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1. Introduction

The Centre for Subatomic Research (CSR) at the University of Alberta was established as the Nuclear Research Centre in 1958. This report summarizes the research activities of the 45th year of the CSR covering the period 1 July 2003 to 30 June 2004. During this period, our research has shown increasing emphasis on high-energy particle physics. In 2003 we hired a new faculty member, Professor Roger Moore, who is a collaborator with the DØ experiment at the Fermi National Accelerator Laboratory (Fermilab).

Our involvement in preparing for the ATLAS experiment at the CERN Laboratory continues to grow. All the experimental faculty in the CSR are now engaged in preparing for this experiment, which should begin data taking in 2007. Meanwhile, we continue our strong efforts on the CDF experiment at Fermilab. Besides our major emphasis on high-energy physics, the CSR has a strong component of its research program in the area of astroparticle physics. The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) located at Sandia National Laboratories is observing high-energy gamma-ray sources. The Alberta Large Area Time Coincidence Array (ALTA) continues to provide a unique educational experience for students of participating Alberta high schools.

We continue to hold the week-long Lake Louise Winter Institute each year in February. The topic in 2004 was Fundamental Interactions.

The work of the CSR is supported by research grants from the Natural Sciences and Engineering Research Council of Canada. The University of Alberta and TRIUMF provide salaries for technical support. The Lake Louise Winter Institute receives support from the above sources as well as from the Institute of Particle Physics.

Douglas M. Gingrich
Director
July 2005
2. Experiment Reports

2.1 ATLAS Experiment at the LHC

B. Caron, C. Cojocaru, J. de Jong, A. Hamilton, D.M. Gingrich, S. Liu, R.W. Moore, 
J.L. Pinfold, R. Soluk, J. Soukup, W-Y. Ting, M.G. Vincter, Y. Yao

The ATLAS experiment is a large multi-purpose detector that is being built for the Large Hadron Collider (LHC) accelerator at CERN. The accelerator and detector will come online in 2007. The primary aim of the experiment is to search for the mechanism that gives fundamental particles their mass. In addition, there is a wealth of other physics measurements as well as discoveries anticipated to be made during the greater than ten years of operation.

The CSR group has a diversified set of research interests and responsibilities on the ATLAS experiment. The group is responsible for the construction and commissioning of electronics for the calorimeter detectors, high-level trigger processing, testing the hadronic endcap calorimeter with particle beams at CERN, and research and development on a forward luminosity detector. The particle physics interests of the group concentrate on searches for heavy Higgs bosons and supersymmetric particles, as well as a determination of the luminosity of the experiment.

2.1.1 Calorimeter Electronics

The ATLAS group in Alberta is responsible for the Canadian contribution to the electronics for the detector. In particular, we are responsible for the production of all the deep submicron chips for the readout of the liquid argon calorimeter. The deep submicron chips are digital application specific integrated circuits fabricated in a 0.25-micron CMOS technology (see Figure 1). The chips include the switched-capacitor array controller (SCAC), the gain selector, and clock fanout circuits. We are also responsible for all aspects of the SCAC, including design, testing, and radiation qualification.

![Deep submicron reticle](image)

Figure 1: Deep submicron reticle, designed in the CSR, for the ATLAS calorimeter readout.

As a last step before the final production of the deep submicron chips, preproduction prototypes were fabricated. Preproduction SCAC prototypes were tested during the summer of 2003. This work was carried out by a team consisting of a faculty member, research associate, NSERC summer student (Doug Gish) and a WISEST (Women in Scholarship, Engineering, Science and Technology) student (Becky Gilday). All 375 parts were functionally tested. For the
355 working parts, the timing and current characteristics were determined. The reliability of the device was estimated by performing room-temperature burn-in on all parts, and performing accelerated high-temperature ageing on a random sample of 11 parts. The SCAC was qualified for radiation tolerance by exposing parts to ionizing radiation from our x-ray accelerator in the CSR. In addition, single-event effect radiation testing was performed using the Proton Cyclotron at the Massachusetts General Hospital. The facility is capable of providing proton fluences about 100 times higher than those previously obtained at the TRIUMF Proton Radiation Facility. This is the first time members of the CSR have made use of this facility in Boston. Based on the success of the preproduction series deep submicron chips, the unmodified design was used for the final production version and submitted for fabrication in 2003 (see Figure 2).

![Figure 2: One of 48 deep submicron wafers for the ATLAS Calorimeter electronics.](image)

The final production chips were tested and radiation qualified in spring and summer of 2004. All 4840 SCAC were tested over a three month period in spring 2004 by hiring part-time undergraduate students. The detailed current, timing, and radiation testing was performed during the summer by an NSERC summer student (Travis Martin). The single-event effect testing was again performed at the Massachusetts General Hospital by Doug Gingrich. The testing indicated a good yield for the SCAC and the parts were radiation qualified for ATLAS. The chips were shipped at the end of summer of 2004 to Nevis Laboratories for mounting on the ATLAS front-end boards.

### 2.1.2 ATLAS Event Filter

The ATLAS Event Filter (EF) aims to reduce an input rate of about 2 kHz (approximately 3 GB/s) after the second level trigger, to an output rate of about 100–200 Hz (approximately 150 MB/s). The EF will perform, for the first time, full event reconstruction and make final trigger decisions on the basis of well-defined physics criteria. The total computing power necessary to achieve this goal is estimated as $2.5 \times 10^8$ SPECint95 units, equivalent to about 1500 dual 8 GHz cpu machines. In addition to its event processing role, the EF is also envisaged to provide general online monitoring and calibration tasks for the ATLAS detector. At this stage, events can be sorted into streams (event classification) for online production. In addition, certain key channels will be immediately analyzed at the EF stage. The EF will also provide online
monitoring and calibration data for the ATLAS detector. This monitoring will be essential for early detection of problems with the detector which might otherwise cause a significant waste of beam time were they to go unnoticed.

The work of the ATLAS TDAQ group has culminated in the production of the ATLAS High Level Trigger, DAQ and Controls Technical Design Report (HLT-DAQ TDR) (last modified in October 2003). The Alberta-ATLAS group contributions to this TDR were major and included: a contribution to the Physics and Event Selection Architecture (PESA) algorithms that included authorship of the subsection on “Tau/Jet/ETmiss Selection”. In the EF infrastructure software/hardware area there were important contributions to the subsection on the “The HLT Vertical Slice” tests and contributions to subsection on “Modeling Results” pertaining to the simulation of the EF system. The effort of refining and extending the material in the TDR has continued during 2003 and 2004 and has resulted in a set of additional studies to which the Alberta group contributed. Another important contribution to the TDR were the studies to determine scalability of supervision architecture carried out on 230 dual cpu nodes of the LXPLUS Linux cluster at CERN. The configurations studied were, for example: constant total number of nodes split into a varying number of sub-farms; and constant number of sub-farms with number of nodes/sub-farm varied. The largest configurations numbered about 1000 processes under HLT control (approximately 10–20% of EF). The tests focused on assessing times to startup, preparation for data-taking, and shutdown of configurations. No significant variation with the number of processing nodes was observed. The large scale tests are due to continue this year and next with resources based in Canada and elsewhere.

An important aspect of the Alberta-ATLAS group contribution to the EF effort over the past two years has been our contribution to test beam studies, utilizing a full slice thought the ATLAS Trigger system. This work involved the use of ATLAS-Canada’s MAGNI cluster at CERN as a prototype EF sub-farm in the 2003 test beam. The HLT system consisted of 29 computers controlled via DAQ running the latest TDAQ and EF software releases. ROOT-based online monitoring was provided for the Silicon Tracker (SCT), Tilecal, Monitored Drift Tube and Resistive Plate Chamber muon system elements (MDT/RPC) combined; and, the Pixel detector stand alone test device. The ATHENA-based Event Filter processing tasks employed were: MOORE (MDT/RPC) and Calib (Tilecal and MDT). The EF test-beam trigger was actually used as a filter to distinguish muons from pions online. In the 2004 test beam program the MAGNI cluster was used as a remote (CERN main site) EF sub-farm connected through a fast link to the H8 test beam. The new mini-MAGNI EF sub-farm prototype (4 dual Xeon 3.2 GHz rack-mount machines) installed at CERN by the Alberta group was utilized as the local EF trigger farm. In 2003 and 2004 data was taken on the H8 beam line, with a set of detector elements that represented a slice through the barrel region of the ATLAS detector.

One of the aims of the Canada group is to implement a prototype of the complete tau-hadron trigger for the 2004 test beam, as part of the PESA effort. The trigger is provided by hardware at Level-1. The Level-2 tau-hadron trigger utilizes the calorimeter (for jet shape and isolation) and the tracking (to identify the small multiplicity of tau-jets). The tau-hadron trigger in the EF uses elements of the “Taurec” online package adapted as an EF processing task. The EF software incorporates improved calorimetric measurements and tracking, as well as high level analysis algorithms. The software for this task is now near to completion and is scheduled for real-time testing towards the end of the extended test-beam period in October 2004.
The Alberta group along with members of CERN, INP Cracow and Niels Bohr Institute (NBI) have initiated an effort to develop a distributed system for real-time event processing using EF sub-farms, primarily for remote online monitoring. The issues that are being studied in this area are the scalability, system robustness, system stability, dynamic allocation of resources and security. Indeed, we are part of an effort to implement a prototype remote EF farm at the 2004 test beam. These tests involved sites in Edmonton, Copenhagen, Cracow, and Manchester. The EF nodes successfully operated at the same time at CERN, and under various scenarios, at the remote sites. We will be requesting additional test-beam time for a second trial in October 2004 in order to further identify limitations in the protocols being used, identify limitations in the online and dataflow software configurations and test scaling numbers for the various EF trigger tasks and processes. Of course, this work represents the beginning of a program of testing and development. Such farms could be very useful in improving the efficiency and lowering the cost of remote monitoring of ATLAS detector systems, including the liquid argon calorimeter.

The Canadian EF group has participated in the EF software in three ways. Firstly, in the EF “infrastructure” software and its integration with the Trigger DAQ online software. Secondly, the group has participated in the simulation of the HLT system within the Ptolemy framework. Sarah Wheeler has been appointed Coordinator of Simulation Studies in the ATLAS EF Group. Thirdly, our group is playing a leading role in the ATLAS Physics Event Selection Algorithms Group (J. Pinfold is the Convenor of the Jet/ETmiss/Tau group). Our PESA effort links up with a large physics involvement in the ATLAS/LAr Jet/ETmiss/Tau performance groups. Indeed, during the last three years the Alberta EF group has made leading contributions to the understanding of: the jet plus ETmiss trigger rate, the overall jet trigger rate, trigger rates involving electrons and photons, trigger rates involving taus, as well as a study of the impact of a reduction of the liquid argon calorimeter record size on HLT rates. Our plan is to now concentrate most of our effort in the PESA Jet/ETmiss/Tau work, in which we are currently playing a leading role. This plan will be reinforced by a continuing and expanding involvement in the liquid argon calorimetry performance software and with active contact with other ATLAS-Canada groups working in related areas, such as test-beam studies. This effort will not only involve the preparation of algorithms for triggering and monitoring, but also it will inevitably involve those infrastructure software tasks that are intimately related to the PESA algorithms. The ATLAS-Canada EF group will also continue its leading involvement in the development of the networking and software systems required to be able to deploy remote EF farms for remote online monitoring. Currently, we are concentrating on the tau and ETmiss algorithms. We envisage that a new group, joining our effort would take responsibility for those aspects of the PESA work related to Jets.

2.1.3 Calorimeter Test-Beam Studies

The Alberta group has undertaken an extensive and successful beam test program using the hadronic endcap calorimeter. These tests were in the H1 cryostat in the SPS North Area of the H6 beam line at CERN, and used beams of electrons and pions with energy up to 200 GeV. The initial beam tests were of individual systems, and were part of the detectors’ quality control and initial calibration. Subsequent tests were of combinations of detectors, using close to final ATLAS electronics and software, and had the physics goals of combining signals from the various detectors. The beam tests established electron and pion energy calibrations for the calorimeters. We will transfer the test beam energy scale to ATLAS using the electronic pulse
calibration systems of the various detectors. These test-beam energy scales will be used in early ATLAS physics runs.

2.1.4 Preparation for Physics Analysis

The Alberta group works on a variety of physics topics in order to be prepared for data taking in 2007. These topics largely form the subject of graduate student theses. For some time now, the Alberta group has been studying Higgs production via vector boson fusion and the decays $H^0 \rightarrow Z^0Z^0$ and $H^0 \rightarrow W^+W^-$. We plan to search for these processes from low masses of about 160 GeV/c$^2$ to high masses of about 1 TeV/c$^2$. These topics form the content of Jeff de Jong’s thesis.

In addition, we are studying Higgs pair production. We have now chosen two channels to look at: $H^0H^0 \rightarrow b\bar{b}b\bar{b}$ and $H^0H^0 \rightarrow b\bar{b}\tau^+\tau^-$. The idea is not only to search for the Higgs this way but also to study the Higgs properties, such as the Higgs trilinear couplings. This forms the topic of Wei-Yuan Ting’s thesis.

Our group is interested in measuring the intensity of the proton-proton collisions delivered by the LHC to the ATLAS experiment. The group is taking the lead role in the design of a luminosity detector called LUCID. We are also interested in determining the luminosity using physics processes. Next-to-leading order calculations plus kinematical restriction are being used to measure the $W$ plus jet cross-section to 1–2% rather than about 5%. Also, using $\gamma\gamma \rightarrow \mu^+\mu^-$ we are studying, using muonbox, the trigger threshold for muons. This work forms the basis of Bryan Caron’s thesis.

There are several other topics the Alberta group is working on. Work continues on the study of zero suppression of calorimeter data. Jim Pinfold has initiated a study of astroparticle physics using the LHC. A webpage had been prepared (http://csr.phys.ualberta.ca/astroATLAS/) and a talk was given at the ATLAS Collaboration meeting in Athens this year.

2.2 CDF Experiment at Fermilab

B. Caron, A. Hamilton, J.L. Pinfold

The Collider Detector at Fermilab (CDF) was constructed to study the high mass states and large transverse momentum phenomena produced in the collision of proton and antiproton beams at the world’s highest energy machine, the Tevatron Collider. The analysis of the data collected during the period 1992-1995 (Run-I) led to the discovery of the top quark, the last undiscovered quark of the six predicted by the Standard Model. The Tevatron collider was upgraded during 1996-2001 in order to operate at approximately ten times higher luminosity. In addition, the centre-of-mass energy of the upgraded Tevatron was increased to 2 TeV. The expected order of magnitude increase in data in Run-IIa opens up an exciting era in CDF physics, one that allows detailed study of top quark properties and provides new vistas in heavy quark physics that provide a unique arena to study $B_S$-meson properties and allow precise measurements of CP violation in the b-quark sector. There is also the tantalizing prospect of new physics.

The final results from LEP-II at CERN suggest that the Standard Model Higgs boson is light and possibly within reach at the Tevatron. Given the compelling nature of the search for the Higgs boson, along with other exciting physics possibilities, the CDF collaboration is planning for a Run-IIb that would deliver up to another factor of ten of recorded data, before the Large
Hadron Collider (LHC) produces its very first data in 2007. There are opportunities here for students to become involved in a host of physics studies as well as become an expert in some aspect of the running of the CDF experiment that is presently taking data at unprecedented energies.

![Figure 3: The CDF detector rolling in for the beginning of Run-II.](image)

With the start of Run II at the Tevatron, the possibility of detecting a light Higgs boson has been the focus of much attention. One area of the Higgs search that has not received as much attention is the search in double diffractive collisions in which the final state contains only intact protons which escape the central detectors. The protons would be tagged in roman pot detectors a long way downstream of the interaction point, allowing a very precise determination of the Higgs mass, using the so-called missing mass method. Such tagging allows a Higgs boson with mass of about 200 GeV/c$^2$ to be observable. Obviously, the missing mass method can only be used in the case where the Higgs production is exclusive. Some calculations of this rate indicate that it is too low to be observable at the Tevatron. Also, we only have roman-pot coverage on one side of the interaction point at CDF. The inclusive process was recently estimated by Boonekamp et al. to be large enough to be detectable. If this turns out to be the case, the double diffractive channel might still provide a relatively clean environment in which to produce the Higgs. We plan to investigate this possibility.

We will also look at two other double diffractive processes: di-bjet production (di-jet production has been measured in Run-I/II at CDF) and di-photon production (which has not been investigated at CDF). The di-photon production is almost certainly high enough to be observable at Run-II. Di-photon production is dominated by the quark-quark double diffractive diagram. This is in contrast to the di-jet and Higgs production processes which are dominated by gluon exchange. The di-photon process therefore provides complementary information to the di-jet process.
We are not expecting to observe the Higgs boson in doubly diffractive events at the Tevatron. However, we will be able to study processes, such as those described above, as well as other parameters, such as gap survival probabilities, that will involve a search for the Higgs in diffractive production at the LHC. The topic of Andrew Hamilton’s PhD thesis is the study of exclusive diffractive di-photon samples at CDF.

In fulfillment of its service role the Alberta CDF group, during 2003-2004, worked in the CDF database group helping to monitor offline database usage and develop software tools to assist in offline database monitoring. The goal of the offline database monitoring effort is to ensure the CDF offline database meets the heavy demands of the CDF collaboration without interruption due to an overload failure. The bulk of the work is determining which users are putting the highest demands on the database and then determining if that demand can be reduced without sacrificing the user’s physics goals. This work will be necessary as long as the CDF computing environment continues to evolve.

The Alberta CDF group also collaborated in the development of freeware database tools that will enable institutions to analyze CDF data without the need to have a continuous connection to the CDF databases. The demand for this utility comes from institutions that are far enough away from Fermilab that network latency in the database information transfer becomes a dominant factor in the user’s total job execution time. Bill Burris will tackle the major issues facing this effort, including, but not limited to, on-demand Oracle to MySQL replication, data integrity, and memory leakage issues. Recent emphasis on cost savings at Fermilab may increase the urgency of this work.

At present, prototype installations of CDF CAF (Central Analysis Facility) and SAM (Sequential Access to Metadata) Grid servers are installed at Alberta and are integrated with the THOR Linux cluster. Once both the remote CAF and SAM stations have been fully tested the JIM (Job and Information Management) system of the CDF Grid installation will be added to the Alberta infrastructure. The JIM system acts as the front-end and glue to the CDF Grid system, taking care of global job submission and brokering using Condor-G and job transfer using GRAM (Globus Resource Allocation Manager). Once JIM is in place, the Alberta THOR Linux cluster will be able to participate in the global user analysis of collected data, as well as expand its current participation in the off-site simulation production for CDF. In addition to the CDF SAM Grid installation, members of the Alberta CDF group are actively contributing to the configuration of the performance monitoring information provider for the central CDF CAF system.

2.3 DØ Experiment at Fermilab

R.W. Moore

The DØ experiment is a general purpose detector at the Tevatron collider at the Fermi National Accelerator Laboratory (Fermilab). The Tevatron is currently the world’s highest energy collider, creating proton-antiproton collisions at 1.96 TeV centre-of-mass energy. The experiment is run by a collaboration of approximately 650 physicists from more than 80 institutions in 19 countries, including Canada.

The first run of the DØ detector was from 1992 to 1996. Following this the Tevatron was upgraded to boost the centre-of-mass energy from 1.8 TeV to 1.96 TeV, and to increase the
luminosity. As a consequence the DØ detector was also heavily upgraded with the introduction of a central magnetic field, new tracking detectors, and a new trigger and data acquisition system.

The upgraded DØ detector covers the full solid angle. The central region consists of a 2 T superconducting solenoid containing a silicon micro-strip detector and a central fibre tracker. This is contained within a liquid argon/uranium calorimeter. Surrounding this are the muon chambers consisting of three tracking layers and a 1.9 T toroidal magnetic field. The excellent calorimetry and extensive muon coverage are two of the noted strengths of the DØ detector. The addition of the central magnetic field and improved tracking detectors has significantly improved the capabilities of the detector.

DØ has a wide ranging physics program which highlights the rich variety of physics accessible at the Tevatron. The main areas of the program are: the search for new physics beyond the Standard Model, the search for the Higgs boson, measurement of the properties of the top quark, precision electroweak measurements, b-physics, and quantum chromodynamics (QCD) studies.

Since the discovery of the top quark in 1995, by DØ and CDF, the one remaining piece of the Standard Model is the Higgs boson which gives the other particles mass. Direct searches by the Large Electron Positron (LEP) accelerator at CERN have put a lower limit on the Standard Model Higgs mass of 115 GeV/c². Until the Large Hadron Collider (LHC) starts running in 2007 the Tevatron provides the only opportunity to hunt for the Higgs. The current predictions are for between 4–8 fb⁻¹ of integrated luminosity by this time. Figure 4 shows the limit, evidence, and discovery reaches for the Higgs as a function of the luminosity. With the current predictions this would raise the Higgs mass limit to 130-136 GeV/c² and provide evidence for the Higgs up to approximately 122-130 GeV/c².

![Predicted Higgs exclusion, evidence, and discovery reach as a function of luminosity.](image)

Figure 4: Predicted Higgs exclusion, evidence, and discovery reach as a function of luminosity.

Being at the energy frontier makes DØ an excellent place to search for new physics beyond the Standard Model. Searches being performed include supersymmetry, large extra-dimensions and leptoquarks. In particular the DØ Alberta group has been searching for evidence of supersymmetry, a proposed symmetry between force and matter. There are compelling
theoretical arguments that, if this is a symmetry of nature, it is likely to exist at an energy scale within reach, or only slightly above, that of the Tevatron. Discovery of such physics would have huge implications not only for subatomic physics but also for cosmology since supersymmetric particles could be a significant source of dark matter.

Evidence of supersymmetry could come from a variety of different event signatures. The particular model that the DØ Alberta group has been looking for is for production of three charged leptons. Since each lepton has either a positive or negative charge two of them must have the same charge. Such an occurrence is extremely hard to produce with known, Standard Model, physics and so its observation would be a clear indication of supersymmetry. This analysis is nearing completion and will be published next year.

The Tevatron beams collide too frequently to store the results of every collision. Consequently the detector must select which events look interesting enough to read out and write to tape. The software and electronics which does this is known as the trigger. The Alberta group is a major participant in the DØ trigger with Roger Moore becoming co-head of the Level 2 trigger this year. The group has lead the upgrade of the Level 2 trigger software, expanding the current 128 trigger bits at Level 2 to 4096 bits. In the coming year focus will shift to the upgrade of the Level 2 trigger calorimeter workers. This work will be done in close collaboration with the DØ group at York University who are working on the Level 1 calorimeter trigger upgrade.

2.4 STACEE Experiment at Sandia National Laboratory

D.M. Gingrich, D. Wakeford

The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) uses the large steerable mirrors (heliostats) of the National Solar Thermal Test Facility at Sandia Laboratories in New Mexico to capture the Cherenkov light from high-energy gamma rays (see Figure 5). This Cherenkov light is emitted by electrons and positrons produced when a high-energy gamma ray impinges on the atmosphere. The technique allows us to detect gamma rays that are of higher energy than those that can be studied with space-borne instruments, but lower energy than those with other ground-based instruments. This energy range is important for the study of many types of astrophysical sources, and primarily active galactic nuclei (AGN), galaxies believed to harbour and be powered by a billion solar-mass black hole. STACEE data is important in multi-wavelength campaigns on these objects. The STACEE detector is now completed and we are detecting gamma-ray emission from AGNs and from other astrophysical objects.

The analysis and publication of our results on W Comae occurred in 2003. W Comae is an AGN of the blazer category with a redshift of 0.1 that has not been detected by ground based instruments. STACEE has set upper limits on the gamma-ray flux which restricts a range of hadronic models used to describe gamma-ray jet production from this source.

A large data sample on the BL Lac object 3C 66A was collected during the 2004 observing season. This was accumulated during a multi-wavelength campaign involving x-ray (RXTE), ground-based optical, and radio instrumentation. The data is under analysis. 3C 66A is interesting because although it has a high redshift of about 0.44, it has a higher energy synchrotron peak than other BL Lac objects.

The STACEE group in Alberta consists of one faculty member and one graduate student. The group is involved in the operation of the experiment, development of an upgrade to the
trigger system, and analysis of the data. Significant time was spent this season by the group operating the detector in Albuquerque. The complete set of software for simulating and analyzing the data from STACEE is operational in Alberta. The group is currently active in the analysis of data taken on the AGN BL Lacertae and studies of the coherent noise in the electronics system.

![National Solar Thermal Test Facility at Sandia Laboratories in New Mexico.](image)

Figure 5: National Solar Thermal Test Facility at Sandia Laboratories in New Mexico.

### 2.5 ALTA Cosmic Ray Experiment

*J.L. Pinfield, R. Soluk*

In 1994 the Centre for Subatomic Research started the Alberta Large-area Time-coincidence Array (ALTA) experiment to create a sparse array of cosmic-ray detectors located on the roofs of Alberta high schools (http://www.ualberta.ca/alta). Cosmic rays, made up primarily of protons and atomic nuclei, were used to make many of the early discoveries in particle physics and are now the focus of numerous current experiments because they allow one to probe much higher energies than can be reached by terrestrial accelerators. ALTA was the first project to take advantage of the existing high school infrastructure to create a sparse cosmic ray detection array and allow high school students and teachers to become involved in a real ongoing experiment. This idea has proved to be extremely popular with experiments similar to ALTA now appearing all over the world (the ones in North American can be located at http://www.ualberta.ca/nalta).

The main research aim of the ALTA collaboration is to search for a non-random component in the high energy cosmic-ray flux by looking for pointing and time coincidences between widely separated detector stations. The global positioning satellite (GPS) system employed by ALTA allows precise timing between sites separated by distances ranging from a few kilometres to hundreds of kilometres. The geographical layout of the detectors present in the year 2003-2004 and planned detectors forming the ALTA array is shown in Figure 6.

As of mid-2004 ALTA has 13 school sites collecting data in addition to two located on the University of Alberta physics building. ALTA detectors have also been installed at the
University of Victoria and the Institute of Experimental and Applied Physics of the Czech Technical University in Prague, who are both collaborating with the Centre for Subatomic research to create their own ALTA-style experiments. The ALTA “educational” cosmic ray array was the first in the world and it has inspired similar projects in the USA and in Europe. ALTA is the lead group in the NALTA collaboration which consists of similar experiments that have started up in Canada and the United States. In addition, the ALTA collaboration has provided startup advice to the EEE (Extreme Energy Events) project in Italy, and to a fledgling effort in the UK at King’s College London. By allowing teachers and students to become involved in ongoing research, ALTA helps to promote physics at the high school level and anecdotal reports indicate a significant number of students have changed their career paths towards the physical sciences.

Figure 6: The geographical distribution of detectors in the ALTA array.

2.6 TWIST Experiment at TRIUMF

A. Gaponenko, P. Kitching, R. MacDonald, M. Quraan

TWIST is an experiment to measure the muon decay spectrum and to extract the precise values of three of the four decay (“Michel”) parameters. If the results differ from the Standard Model prediction, the deviations indicate contributions from physics beyond the Standard Model.
The goal of TWIST is to simultaneously determine these decay parameters with experimental precision better than $10^{-3}$, to eventually achieve approximately a tenfold improvement over the existing precision. When this goal is met, it will set new limits on the right-handed coupling of the muon in a model independent way, as well as squeeze the parameter space for certain classes of extensions to the Standard Model.

The TWIST collaboration began to collect data in late 2002. During that first running period, measurements were made with the goal of providing an initial measurement of two of the Michel parameters, as well as investigating systematic dependences and sensitivities to many different experimental variables. Further data were taken during the summer and fall of 2003, with improved understanding of the systematic requirements, a better stopping target, and other enhancements.

Following the collection of about six billion events during 2002, the simulation and various analysis codes, including the newly developed blind analysis code, were tested and validated in 2003. The availability of the WestGrid computing facility has enabled us to compare high statistics analyses of combinations of many experimental and Monte Carlo simulated data sets. Comparisons of the GEANT3-based Monte Carlo program currently in use with GEANT4 have begun in the year, and a more detailed study is continuing.

![Figure 7: Cutaway view of the TWIST spectrometer.](image)

We have also improved the functionality and reliability of the M13 beam line, established an improved beam tune, and extended the region of the spectrometer magnetic field map. As a result of the analysis of the 2002 data where the muon stopping target was 125-micron mylar, the target was changed to a 71-micron, 99.99% pure aluminium foil.

Ensuring a very high (approximately 100%) polarization of the muons which stop in the detector is vital to the measurement of one of the Michel parameters, $P_{\mu} \xi$. Most depolarization effects related to beam transport can be minimized by using a small momentum acceptance, beam divergence, and beam size. During 2003, these have been measured as a function of the beam line element settings (beam tune) using a movable slit and fast wire chambers, and a new tune has been established. For frequent monitoring of the beam size and divergence, a time expansion chamber (TEC) has been designed and constructed, and is being tested.
The stability and reproducibility of the beam line magnet power supplies were previously improved by installing precision direct current transformers. Plans were made for a further upgrade with installation of a new vacuum isolation valve at the first focus point of the beam line as well as a removable window valve to prevent radioactive residual gases from migrating from a graphite production target to the end of the M13 beam line and disrupting the TWIST detectors. The currently used beryllium production target can then be replaced by a graphite target to improve beam characteristics. The solenoid field has been mapped to the position of the last quadrupole of the beam line, so that the fringe field depolarization can be estimated precisely.

The software and analysis were improved to reduce granularity effects and otherwise improve particle tracking. In particular, code was developed to allow the software to account for the scattering of the positrons in the tracking chamber materials.

Several calibration procedures were refined. Calibration of the relative TDC times can now be done with both straight and helical tracks, and the accuracy of the energy calibration has been improved. The fitting of 120 MeV/c pion tracks in zero magnetic field has been complemented with the use of decay positron helices for determining translational and rotational alignments of chamber planes.

Many improvements to TWIST’s Monte Carlo simulation during 2003-2004 were made, including the incorporation of realistic ionization distribution in the chambers, and the implementation of translational and rotational (mis)alignments. The phase space of the M13 beams used in 2002 was characterized this year and included as input. The simulation was verified against real data using a variety of specialized data sets and shown to be sufficiently accurate for the first TWIST physics results. Additionally we have carried out a series of comparisons between the GEANT3 and GEANT4 detector simulation packages to explore differences which might affect our results.

Much of the development and testing of our analysis software has been accomplished using a local cluster of some 30 computers. In November 2003, TWIST became a beta-tester of the WestGrid computing cluster of over 1000 processors at UBC, and has been one of WestGrid's primary users ever since. WestGrid has allowed full scale simulation and data analysis. Submission scripts had to be revised significantly to conform with WestGrid disk storage architecture, while instabilities in the storage and queuing systems in 2003 added additional complications. Nevertheless, access to this powerful system permitted the generation and analysis of many Terabytes of simulation data, and the analysis of the 2002 and 2003 data sets. Twelve separate analyses were performed on a “standard” data set to study various analysis-dependent systematics.

To account for the effect of the detector response function on the measured decay spectrum, the Michel parameters are measured by comparing the measured spectrum against the Monte Carlo simulation with known values of the parameters. In 2003 a technique was designed and tested to do this comparison in a blind way, by hiding the parameter values used in the simulation. This technique can be used to fit experimental distributions, and to estimate biases and systematic effects, without revealing the final measurement of the Michel parameters until we are ready to publish.

TWIST’s development and analysis activities in 2003-2004 were in preparation for a publication of our first physics results, at the $10^3$ level, scheduled for fall 2004.
2.7 MOEDAL Experiment

B. Caron, J.L. Pinfold, J. Soukup, W.J. McDonald

The international MOEDAL (MOnopole and Exotic object Detector At the LHC) experiment is an experiment that has been proposed to run at the LHC at CERN. It is a collaboration of groups from the University of Alberta, Bologna University, CERN, the University of Cincinnati, the University of Montreal, and Northeastern University. This experiment is dedicated to the search for magnetic monopoles or Dyons and other highly ionizing exotic particles produced in the proton-proton collisions at the LHC. A Letter of Intent (LOI) to do this experiment has been submitted to the LHCC (LHC Committee) by the spokesman of the experiment (James Pinfold of the University of Alberta) and was accepted in 2002. However, before the experiment can be accepted we have to submit a Technical Design Report – we are in the process of doing this. Thus at the moment the experiment has not been approved but will soon be submitted for full approval. This experiment builds on a previous experiment (called MODAL) that was performed at CERN, searching for monopoles in high energy electron positron collisions at LEP. James Pinfold was also the spokesman for this international experiment. The experiment ran in 1990 and 1991. The new MOEDAL experiment, if approved, would start in 2007-2008.

The MOEDAL detector is unique in that it is formed from a plastic ball. This ball is essentially a photographic film that is only sensitive to highly ionizing particles like the magnetic monopole. The plastic used is a special form of a plastic generically called “CR39”. At regular intervals this special “photographic film” is taken away and developed. We are proposing to deploy the MOEDAL detector in the intersection region of another LHC experiment called LHCb – an experiment concentrating on the study of “beauty”, “bottom”, or “b” quarks. A diagram showing the placing of the MOEDAL detector is given in Figure 8.

![Figure 8: A cross-section through the LHCb detector and intersection region. The red ball shows the placing and rough size of the MOEDAL detector which surrounds the LHCb vertex (or intersection) point.](image)

MOEDAL is a David compared to the other LHC Goliaths such as ATLAS, CMS, and even the LHCb. Rather than costing a few to several hundred million dollars it is likely that MOEDAL will cost less than $50,000. A ratio of costs of the order of 50,000 to one! One of the many reasons for this is that MOEDAL concentrates on detecting particular phenomena, i.e. high
ionizing particles such as the magnetic monopole. However, the discovery of a magnetic monopole would probably have a much more profound effect on physics than the discovery of the Higgs particle.

Even though Maxwell’s equations formally allow the existence of magnetic monopoles, interest in these kinds of objects arose only in 1931 after the paper of P.A.M. Dirac, in which it was shown that magnetic charges can be introduced in the framework of quantum mechanics and that the product of the basic electric charge and of the basic magnetic charge is quantized. Such a particle is called a magnetic monopole if it carries only a magnetic charge, and a Dyon if it carries both magnetic and electric charges (a monopole bound with a nucleus behaves effectively as a Dyon). Dirac could not constrain the monopole mass; rough estimates indicated that the magnetic monopole mass should be larger than several GeV/c². Many types of searches for magnetic monopoles with masses not much larger than the proton mass were performed at each new accelerator and in bulk matter. Very many theoretical studies on magnetic monopoles have been published.

The other date of fundamental importance in the history of monopoles is 1974. In that year 't Hooft and Polyakov demonstrated that Grand Unified Theories (GUT) of the electroweak and strong interactions implied the existence of magnetic monopoles with masses of the order of $10^{17}$ GeV/c². In addition, other theories like “light gauge theories” of monopoles have been proposed, for example, string theory. Although it is assumed that GUT monopole masses are too large for monopoles to be produced at present or future high-energy accelerators or somewhere in the present universe, there are theories (again such as string theory) that could admit “gauge theory” monopoles with masses light enough to be discovered at the LHC, and higher energy future machines.

Monopoles could have been produced immediately after the big bang, either as topological defects or in very high energy collisions immediately after the phase transition at the end of the GUT epoch; thus GUT monopoles could be present in the cosmic radiation, since the lightest monopole should be stable, due to conservation of magnetic charge. From 1974 to the present time a very large number of theoretical studies were made on magnetic monopoles; also many experimental searches were performed. Experiments continue to be performed as new accelerators open up new energy frontiers.

It is extremely easy to accelerate monopoles in a magnetic field. For example, a 10 m magnet with a 10 Tesla magnetic field (like an LHC magnetic) would be able to accelerate a magnetic monopole to an energy of around 5 TeV. Thus it would take only two of these magnets, to accelerate monopoles to energies exceeding the beam energy of the LHC! One could imagine accelerators with energies in excess of the LHC in a large laboratory room. Monopoles have many other interesting and incredible properties.
3. Theory Reports

3.1 Andrzej Czarnecki

During this period my group completed a project we had been working on for the previous three years. Our objective had been to determine the influence of a previously unexplored class of quantum effects on the bound state energies and lifetimes of heavy quarks. Determination of such effects has been considered extremely difficult. They have been a source of uncertainty in theoretical predictions for various observables.

There were two main obstacles in this study. One was the very large number of contributions, which had to be expressed in terms of so-called master integrals. We attacked this problem from two directions. The major part of Ian Blokland’s thesis was to explore the structure of relations among various contributions. Ian succeeded in finding a solution of a large system of recurrence relations and implemented it in a computer algebra system that we had available at the Centre for Symbolic Computation within the CSR.

The other direction was a novel algorithm for which a dedicated, very fast system for algebraic manipulations has been developed. The availability of two independent approaches helped us complete both, because we were able to compare intermediate results and debug very complex computer codes.

After the reduction was completed, there remained the second challenge: the evaluation of several resulting “master” expressions, forming a basis in which all contributions can be described. Because of their singular nature, traditional numerical methods could not be employed. Instead, we took advantage of the recently discovered properties of harmonic polylogarithms. Using them, we were able to obtain exact analytic expressions and complete our solution.

We now have a powerful and sophisticated tool which we will employ to describe decay processes of quarks and spectra of their bound states, as well as corrections to energy levels of normal atoms. Our first results were published in Physical Review Letters: we presented there two results on decays of top and bottom quarks, and verified for the first time previously computed corrections to the muon and bottom quark lifetimes. Subsequently, we have derived a new class of corrections to radiative heavy quark decays.

3.2 Faqir Khanna

My research program is devoted to three different areas:

i) Since we have established that a covariant Galilean approach to non-relativistic problems is appropriate, an extensive study is undertaken to write the usual equations of fluids in a Lagrangian formulation. Then the question of being able to quantize such covariant Galilean theories is being undertaken. Almost all many body systems in nuclear physics and condensed matter physics fall in this category.

ii) Applications of finite temperature field theory to problems of nuclear reactions, formation of quark-gluon plasma, and Casimir effect are undertaken. These aspects can be studied within thermo-field dynamics. The question of quark-gluon plasma with its phase transition is studied within a Schrödinger approach.
iii) Some problems in the foundations of quantum mechanics are considered. In particular the optimization of Bell’s inequality for continuous variable systems is studied. Other similar problems with implications for quantum computing are also being considered.

3.3 Helmy Sherif

The main thrust of the research program is the study of reactions induced in nuclei by electromagnetic and weak probes.

We have developed an approach to reactions based on a relativistic description of nuclear dynamics. In these studies the nucleus is regarded as a relativistic system in the spirit of the Walecka relativistic mean field theory (Quantum Hadrodynamics or QHD). We investigate reactions induced by photons and electrons in the intermediate energy range, with atomic nuclei.

Our recent work on meson photoproduction has been concerned with the photoproduction of $\eta$ mesons on nuclei, with particular emphasis on the second resonance region of the nucleon. We have just completed an important improvement of the reaction model by including non-local effects, which allows us to take into account the interaction of the propagating nucleon resonance with the nuclear medium. This has been done for both the quasifree and the incoherent photoproduction processes. The effects of possible medium modifications of the N*(1535) properties on the production cross-sections have been studied in detail.
4. Lake Louise Winter Institute, 15-21 February 2004

The Winter Institute was focussed on some of the most interesting problems in Fundamental Physics. Status of Neutrino physics was critically analysed by D. Warke. Outcome of physics from B-factories was brought clearly by H. Quinn. Problems in Nuclear astrophysics were clearly brought out by C. Brune. The outstanding results from RHIC were summarized by J. Nagle. The status of the experimental observation of Gravity waves was clearly laid out by P. Brady. These pedagogical talks were supplemented by contributed talks from almost all the experiments in particle physics. There were theoretical contributions on problems of topical interest.

The Winter Institute was supported by the Institute of Particle Physics, TRIUMF, University of Alberta Conference fund and by the Dean of Science, University of Alberta. The University of Alberta Physics Department provided all the infrastructure support. The organizing committee thanks all of them for their support of the Winter Institute. The details of the Institute set-up and liaison with the Chateau Lake Louise was ably handled by Lee Grimard. The conference proceedings are prepared by the hard work and devotion of Suzette Chan.
5. Role of TRIUMF in the Centre for Subatomic Research

TRIUMF is Canada’s National Laboratory for Particle and Nuclear Physics, located on the campus of the University of British Columbia. TRIUMF was established in 1968 as a laboratory operated by the University of Alberta, the University of British Columbia, Simon Fraser University, and the University of Victoria under a contribution agreement from the National Research Council of Canada. The CSR has played an essential role in the development of TRIUMF from the beginning.

The CSR currently has a number of joint staff positions with TRIUMF. The TRIUMF Director, A.C. Shotter, is a Professor of Physics at the University of Alberta. Professors D.M. Gingrich, L.G. Greeniaus, and F.C. Khanna hold, or held, shared University of Alberta and TRIUMF positions. TRIUMF currently supports five research scientist positions: B. Caron and G.M. Stinson resident at the CSR, and W. Faszer, D.A. Hutcheon and C.A. Miller resident at TRIUMF. In addition, TRIUMF supports electronic technician J. Schaapman and office assistant V. Kuhn at the CSR. The CSR Major Facilities Access Grant from NSERC supports electronics technician G.H. Coombes at TRIUMF.

Many TRIUMF research staff collaborate on experiments with members of the CSR. In addition to the projects mentioned in this report, CSR staff are participating in experiments using the ISAC facility at TRIUMF. These include A.C. Shotter working on the TRIUMF UK Detector Array (TUDA) and D.A. Hutcheon on the TRIUMF Detector Recoils and Gammas of Nuclear Reactions (DRAGON) experiment. C.A. Miller works on the HERMES experiment at the DESY laboratory in Hamburg, Germany.
6. Facilities and Technical Developments

6.1 Computing Facilities and Developments

6.1.1 General Research Computing

The computing environment within the CSR consists primarily of Linux workstations and servers, along with several Windows 2000 and XP based systems. Several Linux servers provide services including World Wide Web publishing, remote SSH login access, collaborative tools, and Network File System (NFS) support to systems within the CSR.

The principle amount of research computing performed in the CSR utilizes the THOR Linux Computing Facility. The THOR Linux system is a cluster of ten servers and nearly 70 dual-processor worker nodes interconnected by a fast (100 Mbps) and Gigabit (1000 Mbps) Ethernet network. All systems are 32-bit processors either from Intel or AMD. Included within the THOR Linux cluster are a series of 25 dual Intel Pentium III 1.44 GHz systems from Dell interfaced by low latency interconnect (SCI) for parallel applications and codes in particle physics. The Dell hardware was acquired for the Centre for Symbolic Computation and is managed by the CSR as part of the THOR Computing Facility.

In spring 2004 the CSR received a NSERC Research Tools and Instruments (RTI) Category 1 grant. The RTI grant aided in the purchase of a new multi-Terabyte file server and attached tape storage system for the CSR. The server provides 4 TB of disk capacity on a dual AMD Opteron 64-bit Linux system configured with 3ware Serial-ATA RAID controllers. The tape library system is a Dell PowerVault 136T with one LTO-2 drive (expandable to 6 drives) and 32 tapes (expandable to 62 tapes) yielding a total storage capacity in excess of 12 Terabytes.

Figure 9: THOR computing facility.
Figure 9 shows a schematic of the THOR Computing Facility in the CSR and the associated network connections both internal to the cluster for access to storage and compute nodes, as well as external network connections to the University campus and beyond to outside institutes such as TRIUMF and CERN. The external Gigabit links from the THOR Cluster via dedicated optical fibres bypass the standard campus network which limits the rate of data transfer possible between the CSR and collaborating institutes.

6.1.2 ATLAS Computing

The ATLAS experiment embarked on a series of Data Challenges in the previous year, commencing with Data Challenge (DC) 1, with the aim of testing the ATLAS computing model as well as to generate simulated events needed for the production of the High Level Trigger (HLT) Technical Design Report. Subsequently the CSR has been designated as one of eight principal sites (along with CERN, BNL, RAL, CNAF, Karlseruhe, Lyon, and NorduGrid) designated to maintain the availability of DC1 Monte Carlo data for the entire ATLAS collaboration. In total approximately 4 Terabytes of DC1 data is locally stored on disk at the CSR and accessible using Grid based tools. These datasets have been analyzed by several HLT developers including those at the University of Alberta.

Following the completion of DC1, preparations began for the next round of challenges, DC2, which aimed to expand the scope of the activities beyond DC1 as well as to employ the various computing and data grids (LCG, Grid3, and NorduGrid, for example). These preparations were undertaken by ATLAS Canada along with members of the ATLAS group at the University of Alberta. DC2 was scheduled to commence during summer of 2004.

To support the involvement in DC2, the Alberta group established a direct interface of the THOR Linux Cluster to the LHC Computing Grid (LCG). This required the setup of three Linux servers (Compute Element, Storage Element, and User Interface) that joined the LCG along with several worker nodes from the cluster. This Grid interface was in addition to the existing Grid activities at the CSR involving the Grid Canada Production Testbed.

Finally, in June and July of 2004 the Alberta ATLAS group began preparations for the combined test beam at CERN. This test beam would include a prototype Event Filter farm system for the HLT. As part of these preparations the group evaluated Linux server platforms from an Edmonton based vendor for their suitability within the event filter farm at the test beam.

6.1.3 CDF and DØ Computing

In 2003-2004 the THOR Linux cluster was used as part of the central Monte Carlo production effort for the CDF experiment at Fermilab. During this period approximately 16 million events were simulated on the Alberta Linux farm and subsequently transported back to Fermilab using the high-speed bbftp protocol across the CA*net 4 network. This represented the second largest sample of Monte Carlo generated by any CDF institute.

The CDF and DØ groups at the CSR regularly participate in remote meetings with collaborators at Fermilab and elsewhere either by telephone or video-conference. In spring 2004 the CDF and DØ groups jointly purchased equipment to upgrade the video-conferencing capabilities within the CSR. This purchase included a high-end PC system running Linux and Windows XP and equipped with video capture card, a controllable SONY video camera along
with a television and DLP projector for image display. Although purchased by CDF and DØ the equipment is made available to all CSR members and is located in the CSR Board Room.

6.1.4 Grid Computing

During 2003-2004 the CSR continued its involvement in advanced computing by helping to establish the Grid Canada Production Testbed (later to become known as GridX1). The Production Testbed provided a set of Grid services based upon the Globus Toolkit that enabled the submission of jobs to the computing facilities at the three sites through a single interface. The Production Testbed also utilized a distributed file catalogue system (Globus RLS) for the location and management of data storage across the sites. The Grid Canada Production Testbed was able to successfully complete ATLAS simulation jobs as previously executed as part of DC1, and lay the foundation for future Grid developments by HEP in Canada.

6.1.5 Advanced Networks for High Energy Physics

The demands of high energy physics in terms of data acquisition, distribution, and analysis have continued to be one of the driving forces behind the development of advanced communications networks.

One such advancement being utilized in particle physics is the development of end-to-end LightPaths by CANARIE, Canada’s Advanced Internet organization. In summer and fall of 2003 the ATLAS experiment deployed LightPaths on several occasions between CERN and the CSR at the University of Alberta with the aim of evaluating and testing the network for its suitability for long-haul connectivity and real-time data transfer and processing within ATLAS.

Figure 10 shows a schematic of the network and GPS equipment interconnected between the CSR and CERN to establish the end-to-end LightPath. The LightPath enables the end-hosts to appear on the same physical Local Area Network (LAN) but distributed over several thousands of kilometres. The LightPath further provides a guaranteed amount of bandwidth and quality of service. The tests between CERN and the CSR were able to utilize 940 Mbps of the 1 Gigabit link with zero packet loss.

![Figure 10: Equipment between the CSR and CERN used to establish the end-to-end light path.](image)
These and other tests were carried out as part of the International Grid Testbed (IGT) which was established in 2003 and included several Canadian HEP groups including the Universities of Alberta, Victoria, Carleton, Toronto, and McGill, as well as TRIUMF, CERN, the Netera Alliance, CANARIE and SURFnet. The IGT was also able to demonstrate the first ever Trans-Atlantic 10 Gigabit Ethernet connection as part of the ITU Telecom 2003 event.

6.1.6 Centre for Symbolic Computation

The Centre for Symbolic Computation is a laboratory devoted to developing computer algebra software and to applying it in various branches of mathematics, natural sciences, and engineering. It supports research in areas such as quantum field theory, subatomic physics, condensed matter physics, computational fluid dynamics, and chemical engineering.

The hardware of the Centre for Symbolic Computation consists now of two groups of computers: a 52-processor Pentium cluster, and a 10-processor Opteron cluster. Access to both is provided by a number of user workstations. The Opteron cluster is the latest addition and provides us with presently the fastest workstations for symbolic computations. These computers are equipped with very large memory and enable us to use a new class of algorithms.

Those algorithms are implemented in three types of software: FORM and Bear were donated to us by foreign researchers, while Misiu has been developed within the Centre. Development of software for symbolic computation is now an important direction of the Centre.

During the last year the focus has been on solving very large systems of linear equations. The first algorithm has been successfully implemented and enabled us to determine a new class of quantum effects in heavy quark decays.

6.2 X-ray Accelerator

The x-ray accelerator facility in the CSR has been in operation since September 1998 (see Figure 11). The total time of operating in 2003-2004 was the longest to date. X-rays were used by three different projects to study the tolerance of CMOS electronics to ionizing radiation.

The preproduction version of the ATLAS switched-capacitor array controller (SCAC) was irradiated to simulate the ATLAS environment for 10 years plus safety margins. Ten samples were irradiated beyond the ATLAS radiation tolerance criterion level. This qualified the SCAC for total ionizing dose. Each part was exposed to radiation each day for a period of 1.5 hours. Currents were monitored and showed the novel decrease with radiation that was first observed for the device a few years earlier. The results formed part of the data for a publication.

A second project irradiated transistors using an enclosed-gate layout which were fabricated with the assistance of the Canadian Microelectronics Corporation. Increasing radiation periods were used to obtain radiation levels up to 70 kGy (SiO₂) (7 Mrad). These high levels of radiation were needed to see effects in the transistor parameters. At one point the machine ran three days continuously; the longest to date. The radiation tolerance of these devices formed part of the data set for the thesis of Li Chen. The results show that it is possible to fabricate extremely radiation tolerant electronics in an advanced CMOS technology using commercial resources within a Canadian university. The results are interesting to the ATLAS experiment, particularly in the context of future electronics upgrades, and the space and military sectors.
In summer of 2003, we finalized the program for estimating the total ionizing dose absorbed by a device under test. The procedure includes recording ion-chamber rates with and without the device under test. A computer program calculates the dose, and all the systematic and statistical errors based on ion-chamber counts.

In 2004 a project student (Matt Larocque) developed a technique to measure the dose using photodiodes. The diodes have been calibrated against the ion chamber and provide an alternative measurement of the dose from the x-ray accelerator.

6.3 Mechanical Facilities and Developments

6.3.1 LUCID Design Development

The first iteration in the design of the LUCID detector was accomplished during early summer of 2003. The preliminary design concept was created in the format of the ProEngineer CAD software, which became available through cooperation with the Mechanical Engineering Department. Prof. Roger Toogod also provided generous consultation in the use of the software.

The first preliminary design took into consideration the physics of the Cherenkov detector, the available space for its placement within the engineering complexes of the beamline and the shielding in the two symmetrical end-regions of the ATLAS detector assembly, as well as the concerns of the high energy-high intensity radiation flux in the location of the detector.

The first concept was based on an array of 1.5 m long graphite/epoxy composite tubes arranged in a densely packed array of four concentric layers within the available space around the beampipe within the beampipe-support cone. The light composite material tubes were augmented with reflective aluminium foil liner to guide the Cherenkov light to the downstream ends. These were then fitted with internally reflective hollow Winston cones, which were used to focus the light into the front of a fused and polished bundle tip of quartz optical fibres.
The beamline support cone was mounted off the front face of the TX1S shielding nose-piece, through which the bundles of the optical fibres were to be channelled via assigned service grooves to a multi-channel photomultiplier interface – safely remote from the intense radiation flux. From this point on, they would proceed as electronic pulses.

The working medium in the generation of Cherenkov light was to be heavy organic compound gas, which was to fill the volume of each tube and cone in an overall shared volume of a LUCID detector vessel. The latter would envelop the beampipe with its hollow core and the outer conical surface of the vessel would then fit inside the beamline support cone. The gas-fill and exhaust-pipes would then be channelled through the same routing as the signal bundles, with a gas-handling plant located outside the ATLAS radiation area.

The exercise of the preliminary design was to facilitate an open discussion of the practical engineering terms of the LUCID detector with the CERN engineers and, together with the physical testing of the light collection features of the graphite/epoxy tubes, thus helped crystallize the main concerns and further details for its next iteration of development.

The first wave of discussions of the LUCID design at CERN suggested a strong desire to use only low atomic number materials in its construction. Carbon fibre/epoxy composite emerged as an obvious possible material of choice for the Cherenkov tubes. With a prior satisfactory experience, we turned to Sky-Pole Inc. of Costa Mesa, California with the request for manufacturing some initial tube prototypes. The friendly cooperation with Sky-Pole stretched over a two-year period during which carbon fibre tube prototypes evolved from short length sections to the full 1.5 m tubes of 19.05 mm inside diameter lined with aluminium foil. The short prototypes were assessed in testing for reflectivity of light in a setup with a light-emitting diode and a photomultiplier tube in a light-tight dark-box. The LED was mounted on a pivoting arm to allow for studying of different incident angles of the light beam on the tube liner surface. The short samples also served as prototypes to test various types of the aluminium foil for the tube liner, both for reflectivity, wrinkling and blistering. As the LUCID components are required to withstand the beamline-baking temperature of up to 400°C, we tested the composite tubes in an oven under vacuum. The initial prototypes – made with standard epoxy resin – were heated to the maximum temperature of only 270°C, which is available in our oven. At this temperature, many of the samples formed blisters on the internal foil liner. After eventual removal of any
other types of possible problems with the composite tubes, the final product was to be made with high-temperature epoxy resin matrix, which would be much more expensive and more challenging in the manufacturing process.

In parallel with the development and testing of the tubes, work progressed on prototypes of Winston cones, which were to be fitted on the tube ends to concentrate the generated light. John McDonald provided numerical calculation results for the shape parameters of a polished aluminium cone standard, which could be scaled to different tube diameters. Paul Zimmermann of the Physics Machine Shop developed a set of shaped reamer-like tools that were used to hone the final internal shape of the cones after an initial roughing on a lathe.

Six full-length (1.5 m) x 19.05 mm internal diameter x 0.5 mm wall thickness carbon fibre tubes with a liner of heavy-duty kitchen-grade aluminium foil were used in the construction of a test subset of LUCID to be tested with cosmic rays. The Cherenkov light, generated by the cosmic rays in an Isobutane gas fill of the tubes was concentrated by six Winston cones onto a common flat acrylic adaptor (“cookie”) on a single 5” photomultiplier tube. The “cookie” also served as a “cork” to seal gas enclosure with an O-ring around it. The photomultiplier header was adapted to have a positive high voltage on the anode in order to allow a ground potential on the outside structure parts, which could not be otherwise insulated. All parts of the test setup were made with recycled parts and material from the laboratory stock. A simple gas-handling system was also built to manage the gas filling and flushing of the system. The setup was mounted on a wall in a system, which allowed tilting the assembly to study the effect of incident particle alignment.

The next phase in the development of LUCID design commenced with the refined proposal for its tube layer pattern.

![Mock-up of the shielding in the region of LUCID.](image)

As part of the LUCID detector development, it was decided to build a full-scale mock-up of the TX1S shielding “nose-piece”, together with a mock-up of the beampipe, beampipe-support cone and LUCID detector itself. The plywood and acrylic model of the setup was to facilitate
visualization as well as physical trying of the various schemes and corresponding logistics in the routing of the optical fibre bundles and other LUCID services through the available spaces.

### 6.3.2 MOEDAL Detector

MOEDAL is a parasitic detector, which analyzes proton-antiproton collision fragments after they have emerged from the VELO detector, which it envelops at the LHCb vertex of the LHC at CERN. MOEDAL, which consists of radiation-sensitive plastic film facets, must be capable of coming out of the way quickly, whenever access is required to the VELO system. It is therefore desirable for its structure to be very light and possess some mode of collapsibility. Furthermore, the structure should allow for breaking up of the total area of the detecting film into smaller-size facets, manageable in the track-evaluation process under microscope. Ideally, the facets should be oriented perpendicularly to the rays originating in the beam intersection point.

![Figure 14: A schematic view of how the plastic ball can be opened to allow access to the LHCb vertex region.](image)

Based on these kinds of considerations, the proposed design emerged as a geodesic globe structure consisting of light, yet structurally rigid aluminium triangle frame elements, which each hold a telescope of three sensitive film layers spaced from each other within its depth to allow efficient removal of background through correct directional tracking requirement. There are two kinds of triangular elements, those that either form pentagonal or hexagonal configurations alternating throughout the geodesic globe structure pattern. Any one of these triangles or their group can be independently removed from the globe structure to make room for cooling air convection flow from VELO, or to accommodate the protrusions of the VELO structure. Obviously, the whole bottom part of the geodesic globe is left out where it is obstructed by the VELO support pedestal.

The initial proposal in 2003 for moving MOEDAL out of the way for access to VELO was for opening the structure into two hinged halves gull-wing style against the ceiling.

### 6.3.3 Studies of Heat Transfer in the HEC-FCAL Interface Region

A series of finite element analysis (FEA) simulations was performed during the period of 2003-2004 to study the concerns of the safe dissipation of the heat, generated in the FCAL detector in the HEC mass through the interleaving layer of liquid argon without boiling of the
liquid phase. The software used in the simulations was ANSYS Multiphysics University Advanced release. The physics subset of the software applied in these problems was FLOTRAN.

The first simulation analyzed was a study for a possible inclusion of a kapton foil “Junk Catcher”, which was proposed to stop particulate debris that could be washing out of the FCAL structure and precipitating down into the gaps of the HEC calorimeter. The concern was that this could cause high-voltage shorts. The results of the FEA analysis showed that the flow obstruction, represented by the “Junk Catcher” foil, in the convective circulation of liquid argon would cause much more serious problems in the form of formation of hot spots on the FCAL surface, which would boil liquid argon. The “Junk Catcher” proposal had to be consequently abandoned.

6.4 Electronic Facilities and Developments

6.4.1 The ALTA Design

Each ALTA site consists of three weatherproof insulated enclosures mounted on a building roof with a detector at each of the vertices of an equilateral triangle, with approximately 10 m sides. On or near these enclosures is a GPS antenna mounted on a length of conduit to raise it above any structures on the roof. Each enclosure houses a temperature controller connected to a length of heater tape and a light-tight box which contains a sheet of scintillator (1cm × 60cm × 60cm) read out by a light guide and photomultiplier tube (PMT). Cables from each enclosure run through grounded metal conduit to custom electronics housed in a Eurocrate and read out by a computer (Figure 16).

An incoming shower of large enough extent (i.e. greater than about $10^{14}$ eV) will cause a local coincidence between the three detectors. Comparing the local timing of the three detector hits allows the direction of the incoming shower to be measured. Each local coincidence is stamped with the GPS time and the whole event is written to the data acquisition computer. The data from each detector station is uploaded every two hours to a central site. Using the GPS times a search is made for coincident events at different locations or bursts of events at one or more sites.
Although by involving schools ALTA has an outreach component, it is primarily designed as a physics experiment and so all of its components are required to maintain the level of quality and accuracy expected in any subatomic physics experiment. The detectors, readout electronics and data acquisition software were all designed and constructed by the electronics shop at the Centre for Subatomic Research. The heart of each ALTA detector system is the readout electronics which is based on a modular, crate mounted design which consists of seven circuit boards housed in a 6U Eurocrate, as shown in Figure 17.

A common design element of the ALTA boards is the use of a field programmable gate array (FPGA) to do most of the data handling and storage. All boards accumulate data in a first-in, first-out (FIFO) memory located in their FPGA. The GPS one second pulse is used to generate an interrupt in the DAQ computer which then reads out all of the data collected in the crate once per second.

The coincidence, analog, calibration, temperature, and high voltage control boards all have functions that use computer controlled numerical values. These values are set using digital to analog converters (DAC) then the output of the DAC is sampled by an analog to digital converter (ADC) and echoed back to the computer. In this way when you set a value you immediately have confirmation that the correct value has been received and set by that particular board.

The outputs from the three photomultiplier tubes enter the coincidence module which makes the trigger decision on whether or not a ‘good’ event has occurred. An important measurement
for ALTA is the local time difference between the three detectors which is used to determine the incoming direction of the cosmic ray air shower. The input PMT pulse is amplified by a factor of two then split into two channels, one which goes to the analog board the other into discriminators on the coincidence board. Constant fraction discriminators were chosen because they yield a more consistent timing measurement than conventional discriminators which are much more sensitive to rise time and pulse height variations.

The discriminator outputs are each split into two channels. One is delayed by 100 ns while the other goes to a coincidence network which makes the trigger decision. The coincidence network can be set in software to require that only one, any two, or all three of the discriminators be simultaneously fired. The individual channels can be ‘disabled’ which sets them as always true for purposes of the coincidence logic. In most cases the coincidence level is set to three so that all three PMT’s need to have produced pulses above threshold within a window of approximately 90 ns. The output of the coincidence network is fanned out three times to amplitude converters (TACs) on the coincidence board where it provides the start time. It is also sent by the back plane to the analog board, where it triggers the PMT pulse area measurement, as well as through a front panel output to the time-tag board, where it is used to define the global event time. The stop time to the three TACs comes from the 100 ns delayed discriminator outputs and the resulting local time between the different PMT hits is read by a 12-bit ADC and stored in the FPGA memory.

The analog board receives the trigger decision from the coincidence board and the amplified PMT signals, via the crate backplane. One of the central features of the analog board is a pair of chips designed for the Sudbury Neutrino Observatory (SNO). The trigger drives the SNO discriminator chip which is used to control gates on the SNO integrator chip. The SNO chips support four channels of inputs and two different possible gains for each input. The PMT signals are delayed 125 ns, put through a 400 ns shaping amplifier then enter the SNO integrator which integrates the pulse area over 600 ns. As with the coincidence board, the results of the integrator are read out with a 12-bit ADC and stored in the local FPGA.

The coincidence board records the local timing of the three scintillation detectors relative to each other, the time-tag (TTAG) board records the global timing of one site relative to another. The first ALTA TTAG boards were computer mounted ISA boards based on a design from Leeds but they have since been redesigned to be consistent with the rest of the ALTA electronics. The TTAG board receives front panel inputs from the GPS receiver and the coincidence board. It tags each good event with a number representing where in the interval between two GPS second ticks the event occurred and generates the interrupt which causes the DAQ computer to read out the data stored in memory on the various boards. The heart of the TTAG board is a 100 MHz temperature compensated oscillator connected to a 30-bit counter. The oscillator frequency drifts by a few Hertz a month but some temperature dependent effects have been seen so using GPS data the frequency of the oscillator is recalculated every 15 minutes to ensure the most accurate result possible. The free running counter is incremented on every 10 ns clock cycle. The value of this counter is recorded at the instant that either the GPS one second pulse (ALATCH) or coincidence trigger pulse (BLATCH) arrives. The difference of the ALATCH and BLATCH counter values allows the timing of the coincidence trigger, relative to the GPS second tick, to be determined to within 10 ns.

The calibration module has three computer controlled outputs which drive the LEDs mounted in the scintillators. This board has the largest number of user controls. How often the
LEDs are pulsed can be set from once per second to once per several hundred seconds, or they can be turned off completely. They can be synchronized to the GPS second, so that the LEDs are always flashed at the same time relative to when the GPS one second pulse arrives, or allowed to fire randomly during the GPS second. All three LEDs are driven with the same amplitude pulse set with a software controlled range of 0–3.5 V. Pulse duration is 15 ns, but each of the three LEDs has an independent user controlled delay of 0-100 ns. The calibration board can be used to simulate both the energy and time offsets of real cosmic hits and is normally set to fire once per minute synchronized to the GPS pulse to allow monitoring of both detector gain and timing performance of the coincidence and TTAG modules. The calibration board is very useful for trouble-shooting systems and it can also be used to generate controlled data runs for testing offline analysis code.

The temperature board reads in one temperature sensor from the backplane and three from its front panel. The front panel inputs are from temperature sensors in the three detector enclosures, the backplane input is from a sensor in the crate which monitors crate temperature. The sensors are Dallas Semiconductor DS1631 digital thermometer/thermostats which also act at temperature controllers and, once initially set up via the temperature board, will regulate the temperature even if the rest of the electronics are disconnected. The temperature controller turns on heat tape in each enclosure if the temperature falls below freezing. The unit mounted in the crate is used just as a temperature sensor.

The PMT high voltage supplies are Spellman model MS2.5N12/C DC to DC converters which output -2500–0 V with 3 W of power. The high voltage control board uses a 12-bit digital to analog converter to independently set the high voltage values to an accuracy of 1 volt. In addition to the normal echoing back of the output of the DACs a voltage divider circuit is used to measure the actual output voltage of each high voltage supply. These HV values are recorded with each event.

The crate controller allows interaction between the crate and the DAQ computer via a 16-bit parallel cable. The original crate controller connected to a custom made ISA board located in the DAQ computer. Because the ISA bus standard is now obsolete and becoming difficult to find, the new version of the crate controller is designed to connect to a standard off the shelf PCI parallel card. A crate controller which connects directly to a standard USB port is under development.

The custom ALTA software written at the CSR controls the programming and readout of the electronics, assembles the data read from the crate and combines it with additional information from the GPS receiver then writes it to disk. It also provides sockets so that the DAQ program can be started, stopped, or controlled from a remote computer so that all of the detector sites can be centrally monitored and controlled. For example, if students at a school perform some of their own experiments and do not return the electronics to the normal default setting for that school, the mistake will be detected and corrected automatically by the main data collection server at the CSR. The software provides a graphical user interface which in addition to allowing control of the board settings also creates and displays graphs of the data being collected and provides interactive tools to perform simple statistical analysis of the results. Many student projects and most testing and trouble shooting can be done simply using the ALTA DAQ software without having to analyze the raw data.
6.4.2 Trigger Electronics for STACEE

Using information gained from a prototype trigger system developed for STACEE and practical experience in the field at Sandia, a new trigger system was designed at the CSR. This redesign also allowed us to use new field programmable gate array (FPGA) technology. The coincidence and trigger boards were redesigned to use the Virtex-II from Xilinx. This allowed the clock speed to be doubled and thus the number of parallel channels on the board to be reduced from eight to four; a reduction in circuit size of almost one half. Great care was taken in the design of the clock distribution on the printed circuit board. Modeling of the parasitic capacitance allowed the board to be simulated for timing, a first in the CSR. In addition, a ball-grid array (BGA) package for the FPGA was chosen. These packages were soldered on the printed circuit boards by a local Edmonton company with good results. This use of BGA packed chips was also a first for the CSR.

A single-board trigger system was tested in the field in 2003. A four board system (1/2 entire system) was tested in the CSR. In addition, a simulation model was developed in C++ to predict the trigger rates and efficiencies as a function of the coincidence window width.

6.4.3 The Effects of Ionizing Radiation on IDDQ Testing

A project to study the effects of ionizing radiation on IDDQ testing in collaboration with Professor Xiaoling Sun in the Department of Electrical and Computer Engineering is in progress. IDDQ testing is a method used by the electronics industry to sort newly fabricated digital parts into functional and non-functional categories. As CMOS technologies scale down in size the ability of IDDQ testing to distinguish functional from non-functional parts is reduced. This project is attempting to determine if irradiating devices for a short time will increase the sensitivity of IDDQ testing.

A test chip was designed and submitted to the Canadian Microelectronics Corporation (CMC) by student Kaston Leung. The chips have been received back from fabrication and packing, and are now being set up for testing.

6.4.4 GPIB to USB Interface

A small project to develop a GPIB to USB interface card was started. GPIB is a common interface protocol used to control and readout electronic instruments such as oscilloscopes, power supplies, analyzers, etc. To use this interface requires a dedicated GPIB/PCI interface card to be used in a desktop PC. This eliminates the possibility of using portable computers such as a laptop to control and readout electronics instruments. This is a severe restriction to field work where the transportation and operation of an entire desktop PC is impractical.

Our aim is to develop a small external interface card that can use the USB port found on all modern computers – including laptops – to interface to the GPIB interface protocol. The system is based on a microcontroller, FPGA, and software running under the common Linux operating system.

The availability of this interface card will improve our ability to perform field work such as radiation testing at remote facilities. The project also has possible commercial interest.
6.4.5 Computer Automated Electronic Designs

During the year circuits for several FPGAs from both Xilinx and Altera were developed. We are now using the Quartus II software from Altera and Xilinx ISE Foundation software from Xilinx.

The powerful graphical development environment for signal acquisition, measurement analysis, and data presentation, LabVIEW is now being used in the CSR.

This year two 0.18-micron CMOS designs were submitted to the Canadian Microelectronic Corporation (CMC) for fabrication. One chip contained enclosed-gate transistor for studying the effects of radiation on transistor noise, and the second was a test chip to study the effects of ionizing radiation on IDDQ testing.
Appendices

A. Centre for Subatomic Research Personnel, 2003-2004

A.1 Teaching and Research Staff

<table>
<thead>
<tr>
<th>Name</th>
<th>Position/Role</th>
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<tbody>
<tr>
<td>Campbell, Bruce</td>
<td>Professor of Physics</td>
</tr>
<tr>
<td>Caron, Bryan</td>
<td>TRIUMF Sr. Research Scientist</td>
</tr>
<tr>
<td>Czarnecki, Andrzej</td>
<td>Professor of Physics</td>
</tr>
<tr>
<td>de Montigny, Marc</td>
<td>Adjunct Professor (Faculté Saint-Jean, University of Alberta)</td>
</tr>
<tr>
<td>Faszer, Wayne*</td>
<td>TRIUMF Sr. Research Scientist</td>
</tr>
<tr>
<td>Gingrich, Douglas</td>
<td>Professor of Physics/TRIUMF</td>
</tr>
<tr>
<td>Greeniaus, Gordon</td>
<td>Professor Emeritus/TRIUMF</td>
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<tr>
<td>Hutcheon, Dave*</td>
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<tr>
<td>Khanna, Faqir</td>
<td>Professor Emeritus/TRIUMF</td>
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<tr>
<td>Kitching, Peter*</td>
<td>Professor Emeritus</td>
</tr>
<tr>
<td>McDonald, John</td>
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<tr>
<td>Miller, Andy*</td>
<td>TRIUMF Sr. Research Scientist</td>
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<tr>
<td>Moore, Roger</td>
<td>Assistant Professor</td>
</tr>
<tr>
<td>Pinfofold, James</td>
<td>Professor of Physics; Director of CSR</td>
</tr>
<tr>
<td>Roy, Gerry</td>
<td>Professor Emeritus</td>
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<tr>
<td>Sherif, Helmy</td>
<td>Professor of Physics</td>
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<tr>
<td>Shotter, Alan*</td>
<td>Professor of Physics; Director of TRIUMF</td>
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<tr>
<td>Stinson, Glen</td>
<td>TRIUMF Sr. Research Technician</td>
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<tr>
<td>Soukup, Jan</td>
<td>Systems Analyst (Physicist/Engineer)</td>
</tr>
<tr>
<td>Vincter, Manuella</td>
<td>Associate Professor</td>
</tr>
</tbody>
</table>

* Located at TRIUMF
A.2 Postdoctoral Fellows and Research Associates

De Nardo, Lara  Research Associate
Ginges, Jacinda  Postdoctoral Fellow
Liu, Shengli  Research Associate
Quraan, Maher*  Research Associate
Slusarczyk, Maciej  Postdoctoral Fellow
Soluk, Richard  Research Associate
Wheeler, Sarah**  Research Associate
Yelkhovsky, Alexander  Postdoctoral Fellow

* Located at TRIUMF  ** Located at CERN

A.3 Technical and Office Staff

Burris, Bill  Technician (Electronics)
Chan, Suzette  Executive Secretary
Coombes, Herb*  Senior Research Technician (Electronics)
Holm, Lars  Chief Technician Electronics Shop
Kuhn, Viola  Office Assistant
Lachat, Gilbert  Chief Technician Machine Shop
MacKinnon, Jim  Systems Analyst
Paget, Tony  Technician (Mechanical)
Price, Drew  Technologist (Electronics)
Schaapman, Jan  Technician (Electronics)
Tomasevic, Boris  Technician (Mechanical)
Wampler, Len  Technician (Electronics)
Wong, Pat  Technician (Electronics)
Zimmermann, Paul  Technician (Mechanical)

* Located at TRIUMF
### A.4 Graduate Students

<table>
<thead>
<tr>
<th>Student</th>
<th>Supervisor</th>
<th>Degree</th>
<th>Project</th>
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<tr>
<td>Archambault, John Paul</td>
<td>A. Czarnecki</td>
<td>MSc</td>
<td>Theory</td>
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<td></td>
<td>M.G. Vincter</td>
<td>PhD</td>
<td>ATLAS</td>
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<tr>
<td>Blokland, Ian</td>
<td>A. Czarnecki</td>
<td>PhD</td>
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<td>Buczek, Pawel</td>
<td>A. Czarnecki</td>
<td>PhD</td>
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<td>Caron, Bryan</td>
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<tr>
<td>Chen, Li</td>
<td>D.M. Gingrich</td>
<td>PhD</td>
<td>Electrical &amp; Computer Engineering</td>
</tr>
<tr>
<td>Cojocaru, Claudiu</td>
<td>M.G. Vincter</td>
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<td>ATLAS</td>
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<td>de Jong, Jeff</td>
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<td>Dowler, Blaine</td>
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<td>Gaponenko, Andrei*</td>
<td>A. Czarnecki</td>
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<td>Hamilton, Andrew**</td>
<td>J.L. Pinfold</td>
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<td>ATLAS/CDF</td>
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<tr>
<td>Leung, Kaston</td>
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<td>Electrical &amp; Computer Engineering</td>
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<td>MacDonald, Rob</td>
<td>M.G. Vincter</td>
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<td>Maybury, David</td>
<td>B.A. Campbell</td>
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<td>Pak, Alexey</td>
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<td>Wakeford, Daniel</td>
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<td>Yao, Yushu</td>
<td>J.L. Pinfold</td>
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*Located at TRIUMF  **Located at Fermilab
A.5 Summer Students

<table>
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<tbody>
<tr>
<td>Braden, Jonathan</td>
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<tr>
<td>Forde, Jason</td>
<td>MOEDAL</td>
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<td>Gish, Doug</td>
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<td>Martin, Travis</td>
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<td>Sibley, Logan</td>
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<td>Swedish, Stephen</td>
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B. List of Collaborating Institutes

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<tr>
<td>Brookhaven National Laboratory</td>
<td>Upton, New York, USA</td>
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<tr>
<td>CERN</td>
<td>Geneva, Switzerland</td>
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<tr>
<td>DESY</td>
<td>Hamburg, Germany</td>
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<tr>
<td>Fermilab</td>
<td>Batavia, Illinois, USA</td>
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<tr>
<td>Jefferson Lab</td>
<td>Newport News, Virginia, USA</td>
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<td>J-PARC</td>
<td>Tokai, Japan</td>
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<tr>
<td>Sandia National Laboratory</td>
<td>Albuquerque, New Mexico, USA</td>
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<tr>
<td>Stanford Linear Accelerator Center</td>
<td>Menlo Park, California, USA</td>
</tr>
<tr>
<td>TRIUMF</td>
<td>Vancouver, British Columbia, Canada</td>
</tr>
</tbody>
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C. Publications in Refereed Journals

C.1. ATLAS Papers


C.2. DØ Papers


DØ Collaboration (R.W. Moore et al.), “Observation and Properties of the \( \chi(3872) \) Decaying to \( J/\psi \pi^+ \pi^- \) in \( p\bar{p} \) Collisions at \( \sqrt{s} = 1.96 \) TeV”, Phys. Rev. Lett. 93, 162002 (2004).

DØ Collaboration (R.W. Moore et al.), “Search for Doubly Charged Higgs Boson Pair Production in Decay to \( \mu^+\mu^-\mu^+\mu^- \) in \( p\bar{p} \) Collisions \( \sqrt{s} = 1.96 \) TeV”, Phys. Rev. Lett. 93, 141801 (2004).


C.3. HERMES Papers


HERMES Collaboration (L. De Nardo, L.G. Greeniaus, C.A. Miller, M.G. Vincter et al.), “Quark fragmentation to \( \pi^\pm, \pi^0, K^\pm, p \) and \( \bar{p} \) in the nuclear environment”, Phys. Lett. B 577 (2003) 37-46.


C.4. OPAL Papers


OPAL Collaboration (B. Caron, W.J. McDonald, J. Pinfold et al.), “Test of non-commutative QED in the process e\(^+\)e\(^-\) \rightarrow \gamma \gamma \) at LEP”, Phys. Lett. B 568 (2003) 181-190.


OPAL Collaboration (J. Pinfold et al.), “Constraints on anomalous quartic gauge boson couplings from $\nu \bar{\nu} \gamma \gamma$ and $q \bar{q} \gamma \gamma$ events at CERN LEP2”, Phys. Rev. D 70, 032005 (2004).

C.5. Theory Papers


C.6. Other Papers


D. Conference Contributions


E. Student Theses


L. Chen, PhD, 2004, “Radiation Tolerant Design with 0.18 micron CMOS Technology”, (supervisor D.M. Gingrich). Now Assistant Professor of Electrical and Computer Engineering, South Dakota School of Mines and Technology.

F. Design Notes


G.M. Stinson, “An additional beam line in the ISAC-II experimental area”, (TRI-DNA-04-03).

G.M. Stinson, “Beam transport from the medium-B exit to the ISAC-II experimental hall”, (TRI-DNA-04-02).

G.M. Stinson, “A revision of the beam transport to the ISAC-II experimental area”, (TRI-DNA-04-01).


G. Invited Talks

B.A. Campbell
- CERN, Geneva Switzerland, 2004

A. Czarnecki
- Aspen Winter Meeting, Aspen, Colorado, USA
- Summer Nuclear Institute at TRIUMF, Vancouver, BC
- American Physical Society April Meeting, Denver, Colorado, USA
- International Symposium, “Advances in QCD”, Minneapolis, Minnesota, USA
- International Workshop, “Precision Electroweak Physics”, Fermilab, Illinois, USA
- International Conference, “Recontres de Moriond”, La Thuile, Italy

J.L. Pinfold
- The Technical University at Prague, Prague, Czech Republic
- INFN, University of Bologna, Bologna, Italy
- Canadian Association of Physics, University of Winnipeg, Manitoba
- IEEE Instrumentation and Measurement Technology Conference, Lake Como, Italy
- Fermilab, QCD Workshop, talk 1 Fermilab, Batavia, Illinois, USA
- Fermilab, QCD Workshop, talk 2, Fermilab, Batavia, Illinois, USA
- Netera & CA *net 4, Simon Fraser University, Vancouver, BC
- CERN/LHCC Committee Public Meeting, CERN Auditorium, Geneva Switzerland
- 8th International Conference on Advanced Technology and Particle Physics at Villa Olmo, Lake Como, Italy

R.W. Moore
- “The DØ Detector and the Search for Supersymmetry”, Seminar at Wayne State University, USA (Nov 2003)

M.G. Vincter
- Northern Alberta Physics Teachers, Edmonton (Dec 2003)
### H. Visitors

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Matt Dobbs</td>
<td>Lawrence Berkeley Laboratory, California, USA</td>
</tr>
<tr>
<td>Harold Evans</td>
<td>Columbia University, New York, USA</td>
</tr>
<tr>
<td>Karl-Heinz Langanke</td>
<td>University of Aarhus, Denmark</td>
</tr>
<tr>
<td>Claude Leroy</td>
<td>Université de Montréal, Canada</td>
</tr>
<tr>
<td>George Lolos</td>
<td>University of Regina, Canada</td>
</tr>
<tr>
<td>Zisis Papandreaou</td>
<td>University of Regina, Canada</td>
</tr>
<tr>
<td>Robert Svoboda</td>
<td>Louisiana State University, USA</td>
</tr>
<tr>
<td>Fydor Tkachov</td>
<td>Institute for Nuclear Research, Moscow, Russia</td>
</tr>
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