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**THEORETICAL AND EXPERIMENTAL
STUDIES OF ELEMENTARY PHYSICS**

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Task B: Fixed Target Experimentation at Fermilab

i. Direct Photon Production in Hadronic Collisions – E706

(Drs. J. Dunlea, T. Ferbel, G. Ginther, P. Slattery and M. Zielinski;
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Introduction

Fermilab experiment E706 is a second-generation precision investigation of direct photon production by protons and pions interacting with a variety of nuclear targets (primarily H, Be and Cu). Its primary physics focus is the extraction of the gluon structure of nucleons and pions through the measurement of the inclusive cross section for the production of direct photons at the highest energies (500, 530 and 800 GeV/c) available to fixed target experiments, and through studying the character of the high- p_T jets produced in association with these direct photons. Descriptions of the experiment's design, methodology, and goals are contained in the Task B section (pages 6-46) of the University of Rochester HEP group's five-year grant proposal, submitted to the DOE in June 1991. We focus here on the progress of the experiment in the last year.

The initial run of E706 took place in 1987-88, and emphasized proton and π^- collisions at an incident momentum of 500 GeV/c. Physics results from this run have been published^{(1),(2)}, and a comprehensive article on γ , π^0 and η inclusive production at high- p_T , containing a detailed comparison of data with next-to-leading-order predictions from QCD, is in press.⁽³⁾ An analysis of jet fragmentation and γ + jet production is nearing completion, and we expect to submit this work for publication by September 1993.

Status Report – 1990/91 Data Processing/Analysis

The primary running of E706 took place in 1990 and 1991. Table I compares the three data runs for the experiment. In addition to substantially improved statistical precision, the data collected in 1990/91 have significantly reduced systematic uncertainties by virtue of the many improvements made to the E706 apparatus between 1988 and 1990. These changes included: a speeding up of the LAC data acquisition system, which provided the possibility for reading out the entire calorimeter without the imposition of an *a priori* threshold (zero suppression); an increased redundancy and precision in the experiment's charged-particle tracking system, which provided a great improvement in the reconstruction of interaction vertices; and the use of a liquid hydrogen target in the final run. It will be the quality of the results from the 1990 and 1991 data samples that will determine the ultimate scientific impact of the experiment.

The E706 data analysis effort has been centered in the MWest area at Fermilab for two principal reasons:

(1) **To enhance the level of interaction among the graduate students and postdocs carrying out the analysis.** Table II lists the graduate students who will be writing Ph.D. theses using the 1990/91 data, and the postdoctoral physicists who are in residence at Fermilab supervising the E706 analysis. This is a very powerful team, and it is essential that it be kept together to maintain an intellectually coherent group effort.

(2) **To take advantage of the enormous computing power at Fermilab.** Fermilab has pioneered the use of parallel processing computer farms in high energy physics. We employed the first of these systems, the ACP, to reconstruct our 1987-88 data, and to monitor online the quality of our 1990 and 1991 data. Also, we used the ACP to analyze $\sim 10\%$ of our 1990 data, in order to gauge the impact of reading out the entire contents of the LAC. During 1992, we completed the modification of our reconstruction and simulation packages for running on the more powerful UNIX farms that Fermilab has assembled to replace the ACP. Since the start of production processing of the 1990 data in December 1992, we have reconstructed about 20 million events on the UNIX systems; we now reconstruct routinely about 1.5 million events a week. We expect that the complete reconstruction pass, including processing our 1991 data, will be completed within about 12 months. (The analysis of our 1991 data sample has been slowed down by the necessity of modifying our reconstruction software to deal more effectively with certain pileup induced effects that were present during the early part of the run. These modifications have now been completed, and the production analysis of this especially rich data sample has recently begun.) In parallel, we have also been running on the UNIX farms the extensive Monte Carlo simulations required for studying the resolution and backgrounds in the data.

In addition to the very CPU-intensive processes of event reconstruction and Monte Carlo simulation, extracting physics results from our data requires a substantial amount of interactive computing. For many years, we employed for this purpose a Local Area VAX Cluster (LAVC) based on MicroVAX II computers and VAX workstations. This system was barely adequate to carry out the physics analysis of our 1988 data sample, and was woefully inadequate to the task of analyzing our far larger 1990 and 1991 data sets. In 1991, we consequently augmented the existing MWest LAVC with a UNIX cluster. The MWest UNIX cluster, which was designed in close cooperation with the Computing Division of Fermilab, was centered initially around 6 Silicon Graphics (SGI) Indigo Workstations, augmented by a pair of UNIX "seed" workstations, provided to us for evaluation and software development purposes, and appropriate peripherals (disk drives, 8 mm tape drives, X-terminals, etc.). An agreement was reached with the Computing Division of Fermilab

for their purchasing all of the auxiliary equipment, and for the E706 Collaboration to provide 6 SGI Indigo Workstations (including the software). The resulting UNIX cluster was an immediate success. A predictable (and highly desirable) result of this success was the increased use of the UNIX cluster, which served to further highlight the serious limitations of the VAX cluster. It was therefore necessary in 1992 to expand our UNIX cluster to provide an additional 4 Silicon Graphics workstations (and, again, to obtain all the necessary peripheral equipment through Fermilab). With that upgrading, the UNIX cluster now provides E706 with the capabilities needed for completing the analysis of our high statistics data.

Preliminary Results

We are presently in the process of organizing our interactive analysis software to deal efficiently with the very large data sample that has been reconstructed. The immediate goal is to have preliminary high statistics results to present at various international conferences this summer. A general sense of the very high quality of these data can be obtained from Figs. 1-4, which display a representative sub-sample ($\sim 10\%$) of the 530 GeV/c π^- Be data that has to date been reconstructed.

Figures 1 and 2 display the two photon mass distribution in the π^0 and η mass regions, respectively, for photon pairs have $p_T \geq 3.6$ GeV/c. For comparison purposes, the corresponding masses and widths obtained after a full analysis of our 1988 data sample were:

$$m_{\pi^0} = 135.26 \pm 0.06 \text{ MeV}/c^2$$

$$\sigma_{\pi^0} = 8.25 \pm 0.06 \text{ MeV}/c^2$$

$$m_{\eta} = 545.06 \pm 1.38 \text{ MeV}/c^2$$

$$\sigma_{\eta} = 23.98 \pm 1.60 \text{ MeV}/c^2$$

Even at this preliminary stage, not only are the masses obtained by our present analysis in better agreement with the standard values than those obtained using our 1988 data, but the widths of the mass peaks are also narrower. The internal consistency of the data is also improved. Figure 3 displays the mean values of $\gamma\gamma$ pairs in the π^0 and η mass peaks as a function of LAC octant. (For many purposes, the E706 LAC can be usefully subdivided by azimuth into 8 independent detectors.) No systematic mass variation is observed. Figure 4(a) presents the sideband-corrected energy asymmetry distribution for π^0 events, and Fig. 4(b) presents the corresponding distribution for our complete 1988 data sample. The present data is observed to be flat out to significantly larger values of A (defined as $|E_{\gamma_1} - E_{\gamma_2}|/[E_{\gamma_1} + E_{\gamma_2}]$, reflecting our improved ability to detect and measure

low energy photons now that we have eliminated the need to employ zero suppression in the LAC readout.

Previous Results and Expectations from the 1990/91 Data Analysis

The sample of data collected by E706 in 1990/91 is unique in its kinematic range. This is illustrated in Table III, which compares our data with that of earlier experiments. All of these experiments have been completed, and most have published their final results. It is clear that E706 will play a dominant role in measuring the gluon substructure of nucleons and pions, once its analysis is completed.

This point is also illustrated in Fig. 5, which compares the experimental regimes of current direct photon experiments. Gluon distribution functions are plotted at several Q^2 values for two representative sets of parton distribution functions. Figure 5(a) displays a substantial difference between these two gluon distributions at low Q^2 values (4 GeV^2). As shown in Fig. 5(b), for typical fixed-target momentum transfers, this difference is still significant over the accessible x range. However, because of the evolution of the structure functions with Q^2 , as shown in Fig. 5(c), the differences are difficult to distinguish at momentum transfers typical of Tevatron collider experiments. These plots highlight the complementarity of the two kinematic regimes, and the particular advantages of Tevatron fixed target experiments for determining parton distribution functions.

The current status of the experimental situation is summarized in Figs. 6 and 7, where we compare our 1988 data to predictions based on popular structure function sets. The data on direct photons are shown divided by the predictions using the pion structure functions of ABFKW, and the proton structure functions of ABFOW, all evaluated in next-to-leading-order for the scale $Q^2 = p_T^2/4$ (we refer to these as our standard set). The curves in Fig. 6 show the ratios for other structure function choices (evaluated using the PMS scale) relative to our standard set. (The different η_G values correspond to different fall-off slopes for the gluon structure functions.) Similarly, in Fig. 7 the data for π^0 production are displayed relative to a standard set of structure functions, along with similarly normalized alternative structure functions, also evaluated using the scale $Q^2 = p_T^2/4$.

The results obtained to date make it clear that the E706 spectrometer has unique capabilities for studying direct photon production, capabilities that not only do not presently exist elsewhere in the world, but are also unlikely to be duplicated or surpassed in the foreseeable future. It is therefore essential that these capabilities be fully exploited through completion of the analysis over the next two years. Because of the improvement in systematics, as well as in the statistics, we expect our error bars at small transverse momenta to

decrease typically by a factor of 2, and at large transverse momenta by a factor of about 4. This will pin down the gluon structure functions with sufficient precision to distinguish among the current alternatives.

Finally, it has been suggested that, just as for the case of quarks, the gluon structure of nuclei could be quite different from that of simply a collection of nucleons. Our results on Be, Cu and Si targets, in addition to hydrogen, will be particularly useful for investigating such interesting issues.

In summary, the results obtained from the initial run of Fermilab experiment E706, and the preliminary analysis of the 1990 data, have confirmed the soundness of the experiment's underlying design. The large amount of data that has been accumulated will make a unique contribution to the study of the gluon structure of the nucleon and the pion. The MWest UNIX cluster, together with the extremely powerful Fermilab UNIX farms, will enable this interesting physics to be extracted in a timely manner, thus assuring that the very substantial investment that has been made in this project over the past decade bears fruit.

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E706 RUN SUMMARY

1988 Run

<u>Interaction</u>	<u># of Events</u>	<u>Sensitivity</u>
π^- Be @ 500 GeV/c	2×10^6	0.5 ev/pb
$[p, \pi^+]$ Be @ 500 GeV/c	3×10^6	0.75 ev/pb

1990 Run

<u>Interaction</u>	<u># of Events</u>	<u>Sensitivity</u>
π^- Be @ 530 GeV/c	30×10^6	8.6 ev/pb

1991 Run

<u>Interaction</u>	<u># of Events</u>	<u>Sensitivity</u>
pBe @ 800 GeV/c	23×10^6	7.3 ev/pb
pH @ 800 GeV/c		1.5 ev/pb
$[p, \pi^+]$ Be @ 530 GeV/c	14×10^6	6.4 ev/pb
$[p, \pi^+]$ H @ 530 GeV/c		1.3 ev/pb
π^- Be @ 530 GeV/c	4×10^6	1.4 ev/pb
π^- H @ 530 GeV/c		0.3 ev/pb

Total Number of Events : 76×10^6

Table I. Summary of E706 run statistics.

E706 Graduate Students
1990 & 1991 Data Sets

J. Bacigalupi	California-Davis
V. Zutshi	Delhi
L. Apanasevich	Michigan State
A. Maul	Michigan State
L. Sorrell	Michigan State
P. Chang	Northeastern
W. Dlugosz	Northeastern
D. Striley	Northeastern/Missouri
J. Kuchler	Oklahoma
S. Blusk	Pittsburgh
W.-H. Chung	Pittsburgh
M. Begel	Rochester[DOE]
L. DeBarbaro	Rochester[DOE]
G. Osborne	Rochester[NSF]
R. Roser	Rochester[DOE]
N. Varcas	Rochester[DOE]

E706 PhDs at Fermilab

V. Kapoor	Delhi
D. Skow	Fermilab
J. Mansour	Michigan State
C. Lirakis	Northeastern
J. Dunlea	Rochester[DOE]
G. Fanourakis	Rochester[NSF]
J. Ftacnik	Rochester[NSF]
G. Ginther	Rochester[DOE]
M. Zielinski	Rochester[DOE]

Table II. List of current E706 graduate students and postdocs resident at Fermilab.

DIRECT PHOTON EXPERIMENTS

$20 \text{ GeV} \leq \sqrt{s} \leq 40 \text{ GeV}$

Sensitivities (evts/pb)

Experiment	Target	π^-	$\bar{p}$	π^+	p	Lab Energy
WA70	H_2	3.5	–	1.3	5.2	280 GeV
NA24	C	1.3	–	0.2	0.5	300 GeV
E705	Li	6.8	0.2	7.4	4.2	300 GeV
UA6	H_2	–	3.5	–	6.1	315 GeV
E706	H_2, Be, Cu	12.3	–	0.8	9.3	500, 530 GeV
E706	H_2, Be, Cu	–	–	–	10.6	800 GeV

Table III. Comparison of E706 with earlier direct photon experiments.

Two Photon Mass Distribution

Preliminary 1990 Data

Figure 1. Two photon mass distribution in the π^0 mass region for a representative sample of π^- Be data at 530 GeV/c.

Two Photon Mass Distribution

Preliminary 1990 Data

Figure 2. Two photon mass distribution in the η mass region for a representative sample of π^- Be data at 530 GeV/c.

π^0 & η Mass vs LAC Octant

Preliminary 1990 Data

Figure 3. The variation across LAC octants of the mean π^0 and η masses normalized to their accepted values.

π^0 Asymmetry Distributions

(a) Preliminary 1990 Data

(b) Final 1988 Data

Figure 4. The energy asymmetry distribution for (a) a representative sample of 1990 data and (b) the final 1988 data sample.

GLUON STRUCTURE FUNCTION COMPARISON

$$xG(x, Q^2=4)$$

TEVATRON FIXED-TARGET KINEMATIC RANGE

$$xG(x, Q^2=50)$$

TEVATRON COLLIDER KINEMATIC RANGE

$$xG(x, Q^2=1600)$$

Figure 5. Two representative gluon structure functions compared at various values of Q^2 .

Structure Function Comparison Inclusive π^0 Production

(a) π^- -Be at 500 GeV/c

(b) p Be at 500 GeV/c

Figure 6. Comparison of cross sections for inclusive π^0 production evaluated using various parton distribution functions for (a) π^- -Be data at 500 GeV/c and (b) p Be data at 500 GeV/c.

Structure Function Comparison Inclusive γ Production

(a) π^- -Be at 500 GeV/c

(b) pBe at 500 GeV/c

Figure 7. Comparison of cross sections for inclusive direct γ production evaluated using various parton distribution functions for (a) π^- -Be data at 500 GeV/c and (b) pBe data at 500 GeV/c.

Hybrid Mesons and Other Physics Issues in Coulomb Excitation at High Energies

(Drs. T. Ferbel, P. Slattery and M. Zielinski; Graduate Students: D. Casey
and H. Zhu)

Historical Introduction

There has been great interest in the question of the existence and properties of an isovector $J^{PC} = 1^{-+}$ meson, which we will denote as the $\tilde{\rho}$.¹⁾ The quantum numbers of this state are exotic in the sense of the traditional $q\bar{q}$ quark model. States of this kind are expected to exist in the hadron spectrum of the elementary particles, especially in the form of a system composed of a gluon and a $(\bar{q}q)$ color octet. Such hybrid mesons have been discussed on the basis of a variety of QCD-inspired models.²⁾ Although there is uncertainty concerning the widths and specific decay channels for hybrids, most models predict these mesons to have masses in the range of 1.5-2 GeV, and widths comparable to those of ordinary $q\bar{q}$ mesons.

Figure 1. Electromagnetic production of a hybrid $\tilde{\rho}$ in the Coulomb field of nuclear charge Z.

There is general consensus that an object such as the $\tilde{\rho}$ will have a branching width into $\pi\rho$ that is of the order of 1-10 MeV, and a substantially larger rate into more complex channels such as $\pi b_1(1235)$ or $\pi f_1(1285)$.³⁾ The presence of a 1-10 MeV width into the $\pi\rho$ channel assures, through vector-dominance arguments, a rate of $\tilde{\rho}$ into $\pi\gamma$ at a level of 3-30 KeV:

$$\Gamma(\tilde{\rho} \rightarrow \pi\gamma) = \frac{\alpha}{\gamma_\rho^2/\pi} \left(\frac{k_\gamma}{k_\rho}\right)^3 \Gamma(\tilde{\rho} \rightarrow \pi\rho^0) \quad (1)$$

Here α is the fine-structure constant, $\gamma_\rho^2/\pi = 1.98 \pm 0.09$ is the $\rho - \gamma$ coupling,⁴⁾ k_γ and k_ρ are respectively the momenta of the photon and ρ , in the rest frame of the $\tilde{\rho}$.

Figure 2. Cross section for $\pi^+\pi^0$ production in π^+Pb collisions for $t < 0.002\text{GeV}^2$ incident momentum. The curves correspond to different ρ^- line shapes used in the Primakoff calculation.

With a finite branching rate to $\pi\gamma$, such hybrid mesons can be produced through the Primakoff mechanism, in the Coulomb field of nuclei (see Fig. 1). The yield of $\bar{\rho}$ can be written as follows:⁵⁾

$$\frac{d\sigma}{dt} \simeq 24\pi\alpha Z^2 \Gamma_{\bar{\rho} \rightarrow \pi\gamma} \left(\frac{1}{m_{\bar{\rho}}}\right)^3 \frac{(t - t_0)}{t^2} \quad (2)$$

where Z is the nuclear charge, t_0 is the minimum value of the square of the four-momentum transfer (t) required to produce coherently the mass $m_{\bar{\rho}}$. Because of the dependence of t_0 on incident energy, the cross section in the range of Tevatron energies grows as $\log s$ (and far more dramatically for masses $> 3\text{ GeV}$).

Searching for hybrid mesons via the Primakoff mechanism is quite appealing because, as is well known,⁶⁾ the Coulomb production process is well understood and almost background-free at high energies. Figures 2 and 3 display rather typical data from our previous Fermilab experiment (E272) on dipion production on nuclear targets.⁷⁾ The mass spectrum is clearly dominated by the ρ resonance, and the t -distribution exhibits a steep peak at 0° , characteristic of electromagnetic production. (The width of the peak in t is determined almost entirely by the experimental resolution.)

Previous searches conducted for objects such as the $\bar{\rho}$, have met with mixed success. The results of Alde et al.,¹⁾ although exceedingly interesting, are somewhat controversial, and have yet to be confirmed. Similarly, the more recent claims of Condo et al.¹⁾ for a $\pi\rho$

state with exotic quantum numbers need substantiation. Earlier studies published from our experimer' E272 were limited in their mass-reach because E272 was designed for low-mass spectroscopy, and therefore the sensitivity to masses in excess of 1.5 GeV was rather poor.^{7,8)} The data in the $\pi\eta$ and $\pi\rho$ modes showed no effect, and could only be used to set upper limits on the branching rate of the hybrid meson into the $\pi\gamma$ mode. This result is not surprising because the width of a vector hybrid into the above channels is expected to be rather small (several percent of the total width). The upper limits from E272 were not very restrictive for masses beyond 1.5 GeV.

Figure 3. Cross section for ρ^+ production in π^+A collisions at 200 GeV/c. The curves are fits to a coherent sum of strong and Coulomb production contributions.

One of the anticipated major decay modes to which E272 was sensitive was the $\pi^+ f_1(1285)$ channel. In fact, E272 observed an unusual enhancement in the $\pi^+ f_1(1285)$ system that was reported in 1981.⁹⁾ Those data are shown in Figs. 4 and 5. There is

Figure 4. Distributions in $\pi^+\pi^-\eta$ and π^+D mass for coherent production of $\pi^+\pi^+\pi^-\eta$ systems on Pb and Cu targets in π^+A collisions at 200 GeV/c.

some evidence for electromagnetic production of a $\pi^+f_1(1285)$ state (called π^+D in the figure). The peak at ~ 1.6 GeV is essentially a threshold effect, and consequently likely to be an S-state (similar to the $\pi\rho$ threshold A_1 , the $\pi\omega$ threshold B-meson, or the πK^* Q meson, etc). If the peak could be shown to be a resonant S-wave system, then it would be a prime candidate for the $\bar{\rho}$. Unfortunately, the data are too poor to prove that case, but the results are tantalizingly suggestive of this exciting possibility. Assuming the entire enhancement is resonant, yields a radiative width into $\pi - \gamma$ of about 500 KeV; this is a factor of about 10 higher than expected from naive phenomenological arguments, suggesting that the observed effect may not be simple in character. (Very interesting preliminary results on the issue of the production of hybrid mesons in $\pi\rho$, $\pi\eta$, $\pi\eta'$ and $\pi f_1(1285)$ channels in πp collisions were reported by the Zaitsev IHEP group at the Dallas Conference. The work has not yet been published, but the first indications suggest the presence of resonant contributions to $J^{PC} = 1^{-+}$ states in several of these channels.)

Recent Developments

A letter of intent to pursue a next-generation Coulomb-field experiment was written to Fermilab in 1990. Instead of proceeding entirely on our own, we (Rochester, Seattle and Tel-Aviv) have decided to collaborate on our physics goals with the E781 group (Beijing, Bristol, Carnegie-Mellon University, CBPF (Brazil), Fermilab, IHEP, ITEP, Iowa, Moscow

State, St. Petersburg, and São Paulo) that is constructing a new forward-spectrometer for investigating production of charm baryons with a hyperon beam.¹⁰⁾ J. Russ (Carnegie-Mellon University) is the spokesman for the E781/SELEX effort. Adapting this spectrometer to the needs of the Primakoff experiment should be relatively straightforward,¹¹⁾ and we have been welcomed enthusiastically by the E781 collaboration. Aside from responsibility for the data analysis and simulation studies, we will focus on photon detection and on trigger issues (especially on providing several planes of silicon trigger counters and a target veto box). The E781 MOU was signed this year, and we anticipate our first data run in early 1995.

Figure 5. Distribution in the square of the momentum transfer to the nucleus for the π^+D events in Fig. 4(b). The dashed curve is what would be expected for the shape in strong production (diffraction dissociation).

Figure 6 represents the essential part of the E781 geometry relevant to the Primakoff study. Primarily, what will be required is a 500 GeV negative pion beam of about 10^6

particles/sec, which does not pose any great difficulty (the beam will consist of an almost equal mixture of Σ^- and π^-), a veto around the target region to assure that the interacting target nucleus did not break apart, and implementation of several trigger modifications. (The anticipated costs of special hardware are listed below.) The silicon microstrip system required for E781 is more than adequate for meeting our needs. (In fact, it is largely the advent of silicon microstrip detectors that makes the enormous improvement over E272 possible.) A lead-glass photon detector (about 60 cm $\times$ 60 cm in transverse dimensions) is being reconfigured by IHEP, and will be placed approximately 40 m downstream of the target, to provide precise positional resolution for electromagnetic showers.

Figure 6. Schematic of the E781 apparatus that can be used for studying forward production in the Coulomb field. The photon detector (γ) is about 60 cm $\times$ 60 cm, and is located ~ 40 m downstream of the target (T).

The acceptance of the spectrometer is quite high, even for such complicated final states such as the $\pi^+ f_1(1285)$. This is shown in Fig. 7.¹²⁾ The anticipated yields are also large. For example, assuming the 500 GeV π^- beam, and $\Gamma(\bar{\rho} \rightarrow \pi + \gamma)$ of about 50 KeV, provides about 10^5 $\bar{\rho}$ at a mass of 1.6 GeV/ c^2 in three weeks of Fermilab running time. (There would also be about 5×10^6 ρ^- produced in the same period, which is about a factor of 10^2 greater than obtained in E272.) For a 40% branching ratio of $\bar{\rho}$ to $\pi^+ f_1(1285)$, this would yield about 6,000 events in the $\pi^- \pi^+ \pi^- \gamma \gamma$ channel, and a 10% branching fraction into $\pi \eta$ would yield about 4,000 $\bar{\rho}$ events in the $\pi^- \gamma \gamma$ channel. The t -resolution of the spectrometer, crucial for separating Coulomb production from background, is also acceptable (< 15 MeV/ c), and limited primarily by multiple scattering in the target.

Figure 7. Acceptance of the E781 apparatus for two $\tilde{\rho}$ decays, assuming a $\sin^2 \theta$ or isotropic decay of the hybrid.

Our group is looking forward to the next-generation Coulomb field experiment, and plans to re-examine the radiative decays of well known mesons, as well as search for more exotic objects such as the $\tilde{\rho}$. However, in addition to probing questions in meson spectroscopy, the nuclear Coulomb field is a rich source for exploring other physics issues. In particular, deviations from point-like $\pi^- - \gamma$ and $\Sigma^- - \gamma$ Compton scattering can be studied, and provide information pertaining to hadron polarizability.¹³⁾ The chiral anomaly in the $\gamma \rightarrow 3\pi$ transition can be related to that in $\pi^0 \rightarrow 2\gamma$, and to the rate for $\pi\gamma \rightarrow \pi\pi$ at threshold, which can be measured via Coulomb production.¹⁴⁾ The importance of clarifying these issues has been emphasized recently at the 1992 Rochester Conference at Dallas.¹⁵⁾

Request for Capital Funds

The main hardware requirements for the Primakoff part of E781 involve the construction of a special set of silicon counters to assure that an interaction has taken place in the target. Without this add-on the dead-time for the experiment would be unacceptable. We

expect to implement a hodoscope system that will have approximately 200 channels, and an anticipated cost, including silicon planes and readout, of \$25,000. These funds were not budgeted in the initial concept for E781 because the Primakoff part was added later to the experiment. (See ref. 11.)

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Task I: The GEM Experiment at the SSC

(Drs. J. Dunlea, T. Ferbel, G. Ginther, C. Lirakis, F. Lobkowicz (NSF), P. Slattery and M. Zielinski; Technical Associate: D. Ruggiero)

Introduction

The GEM Experiment

The GEM Collaboration was formed in June 1991 for the purpose of developing a major detector for the SSC. At the present time, the collaboration consists of more than 1010 physicists from 114 institutions in 17 countries. GEM ("Gammas, Electrons, and Muons") is designed to provide precision lepton and photon detection, combined with good resolution for measuring hadron jets. The emphasis is on searches for new physics by means of precision measurements of high p_T events using a detector concept involving a compact tracker and a large open-geometry calorimeter and muon system. The experiment's physics goals include the discovery and subsequent study of the mechanism for electroweak symmetry breaking, investigating the origin of mass and flavor, and searching for new physics beyond the standard model.

Figure 1 presents a perspective view of the GEM detector. The design is based on the following principles:

- Using very precise electromagnetic calorimetry without a magnet coil in front of it. This will provide optimized measurements of gamma and electron energies, thus enabling the reconstruction of the mass of narrow states with superior resolution;
- Embedding a precise 4π muon spectrometer in a large superconducting solenoidal magnet, thus allowing measurement of the momenta of high energy muons with a minimum of multiple scattering. The muon system will also operate in a quiet environment, since it is shielded by the thick calorimeter;
- Employing hermetic hadronic calorimetry for the measurement of jets and the reconstruction of missing transverse energy;
- Using central tracking in a magnetic field with sufficiently low occupancy to operate reliably at the highest luminosities that can be anticipated at the SSC ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$). The central tracker is to be compact, allowing for correspondingly compact calorimetry and a large muon tracking volume.

The GEM Collaboration submitted a Letter of Intent [1] in November 1991 and its Technical Design Report [2] in April 1993. This latter document in particular contains a complete description of the GEM detector, and describes in detail the criteria that led to the adoption of this specific design.

Rochester's Participation in GEM

The University of Rochester's overall participation in GEM has the following principal areas of emphasis:

I. Designing, assembling, and testing barrel calorimeter hadron towers. Within this general category, the following specific areas of responsibility have been identified:

a. Designing and assembling from 6 to 12 barrel hadronic prototypes to be exposed to beam during various phases of GEM's Fermilab test beam program. It is anticipated that each of these units could ultimately be installed in GEM, possibly after undergoing modifications in response to test beam results.

b. Working with representatives of those organizations selected to build the barrel hadronic production modules to assure that the experience gained in building the prototypes is reliably and adequately transferred.

c. Developing quality control standards for the barrel hadronic production modules, and monitoring the modules as they are assembled to assure that these standards are met. Room temperature testing of all production modules will be required, along with cryogenic testing of selected units.

d. Addressing electro-mechanical interface issues relevant to the design of signal feedthrus and cable mounts for the overall barrel calorimeter. Such considerations directly affect the barrel hadronic calorimetry, since the readout cables exit the barrel cryostat at the back of the hadron towers in the vicinity of the barrel to end cap transition.

e. Helping install the complete complement of hadron towers into the operational GEM barrel cryostat.

II. Operating the GEM test beam program in Fermilab's MWEST area. Within this general category, the following specific areas of responsibility have been identified:

a. Assuming overall management responsibility for the MWEST test beam program, including negotiating Memoranda of Understanding with Fermilab, accepting overall ES&H responsibility for the MWEST area while it is assigned to GEM, maintaining liaison with Fermilab's Research Division including its safety review committees, working with Fermilab technical staff to prepare MWEST for GEM's use, and hiring and supervising technical support personnel employed by GEM to help operate the MWEST facility.

b. Taking lead responsibility for developing an integrated data acquisition system for MWEST. This system must be capable of not only reading out *ab initio* new and existing test beam equipment (monitoring and tagging devices, tracking chambers, etc.), but also of gradually incorporating elements of the final GEM data acquisition system. Achieving this goal will involve active liaison with the Fermilab Computing Division, with analogous groups at the SSC Laboratory, and with appropriate subgroups within GEM.

c. Equipping MWEST with a versatile test calorimeter transporter capable of providing horizontal, vertical, rotational, and tilting motions. This device is to employ the existing MWEST transverse rail system, and incorporate certain other components of the existing E706 calorimeter gantry.

d. Working with the SSC physicists and engineers who are designing the MWEST test cryostat and its associated cryogenics to assure that this device is well-matched to the calorimeter transporter, and that it uses to the extent practical the extensive cryogenic facilities already present in MWEST. We will also help expedite the process of obtaining the necessary Fermilab safety approvals for the calorimeter test cryostat and its transporter.

e. Developing online monitoring and offline reconstruction software to provide timely diagnostic feedback during calorimeter beam testing.

Personnel

The following Rochester personnel are committed to GEM:

Prof. Paul Slattery. Supported by DOE. Will split his research time between the analysis of E706 (for which he serves as Spokesperson) and GEM, with particular emphasis in GEM on serving as Project Manager for the MWEST test beam program. No additional data is to be acquired by E706.

Prof. Fred Lobkowicz. Supported by NSF. Will devote his research time primarily to GEM, with particular emphasis on designing and building the barrel hadronic calorimetry.

Prof. Tom Ferbel. Supported by DOE. Will devote his research time primarily to non-GEM activities during the next two years.

Dr. James Dunlea. Supported by DOE. Will devote his time primarily to GEM, with particular emphasis on developing the GEM test beam data acquisition system.

Dr. George Ginther. Supported by DOE. Will split his time between the analysis of E706 and GEM, with particular emphasis in GEM on providing on-site supervision of

the MWEST test beam program as Physicist-in-Charge.

Dr. Marek Zielinski. Supported by DOE. Will devote his time primarily to E706 data analysis during the next two years.

Mr. Dan Ruggiero. Supported by DOE. Will devote his time primarily to GEM, with particular emphasis on assisting in the management and operation of the MWEST test beam program.

In addition, operating funds from DOE's Division of High Energy Physics have been requested to hire **Dr. Chris Lirakis** to provide day-to-day supervision to the assembly and testing of the prototype barrel hadronic modules.

Plans for FY1994

In FY1993, the Rochester GEM group received equipment funds from DOE's Office of the SSC and a grant from the Texas National Research Laboratory Commission to accomplish the following tasks:

- (1) Complete the engineering design for the barrel calorimeter hadron modules and purchase sufficient raw materials and components to assemble at least 6 hadronic towers.
- (2) Complete the engineering design of the MWEST calorimeter transporter and secure the requisite Fermilab safety approvals for this design.

A brief technical description of each of these tasks is presented below.

(1) The GEM Barrel Hadronic Calorimeter

The barrel hadronic modules are a total of 4.7λ deep at 90° . Of this, 4.3λ is active volume, while the balance is consumed by supports, electronics motherboards, cables, etc.

A hadronic tower has segmentation in $\Delta\eta \times \Delta\phi$ of 0.08×0.08 . Each hadronic tower thus overlaps nine towers in the EM calorimeter. Mechanically there are two separate modules in depth, each covering 9° in ϕ , and extending from the center support washer to one end of the barrel. The modules in the second hadronic layer are rotated by 4.5° relative to the modules in the first layer. Any particle going through the crack between modules in the first layer encounters the center of a module in the second layer. There are 80 modules in each layer. Electrically there are three layers in depth, as discussed below. An isometric view of a module is shown in Fig. 2.

The electrostatic transformer arrangement

The noise/signal ratio in an ionization calorimeter is proportional to the square root of the detector's electrostatic capacitance. The noise can be reduced by transforming the capacitance of the detector to match the capacitance of the amplifier. Since the GEM calorimeter is inside the magnetic field of the superconducting coil, we cannot use

a conventional magnetic transformer. Instead we use an electrostatic transformer, where several readout gaps are placed in series for readout purposes rather than connecting all ionization gaps in parallel as is usually done. This arrangement increases the effect of the cross capacitance between neighboring channels. This effect is roughly proportional to the absorber thickness in each gap. The optimum transformer ratio (number of gaps in series) lies between 3:1 and 4:1, when one chooses an absorber thickness of 9-10 mm. We have chosen an absorber thickness of 9 mm and a 3:1 ratio (three gaps in series) in the barrel. Two such arrangements can naturally be set in parallel, and this is the unit we call *one cell*. It is sketched in Fig. 3. Each module consists of a total of 6 cells.

Absorber material

If one wants to maximize the absorption length per unit of depth, but is not willing to accept expensive materials such as tungsten, then the natural absorber of choice would be copper. However, copper ($Z = 29$) and krypton ($Z = 36$) are sufficiently similar that there is hardly any electromagnetic suppression, and rough estimates predict an e/h value of 1.9. It was therefore decided to use lead as the primary absorber material, but use copper or brass where both absorption and mechanical rigidity are required. Another advantage of brass (or copper) is the fact that during cool-down its shrinkage is very similar to that of aluminum, the material selected for the overall cryostat.

Absorber planes

There are two different types of absorber material. Every sixth absorber is a *ground plane*. This is a solid copper (or brass) sheet 9 mm thick, extending across the whole module. Electrically each ground plane is tied to the signal ground of the readout cable leading to the amplifiers. All other absorber planes are *tile planes*. A typical tile plane is shown in Fig. 4. It consists of individual tiles, each corresponding to a single tower, separated by approximately 0.3 mm gaps. A 0.5 mm thick copper clad G-10 board is laminated to each side of the tiles with the copper facing outwards. The cladding is subdivided into squares of the same size as a single tower, with only about 0.5 mm between each square. The individual squares are connected by a thin line of resistive ink, providing a resistance of $\sim 1 \text{ M}\Omega$. The pads are thus independent at signal frequency, but are at the same voltage in DC mode. For most of the tile planes one side of these pad structures is tied resistively to high voltage (HV), the other resistively to ground. In the plane where the tiles are connected to the signal line which feeds the capacitively coupled pulse to the preamps, both are tied resistively to HV. These signal lines (not shown) have an impedance of 5-10 Ω .

Electrical readout structure

High energy electrons or photons will deposit a small fraction of their energy in the first layers of the hadronic calorimeter. One cell corresponds to about 11 radiation lengths. The first two cells of the first hadronic module will be read out separately, and thus provide a "tail catcher" to the electromagnetic calorimeter. The next four cells of the first hadronic modules form the second readout group in the first hadronic module. The second hadronic module (2λ) could either be read out as a single readout group or also subdivided into two sections.

(2) GEM's Calorimeter Testing Program at Fermilab

The highest energy beams in the world are those available at Fermilab, which makes this laboratory an ideal location in which to test and calibrate SSC detector elements. GEM proposes to mount a comprehensive test beam program in the Meson West (MWEST) area at Fermilab. The primary goals of the calorimetry component of this program are the following:

- Perform full-scale engineering studies of all calorimeter subsystems: mechanical, electrical and cryogenic;
- Achieve full system integration of the electromagnetic and hadronic cryogenic calorimetry and of the external (scintillating) calorimetry;
- Carry out a full system test of the calorimeter readout and calibration systems;
- Measure the response of the scintillating calorimetry and determine the reproducibility of its performance from module to module;
- Study the calorimeter's resolution at the highest energies available;
- Investigate the calorimeter's single particle response in the vicinity of representative cracks;
- Study the calorimeter's single particle response across the barrel to end cap transition;
- Investigate the calorimeter's response to high energy muons;
- Investigate the calorimeter's single particle response in the forward direction (relative to the GEM axis).

The ultimate goal of the MWEST calorimeter testing program will be to optimize the device's design where this is possible, modify existing modules when this is necessary, and understand in detail the characteristics of the final GEM calorimeter.

To carry out these tests, the MWEST beam line will be instrumented with silicon strip detectors capable of tagging the momentum of incident particles to a precision of $\pm 0.2\%$. It will also be equipped with high energy electron identification. A versatile calorimeter transporter will be constructed and mounted on the existing MWEST rail system. The transporter will provide for independent horizontal and vertical motion, as well as for rotation and tilting capability. Rochester has assumed responsibility for engineering this device. Figure 5(a) displays an end view of the calorimeter transporter with the fully loaded test cryostat in place. Beam is incident at the center line of the EM calorimetry. Figures 5(b) and 5(c) show the test cryostat rotated so as to present to the beam representative cracks in the inner and outer layers of hadronic towers, respectively. Note that as the cryostat is rotated, its vertical height is also adjusted on a set of jacks that descend into the 3 ft deep trench that is spanned by the MWEST rail system.

Figure 6(a) displays the calorimeter transporter in plan view showing the arrangement of test modules within the cryostat. Beam is incident at the mid-point of the barrel calorimetry, where the transporter is perpendicular to the beam direction. Figures 6(b) and 6(c) show the transporter oriented at the extremes of its horizontal motion. Note the correlation between the horizontal and rotational motions that achieves the requisite focussing on the simulated interaction point located approximately 19.5 inches upstream of the outer wall of the test cryostat.

Plans call for the testing of two full-size (4 m long) 9° electromagnetic wedges, each consisting of three readout layers. The hadronic towers are also to be full-size, split at 90° into two 2 m long modules, as in the actual GEM calorimeter. The hadron calorimetry also employs two physical, but three readout layers. To completely contain hadronic showers, the two layers will each contain three modules on each side of the 90° split. As in the actual GEM configuration, the outer modules will be shifted in azimuth by 4.5° relative to the inner modules to minimize the consequence of cracks. The outer endcap hadronic modules (in radius, relative to the GEM axis) are full size, while those at larger η (in the GEM context) are special units truncated to fit within the test cryostat. Behind the test cryostat are two full-size wedges of the external scintillating calorimeter.

Our strategy allows great flexibility in the mix of modules included in a given load of beam testing. These include starting with only one side of the hadron calorimetry, thus postponing the study of the 90° crack, or delaying the installation of the end cap prototypes, thus postponing the investigation of the transition region. The test cryostat and transporter are being designed to accommodate multiple loads with minimum down time. MWEST beam time will be available for other GEM test beam purposes during these transition periods. The GEM end cap calorimeter will employ liquid argon. To

avoid the additional expense of building separate test cryostats, plans call for conducting the MWEST tests using first argon and then krypton throughout a single test cryostat. Monte Carlo simulation will be employed to extrapolate the measured beam data to the actual GEM configuration.

Request for Operating Support

(1) Personnel Costs

The Rochester GEM group requests operating funds from DOE's Division of High Energy Physics to support Dr. Chris Lirakis, who is to lead the Fermilab-based effort to build prototype barrel hadronic calorimeter modules for subsequent beam testing. It is critically important that this construction project proceed expeditiously if we are to assemble the barrel hadronic prototypes and install them in the MWEST test cryostat prior to the start of the next Fermilab fixed target run, which is presently scheduled to begin during the first half of FY1995. It is worth noting that Dr. Lirakis will be the only non-teaching faculty member at Rochester whose primary focus within GEM is on the barrel hadronic prototype construction project.

(2) Travel Costs

Operating funds are also requested to cover the travel expenses of the DOE supported physicists working on GEM. Included are 22 trips to attend GEM Council and Collaboration Meetings, and 26 other trips to BNL and SSCL. Frequent travel by members of the Rochester GEM group is essential if we are to maintain effective coordination with other groups within GEM, particularly those that are building the EM test modules (BNL) and the MWEST test cryostat (SSCL). Only incremental costs incurred as the result of participation in GEM are included; trips to FNAL are to be covered by the existing Rochester operating grant for Task B. Also included is the established subsistence allowance for long-term stationing at FNAL for Dr. Lirakis of \$3420.

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Perspective View of the GEM Detector

Figure 1. Perspective view of the GEM detector.

Figure 2. Isometric view of a barrel calorimeter hadronic module.

Figure 3. A unit cell of an inner barrel hadronic module showing the electrostatic transformer concept.

Figure 4. Typical layer of an inner barrel hadronic module displaying individual tiles.

Figure 5(a). End view of the calorimeter transporter with beam at the center line of the EM calorimetry.

Figure 5(b). End view of the calorimeter transporter with beam centered on a representative crack in the inner hadronic layer.

Figure 5(c). End view of the calorimeter transporter with beam centered on a representative crack in the outer hadronic layer.

Figure 6(c). Top view of the calorimeter transporter with beam entering at the extreme of the end cap calorimetry.

Task C: D-Zero Collider Experiment at Fermilab

(Drs. G. Blazey, T. Ferbel, S. Gruenendahl, P. Slattery.

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General Remarks

After many years of design and construction, the D-Zero experiment is now taking data, and is working remarkably well. Preliminary results have been presented at the Dallas Conference, at Moriond, La Thuille and at various seminars and colloquia. Although our involvement in the upgrade of the detector to D0_β continues, with the anticipated completion of the analysis of data from the test beam, our participation in top physics and QCD issues will greatly increase. However, in order to maintain our group's analysis efforts, we will need an upgrade in our off-line computing resources at Fermilab. This is discussed in detail in Appendix A4.

Descriptions of the D-Zero experiment and its design are available in various conference proceedings and reports. We will therefore summarize here only the most relevant points. The detector is a hermetic device, covering angles down to $\pm 2^\circ$ in the collision frame. The absence of a central magnetic field provides a compact configuration that relies on segmented calorimetry for determining energies of hadrons, photons and electrons, and an outer magnetized-iron detector for measuring momenta of muons. Central tracking chambers contain TRDs that provide excellent π/e discrimination up to several hundred GeV. The electromagnetic sectors of the calorimeters have over 20 radiation lengths of material, and the hadronic sections over 6 interaction lengths. The calorimeters are constructed primarily from depleted uranium (to minimize difference in response to hadrons and electrons, as well as to attain high mass density), with liquid argon serving as the ionization medium. Outside of the cryostats, there is another ~ 7 interaction lengths of instrumented magnetized iron for determining momenta of muons. The D-Zero detector is shown in a cutaway view in Fig. 1. As just mentioned, its three major components are the central detector, calorimetry and the muon system. The central detector is comprised of tracking chambers, with space-point readout, and transition radiation detectors for distinguishing electrons from hadrons. The inner portion of the tracking chamber consists of a closely-spaced wire chamber capable of resolving tracks and decay vertices in the high-multiplicity environment of the interacting beams. The calorimeters are separated into three physical sections [one central (CC) and two ends (ECs)]. The compactness of the calorimeters provides a total depth large enough to contain high energy showers. The

muon system consists of three magnetized-iron toroids, which both bend the muons (providing sign and momentum determination) and absorb all remnant portions of the debris of hadron showers. The full depth of the system varies from 14 to 18 absorption lengths. Muon trajectories are measured before and after the toroids, using proportional drift tubes that provide space-point coordinate readout at ten locations along the track.

D-Zero is an experiment meant to explore the mass regime made available by the TeV-I energy and luminosity. It is the first of the second generation detectors, having been designed on the basis of results from the CERN collider. The detector consequently emphasizes measurement of hadron jets, electrons and muons, and, because of its excellent calorimetry, missing transverse momentum. The primary physics goals of the experiment include a search for the top quark and precision studies of W and Z bosons. It should be possible to detect departures from predictions of the standard model, such as deviations from QCD, and to search for new states or phenomena in the mass region above the W and Z. The D-Zero experiment is in many ways complementary to CDF, and with the completion of the $D0_{\alpha}$ detector, the TeV-I Collider has finally come of age in the 1992-93 run with two powerful detectors exploring the newly accessible mass range.

Past History of Rochester Involvement

Our interest in the long-term research possibilities of the SSC and the more near-term opportunities at the TeV-I Collider, as well as our expertise in liquid-argon calorimetry, were the primary factors in our group's initial decision to enter the D-Zero collaboration. Because of previous commitments, our early contributions to the experiment were somewhat modest. Among these were the following: we set up liquid-argon test vessels to study argon-poisoning properties of materials which were expected to be used in the construction of the calorimeters; we selected high-voltage (HV) cryogenic capacitors for the test-beam calorimeter and participated in the run during the summer of 1985; subsequently, we contributed to various aspects of the analysis of the first test-beam data. Using the EGS programs, we examined the effects of cladding and of thickness and flatness variations of uranium plates on the anticipated properties of D-Zero calorimeters; we investigated the effect of uranium and electronic noise on the resolution of the trigger; we designed and constructed prototype HV connectors for use within the calorimeters and for feedthroughs; and we carried out design work on the mechanical fixtures and the cryostat needed for the test beam program in the NWA experimental hall.

With the expansion in our scientific staff in late 1986, the DOE Rochester group, in collaboration with the group of Prof. Lobkowicz (NSF), has taken on additional responsibilities in the implementation of the test-beam program, as well as in other calorimetry-

related areas. We have concentrated on developing the design of the test-beam cryostat and of the associated mechanical supports and manipulators. Dr. Blazey was responsible for providing temperature and purity monitoring systems, both for the test beam studies and for the final D-Zero calorimeters, and Dr. Draper (currently at the University of Texas at Arlington) guided the day-to-day activity in the NWA experimental area, and helped coordinate preparations for the test beam runs (he also served as Liaison Physicist to the Research Division of Fermilab).

With direct access to the D-Zero programs through DECNET, we worked on the development of the GEANT Monte Carlo system for D-Zero. We examined questions pertaining to mechanical structure of endcap modules and the effect of different design choices on the overall resolution. We have studied aspects of the transition region between the central and endcap calorimeters (see Fig. 2) to determine the effect that additional readout information (e.g., scintillator) might have on the resolution of the detector.

Using a liquid-argon test vessel, we studied aspects of noise and high-voltage breakdown for the geometrical configurations of resistive coating planned for the endcap calorimeter modules. We also continued argon-purity tests to check on contamination properties of sundry laminating glues and epoxies, and low-density filler material, such as Rohacell. Over a dozen samples were cleared for use in D-Zero. In addition, we studied diffusion and adsorption properties of Rohacell, which we selected for use as low-density argon-displacers.

During the 1987/1988 and 1990/1991 test beam runs at NWA, we had responsibility for the overall coordination of the scheduling and supervision of the operations. We also made major contributions to the design and acquisition of the special cryostat and transporter that were used to study and calibrate the detailed performance of the calorimetry during the 1990/1991 runs. In addition, we provided manpower for shift work. We were also responsible for the maintenance and improvement of the argon-purity and temperature-monitoring systems, as well as for the online trigger logic and CAMAC system for the test beam.

Recent Activity

During this past year, the Rochester Group has continued to contribute to D-Zero through analysis of data obtained from the Test Beam (TB), through participation in the collider run, and through the analysis of jet production from collider data (and now also starting to work on top physics). We are playing a major role in the activity of the D-Zero QCD physics analysis group, with one of us (GB) is serving as co-convenor of that activity. As a result, we supervise many of the analysis efforts. Current topics under study

include inclusive and semi-exclusive jet spectra, rapidity gaps in jet production (a matter of great interest for SSC energies), other general characteristics of jet events, and calorimeter calibration. We are also using Monte Carlo events and test beam data for developing programs to analyze collider events. Finally, we have been working with Fermilab, Notre Dame and Purdue in the development of a scintillating-fiber system (SciFi) for the Upgrade of D-Zero.

Test Beam and Issues in QCD

Two of our students are writing their PhD dissertations on the results of the second test-beam run (Load-2) of the calorimetry, and one has just finished a PhD on the first run (1990). We have analyzed pion data from the first test-beam run to examine the characteristics of pion showers and to determine the position resolution of the EC, EM and IH calorimeter modules for hadrons. The test-beam data taken during 1990/1991 are being used to calibrate modules and to tune the response of the D-Zero detector. We have studied issues such as optimization of sampling fractions, longitudinal and transverse shower shapes, energy resolution and correlations in electron and pion showers, and compared the results with Monte Carlo simulations.

In the realm of analysis, we have assumed responsibility for the use of jets for calibrating the D-Zero calorimeters in the collider environment. Various algorithms based on transverse momentum balance in two-jet events are under investigation. In addition, we have been trying to develop an understanding of the response of the calorimeter to jets by combining data from the test beam with jet simulation, as follows. We generate parton jets via the HERWIG and ISAJET programs, and replace the individual particles in such jets with showers of same energy as measured in the test-beam. These pseudo-jets are then studied to gauge the overall response and resolution of D-Zero calorimetry to jets of different transverse momentum and rapidity, and to determine any effects due to zero-suppression, etc. Through these studies we hope to improve the algorithms for reconstructing jets and thereby obtain less ambiguous measurements of jet cross sections in D-Zero.

One of the important aspects of D-Zero jet studies involves the establishment of the relationship between jets reconstructed in the calorimeter (via some standard cone algorithms) and the partons produced in the collisions. Such correlations have to be obtained at the particle as well as at parton levels. Using Monte Carlo simulations (D0GEANT), with QCD events generated by HERWIG, we have started to study production characteristics of jets. The goal is to understand how jet variables such as rapidity and transverse energy become modified at different levels. We are also investigating differences found in

the character of jets for different generators and different structure functions, and how these differences are affected by the energy resolution of the calorimetry.

To determine the degree to which there is transverse energy balance in two-jet events, we have been studying an asymmetry observed in collider data between the hadronic and electromagnetic response of the calorimeter. This has been done using four different algorithms for jet-reconstruction (cones of 0.7, 0.5, 0.3 in $\eta - \phi$ space, and the "nearest neighbor" algorithm). We find 10-15% effects in the differences in energy balance as a function of the electromagnetic content of individual jets; the statistics are still poor, and we are currently increasing the data sample to examine in more detail events jets with large electromagnetic energy fractions.

We are participating in the current collider run through the taking of shifts, maintaining triggers, and monitoring of the calorimeter. In addition, we share responsibility for developing, implementing and deciding which triggers are to be readout in D-Zero. We are also involved in aspects of the work on the Level-2 trigger. The Rochester liquid argon purity monitors are operating during all data taking and have shown the calorimeter purity to be stable to about 0.2% over the course of the run.

Based on data from the test beam, we initiated a program aimed at developing an understanding of the character of the heavily ionizing and minimum ionizing components of hadronic showers. This is based on a comparison between the calorimeter's response to high energy particles and that of signals observed for α and β radioactive sources and for monitoring argon purity. By analyzing the HV plateau for pion-beam data at NWA into α and β -source components, we hope to be able to estimate the fractions of heavily and minimum ionizing energies in pion showers. The preliminary results of our study were reported at the Tokyo Conference on Liquid Ionization Detectors (April 1992, Waseda University), and a more extensive note on this subject is in preparation. At present we are investigating the detailed properties of electromagnetic showers using EGS, and hadronic showers using GEANT, in order to model the effects observed in the data.

D-Zero Upgrade

Finally, as we have stated, we have been developing techniques for making ribbons of scintillating fiber for the cosmic-ray test of the SciFi system, which is anticipated in summer 1993. This is discussed in more detail below.

Charged-particle tracking for the fully upgraded D-Zero configuration will rely on an inner silicon microstrip system and four units of scintillating fibers. The fibers will be epoxied into ribbons, in a double-layered structure, with each ribbon containing 128 fibers per layer. The ribbons will be mounted on thin carbon-fiber-wound cylinders, with two sets

placed coaxially and two sets at small stereo angles per cylinder. The lengths of the fibers will vary somewhat, with the longest being about 2.8 meters. The light produced in the fibers will be transmitted through individual light guides to solid state devices (VLPCs) of high quantum efficiency that will provide signals for further processing. The light will be read out from single ends of the fibers, which will have reflective coatings at their other ends.

Our major concern has been the development of ribbons of scintillating fibers, the measurement of positions of fibers on such ribbons, and the precise placement of such ribbons onto thin cylinders. We have had success producing 2-3 meter long double layers with 128 fibers per layer. (The technique is described in D0 Note 1532.) We have also developed plastic mass connectors for transferring the fiber signals to light guides (D0 Note 1601).

In addition, we have constructed a system for measuring positions of the fibers (on ribbons) to an accuracy of several microns. With this device, we will be able to determine whether any ribbon meets the quality criteria for uniform fiber spacing and straightness needed in the D0 detector. Fiber positions are measured by passing light from a pointlike source across the fibers, at known positions, and detecting that light at the ends of the fibers. The apparatus is contained inside a 3-meter-long light-tight box (D0 Note 1601).

We have also addressed the issue of mounting ribbons on a cylinder. We acquired one aluminum and two carbon-fiber-wound test cylinders for developing satisfactory techniques. We are working closely with Fermilab and Purdue in this effort. The mounting apparatus must guide the ribbons accurately into position and hold them there while they are epoxied in place. We expect to achieve fiber position placement accuracies of less than 50 microns for the completed tracking system of D-Zero. One possibility for the mounting device is based on using grooved blocks with which we can hold the ribbon in position, and a straight edge or a laser system for aligning the blocks. We have investigated various alignment schemes using laser diodes, and believe that, with this technique, mounting axial ribbons will be quite straightforward, however, aligning the stereo ribbons, which must wind around the cylinder, will present a greater challenge. The precision of alignment can be checked using a Cordax machine after the ribbons are fixed in place (D0 Notes 1602a, 1602b, 1623, 1628).

The measuring system for quality control (QC) will also be used for determining light attenuation in fibers, as well as transmission of light through the v-grooved connectors that join SciFi ribbons to light guides (this was also developed at Rochester).

Early in this fiscal year, financial considerations motivated the transfer of all the Rochester equipment and tools associated with ribbon production and QC to Fermilab.

Appropriate facilities are being constructed there for continuing this work, which will be performed under our supervision (SG).

Our involvement in the cosmic-ray test of the SciFi system has also expanded. Rochester has assumed responsibility for the online hardware/software for the data acquisition, we are also developing HV and temperature monitoring tools for the VLPCs, and are concerned with aspects of the trigger for the test. In addition, we have written an online event display (using DI3000) for the test; this will incorporate the monitoring of ADC response and of efficiencies (based on track reconstruction) for each channel. Finally, we will be involved in the preliminary characterizations of the VLPCs prior to their assembly in cassettes for the cosmic-ray test. University of Illinois (at Chicago Circle), Northeastern and Rice Universities are collaborating with us and with Fermilab on this project.

Activities and Talks

The activities of Tom Ferbel, the principle investigator for this task, are described in the introduction section along with the activities of the other PI's. Preliminary QCD results from the DZero experiment were presented by G. Blazey at the Univ. of California at Riverside (3/92), Texas Tech (4/92), the SSCL (11/92), the DPF Meeting of the APS (11/92), the Univ. of Arizona (1/93), the Univ. of Maryland (2/93), Florida State Univ. (2/93), Fermilab (3/93) and the University of Indiana (3/93). He presented a talk on heavily ionizing components of particle showers at the Int'l Conf. on Liquid Radiation Detectors at Tokyo (4/92). S. Durston presented DZero test beam results at Purdue University (8/92), general talks on the DZero experiment at Hobart and William Smith College, (9/92), SUNY Brockport, (11/92) and SUNY Geneseo, (3/93) and will present recent DZero results at the University of Dortmund, Germany, in June 1993.

Publications and Conference Proceedings to be Published

1. **Beam Test of the DZero Uranium Liquid Argon End Calorimeters**, S. Abachi et al, (DZero collab.) Nucl. Inst. and Meth. **A324**, 53 (1993).
2. **Design, Construction, and Performance of the Electromagnetic Module of the DZero End Calorimeter**, H. Aihara et al., (DZero Collab.) Nucl. Inst. and Meth. **A325**, 393 (1993).
3. **The DZero Experiment at Fermilab**, U. Heintz (for the DZero collaboration), Proceedings of the 4th Topical Seminar on "The Standard Model and Just Beyond" San Miniato, Italy June 1992, D0 Note #1486.
4. **The DZero Muon System and Early Results on its Performance**, David

- Hedin, (for the DZero Collaboration) XXVI INT'L CONF. ON H.E.P, Dallas, Texas August 1992, D0 Note #1488.
5. **DZero Triggering and Data Acquisition**, Bruce Gibbard, (for the DZero Collaboration) XXVI INT'L CONF. ON H.E.P, Dallas, Texas August 1992 D0 Note #1496.
 6. **The DZero Monte Carlo**, John Womersley, (for the DZero Collaboration) XXVI INT'L CONF. ON H.E.P, Dallas, Texas August 1992 D0 Note #1520.
 7. **Tests of the DZero Calorimeter Response in 2 - 150 GeV Beams**, Kaushik De, (for the DZero Collaboration) XXVI INTERNATIONAL CONFERENCE ON H.E.P, Dallas, Texas August 1992 D0 Note #1466A.
 8. **The DZero Upgrade Program and its Physics Potential**, Michael Rijssenbeek, (for the DZero Collaboration) XXVI INTERNATIONAL CONFERENCE ON H.E.P, Dallas, Texas August 1992 D0 Note #1495.
 9. **Operation of the DZero Uranium Liquid-Argon Calorimeter System**, Joan Guida (for the DZero Collaboration), Proc. of the 3rd Conf. on Calorimetry (Corpus Christi TX, Oct. 1992). D0 Note #1509.
 10. **The DZero Calorimeter Triggers**, Jan Guida (for the DZero Collaboration), Proc. of the 3rd Conf. on Calorimetry (Corpus Christi TX, Oct. 1992). D0 Note #1510
 11. **The DZero Inter-Cryostat Detector, Massless Gaps and Missing Et Resolution**, K. Streets (for the DZero Collaboration), Proceedings of the 3rd Conf. on Calorimetry (Corpus Christi TX, Oct. 1992). D0 Note #1508.
 12. **Inclusive Single Muon Production with the DZero Detector**, Kamel Bazizi, Proc. of the 7th APS DPF Conf., Nov. 1992 (FNAL). D0 Note #1539A.
 13. **Low Energy Response of the DZero Calorimeter and Jet Energy Measurement**, Pushpalatha C. Bhat, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1546.
 14. **Dijet Angular Distributions in the DZero Experiment**, Proc. of the 7th APS DPF Conf., Nov. 1992 (Fermilab). D0 Note #1547.
 15. **W and Z Decays to Electrons in DZero**, Norman A. Graf, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1551A.
 16. **The DZero Upgrade Silicon Tracker**, Ann Heinson, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1542.
 17. **Dimuon Production in DZero**, Susumu Igarashi, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Notes #1540A.
 18. **Top Quark Search in DZero from the Lepton + Jets Mode**, Boaz Klima, Proc. of the 7th APS DPF Conf., Nov. 1992 (Fermilab). D0 Note #1533A.

19. **Triggering the DZero Detector**, James T. Linnemann, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1572 (Abstract)
20. **Highlights from DZero**, Ronald J. Madaras Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1576.
21. **Upgraded DZero Calorimeter Electronics for Short Tevatron Bunch Space and the Effect of Pile-Up on the W Mass Measurement**, Sandor Lokos, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1562.
22. **Leptoquark Search in DZero**, K. Wyatt Merritt, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1556A.
23. **Electron Identification in the DZero Detector**, Meenakshi Narain, Proc. of the 7th APS DPF Conf., Nov. 1992 (Fermilab). D0 Note #1548A.
24. **Search for the Top Quark in Dilepton Events with DZero**, Richard Partridge, Proc. of the 7th APS DPF Conf., Nov. 1992 (Fermilab). D0 Note #1531.
25. **Direct Photon Production from the DZero Experiment**, Gregory R. Snow, Proc. of the 7th APS DPF Conf., Nov. 1992 (Fermilab). D0 Note #1553A. **A Scintillating Fiber Detector for the DZero Upgrade**, Mitchell Wayne, Proceedings of the 7th APS DPF Conference, Nov. 1992. of the 7th APS DPF Conf, Nov. 1992 (Fermilab). D0 Note #1550. **W and Z Decays to Muons at DZero**, Darien Wood, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1552A.
28. **Measurement of W Boson + Jet Production with the DZero Detector**, Jachoon Yu, Proceedings of the 7th APS DPF Conference, Nov. 1992 (Fermilab). D0 Note #1545.

Figure 1
Cut-away view of D-Zero detector.

DØ LIQUID ARGON CALORIMETER

Figure 2

Cut-away view of D-Zero calorimetry.

Task D: Deep Inelastic Lepton Nucleon Scattering

Participants: Drs. A. Bodek, P. Auchincloss, R. Walker, Mr. U. K. Yang; (with help from H. Budd, W. Sakumoto, P. de Barbaro) (FNAL E744/E770/E815; SLAC E140/E140X/E143)

Overview

The research performed under this task involves neutrino experiments at FNAL and electron scattering experiments at SLAC. The primary activity in the neutrino part of this task during last year was the analysis of data from neutrino experiments E744 and E770 (CCFR). These neutrino experiments comprise the largest and most precise neutrino data set to date. We have submitted for publication the best determination of the four flavor QCD $\Lambda_{\overline{ms}}^4$ from the analysis of xF_3 . Our precise extraction of F_2 indicate that SLAC, BCDMS, and CCFR yield a consistent set of structure functions over a very wide range of x and Q^2 . We have extracted a new precise determination of $\sin^2 \theta_W$ and have extracted a better determination of the charm quark mass and level of the strange sea.

The primary activity in the the SLAC part of this task during the last year was the analysis of SLAC experiment E140X which ran in Fall of 91. Professor A. Bodek is the co-spokesman of SLAC E140 and SLAC E140X. We have also finished the combined analysis of all deep inelastic scattering experiments from SLAC. These data helped resolve the disagreements between BCDMS, EMC, and CDHS data. The inelastic structure functions from the combined analysis were published in 1992, and also submitted for publication new precision measurements of elastic and inelastic form factors from SLAC experiments E140 and NE11. Preliminary results from the analysis of SLAC E140X on $R=\sigma_L/\sigma_T$ have been presented in the April 93 APS meeting in Washington DC.

We are limiting our involvement at SLAC experiment to analysis. We have shifted our efforts in this task to the new FNAL neutrino experiment E815, which is a continuation of our previous neutrino program, E744/E770. The primary goal of E815 is a new measurement of $\sin^2 \theta_W$ and more precise structure functions. For E815 we are responsible for overseeing the restoration of the fast electronics, constructing the new veto wall, and replacing calorimeter phototubes.

Mr U. K. Yang from Rochester is a Ph.D student on E815. He will oversee the new veto wall construction and will do a Ph.D thesis on $R= \sigma_L/\sigma_T$ for E744/E770 and E815 data.

1. Electron Scattering Experiments at SLAC (E140, NE11, E140X)

Results of the following analyses have been published in 1992, presented at conferences or submitted for journal publication in 1993.

- (a) New precise extraction of the electric and magnetic form factors of the proton from SLAC E140 and SLAC NE11. See figure D-1. (publications 4, 5, 17, 19).
- (b) The EMC effect in the deuteron and its affect on the extraction of neutron cross sections from deuterium data. See figure D-2. (publication 1).
- (c) Precision determinations of the structure function F_2 from all SLAC data. (publications 2, 18) Some of the results on the comparison of SLAC, BDCMS, and CCFR data are shown in Figure D-3. These precise SLAC data have provided the low Q^2 anchor for all deep inelastic scattering experiments. See figure D-8.
- (d) Final results on the EMC effect for many nuclear targets from E139. (publication 20) The following analysis efforts are proceeding in FY93 and FY94.
 - (a) New precise extraction of the electric and magnetic form factors of the neutron from SLAC NE11. (first results are in publication 17)
 - (b) New extractions of R at large x and at the resonance region from E140X. SLAC E140X completed taking data in the fall of 1991. First results were presented at the Washington APS meeting in the April 1993. (publication 21).
 - (c) A combined analysis of all SLAC data and E140X in the resonance region.

The data on $R = \sigma_L/\sigma_T$ is sensitive to higher twist effects and to the gluon distribution. Good data on $R = \sigma_L/\sigma_T$ is essential for the extraction of structure function data from all deep inelastic data. Our fit to the SLAC combined analysis data (called R_{world}) is currently in use by the NMC muon collaboration, BCDMS, neutrino experiment CCFR and all other deep inelastic scattering experiments. Figure D-4 shows the results from the combined analysis on R and two structure functions with different gluon distributions that are given in the CERN PDF library. The data on R is getting good enough to favor gluon distributions which extend to higher values of x .

We are continuing our investigation into a better determination of R in SLAC E140X and also using our CCFR neutrino data. Figure D-5a,b shows first results from SLAC E140X (publication 20). The data indicate that at large x , the non perturbative higher twist effects are important and that at low values of x , R is large and favors more gluons at large x (since R is related to the integral over gluon distribution for x to 1.0).

Figure D-1

The high precision results for the magnetic and electric form factors of the proton (G_{mp} and G_{ep}) from SLAC NE11. The ratio of the two form factors F_2 and F_1 times Q^2 approaches a constant as predicted by QCD. The analysis of neutron data is currently in progress.

Figure D-2

(a) A comparison of F_2^n/F_2^p , the ratio of the neutron and proton structure function, extracted from a combined analysis of SLAC and BCDMS data using (solid line) Fermi motion model for the deuteron and (dashed line) EMC effect model of the deuteron.

(b) The F_2^n/F_2^p ratio extracted using all available d/u quark distributions from neutrino and antineutrino data on hydrogen tends to favor the EMC effect model of the deuteron (dashed curve).

Figure D-3

Comparison of the precise extraction of the structure function F_2 from a combined analysis of all SLAC data and comparison to BCDMS higher Q^2 muon results.

Figure D-4 The two curves span the predictions of TM+QCD

Figure 3a Comparison of R with E140 Data in
 $x=0.35$ and $x=0.5$

Figure 3b Comparison of R with Global fit in Low
 and High x

2a. FNAL Neutrino Quad Triplet Runs (E744, E770), CCFR Collaboration

We present recent results from the CCFR collaboration. These results have either been submitted for publication in 1992 and 1993, or have been presented in conference proceedings and are being finalized for journal publication in 1992 and 1993.

(a) The Gross-Llewellyn Smith (GLS) sum rule; [7,14,22,27]

The GLS sum rule predicts that the integral of $x F_3(x, Q^2)$ weighted by $1/x$ equals the number of valence quarks inside a nucleon in the naive quark parton model. With next to leading order (NLO) QCD corrections, the GLS sum rule can be written as

$$S_{GLS} = \int_0^1 \frac{dx}{x} x F_3(x, Q^2) = 3(1 - \frac{\alpha_s}{\pi})$$

A recent α_s^3 calculation predicts $S_{GLS} = 2.63 \pm 0.04$ at $Q^2 = 3 \text{ GeV}^2$ for our measured value of $\Lambda_{\overline{ms}}^4 = 213 \pm 50 \text{ MeV}$ and $n_{flavors} = 4$. We obtain $S_{GLS} = 2.50 \pm 0.018(stat.) \pm 0.078(sys.)$. Figure D-6 shows the value of the GLS sum rule for various neutrino experiments. The dashed line shows the theoretical result.

(b) Extraction of $\Lambda_{\overline{ms}}^4$ from the analysis of $x F_3$; [10,14,26,29]

Figure D-7a shows the logarithmic slopes of $x F_3$ versus Q^2 and comparison to the QCD prediction. $x F_3(x, Q^2)$, the valence structure function, is predicted to have a simple QCD evolution independent of R and gluons. To leading order, $x F_3(x, Q^2)$ is expected to evolve as:

$$\frac{dx F_3(x, Q^2)}{d \ln Q^2} = \frac{\alpha_s(Q^2)}{\pi} \int_x^1 P_{qq}(z) x F_3(\frac{x}{z}, Q^2) \frac{dz}{z} \quad \text{or} \quad \frac{d \ln x F_3}{d \ln Q^2} \approx \alpha_s(Q^2) \Psi(x, Q^2)$$

where $\Psi(x, Q^2)$ is weakly dependent on the assumed form of $x F_3(x, Q^2)$ and has a well determined zero point. Our new more precise slopes from E744/E770, Figure D-7(a,b), agree well with the predicted QCD scaling violations obtained from a next-to-leading order fit to the data with good agreement in the zero crossing point and the variation with x . This is in contrast to the results of the CDHSW group, Fig D-7c, which show a significant disagreement with the QCD prediction. We obtain a value for the QCD scale parameter, $\Lambda_{\overline{ms}}^4$, from a next to leading order fit of:

$$\Lambda_{\overline{ms}}^4 = 210 \pm 28(stat.) \pm 41(sys.) \text{ MeV} \rightarrow \alpha_s(M_Z^2) = .111 \pm .002(exp.) \pm .003(theory)$$

with an additional 0.003 error from a theoretical scale error. The systematic error is dominated by the muon energy scale and relative hadron to muon energy scale calibrations.

(c) Extraction of the structure function F_2 ; [7,10,14,26,29,40,47]

Figure D-8 below shows a comparison of our F_2 values with other experiments. There is good agreement with SLAC and BCDMS, but poor agreement with EMC and CDHS. It appears that the CDHS values of F_2 are much too low at low values of Q^2 . Unlike the CDHS slopes, the logarithmic slopes of the CCFR data are in agreement with QCD.

(d) Extraction of $\Lambda \frac{4}{\text{ms}}$ from combined analysis of $F_2(x, Q^2)$ and xF_3 ; [44,47]

The predicted QCD evolution of $F_2(x, Q^2)$ is coupled to the gluon distribution, $G(x, Q^2)$, according to

$$\frac{dF_2(x, Q^2)}{d \ln Q^2} = \frac{\alpha_s(Q^2)}{\pi} \left[\int_x^1 F_2\left(\frac{x}{z}, Q^2\right) P_{qq}(z) dz + \int_x^1 G\left(\frac{x}{z}, Q^2\right) P_{qG}(z) dz \right].$$

A combined $F_2(x, Q^2)$ and $xF_3(x, Q^2)$ fit yields

$$\Lambda \frac{4}{\text{ms}} = 225 \pm 30(\text{stat.}) \pm 40(\text{sys.}) \text{ MeV} \quad \eta_g = 4.45^{+1.65}_{-1.18} \pm 1.24 \text{ at } Q_0^2 = 5 \text{ GeV}^2$$

where $xG(x, Q^2) = A_g(1-x)^{\eta_g}$. Our value of $\Lambda \frac{4}{\text{ms}}$ can be evolved to a value of α_s at the mass of the Z . This evolution yields a strong coupling constant $\alpha_s(M_Z) = 0.113 \pm 0.002 \pm 0.003$ (with an additional 0.003 from a theoretical scale error). Figure D-9 compares our value $\alpha_s(M_Z)$ with that for other processes, including values calculated by two University of Rochester graduate students from AMY data.

(e) New results on same-sign dimuons; [24,30]

We have combined the data of E744 and E770 along with the E770 test run to calculate the rate of prompt same-sign dimuon events. The more precise CCFR rates are lower than the anomalously high rates reported by previous experiments. However, the small observed rate is still two standard deviations above background. The observed signal cannot be explained by the QCD calculations of production of $c\bar{c}$ pairs in neutrino interaction.

(f) New results on opposite-sign dimuons; [24,31,39,44,48]

Opposite-sign dimuon data from E744 and E770 has recently been published using a leading order (LO) fit. They support the slow rescaling hypothesis for a value of $m_c = 1.31 \pm .24 \text{ GeV}/c^2$. The charm mass error constitutes the single largest source of theoretical uncertainty in precision measurements of the weak mixing angle, $\sin^2 \theta_W$. The new result will reduce this uncertainty significantly, from .0034 to .0024. The CKM matrix element is found to be $|V_{cd}| = .209 \pm .012$. The nucleon strangeness content is measured to be $\eta_s = 2S/(U+D) = .064^{+.0075}_{-.0065}$. This yields a value of $\kappa = 2S/(\bar{U} + \bar{D}) = 0.373 \pm .048$. The strange sea is found to be softer than its non-strange sea. The measurement of the Q^2 dependence of the strange sea structure function, $xs(x)$, shows scaling violations for $xs(x)$. This

measurement of the Q^2 dependence of $xs(x)$ may be used to test perturbative-evolution predictions and evaluate flavor asymmetry in the sea.

We have recently fit the opposite-sign dimuon data with a next to leading order (NLO) fit. The NLO fit give $\kappa = 0.435 \pm .059$ and $m_c = 1.61 \pm 0.23$. This value of the charmed mass is similar to result from the Tagged Photon Spectrometer, $m_c = 1.74^{+0.13}_{-0.18}$. The NLO fit gives similar shapes for the strange and non-strange seas. The LO fit and NLO fit give similar values for $|V_{cd}|$.

The CDHS collaboration obtained $\eta_s = .067 \pm 0.016$ and $\kappa = 0.52 \pm 0.09$. The CCFRR collaboration (narrow band data, E616/E701) obtained $\kappa = 0.52 \pm 0.15$ for $100 \text{ GeV} < E_\mu < 230 \text{ GeV}$. These values agree well with the value of κ measured here.

(g) Recent Results on TeV Muon Energy Loss; [13,34]

During the running of E770, we triggered on cosmic ray muons up to a couple of TeV which horizontally traversed the detector. This study is important for TeV muon identification at the SSC. The worry was that TeV muon electromagnetic interactions would obscure the measurement of the muon momenta. Our results indicate that TeV muon interactions are well modeled by current theory.

We used this data along with beam induced muons for the another result: Both the CDF experiment and SDC will be calibrating their scintillator tile calorimeter with cosmic ray muons. Since tiles are ganged to form towers, this calibrations will involve the sum of muon energy from many tiles. However, testbeam and cosmic ray muons have different energy distributions. The average energy of cosmic ray muons is 3 GeV, while for test beams it is typically 50 - 100 GeV. We have measured muon energy deposit distribution as a function of the energy of the muon. This is done for fixed number of ganged tiles. The most probable energy loss increases by about 6% per 100 GeV for a 20 layer calorimeter. The truncated mean energy (typically used for calibration) changes by about twice that much. The energy dependence of the truncated mean is non-linear. These results were presented at the 1993 Washington APS meeting.

(h) Neutrino tridents and W - Z interference; [8,11,12]

A neutrino trident is the scattering of a neutrino in the Coulomb field of a target nucleus (N)

$$\nu_\mu (\bar{\nu}_\mu) + N \longrightarrow \nu_\mu (\bar{\nu}_\mu) + \mu^+ \mu^- + N$$

The signature is a dimuon event with zero visible hadron energy. We report a trident signal after all corrections of $N(\text{Data}) = 37.0 \pm 12.4$. For W -exchange alone ($V-A$ theory) the predicted number of trident events is: $N(\text{Trident} : V - A) = 78.1 \pm 3.9$. The prediction of the Standard Model including both W and Z exchange is: $N(\text{Trident} : \text{Standard Model})$

45.3 ± 2.3 . Our data, with 37.0 ± 12.4 events, clearly support the destructive interference hypothesis, and rules out the lack of interference at $> 99\%$ CL. This is the first demonstration of the W-Z destructive interference from neutrino tridents.

(i) A new precision determination of $\sin^2 \theta_W$; [32,35,38,49]

To determine the weak mixing angle, we vary the mixing angle until it reproduces the measured ratio of *short* to *toroid* events, $R_{30} \equiv \frac{N_{short}}{N_{toroid}}$, with a Monte Carlo program. To first approximation, $R_{30} \simeq R_\nu$, where R_ν is the ratio of neutral current to charged current cross sections. By comparing Monte Carlo program with the data, we get

$$\sin^2 \theta_W = 0.2222 \pm 0.0057 \quad \Rightarrow \quad M_W = 80.42 \pm 0.29 \text{ GeV}/c^2$$

The largest source of systematic errors are in understanding the ν_e flux, .0025, and charm production, .0024. Our improved measurement of m_c from our dimuon sample reduced this error. These two sources of errors will be addressed in the new neutrino experiment E815. Plot D-10 compares our value of M_W with that from other experiments.

(j) Measurement of $R = \sigma_L/\sigma_T$

Mr. Y. K. Yang is a thesis student on the CCFR data. He will do his thesis extracting $R = \sigma_L/\sigma_T$. In addition to calculating an important physical quantity, this will provide a valuable check of the CCFR structure functions. The extraction of the structure functions involve assumption about R . Mr. Yang thesis will check that the structure functions are consistent with our assumption on R .

2b. FNAL Neutrino Sign Selected Experiment E815

(a) Phase I.

The Collaboration (Fermilab E815) is a group of physicists from Adelphi, Cincinnati, Columbia, Fermilab, Irvine, Ohio State/Kansas, Oregon, and Rochester. E815 is scheduled to run in early 1995. The primary goal of E815 is to measure the weak mixing angle in neutrino interactions to a factor of two better in precision than the current world average: $\Delta \sin^2 \theta_W^{\text{TOTAL}}(\text{E815}) = \pm 0.003$. This will be accomplished by recording high statistics samples of neutrino and anti-neutrino events utilizing a new sign-selected quadrupole triplet beam. The new beam design permits for the first time a precision determination of the quantity

$$R^- = \frac{\sigma^{NC}(\nu N) - \sigma^{NC}(\bar{\nu} N)}{\sigma^{CC}(\nu N) - \sigma^{CC}(\bar{\nu} N)}.$$

R^- permits a determination of the weak mixing angle through the Paschos-Wolfenstein relation, $R^- = 12 - \sin^2 \theta_W$, that is almost entirely free of the large systematic errors

associated with neutrino induced charm production. In addition, the sign-selected beam allows us to considerably reduce the experimental error from ν_e flux uncertainties that limit existing Tevatron $\sin^2\theta_W$ determinations. The beam is targeted away from the Lab E detector, thus removing the ν_e from neutral kaon decays. Improvements in the beam means the intensity of the beam will be near the intensity of the quad-triplet beam used in Fermilab E744 and E770. Furthermore, our sign-selected beam will permit us to measure separately the quantities R^ν and $R^{\bar{\nu}}$, the neutral to charged current cross section ratios for neutrinos and antineutrinos, to a precision of $\pm 0.2\%$ and $\pm 0.5\%$, respectively. The precision that NuTeV will achieve on these neutrino sector electroweak quantities is sufficient to test for the possible presence of new physics beyond the standard model; for example, E815 will be sensitive to the presence of several new types of Z^0 bosons up to a mass scale of 1 TeV.

E815 will measure other unique physics processes. The 10^{-4} rejection of 'wrong sign' neutrinos permits us to make unique measurements of the charm and strange sea of the nucleon, and to reduce systematic uncertainties on other proton structure function, in particular the longitudinal structure function R . We will be able to make a unique measurement of the shape of the strange sea using antineutrinos. In the quad triplet running approximately 1/3 of the antineutrino dimuons are neutrino induced dimuons identified as antineutrino induced dimuons. We plan on extensive calibrations of the Lab E detector. Calibration errors is the largest systematic error in the determination of $\Lambda_{\overline{ms}}$.

The Lab E neutrino detector has been in operation for well over a decade. As such, it is an very well understood detector. A modest funding request will be made to upgrade photomultiplier tubes for the calorimeter and to refurbish the scintillation counters. In order to do continuous calibration, Rochester will be building a New Veto Wall. The old veto design does not permit hadron calibrations during the neutrino running. The vast majority of the detector components exist; and thus the total cost of the experiment is low.

The expertise of the Rochester group is needed in order to bring the Lab E detector to operating status. Rochester personnel were in charge of the on-line data acquisition system, the fast electronics, the Lab E target-calorimeter, the trigger counters and the veto wall, i.e. everything except the drift chambers and their electronics. We will help supervise new collaborators in the recommissioning of the Lab E neutrino detector. In addition, Rochester is responsible the Veto Hodoscope.

(b) Phase II

We are planning a higher involvement in the later Phase II portion of E815, after the CDF hadron calorimeter is constructed. This run is expected to have a factor of 10 to

20 improvement in statistics for more precise determination of structure functions, a more precise determination of the Weinberg angle and other aspects of neutrino physics. This will require a detailed study as to how to reduce the systematic errors to a much lower level. Since Phase II is to run after the 1995/96 CDF collider run, there is sufficient time to investigate major detector improvements. Originally, this was to be accomplished by replacing the iron toroids with expensive air core toroids. The Rochester proposal is much less expensive. It is to have the existing calibration hadron/muon beam incident on the front of the neutrino calorimeter at the same time as neutrino data is being taken. The first part of the neutrino target/calorimeter will need to be modified to be compensating such that hadron and neutrino interactions will be guaranteed to have the same calibrations.

(c) Neutrinos at the SSC

While planning for the next generation neutrino experiments, we are also studying a possible neutrino experiment at the SSC, to detect neutrinos from the $P-P$ collisions at the high luminosity IR's at the SSC and thus measure the low x bottom and charm quark production. This kind of measurement of the prompt neutrino spectrum in the forward direction yields information on the very low x behavior of the gluon distribution. No other experiment can go to such a low values of x . At these lowest values of x , the QCD evolution of the structure functions breaks down at the perturbative level, and enter a new unknown regime. The measurement of prompt neutrinos at the SSC is a tool to measure the low x gluon distribution. The use of neutrinos from the IR for doing standard neutrino physics cannot compete with the high intensity neutrino physics that can be done in our FNAL fixed target program. However, the detector design of our FNAL experiment is rather well suited for measurement of the prompt neutrino spectrum at the SSC, and it is possible that parts of the FNAL detector can be used in the SSC experiment.

3. SDC Cosmic Ray Test and Test Beam Calibration Activities

Our neutrino collaborator at FNAL, Mike Lamm, is also in charge of the cosmic ray and test beam activities for SDC at FNAL. We have been involved in SDC tile/fiber R&D (see task J). As the tile fiber prototype modules are constructed, their initial test will be done using cosmic rays, and then with the SDC test beam at FNAL.

It is not possible for a research associate to devote 100% his time to SDC activities, since SDC is such a long term project. Therefore we anticipate that one research associate from the neutrino task (R. Walker and his future replacement) will work 50% of the time on the SDC cosmic ray and test beam calibration effort. Another research associate from the CDF- tile/fiber task (Dr. P. de Barbaro) will work 50% of his time on SDC tile/fiber R&D, and SDC test beam hanging file analysis in the beginning of FY94. Towards the

end of FY94, de Barbaro's 50% effort on SDC will be more on cosmic ray and test beam calibration of calorimetry modules. The plan is that between task D and task G/J there will be one full time equivalent research associate working on SDC activities at a steady level. (See MOU between SDC and Rochester). The requested budget reflects the financial resources needed to maintain this additional level of effort.

Figure D-6 Calculation of the GLS sum rule for neutrino experiments. The dashed line shows the theoretical prediction for the GLS sum rule.

Figure D-7

- (a) Logarithmic slopes of $x F_3$ from the new CCFR E744/E770 high statistics data.

- (b) Extraction of $\Lambda_{\overline{MS}}^{(4)}$ from the $x F_3$ slopes. These are the most precise extraction of Λ . The QCD prediction of various values of Λ are all zero at $x \approx 0.1$ and pivot about this point.

- (c) Comparison of $x F_3$ slopes of CCFR and the CERN CDHS (The CCFR results agree with QCD, the CERN CDHS slopes at $x \approx 0.1$ are large and positive and cannot be accommodated within QCD). (See figure D-1b.)

Figure D-8

Comparison of CCFR and SLAC results for $F_2(x, Q^2)$ at a few representative values of x . The SLAC and CCFR results are in very good agreement (the Rochester group is involved in both experiments). Their results are also in agreement with the BCDMS CERN muon experiments. There is poor agreement with EMC and the CDHS CERN muon and neutrino experiments.

Figure D-9 The measurement of $\alpha_s(M_Z)$ for various processes.

Figure D-10 The value m_W for various experiments. For the neutrino experiments this is determined from the value of $\sin^2\theta_W$.

Activities, Talks and Publications 1992-93

The activities of Arie Bodek, the principle investigator for this task are listed in the introduction section, along with the activities of the other PI's. The activities of the other members of the group are listed below. Dr. Priscilla Auchincloss holds a half time position as Director for Programs in Women and Science at the College of Arts and Sciences. She has given talks on Women and Science at San Jose State (2/92), and at the Rochester Institute of Technology(12/92), and at Rochester. She served on the APS panel on public affairs in 1992. Dr. Howard Budd has given a talk on the neutrino program at the Conference on Beyond the Standard Model II, on Carleton (6/92). Dr. P. de Barbaro has given at talk on the neutrino program at the Physics in Collision in Boulder (6/92), and at the International High Energy Physics Conference at Dallas (8/92). Dr. W. Sakumoto has given a talk on neutrino induced dimuon events at DPF conference at Fermilab (11/92). Mr. U.K. Yang is doing his Ph.D. thesis on the extraction of $R=\sigma_L/\sigma_T$ from neutrino data, and will also be in charge of the veto wall constrution for FNAL neutrino expeiment E815.

SLAC and Neutrino Publications 1992

SLAC 1992

1. **Extraction of Neutron to Neutron Structure Function Ratio**, A. Bodek (Rochester U.), S. Dasu (SLAC), S.E. Rock (American U.), UR-1244, Proceedings of the Lepton-Photon Conference, Geneva, Switzerland, Jul 1991. S. Hegarty, K. Potter, E. Quercigh editors. World Scientific Publications, 1992, p. 160.
2. **Precise Measurements of the Proton and Deuteron Structure Functions from a Global Analysis of the SLAC deep Inelastic Electron Scattering Cross-Sections**, L.W. Whitlow, E.M. Riordan, S. Dasu (SLAC), Stephen Rock (American U.), A. Bodek (Rochester U.), SLAC-PUB-5442, Oct 1991. 20pp. Published in Phys. Lett. **B282**, 475-482 (1992).
3. **Study of Nuclear Effects in the Deuteron and Extraction of Neutron to Proton Structure Function Ratio**, A. Bodek (Rochester U.), S. Dasu (SLAC), Stephen Rock (American U.), SLAC-PUB-5598, Jun 1991. 4pp. Presented at 4th Conf. on the Intersections between Particle and Nuclear Physics, Tucson, AZ, May 24-29, 1991. In Tucson 1991, Proceedings, Intersections between particle and nuclear physics 768-770 and SLAC Stanford - SLAC-PUB-5598, published 1992.
4. **Measurements of ν W(2) and $R = \sigma_L / \sigma_T$ frm Inelastic Electron - Aluminum Scattering near $X = 1$** , P. Bosted, et al. Phys. Rev. **C46**, 2505 (1992)
5. **Measurements of the Electric and Magnetic Form-Factors of the Proton from $Q^2 = 1.75\text{-GEV}/C^2$ to $8.83\text{-GEV}/C^2$** P. Bosted, et al. Phys. Rev. Lett. **68**, 3841-3844 (1992).

Fermilab Neutrino Experiment Publications 1992

6. **Nucleon Structure Functions, $F_2(X, Q^2)$ and $XF_3(X, Q^2)$, from $FE - \text{Neutrino}$ scattering at the Fermilab Tevatron**, CCFR Collaboration (Sanjib R. Mishra, et al.), NEVIS-1465, Jan 1992. 35pp. Invited talk given at SLAC Summer Inst. on Particle Physics, Stanford, CA, Aug 5-16, 1991. published in Proceedings 1992.
7. **Precision Measurements of Nucleon Structure Functions, F_2 and XF_3 , and Tests of PQCD Predictions**, CCFR Collaboration (Sanjib R. Mishra, et al.), NEVIS-1466, Jan 1992. 10pp. Proceedings of the Lepton Photon '91 Conf., Geneva, Switzerland, Jul 25 - Aug 1, 1991. S. Hegarty, K. Potter, E. Quercigh editors, World Scientific Publications, 1992, p. 135.
8. **Electroweak results from the CCFR Experiment**, CCFR Collaboration (W. H. Smith et al.), WISC-EX-321. Proceedings of the Lepton Photon '91 Conf., Geneva, Switzerland, Jul 1991; S. Hegarty, K. Potter, E. Quercigh editors, World Scientific Publications, 1992. p. 49.
9. **Measuring Muon Momenta with the CCFR Neutrino Detector**, B.J. King, et al. Nucl. Instr. & Methods **A302** (1991) 254-260.
10. **Precision Measurements of $F_2(X, Q^2)$ AND $XF_3(X, Q^2)$ by the CCFR Collaboration using Muon-Neutrino Scattering at the Tevatron**, CCFR Collaboration (P.Z. Quintas, et al.), NEVIS-1457, Aug 1991. 6pp. Presented at Particles and Fields 91, Vancouver, Canada, Aug 18-22, 1991. In Vancouver 1991, Proceedings, Particles and fields '91, vol. 2, 651-655 and Columbia Univ. New York - Nevis R 1457 (91, rec. Oct.) 6 p. published 1992.
11. **Recent Electroweak results from the CCFR Collaboration: Neutrino Tribents and $W - Z$ Interference and the Lorentz Structure of the weak Current**, CCFR Collaboration (S.R. Mishra, et al.), NEVIS-1455, Mar 1991. 27pp. Invited talk at Electroweak Session of Moriond Conf., Les Arcs, France, Mar 10-17, 1991. Published in Moriond 1991, Electroweak, 87-96 (QCD161, R4, 1991, V.1) (published 1992).
12. **Electroweak results from the CCFR Experiment**, CCFR Collaboration (Wesley H. Smith, et al.), WISC-EX-91-318, Aug 1991. 5p. To appear in Proc. of Particles and Fields 1991 Conf., Vancouver, Canada, Aug 18-22, 1991. In Vancouver 1991, Proceedings, Particles and fields '91, vol. 1, 448-452 and Wisconsin Univ. Madison - WISC-EX-91-318 (91, rec. Oct.) published in proceedings 1992.
13. **A Measurement of TeV Muon Energy Loss in Iron**, W.K. Sakumoto, et al. Phys. Rev. **D45**, 3042-3050 (1992).
14. **Nucleon Structure Functions from Muon-Neutrino - FE Scattering at the Tevatron**, CCFR Collaboration (P.Z. Quintas, et al.), UR-1211, May 1991. 8pp. Presented at Conf. on the Intersections between Particle and Nuclear Physics, Tucson, AZ, May 24-29, 1991. In Tucson 1991, Proceedings, Intersections between particle and nuclear physics, 748-755, published 1992.

15. **Search for Right-Handed Coupling in Neutrino N Scattering**, S.R. Mishra, et al. Phys. Rev. Lett. **68** (1992) 3499-3502.
16. **Nucleon Structure Functions from High-Energy Neutrino Interactions, FNAL-I16/701 Experiment**, E. Oltman et al. Z. Phys. **C53** (1992) 51-71.

Task D: Structure Functions, Publication in 1993, Preprints and Reports

SLAC 1993

17. **Measurements of the Nucleon Form-Factors at Large Momentum Transfers**, L. Andivahis, et al. SLAC-PUB-5867, Dec 1992. 7pp. Presented at 1992 International Nuclear Physics Conference (INPC 92), Wiesbaden, Germany, 26 Jul - 1 Aug 1992.
18. **Measurement of Kinematic and Nuclear Dependence of $R = \sigma_L / \sigma_T$ in Deep Inelastic Electron Scattering**, S. Dasu et al. UR-1304 and SLAC-PUB-5814 (Jan 1993) to be published in Phys. Rev. D 1993.
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20. **Measurement of the A-Dependence of Deep-Inelastic Electron Scattering**, J. Gomez et al. SLAC-PUB-5813, Jan 1993. to be published in Phys. Rev. D. 1993.
21. **Measurement of X, Q^2 and Hydrogen-Deuterium Dependence of $R = \sigma_L / \sigma_T$** L. H. Tao et al., presented at April APS Meeting 1993 (Bull. Am. Phys. Soc. 1993)

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22. **Neutrino Scattering Results from CCFR**, W.H. Smith et al. WISC-EX-92-328, Jul 1992. 30pp. SSI, Jul 24, 1992. (to be published in 1993, in Proceedings of the 1992 SLAC summer institute on particle Physics)
23. **A Study of Double Vertex events in the Neutrino - Nucleon Interactions**, CCFR Collaboration (H.S. Budd, et al.), UR-1285, Nov 1992. 5pp. Presented at Conf. on the Intersections between Particle and Nuclear Physics, Tucson, AZ, May 24-29, 1992. to be published 1993.
24. **Neutrino Production of Dimuons at the Fermilab Tevatron**, W.H. Smith et al WISC-EX-326, Jun 1992. 15th Int'l Conference on Neutrino Physics and Astrophysics (Neutrino '92), Granada, Spain. Nucl. Phys. B (Proc. Suppl.) **31**, 262 (1993).
25. **Measurements of Nucleon Structure Functions, $F(2)(X, Q^2)$ and $XF(3)(X, Q^2)$, from the CCFR data: Tests of Perturbative QCD**, A. Bodek et al UR-1261, May 1992. 11pp., Presented at the Les Rencontres de Physique de la Vallée d'Aoste, La Thuile, Italy, Mar 8-14, 1992. Published in Proceedings 1993, page 73. M. Greco editor, Editions Frontieres.
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 29. **A measurement of Λ (MS) from Muon-Neutrino - FE Nonsinglet Structure Functions at the Fermilab Tevatron**, P.Z. Quintas et al. NEVIS-1461, June 1992. 15pp. to be published in Phys. Rev. Letters 1993.
 30. **Neutrino Production of same Sign Dimuons at the Fermilab Tevatron**, P.H. Sandler et al. WISC-EX-92-324, n.d. 38pp. published in Z. Phys. **C57**, 1 (1993).
 31. **Measurement of the Strange Sea Structure Function using Neutrino Charm Production**, S. A. Rabinowitz et al, (CCFR), Phys. Rev. Lett. **70**, 134(1993)
 32. **A Precision Determination of $\sin^2(\theta_W)$ from $\nu_F E$ Scattering at the Tevatron**, T. Bolton et al. in Proceedings of the 28th Rencontres de Moriond, Les Arcs, France, March, 1992. (to be published 1993).
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 34. **A Study of the Energy Dependence of the Most Probable Energy Deposition of High Energy Muons in Sampling Calorimeters**, M. Pillai et al. UR-1302 (April 1993), to be submitted to Nucl. Inst. Meth. Also presented at the March 93 APS meeting, Washington DC (Bull. Am. Phys. Soc. 1993).
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 36. **A Study of Double Vertex Events in Neutrino Nucleon Interactions**, H.S. Budd et al. in Proceedings of "Beyond the Standard Model III, Carleton University, Ottawa Canada, June, 1992. (to be published 1993)
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 38. **Measurement of the Weak Mixing Angle in Neutrino- Nucleon Scattering by CCFR**, R.H. Bernstein et al in Proceedings of the International Conference on High Energy Physics, Dallas, TX, August, 1992. (to be published 1993)
 39. **Neutrino Production of Dimuons at the Fermilab Tevatron**, M.H. Shaevitz et al in Proc. of the Int'l Conf. on High Energy Physics, Dallas, TX, August, 1992.

40. **Measurements of Nucleon Structure Functions, F_2 , XF_3 , and Precision tests of PQCD at the FNAL Tevatron**, S.R. Mishra et al, Proceedings of the International Conference on High Energy Physics, Dallas, TX, August, 1992, (to be published 1993)
41. **A Study of Double Vertex events in Neutrino Nucleon Interactions**, P. de Barbaro et al, in Proceedings of the International Conference on High Energy Physics, Dallas, TX, August, 1992, (to be published 1993)
42. **Neutrino Production of Same-Sign Dimuons at the Fermilab Tevatron**, W. K. Sakamoto et al., UR-1292 (1992), in Proceedings of the Conference of the Division of Particles and Fields, Fermilab, November, 1992, (to be published 1993).
43. **Quantum Chromodynamics fits to Singlet and Non-Singlet Structure Functions**, W.G. Seligman et al. in Proceedings of the Conference of the Division of Particles and Fields, Fermilab, November, 1992, (to be published 1993)
44. **Measurement of the Strange Sea Content of the Nucleon by CCFR**, A. O. Bazarko et al. in Proceedings of the Conference of the Division of Particles and Fields, Fermilab, November, 1992, (to be published 1993)
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47. **Quantum Chromodynamics Fits to Singlet and Non-singlet Structure Functions**, W. G. Seligman et al. To be published in Moriond Proceedings 1993.
48. **Measurement of the Strange Sea Content of the Nucleon by CCFR** A. O. Bazarko et al. To be published in Moriond Proceedings 1993.
49. **Measurement of the Weak Mixing Angle in Neutrino-Nucleon Scattering by CCFR**, B. King et al. To be published in Moriond Proceedings 1993.
50. **Recent Results from the CCFR Neutrino Collaboration** M. Shaevitz et al. To be published in Aosta Proceedings 1993.

TASK E: Nonlinear QED at SLAC

(Drs. C. Bamber, A. C. Melissinos, D. D. Meyerhofer)

(Graduate Students: S. Boege, A. Fry, Th. Kotseroglou)

(Engineer: T. Blalock)

1. Overview

The goal of this task is to carry out the first experiment exploring QED at critical field strength. The experiment will be performed at SLAC and was provisionally approved by the director in December 1991. Complete approval, which was conditioned on a demonstration of full laser power was granted in September 1992. We hope to take some test data this summer and to have the first run in January of next year. Activities during the past year have been focussed on procuring the necessary components for the lasers and integrating them into a working system. We expect to ship this system to SLAC in May.

We have also continued development of ultrashort high power lasers that could eventually provide a second generation version of the present system. In connection with this program we are also studying the feasibility of a high brightness electron source where the electrons are produced by a short laser pulse in a superconducting S-band cavity.

Other activity during the year, included the completion of two extensive papers which have now appeared in the literature. One of these described in detail the "Laser Switched Electron Linac" which was developed by our group. The other documents the axion searches that were carried out by our group at BNL over the past five years. A possible continuation of this work using SSC magnets to search for solar axions is still under consideration.

2. Study of QED at Critical Field Strength in Intense Laser-High Energy Electron Collisions (SLAC Experiment E-144)

(a) Physics Motivation

The recent realization of high power lasers with very short pulses makes it possible to explore in the laboratory electron-photon interactions in electric fields approaching the QED critical field $E = 1.3 \times 10^{16}$ V/cm. A laser pulse of 2.5 J energy focussed to an area of $25 \mu\text{m}^2$ and of duration 1 ps gives rise to peak E and B fields

$$E = 27.4 \sqrt{I \text{ (Watts/cm}^2\text{)}} = 8.6 \times 10^{10} \text{ V/cm}$$

When 46 GeV electrons traverse this pulse, they see in their own rest frame an electric field

$$E^* = 2\gamma E_{\text{LAB}} = 1.55 \times 10^{16} \text{ V/cm}$$

which exceeds the critical field of QED

$$E_{cr} = \frac{m^2 c^3}{e \hbar} = 1.32 \times 10^{16} \text{ V/cm}$$

Such fields are experienced by electrons attached to colliding heavy nuclei during the brief time of nearest approach when $\alpha Z > 1$. They are also presumed to be present at the surface of neutron stars.

The relevant parameters for electromagnetic processes in strong fields are the ratio of the electric field to the critical field

$$\Upsilon = E^*/E_{cr}$$

and the "field strength" parameter

$$\eta = eE/m\omega c$$

The phenomena that we intend to study are:

(a) Electron-positron production in e- ω collisions: This process proceeds principally through the two-step reaction

$$\begin{aligned} e + \omega &\rightarrow e' + \gamma \\ &\rightarrow \gamma + n\omega \rightarrow e^+ e^- \end{aligned}$$

For $\omega \simeq 1 \text{ eV}$ and $\epsilon_\gamma \sim 25 \text{ GeV}$ (which is the maximum energy of the backscattered photons) the threshold for pair production involves the absorption of at least 10 laser photons, such multiphoton absorption being favored at this field strength. The expected yield is shown in Fig. 1 and both the positron and the electron spectra will be measured. These processes are the analog to the beamstrahlung in future linear colliders, where the expected values of Υ are of the same magnitude.

(b) Nonlinear Compton scattering: In this case the spectrum of the forward going (backscattered) photons is measured. This should clearly exhibit multiple photon absorption as shown in Fig. 2, as well as the change in the effective mass of the electron in the intense field. The main experimental challenge to this measurement is the high rate of the γ 's. The yields shown in Fig. 2 for $e + n\omega \rightarrow e' + \gamma$ have been calculated in a semiclassical approximation; these predictions will be tested for the first time by this experiment.

(c) Photon-photon scattering leading to e^+e^- production (Breit-Wheeler process): In this case the backscattered γ 's produced in the first electron-laser collision are brought to

Figure 1

Figure 2

Figure 3

a second interaction point where they scatter off a fraction of the laser pulse. The pairs produced in the reaction

$$\gamma + n\omega \rightarrow e^+e^-$$

continue in the forward direction, whereas the electron beam is being deflected into the dump. The calculated invariant mass spectrum of the e^+e^- pairs is shown in Fig. 3. Departures or structure in this spectrum, (as reported in the Darmstadt experiments), would be an indication of new physics.

(b) Siting of the Experiment

The experiment is sited in the Final Focus Test Beam (FFTB) immediately after the final focus. The FFTB is the only electron beam of sufficient energy and of appropriate emittance for investigating critical field effects in conjunction with high power lasers. Whereas the FFTB rate is 10 Hz the laser system will operate only at 1 Hz. The layout of the first interaction point (IP1) is shown in Fig. 4 and is located between soft-bend dipoles to reduce synchrotron radiation. Permanent magnets are used to dump the electron beam, while at the same time they provide the momentum analysis for positrons and electrons measured in part (a) of the experiment.

The secondary particles from the collision at IP1 are detected with silicon calorimeters at the exit of the vacuum region. Their trajectories are shown in Fig. 5 and we detect $3 < p(e^+) < 30$ GeV and $5 < p(e^-) < 30$ GeV. This covers the entire positron phase space and that of electrons recoiling from multiphoton Compton scattering. Calorimeters are used because they can register multiple hits and are not disabled by the radiation environment of the FFTB tunnel. In addition detection of recoil electrons from the single photon Compton scattering makes possible a measurement of the polarization of the electron beam.

For the nonlinear Compton experiment the high energy γ 's are transported through the FFTB enclosure to a detector located 100 m downstream from IP1. This is shown in Fig. 6. The detector is a magnetic pair spectrometer with CCD readout. Only 0.5% of the incident γ 's are converted in a thin CCD detector placed in front of the magnet. The detector can handle up to ~ 10 γ 's in a single pulse. The CCD's have an active area of 17×27 mm² with a 20 μ m pixel size which leads to a resolution of order 5 μ m. Given the dimensions of the spectrometer the converted pair's tracks are measured to an accuracy $\Delta\theta \sim 35$ μ rad which matches the multiple scattering introduced by the 200 μ m CCD used as the converter. Since the scattering angle of the γ 's is of order 10^{-5} rad, the backscattered photons populate a region of radius 1000 μ m at the spectrometer magnet.

For the multiphoton Breit-Wheeler experiment the same magnetic spectrometer is used but without the converter. Multiple events are sorted out by exploiting coplanarity

Figure 4

Figure 5

and the very small opening angle of the pair. The effective mass resolution is $\Delta M = 18$ keV/c² at a mass $M = 2$ MeV/c². The expected rate is 1 pair/10 laser pulses or 10⁴ events/day.

(c) Laser Development

A Nd:glass laser system capable of delivering 2.5 Joule in 1 ps at 1 Hz rate is being built. It consists of a Nd:YLF mode-locked oscillator whose pulse is expanded in time, by the imposition of a frequency chirp. Next it is amplified in a regenerative amplifier, followed by a further amplifier using a single pass through a 6 mm rod. This pulse drives a "slab" amplifier as the final stage. The pulse is then compressed in time and transported to the interaction region where it is focussed with $f/D = 3$ parabolic mirrors. A schematic of the laser system chain is shown in Fig. 7.

During the past year design, procurement and testing of the components of the laser system and optical transport took place. Most components have been delivered and testing of the "slab" is expected in May. Following the successful test the system will be shipped for installation at SLAC.

All components of the optical transport (from the laser building to the FFTB) for part (a) of the experiment have been designed and are under construction. The vacuum enclosure for IP1 and its positioning system are presently being installed in the beam line. The laser building is complete. IP2 and the corresponding transport lines will be installed in 1994. An optical fiber link which will extend the linac r.f. signal to the experimental site for synchronization of the laser beam is due for installation shortly. Design and construction of diagnostics to measure and maintain the temporal and spatial overlap of the laser and electron pulses is proceeding. To maintain the exact focus and optical path length we use interferometric information to apply feedback to the optical transport elements.

The Nd:glass system lases at $\lambda = 1.054$ nm. However we intend to double the frequency of the light to the green, $\lambda = 527$ nm for the major part of the experiment. We can double with an efficiency of order 80% by using a thin KD*P crystal. Initial tests will, however, be carried out with IR, and the transport line will be converted to green at the end of this year.

(d) High Intensity Laser Test

In July of last year we reached the design intensity at the focal spot of a prototype laser system at the Laboratory for Laser Energetics. This system operated at a low repetition rate, one pulse every 200 s, but is otherwise identical to the system built for the experiment, which will run at a rate of 1 Hz.

Figure 6

Figure 8

Amplifier-Compression System

Figure 7

The laser intensity was measured in two ways. First we measured the energy W , pulse duration, τ , and focal spot area A_f . This yields the focal spot intensity $I = W/A_f\tau$. The results of the measurements were:

$$W > 2 \text{ J}$$

$$A_f = 26 \text{ } \mu\text{m}^2$$

$$\tau = 1 \text{ ps}$$

and therefore

$$I = (7 \pm 3) \times 10^{18} \text{ W/cm}^2$$

This corresponds to a peak electric field in the laboratory, of

$$E_L = 7.3 \times 10^{10} \text{ V/cm}$$

or for 46 GeV electrons, to a rest-frame field

$$E^* = 2\gamma E_L = 1.32 \times 10^{16} \text{ V/cm}$$

We have also confirmed these results by measuring the ionization of noble gases establishing that $I \gtrsim 5 \times 10^{18} \text{ W/cm}^2$. We may have observed highest intensities near 10^{19} W/cm^2 ($Y = 1.2$), but this is dependent on the details of the analysis of the atomic physics data.

These results, which are of the same order as the highest focussed laser intensities ever achieved were obtained with infrared. Since the doubled frequency (green light) can be focussed to a spot diameter half as large as the IR we have another factor of two in field strength that should be achievable with our present laser system.

(e) Detector Development

This work is being carried out by our collaborators from Princeton University and the University of Tennessee. It is included here for completeness.

The positron and electron silicon calorimeters that will be used in part (a) of the experiment are being constructed by the University of Tennessee and are based on wafers that are $6.4 \times 6.4 \text{ cm}^2$ each, with 16 pads per wafer in a 4×4 array. Each calorimeter module consists of 20 radiation lengths of tungsten with one silicon wafer per radiation length. The readout is grouped in three longitudinal segments or towers. It is sufficient to read out only the central two columns of the pads, since all particles of interest in E-144 are dispersed over a vertical strip only 2-3 mm wide. However we plan to read out all pads to improve energy resolution and to do background studies.

We will use (a) a positron calorimeter consisting of four wafers with 96 towers (b) an electron calorimeter of three wafers with 72 towers and (c) a photon beam calorimeter using

only (single wafer) 36 towers. The calorimeters are read out using a system of amplifiers and digitizing modules developed for experiment E-706 at Fermilab. Since we expect a high yield of particles, possibly 10^3 /channel, the amplifiers are being modified to handle this large signal. A highly successful test of a prototype calorimeter module was carried out at SLAC in April using a low intensity electron beam at end station A. Fig. 8 shows the calorimeter response to 25 GeV electrons; up to 25 electrons in a single pulse can be resolved. The energy resolution - without special correction is $\Delta E/E = 0.26/\sqrt{E}$.

The CCD's for the spectrometer detector have been selected and a variant of a commercial readout is being built. The CCD's are mounted on an invar plate to maintain their position and the first test of the system is scheduled for this summer. A vacuum enclosure with appropriate positioning capabilities is being designed.

(f) Laser-Electron Overlap Detector

One of the most difficult aspects of E-144 is ascertaining that the electron beam and laser pulse are exactly on time at the level of 1 ps. Prof. D. Meyerhofer invented a new detection system which correlates the synchrotron radiation from the electron beam with a fraction of the laser pulse to give the relative timing of the two pulses with a resolution of 300 fs. Furthermore the detector is able to measure the length of the electron beam which has until now posed a difficult problem for the diagnostics of the SLC beams. Tests in Prof. Meyerhofer's laboratory have proven the feasibility of the detector and the soundness of the system. We expect to incorporate the detector into the E-144 experiment during the Fall of this year.

(g) Schedule

We give below the tentative schedule for E-144 as requested from SLAC. The experiment should undergo its readiness review in the Fall of 1993 immediately following 10 shifts of beam tests.

(a) January - March 1994:

Two 20-shift runs to measure electron/positron production in $e-\omega$ collisions and to study the dependence of the cross sections on the amplitude of the laser field.

(b) Summer 1994:

Two 20-shift runs to carry out the nonlinear Compton scattering experiment. This necessitates the extension of the beam vacuum and installation of the CCD detector by the Spring of 1994.

(c) January - March 1995:

Two 20-shift runs to study e^+e^- production in γ -laser collisions and examine the pair mass spectrum. This necessitates in addition to the installation of the CCD detector,

the completion of IP2 and of the optical transport to IP2 during the Summer of 1994.

A list of the participants and of the collaborating Institutions is appended.

3. Completion of the Axion Searches

The results from this program were discussed in last year's report and a detailed account of the optical rotation experiment appears in the May 1, issue of Physical Review D. While we are not involved in this program any more, our colleagues from the University of Trieste are preparing a new experiment in an attempt to measure the birefringence of the vacuum (Delbruck scattering) using a 10 Tesla magnet. Another group, including one of our former collaborators is planning to repeat the microwave cavity search for axions that we carried out a few years ago. Our view is that a more promising approach is the search for solar axions by the technique used in our preliminary work of last year [Phys. Rev. Lett. **69**, 16 (1992)]. We have therefore been in contact with physicists on the SSC staff to consider a joint effort using some of the SSC prototype magnets. While the experiment is quite feasible our present commitments do not allow us to initiate a new activity at this time.

4. High Brightness Electron Source

As part of our continuing laser development program we are investigating the possibilities of using our high power, short pulse, laser system to drive a high brightness superconducting r.f. electron gun. The improved brightness is due to the high field at the cathode, which compensates space-charge effects, and to the increased electron yield due to the high laser power. We expect a flux of 10^9 electrons in a single 20 ps pulse. Furthermore the superconducting cavity can be driven at high repetition rate as compared to normal conducting laser r.f. guns.

Usually, high current electron sources use cesiated cathodes. This introduces a level of complication that we will circumvent by using metallic cathodes, specifically Nb or Au. The cathode material will be coated on a sapphire window which will be illuminated from outside the cavity with a UV pulse obtained by quadrupling the IR. Preliminary results, obtained some time ago in our laboratory are shown in Fig. 9. Since then we have improved the vacuum at the cathode which is now at 10^{-9} torr and expect highly increased photoemission yield.

The field lines in one half of an S-band accelerating cavity are shown in Fig. 10 (courtesy of Dr. D. Moffet of Cornell). While S-band is the traditional wavelength for r.f. laser guns we are considering the use of an X-band cavity because this equipment is available in Rochester. For simplicity we will use a vertical cryostat and will detect the

electrons with a multichannel plate electron multiplier. Momentum analysis and emittance measurements will be incorporated in the system at a later time.

The design goals for the source are as follows:

Energy	> 5 MeV
Normalized emittance	< 10^{-6} m - rad
Energy spread	< 0.01
Electrons/pulse	10^9
Pulse length	20 ps

This work is being carried out by Mr. A. Fry and Mr. K. Konkol who will be joining the group this summer. We also hope during the summer to set up a Titanium Sapphire picosecond laser system in collaboration with Prof. N. Bigelow. We will use the Argon-Ion laser from the Brookhaven axion experiment to pump the TiSa crystal. Such a picosecond laser would eventually replace the oscillator in our high power laser system for the SLAC experiment E-144.

5. Equipment Procurement for E-144

Much of the activity during the past fiscal year centered on procuring and testing the components for the E-144 laser system. To this effect a completely new laboratory was set up in the Rochester Physics Building suitable for carrying out the assembly and test of the lasers. This would not have been possible without the wise decision by DOE to commit funds for the purchase of long lead items.

In particular we acquired the slab laser frame, power conditioner and optical glass all of which had delivery times of order 6 months. We also purchased the focussing optics and compression gratings as well as most elements of the optical transport. The enclosure where the laser-electron beam interaction takes place has been manufactured and is currently being installed in the SLAC beam. A substantial number of optical components has been obtained on loan from the Laboratory for Laser Energetics of the University of Rochester.

We have also acquired the "mode locker" and phase stabilization system which will maintain the synchronization of the laser pulse and electron beam at the 1 picosecond level. SLAC is installing a 1 km long optical fiber link in order to provide us with a stable reference source of 119 MHz. The building where the laser system will be installed has been recently completed and we expect to ship the laser system to SLAC in May.

The equipment required to complete the installation will be acquired with F.Y. 94 funds and is as follows:

Interaction point 2 enclosure	40,000
Mounts and controllers for IP2	20,000
Replace IR mirrors with mirrors for green	20,000
Beam Splitter/Doubling Crystal/Waveplates	20,000
Optics for phase front measurement and correction	20,000
	<hr/>
	\$120,000

Of this sum, \$99,000 are part of the original equipment agreement for E-144 which we expect to be allocated this fiscal year.

Personnel Changes

In September of the past year Dr. Charles Bamber took up residence at SLAC in preparation for E-144. Work at Rochester continued under the leadership of Mr. Todd Blalock with graduate students, Theofilos Kotseroglou and Steven Boege. We have also had part-time assistance from an undergraduate student, Mr. Glenn Hallit. Mr. Alan Fry concentrated his efforts on the high brightness electron source and set up a regenerative amplifier which is being seeded from the oscillator used for the E-144 laser system. We have made an offer to Dr. R. Hirosky who will be receiving his Ph.D. in July, to join the E-144 group as a Research Associate, stationed at SLAC. Messrs. Blalock, Boege and Kotseroglou will also move to SLAC during early June and remain there for the duration of the experiment. Prof. D. D. Meyerhofer of the Department of Mechanical Engineering is continuing to play a key role in the experiment and his student Ms. Lilly Zheng has been working on the laser-electron beam overlap monitor discussed in section 2(f).

Figure 9

Figure 10

Publications 1992-93

1. **Search for Solar Axions**, D. M. Lazarus, G. C. Smith, R. Cameron, A. C. Melissinos, G. Ruoso, Y. K. Semertzidis and F. A. Nezrick: *Phys. Rev. Lett.* **69**, 16 (1992).
2. **Search for Photon Regeneration in a Magnetic Field**, G. Ruoso, R. Cameron, G. Cantatore, A. C. Melissinos, Y. Semertzidis, H. J. Halama, D. M. Lazarus, A. G. Prodell, F. Nezrick, C. Rizzo and E. Zavattini: *Z. Phys.* **C56**, 505 (1992).
3. **Electron Acceleration Using Laser-Driven Photoconductive Switching**, C. Bamber, W. Donaldson, E. Lincke and A. C. Melissinos: *Nucl. Instru. and Meth.* **A237**, 227 (1993).
4. **Search for Nearly Massless, Weakly Coupled Particles by Optical Techniques**, R. Cameron, G. Cantatore, A. C. Melissinos, G. Ruoso, Y. Semertzidis, H. J. Halama, D. M. Lazarus, A. G. Prodell, F. Nezrick, C. Rizzo and E. Zavattini: *Phys. Rev. D* (May 1993).
5. **QED at 10^{20} W/cm²**, A. C. Melissinos: To appear in Proceedings of the Conference Ultrafast Phenomena VIII International Conference held at Antibes-Juan les Pins, France June 8-12, 1992.
6. **Second and Third Harmonic Generation of 1.054μ Radiation Using Picosecond Pulses**, T. Wilson, C. Bamber and S. Craxton, Internal Report UR-1271.
7. Proceedings of the E-144 Collaboration Meeting QED at Critical Field Strengths held at SLAC Feb. 19-20, 1993, A. Weideman, Editor.
8. **Report of the Working Group on Gravitational Wave Detection**, G. Gratta, K.-J Kim, A. Melissinos and T. Tauchi: Proceedings of the Workshop on Beam-Beam and Beam-Radiation Interactions: High Intensity and Nonlinear Effects, C. Pellegrini, T. Katsouleas and J. Rosenzweig, Editors.
9. **Study of QED at Critical Field Strength**, K. T. McDonald, C. Bamber, A. C. Melissinos, D. Meyerhoffer, P. Chen, J. E. Spencer and R. B. Palmer: Proceedings of the Workshop on Beam-Beam and Beam-Radiation Interactions: High Intensity and Nonlinear Effects, C. Pellegrini, T. Katsouleas and J. Rosenzweig, Editors.

**STUDY OF QED AT CRITICAL FIELD STRENGTH
IN INTENSE LASER-HIGH ENERGY ELECTRON COLLISIONS
AT THE STANFORD LINEAR ACCELERATOR**

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Tasks F, G and J: The Collider Detector at Fermilab (CDF): AMY/CDF-SVX, CDF PLUG, and SDC

Task F: The CDF Silicon Vertex Detector

(Participants: Drs. P. Tipton, R. Hughes, A. Sill, Mr. P. Koehn, Ms. K. Tollefson, Mr. G. Watts)

Task G: The End Plug Calorimeter

(Participants: Drs. A. Bodek, H. Budd, P. de Barbaro, W. Sakumoto, R. Walker, B. Winer; Messrs. M. Dickson, Q. Fan, P. Koehn, M. Pillai)

The Collider Detector experiment at Fermilab (CDF), is a general purpose magnetic detector system designed to explore the physics of 2 TeV proton-antiproton collisions. CDF consists of a central magnetic tracking detector that covers the polar angular range 15° to 165° , electromagnetic and hadron calorimetry from 2° to 178° , and muon identification and momentum analysis over the angular range from 2° to 15° , 56° to 124° , and 165° to 178° .

The 1992-1993 Tevatron Collider Run is underway. So far we have collected $\approx 17\text{pb}^{-1}$ and the much improved CDF detector is working well. CDF has improved its livetime fraction from the last run to $\approx 75\%$. For many physics processes, the trigger efficiency is also improved. The detector now includes a silicon microstrip detector called the SVX, expanded muon coverage, and new a preradiator for photon physics, in addition to larger muon coverage.

Rochester joined the Collider Detector experiment at Fermilab in January 1990. In preparation for the current collider run, our group has worked on the construction of the silicon microstrip vertex detector (SVX), the recommissioning of the plug electromagnetic calorimeter (PEM), and the setting up and operation of the Fermilab M6 beam line for pre-run tests and calibration. In addition, we are heavily involved in the development and testing of prototypes for the CDF plug calorimetry upgrades planned for Run II.

The CDF Physics Program

Among the many physics topics CDF expects to address with the 1992-1993 data are the following:

1. Discovery of the t -quark or the setting of limits on the t -quark mass. The t -quark mass sensitivity will extend up to 120 GeV for dilepton events and 150 GeV for single lepton plus jets events (see the discussion on heavy-flavor physics given below). Professor Tipton is concentrating on this search by using b -quark tagging in the SVX.
2. Measurement of the W charge asymmetry. Professor Bodek and Mr. Dickson are concentrating on this topic using W s in the PEM.
3. Search for an additional heavy gauge boson an additional Z boson (a Z'). Professor Bodek, Dr. de Barbaro, and Mr. Pillai are working with Fermilab physicists on a search for $Z' \rightarrow e^+e^-$.

4. Measurement of the $W^\pm$ mass and the $W^\pm - Z^0$ mass difference with an uncertainty of order ± 115 MeV with a resulting determination of $\sin^2 \theta_W$ with a precision of ± 0.005 .
5. Studies of b -quark production and decay.
6. Measurement of $R = \sigma B(W^\pm \rightarrow l^\pm \nu) / \sigma B(Z^0 \rightarrow l^+ l^-)$ and a measurement of the W width to about 10%.
7. Measure $\sin^2 \theta_W$ to .005 using the asymmetry in $Z^0 \rightarrow l^+ l^-$.
8. Studies of inclusive jet production. This will enable us to study QCD over a very large x_F range ($0.01 < x_F < 0.5$), and be sensitive to contact terms with mass scales of order 1.5 TeV.
9. Studies of direct photon production. With the addition of a preconverter, CDF will be able to measure photon cross sections out to transverse momentum values of 300 GeV. This will allow a study of the quark-gluon vertex using a photon tag.
10. Studies of high p_T $W^\pm$ and Z^0 production.
11. Searches for supersymmetric particles with masses up to 200 GeV.
12. Searches for leptoquarks. Our mass sensitivity will be about 100 GeV for leptoquarks decaying into $quark + \nu$. For $quark + l^\pm$ decays, the sensitivity will be up to 170 GeV for first generation leptoquarks and 120 GeV for second and third generation leptoquarks.

In the past year, many of the physics results from the successful 1988-1989 CDF run were published. Since January 1992, 22 papers have been published and 10 more have been submitted and are in preprint form. With the top search from the 1988-1989 data completed and in print, the CDF collaboration has focused on other interesting topics, such as b -quark production and decay, and photon production. Four articles summarize new work by CDF in the area of b physics. Three new measurements of the b -quark cross section [20,21,22] have been reported this year. Dr. Winer is on the internal CDF review committee for the first of these publications. We now have measured the b -quark cross section as a function of the b -quark P_T (see Figure F-1) using six distinct methods, which all agree within statistics. This work is interesting because it probes gluon structure functions to very low x values. In addition, we published negative results from search for $\Lambda_b \rightarrow \psi \Lambda$ [30]. This work contradicts earlier claims of discovery made by UA1.

Also published this year were a series of articles on photon production at Tevatron energies [25,27,28]. This work also gives new information about proton structure functions. The inclusive photon cross section and the diphoton cross sections have been measured in addition to the center-of-mass angular distribution. Also published in the area of QCD physics is a comparison of jet production at $\sqrt{S} = 546$ GeV and at 1800 GeV [29].

CDF is currently taking data and as stated previously, the run is progressing well. The SVX performance is particularly noteworthy. Of the 46,000 channels, less than 2% are dead, noisy, or non-functioning. The individual hit resolution is $\approx 13\mu\text{m}$. Figure F-2 shows the SVX display for an event with two displaced vertices. The event is a candidate $B^0 \rightarrow \psi + K^*$, $K^* \rightarrow K^+ \pi^-$ decay. Many of the observed ψ events are from B decay. In Figure F-3 we plot the $c\tau$ distribution of $\psi \rightarrow \mu\mu$ candidates. The flight distance is corrected on average for the ratio of $\beta\gamma$ of the ψ to that of the parent B particle. The positive exponential tail is used to measure the average b -quark lifetime, which is in very good agreement with the world average. (Tipton is the head of the review CDF internal review committee for this b -quark lifetime analysis.) It is clear the data quality of the SVX is high and the SVX will be a useful tool for heavy flavor physics.

The University of Rochester is currently working on physics data analysis in three areas; the top search, a measurement of the lepton asymmetry from W decay, and a search for a heavy gauge boson (Z'). A team consisting of Hughes, Tipton, Watts, Winer, Koehn, and Tollefson, are working on the problem of b -quark tagging with the SVX. We are focused first on issues specific to the search for the t -quark, but most of this expertise will naturally lead into a program of b -quark studies. CDF "blessed" three top-search analyses for discussion at the 1993 Spring conferences. The first was our work searching for b -quark tags in events where one of the t or $\bar{t}$ quarks decays semileptonically and the other decays to jets. The second top search analysis searched for "soft" leptons as a b tag in the same event sample used above. The third analysis looked for dilepton events from top.

Our work uses a b -quark tag which first associates tracks with a specific jet observed in the calorimeter. Secondly, we vertex constrain these tracks to emanate from a common point. We use the direction of the displacement from the primary vertex (finally requiring that the distance be consistent with a positive lifetime) as an indicator of the background tags (most negative lifetime tags must come from mis-measured tracks). We use the inclusive electron triggers, which we have measured to be $\approx 40\%$ from semileptonic b decay, as a control sample to prove our tagging algorithm is efficient. The tagging rate in data agrees with a Monte Carlo of $B\bar{B}$ events. Figure F-4 shows the $c\tau$ distribution for the b -tags in the inclusive electron sample before we require the flight distance be positive. There is a clear excess of positive lifetime tags over negative lifetime tags. The slope of the positive excess is consistent with the world average b -quark lifetime.

We also use a control sample of generic jets, thought to contain only about 1% b -quark jets, as a sample to prove the b -tag algorithm rejects non- b -quark backgrounds. We falsely tag a generic jet as a b -quark jet at a rate of about 0.5%. We can use this mis-tag rate to predict our background in the sample in which we search for top. In the sample of W events with jet activity, the sample which should contain top if it were produced, we run our b -tagging algorithm. The results are displayed in Figure F-5. The jet multiplicity spectrum is shown for data before and after b -tagging. In addition, the estimated number of tags caused by track pattern recognition failures is shown. This was determined from inclusive jet data. The background from real b -tags from non-top sources is not included. We currently see a slight excess over

expected backgrounds, but this excess is not yet statistically significant.

Prof. A. Bodek and Mr. Mark Dickson are working on the extraction of structure function information from the W asymmetry data at CDF. The W asymmetry originates from the difference in u and d -quark distribution and therefore is directly related to the work that we have been involved in in measuring the ratio of structure functions F_2^{ν}/F_2^p in electron scattering experiments. The W asymmetry measurement at CDF is at Q^2 values of 6400 (GeV/c)², which tests the QCD evolution of the u and d -quark distributions to very high Q^2 . Figure F-6 shows the W decay charge asymmetry from the current CDF run through February, 1993. It is compared with predictions using two different structure function choices.

Lastly, Prof. A. Bodek, Dr. de Barbaro and Mr. Manoj Pillai are working on the search for a Z' by explicit reconstruction, using the invariant mass of oppositely charged dielectrons. Figure F-7 shows the mass plot, with one event in excess of 200 GeV/c² in data from the current CDF run through February, 1993. This rate is consistent with the 1.5 events expected from Drell-Yan processes.

Task F: The CDF Silicon Vertex Detector

The Silicon Vertex Detector (SVX) was approved by the Fermilab Program Advisory Committee in 1985 for construction and installation into CDF. The device exploits high-resolution silicon microstrip technology for tagging b -flavored particles by identifying decay vertices that are displaced from the primary $\bar{p}p$ interaction point. Before his arrival at the University of Rochester, Tipton was the Fermilab project leader for the SVX during its construction and installation. The device consists of a four layer, 46,000 channel silicon microstrip vertex chamber, with $\approx 10 \mu\text{m}$ position resolution. Cooling for the approximately 100 watts of power produced by the SVX is provided by chilled water flowing through a system of tubes that follow the contours of the beryllium bulkhead. The chilled water system is maintained at sub-atmospheric pressure so that small leaks will result in gas entering the cooling system rather than water spilling onto the SVX and the rest of the CDF detector. The Rochester SVX group has completed their responsibility for several critical elements in the SVX project. We have specified, designed, and procured a Programmable Logic Controller (PLC) that will be used to control the SVX power supplies and cooling systems to ensure that the SVX is always maintained in a safe state. The device has functioned continuously for over 12 months with no malfunctions. Rochester is also responsible for the temperature monitoring of the SVX. The temperature stability of the device has been very good and this has allowed the $13\mu\text{m}$ resolution we observe with the SVX to be achieved. Thermo-mechanical motion would have mis-aligned the device and forced us to re-align it frequently. This has not been necessary.

SVX Upgrades

While the existing SVX detector represents one of the most sophisticated silicon systems deployed to date, the design was fixed at a time when the projected luminosity of the Tevatron collider was below that already attained, and far below that expected for the upcoming run. Thus, the device uses DC-coupled detectors and radiation-soft electronics, and is not expected to survive for the entire 1992-1993 data-taking

2 of 2

period due to radiation damage. For the above-noted reasons, we are planning a major upgrade of the SVX to be installed in the Summer of 1993. This upgrade, which we have labelled SVX', will consist of replacing the the entire device with AC-coupled silicon detectors and radiation-hardened electronics. The switch to AC-coupled detectors is required in order to maintain the stability of the input amplifiers as the radiation-damage-induced leakage current of the silicon detectors increases. The radiation-hardened electronics is needed because the radiation-soft electronics may either fail completely or sustain a significant increase in the noise level as the radiation exposure increases.

Rochester is participating in the upgrade of SVX to SVX'. The AC coupled silicon detectors have been delivered to Fermilab. Ms. Kirsten Tollefson performed quality assurance inspection and electronic checkout on AC coupled detectors over the summer of 1992. She automated the data-collecting procedure for electronic testing of the detectors. In the summer of 1993, Tollefson will help with the installation of SVX'.

Despite the substantial improvements involved in going from the initial SVX to the upgraded SVX' detector, the resulting device will not be adequate for subsequent collider runs (i.e., those occurring after 1994). The change in the collider operation from 6 bunches to 36 bunches, scheduled to be completed in 1995, means that the readout chip must be redesigned, necessitating another rebuild of the detector, which we have called SVXII. 395 ns between bunch crossings will require the use of an input amplifier/shaper with shorter peaking times and an analog pipeline to accommodate the data during the formation of the level-0 trigger. In addition, it will be desirable that the chip be capable of providing digitized information within 5 microseconds of the beam crossing, for use as input to a proposed level-2 secondary vertex trigger. As with the SVX' detector, a fully radiation-hardened input chip will be used. The Rochester group has taken a lead role in the early stages of the SVXII design. We plan to further involve our group in this effort in the next year.

As previously mentioned, a secondary vertex trigger (SVT) is planned with the SVXII upgrade. This trigger will require a fast outer track processor working on inputs from the Central Tracking Chamber, or CTC. These tracks will then be projected back into the SVXII and hits in the silicon will be added to the fit. CDF's current fast tracker is called the CFT, and is used for the second level electron and muon triggers only. As previously state, the change in the collider operation for Run II implies crossing times of less than 395 ns. Unfortunately, the CFT processing time is typically a few microseconds, and therefore must be replaced. The proposed upgraded fast tracker is called XFT.

The XFT gets $r - \phi$ information from the 5 axial layers of the CTC. Each axial layer is divided into cells, with each cell having 12 wires. The XFT will process information from the CTC in two 132 ns clock cycles. The first clock cycle takes the wire information from each cell and uses a look-up-table to determine if a valid track passed through the given cell. All cells which have been matched are then fed into an $r - \phi$ array. The second clock cycle compares this array to another look-up-table to determine if a valid track candidate passed through all 5 axial layers. A final list of track candidates is then available for further trigger processing.

The Rochester group is taking a leading role in the design of the XFT. Dr. Richard Hughes is working on simulations of various XFT designs. He is optimizing the design for momentum and ϕ resolution. In addition he is investigating matching XFT tracks with the SVT system. The SVT will be used to detect displaced vertices in the second level trigger system and will therefore play an important role in b -quark physics at CDF in run II.

Figure F-1

The b -quark cross section as a function of the b -quark P_T integrated above that P_T . The results from six different analyses of the 1988-1989 CDF data are shown along with a theoretical prediction of the band of expected cross section.

Figure F-2
SVX Display showing two displaced vertices in a candidate $B^0 \rightarrow \psi + K^+ K^- \pi^-$. The length of the tracks is proportional to the particle momenta and the outer ring is 5 mm from the interaction point.

Figure F-3
The $c\tau$ distribution of $\psi \rightarrow \mu\mu$ candidates. The flight distance is corrected on average for the ratio of $\beta\gamma$ of the ψ to that of the parent B particle. The positive exponential tail is used to measure the average b -quark lifetime. The data is from the current CDF run through February, 1993.

Figure F-3
The jet multiplicity spectrum is shown for the W + jets data before and after b-tagging. In addition, the estimated number of tags caused by track pattern recognition failures is shown. This was determined from inclusive jet data. The background from real b-tags from non-top sources is not included.

Figure F-4
The $c\tau$ distribution is plotted for the b-tags in the inclusive electron sample. The dashed histogram represent the $c\tau$ distribution from b-tags in a $b\bar{b}$ Monte Carlo. The fit line has a lifetime (slope) fixed to that found in the ψ b-lifetime analysis; the normalization was allowed to fit the electron data.

Current run (10 pb-1)

Figure F-6
The invariant mass of oppositely charged dielectrons. The lower plot is the same data as the top plot except it is displayed on a log-scale. The data is from the current CDF run through February, 1993.

Mass Distribution of e+e- Pairs

Figure F-7 (a)
The W decay charge asymmetry found in each detector subsystem (central EM, plug EM and central muon) plotted separately and (F-7b) combining muon and electron data from the current CDF run through February, 1993.

Task G: The CDF Plug Task (Participants: Drs. A. Bodek, H. Budd, P. de Barbaro, W. Sakumoto, B. Winer; Messrs. M. Dickson, Q. Fan, P. Koehn, M. Pillai)
1. Plug Electromagnetic Counter, PEM

One of the main improvements to CDF for the present collider run (Run IA), and the next collider run (Run IB), is the availability of the complete use of the end-plug electromagnetic calorimeters (PEMs) in both trigger and offline analysis. In the previous collider run, both PEMs had high voltage problems that prevented a large section from being used in the trigger, creating gaps that made analysis of data difficult. In addition, the PEM calibration was not well understood. These two problems restricted the usefulness of the PEM data in the previous CDF collider runs.

During 1991-1992, Budd and Dickson, in collaboration with the KEK and Tsukuba groups, did an extensive program of repairs, upgrades, and testbeam calibrations to prepare the PEM for collider Runs IA and IB: the high voltage problems were fixed, the front-end electronics were replaced and all 2304 towers of both PEMs were calibrated in a testbeam with 100 GeV electrons. During the calibration, the hardware was carefully checked and monitored to ensure that the calibrations are well understood. This work was very successful: the measured PEM energy resolution is 2.8% for 100 GeV electrons and the tower to tower variation is 5% (rms).

Run IA has been very successful in that both PEMs work as per their original specifications, and that both are relatively trouble free. Budd is the PEM hardware manager and is responsible for monitoring the hardware performance and for fixing hardware problems. Dickson assists in the monitoring. The Run IA physics potential of the PEMs is excellent. Figure G1 shows the W-boson transverse mass distribution of $W \rightarrow e\nu$ events for $e^\pm$ found in the central and PEM calorimeters.

2. CDF Plug Calorimeter Upgrade

To cope with the increase in luminosity and the shorter bunch spacing of the Tevatron upgrades for Run II, the CDF collaboration is replacing the forward (3° to 10°) and plug (10° to 38°) gas calorimeters with a single, compact, hermetic scintillator plate calorimeter with phototube readout. The scintillator planes are constructed from smaller, optically isolated tiles that are organized into projective (η, ϕ) towers. Light from an individual tile in a tower is collected by a separate green wavelength shifting (WLS) fiber placed in a groove on the surface of the tile. Light from the WLS fiber is routed out on its own clear fiber and combined with light from the other tiles of the tower at the phototube.

A design constraint of the plug calorimetry upgrade is the preservation of the gas plug calorimeter's existing steel structure. This constrains the geometry of the hadronic section, but not the electromagnetic (EM) section. The lead/scintillator configuration of the upgraded EM calorimeter is much denser than the existing gas EM calorimeter. The design of the plug upgrade EM calorimeter used the increased density to alleviate prior detector problems. First, one of the major hermiticity problems currently faced by CDF, the "37° crack" is reduced. Second, as the upgrade EM calorimeter requires less longitudinal space, two additional stainless steel absorber plates are to be added for the hadronic section of the calorimeter. In addition to the

Fig. G1: W-boson transverse mass distributions in the central and plug regions from Run IA events (12 pb^{-1}) with a tracked, high E_t electron and large missing E_t . Due to reduced tracking coverage, only 40% of plug electrons have tracks.

better containment of hadronic showers and reduced punchthrough into the muon detectors, these plates provide additional shielding in front of the projective, detector readout crack at 30° .

The decision to replace the gas calorimeters with a compact, tile/fiber calorimeter was made in the fall of 1990. Since then, the plug calorimeter upgrade project has advanced from a proposal to a firm design. The final engineering and technical design is nearly complete. After undergoing several levels of both CDF internal reviews and Fermilab management reviews in 1992, it has received construction approval. Material procurement and pre-production work on the electromagnetic and hadronic sections are well underway. The University of Rochester designed the hadronic section of the plug upgrade calorimeter and is now supervising its construction at Fermilab.

2.1 Hadronic Calorimeter Design

2.1.1 Criteria

The design for the plug upgrade hadronic calorimeter is limited by the constraint that the current gas plug calorimeter's absorber steel and chamber lattice be left unmodified, except for the addition of donut-shaped stainless steel inserts that extend the coverage down to 3° . The upgrade's active detector components must fit into this modified steel structure. The fibers that channel the light from the calorimeter tiles to the phototubes must be routed along the outside of the steel, in the same volume as the readout cables for the gas plug calorimeters. The physics performance criteria are: an energy resolution of $(\sigma/E)^2 = (.8 - .9/\sqrt{E})^2 + (.05)^2$, an ability to identify muons, and a segmentation suitable for efficient and productive physics analyses on

such topics as b- and t-quark physics, and studies of W, Z, γ , and jet production. The physics criteria require the light yield for a minimum ionizing particle (mip) to be more than one photoelectron (pe) per tile. Attaining better than a 5% constant term in the energy resolution requires the longitudinal tile-to-tile light output variation of less than 10% and the transverse response non-uniformity within a tile to be less than 4%.

2.1.2 Device Design

The plug hadron calorimeter design has been finalized and the detailed design report and construction schedule is included as Appendix I. The calorimeter has 22 longitudinal layers consisting of a lattice of 2" thick steel absorber plates followed by a 0.75" counter gap instrumented with 6 mm Kuraray SCSN38 scintillator. There are 432 towers per endcap and a total of 17184 optically separate scintillator tiles for both endcaps. Including the test beam module (60° ϕ coverage) increases the tower (tile) count by 72 (1432).

To reduce the number of individual elements, scintillator tiles from a 30° ϕ section of a longitudinal layer are constructed as a single pie-shaped mechanical unit called a megatile. The tiles are bonded together by thin channels of opaque, white-reflective epoxy that also provide optical isolation. Readout fibers from individual tiles are routed to mass terminated optical connectors at the outer edge of the megatile on a grooved fiber routing plate (3.81 mm thick white, opaque polystyrene) that is secured above the scintillator. Fibers rise out of the scintillator through an oval slot in the routing plate and onto the routing grooves. The routing plate is the same size as the scintillator megatile and its use insures that the fragile optical fibers are securely held and protected. Both the megatile and the fiber routing plate are packaged in an aluminum pan. A cross section of a megatile pan unit is shown in Fig. G2. Details can be found in Appendix I (sect. I.3.1).

A key feature of the design is the use of mass terminated optical connectors. Fibers in a megatile are mass terminated at the edge of the pan into an optical connector. A mass terminated optical cable transports the light from a megatile to the phototube readout. At the phototube readout, an equivalent of a cable "patch panel" assembles fibers from different longitudinal tiles of a tower onto the phototube designated for that tower.

2.2 R&D Program

The research and development in tile/fiber technology for the plug upgrade has been ongoing for the last four years, with the Rochester group playing a major role. This technology has undergone many innovations and has advanced to a "production" technology. The Rochester group concentrated on fundamental aspects as: WLS fiber properties, radiation damage, the effects of WLS fiber geometry within the scintillator tile on light yields and transverse uniformity, etc.

In 1991, the tile/fiber technology was U-shaped WLS readout pattern grooves in the scintillator tile with 1 mm diameter fibers read out at both ends of the U-pattern. During that year, a large, engineering prototype calorimeter utilizing this technology was constructed and beam tested at Fermilab. Rochester was responsible for the successful implementation of the test beam run. Its performance was better than expected. However, it was quickly realized that the readout fiber volume using this

Figure G2: Cross Section of a Hadron Calorimeter Pan

technology is much larger than available in the CDF detector. Thus, R&D on a more advanced tile/fiber technology with a smaller fibers and a single readout fiber per tile began. What emerged was a WLS fiber readout pattern shaped like the Greek letter, σ with 0.75 mm diameter fibers. Its advantage over the previous technology is that the fiber volume is much smaller and the transverse uniformity of the σ -pattern tile is better relative to the U-pattern used in the 1991 engineering prototype. A small 3-by-3 tower electromagnetic test module was also built and beam tested in 1991. Its test beam performance was consistent with expectations and within the within the design specifications for the plug upgrade calorimetry. Consequently, this σ -pattern single-fiber readout was chosen as the baseline design for the plug upgrade calorimeters.

In 1992, the Rochester concentrated on R&D to finalize the design of the hadronic section of the plug upgrade calorimeter using 6mm thick SCSN38 scintillator and 0.83 mm diameter Kuraray Y11, multicladd, green WLS fibers. The scintillator megatile concept and its associated production technique, was developed and perfected by Rochester. Understanding and controlling the light yields and transverse uniformity of scintillator tiles of various sizes so that calorimetry design criteria are met was one of the major R&D tasks. Rochester systematically identified and mapped the effects of the critical parameters such as the geometry of the WLS fiber's σ -groove within the tile. This was done using automatic scanning devices built by Rochester with the cooperation of Argonne National Laboratory. To assess the effect of various detector design options on the physics goals, Rochester initiated and completed a series of detector simulations to the intended physics. The (η, ϕ) segmentation in the final design of the plug upgrade calorimeters came from this study. Optical connectors (and

cables) are an integral and critical part of the hadron calorimeter. Consequently, Rochester started an R&D program in the Fall 1992 to systematically identify and map out its design parameter space. By the end of 1992, the design of the calorimeter was finalized.

In 1993, the Rochester tile/fiber R&D effort is decreasing. A problem of the previous year, inter-tile crosstalk, was reduced to under a percent per side, which is more than adequate. Work is still progressing on optical connector R&D, but it should be completed by mid-year. Presently, R&D is on the "assembly line" production techniques for megatiles. Several mechanical prototypes of the smallest and largest megatile pan units have been made. These have full engineering details. Fiber laying, reflective paper wrapping, light tightening, and mechanical assembly details are being studied.

2.3 Current Work and Production Plan of Hadron Calorimeter

In the first quarter of 1993, the Rochester group participated in finalizing the detailed engineering design of the calorimeter. Material procurement is progressing, with arrivals slated for May or June 1993, the start of full scale production. A good portion of the production material are at Fermilab, including half the SCSN38 scintillator order. Rochester is coordinating the setup of Fermilab facilities for the manufacture and assembly of the megatiles. The facilities are nearly ready for production. Mechanical mockups (without scintillator) of the megatile units of various sizes are in various stages of construction. These are being used in the R&D effort to develop and refine production techniques. Technicians, who will be constructing the megatiles, are assisting in this R&D effort and are receiving training as well.

Megatile units for both CDF and a test beam module will be manufactured. Test beam megatile production is done first so that they will be built and fully tested before the beam test in the Fermilab 1995 fixed target cycle. Megatile construction is slated for May 1993 to August 1994. Additional details are in Appendix I (sect. I.5.3).

Once production gets under way, the Rochester group will oversee the production and monitor the quality assurance procedures performed during production. A number of quality assurance tests must be performed during production to insure the final device meets the design criteria. A summary of these are given in Appendix I (sect. I.4.3). An important measurement is light yields from individual tiles in a fully assembled megatile with a collimated Cs^{137} γ -source. This is required to maintain the tile-to-tile light yield uniformity needed for good energy resolution. Rochester has designed, and is building, a large, automated x-y scanner for this test. This scanner will also be used to test the light yield uniformity of the EM megatiles.

2.4 The Future

Production is expected to be done by August 1994. Rochester will supervise the installation, commissioning, and operation of the plug hadron calorimeter for Run II, scheduled for November 1995. Installation will occur during Fermilab's 1995 fixed target running. Prior to and concurrent with the installation, Rochester will also participate in the beam calibration of the test beam module.

Task J: The SDC Tile/Fiber Calorimetry

(Participants: Professor A. Bodek, Sr. Research Associates H. Budd and W. Sakumoto, Drs. P. de Barbaro, R. Walker, B. Winer, Graduate students: M. Dixon, Q. Fan, P. Koehn, M. Pillai)

1. Overview of the Task Activities

The University of Rochester HEP group has been involved in the R&D of tile/fiber technology for the Solenoid Detector Collaboration (SDC) electromagnetic and hadron calorimeters. During FY92-93, the group has played the crucial role in the construction, data collection and analysis of the results of the Hanging File Calorimeter (HFC). P. de Barbaro, A. Bodek, H. Budd and W. Sakumoto were involved in this experiment. The purpose of this calorimeter was to study the question of e/h compensation for scintillating tile calorimetry. The results of this experiment have been presented by dr. P. de Barbaro at the Division of Particles and Fields (DPF) Meeting in Fermilab, November 1992 and submitted for the publication in NIM.

In addition, the unique instrumentation of the HFC calorimeter (every sampling layer of the calorimeter was read out individually by the photomultipliers) provided the data for many systematic studies of the performance of both electromagnetic and hadronic calorimeters. Such studies included "The effects of tile miscalibrations on the performance of the tile/fiber based hadron calorimeters", a report by P. de Barbaro, A. Bodek and B. Winer published as University of Rochester preprint, January 1993.

The HFC also provided interesting data on the energy leakage of late interacting hadrons. The increased weighting of back layers of the calorimeter reduces some of the energy leakage effects and therefore allows for more compact and economical detector. Some of the results on this topic have been already published by our group. P. de Barbaro, A. Bodek and Q. Fan continue this analysis.

We have also continued the R&D on the tile/fiber calorimetry. The Rochester SDC group was specifically responsible for establishing the design parameters of the tile/fiber assemblies for the SDC Hadron Barrel Calorimeter. Some of the R&D results have been published by our group as the SDC note. Below we describe our most recent results. The results indicate that large (50 cm $\times$ 50 cm) tiles have the light yield of more than 2 photoelectrons per minimum ionizing particle and a very good transverse uniformity of the response. Such tiles meet design criteria for the Hadron Calorimeter for the SDC Barrel detector.

For the FY94, the emphasis in our SDC program will shift from R&D and design effort to the production and testing of full size SDC calorimeter. The testing will involve both the cosmic ray runs (Fall 1993) as well as the test beam runs during the upcoming Fermilab's Fixed Target Run.

2. Recent R& D Results: Introduction

In this note we describe the measurements of tile/fiber assemblies built according to the specifications of the SDC Barrel Hadron Calorimeter. We have used 4 mm thick SCSN-38 from Kuraray as a scintillator material. The light from the tiles was collected by a 0.83 mm diameter WLS fiber Y11(200)¹, multiclاد S-type from

¹The numbers in the parentheses correspond to number of parts per million (ppm) by weight of a fluorescent dye in the fiber core.

layer number	tile size	length of WLS fiber	length of clear fiber
01 (first HAC1)	23.5 cm	90 cm	180 cm
20 (center HAC1)	30.0 cm	110 cm	130 cm
32 (last HAC1)	38.0 cm	150 cm	100 cm
44 (last HAC2)	50.0 cm	190 cm	50 cm

Table 1: Approximate sizes of the selected layers for SDC Hadron Barrel calorimeter. Tile sizes correspond to $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$.

Kuraray, spliced to 0.83 mm diameter, multicladd clear Kuraray fiber. The tile edges were painted with white reflective paint BC-620 from Bicron, and wrapped with white reflective material Tyvek.

The absolute light yield and uniformity of the response of tile/fiber assemblies was measured using the collimated Ru^{106} β source scanner. The relative light yield of various tiles was measured using the Cs^{137} γ source setup. The detailed description of the experimental setup can be found in our previous note.

3. Tile sizes for the SDC Barrel Calorimeter

The sizes of hadron tiles in the central η tower of the SDC Barrel calorimeter, vary from approximately 23.5 cm $\times$ 23.5 cm (9 1/4 " $\times$ 9 1/4 ") for the first layer of the HAC1 to approximately 50.0 cm $\times$ 50.0 cm (20 " $\times$ 20 ") for the last layer of the HAC2². Table 1 lists the sizes of few selected layers for the central η tower of the hadron calorimeter. It also indicates the length of WLS fibers needed for read-out as well as the length of clear fibers to carry the light from the edge of the tiles to photomultipliers located approximately 50 cm behind the HAC2 detector.

4. Absolute light of the 50 cm $\times$ 50 cm tiles with various fiber read-out patterns

We have compared the absolute light yield of a 50 cm $\times$ 50 cm tile using four different patterns of read-out fibers. In all cases we have used the tile with a single groove encircling the perimeter of the tile, with the distance between the tile edges and the fiber groove center 3 mm ($\approx 1/8$ "). The depth of the groove was equal to 2 mm (80 mils).

Figure 1 shows a schematic drawing of various patterns of fiber read-out studied in this note. Individual read-out patterns differed in the number of fibers laid in the groove (one or two WLS fibers) and whether one or both of the ends of WLS fibers were spliced to clear fibers connecting to a photomultiplier (PMT):

- 1 σ pattern: Only one WLS fiber was laid in the fiber groove. One of the ends of WLS fibers was spliced to 50 cm of clear fiber and connected to the PMT. The other end was mirrored and terminated inside the tile;
- 2 σ pattern: Two WLS fibers laid in the groove, each fiber was connected to the PMT via a single, 50 cm long clear fiber. The other ends of WLS fibers were mirrored and terminated inside the tile;

²The SDC Barrel Hadron Calorimeter will consists of 32 layers with 1 inch iron sampling (HAC1), followed by the 12 layers with 2 inch iron sampling (HAC2).

fiber pattern	# of fibers to PMT	abs. l. yield	l. yield rel to 1σ
1σ	1	2.1 ± 0.1	1.0
2σ	2	3.4 ± 0.2	1.6
1α	2	3.4 ± 0.2	1.6
2α	4	5.4 ± 0.2	2.6

Table 2: Light yield of 50 cm $\times$ 50 cm SCSN-38, 4 mm thick tile with various fiber read-out patterns.

- 1α pattern: Only one WLS fiber was laid in the fiber groove. However in this case both ends of the WLS fiber were spliced to 50 cm long clear fibers and connected to the PMT.
- 2α pattern: Two WLS fiber was laid in the fiber groove, with both ends of the WLS fiber were spliced to 50 cm long clear fibers and connected to the PMT. In this case there were total of four clear fibers were carrying the light from the tile to the PMT.

Figure 2 shows the ADC pulse height spectrum for the 50 cm $\times$ 50 cm tile read out using 2σ fiber pattern. The fraction of triggers with no pulse height was equal to $3.5 \pm 0.1\%$, corresponding to the absolute light yield of the tile of 3.4 ± 0.1 photoelectrons per minimum ionizing particle. Figure 3 presents the light yield of the 50 cm $\times$ 50 cm tiles as a function of a pattern of read-out fibers. The highest light yield corresponds to the 2α pattern, with four clear fibers connecting to the PMT. Table 2 summarizes the above results.

The results indicate that one can increase the light yield of large tiles by factor of 1.6 by introducing an additional WLS fiber into the groove. It is important that the second fiber is inserted to the same groove, 2 mm deep for 0.83 mm diameter fibers. In a separate measurement, a tile with two parallel grooves separated by 3 mm, each 1.5 mm deep was cut. In this case, the light yield of the tile with fibers inserted to two separate grooves increased only by 15% relative to the light yield of the tile read out only by the single WLS fiber.

It has been demonstrated earlier that one can correct for some back-leakage of the energy from late interacting particles in a hadron calorimeter by increasing the relative light yield of the layers at the back of the hadron calorimeter. The results from the Hanging File Calorimeter indicated that a factor of ≈ 1.8 for last interaction length of the detector should be applied. If the 1σ fiber read-out pattern is used as a standard for most of the layers of the SDC Hadron Barrel detector, then the 2σ fiber read-out pattern for the last three layers of HAC2 would allow one to achieve proper exit-weighting.

5. Transverse uniformity of 50cm $\times$ 50cm tiles

We have studied the transverse uniformity of light collection of the 50 cm $\times$ 50 cm tile with the 2σ fiber read-out pattern, using the collimated β source setup. Figure 4 shows a plot of transverse scan of the tile.

The uniformity of the response (r.m.s./mean response of the tile) is better than 2%. The similar result was achieved for the tile with 1σ fiber read-out pattern.

6. Relative light yield of tiles from selected layers of HAC1 and HAC2 Barrel Calorimeter

We have compared the relative light yield of the few selected SDC Hadron Barrel calorimeter tiles using a γ source measurement. Figure 3 shows the relative light yield for layer 1, layer 20, layer 32 (HAC1 compartment) and layer 44 (HAC2 compartment) plotted as a function of the depth of the calorimeter expressed in inches of iron absorber. The data points are not corrected for the effect of imperfect collimation of the γ source. We estimate that this correction would reduce the light yield of the layer 44 tile ((50 cm $\times$ 50 cm tile) relative to the layer 1 tile (23.5 cm $\times$ 23.5 cm tile) by approximately 10%.

As we have reported in our previous note, one expects the relative light yield of different size tiles to scale with variable l/A , where l is the length of the WLS read-out fiber and A is the area of the tile. Additionally the relative light yield of the tiles depends on the length of the clear fiber between the tile's edge and the PMT ³. Dashed line on the plot on Fig. 5 indicates the predicted dependence of the relative light yield of the tiles, including both the l/A dependence as well as the attenuation effect due to the clear fiber. The data is consistent with the expectations. We intend to manufacture additional number of tiles of various sizes in order to reduce the systematic error on the measurement of light yield vs tile size.

Earlier, we have reported in UR 1301 on the effects of the systematic variation in the relative light of the tiles belonging to the same calorimeter read-out towers on the energy resolution of the hadronic detector. The study indicated that the decrease in the relative light yield between the front and back layers of the calorimeter would by 20% would lead to the increase in energy resolution of 100 GeV pions by a factor of 1.15. Since HAC1 (layers 1 -32) and HAC2 (layers 33-44) compartments go into separate phototubes and have individually adjustable gains, a small ($\approx 20\%$) variation from front to back in HAC1 or HAC2 can be corrected for by a masking technique at the phototube face.

7. Design of the SDC Hadron Barrel Calorimeter tiles

In Table 3 we have summarized the design parameters of the SDC Hadron Barrel Calorimeter tiles.

8. SDC activities in FY95 and FY96

In addition to SDC tile fiber R&D and analysis of calorimeter test beam data, Rochester is also getting involved in cosmic ray and test beam calibration of the prototype calorimeter modules. This additional effort requires collaboration between members of Task D (Neutrino E815), the members of tasks G/J (CDF/SDC tile fiber).

³The attenuation length of clear Kuraray fiber is ≈ 700 cm.

scintillator material	SCSN38
scintillator thickness	4 mm
fiber groove depth	2 mm
radius of fiber grooves	3 cm
tile edge-fiber groove sepa	3 mm
tile edge treatment	white paint BC-620
tile wrapping	Tyvek 1055B
WLS fiber material	Y11(200)
WLS fiber diameter	0.83 mm

Table 3: Summary of the design parameters of the scintillator tiles for the SDC Barrel Hadron Calorimeter.

As mentioned in the neutrino section of task D our neutrino collaborator at FNAL, Mike Lamm, is also in charge of the cosmic ray and test beam activities for SDC at FNAL. We have been involved in SDC tile/fiber R&D (see task J). As the tile fiber prototype modules are constructed, their initial test will be done using cosmic rays, and then with the SDC test beam at FNAL.

It is not possible for a research associate to devote 100% of his time to to SDC activities, since SDC is such a long term project. Therefore we anticipate that one research associate from the neutrino task (R. Walker and his future replacement) will work 50% of the time on the SDC cosmic ray and test beam calibration effort. Another research associate from the CDF- tile/fiber task (Dr. P. de Barbaro) will work 50% of his time on SDC tile/fiber R&D, and SDC test beam hanging file analysis in the beginning of FY94. Towards the end of FY94, de Barbaro's 50% effort on SDC will be more on cosmic ray and test beam calibration of calorimetry modules. The plan is that between task D and task G/J there will be one full time equivalent research associate working on SDC activities at a steady level. (see MOU between SDC and Rochester). The requested budgets for task D task G/I reflect the finacial resources needed to maintain this additional level of effort.

Fig. J1: Schematic diagram of different patterns of read-out fibers studied in this note.

ADC Pulse Height Distributions

Fig. J2: ADC pulse height spectrum for tiles using electrons from collimated β source:

a) ADC spectrum for the tile built using 4mm thick SCSN-38 scintillator. The transverse size of the tile is 50 cm $\times$ 50 cm, read out with the 2 σ WLS fiber pattern (see Fig 1b). The edges of the tile were painted with white reflective paint BC-620 from Bicon. Light was collected using 0.83 mm diameter Y11(200) multiclاد WLS fiber from Kuraray, spliced to 0.5 m of multiclاد clear Kuraray fiber. One of the ends of the WLS fibers were terminated inside the tile and were mirrored using the sputtering technique. The tile was wrapped using Tyvek 1055B material by Du Pont. The fraction of triggers with no ADC deposition is equal to 3.5 ± 0.1 % corresponding to the average light yield of 3.4 ± 0.1 photoelectrons (p.e.) per minimum ionizing particle (mip).

b) ADC spectrum for the reference tile. The light yield of this tile is ≈ 0.3 PE/mip. The pedestal events are suppressed on Fig. 2b. The position of the one-photoelectron peak was used to calibrate the phototube and determine the number of ADC counts per 1 p.e. One photoelectron peak corresponded approximately to 30 ADC counts above the pedestal.

Fig. J3: The absolute light yield of the 50 cm x 50 cm tile as a function of various patterns of the fiber read-out. The patterns are depicted in Figure J1.

Fig. J4: The scan of 50 cm x 50 cm tile using collimated β source. Due to the size limitations of the scanner box, the data corresponds to a single scan of a half of the tile.

light yield for 4mm scsn-38 tiles

Fig. J5: The relative light yield of the selected tiles from the central η tower. The data points are not corrected for the effect of imperfect collimation of the γ source. We estimate that this correction would reduce the light yield of the layer 44 tile ((50 cm $\times$ 50 cm tile) relative to the layer 1 tile (23.5 cm $\times$ 23.5 cm tile) by approximately 10%. HAC1 compartment corresponds to first 32 inches of Fe. HAC2 compartment covers the remaining back portion of the calorimeter. Note that HAC1 and HAC2 go into different phototubes which will have individually adjustable gains.

Completion of the AMY Program at TRISTAN

The AMY experiment has published results on the following in 1992 and 1993:

(a) Limits on $\gamma\gamma$ states in the TRISTAN region. This study was prompted by the reports of a possible $\gamma - \gamma$ resonance produced at L3 at LEP in association with dilepton events. The AMY experiment conducted a scan in the energy range 55 to 60 GeV looking for such a narrow state. No such state was observed and limits on such a state were published in Physics Letters. (See Figure 1.) It appears that the most likely source of the L3 events is QED background.

(b) In 1992 and 1993 two AMY Ph.D. theses were completed at Rochester. These two theses on the extraction of the strong coupling from Rhadron and multi-jet data in e^+e^- hadronic events are limited by systematic errors. Therefore, in these analyses, AMY data is competitive with LEP.

Y.K. Li's thesis was completed under the supervision of A. Bodek and S. Olsen and investigated 3 rates in e^+e^- hadronic events. The values of α_s were extracted at AMY energies. Figure 2 shows the values of α_s extracted from 3 jet data for all e^+e^- data. The running of α_s as a function of energy as expected in QCD is observed. Note that since these analyses are limited by theoretical uncertainties, the AMY errors are similar to the errors from LEP.

T. Kumita's thesis, under the supervision of A. Bodek, investigated possible deviations of the data on Rhadron from the standard model in the total hadronic cross section in e^+e^- events (Rhadron). At first, it looked like a larger than expected value of Rhadron was due to a possible existence of a Z' boson. However, our Z' analysis of the CDF e^+e^- data (Rochester Ph.D. thesis work being done by M. Pillai) rules out such an interpretation. The larger than expected values of Rhadron could not be explained, but the effect is of the order of 2 deviations. Data for Rhadron measured at LEP also is higher than expected. The result is that values of the strong coupling α_s extracted from Rhadron data in all e^+e^- experiments are larger than the values of α_s extracted from other techniques. This is not presently understood.

Figure 3 shows the value of α_s extracted to the Z mass from several processes. There are 5 results from different Rochester experiments: two results from our CCFR neutrino experiment (from XF3 and F2), one result obtained from BCDMS combined with our SLAC data. The other two results are from Y. K. Li's thesis on AMY 3 jet events, and the result from Rhadron at AMY. Note that all the results are consistent with each other, except the results from Rhadron at AMY and LEP (Z hadronic width). See also figure D-9 from the neutrino section of this report.

Fig. 1 Ratio of observed $\gamma\gamma$ events to the QED prediction. The solid curve is the QED prediction, with $\chi^2/\text{d.o.f.} = 0.68$ for 8 degrees of freedom and a normalization of 0.961. The dashed curve is the maximum likelihood prediction, with $\chi^2/\text{d.o.f.} = 0.47$ for 5 degrees of freedom and a normalization of 0.955.

Measurements from Jet Production Rates

Fig. 2: Energy (E_{cm}) dependence of α_s from different experiments.

Fig. 3: Strong coupling strength α_s at the mass scale of M_Z from determination using different experimental processes. The dot line is through the value determined using NLL model by AMY.

Activities, Talks, Publications, and Preprints 1992-93

The activities of the PI's for tasks F, G and J (Bodek and Tipton) are given in the introduction section). Here we present the activities of the other faculty, staff and graduate students.

Dr. B. Winer has served as the secretary of the plug physics subgroup. He is also on the CDF internal review committee for the most recent b -cross section analysis. He has presented a talk on the experimental search for the top quark to the AAPT Conference at SUNY Brockport in April, 1992. He gave a seminar at Michigan State University entitled "Status of the CDF Top Search" in April of 1993. He has given two major presentations at the Fall 1992 and Spring 1993 CDF Collaboration meetings on the top quark search. He will be presenting the results of the CDF top search at the Physics in Collision conference at Heidelberg in June, 1993.

Dr. R. Hughes is the head of the SVX tracking group for CDF. He has also made major presentations at the last two CDF Collaboration meetings. Hughes presented a status report on the CDF top search at the Aspen conference, Jan., 1993.

Dr. P. de Barbaro presented results on hadron calorimeters using hanging file data at the SDC Collab. Meeting at Pisa, Italy (1/92) and at the APS Meeting in Washington, DC (4/93). He gave a talk on beam tests of a reconfigurable-stack calorimeter at the DPF/APS Meeting (11/92) at Fermilab, and presented optics studies for the SDC hadron calorimeter at the calorimetry workshops at SSCL (10/92 and 12/92) and at Fermilab (4/93). Dr. de Barbaro also gave the main report on the plug upgrade project at the general CDF meeting in Oct. of 1992.

Mr. Manoj Pillai is a Ph.D. thesis student on CDF and his thesis topic is search for Z' Bosons using CDF data from runs 1A and 1B. He presented preliminary results on Z' searches at CDF using run 1A data at the Washington APS meeting (4/93). Mr. Mark Dickson and Mr. Fan Qun are Ph.D. thesis students on CDF and their topic is the measurement of the W production asymmetry from CDF data in runs 1A and 1B respectively. Mr. Dickson presented preliminary results on W asymmetry data from run 1A at the APS meeting in Washington DC (4/93). Mr. Gordon Watts is doing his Ph.D. thesis on the search for the top quark using the SVX detector using data from run 1A. He presented a talk on using the SVX detector for B tagging in the top quark search at the APS meeting (4/93).

Dr. Howard Budd is serving as the coordinator for the Plug Electromagnetic Calorimeter during the 1993 data run, and is also the local person in charge of the construction of plug upgrade hadron calorimeter (when Prof. Bodek is at Rochester). Drs. Budd and de Barbaro are in charge of scintillator megatile module assemblies at FNAL lab 5, and Dr. W. Sakumoto and Mr. M. Olsson are in charge of the cutting and grooving and gluing of scintillator megatiles in FNAL Lab 8.

On the AMY project, Mr. T. Kumita has received his Ph.D. and has taken a position at the Tokyo Cosmic Ray Institute. Mr. Y. K. Li has also received his Ph.D. and has taken a position at Northwestern University. Mr. Li presented his results on the extraction of the strong coupling from e^+e^- data on jets at Northwestern and Yale and at the DPF conference at Fermilab (11/92). There are two remaining Rochester thesis topics to be completed on AMY by B. J. Kim, and C. Velissaris on the subject of photon structure functions extracted from 2-photon e^+e^- interactions.

1992 CDF Publications - Tasks F and G

1. **Inclusive $J/\psi, \psi$ (2S) and B Quark Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **69** 3704, 1992.
2. **Search for Squarks and Gluinos from $\bar{p}p$ at $\sqrt{s} = 1.8$ -TeV.** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **69** 3439, 1992.
3. **Limit on the Rare Decay $W^{+-} \rightarrow \gamma \pi^{+-}$ in $\bar{p}p$ Collisions $\sqrt{s} = 1.8$ -TeV.** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **69** 2160, 1992.
4. **The Dijet Angular Distribution in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ -TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **69** 2896, 1992.
5. **Limits on the Production of Massive Stable Charged Particles** By CDF Collaboration (F. Abe, et al.), Phys. Rev. **D46** 1889, 1992.
6. **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** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **69** 28, 1992.
7. **Measurement of the Isolated Prompt Photon Cross-Sections in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV,** F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. **68**, 2734 (1992).
8. **A Measurement of the B Meson and the b-quark Cross Sections at $\sqrt{s} = 1.8$ TeV Using the Exclusive Decay $B^+ \rightarrow \psi K^+$,** F. Abe et al. Phys. Rev. Lett. **68**, 3403 (1992).
9. **Measurement of the Ratio $\sigma_B(W \rightarrow \tau \text{ Neutrino}) / \sigma_B(W \rightarrow e \text{ Neutrino})$, in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ -TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **68** 3398 (1992).
10. **Measurement of the Isolated Prompt Photon Cross-Sections in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **68** 2734, 1992.
11. **A Measurement of the B Meson and B Quark Cross-Sections at $\sqrt{s} = 1.8$ TeV Using the Exclusive Decay $B^{+-} \rightarrow J/\psi K^{+-}$** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **68** 3403, 1992.
12. **Measurement of the Ratio $\sigma_B(W \rightarrow \tau \text{ Neutrino}) / \sigma_B(W \rightarrow e \text{ Neutrino})$, in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. Lett. **68** 3398, 1992.
13. **A Limit on the Top Quark Mass from $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV,** F. Abe et al. (CDF Collaboration), Phys. Rev. **D45** 3921 (1992).

14. **Lepton Asymmetry in W decays from $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV**, F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. 68, 1458 (1992).
15. **Properties of Events with Large Total Transverse Energy Produced in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. D45 2249 (1992).
16. **A Search for New Gauge Bosons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV**, F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. 68, 1463 (1992).
17. **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. (CDF Collaboration), Phys. Rev. Lett. 68, 447 (1992).
18. **The Topology of Three Jet Events in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), Phys. Rev. D45 1448, 1992.
19. **Inclusive Jet cross-Section in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV**, F. Abe et al. (CDF Collaboration) Phys. Rev. Lett. 68, 1104 (1992).

1993 Publications, Preprints, and Internal Reports

20. **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.
21. **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.
22. **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.
23. **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.
24. **A Measurement of Jet Multiplicity in W Events 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 25, 1993.
25. **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.

26. **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.
27. **Measurement of the Cross-Section for Production of Two Isolated Prompt Photons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), FERMILAB-PUB-92-380-E, Dec 1992. 18pp. Submitted to Phys.Rev.Lett.
28. **A prompt Photon Cross-Section Measurement in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), ANL-HEP-PR-93-09, n.d. (recd Mar 1993) 95pp.
29. **Comparison of Jet Production in $\bar{p}p$ Collisions at $\sqrt{s} = 546$ GeV and 1800 GeV** By CDF Collaboration (F. Abe, et al.), FERMILAB-PUB-92-286-E, Oct 1992. 20pp. Phys. Rev. Lett. 70:1376, 1993.
30. **Search for $\lambda(B) \rightarrow J/\psi \lambda$ in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), FERMILAB-PUB-92-250-E, Sep 1992. 17pp. Submitted to Phys. Rev. Lett.
31. **A Measurement of Jet Shapes in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV** By CDF Collaboration (F. Abe, et al.), FERMILAB-PUB-92-167-E, Jun 1992. 16pp. Phys. Rev. Lett. 70:713, 1993.
32. **Operation of the CDF Silicon Vertex Detector with Colliding Beams at Fermilab** By F. Bedeschi, et al, FERMILAB-CONF-92-263-E, Oct 1992. 7pp. To be published in the proceedings of 26th International Conference on High Energy Physics (ICHEP 92), Dallas, TX, 6-12 Aug 1992.
33. **CDF 2027 Non-W Backgrounds in W+Jet Events**, R. Hughes, P. Koehn, N. Mark Shaw, P. Tipton, G. Watts, B. Winer
34. **CDF 2020 3/26/93 Preliminary Look at the W Decay Asymmetry**, Dickson et al
35. **CDF 2018 A search for New Gauge Bosons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV**, M. Pillai et al
36. **CDF 1959 Status of the Search for Top Quark Using an SVX B-tag in L+Jets**, R. Hughes, P. Koehn, N. Mark Shaw, P. Tipton, G. Watts, B. Winer
37. **CDF 1957 2/19/93 Tale of Two Triggers: Status of the Plug Isolation Trigger**, M. Dickson et al
38. **CDF 1956 The Cone Tagging Algorithm**, G. Watts, R. Hughes, P. Koehn, N. Mark Shaw, P. Tipton, B. Winer

39. **CDF1876 Kinematic Variables in W + Jet and Heavy Top Events**, B. Winer and P. Koehn
40. **CDF 1777 10/16/92 Testbeam 1991: Determination of the PEM Response MAP**, M. Dickson et al
41. **CDF 1707 3/20/92 Classification of Jets from $\bar{p}p$ Collisions at Tevatron Energies**, M. Dickson et al
42. **CDF 1706 3/20/92 Quark/Gluon Discrimination at CDF Using Neural Networks**, M. Dickson et al

CDF/SDC Tile Fiber R&D (Task G and J) publications 1992

1. **A Scintillating Fiber Detector for Electron and Photon Identification at High Luminosity Colliders**, J. Hauser et. al., Nucl. Inst. Meth. **A321**, 497 (1992).
2. **Research and Development Results on Scintillating Tile Fiber Calorimetry for the CDF and SDC Detectors** P. de Barbaro, et al. UR-1229, Aug 1991. Proceedings of the 5th Pisa Meeting on Advanced Detectors. Nucl. Inst. Meth. **A315**, 317 (1992).
3. **The CDF Upgrade Calorimeter**, J. Freeman et al. FNAL conf 92/07. Presented at the 2nd International Conference on Calorimetry, Capri Oct. 91, published in 92.

CDF Tile/Fiber and SSC/SDC R&D Papers to be Published 1993, Preprints and Reports

4. **Recent R&D Results on Tile/Fiber Calorimetry**, P. deBarbaro et al., UR-1299 (Jan 1993), SDC-93-407.
 5. **The Effects of Tile Miscalibration on the Performance of Tile/Fiber Based Hadron Calorimeter**, P. deBarbaro, A. Bodek and B. Winer, UR-1301 (Jan 1993).
 6. **A Study of the Energy Dependence of the Most Probable Energy Deposition of High Energy Muons in Sampling Calorimeters**, M. Pillai et al. UR-1302(April 1993), to be submitted to Nucl. Inst. Meth. Also presented at the March 93 APS meeting, Washington DC (Bull. Am. Phys. Soc. 1993).
 7. **Beam Tests of Composite Calorimeter Configurations from Reconfigurable-Stack Calorimeter**, A. Beretras et al. to be published in NIM 1993.
 8. **The SDC Collaboration, Technical Design Report SDC-92-201, SSCL-SR-1215** (April 1992).
 9. **The CDF Plug Upgrade Calorimeter, Technical Design Report** (1993).
- AMY (Task F) Publications 1992**

1. **Evidence for Hard Scattering of Hadronic Constituents of Photons in Photon-Photon Collisions at TRISTAN** By AMY Collaboration (R. Tanaka, et al.), KEK-PREPRINT-91-14, Apr 1991. Phys. Lett. **B277**,215 (1992)

AMY Articles (Task F) to be published in 1993, Preprints and Reports

2. **Search for Anomalous Gamma-Gamma Production at TRISTAN**, By AMY Collaboration (K.L. Sterner, et al.), VPI-IHEP-93-2, Feb 1993. Phys. Lett. **B303**,385 (1993)
3. **Tests of Models for e^+e^- Annihilation into Hadrons and Leptons**, Tetsuro Kumita, UR-1282 (Oct. 1992), Ph.D. Thesis, supervised by A. Bodek
4. **Determination of the Strong Coupling Alphas from Jet Production Rates in e^+e^- Annihilation at TRISTAN Energies**, Yue Kuan Li, UR-1307 (March 1993), Ph.D. Thesis, supervised by S. Olsen and A. Bodek.

Task A: III. Theoretical Physics

Introduction:

The high energy theory group at the University of Rochester presently consists of four faculty (Professors A. Das, C. R. Hagen, S. Okubo and S. Rajeev), one Senior Research Associate (Dr. V. S. Mathur), two Research Associates (Drs. K. Gupta and Z. Yang) and five graduate students (P. Bedaque, S. Guruswamy, R. Henderson, I. Horvath and T. Turgut). Mr. I. Horvath is pursuing his research under the supervision of Prof. M. Creutz at the Brookhaven National Laboratory. Dr. K. Gupta joined our group in Fall 1992 when our earlier Research Associate Dr. Y. Liang left for a job in the computer industry. Dr. Z. Yang will be leaving the group at the end of August 1993. Two of our graduate students, G. Ferretti and W-J. Huang, graduated in the spring of 1993 and have gone on to post doctoral positions in Sweden (Institute for Theoretical Physics, Göteborg) and Taiwan (Tsing Hua University) respectively. In the past year, we also had a visitor, Dr. C. A. P. Galvao, from CBPF (Brazil) with financial support from the Brazilian Government.

In the Fall of 1993, Professor Lynne Orr will be joining our group as a tenure track faculty. Her expertise in phenomenology nicely complements the more theoretical interests of the other members of the group. We would also be joined in the Fall of 1993 by three visitors – Drs. D. K. Park (from Korea), J. Brunnelli and M. Hott (from Brazil). The visitors will be supported financially through their respective Governments.

The main research interests of our group broadly fall into the following areas.

1. Field Theory
2. Integrable Models
3. Mathematical Physics
4. $2 + 1$ dimensional Field Theory
5. Conformal Field Theory
6. Lattice Field Theory
7. Phenomenological Studies

In what follows, we list the publications by the members during 1992-1993 and describe briefly the future plans for research.

Published Works During 1992-1993:

1. Conformal Edge Currents in Chern-Simons Theories
A. P. Balachandran, G. Bimonte, K. S. Gupta, and A. Stern
Int. Jour. Mod. Phys. **A7**, 4655 (1992).

2. The Chern-Simons Source as a Conformal Family and its Vertex Operators
A. P. Balachandran, G. Bimonte, K. S. Gupta, and A. Stern
Int. Jour. Mod. Phys. **A7**, 5855 (1992).
3. On the Bihamiltonian Structures of the sKdV
J. Barcelos-Neto and A. Das
Jour. Math. Phys. **33**, 2743 (1992).
4. The Zero Curvature Formulation of the KP and the sKP Equations
J. Barcelos-Neto, A. Das, S. Panda, and S. Roy
Phys. Lett. **B282**, 365 (1992).
5. Two Dimensional Baryons in the Large N Limit
P. F. Bedaque, I. Horvath, and S. G. Rajeev
Mod. Phys. Lett. **A7**, 3347 (1992).
6. On the Zero Momentum Limit of Feynman Amplitudes at Finite Temperature
P. F. Bedaque and A. Das
Phys. Rev. **D45**, 2906 (1992).
7. On the Zero Momentum Limit of Feynman Amplitudes at Finite Temperature
P. F. Bedaque and A. Das
Proceedings of the 12th MRST Meeting, ed. P. J. O'Donnell (1992).
8. Feynman Parametrization and the Degenerate Electron Gas
P. F. Bedaque and A. Das
Phys. Rev. **D47**, 601 (1993).
9. Path Integral and Operator Approach for the Podolsky-Schwinger Model
L. Belvedere, C. A. P. Galvao, and C. P. Natividade
Z. Phys. **C56**, 609 (1992).
10. Edge Currents and Vertex Operators for Chern-Simons Gravity
G. Bimonte, K. S. Gupta, and A. Stern
Int. Jour. Mod. Phys. **A8**, 653 (1993).
11. Zero Curvature Condition and 2-D Gravity Theories
A. Das, W. J. Huang, and S. Roy
Int. J. Mod. Phys. **A7**, 3447 (1992).
12. Zero Curvature Condition of $OSp(2/2)$ and the Associated Supergravity Theory
A. Das, W. J. Huang, and S. Roy
Int. J. Mod. Phys. **A7**, 4293 (1992).
13. Temperature Dependent Anomalous Statistics
A. Das and S. Panda
Jour. Phys. **A25**, L245 (1992).

14. The Super W_∞ Symmetry of the Manin-Radul Super KP Hierarchy
A. Das, E. Sezgin, and S. J. Sin
Phys. Lett. **B277**, 435 (1992).
15. The Hamiltonian Structures Associated with a Generalized Lax Operator
A. Das and W. J. Huang
Jour. Math. Phys. **33**, 2487 (1992).
16. A Note on Supersymmetric Gelfand-Dikii Brackets
A. Das and W. J. Huang
Mod. Phys. Lett. **A7**, 2159 (1992).
17. Self-duality in $3 + 3$ Dimensions and the KP Equation
A. Das, E. Sezgin, and Z. Khviengia
Phys. Lett. **B289**, 347 (1992).
18. Chiral Symmetry Breaking in Matrix Quantum Mechanics
G. Ferretti
Phys. Lett. **B284**, 325 (1992).
19. $CP^{(N-1)}$ Model with a Chern-Simons Term
G. Ferretti and S. G. Rajeev
Mod. Phys. Lett. **A7**, 2087 (1992).
20. Baryons as Solitons in Three Dimensional Quantum Chromodynamics
G. Ferretti, S. G. Rajeev, and Z. Yang
Int. J. Mod. Phys. **A7**, 8001 (1992).
21. The Effective Lagrangian of Three Dimensional Quantum Chromodynamics
G. Ferretti, S. G. Rajeev, and Z. Yang
Int. J. Mod. Phys. **A7**, 7989 (1992).
22. Current Algebra in Three Dimensions
G. Ferretti and S. G. Rajeev
Phys. Rev. Lett. **69**, 2033 (1992).
23. Three Dimensional Quantum Chromodynamics
G. Ferretti, S. G. Rajeev, and Z. Yang
Proceedings of the XXVI International Conference on High Energy Physics Published
by the American Institute of Physics, Dallas, TX Aug. 5-12, 1992.
24. Detecting the Higgs Bosons of the Minimal Supersymmetric Model
J. F. Gunion and L. H. Orr
Phys. Rev. **D46**, 2052 (1992).

25. Two Dimensional Quantum Chromodynamics on a Cylinder
S. Guruswamy and S. G. Rajeev
Mod. Phys. Lett. **A7**, 3783 (1992).
26. Parity Conservation in Chern-Simons Theory and the Anyon Interpretation
C. R. Hagen
Phys. Rev. Lett. **68**, 3821 (1992).
27. Topology in Quantum Mechanics in Quantum Non-Integrability
Y. Liang
eds. D. H. Feng and J. M. Yuan, World Scientific, 1992.
28. Translation-Invariant Backgrounds in 1 + 1 Dimensional String Theory
D. Minic, J. Polchinski, and Z. Yang
Nucl. Phys. **B360**, 324 (1992).
29. Is $S = 1$ for $c = 1$?
D. Minic and Z. Yang
Phys. Lett. **274B**, 27 (1992).
30. Nijenhuis-Bianchi Identity and BRST-like Operator
S. Okubo
Jour. Math. Phys. **33**, 895 (1992).
31. Continuous Integrable Systems with Multi-Poisson Brackets
S. Okubo
Jour. Math. Phys. **33**, 2080 (1992).
32. Existence of Gauge Field in Any Partially Integrable Systems
S. Okubo
Jour. Math. Phys. **33**, 2148 (1992).
33. Argument for the Non-existence of the String CP Problems in QCD
S. Okubo and R. E. Marshak
Prog. Theor. Phys. **87**, 1059 (1992).
34. Gluon Radiation in Top Quark Production and Decay
L. H. Orr, V. A. Khoze, and W. J. Stirling
Perturbative QCD and Hadronic Interactions, Proceedings of the XXVIIth Rencontres de Moriond, Les Arcs, France, March 22-28, 1992, ed. J. TrnTanh Vn, Editors Frontieres, Gif-sur-Yvette (1992) 241.
35. High Temperature Partition Function of the Rigid String
J. Polchinski and Z. Yang.
Phys. Rev. **D46**, 3667 (1992).

36. Non-commutative Generalizations of Yang-Mills Theory
S. G. Rajeev
Proceedings of the Joint Lepton-Photon Symposium and Europhysics Conference on High Energy Physics, ed. S. Hegarty, K. Potter and E. Quercigh World Scientific, Singapore, (1992).
37. Anomalous Scaling of Strong Interactions at Low Energies
S. G. Rajeev
1991 Summer School on High Energy Physics and Cosmology, ed. E. Gava, K. Narain, S. Randjbar-Daemi, E. Sezgin and Q. Shafi, World Scientific, Singapore, (1992).
38. Two-dimensional Meson Theory
S. G. Rajeev
1991 Summer School on High Energy Physics and Cosmology, ed. E. Gava, K. Narain, S. Randjbar-Daemi, E. Sezgin and Q. Shafi, World Scientific, Singapore, (1992).
39. Effective Superstrings
Z. Yang
Nucl. Phys. **B377**, 528 (1992).
40. A Remark on Conformal Anomaly and Extrinsic Geometry of Random Surfaces
Z. Yang
Phys. Lett. **270B**, 47 (1992).
41. $C = 1$ Matrix Model and Black Holes
Z. Yang
Proceedings of the 14th Annual MRST Meeting, ed. P. J. O'Donnell (1992).
42. A Note on "Anomalous" Chiral Gauge Theories
Z. Yang
Phys. Lett. **B206**, 151 (1992).

Works (during 1992-1993) Submitted or to Appear:

1. Neutron Acceleration in Uniform Electromagnetic Fields
J. Anandan and C. R. Hagen
to be published in Aharonov's 60th birthday volume.
2. Neutron Acceleration in Uniform Electromagnetic Fields
J. Anandan and C. R. Hagen
submitted to Phys. Rev. Lett.

3. On the Analytic Structure of the Self-Energy for Massive Gauge Bosons at Finite Temperature
P. Arnold, P. Bedaque, A. Das, and S. Vokos,
to be published in Phys. Rev. D.
4. Current Algebra and Conformal Field Theory on a Figure Eight
A. P. Balachandran, G. Bimonte, K. S. Gupta, G. Marmo, P. Salomonson, A. Simoni
and A. Stern
submitted for publication in Int. Jour. Mod. Phys.
5. δ -Expansion and Self-Consistent Calculation
P. F. Bedaque and A. Das
submitted to Phys. Rev. D.
6. Nonleptonic Two Body Decays of Charmed Mesons
P. F. Bedaque, A. Das and V. S. Mathur
(in preparation).
7. Series Expansion without Diagrams
G. Bhanot, M. Creutz, I. Horvath, J. Lacki and J. Weckel
submitted to Phys. Rev. E.
8. Low Temperature Expansions for Potts Models
G. Bhanot, M. Creutz, U. Glassner, I. Horvath, J. Lacki, K. Schilling and J. Weckel
submitted to Phys. Rev. E.
9. Self-Duality and the KdV Hierarchy
A. Das and C. A. P. Galvão
to be published in Mod. Phys. Lett. A.
10. Self-Duality and the Supersymmetric KdV Hierarchy
A. Das and C. A. P. Galvão
to be published in Mod. Phys. Lett. A.
11. Nonleptonic Decays of Charmed Mesons into Two Pseudoscalar Mesons
A. Das and V. S. Mathur
submitted to Mod. Phys. Lett. A.
12. Properties of Soft Radiation Near $t\bar{t}$ and W^+W^- Threshold
Yu. L. Dokshitzer, V. A. Khoze, L. H. Orr, and W. J. Stirling
to be published in Nucl. Phys. B.
13. Soft Photons in W^+W^- Production at LEP 200
Yu. L. Dokshitzer, V. A. Khoze, L. H. Orr, and W. J. Stirling
submitted to Phys. Lett. B.

14. **Magnetic Fields and Passive Scalars in Polyakov's Conformal Turbulence**
G. Ferretti and Z. Yang
to be published in *Europhysics Lett.*
15. **The Classical Electromagnetic Theory Corresponding to the Massless Two-Dimensional Spinor Quantum Electrodynamics**
C. A. P. Galvao and Juan A. Mignaco
submitted to *Int. J. Mod. Phys.*
16. **MSSM Higgs Bosons at Future Hadron Colliders**
J. F. Gunion and L. H. Orr
Proceedings of Physics Beyond the Standard Model III, Ottawa, Canada, June 22-24, 1992, to be published by World Scientific.
17. **MSSM Parameters and Higgs Detectability**
J. F. Gunion and L. H. Orr
(in preparation).
18. **Heavy Quark Solitons**
K. S. Gupta, M. A. Momen, J. Schechter and A. Subbaraman
to be published in *Phys. Rev. D Rapid Communications*.
19. **Spherical Quantum Chromodynamics of Heavy Quark Systems**
K. S. Gupta, S. Guruswamy and S. G. Rajeev
submitted for publication in *Phys. Rev. D*.
20. **Comment on "Gauge Independent Analysis of Chern-Simons Theory with Matter Coupling"**
C. R. Hagen
to be published in *Phys. Rev. Lett.*
21. **Comment on "Disassembling Anyons"**
C. R. Hagen
submitted to *Phys. Rev. Lett.*
22. **Comment on "Attractive Forces Between Electrons in 2 + 1 Dimensional QED"**
C. R. Hagen
submitted to *Phys. Rev. Lett.*
23. **Aharonov-Bohm Cross Sections as a Consequence of Symmetry Breaking**
C. R. Hagen
submitted to *Phys. Rev. D*.
24. **Comment on "Operator Algebra in Chern-Simons Theory on a Torus"**
C. R. Hagen and E. C. G. Sudarshan
submitted to *Phys. Rev. Lett.*

25. Aharonov-Bohm Cross Sections as a Consequence of Symmetry Breaking
C. R. Hagen
submitted to Phys. Rev. D.
26. BRST Operator Supermanifold with Zero Curvature Tensor
W. J. Huang
University of Rochester preprint UR-1265.
27. Super Nijenhuis-Bianchi Identity and BRST-like Operator on Supermanifold
W. J. Huang
(in preparation).
28. Soft Gluon Radiation in Hadronic $t\bar{t}$ Production
V. A. Khoze, J. Ohnemus, L. H. Orr, and W. J. Stirling
(in preparation).
29. Lattice Calculations of Glueball Matrix Elements
Y. Liang, et al.
to be published in Phys. Lett. B.
30. New Properties of the Non-Abelian Anomaly
Y. Liang
to be published in Festschrift for Prof. Luis Witten.
31. A Modified Gerasimov-Drell-Hearn Sum Rule from Extended Current Algebra
Y. Liang
submitted for publication.
32. Triple Products and Yang-Baxter Equation: (I) Octonionic and Quaternionic Triple Systems
S. Okubo
to be published in Jour. Math. Phys.
33. Triple Products and Yang-Baxter Equation: (II) Orthogonal and Symplectic Ternary Systems
S. Okubo
to be published in Jour. Math. Phys.
34. Top Width Effects in Soft Gluon Radiation
L. H. Orr, Yu. L. Dokshitzer, V. A. Khoze, and W. J. Stirling
Proceedings of 1992 Meeting of the Division of Particles and Fields of the American Physical Society, Batavia, IL, Nov. 1992, to be published by World Scientific.
35. Asymptotic Freedom and String Theory
Z. Yang
submitted to Phys. Rev. Lett.

In addition, there are three books written by various members of the group which will be published in 1993.

1. Field Theory: A Path Integral Approach
A. Das
World Scientific Publishing (1993).
2. Introduction to Nuclear and Particle Physics
A. Das and T. Ferbel
John Wiley (1993).
3. Introduction of Octonion and Other Non-Associative Algebras in Physics
S. Okubo
Cambridge University Press (1993).

List of Seminars During 1992-1993:

A. Das

Apr 11 1992	SUNY at Brockport Beyond the Standard Model
Apr 21 1992	Texas A&M Hamiltonian Structures for a Generalized Lax Operator
June 24 1992	Argonne National Laboratory Introduction to Gelfand-Dikii Brackets
July 15 1992	Physical Research Laboratory, India A Geometrical Approach to Integrable Models
July 17 1992	Physical Research Laboratory, India Integrable Models and Spin Algebras
July 21 1992	Physical Research Laboratory, India Introduction to Gelfand-Dikii Brackets
July 24 1992	Physical Research Laboratory, India Integrable Models and 2D Gravity Theories
Aug 8 1992	Institute of Physics, India Introduction to Gelfand-Dikii Brackets
Dec 10 1992	University of Barcelona, Spain On the Feynman Parameterization

Dec 17 1992	University of Zaragoza, Spain Self-Duality and Integrable Systems
<u>P. Bedaque</u>	
May 1992	14th Annual MRST Meeting, Toronto On the Zero Momentum Limit of Feynman Amplitudes at Finite Temperature
<u>G. Ferretti</u>	
Feb 8 1993	Syracuse University Conformal Turbulence with Magnetic Fields
Mar 5 1993	University of California at Davis Three Dimensional Quantum Chromodynamics and its Cur- rent Algebra
<u>K. Gupta</u>	
Feb 1992	University of Illinois at Urbana-Champaign Chern-Simons Theory and the Quantum Hall Effect
May 1992	Trinity College, Ireland Edge Currents and Vertex Operators in Chern-Simons The- ory
July 1992	Indian Institute of Science, India Edge Currents, Vertex Operators and the Quantum Hall Effect
May 13, 1993	15th Annual MRST Meeting, Syracuse University Spherical QCD of Heavy Quark Systems
<u>C. R. Hagen</u>	
Dec 1 1992	University of Rochester Wave Packet Approach to the Electromagnetic Acceler- ation of Neutral Particles
Dec 19 1992	University of South Carolina Neutron Acceleration in Uniform Electromagnetic Fields

Y. Liang

- May 1992 14th Annual MRST Meeting, Toronto
A Modified Gerasimov-Drel-Hearn Sum Rule from Extended
Current Algebra
- June 1992 '92 at Yale University, New Haven
A Modified Gerasimov-Drel-Hearn Sum Rule from Extended
Current Algebra

S. Okubo

- Aug 2 1992 Symposium in Honor of L. C. Biedenharn, Bregenz, Austria
Yang-Baxter Equation and Triple Product System
- May 14 1993 15th Annual MRST Meeting, Syracuse University

L. H. Orr

- Oct 19 1992 Florida State University, Tallahassee
- Jan 11 1993 University of California, Davis
- Feb 1 1993 Syracuse University
- Feb 2 1993 University of Rochester
- Feb 24 1993 University of California, Riverside
- Mar 15 1993 Iowa State University
- Mar 22 1993 University of Rochester
- May 12 1993 Stanford Linear Accelerator Center

S. G. Rajeev

- July 1992 University Naples, Italy
Three Dimensional QCD
- July 1992 University of Naples, Italy
Introduction to Quantum Groups and Poisson Lie Groups
- July 1992 ICTP and SISSA, Trieste, Italy
Three Dimensional QCD
- Aug 1992 XXVIth International Conference on HEP, Dallas
Three Dimensional QCD and Current Algebra

Nov 1992	University of Rochester The Enigma of Strong Interactions
Feb 1993	University of Cincinnati Spherical Quantum Chromodynamics
Feb 1993	University of Iowa Strong Interactions
Feb 1993	Syracuse University Two Dimensional QCD
Mar 1993	University of Rochester Strong Interactions
<u>Z. Yang</u>	
Mar 2 1992	Syracuse University Conformal Anomaly and Extrinsic Geometry of Random Surfaces
Apr 1992	University of Rochester Lectures on the Recent Developments of Black Hole Physics
May 7 1992	MRST Meeting $C = 1$ Matrix Model and Black Holes
Aug 6 1992	XXVI International Conference on HEP, Dallas High Temperature Partition Function of the Rigid String
Jan 8 1993	University of Florida High Energy Behaviors of Rigid and Dirichlet String Theories
Jan 22 1993	Cornell University Strings and QCD
Feb 5 1993	University of Maryland at College Park Strings and QCD

Future Research Plans:

Here is a brief summary of the research projects being carried out currently by the different members of the group.

A. Das

We are currently involved in studying various questions associated with the dynamics of a phase transition such as in the quark-gluon plasma. We are also studying the noncompact symmetries which arise upon dimensional reduction of a type II string. A systematic and detailed analysis of the heavy meson (charmed) decays is being carried out. In addition, we are also interested in various questions in $2 + 1$ dimensional integrable systems.

K. Gupta

We are continuing with our analysis of edge current oscillations in mesoscopic networks. With S. Rajeev we are studying various questions associated with nonperturbative renormalization as well as large N_C expansion in $2 + 1$ dimensional QCD. We are also investigating the decay of mesons in a relativistic string model.

C. R. Hagen

We are investigating the question of flux quantization in nonrelativistic Chern-Simons solitons. With Dr. J. Anandan at the University of South Carolina, we are studying the acceleration of neutrons in uniform electric and magnetic fields. Our work on AB effect for a spin $1/2$ particle is being generalized to include spin effects. With Dr. E. C. G. Sudarshan at the University of Texas, Austin, we are studying the nonintegrable phases of Wilson lines for various cases. In addition, with Dr. L. P. S. Singh, we are analyzing the g -factor for a spin S particle in $2 + 1$ dimensions.

V. S. Mathur

With P. Bedaque and A. Das, we are carrying out a systematic study of all two body decays of charmed mesons using pole dominance model. With A. Das, we plan to study the effective Lagrangians. In particular, we would like to obtain an effective Lagrangian for weak interactions in terms of hadronic degrees of freedom.

S. Okubo

We are continuing with our investigation of the Yang-Baxter equation in some new triple systems.

L. Orr

We are continuing our study of top phenomenology. With Y. Dokshitzer, V. Khoze, J. Ohnemus and W. Stirling, we are investigating the effects of top width on gluon distribution as well as the question of measurement of the top mass. We are also involved in studying various questions with the Higgs phenomenology. With J. Gunion, we are analysing the various prospects for detecting the Higgs boson of the Minimal Supersymmetric Standard Model. With J. Gunion and F. Olness, we are also analyzing the phenomenological implications of a strongly interacting electroweak symmetry breaking sector without a fundamental Higgs. In addition, we are also interested in determining the QCD corrections to various differential cross-sections which will be quite useful from the experimental point of view.

S. Rajeev

We are studying various questions associated with nonperturbative renormalization as well as the large N_C expansion in $2 + 1$ dimensional QCD.

In addition, our student, Mr. I. Horvath who is currently working with Prof. M. Creutz at BNL, is involved in numerical investigations of lattice gauge theories and spin systems. In particular, they have proposed the use of series expansions as an efficient alternate to the diagrammatic expansion for numerical studies.

Appendix I: Construction of the Scintillating Tile-Fiber Plug Hadron Calorimeter for the CDF Upgrade – Design Report (Rochester responsibility)

Task G:

Faculty: Prof. A. Bodek and Sr. Research Associates: H. Budd and W. Sakumoto;
Research Associates: Drs. P. de Barbaro (50%), and B. Winer (50%)

Ph.D. Students: M. Dickson, Q. Fan, M. Pillai

Shop Engineer: T. Haelen; **Technician:** M. Olsson

Appendix I

CDF Plug Hadron Calorimeter Design

I.1 Introduction

In this document, we describe the design of the upgraded plug hadron calorimeter. Section I.2 gives the design criteria the hadron calorimeter. Section I.3 describes the design of the device. Section I.4 details the quality assurance tests which will be used during production to verify the performance of the device. Section I.5 describes the specific details, such as manpower and space requirements, of the production and installation of the calorimeter components. Section I.6 outlines how the energy calibration of the device will be preformed. Finally, Section I.7 gives the organization of manpower and responsibilities for the construction of the hadron detector. Much R&D has been performed leading up to the final design of the calorimeter and this R&D is described in detail in reference [1].

I.2 Design Criteria

The hadron calorimeter design is based upon a number of constraints. First, the upgraded hadron calorimeter will use the existing plug calorimeter steel with stainless steel inserts to extend the absorber down to 3° (see Mechanical Chapter for description of steel modifications). In addition, a more compact EM calorimeter allows two more absorber plates to be added in front of the existing hadron steel structure, bringing the total number of sampling layers to 22. Second, the the active detector components must fit into the modified steel structure. Figure I.1 is a cross sectional view of one endplug showing the steel plates and the 22 gaps for the scintillator. Six millimeter thick SCSN38 will be used for the scintillator and multiclاد 0.83 mm Kuraray Y11 wavelength shifting (WLS) fiber spliced to 0.83 mm Kuraray clear fiber will be used for readout.

Besides the mechanical constraints, there are also performance criteria for the detector. First, the calorimeter resolution should be approximately $80 - 90\%/\sqrt{E} \oplus 5\%$. This requirement has implication on the light yield since photostatistics must be folded into the intrinsic resolution due to sampling. Also, the 5% constant term requires that the variation

Figure I.1: A cross section of one endplug

η Tower	Eng. Tile ID	η Limits	$\Delta\phi$
0	17,18	1.200 - 1.317	7.5°
1	15,16	1.317 - 1.415	7.5°
2	13,14	1.415 - 1.523	7.5°
3	11,12	1.523 - 1.642	7.5°
4	9,10	1.642 - 1.777	7.5°
5	7,8	1.777 - 1.931	7.5°
6	5,6	1.931 - 2.111	7.5°
7	4	2.111 - 2.331	15°
8	3	2.331 - 2.611	15°
9	2	2.611 - 3.000	15°
10	1	3.000 - 3.643	15°

Table I.1: Segmentation for the Towers in the Plug Hadron Calorimeter. Note: η Tower 0 does not extend to the full depth. It only extends between layers 0 and 2.

of the tile-to-tile light yield must be better than about 10% and the transverse uniformity must be better than 5%. Second, the calorimeter should be able to clearly identify isolated muons. Finally, the $\eta - \phi$ segmentation should allow the physics topics, such b-physics, W,Z, and γ physics, and jet physics, to be done in an efficient and productive fashion. The segmentation is given in Table I.2 and shown in Figure I.2.

The hadron energy resolution is dominated by the sampling fluctuations from the existing 5.08 cm (2 in.) steel sampling rather than by photostatistics. For such sampling, the calibration of the calorimeter for hadron shower is about 0.1 GeV/mip/tile, and the intrinsic resolution is about $80\%/\sqrt{E}$. The contribution from photostatistics degrades the resolution to $86\%/\sqrt{E}$, $92\%/\sqrt{E}$, and $102\%/\sqrt{E}$ for the cases of 1, 0.5 and 0.25 photoelectrons (pe) per mip per tile respectively. Therefore, the resolution criteria requires that the light yield be approximately 1 photoelectron per minimum ionizing particle per tile.

Requiring muon identification with the calorimeter also puts strict requirements on the light yield. For 22 depth segments, we define an isolated muon as a particle with energy deposition less than +3 standard deviations and more than -2 standard deviations from the mean muon response. For the case of 1 pe per mip per tile (a muon with a mean of 22 pe 's), the window corresponds to an upper bound of 37 pe 's and a lower bound of 13.5 pe 's. For the case of 0.5 pe 's per mip per tile, the window corresponds to an upper bound of 22 pe 's and a lower bound of 5.5 pe 's. However, for the case of 0.25 pe 's per mip per tile, the window corresponds to an upper bound of 13 pe 's and a lower bound of 1 pe which is not acceptable. Therefore, muon identification also favors having 1 pe /mip/tile but 0.5 pe /mip/tile may be sufficient. Clearly, a light yield of 0.25 pe /mip/tile is too low.

The criteria of a resolution constant term less than a 5% implies that the rms of the

Figure I.2: The segmentation in a 30° section

spatial nonuniformity over the surface of the tile should be less than 4% (assuming the nonuniformity is the same for all tiles in a projective tower). On the other hand, an overall tile-to-tile light output variation of 10%, will only contribute 3% to the constant term because the hadron shower is typically spread out over more than 10 layers. The method for achieving the transverse and longitudinal uniformity is discussed in Section I.2.1 while the quality control procedures to assure the uniformity are discussed in Section I.4.

I.2.1 Achieving Light Yield Uniformity

The design criteria requires that tiles not only have transverse uniformity within the tile but also that the average response between tiles of different sizes be the same. We will use tiles with the sigma pattern for the fiber groove, as shown in Figure I.3. For the higher η tiles, where the sigma pattern could not be used, the fiber groove will have an "J" shape with alternate orientation for even and odd layers. The transverse uniformity of the tiles can be achieved by adjusting the depth of the fiber groove inside the tile. The optimal groove depth for 6 mm thick tiles is 100-120 mils. Figure I.4 (a) and (b) show a response scan of a hadron tile across the tile (a) and the distributions of the response (b). Using the above technique, we estimate the uniformity of individual tiles will be better than 4%.

Recent R&D results indicate [1] the light yield of the tile/fiber assemblies scales approximately as a function of L/A , where L is the length of the WLS fiber embedded inside the tile and A is the tile area. Due to the projective geometry of the towers, the value of the L/A parameter decreases for the tiles at the back of the calorimeter relative to the tiles at the front of the calorimeter. To compensate for this change in light yield, we introduce extra WLS outside the tile which is embedded inside the white plastic cover. The amount of extra WLS fiber decreases from the front (small tiles) to the back (large tiles) of the calorimeter. The attenuation of the light from the extra WLS fiber reduces the light yield of the smaller tiles. Table I.2 shows an example of relative light yield for tiles belonging to η Tower 4. The length of WLS fiber which equalizes the response of all towers is equal to the *total* length of WLS fiber for layer 21. Therefore, ideally, all tiles in a tower have the same length ($L_{in} + L_{out} = \text{constant}$, See Table I.2) of WLS fiber and the smaller tiles have more outside the tile. The above technique is applicable for all layers in η towers 4-8. For the first few layers in η Towers 1-3, there is not enough space in the white plastic to accommodate the full length of the WLS fiber. For this case, we will eliminate the green to clear fiber splice and adjust the tile light yield by changing the distance between the fiber groove and the tile's edge. Since the length (L) of the WLS fiber in the tile decreases with an increase of the distance between the fiber and the tile's edge, this leads to a decrease in the light yield. The combination of the two techniques, will also be used for η Towers 9 and 10. Finally, layer 6 which is the scintillator layer behind the 2.5 " plate also needs special attention. The light yield in this layer will be increased by 25% in order to compensate for the thicker absorber plate. This increase will be done by shortening the length of WLS fiber outside the tile.

Figure I.3: Fiber pattern on various tiles in a 30° section of scintillator

Figure I.4: Response of a 6 mm thick Tile a) Scan across center of tile and b) the distribution of responses

Table I.2: Relative Light Yield for η Tower 4 Tiles.

Layer #	D_{fr}	L_{in}	L_{out}	F_{WLS}	L_{cl}	F_{cl}	Y_i/Y_{21}
0	0.3	38.0	34.4	0.73	157.	0.82	1.01
1	0.3	39.4	32.9	0.74	150.	0.83	1.00
2	0.3	40.8	31.5	0.74	143.	0.83	0.99
3	0.3	42.3	30.1	0.75	137.	0.84	0.99
4	0.3	43.7	28.6	0.76	130.	0.85	0.98
5	0.3	45.2	27.2	0.77	123.	0.85	0.98
6	0.3	46.9	5.0	0.94	115.	0.86	1.18
7	0.3	48.3	24.0	0.78	108.	0.87	0.97
8	0.3	49.7	22.6	0.79	100.	0.88	0.97
9	0.3	51.2	21.1	0.80	92.	0.89	0.97
10	0.3	52.6	19.7	0.81	85.	0.90	0.97
11	0.3	54.0	18.3	0.82	77.	0.91	0.97
12	0.3	55.5	16.9	0.83	69.	0.91	0.97
13	0.3	56.9	15.4	0.84	62.	0.92	0.98
14	0.3	58.4	14.0	0.85	54.	0.93	0.98
15	0.3	59.8	12.5	0.87	46.	0.94	0.98
16	0.3	61.2	11.1	0.88	38.	0.95	0.99
17	0.3	62.7	9.7	0.89	31.	0.96	1.00
18	0.3	64.1	8.2	0.91	23.	0.97	1.00
19	0.3	65.6	6.8	0.92	15.	0.98	1.01
20	0.3	67.0	5.3	0.94	8.	0.99	1.02
21	0.3	67.3	5.0	0.94	0.	1.00	1.00

- Layer #: Layer Number. Inner most Layer = 0, Outer most Layer = 21.
- D_{fr} : Distance (cm) between fiber groove and the edge of the tile.
- L_{in}/L_{out} : Length of the WLS fiber inside/outside the tile.
- F_{WLS} : Correction factor in the light yield due to attenuation of light in WLS.

$$F_{WLS} = 0.2 \times \exp(-L_{out}/20 \text{ cm}) + 0.8 \times \exp(-L_{out}/240 \text{ cm})$$

- L_{cl} : Length of clear fiber cable between pan and back of the calorimeter.
- F_{cl} : Correction factor in the light yield due to attenuation in the clear fiber.

$$F_{cl} = 0.2 \times \exp(-L_{cl}/780 \text{ cm})$$

- Y_i/Y_{21} : Light Yield of layer relative to layer 21 after correction factors have been applied.

Figure I.5: A 30° sector of the Hadron Calorimeter

I.3 Plug Hadron Calorimeter Design

The design of the hadron calorimeter is shown in Figure I.5. The figure shows a 30° section of the calorimeter. The steel absorber plates, the active scintillator, and the protective packaging of the scintillator are shown.

I.3.1 The Megatile Concept

The hadron calorimeter needs a large number of towers, 432 per endcap, each with 22 layers of sampling. This implies that about 20,000 tiles must be constructed. In order to limit the number of individual elements, the tiles from a 30° ϕ section of a longitudinal layer are grouped into a single mechanical unit called a *megatile*. A megatile will have 36 (layers 0-2) or 32 (layers 3-21) tiles¹. In layer 3, the lowest η tower (tower 0) is added to the corresponding η tower 1 (See Figure I.1) The megatile along with the readout fibers will be packaged in aluminum pans, called *pizza pans*, which will be installed into the hadron steel (see Section I.5). A grand total of 594 pizza pan units will be constructed.

¹ η tower 0 (smallest $|\eta|$) does not extend to the full depth. It is shadowed by the wall hadron calorimeter

Figure I.6: Hadron Pan Cross Section

This includes 44 pans for the 60° test-beam module.

A cross section of the pizza pan unit is shown in Figure I.6. The unit begins with a bottom sheet of 0.063" thick aluminum. Then comes the 6 mm thick SCSN38 scintillator megatile covered on both sides with 6 mil thick, white, reflective Tyvek paper. The surface of the scintillator tiles are grooved to hold the wavelength shifting (WLS) fibers. Above the megatile is a 0.150" thick white polystyrene sheet. The fibers rise out of the scintillator through a narrow 2cm slot in the white plastic into grooves on the top side of the white plastic. The grooves route the fibers to the outside of the pan. The clear fibers run to an optical connector at the edge of the pan. Source calibration tubes, 1.27mm O.D., are placed on the bottom of the white plastic. There are four calibration tubes per megatile. Sheets of black, opaque Tedlar are used to wrap and light tight the combined scintillator and white plastic sheets. Finally, a second 0.090" aluminum cover is located on top to provide a complete protective package. The megatile unit is held together by 0.193" diameter rivets (screws).

I.3.2 Scintillator Milling and Glueing

The megatile will be constructed from plates of 6 mm (0.236") SCSN38 scintillator. The dimensions of the scintillator plates and the calorimeter layers cut from these plates are give in Table I.3.2. There will be 27 (24 for the two plugs + 2 for test beam module + 1) megatiles constructed for each layer.

The milling of the scintillator sheets will take place in several steps. First, a plate, with the protective paper removed from the side to be cut, will be positioned on the X-Y

Layers	# Size A	# Size B	# Size C
0+1	27		
2+3	27		
4+5	27		
6+7	23	4	
8+9		27	
10+11		27	
12+13		27	
14+15		27	
16+17		14	13
19+18			27
20+21			27
Spares		3	8
Total	104	129	75

Table I.3: Layer Cutting Scheme. Scintillator Sizes: Size A (143cm x 100cm). Size B (178cm x 128cm), Size C (195cm x 138cm)

milling table (Thermwood) and reference holes will be drilled to provide good alignment. A 35 mil bit will cut the tower separation grooves 226 mils into the scintillator leaving the last 10 mils uncut. The scintillator will be removed from the milling table and the separation grooves filled with white epoxy [1]. The epoxy provides optical separation of the tiles, mechanical support, and a reflective surface at the tile edges. After the epoxy has cured, the scintillator is positioned back on the milling table, and the fiber grooves are routed with a 35 mil bit (see Section I.2.1 for a discussion of the fiber groove pattern). The fiber groove is cut into the same side as the separation grooves. The shape of the groove will be a "keystone" shape, Figure I.7. This shape helps prevent the fiber from coming out of the scintillator. The side of the separation groove with the leftover 10 mils of scintillator is "painted" with a black marker pen. This reduces the adjacent tile crosstalk to under 1% per side. Finally, the edges of the megatiles are painted with white TiO_2 paint to provide a reflective surface on the outside edges of the megatiles. This process leaves a large megatiles that contains individual tiles which are optically isolated but are mechanically one unit.

I.3.3 Fiber Routing and Optical Connectors

The light collected by a WLS fiber inside the tile is transported to the phototube using clear fiber which spliced to the WLS fiber. Within the pizza pan, the clear fibers lay in grooves in the white plastic sheet, providing protection for the fibers. The grooving of the white plastic sheet is performed with an X-Y milling table. The groove pattern example

Figure 1.7: Cross section of the Fiber groove

is shown in Figure 1.8. The fibers travel from the tiles to one of the four mass-terminated optical connectors at the top of the pan. Optical cables in the form of a flat bundle of fibers (0.9 mm) carry the light from the pan to a router box near the phototubes. In the router box, the optical signals are sorted from layers into calorimeter towers. This sorting is performed using 1mm fibers which run from the layer connector to the light mixer for the phototubes (towers). The use of the optical connectors allows for the segmentation of the optical path into three parts, the pizza pan, cable, and router box and provides maximum protection for the fibers at all stages of assembly and installation.

Figure 1.9 shows the optical connector at the edge of the pizza pan. It will be made out of a molded piece of plastic. The fibers entering the connector from the pizza pan will be 0.83mm and the fibers exiting the connector as the optical cable will be 0.9mm. The fibers and optical connectors for the pizza pans are constructed as one unit and tested before installation of the fibers into the tiles.

The connector with fibers for the pans will be made as follows: The fibers will be laid out on a templet which has the lengths for each of the fibers marked on it. Each fiber will be 6mm shorter than the length of its groove. This will allow for variation of the fiber lengths. The fiber lengths will be marked on the templet in the order which they go in the connector. This templet can be drawn by using information from the program which generates the grooves in the white plastic. Each layer will have its own templet. This will assure that the final length of the clear fiber is correct. The fibers will be inserted into the connector. Epoxy is poured into the side of the connector which has been molded to accept the epoxy. The connector will be flipped over and the other side, which has fibers sticking out, will be covered with epoxy. Finally, this side will be faced off with a

Figure I.8: Fiber Routing in White Plastic

Figure I.9: Optical Connector

diamond cutter which will form a clean optical surface for the fiber to mate with the fiber from the other connector.

Tests have shown that each fiber connection introduces an additional 3% variation in the light yield of the entire tile/fiber assembly. The tests were performed with the following combinations of readout, cable, and router box fibers: 0.75mm : 0.83mm : 1.0mm and 0.83mm : 0.83mm : 0.83mm. The results were similar in both cases. These results indicate optical cables will not significantly degrade the performance of the hadron calorimeter.

I.3.4 Source Calibration Tubes

A radioactive wire source will be used to test the megatiles after installation into the plug steel. Small (1.27mm O.D.) stainless steel tubes embedded in the white plastic are used as guides for a radioactive wire source. There are 4 source tubes per pizza pan. The tubes are centered on 3.75° , 11.25° , 18.75° , and 26.75° , and run radially from the inner to the outer edge of the pan. At the outer edge, the tubes are terminated into "funnels", which stick out a small amount from the edge of the pan. They are accessed through holes in the Al skins which cover the hadron steel. The exit points are arranged not to interfere with the optical fiber routing in the readout crack. The holes in the Al skins are to be 0.75cm in diameter. The tubes will be accessible during installation for testing purposes. During normal operation these holes (and source tubes) are covered with black tape to light tight the plug. Between collider runs when the plug is pulled out of the collider detector, the holes can be uncovered and a flexible plastic tube can be attached to the source tubes on the pans. This allows testing of all the tiles in every layer. Four layers (0,4,12,21) have an additional set of 4 tubes per pan that are routed back along the steel like the optical fiber cables. This permits a radioactive source to be run into the calorimeter from the back during a collider run. To avoid jamming the source wire in the tube, the bend radius is kept larger than 3 inches.

I.4 Testing Fixtures and Techniques

I.4.1 Fiber Testing

Most of the light yield variation in the tile/fiber assembly originates from bad splices or varying quality of the fiber, not from the variation in the scintillator. Therefore, the fibers will be pretested using a quick testing setup that is described below. The WLS fibers will be shipped from the manufacture cut to the proper length. There will be 11 different fiber lengths, one length for each eta tower. The quality of WLS fiber will be tested by selectively measuring a small sample of fibers. Second, the mirror process will be monitored by measuring the reflectivity from a control sample. Third, every splice of WLS fiber to clear fiber will be tested. Poor splices will be rejected. We can control the uniformity of the splicing to 5%. The tools which will allow us to test the fibers to the 2% level are the following:

1. A phototube/fiber coupler introducing less than 1% variation in the light yield measurement of a tile/fiber assembly.
2. The use of a permanent reference tile that has a fiber permanently connected to the reference phototube.
3. The use of a standard reference tiles that allows quick insertion and removal of fibers.

To test fibers we will use a large test tile with solid shiny aluminum top and bottom reflectors. The fiber will be pushed into a hole from the side into a straight groove. A reference tile with a fiber permanently connected to the phototube monitors the stability of the phototube gain. The individual test consists of measuring the dark current of the PMT, measuring the light yield of the test tile and fiber, and measuring the light yield of the reference tile.

I.4.2 Pan Testing

Testing the pans assures no fiber was damaged during the assembly process. The each pan will be put into a large dark box. Four fiber cables will run from the pan connectors to a phototube with a randomizer. A collimated gamma source will be positioned on each tile using an automatic x-y scanning device and the response of each tile will be recorded. The box has a permanently attached reference tile to monitor the gain of the phototube.

I.4.3 Summary of Quality Assurance Tests

Below we summarize the measurements that will be performed as a part of the quality control during production of the pizza pans.

1. Receive information about each piece of scintillator from the manufacturer.
2. Measure the light yield of each control piece from each scintillator sheet.
3. Measure the attenuation length of the control piece.
4. Measure a sample of WLS fibers (transmission and light yield).
5. Measure the reflectivity of the mirrors on the end of the WLS fibers. The test is performed by comparing the light yield of a control tile using the fiber with and without the mirroring.
6. Measure the light yield of each mirrored, spliced fiber before it is put in the connector.
7. Measure a sample of the mirrored spliced fibers put in a connector.
8. Measure the light yield of each assembled megatile with a collimated gamma source.
9. Test each cable connecting megatiles to the phototube box.

10. Test each megatile after installation in B0 with an uncollimated wire source. This will use a special data acquisition system using PM cards.

The key to the quality control during construction is contained in Steps 6 and 8. Step 10 is the key quality control step during installation.

If the cutting and epoxying of the megatiles proceeds faster than assembly, a subset of the megatiles will be assembled and tested to insure the quality of the cutting and glueing of the megatiles is not changing. In addition a data base will be set up so we will be able to store the information for a megatile. This information will include:

1. The information sent from the manufacturer about the scintillator pieces.
2. Measurement of the light yield of the scintillator control pieces.
3. Measurement of the attenuation length of the control pieces.
4. The results of the collimated source scan of the megatiles.

I.5 Production and Installation

This section outlines the specific production and installation schedules for the hadron calorimeter. It estimates the manpower and resources necessary for each task and where that task will be performed and who is responsible. Most of the production work will be done at FNAL. However, where appropriate or necessary, industry will be used for fabrication work.

I.5.1 Production

Five hundred fifty megatile units are needed for B0 and 44 megatile units are needed for the test beam mock-up module. (The test beam module covers 60° in azimuth.) There are 22 different sizes of megatiles, one for each longitudinal layer in the calorimeter. The production of these megatile units is split into two separate phases: test beam megatile production and B0 megatile production. The test beam megatile production is done first so that they will be built and fully tested for the beam test in the 1995 fixed target cycle. In this production phase, a pair of megatile units from adjacent longitudinal layers will be completely built and tested, one set at a time, before building more. (These two megatiles are to be made from a single scintillator plate.) Any problems encountered in any of the manufacturing steps will be corrected on the spot. Thus, the test beam megatile production phase will be used to debug the manufacturing process and as a learning process. All-out production will commence with the B0 megatile production phase. Speed optimization of the manufacturing process will be done in the early part of this phase. Wherever possible, tasks will be done in parallel.

The production of the pizza pan units is broken down into a series of tasks.

1. Scintillator Milling

2. Megatile Epoxying
3. White Plastic Milling
4. Aluminum Pan (Cover) Fabrication and screw/rivet machining
5. White Paper (Tyvek) cutting
6. Black wrapping (Tedlar) cutting
7. Fiber Preparation
8. Fiber-Connector Assembly Fabrication
9. Megatile Assembly
10. Megatile Testing

These tasks will be done in Lab 5 and Lab 8. The milling operations on the scintillator and white plastic cover will be done at the Thermwood facility at Lab 8. The megatile epoxying task also will be done in Lab 8, in a production area not far from the Thermwood milling machines. The stamping of the aluminum pan covers will be done in a machine shop, either here at Fermilab or by industry. The scintillator, white plastic, Tyvek and Tedlar wrapping, and the aluminum covers will be partially assembled at Lab 8, put into shipment-storage boxes and then sent to Lab 5. The final assembly and testing of the megatile units will be done at Lab 5. The fiber-connector assembly fabrication is a major task and it will also be done in Lab 5. The following paragraphs describe the production techniques that will be used.

Two megatiles are to be made from a single rectangular piece of SCSN38 scintillator. This pair consists of megatiles from adjacent longitudinal layers: $0 \cdot 1$, $2 \cdot 3$, $4 \cdot 5$, ..., $18 \cdot 19$, and $20 \cdot 21$. All manufacturing steps are therefore geared to produce megatile pairs (instead of single megatiles.) There are three steps in the production of megatiles from a plate of scintillator. First, tile separation grooves are machined out. The outer boundary of the megatile is not cut, just the inner tile separation grooves. Next, the scintillator plate is taken off the milling table, the separation grooves are taped, and the epoxy is injected into the grooves. After the epoxy has cured, the plate is taken back to the milling machine and the megatiles are re-registered to the milling machines's coordinate system. Then the WLS fiber grooves are machined onto the individual tiles and alignment and structural holes are drilled into the megatiles. (The tile separation and fiber grooves are on the same side of the scintillator surface.) Finally, the megatiles are cut out of the scintillator plate.

The machining of the scintillator has been split into three steps due to several technical reasons. The milling operation requires the removal of the scintillator plate's protective paper covering on that side. Since the separation grooves are cut so that only 0.25 mm of material remain, the scintillator plate with separation grooves machined onto it is fragile. However, as the protective paper on the other side is left intact, it gives additional structural support to the plate when it is handled. In addition, the paper prevents surface scratching when the scintillator is moved about. The fiber grooves are not milled along with the tile separation grooves because of a large risk of epoxy seeping into the fiber

grooves from the separation grooves in the epoxying operation. This is because the fiber grooves can be within 3 mm of the separation grooves, and a tape seal in such a small gap is not robust.

An important quality control item in this step of the production is tracking the quality and uniformity of the scintillator plates used for each megatile. As part of the SCSN38 scintillator purchase agreement, Kuraray was required to mark each plate delivered with an ID number that specified the production history of the plate. This information will be included in the manufacturing protocol for the megatiles. In addition, plates from different production batches will be tested and the results included in the protocol. Both the attenuation length and the light yield will be monitored using tests described in the scintillator specification document. With this protocol, the megatile performance having to do with scintillator quality can easily be monitored as the megatile production proceeds.

The milling of white polystyrene plastic cover sheets and stamping of the aluminum cover plates are independent of the scintillator machining. However, the white plastic and aluminum cover pieces must be produced at the same pace at which the scintillator megatiles are cut. The scintillator, white plastic (polystyrene), white paper (Tyvek), light tightening wrapping (Tedlar) and aluminum covers will be assembled into partially finished megatile unit at Lab 8. Only the optical fibers are not part of the assembly. In this assembly, the scintillator is well protected and thus can be safely stored or shipped anywhere in its shipping-storage containers. The designated storage area for these containers is Lab 5. Thus, these containers will be shipped on a regular basis from Lab 8 to Lab 5.

At Lab 5, the fabrication of the fiber-connector assembly, the final assembly of the megatile units, and the testing of these megatile units will be done in parallel. In the final assembly, the top aluminum cover is removed and the fibers of the fiber-connector assembly are stuffed into the individual scintillator tiles through the holes in the exposed white plastic cover and the rest of the fiber laid into its corresponding routing groove in the white plastic. The fibers have already been precut to their proper lengths in the manufacture of the fiber-connector assembly. The connector is mass-terminated and it mates with a "bulkhead feedthrough" piece at the outer radius of the megatile unit. This is a large component of the final assembly task. The rest of the final assembly involves screwing-in the alignment and structural support screws, and light-tightening the megatile unit.

Testing these finished megatile units is an integral part of the production, because it is important to monitor the quality and uniformity of response of the individual tiles within a megatile. Problems must be identified and fixed, especially systematic ones. (In anticipation of this, the first batch of megatile units to be made, the ones for the test beam module, has been appropriately scheduled so that this issue can be addressed.) While the quality of the scintillator is monitored in a previous task, the quality and uniformity of a single tile is affected by other production parameters. They are: the quality of the tile separation grooves, the quality of the wrapping material next to the scintillator, and the quality of the fiber groove to WLS fiber interface. These parameters will be monitored on all megatiles as they "come off the assembly line", until it is clear that the megatile

manufacturing technique is free of defects. Once so, periodic sampling will be done to track the quality. These parameters will be measured using radioactive sources to measure the response of the individual tiles. Such measurements do not require a finished megatile unit with all of the mass-terminated fiber-connector assemblies installed. Individual tiles may be tested with separate, spliced WLS-clear fibers read out by a phototube. However, the mass-terminated connectors will be needed when radioactive source calibrations are taken to provide a record of the initial response of each separate tile just after the finished megatile unit is made. This is for comparison against future, in-situ source responses at B0 and the test beam facility to track the long term time response of individual tiles.

The fabrication of the fiber-connector assembly is a critical and major task. It involves the fiber preparation: cutting the WLS fibers to preset lengths, polishing one end, mirroring it, splicing it onto a clear fiber, and testing these fibers. It also involves the actual construction of the fiber-connector assembly: trimming the spliced fiber to a fixed length equal to the run from the end of the fiber groove inside a tile to the exit connector at the bulkhead feedthrough, potting those fibers into a mass-terminated connector, facing off and polishing the end of the connector, and testing this as well. The actual construction of the fiber-connector assembly may be delayed relative to the fiber preparation due to the longer R&D needed for the mass-terminated connectors. Stringent testing steps are integral parts of both tasks because of the critical nature of this component. The light transmission must be maximized (over $\sim 90\%$ at the WLS-clear splice, over $\sim 80\%$ at the connectors), and the fiber-to-fiber variations in the light loss must be kept to a minimum (under $\sim 5\%$) to achieve the design hadron energy resolution. Thus, absolute light yields of the mirrored WLS fibers must be measured and those that do not pass the cut must be discarded. The WLS fiber to clear fiber splicing operation must be monitored to insure a consistent, high-quality splice. A related, but production independent task is the construction of "shielded" clear fiber, mass-terminated cables which go from the bulkhead feedthrough on the outer edge of the megatile to the fiber patch-panel box outside. This is also expected to be done in Lab 5. Similar quality control measures must also be applied for the same reasons given for the fiber-connector assembly.

I.5.2 Production Time Estimates

The following production time estimates are based on simple calculations that break down complex operations into simple steps whose timing can be measured (or estimated). The megatile count is the standard unit of production and the number needed is shown in Table I.5.2. However, for the Thermwood milling operations, the scintillator plate count is the production unit as it is more efficient to mill two megatiles simultaneously. The total time estimates given below are only for B0 megatile units. The test-beam module megatile units are accounted differently for reasons described previously.

- *Thermwood Operations, Lab 8*

- The production unit is a plate (SCSN38 and white polystyrene). Two megatiles are machined from one plate.

- There are two operations here: scintillator (Sc) milling and white polystyrene (WP) milling. The maximum mill time is for the largest plate, Layer 20 · 21. The mill time decreases roughly linearly down to Layer 0 · 1, which takes about 23% less time.
- Layer 20 · 21 mill time = 7.0 hrs = 4.7(Sc) + 2.3(WP)
- Total time = 275 plate pairs × 7.0 hrs/plate-pair
 = 1925 Thermwood-hours
 = 241 8-hour, Thermwood shifts (12 calendar months)

● *Megatile Epoxying and Partial Assembly, Lab 8*

- The production unit is a megatile.
- The operations involved here are separation groove taping, laying epoxy into those grooves, touch-up, finishing, and partial assembly of the aluminum covers, white plastic and scintillator for shipment to Lab 5. The timing is roughly independent of the megatile size as most of the time is preparation work which depends on the number of individual tiles within a megatile (roughly constant). The timing estimate below includes a 3 hour finishing time.
- Timing = 10.4 man-hours/megatile
- Total time = 550 megatiles × 10.4 man-hours/megatile
 = 5700 man-hours
 = 36 man-months (assuming 160 man-hours/month)

● *Megatile Final Assembly and Testing, Lab 5*

- The production unit is a megatile. For the testing, two large automated (PC controlled) radioactive source/scanner boxes are used. Since the scanning will be automated, the timing is split into personnel time (man-hours) and machine time (PC-hours).
- Final Assembly time = 4.7 man-hours/megatile

1) Setup	0.17 hrs
2) Scintillator wrapping preparation	0.50 hrs
3) Fiber insertion (4 min/fiber)	2.40 hrs
4) Connector installation	0.17 hrs
5) Al Cover assembly	0.50 hrs
6) Edge preparation (light tightening)	1.00 hrs
- Testing time = 1.4 man-hours/megatile, 1.1 PC-hours/megatile

1) Setup	0.33 hrs
2) Collimated γ -scan (1.5min/tower)	0.90 hrs
3) Line-source (2 scans × 5min/scan)	0.17 hrs
4) Result analysis, corrective action	1.00 hrs

Location	Megatile Units	Scint. Plates
B0	550	275
Test Beam	44	22

Table I.4: Megatile and Scintillator Plate Count

- Total personnel time = 550 megatile $\times$ 6.1 man-hours
= 3400 man-hours
= 21 man-months (160man-hours/month)

Excluding Thermwood manpower and cutting times, the estimated "unit" construction time is 16.5 man-hours/megatile. With a four man production crew, and a pace of two megatile units/day, the construction of 550 megatile units is estimated to take 14 calendar months. This does not include fabrication of the fiber-connector assembly, which is budgeted separately and is a Michigan State University responsibility. Fiber related information is included here to provide an overall picture of the situation. However, Rochester will coordinate the overall production pace. For a production pace of two megatile units a work day, eight fiber-connector assemblies per day are required. Three technicians are required for this pace. If the megatile rate per day were doubled, five technicians are required for the fiber-connector assembly construction.

Table I.5.2 shows the overall production schedule and the constraints imposed by the Fermilab physics program schedule. The installation schedule is discussed in depth in the next subsection. Table I.5.2 shows the materials necessary for the production of the two endplugs and a 60° test beam module. Table I.5.2 shows the manpower required for each task and Table I.5.2 shows where each task is performed.

I.5.3 Installation

The Rochester group will be responsible for overseeing the installation of the Hadron Upgrade. In addition, the group will also be responsible for the final checkout of the hadron calorimeter prior to Run II collider running.

The Hadron Steel will be modified by the Upgrade Mechanical Group. These modifications include adding two layers of 2" stainless steel disks and extending the existing steel with stainless steel washers from $\theta = 10^\circ$ to 3° . A 0.375" thick stainless steel cone at the $\theta = 3^\circ$ edge serves as a structural load bearing member. This cone prevents access to the small radial portion of the steel during installation.

The hadron pan mounting scheme is different from the one used for the gas PHA. Thus, modifications to the steel are required. Near the 4-5° region, small alignment rods are placed every 30° in azimuth. In the layer 6-21 region, they are aligned with the outer support ribs. These rods server to catch and align the nose of the pan as it is being inserted. The inner support point of the pan is the structural support cone at 3° and the

TB = Engineering design, Production Startup, and
 Construction of test beam megatiles
 B0 = Construction of B0 megatiles
 FT = Concurrent test beam run and steel reworking
 Ins = B0 installation and checkout
 R2 = Start of Collider Run II.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	TB	TB	TB	TB	TB	TB	B0	B0	B0	B0	B0	B0
1994	B0	B0	B0	B0	B0	B0	B0	B0			FT	FT
1995	FT	FT	FT	FT	Ins	Ins	Ins	Ins	Ins	Ins		
1996	R2											

Table I.5: Schedule for the Hadron Calorimeter Construction with a 2 megatile per day pace. (Fermilab schedule as of Nov92.) The end of 1994 is left as a contingency. B0 installation will not begin until the steel modifications are complete.

Material	Amount
Scintillator: SCSN38 (6 mm)	600 m ²
White Plastic: Polystyrene (3.81 mm)	600 m ²
Reflective paper: Tyvek (0.15 mm)	1200 m ²
Black wrapping: Tedlar (0.04 mm)	1400 m ²
Top Pizza Pan Al: 2.29 mm Thick	600 m ²
Bot Pizza Pan Al: 1.59 mm Thick	600 m ²
Y11 WLS Multiclad Fiber: 0.83 mm	17 km
Clear Multiclad Fiber: 0.83 mm	20 km
Clear 10 Fiber Cable: 1.2 mm OD	4000 m
Source Calib Tubes: SS (1.27 mm OD)	4500 m
Epoxy: Dow DER-332 + DER-736 + TiO ₂	200 kg

Table I.6: Summary of Materials for the of Hadron Calorimeter Construction.

Project Task	Physicists	Engineers	Technicians	Man-hours
PS-Plastic Milling	0.3	0.3	2	620
Scint Milling	0.3	0.3	2	1300
Scint Epoxying	0.3	.	2.5	5700
Megatile Const+Test	3	1	1.5	3400
(Megatile Test)	(1)	.	.	(730)
Fiber-Conn Const	2	.	3	6800
B0 Installation	3	2	8	2500

Table I.7: Summary of Manpower of Hadron Calorimeter Construction for B0 megatiles. The number of personnel is for a 14 calendar month production (2 megatile units/day) schedule.

Project Task	Location
Scintillator Milling	Lab 8
Scintillator Epoxying	Lab 8
White Plastic Milling	Lab 8
Aluminum Pan Cutting	Vendor
Megatile Pre-Assembly	Lab 8
Fiber Preparation	Lab 5
(Fiber Mirroring)	(Lab 7)
Fiber-Connector Const	Lab 5
Megatile Final Const	Lab 5
Megatile Test	Lab 5

Table I.8: Location of production tasks

alignment rods. For layers 6-21, the outer edge of the pan is supported and held at its corners by locking, eccentric cams, mounted on the radial support ribs. The cams push in on the pans: the radial position of the hadron pan is adjusted by adding shim to the nose piece of the pan. In the layer 0-5 region, the alignment rods are also placed every 30° in azimuth, but at a 15° offset to the "radial support" ribs. The outer edge of pans in this region is supported and held at the middle by a set screw in the support rib. In this region, these support ribs must be removed before the hadron pans can be inserted. However, only one rib can be removed at a time because of the extra load of the upgrade. This constrains the pan position and alignment in this region.

Once the pans are mounted in the steel, we will connect a shielded, mass-terminated fiber cable to the pan and route it to a tester to test the response of the pan to a source. The connector in the pan will be pushed up against the upstream steel of the gap. This will give the flat optical cable a bend radius of at least 2.54 cm to make the turn to the outside of the detector. The pans and the cable will be made as light-tight as possible. Thus, we will be able to connect the cable to a phototube and test the configuration without having to light-tight the steel. Next, we run the source through the calibration tube ports to determine if the installation is performing properly. From these results, we can determine whether we need to source all pans after installation or whether we can just source a selected number. After the pan has been checked, the flat fiber cable will be plugged into a fiber "patch-panel" or router box.

As mentioned previously, the steel absorber is to be extended for the plug calorimetry upgrade, and it will be done by the Upgrade Mechanical Group. The exact method that will be used to install the scintillator megatile pans into the newly reconfigured steel absorber is still under consideration. To speed installation, both plugs will be installed at the same time. In this case, 8 FNAL technicians are needed for hadron plug installation. Each end plug would have 4 technicians working on it. Two technicians would work on the north side and two would work on the south side. Some jobs might require more than 2 people. For these the north and south group can help each other. At least 3 Rochester physicists would be supervising the installation and performing the quality control tests.

The entire installation involves mounting 528 pans. With each of the 4 groups doing 2 pans a day, the installation will take approximately 3 months. After the installation we estimate it will take approximately 2 months to shakedown the system. During the shakedown period, we will periodically need technicians to fix problems. As a part of the shakedown, the aluminum skins will be put on the plug to form the light seal for the system. Besides making the the system light tight, the DAQ system and phototubes will also be exercised during the shakedown period.

The Rochester group will oversee the final checkout of the hadron system. Although, the phototube group will check to be sure the phototubes work, we will ensure this is done. In addition, we will ensure the electronics and HV system work. The Rochester group will ensure the proper software is written for the calibrations. These include, source runs, flasher runs, pedestal run and charge injection runs. Typically, these programs are written for other subsystem and we will ensure that they work for the plug hadron system.

I.6 Energy Calibration

I.6.1 Techniques

We are relying on two calibration schemes: (a) muon calibration and (b) source calibration. The source calibration can be used to transfer the calibration from the testbeam to B0. However, with the magnetic field on (plugs closed), only a few layers can be sourced. These few layers can be used to determine the effect of the magnetic field on the scintillator, expected to be a few percent. However, the sources can not be used to determine the effect of the magnetic field on the hadron shower. This effect is expected to cancel since it affects the number of the particles in the steel and scintillator in the same way.

The primary calibration will in be in terms of a minimum ionizing muon signal. That is, all towers will be calibrated relative to one another using the most probable energy deposition, summed over all 22 layers, of minimum ionizing muon (defined as a MIP) and shower energies will be expressed in terms of MIPs. A preliminary calibration between MIPs and hadronic shower energy in GeV has been measured in the 1991 test beam run with the 1991 Upgrade prototype calorimeter. This calibration is only known to $\pm 5\%$ presumably because of nonuniformity in the hadron prototype tiles. The calibration was measured with 175 GeV muons to be 0.43 MIPs/GeV. It is anticipated that in the future, this calibration will be repeated with a new test beam calorimeter. Since the muons in the test beam are on average higher energy than those at B0, the energy dependence of the muon response will be checked. Previous CCFR [8] and Hanging File [7] data indicate the most probable energy deposition of muons in a calorimeter (MIP's) increases by 7% for every 100 GeV of muon energy.

The design specifications call for a muon signal to have the same light yield independent of the size of the tile. Consequently, if tower-to-tower phototube gain variations are normalized to the MIP signal for a tower, the calorimeter's response to localized energy deposition anywhere (transversely and longitudinally) within it will be uniform. Because of this uniformity and relative energy calibration in terms of MIPs, each 30° pizza pan sector can be considered to be identical calorimeters, e.g., with identical MIP to GeV calibrations. A mockup consisting of a 60° sector of the calorimeter (two pizza pans) will be constructed in a manner identical to the actual device and placed permanently in an hadron test beam facility. This will be used to obtain the absolute calibration from MIP's to GeV as well as source response to GeV. It will also be used to study details of the performance of the device.

A radioactive wire source, pushed through the source tubes, will be used for diagnostic testing and backup calibrations. An initial calibration can be made using all layers when the plug is in the open position. When the plug is in the closed position, it is anticipated that only a few selected layers will be monitored continuously. The other source tubes will only be used for diagnostic purposes in case of a major problem. Note that after all towers are calibrated relative to one another, all the tiles in a pizza pan have uniform response. The radioactive source calibration can be cross-checked against calibrations using cosmic ray muons. The cosmic ray muons do not require elaborate tracking to ensure that they remain entirely within a tower. Since the towers are identical except for the gain of the

phototubes, a matrix inversion technique can be used to set the gains of the phototubes from the muon response over several towers (averaged over many events).

As the gains of phototubes do drift with time and environmental changes, the relative gain change of each individual phototube will be monitored with a laser flasher system. If the gain of a tower's phototube changes, the definition of a MIP for that tower changes and therefore it is necessary to monitor these changes to maintain the absolute energy calibration of the calorimeter. Such a system must be reproducible and stable to carry the absolute calibration from one muon calibration to another. It must be assumed that the initial muon calibration be tracked over an entire collider run. Although the actual implementation of such a laser calibration system is the responsibility of the Phototube Group, we will assist in the design and implementation of those subcomponents which directly affects the hadronic phototube calibration.

I.6.2 Electronics Requirements

The readout electronics must be able to clearly distinguish a muon signal from the noise at the low end and have a dynamic range that covers shower energies of up to 600 GeV per channel. For the level of the MIP signal and the shower signal from the calorimeter, we shall use values from the 1991 Upgrade prototype calorimeter. The prototype's photoelectron yield at the peak of the muon dE/dx distribution is 35 $pe's/MIP/22$ layers. (With this level of photostatistics, the rms/peak on the low side of the dE/dx distribution is $\sim 30\%$.) The hadronic shower photoelectron yield is 15 $pe's/GeV$.

We intend to operate the phototubes at a nominal gain of $\sim 5 \times 10^5$. At this gain, the integrated charge out of the PMT for a MIP signal is 2.8 pC and that for a hadron shower is 1.2 pC/GeV (720 pC for 600 GeV). If the phototube signal is assumed to be a triangular pulse with a base width of 40 nsec, then the peak current for the MIP signal is 0.14 mA (7 mV into 50 Ω) and 36 mA for 600 GeV of shower energy. The phototube response should be linear (within 2%) up to 720 pC. If the photoelectron yields are less than expected, phototubes may need to be operated at higher gains. For this reason, the phototubes must also be able to operate at gains of 10^6 .

The ADC should have the same features as the 1992 RABBIT PMA card: a full scale of 750 pC and 16 bits of resolution. With 16 bits of resolution, the most probable value of the muon dE/dx distribution will be at 240 ADC counts. This is more than adequate for a precision calibration of the tower gain via the muon peak. Between 14 and 15 bits of resolution is also acceptable. However, a value of 30 ADC counts (13 bits of resolution) or lower is not acceptable.

I.6.3 Test Beam Calibration

The mockup of the plug upgrade calorimeter that we plan to use at an hadron test beam facility is a 60° section. We plan to use steel absorber from the the old 60° mockup of the gas PHA. However, it will need modifications to make it identical to the planned plug upgrade configuration of the plug steel for collider Run II. This modification is the responsibility of the Mechanical Group. Two additional 5.08 cm (2.0 in) steel plates need

to be added to the front, and the existing steel plates need to be extended from its current angle of $\theta = 10^\circ$ to 3° . The 6.35 cm (2.5 in) thick plate at the the start of the 30° readout crack region needs to have an arc of material added to the outer radius of that plate to simulate the 45° bevel on the corresponding plate on the Collider Detector. Mounting hardware for the aluminum cover skin over the plug steel on the Collider Detector as well as the cover skin should also be duplicated for this new mockup. In any case, we require that the steel and the layout of the support structures for 60° section mockup at the hadron test beam facility be the same as that for the final plug upgrade design for collider Run II. Specially modified, 15° hadron pan sections need to be made for layers 0-5 because of the 15° phase between pan boundaries in these layers relative to layers 6-21.

The relative MIP calibration of the towers will be done with beam muons of a fixed momentum as was done in the 1991 test beam run. The absolute calibration of the shower energy in units of MIPs to GeV will be done using momentum analyzed hadron beams of various energies and it will require an instrumented electromagnetic shower stack to be in front of the hadronic section. This EM calorimeter must be of the same design as the actual plug upgrade EM calorimeter, or the actual device itself. Various other beam tests which study the details of its performance will also be undertaken. Results from the 1991 test beam run indicate that both a large transverse area EM and hadronic stack are needed to understand the combined response of the system to low energy hadrons (i.e., jet hadrons).

The relative calibration in MIP units must also be done on the actual calorimeter at CDF. However, the calibration at CDF must be done with the solenoidal magnetic field turned on. This is because the light yields from ionizing radiation in most scintillators increase with increasing magnetic fields [2]. The increase in light yield is typically under 5%. In principle, any increase in light yields due to magnetic field effects will produce an increased MIP response that should compensate the corresponding increase in the hadronic shower response. Thus to first order, if we get the absolute calibration from MIPs to GeV from the test beam where there is no magnetic field, this absolute calibration can be transferred to CDF as long as the MIP calibration is done with the solenoid magnet on.

The magnetic field can have an additional effect. The hadron response of the CDHS iron calorimeter [3] (which is composed of magnetized steel disks in a toroidal geometry) exhibits a change of a few percent when the steel is magnetized. This is presumably due to the increased pathlength of curling low energy electrons in the magnetized steel. However, in the CDHS toroidal geometry only the steel was magnetized, and the counters were in a much lower field. In the CDF plug geometry, the magnetic field in the steel and in the scintillator is similar. Therefore, the effect is expected to cancel since the fractional increased pathlength in the iron and scintillator will be similar. There is an additional effect which is the change in the response of the scintillator itself in the magnetic field. The field in the scintillator in CDF is much higher than the field in the scintillator in CDHS. This change in scintillator response can be monitored with the radioactive source calibration by comparing the "field on" to the "field off" response and is expected to be a few percent. The effect is the same for source, MIP and hadron calibration.

Faculty	Arie Bodek
Senior RA's	Howard Budd, Willis Sakumoto
RA's	Pawel de Barbaro, Brian Winer
grad stud.	Manoj Pillai, Phillip Koehn, Fan Qun
Engineer	Tom Haelen (at Rochester)
Technicians	Marc Olsson

Table I.9: Rochester Manpower

I.7 Organization

The overall coordination of the R&D and construction of the hadron calorimeter will be done by the University of Rochester. A. Bodek will be the hadron coordinator and H. Budd will be Rochester's local (FNAL) representative of the group. The Rochester manpower is outlined in Table I.7. It is anticipated that the physicists will spend about 50% of the research time on the hadron calorimeter project, with the remaining time participating in the running and physics of the on-going CDF data run or in some cases research for the SDC. However, whenever it is necessary, a large effort can be re-directed towards this project.

The hadron group will also maintain liaisons with the other plug upgrade groups. H. Budd and W. Sakumoto are the liaisons to the mechanical group, B. Winer is the liaison to the Physics group, P. de Barbaro and B. Winer are liaisons to the EM group, W. Sakumoto is the liaison to the phototube group and W. Sakumoto is the liaison to the Shower Max group. The liaison people will communicate the R&D results that are useful to other groups, thus helping achieve a unified design. The liaison will also be responsible for worrying about the boundary interfaces where the responsibility of the hadron groups ends, and other groups begin.

Interface boundaries - These are the items that are to be decided by the other groups (in consultation with the hadron group) and given to the hadron group as fixed parameters.

1. Modifications to hadron steel - Mechanical
2. Modification to test beam 60° mockup - Mechanical
3. Fiber routing - Mechanical
4. Source tube routing/ source drivers - Mechanical
5. Fiber coupler - EM
6. Phototube choice/electronics and optical cables - Phototube
7. Splicing Machinery - Mechanical
8. Choice of Scintillator/Fiber type/Size - Technical board
9. Cookie design and coupling to phototube - Mechanical/Phototube

10. Segmentation - Physics

Responsibilities of Hadron group:

1. Oversee the R&D for production of uniform tiles with the same gain.
2. Oversee quality control during production.
3. Supervise the installation. The installation and fiber routing will be performed by FNAL technicians and the mechanical group.

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