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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 50th year of the CPP covering the period 1 July 2008 to 30 June 2009.

An incident at the Large Hadron Collider (LHC) caused a shutdown of the accelerator soon after the first beam-splash events were recorded. Beam collisions are now anticipated for late fall of 2009. The ATLAS experiment is complete and awaiting collisions. The collaboration is busy preparing to commission and calibrate the detector with the first beam data. We also continue our involvement at the energy frontier on the CDF experiment at Fermilab.

Besides a major emphasis on high-energy physics, the CPP has an active component of its research program in the area of particle astrophysics. The Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) located at Sandia National Laboratories was decommissioned and the final results are being submitted for publication. The Alberta Large Area Time Coincidence Array (ALTA) continues to provide a unique educational experience for students of participating Alberta high schools and beyond.

A third faculty member was hired into the area of astroparticle physics. Darren Grant will join the CPP January 2010. Darren has considerable experience in neutrino physics and is currently performing research with the AMANDA experiment located in Antarctica. The astroparticle physics group is finishing up SNO data analysis, continuing PICASSO runs, and designing the SNO+ and DEAP/CLEAN detectors. The latter two projects have received construction funding.

We continue to successfully hold the week-long Lake Louise Winter Institute each year in February.

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
September 2009
2. Experiment Reports

2.1 ATLAS Experiment at the LHC


The ATLAS experiment is a large, multi-purpose particle physics detector that is being built for the Large Hadron Collider (LHC) accelerator at CERN. The accelerator and detector will come online in 2009. 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, jet algorithm 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.

2.1.1 LUCID and Luminosity Determination

The two LUCID detectors were installed and successfully took their first data in September 2008 in single-beam running. At the time of installation, some calibration fibres were damaged. During the shutdown, in the summer of 2009, we took part in the repair of these calibration fibres, the commissioning of eight LUCID channels read out by fused-silica fibres, and the LUMAT cards containing the final version of the LUCID front-end electronics. Additionally, we took part in a test beam program designed to study, in detail, the properties of the LUCID detector.

We have proposed a new design for LUCID aimed at high luminosity ATLAS running. This design is focused on the problems of increased background at high luminosity, possible C4F10 gas supply problems (due to environmental concerns), and the radiation tolerance problem of the detector. This new design utilizes two arrays of miniature board-mounted photomultiplier tubes (PMTs) separated by a distance of about 1.5 m and deployed in the LUCID region. A precise spatial-temporal coincidence condition is set up between the two planes for tracks pointing directly to the intersection point. A schematic view of this detector design is shown in Figure 1.

The CPP group is leading the project to prepare a dedicated online software application to find the transverse overlap beam size $\Sigma$ during a Van der Meer scan of proton beams. This software package is called the online beam separation scan package. During the Van der Meer scan of a beam, the LHC machine will provide the separation parameters and at the same time various luminosity detectors will provide the luminosity values. The beam separation scan package will combine the information from both the LHC and luminosity detectors, and will produce the results to find the $\Sigma$ of the beam. This package will also collect information from the beam position monitor that is essential for finding the correct position of a beam during the scan, and it will also produce various diagnostic plots during the scan.
2.1.2 Jet Algorithm Studies

To maximize the performance of the ATLAS calorimeter, a variety of techniques must be used to calibrate the jet algorithms. Seema Bahinipati performed a systematic study of a variety of jet algorithms and calibration approaches on Monte Carlo-simulated string ball events. The results for the jet-finding efficiency versus jet energy are shown in Figure 2.
2.1.3 Preparation for Physics Analysis

The CPP group works on a variety of physics topics in order to be prepared for full ATLAS data-taking in 2010. These topics usually form the subject of graduate student thesis.

Seema Bahinipati, Jiansen Lu, Doug Gingrich, and a summer student (Kevin Martell) 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, our main result was to predict cross section limits for a type of quantum black hole in string theory (string ball). Figure 3 shows that a simple model for the cross section could be ruled out with a small amount of early data. Using a model for string balls (also developed by CPP members) best limits on the Planck scale and string scale could be set with 2010 data.

![Figure 3: String ball cross section upper limits assuming a luminosity of 100 pb⁻¹.](image)

After several years of running at full luminosity, ATLAS will search for neutral Higgs bosons in the context of the Minimal Supersymmetric Standard Model. Jiansen Lu and Doug Gingrich participated in a study involving the tau-lepton decay modes in this model. Shown in Figure 4 are the anticipated discover reach and exclusions limits for 30 fb⁻¹ of data.

![Figure 4: Five sigma discovery potential (left) and 95% exclusion limit (right) as function of Higgs boson mass $m_A$ and ratio of vacuum expectation values $\tan\beta$.](image)
One of the most intriguing problems in particle physics is what is the nature of the dark matter that has been indirectly observed in the Universe. There is no particle in the Standard Model which is consistent with the observed data. Most theories that aim to explain the dark matter, such as Supersymmetry, introduce new particles that are massive enough that they will not yet have been produced by current accelerators.

Certain recent results suggest that we may be seeing signs of dark matter. The PAMELA satellite experiment has observed an excess of positrons coming from the centre of our galaxy, a result that was also observed by the balloon experiment ATIC and which has been confirmed by GLAST. Although an unknown astrophysical source cannot be ruled out, one possible interpretation for this excess is that dark matter particles are annihilating to form electron-positron pairs. A problem with this interpretation is that most theories also predict production of anti-protons as well as positrons but the same experiments observe no anti-proton excess.

In 2008 Nima Arkani-Hamed et al. published a dark matter model that could explain such a discrepancy. Their model had the additional benefit of also possibly explaining a controversial positive result for dark matter observation claimed by the DAMA experiment. The theory introduces a complex dark matter sector, which has “dark photons” that weakly couple to Standard Model particles. The mass of these bosons is low enough that they are kinematically constrained to decay predominantly to Standard Model electrons and muons. In most models, the “dark photon” can decay into other dark bosons, which then decay into electrons and/or muons. This results in a striking experimental signature consisting of jets of electrons and/or muons hitting the detector.

Since such an experimental signature has not been suggested before, it presents a challenge to both determine and then optimize the triggering and reconstruction of such events in ATLAS. The very low cross section means that a high trigger and reconstruction efficiency is important, but this is hampered by the low transverse momentum for most of the events. In addition, the close proximity of multiple tracks may present difficulties for the ATLAS tracking system and, in the case of electron jets, there may be a very significant background from parton jets (which have a very large production cross section) that have a large electromagnetic fraction.

Following a presentation at the Lake Louise Winter Institute in February 2009 by Professor Arkani-Hamed, the CPP group have been leading the effort to study the ATLAS trigger and detector acceptances for jets of leptons. The model considered for these studies is the one developed by Dr. Itay Yavin of Princeton and for which a Monte Carlo simulator is available. These studies are still in progress and initial results should be available soon.

In supergravity, where the gravitino is the lightest supersymmetric particle, the next-to-lightest supersymmetric particle (NLSP) decays to the gravitino with a naturally long lifetime ($10^4 - 10^8$ s). However, cosmological constraints favour charged sleptons with lifetimes below a year as the natural NLSP candidate. For this scenario, we have a novel method to accurately determine the slepton lifetime and SUSY cross section from observation of the decays of sleptons trapped in the detector itself.

The CPP is actively involved in the group planning to make precision measurements of the following ratios:

$$R_{WZ} = \frac{(W + n \text{ jets})}{(Z + n \text{ jets})}$$
$$R_W = \frac{(W + n \text{ jets})}{(W + (n + 1) \text{ jets})}$$
\[ R_Z = \frac{Z + n \text{ jets}}{Z + (n + 1) \text{ jets}}, \]

where \( n = 0 \) to 6. We are particularly interested in the channels where the vector bosons decay to \( W \rightarrow \mu \nu \) and \( Z \rightarrow \mu \mu \). The advantage of measuring these ratios is that certain experimental quantities that one might expect are not 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 the Tevatron.

We proposed a measurement on the double ratio \( R = R_W/R_Z \) at different jet multiplicities to investigate that 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. In this endeavour, we are collaborating with Jeppe Andersen who has performed the required higher-order calculations, where the number of jets exceeds two and can reach as high as six.

**2.2 CDF Experiment at Fermilab**

*J.L. Pinfold, L. Zhang*

In CDF, we have observed the reactions \( p\bar{p} \rightarrow p + X + p \), with \( X \) being a centrally produced \( J/\psi, \psi(2S), \) or \( \chi_c^0 \), and \( gg \rightarrow \mu^+\mu^- \) in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \) TeV. The event signature requires two oppositely charged central muons, and either no other particles or one additional photon to be detected. Exclusive vector meson production is as expected for elastic photoproduction, \( \gamma p \rightarrow J/\psi(2S) + p \), observed here for the first time in hadron-hadron collisions. The \( M_{\mu\mu} \) spectrum from 3 GeV/c^2 to 4 GeV/c^2 is shown in Figure 5.

![Figure 5: Dimuon mass distribution (histogram) together with a fit to the \( J/\psi \) and \( \psi(2S) \) signal. Inset: Data above the \( J/\psi \) and excluding \( 3.65 < M_{\mu\mu} < 3.75 \) GeV/c^2 [\( \psi(2S) \)] with the fit to the quantum electrodynamics spectrum times acceptance.](image)
We also observed exclusive $\chi^0_c \rightarrow J/\psi + \gamma$. The cross sections $d\sigma/dy|_{y=0}$ for $J/\psi$, $\psi(2S)$ and $\chi^0_c$ are $3.92 \pm 0.25\text{(stat)} \pm 0.52\text{(syst)}$ nb, $0.53 \pm 0.09\text{(stat)} \pm 0.10\text{(syst)}$ nb, and $76 \pm 10\text{(stat)} \pm 10\text{(syst)}$ nb, respectively, and the continuum is consistent with quantum electrodynamics. We put an upper limit on the cross section for Odderon exchange in exclusive $J/\psi$ production. The photoproduction process has previously been studied in electron-proton collisions at HERA, with similar kinematics ($\sqrt{s} (\gamma p) = 100$ GeV), and the cross sections are in agreement.

The observations described above were named as the 16 October 2008 “Result of the Week” at Fermilab. This is the second time that Fermilab’s Result of the Week has highlighted the work of the CPP CDF group.

We searched for exclusive $Z$ boson production in CDF data at $\sqrt{s} = 1.96$ TeV. The Feynman diagrams that contribute to this process are shown in Figure 6. No exclusive $Z \rightarrow l^+ l^-$ candidates were observed and the first upper limit on the exclusive $Z$ cross section in hadron collisions is found to be $\sigma_{\text{excl}}(Z) < 0.96$ pb at 95% confidence level. This upper limit on the photoproduction of the $Z$ is at a level about 3,000 times higher than Standard Model predictions.

![Figure 6](image-url) (a) Exclusive photoproduction of a $Z$ boson and (b) exclusive dilepton production via two-photon exchange.

### 2.3 SNO Experiment at SNOLAB

_B. Beltran, S. Habib, A.L. Hallin, M. Hedayatipoor, C. Howard, C. Krauss_

The Sudbury Neutrino Observatory (SNO) is a 1,000 T heavy water detector located at the SNOLAB underground laboratory outside Sudbury, Ontario. The detector started to operate in 1999, and has measured the total flux of all neutrinos from the sun, and the flux and energy spectrum of electron neutrinos from the sun. We have shown that solar neutrinos oscillate, thus that neutrinos have mass, and have measured the neutrino mixing angle and difference in mass squared.

There are three reactions in SNO that are sensitive to neutrinos:

\[
\begin{align*}
\nu_e + d &\rightarrow e^- + p + p \quad (\text{Charged Current, CC}) \\
\nu_x + d &\rightarrow \nu_x + p + n \quad (\text{Neutral Current, NC}) \\
\nu_x + e^- &\rightarrow \nu_x + e^- \quad (\text{Electron Scattering, ES})
\end{align*}
\]
where $\nu_e, \nu_x$ refer to electron-neutrinos and neutrinos of arbitrary type, while $d, p, n,$ and $e^-$ refer to deuteron, proton, neutron, and electron, respectively. The NC reaction has equal sensitivity to all three types of neutrinos, while the CC reaction allows the measurement of the flux and energy spectrum of electron-neutrinos.

During 2008, the collaboration published the first results based on the third phase of SNO. In this phase, neutrons from the NC reaction were detected with very low background using $^3$He proportional counters, which were deployed throughout the heavy water volume on a rectangular grid. Neutrons were detected by the reaction

$$n + ^3\text{He} \rightarrow p + t + 764 \text{ keV},$$

where the protons and tritons generate an ionization track within the counters.

The analysis of the third phase data was completed, presented at the Neutrinos 2008 conference, and published in Physical Review Letters. The total active $^8\text{B}$ solar neutrino flux, measured in a way that is independent of the previous SNO results, is found to be $5.54^{+0.33}_{-0.31} (\text{stat})^{+0.36}_{-0.34} (\text{syst}) \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$, in agreement with previous measurements and standard solar models. The global analysis of solar and reactor neutrino results yields $\Delta m^2 = 7.94^{+0.42}_{-0.36} \times 10^{-5} \text{ eV}^2$ and $\theta = 33.8^{+1.4}_{-1.3}$ degrees.

The collaboration has also completed an analysis of the high energy muons that travel through the detector, based on the entire 1,229-day operating period. The cosmic-ray muon flux at SNO depths, shown in Figure 7, is measured to be $3.31 \pm 0.01 \text{ (stat)} \pm 0.09 \text{ (syst)} \times 10^{10} \text{ cm}^{-2}\text{s}^{-1}$. The zenith angle distribution, shown in Figure 8, is consistent with previously measured atmospheric neutrino oscillation parameters. The depth of SNO means that muon-neutrinos can be measured from above the horizon, in a regime where neutrino oscillations are not an important effect.

Figure 7: Flux of cosmic-ray muons as a function of standard rock depth. SNO data (filled circles) shown with best global fit intensity distribution (dashed line), and data from the LVD (empty circles) and MACRO (triangles) detectors.
Figure 8: Distribution of through-going neutrino-induced muons as a function of zenith angle. Data (crosses) are shown with the best-fit simulated spectra of \((\phi_0, \sin^2 2\theta, \Delta m^2) = (1.22 \pm 0.10, 1.00, 2.6 \times 10^{-3} \text{eV}^2)\) (solid box) and prediction with no neutrino oscillation and a best-fit normalization of \(\phi_0 = 1.09 \pm 0.08\) (hashed box). The background due to cosmic-ray muons is shown in the dashed line. The zenith angle cut is indicated in the figure.

Three major SNO solar neutrino analyses continue. The low-energy threshold analysis, which is almost complete, combines the results from the first and second phases of SNO, with significantly increased accuracy. A final, three phase analysis will combine all three phases. This analysis is the central part of Shahnoor Habib’s thesis. We are also doing a three phase analysis in which we look for the previously undetected high energy solar neutrino flux. This is Chris Howard’s thesis.

2.4 PICASSO Experiment at SNOLAB

B. Beltran, C. Krauss, R. Macdonald

PICASSO is a dominantly Canadian experiment that aims to find dark matter and measure properties of spin carrying dark matter particles that could contribute to as much as two thirds to the matter of the universe. The PICASSO detectors use the bubble detector technique. In bubble detectors, interactions with dark matter particles cause nuclear recoils in the active material superheated Freon. The energy deposited by the nucleus causes the superheated liquid to evaporate, creating a shock wave that is picked up by microphones. The experiment is installed at SNOLAB in Sudbury, Ontario.

In 2008, the underground experiment was completed and data taking with 32 detectors started. The system now has an active mass of 1.9 kg of Fluorine or 2.4 kg of Freon. Several trips by CPP researchers to SNOLAB helped to complete the installation of the system. The CPP was responsible for the electronics production, data acquisition maintenance, and data quality. A significant effort in the production of preamplifiers for PICASSO was taken over by the CPP electronics shop. In addition, new stronger detector containers have been developed and constructed at the CPP. These new detector containers are currently being tested.

In summer 2009, PICASSO published an analysis of data acquired during the last two years with just two detectors (see Figure 9). PICASSO was able to set the lowest limit in a direct
search for nucleon proton interactions thus eliminating the standard interpretation of the DAMA observation. Berta Beltran presented these results at the TAUP 2009 conference in Rome, Italy.

![Graph showing cross section limit set by PICASSO for neutralino-proton interactions in fluorine.](image)

**Figure 9:** Cross section limit set by PICASSO for neutralino-proton interactions in fluorine.

Last year’s discovery of a discrimination effect that allows us to distinguish events from neutrons from alpha-induced events will be used for future PICASSO data. It will allow us to suppress alpha background from nuclear recoil events and therefore help improve the sensitivity of the experiment. The CPP group continues to lead the effort of analyzing data from the new detectors.

### 2.5 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. STACEE has finished observing and the telescope was decommissioned during June-July 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 and H 1426+428 (see Figure 10) have not produced detections.
2.6 SLIM Experiment

J.L. Pinfold

The SLIM experiment at the Chacaltaya high altitude laboratory was sensitive to nuclearites and Q-balls which could be present in the cosmic radiation as possible dark matter components. It was sensitive also to strangelets, i.e., small lumps of strange quark matter predicted at such altitudes by various phenomenological models. The analysis of 427 m² of nuclear track detectors exposed for 4.2 years showed no candidate event. New upper limits on the flux of downgoing nuclearites and Q-balls at the 90% confidence level were established by the SLIM Collaboration and published this year. The null result also restricts models for strangelets propagating through the earth’s atmosphere.

It was conjectured a few decades ago that strange quark matter (SQM) composed of approximately the same number of up, down, and strange quarks could be more tightly bound than ordinary nuclear matter. SQM nuggets could be stable for all baryon numbers in the range between ordinary heavy nuclei and neutron stars \((A < 10^{57})\). They may have been produced in the early Universe, and could be present in the cosmic radiation as a possible component of the galactic cold dark matter (with typical velocities of \(<10^{-3} c\)).

As the strange quark is massive compared to the almost massless up and down quarks, surface tensions lead to the suppression of a few strange quarks. Thus, SQM should have a relatively small positive electric charge compared to that of heavy nuclei. In what follows, large quark nuggets neutralized by captured electrons are called nuclearites. Otherwise, and generally for small baryon numbers \((A < 10^6)\), they are assumed to be quasi totally ionized. These SQM nuggets are called strangelets.

Q-balls are hypothetical coherent states of squarks, sleptons, and the Higgs fields that can occur in supersymmetric extensions of the Standard Model of particle physics. Q-balls could
have been copiously produced in the early universe and may have survived till now as a dark matter component. Their general properties are different from those of SQM but in some cases, the flux limits derived for nuclearites can apply also to them.

The limits placed by the SLIM Collaboration on nuclearites and strangelets from the cosmos are given below in Figure 15 and Figure 16, respectively.

Figure 15: 90% confidence level flux upper limits versus mass for intermediate and high mass nuclearites with $\beta = 10^{-3}$ obtained from various searches with nuclear track detectors. The combined flux from MACRO and SLIM is also shown.

Figure 16: 90% confidence level flux upper limits versus $A$ for relativistic strangelets as set by experiments onboard balloons, space-borne experiments, and by SLIM at mountain altitude. The lines are the expected fluxes based on different models: solid line for CFL strangelets, dashed line for ordinary strangelets, and dotted line as evaluated in other experiments. The SLIM upper limit is shown for three different $\beta$ values at the detector level.
2.7 ALTA-COSMOS Project

*J.L. Pinfold, R. Soluk*

The CPP, the Institute of Experimental and Applied Physics of the Czech Technical University in Prague, and the Faculty of Philosophy and Science of the Silesian University in Opava have realized a project that produced its first results this year, for the detection of high energy cosmic rays. In the experiment, a relatively sparse network of detection stations is being built. The detection network covering the area in Canada is called ALTA - Alberta Large-area Time coincidence Array (see Figure 11) and the network located in the Czech Republic is named CZELTA - CZEch Large-area Time coincidence Array (see Figure 12). The hardware of the station is identical for both sub-networks ALTA and CZELTA.
The primary objective of the common project ALTA/CZELTA is to find correlations in the arrival times of air showers over large distances and to find the non-random component of air showers arriving at a single site. The detection stations are placed mainly on the roofs of high school buildings in Canada and the Czech Republic. Students from those schools who are interested in research participate in the project. Therefore, the experiment has not only scientific, but also pedagogical impact.

Extensive Monte Carlo simulations have been provided using the CORSIKA package. The showers were simulated with the perpendicular direction aimed to the centre of the detection triangle. The probability of a shower detection depends on the length and density of penetrated atmospheric column. Therefore, the minimal energy of a primary particle, which can produce a detectable shower, strongly increases with the zenith angle.

The data analysis is connected with the phenomena of large area coincidences. Analyses take into account only times of registration of showers and not directions of primary particles. Let us suppose the detection of events by a single station is a Poisson process. If the total length of overlapping measurement by two station with mean detected frequency $1/\lambda_1$ and $1/\lambda_2$ (mean time intervals between two consecutive events) is $\tau$, the probability of observing of $k$ pairs of randomly correlated events by both stations in a time window with length $t_{12}$ is, $P_2(k) = \frac{(x_2^k)}{k!}e^{-x_2}$, where an expected number of observed pairs $x_2$ can be computed as $x_2 = (2t_{12}/\lambda_1\lambda_2)$. For triple coincidences, we can derive a similar formula: $P_3(k) = \frac{(x_3^k)}{k!}e^{-x_3}$ ($x_3 = 4\tau(t_{12}t_{13} + t_{12}t_{23} + t_{13}t_{23})(3/\lambda_1\lambda_2\lambda_3)$. For two selected stations $i, j$ ($i, j = 1, 2, 3$), we use maximal time window $t_{ij}$ computed as their distance divided by the speed of light. An initial look at the data showed no statistically significant excess of doublets or triplets in the dataset. We are carrying on the search with more sophisticated mathematical techniques and will use other properties of the shower, such as the direction of the shower.

### 2.8 SNO+ Experiment at SNOLAB

* A. Bialek, P. Gorel, A.L. Hallin, M. Hedayatipoor, C. Krauss, C. Ng, J. Soukup

The SNO+ detector is based on the existing SNO infrastructure, but instead of heavy water, the active volume will be filled with linear alkylbenzene liquid scintillator.

This will allow several physics measurements to be made:

- The scintillator will have organometallic compounds of Nd dissolved in it. This will allow a sensitive search for neutrinoless double beta decay. Normal double beta decay is shown by the reaction: $^{150}\text{Nd} \rightarrow^{150}\text{Sm} + 2e^- + 2\nu_e$ and has been measured with a half life of $7.9 \times 10^{18}$ y. Neutrinoless double beta decay will occur if neutrinos are Majorana particles (i.e. identical to their anti-particles) and will allow us to measure a very small neutrino mass. The sensitivity goals for SNO+ are at about the 100 meV scale with natural neodymium (5.6% $^{150}\text{Nd}$) and at about 30 meV with enriched neodymium.

- A precision measurement of the flux of pep solar neutrinos. These neutrinos are particularly interesting, since they are produced with an energy (1.44 MeV); at this energy the matter induced oscillations observed by SNO are predicted to be roughly equal to the vacuum oscillations observed at lower energies. Thus, oscillations at this energy probe novel physics models, including non-standard neutrino interactions and mass-varying neutrinos. These measurements are made possible because the flux of pep...
neutrinos can be calculated very precisely, and because the depth of SNOLAB suppresses the cosmogenics production of $^{11}$C, which is a large background to measurements at a more shallow depth.

- The first measurement of CNO neutrinos. These are important astrophysically – in stars only somewhat more massive than our sun, this energy production cycle dominates. In our sun, it is calculated that CNO neutrinos provide only 1.5% of the solar luminosity.

- A measurement of geo-neutrinos from the decay of uranium and thorium in the earth’s crust. The first measurement of geo-neutrinos, by Kamland in Japan, was reported in *Nature* in 2005. SNO+ will make a more precise measurement, with smaller backgrounds from nuclear reactors, and at a location dominated by continental crust.

- SNO+ will be sensitive to galactic supernova, which are essentially neutrino explosions. In particular, accurate measurements of the time profile and the neutrino fluxes will constrain the astrophysics of supernova, and how the heavy elements were formed.

- SNO+ will measure antineutrinos from reactors, and will allow for an independent measurement of reactor neutrino oscillations.

In June 2009, we received news that SNO+ was funded with a major CFI grant. We have also received NSERC support for the design and development of the detector. The major development includes a scintillator purification system, the design of a hold-down net, various modifications to the cover gas system, and the calibration systems to meet more stringent background radioactivity requirements and to ensure compatibility with the liquid scintillator.

The CPP is leading the engineering effort, and has done extensive work on understanding the stresses that will develop in the vessel with the rope basket. The basket design was chosen based on an analytic set of calculations of rope tensions. The design chosen is to minimize rope tensions and to ensure that we were not overly sensitive to small variations in rope lengths. Simutech, a Seattle based company, has done a finite element analysis showing that the stresses in the detector are acceptable. We have fabricated a test rig that will allow us to measure the interaction of ropes on a section of acrylic vessel. We are collaborating with the Civil Engineering Structures, and are using a specialized stereoscopic camera system to measure strains in acrylic.

The CPP is leading the design of access to the volume under the deck, the modifications to the calibration hardware, and the anchoring system at the bottom of the cavity.

We are also working on the development of the Monte Carlo simulation program and data analysis system for SNO+. The data volume for SNO+ is significantly greater than it was for SNO; and the scintillator has significantly different physical properties. Our work has included the modification of a position fitter from SNO to allow it to work with scintillation light. We have found a simulated resolution of roughly 10 cm. SNO used an automated system of scripts to process data and Monte Carlo simulated data. We have taken responsibility to develop a similar system for SNO+.

### 2.9 DEAP/CLEAN Experiment at SNOLAB

*R. Hakobyan, A.L. Hallin, S. Liu, C. Ng, K. Olsen, J. Soukup*

The leading candidates for dark matter particles are so-called WIMPs, weakly interacting
massive particles. Although such particles have never been observed, they were first postulated (in a theory called supersymmetry) for particle physics reasons, and it is hoped that experiments in the next few years at the Large Hadron Collider in Switzerland might produce such particles. WIMPs would have mass comparable to atoms, but consist of single particles that interact like neutrinos. These particles are thought to pervade galaxies; our solar system is travelling through this galactic “halo” of dark matter particles at a speed of 200 km/s. Occasionally, normal matter will interact directly with a WIMP, and one would get a recoiling atom and a flash of energy without any observable cause. The DEAP/CLEAN detector at SNOLAB is designed to be able to observe such flashes, even at the ultra-low rate of one such interaction per year per ton of detector material. This extends the sensitivity for such measurements by a factor of 100, thereby leading all other international experiments by a significant margin.

The physics goals for DEAP/CLEAN necessitate that the detector maximizes the light yield to allow a threshold of 20 keVee (electron-equivalent energy) and minimizes the backgrounds from the detector materials (cryogen and detector components) and external sources (experimental hall and cosmogenics).

The nominal design for the detector is 3,600 kg of liquid argon contained in a spherical acrylic vessel (AV) with inner radius 85 cm. The vessel is viewed by 266 eight-inch photomultiplier tubes (PMTs) mounted outside the acrylic vessel. The AV/PMT assembly is thermally shielded and placed inside an 8 m water tank to shield from neutrons produced by radioactivity in the rock surrounding the experimental hall. Because of the size of the detector, it will be necessary to assemble most major systems underground. Of the 3,600 kg target mass, position reconstruction is used to create a fiducial volume of 55 cm radius containing 1,000 kg.

The CPP is designing, procuring, and fabricating the acrylic vessel. Since the inside of the acrylic vessel contains the liquid argon and the outside of the lightguides are at room temperature, the acrylic stresses are dominated by thermal effects. We have done detailed finite element calculations to establish a geometry of lightguides that allow us to maintain a safety factor of ten in the acrylic vessel.

The CPP is also working on the analysis of data and the development of electronics. We are developing and testing algorithms for extraction of single photoelectron signals and thereby determining the energy and particle type of the ionizing radiation.

2.10 MoEDAL Experiment

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

In the past year, the MoEDAL experiment has been joined by two new groups, from the Institute of Experimental and Applied Physics (IEAP) at the Czech Technical University in Prague and the Institute for Space Sciences in Bucharest-Magurele, Romania. There are a total of 23 physicists from nine institutes in six countries now involved with the experiment.

This year we deployed two test housings at the site of the deployment of the MoEDAL detector, in the VELO cavern of the LHCb experiment. Also, our derogation request to deploy flammable plastics at point 8 was approved in 2008. This deployment is shown in Figure 13. In addition, we have drilled most of holes required for the deployment of the MoEDAL detector framework. Further work cannot be contemplated until there has been a formal approval of the project by the LHCC and the CERN Research Board.
The MoEDAL Technical Design Report (TDR) was prepared in the spring and summer of 2009 and presented to the LHCC at the beginning of July. The TDR is being considered by a small panel appointed by the LHCC. This panel will subsequently submit their questions to the MoEDAL collaboration. These questions will need to be addressed at the next meeting of the LHCC in September 2009. If the LHCC is satisfied they will submit the experiment to the CERN Research Board for final approval.

2.11 AFP Project

S. Liu, J.L. Pinfold, J. Soukup

The ATLAS Forward Physics (AFP) project – an extension of the LHC FP420 R&D project – is currently under consideration by the ATLAS Collaboration. The AFP project aims to install silicon tracking and ultra-fast timing detectors (QUARTIC and GASToF) in the LHC tunnel at 240 m and 420 m from the interaction points of the ATLAS experiment. In addition, a trigger detector is being proposed for deployment at 220 m.

These detectors would measure precisely very forward protons in conjunction with the corresponding central detectors as a means to study Standard Model physics, and to search for and characterize new physics signals. The physics case for the detector is based on central exclusive production, $pp \rightarrow p + f + p$, in which the outgoing protons remain intact and the central system $f$ may be a single particle such as a Standard Model or Minimal Supersymetric Standard Model Higgs boson. Other physics topics discussed are $gg$ and $gp$ interactions, and diffractive processes.

The CPP is co-leading the development of the QUARTIC ultra-fast timing detector with the purpose of minimizing pile-up background, and leading the development of a quartz fibre trigger detector for deployment at 220 m. Specifically, in the case of QUARTIC, the CPP is leading the development of the front-end readout based around the HPTDC. We have also taken over the
responsibility for the mechanical construction of the QUARTIC detector.

In order to gain maximal benefit from the 220 m AFP detectors, it is critical to have level-1 trigger capabilities. This is a necessary requirement for triggering on a light Higgs in the case where one of the protons is in a 220 m detector, and the other is in a 420 m detector on the opposite side, and would be useful for many other physics topics. The key issues are developing a highly efficient flexibly segmentable trigger detector that can operate within the ATLAS level-1 trigger latency.

A conceptual design for a quartz fibre-based trigger detector (QFT) utilizing Cherenkov light and a micro-channel plate photomultiplier tube (McPMT) is presented in Figure 14. In this scheme, there are two identical detector units (shown with a small separation in the $z$-direction for ease of understanding, although they may be contiguous or else one could be located at $z = 216$ m and one at 224 m) each comprised of a rectangular bundle of thin clad fused-silica (or quartz) fibres. The bundle has a cross-sectional area of $2 \text{ mm} \times 12 \text{ mm} (z)$ and overall length of about 10 cm ($y$). The first 6 cm of the bundle, in the $y$-direction, is formed into a solid matrix (potted), while the last 4 cm of the fibre bundle are left free so that the fibres corresponding to various trigger regions can be mapped onto distinct regions of the McPMT.

![QUARTIC TRIGGER DETECTORS](image)

Figure 14: Conceptual design of the quartz fibre-based level-1 trigger detector.

The corresponding adjacent, regions of the two detectors (A & B) are placed in coincidence, in order to minimize noise triggers. Two fibre sizes are considered: 100 micron diameter, to ensure fine edge definition and spatial resolution; and 1.5 mm diameter, which has the advantage of ease of manufacture. One could also have a composite bundle with small diameter fibres near to the beam edge and larger fibres further from the beam edge. GEANT4-based simulations will be done to investigate the three options, and a pre-prototype will be tested in fall 2009 in test beam. The segmentation could be as small as 0.5 mm for the smaller fibre diameter, and will be optimized based on further physics, and detector simulations and testing.
From experience with the LUCID detector, and taking into account McPMT quantum efficiency and attenuation in the fibres, we estimate that a proton traversing 12 mm deep (in \( z \)) in a fused silica bundle of each detector element of the QFT would result in the order of 50 photoelectrons (PEs) captured in the McPMT. This signal level is entirely adequate to obtain the optimum response from the proposed trigger electronics discussed below.

The AFP project team now has a conceptual design of a flexible level-1 trigger and readout system capable of providing a simple trigger from the 220 m proton detectors within the required ATLAS latency period (greater than 1.9 \( \mu s \)). The detector and readout are both based on known technology, and the system would be straightforward and inexpensive to design, build and test. There are interesting opportunities for this to evolve to give more sophisticated, narrowly targeted triggers as part of the Phase-1 upgrade.
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

My research program is mainly focussed on two different topics: 1) development and applications of finite temperature field theory to diverse problems in physics; 2) developing a theory of gravity based on general covariance with local Galilean symmetry. Results on some of the important experimental measurements like the precession of the perihelion of Mercury, etc. can be easily explained.

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 16-21 February 2009. This year the organising committee decided to try a slightly different format that included only two sets of talks (by W. Unruh and E. Dudas) of pedagogical nature and the rest were of shorter duration. This allowed us to have several more speakers on diverse topics. Contributed talks were focussed on many different experiments. There was a total attendance of 75 people, including 27 students.

The funding was provided by TRIUMF, IPP, Perimeter Institute and the University of Alberta conference fund, as well as by the Dean of Science. The infrastructure support was provided by the physics department as well as TRIUMF.
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. Dave Hutcheon and Glen Stinson have retired but remain 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. In addition to the projects mentioned in this report, CPP staff are participating in experiments using the ISAC facility at TRIUMF. These include Dave Hutcheon on the TRIUMF Detector Recoils and Gammas of Nuclear Reactions (DRAGON) experiment, and the ElectroMagnetic Mass Analyser (EMMA) for the ISAC-II project. Under the new TRIUMF directorship, Andy Miller has been appointed as 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/2000 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 Andrew File System (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 44 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. An NSERC RTI (Research Tools and Instruments) award was received by the CPP experimental researchers to upgrade the existing 4-Terabyte file server, originally purchased in 2004, also through funds awarded by NSERC. The new file server will be deployed later in 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-bit and 64-bit computing using both AMD Opteron and Intel multi-core processors, acquired in August 2006. Fully integrated within the THOR Linux cluster are a series of 25 dual Intel Pentium III 1.44 Gigahertz 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 worldwide 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 Gigabit per second 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 are managed by CPP member Bryan Caron.

6.1.2 ATLAS Computing

In 2008-2009, the CPP group continued to expand the local LHC Computing Grid (LCG) configuration in preparation for data taking. The LCG Compute Element (CE) and monitoring servers, Storage Element (SE) servers, and network infrastructure (all upgraded during the previous period) performed well during the past year. The Alberta site has obtained the best values of availability and reliability during most months of 2008-2009, achieving the expected
Tier-2 criteria for these metrics.

The ATLAS Grid infrastructure resides on a CPP-dedicated network (separate from the regular physics department network) and communicates with the Tier-1 centre 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 storage element consists of five 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 four dCache pool nodes each configured with 5.5 Terabyte of disk storage. A total of approximately 22 Terabyte of storage is provided via the dCache configuration.

During 2008-2009, the evolution of ATLAS computing at the CPP continued with significant advancement in the preparations for transition of the ATLAS Tier-2 computing resources into the WestGrid-Alberta computing infrastructure obtained through the CFI National Platforms Fund. In fall 2008, an RFP was issued and subsequently awarded to SGI for the supply of a new 1,280 core Linux cluster that will provide computational and storage resources to the WestGrid community of users, as well as function as the future Tier-2 for ATLAS computing at the CPP. The new hardware arrived in spring 2009 and has been undergoing commissioning during May and June. Figure 17 shows the installed WestGrid-Alberta Linux cluster that will support ATLAS Tier-2 functions at the CPP starting in either summer or fall of 2009.

![WestGrid-Alberta Cluster “Checkers”](image)

Figure 17: WestGrid-Alberta Linux cluster with 1,280 processing cores and 80 Terabyte of storage. 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 will connect the new cluster to the WLCG and ATLAS Grid. Once fully commissioned, the new WestGrid-Alberta cluster will constitute the official Alberta portion of the Canadian Tier-2 resources, currently provided by the THOR Linux system of the CPP. Following this transition, the THOR cluster will function as the local Tier-3 resources of the ATLAS-CPP group.

In 2008-2009, greater than 135,000 jobs were submitted to the batch processing queues of the THOR Linux cluster by local users, along with another 750,000 submitted via the ATLAS Grid. Figure 18 shows the total amount of CPU utilization from jobs received by the Canadian sites contributing to the WLCG as a function of time. The WLCG setup at the CPP received 5% of the total Canadian CPU job utilization. While the TRIUMF Tier-1 dominated in 2008-2009, the utilization of the Tier-2s for analysis and simulation will increase significantly as the new resources come online.

In 2008 and 2009, ATLAS-CPP members continued to test the updated releases of the Ganga and Panda software frameworks for distributed user analysis. The Canada group within the ATLAS Virtual Organization (VO) continues to enable priority job placement and execution on Canadian computing resources at the CPP and elsewhere, with membership managed by Bryan Caron. Bryan Caron also acts as the overall coordinator for the operations of the ATLAS Tier-2 computing centres in Canada.

6.1.3 Remote Processing Farms for ATLAS Calibration and Monitoring

During the 2008-2009 period, the HLT software infrastructure continued to be maintained and utilized at the CPP, both for the testing and development for the High Level Trigger (HLT) algorithms of ATLAS, as well as for the development of real-time remote processing systems for detector calibration and monitoring (specifically the liquid argon calorimeters). Both quasi-real-time and more direct analysis of commissioning data is being investigated within the context of the ATLAS Data Quality Monitoring (DQM) framework.

![Figure 18: Distribution of total number of job CPU time by the Canadian sites of the WLCG during 2008-2009.](image)
6.1.4 Computing for Astroparticle Physics

Members of the astroparticle physics group 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 5.5 Terabyte of disk, which is fully integrated into the THOR Linux cluster environment. During 2008-2009, additional capacity was added to the storage array bringing the total available disk space to nearly 11 Terabyte.

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 2008-2009, the CPP and ATLAS made extensive use of the LightPath to TRIUMF, regularly achieving over 600 Megabit 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 Grids such as the WLCG.

6.2 Mechanical Facilities and Developments

6.2.1 Development of the LUCID Detector

The LUCID detector was installed in the ATLAS complex during the summer of 2008. At that time, we, in cooperation with CERN surveyors, installed LUCID detectors A and C on either side of the ATLAS detector, lining them up with the beam axis and the ATLAS beam intersection point. Next, we hooked up the supporting systems: the light gas handling; the shield that protects the LUCID detectors from the beam-baking heat; and the chilled water that cools the protective shield. Using cosmic rays, we tested the LUCID detector functions, including the directly coupled photomultiplier tubes; the multi-anode photomultiplier tubes that collect light at the ends of optical fibre bundles; and its data acquisition hardware and software. The extra year’s time afforded by the delayed LHC start-up has been spent fruitfully. It allowed us to repair small malfunctions; improve LUCID A and C’s performance; and gain experience about their data processing behaviour. LUCID is again ready for the new scheduled LHC start-up date of October 2009.

6.2.2 Development of the GlueX Detector Module

After some design and machining preparation work for the production of the GLUEX modules, the CPP participation in the project has been phased out. The collaboration continues in the engineering design of the heavy gas Cherenkov vessel for the SHMS spectrometer at the Jefferson Lab Hall C.

6.2.3 SNO+ and DEAP/CLEAN Detector Development

Both SNO+ and DEAP/CLEAN projects have reached the stage where various design options for their detail components need to be tested to verify their expected performance and
their levels of safety against failure.

In the SNO+ project, a test has been designed to assess the effects of the rope net pressure on the acrylic of the SNO+ vessel. For this purpose, a circular, 28-inch diameter panel has been machined out of a spare curved segment, which had been stored from the time of the vessel construction. A frame has been also designed and fabricated in the physics machine shop to stretch several typical rope junction configurations over the acrylic, which would be capable of stretching the ropes to the same or higher tension values as on the real acrylic vessel. The rope tension, increased by eye bolts, is measured by electronically instrumented load cells (see Figure 19). The resulting strains in the acrylic will be monitored by two methods: strain gauges and photo-tracing of the movement of paint speckle patterns.

![Fig. 19: Test set up for studying the effect of the rope net pressure on the SNO+ acrylic vessel.](image)

The DEAP acrylic vessel design effort has been focussing on selecting the most suitable design options for the various detailed aspects of the overall assembly. In addition to the finite element analysis simulations using ANSYS software, for which we acquired one seat of the most powerful academic package, this process requires physical testing of the anticipated performance of these features. One design decision that has been on the critical path is the finalization of the vessel neck design. CPP has proposed a short narrow acrylic neck, which would allow for relatively easy manipulation of the detector vessel during its integration. This kind of neck would then be extended with a vacuum-insulated stainless steel chimney, which couples to the acrylic of the neck via cryogenic seal (see Figure 20). Several options for the cryo-seal have been received from the industry, but none of these have been proven for our particular combination of materials and the range of working conditions. To convince the collaboration, several such O-rings have been purchased and a test set up has been designed for their performance. The assembly reflects the exact coupling flanges geometry, but, to minimize the cost, it is made shallow to make use of the remnants of the existing 4-inch thick acrylic plate, left over from other test pieces (see Figure 21). Other tests will include a complete 20-inch diameter acrylic vessel, complete with the above described vessel neck features.
6.2.4 QUARTIC Detector Development

A new prototype of the QUARTIC detector has been designed and manufactured at the CPP. It is now ready for testing at the LHC and it serves as a base for a design-improvements process at the CPP. The partially open assembly of the detector is shown in Figure 22.
6.3 Electronics Facilities and Developments

6.3.1 QUARTIC TDC Board Development

We have continued to develop a high performance time to digital converter (TDC) board based on the CERN-developed HPTDC chip. Two TDC boards, each with eight input channels have been built (see Figure 23). Non-linearity correction has been done, bench test and laser excited MCP-PMT tests have showed an RMS resolution around 15 ps has been obtained.
6.3.2 Radon-Suppressed Laboratory Monitor DAQ System

New bias structures for the radon detector were designed, with new preamplifier and shaping circuit boards. A final version of data acquisition (DAQ) board with eight multi-channel analyser (MCA) input channels and 12 slow input channels has been developed (see Figure 24).

Figure 24: DAQ board with eight MCA inputs and 12 slow input channels built at the CPP.

6.3.3 DEAP PMT Test Setup

We have built a test setup for the Hamamatsu R877-100 PMT, with fast preamplifier prototypes (see Figure 25).

Figure 25: Fast preamplifier prototypes for PMT tests for DEAP.
6.3.4 PICASSO Preamplifier Board and Power Supply Board Development

We assembled and tested 150 preamplifiers and eight data acquisition boards for PICASSO.

6.4 Radon-Suppressed Laboratory

A radon suppressed laboratory is being designed and will soon be under construction in CEB B36. Such a laboratory will allow the construction and testing of very sensitive detectors, such as the active elements of DEAP/Clean or the SNO+ calibration devices to be built without contamination from radon daughters in the air.

The current status of the laboratory is that renovations of B36 have been largely completed. The compressor, dryer, and filtration systems and the stainless steel tanks for the absorption system have been delivered. The clean room enclosure has been tendered and a vendor has been selected. We have built and are testing an electrostatic chamber that allows us to measure radon daughters from radon emanation and in an air vent.

The process flow system for the radon stripper has been designed by an engineering firm, KMPS. The radon stripping system works by compressing air, cooling it, and passing it through activated carbon columns. The process of adsorption leads to a condition in which it takes much longer for radon to travel through the column than do nitrogen or oxygen. At the point radon has traversed most of the column, the columns are “purged” with clean air, and the radon removed. We are starting to procure the essential elements of the system: the columns, the compressor, and various valves.

6.5 Low-Background Counting Laboratory

An important part of neutrino and dark matter research is the aspect of achieving low count rates by reducing backgrounds. The CPP is building a low background counting facility to support the dark matter and neutrino physics research, and to further advance the methods and techniques used in low background applications. This facility will be used in conjunction with the radon free environment. 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 being evaluated.

Figure 26 shows a new, large volume radon emanation system. This system will allow to evaluate how much radon gas is emanating from materials and therefore allow the selection of materials with a high radio purity.

Currently, a PICASSO calibration system is being assembled. This system will allow a more precise determination of the detector response to gamma rays.
Figure 26: Radon emanation chamber in laboratory B31B.
Appendices

A. Centre for Particle Physics Personnel, 2008-2009

A.1 Teaching and Research Staff

Blokland, Ian Adjunct Assistant Professor (Augustana Campus, Univ. of Alberta)
Caron, Bryan Adjunct Assistant Professor/TRIUMF (Computing Data Support)
Czarnecki, Andrzej Professor of Physics
de Montigny, Marc Visiting Professor (Campus Saint-Jean, University of Alberta)
Faszer, Wayne* TRIUMF Detector Engineer Physicist
Gingrich, Douglas Professor of Physics/TRIUMF; Director of CPP
Hallin, Aksel Professor of Physics (CRC Chair in Astroparticle Physics)
Hutcheon, Dave* TRIUMF Sr. Research Scientist Emeritus
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
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
Cuzinatto, Rocha  Postdoctoral Fellow
Gorel, Pierre  Postdoctoral Fellow
Hakobyan, Rafael  Research Associate
Hedayatipoor, Mohammad  Research Associate
Kim, Min Suk  Research Associate
MacDonald, Robert  Postdoctoral Fellow
Mondejar, Jorge  Postdoctoral Fellow
Lu, Jiansen  Research Associate
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

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)
Peters, Travis  Technician (Mechanical)
Tomasevic, Boris  Technician (Mechanical)
Wampler, Len  Technician (Electronics)
Zimmermann, Paul  Technician (Mechanical)
A.5 Graduate Students

Ahmed, Hossain      D.M. Gingrich     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
Pak, Alexey         A. Czarnecki      PhD   Theory
Saddique, Asif      J.L. Pinfold      PhD   ATLAS
Swedish, Stephen    J.L. Pinfold      MSc   ATLAS
Ting, Wei-yuan      J.L. Pinfold      PhD   ATLAS
Zhang, Long         J.L. Pinfold      MSc   CDF

A.6 Summer and Visiting Students

Amorim, Ronni       de Montigny and Khanna (University of Brasilia, Brazil)
Beaudry, Joel (NSERC)  ATLAS
Breitkreutz, Dylan (NSERC)  Blokland
Gordon Wolfé, Adam    ATLAS
Hauer, Brad          PICASSO
Marcu, Simona (NSERC)  ATLAS
Martell, Kevin (NSERC)  ATLAS
Newman, Ward         PICASSO
Nicholson, Michael   PICASSO
Olson, Lane (NSERC)  Blokland
Pompeia, Pedro       de Montigny and Khanna (University of Sao Paulo, Brazil)
Schultz, Ryan        ATLAS
Sinn, David          ATLAS
Troitskaia, Alice (NSERC)  ATLAS
Zhang, Carson        DEAP/CLEAN
B. Student Theses


- Long Zhang, M.Sc., (J.L. Pinfold), “Observation of Exclusive Charmonium Production and $\gamma\gamma \rightarrow \mu^+\mu^-$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, 2 October 2008. Now data analyst at Centre for Particle Physics.
C. Publications in Refereed Journals

C.1. ATLAS Papers


C.2. CDF Papers

T. Aaltonen et al., “Observation of Exclusive Charmonium Production and $\gamma\gamma \rightarrow \mu^+\mu^-$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. Lett. 102 (2009) 242001.

T. Aaltonen et al., “Search for Exclusive Z-Boson Production and Observation of High-Mass $p\bar{p} \rightarrow pp\gamma \rightarrow p\gamma ll'$ Events in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. Lett 102 (2009) 222002.

C.3. DØ Papers


V.M. Abazov et al., “ZZ $\rightarrow l^+l^-\nu\bar{\nu}$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. D 78 (2008) 072002.


V.M. Abazov et al., “Measurement of the Inclusive Jet Cross Section in $p\bar{p}$ Collisions at


V.M. Abazov et al., “Measurement of the Forward-Backward Charge Asymmetry and Extraction of sin\(^2\) \( \Theta_{WW}^{ef} \) in \( p \bar{p} \rightarrow Z/\gamma^* + X \rightarrow e^+e^- + X \) Events Produced at \( \sqrt{s} = 1.96 \) TeV”, Phys. Rev. Lett. 101 (2008) 191801.


V.M. Abazov et al., “Search for Decay of a Fermiophobic Higgs Boson \( h_f \rightarrow \gamma\gamma \) with the DØ Detector at \( \sqrt{s} = 1.96 \) TeV”, Phys. Rev. Lett. 101 (2008) 051801.


V.M. Abazov et al., “Measurement of the Polarization of the Y(1S) and Y(2S) States in \( p \bar{p} \) Collisions at \( \sqrt{s} = 1.96 \) TeV”, Phys. Rev. Lett. 101 (2008) 182004.


V.M. Abazov et al., “Measurement of the Semileptonic Branching Ratio of $B_s^0$ to an Orbitally Excited $D_s^{**}$ State: $Br(B_s^0 \rightarrow D_{s1}^+(2536)\mu^+\nu\chi')$”, Phys. Rev. Lett. 102 (2009) 051801.

V.M. Abazov et al., “Measurement of the $Z\gamma \rightarrow \nu\bar{\nu}$ Production Cross Section and Limits on Anomalous $ZZ\gamma$ and $Z\gamma\gamma$ Couplings in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. Lett. 102 (2009) 201802.


V.M. Abazov et al., “Search for Neutral Higgs Bosons at High $\tan\beta$ in the $b(h/H/A)\rightarrow b\tau^+\tau^-$ Channel”, Phys. Rev. Lett. 102 (2009) 051804.


V.M. Abazov et al., “Measurement of $\gamma + b + X$ and $\gamma + c + X$ Production Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. Lett. 102 (2009) 192002.


V.M. Abazov et al., “Measurement of $\sigma(p\bar{p} \to Z + X) Br(Z \to \tau^+\tau^-)$ at $\sqrt{s} = 1.96$ TeV”, Phys. Lett. B 670 (2009) 292-299.


V.M. Abazov et al., “Measurement of the Angular and Lifetime Parameters of the Decays $B_d^0 \to J/\psi K^0$ and $B_s^0 \to J/\psi\phi$”, Phys. Rev. Lett. 102 (2009) 032001.

V.M. Abazov et al., “Evidence for the Decay $B_s^0 \to D^*(s)D^*(s)$ and a Measurement of $\Delta\Gamma_s^{CP}/\Gamma_s$”, Phys. Rev. Lett. 102 (2009) 091801.


C.4. SNO Papers


C.5. PICASSO Papers


C.6. STACEE Papers


C.7 OPAL Papers


C.8. SLIM Papers


C.9. Theory and Phenomenology Papers


D. Conference Contributions


E. Other Publications


The ATLAS Collaboration, E. Barbero et al., “Discovery Potential of $h/A/H \rightarrow \tau^+\tau^- \rightarrow \ell\ell 4\nu$”, ATL-PHYS-PUB-2009-059.


F. Outreach Activities

I. Blokland


D.M. Gingrich


A.L. Hallin

- “One Night of Reality”, Art Gallery of Alberta, Edmonton, panel presentation and discussion, June 2009.

R.W. Moore

- “ATLAS and the LHC” local presentation; interviews with Global TV, City TV, CBC Radio’s Radioactive (Edmonton), Edmonton Journal and Gateway.

J.L. Pinfold

F. Talks

B. Beltran
- “Results from the PICASSO experiment”, TAUP 2009 in Rome, Italy.

B. Caron

D.M. Gingrich

A.L. Hallin

C. Krauss
- “The SNO+ Double Beta Decay Experiment”, TAUP 2009, Rome Italy.

J.L. Pinfold
- “The ATLAS Forward Physics Program”, XVII International Workshop on Deep-


- “High Precision TDC Readout of QUARTIC”, Forward Physics at the LHC Meeting, Manchester University, 6-8 December 2008.

- “Exclusive Charmonium Production and $\gamma \gamma \rightarrow \mu^+ \mu^-$ at CDF”, Forward Physics at the LHC Meeting, Manchester University, 6-8 December 2008.


- “Exclusive production of lepton pairs, $J/\psi$, $\psi'$ and $Y$ at CDF”, Low-$x$ Meeting, at Kolimpari, Crete, Greece, 6-10 July 2008.
G. Awards and Recognition

I. Blokland  Augustana Faculty Teaching Award
I. Blokland  University of Alberta Provost’s Award for Early Achievement of Excellence in Undergraduate Teaching
D.M. Gingrich  Honorary Research Fellow, University College London, England
J.L. Pinfold  McCalla Professorship
J.L. Pinfold  The Leverhulme Trust Award (Unilever Ltd)
J.L. Pinfold  Visiting Professor King’s College London, England
H. Visitors

Buchanan, N.J. Colorado State University, USA
Cooley, J. Stanford University, USA
Galbiati, C. Princeton University, USA
Grant, D. Pennsylvania State University, USA
Kobayashi, M. Gifu University, Japan
Malbousson, A.J.C. CBPF
Malbousson, J.M.C. Federal University of Bahia
Oser, S. University of British Columbia, Canada
Ramos, J. Lima, Peru
Revzen, M. Technion, Israel
Santana, A.E. Federal University of Brasilia, Brasil
I. Collaborating Institutes

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<tr>
<th>Institution</th>
<th>Location</th>
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<tbody>
<tr>
<td>CERN</td>
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<tr>
<td>TRIUMF</td>
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