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**ARGONNE NATIONAL LABORATORY  
HIGH ENERGY PHYSICS DIVISION**

**SEMIANNUAL REPORT OF  
RESEARCH ACTIVITIES**

**July 1, 1986 – December 31, 1986**



**ARGONNE NATIONAL LABORATORY**

**Argonne, Illinois**

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**HIGH ENERGY PHYSICS DIVISION**  
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**MASTER**

High Energy Physics Division Semiannual Report of Research Activities  
July 1, 1986 - December 31, 1986

I. EXPERIMENTAL PROGRAM

A. Physics Results

1. High Resolution Spectrometer

Six papers were published during the period: "Observation of Tensor and Scalar Mesons Produced in  $e^+e^-$  Annihilation at 29 GeV," Phys. Rev. Lett. 57, 1990 (1986); "Experimental Study of the Reactions  $e^+e^- \rightarrow e^+e^-$  and  $e^+e^- \rightarrow \gamma\gamma$  at 29 GeV," Phys. Rev. D34, 3286 (1986); "Study of Quark Fragmentation in  $e^+e^-$  Annihilation at 29 GeV: Charged Particle Multiplicity and Single Particle Rapidity Distribution," Phys. Rev. D34, 3304 (1986); "Asymmetry in the Angular Distribution of Inclusive  $\Lambda$  Baryons from  $e^+e^-$  Annihilation at  $\sqrt{s} = 29$  GeV," Phys. Lett. 181, 403 (1986); "Search for Wrong-Sign  $D^0$  Decays," Phys. Lett. 182, 101 (1986); "Performance of the Barrel Calorimeter System of the High Resolution Spectrometer," Nucl. Inst. Meth. A249, 185 (1986). Five additional papers were submitted for publication.

A search was conducted for the wrong sign decays  $D^0 \rightarrow K^+\pi^-$  using a sample of  $D^{*+} \rightarrow D^0\pi^+$  events selected from  $300 \text{ pb}^{-1}$  of data. Observation of such decays would be a signal for  $D\bar{D}$  mixing. Figure 1 shows the two dimensional distributions of the events in  $K\pi$  effective mass and in the mass difference  $M(K\pi\pi) - M(K\pi)$ . With the normal assignment of K and  $\pi$  charges a strong clustering is observed in the box outlined in Fig. 1(a) for the allowed sequence  $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$ . By contrast there is only one entry in Fig. 1(b) for the wrong sign decay sequence  $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^+\pi^-\pi^+$ . This leads to an upper limit of 4% at the 90% c.l. for the ratio of the wrong sign to the right sign decays.

In our continuing study of  $D$  mesons the decay  $D^{*0} \rightarrow D^0\gamma \rightarrow K^-\pi^+\gamma$  was observed. The production cross section in units of the point cross section is  $0.63 \pm 0.22$  for fractional energy  $z > 0.5$ . Figure 2 shows the mass difference plot  $\Delta M = M(K^-\pi^+\gamma) - M(K^-\pi^+)$ : the clear peak at  $\Delta M \sim 0.15$  GeV corresponds to this decay. The fragmentation function is compared to the Jade

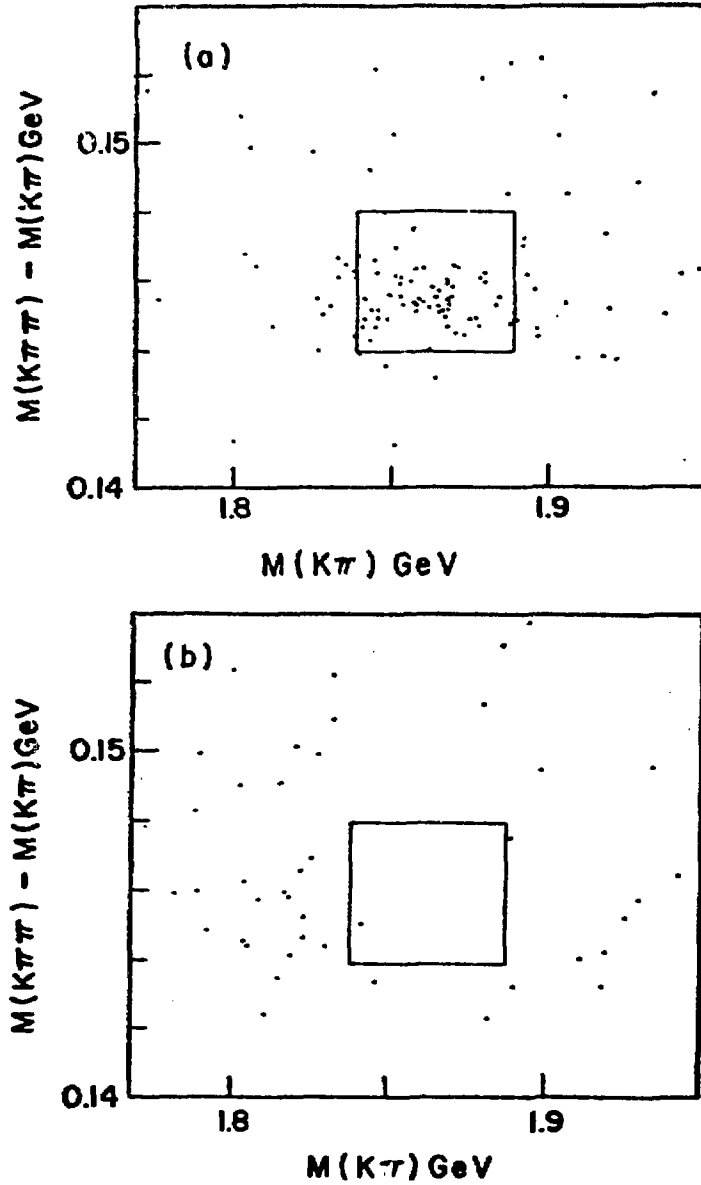


Fig. 1. (a)  $M(K\pi\pi^-) - M(K\pi^+)$  versus  $\delta$ , (b)  $M(K\pi^+\pi^-) - M(K\pi)$  versus  $\delta$ .

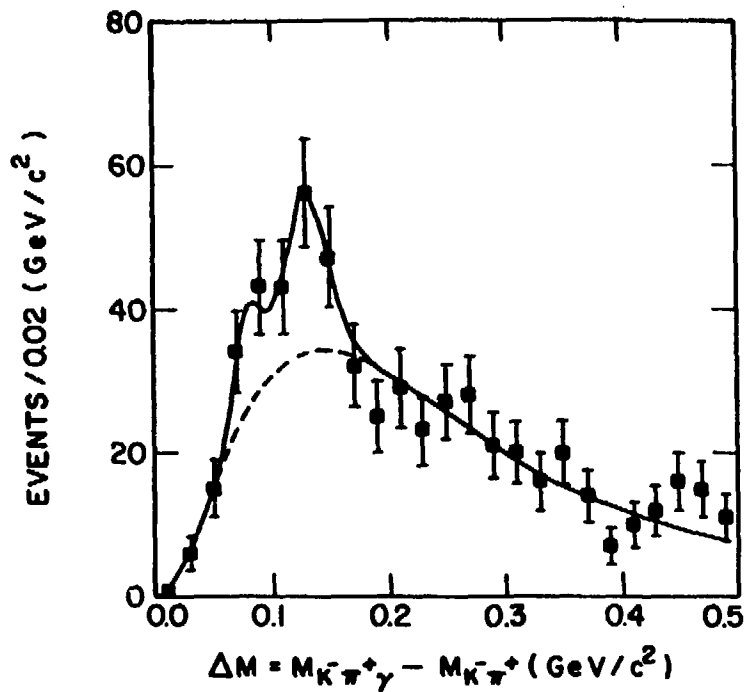


Fig. 2. The mass difference,  $M = M(K^-π^+γ) - M(K^-π^+)$  distribution for  $Z_{Kπγ} ≥ 0.5$ . The solid curve is a fit to the data including a small contribution from the  $D^{*0} \rightarrow D^0 \gamma$  decay in which only one photon cluster is observed.

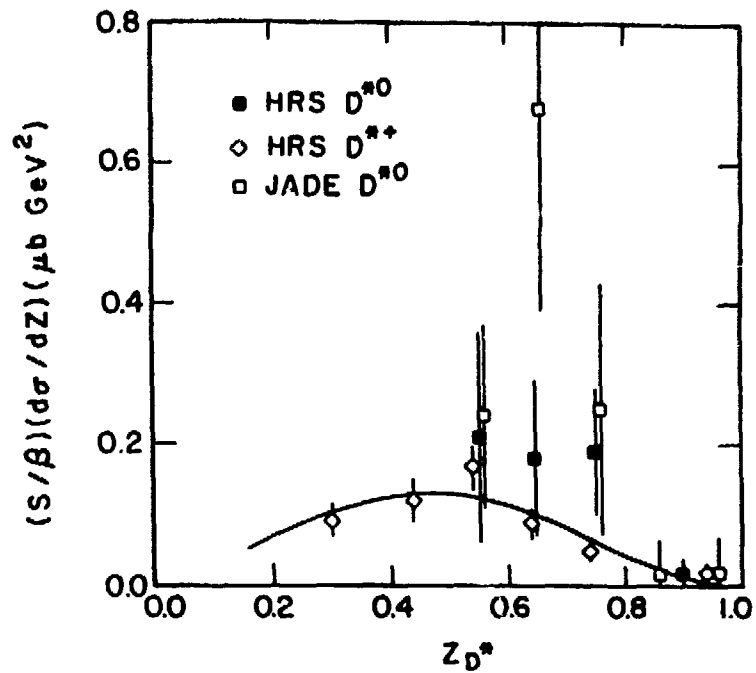


Fig. 3. The fragmentation function for the  $D^{*0}$  measured by the HRS and by the JADE collaboration for  $Z_{D^{*0}} ≥ 0.5$ . The HRS measurement of the fragmentation function for the  $D^{*+}$ ,  $Z_{D^{*+}} > 0.2$ , is shown for comparison. The curve is a fit of the Peterson function to the  $D^{*+}$  data.

measurements of the  $D^{*0}$  and to the HRS data on the  $D^{*+}$  in Fig. 3.

Two lifetime measurements were completed. The first is that of the  $b$  quark using events tagged by a high transverse momentum electron. The distribution in impact parameter for 301 such events is shown in Fig. 4. From a detailed simulation of the  $e^+e^- \rightarrow q\bar{q}$  process plus the detector response, using Monte Carlo techniques, the data sample contains  $(53 \pm 7)\%$  of  $b\bar{b}$ ,  $(22 \pm 3)\%$  of  $c\bar{c}$  and  $(25 \pm 5)\%$  of other final states. The latter, which are mainly hadrons misidentified as electrons, have a zero apparent lifetime. A maximum likelihood fit to the data gives  $\tau_b = 1.02^{+0.4}_{-0.37}$  ps. where the error includes both statistical and systematic effects.

A high precision measurement of the lifetime of the tau lepton was completed. The events of the 3-1 topology were used:  $e^+e^- \rightarrow \tau^+\tau^- + (3 \text{ charged})^+ (1\text{-charged})^-$ . Figure 5 shows the proper time distribution of 1326 clean events with a good reconstruction of the 3 prong decay vertex and with tracks that did not share cells in the vertex drift chamber. The result is  $\tau_\tau = (2.86 \pm 0.15 \pm 0.08) 10^{-13}$  secs. This is currently the best measurement of this fundamental quantity. It is in excellent agreement with the value of 2.86 expected from  $\mu:\tau$  universality with an electron branching ratio of the  $\tau$  decay of  $Be = (17.9 \pm 0.3)\%$ . The world average values of  $\tau_\tau$  and  $Be$  check  $\mu:\tau$  universality at the 4% level as compared to 1% for the  $\mu:e$  comparison coming from the  $\pi_{e2}/\pi_{\mu2}$  branching ratio.

(M. Derrick)

## 2. Computational Physics

Work in this field is being done by D. Sinclair and by M. Grady and is described separately below.

Throughout this period I continued to work on lattice gauge theory using the Hybrid Microcanonical/Langevin simulation technique, to allow the inclusion of dynamical quarks. The study of nuclear matter at finite temperature with E. Kovacs and J. B. Kogut (University of Illinois) continued using a  $10^3 \times 6$  lattice, at a quark mass small enough to observe the return of the finite temperature phase transition ( $m = .025$ ) now driven by chiral

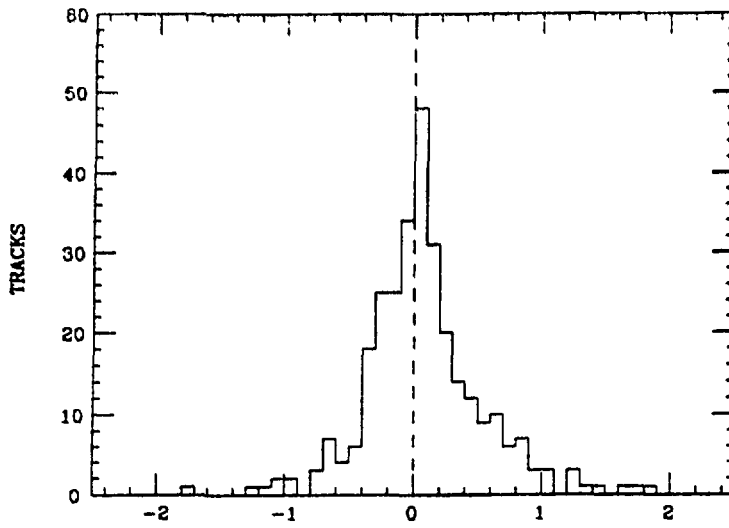


Fig. 4. Impact parameter (mm).

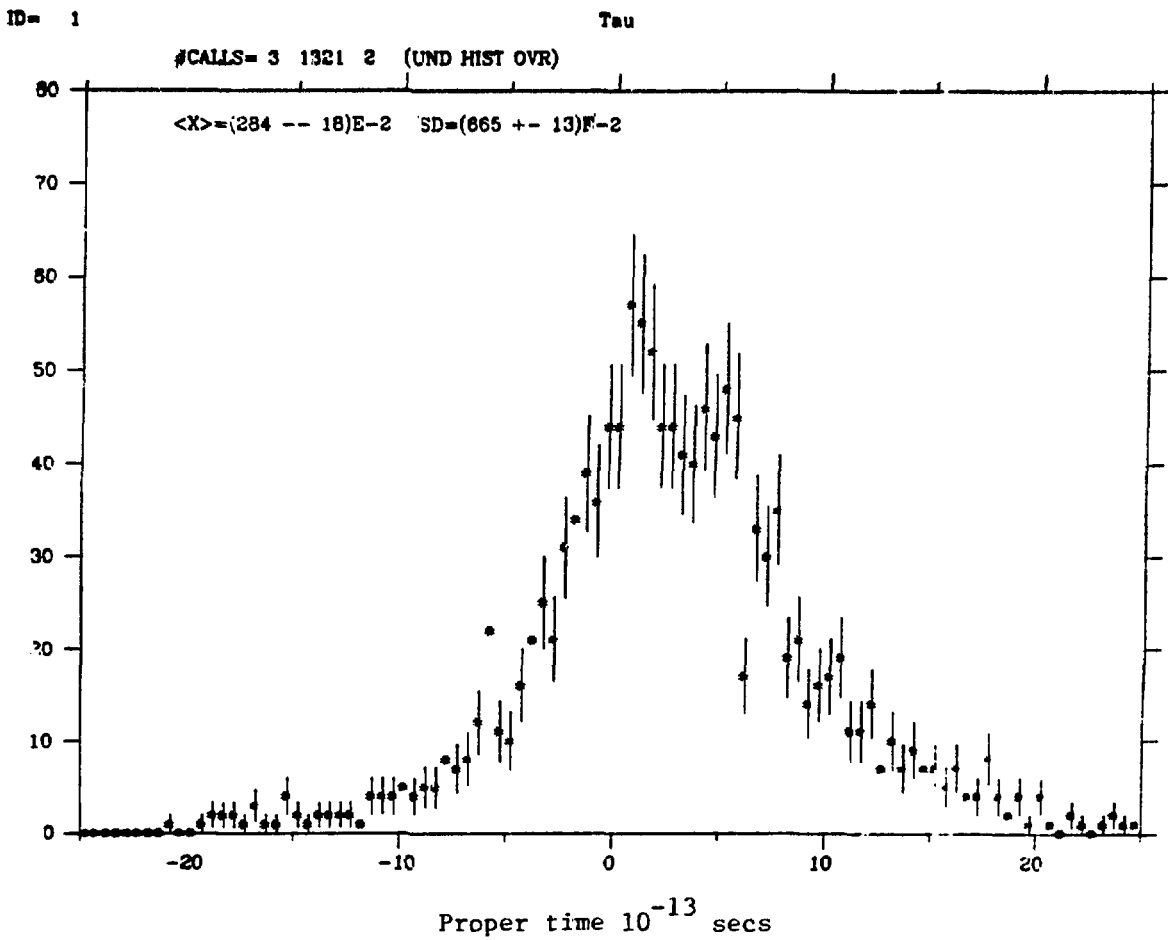


Fig. 5. Proper time distribution for  $\tau$  decay.

symmetry restoration. We did in fact observe this transition (Fig. 6) and were able to determine that it is first order, and that the first order line ends in a critical point. As well as enhancing our understanding of QCD, such a transition should be accessible to direct observation in heavy ion collisions (at RHIC and possibly at CERN). These simulations were performed on the High Energy Physics Division's ST100 array processor.

Code for calculating hadron masses and measuring the interquark potential on an  $8^3 \times 16$  lattice was written and tested on the ST100 in collaboration with M. P. Grady. These simulations will commence in January 1987.

Inspired by our ST100 results, further studies on a smaller ( $8^3 \times 4$ ) lattice were started on the CRAY X-MP/48 at NCSA by J. B. Kogut and myself.

During this period I discovered how to parameterize Lattice QCD so that simulations could be performed in the Landau Gauge. This is essential if we are eventually to employ methods of Fourier Acceleration to our simulation algorithms to decrease the CPU time required by our simulations, essential when we move to larger lattices. Kogut and I will soon begin testing such methods on the CRAY.

We also continued simulations on the CRAY X-MP/22 at NMFEC to study the phase structure of QCD as a function of the number of quark flavors.

(D. Sinclair)

Development of the "look-ahead" fermion Monte Carlo Algorithm, with which I have performed very successful simulations of the lattice Schwinger model continued; the next project will be a four dimensional SU(2) theory. The method promises an order of magnitude improvement in speed and a much lower level of systematic error than algorithms currently in widespread use.

I am investigating the scaling properties of lattice gauge theories in the crossover region and have recently completed a detailed analysis of scaling for the SU(2) and SU(3) pure gauge theories. I find that scaling curves fit extremely well to functions which would be associated with a finite

$$m=0.025 \quad \beta=5.125$$

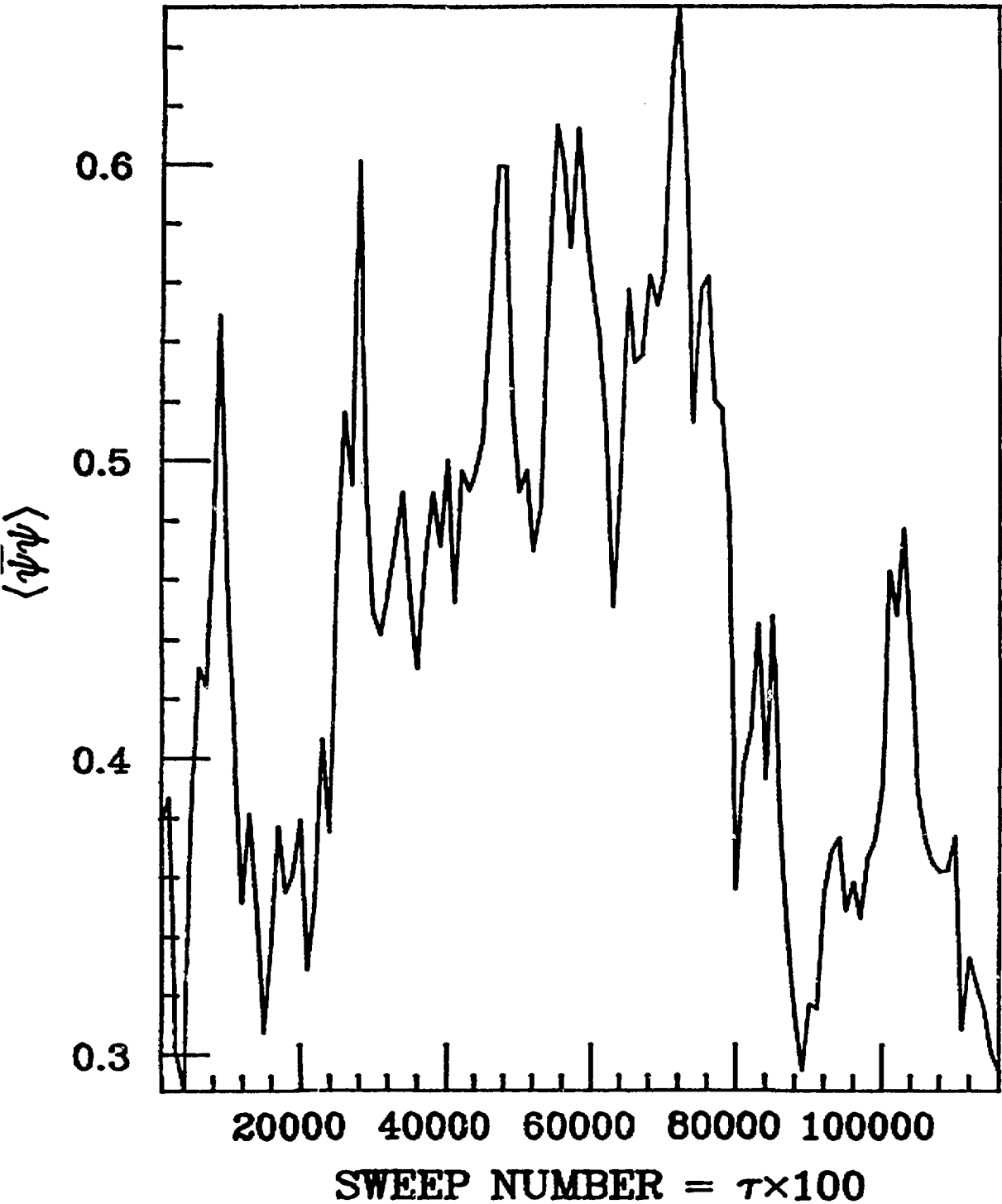


Fig. 6. Time Evolution of  $\bar{\psi}\psi$  on a  $10^3 \times 6$  lattice near the finite temperature phase transition, showing metastability and critical slowing down.

order phase transition at the weak coupling end of the crossover region for each theory. The existence of such phase transitions would have important implications, in that they imply that the confinement seen in Monte Carlo simulations is only a feature of the strong coupling lattice theory, and probably not a feature of the continuum theory.

One may perform lattice gauge simulations with actions which are unbounded functions of the field variables. If the phase transition is present, then it is probably due to condensation of vortex strings which connect monopole-antimonopole pairs. These are topological objects which are a feature of the Wilson lattice formulation, and do not exist in the continuum limit. One can find actions which do not allow the formation of such topological objects, and thus should be free of artifacts caused by them. These actions share with the continuum action the feature that they are not bounded functions of the field variables. They have the same continuum limit as the Wilson action. An example is  $S = \sum - \ln W$  where  $W$  is the  $1 \times 1$  Wilson loop and " $\ln$ " is the power series expansion of the natural logarithm which diverges for negative arguments. I am currently performing Monte Carlo simulations with this action, and have found no evidence for confinement, even for very strong couplings.

In studying the possible role of light dynamical fermions in the confinement mechanism, I am exploring a scenario by which chiral symmetry breaking may itself be responsible for confinement. The mechanism behind this is that the chiral condensate may be incompatible with the presence of strong external color fields, requiring particles with colored constituents to exclude the condensate from a small region of space surrounding them. The condensate pressing in on this region produces a confining "bag pressure". This research involves both analytical calculations and planned Monte Carlo simulations.

I am also working with Don Sinclair and John Kogut performing simulations of lattice QCD on the ST100, using a hybrid microcanonical/Langevin dynamical fermion algorithm. The current project involves determining the effects of dynamical fermions on the hadronic spectrum and on the interquark potential.

(M. Grady)

## B. Experiments Taking Data

### 1. Spin Physics at LAMPF

In the past half year, there was work on four separate experiments. Experimental runs were performed for E-961 (measurement of the np elastic scattering spin parameter  $C_{NN}$  at 800 MeV) and for E-965 (calibration of the detection efficiency of NaI counters for neutrons with energies between  $\sim 50$ -750 MeV). Tests were conducted for E-960 (measurement of the difference in total cross sections for longitudinally polarized polarized beam and target  $\Delta\sigma_L(np)$ ). Finally, data analysis continued on the past experiments of spin parameters in np elastic scattering (E-665/770 -  $C_{LL}$ ,  $C_{SL}$ ,  $C_{LL}$ ).

Argonne physicists assisted in the setup, debugging and data acquisition phases of E-961. This work involved help in mounting and surveying various detectors, assistance with chamber readin electronics, and with beam intensity monitors. The experiment encountered severe delays resulting from the slow turn-on of the beam bunchers and the polarized proton target; these items were the responsibility of LAMPF personnel. Good data were collected during the last month of the run. Assistance was provided to understand the observed missing mass spectra collected on-line, and the widely changing trigger rate. Texas A&M University has responsibility for data analysis.

In order to measure the efficiency of the NaI counters, neutrons from elastic np scattering were used. The proton was detected in a scintillation counter telescope with a range requirement (mostly constructed by our group) while the neutron was detected at the conjugate angle; the response of the NaI counters was recorded. Argonne physicists provided assistance in establishing beam intensity monitors and in early runs to establish the elastic scattering signal. The beam buncher worked well, and these measurements were very successful resulting in efficiencies measured to higher precision and at more energies than proposed. The data will be analyzed by the University of New Hampshire physicists.

Considerable progress was made, in collaboration with New Mexico State University, on E-960. Mechanical problems with the neutron counters were found and a scheme to fix them was determined. Calibration procedures for the neutron counter gains, the time averagers and the Fast TDC's were found. Both the coincidence and fast TDC electronics schemes were shown to work, with relative count rates of 1:3, and the fast timing on the buncher RF was demonstrated to operate reliably. Finally, the sensitivity of beam intensity monitors to beam position was measured, showing that feedback is needed on beamline magnets to keep the beam center fixed to about 1-2 mm. Tests of systematic errors revealed no problems at the level of about 10 mb. The statistical uncertainty for the measurements should be about  $\pm 1$  mb for data runs. The beam structure with the buncher is shown in Fig 7. Remaining problems primarily concern beam profile monitors, which did not work during the tests, and understanding some details of the neutron counter array behavior.

Data analysis for E-665/770 has been progressing well. Results for  $C_{LL}$  and  $C_{SL}$  at 500 MeV and  $\theta_{c.m.} \sim 80-160^\circ$  have been obtained. Calibrations for the 650-MeV data are completed and the evaluation of the spin parameters should be finished in a short time. A letter on these results will be written during the next six months. (H. Spinka)

## C. Experiments in Preparation Phase

### 1. Collider Detector at FNAL

During the past six months, the CDF detector was prepared for installation and then rolled into position at B0. The base detector is complete except for half the forward hadron chambers, every other slot being left empty. Collisions had already been reestablished in the Tevatron when, in December, the CDF central detector rolled in to begin checkout for data taking. Serious data taking should be possible at the beginning of March, after two months of detector check out and accelerator studies. Primary goals of the checkout period are understanding detector systems and installing and debugging the various aspects of the trigger.

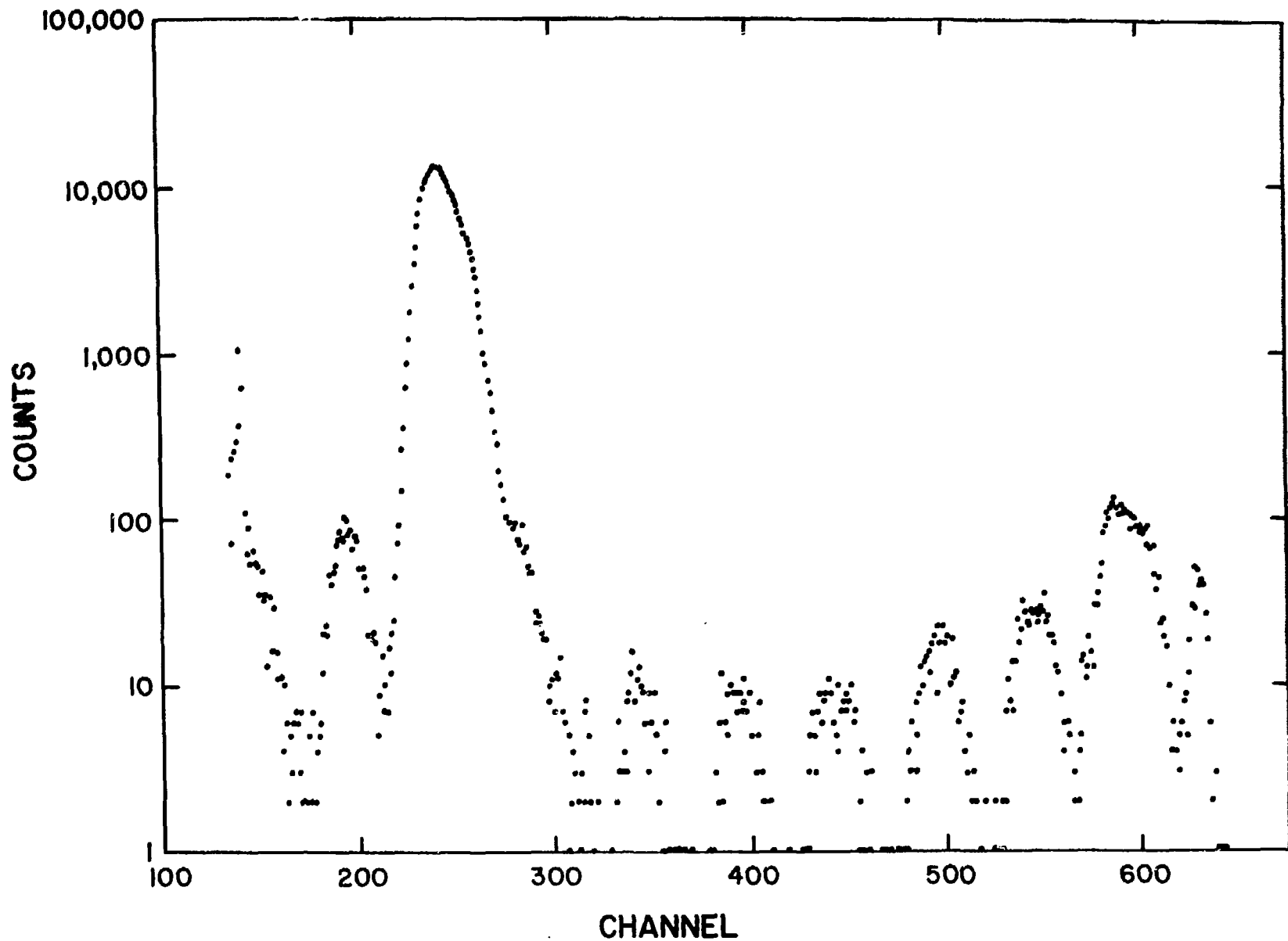


Fig. 7. Time of arrival of protons near the neutron production target in the beamline for E-960 compared to the LAMPF accelerator 10 MHz buncher signal. The horizontal scale corresponds to roughly 0.1 nsec/channel. Small amplitude pulses spaced 5 nsec apart can be seen along with the bunched pulse near channel 250.

In particular, the Argonne group oversaw completion and installation of crack calorimeter detectors and gas and high voltage systems for both crack and central electromagnetic strip chambers. Readout of the crack and strip chambers was included while rebuilding the system from the previous run. The photomultiplier cleanup campaign has resulted in a considerable reduction in triggering from single phototube noise in the central electromagnetic detector.

Ongoing efforts of the Argonne group include data base and online software for analog bus readout electronics ("Rabbit"), and online data monitoring of the whole detector performance. Study of test beam systematics is leading to development of software for offline monitoring and performance study of the various aspects of the central electromagnetic detectors. Online software for the trigger is also under development.

Our immediate goals are to understand the behavior of the central electromagnetic detectors in collision data so that physics analysis can proceed; in planning for physics, members of the Argonne group are particularly involved with electron identification and missing transverse energy.

An early two jet event is shown in Figure 8. Our next report should be much more interesting. (L. Nodulman)

## 2. Nucleon Decay

The installation of the Soudan 2 experiment began in earnest during the latter half of 1986, as the new cavity was transformed from a construction site to an underground physics laboratory. The counting house structure was finished, and the electrical wiring and lighting were completed. Figure 9 is a photograph of the counting house taken from the detector support structure. The VAX 11/750 online computer was installed and turned on, along with a temporary CAMAC data acquisition system, and was linked by DECNET to the computer installations at Argonne and the University of Minnesota. Modification of the special cage for carrying 5-ton modules down the mine shaft was completed; the cage was installed and used to move eleven U.S.

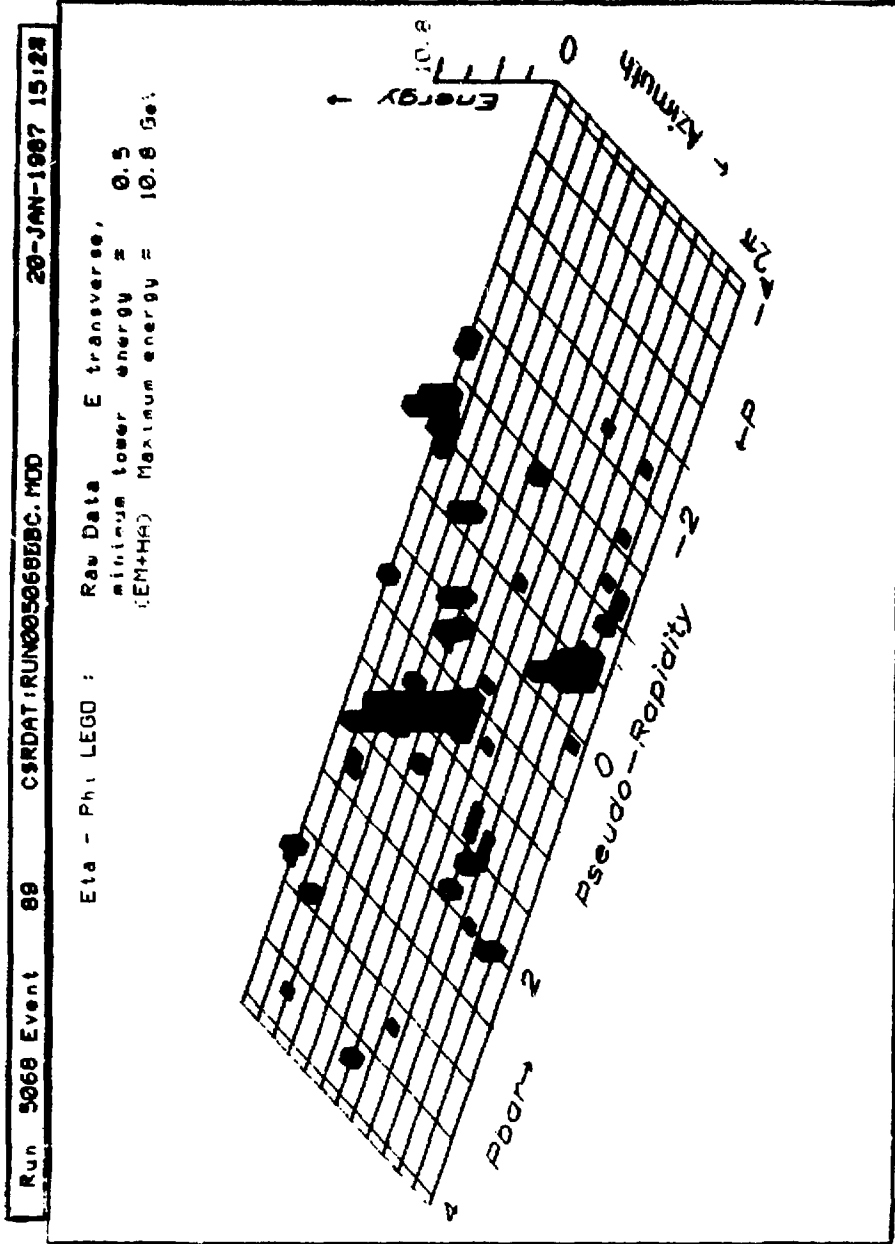


Fig. 8. A three-jet event in the Collider Detector at Fermilab.

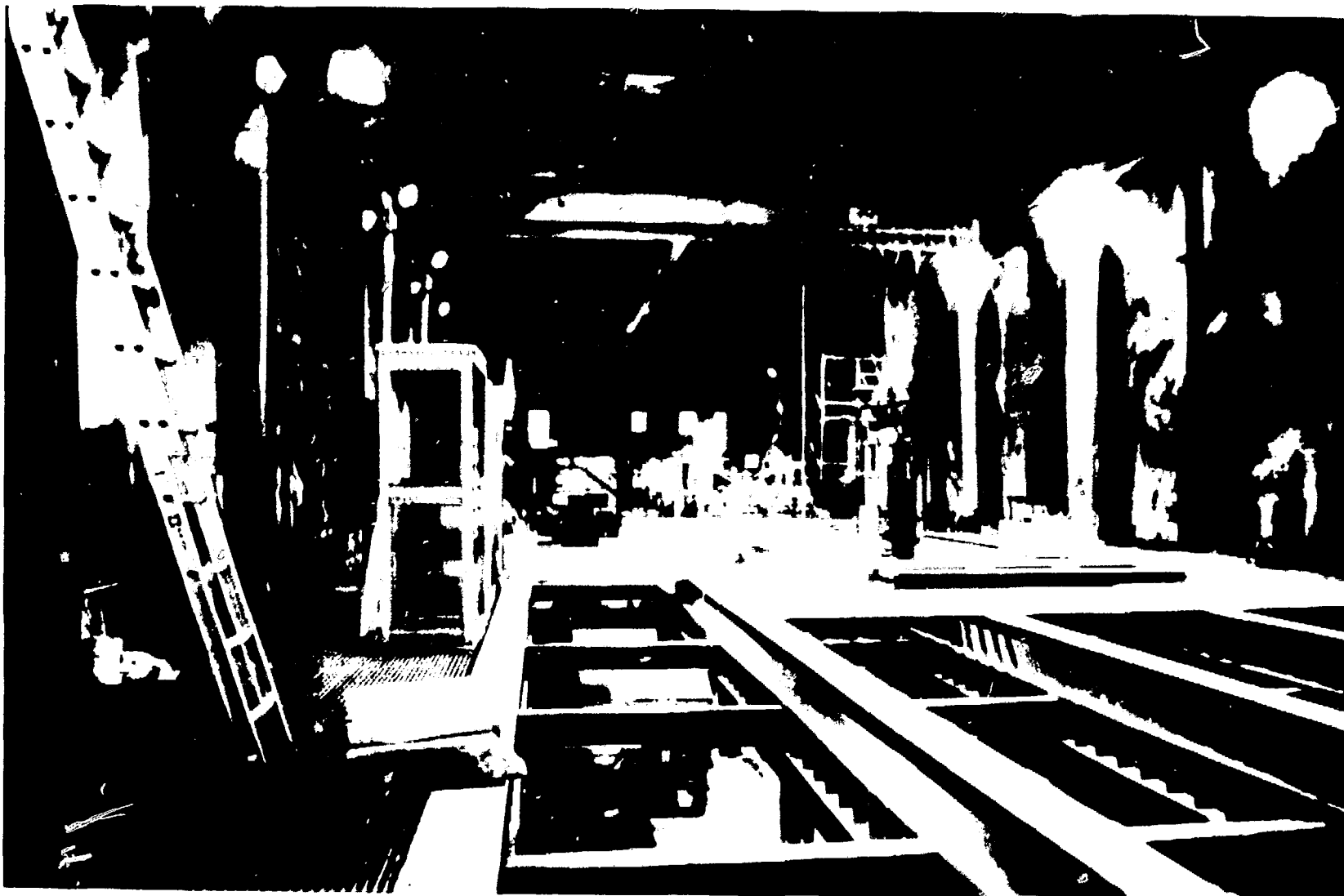


Fig. 9. Photograph of the Soudan 2 counting house. The detector support structure and overhead crane can be seen in the foreground.

modules and one U.K. module underground. This operation required the use of the 12-ton mobile crane to load modules onto the cage on the surface, and the electric forklift to remove modules from the cage underground. Figure 10 shows a truckload of four 5-ton modules arriving at the mine, and Fig. 11 shows the unloading process. The gas recirculation and purification systems for the first 5-ton modules and for the active shield arrived from Oxford and were soon in routine operation. Two 23-ft wide floor-to-ceiling panels of active shield proportional tubes were installed, along with the first 23-ft square ceiling panel, and the installation of gas plumbing and electronics for the shield is now well under way.

Preparations for the operation of the first 5-ton modules underground proceeded on two parallel fronts. The first segment of the Soudan 2 detector to be operated will consist of eight modules assembled into a "halfwall" -- four modules across and two high -- to be built in the southeast corner of the detector area. This halfwall will be installed using the final cabling and electronics, much of which is shared with other halfwalls, and will take several months to set up and turn on. In order to get an early look at new problems which might be encountered with the operation and readout of modules in the underground environment, a temporary test area was set up, allowing Modules U.S. #8 and U.K. #4 to be brought into operation. This has given valuable experience with triggering, noise pickup, and module interconnection problems, and will speed up the turnon of the first halfwall considerably. Figure 12 is a photograph of the detector support structure showing the two modules in the test area.

Preparations to assemble the first halfwall also proceeded well. Because 5-ton modules are shipped with readout planes removed, a "clean room" was constructed under crane coverage to provide a work area where readout planes can be installed and aligned. This structure was completed and used to reassemble five of the eight modules for the first halfwall. These were then used to test mechanical assembly and rigging techniques for the halfwall, they were leak tested, and purged with argon in preparation for final high voltage testing. Additional preparations for the halfwall turnon included construction of two large cable trays running the full length of the east side

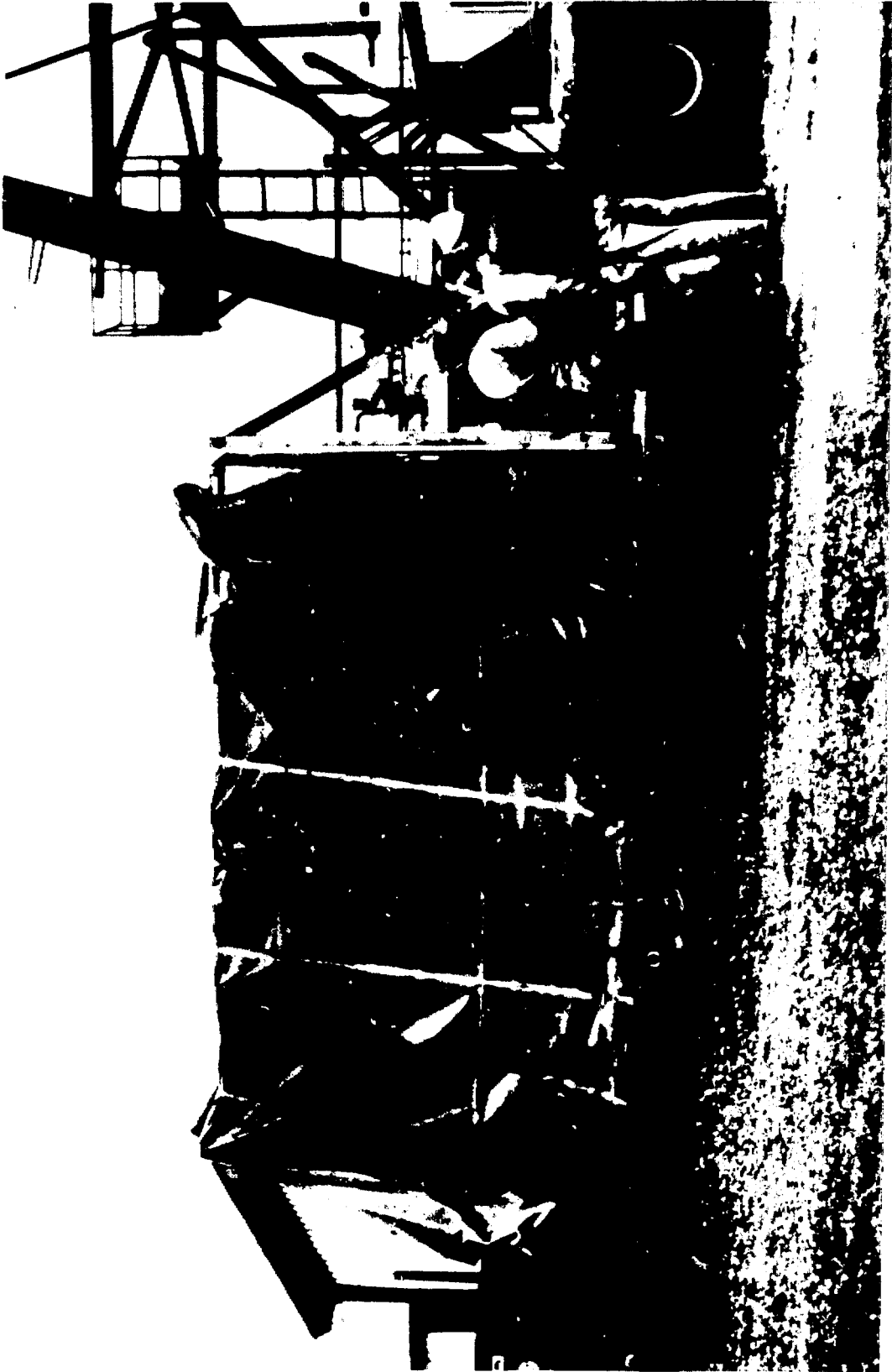


Fig. 10. Arrival of a truckload of four 5-ton calorimeter modules at the Soudan mine. The module stacks are braced internally, and against each other, to prevent shifting of the corrugated steel sheets. The 600-mile road trip from Argonne takes about 16 hours.



Fig. 11. Unloading of 5-ton modules at the Soudan mine. The cab of the 12-ton mobile crane is visible in the foreground. Norm Hill of the HEP Division can be seen on top of the modules.



Fig. 12. Photograph of the Soudan 2 detector support structure showing Modules U.S. #8 and U.K. #4 in the temporary test area. Stacks of active shield proportional tubes can be seen in the foreground.

of the detector, and completion of the electrical power distribution system for the east side of the detector. The steel bases for the first three halfwalls have been delivered and installed.

Work at the Argonne module factory concentrated on establishing efficient production-line methods for the construction of 5-ton calorimeter modules. Considerable progress was made on the development of fixturing for rapid and precise mounting of readout planes. The time required for this operation was reduced by more than a factor of two, and the flatness of the installed planes was also significantly improved. The second major activity was the development of procedures for shipping completed modules to the mine by truck. U.S. Module #1 (which will not be part of the actual detector) was shipped during the summer and dimensional measurements indicated that it withstood the trip well. Modules #8 (without insulating inserts) and #17 (with inserts) were shipped in September, as soon as they could be moved underground. Both modules travelled well, although the Module #17 stack had to be realigned after the trip.

The stacks for Modules #17 through #26, all of the final design, were completed during the summer and fall. All of these stacks passed rigorous high voltage tests. Readout planes have been constructed for 11 of the 16 good module calorimeter stacks which have been built to date at Argonne, and 10 of these modules have been moved to the Soudan mine. Three modules were turned on at Argonne and performance tested with cosmic rays during the latter half of the year. In parallel with the cosmic-ray tests, work continued on the optimization of track reconstruction software and of the front-end electronics.

The fabrication of Soudan 2 electronics continued at a slower pace than planned because of funding shortfalls, but the systems needed for turnon of modules in the mine were pushed ahead rapidly. Production of the 720 channels of front-end electronics for readout of the first module in the mine was completed, and assembly of the trigger electronics and development of associated software culminated in the observation of the first cosmic ray muon tracks in the new Soudan 2 laboratory. The second level trigger logic worked

well to reject triggers from local radioactivity, and to select muon tracks. The rate of radioactivity triggers in the mine was higher than anticipated, due to Compton electrons in the readout plane volume producing simultaneous hits on adjacent wires and strips. A new fast trigger board to reject such events at the primary trigger level was designed and constructed, and will be tried in the mine early next year.

Production fabrication of the calibration electronics was nearly completed, and the first 64-channel preamplifier motherboards of the final design were assembled and tested. Fabrication of the next eight crates of ADC electronics was started, along with assembly of preamplifiers and front end electronics needed for the operation of the first halfwall. Fabrication of prototype components of the drift voltage supply, distribution, and control system was completed, with testing and installation in the mine scheduled for early next year.

The geometry of the face of the calorimeter stack and the adjacent readout plane is one of the most difficult to control and potentially one which has a very important influence on the uniformity of response of the detector. The electrostatics of this region has now been modelled in detail using the field mapping program TOSCA. In particular, the efficiency of transmission of drifting electrons from the drift tube ends to the proportional wires was determined for several variations of the nominal geometry in order to verify the adequacy of the dimensional tolerances currently in use. The placement of the ground equipotential strips on the drift tubes turned out to be the most critical parameter studied, with a transmission loss of 13% per millimeter of displacement. Displacement of the tube ends relative to the stack face caused a transmission loss of 6% per millimeter. The tolerances currently in use for both of these parameters appear to be adequate for the required uniformity of response over the readout face area.

Argonne engineers and physicists continued to work out detailed plans for the installation of modules and electronics in the underground laboratory. Design of the electrical power distribution system was completed, and work on

the layout of relay racks, cable trays, and electronic components continued. In addition, bids were awarded for the fabrication of the major components of the transporters, which allow the halfwalls of the assembled detector to be moved around in order to gain access to the interior. These devices will also be needed to move halfwalls together after they are assembled.

Finally, the Soudan 1 experiment continued to collect data for cosmic ray physics during the summer and fall. A direct link has now been established between the Soudan 1 data acquisition computer (on the 23rd level) and the Soudan 2 VAX (400 ft below on the 27th level), which allows Soudan 1 data to be transferred via DECNET directly to the University of Minnesota VAX in Minneapolis. The detector operated smoothly during September and October, when a Cygnus X-3 radio outburst had been predicted, but the radio event did not occur and preliminary analysis revealed no unusual muon activity in Soudan 1. The analysis of underground muon data from Soudan 1 focussed on the search for signals from the 1E2259+63 and Hercules X-1 pulsars; analysis techniques were optimized to take advantage of the special properties of each system.

(D. Ayres)

### 3. Fermilab Polarized Beam

Most of the activity has been focused on getting ready for the E-581/E-704 test run in March 1987. We have also been preparing long-lead items for the first physics run in late 1987 or early 1988. There were collaboration meetings at Fermilab in October and at Saclay and Serpukhov in November.

Responsibilities of the Argonne contingent include leading the overall organization and many of the projects, as well as working with collaborators on other projects. The online data acquisition system is operational and work has begun on analysis programs. The VAX-780 link to the front end computers is operating with two PDP/11's. Both parallel and serial camac branches are working and being used for testing electronics. The front end computers acquire data, write it on tapes, and send selected events to the host VAX. Camac diagnostics can also be run from the host. The two high voltage

systems, Lecroy 1440 and 4032 are now operated through camac.

The tagging electronics was revised and the momentum part of the tagging was tested under the sampling mode which will be used for beam tuning. The RMH mwpc readout system has been investigated, tested, and documented, largely by Argonne people. Work continued on medium and smaller (50cm x 50cm) wire chambers. One was completed and tested and another is almost ready. The printed circuit design for medium size (100cm x 70cm) chambers was modified so as to be usable for larger (150cm x 50cm) chambers. Other printed circuit boards were ordered for all chambers which will be used in the physics run to follow the test run.

Three of the twelve spin precession snake magnets being assembled and tested at Argonne were completed and delivered to Fermilab. Much of the assembly was completed on the others. Field measurements are made on each magnet for purposes of both correcting and sorting of magnets for proper matching.

Progress during this reporting period on the polarized target development is described in the Facilities R&D section.

Some parts of the experiment that involve Fermilab have progressed well. The primary beamline is completed, except for possible water damage to two magnets. The secondary beamline is almost complete, except for cabling, vacuum, surveying and three quadrupoles. There are Portakamps in the experimental hall for computers, some electronics, and an office. The BM109 analysis magnet is installed on tracks and was field mapped in place by the experimenters using the Fermilab zip track. Installation of electrical power, cable trays and shielding is almost complete.

The Soviet engineer and technicians finished the mechanical installation of the large (1000 block) lead glass calorimeter and left in November. Rice University installed the large (6 ft x 82 ft) Cerenkov tank and also got a track finding program running on Monte-Carlo events. Northwestern University is building tagging hodoscopes and doing simulations of tagging and the total cross section measurement. Trieste, Los Alamos, Texas and others have installed supports for wire chambers in the spectrometer and tested

compatibility with other parts of the experiment and test run. Saclay is continuing preparation of the dilution refrigerator for the polarized target and is also building one of the hodoscopes needed for both the total cross section and polarimeters.

Overall, good progress is being made toward being ready for the two upcoming runs. (D. Underwood)

#### 4. ZEUS Detector at HERA

Argonne has, within the U.S. HERA/ZEUS collaboration, principal responsibility for the mechanical design of the barrel calorimeter and, together with University of Wisconsin, a lead role in the R&D to produce and clad the uranium plates.

Mechanical Design. The detailed design of the mechanical structure is influenced by several components of the barrel calorimeter, e.g., the magnetic shielding design for phototubes, the design of the adiabatic light guides and just how the electronics is multiplexed and packaged locally at the module. In the second half of 1986 the mechanical design was developed along lines general enough to accommodate such requirements with only small changes to the basic structure. Design of the box and beam structure which contains most of the major two hadronic (HAC) sections of the calorimeter, was completed to the stage of the assembly drawings needed for the bidding process. Drawings were submitted to several vendors for bids. The design will allow the use of either circular cross section tie-rods and spacers or rods and spacers of rectangular cross section, and both techniques are being tested.

The front section of the calorimeter, comprised of the first ten plates of HAC1 and all of the electromagnetic (EMC) section, is still being designed. This section is cantilevered from the front steel plate of the box-beam section: it is a hybrid of nonprojective HAC tower geometry and projective EMC geometry, which restricts the freedom in choosing a simple geometry for the rods to compress this stack and provide the frictional forces that will hold it together. Designs explored so far again involve either

circular cross section or rectangular cross section tie rods. However, here they must pass through the scintillator whereas in the box-beam section they can be located at the tower-tower boundary, minimizing any effects on light transmission through the scintillator.

Mechanical Tests and Simulations. The front cantilevered section of the calorimeter has been modelled extensively. The most complete study has used a four foot long section comprising the full 35 plates, but steel rather than uranium. By suitably loading these plates the weight of uranium is simulated and the distortion of the stack can be studied for different orientations of the stack, corresponding to those which might be adopted when in the actual detector or in transportation. Measurements have been made for steel rods, diameter 3/8 in., and circular washers, diameter 3/4 in., both flat and shouldered so as to partially insert into the steel plates. (The spacers in the actual calorimeter will define gaps into which the scintillator can be inserted without it experiencing pressure). A typical deflection curve versus bolt torque, measured for flat spacers with the stack horizontal i.e., plates in the vertical plane, is shown in Fig. 13. We can define a plate slippage point, as shown, and so measure the safety factor for any specified torque. Alternative rod materials will be studied, the object being to reduce the rod diameter as much as possible.

A somewhat smaller stack is being assembled to test the use of rectangular cross section tie-rods, 1 in. x 1/8 in. in section. Such a cross section would be particularly attractive in the box and beam section of the calorimeter. The tests will not only study the stack deflection but will also allow development of techniques to maintain the rods in tension. These tests will be concluded in the early part of 1987.

In selecting the geometry of the tie rod to be used in compressing the stack it is necessary to understand their effect on the calorimeter, either through barriers introduced to the light transmission in the scintillator, or as a result of shower propagation in the rod-material itself. These effects are being studied, through bench tests, test beam studies, and computer simulations, both in the U.S. and Europe. At Argonne, an EGS simulation of the use of circular cross section rods and spacers in the EMC section was

Deflection measured with model in horizontal position  
 Bolt spacing 4 inches between centerlines  
 Bolt 3/8 inch - 16 thread stainless steel  
 Beam length 13.25 inches (33 plates mild steel)  
 One stainless steel spacer between plates  
 Spacer OD. 3/4 in., ID 25/64 in., thk. .236 in. nom.  
 Diameter of hole in plate 25/64 in.  
 Stainless steel can on plate thk. 0.015 in.

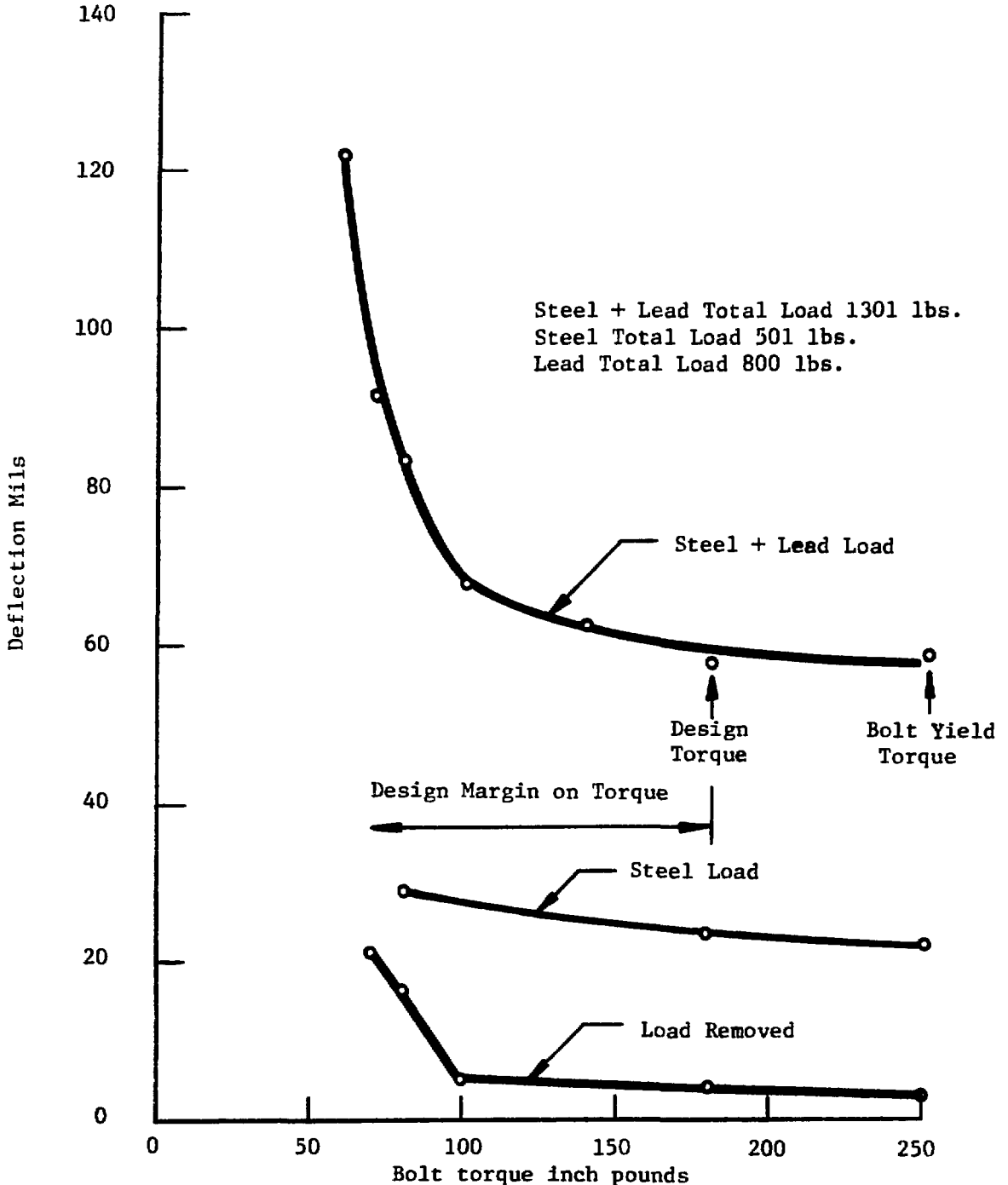


Fig. 13. Torque vs. deflection four foot model test - horizontal position.

begun in December. These results, together with bench tests of the effects on light transmission resulting from circular holes in the scintillator (Ohio State University) and test beam studies of Pb-scintillator stacks with tie rods (in Europe) have pointed to the tentative conclusions:

a) the use of circular cross section rods and spacers passing through the scintillator should be avoided in the front cantilevered section of the calorimeter. This may not be true for the rectangular section rods described above provided the complications of cutting slits in the scintillator can be handled;

b) either circular cross section (as small as possible) or rectangular cross section rods are acceptable for the box and beam part but these should be located at the tower-tower boundaries.

The requirements of the magnetic shielding for the photomultiplier tubes is being studied. The end view of the calorimeter module in Fig. 14 shows, schematically, the tubes relative to the T-beam. It was realized in December that the field to be shielded against was higher, around 600 gauss, than previously expected and that possibly by laminating the base of the T-beam with layers of magnetic steel plate, this could be reduced to around 200 gauss. Magnetic field calculations will be done, starting in January 1987, by the University of Wisconsin using the program TOSCA, which is licensed to run on the ANL-HEP VAX computer. This study may result in the choice of magnetic steel for the T-beam and may modify the beam design somewhat. It will also define the amount of shielding required around the phototubes.

The detailed layout of the T-beam, e.g., just where stiffeners can be placed, is also influenced by just how the adiabatic light guides are folded within the space of the T-beam, schematically shown in Fig. 14. Further claims on this space also developed in this reporting period with the suggestion to multiplex the readout electronics at the module, which would lead to considerable simplification in the cable routing. The electronics cards and associated bus would be located in the T-beam cavity, substantially extending the requirements for cooling in this region. All these different demands are being modelled, at ANL and at Ohio State by full scale wooden



models to lay out the light guides and at Columbia by using a small section of steel T-beam to study cooling problems.

Uranium Plate R&D. Considerable progress was made in this reporting period on the rolling of depleted uranium (1.7% Nb by weight) plates of length 3.2 m, thickness 3.2 mm and widths around 20 cm; this is work done by the University of Wisconsin and Argonne. A test of the rolling process was carried out at Manufacturing Sciences Corporation (MSC) in September using two billets from the Martin Marietta Y12 facility. An important conclusion from these tests was that at least one stage of vacuum annealing was necessary in rolling from the 4-in. thick billets down to plate of 3.2 mm thickness. Several plates 10 ft long and 3.2 mm thick were obtained by making use of salt-bath annealing but the material was susceptible to fracture, as occurred with some plates, and the process is not suitable for production. The tolerances in thickness which were achieved were very encouraging, but no clear conclusion was reached on either the achievable flatness or on the extent of "banana" effect to be expected. The results of these tests were documented and circulated to the CERCA company who are likely to be involved in the bidding process for the plate rolling.

Subsequent to this, MSC decided to acquire a 12-ft vacuum anneal furnace which is expected to be working in March 1987; at this time the collaboration intends to conduct a six billet rolling test to measure the yield and the tolerances in thickness, length, width and flatness achievable for full size plates.

Given that the uranium must be separated from the scintillator by stainless steel absorbers to achieve acceptable dc phototube current, the question arises whether the uranium could be completely enclosed in a stainless steel jacket, similar to cladding reactor fuel elements. During this reporting period, R&D on this cladding was begun at Argonne, at DESY and in Canada. The problem factors into finding a cheap way to form the stainless steel jacket from the sheet (8 mil for the EMC and 15 mil for the HAC), taking into account the dimensional tolerances expected for the uranium plate, and finding an acceptable technique to weld up the jacket. If successful, this cladding would substantially reduce the radiation exposure of personnel during

the calorimeter module assembly as well as satisfying the safety requirements at DESY. Several welding techniques were explored at Argonne using steel plates instead of depleted uranium; these included plasma arc, laser beam and electron beam. This R&D program will continue in 1987 using actual uranium plates of a size which will allow confident extrapolation to the real situation.

A parallel effort was also explored to clad the uranium by using epoxy rather than welding up the jacket; in addition to two part epoxies, stage-B epoxy films were investigated. Again, steel plates rather than uranium were used. One stage-B epoxy film was found to satisfy requirements on bond strength and ease in handling. These studies will continue.

Summer Student Activities. Two students joined in the R&D activities over the period June through August. One of these conducted a series of measurements on the uranium noise current in a uranium-scintillator sampling calorimeter and on the light yield for minimum ionizing particles; the other modified and used an automated mapping system developed by the CDF group to study the uniformity of the response of the wavelength shifter-light guide assemblies described in the ZEUS Technical Proposal to scintillator light injected at different plates in the wavelength shifter.

The calorimeter was a single tower with plate size 23 cm x 5 cm, consisting of 46 layers of 1/8 in. depleted uranium and 5 mm SCSN 38 scintillator. Readout was on two sides with Y7-doped acrylic wave shifter and Amperex 2072B phototubes. The variation of the dc uranium noise current with stainless steel absorber thickness, placed between scintillator and uranium, was in good agreement with depth-dose curve measurements made at DESY using X-ray dosimeter films in uranium-absorber stacks; this is summarized in Table 1. Measurements made with this calorimeter are in good accord with the present choice of 0.2 mm stainless steel absorber for the EMC section and 0.4 mm stainless steel for the HAC sections (where the tower size is larger). Light yield measurements were made for cosmic ray muons traversing the stack using light guides similar in length to those to be used in the actual calorimeter. The measured yields of one photoelectron per 2.5 mm SCSN38 per

readout per minimum ionizing particle were about half those reported from ZEUS calorimeter tests at CERN. These latter used K-27 doped acrylic readout which is claimed to provide better yields than Y7. More detailed tests using K-27 are being done at Ohio State.

Table 1

<u>Absorber Thickness mm of Fe</u>	<u>Normalized Dose DESY Measurement</u>	<u>Normalized Dose Calorimeter Measurement</u>	
		<u>Readout A</u>	<u>Readout B</u>
0.0	1.0	1.0	1.0
0.203	0.4	0.36	0.36
0.394	0.16	0.16	0.14
0.813	0.03	0.07	0.07

Considerable progress has been achieved on the design of the wavelength shifter-light guide interface for the projective EMC towers. The design shown in the ZEUS Technical Proposal of April 1986 incorporated an abrupt change in direction from projective wave bar to nonprojective light guide at the end of the EMC section. The nonuniformities of response, as a function of just where the light was injected in the wave bar, were studied with ray-tracing programs and through measurements at Argonne. Both approaches agreed well in predicting severe nonuniform response, up to a factor of 3 variation, and large light losses. This problem was solved by using an adiabatic design (Columbia) which was actually realized in this reporting period by using a laser cutting technique (Ohio State). Measurements indicated a response which was uniform over the wave bar to better than 10% for all projective towers in the calorimeter.

(B. Musgrave)

## II. THEORETICAL PROGRAM

The theory group continues to study a broad range of problems of current interest. These include the formulation and properties of new string theories, lattice gauge theory problems, proton decay, dynamical symmetry breaking, classical gauge fields, thermal field theories, and phenomenological studies of heavy flavor production, supersymmetry, deep inelastic and Drell-Yan physics.

### String Theories

Cosmas Zachos completed the analysis of the novel classical solutions of the closed string with rigidity, found in collaboration with T. Curtright and G. Ghandour (U. of Florida). These solutions dictate nonlinear Regge trajectories, which motivate applications in Pomeron physics and had initially encouraged speculation on eliminating the tachyon of the bosonic string [Phys. Rev. D34 (1986) 3811].

In the aftermath of the Argonne informal summer institute on strings (June 2-20), however, he performed a stability analysis of the quantum fluctuations about these solutions with E. Braaten (Northwestern U.). It emerged that a unique mode in the space of quantum perturbations--the azimuthally symmetric radial dilatation--is unstable, inducing the solution to "run away" [Phys. Rev. D35 February (1987)]. The above intriguing motions thus do not automatically provide a suitable ground state, unless the theory is further stabilized by the addition of extra interaction terms in the action (in analogy to the Lorentz stabilization of runaway solutions in the context of radiation damping in classical electromagnetism). The form of such a stabilization is under investigation.

Yannick Meurice has been studying the construction of "generalized bosonic strings" [string theories with several bosonic coordinates  $x_{\mu}^A(\sigma, \tau)$ ]. He has worked out the simplest cases (the spectrum) and found the general conditions coming from Jacobi identities. Meurice has also been studying

quantum mechanics and quantum field theories over finite rings (in particular Galois fields). The aim is to construct "string-like" objects with a finite number of degrees of freedom. He has investigated simple examples with one, two or three oscillators and found how commutation relations and Fourier Transforms can be defined.

### Lattice Gauge Theory

Geoffrey Bodwin and Eve Kovacs (University of Illinois, Chicago Circle) have continued their investigations of various proposals for incorporating fermions into lattice field theory. One aim of these proposals is to deal with the problem of the doubling of the fermion spectrum on the lattice. The conventional wisdom, as embodied in various "no-go" theorems, is that the solution of the doubling problem entails at least a partial breaking of chiral symmetry. However, it has been claimed that some of the proposals for fermions on a lattice circumvent the no-go theorems in one way or another.

In their initial studies, Bodwin and Kovacs worked out the chiral and doubling properties for various lattice fermion schemes in the context of a completely solvable model--namely the Schwinger model. They concluded that the Wilson fermion prescription leads to the continuum results, but that the SLAC Lagrangian formulation yields a noncovariant axial vector current and a doubled spectrum, and is, therefore, unsatisfactory as a lattice transcription of the continuum theory.

More recently, Bodwin and Kovacs have turned their attention to the Quinn-Weinstein and Rebbi lattice fermion proposals. Their studies have concentrated on the one-loop properties of the weak-coupling expansion in four dimensions. The Quinn-Weinstein scheme is a gauge-fixed Hamiltonian formulation that preserves chiral symmetry and avoids spectrum doubling. However, Bodwin and Kovacs have found that it does not respect the usual Ward identities associated with vector current conservation. As a consequence, the vacuum polarization gives rise to a quadratically divergent photon mass. In the Rebbi proposal, the doubling problem is avoided by factoring the fermion propagator into a spinor numerator times a scalar denominator--with the

Laplacian in the scalar denominator being given by the nearest-neighbor lattice transcription. In this scheme there is a chiral symmetry in the massless theory, but it is insufficient to protect the scalar part of the fermion propagator from dynamical mass corrections. Bodwin and Kovacs have shown, by explicit calculation, that the scalar part of the fermion propagator does indeed develop a quadratically divergent dynamical (mass)<sup>2</sup>.

The successful application of perturbative Quantum Chromodynamics(QCD) over recent years to many "hard" processes has relied on the ability to absorb "long-distance" nonperturbative effects into universal hadron distribution and fragmentation functions in the case of inclusive processes, and quark distribution amplitudes, or wave functions, in the case of exclusive processes. The universality of these distributions allows different processes to be related to one another order by order in perturbation theory. The development of lattice gauge theories, however, has finally provided the opportunity of calculating these quantities directly within the framework of QCD. This goal is currently being pursued by David Richards.

In a long paper (Southampton University preprint SHEP 85/86-24), to be published in Nuclear Physics, D. Richards, C. Sachrajda and C. Scott studied the 3-quark operators which govern the short-distance and light-cone properties of the proton's wave function. In particular expressions were found for the matrix elements of these operators in various continuum renormalisation schemes in terms of analogous operators measured on the lattice.

### Proton Decay

As an application of the Richards *et al.* formalism, K. Bowler, D. Daniel and T. Kiew (Edinburgh), C. Scott (Southampton) and D. Richards (Argonne) have made measurements of the short distance matrix elements relevant to the calculation of the proton decay rate in Grand Unified Theories. The results are encouragingly close to those obtained using bag model and sum rule techniques, but are unable to rescue the minimal SU(5) Grand Unified Model from its conflict with the experimental lower bound on the proton's lifetime.

### Dynamical Symmetry Breaking

John Oliensis has been studying dynamical symmetry breaking at strong coupling, and especially the possibility of symmetry restoration. This is the idea that a symmetry breaking condensate might be eliminated upon being coupled strongly to a gauge field. With Peter Suranyi, he has examined this idea on the lattice and obtained analytical results. They studied the non-compact abelian Higgs model and analytically established the phenomenon of symmetry restoration and the full phase structure of the model. Presently, Oliensis is exploring this idea in a Schwinger-Dyson approach. He has also made progress on model-building based on the assumption that symmetry restoration does occur.

### Classical Gauge Fields

Dennis Sivers has been studying the interaction of classical gauge fields with fermions. Some aspects are covered in two recent papers. In an article entitled "Weyl-Dirac Equation for an SU(2) Gauge Theory with Spherical Symmetry" [Phys. Rev. D35, 707 (1987)] the coupling of chiral fermions in a fundamental representation of SU(2) to a general set of spherically symmetric gauge fields is calculated. The reduction of the Weyl-Dirac equations using the explicit spherical symmetry shows that the system of fermions and gauge fields in 3 + 1 dimensions leads to an effective theory involving an Abelian gauge field, a charged scalar and fermions in a curved 1 + 1 dimensional space. The paper "Extended Solutions of an SU(2) Gauge Theory with Fermions" (ANL-HEP-PR-87-02) explores some interesting simple solutions which represent extended systems. The SU(2) gauge theory with spherical symmetry is shown to admit a vacuum solution with nonvanishing chiral order parameter. The behavior of massive fermions in the field of a Wu-Yang monopole is shown to provide interesting constraints.

Further studies are envisioned which utilize the techniques developed in these papers and earlier work on gauge theories. Sivers is now looking at classical solutions representing fermions in the background of a meron pair

and is exploring various techniques in 1 + 1 dimensional field theories with the intent of extending them to spherically symmetric 3 + 1 dimensional systems.

### Heavy Flavor Production

Ed Berger has been engaged in a detailed study of bottom quark production spanning the energy range from that of fixed target experiments to the Super Collider. In a contribution to the Snowmass 1986 SSC Workshop (ANL-HEP-CP-86-134), Berger, J. Collins, and D. Soper present predictions for the rapidity and transverse momentum distributions for inclusive production of bottom quarks at SSC energies,  $pp \rightarrow bX$ . Their computations are based on the simplest, lowest-order QCD mechanisms. To estimate uncertainties, they use three different choices for the gluon structure function,  $G(x,Q)$ , different choices for the evolution scale  $Q$ , as well as different choices of the bottom quark mass. The poorly constrained functional form of the gluon distribution at small  $x$  is the principal source of uncertainty, leading to a factor of  $\sim 10$  variation in predictions for  $d\sigma/dy$  at  $y = 0$ . In an independent investigation, Berger has produced curves showing bottom quark cross sections,  $\sigma(b\bar{b})$ , versus beam momentum in the fixed target ranges, 300 to 1000 GeV/c, for  $\pi^-$ , proton, and antiproton beams, as well as differential cross sections  $d\sigma/dx_F$  and  $d\sigma/dp_T^2$  for  $hN \rightarrow bX$ . His work includes a specification of the range of theoretical uncertainty associated with different choices of  $b$  quark mass, structure functions,  $Q^2$  evolution scale, and so forth. Results were presented in a seminar at Fermilab on December 4 and have been incorporated into proposals for new fixed-target experiments at FNAL. In marked contrast to the situation for charm production, Berger concludes that lowest-order QCD theory and (admittedly very limited!) fixed target and collider data on bottom quark production are in agreement at better than the factor of two level.

### Deep Inelastic Physics

The European Muon Collaboration (EMC) effect is the observation that deep-inelastic inclusive structure functions of nuclei,  $F_2^A(x,Q^2)$ , differ from those of free nucleons,  $F_2^N(x,Q^2)$ . In terms of the quark model interpretation

of structure functions, the data imply directly that the quark and antiquark densities in nuclei differ significantly from those of nucleons. In invited reviews prepared for the XXIII International Conference on High Energy Physics at Berkeley in July 1986, and for publication in *Annales de Physique*, Paris, Ed Berger summarized the data and surveyed the full range of theoretical interpretations of this effect. Alternative explanations include those based on the hypothesis that the short distance properties of bound nucleons are altered, as well as interpretations based on conventional long distance nuclear binding. Berger showed that the pion exchange model he developed at Argonne in collaboration with F. Coester of the Physics Division provides a quantitative description of the data for all  $x$  and  $Q^2$ . His reviews conclude with a list of desirable future experiments.

In subsequent work, Berger has been studying nuclear effects in semi-inclusive (or "coincidence") processes,  $eA \rightarrow e'hX$ ;  $h$  is an observed final state hadron, interpreted as a fragment of the struck quark in the deep inelastic reaction. Semi-inclusive data provide information on the nuclear medium dependence of the fragmentation process as well as further constraints on models of the EMC effect. One contribution to  $eA \rightarrow e'hX$  is the coherent subprocess  $e\pi \rightarrow e'\pi$  in which the initial pion is bound in the nucleus. Berger and Coester have computed detailed cross sections for this subprocess. Its identification would permit a direct measurement of the pion momentum distribution in nuclei.

Dennis Sivers' recent work on nuclear physics involves a study entitled "Quark Mobility in a Nuclear Medium". Using a flux-tube model to approximate long-distance chromodynamics, he studies the propagator of a high-energy quark within an extended nuclear medium. The study suggests that experimental measurements of quark fragmentation functions in deep inelastic experiments involving nuclei can determine important aspects of the problem of chromodynamic force saturation.

### Massive Lepton Pair Production--Drell-Yan Process

In his second invited review at the XXIII International Conference on High Energy Physics, Ed Berger surveyed the understanding of both pion structure functions and nuclear dependence of structure functions derived from studies of the Drell-Yan process  $hA \rightarrow (\mu\bar{\mu})X$ . Berger summarized data and current theoretical understanding of high twist contributions in the pion structure function and quark fragmentation functions. He showed that studies with nuclear targets offer the possibility for gaining unique insight into the nuclear A dependence of the quark and antiquark densities,  $q^A(x, Q^2)$  and  $\bar{q}^A(x, Q^2)$  of nuclei. Measurements are crucial for testing whether the A dependence of deep-inelastic structure functions, known as the EMC effect, is a universal, process independent property of parton densities. Precise experiments with pion and nucleon beams on nuclear targets would extend knowledge of the A dependence of quark and antiquark densities of nuclei into important intervals of the fractional longitudinal momentum variable x which are not accessible easily in deep inelastic scattering. For tests of quantum chromodynamics, isolating nuclear dependence is necessary before definite conclusions can be drawn on the behavior of the pion structure function and on the magnitude and kinematic variation of predicted higher order terms (K factor). Berger indicated the sensitive regions of phase space and the increased level of experimental precision which is needed if a contribution is to be made to determining the A dependence of quark and antiquark densities from the Drell-Yan process. Berger's theoretical work on this subject motivated experiment E-772 being mounted at Fermilab by a Los Alamos-Fermilab-Stony Brook collaboration.

### Collider Physics

Searches for supersymmetric particles at UA1 (CERN) have resulted in mass limits being placed on squarks ( $m_{\tilde{q}} > 70$  GeV) and gluinos ( $m_{\tilde{g}} > 60$  GeV). These limits depend on three assumptions: 1) that the photino ( $\tilde{\gamma}$ ) is the lightest supersymmetric particle and escapes experimental detection, 2) that  $m_{\tilde{\gamma}} = 0$ , and 3) that the five contributing flavors of right and left squarks are mass degenerate. Howie Baer and collaborators have examined the effect of relaxing

these conditions on the quoted mass limits. The limits are found to be quite stable.

If assumptions 1 and 2 are indeed valid, then there should exist superpartners of the W-boson (the  $\tilde{W}$  gaugino) and the Z-boson (the  $\tilde{Z}$  gaugino) with masses  $m_{\tilde{W}} < m_W$  and  $m_{\tilde{Z}} < m_Z$ , so that the decays  $W \rightarrow W\tilde{\gamma}$ ,  $WZ$  and  $Z \rightarrow W\tilde{W}$  may be allowed. Baer et al. have calculated in detail the different leptonic and hadronic signals from these decays at  $p\bar{p}$  colliders, and found a lack of clear multi-lepton signals at the CERN collider imply  $m_{\tilde{W}} + m_{\tilde{Z}} > m_W$ , and also they found the UA1 limit on a heavy lepton ( $m_L > 41$  GeV) can be transformed to a limit on gauginos of  $m_{\tilde{W}} \geq 44$  GeV, corresponding to  $m_{\tilde{Z}} \geq 49$  GeV, for  $m_{\tilde{q}} < 10-15$  GeV. If  $m_{\tilde{q}}$  or  $m_{\tilde{g}} > 150-200$  GeV, then they must be searched for at the proposed SSC. They calculated the different decay modes of ultra-heavy  $\tilde{g}$  and  $\tilde{q}$ , which turn out to be cascade decays through the different gauginos, which results in hard multi-leptons and final state gauge bosons, but less missing transverse energy than previously anticipated.

Finally, in  $E_6$  grand unified models inspired by the superstring, there exists an extra  $Z'$  boson, which should be easily discoverable at the SSC. If this is the case, then the Higgs boson mass will likely be less than about 150 GeV. Baer et al. examine the decays  $Z' \rightarrow ZH$  at the SSC against the background of  $pp \rightarrow Zt\bar{t}$ , and find favorable prospects for detecting an intermediate mass Higgs.

Using the latest sets of parton structure functions, Ed Berger has computed differential luminosities and expected event rates at Fermilab Tevatron collider energies for hard scattering processes including hadronic jet production, production of W's and Z's in association with jets, heavy flavor production, and production of supersymmetric particles. Together with observations made at  $\sqrt{s} = 630$  GeV at the CERN collider, Berger's calculations permit good estimates of the extended discovery reach for new phenomena afforded by the Fermilab Tevatron as well as of the increases in event yields for established processes. Of particular importance are both the expected hardening of the missing transverse momentum ( $\cancel{p}_T$ ) spectrum, associated with the larger mass supersymmetric (SUSY) states accessible at the Tevatron

collider, and the much larger cross sections for a given SUSY mass scenario, permitting harder  $p_T$  selections in an effort to reduce standard model backgrounds. Some of these results, as well as other material, were presented in lectures at Brown University in July, 1986, at the D-Zero collaboration meeting.

In a paper for publication in the proceedings of the Madison SSC workshop (ANL-HEP-CP-86-83) Ed Berger (ANL), J. Collins (IIT), D. Soper (Oregon) and G. Sterman (Stony Brook), discuss high energy hadron collisions that contain a hard scattering, such as W, Z, heavy quark, or high  $p_T$  jet production, yet are diffractive, in the sense that one of the incident hadrons is scattered with only a small energy loss. In their approach, the cross section for such diffractive hard scattering is a part of the normal hard scattering inclusive cross section, as calculated using perturbative quantum chromodynamics. Treating the Pomeron as an factorizable exchanged hadron, they provide theoretical constraints on the distribution of gluons in the Pomeron at small and large  $x$ . They estimate that a substantial fraction (perhaps 30%) of all hard scattering events are diffractive. In contrast to naive expectations, the distribution in rapidity,  $y$ , of heavy objects produced diffractively is shown to be concentrated at small values of  $y$ , meaning that these objects will be observed in the central detectors of typical collider experiments. Berger et al. emphasize that data on diffractive hard scattering would probe the short distance character of diffractive amplitudes and provide measurements of the quark and gluon structure functions of the Pomeron.

Ken Kowalski has been considering possible tests of the Donnachie-Landshoff pomeron-photon analogy model with respect to partonic interactions by applying the proposal to various pomeron-pomeron and pomeron-photon scattering situations as well as to diffractive direct-photon and direct-gluon production. Work on this project is still in progress.

Alan White has been studying the consequences of dynamical electroweak symmetry breaking by color sextet quarks for some time--a large part of the motivation being to obtain a theoretically and phenomenologically realistic description of diffraction. The possible observation of vector-boson pair

production at the CERN SppS, with a cross-section considerably higher than that given by the standard model, is very suggestive that the longitudinal  $W^\pm$  and  $Z^0$  bosons are indeed composed of higher color quarks. Direct QCD production is perhaps the least radical and most plausible explanation of enhanced vector boson pair production so close to threshold.

In a recent paper (ANL-HEP-PR-87-06), White has used a mixture of current algebra analysis of final-state interactions and the scaling properties of diffraction to relate  $W^+W^-$  pair production to  $\pi^+\pi^-$  pair production. He argues that

$$\sigma_{W^+W^-}^D \sim \left( \frac{f_{\pi 3}}{f_{\pi 6}} \right)^2 \sigma_{\pi^+\pi^-}^D,$$

where  $f_{\pi 3}$  and  $f_{\pi 6}$  are the pion chiral constants for triplet and sextet quarks respectively. The result is that the cross-section implied by the CERN events is of the expected order of magnitude. Other kinematic properties of the CERN events are compared with those scaled up from pion pair production. White argues that all properties are consistent with the hypothesis that vector-boson pairs are produced as hadrons but with all masses and momenta scaled up appropriately.

### Field Theories at Finite Temperature

Ken Kowalski has been studying several unusual features of the effective potential of the  $CP^{N-1}$  model in the leading order of the  $1/N$  expansion both at zero and high temperatures. A preliminary manuscript has been written in collaboration with Ashok Das (U. of Rochester).

Kowalski has also found a simple proof of the thermal Goldstone theorem in a way which is independent of any of the customary technical devices that are usually used to incorporate the Kubo-Martin-Schwinger conditions into relativistic thermal field theories. In addition, and under the same conditions, a thermal version of the Schwinger action principle is found for the first time; its uses in deducing the constraints imposed by various symmetries are pointed out. This work has been submitted for publication to the Physical Review (ANL-HEP-PR-86-127).

The development of the path integral formulation of the generating functional and its use for the extraction of Feynman rules have been considered by Kowalski for real-time thermal field theories containing fermions. Ambiguities in the analysis and the results of previous investigations have been identified and resolved. This work has been submitted for publication to the *Physical Review* (ANL-HEP-PR-86-140). Kowalski has also, by means of a careful analysis of several products of distributions arising from the gauge-fixing term, formulated the correct Feynman rules for real-time field theories containing an arbitrary set of non-Abelian gauge fields in covariant gauges. A manuscript is in preparation.

#### General Properties of Field Theory

Yannick Meurice has developed a method for studying interactions in BRST point-field theory as a continuation of his previous work on free field theories. The vertex operator for Yang-Mills theories can be derived with his formalism and an extended systematic investigation is under progress.

Meurice is also preparing a Physics Report with D. Amati, K. Konishi, G. C. Rossi and G. Veneziano which is devoted to nonperturbative phenomena in supersymmetric gauge theories with an emphasis on instanton calculations.

Calculations that Ken Kowalski has done of amplitudes that are supposed to vanish identically as a general consequence of supersymmetry and gauge invariance have revealed ambiguities in the conventionally stated Feynman rules involving Majorana fermions. New unambiguous rules which resemble those for Dirac fermions have been formulated along with a simple vertex-propagator recipe that (formally) eliminates the need for the usual two fermion-number nonconserving propagators. A manuscript is presently in preparation in collaboration with Evalyn I. Gates, CWRU.

Spin Physics

Hadronic phenomenology involving spin-related observables involves several interesting issues. An important topic which Dennis Sivers is now considering involves the impact of the  $J_z = 1/2$  sum rule for polarized protons on the calculability in perturbative QCD of single spin asymmetries. Since there may be important new data involving high energy polarized protons within the next few years. This whole topic has once again become timely.

### III. EXPERIMENTAL FACILITIES RESEARCH

#### A. Mechanical Support

##### Nucleon Decay

During this period work has continued on the installation of electrical distribution both for the required quiet power and normal power. Cable trays for the routing of the necessary signal cables were designed and installed at the mine. Design parameters for the final configuration for mounting of the electronics on the half walls and the routing of the cables into the cable trays were defined. The necessary module changes to fit those parameters have been completed and are being incorporated.

Fixtures for lifting and handling of the modules in the mine were designed and built. The techniques for using these fixtures and in general for loading and removing modules from the shaft cage were tried and proved generally adequate although improvements have been suggested and are being discussed. The methods for blocking and supporting modules during shipment were perfected and tested in the shipment of modules to the mine.

Bids for the fabrication of the module half wall transporters were solicited and the contract has been awarded for fabrication. The hydraulic systems and motor control components are being procured and will be installed and tested at Argonne in early spring.

Methods of measuring modules and the necessary fixtures for accomplishing this task were developed and improved. This will reduce the time required and increase the precision with which modules can be fitted with wireplanes. Wireplane improvements were incorporated into construction to allow for a final precision adjustment. This precision should now be within the required tolerances.

#### Fermilab Polarized Beam E704

The installation of the helium dilution refrigerator platform and the target solenoid magnet platform has been completed and they have been tested. Both perform according to design criteria. Installation of equipment on the platforms will begin in the near future. Design of the vacuum pump lines and fittings was completed and the drawings turned over to Argonne central shops for fabrication.

Progress has been made in the assembly and measurement of the snake magnets. Three magnets have been shipped to Fermilab for installation in the MP beam line.

Work has continued on the assembly of the wire drift chambers for installation in early spring. Some minor modifications were made to the hodoscope and drift chamber support that will be installed at the end of the beam line.

#### HERA ZEUS Prototype Model

A development model of the front EMC section of the barrel calorimeter was constructed and measurements are proceeding to determine deflection characteristics.

Conceptual design has continued throughout this period and plate sizes, construction techniques and other design concepts have been investigated. Two billets of depleted uranium (1.7% Nb content) were rolled to ZEUS plate thickness (3.2 mm) and length (3.2 meters) to demonstrate that the alloy material could be rolled to the desired thickness and length. The intent of the rolling activity was achieved and also identified manufacturing features to improve the rolling process.

(N. Hill)

### B. Electronic Support

Support of the Nucleon Decay Experiment continued to be a major effort during this period. Production neared completion on eight more data crates; each consisting of a CPU card, a Compactor card set, 16 Analog cards, a Trigger Communication Card, a Calibrate card, and a CAMAC interface module. Six of each of four types of motherboards were built for modules destined for the Soudan mine. The motherboards mount the thick film hybrid preamps, and distribute anode HV to the proportional wires in the modules. Also during this period, the last of the thick film hybrid preamps was delivered. These hybrids had all been tested prior to shipment on a test fixture managed by an IBM PC, previously built at Argonne. Fifty 16-channel Receive Amplifier cards were built and production was initiated on another two hundred and thirty. A prototype of the system for control and monitoring through CAMAC of the drift and wire HV was built and tested. The prototype works well and production is being initiated of the hardware for the drift and wire HV for the mine. The trigger processor was run with a module in the module factory, implementing a second level trigger. One algorithm which was run for a period of time required the signature of a stopping muon. Also during this period, the trigger processor was implemented in the mine and a number of triggers were accumulated looking at muon tracks. These data have given good assurance of the proper functioning of the trigger electronics.

The 8-layer cards for the Enhanced 8086 CAMAC Crate Controllers for the FNAL polarized beam were produced. These modules are implemented in surface mount high performance CMOS devices. The prototype was loaned to the Physics Division and currently is being used in an experiment measuring the weak vector coupling constant.

(J. Dawson)

### C. Computer Support

Several significant upgrades were made to the VAX systems. SILINK, an ethernet based cluster facility was installed. This system allows all three VAX processors to share the disk subsystem and also allows batch and print queues to be distributed among all the processors. Three VAX 11/750 processors borrowed from SLAC were installed. These systems will be made part

of the cluster next quarter. A 12-page per minute laser printer was installed. Typesetting software to drive the printer was also installed. Both a Unified Graphics driver and a DI-3000 driver were adapted to use the vector graphics mode of the laser printer.

Production runs on the ST-100 array processor were primarily devoted to lattice gauge theory which logged approximately 3300 hours, 90 percent of the available CPU time. Development has continued on TMAPOL, the high level language designed to optimize parallelism on the ST-100 with specific applicability in such areas as lattice gauge theory and molecular modelling. Also, development of macro-code for molecular dynamics applications continued on the ST-100.

The second level trigger program for the Soudan 2 nucleon decay experiment was brought into operation. This system consists of a compiler and translator which produces a machine independent representation of a set of trigger conditions from a simple language. The original purpose of this project was to test the trigger hardware at the module factory at Argonne but the system was so successful that it was used at the Soudan mine on the first module to be made operational there. (J. Schlereth)

#### D. Polarized Target Development

During this period, the moving platform system of the Fermilab polarized target took shape, with completion of the rails, decks, motor drives, and counterweight assembly. Final designs were made for the target holder molds, and for the cryogenic valve insert for the polarizing solenoid service dewar. Procurement continued for parts of the  $^3\text{He}$  gas handling system and pump line, and the  $^3\text{He}$  pumps were shipped to the Polarized Beam hall. Fabrication of the solenoid support stand was started. Work continued on the motor drive interface and NMR.

In the area of target materials research, the search for a suitable fluorine-rich substance for spin-polarized  $^{19}\text{F}$  targets was successfully completed. Earlier in the year, two substances, both fluorinated alcohols, had been

selected on the basis of non-polarizing screening tests for desirable chemical and physical properties. In July and August, polarizing tests yielded substantial nuclear polarization in both materials. The best results were obtained with a eutectic mixture of water (7 wt.%) with 1,1,1,3,3,3-hexafluoro-2-propanol ( $C_3H_2F_6O$ ). The mixture contains 63 wt.% fluorine, and polarizations of 80% were achieved. There is a significant "background" of polarized protons in the material, since the hydrogen nuclei are also polarized. However, the nuclear scattering experiments contemplated for such a material can kinematically exclude this background. A paper covering these results is in preparation. (D. Hill)

#### IV. ACCELERATOR RESEARCH AND DEVELOPMENT

##### A. Wake Field Facility

During this period, the wake field test facility was installed in the linac building and initial tuneup begun. The spectrometer was not yet assembled, but will soon be ready for installation. Details of various activities of the project are given below.

The average level of group activity remained about constant. Jim MacLachlan, on leave from FNAL, returned to FNAL in the latter part of December. His work on design of the spectrometer and on fine tuning the facility design were very helpful. Two post doctoral new hires joined the group in October.

Several members of the group participated in the Symposium on Advanced Accelerator Concepts held at the University of Wisconsin, Madison. The status of, and plans for using, the test facility were presented in several papers. There was considerable interest in our work in both general and working sessions.

Several modifications to the design of the beam transport lines in the facility were made in November following a final, careful second-order optics study. An error in design of the 280 degree bend magnet (wrong edge angle) was corrected by retuning and minor rotations of two small benders. Otherwise, these studies confirmed previous predictions of performance.

All magnets were completed, installed, and aligned on the main base of the facility. Magnetic field measurements were carried out for several bending magnets to confirm basic design parameters and, more importantly, to determine the effectiveness of the special end guards with which all these magnets are equipped. The measurements conclude that the magnets perform as designed.

The complex vacuum chamber was fabricated, leak checked, and field welded during installation. Mechanical distortions due to weld stresses were well within tolerance. Pressures of less than  $10^{-7}$  Torr are easily obtained within a short pumping time, much better than is required for facility operation.

Chopper-type power supplies were completed and installed in the facility control room. A few reliability problems were experienced in the early operation of these supplies, but they do not seem to be fundamental in the design and are being remedied.

The IBM PC control computer was moved to the control room and connected to facility equipment. Software developed for control and data acquisition works well.

Beam diagnostics incorporate phosphorescent screens which intercept the beam and are viewed by CCTV cameras. Frames are digitized and processed under control of the PC. These screens are manipulated by small air cylinders through bellows actuators. All but four of the total number of thirteen have been installed and are operating.

After working well on the bench for several months, the stepping motor driver module (used to position the 180 degree bend magnet in the trombone) failed. The cause for the failure is still uncertain, but an induced transient on the cables between the module and the motor is suspected. Shielded conductors are being installed to prevent further problems.

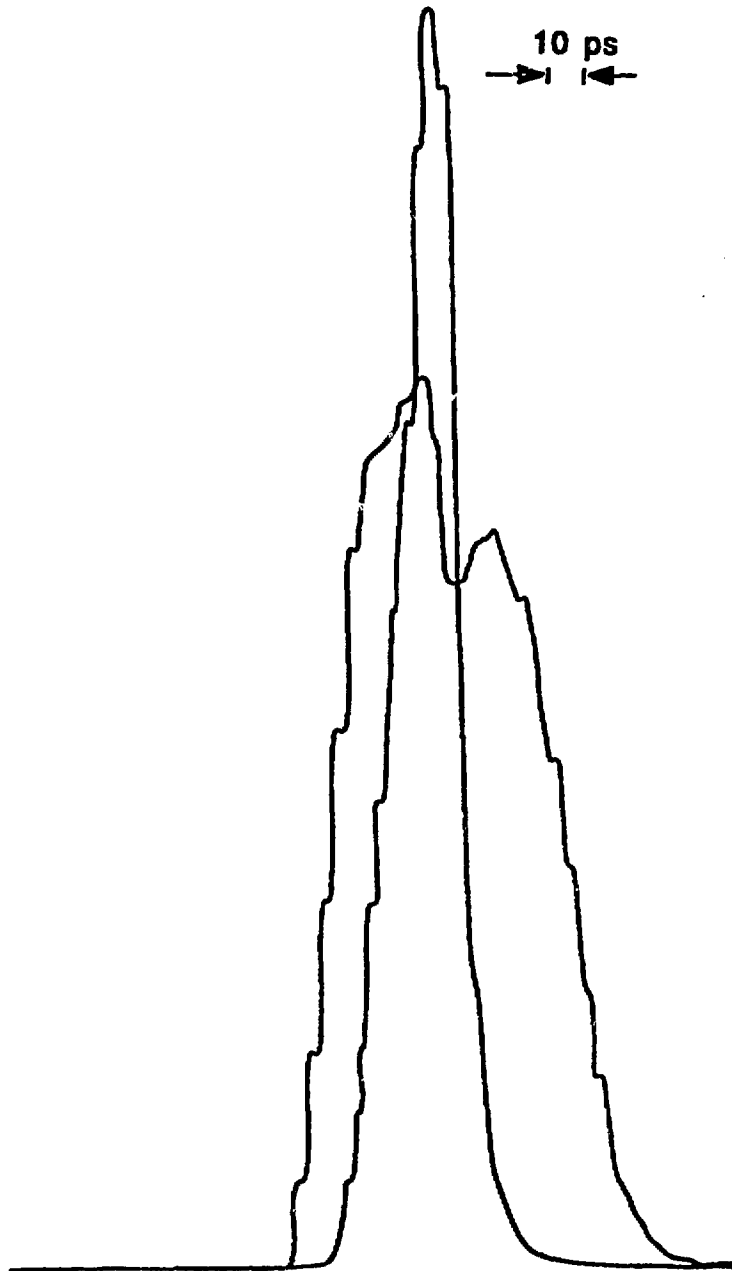
Spectrometer magnet components are complete, including the coils. Final assembly must be done at the facility due to the size and weight of the magnet. Design of focal plane hardware is not final. Several schemes are being considered for the design of the light shields and phosphor screen.

All services (water, power, and air) have been installed in both the control room and facility areas. Cable trays have been installed and all cables pulled between the control room and the facility.

At this time, all beam transport equipment from the linac through the facility is in place and is being commissioned.

The components for wake field experiments are pretty well complete. Washers for the cavity wake experiment device and the outer containment tube have been completed. A flange and minor welding is needed to complete the assembly.

### Compressed and Expanded Pulse from Argonne L-Band Linac



12/5/86

Fig. 15. Streak camera measurements of compressed and expanded beam pulses after double 90 degree bend section. Neither the streak camera system nor the beam transport were optimized when this data was obtained.

At the University of Wisconsin, the plasma cell is complete and operating. Probes indicate a plasma density of about  $5 \times 10^{13}$  in the discharge. This is the design value. The cell will be moved to Argonne in early spring in preparation for its installation into the test facility.

First tests of the important bunch shortening system were conducted in mid-December. Beam was transported through the double 90-degree section to the chemistry experiment area where a streak camera was set up. The streak camera was nominally rated as having 10 picoseconds resolution (our new 2 picosecond camera is just now being ordered). All systems appear to work well, and the results of this first test are shown in Figure 15. This was a proof of principle test, and ultimate performance is expected to be much better than shown here.

These tests provided an opportunity to check many transport calculations. We are very pleased to find that the transports operate very close to calculated parameters.

A milestone was achieved when beam was transported through the total wake facility high energy line to the wake experimental section. The next step is to conduct careful tuning to establish all the simultaneous beam properties required for wake field experiments.

## B. Advanced Photon Source

Accelerator design work for this project is being carried out by members of the light source design team who are presently staff members of the HEP Division. This work is funded by DOE/BES.

During the period the 6-GeV synchrotron X-ray source project was named the Advanced Photon Source (APS), the ring design energy was raised to 7-GeV, and the search for a permanent project director began.

The APS project team's main efforts have been toward establishing the optimum energy and related parameters of the machine, as well as implementing various recommendations of the DOE/ER Review Committee led by Ed Temple, which carried out a review of the initial Conceptual Design Report (CDR) in March,

1986. While there has been steady progress toward refining all facets of the conceptual design, certain areas received particular attention over this reporting period. As 7 GeV was chosen as the standard beam energy, main ring magnet lattice studies were intensified, and the necessary changes to the size and configuration of the machine were defined and potential cost differentials estimated. A major R&D effort has been launched to demonstrate the feasibility of the innovative design proposed for the vacuum system. These and many additional efforts are aimed at refining the 1986 conceptual design for the next DOE/ER review scheduled for late spring of 1987.

The first annual APS users meeting was held at Argonne November 13-14, 1986, and was attended by nearly 300 people from 38 universities, 10 laboratories, and 20 companies. The meeting was an excellent forum for the user community to provide comments on the latest design concepts for the APS. Special emphasis was placed on discussions of the machine's capability to meet the user's demands for high brilliance, tunable undulator radiation. In addition, policies for funding and use of the beam lines by "participating research teams" were discussed. With the election of representatives of the user community, the APS Steering Committee became the official conduit for communication between the potential user community and the staff of the project.

Major tasks to be addressed in early 1987 include detailed computational studies of properties of the machine lattice, determination of the final location based upon the new machine dimensions, as well as topological and geotechnical considerations, and completing the environmental assessments necessary to clear the path for construction of the project. (J. Day)

## V. PHYSICS IN COLLISION MEETING

The 1986 meeting was the sixth in the annual series of conferences that review the status of the field with particular reference to experiments done with colliding beam facilities. The three day meeting was held at the American-Congress hotel in Chicago and was organized by E. Berger, J. Day, M. Derrick and L. Nodulman of the High Energy Physics Division. About 100 physicists attended the meeting as official participants and a number of students and younger physicists from universities and laboratories in the area also attended some of the sessions. The program of the meeting is given below.

### Physics in Collision VI American Congress Hotel, Chicago, IL September 2-4, 1986

#### Session I: High Energy and Multiparticle Phenomena Chairman: T. Fields (ANL)

Experimental Review of $\sigma_T$ , $\sigma_{el}$ , Diff	M. Haguenaer (Ecole Poly.)
Multiparticle Experiments	G. Ekspong (Stockholm)
Multiparticle Phenomenology	A. Giovannini (Turin)

#### Session II: The Standard Model and Beyond Chairman: J. Bjorken (Fermilab)

Review of W and Z Properties	M.-N. Minard (CERN)
Standard Model Tests Using $e^+e^-$	A. Bodek (Rochester)
Collisions and Neutrino Beams	
Quantitative Hadron Jet Physics	D. Froidevaux (CERN)
Experimental Limits on new Physics	A. Norton (CERN)
Physics with TeV I	J. Peoples (Fermilab)

Session III: Heavy Flavors I

Chairman: G. Weber (DESY)

Heavy Quark Bound States	K. Koenigsmann (DESY)
Heavy Quark Spectroscopy	W. Schmidt-Parzefall (DESY)
Heavy Flavor Production in Hadronic Collisions	S. Reucroft (Northeastern)
Heavy Quark Decays	B. Eisenstein (Illinois)

Session IV: Heavy Flavors II

Chairman: B. Aubert (LAPP)

Experimental Determination of the KM Matrix Elements	S. Stone (Cornell)
KM Matrix Theory	A. Sanda (Rockefeller)
Charm Physics in Photoproduction	M. Witherell (Santa Barbara)
Particle Decays Beyond the Standard Model	M. Zeller (Yale)

Session V: QCD

Chairman: F. Muller (CERN)

Review of Direct $\Upsilon$ Experiments	H. Boggild (Copenhagen)
Review of Two Photon Physics	S. Cartwright (Rutherford)
Properties of Gluon Jets	K. Sugano (ANL)
Physics of Fragmentation	T. Gottschalk (Caltech)

Session VI: The Near- and Long-Term Future

Chairman: K. Takahashi (KEK)

Perspectives in $e^+e^-$ Physics	G. Feldman (SLAC)
Perspectives in Lepton-Hadron Scattering	F. Eisele (DESY)
Physics with Future Colliding Hadron Beam Machines	L. Pondrom (Wisconsin)
Concluding Remarks	H. Lipkin (ANL/Weizmann)

(M. Derrick)

## VI. PUBLICATIONS

A. Journal Publications, Conference Proceedings, Books

Can the CERN  $p\bar{p}$  Collider Limit Gauging Masses?

H. Baer (ANL), K. Hagiwara (DESY), X. Tata (Univ. of Oregon)  
 Phys. Rev. Lett., 57, 294 (1986).

Trajectories of Strings with Rigidity

C. Zachos (ANL), T. Curtright (Univ. of Florida), G. Ghandour (Kuwait Univ.)  
 Phys. Rev. Lett., 57, 799 (1986).

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M. Derrick, K. Gan, P. Kooijman, J. Loos, B. Musgrave, L. Price, J. Repond, K. Sugano, J. Weiss, D. Wood (ANL); S. Abachi et al. (Purdue Univ.); D. Blockus, et al. (Indiana Univ.); C. Akerlof et al. (Univ. of Michigan); B. Cork (LBL)  
 Phys. Rev. Lett. 57, 1990 (1986).

Relations Between Meson and Baryon Hyperfine Splittings

Harry J. Lipkin  
 Phys. Lett. B171, 293 (1986).

Magnetic Monopoles, Electric Currents, and Dirac Strings

H.J. Lipkin and Murray Peshkin  
 Phys. Lett. B179, 109 (1986).

The OZI Rule in Charmonium Decays above DD Threshold

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 Phys. Lett. B179, 278 (1986).

Asymmetry in the Angular Distribution of Inclusive  $\Lambda$  Baryons from  $e^+e^-$  Annihilations at  $\sqrt{s} = 29$  GeV

M. Derrick, E. Fernandez, R. Fries, L. Hyman, P. Kooijman, J.S. Loos, B. Musgrave, L.E. Price, J. Schlereth, K. Sugano, J.M. Weiss, D. E. Wood (ANL/HEP); G. Baranko et al. (Indiana Univ.); C. Akerlof et al. (Univ. of Michigan); S. Abachi et al. (Purdue Univ.)  
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 Phys. Lett. B182, 101 (1986).

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E.L. Berger, H. Baer (ANL)

Phys. Rev. D34, 1361 (1986).

Electroweak Form Factors of the Skyrmion

C.R. Willcox (ANL), E. Braaten et al. (Northwestern Univ.)

Phys. Rev. D34, 1482 (1986).

K-Meson Production by  $\nu$ -Deuteron Reactions Near Threshold: Implications for Nucleon-Decay Searches

M. Derrick, B. Musgrave (ANL), W.A. Mann et al. (Tufts Univ.), R. Amar et al. (Univ. of Kansas)

Phys. Rev. D34, 2545 (1986).

Observation of a New Structure in the Difference Between the pp Total Cross Sections for Antiparallel and Parallel Longitudinal Spin States

I. Auer, E. Colton, H. Halpern, D. Hill, R. Miller, H. Spinka, G.

Theodosiou, K. Toshioka, D. Underwood, R. Wagner, A. Yokosawa, (ANL)

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Experimental Study of the Reaction  $e^+e^- \rightarrow e^+e^-$  and  $e^+e^- \rightarrow \gamma\gamma$  at 29 GeV

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Classical Dynamics of Strings with Rigidity

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Phys. Rev. D34, 3811 (1986).

Weyl-Dirac Equation for an  $SU(2)$  Gauge Theory with Spherical Symmetry

D. Siverson (ANL)

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**Effects on Spin Asymmetries of Special Effects at  $90^\circ$** 

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A Unique SU(5) and SO(10) Unification with Complete Dynamical Symmetry  
Breaking

A. White (ANL), K. Kang (Brown Univ.) ANL-HEP-PR-86-53  
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Phys. Rev. D.

Bottom Quark Production at Hadron Colliders

E. L. Berger (ANL), J. Collins (ANL/IIT), D. Soper (Univ. of Oregon)  
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When Perturbative Corrections are Included

L.E. Roberts (ANL/Lincoln Univ/Inst. for Scientific Studies)  
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J. Van Polen, R. T. Hagstrom, G. Hirsch (ANL) ANL-HEP-PR-86-90  
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Gauginos as a Signal for Supersymmetry at  $\bar{p}p$  Colliders

H. Baer (ANL), K. Hagiwara (KEK), X. Tata (Univ. of Wisconsin-Madison)  
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**On the Squark and Gluino Mass Limits From the CERN  $p\bar{p}$  Collider**

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C. Zachos (ANL), E. Braaten (Northwestern Univ.) ANL-HEP-PR-86-114  
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**Limit on  $\tau$  Decay to Seven Charged Particles**

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**Goldstone Theorem at Finite Temperature and Density**

K.L. Kowalski (ANL) ANL-HEP-PR-86-127  
Phys. Rev. D.

**Detecting Gluinos at Hadron Supercolliders**

H. Baer, D. Karatas (ANL), V. Barger et al. (Univ. of Wisconsin)  
ANL-HEP-PR-86-128  
Phys. Rev. D.

**Charged Particle Multiplicity Distributions in  $e^+e^-$  Annihilation at 29 GeV: A  
Comparison with Hadronic Data**

M. Derrick, E. Fernandez, R. Fries, L. Hyman, P. Kooijman, J.S. Loos, B.  
Musgrave, L.E. Price, J. Schlereth, K. Sugano, J.M. Weiss, D. E. Wood  
(ANL/HEP); G. Baranko et al. (Indiana Univ.); C. Akerlof et al. (Univ. of  
Michigan); S. Abachi et al. (Purdue Univ.) ANL-HEP-PR-86-129  
Zeitschrift fuer Physik

**The Phase Structure of the Non-Compact Abelian Higgs Model**

J. Oliensis (ANL), P. Suranyi (Univ. of Cincinnati) ANL-HEP-PR-86-135  
Nucl. Phys.

**A Proton Accelerator for Medical Applications**

R. Martin (ANL) ANL-HEP-PR-86-136  
Nucl. Inst. Meth.

**Return of the Finite Temperature Phase Transition in the Chiral Limit of Lattice QCD**

D. Sinclair, E. Kovacs (ANL), J. Kogut (Univ. of Illinois-Urbana)  
ANL-HEP-PR-86-137  
Phys. Rev. Lett.

**Limit on  $\tau$  Neutrino Mass**

M. Derrick, E. Fernandez, R. Fries, L. Hyman, P. Kooijman, J.S. Loos, B. Musgrave, L.E. Price, J. Schlereth, K. Sugano, J.M. Weiss, D. E. Wood (ANL/HEP); G. Baranko et al. (Indiana Univ.); C. Akerlof et al. (Univ. of Michigan); S. Abachi et al. (Purdue Univ.) ANL-HEP-PR-86-138  
Phys. Rev.

**Real-Time Fermion Thermal Field Theories**

K. Kowalski (ANL) ANL-HEP-PR-86-140  
Phys. Rev. D.

**Cancellations in Two-Step OZI-Violating Transitions**

H. Lipkin (ANL) ANL-HEP-PR-86-143  
Nucl. Phys. B.

**Measurement of the Lifetime of Hadrons Containing b-Quarks**

M. Derrick, E. Fernandez, R. Fries, L. Hyman, P. Kooijman, J.S. Loos, B. Musgrave, L.E. Price, J. Schlereth, K. Sugano, J.M. Weiss, D. E. Wood (ANL/HEP); G. Baranko et al. (Indiana Univ.); C. Akerlof et al. (Univ. of Michigan); S. Abachi et al. (Purdue Univ.) ANL-HEP-PR-86-144  
Phys. Rev. Lett.

**C. Papers or Abstracts Contributed to Conferences****Hard Diffractive Processes: QCD Models**

E. Berger, J. Collins (ANL), D. Soper (Univ. of Oregon), G. Sterman (SUNY)  
ANL-HEP-CP-86-83

Proceedings of the Workshop on Physics Simulations at High Energy,  
Madison, WI, May 5-16, 1986.

**Low  $p_{\perp}$  Properties of the Pomeron--Theoretical Implications in QCD**

A. White (ANL) ANL-HEP-CP-86-84  
Ibid.

**Diffractive Heavy Flavor Production - Including  $W^{\pm}$  and  $Z^0$** 

A. White (ANL) ANL-HEP-CP-86-85  
Ibid.

**Particle Production in  $e^+e^-$  Annihilation at 29 GeV**

M. Derrick (ANL) ANL-HEP-CP-86-94

XVII International Symposium on Multiparticle Dynamics, Univ. of Vienna, Seewinkel, Austria, June 16-20, 1986.

**A Simple Example of Track Finding by Fourier Transform and Possibilities for Vector or Optical Processors**

D. Underwood (ANL) ANL-HEP-CP-86-98

Proceedings of the Summer Study on the Physics of the Superconducting Supercollider, Snowmass, Colorado, June 22-July 11, 1986.

**Intrinsic Polarization of the High Energy W-Boson Structure Functions**

J. Ralston (ANL/Univ. of Kansas), F. Olness (IIT) ANL-HEP-CP-86-104

Ibid.

**Nucleon Decay Experiments: Status and Prospects**

D. Ayres (ANL), W. Beier (Univ. of Pennsylvania), B. D'Ettore Piazzoli (Univ. di Torino), J. Erwein (CEN), T. Gaisser (Bartol Research),

S. Seidel (Univ. of Michigan), L. Sulak (Boston Univ.) ANL-HEP-CP-86-107

Ibid.

**Report of Test Beam Subgroup**L. Nodulman (ANL), D. Groom *et al.* (LBL), R. Gustafson (Univ. of Michigan), T. Kirk (Fermilab) ANL-HEP-CP-86-109

Ibid.

**A Personal Extrapolation of CDF Test Beam Use to the SSC**

L. Nodulman (ANL) ANL-HEP-CP-86-110

Ibid.

**Extending the Reach of the SSC**

R. Diebold (ANL) ANL-HEP-CP-86-122

Ibid.

**Nonaccelerator Physics Working Group Summary**D. Ayres (ANL), E. Beier *et al.* (Univ. of Pennsylvania), W. Marciano (BNL) ANL-HEP-CP-86-124

Ibid.

**Detection of Higgs Bosons Decaying to Bottom Quarks**

L. E. Price (ANL), F. J. Gilman (SLAC) ANL-HEP-CP-86-125

Ibid.

**Report of the Working Group on Detector Simulation**

L.E. Price (ANL), P. Lebrun (Fermi) ANL-HEP-CP-86-126

Ibid.

**Bottom Quark Production at the SSC**

E. Berger (ANL), J. Collins (IIT), D. Soper (Univ. of Oregon)

ANL-HEP-CP-86-134

Ibid.

**The Soudan 2 Detector as a Time-Projection Calorimeter**I. Ambats, D. Ayres, L. Barrett, J. Dawson, T. Fields, M.C. Goodman, N. Hill, J. Hoftiezer, D. Jankowski, E. May, N. Mondal, E. Peterson, L. Price, J. Schlereth, J. Thron (ANL); W. Allison et al. (Univ. of Oxford); J. Alner et al. (Rutherford Appleton Lab); H. Courant et al. (Univ. of Minnesota); T. Kafka et al. (Tufts Univ.) ANL-HEP-CP-86-64

Proceedings of the XXIII International Conference on High Energy Physics, University of California, Berkeley, Cal., July 16-23, 1986.

**The EMC Effect**

E. Berger (ANL) ANL-HEP-CP-86-103

Ibid.

**The  $D^*$  Width and the Study of  $F$  and  $F^*$** 

K. Sugano (ANL) ANL-HEP-CP-86-113

Ibid.

**Jet Fragmentation at PEP**

P. Kooijman (ANL) ANL-HEP-CP-86-116

Ibid.

**Advanced Accelerator Research at Argonne**

R. Konecny, J. MacLachlan, J. Norem, A. Ruggiero, P. Schoessow, J. Simpson (ANL) ANL-HEP-CP-86-87

Proceedings of the International Conference on High Energy Accelerators, Novosibirsk, USSR, August 7-11, 1986.

**The ANL Experiment for a Wake Field Accelerator Using an RF Structure**

A. Ruggiero, P. Schoessow, J. Simpson (ANL) ANL-HEP-CP-86-105

Proceedings of the Symposium on Advanced Accelerator Concepts, Univ. of Wisconsin, Madison, Wisconsin, August 21-27, 1986.

**The Los Alamos Experiments on the Few Nucleon Systems**

H. Spinka (ANL) ANL-HEP-CP-86-95

XI International Conference on Few Body Systems in Particle and Nuclear Physics, Sendai Univ., Tohoku Univ, RIKEN, August 24-29, 1986.

**Concluding Remarks**

H. Lipkin (ANL) ANL-HEP-CP-86-131

Proceedings of the Physics in Collision VI, Argonne National Laboratory, Americana-Congress Hotel, Chicago, IL, September 3-5, 1986.

**Properties of Gluon Jets**

K. Sugano (ANL) ANL-HEP-CP-86-133

Ibid.

**Microcanonical and Hybrid Simulations of Lattice Quantum Chromodynamics with Dynamical Fermions**

D. K. Sinclair (ANL) ANL-HEP-CP-86-121

Proceedings of the International Symposium on Lattice Gauge Theory, 1986, Brookhaven National Laboratory, Upton, NY, September 15-19, 1986.

**Tests of QCD in High Energy Spin Reactions**

H. Lipkin (ANL) ANL-HEP-CP-86-130

Proceedings of the 7th International Symposium on High Energy Spin Physics, Protvino, USSR, Inst. for High Energy Physics, Serpukhov, September 22-27, 1986.

**Decoupled Control Techniques for Dual Flying Capacitor Bridge Power Supplies of Large Superconductive Magnets.**

R. Kustom (ANL), M. Ehsani et al. (Texas A&M Univ.)

ANL-HEP-CP-86-115

Proceedings of the Applied Superconductivity Conference, Hyatt Regency Hotel, Baltimore, MD., September 28-October 3, 1986.

**Why Gamma Rays are Different—Some Notes for Pedestrians**

H. Lipkin (ANL) ANL-HEP-CP-86-132

Proceedings of the 1986 International Laser Science Conference, Univ. of Washington, Seattle, Washington, October 20-24, 1986.

**An Enhanced 8086-Based CAMAC Crate Controller**

J. Dawson, J. Bayer, L. Chan, D. Clarlette, W. Haberichter, R. Stanek (ANL) ANL-HEP-CP-86-123

Proceedings of the IEEE Nuclear and Plasma Science Symposia, IEEE Trans. Nucl. Sci., Shoreham Hotel, Washington, DC, October 29-31, 1986.

**A Proton Accelerator for Medical Applications**

R. Martin (ANL) ANL-HEP-CP-86-136

9th Conference on the Application of Accelerators in Research and Industry, Denton, Texas, November 10-12, 1986.

**Focussing of Electric Field in the Active Site of Cu, Zn Superoxide Dismutase Effects of Ionic Strength and Amino Acid Modification**

R. Hagstrom (ANL), B. Honig (Columbia Univ.) ANL-HEP-CP-86-142

Proceedings of the Macromolecular Modeling for Biological Applications, National Institute of Health, Bethesda, MD, November 10, 1986.

D. Technical Notes

- ANZEUS-4 ZEUS Calorimeter Tests: DU Noise Current Measurements and Cosmic Ray Muon Light Yields  
J. D. Anderson, J. Dawson, B. Musgrave
- CDF-470 The Deadlist Database  
L. Nodulman
- CDF-473 The CDFdb, A Reference Manual for the CDF Database  
P. Kesten, J. Proudfoot
- CDF-505 The CDF Central Shower Counters  
L. Balka, K. Coover, R. Diebold, W. Evans, N. Hill, W. Li, L. Nodulman, J. Proudfoot, R. Rezmer, J.R. Sauer, P. Schoessow, D. Underwood, R. Wagner, E. Walschon, A.B. Wicklund, T. Kamon, Y. Kikuchi, K. Kondo, T. Takikawa, A. Yamashita, J. Elias, H. Jensen, H. Kautzky, Y. Yasuoka, T. Devlin, U. Joshi, D. Bauer, D. Conner, J. Cooper, S. Hahn, M. Miller, R. Vanberg, H.H. Williams, S. Kobayashi, A. Murakami, S. Mikamo
- CDF-506 Missing  $E_{-t}$  Analysis Plan  
B. Eposito, H. Frisch, L. Nodulman
- HRS-346 On Radiative Corrections and All That Jazz  
P. Kooijman
- LS-53 Optimization of  $\beta$  Functions through Insertion Devices  
Y. Cho
- LS-56 Electromagnetic Properties of the Vacuum Chamber  
R. Kustom, J. Cook
- LS-63 The Effects of Adding a Higher Harmonic Cavity  
T. Khoe
- LS-64 The Argonne National Laboratory 6 - 7 GeV Synchrotron X-ray Source  
L. C. Teng
- LS-66 Considerations in the Design of Undulators  
L. C. Teng
- LS-67 RACETRACK at ANL  
S. Kramer
- LS-68 Touschek Lifetime Calculations  
S. Kramer
- LS-70 Response to Vibrational Disturbance of the Magnet Foundation  
T. Khoe

- LS-75            Storing Electrons Instead of Positrons without Trapping of Positive Ions  
T. Khoo
- LS-76            Visit to Taber Metals to Impact APS Vacuum Chamber Extrusions  
R. Nielsen, R. Wehrle
- PDK-280        Minutes of Collaboration Meeting June 10-13, 1986 at Argonne National Laboratory  
M. Goodman
- PDK-283        Soudan 2 Nucleon Decay Experiment Quarterly Activity Report April - June 1986  
D. Ayres
- PDK-284        Status Report on Tosca Simulation  
J. Dawson
- PDK-285        Effects of Geometric Perturbations on Effective Aperture of Drift Tubes in Soudan 2 Detector  
J. Dawson, S. Warkema
- PDK-286        End Plane Mounting and Cathode Board Warping on the Soudan 2 Detector  
E. Michlovich
- PDK-287        U.S. Module Heights  
M. Goodman, N. Hill, E. Michlovich, K. Barron
- PDK-288        Analysis of 1E2259 Data  
E. Peterson
- PDK-291        Locating and Repairing Dielectric Faults in the Soudan 2 Nucleon Decay Detector  
K. Barron
- PDK-293        Review of Mounting Arrangements for the Veto Shield  
N. Hill, A. Mann, E. Petereit
- PDK-298        Soudan 2 Nucleon Decay Experiment Quarterly Activity Report, July-Sept. 1986  
D. Ayres
- PDK-300        HV Acceptance Tests for Bandolier Connectors  
D. Jankowski
- WF-34           Plasma Wake Field Acceleration: Beam Profiles, Radial Focussing and Emittance Matching  
J. Norem

- WF-35      Second Set of Calculations of Energy Loss and Gain in a Metallic  
            rf Cavity with TBCI  
            A.G. Ruggiero, P. Schoessow
- WF-36      Calculation of the Mixing Frequency for the WAKEATRON in Linear  
            Approximation  
            A.G. Ruggiero
- WF-37      Linac Emittance Measurement  
            P. Schoessow, G. Mavrogenes
- WF-38      Nonlinear Plasma Dynamics in the Plasma Wakefield Accelerator  
            J. Rosenzweig
- WF-39      Preliminary Results of the Beamline Magnet Measurements  
            B. Cole
- WF-40      Excitation of a Pill-Box Cavity filled with a Medium  
            A. Ruggiero
- WF-41      A Proposed Plasma Focusing Experiment  
            J. Rosenzweig, B. Cole
- WF-42      Third Set of Calculations of Energy Loss and Gain in Metallic RF  
            Cavities with TBCI  
            A.G. Ruggiero, P. Schoessow
- WF-43      The Generalized Deflection Theorem  
            A.G. Ruggiero
- WF-44      A Minor Correction to the Calculation of WF-40 for the Excitation  
            of a Pill-Box Cavity  
            A.G. Ruggiero
- WF-45      First and Second Order Beam Optics of the Test Facility and  
            Chemistry Experiment Beamlines  
            J. MacLachlan
- WF-46      The Plasma Wake Field Accelerator and Emittance Growth due to  
            Coulomb Scattering  
            A. Ruggiero
- WF-47      Deflection Theorem Revisited  
            J. Rosenzweig

## VII. PUBLICATIONS BASED ON ZGS EXPERIMENTS

ZGS Experiment

E-447,  $\Delta\sigma$  Measurements Between  
1 to 6 GeV/c (ANL)

Publication

Observation of a New Structure in the  
Difference Between the pp Total Cross  
Sections for Antiparallel and Parallel  
longitudinal Spin States, I. Auer, E.  
Colton, H. Halpern, D. Hill, R.  
Miller, H. Spinka, G. Theodosiou, K.  
Toshioka, D. Underwood, R. Wagner, A.  
Yokosawa (ANL), Phys. Rev. Lett., D34,  
2581 (1986).

**VIII. HIGH ENERGY PHYSICS RESEARCH PERSONNEL**Accelerator Physicists

Y. Cho	J. MacLachlan
W. Chou	R. Martin
E. Crosbie	J. Noren
A. Hassan	A. Ruggiero
Y. Jin	J. Simpson
T. Khoe	L. Teng
S. Kramer	

Experimental Physicists

D. Ayres	L. Nodulman
W. L. Barrett	Y. Ohashi
M. Derrick	E. Peterson
R. Diebold	L. Price
T. Fields	J. Proudfoot
H. Figueroa	J. Repond
M. Goodman	P. Schoessow
W. Gai	T. Shima
D. Grosnick	H. Spinka
R. Hagstrom	R. Stanek
Y. Jin	K. Sugano
P. Kooijman	J. Thron
W. Li	D. Underwood
F. Lopez	R. Wagner
D. Lopiano	A. B. Wicklund
E. May	A. Yokosawa
B. Musgrave	

Theoretical Physicists

H. Baer	D. Sinclair
E. Berger	D. Sivers
G. Bodwin	W. K. Tung
J. Collins	G. Richards
W. Grady	A. White
Y. Meurice	C. Zachos

Engineers, Computer Scientists and Applied Scientists

J. Cook	R. Kuston
J. Dawson	G. Mavrogenes
D. Hill	K. McConnell
N. Hill	J. Schlereth
E. Kovacs	D. Suddeth

Technical Support Staff

I. Ambats	R. Konecny
L. Balka	R. Laird
J. Biggs	R. Miller
H. Blair	R. Nielsen
W. Evans	R. Rezmer
W. Haberichter	J. Sheppard
D. Jankowski	E. Walschon
T. Kasprzyk	

**Appendix A**  
**COLLOQUIA AND CONFERENCE TALKS**

D. Ayres

"Nonaccelerator Physics Summary"  
1986 DPF Summer Study, Snowmass, CO (July 1986)

H. Baer

"Supersymmetry in  $p\bar{p}$  Collisions"  
Carleton Univ., Ottawa, Canada (December 1986).

E. Berger

"Bottom Quark Production from Fixed Target Energies to the Super Collider"  
Fermi National Accelerator Laboratory (December 1986).

"Heavy Target Effects in Dimuon Production"  
Fermi National Accelerator Laboratory (December 1986).

"Elementary Particles: Fundamental Constituents and their Interactions"  
Central States Universities/Argonne National Laboratory Conference on  
Collaborative Research at DOE National Laboratories, Argonne (October  
1986).

"The EMC Effect"  
Argonne National Laboratory High Energy Physics Seminar (October 1986).

"Aspects of the EMC Effect"  
Fermi National Accelerator Laboratory (September 1986).

"Prospects for Collider Physics at the Fermilab Tevatron"  
D-Zero Collider Collaboration Workshop, Brown University (July 1986).

"Structure Functions and Massive Lepton Pair Production"  
XXIII International Conference on High Energy Physics, Berkeley, CA  
(July 1986).

"The EMC Effect"  
XXIII International Conference on High Energy Physics, Berkeley, CA  
(July 1986).

"Massive Lepton Pair Production--the Drell-Yan Process--with Nuclear Targets"  
International Symposium on Weak and Electromagnetic Interactions in  
Nuclei, Heidelberg (July 1986).

Y. Cho**"Accelerators in Science and Technology"**

Korea Federation of Scientific and Technological Societies, Seoul, Korea  
(July 1986).

**"Synchrotron Radiation and Its Utilization"**

Korea Advanced Institute of Science and Technology, Seoul, Korea  
(July 1986).

**"Status of Synchrotron X-ray Source Project at Argonne"**

European Synchrotron Radiation Facility, Grenoble, France  
(September 1986).

**"Storage Ring Energy of Argonne Advanced Photon Source"**

European Synchrotron Radiation Facility, Grenoble, France (November 1986).

M. Derrick**"Review of Multiplicity Measurements"**

Workshop on Multiparticle Phenomena, Aspen, CO (July 1986).

**"Multiplicity Distribution in  $e^+e^-$  Annihilation and the Nature of Hadronic Interaction"**

DESY, Hamburg, Germany (November 1986).

**"Tau Lepton Production and Decay Studied in the High Resolution Spectrometers"**

NIKHEF, Amsterdam, Netherlands (October 1986)  
Northwestern University (November 1986).

M. Grady**"Numerical Study of the Lattice Massive Schwinger Model Using a Fast Fermion Monte Carlo Algorithm"**

Univ. of Illinois at Chicago Circle (November 1986).

D. Grosnick**"Rare Muon Decays with the Crystal Box"**

Univ. of Chicago (October 1986).

K. Kowalski**"High Energy Physics at Finite Temperature"**

Illinois Institute of Technology (August 1986)  
Northwestern University (September 1986).

R. Martin

"A Proton Accelerator for Medical Applications"  
Conference on Applications of Accelerators in Research and Industry  
(November 1986).

K. McConneil

"Molecular Modeling at ANL"  
National Institutes of Health, Bethesda, MD (November 1986).

Y. Maurice

"BRST Point Field Theory"  
Univ. of Minnesota (October 1986).

"From Points to Gauge Fields"  
Univ. of Florida (Gainesville) (November 1986).

A. Ruggiero

"The ANL Experiment on a Wake Field Accelerator"  
Symposium on Advanced Accelerators, Madison, WI (August 1986).

"The Superconducting Super Collider (SSC)"  
Univ. of Wisconsin (November 1986).

H. Spinka

"The Los Alamos Experiments on the Few Nucleon Systems"  
Eleventh International Conference on Few Body Systems in Particle and  
Nuclear Physics, Tokyo, Japan (August 1986)  
Kyoto University, Kyoto, Japan (September 1986).

K. Sugano

"The  $D^*$  Width and the Study of  $F$  and  $F^*$ "  
The XXIII International Conference on High Energy Physics, Berkeley, CA  
(July 1986).

"The Properties of Gluon Jets"  
Physics in Collision VI, Chicago, IL (September 1986).

A. White

"The Pomeron in QCD"  
Workshop on Multiparticle Strong Interaction Phenomena, Aspen, CO  
(August 1986).

D. Underwood

"The Status of the Fermilab Polarized Beam Experiment"  
VII International Symposium on High Energy Physics, Protvino, USSR  
(September 1986).

"Polarized Beams from Hyperon Decay"  
Workshop on Polarized Beam Acceleration and Storage, Novosibirsk, USSR  
(September 1986).

A. Yokosawa

"Recent Results on Polarization and the Present Status of the Fermilab  
Polarized Beams"  
Spin Phenomena in Hadronic Interactions Workshop, Wuppertal, West Germany  
(September 1986).

C. Zachos

"Classical Motions of Strings with Rigidity"  
Illinois Inst. of Technology (October 1986)  
Univ. of Cincinnati (November 1986).

"A Superstring Primer"  
Case Western Reserve Univ. (December 1986).

**Appendix B**  
**HIGH ENERGY PHYSICS COMMUNITY RESPONSIBILITIES**

HEP Division Personnel accepted the following responsibilities for organizing conferences, serving on review committees, and similar activities.

Y. Cho

Machine Advisory Committee, European Synchrotron Radiation Facility, Grenoble, France.

Working Group Chairman, Workshop on Lattice Choice of the European Synchrotron Radiation Facility, Grenoble, France (November 19-21, 1986).

J. Simpson

Organizing Committee, Symposium on Advanced Accelerators, Madison, WI (August 1986).