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HIGH ENERGY PHYSICS
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SECTION 1.0
EXECUTIVE SUMMARY

1.0 Executive Summary**1.1 Overview of Research Program in 1992**

This Progress Report presents a review of the research done in 1992 by the Duke High Energy Physics Group. This is the first year of a three-year grant which was approved by the Office of High Energy Physics at DOE after an external review of our research program during the summer of 1991.

Our research is centered at Fermilab where we are involved with two active experiments, one using the Tevatron collider (CDF, the Collider Detector Facility) and the other using a proton beam in the high intensity laboratory (E771, study of beauty production). In addition to these running experiments we are continuing the analysis of data from experiments E735 (collider search for a quark-gluon plasma), E705 (fixed target study of direct photon and χ meson production) and E597 (particle production from hadron-nucleus collisions). Finally, this year has seen an expansion of our involvement with the design of the central tracking detector for the Solenoidal Detector Collaboration (SDC) and an increased role in the governance of the collaboration.

Descriptions of these research activities are presented in the following sections. The collider program is described in Section 2. This contains a discussion of recent results obtained from experiment E735 (Section 2.2), a description of our CDF activities (Section 2.3), and a discussion of SSC detector R&D and related preparations for the SDC experiment (Section 2.3). The fixed-target program at Fermilab is described in Section 3, including both analysis results from experiment E705 and the status of the data obtained from the recent run of experiment E771. The development of our local research facilities is described in Section 4. This includes a major addition to our computer complex and an expansion of detector construction laboratories as required by our CDF and SSC detector R&D. A projection of expenditures is described in Section 5. These are divided into four tasks: Fermilab collider physics (Task A); Fermilab fixed-target physics (Task B); development of Duke facilities (Task C); and SSC detector development (Task D).

1.2 Overview of Research Personnel and Facilities

During the past year we have added two physicists to our research group. Dr. Chiho Wang joined our group in January of 1992 and is working primarily on straw tube tracking detector development for the SDC detector. Recently Dr. Alfred Lee has accepted an Assistant Professor position at Duke and will be joining our research group in August. With these additions the Duke HEP group now consists of ten Ph.D. research scientists, six graduate students and a support staff consisting of a mechanical engineer (under contract work), a programmer and a research secretary. In addition we typically have two undergraduate students working in our group. The current (summer 1992) members of our group are listed below.

Scientific Personnel

L. R. Fortney	Professor of Physics
A. T. Goshaw	Professor of Physics
W. Kowald	Senior Research Scientist
A. M. Lee	Assistant Professor of Physics
S. H. Oh	Associate Professor of Physics
T. J. Phillips	Research Assistant Professor of Physics
W. J. Robertson	Senior Research Scientist
W. D. Walker	James B. Duke Professor of Physics
C. Wang	Research Associate
B. Zou	Research Associate

Support Personnel

W. Ebenstein	Scientific Programmer
P. Hoyt	Research Secretary
M. van Haaren	Mechanical Engineer (contract work)

Graduate Students

J. Elder
S. Hauger
D. Hennessey
C. Loomis (graduated June 1992)
Q. Shen (graduated June 1992)
R. Tesarek
M. Yin

The high energy research facilities are located on the third floor of the Duke Physics Building. They consist of eleven offices plus about 2500 ft² of laboratory space in four rooms. Two of the laboratories are currently being

used for SSC detector development and one for CDF detector testing. The local VAX cluster consists of two model 3100 and four model 3200 VAX stations with a 56K baud fractional T1 link to Fermilab. One VAX 3200 and two PC's can be used for data acquisition via CAMAC for local detector development. In addition we have ten Macintosh computers connected to the local VAX cluster and one PC setup for CAD work.

1.3 Ph.D. Theses, Publications and Reports

In this section we summarize publications of various types describing research work done recently by our group. The publications are included in a separate volume included with this Progress Report.

Ph.D. Theses

1. Production of π^0 's, η 's and Direct γ 's using 300 GeV/c Pion and Proton Beams, Qifeng Shen (completed June 1992).
2. Low Energy Photon Production from pp Collisions at $\sqrt{s} = 1.8$ TeV, Charles Loomis (completed June 1992).
3. Charmonium Production using 300 GeV/c Pion and Proton Beams, Richard Tesarek (completion expected September 1992).

Publications, Refereed Journals (published/submitted)

1. Hyperon Production from pp Collisions at $\sqrt{s} = 1.8$ TeV (accepted for publication in Phys. Rev. D 1992).
2. Mass Identified Particle Production in pp Collisions at $\sqrt{s} = 300, 540, 1000$ and 1800 GeV (submitted for publication in Phys. Rev. D 1992).
3. A Technique to Measure the Sense Wire Position of Low Mass Drift Chambers (submitted to Nuclear Instruments and Methods A 1992)
4. Multiplicity Dependence of Transverse Momentum Spectra of Centrally Produced Hadrons in pp Collisions at $0.3, 0.54, 0.9$, and 1.8 TeV Center of Mass Energy (submitted to Physics Letters 1992)
5. A Measurement of J/ψ and ψ' Production in 300 GeV/c Proton, Antiproton and $\pi^\pm$ Nucleon Interactions (submitted for publication in Phys. Rev. D 1992)
6. Production of J/ψ via ψ' and π Decay in 300 GeV/c Proton and $\pi^\pm$ Nucleon Interactions (submitted for publication in Physical Review Letters 1992))
7. Construction and performance of a 2.7 m Long Straw Drift Tube Prototype Chamber for the SSC (Nuclear Instruments and Methods in Physics Research A309 (1991)
8. Photoproduction of an Isovector $\rho\pi$ State at 1775 MeV, Phys. Rev. D43 (1991)

Physics and Technical Reports

1. An Estimate of the Quark-nucleon Cross Section, W.D. Walker et al., (June 1992)
2. Straw Tube Position Measurement, M. van Haaren, A.T. Goshaw, (May, 1992)
3. Effects of High Energy Protons on the E771 Silicon Microstrip Detector (presented at Florida Workshop May 1991)

SECTION 2.0

COLLIDER PROGRAM

2.0 Collider Program

Task A: Tevatron Collider Research (E735 and CDF)

Task Leaders: A. T. Goshaw and W. D. Walker

Task D: SSC Research (SDC)

Task Leaders: A. T. Goshaw and S. H. Oh

Research Staff

Physicists:

A. T. Goshaw	Professor
S. H. Oh	Associate Professor
T. J. Phillips	Research Assistant Professor
W. J. Robertson	Senior Research Scientist
W. D. Walker	James B. Duke Professor
C. Wang	Research Associate

Graduate Students: J. Elder, S. Hauger, D. Hennessy, M. Yin

Undergraduate Students: L. Daniels, C. Barone

2.1 Introduction

Duke's collider research has made good progress in three research areas during the past year. The first involves continuing analysis of the data obtained from the Tevatron collider experiment E735. This has resulted in a total of three new papers and the completion of the Ph.D thesis of Duke student, Charles Loomis. The data from this experiment is providing unique measurements of particle production properties (γ , π , K, p, Λ , Ξ) from $\bar{p}p$ collisions at the highest cm energy currently available. See Section 2.2.1 for more details of the E735 data analysis.

We have put a large effort into commissioning the new CDF tracking chamber. In order to maintain this effort we have two senior people and two students at Fermilab with the rest of our staff working at Duke and commuting as needed. Our responsibilities include setting up and testing the electronics for the new time-projection chamber (the VTX), aligning and surveying the VTX and new silicon tracker (the SVX), calibrating the VTX and determining its drift chamber properties, and setting up radiation hardness testing of VTX chamber and the outer CDF tracker (the CTC). One of our students (S.Hauger) has served as an "ACE" on CDF shifts for the past three months and the rest of our group has been participating in the normal 10 day shifts. We are now beginning to analyze CDF data with a special emphasis on minimum bias physics and the production of W/Z bosons. See Section 2.2.2 for more details.

The third part of our Collider Program consists of detector R&D for the SSC, in particular design of the Solenoidal Detector's tracking system. One of our group (SHO) has developed an extensive straw tube drift chamber R&D program at Duke and is coordinating this research activity within the

SDC collaboration. Duke has also been given the responsibility for developing the survey and alignment procedure for the SDC barrel tracker. Finally, one of our group (ATG) has been elected Chairman of SDC's Institutional Board and is involved with governance matters within the Collaboration. These activities are discussed in Section 2.3.

2.2 Research at the Tevatron Collider

2.2.1 Experiment E735: Quark-gluon Plasma Search

The E735 experiment is continually productive in terms of physics publications. The hyperon paper which is being analyzed and written at Duke (S.Oh) will be published in Physical Review D (copy included with this report). Another paper being written at Duke (S.Oh) is to be submitted shortly to Physics Letters. The title of the newest paper is "Multiplicity Dependence of Transverse Momentum Spectra of Centrally Produced Hadrons in Proton-Antiproton Collisions at 0.3, 0.54, 0.9 and 1.8 TeV Center of Mass Energy". A copy of this paper is also included with this report. In this paper we present a detailed study of the production properties of hadrons as a function of multiplicity. Our data is unique to the world because of the lower limit on the momentum measurement (150 MeV/c) and the study of collisions with extremely high multiplicity. The study of the low momentum particles at the high multiplicity region is important because some of the signatures of a QCD phase transition may show up in this phase space. The multiplicity can be related to the energy density, and the phase transition is expected to occur in collisions which produce high energy density.

One of the interesting plots of the paper is shown in Figure 2.1. In this figure the invariant pt distribution is plotted for several multiplicity regions. In the highest multiplicity region, there is an excess of low momentum particles. Although a similar feature was observed in heavy ion collision, this is the first time it has been seen in hadron-hadron collisions. These pions could have been produced from the condensation of a quark-gluon plasma. Another explanation is that these pions may be produced through an intermediate system of cold, non-thermal partons.

Another paper in preparation, to be submitted to Physical Review D, is the study of pions, kaons and protons as a function of center of mass energy and multiplicity. Although the paper was prepared at the University of Notre Dame, Duke (S.Oh) has made a great deal of contribution in terms of generating plots and rechecking the results. A copy of this paper is included with this report. The title of the paper is "Mass Identified Particle Production in Proton-Antiproton Collisions at 300, 540, 1000 and 1800 GeV Center of Mass Energy". In Figure 2.2 the transverse velocity (after Levai and Mueller) is calculated as a function of the multiplicity using the

experimentally determined $\langle p_t \rangle$. We found that the transverse particle velocity approaches a constant value of $0.6c$ for all particles produced in high multiplicity events (high collision energy density), which is consistent with the sound velocity in a relativistic hadronic/quark-gluon gas.

Duke has also been responsible for the measurement of inclusive photon production from the E735 data. The most recent data comes from a NaI detector which can detect photons with p_t up to about $5.0 \text{ GeV}/c$. The main purpose of this measurement is to search for an anomalous signal of low p_t photons, which could be a signal from quark-gluon plasma production. This research work is in an advanced analysis stage and forms the subject of the thesis of a Duke student (C. Loomis). Our analysis finds no evidence for a low energy photon signal and can explain the measured photon production spectrum in terms of photons from hadron decays (dominated by neutral pions). Figure 2.3 shows the measured inclusive photon p_t spectrum compared to the predictions of two QCD-based models of hadron production from $\bar{p}p$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$. As can be seen, these QCD models explain the photon spectrum and we find no evidence for any low p_t photon excess.

There are other E735 papers in preparation at different universities; a study of π production, a HBT study and a measurement of the charged particle multiplicity distribution. We expect to submit these papers in the near future.

FIGURE 2.1 Invariant p_t spectrum for different multiplicity ranges.

FIGURE 2.2 The transverse expansion velocity as a function of multiplicity density.

Fig. 2.3 a) Prediction of the Pythia Monte Carlo compared to the measured differential inclusive photon cross-section.

Fig. 2.3 b) Prediction of the HIJING Monte Carlo compared to the measured differential inclusive photon cross-section.

2.2.2 Research at CDF

Duke has been a member of the CDF Collaboration since October 1990. Our main technical responsibility has been to assist with the upgrade of the CDF tracking system. Four FTE senior physicists are working on CDF, with half of this effort in residence at Fermilab. We have already attracted four students to the project in the short time since we joined the collaboration. Although the past year has been devoted primarily to assembly and testing of the CDF tracker, we are now beginning some data analysis. A summary of our work is given in this section.

Technical Contributions to CDF

Up to this time, most of our effort has been directed towards the vertex tracking chamber upgrade. The VTX replaces a similar chamber which could not operate at the high luminosities expected in the future. It surrounds the beam pipe in the interaction region and provides an R- ϕ view of charged-particle tracks near the event vertex. It provides the primary means for locating the position of interactions along the beam and for counting the number of interactions in a given beam crossing. The VTX consists of 28 modules assembled into two units. Each module has two halves, with each half consisting of octants of either 16 or 24 tangential sense wires. The 16 wire modules are used in the center of the detector and support the silicon strip detector. The 24 channel modules are used on the outsides and provide better coverage for tracks at large rapidity. Figure 2.4 shows a two-vertex event measured in the VTX during a recent CDF run. Specific work done by Duke on the VTX chamber is described below.

1) VTX Mechanical and Electronics Work

In order to provide the best tracking resolution, the VTX needs to be assembled with tight mechanical tolerances. The individual modules were assembled into the final detector on a granite-table based fixture where tolerances were limited to the few-mil level. This work and the subsequent survey of the VTX in the CDF tracker was carried out by one of our group (TJP).

The front end electronics for the VTX consists of preamplifiers mounted directly on the modules, amplifier-shaper-discriminator (ASD) cards mounted on the main detector and LeCroy FASTBUS TDC's in the counting room. A significant effort was required to update the electronics for the VTX because of the increased channel count (8448 channels) and faster TDC clock speeds (2ns time bins). The electronics is now working at the 99% level. Duke will retain the responsibility for maintenance of the VTX electronics.

2) Calibration of the VTX Chamber

Some of us (S.Oh, M.Yin) are involved with the calibration of the VTX. Like any other detector, an understanding of the calibration is very important if the full potential of the detector is to be realized. During last year and early this year most of the work involved Monte Carlo generated data. Presently we are studying the real data taken in June 1992.

The calibration involves calculating the drift velocity, determining the T0's, calculating the slope correction factor, and finding the sense wire plane position along the beam axis.

The drift velocity must to be determined to better than 0.2% accuracy in order to obtain the design resolution (200 microns per measurement) and has to be monitored throughout the experiment. To calculate the drift velocity, we have devised a technique of using tracks crossing the high voltage plane. From the track we find the maximum drift time and the drift velocity is calculated from the maximum drift time since the distance between the sense wire plane and the high voltage plane is known. In Figure 2.5 the calculated drift velocity is plotted and found to be about 52 microns/ns. The velocity was monitored over a period of a month and it shows little (less than 0.5%) change over the period.

The T0 has to be monitored throughout the experiment. The T0 is calculated using tracks crossing the sense wire plane. The hits from either side of the sense wire plane are refitted with separate straight lines and the difference of the intercepts at the sense wire plane is plotted. If the T0 is exact, then the difference should be centered around zero. Using the method, the T0 can be determined to better than 1 ns. The T0 has to be calculated for each module since module to module variation is expected.

The slope correction is necessary because of the different path lengths of the ionized electrons. The electronics is triggered by the first arriving electron (shortest path to the sense wire) and the shortest path depends on the slope of the particle. This correction is very important for steep tracks. The correction is calculated using the tracks crossing the high voltage plane and it can be determined to better than 2 ns accuracy (~ 30 microns error). Using this technique, we found that the correction used earlier is off by as much as 20%.

In Figure 2.6, the effect of the calibration is shown. In this plot the residual of tracks is plotted under different conditions. There are three curves in the plot. The solid line is from using the expected T0 and drift velocity with the slope correction. The dotted line is with the calculated T0 and drift velocity with old slope correction and the dot-dashed curve is with full corrections including the new slope correction. As shown in the plot improvement is obvious. We note that the σ of the residual is larger than

the expected resolution of about 200 microns. This is because the plot includes low momentum tracks whose path are changed by the multiple scattering but also are bent by the magnetic field.

The next step is to calculate the sense wire location (along the beam axis). This is calculated by comparing the track vertex and the event vertex from individual modules. The study with Monte Carlo data suggest that we can calculate the sense wire position with the accuracy of 60 microns. For this study, a fair amount of data has to be used and presently we are collecting data.

3) Other Software Work for CDF

Most of the pattern recognition software for the vertex tracking chamber is new for this run. Duke has contributed to this programming effort, primarily with the regional tracking code. The objective of regional tracking in the online data acquisition level 3 trigger is to improve the efficiency for identifying interactions in which electrons are produced in association with the primary vertex. If an event results in sufficient energy deposition in the electromagnetic calorimeter, a test is made in the online software to look for hits in the tracking chambers which lie in the trajectory of a line from the beam interaction point to the region of energy deposition in the calorimeter.

Such a regional tracking program must be effective in selecting possible electron signatures while efficiently rejecting the much higher background arising from photons. The program must also be fast, able to process the wire hit data from the tracking chambers and select or reject a potential signal from the electromagnetic calorimeters in less than 20 msec. If sufficient hits are observed along the trajectory then the energy deposition will be flagged as coming from the entrance of an electron into the calorimeter. Otherwise the energy deposition will be assumed to have arisen from the passage on one of the copious background of photons which come mainly from the decay of neutral pions.

Duke has other service responsibilities for CDF beyond this work on tracking. We are also responsible for a number of important software jobs and we are contributing to the general manpower pool. For example, we are responsible for most of the missing transverse energy reconstruction code. This includes both online and offline analysis code and filters. This code was either completely rewritten, or substantially upgraded for the current run. Monitoring and maintaining the code and the missing E_t data sets will be an ongoing responsibility.

4) Radiation Hardness Testing of CDF Tracking Chambers

In addition to commission the VTX, our group is also performing some wire aging and radiation damage tests of the CDF tracking chambers. In order to carry out this work we have setup VTX modules at Duke with the associated gas flow system and electronics. We irradiate one octant of a VTX chamber with a 25 millicurie strontium 90 source and monitor the gain changes using an Fe55 source. We periodically compare the wire gain of the irradiated octant to the gain in a different octant to monitor the stability of the chamber performance. We have had a problem recently with a contaminated gas supply from a local dealer and in the future will measure the gas gain with a simple straw tube drift chamber before using in the VTX module. We plan to have results from these tests in the early fall of 1992. In parallel with this work we are constructing a CTC module which will also be used for radiation hardness studies. These measurements will provide important information for the design of the next upgraded CDF tracker.

Physics Analysis at CDF

Fermilab is currently beginning an extended collider run. The first $Z \rightarrow e\bar{e}$ candidate from this run is shown in the Fig. 2.7. Within the next year, we expect to have a large amount of data on tape. With this in mind, we anticipate a substantial analysis effort centered at Duke. We are currently setting up the CDF analysis programs on the local Duke VAX cluster.

Most of the CDF physics analysis at Duke is still at a fairly preliminary stage. However, we have several projects that are further along. One of us (TJP) has been a member of the CDF collaboration for six years, and has worked extensively on the W mass analysis and various aspects of electroweak physics. We expect this analysis to continue when new data become available in this run. We are currently contributing to an analysis of the underlying events in W/Z events and starting work on CDF minimum bias events.

The Current CDF Run

All the members of our group have been taking shifts. While most of us have been taking the standard 10 day shifts, our most advanced student has become a CDF Ace. Aces are trained in the details of operating and repairing the CDF detector and they are assigned a series of shifts over a three month period. The Aces are the people who really run the CDF detector, and this responsibility is an excellent learning experience for students.

Figure 2.4 The vertex tracking chamber view of the first $Z \rightarrow e e$ candidate from the 1992 CDF run. Only tracks in two octants are shown. The VTX is still being commissioned, so the reconstruction accuracy is expected to improve.

Figure 2.5 Drift velocity for the VTX (CDF) using experimental data.

Resolution plot under different calibration condition.

Figure 2.6

Figure 2.7 a) The central tracking chamber view of the first $Z \rightarrow e\bar{e}$ candidate from the 1992 CDF run. The second electron was at too high of a rapidity to be seen in the CTC.

Figure 2.7 b) The calorimeter transverse energy for the first $Z \rightarrow e\bar{e}$ candidate from the 1992 CDF run. The two clusters are in the electromagnetic calorimeter. Note how clean the rest of the event is.

2.3 Research at the SSC**2.3.1 The Solenoidal Detector Collaboration**

Duke has been an active participant in the Solenoidal Detector Collaboration since its formation. Over the past year we have taken part in a large number of reviews which have led to the selection of a base line tracker consisting of a silicon inner tracker, a straw tube barrel tracker and a gas microstrip intermediate tracker (see Figure 2.8). Our interest is mainly with the outer barrel tracker which will cover a cylindrical volume of length 8 meters and radii from 0.8 to 1.7 m. We joined together with Colorado University, the University of Indiana, Oak Ridge National Laboratory and Westinghouse Science and Technology Center to produce the straw tube barrel tracker design that was included in the April 1, 1992 SDC Technical Design Report. These activities within SDC have been fairly time consuming. Seog Oh is acting as coordinator of the straw tube drift chamber development. Al Goshaw is a member of the SDC Tracking Steering Committee and Chairman of the SDC Institutional Board.

2.3.2 Tracking Detector R & D**Outer Tracking Chamber R & D for SDC**

We have been spending a great deal of time on R&D work for the outer straw tracker for the SDC. There are two main areas of research. One is to construct and test a full size prototype module; the other is to test the electronics developed for these chambers. The tests involve noise, sensitivity and cross talk measurements. The electronics (amplifier-shaper discriminator) are being developed at the University of Pennsylvania, University of Colorado and ORNL, and TDC's are being developed at KEK.

Prototype Construction

The proposed straw outer tracking chamber for SDC is made of 4 mm diameter straws with wall thickness of 30 microns. The tubes are made of copper coated (1500 angstrom thick) kapton. Although the exact number of channels is not decided, about 120,000 straw channels or 250,000 scintillating fiber channels are expected. The present design for the tracker is based on the 4 meter long modules containing 200 straws. These modules are mounted on carbon fiber cylinders. Some modules have 8 tube layers and some 6 tube layers, depending on the location of the modules. There are 5 superlayers in the outer barrel tracker.

For the prototype, we have constructed and tested a 4 meter long 159 channel module. The cross section of the module is shown in Figure 2.9. It is a trapezoid shape with 29 straws at the bottom and 25 straws at the top. It has 6 layers of tubes. The shell which contains the straws is made of

rhocell between carbon fiber. The radiation length is less than 0.1%. The shell we are using was provided by the University of Indiana. Inside each straw, there are wire supports every 100 cm for electrostatic stability of the sense wires.

Sense wires of diameter 25 microns (gold plated tungsten wire) were strung with 50 grams of tension. After stringing, each channel was tested for high voltage and we find that the voltage can be raised to at least 2400V, which is much higher than the expected operating voltage of 1900-2000V.

After the chamber was sealed for gas leaks, 48 channels were instrumented with electronics (amplifier-shaper-discriminator-TDC) and the chambers were triggered with cosmic rays. The amplifier-shaper-discriminator (ASD) used in this set up was LeCroy 2735DC. Figure 2.10 shows a time distribution from a channel with a gas mixture of CF₄-C₂H₆ (50-50). The cosmic ray tracks were reconstructed and the residuals were calculated as shown in Figure 2.11. The σ is about 125 microns, which is compatible with our earlier measurements using a 2.7 meter prototype chamber. The chamber was operating at 2100V.

Electronics Testing

One of the main areas of R&D is in the development of highly sensitive and low noise amplifier-shaper-discriminators (ASD). With the present LeCroy 2735DC ASD, the chamber has to run with the gas gain of about 100,000. With the new electronics we hope to operate the chamber with a gas gain about 30,000. With the lower gain there is less problem with aging and space charge. The first prototype ASD was tested using the 2.7 meter chamber by replacing the LeCroy ASD. In Figure 2.12, the resolution was measured as a function of high voltage for the two different ASD's. As can be seen in the figure, the measurement using Penn ASD is much better than the one using LeCroy ASD at the same high voltage. The plot implies that the chamber can be operated at 1900 Volts without degrading the resolution. The measured gas gain at this voltage is about 40,000.

An improved version of the ASD is being mounted on the new 4 meter, 159 channel chamber. We hope to operate the chamber with the new electronics within a few weeks.

Sense Wire Position Measurement

One of the challenging task in the construction of the tracker is to map the wire locations. The locations of wires near the wire support have to be measured. This is important in order to obtain the resolution closest to 100 microns. We devised a scheme to measure the wire location using a collimated Sr90 source. In this scheme the region around the sense wire is scanned with the collimated beam and the drift time is plotted as a function of the slit position as shown in Figure 2.13. The sense wire location is the

intersection point between the two curves (left and right side of the minimum point). Using this technique, we were able to measure the sense wire location with an accuracy of about 25 microns. The detailed description of this technique is described in the paper attached to this report. The paper has been submitted to NIM for publication.

Long Range Goals

The construction schedule for the chamber shows that the production of the modules should start within a year. It is likely that the three universities (Duke, Indiana University, University of Colorado) will construct the necessary modules which is about 700 in number. In order to accomplish this each university has to produce at least one to two modules every week for several years. It took us two months to construct the prototype. Simple extrapolation shows that the required manpower would be ten full time personnel. As soon as funding is available, we will begin hiring the necessary staff.

2.4 Hadron-nucleus Studies

W.D. Walker has had a long term interest in hadron-nucleus collisions. We found a few years ago that resonances (ρ^0, Σ^0) are not produced with the expected large cross sections in hadron-nucleus collisions. Recently we have been studying leading (fast) particles from hadron-nucleus collisions. By making simple assumptions about the interactions we can make estimates of the quark and di-quark nucleon cross sections. These cross sections are quite small (4-6 mb). These results seem however quite consistent with other hadron-nucleus data. We believe this is the first time an experimental estimate of q-nucleon cross section has been made.

Fig. 2.8 a) Full SDC tracking system including inner silicon layers, outer straw tube barrel and forward gas microstrip detectors.

Fig 2.8 b) Schematic view of 1/4 of the SDC tracking system. All dimensions are are mean radius or z in mm.

Figure 2.9

Cross section of the prototype module.

Time distribution obtained using the prototype module with gas mixture of CF₄-C₂H₆(50-50). HV=2100.

Figure 2.10

Residual from the prototype obtained using cosmic rays.

Figure 2.11

Residual as a function of high voltage using
two different ASDs.

Figure 2.12

Average time as a function of slit position.
The wire position is at the minimum point.

Figure 2.13

SECTION 3.0

FIXED TARGET PROGRAM

3. FIXED TARGET PROGRAM: TASK B

Senior Research Staff: L. Fortney, W. Kowald, B. Zou
Graduate Students: R. Tesarek, Q. Shen

3.1. Introduction

We expect to conclude most aspects of the E705 work by the end of this contract period. Initial physics publications have been submitted to PRL and PR with others to follow in short order. A comprehensive paper on the calorimeter should be ready to submit to the collaboration by the end of the summer. Q. Shen completed his thesis and has begun work with Purdue on the CDF experiment, and R. Tesarek is expected to complete his thesis in the next few months.

E771 ran during the fall/winter 1991 and achieved approximately one month running time with most elements of the experiment operational. Our silicon monitoring and event display software packages were operational from the beginning of the running period, and we developed a comprehensive new data monitoring package during the run. Some 1800 Exabyte tape were written with an as yet undetermined number of useful event triggers. Our work with this data has been confined to studies of the silicon strip detector data in an attempt to understand the operation and future potential of this device.

3.2. Experiment E705: Hadroproduction of χ and Direct Photons**3.2.1 Introduction**

As of this writing, two charmonium papers have been submitted for publication. A third is awaiting the final results of R. Tesarek's work to achieve the best possible energy scale, resolution, and chi splitting. A paper on this work is in preparation.

Q. Shen has completed his work on the high p_T production of p^0 and η mesons and a paper on this work is in preparation.

The study of direct photon production requires some revision of the software and extensive Monte Carlo running. Completion of this effort is still many months away.

3.2.2 High p_T Physics

With the completion of W. Shen's thesis we have completed the analysis of the high p_T production of π^0 and η mesons in the entire data set and expect to submit these results in a PR paper before the end of the year.

Figures 3.1a, b, c show summary plots from his thesis comparing his pizero production invariant cross section with previous experiments for the p-, p+, and p beam types. The plots are given as a function of the variable

$$x_T = \frac{2p_T}{\sqrt{s}}$$

to remove most of the energy scaling effects between experiments. We are in general agreement with these previous experiments although there are areas of serious disagreement, most often with the results of WA70. The dashed line on these plots is the fit to our data of the standard phenomenological form

$$E \frac{d^3\sigma}{dp^3} = C \frac{(1-x_D)^n}{p_T^m},$$

where

$$x_D = \sqrt{x_T^2 + (x_F - x_0)^2}.$$

Our x_F distributions in restricted p_T regions are also generally well described by this fit.

As expected we find that the ratio of cross-sections induced by π^+ and π^- is consistent with one in all p_T bins. The ratio for π^+ and p beams is shown in Figure 3.2 and rises with increasing p_T as predicted by the naive quark model.

We also find that the ratio of η/π^0 production is essentially independent of p_T with the values 0.471 ± 0.031 , 0.457 ± 0.057 , and 0.562 ± 0.074 respectively in π^- , π^+ , and proton induced reactions. This result is consistent with other fixed target experiments, is somewhat larger than would be expected from basic QCD and the mass derived mixing angle, but is substantially less than the near unity value recently reported by CDF.

3.2.3 Charmonium Physics

In the last year we have made several improvements to the shower reconstruction code, identified and removed a pressure dependent gain variation in the LGC, achieved a better understanding of the remaining gain variations observed in this device, and rerun the Monte Carlo simulations to get revised efficiency and error estimates.

While these changes have modified the mass distributions and error estimates in detail, the bottom line is that our resolution is still insufficient to resolve the two chi states. Since χ_1 and χ_2 have different branching ratios to J/ψ , in order to quote a cross section for χ production, we must know the observed ratio of χ_1/χ_2 . Our first submitted article used the WA11 ratio seen in π production, but there is no existing measurement for proton production.

Due to what appears to be an error in the quoted result from WA11, we may still be able to make an estimate of the pion induced χ_1/χ_2 production ratio with a similar error estimate to WA11. However, because the χ_1 and χ_2 are not clearly resolved in our data, this ratio is strongly affected by our energy scale. Our current analysis of the $\mu\mu\gamma$ mass spectrum is shown in Figure 3.3 for various subsets of our data. These plots are preliminary and were only made to get an estimate of the fitted uncertainty on the χ_1/χ_2 ratio. The ratio given is for produced χ 's and the error estimates do not include the effects of uncertainties in our energy scale so are the best we can expect to achieve. Our energy scale is determined from E/p studies and corroborated by π^0 and η mass determinations. We are continuing to refine both the selection of events, the corresponding resolution function for the chi states, and the fitting procedure.

3.3. Experiment E771: Hadroproduction of Beauty

3.3.1 Introduction

3.3.2 Installation and Running

3.3.2.1 Commissioning the SSD

At the June, 1991 E771 general meeting, W. Kowald presented his detailed plan for commissioning of the SSD system. This plan was designed to explore the phase space of the critical parameters for the SSD system and was based on past experience with the development of diagnostics software for the SSD system. Unfortunately this plan was never fully appreciated nor implemented, and many of the proposed tasks were never executed. There were several other problems related to organization, procedure, and installation which we noted prior to and during the running but were unable to influence because of the imposed division of responsibility.

As a result, even after the run we have very little knowledge of the underlying performance of the SSD system (noise, cross talk, pulse shapes, timing distributions, pulse shape and timing as a function of bias voltage settings, etc.). From the limited information we have been able to extract from the standard triggers is apparent that the silicon has problems in several of these areas.

3.3.2.2 FASTBUS, SSD, and Silicon Monitoring (W. Kowald)

Duke had responsibility for the FASTBUS readout system. Its elements are the controller (FSCC), the post-amp comparator (PC), the delay encoder (DE), the master timing controller (MTC), and the sequencer (SE). The FASTBUS crates are located in the experimental area, and could not be monitored visually during beam time. This put extra requirements on the setup and monitoring of these system.

Drawing on previous work on the development of this readout system, we designed and implemented the Setup and Readout software packages for the Silicon Strip Detector (SSD), the Resistive Plate Counters (RPC) and the PAD chamber (PAD) readout systems. All three systems use different front end modules but the same, FASTBUS based, readout system. The aim was to develop software, which could be used without modifications for all three detectors.

The main features of the implemented software are :

1. Communication with the FASTBUS Smart Crate Controller (FSCC) over ETHERNET using a VS2000 as the controlling work station.
2. Fast download of software to the FSCCs over ETHERNET.
3. Setting of Control Space Registers (CSR) in all FASTBUS modules and keeping track of the values in a database and parameter files.
4. Existing diagnostics software, which was developed in the previous years, can be used without modifications.
5. A FASTBUS diagnostics program, which was developed previously, resides in EPROM.
6. Parameter files, which define the status of each board in each crate and give the mapping of channels to physical planes and strips are generated from the control programs database.
7. The system adapts easily to upgrades or downgrades of the readout system.
8. Automatic polling of status information of each crate and signaling error conditions.
9. On-line histogramming of hits for each plane. (The silicon delay curves shown in Figure 3.4 are examples.)
10. Automatic generation of delay curves for full crates, single boards or channel regions.
11. Automatic generation of maps of threshold values for predefined noise rates per strip.
12. Readout time for the SSD system is smaller than 100 μ sec.

After it proved impossible to implement TCP/IP on the FSCC because of memory limitations, it was decided in cooperation with the Computing Department to implement a special communication protocol. On the basis of this, the download and communication over ETHERNET was implemented. The communication itself was implemented as Remote Procedure Calls and low level ETHERNET transfers. The control software was implemented in C. The server routines reside on the individual FSCCs and the client main control program on a VAX/VMS system.

The data readout was implemented in Assembler communicating via status blocks, which can be accessed asynchronously, with the server routines. During the run, the number of FASTBUS crates increased from 3 in August to 18 at the end of October. The last upgrade was done in the middle of December by adding the last PC/DE pair to the beam silicon crate.

Of the 18 crates, 3 were used by the RPCs, 7 by the PAD chambers and 8 by the SSD. The achieved mean readout time for all 18 crates was 125 μ sec. The SSD alone took about 60 μ sec.

Other activities included continued support for the diagnostics of FASTBUS boards for all three systems (RPC,PAD,SSD), installation and debugging of the 400 feet long RS485 readout chain to the VDAS buffers and the integration of the above readout into the E771 on-line system.

Besides taking the normal shift duties, Duke was one on call for the SSD, RPC and PAD readout and the SSD detector. After the experimental run, we spent some time to simulate problems we encountered during the run. Together with the FERMILAB Computing Department we were able to isolate bugs in the communication software and a possible hardware problem on the FSCC, which can be fixed with a software change in the ETHERNET driver.

3.3.2.3 The Event Display (L. Fortney, B. Zou)

The event display program took its main structure from that of the E705 program. The new program was implemented with GKS primitives and was thus able to display events on a variety of workstations and terminals.

This 3-D display was implemented along the lines described in our 1991 progress report and was able to display a wide variety of detector elements in various relationships. Its inherent flexibility allowed us to quickly define new presentations when detector questions arose. About mid-way through the run we were able to implement GKS features that gave us the ability to interactively (with a mouse on a workstation) magnify portions of a display and overlay lines to simulate tracking. This was particularly helpful in looking at the silicon hit patterns as the display could be expanded transversely to display full dimensionality of individual silicon hits. Figure 3.5 shows an event display example with manually overlaid lines.

This program makes use of the "official" data decoding routines provided by various detector specialists. This has the disadvantage of making us dependent on a number of programmers of varying programming and documentation skills, but it had the overwhelming advantage of providing a quick visual check of the operation of both the detector and its related software.

With this design, the on-line event display program provided information that was high complimentary to the traditional histograms of various data streams. Using the event display, it was apparent early on that the silicon was behaving in a anomalous way and was having fundamental noise and timing problems, but the lack of detailed silicon studies made it impossible to pinpoint the problem.

3.3.2.4 Data Monitor Program (L. Fortney and B. Zou)

The standard on-line monitoring at Fermilab is done with "Consumer Programs" running in a standard laboratory provided environment known as *Vax On-line*. This system had a few good features and several bad ones. In particular it was a computer hog and accumulated data and displayed results very slowly in many different programs.

For the event display program we had learned how to extract raw event data using the *Vax On-line* primitives, and B. Zou realized that this capability could also be used to produce an improved histogramming monitor for on-line data. Making use of the same decoding packages used in the event display, we developed a comprehensive general monitoring package that provided histograms of the hit profiles and frequencies of every plane in the spectrometer, nearly 300 plots in approximately 30 windows. By the time of serious running in December, this program could acquire a full "snapshot" of the spectrometer operation and automatically compare it with a standard saved from earlier running. This program (called DMONITOR) was run almost continuously by various members of the collaboration, but only rarely the full power of its automatic failure catching features. Figure 3.6 shows a typical window produced by this program.

3.3.3 Analysis

3.3.3.1 Analysis of SSD Data

Since early in the running, it has been our concern that the data taken by E771 would not prove be of sufficient quality for serious b-physics. We would also like to know to what extent the effects we see are correctable in future running. Consequently our efforts have been directed to trying to understand the still mysterious behavior of the FASTBUS/SSD system.

Starting from a simple program written during the last few days of the run, we have evolved a series of progressively more sophisticated programs to study beam tracks in the SSD. Making use of the zero slope characteristic of beam tracks, and using beam and randomly timed LED triggers we have concentrated our study on interaction free triggers.

Our initial on-line observation with the event display program was that sometimes tracks (both beam and secondary) were obvious in the detector while at other times for many triggers in a row there would be little visual evidence of tracks. Our immediate impression was that there were intermittent timing problems such that some planes were missing the triggering event.

We have eight x and eight y planes that can see beam tracks. In our subsequent off-line studies, we have defined tracks with two, three, and four hits then looked in the other planes to determine each plane's efficiency (recently as a function of x and y as well). From this highly redundant study, it is obvious that some common factor is at work that links the behavior of groups of planes; to the extent that it makes little sense to assign an independent hit efficiency to each plane. Depending on how

you define the track, the efficiency of a given x -plane may be nearly independent of x , or it may show a hole in the center.

We have also shown that there is a large loss of beam tracks in the central portion of most of the x -planes. The effect is much smaller in the y -planes, so it appears to be the result of electronic problems and not radiation damage. This feature and the magnitude of the hit efficiency have been the subject of considerable debate within the collaboration, centered over the content and wording of a technical paper (Item 3 under Technical and physics Reports in Section 1.3 of this report) that was submitted to a workshop proceedings. It is our position that the efficiencies are not known at the present time, and that the traditional definition may not even have meaning within the context of the present data.

There also appear to be timing problems with the silicon data. Our trigger always reads out two beam buckets, and we set a flag for each hit if it was present in the first of these two buckets. Figure 3.7 shows the distribution of the fraction of hits which have this flag set.

Interaction triggers and beam triggers clearly give different results indicating different timing for these two trigger types. This result is not understood: Interaction triggers were timed to produce a maximum in the number of hits in two buckets (shown in Figure 3.4), and the easy assumption is that beam triggers were simply mistimed relative to interaction triggers. But this may not be the answer as variations between planes are nearly as bad as between these two trigger types. It is also possible that ringing of some channels resulted in an incorrect timing based on the maximization of hits in the readout buckets.

Most of the data was taken during running at approximately 2×10^6 interactions/second. There is no direct evidence that any of these problems are rate related, but since the source of the problems are not understood, there is also no evidence that the system can be made to operate in a rational way at these or higher rates.

A relatively small fraction of interaction triggered events look usable. As mentioned in the accompanying proposal, we plan to extend these studies and develop an alternative tracking program for the silicon data.

3.3.3.2 Partitioning of Data Sets (W. Kowald)

Our recorded data include the following triggers : 1μ , 2μ , and LED. Most of the 2μ triggers are background events selected to have a large number of tracks (more $\pi \rightarrow$ more μ). The beam structure of the incoming proton beam had a poor duty cycle during spill. The data were mostly taken at very high intensities in a beam which had a poor duty cycle (most buckets contained no beam particles while others contained many), and the decision was unilaterally made not to impose a cut on the multiplicity of hits in the silicon planes. As a result most of the data written to tape is much too complicated to analyze.

In order to have a sample of 1μ and 2μ events with reasonable number of tracks, a partitioning of a selected set of tapes was undertaken. This became the first implementation of E771 off-line software on the

FERMILAB Silicon Graphics FARM. The following software packages were implemented :

1. Tape and disk I/O routines for the UNIX platforms.
2. Communication packages for the E771 off-line analysis on the basis of the Cooperative Processes Software System (CPS), developed by FERMILAB.
3. Support software for the generation of job control files.

As a first production run we are partitioning events from 10 tape sets (120 tapes) into 10 partitions depending on the number of beam tracks, the trigger (1μ , 2μ , LED, pt class) and hit multiplicity's in the SSD. We are using two nodes with four tape drives. Three output streams are written to tape and seven to disk with up to 12 input tapes are processed per job. Almost all the software developed for this task will be used also for the next stages (passes) of the analysis.

The following table gives an overview of the results of the partitioning of events taken during low intensity (2×10^8 beams/second) and at normal intensity (2×10^9 beams/second):

	Cuts used to make partition selection	Trigger	% kept	% kept
			low int	high int
1	>1 beam hits, <30 hits/plane, possible vertex	$1\mu/2\mu$	7.0	15.1
2	>1 beam hits, <30 hits/plane, possible vertex, multiplicity jump	$1\mu/2\mu$	not run	1.9
3	<3 beam hits, <40 hits/plane	1μ	14.5	4.7
4	>2, <6 beam hits, <40 hits/plane	1μ	2.6	11.1
5	>6 beam hits, <40 hits/plane	1μ	7.6	16.7
6	<3 beam hits, <40 hits/plane	2μ	39.1	9.5
7	>2, <6 beam hits, <40 hits/plane	2μ	7.0	16.7
8	>6 beam hits, <40 hits/plane	2μ	17.8	24.9
9	not in 3-8	$1\mu/2\mu$	12.0	15.5

The selections on the first two lines of this table correspond to a Duke algorithm designed to identify a rich sample of events with vertex-like structure associated with an upstream beam track. The other partitions were requested by the U. Penn group for its silicon tracking effort.

As soon as the tracking code is ready, the first pass for 10% of E771's data will be done, using a farmlet of one I/O node and 10 worker nodes.

Figure 9.15: Invariant cross section $\sigma(\pi^- + \text{Li} \rightarrow \pi^0 + X)$ as a function of x_T . Errors are statistical only.

Figure 9.16: Invariant cross section $\sigma(p + \text{Li} \rightarrow \pi^0 + X)$ as a function of x_T . Errors are statistical only.

Figure 9.14: Invariant cross section $\sigma(\pi^- + \text{Li} \rightarrow \pi^0 + X)$ as a function of x_T . Errors are statistical only.

Figure 3.1

Figure 9.8: Ratio of π^0 invariant cross sections $\sigma(\pi^+ + \text{Li} \rightarrow \pi^0 + X)/\sigma(p + \text{Li} \rightarrow \pi^0 + X)$ as a function of p_T . The curve is from the division of the curve shown in Figure 9.2 by the curve shown in Figure 9.7.

Figure 3.2

Figure 3.3 Preliminary results from χ analysis. Useful mainly as indication of the errors that we can expect on the χ_1/χ_2 ratio.

Figure 3.4 Delay curves showing number of hits in two read-out buckets from the silicon strip detector. These plots are from the on-line silicon monitoring program.

Tape 20331

Spill 1

Event 2148

Trigger: 1E10

10-JUN-92

USD, SSD x without target

USD, SSD y without target

Figure 3.5 A clean event displayed by the DISPLAY program. This image can be interactively magnified to show the dimensions of individual hit strips.

Page 18 MULT-1 Tape No. TS20138 No. of Events: 04500 Trig mask: 0000

Figure 3.6 A typical window from the DMONITOR program showing the hit multiplicity distributions for approximately half of the planes in the detector.

Figure 3.7 The ratio of hits with $rfbit=1$ to total hits in an event shows significant variation between interaction triggers and beam triggers. The cause may be a simple mistiming between these two trigger types, or it may indicate that the timing of the interaction trigger was strongly influenced by late noise hits.

SECTION 4.0

FACILITIES

4.0 Facilities**4.1 Computers**

Our computational system is comprised of a collection of VAX station 3200's and 3100's linked together in a local area VAX cluster. There are four 3200 and two 3100 nodes in the cluster with one 3200 serving as the boot node and having a 56 kbaud fractional T1 link to a Fermilab cluster server.

With the exception of memory upgrades and the addition of tape and disk peripherals to our VAXstation 3100 systems, as of the writing of this report, our local area VAX cluster has not been modified for the past year. As discussed in the accompanying Proposal, we intend to add DEC Alpha computers to our local Vax cluster as soon as possible. We have acquired four more Macintosh IIsi's for office use and to serve as terminals for access to the VAX cluster via ethernet connection. DEC Pathworks software makes it possible to transfer files Mac <-> VAX and to get hard copy of Mac screen dumps on a VMS laser printer queue.

The 56 kbaud fractional T1 link to Fermilab has proven to be a valuable enhancement to our computing needs in place of the 9600 baud leased telephone data line we formerly had. It is now practical to run procedures either here or at FNAL which access data from remote computers. We are also going to be installing the CDF offline software package, together with a network server process which will do the periodic code updating necessary with such an evolutionaly product.

All of our computing resources have been utilized continuously to do data analysis and detector simulation studies for fixed target (E705 and E771) and collider (E735 and CDF) experiments. When the full software package for CDF offline and simulation analysis is implemented, and as data from the current CDF run becomes available, our current computing capabilities will not nearly meet our needs.

4.2 Detector R & D Laboratories

We currently have two programs in place to study particle detector performance. One is a new facility to do aging and radiation hardness tests on a module of the type used to build the new CDF vertex wire tracking system (VTX). The other is an ongoing effort to develop a straw tube intermediate tracking system for the Solenoidal Detector Collaboration (SDC) at the SSC. The SSC laboratories have been described in past progress reports, and we discuss here only the new lab that has been setup for CDF detector tests.

The VTX testing facility has been assembled with existing and newly purchased electronics and gas systems, together with components and systems on loan from Fermilab. In addition, we have obtained a permit from the Duke University Radiation Safety office to store and use a 20 mCi source of Sr 90 to irradiate the VTX module.

A contaminated, or even mislabelled, bottle of drift chamber gas (Ar-Ethane 50/50% mix) resulted in damage to the drift cells we were testing. The exact composition of the offending bottle of gas is now being determined. However, the module is constructed with two isolated halves, so we are rewiring the module to look at signals on the other side and reassembling the VTX module test box with new gas and signal cable feed throughs on O-ring seals.

In addition to testing the VTX module, a test cell of the CDF Central Tracking Chamber (CTC) is nearing completion at Fermilab which will be brought to Duke for similar radiation hardness studies. The fact that the CTC cell requires eleven different high voltage levels for proper operation made it necessary to receive on loan from Fermilab a NIM crate and six dual supply wire chamber adjustable high voltage modules (Droege supplies). We have also purchased and await shipment of a temperature bath to maintain the correct level of alcohol in the drift gas mixture for the CTC test module. The amount and type of alcohol for the CTC differs from that for the VTX module.

1.0 Executive Summary

1.1 Overview of Research Program in 1992

This Progress Report presents a review of the research done in 1992 by the Duke High Energy Physics Group. This is the first year of a three-year grant which was approved by the Office of High Energy Physics at DOE after an external review of our research program during the summer of 1991 .

Our research is centered at Fermilab where we are involved with two active experiments, one using the Tevatron collider (CDF, the Collider Detector Facility) and the other using a proton beam in the high intensity laboratory (E771, study of beauty production). In addition to these running experiments we are continuing the analysis of data from experiments E735 (collider search for a quark-gluon plasma), E705 (fixed target study of direct photon and χ meson production) and E597 (particle production from hadron-nucleus collisions). Finally, this year has seen an expansion of our involvement with the design of the central tracking detector for the Solenoidal Detector Collaboration (SDC) and an increased role in the governance of the collaboration.

Descriptions of these research activities are presented in the following sections. The collider program is described in Section 2. This contains a discussion of recent results obtained from experiment E735 (Section 2.2), a description of our CDF activities (Section 2.3), and a discussion of SSC detector R&D and related preparations for the SDC experiment (Section 2.3). The fixed-target program at Fermilab is described in Section 3, including both analysis results from experiment E705 and the status of the data obtained from the recent run of experiment E771. The development of our local research facilities is described in Section 4. This includes a major addition to our computer complex and an expansion of detector construction laboratories as required by our CDF and SSC detector R&D. A projection of expenditures is described in Section 5. These are divided into four tasks: Fermilab collider physics (Task A); Fermilab fixed-target physics (Task B); development of Duke facilities (Task C); and SSC detector development (Task D).

END

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