The ratio of W to Z production cross sections.
(Ray Schwartz. Work in progress.)
- 3) Z production at $\sqrt{s} = 1.8$ TeV
(David Kardelis. Work in progress)

PhD degrees granted:

- 1) Measurement of Drell-Yan production of di-muon pairs.
(Victor Scarpine. Submitted to Physical Review.)

PUBLICATIONS

"A Measurement of the B Meson and b Quark Cross Sections at $\sqrt{s} = 1.8$ TeV Using the Exclusive Decay $B^0 \rightarrow J/\psi K^*(892)^0$," F. Abe et al., The CDF Collaboration, to be submitted to Phys. Rev. D or Rapid Communications.

**

"A Measurement of the Bottom Quark Production Cross Section in 1.8 TeV Proton-Antiproton Collisions Using Semileptonic Decays to Muons," F. Abe et al., The CDF Collaboration, to be submitted to Phys. Rev. Lett.

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"Inclusive χ_c and b-quark Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, to be submitted to Phys. Rev. Lett.

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"A Search for First-Generation Leptoquarks in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV at CDF," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. D, Rapid Communications, April 1, 1993. Also, FERMILAB-PUB-93/070-E.

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"A Measurement of Jet Multiplicity in W Events Produced in $\bar{p}p$ Collisions at $s = 1.8$ TeV," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. Lett. March 25, 1993.

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"The Center-of-Mass Angular Distribution from Prompt Photons Produced in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. Lett. March 1, 1993. FERMILAB-PUB-93/-32-E.

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"A Study of Four-Jet Events and Evidence for Double Parton Interactions in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. D, January 8, 1993. FERMILAB-PUB-93/003-E.

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"Search for $\Lambda_b \rightarrow J/\psi \Lambda^0$ in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, submitted to Physical Review D, Rapid Communications, January 11, 1993. FERMILAB-PUB-92/250-E.

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"Comparison of Jet Production in $\bar{p}p$ Collisions at $\sqrt{s} = 546$ and 1800 GeV," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. Lett. October 19, 1992. FERMILAB-PUB-92/286-E.

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"Analysis of Jet Charged Momentum Distributions for Quark-Gluon Separation in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, to be submitted to Phys. Rev. D.

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"Inclusive J/ψ , ψ' and b-Quark Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 69, 3704 (1992). FERMILAB-PUB-92/236-E.

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"Search for Squarks and Gluinos from $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 69, 3439 (1992). FERMILAB-PUB-92/221-E.

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"Measurement of Drell-Yan Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, to be submitted to Phys. Rev. Lett.

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"Limits on the Production of Massive Stable Charged Particles," F. Abe et al., The CDF Collaboration, Phys. Rev. D, Rapid Communications, 46, R1889 (1992). FERMILAB-PUB-92/152-E.

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"A Measurement of the Bottom Quark Production Cross Section Using Semileptonic Decay Electrons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, submitted to Phys. Rev. Lett. April 19, 1993. FERMILAB-PUB-93/091-E.

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"The Dijet Angular Distribution at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 69, 2897 (1992). FERMILAB-PUB-92/182-E.

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"A Measurement of the Production and Muonic Decay Rate of W and Z Bosons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 69, 28 (1992). FERMILAB-PUB-92/69-E.

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"A Limit on the Top Quark Mass from Proton-Antiproton Collisions at $\sqrt{s} = 1800$ GeV," F. Abe et al., the CDF Collaboration, Phys. Rev. D. 45, 3921 (1992). FERMILAB-PUB-91/352-E.

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"Properties of Events with Large Total Transverse Energy Produced in Proton-Antiproton Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. D. 45, 2249 (1992). FERMILAB-PUB-91/283-E.

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"A Lower Limit on the Top Quark Mass from Events with Two Leptons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 68, 447 (1992).

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"Measurement of the Ratio $\sigma(B \rightarrow \tau \nu) / \sigma(B \rightarrow e \nu)$ in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV, as a Test of Lepton Universality," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 68, 3398 (1992). FERMILAB-PUB-91/356-E.

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"Measurement of $B^0 \bar{B}^0$ Mixing at the Fermilab Tevatron Collider," F. Abe et al., The CDF Collaboration, Phys. Rev. Lett. 67, 3351 (1991). Fermilab PUB-91/201-E.

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Conference Proceedings and Conference Talks

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"Recent Results and Prospects from the Collider Detector at Fermilab," The CDF Collaboration, T. M. Liss, Invited abstract submitted to the Spring Meeting of the American Physical Society, Washington, DC, April 12-15, 1993.

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"Measuring the Mass of the W with Muons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV," The CDF Collaboration, R. W. Keup, Abstract submitted to the Spring Meeting of the American Physical Society, Washington, DC, April 12-15, 1993.
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"Search for Top Quark Production in Muon Plus Jets at the Collider Detector at Fermilab," The CDF Collaboration, A. J. Martin, Abstract submitted to the Spring Meeting of the American Physical Society, Washington, DC, April 12-15, 1993.
**

Solenoidal Detector Collaboration at the SSC

Steve Errede, Tony Liss, Jon Thaler, and Jim Wiss

Scientific and Professional Staff:

Todd Brandys, Deborah Errede, Steve Errede, Rob Gardner, Eric Hughes,
Tony Liss, Dan McLaughlin, Jon Thaler, and Jim Wiss

TASK SUMMARY

We are working on two parts of the SDC detector, the data acquisition (DAQ) and muon subsystems. We describe each part separately.

A: SDC DAQ Design

We are working on two aspects of the design of the SDC data acquisition (DAQ) subsystem: the comparison via simulation, of alternative DAQ designs, and the incorporation of diagnostics and monitoring. Mike Haney is the leader of the simulation work (DAQSIM), which involves groups at the SSCL and UC Irvine as well as Illinois. Jon Thaler is working on the design of DAQ monitoring. He also is a member of the integrated systems engineering working group (ISEWG), which is responsible for the coordination of the design of the various front end subsystems, the DAQ, and the online processor farm.

B: SDC Muon Subsystem

We are in the process of setting up a drift tube production facility for the fabrication of 700 SDC muon tubes for the Intermediate Muon portion of the SDC Muon Subsystem. We have converted our high-bay laboratory from production of CDF Muon Upgrade chambers to SDC muon tube production. Many specialized tools, jigs, fixtures, etc. are being made, and various test-stands for quality assurance are

being set up. A clean room has been put together for wire stringing and assembly of drift tubes.

PROJECT DESCRIPTIONS

The SDC collaboration is working on the design and construction of a large general purpose detector which will take data at the Superconducting Super Collider in Waxahachie, Texas. We are presently in the design and prototyping phase of development.

Physics Program

The SDC physics program is very diverse. The most prominent goal is the study of the mechanisms responsible for electroweak symmetry breaking, which is expected to lead to the discovery of the Higgs particle or its dynamical equivalents. Other goals include the study of the properties of the top quark, the search for supersymmetric particles, and the search for quark and lepton substructure.

It has proved difficult in the past to predict the direction that research will take at hadron machines. For this reason, it is important to build the most versatile detector possible. We plan that the SDC will be sensitive to unexpected phenomena as well as the ones that we anticipate.

ILLINOIS HARDWARE AND SOFTWARE RESPONSIBILITIES

A: SDC DAQ Design

At this stage of DAQ design, we are not building hardware. Our work concentrates on the modeling and simulation of proposed designs. This serves a similar function as does Monte Carlo simulation for the study of a detector's physics capabilities. We expect that within the next year the DAQ design will begin to

stabilize, and prototype components will be built. At that time, previous design studies that we did within the SSC generic R&D program will speed the construction of the final SDC DAQ subsystem.

B: SDC Muon Subsystem

We are responsible for the fabrication of all drift tubes for the SDC Intermediate Muon Subsystem, which is composed of two complete sets of octant modules, totaling 11,200 drift tubes. Our activities for this year are focused on setting up a drift tube production facility for the fabrication of 700 drift tubes, enough to build one octant module. We are working in collaboration with the University of Wisconsin and the University of Minnesota, who are responsible for the Intermediate Muon module assembly and Intermediate Muon scintillation counters, respectively.

We have also done extensive, detailed analytic and Monte Carlo simulation studies of the overall SDC Muon Subsystem design, on issues related to the optimization of the muon chamber layer configuration(s), momentum resolution, level-1 and level-2 triggerability, track matching and muon chamber alignment criteria and tolerances. We intend to continue these studies.

GOALS and MAJOR RESULTS to DATE

A: SDC DAQ Design

Major Results to Date

The major result that has emerged from our work is the acceptance by the SDC collaboration of the usefulness of behavioral modeling and simulation. We were able to demonstrate that simulations of DAQ performance can reveal important features

(such as data rate limitations) of proposed designs which would not be apparent otherwise, even to the trained eye.

Status of Our Detector Work

We are working on two DAQ projects at this time. The first is the creation, in collaboration with SSCL and UCI, of a DAQ modeling and simulation program (DAQSIM), written in MODSIM. Our goal is to be able, before the end of 1993, to study proposed DAQ implementations. We will use DAQSIM to guide the design of the data acquisition subsystem and to specify its behavior and communications with other SDC subsystems.

We also are working on the incorporation of diagnostic, monitor, and control methods into the trigger and DAQ. One objective is the use of a common format for the communication between the various front end subsystems and the humans who operate the detector. Our goal is to issue a requirements document to the collaboration before the end of 1993. To achieve this goal, we need to gather information from each of the subsystems so that we can identify a common set of diagnostic needs. This work is being done as part of the ISEWG, which has the responsibility to maintain an integrated detector design.

B: SDC Muon Subsystem

Major Results to Date

We have contributed in a major way to the design of the overall SDC Muon Subsystem, in terms of the overall number of layers, layer placement, muon momentum resolution, muon chamber alignment criteria and triggering issues. Much of this work is incorporated into the muon section of the SDC Technical Design Report.

Status of Our Detector Work

We are in the process of completing the SDC Intermediate Muon drift tube production facility, and fabricating a small quantity (50) of prototype drift tubes. A CAMAC-based DAQ cosmic-ray test stand and other testing facilities are being set up. We will begin production of the first 700 drift tubes this summer. They are to be shipped to the University of Wisconsin for assembly into the first Intermediate Muon octant module.

PUBLICATIONS

T. Brandys, M. Haney, E. Hughes, and G. Tharakan, "A Prototype DCC Chip for the SDC," presented to the IEEE NSS, October, 1992.

T. Brandys, M. Haney, and E. Hughes, "SDC Data Acquisition Simulation with MODSIM," to be presented at Real Time '93, June, 1993.

SSC SOLENOIDAL DETECTOR TECHNICAL NOTES

SDC-89-00001 FIRST DAY PRESENTATIONS, DALLAS SOLENOIDAL DETECTOR MEETING, JUNE 26-29, 1989 (Copies of transparencies) G. Gilchriese, R. Cahn, H. Williams, S. Mori, H. Ogren, H. Sadrozinski, H. Gordon, M. Pripstein, D. Bintinger, A. Lankford, S. Errede

SDC-89-00002 WORKING GROUP REPORTS, DALLAS SOLENOIDAL DETECTOR MEETING, JUNE 26-29, 1989 (Copies of transparencies) G. Hanson, G. Abrams, J. Bensinger, S. Errede, P. Sinervo, D. Theriot

SDC-89-00015 MUON DETECTOR MOMENTUM RESOLUTION J. Wiss, S. Errede
Nov. 15, 1989

SDC-89-00016 SSC MUON ACCEPTANCE STUDIES S. Errede Nov. 15, 1989

SDC-91-144 BARREL MUON DETECTOR DESIGN CONSIDERATIONS Jim Wiss
January 10, 1990

SDC-91-145 ANGLE DEPENDENCE OF FORWARD MUON MOMENTUM
RESOLUTION Jim Wiss September 12, 1990

SDC-91-146 COMPARISON OF MUON MOMENTUM RESOLUTION FOR THE
SOLENOIDAL DETECTOR VERSUS MUON MOMENTUM RESOLUTION
FOR EXTERNAL-ONLY MUON SYSTEMS Steve Errede March 8, 1990

SDC-91-147 ACCEPTANCE AND MASS RESOLUTION STUDIES FOR SDC
MUON EOI SUBSYSTEM DESIGN Jim Wiss and Steve Errede October 4,
1990

SDC-91-148 ACCEPTANCE AND ON-LINE MASS RESOLUTION STUDIES FOR
SDC LOI MUON SUBSYSTEM DESIGN Jim Wiss and Steve Errede January
8, 1991

SDC-91-149 ACCEPTANCE AND OFFLINE MASS RESOLUTION STUDIES FOR
SDC MUON LOI SUBSYSTEM DESIGN Steve Errede January 8, 1991

SDC-91-150 SDC MUON PHYSICS ACCEPTANCE IMPACT IF DELETE THE
FORWARD MUON SYSTEM Steve Errede May 30, 1991

SDC-91-151 EFFECTS OF DESCOPING OPTIONS FOR THE MUON SYSTEM
Jim Wiss August 1, 1991

SDC-91-152 OCTAGONAL GEOMETRY EFFECTS Jim Wiss September 23, 1991

SDC-91-153 ALIGNMENT RESOLUTION STUDIES OF THE MUON SYSTEM Jim
Wiss October 26, 1991

SDC-91-154 MUON SYSTEM ALIGNMENT STUDIES Jim Wiss October 30, 1991

SDC-91-155 BW3-BW2 RADIAL SEPARATION STUDIES Jim Wiss November 9,
1991

SDC-91-156 MUON MATCHING STUDIES Steve Errede, Jim Wiss and Rob
Gardner November 11, 1991

SDC-91-157 CHAMBER RESOLUTION STUDIES Jim Wiss November 26, 1991

SDC-92-201 TECHNICAL DESIGN REPORT The Solenoidal Detector Collaboration
April 1, 1992

SDC-92-214 GENERAL MUON RESOLUTION CALCULATIONS Jim Wiss
January 23, 1992

SDC-92-215 MORE MUON MOMENTUM RESOLUTION CALCULATIONS Jim
Wiss February 25, 1992

SDC-92-220 SDC MUON ACCEPTANCE AND MASS RESOLUTION STUDIES
Steve Errede February 25, 1992

SDC-92-221 STUDIES OF HEAVY $W \rightarrow \mu\nu$ AND $Z \rightarrow \mu^+\mu^-$ PRODUCTION AND
RADIATIVE DECAY February 25, 1992 Steve Errede

SDC-92-238 PHYSICS IMPACT OF PHI CRACKS IN THE SDC BARREL MUON
SYSTEM April 6, 1992 Steve Errede, Jim Wiss

SDC-92-270 MORE ON LAYER PLACEMENT May 22, 1992 Jim Wiss

SDC-92-271 MORE ON MUON MATCHING (LAYER PLACEMENT) Steve Errede,
Rob Gardner, Jim Wiss April 8, 1992

SDC-93-476 RATIOS OF $W\gamma$ AND $Z\gamma$ CROSS SECTIONS: NEW TOOLS IN
PROBING THE WEAK BOSON SECTOR AT THE TEVATRON AND THE
SSC March 23, 1993 Ulrich Baur, Steve Errede, Jim Ohnemus

Neutral Beams at Fermilab

Scientific and Professional Staff

J. Wiss, R.W. Gardner, R. Culbertson

R. Greene, D. McGlaughlin

Overview

E687 represents a collaboration between the University of Illinois, and other groups from the United States and Italy. This experiment, a continuation of our neutral beam efforts at Fermilab dating from 1972, studies high energy photoproduction at ≈ 200 GeV with an emphasis on the photoproduction of charmed particles.

E687 is a multiparticle magnetic spectrometer with excellent particle identification, calorimetric, and lifetime tagging capabilities. Lifetime tagging is provided by a fine pitch silicon microstrip detector which offers a proper time resolution of about 0.045 picoseconds for charm particles – roughly 1/10 the D^0 lifetime. Charged particle identification is provided by a Cerenkov system which consists of three ≈ 100 cell Cerenkov counters. The spectrometer features fine grain electromagnetic shower calorimetry and an extensive array of muon counters shielded against hadron punch through by steel walls. A complete description of the E687 detector can be found in Reference (1).

The University of Illinois group has played a significant role in all aspects of E687 including the construction of one of our three Cerenkov counters, the construction of several components of the data acquisition system, and contributions to the E687 trigger hardware. Our major contribution to the experiment has been in the area of software development and data analysis. Contributions to the experimental data reduction software including the algorithms for Cerenkov identification of charged particles, the programs for the identification and measurement of neutral Vees, magnetic field tracing and chamber alignment, the vertex finder used to tag charm particles, and many of the routines to reduce our huge data samples down to a manageable size by skimming off events contain-

ing charm. The University of Illinois contributions to the (published) E687 data analysis effort include, studies of the performance of the E687 spectrometer⁽¹⁾, measurements of the D^0 & D^+ lifetimes⁽²⁾, new measurements of Cabibbo suppressed branching ratios⁽³⁾, Dalitz amplitude analyses⁽⁴⁾, measurement of the form factors⁽⁵⁾ for $D^+ \rightarrow \overline{K}^{*0} \mu^+ \nu$ decay, and a study of $D\overline{D}$ correlations⁽⁶⁾ in events with two fully reconstructed charm particles. We also wrote and maintain the experiment's Monte Carlo program.

In 1988 we concluded our first major data run of the experiment in which 80 million photo-hadronic triggers were recorded. The analysis of this data is complete and we have published results on a sample of about 10,000 fully reconstructed charm particle decays. Our second data run of the experiment was completed in early 1991 in which 525 million triggers recorded resulting in an fully reconstructed charm sample of about 100,000 fully reconstructed charm particles.

1992 Accomplishments

Data reduction and the distribution of data summary tapes to all member institutions was completed in 1992. We played significant roles in the processing and certification of this data during the last year. Lately our primary efforts have been in data analysis both in extracting charm physics from the data and in upgrading both the hardware simulation and physics simulation of our Monte Carlo. Quite a bit of effort at the University of Illinois has gone into recent upgrades of the E687 Monte Carlo. Studies of detector performance were used to upgrade the E687 Monte Carlo to accurately simulate 1990/91 data as well as 1987/88 data. We have also re-written the physics generators of the E687 Monte Carlo to incorporate the LUND-Pythia model of photon-gluon fusion and quark fragmentation. Generally speaking this model does an excellent⁽⁶⁾ job at reproducing many features of high energy charm photoproduction.

E687 has made substantial progress in data analysis since last year. We are about to submit a paper on the masses and widths of several $L = 1$ D^{**} states

including the D^{*++} , D^{*+} and D_s^{*+} . We have recently submitted papers on the lifetime of the D_s^+ based on the analysis of the data from the 1990-1991 run⁽⁷⁾ which represents a significant advance over previous measurements and are in the process of preparing papers on the D^+ and D^0 lifetimes using this large data sample. We have published a series of papers on charm baryon spectroscopy and lifetimes. These include a new precise⁽⁸⁾ measurement of the lifetime of the Λ_c^+ , and measurements of the lifetimes^(9,10) of the Ξ_c^+ and Ξ_c^0 based on dramatically higher statistics than previous measurements. Our final baryon result⁽¹¹⁾ was a first observation of $\Omega_c^0 \rightarrow \Omega^- \pi^+$ which is a ground state baryon constructed from ssc quarks. The below table gives a summary of E687 results on meson lifetimes and baryon spectroscopy and lifetimes.

E687 Charm Particle Lifetimes

	τ (ps)
D^0	$.42 \pm .011 \pm .007$
D^+	$1.075 \pm .040 \pm .018$
$^\dagger D_s^+$	$0.472 \pm 0.020 \pm 0.010$
$^\dagger \Lambda_c^+ (udc)$	$0.215 \pm 0.016 \pm 0.008$
$^\dagger \Xi_c^0 (csd) (2462)$	$0.101^{+0.025}_{-0.017} \pm 0.005$
$^\dagger \Xi_c^+ (csu) (2464)$	$0.41^{+0.11}_{-0.08} \pm 0.02$
$^\dagger \Omega_c^0 (css) (2706)$	?

[†]From publications completed in 1992-1993

A great deal of experimental and theoretical interest centers around the determination of the $K^* \ell^+ \nu$ form factors, and several important semileptonic decay branching ratios. We have made considerable progress in the field of charm meson semileptonic decays. We have completed three analyses in the areas of $D^+ \rightarrow \bar{K}^* \mu^+ \nu$ form factors⁽⁵⁾, the isospin related reaction $D^0 \rightarrow (K_s \pi^-) \mu^+ \nu$,

and the analogous decay $D_s^+ \rightarrow \phi\mu^+\nu$. We will soon submit a publication on the branching ratio of D_s^+ decays into $\phi\mu^+\nu$ relative to $\phi\pi^+$ and a new determination of the $D_s^+ \rightarrow \phi\pi^+$ absolute branching ratio. We feel that this is an important, new result because since the vertexing capabilities of our fixed target experiment provide powerful ways of assessing the level of charm backgrounds to $D_s^+ \rightarrow \phi\mu^+\nu$ which is difficult to eliminate in e^+e^- collider experiments. These three semileptonic results, along with the E687 limits on $D^0 - \bar{D}^0$ mixing⁽¹²⁾ form the focus of Ray Culbertson's thesis.

Recent $D^+ \rightarrow \bar{K}^*\mu^+\nu$ form factor Measurements

	R_v	R_2	Γ_ℓ/Γ_t
E687 ⁽⁵⁾	$1.74 \pm .27 \pm .28$	$.78 \pm .18 \pm .10$	$1.20 \pm .13 \pm .13$
E691	$2.0 \pm .6 \pm .3$	$0.0 \pm .5 \pm .2$	$1.8 \pm .6 \pm .13$
E653	$2.00 \pm .34 \pm .16$	$.82 \pm .22 \pm .11$	$1.18 \pm .18 \pm .08$

We are also far along in studies of the decay mode $D^0 \rightarrow K^-\mu^+\nu$ which can be used to measure the q^2 dependence of the semileptonic form factor of the D^0 .

Finally we have submitted the first⁽⁶⁾ of what we hope in what we hope will be a series of papers comparing QCD based models of charm photoproduction to our data. This first paper, written by Rob Gardner, concentrates on studying the correlations within events with two fully reconstructed $D\bar{D}$ mesons or events with one fully reconstructed charmed particle recoiling against a kinematically tagged $\bar{\pi}$ from $D^{*+} \rightarrow \bar{\pi}D^0$ decay. The doubly, fully reconstructed signal, shown in the scatterplot of Figure 1a, consists of about 320 events where both the D and $\bar{D}$ are fully reconstructed into the decay modes $K^-\pi^+$, $K^-\pi^+\pi^+$, & $K^-\pi^+\pi^+\pi^-$. This represents over an order of magnitude larger photoproduction sample than has been previously studied. Figure 1b compares our data on acoplanarity angle ($\Delta\phi$), defined as the azimuthal angle between the D and $\bar{D}$ momentum vectors in the plane transverse to the photon direction, to the predictions of the LUND-Pythia model. In the absence of fragmentation and intrinsic gluon P_t effects, this

distribution would be spiked at π radians. Figure 1c shows a sample $\approx 44,000$ reconstructed $K^-\pi^+$, $K^-\pi^+\pi^+$, & $K^-\pi^+\pi^+\pi^-$ decays which were used in our search for kinematically tagged $\bar{\pi}$ from $D^{*+} \rightarrow \bar{\pi}D^0$ decay. A sample of 4,000 kinematically $\bar{\pi}$'s were reconstructed against the 44,000 D 's shown in Figure 1c using a combination of charge and P_t correlation. The rapidity difference between the $\bar{\pi}$ and fully reconstructed D is compared to the LUND-Pythia model in Figure 1d.

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Figure Caption

Figure 1 a) Scatter plot of the normalized mass of detached D candidates versus the normalized mass of the detached, recoil $\bar{D}$ candidates. The normalized mass is $\Delta M/\sigma$, where ΔM is the difference between the reconstructed mass (with error σ) and the nominal mass. The decay modes $K^-\pi^+$, $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^-$ are combined. b) Background subtracted acoplanarity distribution $\Delta\phi$ for fully reconstructed $D\bar{D}$ pairs compared to the Monte Carlo (solid histogram). c) Normalized mass distribution for starting sample of recoil charm mesons $D \rightarrow K\pi, K2\pi, K3\pi$ used in the soft pion tagging analysis. These events were required to satisfy $\ell/\sigma > 0$ to 7, depending on the topology. d) Rapidity difference $Y_D - Y_{\bar{D}}$ for events with a fully reconstructed charm particle and a kinematically tagged $\bar{\pi}$ from $D^{*+} \rightarrow \bar{\pi}D^0$ decay. The solid curve is the production of the LUND-Pythia Monte Carlo. The outer dashed curve shows the (arbitrarily normalized) prediction for an apparatus with 100 % acceptance.

Figure 1: D Meson Production Studies

Experiments at e^+e^- Colliders

B. Eisenstein, G. Gladding, G. Gollin, M. Selen, J. Thaler

Scientific and Professional Staff:

T. Bergfield, B. Downing, B. Eisenstein,

G. Gladding, G. Gollin, M. Haney, I. Karliner, D. Lesny,

B. Ong, V. Simaitis, M. Selen, G. Stewart, J. Thaler

TASK SUMMARY

This section describes our participation in three e^+e^- experiments, the Mark III and SLD at SLAC and CLEO at Cornell. The Mark III is nearly done; the last student will finish her Ph.D. thesis in the next year. The SLD is currently taking data to study the Z^0 boson. Our involvement in SLD has been reduced to the analysis of data which exploits the vertex detector to do b-physics. We joined the CLEO collaboration, which operates a detector at the CESR e^+e^- storage ring at Cornell, in January, 1993. We are just beginning to start work on various projects, especially hardware associated with the silicon vertex detector. We currently have two graduate students and one post-doc; our plans are for two or three post docs and four graduate students. Our equipment request is for a VME test stand to support development work on the silicon.

PROJECT DESCRIPTIONS

A. Mark III:

The Mark III experiment took data at 4 center of mass energies: 3.1 GeV (J/Ψ), 3.7 GeV(Ψ'), 3.77 GeV(Ψ''), and 4.03 GeV. The last data run was completed in 1989. Our last graduate student on this experiment, G. Stewart, is currently writing her thesis using this data.

B. SLD:

The SLD experiment is designed to obtain data on Z^0 production and decay at the SLAC Linear Collider (SLC). The SLC provides polarized electrons to the SLD, making the sensitivity to some weak interaction effects greater than at LEP even with a smaller data sample. Our superior vertex detector and smaller beam pipe will also allow cleaner identification of B-mesons. Specific Illinois contributions to the SLD have been the event trigger, the Fastbus plant and monitor software, and the vertex detection software. The first data run(1992) produced 10000 Z decays with an average beam polarization of 20%. We have already (April, 1993) collected over 14000 Z decays in this year's run with an average polarization of 60%. Our goal for this year's run was 40000 Z decays with a polarization of 40%; barring unforeseen problems, we should easily surpass this goal.

C. CLEO:

The CLEO detector is located at the Cornell Electron Storage Ring (CESR). It currently operates at and just below the $Y(4s)$ resonance (about 10.58 GeV and 10.51 GeV respectively). The collaboration is composed of about 65 faculty, 55 postdocs, and 70 students from 21 universities. The CLEO experiment is currently one of the world's leading facilities for the study of heavy-flavor physics. The exceptional

performance of the accelerator and storage ring (CESR), together with the high quality data obtained with the CLEO-II detector, is allowing precision studies of the b and c quarks, the tau lepton, and other physics processes such as those obtainable through gamma-gamma interactions.

In early 1994, the CLEO-II detector will be fitted with a new silicon micro-strip vertex detector. This three-layer, double-sided device is the result of a large cooperative effort involving many of the CLEO collaborating institutions. Illinois (Selen) has been heavily involved in the design and prototyping of the readout electronics for this device. Selen and Ong will have a continuing responsibility for this hardware through the installation and commissioning phase. Illinois is also responsible for the design and construction of a slow control and monitoring system for the silicon detector, and this work is at a preliminary stage. Illinois will contribute to new vertex finding and fitting software, drawing on our experience with the SLD vertex detector.

Coinciding with the installation of the vertex detector, the bunch structure in CESR will change from seven bunches per beam to twenty seven. To accommodate this change, the Illinois group will make the necessary modifications to the CLEO-II trigger timing system.

Goals and Major Results to Date

A. Mark III:

The Mark III experiment has been quite successful. The current publication count stands at 24 Phys. Rev. Letters, 11 Phys. Rev. D articles, and 5 Phys. Letters. Seven University of Illinois graduate students have received their Ph.D.'s for work on

this experiment. Our final student on this experiment should be finishing her thesis during 1994.

Stewart is studying our sensitivity to CP violation in the Ψ'' data. Differences between partial decay rates for particle and antiparticle states represent a model-independent test of CP violation. The asymmetry in rates between D and $\bar{D}$ decays to the CP=+1 state K^+K^- has been measured to be 0.20 ± 0.15 by E691 at FNAL. We hope to make a more sensitive measurement using this and other final states.

B. SLD:

We are currently taking data in a run which is scheduled to last until the end of August, 1993. At the present time (April 1993), we have accumulated approximately 14000 hadronic Z^0 decays with beam polarization of 60%. We are currently acquiring about 500 Z decays per day. Consequently, obtaining an additional 50000 or more Z decays in this run seems quite possible. Using last year's sample of 10000 Z decays, we now report a measurement of $\sin^2 \Theta_W^{\text{eff}} = 0.2378 \pm 0.0056(\text{stat.}) \pm 0.0005(\text{syst.})$, based on our determination of A_{LR} . The current quoted uncertainty in $\sin^2 \Theta_W$ from a single LEP experiment is $\approx \pm 0.002$. With the improved polarization and additional events expected from this run, we should be able to measure $\sin^2 \Theta_W^{\text{eff}}$ to a precision of $\approx \pm 0.0008$.

All of the Illinois hardware contributions to the SLD are complete. These include the trigger, LAC online software, data acquisition software, online controls and monitors, and Fastbus system. Details of this work were given in our proposal for FY1992.

The secondary vertex reconstruction software is complete. Details of this work were given in the proposal for FY1992. We have completed our development of the

final track-fitting code. Current analysis work is focused on refining the gamma conversion and K_s and Λ decay finding code. The analysis focus of the Illinois group will be B meson decay measurements which use reconstructed secondary vertices. In particular, we will concentrate initially on semileptonic decays and a measurement of the ratio of the lifetimes of the charged to neutral B-mesons.

C. CLEO:

The last year has been one of great successes at CLEO. Since the beginning of 1992, seventeen papers have been published and another three have been submitted and are in the referee review process. Seven others have been deemed ready for journal publication by the collaboration, and will be submitted in the near future.

Some of the highlights are:

- * Observation of the decay $B \rightarrow K^* \gamma$.
- * Observation of the doubly-Cabibbo-suppressed decay $D^0 \rightarrow K^+ \pi^-$.
- * Measurement of the branching ratios for $D^0 \rightarrow \pi^+ \pi^-$, $D^0 \rightarrow \pi^0 \pi^0$ and $D^+ \rightarrow \pi^+ \pi^0$ (a first observation).
- * First observation of the Cabibbo-suppressed semileptonic charm decay $D^- \rightarrow \pi^0 l^- \nu$
- * Measurements of the rate for b-quark decays into u-quarks indicating a value of $|V_{ub}|$ significantly lower than indicated by previous experimental results
- * Highest precision measurement of $B\bar{B}$ mixing, using two complementary techniques.
- * The definitive measurements of τ decays to one-prong plus multiple π^0 s.

- * The worlds best single measurement of the electronic branching ratio of the τ lepton.
- * Best limit on the decay mode $\tau \rightarrow \mu \gamma$.
- * First measurements of the masses of the three Σ_c states in the same experiment.

The design of the silicon vertex detector readout system was finished in late 1992, and wire-wrap prototypes of the 32 channel VME based smart ADC boards and readout sequencer controller board have built and tested. Prototype PCB versions of the ADC board are now under construction by our Canadian collaborators at Carleton University in Ottawa, and will be tested at Cornell by us early this summer.

The preliminary design of the silicon slow control and monitoring system is nearing completion, although no hardware has been purchased, and final development work has not yet been done. We must set up a VME test stand in Urbana in order to complete this work. Our budget includes the equipment costs for this test stand.

Work to prepare the CLEO-II trigger timing system for twenty-seven bunch running has begun. Selen is supervising a Cornell graduate student who is producing schematics for the present system using a CAD package. When these are completed and verified, the new system will be designed using this database as a foundation.

With the ultimate goal of increasing the discriminatory power of the event trigger, we are studying ways of improving the information provided by the crystal calorimeter to the second level trigger hardware. This is presently in the preliminary study phase, involving trigger rate studies and analysis of trigger and Monte Carlo events. If results of these studies prove promising, a proposal for specific hardware modifications will be made to the CLEO collaboration.

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Studies of CP and CPT in the Neutral K System

George Gollin

Scientific and Professional Staff:

E. M. Collins, G. D. Gollin, M. Sendelbach, M. Palmer

OVERVIEW

This group performs CP and CPT studies in the K meson system at Fermilab using a twin beam spectrometer with active regenerators. Novel features of the detector include excellent veto coverage to reduce backgrounds from $K_L \rightarrow 3\pi^0$ decays, an 804-block lead glass array, and a high-rate, high-precision tracking chamber system. We have been searching for signs of a direct CP-violating amplitude in $K \rightarrow \pi\pi$ decays in Experiment 731's data. We are performing a CPT test through a measurement of $\text{Arg}(\eta_{00}) - \text{Arg}(\eta_{+-})$ using Experiment 773's data, and are searching for the decays $K_L \rightarrow \pi^0 e^+e^-$ and $K_L \rightarrow \pi^0 \mu^+\mu^-$ in Experiment 799's data.

1) Search for direct CP violation by Experiment 731

(G. Blair, G. Gollin, G. Grazer, M. Karlsson, and J. Okamitsu, and in collaboration with physicists from the University of Chicago, Elmhurst College, Fermilab, and CEN Saclay)

Analysis of Fermilab E731's 1987-1988 data sample is nearing completion. We have published a number of results based on the full data set. The physics issues addressed to date by E731 publications include the following:

a) **Determination of $\text{Re}(\epsilon'/\epsilon)$ in $K \rightarrow \pi\pi$ decays.** If the Standard Model's description of the electroweak interaction is correct, there should be a small amplitude for CP violation which makes possible the decay $K_2 \rightarrow \pi\pi$. $\text{Re}(\epsilon'/\epsilon)$ depends on the top quark mass but is expected to be less than .001. NA31 at CERN has reported that $\text{Re}(\epsilon'/\epsilon) = .0022 \pm .0007$; a value this large is difficult to reconcile with Standard Model calculations. We do not confirm the NA31 result. Based on our full data set,

we conclude that $\text{Re}(\epsilon'/\epsilon) = .00074 \pm .00052 \pm .00029$. This result was published in 1993.

b) **Measurement of $\text{Arg}(\eta_{00}) - \text{Arg}(\eta_{+-})$ with E731's data.** The phase difference between η_{00} and η_{+-} should be smaller than one degree if CPT is conserved in the K meson system. The earlier value for $\text{Arg}(\eta_{00}) - \text{Arg}(\eta_{+-})$, $(12 \pm 6)^\circ$, came from an experiment performed more than 14 years ago. We have obtained a new measurement of the phase difference from the E731 data; our result is $(-1.6 \pm 1.2)^\circ$ from our full data set. This result was published in 1993. We will measure the phase difference with a new method in E773 (described below); the new technique minimizes sensitivity to such systematic perils as acceptance corrections and ignorance of the value of $\text{Re}(\epsilon'/\epsilon)$.

c) **Measurements of Δm , τ_S , and $\text{Arg}(\eta_{+-})$.** We find that $\Delta m = (0.5286 \pm 0.0028) \times 10^{10} \text{ hs}^{-1}$, $\tau = (0.8929 \pm 0.0016) \times 10^{-10} \text{ sec}$, and $\text{Arg}(\eta_{+-}) = (42.2 \pm 1.4)^\circ$. This result was published in 1993.

d) **Simultaneous measurement of K_S and K_L decays into $\pi\pi\gamma$.** We have measured the relative rates and form factors for the decays $K_S \rightarrow \pi\pi\gamma$ and $K_L \rightarrow \pi\pi\gamma$. The results have been submitted for publication.

e) **A measurement of the quadratic slope parameter in the $K_L \rightarrow 3\pi^0$ decay Dalitz plot.** We have measured the quadratic slope parameter in the $K_L \rightarrow 3\pi^0$ decay Dalitz plot to be $-(3.3 \pm 1.1 \pm 0.7) \times 10^{-3}$. This is the first measurement of this parameter; its value can be used to constrain chiral perturbation theory calculations. This was published in 1992.

f) **A limit on the decay $K_L \rightarrow \pi^0\nu\nu$.** The decay $K_L \rightarrow \pi^0\nu\nu$ is almost entirely due to a decay amplitude which directly violates CP conservation. No previous limits on the decay rate have been reported. Our limit is $B(K_L \rightarrow \pi^0\nu\nu) < 2.2 \times 10^{-4}$ (90% CL). The expected Standard model rate is quite small, below 10^{-11} . This was published in 1992.

We will set limits on (or observe) a number of other rare K decay modes. This group's responsibilities in E731 have included the photon veto system and most of

the scintillator banks, in addition to analysis work. The E731 data have been very rich in physics.

2) An improved measurement of $\text{Arg}(\eta_{00}) - \text{Arg}(\eta_{+-})$ by Experiment 773

(E. Collins, G. Gollin, W. Hogan in collaboration with physicists from the University of Chicago, Elmhurst College, Fermilab, and Rutgers University)

Systematic and statistical uncertainties limit the precision of an E731-style experiment which measures the η_{00} , η_{+-} phase difference to be about 1.5 degrees at best. The chief sources of systematic error involve the necessity of understanding the differences in detector response for K_L and K_S decays, which exhibit different decay z distributions. Resolution effects, coupled with the steeply falling z spectra, make it difficult to extract sufficient information from the experimental distributions to determine the phases accurately. In addition, ignorance of the value of ϵ' couples directly into the extracted value of the phase difference. Most of these problems are avoided by E773. The E773 detector used a pair of K_S beams created by regenerators spaced along the beam direction by 12 meters. By tuning the relative thicknesses and separations of the regenerators, it was possible to produce decay spectra which were nearly identical inside the fiducial decay volume for both beams. The E773 spectrometer was based on the E731 detector with modifications and new hardware as appropriate. To reduce possible backgrounds from inelastic and diffractive K_S production, we replaced the boron carbide E731 regenerator with finely segmented, solid scintillator regenerators. The regenerators switched beams after every machine spill.

University of Illinois contributions to E773 included phototubes, bases, and moving machines for the regenerators, controlling electronics for the movers, and additional lead/lucite photon antis. The new photon antis were built at Illinois and installed in the vacuum region between the two regenerators to veto possible background events from $K_L \rightarrow 3\pi^0$ decays. George Gollin is the spokesman for the experiment. A diagram of E773 appears in the following figure:

Figure 1. E773: $\phi_{+-} - \phi_{00}$ (elevation view)

E773 wrote 450 million triggers to tape during the first half of Fermilab's 1991 fixed target run. We are presently analyzing the run's data; we estimate E773's ultimate statistical error to be about 0.4° ; the systematic uncertainty should be less than 0.2° . All of the data have been run through the first pass analysis. Monte Carlo development and the generation of accurate calibration constants for the lead glass and drift chambers is in progress. The following figure shows mass plots for candidate $\pi^+\pi^-$ and $\pi^0\pi^0$ events from both beams. The figure represents a small fraction of the run's data.

preliminary E773 mass plots, 20% of full data sample

$\pi^+\pi^-$ mass, upstream regenerator

$\pi^+\pi^-$ mass, downstream regenerator

$\pi^0\pi^0$ mass, upstream regenerator

$\pi^0\pi^0$ mass, downstream regenerator

3) A search for the decays $K_L \rightarrow \pi^0 e^+e^-$ and $K_L \rightarrow \pi^0 \mu^+\mu^-$ by Experiment 799

(E. Collins, G. Gollin, W. Hogan in collaboration with physicists from the University of Chicago, Elmhurst College, Fermilab, Rutgers University, and U.C.L.A.)

There have been a number of interesting developments in high energy physics in the last two years. CDF sees no evidence for a top quark with mass below 90 GeV. The nonzero value of ϵ'/ϵ reported by CERN has not been confirmed by our data from E731. SLAC and LEP experiments report that there are only three generations. These new results place tight constraints on the Standard Model and cast some doubt on its ability to describe completely the electro-weak interaction. Consequently, it is important to study other rare processes to check the level of agreement between experiment and theory. In particular, a search for the (unobserved) decays $K_L \rightarrow \pi^0 e^+e^-$ and $K_L \rightarrow \pi^0 \mu^+\mu^-$ is appropriate at this time. The decays are expected to occur with branching ratios of $\sim 5 \times 10^{-12}$ and $\sim 1.3 \times 10^{-12}$ respectively. It is expected that the dominant amplitude contributing to both decay modes is CP violating. A determination of the decay rates serves as a test of the Standard Model. Some extensions to the Model (such as the existence of a non-standard Higgs sector) could produce an unusual ratio between the muonic and electronic branching ratios.

E799 has been approved to search for the decays $K_L \rightarrow \pi^0 e^+e^-$ and $K_L \rightarrow \pi^0 \mu^+\mu^-$ in two runs, the first was completed in 1992. The systematic uncertainties associated with a $\pi^0 \mu^+\mu^-$ search are very different from those of a $\pi^0 e^+e^-$ search: backgrounds from the copious decay $K_L \rightarrow \pi^0 \pi^+\pi^-$ with one or both pions decaying to $\mu\nu$ must be eliminated. In its first run, a transition radiation detector and fine-grained dimuon trigger hodoscope were added to the E773 spectrometer to perform the $\pi^0 e^+e^-$, $\pi^0 \mu^+\mu^-$ search. Expected sensitivity for $\pi^0 e^+e^-$ and $\pi^0 \mu^+\mu^-$ decays is approximately 3×10^{-10} from the first run and 10^{-11} from the second. Analysis of the run's data is now in progress, and preliminary results have been obtained for the following processes:

a) A measurement of the decay $\pi^0 \rightarrow e^+e^-$. The minimum rate for the decay $\pi^0 \rightarrow e^+e^-$ is determined by unitarity; we measure it to be $(8_{-2.9}^{+4.1} \pm 0.5) \times 10^{-8}$, consistent with theoretical expectations. This result has been submitted for publication.

b) A measurement of the decay $K_L \rightarrow \mu^+ \mu^- \gamma$. The result was reported at the DPF meeting in November, 1992. The final result is in preparation.

c) An upper limit for the decay $K_L \rightarrow \pi^0 \mu^+ \mu^-$. This result was also reported at the November '92 DPF. The final result is in preparation.

d) A study of the decay $K_L \rightarrow \pi^\pm \pi^0 e^\mp \bar{\nu}^{(-)}$. The result was reported at the DPF meeting in November, 1992 and has been submitted for publication.

4) Development work for CsI array trigger processing

(E. Collins, G. Gollin, M. Haney, R. Downing, V. Simaitis, M. Palmer, and M. Sendelbach)

We have been investigating the possibility of using Xilinx XC3000 field programmable gate array logic cells to build a processor which will count the number of "clusters" striking a CsI gamma detector array. Originally conceived as a processor for KTeV (E799II/E832), the design might prove useful in the CLEO trigger at CESR. The conceptual design of the system's architecture is complete; the circuit diagrams for most of the processor finished.

1992, 1993 Publications for George Gollin

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The HiRes Detector

Thomas A. O'Halloran, Jr.

Scientific and Professional Staff:

D. Bird, T. A. O Halloran, Jr., M. J. Kidd

OVERVIEW

HiRes is a detector located at Dugway Proving Grounds approximately 100 miles from Salt Lake City, Utah. It is being built by a collaboration consisting of physicists from Adelaide University, Columbia University, the University of Illinois and the University of Utah. When completed it will detect cosmic ray showers with improved resolution and an energy spectrum that extends an order of magnitude above present experiments. The experiment will offer a unique blend of astrophysics and particle physics. The higher energies attainable with this detector will allow us to address the question of galactic or extra-galactic origin of these particles and to measure the energy spectrum at energies for which theorists have predicted variations from the power law exhibited at lower energies. The detector will also measure showers significantly higher than any energy attainable by terrestrial accelerators and we will search for anomalous shower behavior as a manifestation of new physics at these new energies.

ACCOMPLISHMENTS IN FY 1993

There are good years and bad years, FY 1993 was definitely a good year for HiRes, except for funding.

During the past year we demonstrated the first few mirrors were tested using laser beams. The analysis of these tests clearly demonstrated that we had achieved and, in most cases, exceeded the design specifications in pointing accuracy, spot size and stability. The net effect is that we believe that the aperture in the proposal can now be achieved with two sites

instead of the three in the proposal. This must be checked and we have requested funds from NSF which will allow us to build four mirrors on the next site and to check the new aperture. These funds have been approved and construction will proceed in FY94.

For some time now our group has been vacillating between two electronic designs, the traditional sample and hold used by the Flyseye detector and a Flash ADC system. After testing them we have decided to implement the FADC in the final system. There were several reasons for this decision:

- a. The signal to noise ratio was somewhat better in the FADC than in the S&H.
- b. The timing was not subject to slewing corrections since the pulse is directly measured in the FADC.
- c. The pedestal was measured simultaneously with the signal.
- d. Triggering could be more flexible.
- e. Finally we felt that the discovery potential of the experiment was enhanced due to the flexibility of the FADC.

Finally the HiRes prototype (known as the Tower of Power (TOP)) became operational. TOP consists of 14 mirrors (FIG 1) which overlook the CASA/MIA arrays which are 3.4 km to the Northeast. In Figure 1, a shower impacting on the CASA/MIA array would be between the mirrors labeled 5 and 7. At the time of writing of the proposal (April, 1993), we have just finished our second data run. There is, of course, a learning curve on the operation of the detector, but we will evaluate the full detector design and carry out a limited investigation into the primary cosmic ray events coincident with the CASA/MIA array. Some of the early events are shown in Fig 2. The distortion in the events is caused by the projection of a sphere onto a flat surface. No corrections have been made on these event displays.

PUBLICATIONS

The following publications have been submitted to the International Cosmic Ray conference(XXIII ICRC, Calgary 1993)

Papers based on Flyseye Data

The only author from the University of Illinois on these papers is D. J. Bird:

The Fly's Eye Extremely High Energy Cosmic Ray Spectrum, D. J. Bird et al

Cosmic Ray Spectrum above 0.1 EeV, D. J. Bird et al

Small Scale Anisotropy , D. J. Bird et al

Large Scale Anisotropy, D. J. Bird et al

Stereo Anisotropy, D. J. Bird et al

Papers based on HiRes/CASA/MIA data

The authors on these papers from the University of Illinois are D. J. Bird, R. W. Downing, M. J. Kidd, and T. A. O'Halloran, Jr.:

The HiRes Resolution Fly's Eye(HiRes) Project, D. J. Bird et al

The HiRes Fly's Eye Prototype Detector- A Status Report, D. J. Bird et al

Coincident Observation of Air Showers by the HiRes prototype and CASA/MIA experiments, D. J. Bird et al

Reconstruction Techniques and Tests Using the HiRes Prototype, D. J. Bird et al

Electronics and Data Acquisition System for the HiRes Prototype, D. J. Bird et al

Calibration of Photomultiplier Tubes for the HIRes Experiment, D. J. Bird et al

Performance of a Prototype FADC Electronics System for the HIRes Fly's Eye,
D. J. Bird et al

Fig 1: Sky Coverage of the TOP

Fig 2(a): Vertical Flasher

Fig 2(b): Near-Horizontal Flasher

Fig 2(c): Cerenkov Blast

Fig 2(d): Near-Vertical Cosmic Ray Track

Fig 2(e): Inclined Cosmic Ray Track

Fig 2(f): Near-Overhead
Cosmic Ray Track

Computational Facilities (Task Group F)

Jerald J. Wray
Scientific and Professional staff: Jerald J. Wray,
David D. Lesny

Descriptions of the activities of the computer subgroup, the types of work we expect to be carried out on the High Energy Physics Group's computer facility and the plan guiding the direction of the facility's development were provided in the June 1991 proposal. An updated version is included at the end of the Task Group F section of the FY '94 proposal.

SYSTEM USE:

Members of the Group in Urbana are involved in a number of different collaborations in various stages of design and construction, data acquisition and analysis. During the past year we have seen the following:

Fermilab E687 increased its previous data sample by approximately a factor of ten. They used several thousand hours of cpu time on the HEPG systems in Urbana, first doing data skims to provide tapes of selected events to other collaborators, and then doing the intensive physics analysis of the events of interest to our group. Monte Carlo runs have also taken a significant amount of time. This group is currently the largest user of CPU time on our system.

The current CDF data runs are increasing their data sample by a factor of approximately 20. We still anticipate that at least 50 GB of disk will be needed locally to support the timely analysis of the summary data sets. Approximately 25Gb of the additional disk storage has been added this year. During the last few months

CDF processing has regularly taken a few hundred hours of CPU time per week, with peak usage being many times that. This use is expected to increase considerably.

A number of simulation studies for the SDC muon subsystem were carried out during the past year to optimize the design and performance of this system, both at the trigger level and offline. Muon chamber alignment tolerance requirements were also studied. More detailed studies are now in progress. These simulations typically required several hours on our faster VAXs, so the addition of an Alpha to the system was quite welcome. These studies have had 3.6GB of disk space assigned to them and have been somewhat hampered by that restriction.

The overall processing plan for Fermilab experiment E773 has changed, and less of the early processing of the data has taken place on the University of Illinois system than originally expected. They do use the group's network connections to Fermilab extensively and do some final states analysis here.

It is clear that the major use of the systems is standard HEP data processing, but for some members of the group the most important feature of the facility is the access it provides to their remote sites. It is only because the machines and networks support those connections that they can effectively participate in their collaborations.

Nearly every member of the group also uses the computer facility in his or her daily work. They use the networks to exchange drafts of papers, to retrieve or send programs, to exchange electronic mail and to see a display locally of the work being done on remote systems. Other uses of the local machines are to write and print papers, to access the archives of public domain information, including preprints of physics papers and catalogues of libraries across the nation. These uses do not greatly increase the load on the systems, but they contribute to the richness of the intellectual environment of the group and support its productivity as well.

INDUSTRY DIRECTIONS AFFECTING OUR CHOICES:

In the past year two developments made significant improvements in the computing environment we can provide for the physicists possible. One was Digital Equipment Corporation's release of VMS-clusterable systems based on the very fast Alpha chips. The other has been the decreasing cost of providing large amounts of disk storage.

On the software front progress has been less exciting. It is clear that though vendors are claiming to support software standards most still feel the need to put their own stamp on "open" systems. Some progress has been made on providing standardized software interfaces, which is probably much more important in the long run. The Posix standard, distributed file services, remote calling procedures, network standards, and the X-11 windows standard, are some components of truly distributed computing and/or portable applications. Though foundations seemingly have been laid, only limited improvements have been made to the end users. This has remained an area to watch.

SOME SPECIFIC ACCOMPLISHMENTS:

Upgrades to the HEP group facility in Urbana during the past year have mostly taken advantage of improvements in computer hardware. We did not make any significant changes in the type of acquisitions originally proposed for 1993, though some disk storage was added earlier than anticipated and a very high speed processor was added to the VMS cluster instead of adding a server to the group of Ultrix machines.

The facility currently consists of a 20 node VAX Cluster, which includes the recently acquired Alpha based DEC 3000 Model 400. Some nodes were upgraded to

faster machines using monies from special grants to faculty members. A 4-node group of DECStations running Ultrix which uses a DS5000/200 as a server is also available. The VAXStations in the VMS cluster provide about 130 MicroVAX Units of Processing power (mVUPs), the 3000/400 (The Alpha) another 90mVUPs.

The 3000 is an extremely fast system, and moving programs to it has been relatively easy. Bugs have been found in the porting process, of course, and to take full advantage of its speed some different programming techniques are being learned. The addition of this box has increased the amount of time spent consulting. From the management point of view, it has been an easy machine to integrate into our systems and its interoperability is expected to increase as time passes. By mid-year it is expected to be in full use.

Since the beginning of calendar 1993, nearly 50% of all available CPU power of the VAXs in the cluster has been used, measured on a 7-day a week, 24-hour a day basis. It is at a point where time sharing users see uneven response times because the systems are so busy during the day. The Alpha based machine has only been available since early March, but the use of that machine is ramping up sharply as frequently used compute intensive programs are ported to it. Though the Ultrix based systems can provide almost half the CPU power available on the VAX Cluster, they are not as easily used and utilization runs under 25% on the same 7-day, 24-hour basis.

Essentially all experiments are finding that they need more on-line storage than they projected earlier in order to have adequate amounts of data available for analysis. Funds from the University's Research Board and grants to individual faculty members have allowed us to acquire some of the disks needed. As we projected, faster disks with more capacity are coming down in price, so our approach of delaying

acquisition until close to the time when they are actually needed continues to make good fiscal sense.

We have found that it is important to provide physicists with the right tools to take full advantage of the systems they are using. Some X-windows terminal or workstations which run Motif have been added to our systems. Some of the older terminals and workstations have been upgraded or replaced by newer machines which are faster and have greatly improved graphics.

So far we are avoiding the extreme overloading and some of the obsolete system problems we experienced in the past, but those problems are now clearly on the horizon. As some of the components of the systems are upgraded to allow us to process the large amounts of data experiments are producing, we must do some equipment reconfiguration and add some new equipment to maintain a balance throughout the system. Our plans for the coming year, which are reflected in the proposal section, take this into account.

Electronics Support FY93 Accomplishments

The primary task of the engineering group is the support of experiments undertaken by other members of this contract. This support is in the design, construction, and testing of electronics and associated hardware for specific experiments.

The secondary task of this group is to acquire, develop, and employ general purpose CAE "tools" which can be used to support current and future needs of the researchers on this contract. This task, along with other SSC and related tasks, will be developing methods for high level simulation of physics data acquisition systems. We will be updating our old and acquiring new CAE tools on a regular basis. Analog and mixed analog/digital simulation will become a larger part of our efforts as higher speed technologies become viable. Analysis tools for transmission lines, thermal, mechanical, etc. will have to be added to the design software tool set.

We will continue to supply our internally developed simulation tools and models to others in the Physics community. FNAL, SLAC, Los Alamos, CERN/LEP and TRIUMF are using these tools to simulate FASTBUS modules. We regularly cooperate with standards groups and other general organizations which aid the entire physics community.

We have started working on the Muon system data acquisition upgrade at CDF. This consists of the Level 1 and the Level 2 trigger logic and associated electronics. The actual construction of the hardware will begin next year.

We have finished two FASTBUS boards for E773 at FNAL. We have also designed a fast cluster finder using FPGA s. The simulation tools we have acquired have greatly facilitated this design process.

We have begun to take some responsibility for the coordination and simulation of the SDC data acquisition system, This work has begun in the middle of the contract year.

The design work for HiRes is in abeyance due to the funding situation at NSF. As of the writing of this report we do not know when or if this project will be resumed.

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