ANL-HEP-TR-04-33

HIGH ENERGY PHYSICS DIVISION SEMIANNUAL REPORT OF RESEARCH ACTIVITIES

July 1, 2003 – December 31, 2003

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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 through December 31, 2003. 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.

Table of Contents

I. EXPERIMENTAL RESEARCH PROGRAM

I.A. EXPERIMENTS WITH DATA

I.A.1. Medium Energy Polarization Program

The RHIC physics program has two main components. One is the study of heavy ion interactions and a search for a new state of matter. The second is the investigation of polarized proton collisions to determine the proton's spin structure. ANL physicists have been interested in this second component of the RHIC program, and have been involved in polarization development studies at the AGS for many years. As part of this program, they collaborated on the construction, installation, and commissioning of an endcap electromagnetic calorimeter (EEMC) for the STAR detector, to enhance capabilities for jet and direct-photon detection.

The STAR detector was upgraded during July – December 2003, and was being prepared for Au + Au collisions at the very end of the year. Upgrades included installation of most of the remaining EEMC hardware, additions to the barrel electromagnetic calorimeter, and a photon multiplicity detector. In addition, several papers on STAR physics results were published and a number of others were submitted for publication. Preliminary results shown in the last semi-annual report for two-particle azimuthal distributions for minimum bias d + Au and p + p and for central d + Au and Au + Au collisions were published ("Evidence from d + Au Measurements for Final-State Suppression of High-p_T Hadrons in Au + Au Collisions at RHIC," Phys. Rev. Lett. **91**, 072304 (2003)).

One of the physics articles ("Pion-Kaon Correlations in Au + Au Collisions at $\sqrt{s}_{NN}$ = 130 GeV," Phys. Rev. Lett. **91**, 262302 (2003)) describes the determination of two-particle correlations using identified charged particle tracks in the STAR time projection chamber (TPC). Particle identification and momentum resolution effects are taken into account. The data are interpreted to indicate that pions and kaons are not emitted at the same average space-time position for Au + Au collisions at $\sqrt{s}_{NN}$ = 130 GeV. The results are consistent with (and provide new independent evidence for) a system whose dominant feature is a collective transverse expansion, for example from rescattering of hadrons in a hadronic cascade model (or the relativistic quantum molecular dynamics model - RQMD). The measurements significantly challenge models that attempt to explain pion, kaon, and proton spectra by purely initial state effects.

Another paper ("Three-Pion HBT Correlations in Relativistic Heavy-Ion Collisions from the STAR Experiment," Phys. Rev. Lett. **91**, 262301 (2003)) describes a high statistics measurement of the three-pion correlation function and the normalized three-particle correlator. The goal is an estimate of the degree of chaoticity of the pion source at freeze-out, where a completely chaotic pion source would have hadronized pions created with random quantum particle production phases. The chaoticity is better determined from three-pion correlations than from two-pion Hanbury Brown and Twiss (HBT) interferometry since effects from particle misidentification and decay contributions can be removed. The data show that the degree of chaoticity seems to increase with increasing particle multiplicity; see Fig. 1.

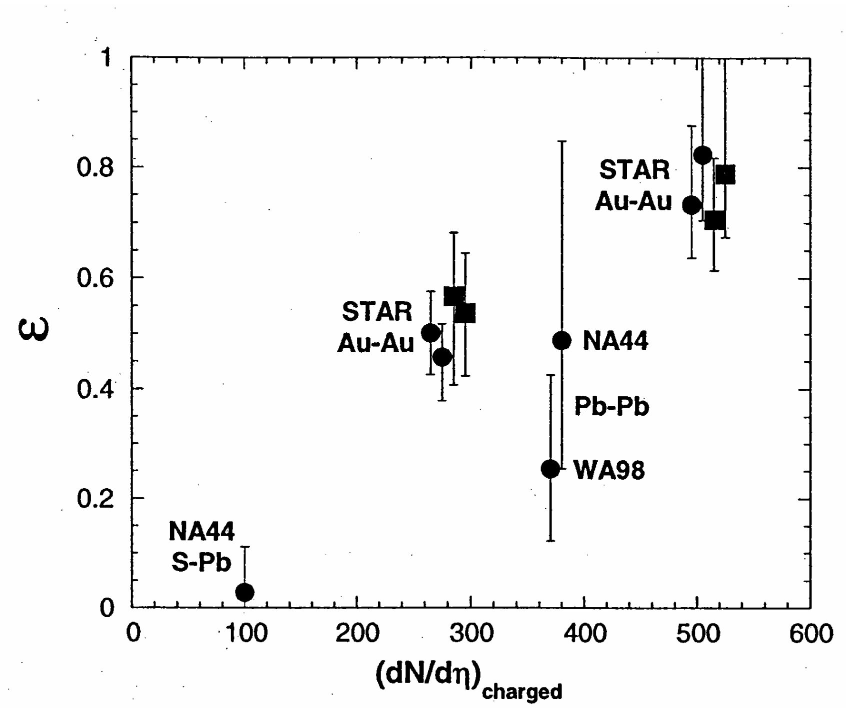


Figure 1. Chaotic fraction plotted versus charged particle multiplicity from STAR and two CERN heavy-ion experiments. STAR results are shown for π^+ (filled squares) and π^- (filled circles) for two centrality classes. The CERN experiments use π^- data only.

High statistics measurements at $\sqrt{s}_{NN}$ = 200 GeV of inclusive charged hadron production are reported in "Transverse Momentum and Collision Energy Dependence of High p_T Hadron Suppression in Au + Au Collisions at Ultrarelativistic Energies" (Phys. Rev. Lett. **91**, 172302 (2003)). Fig. 2 shows the p_T dependence for the ratio (R_{AA}) of the number distribution of charged hadrons in Au + Au collisions to the inelastic scattering cross section for nucleon-nucleon interactions, scaled with a factor ($T_{AA} = \langle N_{binary} \rangle / \sigma_{inel}^{NN}$), where the mean number of binary collisions is estimated from a Glauber calculation. The fractions 0-5 %, …, 60-80 %, are centrality classes for the Au + Au collisions, with the most central events having the lowest values. Ratios of data in Fig. 2

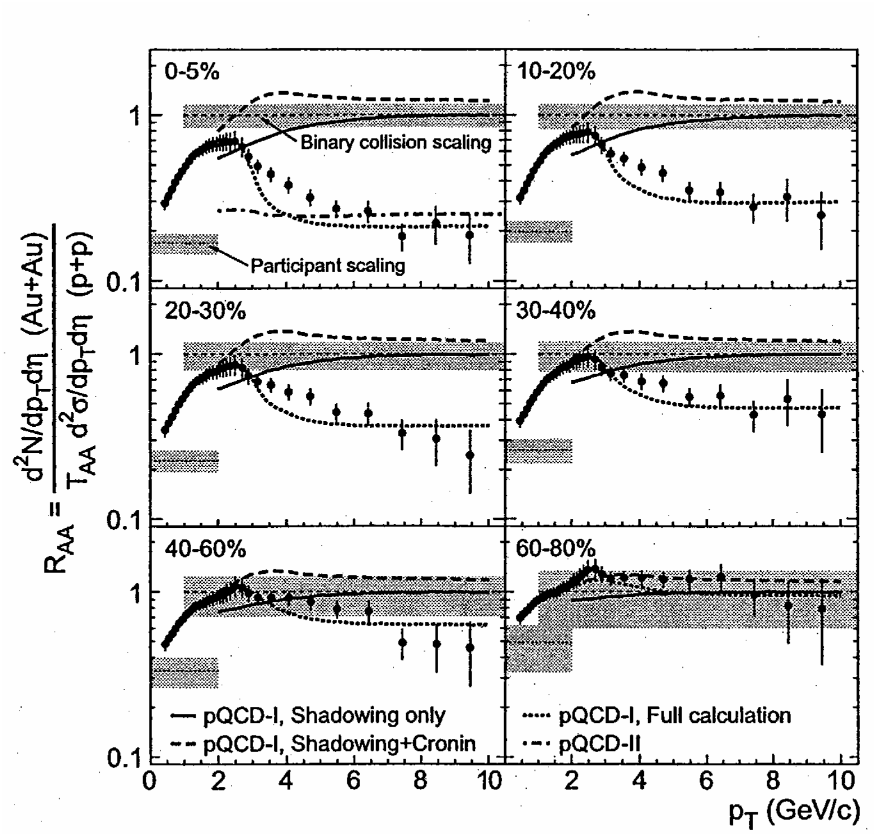


Figure 2. The ratio R_{AA} for charged hadron production in $|\eta| < 0.5$ for centrality-selected Au + Au spectra relative to the measured p + p spectrum at $\sqrt{s_{NN}} = 200$ GeV as a function of transverse momentum. Perturbative QCD calculations containing shadowing only, shadowing and the Cronin effect, and those contributions plus partonic energy loss are shown.

for two pairs of centrality classes are plotted in fig. 3. It can be seen that the Cronin enhancement and shadowing alone do not account for the suppression of R_{AA} in central events. However, models also incorporating initial state gluon saturation ("saturation" curve) or partonic energy loss in dense matter (pQCD-I, II) are largely consistent with observations. There is no evidence of p_T–dependent suppression, which may be expected from models incorporating jet attenuation in cold nuclear matter or scattering of fragmentation hadrons.

A fifth STAR paper was "Multiplicity Fluctuations in Au + Au Collisions at $\sqrt{s}_{NN} = 130$ GeV" (Phys. Rev. C**68**, 044905 (2003)). Event-by-event net charge fluctuations for inclusive non-identified charged particles and for identified pions, kaons, protons and antiprotons are reported as a function of pseudo-rapidity and centrality in the range $|\eta| < 1.0$. The non-identified charged particle fluctuations are finite and exceed by

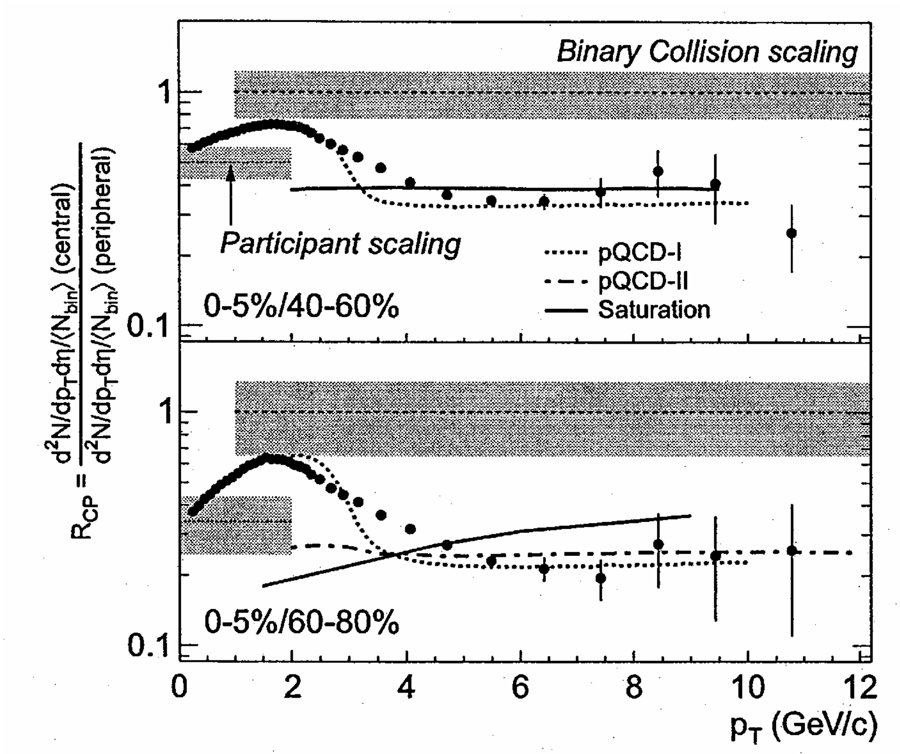


Figure 3. Ratios of the number distributions of charged hadrons, corrected for the mean number of binary collisions, are shown as functions of transverse momentum. Theoretical predictions with shadowing, the Cronin effect, and either initial state gluon saturation or partonic energy loss in dense matter are also shown.

nearly a factor of two expectations based on charge conservation. Kaons and protons are found to exhibit fluctuations that are 2 to 4 times larger than those observed for all charged particles.

A paper was also published from results with the Crystal Ball detector at Brookhaven. "Dynamics of the $\pi^- p \rightarrow \pi^\circ \pi^\circ$ n Reaction for p_π < 0.75 GeV/c" (Phys. Rev. Lett. **91**, 102301 (2003)) reports the data and multipole analyses to search for a $f_0(600)$ meson. It is concluded that the data for this reaction do not provide any substantive evidence for a low mass scalar meson, and the results are inconsistent with the expected properties of such mesons. Rather, the reaction appears to be dominated by $\pi^- + p \rightarrow \pi^\circ + \Delta^\circ(1236) \rightarrow \pi^\circ + \pi^\circ$ + n processes, including interference effects, rather than $\pi^- + p \rightarrow f_\circ$ + n$\rightarrow \pi^\circ + \pi^\circ$ + n.

A final paper describes results from an experiment at the Indiana University Cyclotron Facility (IUCF) ("Observation of the Charge Symmetry Breaking d + d $\rightarrow$ ^{4}He + π° Reaction Near Threshold," Phys. Rev. Lett. **91**, 142302 (2003)). Rather than zero, a small cross section for this reaction was expected because of the up-down quark mass difference and quark electromagnetic effects that contribute in part through meson mixing (e.g., $\pi^{\circ} - \eta^{\circ}$) mechanisms. Previous searches had difficulties with background from the d + d → α + γ + γ process, which does not violate charge symmetry. The small momentum spread and divergence of the beam from the IUCF Cooler, operation near threshold so the α's were confined to a forward cone with small opening angle, and major contributions of ANL equipment (100 lead glass counters, MWPC electronics and cables) made this experiment feasible. The reaction was observed at two nearby energies as shown in Fig. 4.

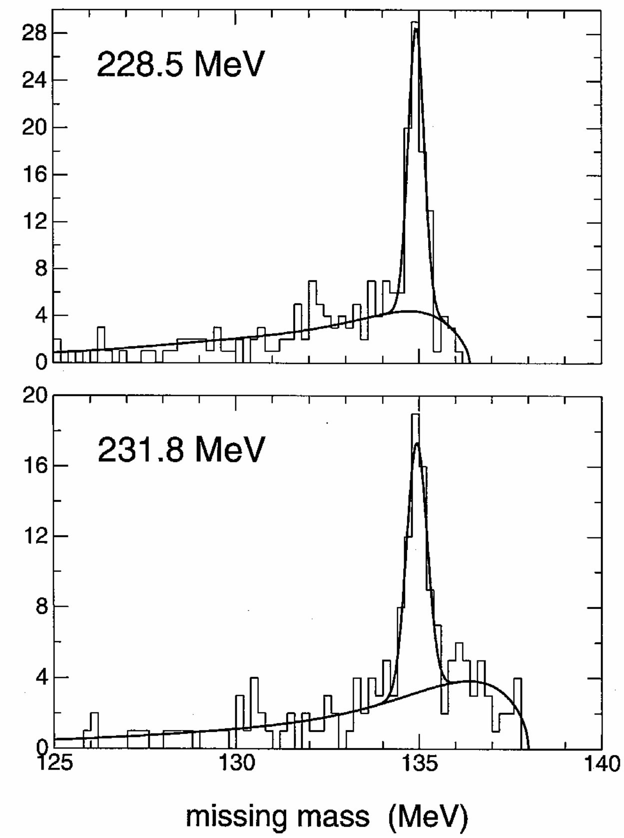


Figure 4. Histograms of the d + d → ^{4}He + π^0 candidate events at the two deuteron bombarding energies as a function of their missing masses, which were measured from the α's detected in a magnetic spectrometer. The curves are Gaussians and a continuum taken from alphas detected without coincident photons.

Two reports were completed on AGS and RHIC polarimeter studies. The first report ("Analysis of Polarimeter Data for the 2001-2002 RHIC Run", ANL-HEP-TR-03-108) contained analyses by a number of physicists, including some from Argonne. Some studies of systematic effects and polarimeter performance were conducted that complement work by BNL and RIKEN physicists. A second report ("Comments on the Operation of the RHIC CNI Polarimeters", ANL-HEP-TR-03-107) documented an explanation for these systematic errors in terms of rate effects in the silicon detector electronics. Numerical estimates were consistent with the magnitude of the observed systematic errors.

Finally, a paper was submitted to Nucl. Instr. Meth. titled "Estimating Relative Luminosity for RHIC Spin Physics." Relative luminosities for different beam spin states must be determined to better than 10^{-4} - 10^{-3} in order to measure spin asymmetries to the desired accuracy at RHIC. It is shown that the standard formula used at CDF and D0 to correct luminosity monitor counts for high rates is biased, but this bias is acceptably small (< 10^{-4}) for anticipated RHIC running conditions.

(H.M. Spinka)

I.A.2. Collider Detector at Fermilab

a) Physics

Before the fall shutdown we accumulated good data samples of about 190 pb^{-1} of which 160 pb^{-1} had good silicon. On the *b* physics side, the low transverse momentum muon, low transverse momentum J/Ψ analysis which Tom LeCompte has been pushing has been extended to a *b* to J/Ψ cross section which is shown in Fig. 1. There is no longer any ambiguity about QCD k_T in interpreting the *b* cross section, and indeed, the *b* cross section which historically has been regarded as being in excess of QCD predictions is now completely compatible with the latest QCD predictions; there is no more *b* excess.

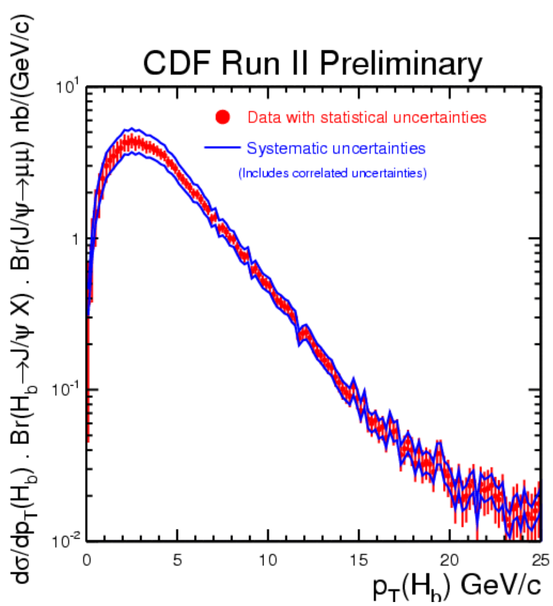


Figure 1. Differential cross section for hadronic *b* production, where the b decays to a mode including a dimuon J/Ψ. The extension of the measurement to small transverse momentum allows a robust comparison to QCD predictions, which now agree.

The dimuon search analysis developed by Bill Ashmanskas gave a result now published on D decay. This has now been extended from charm to a B_s limit as shown in Fig. 2. A sample of 171 pb^{-1} gives a 90% CL limit of 5.8 x 10^{-7} on the branching ratio, surpassing the previous limit from Belle. Bill himself has moved on to work with the Fermilab Accelerator Division on the improving the Tevatron collider.

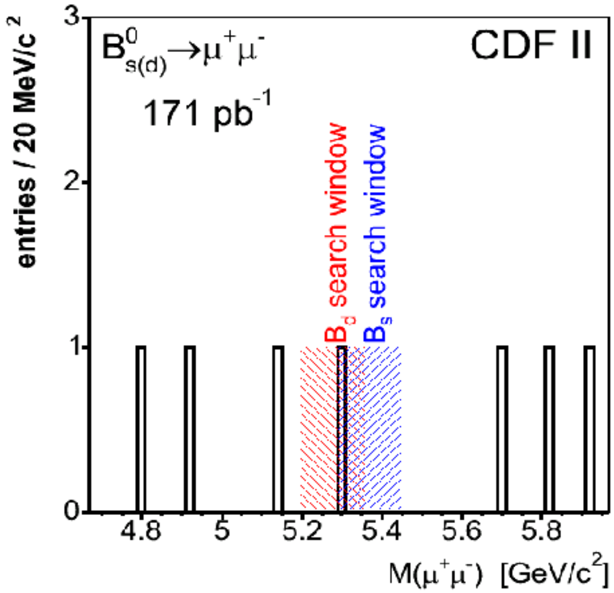


Figure 2. Dimuon search which yields an 90% CL upper limit on the branching ration for B_s to μμ of 5.8 x 10^{-7}.

Masa Tanaka and Barry Wicklund continue the investigation of systematic effects in lifetimes as measured in semileptonic modes, which are systematically shorter than fully reconstructed mode measurements. Understanding the semileptonic sample will be a key to being able to do precise tagged mixing studies. Bob Wagner is investigating the J/Ψη decay mode.

Larry Nodulman is working with a group predominantly from Toronto and Duke on the run 2 W mass measurement. A new cosmic ray drift chamber alignment has been demonstrated to improve systematics as illustrated in the muon W sample transverse mass plot of Fig. 3.

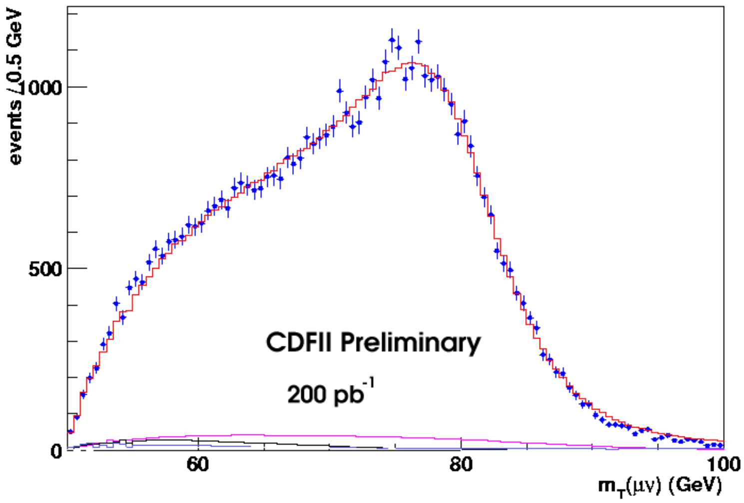


Figure 3. The W boson transverse mass spectrum for muons using the improve drift chamber alignment. Background levels are illustrated; the largest is lost leg Z muon pairs.

Steve Kuhlmann and Bob Blair continue to work with the QCD and exotics photon analysis group. An example of the output is a limit on gravity mediated SUSY models using the two photons with missing transverse energy signature, as shown in Fig. 4.

Tom, Masa and Barry have continuing subgroup leadership roles in b physics. Steve continues to lead the dijet mass reconstruction optimization group. Larry has been appointed to head the internal review for lepton plus jets top mass measurement.

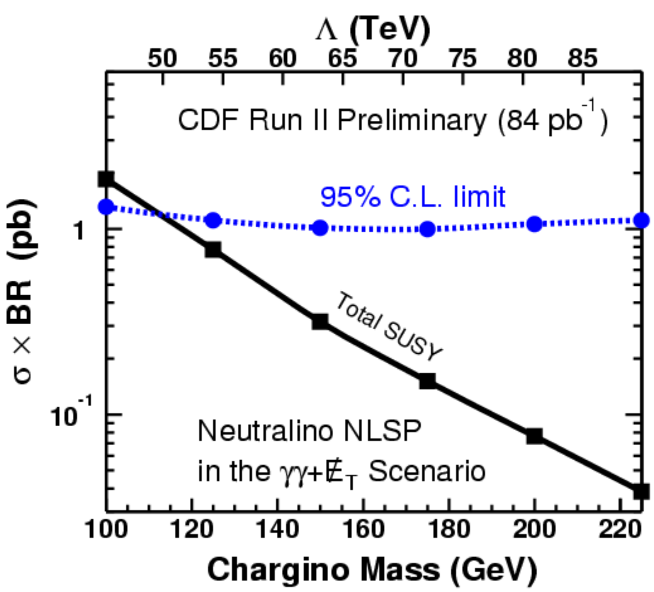


Figure 4. The absence of an excess of events with two photons and missing transverse energy places limits on SUSY scenarios.

b) Operations

Smooth operations continued up to the fall shutdown for recycler work. During the shutdown, a central calorimeter arch was pulled out to investigate scaffolding needs for installing the preradiator upgrade in the pit. The collider and detector recovered slowly from the shutdown, as seen in Fig. 5.

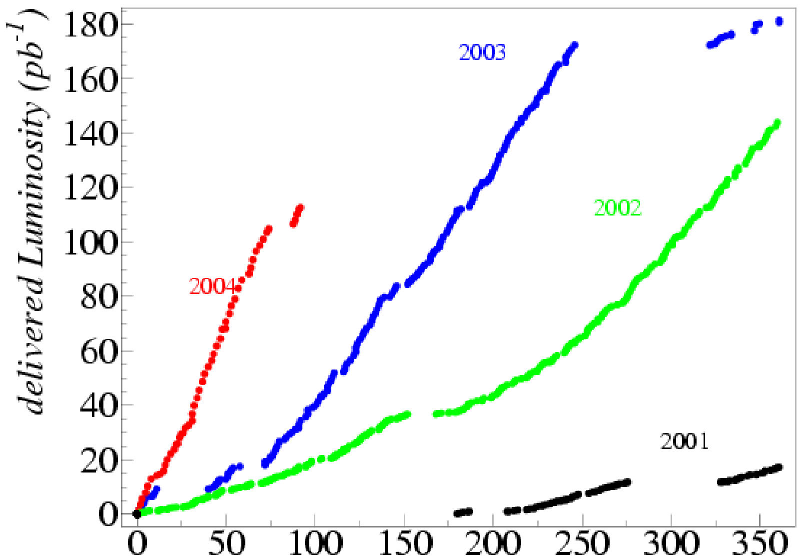


Figure 5. Tevatron delivered luminosity accumulated for each of the last several years. The fall shutdown and slow recovery are apparent.

Jimmy Proudfoot completed his term as Deputy Head of CDF operations. The CDF operational efficiency is shown in Fig. 6. Masa Tanaka served as an Operations Manager in this period. Larry Nodulman continued as calorimeter co-leader, Karen Byrum continued to lead the shower maximum support, and Karen, Masa and Steve Kuhlmann were active in supporting the Level 2 Trigger.

Larry continued to provide offline and online calibrations for the central EM calorimeter as well as cross checks of the other calorimeters. A shift in silicon alignment disrupted E/P calibration for a while.

Several members of the HEP division have been actively supporting the Tevatron program at Fermilab, Jim Norem helping with the Booster, Wei Gai helping with electron cooling, and Bill Ashmanskas working with Bill Foster on fast digital beam feedback. Before Bill gave up his silicon trigger (SVT) role, he wrote up the project as a published NIM proceeding.

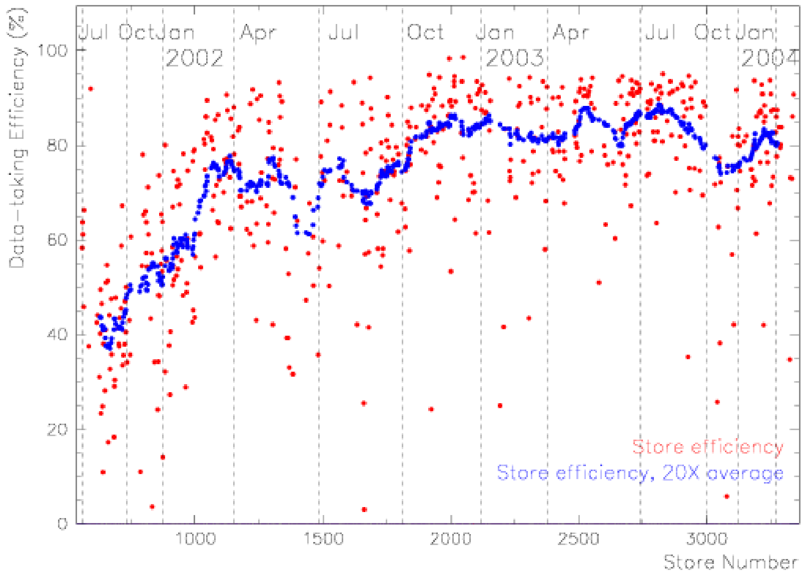


Figure 6. CDF Data taking efficiency versus time.

I.A.3. The CDF Upgrade Project

a) Run IIb Planning

During the shutdown, EM timing was installed on the plug and a small sample of the central calorimeter. A procedure for installing the preradiator upgrade in the pit was developed, since without the silicon upgrade, the detector will not come out of the hall. Several design details were settled and the irreducible level of cross talk seen in the MPMTs in the CDF plug upgrade was confirmed as shown in Fig. 7, which shows signal in an adjacent pixel. The fiber run and the measurement itself were adjusted to minimize

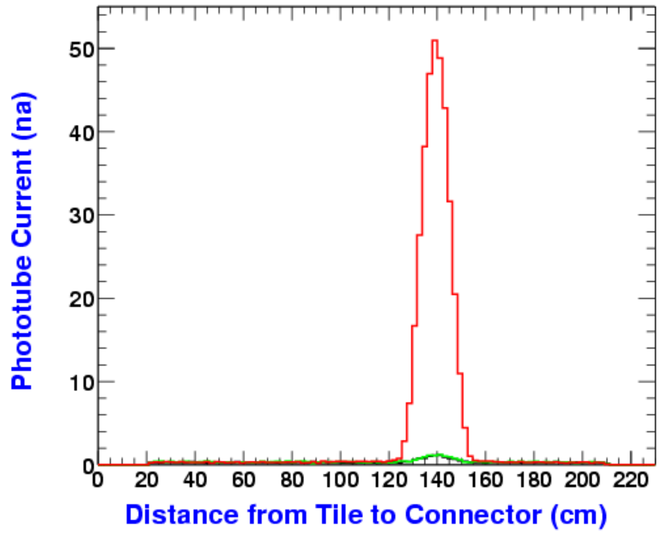


Figure 7. Azimuthal scan of a crack detector showing the signal in the illuminated pad (red) and the adjacent pixel of the MPMT which is not adjacent in the detector.

cross talk, and a crack detector scan after revisions is shown in Fig. 8. All parts are now on order and mass production of detectors should begin in spring, with as much as possible to be installed during the August recycler/construction shutdown. Installation of EM timing should be completed then. Some of the preradiator installation may be finished in FY2005.

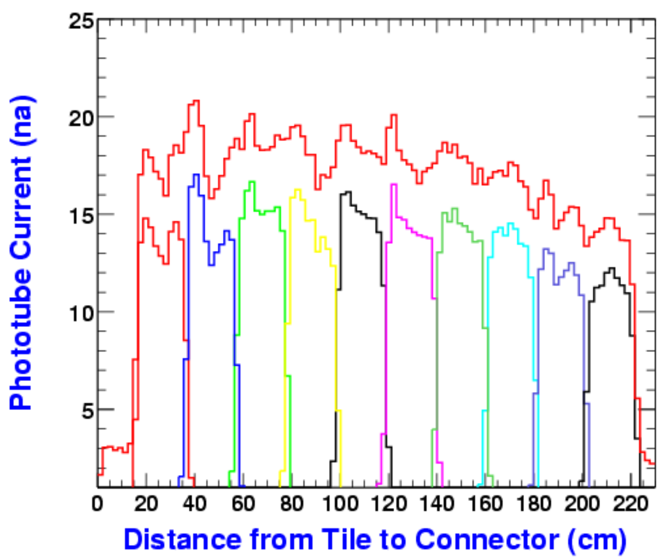


Figure 8. Longitudinal scan of a crack detector. Individual tower responses may be compared to an overall current level; the initial fiber layout created cross talk that made response at the boundary between tiles high.

(L. Nodulman)

I.A.4. ZEUS Detector at HERA

a) Physics Results

Seven papers were published in this period and eight more manuscripts were submitted for publication. In the following, we shall summarize some of the published papers.

i) *Measurement of High-Q^2 Charged Current Cross Sections in e^+p Deep Inelastic Scattering at HERA*

Cross sections for e^+p charged current deep inelastic scattering at a centre-of-mass of 318 GeV have been determined with an integrated luminosity of 60.9 pb^{-1}. The differential cross sections $d\sigma/dQ^2$, $d\sigma/dx$, and $d\sigma/dy$ for $Q^2 > 200$ GeV^2 have been presented. In addition, $d^2\sigma/dxdQ^2$ has been measured in the kinematic range 280 GeV^2 < Q^2 < 17,000 GeV^2 and $0.008 < x < 0.42$. The predictions of the Standard Model are shown together with the data in Figure 1 and agree well with the measured cross sections. These measurements are particularly sensitive to the down and strange quark content of the proton as indicated in the Figure. The mass of the W boson propagator is determined to be

$$M_W = 78.9 \pm 2.0\ (\text{stat.}) \pm 1.8\ (\text{syst.})\ ^{+2.0}_{-1.8}\ (\text{PDF})\ \text{GeV}$$

from a fit to $d\sigma/dQ^2$. The chiral structure of the Standard Model was also investigated in terms of the $(1-y)^2$ dependence of the double-differential cross section. The structure function F_2^{CC} has been extracted by combining the measurements presented in this paper with previous ZEUS results from e^-p scattering, extending the measurement obtained in neutrino-nucleus scattering experiments to a significantly higher Q^2 region

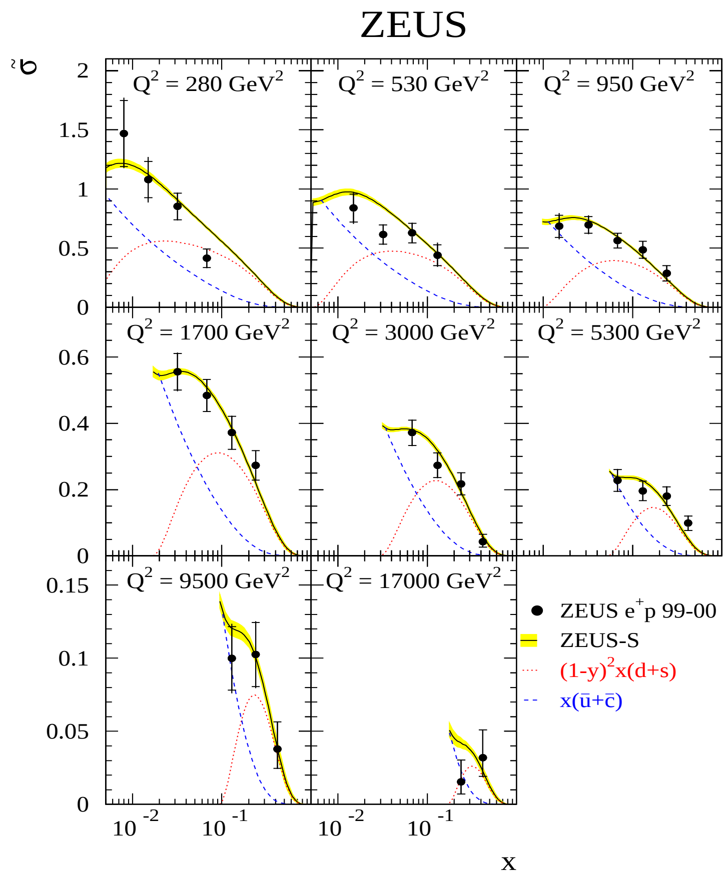


Figure 1. The reduced cross section as a function of x, for different values of Q^2. The data are shown as the filled points. The expectation of the Standard Model evaluated using the ZEUS-S parton density functions is shown as a solid line. The shaded band shows the uncertainties from the ZEUS-S fit. The separate contributions of the PDF combinations $x(\bar{u}+\bar{d})$ and $(1-y)^2x(d+s)$ are shown by the dotted and dashed lines, respectively.

ii) *Dijet Angular Distributions in Photoproduction of Charm at HERA*

Dijet angular distributions of photoproduction events in which a $D^{*\pm}$ meson is produced in association with one of two energetic jets have been measured using an integrated luminosity of 120 pb^{-1}. Differential cross sections as a function of the angle, θ^*, between the charm-jet and the proton-beam direction in the dijet rest frame have been measured for samples enriched in direct or resolved photon events, see Figure 2. The results were compared with predictions from leading order parton-shower Monte Carlo models and with next-to-leading-order QCD calculations. The angular distributions show clear evidence for the existence of charm originating from the photon.

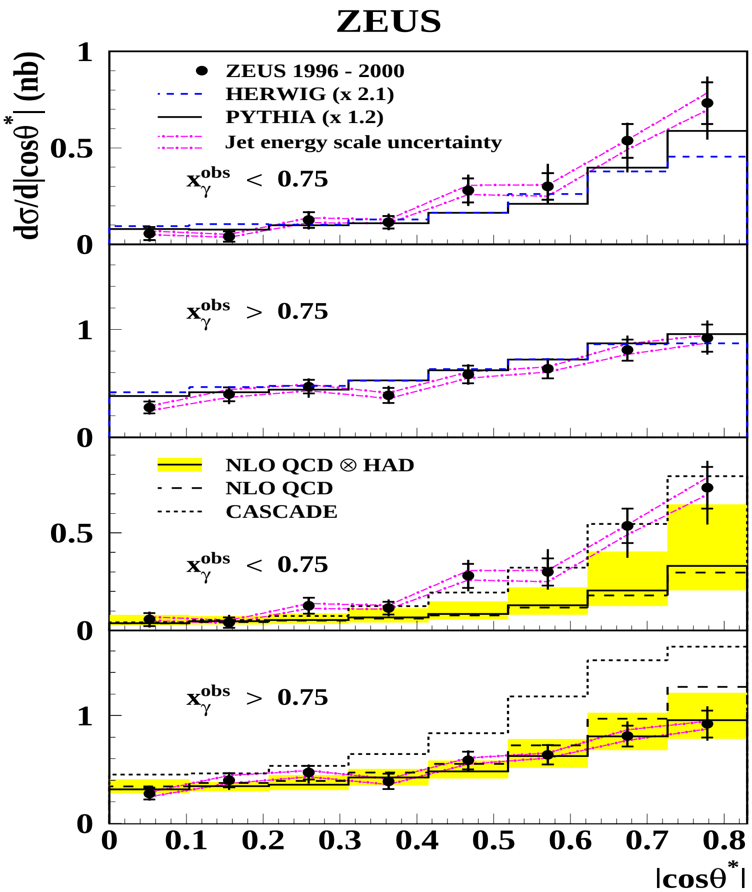


Figure 2. Differential cross-sections $d\sigma/d\cos\theta^*$ compared with PYTHIA and HERWIG MC simulations (a-b); CASCADE MC simulations (c-d), and NLO fixed-order calculations (c-d). The results are given separately in (a,c) for the samples enriched in resolved photon events and in (b,d) for samples enriched in direct photon events.

iii) *Measurement of Deeply Virtual Compton Scattering at HERA*

The cross section for deeply virtual Compton scattering in the reaction $ep \rightarrow e\gamma p$ has been measured using an integrated luminosity of 95.0 pb^{-1} of e^+p and 16.7 pb^{-1} of e^-p collisions. Differential cross sections were presented as a function of the exchanged photon virtuality, Q^2, and the centre-of-mass energy W, of the γ^*p system in the region $5 < Q^2 < 100$ GeV^2 and $40 < W < 140$ GeV. The measured cross sections rise steeply with increasing W. Figure 3 shows the measured differential cross sections versus Q^2 for both the e^+p and e^-p data samples. The measurements agree well with QCD calculations based on generalized parton distribution functions.

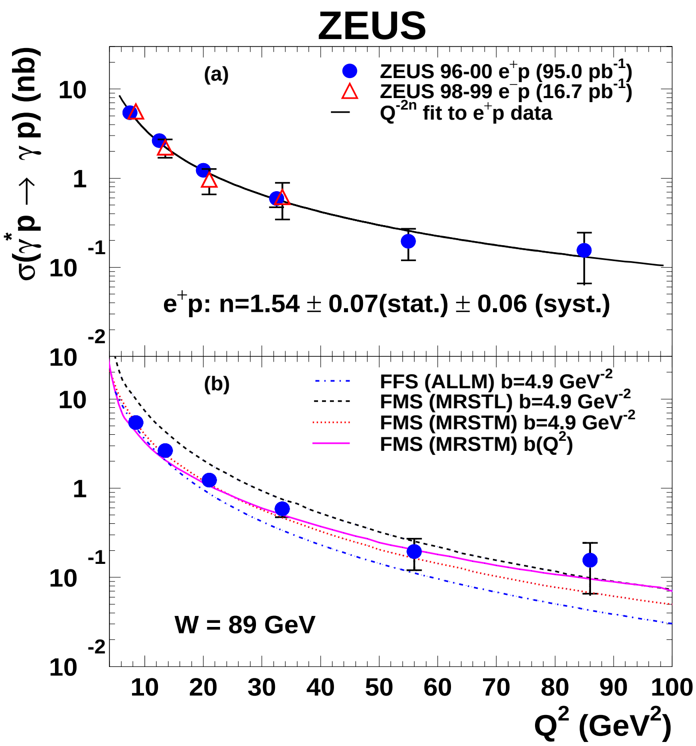


Figure 3. a) the Deeply Vittual Compton Scattering cross section as a function of Q^2 for W = 80 GeV, separately for e^+p (dots) and e^-p (triangles) data. The solid line is the result of a fit of the form $\sigma_{DVCS} \propto Q^{-2n}$ to the positron data. b) the same positron data compared to various theoretical predictions based on Generalized Parton Density Functions.

iv) *Observation of $K_S{}^0K_S{}^0$ Resonances in Deep Inelastic Scattering at HERA*

Inclusive $K_S{}^0K_S{}^0$ production in deep inelastic ep scattering at HERA has been studied using an integrated luminosity of 120 pb^{-1}. Figure 4 shows the $K_S{}^0K_S{}^0$ invariant mass spectrum for $K_S{}^0$ candidates with $\cos\theta_{KK} < 0.92$. The $K_S{}^0$ pair candidates that fail the $\cos\theta_{KK} < 0.92$ cut are shown separately. Two states are observed at masses 1537^{+9}_{-8} MeV and 1726 ± 7 MeV, as well as an enhancement around 1300 MeV. The state at 1538 MeV is consistent with the well established f_2'(1525). The state at 1726 MeV may be the glueball candidate f_0(1710). However, its width of 38^{+20}_{-14} MeV is significantly narrower than 125 ± 10 MeV observed by previous experiments for the f_0(1710).

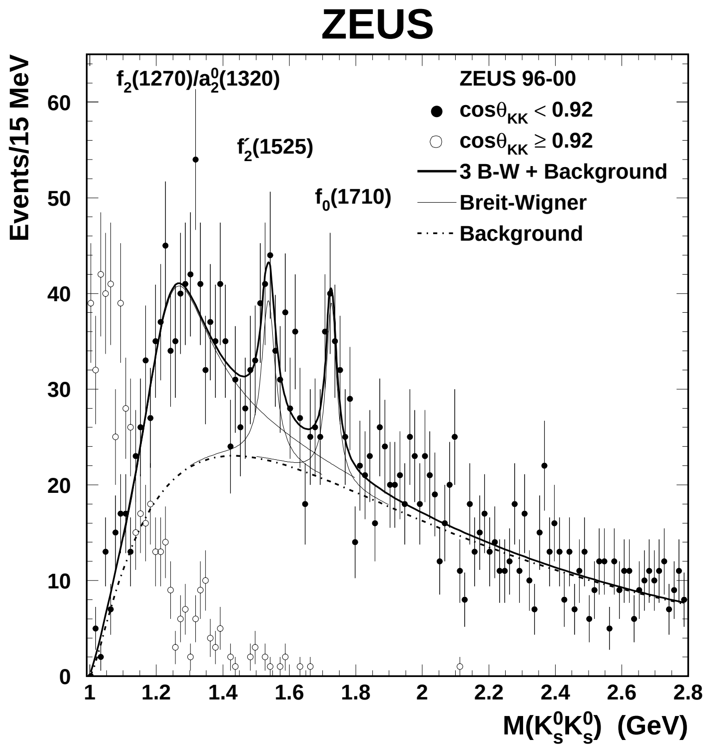


Figure 4. The $K_S{}^0K_S{}^0$ invariant mass spectrum for $K_S{}^0$ pair candidates with $\cos\theta_{KK} < 0.92$ (filled circles). The thick solid line is the result of a fit using three Breit-Wigner (thin solid lines) and a background function (dotted-dashed line). The $K_S{}^0$ pair candidates that fail the $\cos\theta_{KK} < 0.92$ are also shown (open circles).

v) *A Search for Resonance Decays to Lepton+Jet at HERA and Limits on Leptoquarks*

A search for narrow-width resonances that decay into electron+jet or neutrino+jet has been performed using an integrated luminosity of 144.8 pb^{-1} e^+p data and 16.7 pb^{-1} e^-p data. No evidence for any resonance was found. Limits were derived on the Yukawa coupling, λ, as a function of the mass of a hypothetical resonance that has arbitrary decay branching ratios into eq or eν. These limits also apply to squarks predicted by R-parity violating supersymmetry. Limits for the production of Leptoquarks described by the Buchmüller-Rückl-Wyler model were also derived for masses up to 400 GeV. For λ=0.1, leptoquark masses up to 290 GeV are excluded. Figure 4 shows the excluding limit for scalar and vector Leptoquarks.

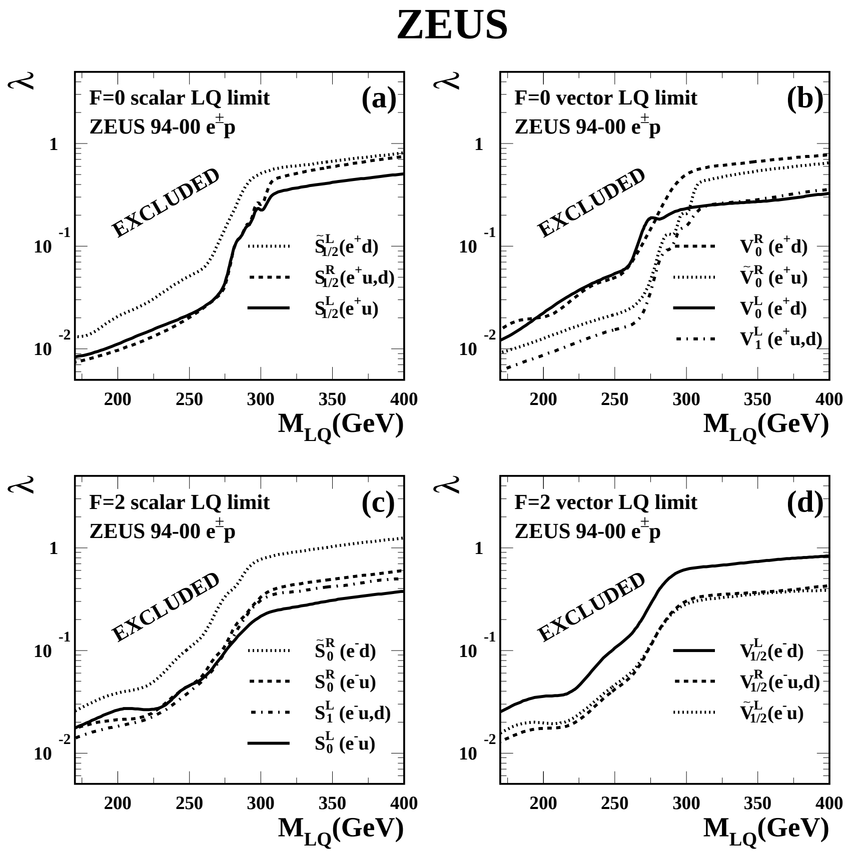


Figure 5. Coupling limits as a function of Leptoquark mass for scalar (a) and vector (b) F = 0 BRW Leptoquarks and for scalar (c) and vector (d) F = 2 BRW Leptoquarks. The areas above the curves are excluded.

b) HERA and ZEUS Operations

The second half of 2003 was dedicated to the re-commissioning of the HERA collider after the shutdown period which had ended in June. The machine delivered an integrated luminosity of approximately 6 pb^{-1}. While this is per se not impressive, it still provides cause to optimism for the future performance of the machine. The background conditions which have prevented machine operation with high beam currents in the past, have drastically improved after the shutdown. Given the current conditions the central tracker will be able to operate with the design beam currents of 100 mA (protons) and 40 mA (positrons). While the machine is being commissioned with positrons, the decision of switching over to electrons will be revisited in early 2004.

The ZEUS detector is performing well. The new components, i.e. the Micro-vertex detector and the forward Straw Tube Tracker, are being integrated fully into the ZEUS tracking system. Tracks have been reconstructed with segments in the Micro-vertex detector, the Straw Tube Tracker and the Central Tracking Detector

(J. Repond)

I.B. EXPERIMENT IN PLANNING OR CONSTRUCTION

I.B.1. The Endcap Electromagnetic Calorimeter for STAR

This will be the final semi-annual report on the construction of the Endcap Electromagnetic Calorimeter (EEMC) for the STAR experiment at RHIC. The EEMC, which covers the full azimuthal angle over the pseudorapidity interval $1.1<\eta<2$, was built primarily to measure the QCD-Compton scattering process $q+g\rightarrow q+\gamma$ in polarized proton-proton collisions at kinematics where the sensitivity to the gluon helicity is greatest. It will also enhance STAR's heavy-ion program, for example by improving trigger capabilities for rare processes such as J/ψ and Υ production.

Argonne's commitments to the construction of shower maximum detector (SMD) modules for the EEMC were completed during the second half of 2003. During this period, we assembled the final two spare modules and tested a total of seven modules with cosmic rays. A total of 16 modules were installed in the EEMC at STAR, most of which were transported to Brookhaven National Lab by Argonne personnel. Added to the eight modules installed during 2002, this provides SMD coverage over the full calorimeter. Three spares were constructed and tested, and these will be stored at Argonne. One member of our group also assisted with the assembly of some of the first readout boxes for the SMD, which were installed during the RHIC shutdown between June and November of 2003. He is expected to also contribute to assembly of further readout electronics; only one-third of the SMD electronics is available for the 2004 run. With the completion of the assembly the rest of our group has begun to turn our attention to commissioning and data analysis tasks. For example, we are working on Monte Carlo simulations to study effects such as light attenuation in the SMD strips, and we are using cosmic ray data taken for the purposes of module testing to study the effects of MAPMT crosstalk.

In December, our production facilities and some of our remaining scintillator strips were used to construct SMD modules for STAR's zero-degree calorimeters (ZDCs). This upgrade is expected to allow a measurement of the reaction plane in heavy-ion collisions independently of the measurements already made by the time projection chamber at mid-rapidity. It may also allow the ZDCs to be used for local polarimetry at STAR during proton running. These detectors were installed at STAR during a maintenance access early in the 2003-2004 running period and were an almost immediate success. We look forward to STAR results which will be enhanced by Argonne's contributions to the EEMC, the ZDC, and the Forward Pion Detector.

(R. V. Cadman)

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

The phenomenon of neutrino oscillations allows the three flavors of neutrinos to mix as they travel through space or matter. The MINOS experiment will use a Fermilab muon neutrino beam to study neutrino oscillations with higher sensitivity than any previous experiment. MINOS is optimized to explore the region of neutrino oscillation parameter space (values of the Δm^2 and $\sin^2(2\theta)$ parameters) suggested by atmospheric neutrino experiments: IMB, Kamiokande, MACRO, Soudan 2 and Super-Kamiokande. The study of oscillations in this region with an accelerator-produced neutrino beam requires measurements of the beam after a very long flight path. This in turn requires a very intense neutrino beam (produced for the MINOS experiment by the Fermilab Main Injector accelerator) and massive detectors. MINOS compares the rates and characteristics of neutrino interactions in a 980-ton "near" detector, close to the source of neutrinos at Fermilab, and a 5400-ton "far" detector, 735 km away in the underground laboratory at Soudan, Minnesota. The MINOS detectors are steel-scintillator sandwich calorimeters with toroidally magnetized 1-inch thick steel planes. The detectors use extruded plastic scintillator with fine transverse granularity (4-cm wide strips) to provide both calorimetry (energy deposition) and tracking (topology) information. The neutrino beam and MINOS detectors are being constructed as part of the NuMI (Neutrinos at the Main Injector) Project at Fermilab.

Results from the Super-Kamiokande, Soudan 2 and MACRO experiments provide evidence that neutrino oscillations are taking place within the region of parameter space that MINOS was designed to explore. The best value of Δm^2, around $2.5 \times 10^{-3} eV^2$, has motivated the use of a lower energy beam for MINOS than was initially planned in order to improve sensitivity at low Δm^2. Argonne physicists and engineers have been involved in several aspects of MINOS construction: scintillator-module factory engineering, near-detector scintillator-module fabrication, near-detector front-end electronics, near- and far-detector installation and the construction and installation of neutrino beamline components.

One major focus of work by the Argonne MINOS group has been scintillator module construction. ("Modules" are subassemblies of 20 or 28 extruded plastic scintillator strips.) Scintillator module assembly for MINOS was performed at assembly facilities at Argonne, Caltech and the University of Minnesota in Minneapolis. The

Argonne group designed and built the assembly machines and tooling for all three module factories. Argonne physicists and engineers served as NuMI Project WBS Level 3 Managers for the design and construction of the machines needed to assemble scintillator modules and for the operation of the three factories. In November 2002 the Argonne factory completed the assembly of all 573 near-detector modules. The Caltech and Minnesota factories completed the assembly of 4147 far-detector modules in the spring of 2003.

The second major focus of the Argonne MINOS group is electronics and data acquisition for the experiment. The near detector must have fast front-end electronics with no dead time because of the high instantaneous rate of neutrino events at Fermilab. This is accomplished using a special MINOS modification of the Fermilab QIE ASIC chip. Most components of the near-detector front-end electronics, along with protocols for communication among the various boards, are the responsibility of the Argonne electronics group. The group also developed software to operate and study the performance of the readout electronics chain and performed simulations of electronics response. An Argonne engineer continued to serve as the Level 3 manager for the near-detector front-end electronics in 2003. The Argonne physicist who was previously the Level 2 manager for all detector electronics completed his term at the end of 2002 and became Level 2 co-manager for near detector installation.

During the first three years of the project the Argonne MINOS group played an important role in far-detector installation and the specification of underground infrastructure at Soudan. In the past two years, Argonne physicists have become heavily involved in the design and construction of neutrino beam components and NuMI target hall infrastructure, as described below. As construction work winds down the group has also been able to devote some effort to the analysis of far detector cosmic ray data and to the design of next-generation neutrino experiments (as described in the Detector Development section of this report).

MINOS far-detector work was highlighted by several important achievements during the second half of 2003. Far detector installation at Soudan was completed in July with the commissioning of the Supermodule 2 magnet coil. The veto shield covering the top and upper sides of the detector was completed in August, when atmospheric neutrino data taking with the full detector began. Figure 1 is a photograph of the completed MINOS far detector. With the installation completed, the MINOS collaboration turned its attention to improving data quality and the data-acquisition duty cycle. The fraction of dead channels continued to improve and is now well below 1%. Data-acquisition system improvements now allow interspersed light-injection calibration data and cosmic-ray data, and the overall data-acquisition duty cycle has improved from 50% to over 90%.

Figure 1. The completed MINOS far detector. The photograph shows the MINOS far detector at Soudan in July 2003, following the completion of installation, including the magnet coil and the cosmic-ray veto shield. The coil wires and cooling water tubes can be seen emerging from the central hole in the last steel detector plane. The large aluminum-covered panels above the detector are the scintillator modules that make up the completed top section of the veto shield. The nearly completed side sections of the shield, constructed of vertical and 45 degree panels, can be seen along the sides of the detector.

The magnetization of the steel planes of the MINOS far detector enables us to perform a unique atmospheric-neutrino measurement. The bending of charged particles in the magnetic field distinguishes positive from negative muons up to about 70 GeV/c, which allows the detector to measure charged-current muon-neutrino and antineutrino interactions separately. A difference in the oscillation parameters of neutrinos and antineutrinos would constitute a violation of CPT symmetry, which could not have been observed in earlier experiments. The study of atmospheric neutrino events in MINOS data (unlike beam neutrino events) requires a veto shield to suppress backgrounds from downward going cosmic-ray muon interactions. The shield covering Supermodule 1 was completed in January 2003, allowing the search for CPT violation in atmospheric neutrino events to begin. The shield over Supermodule 2 was completed in August as described above.

Argonne physicists and engineers were heavily involved in the production and testing of electronics for the MINOS near detector during the second half of 2003. The production of most front-end electronics was completed by the end of the year and checkout was nearly complete as well. Fabrication of M64 photomultiplier signal cables and the last few electronics boards (MINDER and PIN-diode AUX cards) is scheduled for completion in early 2004. The Argonne MINOS group played a particularly important role in the third and final run of the MINOS Calibration Detector in a test beam at CERN. This two-month run, which was completed in October, was mainly devoted to near detector electronics calibration. The exercise identified a number of subtle electronics performance anomalies, which have now been either repaired or understood and well characterized. This final test beam run produced a large quantity of excellent calibration data, which is now being analyzed and will soon be incorporated into data simulation and analysis programs.

The Argonne MINOS group also has major responsibilities for near-detector installation, which is scheduled to begin in April 2004. An Argonne physicist is now co-manager for MINOS near detector installation. Assembly of the steel and scintillator detector planes was completed in 2002 and the assembly near-detector electronics racks was over 80% complete at the end of 2003. The first nine detector planes that will be installed underground are now being connected to their readout and data acquisition electronics as part of a commissioning test at Fermilab. This exercise is giving valuable experience with the cabling of planes and the commissioning of electronics and the data acquisition system. Other preparations for installation during the last six months included the successful testing of the cart that will transport detector planes from the underground shaft station to the near-detector hall. Figure 2 is a recent photograph of the near-detector assembly and commissioning area in the New Muon Lab at Fermilab.

Figure 2. The MINOS near-detector planes in the New Muon Lab at Fermilab. The four storage racks along the wall in the background contain the assembled steel and scintillator planes. The planes in the storage rack at the far left are being used for the nine-plane commissioning test. The plane-installation transport fixture, which will carry planes from the underground shaft station to the near-detector hall, can be seen in the lower left corner of the photograph.

As MINOS detector work ramps down, Argonne physicists have been able to devote more time to construction and testing of NuMI neutrino beam components at Fermilab. This work spans a range of activities. One physicist is the Deputy Level 3 Manager for Neutrino Beam Devices and is also responsible for preparation of the hot work cell facility, which will be used to repair highly radioactive beam components. Other group members are responsible for vibration measurements of the production target and magnetic focusing horns, horn magnetic-field measurements and the readout and integration of target hall instrumentation. Achievements in these areas during the second half of 2003 are summarized in the paragraphs below.

The most complex part of the hot work cell is the remotely controllable lift-table system, which is used inside the hot work cell shielded enclosure to attach or remove a target or horn from its support module. In November 2003 the lift table system was assembled and used to attach Horn 1 to its module for the first time. In a parallel effort, the preassembly of the hot work cell shielding enclosure was nearly completed in the New Muon Lab at Fermilab at the end of the year. The structure is being assembled prior to underground installation in order to save time underground. Figure 3 is a photograph of the assembled hot work cell structure.

Figure 3. NuMI hot work cell preassembly at Fermilab. The photograph shows the concrete and steel hot work cell after preassembly in the New Muon Lab at Fermilab. The hot work cell will be used to work on NuMI beamline production-target and magnetic-horn assemblies that develop faults after becoming radioactive. The four apertures in the walls of the structure (three in the concrete-block sidewall and one in the steel endwall) will be filled with lead glass to provide a clear view of radioactive components. Usually a faulty target or horn will not be repairable but must be replaced with a spare unit using the remotely controlled devices in the hot work cell.

Cooling-air vibration measurements of the NuMI production target in its operating location, inside the neck of Horn 1, were completed in June 2003. Similar measurements with the target mounted in the carrier assembly were completed in December. Both tests concluded that target vibrations induced by cooling-air flow are quite small and do not require any design changes. Vibration measurements with target cooling water, which will complete this study, are scheduled for early 2004. Argonne physicists also worked on the design and prototyping of both the Bdot coils and the horn-alignment crosshairs. Modified Bdot coils, which monitor the magnetic field produced by the horns during operation, were successfully tested on Horn 2 in December. The original design allowed cooling water to collect inside the feed-through fixture of the lower coils, which could short out the signal. Also in December, the final Horn 1 alignment crosshair assembly, which is used to check the relative locations of the horn and the proton beam, were installed on the horn.

In 2003 Argonne physicists and engineers also continued work on the preparation of the electronics used to read out target hall instrumentation. Argonne's instrumentation readout responsibilities include the thermocouples that measure temperatures at many locations in the target hall, the beam-loss monitors used for horn-crosshair alignment measurements, the readout of the precise positions of remotely movable devices, and the specification of radiation-hard instrumentation cabling. Argonne work on the design of signal conditioning electronics, which is used to interface instrumentation signals to the ACNET data acquisition system, also continued during this period. In November the group completed the first successful test of a thermocouple readout through ACNET.

(D.S. Ayres)

I.B.3. ATLAS Detector Research & Development

a) Overview of ANL ATLAS Tile Calorimeter Activities

The TileCal subsystem continued making good progress in the second half of 2003. Argonne technical staff made significant contributions to the pre-assembly of the Barrel cylinder, which was successfully completed in November, and to the continuing work to prepare EBA modules for pre-assembly. Argonne engineers also continue to make good progress in collaboration with Atlas Technical coordination on areas associated with the calorimeter and shielding movement systems.

(J. Proudfoot)

I.C. DETECTOR DEVELOPMENT

I.C.1. Atlas Calorimeter Design and Construction

The focus of our effort is now primarily associated with the final assembly of the tile calorimeter in the Atlas cavern. The areas of ongoing work comprise: testbeam measurement of detector performance; engineering and technical support of the pre-assembly efforts at CERN (EBC, Barrel and EBA); continued engineering evaluation of the detector design as changes are requested from other subsystems; work in collaboration with Atlas Technical Coordination on components associated with the movement systems on the Atlas main rails (guide brackets, the hydraulic system and controls).

a) Module Repairs, Modification and Testing

An Argonne technician went to CERN to complete repairs to a module, which had significant damage to fibers. In parallel, this technician also contributed to other module preparation for EBA modules (checking torque on Submodule mounting bolts, fastening covers over the region of the girders and installing final covering paper on the surfaces of the modules.) We expect this work to continue through FY 2004. Six EBA modules required a modification of mounting holes in the girder to accommodate a change in our improved understanding of the bolt stresses in these locations. Argonne technicians made 2 trips to CERN to carry out the conversion of these tapped holes from M30 to M36. This work was completed.

(J. Proudfoot)

b) Testbeam Program

R. Stanek from Argonne continued to be the testbeam coordinator for the Tile Calorimeter testbeam program. 2003 is the final year of testbeam calibration of tile calorimeter production modules. Next year's program will concentrate not on calibration, but on assembling a working system of subdetectors readout in a common structure.

At the end of this stage of the testbeam program, we can identify the following important achievements:

- We achieved (almost) our goal of 12% of production modules calibrated using electrons and muons, with the gain set solely by setting the ^{137}Cs current in the tiles;

- We are confident that, using the Cs, the gain can be set to better than 4% for all modules;

- We measured the response of the Tile Calorimeter to pions of energies down to 1 GeV/c;

- A ROOT-based online monitoring program was implemented;

- The results from the bunched beam taught us how to use the laser to set global timing in ATLAS;

- We demonstrated that TileCal can be successfully integrated in the readout with other sub-detectors.

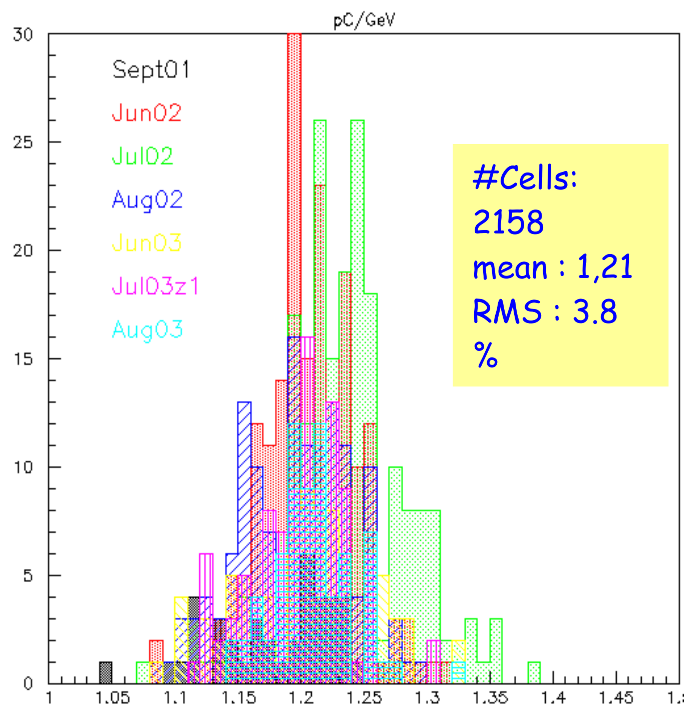


Figure 1. Distribution of electron response for cells set using the Cs

There were some problems with the beam and with our scanning table this year that did not allow us to complete the full compliment of modules to be calibrated. Our original goal was to have calibrated 8 Barrel Modules and 18 Extended Barrel modules. Our final calibration was completed on 9 Barrel modules and 14 Extended Barrel modules. Although we calibrated fewer modules than intended, we still are confident that we can set the EM scale using Cs alone. Our goal has always been to set each cell to the EM scale of 1.2 pC/GeV. This number is somewhat historic and depends slightly on the algorithm to calculate charge. With a consistent algorithm, we find that our value of

1.2 pC/GeV is realized for electrons (with a spread of 4%), and the uniformity seen with muons is also better than 3%.

In Atlas, the calorimeter response will be monitored using penetrating muons, as well as the Cs response and minimum bias currents. The muon response by cell for the modules calibrated in the testbeam is shown in Fig. 2. In Atlas, this measurement will provide a cross-check of the calorimeter calibration using Cs, as well as a continuous monitor of short timescale variations.

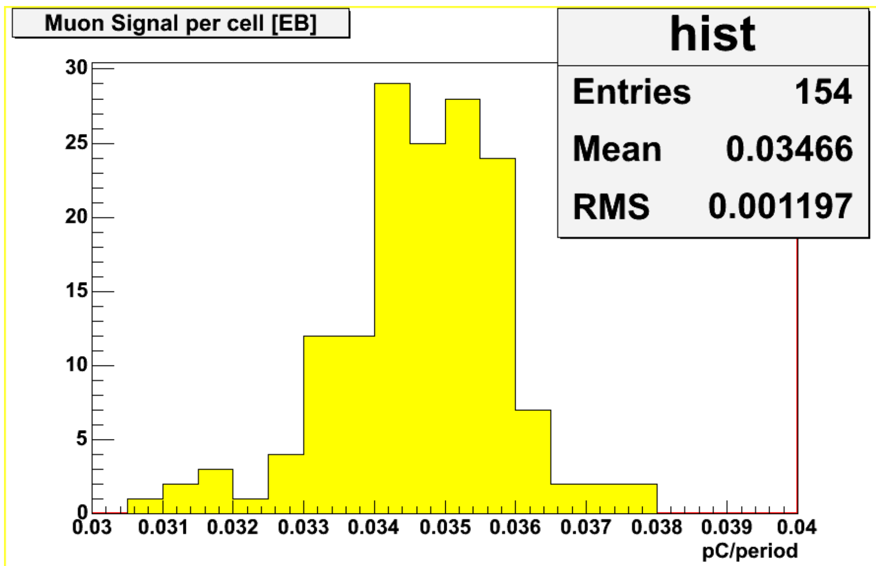


Figure 2. Distribution of muon response for cells set using the Cs. The rms of the distribution is 2.7%

Jets consist mainly of low-energy particles and, therefore, it is very important that we know the response of our detector to low energy pions. Monte Carlo predictions are unreliable at low energies and, so, this response must be measured in a beam. In August 2003, a very low energy beam (VLE) was developed for us, using a tertiary target close to our detector. In Fig. 3, we see that at the low energies, pions and electrons will behave similarly. We have data at 1 GeV/c, however, muon contamination from the primary beam does not allow for easy separation of the pion signal. These measurements will continue in 2004 with the LAr detector in front of the Tile calorimeter.

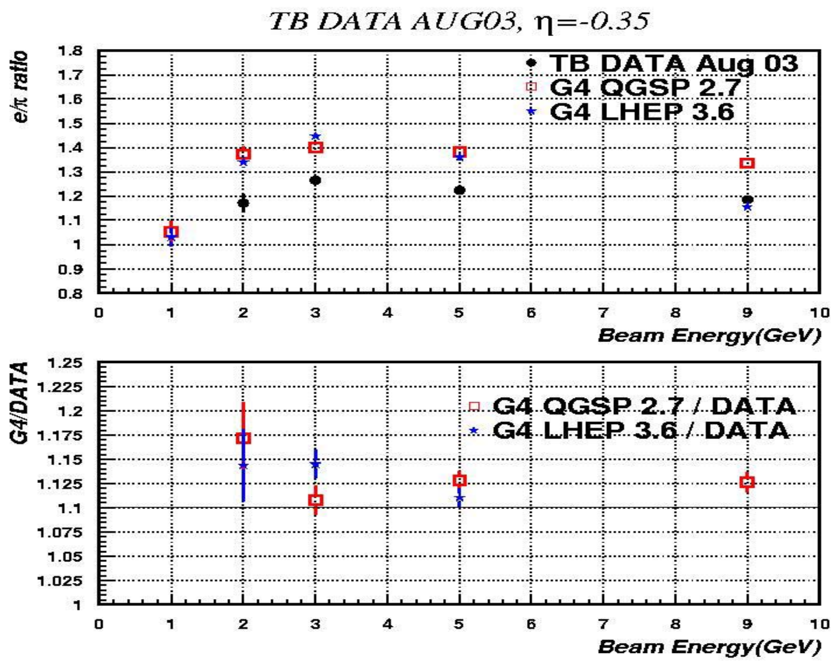


Figure 3. Testbeam data and Monte Carlo predictions for the response of the Tile Calorimeter to low energy particles

Using the data from the 25 nsec bunched beam runs, we were able to determine if we could predict the timing of each calorimeter in ATLAS by using the laser data. With corrections to time dispersion across mother boards, delays of laser fibers and geometrical effects in the testbeam, we find we can easily set the global timing to a few nsec as is shown in Fig. 4. Most of the variation is dominated by the fact that only 6 PMTs in a group have their timings adjusted relative to other groups of 6 PMTs.

Finally, in September we did a second combined test run with the Tiles, pixels and MDT detectors. The run went more smoothly than that in 2002. Combined ntuples were written, and we took the opportunity to put different programs in the Read Out Drivers (RODs) rather than the standard programs, which we used before. In these runs, the RODs were calculating charge and time and, these variables, as well as the raw data,

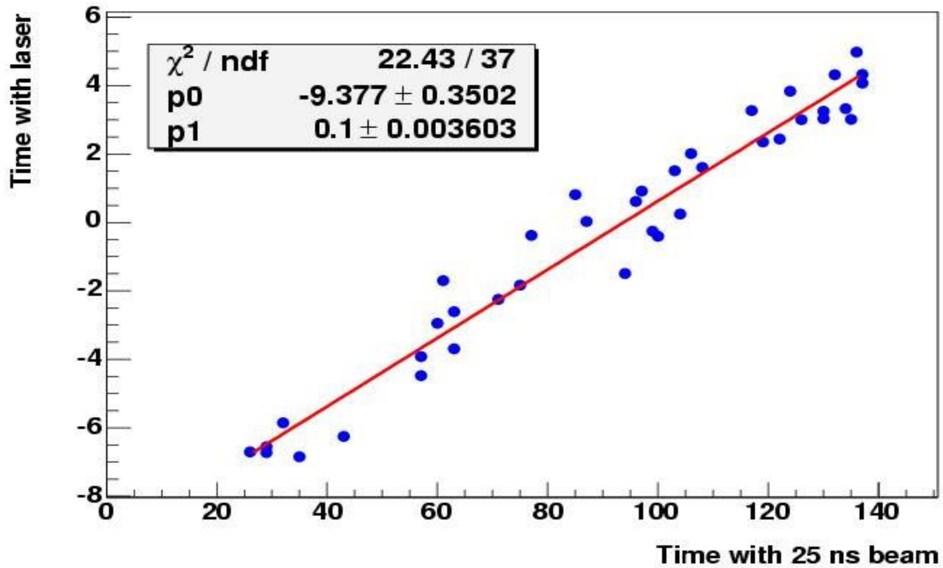


Figure 4. Time reconstructed using the laser system compared to that obtained using beam particle

were passed to the event builder. In addition, we exercised the future capability of the software. This not only included the ROD software, but also a monitoring system, which looked at all three subdetectors. This monitor was essential in debugging the detectors and the beam quality on a real-time basis.

(R. Stanek)

c) Engineering Design and Analysis

Argonne engineering staff has the responsibility for several of the engineering tasks associated with the assembly of the calorimeter, as a whole and, with its support structure. These tasks include: evaluation of stresses in the cylinder connecting elements, deflections in the cylinder during pre-assembly (at each stage and including the cryostat dummy load when appropriate), and evaluation of the stability of the assembly as a whole (with special emphasis on the conditions during the initial mounting of the cryostats).

Several engineering calculations are in progress or have been completed in this period:

- FEA calculations were performed to estimate deflections and stresses in the barrel calorimeter structure at various stages during pre-assembly. This work is ongoing and a particular issue is the stability of the structure if the cryostat dummy load is applied after 32 modules are mounted (rather than after the cylinder is closed). In December, the cryostat dummy load was applied with 44 modules in place and then removed. The cryostat dummy load will be applied again with 32 modules in place in early January. The initial comparison of the barrel survey data with the predicted FEA deflections were not a good correlation as they did not take into account friction between the cryostat and the A-frame on the barrel which supports it. When the affect of friction was added, there was a very strong correlation between the FEA model and the survey results.

- Transportation specification and the fixtures for securing the barrel modules to the support cradle were done by ANL for the transport of the cradle with 10 (or 8) barrel modules from Building 185 to the Atlas cavern.

- ANL continued to provide technical support for the assembly of the Barrel and EB. Specifically, ANL provided guidance on:

  - The installation of the barrel saddles and the proper shimming of the key, Determining the pre-stress on the swivel bolts in the EB and Barrel, Performing detailed analysis to show that the barrel was stable when the cryostat load was applied,

  - Detailed analysis of the key bearing stresses in order to insure that there is not a problem due to differential loading along Z and due to reduced bearing area due to saddle deflections,

  - Perform analysis of EB stability when cryostat load is applied at 24 modules and design a chain link between saddles to insure stability.

d) Calorimeter Pre-Assembly and Installation

Argonne technical and scientific staff have had significant participation in the ongoing preassembly of the EBC cylinder at CERN. J. Proudfoot is one of the three leaders of the pre-assembly team and with V. Guarino has the responsibility for the evaluation of the geometrical envelope and deformation of the cylinder under its static load. The modls used to interpret the data from the pre-assembly of EBC were extended and used extensively to monitor the cylinder shape during assembly. We succeeded in coming within 5mm of our overall envelope and of predicting the shape of the cylinder to within a few mm at the top (i.e. prior to the insertion of the last module). This data, in combination with the predictions from the FEA model of the effect of the cryostat, are now being evaluated to finalize the plan for the assembly of the barrel cylinder in the cavern in 2004.

In addition, Argonne technical and scientific staff have had significant participation in the development of the plan to allow the barrel installation to be carried out some 2 months earlier than planned (now scheduled to begin on March 1, 2004). This is to accommodate delays in the fabrication of the barrel toroids. As part of this task, we have initiated the first steps to understand the integration and design issues associated with the installation of services.

(J. Proudfoot)

e) Work in Collaboration with ATLAS Technical Coordination

Argonne technical staff has established a strong collaboration with ATLAS technical Coordination to design the guide and movement systems for the several components, which must be moved on the main rails to access the detector. In this period, several significant steps forward were made. The design of the calorimeter Z bracket has been completed. The design and fabrication drawings have been completed for the Toroid X and Z brackets. An initial layout of the components needed for the support and movement of the JD disk was completed.

During the period July 2003 through December 31, 2003, progress was made in bringing the movement hardware to completion:

- Several modifications were made to the Toroid EndCap (TE) Z-brackets to account for various interface changes and other fabrication requests. The drawings for these components, as well as the TE X-brackets, were sent out for fabrication;

- The specification for the Barrel and Extended barrel blocking jacks was finalized and delivered to CERN procurement for bidding;

- The calorimeter X-bracket required relocation from the outside rail edge to the inside for better seismic protection. Additionally, a conflict with the muon supports needed to be resolved. The bracket was redesigned and analyzed and fabrication drawings were produced. The new layout is shown in Fig. 5;

- The calorimeter Z-bracket design was finalized and fabrication drawings were produced for the main bracket components. The cylinder connection detail requires final confirmation with the final cylinder selection and a spring support for manipulating the bracket requires final design.

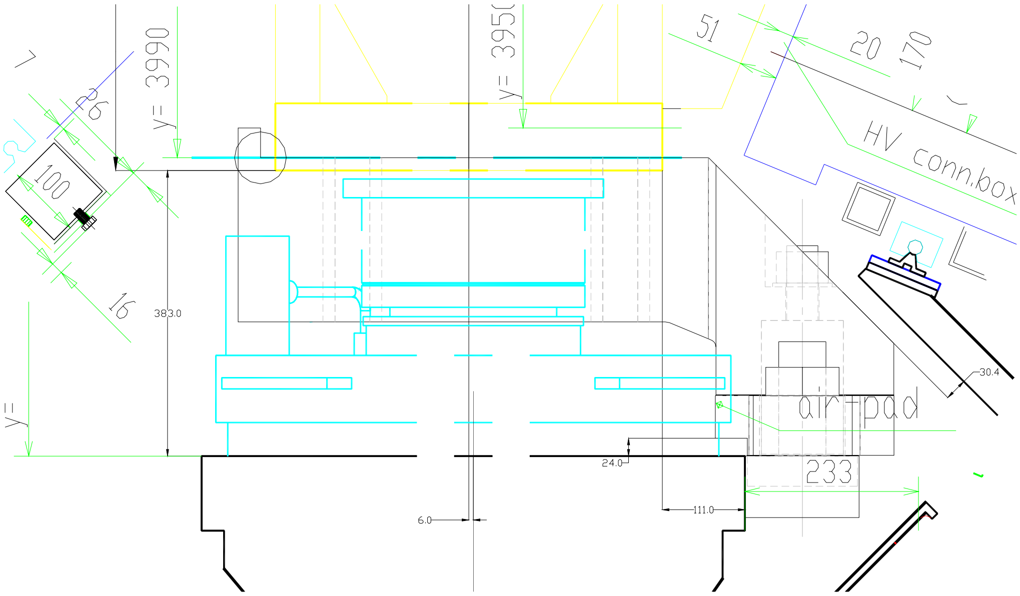


Figure 5. Calorimeter X-bracket moved to inside rail position. A conflict with a muon support has been resolved to provide 30mm clearance.

Figure 6. The HF Truck loaded with 1800 tons. The lateral movement of the truck is controlled by the system developed at ANL.

f) TC Control System Work

Significant progress was made in the development of the control system. In July, the first HF truck (Fig. 6) was load tested at CERN and, as part of the safety acceptance, was further required to demonstrate safe movement under load. This set-up offered a first test of the PLC based system moving a load supported by airpads. Although the main goal was to use the control system's ability to gently accelerate the load, the test became an opportunity to test and develop a better understanding of the system as a whole. In order to capitalize on this test, a data acquisition feature was added to the control system that allowed capturing important performance data such as the position error and system pressures. A set of tests were then planned to understand many features, including the hydraulic system dynamics, for the purposes of system modeling. The following accomplishments were made during the July test:

- The truck movement was tested from no load conditions up to 220 tons. The truck was moved successfully for all tests, showing that the basic system features were satisfactory;

- The basic user features and fault routines were tested and debugged as necessary. The tests were very successful in also identifying additional needs of the system;

- The system was able to drive the two parallel cylinders in a synchronized fashion with a steady, state error less than 0.5mm;

- The most interesting development in the July test is illustrated in Fig. 7. The motion of the two cylinders (x1 and x2 on the plot) revealed a "stick-slip like" motion that was not expected.

A second test of the HF truck movement was performed in October when the load was increased fully to 1100 tons (the maximum load the truck needs to move – the static load test was carried out for 1800 tons). Functional improvements were added to the system based in the experience of the July tests. In particular, the DAQ was enhanced so that it could take unlimited data (it was limited to 15s in the July tests.) New tests were planned based on the results of the July tests, and were aimed at developing a better understanding of the system dynamics and, in particular, eliminating the "stick-slip motion" (the “stairstep” motion seen in Fig. 7).

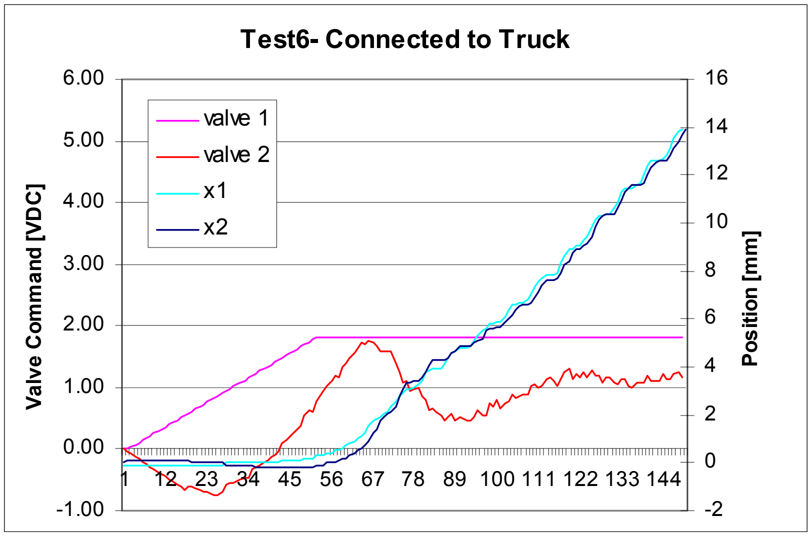


Figure 7. Movement test showing stick slip friction.

Once again there were many successes with these tests. The tests: confirmed a hunch about the hydraulic hose compliance; established a non-linear valve pressure flow relationship; demonstrated robustness of the feedback tuning parameters over a wide range of loads; showed that the steady state position error was less than 0.2mm (Fig. 8).

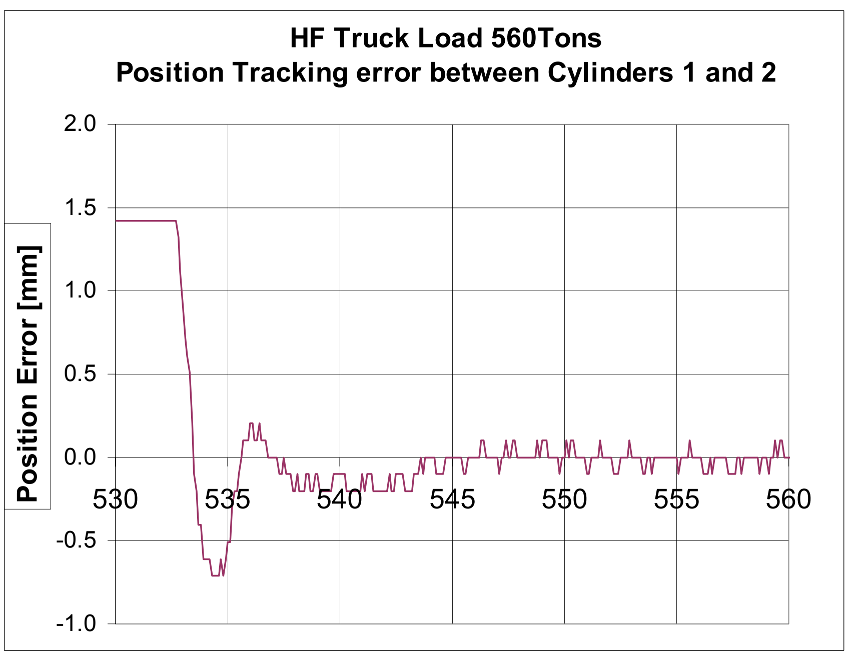


Figure 8. Cylinder position tracking error is less than 0.2mm in steady state after being started initially with a 1.4 mm error.

Finally, the tests provided new information regarding the "stick slip problem". In particular, it was shown that by increasing the system stiffness (through the driving pressure), the oscillations could be minimized.

(J. Grudzinski)

I.C.2. Computational Projects

a) ATLAS Computing

This period was in between two major “data challenges” for ATLAS - after the end of Data Challenge 1, the first large scale test of ATLAS software and Data Challenge 2, intended to test the distributed computing model ATLAS will be using. Effort and activities in this area focused on long time-scale software development leading towards readiness for Data Challenge 2 and the software needs for the combined test beam run, both in mid-2004. Switching from the GEANT 3 simulation framework to GEANT 4 and implementing the LHC-wide persistency solution POOL are examples of these efforts. Both of these depend critically on ATLAS data management.

Argonne continued to hold several leadership positions in international ATLAS data management in the second half of 2003. David Malon continued to serve as offline database coordinator for the international ATLAS collaboration, and as the manager responsible for databases and data management in the U.S. ATLAS organization. Alexandre Vaniachine was responsible for database server and service deployment for international ATLAS and, more broadly, for the LHC Computing Grid applications area. In these capacities, Argonne delivered or oversaw:

- successful integration by ATLAS of the collaboratively developed POOL persistence infrastructure as its primary storage technology,
- a major redesign of control framework persistence services in preparation for the 2004 ATLAS data challenge,
- a persistence infrastructure plan to support the ATLAS 2004 combined test beam runs;
- a plan for server deployment for ATLAS combined test beam activities;
- initiation of an effort to articulate requirements and begin design of an ATLAS metadata system, with a kickoff workshop on metadata organized and run by the Argonne group in July 2003;

On the software development front, Argonne continued to be responsible for the NOVA database infrastructure, used by ATLAS for the primary numbers that parameterize detector description, and, increasingly, for other kinds of data as well. The success of this effort is evident in the load (ATLAS hit a 1,000-simultaneous-connection limit to the NOVA database), and in the continually increasing range of data being stored via NOVA. Much development effort was therefore devoted to enhancing the robustness of the software and servers, and to improving the process of generating the code that must be synchronized with versions of the database. Tools to browse, inspect, and manage the database were also part of this period's development effort.

Argonne (David Malon) also leads the LHC-wide POOL collections and metadata work package, and is principally responsible (Kristo Karr) for relational database implementation. A primary focus of this work during the second half of 2003 was performance and scalability testing and improvement. Preliminary results were reported by the Argonne group in an LHC-wide forum in the fall. Kristo Karr thereafter accomplished a major (link-table-based) implementation of database-hosted collection implementations, resulting in significant storage savings.

Tom LeCompte was named International ATLAS Planning Officer at the end of the last reporting period. In conjunction with the subdetector systems, he developed a 1500-task resource loaded schedule and work breakdown structure. This allowed task interferences to be discovered and mitigated (for example, the first schedule had the software for DC2 unavailable until after DC2 had started) and the profile of manpower needs calculated. The manpower needs were reviewed by CERN in September, and the review committee's conclusions matched the experiments. Transparency in planning has been a priority; all schedules are publicly available on the main ATLAS web page, along with completion estimates, both current and historical.

(T. LeCompte)

I.C.3. Detector Development for the Linear Collider

In the second half of calendar year 2003 the Linear Collider Detector R&D group continued to pursue their efforts aiming at the development of a design of the hadron calorimeter for the Linear Collider detector. Progress was made on both the Monte Carlo simulation and the hardware development front.

a) *Monte Carlo Simulation studies*

The results presented in previous such reports were based on GEANT3. In Mid-December a new simulation code of the linear collider detectors became available based on GEANT4. The group repeated their previous studies with the new tool and, in general, confirmed the results obtained previously with GEANT3.

Work on the ingredients to a complete Particle Flow Algorithm continued. A track-calorimeter deposit matching routine based on the identification of the first interaction layer and using narrow cones to follow the hadronic showers from layer-to-layer was developed. Energy deposits in the calorimeter belonging to neutral hadrons were identified as the energy left over after subtraction of the charged particle energy and the energy belonging to electromagnetic showers as identified by the electromagnetic calorimeter. Applying these algorithms to Z^0 decays at $\sqrt{s}$ = 91 GeV, showed a clear correlation between generated and reconstructed energy of neutral hadronic particles, see Figure 1.

b) *Development of Resistive Plate Chambers as active medium of a digital hadron calorimeter*

In the second half of 2003 the group continued its vigorous R&D program to develop Resistive Plate Chambers as active medium of a digital hadron calorimeter. In the following we briefly summarize the major highlights of the project:

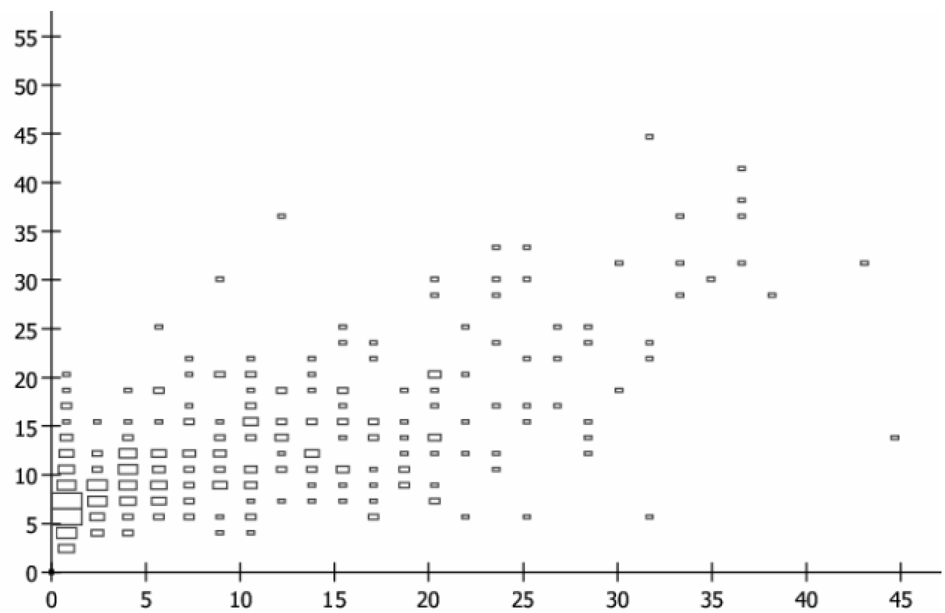


Figure 1. Reconstructed versus generated energy of neutral hadrons. The scales are GeV.

b. 1. Construction of chambers

Two more chambers each with an area of 20 x 20 cm^2 were built. In contrast to the chambers built previously at Argonne, these chambers feature only one single gas gap. The surface resistivity of the graphite layer was measured to be approximately 1 – 50 MΩ. The chambers were tested thoroughly with cosmic rays and were found to perform with high efficiency (>95%) and low noise rates. The induced charges on the readout pads were measured to be significantly larger than the average charges obtained with 2-gas gap chambers.

b. 2. Tests with different gas mixtures

Our previous studies were performed with a gas mixture optimized for running in streamer mode: Freon:Argon:Isobutane = 62:30:8. In this period we explored gas mixtures without Freon, such as Argon:Isobutane:SF_6 mixtures and a mixture without Argon, namely Freon:Isobutane:SF_6. We found that operation with the Argon free gas mixture, with a relative concentration of 94.5:5.0:0.5, gives signals with significantly higher charge in avalanche mode compared to the other gas mixtures. Figure 2 shows the measurement of the efficiency and the streamer fraction as a function of applied High Voltage. A plateau with a width of about 660 V is observed where the efficiency is greater than 95 % and the streamer fraction is only a few percent.

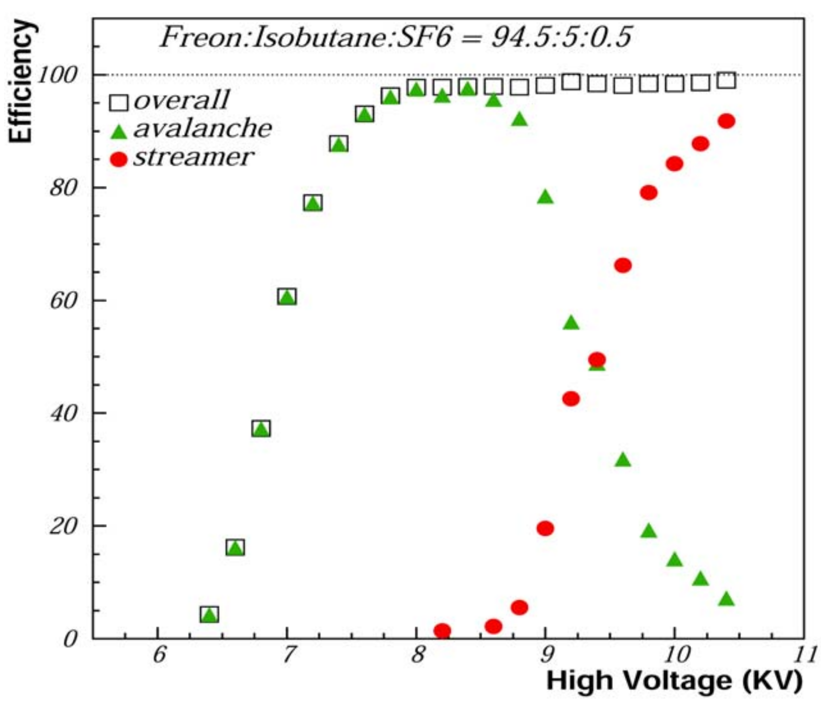


Figure 2. Efficiency and streamer fraction as a function of applied High Voltage for a 1-gas gap chamber.

b. 3. Understanding of wrong sign signals

Measurements with 25 readout pads of 1 cm^2 each showed that the charge induced in the surrounding pads of the pad hit changes sign, see last report. By adding a large pad on the opposite side of the readout pad connected to the ground, these wrong sign signals could be eliminated. As a further bonus of adding a pad on the opposite side, the average charge recorded in the readout pad increased by about a factor of two.

b. 4. Multiplicity studies

Extensive studies of the pad multiplicity were performed using the RABBIT system. It was found that for cosmic rays the average pad multiplicity is relatively high, of the order of 2.7 for a high voltage and threshold setting giving 95% detection efficiency, see Figure 3. Additional tests with the prototype digital readout system (see below) are planned for the near future.

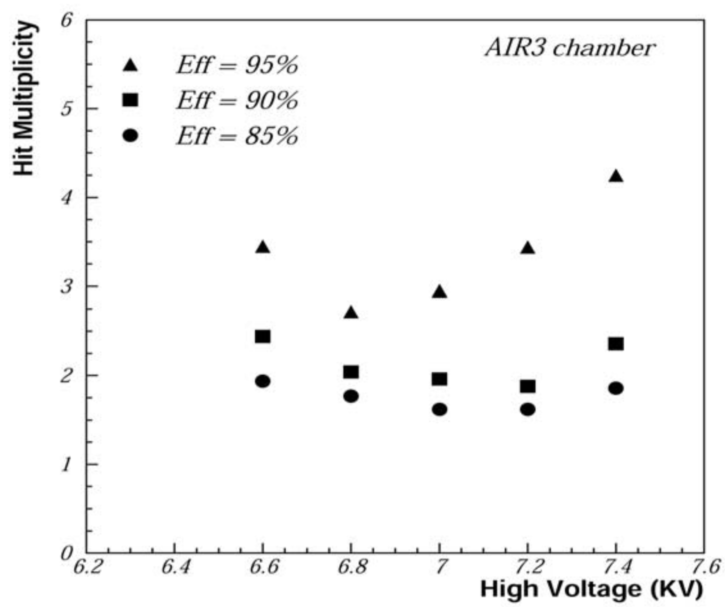


Figure 3. Average pad multiplicity as a function of applied High Voltage for a signal threshold yielding 85, 90, and 95% MIP detection efficiency.

b. 5. VME readout system

We designed, built and commissioned a VME based readout system for the multiple pad studies. The system consists of 6U VME cards able to readout up to 64 input channels. Each channel consists of an amplifier, shaper and discriminator. The data acquisition runs in self-triggering mode. Each recorded event consists of the hit pattern and a time stamp with a 100 ns time resolution. The system works well with RPCs operating in streamer mode. Operation in avalanche mode requires additional amplification of the signal with the amplifier located close to the readout pad. The data acquisition software is based on the FISION library and was written by one of the members of the Argonne group.

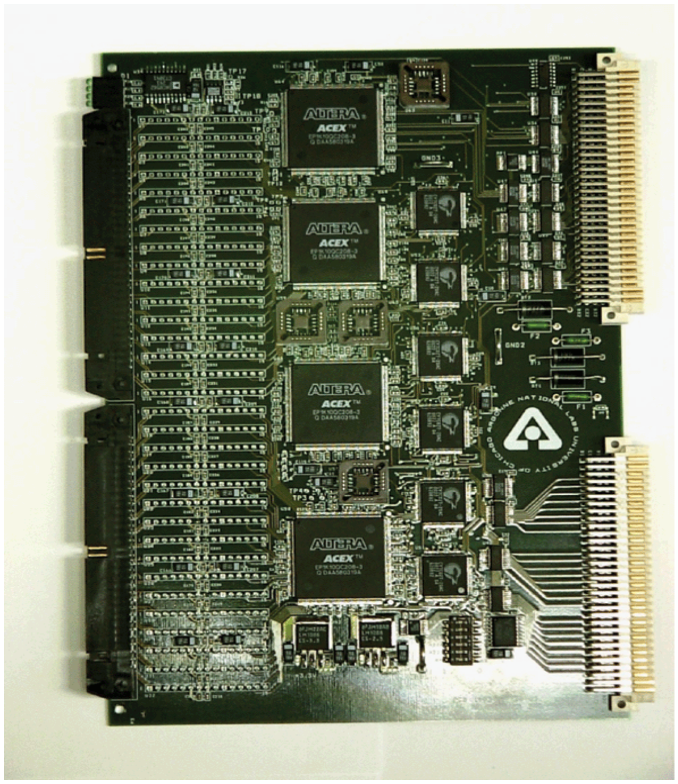


Figure 4. Photograph of the 6U VME card able to readout 64 channels

b. 6. Mechanical studies

In order to develop a viable design for the larger chambers to be used in a physics prototype section of the hadron calorimeter, the group performed measurements of the mechanical properties of the glass sheets. Figure 5 shows the measured deflection in the center of the glass as a function of pressure. The pressure was applied by pouring water on the surface of the glass. A watertight rim was affixed to the perimeter of the glass to prevent the water from flowing off. Similar measurements were performed as a function of applied High Voltage. The results indicate that the electrostatic force compressing the two glass plates is significantly larger than the opposite force exerted by the gas pressure inside the chamber. Based on these results, larger chambers can be built without the need to glue the spacers to the glass plates, in order to hold the two glass plates together.

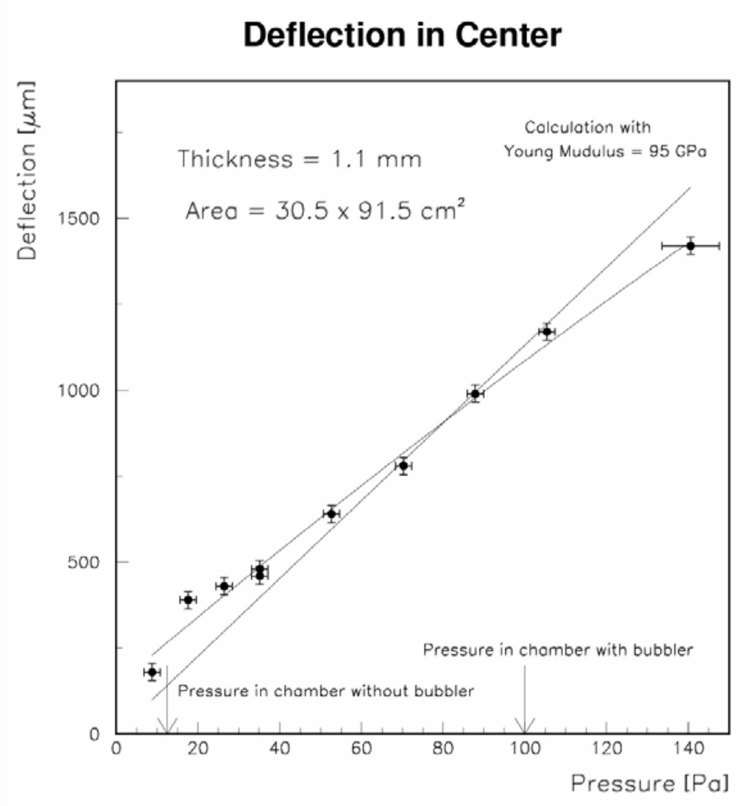


Figure 5. Measurement of the deflection at the center of a 30.5 x 91.5 cm^2 glass plate as a function of pressure.

(J. Repond)

I.C.4. Electronics Support Group

CDF: We had major responsibilities for electronics for the CDF Detector at Fermilab, as part of the upgrade for Run IIA. These included the building of the front-end electronics and read-out system for the Shower Max Detector, and two sets of boards for the Level 2 Trigger called RECES and Isolated Photon Trigger. These were major projects for our group. For the Shower Max Detector, the work involved the coordination of the design engineering and system integration for the entire system, overseeing the production of all components, and ensuring that the overall system meets performance requirements. The system has 20,000 channels of low-noise electronics, and services two detector subsystems. The development work was a collaborative effort between Argonne and Fermilab.

The production work for the electronics was completed in the spring of 2001. All electronics were installed on the detector and commissioned for operation. We were successful in meeting the schedule goals in getting ready for Fermilab Run II, which is now in progress. To date, the system has performed well, with no significant problems.

In this period, we continued our participation with the experiment by providing technical support for the maintenance and repair of all of the electronics for this subsystem. This includes those projects that were designed and produced by Fermilab personnel. We anticipate providing this support through the life of the experiment. The system includes 100 VME read-out boards called SMXR Modules, 600 front-end boards called SMD Modules, 6000 front-end daughter cards called SQUIDs, 100 front-end crate controllers called SMC Modules, 600 preamp boards, 15,000 preamp SIPS (Single In-line Package), and 60 crate monitor boards. We also support the two sets of boards that we built for the trigger system.

There are several upgrades being planned for the detector for the second part of Run II. One of these is the replacement of the Central Preradiator Chambers (CPR). They currently are wire chambers, similar in construction and performance to the Shower Max detector. The plan is to replace them with scintillator and phototubes. Another is the replacement of several components of the trigger system. We are working with division physicists who are involved with these projects, and expect to provide support for building these new components.

ATLAS: We have major responsibilities in the development of electronics for the Level 2 Trigger of the ATLAS Detector at CERN. Working with colleagues from Michigan State University, we are responsible for the development of two parts of this system: the Level 2 Trigger Supervisor, and the Region of Interest (ROI) Builder.

The ROI Builder is the interface between the first level trigger and the second level trigger. When an event occurs in the detector, signals are sent from the front-end electronics to the Level 1 Trigger. The Level 1 Trigger collects event fragments from the front-end electronics over the entire detector, and stores them in a Readout Buffer. It evaluates the data, and identifies regions of the detector that could have an interesting event. The Level 1 Trigger boards then sends a list of addresses called pointers to the ROI Builder, identifying where the event data from the "Region of Interest," can be found. The ROI Builder collects the pointers for the event, and "builds" the event using the pointer list. It then sends the result to the Trigger Supervisor for distribution to Level 2 processors. The selected Level 2 Processor then executes algorithms using the pointers, and can request information to be sent from the Readout Buffers as needed. The ROI Builder is highly complex, using high-speed, highly complex Field programmable Gate Arrays (FPGAs) to implement the functionality.

In early 2001, we built the first ROI Builder prototype, and sent it to CERN for testing in a system there called the ATLAS Test Bed. The tests were largely successful, and helped refine the system requirements and specifications. In the fall of 2001, we built a card called the Gigabit Ethernet Link Source card. This card receives information from the front-end electronics, buffers it, and then sends it to the ROI Builder using

Gigabit Ethernet protocol. The cards make extensive use of large programmable logic arrays. They also have a large, fast synchronous memory that might allow their use as an intermediate data storage element. Testing of the prototype occurred at Argonne and at CERN in the winter of 2001-2002. The system worked very well. In February 2002, the ROI Builder was reviewed by an internal ATLAS review committee. Certain improvements were recommended associated with error reporting and data slow control. In early 2003, we created a new design document that incorporated the recommendations. In this period, work is in progress to design a new set of hardware. We plan to test the new hardware in the ATLAS testbeam at CERN in the summer of 2004.

MINOS: We have major responsibilities for the development of electronics for MINOS, the Neutrino Oscillation Experiment at Fermilab and the Soudan Mine. We are responsible for the design, development, and production of electronics Near Detector, one of the two major detectors for this experiment. One member of our group is the Level 3 Manager for the Near Detector Electronics.

The heart of the front-end electronics for the Near Detector is a custom integrated circuit designed at Fermilab, called the QIE. The QIE digitizes continuously at 53 MHz. The operations are pipelined so that there is no deadtime due to digitization. The digitized data will be stored in a local memory during the entire period of the beam spill. The data will be sent from the local memory to a read-out board after the spill is over. In between spills, the electronics will record data from cosmic rays.

The QIEs and associated circuitry will be built on small daughter boards called MENU Modules, which resemble memory SIMMs. The boards contain a high density of surface mount parts. The MENU Modules plug in to a motherboard called the MINDER Module. The MINDERs reside in front end crates called MINDER Crates, which are a semi-custom design. There is a crate controller in the MINDER Crates called the KEEPER, which controls all activity in the crate. When data is acquired, it is stored on the MENU Modules. After data is acquired, the MINDER then initiates a readout operation, where the data is sent from the MENUs to a VME readout board, called the MASTER Module. The MASTER resides in a 9U VME crate located some distance away from the MINDER Crates. All of the board designs contain a high level of programmable logic to do the complex processing of data and control of operations.

The chip design, and the development of the QIE daughter board, are responsibilities of Fermilab. Argonne is responsible for the design the MASTER Module, the MINDER Module, the KEEPER, the MINDER Crate, signal and data cables, and AUX cards for receiving signals in through the back of the VME Crates. We also have overall responsibility for the design of the rest of the system for the Near Detector, including the specifications for the QIE performance. This is a major design and production project for our group.

In 2002, we completed the development stage of this project, including the building and testing of 200 channels of the read-out system. The system was sent to CERN for use in a test beam, which was set up to calibrate the detector. In early 2003, the final design changes were implemented on all parts of the system, and all sub-projects were signed off for production. Argonne is responsible for the production of 100 MASTERs, 600 MINDERs, and 60 KEEPERs. We have outside vendors do the printed circuit board fabrication and board assembly. We do the checkout work in-house with our staff technicians. In this period, all boards have been fabricated and assembled, and checkout is in approximately 95% complete. The first units from the production line were sent to CERN for another test beam run, which ran September to October, 2003. We again sent personnel over to CERN to help install, commission, and run the system during the run. The run was very successful, and the electronics performed well. We expect to complete the production work in the early part of calendar year 2003, and will assist in teh installation and commissioning of the system at Fermilab.

<u>ZEUS</u>: We were involved with the development of front-end electronics for the new Straw Tube Tracker Detector of the ZEUS experiment at DESY. The front-end electronics is situated directly on the detector. It uses a custom integrated circuit designed at PENN, called the ASDQ. The device receives charge pulses from the detector, and sends a digital signal to the "back end" electronics located off the detector in a counting room, where a timestamp for the signal is recorded. The back end processors then use the timestamps to reconstruct the trajectory of the particle through the tracking detector. There are ~12,000 channels in the detector in total, although the front end electronics multiplexes 6 detector channels into each readout channel to reduce the number of signal wires between the front end and the back end.

The production and installation of 200 electronics boards was completed in the spring of 2001. In the time since, significant experience was obtained in operating the detector and electronics, and two problems have emerged. One problem is that the fuses on the front-end boards are blowing, despite the fact that they are sized with a factor of two above nominal operating conditions. The other problem is that the digital signals produced on the front- end boards are radiating noise into other detector components. In 2002, we studied the problems, and developed solutions for them. The solutions were reviewed by a committee appointed by the ZEUS management in November. In early 2003 we built small circuit boards that were part of the modifications to the system. There was a shutdown of the experiment in the spring of 2003, where we had an opportunity to work on the STT. We sent personnel to DESY to assist with installing the boards and implementing other repairs to the detector. The detector has now been reassembled, and data taking has resumed. Tests indicate that the problems have not recurred. To date the electronics and read-out have worked well.

(G. Drake)

I.C.5. Experiments to Measure the θ_{13} Neutrino Mass-Mixing Parameter

a) NuMI Off-axis Experiment

Argonne physicists and engineers began a study of the design of a next-generation long-baseline experiment in the NuMI neutrino beam in 2002. This experiment would perform a high sensitivity search for $\nu_\mu \rightarrow \nu_e$ oscillations by taking advantage of the narrow energy spectrum of neutrinos produced a few degrees away from the axis of the NuMI neutrino beam. The detector design for this off-axis experiment must optimize both efficiency and background rejection for electron neutrino events. The observation of $\nu_\mu \rightarrow \nu_e$ oscillations would allow a measurement of the θ_{13} neutrino-mass mixing parameter. Despite the lower neutrino flux at this location, the narrow neutrino energy spectrum allows a much more sensitive search for (or measurement of) the θ_{13} parameter. Figure 4 shows a comparison of the predicted energy spectra at on-axis and off-axis locations in the NuMI beam. The peak energy depends on the off-axis angle, which would be chosen to give an energy close to the first maximum of the oscillation probability distribution. The reduced flux of high-energy neutrinos in the off-axis beam significantly lowers the background from neutral current events. Measurement of a nonzero value of θ_{13} could eventually lead to the construction of an even larger off-axis detector to search for CP violation effects.

Argonne physicists were co-authors on a Letter of Intent, submitted to Fermilab in June 2002, to build a new 50,000-ton detector to search for $\nu_\mu \rightarrow \nu_e$ oscillations. The detector would be built about 12 mrad off the axis of the NuMI beamline in Minnesota or Canada. During 2002 and 2003, Argonne physicists and engineers worked with the Fermilab off-axis group to design a detector using resistive plate chambers (RPCs). At the same time, other groups in the new off-axis collaboration developed designs based on other technologies, including plastic scintillator strips and a liquid argon TPC. In September 2003 the collaboration chose liquid scintillator as the baseline technology for the off-axis proposal. However, design and prototype work on both the liquid scintillator

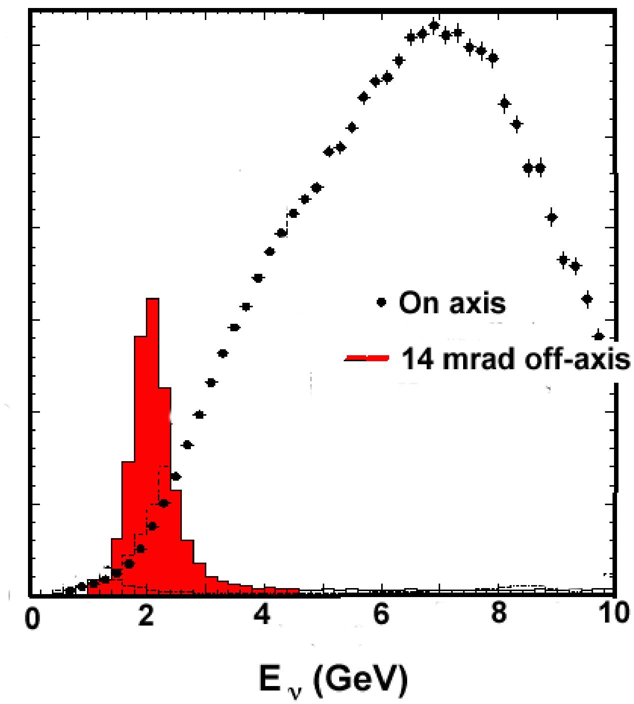


Figure 4. Neutrino energy spectra for on-axis and off-axis beams. The simulated data points show the expected on-axis energy spectrum for the NuMI medium-energy beam configuration. The histogram shows the spectrum expected 14 mrad off axis at 800 km from Fermilab. The off-axis spectrum gives a higher rate of neutrino events around 2 GeV (near the maximum of the oscillation probability) and a much lower rate of background events (from higher energy neutral current events) than the on-axis spectrum.

and RPC technologies will continue in 2004, with the final design choice scheduled for the end of the year. The collaboration has also made a tentative choice of the optimum site for the off-axis detector, in Ash River Minnesota, which is shown in Figure 5. This site provides the longest baseline possible within the U.S. (to maximize matter effects), good road access, existing basic infrastructure and minimal environmental concerns.

The Argonne neutrino group is continuing work on RPC detector design in close collaboration with the Fermilab off-axis group and the Argonne linear collider group. The latter proposes to use RPCs to instrument a digital calorimeter, as described elsewhere in this report. In 2003 Argonne physicists and engineers worked on detector structural engineering, and the design of gas, readout electronics and high voltage systems. In December, the group completed fabrication of a 20-channel Cockroft-Walton

Figure 5. Map of possible sites for the NuMI off-axis far detector. This map of northern Minnesota and southern Ontario shows surface projections of the NuMI beamline (central line) and lines that are ± 13 mrad off axis. The star on the central line indicates the location of the MINOS far detector at Soudan. As described in the text, the Ash River site (810 km from Fermilab) is currently favored.

high-voltage system for use in a large RPC array that will be built at Fermilab in 2004. The off-axis collaboration presented a status report on the experiment design to the Fermilab PAC in December 2003 and plans to submit a full proposal in the spring of 2004. A first draft of the proposal, co-edited by physicists from Argonne and the University of Minnesota, was available at the end of 2003.

(D.S. Ayres)

b) A New Reactor Neutrino Experiment

A new reactor neutrino experiment is being considered that would use multiple detectors to search for anti-electron neutrino disappearance as evidence for a non-zero value for the parameter θ_{13}. In its simplest form, the 3 by 3 MNS neutrino mixing matrix can be parameterized with three angles and one phase. Experiments using atmospheric neutrinos have shown clear evidence for neutrino oscillations. The mixing angle, now called θ_{23}, is near its maximal value of 45^o. The long standing solar neutrino problem is now also solved by neutrino oscillations and a large value of the parameter $\theta_{12.}$

As part of the neutrino groups work in helping to plan for a new superbeam or off-axis experiment, whose main goal is to measure the parameter θ_{13}, it is now widely recognized that the possibility exists for a rich program of measuring CP violation and matter effects in future accelerator ν experiments. However, that possibility can be fulfilled only if the value of θ_{13} is not zero or very low. Argonne has been instrumental in the establishment of an International Working Group of physicists who believe that a timely new experiment at nuclear reactors sensitive to θ_{13} has a great opportunity for discovery. The following factors have combined to motivate this effort at this time:

1. The best present limit comes from a reactor experiment, CHOOZ, which was limited by statistics, but also by systematic errors coming from the fuel cycle. It is now realized that an experiment can use a near detector to cancel the largest systematic errors in that experiment.

2. The reactor experiment KamLAND has shown that a properly designed reactor neutrino experiment can be built with very low backgrounds.

3. The accelerator experiments can measure physical quantities which are a combination of several parameters as a search for θ_{13}, there are ambiguities and degeneracies. A reactor anti-ν_e disappearance experiment at these baselines is a pure measurement of θ_{13}.

4. A reactor experiment with a similar sensitivity to θ_{13} as the accelerator experiments would be much less expensive.

If a non-zero value for θ_{13} is measured, only accelerator experiments can carry on with a measurement of CP violation and/or matter effects. However a high precision measurement of θ_{13} from a precision reactor experiment would be very helpful in the interpretation of high statistics off-axis and superbeam experiments, by helping to resolve ambiguities and degeneracies.

An illustration of how a reactor experiment could measure θ_{13} is shown in Figure 1. In that plot, the disappearance of reactor neutrinos is shown for the approximately known values of θ_{12}, $\Delta m_{31}{}^2$ and $\Delta m_{21}{}^2$ and a hypothetical value of θ_{13}. The large wiggle on the right comes from the solar neutrino parameters and has been confirmed by KamLAND, using reactor neutrinos and an average baseline of 180 km. The hypothetical smaller wiggle at L/E ~ 0.5 km/MeV could be tested by a precision reactor experiment using a baseline of 1.5 km.

Argonne physicists became interested in this problem and co-organized a workshop at the University of Alabama in March 2003. Physicists from Russia, Europe and Japan were all present and agreed to work together on a document to present to the physics community.

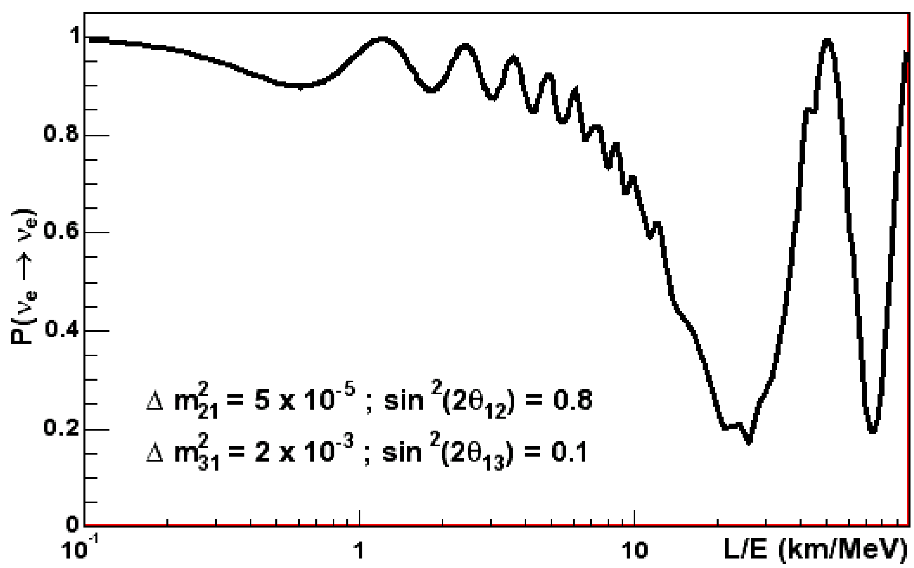


Figure 1: Illustrative plot of the L/E distribution for a hypothetical value of θ_{13}. Note that θ_{12} and both values of Δm^2 are approximately known, and that a large value of θ_{13} has been used. The huge dip at L/E ~ 25 km/MeV is what has been measured by the KamLAND reactor experiment with an average distance 180 km. The new reactor experiments would go back to L/E ~ 0.5 km/MeV and look for the smaller disappearance effect

The White Paper was finished in December 2003, and printed at Argonne in January 2004. It was signed by 125 physicists from 40 institutions in 9 countries. Over 30 contributed to the text, which included 13 chapters and 7 appendices in 167 pages. Argonne scientists organized the effort. The document covered a theoretical motivation and previous reactor experiments, and detector design, location optimization, calibration, backgrounds as they affect the required overburden and systematic errors. There was a chapter on possible sites, as well as seven appendices about specific site locations. There was section on physics other than θ_{13} which could be done, as well as tunnels & shafts, outreach and safety. The cover of the White Paper is shown in Figure 2.

Figure 2: Cover of the White Paper written by the International Reactor θ_{13} Working Group. Clockwise from upper left is KASKA (Japan), Illinois, Krasnoyarsk (Russia), Diablo Canyon (California), Angra (Brazil) and CHOOZ (France).

A sketch of the basic detector design is shown in Figure 3. The inner volume is Gd loaded scintillator, which serves as a well defined fiducial target for the reactor neutrinos. This is surrounded by a layer of scintillator without Gadolinium, which serves to completely contain all positron signals, so that no fiducial volume cut is required. A third layer of mineral oil without scintillator serves as a gamma catcher and shields the fiducial volume from gammas emanating from the glass in the phototubes. The entire detector is then surrounded by a muon cosmic ray veto.

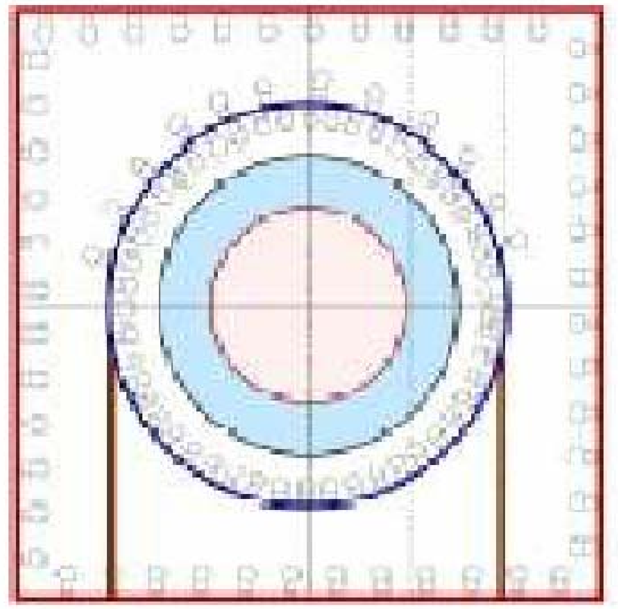


Figure 2. Conceptual design for the detector for a new reactor neutrino experiment. The diameter of the outer sphere would be 7 meters. Volumes are described in the text.

A measurement of anti ν_e disappearance at the O(1%) level will require a new level of control of systematic errors compared to what has been done before. Most of the technical requirements of a new experiment are understood, but the details of the detector design still need to be optimized. Some of the open questions under consideration are the following: liquid scintillator loaded with 0.1% Gadolinium has been used in the past, but there are concerns regarding its stability in solution and attenuation length degradation needs to be understood. If movable detectors are chosen, there must be confidence that moving the detector does not introduce additional time-dependent effects. The use of a second detector will be used to control many systematic errors, but the relative energy calibration and efficiencies will need to be controlled and understood. A major challenge is the reduction of cosmic ray associated backgrounds, such as neutron spallation products and 9Li spallation and their accurate estimation, particularly if the near detector and far detector are at different depths. The reduction of gamma ray background is also important because it will affect the ability to put the threshold below 1 MeV, the minimum energy expected from the positron.

The measurement of reactor neutrinos in a reactor experiment is straightforward. The inverse beta decay reaction is anti-ν_e p $\rightarrow e^+$ n, followed by neutron capture. The positron annihilates with an energy release of 1-8 MeV. The reaction takes place on Hydrogen, which is a component of all scintillators. The neutron will capture on Hydrogen giving gamma rays with an energy of 2.2 MeV. Smaller experiments found it advantageous to add 0.1% Gd, which has a huge neutron capture cross section and gamma rays with an energy of 8 MeV. In CHOOZ 87% of the neutrons were captured on Gd.

The White Paper described the motivation for a reactor neutrino experiment. More than one collaboration is in the process of forming. Argonne has initiated two sites, the one at Brazil, which is currently going forward, and the one in Taiwan, which is not. Argonne scientists have also joined the effort to develop a proposal for a site at Braidwood Illinois, 50 miles south of ANL. This involves site dependent engineering work, which is being initiated, as well as some site-independent detector R&D. We are also interested in the CHOOZ experiment, which is likely the first one to start.

(M.C. Goodman)

II. THEORETICAL PHYSICS PROGRAM

II.A. THEORY

II.A.1. Associated Production of a Top Quark and a Charged Higgs Boson

Ed Berger and Jing Jiang, working in collaboration with Tao Han (University of Wisconsin, Madison) and Tilman Plehn (CERN), completed a major study of the production of a charged Higgs boson $H^{\pm}$ in association with a top quark *t*. Their results are summarized in Argonne report ANL-HEP-PR-03-056, hep-ph/0312286, submitted for publication in Physical Review D.

In the standard model (SM), one neutral scalar Higgs boson is assumed to exist, and it is associated with the generation of the masses of the electroweak gauge bosons and of the fermions. The minimal supersymmetric extension (MSSM) of the SM requires two doublets. They yield five physical Higgs bosons: two neutral CP-even states, a CP-odd state, and a pair of charged scalars. The observation of at least one of the two CP even Higgs bosons may not pose a problem for experiments at the CERN Large Hadron Collider (LHC), but it will be challenging to distinguish it from its SM counterpart. The identification of a charged Higgs boson would provide evidence for a Higgs sector beyond the standard model, meaning at least two Higgs doublets, and possibly a supersymmetric Higgs sector.

If the charged Higgs boson is lighter than the top quark, there is a chance that it will be discovered via the decay channel $t \to bH^{\pm}$ at the Fermilab Tevatron or at the LHC. If the charged Higgs boson is heavier than the top quark, its observation at hadron colliders becomes more demanding. The most promising search channel known for a heavy $H^{\pm}$ is the associated production of a top quark and the charged Higgs boson $pp \to tH^{-}X$. The advantage in this channel is that the Yukawa coupling to a top quark and a bottom quark is enhanced by a power of $\tan\beta$ for large values of $\tan\beta$, the ratio of the two Higgs boson vacuum-expectation values.

The total rate for the process $pp \to \bar{b}tH^{-}X$ is subject to large corrections from collinear logarithms, originating from the radiation of a forward bottom quark jet. These logarithms can be resummed to all orders in the strong coupling strength α_s. In their paper, Berger *et al*. present fully differential cross sections at next-to-leading order (NLO) in perturbative quantum chromodynamics (QCD) and in supersymmetric QCD.

For small Higgs boson masses they include top quark pair production diagrams with subsequent top quark decay into a bottom quark and a charged Higgs boson. The differential distributions are desirable, as are predictions of expected correlations among the final state observables, since selections on final state kinematic variables must be made in experimental studies, for reasons of event acceptance and background rejection. Berger *et al*. study the NLO production rates at the LHC and the Tevatron and discuss the associated theoretical uncertainties. They present typical kinematic distributions in a single variable, as well as final state momentum correlations. For searches in the framework of the MSSM they perform a systematic study of the effects of leading and sub-leading supersymmetric QCD corrections. The effects of supersymmetric loop contributions are explored, and only the corrections to the Yukawa coupling are found to be sizable in the potential discovery region at the LHC. All expressions and numerical results are fully differential.

Using the two-cutoff scheme to treat the soft and collinear singularities, Berger *et al*. find stable results for total and differential cross sections over large ranges of the cutoff parameters, as well as of the factorization and renormalization scales. While the QCD corrections to the total rate are sizable at the LHC, with *K*-factors ~ 1.4, the shifts in the normalized kinematic distributions of the heavy final state top quark and Higgs boson are modest. The scale dependence gives a reasonable estimate of about 20% on the remaining theoretical uncertainty. The effects of the NLO corrections on the total cross sections for the process $gb \to tH^-$ at the LHC are shown in Fig. 1, versus $\tan\beta$ and versus the charged Higgs boson mass m_H. The fully differential nature of the two-cutoff method permits the study of correlations among the kinematical variables. The left panel of Fig. 2 shows the differential cross section as a function of $\Sigma p_T = (\vec{p}_t + \vec{p}_H)_T$. In the right panel, the correlation between Σp_T and $\Delta\phi = |\phi_t - \phi_H|$ is shown ($\Delta\phi$ is the difference between the azimuthal angles of the Higgs boson and the top quark). At LO, the distribution is a δ-function at $\Sigma p_T = 0$ and $\Delta\phi = \pi$, but at NLO it is spread out on the $\Sigma p_T - \Delta\phi$ plane.

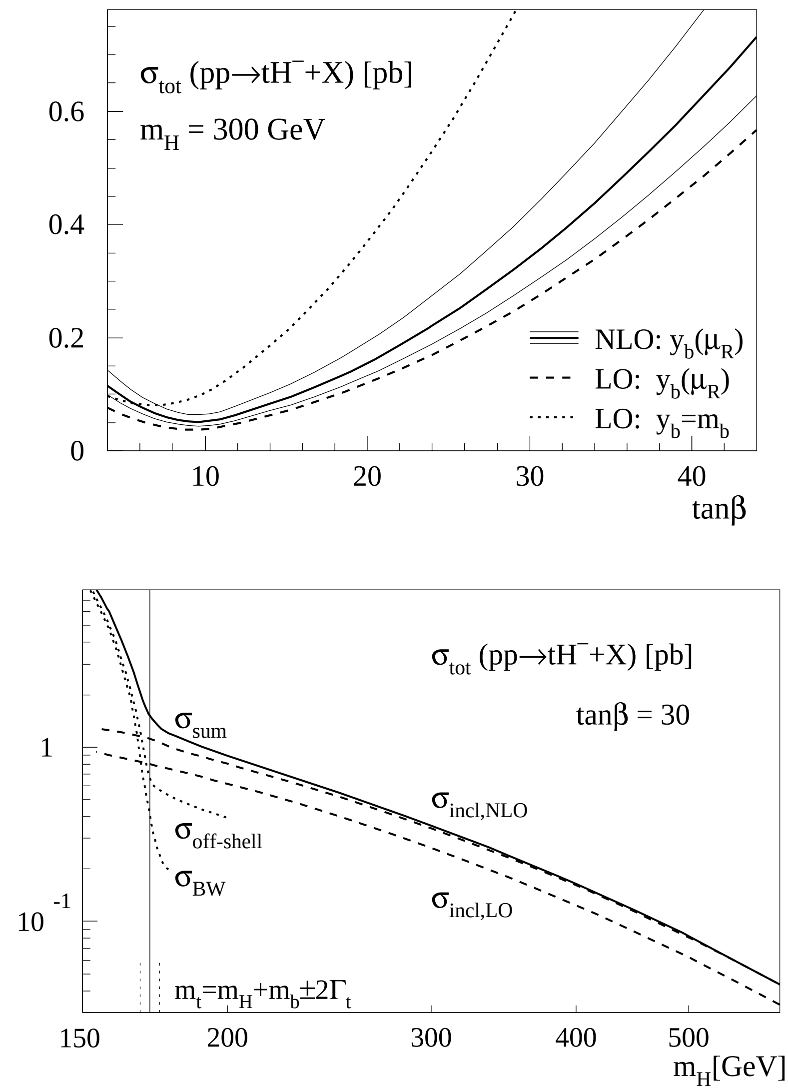


Figure 1. *Top*: The $gb \to tH^{-}$ cross section at the LHC as a function of $\tan\beta$. The solid curve is the NLO result, with the scale variations around the central scale $\mu/\mu_0 = 1/4 - 4$ indicated by the thinner solid curves. Also shown are the leading order results with a running bottom quark Yukawa coupling (dashed curve) and a pole mass Yukawa coupling (dotted curve). *Bottom*: The total cross section at the LHC as a function of the charged Higgs boson mass as the solid curve. The NLO and LO cross sections are shown as the dashed upper and lower curves, respectively. The dotted curves show the cross sections for $pp \to t\bar{t}X$ with a subsequent decay $\bar{t} \to \bar{b}H^{-}$ in the Breit-Wigner approximation (σ_{BW}) and that including the complete set of off-shell diagrams ($\sigma_{\rm off-shell}$).

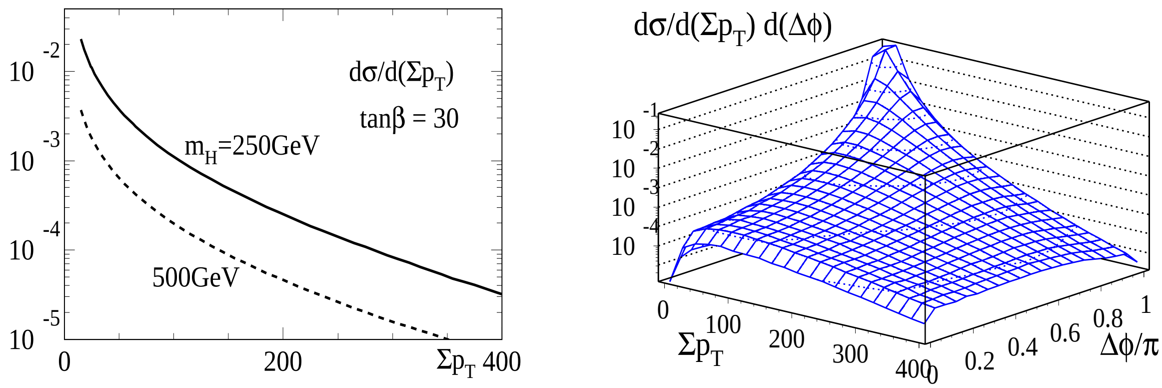


Figure 2. *Left*: The distribution in Σp_T (defined in text) for the NLO inclusive process $gb \rightarrow tH^-$ with m_H = 250 GeV and 500 GeV. *Right*: The correlation between Σp_T and $\Delta\phi$.

(E. L. Berger and J. Jiang)

II.A. 2. Lower Limits on *R*-Parity-Violating Couplings in Supersymmetry

Ed Berger and Zack Sullivan interpreted the results of searches for strongly interacting massive particles to place absolute lower limits on *R*-parity-violating couplings for squarks with mass $m_{\tilde{q}}$ below 100 GeV. Their analysis and conclusions are presented in Argonne Report ANL-HEP-PR-03-073, accepted for publication in *Physical Review Letters*.

In supersymmetric extensions of the standard model of elementary particle physics, particles are typically assigned a new quantum number called *R* parity (R_p). Particles of the standard model are defined to have even R_p, and their corresponding superpartners have odd R_p. If *R* parity is conserved, then superpartners must be produced in pairs, each of which decays to a final state that includes at least one stable lightest supersymmetric particle (LSP). One appealing feature of *R*-parity conservation is that if the LSP is a neutralino, then it is naturally predicted to exist with the necessary relic density to explain the dark matter density in the universe.

In contrast, if *R* parity is not conserved, then supersymmetric particles may decay into standard model particles, and supersymmetry may not provide an explanation of dark matter. Furthermore, many of the postulated signatures of supersymmetry (SUSY), such as missing energy in high energy collider experiments, may not exist. Many of the exclusion limits on squark masses may no longer apply if *R* parity is violated. On the other hand, if the *R*-parity-violating couplings are small enough, then superparticles may appear to be stable on a time-scale relevant for collider searches. In the search for physics beyond the standard model in cosmological and terrestrial experiments, it is of substantial importance to address explicitly the question of *R*-parity violation, a possibility that Berger and Sullivan explore in their paper.

Upper bounds on possible *R*-parity-violating couplings are obtained principally from next-to-leading order quantum corrections to the rates for particle decays and neutral meson mixing. These bounds are relatively restrictive for the first generation of quarks and leptons, but are much less so for states of the second and third generations. Berger and Sullivan approach *R*-parity-violating couplings from the other direction. They demonstrate that there must be strong *lower* bounds on *R*-parity-violating couplings for a large range of squark masses. Otherwise, squarks with mass in these ranges cannot exist. They focus on squarks with mass below 100 GeV. Although it is widely held that squarks in this range are ruled out by experiment, this limitation does not apply in general SUSY-breaking scenarios if the states with lowest mass are coupled feebly to the neutral gauge boson *Z*.

If there are squarks with mass less than about 90 GeV, Berger and Sullivan show that both exotic isotope searches and data from LEP require that they are not stable. Exotic isotope searches imply that *R*-parity-violating couplings greater than $10^{-22} - 10^{21}$ must be present if there are squarks of mass 18-100 GeV. The data from LEP improve this lower bound by 14 orders of magnitude, and require there to be a baryon-number or lepton-number violating coupling greater than $10^{-8} - 10^{-7}$ for squarks of mass less than 90 GeV. These lower limits can be significantly larger if there is large mixing in the squark sector or non-vanishing coupling to the *Z* boson. The curves in Fig. 1 show that there must be a baryon-number-violating coupling $\lambda'' \gtrsim 5 \times 10^{-9} - 10^{-7}$ for squark masses less than 90 GeV. In this figure, Berger and Sullivan distinguish the minimal couplings obtained in the cases where the lightest squarks decouple from the *Z* boson. The decrease with mass of the lower limits in part reflects the fact that partial widths are proportional to the squark mass.

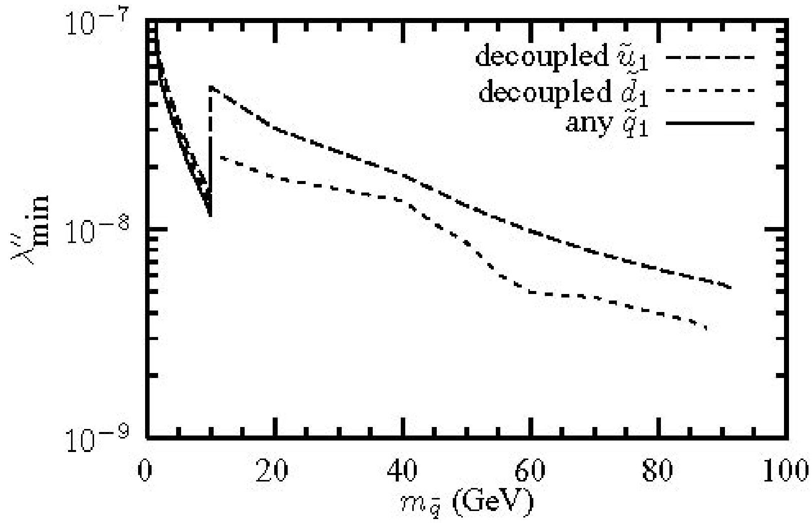


Figure 1. Lower limits on the baryon-number-violating couplings λ'' as a function of squark $\tilde{q}_1$ mass. The solid line ($m_{\tilde{q}} < 10$ GeV) indicates an absolute lower limit on the couplings. The dashed lines indicate the limits where $\tilde{d}_1$ or $\tilde{u}_1$ decouple from the *Z*-boson ($\sin\theta_{\tilde{d}} \approx 0.39$ or $\sin\theta_{\tilde{u}} \approx 0.56$). For $m_{\tilde{q}} > 10$ GeV the dashed lines are also absolute lower limits.

The existence of *R*-parity-violating couplings means that a neutralino LSP will decay through an off-shell squark to standard-model particles. A minimal *R*-parity-violating coupling of 10^{-22}, as allowed by exotic isotope searches, is not large enough to significantly reduce the number density of relic neutralinos. However, the data from LEP imply a lifetime of neutralinos that is 10^{28} times shorter, meaning that the neutralinos will have a negligible relic density. Hence, neutralinos cannot explain the excess of dark matter in the universe in the presence of squarks with mass less than 90 GeV.

When combined with upper limits on *R*-parity-violating couplings, the study by Berger and Sullivan argues that there may be very interesting signals of *R*-parity-violating supersymmetry at high energy colliders. In particular, squarks may be produced with lifetimes that are long enough to produce displaced vertices when they decay. In addition, *R*-parity-violation offers the possibility that superpartners may be produced singly, rather than in pairs, a subprocess that has significant advantages especially at collider energies that are not substantially higher than the masses of the produced states.

(E. L. Berger)

II.A.3. Lattice Computation of Spin Correlations in NRQCD Color-Octet Matrix Elements

Geoffrey Bodwin, Jungil Lee, and Don Sinclair have begun a calculation of the correlation between the quark-antiquark polarization and the J/ψ polarization in NRQCD color-octet decay matrix elements.

At large p_T, J/ψ production at the Tevatron proceeds predominantly through the fragmentation of a gluon into a heavy $Q\overline{Q}$ pair in a ${}^3S_1$ color-octet state. The $Q\overline{Q}$ pair takes on the polarization of the gluon, which is essentially transverse because the gluon is off its mass shell by an amount that is much less than its energy. The quark-antiquark pair then evolves nonperturbatively into a J/ψ state through the emission of soft gluons. The Nonrelativistic QCD (NRQCD) velocity-scaling rules predict that the spin-flip interactions with the soft gluons are suppressed by v^2 relative to the non-spin-flip interactions. (Here, v is the heavy-quark or heavy-antiquark velocity in the quarkonium rest frame, with $v^2 \approx 0.3$ for charmonium.) Hence, it is expected that a substantial amount of the quark-antiquark polarization is transferred to the J/ψ. In existing theoretical calculations, it is, in fact, assumed that 100% of the polarization is transferred.

To date, the CDF data do not confirm this expectation of large transverse polarization, although the experimental uncertainties are large. This situation has led to a re-examination of the theoretical basis for the prediction of large transverse polarization. The velocity-scaling rules give the power behaviors of matrix elements and interactions in the limit of zero velocity. At finite velocity, the detailed dynamics could produce other factors that are more important than the factors of velocity that derive from the velocity-scaling rules. Hence, the velocity-scaling rules should not be regarded as giving precise predictions of the relative sizes of interactions---only estimates. It is entirely possible that the nonperturbative spin-flip and non-spin-flip interactions could have relative sizes that are quite different from estimates based on powers of velocity alone. Furthermore, it has been suggested (Brambilla, Pineda, Soto, Vairo; Fleming, Rothstein, Leibovich) that the velocity-scaling rules themselves may need to be modified, owing to confinement effects, in the ultrasoft gluon-momentum region, which gives an important contribution to the non-spin-flip interactions.

Ideally, one would resolve these theoretical issues through a lattice computation of spin correlations in the ${}^3S_1$ color-octet production matrix elements. Unfortunately, it is not yet known how to formulate the computation of production matrix elements on the lattice. However, one can address the issues of the validity of the velocity-scaling rules and the relative sizes of spin-flip and non-spin-flip interactions by studying the corresponding $^3S_1$ color-octet *decay* matrix elements. Calculation of those matrix elements has begun.

Work has been completed on the coding and debugging of the subroutines that compute the heavy-quark and antiquark propagators for an NRQCD action that is accurate through relative order v^2. Work is in progress on the subroutines that compute the quarkonium propagators and the annihilation interactions and on the code for the matrix-element calculation that calls these subroutines. It is expected that results will be forthcoming on a time scale of several months, with a complete analysis, including reliable error estimates, taking somewhat longer.

The results should be very interesting. Either they will change the conventional wisdom about velocity-scaling estimates of relative sizes of matrix elements---estimates which are at the heart of current theoretical predictions for quarkonium production and decay rates---or they will establish more firmly that large transverse polarization of J/ψ's at large p_T is a prediction of QCD.

(G. T. Bodwin)

II.A.4. Relativistic Corrections to Gluon Fragmentation to J/psi

Work on this subject by G. Bodwin and J. Lee was discussed previously in the report for July 1, 2002--December 31, 2002. A paper describing this work (ANL-HEP-PR-03-065, hep-ph/0308016) has been accepted for publication in Phys. Rev. D.

(G. T. Bodwin and J. Lee)

II.A.5. Lattice Gauge Theory

We are performing simulations of lattice QCD to determine its thermodynamic properties, and to predict and analyze the properties of hadrons and their strong interactions.

We are simulating 2-flavour QCD at a finite chemical potential μ_I for isospin (I_3) and temperature. In the small μ_I regime we have measured the μ_I dependence of the temperature of the crossover from hadronic matter to quark-gluon plasma, for 3 quark masses, $m = 0.05$, $m = 0.1$ and $m = 0.2$. Figure 1 shows this dependence for the lightest of these quark masses. Here, based on the work of the Bielefeld-Swansea collaboration,

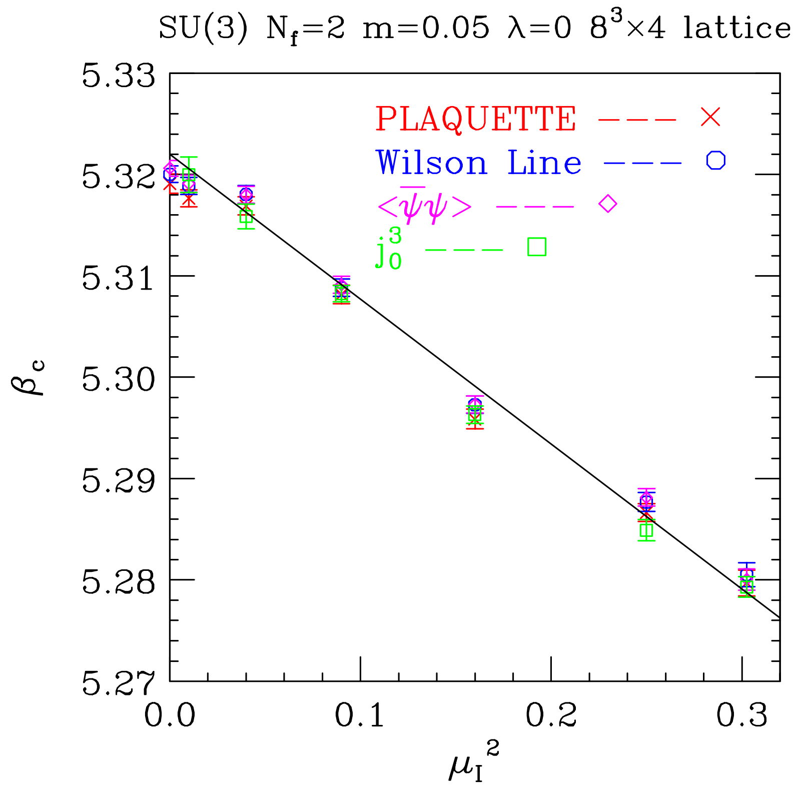


Figure 1. The position of the finite temperature phase transition as a function of the isospin chemical potential.

we expect that the dependence of the transition temperature on μ_I should be the same as its dependence on the quark-number chemical potential μ_q. Indeed, the dependence we observe is consistent with what others have calculated. Hence, we have a way of obtaining information about finite quark-/baryon-number density, which we do not know how to simulate, from QCD at finite isospin density, which we are able to simulate. We have looked for the expected critical endpoint where the crossover changes to a first order transition for $\mu_I < m_\pi$, for all 3 quark masses, but have not found any evidence for it. We conclude that, if the critical endpoint does exist for finite μ_q, it must be at $\mu_q > m_\pi / 2$, where the relationship, between QCD at finite μ_I and QCD at finite μ_q, breaks down. We are also studying the finite temperature transition in the $\mu_I > m_\pi$ regime, where it describes the evaporation of the charged pion condensate, which forms at low temperatures and is thus a true phase transition. We are particularly interested to observe if and where this phase transition changes from second to first order.

We have started extending the above simulations to the more physical 3-flavour case. Here, since the transition becomes first order, even at zero μ_I/μ_q, for quark masses $m < m_c \approx 0.033$, we expect to find a critical endpoint as close to $\mu_I = 0$ as we desire, by using $m > m_c$ near enough to m_c.

We have commenced a project to calculate spin-dependent colour-octet decay matrix elements for charmonium, in the context of the Bodwin-Braaten-Lepage non-relativistic QCD (NRQCD) factorization scheme. The long distance matrix elements involved are calculated using Lattice NRQCD (the short distance factors can be calculated perturbatively). Although of limited interest in their own right, these matrix elements could be expected to indicate the order of magnitude of the corresponding J/ψ octet production matrix elements, which are supposed to describe J/ψ production at large transverse momentum.

In addition, knowing the size of the spin-flip matrix-elements relative to the spin-non-flip elements, could help us understand the polarization of the produced J/ψ s.

We are continuing our simulations of the finite temperature chiral phase transition for QCD with 2 massless quark flavours using our action, which differs from the standard Lattice QCD action by the addition of an irrelevant chiral 4-fermion interaction. It is this modification, which permits simulations at zero quark mass. We are currently accumulating statistics on $16^3 \times 8$ and $24^3 \times 8$ lattices. The indications are that the transition is second order, as expected, and we will extract the critical exponents thus determining the universality class of this transition. Previous attempts to calculate these exponents have been hampered by the fact that traditional actions cannot be simulated at zero quark mass, and simulating them at very small quark masses is prohibitively expensive.

(D. K. Sinclair)

II.A.6 Beautiful Mirrors, Unification of Couplings and Collider Phenomenology

The Standard Model provides an excellent description of the observables measured at high energy lepton and hadron colliders. However, measurements of the forward-backward asymmetry of the bottom quark at LEP suggest that the effective coupling of the right-handed bottom quark to the neutral weak gauge boson is significantly different from the value predicted by the Standard Model. Such a large discrepancy may be the result of a mixing of the bottom quark with heavy mirror fermions with masses of the order of the weak scale. To be consistent with the precision electroweak data, the minimal extension of the Standard Model requires the presence of vector-like pairs of *SU*(2) quark-doublets and singlets.

The introduction of such extra quarks has several interesting phenomenological consequences. On one hand, they lead to a modification of the beta-function of the three standard model gauge coupling, leading to an improvement of the gauge coupling unification condition. Figure 1 shows the predicted value of the strong gauge coupling, assuming exact unification of the three gauge couplings at higher energies. The predicted values of the strong gauge coupling are in excellent agreement with the experimentally measured value, $\alpha_s(M_Z) = 0.119 \pm 0.003$.

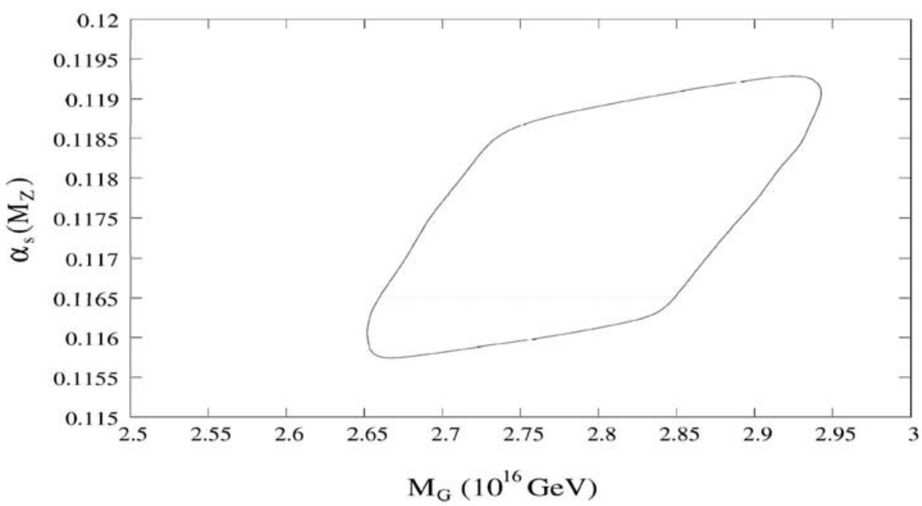


Figure 1. Range of α_s consistent with a 1% unification of the gauge couplings plotted against the unification scale M_G.

Second, an improvement of the precision electroweak observables is only achieved for vector-quark masses of the order of the weak scale. A top-like quark, χ, should be present in the spectrum, with a mass below 250 GeV. Its predominant decay must be into a bottom quark and a charged weak gauge boson. Moreover, a bottom-like quark, ω, with a mass below 300 GeV, must also be present. The Tevatron collider, with a total integrated luminosity of order $4\ fb^{-1}$ must be able to find such heavy quark states.

The presence of these heavy quark states have also implications for Higgs physics, since they modify the Higgs couplings to gluons and also, due to mixing effects, to bottom quarks. This has relevant effects on Higgs searches at the Tevatron and the LHC. The enhancement of the gluon fusion Higgs production cross section and the reduction of the bottom-quark decay branching ratio make the search for the Higgs boson at the Tevatron easier in the $gg \to h \to \tau^+\tau^-$ channel than in the channels in association with the weak gauge bosons.

Figure 2 shows the minimum luminosity necessary to get a $3-\sigma$ evidence of the presence of a Higgs boson at the Tevatron collider in different production and decay channels. The dashed lines show the Standard Model results, while the solid lines show the results for the model with heavy vector quarks. In general, there is reduction of the total integrated luminosity needed for Higgs observation in comparison to the Standard Model case. A total integrated luminosity of $4\,fb^{-1}$ to $8\,fb^{-1}$ will be sufficient to provide evidence of a Higgs boson with mass between 120 GeV and 180 GeV.

Therefore, the Tevatron collider with a total integrated luminosity of $4-8\,fb^{-1}$ of integrated luminosity will have the potential to discover the heavy quarks, while observing a $3-\sigma$ evidence of the Higgs boson in most of the parameter space.

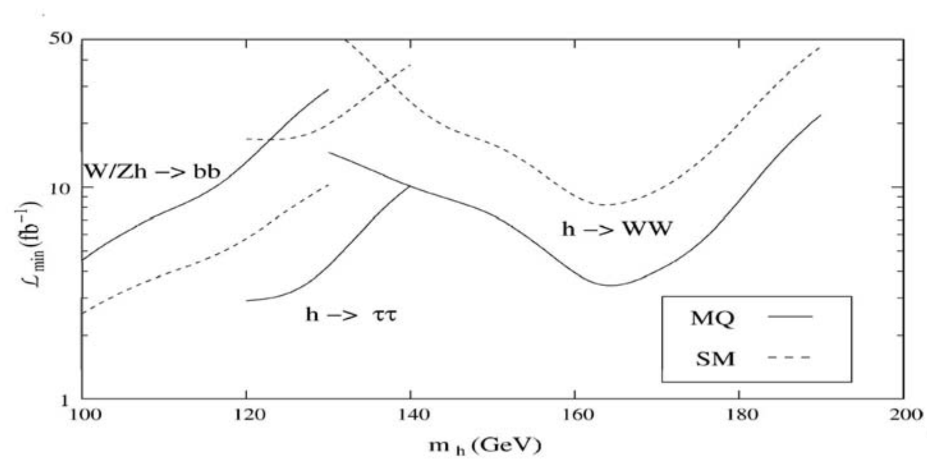


Figure 2. Minimum luminosity needed for a $3-\sigma$ Higgs signal at the Tevatron for m_ω = 250 GeV.

The predictions of the model for the LHC are less dramatic, although the improvement in the $gg \to h \to \gamma\gamma$ process will make a light Higgs boson much easier to observe. For intermediate Higgs masses, the inclusive $h \to WW$ channel becomes competitive with the $VV \to h \to WW$ channel. For masses larger than the ones displayed in Fig. 3, searches for the Higgs at the LHC can proceed via the golden mode $h \to ZZ$. Similarly to the Tevatron case, the Higgs discovery reach in all main production channels is improved, due to the enhancement in the gluon fusion production cross section and the enhancement of the branching ratio of the Higgs decay into two $\tau-$leptons.

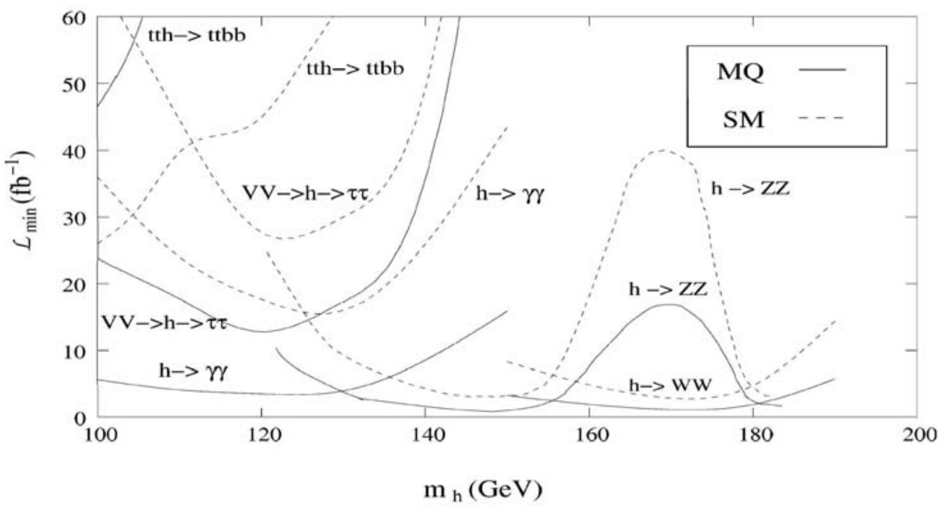


Figure 3. Minimum luminosity needed for a $5-\sigma$ Higgs discovery at the LHC for m_ω = 250 GeV.

(C.E.M. Wagner and D. E. Morrissey)

II.A.7. Branes, Strings, and Odd Quantum Nambu Brackets

Unlike strings, whose quantum behavior is under control, higher-dimensional brane systems have not been fully quantized consistently, even though they are thought to underlie strings and, hence, gravity blended into all other interactions. On the basis of their prior work on the quantization of topological open branes [Phys. Lett. **B570**, 82-88 (2003)] through even Quantum Nambu Brackets (QNBs) [Phys. Rev. **D68**, 085001 (2003), with T. Curtright], C. Zachos and T. Curtright recently resolved the quantization conundrum of odd Nambu Brackets (ANL-HEP-CP-03-114, hep-th/0312048).

Nambu Brackets are a multilinear generalization of Poisson Brackets, an intriguing theoretical instrument whose utilization in quantum contexts had been hampered for decades. By re-framing the outstanding quantization issues properly in a way conducive to progress in M-theory, and through practical avoidance of virtually established pitfalls, Curtright and Zachos point the way for further application in membrane quantization work. Classically, the evolution of topological p-branes is controlled by Nambu Brackets: (p-2)-branes, including vortex strings for p=3, embedded in p-space evolve according to a (p-1)-form action. The respective equations of motion extremizing this action are Nambu's rather than Hamilton's equations.

In the past, Curtright and Zachos had demonstrated that an inconsistency of quantization of NBs was, ultimately, only obstructing (p=odd)-branes--they had resolved all other perceived inconsistencies for (p=even)-branes, illustrating quantization with a plethora of explicit examples. This time, they showed that this genuine inconsistency has its origin in the improper classical limit of the odd QNBs. The solution to the problem then, lay in regarding odd NBs as embedded in even ones, with one extra dynamical variable suitably saturated. Upon quantization, this "extraneous" variable is seen to be actually unavoidable and ubiquitous as the conjugate operator to the unpaired variable (out of the odd array). Thus, odd NBs were seen to be quantized consistently through even QNBs (quantum Pfaffians), whose proper classical limit successfully reduces to the original odd NBs. A number of pedagogical examples were worked out to illustrate the quantization method, including one, which does not amount to Hamiltonian systems. Finally, novel systematic features of quantum solenoidal flows were calculated of possible utility in brane physics.

As a wrap-up (fond farewell) of his results in Deformation Quantization in the last six years, Zachos submitted to World Scientific Publishing, by invitation, the completed manuscript of a book, *Quantum Mechanics in Phase Space*, co-authored with T. Curtright and D. Fairlie. It is comprised of an introduction to the theory, suited to teaching part of a course, as well as a collection of seminal reprints.

(C. Zachos)

III. ACCELERATOR RESEARCH AND DEVELOPMENT

III.A. ARGONNE WAKEFIELD ACCELERATOR PROGRAM

III.A.1. The Argonne Wakefield Accelerator Facility Status

We continued our commissioning and beam physics studies of the new gun. The beam energy has now reached 8 MeV, with a minimum of dark current. Using a Mg photocathode, an electron beam charge ranging from 1 nC to 100 nC was produced. The electron bunch length was measured using Cherenkov light emitted from an electron beam passed through a thin quartz plate. The measured rms bunch length is in a good agreement with the design and its FWHM < 13 ps for beam up to 70 nC. During this 6 month period, one of the AWA laser amplifier rods was damaged and its repair required suspending operation for an extensive period.

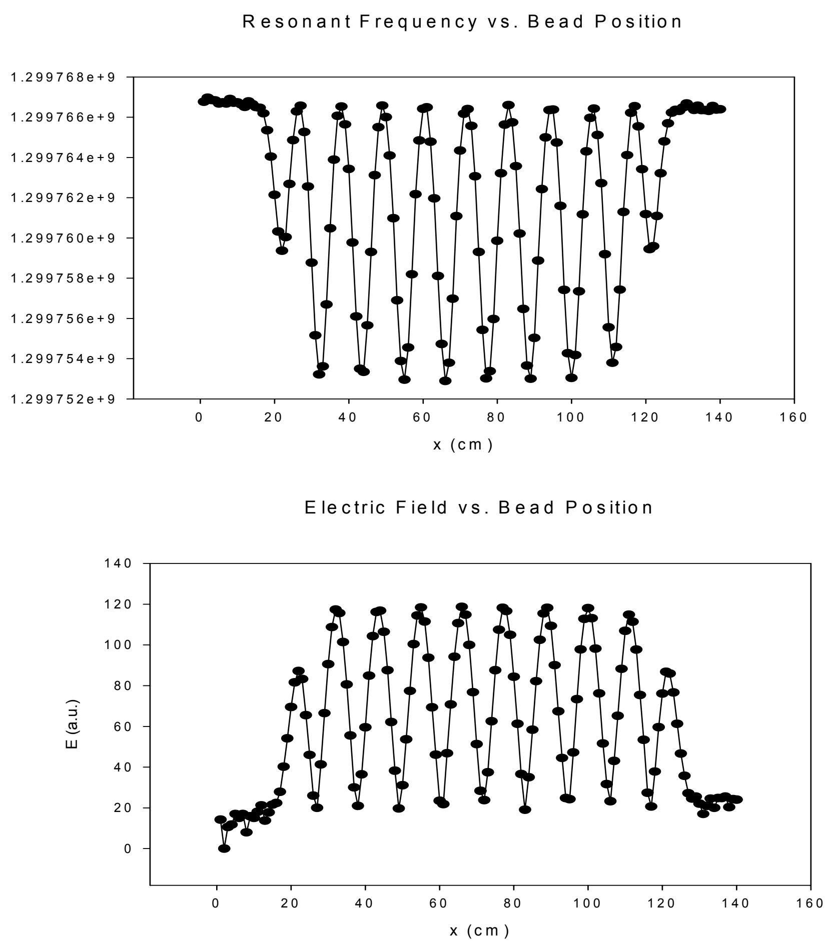


Figure 1. Bead pull measurements of the axial electrical field distributions in the Linac tank.

For the anticipated series of high-gradient wakefield experiments that we have planned, including our goal for the 100 MeV demonstration, the drive beam energy needs to be doubled 8 to >16 MeV by adding a linac tank from the original AWA beamline. During this period, we took the linac tank out for reconditioning since its surface had become contaminated by the oil-based, vacuum pumps on the original beamline. While the linac was out of the beamline, we took advantage of this opportunity to conduct a bead pull measurement of the linac, which gives the longitudinal electrical field distribution. The measurement showed that the linac is still in good condition after many years of use. The bead pull result is showing in Figure 1. The linac tank is now fully recovered and ready for ultrahigh vacuum operation in the new beamline

III. A. 2. Development of Externally-Driven, 11.424 GHz, Dielectric-Loaded Structures and High-Power Tests at NRL

A series of high power tests were conducted at NRL during this period, and a number of significant physics results were obtained that may impact the eventual use of these devices for future high energy accelerators.

Using the modular structure developed in the previous year, the structure development cycle was significantly reduced for the two kinds of dielectric materials, Alumina and MCT20. We completed three high-power RF tests of dielectric-loaded accelerating structure within 6 months. In each of the high-power tests we observed new physical phenomena that advanced our understanding of the structures. We have also uncovered new problems associated with the mechanical design and now believe that we have solved them. Better performance is expected for the coming experiments.

In order to suppress Secondary Electron Emission (SEE), which leads to multipactor in the alumina loaded structure, we planned to coat the inner surface of the four alumina tubes with TiN and perform a high-power test. However, due to scheduling difficulties, one of the four pieces of alumina in the structure did not get coated (at the downstream end), and thus, we performed a high power test of a partially-coated alumina structure. Even though the structure was only partially coated, it showed improved multipactoring properties compared with the uncoated structure. First, the SEE onset occurred at higher field strength (E ~1.6 MV/m) compared to the uncoated alumina structure (1 MV/m) that we tested last year. Second, the multipactor process saturated near 2MW incident power, which is equivalent to 5 MV/m E-field, whereas the uncoated structure never saturated. And third, the incident power reached 6.5 MW (9 MV/m on axis) compared to 5 MW in the uncoated structure. Finally, as in the case of totally uncoated alumina structure, we did not observed any RF induced breakdowns during the high power test. We expect to perform a high power test of a totally coated dielectric loaded accelerating structure in next experiment.

We also conducted a high power test of another dielectric loaded structure based on a ceramic material called Magnesium Calcium and Titanate (MCT-20). MCT has advantages over the alumina based tube design due to its higher dielectric constant (around 20). A cold test done with a network analyzer showed good transmission and reflection properties. However, after the structure was high temperature baked for vacuum, the transmission coefficient dropped dramatically. We discovered that during the baking process, a small vacuum gap developed between adjacent dielectric tubes, due to differences in the rate of thermal expansion between the copper holder and the dielectric tubes. Unfortunately, when the structure cooled down to room temperature, the dielectrics resettled to a different position, and thus the gaps remained. This caused a significant reduction in the RF transmission (as we later confirmed with simulations) and more importantly, it caused standing waves to occur and increased the local field strength by a factor of up to 15 - 20, thus causing RF breakdown. During the high power test, when the incident RF power level was raised to 270 kW, we observed the sudden appearance of light emission and a breakdown of the RF signals as recorded on an oscilloscope. By adjusting the focus of the CCD cameras, we were able to localize a bright spot of light and, after the tube was disassembled, we verified that the location of light was a permanently damaged arcing spot. Numerical simulations show that the highest electric field exists at the gap, and was around 15 times higher than a structure without a gap under the reflection coefficient of 0.5 at that boundary being considered. Under the condition of 15 times field enhancement, the electric field at the gap could be 86 MV/m at 1MW incident power.

To improve the contact between the dielectrics, we re-machined the flange joints, and high-power tested a second MCT-20 structure in Jan. 2004. However, just before the experiment, we found that one of MCT dielectric sections had a small defect at its end, which is expected to cause a strong local field enhancement for the same reason as the gap effect described above. This small defect did not affect the RF transmission and thus no standing wave was established, but it limited the input RF power to 1.2 MW due to the arcing near the defect; the estimated field level at the arcing location is ~ 65MV/m, which is consistent with the previous test. After disassembly of the structure, it was once again verified that the arcing took place at the defect location. We are currently machining a new set of dielectric sections that will have better power transmission characteristics and be less susceptible to mechanical imperfections and is expected to be available for high power testing within a few months. Furthermore, during the high power RF conditioning of the second MCT structure, we measured similar transmission and reflection trends when compared to the alumina-loaded tube test but less severe. This implies that the MCT structure underwent multipactor, similar to the alumina structure. However, the multipactor may be less severe for MCT than alumina since it did not show any visible light emission and the power transmission coefficient drop was less than the alumina structure. Detailed data analysis is still ongoing.

In collaboration with Dr. S. Gold of NRL, a dedicated X-band accelerator test facility has been established to conduct high power tests of these dielectric loaded structures and other applications. This facility will provide up to 100 MW RF power at 11.424 GHz. A new electron source is being designed and constructed by Tsinghua University, China as an injector for this facility. The injector is to be delivered in this coming summer.

III. A. 3. Other Significant Beam Physics Related Studies

We have investigated high-brightness electron beam generation at the ANL and its application to a precision Wakefield measurement system. Through collaborative work with Fermilab and ANL-APS, it was apparent to us that a compact, high-brightness electron beam could be used for precision transverse wakefield measurements of linear collider structures. We have performed numerical simulations of a low charge 1 nC beam in the new AWA gun and, without making any attempt at optimizing the hardware parameters (because the gun is already installed in place), PARMELA simulations predict transverse emittance ~ 1 mm mrad and a pulse length of 5 ps for a 1 nC beam. These parameters are comparable to other RF photocathode guns that were extensively optimized for 1 nC operatoin. However, due to lower magnetic fields from the real gun solenoids (since it was optimized for high charge operation) than used in the simulation, a higher emittance of 2 mm mrad is predicted from PARMELA. Based on these simulation results, we performed transverse emittance measurements using a three-screen technique that was modified to include space charge. Preliminary data analysis showed that the 1 nC beam emittance was 4 – 10 mm mrad at ~7 MeV, slightly higher than PARMELA predictions of 2 mm mrad, but this may be within the experimental resolution of the 3-screen method. In any case,it shows that this gun is in the same neighborhood as other high brightness guns.

In addition to the efforts described above, there are a number of other research areas worth mentioning. Most involve collaborative efforts with outside institutions, and demonstrate the flexibility and vitality of the AWA program.

Design of a decelerator for CLIC using a thin dielectric layer. Working with DULY research, using Phase II SBIR funding, a new 15.6 GHz decelerator was designed and is under fabrication for a dielectric-based power extraction device. This is based on previous experimental results from CLIC Test Facility II. The next experiment is scheduled for Spring 2004 at the new AWA facility.

Further studies of new structures for advanced accelerator applications. Working with Drs. Shvets and Klamp of IIT, we have begun to investigate some exotic accelerating structures. A mechanical design for a 3D wire mesh based structure, that has the unusual property of being left-handed, was completed. The structure will be built at ANL this summer by their students. Secondly, progress was made toward fabricating a all-dielectric accelerator, using a negative dielectric constant material, SiC. We obtained internal individual LDRD funds to carry out this work in the upcoming year.

(W. Gai)

III. B. MUON COLLIDER AND NEUTRINO SOURCE ACTIVITIES

a) Lab G Operation

The Lab G cavity operated continuously for most of this period, however an 8 week shutdown at Fermilab made technician help unavailable, so it was impossible to change the Be window in the pillbox cavity. During this period extensive measurements were made of the operating stability of the cavity, and its sensitivity to presumed mechanical motion of the thin, flat Be window.

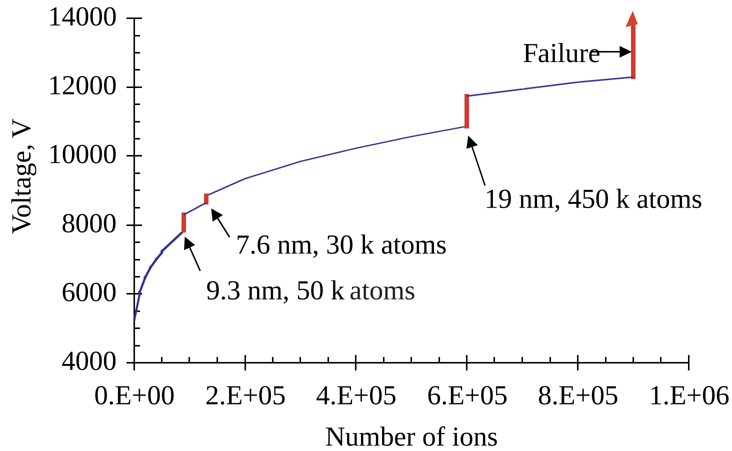
b) Workshop on High Gradient RF

The Muon Collaboration at Argonne was host to an International Workshop on High Gradient RF. Roughly 90 people came to Argonne Oct. 7-9, 2003 to hear talks from KEK, SLAC, CERN, Fermilab and other places. Although much of the work in this field has been directed at linear colliders, the Muon Collaboration work has also begun to explore field gradient limits for low frequency cavities. A two-page summary of the workshop appeared in the Jan/Feb edition of the CERN Courier.

c) Model of RF breakdown

We have been developing a model of rf breakdown. The general features of involve electric field induced fracture of field emitters, and the interactions of high current densities with grain boundaries and defects. The first paper with this idea was published in Phys Rev STAB. This work developed from detailed measurements of dark currents in two different cavity geometries at Lab G in Fermilab done as part of the MUCOOL and Muon Ionization Cooling Experiments (MICE). This work has lead in directions that are different from those pursued by most of the rest of the rf community, and the rf Workshop was an effort to present our work to the community and find out what the latest data are showing.

We have been continuing to refine the breakdown model for rf cavities. Following a suggestion by Z. Insepov of ANL/ET, we began looking at field evaporation, which lead to productive interactions with the atom-probe-field-microscopy (APFIM) community, and specifically David Seidman at Northwestern University. While we had argued for some time that fragments should be produced from field emitters for some time, there was little experimental evidence for this behavior. It is a common phenomenon in APFIM systems, however, and we found out that this data is systematically jettisoned when a sample fractures, because the sample is then of no use for materials studies. The example shown is from the book *Atom Probe Tomography* by D. K. Miller, and represents one of the very few examples of this data in the literature,

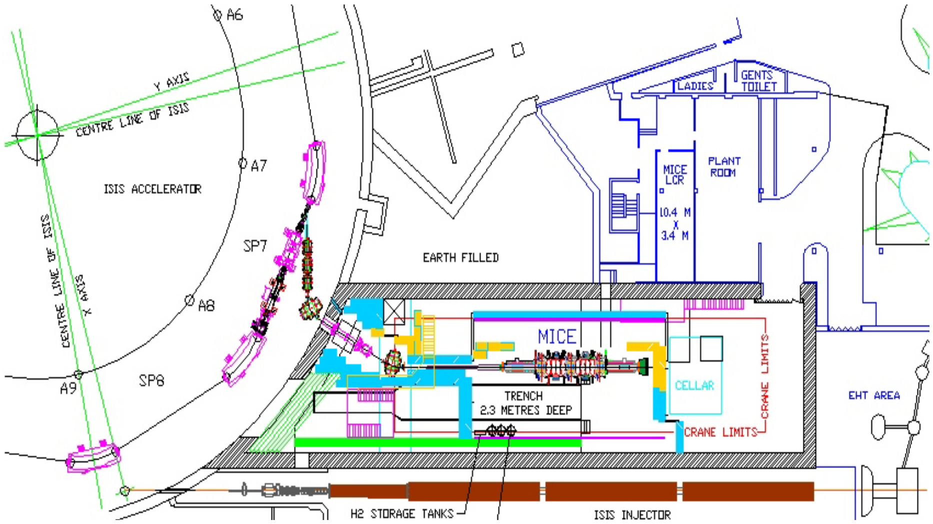


Fragments produced in APFIM studies

known either to Seidman or Miller. The dynamics of fragment production by emitters produce many of the requirements for a trigger for rf breakdown. Since single electrons and single ions seem to be able to be emitted in cavities without producing any localized heat deposition on the surface, we began to look at the emission of clusters, which could be emitted, but then become heated by dark currents. The power deposited in the surface of these fragments could be extremely high, making this mechanism a candidate for a breakdown trigger.

d) Proposal for rf Studies

We are proposing a new effort which will be directed at the surface science of breakdown and field emission. The work will primarily be done by materials scientists and plasma modeling experts at Argonne and Northwestern University. The goals will be general, in order to compete for funding. The effort will consist of four tasks: (1) simulation of surface effects, (2) measurement of materials at high electric fields, (3) measurement of materials at high current densities, and (4) testing with rf structures. The high electric field parts of this effort will be done with a specially modified atom-probe-field-ion-microscope, able to produce the electric fields expected at field emitters in a controlled environment at Northwestern University. Recent results from this program include a new model of rf breakdown and suggestions on surface materials to reduce dark currents. Reduction of dark currents would be of immediate benefit to the Muon Ionization Cooling Experiment (MICE), whose proposal was approved at RAL.



The Muon Ionization Cooling Experiment, approved at RAL

(J. Norem)

IV. PUBLICATIONS

IV.A. Books, Journals and Conference Proceedings

805 MHz and 201 MHz RF Cavity Development for MUCOOL
J. Norem
J. Phys. **G29**, 1683-1687 (August 2003).

A Compact Wakefield Measurement Facility
J. G. Power, W. Gai, J. Lewellen, S. Milton, K.J. Kim, J. Simpson, H. Wang, D. Finley and H. Carter
In: *Proceedings of the 2003 Particle Accelerator Conference,* (PAC2003), Portland, Oregon, ed. by J. Chew, P, Lucas and S. Webber, pp. **1813-1815 (**October 2003).

A Diquark-Triquark Model for the KN Pentaquark
M. Karliner and H. J. Lipkin
Phys. Lett. B **575**, 249-255 (November 2003).

A Modified Quadscan Technique For Emittance Measurement for Space Charge Dominated Beams
J.G. Power, C. Limborg and S. Gierman
In: Proceedings of the 2003 Particle Accelerator Conference, (PAC 2003)*,* Portland Oregon, ed. by J. Chew, P. Lucas and S. Webber paper TPPG033**,** pp. **2667-2669** (October 2003).

A New High Intensity Electron Beam for Wakefield Acceleration Studies
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In: *Proceedings of the 2003 Particle Accelerator Conference* (PAC 2003), Portland, Oregon, ed. by J. Chew, P. Lucas and S. Webber, pp. **2032-2034** (October 2003).

A Search for Resonance Decays to Lepton+Jet at HERA and Limits on Leptoquarks
M. D. S. Chekanov, D. Krakauer, J. H. Loizides, S. Magill, B. Musgrave, J. Repond, R. Yoshida and ZEUS Collaboration
Phys. Rev. **D68**, 052004 (2003).

Abelian D Terms and the Superpartner Spectrum of Anomaly Mediated Supersymmetry Breaking
B. Murakami and J. D. Wells
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Central Pseudorapidity Gaps in Events with a Leading Antiproton at the Fermilab Tevatron $p\overline{p}$ Collider

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Phys. Rev. Lett. **91**, 011802 (July 2003).

Classical and Quantum Nambu Mechanics

T. Curtright and C. Zachos

Phys. Rev **D68**, 085001 (October 2003).

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M. Carena, J. Ellis, S. Mrenna, A. Pilaftsis and C.E.M. Wagner

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J. Norem et al

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Dark Current, Breakdown, and Magnetic Field Effects in a Multicell, 805 MHz Cavity

J. Norem et al

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C. K. Zachos and T. L. Curtright

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Determining $\tan\beta$ with Neutral and Charged Higgs Bosons at a Future e^+e^- Linear Collider

J. Gunion, T. Han, J. Jiang and A. Sopczak

Phys. Lett. **B565,** 42-60 (July 2003).

Differential Cross Sections for Higgs Boson Production at Tevatron Collider Energies

E. L. Berger and J.-W. Qiu

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Dijet Angular Distributions in Photoproduction of Charm at HERA

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R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
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W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, M. Tanaka, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund

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E. Blair, K. L. Byrum, J. Dawson, G. Drake, V. Guarino, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund

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S. Chekanov, M. Derrick, D. Krakauer, J. H. Loizides, S. Magill, B. Musgrave, J. Repond, R. Yoshida and ZEUS Collaboration

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Membranes and Consistent Quantization of Nambu Dynamics

C. Zachos

Phys. Lett. **B570**, 82-88 (September 2003).

Net Charge Fluctuations In Au+Au collisions at $\sqrt{s}_{NN}$ = 130 GeV

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C.-W. Chiang and J. L. Rosner

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M. C. Goodman
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J. M. Campbell, R. K. Ellis and D. Rainwater
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Observation of the Charge Symmetry Breaking d + d $\rightarrow$ ^{4}He + π^o Reaction Near Threshold
H. M. Spinka
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H. Spinka and D. G. Underwood
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R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
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G. T. Bodwin
In: *Gargnano 2002: Quark Confinement and the Hadron Spectrum*, ed. by N. Brambilla and G. M. Prosperi (World Scientific, 2003) pp. **63-72**.

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J. Norem, D. Li, A. Bross, A. Moretti, Y. Torum and E. McKigney

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RF Tests of an 805 MHZ Pillbox Cavity at Lab G of Fermilab

J. Norem, Derun Li, M. Zisman, R. Rimmer, Y. Torun and et al

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Search for the Flavor-Changing Neutral Current Decay $D^{\circ} \to \mu^{+}\mu^{-}$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, M. Tanaka, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund

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Selection and Reconstruction of the Top Quarks in the All-Hadronic Decays at a Linear Collider

S. Chekanov and V. L. Morgunov

Phys. Rev. **D67**, 0740111 (2003).

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C. E. Allgower and H. Spinka

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Phys. Rev. Lett. **91**, 171602 (2003).

Search for Pair Production of Scalar Top Quarks in R-Parity Violating Decay Modes in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

W. Ashmanskas, R. E. Blair, K. L. Byrum, E. Kovacs, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, M. Tanaka, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund

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Search for the Flavor-Changing Neutral Current Decay $D^{\circ} \rightarrow \mu^+\mu^-$ in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV

W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, M. Tanaka, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund

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Search for Single-Top Production in ep Collisions at HERA

S. Chekanov, M. Derrick, D. Krakauer, J. H. Loizides, S. Magill, B. Musgrave, J. Repond, R. Yoshida and ZEUS Collaboration

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Strange Anti-Particle to Particle Ratios at Mid-Rapidity in $\sqrt{s}_{NN}$ = 130 GeV Au+Au Collisions

R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood

Phys. Lett.**B567**, 167-174 (August 2003)

The Radionactive Universe

E. W. Kolb, G. Servant and T.M.P. Tait

JCAP **0307**, 008 (July 2003).

The Pseudo-Goldstone Spectrum of 2-Colour QCD at Finite Density

J. B. Kogut, D. Toublan, and D. K. Sinclair

Phys. Rev. **D68**, 054507 (September 2003).

The STAR Encap Electomagnetic Calorimeter

R. V. Cadman, K. Krueger, H. Spinka, D. Underwood and A. Yokosawa

Nucl. Inst. Methods, **A499**, 740 (2003). *[not previously reported]*

Three-Pion HBT Correlations in Relativistic Heavy-Ion Collisions from the STAR Experiment

R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood

Phys. Rev. Lett. **91**, 262301 (2003).

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W. Gai, J. G. Power, A. Kanareykin, E. Nenasheva and A. Altmark
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Transverse Momentum and Collision Energy Dependence of High pT Hadron Suppression in Au+Au collisions at Ultrarelativistic Energies
R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
Phys. Rev. Lett. **91** 172302 (October 2003).

IV.B. Major Articles Submitted for Publication

Associated Production of a Top Quark and a Charged Higgs Boson
E. L. Berger, T. Han, J. Jiang and T. Plehn
Phys. Rev. D
ANL-HEP-PR-03-56

Beautiful Mirrors, Unification of Couplings and Collider Phenomenology
D. E. Morrissey and C. E. M. Wagner
Phys. Rev. D
ANL-HEP-PR-03-57

Charmless $B \to VP$ Decays Using Flavor SU(3) Symmetry
C.-W. Chiang, M. Gronau, Z. Luo, J. L. Rosner and D. A. Suprun
Phys. Rev. D
ANL-HEP-PR-03-61

Chiral Perturbation Theory For Pentaquark Baryons And Its Applications
P. Ko, J. Lee, T. Lee and J.-H. Park
Phys. Rev. Lett.
ANL-HEP-PR-03-102

CP^H : A Computational Tool for Higgs Phenomenology in the Minimal Supersymmetric Standard Model with Explicit *CP* Violation
J.S. Lee, A. Pilaftsis, M. Carena, S.Y. Choi, M. Drees, J. Ellis and C. E. M. Wagner
Computer Phys. Journal
ANL-HEP-PR-03-60

Electroweak High-Energy Scattering and the Chiral Anomaly
A. R. White
Phys. Rev. D
ANL-HEP-PR-03-95

Estimating Relative Luminosity for RHIC Spin Physics
H. Spinka
Nucl. Inst. Methods
ANL-HEP-PR-03-103

Event-By-Event <p_T>Fluctuations in Au-Au Collisions at $\sqrt{s}_{NN}$ = 130 GeV
R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
Phys Rev. Lett.
ANL-HEP-PR-03-81

Horizontal Muons and a Search for AGN Neutrinos in Soudan 2
D. S. Ayres, T. Fields, M. C. Goodman, T. Joffe-Minor, J. Thron et al
Astroparticle Phys.
ANL-HEP-PR-03-17

Inclusive Double Pomeron Exchange at The Fermilab Tevatron $p\overline{p}$ Collider
W. Ashmanskas, R. E. Blair, K. L. Byrum, E. Kovacs, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund
Phys. Rev. Letts
ANL-HEP-PR-03-106

Lower Limits on *R*-Parity-Violating Couplings in Supersymmetric Models with Light Squarks
E. L. Berger and Z. Sullivan
Phys. Rev. Lett.
ANL-HEP-PR-03-73

Measurement of the Average Time-Integrated Mixing Probability of b-Flavored Hadrons Produced at the Tevatron
W. Ashmanskas, R. E. Blair, K. L. Byrum, E. Kovacs, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund
Phys. Rev. D
ANL-HEP-PR-03-79

Measurement of the Polar-Angle Distribution of Leptons from W Boson Decay as a Function of the W Transverse Momentum in $p\overline{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV
W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. G. Wagner and A. B. Wicklund
Phys. Rev. D
ANL-HEP-PR-03-109

Multi-Strange Baryon Production in Au-Au Collisions at $\sqrt{s}_{NN}$ = 130 GeV
R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
Phys. Rev. Letts
ANL-HEP-PR-03-83

Next-to-Leading Order QCD Predictions for W+2 Jet and Z+2 Jet Production at the CERN-LHC
J. M. Campbell, R. K. Ellis and D. Rainwater
Phys. Rev. D
ANL-HEP-PR-03-63

Nonleptonic Λ_b Decays to $D_s(2317)$, D_s (2460) and Other Final States in Factorization
A. Datta, H. J. Lipkin and P. J. O'Donnell
Phys. Rev. D
ANL-HEP-PR-03-118

Observation of $K^o_s K^o_s$ Resonances in Deep Inelastic Scattering at HERA
S. Chekanov, M. Derrick, D. Krakauer, J. H. Loizides, S. Magill, B. Musgrave, J. Repond , R. Yoshida and ZEUS Collaboration
Phys. Lett. B
ANL-HEP-PR-03-71

Observation of the Narrow State X(3872) $\rightarrow$ J/psi $\pi^+\pi^-$ in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV
W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund
Phys. Rev. Letts
ANL-HEP-PR-03-116

Optimized Search For Single-Top-Quark Production At The Tevatron.
W. Ashmanskas, R. E. Blair, K. L. Byrum, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. G. Wagner and A. B. Wicklund
Phys. Rev. D
ANL-HEP-PR-03-115

Pion, Kaon, Proton And Anti-Proton Transverse Momentum Distributions From p+p And d+Au Collisions at $\sqrt{s}_{NN}$ = 200 GeV
R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
Phys. Rev. Letts
ANL-HEP-PR-03-82

Quantum Mechanics in Phase Space (an Overview and Reprint Volume)
C. K. Zachos, D. Fairlie and T. L. Curtright
World Scientific

Rapidity And Centrality Dependence Of Proton And Anti-Proton Production From ^{197}Au+^{197}Au Collisions At $\sqrt{s}_{NN}$ = 130 GeV
R. V. Cadman, K. Krueger, H. M. Spinka and D. G. Underwood
Phys. Rev. Letts
ANL-HEP-PR-03-86

Relativistic Corrections to Gluon Fragmentation into Spin-Triplet *S*-wave Quarkonium
G. T. Bodwin and Jungil Lee
Phys. Rev. D
ANL-HEP-PR-03-65

Search for Kaluza-Klein Graviton Emission in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV using the Missing Energy Signature
W. Ashmanskas, R. E. Blair, K. L. Byrum, E. Kovacs, S. E. Kuhlmann, T. LeCompte, L. Nodulman, J. Proudfoot, R. Thurman-Keup, R. G. Wagner and A. B. Wicklund
Phys. Rev. Letts.
ANL-HEP-PR-03-92

The Anticharmed Exotic Baryon θ_c and Its Relatives
M. Karliner and H. J. Lipkin
Phys. Rev. Lett.
ANL-HEP-PR-03-74

IV.C Papers or Abstracts Submitted to Conference Proceedings

A *DK* Molecule or Other *4q* Model for the $D_s\pi$ Resonance at 2.32 GeV
H. J. Lipkin
Proceedings of CIPANP, New York, NY, May 19-24, 2003.
ANL-HEP-CP-03-72

A Digital Hadron Calorimeter with Resistive Plate Chambers
J. Repond
Proceedings of the VII Workshop on Resistive Plate Chambers and Related Detectors, Clermont-Ferrand, France, October 20-22, 2003.
ANL-HEP-CP-04-1

Advanced Grid Technologies in ATLAS Data Management
A. Vaniachine
Proceedings of the XIX International Symposium on Nuclear Electronics and Computing (NEC2003), Varna, Bulgaria, September 15-20, 2003.
ANL-HEP-CP-03-93

Anomaly Mediated Supersymmetry Breaking and the Ancillary U(1) Formalism
B. Murakami
Proceedings of SUGRA 20, Boston, MA, March 17-21, 2003.
ANL-HEP-CP-03-64

Branes, Strings, and Odd Quantum Nambu Brackets
T. L. Curtright and C. K. Zachos
Proceedings of QTS3: 3rd International Symposium on Quantum Theory and Symmetries, Cincinnati, OH, September 10-14, 2003 (World Scientific, 2004).
ANL-HEP-CP-03-114

Determining the Extra-Dimensional Location of the Higgs Boson
A. Aranda, C. Balazs, J. L. Diaz-Cruz, S. Gascon-Shotkin and O. Ravat
Presented at Workshop on the Physics at TeV Colliders, Les Houches, France, 26 May - 6 June 2003.
ANL-HEP-CP-03-112

Exclusive Two Charmonium Versus Charmonium Glueball Production at BELLE
Jungil Lee
Proceedings of 2nd International Conference on Flavor Physics (ICFP 2003), Seoul, Korea, October 6-11, 2003.
ANL-HEP-CP-03-117

Finite Density Lattice Gauge Theories with Positive Fermion Determinants
J. B. Kogut, D. K. Sinclair and D. Toublan
Proceedings of the Workshop on Finite Density QCD at Nara, Japan, July 10-12, 2003.
ANL-HEP-CP-03-97

Hard Probes in Heavy Ion Collisions at the LHC: Heavy Flavor Physics
G. T. Bodwin, Jungil Lee, R. Vogt et al.
CERN Yellow Book of the 3rd Workshop on Hard Probes in Heavy Ion Collisions at the LHC, Geneva, Switzerland, October 7-11, 2002.
ANL-HEP-CP-04-12

Higgs Boson and Diphoton Production at the LHC

P. Skands, B. C. Allanach, H. Baer, C. Balazs et al.

Workshop on the Physics at TeV Colliders, Les Houches, France, 26 May - 6 June 2003.

ANL-HEP-CP-03-111

Inclusive Quarkonium Production and the NRQCD-Factorization Approach

G. T. Bodwin

Proceedings of the 2nd International Conference on Flavor Physics (ICFP 2003), Korea Institute for Advanced Study (KIAS), Seoul, October 6-11, 2003.

ANL-HEP-CP-03-113

Lattice QCD at Finite Isospin Density and/or Temperature

D. K. Sinclair

Presented at 21st International Symposium on Lattice Field Theory (LATTICE 2003), Tsukuba, Ibaraki, Japan, 15-19 July 2003.

ANL-HEP-CP-03-77

Open Charm Production In DIS At HERA

S. Chekanov

Proceedings of the International Europhysics Conference on High Energy Physics, Aachen, Germany, July 17-23, 2003.

ANL-HEP-CP-03-75

Quark Masses, Hyperfine Interaction and Exotic Baryons

M. Karliner and H. J. Lipkin

Proceedings of the Light Cone Workshop (LC03) "Hadrons and Beyond", Durham, UK, August 5-9, 2003.

ANL-HEP-CP-03-98

The Sensitivity of the LHC for TeV Scale Dimensions in Dijet Production

C. Balazs, M. Escalier, S. Ferrag, B. Laforge and G. Polesello

Proceedings of the Workshop on the Physics at TeV Colliders, Les Houches, France, 26 May - 6 June 2003.

ANL-HEP-CP-03-110

IV D. Technical Reports and Notes

CDF Notes:

CDF-6716

Evaluation of Errors on eps, D, and epsD**2
A. B. Wicklund
CDF/DOC/BOTTOM/CDFR/6716

CDF-6728

CEM Gain From 8 GeV Electrons for 02-03 Data
Larry Nodulman
CDF/MEMO/ELECTRON/CDFR/6728

CDF-6745

Stntuple modules for central jet four-momentum recalculation using tracks Fabrizio Margaroli,
Steve Kuhlmann
CDF/ANAL/JET/CDFR/6745

CDF-6793

B Flavor tagging using opposite side electrons
Tania Moulik, Masa Tanaka, Barry Wicklund
CDF/ANAL/BOTTOM/CDFR/6793

PDK Notes:

PDK-808

Observation of Atmospheric Neutrino Oscillations in Soudan 2
M. Sanchez, D.S. Ayres, T. Fields, M. Goodman, T. Joffe Minor, J. Thron et al
July 29, 2003
ANL-HEP-PR-03-59

WF Notes:

WF-218

A Study of Bunch Length Measurement at Argonne Wakefield Accelerator
Greg Betzel, Northern Illinois University
August 15, 2003.

WF-219

Measurements of High-Brightness Electron Beam
H. Wang, J. Power, W. Liu, and W. Gai
January 26, 2004.

Technical Reports

Analysis of Polarimeter Data for the 2001-2002 RHIC Run
R. V. Cadman, K. Krueger, H. Spinka and D. Underwood
ANL-HEP-TR-03-108

Comments on the Operation of the RHIC CNI Polarimeters
H. Spinka
ANL-HEP-TR-03-107

High Energy Physcis Division SemiAnnual Technical Report of Research Activities
H.M. Spinka, L.J. Nodulman, M.C. Goodman, J. Repond, D.S. Ayres, J. Proudfoot, R. Stanek, T. LeCompte, G. Drake, E.L. Berger, G.T. Bodwin, D.K. Sinclair, C. Zachos, W. Gai and J. Norem
ANL, IL, July-December, 2003.
ANL-HEP-TR-04-33

White Paper Report on Using Nuclear Reactor to Search for a value of θ 13, January 2004
D. Ayres, M. Goodman, J. J. Grundzinski, V. J. Guarino, D. Reyna, R. Talaga, J. Thron et al
A New Nuclear Reactor ν Experiment to Measure θ13 , Jan. 2004., Argonne, IL, **157** pages, January 2004.
ANL-HEP-TR-04-10

V. COLLOQUIA AND CONFERENCE TALKS

Csaba Balazs

How Robust are the ResBos Predictions?
CDF Meeting, University of Toronto, Montreal, Canada, December 5, 2003 (via video).

ResBos Introduction
W Mass Theory Workshop, FNAL, Batavia, IL, November 6, 2003.

Resummation at NNLL
CTEQ Meeting, Michigan State University, East Lansing, October 18, 2003.

The Five Dimensional Two Higgs Doublet Model
19th International Workshop on Weak Interactions and Neutrinos (WIN03), Lake Geneva, WI, October 8, 2003.

Edmond L. Berger

Light Bottom Squark Phenomenology
2nd International Conference on Flavor Physics (ICFP 2003), Korea Institute for Advanced Study (KIAS), Seoul, October 10, 2003.

Higgs Boson Decay into Hadronic Jets
Enrico Fermi Institute, University of Chicago, IL, July 26, 2003.

Higgs Boson Decay into Hadronic Jets
American Linear Collider Workshop, Cornell University, Ithaca, NY, July 15, 2003.

Measurement of Squark Mixing Angles at LEP-II and at a Linear Collider
American Linear Collider Workshop, Cornell University, Ithaca, NY, July 14, 2003.

Geoffrey T. Bodwin

Inclusive Quarkonium Production and the NRQCD Factorization Approach
2nd International Conference on Flavor Physics (ICFP2003), Seoul, Korea, October 6-11, 2003.

John Campbell

Making NLO predictions for Method 2
Matrix Element/Monte Carlo Workshop, FNAL, Batavia, IL, December 2003.

Making NLO predictions for Method 2
CTEQ Meeting, MSU, East Lansing, MI, October 2003.

Maury Goodman

Detectors for Future Neutrino Experiments
8th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Applications, Como Italy October 7, 2003.

Plans for Experiments to Measure θ_{13}
Coral Gables Conference on High Energy Physics and Cosmology, Fort Lauderdale Florida, December 19, 2003.

Status of the Reactor θ_{13} White Paper
2nd Workshop on Future Low Energy Neutrino Experiments, Munich Germany, October 12, 2003.

Search for θ_{13} in the Neutrino Sector
University of Illinois High Energy Physics Seminar, September 29, 2003.

The Neutrino Oscillation Industry
Kansas State University Physics Colloquium, September 23, 2003.

Jungil Lee

Relativistic Corrections to Gluon Fragmentation into Spin-Triplet *S*-Wave Quarkonium
Korea Institute for Advanced Study (KIAS), Seoul, Korea, November 21, 2003.

BELLE $J/\psi + \eta_c$ Anomaly – The Largest Discrepancy in the Standard Model
Yonsei University, Seoul, Korea, November 4, 2003.

Exclusive Two Charmonium Versus Charmonium Glueball Production at BELLE
Sejong University, Seoul, Korea, October 30, 2003.

Symbolic Manipulation in Particle Phenomenology
Korea Advanced Institute of Science and Technology (KAIST), Daejon, October 17, 2003.

Exclusive Two Charmonium Versus Charmonium Glueball Production at BELLE
Korea Advanced Institute of Science and Technology (KAIST), Daejon, October 17, 2003.

Exclusive Two Charmonium Versus Charmonium Glueball Production at BELLE
Korea University, Seoul, October 7, 2003.

Exclusive Two Charmonium Versus Charmonium Glueball Production at BELLE
2nd International Conference on Flavor Physics (ICFP 2003), Seoul, Korea, October 6-11, 2003.

Harry J. Lipkin

New Meson and Baryon Data. Exotic (?) Challenges for QCD
Department of Physics, U California, San Diego, La Jolla, CA, October 31, 2003.

New Meson and Baryon Data. Exotic (?) Challenges for QCD
Caltech, Pasadena, October 27, 2003.

Charm and Beauty Spectroscopy
Research Workshop of the Israel Science Foundation, "Heavy Quark Physics at the Upgraded Hera Collider", Rehovot, Israel, October 21, 2003, via video conference from Argonne, IL.

New Meson and Baryon Data. Exotic (?) Challenges for QCD
Department of Physics, University of Toronto, Canada, October 7, 2003.

New Meson and Baryon Data. Exotic (?) Challenges for QCD
ANL-HEP Division Seminar, Argonne, IL, September 15, 2003.

David Morrissey

Beautiful Mirrors, Gauge Unification, and Collider Phenomenology
Theoretical Physics Seminar, ANL-HEP, Argonne, IL, September 15, 2003

Brandon Murakami

Establishing Supersymmetry Through Forthcoming Lepton Flavor Violation Experiments

Department of Physics, University of Hawai'i, Manoa, Honolulu, HI, December 3, 2003.

Establishing Supersymmetric Seesaw through Lepton Flavor Violation and Cosmology

Department of Physics, MSU, East Lansing, MI, October 21, 2003.

Anomaly Mediated Supersymmetry Breaking and the Ancillary U(1) Formalism

SLAC, Stanford, CA, September 10, 2003.

The Impact of Muon Conversion Experiments on Linear Collider Studies

American Linear Collider Workshop, Cornell University, Ithaca, NY, July 14, 2003.

James Norem

A New Way to look at rf Breakdown

Fermilab Accelerator Science and Technology Seminar, December 4, 2003.

Materials Science Problems Associated with rf Breakdown in Accelerator Systems

Northwestern University Materials Science and Engineering Department, December 5, 2003.

New Ways to look at RF Breakdown

Argonne HEP Division Lunch Seminar, December 16, 2003.

rf Breakdown and High Gradient Phenomena

Workshop on High Gradient rf, Argonne, October 7-9, 2003.

Jose Repond

A Digital Hadron Calroimeter with Resistive Plate Chambers

VII Workshop on Resistive Plate Chambers and Related Detectors, Clermont-Ferrand, France, October 2003.

Development of a DHCAL with Resistive Plate Chambers

American Linear Collider Workshop, Cornell University, Ithaca, NY, July 2003.

Digital Hadron Calorimeter: A Worldwide Review
Worldwide Linear Collider Calorimetry Meeting, Montpellier, France, October 2003.

Report from the CALICE Collaboration
American Linear Collider Workshop, Cornell University, Ithaca, NY, July 2003.

Simulation of the DHCAL Prototype
American Linear Collider Workshop, Cornell University, Ithaca, NY, July 2003.

David Reyna

Neutrinos at 1%: The Next Generation of Neutrino Experiments
Colloqium at University of Sao Paolo, Sao Paolo, Brazil, September 24, 2003.

Neutrinos at 1%: A Reactor Based Measurement of θ_{13},
Seminar at University of Sao Paolo at Campinas (UNICAMP), Campinas, Brazil, September 25, 2003.

Neutrinos at 1%: A Reactor Based Measurement of θ_{13},
Seminar at the Center for Brazilian Particle Physics (CBPF), Rio de Janiero, Brazil, September 29, 2003.

Neutrinos at 1%: A Reactor Based Measurement of θ_{13},
XXIV Brazilian National Conference on Physics of Particles and Fields. Caxambu, Brazil, October 1, 2003.

Kuo Sheng--Taiwan (Tunnel to the Future?)
Second Workshop on Future Low-Energy Neutrino Experiments, Munich, Germany, 9 October, 2003.

Angra dos Reis, The Brazilian Option
Second Workshop on Future Low-Energy Neutrino Experiments, Munich, Germany, October 9, 2003.

Neutrinos at 1%: A Reactor Based Measurement of θ_{13}
Seminar at Argonne National Laboratory--Physics Division, Argonne, IL, October 20, 2003.

Geraldine Servant

Kaluza-Klein Dark Matter
Department of Physics, University of Illinois, Urbana, November 3, 2003.

Dark Matter from Approximate Baryon Number Symmetry
Department of Physics, University of Michigan, Ann Arbor, October 31, 2003.

SO(10) Grand Unification in Warped Space
Department of Physics, Cornell University, Ithaca, NY, October 22, 2003.

Dark Matter and Baryon Number in Warped Geometries
Workshop on Branes and Generalized Dynamics, Argonne, IL, October 20, 2003.

Kaluza-Klein Dark Matter
Workshop on String Cosmology, KITP, Santa Barbara, CA, August 14, 2003.

Donald K. Sinclair

Lattice QCD at Finite Isospin Density and/or Temperature
XXI International Symposium on Lattice Field Theory (LATTICE 2003), Tsukuba, Japan, July 15-19, 2003.

Finite Density Lattice and QCD and Related Theories
International Workshop on Finite Density QCD, Nara, Japan, July 10-12, 2003.

Harold Spinka

Polarimetry at RHIC and the AGS
Advance Studies Institute - Symmetries and Spin (SPIN-Praha-2003), Prague, Czech Republic, from July 12-19, 2003.

Some Spin Physics Measurements with STAR
Advance Studies Institute - Symmetries and Spin (SPIN-Praha-2003), Prague, Czech Republic, from July 12-19, 2003.

Alexandre Vaniachine

Advanced Grid Technologies in ATLAS Data Management
XIX International Symposium on Nuclear Electronics and Computing (NEC2003), Varna, Bulgaria, 15-20 September 2003.

Carlos Wagner

Precision Electroweak Measurements and Unification of Couplings
Department of Physics, University of Wisconsin, Madison, November 21, 2003.

Precision Electroweak Measurements and Unification of Couplings
Department of Physics, Texas A&M University, College Station, October 26, 2003.

Precision Electroweak Measurements and Unification of Couplings
2003 Summer Workshop, Aspen, CO, July 2003.

Cosmas Zachos

Membranes and Consistent Quantization of Nambu Brackets
Workshop on Branes and Generalized Dynamics, Argonne, IL, October 21, 2003.

Branes, Strings, and Odd Quantum Nambu Brackets
3rd International Symposium on Quantum Theory and Symmetries (QTS3), Cincinnati, OH, September 12, 2003.

VI. HIGH ENERGY PHYSICS COMMUNITY ACTIVITIES

Edmond L. Berger

International Advisory Committee, HADRON 2005, Rio de Janeiro, Brazil, 2005.

Steering Committee, International Conference on Flavor Physics 2005 (ICFP 2005).

Organizing Committee, 9th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2005), 2005.

Scientific Program Committee, Vth Rencontres du Vietnam, Hanoi, Vietnam, August 6-11, 2004.

Co-Organizer, Argonne Theory Institute on The Physics of Supersymmetry, Higgs Bosons, and Extra Dimensions, High Energy Physics Division, Argonne, IL, May 24-28, 2004.

Scientific Program Organizing Committee, XXXIXth Rencontres de Moriond, QCD and High Energy Hadronic Interactions, La Thuile, March 28—April 4, 2004.

Organizer, ANL 2nd Lab-Wide Theory Afternoon, Argonne, IL, February 16, 2004.

Co-Chair, Aspen Winter Conference on Particle Physics, “Where We Are and Where We Are Going”, Aspen Center for Physics, CO, February 1-7, 2004. (http://gate.hep.anl.gov/berger/Aspen04)

International Advisory Committee, HADRON 2003, Aschaffenburg, Germany, August 31—September 6, 2003.

Scientific Organizing Committee and Convener of the Session on the Polarized Gluon Density, Fourth Circum-Pan-Pacific Symposium on High Energy Spin Physics, University of Washington, Seattle, August 4-7, 2003.

Leader, North American Node, Quarkonium Working Group QWGNET Proposal to the European Community to fund a Marie Curie Research Training Network on Heavy Quarkonium, 2003.

Scientific Advisory Board, Argonne Theory Institute, 2003— (http://www.anl.gov/OPA/theoryinstitute/index.html)

Member, Committee on International Scientific Affairs, American Physical Society, 2003—

Member, Andrew Gemant Award Committee, American Institute of Physics, 2002—

Member, American Linear Collider Working Group, 2002—

Adjunct Professor of Physics, Michigan State University, East Lansing, MI, 1997—present.

Member, Coordinated Theoretical-Experimental Project on QCD (CTEQ) Collaboration

Geoffrey T. Bodwin

Convener, Production Section, Quarkonium Working Group QWGNET Proposal to fund a Marie Curie Research Training Network on Heavy Quarkonium 2003--present.

Member, Local Organizing Committee, Second International Workshop on Heavy Quarkonium, Fermilab, September 20-22, 2003.

Member, Quarkonium Working Group, 2002—present.

Member, Working Group on Heavy Flavors, Workshops on Hard Probes in Heavy Ion Collisions, CERN, 2001--2003.

Maury Goodman

Editor, Long-Baseline Newsletter.

International Advisory Committee, Neutrino 2004 Conference (Paris).

Investments Committee of the American Physical Society.

Member Particle Data Group.

Nominations Committee, Forum on Physics and Society of the American Physical Society (Chairman).

Organizer, Kickoff Meeting for the APS Neutrino Study, December 2003, Argonne.

Program Committee, Second Workshop on Future Low-Energy Neutrino Experiments, October 2003 (Munich).

Program Committee of the Weak Interactions and Neutrinos Workshop, WIN2003, Lake Geneva Wisconsin, October 2003.

Harry Lipkin

Member, International Advisory Committee, HADRON 2003, Aschaffenburg, Germany, August 31--September 6, 2003.

James Norem

Hosted the International Workshop on High Gradient rf, at Argonne National Laboratory, October 7-9, 2003.

Harold Spinka

He is a co-convenor of the STAR Spin Physics Working Group July-December 2003.

Jose Repond

Member of the International Advisory Committee for the 'Deep Inelastic Scattering Workshop' series.

Member of the Local Organizing Committee for the International, Conference on High Energy Physics, ICHEP'03, Fermilab, IL.

Carlos Wagner

Co-Organizer, Argonne Workshop on Branes and Generalized Dynamics, Argonne, IL, October 20-24, 2003.

Head, Theory Committee, Argonne National Laboratory, 2003--

Associate Professor, Lecturer for Courses on Supersymmetry and Advanced Electrodynamics, U Chicago, IL, 2000--2003.

Head, Theory Group, HEP Division, Argonne National Laboratory, September 2002—

Cosmas Zachos

Principal Organizer, Argonne Workshop on Branes and Generalized Dynamics, Argonne, IL, October 20-24, 2003, and Editor of its E-Proceedings, http://www.hep.anl.gov/czachos/ANLworkshop.html.

Member, International Advisory Board of the (Next) Conference on Differential Geometric Methods in Theoretical Physics, 2003.

Member, Advisory Panel, J. Phys A: Math Gen (IOP).

VII. HEP DIVISION RESEARCH PERSONNEL

Administration

Price, L.
Hill, D.

Accelerator Physicists

Conde, M.
Gai, W.
Norem, J.
Power, J.
Yusof, Z.

Experimental Physicists

Ayres, D.
Ashmanskas, W.
Blair, R.
Byrum, K.
Cadman, R.
Chekanov, S.
Derrick, M.
Fields, T.
Goodman, M.
Krakauer, D.
Kuhlmann, S.
LeCompte, T.
Magill, S.
May, E.
Musgrave, B.
Nodulman, L.
Proudfoot, J.
Repond, J.
Reyna, D.
Spinka, H.
Stanek, R.
Talaga, R.
Tanaka, M.
Thron, J.
Underwood, D.
Wagner, R.
Wicklund, A.
Xia, L.
Yokosawa, A.
Yoshida, R.

Theoretical Physicists

Balazs, C.
Berger, E.
Bodwin, G.
Campbell, J.
Chiang, C. W.
Jiang, J.
Lee, J.
Murakami, B.
Servant, G.
Sinclair, D.
Wagner, C.
White, A.
Zachos, C.

Engineers and Computer Scientists

Dawson, J.
Drake, G.
Grudzinski, J.
Guarino, V.
Gieraltowski, J.
Karr, K.
Kovacs, E.
Malon, D.
Schlereth, J.
Vaniachine, A.

Technical Support Staff

Adams, C.
Ambats, I.
Cox, G.
Cundiff, T.
Farrow, M.
Franchini, F.
Haberichter, W.
Kasprzyk, T.
Konecny, R.
Nephew, T.
Reed, L.
Rezmer, R.
Skrzecz, F.
Wood, K.

Laboratory Graduate Participants

Loizides, J.
Miglioranzi, S.
Jing, C.
Morrissey, D.
Wang, H.

Visiting Scientists

Kovacs, E. (Theory)
Krueger, K. (STAR)
Liu, W. (AWA)
Lipkin, H. (Theory)
Ramsey, G. (Theory)
Uretsky, J. (Theory)