HIGH ENERGY PHYSICS DIVISION SEMIANNUAL REPORT OF RESEARCH ACTIVITIES

January 1, 1997 – June 30, 1997

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Prepared from information gathered and edited by
the committee for Publications and Information:

Members: J. Norem
R. Rezmer
R. Wagner

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I. EXPERIMENTAL RESEARCH PROGRAM

I.A. EXPERIMENTS WITH DATA

I.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. These 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 Jefferson Lab (CEBAF).

Work on the analysis of a large amount of pp elastic scattering data from Saclay continued during this period. The spin observables $P = A_N = A_{\text{ono}} = A_{\text{oon}}$ and $C_{NN} = A_{NN} = A_{\text{oonn}}$ were measured for $\theta_{\text{c.m.}} \sim 60^\circ - 90^\circ$ at over 30 beam kinetic energies between 1800 and 2800 MeV. Final results were derived at all beam energies. These data were described in a Ph.D. thesis by Chris Allgower, who has been supported by Argonne for this research. His thesis defense will occur early in the next period, and he traveled to MIT to discuss the interpretation of these data with Earle Lomon. The results still need to be combined with those from an independent analysis in Saclay. Work continued at Argonne on two papers describing these data.

Two other papers were written by Saclay collaborators describing results from these experiments. One titled "Dependence of Proton Beam Polarization on Ion Source Transition ~Configurations" describes operation of the Saclay polarized ion source and the magnitudes of the four polarization states. These magnitudes were obtained from special tests with both the polarized and unpolarized sources at the Saturne accelerator. This paper was submitted to Nucl. Instrum. and Methods. The other article, titled "Proton-Proton Elastic Scattering Analyzing Power in the 2.16 to 2.28 GeV Energy Region" described data collected with an unpolarized beam and polarized target. The paper was submitted to Z. Phys. C, and the results are shown in Fig. 1.

The second major portion of the medium energy physics program involves experiments with the Crystal Ball detector at the Brookhaven AGS. The goal of experiments E913 and E914 will be to study hadron spectroscopy via π^-p and K^-p reactions into all neutral final states. During this period, preparations continued for experimental runs. An Argonne physicist spent

considerable time with an Arizona State University graduate student, Kelly Craig, and others to perform a preliminary calibration of the 672 NaI crystals with ^{137}Cs and ^{60}Co radioactive sources. Various hardware problems were diagnosed, and most of them solved. The resulting calibration gave excellent results on-line.

Another task was the testing, installation, and cabling of a set of large plastic scintillation neutron counters for the experiments, and the construction of the support for these counters. The Crystal Ball subtends laboratory angles from $20 - 160^\circ$, and the neutron counters were located over part of the forward 20° not covered by the Crystal Ball. Essentially all hardware for this task, including electronics, was Argonne equipment that had been shipped to BNL from LAMPF some time ago.

A two week test run occurred in early April. It was established that event rates and backgrounds were acceptable with pion beams from 300 - 750 MeV/c. Charged particle veto counters worked adequately, and a calibration with the $\pi^- p \rightarrow n\gamma$ reaction with stopped pions was performed. The liquid hydrogen target was not yet available from the Brookhaven cryogenics group. An early on-line $\gamma - \gamma$ invariant mass plot is shown in Fig. 2.

A two week experimental run took place in late May. This was quite successful, with data collected at 12 momenta with pions incident on a liquid hydrogen target. Target empty data and various backgrounds were also measured. The beam momentum was calibrated with a variety of methods, including time of flight and range.

It is believed that there are sufficient data at several momenta on the $\pi^- p \rightarrow \pi^0 \pi^0 n$ reaction to study the Dalitz plot and to serve as the basis of a Ph.D. thesis for Kelly Craig. Note, $p^0 \rightarrow \pi^0 \pi^0$ is forbidden by isospin conservation, and there are few other detailed studies of this reaction below 750 MeV/c. In this period we were unable to obtain good quality data with kaons due to hardware problems and lack of sufficient running time. However, it is expected that the pion data will allow a number of important physics results to be obtained, such as for the $\pi^- p \rightarrow \pi^0 n$, $\rightarrow \gamma n$, and $\rightarrow \eta^0 n$ reactions.

Simulations and some preliminary data analysis occurred jointly by members of Argonne and Valparaiso University (a Valparaiso professor was supported for this work during the summer). The results of the kaon tests are being studied, but do not appear to be good quality. Comparisons of energy clusters from photons and neutrons are being pursued, and the single

event display software is being improved. This work will continue in the early part of the next period.

Fig. 1. Experimental measurements of the single spin observable A_{oon} for pp elastic scattering at various beam kinetic energies. These data (solid circles) were collected at Saclay with an unpolarized beam incident on a polarized proton target. Results from other groups are also shown, and the curves represent phase shift analysis predictions by R. A. Arndt, et al.

Fig. 2. One of the first on-line plots obtained from the Crystal Ball detector at the Brookhaven AGS accelerator. The invariant mass of two energy clusters is plotted using calibrations from radioactive sources. The π^0 and η^0 peaks are clearly visible. These results are now improved using various other methods to calibrate the individual counters in the Crystal Ball.

(H. Spinka)

I.A.2 Polarized Proton Physics at FNAL

A paper on "Measurement of Single Spin Asymmetry in η -meson production in $\bar{p} \uparrow p$ and $\bar{p} \uparrow p$ Interactions in the Beam Fragmentation Region at 200 GeV/c" is complete and will be sent for publication. The average value of the asymmetry over the x_F region $0.4 < x_F < 0.7$ is $A_N = 17 \pm 5\%$. The asymmetry in $\bar{p} \uparrow p$ interactions is consistent with zero. Within the error bars, the experimental result is consistent with the prediction of the Berliner model.

(A. Yokosawa)

I.A.3. Collider Detector at Fermilab

a. QCD Studies

Bob Blair and Steve Kuhlmann continued to work to bring the Run Ia direct photon analyses to a close, while guiding the new Run Ib students. The final run Ia photon analysis to publish is photon+muon production, which was the thesis of Rowan Hamilton from Harvard. Unfortunately there were many unfinished details when Rowan took a job. Steve and Bob and the run Ib photon+muon student, Koichi Kurino from Hiroshima University, are trying to finish this paper, which is under review. The run Ib photon+muon analysis is getting underway.

b. TeV-33 Studies

The first results of the studies of dijet mass resolution are published as CDF and ATLAS technical notes. Steve Kuhlmann is leading the effort and Stefano Lami from Rockefeller University/INFN-Pisa is heading the group from Pisa. The group meets by video every two weeks. The first note concerns a generic study of jet algorithms in a particle-level $W^- \rightarrow q\bar{q}$ simulation. This lays the groundwork for optimizing the algorithm for any physics topic, including the Higgs search. Work is now beginning on optimizing the use of the detector information.

c. Top Physics

Tom LeCompte's analysis of FCNC decays of top quarks ($t \rightarrow c, u + \gamma, t \rightarrow c, u + Z^0$) was completed and sent to PRL. Assuming three generations of quarks and leptons, we find $B(t \rightarrow q + \gamma) < 0.032$ at 95% c.l., and $B(t \rightarrow q + Z^0) < 0.33$ at 95% c.l. One candidate event survives in each decay mode, consistent with backgrounds expected from standard model sources.

Marcus Hohlmann, who worked with us on the Run II strip chamber electronics readout, completed the analysis of dilepton pair top events containing tau leptons. He submitted a P.R.L. as well as his Ph.D. thesis. Larry Nodulman served on Marcus's thesis committee.

d. W Mass Analysis

Systematic effects on the lepton momentum measurement in the tracking chamber were carried out using the $W \rightarrow \text{electron}$ and $J/\psi \rightarrow \mu^+\mu^-$ samples. The momentum measurement is the basis for all absolute calibrations in CDF. The calorimeter energy scale, for example, is determined from the E/p distribution of W electrons; this distribution is scaled to match the theoretical bremsstrahlung distribution based on known detector material, and it assumes that the momentum is accurately measured in the CTC.

Many misalignment corrections can be derived by comparing E/p for electrons and positrons. Larry Nodulman carried out a detailed study of false curvatures in the momentum measurement using the E/p comparison; the results can be explained by small misalignments of the CTC and SVX detector axes, and overall relative rotations and tension-related twists of the CTC endplates. The final corrections improve the momentum resolution and give uniform momentum calibration over the chamber. As an example, Figure 1 shows the mean E/p for W electrons and positrons, plotted against the polar angle with respect to the beamline; electrons and positrons have opposite slopes with respect to $\cot \theta$.

Fig. 1 Mean E/p for electrons (top) and and positives (bottom) versus $\cot \theta$.

This is a potentially important bias, since electrons and positrons have a production rate asymmetry that also varies strongly with $\cot \theta$. The final scale calibration is provided by the observed J/ψ mass, using relatively low-momentum muons (2-10 GeV/c). Upsilon decays to dimuon pairs are also used to check the momentum scale. Figure 2 shows the final J/ψ and Υ masses after all alignment corrections, plotted against, $1/p_T^2$ where p_T refers to the highest p_T muon. The point at $1/p_T^2 = 0$ is derived from the observed $Z \rightarrow \mu^+ \mu^-$ mass peak. There is some indication of a systematic variation of the J/ψ mass with momentum, which would correspond to a scale error of order 0.1% between the 2-3 GeV/c region and the W/Z mass region. This is under intense scrutiny.

Fig. 2 J/ψ and Υ mass shifts plotted against $1/p_T^2$.

Energy loss corrections are a potential source of miscalibrations. For muons from J/ψ decay, the average energy loss correction is around 5 MeV, or of order 0.1% in the J/ψ mass; this correction is much smaller at the W/Z mass scale, and so errors in the correction can introduce nonlinearity into the momentum scale. Randall Keup has developed a map of energy loss corrections based on the material xray from conversion electrons. The observed distribution

of conversion pairs in the detector, which is proportional to X_0 , is converted to an energy loss distribution, given by the the energy loss per unit radiation length for the given material.

Another momentum scale cross check is provided by decays $J/\psi \rightarrow e^+e^-$ where the electron momenta (not calorimeter energies) are used to define the J/ψ mass; the shape of the mass spectrum then gives the bremsstrahlung contribution, which should be consistent with the same contributions to the W electron E/p spectrum. Figure 3 shows the J/ψ mass using dielectrons; the flat curve is the estimated fake electron background. By fitting templates to this mass spectrum, the expected uncertainty on the mass scale is 0.02% and on the amount of material, of order 10%. This result gives a direct check on high Pt electron momentum scales, including radiative effects, complementary to $Z \rightarrow e^+e^-$.

Fig. 3 Mass distribution for e^+e^- pairs.

A preliminary W mass result, based on the momentum calibration for the $W \rightarrow \mu\nu$ sample, was presented at the winter conferences:

$$- \quad M(W) = 80.390 \pm 0.100(\text{stat.}) \pm 0.120(\text{syst.}) \text{ GeV}/c^2$$

The transverse mass spectrum is shown in Figure 4.

e. **Triboson Couplings**

Work on the $W\gamma / Z\gamma$ analysis concentrated on the missing transverse energy correction during the first few months of 1997. The algorithm for the correction was adapted from a scheme developed by our colleagues at Duke University. It was necessary to modify the code to correctly handle photons in the transverse energy sum and to verify the correction factor applied to unclustered transverse energy in the calorimeter.

Following successful completion of this algorithm, the results were documented in a CDF note (CDF note 4193). The group then began a push to extract the final data samples for inclusive W and Z events as well as $W\gamma$ and $Z\gamma$. Two independent analyses were performed in both the electron and muon channels and work focussed on resolving remaining discrepancies between the analyses.

f. **B Physics**

Many of the CDF b-physics analyses from run I are near publication stage. Larry Nodulman and Barry Wicklund served as godparents for the analysis of the CKM angle $\sin 2\beta$ based on $B^0 \rightarrow \psi K_s^0$

Flavor tagging is a crucial requirement for CP and mixing studies. The flavor tags used so far by CDF include jet-charge, same-side tagging using b fragmentation, and soft electron and muon identification. Barry Wicklund and Karen Byrum worked on improvements to the soft electron tagging algorithms, starting with careful calibration of the CDF electron identification devices (E/p, shower maximum, preshower, and dE/dx in the CTC.) The J/ψ peak in Figure 3 depends on this analysis. This J/ψ sample is obtained using high p_T trigger electrons accompanied by a low- p_T ($p_T > 1 \text{ GeV}/c$) partner electron candidate.

Rare radiative decays, $B^0 \rightarrow K^{*0} \gamma, \rho^0 \gamma$, provide a window on the CKM elements V_{td} and V_{ts} since the top quark is expected to dominate in the short-distance penguin contributions. At a hadron collider, it is difficult to trigger on these decays and also to get good mass resolution

for S/N optimization. A possible solution is to use photon conversions to e^+e^- pairs to identify the photons; the B hadron mass resolution for the $K^{*0}\gamma$ mode is then improved by a factor of four, compared with calorimeter photon identification, and the trigger is improved by requiring an electron. As a test of the resolution, we look at known mass peaks, π^0 and η , first identifying a conversion pair from a trigger electron, then looking for a second pair (second photon) in the accompanying charged tracks. Figure 5 shows the π^0 and η mass peaks from this analysis.

Fig. 4 Transverse mass spectrum for $W \rightarrow \mu\nu$ events.

Figure 4 shows the resulting π^0 and η mass peaks. Extrapolating from these, we estimate around 25 MeV on the mass resolution for $B^0 \rightarrow K^{*0}\gamma$. We are exploring options for CDF run II using $K^*e^+e^-$ triggers.

Fig. 5 Calibration using double photon conversions.

Calibration Using Double Photon Conversions

(B. Wicklund)

I.A.4 Non-Accelerator Physics at Soudan

a. Physics Results

During the first half of 1997 Soudan physicists continue the analysis effort on the identification and characterization of atmospheric neutrino interaction events. Results from the first 1.5 kt-year on the ν_μ / ν_e "flavor" ratio for atmospheric neutrinos were published in Physics Letters. 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.

$$R \equiv \left(\frac{\nu_\mu}{\nu_e} \right)_{data} / \left(\frac{\nu_\mu}{\nu_e} \right)_{MC} \sim \left(\frac{tracks}{showers} \right)_{data} / \left(\frac{tracks}{showers} \right)_{MC}$$

allows a measurement which is independent of an absolute flux or exposure calculation. We have analyzed data from 2.63 fiducial kton-year exposure taken between April 1989 and March 1995. During this period the detector was under construction, starting with a total mass of 275 tons and ending with the complete 963 tons. There were 75 million triggers taken. The goal of the data reduction is to obtain a sample of 'contained events,' defined as those in which no primary particle in the event leaves the fiducial volume of the detector. The fiducial volume is defined by a 20 cm depth cut.

The events are passed through a software filter to reject events with tracks entering or leaving the fiducial volume (mostly cosmic ray muons) or events which have the characteristics of radioactive background or electronic noise. Approximately 1 event per 1500 triggers passes this filter.

The selected events are then double scanned to check containment and to reject background events, using an interactive graphics program. The main backgrounds are residual radioactive and electronic noise, badly reconstructed cosmic ray muons and events where muons pass down the gaps between individual modules, either finally entering a module and stopping or interacting in material in the gap and sending secondary tracks into the modules. Any event with a track which starts or ends on a gap, or which can be projected through a gap to the exterior of the detector is rejected. In addition, events with a vertex in the crack region are rejected. Differences between scanners are resolved by a second level scan. Approximately 1 event in 40 passed by the program filter is finally selected as contained. The average efficiency of individual scanners in selecting contained events was 93.5%.

Monte Carlo events equivalent to 5.9 times the exposure of the real data were inserted randomly into the data stream and processed simultaneously with the data events, ensuring that

they are treated identically. The neutrinos were generated using the BGS flux. The variation of the ν intensity with the solar cycle was corrected using neutron monitor data.

The lepton flavour of each event is determined by the second level 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. Results are shown in Table 1. Events without (with) shield hits are labeled "gold" ("rock") events. As a test of the systematic uncertainties introduced by the classification process, all scanning was done independently by two groups prior to merging for the final results.

Table 1: Classifications for the contained events before corrections.

	<i>Track</i>	<i>Shower</i>	<i>Multiprong</i>	<i>Proton</i>
Data: Gold	75	106	89	22
Data: Rock	237	312	177	130
Monte Carlo	461	445	432	48

The quality of the flavour assignment was measured using the Monte Carlo data. Table 2 shows the fraction of Monte Carlo events selected as contained which were classified in each category. It can be seen that 87% of events assigned as tracks have muon flavour and 96% of showers electron flavour. The ratio of accepted muon to electron charged current events is approximately 1:1, different from the expected ratio of 2:1 from the $\pi \rightarrow \mu \rightarrow e$ decay chain. At these low energies threshold effects due to the difference in the muon and electron masses cause the generated event ratio to be approximately 1.5:1. Acceptance differences for high energy muons and electrons and the cuts required to remove background produced by cosmic ray muons passing down the gaps between modules further reduce the ratio.

Table 2: Monte Carlo identification matrix.

<i>Generated</i>	<i>Assigned</i>			
	<i>Track</i>	<i>Shower</i>	<i>Multiprong</i>	<i>Proton</i>
$\nu_{\mu}cc$	0.87	0.01	0.38	0.24
$\nu_e cc$	0.05	0.96	0.44	0.04
Neutral current	0.08	0.03	0.18	0.72

The majority of the 1148 events classified as contained are due to the interactions of neutral particles (neutrons or photons) produced by muon interactions in the rock around the

detector. Calculations show that only a few percent of such events will not have an accompanying charged track traversing our shield, which 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. The efficiency of the shield has been measured using cosmic ray muons detected in the main detector. It ranges from 81% during the early data runs before the geometrical coverage was complete to 93% at the end of this data period. Also, 8.9% of pulser events overlaid on Monte Carlo events had a random shield coincidence.

Our large sample of rock events enables us to investigate muon induced background by studying the depth distribution of the events in the detector. This allows us to simultaneously measure any backgrounds due to either shield inefficiency or contained events due to neutral particles entering the detector without being accompanied by charged particles in the shield. Neutrino events should be distributed uniformly throughout the detector, while background events are attenuated towards the center. 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.

The background is subtracted using the depth distribution for tracks and showers from the gold, rock and neutrino Monte Carlo samples. The data more closely resembles the neutrino depth distribution than the rock background depth distribution. We note that the measured flavor ratio as a function of shield multiplicity is observed to be a constant value of 0.76 ± 0.07 . We then correct the track to shower ratio in the data by fitting the track and shower depth distribution to a sum of those in the rock events and Monte Carlo, constraining the flavor ratio of the rock events to its observed value. The result of the fit is 20.4 tracks and 26.9 showers in the gold sample are due to background, leading to a corrected neutrino induced rate of 54.6 tracks and 79.1 showers. From this we calculate $R = 0.67 \pm 0.15$, where the error includes the statistical error on the data, the statistical error on the Monte Carlo, and the error on the fit.

Systematic errors have been calculated based on errors on the flux models, neutrino cross sections, scanning, and the assumption that the flavor ratio of the background is independent of shield multiplicity. The latter systematic error, which can be measured by fitting the tracks and showers separately, leads to an asymmetric error. We calculate a total systematic error on R of $+0.04$ and -0.06 .

We also use the contained event samples to search for nucleon decay. From our Monte Carlo, we find that most $p \rightarrow \nu K^+$ decays would be in our track sample. The multiprong sample is used for searches into multiparticle final states. Such searches are complicated by two factors: 1) hadronic intranuclear rescattering can alter the observed topology from the proton decay product final state, through absorption and inelastic scattering; and, 2) pion scattering and absorption in the detector makes the range to energy conversion less reliable than for muon

tracks and electron showers. These effects are quantitatively similar but quantitatively different for each experiment.

After proton decay into νK^+ , most Kaons will decay at rest into a muon of 236 MeV / c momentum and an invisible neutrino. In Soudan 2 we can identify such events with a visible K and muon track. Using Monte Carlo events with the right reconstructed topology, a requirement of a visible Kaon track, and a muon with range corresponding to a momentum between 170 and 260 MeV/c, we find an efficiency times branching ratio of 9.1% within the fiducial volume. In 3.3 fiducial kiloton-years of data, there are no events, leading to a nucleon decay limit in this mode $\tau / B > 3.7 \times 10^{31} \text{ yr}$.

One major advantage of a tracking calorimeter over the water cherenkov detectors is the vertex resolution of $\pm 1 \text{ cm}$. For example, this allows the separation of an event with three or more charged particles coming from a single vertex from one in which a single track scatters multiple times. We define a class of events called “mercedes events” which have three or more charged tracks coming from a single vertex. A list of proton and neutron decay modes which would lead to such events is given in Table 1. An example of a Monte Carlo of the decay mode $p \rightarrow \mu^+ \mu^+ \mu^-$ is shown in Figure 1.

Fig. 1 Monte Carlo simulation of $p \rightarrow \mu^+ \mu^+ \mu^-$ Three views in Soudan are shown. The scale is cm.

A significant number of pions which are created by proton decay are not expected to get out of the nucleus due to intranuclear scattering. Our Monte Carlo takes into account the rescattering of pions within the nucleus using data obtained by comparison of bubble chamber ν interactions on deuterium and neon. We have studied the result of this model on the decay mode $p \rightarrow \mu^+ \pi^+ \pi^-$. We find that 42% of the π 's are absorbed, 28% suffer inelastic scattering, 8% charge exchange and only 19% exit the nucleus with their original momentum. These fractions depend on both the target nucleus and the pion momentum. The comparison of proton decay results from experiment to experiment should be done with a similar intranuclear model or with such effects removed. The results of our intranuclear Monte Carlo on the "mercedes" modes are shown in Table 3. The quoted efficiency is solely the fraction of events in which the proton decay remnants emerge from the nucleus with their original momentum. Most of this "inefficiency" will be reflected as observed proton decay events with less particles and momentum in the final state than would be the case for a free nucleon decay.

In an analysis of 3.3 kton-year of Soudan 2 data, there are 12 mercedes events. Most of them have far too much energy to be a nucleon decay candidate. They are consistent with neutrino multiparticle production. We are concentrating on finding a set of cuts for each decay mode with high efficiency. When that analysis is complete, we will apply the cuts to the 12 data events to determine whether we have any candidates. We expect that most limits on the decay modes in Table 3 will be made with no candidate events.

Table 3: Calculation of nuclear efficiencies for proton decay modes with 3 (top) or 4 (bottom) charged tracks from a vertex. Particle Data Group (Barnett, 1996) limits are shown where they exist.

<i>mode</i>	<i>Branching fraction</i>	<i>PDG limit</i>	ϵ_{nuc}
e^+p^0	1.0	$7.5 \times 10^{31} \text{ yr}$	0.07
μ^+p^0	1.0	11.0	0.07
$e^-\pi^+\pi^+$	1.0	3.0	0.07
$\mu^-\pi^+\pi^+$	1.0	1.7	0.07
$e^+\pi^-\pi^+$	1.0	2.1	0.07
$\mu^+\pi^-\pi^+$	1.0	1.7	0.07
$e^+e^+e^-$	1.0	51.0	1.0
$\mu^+\mu^+\mu^-$	1.0	19.0	1.0
$e^+\mu^+\mu^-$	1.0	8.1	1.0
$\mu^+e^+e^-$	1.0	9.1	1.0
$\mu^-\pi^+K^+$	1.0	0.5	0.26
$e^-\pi^+K^+$	1.0	2.0	0.26
$\mu^+\pi^-K^+$	1.0	x	0.26
$e^+\pi^-K^+$	1.0	x	0.26
$\mu^+\pi^+K^-$	1.0	x	0.26
$e^+\pi^+K^-$	1.0	x	0.26
$\nu\pi^+\pi^+\pi^-$	1.0	x	0.02
$\nu\mu\mu\pi$	1.0	x	0.26
$\nu e e \pi$	1.0	x	0.26
$\nu \mu e \pi$	1.0	x	0.26
$e^+\eta$	0.28	12.0	0.07
e^+K_s	0.69	7.6	1.0
$\mu^+\eta$	0.28	6.9	0.07
μ^+K_s	0.69	6.4	1.0
$\bar{\nu}K^+$	0.06	10.0	1.0
e^-K^+	0.06	3.2	1.0

(Table 3 Cond't)

<i>mode</i>	<i>Branching fraction</i>	<i>PDG limit</i>	ϵ_{nuc}
$\mu^- K^+$	0.06	5.7	1.0
$e^+ K^-$	0.06	0.1	1.0
$\mu^+ K^-$	0.06	0.1	1.0
$\nu K^{*0} \rightarrow \pi^+ K_s$	0.46	2.0	1.0
$\mu^+ \omega$	0.89	5.7	0.07
$e^+ \omega$	0.89	4.5	0.07
$\mu\pi\pi\pi$	1.0	x	0.02
$e\pi\pi\pi$	1.0	x	0.2
$\nu 4\pi$	1.0	x	0.005
$e\mu\mu\pi$	1.0	x	0.26
$ee\pi\pi$	1.0	x	0.26
$\mu\mu\mu\pi$	1.0	x	0.26
$ee\mu\pi$	1.0	x	0.26
$\nu e\mu\pi\pi$	1.0	x	0.07

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. Argonne physicists also continued the development of software to make use of dE/dx information from the detector.

c. Planning Activities

The Soudan group plans to run the detector for nucleon decay, atmospheric neutrino and other cosmic ray studies until an exposure of 5.0 kt-year fiducial volume is achieved. After that, the Soudan detector will become an integral part of the MINOS long-baseline neutrino oscillation experiment. The progress on that project 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.

Heavy quark photoproduction can be used to probe perturbative QCD calculations, where the necessary hard scale is stemming from the heavy quark mass and the high transverse momenta of the produced partons. ZEUS measured the inclusive photoproduction of D^* mesons in the center of mass energy range $115 < W < 280$ GeV and with photon virtualities $Q^2 < 4$ GeV². The cross section integrated over the kinematic region $p_{\perp}^D > 3$ GeV and $-1.5 < \eta^{D^*} < 1.0$ is $10.6 \pm 1.7(stat) \pm 1.3^{+0.0}_{-1.3}(syst)$ nb. Figure 1 compares the measured differential D^* cross section as a function of the transverse momentum of the D^* to different theoretical calculations. The massive charm approach assumes the light quarks to be the only active flavors within the structure of the proton and the photon, while the massless approach treats also charm as an active flavour. In the massive approach charm is generated externally via the photon-gluon fusion process. The different calculations are able to reproduce the shape of the differential cross section, however, the absolute normalization of the theory curves is strongly dependent on the particular choice of renormalization scale and on the assumed mass of the charm quark. This dependence renders it difficult to draw definite conclusions with respect of the underlying production mechanism.

Elastic ω photoproduction at $(W) = 80$ GeV and $|t| < 0.6$ GeV² has been measured. The ω mesons are observed via their decay into $\pi^+\pi^-\pi^0$ ($\pi^0 \rightarrow \gamma\gamma$). This measurement made extensive use of the shower maximum detector installed in the rear calorimeter for the identification of the π^0 's. The elastic cross section for the reaction $\gamma p \rightarrow \omega p$ is measured to be $1.21 \pm 0.12 \pm 0.23 \mu\text{b}$. The result, together with previous measurements from fixed target experiments, is shown in Fig. 2. The W dependence of the cross section in the range $10 < W < 100$ GeV is found to be weak, as predicted by Regge fits to hadronic cross sections. The exponential slope of the differential cross section versus $|t|$ has been determined to be $10.0 \pm 1.2 \pm 1.3$ GeV⁻². Again, this result is in good agreement with Regge theory, which predicts a slow increase of the slope parameter with increase W .

Fig. 1. Differential cross section $d\sigma_{ep \rightarrow D^*X}^{D^*} / dp_{\perp}^{D^*}$ in the kinematic region $Q^2 < 4 \text{ GeV}$, $115 < W < 280 \text{ GeV}$ and $-1.5 < \eta^{D^*} < 1.0$. The different theoretical predictions are indicated by the lines.

Fig. 2. Elastic $\gamma p \rightarrow \omega p$ cross sections versus center of mass energy. The horizontal error bars indicate the W range covered by the measurements. The line is a parametrization based on Regge fits to hadronic data.

The differential cross section $d\sigma/dt$ for elastic ρ^0 photoproduction $\gamma p \rightarrow \rho^0 p$ has been measured in the W range between 50 and 100 GeV . The squared four-momentum exchanged at the proton vertex, t , has been determined directly by measuring the momentum of the scattered proton using the Leading Proton Spectrometer (LPS), a large scale system of silicon microstrip detectors operating close to the HERA proton beam. The t distribution exhibits an exponential shape with a slope parameter $b = 9.8 \pm 0.8(\text{stat}) \pm 1.1(\text{syst}) \text{ GeV}^2$. This measurement is

particularly interesting, since the use of the LPS eliminates the contamination from events with diffractive dissociation of the proton into low mass states.

The reaction $\gamma p \rightarrow J/\psi p$ has been studied as a function of the center of mass energy W at a median photon virtuality Q^2 of $5 \times 10^{-5} \text{ GeV}^2$. The cross section, $\sigma_{\gamma p \rightarrow J/\psi p}$, is observed to rise steeply with W , see Fig. 3. A fit of the W dependence to the form $\sigma_{\gamma p \rightarrow J/\psi p} \propto W^\delta$ yields the value $\delta = 0.92 \pm 0.14 \pm 0.10$. In most recent theoretical models, elastic J/ψ 's are assumed to be produced via the exchange of two gluons. Therefore, the production cross section is expected to be proportional to the square of the gluon density. If a gluon distribution of the form $xg(x, Q^2) \propto x^{-\lambda}$ is assumed, then the value of δ gives $\lambda = 0.23 \pm 0.04 \pm 0.03$ at a scale of approximately a quarter of $M_{J/\psi}^2$. This is consistent with our measurement of the gluon distribution based on an analysis of the proton structure function and extrapolated back to $Q^2 = 2.5 \text{ GeV}^2$.

Fig. 3. The elastic J/ψ photoproduction cross section as a function of W : a) our results together with the result of the fit using the expression $\sigma_{\gamma p \rightarrow J/\psi p} \propto W^\delta$; b) our results together with data from H1 and lower energy measurements. The lines show predictions of various perturbative QCD calculations.

The paper that generated most interest in the community, compared ZEUS data with Standard Model predictions for $e^+p \rightarrow e^+X$ scattering at high x and $Q^2 > 5000 \text{ GeV}^2$. The

results are based on the 20.1 pb^{-1} collected during the years 1994 to 1996. For Q^2 below 15000 GeV^2 , the data appear to be in good agreement with the Standard Model expectations. For $Q^2 > 35000 \text{ GeV}^2$, two events are observed while 0.145 ± 0.013 events are expected, see Fig. 4. A statistical analysis of a large ensemble of simulated Standard Model experiments indicates that with probability 6.0%, an excess at least as unlikely as that observed would occur above some arbitrary Q^2 cut. For $x > 0.55$ and $y > 0.25$, four events are observed where 0.91 ± 0.08 events are expected. A statistical analysis which assigns a probability to the two-dimensional distribution of the events in x and y yields a probability of 0.72% for the region

Fig. 4. The Q^2 distribution of the observed events at high Q^2 compared to the Standard Model e^+p neutral current expectation (histogram).

$x > 0.55$ and $y > 0.25$ and a probability of 7.8% for the entire $Q^2 > 5000 \text{ GeV}^2$ data sample. The observed excess above Standard Model predictions is particularly interesting since it occurs in a previously unexplored kinematic region. The competing experiment H1 at HERA observes a similar excess. Their events appear to cluster in x , suggesting the observation of a resonance in the s -channel. This is not supported by the ZEUS data.

Events of the type $ep \rightarrow \ell + X$ with a final-state lepton of high transverse momentum, $\ell = \mu$ or τ , were sought in the combined 1993 and 1994 data samples, for which the integrated luminosities were 0.84pb^{-1} and 2.94pb^{-1} , respectively. No evidence for lepton flavor violation was found. Limits on coupling versus mass are provided for leptoquarks and R-parity violating squarks. For flavor violating couplings of electromagnetic strength lower limits on leptoquark masses between 207 GeV and 272 GeV are set, depending on the leptoquark species and the final-state lepton. For leptoquark masses larger than 300 GeV, limits on flavor-changing couplings are determined, many of which supersede prior limits from rare decay processes.

b. HERA and ZEUS Operations

After a short shutdown over the end-of-the-year holidays, the 1997 HERA running period had a successful start providing useful luminosity already by the end of February. At the beginning of July, the machine had delivered 14pb^{-1} which was already more than the delivered luminosity in the entire 1996 running period. The goal of 27.5pb^{-1} for 1997 seems easily achievable. Due to the observation of an excess of events at high Q^2 and x , the interest in an extended low energy run to explore the possibility of measuring the longitudinal structure function F_L vanished.

The relatively short shutdown period between the 1996 and 1997 running periods prevented the installation of major new hardware in the ZEUS detector. Apart from the usual minor improvements, there were only a few significant changes to the detector:

1. The installation of the Barrel presampler started with six of the 32 modules installed. The readout system is complete and working. The data are expected to be included in the data stream in the coming weeks.
2. The beam pipe calorimeter was equipped with a silicon tracker to improve both the background rejection and the kinematic reconstruction.
3. The luminosity photon calorimeter was improved by adding a preshower and leakage detector.

(J.Repond)

I.A.6. BNL AGS "Partial Snake Magnet" Experiments

A test run with polarized beam is scheduled this coming summer. This is to overcome intrinsic resonance's using an AC dipole. We concentrated primarily on preparing the internal polarimeter. Our Argonne student, along with several experts, continued to check her calculation using this new method.

(D. Underwood, A. Yokosawa)

I.B EXPERIMENTS IN PLANNING OR CONSTRUCTION

I.B.1 Polarized-Beam Experiments for a RHIC Polarimeter

Installation and testing of E-925 continued to be ready for parasitic beams expected early summer. During this period, we often had access to the experimental area and completed the necessary surveying, magnet energized, cablings, detector testing etc. Some of the tasks, software etc., did not require access to the experimental area.

In June we had a 24-GeV/c primary proton beam to test the apparatus, although we were in a parasitic mode to E-926 that controlled the beam and running conditions. Despite all this, we managed to take data on both the elastic scattering polarimeter and the pion spectrometer with various magnet currents around the preferred p_T kick of 1 GeV/c. We also took data with both magnet polarities (negatives in the pion spectrometer) and B (positives in the spectrometer). The off-line analyses were kept up on both the pion data and elastic data. The pion data indicate that we can attain the desired x_F and p_T distributions.

The E-925 run is tentatively scheduled for next May provided we succeed with

E-880, the partial snake and AC dipole experiment, which is to overcome depolarization up to injection energy into RHIC.

(A. Yokosawa)

I.B.2 STAR Detector for RHIC

Argonne would provide the design engineering in collaboration with Argonne physicists. Argonne and Wayne State would take roughly equal roles in fabrication.

We built a prototype shower maximum detector of a new kind to control the occupancy in the high-multiplicity RHIC environment. We are also developing the hybrid electronic preamplifiers which will be mounted in the shower max to overcome noise. The group participated in the test beam run to test this device.

We are continuing the mechanical engineering of the calorimeter, including the elaborate support structure needed for staged implementation of the EMC within the STAR magnet. The support system is in production.

Simulations for STAR spin and heavy ion physics were carried out including jet quenching in quark-gluon plasma and search for disordered chiral condensate.

Cost estimates are done by the ANL-WSU collaboration.

Figure 1 D_{NN} data as a function of p_T

(A. Yokosawa, D. Underwood)

I.B.3 MINOS--Main Injector Neutrino Oscillation Search

The MINOS long baseline experiment is designed to search for neutrino oscillations in the region of $\sin^2(2\theta)$ and Δm^2 parameter space which is suggested by the atmospheric neutrino flavor ratio anomaly. This effect, which was initially seen in the Kamiokande and IMB water Cerenkov detectors, was confirmed in early 1997 by the Soudan 2 and SuperKamiokande experiments. While the original Kamiokande measurements favored values of Δm^2 around 0.01 eV^2 , new high statistics data from the SuperKamiokande experiment suggest that the value may be closer to 0.001 eV^2 . Such oscillations would be just at the edge of sensitivity for the MINOS reference design, which has been optimized for the lower L/E values suggested by the original

Kamiokande results. Although the new results are still preliminary, the MINOS collaboration is now beginning a serious effort to extend the sensitivity of the experiment to lower values of Δm^2 (higher values of L/E) by investigating lower energy neutrino beams than have been considered previously.

During the first half of 1997 the MINOS collaboration focused its efforts on optimization of the major detector parameters. These parameters, including the active detector technology, detector "strip" width and steel plane thickness, must be specified by the end of the summer if the project is to remain on schedule. The major milestones in this schedule include the submission of the detector Technical Design Report in the spring of 1998, the availability of major detector fabrication funding in FY 1999, and neutrino beam turnon in early 2002 (when the near detector and the first few kilotons of the far detector must be operational). The new SuperKamiokande results described above suggest that the low energy response of the detector should be enhanced by choosing thinner steel and smaller detector strip widths.

The collaboration is now developing three active detector technologies: Aluminum Proportional Tubes (APT's, led by the Argonne group), liquid scintillator and plastic scintillator. The MINOS Detector R&D Advisory Committee held its third meeting in April 1997, and recommended that the collaboration should focus all of its scintillator R&D effort on plastic scintillator. Each of the three technologies is developing a complete design of the 10 kT far detector, including cost estimates and performance studies of full size prototype detectors. The Argonne group's work on the APT detectors is described below in the Detector Development section of this report.

Argonne physicists and engineers are also contributing to the development of plastic scintillator extrusion technology. The group is working with Quick Plastics (the company which produces the APT plastic sleeves) on the development of coextruded plastic scintillator strips. Each 1 cm by 4 cm by 8 m long strip would be enveloped by a layer of reflective plastic to increase light collection. Coextrusion of the reflective coating is less expensive than wrapping the strips with reflective material during assembly, and also provides mechanical protection for the strips. Each strip also has an extruded groove along the center of one of the 4 cm sides to accommodate the wavelength shifting fiber.

There were a number of important developments and accomplishments in other areas of MINOS activity during the first half of 1997. These included:

1. Tau lepton identification. The collaboration prepared a status report on tau identification for the Fermilab PAC's February meeting. If $\nu_\mu \rightarrow \nu_\tau$ oscillations occur in the NuMI neutrino beam, charged current interactions will produce tau leptons whose decays can be identified in

MINOS. The PAC status report described the experiment's sensitivity to tau decays in the $\mu\nu\nu$ and $e\mu\mu$ modes in the narrow band beam, and the detection of $\tau \rightarrow \pi X$ and of inclusive tau signatures in the wide band beam. In addition, the capabilities for tau identification of the Soudan 2 detector and of a hybrid emulsion detector were described.

2. Detector R&D funding. The collaboration obtained a supplemental allocation of \$250k from DOE for its detector R&D program. This amount is in addition to \$400k allocated by Fermilab, increasing the R&D funding level by a factor of 2.5 relative to FY 1996.

3. Electronics development. MINOS collaborators in the U.K. have now formally proposed to assume major responsibility for the design, prototyping and fabrication of the electronics for the experiment. Since no funds have been allocated for electronics R&D work in the U.S., the focus of MINOS electronics work has been in the U.K. for some time. However, Argonne has devoted a substantial effort to the production of electronics for the prototype test beam calorimeter studies at Fermilab. This device requires 1200 channels of preamplifiers and ADC's. The Argonne electronics support group designed APT preamp cards using existing spare hybrid chips for the Soudan 2 detector modules. The group also designed circuits to interface APT preamps to commercial ADC's; fabrication of all 1200 channels of both devices was nearly complete at the end of June.

4. Installation planning. In October 1996 the collaboration established a formal Installation Committee to work out realistic requirements and schedules for the installation of the far detector at Soudan, using different active detector technologies, steel thickness', etc. In early 1997 the committee's charge was expanded to include a comparison of active detector fabrication plans and cost estimates for different technologies. Argonne physicists and engineers have considerable experience in these areas as a result of their work on Soudan 2 installation and MINOS APT development, and have therefore been heavily involved in the work of the Installation Committee.

5. Funding for MINOS excavation at Soudan. The Minnesota Legislature has now appropriated \$400k to be used for upgrading the Soudan mine hoisting facility for MINOS excavation and installation. Most of these funds will be used to implement the recommendations of an outside consultant who was hired to determine whether the existing hoist facility would be adequate for MINOS. The movement of thousands of tons of large (8 meter by 2 meter) steel plates down the shaft and into the underground hall will require a special shaft cage and special rigging equipment at the surface and underground shaft stations.

(D. Ayres)

I.B.4 ATLAS Research and Development

a. Overview of ANL LHC Related R&D Programs

The ATLAS group realized several major milestones in the first half of 1997. Firstly, the extended barrel prototype module was constructed, instrumented, tested and shipped to CERN on schedule. Secondly, trigger hardware tests involving the supervisors built at Argonne were used for system tests at Saclay and CERN. Finally, the US Atlas collaboration went through a major DOE review, which although did not result in the full approval of the project did not, however, uncover any significant technical issues.

(J. Proudfoot)

I.C. DETECTOR DEVELOPMENT

I.C.1 CDF Detector Projects

J. Dawson elected to take on the project of doing the VME digital readout boards for shower max and related detectors in both central and plug calorimeters, doing an initial design. G. Drake, continuing his work on CDF front end electronics now with our division, defined a daughter board project to involve a suitably quiet preamp and the shower max QIE which he has been debugging. K. Byrum and S. Kuhlmann continue working on these projects. Trigger electronics for photon/electron isolation was proposed by S. Kuhlmann, R. Blair and J. Dawson.

R. Keup and L. Nodulman continued to work with V. Guarino on endplate mechanical issues, V. Guarino doing FEA, and insertion tooling for assembly. A prototype insertion tooling set was delivered for use with the prototype chamber.

T. LeCompte continued as CDF project manager for muon upgrades, working with various groups on developing chambers and scintillators for extending muon coverage.

(L. Nodulman)

I.C.2 ZEUS Detector Upgrade (Barrel Presampler)

In January 6 BPRES modules were installed in the ZEUS detector at the bottom of the Barrel Calorimeter (BCAL), covering modules 22 - 27. In addition, 6 PMT housings were installed and the fiber bundles connected. The HV cables were installed by VPI and the BCAL HV software was modified to include the BPRES (using 13 of the 16 spare channels per BCAL module). Analog cards were installed in the Beam Pipe Calorimeter (BPC) analog card crate, and cables were pulled from the PMT housings to these cards. The signal from the 7 BPRES analog cards

was split from the readout cable in the Rucksack and was initially plugged into 2 digital cards of the BPC readout. By the end of January, all 6 modules were powered up with 77 of the 78 channels operational (one channel could not be set to the proper HV). A cosmic ray trigger was set up using some BCAL modules and a test run was taken with the BPRE modules readout through the BPC readout (part of the calorimeter readout system). The following plot shows the results obtained from the cosmic ray run for a single channel. The readout samples (taken every 96 nsec) were reconstructed in the same way as for the calorimeter and a multiplicative constant of 1.4 was used to minimize the width of the Landau fit as shown on the plot. In addition to signals from cosmic muons, timing information was obtained which is necessary to determine the optimal reconstruction algorithm used in future data.

In a related effort at DESY, the calorimeter readout software was being modified to include the BPRE (and other components) in its own digital cards. This was not yet ready by June 1997.

Fig. 1. Results obtained from the cosmic ray run for a single channel.

Construction continued on the remaining 26 modules during this period. Phenolic webs (to hold the scintillator tiles in place) were machined at ANL and glued together and cassettes were constructed. The scintillator grooving was completed, including replacement of some tiles damaged during shipment. After delivery to ANL, the scintillator edges were painted with Bicon BC-600 reflective paint, holes were drilled to accept the LED fibers, and TYVEK wrappers were made and folded onto the tiles. All of the remaining PMT housings were assembled at ANL. Fiber testing at Andrews University continued. Construction of analog electronics continued at Kyungpook University in Korea. By June, two undergraduate students joined the BPRE construction and testing efforts. One student helped in the construction of BPRE modules and set up the first source scanning procedure. The other student worked on setting up the cosmic ray trigger system using parts from the BCAL cosmic ray test stand. These projects were ongoing at the end of this reporting period.

(S. Magill)

I.C.3 STAR Electromagnetic Calorimeter (EMC)

After the Conceptual Design Review for the STAR EMC in December 1996, we continued with design and production of the EMC supports, with integration jobs such as defining electrical power needs, with building more shower max prototypes and testing them in the BNL test beam, and with more physics Monte-Carlo studies. We were also more concerned with the funding profile, and the overall plan of work.

The STAR Electromagnetic Calorimeter, EMC, is to be installed and supported on a rail system. This is because the EMC is a staged detector and the calorimeter modules must be installed inside the magnet after the central tracker, the TPC, is already installed inside the magnet. The rails are supported by so called hangers which extend radially between coils to connect the rails to the backleg iron bars outside the coils. There was a plan in 1995 for these hangers to be produced by casting using an ANL design. In 1996 it was claimed that Wayne state could produce the hangers from machined parts more cheaply using subsidized shops. Argonne engineers re-designed the hangers for this alternate method of producing them. After almost a year, it was realized that there was insufficient labor and machine tools at Wayne State, and the hangers were built at a factory in Detroit. Argonne engineering was involved in supervising the production. The final cost was within a few percent of the original estimates two years earlier.

One of the design changes to the overall EMC system that was made in mid-1996 was to use segmented strips in the shower maximum detector rather than wire signals in order to reduce the occupancy in Au-Au events to a manageable level. This was because the wires had to be at least 1.4 meters long to be supported with minimal dead area. In the new design, segmented strips of approximately 30 cm are used parallel to the wires, in conjunction with strips of about 22 cm transverse to the wires. Monte-Carlo simulations showed that the occupancy of each patch of 0.1 by 0.1 in eta-phi would be low enough to allow finding individual gammas.

There were two competing designs for the physical construction of this detector with two sets of strips. For the test beam run in June, Argonne built a version with the longitudinal strips buried within the aluminum channels surrounding the wires. The Russians at Wayne State used a two sided aluminum extrusion with strips parallel to the wires on one side and strips parallel to a second set of wires on the other side. It was ironic that the two sided version was invented at Argonne while the buried strip version was invented by the Russians. Each group adopted the others idea.

The construction of the buried strip chamber was difficult, in part due to limited resources, but in part due to the design itself. UCLA did the final machining of the aluminum and the wire stringing and the final assembly. Argonne prepared the pre-amplifiers which were mounted

locally on the chamber on an Argonne prepared mother-board. Both designs functioned reasonably well in the test beam, and the data was analyzed both on-line and shortly after the run.

After the run it became clear that the double sampling inherent in the two-sided design had an advantage for separating electrons from pions. The two sided design was adopted.

Several months of physicist time were spent in preparing a plan of work for resolving issues for the upcoming Construction Readiness Review, and for beginning production of the EMC system. Due to difficulties in the collaboration at the time, this was not immediately applied, but served as the basis for work plans and agreements later in the year.

(D. Underwood)

I.C.4 ATLAS Calorimeter Development

a. Hadron TileCal Calorimeter

Work continued in this period on the two main areas in which the mechanical group is involved: construction and instrumentation of the extended barrel prototype module; and structural analysis of the tile calorimeter and its connections and the effect of the supports of the liquid argon cryostat.

a.1 Extended Barrel Module Construction

The construction of the module was a highly collaborative effort in which, in addition to the US groups, groups from Portugal, France and Switzerland also participated. The work fell into three separate areas: mechanical assembly; instrumentation with tiles and fibers; testing using a radioactive source. This was a major milestone for the project. The completed prototype module, prior to being shipped to CERN, is shown in Fig. 1.

a.2 Extended Barrel Module Mechanical Assembly

The full-scale prototype Extended Barrel Module was assembled at Argonne with a girder and submodules that were fabricated by Argonne, submodules from the University of Illinois, and an ITC submodule and assembly base that were constructed at the University of Texas at Arlington. It demonstrated the ability to fabricate components at several different locations and then to bring them together for a final assembly. In addition, the construction of the prototype proved the design of the Extended Barrel structure, demonstrated the fabrication techniques, and demonstrated the procedures for aligning the sub-modules onto the girder. A schematic of the extended barrel module is shown in Fig 2.

Fig. 1. Prototype extended barrel module completed and ready for shipment to CERN.

The support girder is a key element in the module construction due to the tight machining tolerances placed on it to ensure the design gap between modules in the final assembly. The prototype girder was purchased from a local machine shop. On site measurements, made using gauge indicators while the girder was still supported on a machine bed, were taken to ensure that it met all basic design tolerances prior to being shipped to Argonne. Additional measurements were made at Argonne and confirmed that the girder met all flatness requirements. During assembly, a small number of minor manufacturing problems were encountered: one mounting hole which was not tapped to sufficient depth; and the location of some of the cover plate location holes. These were corrected in place with no difficulty. In all other respects, the girder fully met specification.

The girder was installed on an assembly base that had been designed and fabricated by the University of Texas at Arlington. The purpose of the assembly base is to position the girder at a height that makes assembly easy and provide a flat, level surface for locating the girder. The mounting surface of the assembly base was leveled

Fig. 2. Extended barrel module assembly schematic.

within .002in. The girder was then lowered onto the assembly base and bolted into place. Figure 3 shows the girder mounted on the assembly base. The centerline of the girder was located using an optical transit that picked up tooling balls that were positioned in construction holes at either end of the girder. The locations of these two holes and the vertical axis then provide the radial alignment axis for submodule installation. This was proven to be a quite successful approach.

In order to facilitate the phi location of the submodules on the girder, it was felt that all of the submodules should rest on the girder key surface. During this operation we determined that some of the outer radius spacer plates interfered with the outer flanges of the girder and therefore a .015in-thick shim was placed on the girder key surface. This problem has resulted in a minor change to the production girder design; deepening the key to preclude this effect. Submodules were then sequentially placed on the girder key.

The alignment scheme is shown in Fig. 4. The submodules were aligned in phi by an optical transit that aligned the center of the girder with the centerline of the

Fig. 3. Support girder mounted on module assembly base prior to commencing submodule mounting.

submodules using the tooling ball located in the construction hole on the girder and a tooling plate that was mounted to the front plate of the submodules. Shims were placed under the edges of the submodules in order to fill the resulting gap between the weld bars on the submodules and the girder flange surface. This is a critical step in the assembly procedure. During the assembly of the module at Barcelona this step was omitted on one of the submodules, which resulted in an excessive load being applied to the weld bars from the mounting bolts. The weld bars were subsequently sheared off.

The Z position of the submodules was determined along the length of the girder using a stick micrometer that measured the distance from the reference end of the girder to the center of the submodule face. For production we envisage using precision blocks to achieve the same result since the use of a 2-3m stick micrometer is cumbersome. Once the submodules were located and secured on the girder, the front plate was welded into place and the endplates bolted onto the end of the girder. Both of these tasks were carried out with no difficulty and reliable time estimates were obtained for use in establishing a production cost and schedule.

Fig. 4. Alignment scheme used for module assembly.

The installation of the fiber collector rings positioned at each hole location was also carried out as part of the mechanical assembly. These rings are positioned using a precision fixture and epoxied in place. A prototype installation fixture, fabricated at Clermont-Ferrand, was shipped to Argonne. Two Clermont-Ferrand engineers came to Argonne to demonstrate its use and to "train" our own technicians. The fixture itself worked very well with only two minor problems being encountered: interference between the positioning feet of the fixture and the weld seam of the structural tube in the girder (now corrected in the design); and a larger than expected void between the structural tube and the additional steel plates on the girder which required a correspondingly larger volume of epoxy to be used to glue in the rings (a fix for this has also been developed for production).

The final task completed as part of the mechanical assembly, a survey of the surface planarity and position was carried out using a computer controlled laser transit (loaned and operated by Advanced Photon Source survey group personnel). The data demonstrated that on each side of the module the surface was planar to within 0.150mm. The accuracy with which the separate coordinate systems on each side could be cross-referenced proved to be insufficient to draw concrete conclusions. Within this accuracy (of about 0.5mm) the module met the design envelope. Work is in progress to develop a more effective approach to perform this important quality assurance measurement.

In summary, the construction of the Extended Barrel prototype at Argonne demonstrated a relatively easy assembly method that allowed for precise alignment of submodules on the

girder, which is critical for maintaining the design 1.5mm phi gap between modules. This assembly procedure was subsequently used for the construction of the Extended Barrel prototype at Barcelona and has subsequently been adopted by the remainder of the Tile-Calorimeter collaboration for the production of both the barrel and extended barrel modules.

a.3. Extended Barrel Module Instrumentation

The scintillator tiles used for the instrumentation of the module were produced in Protvino and wrapped with masked Tyvek sleeves at Michigan State University. Two minor problems were encountered during insertion of tiles into the slots in the calorimeter structure: the tiles themselves were somewhat thicker than allowed by the design specification; the slots at the outer radius were occasionally blocked by excess glue, which had then to be removed to allow insertion of the tile. These problems are easy to correct for module production. For example, in the case of the glue squeeze-out, we already know that approximately 20% more glue was used than is actually necessary.

The wavelength shifting fibers were procured and prepared by the University of Lisbon and inserted into plastic sleeves ("profiles") at Michigan State University prior to installation into the module. Again in this case, several minor problems were uncovered. The groove in which the profiles are placed was not sufficiently deep and therefore the profiles protruded beyond the envelope of the module by about 0.2mm. Because of this problem, in addition to the mechanical fastening associated with elasticity in the profiles, aluminum tape was used to hold the profile (and thereby the fibers) in contact with the scintillator tiles. The wider gaps between submodules caused this lack of fit to be even more serious and in this case some additional fillers were inserted into the module to fill in the gap and thereby improve the location of the tiles and profiles. Of particular note however, was the ease with which the profiles could be installed into the slots. The Lisbon group had developed a simple yet impressive tool for this and the installation procedure is very much like pulling down on a zipper. The procedure is fast and straightforward. Solutions to the few minor problems encountered will be implemented for production modules.

The fiber routing scheme developed by the Michigan State University group was used for the extended barrel prototype module being built here in the United States (for comparison, a slightly modified version of the routing used for the barrel prototype was used for the module being built in Barcelona). The process was orderly if on occasion time-consuming. Figure 5 shows the module being instrumented. Final QC checks made on the fiber installation were made by illuminating fiber bundles using a flashlight so that their correct location may be verified.

Fig. 5. Fiber installation in progress.

Following gluing of the fiber bundles into the tubes which direct them into the center of the girder, the bundles were polished. This was accomplished using a custom machine which had been designed and built in Europe, and again we hosted collaborators from CERN who participated in this final operation. The setup of the cutting head was straightforward. The only real problem encountered was in realizing a sufficiently well phase regulated 220v supply for the drive motor (we eventually located and used a step-up transformer). US voltage compliant motors will be used for the production tool to be used here.

a.4 Extended Barrel Module Source Testing

The final checkout of the extended barrel involved the certification of the optical system. This process involved numerous institutions. An OS-9 portable standalone system was planned for reading FERMI, controlling 3-in-1 cards in the drawers, and reading the current integrators. Three critical systems involving University of Chicago, Barcelona and the HEP Division were brought together to develop a source scan system in Building 366.

The SDC ^{137}Cs source and source driver, which was initially all CAMAC and Fortran based, were converted to OS-9 operation on a University of Chicago system. The components and software from the development system were then certified at CERN on the actual standalone system, along with the Clermont-Ferrand high voltage system which also used OS-9. Finally the system was shipped to Argonne, assembled here and used to find light leaks and drive the source through each of the eleven source tubes.

Fig. 6. A typical ^{137}Cs scan through a cell of the extended barrel module constructed in Building 366. The top and bottom plots show separate sides of the tile readout.

Assistance with the calculation of the cell geometry was provided by Michigan State. In part, due to the good collaboration, source scans were performed and analyzed on the entire module in only several hours. Figure 6 shows a typical scan for both readout sides of a particular cell. The peaks and valleys indicate the boundaries of the tiles as the source passes through.

(V. Guarino, J. Proudfoot, and R. Stanek)

b. Structural Analysis

Due to the significant work load associated with the construction of the prototype module, a somewhat lower level of effort was available for finite element modeling of the calorimeter structure. The focus in this period became the issues associated with the support of the endcap cryostat by the Extended Barrel calorimeter. The Argonne engineering group was

firmly convinced that because of the asymmetric loading of the front and rear supports and the magnitude of the load on the rear supports, the only feasible solution at the rear would be to carry that load on a wholly external structure rather than within the calorimeter structure itself, as was the present concept. This was analyzed using the model developed in 1996 to optimize the location of the saddles below the calorimeter. A slight complication was a proposal by the muon group to improve their chamber coverage at the expense of a modest redesign of the calorimeter support feet themselves.

The analysis considered the three cases: 1) the old design in which the rear load of 83 tonnes was carried on the calorimeter endplates with the original saddle design; 2) the old design in which the rear load of 83 tonnes was carried on the calorimeter endplates with the new proposal for the calorimeter support design; 3) the new design in which the rear load of 83 tonnes is carried independently of the calorimeter structure on a "donut" and then transferred directly to the saddles (using the new design for these). The loads were not a significant issue for any of the three options. However, the deflection of the support feet themselves varied significantly for each of these solutions and is shown in Table 1.

Table 1. Deflection of Cryostat Rear Support Feet.

<i>Case</i>	<i>Horizontal Deflection (mm)</i>	<i>Vertical Deflection (mm)</i>	<i>Z Deflection (mm)</i>
1	-3.50	-6.53	0.05
2	-3.43	-8.04	-0.05
3	-0.37	-0.75	0.48

The vertical deflections are large unless the "donut" type of support is used. Our assessment is that, given the tight alignment constraints in the endcap (coming mainly from alignment of the beam pipe passing through it), this type of support is essential and a feasible design developed from the very idealistic concept used in this model. This will be our position at an upcoming meeting with the Orsay engineers responsible for the design of the endcap cryostat.

(V. Guarino)

c. Test Beam Program

The first half of 1997 saw activity in the analysis of the testbeam data taken the prior September. Barrel Module 0 as it is known, was sandwiched between a top and bottom layer of the 1 meter prototype modules on the 85-ton capacity scanning table. The module was equipped with fast sampling electronics known as the FERMI readout system. A scheme for obtaining a 16-bit dynamic range incorporated the use of pulse compressors inside the phototube base.

Because of the sampling nature of the FERMI system, and because of some problems in the driver circuitry, the charge reconstruction was very dependent on the sampling phase. Effort at Stockholm provided a complex two-dimensional lookup table that related the injected charge to the relative phase. A comparison of these tables applied to laser data is shown in Fig. 7. It is clear that the two dimensional lookup table is needed to process the data from the current system.

Fig. 7. The reconstructed charge from laser pulses. The linearity as a function of light (charge) intensity is shown for both 1-D and 2-D lookup tables.

(R. Stanek)

I.C.5 ATLAS Trigger Development

a. The ATLAS Level 2 Supervisor and Region-of-Interest Builder

Two complete supervisor subsystems for the ATLAS Level 2 demonstrator program were produced in collaboration with Michigan State University and shipped to Saclay and CERN for integration with the other demonstrator components. Software and network adapters for two

network protocols (ATM and SCI) have been assembled and a third networking option (DS-link) is being worked on. Figure 1 shows one of the two systems that were shipped while it was being tested at Argonne.

Fig. 1. Photograph of one of the demonstration ATLAS Level 2 Supervisors.

The DOE Lehman review in May proved to be a useful planning exercise. While the reviewers felt that the definition of the trigger to date was inadequate to accurately plan precise construction or costing, the general picture of how items would be designed and staged looked manageable. The yearly manpower profiles for two of the ATLAS Level 2 projects as projected for the Lehman reviewers are depicted in Fig. 2.

(R. Blair and J. W. Dawson)

Fig. 2. The expected manpower required for the ANL ATLAS work on (A) the supervisor and ROI building and (B) the global level 2 trigger.

I.C.6 MINOS Detector Development

During the first half of 1997 the Argonne MINOS group has focused its detector development effort on two major activities: preparation for the study, in a Fermilab test beam, of a prototype calorimeter instrumented with APT's (Aluminum Proportional Tubes), and the development of a comprehensive design for the MINOS experiment based on APT detectors. The construction of APT chambers was described in detail in the previous Semiannual Report.

During early 1997, physicists and engineers from Argonne, Dubna and Fermilab prepared a new experimental area in the existing "CDF" test beam at Fermilab. Tests of the Dubna prototype electromagnetic calorimeter, instrumented with plastic proportional tubes, were completed and a new steel structure for the APT hadron calorimeter was designed, fabricated, and installed. The Dubna calorimeter had been initially studied in a SLAC test beam in early 1996, and showed that the change from limited streamer operation to proportional mode did not degrade the electromagnetic shower energy resolution.

The APT calorimeter tests are being performed in two stages using the same "hanging file" steel plane structure. The first stage uses the electromagnetic configuration, consisting of nine planes, each with three APT's and orthogonal cathode strip planes. The second stage uses the hadron calorimeter configuration, requiring 25 planes of six APT's each (without strip planes). The same steel plane structure, consisting of 25 1.5-inch thick steel planes, each 1 meter by 1 meter, is used for both stages. The hadron calorimeter configuration requires a total of 150 1-meter long APT's, which involves a major fabrication effort. By the end of June, the 27-chamber electromagnetic calorimeter was installed and initial results looked very promising. Figure 2 is a photograph of the electromagnetic calorimeter setup. More than half of the 150 chambers needed for the hadron calorimeter had been built and tested at the end of June. One third of these chambers were assembled at Tufts and the remainder at Argonne. The hadron calorimeter test beam studies will be performed in August after the completion of the electromagnetic energy resolution tests.

Good electromagnetic shower energy resolution relies on anode wire charge measurements (pulse height) to provide a measure of the number of shower particles in each APT channel. This technique requires that the 16 anode wires in each APT have uniform gas gain, and that the response of all chambers be very similar. The response of each of the 1 meter long APT's being constructed for the test beam calorimeter was measured with cosmic rays before installation in the calorimeter. Figure 3 shows the excellent response uniformity obtained for the chambers used in the electromagnetic calorimeter.

The Argonne MINOS group is also leading the effort to develop a comprehensive design and cost estimate for the experiment using the APT active detector technology. This is being prepared for the detector technology choice which will be made by the collaboration in September 1997. The APT baseline design has 1-inch thick steel planes, 2-D readout APT planes with 2 cm wide strips orthogonal to anode wires; wires are ganged in pairs to give 2 cm anode "strips". Detector designs and cost estimates are being worked out for eight different combinations of these parameters: 2 cm and 1 inch thick steel, 1D readout (no strip planes) and 2D readout (with strip planes), and 2 cm and 4 cm wide "strips".

The 10 kT APT far detector with the baseline design parameters consists of 896 planes of detectors, each mounted to a 1 inch thick steel plane. Each detector plane is assembled from seven modules of APT chambers, with the wire directions alternating between $+45^\circ$ and -45° from plane to plane. Each 8-m diameter detector plane includes a plane of 2-cm wide cathode strips, oriented perpendicular to the wire directions, to give the orthogonal view of the hits in

each plane. APT anode wires are operated at 3100 V in a nonflammable gas mixture of 9.5% isobutane, 2.5% argon, and 88% CO₂, giving a gas gain of about 2×10^5 .

Fig. 2. Photograph of the prototype MINOS APT calorimeter. The 1 m by 1 m hanging file steel plane structure is used for both the electromagnetic and hadron configurations in a Fermilab test beam. In the electromagnetic configuration shown here, only the central 50 cm by 50 cm area of the first nine planes is instrumented with APT chambers and strip planes. The steel planes are 1.5 inches thick, and are mounted on a carriage which can be moved into and out of the beamline. Argonne physicist Jonathan Thron is shown in the photo.

Fig. 3. Response uniformity of MINOS APT chambers. Each of the 1 meter long chambers built for the prototype APT test beam calorimeter was measured for gas gain uniformity using cosmic rays. The histogram shows the distribution of charge responses from anode-wire pairs for 19 of the chambers built for the electromagnetic calorimeter. Chambers were required to have uniform response, i.e. pulse charge of each wire pair for single cosmic ray tracks within 10%, before they were accepted for installation in the calorimeter.

(D. Ayres)

II. THEORETICAL PHYSICS PROGRAM

II.A THEORY

II.A.1 All-Orders Calculation of the Inclusive Cross Sections for the Production of Top Quarks and of States Predicted in Supersymmetry Models

As reported previously, Edmond Berger and Harry Contopanagos (Electrical Engineering Department, UCLA) developed an original formalism of initial state soft-gluon resummation that they term "perturbative resummation." After their paper appeared in Physical Review **D54**, 3085 (1996), a group of four theorists working at CERN (Catani *et al.*) published a different approach to resummation from which they obtain a somewhat different numerical answer for the inclusive top quark cross section. In a recent paper, Berger and Contopanagos present a thorough analysis of the essential theoretical differences between theirs and the Catani *et al.* approach [Argonne report ANL-HEP-PR-97-01, May 1997 (hep-ph/9706206), accepted for publication in Physical Review D]. The differences reside in the proper treatment of non-universal subleading logarithmic contributions after the Mellin transformation from moment space to momentum space. As a result of their thorough reanalysis of both methods, Berger and Contopanagos are confident that their approach is preferable and better founded theoretically.

The extension of their method to the production of pairs of squarks and gluinos at hadron collider energies accounts for a considerable fraction of their research efforts during the past year. The matrix elements for squark and gluino production are significantly more cumbersome to handle than those for top quark production, and resummation is correspondingly more intricate. They hope to publish their findings shortly. The increase in predicted cross sections above the next-to-leading order answers translates into increases of 20-30 GeV in the lower limits of the masses determined by CDF and D0.

Ed Berger presented the work on perturbative resummation and discussed the differences between the Berger and Contopanagos method and that of Catani *et al.* in invited talks at the 1997 Aspen Winter Conference and at the 5th International Workshop on Deep Inelastic Scattering and QCD (DIS '97). A written summary of the DIS '97 talk appears in Argonne report ANL-HEP-CP-97-33 and is published in the proceedings of the Workshop.

(E. L. Berger)

II.A.2 Isolated Prompt Photon Production—Breakdown of Factorization

Edmond Berger, Xiaofeng Guo, and Jianwei Qiu (Iowa State University) have been pursuing the prospect that all-orders resummation will resolve the problem of the breakdown of factorization at fixed order in perturbation theory that they discovered previously in their calculation of the *isolated* prompt photon cross section, Physical Review **D54**, 5470 (1996). Their goal is to obtain

an infra-red safe observable to be compared with experiment. This case is unusual when compared with other cases in which resummation has been used, such as the transverse momentum distribution in the Drell-Yan process and the thrust distribution in e^+e^- annihilation. In the *isolated* prompt photon case, the partonic hard part is not infra-red finite at the critical point, and the critical point lies within, not at the edge of the physical region. Berger was invited to speak about this work at the 1997 Moriond conference (a written summary appears in Argonne report ANL-HEP-CP-97-32 and will be published in the proceedings).

(E. L. Berger)

II.A.3 Polarization in Hard Scattering Processes

Edmond Berger and Lionel Gordon have been engaged in an investigation of the associated production of photons and charm in polarized proton-proton scattering with a view towards a possible determination of the polarization of the charm quark momentum density of a nucleon. Their analysis is done at next-to-leading order in perturbative QCD. They use a combination of analytic and Monte Carlo integration methods in order to obtain differential distributions, including photon isolation restrictions. In the course of this work, they have derived parametrizations of the polarized charm quark density. Their predictions should be of value for the polarized proton-proton collider program at RHIC.

At the invitation of the PHENIX collaboration, Berger prepared a major review talk on spin physics questions to be addressed at RHIC, presented at their "coalition" meeting in February.

(E. L. Berger and L. Gordon)

II.A.4 Inclusive Decay and Production of Heavy Quarkonium

Some time ago, Geoffrey Bodwin, Eric Braaten (Northwestern U.), and G. Peter Lepage (Cornell U.) formulated a general method for treating the inclusive decay and production of heavy quarkonium rigorously in perturbative QCD [Phys. Rev. **D51**, 1125 (1995)]. Last year they published an extensive erratum to this paper [Phys. Rev. **D55**, 5853 (1997)]. This erratum corrects some typographical errors in the published version of the paper. However, its main purpose is to give a correct accounting of the powers of the heavy-quark velocity v in spin-flip interactions. (In some analyses in the original paper, spin-flip interactions were not properly distinguished from non-spin-flip interactions.) The revised analysis leads to increases in the estimated sizes of some of the heavy-quarkonium matrix elements and to increases in the estimates of the theoretical uncertainties for some processes.

(G. Bodwin)

II.A.5 QCD Predictions for Heavy-Quarkonium Decay Rates

A long-standing difficulty in making predictions for decay rates of S-wave quarkonia is that the one-loop perturbative-QCD corrections are so large as to cast doubt on the convergence of the perturbation series. For example, in the rate for J/ψ decay to three photons, the one-loop correction to the coefficient of the matrix element that is of leading-order in the heavy-quark velocity v is $-13.6(\alpha_s/\pi)$ times the Born coefficient.

Geoffrey Bodwin has observed that, process by process, there is a strong correlation between the size of the one-loop corrections to the coefficient of the v^0 matrix element in the $\overline{MS}$ scheme and the size of the zero-loop coefficient of the order- v^2 matrix element. This suggests that the large one-loop corrections arise from pieces of the loop integrals that correspond to mixing of the order- v^2 matrix element into the order- v^0 matrix element. In a hard-cutoff scheme, such mixing contributions are removed from the corrections to the coefficient of the order- v^0 matrix element and reside entirely in order- v^2 the matrix element. Bodwin has found that, by choosing a cutoff approximately equal to the heavy-quark mass, one can reduce the sizes of all of the one-loop corrections to order α_s/π .

Such use of a hard-cutoff regulator has two additional advantages. First, it explicitly removes the leading IR renormalon from the perturbation series. The uncertainties in the asymptotic perturbation series associated with that renormalon are generically of the same order as the corrections from the order- v^2 operator. In the hard-cutoff scheme, the nonperturbative effects associated with those uncertainties are absorbed into operator matrix elements. A second advantage is that the hard-cutoff scheme reduces the size of the perturbative coefficients in the relations between the lattice matrix elements and the continuum matrix elements. (Lattice regularization is itself a hard-cutoff scheme.) The corresponding reduction in theoretical uncertainty may allow one to make a much more precise comparison between the continuum phenomenology and the lattice computations at higher orders in v .

Current efforts are aimed at understanding whether corrections of order v^4 increase the sensitivity of results to the precise value of the cutoff. If the method appears to be sound at higher orders in v , then the next step is to apply it to a complete phenomenological analysis of S-wave charmonium and bottomonium decays and a comparison of that analysis with lattice results.

(G. Bodwin)

II.A.6 Tadpole Improvement for Staggered Fermions

Lattice perturbation theory is of great importance in relating the results of lattice measurements to continuum quantities. However, straightforward lattice perturbation theory gives notoriously poor results: convergence is much slower than in continuum perturbation theory. Several years

ago G. Peter Lepage and Paul Mackenzie proposed a solution to this difficulty. Their proposal contained two ingredients. First, they proposed that one not use the bare lattice α_s as an expansion parameter, but, rather, a more “physical” coupling, such as α_V , which is derived from the heavy-quark-antiquark potential. (This coupling happens to be close in value to $\alpha_{\overline{MS}}$). Second, they proposed that one “tadpole improve,” that is, that one resum tadpole diagrams, which arise because of the compact “link” formulation of lattice gauge theories. This resummation is accomplished by dividing each gauge-field link in the lattice action by its “mean-field” value. With tadpole improvement and a physical α_s , lattice perturbation theory generally works as well as continuum perturbation theory.

The striking exception is the case of a lattice theory that employs the staggered (Kogut-Susskind) formulation of lattice fermions. For example, in QCD with staggered fermions, the one-loop correction to the relation between the lattice and continuum flavor-diagonal fermion-bilinear operators is large: $\delta Z = -7.84 C_F (\alpha_s/\pi) \log(\mu a/\pi)$. However, the tadpole contribution accounts for only a small part of the total one-loop correction: $\delta Z_{tad} = -2.29 C_F (\alpha_s/\pi) \log(\mu a/\pi)$.

In the past year, Geoffrey Bodwin has proposed an explanation for this failure of tadpole improvement. It is based on the idea that one should “improve” lattice perturbation theory by identifying its differences with continuum perturbation theory and removing these differences, through resummation, from the perturbation expansion. Straightforward perturbation theory for staggered fermions looks very different from continuum perturbation theory. The various flavors are distributed among different sectors of the Brillouin zone. It is not at all clear in the standard formulation of staggered fermions that tadpoles are the only important differences between lattice and continuum perturbation theory.

However, one can make lattice perturbation theory look very similar to continuum perturbation theory by carrying out a unitary transformation of the fields that puts staggered fermions into an explicit continuum-like (Dirac $\otimes$ flavor) form. The transformation maps the 2^d points in the staggered unit cell to the origin of the unit cell and rediagonalizes them in terms of flavor quantum numbers and four-dimensional Dirac matrices. Because the transformation maps fields from one lattice point to another, the transformation itself must contain link variables if it is to result in a manifestly gauge-invariant action. (That is, the transformation must parallel transport the fields.) Therefore, in the transformed action, there are links that arise from the transformation, in addition to the links associated with the original staggered action.

If one tadpole improves the transformed theory, the additional links associated with the transformation result in a tadpole contribution to the bilinear-operator relation that is larger in magnitude than in the untransformed theory: $\delta Z_{tad} = -8.31 C_F (\alpha_s/\pi) \log(\mu a/\pi)$. This essentially reproduces the full one-loop correction. While this result is promising, the method needs to be tested by comparing its predictions with existing calculations of the renormalizations

of other local operators. An additional issue that must be investigated is the effect of such tadpole improvement on the symmetries of the theory. For example, it is not at all clear that the staggered remnant of the chiral symmetry, whose existence is a major motivation for the use of staggered fermions, can be preserved. Work is in progress.

(G. Bodwin)

II.A.7 The Single Gluon Pomeron

The observation of diffractive DIS scaling at HERA may turn out to be almost as significant as the original DIS scaling observation in understanding how QCD describes strong interaction physics. The H1 analysis of deep-inelastic diffractive scaling violations implies that at intermediate Q^2 values the Pomeron behaves like a single gluon, rather than the perturbative two-gluon BFKL Pomeron. More than seventeen years ago, Alan White first described how, if the QCD Pomeron is in a super-critical phase of Reggeon Field Theory, it will appear as a single reggeized gluon in a soft background.

In recent conference papers (ANL-HEP-CP-97-25, hep-ph/9705297 and ANL-HEP-CP-97-68, hep-ph 9709233) White has described his success in putting his earlier work on firmer ground. Although the same global picture re-emerges, the details are different in very important ways. The most important element of the new work is the demonstration that, in special multi-Regge kinematics, massless quark contributions containing the (infra-red) triangle anomaly produce the chirality violation normally associated with nonperturbative instanton interactions. The result is an effective reggeon theory of (massless) quarks and gluons that includes the effects of instanton interactions. When the SU(3) gauge symmetry is broken to SU(2), the triangle anomaly interactions produce infra-red divergence's which select amplitudes containing hadron reggeons scattering via Pomeron exchange. (To carry out this analysis requires a maximal use of multi-regge theory). The result is a Regge pole Pomeron which is in the super-critical RFT phase. It is crucial that the true Pomeron appears only in the scattering amplitudes of hadron reggeons (which have a confinement and chiral symmetry breaking spectrum). The occurrence of the Critical Pomeron phase-transition is related to the restoration of the full gauge symmetry and the effective breaking of the symmetry in DIS scattering is a subtle effect.

(A. White)

II.A.8 Color Sextet Quarks and the High Q^2 Events at HERA

For many years Alan White has also argued that a color sextet quark sector of QCD can produce both an asymptotically unitary Pomeron and electroweak dynamical symmetry breaking. If the large x and Q^2 events seen at HERA and the large E_T excess at the Tevatron are interpreted as the same phenomena, the two effects may be significant evidence that QCD is modified above

the electroweak scale. This is just what would be expected if dynamical electroweak symmetry breaking is due to a flavor doublet of color sextet quarks.

In recent papers (ANL-HEP-PR-97-09, hep-ph/9704248 and ANL-HEP-CP-97-47, hep-ph/9706547) White emphasizes that both QCD and the electroweak interaction are modified above the electroweak scale, and a number of phenomena are inter-related. The QCD β -function has an infra-red fixed point and α_s (almost) stops evolving above the electroweak scale. The resulting enhanced instanton interactions are important for electroweak-scale CP violation, the axion mass, the top mass and new, *chirality violating*, light quark interactions that can be responsible for the excess cross-sections. The h_g acts as an axion below the electroweak scale but not above this scale. Hence QCD interactions above the electroweak scale could be responsible for CP violation. A large h_g mass arises directly from sextet instanton interactions. (Experimentally, the h_g could be confused with the standard model Higgs.) The lowest order instanton interaction can produce both a large top mass below the electroweak scale and large light quark dynamical masses above this scale. Such dynamical masses give a crude qualitative idea of general properties to be expected from the instanton interactions. These include the presence of additional helicity-flip quark final states, an increase of quark jet cross-sections with the jet mass, angular distributions similar to conventional QCD and the enhancement of parton distributions at large x . The presence of gluon initial and final states at the Tevatron implies that effects of the new interactions will be less dramatic than at HERA.

(A. White)

II.A.9 Large Rapidity Gap Events in DIS

Rapidity gaps in Deep Inelastic Scattering or in any other high energy process occur as a consequence of color zero exchange. Within the framework of perturbative QCD, this exchange, which is commonly referred to as Pomeron, is constructed from at least two gluons. Any other colorless exchange involving quarks is subleading and may be neglected at high enough energies.

Based on previous publications, (ANL-HEP-PR-96-11) and (ANL-HEP-PR-96-39), where the exclusive production of quark-antiquark pairs in association with rapidity gaps (two gluon exchange) had been discussed, the emission of one additional real gluon has been considered. The calculation was performed at leading order and for zero total momentum transfer. Gluon emission is the dominant process for large final state masses and needs to be included for a complete theoretical prediction. According to the k_T -factorization theorem the two gluon t-channel state can be factorized and written in terms of the unintegrated proton structure function. The latter was parametrized using data for the inclusive structure function F_2 . This procedure allowed to make an absolute prediction for the cross section of rapidity gap events which shows reasonable agreement with the data. The results have been published in Phys. Rev. **D56**, 4311 (1997), (ANL-HEP-PR-97-3) and were reported at

the 5th International Workshop on Deep Inelastic Scattering and QCD in Chicago, April 14-18, 1997 (ANL-HEP-CP-97-37).

The previously mentioned calculation comprises leading twist terms only. For realistic photon virtualities Q^2 the neglect of higher twist terms might be inappropriate. In collaboration with J. Bartels (ANL-HEP-CP-97-51), M. Wüsthoff has derived twist-four corrections for rapidity gap events in the small and medium mass regime. These corrections have negative sign and provide an explanation for the positive slope in Q^2 as observed in the data.

(M. Wüsthoff)

II.A.10 Matrix Membranes and Integrability

In collaboration with D. Fairlie (CERN) and T. Curtright (U. of Miami), C. Zachos has been studying Matrix Membranes. The structure of spacetime is widely conjectured to be coded in five (essentially 10d) string theories and the 11d supergravity. By now, these have all been understood to interconnect through a web of duality transformations. They represent limits of the still incompletely specified underlying theory of membranes, the M-theory. The most compelling model of the nonperturbative behavior of M-theory is the Matrix Membrane model, introduced by Susskind and collaborators [Phys. Rev. **D55**, 5112 (1997)], which also utilizes past techniques of Fairlie and Zachos], essentially a supersymmetric Yang-Mills quantum mechanics.

In Phys. Lett. **B405**, 37-44 (1997), Curtright, Fairlie, and Zachos introduce novel, trilinear interaction terms for 3 space-dimensional bosonic membranes in symplectic (Poisson Bracket) form. They investigate their symmetries, vacuum degeneracies, and residual unlifted symmetries, which may well have bearing on the pattern of excitations leading to extant M-theory identifications. Their associated first order equations transform to Nahm's celebrated equations; in 3d, these are integrable, by dint of the explicit Lax pair constructed, which also yields the expected infinite collection of conservation laws. A novel solution procedure for these equations is introduced, based on a little-known construction by Euler. Remarkably, these interactions were also discovered to extend to 7d, by virtue of the self-dual (antisymmetric) CDFN 4-tensor in 8d, which generalizes the e_{mns} of 4d.

They further generalize most of this construction to the underlying universal fundamental structure, the Moyal Brackets, and hence commutators (contained within), a connection first introduced by the authors a number of years ago [Phys. Lett. **B224**, 101-107 (1989)]. It is expected that these should prove of utility in further pinning down M-theory, and possibly even in model building.

(C. Zachos)

II.B 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.

We have modified the action of lattice QCD with staggered quarks in order to reduce the flavour symmetry violations at finite lattice spacing. This should allow us to work at larger lattice spacings than previously, and hence on lattices with fewer sites. Our action reduces the coupling of high momentum gluons to the quarks. It thus reduces the flavour mixings associated with high momentum gluons. Measurements we have made on small lattices ($8^3 \times 32$) indicate that for this class of action, we can reduce the flavour symmetry breaking, measured by the splitting in the pion multiplet, by perhaps a factor of 3. We also note a significant improvement over earlier attempts by the MILC collaboration.

We are continuing our studies of lattice QCD with chiral 4-fermion interactions. The 4-fermion term, while not altering the continuum physics does allow us to work at zero quark mass, which is important for studying the nature of the finite temperature chiral phase transition from hadronic matter to a quark-gluon plasma. For these finite temperature studies, we are performing simulations on a $12^2 \times 24 \times 4$ lattice at zero u and d quark mass. At the relatively weak 4-fermion coupling at which we work, we have identified the phase transition which appears to be first order Fig. 1. In addition we have been able to measure the p , $s(f_0)$ and $d(a_0)$ screening masses. The p mass is zero in the hadronic phase and rises from zero towards its high temperature value ($2p\ T$), as we cross the transition. The s mass falls as the transition is approached, and then rises degenerate with the p mass above this transition. Since we suspect that we get a first order, rather than the expected second order transition, because the 4-fermion coupling is too high, we have now started runs at a weaker coupling. Preliminary simulations on a $12^3 \times 6$ lattice suggest that here we really are seeing the expected second order transition.

We have completed our work on studying the difference between the effective (screening) masses of flavour singlet and flavour triplet mesons at finite temperatures in lattice QCD with dynamical quarks. By generating configurations at a new gauge coupling (and hence temperature) we confirmed that screening masses for the singlet and triplet scalar mesons remain different across the finite temperature chiral transition, and that this difference comes from the disconnected contributions to the singlet meson propagator. This means that, although $SU(2) \times$

SU(2) chiral symmetry is restored at this transition, the U(1) axial symmetry remains broken. In addition we have been able to associate this breaking with instantons, indicating that instantons continue to play a vital role in the quark-gluon plasma.

The above calculations are being performed on the CRAY C-90 and more recently on the CRAY T3E at NERSC. Small lattice calculations continue to be performed on our group's workstation and PC.

Fig. 1. Wilson/Polyakov line and chiral condensate ($\langle \bar{\psi}\psi \rangle$) on an $12^2 \times 24 \times 4$ lattice as

functions of $\beta = \frac{6}{g^2}$.

(D. K. Sinclair and J.-F. Lagaë)

III. ACCELERATOR RESEARCH AND DEVELOPMENT

III.A ARGONNE WAKEFIELD ACCELERATOR PROGRAM

III.A.1 AWA Facility Status/Experiments and New Ideas

During this period we embarked upon an ambitious series of experiments designed to map out the parameter space of the AWA drive linac. These measurements are important in defining empirically the envelope of capabilities of the AWA.

a. AWA Drive Linac Measurements

We measured the bunch length of the drive beam as a function of the RF launch phase, for several values of the laser beam energy. By varying the laser energy we change the amount of charge emitted by the photocathode, and thus the influence of the space-charge force in the dynamics of the electron bunches. Figure 1 shows RF phase scans for two different laser beam energies. In these plots the relative RF phase between the drive gun and the linac tanks was kept constant, and only the phase of the klystron power with respect to the laser pulses was changed.

The plots show how the bunch length and the extracted charge vary as a function of the launching RF phase. We notice that the dependencies on the RF phase are stronger in the higher

Fig. 1. AWA drive linac rf phase scans shown for two different beam energies

charge case, since in that case the space-charge forces are stronger and it becomes more critical to optimize the RF fields. It is also important to optimize the focusing solenoidal fields, otherwise the bunch length may become much longer and even show a bimodal temporal distribution of charge. Figure 2 shows bunch length as a function of bunch charge. In this plot the RF phases have been set to their optimum values. We have plotted the 95% RMS value of the bunch lengths and also the corresponding FWHM. The ratio between the 95% RMS and the FWHM values shows that the pulses are not gaussian. The large fluctuation in the FWHM of the pulses also shows that the detailed shape of the temporal profile varies considerably from pulse to pulse. In Fig. 2, the data points represented by circles correspond to the optimum points observed in five RF phase scans (two of which are shown on Fig. 1). The points represented by squares and triangles were measured when the input RF power into the drive gun was at a higher level. We notice that the points represented by the triangular symbols indicate remarkably shorter bunches; this is our most recent data and we are presently performing a more comprehensive study of operation near these settings.

Eminence measurements of high charge electron beams are quite difficult. We attempted to measure the eminence of the drive beam with a pepper-pot plate. Unfortunately, the resulting images are rather irregular. We are now trying to determine if that is caused by scattering on the holes, by nonlinear response of the phosphor screen, or simply by a very irregular distribution of particles in the phase space.

Fig. 2 Bunch length vs. bunch charge.

b. New Drive Linac Photoinjector Design Studies

RF photocathode technology has experienced tremendous growth since its first invention. To date, most RF photocathode sources were developed to produce low charge but high brightness beams as injectors for FELs and other applications. In order to achieve high gradient wakefield acceleration, we are presently operating a half cell L-band gun with two additional linac sections as the AWA drive linac. However, the present gun was designed with the constraint that only 1.5 MW rf power would be initially available at the AWA. Thus the gun was designed with high shunt impedance and with output energy of 1.5 MeV.

The present gun was designed to operate with a peak photocathode field of 92 MV/m. During initial tests the interior of the gun was damaged by a vacuum window failure while under full rf power. Although the gun is reaching its design goals, depression of the photocathode field by dark current emission limits further performance improvement. Reaching and exceeding 10 kA will require a new gun cavity.

One possibility is to implement an improved gun design. We have shown that a new design philosophy making use of 10 MW or more rf power available for the drive gun can produce the desired performance improvement for the AWA drive beam.

The choice for this new gun design is a 1-1/2 cell cavity as shown in Figure 3. Although the beam will have lower emittance if one chooses a multi-cell gun cavity, the rf power requirements will be excessive. There have been designs of relatively high charge L-band guns at APEX and TTF, but they produce relatively long beams with moderate charges (<10 nC). Magnetic compression is then used after the gun to produce short bunches.

The key to designing a high charge short pulse electron gun is the use of a high photocathode electric field. The computer codes SUPERFISH and PARMELA were used to model cavity fields and beam dynamics respectively.

For the 100 nC beam case, the RMS pulse length is 1.2 mm and normalized emittance is in the range of the existing AWA gun design ($\sigma_z = 3 \text{ mm}$, and $\epsilon_N = 800 \text{ mm mrad}$). The use of a single AWA linac tank operated at 10 MW in conjunction with the new gun will produce a drive beam energy of 15–20 MeV with electron bunch parameters as above. Numerical simulations indicate that with these parameters the drive beam could generate wakefield gradients in excess of 1 GeV/m in plasma with density of $7 \times 10^{13} \text{ cm}^{-3}$. For dielectric structures, the reduced emittance and bunch length will permit 100 MV/m gradients to be attained for collinear drive-witness geometries. This second generation AWA high current gun builds upon our experience with the original high current gun and pushes the technology frontier further into this previously unexplored region of photocathode source parameter space.

c. Dielectric Device Measurements

In order to increase transmission of the drive beam through smaller (higher impedance) wakefield devices, a quad triplet was located upstream of the wakefield device. The improved optics allowed up to 40 nC drive charge/pulse to be transmitted through a 3 mm radius aperture 10 cm in length. At these intensities background from X-rays and secondary electrons from drive beam scraping caused problems for witness beam detection. After careful radiation shielding and with improved beam monitoring the background became manageable. A 20 GHz device ($a=2.9$ mm, $b=5.0$ mm) was used to study wakefield effects as a function of drive beam intensity and length. The drive beam current was gradually increased by removing neutral density filters in the laser transport line for the drive gun. The beam transport lines were retuned to give maximum transmission for each drive beam intensity. At each point the gradient (maximum witness beam energy change) was measured, along with the drive bunch length. Drive charges for this experiment were in the 5 – 25 nC/pulse range. RMS drive bunch lengths were found to vary from 6 ps at 5 nC to 20 ps at 25 nC. This increase in bunch length resulted in a rolloff in the observed wakefield gradient with drive charge as shown in Figure 4. The Figure also shows the predicted gradient if the length of the drive bunch had not increased with charge, and also the predicted gradient based on the expected $\exp(-k^2\sigma^2/2)$ scaling with bunch length. The scaled gradient generally reproduces the trend of the data.

Fig. 3. Schematic of proposed 1-1/2 cell high current photocathode gun.

Fig. 4. Gradient in 20 GHz dielectric structure vs. charge. Diamonds: measured gradients, Straight line: Predicted gradient based on 10.5 nC measurement, Crosses: Predicted gradient based on 10.5 nC data and measured bunch lengths.

(W. Gai, M. Conde, P. Schoessow)

III.B DEVELOPMENT OF A BEAM PROFILE MONITOR AT SLAC

III.B.1 Progress with Profile Monitor Development

The analysis of data taken on May 24 is proceeding. In a 4 hour run we were able to make tests of repeatability and look at backgrounds in more detail. Although a wide beam on 20 micron Al wires provided a weak signal we were able to measure gross structure of the three wire target and look at backgrounds with a narrow slit.. We were able to close the slits down to a few microns for the first time and make measurements of the background and resolution that that can be obtained with this setup. We also were able to measure slit scattering with a wide slit setting and inclined collimators.

III.B.2 Short Proton Bunches at the AGS (E-932)

Current muon collider designs require that the muons are produced by a proton bunch of 1-3 ns in order to, a) not dilute the longitudinal phase space, and b) permit separation of the two polarization states of the muons. This requirement, together with the required intensity is a challenge for synchrotron technology.

In a 24 hour run at the AGS, a group from Argonne, Brookhaven, and Fermilab were able to show that beams of high intensity ($3 - 5 \times 10^{12}$ protons per bunch) could be bunched by operating near transition. The specific procedure used was to flattop the beam near the nominal transition energy with the g_i jump system turned on, so g_i was then suddenly lowered to the beam energy. The mismatched bunch was then spread in DE and shortened in Dt. The results are shown below.

Fig. 1 Mountain range plot of bunches in the AGS as the transition energy is dropped to roughly the bunch energy.

Although detailed results are being written up, preliminary results show: 1) stable, high intensity bunched beam operation above, below,

and at g, with longitudinal bunches of the size required by the muon collider (~ 1.5 eV-sec), 2) the bunch length was reduced by a factor of three, to 2.7 ns, which is 50% larger than the number commonly quoted for the muon collider, 3) measurements were made over a range of beam energies and for a variety of chromaticities, all producing qualitatively similar data, 4) measurements of the transition energy of the AGS were made using rf phase flip time, synchrotron frequency, and debunching times, all yielding roughly the same results. After the first 1/4 turn in synchrotron space, the bunch seemed to reach an equilibrium with a slightly diluted emittance and the bunch shape did not change subsequently for ~ 50 ms, which was as long as measurements were made. The results are shown below.

These measurements are among the first made at transition in synchrotrons, and seem to indicate that stable bunched beam operation near transition is possible for high current isochronous rings. Besides showing that bunching remittances appropriate to the muon collider may be possible, the data should be relevant to a number of next generation neutron source designs which have considered this option.

III.B.3 Electron Options at Fermilab

At the PAC97 conference we presented a more detailed design of the e^+e^- collider ring which would be designed to operate in the VLHC tunnel. Eric Chojnacki of Cornell contributed a parameter list for the superconducting rf system, and Sushil Sharma, of ANL-ASD, produced a simple design of the synchrotron absorbers. The paper outlined a more detailed design of the collider, along with possible concerns that might drive the collider design. The possibility of an ep collider in one of the injector tunnels was considered, following a suggestion by Malcolm Derrick.

(J. Norem)

IV. DIVISIONAL COMPUTING ACTIVITIES

IV.1 Grand Challenge Applications (GCA): Data Access for High-Energy and Nuclear Physics R&D

Two physicists (L. Price and E. May) and a computer scientist (D. Malon) from DIS division continued to work on the "Grand Challenge Application on HENP Data" project. This is a DOE/ER MICS, HENP-HEP, HENP-NP supported R&D project to provide develop tools to allow High Energy and Nuclear Physicists to analyze and manage the massive amounts of data which will be generated by next generation of experiments. In addition to its direct impact on the success of High Energy and Nuclear Physics experiments, this work will also have impact on other governmental and commercial enterprises faced with massive amounts of data. Laboratory and University collaborating partners are LBNL, ANL, BNL, FSU, UCLA, U Tenn., and Yale. During this interval we worked in the following areas:

We received official notification of the approval of GCA HENP proposal. We had a series of meetings with GCA/HENP collaborator to plan work. Much of the initial work will be done on the PDSF facility at LBNL. We ported the ANL PASS developed Object Manager system to the PDSF, prepared demos and evaluations of using it in the GCA/HENP environment. We began work on the GCA/HENP architectural model which uses much of our experience in the PASS project. At the direction by DOE/MICS the initial implementation will be aimed at the RHIC: STAR and PHENIX experiments at BNL, however, many of the methods and tools developed will be of interest and usable by the CERN LHC program, e.g., the Atlas experiment.

A paper was prepared, accepted and presented at the CHEP'97 conference in Berlin: "An ODMG-Compatible Testbed Architecture for Scalable Management and Analysis of Physics Data."

(Ed May)

V. 1997 PUBLICATIONS

V.A. JOURNAL PUBLICATIONS, CONFERENCE PROCEEDINGS, BOOKS

"A High Charge and Short Pulse RF Photocathode Gun for Wakefield Acceleration"

W. Gai, X. Li, M. Conde, J. Power, and P. Schoessow

Accepted for publication in Nucl. Inst. & Meth. in Phys. Res. A (NIMA 695)

"A Lattice Formulation of Chiral Gauge Theories"

G. T. Bodwin

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ZEUS Collaboration, J. Breitweg, *et al.*

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E. L. Berger, *et al.*

New Directions for High Energy Physics, Proceedings of the 1996 DPF/DPB
Summer Study on HEP, edited by D. G. Cassel, L. Trindle Gennari, and
R. H. Siemann (SLAC, Menlo Park, CA, 1997) p. 760

V.B. PAPERS SUBMITTED FOR PUBLICATION

“A 3.9 MeV Photoinjector and Delay System for Wakefield Measurements”

J. G. Power and M. E. Conde

Submitted for publication in J. Appl. Phys.

“Anomalous $W^+W^-t\bar{t}$ Couplings at the e^+e^- Linear Collider”

T. Tait (ANL), F. Larios, and C.-P. Yuan

Submitted for publication in Phys. Rev. D.

“Bounds on the Lightest Higgs Boson Mass with Three and Four Fermion Generations”

D. Dooling (ANL), Kyung Seh Kung, Sin Kyu Kang

Submitted for publication in Nucl. Phys. B

“Dependence of Proton Beam Polarization on Ion Source Transition Configurations”

C. Allgower, T. Kasprzyk, H. Spinka (ANL), *et al.*

Submitted to Nucl. Instrum. & Meth.

“Direct Reconstruction of np Elastic Scattering Amplitudes Between 0.80 and 1.1 GeV”

H. M. Spinka, *et al.*

Submitted to Z. Phys. C

“Discovering a Light Mass Higgs Boson at the Tevatron Collider”

S. Mrenna

To be published in Perspectives in Higgs Physics II, ed. G.L. Kane
(World Scientific)

“Electroweak-Scale Excess Cross-Sections in the Sextet Quark "Standard Model”

A. White

Submitted for publication in Phys. Rev. D

“Effects of QCD Resummation on W^+H and $t\bar{b}$ Production at the Tevatron”

S. Mrenna and C. -P. Yuan

Submitted for publication in Phys. Lett. B

“HERA Events Tevatron Jets and Uncertainties on Quarks at Large x^* ”

S. Kuhlmann (ANL), H. Lai, and W. Tung

Submitted to Phys. Lett.

“Measurement of Single Spin Asymmetry in η -meson Production in $p \uparrow p -$ and $\bar{p} \uparrow p -$ Interactions in the Beam Fragmentation Region at 200 GeV/c”

D. Grosnick, D. Hill, M. Laghai, D. Lopiano, Y. Ohashi, T. Shima, H. Spinka, R. Stanek, D. Underwood, and A. Yokosawa and the FNAL E-704 Collaboration

Submitted for publication in Nucl. Phys. B.

“Overcoming Intrinsic Spin Resonances with an RF Dipole”

H. Spinka, D. G. Underwood, A. Yokosawa, *et al.*

Submitted to Phys. Rev. Lett.

“Photon Pair Production with Soft Gluon Resummation in Hadronic Interactions”

C. Balazs, E. L. Berger, S. Mrenna and C.-P. Yuan

Submitted for publication in Phys. Rev. D.

“Prompt Photon Plus Jet Photoproduction at HERA at Next-to-Leading Order in QCD”

L. Gordon

Submitted for publication in Phys. Rev. D.

“Rapidity Correlations and ΔG from Prompt Photon plus Jet Production in Polarized pp Collisions”

L. Gordon

Submitted for publication in Phys. Rev. D

“Spin Dependent Drell Yan in QCD to $O(\alpha_s^2)$ (I). (The Non-Singlet Sector)”

L. Gordon (ANL), S. Chang, C. Coriano, and R. Field

Submitted to Phys. Rev.

“Spin Dependent Drell-Yan Beyond Leading Order: Non-Singlet Corrections to $O(\alpha_s^2)$ ”

L. Gordon

To be published in Phys. Lett. B.

“Supersymmetric Event Generation and the Reach of Colliders for Supersymmetry”

S. Mrenna and H. Baer

To be published in Perspectives in Supersymmetry, ed. G.L. Kane (World Scientific)

“The Structure of the Bern-Kosower Integrand for the N-Gluon Amplitude”

C. Schubert

Submitted for publication in Phys. Lett. B.

“Threshold Resummation of the Total Cross Section for Heavy Quark Production in Hadronic Collisions”

E. L. Berger and H. Contopanagos

Accepted for publication in Phys. Rev. D.

V.C. PAPERS OR ABSTRACTS CONTRIBUTED FOR CONFERENCES

“A High Charge and Short Pulse RF Photocathode Gun for Wakefield Acceleration”

W. Gai, X. Li, M. Conde, J. Power, and P. Schoessow

Presented at the ICFA Workshop on Beam Dynamics, Japan, June 1997
ANL-HEP-CP-97-76

“Deep Inelastic Diffraction and the Pomeron as a Single Gluon”

A. R. White

Presented at the International Conference (VIIth Blois Workshop) on Elastic and Diffractive Scattering - Recent Advances in Hadron Physics, Seoul, Korea, June 10-14, 1997
ANL-HEP-CP-97-68

“EPR in B Physics and Elsewhere”

H. J. Lipkin

Presented at the Symposium: Twenty Beautiful Years of Bottom Physics (b20), Illinois Institute of Technology, Chicago, IL, June 29-July 2, 1997
ANL-HEP-CP-97-61

“Excess Cross Sections at the Electroweak Scale in the Sextet Quark “Standard Model”

A. R. White

Presented at the Fifth International Workshop on Deep Inelastic Scattering & QCD (DIS '97), April 14-18, 1997
ANL-HEP-CP-97-47

“Externally Powered Dielectric Loaded Waveguides as Accelerating Structures”

W. Gai, R. Konecny, and J. Simpson

Presented at the 1997 Particle Accelerator Conference,
Vancouver, BC, May 12-16, 1997
ANL-HEP-CP-97-52

“High Gradient Dielectric Wakefield Device Measurements at the
Argonne Wakefield Accelerator”

P. Schoessow, M. Conde, W. Gai, R. Konecny, J. Power, and J. Simpson

Presented at the 1997 Particle Accelerator Conference, Vancouver, BC,
May 12-16, 1997
ANL-HEP-CP-97-53

“Higher Twist in Diffractive Dissociation”

M. Wusthoff and J. Bartels

Presented at the 5th International Workshop on Deep Inelastic Scattering and
QCD (DIS '97), Chicago, IL, April 14-18, 1997
ANL-HEP-CP-97-51

“Isolated Prompt Photon Production”

E. L. Berger (ANL), X-F. Guo, and J-W. Qin

Invited paper presented by E. L. Berger at XXXII Recontres de Moriond on QCD
and High Energy Hadronic Interactions, Les Arcs, Savoie, France, March 22-29,
1997
ANL-HEP-CP-97-32

“Isolated Prompt Photon Plus Jet Photoproduction at HERA”

L. E. Gordon

Presented at the Eleventh International Workshop on Photon-Photon Collisions
(PHOTON '97) Egmond aan Zee, The Netherlands, May 10-15, 1997
ANL-HEP-CP-97-41

“Large Rapidity Gap Events in DIS”

M. Wusthoff

Presented at the Fifth International Workshop on Deep Inelastic Scattering and
QCD (DIS '97), Chicago, IL, April 14-18, 1997
ANL-HEP-CP-97-37

“Matrix Membranes and Integrability”

C. Zachos, *et al.*

Presented at the Supersymmetry and Integrable Models Workshop (2nd Annual
UICHEP Summer Workshop Series), Chicago, IL, June 12-14, 1997
ANL-HEP-CP-97-70

“New Puzzles in Nonleptonic B and D Decays”

H. J. Lipkin

Presented at B Physics and CP Violation Conference, Manoa, Hawaii,
March 23-28, 1997
ANL-HEP-CP-97-56

“Pentaquark Phenomenology”

H. J. Lipkin

Invited talk presented at the Sixth Conference on the Intersections of Particle and Nuclear Physics, Big Sky, Montana, May 27 - June 2, 1997
ANL-HEP-CP-97-60

“Physics Results from Polarized DIS

G. P. Ramsey

Presented at Fifth International Workshop on Deep Inelastic Scattering (DIS '97),
Chicago, IL , April 14-18, 1997
ANL-HEP-CP-98-19

“Recent Electroweak Measurements from the Tevatron”

R. Wagner for the CDF & DO Collaborations

Presented at the Conference on Beyond the Standard Model V,
Balholm, Norway, April 29 - May 2, 1997
ANL-HEP-CP-97-66

“Spin Dependent Drell-Yan and Double Prompt Photon Production to NLO QCD”

L.Gordon (ANL), S. Chang, C. Coriano, and R. Field

Presented at the Fifth International Workshop on Deep Inelastic Scattering and QCD (DIS '97), Chicago, IL, April 14-18, 1997
ANL-HEP-CP-97-22

“The Argonne Wakefield Accelerator: Diagnostics and Beam Characterization”

M. Conde, W. Gai, R. Konecny, X. Li, J. Power, P. Schoessow

Presented at the 1997 Particle Accelerator Conference, Vancouver, BC,
May 12-16, 1997
ANL-HEP-CP-97-54

“The Argonne Wakefield Accelerator: Upgrade Scenarios and Future Experiments”

W. Gai, M. Conde, R. Konecny, X. Li, J. Power, P. Schoessow & J. Simpson

Presented at the 1997 Particle Accelerator Conference, Vancouver BC,
May 12-16, 1997
ANL-HEP-CP-97-50

“The Pomeron Beyond BFKL”

A. R. White

Invited talk presented at the Fifth International Workshop on Deep Inelastic Scattering & QCD (DIS '97), Chicago, IL April 14-18, 1997
ANL-HEP-CP-97-25

“The VIIth BLOIS Workshop: Theory Summary and Factorization Issues”

A. R. White

Presented at the International Conference (VIIth Blois Workshop) on Elastic and Diffractive Scattering - Recent Advances in Hadron Physics,
Seoul, Korea, June 10-14, 1997
ANL-HEP-CP-97-73

“Threshold Resummation and the Total Cross Section for Top Quark Production”

E. L. Berger and H. Contopanagos

Invited talk presented at the Fifth International Workshop on Deep Inelastic Scattering and QCD (DIS '97) Chicago, IL April 14-18, 1997
ANL-HEP-CP-97-33

V.D. TECHNICAL REPORTS AND NOTES

“A 4 MeV Photocathode Beam for Measurements of the Dielectric Wakefield Accelerator: An Experimental Thesis”

J. Power

ANL-HEP-TR-97-57

“Crystal Ball Single Event Display”

C. Allgower

Technical Report # CB-97-010
ANL-HEP-TR-97-86

“Measurement of Proton-Proton Elastic Spin Observables A_{ono} and A_{onn} in the Range 1.8 - 2.8 GeV”

C. Allgower

Ph.D. Thesis
ANL-HEP-TR-97-71

“Measurement of the $\gamma + D^*$ Cross Section in Neutrons and the Crystal Ball Experiments”

C. Allgower

Technical Report # CB-97-009
ANL-HEP-TR-97-87

CDF Note 4036

Some Software Tools for Using CES Data

A. B. Wicklund, L. Nodulman

CDF Note 4052	Measurement of Upsilon Masses for the Run Ib W Mass Measurement Adam Hardman
CDF Note 4056	On False Curvatures in 1b L. Nodulman.
CDF Note 4060	CFT Trigger Bias in the Run 1b W $\rightarrow$ μ ν Mass Measurement J. Proudfoot
CDF Note 4062	A Conceptual Design for Run II Muon Reconstruction T. LeCompte
CDF Note 4073	The Run 1B Trigger Bias Systematic in the W $\rightarrow$ μ ν Mass Measurement K. Pitts, J. Proudfoot
CDF Note 4121	Setting Limits with the $\gamma\gamma$ +Met Analysis D. Toback, H. Frisch, R. Culberson, P. Wilson, J. Berryhill, and B. Blair
CDF Note 4144	Search for Flavor Changing Neutral Current Decays T. LeCompte (for CDF)
CDF Note 4151	Overview of Calorimeter Isolation Trigger For Run II R. Blair J. Dawson S. Kuhlmann
CDF Note 4153	Calculating Top to Lepton Branching Fractions T. Liss, R. Roser, L. Nodulman
CDF Note 4156	Photon 23 Trigger Efficiency and its Application to the Rare Decay W $\rightarrow$ π + γ R. W. Kadel, Steve Kuhlmann,
CDF Note 4175	CDF Muon Shielding Plans For Run II T. LeCompte, J. Cooper, O. Krivosheev, N. Mokhov S. Klimenko, J. Konigsberg, A. Nomerotski, M. Franklin J. Troconiz, J. Bellinger, D. Carlsmith, L. G. Pondrom
CDF Note 4181	Analysis of the COT Endplate Deflections V. Guarino

- CDF Note 4183 Summary of the GammaGamma + X Counting Experiments
D. Toback, H. Frisch, P. Wilson, R. Culbertson, J. Berryhill and R. Blair
- CDF Note 4193 The Missing ET Correction for the Run 1 W/Z + Gamma Analysis
D. Benjamin, L. Christofek, D. Errede, S. Errede, K. Hara, M. Lindgren,
T. Muller, D. Neuberger, H. Sato, M. Shimojima, R. G. Wagner
- STAR 281 STAR Offline Simulations and Analysis Software Design
T. LeCompte, *et al.*
- STAR 287 Dielectron Backgrounds and their Impact on J/psi Physics
T. LeCompte

VI. COLLOQUIA AND CONFERENCE TALKS

E. L. Berger

“Perturbative Quantum Chromodynamics”

Plenary review lecture presented at Frontiers in Contemporary Physics 1997--
Fundamental Particles and Interactions, Vanderbilt University, Nashville, TN,
May 13, 1997

“Isolated Prompt Photon Production--Breakdown of Conventional Factorization”

Invited seminar presented at the XXXII Recontres de Moriond on QCD and High Energy
Hadronic Interactions, Les Arcs, Savoie, France, March 25, 1997

“Tests of Perturbative QCD and Determination of the Spin Dependent Parton Densities at RHIC”

Invited review presented at the PHENIX Spin Coalition Meeting, NM, February 24, 1997

“Threshold Resummation for Heavy Quark Production at Hadron Colliders”

Invited review presented at the Aspen Winter Conference, Aspen, CO, January 1997

“Threshold Resummation and the Total Cross Section for Top Quark Production”

Invited talk presented at the Fifth International Workshop and Deep Inelastic Scattering
and QCD (DIS '97), Chicago, IL, April 17, 1997

R. Blair

“Photons and Diphotons from the Tevatron”

Invited talk at 5th International Workshop on Deep Inelastic Scattering and QCD,
Chicago, IL, April 1997

G. T. Bodwin

“Decay and Production of Heavy Quarkonium: The Color-Octet Model is *Not* a Model”

ANL High Energy Physics Division Seminar, Argonne, IL, May 21, 1997

M. Derrick

“New Results from ZEUS on DIS at High X”

HEP seminar talk for the University of Maryland, February 1997

“The Relationship Between Basic Research and Economic Prosperity”

Colloquium at Elmhurst College, March 1997

“What Does Proton Look Like These Days?”

Colloquium at University of Minnesota, April 1997

M. C. Goodman

“Atmospheric Neutrino Flavor Ratio in Soudan 2”

Invited talk presented at the 6th Conference on the Intersections of Particle and Nuclear Physics, Big Sky, Montana, May 27 - June 2, 1997

“Fermilab Fixed Target Program”

Invited talk presented at the ANL-HEP Division Lunch Seminar, June 17, 1997

“The Fermilab Long-Baseline Neutrino Program”

Talk presented at the 6th Conference on the Intersections of Particle and Nuclear Physics, Big Sky, Montana, May 1997

T. LeCompte

“Quarkonium Production at the Tevatron”

Invited talk for the 5th International Workshop on Hard Probes in Nuclear Collisions, Lisbon, Portugal, 1997

H. J. Lipkin

“Pentaquark Phenomenology”

Invited talk presented at the Sixth Conference on the Intersections of Particle and Nuclear Physics, Big Sky, Montana, May 27 - June 2, 1997

D. Malon

“An ODMG-compatible Testbed Architecture for Scalable Management and Analysis of Physics Data”

Invited talk at the CHEP'97 Conference, Berlin, Germany, April 1997

G. Ramsey

“Physics Results from Polarized DIS”

Presented at the Fifth International Workshop on Deep Inelastic Scattering and QCD (DIS '97), Chicago, IL, April 14-18, 1997

J. Thron

“The MINOS Experiment”

Talk presented at the Main Injector Workshop, Fermilab, May 1-4, 1997

R. Wagner

“Recent Electroweak Measurements from the Tevatron”

Invited talk at Beyond the Standard Model V, Balholm, Norway, April 1997

A. R. White

“Color Sextet Quarks; New Physics at Large E_T and Q^2 ”

Theory seminar presented at the Center for Theoretical Physics, Seoul National University, Seoul, Korea, June 18, 1997

“Deep-Inelastic Diffraction and the Pomeron as a Single Gluon”

Invited talk presented at the International Conference (VIIth Blois Workshop) on Elastic and Diffractive Scattering, Recent Advances in Hadron Physics, Seoul, Korea, June 10-14, 1997

“Theory Summary”

Invited talk presented at the International Conference (VIIth Blois Workshop) on Elastic and Diffractive Scattering, Recent Advances in Hadron Physics, Seoul, Korea, June 10-14, 1997

“The Pomeron Beyond BFKL”

Invited talk presented at the 5th International Workshop on Deep Inelastic Scattering and QCD (DIS ‘97), Chicago, IL, April 14-18, 1997

“Excess Cross-Sections at the Electroweak Scale in the Sextet Quark ‘Standard Model’”

Invited talk presented at the 5th International Workshop on Deep Inelastic Scattering and QCD (DIS ‘97), Chicago, IL, April 14-18, 1997

C. Zachos

“Matrix Membranes and Integrability”

Presented at the UIC Workshop on Integrable Models and Supersymmetry, Chicago, IL, June 13, 1997 (Session Chair)

“Topics in Matrix Membranes and Integrability”

Presented at the Enrico Fermi Institute, University of Chicago, IL, May 21, 1997

“Nonabelian Duality: a Nonlocal Canonical Equivalence of Field Theories”

Presented at Purdue University, Lafayette, IN, March 18, 1997

VII. HIGH ENERGY PHYSICS COMMUNITY ACTIVITIES

D. S. Ayres

Deputy Spokesperson of the MINOS Collaboration.

E. L. Berger

Member, High Energy and Nuclear Physics Advisory Committee, Brookhaven National Laboratory, Batavia, IL, 1995-98.

Member, International Advisory Board, Fifth International Symposium on Weak and Electromagnetic Interactions in Nuclei (WIEN '98), Santa Fe, NM, June 14-21, 1998.

Member, Local Organizing Committee, Workshop on Physics at the First Muon Collider, Fermilab, Batavia, IL, October 23-26, 1997.

Member, International Advisory Committee, Seventh International Conference on Hadron Spectroscopy, Brookhaven National Laboratory, Upton, NY, August 24-30, 1997.

Member, International Advisory Committee, Symposium: Twenty Beautiful Years of Bottom Physics, Illinois Institute of Technology, Chicago, IL, June 29 - 2 July 2, 1997.

Organizing Committee, Sixth Conference on the Intersections Between Particle and Nuclear Physics, May 1997.

Consultant, Department of Energy Annual Review of the Stanford Linear Accelerator Laboratory, April - May 1997.

Member, Scientific Program Committee, XXXII Recontres de Moriond, "QCD and High Energy Hadronic Interactions," Les Arcs, France, March 1997.

T. LeCompte

Head of the Nuclear Physics Aspects of the STAR Detector, guiding the simulations, (1997).

E. May

Member of staff, Esnet Steering Committee.

L. Price

Chair, Esnet Steering Committee.

A. R. White

Member, International Advisory Committee, International Conference on Elastic and Diffractive Scattering - Recent Advances in Hadron Physics Conference (VIIth Blois Workshop), Seoul, Korea, June 1997.

Member, International Advisory Committee, International School on High Energy Physics LAFEX/CBPF (LISHEP '98), Rio de Janeiro, Brazil, February 1998.

C. Zachos

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

VIII. HIGH ENERGY PHYSICS DIVISION RESEARCH PERSONNEL

Administration

L. Price

D. Hill

Accelerator Physicists

M. Conde

W. Gai

J. Norem

J. Power

P. Schoessow

J. Simpson

Experimental Physicists

D. Ayres

R. Blair

K. Byrum

M. Derrick

T. Fields

M. Goodman

D. Krakauer

S. Kuhlmann

T. LeCompte

W. Leeson

S. Magill

E. May

B. Musgrave

L. Nodulman

J. Proudfoot

J. Repond

H. Spinka

R. Stanek

R. Talaga

J. Thron

D. Underwood

R. Wagner

A. Wicklund

A. Yokosawa

Theoretical Physicists

E. Berger

G. Bodwin

L. Gordon

J. -F. Lagae

S. Mrenna

D. Sinclair

A. White

M. Wusthoff

C. Zachos

Engineers, Computer Scientists, and Applied Scientists

J. Dawson

G. Drake

W. Haberichter

N. Hill

J. Schlereth

X. Yang

Technical Support Staff

I. Ambats
R. Blair
G. Cox
V. Guarino
D. Jankowski
T. Kasprzyk
C. Keyser

L. Kocenko
R. Konecny
E. Petereit
R. Rezmer
R. Taylor
K. Wood

Laboratory Graduate Participants

C. Allgower
N. Barov
A. Hardman

D. Mikunas
H. Zhang

Visiting Scientists

G. Ramsey (Theory)
J. Uretsky (Theory)
H. Lipkin (Theory)

X. Li (AWA)

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