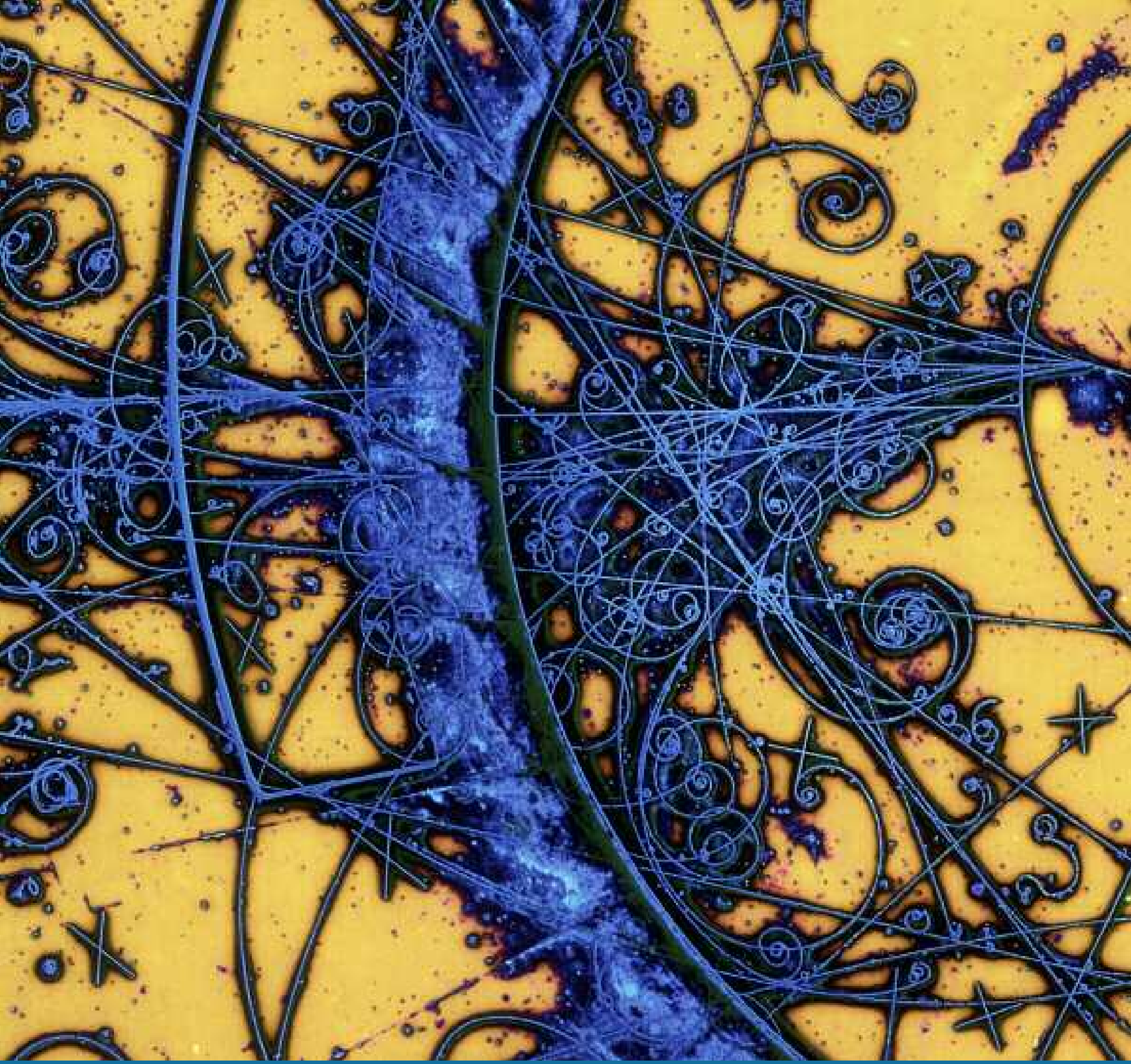


Subatomic Physics in Canada

to be fixed

Superconducting accelerating cavity prototypes for a future International Linear Collider (ILC). The ILC will be a reality in the next ten years, and Canadian physicists hope to be a major part of the project.

In this century, new findings in subatomic research will affect our lives, change our understanding of the world and help establish our place in the cosmos. Canadians must participate in these discoveries.

Subatomic Physics at a glance

WHAT ARE THINGS MADE UP OF?
HOW ARE THEY HELD TOGETHER?
HOW DO THEY WORK?
WHERE DO THEY COME FROM?

Subatomic physics is the study of the simplest building blocks of our universe. Today we have a detailed, but still incomplete, understanding of what matter is made of down to a scale of about one one-thousandth of the size of an atomic nucleus, and back to a time just a few seconds after the Big Bang, more than 14 billion years ago. Canadian physicists are leaders in the world-wide effort to extend this knowledge.

Experiments in which Canadians play key roles may lead to dramatic breakthroughs in our understanding of nature in the next decade.

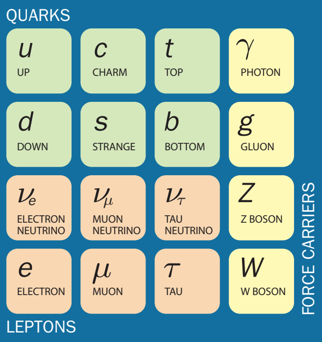
HOW DOES SUBATOMIC PHYSICS IMPACT OUR LIVES?

The science-driven demands of subatomic physics lead to innovations that benefit society as a whole.

For example, accelerator technology that was originally developed for basic subatomic physics is now widely used for such diverse applications as cancer therapy, studying the structure of viruses, designing new drugs, and developing new semiconductors and microchips.

- The World Wide Web was originally developed by subatomic physicists as a means of sharing data
- modern medical radioactive tracers were a product of particle accelerator research
- MRI machines use high-field superconducting magnets for medical imaging, first used in subatomic research
- cancer therapy now uses accelerated proton beam technology
- the "Grid" – sharing of multiple computing power over the internet – is a spinoff of particle physics experiments.

SUBATOMIC PARTICLES



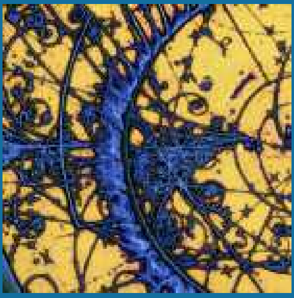
QUARKS

u UP	c CHARM	t TOP	γ PHOTON
d DOWN	s STRANGE	b BOTTOM	g GLUON
ν_e ELECTRON NEUTRINO	ν_μ MUON NEUTRINO	ν_τ TAU NEUTRINO	Z Z BOSON
e ELECTRON	μ MUON	τ TAU	W W BOSON

LEPTONS

FORCE CARRIERS

THE TABLE OF SUBATOMIC PARTICLES
Quarks, Leptons and Force Carriers comprise the basic known subatomic world.



ON THE COVER:
The cover shows a colourized photograph of particle interactions in a bubble chamber. Although bubble chambers are no longer used in state-of-the-art detectors, subatomic researchers still seek to visualize the particle collisions they study.

The Canadian Contribution

WHAT AREAS DO CANADIANS EXCEL IN?

Canada has two world-class research facilities where Canadians, and their international collaborators, pursue the exciting questions of subatomic physics. These are the TRIUMF laboratory in Vancouver, BC, and SNOLab in Sudbury, Ontario.

Canadian researchers from universities across the country pursue subatomic physics research at these facilities as well as at laboratories in Europe, the US, and Japan.

CANADIAN SUBATOMIC RESEARCH FACILITIES AND UNIVERSITY RESEARCH GROUPS

● **RESEARCH FACILITIES**

British Columbia
TRIUMPH

Ontario
SNOLab

● **UNIVERSITY RESEARCH GROUPS**

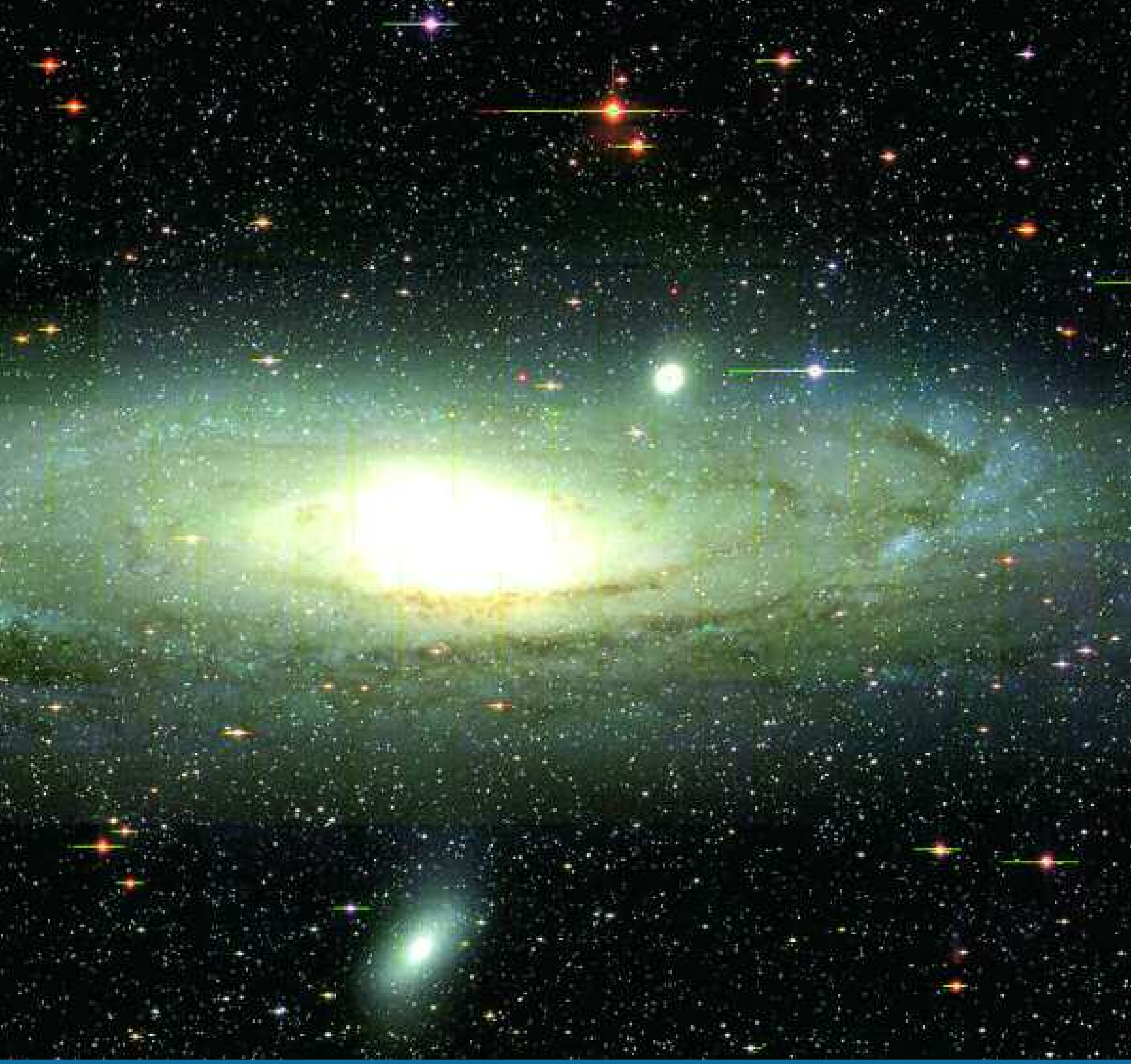
British Columbia
University of British Columbia
University of Victoria
Simon Fraser University
University of Northern British Columbia

Alta/Sask/Man
University of Alberta
Lethbridge University
University of Regina
University of Brandon
University of Winnipeg
University of Manitoba

Ontario
Perimeter Institute for theoretical Physics
Carleton University
York University
Queen's University
University of Western Ontario
McMaster University
Guelph University
University of Toronto
University of Waterloo
Laurentian University

Quebec
Bishop's University
Concordia University
McGill University
Université Laval
Université de Montréal
Université du Québec à Montréal

Atlantic
Saint Mary's University
Acadia University
University of Moncton
Mount Allison University
Dalhousie University



A LOOK AT THE UNIVERSE

New discoveries in subatomic physics are answering riddles of the cosmos, including the prevalence of dark matter. Scientists now believe that visible matter comprises only 5% of the universe, with the remainder being dark matter and dark energy. Detecting this dark matter is a key area of study for Canadian physicists.

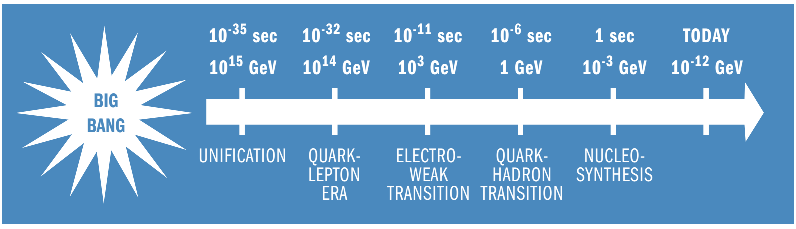
The Critical Questions

Recent discoveries indicate that roughly 95% of the universe consists of “dark” matter and energy – forms completely unknown to us. Normal matter, including all we see around us, constitutes only 5% of the universe. Discovering what the dark matter and dark energy are, and what their existence means for the evolution of the universe, is one of the most exciting areas of science today. Some of the critical questions are:

The distribution of mass in the Messier 31 galaxy, the largest galaxy in the neighborhood of the Milky Way, led to the recognition that galaxies are filled with dark matter.

- What is gravity? How does it work? Can a unified theory of gravity and particles be developed?
- How do particles acquire mass?
- How did the universe come to be? How is it evolving? What are the dark matter and dark energy?
- Why does the visible universe consist of matter? When and how was the symmetry between matter and anti-matter broken?
- After the creation of the primordial hydrogen and helium in the Big Bang, what mechanism produced the heavy elements?

Answering these profound questions requires experimental efforts and theoretical analysis involving subatomic physics, cosmology, and astronomy. These three sciences are closely linked because of the emergence of today’s universe from the particles produced in the Big Bang. The goal of subatomic physics is, ultimately, to understand the evolution of the universe and the matter within it.



The extremely hot and dense early universe of the Big Bang gave rise to a sea of particles in constant interaction with one another, governed by a single force. As it expanded and cooled, it underwent a series of changes from a very hot soup of particles called quarks and leptons, to nuclear matter that was to make up the first stars.

The extreme conditions of that early universe can be recreated in laboratories using accelerators. Physicists in Canada working in the sub-disciplines of nuclear physics, particle physics, and particle astrophysics probe all of the physics depicted in the time-line in order to answer the fundamental questions listed above.

Canadian Success Stories

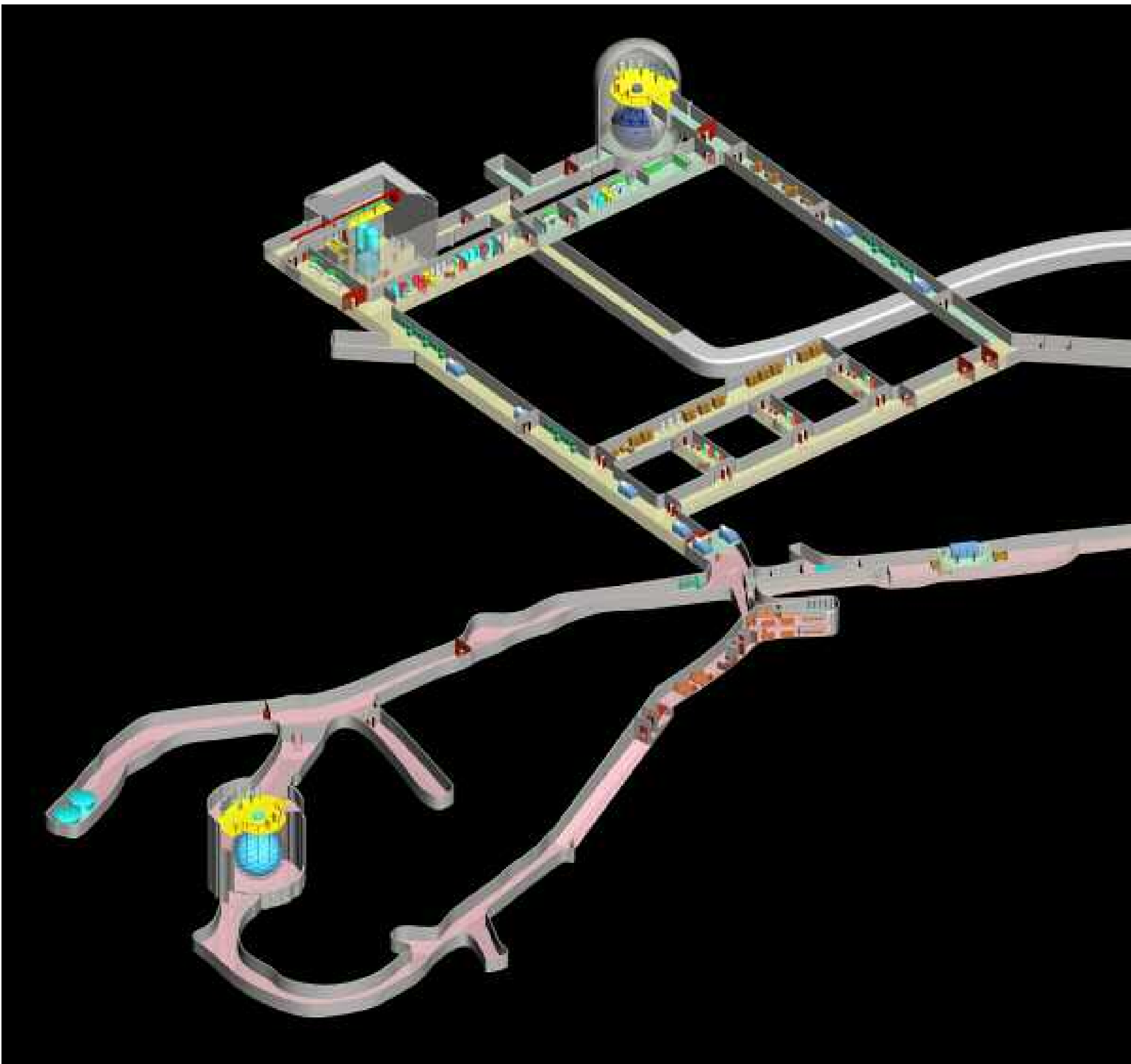
The SNO detector before the cavern, nearly 2 km underground near Sudbury, was filled with water.

SOLAR NEUTRINO STUDIES

Subatomic physics is an international endeavor, and Canadians have made important contributions. One of these is the resolution of the so-called "solar neutrino problem" by the Sudbury Neutrino Observatory (SNO), which answered important questions about the Sun as well as discovering fundamental new properties of subatomic particles called neutrinos.

For over thirty years scientists have observed fewer neutrinos emitted by the Sun than predicted by solar models. Either our understanding of the Sun was fundamentally flawed, or the neutrinos were not behaving as they should be.

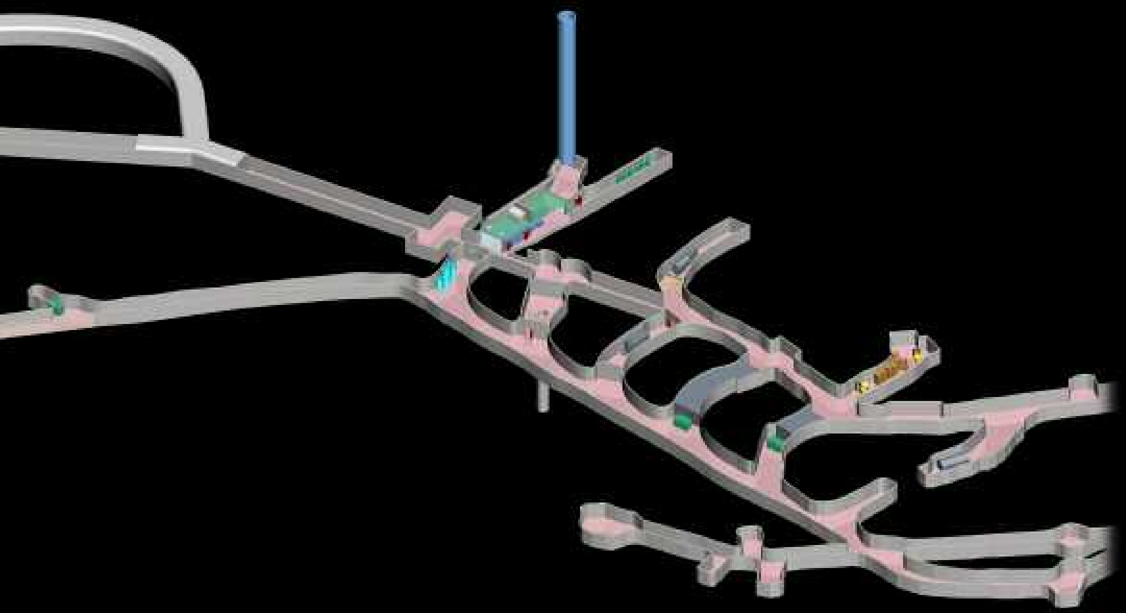
This puzzle was solved by the Sudbury Neutrino Observatory, in one of the great scientific discoveries of the last decade. SNO was based on two unique Canadian resources: 1000 tonnes of heavy water available via the CANDU reactor program, and a location two kilometres underground in an INCO nickel mine near Sudbury, Ontario.



SNO determined that the neutrinos from the Sun were changing their identity – mutating – during their trip to Earth, and that the total number of neutrinos in fact agreed with the solar model predictions. This behaviour, called “oscillation”, is only possible for neutrinos having mass; prior to the SNO results, neutrinos were believed to be massless.

The discovery that neutrinos have mass has raised intriguing new questions about their behaviour. Using the expertise acquired while building and operating SNO, Canadian scientists have now moved ahead with the construction of an expanded laboratory at the SNO site called SNOLab, funded by the Canada Foundation for Innovation. Experiments at SNOLab – the best deep underground lab in the world – will help to address these new questions, improving our knowledge of neutrinos, dark matter, and their role in the evolution of the universe.

A schematic layout of the 6800-foot level of the Creighton mine, near Sudbury. The cavern on the far left is approximately 25-m high and houses the SNO experiment; the new SNOLab facility is the square set of tunnels at the top-left of the figure.



Two panoramic views of the ISAC beamlines at TRIUMF in Vancouver.

Canadian Success Stories

Nuclear Structure and Nuclear Astrophysics Studies

Only the lightest elements (hydrogen, helium, and lithium) were created in the Big Bang; all of the heavier elements, including everything we are made of, have been synthesized through nuclear reactions involving unstable exotic nuclei in normal stars and explosive astrophysical environments. The study of the structure and reactions of these exotic nuclei in the laboratory is the field of Nuclear Structure and Nuclear Astrophysics, and again Canadian scientists are leaders.

The Isotope Separator and Accelerator Complex (ISAC) facility at TRIUMF, Canada's national nuclear and particle physics laboratory in Vancouver, is recognized as the world's most advanced laboratory for the production of

The world's largest cyclotron, at TRIUMF.

exotic isotopes. Canadian physicists, working with state-of-the-art detection systems at ISAC, are world leaders in studying the structures and reactions of nuclear matter under extreme conditions. Early studies have already led to a better understanding of the production of radioactive isotopes in explosive astrophysical environments.

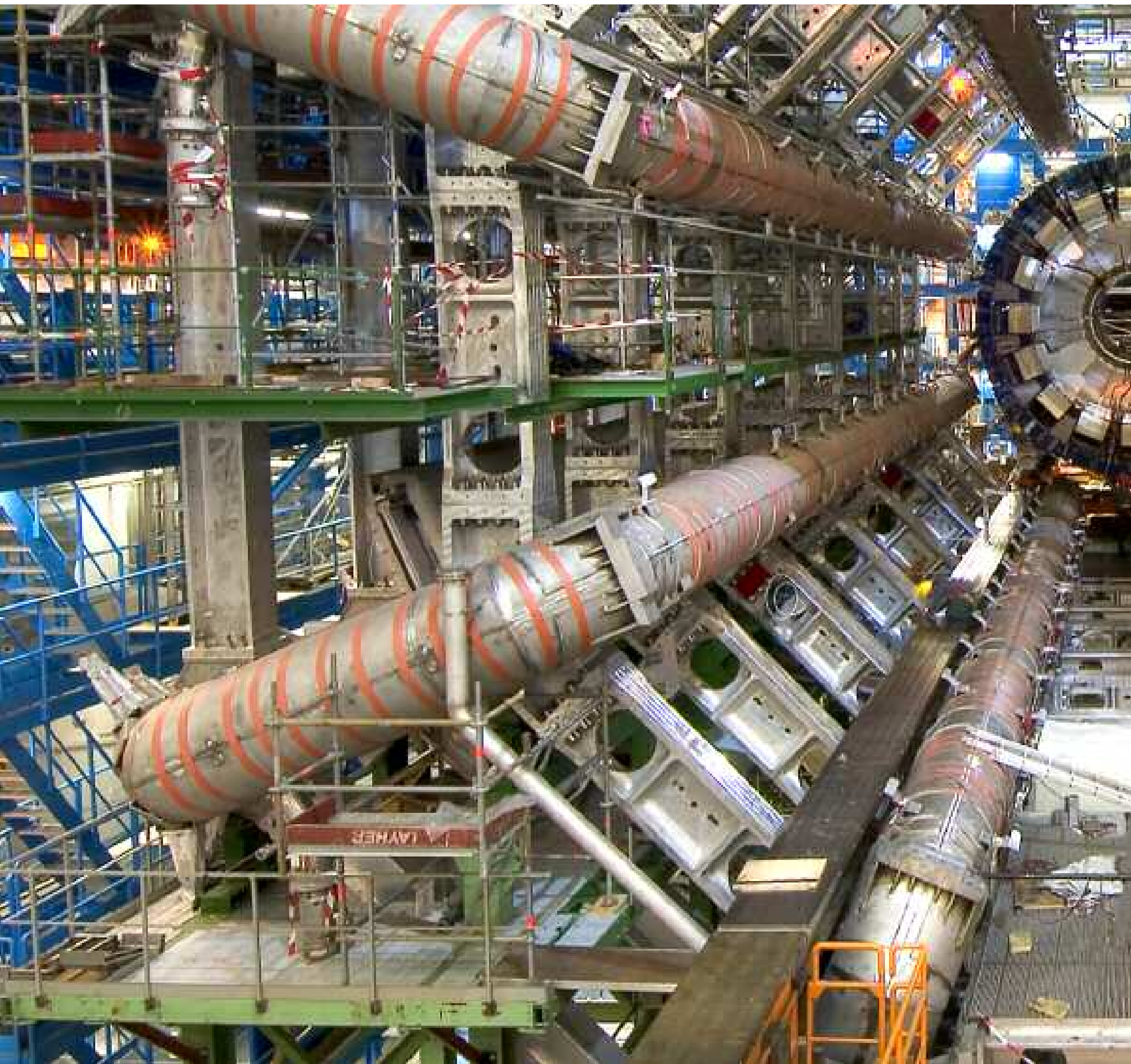
Canadian scientists are now completing a major upgrade to ISAC, called ISAC-II. ISAC-II will accelerate heavier exotic beams to higher energies, and use these beams to study nuclei involved in the production of the heaviest elements. The combination of ISAC and ISAC-II will shed new light on the life cycle of stars and the origin of the elements, and ensure continued Canadian leadership in this exciting field of science.

Some of the more than 1800 scientists from around the world who are members of the ATLAS collaboration.

PHYSICS AT THE VERY HIGHEST ENERGIES – THE LHC & THE ILC

Canadian physicists are heavily involved in the ATLAS project, studying proton-proton collisions at the highest energies available on earth. ATLAS will start taking data in 2007 at the Large Hadron Collider (LHC) at the CERN laboratory in Switzerland. The high energy of the LHC collisions will allow new particles – if any exist – to be discovered and studied. Among the most anxiously awaited is the so-called Higgs boson. In the current theoretical framework of subatomic physics, called the Standard Model, the Higgs is predicted as the particle responsible for endowing mass.

The Standard Model has been an excellent description of particle physics to date, but we know that it is not a complete theory – it includes neither dark matter, nor gravity. Numerous extensions to the Standard Model exist, and embed dramatic new ideas like extra space and time dimensions beyond the four we know. Collisions at the LHC will allow us to test many of these ideas. Canadians

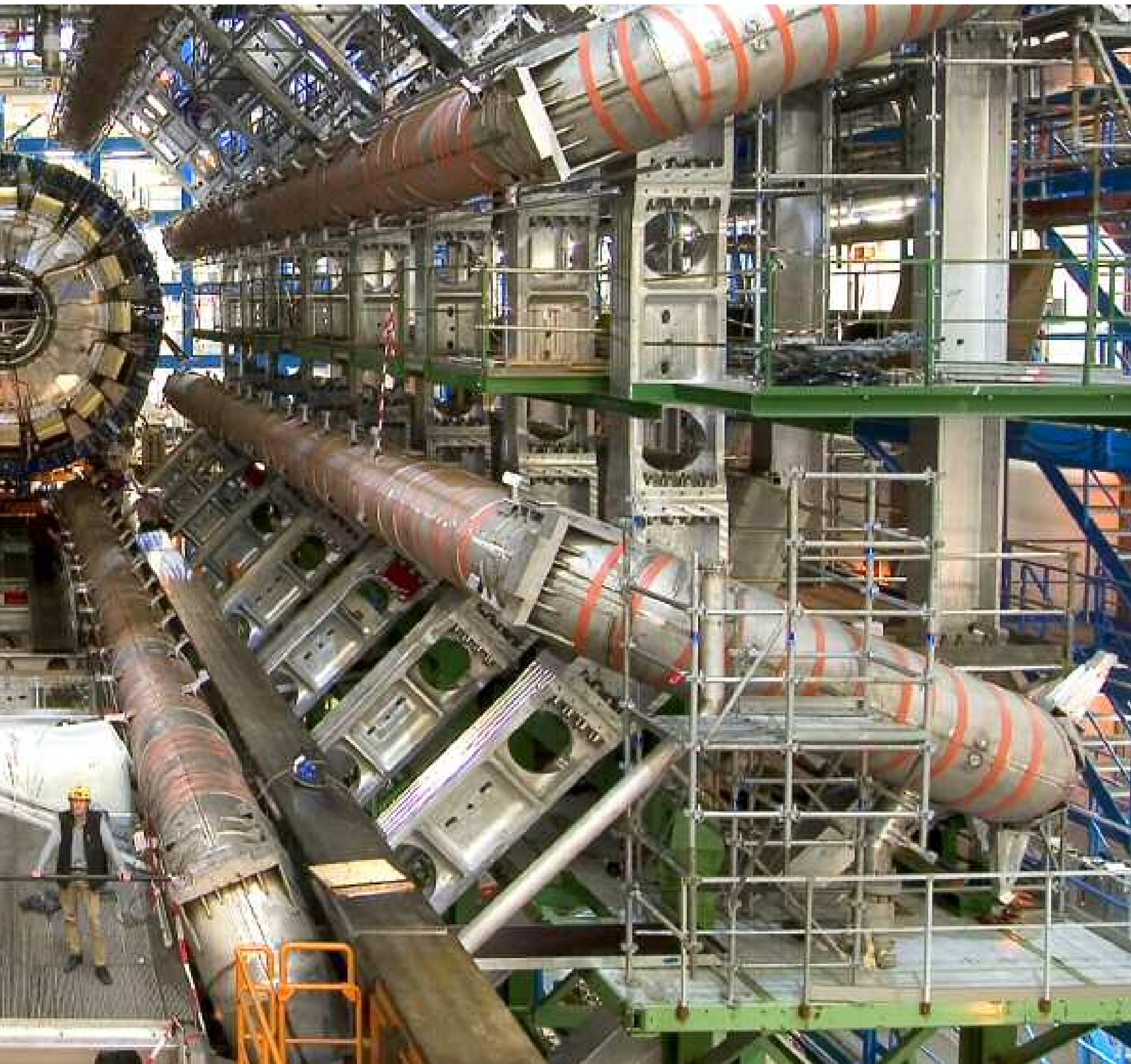


in the ATLAS experiment are involved in all of these 'discovery-potential' searches.

ATLAS and the LHC are likely to operate for more than a decade, and are expected to produce a vast array of exciting results, giving rise in turn to new questions. Further in the future is the proposed International Linear Collider (ILC). The ILC, colliding electrons and positrons (anti-electrons), will provide cleaner conditions than those of the LHC, helping to clarify and extend discoveries made there. The complementary approaches of the LHC and the ILC will be essential to fully understand physics beyond the Standard Model.

Canadian physicists are already key players in ATLAS; new investment in our science will ensure that we are among the leaders, and not just bystanders, in the ILC project and the discoveries that will be made there.

The partially-assembled ATLAS detector at CERN's LHC accelerator, as it appeared in late 2005. To set the scale, note the man standing at the bottom-centre of the photograph.



Subatomic Physics and the Economy

Modern experiments in subatomic physics are challenging and typically require technical innovations. For example, the goal may be to measure the rare decay of a new particle in order to challenge a prevailing theory. This may require a detector of unprecedented resolution, or a novel way to suppress background sources. As a result, experiments in subatomic physics drive detector and electronics technology, often leading to new technologies. Examples of such technologies include high precision particle detectors at the heart of medical imaging devices; the World Wide Web, invented to allow subatomic physicists to efficiently share data world-wide; radioisotopes produced at particle accelerators that aid in the detection and treatment of disease; and high performance computing, driven by the insatiable demands of large particle physics experiments, that today aids in the development of new pharmaceuticals.

Of course, the results of basic research such as subatomic physics cannot be predicted, but it is equally clear that the outcomes are often of practical and economic importantance. Studies have estimated that the annual return on investment in basic research ranges from 28% to 50%, and that Canada's investment in subatomic physics research has paid for itself many times over.

As Canada's economy shifts from resource- to knowledge-based, scientists and technologists are essential to ensure that basic research advances are transformed into new industrial processes and products. Subatomic physics research pushes the frontiers of human knowledge, but also lays the foundations for new technologies in the physical and life sciences, changing the way we travel, communicate, and work. The people who do the science are an important resource in themselves; an investment in subatomic physics training is an investment in a technologically innovative economy.


Canadian technology developed by subatomic physicists, such as these test tube-sized radiation detectors from Bubble Technology Industries, is now sold around the world.

I'm a physicist in the pulp and paper sector. Designing the experiments, analyzing and documenting the results, and offering simplified explanations without losing the science are all skills that I learned during my Ph.D. in experimental high energy physics.

Reena Meijer-Drees, Ph.D.
(University of British Columbia, 1991)

In subatomic physics one has many opportunities to see how successful scientists understand a system at various levels of abstractions, from black box all the way down to root cause when required. IBM's Blue Gene/L supercomputer is a nice demonstration of the value of training in subatomic physics.

Burkard Steinmacher-Burow, Ph.D.
(University of Toronto, 1994)
Blue Gene/L System Development, IBM

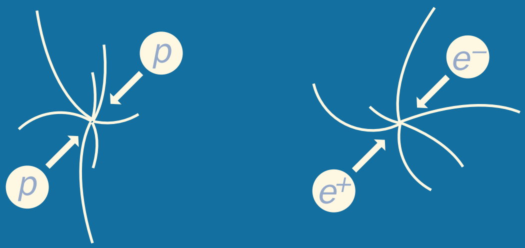
My training led me to a postdoctoral stay at the Fermi National Accelerator Lab near Chicago studying proton-antiproton collisions at the highest energies, and then back to Montreal for a faculty job where I'm now working on the ATLAS experiment at CERN. To contribute to a project of the magnitude and scientific importance of ATLAS is a once-in-a-lifetime opportunity.

Brigitte Vachon, Ph.D.
(University of Victoria, 2002)
Canada Research Chair, McGill University

Obtaining a physics Ph.D. is a valuable discipline to learn; it means tackling a large, complex problem to which the solution cannot immediately be seen. The patience, persistence and detachment necessary to complete the research are skills that translate readily to the business world.

LeeAnn Janissen, Ph.D.
(Carleton University, 1993)
Vice President & Director, TD Securities

2 PATHS TOWARDS DISCOVERY



In the near future, the Large Hadron Collider (LHC) will collide protons (left). Beyond that, the International Linear Collider (ILC) will produce electron-positron collisions (right). Studies at the ILC will be necessary to fully understand any new particles discovered at the LHC.

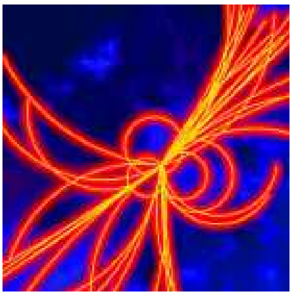
The Next Decade for Subatomic Physics in Canada

Canada has a strong position in subatomic physics, with a record of accomplishment and the people to retain that position. Physicists in Canada have focussed on the most important questions in this field. Increased research funding over the next several years would enable us to make full use of the facilities and experiments we have helped to develop – including the world-class SNOLab and ISAC facilities in Canada – and to be leaders in the exciting new physics that will be done there.

Over the longer term such support would ensure that we participate in the next generation of leading-edge physics at facilities such as the International Linear Collider, while maintaining the diversity of research efforts that is necessary for the health of our field.

Increased funding for subatomic physics would enable Canada to maintain its position at the very forefront of our science, participating in the excitement that will emerge from today's laboratories and leading the new projects that will help to answer some of the most compelling questions in science.

An artist's conception of the future International Linear Collider, which will collide electrons and positrons at an energy of approximately 500 GeV and will start operations in the next decade.



A simulation of particles emerging from the decay of a Higgs particle produced in a high-energy electron-positron interaction.

A view of the ATLAS Hadronic Endcap Calorimeter prior to installation. The HEC was constructed in Canada and assembled at TRIUMF.

With continued strong support, Canada will be a leader in what may be the next renaissance in science.

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