# Table of Contents

1. Introduction ......................................................................................................................... 3

2. Experiment Reports .............................................................................................................. 4
   2.1 ATLAS Experiment at the LHC .................................................................................... 4
   2.2 CDF Experiment at Fermilab ......................................................................................... 8
   2.3 SNO Experiment at SNOLAB ....................................................................................... 9
   2.4 IceCube Experiment at South Pole Station ................................................................. 9
   2.5 PICASSO Experiment at SNOLAB .............................................................................. 11
   2.6 STACEE Experiment at Sandia National Laboratory .................................................. 12
   2.7 SNO+ Experiment at SNOLAB ................................................................................... 12
   2.8 Deap 3600 Dark Matter Detector at SNOLAB ........................................................... 13
   2.9 MoEDAL Experiment at the LHC ................................................................................. 14
   2.10 ATLAS Forward Physics Project ............................................................................... 16
   2.11 DM-Ice Prototype ....................................................................................................... 18

3. Theory Reports ..................................................................................................................... 20
   3.1 Ian Blokland ............................................................................................................... 20
   3.2 Faqir Khanna .............................................................................................................. 20
   3.3 Marc de Montigny ....................................................................................................... 20

4. Lake Louise Winter Institute .............................................................................................. 21

5. Role of TRIUMF in the Centre for Particle Physics ......................................................... 22

6. Facilities and Technical Developments ............................................................................ 23
   6.1 Computing Facilities and Developments .................................................................... 23
   6.2 Mechanical Facilities and Developments .................................................................... 25
   6.3 Electronics Facilities and Developments .................................................................... 26
   6.4 Radon-Suppressed Laboratory ................................................................................... 28
   6.5 Low-Background Counting Laboratory ...................................................................... 28

Appendices ............................................................................................................................ 30
   A. Centre for Particle Physics Personnel, 2009-2010 ....................................................... 30
   B. Publications in Refereed Journals ................................................................................. 33
   C. Conference Contributions ............................................................................................. 37
   D. Other Publications ........................................................................................................ 38
   E. Outreach Activities ...................................................................................................... 39
   F. Talks ............................................................................................................................ 42
   G. Awards and Recognition .............................................................................................. 44
   H. Visitors ......................................................................................................................... 45
   I. Collaborating Institutes ............................................................................................... 46
1. Introduction

The Centre for Particle Physics (CPP) at the University of Alberta was established as the Nuclear Research Centre in 1958. This report summarizes the research activities of the 51st year of the CPP covering the period 1 July 2009 to 30 June 2010.

The Large Hadron Collider in Geneva started operation near the end of 2009 and is currently running at 7 TeV centre of mass energy. First results have already been published and the CPP group is active in the operation of the ATLAS experiment and analysis of the data. We also continue our involvement in forward physics on the CDF experiment at Fermilab. The astroparticle physics group is finishing up SNO data analysis, continuing PICASSO runs, and designing the SNO+ and DEAP/CLEAN detectors. The CPP is now a member of the IceCube experiment at the South Pole. The MoEDAL experiment was approved by the CERN Research Board at the end of 2009. The ALTA project (now called FUTURA) has become interdisciplinary and continues to provide a unique educational experience for students of participating Alberta high schools and beyond.

There was an unfortunate incidence during the year. Glen Stinson passed away. Glen was a member of the CPP for 34 years.

We continue to successfully hold the week-long Lake Louise Winter Institute each year in February. This year marked the 25th anniversary of the institute.

The work of the CPP is supported by research grants from the Natural Sciences and Engineering Research Council (NSERC) of Canada and the Canadian Foundation for Innovation (CFI). The University of Alberta and TRIUMF provide salaries for technical support staff. The Lake Louise Winter Institute receives support from these sources as well as from the Institute of Particle Physics and the Perimeter Institute.

I am confident that you will discover in this report a powerful record of activity and find it informative.

Douglas M. Gingrich
Director
November 2010
2. Experiment Reports

2.1 ATLAS Experiment at the LHC

S. Bahinipati, A. Butt, B. Caron, K. Chan, D.M. Gingrich, M. Kim, R.W. Moore, J.L. Pinfold, A. Saddique, R. Soluk, N. Soni, J. Soukup, W-Y. Ting

The ATLAS experiment is a large, multi-purpose particle physics detector built for the Large Hadron Collider (LHC) accelerator at CERN. The accelerator and detector came online at the end of 2009. The centre of mass energy of 7 TeV is the largest man-made collision energies ever. The primary aim of the experiment is to discover the mechanism that gives fundamental particles their mass. In addition, a wealth of other physics measurements and discoveries is anticipated during its greater-than-ten-years of operation.

The CPP group has a diversified set of research interests and responsibilities on the ATLAS experiment. The group is responsible for luminosity measurement and monitoring, simulation studies, and distributed (Grid) computing services. The particle physics interests of the group concentrate on searches for the effects of extra dimensions, searches for dark matter and long-lived supersymmetric particles, and forward physics. Figure 1 shows the first high invariant mass event found by the CPP group.

![Figure 1: The first high invariant mass (greater than 800 GeV) event recorded by ATLAS.](image)

2.1.1 Luminosity Measurement

An accurate determination of luminosity is a vital part of any physics measurement at the LHC. Currently, the LHC luminosity is determined in real time approximately once per second using a number of detectors and algorithms, each having different acceptances, systematic uncertainties, and sensitivity to background. These results are displayed in the ATLAS control room and archived every two minutes; a single “preferred” measurement is reported to the LHC. The LUCID detector was chosen as the provider of the official “preferred” ATLAS luminosity determination.

During offline analysis, additional luminosity algorithms are studied and are compared to online results to further constrain systematic uncertainties on the measurement. Relative
luminosities between detectors and methods in general agree to within a few percent. Determination of the absolute luminosity using Monte Carlo calibrations is limited by a 20% systematic uncertainty from the modeling of diffractive components of the cross section.

Smaller uncertainties of 11% are obtained using an absolute calibration of the luminosity via beam separation scans – also known as Van der Meer (VdM) scans after the inventor of the method – and are dominated by the systematic uncertainty on the measurement of the LHC beam current. The CPP group is playing a leading role in the calibration of LUCID using the VdM scan method. The strength of this calibration technique is that it does not require the priori knowledge of any cross section.

Three sets of scans were carried out at ATLAS where beams were displaced in both the horizontal and vertical directions in order to reconstruct the complete beam profile. During the scan, the collision rates measured by various ATLAS luminosity detectors were recorded while the beams were moved stepwise with respect to each other in the transverse plane. For example, the raw instantaneous luminosities over the pseudo-luminosity block (about 2 s) as measured by LUCID using the Event AND algorithm for a VdM scan is shown in figure 2.

![Figure 2: Time history of the raw luminosity for a VdM scan performed on 9 May 2010.](image)

After calculating the transverse beam sizes in the horizontal and vertical directions, the luminosities and the visible cross sections (also called the calibration constant) of various detectors and algorithms are obtained. The measurement of LHC beam currents using the VdM scan method is 11%. It is a big improvement in the luminosity measurement compare to the Monte Carlo calibration method.

The CPP group is responsible for the preparation of a key software package utilized during the VdM scan of proton beams. It is called the “Beam Separation Scan Package” (BSSP). The BSSP operates in the online world of the ATLAS software framework and TDAQ environment. The software is designed as an interface between the machine (LHC) and various luminosity detectors (e.g. LUCID) in ATLAS, during the scan. The BSSP synchronizes the VdM scan data at both ends (LHC and ATLAS). This data can then be further used for the offline analysis.

The primary purpose of the scan is to find the transverse size of a beam in both horizontal
and vertical directions in order that the luminosity can be calculated using the VdM formalism. The luminosity data determined using the VdM scan can be used to calibrate the luminosity detectors and to provide the absolute luminosity for ATLAS physics analysis. Furthermore, the online BSSP provides: the official VdM data for offline analysis; the information from Beam Position Monitors, which is essential for the correct position of a beam during the scan; the online displays for the immediate data quality diagnostics for the ATLAS “Luminosity Desk” shift personnel.

2.1.2 Pileup Overlay

One of the best ways of including background noise events in the simulation of proton-proton collision events is to use real data. Minimum bias, cavern background, beam halo, and beam gas background events can be collected using a zero bias trigger. These events can be overlaid on a simulated collision event with the correct timing distribution and in the correct proportions. Software to read-in several steams of events at the GEANT Hits level and properly merge them has been written. The CPP has the responsibility for validating the code for the liquid argon calorimeters and has made good progress in this validation during the last year.

2.1.3 Preparation for Physics Analysis

The CPP group works on a variety of physics topics using the data collected by ATLAS in 2010. These topics usually form the subject of graduate student theses.

Seema Bahinipati, Doug Gingrich, and a summer student (Joel Hutchinson) study the detection of extra-dimensional space-time with ATLAS. In particular, we are interested in the possibility of producing mini black holes with the LHC, if gravity is present in the extra dimensions. This year, we searched at 7 TeV centre of mass energy. The invariant mass distribution for the first 780 \( \mu b^{-1} \) of ATLAS data, shown in figure 3, is consistent with Standard Model expectations. Preliminary limits have been set that rule out black holes being produced at the Planck scale of 800 GeV, or lower.

![Invariant mass distribution](image)

**Figure 3:** Invariant mass distribution for data, simulated Standard Model background, and a possible string ball signal.

<table>
<thead>
<tr>
<th>Reconstructed Mass [TeV]</th>
<th>Events/0.1 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^1</td>
</tr>
<tr>
<td>0.5</td>
<td>10^2</td>
</tr>
<tr>
<td>1</td>
<td>10^3</td>
</tr>
<tr>
<td>1.5</td>
<td>10^4</td>
</tr>
<tr>
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<tr>
<td>3</td>
<td>10^7</td>
</tr>
<tr>
<td>3.5</td>
<td>10^8</td>
</tr>
</tbody>
</table>

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Centre for Particle Physics Annual Report 2009-2010
In supergravity, where the gravitino is the lightest supersymmetric particle (LSP), the next-to-lightest supersymmetric particle (NLSP) decays to the gravitino with a naturally long lifetime (about 100 s). However, cosmological constraints favour charged slepton NLSPs with lifetimes below a year as the natural NLSP candidate. For this scenario, we have developed a method to accurately determine the slepton lifetime and SUSY cross-section from observation of the decays of sleptons trapped in the material comprising the main detectors at the LHC (ATLAS, CMS). A measurement of the lifetime to 5% is possible after three years at nominal luminosity and running conditions. This method is sensitive to the cosmologically preferred stau lifetime of about 37 days.

We used a GEANT based description of a general purpose LHC detector, which we chose to model on ATLAS, using the decays of sleptons trapped in the detector itself. We study the mode where the slepton (a stau) decays to a muon (from a tau lepton decay) plus a gravitino LSP. No use is made of additional water traps or underground reservoirs, or special modes of operation of the LHC requiring, for example, experiment initiated beam dumps. The cosmic ray background is essentially eliminated by the depth of the detector underground (about 100 m) and by only utilizing upward going muons from slepton decays. The background from upward going neutrino interactions, and back-scattered particles from cosmic rays interactions, giving rise to upward going muons, is eliminated by considering only upward going decay products originating from inside the detector, in a fiducial volume defined to be within the outer muon resistive plate chambers and thin gap chamber. Also, we only search for muon decays when the detector is turned off in order to eliminate the background from muons from proton-proton collisions.

Figure 4 shows the fit to the slepton decay data over three years of data taking (two years low luminosity and one year high luminosity) of the number of stau decay products seen by the model trigger as a function of elapsed time during the LHC shutdown period. The fit to the distribution results in a lifetime of 29.9 ± 1.5 days and a SUSY cross-section of 18.9 ± 1.3 pb.

![Figure 4: Number of stau decays as a function of days after beam shutdown.](image)

We are actively involved in the Standard Model group to make precise measurements of the following ratios:
\[ R_{(W/Z+n \text{ jets})} = \frac{(W+n \text{ jets})}{(Z+n \text{ jets})} \]
\[ R_W/R_Z = \left[ \frac{(W+n \text{ jets})}{(W+(n+1) \text{ jets})} \right] / \left[ \frac{(Z+n \text{ jets})}{(Z+(n+1) \text{ jets})} \right] \]

where \( n = 0 \) to 6. We are interested in channels where the vector bosons decay to \( W \to \mu \nu \) and \( Z \to \mu \mu \). The advantage of measuring these ratios is that certain experimental quantities that one might expect to not be well known in early data, such as luminosity and lepton identification, cancel out in the ratio. Also, one can compare with the same quantities measured at Tevatron.

We proposed a measurement on the double ratio \( R = R_W/R_Z \) at different jet multiplicities to investigate to what extent the double ratio is in fact independent of jet multiplicity. Normally one would expect \( R = 1 \). A strong dependence of the double ratio on the number of jets would be an indication of new physics.

Another focus of the CPP group is the extension of the analysis beyond one and two jets to three and above.

### 2.2 CDF Experiment at Fermilab

**J.L. Pinfold, L. Zhang**

Following from our published study of exclusive charmonium and QED production with a muon-pair final state, we report new studies of exclusive di-muons from bottomonium (\( \Upsilon(1s) \), \( \Upsilon(2s) \), \( \Upsilon(3s) \), and the \( \chi_b \)) and QED production in the region 8 GeV to 40 GeV. The Upsilonons \( \Upsilon \) are photo-produced in a photon-pomeron interaction and the \( \chi_b \) is a result of double pomeron exchange. The Feynman diagrams relating to the processes studied are shown in figure 5. In an exclusive di-lepton process there are no particles produced other than the lepton pair, and the incident hadrons do not dissociate. This analysis uses a data set corresponding to an integrated luminosity 1.14 ± 0.06 fb\(^{-1}\) collected by the run II Collider Detector at Fermilab (CDF II).

![Feynman diagrams](image)

Figure 5: Feynman diagrams for exclusive di-muon production (left), photo-production of charmonium and bottomonium (middle), and central exclusive (double pomeron exchange) production of the \( \chi_b \) and \( \chi_c \) (right).

In our previous analysis, the experimental signature of exclusive \( \mu^+ \mu^- \) production was a muon-pair with no other particles detected down to a pseudorapidity of 7.3. In this analysis this requirement is dropped in order to increase the detection efficiency – a requirement for the observation of exclusive upsilon and \( \chi_b \) production. Instead, we specify an isolated muon-pair vertex. In addition, we use the two classic signatures of exclusive production of muon pairs: small \( p_T \) of the muon pair; and, the “back-to-backness” of the two muons in the in the \( r-\phi \) plane.

After background subtraction and correction for efficiencies, we calculated the cross-section
for QED production of exclusive muon pairs in the mass range 8 GeV to 40 GeV. It was found to be $0.26 \pm 0.05 \pm 0.03$ pb in excellent agreement with the theoretical prediction from the LPAIR Monte Carlo generator of $0.27 \pm 0.04$ pb. This agreement gives us confidence that our analysis procedures do select out central exclusive events (those events where the central state is exclusive but the scattered protons may or may not break up).

Similar analysis procedures are now being applied to the search for “centrally exclusive” Upsilon production. If the same $p_T$ and $\Delta \phi$ analysis cuts are applied to the mass region 8 GeV to 10.5 GeV (allowing up to five associated tracks per muon pair vertex) one can clearly discern the $\Upsilon(1s)$, $\Upsilon(2s)$, and $\Upsilon(3s)$ states as shown in figure 6.

![Figure 6: The mu-pair mass spectrum from 8 GeV to 10.5 GeV.](image)

### 2.3 SNO Experiment at SNOLAB

**B. Beltran, S. Habib, A. Hallin, C. Howard**

The final data analysis of SNO data involves combining all three phases of the SNO data into a single analysis. Chris Howard’s thesis involves a search of the three phases of SNO for the so called hep neutrinos, which have not previously been seen. We expect that this will certainly present the best limit on such neutrinos and may even report a non-zero result for the first time. Shahnoor’s thesis is a Markov Chain Monte Carlo analysis of the three phases of SNO, combining the information from previous analyses into a single analysis with proper control of correlations and systematic uncertainties. It is envisioned that there will be a final set of papers later this year and next.

SNO has published a low energy threshold analysis, this year, which combined the data from the first two phases of SNO and resulted in a significant decrease in the uncertainties of the boron-8 flux and mixing parameters.

### 2.4 IceCube Experiment at South Pole Station

**D. Grant**

The IceCube Neutrino Observatory, see figure 7, is the world’s largest neutrino detector, located within the deep Antarctic ice at South Pole Station. IceCube is designed to have a total
instrumented volume of approximately 1 cubic-km, and as of January 2010, 92% of the detector has been deployed. In 2008, the design of the IceCube observatory was augmented with the addition of a low-energy extension, called DeepCore. DeepCore allows the observatory to reach a minimum neutrino energy threshold of about 10 GeV, almost two orders of magnitude lower than the IceCube baseline design. This energy threshold, combined with DeepCore’s location in the deepest ice at the centre of the observatory allows one to use the IceCube array as an active veto and thus obtain a very pure sample of neutrinos independent of an otherwise dominant cosmic ray muon background.

Figure 8: IceCube neutrino observatory.

In January 2010, the deployment of DeepCore, including the three complete rings of IceCube detectors which are needed to optimize the veto capabilities, was completed and the detector system has been actively taking physics quality data since May 2010. The IceCube group at the CPP has responsibility for the Monte Carlo simulation production of the signal and background datasets for the DeepCore detector, and much of this is accomplished with the computing resources at the university, including CPP and WestGrid. The WestGrid resources are also currently producing the weakly interacting massive particle (WIMP) signal simulation in preparation for first full detector WIMP searches. We also continue to be responsible for the primary trigger and filter algorithms for DeepCore. In preparation for analysis of the first year’s dataset, we are leading the development of a novel first-guess reconstruction algorithm for the low-energy events, and event identification techniques to separate muon from electron and tau events.
2.5 PICASSO Experiment at SNOLAB

C.B. Krauss, R. MacDonald

PICASSO is a leading experiment in the search for spin carrying dark matter. Dark matter could contribute as much as two thirds to the matter of the universe. Particle physics theories predict particles that could have the same properties as dark matter observed in cosmology.

The PICASSO detectors use the bubble detector technique. In these detectors interactions with dark matter particles cause nuclear recoils in the active material, superheated perfluorobutane ($C_4F_{10}$). This gas was chosen because of the large fluorine content which maximizes the sensitivity to spin carrying dark matter. Energy deposited in a superheated liquid $C_4F_{10}$ droplet causes a phase change into a gaseous bubble, creating a shock wave that is picked up by microphones.

The experiment currently has 32 detectors installed at SNOLAB in Sudbury, Ontario, shielded from cosmic background radiation by 2000 m of rock (see figure 8).

In 2009 and 2010, the underground experiment was taking data with 32 detectors. The system now has an active mass of 2.0 kg of fluorine or 2.6 kg of perfluorobutane. The CPP group has played a major role in the analysis of the data taken underground. A specific focus on the neutron calibration data helped further the understanding of bubble detection. The CPP was responsible for electronics repairs, data acquisition system maintenance, and data quality. The physics department electronics shop has developed a new pulser calibration system that will allow a channel-to-channel calibration of the electronics chain. This will improve the neutron-alpha discrimination on an event by event basis compared to previous data that was taken without the calibration system. The electronics shop also provided two fully tested spare modules for the heating of PICASSO detectors. One of these units is now in use at the CPP low-background counting facility.

The new, stronger detector containers developed by the CPP group last year are now in use in the underground system and perform well.
The PICASSO experiment will move to a new, larger location within SNOLAB in late
summer 2010. The CPP group was involved in the design of the improved neutron shield and the
new geometry of the setup. The new location of the experiment will allow PICASSO to continue
data-taking in a better environment with lower neutron background and without sharing the
space with other experiments.

2.6 STACEE Experiment at Sandia National Laboratory

D.M. Gingrich

The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) used 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. This Cherenkov
light is emitted by electrons and positrons produced when a high-energy gamma ray impinges on
the atmosphere. The technique allowed us to detect gamma rays that are of higher energy than
those that can be studied with space-borne instruments, but lower energy than other ground-
based instruments at the time. STACEE has finished observing and the telescope was
decommissioned in 2007.

This year we have analyzed the data from two high-frequency peaked BL Lac objects 1ES
1218+304 and H 1426+428. Both sources have been predicted to be high energy gamma-ray
emitters above 100 GeV, detectable by ground-based Cherenkov telescopes. STACEE
observations of 1ES 1218+304 (see figure 9) and H 1426+428 have not produced detections.

![Figure 9: Gamma-ray spectrum of 1ES 1218+304, as measured by VERITAS and MAGIC, with the STACEE 99% flux upper limit at 155 GeV. Note that the different observations are not contemporaneous.](image)

2.7 SNO+ Experiment at SNOLAB

C. Ng.

SNO+ is a neutrino experiment at SNOLAB. It will measure the low energy region of solar
neutrinos, geo neutrinos, and reactor neutrinos. With the addition of Nd to the liquid scintillator, it will also measure neutrinoless double beta decay. SNO+ uses the SNO detector, which will be modified so that liquid scintillator can take the place of the heavy water target. In the current phase of the experiment, the design is finalized and the construction of new components has started. Within a year and a half SNO+ will be ready to be filled with liquid scintillator and ready to start data taking.

The CPP group has taken responsibility for engineering the hold-down system which will anchor the acrylic vessel and the buoyant scintillator to the floor of the underground cavity. An engineering test with full scale forces and materials (see figure 10) was successfully conducted at the CPP. The test showed that the interactions between the rope net and the acrylic are properly modeled and well understood. The rope net and hold down hardware are currently being procured and will be installed in the SNO cavity in late 2010 and 2011.

![Image](image_url)

Figure 10: Test setup for acrylic-rope interaction in the heavy lab in the basement of CEB. In the centre, a SNO acrylic panel can be seen. The ropes apply pressure on the panel while the displacement is being measured.

In addition, the CPP group is developing a gamma ray calibration source for the experiment. A possible geometry exists and is currently simulated and optimized. Development on the reconstruction algorithms for neutrino events within SNO+ is continuing to progress. The CPP-developed algorithm for energy and position reconstruction is still the only well-understood and universally usable algorithm within SNO+.

### 2.8 Deap 3600 Dark Matter Detector at SNOLAB


The Deap-3600 experiment is a dark matter experiment consisting of 3600 kg of liquid argon contained in an ultra-pure acrylic vessel and observed by 260 photomultiplier tubes. The detector is unique in that the acrylic vessel is a cryogenic vessel – we use the light guides, augmented by acrylic or polyethylene filler materials, to serve both as a thermal insulator and a neutron shield. The result is that we are able to use the photomultiplier tubes at room temperature. The entire detector is enclosed in a stainless steel pressure vessel and submerged in a water tank.

The capital cost of the detector is covered by a CFI/ASRIP grant; the CPP component of this
is split evenly between DEAP and SNO+.

CPP has been responsible for the design of the inner acrylic vessel, the machining of the shell, the design of the steel shell, and the bonding of the acrylic lightguides to the shell. The design is essentially complete; we have done extensive finite-element analysis calculations on the thermal and mechanical stresses in the vessel, and have shown the overview of the detector in a previous CPP annual report.

We have purchased a rotary table that has been integrated into the Toshiba Mill to make a fully functional five-axis CNC milling machine, which will be used to fabricate the vessel. To start, we have been machining a 1/3 scale prototype test vessel.

We have also done extensive work on the process for attaching the light guides to the acrylic vessel. This is innovative because the bonds need to withstand cryogenic temperatures, which means that acrylic monomer needs to be polymerized to use as a bonding agent. We have tested other bonding agents, in particular acrylic solvents, but they invariably change the thermal characteristics of the bond and shatter at cryogenic temperatures. A set of bonding clamps and dams and a procedure for bonding has been extensively developed and tested. This will almost certainly lead to a final bonding system for the DEAP vessel.

CPP has developed the signal conditioning board and preamplifier for the photomultiplier tubes. This is currently being tested.

We have also developed a software fitting algorithm that allows us to count individual photons from the digitized waveform in DEAP. This has been extensively tested with the data from the DEAP-1 detector, and allows us to evaluate the impact of different electronics, digitization schemes, and photomultiplier tube characteristics on the detector.

2.9 MoEDAL Experiment at the LHC

J.L. Pinfold, R. Soluk, J. Soukup

On 2 December 2009, the CERN Research Board approved the LHC’s seventh experiment: the Monopole and Exotics Detector At the LHC (MoEDAL). The prime motivation of this experiment is to search for the direct production of the magnetic monopole at the LHC. Another physics aim is the search for exotic, highly ionizing, stable (or pseudo-stable) massive particles (SMPs) with conventional electric charge. Although MoEDAL is a small experiment by LHC standards, it has huge physics consequences that complement the already wide vista of the existing LHC experiments.

At CERN, the search for magnetic monopoles – using dedicated detectors – began in 1961 with a counter experiment to sift through the secondary particles produced in proton-nucleus collisions at the proton synchrotron. Over the following years, searches took place at the Interacting Storage Rings and at the super proton synchrotron. At the Large Electron-Positron (LEP) collider, the hunt for monopoles in electron-positron collisions was carried out in two experiments: MODAL (the Monopole Detector at LEP), deployed at intersection Point I6 on the LEP ring; and the OPAL monopole detector, positioned around the beam pipe at the OPAL intersection point. These established new limits on the direct production of monopoles.

The international MoEDAL collaboration, made up of physicists from Canada, CERN, the Czech Republic, Germany, Italy, Romania and the USA, is preparing to deploy the MoEDAL detector during the next long shutdown of the LHC, which will start late in 2011. The full
detector comprises an array of approximately 400 nuclear track detectors (NTDs). Each NTD consists of a 10-layer stack of plastic (CR-39 and MAKROFOL) and altogether they have a total surface area of 250 m$^2$. The detectors are deployed at the intersection region at Point 8 on the LHC ring around the VErtex LOcato (VELO) of the LHCb detector, as figure 11 indicates. The MoEDAL collaboration positioned 1 m$^2$ of test detectors before the LHC was closed for operation in November 2009. If feasible, they will be removed for analysis during the planned short shutdown at the end of 2010 and a substantial subset of the full detector system will be deployed for the run in 2011.

![Figure 11: Artist’s impression of the MoEDAL detector adjacent to the LHCb detector at Point 8 on the LHC ring.](image)

The MoEDAL detector is like a giant camera for photographing new physics in the form of highly ionizing particles, and the plastic NTDs are its “photographic film”. When a relativistic magnetic monopole – which has approximately 4700 times more ionizing power than a conventional charged minimum-ionizing particle – crosses the NTD stack, it damages polymeric bonds in the plastic in a small cylindrical region around its trajectory. The subsequent etching of the NTDs leads to the formation of etch-pit cones around these trails of microscopic damage. These conical pits are typically of micrometre dimensions and can be observed with an optical microscope. Their size, shape, and alignment yield accurate information about the effective $Z/\beta$ ratio, where $Z$ is the charge and $\beta$ the speed, as well as the directional motion of the highly ionizing particle.

The main LHC experiments are designed to detect conventionally charged particles produced with a velocity high enough for them to travel through the detector within the LHC’s trigger window of 25 ns – the time between bunch crossings. Any exotic, highly ionizing SMPs produced at the LHC might not travel through the detector within this trigger window and so will have a low efficiency for detection. Also, the sampling time and reconstruction software of each sub-detector is optimized, assuming that particles are travelling at close to the velocity of light. Hence, the quality of the read-out signal, reconstructed track or cluster may be degraded for an SMP, especially for subsystems at some distance from the interaction point.
Another challenge is that very highly ionizing particles can be absorbed before they penetrate the detector fully. Additionally, the read-out electronics of conventional LHC detector systems are usually not designed to have a wide enough dynamic range to measure the very large $dE/dx$ of highly ionizing particles properly. In the case of the magnetic monopole there is also the problem of understanding the response of conventional LHC detector systems to particles with magnetic charge.

The MoEDAL experiment bypasses these experimental challenges by using a passive plastic NTD technique that does not require a trigger. Also, track-etch detectors provide a tried-and-tested method to detect and measure accurately the track of a very highly ionizing particle and its effective $Z/\beta$. Importantly, heavy-ion beams provide a demonstrated calibration technique because they leave energy depositions very similar to those of the hypothetical particles sought. If it exists, a magnetic monopole will leave a characteristic set of 20 collinear etch-pits. There is no other conventional particle that could produce such a distinctive signature – thus, even one event would herald a discovery.

### 2.10 ATLAS Forward Physics Project

_S. Liu, J.L. Pinfold, J. Soukup_

We are involved in two projects to development detectors and electronics for the ATLAS forward region: LUCID Phase-II and the QUARTIC detector.

The new baseline design of LUCID Phase-II (figure 12) replaces the existing gas Cherenkov with two planes of mini PMTs (mPMTs) separated by 1.5 m. The two detector planes are maintained in place by a rigid but lightweight supporting framework. The prototype fast frontend readout required already exists and is the same as that utilized by the QUARTIC precision time-of-flight (ToF) counter for the ATLAS Forward Physics project. The detector operates by determining a tight spatial-temporal coincidence between the two planes of PMTs – satisfied only by primary particles traveling from the ATLAS interaction point and boosted hard secondaries from primary particles interacting as they exit the beam pipe.

*Figure 12: The basic concept for LUCID Phase-II.*

This simplified, low cost, new design severely reduces soft backgrounds, and does away
with the need for a gas supply, the LUCID gas vessel, Cherenkov tubes, and fibre-optic readout cables, which are themselves a source of soft backgrounds at high luminosity. It is designed for ease of alignment, PMT replacement, and detector replacement, thus ameliorating the problems of working in a highly activated area and enabling us to replace the detector every few years.

The QUARTIC detector, which utilizes Fused Silica (FS) bars as radiators, is a joint development effort of CPP, Fermilab, and University of Texas, Arlington. Figure 13 shows an eight bar prototype fabricated at the CPP. A proton passing through the silica bars would radiate photons that are measured by a MCP-PMT. The QUARTIC detector design, a 4 x 8 array of bars 15 mm in length with a 6 mm x 6 mm cross section, is mounted at the Cherenkov angle, 48°, minimizing the number of reflections as the light propagates to the MCP-PMT through an air-filled aluminized light guide. Air light guides are being considered as well as long silica bars since one can avoid the time dispersion, from the wavelength dependence of the index of refraction – but at the cost of less light. The final detector configuration is still under review.

The QUARTIC precision ToF counter is designed to be deployed via a Hamburg pipe arrangement within millimetres of the LHC beam at ±220 m and ±420 m from the ATLAS interaction point. The readout electronics developed by the CPP group consists of an amplifier and constant fraction discriminator – TDC chain. We have use the high precision TDC chip (HPTDC). We have demonstrated a timing precision using our readout chain of about 15 ps. With 16 measurements planned per proton detected, we should be able to achieve an overall timing resolution for the deflected beam protons of about $15/\sqrt{16} = 5$ ps, assuming that the individual measurements are uncorrelated.

The CPP group also proposed the use of Cherenkov bars comprised of fused silica fibres and some prototypes were constructed as shown in Figure 14. Although the amount of light collected by the bars comprised of fused-silica fibres (fibre-bars) is lower than the solid fused-silica bar, the timing resolution obtained with the fibre-bars was 30% better than those obtained with the solid bars, as predicted. This allows the overall precision per measurement of 15 ps to be reduced to about 10 ps, and the overall timing resolution to fall to around 3 ps for 16 uncorrelated measurements.
2.11 DM-Ice Prototype

*D. Grant*

The search for the nature of the dark matter, which makes up nearly 25% of the energy density of the universe, remains one of the fundamental pursuits of the astroparticle physics community. Recent experimental results have indicated that a discovery may be near at hand. In particular, the DAMA/LIBRA collaboration has recently updated its measurement of an annual modulation in their detectors to 8.9 standard deviations. The DAMA/LIBRA collaboration has interpreted this signal as the first direct evidence for dark matter. However, controversy exists with this interpretation, in particular from competing experiments that have excluded all but a very small fraction of the allowable signal region with null search results. A definitive test of the DAMA/LIBRA signal would be to operate a detector of the same technology in an underground lab in the southern hemisphere. Possible backgrounds that could produce seasonal variation like the DAMA/LIBRA signal will have a different phase in the southern hemisphere whereas a signal from a WIMP source would see no shift in phase. This is the principle behind the DM-Ice prototype detector (see figure 15). The prototype is about a 10 kg NaI detector read-out with two PMTs enclosed in stainless steel housing designed to withstand the very high pressure of deployment in the deep ice at the South Pole. In many ways the ice near the bottom of the IceCube-DeepCore detectors is an ideal location for this experiment as it is known to be quite ancient, and thus has low radioactive backgrounds, and provides a truly static environment for its operation. At the CPP, we have completed the Monte Carlo simulation studies of the possible muon backgrounds for the detector, in particular to estimate the rate of potential un-vetoed muons that may interact near the crystal to produce spallation neutrons. With the assistance of the low-background counting facility at SNOLAB, we have also been integral in the material selection for construction of the pressure housing and optical coupling of the PMTs to the NaI crystal. The prototype is planned for deployment in December 2010 and, with proof of successful operation, a proposal is in development for a full LIBRA scale (250 kg) detector. It is anticipated the CPP will play crucial roles in the fabrication of the pressure chambers for the full detector,
assembly to occur in the group’s future radon-free environment, and utilize the extensive local computing resources to participate in the full simulation and final analysis of the data.

Figure 15: DM-Ice prototype detector.
3. Theory Reports

3.1 Ian Blokland

In conjunction with an undergraduate student research assistant, I have been using “experimental mathematics” to investigate integer relation algorithms. The basic idea is to use computer programs to reveal potential patterns which can then be established more rigorously. One application of this is to bridge numerical estimates with exact analytic expressions for the Feynman integrals which arise in higher orders of calculations in perturbative quantum field theory.

3.2 Faqir Khanna

With a Ph.D. student, I am pursuing aspects of the quark-gluon plasma at finite temperature. Several decay processes are being investigated.

A program to study a role of non-equilibrium processes in many body systems is being initiated. This will include a study of the quark-gluon plasma. A study of the Casimir effect in a spherical geometry is being investigated with collaborators in Tashkent. This should have implications to the break-up of the nucleon in heavy ion collisions.

A change of pace is the study of gravity with local Galilean symmetry. Several aspects have been considered and some of the work is published. Additional studies are starting with several collaborators from Brazil.

3.3 Marc de Montigny

My general research program concerns applications of symmetries, Lie algebras, and their representations in field theory. With Claudia Daboul (Germany) and Jamil Daboul (Israel), I am developing the concept of “closure” of dynamical algebras, which yields twisted and untwisted Kac-Moody superalgebras. Two motivations are the dynamical symmetry of the hydrogen atom, and an infinite superalgebra recently observed in the Dirac theory of a Taub-NUT model.

With Faqir Khanna and collaborators, we have pursued our study of a Lorentz-like approach to Galilean covariance with a (4+1)-dimensional space-time. With Masanori Kobayashi (Gifu, Japan), we have used this approach to investigate the connection between spin and statistics in the Galilean covariant theories by using Galilean invariant delta functions. With Rodrigo Cuzinatto and Pedro Pompeia (both from Sao Paulo, Brazil), we have applied the Galilean covariant approach to two problems of general relativity: a Schwarzschild-type solution for an effective gravitational theory with local Galilean invariance, and the weak-field approximation of gravitational theories. We are currently examining Galilean de Sitter solutions.
4. Lake Louise Winter Institute

The Lake Louise Winter Institute was held from February 15-20 at the Chateau Lake Louise. This was a celebration of 25 years of continuous operation of the Winter Institute highlighting the contributions and participation of the Canadian community in the International program not only in particle physics but also in nuclear astrophysics.

The pedagogical talks were presented by John Ellis (Physics at LHC), Michael Turner (Cosmology), Aksel Hallin (SNO and SNOlab), Dean Karlen (Neutrino Experiments), and Rick Field (Early QCD at LHC). These were supplemented by about 50 contributed talks that provided recent developments in experimental and theoretical physics.

It was a pleasure to have Nobel Laureate and Professor Richard Taylor and Professor Alan Astbury present for this special occasion since these two people have been the biggest boosters of the Winter Institute.

The Winter Institute got financial support from TRIUMF, Institute Of Particle Physics, and Perimeter Institute. The Dean of Science and the conference fund at the University of Alberta provided financial support for this event. Infrastructure support by the Physics department, University of Alberta, and TRIUMF was crucial in making the Winter Institute a success.
5. Role of TRIUMF in the Centre for Particle Physics

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 CPP has played an essential role in the development of TRIUMF from the beginning.

The CPP currently has a number of joint staff positions with TRIUMF. Professors Doug Gingrich and Faqir Khanna hold, or held, shared University of Alberta and TRIUMF positions. TRIUMF currently supports three research scientist positions: Bryan Caron, resident at the CPP, and Wayne Faszer and Andy Miller, resident at TRIUMF. Glen Stinson had retired but remained active. In addition, TRIUMF supports electronics technician John Schaapman and faculty assistant Katalin Kovacs at the CPP.

Many TRIUMF research staff collaborate on experiments with members of the CPP. Andy Miller is head of the Detector Facility. Peter Kitching is a collaborator on the JHF-T2K experiment in Japan.
6. Facilities and Technical Developments

6.1 Computing Facilities and Developments

6.1.1 General Research Computing

The computing environment within the CPP consists primarily of Linux workstations and servers, along with several Windows XP and Mac OS X based systems. Several Linux servers provide services including World Wide Web publishing, remote SSH login access, collaborative tools (including video conferencing), and Network File System (NFS) support to systems within the CPP and beyond via AFS. The majority of Linux servers run Scientific Linux, a free distribution based upon the Red Hat Enterprise Linux releases, commonly used in high energy and particle physics experiments. A central 4 Terabyte disk file server provides fast access storage for both user home directories as well as large experiment datasets. A further 34 Terabytes of disk storage are available for more experiment specific applications and data storage. This is supplemented by a tape library system in the form of a Dell PowerVault 136T with support for up to 60 LTO-2 cartridges and six LTO-2 drives, enabling the storage of greater than 12 Terabytes for archival or disaster recovery purposes. The new file server arrived in August 2009.

The principle amount of research computing performed in the CPP utilizes the THOR Linux Computing Facility within the Particle Physics Computing Centre (PPCC). The THOR Linux system is a cluster of ten servers and nearly 120 single and dual-core dual processor worker nodes interconnected by a Gigabit (1000 Mbps) and fast (100 Mbps) Ethernet network. The majority of systems support 32- and 64-bit computing using both AMD Opteron and Intel multi-core processors. Fully integrated within the THOR Linux cluster are a series of 25 dual Intel Pentium III 1.44 GHz systems that comprise the resources for the Centre for Symbolic Computation.

Access to THOR is available to local users via several interactive login nodes which support software and analysis development, as well as to external collaborators through Grid software tools such as the Globus Toolkit used by Canadian and Worldwide LHC Computing Grids. High-speed networking between the CPP and its collaborating institutes world-wide is provided via 24 strands of dedicated single-mode fibre between the PPCC and the main campus network operations centre in the General Services Building (GSB). It is in GSB that the CPP fibre is connected to both the provincial (Cybera) and national (CANARIE CA*net4) academic networks. This 1 Gbps link enables projects and users to bypass the standard and slower campus network when transferring large data files to and from remote destinations. All computing and networking resources were managed by a CPP Physicist/IT staff member funded via TRIUMF until July 2010.

6.1.2 ATLAS Computing

In 2009-2010 the Alberta group continued to efficiently operate the local Tier-2 LHC Computing Grid (LCG) infrastructure as the LHC resumed data-taking with colliding beams. The Grid components consisting of the LCG Compute Element (CE) and Monitoring servers, Storage Element servers, and network infrastructure performed well during the past year.

During 2009-2010 the evolution of ATLAS computing at Alberta continued with the transition of the ATLAS Tier-2 computing resources into the WestGrid-Alberta computing
infrastructure obtained through the CFI National Platforms Fund. A new 1280 core Linux cluster provides computational and storage resources to the WestGrid community of users, as well as function as the future Tier-2 for ATLAS computing at Alberta. The new hardware arrived in spring 2009 and was commissioned during May and June. Installation of the ATLAS WLCG Grid Services followed in August and September, with full commissioning and turn on for ATLAS activity in December.

The ATLAS Grid infrastructure within WestGrid-Alberta resides on an ATLAS-dedicated network (separate from the regular WestGrid network) and communicates with the Tier-1 at TRIUMF via a dedicated 1 Gigabit per second LightPath link. Automatic failover of the LightPath network to the university academic research network is implemented via the BGP capable router from HEPnet Canada. The ATLAS Tier-2 functions on the cluster are supported through dedicated Grid services interface nodes, such as the Compute Element and Storage Element, which connect the cluster to the WLCG and ATLAS Grid. The Storage Element (SE) consists of servers running the dCache services, with database and administrative services handled by one high-capability server, and all data file input/output services handled by dCache Pool nodes each configured with 32 Terabytes of disk storage. A total of approximately 70 Terabytes of storage is provided via the dCache configuration as of June 2010.

The fully commissioned WestGrid-Alberta cluster constitutes the official Alberta portion of the Canadian Tier-2 resources. Following this transition in December 2009, the THOR cluster has been used as the local Tier-3 resources of the ATLAS-CPP group.

Figure 16 further shows the fraction of the total CPU utilization at each of the Canadian sites during the last 12-month period. The WLCG setups at the CPP and WestGrid-Alberta combined received 6.5% of the total Canadian CPU job utilization, an increase of 1.5% compared to 2008-2009.

![Figure 16: Distribution of the total number of jobs processed in Canada between the WLCG sites for 2009-2010.](image)

The ATLAS-Canada Group within the ATLAS Virtual Organization (VO) continues to enable priority job placement and execution on Canadian computing resources at Alberta and elsewhere, with membership managed by B. Caron from the CPP. B. Caron also acts as the overall coordinator for the operations of the ATLAS Tier-2 computing centres in Canada.
6.1.3 Computing for Astroparticle Physics

Members of the Astrophysics Physics group within the CPP utilize the PPCC and THOR Linux cluster facility for their simulation and data analysis needs. The group utilizes a dedicated storage server (Dell PowerEdge 1950) with dual quad-core Intel processors and a MD1000 RAID storage array with 11 Terabytes of disk, which is fully integrated into the THOR Linux cluster environment. During 2009-2010 an additional Dell server with eight processing cores was purchased and added for the group’s batch processing activities using the THOR Linux cluster.

6.1.4 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 2009-2010, the CPP and ATLAS made extensive use of the LightPath to TRIUMF regularly achieving over 600 Mbits per second of traffic on the network link, well above the levels of traffic seen collectively by the rest of the Alberta campus. Additionally, the CPP has continued to maintain contact with other universities and industry partners with interests in the areas of distributed data storage, data movement over Wide Area Networks, and network diagnostics and monitoring for large-scale clusters and Grid such as the WLCG.

6.2 Mechanical Facilities and Developments

6.2.1 BetaCage

Low-energy electrons may be detected with special purpose thin-dead-layer detectors such as Si(Li) or B-implanted HPGe, but these detectors have very small effective areas (at largest tens of cm), have vacuum windows that may stop or scatter some of the signal particles, and suffer from backscattering at the detector surface that can distort the measured energy spectra. Ultimately, the common challenge for these ultra-low rate detectors are particles with very short mean free paths such as alpha particles and low-energy electrons. An ideal detector would place the test sample directly in a gaseous detector medium to eliminate backscattering and dead-layer effects and provide a large sensitive area. This is the principle around which the BetaCage has been designed.

The BetaCage is an ultra-low-background multi-wire drift chamber optimized to detect electrons and alpha particles with energy less than 200 keV. Three principle goals have guided the design of the detector: a minimal amount of gas, the detector medium, needed to stop particles of interest and minimize the background from ambient penetrating gamma-rays; a minimum possible surface area since the detector itself may be a source of background; sufficient spatial information such that events may be distinguishable as originating from the sample surface versus scattered external background particles in the gas.

At the CPP, we are participating in the design and construction of the prototype BetaCage (see figure 17). The precision fabrication of the BetaCage frame is happening in the physics department machine shop, drawing on the expertise acquired in constructing other detector systems. The electronics for the BetaCage are also being designed and produced in the physics department electronics shop with the assistance of CPP members. Once complete, the detector is expected to be the world’s first background screener with sensitivity for low energy electrons at a rate of $1 \times 10^{-5} \text{keV/cm}^2\text{/day}$ as well as one of the world’s most sensitive alpha detectors.
6.3 Electronics Facilities and Developments

6.3.1 QUARTIC TDC and Constant Fraction Discriminator Development

Together with the high performance time-to-digital conversion (TDC) cards, which we developed at the CPP, we have helped to design and built a high performance constant fractional discriminator (CFD), which could give a time walk (see figure 18) of less than 20 ps within the input range of 200 mV to 1000 mV. As a CFD based on the commercial components, this is an excellent performance.

![ALCFD time walk](image)

Figure 18: Constant fraction discriminator time walk.

The form factor of the CDF is NIM module (see figure 19), which could hold eight mini-CFD modules and have remote control for the threshold.
6.3.2 Radon-Suppressed Laboratory Monitor DAQ System

We continued to improve the detector and preamplifier. Several changes have been made to both of them. More DAQ boards with eight multi-channel analyser input channels and 12 slow input channels have been built.

6.3.3 DEAP 3600 DAQ Signal Conditioning Card Development

The signal conditioning card (see figure 20) functions as both a preamplifier and shaping circuit for the DEAP-3600 PMT signals. It also provides the “one” cable scheme, which allows one cable to carry both the high voltage and the signal to the PMT from the control room to the detector site. The circuit has a 75 ohm input impedance, and is a fast amplifier circuit with a bandwidth of about 125 MHz. The first prototype has been built and tested. Its performance meets the requirements of the DAQ system.
6.4 Radon-Suppressed Laboratory

The radon free (suppressed) laboratory consists of a radon stripping system, a hermetically sealed clean room, radon monitoring equipment, and facilities for fabricating and testing apparatus inside the clean room. The radon stripping system is almost complete – we are waiting the delivery of a chiller system and a valve cabinet to enable the complete assembly and testing of the system. We have constructed a small part of the clean room; the first antechamber of the final clean room in room B36 of CEB to test the construction, sealing, and radon performance of the room. The full clean room will be fabricated in the Centennial Centre for Interdisciplinary Science in the very near future. Our radon emanation chamber and radon monitoring system in an air vent have become operational.

6.5 Low-Background Counting Laboratory

The CPP is continuing to build a low background counting facility to support dark matter and neutrino physics research and to further advance the methods and techniques used in low background applications. An important part of neutrino and dark matter research is the aspect of achieving low count rates by reducing internal backgrounds. The low background counting facility will be used in conjunction with the radon-free environment once the move to the new building is complete. Together they will allow the construction of new detector components with unprecedented low backgrounds.

For the radon-reduced environment, a low level, high volume throughput radon monitoring system has been developed and is currently in use to study the radon activity within the CEB basement.

Figure 22 shows a spectrum from the large volume radon emanation system. This system allows evaluation of how much radon gas is emanating from materials and therefore allows the selection of materials with high radio purity. It was used for several samples for SNO+ and for the evaluation of samples for the construction of the low-radon environment.

![Emanation Spectrum Rubber sample. 5kV, Run393](image)

Figure 22: Spectrum of the CPP developed radon emanation chamber. The sample emanated in this run contains a lot of uranium chain contaminations. The peaks are: $^{218}$Po, $^{214}$Po, and $^{212}$Po.
In 2010 a new high purity Germanium detector will be added to the available equipment. It will have a state of the art veto counter to achieve maximum sensitivity for a surface gamma counting system.
Appendices

A. Centre for Particle Physics Personnel, 2009-2010

A.1 Teaching and Research Staff

Blokland, Ian  Assistant Professor, Augustana Campus, University of Alberta
Caron, Bryan  Adjunct Assistant Professor/TRIUMF (Computing Data Support)
Czarnecki, Andrzej  Professor of Physics
de Montigny, Marc  Professor, Campus Saint-Jean, University of Alberta
Faszer, Wayne*  TRIUMF Detector Engineer Physicist
Gingrich, Douglas  Professor of Physics/TRIUMF; Director of CPP
Grant, Darren  Assistant Professor
Hallin, Aksel  Professor of Physics (CRC Chair in Astroparticle Physics)
Khanna, Faqir  Professor Emeritus/TRIUMF
Kitching, Peter*  Professor Emeritus
Krauss, Carsten  Assistant Professor
McDonald, John  Professor Emeritus
Miller, Andy*  TRIUMF Sr. Research Scientist
Moore, Roger  Associate Professor
Pinfold, James  Professor of Physics
Sherif, Helmy  Professor Emeritus
Stinson, Glen  TRIUMF Sr. Research Scientist Emeritus (d. Nov. 2009)
Soukup, Jan  Systems Analyst (Physicist/Engineer)

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

Bahinipati, Seema  Postdoctoral Fellow
Beltran, Berta  Research Associate
Bialek, Aleksandra  Postdoctoral Fellow
Gorel, Pierre  Postdoctoral Fellow
Hakobyan, Rafael  Research Associate (ended 31 December 2009)
Hedayatiipoor, Mohammad  Research Associate
Kim, Min Suk  Research Associate
MacDonald, Robert  Postdoctoral Fellow
Mondejar, Jorge  Postdoctoral Fellow
Piclum, Jan  Postdoctoral Fellow
Ramos, Jairzinho  Postdoctoral Fellow
Soni, Nitesh  Research Associate

A.3 Technical and Office Staff

Davis, Paul  Technologist (Electronics)
Kovacs, Katalin  Faculty Assistant
Ng, Christopher  Engineer (Mechanical)
Schaapman, Jan  Technician (Electronics)
Soluk, Richard  Technician (Detector)
Zhang, Long  Data Analyst (ended 31 July 2009)

A.4 Physics Support Personnel

Burris, Bill  Technician (Electronics)
Chan, Suzette  Executive Secretary
Lachat, Gilbert  Chief Technician, Machine Shop
Liu, Shengli  Senior Electronics Supervisor
Mackinnon, Jim  Systems Analyst
Paget, Tony  Technician (Mechanical)
Tomasevic, Boris  Technician (Mechanical)
Wampler, Len  Technician (Electronics)
Zimmermann, Paul  Technician (Mechanical)
A.5 Graduate Students

Butt, Aatif      J.L. Pinfold      PhD     ATLAS
Chan, Kevin     R. Moore         PhD     ATLAS
Dowling, Matthew A. Czarnecki    PhD     Theory
Habib, Shahnoor A.L. Hallin      PhD     SNO
Howard, Chris   A.L. Hallin      PhD     SNO
McGrath, Paul   A. Czarnecki    MSc     Theory
Olsen, Kevin    A.L. Hallin      MSc     DEAP/CLEAN
Petriw, Zachary A.L. Hallin      MSc     SNO+
Saddique, Asif  J.L. Pinfold     PhD     ATLAS
Sibley, Logan   A.L. Hallin      PhD     SNO+
Ting, Wei-yuan  J.L. Pinfold     PhD     ATLAS

A.6 Summer and Visiting Students

Amorim, Ronni          de Montigny and Khanna (University of Brasilia, Brazil)
Beaudry, Joel (NSERC)  ATLAS
Breitkreutz, Dylan (NSERC)  Blokland
Catuceanu, Andrei       PICASSO
Chekerker, Merzak       Khanna (Algeria)
Chouinard, Rhys         DEAP
Clarke, Haley           Czarnecki
Gorden Wolfe, Adam      ATLAS
Hanchurak, Stephen      SNO+
Hauer, Brad             PICASSO
Hutchinson, Joel        ATLAS
Martell, Kevin          ATLAS
McElroy, Thomas         DEAP 3600
Nicholson, Michael      PICASSO
Nowicki, Sarah          SNO+
Rochfort, Dominic       Pinfold
Pompeia, Pedro          de Montigny and Khanna (University of Sao Paulo, Brazil)
Wood, Tania             IceCube
Troitskaia, Alice (NSERC)  ATLAS
Zhang, Carson           DEAP/CLEAN
B. Publications in Refereed Journals

B.1. ATLAS Papers

B.2. CDMS-II

B.3. DØ Papers
V.M. Abazov et al., “Search for Next-to-Minimal Supersymmetric Higgs Bosons in the $h \rightarrow AA \rightarrow \mu \mu \mu \mu$, $\mu \mu \tau \tau$ Channels Using $p\bar{p}$ Collisions at $s^{1/2} = 1.96$ TeV”, Phys. Rev. Lett. 103 (2009) 061801.
V.M. Abazov et al., “Measurement of the t-channel single top quark production cross section”,
V.M. Abazov et al., “Determination of the strong coupling constant from the inclusive jet cross section in $p\bar{p}$ collisions at $s^{1/2} = 1.96$ TeV”, Phys. Rev. D 80 (2009) 111107.


V.M. Abazov et al., “Search for Resonant Pair Production of Neutral Long-Lived Particles Decaying to $b\bar{b}$ in $p\bar{p}$ Collisions at $s^{1/2} = 1.96$ TeV”, Phys. Rev. Lett. 103 (2009) 071801.


B.4. IceCube


B.5. OPAL Papers

B.6. PICASSO Papers

B.7. SNO Papers


B.8. Instrumentation Papers

B.9. Theory and Phenomenology Papers


C. Conference Contributions


D. Other Publications


A. Bertin et al., “Calibrating the ATLAS luminosity detectors using beam separation scans”, ATL-COM-LUM-2010-021.


E. Outreach Activities

E.1 FUTURA Project

A.L. Hallin, R.W. Moore, J.L. Pinfold

There is a continuing failure to attract sufficient numbers of gifted students to all scientific disciplines. The USA was one of the first to recognize that this problem begins at the undergraduate level, and to identify a solution to actively recruit students to the sciences and retain them at the graduate level. The USA analysis proposed that science students were losing interest in their subjects because of a lack of engagement with genuine research, and that they would be more likely to continue to postgraduate level and beyond if they were individually engaged in real, “hands on”, front-line research, rather than just conventional coursework.

The FUTURA project is an innovative interdisciplinary venture spearheaded by CPP researchers, students, and the community in the area of undergraduate (UG) research. FUTURA has two main aims: firstly, to use the physical, intellectual, and social infrastructure available via big science projects in order to empower the creativity and imagination of our students in discovery-based learning through direct “hands on” involvement and contributions. The physics department is involved in three such projects: LHC Physics at CERN (Switzerland); Astroparticle Physics with SNOLAB (Sudbury), and Space Physics with the CARISMA array (Northern Canada). In Phase-1 we will concentrate on the single project that has the best long term international track record in UG research in terms of resources, experience, and infrastructure: the ATLAS/LHC project at CERN. We expect there to be strong student interest in joining an LHC project which is an internationally acclaimed big-science project par excellence, one that is expected to make significant advances in the coming years.

Undergraduate students – from Canada and around the world – have already been involved in research at CERN through the CERN summer student program; NSERC funded summer studentships; Institute of Particle Physics (Canada) Summer Studentships; and project courses, such as PHYS499 and PHYS397. In addition to UG student involvement with the existing ATLAS detector and its research program we envisage a detector upgrade to ATLAS that will be a clear and identifiable contribution of our undergraduates to the ATLAS experiment, i.e., the ATLAS Cosmic Muon and Exotic particle array (ACME), strongly based on our extensive experience with the award winning ALTA cosmic ray array project. The ACME array would be comprised of two main pieces and underground trigger detector (see figure 22) just above ATLAS (or a suitable modification to the ATLAS trigger system) and a surface array (see figure 23) situated on the surface above the (underground) ATLAS detector.
Figure 22: The ACME trigger detector – a plastic scintillator plane suspended above ATLAS and above the ATLAS crane system.

Figure 23: ACME surface array.

E.2 Individual Contributions

B. Caron

- St. Albert Gazette, April 2010
  http://www.stalbertgazette.com/article/20100421/SAG03/304219996

D.M. Gingrich

- St. Albert Gazette, April 2010
  http://www.stalbertgazette.com/article/20100421/SAG03/304219996
R.W. Moore

- “Lasers and Diffraction”, Grade 4 classes at Michael A. Kostek elementary school as part of their “Light and Shadow: unit, June 2010.

J.L. Pinfold

F. Talks

I. Blokland

• “Comic Strips in the Classroom”, Canadian Association of Physicists Congress, Toronto, June 2010.

B. Caron


D.M. Gingrich

• “Transplanckian Physics in Early ATLAS Data”, Perimeter Institute, Waterloo, December 2009.

D.R. Grant

• “IceCube/DeepCore: A New Window to the Dark Universe”, Department of Physics Seminar, Carleton University, Ottawa, July 2009.
• “Indirect Dark Matter Searches with the IceCube Neutrino Observatory”, Joint Relativity/Cosmology/High Energy Physics Seminar Syracuse University, Syracuse, USA, October 2009.
• “DeepCore Extensions and Other Possibilities”, Low Energy Neutrino Workshop, University Park, USA, June 2010.
• A New Window to the Dark Universe”, Department of Physics Seminar, Carleton University, Ottawa, July 2009.

A.L. Hallin

• Erice International School Of Nuclear Physics: 31th Course: Neutrinos In Cosmology, In Astro-, Particle- And Nuclear Physics, Erice, Sicily, Neutrino Physics from SNO, Sep
2009


**R. MacDonald**


**R.W. Moore**

- Undergraduate Physics Conference, Edmonton, October 2009.

**J.L. Pinfold**

- “Dirac’s Dream, the Search for the Magnetic Monopole”, Physics Department, University of Perugia, Italy, December 2009.

**N. Soni**

G. Awards and Recognition

D.M. Gingrich        Honorary Research Associate, University College London, England
J.L. Pinfold        Teaching and Learning Enhancement Fund Award
J.L. Pinfold        McCalla Professorship
J.L. Pinfold        Leverhulme Foundation Award
J.L. Pinfold        Visiting Professor King’s College London, England
H. Visitors

Malbousson, A.J.C.      CBPF, Brazil
Malbousson, J.M.C.      National University of Bahina, Brazil
Ramos-Medina, J.        Lima, Peru
Revzen, M.              Technion, Israel
Santana, A.E.           University of Brasilia, Brasil
Singh, K.               Vrije Universiteit Brussel, Belgium
Szydagis, M.            University of Chicago, USA
# I. Collaborating Institutes

<table>
<thead>
<tr>
<th>Institute</th>
<th>Location</th>
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</thead>
<tbody>
<tr>
<td>CERN</td>
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<td>Fermilab</td>
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<tr>
<td>TRIUMF</td>
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