Project # 1

Project name	Advanced Rare Isotope Laboratory (ARIEL)
Collaborators	U. of Alberta, U. of British Columbia, U. of Calgary, Carleton U., U. of Guelph, U. Laval, U. of Manitoba, McGill U., McMaster U., U. de Montréal, U. of Northern British Columbia, Queen's U., U. of Regina, Saint Mary's U., U. de Sherbrooke, Simon Fraser U., U. of Toronto, U. of Victoria, Western U., U. of Winnipeg, York U.
Project description	The Advanced Rare Isotope Laboratory (ARIEL) will greatly expand the scientific capabilities of TRIUMF’s rare isotope program by providing more exotic isotope species with very high intensities. This will be achieved with two new production target stations producing rare isotope beams (RIBs) in parallel to the existing station at ISAC. Together, these three stations will enable the full exploitation of the numerous existing experimental facilities at ISAC, including those for medical isotope research, nuclear astrophysics, material studies, fundamental nuclear studies, and searches for new physics beyond the standard model. **ARIEL-I:** The first phase of the ARIEL project, ARIEL-I, consisted of the ARIEL building (which houses the target stations and associated infrastructure, such as hot cells and chemistry laboratories), the low energy beam-delivery infrastructure, the SRF electron linac (e-linac), as well as the tunnel from the driver accelerator building to the ARIEL targets. ARIEL-I was completed in 2014 and successfully demonstrated a 24MeV electron beam from the e-linac. Ultimately, the e-linac will deliver up to 30-35 MeV, 100kW cw electron beam as a driver for photo-fission of actinide targets and photoproduction on other targets to produce RIBs for nuclear physics, materials science, and life sciences research. The electron beam is generated in a 300 kV DC thermionic gun, bunched in a room temperature 1.3 GHz buncher cavity, and accelerated by three 1.3 GHz superconducting cavities. One of these cavities is housed in the injector cryomodule whose energy gain is 10MeV, and the others are housed in accelerator cryomodules with two cavities for an energy gain of 20 MeV. Future e-linac upgrades could include a second accelerator cryomodule (boosting the energy to 50-75 MeV) and a recirculation arc for either energy recovery (ERL) or energy doubling (RLA) operation. **CANREB:** The CFI-funded CANadian Rare-isotope facility with Electron Beam ion source (CANREB) project will construct critical RIB preparation and delivery infrastructure to facilitate the delivery of clean, high quality RIBs to a variety of experimental stations in the ISAC facility. CANREB consists of a high-resolution magnetic spectrometer (HRS), a radiofrequency quadrupole (RFQ) beam cooler and buncher, an Electron Beam Ion Source (EBIS) for charge breeding the rare isotope beam, and a Nier-type spectrometer. RIBs from ARIEL pass through the HRS, which separates out the nuclide of interest from isobaric contaminants. The selected beam is cooled and bunched in the RFQ beam cooler and buncher, after which it is sent to the EBIS for charge breeding. The charge-bred beam is filtered by charge state using the Nier spectrometer and sent to the ISAC facility for post-acceleration. Starting in 2019, the CANREB charge breeder, consisting of the RFQ cooler and buncher, EBIS, and Nier spectrometer, also will be used to charge breed RIBs produced in the ISAC target for acceleration in the ISAC heavy ion accelerator chain which is limited to accelerating ions with mass-to-charge ratio below 30. CANREB is effectively integrated with Phase 3 of the ARIEL-II project.

	ARIEL-II: The second major phase of the ARIEL project, ARIEL-II, will enable science delivery in several stages. The overall ARIEL-II program's goal is to triple TRIUMF's output of RIBs (from 3000 hours/year to 9000 hours/year) destined for the ISAC-I/II experimental facilities by building two new target stations - one driven by the new e-linac and one driven from a new beamline (BL4N) originating from the cyclotron. ARIEL-II's objectives are to build the target stations, driver beamlines, RIB lines, scientific instruments, hot cells, laboratories, safety systems and technical infrastructure needed to accomplish this goal. The ARIEL-II program is sequenced into four phases, each with a scientific deliverable, so that TRIUMF's users won't have to wait until the end of the full program to get scientific results. Phases 1, 2 and 4 are in the planning/concepting stage while Phase 3 is in the implementation stage. To level the workload, ARIEL-II is currently focusing on Phase 1 and 3. ▪ Phase 1: RIBs from the electron target station to ISAC's Beta-NMR experiment ▪ Phase 2: RIBs from photo-fission at the electron target station ▪ Phase 3: Beamlines to inter-connect the CANREB equipment ▪ Phase 4: RIBs from the proton target station to an ISAC experimental station As shown below, ARIEL-II is a program made of numerous subprojects. It is the ARIEL-II Project Management Office's (PMO's) role to coordinate the various projects within each phase. This includes management of the CANREB and Symbiotic Target Station projects. **Symbiotic Target Station:** The installation of a symbiotic target in the beam dump of the ARIEL proton target station will enable the production of medical isotopes such as ^{225}Ac for targeted radionuclide cancer therapy. The project includes the target infrastructure in the beam dump, a pneumatic transfer system from the target station to the hot cells, as well as a processing and packaging hot cell for the medical isotope targets. The Symbiotic Target Station is effectively integrated into Phase 4 of ARIEL-II.
Project value	▪ ARIEL-I: $63M materials (completed) ▪ ARIEL-II: $37.6M materials (for TRIUMF resources, see resource profile below) ▪ CANREB (part of ARIEL-II Phase 3): $4.2M materials ▪ Symbiotic Target Station (part of ARIEL-II Phase 4): $9.9M materials
Program team	The top-level WB structure of the ARIEL program complex is shown in the figure below. The program includes the ARIEL-II project with various WBS elements as well as CANREB and the Symbiotic Target Station project, is managed by the ARIEL Project Management Office. Overall Project Leadership lies with R. Kruecken and O. Kester. The PMO is led by the Project Engineer, E. Guetre. The e-linac commissioning and the e-linac beam dump project generally belong to the ARIEL program complex but are managed independently. Over 150 TRIUMF staff from across the whole laboratory are working on ARIEL with peak months requiring 70-80 FTE.

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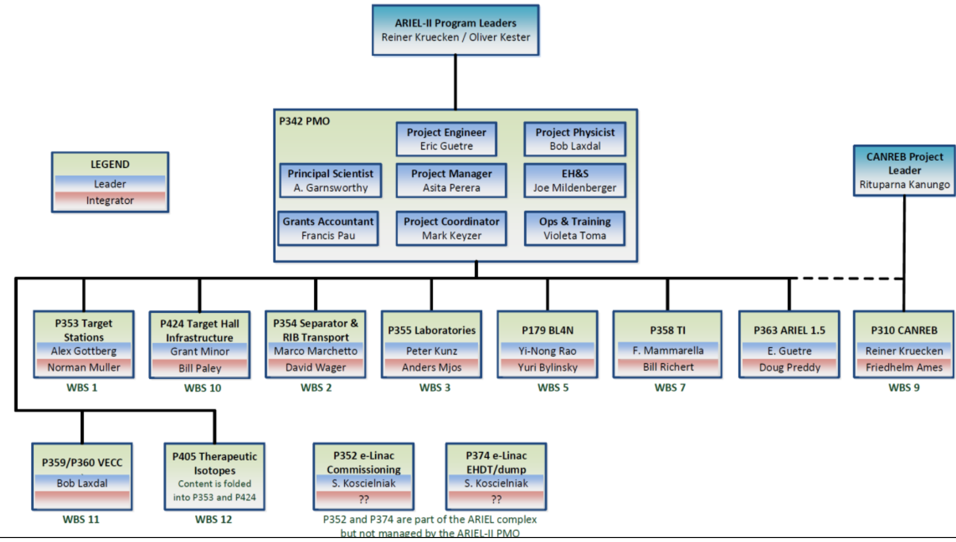
<tr><td></td><td>
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<tr><td>Project timeline</td><td>

ARIEL-I: 2010-2014
ARIEL-II: 2017-2023
CANREB: 2014-2019
Symbiotic Target Station: 2018-2023

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<tr><td>Other information</td><td>
Project oversight for TRIUMF's flagship project is provided by the ARIEL Scientific Steering Committee, comprised of international experts [D. Karlen (UVic), W. Fischer (BNL), J. Lettry (CERN), P. Manitca (FRIB), P. Ostroumov (FRIB), F. Pilat (ORNL)], which holds 2-day reviews every 6 months and reports to the TRIUMF Board.
ARIEL will capitalize on key opportunities:
Full multi-user capability:
With ARIEL, TRIUMF's rare isotope production will triple, with three independent RIBs taking the research program of our 18 world-class experiments to the next level. 9000 hours of rare isotope beams enable critical studies of nuclear reactions in stars and searches for new forces in nature that require extended hours of beam time.
Expanded isotope reach:
The new electron linac and advances in isotope target and ion source technologies will enable access to new isotopes currently out of reach of our existing Isotope Separation and Accelerator (ISAC) facility. This will enable the study of very short-lived isotopes critical for our understanding of the origin of the elements.
A beta-detected Nuclear Magnetic Resonance (bNMR) user program:
ARIEL will enable the growth of the materials characterization program using rare isotopes from a boutique technique to a world-leading user program that enables the development of new functional quantum materials, next generation batteries, and the understanding of biomolecules.
Symbiotic medical isotope production:
A symbiotic isotope production target behind an ARIEL science target will facilitate the development of critical medical isotopes for next generation targeted radionuclide therapies for metastatic cancers.
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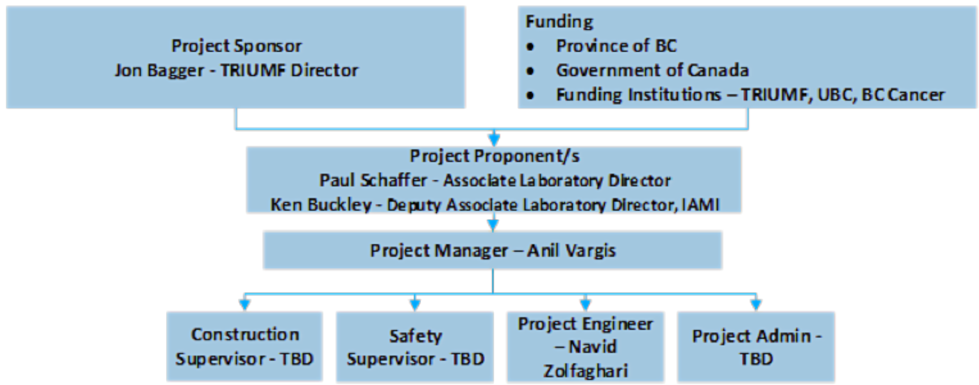
Project # 2

Project name	Institute for Advanced Medical Isotopes (IAMI)
Collaborators	TRIUMF, U. of British Columbia, BC Cancer
Project description	The Institute for Advanced Medical Isotopes (IAMI) will be a research hub and facility at TRIUMF built around a TR-24 cyclotron that will enhance TRIUMF's Life Sciences research and radiopharmaceutical production program, and ensure an ongoing, reliable, and secure isotope supply for British Columbia. By virtue of its location at TRIUMF, IAMI will be able to serve as a conduit for isotopes using TRIUMF's other accelerators; solidifying the province's status as a world leader in isotope-based life sciences research and radiopharmaceutical development. IAMI is primed to produce and develop isotopes with applications to both life-saving treatments and research into some of the most compelling questions in life sciences and medicine. IAMI will foster innovation in a wide range of fields, including radiopharmaceutical development, accelerator research, and advanced isotope development. The IAMI facility will be a 2,500 m^2 (~25,000 ft^2), 5-level building housing a TR24 cyclotron, 6 radiopharmaceutical labs, a non-radioactive chemistry lab, quality control labs, support space, and office space. The radiopharmaceutical labs can be configured as either a Good Manufacturing Practice-compliant space, or not, depending on the demand for each type of space. IAMI will host a multifaceted research, development, and commercialization community based at TRIUMF. It will have five program thrusts: **1.** *Isotope Security:* ^{99m}Tc production for the province of BC (up to 86,000 doses annually) and ^{18}F production to support the BC Cancer clinical imaging program (up to 5,000 doses annually), **2.** *Radiotracer Development:* Support of internal and third-party requests including the use of isotopes as a drug development tool, **3.** *Cancer Therapy:* Processing of theranostic and therapeutic agents produced at TRIUMF, **4.** *Clinical Imaging:* ^{18}F & ^{11}C tracer production to support the brain imaging program at the UBC-based David Mowafaghian Centre for Brain Health (DMCBH) (up to 5 times per day), and **5.** *Radiopharmaceutical Development:* Development of partnerships with industry to establish BC-based operations for clinical trials of radiopharmaceuticals for diagnosing and managing Alzheimer's disease, dementia, prostate cancer, etc.
Project value	▪ TR24: $6.1M ▪ IAMI building: $31.8M
Project team	The project organization is shown below. The first stage of the project is facility construction. The project sponsor is J. Bagger, TRIUMF Director. The project leaders are Paul Schaffer and Ken Buckley. The project manager is Anil Vargis, assisted by the project engineer Navid Zolfaghari. As the project progresses towards construction of the building, additional team members will be added in the roles of Construction Supervisor, Safety Supervisor, and Project Administrator. This team consults regularly with the Life Sciences division

	members to ensure user requirements are met. An architectural firm is currently onboard for the design and preparation of construction documents. TRIUMF Innovations is liaising with potential interested commercial parties. The lead researcher of IAMI is Paul Schaffer. In the design phase, approximately 20 staff and researchers are assisting with the design requirements for the facility. Once in full operation, IAMI will employ just over 50 staff and will train at least 75 HQP over the first five years. 
Project timeline	Significant Milestones: Completed: ▪ A schematic design for the IAMI facility was completed in 2016. ▪ The TR-24 cyclotron was purchased from Advanced Cyclotron Systems Incorporated and delivered to TRIUMF in March 2017. ▪ Provincial funding for IAMI was obtained in 2017, Federal funding in 2018. Pending: ▪ Site Preparation complete Jan 2019 ▪ Design complete Mar 2019 ▪ Construction start June 2019 ▪ Substantial Completion Mar 2020 ▪ Commissioning complete Oct 2020
Other information	IAMI will capitalize on five key opportunities: **Securing isotope supplies:** IAMI promises to secure a supply of several important medical isotopes, including critical imaging isotopes such as ^{99m}Tc and ^{18}F, for the local health care system, and thereby positioning Canadian technology as a player in global markets. **Accelerating global drug development:** Some early-stage drug development trials rely on highly sought-after isotope-based radiotracers to gauge drug efficacy. IAMI will provide a unique infrastructure for radiotracer production, positioning Canada as a key player in this space. **Developing next-generation cancer therapies:** By developing targeted radionuclide therapies for metastatic cancers, IAMI researchers will contribute to improving health outcomes for Canadians, place Canada at the center of this

	promising, fast-growing field, and allow Canadian access to radionuclide therapy markets. **Improving health outcomes for patients:** IAMI will supply additional isotopes to the TRIUMF-UBC neuroimaging program at the Djavad Mowafaghian Centre for Brain Health and bring the power of personalized medicine to more patients who suffer from addiction, dementia, and other mental health issues. It will also boost the supply and diversity of important positron-emission tomography (PET) isotopes for BC Cancer patients, enabling thousands of PET scans annually at UBC and BC Cancer sites. **Attracting industry partnerships and investment to Canada:** IAMI will provide certified infrastructure for isotope production, enabling the development of new diagnostic and therapeutic substances by industry partners. The Institute will also establish a powerful training platform — at the interface between science and business — for young researchers.

Project # 3

Project name	ATLAS detector upgrades and Tier-1 Data Centre
Collaborator	ATLAS Canada (direct contributors, co-applicants): D. Gingrich, J. Pinfold (Alberta), A. Bellerive, D. Gillberg, J. Heilman, T. Koffas, G. Oakham, M. Vincter (Carleton), F. Corriveau, S. Robertson, B. Vachon, A. Warburton (McGill), J-F. Arguin, G. Azuelos, J-P. Martin, C. Leroy (Montreal), D. O'Neil, B. Stelzer, M. Vetterli (SFU), P. Krieger, R. Orr, P. Savard, P. Sinervo, R. Teuscher, W. Trischuk (Toronto), N. Hessey, O. Stelzer-Chilton, R. Tafirout, I. Trigger (TRIUMF), D. Axen, C. Gay, A. Lister (UBC), J. Albert, R. Keeler, R. Kowalewski, M. Lefebvre, R. McPherson, R. Sobie (Victoria), W. Taylor (York)
Project description	**Phase-I upgrades:** TRIUMF is active in two Phase-I upgrade projects to be installed during the second Long Shutdown, planned for 2019-2020: ▪ The LAr calorimeter upgrade increases the granularity of signals sent to the L1 trigger. TRIUMF and U. of Victoria designed, prototyped, and are building a new front-end-crate base-plane and trigger digitizer board for the Canadian-built Hadronic EndCap Calorimeter. Pre-production, acceptance tests and characterization of base-planes have been successfully carried out. Full production has started, and quality assurance tests will be performed jointly at the two sites. ▪ The New Small Wheel (NSW) will allow ATLAS to keep the forward muon trigger momentum threshold low enough for electroweak signatures. TRIUMF and five Canadian Universities (Carleton, McGill, Montreal, SFU, Victoria) are building small-strip Thin Gap Chambers (sTGC) which will allow fast and precise online triggering. Canada is building one quarter of the chambers. TRIUMF is responsible for coating the very large cathodes with a resistive graphite-resin mixture, and for precision assembly of sTGC chamber half-gaps; one third of these have already been completed. TRIUMF personnel carry out quality control for the full international collaboration at the main cathode board supplier at Triangle Labs in Nevada. Several sTGC quadruplet assemblies have been completed by Carleton and shipped to McGill for cosmic ray testing and to CERN for tests with beam and assembly into wedges. In parallel, detector assembly into detector wedges has started at CERN. **Phase-II upgrades:** TRIUMF is taking part in the Phase-II LAr electronics and Inner Tracker (ITk) upgrade projects to be installed during the third long shutdown (2024-26). During the HL-LHC running, the LHC will reach instantaneous luminosities 5-7 times the original design value. ▪ New radiation-hard, low-power, and high-density front-end electronics are required for the LAr detectors. The design challenges are to digitize the data as early as possible and deliver the information to the new readout and trigger processors. TRIUMF, in collaboration with three Canadian Universities (Victoria, Toronto and McGill), contributes to the development and construction of new front-end boards and ASIC. ▪ For the HL-LHC, the current ATLAS inner tracking detector will be completely replaced with an all-silicon based detector. The new ITk tracker will include both pixel and strip layers. Canada will build 1500 of the 7000 strip modules

	required for the ITk endcap at three production sites: two in Vancouver (TRIUMF, SFU) and one in Toronto. Each of these three sites will produce about 500 modules. The ITk silicon sensor and module testing is a joint responsibility of six Canadian Universities (Carleton, Toronto, Montreal, York, SFU, UBC) and TRIUMF. During the final step of the Canadian production, the modules will be placed on carbon support structures, called petals, at TRIUMF. All of the essential infrastructure has been acquired and a high precision gantry has been commissioned to glue readout chips on module hybrids. Work is ongoing to fully automate the placement of modules on petal support structures. **ATLAS Tier-1:** TRIUMF is operating Canada's Tier-1 LHC data centre for the ATLAS experiment. It is a large-scale data-intensive facility operated 24x7 in accordance with the MOU with CERN. It provides dedicated resources for the storage of the raw and secondary datasets, and compute capacity for data processing, simulations, and physics groups analysis activities in a secure environment. During the last decade, the centre has been physically located at TRIUMF. In 2018, the services, compute and storage capacities were being been shifted to the new Compute Canada data centre located at SFU. TRIUMF personnel will continue to be responsible for its operations.
Project value	▪ ATLAS Phase 1 upgrades: $7.2M ▪ ATLAS Phase 2 upgrades: $30.3M ▪ ATLAS Tier-1 Data Centre: $28.1M
Project team	▪ Tier-1: M. Vetterli (SFU/TRIUMF), R. Tafirout (lead), 8 (technical) ▪ LAr: R. Keeler (Victoria), L. Kurchaninov, B. Vachon (McGill) (lead), 1 (scientific), 3 (technical) ▪ ITK (Vancouver/Western Site): B. Stelzer (SFU), N. Hessey (lead), 3 (scientific), 7 (technical) ▪ ITK (Toronto/Eastern Site): R. Teuscher (IPP/Toronto), T. Koffas (Carleton) (lead), 3 (scientific), 6 (technical) ▪ NSW (TRIUMF): O. Stelzer-Chilton, I. Trigger (lead), 2 (scientific), 6 (technical) ▪ NSW (Carleton): J. Heilman (Carleton), A. Bellerive (Carleton) (lead), 2 (scientific), 8 (technical) ▪ NSW (McGill): B. Vachon (McGill) (lead), 1 (scientific), 1 (technical) ▪ NSW ATLAS sTGC Project lead: R. McPherson (IPP/Victoria) ▪ Tier-1 CFI lead M. Vetterli (SFU/TRIUMF) ▪ Phase I CFI lead G. Oakham (Carleton/TRIUMF) ▪ Phase 2 CFI lead P. Krieger (Toronto)
Project timeline	▪ ATLAS Phase 1 upgrades: 2013-2021 ▪ ATLAS Phase 2 upgrades: 2016-2026 ▪ ATLAS Tier-1 Data Centre: 2007-2021 (with further upgrades until 2035)
Other information	The LHC will complete its 4-year 13-TeV physics run (“run 2”) in late 2018. As of July 2018, the LHC has delivered over 150/fb of data to the ATLAS experiment. ATLAS has now published over 740 papers based on collision data. P. Savard (TRIUMF/Toronto) serves as the elected ATLAS Physics Coordinator from October 2018. The TRIUMF group is actively involved in a number of flagship analyses in ATLAS which include the characterization of the Higgs boson and searches for New Physics.

Project # 4

Project name	Ultracold Neutron Facility (UCN) – TUCAN collaboration
Collaborator	C. Bidinosti, B. Jamieson, R. Mammei, J. Martin (co-spokesperson) (Winnipeg), J. Birchall, M. Gericke, J. Mammei (Manitoba), E. Korkmaz (UNBC), K. Madison, T. Momose (UBC), C. Davis, B. Franke, P. Giampa, A. Konaka, F. Kuchler, T. Lindner, L. Lee, R. Matsumiya, R. Picker, E. Pierre, W. Ramsay, W. Schreyer, Wi. Van Oers (TRIUMF), S. Kawasaki, Y. Makida, K. Mishima, T. Okamura, Y. Watanabe (KEK), T. Kikawa (Kyoto University), M. Kitaguchi, H. Shimizu (Nagoya University), K. Hatanaka (co-spokesperson), H. Ong, I. Tanihata (RCNP, Osaka),
Project description	The TUCAN collaboration aims to build a world-leading ultracold neutron (UCN) facility and to commission an experiment capable of detecting a neutron electric dipole moment (EDM) of magnitude 10^{-27} e-cm or less within 400 beam-on days. A second experimental port shall also be available to create a user facility for other fundamental neutron physics experiments.
Project value	▪ Ultracold Neutron facility: \$10.9M ▪ Ultracold Neutron Electric Dipole Moment Experiment: \$15.7M
Project team	Principal Investigator: Jeffery Martin - Project Leader (TRIUMF): Ruediger Picker - Project Leader (KEK): Shinsuke Kawasaki - Project Manager: Chris Gibson - Technical Coordinator: Beatrice Franke - Project Engineer: Cam Marshall - Experimental Safety Coordinator: Chuck Davis The total number of scientific and technical staff involved, including collaborators, is 42, including 13 from TRIUMF.
Project timeline	▪ Ultracold Neutron facility: 2011-2018 ▪ Ultracold Neutron Electric Dipole Moment Experiment: 2018-2023
Other information	▪ Expected new knowledge gained: detection of a neutron electric dipole moment would be a historic achievement and could contribute to solving the matter-anti-matter asymmetry puzzle of the Universe ▪ Expected publications: several instrument and development papers (beamline, cold neutrons, UCN source, EDM experiment), high-impact physics result papers on EDM preliminary and final results ▪ Additional capacity: A Very-Cold-Neutron beamline will also be built for researchers interested in performing experiments on VCNs

Project # 5

Project name	ALPHA-g
Collaborator	ALPHA-Canada: R. Thompson (Calgary), M. Hayden (SFU), M. Fujiwara, D.Gill, A. Olin, (TRIUMF), W. Hardy, T. Momose (UBC), S. Menary (York)
Project description	Project ALPHA (Antihydrogen Laser Physics Apparatus) is an international collaboration, based at CERN. The goal of the ALPHA-g experiment is first to observe the free fall of antihydrogen in the gravitational field of the Earth, and then to study the process precisely to see if there is any difference in the gravitational behaviour of matter and antimatter. The heart of the ALPHA-g system is a cryogenic and ultra-high vacuum vertical trapping volume, roughly two metres long, in which experiments would be performed. This is equipped with Penning trap electrodes (to manipulate positrons and antiprotons, and create anti-H atoms), optics (for laser cooling anti-H atoms, creating an "atomic fountain", and for development towards anti-atomic interferometry), and microwave resonators (for hyperfine spectroscopy experiments and state manipulation). TRIUMF is responsible for several key components: a radial Time Projection Chamber (rTPC) to track pion tracks from antiproton annihilation with a vertical position resolution of several mm; Barrel Scintillators (BS) to veto cosmic rays; and ancillary systems such as external scintillators. Both the rTPC and the BS have been delivered to CERN in August 2018, and are currently being tested at CERN.
Project value	$20.4M
Project team	TRIUMF Lead researcher: Makoto Fujiwara. TRIUMF Project Manager: Pierre Amaudruz; No. of Scientists & Faculty: 5; Technical staff: ~10; Postdocs/RA: ~6; Grad & undergrad students: ~5
Project timeline	2016-2020
Other information	The ALPHA-g trap is the antimatter equivalent of Newton's apple tree. Successful observation of the initial antihydrogen free fall, and subsequent precision measurements, would have a historic significance, since no one has directly observed antimatter falling. Canadians make up more than 1/3 of the ALPHA collaboration, which is made of over 40 scientists from 14 institutions in 8 countries.

Project # 6

Project name	GRIFFIN
Collaborator	C. Svensson, P. Garrett (Guelph), A. Chen (McMaster), J. Leslie, C. Andreoiu, K. Starosta (SFU), G. Ball, D. Bishop B. Davids, I. Dillmann, A. Garnsworthy, G. Hackman, R. Kruecken, C. Pearson (TRIUMF)
Project description	Design, construct, commission and operate a state-of-the-art new high-purity germanium (HPGe) gamma-ray spectrometer for decay spectroscopy research with low-energy radioactive ion beams.
Project value	▪ GRIFFIN: $8.98M ▪ GRIFFIN shields: $1.42M
Project team	C. Svensson (Principal Investigator); A. Garnsworthy (Director of GRIFFIN activities and Project Coordinator). Around 20 TRUMF personnel contributed time to GRIFFIN. The GRIFFIN collaboration includes over 100 researchers from 10 countries.
Project timeline	▪ GRIFFIN, 2011-2015. ▪ GRIFFIN shields, 2016-2018.
Other information	▪ The project was completed on time and on budget. ▪ GRIFFIN is the most powerful HPGe array dedicated to decay spectroscopy studies worldwide. The gamma-gamma coincidence efficiency is a factor 300 higher than for the 8pi spectrometer that GRIFFIN replaces. ▪ Over 60 rare-isotope beam species have been delivered to GRIFFIN from ISAC and the data is now undergoing data analysis within the collaboration. ▪ The spectrometer supports a diverse research program in the areas of nuclear structure, nuclear astrophysics and fundamental symmetries.

Project # 7

Project name	M9H upgrade
Collaborators	J. Brewer, D. Fleming, R. Kiefl, A. MacFarlane (UBC), K. Ghandi (Guelph), G. Luke (McMaster), A. Bianchi (U. Montreal), J. Sonier (PI), P. Percival (SFU), J. Quilliam (U. Sherbrooke), J. Sugiyama (Toyota CRDL Inc.), T. Uemura (Columbia), S. Dunsinger, K. Kojima, S. Kreitzman, I. McKenzie (TRIUMF)
Project description	The muon beam facilities of TRIUMF will be expanded by the addition of a high momentum muon decay channel, M9H (formerly known as M9B), and a service-oriented surface muon channel, M9A. There are three separate but highly integrated parts: ▪ Repair of the M9/T2 vacuum seal, in alignment with TRIUMF's commitment for its 5 Year Plan 2015-2020. ▪ Completion of the surface muon channel M9A and installation of a fixed 3 T µSR spectrometer. ▪ Redevelopment of M9B into a new high momentum muon channel M9H, with associated cryogenic facilities for the superconducting decay section and specialized end station spectrometer infrastructure to maximize high impact research. This new infrastructure will uniquely provide a significant physical parameter space (high pressures + ultra-low temperature + high magnetic fields on M9H) and highly versatile (low temperatures + high fields + Muons-on-Request on M9A) facility with a focus on highly efficient sample characterization for the increasingly important and broad non-expert (in µSR) user community.
Project value	$10.7 M
Project team	S. Kreitzman (Project Leader); Ch. Gibson (Interim Project Manager); Dedicated CMMS facility staff inclusive of six Scientists (D. Arseneau, S. Dunsiger, B. Hitti, K. Kojima, I. McKenzie, G. Morris) and three technicians (R. Abasalti, M. McLay, D. Vyas); Supporting TRIUMF professional staff (engineering / 75 months, technical / 40 months); Major User Community Collaborators (above)
Project timeline	▪ M9/T2 fix: 2017-2019 ▪ M9A operations: 2020 ▪ M9H: design & construction 2018-2022: operations 2023
Other information	This project will provide Canadian and international users of the CMMS µSR facility with unmatched capabilities for the study of quantum systems under normal and extreme conditions. Quantum mechanics is fundamental to materials being developed for transformational technologies. It is also central to physical chemistry, underlying the electronic structure of atoms and molecules and the dynamics of chemical reactions. Specifically, applied science applications related to energy storage, green chemistry and the support of next-generation supercritical water-cooled nuclear reactors are all encompassed by project's research scope. The planned infrastructure provides the necessary tools to contribute to strategic quantum, energy and environmental research priorities in Canada, to nurture innovation partnerships, and to build on the CMMS's proven success developing innovative µSR methods for leading-edge fundamental and applied research.

Project # 8

Project name	EMMA
Collaborator	D. Muecher (Guelph), A. Chen (McMaster), C. Andreoiu, K. Starosta (SFU), M. Alcorta, B. Davids (PI), I. Dillmann, A. Garnsworthy, G. Hackman, D. Hutcheon, R. Kruecken, C. Ruiz (TRIUMF), C. Diget (U. York, UK), A. Laird (U. Edinburgh, UK)
Project description	EMMA, the Electromagnetic Mass Analyser, is a recoil mass spectrometer undergoing the final stages of commissioning for use at the ISAC-II facility at TRIUMF. It simultaneously provides high first-order mass resolving power (500) and large angular (17 msr), mass/charge (±4%), and kinetic energy (±20%) acceptances. These characteristics make it very well suited to the study of nuclear structure and nuclear astrophysics using nuclear reactions induced by the heavy radioactive ion beams available at energies up to and above the Coulomb barrier at ISAC-II. The high efficiency recoil detection and identification capability of EMMA enables unique experiments in nuclear astrophysics and nuclear structure in conjunction with the gamma ray spectrometer TIGRESS, its integrated plunger TIP, and the charged particle detector array SHARC.
Project value	$3.1M
Project team	The principal investigator Barry Davids works closely with 3 graduate students and postdocs, an expert technician, and TRIUMF's ISAC gas target and detector physicist to operate and maintain the spectrometer.
Project timeline	The spectrometer has been built, tested, and characterized; commissioning will be completed in 2018 when the first electrostatic deflector is conditioned to the high voltages already reached by the second.
Other information	The spectrometer has proven its capability to separate and identify the products of nuclear fusion reactions induced by radioactive ion beams at Coulomb barrier energies. Technical publications have been written, submitted, and published. First scientific results are anticipated next year.

Project # 9

Project name	High Luminosity LHC
Collaborator	R. Baartman, D. Kaltchev, O. Kester, R. Laxdal (PI) (TRIUMF), G. Arduini, O. Capatina, L. Rossi (CERN) – for the HL-LHC collaboration
Project description	TRIUMF will deliver five cryomodules, each containing two SRF crab cavities, as a Canadian contribution to the high luminosity upgrade of the LHC (HL-LHC). The cavities will be supplied by CERN. The cryomodule design and assembly is led by TRIUMF with significant interaction with Canadian industry. TRIUMF is also contributing to LHC and HL-LHC beam performance development with emphasis on evaluating numerically the dynamic aperture under the influence of beam-beam effects for a variety of setups.
Project value	▪ Crab cavity cryomodules: $12M ▪ Beam physics: $500k
Project team	Lead researcher for cryomodule: Robert Laxdal. The project will be carried out by TRIUMF's SRF team (4 professionals and 4 technicians) with support from mechanical engineering and the cryogenics group. Lead researchers for beam physics: Dobrin Kaltchev and Rick Baartman
Project timeline	The projects stretch from the beginning of 2017 through to Dec. 2024. The first crab cavity cryomodule would be completed in mid 2022 with two per year in 2023 and 2024. Beam physics investigations are ongoing and extend to UFO related beam losses in LHC.
Other information	SRF/RF and cryomodules are cutting edge accelerator technology, essential to particle & nuclear physics, materials science and health. Canada, through the TRIUMF SRF group, is uniquely positioned to provide the cryomodule to the HL-LHC project. The engagement in a major international project ensures Canadian leadership in this field and ensures training of young personnel. The technologies have impacts across many areas of society, such as material industries, precision machining, electron beam welding, and cleanroom techniques. Developing Canadian industry in cryomodule fabrication will elevate and enhance its role in this competitive international area. Beam physics understanding is crucial for modern high-performance accelerators, as well as for beam transport and manipulation systems. As new particle accelerators operate in new regimes of beam current, beam power and beam energy, a detailed understanding of the interaction of the charges in intense beams with the environment in the machine and with other beam bunches, is mandatory for a safe beam operation. Investigations in this area will enable more powerful accelerators for industrial applications and fundamental research.