Chapter 3

Partnerships: TRIUMF, Canada, and the World

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3.1

TRIUMF's Role in the Canadian University Research System

Introduction

Canadian research is largely driven by the research programs of Canadian universities. In many fields, including nuclear and particle physics, the scientific quest for a greater understanding of nature exceeds the resources of any single institution. A national laboratory, working closely with the university community and drawing together the strengths and capabilities of many institutions, is required. In the context of the Canadian nuclear physics community, this requirement led to the founding of TRIUMF. Launched in 1968 by three universities as a local facility for intermediate-energy nuclear physics, TRIUMF has now grown to be a nationwide effort. The laboratory has also expanded its fields of research from nuclear physics to include particle physics, molecular and materials science, and nuclear medicine. TRIUMF and its user community lead Canada in the search for answers to important science and technology questions.

JESS BREWER
Professor, UBC

Jess Brewer graduated from Trinity College, Hartford, CT in 1967 and completed his graduate work at the University of California at Berkeley. He obtained an M.A. in 1969 and his Ph.D. in High Energy Physics on the topic of muonium chemistry in liquids in 1972. He moved to UBC-TRIUMF in 1973 to help set up a μSR facility, which is now the only one left in the Western Hemisphere. He has been a major factor in the success of the TRIUMF μSR program and an indefatigable advocate for and developer of μSR.

Dr. Brewer is currently a professor in the Department of Physics and Astronomy at UBC and a founding member of the CIfAR Quantum Materials program. He was the recipient of the Killam Research Prize in 1996, the Imagine UBC Professor of the Year in 2003, a Lifetime Achievement Award from the International Society for μSR Spectroscopy in 2005, and Brockhouse Medal of the CAP in 2008.

In 2007, Jess published his first science fiction short story and plans to get back to his original career path as a writer. ■

TRIUMF is an integral part of the Canadian research community. It is owned and operated by a consortium of Canadian universities. The Board of Directors, which has representation from 13 Canadian universities, guides the overall direction of the laboratory. The Policy and Planning Advisory Committee, established in 2008, has members from 15 different universities and provides detailed input into TRIUMF's policy and planning decisions.

As part of the subatomic physics community, TRIUMF scientists participate with university-based physicists in developing the Natural Sciences and Engineering Research Council (NSERC)'s long-range plans for subatomic physics. TRIUMF uses these community-based plans, which discuss the long-term objectives of the field, to develop its own priorities. TRIUMF's decisions about which projects to undertake are also guided by its policy of supporting only those projects that have been independently peer reviewed and endorsed by the scientific community.

TRIUMF's contribution to the Canadian academic community results in world leading advances in science. TRIUMF has many resources to contribute. These include human resources like research scientists, engineers, and technicians. In addition there are physical resources: high quality beams of protons, muons, and rare-isotopes as well as detectors used in conjunction with these beams, facilities for making detectors and detector components. Because TRIUMF has a large user community, it can maintain specialized equipment and resources that can be utilized sequentially by different groups.

The mix of resources at TRIUMF is very different than at a university. This results in different synergies than are possible at a university. In fact, TRIUMF's main strength is that it has a range of resources, both human and hardware, that can be applied coherently to a given problem. A typical TRIUMF user from the Canadian research community obtains technical support, collaborates with on-staff scientists, and may use a TRIUMF project engineer. This is in addition to any use of the physical resources. University-based researchers want to work with TRIUMF because these resources simply are not available at their home institutions. Scientists at TRIUMF become the key points of contact for their research. This contact helps foster collaborative partnerships among Canadian researchers and between Canadian researchers and their international colleagues. TRIUMF also provides salary support (in whole or in part) for about a dozen scientists resident at Canadian universities. This support strengthens the scientific and intellectual ties between TRIUMF and the universities. In addition, as an active research centre, TRIUMF maintains an atmosphere that promotes intellectual activity through seminars, visitor programs, and workshops. Tying it all together is a management structure geared to maximizing the science impact for Canada.

TRIUMF adds significant value to the Canadian academic community in a number of areas including molecular and materials science, subatomic physics, and nuclear medicine. However, its largest impact is in subatomic physics. To quantify this impact, consider the NSERC grants awarded to subatomic physics in fiscal year 2006–2007.[1] During that year, the total NSERC budget for subatomic physics was C$22.4 million. Of this amount, approved proposals with at least one TRIUMF-supported signatory accounted for C$12.1 million while those without a TRIUMF signatory but which used TRIUMF facilities in some manner accounted for another $C4.6 million. Taken together, 74% of the

1 See Appendix B for additional statistics.

NSERC budget for subatomic physics involves TRIUMF. If theory grants are excluded, TRIUMF's involvement with experimental subatomic physics is 86% (C$16.4 million out of C$19.3 million). Included in this figure are projects like TIGRESS and ATLAS as well as projects like the Sudbury Neutrino Observatory (SNO), for which TRIUMF supports two scientists and supplies some infrastructure. What these figures show is that TRIUMF is involved in a large fraction of the Canadian experimental subatomic physics program.

The CFI (Canada Foundation for Innovation) program has had a dramatic impact on the Canadian university research program. Although TRIUMF cannot apply directly for CFI funds because they are available only to university researchers, university teams can apply for CFI awards for projects to be based at TRIUMF. TRIUMF's capabilities have been expanded because a number of universities have elected to compete for, and win, support for TRIUMF-based projects. From 2003–2008, CFI awarded the universities more than C$35 million (including matching funds) to expand TRIUMF's capabilities and competencies. Examples of successful CFI-funded experiments based at TRIUMF are the ATLAS Tier-1 Data Centre, the M20 beam line, the Laboratory for Advanced Detector Development, and projects led by researchers at Saint Mary's University and the University of Guelph.

TRIUMF is well recognized as a key part of the national research infrastructure in subatomic physics by subatomic physicists. However, molecular and materials science researchers and life sciences researchers both exploit the laboratory's unique beams, specialized tools, and expertise.

Molecular and materials science researchers use TRIUMF's muon beams, rare-isotope ion beams, and associated instrumentation (see Section 5.1.4). Working with TRIUMF, the university user community pioneered this area of

Collaboration Or Facility	Major Detector Contribution	Major Accelerator Contribution	Beam or Isotopes	TRIUMF Scientist	Canadian Intellectual Leadership
HERMES					
BaBar					
ATLAS					
T2K					
TIGRESS					
G0, QWEAK					
μSR Facility					
Accelerator R&D					
Medical Technology					

Table 1: The diverse nature of the Canadian university collaborations in which TRIUMF is involved. The representative collaborations are listed vertically, while typical TRIUMF contributions are listed horizontally. The shaded blocks indicate areas in which TRIUMF's contribution is strong.

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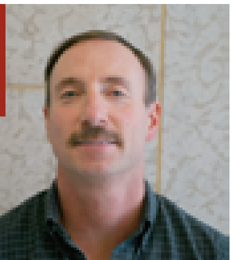

CINP

The Canadian Institute of Nuclear Physics (CINP) is a recent initiative of the Canadian nuclear physics community. CINP's mission is to provide a formal organization to represent fairly and to advocate effectively the interests and goals of the Canadian nuclear physics research community to relevant agencies and parties. The Institute anticipates a broad range of activities, including the fostering of nuclear physics collaborative research and networking, the enhancement of nuclear physics education in Canada, and outreach.

The CINP is owned by Institutional Members and operated by Institutional and Individual Members for the benefit of nuclear physics research and education in Canada. Individual (faculty and associate) membership is open to any Canadian resident who has sufficient training and competence in the discipline of nuclear physics to enable that individual to play a significant role in the activities of the Institute. The affairs of the Institute are managed by a Board of Directors, elected by the Institutional Members. The founding President of the CINP is Dr. Garth Huber, a Professor at the University of Regina.

The Institute's community interacts strongly with TRIUMF. Many use the rare-isotope beams TRIUMF provides while others make use of the infrastructure support. Both are crucial to the continuing health of nuclear physics in Canada. The Institute and TRIUMF anticipate a long and mutually beneficial collaboration.

condensed-matter research. The Canadian Association of Physicists' recent award of The Brockhouse Canada Prize for "Outstanding Experimental or Theoretical Contributions to Condensed Matter and Materials Physics" to J. Brewer (UBC) for his work on μSR recognizes this pioneering role.

The TRIUMF Life Sciences program is built on the lab's unique ability to use its accelerator technology to produce isotopes, radiopharmaceuticals, and radiotracers for the diagnosis and treatment of disease. The centrepiece of this program is the TRIUMF/UBC PET Centre, a joint TRIUMF-university venture that studies the origins, progression, and treatment of Parkinson's disease and other neurological diseases such as Alzheimer's. The PET Centre, established in 1980, also dedicates substantial resources to basic research in psychiatry, the genetic causes of neurodegeneration, and diabetes. It is one of only a few centres in the world capable of this broad, multidisciplinary research program.

The PET Centre depends critically upon TRIUMF and its production of isotopes. In 2005, the British Columbia Cancer Agency (BCCA), the Vancouver Hospital and Health Sciences Centre, and the TRIUMF/UBC PET Centre opened a Centre of Excellence for Functional Cancer Imaging. This centre, with the first publicly funded PET/CT scanner in British Columbia, will improve cancer diagnosis and treatment for patients, build research programs for the discovery, development, and application of new radiotracers, and promote collaboration with a national and international network of functional imaging programs.

No discussion of the TRIUMF-university relations would be complete without a discussion of students and training. Although TRIUMF itself does not grant degrees, it works with the university community to enhance students' and post-doctoral fellows' training and research experience. A separate section of the Five-Year Plan is devoted to this topic and we just indicate the scope of the program here. Between 2003 and 2008, 319 undergraduate students worked at TRIUMF and 104 Ph.D. and 203 M.Sc. degrees were awarded for work done at least partially at TRIUMF.

Examples of TRIUMF's Relationship with University Partners

TRIUMF's partnerships and collaborations with the Canadian academic community are as diverse as the projects and researchers who undertake them. One of TRIUMF's core strengths in its interactions with this community is flexibility, its ability to approach collaborations in a variety of ways (see Table 1 for a sample of TRIUMF's involvement in a number of different experiments). The three most prevalent approaches are now discussed with an example of each type.

University Collaborations Exploiting ISAC's Rare-Isotope Beams

For collaborations undertaking subatomic research at TRIUMF, the laboratory provides particle beams of the desired species, intensity, and energy. Typically, these collaborations include a TRIUMF scientist as well as a specialized apparatus that is already commissioned and operational. In instances where new equipment is being used, it is typical for TRIUMF personnel to be heavily involved in the specification, design, procurement, and commissioning of the new equipment. The actual equipment for individual experiments and most of the detector facilities are funded from outside resources, either Canadian or foreign.

Example: TIGRESS

TIGRESS is a state-of-the-art γ-ray escape suppressed spectrometer for use at the ISAC-II facility. A preliminary CFI grant through the University of Guelph for C$0.6 million was used for initial prototyping. A collaboration headed by Carl Svensson, consisting of eight university-based and two TRIUMF-based physicists, applied for NSERC funding in the autumn of 2002. NSERC awarded the collaboration C$8 million over six years. This award is the largest single NSERC grant ever awarded for nuclear physics. A follow-up CFI grant through Saint Mary's University added an additional third of a million dollars for electronics. Eight of the twelve modules of the full spectrometer are now on site, and three experiments have been performed.

TRIUMF has contributed substantially to this university-based, and university-led collaboration, first and foremost by providing the rare-isotope beams and the dedicated beam line needed to deliver them to the apparatus. Secondly, TRIUMF provided specialized dedicated laboratory services and personnel, engineering support, design office and machine shop time, and installation technicians. While these services may be routinely available at laboratories, the size of the TIGRESS project meant that these contributions were substantial. Finally, two TRIUMF research scientists, G. Hackman and G. Ball, oversaw the day-to-day management of the project and did a lot of the hands-on work that was necessary to make the spectrometer a reality.

The TIGRESS spectrometer provides a world-leading detector system to exploit the beams that only ISAC-II can supply. This unique combination of detectors and beams was only possible because the Canadian university research community, TRIUMF, NSERC, CFI, and foreign collaborators worked together to make it a reality.

Canadian University Involvement at Foreign Laboratories

For experiments with Canadian university involvement at foreign laboratories, TRIUMF normally contributes in the areas of design, fabrication, and installa-

Scientist	Position in ATLAS Canada	Relationship with TRIUMF
Rob McPherson	Spokesperson/Principle Investigator	TRIUMF Resident
Doug Gingrich	Deputy Spokesperson	TRIUMF-University joint appointment
Mike Vetterli	Computing Coordinator	TRIUMF-University joint appointment
Isabel Trigger	Physics Coordinator	TRIUMF Scientist

Table 2: The four principle management positions in ATLAS Canada.

tion of portions of the experimental apparatus. In several instances, there has also been a contribution of systems, such as a set of magnets or power supplies for the accelerator being custom built for the experiment. In large collaborations, TRIUMF scientists often assume senior roles in the management of the collaboration.

Example: ATLAS

The ATLAS collaboration comprises about 2,000 scientists from 167 institutions in 37 countries. Canada represents 4% of the collaboration. The Canadian involvement started in 1991 with research and development from the University of Victoria and the University of Montreal. TRIUMF joined the team in 1994 and led the Canadian accelerator contribution to the large hadron collider. TRIUMF has subsequently been a major player in the experiment and presently hosts one (and the only one in Canada) of the ten ATLAS Tier-1 computing centres that process the data from the experiment.

With the support of NSERC, Canadians made major contributions to the construction of ATLAS, and this effort had a very significant TRIUMF component. Canadians were prominent in the construction of ATLAS primarily in the end-cap calorimeters, but more recently have significant involvements in the luminosity monitor, the diamond beam-conditions monitor, and the trigger.

The Canadian group in ATLAS comprises about 150 people, of whom 41 are university faculty or TRIUMF scientists. The TRIUMF involvement includes five Canadian faculty members who are TRIUMF-university joint appointments, and five TRIUMF resident research scientists. This group is heavily involved in the management of ATLAS Canada (see Table 2). Four Canada Research Chairs (M. Dobbs, W. Taylor, B. Vachon, and M. Vincter) are members of the ATLAS collaboration, as are five of the eight Institute of Particle Physics scientists (F. Corriveau, R. McPherson, S. Robertson, R. Sobie, and R. Teuscher).

It is difficult to provide meaningful quantitative measures of Canadian involvement in the ATLAS experiment. Presently, Canada's participation in the senior management of the collaboration exceeds what might be expected by its 4% involvement in the overall project. Canadians hold two of the 63 senior ATLAS positions, which require approval of the full collaboration. This includes the Collaboration Board Chair, C. Oram, for 2006–2007. Over the past 15 years or so, the Canadian fraction of the leadership has fluctuated but has been consistently high.

Molecular and Materials Science

For experiments in molecular and materials science, Canadian university-based teams provide the samples to be studied, while TRIUMF provides the beam, detection equipment, and data acquisition program. Typically, the focus is on a specific scientific problem (for example, high temperature superconductivity or novel magnetic materials) requiring multidisciplinary investigation. TRIUMF acts as a user facility providing valuable and frequently unique services, but it is often one of several resources used by the group of experimenters.

PEOPLE

IPP

The IPP (Institute of Particle Physics) is a non-profit corporation, operated by 14 institutional members across the country for the benefit of particle physics in Canada. The Institute, funded by NSERC, employs 8 faculty-equivalent research scientists who lead the Canadian efforts in major particle physics experiments around the world and has 200 individual members from universities and labs across the country. The IPP nurtures and coordinates Canada's participation in international particle physics experiments by identifying a core set of experiments that form the IPP physics program. In addition, the IPP leads community planning exercises for NSERC and the NRC and supports particle physics outreach and education efforts. The IPP Director serves as Canada's representative on the International Commission for Future Accelerators and acts as a point of contact for the Canadian particle physics community with major laboratories around the world.

William Trischuk, IPP's current director, has been a member of the Department of Physics at the University of Toronto for 12 years. He is a member of the ATLAS collaboration, where he has built and is commissioning the beam monitoring and abort system. In the past, he has led the Canadian group on the CDF experiment at Fermilab, where he pioneered precision measurements of the W boson mass. In the early 1990s, he was a CERN staff member and became a world leader in the development and construction of precision solid state, vertex detector systems.

There is a strong working relationship between IPP and TRIUMF. TRIUMF scientists lead two (Pi2E and T2K) of the experiments that make up the IPP physics

CONTINUES ▸

Example: ß-NMR / ß-NQR

As implemented at TRIUMF, β-detected nuclear magnetic resonance (β-NMR) uses a low-energy ISAC-I radioactive ion beam as a novel depth-resolved local probe of the properties of thin films and heterostructures. This is an extremely technologically important field of materials science. The β-NMR team consists of three principal investigators from TRIUMF-member universities: A. MacFarlane (UBC, Chemistry), R. Kiefl (UBC, Physics), and K. Chow (University of Alberta, Physics). These three researchers have driven the development of this novel technique, with TRIUMF playing an enabling role.

While the primary isotope of interest, ^{8}Li, is easily produced by the ISAC-I surface ionization source at TRIUMF, these experiments require a spin-polarized beam. This has been achieved through the efforts of TRIUMF scientist P. Levy using an in-flight laser polarization scheme. This complex task is now routine and highly reliable.

β-NMR uses low-energy beams to study phenomena in thin structures (less than about 200 nm thick and as thin as 2 nm). It requires an ultra-high vacuum sample environment with residual pressures in the range of 10^{-9} torr. The design challenges imposed by such criteria necessitated a significant investment, largely by TRIUMF, in design and construction of specialized beam lines. In addition, the TRIUMF Centre for Molecular and Materials Science (CMMS) contributed significantly with technical personnel supported by NSERC's Major Facilities Access grants program. For example, CMMS leader S. Kreitzman designed the system that provides the radio-frequency magnetic field essential for many measurements. TRIUMF also contributed half the salary of a post-doctoral fellow position for the development of β-NMR. The series of scientists that have occupied this position have contributed significantly to technical advances as well as to the scientific productivity of the program.

The novel technique of zero field beta-detected pure-nuclear quadrupole resonance (β-NQR) was first demonstrated at TRIUMF [Salman *et al.*, Phys. Rev. B 70, 104404 (2004)] in a second spectrometer. The β-NQR spectrometer has recently been upgraded with NSERC-funded cryogenic and TRIUMF-funded deceleration capabilities, enabling this new technique to be fully exploited in the study of materials. To maximize the use of valuable ISAC-I beams, the β-NMR team, with TRIUMF technical support, implemented a fast electrostatic switch, allowing the near simultaneous operation of the two spectrometers, and effectively doubling the available experimental time.

The financial contribution of university researchers to this effort has been largely through NSERC-funded personnel in the form of graduate students, post-doctoral fellows, undergraduate students, and NSERC-supported CMMS personnel. However, recently infrastructure funding, in excess of $100,000 since 2005, has been obtained from the NSERC Research Tools and Instruments program to develop spectrometer capabilities.

The β-NMR facility provides an excellent example of the initiating role that TRIUMF plays in research that would be inconceivable in its absence. It also illustrates the potential synergies that exist when university-based research operates in concert with the scientific expertise and infrastructural capabilities of a national facility like TRIUMF.

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program. Significant portions of the IPP program depend critically on TRIUMF contributions. Canadian participation in the BaBar experiment at SLAC was made possible only through TRIUMF's agreement to allocate substantial and critical technical resources and personnel to the assembly of the BaBar central drift chamber.

TRIUMF accelerator expertise was much sought after by CERN during the design phase of the Large Hadron Collider, resulting in prominent, in-kind contributions to the accelerator complex. Subsequently, Canadian researchers have played a leading role in the ATLAS experiment due to TRIUMF leadership in the detector construction and the establishment of a Tier-1 computing centre. Currently, TRIUMF's technical contributions to the design, assembly and testing of major pieces of the T2K near detector are helping Canadians retain their position as the largest foreign contingent on the experiment. ■

3.2

TRIUMF as Canada's Gateway to the World

The pursuit of key questions in physics requires the pooled talents and resources of multiple nations. As a national laboratory on the global stage, TRIUMF is Canada's keystone in international subatomic physics and provides a specialized facility for the international molecular and materials science community. It enables Canadian scientists to make leading contributions in international science projects both in Canada and abroad. Furthermore, by connecting to world-leading efforts, Canadian researchers not only maximize their accomplishments but also access developments around the globe. Ultimately, by having a globally competitive research program with strong international connections, TRIUMF helps attract and retain the best talent for Canada.

What are the benefits to Canada of an international program?

Science, by its very nature, is not confined by international boundaries. Not only does the intellectual quest of science unite humanity, it increasingly requires the combined efforts of many nations to move forward. No country can insulate itself from the global scientific community without seriously handicapping its own scientific and technological ability. This is especially true for a country like Canada with only a modest percentage of the global research community. International connections provide contact with the very best talent, increase the opportunities for collaboration, and allow access to facilities that Canada by itself could never afford. They also allow Canada to attract, train, and retain its brightest minds. Through its strong international connections, TRIUMF, like the Canada Research Chairs (CRC) program, helps attract and retain stellar scientists who would otherwise be lost to Canada.

International connections and collaborations are also the precursors to international business and trade. These strong international connections help Canadian industry benefit from progress made in research from all over the world. For instance, TRIUMF is collaborating with a local company, PAVAC Industries Inc. (PAVAC), to develop Canadian capability in the manufacture of high technology, superconducting radio-frequency cavities (see section 5.3). This initiative would not have been possible without TRIUMF's collaborations with scientists and technical experts based in Germany, Italy, and the USA.

What does it mean to have an international program?

International partnership is a two-way street. In order to participate on the international stage and reap the rewards, Canada must contribute on a level commensurate with its involvement and expected return. Our national laboratories, TRIUMF and SNO/SNOLAB, are Canada's contribution to the set of global subatomic physics facilities. These laboratories have unique capabilities and strong international reputations because of sound investments at the provincial and federal levels as well as the combined efforts of the Canadian scientific community. Internationally leading scientists come to Canada to perform experiments at these laboratories. However, partnership in the international science community also requires involvement in and contributions to projects located outside Canada. The resulting combination of onshore and offshore facilities provides the necessary balance, attracting the best scientists to Canada while enabling the best Canadian scientists to work either at home or abroad.

The international collaborations fostered by TRIUMF extend beyond subatomic physics. For example, the TRIUMF Centre for Molecular and Materials Science (CMMS) benefits from its strong international user community (see Section 4.2.3.1). In the last 5 years, 84 of its experiments[2] had Canadian participation, 56 Japanese, 33 European, 22 American, and 3 South American.

Gateway to the Global High-Technology Community

Canada's world-leading expertise in key areas makes it a welcome member of international scientific collaborations, and in turn we benefit by accessing significantly more expertise and technology than would be possible if all

2 These numbers are obtained from an analysis of Molecular and Materials Science Experiments Evaluation Committee proposals.

developments were done domestically. TRIUMF is the lynchpin of this international involvement, fostering two-way information flow. It has memoranda of understanding with 32 foreign institutions in 16 different countries and has played key roles in Canadian involvement in international projects[3] in Europe, Japan, and the United States. Canada would not have had the same level of visibility or influence in these international experiments without the many TRIUMF contributions detailed elsewhere in this report. These contributions were only possible because TRIUMF combines the traditional strengths of a national laboratory with strong ties to the university research community.

Conversely, foreign collaborators are attracted to TRIUMF by its facilities and expertise. These visitors include senior scientists, post-doctoral fellows, students, and technical experts. Visitors come for lengths of time from a day to a year or two. Some bring equipment or materials, but all bring knowledge or expertise that strengthens the local scientific community.

Examples

International collaborations in science arise for three primary reasons. First, the specialized nature of the facility merits only a few sites worldwide. The original TRIUMF meson factory, ISAC-I and the CMMS fall into this category. Secondly, the undertaking benefits from, but does not require, the pooling of intellectual and physical resources to complete the task expeditiously. The international aspects of the undertaking tend to be limited in this case, but the benefits are very real as can be seen in the example of TITAN given below. Thirdly, the undertaking is too large for any one country to accomplish successfully alone. Therefore, many countries must collaborate in the enterprise, from detector and accelerator development, to construction, to the extraction of the physics results. The ATLAS and T2K experiments, described below, are examples of these collaborations.

Canada, through TRIUMF, is involved in partnerships following each of these models at a level appropriate for the size of the country. Several examples are highlighted here.

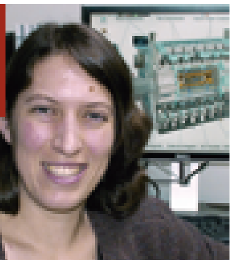
The TITAN Facility

The TITAN project exemplifies the role that TRIUMF plays as a beacon attracting international expertise to achieve Canadian objectives. Not only was this Canadian project significantly enhanced by foreign hardware and expertise, the facility has also achieved global pre-eminence and regularly attracts foreign researchers.

TITAN was first proposed in 2002 as a spectrometer for short-lived isotopes using a Penning trap. What distinguishes it from any other mass spectrometer is its ability to trap highly charged ions; all other such spectrometers work with singly or double charged ions. The critical component that provides the "charge-state boosting" is the electron beam ion trap (EBIT). Canada had limited expertise in the design and construction of an EBIT, and one had never before been coupled to a rare-isotope beam facility. These challenges were

3 These projects include ATLAS, T2K, BaBar, HERMES, G0, and Q_{weak}. Additional analysis is presented in Appendix B.

PEOPLE



ISABEL TRIGGER

TRIUMF Research Scientist

Isabel Trigger graduated with a B.Sc. from McGill in 1994 and went on to complete an M.Sc. and a Ph.D. at the Université de Montréal between 1994 and 1999. Her M.Sc. thesis, "Evolution du spectre de dépôts énergétiques dans les détecteurs au silicium irradiés en protons," studied the ultimate performance of silicon-based precise tracking detectors in the presence of radiation for the LHC. Her Ph.D., "Mesure des couplages trilinéaires anomaux des bosons de jauge avec le détecteur OPAL au LEP," included definitive measurements of the self-coupling of standard model gauge bosons and is considered one of most challenging experimental analyses performed at the Large Electron Positron (LEP) Collider.

Dr. Trigger was awarded the competitive CERN Research Fellowship in 1999, leading to the exceptionally rare offer of a CERN research staff position in 2001. She personally performed the most general and comprehensive search for the "chargino" particles predicted by supersymmetric theories. Isabel was also a leader in the CERN team designing and testing the alignment system that monitors the relative positions of the 22 m diameter ATLAS endcap muon chambers with 50 μm accuracy.

In 2005, TRIUMF recruited Dr. Trigger to lead the establishment of an ATLAS physics analysis group. She is currently the ATLAS-Canada physics coordinator. ■

overcome thanks to TRIUMF's connection to the Max-Planck Institute for Nuclear Physics (MPI-K) in Heidelberg, Germany.

The Heidelberg EBIT group was developing a system for deployment at DESY (Deutsches Elektronen Synchrotron). A joint project was initiated and a memorandum of understanding was signed outlining the tasks of the two partners, MPI-K and TRIUMF. TRIUMF provided expertise for coupling trap systems to an accelerator-based beam line, and MPI-K contributed its unique EBIT expertise. Two identical EBIT systems were built at Heidelberg; one was shipped to Hamburg and the other delivered to TRIUMF.

During the entire two-year construction and commissioning phase, the TITAN group stationed a post-doctoral researcher and a graduate student in Heidelberg. In the final stage, two TRIUMF scientists joined them. Both the student and the post-doc have returned to Canada, bringing their newly acquired expertise. A group from Heidelberg came to help set up their equipment and integrate it into the TITAN experiment. A second Canadian post-doctoral researcher, who had previously worked at Heidelberg, is now in charge of the TITAN-EBIT and brings unique expertise to TRIUMF. In the meantime, having successfully operated the system at TRIUMF, the researchers from MPI-K are planning to carry out experiments in Vancouver. Moreover, upgrades at ISAC-II now foresee an EBIT charge breeder based on the local expertise gained from this international collaboration.

The ATLAS Experiment

The ATLAS experiment at CERN is an example of TRIUMF's role as the keystone of Canadian participation in the world's largest scientific endeavors (see Section 4.2.1.2.1). ATLAS was conceived to undertake the incredible task of searching for, and understanding, the origin of mass, the highest priority in particle physics. To obtain the high energy needed for this quest, the accelerator (the Large Hadron Collider (LHC) based on novel superconducting magnet technology) required an international collaboration. The experiment has taken a decade and a half to design, build, and commission, even with the combined efforts of 2,000 scientists and a corresponding army of technical staff. Every country with a significant scientific community, including Canada, is involved.

With the resources and talent of TRIUMF at its disposal, the Canadian particle physics community was able to actively participate in the ATLAS and LHC projects. TRIUMF accelerator physicists had unique expertise for the design and construction of critical parts of the accelerator. The resulting accelerator contributions were a necessary part of the Canadian investment in the project. TRIUMF scientists and technical staff were also crucial to helping the Canadian university community contribute to the design, construction, and commissioning of the ATLAS detector.

TRIUMF is also home to the ATLAS-Canada Data Centre, funded by the Canada Foundation for Innovation. This centre will pre-process the raw data from the experiment prior to analysis by Canadian and foreign researchers. It will also provide domestic detector experts access to raw data for detailed calibration and monitoring.

Canada is now in a position to reap the scientific rewards of this monumental international undertaking. The rewards promise to be the most exciting advances in decades in our understanding of the fundamental nature of matter. Not surprisingly, four CRC chairs are involved in this exciting research, and

TRIUMF has managed to attract CERN staff member, Dr. Isabel Trigger, back to Canada to lead Canadian analysis efforts of ATLAS data.

T2K

Neutrino physics illustrates the international nature of science and how Canada plays a leading role in international projects. Discoveries of neutrino oscillations in solar and atmospheric neutrinos by Super-Kamiokande (Japan) and SNO (Canada) opened an exciting new era in neutrino physics. Building on these successes, TRIUMF and Japanese scientists initiated the T2K (Tokai to Kamioka) long baseline neutrino project in 2000. This project has become the flagship neutrino project and has grown into an international collaboration of 12 countries from Europe, Japan, and North America, including all the G8 nations. The Canadian group introduced key components of the experimental design such as the off-axis beam concept; ν_{ue} appearance analysis method with water Čerenkov detectors, and CP violation studies. These tools have become standard in all next-generation, neutrino oscillation projects.

TRIUMF accelerator/beam line expertise provided critical input to the neutrino beam line design including a concept for dual kickers to abort and extract the beam, novel optics to transport the 1 MW primary proton beam, and a feasibility study for an innovative focus/bending combined function magnet. Handling of the extremely high radiation is paramount at a neutrino facility. For this TRIUMF engineers, in collaboration with KEK (Japan) and the Rutherford Appleton Laboratory group (UK), contributed to the design and construction of the remote handling mechanism in the target station.

For the detector construction, the Canadian group is in charge of some of the most challenging and critical items of the project: the time projection chamber (TPC), fine-grained calorimeter (FGD), and optical transition radiation detector (OTR). These projects are led by university researchers: TPC by D. Karlen (University of Victoria); FGD by S. Oser (UBC); and OTR by S. Bhadra (York University). These high-profile international contributions were only possible with strong support from TRIUMF, whose high quality work and expertise are recognized internationally. At the same time, accumulated detector expertise such as precision machining of the large TPC, development of scintillator extrusion techniques and fabrication of readout electronics, will be important assets for future Canadian projects.

The high profile Canadian role in the T2K collaboration attracted excellent young scientists to Canada, such as S. Oser (UBC, CRC Chair, Sloan Fellow) and Hirohisa Tanaka (UBC, IPP research scientist).

Collaboration with the Variable Energy Cyclotron Centre in India

The Variable Energy Cyclotron Centre (VECC) in Kolkata is managed and operated by the Government of India's Department of Atomic Energy. The first large accelerator at the centre was commissioned in 1980. VECC is presently commissioning a superconducting cyclotron and several rare-isotope beam accelerators, and they are planning the construction of several additional linear accelerators. TRIUMF's technical expertise in accelerator systems and its reputation for scientific excellence make it a natural partner for the VECC research program. VECC and TRIUMF are both members of the world-wide

Tesla Technology Collaboration (TTC), a collaboration of 45 institutes engaged in the free exchange of knowledge and technology aimed at applications of superconducting RF accelerator technology. A formal collaboration (Memorandum of Understanding) in superconducting radio-frequency technology between TRIUMF and VECC is being prepared.

TRIUMF and VECC are both developing plans to build new 50 MeV superconducting radio-frequency electron linear accelerators, referred to as “e-linac photo-fission drivers,” to produce rare-isotope beams using actinide targets. The collaboration with VECC will allow the TRIUMF e-linac project to proceed on a faster time schedule by sharing technical expertise, resources, and costs. This arrangement benefits VECC in a similar manner. The Canadian and Indian e-linac facilities would follow the Organization for Economic Co-operation and Development recommendation that rare-isotope beam facilities be regionally based.

The goal of the first phase of the VECC-TRIUMF partnership is to develop jointly a single cavity horizontal test cryomodule. Two will be built: one for VECC and the other for TRIUMF. The cavities will be constructed by PAVAC, a local company, thereby bringing industrial activity and expertise to Canada. TRIUMF and VECC will fully develop all aspects of cavity production: high- and low-level RF techniques, power distribution schemes, and 2K cryogenics implementation. Scientific and engineering staff of VECC and TRIUMF will collaborate to develop the design and subsequently to build the required infrastructure. It is expected that Indian physicists and engineers will make extended visits to TRIUMF to share and jointly develop technical expertise. This partnership is an example of TRIUMF’s ability to attract foreign-based researchers and investments to Canada.

3.3

TRIUMF's Role in Creating Synergistic Relationships with Commercial Partners

Although driven by a primary mission focusing on basic research, TRIUMF has positioned itself as a bridge across the traditional "valley of death" that separates inspiration and discovery from product development and commercialization in the marketplace. TRIUMF drives product development and commercialization in three different categories:

1. TRIUMF's expertise is in demand by companies who are looking to enhance their revenue-generating activities. By selling this expertise, either through licenses or by contracting out employees, TRIUMF not only helps these companies, it increases its own expertise and capabili-

ties. The award-winning relationship between TRIUMF and MDS Nordion is an example of this type of interaction.

2. TRIUMF trains people in specialized areas of expertise, and these people, in turn, take their expertise work in existing companies or to start new companies. Dehnel – Particle Accelerator Components and Engineering, Inc. (D-Pace), based in Nelson, BC, was started by Dr. Morgan Dehnel, a scientist who received his training at TRIUMF.

3. TRIUMF, as a laboratory doing leading-edge research, frequently requires equipment that is not available off-the-shelf but must be developed in conjunction with commercial suppliers. The expertise developed by these suppliers, with TRIUMF's help, then aids the supplier to generate additional business and, in some cases, significantly increase its top line. Richmond-based PAVAC Industries Inc. (PAVAC) is a prime example of TRIUMF helping a local company develop commercial expertise, in this case for superconducting cavity constructions.

Table 1 lists TRIUMF's significant business partners and the manner in which the lab interacts with them. "Enabling" cuts across all three of the categories and can involve many difference conduits for the transfer of knowledge. "Licensing" falls into Category 1. "Sales and Contracts" or Category 3 include cases where TRIUMF buys from companies at the same time it transfers knowledge to them. To illustrate how the transfer of expertise happens in practice, we highlight three different companies and show how each of the three categories works, keeping in mind, however, that most companies fall into more than one category.

Collaboration	Country	Enabling	License	Sales / Contracts
Advanced Applied Physics Solutions	Canada	■	■	■
Advanced Cyclotron Systems	Canada	■	■	
Alstom	Canada	■		■
CDS Research Ltd.	Canada		■	
Celco Plastics Ltd.	Canada	■		■
CNC Machining	Canada	■		■
D-Pace	Canada	■	■	■
IE Power	Canada	■		■
Isodose Control	The Netherlands			■
MDS Nordion	Canada	■	■	
Pavac	Canada	■		■
Profile Composites Inc.	Canada	■		■
Superior Electroplating	Canada	■		■
Thales	France	■		■
UMA Engineering	Canada	■		■
Upton Technical & Trading	Taiwan			■

Table 1: TRIUMF's Significant Business Partners and Industrial Connections

Category 1: MDS Nordion

MDS Nordion is a division of MDS Inc., a transnational health and life sciences company based in Kanata, Ontario. It specializes in radioisotope production and radiation-related technologies used to diagnose, prevent, and treat disease. It supplies over two-thirds of the world's medical isotopes used for diagnosing heart disease, brain disorders, and infections. Its Vancouver facility on the TRIUMF site provides more than 15% of Canada's supply of medical isotopes.

The first therapeutic isotope Nordion produced at the Vancouver facility was Palladium-103 used in prostate brachytherapy. This isotope was developed in conjunction with TRIUMF using the first TR30 cyclotron, a cyclotron based on a TRIUMF design. MDS Nordion's new state-of-the-art commercial cyclotron facility at TRIUMF was completed on January 30, 2003. In May 2003, the company started using a second, newly purchased TR-30 cyclotron. Subsequently, with the official activation of the second beam in September 2003, Nordion has been able to double its production capacity of the Palladium-103 radioisotope. This improved production capability from the new machine is estimated to provide additional products for up to one million nuclear medicine procedures around the world each year.

MDS Nordion has licensed medical isotope production knowledge from TRIUMF. In addition, the three small cyclotrons Nordion uses for isotope production are owned and operated, under contract, by TRIUMF. A low-energy proton beam from the main TRIUMF cyclotron is also used to produce heart-imaging isotopes for MDS Nordion. These activities generate royalty income for TRIUMF and help Nordion compete in the global market. If TRIUMF did not exist, the MDS Nordion Vancouver operation would cease as well: the highly skilled labour TRIUMF supplies for this particular work is simply not available anywhere else in Canada. In return for its support of MDS Nordion, TRIUMF benefits from MDS Nordion's skill and experience in commercial production, marketing and transport of isotopes.

A 1995 report by the US Institute of Medicine's Committee on Biomedical Isotopes cited the TRIUMF-MDS Nordion relationship as a model of public-private partnership, one that could be emulated in the United States. The report stated that the Department of Energy: "… should encourage such a partnership between one or more for-profit institutions and at least one not-for-profit institution (university, national laboratory, or some combination) to operate NBTF [National Biomedical Tracer Facility]."

TRIUMF and MDS Nordion won the Natural Sciences and Engineering Research Council of Canada (NSERC) 2004 Synergy Award for Innovation for their outstanding 26-year university-industry partnership. The award was one of only seven awarded that year, and one of two granted in the Large Companies category.

Category 2: Dehnel – Particle Accelerator Components and Engineering, Inc. (D-Pace)

D-Pace is a TRIUMF spin-off company that provides state-of-the-art engineering products and services to the particle accelerator industry. Its founder and president, Dr. Morgan Dehnel received his graduate training at TRIUMF. D-Pace specializes in complete beam line system designs, charged particle transport systems, as well as components for cyclotrons, ion implanters, and linear accelerators, including quadrupole and dipole magnets, vacuum boxes, and beam diagnostic devices. The internationally recognized D-Pace hires out its highly knowledgeable and professional staff to work with engineers and managers of other companies, most notably in the semiconductor industry on ion implantation, and at institutes, such as the Institute of Nuclear Energy Research in Taiwan, on ion source and beam line technologies.

The years of close co-operation between TRIUMF and D-Pace took a major step forward in December 2001 when D-Pace licensed a group of cyclotron component technologies from TRIUMF. The company has since generated sales from the ion source technology it licensed from TRIUMF in Europe and Asia. Since the licensing relationship began, TRIUMF has provided assembly space for training D-Pace's staff and has allowed D-Pace to subcontract TRIUMF when its specialized services are not available elsewhere in Western Canada. D-Pace worked with TRIUMF staff to document much of the lab's know-how into manufacturing drawings and technical manuals, thus preserving valuable knowledge for training and future use. Combined with the licensed technologies, this information is available to both parties through a cross-licensing feature in their agreement.

With continuing encouragement and support from TRIUMF, D-Pace has grown into a successful business that has an impact on both the national and local economies. D-Pace has doubled its revenues in each of the past four years and now has customers from France, Japan, South Korea, Taiwan, the Netherlands, and the United States. D-Pace's success in Nelson, BC has resulted in the hiring of local subcontractors in scientific modeling, electronic engineering, technical writing, web design, marketing, business development, and machining. Moreover, Dr. Dehnel is a founding member of five non-profit organizations dedicated to improving the scientific, technological and business sectors in the Kootenay region in British Columbia, as well as supporting local schools' science and technology programs through judging, donations, and lectures.

TRIUMF and D-Pace won the 2007 Synergy Award for Innovation for small- and medium-sized companies. This award was one of only seven given to university-industrial partnerships within all of Canada.

Category 3: PAVAC Industries, Inc.

On April 14, 2008, a team of BC scientists and engineers drawn from the TRIUMF laboratory and PAVAC Industries, Inc., announced that they had entered into an elite worldwide league of groups that are able to manufacture ultra-sophisticated superconducting accelerator technology. The BC team was able to fabricate, assemble, and test a high-tech device known as a "superconducting radio-frequency cavity" or SRF cavity. These superconducting devices are assembled into modules to form next-generation accelerators with applications in health care, environmental mitigation and remediation, advanced materials science, and high-energy physics. This success is a first for Canada and registers the country as one of only five countries in the world with this coveted capability.

The TRIUMF team had sought out PAVAC Industries, Inc., in Richmond, BC for their expertise in the tricky step of careful welding in a vacuum. PAVAC is a world leader in developing commercial high-energy electron beam applications, most notably the PAVAC LASTRON beam for electron-beam welding, which was integral to the manufacture of the cavities. TRIUMF scientists had developed the first stage of the project using cavities fabricated in Italy. During the second stage of the project, the TRIUMF/PAVAC partnership was formed with the goal of developing a "Made-in-Canada" solution. PAVAC's contract with TRIUMF has translated into a $C600,000 pay cheque for the company. The newly acquired capability will enable PAVAC to bid for other projects at major laboratories and institutions around the world.

Conclusion

A recent Statistics Canada study found that "…it is the broad set of university degree holders in a city that is consistently connected to job growth. However, the effectiveness of this group is enhanced when combined with a higher share of scientists and engineers—specialized workers who are directly involved in developing and implementing innovations" [Statistics Canada, *The Daily*, Jan. 8, 2008]. Statistics Canada found a correlation among technology, science, and industry. TRIUMF and its commercial partners reveal the mechanisms behind the correlations. MDS Nordion, D-Pace, and PAVAC all illustrate the different ways a high-technology facility seeds technological development and job growth.