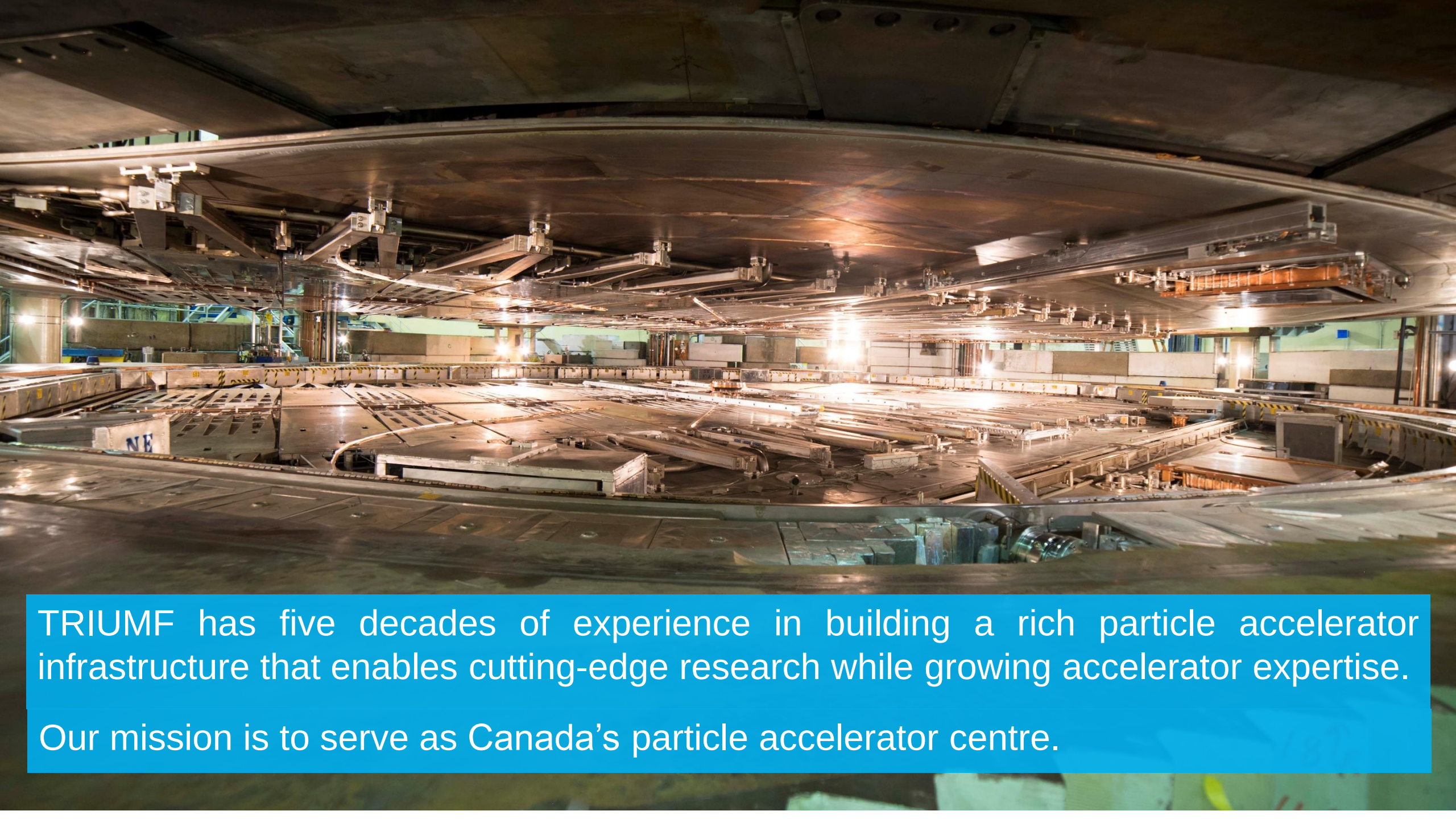
TRIUMF Accelerator Capabilities, Present and Future

Oliver Kester

Associate Laboratory Director – Accelerator Division

Developing New Directions in Fundamental Physics 2020

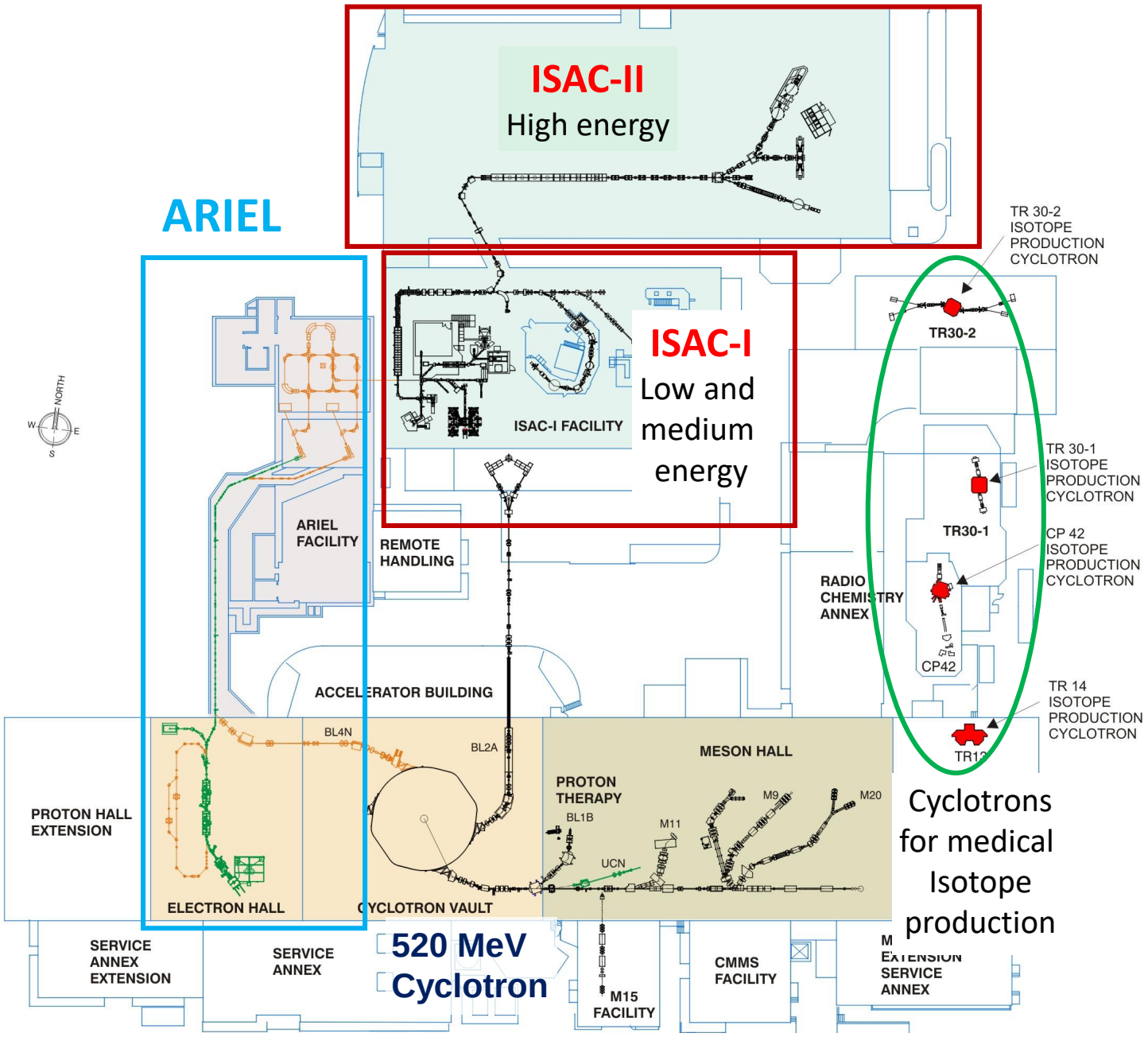
4-6 November 2020



TRIUMF has five decades of experience in building a rich particle accelerator infrastructure that enables cutting-edge research while growing accelerator expertise.

Our mission is to serve as Canada’s particle accelerator centre.

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

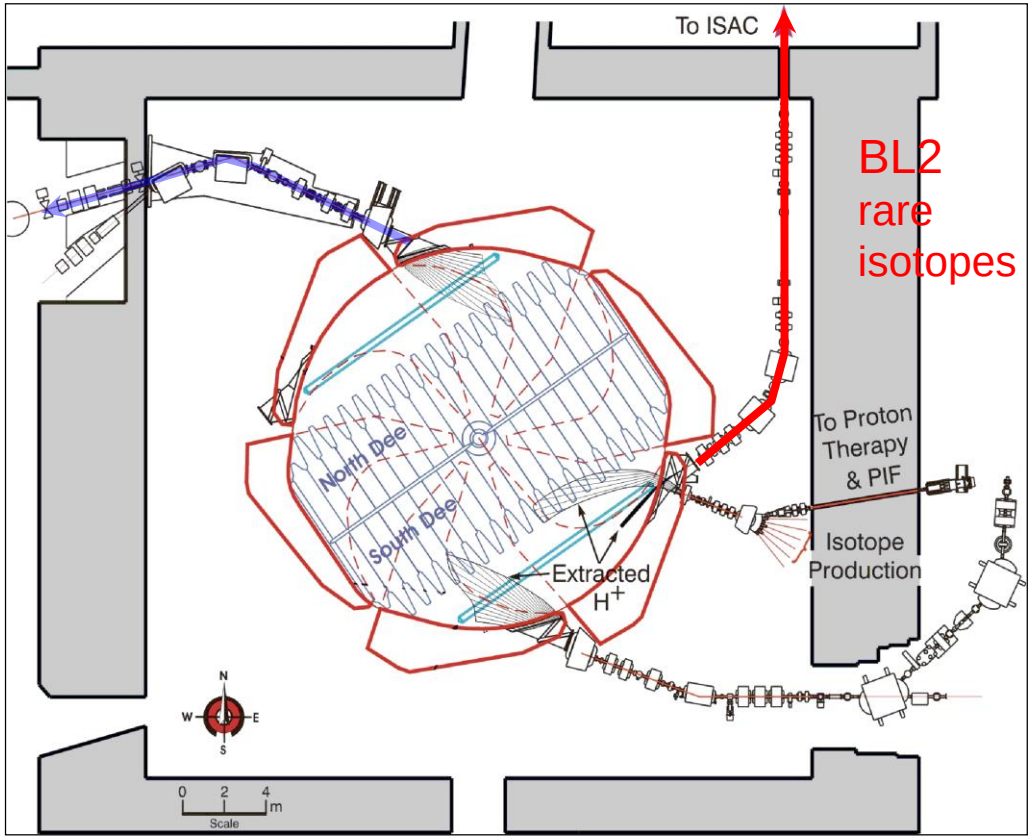
4 Cyclotrons for medical isotope production

- Our mission is reflected in the wide variety of accelerator technologies that populate the campus.
- Our strategy is to use internal projects and external collaborations as springboards to expand core competencies or gain new ones.
- Rather than import technology, we typically develop it, accumulating a broad expertise within a relatively small laboratory.

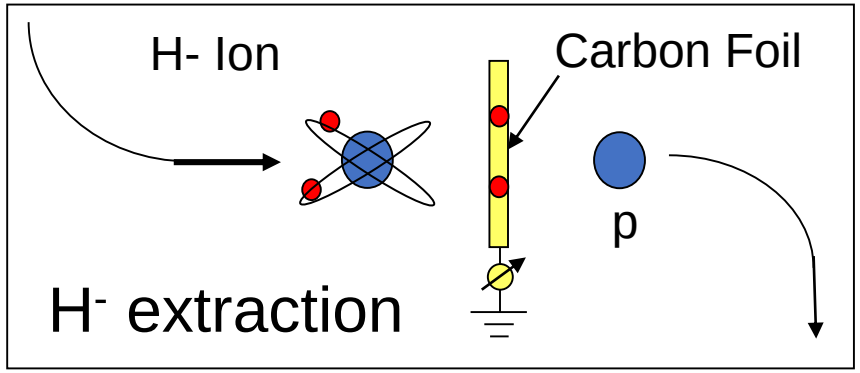
The 520 MeV H⁻-cyclotron

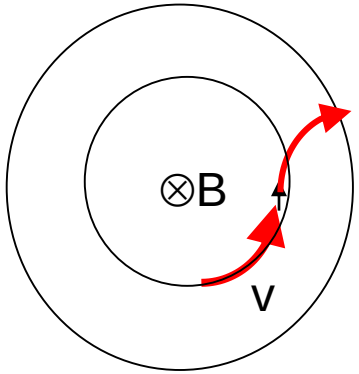
- Started operation in 1975 and is continuously upgraded.
- Largest Cyclotron in the world: D = 18 m
- Magnet weight: 4000 t
- Coil current: 18500 A
- Multiple high-power beams of different energies can be delivered in parallel
  → H^- stripping extraction

BL4
future rare isotope production



BL1
muons, neutrons, medical isotopes





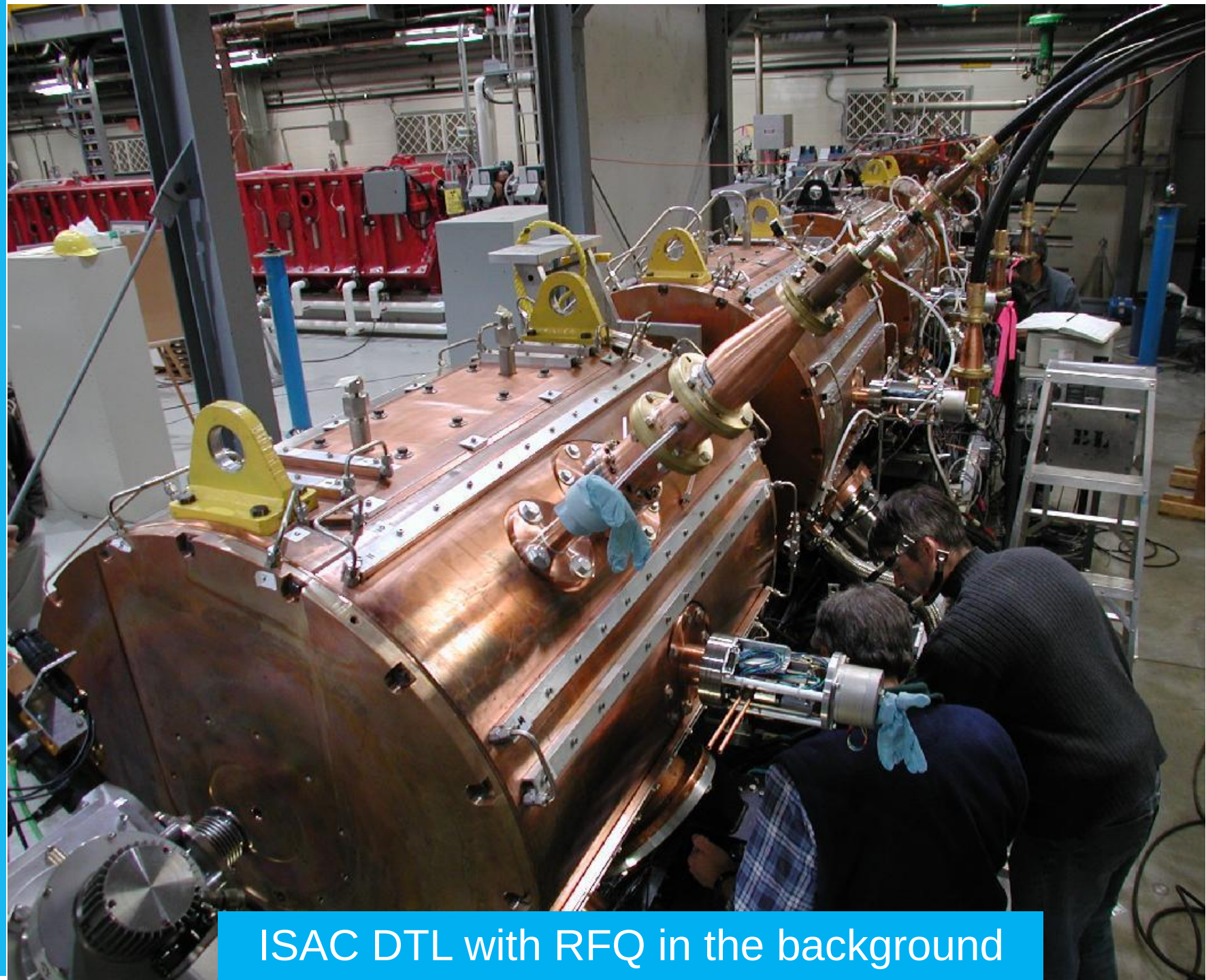
ISAC (1995 - present)

ISAC marked a renaissance for Accelerator physics and technology at TRIUMF

- high power RIB targets,
- ISOL ion sources,
- laser ion sources,
- beam diagnostics for low intensity beams,
- electrostatic optics,
- remote handling

ISAC Post accelerator (1995-2001)

- Room temperature linac design and fabrication for heavy ions
- ISAC RF Quadrupole
- ISAC Drift Tube Linac
- RF bunchers/choppers
- Low level rf (LLRF) systems
- High power rf-amplifiers



ISAC DTL with RFQ in the background

ISAC-II Post accelerator (2001-2010)

- Superconducting RF technology for heavy ions
- Cryomodule design and assembly
- Design and operation of cryogenic systems
- ECR Charge breeder

ISAC-II Cryomodule

ARIEL e-Linac (2008-2014)

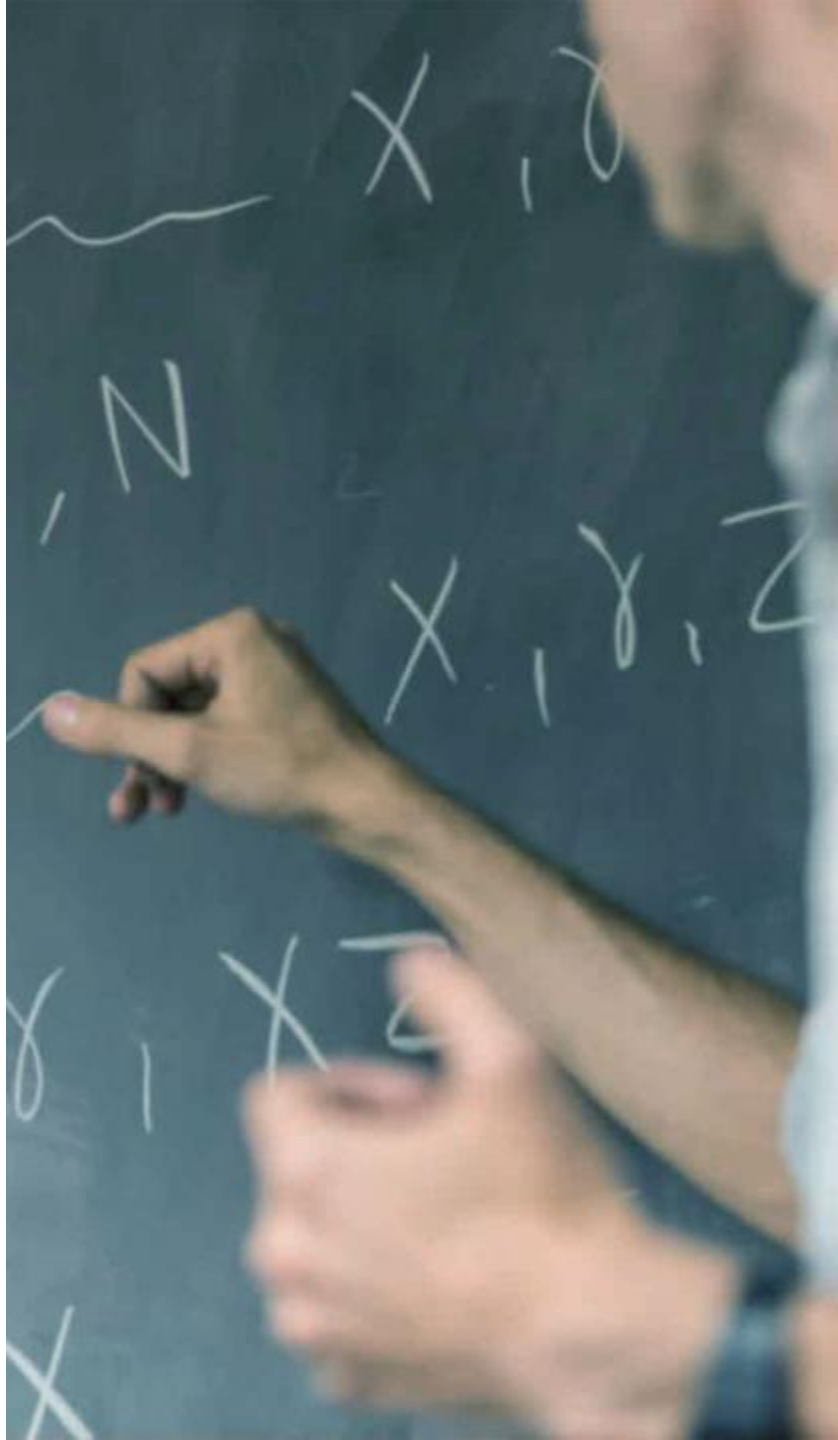
- Superconducting RF technology for electrons
- High Voltage DC gun
- Beam physics of high intensity electron beams
- High Intensity beam diagnostics
- High power klystrons

Accelerator science

- The legacy from this on-going development is diverse cutting-edge infrastructure and staff with expertise in a wide range of technologies
- 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.

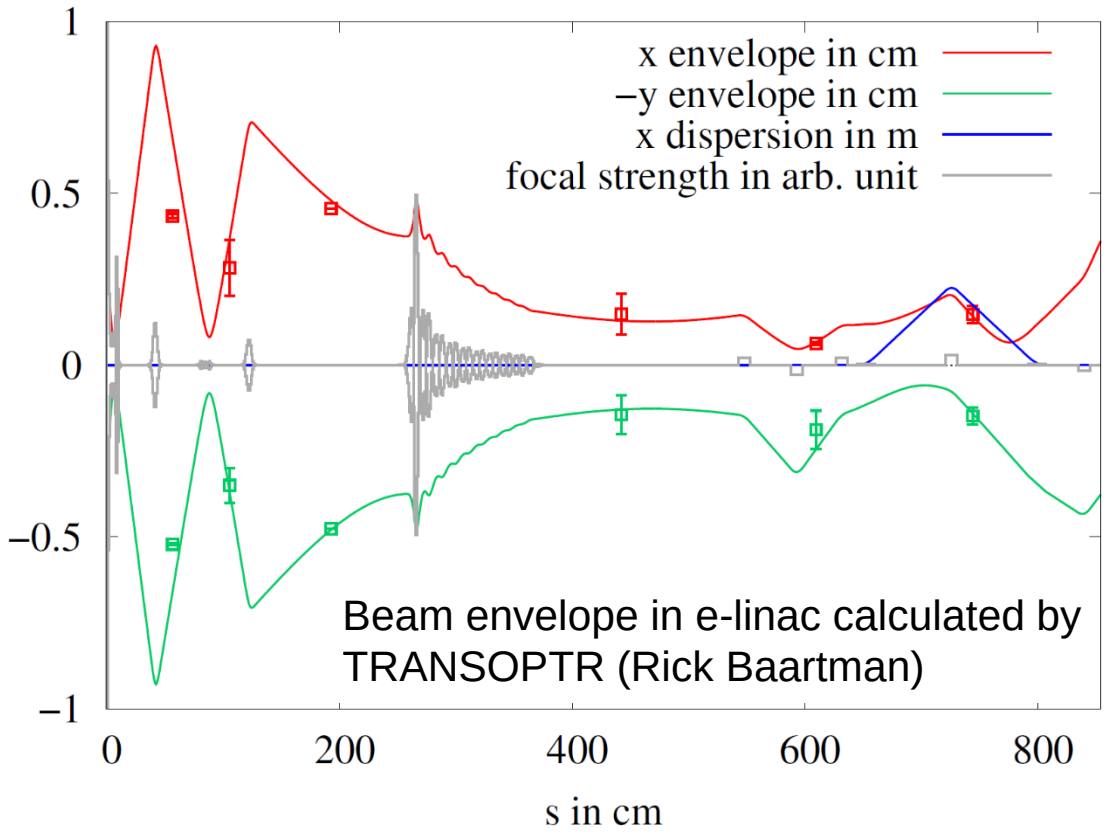
TRIUMF

The Accelerator research program



Beam Physics at TRIUMF

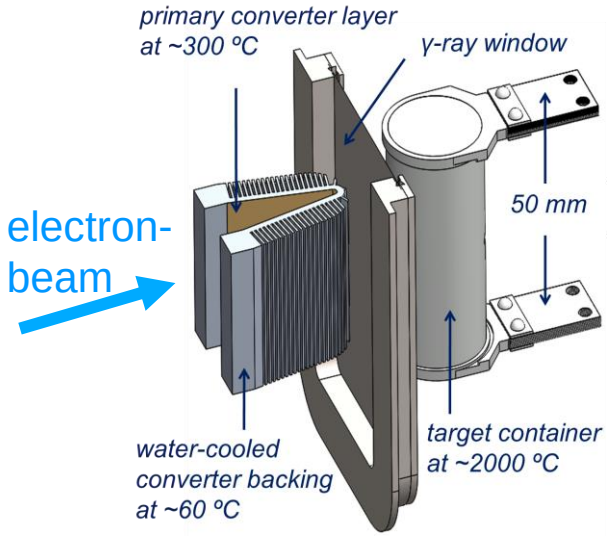
- Space charge dominated beams modelling
  - Reduction of beam losses and therewith reduced activation → less dose for maintenance personnel
  - In the future higher beam intensity in the H- cyclotron will be possible
    (possible application in medical cyclotrons)
  - High power beams in the ARIEL electron linac
- Develop a better understanding of ion sources, beam transport and the post accelerator chain by modelling.
- Reduce tuning and set-up time by providing tools
  → High level applications task force.
  - Model coupled beam tuning (provide set values)
  - Envelope Code allows visualization of tune changes with quadrupole strength, cavity amplitudes etc.
- Beam dynamics investigation in international collaboration - High-luminosity LHC

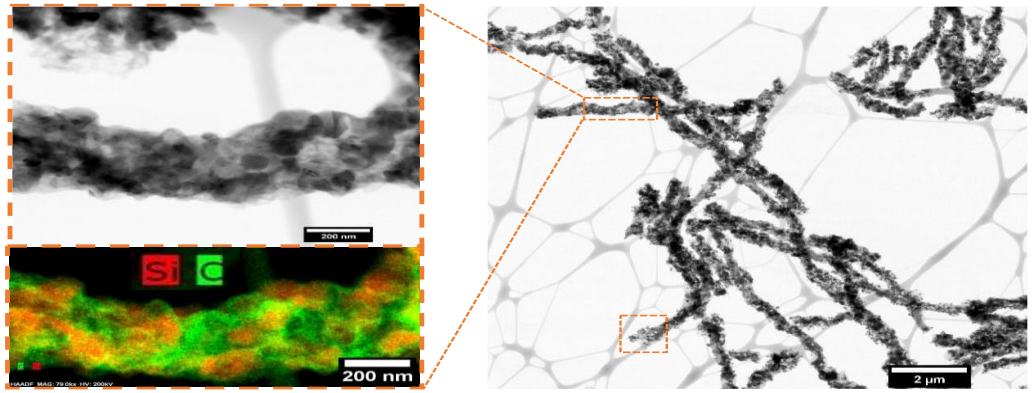


Thesis of P. Jung, P. Belanger, O. Shelbaya and S. Kiy

High power RIB production

- First ever high-power electron-gamma converter RIB production!
  - Converter target material tests with Ta and Au performed → feasibility demonstrated with Ta.
- Proton-to-neutron converter for intense and pure RIB beams
- Target ion sources
  - Towards non resonant ionization and compact Ti-saphire laser for "non-expert" operation
  - Multi-physics approach to understand the mechanism of production and extraction of ions in and FEBIAD Ion sources
- Target Material Research
  - Nanofiber actinide materials
  - Novel target material synthesis and conditioning





Thesis of L. Egoriti, M. Cervantes, F. Boix Pamies

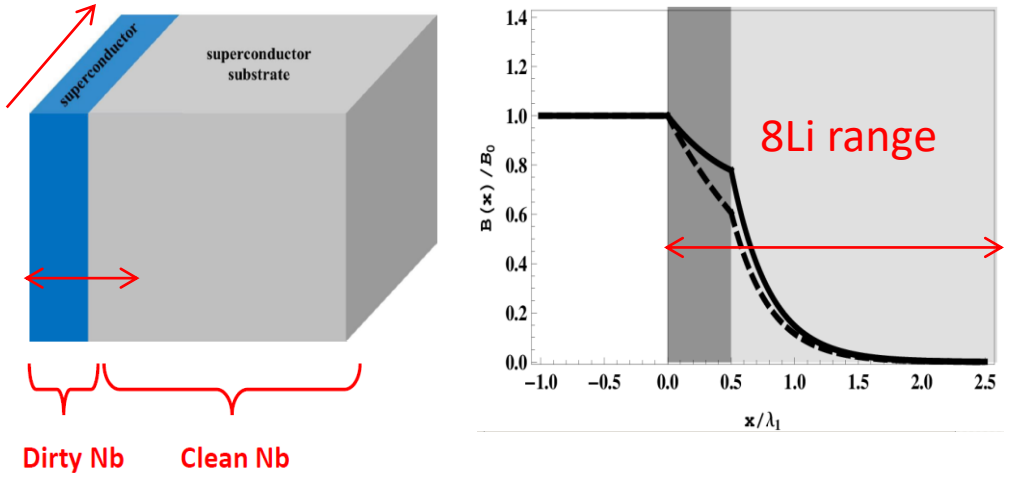
TRIUMF Superconducting-RF Infrastructure

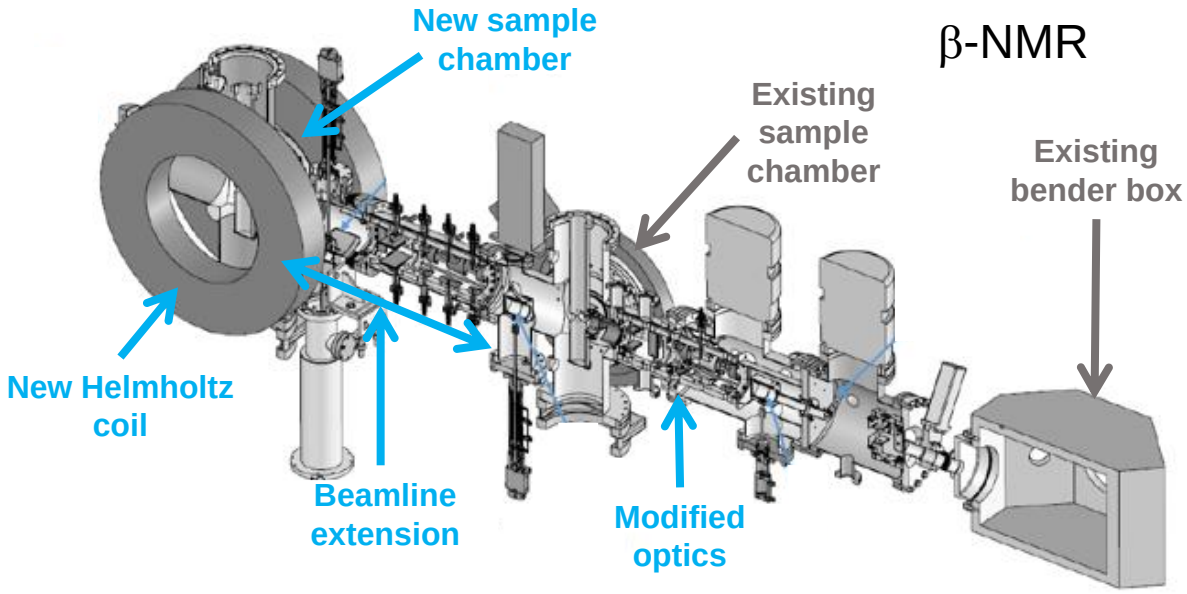
- TRIUMF hosts two SRF linacs (ISAC-II and electron-linac) and SRF supporting infrastructure.
- UHV RF induction oven used to explore various heating/doping recipes → designed to accommodate different cavity types
- Activities range from student R&D on test resonators, to work for others (prototyping cavities and components) to full cryomodule assemblies

P. Kolb (PDR)
Thesis of R. Gregory

Material Science Probes at TRIUMF – muSR and β-NMR

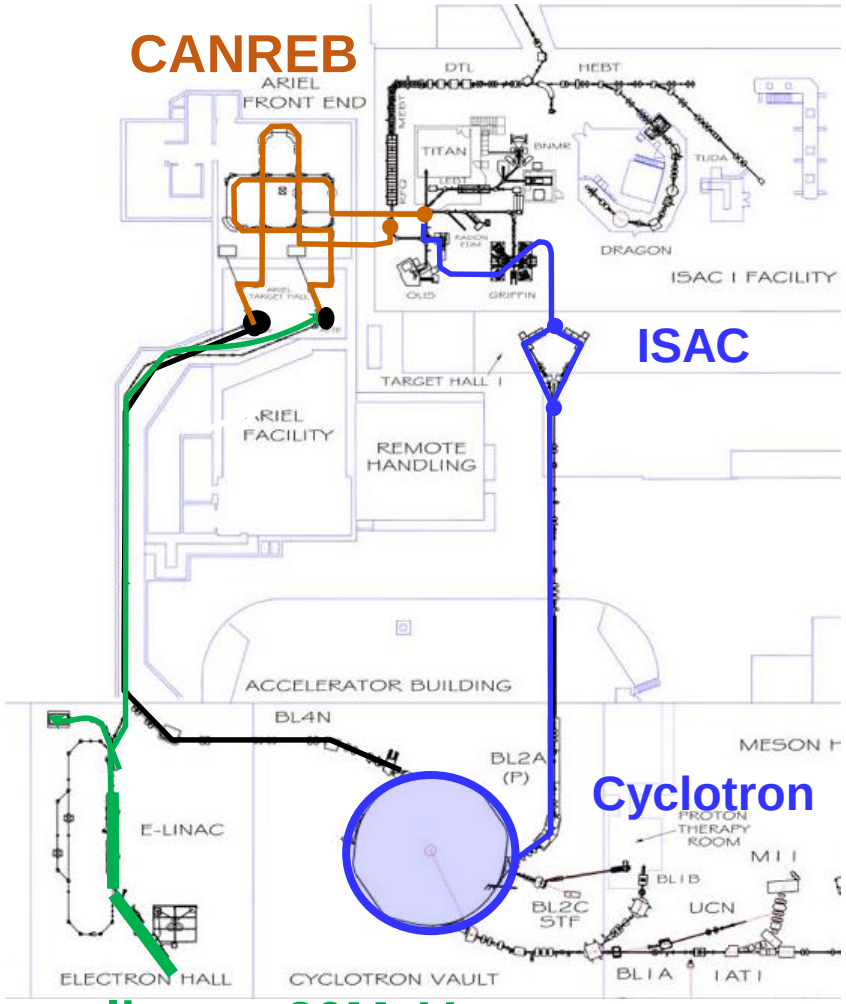
- TRIUMF has two world class material science probes in muSR and betaNMR – the TRIUMF SRF group have used both to shed light on the breakdown fields for SRF application (Tobias Junginger)
- New surface treatments aimed at engineering a `dirty' Nb (doped) surface layer to shield bulk from high surface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





Potential future capabilities and developments

Adding new capabilities - The Advanced Rare IsotopE Laboratory (ARIEL)



- A 30 MeV superconducting electron linac
  300 kW beam power cw, highest power in this energy range
- Two new high-power rare isotope target stations
  - New **100 kW** convertor target station
  - **50 kW** proton target station (with symbiotic target for medical isotope production)
- Unique beam preparation and transport system (CANadian Rare isotope facility with Electron Beam ion source (EBIS) - CANREB)
  - High resolution separator
  - Beam preparation with gas filled Radio Frequency Quadrupole and EBIS

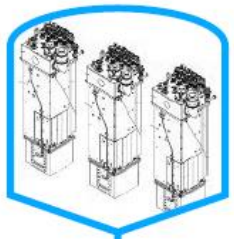
ARIEL the future

- ARIEL will be the combination of CANREB, e-linac, ARIEL-II, and ISAC and
- the only Ion Separation Online (ISOL) based multi-user rare isotope facility in the world and will increase our annual scientific productivity to 2-3 time its current level.
- It will guarantee our future leadership in rare isotope science and provide
  - more exotic isotope species
  - cleaner beams
  - higher intensities
  - more time for long experiments
- At the heart of ARIEL are the unique target stations producing rare isotope beams (RIB) driven by our superconducting electron linac in addition to the 520 MeV cyclotron.

ISAC Target Infrastructure Refurbishment Timeline






- UC_x material production ramp up ✓
- New Target Hall Engineer ✓
- New Target Chemist ✓
- Lift UC_x 10 µA limit ✓
- TM2 source tray ✓
- TM4 source tray ✓
- Source tray assembly line
- Relax spent target disposal limits ✓
- TM3 refurbishment
- May 2021
- TM5 source tray design
- TM5 design complete

Q1 Q2 Q3 Q4 | Q1 Q2 Q3 Q4 | Q1 Q2 Q3 Q4 | Q1 Q2 Q3 Q4 … Q1 Q2 Q3 Q4 …

2018

- Completed TM3 investigation ✓
- New Target Hall Technician ✓

2019

- Overall Target Hall Reliability Analysis ✓
- North Hot Cel (NHC) ✓
- Safe module parking (SMP) ✓
- New source tray design
- April 2020

2020

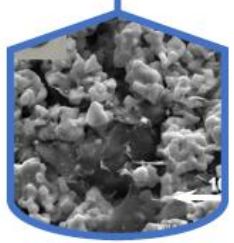
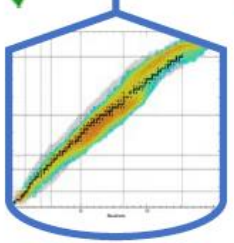
- Ongoing
- Inventory of critical target module spare parts

2022

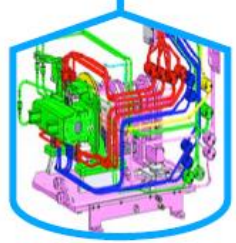
- Regular refurbishment program with 3 modules in full swing
- Start in 2021

2025+

- TM5 drawings package complete

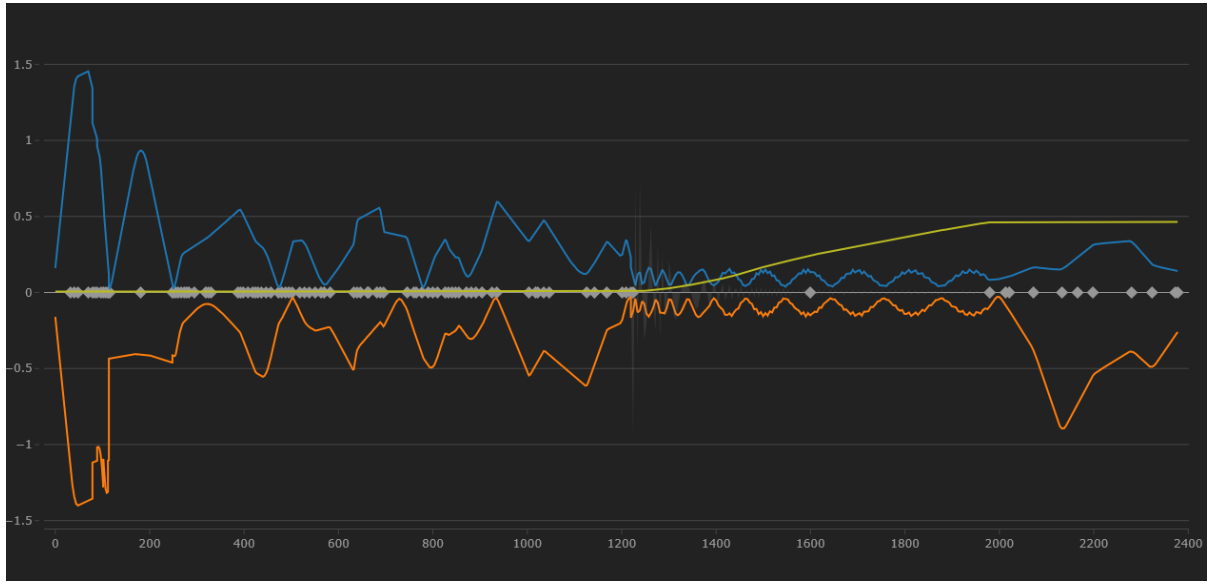


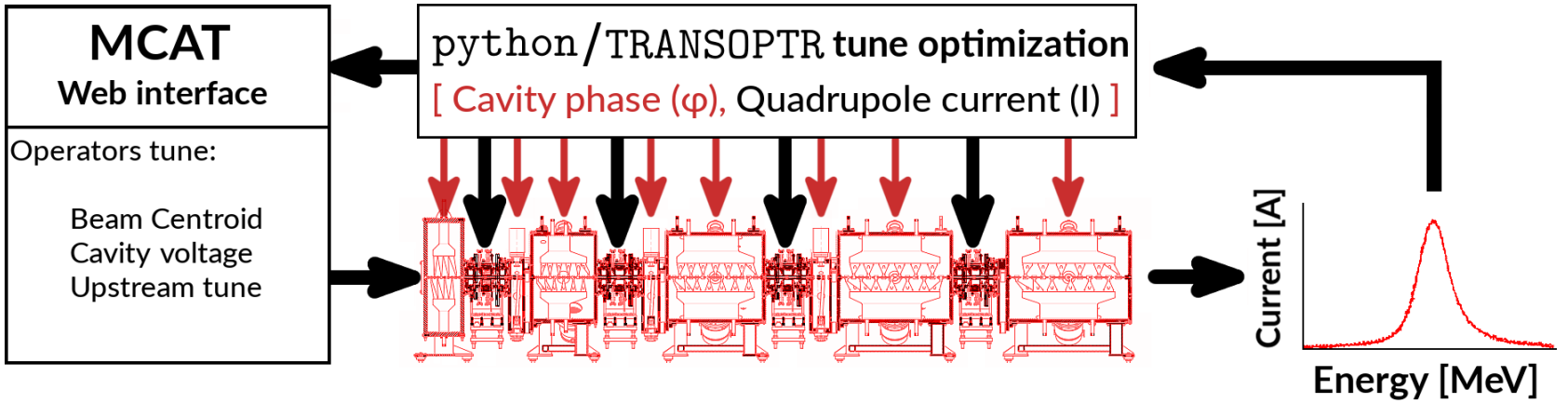



The future of beam development and delivery
Model based beam tuning, machine learning

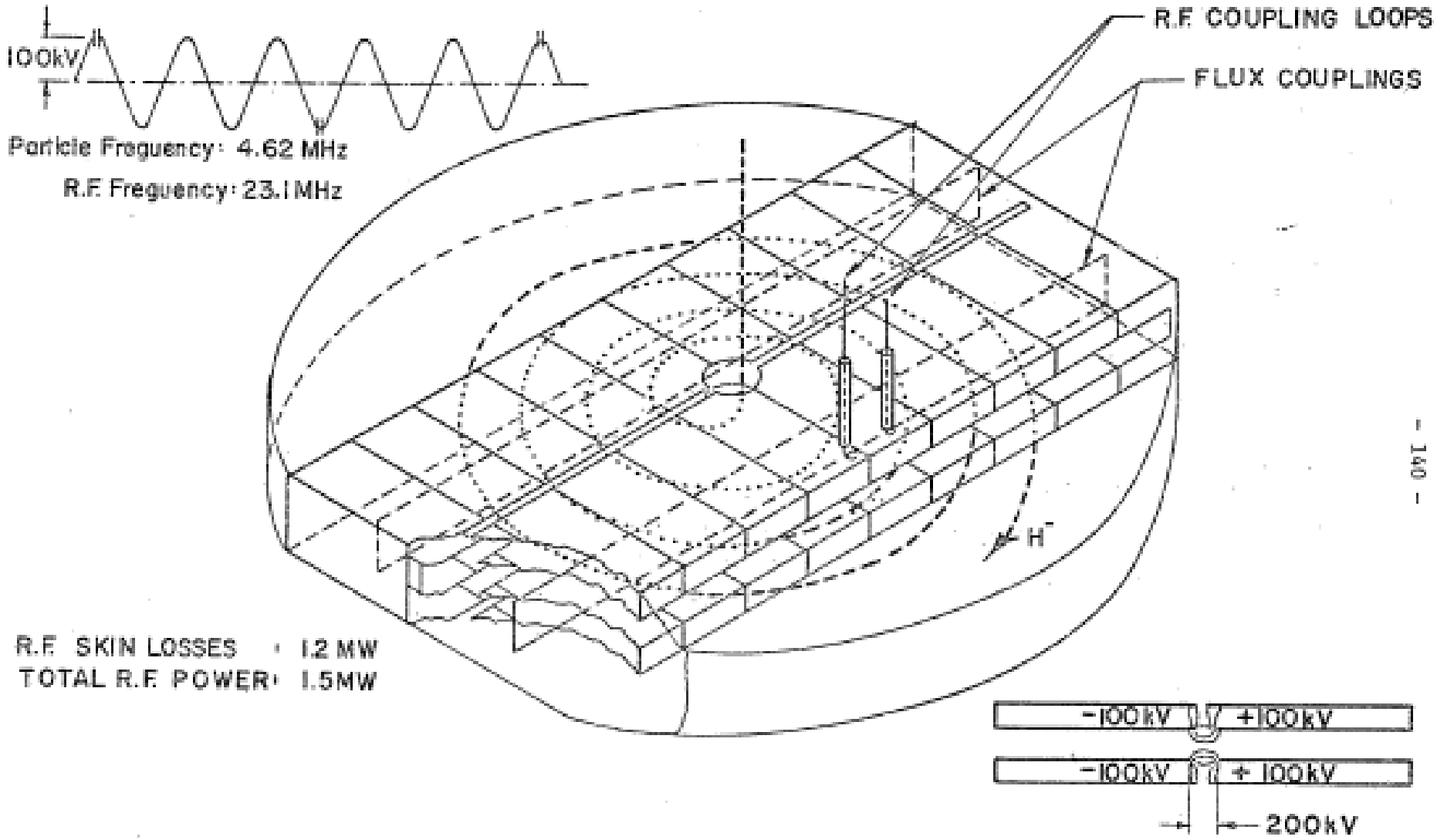
- TRIUMF beam physics department has developed a web-based python interface to communicate with accelerator control system for High-level applications (HLA).
- Example: Model Coupled Accelerator Tuning (MCAT) → All of TRIUMF's accelerators and beamlines converted to model-based tuning.
- Base for MCAT: TRANSOPTR, a Hamiltonian based 6-D envelope code which can optimize accelerator tune and allow for automatic beam tuning in the future

→ Explore the possibilities offered by Machine Learning in Accelerator Operations.





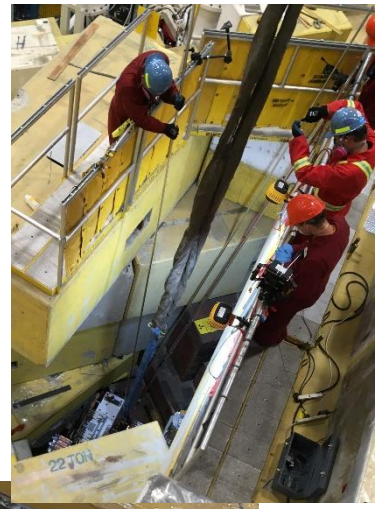
The cyclotron rf was designed for 100kV but has never been operated there. We will engage in a study to find out the limits of the system with a plan to safely raise the voltage.

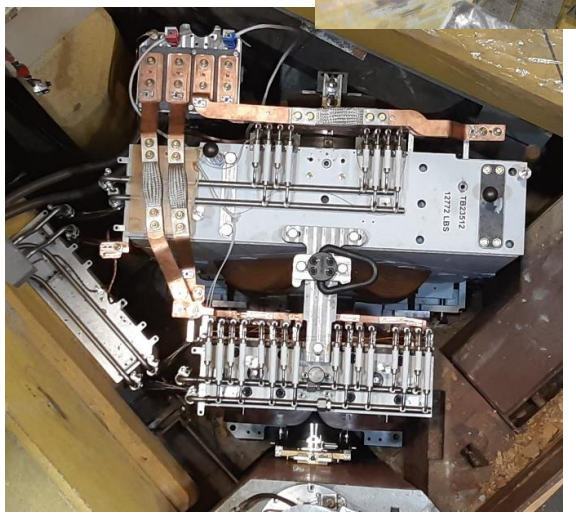


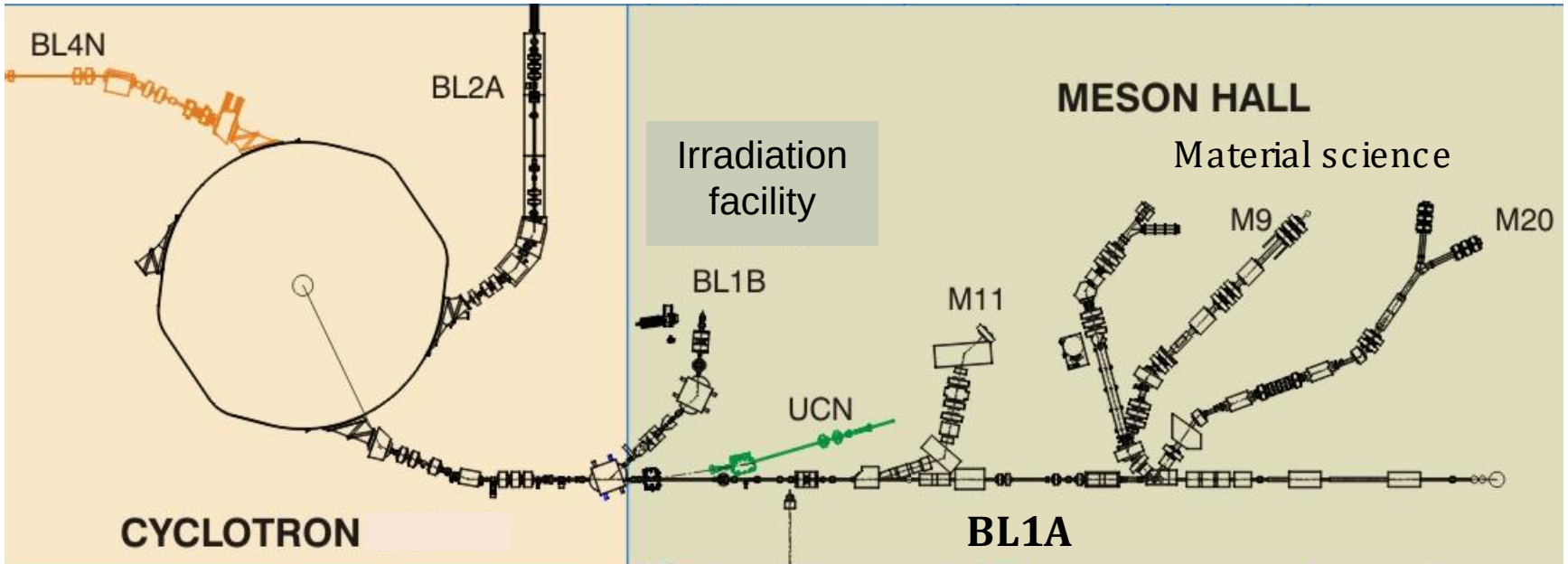
Discovery, accelerated

Future developments of the proton driver at TRIUMF

- Towards 500 μA protons from the 520 MeV Cyclotron
  - Critical → Cyclotron RF-system – accelerating voltage of 110 kV required (presently <85 kV)
  - Reduction of losses (activation) on the high energy side (U-turn)
- Proton beam line refurbishment – Beam Line 1
  - BL1 power supplies, new large dynamic range diagnostics, new collimation
  - Refurbishment of highly activated quadrupoles
  - Remote handling tools and technology and infrastructure upgrade



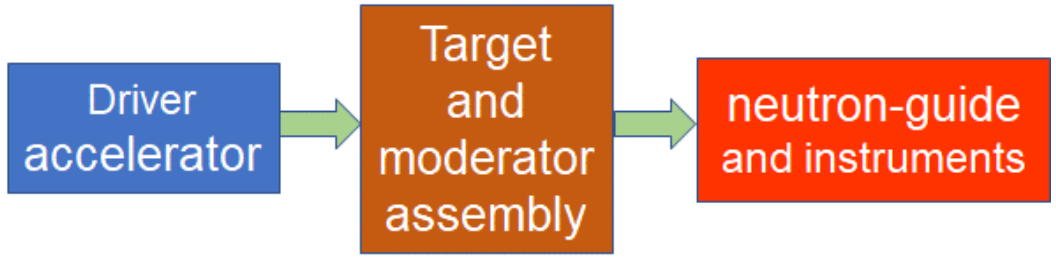




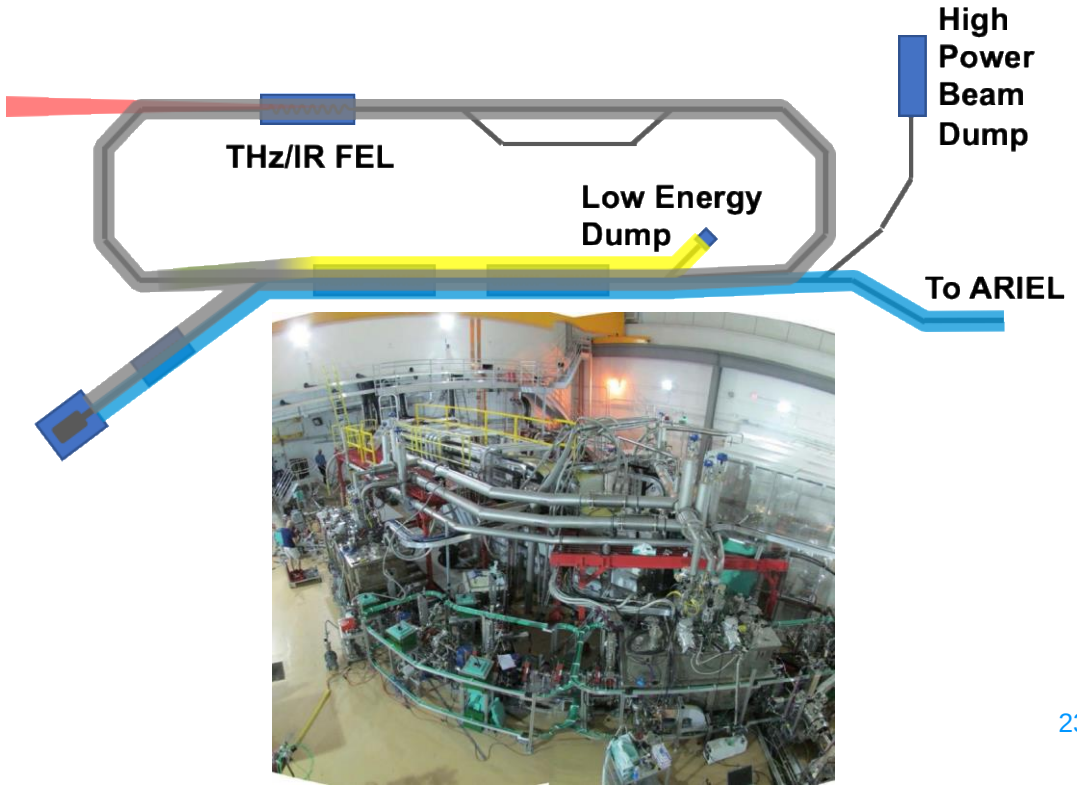
Accelerator Science - National context

ACC division connects to Canadian Universities via the student program
(Coop students, thesis projects, lectures and seminars) and via joint accelerator science projects:

- Compact Accelerator Driven Neutron Sources - common driver beam are protons
- Using the e-linac as sources for intense high field THz radiation
  Collaboration with CLS and USask on SRF, magnets and education (Mark Boland)
- Student education and science program with partner UVic



Compact Accelerator Driven Neutron Sources – CANS

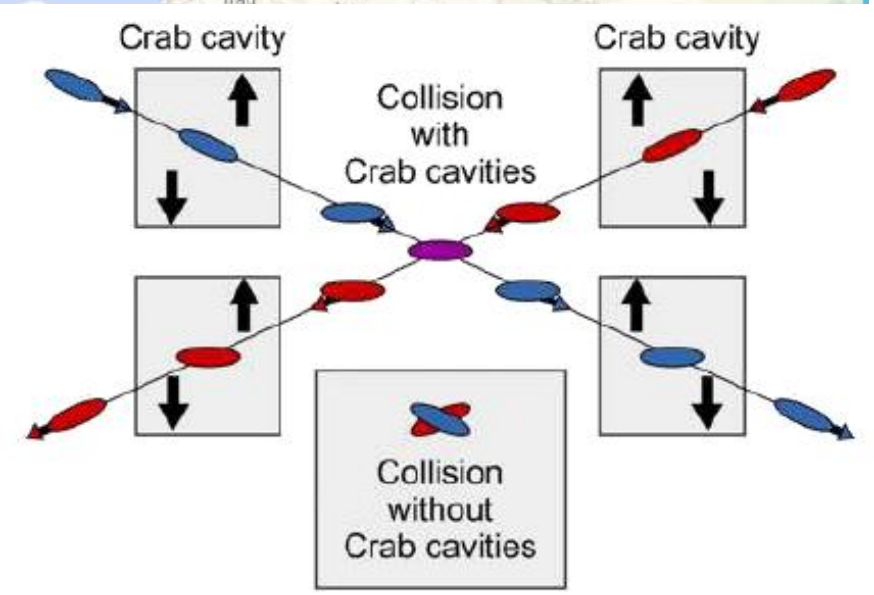


TRIUMF has had an active engagement with CERNon accelerators historically with important contributions to LEP and the LHC (48 twin aperture quads).

This continues through collaborations and contributions towards LHC, Hi-Luminosity LHC and AWAKE:

- Crab cavity cryomodules,
- Beam physics,
- Beam diagnostics

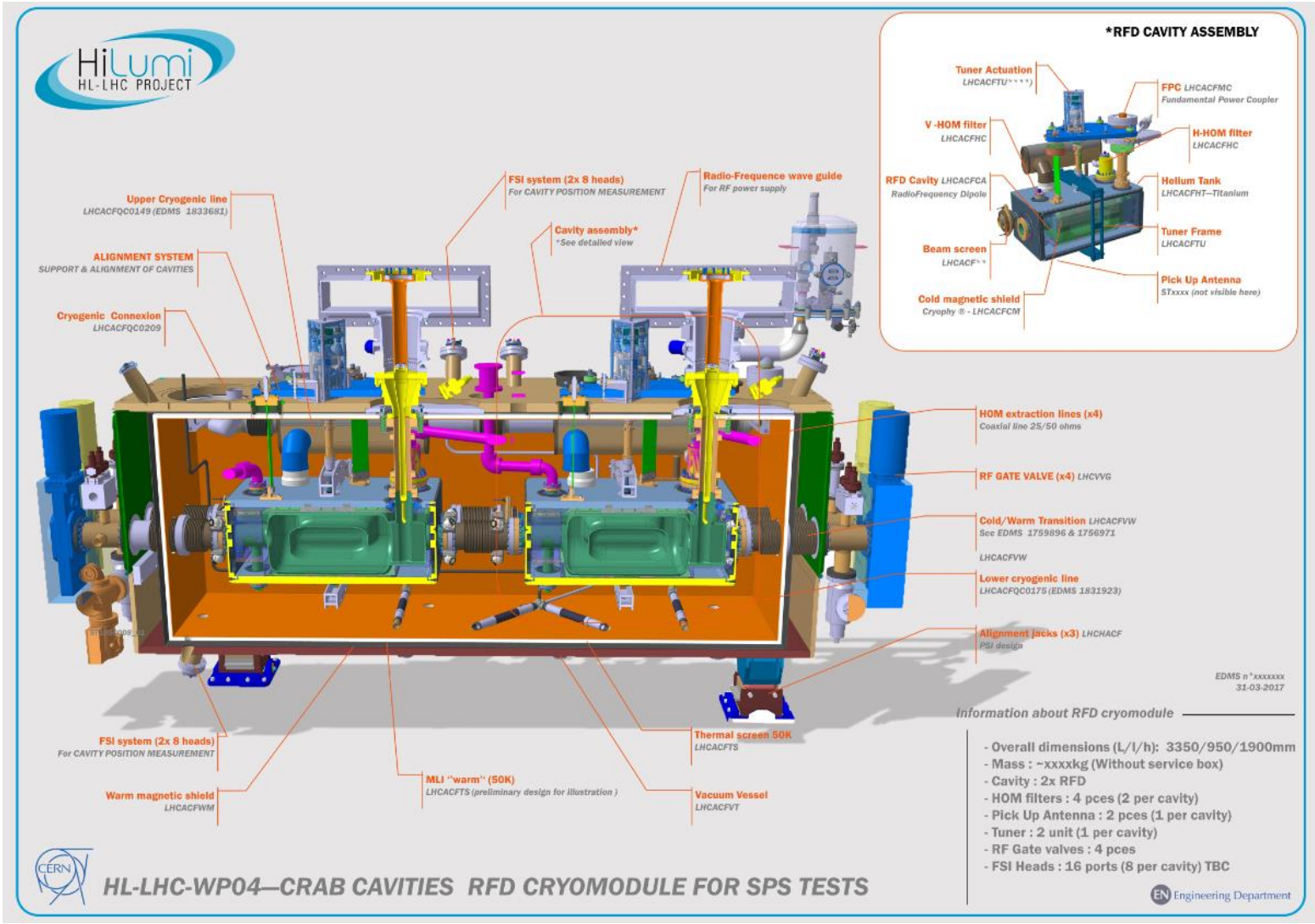
Hi-Lumi Crab Cavities – increase luminosity by skewing the intersecting beams longitudinally at ATLAS and CMS – collaboration with CERN, Russia, UK, USA



HL-LHC Crab Cavity Cryomodules

R. Laxdal

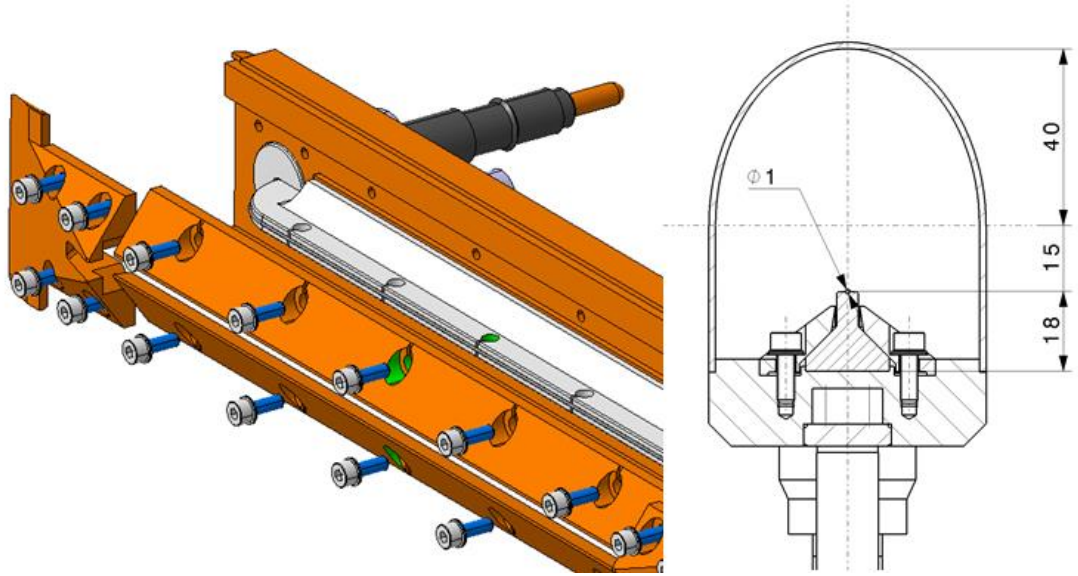
- TRIUMF to receive 10 RF-Dipole (RFD) resonators produced and qualified by US DOE lab consortium (AUP), to assemble each pair of RFDs into five cryomodules.
- TRIUMF to qualify the cryomodules through testing at TRIUMF before packaging and shipping to CERN
- The project advances Canadian core competencies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



Additional beam physics and potential hardware contribution to HL-LHC

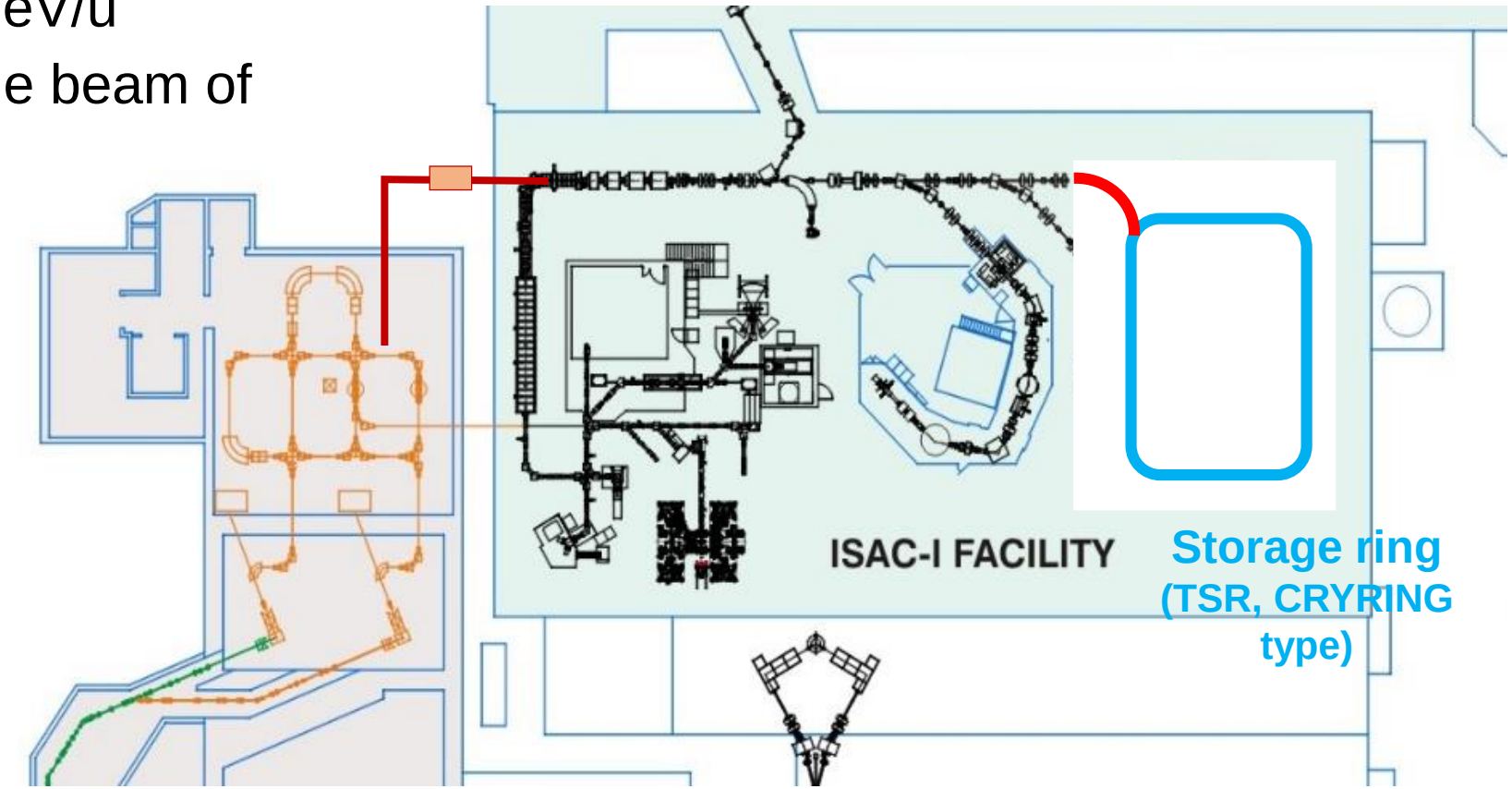
- Beam-Beam Long-Range effect compensation / correction with physical wires, running high currents, are considered a valuable options for HL-LHC to increase dynamic aperture at small crossing angles
  → Tests with four wire prototypes in LHC have demonstrated the potential of a wire corrector
- Dobrin 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 a Hamiltonian based beam physics model why the compensation of the long-range beam-beam effects works so well.
- TRIUMF will further develop the design and could provide the final wire correctors for HL-LHC.



Storage ring at TRIUMF

- Low energy storage ring (similar to TSR in Heidelberg or CRYRING at GSI)
- ISAC-I as injector (150 keV/u – 1.8 MeV/u)
- Storage ring for transfer reactions of RIBs – for instance neutron capture using a (free) neutron target
  Max beam energy < 10 MeV/u
- CANREB EBIS will provide beam of highly charged ions (could be via a second injector path)
- TRIUMF ACC division has the expertise for the ring design.



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

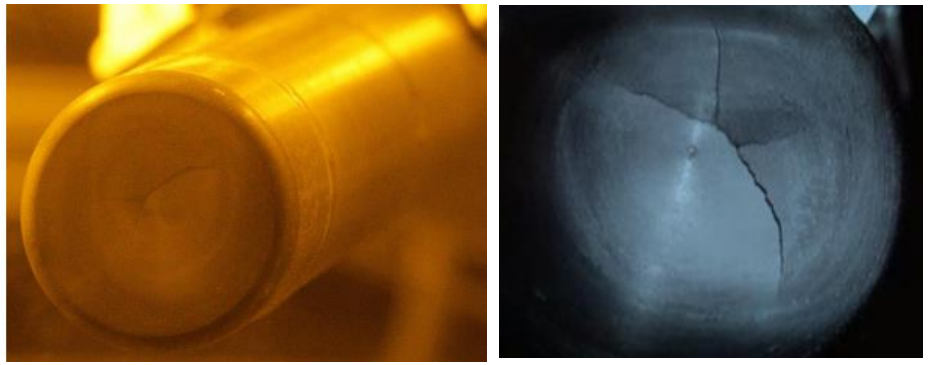
- Based on TRIUMF's previous contributions to T2K TRIUMF is well positioned to make contributions to LBNF and J-Parc in
  - beam diagnostics and remote handling (TRIUMF is internationally recognized for its leading role in remote handling, hot cell design and operation)
  - high power target technology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

- Our developments can support driver accelerators like PIP-II at FNAL with a rf beam splitter cavity for instance and SRF Surface Resistance R&D

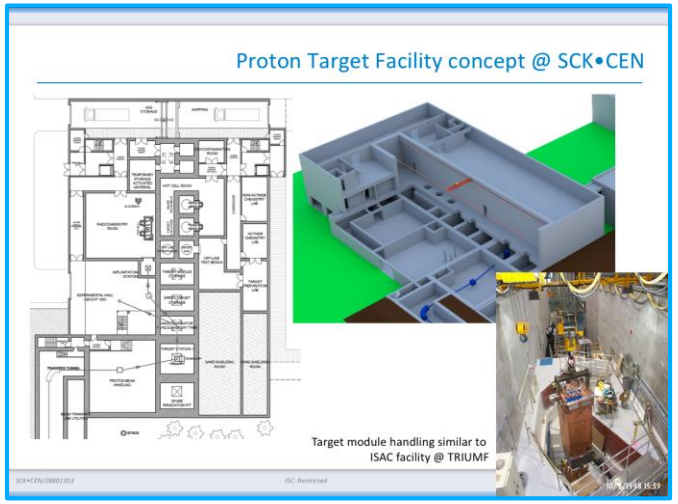
TRIUMF Remote Handling

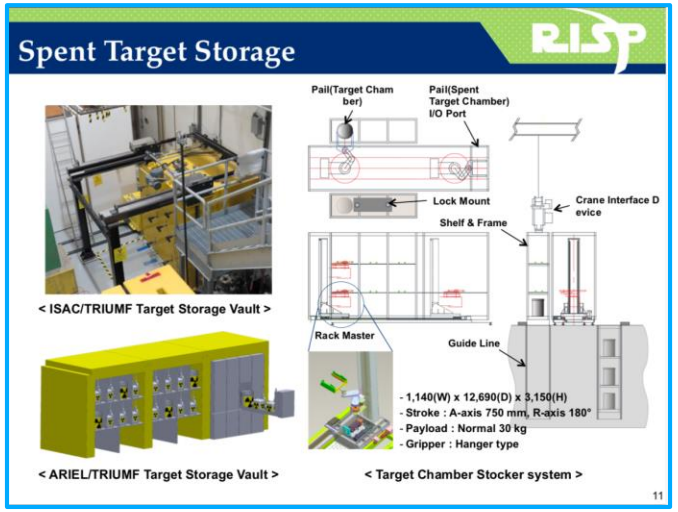
TRIUMF is internationally recognized for its leading role in remote handling, hot cell design and operation.

RH robotics development

TRIUMF RH specialists assisting in T2K target repair

Examples of international designs based on TRIUMF RH:



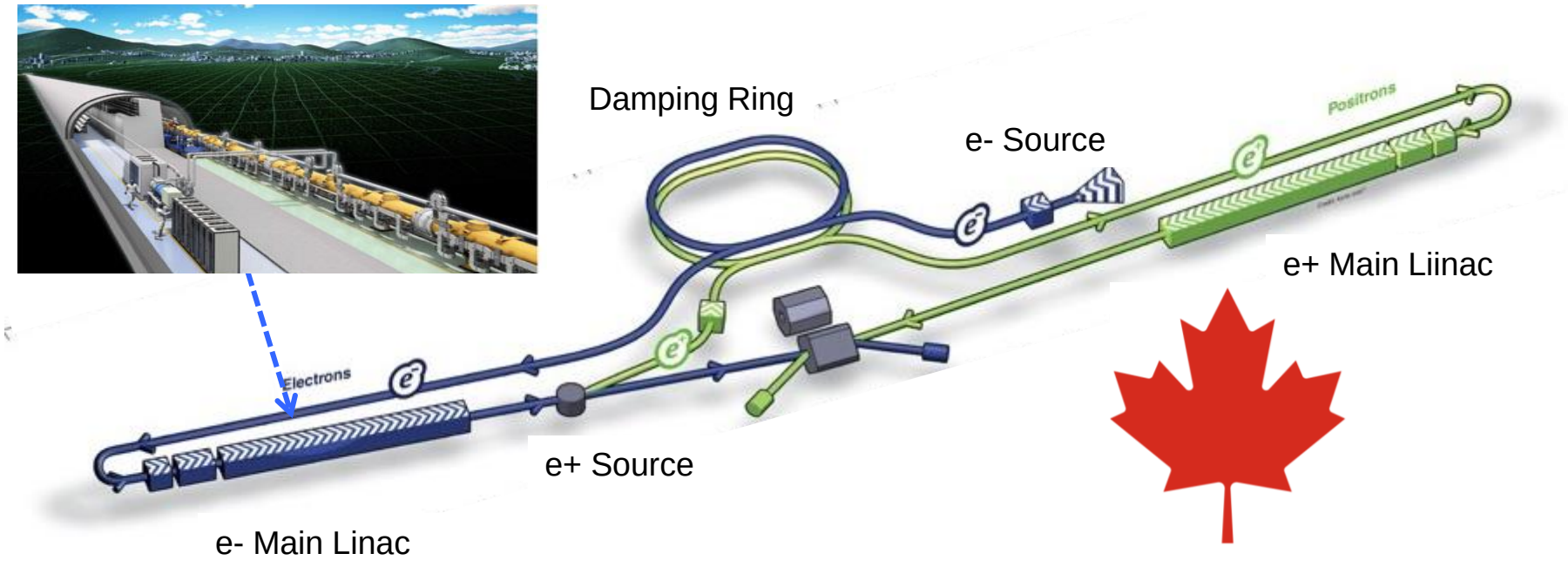


Automation, modern controls

- Design study for robotic inspection and repair tools for the cyclotron and the beam line 1A refurbishment
- TRIUMF remote handling and target technologies as well as the know-howof HQP are valued by international collaborations!
  (T2K, MYRRHA, LBNF, HYPERK)

Potential areas of Canadian Contribution to ILC via TRIUMF

- SRF/RF (crab (or other) cavities, cryomodules, rf ancillaries)
  SRF research on break-down fields and effect of doping
- HV kickers, beam painting magnets and Rf bunch deflectors
- Beam physics (space charge dominated beam, Hamiltonian based fast envelope code, machine learning)
- Normal conducting magnets (also permanent magnet optics for e-beam lines)
- High brightness electron gun, e-beam diagnostics



Summary

- TRIUMF Accelerator Science maintains an active program in national and international collaborations.
- We are designing, constructing and operating high-performing, unique accelerator systems featuring a wide variety of particle beams.
- We support the high performance and availability of TRIUMF’s accelerator complex with new developments or by adding new capabilities in collaboration with Canadian Universities and international partners.
- Canada via TRIUMF supports the international science community and does strengthen Canadian core competences and education.

TRIUMF

Thank you
Merci

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