Abstract

We report on the activities of the High Energy Physics Group at the University of Texas at Arlington for the period 1997-98.

We request renewal of funding from the U.S. Department of Energy for the period FY1999-FY2001 to support our work on the DØ Experiment at Fermilab and on the ATLAS Experiment at CERN. Our responsibilities for DØ include completion of Run I physics analyses, upgrade of the Intercryostat Detector, production of simulated data, and participation in Run II at the Tevatron. In the ATLAS Experiment, we are responsible for tile calorimeter submodule construction, participation in test beam runs, and physics and detector studies.
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Part I

Introduction

This document reports on the activities of the High Energy Physics Group at the University of Texas at Arlington and requests funding to support continued work for the period FY1999 through FY2001.

To assist in the new DHEP review procedures we have implemented the following:

- We have kept the length of this proposal to less than 50 pages by summarizing our many areas of activities and including only a limited number of figures.

- We have created a Web version of the proposal with links to a large body of documentation, technical notes, figures, photographs, etc. at http://heppc1.uta.edu/kaushik/proposal/doe98.htm

We hope that the reader will find it useful to have the electronic version available while reading the hardcopy version.

History and Overview

The High Energy Physics group at the University of Texas at Arlington was formed in 1991. From the beginning we have followed a coherent program of research in hadron collider physics at Fermilab, at the SSC, and more recently at the LHC. We propose to continue our work in the DØ and ATLAS experiments during the period addressed in this proposal and beyond.

Historically, our group personnel have had a long tradition of working on many aspects of the DØ experiment at Fermilab. We proposed the Intercryostat energy correction detector, designed and implemented this system, and supported its successful use throughout Run I of the Tevatron, achieving, for example, considerable improvement in the missing transverse energy ($E_T$) performance of DØ. We have made major contributions to the software of the experiment, and to the generation of simulated data through the use of our computer farm. Finally, and most importantly, we have lead and worked on many physics analyses of the Run I data in the areas of supersymmetry and QCD. Currently, we are engaged in the construction of the redesigned Intercryostat Detector, and many areas of software and physics preparations for Run II.

Since 1994 we have been members of the ATLAS collaboration at the LHC. Building on our experience with energy correction for DØ, our group has successfully proposed to ATLAS the Intermediate Tile Calorimeter as part of the ATLAS steel/scintillator hadronic calorimetry. The first two submodules of this detector have been constructed in our Swift Center detector facility and successfully tested at the CERN test beam. We are now ramping up towards the main construction phase for a further 128 submodules. We have also worked on aspects of physics studies and computing for ATLAS and foresee significant expansion of
these activities during the period covered by this proposal and through the first operation of the LHC.

We view the balanced approach of our DØ and ATLAS projects as essential for making successful contributions to the US High Energy Physics program in the medium and long terms. The experience we have derived from our DØ work will translate into a strong participation over the next 20 years in ATLAS. The potentially exciting physics discoveries to be made in both experiments, particularly in the search for new physics, are a source of stimulation for faculty, staff, and students alike.

This proposal first describes our personnel and group facilities, then summarizes our recent work and describes the work to be carried out during the next three-year funding period. Finally we present our budget request.

**High Energy Physics Group Personnel**

The number of faculty and staff in the HEP group at UTA has remained stable during 1995-98 except for the following: Dr. Peter Rosen is on leave as Associate Director of Energy Research for High Energy and Nuclear Physics at the U.S. DoE. Dr. Lee Sawyer, a Post-doctoral Fellow at UTA since 1991, accepted a faculty position at Lousiana Tech University. Dr. Kaushik De gained tenured status last year and was promoted to Associate Professor of Physics. The full list of current HEP personnel at UTA is as follows:

**Faculty**

- 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. Co-leads (with Dr. Elizabeth Gallas) the ICD Upgrade Project for DØ Run II. Also working on module alignment and verification tooling for the ATLAS Experiment. Member of the HEPAP Subpanel on the Future of U.S. High Energy Physics.

- Dr. Kaushik De, Associate Professor of Physics.

  Member of the UTA faculty since 1993 and promoted to Associate Professor with tenure effective September 1997. Pursuing the search for SUSY at the Tevatron. Led the work on the upgrade of the ICD for Run II till January 1997. Responsible for ICD cosmic ray testing and PMT testing. Level 3 manager of the Intermediate Barrel Tile calorimeter for the ATLAS experiment. Responsible for all PC and HP-UX computer systems in HEP. Convenor of the TeV33 SUSY working group for Run III at the Tevatron.
• Dr. Paul A. Draper, Assistant Professor of Physics.

  Member of UTA faculty since 1991 and member of the DØ collaboration since 1986. Main research interest is tests of QCD at the Tevatron and at RHIC. Working on the DØ ICD upgrade, including responsibility for the calibration system, and testing and tooling for the fiber system. Has lead the UTA participation in PP2PP with primary responsibility for simulations and the generation of reconstruction code for the experiment.

• Dr. Ransom Stephens, Assistant Professor of Physics.

  Member of UTA faculty since 1993. Research responsibilities include: DØ Monte Carlo Production Collective Coordinator, convenor of the DØ Future QCD Analysis Project, DØ data reconstruction code librarian for the DEC AXP platform, participant in the Fermilab PCFarms computing project. Physics analyses include the inclusive jet cross section with jets reconstructed by the $K_{T}$ algorithm in the D0 QCD analysis group, algorithm development for physics analyses, development of algorithms for the study of fractal structures in multiple jet events.

**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 - working on a “jet multiplicity” analysis. Hardware responsibilities include prototype developments and production techniques for the ICD upgrade. Co-leader of the DØ Run II ICD upgrade with A. White.

• Dr. Jia Li

  Responsible for the mechanical design and layout of all elements of the DØ ICD system upgrade; developing the mechanical design of the Intermediate Tile Calorimeter; developing mechanical design of the TileCal Extended Barrel assembly tool and alignment and envelope verification system.

• Dr. Mark Sosebee

  Physics interests focused on DØ searches for supersymmetry - working on a “stop” analysis. Hardware responsibilities include prototype testing for the ICD upgrade and ITC submodule assembly for ATLAS. Also involved in efforts to implement a Windows NT server for the HEP group.

**Secretary**

• Lani Young

  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 work study students, and planning new high energy group office area.

**Technician**

- Victor Reece

  Responsible for maintaining the Swift center detector construction facility, development of construction procedures for the ATLAS TileCal ITC, construction of prototype testing systems for the DØ ICD upgrade, and supervision of undergraduate students working on ICD and ITC projects.

**Graduate students - Physics**

- Ted Eltzroth

  Mr. Eltzroth is a new graduate student in the HEP group. Previously, he has been teaching elementary physics. His research interests are in the areas of QCD and SUSY. Currently testing scintillator prototypes for the ICD and ITC projects.

- Jill Perkins

  Senior graduate student enrolled in the Ph.D. program. Has been working with our group for five years. Conducting research in DØ, with dissertation work on measuring color singlet exchange characterized by QCD events containing a large rapidity gap between two jets. Graduated April 1998. Given departmental McNutt Award.

- Yan Song

  Junior graduate student enrolled in the Ph.D. program. Successfully completed qualifying exams. Projects include PMT testing for the ICD upgrade and analysis of DØ data in searches for supersymmetry.

- Michael Strang

  A second year graduate student studying quantification of fractal dimensions in multi-jet events in $p\bar{p}$ interactions at Tevatron and LHC energies. Mr. Strang will join the DØ experiment upon completion of course requirements.

**Graduate students - Engineering**

- Ravinder Pallerla

  Mr. Pallerla is a Computer Science Engineering graduate student working on the Fermilab PCFarms project, porting the C++ based DØ Run II tracking code to Linux based PCs for testing and performance benchmarking. This work is the basis for his Masters Degree.
Anil Solleti

Mr. Solleti is a Computer Science Engineering graduate student who worked on the Fermilab PCFarms project during the summer of 1997. He ported the DØ Run II GEANT-based detector simulation package to Linux PCs.

Undergraduate students

- Andrew Elliot – Honors student working on the Intermediate Tile Calorimeter prototype project at the Swift Center.
- Obiara Esimai – Honors student working on Run I ICD decommissioning.
- Larry Guerra – Supported in part by local minority program, Mr. Guerra is working on the LED calibration option for the ICD upgrade.
- Santosh Krishnan – Mr. Krishnan, a Computer Science Engineering undergraduate, serves as system manager for the group’s DEC Unix cluster and maintains our World Wide Web server.
- Michael Meador – Honors student working on the Atlas TileCal laser alignment system.
- Andrew McDowell – Mr. McDowell, a physics undergraduate, wrote OO C++ software for studies of fractal dimensions in multi-jet events.
- Andy Nguyen – Mr. Nguyen, a Computer Science Engineering undergraduate, contributes system management effort to the DEC Unix and Linux systems.
- Minh Nguyen – Honors student working on the cosmic ray test stand for ICD.
- Nghia Nguyen – Helping with the organization and maintenance of the Swift Center.
- Brandon Poulson – Working on test equipment in support of the ICD upgrade, and on the laser and LED calibration systems for the ICD.
- Joe Sauder – Developing algorithms for image reconstruction in collider data analysis.
- Brent Scott – Mr. Scott is working on the fiber polisher in support of the ICD upgrade, and also worked on the transportation of the group World Wide Web server to a Linux machine.
- Nicholas Tuefel - Honors student working on the ITC project.
- Cuong Vo – Honors student helping maintain the HP-UX and PC computing facility at the Swift Center.
High Energy Group Facilities

The principal research facilities for our group include:

a) Science Hall. A newly renovated suite of offices and cubicles in Science Hall for faculty, staff, and students. Our computer farm is also located in this area. We also have a laboratory in Science Hall used for PMT testing and tile prototype testing with an UV laser.

b) Swift Center Detector Facility. Established through joint NSF-MRI/UTA funding, this 10,000 sq.ft. facility is the primary site for construction and testing of the DØ Upgrade and ATLAS tile calorimetry. A photograph of this facility is shown above. The major features are a bridge crane, a mechanical workshop, and a computer area, as well as areas devoted to DØ ICD assembly, and ATLAS calorimeter module prototyping and assembly.

c) Computing facilities which comprise:

- The UTA CPU Farm: 6 DEC AXP 3000/400, 1 AXP 3000/300 and 1 AXP 3000/600 running VMS.
- The DEC UNIX cluster: 3 DEC AXP 3000/700 running DEC Unix.
- Workstations: 2 DEC VAXstation 4000/90, 1 DEC VAXstation 4000/60, 1 HP-UX Model 715/80.
- Disk space: 45 Gbytes.
- Tape drives: (4) 8mm drives, (1) 4mm drive.
- 6 TekTronix Xterms.
- 19 Personal Computers, including 2 Windows NT servers and a Linux Web server.

d) Detector development equipment. We have a CAMAC controlled PMT test stand, 2 PC controlled cosmic ray test stands, a VME laser alignment test stand and a PC controlled UV laser scintillator prototype test stand.

e) Mechanical equipment. We have a HEP machine shop at the Swift Center with a CNC Bridgeport milling machine, movable crane and other power tools. For scintillator/fiber work, we have a fiber polisher tool, fiber splicer tool, and high precision glue dispensing machines. In addition, the Physics Department and Engineering Departments provide high quality machine shops on campus.

**Group Milestones**

**General:**

- 1996 - Commissioning of Swift Center detector facility as major component of High Energy Physics group operations.
- 1996 - Graduation of first Ph.D. student, Mark Sosebee, from UTA HEP group.
- 1998 - Graduation of second Ph.D. student, Jill Perkins, from group.
- 1994-97 - Graduation of three students with Masters degrees in high energy physics.
- May 1998 - Completion of renovated High Energy Physics offices and student work area.

**DØ Experiment:**

- March 1996 - Publication of Physical Review Letters paper on search for low energy supersymmetry via chargino-neutralino channel. First major journal publication for UTA HEP group[1].
- January 1998 - Run I ICD box testing complete - last step in decommissioning the Run I detector.
- April 1998 - Satisfactory results from first ICD Run II supertile yield tests.
ATLAS:

- November 1996 - ATLAS collaboration board approval of the Intermediate Tile Calorimeter project.
- February 1997 - The first two full-scale ITC submodules built at UTA shipped to Argonne and Barcelona to be assembled as part of prototype Modules 0A and 0B.
- August 1997 - Performance of Modules 0A and 0B (including the ITC) studied at the CERN test beam with pion and muon beams.

Computing:

- April 1995 - DØ management asks Ransom Stephens to coordinate DØ offsite Monte Carlo Production and UTA CPU farm begins data simulation.
- July 1995 - DØ data reconstruction software ported to, verified on, and released on the DEC Alpha platform.
- March 1996 - UTA becomes the primary site for DØ Monte Carlo production as FNAL machines are switched to data reconstruction.
- December 1996 - UTA CPU farm simulated its 1,000,000th event.
- December 1997 - DØ Run I analyses begin demand for highly detailed simulated data; UTA CPU farm is saturated with “plate-level” GEANT requests.
- February 1998 - UTA CPU farm simulated its 2,000,000th event.

External Presentations

The following conference and seminar presentations were made by members of the UTA HEP group during 1997-98:

- Elizabeth Gallas - *Multijet Cross Section Ratios in* $p\bar{p}$ *Collisions at* $\sqrt{s} = 1.8$ *TeV as a Test of Renormalization Scale Sensitivity of NLO QCD Calculations*, 1998 Joint APS/AAPT Meeting, April 18-21, 1998 Columbus, OH.


- Jill Perkins - *Probing Color-Singlet Exchange at* $\sqrt{s} = 630$ *and* $1800$ *GeV*, LISHEP’98 (February), Rio de Janeiro, Brazil.


- Andrew White - *New Phenomena Searches with the DØ Detector*, Aspen Center for Physics, August 1997.

- Andrew White - *DØ and CDF Results on Gauge-Mediated Supersymmetry*, to be presented at SUSY ’98 Conference, Oxford University, UK, July 1998.

**Part II**

**Report on UTA Work in DØ**

Participation in the DØ Experiment at Fermilab has been an essential core activity for our group since it was formed. Many of us worked on the design and construction of DØ even before this time. UTA personnel have participated in the design, development, fabrication, and operation of the Intercryostat Detector for Run I, and its upgrade for Run II. We have been centrally involved in creating many areas of the calorimeter software, carrying out many simulation studies both of detectors and for physics analyses, and creating very large numbers of simulated events for our DØ colleagues at many institutions using our computer farm. A primary focus of recent activity has, of course, been the completion of Run I data analyses and the preparation of physics publications. We are currently in transition from the development to the production stage of the Run II ICD upgrade and this work will be a large part of our DØ contributions for the next two years.

**Physics Analyses**

**Stop Squarks in the Decays of SM Top Quarks**

Members of the UTA HEP group continued work on the “stop” analysis during this reporting period. Our primary objectives were standardization of our signal Monte Carlo data format, refinements to the selection cuts in the analysis, and improved estimates of backgrounds to
the signal. The analysis we are pursuing is complimentary to direct searches for stop squarks also being carried out in DØ\cite{4,5}.

The decays of stop squarks depend on their masses and hence the various SUSY parameters. In that region of parameter space we have so far restricted ourselves to, the lightest chargino ($\tilde{W}_1$) is heavier than the stop, such that the stop decays into a charm quark plus LSP ($\tilde{Z}_1$) with a 100% B.R. We therefore look for signal with four or more jets plus $E_T$ from the LSPs in the event.

The current version of our analysis makes similar requirements in the data as compared to the version we reported on last year. Hence our set of candidate events still contains between 80 to 100 events, depending on specifics of the selection criteria; see Fig. 2. We have continued our efforts to understand the sources of these events, either physics backgrounds or detector-related effects. We are particularly sensitive to mis-measured $E_T$ arising from “hot cells” in the calorimeter and/or incorrect vertices. Once we are confident we understand the mix of events in the candidate sample, this will allow us to finalize the background calculations.

We have increased the number of Monte Carlo signal events by more than a factor of two in the last year. Previously we were hindered by unlike data storage formats between the collider data compared to our Monte Carlo samples. By porting the ntuple generation code from a UNIX platform at FNAL to our local VMS VAX cluster, we are now able to make direct comparisons between data and Monte Carlo, at the same time reducing the time required to process the data sets.

Figure 2: Number of events (left) in the $E_T$ trigger sample, and (right) expected from stop production.
Planning for Future SUSY Searches

Several members of our group have been active in planning for supersymmetry searches at future colliders. K. De and A. White have convened various SUSY working groups at Snowmass, TeV2000, and TeV33. Recently, De was the organizer for the ‘Missing $E_T$, Multijets and Multileptons’ working group at the DØ Run II physics workshop[6] held at the University of California at Davis. This workshop was attended by many theorists who provided input into future searches for new physics at DØ after the main injector upgrade. M. Sosebee, Y. Song, and T. Eltzroth from UT A are also studying prospects for new physics during Run II at the Tevatron and at ATLAS. De is writing the “DØ Run II New Phenomena Manifesto.”

The Inclusive Jet Cross Section with Jets Reconstructed by the $K_T$ Algorithm

The $K_T$ algorithm has several desirable features lacking in the cone algorithm. It has qualitative appeal in its faithful attempt to follow the physical process of fragmentation, multiple soft gluon emission, through the iterative reconstruction of “proto-jets” into full hadronic jets. Its theoretical appeal is that it does not need ad hoc parameters such as $R_{sep}$[7] for experiment-theory comparison at next-to-leading-order and needs no further refinement for experimental comparison when the largest terms from higher orders in perturbation theory are included.

We have worked for several years in a DØ subgroup investigating the algorithm and performed an exhaustive comparison[8] of jets reconstructed with the cone algorithm and the $K_T$ algorithm[9]. The inclusive $K_T$-jet cross section is the first $K_T$ analysis that requires the full suite of fixtures already developed for the cone algorithm: trigger thresholds, trigger matching scale factors, quality cut efficiencies, jet energy resolutions and detector energy scale correction. To date, at UTA we have determined the trigger efficiency thresholds; developed an algorithm for calculating the trigger matching scale factors; measured the quality cut efficiencies; developed code for extracting the $K_T$-jet energy resolutions and folding the energy resolution into the theoretical cross section; and, developed techniques to extract the luminosity of data that has been processed with the $K_T$ algorithm. The details of this analysis are available in an evolving DØ note available at[10]. The detector energy scale correction, NLO QCD theoretical predictions of the cross section, and processing of data through the $K_T$ algorithm are being performed by DØ colleagues from Michigan State and Northwestern Universities. The cross section measurement is shown in Fig. 3.

The single inclusive cone-jet cross section results have generated excitement in the HEP community with CDF’s observation of a marginal excess above the NLO QCD prediction of the cross section for $E_T > 300$ GeV. The DØ measurement does not confirm this, but, including both statistical and systematic errors, is still consistent with CDF’s. Theorists are working on a QCD calculation that will include the dominant next-to-next-to-leading-order (NNLO) terms in the cross section[11]. These calculations will reduce the error from the renormalization scale. Since the cone algorithm is infrared unstable it cannot be applied to a theory including NNLO terms, but the $K_T$ algorithm can. Therefore, our inclusive $K_T$-jet cross section measurement, likely to be the first such measurement from a $p\bar{p}$ collider, will
shed some light on the state of this fundamental measurement.

The work required in the inclusive $K_T$-jet cross section measurement will provide understanding of the systematics of the algorithm and therefore pave the way for dijet mass analyses, model independent searches for new phenomena by performing exclusive analyses of $p\bar{p}$ interactions, new phenomena searches including final states with $K_T$ and leptons along with $K_T$-jets, and altogether different self-similarity studies of hadronic jets using sub-jets and sub-sub-jets.

**Study of Self-similarity in Jet Events**

QCD predicts that parton fragmentation into final state hadrons proceeds through multiple sub-jet production. This cascade of jets to sub-jets to sub-sub-jets (et cetera) to final state hadrons should demonstrate self-similar behavior\cite{12}. This self-similar behavior can be characterized with a fractal dimension, $D$. A fractal is an object which is embedded in $d$ dimensions, where $d$ is an integer, but only fills a fraction of that space, $D < d$, where $D$ is not an integer. We have developed several algorithms for extracting fractal dimensions in multiple jet events starting with three different well known definitions: The Hausdorff, or box counting, dimension\cite{13} $D$; the correlation integral dimension\cite{14} $\nu$; and, the information-entropy dimension\cite{14} $\sigma$.

In the literature, two techniques for searching for self-similarity in hadronic event data

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure3.png}
\caption{The central $K_T$ jet cross section in 1GeV bins.}
\end{figure}
are commonly used: normalized factorial moments (NFM) — a generalization of the Hausdorff dimension — and bunching parameters (BP) In most published analyses the data is studied in the single dimension $\eta$ and separate events are combined to mitigate algorithmic difficulties arising from finite multiplicities. In our study we demand that events maintain their integrity and that the dimensions be easy to calculate in the full $(\phi, \eta, E_T)$ space.

Michael Strang is using the Herwig and ISAJET Monte Carlo event generators to provide noise-free simulated data samples for algorithm development and evaluation. We ran the generators with and without underlying event and accumulate samples of multiple jet events covering the Tevatron and LHC dynamic range. We used these data, together with a completely random population of particles in $(\phi, \eta, E_T)$ space, to study the behavior of the different fractal dimensions with data having varying levels of order. The completely random data set fills its spatial dimensions so $D = d$. Since Herwig includes color-linked successive gluon radiation it has more order than the ISAJET data. We expect that as the amount of structure in a data sample increases, the fractal dimension calculated from a finite multiplicity event will tend to decrease asymptotically toward the ‘true’ fractal dimension of the infinite multiplicity limit. Thorough investigations of algorithms based on the three definitions demonstrated that the correlation dimension and a special formulation of the information entropy dimension, that we call the HEP-entropy dimension, yielded the most well behaved measures of fractal structure, though the correlation integral calculation is CPU intensive. The $\sigma_{\text{HEP}}$ dimension uses the structure of $(\phi, \eta, E_T)$ space by defining $p_i(l) = E_{Ti}(l)/H_T$ as the probability of an $E_T$ deposition in a calorimeter tower, and $H_T$ is the scalar sum of $E_T$ for all particles in an event. Thus, we define a two dimensional embedding space, $(\phi, \eta)$, and include the $E_T$ information in the definition of the probability used for calculating the entropy.

Figure 4 shows the dependence of the fractal dimension on the scalar sum of the $E_T$ of the particles in an event, $H_T$. We present the correlation integral dimension, defined with particle position in $(\phi, \eta, E_T)$ space, for events in the Tevatron dynamic range, Fig. 4 (a), and for the LHC dynamic range, Fig. 4 (b). Similarly for the HEP-entropy dimension, Fig. 4 (c) in the Tevatron dynamic range and Fig. 4 (d) in the LHC dynamic range. This figure demonstrates the universal, or scale-independent, behavior of fractals in that the dimension changes very little across the huge dynamic range. We also see that the data sample with the greatest correlated order, Herwig without underlying event (the upward triangles in Fig. 4), has the lowest fractal dimension. When the uncorrelated empirical underlying event is included (the downward triangles) the dimensions respond as if noise were introduced. While both measures are monotonically decreasing, the HEP-entropy dimension is more smooth and takes much less computing time to calculate.

The HEP-entropy dimension is easier to calculate than NFMs or BPs and is well behaved for finite multiplicities in the full $(\phi, \eta, E_T)$ space. We are close to submitting this study to the Physical Review and have made a draft of our paper and some background material available in [19].
Figure 4: The dependence of fractal dimension on $H_T$ for the correlation integral dimension, $\nu$, in the Tevatron (a) and LHC (b) dynamic ranges and for the HEP-entropy dimension in the Tevatron (c) and LHC (d) dynamic ranges. The upward triangles are for data from Herwig without underlying event, downward triangles are Herwig with underlying event, and open circles are ISAJET data.

**Rapidity Gaps**

Jill Perkins continues to work with the QCD physics group and a small subgroup studying rapidity gap events. Rapidity gap events feature jets with no hadronic particles in the rapidity interval between the jets in the so-called ‘gap’. Rapidity gaps are signatures for color-singlet exchange. At QCD-scale cross-sections, rapidity gaps occur in about one percent of the events with wide dijet separation. Theoretical work on rapidity gaps\[20\] probe the nonperturbative realm of QCD (where QCD is hard to do), and so provide extremely useful information on how to use QCD at these distance scales. This renewed interest is also evidenced by the experimental initiatives to study diffractive and elastic scattering at the Tevatron, RHIC, and LHC.

Jill’s doctoral dissertation research (expected completion spring 1998) has focussed on the comparison of rapidity gap production cross-sections (or rather, the fraction of events
Figure 5: (left) gap fraction vs. jet $E_T$; (center) gap fraction vs. jet separation; (right) gap fraction vs. parton x.

featuring gaps) at two center-of-mass energies, 1800 GeV and 630 GeV. A special run at the Tevatron offered this unique opportunity to bridge SppS and Tevatron energies with the same detector, reducing systematic errors and allowing a strong discrimination between theoretical models. The dependence of this cross-section on jet transverse energies, jet separation, and parton momentum fraction is also studied with data from these two collision energies, providing additional information. Preliminary results indicate that the cross-section rises with jet transverse energy, is flat or gently rising with jet separation, and rises with increasing participation by the quark content of the incident proton and antiproton. In all cases, the rate of production of rapidity gaps at 630 GeV is about three times higher than at 1800 GeV, but otherwise follows identical behavior with the kinematic distributions; see Fig. 5. Much of the work done in the past year has concentrated on a thorough understanding of systematic errors associated with this measurement. So far, a soft-resummation treatment of the long-distance interaction seems to be favored over a low-order two-gluon Pomeron model or other QCD-inspired models.

Jill has presented her results several times, most recently at APS and at LISHEP 98 (March), and an article for submission to Physical Review Letters is in preparation.
QCD Jet Multiplicity Ratios

Elizabeth Gallas is working on a QCD analysis studying jet multiplicity with Ki Suk Hahn, a graduate student from the University of Rochester. We study the rate of soft jet emission in QCD multijet events in order to determine a preferred renormalization prescription for soft jet emission in NLO calculations. This determination facilitates a deeper understanding of the limitations of pQCD. In addition, QCD multi-jet production is frequently a background to rarer processes. The use of phenomenologically confirmed prescriptions for renormalization scales is crucial to predicting background rates for effective triggering on rare processes at future colliders such as at the Tevatron II and the LHC[21].

We measure the ratio \( R_{32} \) of inclusive 3-jet to inclusive 2-jet production as a function of \( H_T \), the scalar sum of transverse jet energy \( (E_T) \) in an event. By studying the ratio of cross sections, a number of systematic uncertainties are reduced on both the theoretical side (i.e., choice of structure functions) and the experimental side (i.e., luminosity uncertainty). The data points of Fig. 6 show the measured ratio as a function of \( H_T \) for jet \( E_T \) thresholds of 20, 30 and 40 GeV.

![Figure 6: The ratio \( R_{32} \) as a function of \( H_T \) for \( E_T \) thresholds of 20, 30 and 40 GeV. Error bars indicate statistical and uncorrelated systematic errors while the shaded band shows correlated systematic uncertainty for the 20 GeV threshold.](image)

In the current year, we have completed studies of systematic errors in the measurement. Error bars indicate statistical as well as uncorrelated systematic errors which arise from the event and jet cuts and effects due to event selection, triggering, vertex and luminosity uncertainty. Uncertainty in the jet energy scale affects the counting of jets near the threshold as
well as the event $H_T$ and such effects are known to be highly point-to-point correlated. The shaded band at the bottom of Figure 6 shows the correlated systematic errors for the 20 GeV threshold arising from the energy scale.

JETRAD [22] is a NLO Monte Carlo event generator for inclusive 1-jet and 2-jet production in $pp$ or $\bar{p}p$ collisions. The generated two- and three-jet events are inclusive such that the ratio of these cross sections is equivalent to the measured $R_{32}$. The jet finding algorithm approximates the algorithm used in the DØ data reconstruction: A jet is distinct if its jet axis is separated from any other jet by $R_{sep} = \sqrt{(\delta \eta)^2 + (\delta \phi)^2} > 1.3$, a criteria optimized to match the split/merge decision of the DØ cone algorithm [23]. Final state jets are smeared according to known detector resolutions [24] and a jet is counted in the jet multiplicity if its energy is above threshold. The measurement is compared to JETRAD predictions and the sensitivity to renormalization scales in modelling soft jet emission is evaluated. A covariance matrix technique is used to calculate a $\chi^2$ to quantitatively compare the measurement to the theory which accounts for the uncorrelated as well as the correlated uncertainties. Preliminary results conclude that soft jet emission is better modeled using the harder renormalization scale in the event, rather than a softer scale such as the scale of the soft jet emission. These conclusions remained steady for all jet $E_T$ thresholds and for jet counting in wide and narrow pseudorapidity regions. Future studies will indicate the applicability of these conclusions to soft jet emission in events with other topologies. The complete three-jet final state calculations at NLO are in preparation [25] which will enable a direct measurement of $\alpha_s$ at NLO from this $R_{32}$ measurement. Ki Suk successfully defended his thesis April 20, 1998 and a PRL draft (with Elizabeth Gallas as the lead author) is currently in review by a DØ editorial board. Submission for publication should occur within the current fiscal year.

The Future QCD Analysis Project

Dr. Ransom Stephens convenes the Future QCD Analysis Project [26] which consists of studies of the viability and feasibility of prospective QCD analysis topics for Run II. It also includes planning for fundamental detector studies necessary for important physics analyses, e.g., the study of the jet energy scale [27] for the inclusive jet cross section. In FY98 he led meetings of the DØ QCD group at Fermilab and at the DØ summer workshop at Indiana University.

Of particular interest are the trigger needs of important analyses. To this end we are studying the effect of a crude primary vertex measurement on the jet trigger efficiency. We found that the wasted bandwidth associated with the slow trigger turn on can be dramatically reduced with a primary vertex determined to 1 cm accuracy [28].

In Run II we expect the $K_T$ jet reconstruction algorithm [9] to be broadly used. Thus the Run I measurement of the inclusive $K_T$-jet cross section is a preparation for Run II analyses.

Over the next few years leading up to Run II data analysis this group will be busy studying QCD analysis topics and determining the service work needed to support them.

ICD Upgrade

The Inter Cryostat Detector (ICD) plays a crucial role in enhancing the jet energy resolution and the event transverse energy measurement. Responsibility for the design, prototyping,
construction, testing, installation and commissioning of the ICD for Run II lies entirely with the UTA group along with Louisiana Tech who recently joined the DØ collaboration.

The ICD group is currently in the prototyping and production phase of the project. The basic design is laid out in the Technical Design Report \[2\]. Updates to the design are documented in DØ technical notes and weekly ICD group meeting notes accessible through the DØ Run II ICD Home Page on the WWW (http://www-hep.uta.edu/hep/gallas/icd_uta.html). The following subsections briefly describe the current design and status of sub-components of the system.

**Design**

The baseline design for the Run II ICD can be found in the ICD Technical Design Report \[2\]. The main features of the design are shown in Fig. 7. The array is composed of sixteen identi-

![Figure 7: Schematic of one of two ICD tile arrays to be hung on the inner surface of each of the end cryostats for Run II. The array is composed of 16 identical tile modules.](image)

cal aluminum encased modules. Each contains 12 optically isolated scintillating tiles covering the pseudorapidity region from 1.1 to 1.4 in steps of 0.1. There are 64 equal segments in \( \phi \), four segments per module.

Each scintillating tile has a groove cut near its periphery. Two wavelength-shifting (WLS) fibers are set into each groove to capture the scintillation light and transport it to the
connectors at the outer radial edge of the box. Light is transported via 5 meter long fiber cable to the ‘PMT crates,’ which house the photomultiplier tubes (PMTs) and preamplification electronics. There are four such crates, one per quadrant of DØ, located outside the radius of the end cryostats, but inside the muon system chambers. As shown in Fig. 8, each PMT crate consists of three major subsections: the fiber backplane, the iron shielding block containing the PMTs, and the electronics drawers.

Figure 8: Top and front view of one of four ICD PMT crates. The top view shows the three subsections: the fiber backplane, PMTs and electronics drawers. The front view shows bulkhead connections for high and low voltage, pulser and output signal.

The fiber backplane provides the termination point for the long fiber cables and allows for distribution of the light signals to the correct PMTs via clear fibers ending in a “cookie” at the face of each tube. LED calibration signals are also distributed inside the fiber backplane, with calibration fibers sharing the same cookie as the signal fibers. The photomultiplier tubes must be shielded from the residual magnetic field which is expected to be less than 300 gauss in the PMT crate region. This is accomplished by situating the tubes in an iron block. The tubes protrude from the back panel of the electronics drawers which slide into the crate framework attached to the iron block. The drawers, which are the responsibility of
our colleagues at Louisana Tech., contain a motherboard, with plug-in preamplifiers and HV base daughter cards.

**Prototype Development**

Prototypes of every component of the ICD have been or are currently being tested. A cosmic ray test stand has been constructed which can simultaneously test all 12 tiles within an ICD tile module, the results of which are described in a later section. This test stand can also be used to do a cursory measure of the transmission of fiber cables as well as the connector/fiber/cookie assemblies which are used in the fiber backplane. Dedicated fiber assembly transmission testers will be constructed when production of fiber cable and backplane assembly begins.

Machining and painting of the iron blocks is complete. These blocks will be incorporated into the solenoid test at Fermilab scheduled for August of 1998 as described in a later section.

All subcomponent prototypes will be integrated into a full system prototype test. This test will include scintillating tiles, WLS fibers, clear fiber cables, a limited channel fiber backplane including LED calibration fibers, Hamamatsu PMTs, and prototype electronics drawers containing full prototype readout electronics from our collaborators at Louisiana Tech. The resulting signal through this chain reflects the output signal of the system due to a MIP transversing a tile. Uniformity, signal quality and magnitude can be determined and the variation with tile size and other system changes may be studied. After individual component tests and/or the full prototype test, production of every component has begun or will begin in the current reporting period.

In parallel, a duplicate of the Run I cosmic ray test stand was constructed at UTA to test Run I ICD boxes before disassembly in order to provide a baseline for dedicated individual PMT testing. These tests are described in the next section.

**PMT Testing**

The Run I ICD detector used about 450 Hamamatsu R647 phototubes and about 350 Russian PM60 tubes. We plan to reuse 400 of the Hamamatsu tubes for the Run II ICD. The Run I tubes have to be tested rigorously for efficiency, operating characteristics and aging effects. Based on these tests, we will select the best phototubes for use in Run II. A CAMAC based automated PMT testing facility was built at UTA to test 50 replacement tubes for Run I. We are currently upgrading and debugging this facility. PMT testing will be a major hardware task during 1998-99.

**Cosmic Ray Test Stand Results**

We have recently gained considerable information from the ICD cosmic ray test stand running at UTA. The test stand measures the response of ICD tiles to minimum ionizing particles (MIPs), and is also used to quantify the absolute yield of the tiles. The design and operation of the test stand are described in [2].
Our initial tests have concentrated on comparing the MIP response of the tiles for the upgrade compared to those used in the Run I detector. The electronics employed in the tests are similar to those that will be used in the upgrade, except for the preamplifiers, which as yet have not been manufactured in large quantities. A typical spectrum for three representative channels on a supertile (i.e., one bin in $\phi$) is shown in Fig. 9. Tests to date indicate that the light yield from the upgrade tiles is greater by approximately a factor of two compared to the Run I tiles. Thus, we are led to conclude that the light signals will be more than adequate in the upgraded ICD, even after losses associated with fiber cables and connector interfaces are factored into the over-all system.

We will shortly begin modifying the teststand electronics to incorporate higher gain PMT bases. Once this has been done, we will begin a new series of tests to directly measure the photoelectron yield from the individual channels. These data will be used to set PMT operating voltages, thereby ensuring uniformity of response across all channels in the detector.

**Calibration**

Calibration of the ICD must be carefully done and maintained, especially since there will not be a test beam program for the Run II calorimeter calibration. The calibration approach consists of the following: 1) time-zero absolute calibration with cosmic rays in concert with time-zero relative gains established with a light flasher, linearity checking with the light flasher, 2) time-dependent gain monitoring with the light flasher, 3) further relative gain checking with collider data, and 4) conversion from light flasher gains to physics object (e.g., jet) gains with collider data.

In Run I, the ICD was flashed with a laser light source at the scintillator tiles. There were variations in response that were traced to weaknesses in the laser light distribution system, and so UTA embarked on a plan to improve the laser system or replace it. Despite already having a lot of parts in hand for the laser system, we have decided this year to implement a relatively inexpensive LED system. LEDs are easier to fire synchronously with the...
accelerator clock, they are inexpensive to replace and operate, they are more stable pulse to pulse, they can be placed close to the flashed components, and there are no safety issues. We also decided early on to flash the PMTs directly, rather than the scintillator, utilizing cosmic ray signals to check the stability of the tiles.

At each of the four ICD crates, a set of ganged blue (Cree) LEDs are fired with a pulser. The blue LEDs are exceptionally bright, linear and fast, so that a fast pulse is easily obtained. This light is captured and reradiated by a small scintillator block, in which 110 WLS fibers are embedded (96 to PMTs, 4 to monitoring PIN diodes, 10 spare). The 96 WLS calibration fibers are routed in the crate’s fiber backplane to the PMTs, where they terminate in the PMT cookie along with the two signal fibers from the tile. Note that the only light distribution is at a single tier near the PMTs, with the light path from the distribution block to the PMT unbroken by connectors or joints. We have built a prototype system, including the light-tight housing for the distribution block, for installation in the prototype crate and for testing in the solenoidal field. Pulse-to-pulse gain variations are tracked by PIN diodes. Channel-to-channel light gains need not be leveled with a sophisticated optical design, since cosmic ray bench tests interleaved with flasher data can establish gain-leveling constants; all that is important is that the light distribution system be mechanically stable.

This system is similar to an analogous one being designed (by another group in the collaboration) for the muon detector’s cosmic ray veto scintillators, and over time the two designs have nearly converged, so that long-term test results, PIN-diode monitoring, and pulser circuits can be shared efficiently. UTA is providing some of the long-term test results and the PIN-diode monitoring circuits.

In situ, the LED flasher primarily provides gain stability information for each ICD channel. Physics gain constants (such as effective sampling fractions as a calorimeter layer) have to be established using collider data, and here the plan is very similar to Run I. We expect to make some special dijet data runs to correlate single-hadron response to jet response, and to optimize jet-jet and jet-photon balancing.

**Solenoid test**

Rectangular iron blocks were shown[29] to provide adequate PMT shielding from a variety of magnetic field environments which we believe reflect the range of possible field configurations in the Run II detector. The technical design review of the ICD in December 1997 approved the use of these blocks to shield the Run II ICD PMTs from the magnetic field. Forces upon and due to the blocks have been estimated and measures have been taken to ensure mechanical supports can withstand the additional forces within safety limits.

All four iron blocks have been machined and painted early in FY98 and one or all of them may be included in the solenoid test in the late summer of 1998. For this test, the ICD group is particularly interested in instrumenting one block with a prototype LED calibration system and photodetection electronics.

Our reasons for participating in this test are many-fold:

- Test the prototype LED calibration system and prototype photodetection electronics.
- Our studies found that the iron block shielding should be adequate, but local field distortions are difficult to anticipate. The solenoid test gives us one more opportunity to
double check for problems due to the field.

- It will be useful to go through the exercise of attaching the iron to the crate and mounting the assembly into position. In the installation and commissioning of the Run II detector, there will be many other complicating issues. For example, a light-tight rectangular box containing hundreds of delicate fibers (fiber backplane) will be mounted inside the back end of the ICD crate in Run II. We would rather not do this for the first time during a tight installation schedule a few weeks before we roll in.

Run II PMT bases (voltage dividers) and hybrid preamplifiers will be used in the test with a modified output signal compatible with the Run I BLS cards on the platform.

**ICD Construction**

As we complete the prototyping phase of the ICD upgrade we are addressing the production requirements. This involves the physical facilities, the production tooling, and the necessary production procedures.

We have set aside an area of the Swift Center detector facility for the production of the ICD supertiles and crate assemblies. The scintillator is supplied by Bicron. Upon arrival at FNAL (Lab 8), grooves for the wavelength shifting fiber plus those for isolating the individual channels are machined. The tile is then cut into the final trapezoidal shape. All other assembly except fiber mirroring is carried out at UTA. Two jigs are being developed. The first jig will aid the assembly of the WLS fibers/connector respecting the length of fiber needed for each groove and the exact relative location of the connector at the edge of the box. This jig will sit on a rotatable mounting to provide the correct attitude for connector epoxying. The second jig will hold the actual scintillator tile while the fibers are inserted and the connectors are attached to the box. Prior to this the connectors are polished. We have developed our own diamond-bit fiber polishing machine. This machine has been verified to produce high quality results when the connector/fibers are viewed under high magnification on a binocular microscope. Following fiber insertion the tile is wrapped in Tyvek paper cut using a precise template. The wrapped tile is inserted into an aluminum box and the connector mated to its fixed piece in the endwall. Finally the cover is set in place. The polishing tool built at UTA is shown in Fig. 10.

The other main assembly procedure is for the crates. We have already had the iron blocks and fiber backplane enclosures manufactured by a local machine shop. The fiber backplane provides the means of associating the optical channel from a subtile with its correct photomultiplier tube and related readout electronics channel. The backplane construction will consist of creating connector/clear fiber/cookie assemblies and installing them with the correct routing between the side of the backplane, where the fiber cables from the boxes terminate, and the holes in the iron block where the PMTs are located. The calibration fibers will also be installed as part of this procedure.

Finally, the framework for the drawers will be assembled and attached to the iron block(s). Following receipt of completed drawers from Louisiana Tech., entire crate assemblies will be tested for correct connections, continuity and performance, prior to shipping to Fermilab.
**Installation**

Because of its modular nature and relatively small size, installation of the various components of the ICD is simple in comparison to that of other DØ subdetectors. The ICD installation schedule is therefore designed around that of other systems.

At least half of the ICD tile modules and PMT crates are scheduled to be delivered by mid FY 1999. North ICD tile modules and PMT crates can be tested and installed early in the process. Commissioning of the north ICD array can proceed as soon as cabling is complete and Run II platform electronics are available (low voltage, pulsers, high voltage ...).

The south cryostat has been moved off the platform (onto the sidewalk) in order to make way for the positioning of the solenoid and central detectors. The south ICD tile array will be installed while the south cryostat is on the sidewalk, with protective covers for the fiber cable connectors. The cryostat is returned to the platform later in the installation schedule, after which time the north PMT crate can be put in place, cabled and commissioned. The ICD will be built, delivered, installed and commissioned almost entirely by the ICD group composed of personnel from UTA and LT.

**ICD Schedule**

The following milestones from the Run II schedule show important events in the design, prototype and the construction of the ICD:

**Service Activities for DØ**

- All UTA personnel:
  
  ICD Upgrade design, prototyping, fabrication.
First Prototype Test September 1997
Run I Box Testing Complete January 1998
Iron Blocks Machined February 1998
Backplane Enclosures Fabricated March 1998
Full Prototype Tested May 1998
Tile Module Production Begins June 1998
Solenoid Test August 1998
Crates Fabricated September 1998

- Kaushik De:
  Run I ICD Box Decommissioning.
  Editorial Board 62 – SUSY dilepton analysis review committee.
  Convenor – “Missing Et, multijets and multilepton” working group at the Davis New Phenomena Workshop.

- Elizabeth Gallas:
  ICD Upgrade co-manager.
  MTC (Muon Tracking in the Calorimeter) software includes coding, documentation, and support.
  Editor and chair of committee of six assigned by DØ spokesmen to write “The DØ Physics Digest” - a summary of select DØ results at the general scientific level.
  Special Editorial Board – reviewing all ”plain english” summaries of DØ results on the DØ WWW sites.
  Editorial Board 072 – Jet multiplicities and cross section ratios (as co-author).
  Editorial Board 043 – Jets + b’s (mu’s in jets).
  Editorial Board 088 – $Z_{\mu}$ analysis.
  DØ Speakers Bureau.
  Member of the muon software review panel for Run II.

- Jill Perkins:
  Committee to facilitate the DØ Unix conversion (since December 1995).
  Editorial Board 079 – Rapidity Gap Events (Run Ib).

- Ransom Stephens:
  Chair of Editorial Board 096 – Search for a Third Generation Leptoquark.
  Chair of Editorial Board 061 – The Supersymmetric Particle Search in the Dielectron Channel.
  Ported, performed full verification, and released to the collaboration v12.21 of the DØ data reconstruction on the DEC Alpha platform.
  Convenor of the Run II QCD Analysis Group.
Andrew White:
ICD Upgrade co-manager.
One of two DØ representatives (with Paul Grannis) on the HEPAP Subpanel on the Future of High Energy Physics in the US.
Chair of Editorial Board 103 – Run Ia W,Z cross-section PRD.
Editorial Board 066 – W/Z cross-sections from Run Ib.
UTA representative on the DØ Institutional Board.
Member of the committee to review the technical design of the Run II DØ Forward PreShower Detector.
Member of Run II Level 3 trigger algorithm group, responsible for developing the missing transverse energy tool.

Part III
Report on UTA Work in ATLAS

The University of Texas at Arlington (UTA) group is leading the effort to design and build the Intermediate Tile Calorimeter (ITC) to improve hadronic and electro-magnetic calorimeter performance in the intermediate $\eta$ regions of the ATLAS experiment. This region between the Barrel and Extended Barrel Tile Calorimeter modules is populated by services, cables and electronics for the Liquid Argon calorimeters and Inner Tracking Detectors. The ITC provides additional calorimetry in this geometrically complex region. Between $0.8 < |\eta| < 1.0$, the ITC adds between 1-2 absorption lengths of steel-scintillator tile calorimetry. In the region $1.0 < |\eta| < 1.6$, the ITC provides a layer of additional scintillator sampling. In the figure below, we show a schematic drawing of one quadrant of the ATLAS calorimeter including the ITC.

UTA has primary responsibility for the design and production of the ITC. Kaushik De is the level 3 (WBS 1.4.4) manager for this project. Michigan State University (MSU) will play a major role in the design and production of the cryostat scintillators, which are a part of the ITC. The other US Tile Calorimeter (TileCal) institutions – Argonne National Laboratory (ANL), University of Chicago (UC) and the University of Illinois at Urbana-Champaign (UI) will participate in various ITC tasks related to their overall responsibilities for ATLAS. We have already built two prototype ITC submodules which were successfully tested at the CERN Test Beam in 1997.

UTA is also responsible for designing and implementing the module alignment system which will be used at Argonne National Laboratory for the assembly of 10 submodules into a single phi-sector of an extended barrel module. The precision-engineered base for this system has already been used for the assembly of prototype module 0A. Other UTA responsibilities in ATLAS include software development, data simulation, test beam participation and support for module assembly and testing at ANL.

The UTA personnel contributing to the ATLAS Tile Calorimeter project includes three faculty members, Drs. De, Stephens, and White; two postdoctoral fellows, Dr. Elizabeth
Figure 11: Schematic of the Intermediate Tile Calorimeter.

Gallas and Dr. Mark Sosebee; and our scientific engineer, Dr. Jia Li. Many undergraduate and graduate students at UTA are helping with R&D projects and simulations.

Intermediate Tile Calorimeter

For particles which originate at the nominal interaction point, the ITC extends over approximately $0.8 < |\eta| < 1.6$. The region 0.8-0.9 contains 311 mm thick steel-scintillator stacks, similar in design to standard Tile Calorimeter submodules. Between 0.9-1.0, the stacks are 96 mm in the $z$-direction. The combined 0.8-1.0 region of the ITC is called the plug. At higher etas, 1.0-1.6, the ITC consists of scintillator only due to space constraints. The scintillators between 1.0-1.2 are called the scintillator extensions, while those between 1.2-1.6 are called cryostat scintillators.

The plug and scintillator extensions primarily provide hadronic shower sampling, while the cryostat scintillators play an important role in sampling electromagnetic showers. Together, these detectors improve the measurement of total energy in the intermediate region, thereby improving the $E_T$ resolution of ATLAS.
Design

There is one ITC submodule per extended barrel module (0.1 in $\phi$) for a total of 128 submodules in ATLAS. Fibers from each 0.1 $\eta$ division of the plug are routed to two photomultiplier tubes, one for each side. There are 2 scintillator extension tiles per submodule. The segmentation for each of these tiles is 0.1 $\times$ 0.1 in $\eta \times \phi$. For the cryostat scintillators, the segmentation of each tile is 0.2 $\times$ 0.2 in $\eta \times \phi$. The shape of these tiles will be trapezoidal, with the scintillator extensions about 345 mm in $\eta \times 280$ mm in $\phi$, while the cryostat tiles will be about 345 mm in $\eta \times 240$ mm in $\phi$. The space constraints limit the maximum thickness of the tile assemblies, including the light-tight covers, to 20 mm for the extension and 8 mm for the cryostat scintillators.

Figure 12 shows the first prototype of the plug built at UTA being lowered into a shipping crate ready for assembly into Module 0B at Barcelona. The design of the plug [31] has been completed. Further prototype and design work is needed for the scintillator sections. These sections of the ITC have to be optimized for the highest light yield using the fewest number of fibers, all in a very compact profile. The minimum light yield required for the scintillator extension and cryostat tiles is around 5 photoelectrons/MIP. This requirement comes from the need to calibrate these tiles with good precision using muons. This value should be attainable based on our experiences with D0, CDF, and the mid-sampler in the April 1996 test-beam run. Furthermore, the uniformity of response across the tile surface should be better than 5%.
Prototypes

Our primary task during the past year has been construction of two ITC prototypes for testing at the CERN test beam as part of Modules 0A and 0B. Each module is a complete slice (0.1 in $\phi$) of the Tile Calorimeter Extended Barrel. Module 0A was assembled at ANL; Module 0B was assembled at IFAE (Barcelona). We supplied ITC submodules to both assembly sites. Both modules were completed on time and successfully tested at CERN. Construction of these submodules\cite{34} was an important test of the production capabilities at UTA. We show below the ITC after it was assembled as part of Module 0A at ANL.

![Module 0A at Argonne, ready for shipment to CERN test beam. Note ITC submodule in the foreground. Assembly base built by UTA in blue.](image)

We have set up space at our Swift Center Detector construction facility for ITC production. An overhead crane covering approximately half the laboratory space is used to manipulate the half-ton ITC submodules as well as to manipulate the compression plates used during stacking. Another one-ton crane on a moveable frame is also available. The Swift Center is certified for welding and equipped with a small machine shop. We have arranged adequate space for the storage of steel plates and completed submodules.

The unusual stepped shape of the ITC submodules requires special stacking and manipulation tools. A stacking tool which can be used for the assembly of both standard and ITC
submodules was designed and manufactured at UTA. This stacking tool was used to build the first two ITC prototypes. During prototype construction, we determined that each ITC submodule will require four days for assembly. Therefore we have scheduled three years of submodule construction starting in January 1999 to build the 128 ITC submodules at the rate of one per week.

In the picture, the ITC prototype for Barcelona Module 0B is being compressed for the final time on day 3 of the assembly procedure. The stack is complete. After curing the glue overnight, the ITC submodule will be welded using weld bars at the corners of the stack. We have designed and built special manipulation tools to rotate the half-ton submodule, move it to the welding area, dip it in a preservative, and finally pack it for shipment.

We have assembled at UTA various equipment necessary during the prototype stacking process. A washing tub, drying box and gluing templates are some examples. Much of this equipment will be upgraded for final production. We will convert the washing tub into a preservative dipping tub. Thicker gluing templates are being made, and better gluing system is being developed.

**Tooling**

Many special purpose tools are necessary for the construction of the 130 ITC submodules, each of which weigh about half ton. We have refurbished a large bridge crane which covers the primary ITC stacking area. We also purchased a portable crane for lifting and transporting submodules to areas outside the range of our fixed bridge crane.
It will be necessary to replace our pallet jacks based on their performance during prototype construction. Our first jack is leaking hydraulic fluid while the other, a standard duty model purchased in the spring of 1997, was barely able to handle the two weeks of prototype assembly. The weight of the materials we transport during submodule assembly requires high load capacity equipment. Thus, we will acquire two heavy duty pallet jacks to be properly prepared for production.

Our gluing system must be modified for high volume production. We require a system that can handle two components, mix them and then dispense them into measured bead shots. In addition, it should: (a) be an enclosed system to prevent worker exposure to the hazardous components, (b) accurately maintain bead size for every shot, and (c) be capable of dispensing shots as small as 0.2cc. Commercial machines with the above capabilities are typically priced around $12k or higher. We are currently working on an alternative system that can provide the same dispensing capabilities and same level of safety, but for roughly half the cost.

We designed and manufactured a high precision stacking fixture for ITC steel assembly. This stacking fixture was used successfully in the construction of the two prototypes. There will be some minor modifications to it and some changes will also occur in the design of the manipulation tool.

The wash tub used for plate washing during prototype construction will be used for dipping submodules in the rust-proofing solution. Various other tools and measuring devices will be built in 1998-99.

Production

We have made a number of design changes based on the experience of building the two prototype ITC submodules for the test beam. Primarily, these changes involve the weld bars which connect the steel plates at the inner radius. The dimensions of the scintillator tiles and spacer plates have also been changed globally for the Tile Calorimeter. Some tolerances have been relaxed to reduce production cost. We plan to build a third prototype in the next few months to verify these changes. This prototype will not be sent to CERN, but instead will be tested at UTA using cosmic rays. We will continue to optimize the ITC construction process during 1998-99 in order to have the most efficient and safe production plan possible.

During 1997-98, we will also continue setting up the infrastructure for submodule production at the Swift Center. Various templates and measuring tools will be set up. The gluing machine used for prototype submodules requires pre-mixing of the epoxy. This is unacceptable for submodule production, as the epoxy begins to harden before an entire stack has been assembled. Instead, we will modify this machine so that the glue is mixed as it is dispensed. Commercial dispensing-mixer machines are not available for the very small shot sizes used for the Tile Calorimeter.

A handbook for the students who will assist us during production has been written. A final version will be generated after we assemble our third submodule. The current version of the handbook can be found in PDF form at [35].
Laser Test Stand

We have built a computerized test stand\cite{32} which can provide a finely grained scan of scintillator prototypes using an UV laser source. This stand is being upgraded to test the design of the scintillator sections of the ITC.

The laser test stand consists of an UV laser beam focused onto individual scintillator tiles through a fiber. The beam spot on the scintillator is typically less than a millimeter in diameter. The UV light creates scintillation light in the tile which is read out by a photomultiplier tube and subsequently digitized and saved. The tile is placed on a movable x-y stage which is under computer control. This system provides important feedback about the uniformity of response during the design of scintillator tiles.

PMT Testing

UTA is responsible for testing 659 Hamamatsu phototubes for the ITC. We will modify the CAMAC based automated PMT testing facility built for DØ\cite{33} to test the tubes for ATLAS. Many major modifications will be necessary to make this system similar to other PMT testing systems used for the remaining 9,000 ATLAS phototubes. The ATLAS tubes are much smaller, have different base and electronics, require special efficiency and aging tests and may require environmental controls.

The University of Illinois is the primary PMT testing site in the U.S. for ATLAS. UTA will provide a second site in the U.S. for ITC phototubes. PMT testing will be a major
Work Plan

During 1996-98, we completed the mechanical design of the ITC and built two prototype submodules which were successfully tested with pion and muon beams at CERN. We also designed and built the extended barrel module assembly base and measured the alignment of Module 0A using a laser system at ANL. During 1998-99 we will complete the design of the scintillator sections of the ITC and start preparations for full scale production to begin in January 1999. We will build a third prototype to check our design changes. We will also build the first prototype of the scintillator extension and complete the design of the fiber routing scheme. Finally, we will complete the design and prototype of a new system for checking submodule alignment.

Starting in January 1999, we will enter a three-year period of ITC submodule production. This is a major responsibility in ATLAS. UTA is the only production site for ITC submodules and we must keep pace with the schedule for the production of the ATLAS Tile Calorimeter, which will be the first sub-detector to be installed in the collision hall. We request the Department of Energy to provide base funding to support the work at UTA on these critical tasks.

Module Alignment and Envelope Verification

During the assembly of Tilecal modules from submodules on the assembly tool it is necessary to correctly position each submodule on the girder, and to guarantee that all the submodules fall within the maximum allowed envelope for the module. We have previously investigated the use of a laser/targets system to accomplish this task. However, while the alignment function can be achieved using this system, it is only possible to certify the envelope for a submodule at a limited number of locations on the periphery of the submodule. This would clearly leave us vulnerable to excursions of the submodule between measurement locations using the laser system. We have therefore investigated a further system that would allow us to check the entire submodule envelope using a large mechanical gauge.

This new system is based on the use of a precision linear roller guide and an arch template[36] that is precisely made to define the maximum allowed envelope of a submodule. The linear roller guide will be mounted on an I-beam alongside the module assembly tool. As each girder is mounted on the assembly tool base its axis will be aligned parallel to the axis of the guide. Attached to the roller guide will be the arch template, which will be free to move along the axis of the guide. Then, as each submodule is mounted on the girder, the arch template is moved over the submodule and the clearance is checked prior to tightening down the mounting bolts. This procedure is repeated for each submodule, and finally for the entire module once completed.

We are currently working on a prototype system which will allow us to verify the suitability of the linear roller guide, develop techniques for its alignment and establish the accuracy with which we are able to verify the relative location of a reference surface and a surface being tested.
ATLAS Educational Outreach

We are holding a two week summer school program for high school students and a one week summer school for high school physics teachers: “Discovery With ATLAS!”[37]. The two week summer school, Monday through Thursday, two hours per day, is for high school students, and a single week summer school, Monday through Thursday, two hours per day, is for high school teachers. Discovery With ATLAS! was proposed to the ATLAS Education Committee in December and ranked second among the proposals. The program will develop a qualitative understanding of particle physics and the basics of accelerator and detector technology; with the ultimate intent of conveying the physics discovery potential of the ATLAS experiment to high school students and teachers. Enrollment will be limited to 40 students and 40 teachers. The school day will consist of a lecture followed by an investigation session. The teachers will be given essentially the same lectures as the students but there will not be investigative sessions. Rather, the teachers will be provided prepared question sets and the URLs of interesting web sites plus access to campus computers.

The school is being promoted through distribution of fliers to 500 high school science teachers in counties including and surrounding the Dallas/Fort Worth Metropolex; an advertisement in the UTA continuing education summer catalog that is mailed to 156 000 households; posters distributed to area libraries, book stores, and schools; press releases to area newspapers; notice on the UTA Marquee; and, budget permitting, paid advertising in local newspapers.

Part IV

Computing

Our current computing system consists of a DEC Alpha based VMS CPU farm of about 1250 MIPS, a DEC Alpha based UNIX cluster, a Hewlett Packard Unix workstation, a VAXstation cluster, and several PCs. The workstations are all configured in a central location without monitors. Interactive access to the systems is through either X-Terminals or PCs on desktops. We also employ many PCs in the detector development lab’s for data acquisition/analysis.

The acquisition cost of the workstations, their peripherals (etc.), and the X-terminals was about $200,000; of this, $175,000 was provided by UTA, and the remaining $25,000 by the Department of Energy (including our FY98 award).

Our primary research responsibility in computing is for data simulation with the DØ experiment. We plan to expand this service for DØ in Run II and for the ATLAS experiment.

The UTA CPU Farm and Data Simulation

This year the UTA CPU farm[38] continued to operate at better than a 95% duty cycle: no wasted CPU cycles on the UTA CPU farm. As the DØ Run I physics analyses mature, we’ve entered a realm of greater complexity and the need for data simulation of greater precision has increased. Thus, we installed the highly detailed “plate-level” version of the DØ detector simulation and a software package that properly smears the muon momenta and offer
this – along with the standard full GEANT simulation, the much faster showerlibrary-based simulation, and data reconstruction – to our collaborators.

The UTA CPU farm is the primary source of simulated data for Run II detector and physics studies. In the year since our last proposal, the UTA CPU farm has processed 360,000 full GEANT events, 432,000 showerlib events, and 3700 plate-level GEANT events; bringing the historic totals (since the farm began operating in March of 1995) to 875,000 full GEANT, 1,310,000 showerlib, and 3700 plate-level GEANT events. These simulations directly supported the following analyses[40]:

- DØ Run II work: software and hardware design of the trigger system, physics analysis preparation with multiple interactions, tracking software development;
- QCD analyses: color coherance in multiple jet events with $K_T$ algorithm reconstructed jets, measurement of the (forward) dijet cross section at large rapidity intervals and BFKL dynamics, measurement of the forward inclusive and triple differential jet cross sections, accurate determination of the jet energy scale at high rapidity;
- top quark analyses: measurement of the mass and cross section of the top quark in $t\bar{t} \rightarrow 6$ jets, search for flavor changing neutral current decays of the top quark;
- search for supersymmetric top squark in several different channels;
- detector studies/algorithm development: electron tagging within jets, development and verification of hadronic and electromagnetic showerlibraries for the far forward region of the detector;

In spring of 1996 the DØ farm switched from Monte Carlo to data reconstruction, confident that UTA would carry the full load from then on. We are preparing Run II with the understanding that DØ has no funding in the computing budget for simulated data production! The contributions of the UTA CPU farm during Run I have played a large role in giving DØ the confidence that offsite Monte Carlo production can meet the experiment’s needs.

Our computing plans for the next few years include development of a cost-optimized CPU farm, contributions to the development of Object Oriented code for the upgraded DØ detector, participation in ATLAS data access projects, and development of algorithms from the fields of image reconstruction and nonlinear dynamics for application in collider data analysis.

DØ Software Maintenance and Development

We describe many of our future goals in software development in a separate Department of Energy Proposal[39], “Application of Computers in Experimental Elementary Particle Physics,” that has been externally reviewed but whose funding level is still under consideration at the Department of Energy.
Participation in Fermilab’s PC Farms Project

The PC Farms project applies a large number of networked PCs running the Linux operating system to HEP applications. A center point of the project is to determine if PCs are a price/performance optimized solution to large scale data processing and simulated data production. Participation in this project is a labor intensive task and there is a huge need for DØ contributions to the project. Since our computing proposal has been under review since June of 1997, we have participated with few resources to contribute. We have managed to carry two CSE graduate students, Anil Solleti and Ravinder Pallerla, sequentially on a fraction of a research assistantship. Mr. Solleti ported the Run II DØ simulation code, DØGSTAR to the PC Farms last summer and then left our group to take a full RA position in CSE. Mr. Pallerla is currently porting the Run II OO c++ tracking code, trf++, to the PC Farms and will benchmark its performance against the performance on SGI and IBM workstations. This will be the first concrete measurement of the price/performance of Run II OO c++ code and is an integral part of Mr. Pallerla’s Master’s of Science Degree in Computer Science.

We will continue to participate at this level in PC Farms until our computing proposal is funded. Hopefully, thereafter we can make a more significant contribution.

Muon Tracking Code

The MTC (Muon Tracking in the Calorimeter) [41], MTCL2 (MTC at Trigger Level 2) [42], and MTCVTX (MTC vertex finding) [43] utilities use calorimeter information to identify and reconstruct track-like energy deposition in the calorimeter both on and offline in Run I. These significant software utilities for DØ data taking and analysis have been developed and supported entirely by UTA personnel as reported in our annual reviews since 1994. MTC has proven to be far superior to the previously used ‘calorimeter confirmation energy sum’ and is the current standard in calorimeter muon verification for all Run I analyses involving muons.

Plans to upgrade the MTC utilities are underway for use in Run II both on and offline. Elizabeth Gallas has joined the global tracking group, whose goal is to find and fit the tracks in a DØ event using event data from one or more of the DØ subdetectors. As a member of this group, representing the calorimeter, the MTC package is being rewritten in an object oriented framework in order to be compatible with DØ Run II software.

Level 3 Trigger $E_T$ Algorithm

The UTA HEP group has recently undertaken the development of the $E_T$ Level 3 trigger filter tool. This work will be carried out in collaboration with Louisiana Tech. The DØ trigger system for Run II consists of a pipelined hardware stage, Level 1, with tracking and calorimetry, second hardware stage, Level 2, which combines and refines Level 1 information with preprocessors and a global processor, and a software stage, Level 3, in which a farm of processors partially reconstructs events. Various “physics object tools” are required such as for electrons, muons, taus, and $E_T$. The $E_T$ physics object tool will use all available information such as all non zero-suppressed raw calorimeter data, the ICD and massless gap data, and a list of noisy cells. Significant design issues will center around the use of vertex information, and whether to use all calorimeter cells or only clusters in the anticipated environment of multiple interactions.
ICD Upgrade Geant

DØGSTAR is the GEANT Simulation of the Total Apparatus Response for DØ in Run II. Members of the UTA and LT ICD group have joined the detector simulation effort representing the calorimeter detector group. The current version of DØGSTAR includes geometry and digitization of the ICD similar to that used in Run I. Currently under development is an improved representation of the ICD which is object oriented to be compatible with future releases of DØGSTAR.

Interactive Upgrade to Windows NT

The group’s original computing equipment, a cluster of DEC VAXstations model 3100/76 (that were retired this year after failing to boot) and a VAXstation 4000/60 have served as our mail server and central interactive system. In FY98 our Department of Energy award included $20,000 for modernizing this system. We have installed a Windows NT based server employing Cirix WinFrame software to serve PC applications, including e-mail, to desktop thin-clients (a.k.a., NETstations or X-terminals) and PCs. With the FY98 award we also replaced some failed equipment including disk, tape-drives and a printer.

Part V

Budget Discussion

Faculty Support

We request two months of summer salary for each of our four faculty members. The budget pages include a 5% per year increment, implementation of which depends on UTA authorization of general and/or merit raises.

One of our present faculty members, Paul Draper, will be leaving UTA within the next 18 months and we intend to hire a replacement with research interests fully compatible with the group’s activities and commitments.

Postdoctoral Associates

We request support for two postdoctoral associates. The intensive detector design and production tasks we are committed to for the next several years require the energy and creativity of young physicists, providing in turn, excellent training in a demanding environment. Our recent and current postdoctoral associates have made many vital contributions to this work in the past, such as:

- leading the analyses of Run I data in New Phenomena and QCD.
- detector design, prototype development and testing, tooling design and construction.
• creation of innovative software used by the whole DØ collaboration.

**Graduate Students**

Mark Sosebee was the first student to gain his Ph.D. through our group (formed in 1991), and Jill Perkins has recently gained hers. We have recently been very fortunate to attract three new graduate students who have already shown impressive performances in course work, in initial involvement in detector development, and software development for physics analysis in OO C++. The Computer Science graduate students who participate in our program as part of their Master’s of Science Degrees (in collaboration with the CSE Department) have also made considerable contributions to data simulation, software development, and maintenance. We hope to attract further students for Fall 1998.

We request support for four graduate students, including a supplement of $300/month for one of them each year to be based at Fermilab as an essential part of their training.

**Technician**

As we have discussed earlier in this proposal, we have two large detector projects underway at our Swift Center facility. While a limited amount of technical effort has been provided by DØ and ATLAS project funds, we have an urgent need for the services of a full time technician.

**Undergraduate Students**

We have been very pleased with the degree of involvement in our research by many talented undergraduate students in physics, computer science engineering and electrical engineering. High Energy Physics is well recognized for providing interesting and challenging educational and research opportunities for such students. We see this as a very cost effective use of a limited amount of external funding.

**Secretary**

Lani Young has been our group secretary for three years and is an invaluable source of essential administrative support for the faculty, staff, and students working in our group. She is the local expert on the new UT System accounting software and provides a vital source of the accounting information required by the DØ and ATLAS managements. In addition, Lani has recently overseen the project to renovate our office area in Science Hall. We request continued support for Lani in her Senior Secretary position.
Equipment

As discussed in the computing section of this proposal, earlier this year we submitted a separate proposal (Ransom Stephens, PI) to upgrade our group computing facilities and our “farm” in particular. This proposal is currently being reviewed by the Department of Energy and we do not repeat that request here [39]. Instead we request a limited amount of funding for basic infrastructure items, such as electronics modules (VME for compatibility with DØ and ATLAS), routine computing upgrade items, and mechanical equipment (for use at the Swift Center facility), not specifically provided for in either the DØ or ATLAS project budgets.

Travel

Domestic - at Fermilab

We request the provision of $60,000 per year in our laboratory service account at Fermilab. We base this request on analysis of past travel needs and projections for future years. We anticipate an increasing amount of travel to Fermilab for the hardware and software preparations, and data taking activities for Run II. In addition to this we are seeing an increased burden of ATLAS related domestic travel by physicists which cannot be supported by direct ATLAS funding.

Foreign

We are also seeing a steadily increasing amount of foreign travel as our participation in ATLAS develops and we become even more involved in test beam and other work on site at CERN. We are therefore requesting significant DOE base program funding in this area according to US ATLAS guidelines.

Materials and Supplies

We request a small level of support in this area based on analysis of past expenditures. We are always striving to find less expensive sources for regular office items and to hold down routine costs.
Part VI

References

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18. Frank E. Paige, and Serban D. Protopopescu, Monte Carlo event generator for $pp$ and $p\bar{p}$ reactions, BNL 38034 (1986).
19. The draft of the paper being prepared for submission to Phys. Rev. is available at:
http://www-hep.uta.edu/hep/stephens/jet_fractals.html


24. Jets are smeared according to the known detector resolutions. DØ jet resolutions - to be published.

25. Walter Giele, private communication.

26. The Future QCD Analysis Project web page is available at
www-d0.fnal.gov/ransom/future_qcd.html

27. The Run II Energy Scale page is at www-d0.fnal.gov/ransom/run2_escale.html

28. This study will be documented in a DØ note upon completion. It is being integrated with studies of the effect of vertex information on top and bottom triggers performed with DØ colleagues.


30. The ITC home page at http://heppc1.uta.edu/kaushik/tilecal/tilecal.htm contains further detailed information about the ITC.

31. Design drawings of the ITC developed at UTA can be found at http://heppc1.uta.edu/kaushik/tilecal/drawings/drawings.htm


34. Photographs of ITC prototype construction are at http://heppc1.uta.edu/kaushik/tilecal/photos/photos.htm

35. The ITC production handbook is available at http://heppc1.uta.edu/kaushik/tilecal/handbook.pdf


37. The Discovery With ATLAS! Web page is http://www-hep.uta.edu/hep/stephens/discovery.html
38. We maintain the DØ Monte Carlo Production Web page
   http://www-hep.uta.edu/hep/stephens/d0/d0mcsta.html

39. Ransom W. Stephens (P.I.) and Andrew P. White, Kaushik De, and Paul Draper (Co-
   Particle Physics,” a proposal to the US Department of Energy. The complete proposal
   and an updated summary thereof are available at
   http://www-hep.uta.edu/hep/stephens/cpuprop.html

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   http://www-hep.uta.edu/hep/stephens/d0/utalfhist.html

41. DØ Note 2066, “Muon Tracking in the Calorimeter”, E. Gallas.

42. DØ Note 2195, “The MTCL2 Utility - Muon Tracking in the DØ Calorimeter in Trigger
   Level 2”, Elizabeth Gallas and Tom Fahland.

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   the DØ Calorimeter”, (in preparation) Elizabeth Gallas.