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HIGH ENERGY PHYSICS DIVISION
SEMIANNUAL REPORT OF RESEARCH ACTIVITIES

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Table of Contents

I. Experimental Research Program	2
A. Experiments With Data	2
1. Medium Energy Physics Program	2
2. Polarized Proton Physics at FNAL	4
3. Collider Detector at Fermilab	4
4. Non-Accelerator Physics at Soudan	9
5. ZEUS Detector at HERA	15
6. BNL AGS Partial Snake Magnet Experiment	24
B. Experiments In Planning Or Construction	24
1. Polarimeter for RHIC Spin Experiments	24
2. MINOS—Main Injector Neutrino Oscillation Search	24
3. ATLAS Detector Research & Development	27
C. Detector Development	28
1. CDF Detector and DAQ Electronics Development	28
2. ZEUS Detector Upgrade	29
3. STAR Calorimeter and RHIC Polarimeter Development	31
4. ATLAS Calorimeter Development	31
5. MINOS Detector Development	42
6. Electronics Support Group	46
II. Theoretical Physics Program	49
A. Theory	49
1. Total Cross Section for Top Quark Production	49
2. Associated Production of a Prompt Photon and a Heavy Quark	50
3. Isolated Photon Cross Sections	50
4. Lattice Formulation of Chiral Gauge Theories	51
5. Lattice Measurement of Matrix Elements for Decays of Heavy Quarkonium	52
6. Polarized Hadronic Physics	52
7. Photon Structure	53
8. Supersymmetry	53
9. Kinematics of top Quark Production	55
10. Conformal Symmetry in the Regge Limit of QCD	55
11. The Hard Gluon Component of the QCD Pomeron	56
12. Quark-Antiquark Production in Diffractive Deep Inelastic Scattering	56
13. Forward Jet Production in Deep Inelastic Scattering	57
B. Theory Institute: Topics In Non-Abelian Duality	58
C. Computational Physics	59

III. Accelerator Research And Development	61
A. Argonne Wakefield Accelerator Program.....	61
1. AWA Facility.....	61
2. Witness Gun and Wakefield Measurement System.....	61
3. Initial Dielectric Wakefield Experiment	62
4. Non-Linear Plasma Focusing Experiment and Tesla Test Facility.....	63
B. Muon Collider Design	64
IV. Divisional Computing Activities	65
A. High Performance Computing: The PASS Project	65
1. R&D During the Period January 1996 through June 1996	65
V. Publications.....	67
VI. Colloquia And Conference Talks	81
VII. High Energy Physics Community Activities.....	84
VIII. High Energy Physics Division Research Personnel.....	85

Abstract

This report describes the research conducted in the High Energy Physics Division of Argonne National Laboratory during the period of January 1 - June 30, 1996. Topics covered here include experimental and theoretical particle physics, advanced accelerator physics, detector development, and experimental facilities research. List of Division publications and colloquia are included.

I. EXPERIMENTAL RESEARCH PROGRAM

I.A. EXPERIMENTS WITH DATA

1.A.1 Medium Energy Physics Program

The past focus of the medium energy physics program has been on the study of spin effects in nucleon-nucleon scattering. These measurements plus results from other groups will allow the determination of nucleon-nucleon elastic scattering amplitudes. The amplitudes are important for understanding the strong interaction at intermediate energies, nucleon scattering from nuclei, and the interpretation of some electron scattering experiments planned for CEBAF.

Work on the analysis of a large amount of pp elastic scattering data from Saclay continued during this period. The spin observables A_{0N} , A_{NO} and $C_{NN} = A_{NN}$ were measured for $\theta_{c.m.} \sim 60 - 90^\circ$ at over 30 beam kinetic energies between 1800 and 2800 MeV. However, problems with varying wire chamber, scintillation counter, and trigger efficiencies at some energies could lead to sizable systematic errors. As a result, a computer program was written to locate changes in these efficiencies, and all data were checked with this program. Such changes were noted, and cuts were determined to eliminate the affected data. In the process of these checks, a dead spot in one wire chamber was found (see Fig.) that is guessed to have been caused by considerable beam passing through the chamber in a past experiment. In order to prevent possible efficiency changes in the chamber near the spot, cuts were made to remove events passing through this region of the chamber for all runs.

Considerable effort was also made to determine an optimum method of extracting results from the data with minimum impact of possible remaining systematic errors. A number of different methods were considered, but most of them proved inadequate. Work is continuing on this problem.

Modifications to the existing data analysis program have begun to incorporate various cuts on the data. These cuts were chosen based on information from the changes in efficiencies for individual wires or scintillation counters, for large regions in the wire chambers, or for portions of runs where there were trigger or data acquisition problems. Finally, a paper on this experiment has been begun.

The new Crystal Ball collaboration at Brookhaven was joined (E913/914); the physics goal will be to study hadron spectroscopy. The SLAC Crystal Ball of NaI detectors and associated electronics was borrowed and moved to Brookhaven by the collaboration. An Argonne physicist provided assistance to determine a layout and shielding for the experiment. The first stage of the program will use the C6 beamline from the Brookhaven AGS for negative pions of momenta $\sim 400 - 750$ MeV/c and for

negative kaons of momenta $\sim 600 - 750 \text{ MeV}/c$. Final states with all neutrals will be studied, including $n\gamma$, $n\pi^0$, $n\eta^0$, $n\pi^0\pi^0$, $n\pi^0\pi^0\pi^0$ for pion beams, and $\Lambda^0\gamma$, $\Lambda^0\pi^0$, $\Lambda^0\eta^0$, $\Lambda^0\pi^0\pi^0$, $\Sigma^0\gamma$, and $\Sigma^0\pi^0$ for kaon beams.

A major Argonne responsibility will be the design and construction of the mechanical support for the Crystal Ball. Such work has been begun. Another major responsibility will include simulations of some of the reactions, in collaboration with physicists and a student from Valparaiso University. Two topics of interest include the effects of neutron interactions on the extraction of the "signals" for various reactions, and the possibility to use the self-analyzing decays of Λ^0 and Σ^0 hyperons to obtain polarization data for many of the K^- beam reactions.

Fig. 1. A plot of hits in one of the wire chambers for the pp elastic scattering polarization measurements. The "hole" was possibly caused by the beam passing through this part of the chamber in a previous experiment, and its presence was previously unknown to the experimenters.

(H. Spinka)

I.A.2 Polarized Proton Physics at FNAL

i) Recent results on analyzing power measurement in $\bar{p}^\uparrow p \rightarrow \pi^\pm X$ with a 200-GeV/c polarized beam, as shown in Fig. 1, is to be published in Phys. Rev. Lett. Earlier, two theoretical models explained mirror symmetry in $\pi^\pm$ production versus x_F in $p^\uparrow p$ interactions; a) the valence quarks are effectively rotating on the rim of the polarized proton, b) the model relates $pp \rightarrow \pi^\pm X$ to the πp backward scattering. Our results of $\bar{p}^\uparrow p$ interactions indicate $\bar{p}^\uparrow p \rightarrow \pi^+ X$ behave in the same way as in $p^\uparrow p \rightarrow \pi^- X$, and similarly $\bar{p}^\uparrow p \rightarrow \pi^- X$ and $p^\uparrow p \rightarrow \pi^+ X$. The above two models predicted these phenomena correctly.

ii) A paper on "Spin Transfer in "Inclusive Λ Production by Transversely Polarized Protons" is complete, and will be sent for publication. D_{NN} reaches large positive values of about 30% at high x_F and $p_T \sim 1.0$ GeV/c. This result indicates a large spin transfer from the incident polarized proton to the outgoing Λ .

iii) η (550) and K_{short} production in pp and $\bar{p}p$ at large x_F have been investigated.

(A. Yokosawa)

I.A.3 Collider Detector at Fermilab

a. Physics Results

a.1 Top Quark Studies

Analysis of the full $\sim 110 \text{ pb}^{-1}$ sample continues with emphasis on obtaining cross sections in the different modes and extracting the best possible top mass measurement. The W plus two jet sample has also been given a lot of attention as there seems to be a marginally significant excess of b tags in that sample. Tom LeCompte continued his work on FCNC top decays.

a.2 W Mass Measurement

Barry Wicklund's map of conversion points from the inclusive electron sample has been adapted as a basis for material in both dE/dx tracking code and electron bremsstrahlung study. Adam Hardman, a graduate student from Purdue, has been studying the Ψ mass peaks as check of momentum calibrations using the ψ mass. The Ψ peaks are shown in Fig. 1.

Fig. 1. The dimuon Ψ peaks showing a sample fit.

The CEM tower calibration and response trim developed by Larry Nodulman and Karen Byrum was installed in CDF code. Energy and momentum scale issues remain under close scrutiny as the ψ and Ψ masses do not quite agree, and the tracking material determined from conversions does not agree well with the material inferred from the bremsstrahlung tail of E/p for the W electrons.

a.3 Vector Boson Couplings

Bob Wagner has continued to work with colleagues from UCLA, Illinois and Texas Tech on extending the study of W_γ and Z_γ production to the full data set, including central and plug photons.

a.4 High E_T Jets

The excess of jet production at high E_T was published in Phys. Rev. Letters, but it appears that looking for quark substructure in this manner is not possible; the high- x gluon content of the proton is not well enough constrained, as demonstrated by Steve Kuhlmann with his CTEQ colleagues. An apparent disagreement with the D0 inclusive jet measurement seems to be largely an artifact of using different theory curves as shown in Fig. 2.

a.5 Direct Photons

Steve Kuhlmann and Bob Blair have been working on analyses involving photons identified in the central calorimeter. Particular emphasis has been on the study of production of photon pairs with missing transverse energy as a search for new physics which could be related to the $e\bar{e}\gamma\gamma$ event reported last summer. So far, not much else is seen, as shown in Fig. 3.

a.6 b-Physics

Karen Byrum and Barry Wicklund are continuing their work on measuring the b cross section using inclusive electrons. The full 1b inclusive electron dataset is now available on disk at Argonne. Barry has continued working with his former student Fumi Ukegawa, now at Pennsylvania, on obtaining lifetimes for the neutral and charged B mesons using semileptonic decays.

Fig. 2. The CDF and D0 inclusive jet spectra measurements for 1a plus 1b are compatible when normalized to the same theory expectation. This particular fit uses CTEQ4HJ.

Fig. 3. The missing transverse energy spectrum of photon pair events (points) compared with electron pairs (histogram). The outstanding one is the well known $ee\gamma\gamma$ event.

b. CDF Summary of Active Data Taking

The b-physics group was allowed to install various test triggers. Both luminosity and detector performance continued to be disappointing in running at 1800 GeV. The program of diffractive studies using a Roman pot spectrometer and microplug calorimeters worked well. Two weeks before the scheduled end of the run, a wire broke in the central tracking chamber. After that we ran special triggers for diffraction, jet studies and a monopole search. With that finish, we turned off for the rest of the century. Only about 5 pb^{-1} of good high energy data was obtained in run 1c but it did contain a four muon ZZ candidate, shown in Fig. 4, with perhaps 0.1 expected in the whole sample. After looking at such things in SSC and LHC design studies, it is nice to see one in data.

**CDF ZZ CANDIDATE
RUN 75848 EVENT 343716**

Fig. 4. The CDF four muon ZZ candidate as seen in tracking and muon chambers.

Marcus Hohlmann and Larry Nodulman continued supporting the monitoring of data quality. Steve Kuhlmann, Tom LeCompte and Larry Nodulman continued cycles of being shift leaders, and Bob Wagner took an occasional week.

The detector was removed from the collision hall after a period of machine studies and source calibrations for the central EM calorimeter.

c. CDF Planned Activities and Planning Issues

The current nominal plan for run 2 is to roll the detector in during 1999. Unfortunately, the funding profiles given to both CDF and D0 seem more appropriate to completing the upgrades significantly later. The main injector program, on the other hand, seems likely to be able to provide luminosity on schedule. Both collaborations and Fermilab are facing difficult decisions on lowering the scope of upgrades, staging, and/or delay. Schedule options which put fixed target running after the main injector completion are being considered.

The PAC and the laboratory have defined run 2 to start at a luminosity of $10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ and grow by a factor 2 or more from there, although a weaker start and slower growth may result from funding limitations. Datasets of about 2 fb^{-1} is anticipated by about 2002. A permanent magnet antiproton recycler ring in the main injector tunnel is to be included in the main injector project.

A technical design report (TDR) for the upgraded CDF run 2 detector has been largely completed pending intermediate tracking and integrated tracking studies and changes expected from the muon review. Larry Nodulman was the originator of the central calorimeter chapter and a designated reader for the plug calorimeter chapter and the overview. Tom LeCompte is the coordinator for the muon chapter. Karen Byrum wrote a section on central shower max front end electronics issues. Barry Wicklund was a designated reader for the b-physics chapter. The TDR was completed in September.

Several workshops leading to Snowmass were held to study issues of possible high luminosity running following the couple 2fb^{-1} defined as run 2. This 'TeV33' effort is a Fermilab run follow up to TeV2000. Steve Kuhlmann, Karen Byrum, Larry Nodulman and Barry Wicklund have been active in this program.

(L. Nodulman and B. Wicklund)

I.A.4 Non-Accelerator Physics at Soudan

a. Physics Results

During the first half of 1996 Soudan physicists completed the analysis effort on the identification and characterization of atmospheric neutrino interaction events from the first 1.5 kt-year of Soudan 2 data. The goal of this analysis is to measure the ν_μ / ν_e "flavor" ratio for atmospheric neutrinos using quasi-elastic events in Soudan 2. The quantity R is the ratio of the measured flavor ratio to that predicted by Monte Carlo simulations. $R \neq 1$ has previously been interpreted as evidence for neutrino oscillations.

The 1.52 kton-year exposure was recorded between April 1989 and December 1993. During this period the detector was under construction, starting with a total mass of 275 tons and ending with the complete 963 tons. A total of 43 million triggers was taken. The goal of the data reduction is to obtain a sample of 'contained events', defined as ones in which no primary particle in the event leaves the fiducial volume of the detector. The events are passed through a software filter to reject events with tracks entering or leaving the fiducial volume, defined by a 20 cm depth cut on all sides of the detector, or events which have the characteristics of radioactive background or electronic noise. Approximately 1 event per 1500 triggers passes this filter. A preliminary analysis of the first 1.0 kt-year was completed in 1993, using an early version of the Monte Carlo simulation. An extensive upgrade of the Monte Carlo simulation software was completed in early 1995, providing more accurate representations of neutrino interactions and of the detector response to particles produced in these events. At the same time, a new analysis procedure was adopted to provide a better understanding of systematic errors in the atmospheric neutrino flavor ratio measurement.

The analysis relies on the physicist classification of contained events, which is an inherently subjective process involving pattern recognition skills and physics judgments. The physicist scan is carried out by two independent teams on a mixed, unlabeled sample of Monte Carlo and data events. Comparison of event classifications made by the two analysis teams gives a measure of the systematic uncertainties of the scanning process. Comparison of the classification of Monte Carlo events with the actual event types measures the event classification confusion matrix, and allows physics results to be corrected for misidentification effects.

The ANL team finished its analysis in early 1996, and the results of this analysis are recorded in the Ph.D. thesis of Hugh Gallagher. The two teams subsequently met and reclassified those events which were not the same in the two data sets. This joint result is the consensus sample, and forms the basis of the final analysis. Differences between the two independent analyses are used for estimating systematic error due to subjectivity. Approximately one event in 40 data events passed by the program filter is finally selected as contained. Monte Carlo events equivalent to 5.9 times the exposure of the real data were generated and passed through exactly the same data analysis procedure.

The lepton flavor of each data and Monte Carlo event is determined by the scanners who flag them as 'track', 'shower' or 'multiprong'. Tracks which have heavy ionization and are straight are further classified as 'protons'. Proton recoils accompanying tracks and showers are an additional tag of quasi-elastic scattering and are ignored in the classification. Any second track or shower in the event results in a multiprong classification. The quality of the flavor assignment was measured using the Monte Carlo data. Table 1 gives the identification matrix for Monte Carlo events selected as contained. It can be seen that 87% of events assigned as tracks have muon flavor and 96% of showers electron flavor.

<i>Generated</i>	<i>Assigned</i>			
	<i>Track</i>	<i>Shower</i>	<i>Multiprong</i>	<i>Proton</i>
ν_u^{cc}	242	3	98	
ν_e^{cc}	15	255	119	1
Neutral Current	21	9	44	18

Table 1. Monte Carlo identification matrix.

Early data had some contamination of the shower sample from electrical breakdown in some modules. This was much improved as the experiment progressed by optimization of the wireplane voltages and refurbishment of the worst modules. In order to remove this contamination a cut which required ≥ 9 hits was applied to the showers, corresponding to an energy cut of approximately 150 MeV. Raising this cut had no significant effect on the ratio R . A minimum of 6 hits on tracks was required,

corresponding to a muon kinetic energy cut-off of approximately 40 MeV. Tracks produce a very regular pattern of hits in the honeycomb geometry which breakdown processes do not reproduce and there is no evidence of such contamination of the track sample.

A total of 723 data events are classified as contained. This is much greater than the expected neutrino rate of about 100 events/kton-year. We conclude that the majority of these events are due to the interactions of neutral particles (neutrons or photons) produced by muon interactions in the rock around the detector. The active shield is designed to flag such "rock" events by detecting the muon and/or other charged particles which are produced in the muon interaction but do not enter the main detector. It was placed as close to the cavern wall and as far away from the detector as possible to maximize the probability of detecting the accompanying charged particles. Calculations indicate that only a few per cent of such events will not have charged particles traversing the shield. The efficiency of the shield as a function of time and geometry has been measured to be between 81% and 93% using cosmic ray muons detected in the main detector. We estimate that 7 ± 2 zero shield hit "gold" events are due to muon interactions with a charged particle passing through the shield which was not recorded due to shield inefficiency.

Our sample of rock events, used to determine the properties of any potential non-neutrino background, was defined as those with ≥ 2 shield hits since the one shield hit event sample also contains randomly vetoed neutrino events. Table 2 gives the raw numbers of gold, rock and ν Monte Carlo events in our sample, divided into track, shower, multiprongs and proton.

	<i>Track</i>	<i>Shower</i>	<i>Multiprong</i>	<i>Proton</i>
Data: Gold	47	60	51	10
Data: Rock	160	169	90	56
Monte Carlo	278	267	252	25

Table 2. Classifications for the contained events before corrections.

In addition to 7 ± 2 rock events expected in the gold sample because of shield inefficiency, there is also the possibility that neutrons or photons may enter the detector without being accompanied by charged particles in the shield. Our large sample of rock events enables us to investigate this potential background by studying the depth distribution of the events in the detector. The events produced by photons and neutrons will be attenuated towards the center of the detector, whilst the neutrino events will be uniformly distributed through the detector. We define a measure of the proximity of the event to the detector exterior by calculating the minimum perpendicular distance from the event vertex to the detector edge, not including the floor. Figure 1 shows this depth

distribution for gold, Monte Carlo and rock tracks and showers. The Monte Carlo distributions are normalized to the exposure of the experiment and the rock sample is normalized to the same number of events as the data sample.

Comparison of the Monte Carlo and the gold data depth distributions indicates that there may be a small excess of events at small depth in the shower sample whilst the track distribution closely follows the expected neutrino distribution. However the discrimination between rock and Monte Carlo distributions is better in the shower sample because of the short distance photon component. We fit the gold data to a combination of ν Monte Carlo and rock events, constraining the ratio of the background in the gold tracks and showers to be equal to the measured ratio in the rock events. The χ^2 / NDF for the combined track and shower fit is 0.42 and it gives a total background of 20.6 ± 8.9 events, which are to be divided between tracks and showers in the measured rock ratio. The number of background events is consistent with those found in the unconstrained fits and the fit quality is equally good. There is a small systematic error introduced by the assumption that the background in the gold sample is represented by the rock sample.

To calculate R we correct the raw numbers of gold events using the background estimated in the constrained fit. The numbers entering the calculation and the corrected and uncorrected values of R are given in Table 3. The error on R includes the error due to the background subtraction as well as the statistical errors on the numbers of data and Monte Carlo events. The background correction has only a small effect on the value of R but adds to the error.

Fig. 1. The depth distributions for tracks (top) and showers (bottom). The data points are the gold data, the shaded histogram is the gold Monte Carlo, normalized to the experiment exposure, and the unshaded histogram is the rock data, normalized to the same number of events as the data sample.

Number of gold tracks	47
Number of gold showers	60
Number of Monte Carlo tracks	278 (47.1)
Number of Monte Carlo showers	267 (45.3)
Number of rock tracks	160
Number of rock showers	169
Rock track/shower ratio	0.95 ± 0.10
Fraction of rock events in gold sample	0.062 ± 0.027
Corrected number of ν tracks	37.0
Corrected number of ν showers	49.4
Raw value of R (no background correction)	0.75 ± 0.16
Corrected value of R	0.72 ± 0.19

Table 3. Values of the various quantities used in the calculation of R . The Monte Carlo numbers in parentheses are scaled by the nominal factor of 5.9.

The systematic errors which could effect the value of R may be divided into the following categories:

- Systematic uncertainties in the incident neutrino flux ratio.
- Systematic uncertainties in the neutrino generator.
- Systematic uncertainties introduced by the scanning process.
- Systematic uncertainties on the background subtraction.

Our estimated systematic errors are summarized in Table 4. We find $0.72 \pm 0.19^{+0.05}_{-0.07}$. This value is about 1.5σ from the expected value of 1.0 and is consistent with the anomalous ratios measured by the Kamiokande and IMB experiments. However we note that since our acceptance matrix is different from those of the water Cherenkov experiments we would not expect to measure the same value of R , particularly if physics processes are occurring which are not simulated in our Monte Carlo. There is approximately a 7% chance that our measurement would statistically give 0.72 or less if the true answer is 1.0. To this level we support the observation of an anomaly in the atmospheric neutrino flavor ratio in a detector using a completely different detection technique and with different systematic biases. Data taking in Soudan 2 is continuing and

completion of our planned 5 kton-year exposure in 1999 should definitively resolve the question of the presence or otherwise of an anomaly.

Error	δR
Neutrino flux	± 0.038
Monte Carlo systematics	± 0.03
Scanning systematics	± 0.02
Background subtraction	+0.02 -0.05
Total systematic error	+0.05 -0.07

Table 4. Values of the components of the systematic error on R.

b. Experimental Apparatus, Operation and Maintenance

Argonne physicists continued to make substantial contributions to the maintenance and operation of the detector. Major activities included ongoing improvements of detector and electronics performance, and coordination of the module upgrade project. Argonne physicists also continued the development of software to make use of dE/dx information from the detector.

c. Planning Activities

In February, Soudan 2 was asked to present a status report for the new Department of Energy review committee, the SAGENAP panel (Scientific Assessment Group for the Evaluation of Non-Accelerator Physics). This panel heard reports on Soudan 2 progress on proton decay, atmospheric neutrinos, search for neutrinos from Active Galactic Nuclei, studies of cosmic ray muons and multiple muons, coincidences between the Soudan 2 detector and the surface array, and preparations for using the laboratory for the MINOS experiment. Soudan 2 experimenters also devoted a major effort to planning for the new MINOS long-baseline neutrino oscillation experiment, which is described elsewhere in this report.

(M. Goodman)

I.A.5 ZEUS Detector at HERA

a. Physics Results

Six papers were published in this period and three more manuscripts were submitted for publication.

The measurement of deep inelastic scattering (DIS), $ep \rightarrow eX$, at HERA has shown a rapid rise of the proton structure function $F_2(x, Q^2)$ with decreasing x for $x \leq 10^{-2}$. In perturbative QCD the rise of F_2 at low x is ascribed to an increase in the sea quark density. One of the important questions is how far perturbative QCD retains its validity as one probes large parton densities. Figure 1 shows measurements of $F_2(x, Q^2)$ at very low x and Q^2 values as low as 1.5 GeV^2 . The measurements are based on two sets of data, one collected with a vertex shifted in direction of the proton beam and the other containing the subsample of events collected at the nominal vertex, but with substantial initial state radiation. The data are compared to predictions of GRV94 which are based on perturbative QCD using the DGLAP evolution equation. The predictions are in agreement with the data, showing that pQCD can describe the data down to Q^2 values of 1.5 GeV^2 at the low x values of this measurement. The predictions of Donnachie and Landshoff based on Regge phenomenology are also shown and are seen to be ruled out for $Q^2 \geq 2 \text{ GeV}^2$ and disfavored for $Q^2 = 1.5 \text{ GeV}^2$.

The formation of hadrons in DIS is a complicated process which can not be fully calculated in pQCD. In order to model the process, it is convenient to distinguish two phases of the hadron formation. They correspond to a perturbative phase for QCD processes on the parton level followed by a non-perturbative phase describing the confinement of the partons to observable hadrons. Figure 2 shows the average transverse momentum of $\langle p_t^{*2} \rangle$ of charged tracks in the photon-proton center-of-mass system versus the scaled longitudinal momentum, x_F , of the tracks. The ZEUS data, at an average γ^*p center-of-mass, $\langle W \rangle = 120 \text{ GeV}$, are shown together with results from fixed target DIS at lower $\langle W \rangle = 14 \text{ GeV}$. Comparing the results at high and low W , there is a strong increase of $\langle p_t^{*2} \rangle$, by about a factor of three, over the whole range of x_F . The prediction by the Quark Parton Model clearly fails to describe the data. On the other hand, the Monte Carlo models based on leading order effects incorporated either as

ZEUS 1994

Fig. 1. The measured F_2 from the shifted vertex analysis (solid dots), the initial state radiation events (solid triangles), and the 1993 results (open squares) compare with the expectations from GRV94 (solid line) and Donnachie and Landshoff (dashed line).

ZEUS 1993

Fig. 2 $\langle p_t^{*2} \rangle$ as a function of x_F from this analysis compared to results from μp DIS at $\langle W \rangle = 14 \text{ GeV}$. The curves show results from model calculations at HERA energy with the MEPS model (solid curve), the CDMBGF model (dashed curve), and the QPM (dotted curve).

parton showers (Lepto MEPS) or as particle emission from color dipoles (CDMBGF) gives a reasonable description of the data.

The cross sections for diffractive virtual photon-proton scattering, $\gamma^* p \rightarrow X + N$, where N is either a proton or a nucleonic system with $M_N < 4 \text{ GeV}$, have been determined by a novel method which uses the mass M_X of the system X . The distribution in $\ln M_X^2$ exhibits for the non-diffractive component an exponential fall-off towards small values of $\ln M_X^2$. Diffraction is then defined as the excess of events at small $\ln M_X^2$ over an exponentially falling background. Since the non-diffractive background is determined directly from the data, this method reduces the systematic uncertainties of

background estimates compared to methods based on Monte Carlo models. Figure 3 shows the diffractive structure function $F_2^{D(3)}$ versus β , the momentum fraction of the Pomeron carried by the parton which interacts with the photon. The data are compared to various Pomeron models. The model where the Pomeron is considered to be a single-gluon leading to photon gluon fusion, followed by subsequent color-compensation, fails to reproduce the rise of $F_2^{D(3)}$ at small values of β . The predictions of the Hard-POMPYT model, where the γ^* -Pomeron interaction results in a quark-antiquark pair and where the quark momentum density is given by $\beta f(\beta) \propto \beta(1-\beta)^2$, also fails to reproduce the measurement at small values of β . However, agreement can be obtained by the inclusion of a soft component in the Pomeron leading to the form

$$\beta f(\beta) \propto \beta(1-\beta) + \frac{g}{2}(1-\beta)^2,$$

as suggested in the model of Nikolaev and Zakharov. The latter assumes that the Pomeron is identical to a colorless two-gluon exchange.

Photoproduction events which have two or more jets have been studied in the $W_{\gamma p}$ range $135 \text{ GeV} < W_{\gamma p} < 280 \text{ GeV}$. A class of events was observed with little hadronic activity between the jets. Figure 4 shows the fraction of events with a gap between the jets, defined as the absence of particles with transverse energy in excess of 300 MeV, versus the pseudorapidity separation, $\Delta\eta$, of the jets. The fraction decreases exponentially up to a value of $\Delta\eta \sim 3$, as expected for processes in which color is exchanged between the jets, then reaches a constant value of about 0.1. The excess above the exponential fall-off can be interpreted as evidence for hard diffractive scattering via a strongly interacting color singlet object. This result is consistent with similar observations by the experiments at the Tevatron collider, thus suggesting the same underlying process.

ZEUS 1993

Fig. 3 The diffractive structure functions $F_2^{D(3)}$ as a function of β at $x_p = 0.003$. The full line shows the predictions of Hard-POMPYT. The dashed line shows the prediction of Hard-POMPYT with an additional gluon contribution suggested by the Nikolaev Zakharov model and fitted to the data. The dashed-dotted (dotted) line shows the predictions of the Pomeron model based on photon-gluon fusion dynamics at 14 (31) GeV^2 .

Fig. 4 The fraction of events with a gap between jets versus the separation of the jets in pseudorapidity. The data are compared to a fit to an exponential plus a constant.

Fig. 5 The elastic ϕ photoproduction cross section as a function of W . The solid dot is the ZEUS measurement, while the open circles are lower energy data. The line is a description of the fixed target data using $\sigma_{\gamma p \rightarrow \phi p} \propto W^{0.32}$.

Fig. 6 The $\gamma^* p \rightarrow \phi p$ cross section as a function of W for several values of Q^2 . The low energy data come from fixed target experiments. The dashed and solid lines are drawn to guide the eye.

Elastic ϕ production has been studied in deep inelastic scattering as well as in photoproduction. The ϕ mesons are reconstructed via their decay into K^+K^- . The integrated photoproduction cross section was measured at $W_{\gamma p} = 70$ GeV to be $\sigma_{\gamma p \rightarrow \phi p} = 0.96 \pm 0.19^{+0.21}_{-0.18} \mu\text{b}$ and seen to rise only lightly compared to low energy data, see Fig. 5. In DIS the cross section shows a steep rise with W as shown in Fig. 6. This strong dependence can not be explained by production through soft Pomeron exchange.

It is, however, consistent with perturbative QCD expectations, where it reflects the rise of the gluon momentum density in the proton at small x .

b. HERA and ZEUS Operations

The 1995 e^+p data taking was completed at the end of November with HERA delivering 12.2 pb^{-1} and ZEUS logging 7.1 pb^{-1} . The subsequent machine shutdown was used to make a number of significant improvements to both the detector and the collider.

The installation of a tungsten/scintillator calorimeter at 8 meters from the interaction point in direction of the electron beam will allow the precise studies of photoproduction at large $y = 0.90 - 0.95$ and high $W_{\gamma p} \sim 290 \text{ GeV}$. The addition of a remote-controlled moving mechanism for the 44-meter photoproduction tagger, including that section of the beam pipe, will significantly increase the detector's acceptance, now covering a range of $W_{\gamma p}$ between 70 and 120 GeV. The installation of the forward hadron-electron separator, located inside the forward calorimeter, is nearing completion, with an additional eight modules now equipped with silicon diodes.

Due to the installation of the HERA-B detector, the entire west straight section of the HERA machine had to be modified. The modifications were successfully accomplished. Last year's machine operation suffered from an unusually high number of power failures of the electron ring. To improve the machines duty cycle, the capacity and regulation of the water cooling was improved and new hardware for the chopper power supplies was installed.

Many discussions within the ZEUS Collaboration were devoted to the options for the mode of operation for the 1996 running period. Since the dominating systematic error in the determination of F_2 is now given by the uncertainty in the subtraction of the longitudinal structure function of F_L , the ZEUS Collaboration spent a considerable amount of effort in understanding the possibility of its determination in a low proton energy run. However, since the H1 Collaboration recently performed significant upgrades to their detector, their primary interest is in acquiring a large data sample at the nominal proton beam energy. The decision on the machine operation for the 1996 running period will be taken jointly with the DESY Directorate in early August.

(J. Repond)

I.A.6 BNL AGS Partial Snake Magnet Experiment

We continue work on upgrading the capabilities of the AGS polarimeter for the next run. the next run will concentrate on new methods to overcome intrinsic resonances.

(D. Underwood)

I.B EXPERIMENTS IN PLANNING OR CONSTRUCTION

I.B.1 Polarimeter for RHIC Spin Experiments

For a RHIC polarimeter design, asymmetry measurements in inclusive pion production at large x_F with an AGS polarized beam are planned. The measurement would be made using the 23-GeV/c proton beam in an extracted beam line, a spectrometer consisting of an analyzing magnet, scintillation hodoscopes, scintillation trigger counters, and a gas threshold Cerenkov counter. The kinematic range covered by the experiments would be p_T up to 1.0 GeV/c and $x_F = 0.5$ to 0.8. We anticipate measurements will take place at the end of full-energy polarized beam test (likely in July, 1997).

(A. Yokosawa)

I.B.2 MINOS – Main Injector Neutrino Oscillation Search

The goal of the MINOS experiment is to search for neutrino oscillations as extensively as possible in regions of $\sin^2(2\theta)$ and Δm^2 parameter space which have not previously been accessible to accelerator experiments. If oscillations are found, the experiment will be able to measure the parameters and determine the oscillation mode. The experiment requires the construction of a high intensity neutrino beam, produced by Fermilab's new Main Injector accelerator, the excavation of experimental halls at Fermilab and 730 km away at Soudan, Minnesota, and the construction of magnetized iron tracking calorimeter detectors at Fermilab and Soudan. The 10 kiloton "far" detector at Soudan will be an 8-m diameter, 50-m long assembly of 4-cm thick steel planes which alternate with planes of active detector elements. The "near" detector at Fermilab will as similar as possible to the far detector, but will be much less massive owing to the higher neutrino flux. The presence of oscillations will be signaled by changes in the rates and characteristics of observed neutrino interaction events which are not caused by predicted differences in the neutrino beam at the two locations. The MINOS collaboration currently consists of 160 physicists and engineers from 21 institutions in the U.S., U.K., Russia, and China.

During the first half of 1996 the MINOS collaboration continued work to complete the design of the experiment. The designs of major experimental systems must be frozen near the end of FY 1997 in order to be ready for the first neutrino beam in June 2001. The collaboration is in the midst of an intensive development program to optimize the designs of the active detector technology, the fabrication technique for the steel detector planes, the neutrino beam configuration, and the halls for the near and far detectors. Figure 1 outlines the current schedules for key tasks which will allow the experiment to begin taking data with the first third of the far detector and the wide-band neutrino beam in 2001. Important accomplishments during the first half of 1996 include:

1. Completion of the initial version of the comprehensive neutrino beam simulation to be a significant package, GBEAM. This software is based on code developed for MINOS by Argonne physicists and adopted by the MINOS beam group at Fermilab. It is now being used to perform a detailed evaluation of the new three-horn wide-band beam design, which appears improvement over the old two-horn beam design.
2. Development of a collaboration-standard Monte Carlo simulation package for the experiment, GMINOS. This software incorporates the coding standards adopted by the collaboration, and makes use of the neutrino beam simulation provided by GBEAM. It generates Monte Carlo neutrino events in MINOS near and far detectors instrumented with various steel and active detector options, and will be used to determine design parameters which maximize the sensitivity to oscillations.
3. Continued development of alternative active detector technologies. Iarocci chambers are being developed by the Argonne group, as described later in this report, while other MINOS collaborators are working on resistive plate counters (RPC's) and scintillator detectors. A major activity during this period was the study of prototype Iarocci and RPC detectors in an electron test beam at SLAC.
4. Evaluation of alternative steel plane fabrication technologies by the collaboration's Steel Technology Committee. The Argonne MINOS group is developing a "pie laminate" design for the 8-m diameter, 4-cm thick planes as an alternative to the "reference" design.
5. Determination of supplemental MINOS R&D funding for FY 1996. The collaboration submitted a detailed proposal for R&D work on active detectors, steel planes, and electronics and eventually concluded its discussions with Fermilab and with the DOE Division of High Energy Physics. This resulted in funding allocations from both Fermilab and DOE which totaled about 25% of our request. Although some work was curtailed because of this shortfall, much was

MINOS Timelines

Fig. 1. Overall design and construction schedule for the MINOS experiment. The time scale shown is in fiscal years.

accomplished using institutional resources, including two Argonne National Laboratory LDRD grants to the Argonne MINOS group.

6. Development of a comprehensive R&D plan and supplemental funding request for FY 1997 and FY 1998. This proposal was presented to the Fermilab Physics Advisory Committee in June and is still being discussed. The document includes a physics update, with a comparison of MINOS to the neutrino oscillation experiments being planned in Japan. One of these involves a high intensity neutrino beam from the new 50 GeV JHP accelerator to the 50 kiloton SuperKamiokande water Cerenkov detector. Although the detector is already in operation, the beam would not be ready until several years after MINOS begins data acquisition.
7. Initiation of a physics-based detector requirements study. The collaboration held a week-long workshop at a Minnesota resort near the Soudan mine in June. A

major focus of the workshop was the organization of a series of systematic studies of how the sensitivity of various oscillation tests in MINOS is related to detector parameters. Working groups were established to study four types of oscillation tests: NC/CC and near far, CC event energy, electron identification, and explicit tau identification. The conclusions from these studies could lead to significant changes in detector parameters, such as transverse granularity and steel thickness, and may also have an impact on the choice of active detector technology.

(D. Ayres)

I.B.3 ATLAS Detector Research & Development

a. Overview of ANL LHC Related R&D Programs

The Tile calorimeter subsystem realized a major milestone in the first half of 1996, in the construction of a full scale barrel prototype module. Argonne contributed extensively to this effort: 4 submodules were stacked at Argonne in February and shipped to DUBNA, in the Former Soviet Union, for module assembly and a technician was sent to CERN for the month of June to contribute to the instrumentation of the structure with scintillator tiles and wavelength shifting fibers. Our intention to participate in the module assembly was unfortunately blocked by an administrative ban on travel to the Former Soviet Union, exactly during the period when the module assembly took place. Following completion of the submodules, the mechanical work shifted to finite element modeling of the calorimeter structure. Several issues were raised without resolution, at an engineering meeting held at CERN at the end of June. This work is continuing. The testbeam was the other main activity of the calorimeter group. A combined liquid argon and tile calorimeter run was held during April; and we contributed shift personnel, one of the (two) run coordinators and software to provide realtime feedback on the quality of the data. In addition, in preparation for the beam test of the barrel prototype module scheduled for August of this year, motors and controls for the transporter to be used to carry the module were procured and assembled as an operating system at Argonne for testing prior to shipment to CERN at the end of June. Finally, the US ATLAS project as a whole began the process of re-evaluating the project cost and scope. The TileCal subsystem held a meeting in April at MSU to address these issues in preparation for US ATLAS executive board meetings at Brookhaven and the University of Santa Cruz. In addition, a meeting was held at Argonne in June to begin planning the distribution and schedule for work on the extended barrel prototype module to be built in the upcoming fiscal year.

The following internal Technical notes and papers have been submitted during this report period.

1. Experiences with stacking the first four ATLAS submodules at Argonne

2. Plate stamping of masterplates for the Tile-cal hadronic calorimeter used in the ATLAS detector at CERN
3. Numerical Calculation of the Sampling Variation Intrinsic to the TileCal Scintillator Geometry

(J. Proudfoot)

I.C DETECTOR DEVELOPMENT

I.C.1 CDF Detector and DAQ Electronics Development

a.1 Tracking Devices

a. Central Tracker

The Argonne group, with Bob Wagner in the lead, worked with the Duke and Michigan groups and others to develop a straw tracker based on SDC experience to replace the CTC. The alternative was an open cell chamber like the CTC with smaller cells which would allow considerable recycling of expertise from the CTC. Bob Wagner worked with Phil Schlabach and Bob Kephart at Fermilab to develop a sufficiently worked out design to allow a detailed cost and schedule to be developed. A pseudocontinuous fanned out scheme was proposed for stereo straws. Barry Wicklund developed tracking code and simulations which showed that the straw tracker was technically viable.

Cost and schedule concerns were predominant factors in a large scale internal review of central tracking in March. The substantial cost advantage and significant schedule advantage of the open cell design were pointed out by the review, and the collaboration adopted the open cell design. Our group is becoming involved in this project, and in particular, Vic Guarino has started important FEA studies of the end plate mechanics.

b. Intermediate Tracker

A similar internal review of the intermediate fiber tracker project found substantial concerns about cost, schedule, management and technical viability. In parallel to attempts at remedying the problems of the fiber tracker design, alternative proposals were called for. Barry Wicklund led an effort by the Argonne group and others to demonstrate the viability of a straw system for these purposes. In particular, he worked out a clever and easy to build scheme for stereo straws.

An open cell option and an extension of the silicon system were also put forward. Of the four options, the open cell option was found not to be viable. A choice was needed by early August. The project managers recommended the silicon extension, named ISL, which provides two additional double-sided readout planes in the two $1 < |\eta| < 2$ and one plane in between. Space will be left for a possible fast trigger tracking device, such as a straw superlayer, to be added later.

c. Front End Electronics

Karen Byrum has taken charge of interfacing the CES into the DAQ and trigger. The CES test setup was moved into an office and the background noise is much reduced. John Dawson was not able to come up with a quiet enough amplifier for CES, and we are now working with Fermilab engineers on this. The cards for these amplifiers and the QIE/ADCs for shower max being developed by Aesook Byon and Bill Foster at Fermilab remain our responsibility.

Karen Byrum, Larry Nodulman and Gary Drake of Fermilab did a noise study on the detector before it was removed from the collision hall which demonstrated that a different grounding scheme would be more favorable for noise rejection. Previously the chamber ground was provided by the ground side of the readout twisted pairs. It is better to float those and ground the chamber on the high voltage side.

d. Muon Upgrades

Tom LeCompte was appointed co-project manager for muon upgrades. As a first duty, a comprehensive review of forward muon plans was scheduled for early August. We expect to become involved in the engineering for providing movement capability for the repositioned toroids.

(R. Wagner)

I.C.2 ZEUS Detector Upgrade

a. Barrel Presampler (BPRES)

The final proposal for the barrel presampler was finished by January 1 and released to the ZEUS collaboration. It was presented to the DESY Physics Research Committee (PRC) at its January 16-17, 1996 meeting where final approval for the project was given.

Final construction and installation schedules were completed and a revised final budget was developed in preparation for presentation to the U.S. DOE. The presentation was made at the DOE Germantown Headquarters on February 12, 1996 by Wesley Smith

of the University of Wisconsin, Malcolm Derrick, and Steve Magill. Table 1 shows the budget as presented to the DOE representatives. The presentation of the budget profile was made in two scenarios - full funding in the remainder of FY96 and partial funding in each of FY96 and FY97.

<i>Item</i>	<i>Number</i>	<i>Unit Cost \$</i>	<i>\$ Spent</i>	<i>\$ Needed</i>
Hexcel covers	66	-	-	28000
Aluminum sides	66	-	1600	-
Aluminum trays	33	-	-	1600
Plastic tile supports	33	-	3131	5500
Source tubes	33	-	403	-
Cassette TOTAL	33	1220	5134	35100
Tile machining	864	-	3730	20300
WLS and clear fiber	1728	16	3750	24300
Scintillator TOTAL	864	60	7480	44600
R647-01 PMTs	435	280	-	122000
PMT bases	450	130	-	59000
PMT housing	32	1710	-	54700
Calibration system	-	-	-	5000
Digital electronics	480 chan	110	-	52800
Contingency				20000
Equipment TOTALS	33	12300	12614	3932000
Grand TOTAL US EQUIPMENT			405800	
Estimated Effort			121000	
Grand TOTAL US			526800	

Table 1. ZEUS Barrel Presampler Budget

Some work was done in this period using \$65K of funding from AMZEUS FY96 equipment funds while waiting for final DOE approval and funding allocation. This primarily involved procurement of cassette construction material and some initial preparation of parts. As additional \$80K of FY96 funds and \$100K of FY97 funds from the ANL HEP base equipment budget was promised upon DOE approval.

Final approval by the DOE came in June 1996, along with a funding scenario which provided for approximately 60% of the remaining required funding in FY97. The final 40% was made up of additional contributions from DESY (in the form of parts procurement and preparation) and AMZEUS.

Procurement of parts started in earnest in June 1996 and preparations for module construction at ANL and installation at DESY in the 1996-97 HERA winter shutdown began.

(S. Magill)

I.C.3 STAR Calorimeter and RHIC Polarimeter Development

a. STAR Calorimeter

We were involved in studies of how to detect and measure jet quenching in a Quark-Gluon Plasma. Simulations showed that the low energy jets are hard to measure individually due to the large background. We expect about 900 MeV per 0.1 by 0.1 (eta-phi) calorimeter tower, with large fluctuations. Gamma-jet and jet-jet processes were considered for purposes of normalization. This was documented.

We began work on a more realistic fiber-routing model for the calorimeter modules. We also began optical studies for possible use of "Mega-Tiles" as an alternative to using edge-readout tiles.

We continued simulations of the effects of dead areas, cracks, in the STAR EMC. This work was aided by visiting faculty and our new assistant physicist.

b. RHIC Polarimeter

We did more development work on the toroidal magnet scheme for RHIC polarimeters and improved the documentation. This was received enthusiastically by RHIC SPIN. Magnet design studies began at BNL on the basis of this design.

This design minimizes the magnetic field effects on the beam, and allows measurements over the full energy range without physically moving the magnets.

(D. Underwood)

I.C.4 ATLAS Calorimeter Development

a. Hadron Calorimeter Mechanical Design

1. Submodule Stacking

Beginning the end of January, 4 submodules to be included in the barrel module 0 prototype were assembled at Argonne over a period of about three weeks. A great deal

of information was obtained from this task and was documented in a TileCal internal report for use in the development of the production plan. The thickness of the master plates was measured before and after surface preparation to determine the average reduction in thickness applied by the process. This data, taken together with similar measurements made in Prague for the spacer plates, was used in a comparison to the stack height of a "dry" stack (one in which no glue was applied and the stack compressed to a point at which no additional decrease in height could be observed). This allowed confirmation of our basic component specification and the dry stack height itself used to determine the volume of glue required to bring the stack to the design height of 293.2mm. A three- person crew was used for the assembly, and we determined that this would allow the production of 2 submodules per week. Due to delays in the assembly of the components for an automated gluing system, the 2-component epoxy was applied manually using templates to define the location and size of glue spot. A completed stack on the stacking table loaded with the compression plate during the epoxy curing period is shown in Fig. 1. Information was also obtained on shrinkage and module deformation associated with the welding of the inner and outer radius straps. The four submodules fully met the TileCal specification and were subsequently successfully assembled into the barrel prototype module.

Fig. 1. One of the four submodules assembled at Argonne for the barrel prototype module. At this stage the stack has been compressed with the load plate while the glue cures (a period of about 16 hours.)

2. Module Assembly

The submodules fabricated at Argonne were shipped to Dubna at the beginning of March where they were assembled together with submodules fabricated at 5 other collaborating institutions into a barrel prototype module. Due to an administrative ban on US travel to the former Soviet Union, Argonne was the only institution not represented in this effort. The mechanically assembled module is shown in Fig. 2. The assembly required only 7 days and was accomplished with reasonable ease. However, although successful, the operation was significantly different from the planned approach due to problems with the assembly tooling; and, therefore, it was particularly unfortunate that no Argonne engineer was present, since we now have to replicate a modified assembly scheme without the benefit of this experience.

The mechanically assembled module was transported by truck to CERN for instrumentation with scintillators and fibers, tasks for which Argonne contributed one of the 4 technicians. The module transportation also uncovered some flaws in our approach of loading and handling the module, which will be corrected prior to fabrication of the two extended barrel prototype modules, scheduled for CY97. At the end of June, this module was essentially fully instrumented with readout scintillators and fibers and awaited the installation of readout electronics.

Fig. 2. Barrel module 0 assembly at DUBNA in Russia

3. Master Plate Die QC

As part of the contract with Banner Tool and Die Corporation for the stamping of 1200 master plates, 14 plates were subjected to a certified inspection, which was carried out by Quality Calibration Service. The inspection data fell into two classes: dimensions defining the plate envelope; and dimensions defining relative internal positions. Figure 3 shows the difference between the actual and the nominal dimension for the ensemble of dimensions defining the plate envelope. All points are within specification which in general was $\pm 0.1\text{mm}$ (the one point lying below -0.1mm has in fact a specification of $\pm 0.25\text{mm}$). A more detailed analysis of this data shows that the plate-to-plate uniformity can be expected to be somewhat better than the general specification (as might be expected from the method of fabrication).

Fig. 3. Die tolerance envelope verification from a sample of 14 plates subjected to a certified inspection. All dimensions are within specification.

4. Stacking Fixture Integration with Automated Glue System

The stacking table and glue head assembly is shown in Fig. 4. The glue head assembly rides along a pair of Thompson rails along the length of the stacking table in order to gain access to the entire submodule which is being assembled. The glue head assembly consists of the glue head dispenser, containers for the glue components, the x,y,z table, and the controllers for the motion table and the glue dispenser. A personal computer next to the stacking table contains the programs which control the motion of the x,y,z table. The glue head assembly is moved manually to each spacer plate location, a control push-button on the glue head assembly is then pushed to put in motion the x,y,z table, which positions the glue head at the appropriate points to dispense glue. The x,y,z table and the glue head are electronically connected so that when the appropriate location is reached, the table controller sends a signal to the glue controller to dispense a shot of glue. Upon completion, the glue controller sends a signal back to the table controller, indicating that glue has been successfully dispensed and to move on to the next position.

Initially this system took approximately 6 hours in a dry run to complete one submodule. The system was limited by the speed of the drive motors on the x,y,z table. Higher torque motors were purchased and installed which reduced the cycle time for a submodule to 3 hours.

Fig. 4. Automated glue head integration with stacking table (schematic).

5. Structural Analysis

The Atlas extended barrel will be subjected to different loading conditions during construction, upon final assembly, and from external loads (such as the cryostat). Each of these separate loading conditions must be fully understood in order to properly design the necessary fixturing, assembly procedures, and connections between individual modules. A series of analyses were performed in order to begin to gain an understanding of the forces and their distribution in the extended barrel. These were performed in two stages. Firstly, a 2-dimensional analysis was performed, which was based upon the modules within the barrel being in static equilibrium. Secondly, a 3-dimensional finite element model was created of a complete extended barrel, which is connected across the top. It was assumed in each analysis that each module was supported only by a bearing force at the inner and outer radius and a radial force at the outer radius.

The initial analysis calculated the forces between modules in the extended barrel by solving for static equilibrium. Only half of the barrel was modeled, symmetric boundary conditions were applied at the 6 o'clock position but at the 12 o'clock position, the module was assumed to be free from external forces. Within every given module all forces must be in equilibrium. Solving for static equilibrium for every module then results in a series of linear equations which were solved for the connecting forces utilizing a fortran program. This calculation, unlike the finite element calculation described below, does not require knowledge of the stiffness of the modules and girder. The static analysis assumed a single point of support and several iterations were run in which the point of support was varied from the very bottom of the barrel to the 10th module from the bottom. In each of the separate analyses, the compressive bearing force on the front plate begins to increase after the point of support is reached. All of the analyses show a maximum compressive force on the front plate of 123 metric tons (1,200 kN). If it is assumed that this load is evenly distributed over the full 2.6m of the extended barrel on the 7mm wide inner radius plate then the bearing stress on the front plate is 66.3N/mm^2 (9615 psi). Tests on a submodule which have been performed by J. Blocki indicate that the bearing area which is actually available to carry this compressive load is significantly smaller, which will significantly increase the compressive stress on the front plate. The results of this analysis were identical to a similar analysis performed by J. Blocki at CERN.

Following on from the analytical calculation, a 3-dimensional finite element model of the extended barrel was created to simulate the static situation implied by it. In this analysis a complete extended barrel was modeled in which forces are carried across the module at the 12 o'clock position. Only half of the barrel was modeled with symmetric boundary conditions applied at the 6 and 12 o'clock positions. As in the static analysis above, it was assumed that the modules were connected by a bearing force at the front plate and a bearing and radial force at the outer radius. A further assumption was that the extended barrel was supported only at $z=0$ and at $z=2.6\text{m}$ at modules 5 through 10.

The front plate and girder were modeled using plate elements. The submodules, however, were modeled using solid elements since the problem would have become too large if it were cast at the level of individual master and spacer plates. The limitation of this modeling method is that the stiffness of the submodules is required and is unknown.

For the initial analysis it was assumed that the submodules had a stiffness of solid steel, 206.9 kN/mm^2 . This analysis showed that the maximum bearing force on the front plate is 108 metric tons (1,000 kN) and occurs at the 19th module from the top. This results in a bearing stress of 58.2 N/mm^2 (8,441 psi), again for a 7mm bearing surface along the full length of the module. The FEA calculation also shows a tension force along the front plate at the first five modules from the top of the barrel. The maximum tensile force is 15 metric tons and demonstrates the need to design a tensile connecting member across the front plates. The maximum bearing force at the outer radius is 94 metric tons and occurs at module 24. The maximum radial force at the outer radius is 101 metric tons and occurs at module 23.

To set a plausible bound on the effects of the submodule stiffness on the loads, an analysis was performed in which the stiffness of individual modules was lowered to a value which was a sixth of solid steel, 34.5 kN/mm^2 . By creating an upper and lower boundary for the submodule stiffness, it was hoped to be able to determine a boundary within which the connecting forces between modules must fall without actually knowing the stiffness of the submodule. While the distribution of forces between the two cases was very similar, differences as great as 20 metric tons occurred. This indicates that the stiffness of the submodule is a significant factor in determining the magnitude of the connecting forces between modules. Further work needs to be performed in order to empirically determine the stiffness of the submodules.

The deflection of the extended barrel in both cases was also examined. Figure 5 shows the vertical deflection of the extended barrel. The stiffer module used in Case 5 results in significantly less deflection than the more flexible module used in Case 6. The maximum vertical deflection of the extended barrel occurs as expected at the top of the barrel and is -1.2mm in Case 5 and -2.4mm in Case 6. The horizontal deflections also show a similar effect from the module stiffness. The extended barrel wants to eggshell which results in the maximum horizontal deflections occurring at the 3 o'clock position. The maximum horizontal deflection in Case 5 is 0.7mm and 1.4mm in Case 6. In both cases it should be noted that the horizontal deflection is not zero at the 12 o'clock position which would be expected. These are caused by the deflection of the elements used to connect the modules together

Fig. 5. Finite element calculation of the vertical deflection in the extended barrel for two cases of the assumed submodule stiffness.

(V. Guarino and J. Proudfoot)

b. Test Beam Program

The thrust of the current year's effort was to mount two testbeam experiments at CERN within a period of 5 months. The first of these experiments was in April 1996, and consisted of a measurement of the response of a liquid Argon EM calorimeter positioned upstream of a stack of five TileCal test modules. The second measurement due in September 1996, will focus on the response of Module 0 to high energy particles.

HEP finished the design and construction of the VME-based charge injection system (CIS) and provided a standalone software package to manipulate the features of the electronics. The system was implemented in the April run to calibrate the ADCs which read out the TileCal test modules. HEP staff was heavily involved in the April run manning shifts, verifying the initial calorimeter system, and writing CIS monitoring software. HEP staff are taking an active part in the ongoing analysis of the April data.

A new result from this combined run is from the Midsampler counters, which are five scintillators placed on the front face of the Tile Calorimeter. There is about $1X_0$ of dead material in the liquid argon cryostat between the two calorimeters. The Midsamplers allow us to verify the energy correction due to loss in the dead material. It is indeed found that the energy measured in the Midsampler is proportional to the

geometric mean of the energy measured in the last sampling of the EMC and the first sampling of the HAC as seen in Fig. 6.

Fig. 6. Midsampler pulse height total for 300 GeV (a) muons, (b) pions and (c) electrons. The distinction between MIPS through the Midsampler and pions interacting in the liquid argon is clear. The electron plot shows a signal from low energy photons emerging from the cryostat. (d) The Midsampler total pulse height vs. the geometric energy mean of the last liquid argon sample and the first TileCal sample (arbitrary units).

Besides the construction and instrumentation of Module 0 for the September run, the HEP group was heavily involved in the coordination of the testbeam effort, and

the design and construction of the new 85 ton-capacity scanning table, particularly the drive mechanisms. The drives were designed such that the table would be fully operational under local or VME control for any of the z , θ or two ϕ coordinates. Four motors and controllers were purchased commercially. HEP designed and constructed a logic interface to VME, soft and hard limit switches, and absolute encoders, and the completed system was delivered to CERN in June. HEP personnel were at CERN installing the drives and control system, satisfying CERN safety requirements, and certifying precise operation in the testbeam environment.

(R. Stanek)

c. The ATLAS Level 2 Supervisor and Region-of-Interest (ROI) Builder

The ATLAS level 2 group has embarked on a program to explore three distinct trigger architectures. In order to quantify the flexibility and capabilities of these three architectures the group will build small prototypes of each. The Argonne group in collaboration with MSU will provide a Supervisor which will be suitable for all of them. The Supervisor will consist of several VME based PowerPC computers with dedicated routing hardware on the input and output (see Fig. 7). The Supervisor receives the level 1 trigger information for an event and allocates level 2 resources for processing the event and coordinates the dispatching of the data from the appropriate buffers to the level 2 processing farm through the readout buffer (ROB) and later to the DAQ if the event is accepted.

The dedicated hardware for I/O routing will be based on a PCI bus mezzanine card. A design for the dedicated hardware will proceed in several steps. The first step that has been completed is the fabrication and testing of a card to interface between the PCI bus and a FIFO. The next steps will add further I/O capabilities to next generation mezzanine cards. Benchmarking and timing estimates using measured transfer rates for the VME processors that will be used indicate that the system as designed should be able to function at the required 100kHz level 1 trigger rate.

On June 3 and 4 the Argonne group hosted a meeting to discuss details of the demonstrator program focused mainly on the ATM based architecture C. A number of participants attended from CERN, Saclay, MSU and Argonne. This architecture will be somewhat different than the other two and will not use some of the dedicated hardware, since the data requests to the readout buffers will be done by the level 2 processors directly and communication between the Supervisor and the level 2 processors will be through an ATM network. The challenge for this architecture will be to organize the Supervisor CPU tasks in a way that allows for a scalable system and to distribute communications tasks in a way that avoids bottlenecks.

Fig. 7. Functional model of the ATLAS level 2 Supervisor.

This work should produce data that will form the basis for projections of level 2 performance for the three architectures in the summer of 1997. During fall of 1997 the decision on which architecture will be used for the ATLAS experiment will be made.

(R. Blair and J. W. Dawson)

I.C.5 MINOS Detector Development

During the first half of 1996, MINOS R&D work at Argonne made substantial progress in all three areas described in the previous Semiannual Report: Iarocci chamber development, magnetized steel plane design, and electronics.

a. Iarocci chambers

Iarocci chamber development work has involved collaboration with MINOS groups at Argonne, Tufts, JINR-Dubna, PNPI-St. Petersburg, and IHEP-Beijing. Dubna and Beijing have previously operated Iarocci tube factories for large colliding beam detectors, providing much valuable experience in this area.

Iarocci tubes operated in limited streamer mode are used in the MINOS "reference detector," whose design is described in the MINOS proposal. The traditional Iarocci tube design involves the use of flammable gas (at least 30% isobutane), PVC plastic which may be unacceptable due to safety considerations, and mechanical tolerances which may be inadequate for MINOS calorimetry measurements. Thus some changes to the traditional design are required for MINOS, although much of the experience gained with very large Iarocci tube arrays built for other experiments will still be relevant.

As a result of laboratory studies of small prototype chambers with cosmic rays and radioactive sources, the Argonne MINOS group has proposed the following changes to the MINOS reference design.

- a) The chambers will be operated in saturated proportional mode instead of limited streamer mode. This allows the use of a nonflammable gas mixture. The anode wire diameter will be reduced from 100 microns to 50 microns to improve proportional mode performance.
- b) The traditional PVC "comb" extrusion will be replaced by a similarly shaped aluminum extrusion, which can be mass produced with better mechanical tolerances than plastic, and also does not require a conductive coating. This should give the uniform response needed for calorimetry without an increase in fabrication cost.
- c) The chambers will be built in 16-cm wide, 16-cell units instead of the traditional 8-cell units. This should result in substantial fabrication cost savings due to the smaller number of pieces which must be handled, although initial tooling costs will be higher.
- d) The chambers will be operated with high voltage on the anode wires, as in traditional chambers. The cost of the resistive covers needed to run the

chambers with high voltage on the comb extrusions, as described in the MINOS proposal, makes this technique much less cost effective than originally thought.

- e) After consideration of several alternative plastics for the gas sheaths (which surround the comb extrusions), it now appears that the traditional PVC plastic may be the preferred material, despite initial concerns about its ability to release corrosive fumes in the event of a fire.

The performance of this new reference design was investigated in a test beam at SLAC during April and May. The response of prototype chambers to electron showers was measured after 6 cm of steel (near shower maximum) at several energies. The proportional-mode response was compared with that of plastic scintillation detectors at the same location, and with traditional Iarocci tube detectors operated in limited streamer mode. Figure 2 is a scatter plot of the charge measured in a proportional-mode Iarocci chamber versus that measured by the reference scintillation counter. The ratio of charges is approximately independent of charge over a wide range of energies, for both streamer and proportional modes.

Figure 3 shows the energy dependence of the measured charge in a prototype chamber located near shower maximum, for both streamer and proportional mode operation. While the response appears to be linear in proportional mode, there is some evidence of saturation (undercounting of closely spaced hits in high energy showers) for streamer mode. In addition to these single-chamber studies, the test beam exposure was used to measure the response of a complete Iarocci chamber calorimeter, built by the Dubna group with PVC chambers and operated in both proportional and limited streamer modes. The energy resolution and charge responses obtained agree well with expectations.

During the second half of 1996 Iarocci chamber development work at Argonne will focus on the construction of full size chambers using components obtained from local commercial suppliers. The response of a prototype EM calorimeter using chambers built from these components will be measured in a Fermilab test beam during 1997.

Fig. 2. Scatter plot of the charge measured after 6 cm of steel in developing electromagnetic showers in the SLAC test beam by a prototype MINOS Iarocci chamber, compared to the response of a nearby scintillation counter. The expected linear dependence is observed.

Fig. 3. The energy dependence of charge measured in the SLAC electron test beam by a prototype MINOS Iarocci chamber located near shower maximum, for both streamer and proportional mode operation. While the response appears to be linear in proportional mode, there is some evidence of saturation (undercounting of closely spaced hits in high energy showers) for streamer mode.

b. Steel and magnet design

The "pie laminate" design of the magnetized steel detector planes is being developed at Argonne as an alternative to the "reference" fabrication scheme being

pursued at Livermore. Initial engineering studies were completed by the Argonne group during the first half of 1996. In this fabrication technique, each 8-m diameter, 4-cm thick steel plane is assembled from four 1-cm thick layers; each layer is constructed from 12 identical wedges. Each layer is rotated relative to adjacent layers so that the gaps between wedges do not line up at the same azimuth. The construction is designed to minimize the magnetic effect of gap irregularities and to provide very flat sheets. The larger number of components making up each plane (compared to the reference design) simplifies handling as the pieces are moved down the mine shaft, but may increase underground assembly time. The group submitted a proposal to the MINOS Steel Technology Committee to build and measure a full-size prototype pie-laminate plane during 1997.

The Argonne group is also performing magnetic field calculations for all steel plane geometries to determine how field quality depends on fabrication technique. Calculations during the first half of 1996 focused on comparisons of field nonuniformities caused by gaps between the segments of a single steel plane, in the reference and pie-laminate designs. The group also measured magnetization curves of steel samples with different compositions and manufacturing methods. In addition, the group made magnetic measurements on a small scale model of a MINOS steel plane and compared them to the results of calculations. Magnetic field quality considerations could be important in the collaboration's choice among the different steel-plane fabrication methods. The group will complete this phase of its work during the second half of 1996, when some initial decisions about steel plane fabrication may be made. collaboration.

c. Electronics R&D

Electronics design work is being performed by Argonne physicists and engineers in close collaboration with groups at Columbia, Oak Ridge, and Oxford. During the first half of 1996 these groups continued their work on the design of the overall architecture of the MINOS electronics triggering and readout system. In addition, the Argonne group designed and constructed front-end electronics for Iarocci chamber and RPC measurements in the SLAC test beam. They built a chassis containing 24 preamplifier channels with variable gain to accommodate the wide range of signal sizes from different detectors. Each channel also incorporated a self-triggering fast gate to eliminate afterpulsing in RPC's, so that the measured charge response would include only the initial pulse from each electromagnetic shower particle. This electronics performed well during the SLAC test beam run.

(D. Ayres)

I.C.6 Electronics Support Group

Work continued in support of the Nucleon Decay Experiment, Soudan 2. Our involvement during the period was one primarily of construction and maintenance. We

repaired 3 Anode H. V. Distribution Boxes, repaired 8 Anode Summer cards, repaired 65 Receive Amplifiers, repaired 8 Calibration Pulser Card, and repaired 3 Preamp Motherboards. Miscellaneous other pieces of electronic equipment were maintained as necessary. We have begun some work relating to the Long Baseline Detector (MINOS), and cooperated in building and testing prototype hardware. We designed and built one Afterpulse Suppression Box for use with the limited streamer chambers, and spent some time building and testing small electronic items to support the ongoing chamber development effort. We look forward to significant involvement in the hardware for the MINOS test beam running.

Historically, our major effort with regard to support of the ZEUS calorimeter was the development of the first level calorimeter trigger processor (CFLTP) and the trigger for the Small Angle Rear Tracker (SRTD). The ZEUS calorimeter first-level trigger processor presents summary data on energy deposition in the uranium/scintillator sampling calorimeter to the global first-level trigger (GFLT). The summary data includes global and regional sums of electromagnetic and hadronic energy deposition, the number of isolated muons and isolated electrons, missing transverse energy, jet cluster information, and the likelihood of beam-gas background. The CFLTP receives data from 16 regional trigger pre-processors which digitize the calorimeter signals and perform regional energy sums and logical operations. Design and construction of these regional pre-processors was the responsibility of our collaborators from Wisconsin.

A new trigger which we built was added to the ZEUS detector last year and has become the principal DIS physics trigger. The Small Angle Rear Tracking Detector (SRTD) has 272 scintillation fingers arranged as four quadrants in two overlapping planes around the beampipe and in front of the Rear Calorimeter. The scintillators are viewed by photomultipliers via fiber bundles. As photomultiplier outputs are carried to the data acquisition system, they are spied upon by the trigger. High impedance amplifiers, dual level discriminators, and coincidence logic furnish stops to four rapid cycling TDC's which are cleared by the HERA clock every 96 ns. The trigger data furnished to the Global First Level Trigger by the SRTD on every beam crossing consists of 32 bits. One 8-bit word is generated for each SRTD quadrant. It represents the TDC time (6 bits) with a resolution of 1 ns and the position (2 bits) of the hit or hits closest to the beampipe. The trigger hardware includes programmable thresholds, delays, and circuitry to capture scintillator hit patterns and trigger times of interest. An extensive set of diagnostic and operational software has been developed.

During the period we continued to build and test some electronics for support of ZEUS. These included 3 EVB/FLT Cards for the SRTD Trigger, an SRTD Pulser box and Battery Pack which can be used to maintenance and testing of the SRTD trigger electronics, and 28 small Latch Filter Boards which are used to eliminate crosstalk in the CFLTP backplane in the missing E_T trigger. In addition we built a prototype trigger for

the Beam Pipe Calorimeter (BPC), which will be installed later. Hopefully this may lead to inclusion of the BPC in the GFLT.

We are beginning a heavy involvement with the Level 2 Trigger for the ATLAS Detector at the LHC at CERN. We expect that this work will lead to our having the responsibility in conjunction with our colleagues from Michigan State University for the design and construction of the Level 2 Trigger Supervisor and Region of Interest Builder. These are major efforts which will require effort for a number of years. The primary thrust currently of the Second Level Trigger effort is the Demonstrator Program, which is a combined simulation and prototype hardware effort intended to lead to a selection of the architecture for the ATLAS Second Level Trigger. During the latter half of 1996, we will begin very substantial hardware development to support the Demonstrator Program. During the current period we designed and built a Prototype PMC Mezzanine Card to interface to the PCI port on a high performance RIO2 processor. This work is our first development for the level 2 demonstrator program hardware system integrations.

We also are involved in the ATLAS testbeam effort with regard to the Tilecal and during the period designed and built a Charge Injector System VME Module, a Charge Injector System CAMAC Crate Controller, 22 Charge Injector System CAMAC Modules, an Encoder Readout with Limits Chassis, to provide charge injection calibration for the ADC's in the test beam.

Previously, we had built and tested electronics for the CDF trigger upgrade which concluded very satisfactorily. This was an effort to bring the preshower radiator and shower max detector wires into the trigger at second level to improve the efficiency for B physics, and in fact did improve the efficiency of triggering on B's by a factor of 3. We hope to have a part in the upgrade to 132 ns operation, and during the period the study of noise problems continued. We expect to have a significant part in this upgrade in the areas of data acquisition from the shower max and preshower chambers and formulation of the trigger using shower max and tracking data. We also hope to be responsible for the development of an isolation trigger operating at second level in conjunction with the Cluster Finder being developed by our colleagues at Michigan.

We continue to do some work in support of the Advanced Accelerator Group, and during the period built a system for pulsing quadrupole magnets to be used in their work at Argonne.

(J. Dawson)

II. THEORETICAL PHYSICS PROGRAM

II.A THEORY

II.A.1 Total Cross Section for Top Quark Production

Edmond L. Berger and Harry Contopanagos completed a major paper on the total cross section for top quark production at hadron collider energies within the context of perturbative quantum chromodynamics (QCD). This paper, entitled "The Perturbative Resummed Series for Top Quark Production", Argonne report ANL-HEP-PR-95-82, March 1996, has been published in *Physical Review* **D54**, 3085–3113 (1996). The technique used by Berger and Contopanagos incorporates initial state soft-gluon radiation to all orders in the strong coupling strength. It provides a final cross section as a function of the top quark mass that is more reliable theoretically than can be obtained with fixed-order perturbation theory. In their long paper, Berger and Contopanagos present a thorough exposition of their method of soft-gluon resummation. They derive the perturbative regime of applicability of the resummed series, starting from the principal-value resummation approach and isolating the perturbative gluon radiation phase space upon analytic inversion of the corresponding Mellin transform. They show explicitly that their perturbative result is independent of the manner principal-value resummation regularizes non-perturbative effects. They demonstrate that their resummed cross section is stable under variation of the renormalization and factorization scales, and they discuss factorization scheme dependence and remaining theoretical uncertainties. Their method can be applied to other problems of substantial current interest including the production of hadronic jets at large transverse momentum and the production of pairs of supersymmetric particles.

The quantitative reliability of the theoretical cross section for top quark production is an important issue. The cross section that Berger and Contopanagos calculate is in agreement with the measurements by the Collider Detector at Fermilab (CDF) and D0 Collaborations. Improvements in experimental precision might eventually demonstrate an excess that could signal new physics, possibly associated with the large mass of the top quark. Berger and Contopanagos provide predictions of expected yields at an upgraded Tevatron collider operating at a center-of-mass energy of 2 TeV. Subsequent to the publication of the work of Berger and Contopanagos, a group of theorists working at CERN computed a total cross section that differs by 10%. In Argonne report ANL-HEP-CP-96-51, June 1996, Berger and Contopanagos show that the difference in final results is traced to the inconsistent retention by the CERN theorists of numerically large non-universal subleading logarithmic terms. The Berger and Contopanagos formalism incorporates the exact next-to-leading order (one-loop) cross section and the universal leading logarithmic structure at two-loops, a statement that others cannot make. Aspects of the work were presented by Berger in plenary talks at the Aspen Winter Conference in January, 1996, at the International Symposium on

Developments in Particle Phenomenology, University of Wisconsin, Madison, in April, 1996, and at the XI Topical Workshop on Hadron Collider Physics, Padova, Italy, in May, 1996, and by Contopanagos in invited talks at the XXXI Rencontres de Moriond, Les Arcs, France, in March, 1996, at CERN, and elsewhere. The written versions of the Moriond and Padova talks, ANL-HEP-CP-96-34 (hep-ph/9605212) and ANL-HEP-CP-96-51 (hep-ph/9606421), will be published in the proceedings of the two conferences.

(E. Berger and H. Contopanagos)

II.A.2 Associated Production of a Prompt Photon and a Heavy Quark

Edmond Berger, Lionel Gordon, and Bob Bailey (Eckerd College) concluded a calculation of the inclusive production of a prompt photon in association with a heavy quark at large values of transverse momentum. This analysis was done at next-to-leading order in perturbative quantum chromodynamics (QCD). It used a combination of analytic and Monte Carlo integration methods in order to obtain several differential distributions in transverse momentum and rapidity, including photon isolation restrictions, that should facilitate contact with experimental results at hadron collider energies. Their paper, Argonne report ANL-HEP-PR-95-87, February 1996, was published in *Physical Review D* **54**, 1896–1907 (1996). The two-particle inclusive cross section probes QCD dynamics in more detail than a single particle inclusive cross section. Specification of the theoretical cross section is correspondingly more challenging. Berger, Gordon, and Bailey show that the study of the two-particle inclusive distribution, with specification of the momentum variables of both the final prompt photon and the final heavy quark, tests correlations inherent in the QCD matrix elements and provides a means for measuring the charm quark density in the nucleon. Seven partonic subprocesses contribute at order α_s^2 , but dominance of the subprocess initiated by gc scattering is preserved after the next-to-leading terms are included, justifying use of data from $p + \bar{p} \rightarrow \gamma + c + X$ in attempts to measure the charm quark momentum density in the nucleon. Comparison with data published by the Collider Detector at Fermilab (CDF) Collaboration shows good agreement. A summary of the work was also presented by Gordon in an invited talk at the XXXI Rencontres de Moriond, Les Arcs, France, in March 1996, Argonne report ANL-HEP-CP-96-33.

(E. Berger and L. Gordon)

II.A.3 Isolated Photon Cross Sections

Edmond Berger, Xiaofeng Guo, and Jianwei Qiu (Iowa State University) wrote a long paper entitled “Isolated Prompt Photon Production in Hadronic Final States of Electron-Positron Annihilation”, Argonne report ANL-HEP-PR-96-37, May 1996, published in

Physical Review **D54**, 5470–5495 (1996). This paper is the most recent in a series of papers in which Berger and Qiu explore theoretical issues involved in the production of inclusive and isolated prompt photons in electron-positron and hadron-hadron reactions. High energy photons have long been considered an excellent probe of short-distance physics in strong interactions. In electron-positron and in hadron-hadron reactions at collider energies, prompt photons are observed and their cross sections are measured only if the photons are relatively isolated in phase space. Much of the predictive power of perturbative QCD derives from factorization theorems. Conventional factorization expresses a physical quantity as a convolution of a partonic term with a non-perturbative long-distance matrix element, and it requires that the partonic term, calculated perturbatively order by order in the strong coupling strength, have no infrared singularities. Isolation of the photon restricts the final-state phase space accessible to accompanying quarks and gluons. In their paper, using $e^+e^- \rightarrow \gamma X$ as an example, Berger, Guo, and Qiu demonstrate that this phase space restriction inevitably breaks the perfect cancellation of infrared singularities between real gluon emission and virtual gluon exchange diagrams that is required to yield an infrared safe partonic part in each perturbative order. Breakdown of the cancellation of infrared singularities appears first at next-to-leading order in the fragmentation contributions. Breakdown of factorization limits the region of $x_\gamma = 2E_\gamma/\sqrt{s}$ in which quark-to-photon fragmentation functions may be extracted reliably from electron-positron reaction data. For production of isolated photons at hadron-hadron colliders, the physical cross section is obtained after an integration over the momentum fractions of incoming partons. One is not free to impose a selection on x_γ analogous to that in e^+e^- annihilation, and the integration is done throughout the part of phase space where the breakdown of factorization takes place. Convolution with the parton fluxes of the incident hadrons enhances the influence of the region of infrared sensitivity. The results in both the e^+e^- and hadron-hadron cases require that a modified factorization scheme be devised and/or that a more appropriate infrared safe observable be defined. A summary of aspects of the work was also presented by Xiaofeng Guo in a talk at the XIV International Conference on Particles and Nuclei (PANIC), Williamsburg, VA, May, 1996 (Argonne report ANL-HEP-CP-96-53).

(E. Berger, X. Guo, and J. Qiu)

II.A.4 Lattice Formulation of Chiral Gauge Theories

Geoffrey Bodwin has developed a new method for formulating gauge theories of chiral fermions, such as the Standard Electroweak Model, on the lattice. A detailed account of this work can be found in the report covering the period July 1, 1995–December 30, 1995. A paper on the subject (ANL-HEP-PR-95-59) has been accepted for publication in Physical Review D.

(G. Bodwin)

II.A.5 Lattice Measurement of Matrix Elements for Decays of Heavy Quarkonium

Geoffrey Bodwin, Seyong Kim, and Don Sinclair have completed the initial round of a project to determine the nonperturbative operator matrix elements that govern the decays of S-wave and P-wave charmonium and bottomonium. Bodwin, Kim, and Sinclair first determined the lattice-regulated matrix elements in a numerical simulation. They then related the lattice-regulated matrix elements to the continuum-regulated ($\overline{MS}$) matrix elements through a perturbative QCD calculation. Details of this procedure are given in the report covering the period July 1, 1995–December 30, 1995.

The results for the leading color-singlet matrix elements for charmonium are in agreement with values extracted from experiment—within the theoretical uncertainty of about 20%. The subleading S-wave color-singlet matrix element is poorly determined, owing to power-divergent renormalizations in the lattice-to-continuum calculation. The result for the P-wave color-octet matrix element is also in agreement with experiment, but here the theoretical uncertainty is about 50%.

Similar theoretical uncertainties appear in the case of the bottomonium matrix elements. Only the leading S-wave color-singlet matrix element has been fixed by experiment. The lattice results for the P-wave matrix elements translate immediately into predictions for the, as yet unmeasured, decay rates of the χ_b and h_b states.

A paper describing these results has now been published in Phys. Rev. Lett. **77**, 2376 (1996).

(G. Bodwin)

II.A.6 Polarized Hadronic Physics

Claudio Corianò and Lionel Gordon continued the study of double prompt photon production in polarized proton-proton collisions by applying their next-to-leading order calculation to collisions at RHIC energies. Estimates were made for the cross section using the newly available polarized parton distributions evolved in next-to-leading order for the first time in this type of calculation. The paper is published in Physical Review **D54**, 781 (1996).

Lionel Gordon and Werner Vogelsang continued their studies of polarized single prompt photon production by calculating expectations for the cross section at the proposed HERA- $\bar{N}$ collider. The study was done in next to leading order QCD. The sensitivity the double spin asymmetry to the protons polarized gluon distribution Δg was estimated along with the expected statistical precision in its determination. The paper is published in Physics Letters **B387**, 629 (1996).

(L. Gordon)

II.A.7 Photon Structure

Lionel Gordon and John Storrow made a new parametrization of the parton distributions of the photon. All available data on these distributions were incorporated in the analysis as well as recent data on jet production at TRISTAN. The main focus was an attempt to constrain the gluon distribution of the photon about which very little experimental information is currently available. The results are contained in "New Parton Distributions Functions for the Photon" ANL-HEP-PR-96-38, MC-TH-96-16, which will be published in Nuclear Physics B.

The new distributions for the photon were used in two next to leading order calculations. The first was a study of inclusive single prompt photon production at LEP2 by Lionel Gordon and John Storrow published in Physics Letters **B385**, 385 (1996). The second a study of single isolated prompt photon production at HERA by Lionel Gordon and Werner Vogelsang. The results were presented by W. Vogelsang at the "International Workshop on Deep Inelastic Scattering and Related Phenomena" Rome, Italy, April 15-19, 1996. Both studies focused on sensitivity of the cross section to the gluon distributions of the real photon.

(L. Gordon)

II.A.8 Supersymmetry

Stephen Mrenna, and collaborators at the University of Michigan, observed that an unusual event observed by the CDF collaboration at the Tevatron could be understood as a signal of low-energy supersymmetry (SUSY) (Phys. Rev. Lett **76**, 3498 (1996)). Like the Standard Model, SUSY contains a number of mass parameters not fixed by the theory. Mrenna *et al.* determined the regions of SUSY parameter space that can accommodate this interpretation of the unusual event, and used their results to predict the most probable cousin events that should be observed at the Tevatron and LEP. It is possible that the Tevatron experiments have observed corroborating events, and very likely that LEP will see hard evidence of low-energy SUSY when upgraded to an energy of 190 GeV, if this interpretation is correct. At the very least, they demonstrated that the analysis of a single event can lead to a large number of testable predictions, which can prove or disprove a SUSY interpretation. A more thorough analysis of the event and discussion of event signatures will appear soon in Phys. Rev. D. Attempts to understand the SUSY parameters consistent with this interpretation at a more fundamental level have led to a flurry of theoretical activity.

Using the effective SUSY Lagrangian determined by the previous analysis, Mrenna and G.L. Kane (Univ. of Mich.) pursued the possibility that the stop squark, the superpartner of the top quark, is light (Phys. Rev. Lett. **77**, 3502 (1996)). If this is true,

then top quarks will decay into stop squarks and the lightest superpartner, thereby depleting the observed top signal. Since this is not consistent with the data, the stop squark in these models can only be light if there is a new source of top quark production. If the gluino, the superpartner of the gluon, is heavy enough, then it will decay to a top quark and a stop squark. If it is not too heavy, the gluino can be produced, then decay to top quarks, at a rate comparable to Standard Model top quark production. Furthermore, squarks which are superpartners to light quarks can contribute to final states that look similar to Standard Model top decays. This complete scenario was found to be consistent with the present top data sample and, in some respects, gave a better description.

An alternative SUSY interpretation of the unusual Fermilab event involves the decay of superpartners into a very light gravitino ($\tilde{G}$), the superpartner of the graviton. In most formulations of SUSY previously studied, the gravitino is relatively heavy, only couples weakly to matter, and can generally be ignored in collider phenomenology. However, in some models, the gravitino is light, with the consequence that every SUSY event has the signature $\gamma\gamma\tilde{G}\tilde{G} + X$, where the gravitinos escape the detector as missing energy. Such events would appear with unusually large missing transverse energy in a standard di-photon search. Mrenna, and collaborators, studied this inclusive signal, and showed that Fermilab can already restrict SUSY models with a light gravitino, so that future LEP upgrades have little chance of verifying or refuting the light gravitino interpretation (Phys. Rev. **D54**, 5395 (1996)). With Mrenna's input and encouragement, several members of the CDF collaboration have determined a limit on superpartner masses within those models (to be published).

Mrenna has also released the Monte Carlo program used for his studies of SUSY signals (to appear in Computer Physics Commun.). SPYTHIA is a supersymmetric extension of the phenomenologically successful PYTHIA Monte Carlo program. In the near future, Mrenna's program will become part of the standard PYTHIA release. This collaboration was started at Mrenna's visit to Lund University at the beginning of 1996. Experimental groups at the Tevatron, HERA, and LHC are already using this program for their new particle searches and event simulations.

Finally, Mrenna attended the Snowmass Workshop on New Directions in Particle Physics, where he participated in the Supersymmetry Theory Working Group. The group report is an evaluation of the prospects of discovering or ruling out low-energy SUSY in the next generation of collider experiments. Mrenna was the main author of two sections of the report, and contributed significantly to a third. Additionally, Mrenna wrote a short contributed paper to the workshop proceedings with B. A. Dobrescu (Boston Univ.) entitled "Signals of Dynamical Supersymmetry Breaking in a Hidden Sector".

(S. Mrenna)

II.A.9 Kinematics of Top Quark Production

Mrenna and C.-P. Yuan (Mich. State Univ). completed a study of the kinematics of top quark production at the Tevatron including the transverse momentum resummation of soft gluon emission in perturbative QCD (to appear in Phys. Rev. D). In contrast to work using threshold resummation schemes, which predict the total cross section, this scheme (developed by Collins, Soper, and Sterman) avoids certain ambiguities and preserves the kinematics of the individual t or $\bar{t}$ quarks, so that this work makes a more accurate prediction of the correlations between t and $\bar{t}$. A correct understanding of these correlations may be important for interpreting the top quark mass extracted from the Tevatron data. Mrenna and Yuan, with Ed Berger, are also applying this method to study the kinematics of single top quark production, which requires a generalization of the formalism to accommodate space-like W boson exchange. These studies are complementary to the resummation calculations of Berger and Contopanagos.

(S. Mrenna)

II.A.10 Conformal Symmetry in the Regge Limit of QCD

It is well-known that the leading-log BFKL equation describing the Regge limit in QCD is conformally symmetric. Although the symmetry must be lost as scale-dependence enters the theory in next-to-leading order, it is attractive to suppose that conformal symmetry could nevertheless play a vital role in solving the full dynamical problem of the QCD Pomeron. It would be encouraging, if this is to be the case, to see that perturbative contributions beyond leading-log are related to conformally symmetric interactions. The results derived in a recent paper, (ANL-HEP-PR-96-75) by Mark Wüsthoff and Alan White, from ANLHEP, and Claudio Corianò from the University of Florida, are perhaps a first step in the right direction. Explicit conformal symmetry is shown for an interaction, derived first by White using t -channel unitarity arguments, that is anticipated to be an infra-red approximation to the NLO kernel of the BFKL equation.

That a conformally invariant representation exists is shown first by relating the kernel directly to a physical problem in which it is known how to implement conformal symmetry, i.e., the diffractive excitation of virtual photons via two gluon exchange. The symmetry is then manifest in the remarkably simple impact parameter representation that is subsequently derived, i.e.

$$\tilde{K}(\rho_1, \rho_2, \rho_{1'}, \rho_{2'}) = g^4 N^2 \ln^4 \left[\frac{|\rho_1 - \rho_{1'}| |\rho_2 - \rho_{2'}|}{|\rho_1 - \rho_{2'}| |\rho_2 - \rho_{1'}|} \right]$$

There were good arguments that conformal symmetry should be present in some form, but the simplicity of this representation was not expected. The authors also discuss operators corresponding to general powers of the logarithm of the harmonic ratio

appearing in the above expression and suggest obtaining the spectra of such operators from a generating function.

(A. White and M. Wüsthoff)

II.A.11 The Hard Gluon Component of the QCD Pomeron

The observed scaling violations in deep-inelastic scattering determine the hadronic partonic structure that is the basis for application of perturbative QCD to a wide range of hadronic physics. The observation of diffractive deep-inelastic scaling at HERA has opened up a new realm of strong interaction physics. Diffractive scaling violations will give crucial information on the structure of the Pomeron and, as Alan White argues in a recent paper (ANL-HEP-CP-96-74), major insight into the formulation of the parton model within QCD may actually result.

White shows that the logarithmic scaling violations seen experimentally by H1 are in conflict with the scale-invariance of the BFKL Pomeron and with phenomenological two-gluon models. As the H1 analysis shows, at short distances, the Pomeron behaves like a single hard gluon. Within QCD, gauge invariance makes this a very difficult property to realize. However, White shows that if the Pomeron is in a Super-Critical phase at short distances, logarithmic scaling violations due to the dominance of a single hard gluon are just what is expected.

In first approximation the Pomeron is a "reggeized gluon", with a dynamical mass, in a "reggeon condensate" background. The condensate can be thought of as approximating a very soft gluon configuration accompanying the reggeized gluon. The reggeized gluon mass scale and the condensate scale can be distinct because they carry opposite color charge parity. The resulting Pomeron is then distinguished from (higher-order corrections to) the BFKL Pomeron in that it carries odd color charge parity. Necessarily, hadrons are not eigenstates of color parity. This is due to the appearance, in an infinite momentum hadron, of a condensate (soft gluon) component with non-trivial color properties. The presence of this component is also directly related to chiral symmetry breaking and is an essential part of the "parton" description of an infinite momentum hadron. The appearance of the Super-Critical Pomeron phase within QCD has been argued for by White for many years.

(A. White)

II.A.12 Quark-Antiquark Production in Diffractive Deep Inelastic Scattering

Diffractive was firstly observed in soft hadronic reactions where at high enough energies Pomeron exchange is the dominant exchange. Diffractive Deep Inelastic Scattering is of particular interest because it provides the opportunity to study the substructure of the

Pomeron by probing it with a highly virtual photon. The proton to which the Pomeron couples stays intact and is only slightly deflected, whereas the virtual photon dissociates into hadrons. The produced hadrons are well separated in rapidity from the proton which allows to identify diffraction by requiring a large rapidity gap.

In all diffractive reactions, the Pomeron stands for a colorless exchange that leads to a roughly constant or slightly rising cross section. It is a major challenge to uncover the physical nature of the Pomeron and to understand in which way it is related to QCD. In perturbative QCD, the simplest model for a Pomeron is the two gluon exchange which forms a color singlet state. The problem, however, is that the relevant scale is not only determined by the virtuality of the photon but also by the transverse momentum of the hadronic final state, and this scale is usually rather small.

To ensure the use of perturbation theory, i.e. to test the hard Pomeron, one has to enforce a large scale in the final state. This can only be done by looking for jets in the final state with no soft background. The leading order contribution is given by the production of quark-antiquark pairs with large transverse momenta. This process was calculated by M. Wüsthoff (ANLHEP) in collaboration with J. Bartels and H. Lotter (Hamburg University) [ANL-HEP-PR-96-11] where it was shown that the relevant scale is proportional to the transverse momentum enhanced by a factor which becomes large when the mass of the final state becomes small. The two Pomeron exchange then undergoes the usual QCD-evolution and can be identified at zero total momentum transfer with the common gluon structure function. This allows to make absolute prediction for the jet-cross section. In a second paper with participation of C. Ewerz (Hamburg university) [ANL-HEP-PR-96-39] the previous work was extended by including the dependence on the azimuthal angle of the quark-antiquark pair with respect to the scattered lepton-proton plane. The analysis of the azimuthal distribution may be a valuable tool to discriminate the perturbative two gluon model from other models.

(M. Wüsthoff)

II.A.13 Forward Jet Production in Deep Inelastic Scattering

At very small x -Bjorken and high energies the hadronic final state tends to contain multiple jets. It is obvious that finite order perturbation theory is insufficient to describe this case and needs to be replaced by a resummation to infinite order of perturbation theory. Each term in the sum can be evaluated to leading logarithmic accuracy either by picking out collinear singularities or by going to large rapidities. The first case is associated with a conventional parton shower where the transverse momenta of the partons in the final state are strongly ordered. In the second case the final state partons are strongly ordered in rapidity but their transverse momenta are of similar size. In this case resummation is effectively performed by solving the BFKL-equation.

Several years ago A.H. Mueller proposed forward jet production in Deep Inelastic Scattering as a good process to test BFKL dynamics. The transverse momentum of the jet is forced to be of the same order as the virtuality of the photon, so that contributions from a conventional parton shower are nearly completely excluded. In collaboration with J. Bartels (Hamburg University), Vittorio Del Duca (University of Edinburgh), A. De Roeck (DESY) and D. Graudenz (CERN), M. Wüsthoff (ANLHEP) calculated this process, compared it with 1993-data from H1 and made prediction for the 1994-data [ANL-HEP-PR-96-23]. The PROJET-Monte Carlo program of D. Graudenz was used to calculate the cross section at third order in perturbation theory exactly. It was found that under appropriate cuts the BFKL-result exceeds the fixed order result by a factor of 3 - 4. The data show a similar excess over the fixed order result and compare better with the BFKL-prediction. They undershoot the BFKL-cross section by roughly 20% which is due to the fact that the BFKL-resummation is an approximation which violates energy conservation. Corrections towards an exact implementation of energy conservation tends to lower the result.

(M. Wüsthoff)

II.B THEORY INSTITUTE: TOPICS IN NON-ABELIAN DUALITY

Duality spans a range of theory-connecting techniques that have recently led to substantial and rapid advances in Field and String Theory. With ALD support, C. Zachos organized "Theory Institute: Topics in non-Abelian Duality". About 30 experts came together at Argonne (June 27 - July 12, 1996) to review progress, compare notes, and collaborate on work submitted for publication.

Like much research documentation in the field, the proceedings of the Institute (edited by Zachos) are *electronic*, available on the WWWeb.[<http://www.hep.anl.gov/theory/tdual.html>] They have been cataloged in, and are also accessible (linked) from, the SPIRES conference subfile (C96/06/27), the Maryland robot confmenu proceedings catalog[<http://www.physics.umd.edu/robot/confer/pcatalog.all>], and several other catalogs and search engines, as well as the HEP divisional web-pages. Even while under construction, they have been utilized frequently, virtually immediately after the end of the Institute, by a broad range of international browsers.

Speed of utilization, negligible cost, universal access, and long-term archiving are quickly making e-proceedings a favorite practical scientific communication tool. Shortly after posting of these e-proceedings, the Strings96 conference (UCSB) also opted for paperless e-proceedings.

(C. Zachos)

II.C COMPUTATIONAL PHYSICS

The computational physics effort is devoted to numerical simulations of lattice quantum field theories, primarily lattice quantum chromodynamics (QCD). Use of a finite lattice reduces the field theory to one with a finite number of degrees of freedom, allowing numerical simulations. The finite lattice spacing provides the needed ultraviolet regularization of the theory. For QCD, such lattice methods provide the only reliable way of calculating non-perturbative results. This enables one to calculate the basic properties of hadrons such as their masses and decay rates. In addition it enables one to determine the properties of hot and/or dense nuclear matter, which is not only relevant to neutron stars and the early universe, but is also expected to be relevant to relativistic heavy ion collisions, such as will be observed at RHIC.

Much of our recent effort has been devoted to studying a version of lattice QCD where the lattice action is modified by the addition of a chiral 4-fermion interaction, in collaboration with J. B. Kogut at the University of Illinois. Since such a term is an "irrelevant" operator, it should not modify the continuum physics. However, on the lattice it enables us to work at zero quark mass, which is impossible with the conventional lattice action, and at the physical quark mass with an order of magnitude less computer time than would be needed with the normal lattice action. We are performing simulations of this theory at finite temperatures, using zero quark mass to enable us to obtain the equation of state at the transition from hadronic matter to the quark-gluon plasma. Figure 1 shows preliminary results for the behaviour of the chiral condensate and the Wilson/Polyakov line, which measures the increase in free energy when a free quark is added to the system, close to the transition. We are also using this new action to look at the hadron spectrum for zero quark mass.

We have been looking at the screening masses for flavour singlet mesons close to the finite temperature transition with the standard lattice QCD action, both for full QCD with light quarks and for quenched QCD. The propagators for such mesons have disconnected contributions which had been previously ignored. Preliminary indications from our calculations are that the chiral $SU(N_f) \times SU(N_f)$ symmetry is restored (as expected) at this transition, but that the $U(1)_A$ symmetry is not (as some have suggested). In performing these calculations, we discovered that, at high temperatures, the quark propagators can be well approximated by a few low lying modes of the Dirac operator, indicating that the physics is dominated by the zero modes associated with the instantons of the theory. This work is also in collaboration with J. B. Kogut.

For several years, we have collaborated with G. T. Bodwin (Theory) and S. Kim (Seoul National University) on a project aimed at calculating the matrix elements which describe the decays of S- and P-wave bottomonium and charmonium. Here we find good agreement with experimentally derived numbers for charmonium, while our bottomonium elements are 30–40% too low. In this time period we have checked that the

bottomonium matrix elements are (within errors) independent of the lattice spacing used in the simulations.

Finally, one of us (JFL) has been calculating the partition of components of the pion energy between the partons (quarks and gluons) of which it is composed. Such calculations shed light on the structure of hadrons, and can be compared with experiment.

The simulations and calculations reported above are being performed on the CRAY C-90 at NERSC.

Fig. 1. Chiral condensate and Wilson/Polyakov line for chirally extended QCD as functions of the the gauge coupling.

(D. K. Sinclair and J. F. Lagaë)

III. ACCELERATOR RESEARCH AND DEVELOPMENT

III.A ARGONNE WAKEFIELD ACCELERATOR PROGRAM

III.A.1 AWA Facility

The main focus of this period was the installation and commissioning of the AWA facility, particularly integrating the drive linac, witness gun, beam transport and experimental sections. Preliminary wakefield experiments were performed and the AWA was completely commissioned. A discussion the status of each AWA section follows.

a. AWA Drive Linac

We continued our investigation of the Magnesium quantum efficiency problem. Based on the suggestions made by Trevini Rao of BNL, we used hexane as the final cleaning agent which increased the QE by a factor of 2. Although it is still lower than expected, it will be good enough for our current experiment.

III.A.2 Witness Gun and Wakefield Measurement System

The witness gun is used to produce the 4 MeV bunches used to diagnose wakefields. By delaying the laser pulse to the gun and simultaneously adjusting the rf phase to maintain a constant energy, the delay of the witness beam may be varied continuously to map out the wake potential of the drive beam in the device under test. During this reporting period the witness gun, beamlines, laser and rf delay systems and software were installed and commissioned.

The gun was returned from brazing at Pyromet. After repairing a number of vacuum leaks it was installed in the AWA vault. Tuning and conditioning of the gun were accomplished smoothly. The performance of the witness gun was measured using a straight-through diagnostic port. Quadrupole scans were performed to measure the emittance; the normalized emittance 1π mm-mr at 0.5 nC was found to be in excellent agreement with the design simulations. The bunch length was measured using a Cherenkov radiator and streak camera. The observed bunch length of 8 ps was again in good agreement with the numerical model of the gun. In order to perform wakefield measurements the drive and witness beams must be made to pass along parallel trajectories through the wakefield device under test. Figure 1 shows the beamlines used to combine the two beams. Installation and testing of these beamlines was completed during this reporting period.

Beamline Detail

Fig. 1. The witness beam line.

The optics for generating the delayed laser pulse to the witness gun were completed. A beam splitter is used to transmit $\sim 15\%$ of the laser energy through an optical trombone. The optics are designed so that the main and delayed pulses emerge from the laser room with a small vertical separation so that the two pulses can be separated in the vault and directed to their respective guns.

The optical delay and gun phase shifter are moved simultaneously under computer control to vary the delay while maintaining a constant laser injection phase. Delays of several ns are possible, although most measurements will require a range of < 0.5 ns.

III.A.3 Initial Dielectric Wakefield Experiment

We have measured the wake field in two different dielectric structures (7 and 15 GHz). The results for the 7 GHz structure are shown in Figure 4. The wake amplitude is 1.5 MV/m for 20 nC drive beam. The structure has an inner radius of 1.25 cm and an outer radius of 1.6 cm with dielectric constant of 4. The measured wakefield amplitude and frequencies agree well the theory. This directly tested all the components of the AWA facility, and the results are satisfactory.

Another dielectric tube with inner radius 5 mm and outer radius 7.7 mm was also studied in the wake field experiments. The resonant frequency for this tube is 15 GHz. A wake field amplitude of > 5 MV/m was observed. Further tuning of the drive

beam (more charge and shorter pulse length) should produce a wake field in the excess of 15 MV/m in this structure.

Fig. 2. Dielectric wakefield data (preliminary)

The first dielectric structure wakefield measurement at the AWA obtained using the witness beam is shown in fig. 2. Initial gradients were small due to limited drive beam transmission through the test device. Additional focusing before the test section is planned to improve transmission. The wakefield measurement system has now been successfully demonstrated to work as designed.

III.A.4 Non-Linear Plasma Focusing Experiment and Tesla Test Facility

a. Plasma Wakefield Acceleration and Focusing Experiment

In collaboration with an UCLA group, we have performed several preliminary experiments to study the plasma wakefield acceleration in the blowout regime. The first set of experiments demonstrated acceleration of a witness beam as a result of the plasma wave excitation caused by the drive beam. There is a current effort to study the self

focusing of the drive beam. In order for the drive beam energy to be optimally coupled to the plasma wave, the drive beam must be focused to a very small spot, and the radius of a significant part of the beam must be kept nearly constant by the plasma's focusing force for the length of the plasma. The aim of the current experiment is to quantify this focusing and propagation, which depends greatly on the beam's emittance, charge and initial matching, as well as on the plasma properties.

b. Tesla Test Facility

The Tesla Test Facility gun produced its first beam. A linac tank to boost the TTF beam energy to 10 MeV was installed and commissioned. Performance of the gun was found to be in agreement with design simulations.

Other Activities:

a. 11.4 Ghz SLAC NLC Dielectric Structure

A prototype dielectric structure with dielectric constant of 20 was built to test the idea of possible alternative structure for the next linear collider. In this method, RF from the X-band klystrons developed for NLC would be used to drive a dielectric structure. Further study is underway to couple the RF into this structure. An arrangement with SLAC was made to study the dielectric breakdown using NLC RF power sources.

b. Laser Acceleration using Dielectric Supported Structures

We have studied acceleration method using laser as power sources. The structures under the study were either cylindrical dielectric waveguide or parallel dielectric plates. Both analytical and numerical methods were used in our investigation. The results indicate that GV/m gradient can be achieved by using only modest amount of laser power (100 kW ~ 100 MW).

(W. Gai)

III.B MUON COLLIDER DESIGN

The Muon Collider has been studied seriously for perhaps a year by a group from Brookhaven, Fermilab, Berkeley, Argonne and a number of laboratories and universities. In principle, this facility should permit the acceleration of leptons using techniques which should ultimately produce a facility which is smaller, cheaper and higher energy than other methods, because the high mass of muons permits the use of circular accelerators without severe synchrotron radiation losses

During the first half of 1996 the majority of the work for the muon collider design study was done. The Argonne contribution to this effort was to develop and edit

the proton driver section as well as produce a number of calculations showing bunching of protons and stability of short bunches in an accelerator for a few turns after bunching.

Argonne experience with the IPNS accelerator and neutron source designs was useful in developing preliminary parameters for a 10 GeV option, which was done in parallel with a 30 GeV option developed at Brookhaven. A majority of the effort was directed at producing simulations of bunching to produce very large charges ($2.5 - 5 \times 10^{13}$ protons/pulse) with 1 ns bunch lengths. The technique proposed, with operation near transition while a the rf produces a vertical sheer in the bunch, followed by a quick rotation to a vertical bunch, seems to satisfy the requirements. Another technique, proposed by Jim Griffin of Fermilab, using adiabatic bunch spreading followed by bunch rotation, should also work. Experimental tests of these methods are being proposed at the AGS at Brookhaven.

The stability of large bunches has also been studied both during acceleration and bunching, with the unexpected conclusion that there are a number of factors which would work to stabilize short bunches, particularly if the bunching was done in a comparatively few turns.

(J. Norem)

IV. DIVISIONAL COMPUTING ACTIVITIES

IV.A HIGH PERFORMANCE COMPUTING: THE PASS PROJECT

IV.A.1 R&D During the Period January 1996 through June 1996

Two physicists (L. Price and E. May) and a computer scientist (D. Malon) from DIS division continued to work on the "Petabyte And Storage Solutions" (PASS) project. This is a HPCC and HEP supported R&D project to study the use of database technologies for the storage of and access to scientific data on the scale of a few petabytes (10^{15} bytes). Future HEP experiments will collect data at the rate of 1 petabyte per year; new advanced technology (both hardware and software) is required to provide the access to this quantity of data in a fast and efficient manner for a world-wide HEP environment. This work is being done in collaboration with the University of Illinois at Chicago (UIC), University of Maryland, and Lawrence Berkeley lab (LBL). I describe briefly some PASS activities in which ANL staff had the principal role or made important contributions.

During this interval we worked in the following areas:

We wrote two papers for conferences "On Persistence Interfaces for Scientific Data Stores" and "Flexible Storage Services for Parallel Data Mining".

Upgraded the ANL Object manager software to comply with version 1.2 of the ODMG standard. The ANL persistence manager (LWOM) was upgraded to support transactions and writebacks, among a number of new features. This is described in some detail in the close-out report for DOE which we have begun to prepare, as this is the last year of the PASS project.

We began meeting with the MINOS software group to help in the design an object oriented data system.

Installation and testing of DCE and DFS over ATM on our solaris sparc-station. This is an alternative (and somewhat conservative) approached to a distributed programming paradigm compared to OMG CORBA methodology previously examined.

During this interval a call from DOE for the next round of "Grand Challenge Applications" proposals for supercomputing application was received. We were invited to collaborate with BNL, LBL, NERSC and several universities to prepare a joint HEP and NP proposal for data access and storage systems for the next generation of accelerator based experiments at the CERN LHC and the BNL RHIC facilities. We prepared and wrote sections on parallel ODMG based database systems and object oriented data models for a joint proposal which was submitted in June.

(Ed May)

V. PUBLICATIONS

V.A JOURNAL PUBLICATIONS, CONFERENCE PROCEEDINGS, BOOKS

A High Energy e^+e^- Collider in a "Really Large" Tunnel

J. Norem, E. Keil (CERN)

Published in the Proceedings of the Snowmass Workshop, (1996).

A Lattice Formulation of Chiral Gauge Theories

G. Bodwin

Phys. Rev. D54, 6497 (1996)

Published in the Proceedings of Lattice 96: 14th International Symposium on Lattice Field Theory, edited by Claude Bernard, Maarten Golterman, Michael Ogilvie, Jean Potvin, North Holland, p. 644, St. Louis, MO, June 1996

A Perturbative Approach to Diffractive Deep Inelastic Scattering

J. Bartels and M. Wusthoff

J. Phys. G22, 929 (1996)

A Search for AGN Neutrinos with the Soudan 2 Detector

D. DeMuth *et al.*,

Proceedings of the 24th International Cosmic Ray Conference, HE 5.3.18,
Rome, Italy, August 28-September 8, 1995

An Inverse Cherenkov Accelerator Using a Dielectric Channeled Waveguide

W. Gai and J. D. Simpson

Proceedings of the Advanced Accelerator Concepts Workshop, Tahoe City, CA
(1996)

Analytic Calculation of Prompt Photon plus Associated Heavy Flavor at Next-to-Leading Order

E. L. Berger and L. E. Gordon

Phys. Rev. D54, 2279 (1996)

Analyzing Power Measurement in Inclusive Λ^0 Production with a 200 GeV/c Polarized Proton Beam

FNAL E-704 Collaboration, A. Bravar *et al.*,

Phys. Rev. Lett. 75, 3073 (1995).

Angular Distributions and Lifetime Differences in $B_s \rightarrow J/\Psi \phi$ Decays

H. J. Lipkin

Phys. Lett. B369, 144 (1996).

Application of Low Temperature Calorimeters for the Detection of Energetic Heavy Ions

I. Ambats *et al.*,

Nucl. Instrum. Meth. A368, 364 (1996).

Associated Jet Production at HERA

J. Bartels, V. DelDuca, A. DeRoeck, D. Graudenz, M. Wüsthoff
Phys. Lett. B384, 300 (1996).

Azimuthal Distribution of Quark-Antiquark Jets in DIS Diffractive Dissociation

J. Bartels, C. Ewerz, H. Lotter, M. Wüsthoff
Phys. Lett. B386, 389 (1996).

Breakdown of Conventional Factorization for Isolated Photon Cross-Sections

Edmond L. Berger (ANL), Xiaofeng Guo, Jian-Wei Qiu
Phys. Rev. Lett. 76, 2234 (1996).

Calculation of the Cross Section for Top Quark Production

E. L. Berger and H. Contopanagos
Invited review published in the Proceedings of the XI Topical Workshop on Hadron Collider Physics, edited by D. Bisello, G. Busetto, and L. Stanco (World Scientific, Singapore, 1996). Abano Terme, Padova, Italy, May, 1996

Chapter 3, The Proton Source, the Muon Collider: A Feasibility Study

J. Norem
Published in the Proceedings of the Snowmass Workshop 1996 (In Press),
June 24-July 12, 1996, Snowmass, CO

Collider Spin Physics at RHIC and STAR

A. Yokosawa
Proceedings of the Adriatico Research Conference on "Trends in Collider Spin Physics", Trieste, Italy, December 5-8, 1995

Conformal Invariance of the Transition Vertex $2 \rightarrow 4$ Gluons

J. Bartels, L. N. Lipatov, M. Wüsthoff
Nucl. Phys. B464, 298 (1996)

Detecting a Light Stop from Top Decays at the Tevatron

S. Mrenna and C. P. Yuan
Phys. Lett. B367, 188 (1996).

Diffractive Production of Vector Mesons at Large t

J. Bartels, J. R. Forshaw, H. Lotter, M. Wüsthoff
Phys. Lett. B375, 301 (1996).

Do About Half the Top Quarks at FNAL Come from Gluino Decays?

G. L. Kane and S. Mrenna
Phys. Rev. Lett. 77, 3502 (1996).

Forward Backward Charge Asymmetry of Electron Pairs Above the Z0 Pole

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 77, 2616 (1996).

Further Properties of High-Mass Multijet Events at the Fermilab Proton-Antiproton Collider

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. D54, 4222 (1996).

Gauge Theory High-Energy Behavior from J Plane Unitarity

C. Coriano, A. R. White
Nucl. Phys. B468, 175 (1996).

Geometry and Duality in Supersymmetric σ - Models

T. Curtright, T. Uematsu, and C. Zachos
Nucl. Phys. B469, 488 (1996).

High p_T Higgs Boson Production at Hadron Colliders to $O(a_s G_F^3)$.

S. Mrenna, C.-P. Yuan
Phys. Rev. D53, 3547 (1996).

Inclusive Charged Particle Distributions in Deep Inelastic Scattering Events at HERA

ZEUS Collaboration, M. Derrick *et al.*,
Z. Phys. C70, 1 (1996).

Inclusive Jet Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 77, 438 (1996).

Inclusive Production of $t\bar{t}$ Pairs in Hadronic Collisions

E. Berger, H. Contopanagos
Published in "Proceedings of the 1996 DPF/DPB Summer
Study on New Directions for High Energy Physics", Snowmass,
CO, June 24-July 12, 1996.

Inclusive Prompt Photon in Hadronic Final States of Electron-Positron Annihilation

Edmond L. Berger (ANL), Xiaofeng Guo, Jian-Wei Qiu
Phys. Rev. D53, 1124 (1996).

Inclusive Prompt Photon Production in Polarized pp Collisions at HERA- $\vec{N}$

L. Gordon and W. Vogelsang
Phys. Lett. B387, 629 (1996).

Isolated Prompt Photon Production in Hadronic Final States of e^+e^- Annihilation

E. Berger, Xiao-feng Guo, Jian-Weu Qiu
Phys. Rev. D 54, 5470 (1996).

Large Transverse Momentum Jet Production and the Gluon Distribution Inside the Proton

S. Kuhlmann *et al.*,
Phys. Rev. Lett. 77, 444 (1996).

Light Hadron Spectroscopy

D. K. Sinclair
Nucl. Phys. Proc. Suppl. 47, 112 (1996).

Long-Baseline Neutrino Oscillation Experiments

D. Crane and M. Goodman
Proceedings of Snowmass '94, Particle and Nuclear Astrophysics and Cosmology
in the next Millenium, Snowmass, CO, pp. 225-229 (1994)

Manifestations of the Axial Anomaly in Finite Temperature QCD

J. B. Kogut, J.-F. Lagae, and D. K. Sinclair
Nucl. Phys. Proc. Suppl. 53, 269 (1997).

Measurement of a_s from Jet Rates in Deep Inelastic Scattering at HERA

ZEUS Collaboration, M. Derrick *et al.*,
Phys. Lett. B 363, 201 (1995).

Measurement of Correlated μ - b Jet Cross Section in pp Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. D 53, 1051 (1996).

Measurement of the Λ_b^0 Lifetime Using $\Lambda_b^0 \rightarrow \Lambda_c^+ \ell^- \bar{\nu}$

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 77, 1439 (1996).

Measure of the B_s^0 Lifetime of the Meson Using the Exclusive

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 77, 1945 (1996).

Measurement of $\sigma B(W \rightarrow e\nu)$ and $\sigma B(Z^0 \rightarrow e^+e^-)$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 3070 (1996).

Measurement of the B^- and $\bar{B}^0$ Meson Lifetimes Using Semileptonic Decays

CDF Collaboration, F. Abe *et al.*,

Phys. Rev. Lett. 76, 4462 (1996).

Measurement of the Diffractive Cross Section in Deep Inelastic Scattering

ZEUS Collaboration, M. Derrick *et al.*,

Z. Phys. C70, 391 (1996).

Measurement of the Mass of the B_s^0 Meson

CDF Collaboration, F. Abe *et al.*,

Phys. Rev. D53, 3496 (1996).

Measurement of the Proton Structure Function F_2 at Low x and Low Q^2 at HERA

ZEUS Collaboration, M. Derrick *et al.*,

Z. Phys. C69, 607 (1996).

Measurement of the Reaction $\gamma^*p \rightarrow \phi p$ in Deep Inelastic e^+p Scattering at HERA

ZEUS Collaboration, M. Derrick *et al.*,

Phys. Lett. B380, 220 (1996).

Measurement of the W Mass at CDF

L. Nodulman

Proceedings of the 12th International Symposium on High-Energy Spin Physics
pp. 19-22, Amsterdam, The Netherlands, 10-14 September 1996.

Measurements at Soudan 2

N. P. Longley *et al.*,

Physical Review D52, 2760 (1995).

Measurements of the Argonne Wakefield Accelerator's Low Charge, 4 MeV RF Photocathode
Witness Beam

J. Power, M. Conde, W. Gai, R. Konecny, P. Schoessow, J. Simpson (ANL),

E. Chojnacki (Cornell)

Published in Proceedings of the Advanced Accelerator Concepts
Workshop, Tahoe City, CA (1996).

Muon Collider Design

R. Palmer, J. Norem, *et al.*,

Proceedings of the Symposium on Physics Potential and Development of $\mu^+\mu^-$
Colliders, San Francisco, CA, Nucl. Phys. B (Proc. Suppl.) 51A, 61 1996.

Muon Colliders

R. Palmer, J. Norem, *et al.*,

Proceedings of the Workshop on Advanced Beam Dynamics and Technology
Issues for Muon Colliders, Montauk, NY (1995), AIP Proceedings 1996.

Neutral Strange Particle Production in Deep Inelastic Scattering at HERA

ZEUS Collaboration, M. Derrick *et al.*,

Zeitschrift fur Physik C68, 29 (1995).

Neutrino Oscillation Experiments with Atmospheric Neutrinos

T. Gaisser and M. Goodman

Proceedings of Snowmass '94, Particle and Nuclear Astrophysics and Cosmology
in the Next Millenium, Snowmass, Colorado, pp. 220-224,
June 29 - July 14, 1994.

Neutron-Proton Elastic Scattering Spin-Spin Correlation Parameter Measurements Between 500 and 800 Mev. 3. Mixtures of C(ss), C(ls), C(ll) and C(nn)

V. Carlson *et al*

Phys., Rev. D53, pp. 3506-3533.

New Particle Searches at CDF

L. Nodulman

Proceedings of the 12th International Symposium on High-Energy Spin Physics
pp. 297-298, Amsterdam, The Netherlands, 10-14 September 1996.

π N Sigma Term, $\bar{S}S$ in Nucleon, and Scalar Form-Factor: A Lattice Study

S. Dong, J.-F. Lagae, K.-F. Liu

Phys. Rev. D54, 5496 (1996).

Pathologies of Quenched Lattice QCD at Nonzero Density and Its Effective Potential

M. P. Lombardo, J. B. Kogut, and D. K. Sinclair

Phys. Rev. D54, 2303 (1996).

Penetration of Cosmic Ray Muons into the Earth

J. L. Uretsky

Accepted for publication in NIM A

Performance of the Argonne Wakefield Accelerator Facility and Initial Experimental Results

Wei Gai, M. Conde, G. Cox, R. Konecny, J. Power, P. Schoessow,

J. Simpson, N. Barov (UCLA)

Paper presented at XVIII International LINAC Conference.

Geneva, Switzerland, August 26-30, 1996.

Photon Plus Charm and Diphotons at $\sqrt{s} = 1.8$ TeV

R. Blair

For the Proceedings of the 10th Topical Workshop at $\bar{p}p$ Collider Physics,
pp. 557-567, Batavia, IL (1995).

Physics of Beams

W. Gai, J. Simpson (ANL), A. D. Kanareykin, A. L. Kustov (USSR).

Submitted for publication in Phys. Rev. E (1996), accepted.

Polarized and Unpolarized Double Prompt Photon Production in Next-to-Leading Order QCD

C. Coriano and L. E. Gordon

Nucl. Phys. B469, 202 (1996).

Polarized Double Photon Production on QCD to Order α_s

C. Coriano and L. Gordon

Phys. Rev. D54, 781 (1996)

Production of a Prompt Photon in Association with Charm at Next-to-Leading Order in QCD

B. Bailey, Edmond L. Berger and L. E. Gordon

Phys. Rev. D54, 1896 (1996).

Prompt Photon Production in $\gamma\gamma$ Collisions and the Gluon Content of the Photon

L. Gordon and J. K. Storrow

Phys. Lett. B385, 385 (1996).

Properties of Jets in Z Boson Events from 1.8 TeV $\bar{p}p$ Collisions

CDF Collaboration, F. Abe *et al.*,

Phys. Rev. Lett. 77, 448 (1996).

QCD with Chiral Four Fermion Interactions

J. B. Kogut and D. K. Sinclair

Nucl. Phys. Proc. Suppl. 53, 272 (1997).

Quantum Mechanical Time-Development Operator for the Uniformly Accelerated Particle

R. W. Robinett

Am. J. Phys. 69, 803 (1996).

Quark-Antiquark Production in DIS Diffractive Dissociation

J. Bartels, H. Lotter, M. Wüsthoff

Phys. Lett. B379, 239 (1996).

Quarkonium Decay Matrix Elements from Quenched Lattice QCD

G. Bodwin, D. K. Sinclair, and S. Kim

Phys. Rev. Lett. 77, 2376 (1996).

Rapidity Gaps Between Jets in Photoproduction at HERA

ZEUS Collaboration, M. Derrick *et al.*,
Phys. Lett. B369, 55 (1996)

Reconstruction of $B^0 \rightarrow J/\psi K^0_s$ and Measurement of Ratios of Branching Ratios Involving
 $B \rightarrow J/\psi K^{(*)}$

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 2015 (1996).

Resummation of Gluon Radiation and the Top Quark Production Cross Section

Edmond L. Berger and Harry Contopanagos

Proceedings of the International Europhysics Conference on High Energy Physics,
Brussels, Belgium, 27 July –2 August, 1995, edited by J. Lemonne, C. Vander
Velde, and F. Verbeure (World Scientific, Singapore, 1996) pp. 645–648.

Scale Invariant $O(g^4)$ Lipatov Kernels at Nonzero Momentum Transfer

C. Coriano, R. R. Parwani, A. R. White
Nucl. Phys. B468, 219 (1996).

Search for Charged Higgs Boson Decays of the Top Quark Using Hadronic τ Decays

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. D54, 735 (1996).

Search for Chargino-Neutralino Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 4307 (1996).

Search for Flavor-Changing Neutral Current B Meson Decays in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 4675 (1996).

Search for Gluino and Squark Cascade Decays at the Fermilab Tevatron Collider

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 2006 (1996).

Search for Supersymmetry with a Light Gravitino at the Fermilab Tevatron and CERN LEP
Colliders

S. Ambrosanio, G. L. Kane, G. D. Kribs, S. P. Martin, S. Mrenna
Phys. Rev. D54, 5395 (1996).

Search for the Rare Decay $W^\pm \rightarrow \pi^\pm + \gamma$

CDF Collaboration, F. Abe *et al.*,
Phys. Rev. Lett. 76, 2852 (1996).

Single-Spin Asymmetries and Invariant Cross Sections of the High Transverse-Momentum Inclusive π^0 Production in 200 GeV/c pp and $\bar{p}p$ Interactions

FNAL E-704 Collaboration, D. L. Adams *et al.*,
Phys. Rev. D 53, 4747 (1996).

Single-Spin Asymmetries in Inclusive Charged Pion Production by Transversely Polarized Antiprotons

FNAL E-704 Collaboration, A. Bravar *et al.*,
Phys. Rev. Lett. 77, 2626 (1996).

Studies of Hadron Electron Separators for the ZEUS Barrel Calorimeter

I. Ambats, D. Bortz, A. Connolly, A. Derlicki, M. Derrick, W. Kahle,
S. Magill, D. Mikunas, B. Musgrave, J. Schlereth, R. Stanek, J. Thron
Nucl. Instrum. Meth. A 368, 364 (1996).

Study of Atmospheric Neutrino Interactions and Search for Nucleon Decay in Soudan 2

W. A. Mann, *et al*
Proceedings of the International Workshop on Future Prospects of Baryon
Instability Search in p-Decay and $n \rightarrow \bar{n}$ Oscillation Experiments, Oak Ridge,
TN, March 28-30, 1996, pp. 175-188, Ed. J. S. Ball and Y. A. Kamyshev.

Theory Institute: Topics in non-Abelian Duality

C. Zachos (ed.)
Electronic proceedings [<http://www.hep.anl.gov/theory/tdual.html>].

The Perturbative Resummed Series for Top Quark Production

Edmond L. Berger and Harry Contopanagos
Phys. Rev. D 54, 3085 (1996).

The Soudan 2 Detector. The Design and Construction of the Tracking Calorimeter Modules

W. W. M. Allison *et al.*,
Nucl. Instrum. and Meth. in Phys. Res. A 376, 36 (1996).

The Soudan 2 Detector. The Operation and Performance of the Calorimeter Modules

W. W. M. Allison *et al.*,
Nucl. Instrum. and Meth. in Phys. Res. A 381, 385 (1996).

Top Decay Physics at CDF and Measurement of the CKM Element V_{tb}

T. LeCompte
Proceedings of the IId Recontres du Vietnam Conference "At the
Frontiers of the Standard Model", Ho Chi Minh City, Vietnam,
October 20-28, 1995.

Top Quark Production Dynamics in QCD

Edmond L. Berger and Harry Contopanagos

Proceedings of the International Symposium on Heavy Flavor and Electroweak Theory, Beijing, August 16-19, 1995, edited by Chao-Hsi Chang and Chao-Shang Huang (World Scientific, Singapore, 1996) pp. 25-36.

Ultra High Energy Cosmic Ray Composition from Surface Air Shower and Underground Muon Measurements at Soudan 2

N. P. Longley *et al.*,

Physical Review D 52, 2760 (1995).

Upsilon Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

CDF Collaboration, F. Abe *et al.*,

Phys. Rev. Lett. 75, 4358 (1995).

Visualizing the Solutions for the Circular Infinite Well in Quantum and Classical Mechanics

R. W. Robinett

Am. J. Phys. 64, 440 (1996).

V.B PAPERS SUBMITTED FOR PUBLICATION IN JOURNAL/CONFERENCE PROCEEDINGS

Associated Production of Charm and a Hard Photon

B. Bailey, E. Berger and L. Gordon

To be published in Proceedings of the XXXIst Recontres de Moriond on QCD and High Energy Hadronic Interactions, Les Arcs, France, March 23-30, 1996.

Electroweak Physics at CDF

L. Nodulman for CDF

To be published in Proceedings of the International Conference of High Energy Physics '96, FERMILAB-CONF-96-164-E

The Perturbative Resummed Series for Top Quark Production

Edmond L. Berger and Harry Contopanagos

To be published in the Proceedings of the XXXIst Recontres de Moriond on QCD and High Energy Hadronic Interactions, Les Arcs, France, March 23-30, 1996.

Breakdown of Conventional Factorization for Isolated Photon Cross-Sections

E. Berger, X. Guo, J. Qiu

To be published in Proceedings of the XIV International Conference on Particles and Nuclei (PANIC 96)", Williamsburg, VA, May 22-28, 1996.

New Parton Distribution Functions for the Photon

L. E. Gordon and J. K. Storrow

To be published in Nuclear Physics B

V.C PAPERS OR ABSTRACTS CONTRIBUTED TO CONFERENCES

Breakdown of Conventional Factorization for Isolated Photon Cross-Sections

E. Berger, Xiaofeng Guo, Jian-Wei Qiu

Paper presented at "XIV International Conference on Particles and Nuclei (PANIC 96)", Williamsburg, VA, May 22-28, 1996.

Lattice Calculation of Quarkonium Decay Matrix Elements

G. Bodwin, D. K. Sinclair (ANL), S. Kim (Seoul National University)

Conference paper presented at the "Quarkonium Physics Workshop: Experiment Confronts Theory", Chicago, IL, June 13-15, 1996.

V.D TECHNICAL NOTES

Measurement of the Differences in Total Cross Section for Antiparallel and Parallel Longitudinal Spins and a Measurement of Parity

H. Spinka

ANL-HEP-TR-96-36

Plate Stamping of Masterplates for the Tile-Cal Hadronic Calorimeter Used in the ATLAS Detector at CERN

N. Hill

ANL-HEP-TR-96-42

A Proposal for Laminated Pie Mechanical Construction of a Toroidal Magnet for the Far Detector for the MINOS Experiment

N. Hill

ANL-HEP-TR-96-45

CDF Note 3462

Large Transverse Momentum Jet Production and the Gluon Distribution
J. Houston, E. Kovacs, S. Kuhlmann *et al*

CDF Note/VFG-3465 Top Decay Physics at CDF and the Measurement of the CKM Element VTB

T. LeCompte for CDF

CDF Note 3469

Significance of the High ET Jet Excess Volume III
S. Kuhlmann

- CDF Note 3486 QCD Tests at CDF
E. Kovacs for CDF
- CDF Note 3529 W γ and Z/DY γ Production in Run 1a plus 1b
D. Benjamin, R. G. Wagner *et al*
- CDF Note 3593 CDF Direct Photon Cross Section at 630 GeV
S. Kuhlmann and A. Maghakian
- CDF Note 3614 A Prompt Photon Cross Section in the Plug Region
T. Ino and S. Kuhlmann
- CDF Note 3643 Detector Counting Rates in the 93-96 Run
L. Nodulman
- CDF Note 3665 Level 2 Trigger Efficiency for 9 GeV Electrons for Run 1A Part II
K. Byrum and B. Wicklund
- CDF Note 3694 First Look at the b Quark Cross Sections at 630
T. LeCompte, J. D. Lewis and S. Tkaczuk
- CDF Note 3704 IFT Review Committee Report
P. de Barbaro, D. Stuart, R. G. Wagner *et al*
- CDF Note 3707 On CEM and Company at 10^{33}
L. Nodulman
- CDF Note 3726 Diphoton Missing E_τ for Run 1B
R. Blair, S. Kuhlmann and T. Takano
- CDF Note 3728 Electroweak Results from CDF
L. Nodulman for CDF
- CDF Note 3733 Measurement of Ratio of b Quark Production at $\sqrt{s} = 630$ and 1800 GeV
J. D. Lewis, S. Tkaczuk and T. LeCompte
- NuMI-L-161 Minutes of the MINOS Collaboration Meeting at Fermilab, February 1996,
D. S. Ayres
- NuMI-L-162 Minutes of the MINOS Technical Board Meeting at Fermilab, February 1996,
D. S. Ayres
- NuMI-L-163 Minutes of the MINOS Detector R&D Committee Meeting at Fermilab, February
1996, D. S. Ayres
- NuMI-L-165 Transparencies of February 1996 MINOS Collaboration Meeting, D. S. Ayres.

- NuMI-L-166 Minutes of the MINOS Executive Committee Meeting, February 9, 1996, D. S. Ayres.
- NuMI-L-167 MINOS Organization Chart, February 7, 1996, D. S. Ayres.
- NuMI-L-176 Minutes of the MINOS Executive Committee Meeting, April 14, 1996, M. Goodman.
- NuMI-L-177 Transparencies from the MINOS Meeting, April 15-17, 1996, D. S. Ayres.
- NuMI-L-178 Minutes of the Detector R&D Committee from the MINOS Meeting at Oxford, April 15-17, 1996, D. S. Ayres.
- NuMI-L-179 Minutes of the Technical Board from the MINOS meeting at Oxford, April 15-17, 1996, D. S. Ayres
- NuMI-L-180 Minutes of the MINOS Collaboration at Oxford, April 15-17, 1996, D. S. Ayres.
- NuMI-L-184 MINOS Experiment R&D Plan: FY 1996-1998, May 1996. D. S. Ayres for the MINOS Collaboration.
- NuMI-L-186 Minutes of the MINOS Executive Committee, Lutsen, MN, June 5, 1996, M. Goodman
- NuMI-L-187 Transparencies from the June 1996 (Lutsen) MINOS Meeting, D. S. Ayres.
- NuMI-L-189 Minutes of the MINOS Executive Committee, Lutsen, MN, June 10, 1996, D. S. Ayres.
- NuMI-L-190 Minutes of the Detector R&D Committee from the MINOS meeting at Lutsen, MN, June 7, 1996, D. S. Ayres.
- NuMI-L-191 Minutes of the Technical Board from the MINOS Meeting at Lutsen, June 8, 1996, D. S. Ayres.
- NuMI-L-192 Minutes of the MINOS Collaboration Meeting at Lutsen, June 5-10, 1996, D. S. Ayres.
- PDK-631 CEV Analysis of the 3rd Data Set, November 1995, R. Seidlein
- PDK-632 Ntuples for CEV Analysis, March 13, 1996, R. Seidlein
- PDK-634 Minutes of the CEV Meeting at RAL, Rutherford Labs, United Kingdom, March 18-22, 1996, R. Seidlein

- PDK-635 Decisions of the Soudan 2 Collaboration Meeting at Rutherford, March 19-21, 1996, D. S. Ayres
- PDK-636 Soudan 2 Experiment Quarterly Status Report, January-March 1996, D. S. Ayres.
- PDK-641 Soudan 2 Experiment Quarterly Status Report, April-June 1996, D. S. Ayres.
- STAR 242 Jet Quenching Using Gamma-Jet Events
T. J. LeCompte and D. G. Underwood
- STAR 245 A Study of Effects of Phi Cracks in the STAR EMC
K. Krueger, D. Underwood and T. LeCompte

VI COLLOQUIA AND CONFERENCE TALKS

D. S. Ayres

“Results from the Soudan Experiment”

Seminar presented at the University of Chicago

“The Soudan Underground Physics Laboratory”

Talk presented at the Workshop on Solar Neutrino Experiments at Fermilab.

E. L. Berger

Calculation of the Cross Section for Top Quark Production

Invited Talk at 11th Topical "Workshop on Proton-Anti-Proton Collider Physics (PBARP 96)", Padua, Albano Terme, Italy, May 26-June 1, 1996.

Top Quark Production Dynamics in QCD

Invited review given at Aspen Winter Conference, Aspen, CO, January 8, 1996.

Top Quark Production in Hadron Reactions

Invited plenary review given at International Symposium on Recent Developments in Phenomenology, University of Wisconsin, Madison, April 3, 1996.

Theory of Top Quark Production in Hadron Collisions

Invited plenary talk presented at the XI Topical Workshop on Hadron Collider Physics, Abano Terme, Padova, Italy, May 26-June 1, 1996.

Associated Production of Charm and a Hard Photon

B. Bailey, E. Berger and L. Gordon

Talk given at XXXIst Recontres de Moriond, “QCD and High Energy Hadronic Interactions”, Les Arcs, France, March 23-30, 1996.

G. Bodwin

“A Lattice Formulation of Chiral Gauge Theories”

Presented at Physics Department, Iowa State University, April 18, 1996.

“A Lattice Formulation of Chiral Gauge Theories”

Presented at Lattice '96, The 14th International Symposium on Lattice Field Theory, Washington University, St. Louis, Missouri, June 8, 1996.

“Quarkonium Decay Matrix Elements from Lattice QCD”

Presented at the Quarkonium Physics Workshop: Experiment Confronts Theory, University of Illinois, Chicago, June 15, 1996.

M. Derrick

“Physics with e-p colliding beams”

Presented at the University of California-Irvine, February 1996.

“Review of Diffractive Phenomena”

Presented at Physics in Collision Conference, Mexico City, Mexico, June 1996.

L. E. Gordon

“Isolated Prompt Photon Production at HERA”

Invited Talk at International Workshop on "Deep Inelastic Scattering and Related Phenomena (DIS 96)", Rome, Italy, April 15-19, 1996.

D. Krakauer

“Proton Structure and QCD Results from HERA”

Presented at High Energy Physics Seminar, Argonne National Laboratory, May 1, 1996.

“New Results on Nucleon Structure”

Invited talk at DPF Quantum Chromodynamics Symposium at the APS Spring Meeting, Indianapolis, IN, May 5, 1996.

S. T. Kuhlmann

“Large Transverse Momentum Jet Production and the Gluon Distribution Inside the Proton”

Presentation at the XXXIst Recontres de Moriond on QCD and High Energy Hadronic Interactions, Les Arcs, France, March 22-31, 1996.

L. J. Nodulman

“CDF Central EM Calorimeter at 10^{33} ”

Presented at TeV³³ Workshop, Fermilab, March 96.

J. Norem

“The Proton Driver for the Muon Collider”

Presented at Fermilab, April 1, 1996.

L. E. Price

“High Speed Networking in the US”

Presented at the High Energy Physics Computer Coordinating Committee (Europe), February 1996.

"Argonne Program in HEP"

Presented at HEPAP, May 1996.

"International Networking"

Presented to Esnet Steering Committee, May 1996.

A. R. White

"The Hard Gluon Component of the QCD Pomeron"

Invited talk at "3rd AUP Workshop on QCD: Collisions, Confinement and Chaos", Paris, France, June 3-8, 1996.

"Buchmuller Scaling and the QCD Pomeron"

Invited talk at Topical Conference on Hard Diffractive Processes, Eilat, Israel, February 18-23, 1996.

"Pomeron Physics in QCD - from Conformal Symmetry to Sextet Quarks"

Seminar, University of Florida, March 8, 1996.

"Is There New Strong Interaction Physics at the Electroweak Scale"

Colloquium, Northwestern University, April 17, 1996.

"Physics in Asymptopia"

Invited talk at Symposium on the Occasion of the retirement of Martin Block, Northwestern University, May 4, 1996.

"The Hard Part of the Soft Pomeron"

Invited talk at Workshop on Quantum, Chromodynamics and Chaos, American University of Paris, France, June 3-8, 1996.

M. Wusthoff

"A Theoretical Overview on Single Hand Diffraction"

Invited talk given at "XI Topical Workshop on Proton-Antiproton Collider Physics", Abano Terme, Italy, May 26-June 1, 1996.

A. Yokosawa

"Collider Spin Physics at RHIC and STAR"

Presented at the Adriatico Research Conference on "Trends in Collider Spin Physics", Trieste, Italy, December 5-8, 1995.

C. Zachos

"Duality and Nonlocal Canonical Equivalence in Field Theory"

Talk presented to Physics Department of the University of Florida, April 19, 1996.

VII HIGH ENERGY PHYSICS COMMUNITY ACTIVITIES

D. S. Ayres

Deputy Spokesman and Acting Project Manager of the MINOS Collaboration.

E. L. Berger

Member, Committee on Meetings, American Physical Society, 1991-present.

Member, Scientific Program Committee, XXXI Rencontre de Moriond, "QCD and High Energy Hadronic Interactions", Les Arcs, France, March 1996.

Member, Argonne Laboratory Director's Review Committee, Individual Investigator Laboratory Directed Research and Development Program, 1994-1996.

Member, High Energy and Nuclear Physics Advisory Committee, Brookhaven National Laboratory, 1995-1998.

Member, International Advisory Committee, Snowmass Summer Study, Division of Particles and Fields of the American Physical Society, Snowmass, CO, June-July 1996.

Member, Steering Committee, 11th Topical Workshop on Hadron Collider Physics, Padova, Italy, May 1996.

D. A. Krakauer

Sub-group Convenor, "New interactions Subgroup" - New Directions in High Energy Physics Workshop, Snowmass 1996, Snowmass, CO, June 24-July 12, 1996.

L. E. Price

Chair, ESnet Steering Committee.

Member, Organizing Committee, Snowmass 96.

U.S. ATLAS Executive Committee.

Member, U.S./China Joint Committee on Cooperation in High Energy Physics.

Member, International Advisory Committee, Computing in HEP, Berlin, 1997.

Member, International Advisory Committee, 5th International Conference on Advanced Technology and Particle Physics, Italy, 1996.

J. Repond

Chairperson, Local Organizing Committee for DIS 97.

C. Zachos

Principal Organizer of the Argonne Theory Institute "Topics in non-Abelian Duality", June 27-July 12, 1996, and (Editor of their Electronic Proceedings - Covered in this Semiannual Report).

Member of the Board of Editors, Journal of Physics A: Mathematical and General, (UK).

VIII

HIGH ENERGY PHYSICS DIVISION RESEARCH PERSONNEL

Administration

L. Price

D. Hill

Accelerator Physicists

W. Gai

P. Schoessow

J. Norem

J. Simpson

Experimental Physicists

D. Ayres

L. Nodulman

R. Blair

J. Proudfoot

K. Byrum

J. Repond

D. Crane

R. Seidlein

M. Derrick

H. Spinka

T. Fields

R. Stanek

M. Goodman

R. Talaga

D. Krakauer

J. Thron

S. Kuhlmann

D. Underwood

T. LeCompte

R. Wagner

S. Magill

A. B. Wicklund

E. May

A. Yokosawa

B. Musgrave

Theoretical Physicists

E. Berger

S. Mrenna

G. Bodwin

D. Sinclair

H. Contopanagos

A. White

L. Gordon

M. Wüsthoff

J. F. Lagae

C. Zachos

Engineers, Computer Scientists, and Applied Scientists

J. Dawson

J. Nasiatka

V. Guarino

J. Schlereth

W. Haberichter

X. Yang

N. Hill

Technical Support Staff

I. Ambats

T. Kasprzyk

L. Balka

L. Kocenko

H. Blair

D. Konecny

G. Cox

R. Rezmer

D. Jankowski

Laboratory Graduate Participants

C. Allgower

M. Hohlmann

N. Barov

D. Mikunas

M. Bai

J. Okrasinski

H. Gallagher

J. Power

A. Hardman

H. Zhang

Visiting Scientists

M. Conde (AWA)

E. Levin (Theory)

C. S. Kim (Theory)

H. Lipkin (Theory)

K. Krueger (Pol. Beam)

G. Ramsey (Theory)

Y. W. Law (Theory)

D. Richards (Theory)