HIGH ENERGY PHYSICS DIVISION SEMIANNUAL REPORT OF RESEARCH ACTIVITIES

July 1, 1992 – December 30, 1992

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July 1, 1992 - December 30, 1992

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July 1993

MASTER

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Abstract

This report describes the research conducted in the High Energy Physics Division of Argonne National Laboratory during the period of July 1, 1992 - December 30, 1992. Topics covered here include experimental and theoretical particle physics, advanced accelerator physics, detector development, and experimental facilities research. Lists of division publications and colloquia are included.

I. EXPERIMENTAL PROGRAM

A. Physics Results

1. Collider Detector at Fermilab

The CDF detector began taking data for run 1A in August, 1992, and by year's end collected a total of 6 events/pb on tape out of 9 pb⁻¹ delivered by TeV-I. This may be compared with the total luminosity of 4.2 events/pb accumulated during the 1988-89 run. CDF was substantially upgraded in the period between runs, and features the new silicon vertex detector ("SVX"), the central preshower detector ("CPR"), and the upgraded muon coverage (extra absorption material in the region $\eta < 0.6$, and extended coverage between $\eta = 0.6$ and 1.0). In addition, the trigger capabilities have been improved substantially over the previous run, with higher bandwidth allocated to interesting b-physics channels, neural net hardware for isolated prompt photon triggers, and a greatly enhanced (1100 Mip equivalent) level-3 processor farm to handle the increased data rate. Much of the analysis effort has been focused on understanding the new detector components, and verifying the detector performance against the 1988-89 benchmark.

Figure 1 illustrates the increased rate capability for inclusive central electrons for b-physics studies. The shaded portion shows the cross section for the 1988-89 electron trigger, while the solid points show the distribution for the 1992 electron trigger. The overall b-physics rates are a factor of five higher in the 1992 data, corresponding to an expected yield of 500,000 semileptonic b decays in the 25 pb⁻¹ expected for run 1A. Figure 1 also shows a prescaled lower Et trigger (open points), used primarily for calibration purposes. Of course, the yield of W and Z decay electrons for electroweak studies and for the top search scales with luminosity, and the expected yield of W electrons for run 1A is around 25,000 events in the central and plug calorimeters.

Figure 2 shows the improvement in the quality of the central muon signal achieved with the additional three absorption lengths of steel in the upgraded central muon system ($\eta < 0.5$). What is plotted is the calorimeter energy distribution in the cell containing the muon candidate, for the upgraded muon system (shaded histogram), and the original (five absorption lengths) muon chambers. The bulk of the muon trigger rate comes from hadronic punchthrough in the baseline system; this background is reduced by a factor of twenty with the upgrade, leaving a relatively clean muon signature for electroweak studies and b-physics.

Fig. 1. Inclusive electron spectrum, showing 1992 data (points) and 1989 data (shaded plot).

Fig. 2. Calorimeter energy distribution for muon candidates, showing baseline central muon detector after five absorption lengths (dotted histogram), and upgraded muon detector after eight absorption lengths (shaded plot).

The dimuon trigger cross section was substantially increased for run 1A, by means of three specific improvements: (1) lower Pt thresholds on the muons, (2) less restrictive matching requirements between central tracks and muon hits at high Pt, and (3) extension of the muon coverage to $\eta = 1$. Figure 3 shows the J/ψ Pt spectrum for the 1992 data (solid histogram) and the 1988-89 data (dashed histogram), both normalized to the same integrated luminosity. The overall J/ψ yield, which includes ψ 's from b-decay and ψ 's from direct $c\bar{c}$ production, is increased by about a factor of five over the 1988-89 run, corresponding to a yield of 40,000 $b \rightarrow J/\psi$ decays in the expected 25 pb⁻¹. Figure 4 illustrates the impact of the SVX on tagging the $b \rightarrow J/\psi$ decays. The proper decay time is plotted. Monte Carlo calculations were used to relate the observed J/ψ momentum to the $\beta\gamma$ factor for the parent B-hadron. The distributions on and off resonance are shown on the top left and right, respectively, and the side-band subtracted distribution is shown on the bottom. The subtracted distribution shows a prompt component, peaked at zero proper time, and a long lived component due to b-decays. The dashed curve shows the expected behaviour for the b-decay component, based on the world average b-lifetime. With the full sample, CDF can expect to measure lifetimes for individual B-hadrons via their exclusive decay modes, e.g. $B^+ \rightarrow \psi K^+$, $B^0 \rightarrow \psi K^{0*}$, $B_s \rightarrow \psi \phi$ (1020), and $\Lambda_b \rightarrow \psi \Lambda$.

One of the main reasons for examining the b-decays, in addition to the unique b-physics capabilities of CDF, is to calibrate b-tagging efficiencies for the top search. For example, for a top mass of 140 GeV, selecting $W \rightarrow \ell \nu + 3$ jet events, we would expect a yield of about 18 $t\bar{t}$ events, with the decay b-hadron identified in the SVX or via soft lepton decay. Without any b-tagging, the QCD production of $W + 3$ jets would yield around 125 events; with the b-tags this background would be reduced to around 5 events. The presence of a healthy b signal from direct production of $b\bar{b}$ pairs, provides an invaluable calibration for the b-tagging efficiency and fake rates.

The new preshower detector, built at Argonne, functions well. The CPR provides an additional independent handle on electron identification, and should improve $e-\pi$ separation by an overall factor of two, as compared with the baseline detector (hadron backgrounds are about 20% of the electron signal without the CPR information). Figure 5 shows the CPR pulse height distribution for electrons from W decay, and inclusive charged tracks (mostly minimum ionizing hadrons). The overall separation provided by the CPR alone, is around a factor of 20, depending on the choice of electron efficiency (CPR cutoff). In addition to electron-hadron separation, a primary function of the CPR is to separate single photon showers from π^0 's. The principle of the method is that the CPR samples the shower pulse height following the approximately 1.1 X_0 of material

Fig. 3. J/ψ yields versus P_t for 1992 trigger (solid plot), and 1989 trigger (dotted plot), both normalized to 0.5 pb^{-1} .

Fig. 4. J/ψ lifetime distribution in the J/ψ mass band (top left), in the sidebands (top right), and sideband-subtracted (bottom).

Fig. 5. CPR pulse height response for W electrons (points) and inclusive charged tracks (histogram), normalized to equal numbers of events.

provided by the solenoid coil. At this depth, the expected number of shower secondaries for a single photon is small (0 or 2 minimum ionizing particles), while that for a two-photon (π^0) shower is of course, twice as large, on average. Figure 6 illustrates the calibration technique. At low energies ($E_t > 6$ GeV), the photon trigger collects π^0 's and η 's, which can be reconstructed using the shower maximum detector. The π^0 's provide a calibration for two-photon showers, while the photons from η -decay can be used in principle to confirm the single-photon response (the η -decay photons are well separated at the calorimeter). Figure 7 shows the fraction of π^0 's that pass a CPR pulse height cut, as compared with a GEANT simulation which takes into account the shower development in the CDF coil (1.1 X0) and the observed CPR response to minimum ionizing charged tracks. The fraction is plotted against the Z coordinate, and shows the expected increase in CPR response due to the $1/\sin \theta$ variation of the coil thickness. Agreement is excellent, and the CPR provides good separation of single photons and π^0 's out to the highest E_t that can be detected.

(A. B. Wicklund)

2. Soudan Data Analysis

Many man-years of data analysis effort by Soudan physicists came to fruition in November when preliminary measurements of atmospheric neutrino interactions in Soudan 2 were presented at the Division of Particles and Fields meeting at Fermilab. The first 0.5 fiducial kiloton year of contained event data was used to measure the flux ratio of muon neutrinos to electron neutrinos. This was the subject of Argonne graduate student Don Roback's Ph.D. thesis, which was completed in August. His result was checked and refined by the contained event analysis team before it was presented at the Fermilab meeting. Although the statistics are still limited, the Soudan measurement of the ratio of muon to electron neutrinos appears to support the anomalously low value obtained by the IMB and Kamiokande experiments. The Soudan sample will soon be doubled when analysis of data already in hand is completed.

One hypothesis for the unexpectedly low muon to electron neutrino ratio is that muon neutrinos oscillate into τ or electron neutrinos as they travel from their production site in the atmosphere. Physicists from the Tufts University Soudan group recently published in *Physics Letters* an even more audacious idea: the electron neutrino rate may appear high because of contamination by positrons from proton decay in the mode $p \rightarrow e^+ \nu \nu$. Although physicists building big underground detectors have worked very hard over the years to reduce the background to nucleon decay from atmospheric neutrinos, until now few have worried seriously about a possible background to neutrino events from nucleon decay! With its ability

Fig. 6. Two-gamma mass spectrum using 6 GeV photon triggers.

Fig. 7. Comparison of GEANT simulation and observed π^0 response in CPR; the points give the fraction of π^0 's that pass a fixed CPR pulse height cutoff.

to cleanly identify a fraction of neutrino events by observing their recoil proton tracks, the Soudan detector will be able to test this idea experimentally.

The Soudan collaboration has also proposed to search directly for neutrino oscillations using a 730 km long neutrino beam from Fermilab. A high intensity 20 GeV muon neutrino beam produced by the new Fermilab Main Injector would be aimed towards Soudan at a 3.3 degree angle below the horizon. If the atmospheric neutrino result is due to oscillations, many of the muon neutrinos in the Fermilab beam will become τ or electron neutrinos on their trip to Soudan. This will decrease the fraction of the 900 interactions per year containing final state muons, and provide an unambiguous signal of neutrino oscillations. This proposal (P-822) is being taken quite seriously by Fermilab, which completed an engineering study of the beam during the fall of 1992. The current design of the main injector includes provision for extraction of the protons needed for the high intensity neutrino beam to Soudan.

Two attractive features of the proposal are the existence of the operating Soudan 2 detector and the possibility of building a new more massive detector at the same site. When DOE approved the Soudan 2 cavity excavation in 1983, they allowed for future follow-on experiments by funding a laboratory large enough for a second large detector in addition to Soudan 2. Figure 8 is a photograph of part of the available underground laboratory space. Several ideas for a new detector for the long baseline experiment are now being developed by the Soudan collaboration and at Fermilab. The neutrino beam from Fermilab could be ready about 1998, after completion of the planned 5 kiloton year Soudan 2 exposure for nucleon decay.

In December, the paper describing the search for heavily ionizing magnetic monopole tracks in Soudan 2 data was published in Physical Review D. Argonne physicists presented Soudan 2 results on the monopole search, neutrino interactions, and on the first limits on nucleon decay (described in the previous HEPD Semiannual Report) at the Fermilab DPF meeting and at the XXVI International Conference on High Energy Physics in Dallas in July. Argonne physicists also wrote a number of internal PDK notes during the second half of 1992.

(D. Ayres)

Fig. 8. Photograph of some of the space which could be used for a new detector in the Soudan 2 underground laboratory. Nearly two-thirds of the laboratory area will be available for a new long baseline neutrino oscillation detector when Soudan 2 is completed. As shown here, this space is being used as a staging area for Soudan 2 construction. The counting house can be seen at the far end of the cavity.

3. Polarized Proton Physics

Considerable effort was devoted to preparation of the proposal on spin physics using the RHIC Polarized Collider. The proposal was presented at the Brookhaven PAC meeting in September 1993 and received a favorable response (see Section C). In parallel, the Fermilab E-704 data analysis is proceeding.

Our new experimental results are the analyzing power and the depolarization in inclusive Λ production. They are found to be near zero in all kinematic ranges.

The analyzing power for inclusive Λ production (including Σ^0 contamination) is shown in Fig. 9. The depolarization $D_{NN} = (1/P_B) (N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}) / (N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow})$ is shown in Fig. 10.

The on-going analyses of FNAL E-704 data are:

- $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(\bar{p}p)$, difference in total cross section in pure spin states,
- Direct-gamma collected simultaneously with π^0 data
- Detailed analysis of π^0 and η production. (A. Yokosawa)

4. Spin Physics at LAMPF

In the past few years, the measurement of sufficient np elastic scattering spin observables to determine the isospin-0 amplitudes and phase shifts between kinetic energies of 500 and 800 MeV has been the goal of the ANL-HEP medium-energy physics program at LAMPF. The measurements include LAMPF experiments E-665/770, E-876, E-960, and E-1234.

During the July-December 1992 period, a major paper was published describing apparatus and measurements of np spin observables C_{SL} and C_{LL} with the polarized neutron beam elastically scattered from a polarized proton target. The data were collected at 484, 634, and 788 MeV and c.m. angles between 80° and 180° . A second major paper on E-770 was accepted for publication. The results include C_{LS} and C_{SS} at 484, 634, 770, and 788 MeV for c.m. angles between 25° and 80° . Data analysis is continuing for a third paper covering the remaining E-770 np elastic scattering results and the E-665/770 data for the $np \rightarrow d\pi^0$ reaction.

Effort to finalize results of E-960, a measurement of the total cross section difference, $\Delta\sigma_L(np)$, between parallel and antiparallel longitudinally-polarized neutron beam and proton target, has also continued in this period. A detailed analysis of the polarized target results was completed which slightly modified the results published in a letter some time ago. A draft of the final paper is nearly complete, and may be submitted for publication in the next six months.

Fig. 9. A_N vs. x_F for Λ production. The dashed line is a prediction from a theoretical model.

Fig. 10. D_{NN} vs. x_F integration over p_T for a production. The dashed line is a prediction using the same theoretical model as in Fig. 9.

Two papers were published in Physical Review C with results from E-876/1234. The polarized neutron beam was scattered from liquid hydrogen and deuterium targets, respectively. Outgoing protons were detected in a magnetic spectrometer and the spins measured with a carbon polarimeter. Early in this period, additional E-876 measurements were performed for the spin parameters $P = A_N$ and K_{NN} at 485, 635, and 788 MeV for c.m. angles between 60° and 170° . These data have been analyzed (see Figs. 11, 12) and a paper describing the measurements is being written. Finally, an instrumentation article on the relative neutron polarimeter used for E-876/1234 has been accepted for publication. A proposal to extend the $P = A_N$ data at these same energies to smaller c.m. angles was submitted to the LAMPF Program Advisory Committee as P-1293. The same apparatus and beamline would be used as E-876, and the measurements might be performed in the summer of 1993. A continuation of E-876 to 720 MeV has also been proposed. These experiments utilize the ANL neutron counters and associated electronics.

5. Computational Physics

The computational physics effort is devoted to numerical simulations of quantum field theories defined on discrete lattices. Foremost among the lattice field theories we have been studying is lattice quantum chromodynamics (QCD) in which QCD is defined on a discrete spacetime lattice which supplies the needed ultraviolet regulation of the theory and facilitates numerical simulations. Such lattice QCD simulations are aimed at measuring such nonperturbative phenomena as hadron masses and the strong interaction contributions to low energy matrix elements; and at studying QCD at high temperatures and/or high baryon number density. These latter studies are relevant to relativistic heavy ion collisions, the nature of the early universe, and the interior of neutron stars. We are also using lattice methods to study the electrodynamics of a compact scalar field to understand better the nonperturbative interplay between the Higgs fields and vector gauge fields. Such studies should help in understanding the Higgs sector of the standard model.

We have been using the Intel Touchstone Delta computer at Caltech to perform calculations to estimate the spectrum of low lying hadrons in the quenched (valence quark) approximation to lattice QCD. This high performance massively parallel computer has enabled us to use large lattices ($32^3 \times 64$) which allow lattice spacings small enough ($a \sim 0.05$ fm) that one can hope to extrapolate to the continuum limit (i.e., we believe this to be in the scaling regime). The dimensions of the spatial box (length ~ 1.6 fm) are large enough that lattice QCD is in its hadronic phase.

Fig. 11. Final results of the np elastic scattering spin observables K_{NN} at 484, 635, and 788 MeV as a function of c.m. angle. The curves are various phase shift predictions.

Fig. 12. Final results of the np elastic scattering spin observable $P = A_N$ at 485, 635, and 788 MeV as a function of c.m. angle. The curves are various phase shift predictions, and data from other experiments are included for comparison.

While this box size is still too small to accommodate 140 MeV pions, we have been able to consider pions with masses down to (~ 300 MeV) which still represents the state-of-the-art for lattice calculations. We have generated 100 independent equilibrated configurations at this lattice spacing using Metropolis Monte Carlo and microcanonical techniques. On each of these configurations we have extracted quark, and hence, hadron propagators using the conjugate gradient algorithm to invert our Dirac operators. With the carefully chosen quark sources we use, this should be adequate to get hadron masses with small statistical errors. Preliminary masses from a subset of these configurations are presented in Fig. 13. We have just started simulations with larger lattice spacing ($a \sim 0.1$ fm). Since the spatial box now has larger dimensions (length ~ 3.2 fm), we shall be able to accommodate smaller quark and hence pion masses, but will be further from the continuum.

As part of the multi-institutional HTMCGC collaboration we have been extending our simulations of the thermodynamics of lattice QCD on a $16^3 \times 8$ lattice to a lower quark mass ($m_q/T=.05$ down from $m_q/T=.1$), closer to the true u and d quark masses for temperatures, T , of interest. Here we are trying to determine the position and nature of the transition from hadronic matter to a quark-gluon plasma, and to measure those properties of the plasma which might help distinguish it from the hadronic matter phase if it is produced in heavy ion collisions. For these simulations we are using the Connection Machine (CM-2) at PSC. We use the hybrid molecular dynamics simulation method which allows for the inclusion of light dynamical quarks.

In collaboration with John Kogut (University of Illinois) we have been studying the electrodynamics of a compact scalar field using the CRAY C-90 at NERSC. The monopole loop excitations of such a theory give hope that it might possess a nontrivial phase structure. If so then this would indicate that the Higgs sector of the standard model might have nontrivial nonperturbative behavior once the effect of gauge fields is taken into account. Early studies of this theory indicated that it did indeed have 2 phases and that part of the phase boundary was second order. We are now completing a detailed study of the scaling properties of the specific heat of this theory.

We have also been involved with John Kogut and Maria-Paola Lombardo (University of Illinois) in an attempt to study the behavior of lattice QCD with a finite chemical potential for baryon number, within the quenched approximation. Here, by looking at the hadron spectrum in addition to other order parameters we hope to sort out the confusion that has arisen from earlier attempts to study this domain. So far we have produced code to run on the NERSC CRAY's and are developing similar codes to run on the CM-2 at PSC or the CM-5 at NCSA.

Fig. 13. Preliminary "Edinburgh" plot of hadron mass ratios (quenched) from our Intel Touchstone Delta simulations.

Finally, we have been involved in various activities associated with the QCD Teraflop proposal, which seeks to acquire a computer with performance in excess of 1Tflop for lattice gauge theory. This has included work necessary to move the proposal towards approval as well as porting some of our codes to the CM-5 on whose architecture the Teraflop computer is to be based. This will help to identify potential problems with attaining optimal performance from such a machine. (D. Sinclair)

B. Experiments Taking Data

1.. Soudan 2

The Soudan 2 experiment continued routine data acquisition for contained events (neutrinos and nucleon decay) and cosmic ray muons during the last half of 1992. In addition, data from the 40 m² surface array were recorded in coincidence with Soudan 2 in order to measure the energies of some of the cosmic ray air showers which produce underground muon events. The experiment recorded data for 134 days of livetime, giving a duty cycle of 73%. This brought the total Soudan 2 exposure to 3.0 years, or 1.3 fiducial kiloton years for contained events. Of this total, 1.1 fiducial kiloton years is useful for nucleon decay and atmospheric neutrino physics. The detector is operated for physics data primarily during night and weekend periods when installation work is not in progress and the underground laboratory is unoccupied.

The anode-cathode edge trigger, which was devised for neutrino interactions and nucleon decay, has high efficiency for cosmic-ray muon tracks as well. The data from all triggered events is processed by track reconstruction programs and the analysis results are recorded on 8 mm magnetic tape cassettes for distribution to the collaborating institutions.

(D. Ayres)

2. Spin Physics at Saclay

The nucleon-nucleon scattering program at Saclay, France was begun approximately 1-1/2 years ago with goals to extend the LAMPF isospin-0 measurements to higher energies and to study the origin of energy-dependent structure in various pp spin observables near 2100 MeV.

The first experimental run in this program to study the isospin-0 scattering occurred in November. The target material consisted of polarized ⁶LiH and ⁶LiD that was in the form of chunks of material that had been irradiated in an electron beam. This was the first use of such materials in the Saclay nucleon-nucleon program and there were problems achieving reasonable polarizations. Improvements to the polarizing magnet

power supply by a member of the ANL team were essential for the polarization that was achieved. Modifications to the NMR system to determine the target polarization more accurately are currently in progress.

The new data acquisition system, based on a SUN computer, was tested during the run. Some of the new software was written by ANL physicists, and some ideas for further improvements suggested by these physicists were adopted. The ANL multiwire proportional chamber was successfully read into the new data acquisition system, and its performance optimized (delays, thresholds, and chamber high voltages determined). However, problems with some of the software resulted in the use of the older data acquisition system for much of the run. It is anticipated that these problems will be corrected by the time of the next run.

Approximately 2-3 years ago, two members of the ANL-HEP Division assisted in experimental runs at Saclay to determine the feasibility of collaborating with the nucleon-nucleon groups. Some of the results of those experiments have been analyzed, and four papers submitted to Nuclear Physics B and Nuclear Instruments and Methods. These experiments used a polarized neutron beam and a polarized proton target, and extended up to 1100 MeV kinetic energy of the beam. (The recent measurements will begin at 1100 MeV and extend to higher energies.)

Finally, the pp elastic scattering results from the run in March/April 1992 are being analyzed and a paper is being prepared for submission to Nuclear Physics. Very interesting results are suggested based on the preliminary data at 14 beam energies.

(H. Spinka)

3. Collider Detector at Fermilab

The CDF collaboration declared its commissioning phase over and the top search resumed in August. All detector and trigger systems were installed and functioning except the trigger for the muon extension and the University of Pennsylvania track processor. The tracklist trigger and neural net hardware for photon isolation were commissioned later. The lower wire gain needed for longevity on the inner superlayers of the central tracking chamber has been mostly compensated electronically. The new vertex drift chambers have had some high voltage difficulties which required an access and led to occasional loss of data from one or two of the 28 modules. The silicon vertex detector (SVX) has performed quite well; there was a leakage current problem but it was a surface effect and has been brought under control. While beam related radiation effects are noticeable, the SVX should survive the current run.

The Tevatron Collider reached a peak luminosity of about $7.5 \cdot 10^{30} \text{ cm}^{-2}\text{sec}^{-1}$ and typical initial luminosities of $5 \cdot 10^{30}$. Accumulated luminosity got as high as 1 pb^{-1} per week. By the end of the year CDF had accumulated more than 6 pb^{-1} which was about 70% of the available luminosity, see Fig. 14. A shutdown is scheduled for late January to work on various accelerator improvements which should allow further luminosity gains. Thick beam pipe and flange assemblies at CDF are to be replaced; the reduced material should help the muon extension trigger. At the highest luminosities, the track trigger (CFT), which is designed to be over efficient, in the presence of extra overlapping minimum bias events, loses its rate linearity with luminosity. This may cause a squeeze in triggering if luminosity improvements work but the top search triggers should be safe.

Due in part to the gradual development of an effective trigger, 7 million events were written. Computing resources were adequate to keep up reconstructing the events in nearly real time although refinements in tracking will require reprocessing. Access to the high volume of data has become the priority issue although highly selected express samples are readily available. (L. Nodulman)

C. Experiments in Preparation Phase

1. Collider Detector at Fermilab

The current running period (1a) is to end when the goal of 25 pb^{-1} is accomplished which could be as soon as May 1993. The next cycle, 1b, with the linac upgrade, could begin as soon as August 1. The next generation of AC coupled rad hard silicon vertex detector as well as various DAQ and trigger upgrades will be needed for CDF to deal with the expected intensity increase to perhaps $2 \cdot 10^{31}$. Prototype front end cards for the shower max and preradiator trigger have been installed and the upstairs FASTBUS electronics, from Argonne, is being checked out. A review has been scheduled in February to determine if there are resources available to build the front end cards needed to implement this trigger in run 1b.

The current Fermilab schedule calls for multibunch (132 nsec) running to begin in 1996. The resources available on that time scale may force hard decisions on which upgrades will be possible. One which is required is to replace the front end electronics. Our group has become involved with the development of a digital front end system, with particular responsibility for reading out the shower max and preradiator chambers. These will be a particular challenge as, unlike PMTs, the needed gate times are longer than the bunch cycle.

Fig. 14. TeV-I and CDF Data Logging Performance.

2. Soudan Detector Installation

A major milestone was passed in late December with the completion of the final 5-ton module for Soudan 2 at the Argonne module factory. A total of 19 modules were constructed during the last six months of 1992, including the complete rebuild of an early module (US#17) which was returned from the Soudan mine site in November. A total of 155 good U.S. modules have been built at Argonne since construction began in 1985. A record 34 modules were assembled at Argonne during 1992. Twenty four modules (including the rebuilt US#17) were shipped to the mine site from the Argonne module factory, bringing the total number of modules underground to 223 (959 tons). The last three US modules and the one remaining UK module will be shipped to Soudan in 1993.

Two new halfwalls were added to the Soudan 2 detector during the last half of 1992. (A halfwall is a subassembly of eight 5-ton modules, stacked four across and two high.) This increased the operating mass from 722 to 791 tons. In addition to new halfwall construction, several individual 5-ton modules in five operating halfwalls were replaced in order to improve performance. These modules are being repaired and will be reinstalled in the detector. A number of anode high voltage splitters, which allow top and bottom modules to operate at different, optimum wireplane voltages, were installed while the detector was open for module replacement.

Argonne physicists and engineers continued to make substantial contributions to the installation and operation of the detector during 1992. Major activities included the monitoring of the module heat treatment facility, study of detector and electronics performance, coordination of module assembly and installation, and improvements in several electronics systems. (D. Ayres)

3. ZEUS Detector at HERA

a) HERA Status

The first luminosity run with 10 on 10 bunches started June 28 and continued to August 3. At this point a two-week shutdown for machine maintenance also allowed the ZEUS detector to make necessary repairs. During this first period an integrated luminosity of 3 nb^{-1} was achieved by ZEUS with typical luminosity of a few $\times 10^{28} \text{ cm}^{-2} \text{ sec}^{-1}$. Operation began again August 17, still with 10 bunches, but luminosity running did not occur until September. Greatly improved machine performance allowed ZEUS to achieve an integrated luminosity of 27 nb^{-1} in the second running period, which ended early in November. In the month of October, 33% of the available machine time was devoted to data taking and about 42% in preparing the beams for collision, much of this time being spent in recovering from technical failures. The machine was run for accelerator studies

in November and the number of stored proton bunches was increased from 10 to 160 with currents up to 15% of design. The severe limitation experienced thus far in stored electron current (the lifetime decreased rapidly for currents in excess of 2 mA) was traced to a section of the vacuum pipe containing a getter pump which was strongly irradiated by synchrotron radiation. After replacing this with a beam pipe without the pump, electron currents of 23 mA were achieved with good lifetime. This was due also to successful operation of the multibunch feedback system. Up to 100 electron bunches were stored.

b) ZEUS Operations

The ZEUS detector operated well through the end of the first running period on August 3, achieving an integrated luminosity of 3 nb^{-1} . The number of bad calorimeter channels never exceeded the few percent level. A two-week shutdown provided the opportunity to replace defective photomultiplier bases and to make repairs to on-module readout and trigger electronics. Experience in this first running period suggested that a regular one shift access every two or three weeks would be needed to maintain the number of bad calorimeter channels below the 2-3% level. Machine operation commenced again August 17 but significant data taking did not start until early September and the most productive period occurred in the month of October. An integrated luminosity of 27 nb^{-1} was achieved by the ZEUS detector in the second running period. The luminosity per day collected by ZEUS in these two running periods is shown in Fig. 15.

Many improvements were made to the calorimeter calibration in the second half of 1992. The timing resolution was improved by detailed measurements of channel timing offsets using laser pulse techniques. In the RCAL, where most of the effort was directed, a resolution of $\sim 0.6 \text{ ns}$ was achieved. This was slightly worse in the BCAL and FCAL. Precise timing information is extremely powerful in rejecting beam-gas background.

The data analysis chain established prior to the data taking performed extremely well. Not only was there rapid daily feedback on the performance of the detector but physics results on the first 3 nb^{-1} accumulated luminosity were available by the fall. Three letters were submitted for publication in the second half of 1992.

The first publication was a measurement of $\sigma_{\text{tot}}(\gamma p)$, the total photoproduction cross section, with virtual photons in the range $10^{-7} < Q^2 < 2 \times 10^{-2} \text{ GeV}^2$. The γp total cross section in the γp centre of mass energy range 186-233 GeV is 154 ± 16 (statistical) ± 32 (systematic) μb . This result was in excellent agreement with a similar measurement using the H1 detector, as is shown in Fig. 16. No dramatic rise in total cross section is

Fig. 16. The total γp cross section as a function of the c.m. energy W as measured below 18 GeV and by H1 and ZEUS near $W = 200$ GeV. The lower solid curve is the prediction of the ALLM parametrization and the higher solid curve is that of DL. The dotted (dashed) line uses the LAC1 parametrization for the photon with $p_{Tmin} = 1.4$ GeV/c (2 GeV/c). The dashed-dotted lines use the DG parametrization for the photon with $p_{Tmin} = 1.4$ GeV/c (upper line) and $p_{Tmin} = 2$ GeV/c (lower).

Fig. 15. Luminosity per day collected by ZEUS during the first and second running period (from U. Schneekloth).

observed between the low energy regime, 18 GeV, and the HERA result at 200 GeV. A strong rise might have been expected in the HERA regime from current interpretation of observed "diffractive" air showers and an excess of muons in very energetic cosmic air showers. Some Regge models fit to the hadronic and pre-HERA photoproduction data, labelled ALLM and DL, were found to agree quite well with the HERA measurements.

Hard scattering in photoproduction due to the direct and resolved photon processes is expected to be important at HERA. A second publication reported the observation of hard scattering from an analysis of the transverse energy behavior of photoproduction events at low Q^2 . A sample of 576 photoproduction events, with contamination from beam gas and deep inelastic scattering processes below 5%, was separated by applying cuts to the data sample. The distribution in γp centre of mass energy, W , is shown in Fig. 17(a). Also shown, dashed histogram, are the subset of these events for which the scattered electron was detected in the luminosity monitor downstream of ZEUS with no coincidence detection of a photon. The good agreement of the ratio of electron tagged events to total with Monte Carlo predictions for pure photoproduction events, demonstrates the data are consistent with originating from photoproduction.

The distributions of the total transverse energy, E_T , of the event sample and the missing transverse momentum, P_{Tmis} , are shown in Fig. 17(b,c), respectively. The average P_{Tmis} of 1.5 GeV demonstrates overall P_T balance, as expected for photoproduction. By contrast, the E_T distribution has a pronounced tail extending beyond 10 GeV, much larger than that expected from soft γp interactions which, dash-dotted curve, only extends to 10 GeV. The events were searched for jets using the cone algorithm with radius ~ 1 unit and a jet definition requiring $E_T > 4$ GeV and pseudo-rapidity, η , less than 2. Some 41 events were found to contain two jets. The two-jet sample showed predominantly back-to-back jet production in the transverse plane, as expected. An example of a two jet event is shown in Fig. 18(a). Although the statistics of this initial data run were limited, there was also a clear indication that in some events where both jets go forward in the laboratory, a substantial amount of energy is emitted also in the backward, or electron, direction and close to the direction of the incident photon. While most of the 2-jet sample results from the direct photon contribution, the above event topology is expected for resolved photon processes, where the photon remnant goes approximately in the direction of the incident photon. One of the resolved photon candidates is shown in Fig. 18(b). It has two jets in the forward direction and a cluster of energy going backwards.

Fig. 17. Hard scattering in photoproduction as analyzed by ZEUS: (a) Distribution of the γp c.m. energy W for all events (solid histogram) and for events with a tagged electron (dashed histogram); the curves show the Monte Carlo expectations; (b) Total transverse energy and missing transverse momentum distributions for all events (solid histogram) and for events with a tagged electron (dashed histogram); the dashed curve shows the expectations from the Monte Carlo simulation including direct and resolved photon contributions with $p_{Tmin} = 1.5$ GeV/c; the dotted curve shows the transverse energy distribution for soft γp interactions.

Fig. 18. Examples for events from hard scattering in photoproduction as observed by ZEUS in $\eta - \phi$ space: (a) An event with a two-jet structure; (b) An event showing a two-jet structure plus additional energy in the direction of the incident electron associated with the photon remnant.

At the end of CY1992, a paper was submitted for publication describing the isolation of neutral current deep inelastic scattering from background, providing a measurement of the differential cross section $d^2\sigma/dx dQ^2$ for two intervals of the Bjorken x variable, one extending down to 5×10^{-4} . This is two orders of magnitude smaller in x than previously possible in DIS.

The critical component in this first data taking by ZEUS at HERA was the high resolution calorimeter. The performance of the calorimeter was exemplary. The U.S. collaboration made a major contribution to the calorimeter construction, to its operation, and to the data analysis. As part of this effort, the ANL group was active in the neutral current deep inelastic scattering studies; this included overall direction of the effort by Malcolm Derrick and participation by all members of the group. (B. Musgrave)

4. Polarized Proton Physics

a) BNL E-880 Experiment

The construction of the 4.7 Tesla-meter room temperature solenoid snake will be completed and installed in the 10-foot long AGS straight section, I20, in April 1993. The goal of the partial snake experiment is intended to provide polarized proton acceleration through all depolarizing resonances without using harmonic orbit correction.

The Argonne group is responsible for the design and construction of the internal polarimeter in the AGS. The polarimeter target mechanism is currently under study.

The E-880 experiment will run in the fall of 1993.

b) Polarized pp Collisions by RHIC Spin Collaboration (RSC)

A proposal on spin physics using the RHIC polarized collider was submitted in August 1992. The proposal consists of three parts. Section A describes the general RHIC spin-physics program and proposes the hardware additions for the acceleration of polarized protons in RHIC. Sections B and C describe the program of the PHENIX and STAR detectors, respectively. The Argonne group is involved in Sections A and C.

The proposal was presented before the Brookhaven PAC in September 1992, and received a favorable response. We primarily presented experiments using STAR. The STAR detector utilizes a time projection chamber to measure hadron production over a large solid angle. Other important components of STAR for which the Argonne group is responsible include an EM calorimeter and shower maximum strip detector. With these

components, STAR would offer ample opportunities to carry out spin physics. The physics issues for polarized colliders include:

- Parton helicity distributions in a polarized proton
- Parity-violating asymmetry in W and Z production
- Quark transversity distribution in polarized protons
- QCD tests

(A. Yokosawa)

II. THEORETICAL PROGRAM

Supersymmetry and Nonlocal Deformation Symmetries

Some of the most productive probes of the nonperturbative structure of quantum field theory are Polyakov's nonlocal disorder variables which are predicated on the nonlocal symmetries of solvable two-dimensional models. Following the recent identification of the algebraic structure of these nonlocal charges as a "Yangian" (deformed Kac-Moody) algebra, it was noted that, owing to a remarkable but simple quantum effect, they provide a nontrivial extension of the Lorentz group. Belavin applied the ensuing additional "kinematic" constraints on the physical states to rederive cogently the mass spectrum of the nonlinear σ -model.

In ANL-HEP-PR-92-89, C. Zachos and T. Curtright (Univ. of Miami), reveal such a quantum extension of the Lorentz group in the nonlocal Yangian deformation currents and charges that they discovered in the two-dimensional non-linear supersymmetric σ -model. More specifically, they show that, quantum mechanically, the supercurrent supermultiplet (which contains the energy-momentum tensor) is transformed by the nonlocal charge into the isospin current supermultiplet. This effect incorporates supersymmetry into the above phenomenon, but without producing additional constraints for the determination of the mass spectrum (which is thus the standard Fermi-Bose replication of the bosonic spectrum). Based on a previous result of theirs, Zachos and Curtright further conjecture an elegant generalization to *all* higher-order nonlocal charges, such that their generating function, the so-called "master charge", has a definite Lorentz spin that depends on the spectral parameter.

The η_6 at LEP and TRISTAN

There has been much excitement and controversy recently concerning a small number of $Z^0 \rightarrow \ell^+ \ell^- + \gamma\gamma$ events seen at LEP, in which $m_{\gamma\gamma}$ is close to 60 GeV. These events may indicate the existence of a new particle and new physics associated with its production.

Three years ago A. White, in collaboration with K. Kang (Brown University), suggested that the η_6 particle, composed of color sextet quarks, may have a mass of this order of magnitude, that it may have been seen in exotic Cosmic Ray events, and that it may be responsible for the anomalous behavior of the real part of the elastic scattering amplitude measured at the CERN collider. Kang and White proposed looking directly for the η_6 in accelerators via its two-photon decay mode.

In recent papers (ANL-HEP-CP-92-117 and ANL-HEP-PR-93-4), I. G. Knowles and A. White, in collaboration with K. Kang, have considered the possibility that the η_6 is the new particle seen at LEP. The η_6 is a "heavy axion" remnant of dynamical electroweak symmetry breaking by a color-sextet quark condensate. Electroweak-scale color instanton interactions allow the η_6 to be very massive, and yet, to be responsible for Strong CP conservation in the color-triplet quark sector. If the η_6 is the axion responsible for triplet CP conservation, then sextet quark interactions will not be CP conserving. In particular there will be large CP-violating vertices involving the η_6 and longitudinal W 's and Z^0 's, which can give large enough amplitudes to produce the two photon events at LEP and, perhaps, also the hadronic events seen at TRISTAN. The involvement of a longitudinal Z^0 in the LEP events implies that the amplitude will be proportional to the lepton mass. Consequently, it is predicted that the signal for a new particle will be in the muon events only and not in the electron events. A plot of the latest collection of events from the LEP collaborations is shown in Fig. 19 and seems to confirm this prediction. (Note that the background for electron events will be larger because of t-channel photon exchange.)

Knowles, White and Kang also expect the η_6 to have high-multiplicity hadron decay modes which have not yet been identified at LEP. However, if the η_6 couples sufficiently strongly to electrons, the hadronic decay modes may perhaps be responsible for a small bump, which appears at just the right energy in the TRISTAN hadronic cross-section data, as shown in Fig 20. At the order-of-magnitude level, sextet quark amplitudes do give a consistent set of cross-sections and decay rates to explain the current experimental situation at both LEP and TRISTAN.

Parton Densities

E. Berger and R. Meng have continued their research aimed at extracting a new set of parton densities of the nucleon that is consistent with all hard-scattering data from high energy interactions. Their earlier research, described in the previous semi-annual report, was focused on the constraints that bottom-quark production data provide on the gluon density at intermediate values of Bjorken's x . During the past six months, they have extended their work to incorporate the support for the gluon density at larger x supplied by prompt-photon production data at fixed target energies, and to incorporate as well new data from the deep inelastic scattering of muons and of neutrinos. Their new global fits to data are reported in two recent papers: "Constraints on the Gluon Density from Bottom Quark and Prompt Photon Production" (Argonne report ANL-HEP-CP-92-79, written with J. Qiu (Iowa State University), to be published in the Proceedings of the

Fig. 19. The two photon mass distribution for the LEP events.

Fig. 20. The error-weighted average of data from TRISTAN compared with a Standard Model prediction.

XXVI International Conference on High Energy Physics, Dallas, August, 1992) and "The Gluon Density" (Argonne report ANL-HEP-CP-92-108, to be published in the Proceedings of the Meeting of the APS Division of Particles and Fields, Fermilab, November, 1992). Figures from the papers of Berger and Meng were displayed by S. Bethke and R. K. Ellis in their plenary rapporteur talks at Dallas and Fermilab, respectively.

Although motivated initially by the goal of a better determination of the gluon density, the global fits necessarily yield a new determination of the quark and antiquark densities as well. Berger and Meng extract their new densities from a simultaneous fit to Fermilab CDF and CERN UA1 collider data on bottom-quark production, the CERN WA70 and Fermilab E706 fixed-target prompt-photon-production data, data from deep inelastic lepton scattering, including the most recent CERN NMC and Fermilab CCFR results, along with data from massive-lepton-pair production. Their analysis employs next-to-leading-order hard-scattering cross sections in QCD for bottom-quark and prompt-photon production. The fits were carried out in the $\overline{MS}$ factorization scheme, and evolution of the parton densities was done to two-loop level. Although data on the production of hadronic jets at collider energies were not included in the simultaneous fits, it is interesting to note that the densities obtained by Berger and Meng yield good fits to CDF's inclusive hadronic jet cross section data at $\sqrt{s} = 1.8$ TeV and do as well as other published densities at $\sqrt{s} = 546$ GeV. There are significant and interesting differences between the densities extracted by Berger and Meng and those of other published sets--differences that could be explored further with data on the longitudinal structure function F_L from experiments at DESY's ep collider HERA.

Prompt-Photon Production

Continuing their studies, described in the previous semi-annual report, of prompt photon production in hard interactions in hadron-hadron and e^+e^- collisions, E. Berger and J. Qiu (Iowa State University), along with graduate student X. Guo (Iowa State) wrote a paper "Direct Photon Production" (Argonne report ANL-HEP-CP-92-116). The paper was an invited parallel-session review and will be published in the Proceedings of the Meeting of the APS Division of Particles and Fields, Fermilab, November, 1992. In this paper, Berger, Guo, and Qiu review the status of their calculations in perturbative QCD of the cross sections for production of inclusive and isolated prompt photons. They also describe a method for extracting the non-perturbative quark-to-photon fragmentation function from experiments at the CERN e^+e^- collider LEP.

Decay and Production of P-Wave Quarkonia: New Factorization Theorems

Some time ago G. Bodwin, E. Braaten (Northwestern), and G. P. Lepage (Cornell) presented a new factorization theorem that allows one to make rigorous QCD predictions for the decay rates of P-wave quarkonium states. The theorem is valid to leading order in the heavy quark-antiquark ($Q\bar{Q}$) relative velocity and to all orders in the running coupling constant of QCD.

According to the theorem, the decay rates for the P-states into light hadronic or electromagnetic final states can be expressed in terms of two nonperturbative parameters, whose coefficients are calculable in QCD perturbation theory. One of these parameters is proportional to the square of the derivative of the color-singlet $Q\bar{Q}$ P-state wave function at the origin. This quantity appears in conventional analyses of P-wave decays. The second parameter is related to the probability for the Q and $\bar{Q}$ to be in a color-octet S-wave state relative to each other. Infrared logarithms that appear in conventional perturbative calculations of P-wave decay are factored into this color-octet parameter in the new analysis.

Both of the nonperturbative parameters have precise definitions in terms of operator matrix elements. Hence, they can, in principle, be measured in lattice simulations. Alternatively, they can be determined by comparison with experiment. To leading order in the $Q\bar{Q}$ relative velocity the nonperturbative parameters are independent of the spin of the state. Applying this formalism to the charmonium system, Bodwin, Braaten, and Lepage used the measured decay rates for the χ_{c1} and χ_{c2} into light hadrons to determine the nonperturbative parameters and to predict the electromagnetic decay rates for the χ_{c1} and χ_{c2} and the electromagnetic and hadronic decay rates for the χ_{c0} and h_c . This phenomenological analysis is described in Phys. Rev. D46, R1914 (1992).

More recently, Bodwin, Braaten, and Lepage, in collaboration with T.C. Yuan (Northwestern), have extended their formalism to the case of production of P-wave quarkonia. The factorization theorem for the production rates states that they, too, are expressible in terms of two non-perturbative parameters, whose coefficients are perturbatively calculable. One of these nonperturbative parameters is the same quantity, related to the derivative of P-state wave function at the origin, that appears in the color-singlet contribution to the P-wave decays. The other nonperturbative parameter corresponds to production of the $Q\bar{Q}$ pair in a relative color-octet S-wave state. It is related to the color-octet decay parameter by crossing: the production parameter is analogous to a parton fragmentation function, whereas the decay parameter is analogous to a parton distribution function. Since the crossing relation is not simple beyond low-

order perturbation theory, one must determine this new decay parameter phenomenologically (or through a lattice measurement).

Bodwin, Braaten, Lepage, and Yuan have applied this formalism to the production of charmonium P-wave states in decays of B mesons. They have used the measured rate into the χ_{c1} state to determine the new nonperturbative production parameter and to make predictions for the (as yet unobserved) decays into the other three P-wave states. The color-singlet component yields decays only into the χ_{c1} , to leading order in the strong coupling. Hence, observation of decays into the other P-wave states would be direct evidence for the presence of the color-octet mechanism. This analysis has been published in Phys. Rev. D46, R3703 (1992). All inclusive processes for production of P-wave charmonium states involve the same two nonperturbative parameters that appear in production via B-meson decay. Consequently, the determination of these two parameters allows one, in principle, to compute production rates for P-wave charmonium states in photoproduction, leptonproduction, and hadron-hadron collisions.

A number of these results are summarized in ANL-HEP-CP-92-109, which was presented at the Fermilab meeting of the Division of Particles and Fields and will be published in the Proceedings of that meeting. A paper describing the details of the formalism for computing decay and production rates for P-wave quarkonia is in preparation.

Can $b \rightarrow s\gamma$ Close the Supersymmetric Higgs Production Window?

In a recent paper (ANL-HEP-PR-92-110, Phys. Rev. Lett. 70, 1045 (1993), J. Hewett shows that the present limit from the CLEO Collaboration on the inclusive decay $b \rightarrow s\gamma$ provides powerful constraints on the parameters of the charged Higgs sector in two-Higgs-Doublet-Models, yielding bounds which are stronger than those from other low-energy processes and from direct collider searches. The CLEO 90% C.L. upper bound on the branching fraction for this mode is $B(b \rightarrow s\gamma) < 8.4 \times 10^{-4}$, and it is expected that either the CLEO limit will be strengthened, or the decay may actually be observed in the near future. Many extensions of the Standard Model predict the existence of two Higgs doublets. The physical spectrum of these models consists of three neutral Higgs scalars, two CP-even (h^0, H^0) and one CP-odd (A^0), and two charged Higgs scalars ($H^\pm$). The ratio of vacuum expectation values of the two doublets, $\tan \beta$, is the remaining model parameter. Here, two such models are examined, Model I, where one doublet provides masses for all fermions and the other doublet decouples from the fermion sector, and Model II, which is present in supersymmetry. For certain ranges of

the model parameters, the resulting value of $b \rightarrow s\gamma$ exceeds the CLEO bound, and consistency with this limit excludes part of the $\tan\beta - m_{H^\pm}$ plane. Hewett finds that in Model I only a small region of the parameter space is excluded. However, in Model II a lower limit on $m_{H^\pm}$ is obtained for all values of $\tan\beta$. For example, $m_{H^\pm} > 110$ GeV with $m_t = 150$ GeV. If the CLEO limit were to improve substantially, then the constraints in Model II would strengthen drastically, while those in Model I would be essentially unchanged. Hewett also finds that the decay $t \rightarrow bH^+$ would be kinematically forbidden in Model II if the CLEO $b \rightarrow s\gamma$ upper limit were to improve to 6×10^{-4} . In the supersymmetric case, the bounds are more conventionally displayed as an allowed region in the $\tan\beta - m_A$ plane as shown in Fig. 21. For $m_t = 150$ GeV, Hewett finds that the excluded region is comparable to that which can be explored by LEP I and II. If $B(b \rightarrow s\gamma) < 6 \times 10^{-4}$ then the window of parameter space left uncovered by both e^+e^- and hadron collider searches would be excluded. This would imply that the SSC/LHC could cover the entire remaining allowed supersymmetric Higgs parameter region.

Signals for Virtual-Leptoquark Exchange at Colliders

Many theories which go beyond the Standard Model are inspired by the symmetry between the quark and lepton generations and try to relate them at a more fundamental level. As a result, many such models contain new particles, called leptoquarks, which naturally couple to a lepton-quark pair. These particles need not be heavy; in fact, leptoquarks can have a mass ~ 100 GeV and still avoid conflicts with rapid proton decay and large flavor-changing neutral currents. M. Doncheski (Univ. of Wisconsin) and J. Hewett have continued their examination (in ANL-HEP-CP-92-126) of virtual leptoquark exchange at colliders. The influence of these effects on charged-current and neutral-current processes at HERA, on dilepton production at the Tevatron, and on quark-pair production at LEP II have been considered. The areas of parameter space that can be excluded at these colliders by searching for deviations from Standard Model expectations are presented. In e^+e^- collisions, leptoquarks can contribute to the process $e^+e^- \rightarrow q\bar{q}$ through t-channel exchange via their Yukawa couplings. The 95% C.L. search limits which can be obtained at LEP II from such reactions includes leptoquark masses up to 1000 GeV. It is found that the best search technique at HERA is to examine the ratio of neutral current to charged current cross sections, $R = \sigma_{NC} / \sigma_{CC}$, for which discovery limits can reach leptoquark masses of order 800 GeV at design luminosity. This ratio is advantageous because several systematic uncertainties cancel, as do uncertainties from parton distributions. In hadron colliders, leptoquarks contribute to the process

Fig. 21. The excluded region obtained by Hewett, from the CLEO limit on the branching fraction for $b \rightarrow s\gamma$, displayed in the $\tan\beta - m_A$ plane for the supersymmetric version of two-Higgs-doublet models with various values of the top-quark mass as indicated. In each case, the excluded region lies to the left and below each curve.

$q\bar{q} \rightarrow e^+e^-$. However, preliminary investigation shows that it is difficult to distinguish the leptoquark signal from the background in this case. Work is continuing in this area.

Particle Mass Predictions

Currently *en vogue* are schemes to predict/parametrize the observed pattern of fermion masses and mixings using specific *Ansätze* for the unification-scale Yukawa-coupling matrices within a supersymmetric theory. In two papers, Phys. Lett. B298 (1993) 356 and ANL-HEP-CP-92-120 (to appear in the proceedings of DPF '92), I.G. Knowles, C.D. Froggatt (Glasgow) and R.G. Moorhouse (Glasgow) have studied the determining role of the renormalization-group equation's quasi-fixed points for the Higgs and third-generation fermion masses. It was found that an acceptable value for m_b / m_τ does not require $g_b(M_X) = g_\tau(M_X)$ and that the top/Higgs mass predictions, $O(180/120)$ GeV/c^2 , are generic and will obtain in many models. The ambiguities in the mass predictions due to uncertainties in the value of the strong coupling and the supersymmetry breaking scale were also elucidated, see Fig. 22.

Weak-Boson Sector in $Z\gamma$ Production at Hadron Colliders

Experiments at the Tevatron $p\bar{p}$ collider are expected to collect data corresponding to an integrated luminosity of approximately 100 pb^{-1} in the 1992 -- 1993 run; an increase of more than one order of magnitude in statistics over the data sample presently available. The significant increase in integrated luminosity will make it possible to probe previously untested sectors of the Standard Model (SM) of electroweak interactions, such as the vector-boson self-interactions. Within the SM, at tree level, these self-interactions are completely fixed by the $SU(2) \times U(1)$ gauge-theory structure of the model. Their observation is thus a crucial test of the model. As discussed by Berger and Baur in Phys. Rev. D41, 1476 (1990), precise measurement of the $WW\gamma$ vertex can soon be expected from data on the reaction $p\bar{p} \rightarrow e^\pm \nu \gamma X$ in the ongoing Tevatron run.

Besides significantly improved bounds on the structure of the $WW\gamma$ vertex, the new Tevatron data will also offer the possibility to search for evidence of nonzero $ZZ\gamma$ and $Z\gamma\gamma$ couplings in $Z\gamma$ production. All $ZZ\gamma$ and $Z\gamma\gamma$ couplings vanish in the SM at tree level, and the rates for $W^\pm\gamma$ and $Z\gamma$ production are similar. In a recent paper (Argonne report ANL-HEP-PR-92-91, accepted for publication in Physical Review D), E. Berger and U. Baur (Florida State University) study the capabilities of hadron-collider experiments to probe the $ZZ\gamma$ and $Z\gamma\gamma$ vertices via $Z\gamma$ production. In the past, the reaction $p\bar{p} \rightarrow Z\gamma X$ has usually been considered for a restricted set of anomalous

Fig. 22. The dependence of particle masses on the value of the strong coupling (for $M_S = 1 \text{ TeV}/c^2$) and the supersymmetry breaking scale (for $\alpha_s(M_Z) = 0.125$). Assuming a large value for $\tan \beta$ and random initial conditions, one uses the renormalization group equations, with supersymmetry extant above a fixed scale, to evolve the Yukawa couplings to low energies, where quasi-fixed point predictions for the top, Higgs and bottom masses are made.

couplings only. The study of Berger and Baur improves on the existing literature in that they include the full set of anomalous couplings allowed by Lorentz and electromagnetic gauge invariance. They also take into account the form factor effects of the non-standard $ZZ\gamma$ and $Z\gamma\gamma$ couplings; use the full set of tree-level Feynman diagrams, including timelike-virtual-photon and final-state-bremsstrahlung diagrams; and derive realistic sensitivity limits. Their analysis is based on the calculation of helicity amplitudes for the complete processes

$$q\bar{q} \rightarrow Z\gamma \rightarrow \ell^+\ell^-\gamma \quad (1.1)$$

and

$$q\bar{q} \rightarrow Z\gamma \rightarrow \bar{\nu}\nu\gamma, \quad (1.2)$$

where $\ell = e, \mu$.

In the paper, Berger and Baur discuss the signatures of anomalous $ZZ\gamma$ and $Z\gamma\gamma$ couplings in $p\bar{p} \rightarrow \ell^+\ell^-\gamma$ and $p\bar{p} \rightarrow \bar{\nu}\nu\gamma$ at the Tevatron. The $\ell^+\ell^-\gamma$ invariant mass, the photon transverse momentum and the $\cos \Theta^*$ distributions are sensitive indicators of anomalous couplings. Here Θ^* is the polar angle in the $\ell^+\ell^-$ rest frame with respect to the $\ell^+\ell^-$ direction in the $\ell\ell\gamma$ rest frame. Cuts are described which select a region in phase space that is particularly sensitive to anomalous couplings. A typical signal for non-standard couplings will be a broad increase in the invariant mass distribution of the $\ell\ell\gamma$ system at large values of the invariant mass, as shown in Figure 23.

Berger and Baur also consider the most important backgrounds and discuss the sensitivity of experiments at the LHC and SSC to non-gauge-theory $Z\gamma V$ vertices. The paper includes a comparison of the limits on anomalous $ZZ\gamma$ and $Z\gamma\gamma$ couplings expected from hadron-collider experiments with low energy bounds and with the sensitivity of present and future e^+e^- collider experiments.

Final-State Interaction of Longitudinal Vector Bosons

The most direct probe of the mechanism for electroweak symmetry breaking is longitudinal vector boson scattering. Indeed, in the standard Higgs model, the Higgs boson appears as a resonance in this process. Data from the LHC and the SSC will provide the first opportunity to study longitudinal-vector-boson scattering directly. Since there are various mechanisms for the production of pairs of longitudinal vector bosons at supercollider energies, it is important to investigate whether and how longitudinal-vector boson scattering could also be studied indirectly via the final-state interactions (rescattering) of vector bosons. This question is addressed in a recent paper, ANL-HEP-PR-92-93, by E. Berger, J.-L. Basdevant (University of Paris), D. Dicus (University of

Fig. 23. Calculation by Berger and Baur of the invariant mass distribution of the $ll\gamma$ system at the Tevatron for the Standard Model (solid line) and for two choices of the anomalous $ZZ\gamma$ couplings, with two choices of the form-factor scale Λ .

Texas), C. Kao (Florida State), and S. Willenbrock (Fermilab and Brookhaven). The paper has been submitted for publication in Physics Letters B.

An important source of longitudinal vector boson pairs at supercollider energies is the process $gg \rightarrow V_L V_L$, where subscript L denotes longitudinal polarization. The process proceeds via a top quark loop. In the standard Higgs model, the Higgs boson couples directly to the top quark as an s-channel resonance. Thus, it is conceptually difficult in the standard Higgs model to distinguish the effects of final-state rescattering of the vector bosons from the direct coupling of the bosons to the Higgs. In order to separate the two effects, Berger *et al.* adopt a simple two-Higgs doublet model in which one of the doublets (H_1) couples directly to $Z_L Z_L$ but not to $t\bar{t}$. The other doublet (H_2) couples directly to the $t\bar{t}$ system. In the context of this model, Berger *et al.* develop both the tree-level amplitude for $t\bar{t} \rightarrow Z_L Z_L$ and the one-loop amplitude, which includes the effects of final-state interactions. They demonstrate that, via final state interactions, H_1 manifests itself as a *dip, not a peak*, in the cross section for $t\bar{t} \rightarrow Z_L Z_L$. Results of their calculation are shown in Fig. 24. In the paper, Berger *et al.* also discuss the possibilities for observing such dips at SSC energies. The dip-peak structure that Berger *et al.* calculate in the case of longitudinal-vector-boson scattering is similar to the earlier calculation of Basdevant and Berger for the two- resonance, two-channel case of the strange axial vector $J^P = 1^+ K\pi\pi$ meson system (Phys.Rev. D19, 239 and 246 (1979)).

Backgrounds for Three-Body Decays of New Gauge Bosons

J. Hewett and T. Rizzo have examined (ANL-HEP-PR-92-33, Phys. Rev. D, in press) the Standard Model background at the SSC/LHC to the observation of the three-body decay $Z_2 \rightarrow Z\bar{\nu}\nu$, which arises from the conventional process $\bar{q}q \rightarrow ZZ \rightarrow Z\bar{\nu}\nu$. As discussed in their earlier work, this is one of only two potentially observable three-body Z_2 decay modes which are found to be highly sensitive to the couplings of these new gauge bosons. The Standard Model background missing- p_T distribution falls rapidly with increasing p_T and is highly sensitive to the applied rapidity cuts, owing to the presence of t- and u-channel poles in the amplitude. On the other hand, since the missing p_T in the Z_2 case is the result of a bremsstrahlung process, it was shown that this distribution is rather soft and reasonably insensitive to such cuts. Hewett and Rizzo showed that, for a wide class of models, the ratio of signal to background was largest when strict rapidity cuts were applied, but that the signal always remained a factor of 2-3 below the background in almost all cases examined. From this analysis, it would appear

Fig. 24. Calculation in the two-Higgs doublet model by Basdevant, Berger, Dicus, Kao, and Willenbrock of the square of the zeroth partial wave for $t\bar{t} \rightarrow Z_L Z_L$, with the t and $\bar{t}$ of the same helicity and opposite color, versus center-of-mass energy, for Higgs masses $m_1 = 500$ GeV and $m_2 = 300$ GeV, and top mass $m_t = 130$ GeV. Both the tree amplitude (dashed) and the amplitude including the final-state interaction of the longitudinal vector bosons (solid) are shown. The H_2 resonance produces the expected peak, while the H_1 , which does not couple directly to the top quark, produces a dip.

that a clean observation of the three-body decay process seems to be hopeless unless the background distribution could be determined directly from the experimental data by some other means. Such a possibility is currently being investigated.

$SO(10)$ Grand Unification with a Low-Energy M_R

Grand Unification groups larger than $SU(5)$ allow for the symmetry breaking down to the Standard Model to occur in several stages at mass scales intermediate between the GUT and electroweak scales. It is commonly believed that present limits on the lifetime of the proton combined with the precision data from LEP forbid these intermediate mass scales from being close to the electroweak scale. In particular, for the $SO(10)$ GUT group, the scale associated with the breaking of the intermediate left-right symmetry group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, M_R , was found in previous analyses to be larger than about 10^9 - 10^{10} GeV. In a recent paper (submitted to Phys. Rev. Letts.), N. Deshpande (Oregon), E. Keith (Oregon), and T. Rizzo showed that, within a supersymmetric version of this model, a simple solution exists which allows M_R to be as low as a TeV and still remain consistent with present data. While the breaking of the Standard Model symmetry is performed as usual by Higgs fields in the $SO(10)$ 10 representation, $SU(2)_R$ breaking arises from three pairs of $SU(2)_R$ doublets in the $SO(10)$ 16 and $\overline{16}$ representations instead of the usual 126 and $\overline{126}$ representations. At one-loop, the renormalization group equations for this model yield results which are identical to supersymmetric $SU(5)$, since the running of the $SU(2)_R$ coupling constant is found to decouple from those of $SU(3)_C$ and $SU(2)_L$, see Fig. 25. A full two-loop analysis, which included the effect of thresholds as well as the running top-quark Yukawa coupling, was performed using dimensional reduction. This analysis shows that the one-loop results are stable. Low energy parameters, such as $\sin^2 \theta_W$, were found to be highly insensitive to the value of M_R . The model predicts the ratio of the left-handed to right-handed gauge couplings, $\alpha_{2L} / \alpha_{2R}$, to be near 1.5, implying a lower limit of 480 GeV on the mass of the W_R from direct collider searches. Since the symmetry-breaking pattern forbids the generation of large tree-level Majorana mass terms, see-saw neutrino masses are generated radiatively.

Fig. 25. Evolution of coupling constants for the symmetry breaking chain $SO(10) \rightarrow SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y$, with $X = B - L$, using the low-energy input parameters and uncertainties from LEP data, assuming $M_R = 1$ TeV and SUSY particle masses degenerate with the Z .

Probing Z' Couplings via Associated Production at the SSC

The production of a Z' at the SSC in association with a photon or jet was analyzed by T. Rizzo (ANL-HEP-PR-92-58, Phys. Rev. D, in press) as a means to probe the nature of the Z' couplings. Associated jet production was found to be rather insensitive to these unknown couplings and to suffer from large theoretical uncertainties as well as substantial standard-model backgrounds. On the other hand, the ratio of rates for associated photon- Z' production to that of conventional Z' production, R_γ , was found to have a clean signature, once appropriate rapidity, minimum-photon-energy, and p_T cuts are made, and was found to be quite sensitive to the couplings of the extended electroweak model. In addition, this ratio was found to be insensitive both to structure function uncertainties and to higher-order QCD corrections. For a Z' of mass 1 TeV, it was found that an integrated luminosity of 10 fb^{-1} at the SSC would allow for a determination of R_γ at the level of 10-20% once identification efficiencies are accounted for. Unfortunately, for significantly larger Z' masses, insufficient statistics will be available to use this technique as a probe of Z' couplings.

Lepton-Number Violating W Decays in Models with Explicit R-parity Violation

In the simple Minimal version of the Supersymmetric Standard Model (MSSM), both baryon(B) and lepton(L) numbers are conserved quantities, owing to the imposition of a discrete symmetry called R-parity. Of course, this minimal approach may not be the one realized in nature, since gauge symmetries alone do not forbid the existence of explicit R-parity violating (hence B and/or L violating) terms in the superpotential. Phenomenologically viable models of this kind are easily constructed which satisfy both astrophysical and cosmological constraints. Such models possess an additional discrete symmetry, baryon parity, which renders the proton stable in the absence of GUT interactions. One of the signals for such a scenario would be the observation of L -violating, radiative W decays involving the supersymmetric partners of the muon or tau leptons. The possibility of such a signal has recently been investigated by T. Rizzo (ANL-HEP-PR-92-81, submitted to Phys. Rev. D). Given the helicity structure of the R-parity violating terms allowed by the gauge symmetries and the fact that the W couples only to left-handed currents, the rate for such a decay was found to be suppressed even if large Yukawa couplings of order the electromagnetic strength are allowed. For example, if the slepton mass were 50 GeV and the top-quark mass were 100 GeV, then the branching fraction for this lepton-number violating decay would only be of order 10^{-8} . This result was found to hold in all models with explicit R-parity violation and could only be circumvented in a scenario in which R-parity violation occurs spontaneously.

Radiative W and Z Decays and Spontaneous R-Parity Violation

The spontaneous breaking of R-parity generally requires the enlargement of the gauge symmetry of the Standard Model such that some neutrino-like weak isosinglet can obtain a non-zero vacuum expectation value (VEV). R. Mohapatra (Maryland) and T. Rizzo have recently examined (ANL-HEP-PR-92-113, submitted to Phys. Rev. D, Rapid Communications) such a model based on the $SU(2)_L \times U(1)_R \times U(1)_{B-L}$ gauge group; a similar analysis would apply to the more complex Left-Right Symmetric Model. In the model, $B - L$ as well as R-parity are spontaneously broken by a vev generated for the scalar partner of the right-handed neutrino at the TeV scale, which leads to viable neutrino masses and a rich phenomenology. Since it is a sneutrino which obtains a VEV, baryon number is automatically conserved. One signal for this model that was examined by these authors is the enhancement of the branching fraction for the lepton-number-violating radiative decays of the W and Z bosons in comparison to that which is obtained in scenarios with explicit R-parity violation. The structure of the one-loop induced interaction of sleptons with third-generation quarks in this model has the opposite chiral structure to that in models with explicit R-parity violation and is the cause of this enhancement. For the W , the assumptions of a slepton mass of 50 GeV and a top-quark mass of 100 GeV lead to the prediction for the branching fraction of $3 \cdot 10^{-6}$, with a similar result for radiative Z decay if the relevant Yukawa coupling is of electromagnetic strength. Since rates this large can occur within the context of extended gauge models only in scenarios with spontaneous lepton-number and R-parity violation, the observation of these decays would imply the existence of new gauge symmetries. A further prediction of the model, in contrast with other R-parity breaking models, is that the lightest supersymmetric particle (LSP), which is primarily a photino, can decay only to $\tau \bar{c} s$.

A Separate Higgs?

In the Standard Model (SM), the masses of the fermions and gauge bosons are generated via the vacuum expectation value of a single Higgs field. Since the true origin of the symmetry breaking is unknown, V. Barger (Wisconsin), N. Deshpande (Oregon), J. Hewett, and T. Rizzo examined (ANL-HEP-PR-92-102, submitted to Phys. Rev. Lett.) the possibility that a phenomenologically viable model could be constructed wherein *different* Higgs fields are responsible for producing fermion and gauge boson masses. The simplest scenario of this kind can be realized within the framework of the Two Higgs Doublet Model by a fine-tuning of the parameters in the Higgs potential. More complex

models, which are supersymmetric and require less fine tuning, are also possible, but are difficult to analyze due to the large numbers of parameters they contain. The couplings of the physical Higgs fields in such a model are found to be quite different from *both* the SM as well as the Minimal SUSY model (MSSM). The lightest neutral CP-even field (h) was found to have vanishing couplings to fermions at the tree level, while still maintaining almost-Standard-Model-strength couplings to the gauge bosons. The heavier neutral CP-even (H), as well as the neutral CP-odd (A) and charged fields have enhanced couplings to fermions with somewhat reduced couplings to the gauge fields. If h is lighter than the W , then it can decay essentially only into pairs of photons and could be seen at LEP in Z decay; i.e., $Z \rightarrow h\bar{f}f \rightarrow \gamma\gamma\bar{f}f$, where f is a quark or lepton. It is possible that a scenario such as this might provide an explanation of the anomalous events observed at LEP. The rates for production as well as discovery signatures for H and A at the SSC were found to be substantially different from both the SM and the MSSM. For example, in comparison to the SM, the WW fusion process was found to be suppressed in rate by two orders of magnitude, while for H and A of intermediate mass, the gluon fusion processes, $gg \rightarrow H, A \rightarrow \gamma\gamma, \bar{t}t$, were found to be substantially enhanced. Further consequences of this scenario are currently under investigation. (C. Zachos)

III. EXPERIMENTAL FACILITIES RESEARCH

A. Mechanical Support

SDC. Refer to the Mechanical Section for SDC.

STAR. The conceptual drawings for the EM Section were completed during this reporting period. Engineering effort was contributed by Tom Fornek and Ed Bielick, who are working for the HEP Division. Messrs. Fornek and Bielick are on loan from the Engineering Physics Division. There was a major revision in the design that required changing from a superconducting solenoid that was inside the calorimeter to a conventional coil outside the calorimeter. This change required a complete redesign of the concept (see Figures 26, 27 and 28).

CDF. No mechanical support effort on CDF during this reporting period.

ZEUS. Some engineering and technical staff effort was used to assist Andrzej Derlicki in the design and construction of prototype wire chambers for the shower maximum detector to be installed in the barrel EM calorimeters for ZEUS.

PDK

The construction of modules for the detector was essentially completed during this reporting period with a total of 177 modules constructed, of which twelve required rebuilding due to various operational problems. The module factory in Building 366 will now be rearranged to accommodate construction of the SDC components.

Wakefield. Work continued on the design and construction of linac components with a major portion of the effort devoted to the support systems. A significant amount of technical staff, design, and technician effort was used to install components as they were being fabricated. The design of the laser pulse shaper was completed and fabricated during this reporting period. It will now be tested for performance by the Accelerator R&D group. (N. Hill)

B. Electronics Support

Work will continue to support the Nucleon Decay experiment, Soudan 2. We expect that our involvement in FY 1994 will be one primarily of construction and maintenance. The Argonne HEPD is a collaborator in a Fermilab proposal to construct a long baseline neutrino oscillation experiment (Fermilab P822) incorporating the Soudan mine facility. As the course of events with regard to P822 becomes clearer we would hope that there would be areas of development which we could undertake.

Fig. 27. Flux return bar support.

Fig. 26. Solid aluminum ring support.

Fig. 28. Barrel Calorimeter Quadrant Cross Section.

Our major effort with regard to support of the ZEUS calorimeter has been the development 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. Construction and testing of this hardware were completed in FY 1993 and the first operation of this trigger for physics was in spring 1993. During FY 1994 we expect to do some upgrading and revision of electronics associated with the CFLTP. We have proposed that a shower max chamber for the barrel calorimeter be developed using proportional wires and strips to be implemented instead of the silicon Barrel Hadron Electron Separator (BHES) which had previously been proposed. This would naturally be cost advantageous, but the impact on physics needs to be understood. Prototype development on this hardware is proceeding together with a Monte Carlo study of the effect on physics. A proposal has been submitted to the directorate to add a Small Angle Rear Tracker to the ZEUS detector. We expect to be responsible for the trigger electronics and a section of the data acquisition electronics for this device, and have begun development of the requisite electronic hardware. We expect to have a prototype set of hardware in place in the HERA ring in summer 1992. The construction of the electronic hardware for the SRTD will take place during FY1994.

During FY 1992 and FY 1993 we have built and tested electronics for the CDF trigger upgrade. This is an effort to bring the preshower radiator and shower max detector wires into the trigger at second level to improve the efficiency for B physics. We are responsible for the digital aspects of the work and our collaborators from the University of Chicago and the University of Michigan are responsible for the analog electronics. Four FASTBUS CES/CPR cards were produced and tested. During FY 1994 we expect to take an expanded role in the upgrade of CDF which will allow operation with the 132 nanosecond crossing period. Our work will include the upgrading, redesign, and reconstruction of electronics to support this mode of operation.

We have begun development of hardware for the first level calorimeter trigger for the STAR detector at RHIC. We expect to take responsibility for this trigger and the interface to the data acquisition from the calorimeter.

(J. Dawson)

C. Computer Support

During the past half year the Silicon Graphics Unix operating system IRIX was upgraded to Version 4.0.5 on eight workstations. A HEPLIB was established to provide standard utilities to SGI users beyond the CERNLIB. These include postscript previewers, WorldWide Web, gnu emacs, gnu plot, TeX, Latex, tcsh, TopDrawer, etc. A 2 Gigabyte disk was added for CDF software and data access.

An upgrade to the video telecommunications codec was ordered and planning was begun for the upgrade of the network interface was begun.

Additional NCD X terminals were acquired and installed bringing the total to ten supported on the HEP LAN. Testing of Xremote was conducted to supply X11 services to home personal computers based on 9600 baud modems. Testing and installation of X11 software for pc's on the HEP lan was done.

A Sun Sparcstation 2 with 3 Gbytes was acquired and installed for the PASS project. A 50 MHz 486 personal computer was acquired and installed for software and hardware testing, system and network administration, and monitoring by the computing group.

Continuing support for maintenance and system administration for the division central VAX cluster, the Sgi Unix network, the AppleTalk Mac's and the PC's was provided.

Support for design and implementation of software for the ZEUS data acquisition system was provided.

(E. May)

IV. ACCELERATOR RESEARCH AND DEVELOPMENT

A. Advanced Accelerator Test Facility (AATF) Program

Once again, the AATF facility demonstrated its unique wake effect measurement capabilities; this time by measuring prototype liners developed at the SSC. The liners are being considered for use in the SSC to allow for possible increases in stored beam current over that specified originally. While liners can shield equipment from synchrotron radiation, the "holes" required for pumping can produce short range wakes as beam pulses pass. These in turn can produce single bunch emittance growth and undesirable energy spread. The goal is to keep these wakes small by judicious choice of hole/slot layouts.

As did the NLC cavity measurements (see the previous semi-annual report), these measurements tested the limit of the AATF's experimental reach. Whereas the NLC tests challenged the delay range and beam spot size, the SSC liners challenged the sensitivity of the facility. Nevertheless, wakes were conclusively measured in the experiment at levels below the advertised sensitivity of the AATF. The results are being compared to computer simulation predictions which are presently difficult to make with confidence.

B. Progress on the Argonne Wakefield Accelerator (AWA)

1. rf Supply and Cavities

During the period from June through December of 1992 the construction proceeded well. The photocathode cell was cleaned and refurbished following its rf conditioning and was installed on its supports inside the AWA shield vault. The cathode manipulator and preparation cell were mounted and attached to the photocathode cell.

The rf cells to make the preaccelerator cavities were polished and successfully brazed together. After fine-tuning the coupling apertures, the cavities were tuned by deforming the tuning divots machined in the outer walls. Finally, the completed cavities were mounted on their supports in the AWA vault and connected to the photocathode gun. The system was then placed under vacuum, nearly ready for rf power.

The non-linear focussing solenoids were assembled at their designed locations and connected to their power supplies. Magnetic field measurements of one of the solenoids confirmed the design.

Installation of the radiation safety system controls and wiring is nearly done.

The project suffered a setback when the 25 MW rf supply vendor filed bankruptcy in October. At the time, the supply was behind schedule by more than two months, but that in itself was not totally unexpected. Following concerted efforts between ANL's legal department and court appointed bankruptcy attorneys, we successfully retrieved from the defunct company's former premises all identifiable ANL owned equipment. We are now evaluating the true status of fabrication, but can already conclude that there is much to be done to complete the supply. This is no small perturbation on the group's resources, but we are confident that we can complete the supplies here at ANL.

Because there are a number of relatively long lead-time components which are missing and because our effort is drawn away from other activities the AWA project will be delayed by at least six months.

On a brighter note, many of the various wave guide components (guides, circulator, couplers, etc.) have arrived and are ready to install.

2. Laser System

The wave front shaping mirror system has been fabricated and assembled. Tests using a streak camera to resolve the resulting pulse shape are now being set up. The computer controls for the pulse shaper are complete. The control system is designed to make pulse shaping convenient by its use of a graphical interface.

Reliability of a small but critical element in the YAG laser used to pump the short pulse dye laser has been troublesome. The problem is with the temperature readout of a doubling crystal. The manufacturer is very cooperative in resolving the problem and acknowledges responsibility. The component may require redesign by the manufacturer, but this is not expected to delay AWA commissioning. (J. Simpson)

C. Development of a High Resolution Beam Profile Monitor

Components for a test run of the beam profile monitor using parasitic bremsstrahlung at the APS Linac have been designed and built. The system consists of two stands, one with the primary collimator and shielding, and the other with detectors reading into a control system. The positions of the collimators are controlled by encoder motors. The bremsstrahlung beam is actually imaged by converting photons to electron-positron pairs and imaging cherenkov light from the pairs. A CCD linear image sensor with a two stage gated image intensifier will be used as a detector. The system is operated with a 486 personal computer using LabWindows.

During the period of this report, the mechanical design was produced, components were ordered, and the mechanical, electronic and data acquisition systems were assembled. Operation of the encoder motors, computer and associated hardware, other camac components and control software was demonstrated.

The central focus of this work was the design and construction of a CAMAC module which read out the CCD chip into a FIFO buffer. It also provides communication with the rest of the system in the form of latches, timing and control voltages. The first images through the camera system, looking at ceiling lights thru a pinhole, confirmed that the CCD chip readout and display worked. (J. Norem)

V. SSC DETECTOR RESEARCH AND DEVELOPMENT

A. Overview of ANL SSC Related R&D Programs

During the second half of calendar 1992, the technical organization of SDC was put in place following the submission of the Technical Design report in April and its favorable review by the SSC Program Advisory Committee in May. Jim Proudfoot and Norm Hill became Task managers within the Calorimetry group. Proudfoot will be responsible for the overall barrel electromagnetic calorimeter and Hill will oversee the final assembly process before lowering the calorimeters into the SDC interaction hall. Jim Proudfoot and Barry Wicklund became members of the Calorimeter Technical Board, which guides the calorimeter subsystem development. Larry Price, Jim Proudfoot, and Barry Wicklund were named to the collaboration's Technical Board which sets technical directions for the detector as a whole. These appointments were part of a broader organization of the technical effort by Tom Kirk after he became SDC Project Manager and co-spokesman in May.

Technical choices and reviews continued to take place as the design of the SDC nears completion. Argonne people were involved in the choice of central tracker technology and in calorimeter reviews of the optical system and front-end electronics. Argonne's design for the barrel electromagnetic calorimeter was reviewed positively in June (Conceptual Design Review) and affirmed by the Technical Board in July.

In October, the SDC Technical Design Report along with subsequent design and planning were reviewed by the DOE and many consultants. Most comments were positive, though many suggestions were made for improvements to specific plans.

In computing, Irwin Gaines (FNAL) took the leadership of the working group, succeeding L. Price (ANL). Argonne remains strongly involved in the SDC computing effort, particularly in the area of data management through collaboration on the PASS high performance computing project. L. Price remains spokesman of PASS. The PASS group completed a study and performance benchmarking of two commercial databases and one locally developed system. Significant performance advantages were seen compared to the methods currently used in high energy physics experiments.

Work was begun on a "reference model" for PASS that will attempt to set long-range goals for the project. In addition, the reference model document will set out at least one specific scenario for the architecture and data flow of a practical system.

Demonstration projects are planned during the next year. The first will be done at the 10 GB level using equipment at SSCL. This will continue to make use of CDF data to be sure of dealing with the difficulties of real HEP data. Second will be a test at the 1 TB level using the planned HPCC installation with IBM equipment in the MCS division at ANL. This test will allow full exploration of the issues raised by hierarchical storage systems since both RAID disk and DD2 tape robot systems will be available. This large-scale development will be moved over to simulation data from the revised SDC simulation programs as they become available in FY 1994. (L. Price)

B. SDC Calorimeter Engineering Design

Introduction

The cast lead concept for fabrication of the barrel electromagnetic calorimeter became the SDC baseline with no alternates as of July 1992. This design has been developed by a collaboration between Argonne and engineers at the Westinghouse Science and Technology Center in Pittsburgh. WSTC has developed the mold design and casting process (under the technical oversight of Argonne) and Argonne has developed the basic design characteristics of the absorber structure. Several design issues were raised when the decision was made by the SDC to pursue this design with no alternates. These included a better understanding of stresses and deflections in the structure; the precision with which tiles can be calibrated, as in this design the tubes through which sources are run are embedded in the lead absorber plates; potential problems with light yield and uniformity in the large tiles at high η which have 26° bevels on the Z edges; an improved cost estimate and a more complete analysis of testbeam data to characterize the response in the region of the stainless steel bulkheads. In this reporting period, work was carried out to address all of these issues, and others pertinent to finalization of the design.

1. SDC Barrel EM Calorimeter Engineering Mechanical Design. The work completed in this reporting period comprised finalizing design details of the frame and mold to allow fabrication of four prototype modules in FY93. During this period, the design had three design reviews (two within the SDC and one internal to the ANL/WSTC collaboration) to confirm the design criteria.

In August, the primary concerns of the SDC were those of stresses and deflections in the module. FEA calculations were carried out and showed that with the appropriate boundary conditions (supports at $Z = 0$), the design met the SDC requirements of no load being imparted to the scintillator tiles. This design uses a calcium/tin/lead alloy and reinforcing bars within the structure at high η . The details of these FEA calculations are given in Section B.2 below. In addition, we initiated a series of tensile stress

measurements on lead alloys (Section B.3). We also designed a test cell to confirm the design at high η where the aluminum insert plates are largest and are, therefore, subject to the most potential difficulty in fabrication to the necessary tolerance and receive the largest stresses during the thermal cycle. The description, specifications, and goals of this test are given in Section B.4.

Prior to the start of fabrication the ANL/WSTC team met in October and December to review the design specifications associated with the integration of the frame and mold -- in particular the dimensional tolerances and thermal cycle. The responsibility for this aspect of the design lies with WSTC.

The final design was presented to the SDC Calorimeter Group in December. Fabrication of fixtures and pieces for four test modules to be built in FY93 was begun in December. Some of the details associated with this aspect of the program including fabrication and assembly procedures as well as the anticipated schedule are given in Section B.8).

2. FEA Analysis - V. Guarino. Finite element calculations were performed for towers 9 to 14 to compute expected deflections which might have caused material to bear on the scintillator. Some details of the absorber structure are shown in Fig. 29. The finite element analysis which was performed used four node shell elements to model the lead plates, the 3 mm thick front plate, and the bulkheads. The FEA model was fully restrained along the back of the module where the EM section was attached to the HAD1 portion of the module. The moduli of elasticity used were 3 million psi for the lead and 30 million psi for the steel. All of the bulkheads were 0.5 mm thick except where noted.

Figure 30 shows the lead plate deflections of towers 13 and 14. The lead layers are numbered from 1, which is along the front plate, sequentially back into the module. The legends labeled 1.2, 1.3, and 1.4 are plots of the deflections of the lead plate where they are connected to the bulkhead at η of 1.2, 1.3, and 1.4, respectively. The legends labeled T-13 and T-14 are plots of the deflections of the lead plates in the middle of the 13th and 14th towers, respectively. The deflections in the middle of the 13th increase with layer until layer 4, where there is a sudden jump to 0.7 mm. In the design to accommodate constraints imposed by the shower maximum detector, this plate terminates at the $\eta = 1.2$ bulkhead. Therefore, there is no lead plate on the opposite side of the bulkhead to oppose the bending moment and this results in a larger deflection than would otherwise be the case. A similar, though less severe, effect is seen at the bulkhead terminations. Similar effects were observed in towers 9-12 leading us to the conclusion that the bulk of the severe deflections in the absorber structure come from unbalanced forces at these specific terminations. We, therefore, decided to consider the effect of increasing the stiffness of these bulkheads by making them thicker. Figure 31 shows the

Fig. 29. Barrel EM absorber structure at high η . Stainless steel bulkheads are located in $0.1 \Delta\eta$ intervals. Only those at $\eta = 1.0$ and 1.2 penetrate the slot for the shower maximum detector.

TOWER 13--14 RADIAL DISPL.- 12 O'CLOCK

Fig. 30. Lead plate deflections computed using an FEA model of the barrel structure. The towers are as shown in Fig. 29. The layers are numbered from the inner radius.

TOWER 13--LEAD PLATE DISPL. RADIAL DISPL.-12 O'CLOCK

Fig. 31. FEA calculation of the lead plate deflections in Tower 13 for the case that the 0.5 mm bulkhead is replaced by one 1.5 mm thick.

lead plate deflections in tower 13 for a 1.5 mm thick bulkhead. The first curve, with a label of 0.5 mm, is the standard configuration. The second curve with the label of 1.5-A is the standard model with the bulkheads at η of 1.2 and 1.3 changed to 1.5 mm thick. The third curve with a label of 1.5-B is the standard model, but with only the bulkhead at η of 1.2 changed to 1.5 mm thick. It can be seen in Fig. 31 that the peak deflection can be reduced from 0.7 mm with the bulkheads 0.5 mm thick to 0.5 mm with only the bulkhead at η of 1.2 changed to 1.5 mm thick. The deflections are reduced further to 0.45 mm when the bulkheads at η of 1.2 and 1.3 are changed to 1.5 mm thick. A single lead plate terminating at a bulkhead such as at η of 1.2 applies a bending moment to the bulkhead that increases deflections. Increasing the thickness of the bulkhead increases the ability of the bulkhead to resist this deflection.

At the present time, we feel that our baseline with 0.5 mm bulkheads presents no unacceptable risks. The high η test casting will allow us to check the bulkhead terminations and to verify the results of the preceding FEA calculation.

3. Tensile Stress Measurements on Lead Alloys - J. Nasiatka. Extensive tensile testing of the mechanical properties of the 0.06% Ca, 1.3% Sn lead alloy was conducted to determine its average yield stress and Young's modulus of elasticity. A plot of the stress vs. strain curves is shown in Fig. 32 along with the boundaries for Young's modulus. The results from this test show that the higher tin alloy has tensile characteristics that are approximately a factor of two higher than the lower tin alloy, and a factor of six better than those of pure lead. Additional samples of the 0.06% Ca, 0.5% Sn lead alloy were cast in preparation for creep characteristic testing, and for additional tensile testing to provide confirmation of the previous set of tensile test data.

To obtain precision measurements of the high-stress creep test, it was decided to use strain gauges mounted on the lead samples for measuring the elongation. A Micro-Measurements System 4000 strain gauge scanner was purchased. To test the calibration of the system, a known weight was placed on a strap with a strain gauge mounted on it, and the resulting strain was measured and compared to the calculated value (Fig. 33). The measured strain matches the calculation within 10%. The difference between the two is because the strap used was very thin and started to twist during the test.

4. High η Test Casting - V. Guarino. In the past year and a half, three 10 tower test castings have been made to demonstrate our ability to cast the relatively short lead plates which occur at the low η end. The ability to cast the long lead plates at the high η end had not been tested to date. Calculations had shown that the deflections of these plates under their own weight was close to 0.5mm. It was necessary to know how much these plates will deflect since any deflections over 0.5mm will prevent the scintillator

Stress - Strain Curves for L50750 Lead Alloy
0.06% Ca 1.3%Sn

Fig. 32. Stress-strain curves for samples of L50750 alloy (0.06% CA, 1.3% Sn).

Fig. 33. Measured strain in a thin strap. The calculated value of 823 μE agrees to within 10% of the measured data.

from being inserted. In order to test our ability to cast the long plates at the high η end and to measure the deflections of these plates it was decided to make a test casting of the first 5 plates of the 13th and 14th towers. This casting would also test our ability to terminate lead plates at a bulkhead and to cast reinforcing tubes into the lead plates. The casting frame consisted of a 3mm plate bent in a "U" shape and connected in the back by a 1" thick stainless steel plate as shown in Fig. 34. The $\eta = 1.3$ bulkhead was bolted to the back plate and was attached to the front plate by bent tabs the same way it would be in the full scale module. The casting consists of five lead plates including a shower max gap. A step in shower max occurs at the bulkhead. We also expect to acquire data on fabrication of the largest aluminum spacer plates required for the design (both on costs and achievable tolerances) and on the dimensional specifications in the design associated with the thermal cycle.

It has been decided, based on a suggestion by the lead vendor, to test silicone as a mold release on this casting. Silicone may be more effective than the graphite release which we have used previously.

5. WSTC Work on Mold Design - J. Proudfoot. Westinghouse Science and Technology Center is responsible for the design of the mold and casting process to be used for the fabrication of four full scale prototype modules. This work is being carried out by WSTC under the technical direction of Argonne. A sketch of the mold design is shown in Fig. 35. The major parts of this component were released for quotes on fabrication in late December. Within this reporting period two critical design issues were raised and resolved. The first of these was that of the cooling system to be used in the casting. The issues considered for the active part of the cooling phase (liquid lead $\rightarrow$ all solid) were minimize porosity, which favors rapid cooling, maximize alloy stability, which favors rapid cooling, and minimize thermal stresses, which favors slow cooling. The optimization of these conflicting requirements lead to the judgment that the desired time to solidification was between 15 and 45 minutes. A thermal analysis was carried out to determine the heat distribution within the casting and thereby determine the boundary conditions (insulation on top and sides, cooling capacity). Forced air and a water spray were considered as cooling sources. The former was rejected as it would require baffles and fins on the mold bottom, and would be difficult to modify in the field. The thermal cycle for the water based cooling system is shown in Fig. 36. A summary of the thermal parameters is shown below in Table A.

Fig. 34. Schematic of the high η test casting frame and mold.

Fig. 35. Sketch of the mold components being designed and supplied by Westinghouse STC for use in casting the prototype module.

TEMPERATURE DISTRIBUTION IN CASTING DURING COOLING

Fig. 36. Results of a one-dimensional calculation of the temperature distribution within the casting for the designed cooling system and boundary condition of solidification of the top (last) in 30 minutes.

Table A

EM Absorber Prototype Casting Program

Summary of Thermal Parameters

Mold Design

Insulating Lid Thickness	2 in.	51 mm
Base Plate Thickness	0.75 in.	19 mm

Cooling System Design

Cooling Fluid	Water	
Flow Rate	65 gpm	246 l/min
Number of Jets	1000	
Jet Diameter	0.06 in.	1.6 mm
Jet Velocity	25000 ft./hr.	2.1 m/sec
Jet Spacing	3.06 in. ²	19.7 cm ²

Cooling System Performance

Time to Full Solidification	29.3 min	
Max Surface Heat Flux	24,000 Btu/hr.-ft. ²	7.5 W/cm ²
Minimum Surface Heat Flux	14,000 Btu/hr.-ft. ²	4.3 W/cm ²
Max Temperature Gradient in Base Plate	144°F/in.	31.5°K/cm
Last Lead to Freeze	Top	

The second critical issue was that associated with dimensional tolerances and frame-mold fitting. A careful evaluation of stacking and fabrication tolerances was carried out with particular emphasis on the steel HAC section. It is essential to ensure that the cavity formed by the bulkheads always allows sufficient radial space such that the aluminum inserts can be placed in their slots in the mold base. To preclude interference as a result of stacking tolerances, the nominal free radius dimension of the frame was increased by 1 mm. This decision unfortunately cost us two weeks schedule delay. However, experience since then with the high η test casting justified the decision.

In addition to these tasks, WSTC has also assisted in the high η test by fabricating the aluminum inserts. The specifications for these plates were completed in December and sent out for bid.

6. Optical System Design - D. Underwood. In this period we focussed on topics which were assigned at the SDC meeting on EM calorimetry and optics in Dallas. The main area was the response of high η tiles which are large, have high aspect ratio, and have beveled edges. We started to set up a way to measure the damage of waveshifter fiber by UV light. We also did more on understanding the measurement of number of photoelectrons with a tube and tile. A study of photocathode efficiency vs. voltage is helping us to understand our test beam data.

Beveled Tiles:

The main activity was mapping high- η beveled tiles with different wrappings and edge treatments. Most of these tiles have two edges beveled at 28° to the front surface. The unbeveled edges are relatively long compared to the width of the tile, by about a factor of 2.5. A variant tile configuration has only one beveled edge. This will make calorimeter assembly much easier and may allow the use of mini-mega-tiles.

Our intent is to study high η tiles which are as close to the final design as possible. To this end we modified some sample tiles in several ways: 1) The edges were re-machined with conventional machining rather than a diamond fly cutter. 2) A tile was made with one beveled edge and one square edge. This shape minimizes the number of beveled edges to machine as the gaps between bulkheads are 0.2 in η and the tile size is 0.05 in η . Some 1 mm diameter sigma fibers were made with one aluminized end and 3m of clear fiber spliced on. We began studies with paint on the edges of the tile after some preliminary studies with various wrappings.

We began re-mapping tiles that were prepared 6 months ago with diamond milled edges, two-ended fibers, and no paint. We now find a dip in the response in the center of the tile of about 10 percent (Fig. 37). The previous maps were approximately 7% low in a line along the center with respect to a line along a long edge, but flat along each line to

Two-end fiber readout; aluminized mylar wrapping

Fig. 37. A response map of a scintillator tile readout using two fibers. The left edge of the tile was cut at right angles to the surface. The right edge was cut with a 26° bevel.

better than 2%. We thought this change might be due to the aluminized mylar wrap wetting the surface, but after re-wrapping there was no change. The response inside the beveled region was slightly high, as seen previously. This may be related to the effect seen in the CDF waveshifter plates, where the response was higher near acute angles and low near obtuse angles. This effect was also seen in the ray-tracing simulation.

In order to more closely simulate what we expect to be the final tile design, we next used tiles with conventional machining on the edges, Bicron white paint on the long edges, no paint on the beveled edges, and white wrapping like tyvek envelope material. These tiles showed a similar and slightly worse drop of response in the middle. The light output was very similar to our previous tiles. Due to the quality of the 3 m long clear fiber used, the output was only roughly 1 photoelectron/mip, but this should be much better with different fiber.

We also tried a crude masking study with black paper on the beveled edge. The response of the tile was grossly affected, with losses of 20% to 30% near the end and a slope in response over a range of more than 15 cm.

We will try more painting and wrapping configurations, but we suspect that some sort of masking near the edges may be needed for the high η tiles due to the aspect ratio.

Next we discovered that none of the 9 fibers we had prepared at Fermilab would give more than 1.3 photoelectrons in the new tiles, and most gave 0.5 to 0.6 photoelectrons. A test with a very long shifter fiber which was calculated to have the same attenuation as 3 meters of clear gave 3.2 photoelectrons. A test of the aluminized fibers with a red laser showed some leakage through the aluminizing. However, when we cut off the aluminization and used white paint, the output was the same. We concluded that there was some problem in the fibers themselves.

We tried roughly 8 of the 13 fibers made by Fermilab for the high η tile test and all gave roughly 1 pe/mip. A test with a very long wls fiber, no clear fiber, no aluminization, both ends read out gave 3.3 pe/mip.

We started cutting 1 meter at a time off the clear fiber and found that the attenuation length was 3.75 meter. The output extrapolated to about 2.4 photoelectrons for no clear. We had previously checked the aluminization on several similar fibers with similar output by cutting off the aluminization and using white paint. The light output had been similar.

We next set up another tile with the very long green fiber again and no clear fiber. We cut off 15 cm at a time and found that the output extrapolated to over 6 pe/mip at the point where clear is normally spliced. For two-ended fiber readout, part of the problem is the long 70 cm fiber inside a high η tile which, in combination with aluminization and

attenuation length, leads to a factor of roughly 0.7 for sigma fibers with 100% reflectivity relative to the two ended configuration. So overall, we are losing a factor of 6 with the sigma fibers that we had available. Some of this is unavoidable in any case as the near measurements include light which is trapped in the cladding for longer transits.

Damage to Fibers:

For the tests of UV damage, we have prepared a box with a stable UV source which will hold the fibers in fixed positions attached to PIN diodes for checking the output at intervals. We have not yet calibrated the strength of UV or set up the computer readout.

Photoelectrons:

In order to check the calibration of the number of photoelectrons, we used one tile with both a Quanticon and our usual phototube. An LED pulser was used with both tubes and the number derived from the RMS width was compared with the peak positions for 0,1,2 pe. There was fair agreement to about 20%. Unfortunately the Quanticon was very old and had been exposed to room light for years and had a low photocathode efficiency. A calculation of broadening by statistics showed that the rms method could be broadened by 10% due to electron statistics in the tube stages after the photocathode. This study is also continuing. We have had trouble interpreting our test beam data at high energy where we were looking for a constant term in the resolution. At low energy, 35 GeV, early in the run the resolution was as predicted from stochastic effects. When we later ran various energies up to 100 GeV, the resolution got worse. An improved beam momentum tagging system did not help. It now appears that the phototube voltages were lowered to accomodate the signals from 100 GeV in the ADC without too many attenuators. A measurement with an R580 tube with a similar divider chain shows that the number of photoelectrons could have gotten worse by a factor of two, and the resolution worse by a factor of $\sqrt{2}$. This data is shown in Fig. 38.

7. Source Calibration - R. Stanek. The SDC testbeam calorimeter has been moved to Building 362 along with the source drive mechanism from Purdue. Source scans have been made using each of the 32 source tubes. The data is being analyzed and a comparison with previous scans at Fermilab will be made. Phototube base failures may make some of these comparisons difficult, however.

In order to determine the accuracy to which source tubes need to be positioned in the EMC lead and HAD1 iron, we have measured the effect of displacing the source in either of these media. A Cs^{137} source was driven over a scintillator tile with varying amounts of Pb or Fe absorber between them and the resulting integrated current recorded. Fig. 39 shows the result of these measurements. At a nominal 2mm absorber depth, both

Fig. 39. Measurement of the signal attenuation of a Cs^{137} source as function of absorber thickness for lead and iron. The curves are the results of a calculation.

Fig. 38. Light yield for an R580 as function of base high voltage.

Fe and Pb show about a 25% change in current if the source tube is displaced in the absorber by 1mm. The dotted curve in the figure is from a calculation of the acceptance and attenuation of the source. The photons from the Cs^{137} source illuminate scintillators on either side of the absorber so that by summing both tiles, the effect of a displaced source tube is minimized. If we assume uniform tile response, Fig. 40 shows that by summing two tiles, the source can be displaced by up to $\pm 0.5\text{mm}$ and still maintain a 1% calibration.

Work is now proceeding on determining the actual position of the source tubes within the various Pb layers by looking at the source current from tiles placed on either side of the source tube layer. Work is also proceeding on determining the response of each piece of scintillator using longitudinal and transverse scans of the towers.

8. Calorimeter Assembly/Installation - J. Nasiatka. Initial work on planning the assembly and installation of SDC barrels and endcaps was started during this reporting period. We began by determining the requirements for assembly of the calorimeter halves to meet the schedule set forth in the TDR -- there would have to be space allocated for simultaneous assembly of two calorimeters, storage for 16 barrel and 16 endcap modules, and space for testing 4 modules of either type, along with various safety features like adequate personnel walkways and enough space for clear crane access/vision while moving modules.

While laying out the necessary space on the building proposed in the TDR, it was found that enough space was available only for one assembly area. Additional layouts were made for a modified building with additional space, and for the final building set forth in the Title I proposal as shown in Fig. 41. These drawings went through several revisions as the schedule became more detailed, and the final design of the building became clear. Sets of drawings showing the calorimeter assembly area during the various stages of assembly were made to correspond to our schedule.

At the same time, we were setting up and detailing a shipping/assembly schedule that would fit within the deadlines set forth in the TDR. The schedule was broken down into a week by week progression, detailing where each module is throughout the assembly process. Figure 42 shows a representative sample of the first three months of assembly. The schedule requires shipping of four modules per week, with each module spending a week in a test stand to ensure that it survived transport to the SSC Laboratory. The modules would then move into storage until they were needed to be placed into the calorimeter assembly. Figure 43 shows where calorimeter assembly and installation fits into the overall schedule. Module shipping (for assembly) is set to begin in late

Fig. 40. Calculated sensitivity to position of Cs^{137} source embedded in lead under the assumption that scintillator tiles above and below the plate contribute to the response .

Fig. 41. SDC calorimeter surface assembly building floor layout. Shown are the storage areas, test areas, and two calorimeter assembly stations.

Calorimeter Assembly Schedule (Preliminary)

Month	Week	Test 1	Test 2	Test 3	Test 4	Storage	Assy. 1	Assy. 2	Notes
12 SRPT 1996									Shipping 4 mod./week.
									Inst. 2 modules/week/assembly
	1	B1	B2	B3	B4				Begin Barrel Module Shipping
13 OCT 1996	2	B5	B6	B7	B8	B1 2 3 4			
	3	B9	B10	B11	B12	B1 2 3 4 5 6 7 8			
	4	B13	B14	B15	B16	B1 2 3 4 5 6 7 8 9 10 11 12			
	5	B17	B18	B19	B20	B1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16			
	6	B21	B22	B23	B24	B5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	B1/B2	B3/B4	Start Barrel I & II Assembly
14 NOV 1996	7	B25	B26	B27	B28	B9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	B5/B6	B7/B8	
	8	B29	B30	B31	B32	B13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	B9/B10	B11/B12	
	9	B33	B34	B35	B36	B17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32	B13/B14	B15/B16	
	10	B37	B38	B39	B40	B21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36	B17/B18	B19/B20	
15 DEC 1996	11	B41	B42	B43	B44	B25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40	B21/B22	B23/B24	
	12	B45	B46	B47	B48	B29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44	B25/B26	B27/B28	
	13	B49	B50	B51	B52	B33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	B29/B30	B31/B32	

Fig. 42. Calorimeter assembly schedule indicating storage and test time constraints associated with meeting the SDC installation schedule given in the TDR.

Fig. 43. Calorimeter fabrication and shipping schedule deemed necessary to meet the assembly schedule indicated in Fig. 42.

September, 1996. The barrel assemblies will be completed by February 1997, and endcap assembly will be finished by September 1997.

Upon reviewing the Title I construction drawings of the SDC assembly building, it was found that the 12 m (39'5") lifting height specified for the main (50 ton) crane would not allow enough clearance between the top of the assembled calorimeter halves and the crane bridge, making it impossible to complete the assembly of the barrel and endcap calorimeters.

Figure 44 shows the height of the calorimeter assembly from the floor to the top of the electronics crates is 11.66 m (38'1") (including the cradles and transport fixtures). Leaving .34 m (16") clearance between the top of the calorimeter and the crane bridge for lifting fixtures and the hook. The minimum depth of section for the spreader bar portion of the lifting fixture is 16-18" and when the eye for the crane hook is added in, the depth would increase to around 48". In addition, free rotation of the modules is necessary to place them in the calorimeter. This requires another 12" of clearance from the top of the electronics to the bottom of the spreader bar, making the crane height short of what is required by at least 34". When the clearance required to move the module in place without hitting adjacent modules is added in for any of the possible insertion schemes - either overhead, end-on, or a combination of the two - the required clearance increases to between 6 and 12 feet.

To remedy this problem, we proposed several solutions, including raising the crane height and the building, and lowering the assembly areas into a pit. Our final solution is shown in Fig. 45. The picnic table height transport fixture was removed, and the cradles now ride directly on the rail system to the top of hole. This lowered the calorimeter height to about 10.54 m. We replaced the hook with a low-profile hoist, eliminating the hook height and giving us an additional 36" (0.9m). The assembly procedure was also slightly modified. Two lifting fixtures for the barrel and two for the endcap are now proposed. One would be larger in height, allowing for the modules to have full rotation with the electronics crates attached. This would be used for the bulk of the modules where there are no height constraints. The last three modules would have their electronics crates temporarily removed reducing the clearance height constraints, and they would only be allowed to rotate across a limited arc, further reducing the fixture clearance height. After the modules are installed, the electronics packages would be re-attached. To facilitate installation of the last modules, the calorimeter orientation has been rotated 5.625° so that the last module is vertical when it is inserted.

Fig. 44. Main crane lift height in the calorimeter assembly building as shown in original Title 1 building drawings.

Fig. 45. Revised main crane concept in the calorimeter assembly building. Both removal of the calorimeter intermediate support structure and the use of a low profile crane are shown as necessary to allow installation of the upper modules.

9. Neutron Fluence Calculations for the SDC Detector - P. K. Job. We used ISAJET in combination with CALOR89 to make an accurate prediction of neutron fluence at the various locations of the SDC detector. The low energy neutrons are important because they can produce radioactive nuclides in large quantities.

Figure 46 shows a schematic diagram of the code system. The output particle data produced by ISAJET from 20 TeV pp collisions is read by the subroutine SORS to HETC[8]. The particle production from ISAJET has taken into account only the minimum bias events. The output from HETC is analysed by SPECT, which collected information on neutrons of energy ≥ 20 MeV and by MORSE which further transports the neutrons of energy ≤ 20 MeV through the detector. The neutron spectrum ≤ 20 MeV was calculated in MORSE in 105 energy intervals. The cylindrical configuration is divided into 24 radial and 40 axial intervals. This provides 960 separate meshes (locations) at which neutron fluxes are calculated.

The summary results of these calculations are given in Table B. The results are also shown in Fig. 47. The flux and fluence values integrated over the energy range of ≥ 20 MeV and ≤ 20 MeV at specific locations of the detector are given. It can be seen that the high energy neutron flux (≥ 20 MeV) at every location of the detector is an order of magnitude smaller than the low energy neutron flux. The maximum low energy neutron fluence is experienced by the front edge of the forward calorimeter. The tracking volume experiences a neutron fluence of 1.88×10^{12} neutrons/cm²/year. The neutron fluence at the endcap edge is ten times larger than that at the tracking volume. The neutron fluence at the back of the hadronic calorimeter is 5.5×10^{10} neutrons/cm²/year. A complete flux map at 960 locations of the detector is also available from this work.

The results show that CALOR89 in combination with ISAJET can make reasonable predictions of neutron fluences in the SDC detector. These predictions are not alarmingly higher than the earlier conservative rough estimates for the given luminosity. However the greatest uncertainty in these estimates is in the particle production profile as a function of pseudorapidity in the minimum bias events. Fine tuning of this function will add considerable accuracy into these calculations.

Fig. 46. Schematic diagram of code system used for neutron flux calculations.

Fig. 47. Summary results of the neutron flux in the SDC detector volume.

Table B**Summary Results of Neutron Fluence for the SDC Detector**

Detector Location		Neutron Flux 10⁸ pp/colli.sec (neut./cm²/sec)	Neutron Fluence 10⁷ sec/year (neut./cm²/year)
Tracking Volume (average)	≤ 20 MeV	1.85 × 10 ⁵	1.85 × 10 ¹²
	≥ 20 MeV	3.00 × 10 ³	3.00 × 10 ¹⁰
Endcap (edge)	≤ 20 MeV	1.60 × 10 ⁶	1.60 × 10 ¹³
	≥ 20 MeV	5.05 × 10 ⁴	5.05 × 10 ¹¹
Forward Calorimeter	≤ 20 MeV	3.60 × 10 ⁸	3.60 × 10 ¹⁵
	≥ 20 MeV	2.00 × 10 ⁷	2.00 × 10 ¹⁴
At the Back of Barrel Calorimeter	≤ 20 MeV	5.00 × 10 ³	5.00 × 10 ¹⁰
	≥ 20 MeV	5.00 × 10 ²	5.00 × 10 ⁹

C. SDC Data Systems R&D

Two HEP physicists continued to participate in meetings and workshops associated with SDC computing working group and various task forces.

A principal focus of this effort is the design and prototyping of offline computing environment and the data access and storage systems for the SDC experiment.

Two physicists and a scientific programmer/analysis continued to work on the "Petabyte And Storage Solutions" (PASS) project. This is a HPCC and HEP supported R&D project to examine the use of database technologies for the storage and access to scientific data of the scale of a few Petabytes. The SDC experiment will collect data at the rate of 1 Petabyte per year, new advanced technology (both hardware and software) is required to provide the access to this quantity of data in a fast and efficient manner for a world-wide HEP environment.

This work is being done in collaboration with the University of Illinois at Chicago (UIC), University of Maryland, LBL and SSCL.

An Object manager developed at UIC was used as the basis of a demonstration project shown as part of the SIGgraph meeting at Chicago in July. CDF data was loaded into the object manager and a show-and-tell user interface was developed in Motif on a Sun workstation to make simple queries and graphically display single event track and jet 4-vectors and lego plots.

The Mark 0 testing of various database technologies was completed. This phase of the PASS project took a sample of CDF J/psi data and loaded it into three different database technologies for comparison with the traditional CDF sequential access YBOS based analysis system. The technologies were the UIC object manager PTool, a commercial unix based relational database management system, and a commercial unix based object-oriented database management system. The results were very encouraging with regard to using object-oriented data models and data access methods for typical HEP data.

In collaboration with the SSCL people a detailed redesign of the CDF J/Psi data structures was completed using two advanced data modeling tools. The first was ERDRAW an extended entity-relationship model developed at LBL. The second was a fully object-oriented data model using Rumbaugh technology and a tool set from General Electric Research and Development Center. These two data models will be used to build databases and storage systems for the Mark 1 versions of the PASS demonstrations.

Software was designed and implemented to provide 8mm tape access for the VTool part of the PASS object manager being developed by UIC. This will provide a true hierarchical storage manager for data systems using the PTool/VTool software. The programming model presented to the user is that objects are either transient or persistent, and PTool/VTool provides transparent access and storage in memory, on disk and on magnetic tape for those objects which are persistent.

Two papers describing the requirements, goals and prototype implementations of the PASS database and data systems approach were prepared and submitted for invited talks at the 12th IEEE Symposium on Mass Storage Systems. (E. May)

VI. PUBLICATIONS

A. Journal Publications, Conference Proceedings, Books

A Search for Magnetic Monopoles with the Soudan 2 Detector

J. Thron, I. Ambats, D. Ayres, L. Balka, W. Barrett, T. Brock, W. Dawson, T. Fields,
M. Goodman, N. Hill, J. Hoftiezer, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth,
H. Trost (ANL), & Soudan 2 Collaboration
Phys. Rev. D46, 4822 (1992)

Anomalous Nuclear Enhancements in Hard pA Collisions at Fermilab Energies

T. Fields (ANL) & E609 Collaboration
Nuclear Physics A, 544, C565 (1992)

Chiral Symmetry Breaking in Gauge Theories from Reggeon Diagram Analysis

A. White (ANL)

Proceedings of the Int'l. Workshop on Electroweak Symmetry, World Scientific, edited
by W. Bardién (1992)

Composition Studies Based on Coincident Air Shower Array and Underground Muon Data

T. Fields (ANL), W. DasGupta and K. Ruddick (U. of Minnesota)
Phys. Rev. C45, 1459 (1992)

Construction of $\Delta m^2 - \sin^2 2\theta$ Plots

M. Goodman (ANL) and R. Snyder (Oberlin College)

Proceedings of the Workshop on Long-Baseline Neutrino Oscillation, Fermilab,
edited by M. Goodman, 491 (1992)

Contributions to the W-Boson Anomalous Moments in the Two-Higgs-Doublet Model at Collider Energies

T. Rizzo (ANL)
Phys. Rev. D46, 3394 (1992)

Dijet Angular Distribution in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

L. Nodulman & CDF Collaboration
Phys. Rev. Lett. 69, 2896 (1992)

Dilepton Signatures at TeV e^+e^- and e^-e^- Collisions

T. Rizzo (ANL)
Phys. Rev. D46, 910 (1992)

Experimental Results with the Fermilab Polarized Beams

A. Yokosawa (ANL)
Polarization Dynamics in Nuclear and Particle Physics, World Scientific (1992)

Experimental Study of Neutrino Absorption on Carbon

D. Krakauer, R. Talaga (ANL); R. Allen, H. Chen R. Hausmann, W. Lee,
X. Lu, H. Mahler, and K. Wang (U. of California); T. Bowles, R. Burman, R. Carlini,
D. Cochran, P. Doe, J. Frank, E. Piasetzky, M. Potter, V. Sandberg (LANL)
Phys. Rev. C45, 2450 (1992)

Implications of Bottom Quark Cross Section Data at Hadron Collider Energies

E. Berger, R. Meng (ANL), W.-K. Tung (IIT)

Phys. Rev. D46, 1895 (1992)

Limit on Flavor-Changing Neutral Currents from a Measurement of Neutrino-Electron Elastic Scattering

D. Krakauer, R.L. Talaga (ANL), R. Allen, H. Chen, R. Hausmann, W. Lee, X. Lu, H. Mahler, and K. Wang (U. of California); T. Bowles, R. Burman, R. Carlini, D. Cochran, P. Doe, J. Frank, M. Potter, V. Sandberg (LANL); E. Piasetzky (Tel Aviv U.)

Phys. Rev. C45, 975 (1992)

Limit on Rare Decay $W^\pm \rightarrow \gamma\pi^\pm$ in pp Collisions at $\sqrt{s} = 1.8$ TeV

L. Nodulman (ANL) & CDF Collaboration

Phys. Rev. Lett. 69, 2160 (1992)

Limits on the Production of Massive Stable Charged Particles

L. Nodulman (ANL) & CDF Collaboration

Phys. Rev. D46, R1889 (1992)

Measurement of Atmospheric Neutrino Composition with the IMB-3 Detector

D. Sinclair (ANL)

Phys. Rev. Lett., 66, 2561 (1992)

Measurement of the Production and Muonic Decay Rate of W and Z Bosons in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

R. Blair, S. Kuhlmann, W. Li, L. Nodulman, J. Proudfoot, D. Underwood, R. Wagner, A. Wicklund (ANL) & CDF Collaboration

Phys. Rev. Lett. 69, 28 (1992)

NP Elastic Spin-Transfer Measurements at 485 and 635 MeV

H. Spinka (ANL); M. McNaughton, K. Koch, I. Supek, N. Tanaka (LANL); K. McNaughton, P. Riley, D. Ambrose, J. Johnson, A. Smith (U. Texas at Austin); G. Glass, J. Hiebert, L. Northcliffe, A. Simon (Texas A&M); D. Adams (Rice U.); R. Ransome, D. Clayton (Rutgers U.); R. Jeppesen (U. of Montana); C. Tripard (Washington State U.)

Phys. Rev. D46, 47 (1992)

New Probes for Extended Gauge Structures at HERA

T. Rizzo (ANL)

Phys. Rev. D46, 3751 (1992)

Observation of Hard Scattering in Photoproduction at HERA

M. Derrick (ANL) & ZEUS Collaboration

Phys. Lett. B 297, 404 (1992)

P-Wave Charmonium Production in B-Meson Decays

G. Bodwin, L. Braaten (ANL), T. Yuan (Northwestern U.), G. Lepage (Cornell)

Phys. Rev. D46, 3703 (1992)

Phenomenology of R-parity Breaking in E₆ Models

T. Rizzo (ANL)

Phys. Rev. D46, 5102 (1992)

Prospects for Long Baseline Neutrino Oscillation Experiments

M. Goodman (ANL) & Soudan 2 Collaboration

Proceedings of the Workshop Long-Baseline Neutrino Oscillation,
Fermilab, edited by M. Goodman, 53 (1992)

QCD Thermodynamics with Eight Staggered Quark Flavors on a $16^3 \times 6$ Lattice

S. Kim (ANL), S. Ohta (Riken)

Phys. Rev. D 46, 3607 (1992)

Realization of Large Systems - A Summary Talk

M. Derrick (ANL)

Proceedings of the Second International Conference on Calorimetry in High Energy Physics,
World Scientific, edited by A. Ereditato (1992)

Resolving the Unitary Gauge Puzzle of Thermal Phase Transitions

P. Arnold, S. Vokos (ANL/HEP), E. Braaten (Northwestern Univ)

Phys. Rev. D 46, 3576 (1992)

Rigorous QCD Predictions for Decays of P-Wave Quarkonia

G. Bodwin (ANL), E. Bratten (Northwestern U.), G. Lepage (Cornell)

Phys. Rev. D 46, 1914 (1992)

Search for AGN ν 's with the Soudan 2 detector

I. Ambats, D. Ayres, L. Balka, W. Barrett, T. Bruck, W. Dawson, T. Fields, M. Goodman,
N. Hill, J. Hoftiezer, D. Jankowski, F. Lopez, E. May, L. Price, J. Schlereth, J. Thron,
H. Trost (ANL), & Soudan 2 Collaboration

High Energy Neutrino Astrophysics, World Scientific, edited by V. Stenger, et al.,
p. 243 (1992)

Signals from Cosmic Ray Sources, Some Statistical Issues

M. Goodman (ANL)

Research Directions for the Decade. Snowmass 1990, World Scientific,
edited by E. Berger (1992)

Status of Search for Atmospheric Neutrino Oscillations with the Soudan 2 Detector

D. Roback (ANL and U. of Minnesota) & Soudan 2 Collaboration

Proceedings of the Workshop on Long-Baseline Neutrino Oscillation, Fermilab,
edited by M. Goodman, p. 171 (1992)

Thermodynamics of Lattice QCD with 2 Light Dynamical (Staggered) Quark Flavors on a $16^3 \times 8$ Lattice

D. Sinclair (ANL), S. Gottlieb, A. Krasnitz (Indiana U.), U. Heller, A. Kennedy
(Florida State U.), J. Kogut (U. of IL), W. Liu (Thinking Machines Corp.), R. Renken
(U. of Central Florida), R. Sugar (U. of CA, Santa Barbara), D. Toussaint (U. of
Arizona), and K. Wang (U. of South Wales-Australia)

Proceedings of LATTICE '91, edited by S. Brodsky, et al (1992)

Two Scalar Doubles Models with Softly Broken Symmetries

I. Knowles (ANL), C. Froggatt, R. Moorhouse (U. of Glasgow)

Nucl. Phys B 386, 63 (1992)

^2H (p,n) 2p Spin Transfer from 305 to 788 MeV

H. Spinka (ANL); M. McNaughton, I. Supek (LANL); K. McNaughton, K. Johnson, P. Riley, D. Ambrose, A. Smith (U. Texas at Austin); G. Glass, J. Hiebert, L. Northcliffe, A. Simon (Texas A&M); D. Mercer (U. of Colorado), D. Adams (Rice U.); R. Jeppesen (U. of Montana); G. Tripard (Washington State U.)
 Phys. Rev. C 45, 2564 (1992)

B. Papers Submitted for Publication and ANL Reports**Thermodynamics of Lattice, QCD with Two Light Quarks on a $16^3 \times 8$ Lattice**

D. Sinclair (ANL); S. Gottlieb, A. Krasnitz (Indiana U.); U. Heller, A. Kennedy (Florida State); J. Kogut (U. of IL); R. Renken (U. of Central Florida); R. Sugar (U. of California); D. Toussaint (U. of Arizona); K. Wang (U. of New South Wales)
 ANL-HEP-PR-92-57
 Submitted to Phys. Rev. D

The Production of Z' Associated with Photons or Jets as a Probe of New Gauge Boson Couplings

T. Rizzo (ANL)
 ANL-HEP-PR-92-58
 Submitted to Phys. Rev. D

Supersymmetric Renormalization Group Fixed Points and Third Generation Fermion Mass Predictions

I. Knowles (ANL), C. Froggatt, R. Moorhouse (U. of Glasgow)
 ANL-HEP-PR-92-62
 Submitted to Phys. Lett. B

Bremsstrahlung Contributions to Hadronic $W^\pm\gamma$ and $Z\gamma$ Production

J. Ohnemus (ANL), W. Stirling (U. of Durham)
 ANL-HEP-PR-92-73
 Submitted to Phys. Lett. B

Proton-Proton Elastic Spin Observables at Large t

G. Ramsey (ANL), D. Sivers (Portland Phys. Institute)
 ANL-HEP-PR-92-75
 Submitted to Phys. Rev. D

Nuclear Rescattering Effects in Massive Dihadron Production

T. Fields (ANL), M. Corcoran (Rice U.)
 ANL-HEP-PR-92-76
 Submitted to Phys. Rev. Lett.

Lepton Number Violating Radiative W Decay in Models with R-Parity Violation

T. Rizzo (ANL)
 ANL-HEP-PR-92-81
 Submitted to Phys. Rev. D

Implications of τ Decays into Strange Scalar Axial Vector Mesons

H. Lipkin (ANL)
 ANL-HEP-PR-92-87
 Submitted to Phys. Lett. B

Supersymmetry and the Nonlocal Yangian Deformation Symmetry

C. Zachos (ANL), T. Curtright (U. of Miami)
 ANL-HEP-PR-92-89
 Submitted to Symmetries in Science VI: From the Rotation Group to Quantum
 Alegbras, Plenum Press

Probing the Weak Boson Sector in $Z\gamma$ Production at Hadron Colliders

E. Berger (ANL/HEP, U. Bauer (Florida State U.)
 ANL-HEP-PR-92-91
 Submitted to Phys. Rev.

Final State Interaction of Longitudinal Vector Bosons

E. Berger (ANL), J-L. Basdevant (Inst. de Phys.), D. Dicus (U. of Texas),
 C. Kao (Florida State), S. Willenbrock (FNAL)
 ANL-HEP-PR-92-93
 Submitted to Phys. Lett. B

A Measurement of $\sigma_{\text{tot}}(\gamma p)$ at $\sqrt{s} = 210$ GeV

B. Musgrave (ANL) & ZEUS Collaboration
 ANL-HEP-PR-92-96
 Submitted to Phys. Rev. Lett.

The Mechanical Universe and a "Dialogue" Lab in a Community College

J. Uretsky (ANL)
 ANL-HEP-PR-92-98
 Submitted to Am. Journal of Phys.

A Separate Higgs?

T. Rizzo, J. Hewett (ANL), H. Deshpande, V. Barger (U. of Wisconsin)
 ANL-HEP-PR-92-102
 Submitted to Phys. Rev. Lett.

Apparatus for the Measurement of Spin Dependent Observables in np and pp Elastic and Quasielastic Scattering

M. Beddo, D. Grosnick, T. Kasprzyk, D. Lopiano, H. Spinka (ANL)
 & Saclay Collaboration
 ANL-HEP-PR-92-104
 Submitted to Nuclear Instruments and Methods

Angular Dependence of Analyzing Power in np Elastic Scattering Between 0.312 and 1.10 GeV

D. Lopiano, H. Spinka (ANL) & Saclay Collaboration
 ANL-HEP-PR-92-106
 Submitted to Nucl. Phys. B

Angular Dependence of the Beam and Target Analyzing Powers A_{ono} and A_{oon} in np Elastic Scattering Between 0.477 and 0.940 GeV

D. Lopiano, H. Spinka (ANL) & Saclay Collaboration
ANL-HEP-PR-92-105
Submitted to Nucl. Phys. B

Angular Dependence of the Spin Correlation Parameter A_{onn} in np Elastic Scattering Between 0.8 and 1.1 GeV

D. Lopiano, H. Spinka (ANL) & Saclay Collaboration
ANL-HEP-TR-92-107
Submitted to Nucl. Phys. B

Can $b \rightarrow s\gamma$ Close the Supersymmetric Higgs Production Window?

J. Hewett (ANL)
ANL-HEP-PR-92-110
Submitted to Phys. Rev. Letter

C. Papers or Abstracts Contributed to Conferences

Symmetry of Wavefunctions in Quantum Algebras and Supersymmetry

C. Zachos (ANL)
ANL-HEP-CP-92-53
Submitted to XXIst Int'l Conference on Differential Geometric Methods in Theoretical Physics

Argonne's New Wakefield Test Facility

J. Simpson (ANL)
ANL-HEP-CP-92-54
Submitted to the XVth International Conference on High Energy Accelerators, Hamburg, Germany, July 20-24, 1992

The Argonne Wakefield Accelerator (AWA) Laser System and Its Associated Optics

W. Gai, R. Konecny, J. Power (ANL)
ANL-HEP-CP-92-55
Submitted to the XVth International Conference on High Energy Accelerators, Hamburg, Germany, July 20-24, 1992

Argonne Wakefield Accelerator Update '92

M. Rosing, L. Balka, E. Chojnacki, W. Gai, C. Ho, R. Konecny, J. Power, P. Schoessow, J. Simpson (ANL)
ANL-HEP-CP-92-65
Submitted to the 1992 Linear Accelerator Conference, Ottawa, Canada, August 23-29, 1992

A High Resolution, Single Bunch, Beam Profile Monitor

J. Norem (ANL)
ANL-HEP-CP-92-72
Submitted to the Conference on Advanced Accelerator Concepts, June 15-20, 1992

Constraints on the Gluon Density from Bottom Quark and Prompt Photon Production

E. Berger, R. Meng (ANL), J. Qiu (Iowa State)

ANL-HEP-CP-92-79

Submitted to the Proceedings of the 26th Int'l. Conference on High Energy Physics
August 5-12, 1992

The SDC Central Calorimeter

J. Proudfoot (ANL) & SDC Collaboration

ANL-HEP-CP-92-80

Submitted to the Proceedings of the 3rd Int'l. Conference on Calorimetry in High Energy Physics, September 29 - October 2, 1992

Results from the Soudan 2 Detector

J. Thron, I. Ambats, D. Ayres, L. Balka, W. Barrett, T. Brock, W. Dawson, T. Fields,
M. Goodman, N. Hill, J. Hoftiezer, D. Jankowski, F. Lopez, E. May, L. Price,

J. Schlereth, (ANL), & Soudan 2 Collaboration

ANL-HEP-CP-92-85

Submitted to the Proceedings of the 26th Int'l. Conference on High Energy Physics
August 5-12, 1992

Hadron Spectrum of Quenched QCD on a $32^3 \times 64$ Lattice

S. Kim, D. Sinclair (ANL)

ANL-HEP-CP-92-92

Submitted to the Proceedings of LATTICE '92, September 15-19, 1992

Some Fiber-Tile Optical Studies for SDC Electromagnetic Calorimeter

D. Underwood (ANL)

ANL-HEP-CP-92-94

Submitted to the Proceedings of the 3rd Int'l. Conference on Calorimetry in High Energy Physics, September 29 - October 2, 1992

The Electromagnetic Calorimeter for the STAR Experiment at RHIC

D. Underwood (ANL)

ANL-HEP-CP-92-95

Submitted to the Proceedings of the 3rd Int'l. Conference on Calorimetry in High Energy Physics, September 29 - October 2, 1992

A Streamlined Method for Chiral Fermions on the Lattice

G. Bodwin (ANL) and E. Kovacs (FNAL)

ANL-HEP-CP-92-103

Submitted to the Proceedings of LATTICE '92, September 15-19, 1992

The Gluon Density

E. Berger and R. Meng (ANL)

ANL-HEP-CP-92-108

Submitted to the Proceedings of the 7th Meeting of the American Physical Society, Division of Particles and Fields, Fermilab, November 10-14, 1992

Rigorous QCD Predictions for Decays of P-Wave Quarkonia

G. Bodwin (ANL), E. Braaten (Northwestern U.), G Lepage (Cornell)

ANL-HEP-CP-92-109

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992**QCD with 2 Light Quark Flavors: Thermodynamics on a $16^3 \times 8$ Lattice and Glueballs and Topological Charge on a $16^3 \times 32$ Lattice**S. Kim, D. Sinclair (ANL); K. Bitar, R. Edwards, U. Heller, A. Kennedy (Florida State);
S. Gottlieb, A. Krasnitz (Indiana U.); J. Kogut (U. of IL); W. Liu (Thinking Machines);
M. Ogilvie (Washington U.); R. Renken (U. of Central Florida); R. Sugar (U. of
California); M. Teper (U. of Oxford); D. Toussaint (U. of Arizona); K. Wang (U.
of South Wales, Australia)

ANL-HEP-CP-92-113

Submitted to the Proceedings of LATTICE '92, September 15-19, 1992

The η_6 and Massive Photon Pairs at LEP

A. White and I. Knowles (ANL), K. Kang (Brown U.)

ANL-HEP-CP-92-117

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992**Heavy Fermion Mass Predictions and Renormalization Group Equations**

I. Knowles (ANL), C. Froggatt and R. Moorhouse (Glasgow Univ)

ANL-HEP-CP-92-120

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992**Nuclear Rescattering Effects in $pA \rightarrow$ Dihadrons**

T. Fields (ANL) and M. Corcoran (Rice U.)

ANL-HEP-CP-92-121

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992**Interactions of Atmospheric ν_μ and ν_e Observed in Soudan 2**

M. Goodman (ANL) & Soudan 2 Collaboration

ANL-HEP-CP-92-124

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992**Constraints on the Charged Higgs Sector from B Physics**

J. Hewett (ANL)

ANL-HEP-CP-92-125

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992

Signals for Virtual Leptoquark Exchange at Colliders

J. Hewett (ANL) and M. Doncheski (U. of Wisconsin)

ANL-HEP-CP-92-126

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992

Quenched Hadron Spectrum of QCD

S. Kim (ANL)

ANL-HEP-CP-92-127

Submitted to the Proceedings of the 7th Meeting of the American Physical Society,
Division of Particles and Fields, Fermilab, November 10-14, 1992

D. Technical Notes

High Energy Physics Division Semiannual Report of Research Activities ; January 1, 1992 - June 30, 1992

P. Moonier, P. Schoessow, R. Talaga, R. Wagner (ANL)

ANL-HEP-TR-92-50

Noise Events in the Contained Event Sample of Soudan 2

A. Lopez, M. Goodman (ANL) & Soudan 2 Collaboration

ANL-HEP-TR-92-61

Estimates of Rates and Errors for Measurements of Direct- γ and Direct- γ + Jet Production by Polarized Protons at RHIC

M. Beddo, H. Spinka, D. Underwood (ANL)

ANL-HEP-TR-92-59, Star Note #77

Response to Concerns of the EM Review Committee

N. Hill, V. Guarino, J. Nasiatka (ANL)

ANL-HEP-TR-92-67, SDC-92-00299

Calibration of the Fermilab E-704 Polarized Target

D. Hill (ANL)

ANL-HEP-TR-92-68

A High Current, Short Pulse Electron Source for Wakefield Accelerators

C. Ho (ANL)

ANL-HEP-TR-92-74

The Prospects for Polarized Target Materials with Pure Carbon Background

D. Hill (ANL)

ANL-HEP-TR-92-88

Effect of Pb and Air Absorber Thickness on ^{137}Cs Signal

D. Jankowski, D. Lopiano, R. Stanek (ANL)

ANL-HEP-TR-92-97, SDC-92-350

Calibration of the LAMPF E-960 Polarized Target

D. Hill (ANL)

ANL-HEP-TR-92-111

Estimates of the Neutron Fluence for the SDC Detector

P. Job, L. Price (ANL), T. Handler (U. of Tennessee), and T. Gabriel (ORNL)
ANL-HEP-TR-92-112

Measurement of Radiation Dose Using Radiochromic Film

D. Jankowski, J. Proudfoot (ANL)
ANL-HEP-TR-92-114, SDC-92-373

Final Report on Cost Estimate of Forward Superconducting Air Core Toroid

T. Fields (ANL)
ANL-HEP-TR-92-122, SDC -92-384

Nucleon Spin Structure Studies with Polarized Proton and Antiproton Beams

H. Spinka (ANL) & P-863 Collaboration
ANL-HEP-TR-92-128

Database Computing in HEP-Progress Report

E. May, D. Lifka, E. Lusk, L. Price (ANL), C. Day, S. Loken, J. MacFarlane (LBL),
A. Baden (U of Maryland), R. Grossman, X. Qin (U of Illinois, Chicago),
L. Cornell, P. Leibold, D. Liu, U. Nixdorf, B. Scipioni, T. Song (SSCL)
HEP TR 92-129

AGN-20	CAMAC Module Voltage-Optic and Optic-Voltage Converter
E. Chojnacki (ANL)
AGN-21	Low-Power, High Resolution, Stepping-Motor-Driver Phase Shifters
E. Chojnacki (ANL)
AGN-22	Results from the SSC Liner Run
P. Schoessow (ANL)
AGN-23	A String of Beads Pulse Monitor
J. Simpson (ANL)
CDF-1796	YMON Slides and Text Spew
L. Nodulman
CDF-1802	A Programmer's Guide to YMON
L. Nodulman
CDF-1809	Central Electron Level 2 Trigger Efficiency
P. Kesten, J. Proudfoot
CDF-1815	Central Electron Level 3 Trigger Efficiency
P. Kesten, J. Proudfoot
CDF-1817	AMON-Tools for Electron Stripping, Monitoring, and Calibration
P. Kesten, J. Proudfoot
CDF-1831	PAWing Your Way Through YMON Rates
L. Nodulman

- CDF-1855 Update on the CHI-C Cross Section Measurement
C. Boswell, R. Snider, R. Blair, A. Yagil
- CDF-1862 Electron and B-Quark Transverse Momentum Spectra
F. Ukegawa, A. B. Wicklund
- CDF-1867 Energy Outside a Clustering Cone Radius of 0.4
P. Maas
- CDF-1881 QCD Tests at Hadron Colliders
S. Kuhlmann
- CDF-1884 CEM Level 2 Trigger Efficiency for W's
J. Proudfoot
- CDF-1903 Isolated Prompt Photon Production at CDF
P. Maas, CDF Collaboration
- CDF-1904 Study of Calibration Pedestals Versus Time
R. Wagner
- PDK-523 Quarterly Activity Report April - June 1992
D. Ayres (ANL)
- PDK-535 Decisions of the Tower Collaboration Meeting, October 3-6, 1992
D. Ayres (ANL)
- PDK-537 Quarterly Activity Report July - September 1992
D. Ayres (ANL)
- PDK-544 Soudan 2 Experiment Quarterly Status Report October - December 1992
D. Ayres (ANL)
- WF-168 Self Consistent Theory of Charged Particle Motion and Radiation
M. Rosing (ANL)
- WF-169 Computer Modeling of Cherenkov Wakefield Accelerator Structures
P. Schoessow (ANL)
- WF-170 Generic Solution for Two Region Cylindrical Geometry
M. Rosing (ANL)

VII. COLLOQUIA AND CONFERENCE TALKS

G. Bodwin

"A Streamlined Method for Chiral Fermions on the Lattice"
Lattice '92 Symposium, Amsterdam, The Netherlands (September 1992)

"Rigorous QCD Predictions for Decays of P-Wave Quarkonia"
DPF 92, Fermilab (November 1992)

"Production and Decay of P-Wave Quarkonia: A New Factorization Theorem"
Purdue University, Dept. of Physics, Lafayette, IN (December 1992)
HEP Theory Group, ANL (December 1992)

M. Derrick

"Initial Physics Results from ZEUS"
University of Brussels, Belgium (November 1992)

T. Fields

"Nuclear Effects on Massive Dihadron Production"
DPF Meeting, Fermilab (November 1992)

M. Goodman

"Prospects for Long Baseline Neutrino Oscillation Experiments"
Physics Colloquium, Rice University (September 1992)

D. Grosnick

"Results from the Fermilab Spin Experiments"
Valparaiso University (October 1992)

J. Hewett

"Signatures for New Particles at Colliders"
Gordon Research Conference, Andover, NH (July 1992)
Workshop on Extended Gauge Model Phenomenology at High Energy Colliders,
Gyöngyöstarján Hungary (September 1992)

"Searches for New Gauge Bosons"
Search for New Phenomena at Colliding Beam Facilities, Yale University, New
Haven, CT (October 1992)

"Top and Rare Decays"

Studies of Top-Quarks at Colliding Beam Facilities, University of Wisconsin,
Madison, WI (November 1992)

"Constraints on the Charges Higgs Sector from B-Physics"

Division of Particles and Fields 1992, Fermilab (November 1992)

"Signals for Virtual Leptoquark Exchange at Colliders"

Division of Particles and Fields 1992, Fermilab (November 1992)

"The Physics of Two-Higgs Doublet Models"

University of Oregon, Eugene, OR (November 1992)

S.-Y. Kim**"Hadron Spectrum of Quenched QCD on a $32^3 \times 64$ "**

Amsterdam, The Netherlands (September 1992)

"Quenched Hadron Spectrum of QCD"

Fermilab, DPF '92 Meeting (November 1992)

E. May**"Demonstration of PASS Database of SIGGRAPH '92"**

McCormick Place Expo Center (July 1992)

L. Nodulman**"Electroweak Physics at CDF"**

MSU (November 1992)

ANL High Energy Physics seminar (November 1992)

T. Rizzo**"Finding and Identifying the Origin of New Gauge Bosons at Hadron Supercolliders"**

University of Oregon (October 1992)

"New Gauge Boson Physics at Future Colliders"

Gordon Research Conference-Particle Physics in the 90's, Andover, New
Hampshire (July 1992)

"The Physics of New Gauge Bosons at Future Colliders"

Workshop on Extended Gauge Model Phenomenology at High Energy Colliders,
Gyöngyöstarján, Hungary (September 1992)

R. Talaga

"ZEUS: History, Performance, and Physics"
 DESY, Hamburg, Germany (October 1992)

D. Underwood

"Some Fiber-Tile Optical Studies for SDC Electromagnetic Calorimeter"
 Third International Conference on Calorimetry in High Energy Physics, Corpus Christi, TX (October 1992)

"The Electromagnetic Calorimeter for the STAR Experiment at RHIC"
 Third International Conference on Calorimetry in High Energy Physics, Corpus Christi, TX (October 1992)

A. B. Wicklund

"B-Physics at CDF"
 FNAL B Physics Workshop (November 1992)

A. Yokosawa

"Recent Experiments on Spin Physics in High Energy Hadron Interactions"
 10th International Symposium on High Energy Spin Physics, Nagoya, Japan
 (November 1992)

"Overview of Spin Physics"
 RCNP Kikuchi School, Osaka, Japan (November 1992)

C. Zachos

"Supersymmetry and the Yangian Deformation Symmetry"
 University of Rochester (October 1992)
 ANL (November 1992)

VIII . HIGH ENERGY PHYSICS COMMUNITY ACTIVITIES

D. Ayres

Co-covenor of parallel session on Nonaccelerator Physics, 1992 DPF Meeting (Fermilab, Nov. 10-16, 1992)

E. Berger

Member, U.S. Department of Energy High Energy Physics Advisory Panel (HEPAP), 1991-

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

Session Organizer, Particle Physics in the '90's, 1992 Gordon Research Conference, July 13-17, 1992, Andover, N.H.

International Advisory Committee, 7th Meeting of the Division of Particles and Fields of the American Physical Society, Fermilab, November 1992

Local Organizing Committee, 7th Meeting of the Division of Particles and Fields of the American Physical Society, Fermilab, November 1992

Member, U.S. Contact Person, Scientific Program Committee, XXVIIIth Recontre de Moriond, "QCD and High Energy Hadronic Interactions", Les Arcs, France, March 1993

Organizing Committee, Fifth Conference on the Intersections between Particle and Nuclear Physics, May 1994

J. Dawson

Co-Chairman, IEEE 1992 Nuclear Science Symposium

T. Fields

Member, U.S.-Peoples Republic of China Joint Committee for Cooperation in High Energy Physics

International Advisory Committee - CERN Conference on History of the Bubble Chamber

URA Visiting Committee, Fermilab

S. Kuhlmann

Organization of the FNAL Small-X Workshop (September 16-18, 1992)

E. May

Chairman of HEPNET Technical Coordinating Committee (HTCC); organized and ran Sept. 92 meeting of HTCC

P. Moonier

IEEE Registration Chairman - 1992 Nuclear Science Symposium

L. Nodulman

IEEE Program Committee, Orlando 1992

A. White

Co-chairman - Workshop on Small-n and Diffractive Physics at the Tevatron, Fermilab, September 16-18, 1992

Organizing Committee - SSC Physics Symposium - University of Wisconsin, March 29-31, 1992

Co-chairman - XXIII International Symposium on Multiparticle Dynamics, Aspen, September 12-17, 1992

A. B. Wicklund

FNAL DPF Organizing Committee for DPF '92

IX. HIGH ENERGY PHYSICS RESEARCH PERSONNEL

Administration

L. Price/T. Kirk P. Moonier

Accelerator Physicists

W. Gai	M. Rosing
C. Ho	P. Schoessow
J. Norem	J. Simpson

Experimental Physicists

D. Ayres	E. May
R. Blair	B. Musgrave
K. Byrum	L. Nodulman
M. Derrick	J. Proudfoot
T. Fields	J. Repond
M. Goodman	H. Spinka
D. Grosnick	R. Stanek
R. Hagstrom	R. Talaga
P. Job	J. Thron
D. Krakauer	D. Underwood
S. Kuhlmann	R. Wagner
D. Lopiano	A. B. Wicklund
S. Magill	A. Yokosawa

Theoretical Physicists

E. Berger	T. Rizzo
G. Bodwin	D. Sinclair
J. Hewett	S. Vokos
S. Y. Kim	A. White
I. Knowles	C. Zachos
R. Meng	

Engineers, Computer Scientists and Applied Scientists

E. Chojnacki	N. Hill
J. Dawson	J. Nasiatka
V. Guarino	J. Schlereth
D. Hill	

Technical Support Staff

I. Ambats	D. Jankowski
L. Balka	T. Kasprzyk
H. Blair	R. Konecny
A. Derlicki	R. Rezmer
W. Haberichter	

Laboratory Graduate Participants

J. Power	D. Roback
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**DATE
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6/3/94

END