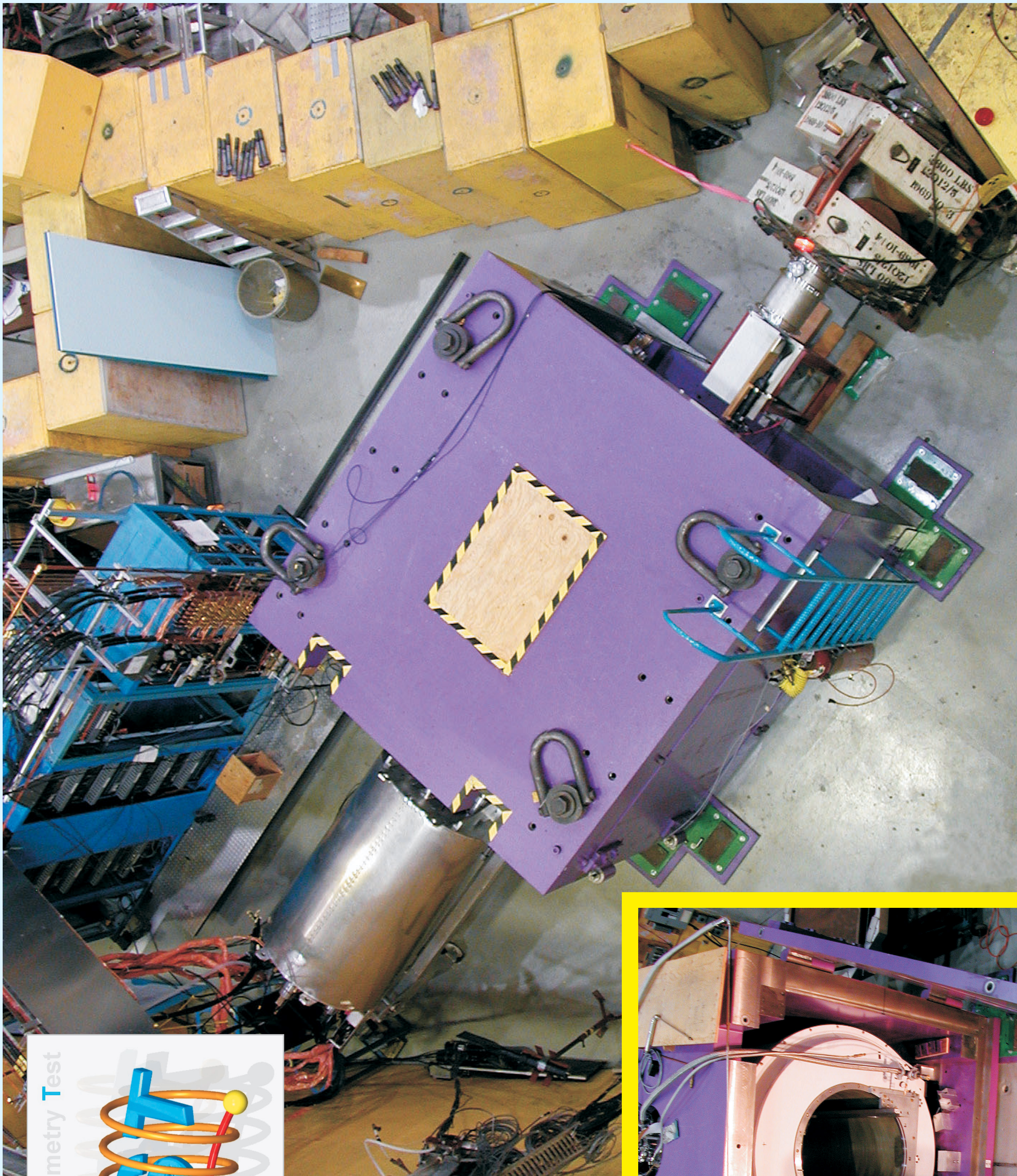
2000-2001

TRIUMF

Annual Financial & Administrative Report



TWIST
Weak Interaction Symmetry Test
TRIUMF

Alan Astbury

DIRECTOR'S REPORT

"Cure the disease and kill the patient."

Francis Bacon

Since this is the last piece of general interest which I will try to write for this august journal, it does seem unfair to leave you firmly impaled on the horns of a dilemma. I hope you can be convinced that there is a real dilemma; one which can have a serious impact on the future of science. It seems only fair to disclose that the author is an experimental particle physicist, who during an administrative spell as a director pursued, in his spare time, some interesting thoughts and observations concerning the genesis of human cancer. The only tools we will use are the infallibility of hindsight, and a rather simple minded look at what we think we can see around us.

The funding for scientific research in Canada can at best be described as *ad hoc.* The various agencies, Industry, Health, Agriculture, Natural Resources etc. retain jealous control over their individual research budgets. Scientific proposals are politicized almost immediately, and there is little or no critical intercomparison of them. Deals are struck between geo-graphical regions, and ministers are quick to claim all manner of potential, but often specious economic benefits. To this must be added the confounding influence of the Canadian Foundation of Innovation. Any real co-ordinated scientific planning appears totally absent. Let us suppose that all of this changed. A full cabinet position, albeit a junior one, has been created with responsibility for all science, and you are the first incumbent. You have a small staff of experts, seconded and carefully selected to be very well connected internationally; all run by a Science Advisor.

Your first decision is likely to determine an appropriate level of expenditure on scientific research. You will seek guidance from a sum which is usually presented as a percentage of GDP spent on R&D. It runs anywhere from 0.5% – 3.5%, and your staff will rapidly produce a list of the percentages from most of the so-called industrialized nations. You are a Canadian thoroughly steeped in the psyche that Canada is a nation which strives to come third. This will to a large extent direct your choice. There will be no desire to lead the pack, however you feel strongly that Canada should invest more than they do. You will end up a little under 1.5% and may even feel proud of your first decision, but perhaps not too proud, since if the truth be told, other nations likely arrive at their percentages in a similar fashion. Your cabinet colleagues applaud your announcement, but you wish the Science Advisor had not written in your briefing notes "eighteenth is not so bad for a G7 nation." His logic, or possibly his humour, is lost on you.

The real decision is a much more difficult one, namely how to divide the funds among the various disciplines. Of course you have already decided to consult a panel of experts in addition to your staff. Here we can offer some guidance from hindsight, well presented by Sir John Meurig Thomas in his paper entitled "Predictions" in the "Notes and Records of the Royal Society." He suggests that we "reflect upon the following statements made by scientists of impeccable credentials."

- Heavier than air flying machines are impossible. (Lord Kelvin 1885)
- I have not the smallest molecule of faith in aerial navigation other than ballooning. (Lord Raleigh, 1889)
- The abdomen, the chest and the brain will forever be shut from the intrusion of the wise and humane surgeon. (Sir John Erickson, Surgeon Extraordinary to Queen Victoria, 1873)
- Anyone who expects a source of power from the transformation of (the nuclei of) atoms is talking moonshine. (Lord Rutherford, 1933)
- A few decades hence, energy may be free, just like the unmetered air. (J. vonNeumann, 1956)
- The possibility of travel in space seems at present to appeal to schoolboys more than to scientists. (Sir George Paget Thomson, 1956)
- Space travel is utter bilge. (Sir Richard van der Riet Woolley, Astronomer Royal, 1956)

The gist of Sir John's paper is that history has taught us to beware of the predictions of experts. They have routinely made errors, and have been guilty of grave omissions. Of course you could always follow the good old Canadian method of assembling a panel comprised largely of over-used non-experts, and then pay no heed to their recommendations. It is still not clear whether this is merely bureaucratic ineptness, or possibly the hand of some evil genius.

If an expert panel appears fraught with hazards, perhaps more general social issues can provide a guide. You are ambitious, you would like to be popular, and above all remembered for a real policy shift. Why not implement and finance a drive towards a cure for cancer; make it your top priority. Sadly, hindsight may dampen your enthusiasm. In 1971, Richard Nixon as President, in a speech to the American people declared "War on Cancer", with a cure promised within a decade. Presumably he was advised by experts. The fact is that age adjusted death rates from cancer have remained remarkably constant in the US, and one finds quotes like that of John C. Bailar III, Chair of the Department of Health Studies in the University of Chicago; a man with a lifetime of experience devoted to statistical evidence in medicine, with special emphasis on cancer. Bailar concludes "that years of intense effort focused largely on improving treatment must be judged a qualified failure." Between 1970 and 2000 in the US funding to the life sciences through the National Institutes of Health more than tripled in constant dollars. If there was a war, it was expensive, and cancer emerged barely dented.

At difficult times like this you notice that your expert staff from different disciplines have a tendency to become partisan, and you hear the comment that "you will never find a cure for cancer if you continue to pump money into particle and nuclear physics." This doesn't appear very perceptive or deep, and seems rather akin to advising a neighbour that he will never have a green fence, so long as he continues to purchase brown paint. But let us explore a little. Perhaps the only real cure for cancer rests with early detection of the tumour, when it is localized and operable. The skill of the surgeon can win. Arguably one of the best means of detecting such a tumour is by a full-body scan using Positron Emission Tomography (PET). A radioactive form of fluorine, provided by nuclear physics, is attached by a chemist to a form of glucose. This tracer becomes concentrated in the body at the location of the tumour as it feeds on the glucose. The fluorine decays producing a positron – the first discovered example of an antiparticle – which annihilates with an electron to produce a pair of gamma rays – yet more 'particles'! These are detected outside the body by scintillating crystals. The image which builds up from multiple decays reveals the site of the tumour. The example of PET serves to illustrate the interdependence of the sciences; starve one and you will certainly slow down progress in others.

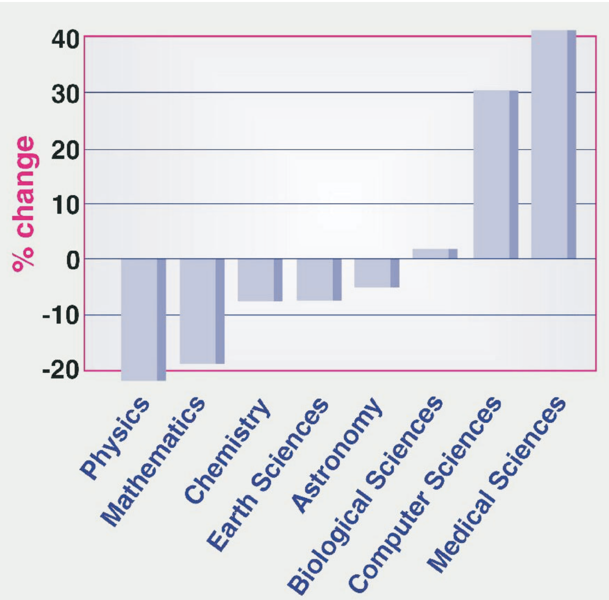
Unfortunately PET finds its main use in the management of cancer; to decide whether it is worth spending the money and theater time to operate on a poor soul where cancer has spread to secondary sites. Nonetheless, should you feel the need to insist on your full-body PET screening, just for peace of mind, the lines would try even the legendary patience of Canadians – currently there exist but five full-body scanners in Canada – not a practical solution!

As the determined new Minister, you remain undaunted by the Nixon experience with cancer. After all, huge gains have been made in the understanding of the molecular underpinnings of tumours, and hasn't the human genome been sequenced in the meantime? You distinctly recall the speech of President Bill Clinton during the joint Anglo-American announcement of the successful sequencing. It went something like "not in our lifetime, possibly not in our childrens' lifetime, but certainly in our childrens' childrens' lifetime, the word 'cancer' will be reduced to the name for a constellation in the sky." Unfortunately this kind of hyperbole surrounds pronouncements on the genome, and on the applications of the knowledge to a cure for cancer. The situation concerning genetics and cancer remains very unclear. Data analyzed by one epidemiological model is claimed to indicate the overriding importance of environmental factors in the incidence of cancer. The same data, with another model, suggests a preponderance of genetic factors. In such confusion, one is perhaps wise to apply some common sense.

Consider the following observations:

- If everyone on the planet smoked, it is highly unlikely that the causal environmental link between smoking and lung cancer would have been uncovered.
- If every male on the planet lived in North America, the age adjusted death rate from prostate cancer in the US would be the accepted norm. However, the age adjusted death rate in Japanese males is approximately one-third of the current US rate, but the Japanese rate in the early '50s was only one tenth of that in the late '90s. Add to this the fact that males of Japanese descent born and raised in the US assume the American rate.
- The age adjusted death rate from breast cancer in Japanese females has risen by approximately a factor of two from the early '50s to the late '90s. Currently it is a little less than half of the US rate which has remained constant over the same period. Spanish females have seen their age adjusted death rate climb by a factor of three over a similar period.

There are numerous other simple facts which, without complicated epidemiological models, suggest that environmental factors play a very important role in the incidence of cancer. What is it that different people do differently for themselves? A thorough understanding of these environmental factors, while not producing a cure, could render cancer a preventable disease. The much touted genetic silver bullets, aimed at individual cancers, may take a very long time to arrive.



Source: The U.S. National Research Council

By now, as the Minister, you are quite confused. Where is the best place to put your money to buy your cure? Being a good Canadian you ask what the US is doing. Very commendably the Americans do monitor their system closely; they collect statistics and publish them so that one is at least aware of what is happening. Between 1993 and 1999 federal funding of the physical sciences in the US declined by 18% in constant dollars, while that in the life sciences increased by 28%. Similar trends have occurred in many countries. This is a very large distortion, and can have an immediate but lasting effect. Hiring patterns change, new positions are created in the universities and old positions are moved to where the money is going. The changes can happen quickly, but once in place will naturally exist for roughly a generation.

The consequences are already evident. The figure, adapted from 'Nature', indicates the percentage changes in the US of the number of full-time graduate students in the various disciplines over the same period. If the trends continue, in twenty years or so, there will be three times the number of researchers in medical sciences, the physics community will have diminished by over a factor of two and Lord knows what one will do with all those computer scientists! One can only hope that the NASDAQ surpasses its former giddy heights.

We seem to be embarking on a huge gamble on the future of science. The bets have almost been placed already. The odds are very long. We could win big, but from all our experience, hindsight and knowledge of the interdependence of disciplines, it seems very unlikely. Most likely we will lose our shirts, and a lot of money will be wasted. No professional gambler would place this bet, so why are the funding agencies, presumably on the advice of some professional scientists, prepared to take the risk? Therein lies the dilemma.

Alan Astbury

Jean-Michel Poutissou

THE LAST 7 YEARS

Dr. Alan Astbury, an experimental particle physicist, was Director of TRIUMF from April 1994 to his retirement in August 2001. Alan received his BSc and PhD degreesfrom the University of Liverpool and went on to do his post doctoral work at the Lawrence Radiation Laboratory in Berkeley California. In 1964 he returned to the Rutherford Laboratory in the UK where he remained for nineteen years, leading experiments on the local proton synchrotron as well as being the leading UK physicist on projects at CERN.

In 1977 Alan Astbury joined Dr. Carlo Rubbia in the SPS proton-antiproton experiment UA1 in CERN. In 1978 he was invited to become co-spokesperson for this experiment which eventually won Dr. Rubbia and Dr. van der Meer the 1985 Nobel prize. Dr. Astbury did not go unrewarded for his central role in this important experiment. In 1986 he received the Rutherford Medal of the Institute of Physics, UK and later, a Fellowship in the Royal Society of London. In 1983 Dr. Astbury accepted the Pearce Chair of Physics at the University of Victoria where he attracted a number of outstanding young Canadian particle physicists involved in experimental particle physics world-wide.

When Alan came to TRIUMF as Director the laboratory was fighting for a future. Was TRIUMF to be decommissioned, suffering the same fate as other laboratories in Canada? Would TRIUMF become little more than a staging laboratory for Canadian physicists working at laboratories in other countries? There was a need for that kind of infrastructure support. But Alan clearly recognized that effective infrastructure support could only be provided by a strong laboratory with a home-based world-class program. From his prior work at TRIUMF he knew that the laboratory had talented people and unique skills. He believed that Canada and Canadian physicists needed TRIUMF and needed a strong laboratory to be a full partner in the world physics community. Alan Astbury fought hard for TRIUMF's future and in 1995 the Federal Government, through the National Research Council, awarded TRIUMF the first of two Five-Year Funding Plans that Alan would negotiate on behalf of TRIUMF.

With this funding came a daunting statement of work. TRIUMF would become Canada's national laboratory for particle and nuclear research, would provide infrastructure support for Canadian scientists working at laboratories around the world, would make the Canadian contribution-in-kind to the new LHC facility at CERN, would continue and enhance technology transfer efforts and provide measurable economic benefits to Canadian industry. In addition TRIUMF was to build the first stage of ISAC, an intense radioactive beams facility, which would be unique in the world. TRIUMF was also to continue its on-site experimental work and increase its role in the Life Sciences work that had been initiated earlier. All this was to be done with the same number of people and unchanged funding levels.

Under Alan's leadership TRIUMF accomplished all of this. Alan organized the laboratory to simultaneously focus on all the tasks at hand. Now, after almost seven years, ISAC-I is complete, producing science and attracting experimenters from Canada and around the world. Canada has received international recognition for the quality of the TRIUMF in-kind contribution to the CERN LHC and we are providing infrastructure support for Canadian scientists and their experiments in laboratories in Europe, CERN and the US. TRIUMF continues to work successfully on its Life Sciences and Technology Transfer efforts while the experimental program based at TRIUMF is growing in strength.

In April 2000 the Federal Government gave a renewed vote of confidence to Alan Astbury and TRIUMF by granting a new Five-Year Funding Plan. The statement of work remains much the same but additional funds were provided to TRIUMF to increase the energy of ISAC above the Coulomb barrier. This will enable scientists to study the nuclear physics of exotic nuclei as well as nuclear astrophysics. TRIUMF will have the premier radioactive beam facility in the world when ISAC-II is complete sometime in 2006.

The staff and management of TRIUMF are rightly proud of their accomplishments and very proud indeed to have had Dr. Alan Astbury as their Director. Alan's ability and willingness to work with all levels of government, the national and international science communities, and our Canadian university constituency made TRIUMF's success possible. Without him, it is unlikely Canada would now have a thriving national laboratory for particle and nuclear physics.

Alan is enjoying a well deserved retirement which, for him, means going back to his first love, experimental physics with his group in Victoria. Enjoy your retirement Alan.

Thank you.

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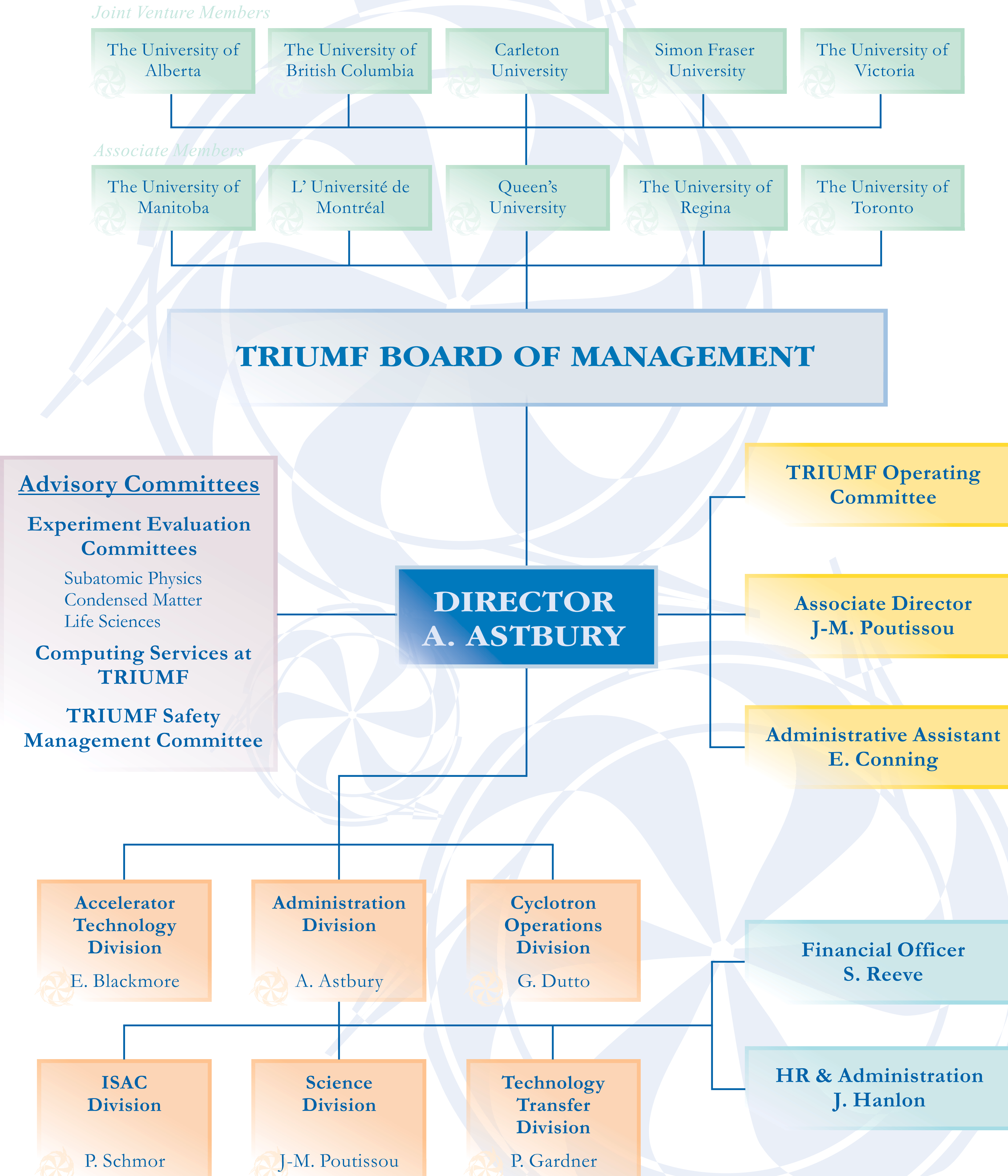
ORGANIZATION CHART



TRIUMF Users' Group

Chair	Nathan Rodning *University of Alberta*
Chair Elect	Graeme Luke *McMaster University*
Past Chair	Jess Brewer *University of British Columbia*
Members	Richard Helmer - *TRIUMF* Gerald Morris - *TRIUMF* Allena Opper - *Ohio University* W. D. (Des) Ramsay - University of Manitoba
Liaison Officer	Martin Comyn - *TRIUMF*

The TRIUMF Users' Group is defined as follows in its own Charter:

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

- *to provide a formal means for exchange of information relating to the development and use of the facility;*
- *to advise members of the entire TRIUMF organization of projects and facilities available;*
- *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.*

The TRIUMF Users' Group facilitates communication among the users, and provides a forum for working with the TRIUMF administration. The Users' Group can play a vital role in facilitating long range planning. Current examples include participation in the planning for a new TRIUMF housing facility, participation in the selection of Alan Shotter as the new director of TRIUMF, the organization of a workshop on "New Opportunities for Accelerator-Based Materials Research in Canada" held at TRIUMF in August 2001, and the organization of a workshop on "Future Opportunities in Neutrino Physics" planned for November 2001. As well, the Users' Group organizes an annual meeting of the users.

The Users' Group membership presently comprises 244 scientists from 11 countries. Further information on the TRIUMF Users' Group, including a membership application form, can be found at http://www.triumf.ca/tug/.

Nathan Rodning, TUEC Chair

PRICEWATERHOUSECOOPERS

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June 1, 2001

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, 2001 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 1, 2001.

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

	2000/2001		1999/2000	
SOURCE OF FUNDS	**$,000**	**%**	**$,000**	**%**
NATIONAL RESEARCH COUNCIL	39,000	76.53%	34,318	72.41%
NSERC	6,793	13.33%	7,663	16.17%
MDS NORDION INC	2,496	4.90%	2,166	4.57%
AFFILIATED INSTITUTIONS	1,812	3.56%	2,219	4.68%
COMMERCIAL REVENUE	445	0.87%	710	1.50%
INVESTMENT AND OTHER INCOME	413	0.81%	317	0.67%
TOTAL	50,959	100.00%	47,393	100.00%

TRIUMF
Statement of Financial Position
As at March 31, 2001

	2001 $	2000 $
Assets		
Cash and temporary investments	5,925,389	5,788,363
Funding receivable	970,925	1,140,137
Total assets	6,896,314	6,928,500
Liabilities		
Accounts payable	2,038,561	1,583,136
Funds received in advance	1,109,104	713,123
	3,147,665	2,296,259
Due to (from) joint venturers		
The University of British Columbia	(33,390)	(125,309)
The University of Alberta	(1,345)	(7,981)
The University of Victoria	(12,520)	15,566
Simon Fraser University	(17,438)	9,087
	(64,693)	(108,637)
	3,082,972	2,187,622
Fund Balances		
Restricted		
Natural Sciences and Engineering Research Council Fund	2,274,694	3,900,561
MDS NORDION Inc. Fund	100,000	100,000
Provincial Government Building Fund	-	-
Affiliated Institutions Fund	143	143
	2,374,837	4,000,704
Other		
Commercial Revenue Fund	972	2,981
General Fund	767,067	424,761
Intramural Accounts Fund	670,466	312,432
	1,438,505	740,174
	3,813,342	4,740,878
Total liabilities and fund balances	6,896,314	6,928,500

PRICEWATERHOUSECOOPERS

TRIUMF
Statement of Combined Funding/Income and Expenditures and Changes in Fund Balances
For the year ended March 31, 2001

	2001 $	2000 $
Funding/income		
National Research Council Fund	39,000,000	34,318,000
Natural Sciences and Engineering Research Council Fund	6,792,528	7,662,451
MDS NORDION Inc. Fund	2,495,762	2,165,597
Affiliated Institutions Fund	1,812,417	2,219,207
Commercial Revenue Fund	445,019	710,283
General Fund	413,393	317,043
	50,959,119	47,392,581
Expenditures		
Buildings and improvements	229,594	336,485
Communications	200,707	147,478
Computer	1,265,353	958,288
Equipment	6,359,572	5,847,332
Power	1,712,516	1,808,363
Salaries and benefits	27,420,958	25,344,385
Supplies and other expenses	14,697,955	10,314,745
	51,886,655	44,757,076
(Deficiency) excess of funding/income over expenditures for the year	(927,536)	2,635,505
Fund balances - Beginning of year	4,740,878	2,105,373
Fund balances - End of year	3,813,342	4,740,878

PRICEWATERHOUSECOOPERS

TRIUMF
Notes to Financial Statements
March 31, 2001

1. Nature of operations

TRIUMF is Canada's national laboratory for particle and nuclear physics, owned and operated as a joint venture by the University of Alberta, Carleton University, the University of Victoria, Simon Fraser University and the University of British Columbia, under a contribution from the National Research Council of Canada. As a registered charity, TRIUMF is not subject to income tax.

As of April 1, 2000, Carleton University was admitted to TRIUMF as a full joint venture partner. Each University owns an undivided 20% (2000 - 25%) interest in all assets and is responsible for 20% (2000 - 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. The sources and purposes of these funds are 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 TRIUMF 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

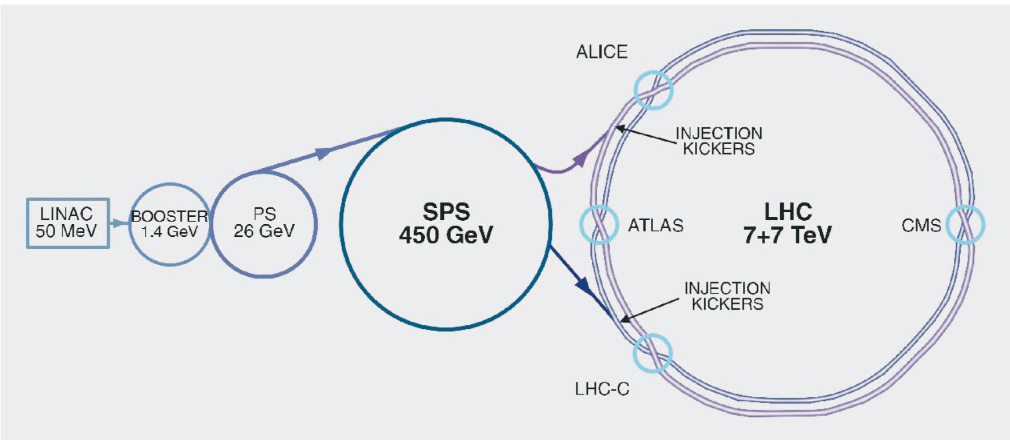
Net recoveries for internal projects and services. The recoveries of expenditures are charged to the appropriate TRIUMF funding source by Intramural Accounts.

PRICEWATERHOUSECOOPERS

Gary Wait and Michael Barnes

LHC INJECTION KICKERS

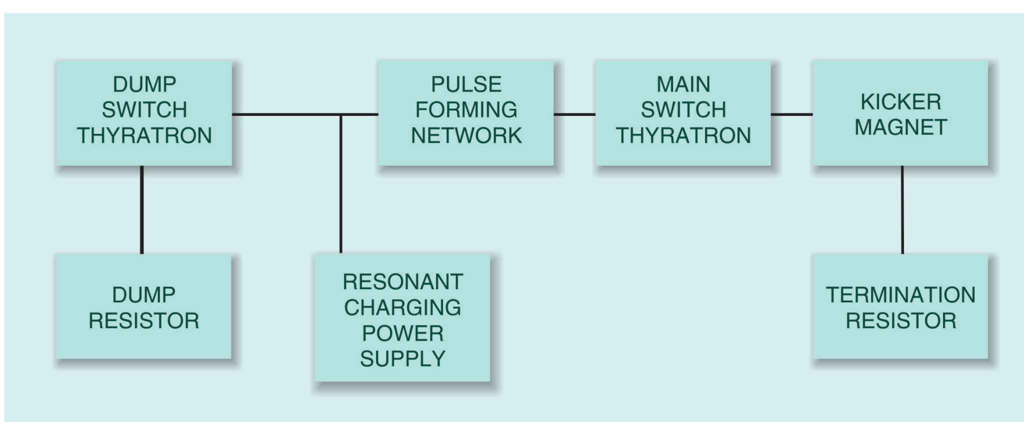
The European Laboratory for Particle Physics (CERN) is constructing a very high energy particle accelerator, the Large Hadron Collider, LHC. In the LHC two counter-rotating beams of 7 TeV protons will be brought into collision at up to 4 interaction points along the 27 km circumference of the machine where experiments will be performed. The LHC is the final stage of a series of accelerators each one of which raises the proton energy in preparation for injection into the following stage (see figure). The energy is increased by radio frequency (RF) electric fields and the protons' orbit kept at constant radius by a matching increase in the strength of the guiding magnetic field. Each stage has its characteristic cycle time - from beam injection to reaching maximum energy. The RF imposes a time structure on the beam, forming it into many bunches separated by 25 nanoseconds (25 billionths of a second). After the first circular booster stage the proton speed, because of relativistic effects, changes very little. What does increase is the proton's mass. As the proton energy increases so does the size of each accelerator ring because of the limitation in the strength of the magnetic guide fields that can be reached. Super-conducting magnets of a novel, compact design are required in the final ring due to the very high magnetic fields (8.3 Tesla) that are required. An earlier stage has to go through several acceleration cycles in order to produce enough beam to fill the circumference of a later stage.



CERN accelerator complex, showing the locations of the two sets of kicker magnets.

Kicker magnets are used to extract the beam from one circular acceleration stage and inject it into the next. These magnets must be capable of going very quickly from zero magnetic field to full stable field (0.15T), then rapidly back to zero field in preparation for the next cycle. High magnetic fields and rapidly changing magnetic fields are conflicting design requirements. Varying length time gaps are introduced in the beam bunches to allow time for the kickers to reach their maximum field strength while other time gaps allow the field to revert to zero. This prevents beam from being sprayed onto equipment that surrounds the beam trajectory, damaging it and making it highly radioactive. Spilled beam will quench the super-conducting magnets. The time gaps are quite short, less than a millionth of a second (microsecond) to reach maximum field and a few times this to fall back to zero.

Magnetic fields surround all current carrying conductors. In general in order to maximize field strength conductors are looped into coils with many turns that often surround a solid ferromagnetic material such as iron. However both these techniques lead to sluggishness in response to current changes and cannot be used for fast-acting kicker magnets. Kicker magnets have only single turn coils and special ceramic magnetic materials are employed. In addition the kicker magnets are actually transmission lines made up of many cells designed to a high precision to match the impedance of the driving system to within 1%. The resulting limitation in the kicker magnet field



Arrangement of the components of the CERN kicker magnet system.

Gary Wait and Michael Barnes

LHC INJECTION KICKERS

means that four kicker magnets in sequence are required, each 2.3 m long, to get the required bending of the beam for injection into the LHC.

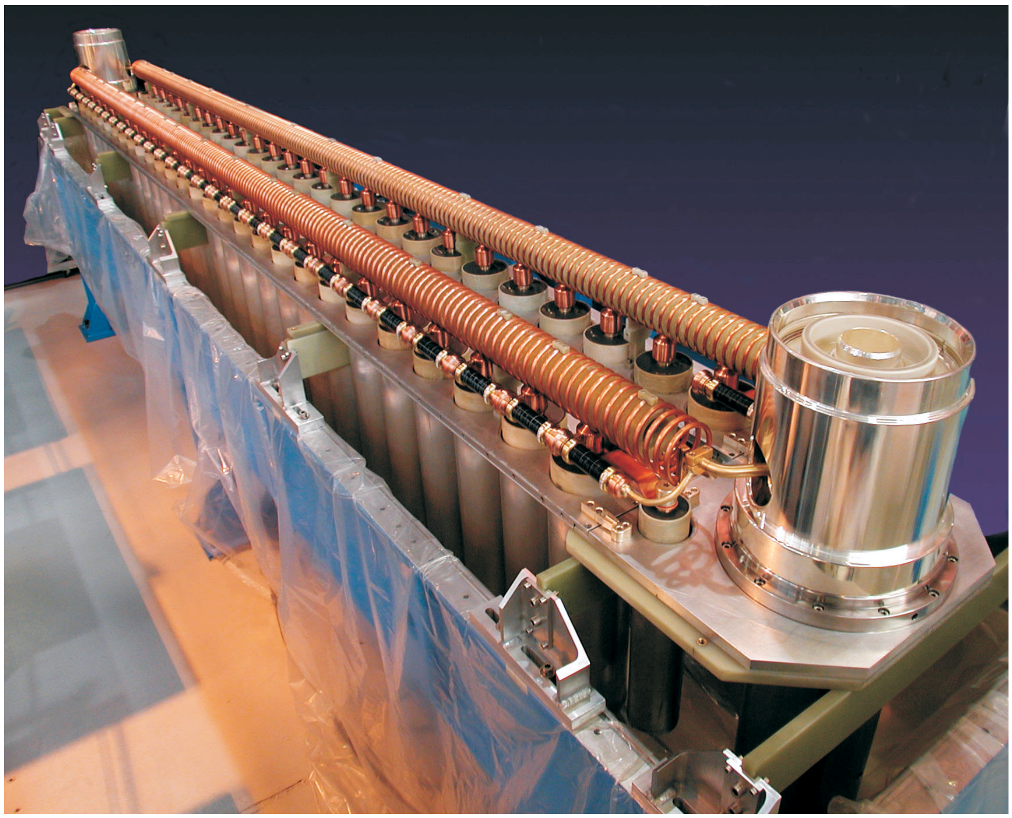
As part of the Canadian contribution to CERN, TRIUMF is designing and building all the electrical equipment needed to energize the two kicker magnet systems that feed the LHC, one for each direction of rotation of the beam. The major components of this equipment are Pulse Forming Networks (PFNs), Thyratron Switch Tanks, and Resonant Charging Power Supplies (RCPS).

The arrangement of these components is shown in the block diagram. Shortly before the kicker magnets are to be energized, the RCPS is turned on and charges up the capacitors in the PFN. Then the "main switch" thyratron is triggered allowing the accumulated charge to pulse towards the kicker magnets. A short time later the "dump switch" thyratron is triggered allowing the charge on the PFN to also pulse out towards the dump resistor. The sending of current pulses both towards and away from the kicker magnets allows the width of the kicker magnet pulse to be precisely controlled by the timing of the thyratrons.

Thyratrons are large ceramic vacuum tubes that are filled with controlled amounts of deuterium gas and act as high current switches at high voltages. They can be turned on (triggered) at times determined to within a few nanoseconds and can pass the very high current, 6,000 amperes, required by the kicker magnets. Unfortunately they also have a tendency to trigger spontaneously when high voltage is applied. In order to minimize this difficulty, the RCPS are designed to apply the high voltage to the PFN and the thyratrons in less than a millisecond (thousandth of a sec).

The "main switch" thyratron is used to switch the PFN current into the kicker magnet through special high voltage transmission lines. The "dump switch" thyratron is used to vary the duration of the current pulse from zero to 10 microseconds and to improve the fall time of the magnetic field. Excess power is dumped into the massive water-cooled resistors shown as termination resistors in the diagram. The thyratron switch tanks, coils and capacitors are immersed in silicone fluid to provide cooling and high voltage insulation.

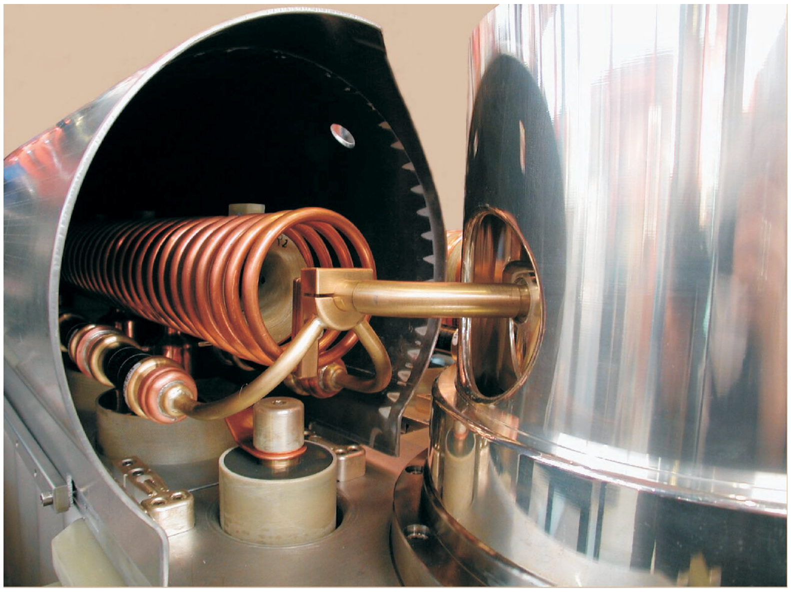
When charged to 60,000 volts a PFN will, in the arrangement shown, form well-shaped 30,000 volt, 6,000 ampere pulses with unprecedented accuracy to power the kicker magnets. The PFN consists of 2 parallel precision coils, each mounted on a line of capacitors and placed in a 5.2 m long tank, to form lumped element transmission lines. The picture below shows an almost completed PFN. This PFN is the first of 9 built at TRIUMF to exacting component specifications supplied by TRIUMF.



A view of the pulse forming network before being placed in its tank

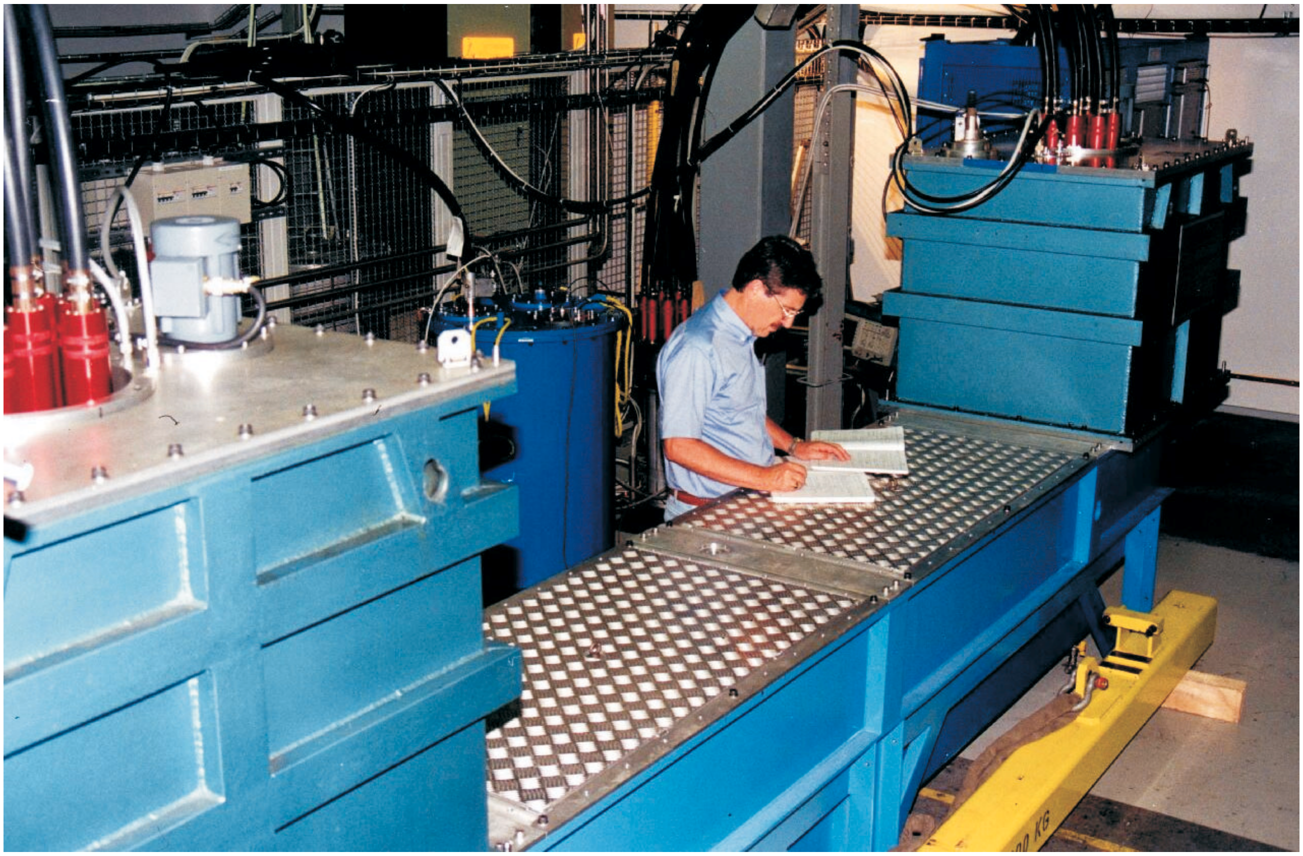
A prototype 66,000 volt RCPS was designed, constructed and successfully commissioned at TRIUMF and sent to CERN in June 1998. It has a charge time of less than a millisecond and very good pulse-to-pulse uniformity, much better than ±0.1% easily satisfying the stability requirement for the injection sequence of the LHC. It has operated for over 1 million cycles (equivalent to 50 years of use at LHC!) in conjunction with the prototype 60,000 volt, 25 cell PFN which was designed by CERN and TRIUMF and built at CERN. Measurements were performed on the prototype PFN at CERN. In the first test 30,000 volt pulses were generated to provide a 6,000 ampere current which remained constant to within 0.2% during the time that beam will pass through the kickers. This is 5 times better than previously attained at CERN. The pulse rise and fall times of 0.83 microseconds and 2.94 microseconds respectively met the specifications. The prototype RCPS is still in operation for testing of the prototype thyratron switches.

All 5 RCPS have been fabricated and will be tested at TRIUMF this year. Four of these will be sent to CERN at the end of 2001 and one will remain at TRIUMF for testing the PFNs and thyratron switches. Four PFNs are completed. The remaining 5 will be assembled by the fall of 2001 ready for high voltage testing. Tests on prototype thyratron switches are being carried out at CERN and the final design completed in June 2001. Assembly of the thyratron switches at TRIUMF commenced in the fall of 2001. We expect to complete the high voltage testing of one set of 4 PFNs, together with 8 thyratron switches, for delivery to CERN in January 2003. The second set will be delivered to CERN in September 2003. TRIUMF will provide assistance during commissioning of the LHC at CERN.



Detail of partially assembled pulse forming network

Gary Wait and Michael Barnes are Research Scientists at TRIUMF.



The pulse forming network in its insulation tank ready for testing at CERN

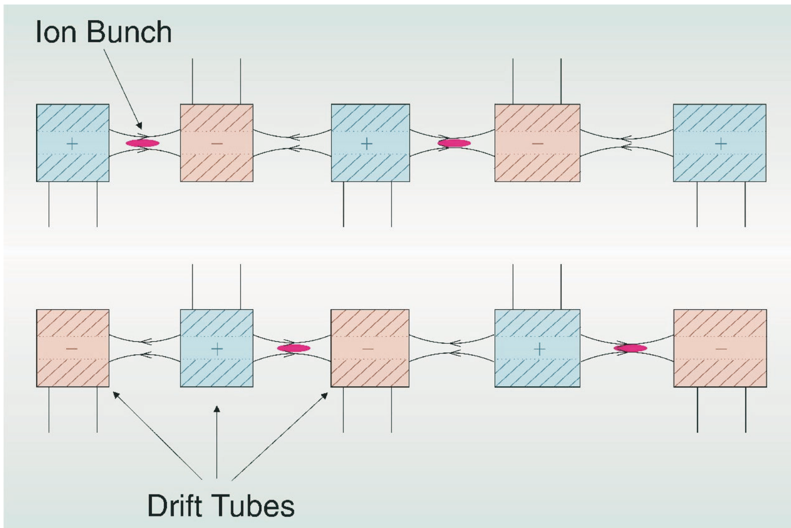
Robert Laxdal

ISAC SEPARATED FUNCTION DTL

On December 21, 2000 the ISAC project reached, for the first time, its full energy by accelerating $^4He^{1+}$ (singly charged helium ions also known as alpha particles) through the new ISAC Drift Tube Linac. The moment culminated a huge effort that had escalated to superhuman scale in the weeks leading up to the event in order to meet the project goal of full energy beam before Christmas 2000.

The ISAC project involves the production of and experimentation with radioactive ions. An ion is a particle with electric charge due either to missing or additional electrons. The ions are transported to experiments in either the low energy area or are accelerated for use in high energy experiments. The ISAC accelerator consists of two large linear accelerators. An 8 m long RF quadrupole increases the velocity of the beam for ions whose mass is less than 30 atomic mass units from 0.2% to 1.8% of the speed of light corresponding to energies between 2 keV per mass unit and 153 keV per mass unit. The 5.6 m long Drift Tube Linac (DTL) is fully variable in energy giving final velocities in a range between 1.8% and 5.6% the speed of light (153 keV/u to 1.53 MeV/u). The RFQ was commissioned in 1999. It was described in last year's Financial Report. Here we describe the design, installation and testing of the ISAC DTL.

A drift tube linac is so called because the acceleration is produced by a series of hollow conducting cylinders or tubes that are arranged in a line. These drift tubes are supplied with a time-varying voltage and configured so that adjacent tubes always have opposite voltages thus creating an electric field between them. Ions feel no electric forces when in the tubes. When in the gaps between the tubes ions are either accelerated or decelerated, depending on the direction of the electric field at the time. The ions are grouped together in bunches timed so that they are accelerated when crossing the gaps. If the length of each drift tube is such that the oscillating field goes through half an oscillation period during the time it takes the bunch to cross to the next gap then the bunch will again be accelerated. As the ions gain velocity the width of the gaps and the drift tube length must be increased to maintain the correct timing. The frequency of the accelerating field in the DTL is 106 MHz, or over 100 million times a second. Nevertheless the speed of the ions is such that, even at this frequency, the ions still travel the several centimetres to the next gap in half a cycle.



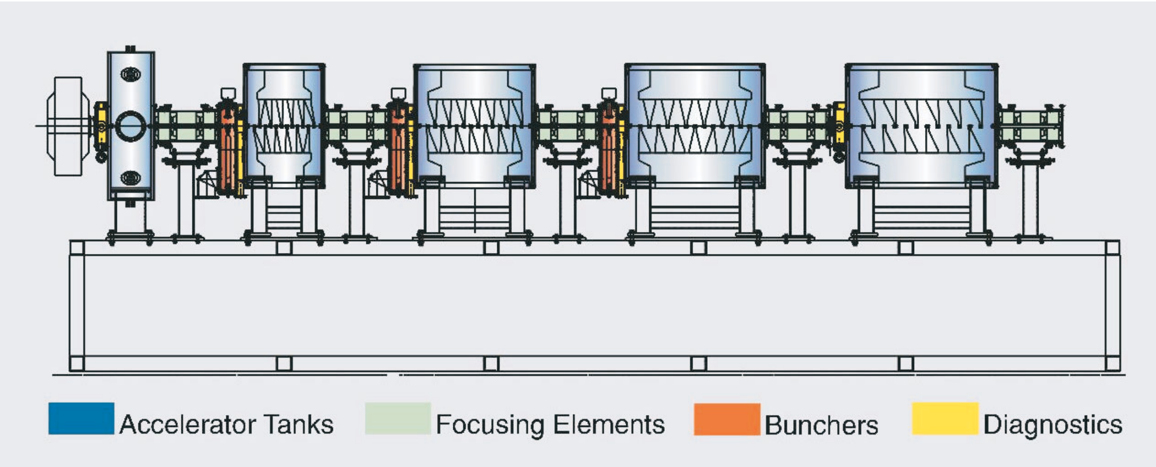
Illustrating the progress of a beam bunch through the DTL. During the time the red beam bunches are between tubes, they experience an accelerating electric field. While the beam bunches drift through the field-free region in the tubes, the alternating voltage on the tubes reverses. This leads leads to further acceleration of the beam bunches as they emerge from the tubes (lower diagram).

There are small variations in the speed of individual ions as they move through the system. This results in an increase in the bunch time-width since faster particles will, as time goes on, move ahead and slower ones fall behind in the bunch. To overcome this the time when a bunch enters a gap is adjusted so that the bunch does not receive the peak accelerating voltage. The accelerating voltage changes as the bunch goes through the gap. Proper timing results in the slower ions in the bunch being given a greater acceleration kick than the faster ones, thus helping to keep the bunch together in time. With this scheme ions gradually migrate back and forth between the front and rear of the bunch. On the negative side, accelerating off the peak of the wave reduces the efficiency of acceleration.

Ion beams have a small velocity component at right angles to their direction of motion. Hence they tend to increase in size as they move forward. Most drift-tube linacs consist of long tanks with quadrupole magnetic lenses in each drift tube to keep the beam focussed spatially. Quadrupole lenses cause problems too, requiring an increase in the size of the drift tubes resulting in the need for larger amounts of power to create the neces-

Robert Laxdal

ISAC SEPARATED FUNCTION DTL



Cross section diagram of the DTL. The beam is accelerated from left to right.

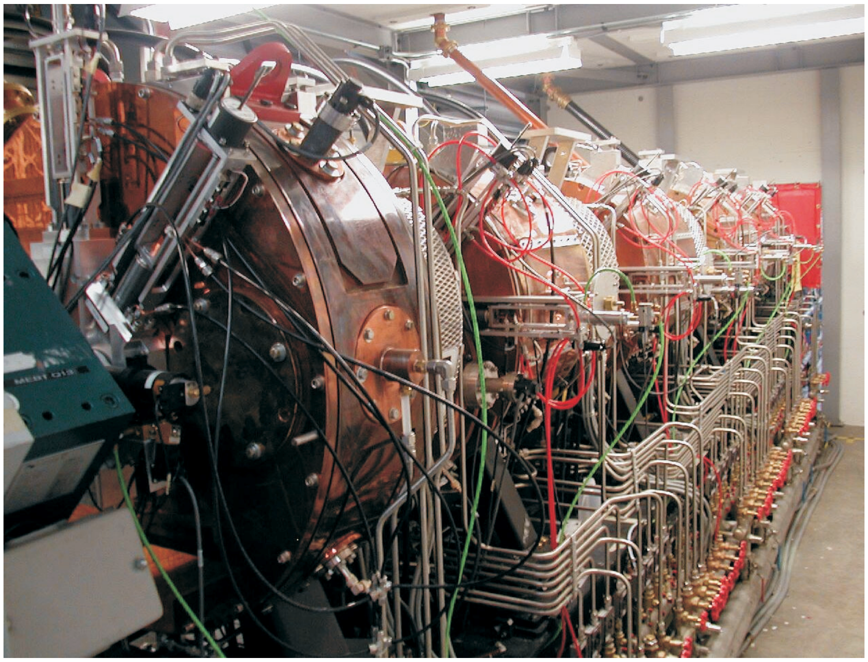
sary accelerating field. Linacs are pulsed to reduce the heat dissipated by the accelerating fields, delivering beams only a fraction of the time.

Since radioactive beams are difficult to produce and experiments are usually "event starved," all linacs in ISAC were specified to operate continuously to maximize beam intensity. To reduce power and optimize variable energy beam delivery the linac has been configured as a unique separated function DTL. There are three main components distributed in modular fashion throughout the linac. First there are five short (<1m) accelerating tanks consisting of small drift tubes with no focussing that accelerate beam on the peak of the waveform. Then a triplet of quadrupole lenses between the tanks refocuses the beam. Finally, before the second, third and fourth tanks there are short, three-gap cavities that provide periodic beam rebunching. To achieve a variable final energy, the higher energy acceleration tanks are turned off sequentially starting at the downstream end and the voltage and phase in the last operating tank is varied to alter the amount of acceleration given to the bunch. The triplets can be adjusted to transport any energy beam through the linac. The bunching cavities prepare the beam bunch time structure before acceleration as well as reduce the velocity spread in the bunch in preparation for transport to the experiment.

The three bunchers in the ISAC DTL were designed and manufactured in Russia through a collaboration with the Institute for Nuclear Research in Troitsk. INR was also able to supply key personnel during crucial phases of the project. The triplets were designed at TRIUMF with the steel manufactured in Vancouver, the coils manufactured in Denmark with final assembly at TRIUMF. The accelerating tanks were made in Vancouver by many different firms. The precise assembly and testing of the tanks took place at TRIUMF.

Installation of a linac is a massive undertaking involving not only the testing and installation of the linac components but also the vacuum system, diagnostics, cooling water, rf amplifiers, power supplies and controls. After the success of the first beam acceleration, commissioning continued through January 2001 with full confirmation of the design concepts: stable operation of the rf tanks and bunchers and full energy variability. In March the ISAC linac produced stable accelerated species to commission the TUDA experiment in preparation for the first accelerated radioactive beam test in June 2001. It is indeed a credit to the ISAC accelerator team that such a complicated device was delivered on time and now is delivering quality beams to experiment so soon after initial commissioning.

Robert Laxdal is a Research Scientist at TRIUMF.

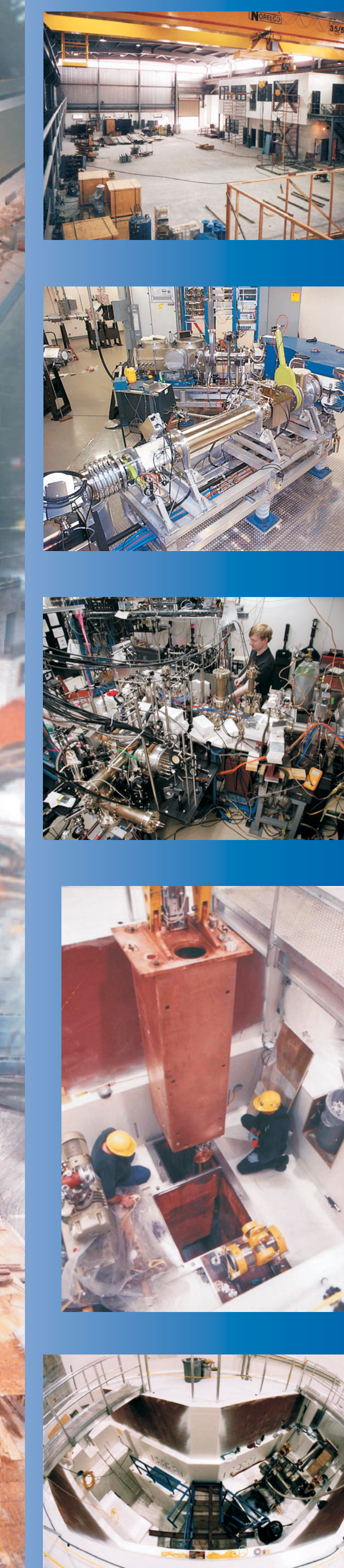


A view of the DTL looking along the beam direction.

ISAC
Isotope Separator/Accelerator

ISAC will accelerate radioactive isotopes to high velocities, a capability which will allow scientists to replicate reactions which occur in stars in the distant universe, and to study nuclear structure, the behavior of unusual atomic nuclei, condensed matter physics and life sciences projects. This is recognized worldwide as leading edge research and will place Canada back in the forefront of nuclear physics. The world physics community wanted ISAC, and Canada was in a unique position to develop it because TRIUMF can use the high power proton beam from the existing TRIUMF cyclotron to produce the copious beams of exotic, short-lived radioisotopes needed for the ISAC facility.

1 **ISAC ground breaking, April 1996**
2 **Installing first shielding in the target hall**
3 **Aerial view of TRIUMF**
4 **ISAC building from the southeast**
5 **Early construction phase of the target hall**
6 **Beam line 2A transports the proton beam from the TRIUMF cyclotron to the target in the new ISAC facility**
7 **Installing the Radio Frequency Quadrupole tank**
8 **Tunnel construction from the cyclotron to the ISAC Facility**
9 **Completed ISAC building, February 1998**



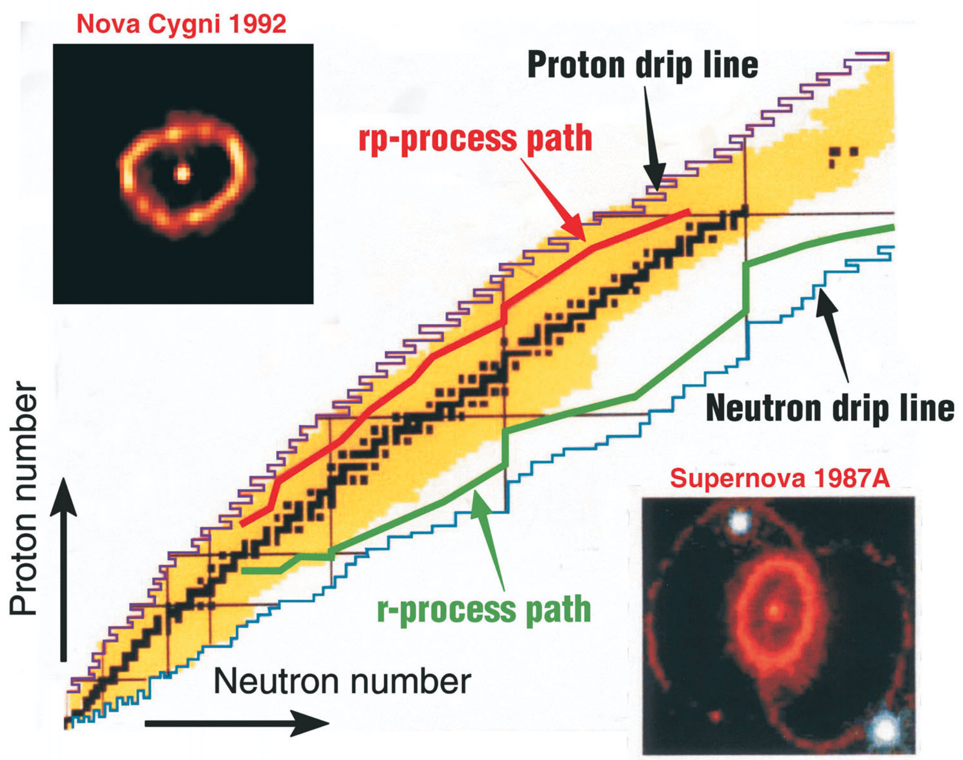
John D'Auria and Patrick Walden

NUCLEAR ASTROPHYSICS WITH DRAGON AND TUDA AT ISAC

One of the most surprising scientific revelations of the 20th century was the discovery that we are all products of matter generated from stellar cataclysms. All heavy elements such as the carbon we are made of, the oxygen we breathe, the very stuff of life, originated in nuclear cooking processes in the interior of stars. "We are" as Carl Sagan noted "made of star stuff." How did the stuff get out of the stars and into the solar nebula that became the solar system?

Some of this material is ejected into space in the death throes of stars contracting to burnt out cinders after the nuclear fires have died, the fate of many stars, including the sun. However this source cannot account for all of the abundance of the light elements such as carbon and oxygen, and it fails completely to account for the existence of the really heavy elements such as iron, gold, lead, and uranium. The difference is made up from stellar cataclysms known as nova, supernovae, and their kin which explode briefly into the brightest objects in the galaxy. Thus the composition of the earth, the rocky planets, indeed all the metallic content of the solar system came from the stuff which spilled out of stars which ripped apart their guts in explosions 4.5 billion years ago. Remnants of recent cataclysms, nova Cygni 1992 and supernova 1987a, are shown in the figure below.

The elements are made in stellar burning by the fusion of nuclei of the lightest elements, hydrogen and helium (99% of all nuclei in the universe), into the nuclei of all heavier elements. Fusion reactions involved in normal stellar burning, like those which now occur in the sun, proceed at a slow pace, slow enough to allow any radioactive nuclei produced to decay to stable nuclei before becoming involved in further reactions. Recreating these reactions in the laboratory is a straightforward and relatively simple process in which beams of either hydrogen or helium strike targets of different stable nuclei. Hence they have been extensively studied and, as a result, are well understood. In 1983 William Fowler won the Nobel Prize in Physics for his leadership in the drive to perform such studies which have led to our understanding of stellar environments and nucleosynthesis.



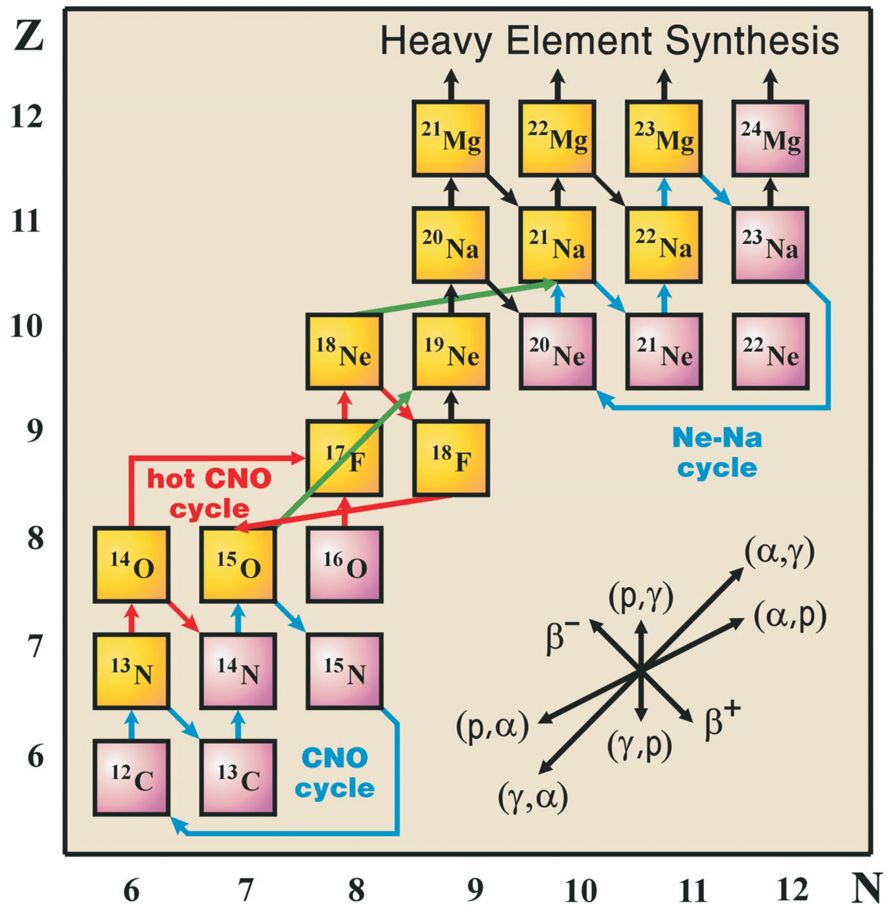
The reaction paths of heavy element synthesis. The dark squares indicate the positions of the stable nuclei, the yellow the known unstable nuclei. The drip lines enclose the region beyond which it is thought that no nuclei can exist. More details are in the text.

During explosive events, however, things happen so quickly that the radioactive nuclei do not have time to decay. Instead these short-lived exotics are involved in subsequent nuclear reactions leading to a chain reaction in which heavier and heavier nuclei are created. Two nucleosynthesis processes produce these explosive chain reactions, and both are illustrated in the adjacent figure.

The r-process takes place inside supernovae, a catastrophic explosion which is the fate of stars that are heavier than 8 solar masses. When the nuclear fuel in the stellar core is exhausted, gravity is strong enough to cause the core to collapse which generates a flood of neutrons. This touches off the r-process which is a series of rapid neutron captures in which seed nuclei like that of iron are pummelled with the neutrons from the collapse. Heavier nuclei are rapidly built by successive neutron captures and ultra fast beta decays (a beta decay is the emission of an electron leading to a change in the element) via the reaction route indicated by the green line in the figure on the previous page. Once the process has run its course the nuclei have a chance to decay into normal stable heavy elements.

The rp-process occurs on the surface of a burnt out star known as a white dwarf. This type of star has about the mass of our sun packed into roughly the volume of the earth. All stars less than 8 solar masses are believed to eventually end up as white dwarfs, a fate that awaits our sun. As can be imagined the gravitational field around the star is very intense. In many cases the white dwarf has a red giant companion star. The red giant's atmosphere is quite extended, vacuous and composed mostly of hydrogen. Part of this atmosphere comes under the intense gravitation attraction of the white dwarf and is sucked onto the surface of the dwarf where it is compressed to unimaginable pressures and subjected to unbelievable temperatures. This hydrogen forms a dense atmosphere around the star and mixes with the dwarf's surface material which is mostly carbon and oxygen. Eventually a flash point is reached and the hydrogen explosively reacts with the carbon and oxygen. Heavy nuclei are rapidly built up along the red path in the figure on page 20, in a proton version of the r-process. The atmosphere of the star is blown off into space in a violent luminous cataclysm known as a nova. Unlike a supernova, a nova leaves the original star intact and the process can be repeated. The light output of a nova is about 10,000 times less intense than that of a supernova.

Theoretical studies of explosive events have reached the stage where sophisticated and time-consuming computer models can follow the evolution of these stellar cataclysms up to and beyond the resultant explosion. However, for the results of such complex and intensive calculations to have any validity they must be based upon experimental data for a number of key reactions. Without this information, these programs may work correctly, but still produce inaccurate results. (Garbage in - garbage out!) For example, using our current experimental knowledge, these models have predicted that nova explosions should result in the production of cer-



The CNO, hot CNO, and NeNa cycles of helium synthesis from hydrogen. These cycles are explained in the text. The red boxes indicate the stable nuclei, and the yellow the unstable ones. Green arrows indicate reactions thought to initiate the runaway explosive rp-process. Directional arrows indicate the type of nuclear reaction occurring between the boxes. The symbol (x,y) means particle x hit the nucleus and particle y was ejected. Other symbols are p:proton, α:^{4}He, and γ:gamma. Beta decays, indicated with a β, are ejections of electrons, positive and negative, which turn protons into neutrons and vice versa. ^{n}XX are symbols for the elements where n is the total number of neutrons and protons in the nucleus. The axes indicate the number of protons Z, and the number of neutrons N in each nucleus. Note that the type of element depends on Z only.

tain easily identifiable gamma rays (high energy photons or particles of light). However, not all of these gamma rays have been detected by orbiting galactic gamma-ray observatories. This is a clear indication that our understanding is far from complete and that the models require more detailed and accurate information on the key reactions.

These key reactions involving radioactive nuclei thus play an important role in the ignition of nova and supernova explosions. Owing to the extreme difficulty of creating and using the short-lived exotic nuclei involved, the properties and probabilities of the reactions have yet to be measured.

R-process reactions are currently impossible to measure experimentally. Both the nuclei and the neutrons involved in the process are unstable. There is no way in the laboratory to create an unstable nucleus and an unstable neutron and bring them together promptly enough to react before they decay. Conditions on earth cannot be made to duplicate those of a supernova interior. The r-process can only be studied using indirect methods.

On the other hand ISAC, with its ability to produce beams of unstable nuclei, allows us to study the rp-process. The targets are now gaseous hydrogen or helium which are stable and the beams are unstable, short-lived nuclei, as opposed to a beam of hydrogen or helium striking a stable target. This technique will allow us to measure the rates of reactions believed to occur in explosive events. Fowler recognized the need for this in his Nobel Prize lecture: "It is my view that continued development and application of radioactive ion-beam techniques could bring the most exciting results in laboratory Nuclear Astrophysics in the next decade".

ISAC's radioactive beams in combination with new experimental facilities such as DRAGON and TUDA, will allow us to reach the exciting results that Fowler alluded to. Compared to present day major high-energy accelerator laboratories located around the world, ISAC is unique as an excellent low-energy facility, designed to search for the trigger that makes the stardust we are made of.

DRAGON

(*Detector of Recoils And Gammas Of Nuclear Reactions*)

THE FACILITY

The goal of the DRAGON facility is to study the probability of reactions involving the capture of hydrogen or helium by a short-lived exotic isotope which result in the emission of electromagnetic radiation only. In stellar interiors, these radiative capture reactions occur at low rates because the energies of the two participants are low, making it difficult for them to overcome their electrical repulsion and thus to get close enough to fuse. In the laboratory these reactions can only be studied by using a beam of the radioactive isotope striking a gaseous target of hydrogen or helium. To measure the rate of the reaction, the product must be efficiently and cleanly separated from the relatively more intense incident beam and related background sources.

The illustration on page 23 is an artist's conception of the 20 meter long DRAGON facility located in the ISAC experimental hall. At the front end we have a windowless gas target into which hydrogen or helium flows. Many high-speed vacuum pumps are needed to maintain the required low pressure on either side of the high pressure region containing target gas. At the centre of the gas target the pressure is almost 10,000,000 times that a few meters on either side of it, despite the fact that the gas is unconfined. The radioactive beam from ISAC passes through the gas target, striking and occasionally fusing with atoms of the gas. Thirty bismuth germinate (BGO) gamma-ray detectors surrounding the gas target are used to detect the prompt gamma radiation from the nuclear fusions that do occur.

Nuclei formed by the radiative capture reaction continue moving in the forward direction along with the incident beam. Both have about the same momentum (mass times velocity) and both, because of atomic collisions with the gas target, are now in several different charge states. These two facts, similar momenta and multiple charge states, make separation of the reaction product from the incident beam very difficult, especially when it is realized that the nuclei in the transmitted incident beam are about a million billion times more numerous than the reacion product nuclei. A complicated system of bending magnets, focusing magnets and electrostatic deflectors is required to carry out this separation. The separation system is followed by a series of nuclear detection systems to count and identify the reaction product.

The DRAGON facility was built over a three-year period using funds from both TRIUMF and NSERC. With this facility, we now have the ability to study a number of nuclear reactions involving short-lived radioactive reactants. These reactions, some of which are shown on page 21, are important to our understanding of the mechanism of nova explosions.

As with any new facility, the first study will set the format for the use of such a complex facility over a long period of time.

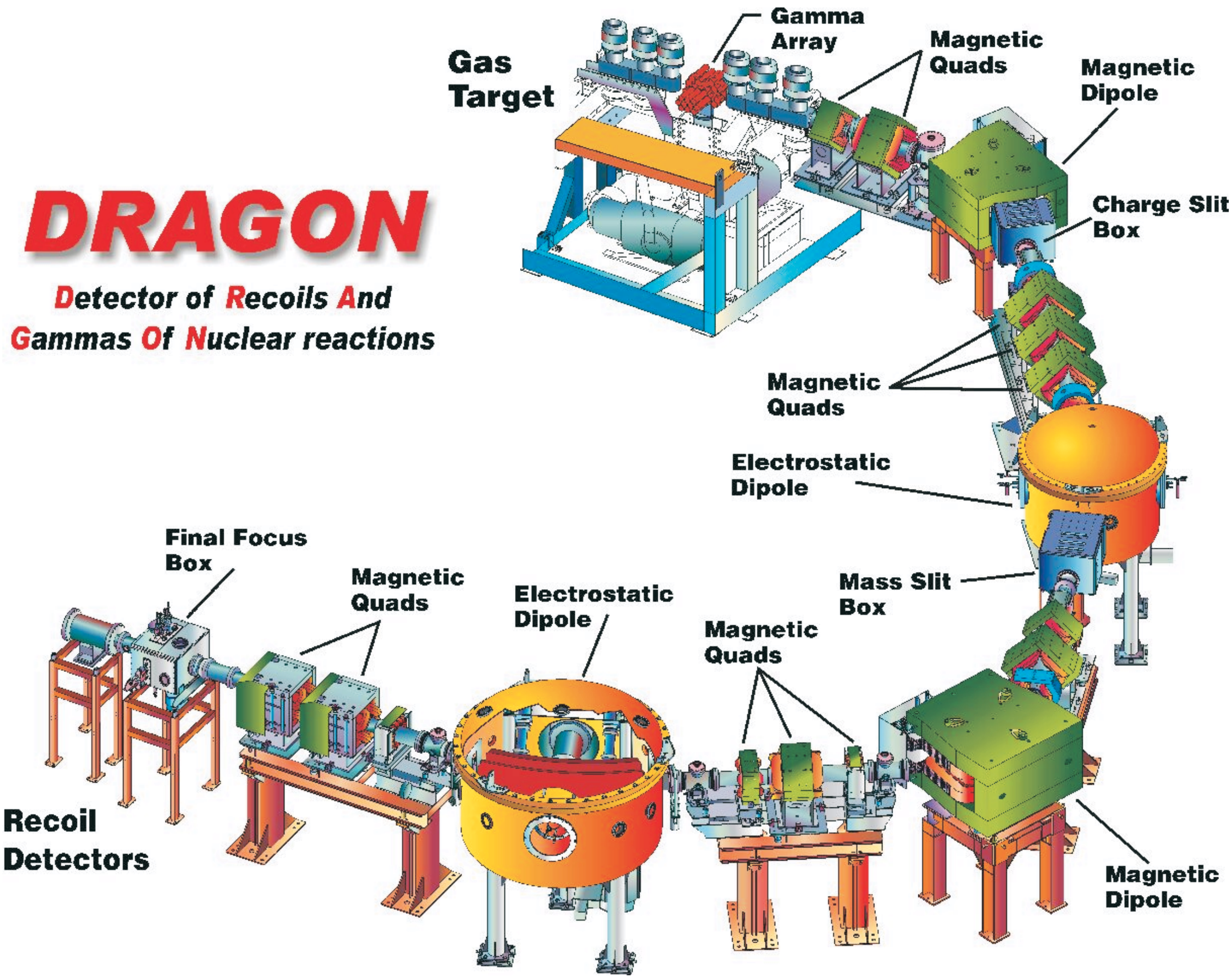
John D'Auria and Patrick Walden

NUCLEAR ASTROPHYSICS WITH DRAGON AND TUDA AT ISAC

THE FIRST STUDY

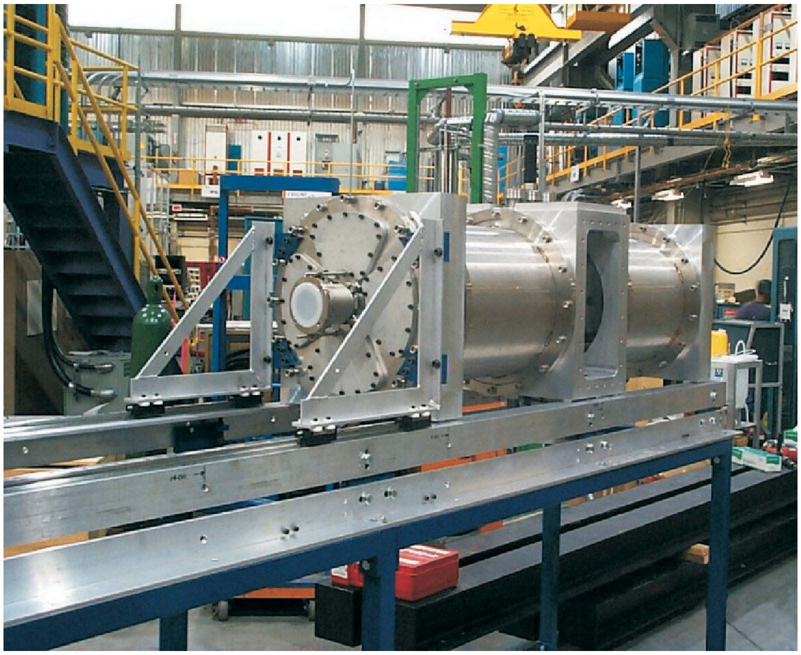
It is speculated that the NeNa cycle of nuclear reactions plays an important role in certain Nova explosions. Through a series of radiative proton capture reactions and beta decays neon is converted into the unstable isotope, ^{22}Na which decays with a lifetime of 3.8 years to the stable isotope ^{22}Ne. Current models predict that after a nova explosion the ^{22}Na will decay with the emission of a characteristic 1.3 MeV gamma ray. The ^{22}Ne product of this decay is not involved in the rp process, hence is not linked to other nuclei in the diagram on page 21. Sensitive gamma-ray telescopes should be able to observe this gamma-ray. While other gammas have been observed, this one has not. Hence our input to the models are most likely incorrect. One of the important reactions in the production of ^{22}Na during a Nova explosion is the fusion of protons with the unstable isotope, ^{21}Na producing ^{22}Mg and a gamma ray. The rate of this reaction as a function of temperature has never been measured. This is the first experiment planned for the new DRAGON facility. If the rate found is considerably different than currently assumed, we would have a reason for the lack of the 1.3 MeV gamma rays and a better understanding of what occurs during explosive events.

A beam of ^{21}Na ions (lifetime of 32.4 s) will be generated by bombarding a thick target of silicon carbide with 500 MeV protons from the TRIUMF cyclotron. The resulting ^{21}Na are ionized using a hot surface ion source, then extracted and accelerated in the new ISAC linear accelerator. This beam will then enter the DRAGON apparatus, striking and reacting with a hydrogen gas target. All of the reaction products move in the forward direction and are captured by the electromagnetic entrance of the DRAGON. There they will be separated from the much more numerous, but similar,



A drawing of the DRAGON facility

beam particles. The fusion product from the reaction of interest will be detected at the end of DRAGON using sensitive, thin-window gas counters. Since the energy range of interest in stellar interiors for these studies is quite low the reaction products have energies that make them difficult to distinguish from the the incident beam.



General view of the TUDA target and detector system.

According to estimates based upon our understanding of the nuclear structure of the species involved in the study, we expect a counting rate of the order of a few counts per hour. Such studies usually take many days to complete to the required degree of accuracy (about 15%) due to the low reaction rates. An important aspect of such studies will involve a good understanding of how this complex facility, DRAGON, really does perform. This will be obtained over a period of months using beams of stable heavy ions to properly commission and calibrate DRAGON before the experiment begins.

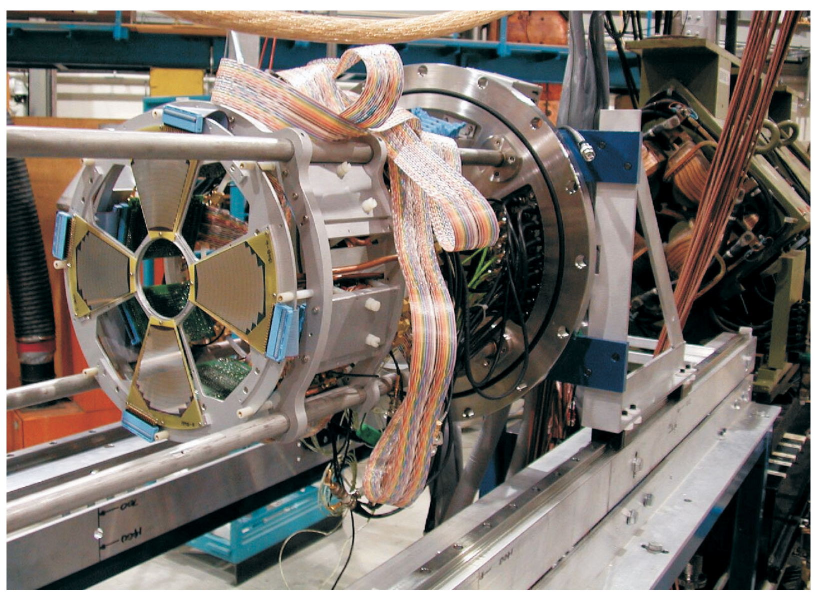
TUDA

(TRIUMF U.K. Detector Array)

The two new facilities, DRAGON and TUDA, are complementary. DRAGON is designed for radiative capture studies where uncharged gamma rays are emitted. TUDA is used for the study of nuclear reactions in which all outgoing particles have an electric charge.

The ISAC TUDA facility is an extremely flexible nuclear physics apparatus which can be modified (internally) to meet the needs of a variety of experiments. These are scattering experiments in which radioactive ion beams from ISAC are focussed onto targets inside the chamber and products from nuclear reactions between the ion beam and the target material are detected downstream in an array of silicon strip detectors.

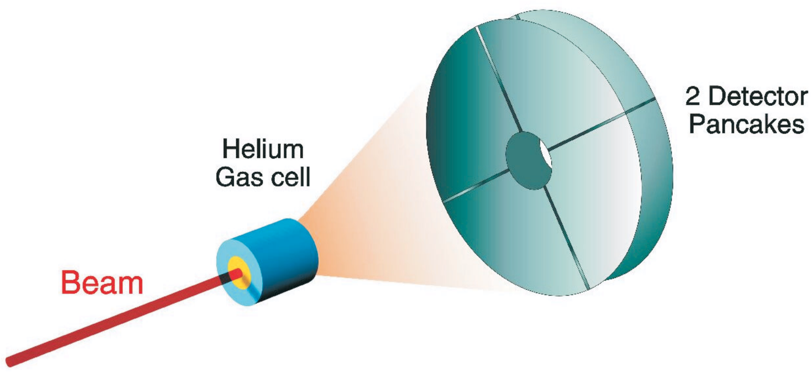
The chamber itself is divided into three rectangular sections separated by two cylindrical sections. The cylindrical sections provide drift space for the beam and nuclear reaction products. The rectangular sections house the internal apparatus. The beam entrance section houses a collimator wheel, the middle section holds the target, and the end section houses the downstream flange to which the detectors are mounted. In the picture below the downstream flange has been pulled back from the chamber to expose a detector pancake and its mounting. As shown, the detector (the flat plate with the cross) is mounted on long forks attached to the downstream flange. The structure behind houses the electronics. The detector shown is composed of 8 pie shaped segments (only 4 are installed in the picture) that each have 16 individual concentric silicon strip detectors, 0.3 mm thick. Thus each detector pancake has 128 individual independent chan-



The TUDA detector system.

John D'Auria and Patrick Walden

NUCLEAR ASTROPHYSICS WITH DRAGON AND TUDA AT ISAC



A schematic of TUDA showing the relationship between the target gas cell and the detector system for the ^{15}O reaction study.

nels. When one of the individual strip detectors detects a particle not only is the energy measured, but also the position is determined. The hole in the centre of the array allows the unscattered beam to pass through. It is possible to stack several detector pancakes together and assemble TUDA experiments in a variety of configurations depending on the reaction being studied.

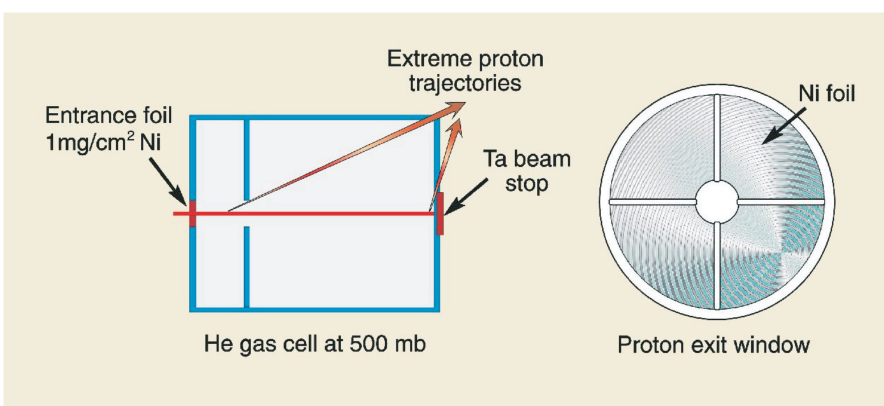
One reaction that will be investigated is a possible trigger for the rp-process. The figure on page 21 shows the nuclear reaction processes that take place on the surface layer of a proto-nova. One process, called the CNO cycle (blue arrows), converts hydrogen nuclei (protons) into helium nuclei (alpha particles or ^{4}He) with a subsequent emission of energy. Carbon, Nitrogen, Oxygen (hence the name CNO) and other nuclei are used as catalysts for this conversion and are not consumed. This cycle also goes on in the sun and is the source for a small fraction of the sun's energy.

When the density and temperature are high enough (T=0.2-0.4 billion degrees) branches of the CNO cycle (the Hot CNO cycle, red arrows) are initiated where unstable nuclei (yellow boxes) are involved because they successively capture protons and alpha particles before they have a chance to decay. Two such nuclei are ^{15}O and ^{18}Ne with lifetimes of 176 and 2.41 seconds, respectively. At the flash point of a nova, it is thought that alpha particle captures (thick green arrows) on these two nuclei will create ^{19}Ne and ^{21}Na nuclei. Both these unstable nuclei are seed nuclei for the runaway rp-process (black arrows) and explosive heavy element nucleosynthesis leading to a nova explosion

The ^{15}O reaction involves a gamma emission and, as such, is part of the DRAGON experimental program. The ^{18}Ne reaction has two charged particles in its final state, a proton and a ^{21}Na nucleus which can be studied with TUDA. The setup to study this reaction is shown in the adjacent figure. A beam of ^{18}Ne (2.41 seconds is lots of time to create a ^{18}Ne and transport it to TUDA) hits a helium gas target (alpha particles). The ^{18}Ne captures an alpha and spits out a ^{21}Na and a proton. The ^{21}Na does not get out of the target but the proton has enough energy to reach the detectors. To eliminate background, the helium gas cell (see the figure below) has been designed with baffles such that protons from beam interactions in the nickel entrance foil cannot reach the detectors. Likewise to prevent background from any exit foil, the beam will be stopped in a tantalum plug. The plug is thick enough to prevent any charged particle from escaping. The protons produced by the ^{18}Ne reactions with the helium can reach the detectors (see arrows) through the thin exit nickel foils.

Reactions rates for this process will be measured at a variety of beam energies. These rates will be a crucial piece of information in modelling the rp-process and heavy element synthesis. It is only through a detailed understanding of this reaction and others that we can start to understand how stars explode.

John D'Auria is Professor of Chemistry at Simon Fraser University. Patrick Walden is a Research Scientist at TRIUMF.

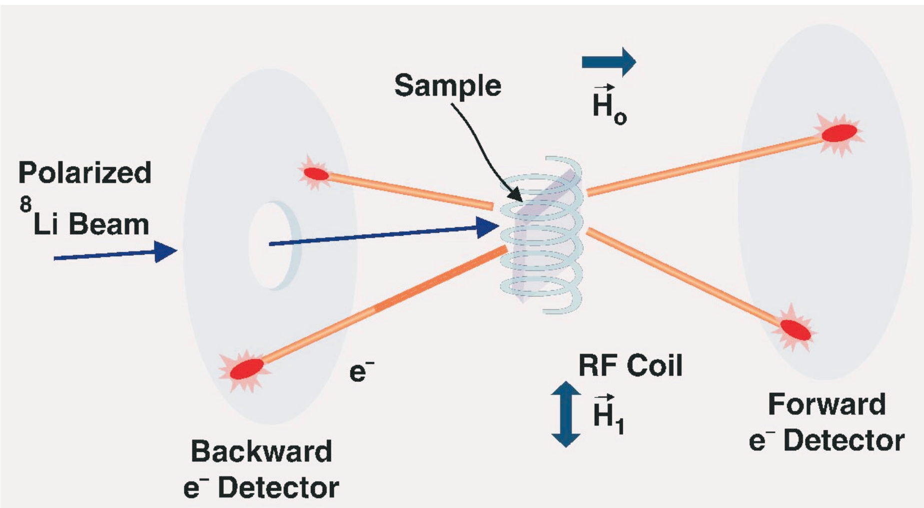


Details of the TUDA target gas cell. The radioactive beam enters through a thin foil and is stopped by the tantalum disk. Charged particles from reactions in the cell exit through a thin nickel foil.

Gerald D. Morris

β-DETECTED NUCLEAR MAGNETIC RESONANCE AT ISAC

We are developing a β-detected nuclear magnetic resonance (β-NMR) facility primarily for studying materials and phenomena of interest in condensed matter physics using the intense beams of spin polarized ions that are available at ISAC. Magnetic resonance is a powerful experimental technique that yields information about the electronic, chemical and magnetic environment and dynamics present in materials. β-NMR provides some unique capabilities that complement other techniques such as conventional NMR and muon spin relaxation. All of the proposed experiments involve both fundamental physics and materials which are the basis for important technologies.



Sketch of β-NMR apparatus.

In all nuclear spin relaxation techniques one first produces a non-equilibrium polarisation (the degree to which the magnetic moments are aligned). Information about the host material is obtained by monitoring how the polarisation evolves in time as it relaxes back to thermodynamic equilibrium. However, the details of the various techniques vary widely, and it is these specific and often unique characteristics of each which make them particularly well suited for certain measurements.

The principal differences among the various spin relaxation techniques lie in the ways the initial polarisation is generated and the method of monitoring its subsequent evolution. In conventional NMR a very small initial polarisation is generated by simply applying a large magnetic field to a sample. A signal monitoring the polarisation is obtained by measuring the small voltage induced in a pickup coil which senses the tiny magnetic field due to the nuclear magnetic moments. (The moments precess at a frequency which depends on the strength of magnetic field.) In some cases, this can yield measurements with exquisite precision, with frequencies measured to much less than a part per billion. Applied to chemical analysis, tiny differences in frequency can be interpreted to yield information about the structure of molecules. Another important practical application of conventional NMR is magnetic resonance imaging (MRI), in which the spatial variations in the resonance signal can be interpreted to reveal structural information thus providing a very powerful tool for medical diagnosis.

On the other hand, the nuclear-detected techniques of β-NMR, muon spin relaxation (μSR) and related techniques employ beams of radioactive, spin-polarized probe particles which are implanted into the material being studied. The key parts of a β-NMR spectrometer are shown schematically in the figure to the left. Radioactive atoms or ions enter the apparatus where they land on the sample situated between a pair of particle detectors. For many experiments a strong and constant magnetic field $\vec{H}_0$ may be applied to the sample by a magnet (not shown), and for the NMR experiments the much weaker oscillating magnetic field $\vec{H}_1$ is generated by a small coil around the sample. When the implanted radioactive nucleus decays the resulting beta particle (simply an energetic electron) may pass through one of the detectors, producing a pulse which is counted electronically. In this kind of radioactive decay, the trajectory of the outgoing beta particle is correlated with the orientation of nuclear spin at the instant of decay, so it is possible to monitor the spin polarization through the asymmetry in count rates in the two detectors. The large initial polarisation and direct method of detecting the spin make it possible to perform NMR experiments with only about ten million atoms, as compared to about 10^{18} atoms for conventional NMR. This huge increase in sensitivity enables some novel experiments on extremely thin samples.

Isotopes from the ISAC production targets are accelerated through a potential difference of 30 kV and formed into an atomic beam which is then transported to an experiment. Unlike relatively high energy (4.2 MeV) muon beams, such a low energy makes it possible to vary the implantation energy with simple electrostatics by biasing the sample to a high voltage. The design of the spectrometer takes advantage of this so that the ion energy at the sample surface may be varied from about 1 to 90 keV. The resulting mean implantation depth ranges from about 50–3000Å. This ability is one of the key features of β-NMR. Typically, one might measure the asymmetry over a range of sample temperatures, implantation energy, magnetic field strength or resonance frequency, depending on the purpose of the experiment and the nature of the sample.

The figure below shows a false colour image of the light produced by a radioactive ^{8}Li beam stopping in a scintillator located at the centre of the spectrometer. Such images of the beam spot are useful in tuning the beam line components and focusing the beam onto samples. The beam spot has a diameter of about 2 mm.

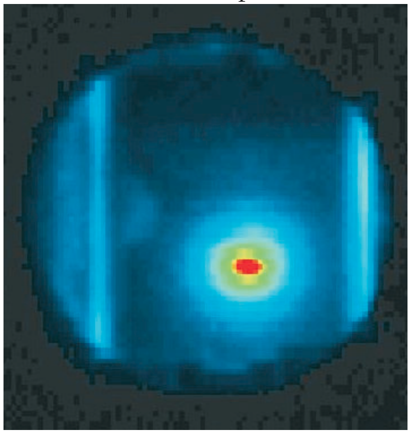


Image of beam spot.

Another characteristic of the decay-detected techniques is that experiments may be performed in very low or zero applied magnetic fields where conventional NMR cannot be used. Some of the experiments that have been proposed for the ISAC facility which use these characteristics of β-NMR are outlined below.

Magnetism plays a fundamental role in superconductors – materials which lose all resistance to the flow of an electrical current when they are cooled to cryogenic temperatures. At present superconductors are used in a few applications such as high field magnets and sensors of extremely weak magnetic fields. More recently, pilot projects have begun to test superconducting cables for power distribution. A practical consideration which limits the use of superconductors is the need to cool them to very low temperatures. The range of applications of superconductors will grow as materials with higher transition temperatures and suitable mechanical properties are developed. It is reasonable to expect that fundamental research into the nature of superconductivity will play a role in driving these advancements.

Beta-NMR is poised to contribute to the field of superconductivity in ways that complement the muon spin rotation/relaxation experiments performed at TRIUMF and other muon facilities. When placed in moderate magnetic fields some superconductors allow the magnetic field to penetrate into non-superconducting regions, so the magnetic field throughout the bulk is not uniform. The spatial dependence of the magnetic field inside the sample is revealed through the NMR signal. How the distribution of magnetic field depends on temperature, applied magnetic field and composition of the material, provides key information about the mechanisms of superconductivity.

Since the lifetimes of radioisotopes used for β-NMR are typically on the order of a second (a million times longer than the muon lifetime) there is sufficient time to manipulate the spins with pulses of radio-frequency (RF) magnetic fields. Only nuclei on resonance respond to the RF field, so one can select spins of nuclei in a part of the resonance spectrum by their resonance frequency. It should then be possible to measure the temperature dependence of the relaxation rate, which is sensitive to fluctuations in the field felt by the probe spin, in various parts of the superconductor, yielding new and detailed information about the nature of the superconducting state.

The low and variable implantation energy capability of the high-field β-NMR spectrometer will enable experiments to be performed in ultra-thin samples. Typical muon beams at 4.2 MeV/muon penetrate far too deeply (on the order of 0.1 mm in many materials) to study surface effects. This has led to the development of ultra-slow muon beams, first at TRIUMF and now at the Paul Scherrer Institute, Switzerland. Although the slow muon rates are increasing they are about 5 orders of magnitude lower than the flux of low-energy ions at ISAC. Experiment 897 will use this low energy capability to directly probe the magnetic field just within the sample surface, providing data that is difficult or impossible to obtain with other techniques.

It is anticipated that a second β-NMR experiment constructed during the summer of 2001 will be able to perform NMR experiments in very weak magnetic fields (on the order of 0.01 T) which is impossible to do with conventional NMR.

Studies of extremely dilute impurities in materials are inherently difficult due to the lack of a signal with most techniques. Muons implanted in semiconductors (such as silicon and gallium arsenide) have provided most of the available information about isolated hydrogen-like centres in these materials. β-NMR should be able to contribute in a similar way with a variety of radioactive nuclei, many of which are representative of impurities found in semiconductors. One is interested in the properties of impurity atoms inserted into the semiconductor where they interact with the conduction electrons, often forming bound states. The NMR signal and its temperature dependence reveals a great deal about the state of the impurity. Such studies can be expected to yield information about how dilute impurities affect the bulk properties of these technologically important materials.

Low-energy implantation should also allow studies of the electronic states of an impurity in a thin semiconductor film where electrons are confined to essentially two dimensions and, consequently, have radically different properties compared to bulk materials.

Properties of novel materials not found in nature are often the basis of useful devices. One of these properties is the giant magnetoresistive (GMR) effect in which the flow of electrons moving through a structure of magnetic and non-magnetic layers depends on the strength of an external magnetic field. The discovery of magnetoresistance is of fundamental interest in materials science, but it also has had an immediate impact on the data storage industry. Essentially all computer hard drives on the market today employ a GMR material in their read heads to sense the data encoded on magnetic disks. This application of the GMR effect is largely responsible for the enormous increase in the capacity of magnetic data storage devices over the past several years.

GMR materials are typically made of extremely thin alternating layers of metals such as (non-magnetic) copper and (magnetic) cobalt, each a few nm thick. Induced magnetisation in the intervening copper layer mediates a weak coupling between the magnetic layers. The addition of an external magnetic field, which might be due to a single magnetized bit on a data storage medium, for example, is then enough to change the antiferromagnetic (anti-parallel) alignment of adjacent magnetic layers to ferromagnetic (parallel) alignment. This also results in a change in the scattering rate – and hence resistance to flow – of the electrons moving from one layer to the next. The layered structure becomes an electronic sensor of magnetic fields.

Experiment 815 proposes to use β-NMR to study the magnetism in individual layers of these kinds of layered magnetic materials. By implanting at very low energies (about 1 keV or less) it should be possible to deposit the ions within about 1 nm of the interface between the two metals. The distribution of magnetic field and shifts relative to the applied field will be reflected in the width and frequency of the NMR signal. The dynamics of the induced magnetism could then be studied by measuring the spin-lattice relaxation rate as a function of temperature and applied magnetic field. By varying the implantation energy different regions of the layered structure can be examined. While the principal motivation for these experiments is the fundamental physics to be learned, it is likely that a greater understanding of the GMR and related effects will enable the fabrication of more sensitive, smaller and faster devices.

In summary, the spectrometers have been designed to make use of the intense, low-energy spin-polarized radioactive ion beams available at ISAC for studying a wide range of phenomena in materials. Construction of the high field β-NMR spectrometer is essentially complete and we are now beginning the first experiments while exploring the capabilities of the facility. High sensitivity and a small and variable implantation depth will enable experiments on extremely thin structures and the ability to perform experiments in strong as well as very weak (and zero) magnetic fields, complements the capabilities of μSR and conventional NMR techniques.

Gerald Morris is a Postdoctoral Research Associate at the Los Alamos National Laboratory

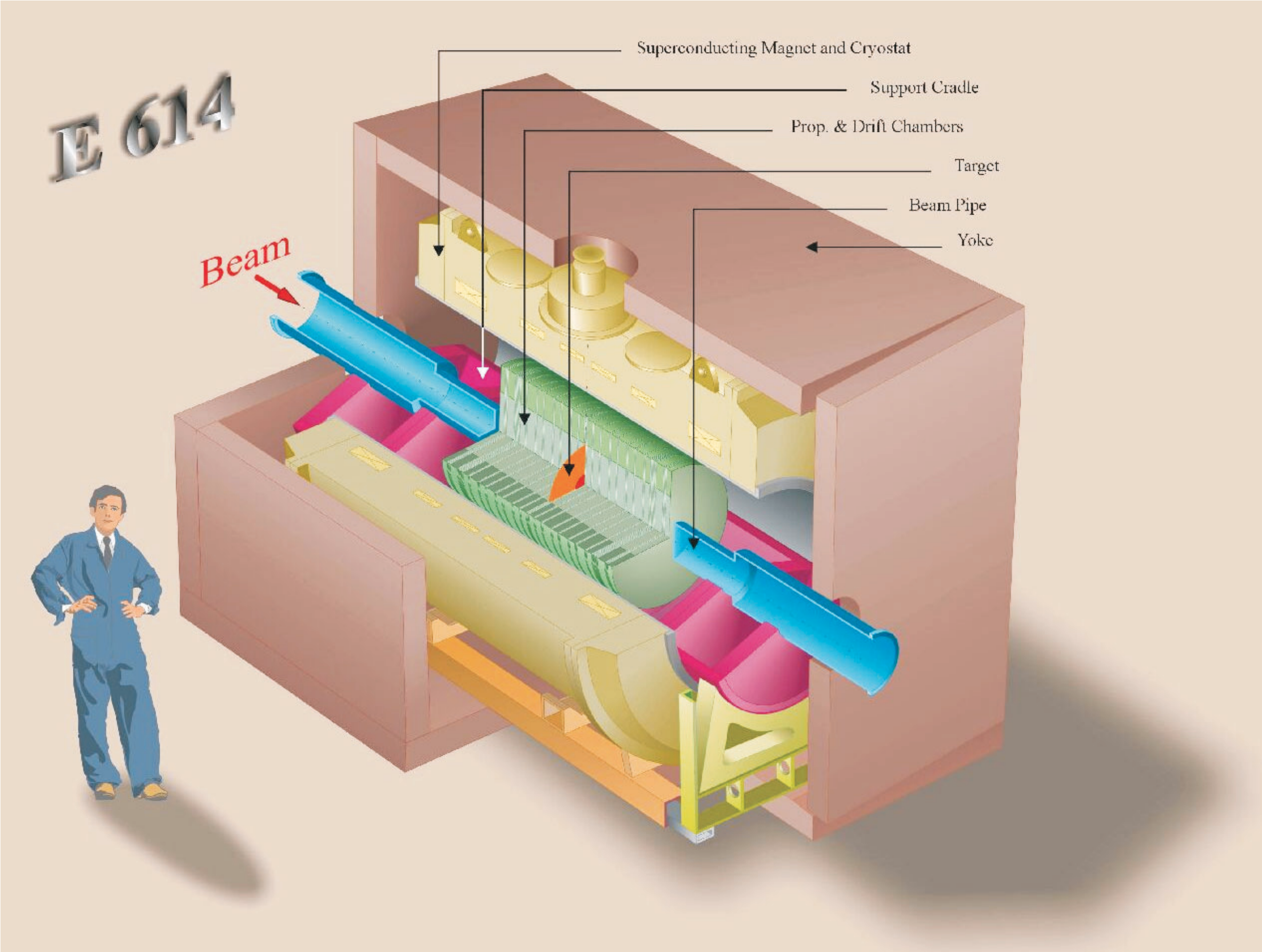
The high field β-NMR spectrometer consists of a superconducting magnet and cryogenic systems enclosed in an ultra-high vacuum chamber.

Nathan Rodning

For nearly 30 years the Standard Model of particles and their interactions has been quite successful at predicting phenomena throughout particle physics. Indeed, the theory has been so successful that many particle physicists would equate the search for a flaw in the theory with the quest for the Holy Grail. Most feel that the Standard Model cannot be the fundamental theory, in part because it requires 19 finely tuned parameters for which we don't have any satisfying explanation.

The state of classical mechanics a century ago may have been somewhat similar. At that time, Newtonian mechanics was about 200 years old, and quite successful. Planetary orbits were explained without many surprises. Many people thought that the future of physics was pretty well wrapped up. But at about that time, Albert Einstein proposed his theory of Special Relativity, suggesting that our view of mechanics was incomplete. Newtonian mechanics – while successful at predicting a wide variety of phenomena that occur in the limited circumstances in which we normally find ourselves– was found to be only a special case of relativistic mechanics. In an analogous fashion, perhaps the Standard Model is really just a glimpse of some deeper theory.

The Standard Model describes the interactions of the quarks (particles which make up things like protons and neutrons) and leptons (the most familiar of which is the electron). These particles interact through the strong force, the electromagnetic force, the weak force, and the gravitational force – in order of the strength of these forces. The weak force is responsible for some forms of radioactive decay. The gravitational force is so feeble that its omission from particle physics theories does not cause any apparent difficulties. Yet "theories of everything" are being developed which strive to encompass all known forces. Some extensions of the Standard Model are directed toward this goal.



A cutaway view of the TWIST spectrometer. A primary design consideration is to provide high precision tracking of decay positrons while putting very little material in the path of the incoming beam.

Nathan Rodning

TWIST

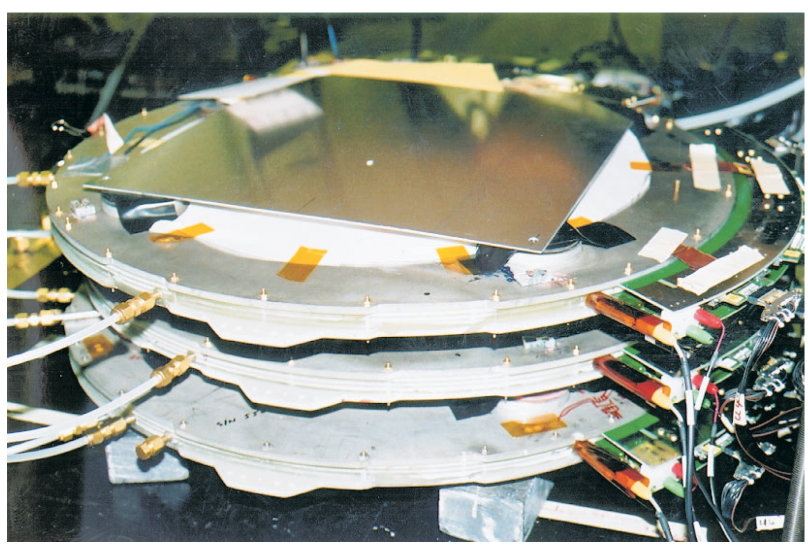
The TWIST wire planes are strung in a clean environment to reduce the impact of dust on the components. The wires are placed accurately with position variations of about 0.003 mm.

It happens that the "strong force" is so strong, that interactions involving it are difficult to calculate with high precision. This is because we are unable to carry out these calculations directly in one step. Rather an iterative technique has to be used in which an approximate calculation is made, corrections for some known effects applied to the result and the calculation – now more accurate - repeated. If the corrections start small and get progressively smaller, one can have some confidence in the results. This is not the case for calculations involving the strong force but is true for the weak force where remarkable agreement with some experiments has been obtained.

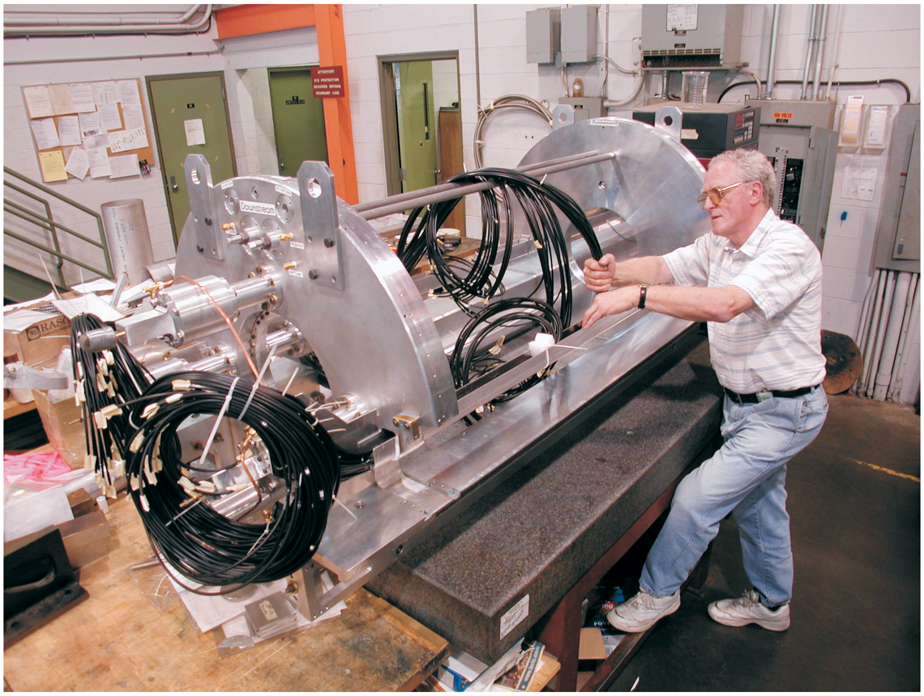
Most often, the weak force is referred to as the "electroweak force", since a successful theoretical framework allows us to think of the weak force and the electromagnetic force as two facets of a single force. While quarks are subject to strong, electroweak, and gravitational interactions, leptons are subject to only the electroweak and gravitational interactions. They float past strong forces with total indifference. This means that leptons can be used to study the weak interaction with high precision.

The TRIUMF Weak Interaction Symmetry Test (TWIST) is a collaboration of approximately 50 scientists from Canada, the United States, and Russia that proposes to study with unprecedented precision a weak process that involves only leptons in the search for a flaw in the Standard Model which would be the signature of new phenomena. In particular, TWIST will study the decay of a lepton called the muon. Muons are particles that bear a striking resemblance to electrons. They can be thought of as being electrons, but with a mass about 200 times as great as actual electrons. Indeed, you may ask why we need an "extra kind" of electron. The renowned physicist Isador Rabi asked "Who ordered that?" when he first heard of the muon, and 70 years later, we still don't know why nature requires this extra kind of electron. The extra mass allows a muon to undergo radioactive decay, through a weak interaction, resulting in an electron and two neutrinos. Because the decay is weak, the muon is rather stable, and lives on average about 2.2 millionths of a second. This time scale gives us plenty of time to create and deliver muons to an experiment suited to the measurement of their decay properties.

One characteristic of muon decay that is readily calculable is the distribution of the electrons (electrons from μ^- decay, or positrons from μ^+ decay) emitted in the decay. The neutrinos are much more difficult to detect than electrons, as our detectors are based on atomic processes, which involve primarily electromagnetic forces. Since neutrinos do not involve themselves in



A final production test of the chamber involves the tracking of cosmic ray particles through a limited number of detectors.



The TWIST detector planes are held in a “cradle” which slides into the magnet

electromagnetic interactions, they can typically glide right through the earth without even taking notice. The TWIST experiment proposes to study the distribution of positron energies and angles as they are emitted in μ^+ decay. This distribution is very sensitive to interesting aspects of the weak interaction. TWIST should have sensitivity to the shape of this distribution beyond that of any previous measurement.

One characteristic of the weak interaction, which TWIST can explore, is the dependence of the weak interaction on the chirality (essentially the spin direction) of the leptons involved in the muon decay. The Standard Model does not allow for the weak interaction of leptons spinning to the right (their chirality). Only leptons spinning to the left engage in weak interactions. Imagine a baseball pitcher who can throw a curve ball that spins either to the left or to the right, but a batter forced to wield a bat that allows balls spinning to the right to pass right through the bat! This bizarre state of affairs may well exist in particle physics, but it may not. The asymmetry between left- and right-handed interactions has been built into the Standard Model without any conclusive evidence to explain why this asymmetry exists. There is no fundamental reason for the existence of this asymmetry. While we do know that right-handed interactions are pretty feeble, we do not know that they never occur. If evidence of such right-handed interactions is found, a striking flaw in the Standard Model will be exposed. If no such evidence is found, the Standard Model will have survived a very significant challenge.

The TWIST proposal (TRIUMF Experiment 614) is to bring muons with a prepared spin orientation into a highly symmetrical detector one at a time. After the arrival of each muon, the detector will be watched for ten millionths of a second, while evidence of the decay of the muon can be collected.

The TWIST spectrometer sits within a large-bore super-conducting magnet, which was originally designed for whole-body medical MRI. The magnet serves a dual purpose: on the one hand, it helps to preserve the spin orientation of the muons within the experiment; on the other hand, it causes the decay positrons to follow a helical path which allows us to determine the positron energy. The TWIST magnet and its 60-ton iron return yoke is on the floor at the focus of the M13 beamline at TRIUMF. This beamline is ideally suited to this experiment, able to deliver a high flux of highly polarized muons with an ideal time structure.

TWIST provides an excellent opportunity for the involvement of undergraduate and graduate students, who contribute to all aspects of the experiment.

The TWIST detectors are fabricated to very high precision, involving the placement of thousands of wires within a tolerance of a few microns. Variations in the wire positions are typically about 0.003 mm, or about 1/25 the diameter of a human hair. These detectors are stacked into multiple layers, which identify points along the paths of the charged particles. In total, TWIST will utilize 56 detector planes.

The detectors were moved into the TWIST beamline in July of 2001, in preparation for commissioning of the spectrometer during the summer and fall of 2001.

Data will be acquired from TWIST at a very high rate. Less than a week will be required for the acquisition of one billion muon decay events. It will take years, however, to confirm and study the consequences of instrumental effects on the measurements. Multiple data sets will be required for the study of systematic effects in the experiment. The data volume will add up to about 90,000 Gbytes per year, and will require significant processing time. Total data may be as much as 500,000 Gbytes.

The "systematic effects" which we need to measure tend to be characteristics of the detector. The idea is that because we are attempting to measure a very subtle effect, so we need to understand our detector very well. For example, when a muon decays and a positron travels through our detector, it is always possible that we may miss an occasional decay. We need to know how often, and under what circumstances we will fail to notice a decay. Our chambers employ fine wires strung under high tension. When these wires sag under gravity, how much is the accuracy of their position measurement compromised? Our events are timed to an accuracy of about one billionth of a second, but even that is not perfect. What is the consequence of these timing errors? All of these questions and others must be clearly understood before the final interpretation of the data can be made.

During that time, there will be multiple results that will be obtained. In particular, aspects of the decay distributions that do not require precise muon polarizations will be determined most quickly. As well, preliminary results with decreased precision will be of considerable interest. Final results are expected to require five years of work beyond the initial commissioning.

So, will TWIST find a flaw in the Standard Model? There is no theoretical reason to say that we will not. The Standard Model incorporates a total left-right asymmetry by fiat. As for experimental predictors, no experiment to date approaches the precision expected from TWIST. Although deviations from the Standard Model may be seen only as minor corrections in our present universe, they may have played a crucial role in the development of the early universe. Indeed they may help to explain why we exist at all. Present theories in particle physics are of fundamental importance in understanding the development of the entire universe. With questions as exciting as these, the TWIST team is enthusiastic about the prospects of breaking new ground, and contributing to our understanding of the most basic forces in the universe.

Nathan Rodning is Professor of Physics at the University of Alberta.

Installation of the TWIST detector cradle.

Anthony Glass

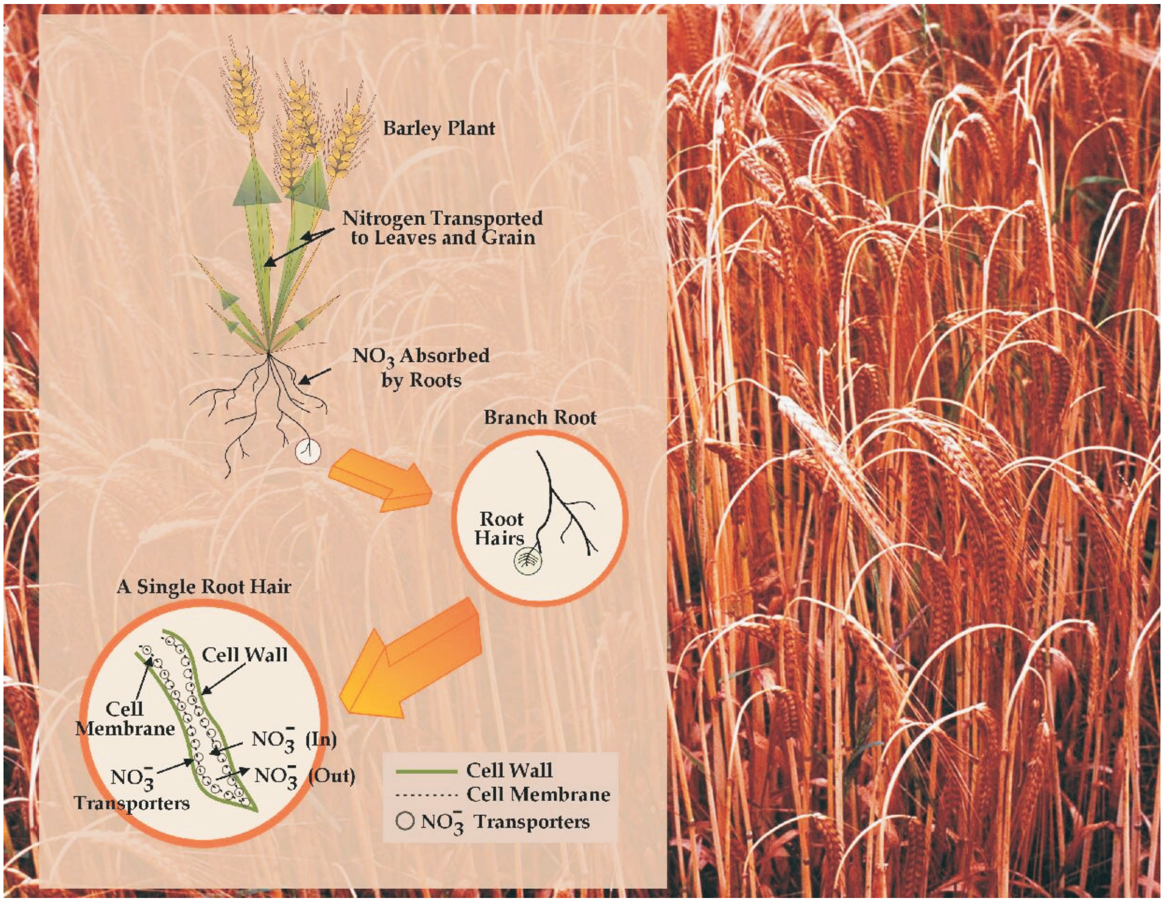
NITROGEN UPTAKE BY PLANTS

Carbohydrates and fats are composed of three chemical elements, namely carbon (C), hydrogen (H) and oxygen (O). In addition, all living organisms (animals and plants) require a third major food group, namely, proteins that contain nitrogen (N), in addition to C, H and O. Animals obtain their proteins ready-made in the form of meat or plant proteins (e.g. seeds and nuts), while plants make their own proteins from soil nitrogen (nitrate and/or ammonium) absorbed by their roots. These proteins are very important for plant growth. For example 50% of leaf protein is in the form of an enzyme that converts carbon dioxide into sugars through the process of photosynthesis. When there is a shortage of nitrogen, photosynthesis slows down and crop yield is reduced.

Left to itself Nature knows how to maintain an adequate supply of nitrogen in the soil for plants to use. Many animals eat plants and deposit urine and feces containing nitrogen back onto the soil. Plants die and microorganisms break down the plant proteins, making use of them for their own purposes, and releasing them back to the soil as nitrates and ammonium. Undisturbed, the Nitrogen cycle stays in equilibrium.

However, in agriculture, as crop plants mature they export leaf protein into the grain or seeds that we consume, thus depleting the nitrogen content of the soil. To make up for this loss we add nitrogen and other elements to the soil in the form of manure, compost, or commercial fertilizers. Each year about 10^{11} kg of nitrogen fertilizer costing around 5 billion dollars is used around the world. While solving the problem of adequate nitrogen for plants, this prodigal use of fertilizers causes other problems.

Only about half of the nitrogen fertilizer used is absorbed by the crop plants; the rest runs off the land into ground water, streams, rivers and oceans. Nitrogen-rich pastures lead to nitrogen-rich manure from animals adding to the amount of nitrogen in the runoff water. Hence parts of our ecosystem receive much more nitrogen than they can deal with resulting in problems such



A barley crop and diagrammatic representation of nitrogen absorption and transport to leaves and grain.

as algal blooms, shellfish poisoning and fish kills. Drinking water can be affected (as it has been for the Abbotsford-Sumas aquifer near Vancouver) and forest growth may actually be reduced because excess nitrogen can be toxic to trees.

In summary, there is both an economic and, perhaps more importantly, an environmental cost associated with inefficient nitrogen use by plants and excess nitrogen in the environment.

A goal of our research at the UBC Botany Department is to better understand how plants absorb nitrogen

Anthony Glass

NITROGEN UPTAKE BY PLANTS

and turn it into protein. With this understanding we hope to be able to find ways to maintain the nitrogen content of the soil without suffering the consequences caused by the present agricultural methods.

The absorption process starts with electrically charged molecules like nitrate (NO_3^-) and ammonium (NH_4^+) crossing the cell membranes of roots to enter the metabolic pathways that produce proteins. TRIUMF has been making radioactive forms of nitrate and ammonium that greatly improve our ability to trace these nitrogen molecules into and out of plant roots. The isotope is short-lived; it has a half-life of 10 minutes, so our experiments using radioactive tracers can last only about an hour at most.


Typical nitrate-laden runoff slough.

Some information about the process of nitrate or ammonium uptake by plant roots can be obtained by determining the effect of different concentrations of these molecules on their rate of absorption. A simple model would predict that the greater the concentration, the greater the rate of absorption. At low concentrations uptake increases proportionately with concentration but, as the concentration increases further, nitrate and ammonium uptake begins to saturate. Increasing nitrogen concentrations further does not increase rates of uptake. Under agricultural conditions, nitrate in excess of what the plant requires is very susceptible to leaching into ground waters. This is because soil particles are negatively charged and so is nitrate (NO_3^-), and "like charges repel". This is not the case for ammonium (NH_4^+); being positively charged this molecule is strongly bound to soil particles. If we could supply the nitrate fertilizer in several smaller applications at a rate that matches the plant demand, the leaching of excess nitrate into ground waters would probably not happen. In our hydroponic greenhouses it is easy to supply circulating fertilizer solutions at a rate that matches plant demand, but in the field situation this is inconvenient. Farmers typically want to apply fertilizers only once, at the beginning of the growing season. Furthermore fertilizers are relatively inexpensive compared to other costs of the agriculture business, so for the present we live with the inefficient use of fertilizers. Increasingly, concerns about pollution and health hazards of excess environmental nitrogen may change this situation.

Another thing we've learned about nitrate uptake that makes it different from the uptake of the other 16 chemical elements required by plants is that when nitrate is first supplied, plants are unable to absorb it effectively. There is a delay of about 6 to 12 hours while the plants manufacture the necessary enzymes (transporters) to absorb nitrate. Using the radioactive nitrate produced by TRIUMF we can measure even trace amounts of nitrate uptake. We have shown that when plants are first exposed to nitrate they do possess a very small number of the enzymes needed to absorb nitrate and that these enzymes enable small amounts of nitrate to enter the plant root. This nitrate acts as a signal that nitrate is available in the soil. The plant then begins to make large amounts of the enzymes required for absorbing nitrate and other enzymes necessary for converting it to proteins. Using biotechnology methods we have cloned the genes that encode these enzymes and found that the genes get "switched on" within 30 minutes of exposure to nitrate.

It takes several more hours before the plant is at maximum capacity.

Again, using the radioactive nitrate tracer we have found that the peak capacity for nitrate uptake lasts for only about two days after which the plant begins to switch off the genes involved in this process. This causes a slowing of nitrate uptake and leads to a greater potential for nitrate leaching We might apply larger and larger amounts of fertilizers in a futile attempt to increase food production but these self-regulating processes which curtail excessive uptake of nitrogen, perhaps to avoid toxic side effects, would defeat us.

Another very useful feature of the radioactive form of nitrate that TRIUMF makes for my group is that it has enabled us to find out that as the plant accumulates more and more nitrate there is a larger and larger leak of nitrate back out of the root into the soil. This two-way traffic of nitrate (into and out of the root) was unexpected given how important nitrogen is to plants. However, for reasons we don't understand, it seems that the root is leaky, and up to 30% of nitrate that is absorbed into the root cells finds itself pushed back out again. This adds to the inefficiency of nitrate utilization.

Studying forest trees we have found that some species such as spruce grow in soils where nitrate concentrations are usually quite low and there is much more ammonium present. In the laboratory, using radioactive nitrate and ammonium we found that rates of ammonium absorption by spruce seedlings were up to 20 times greater than rates of nitrate absorption. Given the low availability of nitrate in their natural habitats this is not altogether surprising; spruce has become a specialist at absorbing ammonium. However, after clear cuts or forest fires there is commonly a great increase of nitrate availability in these forest soils and we considered that spruce seedlings replanted after such events might be at a disadvantage compared to other species that are able to take up nitrate efficiently. Therefore we are trying to "engineer" spruce seedlings so that they can better express the genes encoding the enzymes that absorb nitrate. This research involves a combination of bioengineering to introduce new genes into forest species and tracer studies to investigate how successful we have been in improving the uptake of nitrate.

Hydroponic greenhouse in which fertilizer is continuously applied to plants.

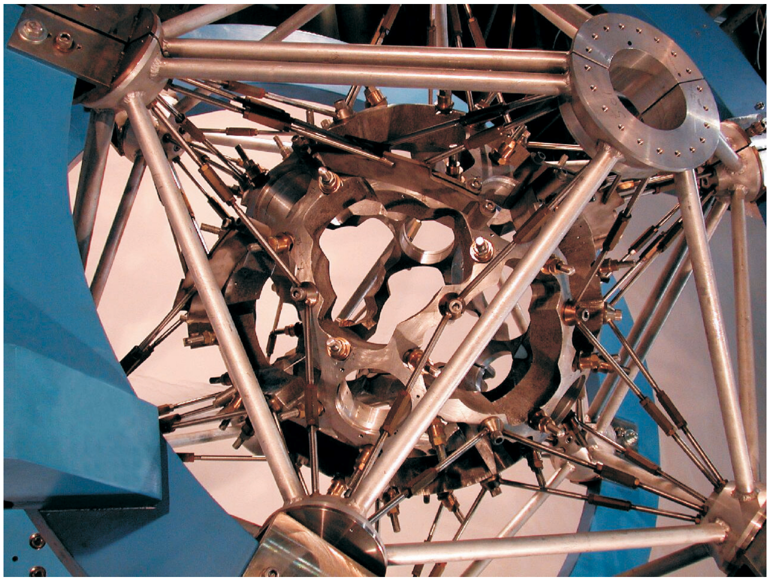
Our research has been funded by the Natural Sciences and Engineering Research Council of Canada in collaboration with a local biotechnology company. It is a slow process trying to unravel the sometimes complicated mechanisms involved in such seemingly simple processes as root nitrogen uptake. In 1840, a famous German chemist called Justus von Liebig, who really didn't know much about plants (although that didn't stop him writing a famous book about agriculture) wrote that "all substances in solution in a soil are absorbed by the roots of plants, exactly as a sponge imbibes a liquid and all that it contains, without selection." How wrong he was!

Anthony Glass is Professor of Botany at the University of British Columbia. *He acknowledges, with thanks, the encouragement and support of Dr. Thomas Ruth at TRIUMF.*

Gordon Ball

8 π SPECTROMETER

Last year's Financial Report cover included the picture reproduced below of the inner support structure of the 8π gamma-ray spectrometer. Designed by Canadian physicists in 1985 this spectrometer was a world-class, state-of-the–art device and was widely recognized as the best second-generation gamma-ray spectrometer ever built. In March 2000, the 8π was moved to TRIUMF where it is being reconfigured to optimize its performance for a vigorous program of decay studies with the non-accelerated radioactive beams from ISAC. A key element of this program will be superallowed Fermi beta decay studies that lead to precision tests of the validity of the Standard Model (see Financial Report 1998-1999).

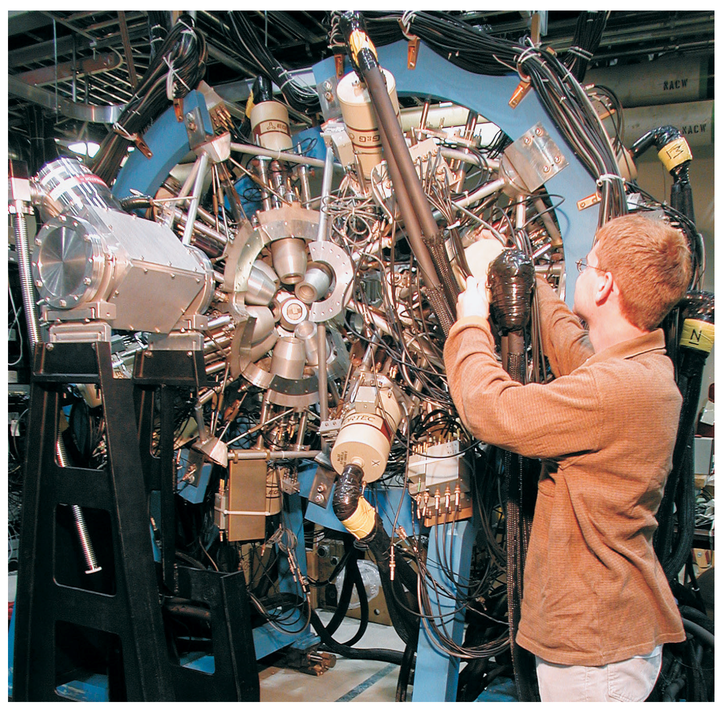


The 8π spectrometer as it appeared last year.

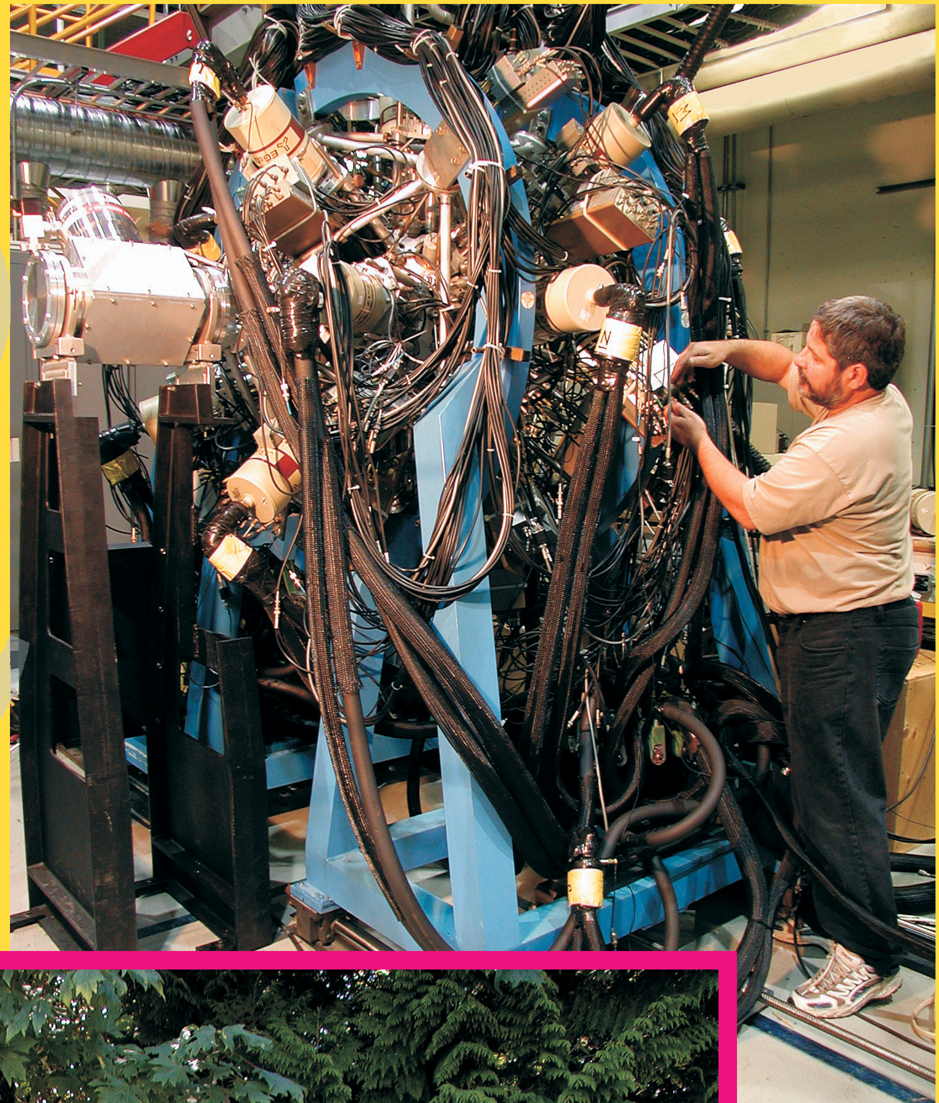
In its new configuration the 8π spectrometer is comprised of two subsystems. The first is a close-packed array of 20 High Purity Germanium (HPGe) detectors used to measure very precisely the energy of one or more gamma-rays emitted by a decaying nucleus. Gamma rays that do not deposit all their energy in a HPGe detector are eliminated by surrounding Bismuth Germanate (BGO) detector shields (Compton-suppression shields). The second subsystem is an inner spherical shell of plastic scintillator detectors that will be used to detect the beta particles (i.e. electrons). The low-energy radioactive beams from ISAC will be implanted onto a moving tape collector located at the center of the 8π spectrometer.

Considerable effort is required to reconfigure, assemble and commission an experimental apparatus of this complexity before any new scientific investigations can begin. This project, not unlike many others carried out at TRIUMF, is truly a team effort requiring in addition to the physicists and students, the expertise of many different TRIUMF support groups including: the design office, machine shop, electrical services, detector development, electronics development, experimental technical support, beamlines and plant group. There is of course a lot of manual labor and careful thought required to unpack and build this giant 3D jigsaw puzzle complete with hundreds of signal, high voltage and control cables, six large racks of electronics modules and two data acquisition and control computers. There is also an automatic liquid nitrogen filling system required to maintain the HPGe detectors cold (-200^{0}C) at all times. One broken or misconnected cable can sometimes require hours to diagnose. Some of the more challenging tasks are: aligning the assembled array with respect to the optical beam axis to a tolerance of 0.2 mm; machining the tungsten alloy (hevimet) collimators for the BGO shields; and designing and fabricating the compact (8 cm diameter) plastic scintillator array with optical fiber light guides. Commissioning of the spectrometer HPGe detector array and assembly of the low-energy beamline is scheduled for completion this fall and first experiments with radioactive beams will begin in the spring 2002.

Gordon Ball is a Research Scientist at TRIUMF.

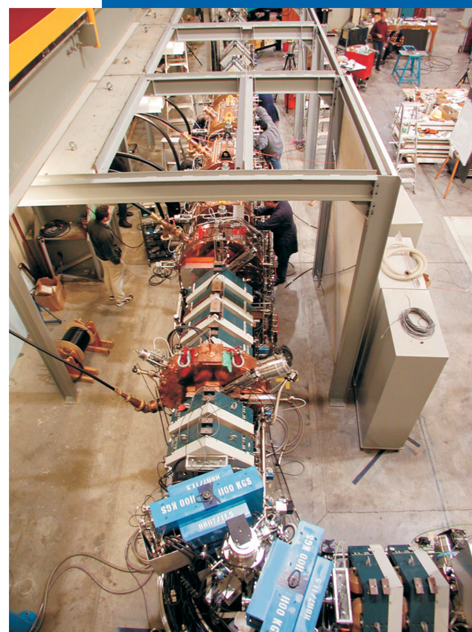


The 8π spectrometer as it now appears.
The underlying support structure is partially hidden by the installed detector systems.



The 8π collaboration includes physicists and students from McMaster University, University of Guelph, Queen's University, University of Surrey, Louisiana State University, Georgia Tech., Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, and TRIUMF at an 8π work week.

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



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