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RESEARCH IN EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS

A PROPOSAL TO THE U.S. DEPARTMENT OF ENERGY

THE UNIVERSITY OF TEXAS AT ARLINGTON

Principal Investigator : Andrew P. White

Co-Principal Investigators : Kaushik De

Paul A. Draper

Ransom Stephens

Abstract

We report on the activities of the High Energy Physics Group at the University of Texas at Arlington for the period 1994-95. We propose the continuation of this research program for 1996-98 with strong participation in the detector upgrade and physics analysis work for the DØ Experiment at Fermilab, prototyping and pre-production studies for the muon and calorimeter systems for the ATLAS Experiment at CERN, and detector development and simulation studies for the PP2PP Experiment at Brookhaven.

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Chapter 1

Introduction

1.1 Overview

The High Energy Physics group at the University of Texas at Arlington was formed in 1991 with the intention of developing a coherent program of research in hadron collider physics. The program initially consisted of participation in the DØ experiment at Fermilab and the SDC experiment at the SSC Laboratory. This program was followed until the demise of the SSC project in Fall 1993. The SDC activity has now been replaced by initial participation in the ATLAS experiment at the CERN Large Hadron Collider. We are also participating in a smaller proton-proton elastic scattering experiment at RHIC known as PP2PP. Thus we have been able to adhere to our original goal with respect to hadron collider physics and intend to pursue this direction during the requested funding period of this proposal.

The University of Texas at Arlington (UTA) has made a significant investment over a three year period in the creation of this new research area. High Energy Physics is viewed as one of the leading research areas for UTA and the University continues to provide substantial and continuing support beyond the startup period.

The UTA HEP group now consists of four faculty (plus Dr. S. Peter Rosen, Dean of the College of Science), three postdoctoral associates, group secretary, and many graduate and undergraduate students from Physics, Computer Science Engineering, and Electrical Engineering. All faculty, postdocs, and several students participate in the DØ experiment at Fermilab. All our faculty had invested considerable effort in the design, construction, and commissioning of the DØ detector before arriving at UTA. Our group has a strong commitment to the full exploitation of the physics from DØ, and the further development of DØ through its upgrade program.

The UTA group joined the ATLAS/LHC Experiment in March 1994 and has since become heavily involved in the development of the muon measurement system, with plans for participation in the final chamber production. Recently, we have been encouraged by ATLAS management, both at CERN and the US, to lead the initial studies of the proposed intermediate barrel tile calorimeter. We are also leading an initiative related to computing and software development for US ATLAS.

Finally, we are participating in studies and test beam activities for the PP2PP Experiment at RHIC. Since PP2PP is a small experimental collaboration, UTA can contribute to a significant fraction of the experimental responsibilities, and we have taken the leading role in simulation studies and are strongly involved with detector prototype construction and testing. The PP2PP detector development work shares many common elements with our DØ upgrade plans and our ATLAS calorimeter activities.

This proposal consists of a description of our personnel and facilities at UTA, a report on activities for the period 1994-95, our proposed activities for the period 1995-96, and finally our requested budgets for FY '96, FY '97 and FY '98.

1.2 High Energy Physics Group Personnel

The full list of personnel is as follows:

1.2.1 Faculty

- Dr. S. Peter Rosen, Dean of the College of Science and Professor of Physics

  submitting a separate proposal for the UTA HEP Particle Theory task.

- Dr. Andrew P. White, Professor of Physics and Director of the Center for High Energy Physics and Technology.

  UTA High Energy Physics Group Leader responsible for the overall management of research programs, facilities, personnel, budgets, and administration. Member of the DØ experiment since 1986, and New Phenomena Physics Convenor for Tevatron Run Ia. Main physics interest is the search for supersymmetry at the Tevatron and LHC. Leads the UTA participation in the ATLAS experiment with direct responsibility for the muon system development. US ATLAS muon detector physics coordinator.

- Dr Kaushik De, Assistant Professor of Physics.

  Member of the UTA faculty since 1993. Member of the DØ collaboration since 1987. Led the design, construction, installation and commissioning of the ICD detector for DØ, while at the University of Michigan. Leads the work on the upgrade of the ICD. Proposed and led the work on the new EMICD and the forward preshower detectors for DØ. Leading the proposal for the new intermediate barrel tile calorimeter for the ATLAS experiment. Actively pursuing the search for SUSY at the Tevatron. Convenor of the "TeV2000 SUSY working group."

- Dr. Paul A. Draper, Assistant Professor of Physics.

  Member of UTA faculty since 1991. Detector interests are calorimetry and scintillator-based tracking, with additional experience with muon spectrometers. Member of the DØ collaboration since 1986, with analysis focus in the QCD Physics group. Leads the UTA participation in PP2PP with primary responsibility for simulations. Conducted SDC closeout work at UTA.

- Dr. Ransom Stephens, Assistant Professor of Physics.

Member of UTA faculty since 1993. Director of the UTA Alpha computer farm. Initiating the development of exclusive analyses in $p\bar{p}$ interactions including the study of the K_T jet reconstruction algorithm in the DØ QCD analysis group. Coordinating Monte Carlo studies of the ATLAS TileCal intermediate barrel detector and whole-detector studies of the ATLAS muon system. Measuring the relative gain of photo-multiplier tubes in large magnetic fields in support of the DØ upgrades of the ICD and muon systems, and the ATLAS TileCal.

1.2.2 Scientific Software Engineer

- Dr. Marc Turcotte

  Information Technologies Group, ARRI-UTA Joined SSCL PRD in 1990 and contributed to SDC detector R&D and physics research with CDF. After the closure of the SSC, joined UTA to initiate ATLAS calorimeter response studies and scientific software engineering. Leading collaborative computing effort with ARRI. Physics interests: Higgs, top and SUSY.

1.2.3 Postdoctoral Associates

- Dr. Elizabeth Gallas

  Stationed at Fermilab. Wrote the MTC (Muon Tracking in the Calorimeter) software package, which plays a crucial role in muon identification, muon global tracking and muon trigger. Physics interests include SUSY and QCD. Hardware responsibilities include the ICD upgrade. Dr. Gallas has also been the main author on a paper from experiment E733.

- Dr. Jia Li

  Responsible for the mechanical design and layout of all elements of the DØ ICD system upgrade; leading the ATLAS muon tube development and module construction jigging design work at UTA; working on the equipping and commissioning of the Swift Center detector facility. Worked on the DØ Muon System in 1989, the ICD Detector in 1992, SDC Muon System in 1993, and now working on the ATLAS Muon System. Design and development of the Muon tube prototype precision study system by piping UV Laser light into a high pressure Muon tube. Design and test of Tile & Fiber System for the ICD and EMICD. Designed a laser scanning xy table.

- Dr. Lee Sawyer

  Leading the DØ search for low energy supersymmetry via chargino-neutralino states decaying to three charged leptons, and lead author on the Physical Review Letters paper for this analysis. Led the studies for the EMICD and FPS upgrades for the DØ detector. Working with EE student P.Tacconi on pulse shape studies for ATLAS muon drift tubes. Responsible for the day to day operation of the UTA HEP VAX cluster and maintenance of software libraries.

1.2.4 Secretary

- Grace Sauce

  Responsible for all administrative support functions in the high energy group. This includes daily tracking of budgets, preparation of budget summaries, travel request and reimbursement processing, purchase order processing, payment of accounts, personnel transactions, hiring and supervising work study students.

1.2.5 Graduate students

- Charlotte Brisbon

  Master's student completing her thesis on the development of the laser calibration system for the SDC hadron calorimeter.

- Richard Kaiser

  First year graduate student developing a laser scanning test stand. Spent summer 1994 at Fermilab helping with ICD repair and recalibration work.

- Jill Perkins

  Junior graduate student about to enter the PhD program. Has been working with our group for two years. Conducting research with DØ, with dissertation work on the characterization of QCD events exhibiting a rapidity gap. Also performing service work developing online verification code for the hardware (Level 1) trigger and its software emulator.

- Suemee Shin

  Ms. Shin is currently finishing her first year as a graduate student. She is currently involved in running the next to leading order QCD simulation. Ms. Shin plans to spend the summer at Fermilab working with the data production subgroup.

- Mark Sosebee

  Senior graduate student currently writing his PhD thesis on the DØ search for low energy supersymmetry via chargino-neutralino states decaying to three charged leptons. He has just completed a year at Fermilab where he had responsibility for the operation of the ICD detector system .

1.2.6 Non-thesis graduate students

We employ many graduate students on a part-time basis to provide specialized support in our laboratory and for our computing. These students are primarily from the Computer Science Engineering or Electrical Engineering departments.

- Nijeshwar Chadha

  Assembling the electronics for a two dimensional motion table to be used for a laser scanning test stand.

- Manohar Citambaram

  Performing APD studies to evaluate their usefulness for low light level scintillator calorimetry.

- Krishnan Meiyyappan

  Mr. Meiyyappan assists with the verification of PP2PP simulation code.

- Srinath Nanduri

  Mr. Nanduri participates in the development of the UTA multitasking software and provides research assistance in the development of pattern recognition algorithms for the $p\bar{p}$ exclusive techniques.

- Vanketeswara Potluri

  Mr. Potluri assists in the system management of the UTALF farm.

1.2.7 Undergraduate students

- Gregory Cooper

  Mr. Cooper is working on the UTA multitasking software and code maintenance for the UTA Alpha computing farm.

- Andy Fan

  Mr. Fan is working on the measurement of PMT gains in large magnetic fields with varied shielding configurations.

- Timothy Joe Pool

  Mr. Pool is working on the measurement of PMT gains in large magnetic fields with varied shielding configurations and serves as the HEP preprint librarian.

- Victor Reece

  Developing C++ programs for the laser test stand. Mr. Reece also assembled all the electronics for the PMT box used at the PP2PP test beam.

- John Seeliger

  Testing the new mesh-dynode 5600 series tubes from Hamamatsu. These tubes are being evaluated for use in the DØ upgrades and ATLAS.

- Pablo Tacconi

  Mr. Tacconi has developed a system for capturing pulses from an ATLAS muon drift tube prototype. He will be working with us to develop a method for certifying the drift tubes following their construction.

1.3 High Energy Physics Group Funding History

The following is a summary of the funding for high energy physics from the inception of the group in 1991:

1995 ATLAS FY'95 $25,000

1994 UTA HEP Group support, US DOE, $310,000

1994 UTA local support, $160,000

1994 SDC Calorimeter system closeout, DOE SSC, $13,000

1993 UTA HEP Group support, US DOE, $280,000

1993 UTA local support, $248,000

1993 SDC Muon system development, TNRLC, $250,000

1993 DØ ICD support, DOE FNAL, $18,000

1992 UTA HEP Group support, US DOE, $235,000

1992 UTA local support, $235,000

1992 Renovation of Swift Center, NSF + UTA, $300,000

1992 SDC Muon system development, TNRLC, $130,000

1991 UTA HEP Group support (6 months), US DOE, $85,000

1991 UTA local support, $340,000

1991 SDC Calorimeter system development, DOE SSC, $60,000

1991 Private award for student support, Mr. and Mrs. Scharff, $25,000

1.4 Summary of HEP Group Achievements

As an overview of our activities we give below a summary of our group's achievements since 1991.

General

- Establishment of entirely new high energy physics group from scratch.
- Creation of a major new facility for detector development and construction (Swift Center).
- Establishment of high energy physics as a recognized leading research area at UTA.

DØ Experiment

- Completion, installation, commissioning and successful use of the Intercryostat detector
- Creation and leadership of the New Phenomena physics group through production of the first results.
- Completion of the first search for low energy supersymmetry via the wino-zino channel.
- Development and creation of the MTC package to find muons in the calorimeter.
- Leadership of the electromagnetic intercryostat detector and the forward preshower detector for the Run II upgrades through the proposal stage.

SDC Experiment

- Creation of production engineering study and comprehensive plan for construction of muon modules.
- Delivery of a laser calibration system for the hadronic calorimeter prototype.

ATLAS Experiment

- Construction and operation of prototype muon drift tubes.
- Leadership of simulation and design studies of the newly proposed intermediate barrel tile calorimeter.

Computing system

- Creation of a "farm" of RISC based processors and the creation and successful use of the UTAMulti control system in massive data simulation tasks.

PP2PP experiment

- Successful completion of the recent test beam run at BNL in which the prototype strip detectors proposed by UTA were tested.

1.5 Group Facilities and Future Improvements

Since the ability of our group to carry out the present and proposed activities depends on our physical, detector, and computing resources we give below a description of these facilities.

1.5.1 Science Hall Facilities and Future Renovation

The UTA high energy physics group presently occupies a suite of offices in Science Hall, which is a facility shared between the Departments of Physics and Chemistry. We also have an adjacent detector development laboratory of approximately 1,200 sq.ft. Additional 1,800 sq. ft. of detector development laboratories are located in the basement of Science Hall. Current University plans call for the two-phase construction of a new chemistry building (the first phase is essentially complete). In the same plan Science Hall is scheduled for a major renovation and transformation to sole use by the Department of Physics. We expect these activities to lead to substantially increased office and laboratory space for high energy physics in the next few years.

1.5.2 Swift Center

In order to carry out construction projects for the DØ upgrade, and to allow us to become a production site for ATLAS detector components, we have been renovating a 11,000 sq.ft. building on the UTA campus. We were awarded an Academic Research Infrastructure grant from the National Science Foundation for $150,000, matched by an equal contribution from the University. This represents another part of the University's commitment to a strong high energy physics program.

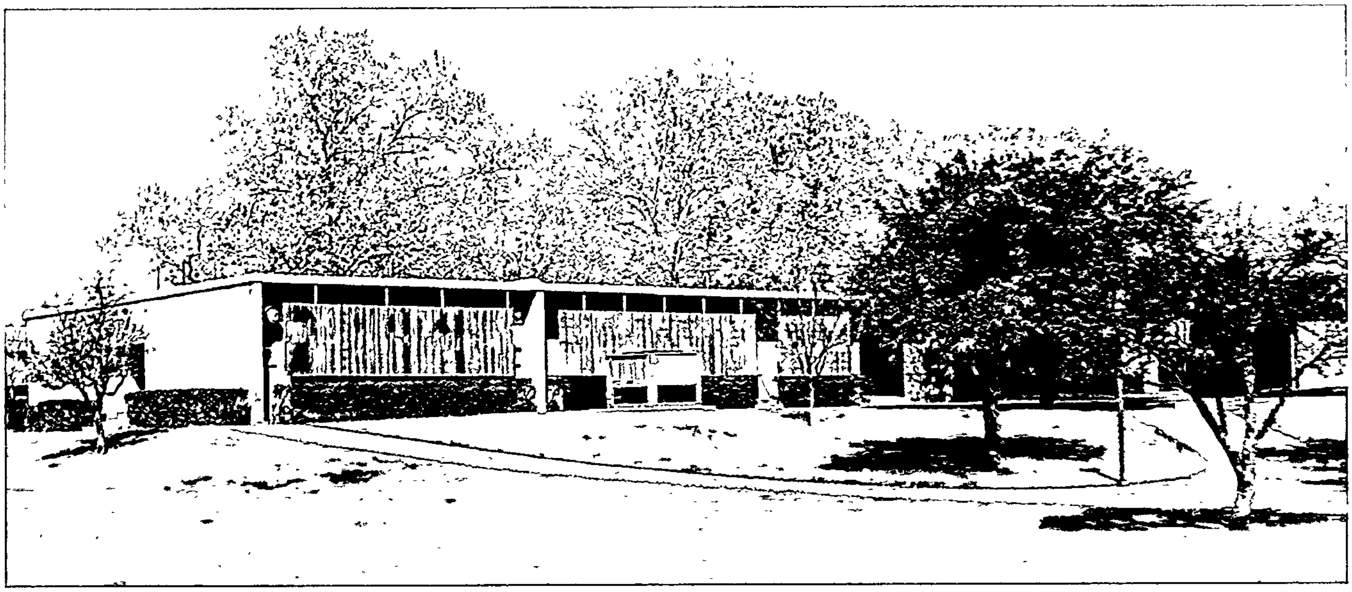
The building has been completely renovated with new air-conditioning system, new roof, and services such as power distribution. The details of the facility as shown in Figs. 1.1-1.2 are respectively:

1. An exterior view of the wing of the building assigned to high energy physics.
2. A view of the full length of the detector development/assembly area.
3. As in 2, but from the North end showing the existing bridge crane.
4. The main assembly area in which the ATLAS muon modules will be fabricated.
5. The large chiller plant installed to provide good temperature control for the facility.
6. The separate room set aside for computer terminals and electronics development.
7. The South end area reserved for the installation of machine tools.

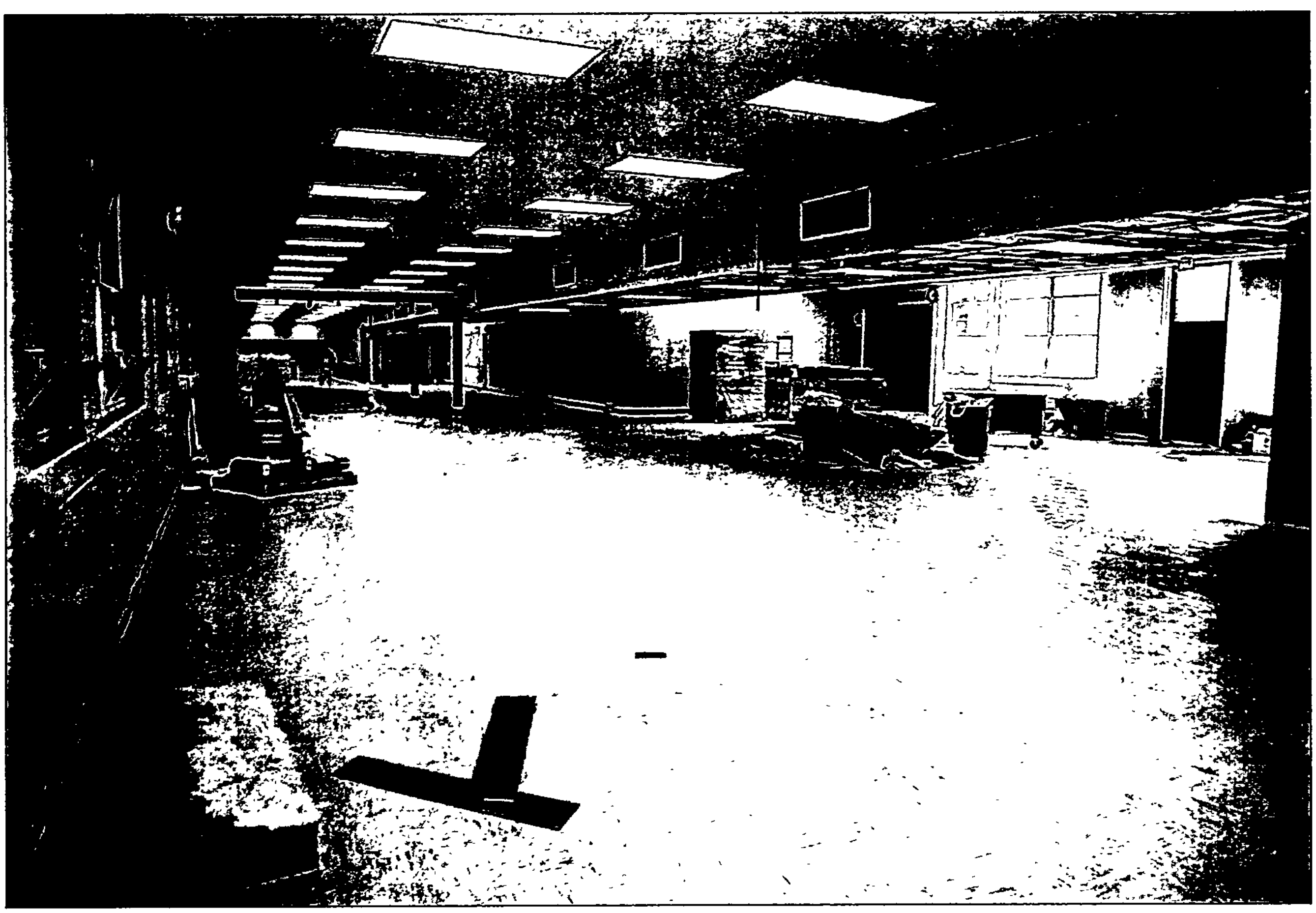
We are presently equipping the building with machine tools, storage facilities, and a fiber optic network connection.

The first projects to be carried out in the Swift Center facility will be the development and construction of the reworked intercryostat detector for DØ, the development

Swift Center Facility

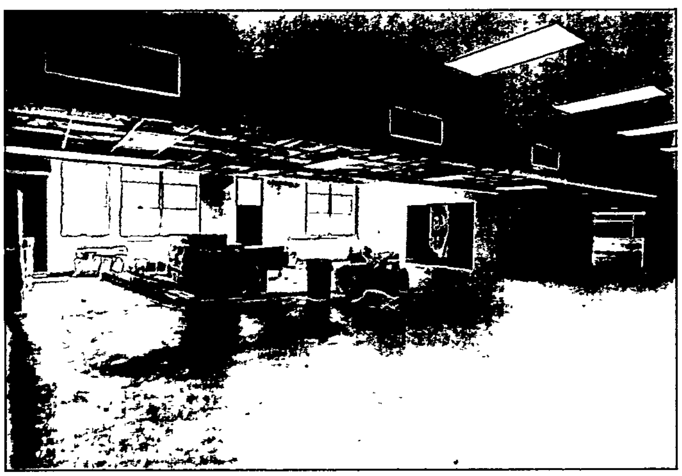


1. General View of outside of facility.

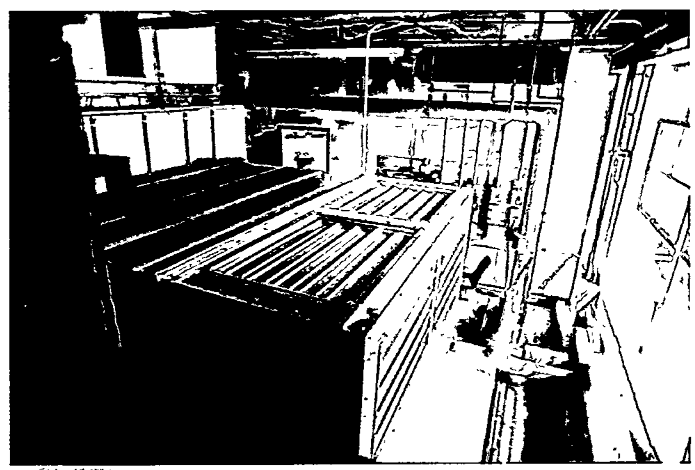


2. Perspective View of Main Assembly Area

3. Perspective View from North End

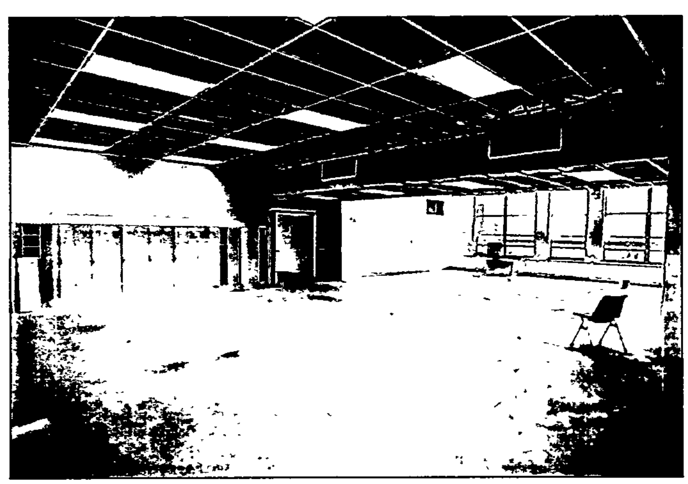


4. Central Working Area



5. Chiller Plant

6. Computer Terminal Area



7. Machine Shop Area

and construction of muon drift tubes for ATLAS prototype chambers, and prototype development of the ATLAS intermediate barrel tile calorimeter. Eventually we will be developing an ATLAS muon chamber production facility at this location and will build substantial components of the intermediate barrel tile calorimeter. We may also use it for construction of part of the DØ forward preshower detector.

1.5.3 Detector Laboratory Facilities

The UTA HEP group occupies a total of more than 3,000 square feet of laboratory space in the physics building. This space is primarily used for detector research and development work for the DØ, ATLAS, and PP2PP experiments.

Within the period of three years since the inception of the group, we have set up a variety of test stands and data acquisition systems in our laboratories. These facilities are under continuous use in studies for the ICD upgrade, the EMICD proposal, the forward preshower proposal, the ATLAS muon system, the intermediate barrel tile calorimeter proposal, and the PP2PP strip detector studies. The facilities include:

- PMT test stand – an automated facility to study properties of PMT tubes. A PC is used to control a CAMAC data acquisition system. The test stand can vary the light intensity, the high voltage and the rate of signals applied to a maximum of five tubes. Data collected by the test program is analyzed and histogrammed online providing immediate feedback, as well as written to database files. The PMT test stand was built and used successfully to characterize 60 Hamamatsu R647 PMT's (leading to the Master's thesis of Ms. Xia Yu). It has also been used to test the new mesh dynode R5600 PMT's and APD's from Hamamatsu.

- CR test stand – for cosmic ray testing of scintillator detectors. This test stand currently shares the PC and data acquisition system with the PMT test stand. Scintillator paddles are used to generate cosmic ray triggers. The data is collected and analyzed online with a PC. The CR test stand was used to determine the relative yield of various scintillator prototypes for the proposed DØ forward preshower detector. In the future, we plan to make this an independent facility with a segmented trigger hodoscope.

- SDC laser test stand – CAMAC data acquisition system interfaced to a Mac. This facility uses LabView to access CAMAC through a GPIB interface. It was developed for SDC laser calibration system R&D. The modular design of LabView makes this an ideal test facility for generic R&D with moderately low data acquisition speed. A special custom CAMAC module was designed for this system to digitize the SDC laser signal as monitored by a PIN diode. Signal shape studies and timing studies have been performed successfully.

- Muon test stand – data acquisition system for ATLAS muon tubes. This facility shares the CAMAC system with the Mac. However, for greater data acquisition speed, a PC is interfaced to the GPIB system. It is primarily used for performance studies of the muon tubes for the ATLAS experiment. A custom signal shaping circuit has been built and implemented to digitize the signal from drift tubes. We have also developed custom GPIB software on the PC for this system.

- Magnet facility test stand – PC based CAMAC test stand. This independent system uses a PC interfaced to a CAMAC crate through GPIB to test the effect of magnetic field on PMT tubes. We have added this second GPIB system to our laboratory to make optimal use of the custom GPIB software and hardware which we have developed.

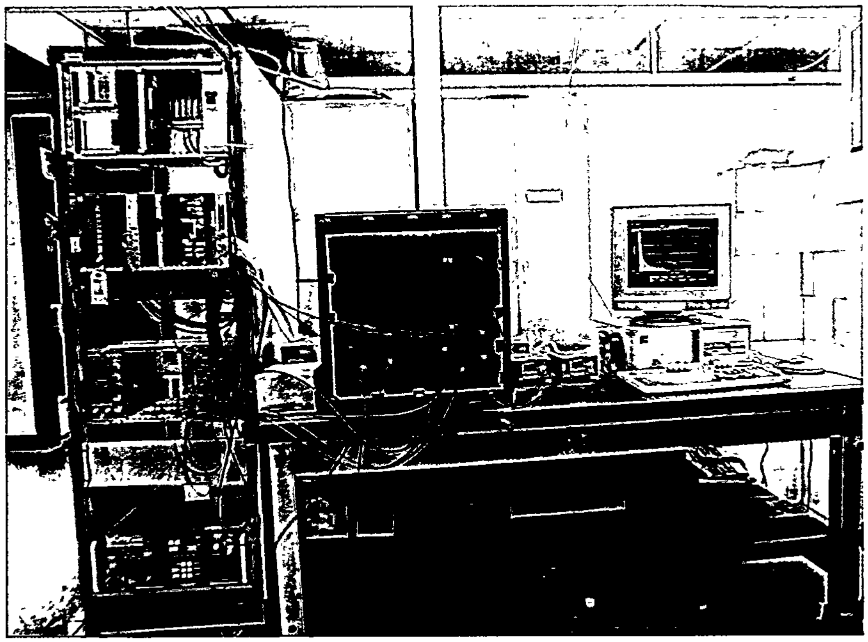
- Laser test stand – dedicated PC based test stand. We are developing a new test stand using direct EISA bus data acquisition with a PC. This specialized system will use a pulsed UV laser and an automated two dimensional motion table to scan the response of prototype scintillator detectors as a function of position. In order to build an economical system, we are not using CAMAC or GPIB. Instead, we are using commercially available multipurpose digital I/O boards and custom hardware and software to interface the test facility with the PC.

In summary, we have put together six different computer controlled data acquisition systems in our laboratories to provide a variety of generic detector development and test facilities. Pictures of some of these facilities are shown in Fig. 1.3. These facilities provide a solid foundation for future participation in the DØ upgrade, the ATLAS experiment, and the PP2PP experiment. Some of the systems currently share the same resources. In the near future, as demands for the use of these test stands grow, we plan to upgrade them into independent facilities.

1.5.4 Computing Facilities

With the opening of the Swift Center, our computational facilities will consist of three separate clusters: an interactive VAX cluster, a Monte Carlo production farm, and, at the Swift Center, a multiplatform/Unix cluster. Our initiatives in computational physics are as follows: First, our interactive computational activities consist of software development specifically in support of our participation in detector studies and physics analyses for the DØ, ATLAS, and PP2PP experiments. Second, development of multitasking software and massive data simulation with our 800MIPS computer farm ('The UTALF farm' as shown in Fig. 1.3B). And third, investigation of and experimentation with modern computational methods both in terms of software products and inter-cluster/inter-platform communications.

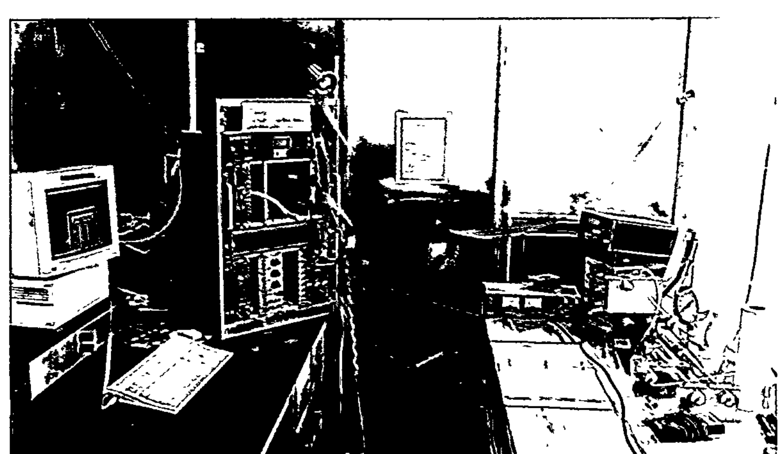
Our first purchases included numerous Digital Equipment Corp.'s (DEC) VAXstation 3100's some four years ago, and our most recent purchase was a DEC AXP (alphachip) 3000/500. Our experience with DEC's AXP architecture began with a cooperative agreement with DEC to serve as a test site for an AXP machine. The move toward the 64-bit RISC AXP platform was natural for our group because it supports multiple operating systems, including VMS, Unix, and Windows NT. While the DØ experiment is inextricably linked to DEC's VMS operating system, the ATLAS experiment supports primarily the Unix operating system. Through it's support of both platforms, the AXP will enable us to make a staged transition to the ATLAS experiment as our computational obligations expand.



A. Automated PMT Test Stand

B. ALPHA Computer Farm

C. Laser Test Stand



D. Muon Test Stand

By connecting our office and laboratory Macintoshes and the office PC-compatibles with a LocalTalk-based local area network, which is then connected to the Ethernet backbone via a router, we ensure that they can freely exchange data with each other and our workstation clusters. Additionally, other PC's in the laboratory are connected directly to the local Ethernet backbone providing faster data transfer rates.

The computing configuration is shown in Fig. 1.4. Our major computational facilities consist of two separate clusters. The first is a VAX cluster which has historically served our interactive computing needs (software development, e-mail, vaxnews, WWW access, et cetera) and the second is an AXP cluster including a high speed computational farm - the UTALF farm. The VAX cluster presently consists of five workstations (four VAXstation 3100s and one VAXstation 4000/60) and one X-terminal. The division between interactive and farm clusters is disappearing. As the group has grown over the last two years, we have begun migrating our interactive applications toward AXP based systems: we have added a DEC AXP 3000/300, a 3000/500 and two X-terminals to the UTALF farm of six AXP3000/400s. The tremendous CPU advantage of the AXP systems requires that those members of our group with the most computationally intensive responsibilities obtain seats on the AXP cluster. We also have a VAXstation 4000/90 and a VAXstation 3100 on the FNALD0 cluster at Fermilab along with one X-terminal. All together, we currently support ten interactive seats at UTA and three at Fermilab.

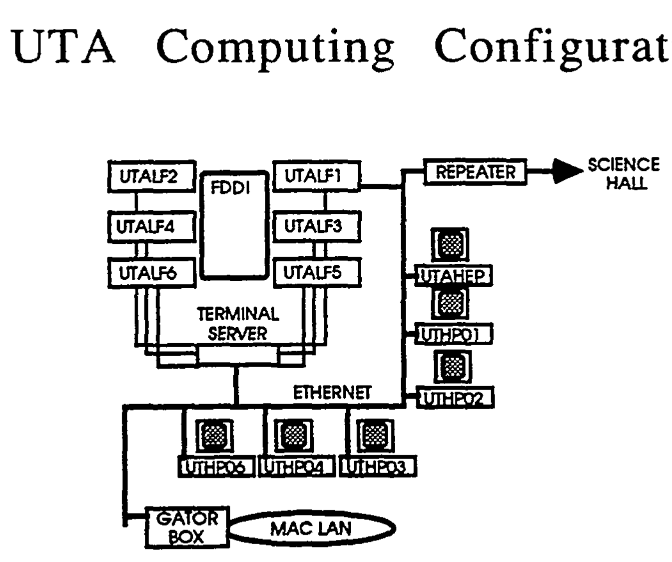


Figure 1.4: Computing facilities - UTA High Energy Physics.

For the immediate future we plan to continue the migration of interactive support from the VAX cluster to the AXP cluster. To replace these nodes and to provide an easily upgradeable system to address the interactive needs of our expanding group, we propose the purchase of a central symmetric multi-processor server along with X-terminals phased in for desktops. This will permit us to migrate our VAXstation 3100's to the DØ cluster, FNALD0, at Fermilab, addressing our increasing needs for interactive seats on site. This plan serves many purposes including centralization of resources, increased interactive CPU power at UTA in step with our expanding obligations and expansion of our Fermilab-based VAXstation support.

Chapter 2

Report on Activities for FY'95

2.1 Overview

The past year has seen strong participation by the UTA group in the analysis of initial data from the DØ experiment at Fermilab and the design and development of elements of the DØ detector upgrade. Our initial activities on the ATLAS experiment at the LHC/CERN have focused on the muon and calorimeter systems, and have recently extended to an initiative in software development. Work on the PP2PP experiment at Brookhaven has been in the areas of detector studies and simulations. Locally we have installed and developed a farm of RISC processors, developed the UTAMulti control system, and have begun production of large Monte Carlo data sets for our various experiments.

In this section we give a comprehensive review of all the aspects of our contributions to the above experiments and local developments during the past year.

2.2 DØ

2.2.1 Overview of UTA participation in DØ

The cornerstone of the experimental high energy physics program at UTA has been participation in the DØ experiment at Fermilab. The four faculty members at UTA have a long history of contributions (total of over 15 years) to DØ before joining UTA. This tradition has continued with strong participation in DØ by the three postdoctoral fellows and our graduate students.

The UTA group has participated in a variety of activities in DØ. We continue to carry the primary responsibility for maintaining the inter-cryostat detector (ICD) – a component of the DØ detector which corrects for energy lost in the inactive material between the central and end cap calorimeters' cryostats. We are solely responsible for upgrading the ICD for Run II. We have proposed and led simulation and detector studies of the electro-magnetic ICD (EMICD) – a proposed device which could include electro-magnetic sampling in this difficult region – and the forward preshower detector. We have played leading roles in and participated in a number of physics analyses. We have written the muon tracking in the calorimeter (MTC) and MTC-level 2 (MTCL2) software packages which are now widely used. We provide computing farm facilities for Monte Carlo event generation. We participate in taking shifts and other service tasks. We have chaired and participated in editorial boards leading to the first generation of DØ publications. In summary, UTA has played an active and visible role in all aspects of the DØ experiment as shown schematically in Fig. 2.1. We plan to continue and expand on this role in future years as DØ continues to collect more data and begins preparation for the next upgrade.

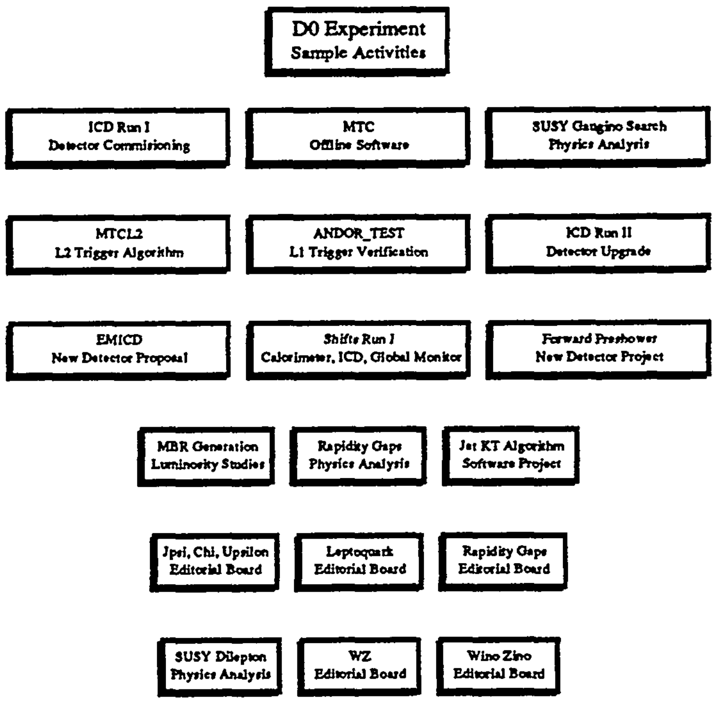


Figure 2.1: A sampling of current activities in the DØ experiment at Fermilab

2.2.2 Physics Analyses

Wino-Zino searches

SUSY investigations at hadron colliders have traditionally focused on searches for strongly interacting squarks and gluinos, usually in channels with multi-jets and large missing transverse energy. An attractive, complimentary search channel has gained considerable interest of late: the direct production of gaugino pairs, with their subsequent decays to leptons plus some amount of missing transverse energy (generally less than that from squark gluino decays).

One of the major analyses that UTA has been leading is the search for pair production of the lightest chargino and next-to-lightest neutralino states of the Minimal

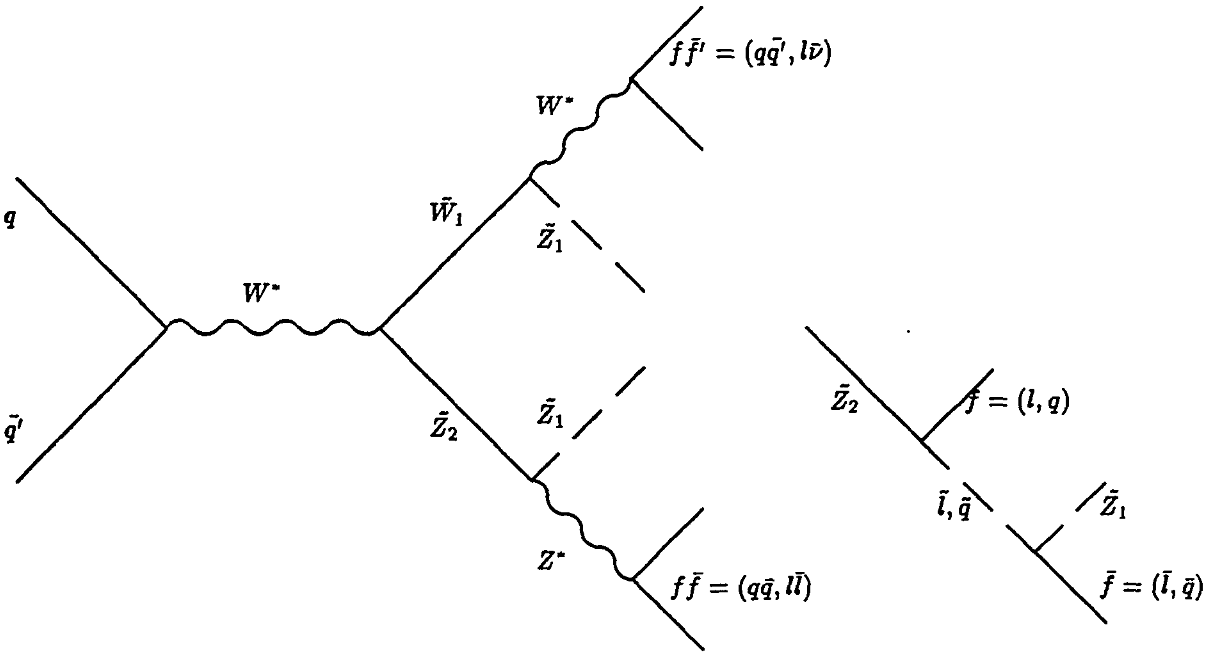


Figure 2.2: Production and decay diagrams for $p\bar{p} \rightarrow W^* \rightarrow \tilde{W}_1\tilde{Z}_2$

Supersymmetric Standard Model. Production at the Tevatron proceeds via quark antiquark annihilation into a virtual W boson (the dominant process at the Tevatron – see Fig. 2.2), or via a t-channel squark graph.

Production cross sections are predicted to be between 100 to 1 pb for masses between 45 to 100 GeV/c^2 [1][2], and thus may be accessible for Run Ia at the Tevatron. The decays of the $\tilde{W}_1$ and $\tilde{Z}_2$ produce final state topologies with various combinations of leptons and jets; the present search centers on a trilepton final state characterized by three isolated leptons and little hadronic activity (any jets in these events are presumably from initial state radiation). Since this channel is relatively free of Standard Model backgrounds it is a very promising mode in which to search for new physics. Additionally much of the SUSY parameter space favors these low-mass chargino- neutralino states. There is considerable optimism that the initial experimental signatures of supersymmetry are likely to come from precisely this type of search [3].

One of the major components of this analysis has been the determination of efficiencies for low momentum leptons. Figure 2.3 shows the p_T distributions of the three leading leptons from an ISAJET [6] Monte Carlo simulation of wino-zino events subsequently processed with the full detector simulation D0GEANT and the reconstruction program D0RECO (the $\not{E}_T$ is shown for the *eee* channel; a cut on $\not{E}_T < 10$ GeV is made to reduce the background from Z/Drell-Yan events with a third lepton from γ conversions, jet fluctuations, etc.) As indicated in the plot, the third lepton (ordered in decreasing transverse momentum) is expected to be soft.

DØ has collected a large sample of Z boson events decaying to two electrons; such events are ideal for calculating electron identification efficiencies for high p_T objects. Unfortunately there is no comparable sample of low momentum electrons to use for estimat-

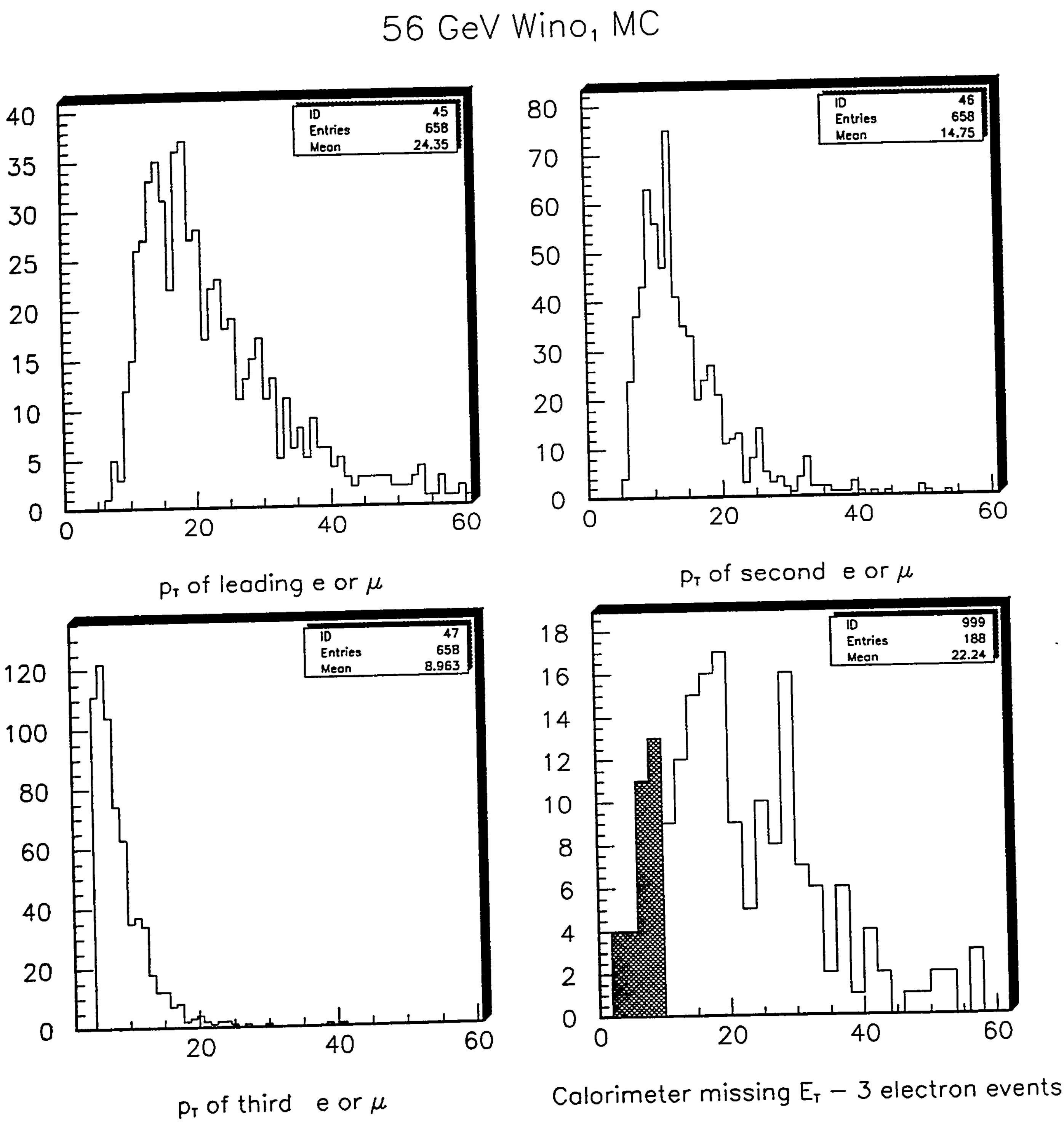


Figure 2.3: p_T distributions for the three leading leptons for $\tilde{W}_1\tilde{Z}_2$signal MC events, plus the $\not{E}_T$ in the eee channel. The mass of the $\tilde{W}_1$is 56 GeV/c^2 in these plots.

ing efficiencies at lower p_T . We have instead carried out extensive studies using plate geometry D0GEANT simulations of single electron tracks. The plate geometry provides the most accurate modelling of the DØ calorimeter; however, this level of detail comes at the expense of large amounts of computer CPU time. The UTALF farm was extremely useful for generating the plate D0GEANT simulations. Figure 2.4 shows the efficiencies for electron shower shape and isolation cuts as a function of electron p_T . The simulation results for high p_T indicate good agreement with electrons from Z's in data providing a useful check of our results.

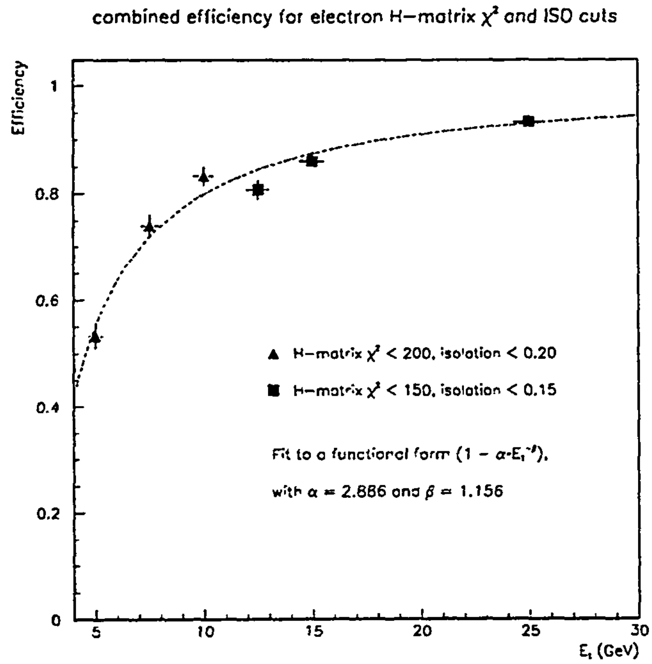


Figure 2.4: Efficiencies for electron shower shape and isolation cuts, derived from plate-level D0GEANT simulations.

Because Standard Model backgrounds are expected to be small compared to a trilepton signal, particularly in a search based on the amount of data in Run Ia, we have chosen to estimate backgrounds using data whenever possible. This method has the advantage that detector effects are automatically taken into account; such effects are difficult to fully model in a Monte Carlo simulation. As a result, we have concluded that the largest source of background to the three electron channel is Z/Drell-Yan events decaying to two electrons, plus a photon which converts to mimic a third electron. The "photon" in this case is either a real radiated photon, or a π^0 which decays into photons. The background estimate is made by counting the number of events in the entire Run Ia sample with $(N_e + N_g) \geq 3$, where N_e and N_g are the number of electrons and photons in the event, respectively, and then multiplying this number of events by the appropriate photon/π^0 conversion probability. A similar technique was used to estimate the background from Z/Drell-Yan events plus one or more jets, in this case using the probability of a jet fluctuating to look like an electron. Table 2.1 summarizes the background estimates in all of the channels from both instrumental sources, which are the main contribution, as well as real physics processes.

Background Process	eee Channel	$ee\mu$ Channel	$e\mu\mu$ Channel	$\mu\mu\mu$ Channel
Drell-Yan and $Z \to l\bar{l} + \gamma$	0.5	0.1	0.3	NA
Drell-Yan and $Z \to l\bar{l}$ + jet	0.2	0.1	0.1	–
$W^{\pm}$ + 2 jets	–	–	–	–
$WZ \to 3l$	–	–	–	–
$b\bar{b}$	–	–	0.1	0.1
QCD 3 jets	0.1	–	–	–
Total :	0.7	0.2	0.5	0.1

Table 2.1: A summary of sources of background to the $\tilde{W}_1\tilde{Z}_2 \to 3l$ search. Estimates are given for channels contributing 0.1 events or more per final state.

We have conducted a search of the entire DØ Run Ia event sample for evidence of trilepton events. No candidates have been found. A 95% C.L. limit, based on this search, has been set on the production cross section times the branching fraction into trileptons, as a function of the mass. This limit is shown in Figure 2.5. The search is currently being finalized and a draft paper Physical Review Letters has been produced. Preliminary results from this search have been presented by Mark Sosebee at the Gulf Shores Workshop on Fundamental Interactions, by Kaushik De at the Aspen Winter Workshop, and by Lee Sawyer at the Fermilab Joint Theoretical and Experimental Seminar.

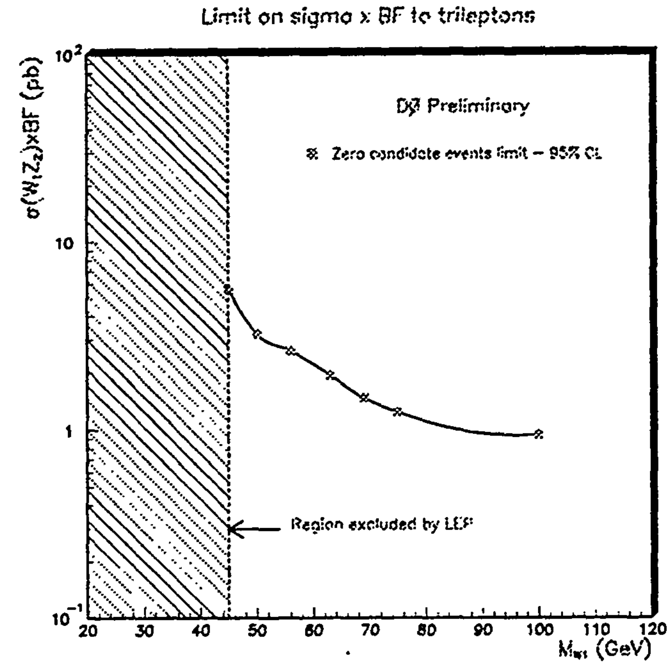


Figure 2.5: Limit on $\sigma \times BF$ for the process $\tilde{W}_1\tilde{Z}_2 \rightarrow$ 3 leptons.

SUSY multilepton channels

Traditionally, SUSY seaches for squarks and gluinos have concentrated on events with large $\not\!\!E_T$ and many jets. This technique provides the highest limit on squark and gluino masses with limited data samples. However, this technique also requires a careful calucula-tion of background. The signal to noise ratio is at best unity. An alternative technique [4] holds great promise with the increased data sample expected by the end of Run I. In this technique, we require two leptons and $\not\!\!E_T$. The only background comes from top quark decays. Currently, UTA is involved in the search for these 'gold-plated' SUSY decays along with physicists from the Tata Institute of Fundamental Research and Michigan State University.

TeV2000 SUSY Working Group

The TeV2000 group was formed at a special ad hoc meeting in Ann Arbor organized by Dan Amedei and Chip Brock on October 22-24, 1994. The meeting was attended by members of the DØ collaboration, the CDF collaboration, theorists, members of the Fermilab accelerator division, and the Fermilab directorate (John Peoples and Ken Stanfield). The primary goal of this group is to study the physics possibilities, and recommend the future directions at the Tevatron beyond the year 2000.

Three distinct topics emerged as crucial for physicists to study at the Tevatron during and after Run II: the top quark, low energy Supersymmetry, and low mass Higgs. Because of the strong interest in SUSY at UTA, Kaushik De was chosen as one of the two convenors of the SUSY working group. Since October, the SUSY working group has met on numerous occasions and the work is progressing rapidly towards a written document by summer 1995.

The case for low energy SUSY has never been stronger. Precision LEP results show the first evidence for unification of the three coupling constants α_1, α_2, and α_3 at the GUT scale if superpartners are present. The three couplings diverge if only Standard Model particles are present in the renormalization group equations. Furthermore, the elegant solution to the "fine tuning" problem provided by SUSY and the natural choice of the lightest supersymmetric particle for cold dark matter continue to make low energy SUSY one of the prime candidates for physics beyond the Standard Model.

In order to connect to the electroweak scale while preserving the fine tuning solution, it is expected that low energy SUSY particles should occur in the mass range of 100 GeV/c^2 to 1000 GeV/c^2. The squarks and gauginos are expected to occupy the high end of the mass spectrum. The charginos and neutralinos should have masses one-half to one-third that of the squarks and gluinos. Because of their light mass, there is a good chance for the discovery of SUSY at the Tevatron via the trilepton decay mode of these particles.

The TeV2000 group is working with the TEV33 accelerator design group at Fermilab to study the physics possibilities for upgrading the Tevatron to run at 10^{33} cm^{-2}s^{-1} instantaneous luminosity. At this luminosity, two years of data at the Tevatron can lead to the discovery of SUSY over 95% of the allowed parameter space if the sign of μ (μ is the Higgsino mass mixing parameter in SUSY models) is negative. A substantial region of the parameter space is also accessible for positive values of μ.

Rapidity gaps

The study of interactions produced by QCD processes generated enthusiasm with DØ's discovery of rapidity gap events [5]. These events are believed to be mediated by color singlet exchange. UTA's contribution to this effort has focussed on understanding the QCD background to this signal. In order to accurately assess the low multiplicity excess, work has been done in trying to model the color octet multiplicity distribution using various Monte Carlo generators. Empirically, a negative binomial distribution fits the color octet multiplicity well. However, there is no sound theoretical reason why any statistical distribution should be preferred. Therefore, Monte Carlo studies have become increasingly important. Several Monte Carlo data files have been generated with competing generators (Herwig, Pythia, and Isajet) and some of these simulated runs have been processed through the detector simulation, and we are in the process of generating a larger event sample. Once this has been done, we can look at detector efficiencies, study the correspondence between particles and calorimeter towers, and determine whether the inclusion of particle tracking increases detection efficiency.

The future direction of this analysis involves continued attempts to provide information for theory with the observed cross-section, and to examine these events for characteristics other than the gap that distinguish these events from conventional color-exchange processes. We have primary responsibility for this effort. The present trigger is not prescaled and is biasless (i.e. it does not require a gap), but the jet threshold is efficient for jet $E_T > 30$ GeV. To acquire more statistics, a new trigger is being implemented that does require a gap and in this way we are able to require a lower jet E_T threshold. (The behavior of the rapidity gap production as a function of E_T is also of interest.) The studies to be conducted with the present and coming data sets are discussed in the section below on proposed activities.

Exclusive Techniques

We are initiating an analysis thrust within the QCD group. The goal of this initiative is to develop techniques for *exclusive* analyses. This project is in its infancy and is therefore described in greater detail below in the section on proposed future activities. Essentially the idea is to differentiate between the hard primary scattering and soft underlying event (or beam jet) in $p\bar{p}$ interactions enabling the calculation of the center of mass energy, $\sqrt{\hat{s}}$, of the primary scattering. The development of these techniques allows access to a host of other important topics in QCD and New Phenomena.

We have investigated four distinct approaches to the problem of a) assigning specific tracks or showers to either the primary scattering or the beam jets, b) weighting individual tracks/showers as a measure of the degree to which they participate in the primary scattering or beam jet, or c) predicting the content of the event which is lost down the beam pipe. These approaches include a straightforward new jet-finding algorithm, the K_T or Durham algorithm [7]; a maximum likelihood approach to pattern recognition; the use of a neural network; and, application of a pattern recognition technique used in nonlinear dynamics, time-ordered series.

In FY'95, as well as studying the prospects and techniques involved in each of the techniques, we have begun implementation of the K_T/Durham jet finding algorithm for exclusive purposes. This algorithm is a successive combination approach which mimics the physics sequence of fragmentation: merging proto-jets which are close in both configuration and phase space. A sub-group of DØ colleagues has already implemented a simplified version of the algorithm which neglects the beam jets [8]. This serves as a natural starting point: working both in service for the DØ QCD group to study differences in the cone and K_T algorithms (of particular interest are differences between the two algorithms in cross section and energy scale) and to demonstrate the feasibility of the exclusive analysis. Thus, we are studying the ratio of inclusive single jet cross sections for the two algorithms. The QCD group expects the K_T algorithm to ultimately replace the cone algorithm as the utility of the cone algorithm is exhausted. The K_T algorithm is finding favor in the study of subjets/fragmentation, angular ordering of jets, and color flow. As this menu expands, the demand for understanding the jet energy scale with this algorithm will increase. Our study comparing the K_T with the cone algorithm will address and solve this problem.

2.2.3 External Activities

- Andrew White was Chairman of the 1995 Aspen Winter Conference on "Heavy Quarks, Heavy Leptons, and Massive Neutrinos".

The following conference presentations were also made:

- May 1994 – "Search for Trilepton Events With the DØ Detector", Lee Sawyer, SUSY '94 Meeting, U.Michigan, Ann Arbor.

- August 1994 – "Summary talk on Search for New Phenomena", Andrew White, DPF meeting, U.New Mexico, Albuquerque.

- September 1994 – "Search for Supersymmetry and Top in the DØ Experiment", Andrew White, US-Polish Workshop on "Physics from Planck Scale to Electroweak Scale", U. Warsaw, Warsaw, Poland.

- September 1994 – "The D0 Detector", Kaushik De, Conference on the Application of Accelerators in Research and Industry, U.North Texas.

- September 1994 – "The Large Hadron Collider Project at CERN", Andrew White, Conference on the Application of Accelerators in Research and Industry, U. North Texas.

- September 1994 – "A Proton-Proton Elastic Scattering Experiment at RHIC" to the Eleventh International Symposium on High Energy Spin Physics and the Eighth International Symposium on Polarization Phenomena in Nuclear Physics which was held in Bloomington, Indiana.

- October 1994 – "Top Quark Search Results from DØ", Elizabeth Gallas, Texas APS Meeting, U.Texas at Austin.

- October 1994 – "Search for Wino-Zinos in DØ", Mark Sosebee, Poster session, Texas APS, Meeting, U.Texas at Austin.

- October 1994 – "Search for Squark/Gluinos in DØ", Lee Sawyer, Poster session, Texas APS Meeting, U.Texas at Austin.

- January 1995 – "Search for Supersymmetry at the Tevatron", Kaushik De, Aspen Winter Conference on Elementary Particles.

- January 1995 – "SUSY Searches Using the DØ Detector at the Tevatron", Mark Sosebee, 4th Annual SAHEP Gulf Shores Meeting, Gulf Shores, AL.

2.2.4 ICD Detector Support

Description of the ICD

The DØ liquid argon calorimeter system is contained in three separate cryostats. The central cryostat (CC) provides complete electromagnetic and hadronic sampling in the pseudorapidity ($\eta \equiv -\ln\tan(\theta/2)$) region $-0.8 < \eta < 0.8$. The end cryostats (EC) provide full sampling in the region $1.4 <| \eta |< 4.0$. The intermediate region $0.8 <| \eta |< 1.4$ is covered partially by modules in the central cryostat and partially by overlapping modules in the end cryostats.

Due to the triple-cryostat design of the DØ calorimeter, there is substantial unsampled material in the intermediate region, which degrades energy resolution. In order to solve this problem, additional layers of sampling are introduced in DØ between the cryostats [10]. One layer is inside the central cryostat and called the central massless gaps (CCMG). Another layer is inside the end cryostat and referred to as end cryostat massless gaps (ECMG). A third layer of scintillator sampling used between the cryostats is called the Inter-Cryostat Detector (ICD). The ICD is attached to the exterior surface of the end cryostats.

With a 0.1×0.1 segmentation in η and ϕ (azimuthal angle), the ICD comprises of 768 channels. Each channel is composed of a scintillator plate, wave- shifting fibers, PMT, voltage divider, charge integrating amplifier, digitization electronics, charge pulser, laser pulsing system and readout electronics. Three channels are housed in a single box. Pictures of ICD boxes are shown in Fig. 2.6.

There are 256 boxes covering the faces of the two end cryostats. Power distribution patch panels, pulser fanouts and other electrical support systems are placed in racks underneath the detector. Readout of the electrical signals is integrated as part of the liquid argon calorimeter ADC-BLS readout system. A laser calibration system is implemented in the moving counting house.

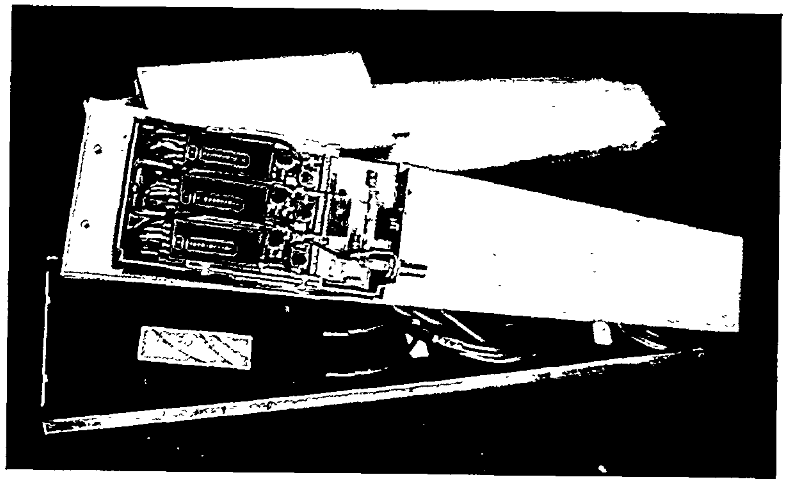
ICD Operation

The responsibility for day-to-day operation and maintenance of the ICD detector in DØ during Runs Ia and Ib has been shared by the UTA and University of Michigan groups. This work includes ensuring that the ICD is operating properly during the run, plus any corrective actions that must be carried out during accelerator downtime when the detector is available for maintenance and/or repairs. Our work during the past year (Run Ib) has included: 1) extensive high voltage repairs necessary after the discovery of a moisture condensation problem in the high voltage racks; 2) rebuilding problem channels in the outer ICD modules by replacing the original PM60 photomultiplier tubes with superior Hamamatsu R647 PMT's.

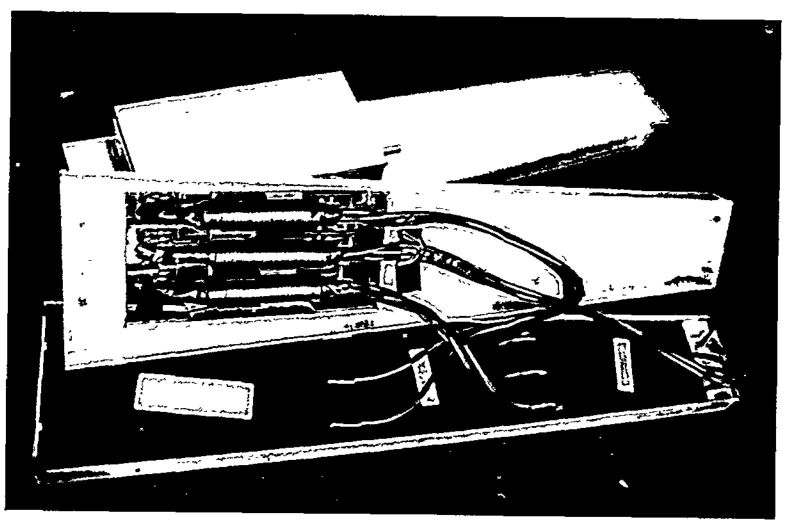
Most of the Run Ib ICD repair work was carried out during the February 1995 accelerator shutdown period at Fermilab. In addition to PMT replacement we performed troubleshooting procedures on several other ICD channels, making any necessary repairs. Finally, as a result of replacing PMT's and other modifications made to the ICD, it was necessary to obtain an up-to-date set of calibration constants to reflect these changes. These calibration constants are determined from cosmic ray runs using a test stand we have set up at Fermilab. The cosmic ray data is collected and stored on a PC. We fit the data to a Landau distribution [9] to obtain the most probable response, the 'MIP peak'. Figure 2.7 shows the change in gain for a sample of Hamamatsu R647 PMT's tested during the shutdown period; these tests provide useful information about the long-term stability of the ICD. Such information has been utilized to periodically modify the ICD calibration constants over the course of Runs IA and Ib. When accelerator operations resumed at the conclusion of the shutdown, ICD performance had been restored to an optimal level, in anticipation of the second half of collider Run Ib.

UTA has maintained a long-standing commitment to understanding DØ calorimetry, especially in the inter cryostat region (ICR). Prompted by the DØ upgrade review in January 1995, a number of studies were undertaken to better understand the importance of the ICD relative to the overall calorimetric measurements in the ICR during Run I.

The ICR detector elements include the ICD and the massless gaps (MG) in the central calorimeter (CCMG) and the endcap calorimeters (ECMG). Previous studies looked at the combined contribution of all the ICR detectors (the ICD and MG's) to jet energy



A. ICD Electronics Layout



B. ICD Phototubes, fibers and scintillators

Figure 2.6: View inside the ICD boxes used in Run I of D0.

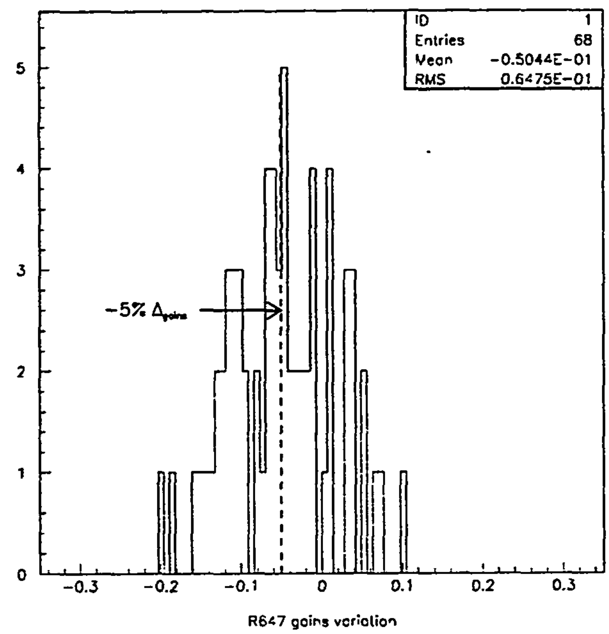


Figure 2.7: Variation in gains for a sample of Hamamatsu R647 PMT's over an extended period of running.

measurement resolution. The ICD, as it exists in the Run I detector, will not operate in the high magnetic field environment of the Run II detector. The two studies described here focus solely on the importance of the ICD in the ICR.

Missing Transverse Energy Resolution

The measurement of missing transverse energy ($\not\!\!E_T$) is of paramount importance for a broad range of physics topics studied using the DØ detector. DØ note 2494 [11] demonstrates the contribution of the ICD to the DØ detector's $\not\!\!E_T$ resolution using data collected in Run I. Missing transverse energy resolution, by its nature, is inherently a difficult quantity to measure directly since one never knows exactly how much $\not\!\!E_T$ a given event should have. QCD events, however, are expected to have very little inherent $\not\!\!E_T$. Missing transverse energy seen in these events is dominated by detector sources of $\not\!\!E_T$, or 'fake $\not\!\!E_T$ ', caused by energy resolution fluctuations or incompletely instrumented regions of the detector. Two distinct QCD data samples were used to study the $\not\!\!E_T$ resolution; however, results from only one of the samples will be presented here.

QCD multijet event samples were used to study the $\not\!\!E_T$ resolution. Events were required to satisfy one or more level 2 jet triggers with E_T thresholds ranging from 20 to 85 GeV. Events classified as multiple interactions were rejected. Offline, the events were required to have 2 or 3 jets with a cone size of 0.5. The jets were not required to be in the ICR. The contribution of the ICD to the $\not\!\!E_T$ resolution was studied by comparing the measured $\not\!\!E_T$ with and without the ICD information. The sampling weights were reoptimized to provide the best response without the ICD. Results demonstrate that the measured $\not\!\!E_T$ without the ICD information was systematically higher than that measured with the ICD for events with $\not\!\!E_T$ measurements above 15 GeV. This can be expressed directly as an increase in the rate of fake $\not\!\!E_T$ as shown in Table 2.2. For example, the

QCD multijet events			
$\not\!\!E_T$ threshold	number of events with $\not\!\!E_T$ > threshold		% increase in fake $\not\!\!E_T$ rate
	with ICD	w/out ICD	
20 GeV	1871	2218	19%
25 GeV	916	1200	31%
30 GeV	488	703	44%
35 GeV	271	424	57%
45 GeV	107	166	55%

Table 2.2: For the QCD multijet sample, this table shows the increase in the rate of fake $\not\!\!E_T$ as a function of $\not\!\!E_T$ due to removal of ICD information.

number of events with $\not\!\!E_T$ above 20 GeV jumps from 1871 events with the ICD to 2218 events in the absence of the ICD. This represents a 19% rise in the rate of fake $\not\!\!E_T$ above 20 GeV. As indicated in the table, rates of fake $\not\!\!E_T$ rise with $\not\!\!E_T$ threshold, reaching 55 to 60% for $\not\!\!E_T$ thresholds of 35 to 45 GeV.

Additional studies were performed requiring one jet to be in the region covered by the ICD. For these data samples, the increase in rate of fake $\not\!\!E_T$ is more than a factor of 2 higher than the rate increases shown in Table 2.2. Therefor, without the ICD, we observe a large increase in the rate of fake $\not\!\!E_T$ at $\not\!\!E_T \geq 15$ GeV for events with jets in the ICD region as well as for events in general.

The conclusion of these studies is that the ICD played a crucial role in preserving the hermeticity of the DØ detector in Run I, and that it must be rebuilt in the interest of maintaining Run I $\not\!\!E_T$ resolution in the post Run I era.

Energy Resolution in the ICR

The ICD and Massless Gaps (MGs) augment the energy measurement in the pseudorapidity region $\eta = 0.7$ to 1.4. This is a difficult region in which to measure jet energy because of the reduced EM sampling between $\eta = 1.1$ to 1.4 and the non-uniform energy deposition as a function of eta due to the cryostat knuckle on each end of the CC, and other dead material. The combination of the ICD and MGs serves to sample showers which might otherwise be lost in the dead material.

Test beam data seems more ideal for gauging a calorimetric energy measurement since the known beam energy serves as a benchmark against which the detector response may be compared. However, jets in real DØ collider events fragment differently than single pions, so a study of jet energy resolution using a sample of real jets should be included. Previous results have been presented demonstrating the combined effect of the ICD and MG's using test beam pion data. This new study, summarized in DØ Note

2519 [12], investigates the independent contribution of the ICD to the energy resolution using test beam data as well as collider data.

The test beam data used was from 100 GeV pion runs. Using collider data, there is no independent measurement of particle energy to repeat this technique in situ. However, with some loss in resolution, a well measured jet in the CC can serve as the known jet energy for a balancing jet in the ICR. Therefore, the collider data used for this study was a QCD dijet sample that had events which satisfied a level 2 jet filter with an E_T threshold of 50 GeV. In addition, we required identically 2 jets in the event, with one jet central ($|\eta| < 0.6$) and one jet within the ICD region ($0.8 < |\eta| < 1.4$). The opening angle $\Delta\phi$ between the 2 jets was $> 160°$. The central jet was required to have a jet E_T in the range 54 to 62 GeV, and matched a level 2 jet within $\Delta R < 0.15$ and $\Delta E_T < 15\%$. In this situation, the transverse jet energy of the ICD jet should balance that of the central jet.

The contribution to jet energy measurements from the ICD was studied by comparing jet energy measurements with and without the ICD information, readjusting the sampling fractions appropriately. For the test beam and DØ collider data sets, the distribution of measured jet energy was compared with and without ICD information.

Table 2.3 summarizes the fractional energy resolution $\frac{\sigma}{\sqrt{E}}$ for the two configurations as well as the change in the resolution upon removal of the ICD for both data sets. As

Energy Resolution by η bin in ICR						
η	100 GeV test beam pions			DØ collider QCD dijet events		
bin	with ICD	w/o ICD	Δ%	with ICD	w/o ICD	Δ%
0.85	94%	106%	+12	109%	116%	+7
0.95	102%	121%	+20	94%	104%	+10
1.05	119%	128%	+10	114%	120%	+6
1.15	163%	184%	+21	110%	124%	+14
1.25	104%	179%	+74	119%	144%	+25
1.35	112%	227%	+115	102%	146%	+44

Table 2.3: Summary of jet energy resolution for 100 GeV test beam pions and QCD dijet events with and without the ICD by η bin.

expected, the effect of removing the ICD is most pronounced for the 3 innermost eta bins ($1.1 < \eta < 1.4$), as the coverage of the MG's is incomplete in this region and the contribution from the ICD more crucial.

By removing the ICD readout and reoptimizing the sampling weights for the MG's we have been able to study the contribution of the ICD to the energy resolution in the ICR. The trend of worsening energy resolution after the removal of the ICD is consistent in both test beam and QCD dijet data. The magnitude of the degraded resolution is not as large for jet data compared to test beam pions since jets are broader objects (for this analysis we used a cone algorithm with R = 0.5), and hence the effect is spread out over many cells. However, as a result, the effect of the ICD is felt by jets which are not centered on the ICR.

In conclusion, the ICD plays an important role in jet energy resolution and uniformity, and therefore it must be rebuilt in the interest of maintaining jet energy resolution in the post Run I era.

2.2.5 ICD/EMICD Upgrade

The ICD upgrade review committee recommended the replacement of the ICD for Run II based on the presentations during the January 1995 ICD review by DØ. All the presentations at the review were made by members from UTA. Since the inner etas play a much more dramatic role as shown above, it was decided to replace only the inner ICD covering $1.1 < |\eta| < 1.4$. The primary goal of this upgrade is to move the PMTs to a region of reduced magnetic field. The scintillator tiles and all the electronics will also be rebuilt. Additionally, simulation studies are underway to determine if the ICD should be expanded to cover $1.4 < |\eta| < 1.7$ in order to provide extra sampling in the region where dead material will be introduced by the solenoid cryostats and fiber cables and connectors for the new central tracker.

Since the upgraded ICD will be enveloped in a large magnetic field, we are studying the response of PMT's in large magnetic fields with various shielding configurations. We have borrowed a large dipole magnet (from an NMR lab) and developed a light tight device to hold the tubes between the poles. The data acquisition system for these measurements consist of NIM and CAMAC logic modules interfaced to a PC. Measurements of the relative gain as a function of **B** and (θ, ϕ) with respect to the tube axis, will determine the optimal shielding configuration and spatial orientation for the tubes. This test stand is also being used to test the response of PMT's for the DØ muon upgrade and to confirm measurements of the ATLAS TileCal mesh dynodes. We are also testing the mesh dynode PMT, Hamamatsu's R5600, which was considered for the DØ upgrade.

We had proposed a new electromagnetic ICD (EMICD) detector to DØ in 1994. This detector would have covered the same region as the inner ICD. Using alternate lead scintillator layers, it would have provided electron identification and energy measurement in the ICR region. Various GEANT simulation studies were carried out at UTA to evaluate the performance of this detector. After the January review, DØ management decided not to pursue this detector for Run II. The design and performance characteristics of this proposed detector are detailed in DØNote #2281 [17].

To summarize the performance of the EMICD, we quote some numbers from the initial simulation studies performed at UTA using the upgrade DØGEANT. We found that with a simple algorithm, we could achieve 100% electron identification while achieving fake pion rejection at the level of one in 50 for $1.0 < \eta < 1.1$ with the EMICD. Of course, without the EMICD, there is no electron identification in this region and physics analyses have to suffer the loss of electrons in this 'hole'. Using the same algorithm gave us a rejection of one in 67 for the adjacent η bin using the liquid argon electromagnetic calorimeter. Therefore the performance of the proposed lead scintillator based EMICD is comparable at this level of simulation to the standard DØ electromagnetic calorimeter. For the next two η bins we were able to achieve 90-95% efficiencies with rejection factors about 50 with the EMICD.

2.2.6 Forward Pre-Shower Detector and Forward Study Group

In addition to planning upgrades for the intermediate eta region of the DØ detector, UTA was also involved in planning for upgrades to tracking and calorimetry in the forward region. Members of the UTA high energy group served on the forward study group, which was charged with itemizing the physics arguments for forward tracking and a forward preshower detector. A proposed scintillator-based forward preshower detector was included in the upgrade proposal [17] submitted to the DØ management. UTA led the initial work needed to develop this proposal.

Although the concept of a forward preshower detector has been accepted by DØ, no decision on hardware implementation has been reached. UTA is still actively involved in reaching this decision, both by spearheading the effort to include a preliminary forward preshower detector in the upgrade detector simulation, as well as by prototyping scintillator strip detectors similar to the design proposed to the collaboration.

There are two competing proposals for the forward preshower detector technology. The UTA proposal to build a scintillator strip detector was developed in collaboration with the University of Rochester. Other interested collaborators include Florida State University, SUNY at Stony Brook and the Tata Institute for Fundamental Research.

The alternative detector design uses MicroStrip Gas detectors. This proposal is led by BNL and SUNY at Stony Brook. Once the detector decision is made, UTA will consider whether or not to participate in the construction of the detector based on other current and future committments.

Extensive simulation, prototype and detector development work have been carried out at UTA to prepare the proposal for the ICD, EMICD and forward preshower upgrades. Many data acquisition systems were set up to help with this work. The studies are documented in DØNote #2281 and DØNote #2338 [18].For the sake of brevity, they will not be repeated here. The studies performed for the DØ proposal formed a large fraction of our activities at UTA in 1994-95.

2.2.7 Software Development

Tracking Muons in the Calorimeter

Last year, we reported on a significant new software package for DØ data analysis developed entirely by UTA personnel for muon tracking in the calorimeter. The MTC (Muon Tracking in the Calorimeter) package uses calorimeter information to identify and reconstruct track-like energy deposition in the calorimeter. DØ note 2066 [13] describes how to use the MTC package and provides a description of the algorithms used in the package.

The MTC package became available and was integrated into the DØ event reconstruction (RECO) processing package during the period between Run Ia and Run Ib data taking. All processed Run Ib data contains MTC information, including muon identification and tracking for all candidate tracks.

Prior to RECO V12, the global fit incorporated muon track and central detector (CD) muon track matching only. Due to CD track match inefficiency, muon global fit efficiency was about 81%. Post RECO V12.12_07 processing incorporates MTC track fitting information into the global fit for tracks which miss a matching CD track or have a global fit $\chi^2/\text{ndf} > 50$. With the use of MTC tracking, the global fitting efficiency has risen to nearly $98 \pm 1\%$ [14]. Shown in Figure 2.8 a) and b) is the muon momentum resolution for tracks fitted with the CD and MTC, respectively. Muon momentum resolution is similar for both cases, and agrees with the expected functional form indicated by the solid line.

MTC will have an impact on every Run Ib muon analysis since it has been incorporated into the algorithm for the global fitting of muons in the DØ detector. In addition, a number of Run Ib analyses are planning the use of MTC track verification information. These analyses include topics in all the major physics groups (Top, W/Z, b, New Phenomena, and QCD). The current success of the package has led to a plan to upgrade the MTC package for use in Run 2. Since UTA personnel were solely involved in the development of the package, we expect to play a large part in all future developments.

New Software – MTC in Trigger Level 2

Online triggering on muons in the DØ detector has been problematic due to a number of expected and unexpected difficulties with the muon system. The Muon Tracking in the Calorimeter Level 2 (MTCL2) utility is a streamlined version of the MTC μ identification utility for verifying candidate muons in the calorimeter: it was rewritten specifically to operate in the trigger level 2 environment (L2) with output appropriate for triggering purposes. It is intended to surpass the information provided by the current standard for L2 calorimeter muon confirmation (L2CC) in order to improve muon triggering decisions.

DØ note 2195 [15] describes the algorithms used in the utility, and presents the results of timing, efficiency and rejection studies using the utility in the WAMUS (Wide Angle MUon System) CF ($|\eta| < 1.0$) and WAMUS EF ($1.0 < |\eta| < 2.4$) regions. Optimal running minimizes execution time while maximizing rejection and efficiency. Each of these performance issues are addressed in the note, and a particular emphasis on the comparison of MTCL2 with L2CC results is made. This package was developed by UTA, with assistance in running the Level 2 simulator from Tom Fahland, a graduate student at Brown University.

Information from L2CC is a simple sum of the energy measured in the calorimeter cells about the path of the candidate track. MTCL2 provides additional information by exploiting the fact that muons deposit minimum ionizing energy over the total path length. The calorimeter hermeticity insures a uniform verification efficiency as a function of pseudorapidity and azimuthal angle with no gaps in coverage. Good rejection is possible because the calorimeter depth (7-9 interaction lengths) insures that penetrating particles (e.g. muons) are well isolated in the hadronic section of the calorimeter. Results show that the MTCL2 is able to more consistently able to verify tracks because it has the ability to recognize tracks using the pattern of hit cells in a larger tower about the candidate muon.

Unlike MTCL2, the L2CC algorithm looks in a calorimeter road about a candidate track specified by a direction in η and ϕ from a particular vertex position. This makes L2CC sensitive to vertex uncertainty. The MTCL2 utility is not expected to be vertex dependent and is therefore more appropriate for use in a high luminosity environment.

Both the rejection and efficiency studies were carried out using the Level 2 simulator. The efficiency is defined as the fraction of muons passing the utility criteria out of all

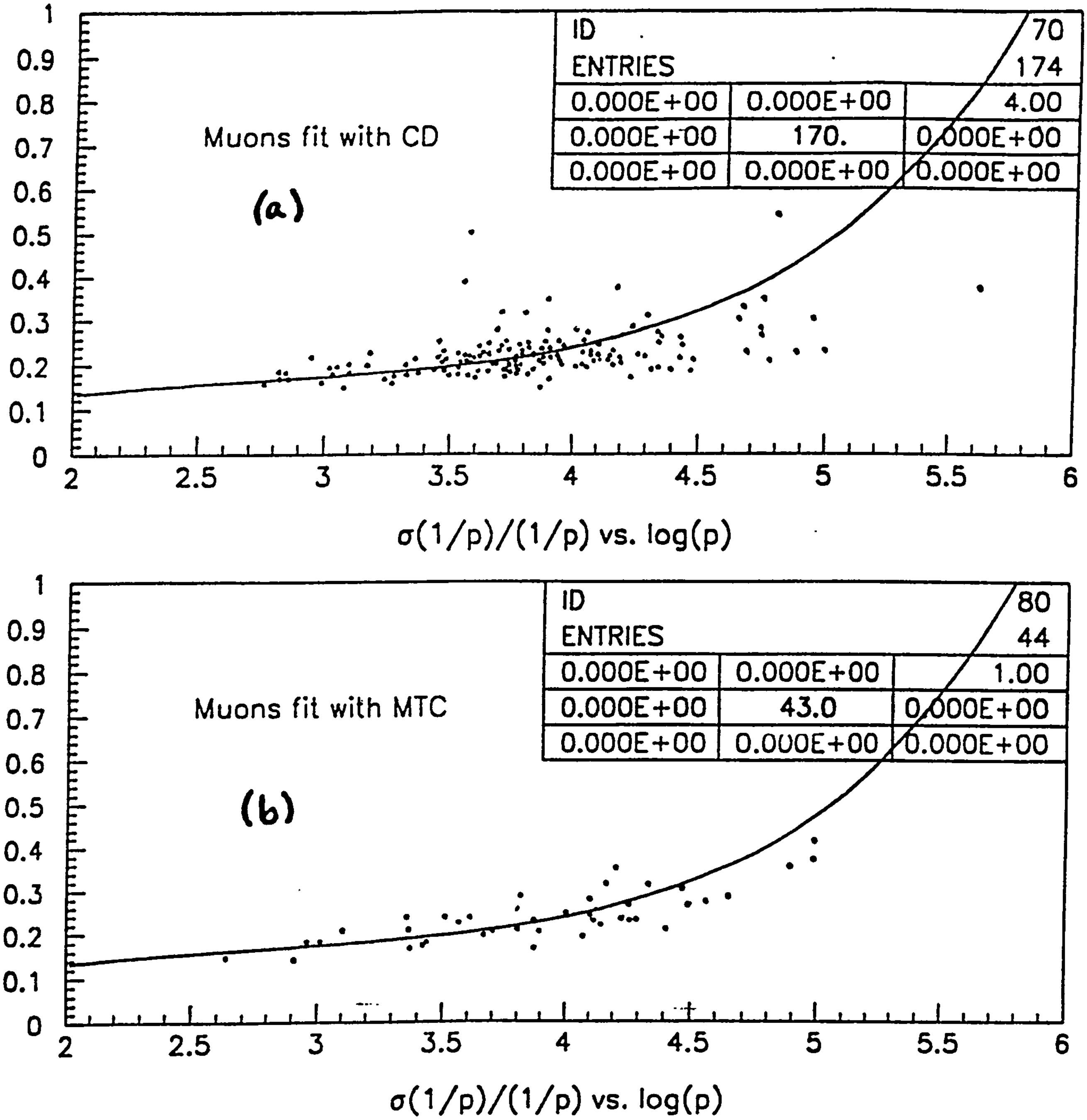


Figure 2.8: Muon momentum resolution for tracks fitted with central detector and MTC information.

muons in the sample passing a set of good muon criteria. We define the rejection as the inverse of the fraction of input candidates passing the specified criteria.

Results have shown that the MTCL2 and L2 calorimeter confirmation utilities require about the same execution time per candidate. Therefore, the utilities and cuts can be compared solely on the basis of efficiency and rejection. Shown in Figure 2.9 a) is the rejection versus the efficiency seen for a sample of Run Ib data containing muons for a number of utility/cut variations as indicated. Our estimate of the L2CC efficiency and rejection, obtained using the L0 vertex, are also shown for comparison.

Muon verification efficiency is ideal for L2CC as well as for the minimal to moderate MTCL2 cuts. However, the rejection is higher for all MTCL2 cuts evaluated in comparison to the L2CC utility. Most notably, an efficiency of 100% and a rejection of a factor of 6.65 can be obtained using the MTCL2 conditions that the fraction of hadronic calorimeter layers hit be > 0.75 and $E^{min} > 0.75$ GeV. This is a factor of 3.5 better in rejection than that obtained using the L2CC utility.

Also notable on this plot is the point representing an MTCL2 fraction of hadronic layers cut of 1.0. Although the efficiency has dropped to 94%, the rejection jumps to 13.9, which is a factor of 7.4 greater in rejection than L2 calorimeter confirmation. This may be considered as a viable option if the rate of fake tracks in the EF region cannot be controlled in any other reasonable manner in the post–February '95 shutdown running period. Shown in Fig. 2.9 b) is the rejection vs. efficiency for muons in the CF region.

We have therefore shown that the MTCL2 utility, with moderate cuts, can verify/reject muon candidates at trigger level 2 with high efficiency and better rejection in comparison to the currently used L2CC utility. Increases in rejection are large in the WAMUS EF region, and more moderate in the WAMUS CF region.

MTCL2 has been incorporated into L2 muon triggers in the EF region for the post February 1995 shutdown running period. Results are forthcoming.

Trigger Verification

Within the last year, DØ has established an online verification of the various levels of the triggering system. This verification consists of checking for agreement between the hardware electronics that make up the triggering system and a detailed simulation of the triggering system. Agreement between hardware and simulation is critical for our understanding of trigger acceptances and efficiencies. Therefore, any discrepancies found by a verification routine indicates that there is a problem with either the hardware electronics or the programming of the trigger simulator.

UTA has been responsible for the development of the online verification procedure ANDOR_TEST. This routine compares the hardware and simulation values for the first level of the calorimeter trigger framework. The level one trigger consists of 256 logical bits that are used to comprise the various physics event triggers and filters. Within the past year, ANDOR_TEST has flagged events that produced discrepancies in bits 156 and 158. These differences corresponded to missing energy terms and were therefore of great concern. Investigation revealed a hardware problem that was subsequently repaired.

Currently, ANDOR_TEST is undergoing expansion to look at other level one information. The new L1_COMPARE will verify agreement between hardware and simulator calorimeter energies. We are adding comparisons of the total calorimeter energy sums, the

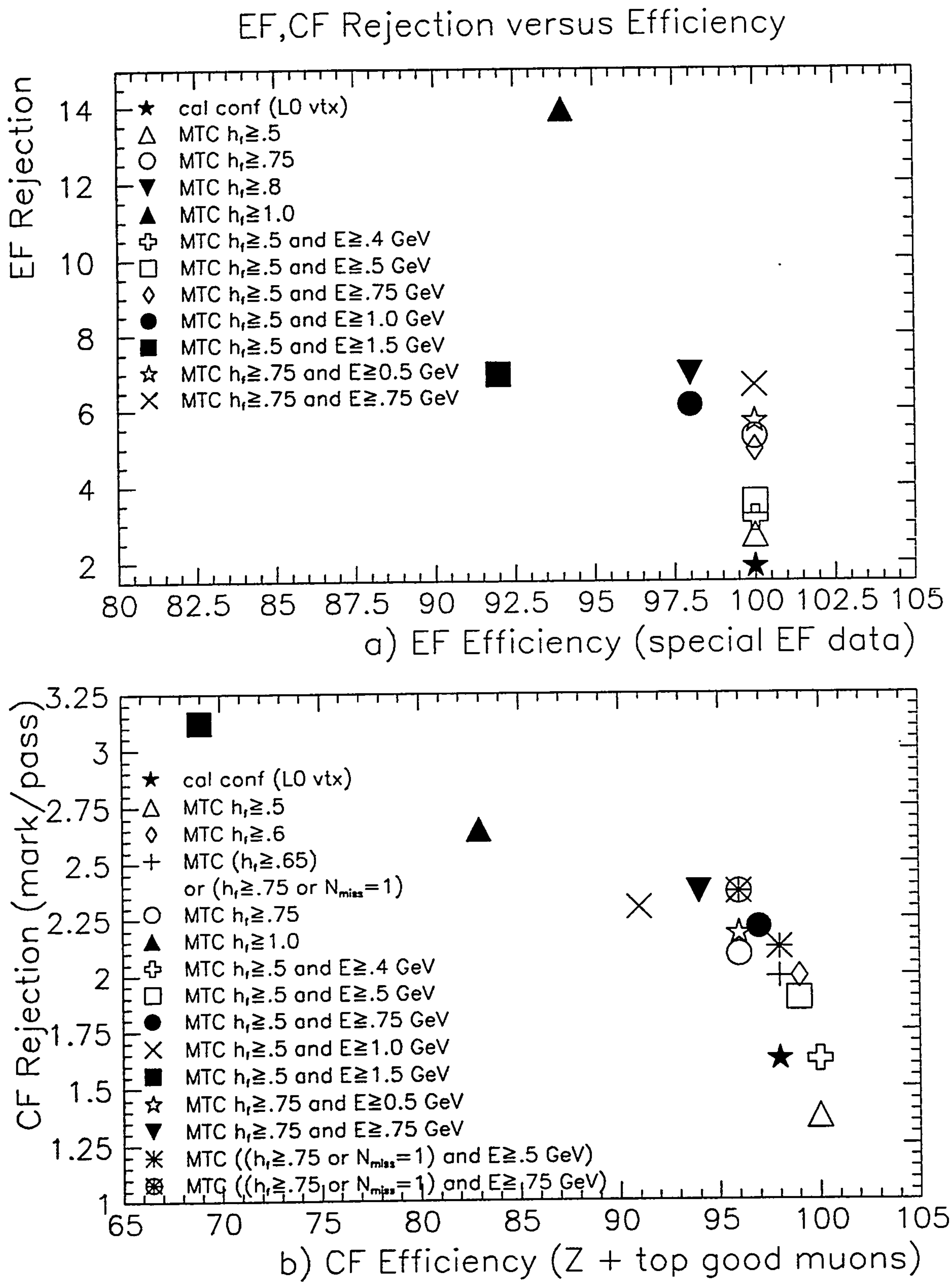


Figure 2.9: The rejection verses efficiency for a variety of MTCL2 cuts as indicated in the WAMUS a) EF and b) CF regions. Corresponding L2CC points are shown for comparison.

sums for the electromagnetic and hadronic calorimeter layers, and the total momentum components. Current testing has not revealed discrepancies among any of these values. Further additions to the routine will include comparison of the jet candidate bit strings. The final version of L1_COMPARE should provide excellent monitoring coverage for the level one trigger framework.

Luminosity Working Group

UTA has contributed to the DØ Luminosity Working Group and has been involved in current calculations of the luminosity monitor constant. Since all luminosity figures from which physics cross-sections are calculated are based on the level zero luminosity, determination of the cross-section sampled by the level zero trigger is of great importance. In the past, DØ has calculated its luminosities for the level zero trigger by using inelastic cross-section measurements of experiments E710 and CDF. In adopting the average between these two cross-section measurements, last year our sensitive cross-section was calculated to be 48.2 mb±12%. Approximation in the efficiencies for detecting single diffractive, double diffractive and "hard core" types of events are partly responsible for the cross-section's large error. However, these efficiencies can be much better understood with Monte Carlo simulation studies.

UTA updated the Minimum Bias Rockefeller (MBR) Monte Carlo generator (CDF note 256), and then created the data samples used in this analysis. The MBR generator was used to create samples of single diffractive, double diffractive, and "hard core" events. The MBR data, along with samples from another Monte Carlo generator, were then processed through a simulation of the detector geometry (D0GEANT), reconstructed using the standard DØ analysis code (D0RECO), and the efficiencies calculated. The resulting cross-section calculation is 46.7 mb ± 5.3%. The remaining error is dominated by the disagreement between the total cross- sections of E710 and CDF.

Modifications to the Upgrade Detector Simulation Package

As part of the development of a proposal for upgrading the intermediate and forward regions of DØ (described above), considerable modifications to the upgrade detector simulation package were made. The package, known as UPG_GEANT, is a GEANT-based [16] detector simulation program incorporating the proposed upgrade subdetectors for DØ. New subdetector packages were created for the EMICD and Forward Preshower subdetectors, while considerable modifications were made to the ICD detector description, in order to match the proposed upgraded detector. The Forward Preshower subdetector software has been recently incorporated into the release version of UPG_GEANT, and other modifications for the upgraded ICD will be released soon. These additions to the upgrade detector simulation are shown in figure 2.10.

Sofware Verification on the ALPHA's

In developing the UTALF farm as a resource for the DØ collaboration our group led the transportation of the DØ data reconstruction programs, D0RECO, from the VAX to the AXP platform. Despitė the fact that both run the VMS operating system, this was no

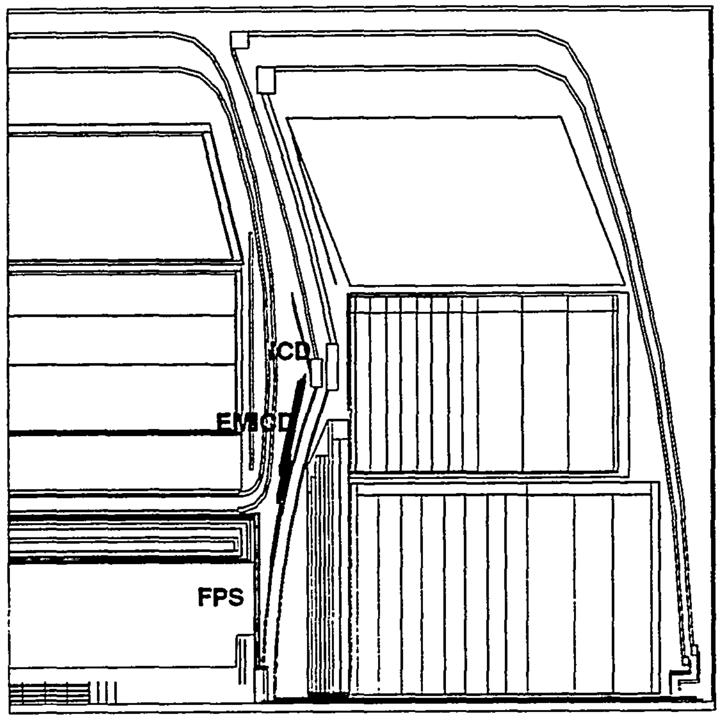


Figure 2.10: ICD and Forward Preshower modifications to the DØ upgrade GEANT.

simple task. Release of the code to the AXP cluster (and now the periodic release of newer versions), includes transporting the code from the DØ VAX cluster to the UTALF farm production area, making minor modifications to the source code for running on the AXP, building object libraries/executables, debugging the code – which includes some very subtle problem finding peculiar to 64 bit machines, performing a complete verification procedure, and, finally, releasing the code to the rest of the DØ Collaboration. We are also performing verification of the results of the Herwig Monte Carlo generator on the AXP platform.

In the larger context of participation in a DØ subgroup developing a full trigger/noise simulation package, we are currently porting the trigger simulation code, TRIGSIM, to the AXP platform. This is a particularly difficult project because TRIGSIM has gone through many modifications during data collection and the simulator must simulate each version according to run number, bugs included! In transporting the code to the AXP we invariably discover bugs which must be fixed in order to build a functioning executable. Thus we are in the precarious position of having to 'simulate the bugs in the simulation code'.

2.2.8 Service Activities

Members of the UTA high energy group have worked on the following service activities for the D0 experiment:

- Forward Study Group: Kaushik De, Elizabeth Gallas, Lee Sawyer, Ransom Stephens
- ICD Commissioning and Operations: Kaushik De, Mark Sosebee

- MTC & MTCL2 software: Elizabeth Gallas
- Luminosity Working Group: Jill Perkins
- Trigger monitoring: Jill Perkins
- WZ Cross-section editorial board: Andrew White (Chair)
- Light top squark editorial board: Ransom Stephens
- Inclusive J/ψ editorial board: Kaushik De (Chair)
- Triple differential jet cross-section editorial board: Paul Draper
- Squark/gluino search in Multijet events editorial board: Lee Sawyer
- Detector shifts: Kaushik De, Mark Sosebee
- Global Monitor shifts: Andrew White

2.3 ATLAS

2.3.1 Overview of UTA participation in ATLAS

Our initial interest in joining the ATLAS experiment in March 1994 was to pursue the same goals we had established during our involvement with the SDC muon system. UTA had been designated as the only SDC muon module production site outside the SSC laboratory. We had been working with members of the UTA Automation and Robotics Research Institute (ARRI) to understand the production engineering aspects of this construction project. We had also established a very fruitful collaboration between UTA and colleagues at the SSC muon laboratory.

Through our association with the high energy group at the University of Washington in the SDC muon system, we agreed to join the ATLAS muon effort after the demise of the SSC. Most of the work up to that point on the muon system had focused on the barrel subsystem. In the subsequent discussions and negotiations the US was encouraged to take responsibility for the "endcap" and "transition" muon subsystems. This has now been agreed as a US responsibility, subject to approval and funding of US participation in the LHC project. A general view of the ATLAS detector is shown is Fig. 2.11.

More recently our group was approached by members of the ATLAS calorimeter subsystem regarding possible participation in the intermediate barrel tile calorimeter, a device that would play a role similar to the intercryostat detector in DØ. Our expertise in developing and constructing the latter detector is of considerable interest to the ATLAS calorimeter group.

Finally, UTA has taken the initiative in the areas of software engineering and information technology for US ATLAS. Little consideration has been given to these issues so far by the US groups in ATLAS, and we feel that we can make a strong contribution in concert with developments underway in Europe.

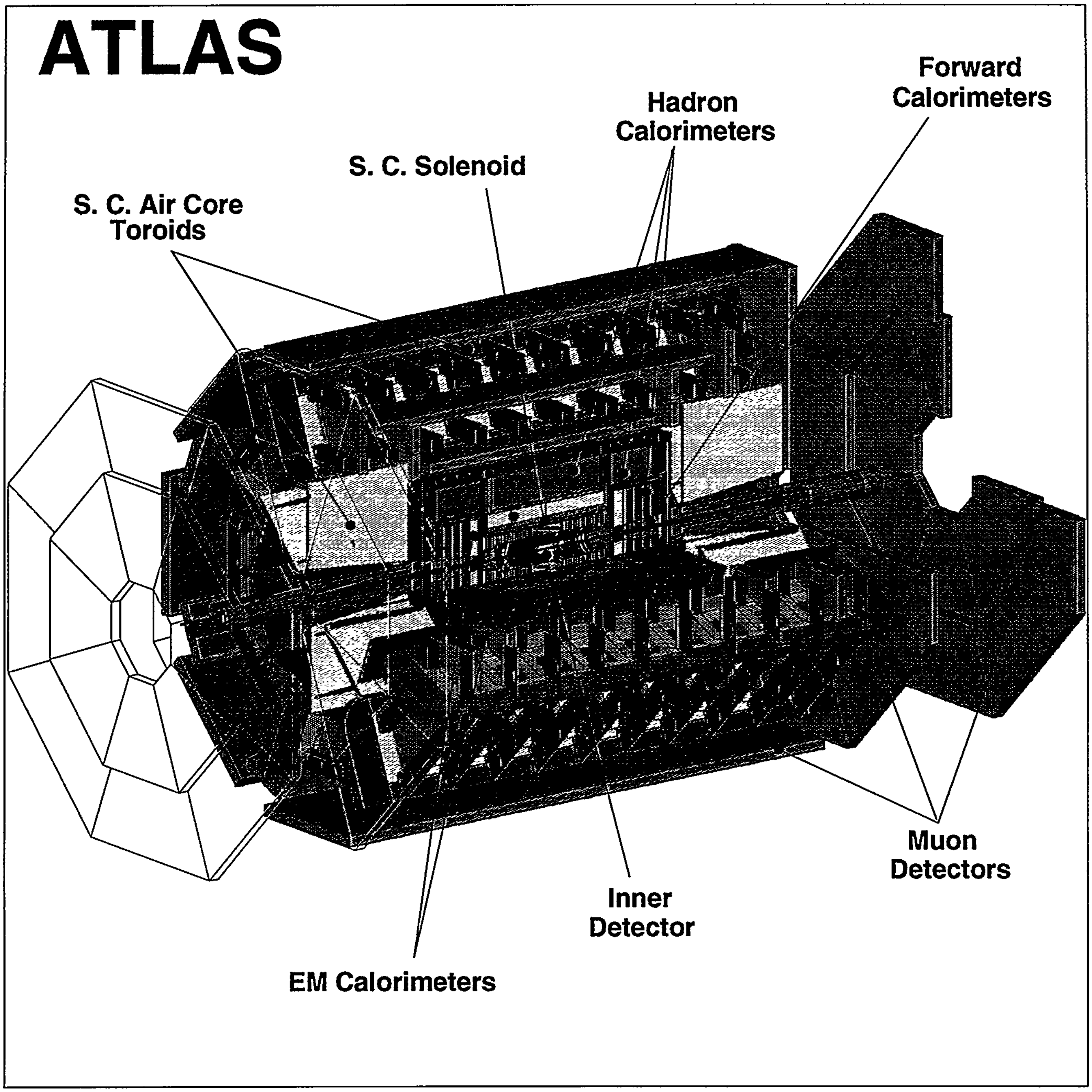


Figure 2.11: The ATLAS detector at the LHC.

2.3.2 Muon subsystem

A general view of the ATLAS muon system is given in Fig. 2.12. It consists of three large superconducting aircore toroid systems, a drift tube (and cathode strip) precision measurement system, and a dedicated trigger system. Work at UTA has focussed on the development of the measurement system in the "transition" ($1.05 < |\eta| < 1.4$) and "endcap" ($|\eta| > 1.4$) regions.

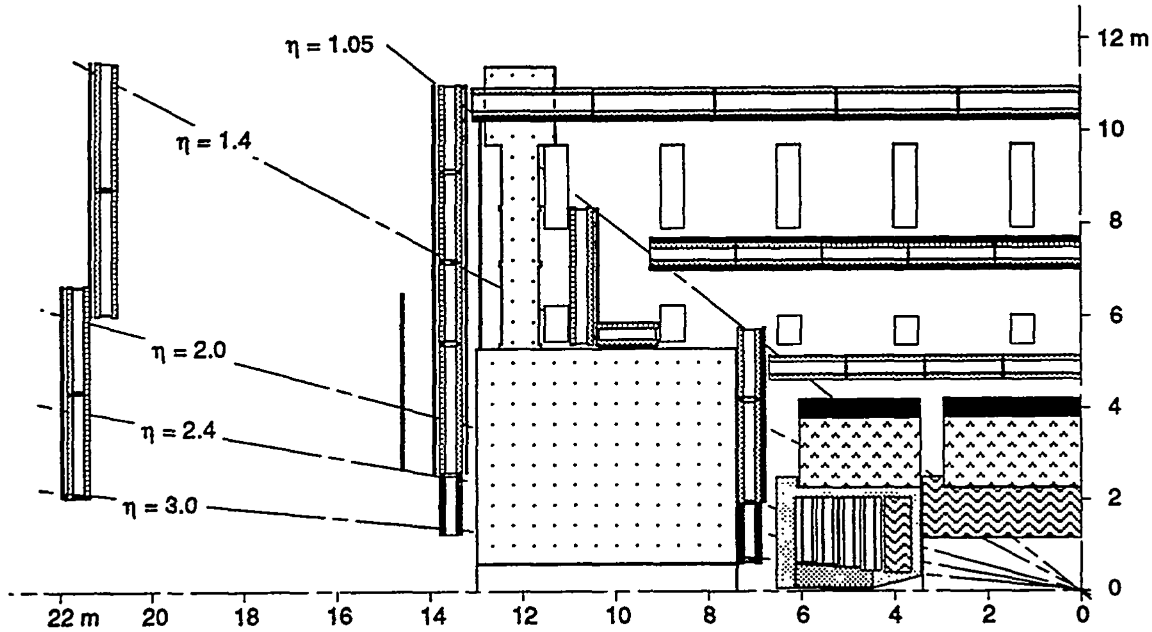


Figure 2.12: Plan view of the ATLAS muon system.

The measurement system, in any given direction, consists of three chambers spaced radially. Each chamber is built from two multilayers of drift tubes with an intermediate support. Each multilayer will have either three or four layers of drift tubes. The endcap and transition chambers are trapezoidal in shape as shown in Fig. 2.13. Each drift tube is 30 mm. in diameter with a single sense wire at its center. Tubes can reach 6 m. in length and those 3 m. or longer are anticipated to require a central wire support. A variety of designs exist for the endplugs. Current thinking focuses on locating only passive components in the endplug, with active components located within accessible areas at the ends of the chambers. The key specifications for the muon measurement system are a single cell resolution of 60 μm and a precise mechanical assembly that will allow effective use of this level of resolution.

The UTA group is engaged in a number of activities related to the development of individual drift tubes, pulse studies for quality assurance during tube production, the mechanical assembly of multilayers and chambers, and the establishment of a muon drift tube and chamber production facility at UTA.

Tube Prototypes

We have designed and built a high pressure Muon Drift Tube (MDT) prototype system which includes:

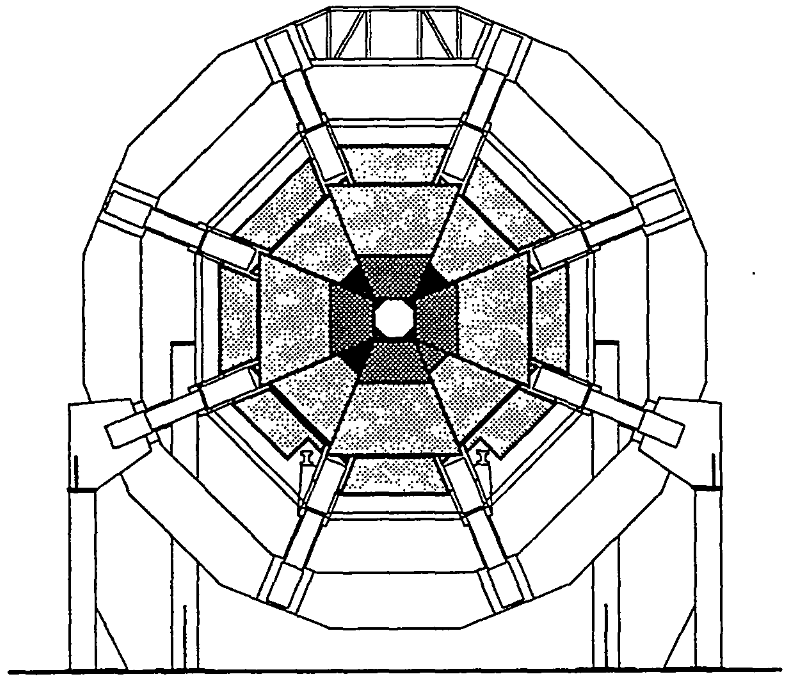


Figure 2.13: ATLAS muon system; first station of the transition and endcap detectors.

1. Two complete drift tubes with end plugs designed at UTA: One has a 0.050 mm diameter wire with a tension of 250 g, the second has a 0.090 mm diameter wire with a tension of 600 g. The feedthroughs on the end plugs are similar in design to those for the SDC Muon Detector with some modifications. The length of the aluminum drift tubes is 2.5 feet and the O.D. is 1.25in.(31.75mm.) with 0.022in.(0.56mm.) wall.

2. There is a 0.7mm. diameter hole and a fiber connector in the middle of each tube, as shown in Fig. 2.14. This design allows UV light to be shone inside the tube while maintaining high gas pressure.

3. A front-end preamp. and a high voltage system.

4. A gas supply system.

5. A DAQ System.

6. A Nitrogen Laser with an optical fiber system.

7. Two small trigger counters with their high voltage and readout system.

We have done preliminary tests on the prototypes with high gas pressure in the two tubes up to 70 psig ($\sim$6 bar) and high voltage on the wires up to positive 6000 volts. The whole system works well and is stable in operation. The basic idea of our design is to develop a method of absolute measurement of the electron drift time in high gas pressure drift tubes by using the narrow pulse width ($\sim$0.6 ns) of a Nitrogen laser emitting UV light. The advantage of the method is the high precision in drift time measurements for

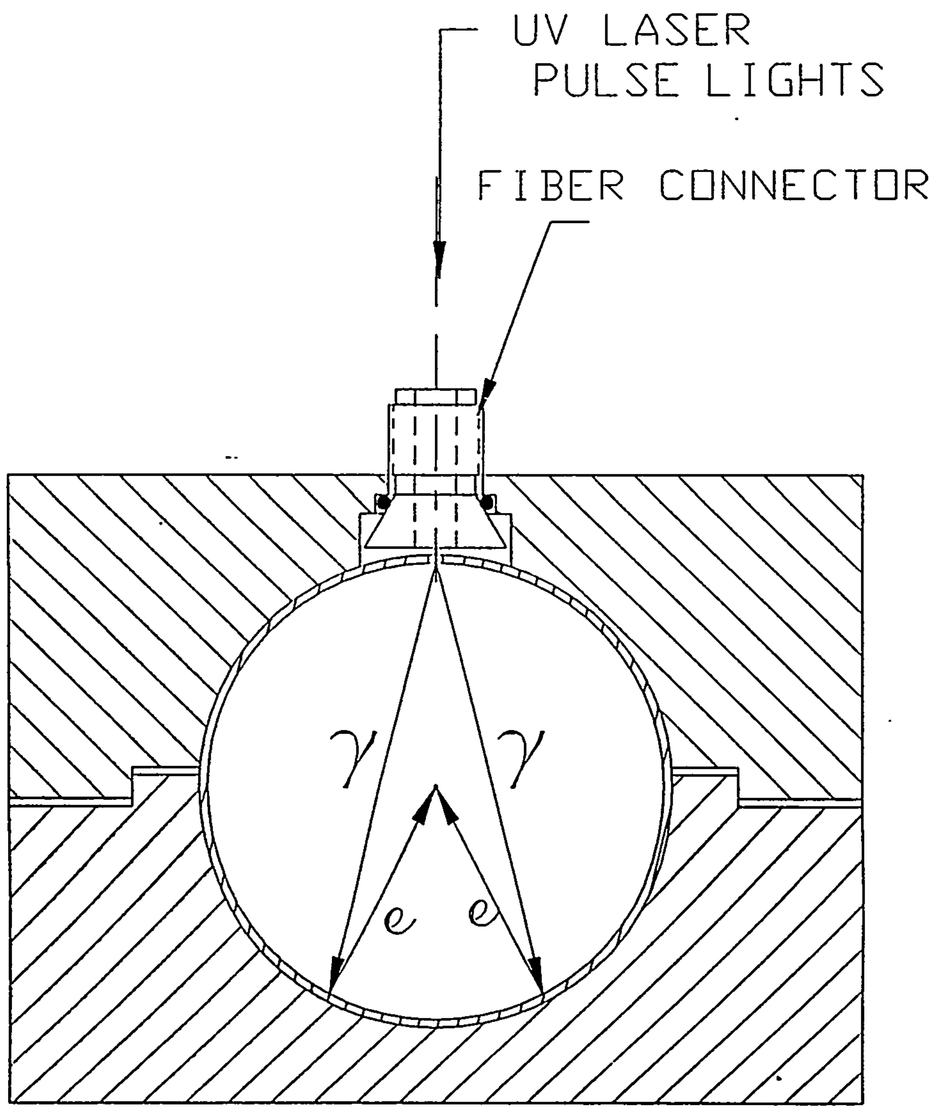


Figure 2.14: Design of laser connector attachment to high pressure muon tubes

a single pressurised tube, especially for the study of different gas mixtures at different pressures and different wire diameters. Traditional methods (such as using a source) are not very accurate, since it is very hard to define the particle track within ± 0.025 mm. The Nitrogen laser light does not ionize the gas, but does release electrons from the aluminum tube wall. The electron drift distance is strictly fixed by the geometry of the tube. The UV light can be split and read out by a photo-diode as the "start" signal. The pulse from the sense wire can be used as the "stop" in the drift time measurement. Since the Nitrogen UV laser pulse width is so narrow (0.6ns) compared with the 300-600ns of total drift time (depending on the gas pressure), the measurement meets the accuracy requirements for the muon system of the ATLAS detector. A layout of the laser test stand is shown in Fig. 2.15.

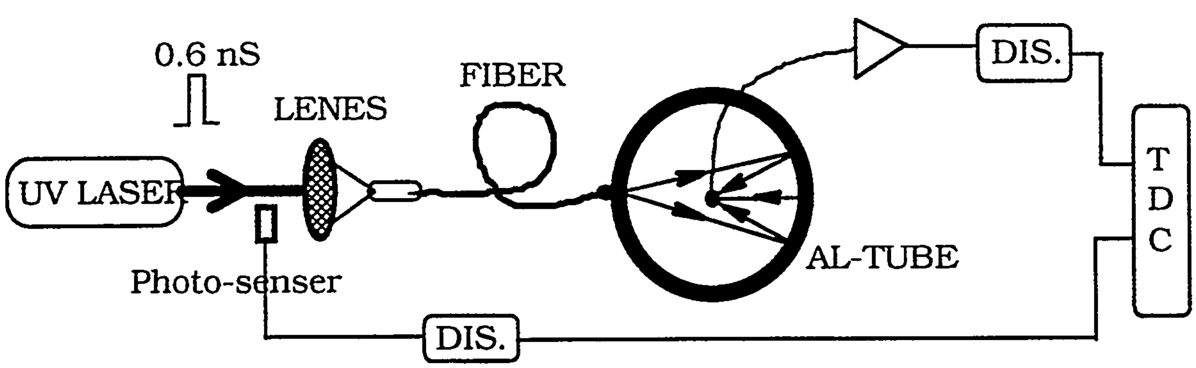


Figure 2.15: Layout of the laser test system for high pressure muon tubes

This method could also be developed as a basic study tool for the ATLAS muon detector, by using single photo-electrons. It is almost impossible to get a single electrons by the traditional methods used to study the physics of muon drift tubes at different gas conditions. Our method offers the possibility of studying diffusion and measuring resolution without the usual variation in the amount of primary ionization.

Since the photoelectric work function of aluminum is comparable to the UV photon energy, the quantum efficiency for producing photoelectrons from the wall is very small. Thus we have the ability to obtain single photo-electrons from the wall by tuning the laser beam intensity. There are two ways we can determine that we are seeing single photo-electrons:

1. The size of output signal does not change when the intensity of the UV light is decreased.

2. Due to the very low quantum efficiency and large number of UV photons, the number of photo-electrons in each pulse should vary according to a Poisson distribution. We can reduce the UV light until we are at 10-20% of the trigger efficiency. Then at least 99% of recorded events should be initiated by single photon-electrons.

Initial results have been obtained recently for the maximum drift time and timing resolution as functions of high voltage. Some example results are shown in Fig. 2.16, which indicates a typical time distribution with width $\sim$ 1 ns.

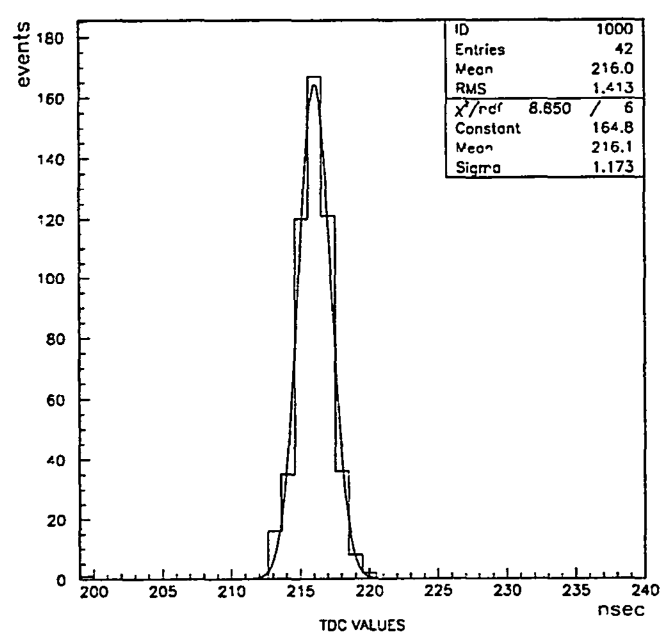


Figure 2.16: Distribution of drift time pulse widths.

Mechanical assembly

The construction of an entity as large as the endcap muon system, with mechanical tolerances of the order of 20μm, represents a considerable challenge. First there are the issues concerning the production of a large number of long, thin walled tubes each as a working drift tube, and then there is the integration of these tubes, each with a precise location, into a muon chamber module. Our colleagues at the University of Washington has developed a number of approaches to the latter problem. UTA personnel have worked with UW to understand and assist in the development of techniques and devices for chamber assembly. We have also looked into our own variations of the jigging, and example of which is shown in Fig. 2.17. The main principle is to use precise jigging and allow the positions of the center layer(s) of a multilayer to be defined by those tubes that are in contact with the jig elements.

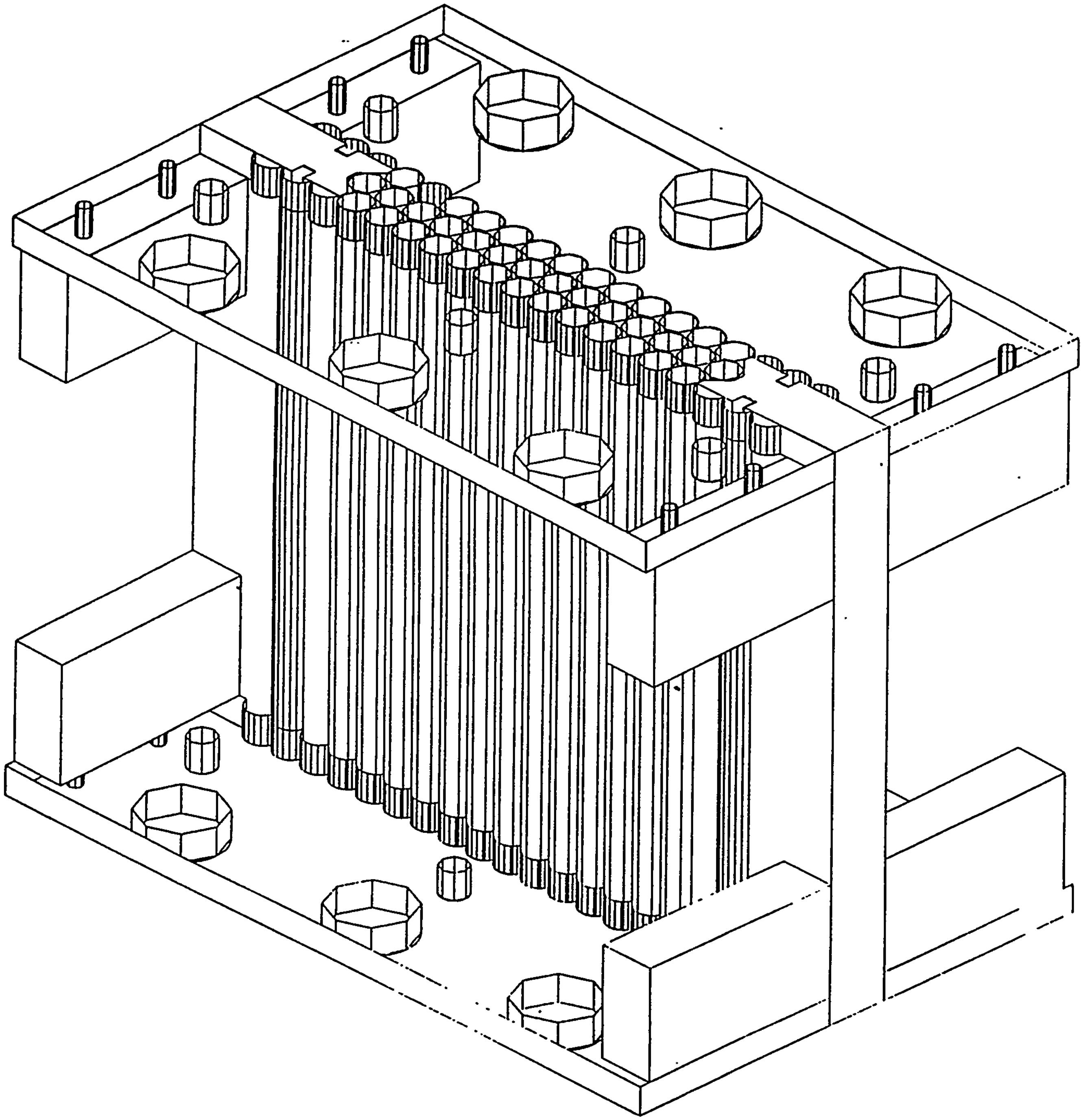


Figure 2.17: UTA design of the jigging for ATLAS muon chamber assembly.

Tests of the UW approach have shown that it is possible to achieve placement accuracies of $15\mu m$ (RMS) with respect to the desired locations of the tube centers.

Pulse shape studies

There are a number of reasons why a good understanding of pulse shapes is needed: it aids in understanding the physics of the drift tube itself, it provides information for groups designing the front-end electronics, and pulse shapes can be used for quality assurance to discriminate against bad tubes. To this end UTA has begun pulse shape studies of the ATLAS muon drift tubes. The test stand consists of short lengths of muon drift tubes connected to high voltage and gas. The tube working point is not determined in the present setup, so nominal values of pressure and high voltage are used. A custom preamp is used, which has a very high bandwidth. The amplified pulse is passed to a fast sampling digital oscilloscope, and the captured waveform can be readout from the oscilloscope by a computer. A number of pulses have been captured and are being analyzed. A schematic of the setup is shown in Fig. 2.18, and some sample captured pulses are shown in Fig. 2.19. We aim to produce a pulse QA system that can be copied by other tube construction sites.

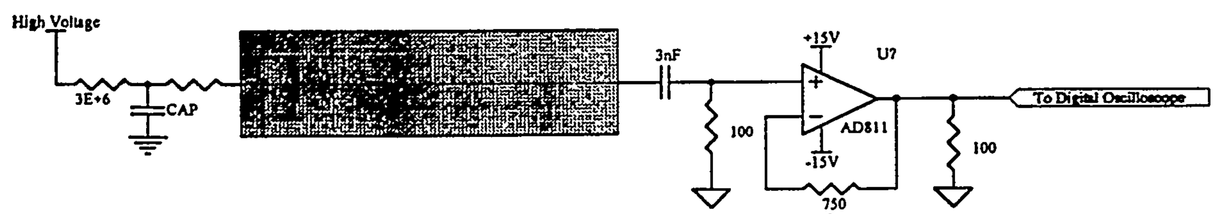


Figure 2.18: Schematic of the setup to study pulse shapes from the ATLAS muon tubes.

2.3.3 Calorimeter subsystem

TileCal Overview

UTA has joined Argonne National Laboratory, University of Chicago, University of Illinois, and Michigan State University to collaborate on the design, R&D, and construction of the steel/tile/fiber hadronic calorimeter. The US groups propose to construct about one-third of the calorimeter system, including associated front-end electronics and trigger systems, and to participate fully in ongoing design, optimization, and prototyping of the calorimeter.

Hadronic calorimetry is provided in the central region of the ATLAS detector by a scintillating tile calorimeter (TileCal). The TileCal is separated into three sections, the

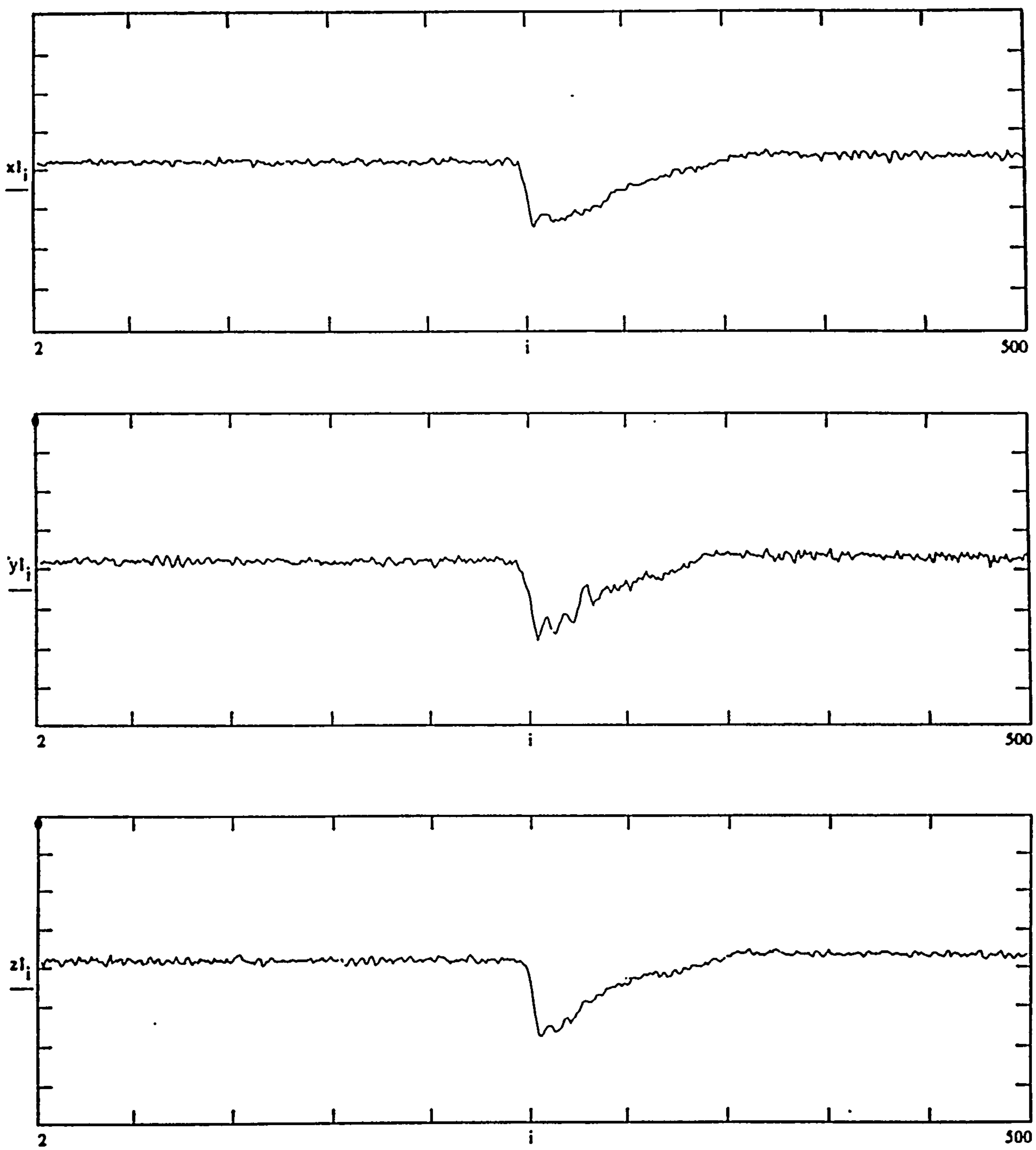


Figure 2.19: Pulse shapes captured from prototype ATLAS muon tubes.

barrel covers $|\eta| < 1$, and the two extended barrels cover $1.0 < |\eta| < 1.6$. Thus the TileCal surrounds the full length of the LAr barrel calorimeter as shown in Fig. 2.20. A fourth component of the TileCal has been proposed – the intermediate barrel tile calorimeter (IBTC) – which will provide hadronic calorimetry in the uninstrumented region between the barrel and extended barrel and will share the basic design technology of the TileCal. UTA is leading the simulation and design studies of the IBTC.

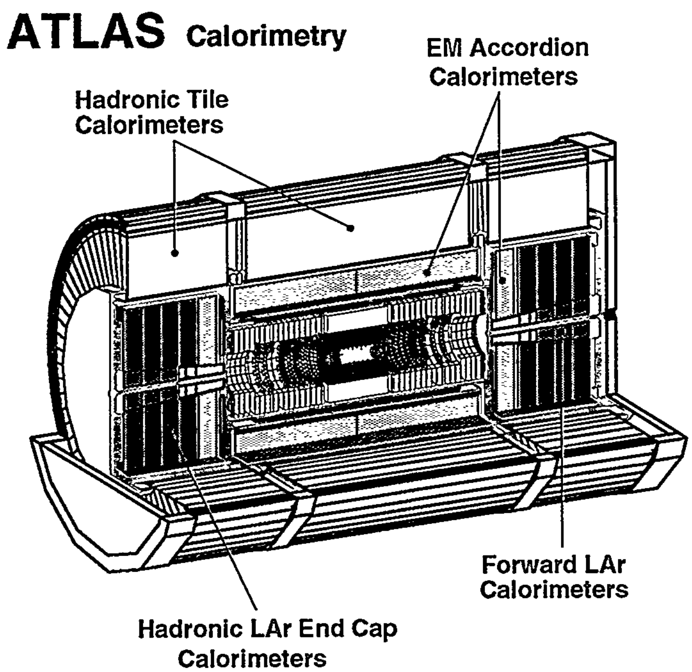


Figure 2.20: The tile calorimeter (TileCal) for the ATLAS detector.

The TileCal is based on a sampling technique using plastic scintillator plates (tiles) and iron absorbers with wavelength shifting (WLS) fibers transporting the scintillation light to photomultiplier tubes (PMT's). The tiles are oriented perpendicular to the beam axis and staggered in depth; see Fig. 2.21. Monte Carlo simulations indicate that this geometry provides good sampling homogeneity when placed behind the roughly two interaction lengths of material from the LAr calorimeter and coil.

The TileCal is a cylindrical structure with an inner radius of 2.28 m and outer radius of 4.23 m. The barrel is 5.64 m long and the extended barrels are each 2.65 m long. The three detectors are separated into 64 azimuthal modules and three radial layers with approximate thicknesses of 1.5λ, 4.2λ and 1.9λ at $\eta = 0$. The scintillator tiles lie in the $r - \phi$ plane and span the width of the module in the ϕ direction. WLS fibers running radially collect light from the tiles at both of their open edges. Readout cells are defined by grouping together a set of fibers onto a PMT. The $\eta \times \phi$ segmentation is 0.1×0.1 (0.2×0.1 in the last radial layer).

Each sector module is composed of a stack of repeating elements, *periods*, which consist of four layers. The first and third layers, called *master plates*, are 5 mm thick steel and span the full radial dimension of the module. In the second and fourth layers, smaller steel plates (spacer plates) 4 mm thick alternate with 3 mm thick scintillator tiles

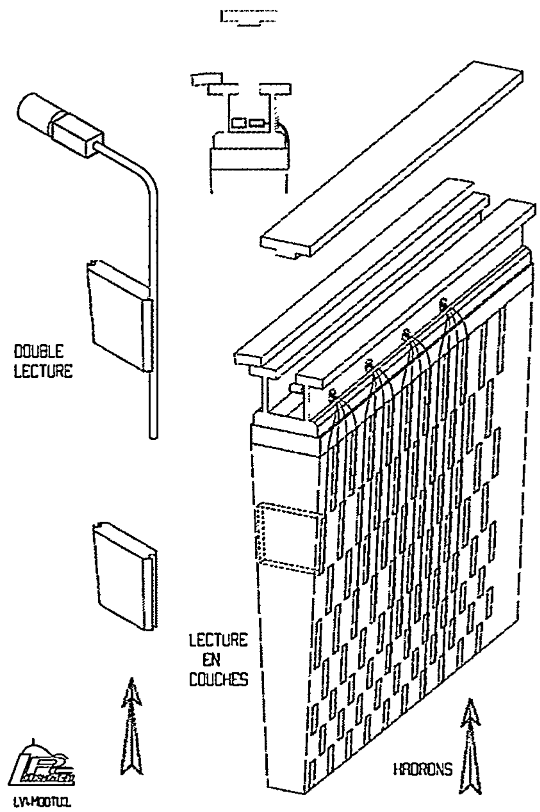


Figure 2.21: Individual sector module for the ATLAS TileCal.

along the radius. The iron to scintillator ratio is 4.67 : 1 by volume. A rigid girder at the outer radius, a 10 mm thick front plate at the inner radius and two 2 cm thick end plates at the extremities provide structural integrity and allow modules to be joined into a self-supporting cylinder. The girder houses the PMTs and front end electronics, provides the magnetic flux return path for the inner solenoidal fields and shields the readout electronics and PMTs from stray fields associated with the muon toroids.

In the preliminary planning exercises of the TileCal group, a contribution of 30% of the calorimeter was assigned to the US groups. This was a fraction that fit both the resource requirements of the subsystem collaboration and the capabilities and strengths of the US groups. It is also a good match to the fraction of the physicist effort contributed by the US. Given the size of the US contingent, UTA can play a substantial role in all aspects of the US Tile Calorimeter effort.

The scenario that has been provisionally agreed within the TileCal collaboration has the US taking responsibility for (a) mechanics, instrumentation, and testing of one extended barrel calorimeter, or one of the three major subassemblies of the Tile Calorimeter; (b) one-third of the photomultiplier tubes and associated assemblies; (c) half of the front-end amplifier/shaper/digitizer systems; and (d) all of the intermediate barrel calorimeter, which will fill part of the space between barrel and extended barrel units, restore the resolution that would otherwise be lost from the separation of the units and the material in the gap, and reduce the flux of neutrons flowing through the gap to the muon system.

The Intermediate Barrel Tile Calorimeter Design

The design of the ATLAS Tile Calorimeter currently includes a 630 mm gap between the barrel and the extended barrel modules. This gap provides room for cryogenic services and electronics readout boards needed for the e.m. calorimeters. ATLAS management has urged US groups to study the performance of the Tile Calorimeter in this region. Based on preliminary simulation studies and based on past experience with the ICD built by the UTA group for DØ, the ATLAS TileCal groups are proposing a new Intermediate Barrel Tile Calorimeter (IBTC) for ATLAS. US groups (UI, MSU and UTA) have been encouraged to take on this project. Due to the independent design and structure of this detector, it could be manufactured completely in the US and could be a significant new contribution to ATLAS by US groups.

For particles which originate at the nominal beam position, the proposed IBTC extends approximately 0.7-1.2 in $|\eta|$. There will be two assemblies – one for each end (positive and negative η). The current width of the stack at each end is 150 mm. To make room for cryogenic services, the inner radii is reduced. Additional scintillator tiles may be placed to provide coverage to the regions not covered by the 150 mm stack. The design of the IBTC stack is expected to closely parallel the design of the barrel TileCal. The steel and scintillator plates are arranged in alternating $r - \phi$ layers. WLS fibers are placed radially. Each end assembly consists of 64 modules in ϕ. Each module contains a maximum of 13 periods, where the usual TileCal design is used for each period of 18 mm width.

Special treatment may be necessary for the first and last half periods. The barrel and extended barrel Tile Calorimeters use 20 mm thick end plates for structural integrity. In order to maintain the nominal 4.67:1 ratio in volume, the first and last half-period of the proposed IBTC will require an entire surface of 5 mm scintillator tiles mounted behind thin 4 mm plates. The approximate segmentation of the tiles will be 0.1×0.1 in $\eta \times \phi$. There will be a maximum of two depths in each module.

The IBTC could mechanically be attached to the extended barrel girders. Drawers inside the girders will hold the estimated maximum of 1024 tubes required at each end. Many details on the exact dimensions and mechanical support of these modules remain to be worked out in 1995-96 in close consultation with other TileCal and EM calorimeter integration groups.

IBTC Simulation Studies

Initial simulation studies of the region covered by the IBTC were performed at UTA with single pions in Fall 1994. The results were presented during the November 1994 ATLAS week. Based on these first results, the Barcelona group has modified the TileCal simulation to include additional information about energy lost in dead material. We are currently in the process of installing the latest simulation package on the UTA farm system. New simulation studies are underway to understand the jet and $\not{E}_T$ response in this region.

Our intial studies, which were limited by the preliminary nature of TileCal simulation code in 1994, showed the first scan of the response of the calorimeter as a function of eta. A dip in energy reponse was seen from DICE studies in the IBTC region. However, the dip could not be found in studies using ATRECON. Both studies were found to be flawed due to incomplete simulatiion code. With the new release of code from Barcelone, we are attempting to redo the previous studies.

2.3.4 Software Development

This section describes the basis for the initiative we have started in US ATLAS in connection with the introduction of modern software techniques. We also describe our initial work on two software development projects.

The first part of this decade has seen a revolution in software engineering with profound implications on how commercial applications software is designed and built. Object Oriented modeling and design is well established, but in experimental high energy physics, these concepts have yet to become mainstream. There is now robust modern commercial software technology that will permit significant savings in scientific software development and maintenance leading to the commissioning of ATLAS. The real step forward in technology is achieved by adopting a full Object Oriented (OO) re-implementation or by developing in OO right from the start. New integration and design software products, many based in C++, offer the power needed to make this step forward backed by the established US and worldwide software industries. This new technology will allow the timely delivery of reliable, powerful, flexible, integrated, distributed and more easily maintainable software systems. It will finally allow the decoupling of "mostly scientific" contributions to scientific software engineering from those "mostly engineering" ones.

We started in FY'95 by pursuing an educational "experimental" approach to modern software engineering. Since Object Oriented technology requires a shift in approach to analysis, design, and implementation, we believe the development of modern prototypes of traditional HEP software is a necessary first step. Our first activities concentrated on understanding work centered at CERN where DRDC project P55 became RD41(MOOSE) [19]. The aim of this effort is to develop an understanding of how OO software engineering can usefully contribute to experimental high energy physics. The main areas of activity in MOOSE are: 1) training in OO analysis, design, and programming; 2) development of working prototypes of OO off-line analysis tracking and calorimetry code; and, 3) use of videoconferencing based on Internet access.

At UTA, two prototypes of OO software were developed based on Industry standard C++ using off-the-shelf commercial development environments on two types of commonly used micro-computers. They include a data acquisition engine based on a flexible class hierarchy: DAQ++; and a basic OO histogramming engine: HISTO++. We also experimented with MOOSE style videoconferencing.

In the **DAQ++** project, our goal was to develop DAQ software for reading standard CAMAC using OO technology. We used Microsoft's Visual C++ coupled to the IEEE 488.2 GPIB to Camac interface with an Intel 386 class computer. We modeled an object corresponding to a CAMAC crate controlled by a LeCroy 8901A GPIB to CAMAC controller. At a later stage, we anticipate generalizing our object to a CAMAC crate controlled by a generic crate controller. Figure 2.22 depicts the implemented object class hierarchy in the standard notation of Rumbaugh [20]. It is apparent that abstraction of the derived class will result in a more flexible and powerful structure applicable to a

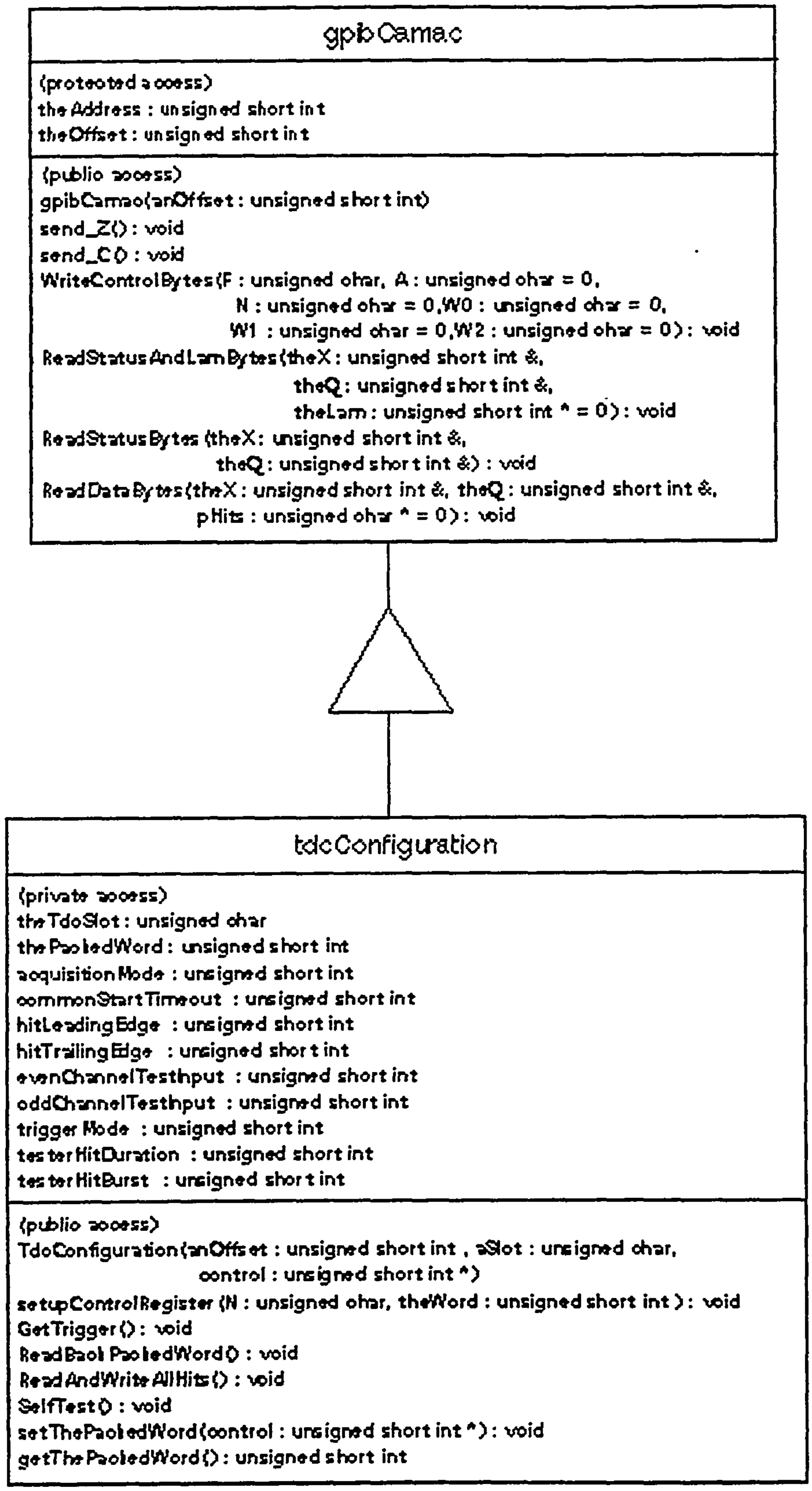


Figure 2.22: Implemented class hierarchy.

wider class of CAMAC TDC's. We learned from this exercise that C++ is a flexible and powerful programming language that allows rapid development of complex applications immediately useful in high energy physics; that widely available commercial libraries written in C are easily integrated into C++; and that commercial development environments are ideal for building scientific software engineering products.

If one is ultimately interested in modeling an entire HEP analysis chain using OO techniques, histogram objects are not necessarily the best type of object to start with. It would be better to start at the top and model data analysis starting with physics objects. Nevertheless histogram objects represent a fairly simple self contained example of applicability of OO techniques and the use of C++; they can be modeled to have attributes and methods and need not be made to interact.

We developed **HISTO++** on a Macintosh computer using Symantec's C++ development environment and compiler. Figure 2.23 illustrates the implemented classes using the notation of Rumbaugh. Both DAQ++ and HISTO++ are meant to be prototypes of engines residing at the heart of a data acquisition and histogramming package that should be flexible, portable and functional, independent of platform make or size. Notice that HISTO++ makes use of the concept of meta-data: rather than containing data by themselves, objects of the class "histogram" point to the actual data instead. This is a useful and powerful concept which decouples the histogram (really just a "view" of the data) from the actual data itself.

While the implementation scale of DAQ++ and HISTO++ was chosen to be small, the extensibility of the classes defined is considerable: much more complex software products running on powerful (distributed) computers can inherit directly from the code prototyped here.

2.4 PP2PP

2.4.1 Overview of UTA participation in PP2PP

UTA was accepted into the PP2PP collaboration at the beginning of 1994. We have taken responsibility for updating the initial simulation studies that were performed as a design program, and we continue to expand this program. In addition, UTA has collaborated with Brookhaven on the development of a new design for a scintillator-based detector, and is participating strongly in the fabrication of an 8-layer prototype and its testing in a beam. Draper presented the status of the experiment at the Spin '94 Workshop in Bloomington, Indiana, in September 1994.

PP2PP proposes [21] to measure elastic scattering parameters at RHIC, where proton-proton collisions over a wide, unexplored range of $\sqrt{s}$ can be studied. We will be able to measure this cross-section well into the $|t|$ range where the well-understood Coulomb amplitude dominates (affording normalization *gratis*) up through the Coulomb-nuclear interference region, and up to $|t|$ values beyond the dip region. In addition, the availability of polarized protons (purity predicted to be 70%) at RHIC allows our experiment, without change of experimental setup, to measure asymmetry parameters that will illuminate the behavior of spin-flip terms in the scattering amplitude. This is of special interest to theorists who are at a loss to explain lower energy data without non-standard

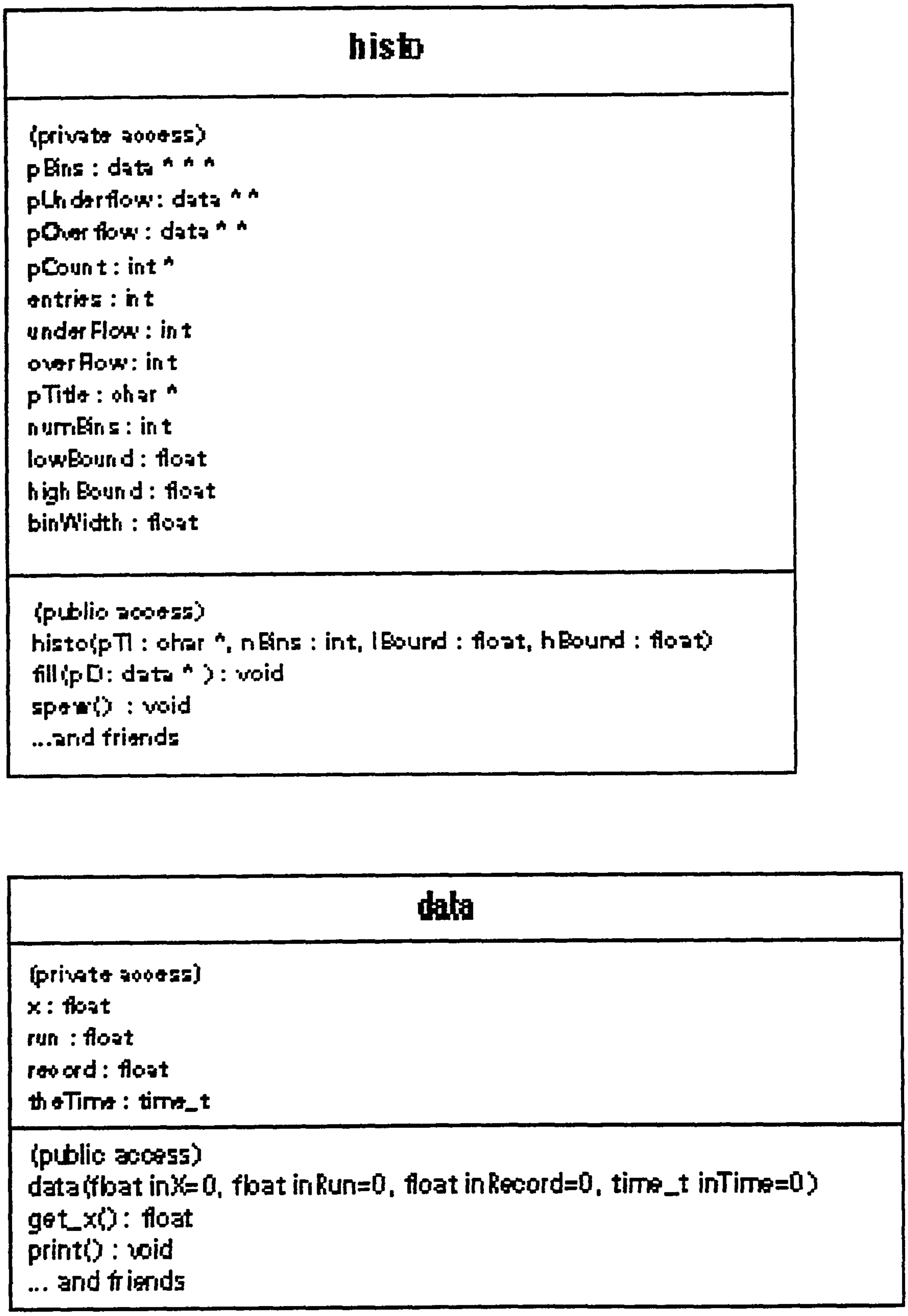


Figure 2.23: Implemented classes in the Rumbaugh notation.

QCD processes such as Odderon exchange. We are actively exploring ways to extend this reach in momentum-transfer up to the hard-scattering regime.

This experiment rounds out UTA's hadron collider program, serving in apposition to the high-E_T physics of DØ and ATLAS. In particular, this arena serves to illuminate regions of QCD where perturbative calculations do not apply well. It also fits well into the calendar of physics effort at UTA, forming a moderate-scale investment in productive physics between the time scales of the Tevatron Run II and LHC.

2.4.2 Simulation Studies

Simulations to study the design of the PP2PP experiment were developed by Stony Brook and Brookhaven, and largely carried out on Unix machines at BNL. Because of our substantial computing facilities at UTA, we agreed to take the lead in further simulation work, in collaboration with M. Rijssenbeek at Stony Brook. Since that time, we have ported RISC code to OpenVMS on the AXP farm, and have generated approximately 100 million events on the farm, partly as a verification of the port (and to fix found bugs), and to further the studies.

Initial studies have focussed on detector resolution and acceptance issues, and the simulation has included the generation of collisions with accurate representation of beam and intersection parameters, propagation through the lattice, smearing of detector hits with resolution functions, and the reconstruction of physics parameters.

The next stage of the simulation has to deal with imperfect understanding of lattice parameters: a beam momentum offset, imprecision in the transport matrix due to magnet field tolerances, and emittance growth and luminosity variation as a function of time. This is being done in close collaboration with the accelerator design group, and this is a distinct advantage for the success of the experiment. For example, from our input, a tune was developed with longer bunch length and lower emittance growth. The length of the intersection diamond hurts our performance much less than emittance growth would, as shown by this study: an increase in the emittance from 5π mm mrad to 10π mm mrad results in an increase in our resolution of the elastic scattering parameter ρ by nearly a factor of two, while preserving low emittance costing a concomitant payment in σ_z from 12 cm to 100 cm has no measurable effect. The study of the sensitivity to the lattice transport matrices is in progress. S. Tepekian of the RHIC Accelerator Group is generating representative transport matrices that span the expected magnet variations, which we will use to generate scattering events and reconstruct with ideal parameters to ascertain this limit to our precision.

We have since spent some effort restructuring the simulation code completely in anticipation of the next step in simulation: addition of physics and beamline background; the fine-tuning of detector parameters and geometries (including, for example, non-uniform channel widths); and background rejection using something like real analysis cuts in the reconstruction. This has involved separating the code into event generation, lattice and detector simulation, and reconstruction stages.

2.4.3 Hardware and Detector Prototypes

PP2PP Detector Goals

The PP2PP experiment requires precision tracking detectors to measure the scattering angle of the outgoing protons. Constraints on detector design include the need to reach very close to the beamline and very low material profile in the direction of the scattered particles. UTA proposed a design for such a detector using scintillators as the active material. Wave-length shifting fibers and phototubes will be used to transmit and convert the scintillation light to electrical signals which will then be digitized.

The detector elements used for precision position measurement will be housed inside four pairs of Roman pots (RP). Each RP pair will house two identical sets of detectors. Each detector will consist of two orthogonal planes to measure X and Y at a fixed Z position along the beam. There will be a total of 40 planes (elements). The size of each plane will vary between 6 cm × 3 cm to 12 cm × 6 cm. Except for overall size, individual strip size, and orientation, the detector elements will be identical in all other aspects. The different orientation of the X and Y planes will also change the path followed by the fibers used to transmit the light to the photomultiplier tubes.

We have assumed the following requirements in designing the detector elements (a detector element is considered here to be a single plane as described above):

1. Position resolution better than 100 μm.
2. Minimal amount of material along the detection path.
3. Uniformity of detection efficiency across the active area of the detector.
4. Minimal dead space close to the beam.
5. Low systematic errors in position measurement.
6. Good time resolution to reduce background.

PP2PP Detector Design

For reasons of cost and due to the abundance of experience with such detectors in other experiments, we have proposed a scintillator based detector for PP2PP. A scintillating fiber based detector similar to the one used by UA4/2 is the backup option for the experiment. The scintillating strip detector discussed here represents an innovative approach which could provide superior uniformity and coverage to the UA4/2 detector at a lower cost.

The active detection area will consist of narrow 2.4 mm scintillator strips perpendicular to the incident particle. The design will be identical for X or Y planes. Each plane, consisting of many adjacent strips, will be machined from a single sheet of 3 mm thick scintillator (Bicron BC408B or equivalent) thereby reducing systematic errors in the positioning of each strip. The scintillator sheet will be cut to the size of the plane and glued to a substrate composed of Tyvek paper backed by a thin sheet of aluminum (about 1.6 mm). Next 0.3 mm separation grooves will be machined to create the individual strips. Finally, 0.9 mm deep and 0.82 mm wide grooves will be machined along the center of each strip. These grooves will have a rounded bottom to accommodate wavelength shifting fibers. A drawing of the tile-fiber system is shown in Fig. 2.24.

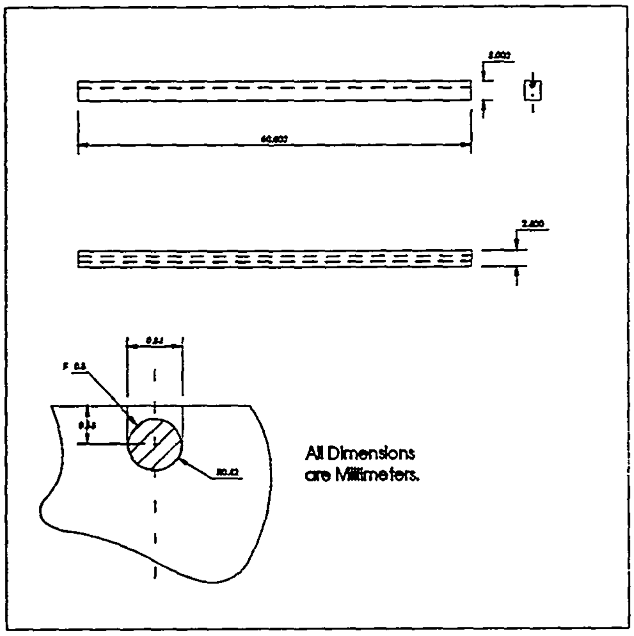


Figure 2.24: Design of individual scintillator strips and wavelength shifting fibers proposed for the PP2PP experiment.

We plan to use 0.8 mm diameter green (Y11 doped or equivalent) wavelength shifting fibers to transport the light from each strip to photomultiplier tubes. For prototype work, we plan to use Hamamatsu R647-02 tubes which are 0.5 inch in diameter. The final choice of photomultiplier tubes to be used in the detector will be made later.

There will be 9 layers of overlapping strips in each detector plane staggered by 0.3 mm relative to each other. Therefore, the 'intrinsic' strip width of the detector is 0.3 mm. The expected average position resolution will be $0.3/\sqrt{12} = 87\mu m$. We believe that the actual position resolution should be around $100\mu m$.

Due to the uniform thickness of scintillator traversed by particles independent of incident position, we expect a high level of efficiency (> 99%) uniformly across each strip. The redundant measurement in 9 layers will keep the average occupancy greater than 8 layers and should add no inefficiencies due to the 0.3 mm gap between strips. This design provides superior uniformity and efficiency compared to scintillating fiber detectors with 'bumpy' profiles. In fact, the uniformity of the detector is independent of the number of layers. The additional layers are only needed to improve the position resolution.

We have paid special attention to the boundary region near the beam for the Y planes. We believe that the design presented here can achieve uniform efficiency all the way down to the beam. However, the position resolution will degrade somewhat at the edge since the 9-fold redundancy of layers used in the measurement at the center of the detector will be reduced at the edge (to a minimum of 4 layers at the farthest point). We are also considering 'u-v' strip orientation to minimize the inefficiency near the edge.

In this design, each detector plane is machined from a single piece of scintillator. No positioning or alignment of the strips after machining is planned. This monolithic approach should reduce the traditional source of systematic errors due to the misalignment of the tracking elements.

Wavelength shifting fibers will be glued into the grooves in each scintillator strip manually. Note that there are no special alignment requirements in this process since the only active detectors are the scintillators. We have chosen 0.8 mm fibers for their good match to the strip width. Double clad fibers will be used because of their superior light transmission properties (50% increase compared to single clad fibers).

We plan to fill the separation grooves between adjacent strips with white epoxy available from Fermilab which was developed for similar use in SSC detectors. The fibers will be diamond cut and polished at current facilities at Fermilab or future facilities at BNL. The far end of the fibers, which are not attached to phototubes, will be mirrored via sputter deposition.

The engineering design of the placement of the photomultiplier tubes has not been worked out yet. However, we do not expect the tubes to be more than 50 cm away from the detector elements. Since the attenuation length of the fibers is in excess of 3 meters, we do not expect significant loss in transmission.

PP2PP Detector Development

In collaboration with BNL and Fermilab, we have successfully built and tested two strips. The photelectron yield was measured to be 14 for the first prototype. After some improvements, we found a yield of 20 photoelectrons for the second strip. Such exceptionally high yields provide an extra margin of robustness in the detector design.

We have recently built a full plane prototype (8 layers which include 80 strips). This prototype was tested at the BNL test beam facility during March 1995 to measure the position resolution and efficiency of the proposed detector. The data analysis is currently underway. Based on our experience with the first test, we expect to carry out further beam tests in May-June 1995.

The test beam setup included a set of 4 drift chambers for beam positioning and scintillator paddles for triggering and timing purposes. The prototype detector was placed in the test beam with strips perpendicular to the test beam incident particle direction.

Each rectangular strip had a depth of 3 mm and a width of 2.4 mm with a groove along one side to accommodate a wavelength shifting fiber. Strips in the same layer are separated by 0.1 mm with epoxy to reduce strip to strip cross talk. Layers were separated by 1mm thick opaque plastic panels. Successive layers were staggered by 0.3 mm, making the effective 'intrinsic' strip width of the detector 0.3 mm.

The 80 fibers were multiplexed into 10 Hamamatsu photomultiplier tubes (PMTs) since the occupancy was expected to be low for single particle traversal. Track position can be determined by selecting aligned hit fibers associated with the photomultiplier tubes with a signal above threshold. Data was taken for two multiplexing schemes to determine which is superior for the elimination of ghost track ambiguities.

With the data taken with the prototype at the test beam, we can determine overall detection efficiency, uniformity of response across and along each strip, the light yield for minimum ionizing particles, and an optimal multiplexing scheme for readout. Test beam data is currently being analyzed at UTA to determine the above. This information can then be incorporated for the optimization of the full scintillation strip detector design. Advantages of the UTA design are expected to be high efficiency, and good resolution with relatively fast signal information available for use in detector triggering.

We have developed a ganging scheme to collect 8 fibers into a single PMT to reduce cost. These fibers were chosen from 8 separate strips, one from each layer. The choice was made in such a way that there are no ambiguities in reconstructing a particle track from the digitized data.

UTA provided the scintillator, the 10 PMTs, and the PMT voltage dividers for this test beam run. We also supervised fiber polishing. We provided shift and DAQ support for the duration of the run. Data analysis is being carried out at UTA. In addition to the significant contributions that we are making to PP2PP, the experience from this detector development work will be very useful in the design of the forward preshower detector for DØ.

2.5 UTA Computing Farm

The UTALF cluster includes six AXP 3000/400 servers networked with fiber optics configured as a "farm". This system was purchased using UTA funds and configured for the purpose of massive Monte Carlo data production. We took delivery of the system early in 1994 and immediately participated in the effort to transport DØ software to this platform. In coordination with DØ and Florida State University, the DØGEANT package and most of the standard DØ libraries were transported. The UTA group took responsibility for transporting the two software packages which formed the greatest obstacles: the DØ data reconstruction program (DØRECO) and the trigger simulation code. The successful implementation of DØRECO was a milestone in establishing the AXP platform as a major resource for the DØ experiment and established UTA as the release and verification site for the DØRECO code on the AXP platform for the rest of the Collaboration. Transporting the trigger simulation code is continuing as this is written. Since both the VAX and AXP platforms run the VMS operating system, we originally thought this would be a simple task, however, differences in the compilers and architectures, mostly having to do with handling of double precision real variables and peculiarities associated with the Alpha RISC chip, provided us with a unique opportunity to find some well hidden bugs in the original code.

As the software was being readied for production, we were developing the first version of UTAMulti: a VMS-based software package which coordinates execution of a given program on multiple platforms in such a way that the farm of servers appears as a single 'super' machine to the user. For example, in running production Monte Carlo of data simulation with D0GEANT, the USER provides a list of input files, output disks, particular CPU node names and a template of how the executable program is meant to run. Then the UTAMulti software submits jobs to servers until all input files have been processed. Behind the scenes, UTAMulti sends the user messages when tapes need to be mounted or dismounted and constantly updates a status report. Thus, given a set of input files, a user need only provide some necessary information to UTAMulti and mount tapes every few days in order to produce an arbitrarily large set of production Monte Carlo. This version of UTAMulti is our first step towards genuine multi- tasking - our plans for further development are described below.

Finally, in February of 1995, with the first version of UTAMulti and the bulk of DØ code transported to and verified on the AXP platform, we solicited our first request for massive Monte Carlo production. This first task was in support of trigger studies of the upgraded forward region of the D0 detector and served two purposes: first, it established the tremendous push that the UTALF farm can provide to ongoing studies by supplying large simulated data sets on a very short time scale; and, second, it gave us a chance to fully debug the first version of UTAMulti in a 'live' setting. Despite the fact that we were ramping up, we produced 1500 events/day in full D0GEANT – representing negligible dead time, but including a few hardware and coordination problems which we could not have anticipated without a live task. We delivered more than 40,000 events in less than a month to the forward trigger study group. A second production run is in progress as this is written, producing roughly 1500 events/day including multiple interactions, to complete our initial production obligation.

Having demonstrated the utility of the UTALF farm, we established a slightly bureaucratic procedure where requests from collaboration members in urgent need of substantial data simulation are routed through the DØ Offline Computing Policy Board to the director of the UTALF farm. This allows our group to provide substantial aid to a large array of analyses and/or detector studies.

Since last summer the UTALF Farm has provided all the simulation for the wino-zino study, all simulations in support of our studies of the FPS, EMICD, and ICD detectors and all simulations for the PP2PP experiment. We are still in the early stages of establishing the UTALF farm as the US center for massive simulation support of the ATLAS experiment. With our roles in the TileCal and Muon groups we anticipate a rapid expansion in this area.

2.6 Experiment E733 - Fermilab

Before joining the UTA group, Elizabeth Gallas worked on an analysis searching for new particles in the Fermilab neutrino beam. Collaborators on experiment E733 include Andrew White as well as researchers from Michigan State University, Fermilab, Florida State University, and Massachusetts Institute of Technology. For the last year or so, work has been ongoing to publish these results. Late in March 1995, the manuscript summarizing the analysis was accepted for publication as a regular article in Physical Review D, with Dr. Gallas as the primary author [23].

In this experiment, a time-of-flight technique was used to search for neutral weakly interacting massive particles (WIMPs) in the Wide Band neutrino beam at the Fermilab Tevatron. With the use of scintillation counters operating parasitically within the E733 neutrino detector, event times relative to the time of beam passage were measured for neutrino events recorded during the 1987 Tevatron fixed target run. The shape of the event time distribution depended on the inherent proton bunch shape and the time resolution of the apparatus. Events with measured event times outside the expected neutrino event time distributions were considered candidates for new particle production. The absence of such anomalous event times was used to set limits on new particle production in 800 GeV/c proton-nucleon interactions based on an integrated number of live protons on target of 1.15×10^{17}. The method used in this experiment is uniquely independent of the specific WIMP event topologies and therefore free from model-dependent background subtraction.

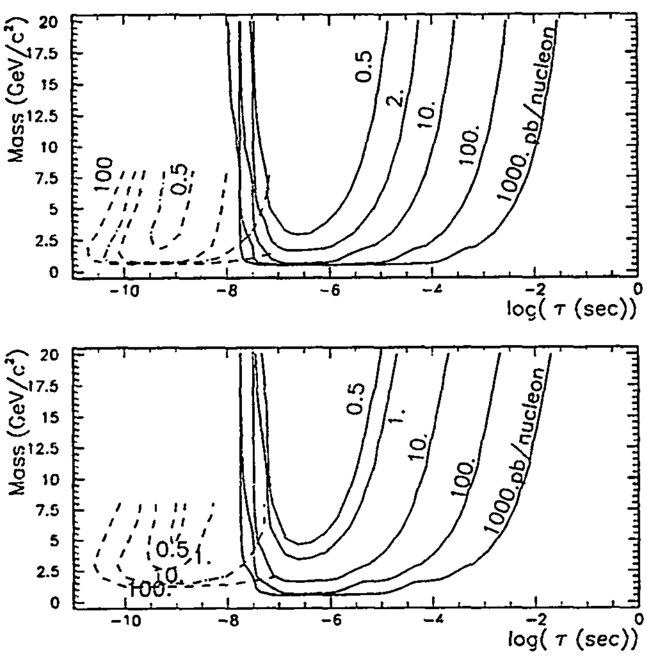


Figure 2.25: For final states that a) contain a muon and b) do not contain a muon, the solid lines indicate contours of equal 90% CL upper limits on production cross section times branching ratio (pb/nucleon) as a function of mass and lifetime for noninteracting unstable particles. Dashed curves indicate results from the NA3 experiment for identical σB and specific final state a) $\mu + \pi$ or $\mu + \mu$ and b) $\pi^{\pm}\pi^{\mp} + X$ (inclusive).

For example, for the case of an unstable WIMP decaying with a muon in the final state, limits on particle mass versus $\log_{10} \tau$ (where τ is the particle lifetime) are shown in Fig. 2.25 a), where contours of equal 90% CL upper limits on σB are indicated. The solid curves represent the E733 results, while dashed curves represent results of NA3 [24], a short beam dump experiment performed at CERN designed to look for charged or neutral massive (> 1 GeV/c^2) particles with $10^{-11} < \tau < 10^{-8}$ s. The E733 and NA3 experiments were complimentary in sensitivities. The long beamline made E733 insensitive to shorter lifetimes, but when combined with the higher integrated luminosity, E733 was more sensitive to longer lifetimes despite lower acceptances. The equivalent contours for final states with no muon were similar but less exclusive by a factor of approximately 2 in σB as shown in Fig. 2.25 b). Again, the solid contours represent the E733 results. The dashed curves show the comparable contours from the NA3 experiment for the specific final state $\pi^{\pm}\pi^{\mp} + X$ (inclusive).

The analysis conclusions include limits at the 90% confidence level reported for a) heavy neutrino production from the decay of heavy quark states, b) massive objects directly produced in 800 GeV/c pN interactions that are noninteracting but unstable with a mean lifetime between 10^{-8} and 10^{-4} s (shown in Fig. 2.25) and c) directly produced massive objects that are stable but weakly interacting with interaction cross sections between 10^{-29} and 10^{-31} cm^2.

2.7 SSC and SDC Closeout Activities

UTA continued to participate in SDC closeout activities, having been granted $13K by DoE SSC Division to contribute to cosmic ray tests of a prototype calorimeter wedge at FNAL. Our deliverable product was a laser flasher system for 20 channels of calorimetry, which we installed in summer 1994. The laser flasher schematic is shown in Fig. 2.26. The elements of this system include a rugged light box containing laser and associated optics, remote control electronics. We provided a pulse-intensity monitoring system with a photodiode, amplifier of selectable gain and digitizers on a custom CAMAC board. Correlation between the photodiode response and a SDC-style PMT from tests performed at UTA showed that PMT response could be monitored to within 1% with this apparatus.

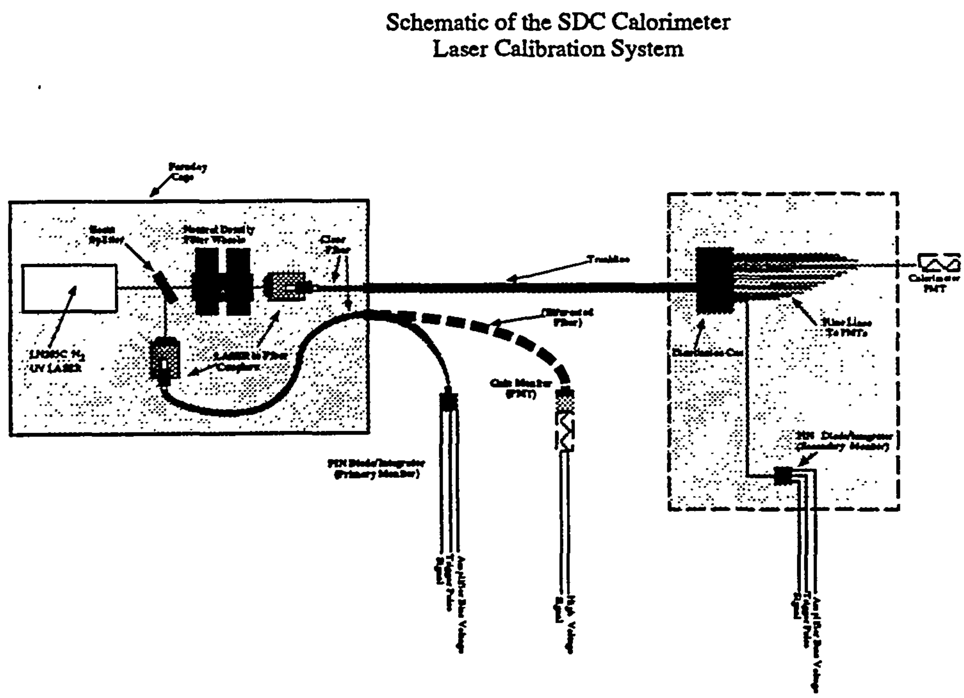


Figure 2.26: Schematic of SDC laser flasher system prototype.

In addition, we assisted the limited manpower effort at FNAL in the construction of a light distribution box of UTA design.

This effort at UTA in the past year has provided a Master's thesis (near completion) and research experience for two undergraduate students.

Cosmic ray studies were conducted during Fall 1994. Despite problems with phototube gain settings and light transmission through the distribution can which were not completely resolved before activities were ordered ceased, reasonable cosmic ray data was taken, with calorimeter response falling within 2-3% of expected values. The final activity report for the wedge test has been submitted under separate cover.

Chapter 3

UTA HEP Proposed Activities for FY'96 – FY'98

In this section we describe our proposed program of research for the next three years. This period will see the construction, installation, and use of elements of the upgraded D0 detector, as well as the emergence of a large number of new physics results from the analysis of data from the present Tevatron collider run. The same period for ATLAS will see the construction and testing of muon and calorimeter components, the specification of final detector designs, and the start of the main construction phase for the ATLAS detector. The development, construction, and setting up for the PP2PP experiment will be essentially completed by the end of this period.

3.1 DØ

3.1.1 Overview of Run Ib

The recent discovery of the top quark by DØ was achieved with only half the data expected during Run Ib of the Tevatron. We hope to get another 40-50 pb^{-1} of data during the remainder of the run, currently scheduled till July 1995. Our service activities will continue during this period, with participation in shifts, maintenance work on the ICD, repairs to the ICD during shutdowns, monitoring the data, and supporting online and offline software. Analysis of the data from Run Ib is expected to continue for 1-2 years after the data collection is completed.

With the total integrated luminosity of 100-125 pb^{-1} expected in Run I, we plan to participate in a variety of new analysis topics. Many low mass SUSY searches are rate limited. For example, the charginos and neutralinos are not expected to be as massive as the squarks and gluinos. Therefore, they are not kinematically limited by the 1.8 TeV center of mass energy at the Tevatron. Other rare SUSY searches will also be explored.

In the next three years the first application of our exclusive techniques will be employed in both QCD analyses and New Phenomena searches. We will also continue the study of colorless exchange interactions to further distinguish rapidity gap events from the more prolific QCD processes.

As the demands for Monte Carlo event generation continue to grow in proportion to the accumulated data, the UTALF farm will be saturated during the next couple of years with DØ simulation production and physics analyses. Regular upgrades to the farm will be necessary to keep up with the workload, as explained in the budget section.

3.1.2 ICD Operation in Run Ib

During the past 3-4 years since installation, the ICD has worked remarkably well. As mentioned before, during extended shutdowns of the Tevatron, we have removed and retested large number of boxes in the cosmic ray test stand. After comparison with benchmark runs, we have found an average of 5% decline in the Hamamatsu PMT gains every shutdown. These changes have been applied to the calibration constants for subsequent data. Similar retesting is expected during summer 1995 and beyond, especially if the collider run continues with additional accumulated luminosity till spring 1996, as requested by DØ.

About 40% of the tubes used in the ICD are the Russian PM60 tubes. Our experience with them have been less satisfactory. Many of these tubes have been replaced during past shutdowns. We expect to retest and replace some more of these tubes before the end of Run Ib.

There are a few unfinished issues in our understanding of the absolute jet energy resolution and efficiencies in the ICD region. Previously, our studies have concentrated on relative resolution of the ICD and MG detectors. In order to use the ICD region in more physics analyses, we have to provide an absolute calibration of energy resolution. We have streamed data samples from both Run Ia and Run Ib which contain events enriched with significant energy deposited in the ICD. We will use these data samples to deterfine the final calibration of the detectors in the ICR.

3.1.3 SUSY Searches in Run Ib

With the increase in luminosity from Run Ib come new opportunities for expanding the search for new phenomena. The current mature search for gaugino pair production and decay to trilepton final states will be continued. Estimates of the reach in $M_{W^{\cdot}one}$ available with 100 pb^{-1} can be seen from Fig 3.1. This plot shows the theoretical prediction of cross section times branching fraction to trilepton states, within the context of the Constrained Minimal Supersymmetric Standard Model [25]. The increase in luminosity alone should allow sensitivity to charginos of mass $M_{\tilde{W}_1} < 100$ GeV. We also expect improvements in electron and muon efficiencies, due to changes in the reconstruction algorithms as well as new particle identification tools.

Other SUSY channels can be pursued with the significant increase in data. Multileptonic final states of squark and gluino decay provide a "golden" discovery channel, relatively free from Standard Model backgrounds (the predominant background is in fact from $t\bar{t}$ production). The cross section for such events is well below that of the jets plus $\not{E}_T$ channel, which have substantial backgrounds. Therefore, the multilepton channel could prove to be a very valuable discovery channel if low energy SUSY turns out to be within the mass reach of the Tevatron.

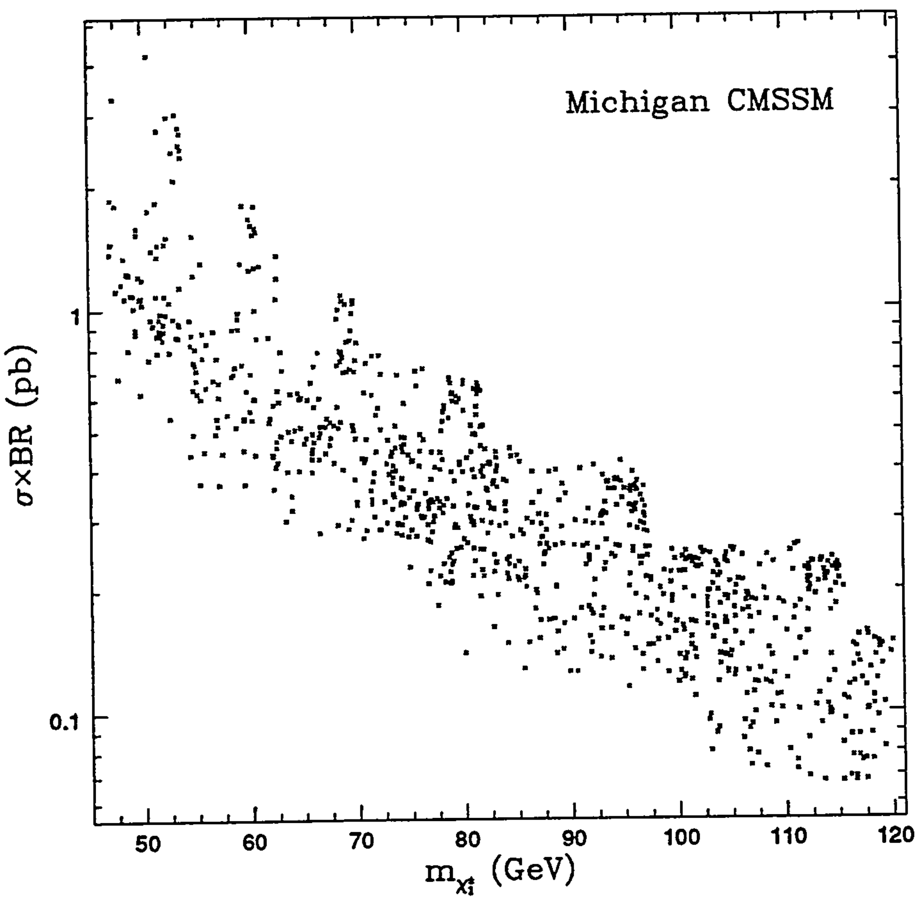


Figure 3.1: $\sigma \times BF$ for gaugino pairs decaying to three leptons in the Constrained Minimal Supersymmetric Standard Model (CMSSM).

3.1.4 QCD Studies in Run Ib

Since the amount of luminosity expected by the end of the current run is ample for conventional QCD processes, focus is turning toward precision tests with QCD and rarer QCD signals.

Color flow within and between jets is an important test of higher order QCD calculations. Many studies have been published of jet shape within Snowmass-cone-definition jets, and DØ has presented preliminary results of this kind of study. However, there is increased interest in more sensitive tests, such as characterization of subjets and angular correlation of energy flow, both within the cone radius of reconstructed jets and between jets and other event objects (other jets, the beams, vector bosons). One way to describe this is as a study of the color "string" between colored objects created during the fragmentation process.

Rapidity Gaps

For rapidity gap events, the evidence for colorless exchange is now established. However, little experimental work has been done to distinguish these events from conventional QCD (color mediated) exchange other than the production of the gap. It is widely suggested that the strongest contributor to colorless exchange is a Pomeron-like mediator, but little is known about this object. UTA has taken an interest in the study of these events, using two primary tools: b- quark production and energy flow studies.

Heavy (b) quark production is described by $2 \rightarrow 2$ quark- and gluon-fusion diagrams, and by higher-order $2 \rightarrow 3$ gluon fragmentation diagrams, some of which are shown in Fig. 3.2.

Theory predicts [26] that the contributions from the $2 \rightarrow 2$ and $2 \rightarrow 3$ processes are comparable. For colorless exchange, the $2 \rightarrow 2$ processes are unavailable, and so the rate of heavy quark production is expected to be significantly suppressed. Depending on the model of the colorless mediator (e.g., a two-gluon Pomeron-like object), additional color factors will suppress production further. Measurements of the rate of b-quark production in dijet events exhibiting a gap would yield important information on the nature of the mediator.

Bottom-quark production is signified by a jet tagged with a muon with a significant p_T with respect to the jet axis. This is being studied presently by members of the Heavy Quark physics group in DØ, but their study is limited to the central region. Our interest would therefore extend this reconstruction to the forward region, where muons are identified by the SAMUS (Small Angle MUon Spectrometer) system, and therefore also provides a service to that group.

Further studies will make use of new analysis tools to examine color flow inside and between the jets in gap events. Color flow in DØ is being examined by parametrizing the energy flow as a function of a fraction of the jet cone radius, and as a function of the azimuthal angle about the jet axis, and by looking for subclusters inside jets with the DØ version of the K_T jet-finding algorithm. Such techniques are just beginning to yield fruit in DØ, and there is obvious applicability for rapidity gap studies. It is expected, in particular, that a rapidity gap event will still exhibit color strings between the "trigger" jets and the beam axes, but that energy flow between the jets, and possibly with the

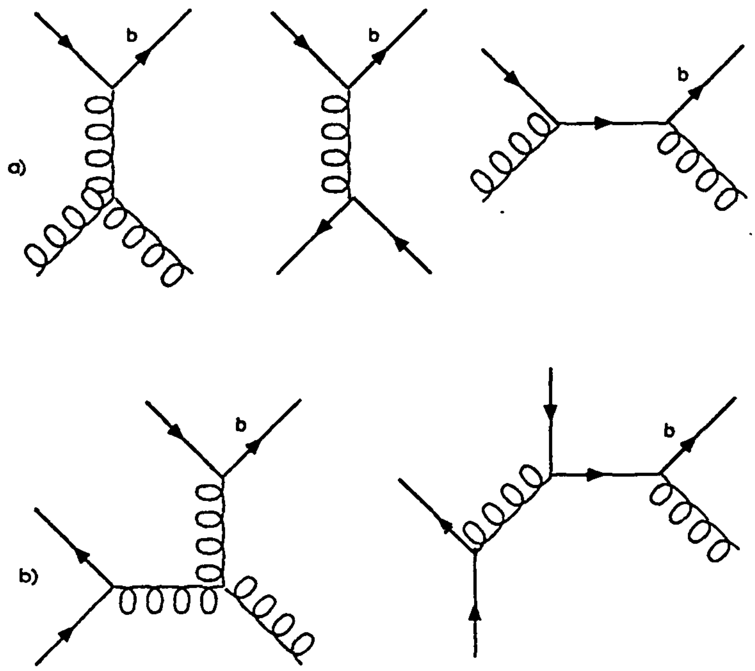


Figure 3.2: a) Some $2 \to 2$ and b) $2 \to 3$ b quark production diagrams.

underlying event, will be suppressed. In one application of these techniques, for instance, we will look for a relative enhancement in the number of subjets toward the nearest beam axis in rapidity gap events.

Exclusive Techniques

The development of *exclusive* techniques in $p\bar{p}$ physics analysis is motivated by the desire to study topological event distributions as a function of the center of mass energy, $\sqrt{s}$, of the primary interaction. The four approaches to this problem which we have considered include: 1) application of the K_T or *Durham* successive combination jet finding algorithm [7] – this makes rigid assignments of tracks/showers to either the beam jets or the primary scattering; 2) image reconstruction in a maximum likelihood setting utilizing the maximum entropy approach [27] – this assigns weights to tracks/showers as a statistical measure of the degree of participation in the beam jets or primary scattering; 3) application of fuzzy logic with a neural network [28] – this also assigns weights to tracks/showers; and, 4) use of a technique common in nonlinear dynamics, time-ordered pattern recognition [29]. This approach shows additional promise as an interdisciplinary project and was suggested by a nonlinear theorist colleague who is interested in collaborating in its implementation – here, the time series is used to predict the content of the beam jets lost down the beam pipe, promising a genuinely *exclusive* technique.

As described above, we have initiated this program in the DØ experiment through development of the K_T algorithm and comparisons with the cone algorithm. We plan to follow this with implementation of the full K_T algorithm [7], and a study of the accuracy of the approach using the Herwig Monte Carlo model of QCD interactions. Our plan is for this study to conclude in publications of analyses concentrating on the topology of QCD multi-jet events – in an exclusive context.

For the longer term, the development and application of exclusive analyses will provide the germinating ground for a host of studies in QCD and searches for New Phenomena.

Since the development of these approaches demands understanding of the underlying event structure, the more sophisticated techniques necessarily begin with an experimental study of non-perturbative QCD. Given development of some of the proposed techniques within the DØ experiment, we expect the pattern recognition algorithms to spin-off in other directions. For example in distinguishing between, say, gluon jets, quark jets, b-jets, and t-jets.

At this point we plan to implement exclusive analyses searching for New Phenomena in a model independent way on the scale of two years. For example, at the kinematic onset of supersymmetry, where $\sqrt{\hat{s}}$ is the gluino or squark pair mass, we will search for a threshold in the missing transverse energy distribution. Another example: many New Phenomena, including Technicolor and Leptoquark theories, are distinguishable by the onset of new fragmentation processes. A clear signal of such a new kinematic domain would be an abrupt increase in jet multiplicity or, if the fragmentation is more subtle, an abrupt increase in event sphericity at some threshold, $\sqrt{\hat{s}_{Thresh}}$.

Another problem these techniques naturally address is the ability to systematically separate superfluous minimum bias events, in multiple interactions, from an interesting hard interaction. For example, at LHC we expect 18 interactions per beam crossing; the ability to systematically distinguish remnants from the 17 minimum bias events from the single hard scattering will clearly be necessary for a host of physics analyses.

3.1.5 Run II Upgrades

ICD

UTA has assumed complete responsibility for upgrading the ICD for Run II at the Tevatron. With the addition of a solenoid in the central region, the PMT tubes used in the ICD will become inoperational. In January, the scope of the ICD and the newly proposed EMICD detectors were reviewed by a panel set up by DØ management (DØ Note 1234). The panel strongly urged the replacement and upgrade of the most critical part of the ICD for Run II. The panel also recommended that further studies be performed to evaluate the EMICD. Due to financial and space constraints, DØ management has decided not to build the EMICD. The ICD will be upgraded to cover at least this region, and possibly further to cover the dead material in the solenoid.

The upgraded DØ detector proposed for operation in Run II includes a 2 Tesla magnetic field in the central detector region produced by a superconducting solenoid extending to $|\eta| < 1.6$ (see DØ Note 1733). The current Inner Cryostat Detector (ICD), located just outside the ends of the solenoid, will not operate in this environment because the phototubes cannot be fully shielded from the field. It is therefore necessary to redesign and construct an upgraded ICD that will perform as well as than the current Run I ICD.

In the interest of saving money in the research and development necessary for the

Run II ICD, the experience with the Run I ICD will be fully exploited, including the salvaging of as much equipment as possible from the Run I detector. However, because of changes in the fiber and electronic readout system, much R&D is necessary to bring this new detector to fruition. UTA is the only institution expected to participate in the redesign, construction, and operation of this detector subsystem.

Based on the DØ upgrade review in January, 1995, it was decided that the Run II ICD will cover the region from 1.1 to 1.4 in pseudorapidity (η) between the central and the end cap calorimeters. Its segmentation will be by 0.1 in η and ϕ, compatible with the DØ liquid argon calorimeter. Like the current ICD, it must also be thin (less than 3 in.)in the direction of the projective towers to fit within the narrow region between the cryostats.

The Run II ICD design includes scintillating tile as the active element (like the current ICD) because of its low cost per unit area, energy resolution, and its ability to operate at room temperature and pressure. Light signals from the 384 ICD tiles will be transported along clear fiber to the location of the new readout system (on average, about 8 meters from the ICD tile location). The only input/output into the ICD region will be the scintillator output signals and the laser calibration input signal. Due to the long fiber lengths involved, tile/fiber material from the Run I ICD cannot be salvaged. We plan to acquire new scintillators and fibers.

The phototubes and readout electronics will be distributed by quadrant onto the trays (now called ICD trays) that move within each of the 4 cable winders (just below the 'pig troughs'). Each ICD tray is at least 40 inches long, 11 inches high, and 22 inches deep. The readout system will include Hamamatsu phototubes, many of which can be salvaged from the current detector. In this location, the field seen by the phototubes will be less than 500 gauss.

The segmentation of the modules of the Run II ICD array will depend on the number of scintillating fibers ganged together at each segment connector. Clear fiber cables will bring the light signals from each ICD segment connector to the readout location through a fiber backplane to individual phototubes inside the ICD drawers on the ICD trays.

An ICD drawer would house PMTs, PMT electronics, and preamplifiers for 3 or more channels of readout. The final number of channels per drawer will be determined based on how the readout signals will be multiplexed to interface with the BLS system. An ICD tray will house a 2-D array of slots holding the ICD drawers. Each drawer will slide individually on rails, making individual maintenance of each drawer easy. Internally, the ICD drawers will have fibers entering the drawer from the back end through the fiber backplane. When a drawer is in the dresser, 3 PMTs will be aligned with 3 fiber bundles from the backplane. The PMT electronics and preamplifier will be located on an electronics card level with the PMTs. Input high voltage and output signal ports will be located on the front of the drawer. A temperature monitoring and heat dissipation system will be required since the power consumption of the upgrade charge integrating preamplifiers has risen by a factor of 3 over the Run I preamplifiers.

The ICD drawer position will be such that the axes of PMT's within it are perpendicular to the field lines. Shielding is still expected to be necessary at the level of shielding on the current PMT's. Studies at UTA are currently underway to determine if more shielding is necessary.

A complete redesign of the readout electronics is necessary in order to be compatible with the DØ upgrade BLS system and the DØ upgrade preamplifier design. The DØ upgrade electronics group is aware that the ICD upgrade will use a modified version of the upgrade calorimeter preamplifiers. They expect to have prototype upgrade preamplifiers by the end of the summer. Coordination with this group is required for the preamplifier design as well as to insure that ICD signals are in time and compatible with calorimeter signals to form the trigger information.

Because of the presence of the magnetic field, an in-situ calibration of the ICD is called for. General studies (Dan Green - SciFi93) showed an 8% per 10 kgauss change in scintillator output due to the presence of an external magnetic field. It will be necessary to calibrate the system with the detector closed and the magnetic field on. Such calibration with a moving source is impractical in-situ because of the limited space available. We will have to rely on particles measured in the tracking system for in situ calibration of the ICD in Run II. Just as with the current ICD setup, a laser calibration technique is planned. Experience with the current laser calibration system suggests that more reference photodiodes should be added to improve the calibration system.

SICD

The DØ upgrade review in January, 1995 approved our request to study the merits of extending the ICD to higher η. This additional array of tiles would be added in the eta region from 1.4 to 1.7 in eta to sample the energy behind the solenoid (the SICD). This would add a maximum of 384 additional channels to be read out by the readout system. GEANT simulations are underway at UTA to establish the usefulness of this device.

FPD

We are continuing to work on a Forward Preshower Detector for the upgraded DØ detector. We are preparing a proposal for a detector based on scintillator strips with wavelength shifting fiber readout. The proposed strip dimensions are similar to the PP2PP prototype described above; we are using the PP2PP test beam studies to understand the performance characteristics of this device. A full proposal to the DØ collaboration will be prepared this summer, in conjunction with Florida State and Rochester Universities.

Schedule for Run II Upgrades

During 1995-95, we will finalize the technical design of the upgraded ICD detector. Extensive mechanical design work is needed to complete the design of the drawers. We have been allocated money from DOE FNAL funds to build a full scale prototype with five ICD modules. We expect to build and test this module by early 1996.

We have started simulation work on the extension of the ICD to cover the dead material in the solenoid cryostat walls. Studies similar to the ones described above to evaluate the ICD will be conducted once the detector geometry has been accurately installed in DØGEANT. We expect this work to determine the need and scope of the device by the end of 1995. Prototype development work will then start in 1996.

Simulation studies of the forward preshower should also be completed by the end of 1995. Once DØ management decides on the technology option, UTA will decide whether to join this construction project. If the scintillator strip technology is chosen, it is likely that UTA will build a part of this detector.

As described above, there is still some uncertainty about which detectors will be built at UTA. At a minimum, the ICD construction will be done at the Swift center during the period 1996-1998. After extensive testing, installation and commissioning, Run II is expected to start in early 1999.

3.2 ATLAS

3.2.1 Overview of ATLAS timeline

Our proposed activities on the ATLAS experiment will necessarily be affected by a number of external factors. For this reason we now give our present understanding of the timetable for the development and construction of the ATLAS detector. For the muon system it is anticipated that a period of two years will be required for prototyping and design refinements. Final designs should be complete by mid-1997. There will then be a two year pre-production period through 1999, followed by a main production period of three years. Thus the three year period covered by this proposal will see the completion of the design phase and the initial ramp-up to the production phase.

We expect an initial period of intense activity on the newly proposed IBTC detector for ATLAS. During 1995-96, we will concentrate on defining the scope and the preliminary design of the detector. Final design will not be possible till the choice of liquid-argon calorimeter readout electronics has been made. The design of the feedthroughs and other services in this region will also have to be considered. We expect to define the full scope of the IBTC by the end of 1996. After that, we plan to build prototypes, test performance, and continue simulation studies in order to finalize the complete design by 1998. Construction will probably begin after the period covered by this proposal.

3.2.2 Muon subsystem

Prototype and production planning

The initial objective of the UTA muon work on drift tubes and mechanical assembly is directed towards the production of a prototype chamber module in FY'96. Discussions so far have centered on a scheme in which UTA would establish a facility for the production/testing of the individual drift tubes which would be shipped to UW for integration into the multilayers/chamber. Following the assembly of the tubes at UTA personnel from both institutions (and other maybe other US ATLAS muon institutions) would then participate in the testing of the module in the ATLAS test beam at CERN. We are currently in the project definition stage of this work. A report will be submitted to US ATLAS as a funding request for FY'96.

Muon tube and module production facility

It is the stated intention of the ATLAS muon group to achieve a high level of standardization in the methods for producing muon drift tubes, multilayers, and chambers. This is clearly desirable in a system consisting of approximately 400,000 tubes which will be integrated into chambers at eight production sites in Europe and three sites in the US. Nevertheless, there are many different designs and potential production techniques for the system components and it is essential that a number of these be tested independently in order to be able to select the best approaches for use in the final production. To this end we at UTA intend to work with personnel from the University of Washington and the UTA Automation and Robotics Research Institute (ARRI), as we did on the SDC Experiment, to develop tube, multilayer, and chamber fabrication procedures. As before this will require a detailed analysis of the steps required in the fabrication processes, specification of the required human and material resources, and ultimately the full design for a production facility at UTA. The layout of our Swift Center building lends itself well to use for one or more (parallel) tube assembly lines, in association with a multilayer/module assembly area. Even though we shall necessarily have to incorporate standardized procedures specified by the ATLAS group, we will still need to tailor these to match local realities of space etc. This whole area of work will substantially benefit from collaboration with our ARRI colleagues and use of their production engineering tools.

3.2.3 Calorimeter subsystem

IBTC studies

During 1995-96, IBTC work is expected to proceed along 3 fronts. First, we need to complete the simulation studies to understand the jet and missing E_T response in the intermediate region. Second, we will continue to develop the IBTC structural design given the acute competition for space in this region. Third, we plan to build prototypes of IBTC scintillator tiles using the new Hamamatsu PMTs.

Considerable work needs to be done on the simulation front. The resources available on the UTAHEP Alpha Farm should help. Recently, our collaborators at Barcelona have expanded the ATLAS simulation code to provide information about the energy lost in dead material. This information is essential in order to optimize the design of the IBTC. We plan to generate a large number of dijet events using the latest version of the TileCal simulation package for a variety of thicknesses and geometry of dead material added in the gap.

The degradation of jet energy resolution in the gap is of primary concern. This leads to the degradation of missing E_T which affects many physics topics, including the Higgs search. We will use our experience with the DØ ICD detector to guide our studies and design of the IBTC.

IBTC prototyping

Based on recent negotiations with the electromagnetic calorimeter groups, ATLAS management has chosen the minimal dimensions for the IBTC detector as shown in Fig. 3.3. In this design the detector extends only 150 mm in the z direction. As a result, not all eta regions are covered. UTA has stressed to ATLAS management the need to cover all the eta region in this gap with some active material. Simulation studies are underway to study the minimal detector configuration required. Based on these new simulation studies, we will propose a new configuration for the IBTC by the end of 1995.

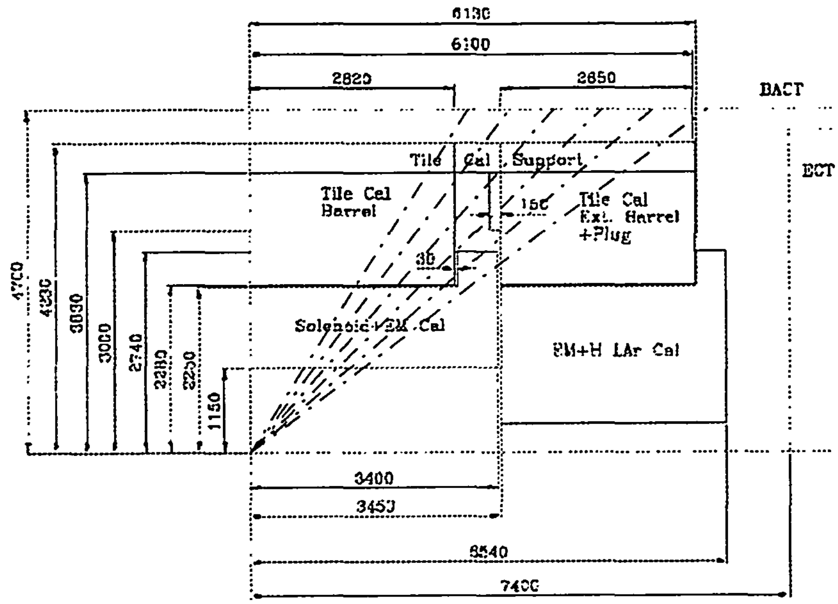


Figure 3.3: Preliminary dimension and location of the IBTC detector in relation to the other calorimeter components.

UTA has also led the preliminary work on the mechanical design of the IBTC along with collaborators from BNL. Based on the preliminary allocation of 150 mm of space, we have developed a mechanical design as shown in Fig. 3.4. We expect this design to evolve during 1995 into a final design by the end of 1996. Detector development and final technical design work will start then and continue till 1998. We expect to build prototypes and study generic detector issues in parallel with this design effort during the entire period of this proposal.

IBTC construction

Due to the greatly increased size and scope of the ATLAS detectors compared to the DØ detector, the IBTC will be a considerably larger and complex device compared to the ICD, even though the coverage in eta is approximately the same. We expect that the IBTC will include many layers of steel and scintillators compared to the single scintillator layer used in the ICD. The actual size of the detector will also be greater in the radial and azimuthal dimensions. The segmentation will be similar – 0.1 in η and 0.1 in ϕ.

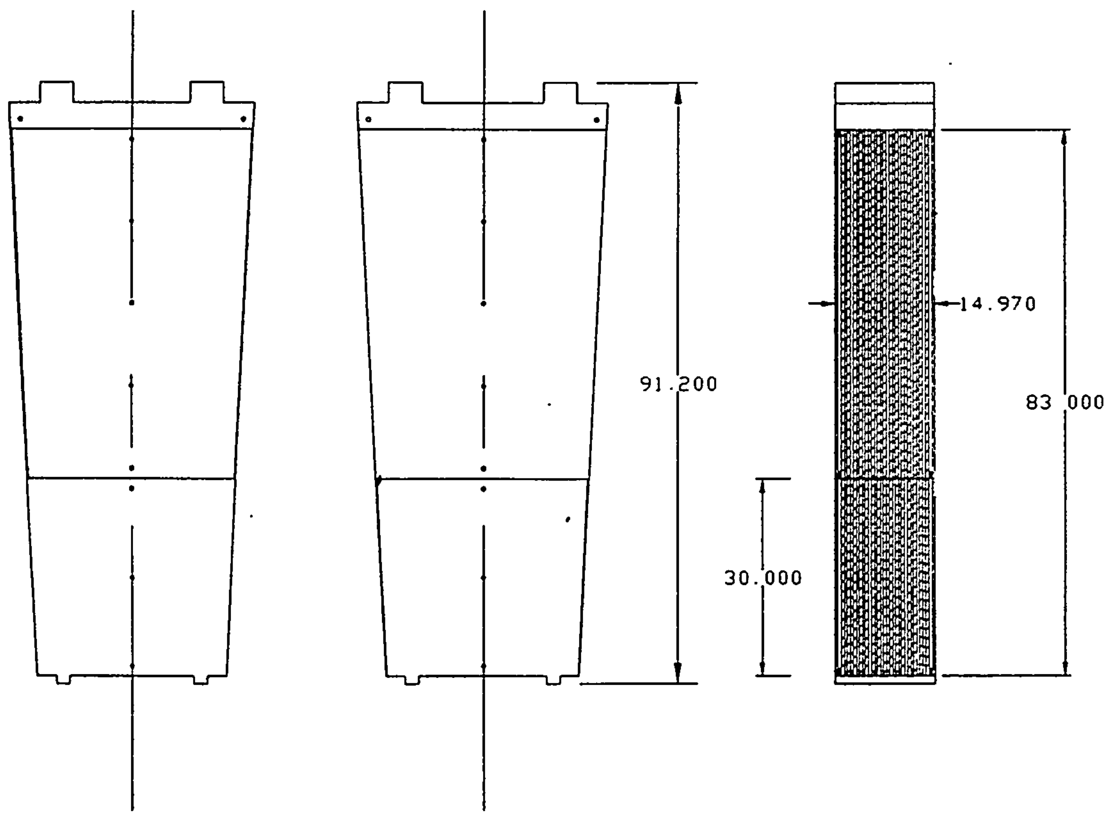


Figure 3.4: Preliminary design of the proposed IBTC modules.

The new Swift center facilities will provide the ideal detector construction and testing space for the IBTC. We expect to start prototype work in 1995, leading to construction work in 1998-99. The exact division of IBTC construction responsibilities has not been decided among the US ATLAS groups. However, it is expected that the entire detector will be built in the US. We expect a substantial part of the construction to take place at UTA. Combined with our DØ upgrade construction responsibilities, and the ATLAS muon construction responsibilities, the TileCal construction will provide UTA with major detector construction activities well into the next century.

Other TileCal Responsibilities

The UTA involvement on the ATLAS TileCal detector is not limited to the design and simulation of the IBTC. We plan to provide support for physics simulations, PMT testing, module construction and testing, shifts at CERN test beam and analysis of test beam data. Test beam runs are scheduled for May-June 1995. Work on module Ø, the first full scale prototype, will continue throughout 1995-96.

More than 10,000 PMTs will be used in the ATLAS tile calorimeter. The US collaborators will be responsible for providing one third of these tubes. Currently, three US sites have expressed interest in testing the tubes - UTA, UI and MSU. At UTA, we plan to test more than a 1,000 tubes. The DØ PMT test stand built at UTA will be upgraded to test these tubes. A new scheme will be necessary to hold the smaller sized tubes to be used in ATLAS. We will also increase the current maximum number of channels from 5 to 10.

The new R5900 series tubes are being developed by Hamamatsu for TileCal. The US groups are yet to receive the first prototype of these tubes. However, we have acquired two R5600 tubes at UTA last year, which are similar in design. Tests are underway to evaluate the performance of these tubes.

When the ICD was designed and constructed, we used the two smallest tubes available in the world – the Hamamatsu R647 and the Russian PM60. New low gain and low current bases were designed and integrated with the charge sensitive preamps. Over 1500 tubes were tested. Our extensive experience with small phototubes used in the DØ ICD will help us to play a similar role in ATLAS TileCal.

3.2.4 Software Development

Our approach to ATLAS computing is a microcosm of our general plans for the future in computational physics, hence it is described in greater detail below. To summarize, it is a two-pronged approach: on one hand we will continue to perform fundamental physics and detector studies making full use of the UTALF farm, and on the other, we will continue to pursue modern software techniques including participation in the development of the ATLAS offline analysis software.

As the existing ATLAS simulation software (which is traditional, FORTRAN based, HEP code) has matured over FY'95, we have played an increasingly stronger role in detector design studies, primarily in support of the Intermediate Barrel Tile Calorimeter (IBTC), but also for whole detector/physics studies of the muon system. Over the next year we will coordinate and perform in depth studies of jet resolution, electromagnetic punch through and so forth, in the intermediate region of the tile calorimeter until the IBTC detector design is optimized. In support of these activities we will produce large samples of simulated data in coordination with colleagues at CERN and Barcelona. We will perform similar tasks to study issues in the muon system including backgrounds, resolution, and triggers to determine the utility of a variety of muon tracking algorithms.

In our continued pursuit of simple, robust, modern software approaches, we plan to finish developing the histogramming and data acquisition engines, HISTO++ and DAQ++, ultimately implementing them as a combined platform independent package deployable on windows-based micro-computers, Macintoshes, Unix workstations, and VMS-based AXP machines. This will install solid object oriented code in the lab, a ground-up approach to adopting OO as a paradigm. Next, we plan to add interactive graphics services and GUI control. Upon completion, these products will be made public for use by high energy physics groups at other institutions.

We also intend to participate in the design of ATLAS offline reconstruction code in C++ (the *de facto* industry standard). Although we will work closely with colleagues at CERN, the standards we adopt will be compatible with the US software industry. This comprises programming languages and CASE tools alike. Object Request Brokers (ORBs), which are described in greater detail below, will provide interoperability across platforms, languages and operating systems.

We expect to have a significant impact in the integration of new physics software tools. This includes integration of legacy and new HEP software using the common object request broker architecture (CORBA) set of specifications originating from the Object Management Group [30]. The initial experiments will see OO prototypes developed for histogramming and data acquisition integrated across architectures, operating systems and physical location using experience from Computer Science Engineering and the Systems Integration Architecture (SIA) project [31].

3.3 PP2PP

3.3.1 Overview of PP2PP timeline

Currently, the startup of physics data collection at RHIC is scheduled for Spring 1999. The schedule for PP2PP development is partially driven by counting backwards from this date, and partially by other milestone dates on which we are dependent, such as accelerator design and construction schedules and available test beams. A projected schedule for further development is shown as follows. The next key milestone is the preparation of a technical design report, planned for submission late 1995 to the laboratory and to DoE.

- Spring/Summer 1995 – Detector prototype beam tests
- Fall/Winter 1995 – Submission of technical design report
- Spring 1996 – Major detector construction starts
- Summer 1998 – Installation and commissioning
- Spring 1999 – Physics running

For the next year, the attention is going to focus on the beam testing of a prototype detector (and the associated analysis), and the refinement of experimental simulations.

3.3.2 Simulation studies

Simulation studies are at the point where detailed questions of background, reconstruction efficiencies including cuts, and acceptances for spin-related physics, must be addressed. To do this requires restructuring the present code to include separate stages for event generation, lattice and detector simulation, and reconstruction code. The first allows inclusion of various physics and beamline backgrounds; the second allows optimization of detector geometries and minor lattice parameter adjustments; and the last will serve as the prototype for final analysis code that includes background rejection. This is a substantial amplification of the present effort, and will make use of of UTA HEP's significant computing resources. UTA continues to take primary responsibility for simulation activities for PP2PP.

In addition, PP2PP is actively pursuing ways to stretch its reach to higher values of $|t|$, where there is even stronger theoretical interest in results with polarized protons at RHIC energies. The detectors for this configuration are of course at larger scattering angles, achieved by placing the detectors closer to the interaction point, where there are detailed issues having to do with the physical layout of the lattice elements and the experimental apparatus. Careful and creative design and acceptance studies are crucial for assuring good physics results in this area. Some accelerator design questions have yet to be answered, especially in the spin-physics program. For example, RHIC administrators are considering the impact of spin-rotators to provide longitudinally polarized protons at the PP2PP interaction point.

3.3.3 Detector development

In the near future, we will continue to study the recently acquired test beam data in order to improve the design of the PP2PP scintillator strip detector. Prototype work will continue at UTA in the Swift center. Additional test beam runs may be necessary before the design is finalized. All the PP2PP detector development work will be extremely valuable for the proposed forward preshower detector for DØ.

In addition, we have performed some preliminary Monte Carlo studies evaluating a technique for unfolding the cross-talk in multi-channel photodetectors. A given hit in the detector may deposit energy in neighboring channels, but this irreducible cross-talk is compounded in many photodetectors (especially reasonably priced ones) by channel-to-channel cross-talk in the photoconversion and amplification stages. This contribution can, in principle, be separated from that in the detector by scrambling the fibers into the multi-channel detector so that no neighboring channels in the detector remain neighbors in the photodetector. The inverse mapping likewise will spread the detector cross-talk to non-neighbors in the detector, thereby separating the spread in the energy due to each of the contributions. This can improve the detector position resolution dramatically if it relies on detailed information on energy sharing in the detector. The performance of this scheme depends on the occupancy rate and noise, and we will continue these studies both with Monte Carlo and test beam data.

3.4 Computing

Over the next several years we will continue to develop UTA as a high energy physics computation center for the DØ, ATLAS, and PP2PP experiments. We will continue to approach the issue of computation from two separate angles, one studying the long term future of software and communications, the other focused both on massive simulated data production and the development of supporting multitasking software. At present these are two separate thrusts, but we expect them to merge on the scale of a few years. In this section we begin with a discussion of our initial motivation in building our program with a strong computational bent; we then describe the two thrusts separately and conclude with a vision of how they might merge.

There are several key aspects to concentrated computational power at off-site institutions. First is the edge that universities need in physics analysis. A singular disadvantage to being displaced from the experimental site is a delay in communication regarding new software packages or trouble with established software packages or data sets, and so forth. In our experience, both at UTA and at institutions where we were previously in residence, local access to high speed computational facilities more than makes up for such disadvantages. In fact, experience shows that with strong computational infrastructure, off-site institutions can obtain their role as analysis centers with the ability to push analyses through to publication.

Another key aspect is the ability to work in an interdisciplinary setting, taking advantage of the talents on campus in the Computer Science Engineering Department and ARRI. At UTA we have developed a tradition of employing computer science graduate students each semester in addition to our strong ties to ARRI. We expect some of these students to pursue their Master's Degrees in computer science through the development of our multitasking software and OO approaches to the development of the foundation of HEP physics software and communication for the ATLAS experiment.

Underlying these tenets is the reality of the strong service role we will play as an off-site center for massive Monte Carlo/Data production. Our previous experience at the University of Florida in both the development and running of a very powerful computational farm, demonstrate that, since on-site clusters are invariably saturated with interactive use or data reconstruction, off-site systems, especially when configured as a farm, can have a big impact on physics analyses and detector design studies.

The development of UTAMulti software emphasizes simplicity in use by making a few simple, but stringent requirements: 1) it must be template driven; 2) the multitasking software must be independent of a given executable; 3) it must report its status directly to the user on a flexible time scale, generally about 24 hours; and, 4) it must be flexible in recognizing which queues are available allowing the dynamic allocation of resources. The first version of UTAMulti, the software we have developed to support our production efforts, was developed during FY'94 and '95. It is a simple package written by us, with computer science graduate students in DCL, the Digital Command Language peculiar to the VMS operating system. An example of the coordination provided by UTAMulti is shown in Fig. 3.5. The production version supports one executable operating with one input and one output file. A test version being developed supports up to three executables with one initial input file which is processed by an initial executable whose output(s) can be written to tape and processed by a second executable whose output(s) can also be written to tape, and so on. This version will find favor when we've successfully ported the DØ trigger simulation software to the AXP platform, where we'll run an extended list of executables serially: event generator - detector simulation - trigger simulation - data reconstruction - each with its own output(s).

Later releases of UTAMulti will build toward platform independence through the use of, first, object oriented technology complete with file queuing across networks within a cluster and later, through the use of Object Request Brokers (ORBs) not only across clusters, but also across wide area networks.

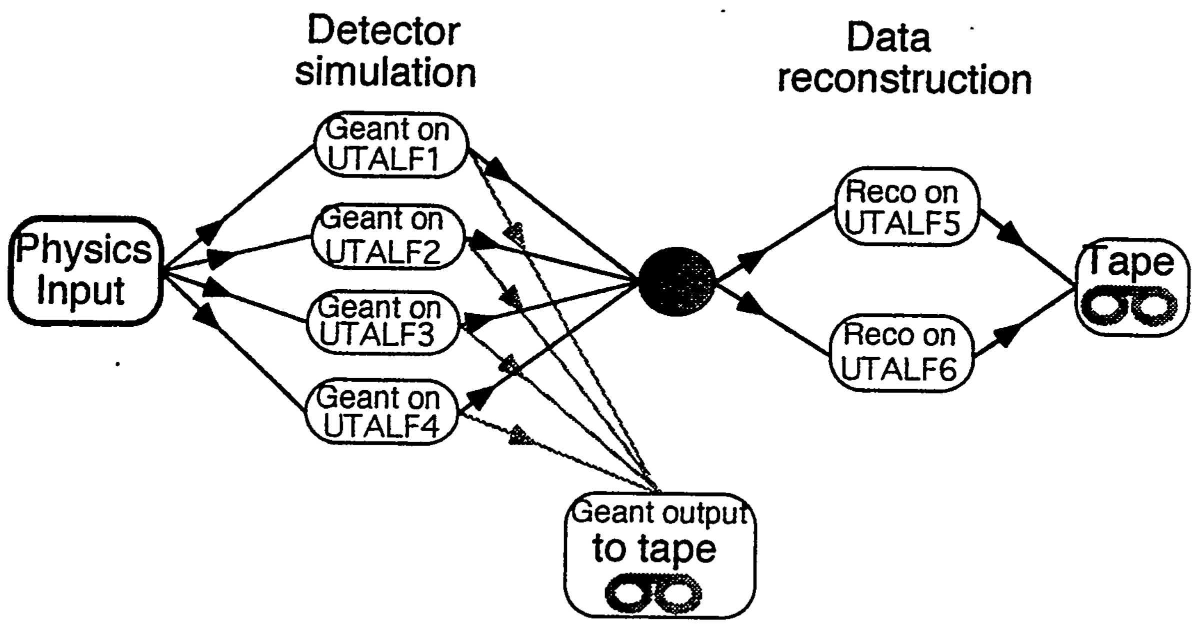


Figure 3.5: Schematic view of the UTAMulti coordination of the DØGEANT-DØRECO sequence.

This brings us to a discussion of our pursuits in modern software. It should be noted here that much of the discussion below represents a new initiative for our group which will require extra support. The discussion above, in all sections, represents either ongoing work or the natural outgrowth of previously funded activities in our program. These new pursuits will be carried out in collaboration with the Information Technology Group of UTA's Automation and Robotics Research Institute and US software firms through ARRI or otherwise.

In HEP, the technology associated with software has rarely taken a predominant role over algorithmic work. Still, there have been groundbreaking efforts to write effective extensions (e.g. YBOS [32], ZEBRA [33]) to commonly used FORTRAN. These extensions have more or less brought the usage of the FORTRAN programming language to a level roughly comparable to C. But in doing so, these extensions have locked multi-million dollar experimental investments involving thousands of physicists into ill supported software technology away from the mainstream. Thus, necessarily, large amounts of manpower must be expended to continue the segregation of scientific software engineering from the vast volume of mainstream commercial software. As HEP suffers from a lack of funding, attracting fewer graduate students, it can ill afford to continue investing in its peculiar software technology. Further, it is unacceptable to require graduate students to study in an environment where the software technology is a null asset in securing a job outside of the field.

Object oriented software technology is being used in industry spanning engineering, telecommunications, and business. In the high energy physics community, resources have been committed [34] to studying and prototyping OO software to be used in tracking and calorimeter software. We propose to write a corresponding prototype of the muon reconstruction software using C++ for the ATLAS experiment. This will include prototyping and test studies of software products necessary to make the entire software of ATLAS agile. Agility refers to the ability of software to respond to unanticipated change but without significant modifications throughout major software subsystems.

It is imperative that software written today be (re)usable in the commissioning of detectors several years from now. Since the physics knowledge incorporated in, for example, simulation code is the result of years of verification it is important that we be able to extract the knowledge from existing software and install it in new, object oriented, supporting technology. Many existing applications (e.g., physics event generators, detector response simulators, etc.) are so well established that rewriting with OO technology will be unreasonable until demanded by fundamental advances in understanding. Fortunately, wrapped products can be provided to allow timely integration. Another application of Object Oriented software technology important, in the context of building a software foundation for an HEP experiment, is the ability to smoothly integrate software (including existing software) across architectures and over networks.

The maturing Object Request Broker (ORB) technology will tear down the barriers separating architectures, operating systems, programming languages and physical location. We anticipate complete interoperability between Unix, VMS, Windows, Macintoshes programmed in C, C++ and other languages – including FORTRAN. ORB's, or similar technology, will be the key components of software integration that true distributed OO computing requires. This integration is also the result of separating the definition of objects from their implementation in various computer languages. This is done through the definition of the interface of objects to brokers in a language called the Interface Definition Language (IDL) [35].

Cooperation with industry is fundamental to the existence of ARRI, hence this proposed collaboration with the IT group at ARRI should spur industrial collaboration in testing object oriented data bases in the context of HEP through, at least, alpha/beta releases.

Specifically, over the entire course of this proposal, we will a) wrap in C++ the common generators of HEP: ISAJET, PYTHIA, etc; b) wrap in C++ legacy GEANT 3.1 or integrate GEANT4, an OO version of former; c) wrap PAW in C++ or use/develop an OO PAW; and, d) demonstrate full interoperability under ORB architectures.

The consequence of full interoperability under ORB (or similar) technology is true distributed computing at a very large scale; much beyond the confines of a single site, cluster or farm and extending to the scale of communication networks linking National Laboratories and Universities worldwide. The issue of massive integration is common to both Science and Industry. This gives us the assurance of the continued availability of commercial solutions and that any specialized solutions will be developed close to mainstream technology.

While UTAMulti addresses the concrete problem of coordinating the execution of several programs with varying input and output demands on several machines within a cluster, ORB/IDL technology addresses large and small scale communication and integration issues spanning architectures (under UNIX, VMS, and other operating systems), programming languages (C++, C, wrapped FORTRAN, etc.) and networks. Ultimately we foresee a merging of these parallel pursuits in a direction where a GlobalMulti would coordinate data access, production, and analysis across continents.

Chapter 4

Supplementary Information

4.1 FY'96 – FY'98 BUDGET REQUESTS

Our budget requests for the years FY'96, FY'97, and FY'98 reflect a number of factors. Firstly we have grown to a group of four faculty, three postdoctoral associates, and a large number of graduate and undergraduate students, all heavily engaged in research on DØ and other experiments. Secondly we have taken on significantly increased responsibilities within the DØ, ATLAS, and PP2PP experiments, and in relation to the use of our computer farm. Lastly, the investments in our program by the Department of Energy and the University of Texas at Arlington have given us the opportunity to make very substantial contributions to the three experiments to which we are committed. We therefore request support for our expanded group that will allow us to capitalize on this opportunity and the strong start that our group has made during its initial period of operation.

4.1.1 Manpower

Faculty

We request two month summer salaries for our four faculty members. As with all the salary and wages figures, we have built in 5% annual increments in the budget tables.

Postdoctoral associates

We request an expansion of support to the level of 2.0 FTE's in this category for FY'96 and 2.5 FTE's in subsequent years. For FY'96, with a similar level of support to be requested from the state, this will allow each faculty member to have a postdoc, a pairing that has led to a high level of productivity in our operations so far.

Scientific Software Engineer

UTA has taken the initiative in the introduction of new software development techniques for US ATLAS. This initiative is also in line with planned future directions in D0 software and will also benefit high energy physics in the US generally. We request 25% support for Marc Turcotte who has recently taken responsibility for Information Technology at the

UTA Automation and Robotics Research Institute (ARRI). Marc will lead a joint UTA HEP and ARRI team on this work, and other related research.

Computing Systems Support

Through the history of our group our system support has been performed primarily by physicists, while minimal support for complicated tasks has come from the Academic Computing Services (ACS) here at UTA. We request 1/4 FTE of system support from DOE which will be leveraged for institutional matching funds to provide partial support of an ACS employee responsible for our system support and maintenance of much of the standard DØ and ATLAS software libraries.

Technician

We request support for a technician to work full time at the Swift Center detector facility. This facility is now operational and will be the focus of many detector development projects ranging from upgrades to the DØ detector, small scale prototyping through the large scale manufacture of muon drift tubes, multilayers, and chambers for the ATLAS muon system, and prototype and construction of the intermediate barrel tile calorimeter for ATLAS. The university is providing a similar level of support for an additional technician. Two full time technicians are the minimum essential to the successful execution of our multiple development tasks.

Graduate students

We currently have two Ph.D. track graduate students and are actively recruiting more so that each faculty member will have at least one student. We therefore request support for four graduate students in each year.

Undergraduate students

We have enjoyed significant success in encouraging Physics, Computer Science Engineering, Mechanical and Electrical Engineering students to participate in work related to high energy physics. A modest level of support allows us to hire many students part time, but at a level where each person can gain meaningful experience working with our research group, while contributing to our research program.

Secretary

We request continued support for our group secretary, Grace Sauce, who has become an invaluable asset in all administrative areas of our group.

4.1.2 Equipment

Computing

We seek funds here to purchase a dedicated interactive server with sufficient memory to meet all of our interactive computing needs. We are investigating cost effective solutions to this upgrade. First, we require an upgradeable system which will not require major system replacement on the scale of five years; second, it must support a dozen or more X-terminals so that we can add users without large cost; and, third, it must be capable of running both the VMS and Unix operating systems. One device which we are considering is the DEC AXP based 2100 server. The 2100's symmetric multiprocessing architecture affords as many as four processors (each at 275 MHz clock speed) and up to 256Mb of RAM. Since it is AXP based, it can run the VMS, UNIX or WindowsNT operating systems as our requirements change. Our specific budgetary request is based on this machine. Since AXP-chip based systems are being built and marketed by vendors other than DEC, we are also investigating new machines built by other vendors.

After acquiring the central-server in FY'96, we will phase acquisition of X-terminals for desktops over three years. The budget request reflects our expected growth rate, culminating in a demand for about 20 interactive seats at UTA, FNAL and the Swift Center.

Our philosophy in upgrading the computer farm is based on two tenets: first, we must stay abreast of the current technology; and, second, timing is the key to advancing from one generation of technology to the next. In this spirit we will delay a major upgrade until the next step forward in technology. Our current guess is that this will occur when second party manufacturers using the AXP chip begin to seriously enter the market. We expect this to occur in FY'97. Given the tenuousness of these predictions, however, we can be expected to pursue opportunities for major upgrades as they arise – and to continue to take advantage of our anticipated strong institutional support in terms of matching funds.

In a more predictable setting, we request funding for peripherals such as a staging disk and tape drives in support of Monte Carlo production on the farm.

The UTA high energy physics group is currently working on videoconferencing with FNAL and CERN, via workstations connected to the MBONE. We have bought a high quality video camera for one of our ALPHA workstations and are attempting to install software compatible with the multicast software in use at the two labs. Upgrades to this system will be required in FY'97.

In order to equip the Swift Center, provide Unix based support for our ATLAS participation, and initiate our studies of modern computational methods regarding inter-cluster/inter-platform communications we propose the purchase of a UNIX workstation (HP 715 with standard peripherals and object request broker software). We have requested additional funds to upgrade this system and our videoconferencing capabilities in FY'97.

In the context of these requests we wish to emphasize that UTA's institutional commitment to making our group a major offline computational/data site is manifest by the fact that, to date, more than 95% of our computer facilities have been purchased with institutional funds.

DØ Cosmic ray test stand

As mentioned before, currently our cosmic ray test stand shares a common data acquisition system with the PMT test stand. This requires considerable switching of hardware and software for each task. As we ramp up our cosmic ray testing of ICD upgrade modules, while simulataneously testing PMTs for the ICD and the IBTC detectors, we propose to build a new independent cosmic ray test stand at the Swift center. We request funds in FY'96 to accomplish this.

Swift Center

We request support for equipping the Swift Center to match the support being provided by the University. We need to purchase machine tools and general tooling for the machine shop area,

ATLAS Muon system development

We request support in FY'96 to purchase a mass flow control gas system to allow the study and use of multi-component drift gases such as the Ar/Ethane/Nitrogen/ Carbon Dioxide mixture currently being used in single tube prototypes. This system will also be used to supply drift tubes for testing following manufacture. We also request in FY'97 and FY'98 for the purchase of items related to prototype chamber production and testing, and for the ramp up to the start of production of tubes, multilayers, and chambers.

ATLAS Calorimeter development

We propose to add additional trigger counters and NIM modules to the DØ cosmic ray test stand proposed above in order to handle the larger tiles used in the intermediate barrel tile calorimeter for ATLAS. This is a very cost-effective upgrade which will allow us to simultaneously use the cosmic ray test stand for two activities. We request funds in FY'96 for this upgrade.

The PMT test stand at UTA is currently being used to test Hamamatsu PMTs for use in DØ. This activity is expected to continue through the Run II upgrade of DØ in 1999. We would also like to test PMTs for the ATLAS TileCal experiment in parallel with the DØ testing. UTA is responsible for testing over one thousand tubes for ATLAS. In order to upgrade the PMT test stand so that we can use it for the testing of two different kinds of tubes, and in order to expand it's capacity, we have requested a modest amount of funds in FY'96.

4.1.3 Travel

(Domestic - at Fermilab)

We request the provision of $60,000 in our laboratory service account at Fermilab for domestic travel. This figure will allow our 10 faculty, postdocs, and graduate students currently working on the DØ Experiment to travel to Fermilab to carry out their responsibilities on detector work, upgrades, physics analysis, software development, and service work.

Foreign

We foresee a rapid development of our participation in the ATLAS Experiment at CERN and the consequent increased travel demands. To effectively interact with personnel at CERN on the muon system, calorimeter system, and software development we need to be able to send a physicist to CERN once per month for collaboration meetings and working group sessions.

4.1.4 Materials and Supplies

We request a modest amount of support for materials and supplies based on current funding levels for this category.

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ER F 4620.1 (11-90)

U.S. Department of Energy
Grant Application Budget Period Summary

(See Reverse for Definitions and Instructions)

Please Print or Type

OMB Approval
No. 1910-1400

Organization: University of Texas at Arlington	Period Covering: From: 11/1/95 To: 10/31/96	FOR DOE USE ONLY PROPOSAL NO: AWARD NO.:
Principal Investigator (P.I.)/Project director (P.D.): Dr. Andrew P. White		

A. SENIOR PERSONNEL PI/PD Co. PIs, Faculty and Other Senior Associates (List each separately with title, A.6 show number in brackets. Attach separate sheet, if required.	DOE Funded Person-Mos. Cal.	Acad.	Sumr.	Funds Requested By Applicant $
1. Dr. Andrew P. White			2	14,714.
2 Dr. Paul A. Draper			2	9,347.
3. Dr. Kaushik De			2	8,974.
4. Dr. Ransom W. Stephens			2	8,647.
5.				
6. (4) TOTAL SENIOR PERSONNEL				41,682.
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				
1. (2) POST DOCTORAL ASSOCIATES	24			64,260.
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12			22,500.
3. (4) GRADUATE STUDENTS				44,393.
4. (5) UNDERGRADUATE STUDENTS				10,000.
5. (1) SECRETARIAL-CLERICAL				18,723.
6. ( ) OTHER				
TOTAL SALARIES AND WAGES (A + B)				201,558.
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				68,435.
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				269,993.
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM) (See Attached Sheet)				
TOTAL EQUIPMENT				131,000.
E. TRAVEL				
1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				
2. FOREIGN				15,000.
F. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES				10,000.
2. PUBLICATION COSTS/PAGE CHARGES				
3. CONSULTANT SERVICES				
4. COMPUTER (ADPE) SERVICES				
5. CONTRACTS AND SUBGRANTS				
6. OTHER				
TOTAL OTHER DIRECT COSTS				10,000.
G. TOTAL DIRECT COSTS (A THROUGH F)				425,993.
H. INDIRECT COSTS (SPECIFY RATE AND BASE) 50% of (A+B+C+E)				142,497.
TOTAL INDIRECT COSTS				142,497.
I. TOTAL DIRECT AND INDIRECT COSTS (G & H)				568,490.
J. APPLICANT'S COST SHARING (IF ANY)				
K. TOTAL AMOUNT OF THIS REQUEST (ITEM I LESS ITEM J)				568,490.
PI/PD TYPED NAME & SIGNATURE Dr. Andrew P. White *Andrew P. White*				DATE 4/18/95
INST. REP. TYPED NAME & SIGNATURE				DATE

Equipment

1) Computing

Server (based on DEC 2100)	$34,000
Three X-terminals	$ 6,000
Peripherals (staging disk, tape drive)	$ 5,000
HP 715 Workstation system	$15,000
	$60,000

2) Cosmic ray test stand for D0 ICD upgrade

CAMAC crate	$ 6,000
DAQ PC	$ 2,000
Trigger counters	$ 2,000
Photomultiplier tubes	$ 3,000
NIM modules	$ 6,000
	$19,000

3) Swift Center

General tooling	$ 5,000
Surface plate	$ 6,000
Drill press	$ 2,000
Band saw	$ 2,000
Lathe	$ 8,000
	$23,000

4) ATLAS muon system

Mass flow control gas system	$13,000

5) ATLAS IBTC

Cosmic ray test stand upgrade	
Trigger counters	$ 4,000
Photomultiplier tubes	$ 3,000
NIM modules	$ 3,000
	$10,000
PMT test stand upgrade	
New PMT mounts and shields	$ 1,000
Bases	$ 2,000
Preamplifiers	$ 2,000
Miscellaneous	$ 1,000
	$ 6,000

TOTAL EQUIPMENT $131,000

ER F 4620.1A
(7-85)

U.S. Department of Energy

GRANT APPLICATION
PROJECT PERIOD SUMMARY

(Must be completed for all new and renewal applications.)

Please Print or Type

OMB Approval
No 1910-1400

Categories	01 Budget Period	02 Budget Period	03 Budget Period	04 Budget Period	05 Budget Period
A. Senior Personnel Totals	41,682.	43,766.	45,954.		
B. Other Personnel Totals	159,876.	203,620.	213,801.		
C. Fringe Benefit Totals	68,435.	82,581.	86,710.		
Total of A, B & C	269,993.	329,967.	346,465.		
D. Equipment	131,000.	126,000.	121,000.		
E. Travel 1. Domestic					
2. Foreign	15,000.	20,000.	20,000.		
F. Other Direct Costs	10,000.	11,000.	12.000.		
G. Total Direct Costs	425,993.	486,967.	499,465.		
H. Total Indirect Costs	142,497.	174,983.	183,232.		
I. Total Direct & Indirect Costs	568,490.	661,951.	682,698.		
J. Applicant's Cost-Sharing (If any)					
K. Total Amount of Request (Item I. Less Item J.)	(1)* 568,490.	(2) 661,951.	(3) 682,698.	(4)	(5)

*This should equal item K on Budget Period Summary (ER/F/4620.1)

ESTIMATE

TOTAL COST OF PROJECT

$ 1,913,139.

(add K(1) thru (5))