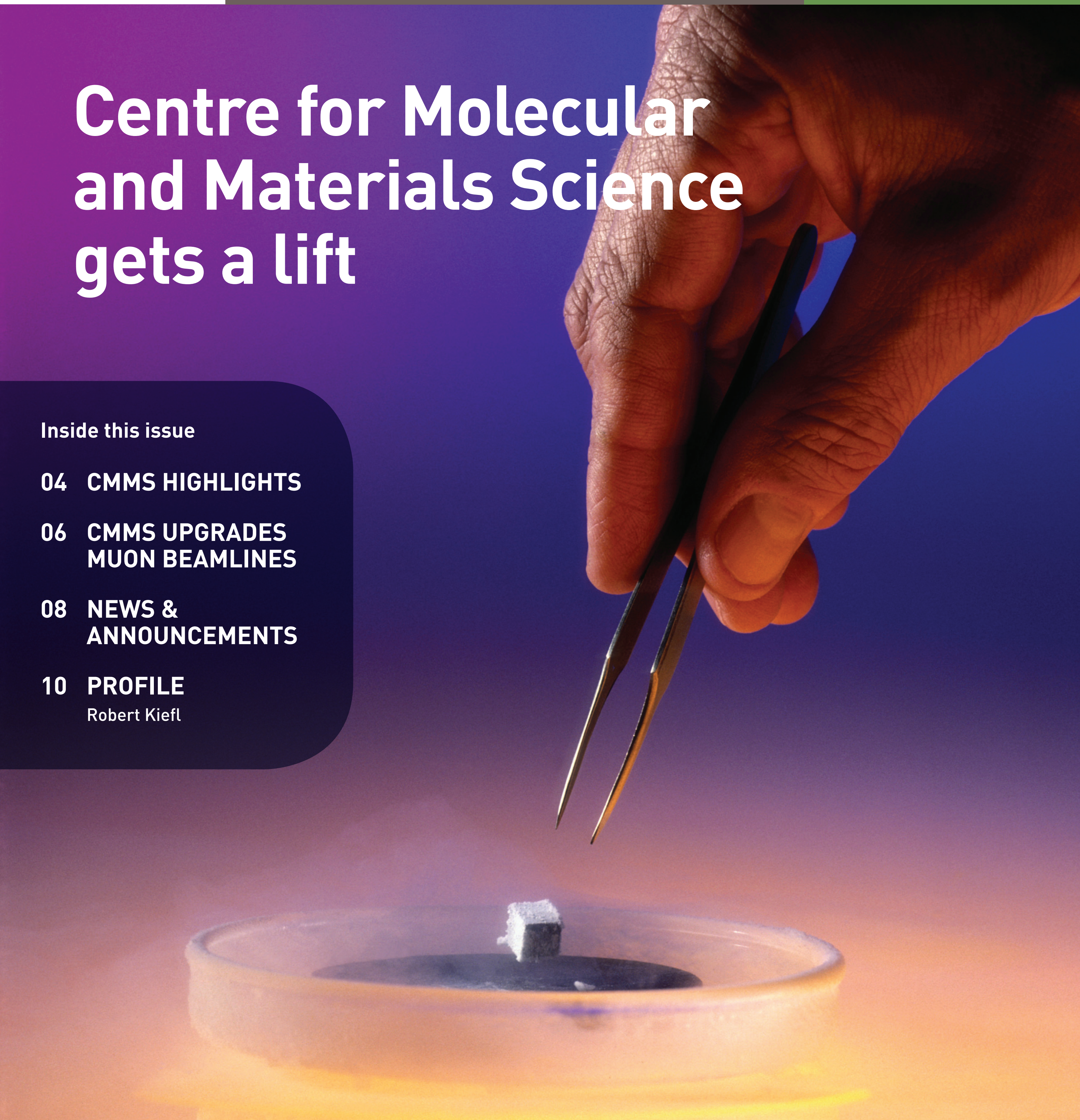
BEAMTIME

TRIUMF

News from Canada's national laboratory for particle and nuclear physics

SPRING 2013 | VOLUME 10 ISSUE 1



Centre for Molecular and Materials Science gets a lift

Inside this issue

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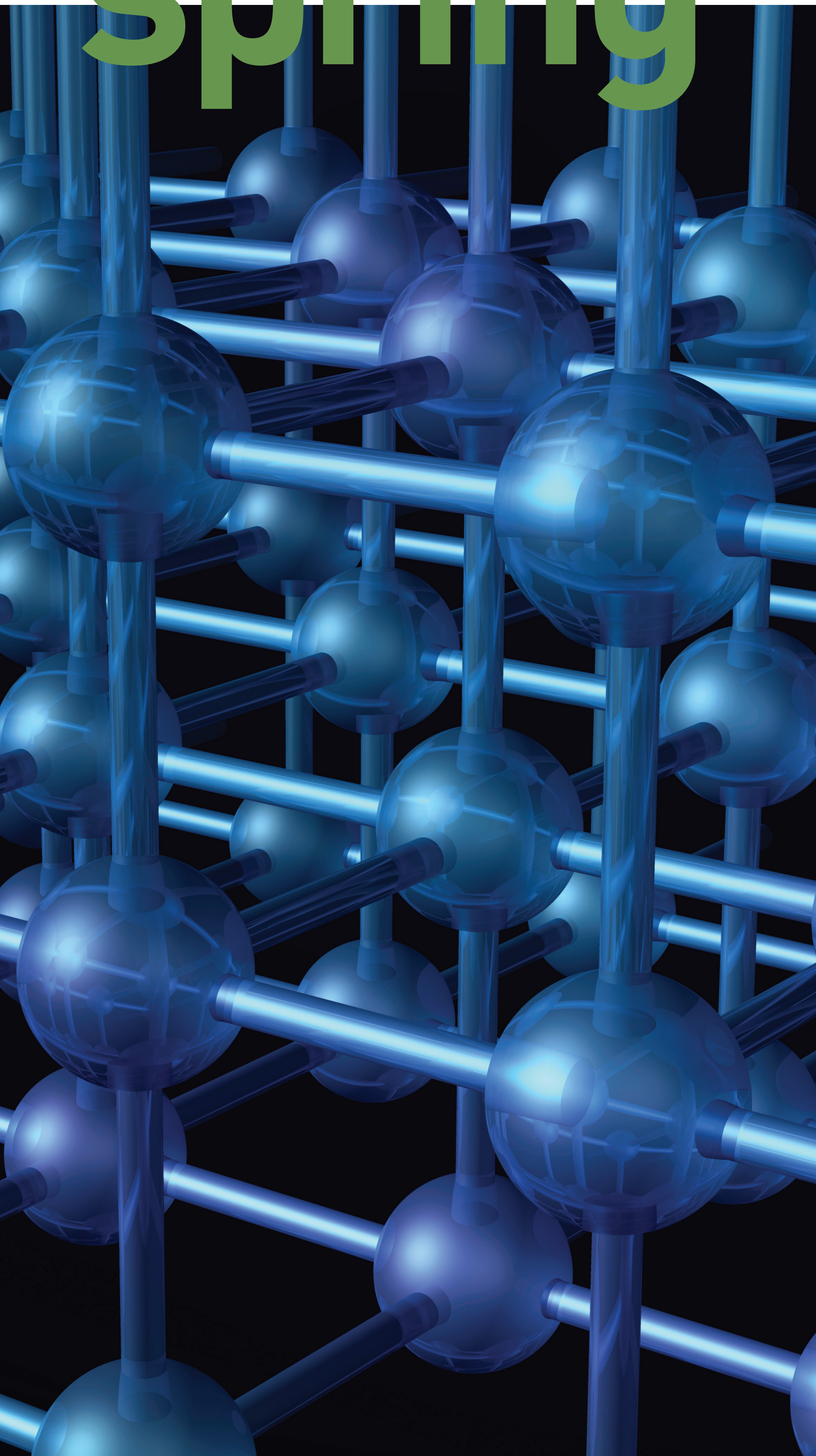

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TRIUMF

TRIUMF is funded by a contribution through the National Research Council of Canada.

The province of British Columbia provides capital funding for the construction of buildings for the TRIUMF Laboratory

Nigel S. Lockyer | Director, TRIUMF

How Innovation Happens: Imagine, Explore, Deliver

Its spring in Vancouver and TRIUMF is celebrating with a brightly-coloured new look "Beamtime."

This first new format issue hits the high points of what is going on at TRIUMF with a couple of in-depth articles, brief news of interest and announcements, and ends with science motivated art to stimulate and challenge a few of your neurons. In this issue, we are highlighting the materials and molecular science program at TRIUMF, a unique facility in North America and one of only four such facilities around the world (UK, Switzerland, and Japan are the others).

We are beginning a big push in materials research with new facilities and a plan for significantly increased beam time. The program has undergone a significant multi-year face lift culminating this year, with three new fully polarized surface muon beam lines coming online for studying the bulk magnetic properties of tiny samples of new and exotic materials. The ever-more interesting studies from ßNMR are probing nanometre-scale magnetic phenomena of ultra-thin materials tens of atoms thick or in interfaces of layered materials. Magnetic phenomena often drive the atomic level behaviour of materials, such as superconductivity. Surprising new phenomena can also emerge from layers of materials — one recent example is the observation that two electrical insulators can be electrically conducting at their interface! Once TRIUMF's flagship project ARIEL completes its first phase in early 2016 and is ready to deliver first science, the ßNMR facility has been chosen to be the first recipient of beam from the new electron accelerator. They will receive up to three times more beam time per year than they receive now. Get the samples ready!

> "the [CMMS] has undergone a significant multi-year facelift"

The Centre for Molecular and Materials Science

TRIUMF's home for condensed matter physics and chemistry

by Iain McKenzie

TRIUMF may be "Canada's national laboratory for nuclear and particle physics", but it is also home to the Centre for Molecular and Materials Science (CMMS), a facility serving a broad community of scientists utilizing beams of muons and radioactive nuclides to investigate diverse areas of chemistry, physics and materials science. CMMS provides equipment and support personnel to enable local and visiting researchers to apply µSR (Muon Spin Rotation/Relaxation/Resonance) or ßNMR (Beta-detected Nuclear Magnetic Resonance) techniques to their scientific problems.

Muon Spin Rotation/Relaxation/ Resonance (µSR)

The acronym µSR represents a set of experimental techniques based on the asymmetric decay of spin-polarized muons into electrons (and non-detectable neutrinos). The name emphasizes the analogy with the well-known magnetic resonance techniques, NMR and ESR (electron spin resonance). The muon acts as a microscopic probe of internal magnetic fields in materials; consequently, µSR is used frequently to study novel superconductors and magnetic materials.

> µSR has grown from an exotic technique...to a valuable characterization tool

In other systems, a muon can bind to an electron to form a short-lived muonium atom, which is, chemically speaking, a light isotope of hydrogen. Muonium can be utilized in studies of hydrogen atom kinetics, organic free radicals and hydrogen-doped semiconductors (see TRIUMF Beamtime Fall 2011, Vol.9 Issue 2). In the past 30 years, µSR has grown from an exotic technique studied for its own interest to a valuable characterization tool with applications in a variety of fields in molecular and materials science.

Recent µSR Highlights

Jeremy Carlo (Villanova) and co-workers recently used µSR at TRIUMF to determine the magnetic phase diagram of the $(Sr,Ca)_2RuO_4$ system (see Figure 1). Their results showed that the magnetic phase diagram is different from previous reports in that there is close proximity between static magnetism and superconductivity. c.f. AFM fluctuations are believed responsible for Cooper pairing in the high-T_c superconductors. This discovery was possible because the muon is more sensitive to weak disordered magnetism than other probes.

In 2009, there was a high profile claim in the journal Nature that µSR could be used to measure the magnetic charge of magnetic monopoles in the spin ice material $Dy_2Ti_2O_7$. "Magnetricity", as it was called, was reported by the BBC and other mainstream media and the search for magnetic monopoles was even mentioned in the television show "The Big Bang Theory". Sarah Dunsiger (TU Munich) and colleagues showed that the features in the µSR spectra that Bramwell et al. thought were the signature of magnetic monopoles were actually due to muons stopping in the silver backing plate. The work by Dunsiger et al. at TRIUMF (see Figure 2) shows the importance of careful measurements and that sensational results can often be wrong.

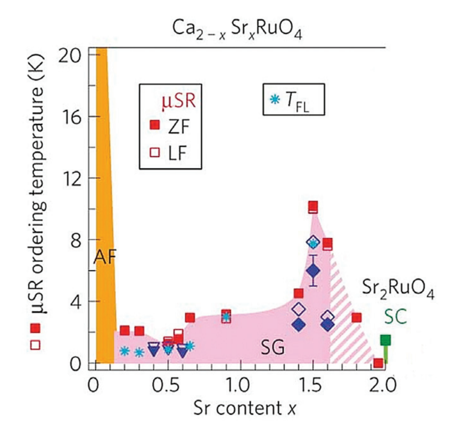

Fig 1: Phase diagram of $Ca_{2-x}Sr_xRuO_4$ as a function of the Sr content, as determined by µSR measurements.There is a close proximity between the unconventional superconductor Sr_2RuO_4 and competing static magnetic order.

ß-Detected NMR (ßNMR)

The ßNMR facility in TRIUMF's ISAC Hall uses a low-energy beam of spin-polarized radioactive ions to probe ultrathin films and surfaces. Although the basic principles of ßNMR and µSR are the

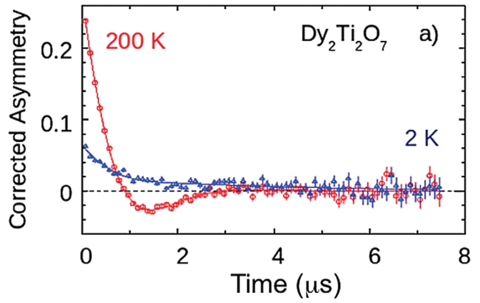

Fig 2: Figure shows the decay asymmetry signal of muons in $Dy_2Ti_2O_7$ at temperatures of 200K and 2K. It had been claimed that the relaxation of the muon precession signal in $Dy_2Ti_2O_7$ was the signature of deconfined magnetic monopoles. The CMMS research found no muon precession in $Dy_2Ti_2O_7$ at low temperature (2 K) due to the large internal field. The research surmised that the claimed signal was an artefact due to muons stopping in the silver backing. (From S.R. Dunsiger et al.)

same, ßNMR provides complementary information. In particular, its high sensitivity associated with nuclear detection of the signal, coupled with the low and variable beam energies (0.1–30 keV), makes the method well suited to the study of materials which are too thin either to carry out conventional NMR or to stop a conventional muon beam. In addition, the lifetime of a typical probe nucleus (e.g. ^{8}Li) is about a million times longer than that of the muon (2.2μs); consequently, the precession and relaxation rates of the nuclear polarization can be observed on a much longer time scale, leading to higher intrinsic resolution.

Recent ßNMR Highlights

A better understanding of superconductivity has enormous technological implications. When a normal metal is placed next to a superconductor it can also become superconducting over the tens to hundreds of nanometers range. Morenzoni, et al. recently used ßNMR to observe the expulsion of magnetic fields (Meissner effect) in a thin silver layer on top of niobium, which is a superconductor below 9.3 K. A peak in the ^{8}Li spin relaxation rate near the critical temperature showed that there are slow fluctuations of the superconducting order-parameter. These fluctuations are not observable with conventional NMR because high magnetic fields suppress sensitivity to fluctuations.

A better understanding of super-conductivity has enormous technological implications.

There is evidence that the interfaces in a multilayer sandwich made up of two insulating and non-magnetic materials ($SrTiO_3$ and $LaAlO_3$) can be magnetic, conducting, and even superconducting at very low temperatures. It's like putting together a couple of pieces of dry bread and suddenly finding you have a Dagwood sandwich with all of the fixings! ßNMR can be used to study the magnetic properties of such buried interfaces. Zaher Salman (PSI) and coworkers found that the magnetism in these multilayers is more than 1,000 times smaller than that in iron and that magnetism disappears at or below a minimal/critical thickness of 5 unit cells of $LaAlO_3$. Normal (ie. resistive) metal in intimate contact with a superconductor exhibits a proximity effect where the superconductivity "leaks" into the metal.

The Future of the CMMS

The mantra of the CMMS is 'Faster and Better' and the facility is taking steps to fulfil this pledge. CMMS is in the middle of building new beam lines (M9A and M20C+D, see G. Morris' article in this issue), developing new spectrometers built around new high-homogeneity magnets and high performance detector sets based on avalanche photodiode detectors and expanding the range of sample environments. Once fully developed, these initiatives will greatly expand the capabilities of the CMMS, allowing researchers to study more materials with more sensitive experiments than is currently possible, securing TRIUMF at the forefront of material and molecular science with subatomic beams.

The mantra of the CMMS is 'Faster and Better'

For More information:

http://www.triumf.ca/research/research-facilities/centre-for-molecular-materials-science

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Bramwell et al. Nature **461**, 956 (2009)].

S.R. Dunsiger et al., Phys. Rev. Lett. **107**, 207207, (2011)

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CMMS upgrades muon beamline capability

Ambitious CFI project bearing fruit

by Gerald Morris

The TRIUMF Centre for Molecular and Materials Science (CMMS) operates a user facility providing muon beams and spectrometers in support of a diverse program of research in condensed matter physics and chemistry (see previous article). To date these research efforts have been performed (primarily) on three beamlines: M15, M9B, and M20. The CMMS obtained funding through the Canada Foundation for Innovation (CFI) and associated agencies to support expansion of the beamline infrastructure. Work on two new positive muon (μ+) beamlines (M9A, M20) are now nearing completion in the Meson Hall.

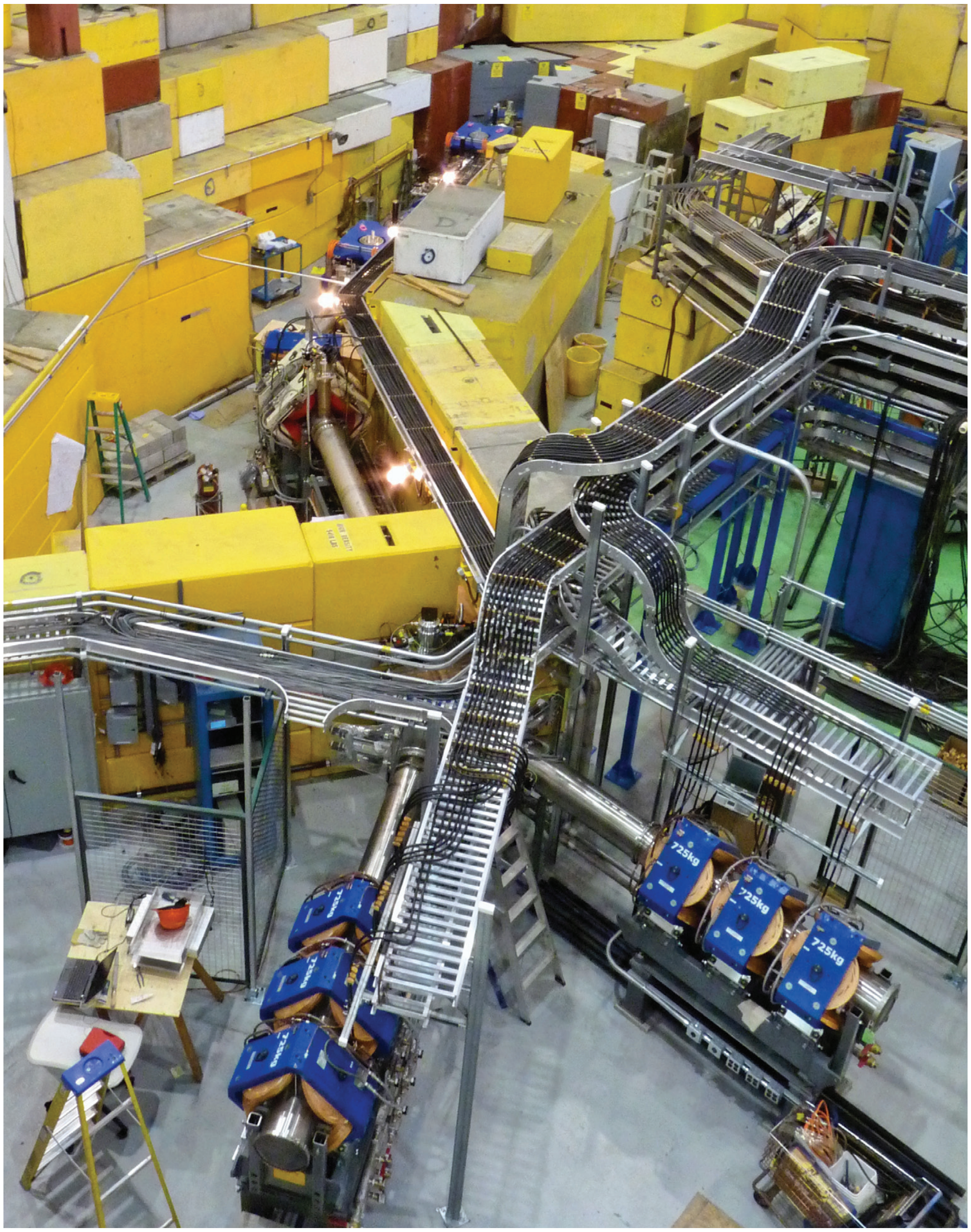


Fig. 1: Overhead view of the new M20C/D experimental area. The two new end stations (foreground) already have begun taking data. The beamline (back left, now covered up) awaits a fast kicker so both end stations can operate simultaneously. (Spectrometers not shown).

The secondary muon channels, M9A and M20C/D, are designed to transport low momentum (30 MeV/c) positive muons (μ+) from the Meson Hall production target T2 to μSR spectrometers situated at the end of each beamline. The principle design objective of these beamlines is to deliver well-focused beams of fully polarized muons into a µSR spectrometer with minimal contamination by other particles. In addition, they will deliver muons with spin transverse to their momentum direction.

The principle design objective... is to deliver well-focused beams of fully polarized muons

M9A is being built in the space formerly occupied by a high-momentum pion/muon channel. Front-end quadrupole magnets and momentum-selecting dipoles shared with the existing M9B high-momentum µ± channel have been retained. M20C/D have been constructed approximately along the former M20B layout (see Figure 1), re-using the front end quadrupole magnets close to the production target, but otherwise an entirely new beam optics configuration has been installed.

At M9A the beam is passed through a fast electrostatic kicker which can be asynchronously driven by the experiment's data acquisition system (DAQ) to turn the beam off and on. Most µSR experiments operate in a time-differential mode in which the elapsed time between the arrival of each muon and the emission of its decay positron is precisely measured. This necessitates the unambiguous pairing of each decay positron with the muon from which it came, within a time window usually fixed at about 10µs. The fast kicker allows the DAQ to turn on the beam until a single muon has arrived, then turn it off until the decay positron is detected. This Muon-On-Request scheme eliminates pile-up events due to extra

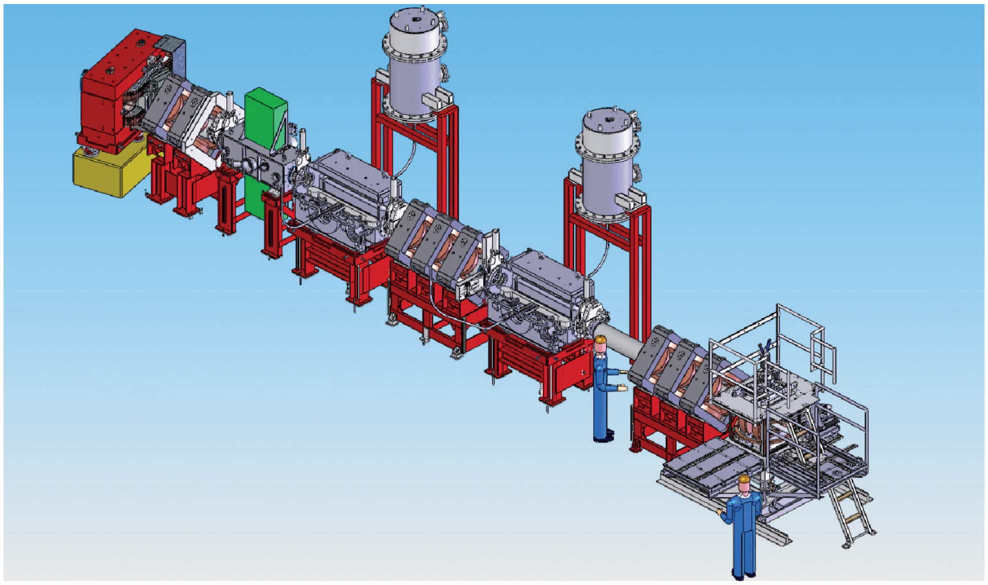


Fig. 2: Engineering model of the new M9A currently under construction. The innovative beamline will employ spin rotators and a Muon-on-Demand fast kicker

muon or positron counts within that time window. It also reduces the background of uncorrelated positrons, so the useful length of the µSR histograms can be doubled to about 10 muon lifetimes. Longer histograms with lower noise will improve the ability to measure low muon spin relaxation rates as well as improved measurement of the distribution of magnetic fields within a sample. At M20C/D, a similar kicker will switch the beam between two spectrometers, one of which will drive the kicker while the other passively receives the remaining beam. Having two end stations at M20 will also reduce the number of equipment changes made to accommodate different experiments' needs.

The beamline upgrades will enable the provision of state-of-the-art µSR capabilities to a widening user community

The new beamlines each have two Wien filters (see Figures 1 and 2) to remove from the beam all charged particles other than those muons having the desired velocity. The filters also will be able to precess the muon spins through 90° so that the muons arrive at the sample with their spins perpendicular to their momentum, a geometry required for muon spin precession experiments in which the sample is placed in a strong magnetic field. The combination of two spin rotators and quadrupole magnets (and at M20, also the pair of dipoles) is non-dispersive in momentum so that the beam spot aberrations are minimized. This beam optics scheme extends our capability by delivering the maximum number of muons into a small beam spot, enabling experiments on high quality but often small single crystal samples measuring only a few millimetre square.

The beamline upgrades will enable the provision of state-of-the-art µSR capabilities to a widening user community, building upon the CMMS' already impressive achievements thus far. It is anticipated that experiments on M20C/D (minus the kicker) will begin in earnest in 2013, while M9A will be accepting experiments in 2014.

For more information, see http://cmms.triumf.ca

News & Announcements

Higgs Boson: Quo Vadis

by Oliver Stelzer-Chilton and Bernd Stelzer

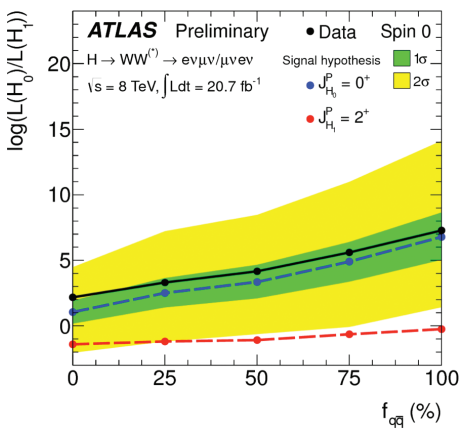


Fig. 1: A statistical measure of Higgs--→ W + W decay from ATLAS, assuming spin zero (blue dashed line) and spin two (red dashed line), inlcuding one- and two-sigma uncertainty bands for spin zero. The observed value (solid black line) clearly favours the spin-zero hypothesis.

On July 4, 2012 two international collaborations (ATLAS and CMS) working at the Large Hadron Collider near Geneva, Switzerland announced the discovery of a new particle "consistent" with the long sought-after Higgs boson. Since the announcement the foremost physics question has been: is it really the Standard Model Higgs boson, or something different? One check is to determine the particle's spin: if it is spin zero, it is likely a Higgs boson, if it is spin two, it is something else (spin one already has been excluded). The spin affects the angles at which the Higgs' decay products emerge. With five times more data recorded since the announcement, the ATLAS Collaboration released a new analysis in March 2013 which measured these angles when the Higgs boson decays into two W bosons. TRIUMF postdoctoral researcher Doug Schouten is one of the coordinators and a driving force in the ATLAS team that produced the result. The most sensitive spin analysis to date favours the spin-zero hypothesis at the 95–99% level (see Figure 1). Together with a large number of other measurements, the new spin results from ATLAS (and CMS) strongly suggest that the new particle is indeed the Higgs boson.

Canada is a Physics Powerhouse

by Tim Meyer

A groundbreaking report released September 27, 2012 by the Canadian Council of Academies identified Canada's six world-leading fields of research. "The State of Science and Technology in Canada, 2012" ranked "physics and astronomy" among the top six drivers for Canada, recognizing "particle and nuclear physics" as particularly key. The Council says of the report "An authoritative, evidence-based assessment of the state of science and technology in Canada has found that Canadian science and technology is healthy and growing in both output and impact. Over the past five years, real improvements have occurred in the magnitude and quality of Canadian science and technology." The report found that the six research fields in which Canada excels are: clinical medicine, historical studies, information and communication technologies (ICT), physics and astronomy, psychology and cognitive sciences, and visual and performing arts. With less than 0.5 per cent of the world's population, Canada produces 4.1 per cent of the world's research papers and nearly 5 per cent of the world's most frequently cited papers. Congratulations to the Canadian research community!

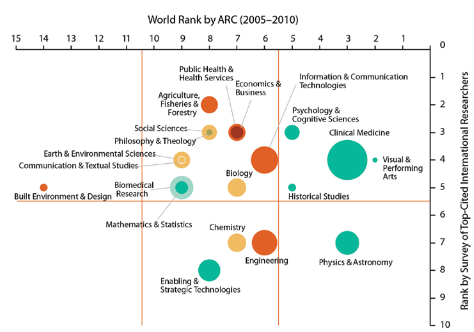


Fig. 2: Canada's research reputation ranking in the survey of top-cited international researchers (y-axis) versus rank in each field by Average Relative Citations (ARC), during 2005–2010 (x-axis). Bubbles are sized proportional to the number of papers produced in 2005–2010, and coloured according to whether their relative world share in that field increased (green), decreased (red), or remained the same (yellow) compared with 1999–2004.

For more information, see http://scienceadvice.ca/en/news.aspx?id=93

TRIUMF-led Team Receives Isotopes Investment

by Tim Meyer

On February 28, 2013, The Honourable Joe Oliver, Canada's Minister of Natural Resources, announced the signing of contribution agreements with three Canadian organizations to develop new sources of the isotope, technetium-99m (Tc-99m). Tc-99m is the most widely used medical imaging isotope and is used in approximately 80 percent of nuclear medicine diagnostic procedures.

The Government is funding teams led by the University of Alberta ($7M), TRIUMF in British Columbia ($7M), and the Prairie Isotope Production Enterprise in Manitoba (~$7.5M) to support the development and application of cyclotron and linear accelerator production technologies. The TRIUMF-led consortium (including BC Cancer Agency, the Centre for Probe Development and Commercialization, and Lawson Health Research Institute) demonstrated in February 2012 the capability to produce Tc-99m on medical cyclotrons already installed in Ontario and British Columbia. Several industrial partners are also involved and are developing commercialization pathways consistent with the program objectives.

For more information, see
http://www.triumf.ca/nrcan-isotopes

Jens Dilling invited to 152nd Nobel Symposium

On June 13, 2012 Jens Dilling attended the 152nd Nobel Symposium in Gothenburg, Sweden. The Nobel Symposium is an invitation-only program bringing together world experts to discuss scientific breakthroughs and progress. The focus of the 152nd Symposium was Physics with Radioactive Beams, where Dilling shared his research on Probing the Nuclear Interaction through Precision Mass Measurements.

According to Dilling, radioactive beams are in high demand because of their threefold benefit — intellectual gain, development of nuclear medicine, and advancement in materials science — and the Nobel Symposium demonstrated the increasing international interest and investment in nuclear physics. It also demonstrated Dilling's ever increasing stature as an expert in all matters nuclear physics worldwide.

Government funds Saint Mary's project at ARIEL

On January 15, the Canada Foundation for Innovation (CFI) announced $1.6 million in funding to support a Saint Mary's University proposal for an advanced research facility at TRIUMF's ARIEL project. The CANadian Rare-isotope facility with Electron-Beam ion source (CANREB) project is led by Saint Mary's University and Dr. Rituparna Kanungo, in partnership with the University of Manitoba, and Advanced Applied Physics Solutions, Inc., and in collaboration with the University of British Columbia, the University of Guelph, Simon Fraser University, and TRIUMF. CANREB will allow scientists to recreate, purify, and condition rare isotopes that haven't existed on the planet for millions of years.

"The facility will dramatically advance Canada's capabilities for isolating, purifying, and studying short-lived isotopes that hold the key not only for understanding the rules that govern the basic ingredients of our everyday lives, but also for crafting new therapies that could target and annihilate cancers cell-by-cell within the human body," said Dr. Kanungo.

The federal fiscal support from the CFI together with additional provincial and private sector investment will allow the $4.5 million project to be operational in 2015.

Calendar

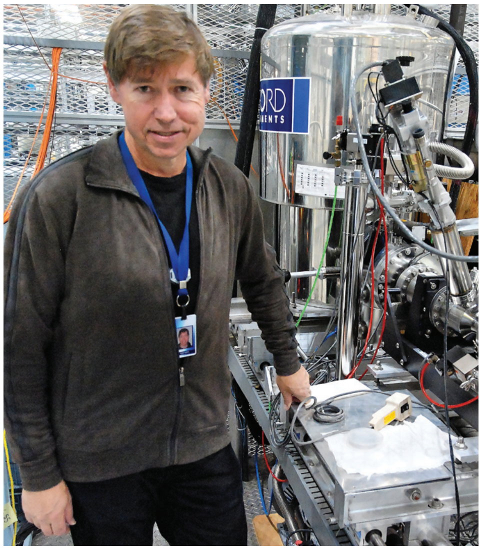
Upcoming Important Events
(at TRIUMF unless otherwise stated)

May 9	Europe Day
May 27–31 University of Montreal	CAP Congress
May 31–June 1	ACOT Meeting
June 20	Hi-Tech Gala
July 1–12	TRISEP Summer School www.trisep.ca
July 15–16	MMS-EEC
July 16	TUG AGM www.triumf.ca/tug
July 17	3rd ARIEL Science Workshop
July 18	8Pi Symposium
July 19–20	SAP-EEC
Aug 19–20	Innovation and Industrial Partnership Workshop
Sept 16–20 Vancouver	Cyclotrons 2013 Conference

TRIUMF Event Calendar
admin.triumf.ca/d2w-pub/eventscal/display

Robert Kiefl

Using ßNMR at the interface between Discovery and Innovation



Beta-detected nuclear magnetic resonance imaging (ßNMR) is closely related to the well known medical technique of magnetic resonance imaging (MRI). However rather than peering inside the human body, ßNMR probes the interiors of ultrathin material layers, even just dozens of atoms thick! The field of probing so-called nanoscale structures is flourishing world wide, with UBC Professor Robert Kiefl leading the charge at TRIUMF with ISAC's unique ßNMR facility.

Rob Kiefl grew up in Ottawa and graduated from Carlton University before heading to the west coast to begin his work at UBC and TRIUMF. Originally interested in fundamental properties of the muon, Kiefl's early work involved working with the production of muonium in a vacuum. It was during this work that his interests shifted from studying the unique properties of the muon, to using it as a probe to study materials. After obtaining his Ph.D in 1982 from UBC under the direction of John Warren, he spent two years as a post-doctoral fellow at the Paul Scherrer Institute in Switzerland before returning to TRIUMF as a research scientist. He joined UBC in 1987 as a University Research Fellow and has been there ever since. Kiefl was a key figure in developing the ßNMR facility at TRIUMF, and now employs it to pursue his main research interests, which are the properties and characteristics of thin films and material interfaces.

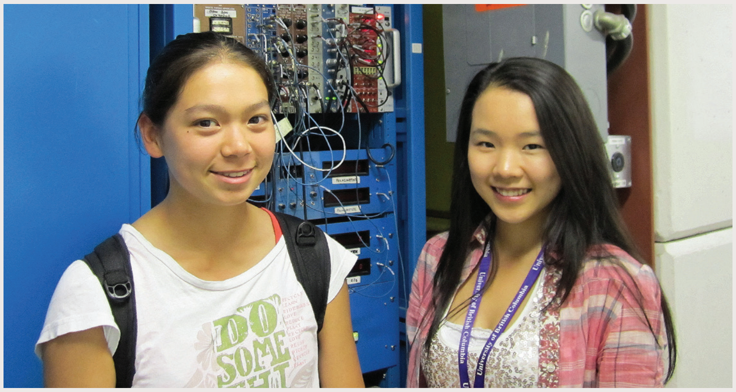
Essentially, ßNMR works by directing a beam of highly spin-polarized Lithium-8 nuclei into a material, where the mean penetration depth can be controlled on a nanometre length scale by adjusting the beam energy. Lithium-8 is radioactive, and when implanted in a material (often subject to an externally applied magnetic field), it decays by emitting an electron preferentially in the direction opposite the nuclear spin. Once stopped, the nuclear spin is affected by the local electric and magnetic characteristics in the material, which can be probed with orders of magnitude greater sensitivity than conventional NMR. Repeating such measurements at precisely controlled penetration depths, one can, for example, gain insight into properties at the interfaces of the different substrates making up the material. This provides invaluable information, since even if the bulk properties of the materials are known very well, once brought together the interface can have fundamentally new properties.

> **"We're in the business of discovery and characterizing the properties of [multimaterial] interfaces."**

The ability of ßNMR to precisely probe multi-material interfaces has made it a valuable tool in the exciting field of nanoscale condensed matter physics. Kiefl summarizes, "We're in the business of discovery and characterizing the properties of these interfaces." His interest in this area is not solely academic — Kiefl and collaborators are working on a proposal to look at spin injection into semiconductors. Today's electronics store and manipulate information via the movement of charge (electrons), which necessarily heats up the circuit. If one could instead move spin around a circuit board, or "spin current", one could circumvent the large heat dissipation associated with moving charge. Kiefl predicts that in the 15 or 20 years, these devices could very well be a reality. Poetically, that would place Kiefl and ßNMR at the interface between discovery and innovation, which is a pretty good place to be.

For more information on ßNMR, see http://bnmr.triumf.ca

AJAS Students Visit TRIUMF: Students from the American Junior Academy of Sciences pose in the TRIUMF lobby after their tour as part of the AAAS Conference in Vancouver, February 2012. About a hundred AJAS students were joined by a dozen local students for a week of seminars, tours, and discussions.

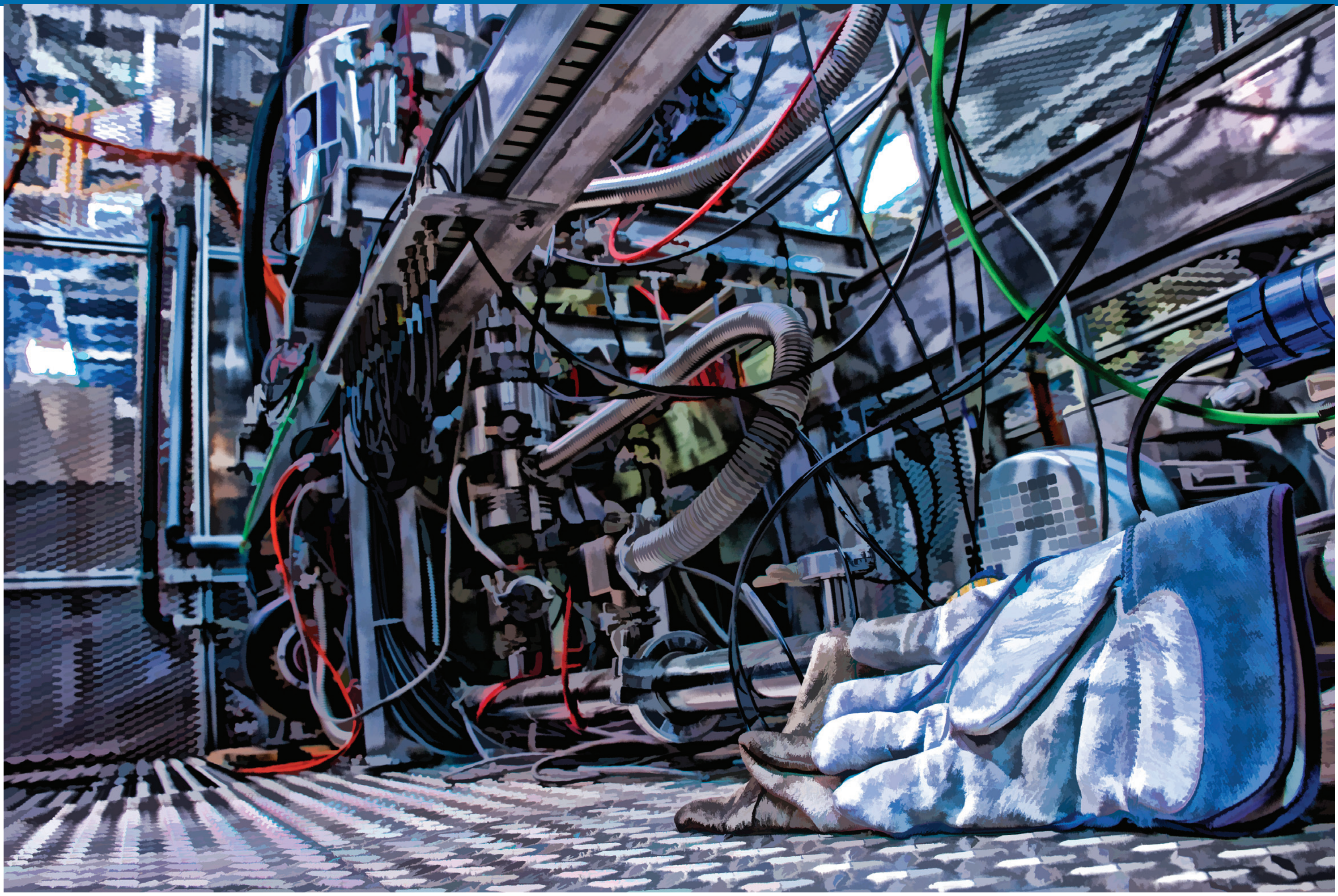


High School Researchers: High School students Carmen Wong (left) and Fellowship recipient Lily Zhang (right) posing in front of a control panel during their research experiences at TRIUMF in July 2012. Wyatt Gronemose and Kevin Multani (not shown) were other Fellowship students.

ATLAS Masterclass: Zoltan Gesce of the ATLAS-Canada Collaboration at UBC explains the finer points of particle physics to a group of local high school students during the 2012 Particle Physics Masterclass.

BC Teacher Pro-D Day: Teachers at the Fall Professional Development Day in late October 2012 listen attentively to Dr. Bernd Stelzer's plenary talk on the discovery of the Higgs Boson. About eighty teachers from across B.C. descended upon TRIUMF for their biennial workshop of lectures and hands-on activities.

Public Lecture at ScienceWorld: Professor Emeritus Gino Segre of the University of Pennsylvania delivers his lecture on 'Physics in Florence" to an attentive public crowd in the Science Theatre at the TELUS World of Science in Vancouver November 20, 2012. Segre's lecture was the second in the "Unveiling the Universe" series, an initiative co-sponsored by TRIUMF and Science World to bring 2–3 lectures per year from world renowned physicists to the local public.



TRIUMF's ßNMR Facility

Artist: Mikey Enriquez

This photograph of TRIUMF's ßNMR facility won 2nd prize locally during the 2010 Global Particle Physics Photowalk. The seemingly industrial landscape of the facility is softened here by a digital texturing technique.

More on the Global Physics Photowalk:
www.interactions.org/cms/?pid=6002