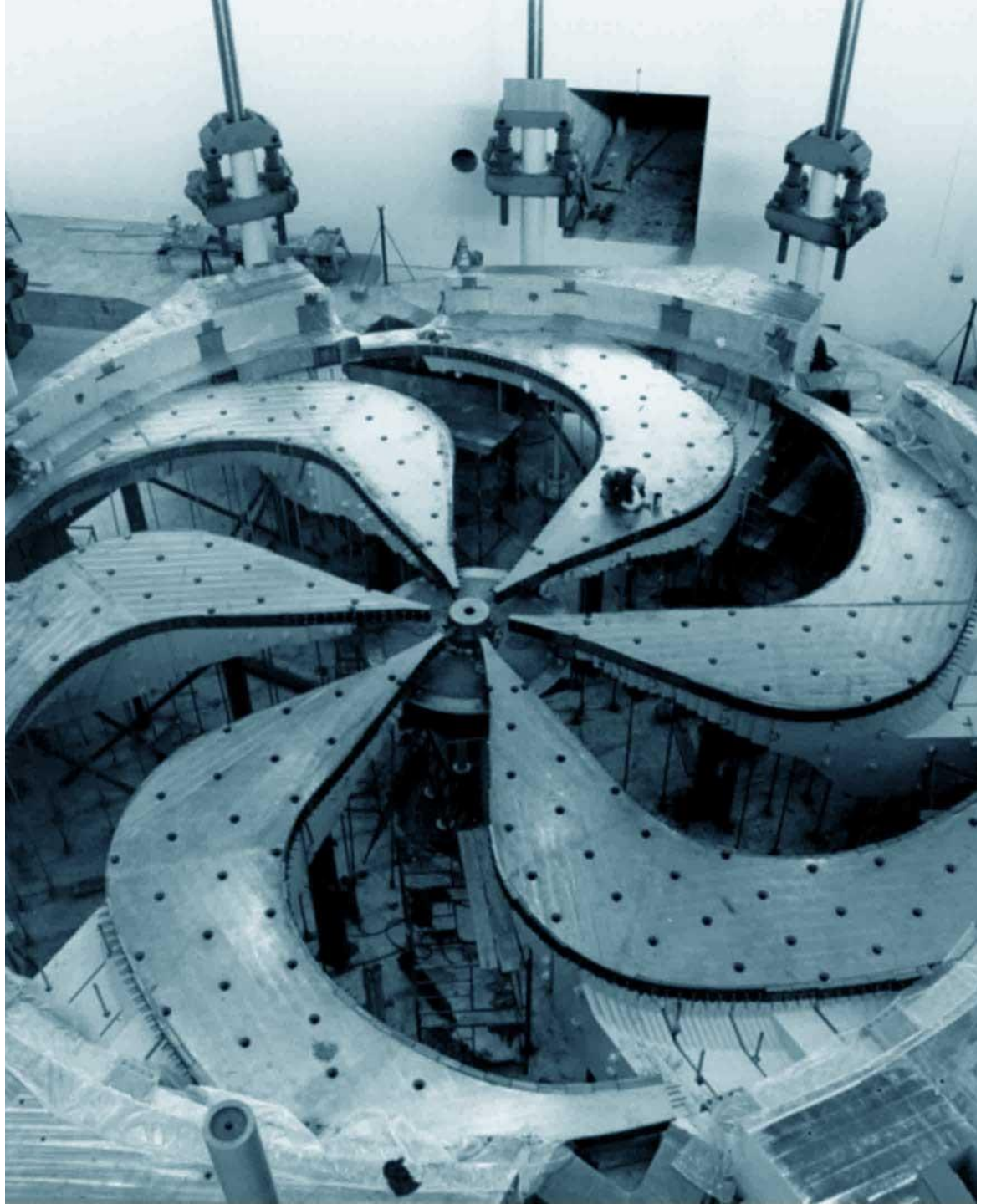
ACC R&D in the LRP 2022-2026 and beyond

O. Kester, R. Laxdal, R. Baartman, T. Junginger, A. Gottberg and T. Planche

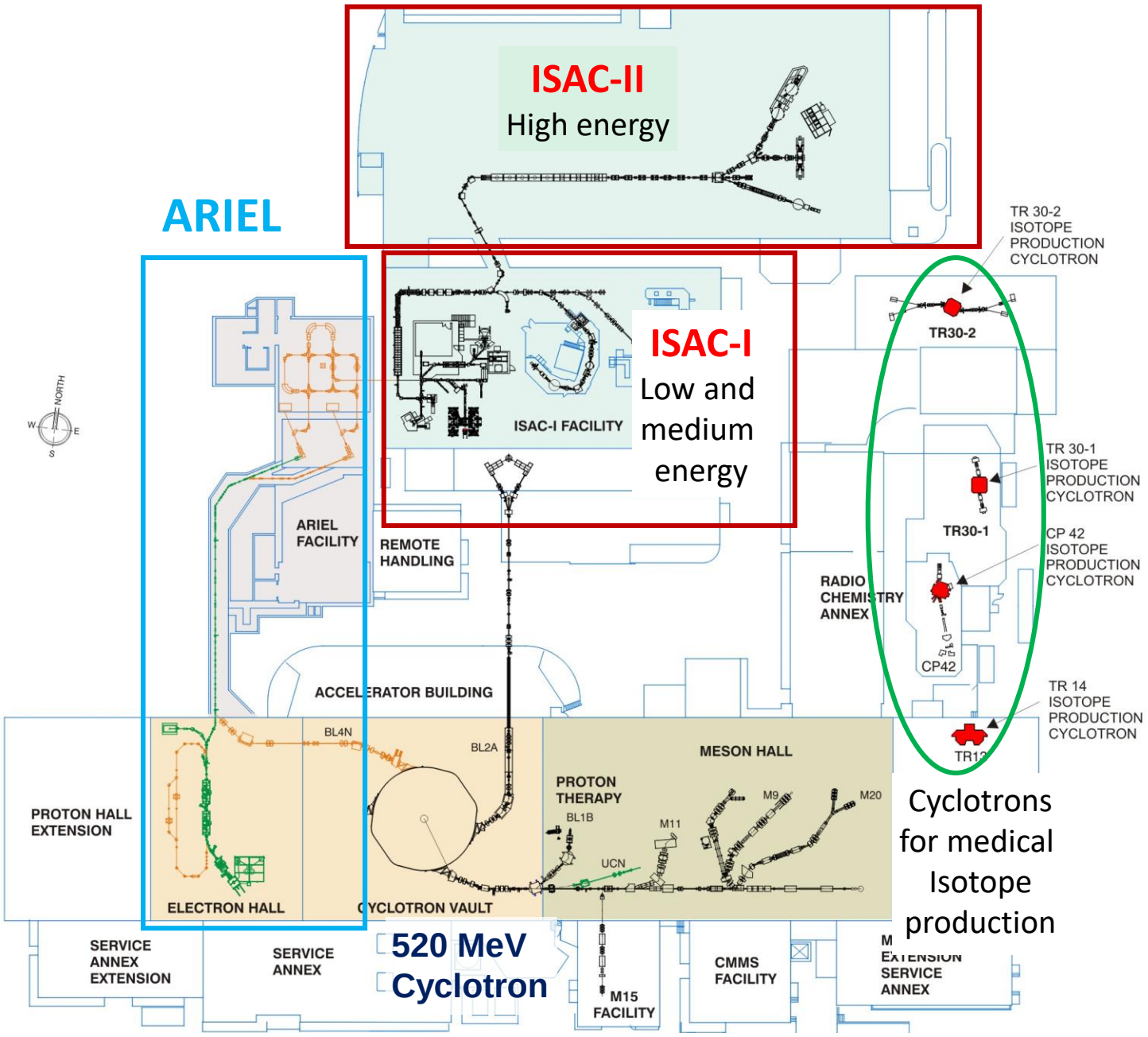
IPP Town Hall July 21, 2020



2020-07-21

TRIUMF has five decades of experience in building a rich particle accelerator infrastructure that nurtures cutting-edge research.

TRIUMF accelerator complex



Cyclotrons for medical Isotope production

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

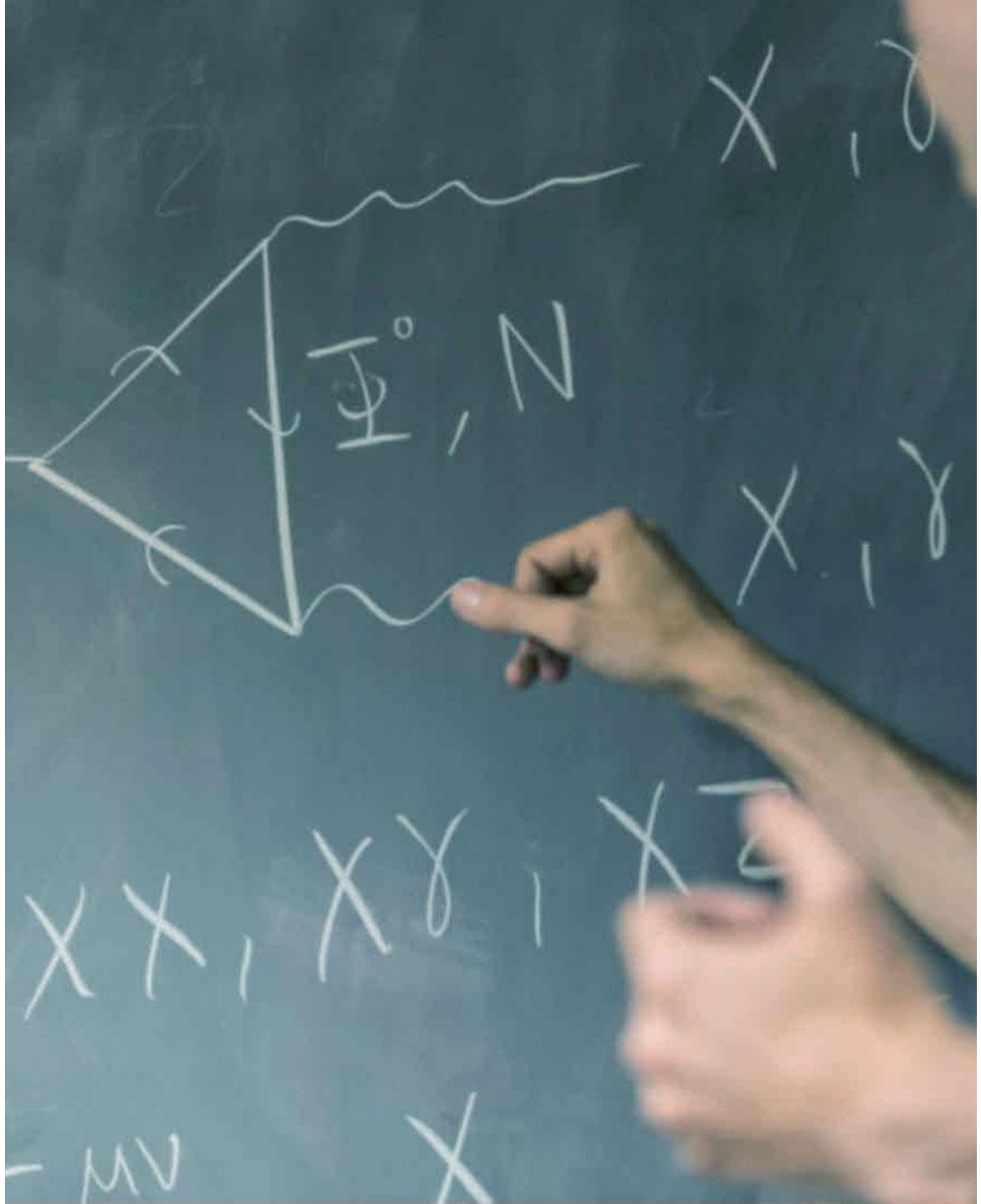
30 MeV, 10 mA, cw

4 Cyclotrons for medical isotope production

The Accelerator research program

- 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.

Particle physics related R&D

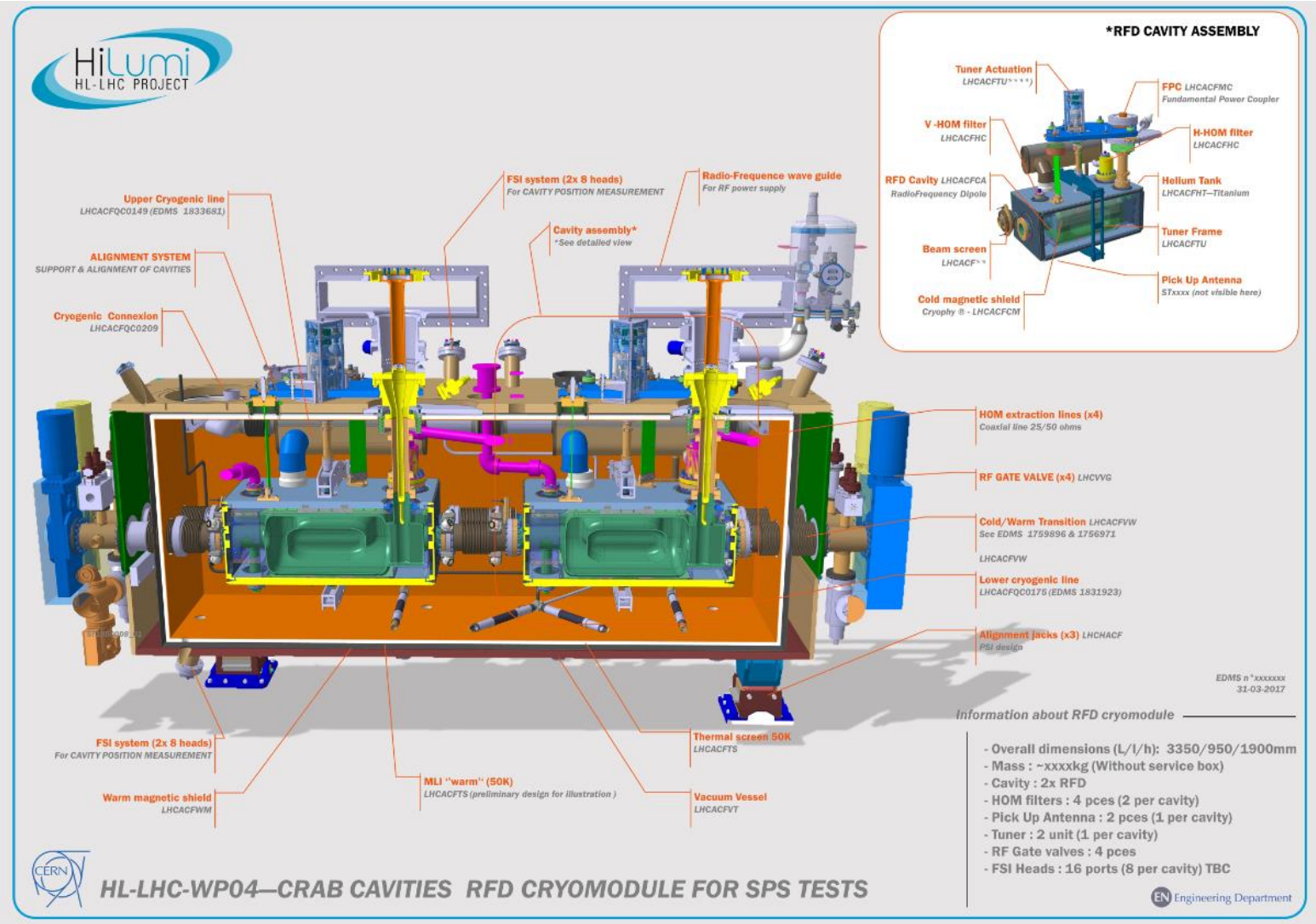


Particle Physics related R&D topics

- CERN program on HL-LHC:
  Crab cavity cryomodules, long range beam-beam interaction simulation studies, wire compensation
- Fundamental TRIUMF R&D on targets and remote handling technologies for neutrino production (e.g. Dune, Hyper-K)
- Polarized beams – Super KEKB
  Spin dynamics, preserve spin polarization
- Extend involvement in the TESLA Technology collaboration (TTC)
  – deputy chair is Bob Laxdal
  R&D on new SRF materials, towards high gradients and high Q-values
- Potential contributions to future machines, e.g ILC and FCC-ee/FCC-hh
  → SRF and beam physics

HL-LHC Crab Cavity Cryomodules

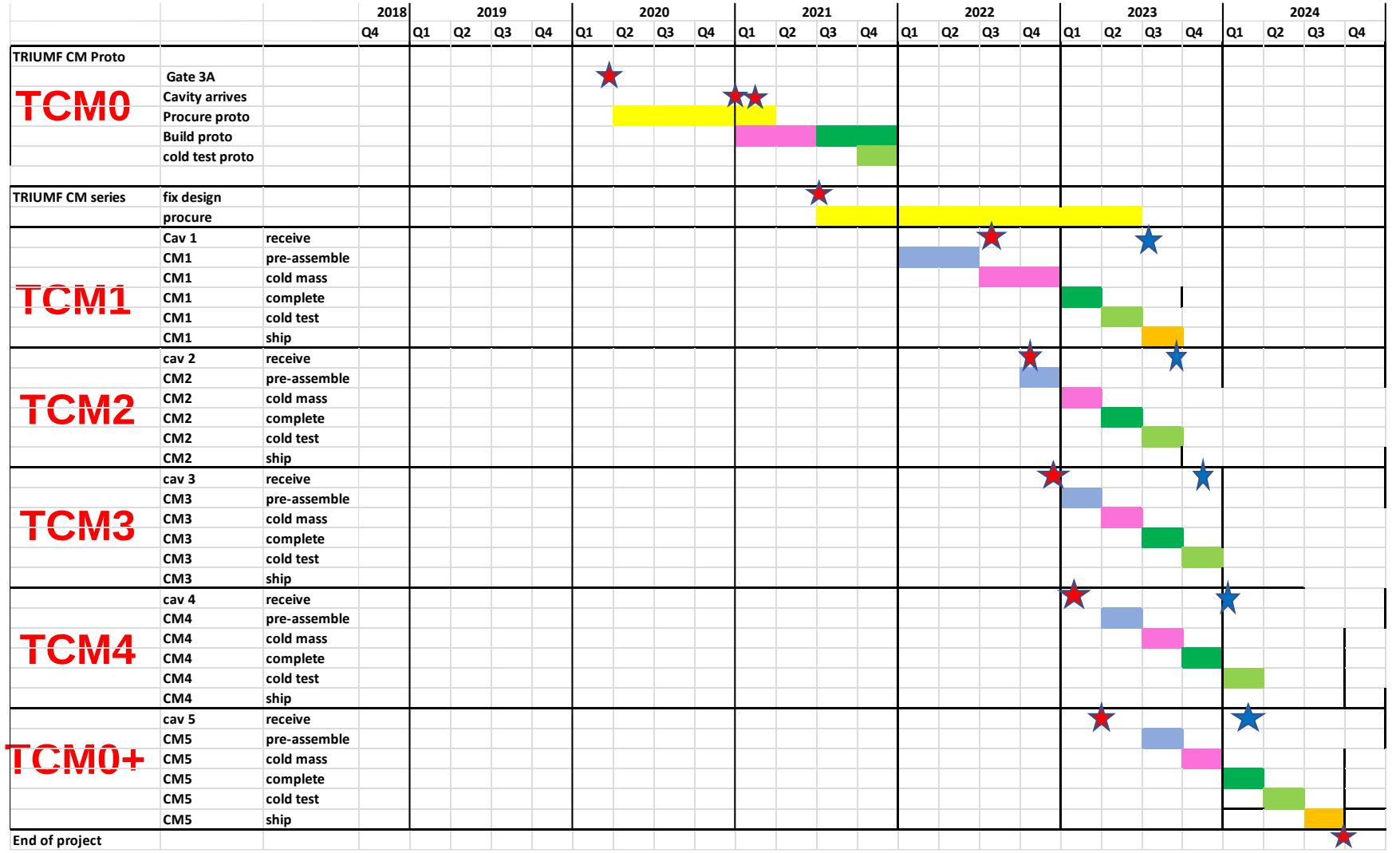
- TRIUMF to receive 10 RF-Dipole (RFD) resonators produced and qualified by US DOE lab consortium (AUP), to assemble each pair of RFDs into five cryomodules
- TRIUMF to qualify the cryomodules through testing at TRIUMF before packaging and shipping to CERN (Project leader – Bob Laxdal)
- The project advances Canadian core competencies in superconducting rf technologies.
- The project supplies critical infrastructure to CERN, supporting both the HL-LHC and the Canadian IPP community



Proposed schedule

TRIUMF will begin the fabrication of a prototype module (TCM0) in 2021

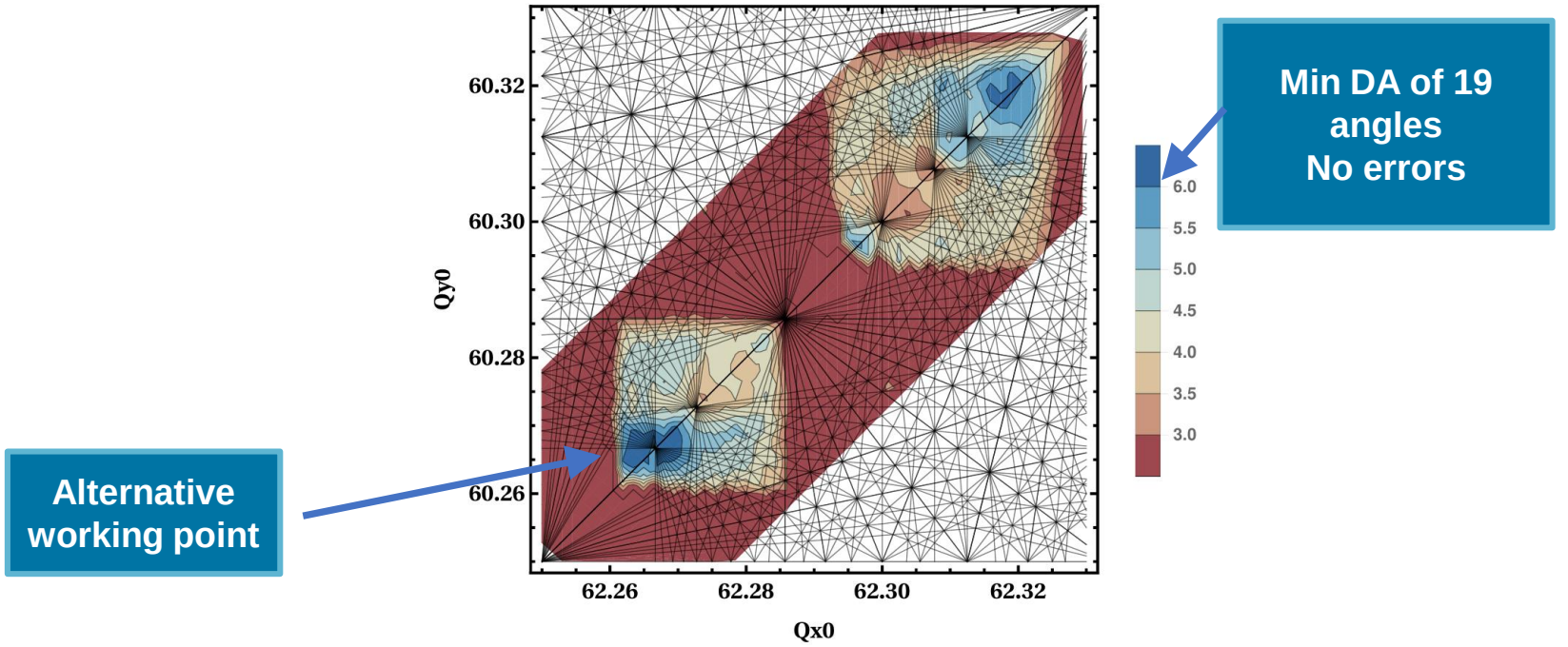
The five production modules will be completed in 2022-24 timeframe.



Beam physics contribution to HL-LHC

- Beam physics studies (Dobrin Kaltchev, Rick Baartman) focus on the general understanding of the impact of resonances to the choice of the optimal working point at collision.
  → HL-LHC optimization of the dynamic aperture (DA) at collision including the option of flat optics and investigations of wire compensation

Wide-range tune-scans for HL-LHC - resonances plot.
Search for alternative working points in tune space.



Additional beam physics and potential hardware contribution to HL-LHC

- Beam-Beam Long-Range effect compensation / correction with physical wires, running high currents, are considered a valuable options for HL-LHC to increase dynamic aperture at small crossing angles
  - either in conjunction with Crab Cavities (HL-LHC round optics)
  - or as back-up solution (reducing the number of crab cavities to those that will be installed)

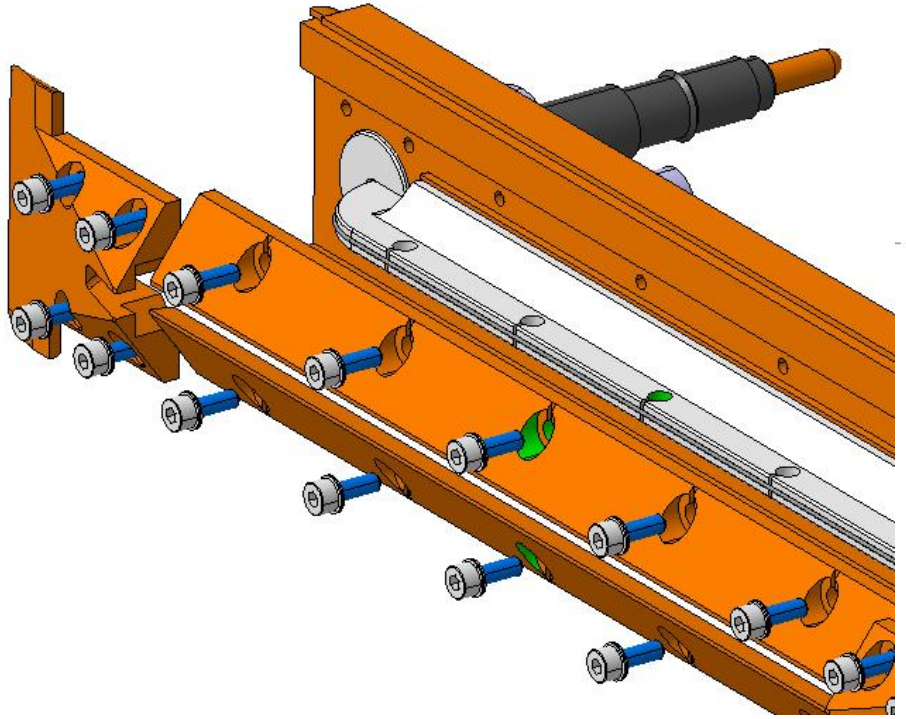
  → Tests with four wire prototypes in LHC have demonstrated the potential of a wire corrector
- Dobrin Kaltchev in the TRIUMF beam physics department does modelling of the wire compensation of the long-range beam-beam effects in the LHC.

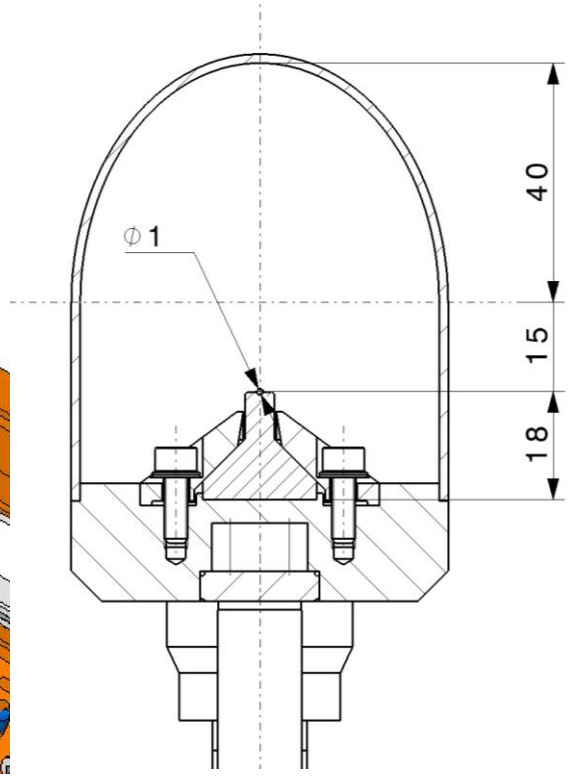
  He could show (for the first time) with his Hamiltonian based beam physics model why the compensation of the long-range beam-beam effects works so well.

Low cost modular design (proposal) from CERN → reviewed by TRIUMF

- Insulator with wire is mechanically clamped to a Cu-based housing, via controlled-torque screws
- Cu clamps to be designed to minimize RF impedance
- Wire active length 1 m; several insulator modules to be assembled (250 ÷ 300 mm long)

Canada via TRIUMF could further develop the design and could provide the final wire correctors for HL-LHC!





Fundamental TRIUMF R&D for neutrino production e.g. Dune, J-Parc

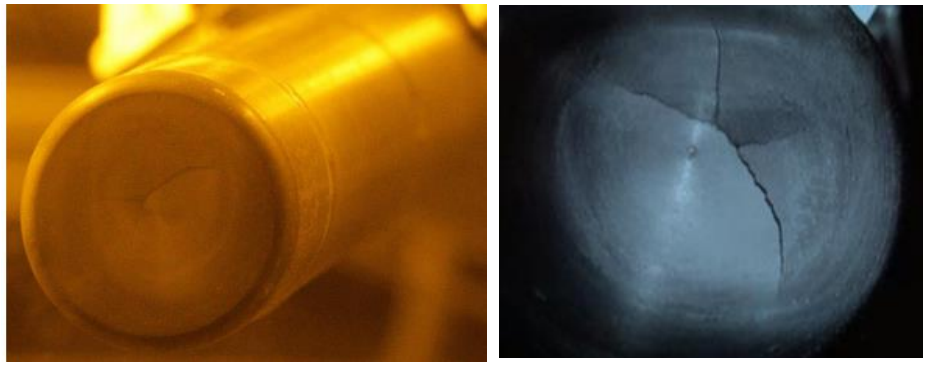
- Based on TRIUMF's previous contributions to T2K TRIUMF is well positioned to make contributions to LBNF and J-Parc in
  - beam diagnostics and remote handling (TRIUMF is internationally recognized for its leading role in remote handling, hot cell design and operation)
  - high power target technology (also beam windows) → Target Material research at TRIUMF

High thermo-mechanical loads from high power driver beams

+

Material aging due to radiation induced defects

Failure of essential accelerator components

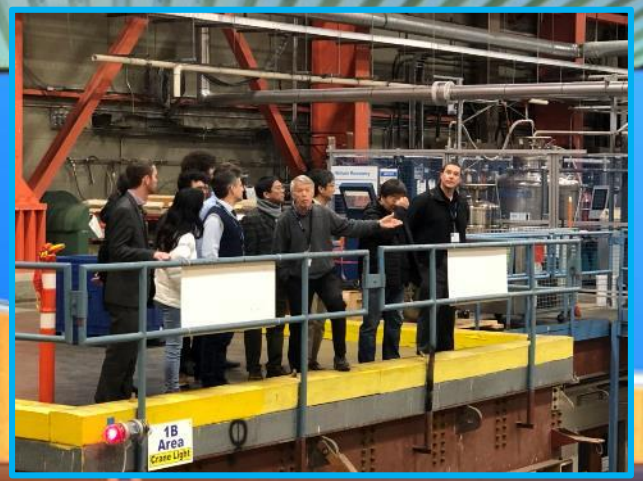


Proton beam window fractured due to He-embrittlement

Driver beam: 800MeV-40μA protons

- Contributions to PIP-II could include niche SRF applications such as a rf beam splitter cavity.
  → SRF Surface Resistance R&D (cw applications, Hadron linacs)

6th RaDIATE Collaboration Meeting



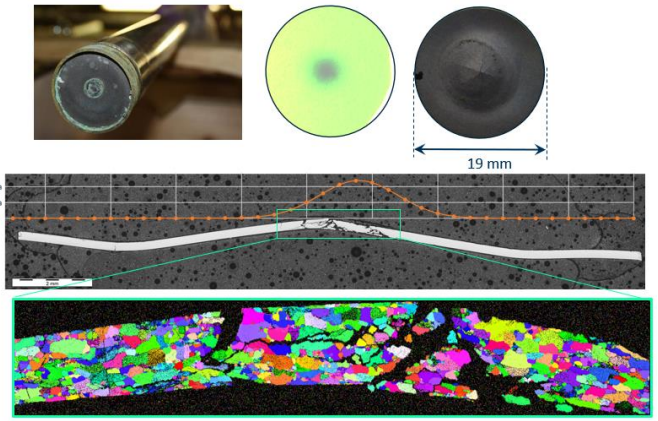
9-13 December 2019

- **33 presentations**
- **17 posters**
- **39 participants from 14 international institutions**

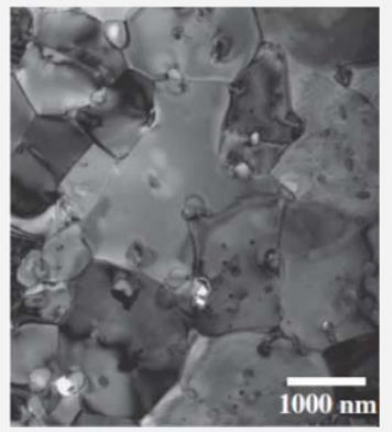
Expert tutorials

- Remote Handling of activated accelerator materials,
- TEM for radiation studies
- Monte-Carlo modeling of material radiation damage

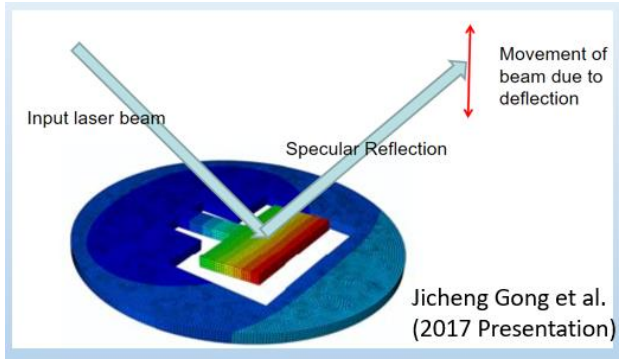
Beam window failure investigations



New Radiation-hard materials
TFGR W-TiC



New characterization techniques



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Radiation Damage in Accelerator Targets Environments

Potential future contributions to Future Machines ILC, FCC-ee FCC-hh

- Based on previous contributions to CERN, Canada via TRIUMF is well placed to contribute `in-kind' to future large global installations like ILC or FCC.
- Contributions would come most naturally from
  - SRF (cavities, towards high gradients, SRF material development) Novel fabrication techniques – utilize reactor grade Niobium, machined cavity from bulk and with TIG welding – First SRF cavity fully fabricated at TRIUMF
  - Beam physics (beam-beam long range interaction, DA, wire compensation)
  - Simulation for the optimization of the LHC collimation system by Dobrin is also requested for FCC-hh

  Contribution could also include beam diagnostics or beamline components

Example: Cavity Treatment High Gradient R&D (ILC)

Bob Laxdal

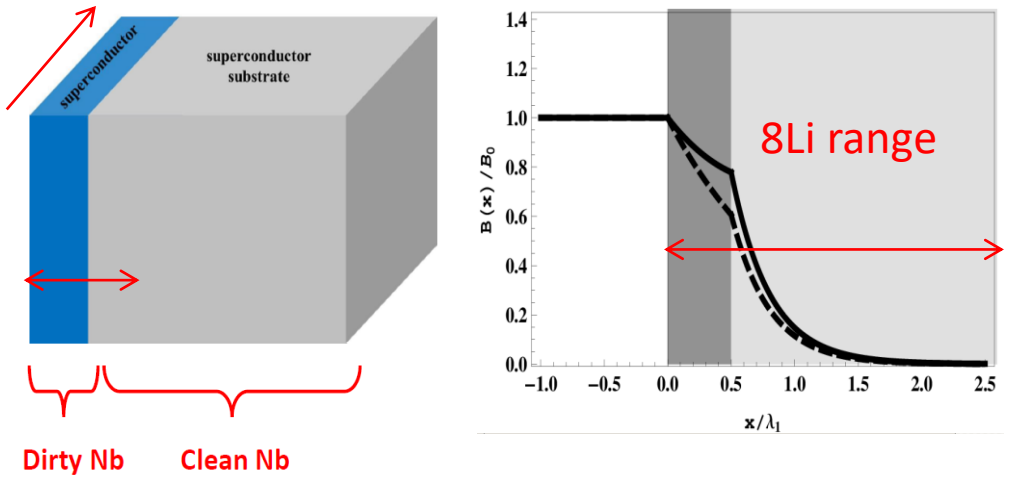
- **UHV RF induction oven** used to explore various **heating/doping** recipes
  - Designed to accommodate single cell and multi-frequency coaxial resonators
  - Couple this program with fundamental studies using μSR and β-NMR
- Developing **vertical electropolishing** with Teflon stirrers to augment doping effort

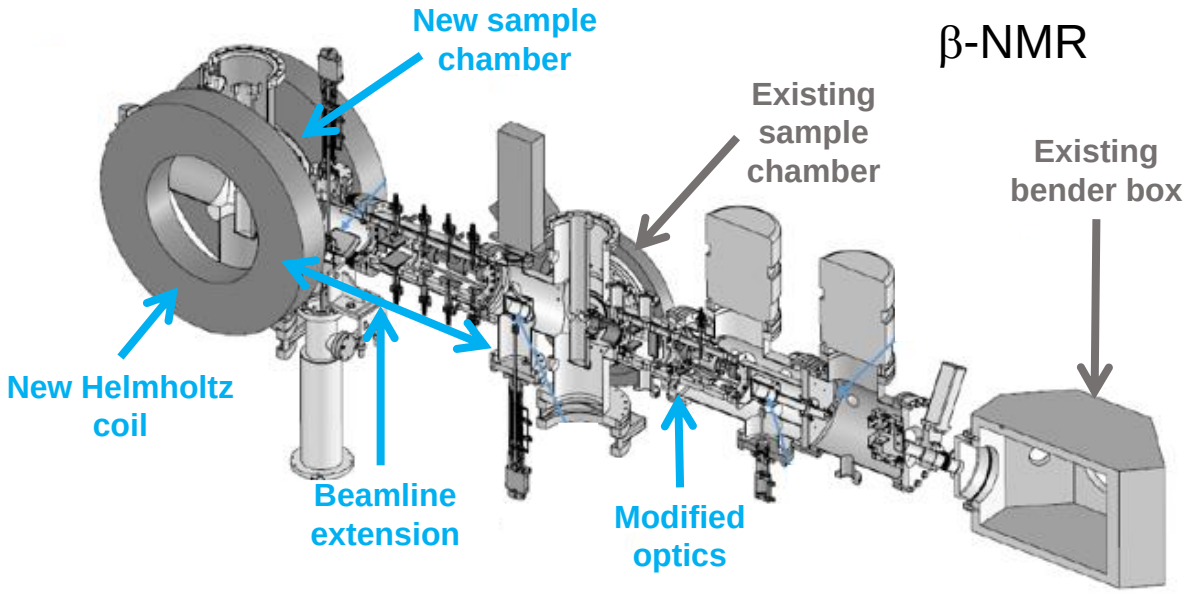
Induction Furnace

Vertical EP

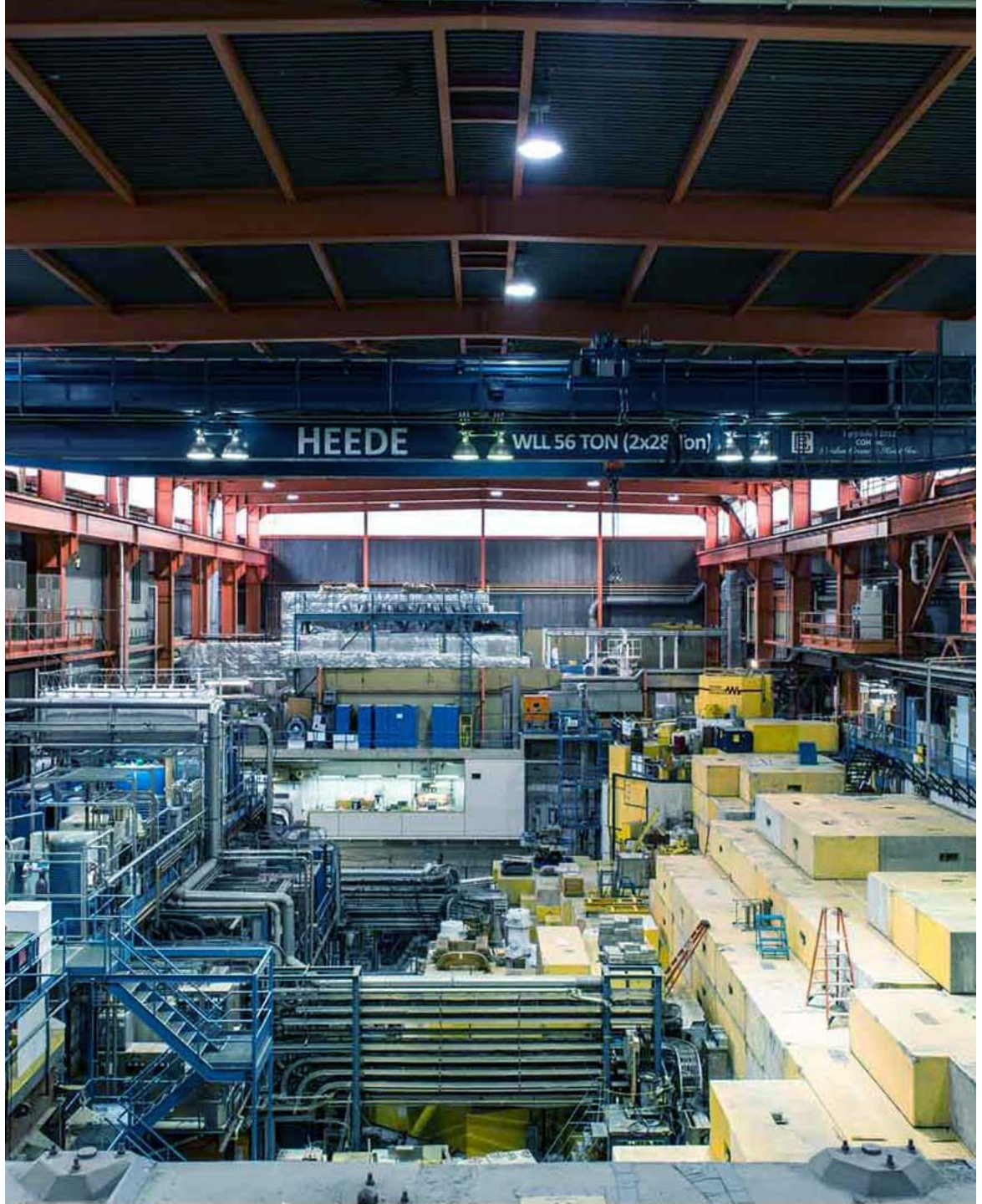
Example 2: Material Science Probes at TRIUMF – muSR and β-NMR

- TRIUMF has two world class material science probes in muSR and betaNMR – the TRIUMF SRF group have used both to shed light on the breakdown fields for SRF application (Tobias Junginger)
- New surface treatments aimed at engineering a `dirty' Nb (doped) surface layer to shield bulk from high surface currents to extend peak field (ILC)
- **New beamline in beta-NMR allows testing doped Nb and new materials to push towards higher gradients**





General Accelerator R&D at TRIUMF, training of HQP and ACC Sciences in Canada



General ACC R&D and projects

- ACC science education in Canada (with Uvic, CLS, Fedoruk centre and McMaster, U of T)
- Model based beam tuning, HLA development, machine learning
- Polarized beams in ring accelerators, spin dynamic (SUPER KEKB, EIC)
- Beyond RF: Ultra high gradient acceleration – AWAKE
- E-linac related FEL research for production of IR and THz radiation
- High intensity proton driver linacs – neutron sources, medical accelerators

ACC science education in Canada

- Canada needs highly qualified personnel trained in Accelerator Sciences. The goal is in the mid and long term to strengthen the education in ACC Sciences.
- UVic has one faculty position in accelerator physics and five adjunct professors from the TRIUMF accelerator division. T. Junginger, O. Kester, R. Laxdal, R. Baartman, A. Gottberg, S. Kocielniak
  Two UVic particle physics faculty members are also involved in accelerator research and education.
- TRIUMF has also adjunct faculties in ACC Sciences at Saint Mary's University, SFU, University of Manitoba and Western University.
- The number of student research projects in Accelerator Sciences at TRIUMF is growing and has reached now 17 graduate students from the associated universities.

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.
  - Last year 14 students from UVic, UBC, UCalgary have taken this class for credit. Up to 10 additional students have audited some lectures.
- Additional courses are planned in the future together with USask.
- CLS machine director Mark Boland is associate professor at the University of Saskatchewan
  - An undergraduate class and research projects for graduate and undergraduate students are offered.
  - TRIUMF an CLS will bring the Joint Accelerator School to Saskatoon in 2022.

Organize the ACC Science community in Canada long term

- We started the discussion at the CAP congress to organize the particle accelerator community in Canada
  → including organizations that run particle accelerators
- TRIUMF and CLS got in touch with the Fedoruk centre, McMaster University, University of Toronto, University of Calgary and University of Montreal
- We collaborate with potential future hosts of particle accelerators in Canada.
- TRIUMF and CLS are well positioned to convince the community to self organize and to strengthen education and training in the period of the next LRP 2022-2026.

TRIUMF

Thank you
Merci

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Backup slides

TRIUMF

TRIUMF accelerators

- Serve a broad scientific and applications program producing muons, neutrons and rare isotopes.
- Provide world's highest driver beam power for the production of rare isotopes.
- Enable science that is world-class in accelerator physics and technology.

TRIUMF Remote Handling

TRIUMF is internationally recognized for its leading role in remote handling, hot cell design and operation.

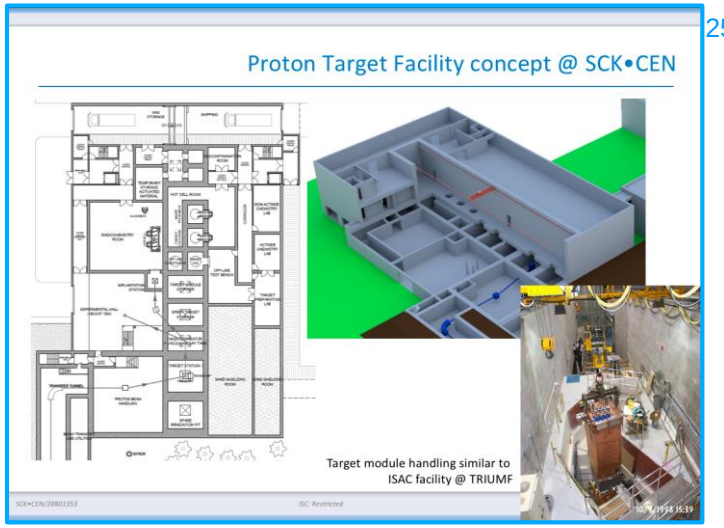
RH robotics development

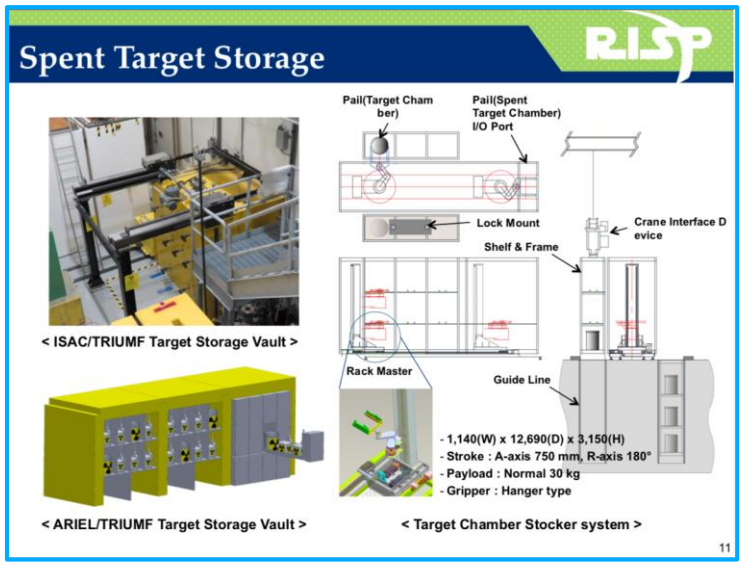
TRIUMF RH specialists assisting in T2K target repair

2025 remote handling vision

- **Full hands-off control of all routine RH activities**
- **Reduce dose and inefficiencies**
- **Reinforce world leadership in RH**
- **Development technology for Canada and the world**

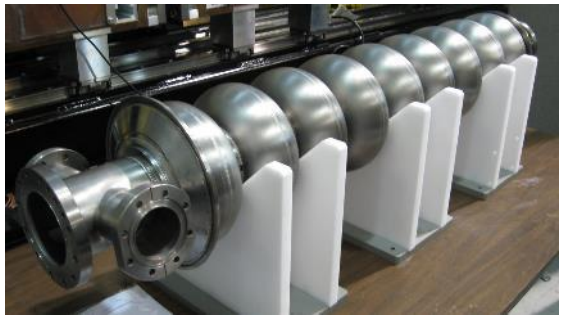
Examples of international designs based on TRIUMF RH:





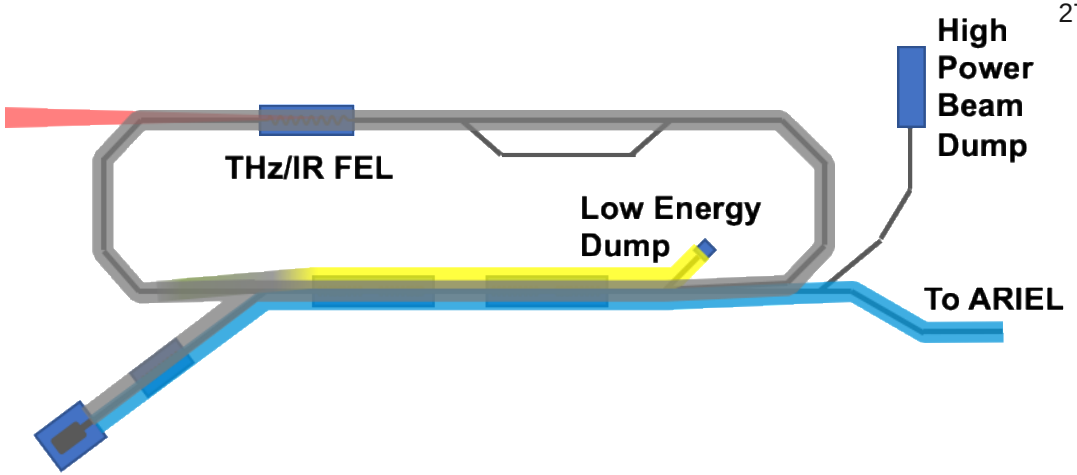
TRIUMF SRF Infrastructure

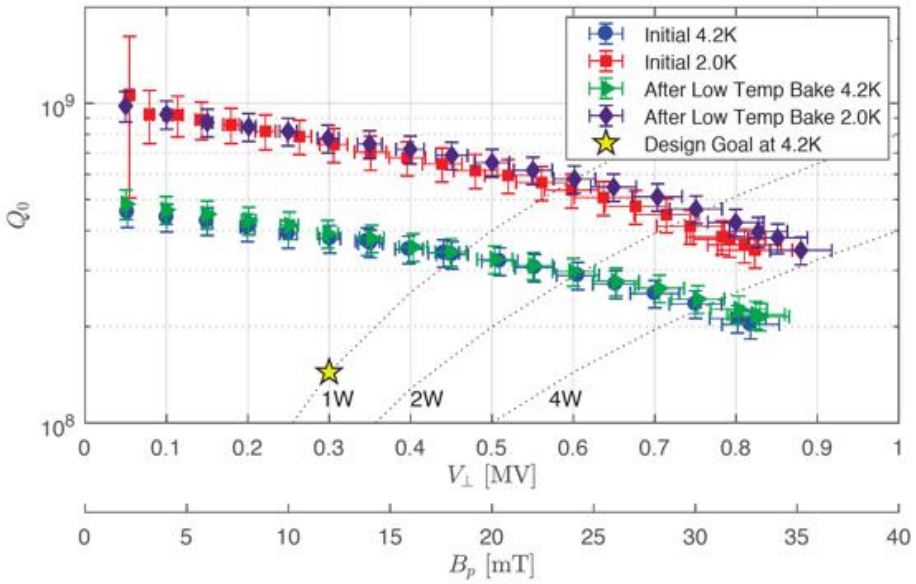
- TRIUMF hosts two SRF linacs and SRF supporting infrastructure.
- Activities range from student R&D on test resonators, to work for others (prototyping cavities and components) to full cryomodule assemblies
- For student training and R&D we have added
  - UHV RF induction oven
  - Coaxial test resonators for fundamental studies
  - New high parallel field spectrometer for beta-NMR

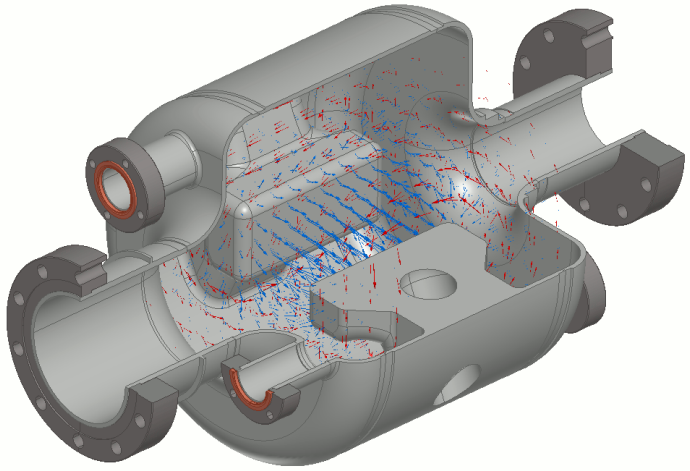


RF Separator Cavity (low cost fabrication - ILC)

- A new unique rf separator cavity was designed to allow ARIEL e-Linac to operate in recirculating mode
- Novel fabrication techniques – utilize **reactor grade Niobium**, **machined cavity from bulk** and **with TIG welding** – First SRF cavity fully fabricated at TRIUMF
- New techniques could lower fabrication costs **(ILC)**

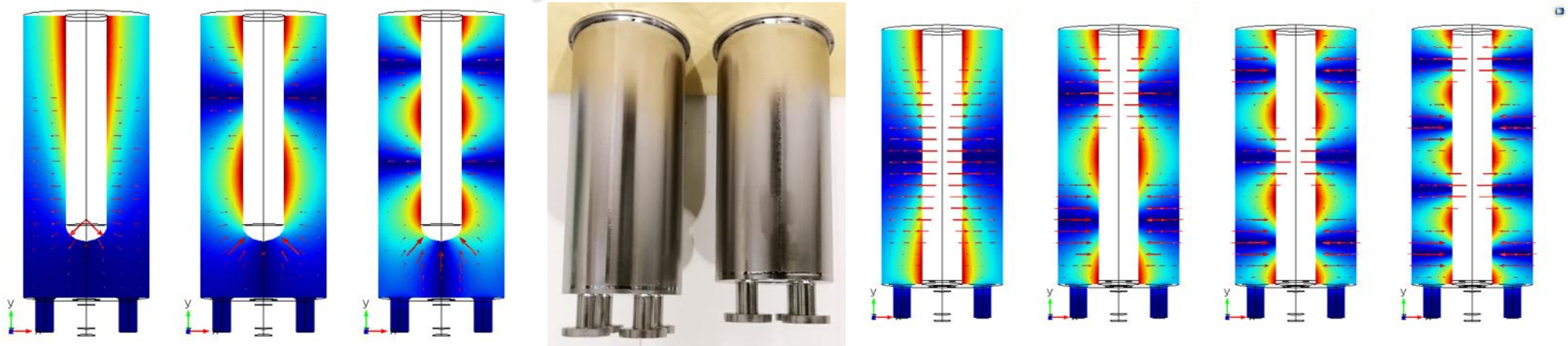






SRF Surface Resistance R&D (cw applications, Hadron linacs)

- Hadron accelerators rely on high performing SRF TEM mode (coaxial) resonators but most development has concentrated on elliptical 1.3GHz cavities (ILC)
- TRIUMF has commissioned two coaxial resonators for optimization studies
  - What is the **role of RF frequency** on field dependent resistance
  - What are the **optimum treatments for low frequency cavities**
  - How does detrimental flux trapping differ in TEM mode cavities
- **Impact for hadron linacs, cw linacs (ie EIC, PIP-II)**



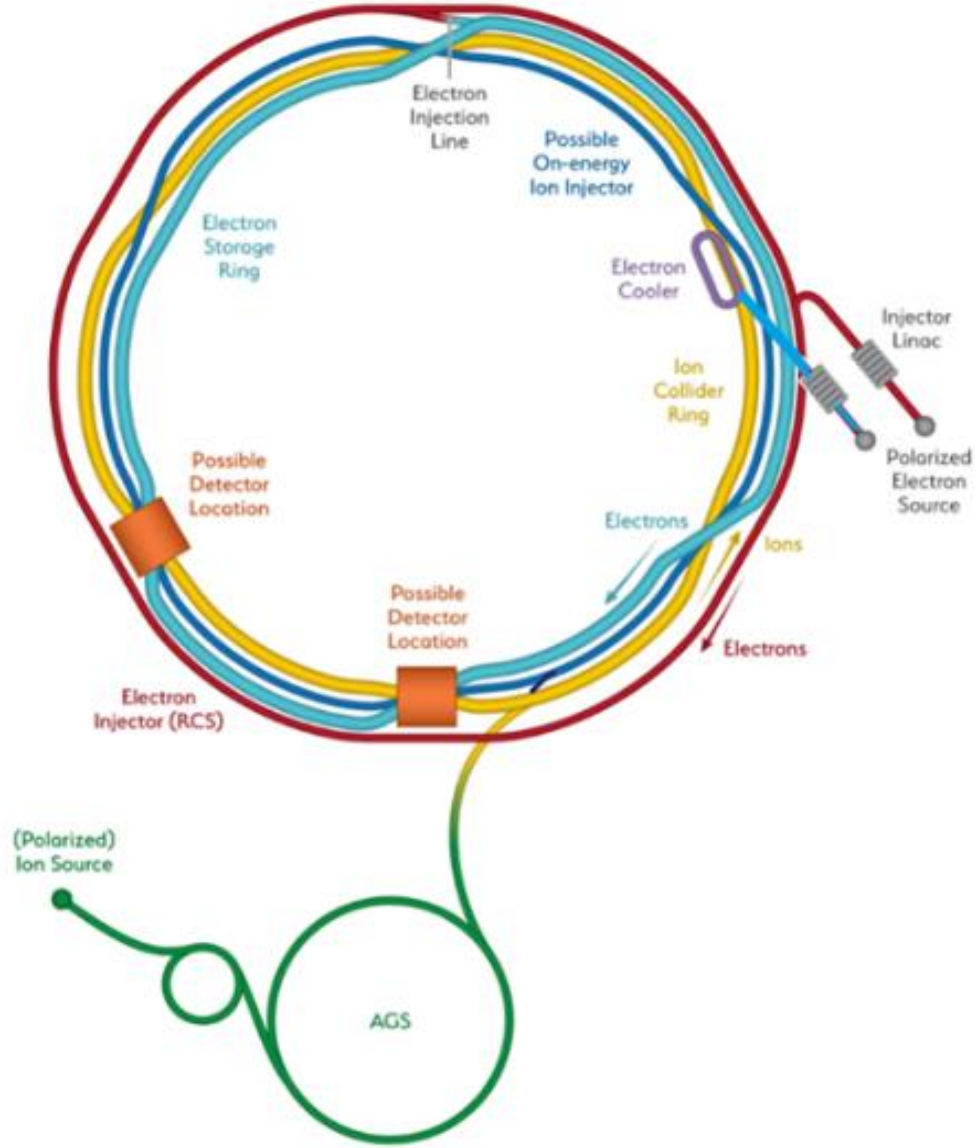
Overlap with Nuclear Physics related topics

- EIC related work
  - SRF - crab cavities, RF-deflectors, ERL technology for beam cooling, high brightness electron gun
- General consideration to increase intensity and quality of Secondary beams
  - high power targets, ion sources
  - Remote handling technologies
- Boost of ISAC-II energy beyond 20MeV/u

  Stripping foil after existing linac + high performance (gradient) cryomodule

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 polarization, SRF, hadron beam cooling and according ERL technologies
- TRIUMF is well positioned to contribute Canadian `in kind' accelerator components or systems
- Such contributions could be
  - in SRF/RF (crab cavities and/or modules)
  - beam physics (including polarized beams), diagnostics
  - high brightness electron gun,
  - ERL technology



The Accelerator science research program – summary

- Beam physics and instrumentation
  - Intense beams, modeling - space charge effects, beam-beam effects
  - Particle sources, automatic beam tuning, beam instrumentation
- Superconducting RF and RF
  - SRF cavity development – RF-separator, cavity processing – towards higher gradients
  - Reduction in production complexity and reduced cost material choices
    → new balloon type single spoke resonator
  - New processes and material investigation with μSR and βNMR.
- Target Material and Target ion sources
  - Target materials and convertor technology
  - Optimization of beam extraction
  - Laser ionization schemes
- Engineering Research and Development – Remote Handling
  - Beam line maintenance in high radiation fields
  - Target station technology – first ever online high-power target transfer system
  - High power target handling