ARGONNE NATIONAL LABORATORY
HIGH ENERGY PHYSICS DIVISION
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July 1, 1989 - December 31, 1989

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High Energy Physics Division Semiannual Report of Research Activities
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I. EXPERIMENTAL PROGRAM

A. Physics Results

1. Collider Detector at Fermilab

Final analyses were carried out on several major topics, based on the 4.4 pb^{-1} sample of data collected in the 1988-1989 CDF run. These included measurements of two fundamental quantities in the electroweak sector - the mass of the neutral gauge boson (Z), and the total decay width of the charged gauge boson (W). In addition, new upper limits were obtained on the top quark mass. We summarize these topics in turn.

The Z mass measurement (see Phys. Rev. Lett. 63, 720 (1989)) was based on event samples of 73 central electron pairs and 132 central muon pairs. Previous measurements at the UA1 and UA2 experiments relied on calorimeter calibrations that were intrinsically limited to 1-2% accuracies. The CDF central calorimeters were initially calibrated in similar fashion, with comparable accuracy, using radioactive sources to relate the energy response in the collision hall to that in the test beam. However, a much more accurate calibration was accomplished in CDF by basing the calorimeter energy scale on the particle momentum measurement from the central tracking chamber. The momentum measurement accuracy is limited in principle only by the accuracy of the magnetic field measurement (0.05%), and by the accuracy of the tracking chamber alignment. Using a sample of "clean" electrons and positrons from $W^\pm$ decays, the chamber alignment was optimized by analyzing the systematic differences in E/p for positrons and electrons (E denotes calorimeter energy, p momentum); since the calorimeter response is charge independent, E/p depends on charge only through chamber alignment errors. In turn, having optimized the chamber alignment, we used the charge-averaged value of E/p to calibrate the calorimeter response. The Z mass for the dimuon sample is based directly on the muon momenta measured in the tracking chamber; for the dielectron sample, the mass is based on the calibrated calorimeter energies. The final result, $M(Z) = 90.9 \pm 0.3 \text{ (stat. + syst.)} \pm 0.2 \text{ (scale) GeV}/c^2$, is consistent

with more recent published values from the LEP experiments (91.10 ± 0.05).

The results on the W-boson width and the top quark masses are all based on a single CDF trigger, namely the requirement of a high P_t (> 12 GeV/c) electron in the central electromagnetic calorimeter. Starting from this common requirement, we identified events having (a) a second electron in the detector, or (b) no second electron and substantial P_t imbalance. From these samples, after geometrical efficiency corrections, we obtained the ratio of cross-section times branching ratio for $W \rightarrow e \nu$ and $Z \rightarrow e^+e^-$. This ratio depends on three quantities, namely the ratio of production cross sections for W and Z, the ratio of partial widths for $W \rightarrow e \nu$ and $Z \rightarrow e^+e^-$, and the ratio of total widths for W and Z decay. The production cross section ratios can be calculated within a 1% theoretical uncertainty (due mainly to uncertainty in structure functions); the leptonic partial widths are given by the standard model. With these input assumptions, we extract the ratio of total widths $r(W)/r(Z) = 0.85 \pm 0.08$. Using the recent LEP values for the Z total width, we obtain $r(W) = 2.19 \pm 0.20$ GeV, to be compared with theoretical total widths of 2.07 (no $t \bar{b}$ decay mode) or 2.76 GeV (open $t \bar{b}$ channel). This result rules out unseen decays of $W \rightarrow t \bar{b}$, with $M_t < 41$ GeV/c², in which the top quark decays into non-detectable final states such as H^+b (charged Higgs decay.)

The direct top quark searches were based on the high P_t central electron sample, and are sensitive to the Standard Model semileptonic decay $t \rightarrow b e \nu$. The first search looked for semileptonic decay of one top quark, with hadronic (multi-jet) decay of the accompanying anti-top quark. Provided that the top mass is less than the combined mass $M_W + M_b$, the invariant mass distribution of the electron and neutrino from the top decay should exhibit a spectrum characteristic of a high mass virtual W. Of course, for top masses above $M_W + M_b$, the top would decay into real (not virtual) W's, and the electron-neutrino mass spectrum would be the same for top events as for directly produced single W's. Figure 1 shows the e- ν mass spectrum, together with the expected contribution for a 70 GeV top mass. Also shown is the electron-neutrino mass distribution for a control sample, consisting of electron + neutrino + 1 or more jets (this sample is expected to come mostly from W + single jet production, the next-to-leading order QCD mechanism for W

Fig. 1. (a) The M_T^{ev} distributions for the electron + ≥ 2 jets data (points), $W + 2$ jet (solid curve), and $t\bar{t}$ production with $M_{top} = 70$ GeV/c² (dashed curve). (b) The M_T^{ev} distribution for the electron + 1 jet data with the $W + 1$ jet prediction.

production). The curves are fits to a superposition of $t\bar{t}$ and $W + \text{jets}$ production. This analysis gives a 95% confidence limit of $77 \text{ GeV}/c^2$ on the top mass.

The second direct search method involves semileptonic decay of both t and $\bar{t}$ quarks, the first into $t \rightarrow e \nu b$ (the trigger electron), the second into $\bar{t} \rightarrow \mu \nu \bar{b}$. Backgrounds from production of $b\bar{b}$ pairs, with semileptonic decays $b \rightarrow e \nu c$, $\bar{b} \rightarrow \mu \nu \bar{c}$, are suppressed by requiring high P_t for both leptons ($P_t > 15 \text{ GeV}/c$). One event is observed in the signal region, having $30 \text{ GeV}/c$ electron P_t and $40 \text{ GeV}/c$ muon P_t , corresponding to a 95% confidence lower limit $M_t > 72 \text{ GeV}/c^2$ (Fig. 2). We remark that the "signal" event has no unique physical interpretation - QCD backgrounds, tau pairs (from Z decay), etc. are expected at this level, but do not match the event characteristics very well. The lego plot for this event is shown in Fig. 3; the muon track is not in fact observed in the central muon chambers, but is identified from the central tracking and calorimetry. With higher luminosity, the $e-\mu$ search can be extended to top masses $M_t > M_W + M_b$, where the first analysis described above is inapplicable.

Additional checks are provided by non-observation of dielectron and dimuon events with appropriate kinematics for double semileptonic $t\bar{t}$ decay. In addition, one can search the $W + \text{multijet}$ sample for vestiges of the bottom particles expected in top decay (eg, $t \rightarrow W^+ + b$, $\bar{t} \rightarrow W^- + \bar{b}$), by identifying additional low P_t ($\sim 2\text{-}3 \text{ GeV}/c$) leptons from the b decays. These searches have yielded no top signal to date. Several of the major CDF upgrades, namely improved central muon coverage, preradiators in the central EM calorimeter (for electron tagging), and the Silicon Vertex Detector (for b and c decays), will significantly extend the bottom-tagging capabilities for the 1991 CDF run.

(A. B. Wicklund)

Fig. 2. Electron transverse energy vs. muon transverse momentum for the CDF data with an integrated luminosity of 4.4 pb^{-1} .

Fig. 3. DAIS E transverse eta-phi LEGO plot.

2. High Resolution Spectrometer

Three papers were published in this period: "Study of Vector Meson Production on e^+e^- Annihilation at $\sqrt{s} = 29$ GeV" Phys. Rev. D40, 706 (1989), "Production Cross Section and Topological Branching Fractions of the τ -Lepton" Phys. Rev. D40, 902 (1989) and "Measurement of the Branching Ratio for $\tau^- \rightarrow e^- \nu_e \nu_\tau$ " Phys. Lett. 226B, 405 (1989). An additional paper was accepted for publication.

A study of final states containing four leptons was completed and the results were compared to the α^4 QED predictions. The reactions studied were:

$$e^+e^- \longrightarrow \begin{array}{l} e^+e^-e^+e^- \\ e^+e^-\mu^+\mu^- \\ \mu^+\mu^-\mu^+\mu^- \end{array}$$

In the region of large angles and high invariant pair masses the cross sections for these final states are at the 0.1 pb level, about one thousand times below the annihilation cross section.

The experiment consisted of studying all four prong events satisfying charge conservation and containing either three or more identified leptons or two identified leptons of the same sign. Electrons were identified by the E/p ratio where E was the energy deposited in the shower counters and p was the track momentum. Muons were required to deposit less than 0.5 GeV in the shower counters. Seventy three candidate events were found of which 43 were uniquely identified. Figure 4 shows three of the uniquely identified events. Backgrounds from final states such as $e^+e^-\tau^+\tau^-$, $e^+e^-h^+h^-$ were studied and found to be small. Table I summarizes the event numbers and the backgrounds. The comparison with QED was done using the Monte Carlo generator of Berends, Dauerveldt and Kleiss which is based on the diagrams shown in Fig. 5. As seen in Table I, 73 events were found as compared to 79.6 events plus background expected, a satisfactory agreement. However, the distribution of the events into the different final states is not in such good agreement

Fig. 4. Diagrams contributing to four-lepton final states; an example from the: (a) bremsstrahlung; (b) annihilation; (c) conversion; and (d) multiperipheral groups.

Fig. 5. Characteristic event pictures of $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$ and $\mu^+\mu^-\mu^+\mu^-$ final states.

Table I. Number of observed and expected events for $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$ and $\mu^+\mu^-\mu^+\mu^-$ and for unidentified four-prong final states. Upper limits for expected backgrounds are at the 90% CL.

$e^+e^-e^+e^-$	$e^+e^-\mu^+\mu^-$	$\mu^+\mu^-\mu^+\mu^-$	Events Failing Lepton ID Requirements	Total	
Data	17	24	1	31	73
Expected signal					
$e^+e^- \rightarrow e^+e^-e^+e^-$ ± 2.2	23.5		± 1.4	10.4	
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ ± 2.5		31.5	± 1.3	8.9	
$e^+e^- \rightarrow \mu^+\mu^-\mu^+\mu^-$ ± 0.7			2.9 ± 0.14	0.14	
Calculated background					
$e^+e^- \rightarrow e^+e^-\tau^+\tau^-$	< 0.2	< 0.2	< 0.2	< 0.2	
$e^+e^- \rightarrow e^+e^-h^+h^-$	< 0.7	< 0.7	< 0.7 ± 0.3	0.3	
$e^+e^- \rightarrow \tau^+\tau^-$	2.3	1.0	< 2.3 ± 1.0	1.0	
$e^+e^- \rightarrow q\bar{q}$	< 3.6	< 3.6	< 3.6	< 3.6	
Total expected events ± 0.04	23.5 ± 2.2 ± 0.04	32.5 ± 2.7 ± 0.04	2.9 ± 0.7 ± 0.04	20.7 ± 2.2	79.6

with expectation probably because of uncertainties in the particle identification probabilities. The kinematic distributions agree fairly well with the predictions of the α^4 calculations. (M. Derrick)

3. Energy Flow in Hard Proton-Nucleus Collisions at 400 GeV/c E609 Collaboration (Argonne, Fermilab, LeHigh, Michigan, Pennsylvania, Rice, and Wisconsin)

In order to obtain new experimental information regarding nuclear effects upon hard collisions, we have used the E609 calorimeter system in a 400 GeV/c proton beam at Fermilab to make detailed studies of the A dependence of energy flow in hard scattering events. We have previously reported that the forward "beam jet" in these hard collisions has a width which varies little with A . This would be expected for a beam parton which fragmented only after emerging from the nucleus. Here we report the results of a detailed analysis of the A dependence of the longitudinal energy flow, emphasizing the backward (target) angular region.

A schematic drawing of the E609 calorimeter layout is shown in Fig. 6. The main calorimeter, consisting of 132 individual towers, covered the full azimuth over a cm polar angular range of $25^\circ < \theta^* < 120^\circ$. The total laboratory energy observed in this calorimeter is called ECAL. The corresponding range of laboratory polar angle is 15 mrad to 118 mrad. Energy flow (BCAL) into the forward region, $\theta^* < 25^\circ$, was measured by the beam calorimeter shown in Fig. 6. Energy flow (EB) into cm polar angles greater than 120° , which we shall call the target region, was not measured directly but was calculated for each event by subtracting the energy observed in the main and beam calorimeters from the incident beam energy of 400 GeV.

The mean laboratory energy flow into the nuclear target (backward) region, $\eta < 2.83$, minus the value for pp collisions is found to vary as $A^{0.33 \pm 0.12}$, and reaches a value of 50 ± 8 GeV for Pb, as shown in Fig. 7. The observed probability distribution of energy flow is shown in Fig. 8 and indicates that the energy transfer to a heavy nucleus seldom fluctuates to small values. We also find that the A dependence of the dijet production cross section, parameterized as A^α , steepens from a linear A dependence ($\alpha =$

Fig. 6. E609 Calorimeter system (plan view)

Fig. 7. Observed dependence upon A of $\langle \text{ECAL} \rangle$, $\langle \text{BCAL} \rangle$, and $\langle \text{EN} \rangle = \text{EB}(A) - \text{EB}(H)$, the mean nuclear target region energy flow. The curves for $\langle \text{ECAL} \rangle$ and $\langle \text{BCAL} \rangle$ are to guide the eye.

Fig. 8. Observed probability distribution of the energy EB , the backward energy flow, as measured for H and Pb targets.

1) for small values of energy flow in the target region to larger values of α as the energy flow to the target region increases. This is shown in Fig. 9. (T. Fields)

4. Computational Physics

The computational physics effort continued to be devoted to lattice gauge theory simulations. These efforts were divided between lattice QCD whose goals are to predict the properties and interactions of hadrons and nuclear matter, and lattice QED whose aims are to understand the newly discovered strong coupling phase of QED. The Hybrid Microcanonical/Langevin simulation methods with "noisy" fermions continued to be the simulation method of choice.

Our simulations of finite temperature QCD on a 12^4 lattice, performed on the HEP division's ST-100 array processor, the CRAY 2S at NCSA and the CRAY Y-MP at PSC, ended early in this period. Our results, clarifying the nature of the finite temperature phase transition have been published and presented at the Lattice '89 conference in Capri. This work was performed in collaboration with J. B. Kogut of the University of Illinois.

In collaboration with J. B. Kogut and R. Renken of the University of Illinois, we have been extending the pioneering work of Kogut & Dagotto on Lattice QED. Here we are extending the simulations aimed at understanding the strongly coupled phase in which chiral symmetry is spontaneously broken, from the 10^4 lattices of earlier simulations, to 16^4 lattices. Here we are using the HEP division's ST-100 array processor and Connection Machines (CM-2's) at NCSA and NPAC. Through use of the CM-2's we are adapting lattice gauge simulations to the new generation of massively parallel computers, the direction of all future state-of-the art computing. What we hope to understand is whether strongly coupled QED represents a consistent non-trivial field theory, an exciting possibility, and if so, what are the properties of this theory. Figure 10 shows some preliminary results.

Fig. 9. α dependence of the dijet production cross section as a function of the backward energy flow EB.

Fig. 10. The chiral order parameter $\langle \bar{\psi}\psi \rangle$ as a function of $\beta = 1/e^2$ for QED with 2 fermion flavors of mass $\approx .03$.

Last but not least, as a part of a large, multi-institutional collaboration (~ 20 people) we have been using the ETA-10G at SCRI to measure hadronic mass spectra and other hadronic matrix elements. Preliminary results of our mass spectra were reported at the Lattice '89 conference in Capri, and show considerable improvement on earlier results by members of the collaboration (including ourselves) and other groups. Our own contribution on glueball masses has begun to bear fruit. (D. Sinclair)

B. Experiments Taking Data

1. Collider Detector at Fermilab

The 1988-89 collider run ended in June 1989. A total of 4.7 pb^{-1} of data were written to tape, out of 9.1 pb^{-1} delivered by TeV-I. Subsequent effort has been focussed on analysis of the full data sample. As of December 1989, four Physical Review Letters had been accepted for publication; these reported on the Z mass measurement, top mass limits, and the ratio of W and Z widths. In parallel, intensive internal reviews have been held on the various hardware upgrades needed for the 1991 collider run and beyond. These upgrades include improvements to the front end electronics, DAQ system and Level-3 farm, and new detector subsystems, namely a four-layer silicon strip vertex detector with surrounding inner vertex TPC, expanded central muon coverage, and preshower detectors for the central calorimeters.

The preshower detectors are a primary responsibility of the ANL group. They are designed to measure pulse height in showers that are initiated in the approximately one XO solenoid coil and cryostat, and are to be located in the gap between the cryostat and the front face of the central calorimeter. The preshower detectors must be sensitive to single minimum ionizing particles, in order to separate single photon showers (typically two minimum ionizing particles) from neutral pions (two-to-four minimum ionizing particles). They should also provide additional rejection against charged hadrons for low-energy electron identification (2-10 GeV electrons). The latter capability is important for the top quark search, since detection of bottom particles produced in top decays (via lepton tagging and secondary vertex

identification) is needed to provide unambiguous evidence for top.

The present design consists of gas proportional chambers; this allows good signal to noise characteristics (i.e., adjustable gain), ease of construction, and economical segmentation, and adequate capability for minimum ionizing signals. The segmentation of the preshower chambers is less fine-grained than the central strip chambers (for example, the preshower detectors have no cathode, only anode, readout). However, the segmentation (64 channels per central wedge) should be quite adequate, given the very detailed shower profile information already provided by the full calorimeter. Each chamber covers five central towers, and altogether 96 chambers are needed to cover the 48 central wedges.

To date, two full scale prototypes have been built and a production module is being built for test beam studies. The prototypes have been tested with cosmic rays and sources. The pulse height resolution for cosmic muons is at least as good as observed in the central strip chambers, and the Fe^{55} response is as expected (8% resolution). Uniformity along the wires and wire-to-wire variations exhibit less than three percent spread, except for the outer edge channels (fifteen percent higher gain). Radiation damage studies performed with an intense Sr^{90} source indicate that negligible wire damage should be incurred in the CDF environment. Studies of wire gain and resolution have led to a final cell size of 5.6 mm (gas gap and sense wire separation). The cells will be grouped to achieve the 32-channel per wedge segmentation.

Pickup noise was studied with standard PIG electronics, both in bench tests and with a chamber mounted on the northwest arch in B0. Pedestal noise effects appear to be satisfactory, using shielded twist-and-flat readout cables. In addition tests were performed in B0 to ensure that the gap between the cryostat and the central arches was adequate; the arches were rolled into position with apiezon inserts placed appropriately to verify the space tolerances.

A final production assembly line has been set up at ANL. This consists of an optical flat bench and equipment for manufacturing hexel-Cu clad G10 sandwiches for the chamber cathodes; and precision bearings for stringing sense and field wires. This system should be adequate to produce two chambers per week, consistent with the CDF roll-in schedule. At present, we are hampered by shortage of the temporary technician(s) needed for full production, and consequently have a single ANL technician on the project. We expect that, as soon as Fermilab CDF budgets are resolved for FY90, the needed technicians will be available from FNAL, as per original agreement.

(A. B. Wicklund)

2. Spin Physics at LAMPF

Most of the work during the past six months involved analysis of np scattering data for a number of different experiments. A small amount of work on hardware for an upcoming LAMPF experiment also occurred.

All data summary tapes (DST's) for the E-665 measurements (C_{LL} , C_{SL} for $np \rightarrow np$ and $np \rightarrow d\pi^0$ at $KE_n = 484, 634$ and 788 MeV and $\theta_{c.m.} = 80-180^\circ$) were completed. Work was begun on determining final cuts and final values of the spin parameters from the data. It is hoped this analysis will be completed within the next year. A draft of a paper exists on this experiment, but considerable work remains. Nearly all DST's for the 1984 E-770 data (C_{SS} , C_{LS} for $np \rightarrow np$ at $KE_n = 484, 634, 720$, and 788 MeV and $\theta_{c.m.} = 40-90^\circ$) were also finished. The time scale to complete this work is about the same as for E-665.

Final values for 1985 E-770 data are being derived, and all work on this experiment should be completed in the next six months. These data are mixtures of C_{LL} , C_{SS} , C_{LS} , and C_{NN} in np elastic scattering at 484, 567, 634, 720, and 788 MeV. Numerical values at small lab angles are being obtained at both 484 and 634 MeV. The contributions from various spin observables to the measured values need to be computed so that pure C_{SS} and C_{NN} can be derived. A draft of the final paper on this experiment exists, but substantial work to make figures and to compare to various model and phase shift predictions remains.

The analysis of E-960 ($\Delta\sigma_L(np)$) was not completed during this period. Final results at two energies (567, 634 MeV) have been obtained. Several different problems arose at 484 and 720 MeV that will require more work to study systematic errors. It is believed that these problems can be overcome and that final results at all five energies and the Ph.D. thesis on this experiment will all be finished in the next six month period. The paper on this experiment would then follow. A paper describing the neutron counters used for the $\Delta\sigma_L(np)$ measurements is being written, and the predicted efficiency was calculated from a Monte Carlo code by Sailor and Byrd. This paper should be finished early in 1990.

There was a variety of hardware work to return equipment to the LAMPF electronics pool, to remove cables running into the experimental area and between some trailers, and to clean up the ANL trailer used for electronics. Also, work has begun to prepare the ANL neutron counters for a new np elastic scattering experiment E-876 (K_{ij} at $KE_n = 634, 788$ MeV and $\theta_{c.m.} = 50 - 170^\circ$). Some electronics have been set up and cabled. It is hoped that the 24 neutron counters can be ready for the data taking period which should start in May 1990. It is not clear how much ANL physicists will be able to assist in the data taking because of responsibilities for Fermilab experiments E-581/704, which should begin early in 1990 and continue into the summer. There are also no plans for E-876 data analysis by ANL physicists, because of the large backlog of analysis tasks on past experiments. (H. Spinka)

C. Experiments in Preparation Phase

1. Nucleon Decay

Summary

The Soudan 2 detector installation and operation continued smoothly throughout the last half of 1989. Two additional halfwalls were installed and brought into operation. (A halfwall is a subassembly of eight 5-ton modules, stacked four across and two high.) At end of the year the total mass of 5-ton modules in the underground laboratory was 499 tons, of which 447 tons (13

halfwalls) were in operation. Data acquisition for the charged particle test-beam calibration of a Soudan 2 module was completed at the Rutherford Laboratory. The collaboration continued to increase the effort devoted to physics analysis of data from Soudan 2.

Detector operation

The Soudan 2 experiment recorded data for 99 days of livetime, giving a duty cycle of 54% during the second half of 1989. This brings the total exposure to 314 days, or 18% of a fiducial kiloton year for contained events. Analysis of Soudan 2 data to identify and characterize neutrino interactions contained within the detector continued. The search for underground muons associated with astrophysical point sources such as Cygnus X-3 also continued using data from Soudan 2, with the emphasis on understanding angular resolution and directional biases in the trigger and event reconstruction.

The Soudan 1 experiment continued to accumulate cosmic-ray data for muon astronomy. The surface array operated in coincidence with Soudan 1 until December when it was shut down for the winter due to cold weather. The surface array measures the energies of primary cosmic-ray showers, and is expected to be useful in determining the nuclear composition of the cosmic-ray primaries which give rise to underground multiple muon events. Figure 11 shows the energy spectrum of multiple muon events recorded by Soudan 1 and the surface array. Figure 12 compares the measured underground muon multiplicity distribution with Monte Carlo predictions for different primary cosmic-ray compositions. These results are taken from the Ph.D. thesis of University of Minnesota graduate student Urmi DasGupta.

Fig. 11. The energy spectrum of cosmic ray events recorded by both Soudan 1 and the air-shower array on the surface. The background shown is due to random coincidences between two low energy shower events, one giving a surface array signal and the other producing underground muons with a very large impact parameter relative to the surface array.

Fig. 12. The measured fraction of events with multiple muons in Soudan 1 as a function of the energy determined from the surface array data. The curves compare these data with Monte Carlo predictions for pure proton and pure iron compositions of the primary cosmic ray flux.

Activities at the Soudan Mine Site

While the eight halfwalls of the Southeast quadrant of the detector continued to operate smoothly, the number of halfwalls in the Southwest quadrant was increased from three to five. Shipments of 5-ton modules from the Argonne and Rutherford module factories, which had been suspended earlier due to a problem with poisoned plastic, resumed in August. Twelve U.S. and seven U.K. modules were delivered to the mine during the last half of 1989. Module shipments were suspended for the winter in early December.

Much progress was made in reducing electronic noise in the new West-side electronics and halfwalls, and at the end of the year the noise rate in the new quadrant was comparable to that in the first quarter of the detector. The installation of the active summers and the calibration electronics for the Southwest quadrant, and of the new cathode edge trigger electronics for the Southeast quadrant, were completed. Currently the edge trigger electronics is implemented only on the eight anode crates, but it will be needed on the cathodes as well in order to maintain high efficiency and low trigger rate as the detector grows. Prototype hardware to allow the top and bottom modules of a halfwall to be operated with different anode high voltages was installed on one halfwall, and worked as expected. This system will further improve efficiency and uniformity when it is installed on every halfwall.

The reliability of the detector was greatly improved during the last half of 1989 by the upgrading of two electronic systems which monitor the experiment. The installation of the pulser calibration electronics was completed and the software which operates it and interprets the results was brought into operation. As a result the number of malfunctioning electronics channels has been much reduced. The Z8 voltage monitor system was also expanded to watch many more of the low and high voltages needed to operate the experiment. If a voltage or current changes outside of its allowed range the Data Acquisition Coordinator is notified so that corrective action may be taken.

The cluster of VAX computers was expanded and reconfigured as part of the ongoing program to increase computing power and to retire the obsolete VAX 11/750, which until recently was required for many critical activities. VMS 5.1 was installed on the cluster, allowing several VAXstation 3100's to be added. CAMAC and DECnet were moved from the 750 to a VAXstation 3200. At the end of the year the cluster consisted of two 3200's, three 3100's, and the 750. All data acquired from Soudan 2 is immediately processed through the event reconstruction programs on the mine VAX cluster. The raw data along with results of the first pass analysis are recorded on 8-mm Exabyte tapes for distribution to the collaborating institutions.

A major milestone was reached with the completion of the new cleanroom at the North end of the detector support structure. The cleanroom is used for assembly of 5-ton modules after they arrive at Soudan from the Argonne and Rutherford module factories. The original cleanroom was a temporary wood and plastic enclosure which rested directly on the detector support structure. It had to be moved to make room for the growing detector. The new cleanroom is a permanent steel-frame structure with easy crane access, excellent lighting, and a larger and cleaner work area.

A new cosmic-ray air-shower surface array consisting of proportional tubes acquired from the Fermilab 15-ft bubble chamber EMI detector is being prepared for operation in coincidence with Soudan 2. It will be housed in a heated trailer so that it can be operated throughout the winter. It will have about the same area as the Soudan 1 surface array, but the leak rate in the tubes will be very much lower in the new array. At the end of 1989 the trailer was in place and the tubes were ready to be shipped from Minneapolis.

Soudan Activities at Argonne

The Argonne module factory completed the assembly of twelve 5-ton module stacks (through Module #90) and eleven pairs of readout planes (through Module #88). Ten modules were shipped from Argonne to the mine site during the last half of 1989. The numbers of modules built is lower than planned because production was stopped from mid May to mid August when it was discovered that

the most recent order of plastic inserts was contaminated with an electro-negative poison. Inserts are the formed polystyrene insulators which surround each corrugated steel sheet, to provide additional protection against drift high-voltage breakdowns. Delivery of replacement inserts took three months. The three modules which were constructed using the poisoned inserts were purged with clean gas during this period, but failed to clean up. They will be disassembled and rebuilt.

The first module (#80) built with the new 23-trace bandolier was completed and installed on the cosmic-ray test stand at Argonne. The extra bandolier traces at both ends of each drift tube are expected to improve short-distance drifting. Data acquisition from the module was just beginning at the end of the year. The high flux of cosmic rays on the earth's surface allows large samples of tracks to be recorded for detailed systematic studies in a much shorter time than is possible in the underground laboratory. Following the completion of the new bandolier performance studies the test-stand module will be used to continue measurements of module performance with different admixtures of methane, which improves performance by increasing the drift velocity. The drift velocity in modules currently in use at Soudan is somewhat slower than originally planned because of the presence of water vapor, which is absorbed by the plastic inserts and bandolier material and is very difficult to remove.

The Argonne electronics group completed work on a number of large systems which have been under construction for Soudan 2 during most of 1989. The second half of the active summer electronics and the calibration hardware for the second quarter of the detector were completed, tested, and installed at the mine site during the fall. The new cathode edge trigger daughter boards were delivered to Argonne and performance testing began. The first half of the 400 boards was completed and installed at Soudan at the end of the year. The checkout of the logic on these boards required the installation at Argonne of the same data acquisition software which is in use at Soudan. This will also facilitate the troubleshooting of other types of Soudan electronics, which is routinely repaired by the Argonne electronics group.

Argonne physicists continued to play a major role in the installation, turnon, and data acquisition activities at the Soudan mine site. Installation and checkout of the new calibration electronics and the cathode edge trigger electronics were major projects for the fall of 1989.

Argonne hosted a meeting of the full Soudan 2 collaboration in December. Progress reports and preliminary results from physics analyses of Soudan 2 data were the main topics of the meeting. The analysis of single muon data for excess flux associated with astrophysical point sources is mainly taking place at Oxford, Minnesota, and Tufts. Analysis of contained event data for neutrino interactions and nucleon decay candidates is being pursued by physicists and students at Argonne, Minnesota, and Rutherford. Analysis of multiple muon events is taking place at Argonne and Tufts, and the search for magnetic monopoles is being undertaken at Argonne. The collaboration agreed on the substance of presentations to be made in January at the 21st International Cosmic Ray Conference in Adelaide.

Many details of detector operation and data processing were discussed, and completion of the active shield installation was planned. The collaboration agreed to investigate the possibility of performing the neutrino test beam calibration at CERN. Until recently this calibration had been planned for Brookhaven but it now seems unlikely that the neutrino beam at Brookhaven will be operated again. Preliminary results from the Soudan module calibration in the ISIS charged particle test beam were described. The final data sample was recorded at ISIS in late December, although the setup will be left intact until the analysis has been completed. (D. Ayres)

2. Fermilab Polarized Beam

In spite of the fact that about 25% of Argonne physicist man hours in the last 6 months went into satisfying and documenting new Fermilab safety standards, significant progress was made on getting ready to run E704. In preparation for the run to begin Feb. 12, the other major activities were on chamber construction and testing, $\Delta\sigma_L$ electronics, $\Delta\sigma_L$ online analysis program, beam checkout, and bringing the polarized target into operation.

Significant effort went into writing a new physics proposal for a direct gamma two-spin measurement to be submitted in March.

The safety documentation for the polarized target has been a significant activity for over a year. Recently, it has been a major focus for HEP staff members: D. Hill, L. vanRossum, A. Buehring, T. Kasprzyk and J. Sheppard and an engineer and a technician from Fermilab. This documentation is required before starting each sub system of the target.

There are 4 proportional chamber gas systems, 3 of which involve flammable gas mixed with Argon. New safety standards required the calculation of the volume of every pipeline, mixing chamber, and wire chamber. The leak rate of 22 chambers was measured, and the seals modified to bring the rates within limits. The overall systems were inspected and leak checked several times. During the several months required for this activity, our Trieste collaborators traveled to the U. S. twice in hopes of testing their chambers before the physics run, but had to return because the gas could not be turned on.

The electrical safety issues were focused primarily on the low-voltage, high-current distribution to amplifier cards on proportional chambers. The new standard, formulated within months of our run, requires a separately fused line for each 10 amperes of current used. Previously, supplies of up to 50 amperes were used directly for each chamber. All old chambers must be modified. The new Argonne chambers will have to have segmented bus bars built and fused distribution systems built for these segments. So far this has been a significant activity for two Argonne physicists and a student. It will continue to involve these people plus two Rice university graduate students. Additional technicians may be supplied by Rice and Fermilab in February to try to get this new electrical system ready for Argonne chambers in time for the run.

An additional problem in bringing the polarized target into operation and in operating it involves radiation safety. Many of the flow controls and readouts for the target must be located close to the target and thus close to the experimental area. A radiation safety fence was built to allow access to

these while the experiment is running, but interlocks must be installed and radiation levels must be measured.

The tagging electronics for the beam are in an area near the beamline shielded from most radiation and in fact only extremely low levels have been measured there at any time. During parasitic running with low intensity beam three years ago, this area was occupied almost continuously for 3 months, often by more than one person. During the upcoming run, the area is to be occupied 1/2 hour at a time. It is possible that this could cause some delay in the final electronics timing.

One of Argonne's contributions to the E-704 experiment is to provide many multiwire proportional chambers. Two of these are large, 200 cm x 50 cm. chambers that each contain approximately 4000 wires on 4 wire planes. The 8 total wire planes were finished being wound and surveyed at Fermilab, and are now ready to be assembled with the high voltage planes. The large support structure that holds these large wire chambers has been fabricated and assembled in the experimental hall. Two smaller chambers, each 50 cm x 25 cm have both been assembled and bench-tested with a radioactive source. These will soon be mounted in the experiment. A 50 cm x 50 cm chamber was redesigned because of its proximity to accommodate changes in the liquid hydrogen target. Most of the data acquisition electronics associated with the wire chambers has been acquired along with the corresponding cables that have been made and put in place. (D. Underwood)

3. ZEUS Detector at HERA

Argonne National Laboratory (M. Derrick)

Module Production

Building the production BCAL modules started in this period and by the end of the year, eight EMC sections and four HAC sections had been stacked and two modules were equipped with the wavelength shifters, laser splitting bars, and the full photomultiplier readout system. The prototype module was shipped to Fermilab for beam tests.

The tooling to produce the final module covers was procured and the first trial set of covers were made and tried on module #1. The only remaining detail yet to be finalized is the exact layout of the electronics and cooling in the back beam region. This will be done early in 1990 before the production modules are shipped to Fermilab for beam testing.

Components were available to complete the stacking of six modules, and preparations were well advanced to ensure a timely flow of components to complete modules at the rate of one per month. The aim is to increase this to two per month by the middle of 1990, in order to meet the anticipated completion date of HERA and the other components of the ZEUS detector.

The times needed to stack the EMC and HAC sections and to install the readout system are well within those originally estimated. However, delays in the availability of various components connected with the delay in completing the ZEUS field map, as well as the delivery of the components purchased in the United States, have caused a 2-month slip in the overall schedule. We will attempt to catch up to the original schedule during the next reporting period.

Preparations to stack HAC sections in Jülich were completed in this period. We have duplicated the Argonne stacking facility and it is now operational at Jülich. Personnel from Germany visited Argonne and participating in stacking one of the modules, and we will, in turn, go to Germany and supervise the stacking of the first Jülich module. Because of a fire at the Jülich Laboratory, this has been delayed until February 1990.

Cosmic Ray Tests

Testing of the prototype module and the first production module with cosmic rays showed an excellent transverse uniformity of the response. The deviations from the expected behavior are at the 1-2% level, well within the required precision. The measurements of the uranium radioactivity showed that most of the towers had a response that was also stable in time at the 1-2% level over four weeks. However, the light yield, as measured by the uranium radioactivity, by the laser calibration system, and by the width of the

minimum-ionizing peak was lower than expected for the EMC towers, averaging about 0.5 pe/layer/mip. Improvements to the lightguides and other changes have increased this to about 0.75 pe/layer/mip for the second module, which is an acceptable number. The light yield of the HAC towers is about a factor of two larger and so well within the acceptable range.

Module Shipping

The design of the shipping fixtures that will be used to send the HAC sections from Jülich to Argonne and the completed modules from Argonne to DESY was done in this period. The fabrication of the first two sets of fixtures was started. The modules mount in a frame that rests on four pneumatic dampers. The top of the module is also held in a similar system to counteract sideways accelerations.

Magnetic Field Mapping

Installation and checkout of the 160 Hall effect magnetic field probes was completed in this period. Each probe measures three orthogonal components of the magnetic field. They are mounted at various positions between the main solenoid and the return yoke in the positions that will be occupied by the forward tracking system and the calorimeter modules. In addition, a number of strain gauges were mounted on the support structures of the coil and the iron. Both the strain gauges and the field probes are readout by a VME-based multiplexer designed and built at Argonne. Both systems were used during the initial testing of the ZEUS solenoid in December.

Louisiana State University (R. McNeil)

Louisiana State University joined the ZEUS production effort in early 1989 and took on responsibility for the production of the ZEUS barrel calorimeter EMC Wavelength Shifter (WLS). The research and development had already taken place at the Ohio State University and Module 1 was completed at OSU. LSU sent technical support there to be trained in the production

techniques and help produce the first module of EMC WLS. The EMC WLS for Module 1 was delivered to ANL at the end of July and assembled on the module by LSU and OSU personnel.

During this time LSU prepared itself for the production of module 2 EMC WLS. Two laboratory rooms were set up for the production and testing of the WLS pipes. After finishing module 1 EMC WLS at OSU, all jigs were shipped to LSU. The number of jigs was only sufficient to produce 5 WLS pipes per day (one module's worth per month) so the LSU Physics Dept. machine shop produced more jigs to allow doubling of the production rate to 10 pipes/day (two modules per month). The extra jig were not finished until late October due to back orders on some parts. A new EMC WLS scanning table was also shipped from OSU to LSU and was hooked up to a new CAMAC system based on a VAXStation 3200. The software from OSU was adapted to the new CAMAC system and debugged by LSU. A small cutting mill, band saw, and bending brake were purchased by LSU to allow the module production to not be impeded by schedule conflicts with the LSU Physics Dept. machine shop. An additional two full-time technicians were hired bringing the total manpower to three full-time technicians and a half-time senior technician. Student labor the equivalent of 2 FTE were lined up to augment the production labor force. These personnel were trained using clear plastic WLS pipes to perform the bending, cutting, and wrapping of the pipes.

Module 2 production began in October with the delivery and installation of an ANL purchased annealing oven at LSU. It began at only 5 pipes/day awaiting the extra jigs from the LSU physics machine shop. The LSU college machine shop was given the task of machining the transition pieces. During the time module was being produced at LSU, assembled module 1 was being tested at ANL. It was found that the light output from the EMC for module 1 was low. Studies were made by OSU and LSU to determine the source of the light losses in the EMC. One source of light loss was the transition piece and it was decided to wrap the transition piece with Al foil to improve the light output. The low light output of module 1 also prompted further refinement of the testing procedure to consider the absolute light output as well as the relative light output over the active area of the pipes. Because LSU had not

yet been able to produce the postscript graphics output file on which the mask is based, the scan files were sent to OSU where the graphics file was made, sent to a Columbus, Ohio printing company and the printed acetate forwarded to LSU for exposure on the mask.

Module 2 EMC WLS was shipped the middle of November 1989. An LSU technician traveled to ANL with the module to train ANL technicians to assemble future modules and perform more absolute light output tests prior to assembly. Eight out of 106 EMC WLS pipes were rejected by these tests and were remade at LSU and shipped to ANL. Afterwards, an absolute light measurement station was set up at LSU so that low output WLS pipes would be replaced before shipping to ANL. This absolute light output not only can be used to reject pipes (and hopefully lead through post-mortum to an understanding of why they were bad) but is also used in the selection of phototubes to optimize the performance of the calorimeter. Further testing of module 2 as an assembled unit found the light output from this module was almost a factor of two better than that from module 1.

Module 3 production began smoothly in November. However, the scanning fell behind the rest of the production as the labor effort went into preparing and testing an absolute measuring station and refining the scanning procedure. Consequently, it was not discovered until mid-December that the light output for about half of the pipes for module 3 were below the minimum criteria for light output. Troubleshooting, interrupted by the shutdown of LSU over the holidays, finally traced the problem to a new batch of transition pieces. These pieces were slightly yellowed due to a problem with the flame polishing done by an outside company, resulting in WLS pipes with around 30% lower light output. Many pipes were thus rejected and a new shipment of transition pieces was expedited to LSU for completion of the module. A transition piece pre-testing station was then set up at LSU to assure that all subsequent transition pieces glued onto pipes have adequate light output.

We believe that all facets of the EMC WLS production will now occur from LSU at the rate of 2 modules per month.

Ohio State University (T. Y. Ling)

The production of scintillator tiles for the BCAL modules is fully underway. The scintillator tiles are laser cut by Laser Services Inc. of Massachusetts, wrapped and scanned for nonuniformity at Ohio State and then shipped to ANL. HAC scintillators for the BCAL production modules 1-9 have been completed. Modules 1-6 and 8 were delivered to ANL and modules 7 and 9 were delivered to Jülich KFA, Germany. EMC scintillators for BCAL production modules 1-10 were completed and delivered to ANL. Laser cutting of EMC scintillator tiles for production modules 11 and 12 has been finished.

The WLS light guides (EMC and HAC) and the reflection masks for the production module 1 were completed and mounted in August. HAC light guides for production module 2-4 have been formed, wrapped and scanned. Reflection masks for uniformity correction for these modules have also been made. Together with EMC light guides, they have been mounted on modules at ANL. HAC WLS-Light guides for modules 5-7 have been formed and wrapped. Scanning for these light guides is in progress.

Starting with production module 2, Louisiana State University has been responsible for the EMC WLS-light pipes. All the jigs and machinery for EMC light guides were constructed, tested at OSU and sent to LSU in August 1989.

A systematic scan with the Co^{60} source was done along each tower of the BCAL prototype module and production module 1. The source scan system was developed and constructed at Ohio State. A 1.0 mCi point source attached to the end of a piano wire is driven by a CAMAC controlled stepping motor down a 2 mm stainless steel guide tube positioned between every other EMC light guide.

The data of the scan for the prototype module when compared with EGS Monte Carlo simulation shows that the longitudinal uniformity is good to within 3% for HAC towers and 5% for EMC towers. An autopsy was made to inspect the towers which has the most nonuniformity. We found that the nonuniformity of a given tower was correlated with the DU plates being cut not exactly rectangular. The "banana" shaped DU plates overhang the scintillator which reduces the transmitted light from the scintillator. Since the

geometric precision is much improved for the production modules, it is expected they will have better uniformity relative to the prototype module. This was indeed the case as the data for production module 1 shows much improvement over the prototype

Fast Clear for ZEUS Trigger System

The Ohio State group is responsible for designing and building of the Fast Clear (FC) processor for the ZEUS trigger system. The purpose of the FC is to ensure that the effective readout rate for each detector component and the input rate to the second level trigger to be 1 kHz. The Fast Clear processes each trigger issued by the Global First Level Trigger (GFLT) and issues a 'fast clear' request to the GFLT if it decides that a trigger is obviously due to beam gas interaction. The GFLT then sends an 'abort' signal to all components to abort reading out the event. Monte Carlo study performed by our group has shown that a reduction factor of 400 against raw interactions is possible.

The conceptual design of the FC processor has been finalized. The hardware of the system consists of four crates: three input crates (serving FCAL, BCAL and RCAL separately) and a control crate. An input crate (custom made) contains input cards, a cluster card and a crate controller card. The control crate (VME) contains three processor cards, a VME interface-trigger card and a VME master computer card. Each input card serves half of a 7 x 8 calorimeter region which contains 56 towers. Since the FCAL and RCAL each consists of 4 such regions and the BCAL when unfolded contains 8 such regions, there are 16 input cards in the BCAL crate and 8 input cards each in the FCAL and RCAL crates.

The data from FCAL, BCAL and RCAL are read in parallel and processed independently in each of the input crates. The data is then sent in parallel to the control crate where it is further processed. The information from the three input crates is combined to form the trigger decision and is formatted for transfer to other ZEUS trigger processors.

During this reporting period the design of the different cards in the system have progressed in parallel. The design of the input card is essentially complete and prototype of the input card is under construction. The design work of the other cards are as follows:

cluster card	40% done
control card	40% done
processor card	50% done
VME interface-trigger card	40% done

The VME master computer has been purchased. It is up and running. Its ethernet TCPIP connection also works. The backplane of the input crates have been laid out and the VME crate has been procured.

The schedule calls for a mini system, i.e., an input crate and the VME crate each containing one each of the various cards, be ready for testing by autumn of 1990.

University of Iowa (U. Mallik)

The University of Iowa has had major responsibilities in the software for E790, the Fermilab fixed target run scheduled for January 1990, to calibrate and debug the ZEUS barrel calorimeter modules.

The University of Iowa was responsible for buying and installing the test beam computer system at Fermilab. The E790 node, FNZEUS, with its software has been operational in the portakamp in lab E since this summer. The installation of the computer and the Fermilab user software were accomplished in coordination with Fermilab. The software for E790 is anticipated to be the dress rehearsal for the ZEUS final software. The University of Iowa has the overall responsibility for the software in the context of calibration and monitoring.

For the test beam effort, the AMZEUS collaboration has decided to use the Fermilab supported online software package VAXONLINE. All the E790 software will be in the context of VAXONLINE, which is modularized into different packages, e.g., Event Builder (collects data from hardware), Consumer (user

interface for unpacking, analysis, monitoring, display, etc.), Mencom (menu package), Global Menu (control of the program by a menu), Run Control (program control), etc.

Iowa is responsible for the overall user interface, Consumer, and for much of the analysis effort in the context of calibration. As of now, it is also taking care of the packages like Mencom, Courier, and Global Menu. The primary responsibility is the task of monitoring, which includes special online displays. A postdoc, Abdelkader Hamrei, from France has recently joined the ZEUS collaboration from the University of Iowa, and is residing at Fermilab. A graduate student, Maria Roco, has completed the course requirements at Iowa and has also moved to Fermilab in October.

Virginia Polytechnic Institute (L. Mo)

The VPI is responsible for the photomultiplier base and high voltage control. The construction of photomultiplier tube bases had a late start due to various delays, mainly caused by late delivery of components and training of people. The sockets had to be provided by our Japanese collaborator which also introduced delay.

Finally, the job was underway. Approximately 1,000 bases were produced by the end of 1989. The production rate has been improved from about 50 a week to about 100 a week. These bases were built with the newly developed hybrid circuits. The small size of the hybrid circuits made the construction job easier because there is more space to work with. Also a 1 mega-ohm resistor is installed in the cathode circuit to protect the base from sparking damages. During the initial operation period of the prototype BCAL module, the bases failed at a rate of 2 to 4 a week. It was found that serious sparkings had occurred across an optical transition piece between the photocathode and the wavelength shifter. These discharges wrecked a good number of bases by destroying the capacitors in the Cockcroft-Walton voltage chain. After rewapping the optical elements and the installation of "spark protectors" by ANL collaborators, the sparkings have been significantly

reduced. The 1 mega-ohm resistor can help further by dissipating the sparking energy.

The high voltage controllers are also changed from the CAMAC modules to the newly developed ones using Ethernet communications. Each BCAL module will have one controller station, located in the middle of the "Holey plate". Each controller station consists of one CPU board and six analogue boards. The CPU board contains a processor, memory, ROM for softwares, Ethernet chips for communications with TCP/IP protocols, and RS232 ports. The database for HV settings will be downloaded into the memory. The CPU will then execute the softwares to control the analogue boards. Each analogue board can control and measure the HV's of 32 bases. The first controller station of this type has been installed on the prototype BCAL at Fermilab. Since the Ethernet softwares are still not yet ready, the controller is operated with the RS232 communication port. The final version of the controller has been frozen and set out for production.

Pennsylvania State University (J. Whitmore)

The Penn State group is responsible for the laser calibration and monitoring system for the ZEUS BCAL modules. During this past six month period, we have designed a laser flasher setup employing a fiber optic distribution system which will simultaneously project the light into all 6000 phototubes (PMT) in the barrel calorimeter. We have located a company to build the fiber splitters and we are now well into production on all aspects of the system.

The table below shows the status of the end of CY1989 and we expect to have the splitters available (either installed, through module # 4, or at Penn State) for modules 1-11 by the end of January. The splitters send the laser light into a 'pigtail' which is glued into the transition piece which is located just in front of the PMT. We are expected a shipment of about 500 pigtails also at the end of January which will be enough to outfit EMC modules 1-8, and HAC modules 1-10.

Module #	Pigtails Shipped		1-to-81 Splitters Installed			
	EMC (106)	HAC (56)	Side A		Side B	
Prototype	ANL 9/23/89	ANL 9/23/89	(#1,20%)	7/31/89	(#4,14%)	9/24/89
1	OSU 7/11/89	OSU 7/11/89	(#3,10%)	8/18/89	(#2,19%)	8/4/89
2	LSU 9/20/89	OSU 9/8/89	(#5,19%)	11/3/89	(#6,93%)	11/7/89
3	LSU 12/15/89	OSU 10/17/89	(#7,15%)	12/8/89	(#8,13%)	12/8/89
4	LSU 12/15/89	OSU 11/28/89	(#10,13%)	12/9/89	(#9,10%)	12/9/89

Over the past four months, we have been acquiring laser data from the prototype and first two production modules. The results indicate that the number of photoelectrons per layer per PMT for the EMC channels average about 0.65 for the prototype and first production module and about 0.97 for the second module. The HAC channels have about 1.35 pe.layer/PMT. These measurements agree well with the measurement using the HV and gain of the PMT, as well as with the cosmic ray measurements. The system appears to be stable to about the 3% level over the measured period of 10 days but more work is needed to understand this limitation and to try to reach the 1-2% level. Two reports describing these results are nearing completion.

Early in CY1990 we expect to have laser data from the prototype located in the test beam stand at Fermilab. Progress is continuing on the software and additional data will be forthcoming in the next month. To date we have spent about \$117 K on the ZEUS project at Penn State. (B. Musgrave)

II. THEORETICAL PROGRAM

Theorists in the High Energy Physics Division have carried out a program of formal and phenomenological research. Topics included in this program are physics at fixed target energies, quantum groups and algebras, transverse spin observables in QCD, spin observables in elastic pp scattering at large t , the gluonic contribution to the proton's spin-dependent structure functions, prompt-photon production with polarized-proton beams, a new strong-interaction threshold, exchange graphs in quantum hydrodynamics, hadronic heavy-quark production, top-quark production in e^+e^- collisions, the impact of new $|V_{ub}/V_{cb}|$ and ϵ'/ϵ measurements on weak mixing angles, gauge-boson couplings, W and Z production, gravity and the false vacuum state, the stability of the vacuum, lattice simulation of meson-exchange forces, sphalerons and instantons.

Physics at Fixed Target Energies

Extracted beams of high energy neutrinos, muons, photons, mesons, hyperons, and nucleons have been employed at Fermilab since early in the decade of the 1970's to carry out a broad and compelling program of investigations. Throughout this period, a steady stream of accelerator and detector innovations has increased the power of the Laboratory's facilities. Recently, further major accelerator upgrades have been proposed to ensure that Fermilab will be able to address the important physics issues of the decade of the 1990's. At the Workshop on Physics at Fermilab in the 1990's, Breckenridge, Colorado, Ed Berger presented an invited introductory review of physics opportunities at fixed-target energies. In his paper, available as ANL-HEP-CP-89-125, Berger examined electroweak tests; deep inelastic lepton-hadron scattering; tests of perturbative quantum chromodynamics; heavy quark production, spectroscopy, and decays; prompt photon production; massive lepton pair production; and spin dependent phenomena. He stressed the interest in precision measurements of $\sin^2\theta_W$ at relatively low Q^2 as well as a comprehensive program of nucleon and nuclear structure studies with deep inelastic lepton-hadron scattering. In charmed meson and baryon production,

he showed that rich possibilities are present at statistical levels of 10, 100, and 1000 times the sample of experiment E691. Berger mapped out a systematic program of studies of bottom physics: cross sections, branching ratios, rare decays, mixing, and perhaps CP violation. Throughout the review, he mentioned tests of QCD dynamics in deep-inelastic scattering, in heavy flavor, prompt photon, and massive lepton-pair production, and in studies of spin dependence. The roles of prompt-photon, massive-lepton-pair, and spin-dependence studies as probes of the parton structure of mesons, nucleons, and nuclei were described.

Quantum Groups and Algebras

Cosmas Zachos, together with Tom Curtright (Univ. of Miami), has made progress in quantum algebras, a subject that has generated considerable excitement during this past year. The mathematical structures of quantum algebras are "quantum deformations" of standard Lie algebras, and occur in numerous, apparently disparate areas of physics, such as factorizable S-matrices of integrable models, rational conformal field theory, vertex models associated with Chern-Simons gauge-theory loops and the concomitant knot theory, and q-strings. They reduce to the conventional Lie algebras in the "classical limit" ($\hbar=0$), and in many ways parallel the features and representation theory of the Lie algebras, despite the occurrence of novel and, occasionally, surprising properties.

Curtright and Zachos invented a method involving invertible functionals that map the SU(2) generators to quantum-SU(2) generators. The resulting quantum generators cover virtually all quantum deformations in the literature. The Curtright-Zachos construction 1) connects any two quantum deformations to each other, 2) relates the representation theory of a quantum algebra to that of its classical limit, 3) generates the comultiplication (tensor multiplication) operation of the deformation in question in a mechanical fashion, and 4) suggests promising candidate deformations of the classical Virasoro algebra. This approach has attracted attention in other institutions, where workers have extended this method to general SU(N) groups and to new quantum deformations.

Transverse Spin Observables in QCD

For light quarks, the conservation of helicity follows from the vector nature of the gauge interactions. Observables that depend directly on quark helicities, therefore, have a natural interpretation in the formulation of QCD. However, when a hadron with large momentum is polarized in a direction transverse to its momentum, the relationship between the hadron's spin and the spin and momenta of the constituent quarks and gluons is more obscure. Dennis Sivers is investigating the information content of transverse spin observables in QCD.

Spin Observables in Elastic pp Scattering at Large t

Gordon Ramsey (Loyola) and Dennis Sivers have proposed a simple model for elastic pp amplitudes at large t that combines the Landshoff mechanism and an approximation to quark interchange scattering. The relative normalization of the Landshoff and quark interchange diagrams provides a free parameter, which is only loosely constrained by theory. It is possible to determine this normalization from one set of spin measurements and to predict the energy and angular dependence of all other spin observables.

Gluonic Contribution to the Proton's Spin-dependent Structure Functions

Recently, the EMC collaboration has measured the proton's spin-dependent structure function g_1 . In the naive parton model, the conclusion drawn from these data is that the quarks carry very little of the proton's spin. This conclusion runs counter to intuition derived from nonrelativistic models of the proton, and it has motivated a good deal of theoretical work. In an attempt to reconcile the EMC result with the conventional wisdom, Altarelli and Ross (AR) and Carlitz, Collins, and Mueller (CCM) have suggested that, in QCD, the first moment of g_1 receives a contribution from the distribution of polarized gluons in the proton. This gluonic contribution would tend to cancel the quark contribution. The proposed gluonic contribution arises from an order α_s process in which the gluon produces a q and a $\bar{q}$, one of which

interacts with the virtual photon. On the other hand, Manohar and Jaffe (MJ) have concluded, on the basis of an analysis involving the operator-product expansion, that the gluon distribution gives no contribution to the first moment of g_1 .

Geoffrey Bodwin and Jianwei Qiu have resolved this apparent contradiction by investigating the claims of AR, CCM, and MJ in the context of QCD perturbation theory (ANL-HEP-PR-89-83). They found that the size of the gluonic contribution depends crucially on the method used to factor the hard, perturbatively calculable part of the QCD process from the soft part of that process, which must be absorbed into the definition of the quark distributions. Bodwin and Qiu argued that the method of factorization employed by AR is unsatisfactory because it violates gauge invariance, while the method of CCM does not ensure that all of the soft contributions have been removed from the so-called hard part. Bodwin and Qiu also showed that, in general, any factorization prescription that respects gauge invariance, Lorentz invariance, and parton-level analyticity leads to a vanishing gluonic contribution to the first moment of g_1 . By relaxing the requirement of Lorentz invariance, they devised a factorization prescription that does lead to the nonvanishing gluonic contribution to g_1 advocated by AR and CCM. The lack of Lorentz invariance in this method is not contrary to general principles, since it amounts to making use of the special Lorentz vector defined by the proton's momentum. However, the resulting quark distributions must be used with caution, since they do not satisfy the Bjorken sum rule in its usual form. The possibility of such a Lorentz-variant factorization method is absent in the analysis of MJ, since, as is conventional, they considered only Lorentz-covariant operators in the operator-product expansion.

On the basis of these results, Bodwin and Qiu argued that the presence or absence of a gluonic contribution to the first moment of g_1 is purely a matter of the convention used in defining of the quark distributions. The choice of convention has no physical consequences, but one must take care to employ a single convention consistently for all processes. At present, there seems to be no argument that establishes one definition of the distributions as being

closer than another to intuition derived from nonrelativistic models of the proton.

Prompt-photon Production with Polarized Proton Beams

Ed Berger and Jianwei Qiu have calculated cross sections for inclusive direct-photon production at large transverse momentum in proton-proton and proton-deuteron interactions. In their Rapid Communication, Phys. Rev. D40, 3128 (1989), they argued that inclusive direct-photon production at large transverse momentum with longitudinally polarized beams and targets is an incisive probe of the polarized gluon density in a nucleon. To help motivate future experiments and to assist in their design, Berger and Qiu provided predictions of the polarization asymmetry for a range of reasonable choices of the polarized gluon density. The cross sections are small at fixed target energies, but the effort to measure them must be made if the polarized gluon density $\Delta G(x, Q^2)$ is to be determined. In order to obtain their predictions, Berger and Qiu parametrized spin-dependent parton densities and computed evolution of these densities with Q^2 . Berger and Qiu's densities provide good agreement with the spin-dependent structure function $g_1^p(x, Q^2)$ measured in deep inelastic lepton scattering. Measurements with polarized deuteron targets would take advantage of recent advances in the technology of polarized target materials.

A New Strong-Interaction Threshold?

Alan White, in collaboration with Kyungsik Kang (Brown University), has studied the apparent conflict between the relatively low $\bar{p}p$ total cross-section recently measured at the Fermilab Tevatron and the large value of the real part of the elastic $\bar{p}p$ amplitude measured at the CERN collider. In a paper that will shortly appear as an Argonne preprint, White and Kang showed, by using a simple dispersion relation model, that the Fermilab and CERN results can be compatible if there is a genuine physical threshold just below the CERN energy range. They also suggested that this threshold be identified with diffractive production of a new particle of mass 30 GeV, which may have been seen in mini-Centauro and Geminion cosmic ray events. White and Kang

argued that, if one assumes the recently-suggested "strong-interaction" properties of high-energy photons, then this new particle can be identified consistently as an η -like state composed of color sextet quarks. The Geminion events can then be identified as two-photon decays via the anomaly. It seems plausible that most (if not all) Cosmic Ray exotic events, including those thought to involve a strongly-interacting photon, may be attributable to a strongly-interacting color-sextet-quark sector of QCD. Such a sextet-quark sector has already been proposed as the origin of the electroweak Higgs sector. White and Kang discussed how this sector could contribute to collider diffractive cross-sections.

Exchange Graphs in Quantum Hadrodynamics

Large- N hadrodynamics has nontrivial selection rules. Among these are the $I_t = J_t$ and proportionality rules recently discovered by Mattis and collaborators. Peter Arnold and Michael Mattis (Los Alamos National Lab) have shown that one consequence of these rules is that it is possible to sum arbitrarily complicated exchange contributions to baryon-baryon and meson-baryon scattering to leading order in $1/N_c$, where N_c is the number of colors. A semi-classical structure is obtained, in close correspondence with vector-meson-augmented Skyrme models.

Hadronic Heavy-Quark Production

Ed Berger has prepared written versions of invited reviews of heavy-quark production given at two major conferences: the IX International Conference on Physics in Collisions, Jerusalem, June 1989, and the Workshop on B Factories and Related Physics Issues, Blois, France, June, 1989. These invited reviews, available as Argonne reports ANL-HEP-CP-89-107 and ANL-HEP-CP-89-109 include a summary of Berger's computations of the cross sections for charm-, bottom-, and top-quark production in $\bar{p}p$, π^-p , and pp interactions at fixed-target and collider energies. The calculations were carried out through next-to-leading order in QCD perturbation theory. Predictions were presented for various measurements, including expected quark-antiquark correlations. Berger explored the sensitivity of results to the choices of renormalization/evolution

scale, parton densities, Λ_{QCD} , and heavy-flavor masses. Comparisons with available data showed that good agreement is obtained for reasonable values of charm and bottom quark masses and other parameters. Open issues in the interpretation of results were summarized, including the large size of the next-to-leading order contributions, the proper definition of the gluon density, the nuclear A-dependence of charm cross sections, the role of final-state interactions, and higher-twist effects.

Top-Quark Production in e^+e^- Collisions

Russel Kauffman has continued his work on the production of top quarks via vector-boson fusion in very high energy e^+e^- collisions. Working in the effective-boson approximation, he has surveyed the range of production processes, calculating cross sections as a function of the top mass for each one. Included were $\gamma\gamma$, WW , ZZ and γZ production of $t\bar{t}$ pairs and γW and ZW production of $t\bar{b}$. Also considered were the interactions of so-called "beamstrahlung" photons, which are hard photons coming from the interaction of the colliding bunches (ANL-HEP-PR-89-118).

Impact of New $|V_{ub}/V_{cb}|$ and ϵ'/ϵ Measurements on Weak Mixing Angles

Chien-Peng Yuan (in collaboration with J. L. Rosner, Enrico Fermi Institute and Department of Physics, University of Chicago) has studied the impact of the new $|V_{ub}/V_{cb}|$ and ϵ'/ϵ measurements on weak mixing angles in the Standard Model, $SU(3) \times SU(2) \times U(1)$. This work is described in the ANL preprint ANL-HEP-PR-89-119. The value of the weak mixing parameter $|V_{ub}|$ has recently been determined to be of order $0.1|V_{cb}|$. A recent determination of ϵ'/ϵ in CP-violating kaon decays gives $(-0.5 \pm 1.5) \times 10^{-3}$, in contrast to an earlier measurement of $(3.3 \pm 1.1) \times 10^{-3}$. The implications of these results for the magnitudes and phases of the Kobayashi-Maskawa matrix elements and for the top quark mass were explored in this work.

Gauge-Boson Couplings

Coincidence $W\gamma$ production and radiative W decays are particularly interesting theoretically, since they depend on the $WW\gamma$ coupling which, so far, has not been tested experimentally. Within the Standard Model (SM), at tree level, the $WW\gamma$ vertex is completely fixed by the gauge-theory structure of the model. The observation of the $WW\gamma$ coupling, thus, is a crucial test of the SM. In their paper, ANL-HEP-PR-89-86, to be published in Phys. Rev. D (1 March, 1990), Ed Berger and Ulrich Baur (CERN/University of Wisconsin) have studied the capability of future collider experiments at the Fermilab Tevatron to probe the $WW\gamma$ vertex via $W\gamma$ production and radiative W decays. In their analysis, they used the most general $WW\gamma$ coupling that is accessible in the annihilation processes $q\bar{q}' \rightarrow W\gamma$ and $q\bar{q}' \rightarrow W \rightarrow f\bar{f}'\gamma$ for effectively massless quarks. Four different anomalous couplings are allowed by electromagnetic gauge invariance and Lorentz invariance. Apart from anomalies in the $WW\gamma$ vertex, Berger and Baur assumed the SM to be valid.

Berger and Baur showed that, at the Tevatron, for an integrated luminosity of 100 pb^{-1} , the $WW\gamma$ vertex can be measured with 25-40% accuracy in $W\gamma$ production. They found that the limits that can be obtained from radiative W decays were found to be significantly weaker. Berger and Baur compared the sensitivity to anomalous $WW\gamma$ couplings expected at the Tevatron with low energy bounds and with the sensitivity expected from $ep \rightarrow eW^+X$ at HERA and $e^+e^- \rightarrow W^+W^-$ at LEP200. They also commented on limits that can be obtained with the present data samples from CDF and the CERN UA2 experiment.

W and Z Production

With W and Z bosons being produced at the Tevatron, there is some urgency to understand their production as well as possible in the context of the standard model. Knowledge of the transverse momentum (p_T) distribution of single W and Z production allows one to make a useful test of the standard model and to compute backgrounds to new physics. Peter Arnold and M. Hall Reno (Centro de Investigacion y Estudios Avanzados del I.P.N.) have completed the calculation of the high- p_T production rate to second order in QCD. They

derived analytic expressions for the parton cross-sections $d\sigma/dq_T^2 dy$ for all processes and convolved these numerically with the proton structure functions.

The analysis was restricted to high and moderate values of p_T . For p_T smaller than about 20 GeV, the naive perturbative analysis breaks down, and the perturbation series must be resummed. The small p_T region is crucial, however, because it contains most of the events. Peter Arnold and Russel Kauffman are currently working to extend the analysis to small p_T .

Gravity and False-Vacuum Decay

False vacuum decay occurs by the nucleation of bubbles of true vacuum within the false vacuum. The nucleation may arise either from quantum tunneling or from thermal excitations. In either case, the nucleation process is associated with a solution to the Euclidean equations of motion of the system. Because vacuum energies act like cosmological constants, space is curved in at least one of the vacua, and, in extreme cases, this curvature can play a role in the tunneling process. Treating gravity semi-classically, Peter Arnold has classified all solutions to the Euclidean equations of motion that have at least $O(3)$ rotational invariance. In addition to the $O(4)$ tunneling solution, long known in the literature, he found two solutions that correspond to the thermal excitation of bubbles by Hawking radiation. The standard $O(4)$ process, however, was found to dominate these newly-discovered $O(3)$ processes.

The Stability of the Vacuum

The electroweak vacuum need not be absolutely stable. For certain top and Higgs masses in the minimal standard model, the vacuum is instead metastable, with a lifetime exceeding the present age of the universe. Some have suggested that a metastable vacuum is generally ruled out because high-energy cosmic ray collisions would have induced its decay long ago. Peter Arnold has shown that this conclusion is erroneous and that, in consequence, upper bounds on the top mass derived from stability arguments are relaxed.

Lattice Simulation of Meson-Exchange Forces

Within QCD, it is desirable to have an approach to deal with systems that contain more than one color singlet. Such systems can provide an introduction to the problems of nuclear physics. Lattice gauge theory shows some promise as a theoretical tool for analyzing these systems. D. Richards (U. of Edinburgh, formerly at Argonne), D. Sinclair and D. Sivers have formulated a lattice calculation of a flavor-changing Green's function involving two light quarks and two heavy quarks. The calculation of this Green's function displays meson exchange in the t -channel and provides nontrivial information concerning the range of the nuclear potential. A preliminary version of the work has been presented at a conference and a paper is being prepared for publication.

Sphalerons and Instantons

The Weinberg-Salam model of electroweak interactions violates baryon number conservation. Although baryon number is conserved classically, it is anomalous. At low energies, the rates for baryon-number-nonconserving processes are infinitesimal, but at temperatures above 1 TeV they become substantial. There has long been confusion surrounding this subject because arguments based on instanton techniques seem, at first sight, to conflict with the claims of substantial baryon-number nonconservation at high temperatures. Peter Arnold and his collaborator, Michael Mattis (Los Alamos National Lab), have put to rest the most recent of the instanton-based arguments by studying the problem in a model system: the finite-temperature Schwinger model on a small circle. Like Weinberg-Salam theory, this model is weakly-coupled and has an anomaly. Unlike the Weinberg-Salam theory, it is exactly soluble, and so provides a good testing ground for formal arguments.

III. EXPERIMENTAL FACILITIES RESEARCH

A. Mechanical Support

Polarized Proton Target

He³ recirculating system, leaks in the large He³ pump were located and repaired. Air leakage passed the shaft seals was not acceptable, so the shaft seals were modified to submerge them in pump oil effectively stopping air leakage passed them. Mechanical vibration from the He³ pumps was affecting the NMR system. This vibration was reduced by adding resonant spoilers and dampers at various points in the system. The counterflow heat exchangers in the nitrogen cooled air trap proved too small at high flow rates so the traps and the heating exchangers were redesigned and refabricated to handle the larger flows. Liquid He⁴ transfer lines to and from the 1000 liter, 300 liter, 30 liter dewars, and superconducting magnet were designed and built by FNAL and ANL personnel. Noise from the He⁴ pumps was annoying and required the construction of an enclosure to isolate them from the inhabited area. The dilution refrigerator was cooled down and operated at temperatures of from 50 - 90 milli kelvin. Remote controls for the dilution refrigeration valves were constructed and operated satisfactorily.

Proton Decay

The construction of 5-ton modules for the Soudan 2 detector resumed in August when a new shipment of polystyrene inserts was received. Module fabrication had been stopped in May when it was discovered that the previous shipment of inserts was contaminated with an unknown electronegative substance which inhibited drifting. Inserts are formed plastic sheets which surround each of the 240 corrugated steel plates in a module in order to provide extra electrical insulation. The three modules which were built with contaminated inserts will be disassembled and rebuilt. Twelve additional modules, #78 through #90, were constructed during the last half of 1989. Twelve modules were shipped to the Soudan mine site before the end of the shipping season in December.

Because of the three month delivery time needed for replacement inserts, there was a substantial period when Soudan modules could not be constructed. During this time an air-conditioned enclosure was installed for heat-sealing the plastic inserts around the corrugated steel sheets. This operation involves handling over four tons of steel for each module, and in the past has been the source of significant delay and discomfort during the hot summer months. This new facility allowed module construction to get off to a fast start when the new insert material was delivered.

Also during this period the first 5-ton module (#80) with the new 23-trace bandolier was assembled. The extra two bandolier traces are expected to improve short distance drifting in the Hytrel drift tubes. The module stack faces were flattened and the proportional wire readout planes were installed using the same techniques as at the Soudan mine. On most modules these operations are not performed until the module and readout planes have arrived at the Soudan mine underground laboratory. The module was then installed on the cosmic-ray test stand so that its performance could be studied using the high flux of cosmic ray muons available on the earth's surface. Data acquisition was just getting underway at the end of the year.

Collider Detector at Fermilab

Fixturing for production preradiators was designed and built. Two prototype chambers were also completed and tested. Modifications were made to the prototype chambers finalizing the design. Production chambers were started.

ZEUS

Duplication of HAC stacking fixtures was completed and they were shipped to KFA Julich. Julich will start production and stacking in January 1990. Design of shipping fixtures for shipment of modules between Germany and the U.S. was completed.

(N. Hill)

B. Electronics Support

Our major effort during this period with regard to support of the ZEUS calorimeter is in the design of the first level calorimeter trigger processor (CFLTP). The ZEUS calorimeter first-level trigger processor presents summary data on energy deposition in the uranium/scintillator sampling calorimeter to the global first-level trigger (GFLT). The summary data includes global and regional sums of electromagnetic and hadronic energy deposition, the number of isolated muons and isolated electrons, missing transverse energy, jet cluster information, and the likelihood of beam-gas background. The CFLTP receives data from 16 regional trigger pre-processors which digitize the calorimeter signals and perform regional energy sums and logical operations. Design and construction of these regional pre-processors is the responsibility of our collaborators from Wisconsin. The CFLTP is a pipelined processor that contains data from a number of crossing periods at any instant. It can capture input and output data from a sequence of up to 4096 consecutive beam crossings or first-level trigger events for detailed examination. All data variables are accessible for histogramming; the histograms are evaluated by 88000 RISC processors that reside in VME buses, embedded within the CFLTP. Input or output data emulation capability is provided to operate the CFLTP at full speed in a stand-alone mode. In addition, the design includes a number of utility functions to inspect the data flow and to assist in troubleshooting. The primary effort during the period has been the design of the input card for the CFLTP. The input card has been designed and prototypes are currently being manufactured as a 12U 400mm VME card. This is a ten layer card designed entirely in surface mount technology. Aside from the input which receives the data at ECL levels, the circuit is designed in high performance CMOS discrete devices with a few EPLD's, and with F logic used at some points where propagation delays are critical. The data from the adder cards is clocked differentially at ECL levels with a 24ns period on ribbon twisted pairs to the CFLTP. Figure 13 shows a block diagram of the CFLTP input card which receives this regional data from 2 of the 16 pre-processor VME crates. Eight of these input cards serve the 16 regions of the calorimeter. Upon arrival, the data bits are latched, de-multiplexed, and synchronized with the local clock. The data are concatenated in pairs of words, and then clocked forward on a 48ns clock. The data paths on the input

Fig. 13. CFLTP input card block diagram.

card are configured by the contents of the on-board status register which is written/read from VME. In addition, a global address register exists on the input cards so that the cards may be addressed in subsets with global writes. There are two memories on the input card - the trigger fifo, a dual-port SRAM which emulates a fifo, and the main memory, 8k 256 bit words of fast CMOS SRAM. The main memory can accumulate crossing data directly, crossing data from the trigger fifo, or simulated crossing data loaded from VME. Data may be stored in the trigger fifo to be written into main memory on receipt of a first level accept, which occurs approximately 35 crossings after the CFLTP has sent this data to the GFLT. VME may have access to the memories at the same time that data is flowing through the CFLTP to the backplane, where the cards are located which implement the global algorithms. Most of the algorithms have been definitized and are regarded as firm. A few algorithms, particularly those which recognize clusters for jet identification, are not entirely finalized. A trigger Monte Carlo has been written and the performance of the algorithms is being studied. The conceptual specifications for the hardware are firm, and detailed design will proceed in step with finalization of the algorithms. Codes for the 88000 processors are being written in C to handle execution of diagnostics, initialization of lookup tables, histogramming variables, data transfer to the host, etc. Plans call for calorimeter modules to be calibrated in an on-going program in a test beam at Fermilab (E790). Subsets of the CFLTP hardware will be operated in the Fermilab test beam in conjunction with calorimeter module tests prior to the actual installation at HERA.

The SSC radhard electronics program in the HEP division is working concurrently on several different goals, including: (1) setting up a test program at various Argonne radiation facilities in order to perform test irradiations of potential SSC electronics; (2) establishing working relationships with several radhard semiconductor fabrication houses including Hughes Aircraft Co. and UPMC; (3) setting up a VLSI development system in the HEP department; and (4) designing a monolithic front-end signal processor for use inside a liquid-argon calorimeter at SSC. In the field of radiation damage testing, two types of radiation are of interest: neutron damage studies and gamma-ray damage studies. We are currently performing neutron

studies at the IPNS facility at Argonne at fluences up to $1\text{E}15$ neutrons/cm². Figure 14 shows a sample of data taken at the IPNS of neutron damage in high performance JFET's. So far, we have irradiated discrete JFET transistors and have determined that at radiation levels expected at the SSC, the damage does not degrade the DC characteristics of the devices and degrades the noise performance to acceptable levels. For gamma-ray studies, we are using the Cobalt-60 source in the Argonne Biological and Medical Research Division. We plan to start doing irradiations of CMOS transistors in early 1990. In order to facilitate the studies, we have purchased a semiconductor noise analyzer and a parameter analyzer to measure DC characteristics and leakage currents. We are currently negotiating with several companies which specialize in radiation-hard semiconductors. Hughes Aircraft Co. has three radhard CMOS processes, including one which is optimized for low noise at low-temperatures. This would be ideal for our application, where the electronics must be situated in liquid argon (90 K). We plan to receive test devices from the three Hughes processes in early 1990, which we will test in the radiation sources here at Argonne. In addition, UPMC has a radhard CMOS process which we will be evaluating as well. In order to actually design monolithic circuits, it is necessary to have the appropriate CAD tools in order to do layout and simulation. We are in the process of purchasing a Sun workstation for this purpose. The workstation will have a 19" color screen in order to do custom CMOS layout as per the design rules of Hughes and UPMC. Analog and digital circuit simulation will be performed on the workstation as well. Initially, the workstation will run public domain software, such as U.C. Berkeley's MAGIC and SPICE programs, and support will be supplied by the instrumentation division at ORNL. Upon evaluation of the CMOS processes from Hughes and UPMC, we will commence designing a complete front-end signal processor for liquid-argon calorimetry. This work will be in conjunction with the instrumentation division at BNL. Current plans consist of designing a charge amplifier, shaping amplifier, analog storage bank, and trigger-summing amplifiers in a combination of CMOS and JFET technologies. Specifically, the design might consist of a JFET input transistor (desirable due to low noise capability) attached to a single CMOS chip (desirable due to low power and high density capabilities) on a ceramic substrate.

N13,14/132L
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Fig. 14. Sample of data taken at the IPNS of neutron damage in high performance JFET's.

In addition, work continued to support the nucleon decay experiment, Soudan 2. Our involvement has become one primarily of construction and maintenance. During the period we performed the following tasks:

- a) Fabricated and tested 400 PDK edge trigger cards.
- b) Modified 150 PDK analog cards with edge trigger rolling or circuit.
- c) Fabricated and tested 6 PDK Anode high voltage distribution modules.
- d) Fabricated and tested 2 PDK gas overpressure protection modules.
- e) Designed and prototyped PDK Top/Bottom high voltage isolation system.
- f) Fabricated and tested 3 PDK Drift high voltage distribution modules.
- g) Repaired existing PDK electronics as necessary.

There were numerous smaller tasks which were performed during the period. A random prescaler was designed for an experiment at Fermilab and is in the process of being built. Several prototype circuits were built to allow checkout and interface to the ZEUS prototype global first level trigger which has been built by Tokyo University. A VME Analog Demultiplexer card was designed and prototyped. We hope that this card will be used in the ZEUS slow control in conjunction with the VME analog multiplexer which is currently in use at CERN, DESY, Rome, and elsewhere. (J. Dawson)

C. Computer Support

During the second half of the year the new MicroVAX cluster was installed and made operational. The cluster consists of three MicroVAX 3800 systems, and three VAXstation 3100 workstations. Two of the MicroVAXes are used for timesharing applications and the third as a file, mail and print server. A high performance disk controller provides access to 5.0 Gbytes of new disk storage capacity and six 8 mm 2.3 Gbyte tape cartridge drives provide backup and data archiving support. Postscript printers were installed with software to support TEX and graphics applications.

The MicroVAX cluster configuration provides efficient general purpose computing resources by offloading most of the system work to the server leaving the timesharing systems more CPU cycles and I/O bandwidth to run batch

and interactive applications. The disk controller provides a direct data path to each MicroVAX relieving the Ethernet of the heavy traffic load typical of most local area clusters. (J. Schlereth)

D. Polarized Target Development

During the second half of 1989, installation of the E-704 target continued at Fermilab, culminating in a test run of the dilution refrigerator in December. The following sections detail the work on each subsystem and the results of the test run.

^3He Recirculation System

Leak checking of the system was completed. Several leaks in the main ^3He pump were located and repaired, including a large leak in the shaft seal of this pump. In order to reduce the leakage to an acceptable level, it proved necessary not only to replace the shaft seal but also to back it up with a second seal and interpose a static oil barrier. The high pressure portion of the system was pressure tested, and the set points of all relief devices and pressure switches were checked. The mechanical vibration of the pump system was found to be too large for proper operation of the NMR system. This problem was cured by the installation of spoilers and dampers. The residual gas analyzer was installed and used to investigate the total air infiltration rate of the system. During these tests it was noticed that the pump set evolves hydrogen gas, presumably as a by-product of pump oil cracking. The amount of hydrogen is such that it may present an operational problem. By year's end, several methods of source reduction or trapping of the hydrogen had been considered, without any clear solution. The air trap was tested and it was found to have inadequate heat exchange at the highest flow rates. The trap was redesigned and then gave satisfactory performance.

^4He System

The gas collection piping was completed, as was the piping for pressurization of the liquid helium dewars and for pneumatic control of the liquid helium transfer valves. A leaky weld was discovered in the 30L helium

dewar. After consultation with the manufacturer determined that this was not a ASME Code weld, this factory defect was repaired by a Fermilab welder. The helium transfer lines from the 1 kL dewar to the 300L and 30L dewars, and from the 300L dewar to the Solenoid were designed jointly by Argonne and Fermilab, and fabricated by Fermilab. The transfer line from the 30L dewar to the DR, furnished by Saclay, was modified by Argonne to fit the E-704 arrangement. A noise-reduction enclosure was built around the ^4He pumps. The dewar instrumentation was labelled with Fermilab-style metal tags.

Dilution Refrigerator

The thermometry system for the DR was designed, built, and installed as part of the system monitor computer. The insulating vacuum pumps, piping, and instrumentation were installed. The DR itself was restored to operating configuration from the condition in which it was shipped from Saclay, and leak checked. The connections to the ^3He and ^4He pumps were plumbed.

Motor Drives

The 12-channel motor controller/readout was completed. The motor drive for the microwave power attenuator was designed and installed, as were the valve drivers for the main DR needle valves and the ^3He gas metering valve.

Miscellaneous

The preparation of the microwave system was finished, including some repairs to the source power supply. The operating system was installed on the system monitor computer. About three-fourths of the system interlocks and alarms were wired.

Safety

Several reviews by the Fermilab Cryo Safety panel took place during this period. More than six man-months of effort were spent on further substantial documentation and analyses of the target systems. During the process, the panel requested some changes to the apparatus. Among these were the replacement of some flexible metal hose sections in the gas collection piping

and the addition of fuses to the emergency pump circuits. These activities sufficed to earn the Safety Panel's (grudging) approval for our three day test run of the DR on December 6, 1989, the date that the test started.

Test Run of the Dilution Refrigerator

The DR underwent its first test since its move from Saclay to Fermilab. The test was timed to coincide with the presence at Fermilab of P. Chaumette, the Saclay engineer responsible for the design and construction of the DR.

The same base temperature (without power dissipation in the target cell) which had been reached at Saclay, around 50 millikelvin, was achieved at Fermilab. It was found that the cool-down procedure and operating conditions for this Frozen Spin Mode were similar to those used at Saclay.

The Fermilab installation thus proved to be well conceived for this refrigerator. The relationship between temperature and the He^3 high pressure, He^3 flow, and He^4 flow was explored. From these measurements we assessed the stability of the DR cryogenic regime around the normal operating point in the Frozen Spin Mode.

During the measurements, one of the diaphragm pumps ruptured a membrane. A few hours were lost to identify the failure and replace the membrane. This was the only equipment failure during the test. Much of the instrumentation was used for the first time during this test and proved to be immediately operational.

Since the DR behaved in the same manner for the cool down and the same final temperature was reached as with the Saclay installation, we decided not to measure the refrigeration power (temperature versus microwave power dissipated in the target cell). This measurement had been made at Saclay, and the refrigeration power sufficed to polarize a full load of pentanol beads to 90% free proton polarization in 2.5 hours. The refrigeration power will be greater at Fermilab because of the higher pumping speed available (5500 m^3 per hour instead of 3000 m^3 per hour at Saclay).

Once the operating point of the Frozen Spin Mode was established, the remaining time was devoted to verifying the power failure mode of operation. After 2.5 hours about 80% of the He^3 mixture was pumped back into the storage

tank, and approximately 5 liters of liquid He^4 had been consumed from the DR service dewar. The operation was interrupted due to an incorrect pressure switch setting on the emergency pump. From the measurements made during the first 2.5 hours it is concluded that for an unattended power failure the system is protected for many hours against loss of He^3 and melting of the target beads.

Contamination consisting of hydrogen and air in the He^3 system had been a concern since its detection a few months ago. During the present DR test, the air trap ran continuously for three days without plugging. Most of the hydrogen in the system is trapped in the DR itself. No plugging was observed during the two days the DR was below 20K, however, there were signs that it was close to the allowable tolerance of contamination. Trapped contaminant gases were analyzed throughout the warm up period. From these measurements it is estimated that the rates of evolution during these tests were on the order of 1×10^{-3} (torr x L)/sec for nitrogen (air) and 4×10^{-3} (torr x L)/sec for hydrogen. These rates are consistent with those expected from the different measurements made prior to the run. Only one air trap was installed during this run. The final tandem installation with two traps will be ready for the next test in January 1990 and will allow trap regeneration without interrupting the DR operation, thus improving the situation with respect to contamination by air. For the hydrogen contamination, the following possibilities are under investigation:

- Replace the present pump oil either by a new load treated at Fermilab by the procedure used for the Main Refrigeration System, or by a different oil currently used in PPT pumps (of different type) at LAMPF.
- Add either a He^4 cooled trap or a Palladium catalyser in the He^3 system.

The next test run starting in January 1990 will be longer and will thus provide more information on the sensitivity of the DR to gas contamination. This is still the major unknown factor because it depends on the places where frost settles initially and resettles after temperature changes. The most sensitive element is probably the He^3 Flow Control Valve. (D. Hill)

IV. ACCELERATOR RESEARCH AND DEVELOPMENT

A. Advanced Accelerator Test Facility

Wakefield Experiments

Experiments performed at the AATF during this period centered on better understanding the properties of Cherenkov Wakefield Accelerator (CWFA) devices.

The initial CWFA experiments performed last spring detected no deflecting wakefields, and the initial analytic calculations seemed to indicate that these transverse wakes would be vanishingly small at the relativistic beam energies used in our experiments. Because of its potential significance to accelerator technology, this result attracted much interest. People within ANL's Accelerator Group and at other laboratories continued to address the difficult mathematics of the problem. After considerable cooperative effort it was determined that deflecting wakes are in fact present, although with apparently smaller amplitudes than had been observed in the AATF structure or plasma wakefield experiments. A series of new experiments compared wakefields in dielectric tubes with those in pillbox resonator arrays having identical bores and similar accelerating mode frequencies. The experiments have shown that CWFA devices do develop deflecting wakes from radially offset drive pulses and that these wakes are smaller than those excited in comparable iris-loaded structures.

Computational Accelerator Physics

Work was initiated on a new wakefield code, ARCHON. Based on a finite difference time domain algorithm, ARCHON was developed for the parallel architecture Connection Machine. In its present form the code is restricted to calculations involving the CWFA geometry; extensions to more general problems are in progress. ARCHON calculations have been verified by comparison with analytic and experimental results. Performance benchmarks have also been obtained. A speedup factor of 2.5 over the same algorithm

implemented on the CRAY XMP has been found for the minimal 8k processor Connection Machine configuration.

AWA Proposal

The AATF has been the basis of an extremely productive and successful research program. All of its original goals have been met and new insights developed. Its performance capabilities do, however, limit our research to very modest accelerating gradients--well below those required to examine some of the problems posed by "real" linear accelerators. Based upon our experience and understanding of wakefield phenomena, we have proposed a phased plan for a new research tool which will extend our work to the next logical level. A feasibility study, preliminary design, and cost estimate was developed for this proposal which promises to provide answers to the most serious questions surrounding wakefield acceleration as a viable new technique for future linacs. The new facility, called the Argonne Wakefield Accelerator (AWA), has the following phases:

- Construction of an intense, short pulse electron source and pre-accelerator. Important for its own sake, this beam would also permit unprecedented studies of nonlinear plasma wakefields and high gradient effects in wakefield devices of all types. The increased drive current would also permit studies of wake phenomena which lie far below the sensitivity of the AATF such as beam coupling impedances of isolated accelerator components.
- Construction of a 1.3 GHz linac especially designed to accept large beam loading. Beam pulses from the electron source will be accelerated to 150 MeV for use in various experiments. Wakefield gradients up to 300 MeV/m should be easily accessible. Another interesting possibility is the use of dielectric-loaded devices for generating high frequency (1-100+ GHz), high power (multi-GW) rf. Such rf sources may find applications in accelerator or other technologies.

- Development of "staging". Staging is the process in which depleted drive pulses are replaced by "fresh" ones in order to extend wakefield acceleration to high energies and to increase the efficiency of a wakefield accelerator. It is expected to be most difficult at low energies where the difference in energies between the driver and accelerated beam is smallest.

The AWA proposal includes development and demonstration of several stages. The final goal of the AWA is demonstration of an efficient, high gradient 1 GeV wakefield accelerator. A succesful AWA program will determine the practical limits and advantages of the wakefield acceleration technique.

(J. Simpson)

V. SSC DETECTOR RESEARCH AND DEVELOPMENT

A. SSC Detector Design Activities

The study group that was begun in May became a major activity during the second half of 1989. Two-day meetings were held in June, July, August, and September (the latter at Oak Ridge National Laboratory). The study grew during this time from the original 50 people from 13 institutions to over 100 physicists from 35 universities and laboratories.

This group of people evolved a detailed concept for a complete general purpose, solenoidal SSC detector. The concept emphasized use of scintillation counters wherever feasible in order to achieve fast the time response needed in the high rate environment at the SSC. Use of scintillator readout in calorimetry was a natural extension of the calorimeters that Argonne and collaborators have developed and built for the HRS, CDF, and ZEUS detectors. The latter two have made use of blue plastic scintillator with sheets of green plastic wavelength shifter. Many of the characteristics needed for an SSC detector have already been achieved by the ZEUS group in the calorimeter they are currently building for use at the HERA ep collider at the German DESY laboratory. Further R&D was focused on the radiation hardness of scintillator, which will be a problem with presently-available scintillator in the endcap region, and on the segmentation and position resolution required by an SSC detector. Use of scintillating fibers in the tracking system built on the R&D done by the Notre Dame group and others during the last few years. Suitable fibers have been developed with adequate light output and attenuation lengths. As for calorimetry, modest improvements in radiation hardness are desirable. Readout of the tracking fibers was suggested to be done with the new Solid State Photomultipliers (SSPM's), silicon devices developed by Rockwell. Although substantial experience must be gained with these SSPM's before we can be confident of their use in an SSC detector, and they have the drawback of being cryogenic devices, they look like an exciting development that may be the key to making scintillating fiber tracking practical at the SSC.

Because of the emphasis on the use of scintillator and other fast devices, the group decided to call itself FAST (Fiber and Scintillator Technology). Detailed concepts were also developed for a muon system, including the interesting possibility of a superconducting air-core toroid for the forward direction, to compensate for the reduction of precision of momentum measurement from the central tracking. John Purcell of Advanced Cryomagnetics, Inc. participated as a consultant, providing a preliminary concept for a "short" (not terminated in iron) superconducting solenoid magnet. Substantial development occurred also for the front-end electronics and triggering system and some understanding was achieved of the requirements on the individual subsystems imposed by the triggering system.

A drawing of the FAST detector concept at the time of the last meeting is shown in Fig. 15. The FAST detector was presented in talks at BNL, FNAL, TRIUMF (Tracking Workshop), and DALLAS (SSC experimenters' meeting) during the summer.

The FAST study group was the nucleus for three proposals made to the SSC Laboratory under the Major Subsystem R&D program. All were approved and have received funding. The three were focused on: a) compensating scintillator plate calorimetry; b) scintillating fiber tracking; and c) muon system. Argonne is directly involved and leading the subsystem project on calorimetry, where H. Spinka is spokesperson, and is pursuing the possibility of superconducting air core toroids in the muon project.

By September, the FAST group was faced with a choice whether to continue the detector design independently to the point of submitting an Expression of Interest to SSCL in May, 1990, or to join with other study groups centered at LBL, FNAL, and KEK, who were pursuing concepts of solenoidal detectors. Although we thought that FAST had some significant advantages over the other concepts, the FAST group recognized that the undertaking was a large one, and that it was preferable for the proponents of a general purpose solenoidal detector to make the technical choices within a collaboration, rather than having a PAC make the choices and having to assimilate "losing" groups later. The various solenoid groups decided to form a joint collaboration at a meeting at FNAL late in September.

Fig. 15a. Side view of FAST SSC detector.

Fig. 15b. End view of FAST SSC detector.

The FAST study group has left Argonne and its FAST collaborators with extensive influence in the new collaboration. Scintillator calorimetry as explored by FAST is arguably the leading technology for that subsystem. Fiber tracking is an important option with great future promise. The collaboration muon group and system concept has grown directly out of the FAST muon group and its work. FAST, along with a KEK group, has made the choice of a short solenoid inside the calorimeter the most likely one to be adopted by the merged solenoid collaboration. Within the leadership of the collaboration Tom Kirk has been a member of the interim steering committee set up to form the new collaboration.

(L. Price)

B. Compensating Scintillator Plate Calorimeter Subsystem for the SSC

A proposal to study compensation scintillator plate calorimeters was submitted to the SSC Laboratory in September. This proposal was an outgrowth of studies of a general purpose (FAST) solenoidal detector design by a large collaboration of physicists. The collaboration involved in the subsystem proposal initially included: Ames Laboratory/Iowa State University, Argonne, Bicron Corporation, Florida State University, Louisiana State University, University of Mississippi, Oak Ridge National Laboratory, Virginia Polytechnic Institute, the Science and Technology Center of Westinghouse Electric Corporation, and University of Wisconsin. The University of Tennessee joined later in the year. Considerable contributions to this proposal were made by several Argonne physicists.

An ad hoc committee was set up by the SSC Laboratory to evaluate the many subsystem proposals received. This committee recommended that our proposal be approved at a somewhat reduced funding level and with a reduced scope. The collaboration met soon after the announcement of the SSC Laboratory's approval of the proposal, and physicists from Argonne, Iowa State and Virginia Polytechnic Institute negotiated funding details in Dallas with SSC Laboratory personnel late in December. The tentative funding level is \$992 K for FY 1990. The memorandum of understanding between the subsystem collaboration

and the SSC Laboratory was discussed, and a first draft produced during the meeting in Dallas. It is hoped that the memorandum of understanding will be completed and funding received so that work can actually begin early in 1990.

(H. Spinka)

C. Muon Subsystem Studies

At Argonne we have carried several responsibilities for the initial design of the muon subsystem for SSC solenoid detector design studies. Overall muon detection design criteria and physics requirements for muon detection were developed and analyzed by a FAST subgroup led by K. Heller of University of Minnesota and T. Fields of ANLHEP. These criteria were documented in September in a report (FASTNOTE 2) which has served as a useful starting point for recent muon studies and muon subsystem proposals.

While the present solenoid detector collaboration was coming together during the fall months, Argonne's work in the muon subgroup focussed upon studying the physics requirements which can be used to define the basic parameters of the forward toroid magnet (field integral, size, and wall thickness). The superior performance of a forward superconducting toroid compared to that of an iron toroid has been analyzed and documented. At the end of 1989, we submitted a subsystem proposal for funding to begin making preliminary engineering designs and cost estimates for the forward superconducting toroid magnets.

(T. Fields)

D. Superconducting Strip Detector R&D

As reported earlier this year, our development work on a superconducting strip microvertex detector has advanced to the point of efficiently detecting X-rays depositing energies approximately 10 times minimum ionizing in granular aluminum strips. Superconducting to normal transitions induced by passage of beta decay electrons from a ^{90}Sr source have also been observed, but the energy spectrum of the electrons makes it unclear whether the transitions were associated with minimum ionizing electrons or were due to more highly ionizing electrons from the low energy region of the beta decay spectrum.

We have followed the completion of this rather successful phase of the work with efforts toward publication of the results, computer simulation of the normal zone formation and propagation processes and preparation for testing similar granular aluminum strips in a high energy hadronic test beam at Fermi National Accelerator Laboratory.

The results and analysis of the testing of granular aluminum strips with radioactive sources will be published in "Nuclear Instruments and Methods in Physics Research" in the near future. The paper includes a discussion of our work on modeling the growth of the initial normal region created by ionization energy deposited by the interacting particle, and also the propagation of a normal zone after it has fully bridged the width of a strip. Numerical analyses of the highly nonlinear differential heat diffusion equation were performed on a computer to estimate the radius of the normal region created by x-ray absorption in the strip or passage of an electron through the strip; and also to determine the conditions necessary for propagation of a normal region along the strip.

Estimates of the normal zone radius created by a minimum ionizing particle are shown in Fig. 16 for three different critical temperatures. The calculations were performed using a naive heat balance model. This mode gives results that are roughly a factor of 2 larger than experimental observations. The more accurate numerical analysis of the heat diffusion equation on a computer gives a point for $T_c = 1.5$ K that agrees with experiment. We have rescaled all the points in Fig. 17 by the ratio of the computer solution to the heat balance solution. The data indicate that for a strip width of $1 \mu\text{m}$ operation near 95% of T_c will be necessary to achieve complete bridging of the strip by the initial normal region. This width is near what we anticipate using for strips fabricated for study in a high energy test beam. Further work on "tuning" the critical temperature, critical current, normal state resistivity, and strip width is continuing in order to have the best probability for successful observation of particle induced transitions from minimum ionizing particles.

MIP radius

Fig. 16. Radius of normal zone created by passage of a minimum ionizing particle through a granular aluminum strip as a function of the ratio of bath-to-critical temperature. Data are shown for three different critical temperatures.

Fig. 17. Time evolution of voltage pulse in granular aluminum film operated in liquid helium at $T = 1.31$ K. The bias current is 2.0 mA and critical current is 2.8 mA. The calculated points are from a numerical analysis using experimentally measured parameters for the film.

The simulation study of the propagation of normal regions bridging the strip width has helped in our understanding of the "turn-on" threshold for detection of x-rays in the aluminum strips. The detection circuitry we use for our studies senses the development of a voltage across the strip. When this condition is detected, the strip bias current is lowered to zero, the strip returns to the superconducting state, and the current is reset to nominal. Even though the initial normal region created in the strip by x-ray absorption always bridges the strip width, we still observe a minimum bias current below which transitions are not detected. Below this current the normal region does not propagate sufficiently to develop a detectable voltage across the strip. The voltage developed in the normal region in this case is on the order of 100 μV and requires a high gain, high bandwidth, low noise amplifier for detection. We are currently studying whether higher resistivity, higher T_c strips will allow us to observe voltage pulses at current levels that produce a collapsing normal region. Again we find good agreement between the experimental data and our simulation of normal region propagation. This includes both understanding the threshold for propagation and the time development of a propagating normal region. Our understanding of the latter process is illustrated in Fig. 17 which shows a comparison between data and simulation of the time development of the voltage across the strip as the normal region spreads along the strip. The agreement of the two lends confidence to our effort of defining the physical strip characteristics via the simulation study.

During the first half of calendar year 1990 we expect to expose granular aluminum strips to a high energy hadronic test beam at Fermilab in order to determine whether we are able to design superconducting strips that can efficiently detect minimum ionizing particles, and, thus are able to function as the detecting medium in a tracking detector with spatial resolution of a few microns.

(R. Wagner)

VI. PUBLICATIONS

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Possible Use of Inclusive Spectroscopy in B Decays

H. Lipkin (ANL/HEP/Weizmann Inst.) ANL-HEP-CP-89-62
 Proceedings of the International Workshop on Weak Interactions and
 Neutrinos, Ginosar, Israel, April 9-14, 1989.

Experimental Studies of Plasma Wakefield Acceleration and Focusing

J. Rosenzweig, B. Cole, C. Ho, W. Gai, R. Konecny, S. Mtingwa, J. Norem,
 M. Rosing, P. Schoessow, J. Simpson (ANL/HEP) ANL-HEP-CP-89-75
 Proceedings of the ITCP Spring College on Plasma Physics, Trieste,
 Italy, May 22-26, 1989.

Confinement and the Pomeron

A. White (ANL/HEP) ANL-HEP-CP-89-104
 Proceedings of the Conference on Elastic and Diffractive Scattering,
 Northwestern University, Evanston, IL, May 2-6, 1989.

Phenomenology of Heavy Quark Production

E. Berger (ANL/HEP) ANL-HEP-CP-89-107
 Proceedings of the IX Physics in Collision Conference, Jerusalem,
 Israel, June 19-22, 1989.

B Production in Hadron Collisions -- Theory

E. Berger (ANL/HEP) ANL-HEP-CP-89-109
 Proceedings of the B Factories and Related Physics Issues Workshop,
 Blois, France, June 26-July 1, 1989.

Current Results from CDF on W, Z, and Top

R. Wagner (ANL/HEP) ANL-HEP-CP-89-110
 Proceedings of the International Workshop on Weak Interactions and
 Neutrino's, Ginosar, Israel, April 9-14, 1989.

Search for Supersymmetric Particles at CDF

R. Wagner (ANL/HEP) ANL-HEP-CP-89-112

Proceedings of the International Workshop on Neutrino's, Ginosar, Israel, April 9-14, 1989.

New Physics Opportunities Possible with Polarized Beam in the Main Injector

D. G. Underwood (ANL/HEP) ANL-HEP-CP-89-115

Proceedings of the Physics in the 1990's Conference, Breckenridge, Colorado, August 15-24, 1989.

Elastic Scattering with and without the Odderon

K. Kang (ANL/HEP/Brown Univ.) ANL-HEP-CP-89-97

Proceedings of the Third International Conference on Elastic and Diffractive Scattering, Northwestern Univ., Evanston, IL, May 2-6, 1989.

The Shell Model Approach--Key to Hadron Structure?

H. Lipkin (ANL/HEP/Weizmann) ANL-HEP-CP-89-87

Proceedings of the International Symposium on the Occasion of the 40th Anniversary of the Nuclear Shell Model, Argonne National Laboratory, May 25-27, 1989.

Hamiltonian Flows, $SU(\infty)$, $SO(\infty)$, $USp(\infty)$, and Strings

C. Zachos (ANL/HEP) ANL-HEP-CP-89-55

Proceedings of the XVIIIth International Conference on Physics and Geometry, Lake Tahoe, July 2-8, 1989, edited by L. Chan and W. Nahm.

B Factory via Conversion of 1 TeV Electron Beams into 1 TeV Photon Beams

S. Mtingwa (ANL/HEP), M. Strikman (Leningrad Nuclear Physics Inst) ANL-HEP-CP-89-96

Proceedings of the Workshop on B Factories and Related Physics Issues, Blois, France, June 26-July 1, 1989.

Argonne's Wakefield Accelerator Program

J. Simpson (ANL/HEP) ANL-HEP-CP-89-88

Proceedings of the XIV International Conference on High Energy Accelerators, KEK, Tsukuba, Japan, Aug. 22-26, 1989.

Getting Maximum Information from Incomplete Data on $B \rightarrow \text{Charmonium-K}_S$ Decays

H. Lipkin (ANL/HEP/Weizmann Inst./Tel Aviv Univ.) ANL-HEP-CP-89-102

Proceedings of the Workshop Towards Establishing b Factory, Syracuse Univ., Syracuse, NY Sept. 6-9, 1989.

Demonstration of Electron Beam Self-Focusing in Plasma Wakefields

J. Rosenzweig (ANL/HEP/FERMI), P. Schoessow, B. Cole, C. Ho, W. Gai, R. Konecny, S. Mtingwa, J. Norem, M. Rosing, J. Simpson (ANL/HEP) ANL-HEP-CP-89-116

Proceedings of the 1989 APS Division of Plasma Physics Annual Meeting, Anaheim, CA., November 13-17, 1989, Phys. of Fluids B

Experimental Tests of Proton Spin Models

G.P. Ramsey (ANL/HEP/Loyola Univ.) ANL-HEP-CP-89-120

Proceedings of the IUCF Topical Conference on Physics with Polarized Beams on Polarized Targets, McCormick's Creek State Park, In., Oct. 16-18, 1989.

Hadron Collider Physics at Fermilab

L. Nodulman (ANL/HEP) ANL-HEP-CP-89-122

Proceedings of the International Europhysics Conference on High Energy Physics, Madrid, Spain, Sept. 6-13, 1989.

Physics Landscape-Fixed Target Energies

E.L. Berger (ANL/HEP) ANL-HEP-CP-89-125

Proceedings of the Workshop on Physics at Fermilab in the 1990's, August 15-24, 1989, Breckenridge, Colorado

QCD Thermodynamics with Light Quarks and Glueball Spectra with Dynamical Quarks

D.K. Sinclair (ANL/HEP) ANL-HEP-CP-89-126

Proceedings of the Lattice 1989 Conference, Capri, Italy, Sept. 18-21, 1989.

Transverse Spin Observables in Chromodynamics

D. Sivers (ANL/HEP) ANL-HEP-CP-89-132

Proceedings of the IUCF Topical Conference on Physics with Polarized Beams on Polarized Targets, McCormick's Creek State Park, IN, Oct. 16-18, 1989.

Surface Underground Coincidences at the Soudan Mine

I. Ambats, D. Ayres, L. Balka, W. Barrett, J. Dawson, T. Fields, M. Goodman, N. Hill, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron (ANL/HEP); U. Dasgupta et al. (Univ. of Minn); W. Allison et al. (Univ. of Oxford); G. Alner et al. (Rutherford-Appleton Laboratory); D. Benjamin et al. (Tufts Univ.) ANL-HEP-CP-89-91

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

Contained Events in Soudan 2

I. Ambats, D. Ayres, L. Balka, W. Barrett, J. Dawson, T. Fields, M. Goodman, N. Hill, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron (ANL/HEP); P. Border et al. (Univ. of Minn); W. Allison et al. (Univ. of Oxford); G. Alner et al. (Rutherford-Appleton Laboratory); D. Benjamin et al. (Tufts Univ.) ANL-HEP-CP-89-92

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

Studies of μ 's Underground with the Soudan 2 Tracker

I. Ambats, D. Ayres, L. Balka, W. Barrett, J. Dawson, T. Fields, M. Goodman, N. Hill, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron (ANL/HEP); J. Kochocki et al. (Univ. of Minn); W. Allison et al. (Univ. of Oxford); G. Alner et al. (Rutherford-Appleton Laboratory); D. Benjamin et al. (Tufts Univ.) ANL-HEP-CP-89-93

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

Cosmic Ray Events in Soudan 2

I. Ambats, D. Ayres, L. Balka, W. Barrett, J. Dawson, T. Fields, M. Goodman, N. Hill, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron (ANL/HEP); J. Kochocki et al. (Univ. of Minn); W. Allison et al. (Univ. of Oxford); G. Alner et al. (Rutherford-Appleton Laboratory); D. Benjamin et al. (Tufts Univ.) ANL-HEP-CP-89-94

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

Underground Muons from the Direction of Cygnus X-3

D. Ayres, T. Fields, E. May and L. Price (ANL/HEP), K. Johns et al. (Univ. of Minn.) ANL-HEP-CP-89-99

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

Underground Muon Observations in the Soudan 2 Detector

I. Ambats, D. Ayres, L. Balka, W. Barrett, J. Dawson, T. Fields, M. Goodman, N. Hill, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron (ANL/HEP); P. Border et al. (Univ. of Minn); W. Allison et al. (Univ. of Oxford); G. Alner et al. (Rutherford-Appleton Laboratory); D. Benjamin et al. (Tufts Univ.) ANL-HEP-CP-89-100

Proceedings of the 21st International Cosmic Ray Conference, Univ. of Adelaide, Australia, January 6-19, 1990.

D. Technical Notes

AMZEUS-92	EGS Calculations for the ZEUS Barrel Shower Counter
M. Karlow, J. Repond
AMZEUS-93	Timing Study of the Perpendicular Cosmic Ray Trigger
W. Davis, K. Sugano
AMZEUS-95	Conceptual Design of the Calorimeter First-Level Trigger Processor
R. Talaga, J. Dawson
AMZEUS-97	Performance Tests of the Drift Tubes for the ZEUS Cosmic Ray Test Stand
M. Hohlmann, R. Talaga

CDF-962	The Tail of MET Spin L. Nodulman, W. Trischuk, P. Hu
CDF-1000	Measuring the W Mass W. Trischuk, L. Nodulman
CDF-1008	Central Electron 12 GeV Trigger Efficiency J. Proudfoot
CDF-1009	Measured Z Mass Correction Due to Structure Functions M. Mangano, R. Wagner
CDF-1010	A Not so Crude W' Limit L. Nodulman, W. Trischuk
CDF-1011	Measurement of Missing ET in the CDF Calorimeter J. Proudfoot
CDF-1032	Current Results from CDF on W, Z, and Top R. Wagner
CDF-1033	Search for Supersymmetric Particles at CDF R. Wagner
CDF-1059	Hadron Collider Physics at Fermilab L. Nodulman, CDF Collaboration
CDF-1061	Preliminary Electroweak Results from CDF Electron Data W. Trischuk, CDF Collaboration
CDF-1070	Godfather Report on Offline Review of October 20, 1989 C. Campagnari, J. Proudfoot
CDF-1079	The W/Z Underlying Event Model W. Trischuk
CDF-1081	E/P Calibration of the CEM Calorimeter S. Errede, W. Trischuk
CDF-1095	Crack Chambers in Energetic Jets L. Nodulman
PDK-398	Soudan 2 Nucleon Decay Experiment Quarterly Activity Report April - June 1989 D. Ayres
PDK-399	Tests of Reduced CO ₂ Argon Gas Mixtures in US 58 F. Lopez

- PDK-400 **Poison Measurements of Modules and Raw Materials**
F. Lopez
- PDK-401 **Surface Underground Coincidences at the Soudan Mine**
M. Goodman for the Collaboration
- PDK-402 **Contained Events in Soudan 2**
M. Goodman for the Collaboration
- PDK-403 **Studies of Muons Underground with the Soudan 2 Tracker**
M. Goodman for the Collaboration
- PDK-404 **Cosmic Ray Events in Soudan 2**
M. Goodman for the Collaboration
- PDK-405 **Decisions of the Tower Meeting - July 25-27, 1989**
D. Ayres
- PDK-406 **An Explanation of Zen in the Soudan 2 Experiment**
J. Kang
- PDK-408 **Some Analytic Estimates Related to the Protheroe Statistic**
J. Uretsky
- PDK-410 **Underground Muons from the Direction of Cygnus X-3**
E. Peterson, K. Ruddick, M. Shupe, D. Ayres, T. Fields,
E. May, L. Price
- PDK-414 **Soudan 2 Nucleon Decay Experiment - Quarterly Activity Report**
July - September 1989
D. Ayres
- PDK-417 **The Fiducial Volume**
D. Roback, M. Goodman
- PDK-419 **Searching for Muon Point Sources**
T. Fields
- PDK-420 **Protheroe's Statistic and Continuous Distributions**
J. Uretsky
- PDK-421 **Decisions of the Argonne Collaboration Meeting,**
December 7-9, 1989
D. Ayres
- WF-115 **Scaling of Hybrid Mode Dielectric Transverse Wake Fields**
J. Rosenzweig

- WF-116 What's a Kilpatrick?
M. Rosing
- WF 117 Preaccelerator Design #1: Basics
B. Cole
- WF-118 Laser Photocathode Tail Problem
M. Rosing
- WF-121 Experimental Studies of Plasma Wake Field Acceleration and
Focusing
J. Rosenzweig
- WF-122 Passive Compensation of Energy Spread in Linac Beams
J. Simpson
- WF-123 Corrections of WF-80 and WF-103
W. Gai, M. Rosing
- WF-124 The Wake Fields in Dielectric Structures
W. Gai
- WF-125 Accelerator Design #2: Theoretical Models
B. Cole
- WF-126 The Characteristics of the Wake Field Silencer
M. Rosing
- WF-127 Transverse Effects in the Argonne Wake Field Accelerator
J. Norem
- WF-128 The Nonexistence of Transverse Deflections in Dielectric Wake
Field Structures - An "Intuitive" Explanation
J. Norem
- WF-129 Numerical Calculation of $m = 1$ Mode Wake Field in a Dielectric
Structure as β goes to 1
W. Gai
- WF-130 Demonstration of Electron Beam Self-Focusing in Plasma Wake
Fields
J. Rosenzweig, P. Schoessow, B. Cole, C. Ho, W. Gai,
R. Konecny, S. Mtingwa, J. Norem, M. Rosing, and J. Simpson
- WF-131 The Complete Proof of Wei Gai's Theorem
M. Rosing
- WF-132 Electric and Magnetic Fields in the Dielectric Wake Field
Device
M. Rosing
- WF-133 Dielectric Breakdown in Cerenkov Wake Field Accelerators
J. Norem, E. Chojnacki, C. Ho, D. Konecny

VII. COLLOQUIA AND CONFERENCE TALKS

P. Arnold

"Is the Electroweak Vacuum Unstable?"
Los Alamos National Laboratory (August 1989)

E. Berger

"Issues in Spin/Polarization Physics at Moderate Energies"
Indiana University, Nuclear Theory Center Seminar (July 1989).

"Physics Landscape - Fixed Target Energies"
Invited plenary review, Workshop on Physics at Fermilab in the 1990's
(August 1989).

"Phenomenology of Heavy Quark Production at Fixed Target and Collider Energies"
Workshop on Physics at Fermilab in the 1990's (August 1989).

"Spin and Polarization Physics at Fermilab"
Workshop on Physics at Fermilab in the 1990's (August 1989).

"A New National Center for Particle Theory/Phenomenology"
Workshop on Physics at Fermilab in the 1990's (August 1989).

R. Blair

"QCD Physics at the FNAL Collider"
Breckenridge, CO (August 1989)

G. Bodwin

"Gluonic Contribution to the Proton's Spin-Dependent Structure Functions"
Cornell University, Laboratory of Nuclear Studies (November 1989).

M. Derrick

"Calorimetry at the SSC"
First Meeting of the SDC Collaboration, Fermilab (December 1989).

A. Gabutti**"Superconducting Strip Detectors"**

III International Workshop on Low Temperature Detectors, L'Aquila, Italy (September 1989).

University of Torino, Torino, Italy (September 1989).

University of Salerno, Salerno, Italy (September 1989).

CERN, Geneva, Switzerland (September 1989).

Universite de Paris VII, Paris, France (September 1989).

CNR Arco Felice, Naples, Italy (September 1989).

M. Goodman**"Status of Soudan 2 Nucleon Decay Detector"**

Tata Institute of Fundamental Research (December 1989).

D. Grosnick**"The New Polarized Proton Beam and Target Facility at FNAL"**

Valparaiso University (November 1989).

T. Kirk**"SSC Detector Cost Estimate Task Force Report"**

Fermilab (December 1989).

S. Mtingwa**"B-Meson Factory via Conversion of 1 TeV Electron Beams to 1 TeV Photon Beams"**

Clark Atlanta University (October 1989).

"Reflections on Life Inside the Soviet Union"

Clark Atlanta University (October 1989).

"Exciting Careers in Science and Technology"

St. James AME Church, Abbeville, SC (October 1989).

"Life in the Soviet Union"

James McDade Classical Magnet School, Chicago (November 1989).

L. Nodulman**"Hadron Collider Physics at Fermilab"**

EPS/HEP Conference, Madrid (September 1989).

SSC Laboratory, Dallas, TX (December 1989).

"Results from CDF"

Oxford University (September 1989).

Rutherford Laboratory (September 1989).

"Report from Madrid"

HEP Lunch Seminar (October 1989).

L. Price**"SSC Detector Studies at ANL"**

Brookhaven National Laboratory (July 1989).

"The FAST Solenoidal Detector Design Study"

TRIUMF (July 1989).

"The FAST Detector Study"

Fermilab (September 1989).

"The FAST Detector Concept"

SSC Laboratory, Dallas, TX (October 1989).

D. Sinclair**"QCD Thermodynamics with Light Quarks and Glueball Spectra with Dynamical Quarks"**

Lattice '89 Conference, Capri, Italy (September 1989).

D. Sivers**"Transverse Spin Observables in QCD"**

University of Indiana (November 1989).

A. B. Wicklund**"Measurement of the Z Mass at CDF"**

Fermilab (July 1989).

"CDF Confronts the Standard Model"

ANL/PHY Colloquium (September 1989).

C. P. Yuan**"How to Study the Longitudinal W's in TeV Region"**

Northwestern University (October 1989).

C. Zachos

"Hamiltonian Flows, $SU(\infty)$, $SO(\infty)$, $USp(\infty)$ and Strings"
Lake Tahoe Physics & Geometry Conference (July 1989).

"Superstrings"
Colloquium at Central Michigan University (October 1989).

VIII. HIGH ENERGY PHYSICS COMMUNITY ACTIVITIES

E. Berger

Chairman, Executive Committee, Division of Particles and Fields, American Physical Society, 1990.

International Program Committee, DPF 90, General Meeting of the Division of Particles and Fields of the American Physical Society, January 1990.

Co-chair, Working Group on "Theoretical Issues for the 1990's", Workshop on Physics at Fermilab in the 1990's, Breckenridge, Colorado, 1989.

Chairman, Organizing Committee, 1990 Summer Study on High Energy Physics, "Research Directions for the Decade", Snowmass, Colorado, June 25 - July 13, 1990.

Scientific Program Committee, XXV Rencontre de Moriond, "High Energy Hadronic Interactions", Les Arcs, France, March 1990.

Organizing Committee, Workshop on Hadron Structure Functions and Parton Densities, Fermilab, April 1990.

National Committee on Particle Theory, 1989 - 1990.

High Energy Physics Advisory Committee (HEPAP) Subpanel on the U.S. High Energy Physics Research Program for the 1990's.

Organizing committee, Workshop on Major SSC Detectors, Tucson, Arizona, February 19-23, 1990.

R. Blair

Workshop on Physics in the 1990's at Fermilab - Cochair of QCD group.

T. Fields

Lawrence Berkeley Laboratory Visiting committee (Chair), September 1989.

T. Kirk

Steering Committee, SSC Solenoidal Detector Collaboration.

Board of Directors, International Industrial Symposium on SSC.

Co-chairman, SSC Detector Cost Estimate Task Force.

Secretary, SSC Users Organization Executive Committee.

ANL APS Accelerator Division Director Search Committee.

E. May

HTCC (HEPNET Technical Coordinating Committee) meeting at St. Louis, MO, September 1989.

S. Mtingwa

Selected 1989 C. Eric Lincoln Lecturer at Clark Atlanta University.

L. Nodulman

Member, Ad Hoc Committee on SSC Physics.
Organizer, Workshop on Physics and Detector Simulation for SSC Experiments, SSC Laboratory, Dallas, TX, December 1989.

L. Price

ESNET Steering Committee.
Users Organization for the SSC Executive Committee: Secretary-Elect.
International Committee for Detector R&D for the SSC.

H. Spinka

LAMPF Board of Directors, August 1989.

R. Wagner

Assisted students at Puffer-Hefty School in Downers Grove with development of Science Fair projects, November 1989.

A. B. Wicklund

Member of the Advisory Committee for the 10th International Conference on Physics in Collision to be held at Duke University, Durham, NC, June 1990.

C. Zachos

Organizing Quantum Group Workshop at Argonne, to take place April 16 - May 11, 1990.

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

S. Mtingwa	M. Rosing
J. Norem	P. Schoessow
J. Rosenzweig	J. Simpson

Experimental Physicists

D. Ayres	Y. Ohashi
R. Blair	J. Panakkal
M. Derrick	L. Price
T. Fields	J. Proudfoot
A. Gabutti	J. Repond
R. Garnett	T. Shima
M. Goodman	H. Spinka
W. Gai	R. Stanek
D. Grosnick	K. Sugano
R. Hagstrom	R. Talaga
S. Kuhlmann	J. Thron
F. Lopez	H. Trost
D. Lopiano	D. Underwood
E. May	R. Wagner
B. Musgrave	A. B. Wicklund
L. Nodulman	A. Yokosawa

Theoretical Physicists

P. Arnold	D. Sinclair
E. Berger	D. Sivvers
G. Bodwin	A. White
R. Kauffman	C. P. Yuan
J. W. Qiu	C. Zachos

Engineers, Computer Scientists and Applied Scientists

A. Buehring	R. Noland
E. Chojnacki	H. Rhude
J. Dawson	J. Schlereth
D. Hill	A. Stevens
N. Hill	W. Wang

Technical Support Staff

I. Ambats	T. Kasprzyk
L. Balka	R. Konecny
J. Biggs	R. Laird
H. Blair	R. Miller
B. Cole	R. Rezmer
W. Haberichter	J. Sheppard
D. Jankowski	

Laboratory Graduate Participants

C. Ho	C. Nantista
D. Karatas	M. Pundurs
D. Keubel	F. Ukegawa
M. Laghai	