CHEP

Centre for High Energy Physics

McGill University

Annual Report 2005–2006

(June 2005 – May 2006)

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Edited by F. Corriveau

Contents

1 Introduction

This 2005-2006 report is a summary of the activities of our members. After the membership is presented, the numerous research activities are described. Our our rich seminar program and the list of publications are made separately available.

This report being the first centrally available from the McGill Research Units web server, will se the detailed activities be presented here once again at length.

Since the Centre is primarily devoted to research and the principal members all have faculty positions in the Physics Department, academic matters, teaching, funding and consulting activities are identical and will not be repeated here. *Please consult the annual report of the Department for details.*

2 Our Centre

Subatomic physics is at the leading edge of fundamental research. It addresses essentially the structure of matter and its interactions. All the known particles of matter can be described as combinations of a very few building blocks, the quarks and the leptons, representing 2 families of 6 particles. Four types of forces have been identified in nature: gravitational, electromagnetic, strong and weak. Illustrating examples could be planetary systems, light emission from atoms, existence of nuclei or slow nuclear disintegrations, respectively. Two of the great scientific achievements of the past decades have been the discovery of the 6th quark "top", and the unification of the electromagnetic and weak interactions as manifestations of a single electro-weak process. Further promising unification efforts are currently being done to include the strong interaction and later on gravitation.

This bold program is carried out experimentally in a few large international collaborations. Our experimental groups are involved in the foremost projects at research centers in the USA and Europe. They contribute significantly to all steps of the projects, from detector construction via detailed data analysis to interpretation and understanding of the results. The theoretical approach is also extremely strong and fully complementary. It moreover can be shown that very high energy phenomena, in astrophysics or cosmology, are ultimately but other aspects of our research axes and therefore are also investigated. The scales and complexity of the field, but also the many scientific and technical ramifications represent the unique characteristics of our Centre and strengthens its dynamics as a research entity.

Our members endeavor to use the Centre to deepen our research efforts, to create an even more stimulating environment for extended collaborations and research, to improve recruitment and formation of young researchers and graduate students, and to coordinate all our common activities. This is being achieved through seminar series, conference and visitor programs, computer network unification, sharing of laboratories and equipment, extensive exchanges of experience and know-how, and development of applications. The "McGill Centre for High Energy Physics" has an almost 20-year long tradition, was already re-structured considerably in 1995 and underwent two years ago another transformation as several new young faculty members joined our efforts and promoted new directions.

3 Composition of the Centre

As will be seen in the next section on research, the Centre membership spans large areas of studies in the fields of high energy physics, particle physics, cosmology, astrophysics and many aspects of nuclear physics. In the following tables, the lists of members are presented, each roughly identified by his/her experimental (X) or theoretical (T) orientation, as well as the general domains of high-energy physics (HEP), nuclear physics (NP) or astro-particle physics (Astro).

Faculty Members

1	Barrette, Jean	McGill University	XNP
2	Brandenberger, Robert	CRC/McGill University	THEP
3	Buchinger, Fritz	McGill University	XNP
4	Cline, James M.	McGill University	THEP
5	Corriveau, François	IPP/McGill University	XHEP
6	Crawford, John	McGill University	XNP
7	Das Gupta, Subal	McGill University	TNP
8	Dasgupta, Keshav	McGill University	THEP
9	Dobbs, Matt	CRC/McGill University	Astro
10	de Takacsy, Nick	McGill University	TNP
11	Gale, Charles	McGill University	TNP
12	Grisaru, Marc	McGill University	THEP
13	Hanna, David S.	McGill University	Astro
14	Jeon, Sangyong	McGill University	TNP
15	Lee, Jonathan	McGill University	XNP
16	Moore, Guy D.	McGill University	THEP
17	Moore, Robert	McGill University	XNP
18	Patel, Popat M.	McGill University	XHEP
19	Ragan, Kenneth	McGill University	Astro
20	Robertson, Steven	IPP/McGill University	XHEP
21	Stairs, Douglas G.	McGill University	XHEP
22	Vachon, Brigitte	CRC/McGill University	XHEP
23	Warburton, Andreas	McGill University	XHEP

Post-Docs and Research Associates

1	Biswas, Tirhabir	McGill University	Postdoc	THEP
2	de Rham, Claudia	McGill University	RA	THEP
3	Gulik, Sidney	McGill University	RA	XNP
4	Katlai, Balaji	McGill University	Postdoc	THEP
5	Kildea, John	McGill University	RA	Astro
6	Knutt, Marcia	Visitor	Lecturer	THEP
7	Mansouri, Reza	Senior Visitor	Postdoc	THEP
8	Notari, Alessio	McGill University	Postdoc	THEP
9	Potter, Chris	McGill University	RA	XHEP
10	Shi, Lijun	McGill University	Postdoc	TNP
11	Stoica, Horace	McGill University	Postdoc	THEP
12	Topor Pop, Vasile	McGill University	RA	XNP
13	Torrieri, Giorgio	McGill University	Postdoc	TNP
14	Santamaria, Cibran	McGill University	RA	XHEP
15	Walsh, Roberval	McGill University	RA	XHEP

Professionals and Technicians

1	Mercure, Paul	McGill University	System manager
2	Nikkinen, Leo	McGill University	Technician

Graduate Students

1	Barnaby, Neil	McGill University	Ph.D.	THEP
2	Bélanger-Champagne, Camille	McGill University	M.Sc.	XHEP
3	Berndsen, Aaron	McGill University	Ph.D.	THEP
4	Biron, Alexandre	McGill University	M.Sc.	XHEP
5	Blomeley, Laura	McGill University	M.Sc.	XNP
6	Bourque, François-Alex	McGill University	Ph.D.	TNP
7	Buzatu, Adrian	McGill University	M.Sc.	XHEP
8	Campbell, Benjamin	McGill University	M.Sc.	XHEP
9	Caron-Huot, Simon	McGill University	M.Sc.	THEP
10	Chen, Fang	McGill University	M.Sc.	THEP
11	Cocolios, Thomas	McGill University	M.Sc.	XNP
12	Elliot, Joshua	McGill University	M.Sc.	THEP
13	Fillion-Gourdeau, François	McGill University	Ph.D.	TNP
14	Fortin, Pascal	McGill University	Ph.D.	Astro
15	Gagnon, Jean-Philippe	McGill University	M.Sc.	TNP
16	Gagnon, Jean-Sébastien	McGill University	Ph.D.	TNP
17	Gianfrancesco, Omar	McGill University	Ph.D.	XNP
18	Gwyn, Rhiannon	McGill University	Ph.D.	THEP
19	Harnois-Deraps, Joachim	McGill University	M.Sc.	XHEP
20	Heredia-Ortiz, Roberto	McGill University	Ph.D.	TNP
21	Hoi, Loison	McGill University	M.Sc.	THEP
22	Hoover, Douglas	McGill University	Ph.D.	THEP
23	Kertzscher, Gustavo	McGill University	M.Sc.	XHEP
24	Klemetti, Miika	McGill University	M.Sc.	XHEP
25	Li, Gang	McGill University	M.Sc.	XNP
26	Lindner, Thomas	McGill University	Ph.D.	Astro
27	Liu, Chuanlei	McGill University	Ph.D.	XHEP
28	MacLeod, Audrey	McGill University	M.Sc.	XHEP
29	Martineau, Patrick	McGill University	Ph.D.	THEP
30	McCann, Andrew	McGill University	Ph.D.	Astro
31	McCutcheon, Michael	McGill University	Ph.D.	Astro
32	McLachlin, Sheila	McGill University	Ph.D.	XHEP
33	Mia, Mohammed	McGill University	M.Sc.	TNP
34	Mueller, Carsten	McGill University	Ph.D.	Astro
35	Patil, Subodh	McGill University	Ph.D.	THEP
36	Qin, Guangyou	McGill University	Ph.D.	TNP
37	Rahman, Tanvir	McGill University	Ph.D.	XNP
38	Rhéaume, Pascal	McGill University	Ph.D.	XHEP
39	Robert, Jean-Marie	McGill University	M.Sc.	THEP
40	Roy, Philippe	McGill University	M.Sc.	XHEP
41	Savov, Ivan	McGill University	M.Sc.	THEP
42	Shuhmaher, Natalia	McGill University	Ph.D.	THEP
43	Turbide, Simon	McGill University	M.Sc.	TNP
44	Valcarcel, Luis	McGill University	Ph.D.	Astro
45	Williams, Greg	McGill University	Ph.D.	XHEP
46	Yamashita, Hiroki	McGill University	M.Sc.	THEP
47	Zhou, Changyi	McGill University	Ph.D.	XHEP

Undergraduate Students

1	Macleod, Audrey	McGill University	NSERC Summer student	XHEP
2	McCutcheon, Michael	McGill University	Summer student	XHEP
3	Roy, Philippe	McGill University	Summer student	XHEP
4	Suter, Lynn	McGill University	Summer student	XHEP
5	Schwartz, Jason	McGill University	Summer student	XHEP
	..			
	(and many others)			

4 Research: Experimental High Energy Physics

Elementary particle physics is the investigation of the structure of matter and the forms of its interactions. In the search for the basic constituents at the smallest possible scale, one has to reach with the highest available energies.

Experimental particle physics is usually the realm of international efforts in large collaborations of physicists around complex detectors. The McGill high energy groups are actively involved in some of those leading edge ventures:

4.1 Experimental Detectors at Colliders

ZEUS at DESY

The HERA accelerator at DESY, in Hamburg, Germany, is an electron-proton machine. The disparity of initial states and the asymmetry in the energies makes it an extremely challenging project, but extremely well suited for deep inelastic scattering measurements and QCD studies. Indeed, the structure of the proton is probed at a very small scale, the attometer! In addition, photoproduction measurements yield very important information on the photon structure.

BaBar at SLAC

The BaBar detector is located at the PEP-II machine of SLAC, Stanford, California, USA. Thanks to the copious production of B-mesons, BaBar is testing the Standard Model description of CP violation. It will be able to over-constrain the CKM matrix Unitarity Triangle.

CDF at Fermilab

CDF is one of the two detectors at the Fermilab Tevatron, near Chicago, Illinois, USA. “Run II” has started and brings the experiments to the energy frontier of the field. Detailed studies of the properties of the top quark will be done, heavy hadron decays will be investigated and many other physics channels will be accessible.

DZero at Fermilab

The DZero detector is located at the Fermilab Tevatron collider, near Chicago. The Tevatron is currently the highest energy particle collider in the world and the only place where the most massive fundamental particle, the top quark, can be directly produced and studied. The search for a new mechanism of top quark production is underway.

ATLAS at CERN

The Large Hadron Collider (LHC) is currently under construction at the CERN laboratory near Geneva, Switzerland. It will collide protons at a centre-of-mass energy of 14 TeV, the highest collision energy ever achieved in laboratory. As such, the LHC offers a broad range of physics opportunities and enormous discovery potential. The ATLAS detector will record the results of these high energy collisions. Searches for new phenomena such as the existence of a Higgs boson, large extra dimensions, supersymmetric particles, etc. will be carried out.

Linear Collider Projects

The next generation accelerator will be an electron-positron machine, but in the linear acceleration mode where massive energy losses through synchrotron radiation are avoided and extremely high particle-on-particle energies reached. The signals for the elusive Higgs particles should be clear. Three such international projects were pushed: TESLA at DESY using superconducting technologies, NLC in the United States with extremely large acceleration field gradients, and JLC in Asia. A decision on cold technology (superconducting) has already been agreed upon in the past year and further R&D international efforts are being pushed at a challenging pace.

4.2 Elementary Particle Physics

The Standard Model

Decades of theoretical and experimental discoveries have lead to the Standard Model, which represents our understanding of particle physics, its constituents and forms of interactions. It already unifies the electromagnetic, weak and forces. Actually, the electroweak sector was spectacularly verified in 1983 by the first direct observations of the heavy intermediate gauge bosons.

QCD

Quantum Chromodynamics is the description of the strong interaction, yet including asymptotic freedom and quark confinement. Current experiments are very challenging to the QCD predictions because low energy phenomena cannot be calculated by perturbative methods.

CP Violation

CP violation phenomena have puzzled physicists for a long time and lead to amazing discoveries. It was shown that a third generation of quarks would lead to large asymmetries which could then be observed in b-hadron decays to test its mechanism.

top production

The ”top” was the last missing basic constituent to be measured and superbly confirmed its expectation from the Standard Model. Detailed studies of its decay modes and properties will provide invaluable information.

The Higgs and more

The Standard Model still requires the Higgs to generate masses. It is expected that the Large Hadron Collider (at CERN) or the future Linear Collider will discover it and map its properties. But this can't be the final story and the chances to come to grip with Supersymmetry or to tap into new physics are very exciting to experimentalists.

4.3 Interdisciplinary Research

Particle Astrophysics - STACEE and VERITAS

The emerging area of particle astrophysics applies the techniques and methods of particle physics to problems in astrophysics. The McGill group is involved in two projects in ground-based gamma ray astrophysics. The STACEE experiment is using a modified solar-power facility in Albuquerque, N.M. to provide a large mirror area for the detection of Cherenkov radiation coming from air showers created by high energy astrophysical gamma-rays. This experiment is currently running. The group is also a member of the VERITAS collaboration, building a new array of imaging telescopes for Cherenkov shower detection, at Mt. Hopkins in Arizona, which will have more sensitivity than the STACEE detector.

Particle Physics Applications

Techniques and methods of particle physics are growing in scope and are making considerable impact in other fields, like medicine, astrophysics and cosmology. Particle physics has always pushed and stimulated developments of high technology, electronics and computing. Their effects are best seen in e.g. the establishment of the World Wide Web, open source methods of programming or innovative uses of special materials in detectors.

5 Research: Theoretical High Energy Physics

Our research interests are diverse, covering most of the active topics in high-energy theoretical physics. Here are some of the topics on which we have worked over the past few years.

5.1 Elementary-Particle Physics

Elementary-particle phenomenology is the study of the properties of elementary particles as theoretically predicted by the Standard Model, or by alternative models of physics at very high energies. The goal of such studies is to make the best contact with experimental results, in order to suggest the kinds of measurements which are most informative on key theoretical questions, or to interpret the theoretical implications of current experimental results.

Neutrino Physics

Recent measurements of neutrino properties appear to disagree with the predictions of the otherwise extremely successful Standard Model of particle interactions. This has stimulated a detailed re-examination of the relationship between the new experiments and older ones, and on how the Standard Model might be modified in order to take the newer results into account. We have studied: which neutrino properties are consistent with the various ongoing neutrino experiments; new types of signals within neutrinoless Double-Beta-Decay experiments; how neutrinos interact with matter fluctuations in astrophysical media.

Precision Electroweak Physics

The Standard Model of the electroweak interactions is currently being tested in accelerator experiments to an accuracy of better than one percent. This permits a better determination of poorly-known quantities, like the mass of the as-yet-undiscovered Higgs boson. It also constrains the kinds of New Physics which one can entertain as replacements for the Standard Model at higher energies. We have developed: effective-lagrangian techniques for efficiently identifying how 'new' physics can appear within well-measured observables; the application of these techniques to identify which kinds of experiments are sensitive to which kinds of new physics.

Strong Interactions

It has been notoriously difficult to unravel the predictions of Quantum Chromodynamics (QCD), which is currently understood within the Standard Model as the theory of the strong interactions. The obstacle lies in the difficulty of the calculations which are required in order to make these predictions. In recent years several new techniques have emerged from unexpected places. We have helped develop these new calculational techniques: string-theory-based techniques for efficiently computing loop amplitudes in QCD; methods for summing infrared-singular amplitudes for soft-gluon emission.

5.2 Field Theory

Quantum Field Theory has emerged as the theoretical framework within which all physical theories are couched. The intricate consistency issues which must be satisfied by any viable quantum field theory turn out to very usefully constrain the theoretical possibilities at extremely high energies, where gravity starts to play an important role at the quantum level. The emergence of string theory as the only known consistent solution to these constraints has initiated considerable progress in understanding very-high-energy physics, even in the absence of direct experimental information.

Our research in this area has included the following topics:

Black Holes

Black Holes are a frontier between known and new physics, since uncontrolled gravitational collapse relentlessly drives a system into a poorly-understood strong-curvature, high-energy regime starting from the well-understood regime of weak fields and low energies. We have: computed string-theory corrections to and dualities amongst black hole spacetimes; evaluated strong-curvature corrections to black-hole entropy; calculated the properties of the photosphere which develops around evaporating black holes.

Duality

Duality is the blanket name which describes the many surprising equivalences which have been discovered amongst apparently unrelated field and string theories. These relationships have revolutionized the current view of extremely-high-energy physics by showing that the many different string theories are duals of one another within a more fundamental framework, known as M-Theory. (Don't ask what 'M' stands for.) Our research involves: the discovery and exploration of the connection between duality and bosonization; the use of duality to construct new solutions to the string equations of motion; the discovery of a new class of superdualities.

String Theory

String theory (or M theory) is the best candidate for the theory which unifies all interactions, including gravity. Within this framework the basic building block of all matter consists of extremely short, infinitesimally-thin one-dimensional strings, rather than the traditional indivisible point particles. Our interests in this area include: higher-dimensional D-brane solutions to the low-energy string equations of motion; the duality between string theories and four-dimensional conformal field theories; the relevance of string theory for the problem of information loss in black holes.

Supersymmetry

Supersymmetry is a beautiful symmetry which arises in many proposals (including,in particular, in string theory) for the ultimate replacement for the currently-successful Standard Model of fundamental interactions. Our work includes: the runaway-dilaton problem in strongly-coupled supersymmetric theories; the viability of supersymmetric models for electroweak baryogenesis.

5.3 Theoretical Cosmology

Inflationary Cosmology

The inflationary universe scenario proposed in 1981 by Guth has provided a theory of the origin for the small density fluctuations which can be measured in cosmic microwave background temperature maps and in galaxy redshift surveys. The original predictions for observables have been spectacularly confirmed in recent experiments. Research at McGill focuses on further developments of the inflationary scenario, with particular emphasis on the study of the conceptual problems of the inflationary paradigm.

Theory of Cosmological Perturbations

Fundamental physics connects to observations through the detailed study of the cosmological fluctuations (density perturbations and gravitational waves) which are produced in the early Universe and propagate through time to produce the present observational signatures. Past work of the

McGill researchers has played an important role in the development of the classical and quantum theory of linearized fluctuations. Current research focuses on higher order effects such as cosmological back-reaction, and on extensions of the formalism to brane world cosmologies.

Superstring Cosmology

The inflationary universe scenario does not eliminate cosmological singularities, nor does it address the question of why only three of the nine or ten spatial dimensions of string or M theory are macroscopic. Research at McGill focuses on 'string gas cosmology', an approach to string cosmology which addresses these questions. Studies of cyclic cosmologies in the context of string cosmology are also in progress.

Baryogenesis

The study of novel mechanisms of cosmological baryogenesis is another key aspect of cosmology research at McGill.

5.4 Interdisciplinary Research

The enormous success of Field Theory has meant that it has come to be applied universally throughout physics. Although the language and experiments usually vary considerably from subfield to subfield within physics, the universality of the underlying theoretical tools permits considerable cross-fertilization of ideas from one area to another. Our own research has intersected the following neighbouring subfields of physics:

Particle Astrophysics

There is considerable overlap between our understanding of the fundamental Laws of Nature and our understanding of the history of the Universe. This overlap arises because the early Universe was much smaller than it is at present, and was at a much higher temperature. As a result typical particles carried extremely high energies than they do now, and so their interactions were governed by the fundamental laws of high-energy physics which are being explored in accelerators today. Our current interests in this overlap involve: exploring whether the excess of matter over antimatter was generated during the electroweak phase transition; the constraints on neutrino properties which may be obtained from cosmology or supernovae.

Condensed Matter Physics

Some of the theoretical tools which were developed in high-energy physics have applications in other disciplines (and vice-versa). We have worked on the applications within the following condensed-matter topics: the Fractional Quantum Hall Effect; Zhang's SO(5) theory of high-temperature superconductors.

6 Research: Experimental and Theoretical Nuclear Energy Physics

6.1 Experimental Nuclear Energy Physics

The current research programs in Experimental Nuclear Physics at McGill include the investigation of nucleus-nucleus collisions at ultrarelativistic energies, the study of nuclear ground state properties of unstable nuclei, and the use of nuclear techniques in applied physics. Most of the experiments in both areas are being performed as international collaborations at major accelerator centers in Europe, the U.S.A. and Canada. However, a great deal of the experimental planning and equipment design, preparation and assembly are carried out at McGill.

A primary motivation for studying nucleus-nucleus collisions at ultrarelativistic energies is the production of nuclear systems at unusually high temperature and baryon density, which is a prelude to the deconfinement of quarks in nuclei. Our main effort in the last few years has been devoted to the E877 experiment at the Brookhaven Alternating Gradient Synchrotron (AGS) that study nucleus-nucleus collisions using a 197Au beam of 10.6 GeV/nucleon. This experiment investigates in detail the mechanism of nuclear stopping, the degree of thermalization in the collision, the distribution of energy flow, and the characteristics of the produced particle spectra. McGill is also actively involved in the experimental program at the Relativistic Heavy-Ion Collider (RHIC) presently under construction at BNL, and is a member of the PHENIX collaboration. The Relativistic Heavy Ion Collider (RHIC) is a machine which can accelerate colliding nuclear beams ranging from protons of 250GeV/c to beams as heavy as Au up to 100 GeV/u per beam. Nuclear collisions at this energy would produce very high energy density baryon-free collision volumes in which, as predicted by QCD, quarks and gluons are deconfined from hadrons, and chiral symmetry might also be restored. A team from our group is part of the PHENIX experiment, which is the largest experiment under construction for RHIC, and is dedicated to the study of this new phase of nuclear matter. A McGill team is responsible for the development and construction of one of the major PHENIX components, the multiwire pad chamber subsystem, which is part of the PHENIX central tracking system.

Nuclear ground state properties such as spin, electromagnetic moments and charge radius of radioactive nuclei are basic properties of the nucleus which serve as important tests of our understanding of the nuclear models and determined also the main decay properties of radioactive nuclei. In highly unstable nuclei far from the valley of stability, laser spectroscopy techniques can be used to measured these properties. These techniques are based on the precise measurements of atomic hyperfine structure in the interaction between the laser beam and the radioactive atoms. In recent years, the McGill group has pioneered in the development of a number of high sensitivity techniques for these studies. At McGill, an apparatus for laser spectroscopic studies of ions stored in an RFQ (Radio-Frequency Quadrupole) trap allows the investigation of relatively long-lived isotopes. Work is also being carried out at the on-line isotope separator facility (ISOLDE) at CERN using collinear and resonant ionization spectroscopic methods, within an international collaboration.

Other experimental projects concern Ion trapping techniques for nuclear mass measurements, Applied Physics and instrumentation, ultrasensitive detection of trace materials, and radiation damage in silicon devices.

6.2 Laser Spectroscopy for Nuclear Studies

In recent years, techniques originally used for atomic spectroscopy have been applied to measure such nucleat properties as spin, electric and magnetic moments, and the change of charge-radius between neighbouring isotopes. These techniques are based on the precise measurement of atomic hyperfine structure in the interaction of laser beams with atomic beams obtained from isotope separators. The laboratory has pioneered in the development of a number of high sensitivity techniques for such studies. Collinear spectroscopic measurements (with a coincident atomic and laser beam) is currently carried out with groups at CERN, Geneva and Brookhaven, USA and Resonant Ionization Spectroscopy using laser desorbed isotopes is done in collaboration with groups working at the Institut de Physique Nucleaire, Orsay, France.

6.3 Ion Trap Techniques for mass Measurement and Laser Spectroscopy

Recently, a technique for "catching" and storing ions from isotope separators in a radio frequency quadrupole trap has been developed by our group and is now being adapted for ion collection in a system designed to measure nuclear masses at CERN (Geneva). The same technique also appears to be very promising one for the capture and bunching of ion beams for use in laser spectroscopic measurements on nuclei. A new colinear spectroscopy beam line has been constructed at McGill as a pilot project to test this technique.

6.4 Heavy-Ion Reactions at Relativistic Energies

In nucleus-nucleus collisions at beam energies above 10GeV/nucleon, nuclear matter can be produced with an energy density many times larger than in normal nuclei and which was previously reached only in the early stages of the universe. This could lead to the production of new forms of nuclear matter. For example, the formation of a quark-gluon plasm in which the quarks that make up the nucleons would be deconfined and would roam freely in the nuclear volume, or to the formation of stable or metastable nuclei containing a large quantity of strange quarks. Part of the Experimental Nuclear Physics group is presently involved in the experiment 877 at the Brookhaven National Laboratory which searches for exotic forms of nuclear matter produced in nuclear induced by 10-15GeV/nuclean heavy-ions. The design of the experiment allows simultaneous multiparameter measurements of the collision products. The same group is also involved in the PHENIX experiment that is to take place at the Relativistic Heavy-Ion Collider.

6.5 Theoretical Nuclear Energy Physics

Modern theoretical nuclear physics can be summarized as the study of strongly interacting many body systems. The 20th century is filled with many break-throughs in physics. One of such break-throughs was the discovery of accurate theory of strong interactions – quantum chromo-dynamics (QCD). This theory predicts that the quarks and gluons which make up the nuclear matter can never exist as free particles in ordinary matter. However under extreme conditions such as one existed a few micro-second after the big-bang, a deconfinement phase transition will take place and quarks and glons can be freed to form a Quak-Gluon Plasma (QGP).

The advent of high energy heavy ion colliders in Europe and North America caused a remarkable advance in this field. New and surprising experimental results and exciting new theoretical insights and predictions are continuously being published while large number of puzzles still remain to be investigated. This is an exciting time to be a nuclear physicist!

7 Research: Experimental Gamma Ray Astrophysics

Gamma-ray astrophysics studies at McGill center on the STACEE experiment, detecting gamma rays in the energy regime between approximately 30 GeV and 300 GeV.

7.1 Overview

The first astrophysical sources of gamma-rays were detected in the 1960's, but the field only really started to develop in the 1970's. All of this early work was done by satellites, because the Earth's atmosphere is opaque to gamma-rays.

The field was revolutionized in the 1990's by two developments. The first was the launch, in 1991, of the Compton Gamma Ray Observatory, a NASA "Great Observatory" dedicated to gamma ray astrophysics and carrying four instruments (OSSE, Comptel, BATSE, and EGRET). The high-energy EGRET instrument established the presence of hundreds of point-like sources, and convincingly demonstrated that the gamma-ray sky was an active and exciting place. EGRET found two major categories of known sources, as well as a plethora of unidentified sources - sources for which there is no known likely gamma-ray emitter at the same location. The two known categories are supernova remnants (SNR), of which EGRET has detected 6, and active galactic nuclei (AGN), of which EGRET has detected more than 100.

The second development of the 1990's was the observation of gamma-rays by ground based detectors. The techniques were pioneered by the Whipple collaboration, using the air Cherenkov effect in which the Cherenkov light generated in air-showers by high-energy particles impinging on the atmosphere is detected at the ground. Currently there are a half-dozen Whipple-like detectors, called "imaging detectors" because they image the Cherenkov light onto a camera made up of photomultipliers, then use image analysis techniques to search for the gamma-ray signal among the more numerous charged cosmic ray background.

The discovery of a large number of gamma-ray sources and the advent of ground-based techniques are both promising strides forward in gamma-ray astrophysics. Taken together, however, these developments present a major conundrum: at EGRET energies (below 10 GeV) there are hundreds of sources; at Whipple energies (above 250 GeV) there is only a handful. Where do all the sources go? Are there intrinsic limits to the gamma-ray energies for many sources? Or are the gamma-rays being absorbed, perhaps by scattering from the intergalactic infra-red background, a relic of light emitted by galaxies early in the history of the universe?

Presumably, the answer lies in the energy range between EGRET and Whipple, but that has, until now, been terra incognita.

One of the ways forward is to increase the sensitivity of ground-based Cherenkov detectors by increasing their mirror area (the threshold energy of the detector scales as the inverse square root of the area). The Whipple mirror is approximately 10 m in diameter, and dramatically increasing the mirror area leads to substantial mechanical challenges.

However, large mirror areas do exist, at solar tower facilities built in the 1970's to explore the use of solar power. These facilities (there are at least 6 in the world) have hundreds of large mirrors used to track the Sun across the sky and direct its light onto a tower for thermal use. STACEE is the acronym for the Solar Tower Atmospheric Cherenkov Effect Experiment, and uses such a facility to track an astronomical source and detect the Cherenkov light created by gamma-ray showers in the atmosphere.

The use of the heliostats (solar mirrors) requires custom secondary optics in order to preserve the granularity – that is, in order to record on a single electronics channel with a single photomultiplier (PMT) the Cherenkov photons that land on a single heliostat. Thus, the STACEE detector requires secondary mirrors and support structures, custom cameras composed of PMTs, and associated electronics to dynamically align the signals from different heliostats.

7.2 STACEE and VERITAS

The McGill group has been involved with STACEE since its inception in 1994 and we have participated in the commissioning of a prototype detector which, in the 1998-1999 observing season, definitely detected the Crab Nebula (considered to be the ”standard candle” in the gamma-ray energy regime). The full detector, using 64 heliostats of the 220 available at the National Solar Thermal Test Facility (NSTTF at Sandia National Labs in Albuquerque, New Mexico is now complete.

We expect to run the full detector for astrophysical observations for at least three years. During this time our priority targets (STACEE is a pointing detector, with a field of view of less than 1 degree) will be SNRs and AGNs. Some of the questions we hope to be able to address are:

- for the Crab Nebula and pulsar, at what gamma energy does the pulsed component (presumably coming from close to the neutron star itself) disappear?
- do SNR energy spectra allow better theoretical models of the emission mechanism, currently thought to be Compton up-scattered synchrotron light from accelerated electrons in the intense EM fields of the pulsar (the so-called SSC, or Synchrotron self-Compton model)?
- where are the energy cutoffs in AGN spectra, which must be between EGRET and Whipple energies?
- do these cutoffs show any systematic change with redshift z, or with any intrinsic property of the AGN such as luminosity?
- for AGNs, which are highly variable sources, can multi-wavelength data together with other (space or ground-based) detectors be used to better constrain the emission models?

The current McGill STACEE group comprises two faculty and several graduate students and post-docs. The entire STACEE collaboration has approximately 15 members, so we are one of the two biggest groups. To date, we have played a leading role in the construction and commissioning of the detector. All of the secondary mirror support structures and the cameras (including optical light concentrators for the PMTs) were constructed at McGill, as well as nano-second programmable delay electronics for the trigger, and a laser calibration system.

The McGill gamma-ray group is also interested in future developments in gamma-ray astrophysics, both ground-based and space-based.

We are also members of the VERITAS collaboration, building and array of imaging Cherenkov telescopes at Mt. Hopkins, Arizona. The initial 4-telescope array was completed in 2006 and will have improved sensitivity as compared to STACEE.

8 Highlights of the Year (excerps only)

Workshops

- *Acfas Congress 2006*, full-day colloquium on high energy physics during the annual congress of the "Association francophone pour le savoir", which was held at McGill. On May 15^{th}, orgranized by Prof. F. Corriveau.
  See *http://www.physics.mcgill.ca/∼corriveau/projects/acfas06.html*.
- *CALICE Collaboration Meeting 2006*, 3-day Spring CALICE Collaboration Meeting at the Department of Physics of McGill University, May 10^{th}-12^{th}, 2006, orgranized by Prof. F. Corriveau.
  See *http://www.hep.mcgill.ca/XHEP/ILC/calice/meeting*.
- *Mini-workshop on calorimetry*, with gurst invited speaker Dr Pierre Petroff (LAL), organized by Prof. B. Vachon, McGill University, Montreal, March 27th-28th, 2006.
- *BaBar Simulation Development Workshop*, with Prof. S. H. Roberson as principal organizer, February 25th, 2006.
- *Workshop on New Ideas in String Theory and Cosmology*, organized by Profs. R.H. Brandenberger and K. Dasgupta, McGill University, January 27th-29th,, 2006.
- *First ATLAS Canada Physics Workshop*, organized by Profs. S. H. Robertson, B. Vachon and A. Warburton, as members of the local organizing committee, McGill University, Montreal, December 7th-8th, 2005.
- *Inflation from String Theory*, two-week research-in-teams project at Banff International Research Station, organized by Prof. J. Cline with Profs. Cliff Burgess, Hassan Firouzjahi, and Keshav Dasgupta (McGill).
- *Workshop on embedded defects*, co-organized by Profs. G.D. Moore and R.H. Brandenberger, McGill University, September 30th to October 2nd, 2005.
- *Workshop on String Gas Cosmology*, organized by Profs. R.Brandenberger and K. Dasgupta, McGill University, September 30th - October 2nd, 2005.
- *Second North American ATLAS Physics Workshop*, Prof. B. Vachon as member of the scientific committee and co-chair of the Trigger session, University of Toronto, Toronto, August 1st-3rd, 2005.
- *D0 Collaboration Workshop*, Prof. B. Vachon as member of the local organizing and scientific committees, Simon Fraser University, Burnaby B.C., June 12th-18th, 2005.

Conferences, Invited Lectures and Talks

- *Nongaussian perturbations from tachyonic preheating*, talk by Prof. J. Cline at the IAP meeting Inflation +25 in Paris.
- *Les Supercordes et l'Origine de l'Univers*, Prof. R.H. Brandenberger, Conférencier Invité, Colloque de Physique des Particules, "Le Savoir: Trame de la Modernité", 74^e Congrés de l'ACFAS McGill University, May 15th, 2006.

- *La nouvelle génération: le Collisionneur Linéaire International*, talk by Prof. F.Corriveau at the Acfas Congress, McGill University, May 15th, 2006.
- *Experimental Prospects for* $b \to s\nu\bar{\nu}$ *and* $B^+ \to \ell^+\nu(\gamma)$, invited presentation by Prof. S. H. Robertson at the 3rd Flavour in the Era of the LHC Workshop, CERN, Geneva, May 15th, 2006.
- *Light propagation simulation in the tiles*, Talk given by Prof. F. Corriveau at the CALICE Collaboration Meeting, McGill University, May 10th-12th, 2006.
- *Nongaussian perturbations from tachyonic preheating*, talk by Prof. J. Cline at the Perimeter Institute, May 2006.
- *Next Generation Cosmic Microwave Background Experiments*, Prof. M. Dobbs, Invited Seminar. Universite de Montreal, April 27th, 2006.
- *International Linear Collider Calorimetry*, HEP seminar by Prof. F. Corriveau at the Department of Physics, McGill University, April 26th, 2006
- *Bolometer Array Systems for Detection of the Cosmic Microwave Background*, Prof. M. Dobbs, Invited speaker. Presented at the American Physical Society April Meeting, Dallas, Texas, 2006.
- *String Theory and the Birth of the Universe*, Prof. R.H. Brandenberger, Physics Colloquium, University of Tennessee, April 3rd, 2006
- *Experimental Evidence of Strong Color Field in (multi)strange Particle Production at RHIC*, talk presented by Vasile Topor Pop, J. Barrette, C. Gale, M. Gyulassi at the Strangeness in Quark Matter Conference, UCLA, Los Angeles, USA, March 26th-31st, 2006.
- *3-D Supersymmetry on the Lattice*, seminar by Prof. G.D. Moore at Syracuse University, March 2006.
- *Towards an Alternative to Inflation*, Prof. R.H. Brandenberger, Pizza Seminar, McGill University, March 1st, 2006.
- *New Physics at BABAR*, talk presented by Hojeong Kim at the DIF2006 International Workshop on Discoveries in Flavour Physics at e+e- Colliders, Frascati, Italy, February 28th - March 23rd, 2006.
- *Gammaray Astrophysics at STACEE and VERITAS*, talk by Prof. K. Ragan at the Lake Louise Winter Institute, Lake Louise, February 22nd, 2006.
- *Probing Inflation and Dark Energy with Next-Generation Cosmology Experiments*, Prof. M. Dobbs, invited Colloquium speaker, joint Carnegie Mellon / U. Pittsburgh / Carnegie Mellon University Physics Colloquium, February 20th, 2006.
- *Heavy Light: TeV Gammaray Astrophysics*, Seminar by Prof. K. Ragan at the Perimeter Institute, Waterloo, February 15th, 2006.
- *Heavy Light: TeV Gammaray Astrophysics*, Originseries colloquium by Prof. K. Ragan at McMaster University, Hamilton, February 13th, 2006.

- *Towards an Alternative to Inflation*, Prof. R.H. Brandenberger, Invited Talk, Banff Workshop "Frontiers in String Theory", February 11th-16th, 2006
- *Calorimetry for the Linear Collider*, HEP seminar by Prof. F. Corriveau at the Department of Physics, University of Toronto, February 7th, 2005
- *Heavy Light: TeV Gammaray Astrophysics*, Colloquium by Prof. K. Ragan at the Department of Physics, Queens University, Kingston, February 1st, 2006.
- *String Theory and the Birth of the Universe*, Prof. R.H. Brandenberger, Physics Colloquium, University of Notre Dame, February 1st, 2006.
- *Plasma Instabilities in Hot QCD*, lecture by Prof. G.D. Moore at Columbia University, January 2006.
- *Developments in Frequency Domain Multiplexing for Large Arrays of Transition Edge Sensor Bolometers*, Prof. M. Dobbs et al., invited speaker, presented at the National Radio Science Meeting, Boulder, Colorado, January 2006.
- *String Gas Cosmology*, Prof. R.H. Brandenberger, Invited Plenary Speaker, "Cosmology 2005: A Reality Check" conference, Niels Bohr Institute, Copenhagen, December 14th-17th, 2005.
- *Advances in Brane Gas Cosmology and Thoughts on the Gravitational Back-Reaction of Cosmological Perturbations*, Prof. R.H. Brandenberger, GRECO Seminar, IAP Paris, December 13th, 2005.
- *D3/D7 Infrationary Model*, talk by Prof. K. Dasgupta, CITA Workshop, University of Toronto, December 12th, 2005.
- *Beauty and the Beast: B mesons and the BaVar Experiment*, invited seminar by Prof. S. H. Robertson at the Department of Physics, Carleton University, Ottawa, Ontario, Nov 29th, 2005.
- *Was there a Big Bang?*, Prof. R.H. Brandenberger, McMaster University "Origins" series colloquium, November 28th, 2005.
- *Search for the Little Bang,* Prof. S. Jeon, Colloquium, Korea Institute for Advanced Study, Seoul, Korea, November 6th, 2005.
- *Fluctuations and Correlations in QGP,* Prof. S. Jeon, Heavy Ion Meeting 2005-11, November 4th, 2005, APCTP, Pohang, Korea.
- *Cosmology 50 Years after WMAP*, Prof. R.H. Brandenberger, Invited speaker, "Cosmological Frontiers in Fundamental Physics", Perimeter Institute/ APC Workshop, Perimeter Institute, October 24th-28th, 2005.
- *Challenges for Inflationary Cosmology*, Prof. R.H. Brandenberger, Invited Speaker and Member of the International Advisory Committee, "100 Years of Relativity" conference, Sao Paulo, Brasil, August 22nd-24th, 2005.
- *Challenges for Inflationary Cosmology*, Prof. R.H. Brandenberger, Theory Seminar, Charles University, Prag, August 1st, 2005.

- *Charge Transfer Fluctuations as a QGP signal,* Prof. S. Jeon, Nuclear Theory / RIKEN Seminar, Brookhaven National Laboratory, July 15th, 2005.
- *Moduli Stabilization in String Gas Cosmology*, Prof. R.H. Brandenberger, Invited Speaker, Yukawa International Seminar, "The Next Chapter in Einstein's Legacy", Kyoto, June 27th - July 1st, 2005.
- *Charge transfer fluctuations as a QGP signal,* Prof. S. Jeon, Heavy Ion Meeting 2005-06, June 27th, 2005, Sungkyunkwan University, Suwon, Korea.
- *Challenges for String Gas Cosmology*, Prof. R.H. Brandenberger, Invited Speaker, 59th Yamada Conference, Univ. of Tokyo, June 20th-24th, 2005.
- *Lectures on Modern Cosmology*, Prof. R.H. Brandenberger, Invited Lecturer, "Workshop on General Relativity", Morningside Center of Mathematics, Chinese Academy of Sciences, Beijing, China, June 10th-20th, 2005.
- *From STACEE to VERITAS*, talk presented by Prof. K. Ragan at the 2005 CAP Congress, Vancouver, June 2005.
- *ZEUS Gets Polarized*, invited Talk by Prof. F. Corriveau at the CAP Annual Congress, University of British Columbia, Vancouver, British Columbia, Canada, June 2005.
- *Super B Factory Prospects*, invited presentation by Prof. S. H. Robertson for the IPP Long Range Planning Town Hall Meeting, Vancouver B.C., June 4th, 2005.
- *Moduli Stabilization in String Gas Cosmology*, Prof. R.H. Brandenberger, Invited Speaker, "Theory Canada I", CAP Theory Meeting, Vancouver, June 2nd-5th 2005.
- *Ultra High Energy Physics with CMB Prof. S. Jeon, Polarization*, Prof. M.Dobbs, Invited talk, presented June 4, 2005 at the Institute of Particle Physics (IPP) Town Hall Meeting at TRIUMF, Vancouver.

Special Publications and Outreach

- *Anges et Démons de Dan Brown: réalit et fiction*, by Prof. B. Vachon, at Cégep Sorel-Tracy, April 26th, 2006.
- *Angels and Demons: Facts and Fiction ... Or What Particle Physics is Really About*, by Prof. B. Vachon, Sigma Xi Annual Banquet Lecture, April 21st, 2006.
- *Dan Brown's Angels and Demons: Facts and Fiction*, by Prof. B. Vachon, at Vanier College, April 12th, 2006.
- *organized outreach distribution of French and English particle physics ..* posters, pamphlets, IPP letters, and McGill physics letters to approx. 130 Québec CEGEPs and other colleges, by Prof. A. Warburton, McGill, December 2005.
- *first undergraduate science fair* and *Public lecture by Dr. Leon Lederman (FNAL): How to win a Nobel prize*, co-organized by prof. B. Vachon, at McGill University, Montreal, September 30th, 2005.

- *Les grands physiciens*, Interview of Prof. J. Barrette for the program "Les annes lumire" on "La premire chaine de Radio-Canada" in the series "Les grands physiciens" at the occasion about the contribution of Rutherford to physics, July 24th, 2005.
- *Collider Physics at the Highest Energies*, introductory high-energy physics talk given to visiting high-school students as part of McGill Explorations Day, by Prof. A. Warburton, McGill, July 5th, 2005.
- *Work on making McGill Physical Society talks available on-line*, Prof. S. Jeon, McGill University.

Research awards

- *T2 Canada Research Chair in Astro-particle physics*, Prof. M. Dobbs, McGill University, stating in 2006.

Committees

International

- *Nobel Prize Committee for Physics (Stockholm): Evaluator of the nominations for the discovery of Neutrino Oscillations*, Prof. D.G. Stairs.
- *Nuclear Physics: Physical Review Letters*, Divisional Associate Editor (continuing), Prof. J. Barrette.
- *Service de Physique Nuclaire, DAPNIA, CEA/Saclay, France*, Members on Conseil Scientifique et Technique (continuing), Prof. J. Barrette.

National

- *NSERC Committee to choose the best three PhD theses in Science*, Prof. D.G. Stairs.
- *NSERC Review Committee for the ATLAS Experiment at the LHC*, Chair, by Prof. D.G. Stairs.
- *NSERC Review Committee for the T2K Experiment at J-Park*, Chair, by Prof. F. Corriveau.
- *NSERC Long Range Planning Committee.* Active participation by Profs K. Ragan (Chair) and A. Warburton. This committe is charged with establishing the roadmap for Canadian Sub-Atomic Physics for the next decade.
- *NSERC Long Range Planning Theory Committee.* by Profs G. Moore as member and adhoc Chair, with presentation at the long range planning Town Hall meeting in Montreal, December 2005.
- *NSERC Long-Range Planning Subcommittee on Computing in Canadian high-energy physics*, member, Prof. A. Warburton.
- *NSERC Special Research Opportunities*, Prof. K. Ragan, grant reviewer.
- *NSERC Discovery Grant*, Prof. G.D. Moore as external reviewer.

- *Association of Canadian Universities for Reseach and Astronomy.* roadmap for Canadian Sub-Atomic Physics for the next decade. D. Hanna is the McGill representative at ACURA and member of its board of management.
- *Canadian Association of Physicists Council*, representative for the North and West regions of Qubec, Prof. A. Warburton, 2005-2007.
- *Institute of Particle Physics of Canada: President of the Board of Trustees*, Prof. D.G. Stairs, since 2002.
- *Institute of Particle Physics of Canada*, elected Council memeber, 2005-2008.
- *HEPnet/Canada advisory committee*, member of committee for computer wide-area networking in Canadian subatomic physics research, Prof. A. Warburton.
- *Canadian Association of Physicists Director of Academic Affairs*, Prof. K. Ragan. Primary responsibility: chair of the CAPNSERC Liaison Committee. In this role he also participated in the national roundtable on the proposed Major Science Investment Panel (MSIP), and coordinated the CAP response to the MSIP proposal.
- *SNOLab Experiments Advisory Committee*, Prof. K. Ragan, member.
- *BaBar Deputy Physics Analysis Coordinator search committee*, with prof. S. H. Robertson as member, July 2005.
- *BaBar Beam Background Simulation Group*, coordinated by prof. S. H. Robertson until June 2006.
- *Joint Committee on Space Astronomy*, science advisory committee to the Canada Space Agency, member since March 2006.

Provincial

- *Québec astrophysics regroupement stratégique*, Prof. K. Ragan, Adjunct Head.
- *CAP College and Cegep Examination Prize 2006*, Coordination by Prof. F. Corriveau of the annual prize by the Canadian Association of Physicists (as the Québec regional coordinator).
- *McGill Physics department outreach committee*, chaired by Prof. B. Vachon.

Referee Work

Several of our members serve as referees for publications in the main journals in the field:

- Physics Letters B
- Physics Review Letters
- Physical Review C
- Physical Review D
- Journal of High Energy Physics

- European Physics Journal C
- Nuclear Physics A
- Nuclear Physics B
- Canadian Journal of Physics
- Institute of Physics Journal of Physics G: (Nuclear and Particle Physics)

9 Seminars

The Centre sponsors five interleaving seminar series instrumental in the training of researchers:

- A formal seminar series within the Centre attracts speakers from across Canada, the United States and European visitors to North America. The seminars are an integral component of our activity and are of great value to all members of the Centre, especially to our students and postdoctoral researchers. They are also organized jointly with the Particle Physics group of the Université de Montréal, so that further exchanges are generated.
- A popular series is the weekly "pizza lunch" seminar, usually featuring a Centre theory member discussing his or her current research in an informal atmosphere encouraging student participation.
- Another series is the "donut afternoon" seminar, where all members of our experimental teams get together and discuss their research.
- Our nuclear physics theory colleagues also maintain frequent seminars where guests from outside are invited to present and share their research.
- Finally, a few major workshops and large meetings are now being initiated by members of our Centre on outstanding topics.

These seminars also provide a familiar setting in which graduate students and postdoctoral researchers gain valuable experience in presenting their work. All of our students, as well as most of our visitors give at least one of these talks sometime during their programme. Our permanent members are also contributing to the series.

The list of seminars are available on the web under
http://www.physics.mcgill.ca/chep/reports/chep_20052006_seminars.html

10 Publications (2005)

Publications, together with the training of our students and postdocs, are one of the most important elements of research, because they stimulate, guide and set goals to our undertakings.

The publications are available on the web under
http://www.physics.mcgill.ca/chep/reports/chep_20052006_publications.html

11 Honours, Awards, Prizes and Consulting Activities

Please consult the annual report of the Physics Department.