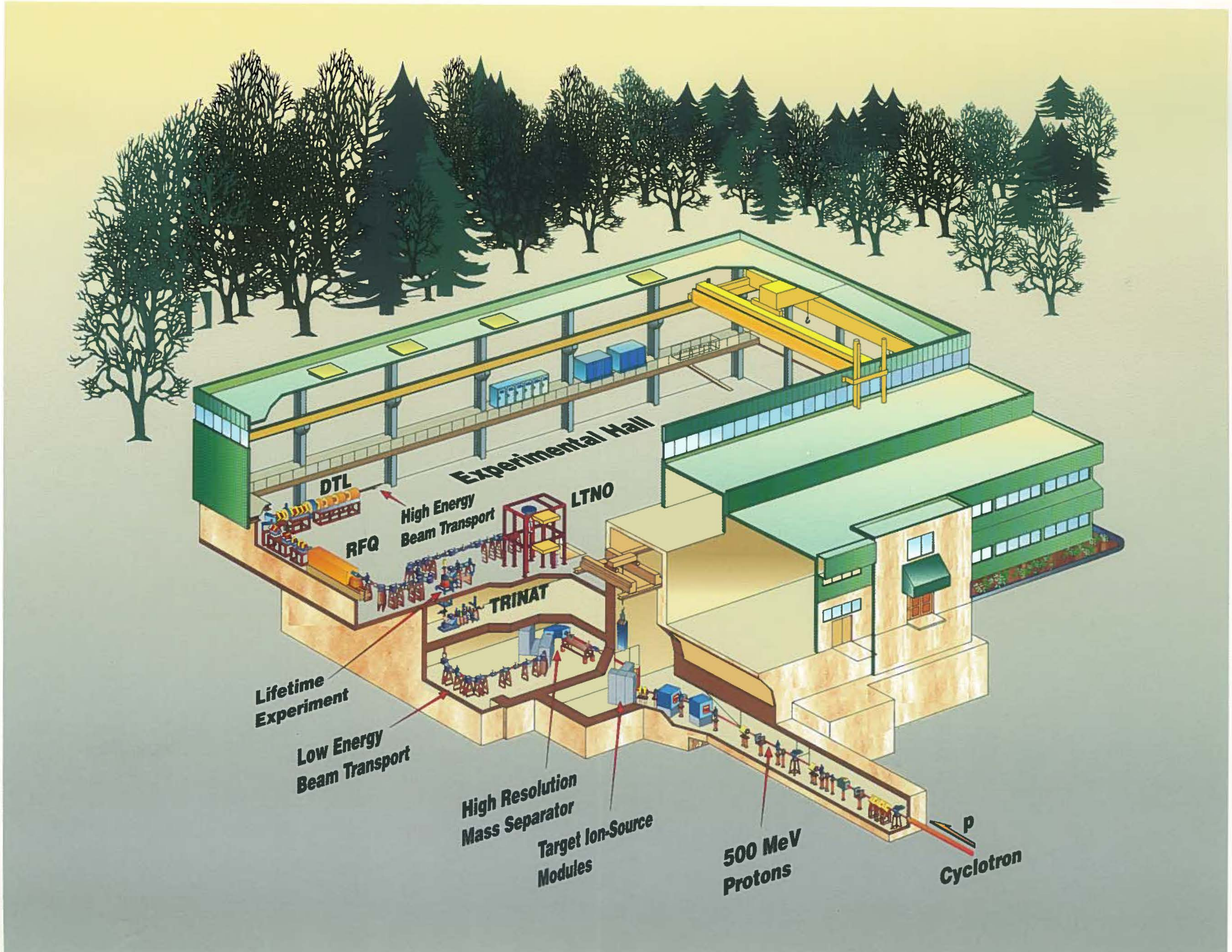
TRIUMF

1998 - 1999

Annual Financial & Administrative Report


Experimental Hall
DTL
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TRIUMF

TRIUMF is Canada's national laboratory for particle and nuclear physics, managed as a joint venture by a consortium of Canadian universities. It is operated under a contribution from the Government of Canada through the National Research Council of Canada.

1998 - 1999

Front Cover: 35 MHz Rebuncher
Inside Front: ISAC Building Cross Section
Inside Back: ATLAS Cross Section
Back Cover Photo: Centre Region of CHAOS Detector

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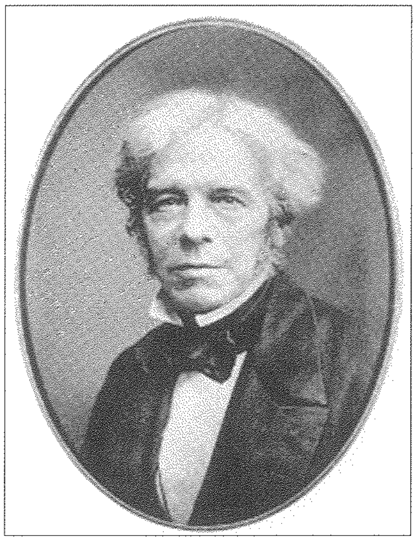
"History is the science of what never happens twice"

This old aphorism of Paul Valéry will undoubtedly prevail in the future, just as it has been shown to be valid in the past. Nonetheless it is interesting to look at the parallels between what concerns today's high energy physicists and what concerned the physicists in the middle of the last century. If history comes close to repeating itself and the economic benefits were to be even one-tenth of one percent of those in the past, governments today would be fighting each other for the right to buy a piece of the action at the high energy frontier.

We have in nature four quite disparate forces. The one we experience all of the time is gravity; it acts on mass, and we work against it all day. It is by far the weakest force, and perhaps the least understood, although in the coming decade it will receive unprecedented experimental scrutiny. The discovery of radioactivity gave us a second so-called weak force which is responsible for radioactive decay. There is then the electromagnetic force which draws sparks from doorknobs and makes distinctive patterns in iron filings. Finally we have the strong force, which binds neutrons and protons inside a nucleus and fuels the fission and fusion processes via the unnerving Einstein equation of $E=mc^2$.

Currently the strong, electromagnetic, and weak forces are impressively described by what is known as the Standard Model. Within the Standard Model the weak and electromagnetic forces are united in the beautiful electroweak theory. Increasingly it appears as if all the forces are different manifestations of a single unified force of nature. What we experience depends upon the energy scale with which we examine them. For example, above a particular energy the electroweak theory describes the behaviour of massless particles, while below this energy we experience our separate weak and electromagnetic forces and mass is created. The quanta of the weak field, the W and Z, are massive, and the quantum of the electromagnetic field, the photon, remains massless.



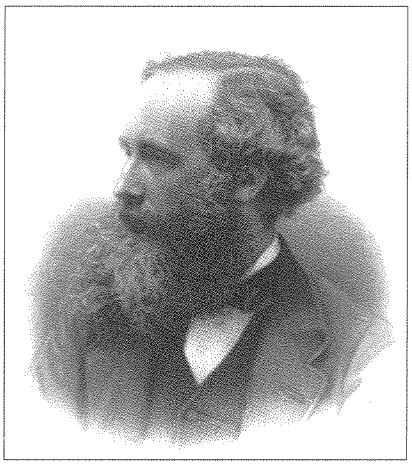
Michael Faraday

At the Large Hadron Collider which is under construction at the CERN laboratory in Geneva, physicists will be able to examine copious collisions of the constituents of matter at energies above what is called "the electroweak threshold" and examine the "electroweak symmetry breaking." These experiments are confidently predicted to reveal the mechanism which separates the unified forces and creates mass in the process.

In the middle of the last century physicists struggled to understand two forces: a magnetic force and an electric force. Two of the giants in the saga were Faraday, a brilliant experimentalist, and Maxwell, a theoretician.

In 1821 Faraday devised an ingenious experiment in which he observed effects caused by the rotation of a magnet around a current-carrying conductor. The first electric motor was born and electrical energy had been converted into mechanical work. In 1831 in a series of experiments Faraday discovered electromagnetic induction - the variation of a magnetic field with time induced an electrical current in a conductor. Here the dynamo was born along with the principles for electric power generation.

The story has it that around 1850 Faraday was visited in his laboratory by William Gladstone then the Chancellor of the Exchequer. One can safety assume that Faraday was not tongue-tied, nor unclear in the description of his work, since he devoted considerable amounts of his time to give public lectures. However the point was reached where Gladstone remarked, "Mr. Faraday, this is all very interesting, but what use is it?" Faraday's reply was, "Sir, I do not know, but I wager that one day you will tax it!" Picture the two men standing in a cluttered laboratory which had in it the principles of the electric motor and the generation of cheap electric power. One can scarcely comprehend the economic benefits which have flowed to governments over the last century from those untidy surroundings.



James Clerk Maxwell

Faraday, always aware of his lack of mathematical ability, nonetheless had developed a clear idea of lines of force and the possibility of electric and magnetic fields. Maxwell built on these ideas and in 1864 formalized the theory of electromagnetism in four elegant equations. The electric and magnetic forces were merely two manifestations of a single electromagnetic force.

Maxwell also realized that one of his equations predicted the propagation of an electromagnetic wave through vacuum with the speed of light - the wave was indeed light! He also predicted the existence of a spectrum of electromagnetic radiation with different wavelengths. We may take, for example, radio waves and simply credit Maxwell with the accrued economic benefits of the radio communications industry.

So far as one can tell neither Faraday nor Maxwell showed the least interest in the practical applications of their work. They were dedicated basic scientists driven in their attempts to understand the electric and magnetic forces. We inherited from their work the single familiar electromagnetic force.

Sometime towards the end of the first decade of the next millennium high energy physicists will likely have understood the unification of the electromagnetic and weak forces, and as a consequence, the mechanism which imparts mass to particles. Can we anticipate the economic cornucopia which flowed from the discoveries of Faraday and Maxwell? Sadly one suspects Paul Valéry may indeed be correct. Some would give the answer of an emphatic "no." More fairly, more correctly, and equally emphatically the answer should be "we simply do not know."

Alan Astbury

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From The Users' Group Charter

The TRIUMF Users' Group is an organization of scientists and engineers with special interest in the use of the TRIUMF facility. Its purpose is:

a.) to provide a formal means for exchange of information relating to the development and use of the facility.

b.) to advise members of the entire TRIUMF organization of projects and facilities available.

c.) to provide an entity responsive to the representations of its members for offering advice and counsel to the TRIUMF management on operating policy and facilities.

Membership of the TRIUMF Users' Group is open to all scientists and engineers interested in the TRIUMF program.

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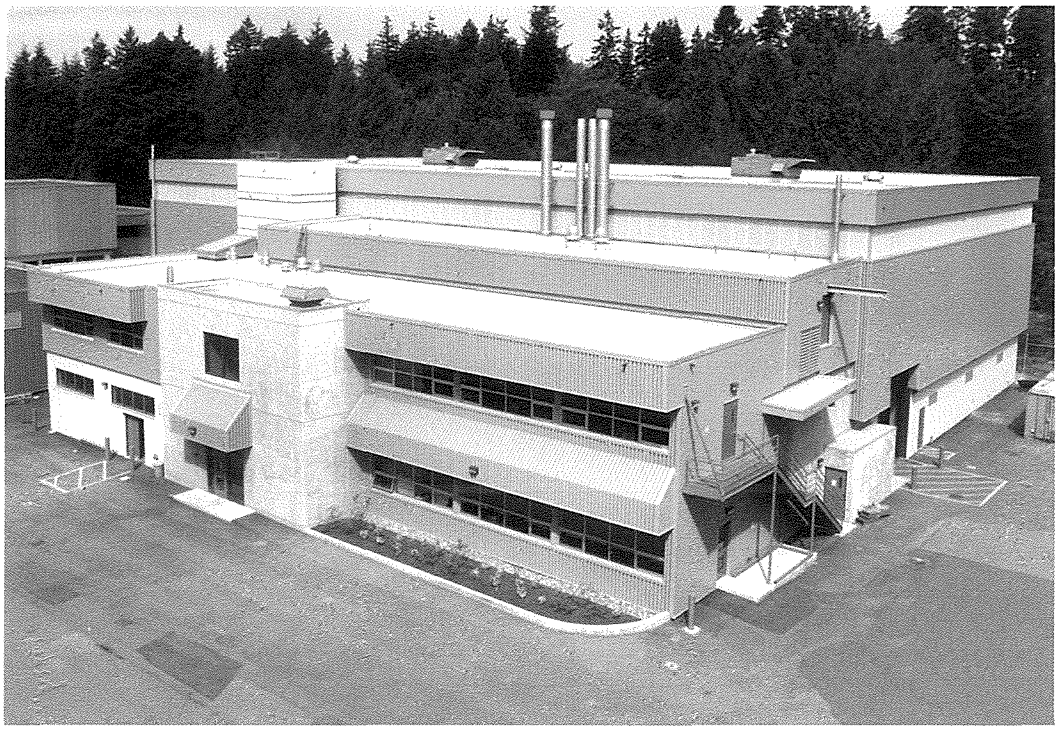
ISAC Facility

The Isotope Separator and Accelerator (ISAC) project at TRIUMF has resulted in a world-leading facility for producing rare, short-lived isotopes for scientific research in Nuclear Astrophysics, Nuclear Physics, Nuclear Chemistry, Condensed Matter Physics and Nuclear Medicine. Funding from the National Research Council of Canada and the Province of BC for a five-year construction phase was announced in June 1995. Facility construction began after the first contract for civil construction was awarded in August 1996.

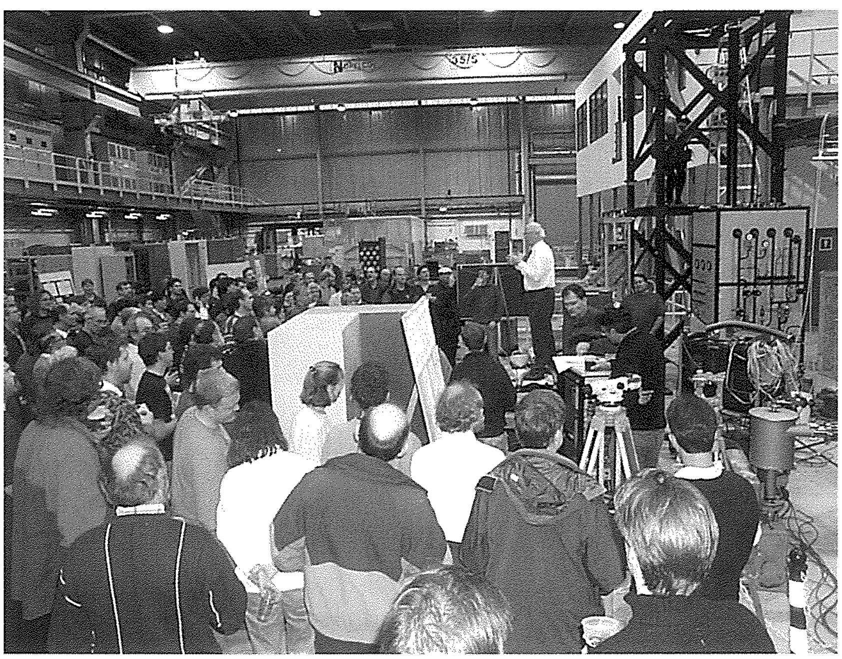
Up to 100 μA. of protons from the TRIUMF cyclotron are transported by a new 500 MeV proton beam line to the ISAC target area. There they interact with material in a target resulting in a number of different isotopes being produced These isotopes effuse from the target material, then diffuse to an ion source where they are captured and formed into an ion beam. In order to obtain isotopes with lifetimes as short as 10 milliseconds it is necessary to reduce the effusion and diffusion times by maintaining the target at temperatures as high as 2000 degrees. The ion beam is fed to a mass spectrometer where the isotope of interest can be selected for transmission to one of two experimental areas. In one (the low-energy area) the isotope beam is used directly. In the other the isotope beam is fed to an accelerator system before being directed to the high-energy experimental stations. A cut-away sketch of the facility appears on the inside front cover.



ISAC Building

Following the formal receipt of the ISAC building occupancy permit early in 1998, the bulk of the ISAC activities switched from overseeing the civil construction to completing the technical facilities required for the initial research programme. A major milestone, namely the delivery of a low-energy beam of a short-lived potassium isotope, was achieved in November 1998, approximately one month ahead of schedule. This milestone signalled the beginning of the experimental programme using ISAC's Rare Isotope Beams in the low energy area. Intensive preparatory work over a number of years at TRIUMF's Test Isotope Separator On Line (TISOL) facility on ion source development and experimental equipment design helped enormously in achieving this important milestone. The low-energy beam-transport system now reaches three experimental stations in the experimental hall. The following article describes the initial experiments.

The nuclear astrophysics experimental programme will examine the processes that determine the relative abundance of the naturally occurring elements. These experiments require that rare isotopes be accelerated to energies from 0.9 to 45 MeV (0.15 to 1.5 MeV/amu). Linear accelerators have been designed and are being constructed at TRIUMF for this purpose. The first linac is a Radio Frequency Quadrupole (RFQ) that operates at 35 MHz. Successful operation of an RFQ requires precise machining and alignment. For instance, the accelerating electrodes in this eight-meter long structure had to be aligned with a tolerance of ±0.05 mm. Beams of stable nitrogen-isotopes were accelerated through the first third of the structure in 1998 and through the complete structure in the summer of 1999. Observed beam properties were in excellent agreement with the numerical simulations. The beam from the RFQ will be transported to a Drift Tube Linac (DTL) consisting of five short, one-meter diameter tanks separated by three rf bunchers and four quadrupole triplets. This chain of rf devices operates at 105 MHz and is designed to allow the energy of the accelerated isotopes to be varied while keeping the beam in well-defined time-bursts. The first tank and first buncher have been successfully tested at full accelerating voltage. The first beams for nuclear astrophysics experiments are scheduled to be available in the high-energy experimental area by the end of 2000.



Alan Astbury addressing TRIUMF staff in the ISAC experimental hall.

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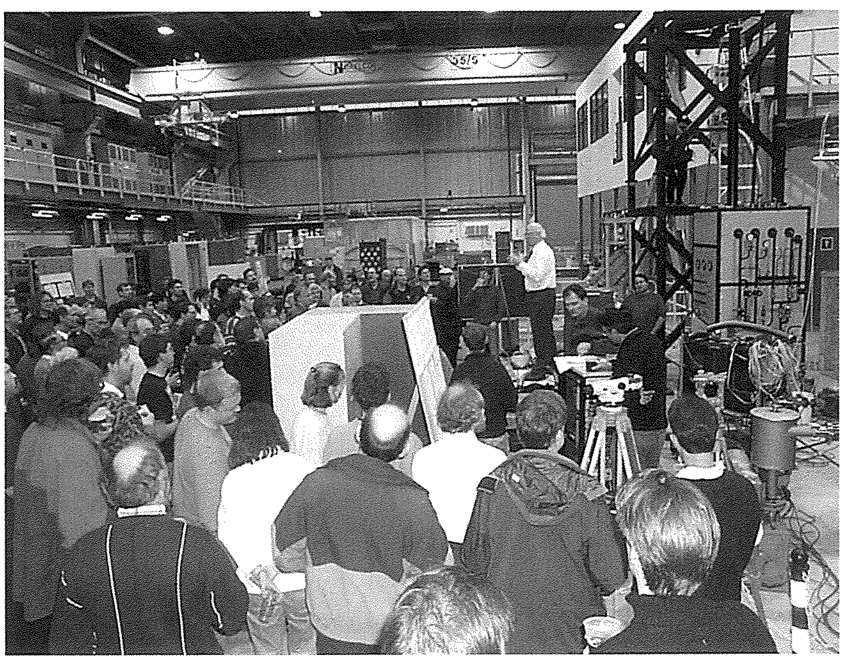


Alan Astbury addressing TRIUMF staff in the ISAC experimental hall.

Early Experiments at ISAC

At ISAC, studies of the decay of radioactive isotopes are being pursued to make a precision test of the validity of the Standard Model. Most radioactive isotopes decay by the simultaneous emission of two energetic particles, a beta (i.e., an electron) and a neutrino. Our present understanding of the *weak* interaction (the force that causes nuclear beta decay) predicts that for a very few special isotopes the decay properties should be identical and related in a simple way to a component of the weak force. Precision measurements of the decay rate for these so-called superallowed Fermi beta decays can be used to test this hypothesis and to determine the strength of the force. The current world data on superallowed Fermi beta decay leads to a result that is tantalizingly close to a definitive disagreement with the Standard model. Since this result would have profound implications it is essential to eliminate all possible "trivial" explanations. Unfortunately, this test is not quite that simple, and small but very important corrections must be computed before the test can be applied.

The ISAC facility will provide beams of these special radioactive isotopes over a wider mass range than previously available. This will allow us to test further the model and to validate the corrections that must be applied. Three quantities must be measured to determine the decay rate for a superallowed transition: 1) the lifetime of the radioactive isotope, 2) the energy released when the nucleus decays, and 3) a measurement of any small non-superallowed components of the decay.

High-precision beta-decay lifetime measurements are being carried out at ISAC using techniques that were perfected in previous studies. Although the measurements are simple in principle, great care must be taken to achieve the required precision (~0.05%). Low-energy radioactive ion beams from ISAC are implanted into an aluminized mylar tape of a fast tape transport system. After a short (< 1 second) collection period the ISAC beam is interrupted and the sample is moved out of the vacuum chamber and positioned in a 4π continuous-gas-flow proportional counter where beta particles from the decaying isotope are counted as a function of time. For most superallowed Fermi beta-decays the half-lives are less than a second. After about 20 half-lives a new sample is collected and the cycle is repeated. A high precision clock accurate to 2 millionths of a second per second is used to provide a time standard for the experiment.

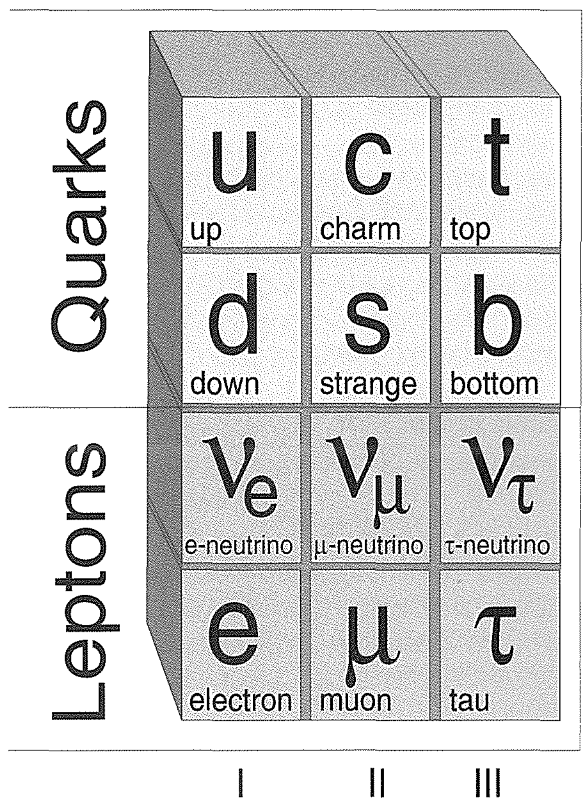
Precision lifetime measurements have been completed for ^{37}K and ^{38m}K. Thanks to the intense beams from ISAC the uncertainty in the lifetime for ^{37}K was reduced by a factor of about 20. The ^{74}Rb beam from ISAC set a world record allowing us to obtain 100 times more data for this isotope than was available previously. In order to complete this study measurements will be made of non-superallowed components of the ^{74}Rb decay.

Our early results show that ISAC produces the radioactive beam intensities needed to extend precision beta-decay studies to heavier nuclei and is realizing its promise as an invaluable tool in studies of this nature for many years to come.

In the last 30 years or so of particle physics, experiments and theory have led to a remarkable understanding of the fundamental constituents of matter and the forces that act between them. The resulting theory is one of the great intellectual achievements of the 20th century. It is known as the "Standard Model" and is a source of pride and frustration. Experimental measurements at many laboratories, including TRIUMF, have demonstrated impressive agreement with its predictions, and yet almost all of its basic parameters have to be fed in from experiment.

The basic building blocks of matter appear to be the quarks and leptons. They interact through the exchange bosons: the photon for the electromagnetic interaction, the W and Z for the weak interaction, and the gluon for the strong interaction. There is no explanation for the vastly different masses of the constituents of the Standard Model and the ephemeral neutrinos are massless. Yet, despite these shortcomings, the theory successfully predicts observable quantities at the microscopic scale to a few parts per thousand. Perhaps the most obvious flaws in the theory are that 90% of the matter in the universe, the so-called "dark matter", is not explained and gravity cannot be accommodated.

However change is near. Experimentally neutrinos now appear to possess a small but non-zero mass. Soon experiments may reveal the mechanism which creates mass, and the force of gravity is being explored as never before. The particles of the dark matter may soon be produced and detected in the laboratory.



Three Generations of Matter

The road beyond the Standard Model will be derived from future experiments. Physicists from Canada will play a crucial role in answering these fundamental questions and, as a national laboratory, TRIUMF will have an important part to play.

The CHAOS Detector

The CHAOS (Canadian High Acceptance Orbit Spectrometer) was designed and constructed in order to study pion induced nuclear reactions. It provides an electronic picture of the trajectory of the incoming pion as well as the trajectories and identities of the outgoing charged particles. This picture is built up from information supplied by a number of different types of nuclear particle detectors arranged in a special vertical cylindrical geometry. Particles arriving at or emitted from the target region near the cylinder's axis can be observed in almost all directions in the horizontal plane if their trajectories are inclined at less than 7 degrees above or below the horizontal.

A particle's trajectory is measured by a set of cylindrical position-sensitive detectors that determine to within several hundred microns where the particle was at different distances from the cylinder's axis. Since the entire cylindrical region is in a vertical magnetic field the charged particle's path will be curved, with the amount of curvature depending on its momentum. Extrapolating the trajectory of each particle back allows the exact site of the reaction to be determined as well as the relative angles of the particles.

More information is required in order to determine the type (electron, proton or pion) and energy of each particle. This is supplied by an outer ring of scintillation detectors which completely absorb the particle thus measuring its energy. The combination of energy and momentum is usually enough to allow the mass to be determined. For cases when it is not, a set of Cherenkov detectors, also in an outer ring, help resolve the ambiguity. These detectors are sensitive to the electromagnetic equivalent of a sonic boom; particles moving close to the speed of light emit this "boom" but slower particles do not.

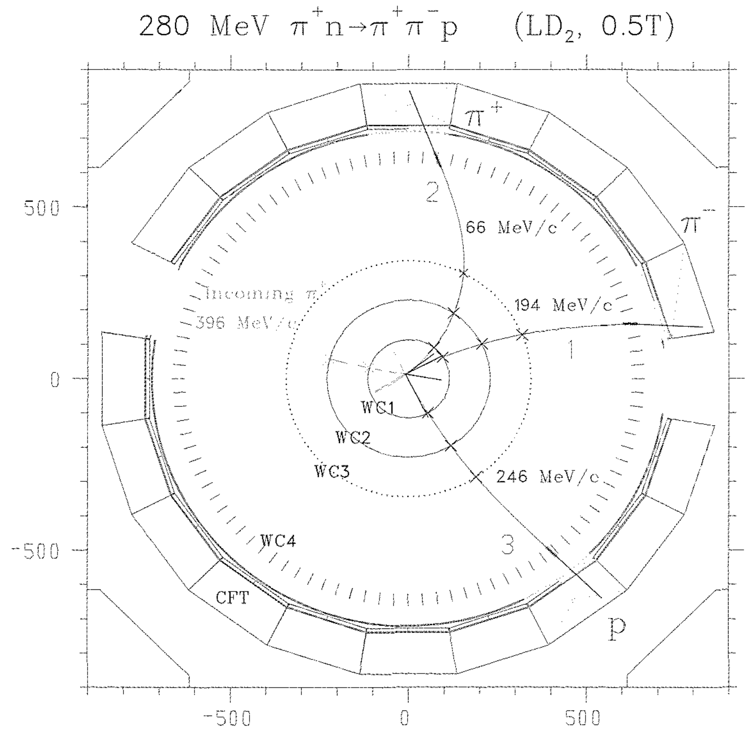


Illustration of a reconstructed $\pi^- p \rightarrow \pi^+ \pi^- n$ event.

Altogether, there are 5,000 possible separate pieces of information available for each event recorded by the spectrometer. In a typical experiment information is acquired from several hundred events each second and recorded by a computer system for later analysis.

There are three basic categories of research which have been performed with CHAOS to date: fundamental particle physics, searches for exotic states of matter, and nuclear physics.

Fundamental Physics with CHAOS

We have made extensive studies of pion-nucleon and pion-pion scattering with CHAOS in order to test the Standard Model and its associated theories. One program was devoted to measuring the difference in the probability of pion-proton scattering when the proton is spin polarized up or down relative to the scattering plane. CHAOS offers a number of unique experimental advantages in such measurements. One of the fundamental quantities these measurements help determine with better precision is the overall strength of the pion-nucleon interaction. The data we acquired are especially useful in determining those parameters which are important near threshold, where tests of the theory can best be made. These parameters were only poorly known prior to our work. The results of the experiment can also be used within the framework of the theory to provide a measure of the so-called 'strange' quark content of the proton. Until recently, the proton was thought to consist of only the two lightest quarks (*up* and *down*). Much work at many laboratories has been geared towards uncovering the role, if any, played by the third lightest quark (the strange quark) in the proton. Although this work is still in progress, the preliminary signs from our work are that the strange quark is in fact an important ingredient in the proton.

Another related program has been geared towards the study of pion interactions with pions. The study of the interaction of fundamental particles with themselves has great theoretical interest. Experimentally it is essentially impossible to study this process directly because of the short lifetime of the pion, only 26 billionths of a second. With CHAOS we have studied pion-pion interactions indirectly by means of the reaction $\pi N \rightarrow \pi\pi N$. The two outgoing pions interact with each other. Careful measurement and analysis of their behaviour can be used to determine parameters which play an important role in the determination of the strange quark content of the proton, mentioned above. Our results confirm the predictions of the theory to within 5%, a factor of 5 improvement with respect to previous experiments.

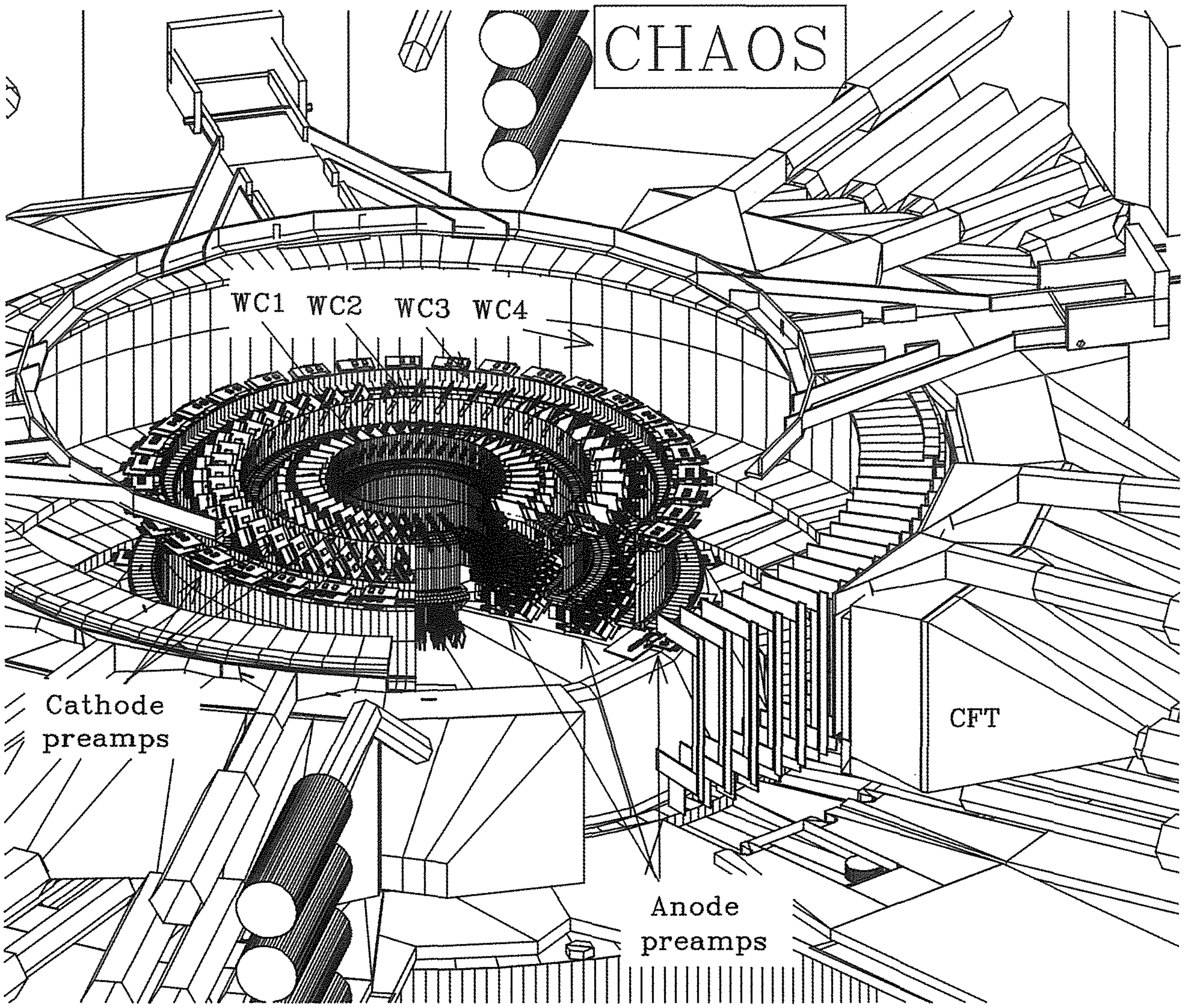
Searches for exotic states of matter with CHAOS

One of the puzzles of the Standard Model has been the absence of particles with combinations of quarks other than the three-quark baryons and the quark-antiquark mesons. This puzzle is all the more enigmatic since the model does not rule out other combinations. Physicists work on the premise that if something is not forbidden, then it must exist. Hence it is a concern that some essential ingredient of the theory is missing.

Physicists have been searching for exotic states of matter for many years. While there have been some spectacular false alarms, no solid candidates have been found to date. False alarms are caused by the fact that if an exotic state of matter exists, the signal for it will be small and buried in the much stronger signals from ordinary states of matter.

Recently, a candidate for a six-quark state of matter (the d’) has received a great deal of attention. It is predicted to occur in a configuration which makes it seem probable and at the same time with properties which would have hidden it from observation in previous searches. Three experiments have been performed with CHAOS to search for the d'. In the first, we studied the reaction $\pi^+ + {}^4He \rightarrow \pi^-$ pppp by detecting the outgoing π and two of the final state protons, all in coincidence. If, the d' exists, then the reaction could proceed as follows: $\pi^+ + {}^4He \rightarrow d'pp \rightarrow \pi^-$ pppp. In that case, rather than seeing a smooth total energy distribution of the products, we would expect to see a bump at the mass of the d'.

In the second experiment only the outgoing π^- was detected. If the d' exists, an enhancement in the probability of the



Details of the central region of the CHAOS detector. The detector is completely cylindrical. In this figure parts of each component of the detector are cut away for clarity.

reaction occurring as function of energy should occur at the threshold energy for d'

Finally, in an even more sensitive experiment, the reaction $\pi^- + {}^3He \rightarrow \pi^+nnn$ was studied. The π^+ was measured using CHAOS and one of the neutrons detected in coincidence with a neutron detector π array. The fact that only one neutron need be detected (instead of 2 protons) in coincidence with the pion greatly enhances the sensitivity of this experiment to d' formation.

All three experiments are still being carefully analyzed. As yet no definitive evidence for the d' has been observed. It appears that the presumed signals seen at other labs may be due to other causes, and that the puzzle of whether matter can exist in exotic combinations is still with us.

Nuclear physics with CHAOS

Only two of the studies in this broad category which have been examined with CHAOS will be mentioned here. The first experiment looked at pion production in nuclei, i.e., $\pi A \rightarrow \pi\pi B$, where A varied from ${}^2H$ to ${}^{208}Pb$. One of the most interesting aspects of the results was the anomalous mass dependence observed in the $\pi^+ \pi^-$ invariant mass spectra, which showed up as an enhancement near threshold which grew with the target mass. The corresponding $\pi^+ \pi^+$ invariant mass spectra exhibited no unexpected dependence on the mass of the target nucleus. Hence the data seem to indicate that the $\pi\pi$ interaction changes in the nuclear medium, an effect completely unanticipated by the theory.

Pions can be absorbed in nuclei, converting all their mass and kinetic energy into kinetic energy of the absorbing nucleons. This cannot be done by a single nucleon and still conserve both energy and momentum. One of the most basic questions in pion absorption has been to find out how many nucleons participate in the absorption. One of the surprises of the studies performed with CHAOS is that while, as expected, two nucleons most often participate in the absorption, three nucleons almost never do, and a substantial fraction of the time four nucleons participate. Previously three-nucleon absorption was thought to be more important than four-nucleon absorption. Our studies have shown that three-nucleon emission is not due to three-nucleon absorption, but rather to two-nucleon absorption followed by a final state interaction which kicks out another nucleon.

One measure of a successful research program is the publications and the theses it fosters. To date, the CHAOS program has generated five instrumentation papers and eleven published scientific papers, with several more awaiting publication and more still in various stages of preparation. In addition, eight M.Sc. degrees and two Ph.D. degrees have been earned at Canadian institutions from CHAOS research, and an additional seven advanced degrees at foreign institutions.

To summarize, a rich and interesting programme of physics with pions, utilizing the novel and powerful CHAOS detector, has been carried out over the last several years. Experiments are planned which promise even more interesting science, capitalizing on the work which has already been done and extending it in exciting directions.

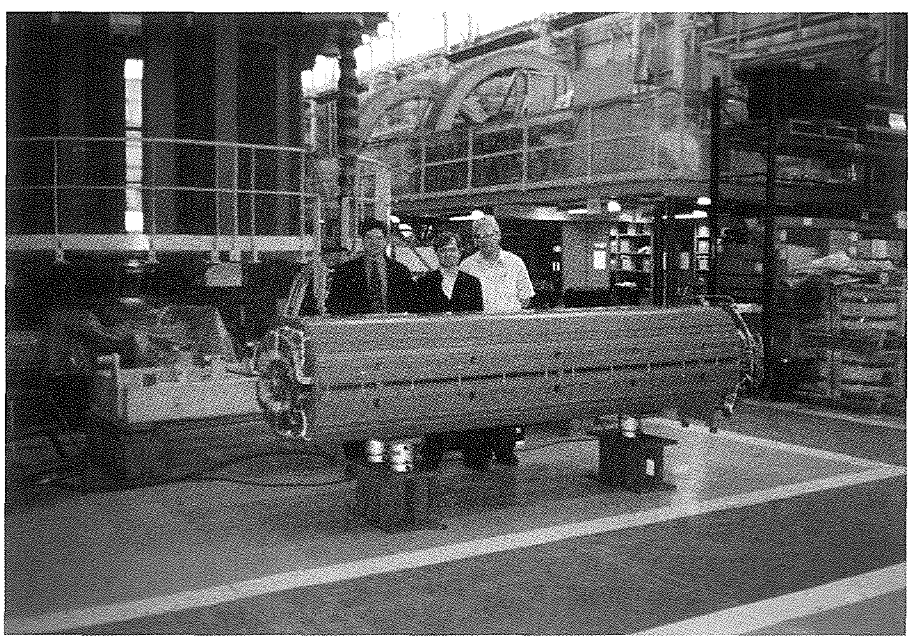
CERN Collaboration - LHC

The Large Hadron Collider (LHC) is an accelerator which is being built in a 27 km tunnel on the border between France and Switzerland near Geneva. Funding for this project comes from the 19 European Member States of CERN with additional contributions from the host countries and five other countries whose scientists are involved in the LHC research program: Canada, India, Japan, the Russian federation and the United States.

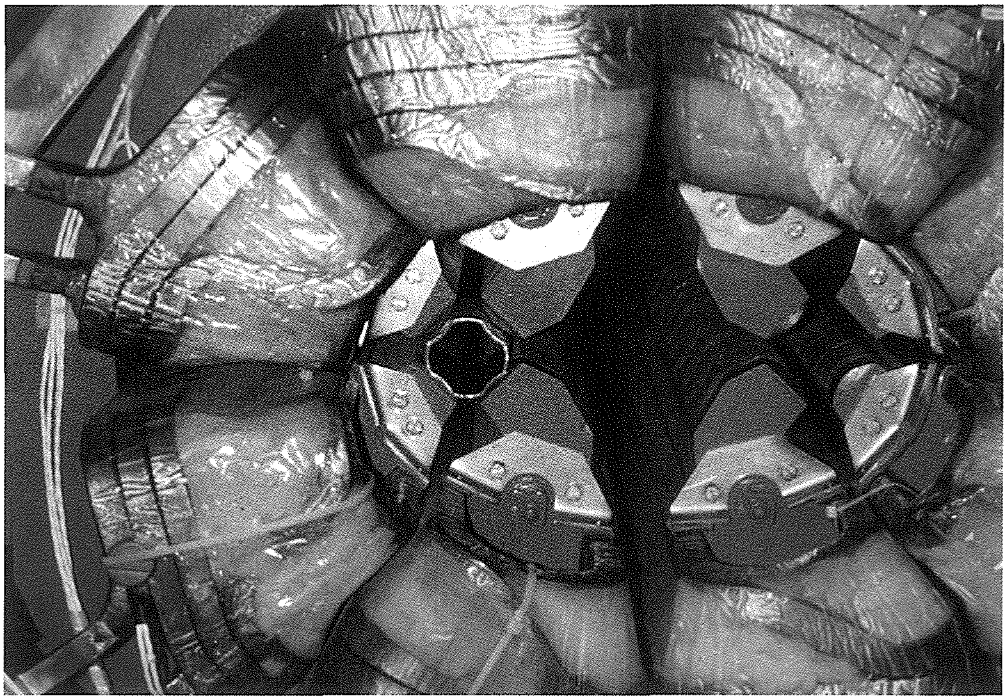
LHC will collide protons at higher energies than ever achieved before, allowing scientists to penetrate still further into the structure of matter and recreate the conditions of the early universe just after the "Big-Bang". Canadian scientists are constructing components for the ATLAS detector, one of the two very large instruments for viewing the proton-proton collisions taking place in LHC. In addition TRIUMF is responsible for coordinating Canada's $30 million contribution to the LHC accelerator. This funding is for five years starting in 1995.

The first phase of the TRIUMF collaboration with CERN on the LHC is essentially complete with the delivery and successful commissioning at CERN of a large number of accelerator components for the Proton Synchrotron (PS) Conversion project. This work involves upgrades to the existing injector synchrotrons to provide proton beams with higher brightness and with the correct time structure for LHC. Much of this equipment was required for the 1997-98 winter shutdown at CERN and by March 1998, beam was extracted from the PS synchrotron with all Canadian components operating reliably. The PS Booster was operated for the first time at 1.4 GeV in March 1999.

TRIUMF staff are responsible for coordinating the design, specification and manufacturing of these "in-kind" contributions to CERN, making use of Canadian industry wherever possible. For the upgrade of the PS Booster main magnet supply, five large transformers were manufactured by Ferranti Packard in



The 3m long turn aperture quadrupole made by ALSTOM Canada.



Close up of the magnet poles in the twin aperture quadrupoles.

St. Catharines, ON and a 20 Mvar reactive power compensator by GEC-Alsthom in the UK but with a significant fraction of the components manufactured in Canada. For the upgrade of the transfer line between the PS and PS Booster, 15 magnets of three different types were designed at TRIUMF, fabricated by industry in Canada and the USA and field-mapped at TRIUMF. About 40 power supplies for the transfer line and for new radiofrequency equipment were built by several Canadian companies, with Inverpower Controls in Burlington, ON providing most of the work. A new contract was awarded to IE Power for a second batch of 100 kW and 250 kW power supplies to complete the power supply upgrades.

For the LHC itself, Canada is contributing to the injection kickers and to the beam cleaning insertions. A prototype of a 60 kV resonant charging supply for powering an injection kicker was developed at TRIUMF and TRIUMF engineers assisted in the design of a pulse-forming network for this system. The largest piece of the Canadian contribution will be the twin-aperture warm quadrupoles used in the beam cleaning insertions of the LHC. This is a critical area of the collider where beam losses during acceleration and collision are collected in a section of warm magnets to protect the superconducting magnets in the rest of the ring. A prototype of the twin-aperture quadrupole was produced by ALSTOM Canada in Tracy, QC and has undergone field-mapping at CERN. This project involves the precision stamping and stacking of a large number of steel laminations and manufacture of eight long copper coils. The prototype measurements indicate that even tighter tolerances are required for the series production of these magnets. In all, 52 of these magnets are required by 2003.

CERN Collaboration - ATLAS

The ATLAS experiment at the Large Hadron Collider (LHC) at CERN is a collaboration of about 2000 scientists, from 144 institutes in 33 countries. This huge collaboration is assembled to explore a fundamental unanswered question of particle physics, namely: what gives particles their mass. For TRIUMF and Canadian particle physicists, not to be involved in such an undertaking would be unthinkable. The Canadian ATLAS group, funded by NSERC, consists of about 30 faculty members from 9 institutes, and about twice that number of junior researchers and technicians. The TRIUMF group, taking advantage of the NRC-supplied infrastructure at the laboratory, is a major player in ATLAS Canada and in ATLAS.

The ATLAS experiment at the LHC will begin exploring the origin of mass when the experiment and detector are ready in 2005. The ATLAS detector is five storeys high, yet able to measure particle tracks to one-hundredth of a millimeter. Its innermost sensors will contain about 10,000,000,000 transistors, nearly as many as the number of stars in the Milky Way. The demands that our science goals make on the ATLAS detector require that we develop new or improved technologies, which often find application in other areas of human endeavour. While working on the great mysteries of physics, we train students who in turn will apply their skills to fields as diverse as science, medicine, industry, government, finance, and journalism.

The Standard Model,(page 9), despite its successes, is unable to predict the masses of the basic building blocks of matter - quarks, leptons, neutrinos, and messenger particles. This failing leads most physicists to believe there is a more fundamental theory underlying the Standard Model. The ATLAS experiment is an attempt to observe a postulated particle, called the Higgs, that we suspect brings mass to the W and Z messenger particles, and perhaps also to the other building blocks of the Standard Model.

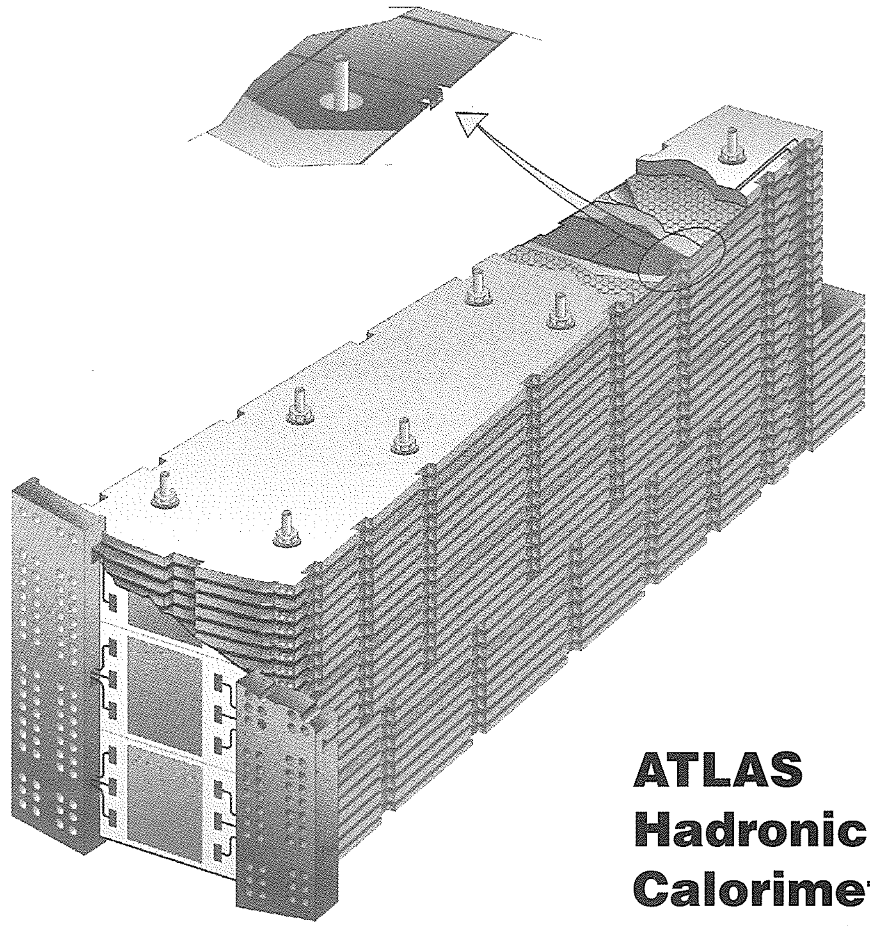
The ATLAS Detector

The ATLAS detector is designed to determine the energies, directions, and identities of particles produced in head-on collisions between of the two beams of protons in the LHC. Some collision products decay very quickly, before they have moved a fraction of a millimeter. Hence ATLAS sees a large, complicated mixture of decay and direct products which have to be accurately and carefully analysed in order to determine what happened.

The anticipated rate of proton collisions is about a thousand million per second. The resulting products from these collisions will produce a data rate in ATLAS equivalent to twenty simultaneous telephone conversations by every man, woman, and child on earth. ATLAS computers will search through this data and select about one in ten million collisions that may manifest new phenomena, and record them. These recorded events will then be inspected carefully by scientists for interesting phenomena.

The ATLAS detector (see inside back cover) weighs 7000 tons, and is located 100 metres underground in the LHC tunnel. It consists of three major components:

1. The Inner Tracker (shown in yellow) that measures the direction and momentum of each particle.
2. The Calorimeter system (shown in green and orange) that measures the energy carried by each particle.



ATLAS Hadronic Calorimeter

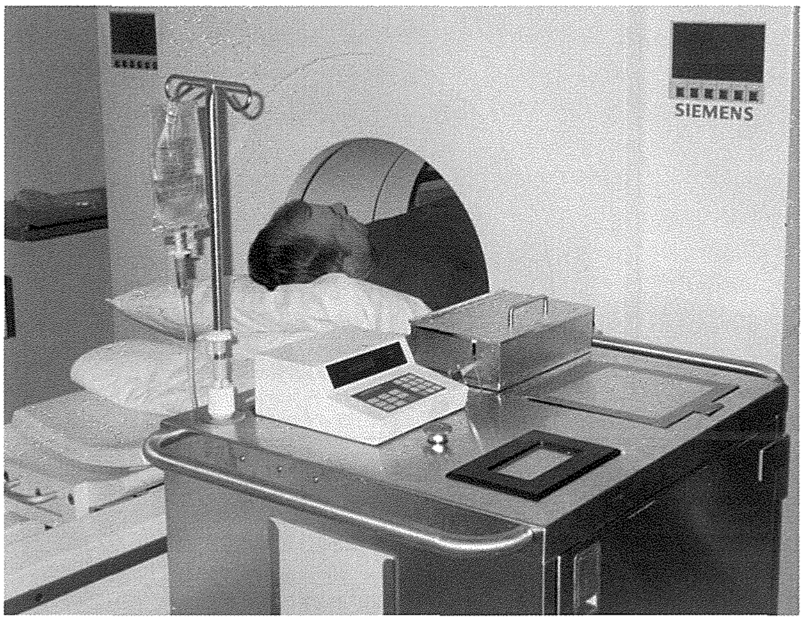
3. The Muon Spectrometer (shown in blue) that identifies muons and measures their momentum accurately.

The proton beams enter each end of the detector and beam collisions occur at its centre. ATLAS is designed to measure accurately all the particles from the collisions except those that escape along the beam vacuum pipe.

The TRIUMF group is involved in designing, prototyping, building, and installing a sub-detector of the Calorimeter system. This 320 tonne sub-detector is built in collaboration with institutes in Canada and abroad (3 Chinese, 3 Russian, 3 German, and one Slovakian). The sub-detector, called the Hadronic EndCap (HEC) Calorimeter is made of copper plates with sensitive readout pads sandwiched between them. The sub-detector is located in a cryostat filled with liquid argon at –187°C. Particles passing through the sub-detector create small electrical pulses on the readout pads. These pulses are amplified by sensitive GaAs amplifiers located in the argon and capable of resolving pulses as small as one thousand electrons. The resulting amplified pulses are sent out of the argon through cryogenic feed-throughs (made by TRIUMF staff resident at the University of Victoria). They then pass through electronics (made by a collaboration including TRIUMF scientists at the University of Alberta) and are digitized to form part of the data flow of ATLAS.

Technology Transfer

Technology Transfer is the TRIUMF Division responsible for the commercial interactions of the laboratory. It is comprised of a small group dedicated to ongoing technology transfer, plus the Applied Technology Group that is responsible for the operations of the on-site commercial cyclotrons on behalf of MDS Nordion.



Ottawa Heart Institute Cardiac PET facility with automatic infusion machine, developed by TRIUMF, in foreground.

The mandate of the Division is the pursuit of financially and technically viable opportunities for commercialising the technologies evolving from research at TRIUMF, in any appropriate manner that will enhance the Canadian economy.

The first step in commercialising new, innovative technologies from a research laboratory is to generate disclosures of such innovations. Experience at research facilities and universities around the world has shown that only a very small percentage of such disclosures actually result in significant commercial products. It is therefore important to encourage and nurture all possible disclosures from TRIUMF, to optimise the probability of achieving a commercial success. With only a very small budget specifically dedicated to this end, it is rewarding to note that TRIUMF staff were able to generate close to thirty disclosures last year. Several of these showed considerable commercial potential, and were funded by TRIUMF, with federal and provincial government assistance, for further development work. The results will likely be seen in future years.

TRIUMF staff are also frequently called upon to assist small Canadian companies with technical problems. Sometimes this assistance is provided in the form of advice, and sometimes it is simply through the use of some highly specialized piece of equipment that TRIUMF is able to make available on a short term basis. Throughout the course of the year, it is estimated that TRIUMF assisted several dozen small companies with everything from leak testing equipment to advice on specialized designs for drying equipment.

Throughout the year, TRIUMF staff continued to assist the BC Cancer Agency with the proton treatment for ocular melanomas, at the clinical facility, here at the TRIUMF site, funded by the Woodward Foundation. Since the inception of this treatment program, close to fifty patients have been successfully treated.

The Proton Irradiation Facility (PIF) at

TRIUMF uses a low intensity beam line which can deliver proton energies between 150MeV and 500MeV to study radiation effects of protons and neutrons on electronic and other components destined for use in space. The PIF is the result of an initiative taken a few years ago by the Defence Research Establishment Ottawa (DREO) that provided the equipment required at TRIUMF for such work. This unique facility is now routinely used by a number of companies and institutions, from Canada, USA and the UK, including DREO, MacDonald Dettwiler, NASA/Goddard Space Centre, Boeing Space Group and DERA Space Group, U.K., to test the potential long-term survivability of their equipment.

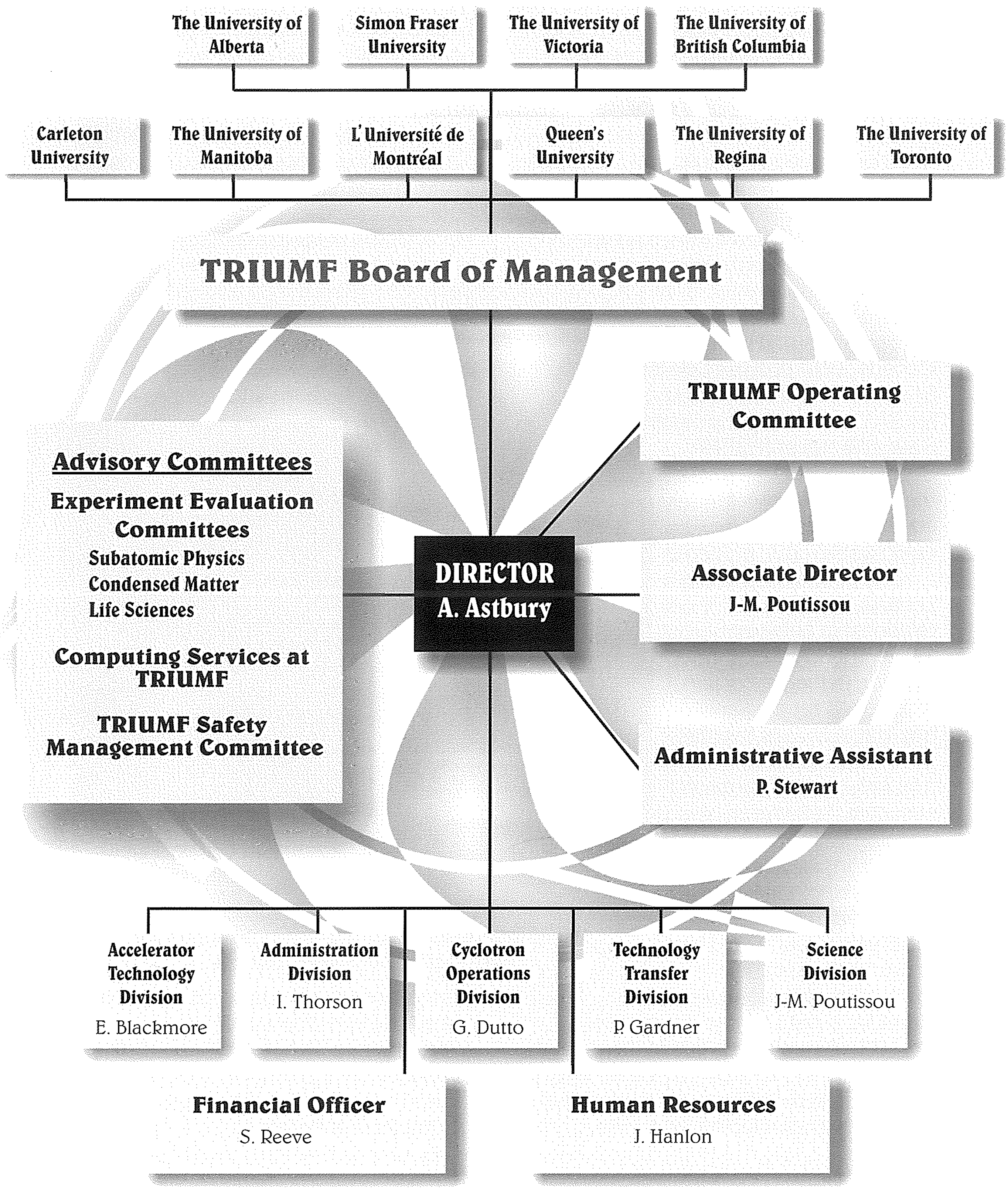
The year also saw the continued successful relationship between TRIUMF and MDS Nordion in the production of isotopes for medical applications. This twenty-year relationship is arguably one of the most successful examples of ongoing technology transfer in Canada. Not only have both sides prospered from the relationship, but also it has provided significant medical benefits to thousands of Canadians right across the country.

TRIUMF's strength lies in the unique aspects of the facilities, combined with the scientific excellence of the staff and the research conducted here. The Division has established a network of contacts with many commercialisation offices and facilities throughout North America and the world, and constantly utilizes those contacts in its own activities. The division is also responsible for patent protection at TRIUMF, but it must be noted that although it can be important in identifying a novel technology, at this level of scientific discovery, merely patenting cannot be relied on as a long-term shield from competitive alternatives.

New technology such as that emanating from TRIUMF is, by definition, a high-risk venture. Although projects may appear to have promising potential, from experience it can be predicted that not all of them will actually meet expectations. The Division always takes a conservative approach in projecting current opportunities into future commercial activities.

Drying wood at the HeatWave Drying Systems plant near Castlegar in British Columbia.

Organization Chart



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June 4, 1999

AUDITOR'S REPORT

To The Joint Venturers of TRIUMF

The accompanying condensed financial statements have been prepared from the statement of financial position of TRIUMF as at March 31, 1999 and the statement of combined funding/income and expenditures and changes in fund balances for the year then ended. We have audited those financial statements and reported thereon without reservation on June 4, 1999

In our opinion, the accompanying condensed financial statements are fairly stated in all material respects in relation to the financial statements from which they have been derived.

PricewaterhouseCoopers LLP

SUMMARY COMPARISON WITH LAST YEAR'S FUNDING

	1998/99		**1997/98**	
SOURCE OF FUNDS	**$,000**	**%**	**$,000**	**%**
NATIONAL RESEARCH COUNCIL	35,000	78.74%	32,954	71.44%
NSERC	5,317	11.96%	4,286	9.29%
MDS NORDION INC	2,135	4.80%	1,681	3.64%
PROVINCE OF BRITISH COLUMBIA	0	0.00%	3.877	8.40%
AFFILIATED INSTITUTIONS	1,427	3.21%	1,980	4.29%
COMMERCIAL REVENUE	382	0.86%	1,210	2.62%
INVESTMENT AND OTHER INCOME	189	0.43%	142	0.31%
TOTAL	44,450	100.00%	46,130	100.00%

TRIUMF
Statement of Financial Position
As at March 31, 1999

	1999 $	1998 $
Assets		
Cash and temporary investments	3,163,093	2,803,057
Funding receivable	1,110,824	1,257,542
Total assets	4,273,917	4,060,599
Liabilities		
Accounts payable	1,158,007	1,602,551
Funds received in advance	1,087,926	769,949
	2,245,933	2,372,500
Due to (from) joint venturers		
The University of British Columbia	(68,790)	(342,719)
The University of Alberta	(1,435)	413
The University of Victoria	(3,558)	20,985
Simon Fraser University	(3,606)	(12,742)
	(77,389)	(334,063)
	2,168,544	2,038,437
Fund Balances		
Restricted		
Natural Sciences and Engineering Research Council Fund	1,619,300	1,458,785
MDS NORDION Inc. Fund	100,000	100,000
Provincial Government Building Fund	18,422	233,616
Affiliated Institutions Fund	143	143
	1,737,865	1,792,544
Other		
Commercial Revenue Fund	(163,918)	219
General Fund	162,243	16,164
Intramural Accounts Fund	369,183	213,235
	367,508	229,618
	2,105,373	2,022,162
Total liabilities and fund balances	4,273,917	4,060,599

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TRIUMF
Statement of Combined Funding/Income and Expenditures and Changes in Fund Balances
For the year ended March 31, 1999

	1999 $	1998 $
Funding/income		
National Research Council Fund	35,000,000	32,954,000
Natural Sciences and Engineering Research Council Fund	5,316,980	4,285,370
MDS NORDION Inc. Fund	2,135,100	1,680,994
Provincial Government Building Fund	-	3,876,978
Affiliated Institutions Fund	1,426,588	1,980,350
Commercial Revenue Fund	382,092	1,210,151
General Fund	189,465	142,328
	44,450,225	46,130,171
Expenditures		
Buildings	486,013	4,209,057
Communications	180,131	235,442
Computer	1,008,276	941,952
Equipment	4,570,967	6,537,208
Power	1,538,542	1,615,447
Salaries and benefits	24,901,116	24,512,124
Supplies and other expenses	11,681,969	10,077,492
	44,367,014	48,128,722
Excess (deficiency) of funding/income over expenditures for the year	83,211	(1,998,551)
Fund balances - Beginning of year	3,296,323	5,472,152
Adjustment to fund balances as a result of a change in accounting policy	(1,274,161)	(1,451,439)
Fund balances - End of year	2,105,373	2,022,162

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TRIUMF
Notes to Financial Statements
March 31, 1999

1. Nature of operations

TRIUMF is a joint venture established by the University of Alberta, the University of Victoria, Simon Fraser University and the University of British Columbia, and has as its goal the establishment and continuance of a national facility for research in intermediate energy science under a contribution from the National Research Council of Canada. As a registered charity, TRIUMF is not subject to income tax.

Each university owns an undivided 25% interest in all the assets and is responsible for 25% of all liabilities and obligations of TRIUMF, except for the land and buildings occupied by TRIUMF, which are owned by the University of British Columbia.

These financial statements include only the assets, liabilities, funding and expenditures of the activities carried on under the control of TRIUMF and do not include the other assets, liabilities, revenues and expenditures of the individual joint venturers.

Sources of funding include grants and contributions from the National Research Council, the Natural Sciences and Engineering Research Council, and governments; advances and reimbursements from other sources; royalty income; and investment income. TRIUMF has established a number of separate funds to account for various funding sources as follows:

National Research Council Fund (NRC)

Funding of operations, improvements and development, expansion of technical facilities (buildings excluded), and general support for experiments.

Natural Sciences and Engineering Research Council Fund (NSERC)

Funding to grantees for experiments related to the science of physics activities. These funds are administered by TRIUMF on behalf of the grantees.

MDS NORDION Inc. Fund

Advances and reimbursements for expenditures undertaken at its TRIUMF site.

Provincial Government Building Fund

Funding from the Province of British Columbia for the construction of new facilities and the upgrade of existing facilities.

Affiliated Institutions Fund

Advances and reimbursements for expenditures undertaken on behalf of various institutions from Canada and abroad for scientific projects and experiments carried out at TRIUMF.

Commercial Revenue Fund

Royalties, revenue and expenditures relating to commercial activities and technology transfer.

General Fund

Investment income for discretionary expenditures incurred by TRIUMF.

Intramural Accounts Fund

Net recoveries for internal projects and services. The recoveries of expenditures are charged to the appropriate TRIUMF funding source by Intramural Accounts.

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