Plans and vision for Accelerator Science and Technology at TRIUMF

Oliver Kester

Associate Laboratory Director – Accelerator Division

TARA Annual General Reunion

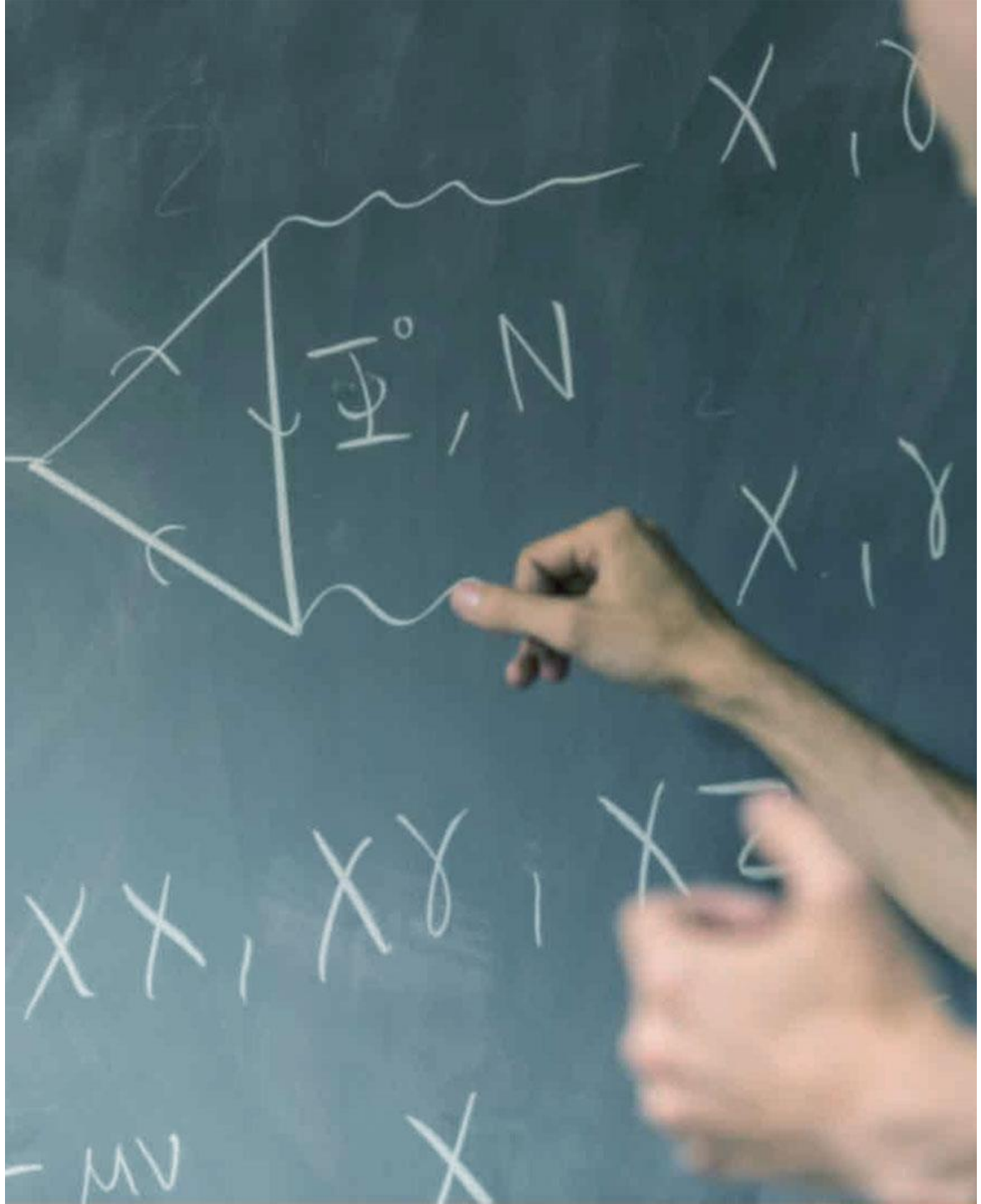
November 9, 2021

Outline:

- Accelerator Science and technology in Canada
- ACC developments and projects at TRIUMF
- Projects driven by our user communities
- The future of ACC science at TRIUMF – 20-year vision

TRIUMF

Accelerator Science in Canada



Discovery, accelerated

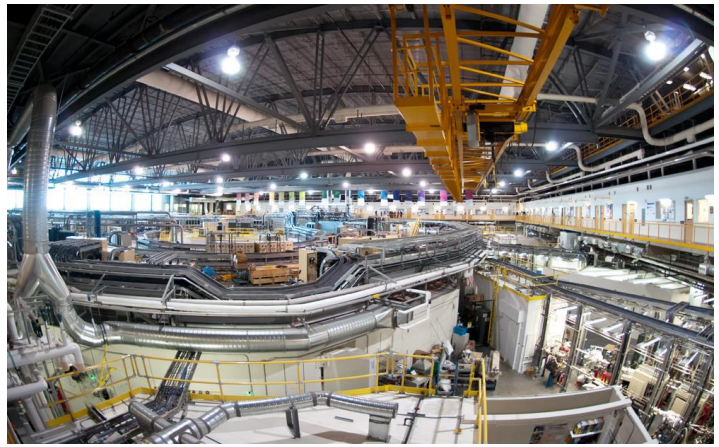
Accelerator Science

- Accelerator Science is a dynamic discipline on its own while providing highly powerful tools for discovery, innovation and societal benefit in many other fields.
- Accelerator Science is the key to maintain continuously evolving cutting-edge accelerator facilities like the TRIUMF accelerator complex.
  It is driven by the demand on particle beams pushing an expanding performance envelope (energy, intensity and brightness)
- Although the laws of physics that governs the motion of charged particles are well know, the beam dynamics (especially collective effects) is surprisingly complex and still a topic of research.
  In-depth theoretical and experimental understanding of the behavior of charged particle beams is key to the performance increase.
- The field trains a wide diversity of highly qualified people who disseminate competencies and culture, across Canada and beyond.
  The demand for accelerator scientists is high and increasing

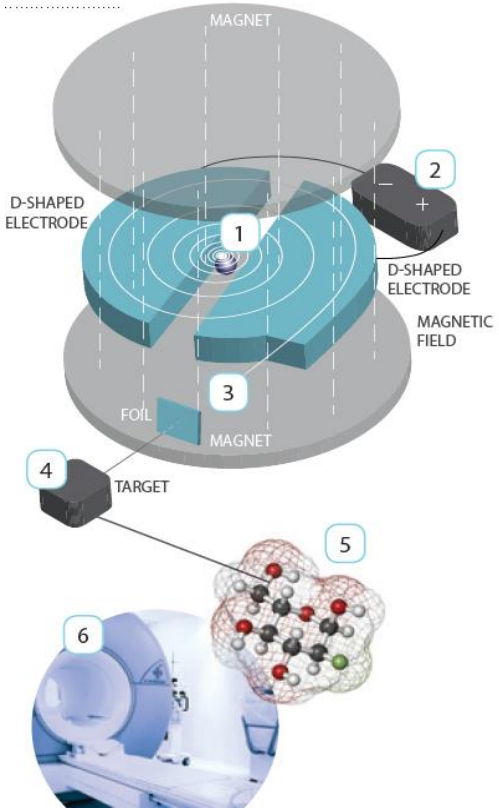
Accelerator Science at TRIUMF

- Accelerator science at TRIUMF provides Canada with a world-class platform in
  - beam physics and instrumentation
  - secondary particle production, and
  - SRF technologies.
- Accelerator science supports the high performance and availability of TRIUMF's accelerator complex, including new facilities such as ARIEL
  and international projects such as HL-LHC.

Accelerator facilities in Canada



- The Canadian Light Source (CLS) – Canada's only synchrotron light source facility!
- TRIUMF - Canada's particle accelerator centre - with over 50 years of experience in building particle accelerators
  Serving SAP, material sciences, life sciences, quantum technologies and applications
- Fedoruk Centre - The Saskatchewan Centre for Cyclotron Sciences.
  Supplies radioisotopes for use in the PET-CT scanner and research for instance of plant growth studies.
- The McMaster Accelerator Laboratory (MAL) with electrostatic accelerators (tandem and van de Graaf) and the McMaster University Cyclotron Facility
- The AEL AMS laboratory of the University of Ottawa (3 MV tandem)

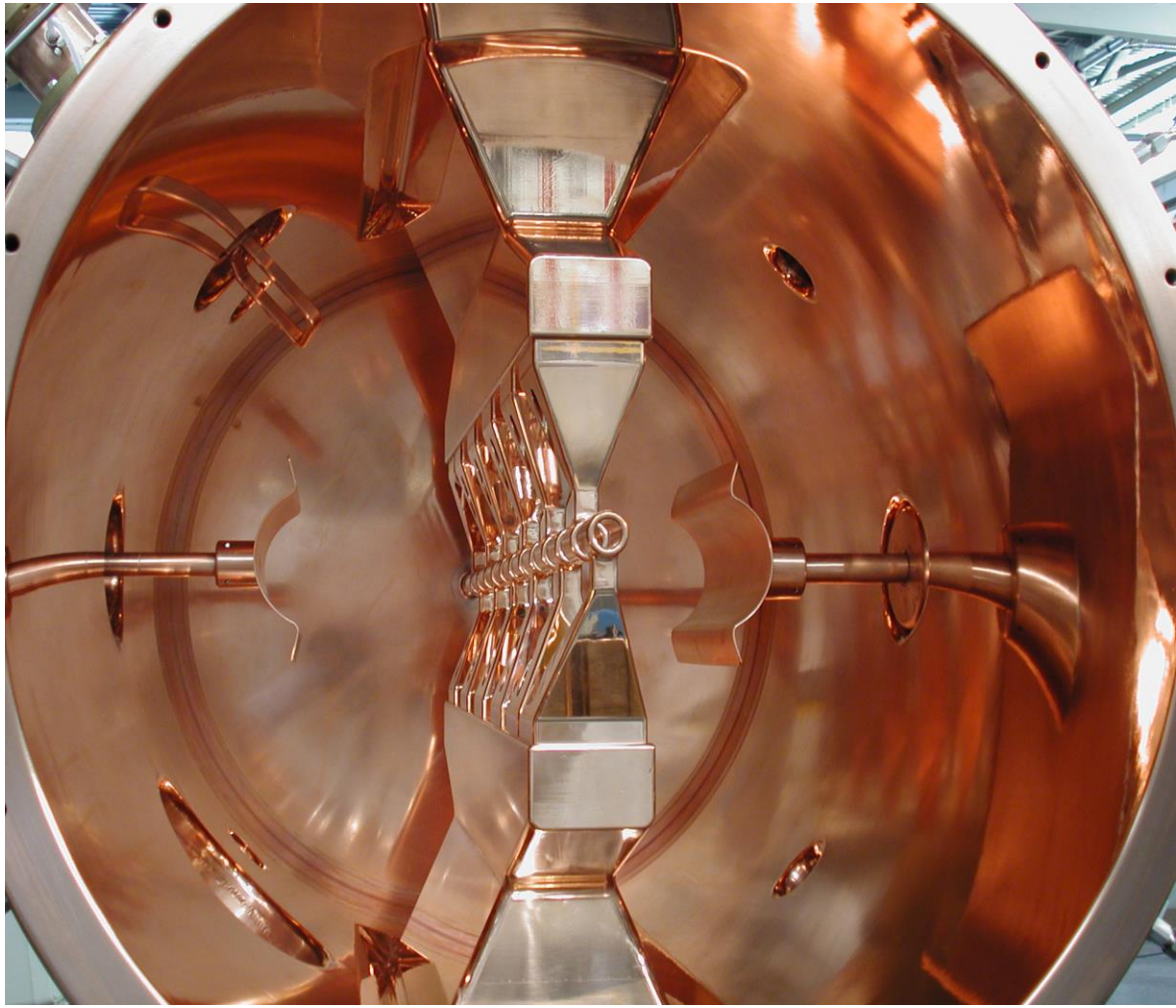


Accelerator science education in Canada

- Canada needs highly qualified personnel trained in Accelerator Sciences.
- UVic and UofS have one faculty position in accelerator physics each. Five members of the TRIUMF accelerator division have adjunct professor status at UVic.
- TRIUMF has also adjunct faculties in accelerator science at Saint Mary's University, SFU, University of Manitoba and Western University.
- Two particle physics faculties from UVic are also involved in accelerator research and education.
- The number of student research projects in Accelerator Sciences in Canada is growing but is not sufficient to provide the required qualified resources to research and industry.

TRIUMF

Accelerator developments and projects at TRIUMF



ACC projects in the 5-year plan $25M complement

520 MeV facility related

- P481 - Renewal of the horizontal part of the cyclotron injection beam line [Gate 1]
- P495 - Cyclotron systems refurbishment (Mainly vacuum, and P372 – New injector I2) [Gate 2]
- P492 - Cyclotron RF refurbishment [Gate 2]
- P491 - BL1A power supplies replacement [Gate 3]
- O519 - BL1A refurbishment project – prototyping of diagnostics

ISAC refurbishment related

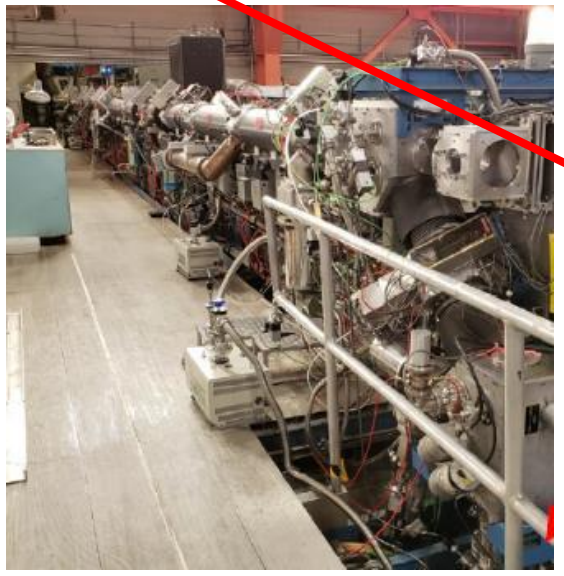
- P496 - ISAC target hall consolidation, including target module (TM) refurbishment [Gate 1]
  part of it is P416 - TM3 refurbishment, which is nearing completion [Gate 3]
- P494 - TRILIS upgrade (laser ion sources) [Gate 3]
- P493 - ISAC RF systems [Gate 3]
- P497 - RIB beam delivery improvements [Gate 0]

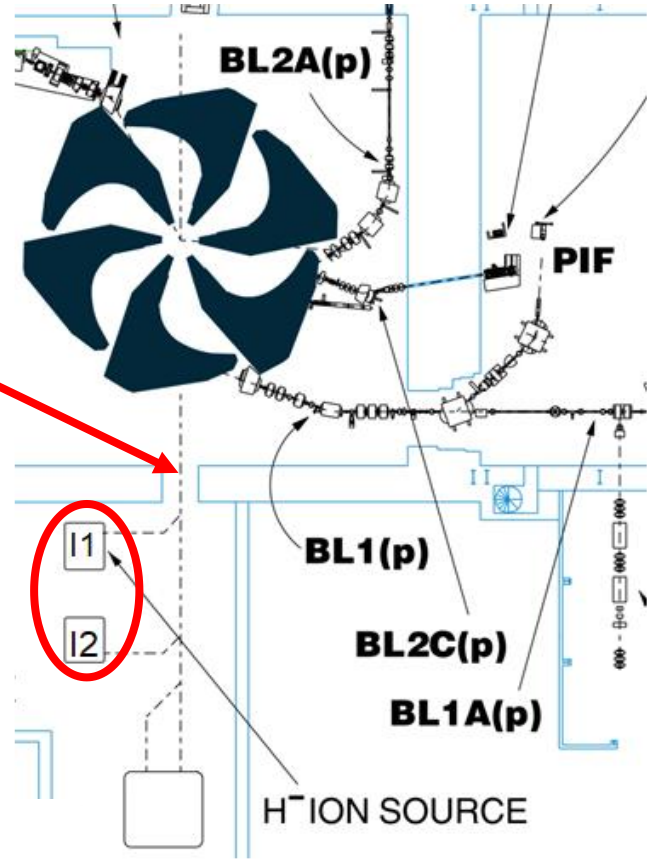
Infrastructure projects

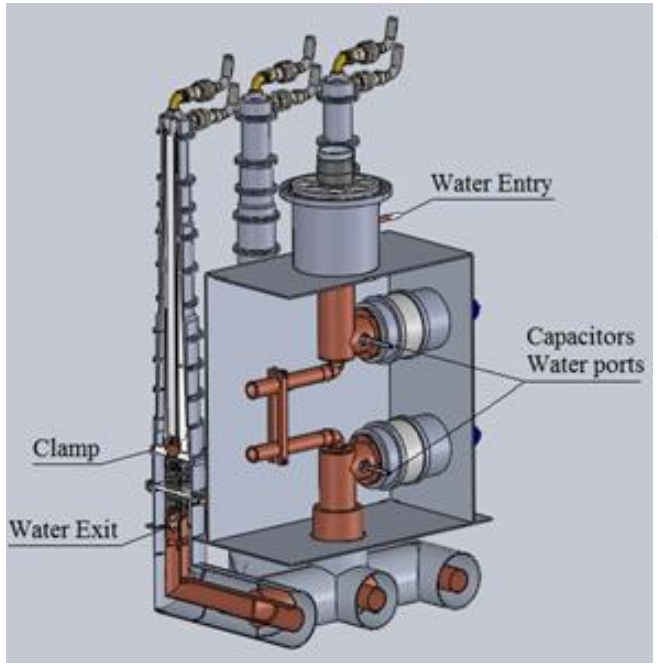
- P356 - TRIUMF Control Center (TCC) [Gate 1]
- O502 - Remote Handling infrastructure

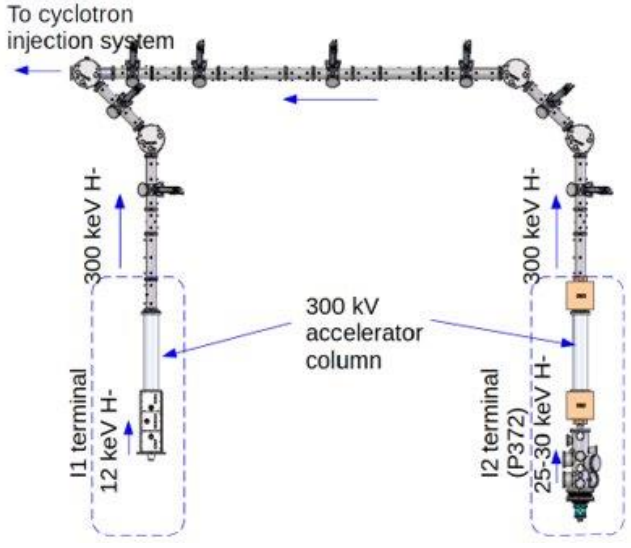
520 MeV facility related

- P481 - Renewal of the horizontal part of the cyclotron injection beam line
- P495 - Cyclotron systems refurbishment
  Cryo systems for cyclotron vacuum, new injector I2 (P372) and CCS upgrades to EPICs
- P492 - Cyclotron RF refurbishment
  - New tubes and tube test stand test stand for tube conditioning
  - New 0.8 MW dummy load for power amplifiers (250 kW each)
  - LLRF upgrade







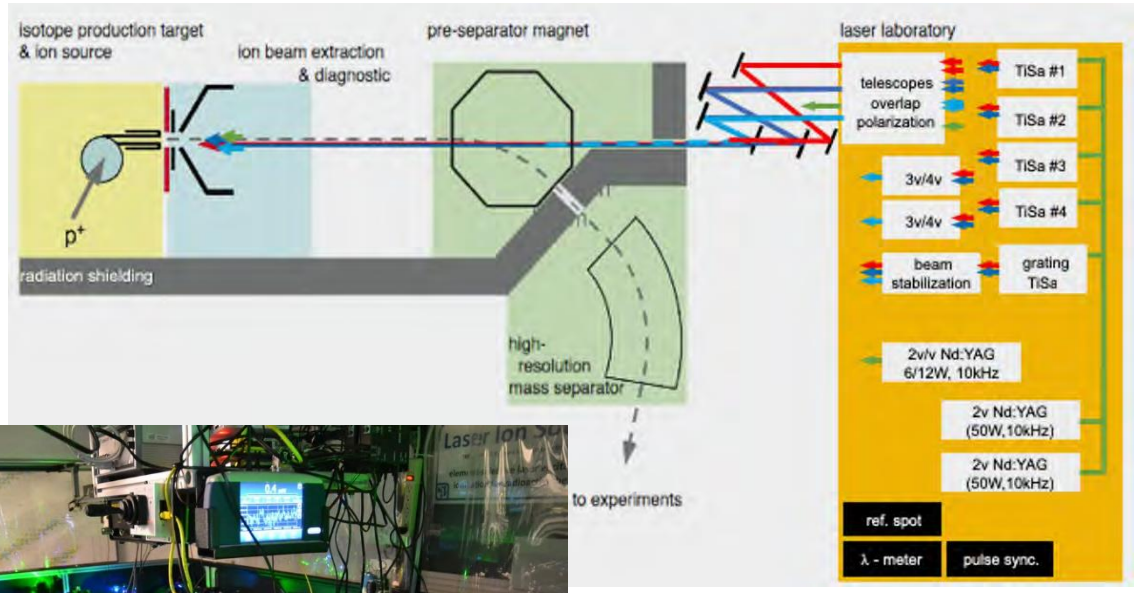


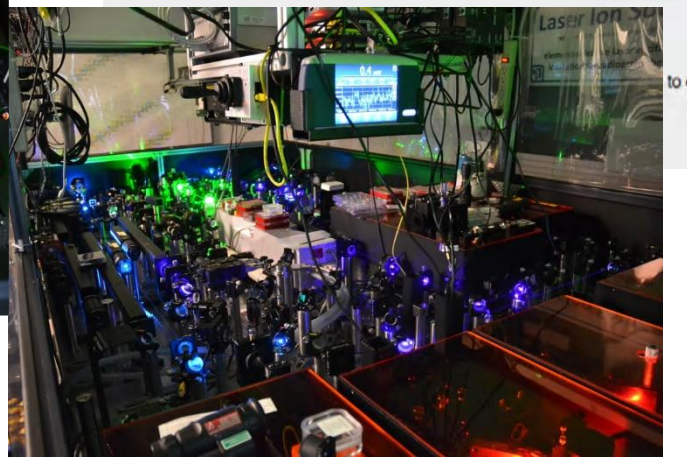
P372 - New injector I2

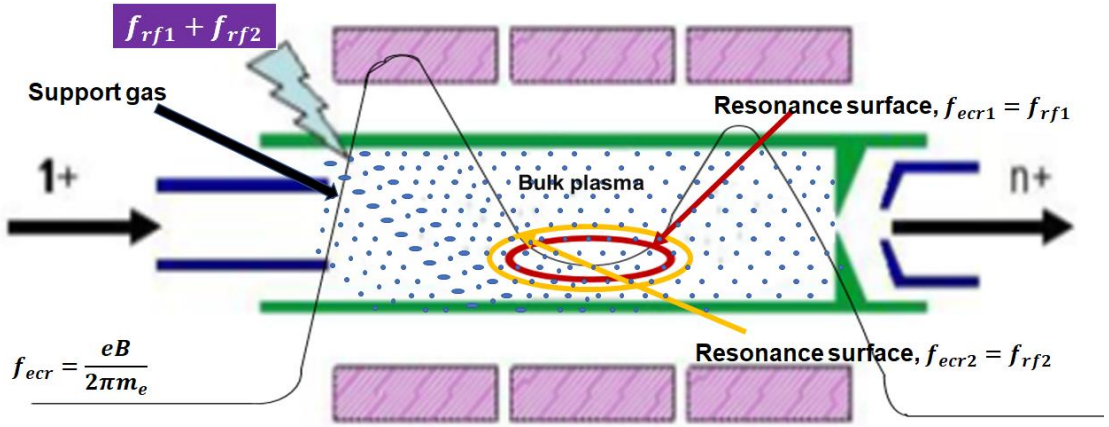
- New source and terminal
- First beam from new source planned on test bench in April 2022
- First 300 kV beam on beam dump in December 2023

ISAC refurbishment

- P496 - ISAC target hall consolidation
  Refurbishment of modules, service space connections and smaller refurbishments of the SHC and the conditioning station cooling system
- P494 - TRILIS upgrade (laser ion sources)
  - non-resonant ionization
  - Remote tuning
    - motorize frequency selective elements for each TiSa laser system
    - possibility for automated beam pointing stabilization



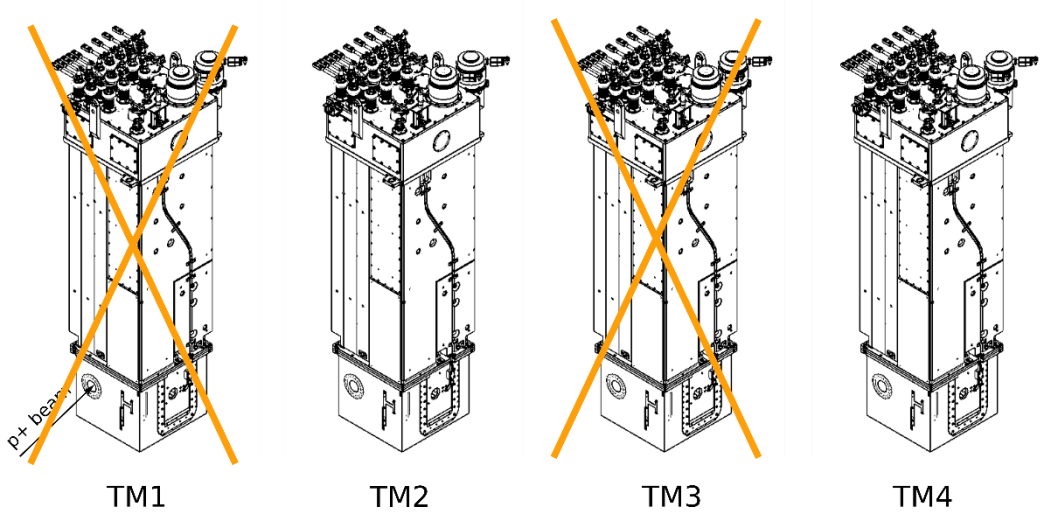




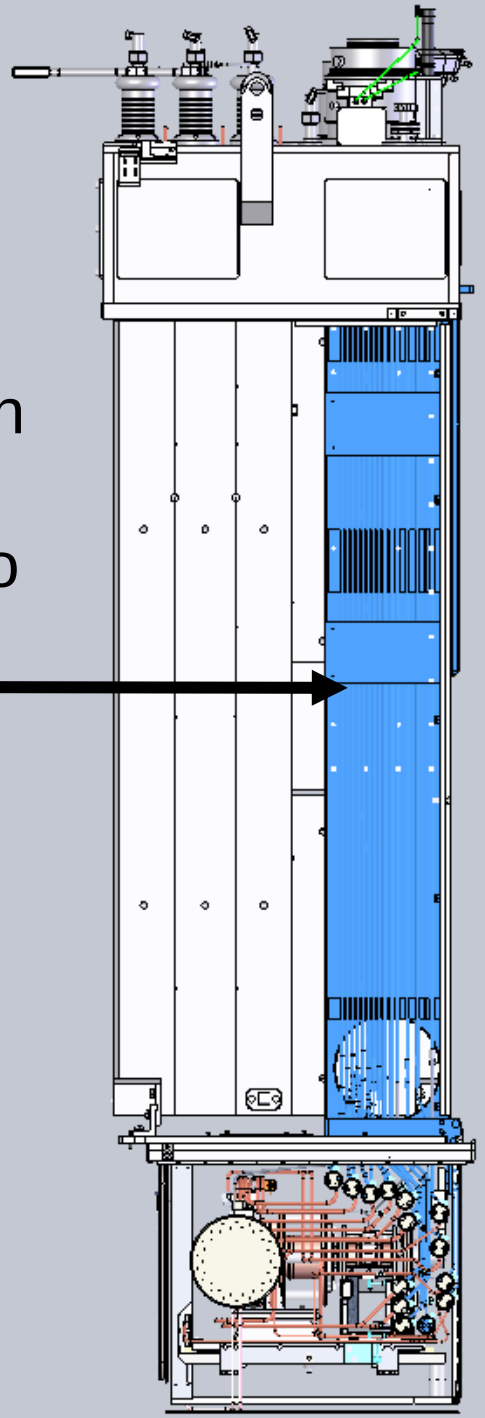
- P497 - RIB beam delivery improvements
  → Gate 1 review in May
  - Two frequency heating for TRIUMF charge state booster ECRIS established
  - Off-line ion source (OLIS) separator power supply and slits

TM3 Refurbishment Progress

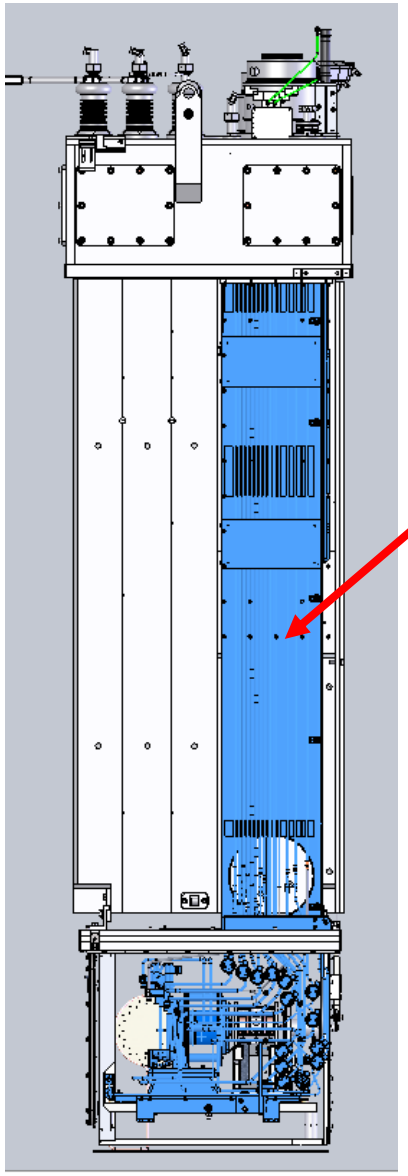
Currently ISAC delivers beam with only two modules, meaning a failure of one automatically causes down time



- The TM3 refurbishment project's main focus is on getting TM3 back in rotation by redesigning and replacing the service tray to enable HV delivery
- This is challenging since
  - It has not been done before
  - No hands-on fitting or inspection is possible
  - Design documentation is fragmentary



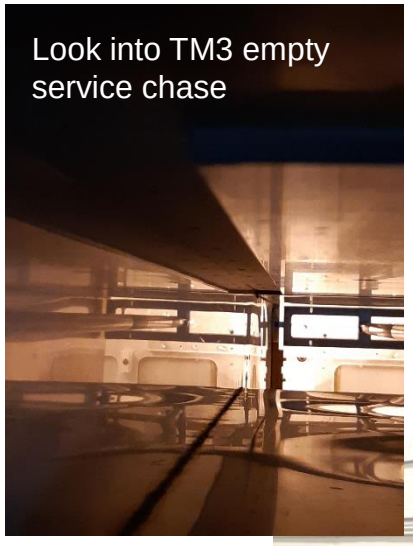
TM3 refurbishment – test for ISAC TM refurbishment



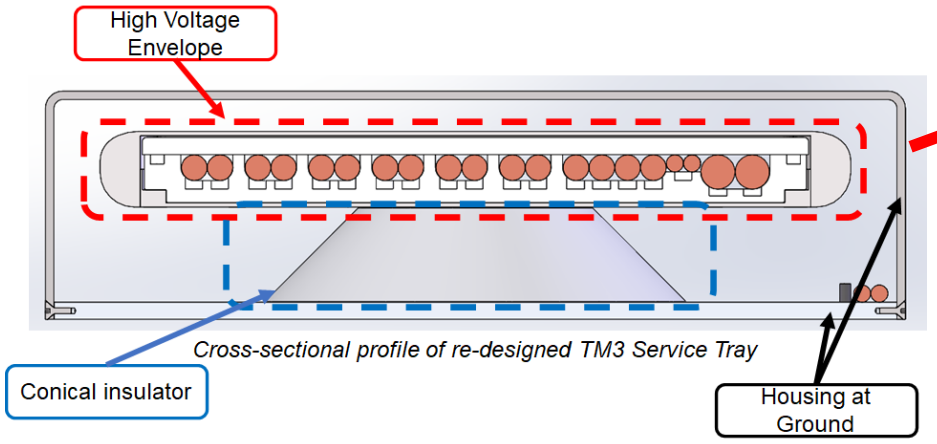
Service tray

Delivers all HV services from the module cap to the source tray

- HV design experimentally validated with prototype
- Installation procedure developed and tested on the module
- Design of the service tray and new source tray complete
- TM3 will be back into operation in 2022



Two sheath design to separate HV services from ground plane
→ HV performance is improved by controlling the HV/ground interface(s)

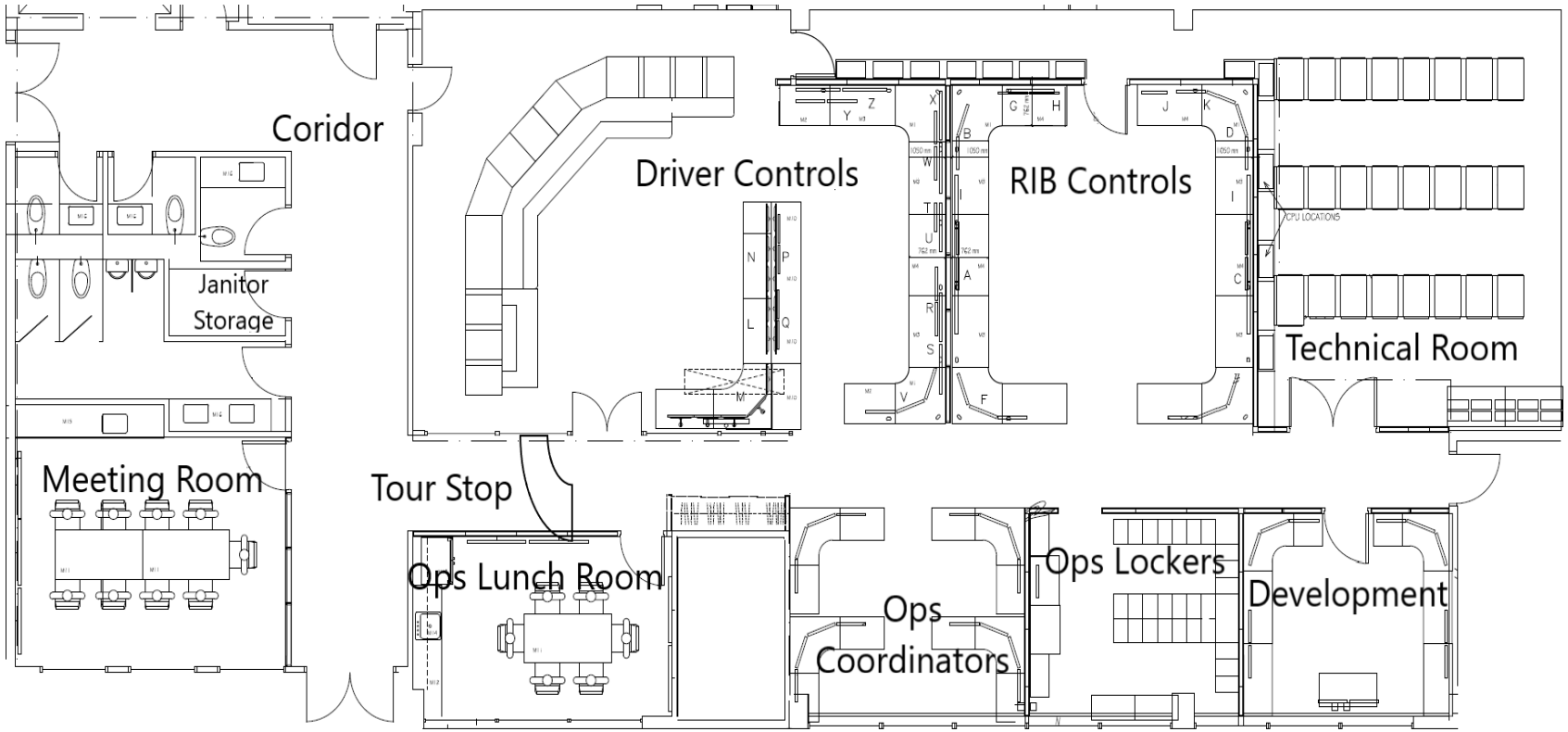


Cross-sectional profile of re-designed TM3 Service Tray

P356 – TRIUMF Control Centre (TCC)

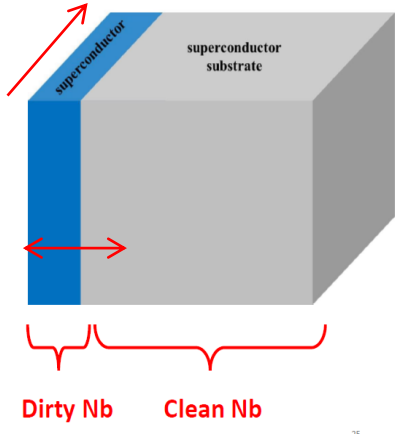
- The objective of P356 - TCC project is the consolidation of the Operation's Control Rooms into a single modern control centre.
- TCC will be located in the cyclotron building, Service Annex ground floor, south (adjacent to current Driver Control Room).

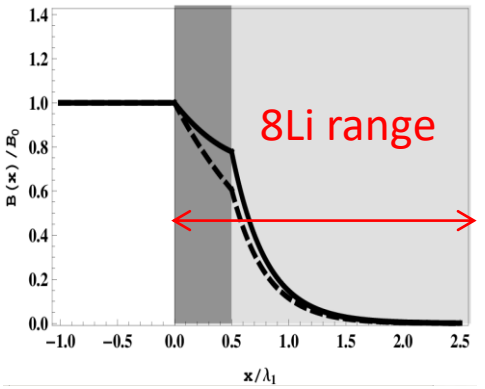
- It will accommodate space for:
  - Beam delivery (Driver accelerator - 520MeV cyclotron & e-LINAC and RIB - ISAC & ARIEL)
  - Beam development, commissioning and training
  - Racks for Controls, Diagnostics and Network in the new technical room,
  - Operator's space (kitchen, meeting room. Desk space)



Superconducting RF

- Canada has world-known expertise in SRF via TRIUMF (cavities, cryomodules and materials)
- TRIUMF has two world class material science probes in μSR and βNMR
  Together with UVic, TRIUMF SRF group have used both to shed light on the breakdown fields for SRF applications
  New beamline in beta-NMR allows testing doped Nb and new materials to push towards higher gradients.
- Developing cavity surface treatments for high gradients and quality factors → ILC
- Hadron accelerators rely on high performing SRF coaxial resonators
  → Test cavities for optimization of shape and processing

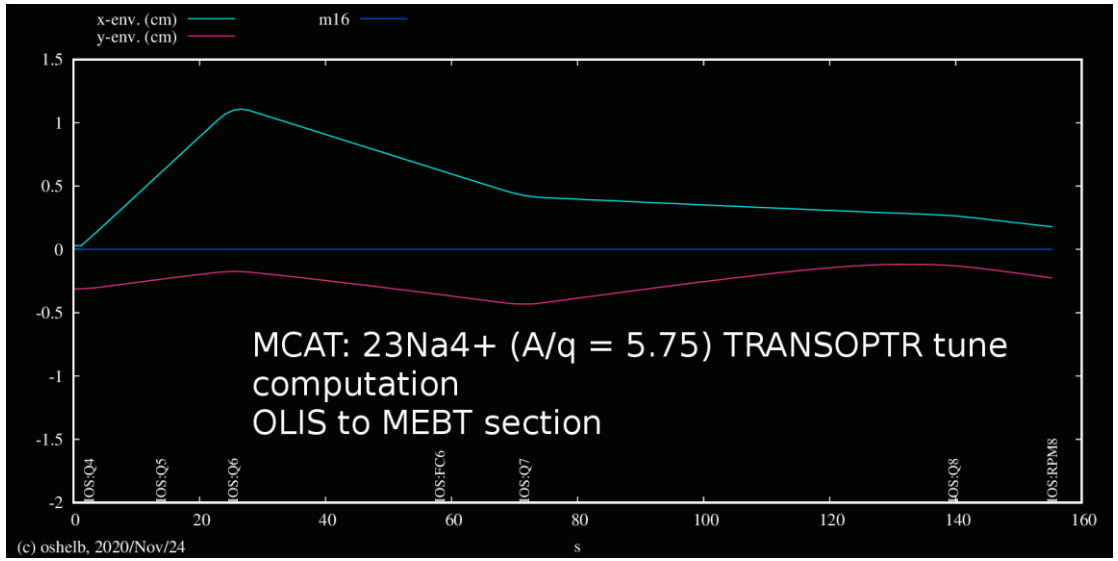




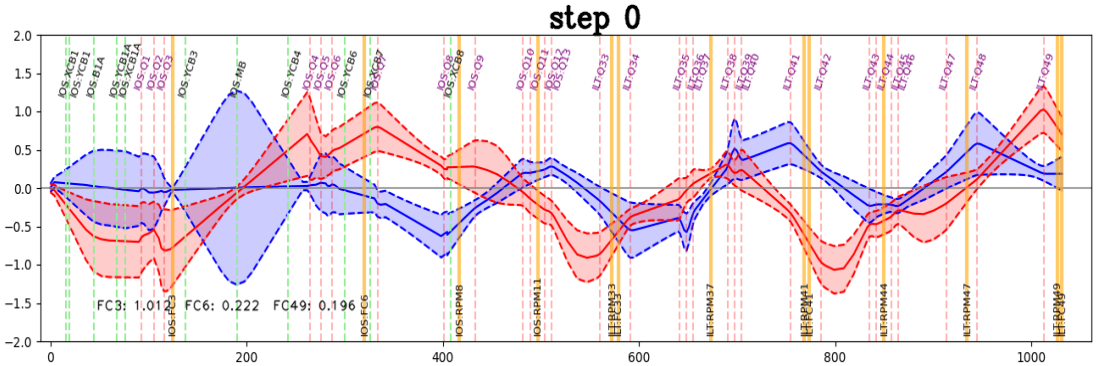
Induction Furnace

Beam physics: The future of beam development and delivery - Model based beam tuning

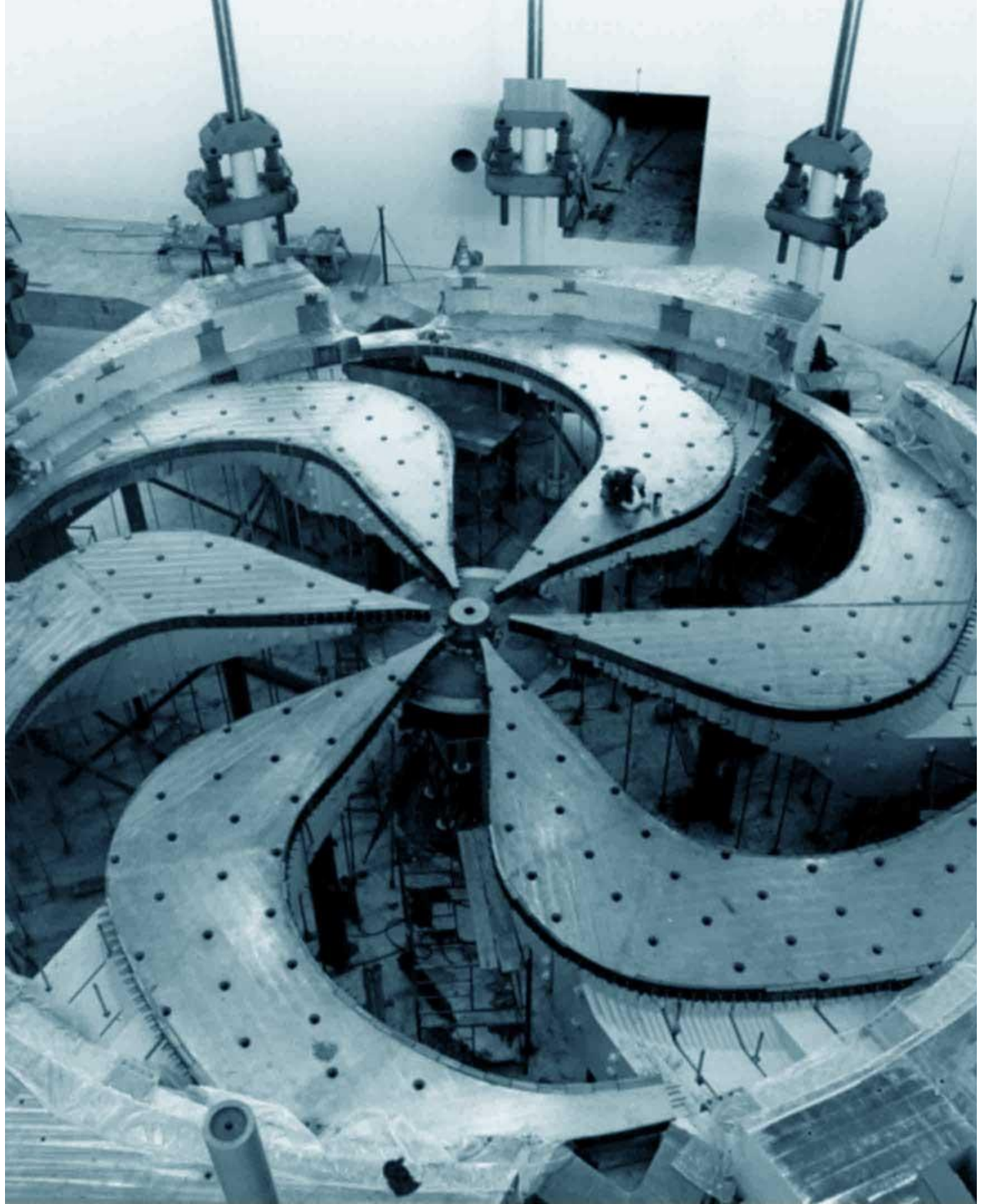
- A TRIUMF task force has developed a web-based python interface to communicate with the accelerator control system for High-level applications (HLA).
  → Model Coupled Accelerator Tuning (MCAT)
- All of TRIUMF's accelerators and beamlines are planned to be integrated in model-based tuning.
- Beam development has been performed to better understand the matching of OLIS beam into the ISAC accelerator and new ISAC-I DTL and ISAC-II linac tunes have been established.
- Machine learning
  Guided by beam physics, a Coop student and a student from FZ Juelich (supported by MITACS) are working on autotuning applications.



Sequential Tune Optimization in TRANSOPTR
O. Shelbaya, S. Kiy, S. Raedel

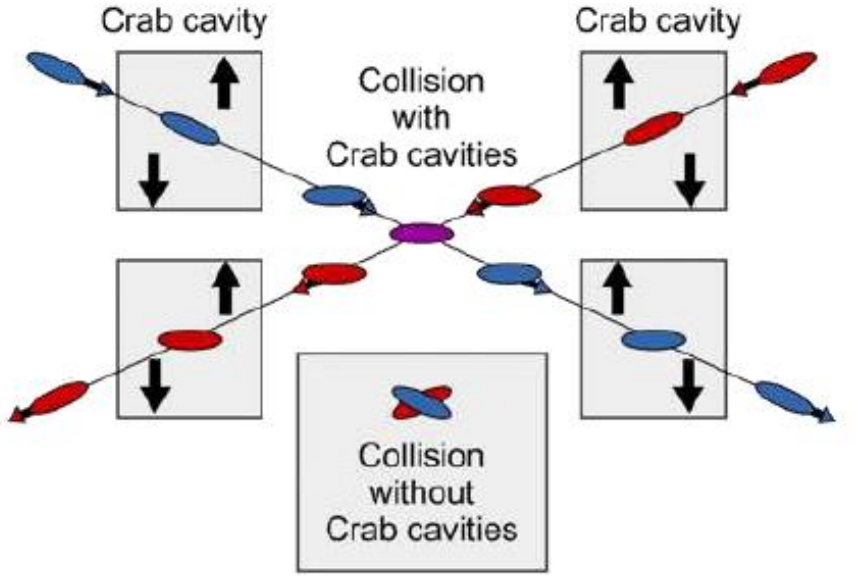


Projects driven by our user communities



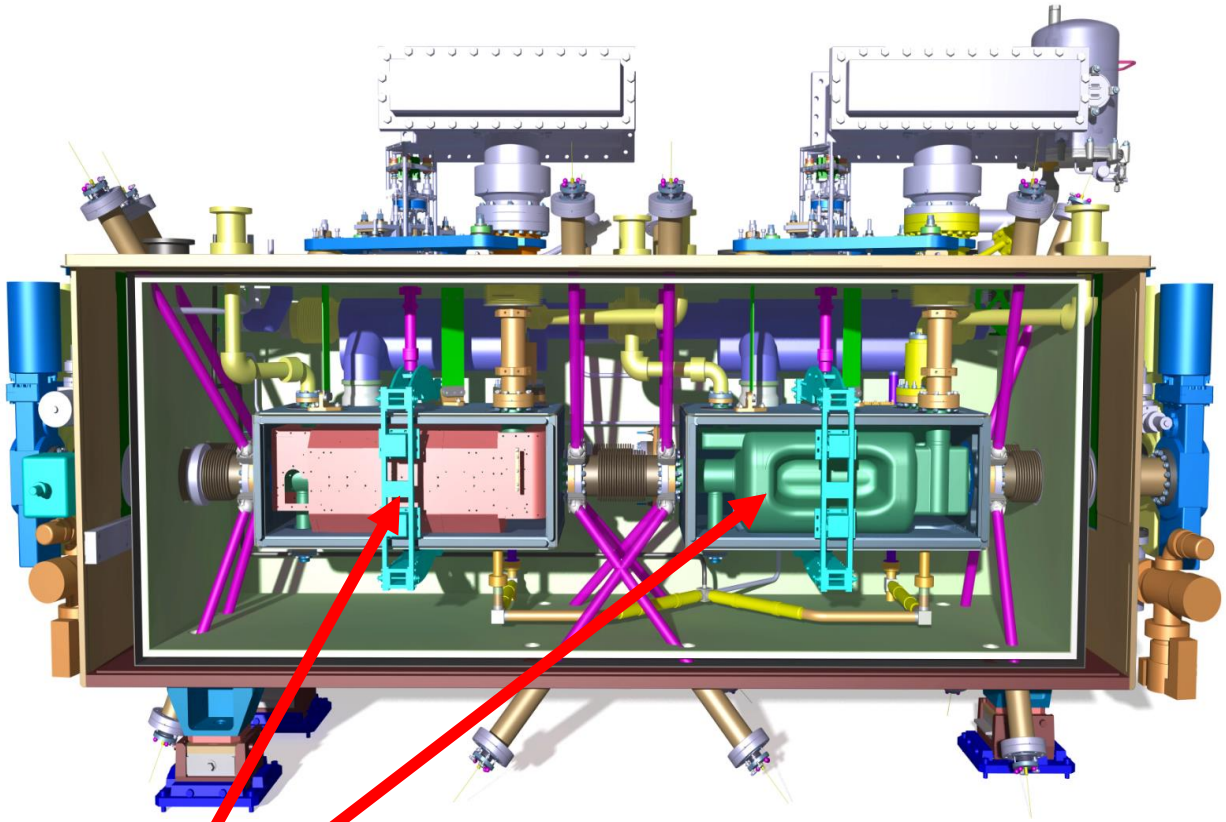
High Luminosity – Large Hadron Collider (HL-LHC)

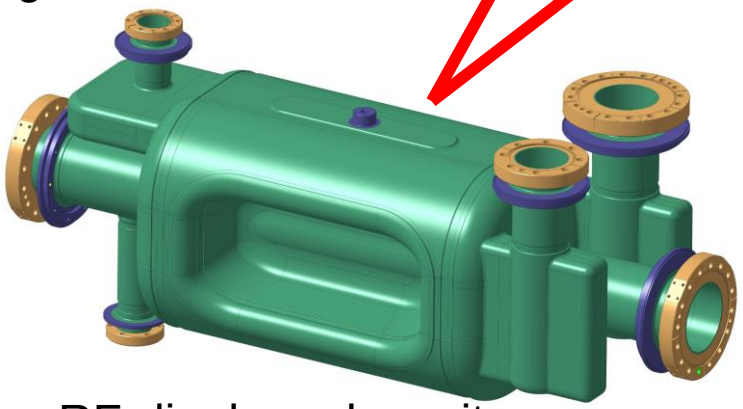
Crab Cavities – increase luminosity by skewing the intersecting beams longitudinally at ATLAS and CMS – collaboration with CERN, Russia, UK, USA



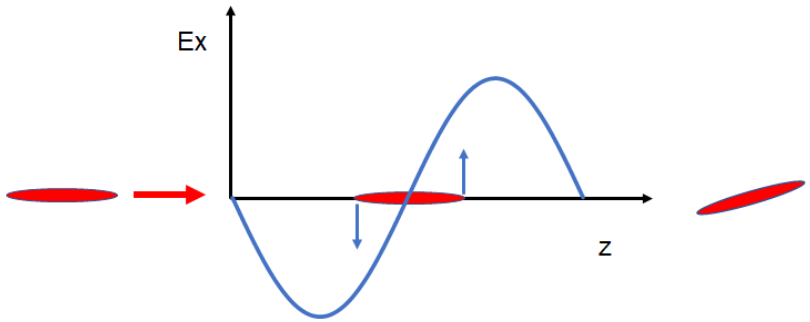
HL-LHC crab cavity cryomodules

- The RF Dipole (RFD) cavities produce time varying electric fields that deflect the beam transversely.
  → head and tail are deflected in opposite direction to maximize the collision rate
- TRIUMF will receive 10 dressed RFD resonators from US-AUP, to re-qualify, install the fundamental power coupler and to assemble each pair of RFDs into five hermetic strings.
- TRIUMF to assemble hermetic strings into five cryomodules.
- TRIUMF to qualify the cryomodules through testing at TRIUMF before packaging and shipping to CERN
- TRIUMF to work with CERN and UK to establish a suitable shipping method



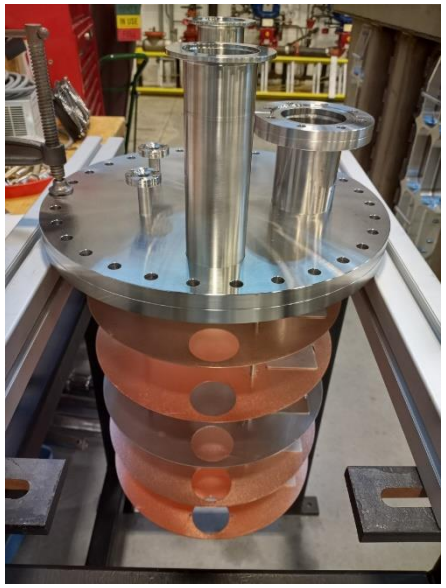


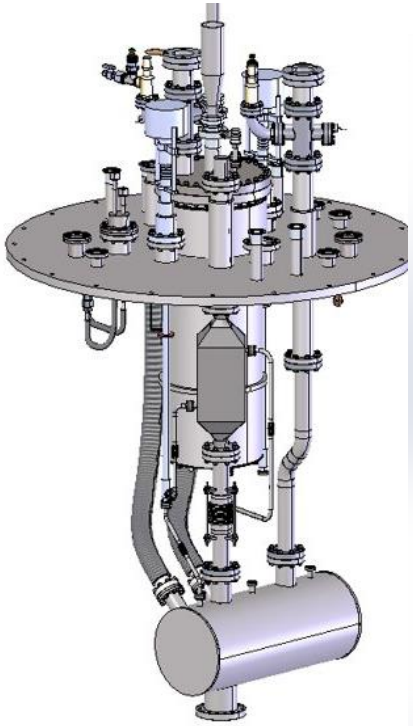
RF-dipole crab cavity

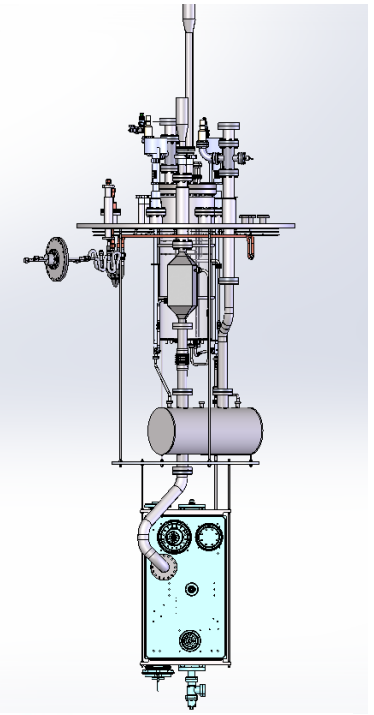


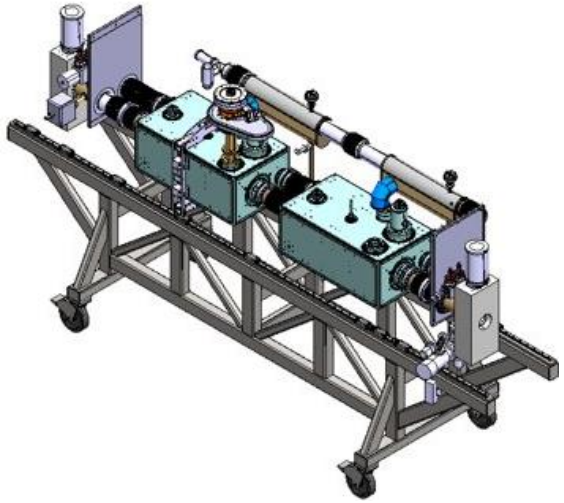
TRIUMF status - SRF infrastructure upgrade to be compatible with Hi-Lumi scope

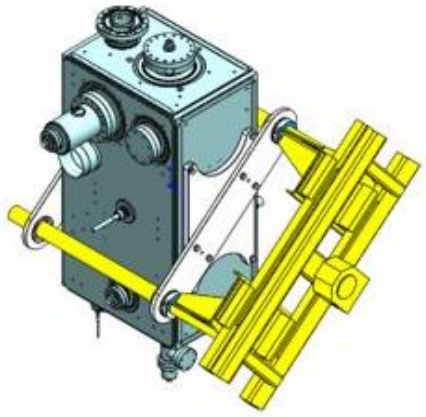
- Gate 3A for the construction of TCM0 (prototype cryomodule) has been completed
- Clean room upgrades to reduce chance of particulate pollution
  Procurements for clean room and cavity testing on-going and well advanced.
- Will have full capability to qualify the AUP dressed cavities at 2K in jacketed mode
- Testing infrastructure
  Prepare 4K/2K insert for multi-purpose cryostat to allow testing dressed cavities at 2K in jacketed mode.
  Upgrade cavity test diagnostics and 2K pumping capacity.
- Assembly fixtures
  Cavity handling tooling and hermetic string assembly





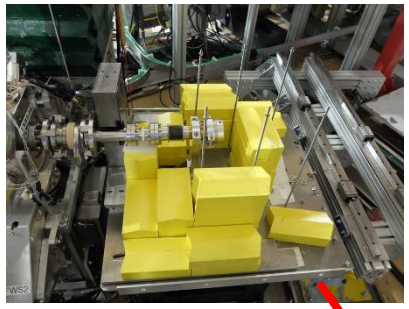


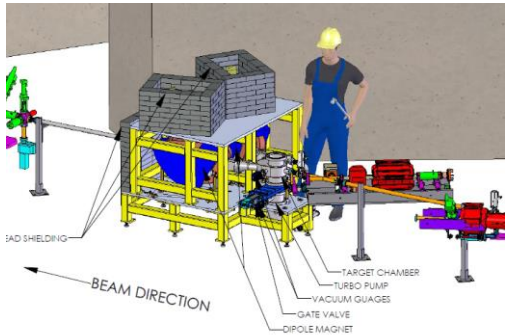


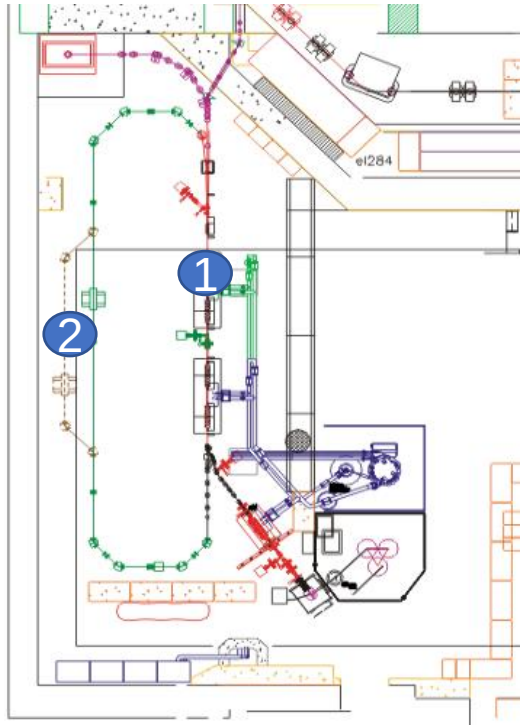


Science supported by the e-linac

- FLASH radiotherapy
  Involves the ultra-fast delivery of radiation treatment at dose rates several orders of magnitude greater than those currently in routine clinical practice
  → Chamber and shielding are installed – first beam tests in the next months
  Proposals to NFRF and CFI are in preparation
- Dark matter search
  DARK LIGHT experiment looking for a 5th force (dark photons) at a low energy e-linac
  Experiment gets additional motivation from recent results from the muon g-2 experiment at FNAL
  → Initial target chamber installed – first beam tests in the next months
  Proposal to NSERC submitted and proposal to CFI is in preparation to include and energy upgrade and a recirculation.







The future of ACC science at TRIUMF 20-year vision

Canadian Subatomic Physics Long Range Plan – 2022-26

- The Canadian subatomic physics (SAP) community establishes its scientific priorities through five-year Long-Range Plans (LRP).
- These plans advise the Canadian subatomic physics research community and relevant stakeholders on priorities for both current and future endeavours.
- A document on Accelerator Science support has been provided for the SAP LRP. Developments and contributions to Canadian facilities and international projects like HL-LHC, EIC and ILC are described.
- A plan for TRIUMF to strengthen education and training of HQP in Accelerator Science in the period of the next LRP 2022-2026 is described.

Our 20-year Vision for TRIUMF Accelerator Science and Facilities

Isotope Valley

With ISAC+ARIEL+IAMI we will greatly expend our capabilities, and establish TRIUMF as a leading global center for isotope research.

- Isotopes for physical science
- Isotopes for life science
- Isotopes to cure Canadians

Canadian Hub

We are Canada's centre of excellence in accelerator-related science and technology.

We centralize knowledge, and diffuse it through training, counsel, and collaborations.

With our always evolving expertise we remain a leader in Canada's transformation to a knowledge based economy.

Big Science — Big Tech

International collaborations are key to contribute to the most significant discoveries, attract talents, and maintain cutting-edge expertise.

We support international projects by leveraging our core knowledge and engaging Canadian industry.

We build on our strengths to serve science and invent life-changing technologies.

https://beamphys.triumf.ca/~tplanche/20-year-vision-acc.pdf

TRIUMF as global center for the study and development of isotope science and applications.

- Develop the full potential of the new ARIEL/CANREB/IAMI infrastructures including their high-power drivers: Cyclotron & e-Linac
- Leverage infrastructure and know-how to pursue new technologies/capabilities
  - Leverage ARIEL e-Linac to develop Canadian THz source
  - Leverage SRF capability to advance ISAC post-accelerator to world leading ion energy
  - Leverage strength in beam physics to develop and implement unique low energy storage ring for neutron capture
- Design and build next generation medical accelerators
  - Develop next generation TR100 cyclotron and exploit for medical isotope production to support Canadian industry and community health

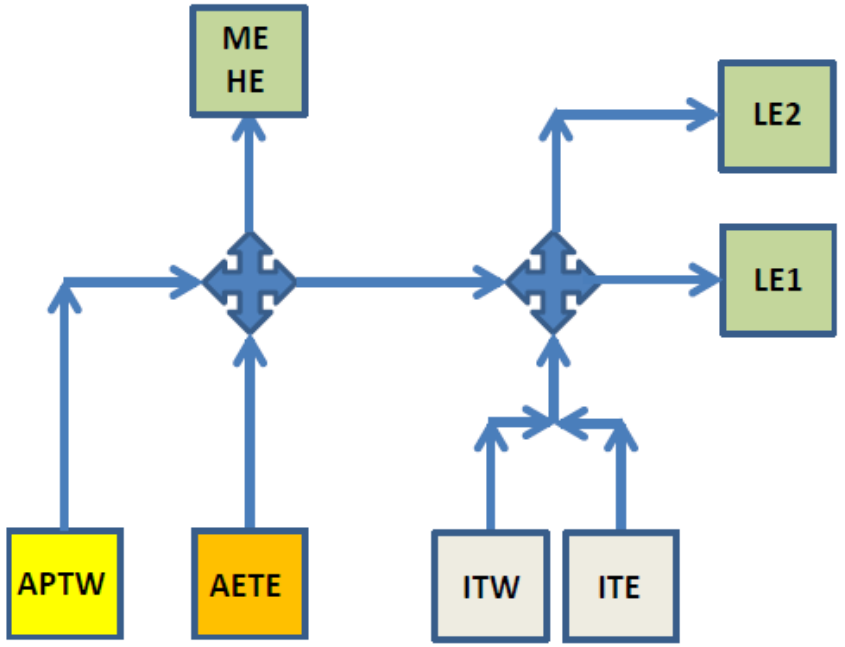
The Advanced Rare IsotopE Laboratory – ARIEL operation era

The operational model in the ARIEL operations era will allow for beam delivery of three simultaneous beams

- An assembly-line approach
- Standardized target cycles and lifetimes
- Regular maintenance and development periods
- Frequent target changes to reduce impact of failures

Based on a 3 week interleaved target cycle for each of ITE/ITW, APTW and AETE

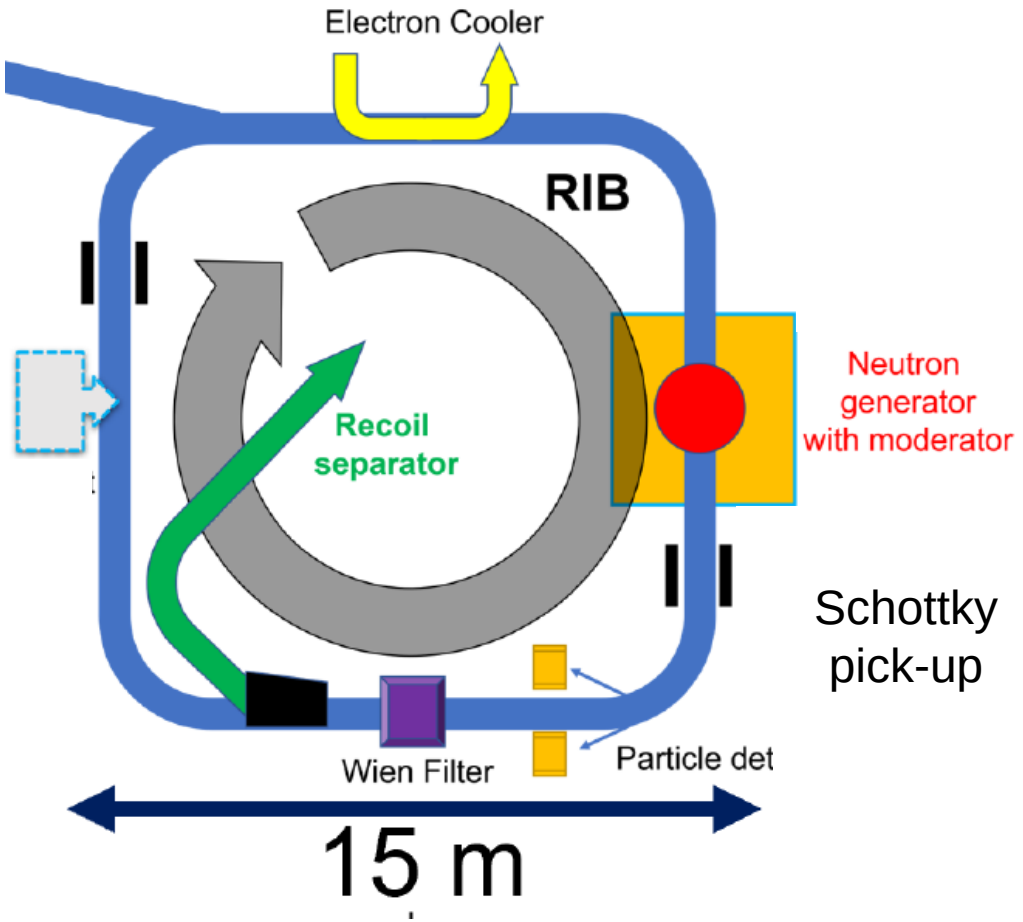
- Includes target exchanges, development shifts, yield measurements, maintenance
- This operation era will see a ramp-up to 9000 RIB hours as a reasonable goal.
- `RIB Factory' model: Maintaining the target cycle becomes a higher priority than maintaining flexibility.

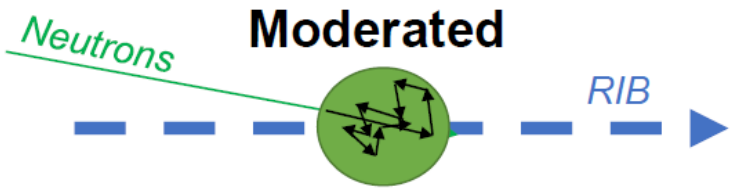


Schematic of allowed paths to the three generic experimental areas (low, medium and high energy, LE, ME, HE).

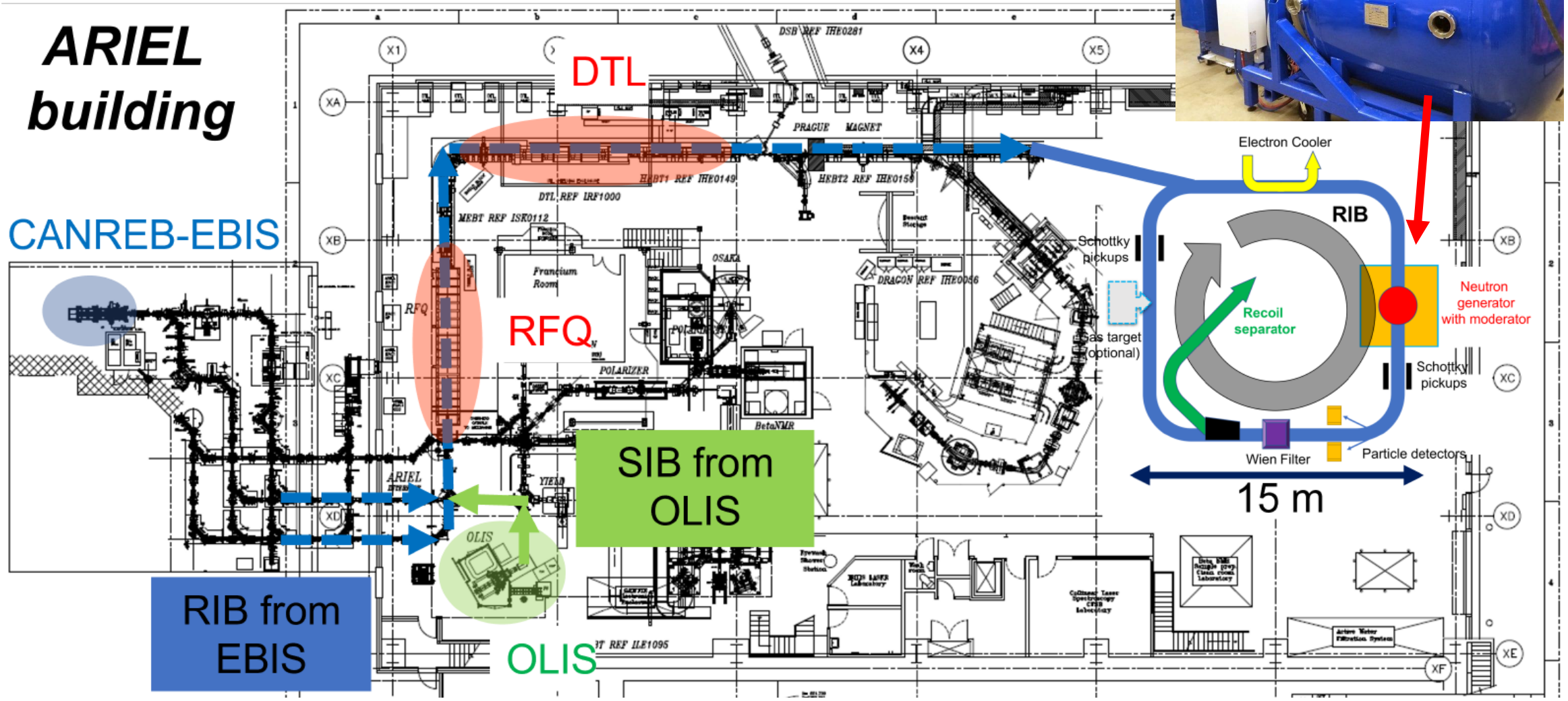
A low energy storage ring coupled to ISAC-I

- Low energy ring (0.1 – 10 MeV/u)
  Repetition rate allows higher luminosity compared to single pass experiments
- ISOL provides high intensity, short lived rare isotope beams
- CANREB EBIS is the optimum injector because of very short injection pulses that allow single turn injection
- To measure neutron capture cross sections by providing a neutron target, based on a high-flux neutron generator integrated in the ring.
  → Conceptual design study with company SHINE/PHOENIX LLC



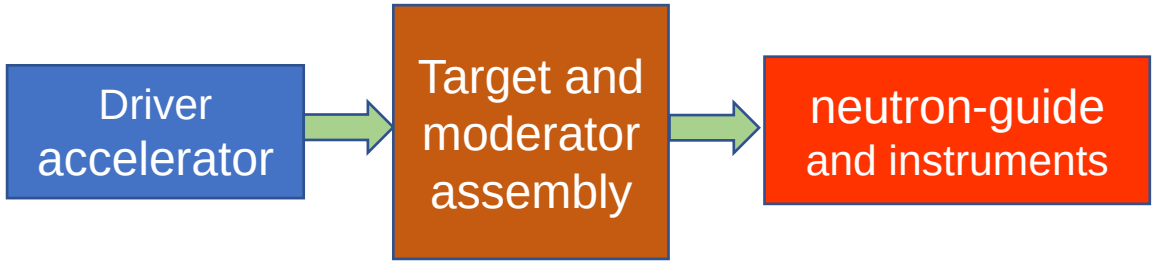


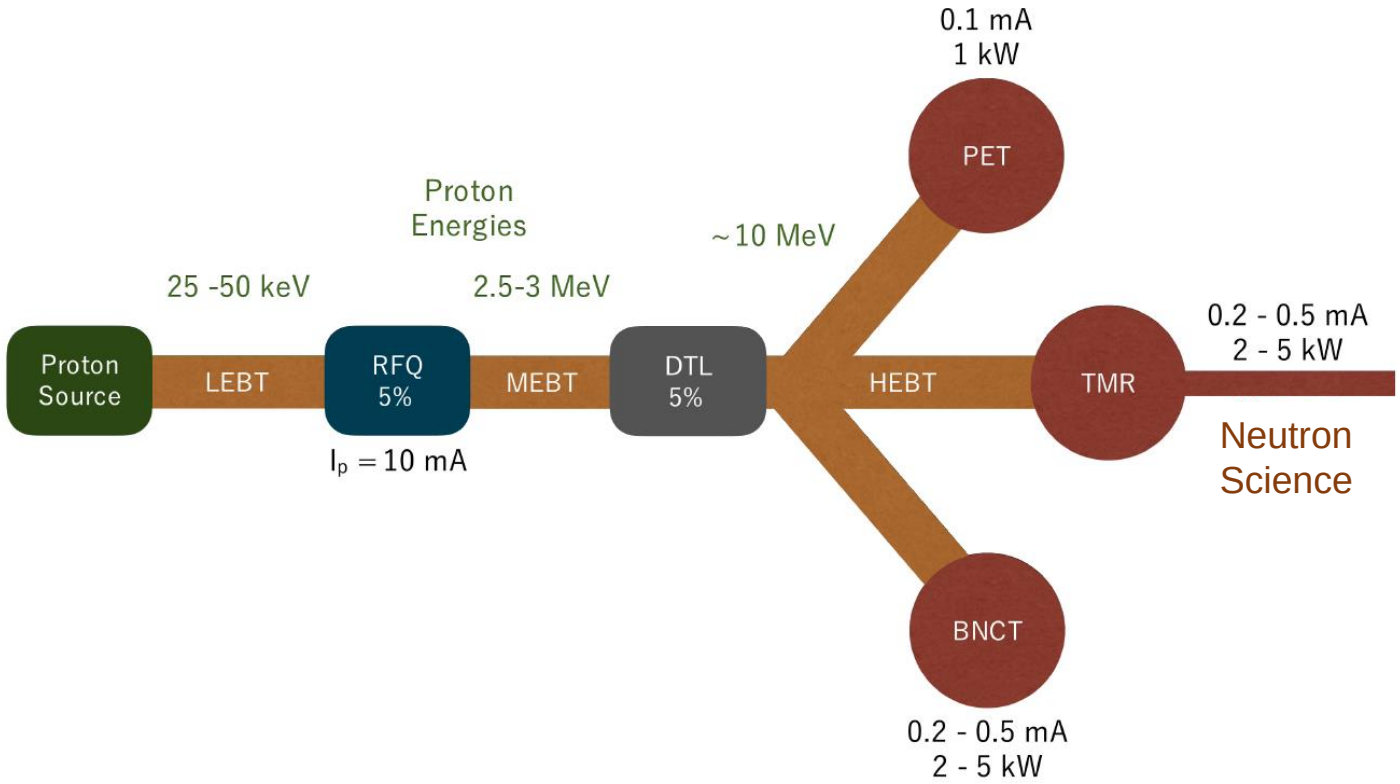
A low energy storage ring - TRISR



Users community support a Canadian Compact Accelerator Driven Neutron Source (CANS)

- TRIUMF is collaborating with the University of Windsor and the Canadian neutron community towards an accelerator-based neutron facility
- Collaboration has conceptualized a stagable prototype CANS facility, PC-CANS, based on linac technology.
- PC-CANS will allow competitive rates for neutron science, while simultaneously producing F18 for PET and neutrons for a dedicated BNCT research and development facility.
- The PC-CANS prototype will be the first CANS in Canada and the first for BNCT in North America.



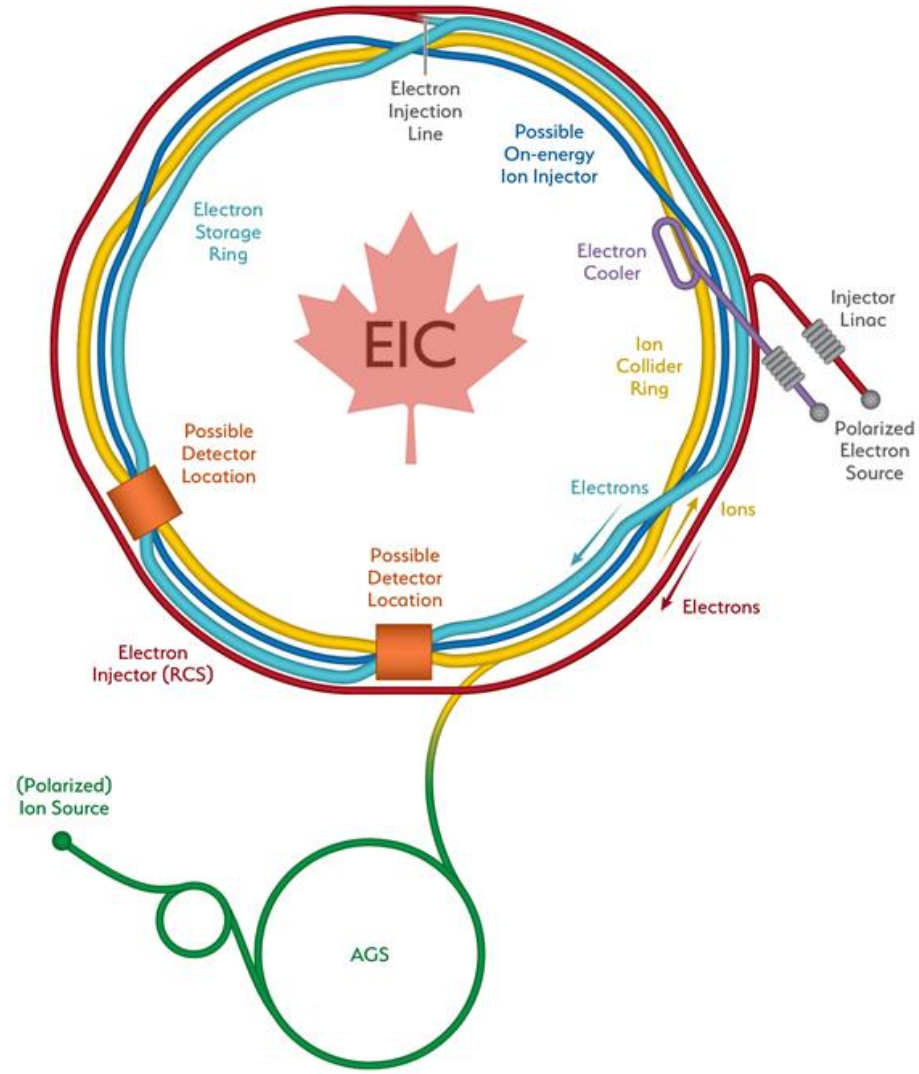


TRIUMF as key global partner with critical expertise in cutting edge technologies and key links with Canadian industry.

- Complete Hi-Lumi deliverables on crab cavity cryomodules, beam physics and wire correctors
- Establish deliverables for EIC, ILC and other large global initiatives to support and strengthen our partnership with CINP and IPP
- Develop and strengthen core competences in SRF, beam physics, and high-power accelerator and target technologies.
- Develop key relationships with Canadian industry while delivering cutting edge technology

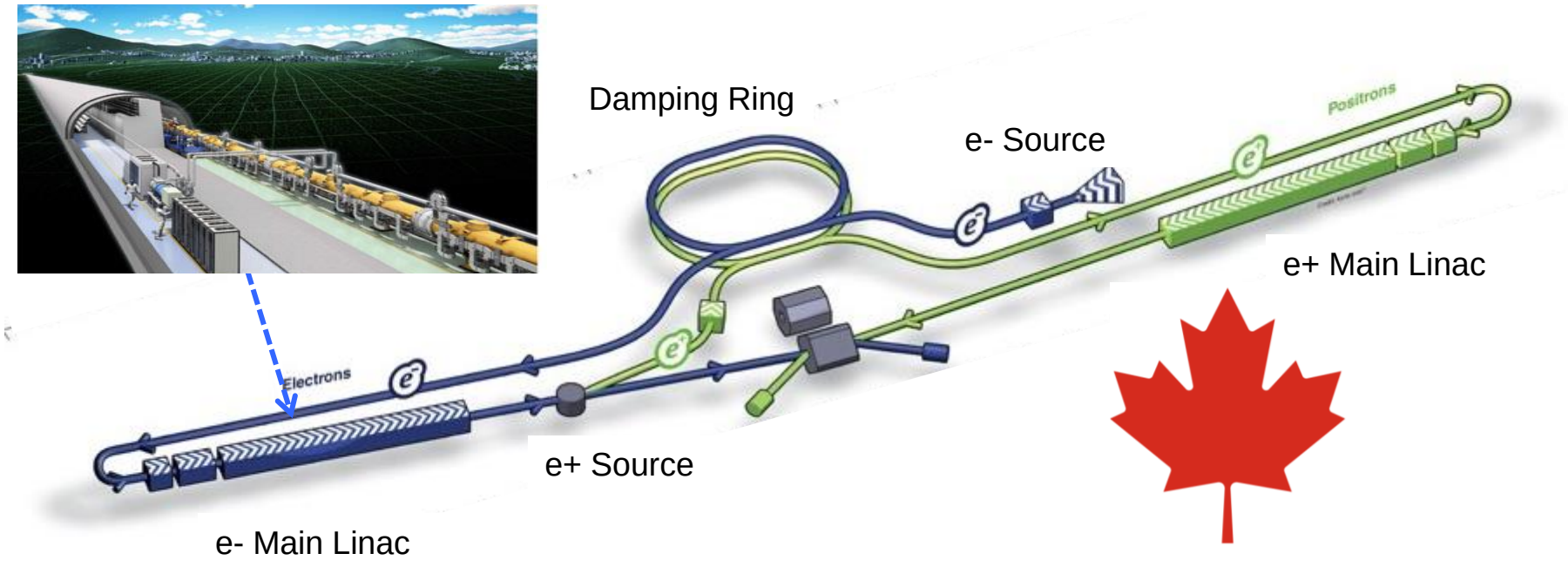
Electron Ion Collider (EIC) related R&D

- The EIC is the first major collider to be built in North America in the 21st century.
- The EIC is a challenging accelerator project with most demanding operational parameters in terms of intensity and luminosity
  → requires high degree of polarization, high intensities, short bunches, hadron beam cooling and according ERL technologies
- Canada via TRIUMF is well positioned to provide expertise for accelerator components or systems and potential “in-kind” contributions.
  → SRF cavities (crab cavities for instance), beam optics systems, diagnostics, pulsed magnets



Based on previous contributions to CERN, Canada is well placed to contribute `in-kind' to future large global installations like ILC or FCC.

- SRF/RF (crab (or other) cavities, cryomodules, rf ancillaries)
  SRF research on break-down fields and effect of doping for highest gradients
- HV kickers, normal conducting magnets and RF-bunch deflectors, beam instrumentation
- Beam physics (space charge dominated beam, Hamiltonian based fast envelope code, machine learning)



A long-term vision for Accelerator Science in Canada

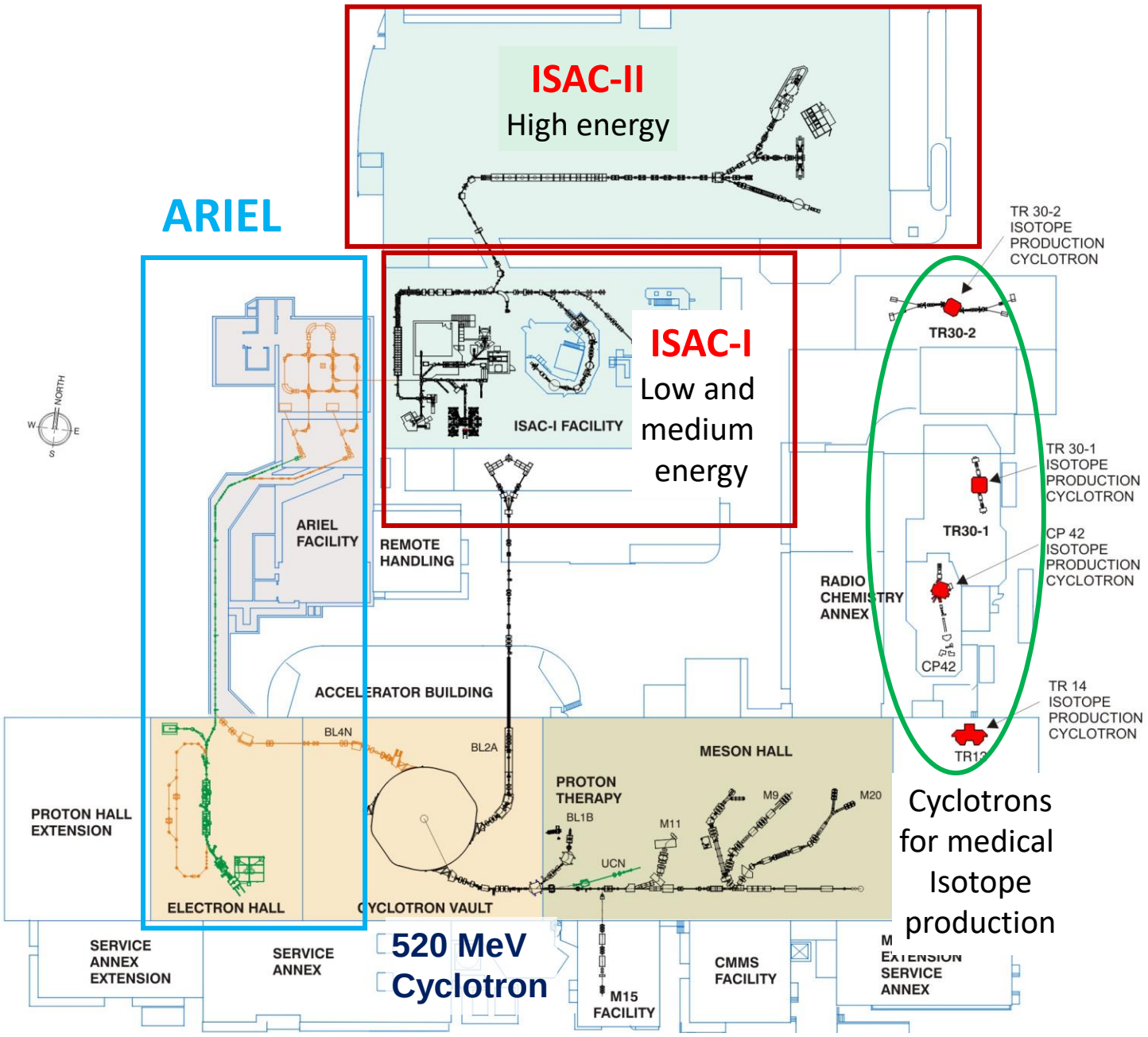
- Strengthen the education and grow the number of student research projects.
- Sustain fundamental R&D on key accelerator technologies
  SRF, beam physics and accelerator systems, high power targets and remote handling technologies, secondary particle production, applications
- Extend the involvement in Canadian and international projects (CANS, light sources, medical accelerators, HL-LHC, EIC, ILC etc.)
  Collaborations and projects are springboards to consolidate and expand Canadian core competencies and to acquire new ones.
- Use Accelerator Science and technology to support Canada's transformation to a knowledge-based economy (fundamental science and applications).

TRIUMF

Thank you
Merci

Backup slides

TRIUMF accelerator complex



Primary beam driver:

Cyclotron, 520 MeV, H^-

Produces rare isotopes, neutrons and muons!

Isotope Separator and Accelerator facility - ISAC

Isotope Separator Online (ISOL) facility

ISAC-I: Normal conducting-linac, 0.15-1.8 MeV/u

ISAC-II: Superconducting-linac, 1.5-16.5 MeV/u

Advanced Rare Isotope Laboratory - ARIEL

Superconducting electron linac

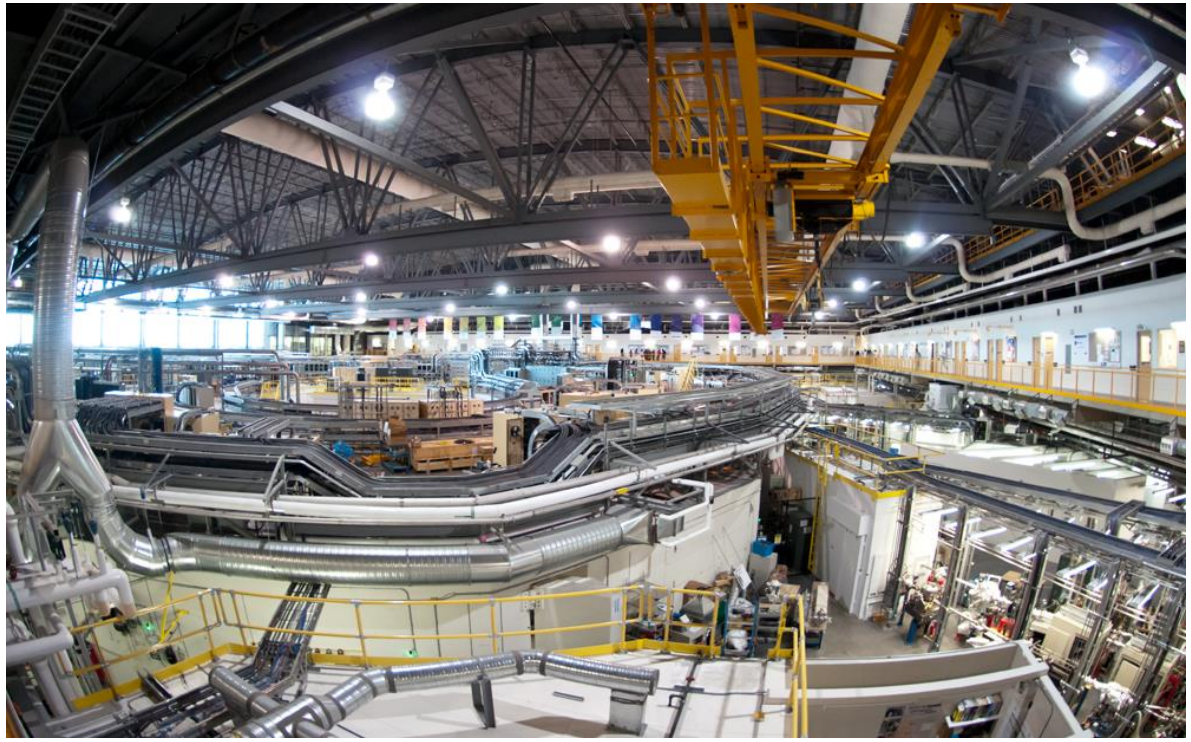
30 MeV, 10 mA, cw

4 Cyclotrons for medical isotope production

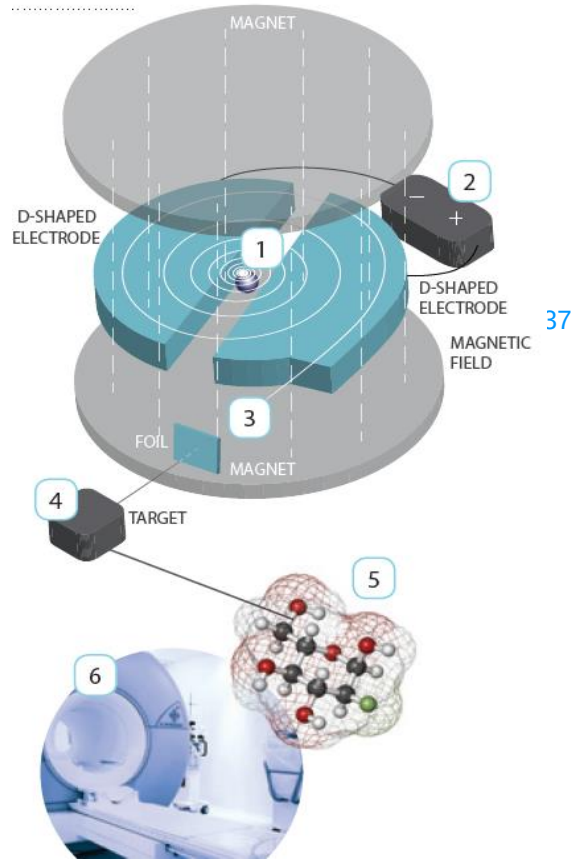
Canadian Light Source | Centre canadien de rayonnement synchrotron

The Canadian Light Source (CLS) on the University of Saskatchewan (UofS) campus

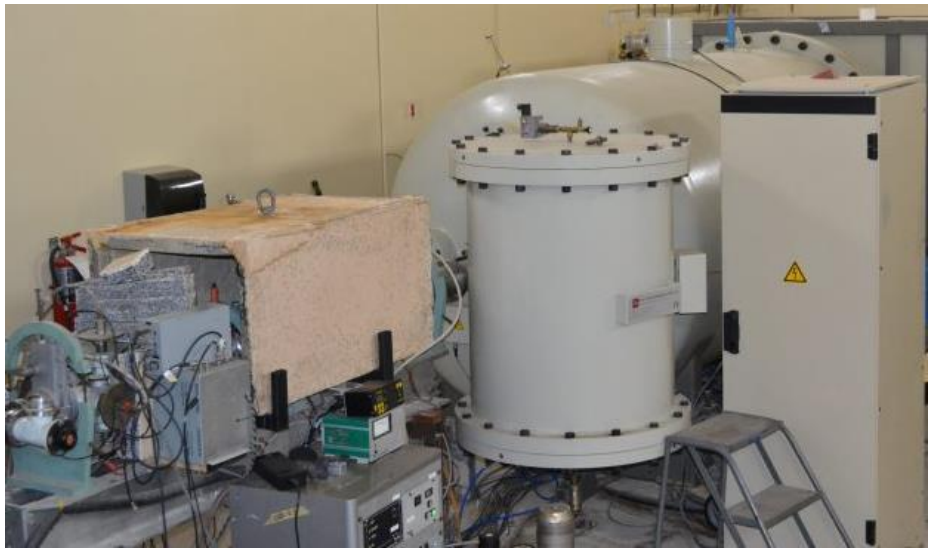
- National Light Sources facility – Canada's only synchrotron light source!
- Owned by the UofS and funded primarily through federal funding.
- Operating since 2005 for open user access.
- Used by thousands of researchers from Canada and around the world.
- CLS built on the historical Saskatchewan Accelerator Laboratory (SAL) established in 1962.



Further Canadian institutions



- Fedoruk Centre - The Saskatchewan Centre for Cyclotron Sciences.
  - The province's cyclotron facility supplies radioisotopes for use in the PET-CT scanner at Royal University Hospital and for research.
  - PhytoPET changes the scope of plant research in Saskatchewan (using PET isotopes for plant research)
  - Looking at technical and regulatory aspects of small nuclear power plants.
- The McMaster Accelerator Laboratory (MAL)
  - houses three low energy particle accelerators (two 3 MV Van de Graaf and a 1.25 MV TANDETRON tandem accelerator all high current)
  - µBeam Microprobe Facility is used to study low level radiation dosimetry by delivering single helium or hydrogen ions into individual cells.
- McMaster University Cyclotron Facility
  Is home to a 16.5 MeV GE PETtrace H- cyclotron designed for the production of short-lived PET isotopes such as F-18.



ACC science education in Canada, cont.

- One TRIUMF/UVic/UBC joint graduate lecture class is taught yearly by TRIUMF ACC division members.
  - The course is televised, recorded and offered to students nationwide.
  - Between 5 and 11 students mainly from UVic and UBC take this class for credit
- CLS machine director Mark Boland at UofS and Tobias Junginger at UVic offer undergraduate classes and research projects.
- TRIUMF and CLS will bring the **Joint International Accelerator School** to Saskatoon in 2022.
  - The U.S. Particle Accelerator School, the CERN Accelerator School, the Asian Committee on Future Accelerators and the Budker Institute for Nuclear Physics in Russia are partners in organizing this School.
  - This international series compliments the general schools by providing in-depth courses and seminars in specialized areas, like Superconducting RF.

HL-LHC contribution – beam physics

- Beam Dynamics Investigations carried out by Dobrin Kaltchev on the theory of Resonance Driving Terms explain the wire compensation for long-range beam-beam effects and the so-called magic positions in LHC.
- A Ph.D. student is working on a MAD-X model of the wire compensation in conjunction with other elements.
- Prototype wires embedded in collimators in LHC have already demonstrated the potential of a wire corrector.
- TRIUMF does support the prototype development and is asked by CERN to support the construction of the wires for HL-LHC!
  However, the submission of a CFI proposal via Carleton University has been delayed to the next CFI round to use the time for LHC machine development and a review at CERN on the wire systems in Run 3.