TRIUMF Accelerator Capabilities and Contributions

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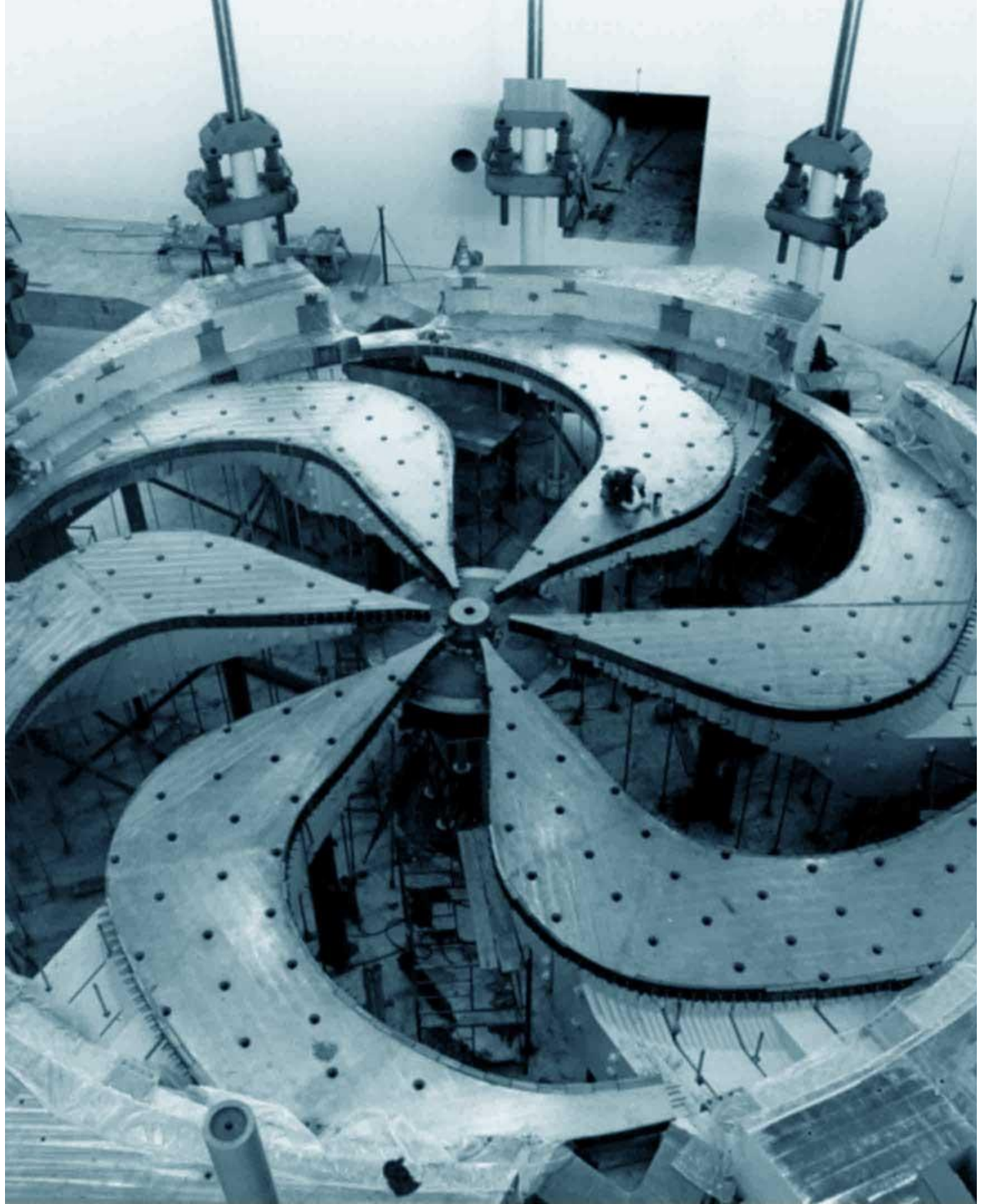
Deputy Director – Accelerator Division

W1-1 SYMPOSIUM; Future Particle Physics Energy Frontier Facilities

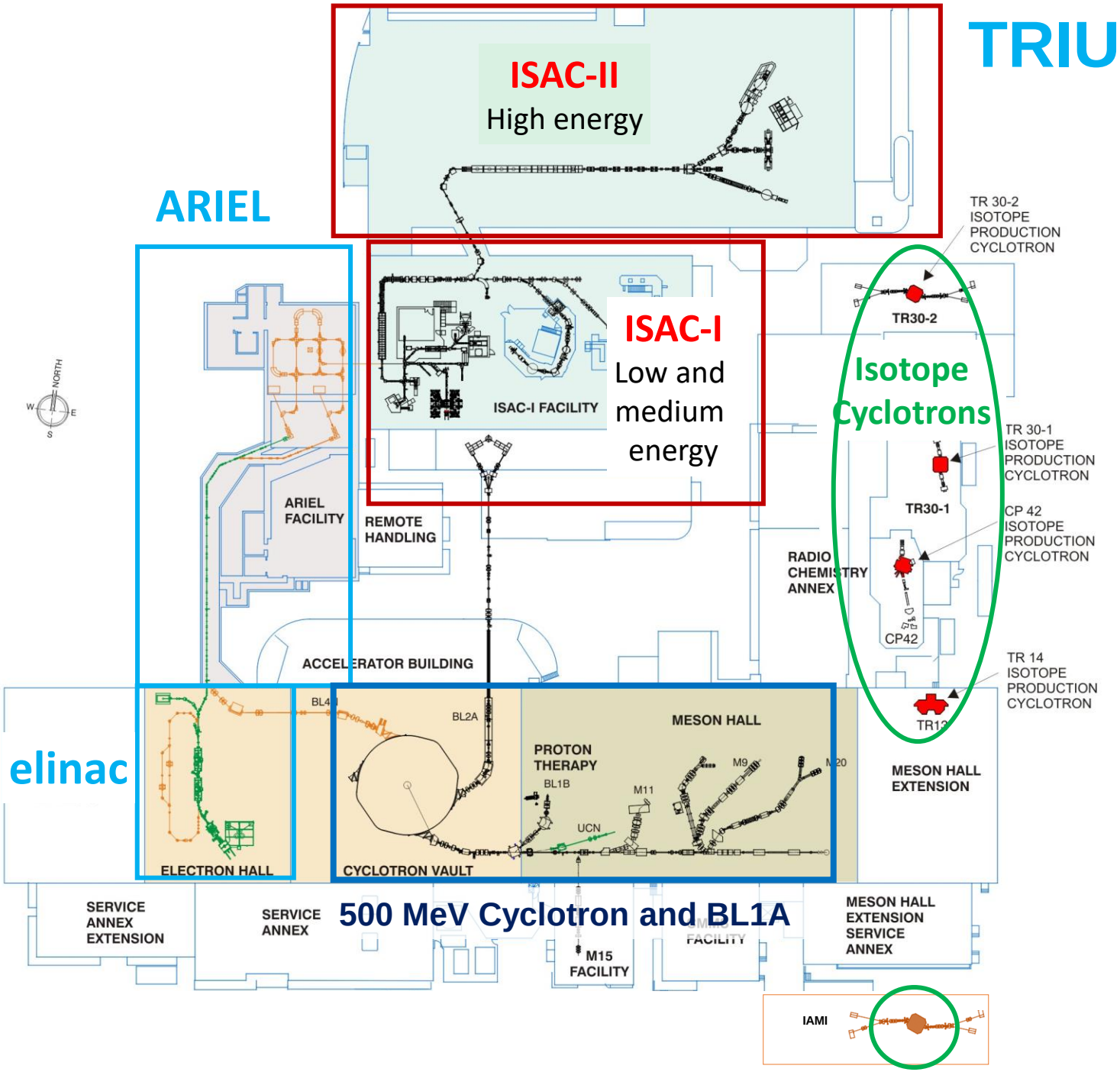
CAP June 24-25, 2026



TRIUMF is Canada's **particle accelerator** centre

TRIUMF has five decades of experience in building a rich particle accelerator infrastructure that enables cutting-edge research and supports accelerator R&D.

TRIUMF accelerator complex



Primary beam driver (1974):

500 MeV Cyclotron, 300 μA, H^-
Produces rare isotopes, neutrons and muons

Isotope Separator and Accelerator facility – ISAC (1996)

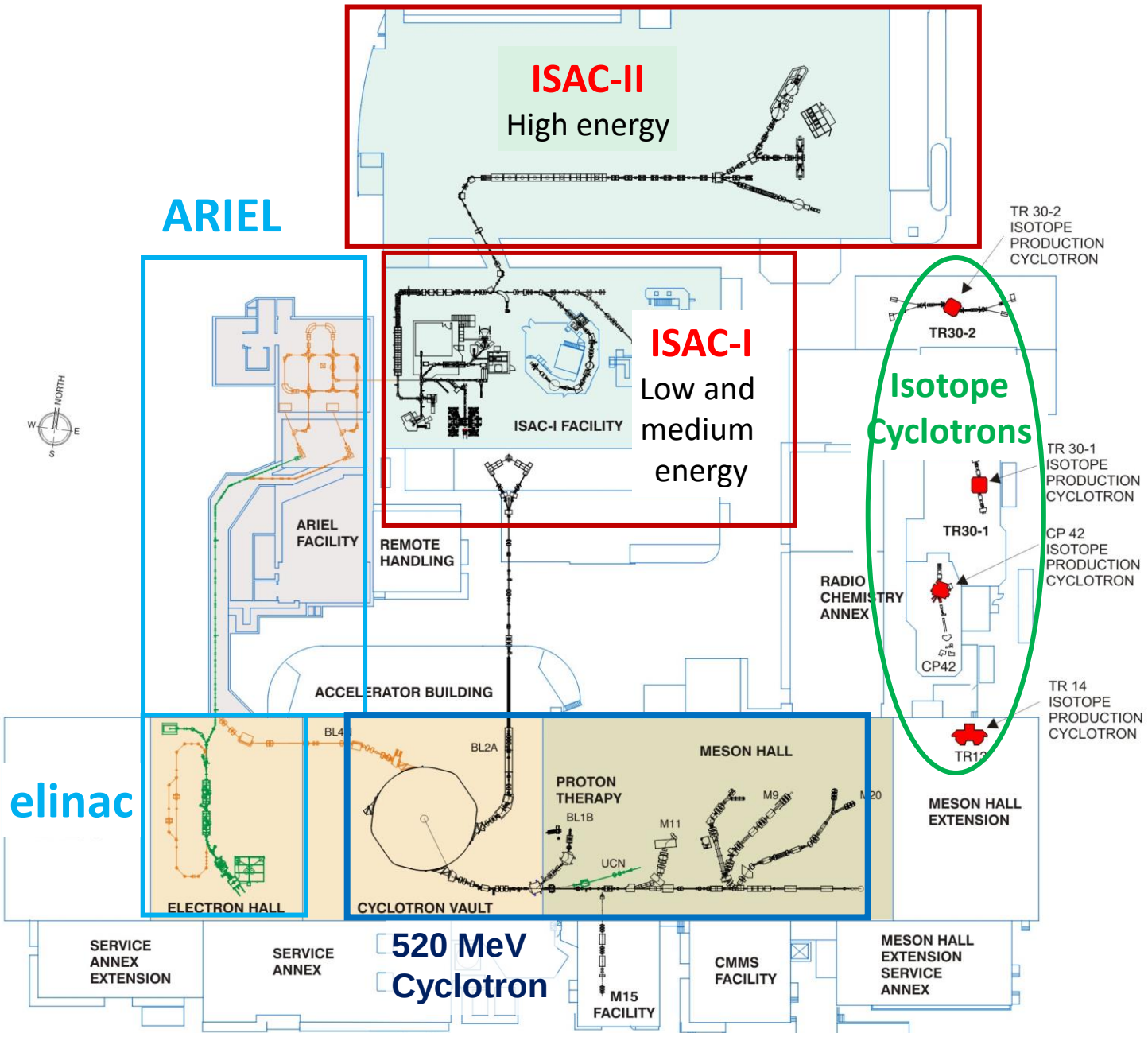
- ISAC-I: Normal conducting-linac
  - 0.15-1.8 MeV/u (2000)
- ISAC-II: Superconducting-linac
  - 1.5-16.5 MeV/u (2006)

Advanced Rare Isotope Laboratory – ARIEL (in progress)

- Superconducting electron linac
  - 30 MeV, 10 mA, cw (2019)

4 (+1) Cyclotrons for medical isotope production – TR30 and TR13 designed by TRIUMF

TRIUMF



A wide variety of accelerator technologies populate the campus.

Our strategy is to use internal projects and external collaborations as springboards to expand core competencies or gain new ones.

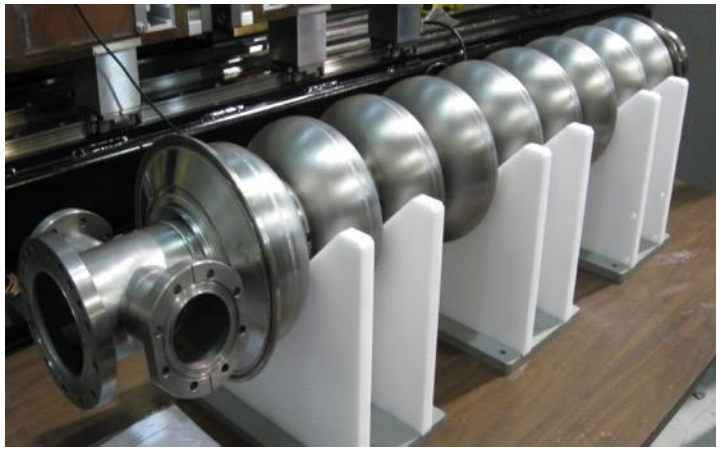
Competencies include:

- Superconducting radio-frequency
- Beam physics of electrons and hadrons
- Secondary beam production
- Cyclotrons and linear accelerators
- Beam diagnostics
- High power targets
- Remote handling

Example: SRF Technology at TRIUMF since 2001 –> In house linear accelerators

40MV ISAC-II SRF heavy ion linac
@ 106 and 141 MHz
in operation since 2006

30MV ARIEL SRF 10mA electron linac
@ 1.3 GHz
first beam 2014



The SRF lab supports the in-house accelerator program, SRF research, work for others and external collaborations

SRF Facilities

Dirty assembly

Clean room

EMMA

RF

HPWR

Prep room

Cryo-testing

Clean assembly

BCP

SC LINAC

SEBT

1 2 3 4 5

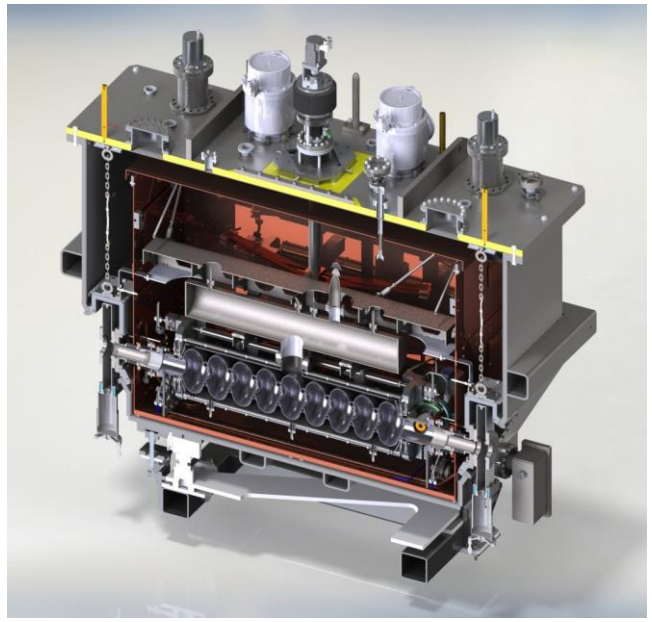
DSB

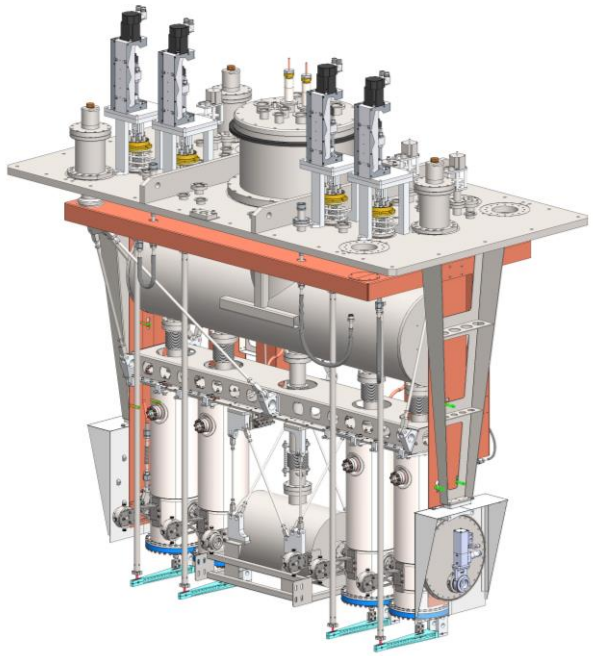
CRYOGENICS

TRIUMF Work for Others -VECC (India)

TRIUMF SRF group designed, fabricated and delivered

- 2018 - A1.3GHz SRF cryomodule for accelerating electrons
- 2022 - A 110MHz SRF cryomodule for accelerating heavy ions

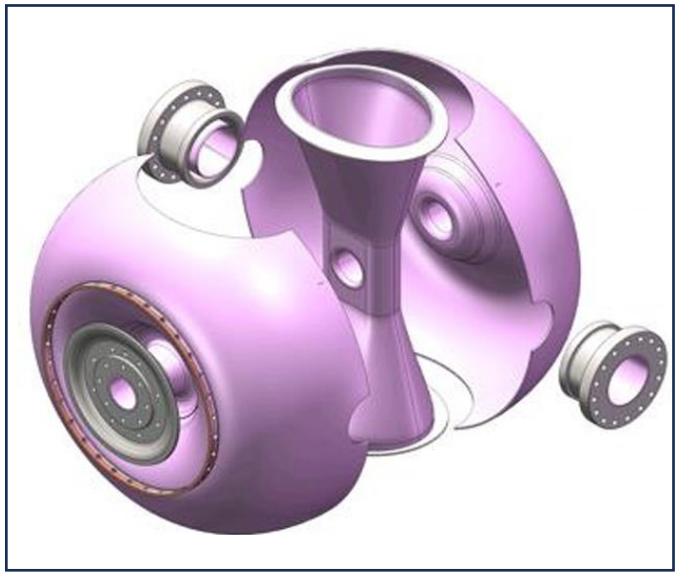




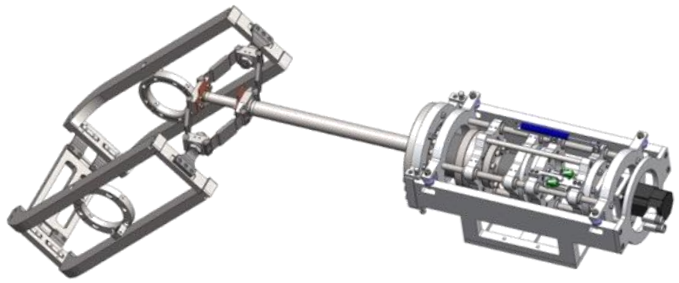
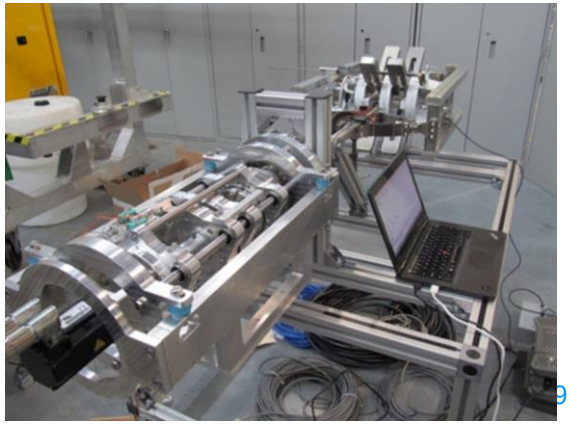
TRIUMF Work for Others -RISP (S. Korea)

TRIUMF SRF group designed, fabricated and delivered

- two prototype SRF single spoke resonator (SSR) cavities at 325 MH
- Prototype rf frequency tuner for SSR cavity





TRIUMF and External Collaboration

Value of external collaborations

The TRIUMF Accelerator Division has a long tradition of international collaboration to provide Canadian contributions to particle physics projects abroad.

- **Enhance expertise:** - Collaborations strengthen and expand core competency and broaden our expertise in accelerator physics and technology.
- **National resilience:** The collaborations draw Canadian industry into world-class projects, building national resilience in cutting edge technologies.
- **Develop HQP:** The collaborations also provide opportunities to students and young researchers enriching knowledge and experience in critical technologies.

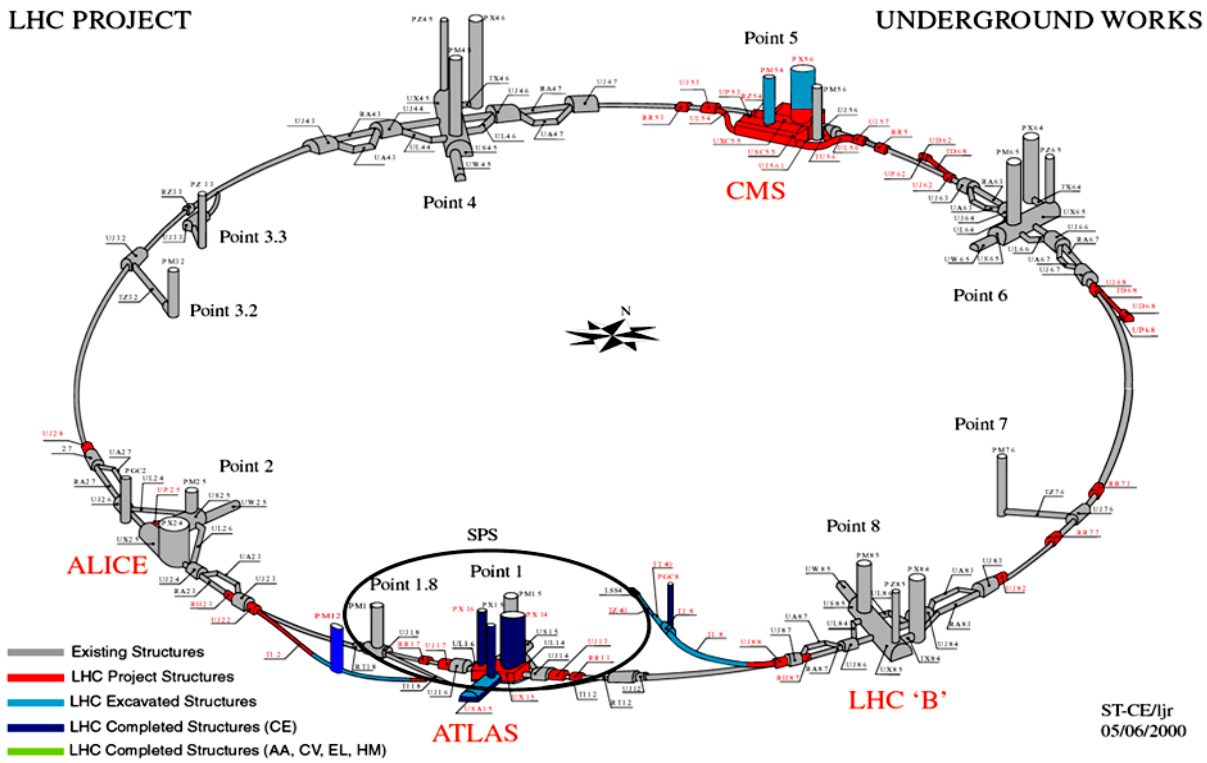
TRIUMFs Contributions to LHC (1995-2005)

1995-2005 - $41.5M

- TRIUMF was given the mandate to act as Canada's main connection with CERN and to develop and construct components for the Large Hadron Collider.
- Contributions included beam physics support and hardware including magnets, beam instrumentation, rf systems, kickers

>80% Canadian industry involvement

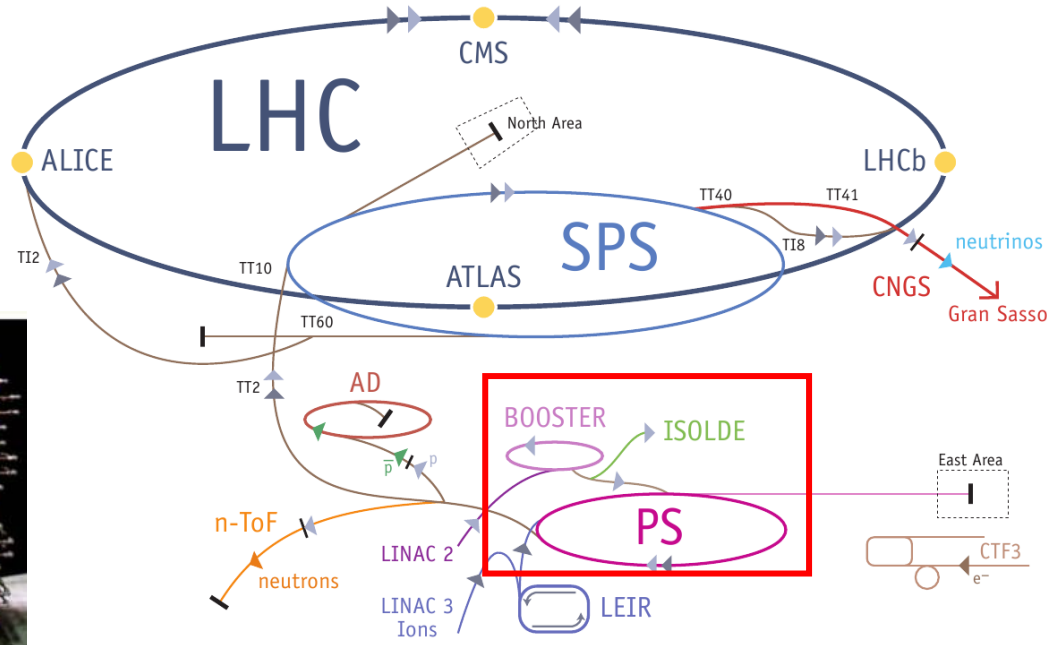
8-10 FTEs from TRIUMF per year



TRIUMFs Contributions to LHC – Phase 1 (1995-2000)

1995-2000 – Phase I - $30M – Proton synchrotron conversion

- upgrades to the injector synchrotrons - double beam brightness, control emittance, and modify bunch spacing for LHC operation.
- TRIUMF contributions in beam dynamics, instrumentation, power supplies, magnets and RF.
  - four first-harmonic rf cavities for the PS Booster
  - development of a 40 MHz cavity for the PS plus higher order mode (HOM) dampers
  - magnets and power supplies for the upgraded 1.4 GeV transfer line between Booster and PS
  - new transformers for the Booster main magnet supply



TRIUMFs Contributions to LHC - Phase 2 (2000-2005)

2000-2005 - $11.5M

- TRIUMF - production of the components for four LHC injection kicker systems
  - Pulse forming networks, power supplies, thyratron switches and kicker magnets.
  - A new clean room and assembly area was constructed at TRIUMF for production and testing
- ALSTOM (Quebec) - Production of 52 twin aperture quadrupole magnets in Canadian industry

PFNs for Kickers

Twin-Aperture Quads

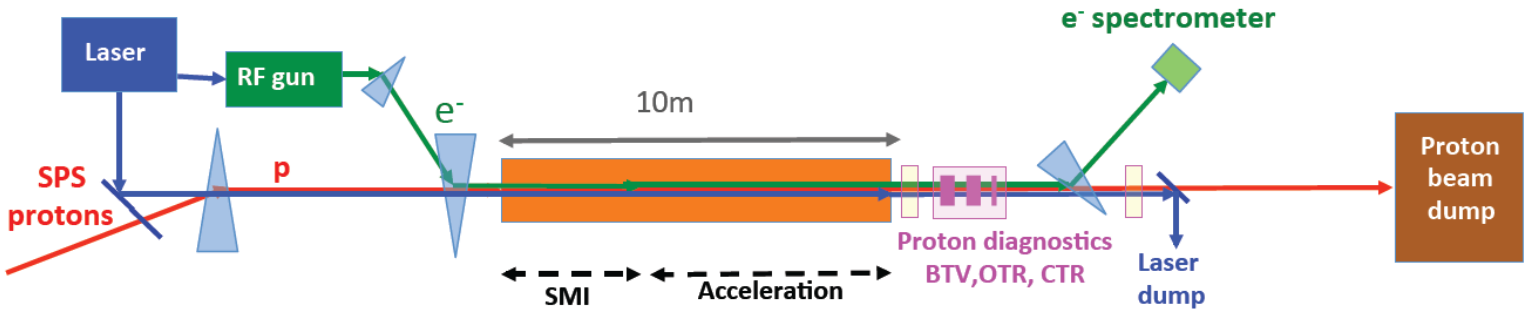
TRIUMF / CERN beam physics towards LHC

TRIUMF has a long-standing collaboration with CERN on beam physics.

- The beam dynamics group assisted in beam simulation studies towards higher currents in the Booster.
  - specification of multi-stage collimation system and optics design
- LHC beam-beam simulations:
  - Simulating beam cleaning efficiency of the collimation system, halo dynamics, and multi-turn losses
  - full 3D beam-beam solutions including longitudinal variation of beam sizes and finite crossing angle

TRIUMF @ AWAKE at CERN

TRIUMF was a collaboration partner in the Advanced Wakefield Experiment (AWAKE) at CERN



- R&D experiment at CERN towards developing accelerator technologies for future accelerators → Exploits acceleration by plasma waves driven by a high energy proton beam
- 400 GeV protons from the CERN Super Proton Synchrotron (SPS) → 10 m long Rubidium plasma channel (plasma generated by the laser)
  - electrons accelerated from 20MeV to 2 GeV – 200MV/m

- TRIUMF provided beam diagnostics for the electron beams (beam position and current)

Beam position monitor

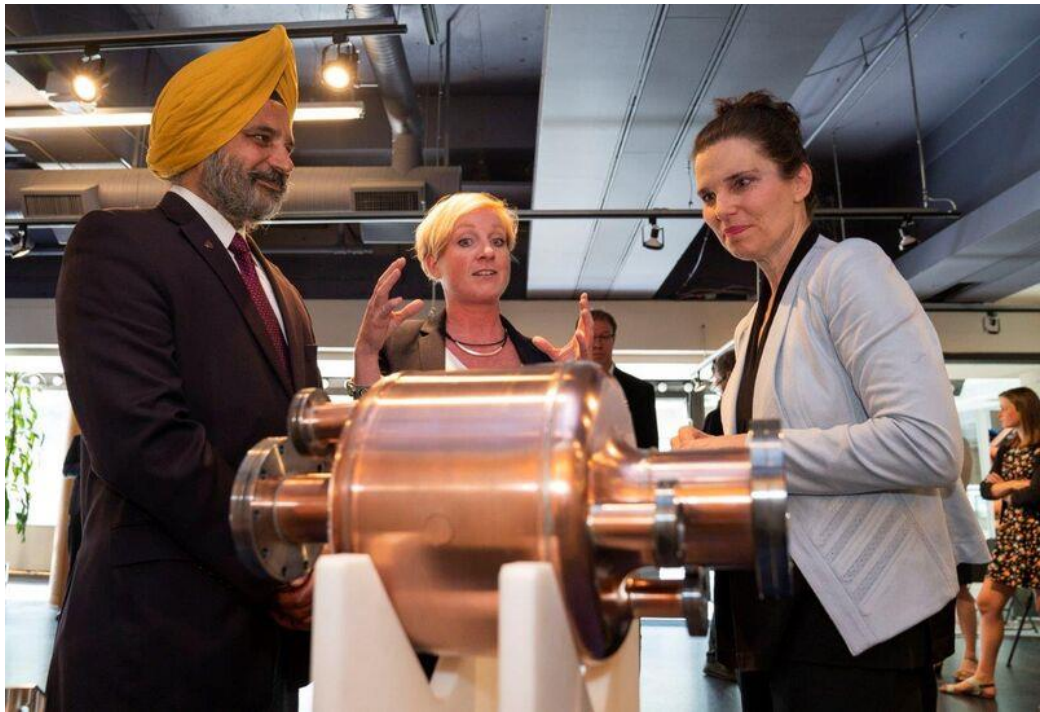
Faraday cups

Hi-Lumi @ CERN

June 25, 2018
“Great science knows no borders.” Minister Kirsty Duncan

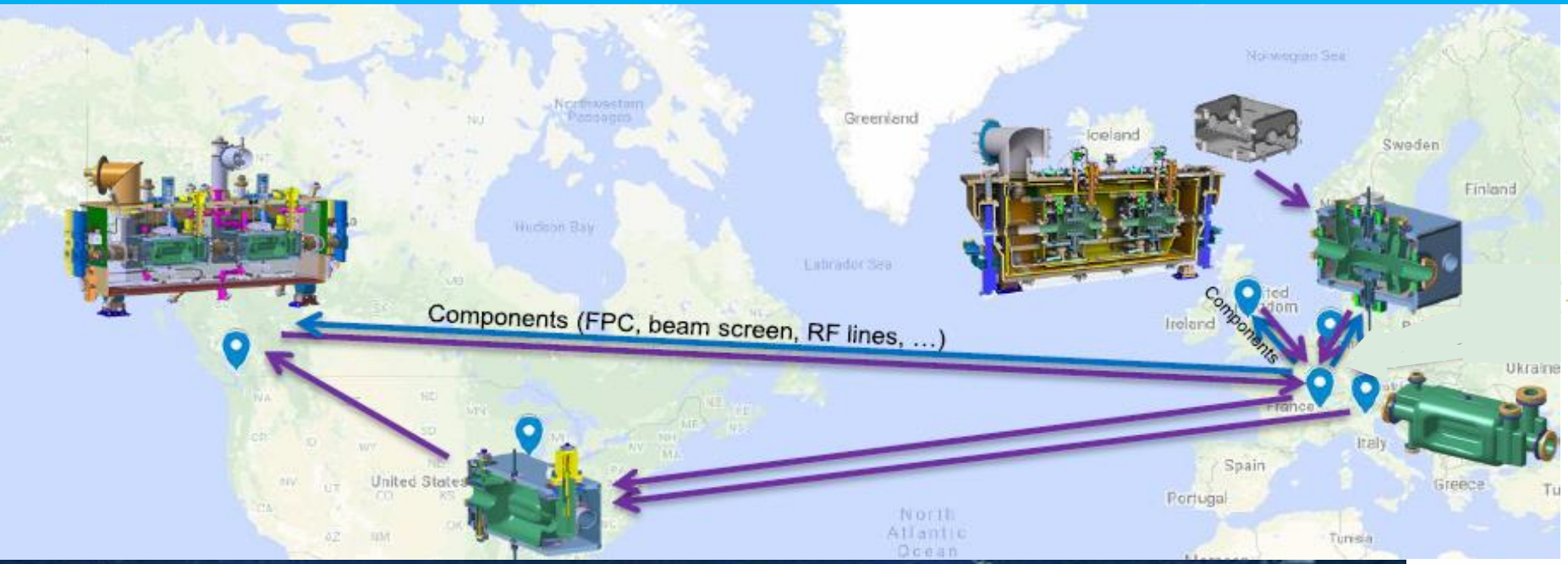
Canadian Minister of Science and Sport Kirsty Duncan announces 10M$ support for TRIUMF to build 5 Hi Lumi LHC RFD Crab Cavity Cryomodules

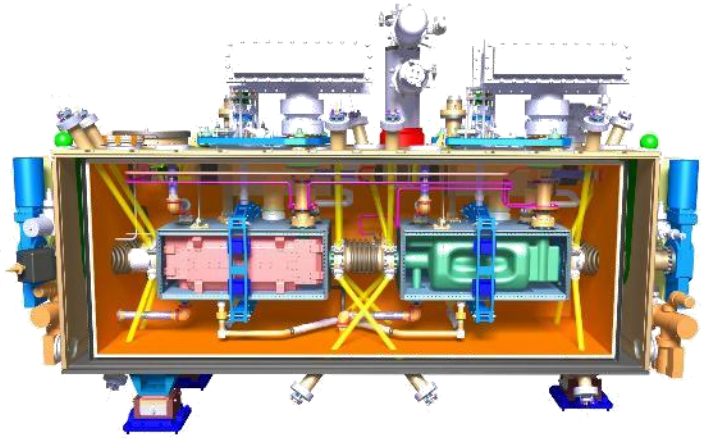
Working with the Canadian research community and industry, TRIUMF will lead the production of the cryomodules with a $2 million in-kind contribution for a total project value of $12 million.

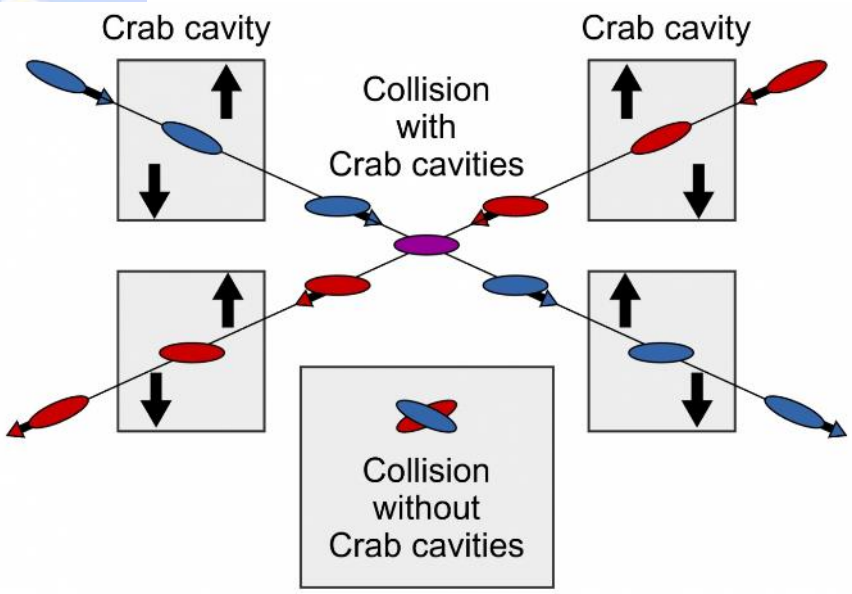


HiLumi HL-LHC PROJECT

TRIUMF is part of global collaboration (CERN, US, UK) that will deliver 5 RFD Crab Cavity modules as a Canadian contribution to HL-LHC

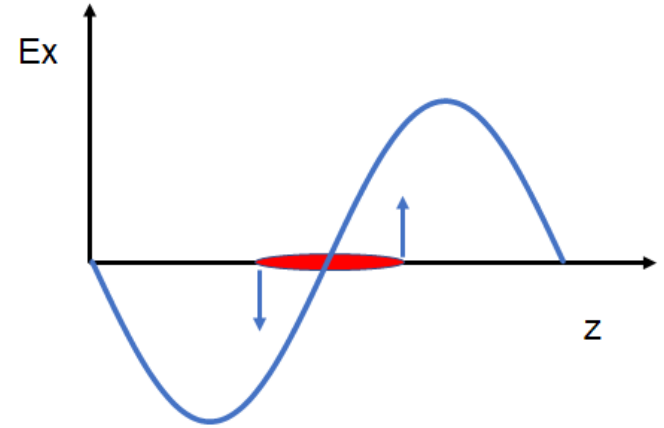


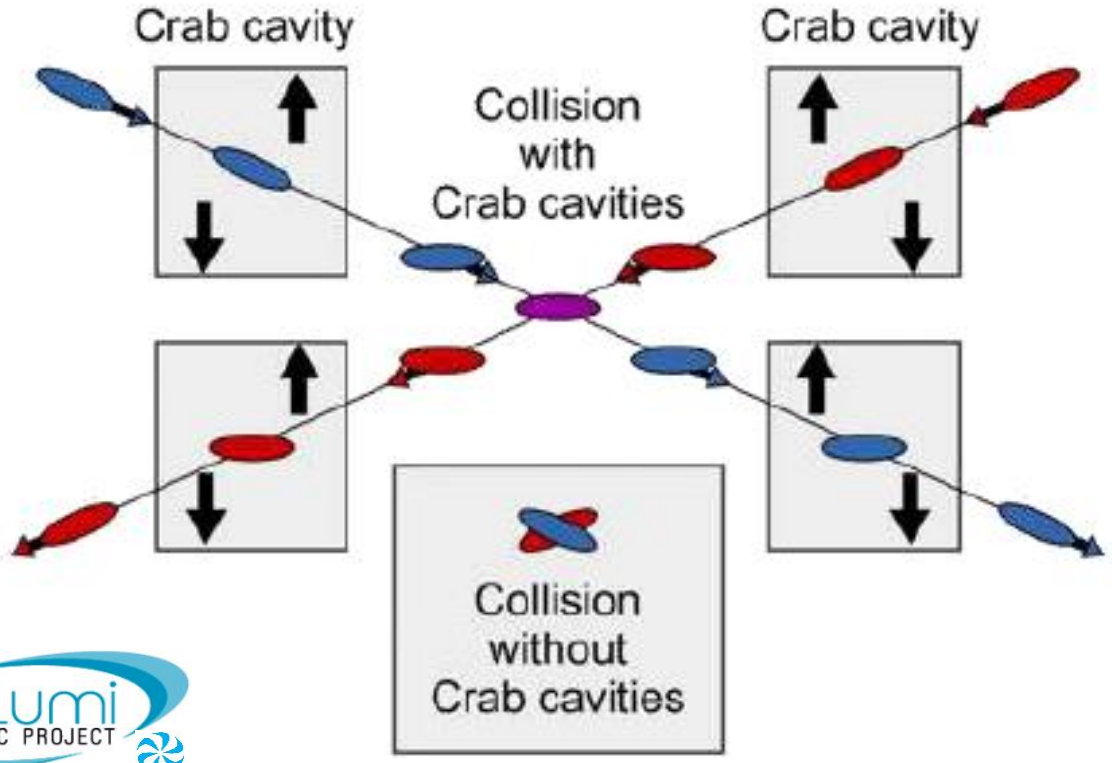


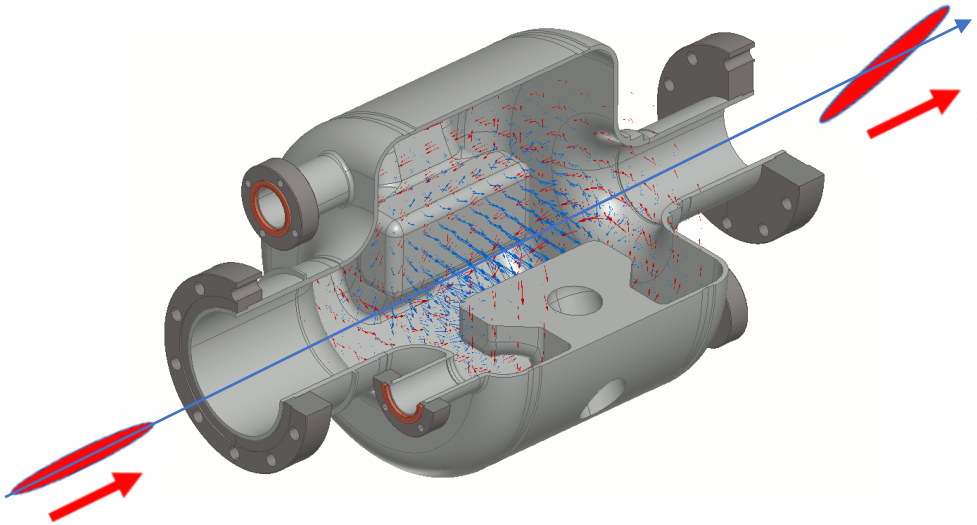


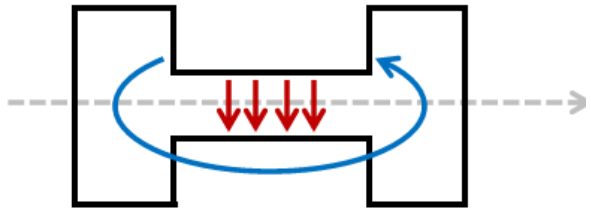
What is a crab cavity?

- A crab cavity is designed to produce a deflecting (rather than accelerating) electro-magnetic rf field.
- A charged particle bunch passing through the cavity at the zero-crossing will experience a transverse skewing (crabbing) so the bunch is rotated to be at an angle with respect to the beam path
- This skewing compensates for the crossing angle at the collision point and increases the probability of collision (luminosity)





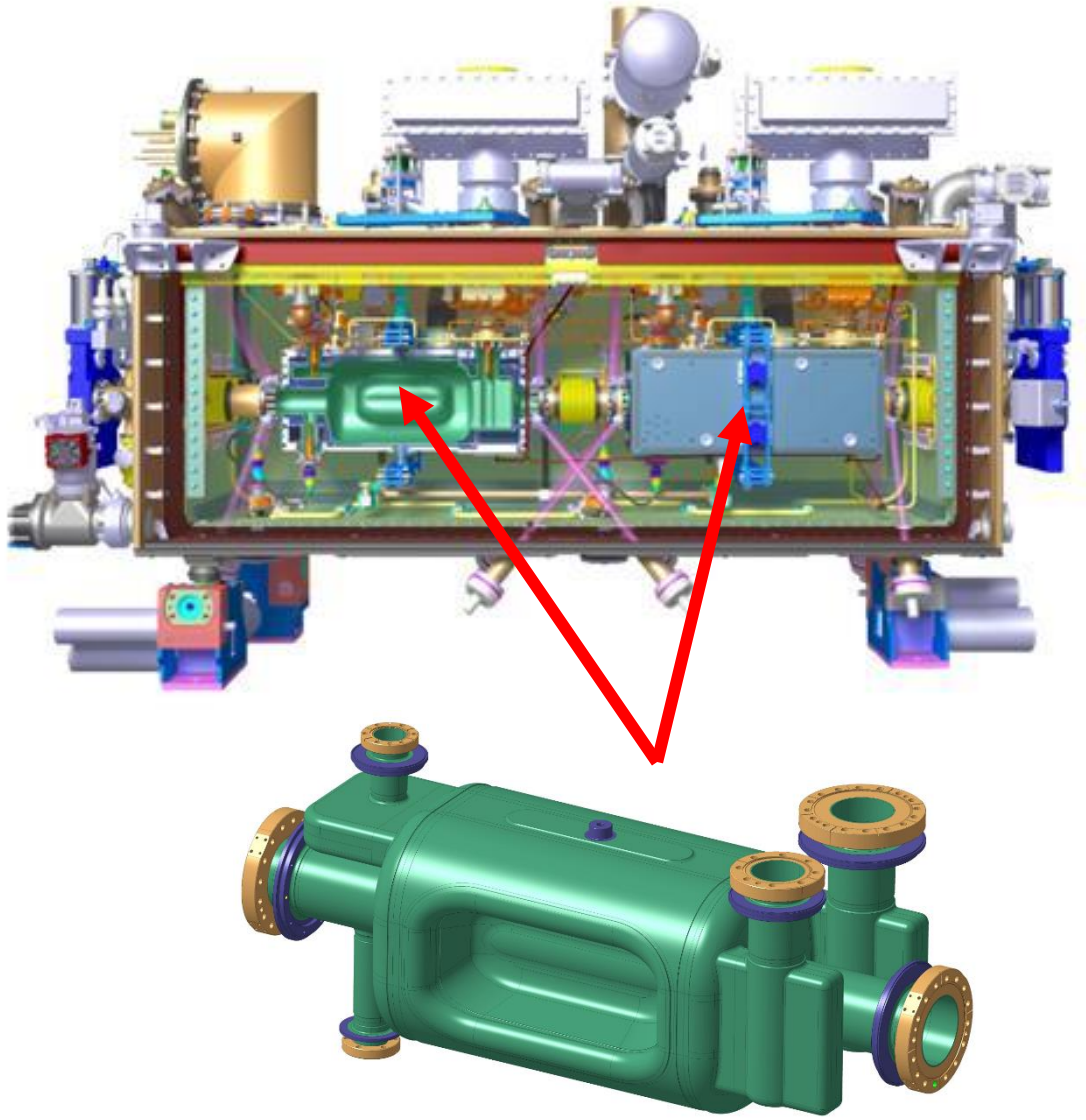




Discovery, accelerated

TRIUMF @ HL-LHC

- TRIUMF will receive 10 RF Dipole crab cavity resonators from US-Accelerator Upgrade Project (AUP)
- Cavities will be re-qualified (cold tested in a dewar) and assembled into five cryomodules.
- TRIUMF to qualify the cryomodules through testing at TRIUMF before packaging and shipping to CERN



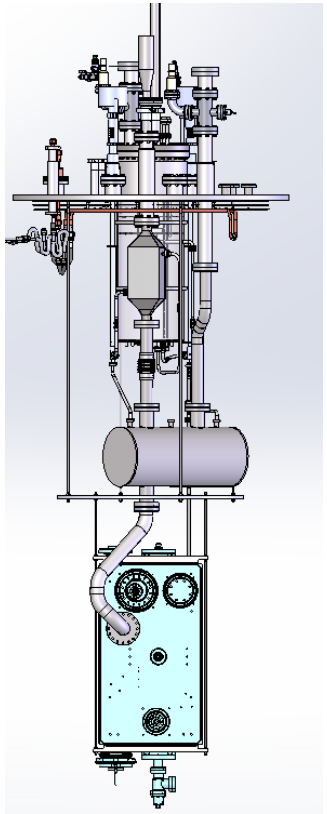
RF-dipole crab cavity

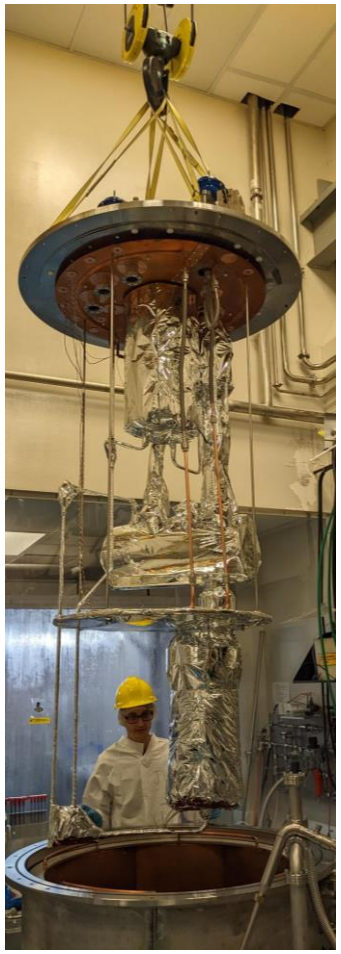
Infrastructure at TRIUMF

Major tooling and infrastructure including new clean room and cavity test cryostat are in hand.

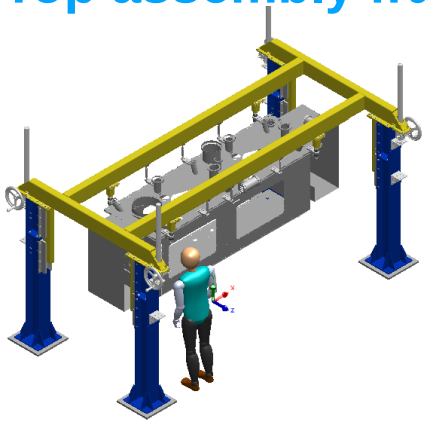
New SRF clean room

Test cryostat

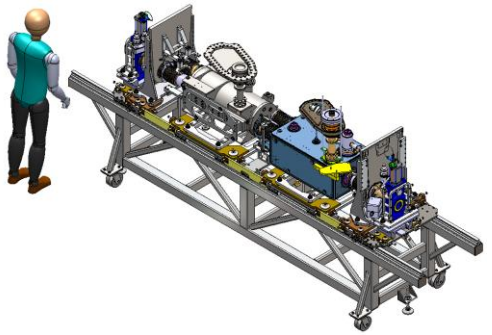




Top assembly frame



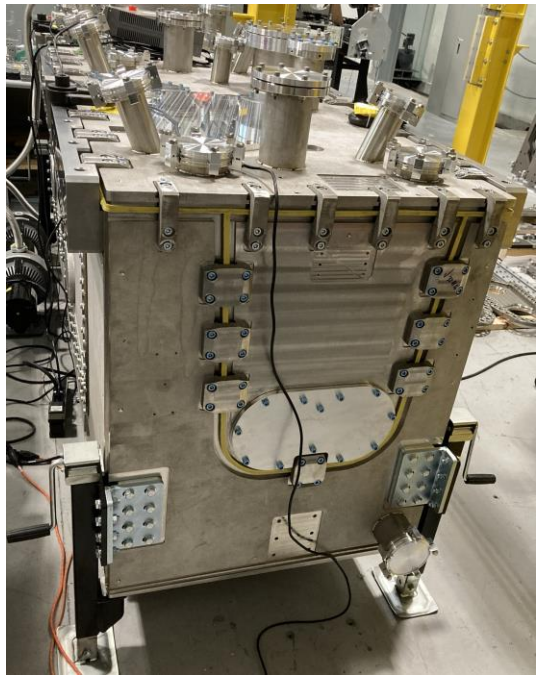
String assembly cart

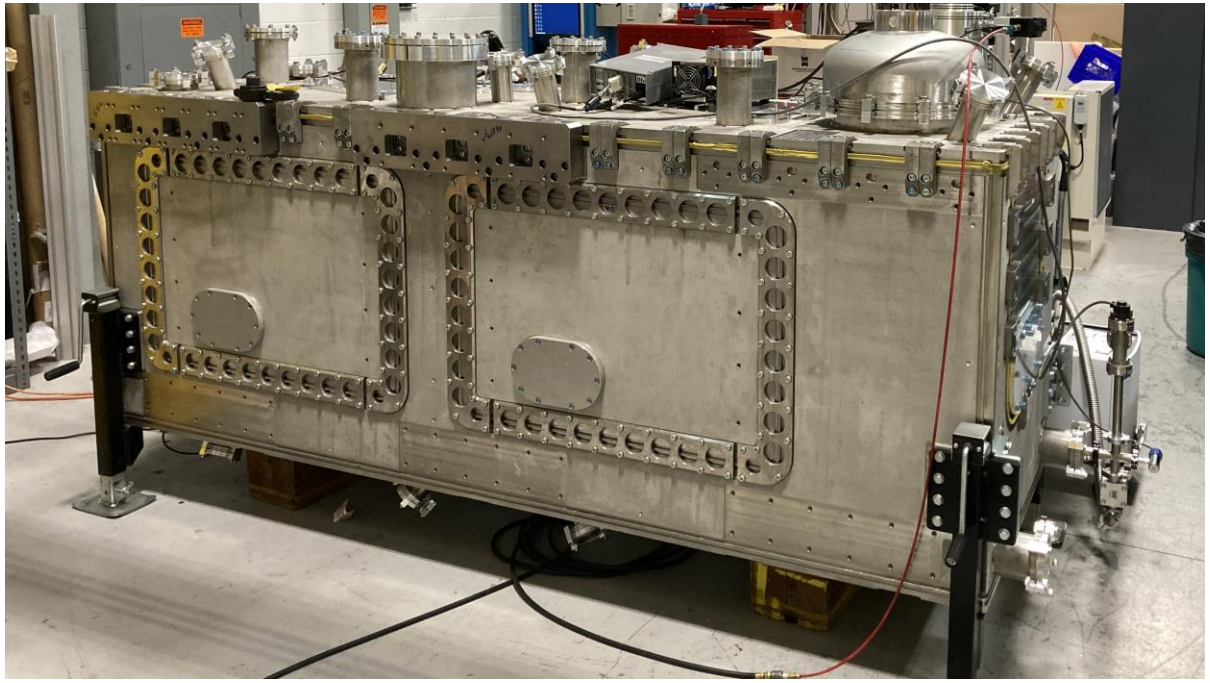


HiLumi HL-LHC PROJECT

Status

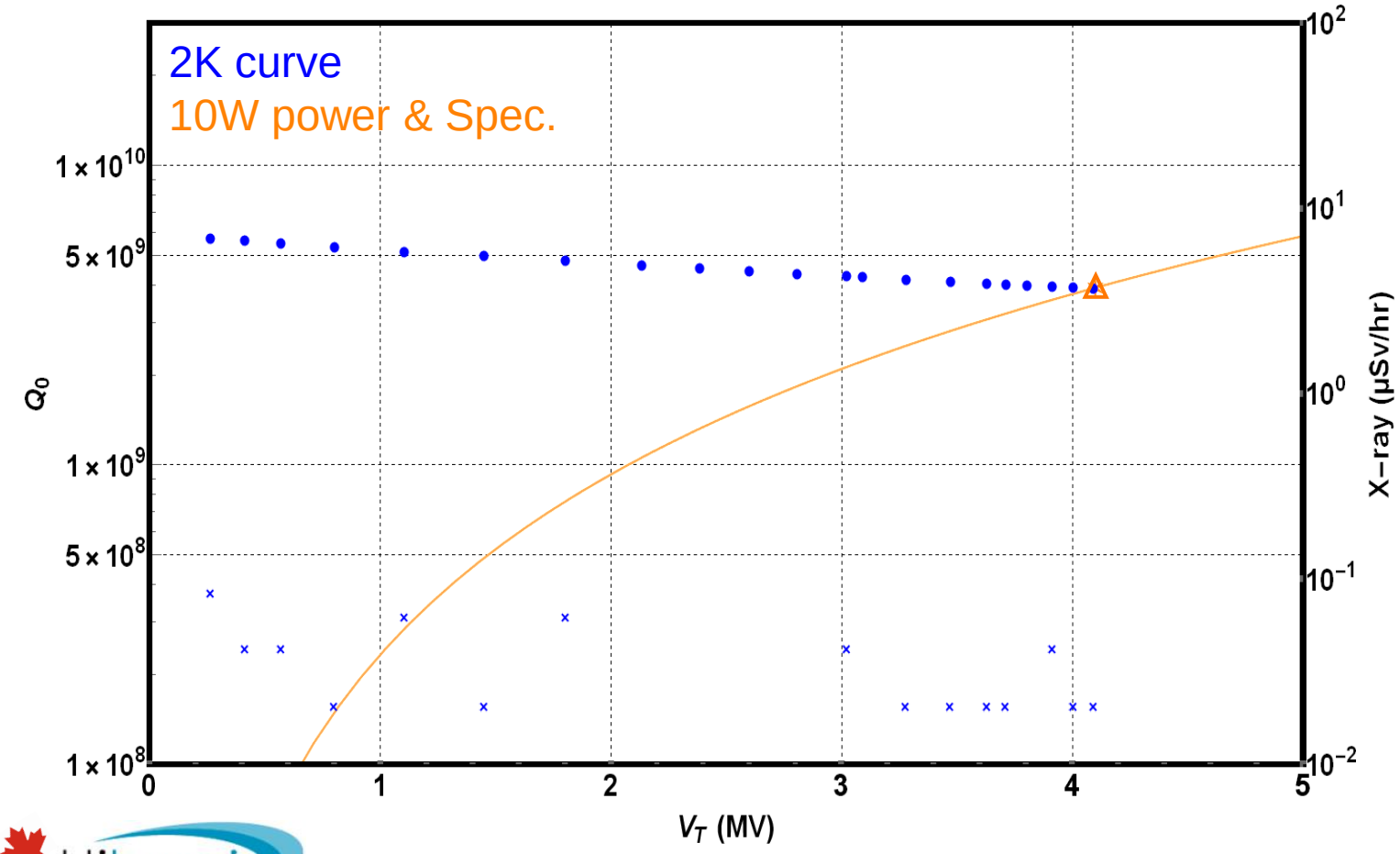
- Mock string assembly in progress in the clean room
- Vacuum chamber and major components are in hand





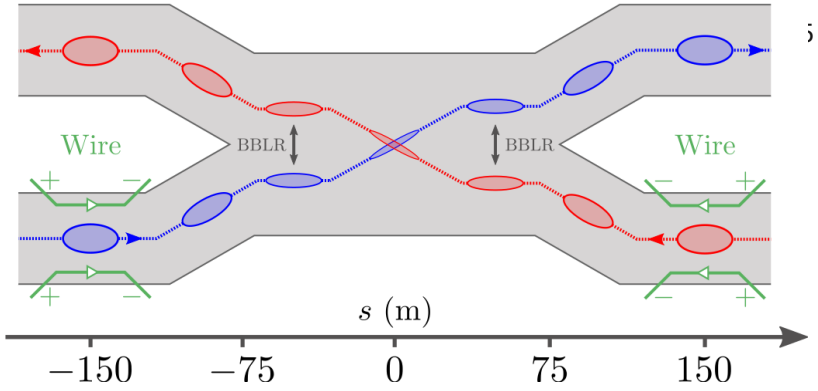
First cavity received from US Collaboration

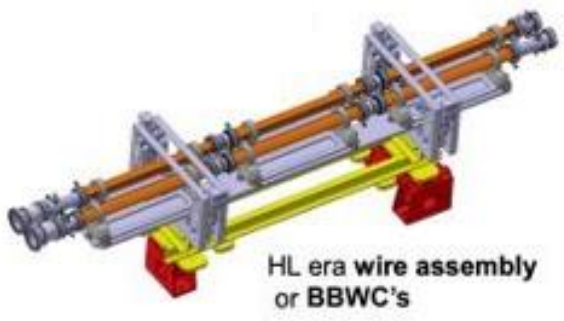
- First cavity received and tested at TRIUMF - Meets rf specification
- 2nd cavity expected in Aug. 2026 and First string assembly by end of 2026

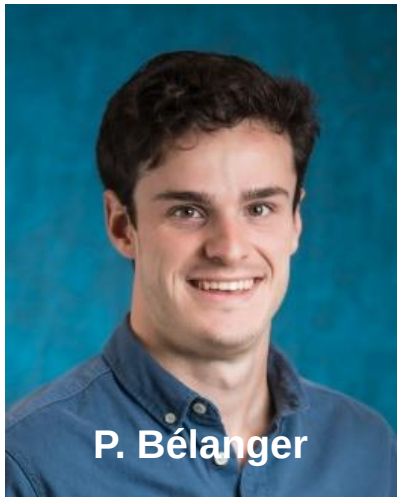


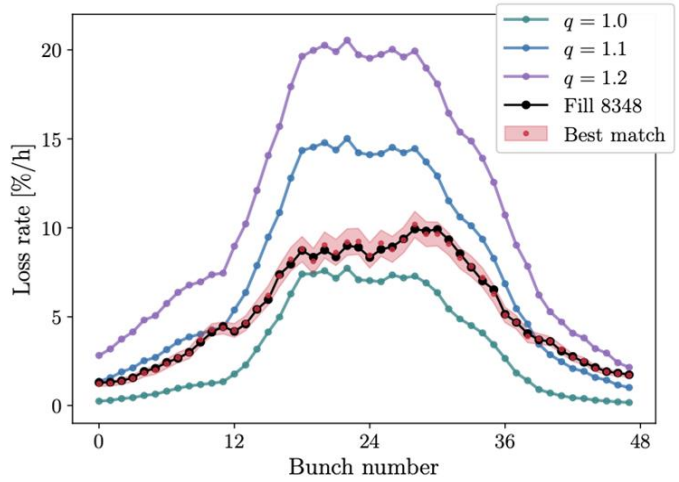
TRIUMF @ Hi-Lumi - Beam-Beam Long-Range compensation

- Beam-beam interactions in the LHC near interaction regions can degrade beam quality leading to beam loss, loss of luminosity and loss of dynamic aperture
  → TRIUMF beam physics is contributing key insight into this problem
- Wires can be added at strategic location in LHC to reduce beam-beam effects
- TRIUMF has interest in supplying hardware for the wire compensation









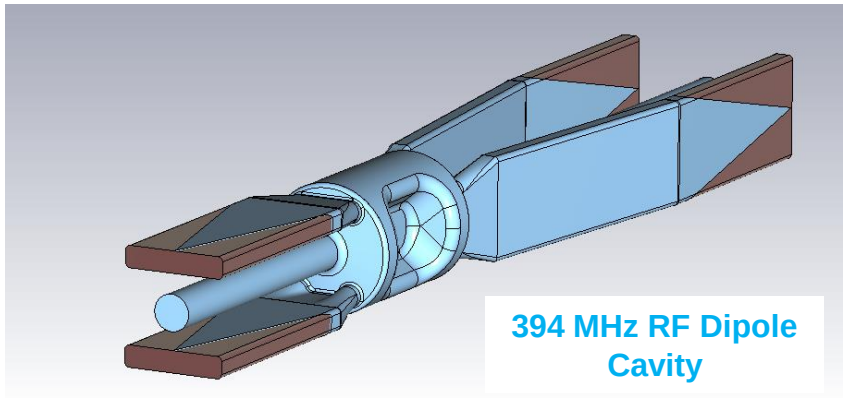
IPAC' 24 paper (Belanger et al) documenting the improved simulation model that predicts LHC losses due to beam beam effects

Topological formulation of beam dynamics : a study of quasiperiodic motion in Hamiltonian systems – P. Belanger – UBC PhD Thesis

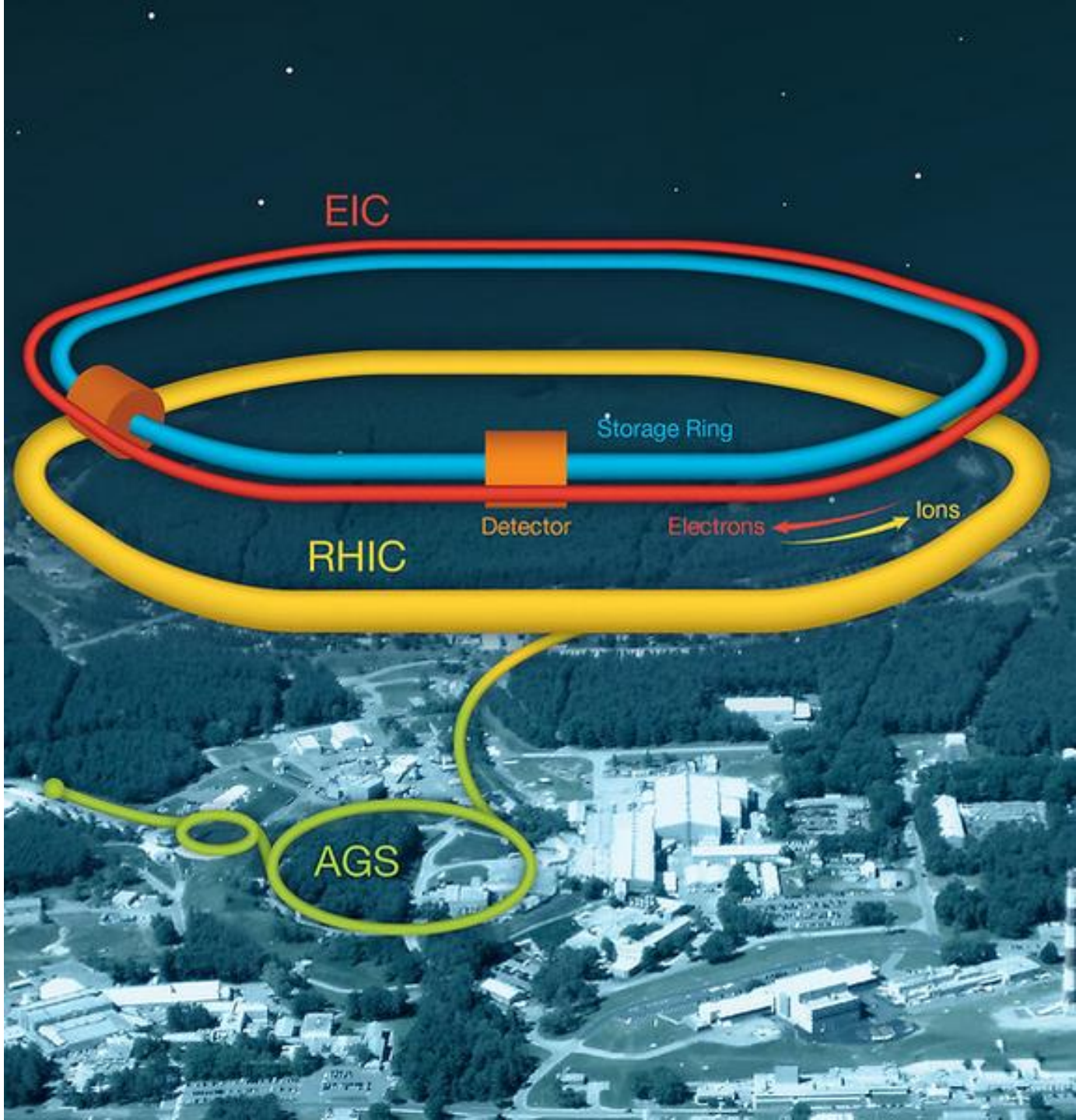
Electron Ion Collider

The EIC at Brookhaven will be the next international discovery machine.

- TRIUMF is working with EIC-Canada on a CFI project to deliver in-kind contributions.
- TRIUMF's SRF group has started work on the design of the 394 MHz crab cavity – similar size to HL-LHC 400 MHz crab cavity



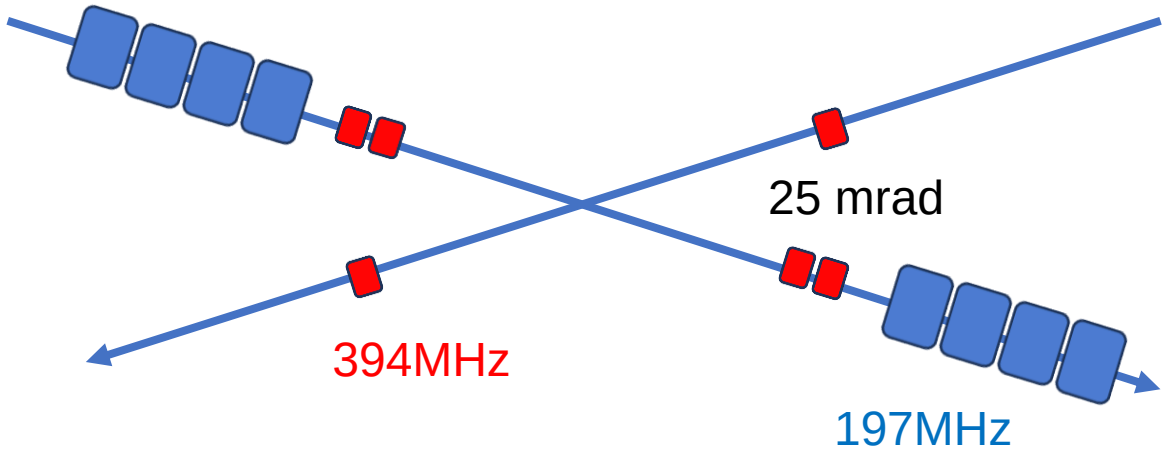
394 MHz RF Dipole Cavity



Future: EIC CRAB Cavities

- The performance of the crab cavities is critical to the success of EIC – they increase luminosity by a factor of 10
- The EIC requires crab cavities on both the hadron storage ring (HSR) and the electron storage ring (ESR)
- HSR – long bunch, high rigidity
  - requires eight 197MHz crab cavities and four 394MHz cavities to linearize the deflection
- ESR – short bunch, low rigidity
  - requires two 394 MHz cavities
- **Our proposal keys on the 394 MHz cavities as the Canadian contribution**

	Voltage/cavity Vt (MV)		**No. of cavities**	
System	HSR	ESR	HSR	ESR
197 MHz	8.5	-	8	-
394 MHz	2.4	2.9	4	2



Beyond EIC – FCC-ee at CERN?

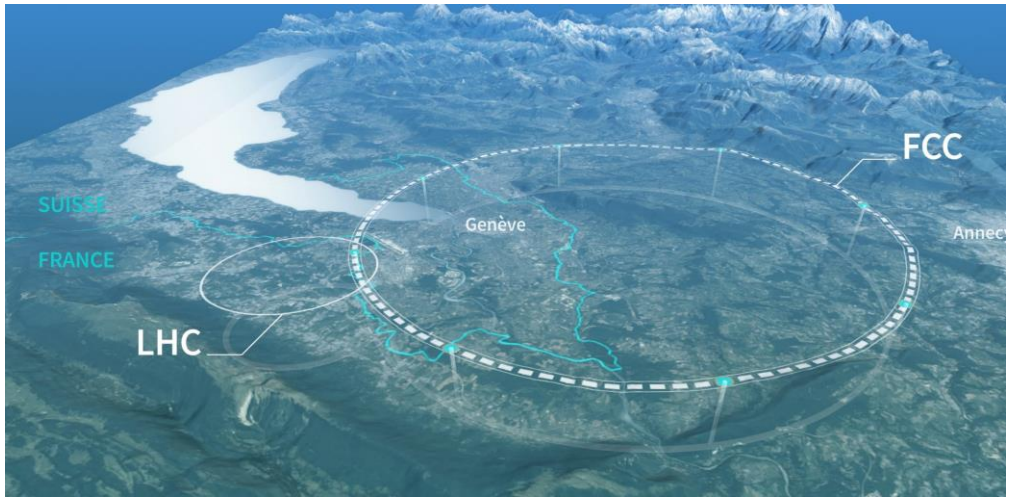
Realization of the FCC will require a significant international participation.

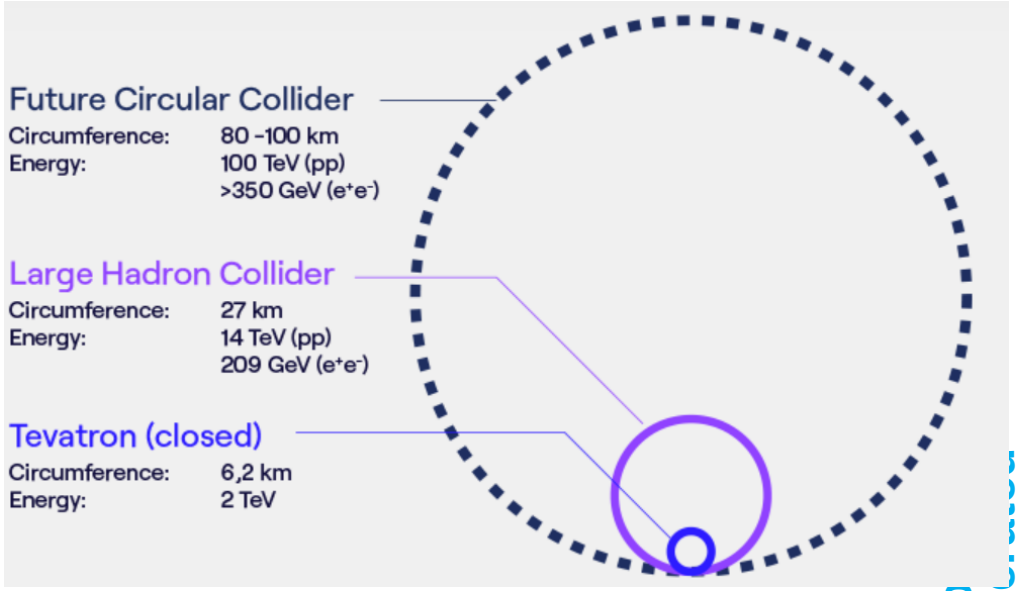
FCC-ee has huge synchrotron radiation losses, requiring large installed rf voltage. Development is required for

- More efficient acceleration systems
- SRF materials, more efficient klystrons

Canada, through TRIUMF, is well poised to make significant in-kind contributions in

- Beam physics
- SRF – cavity/material development
- RF Systems and power supplies
- Beam instrumentation
- Kickers
- Superconducting magnets

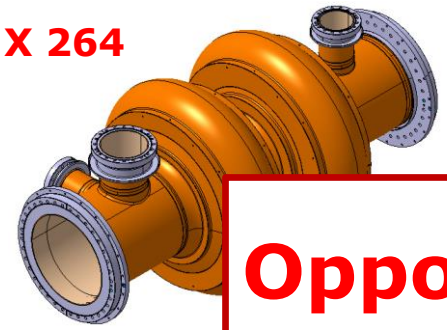




Example: FCC-ee SRF Cavities and Cryomodules
Conceptual & preliminary designs

Z, W, H

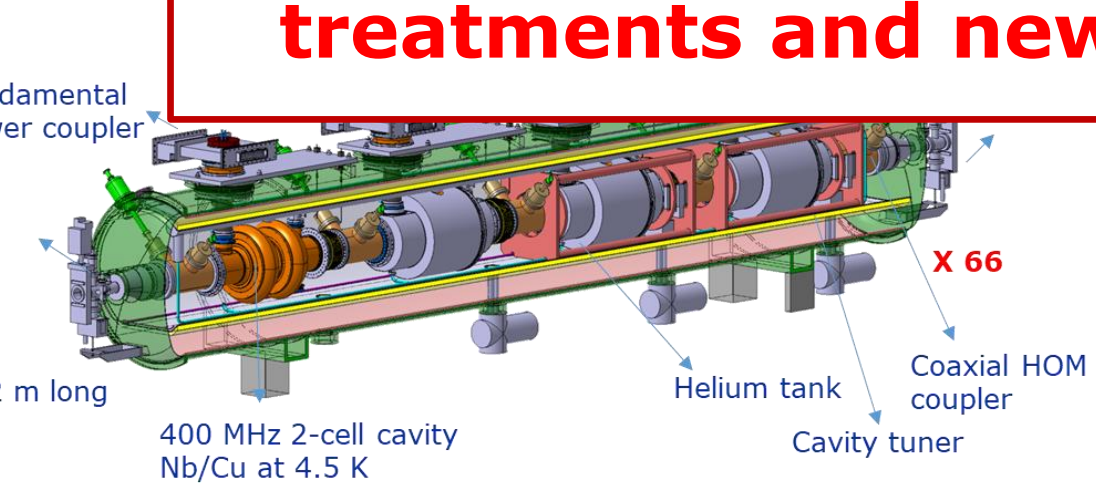
X 264



400 MHz

Niobium thin film on Copper

Operation at 4.5 Kelvin



ttb, booster

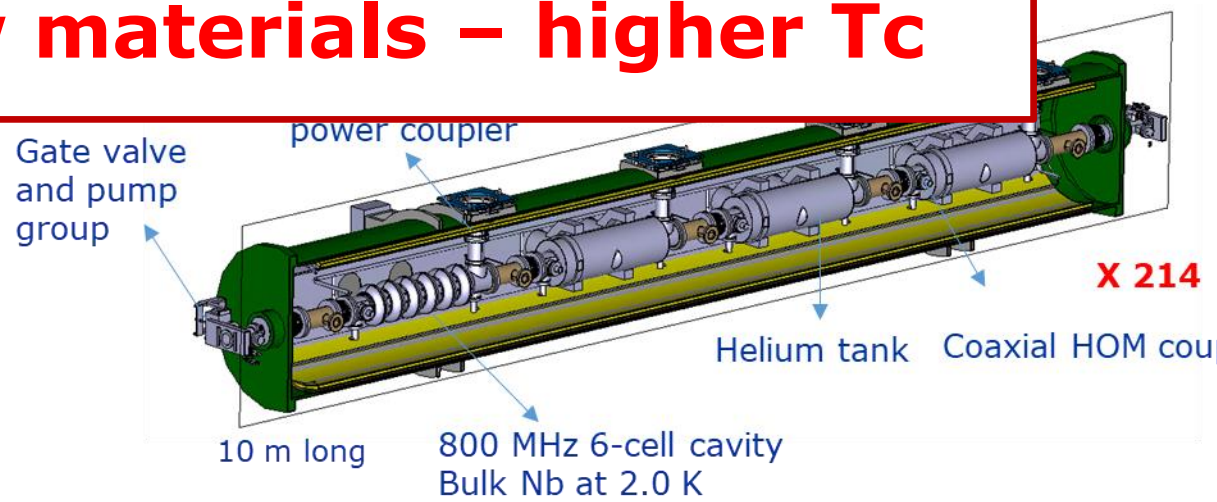
X 856

800 MHz

Sn possibly)

vin

= 3.8 x 10^{10}



Opportunity for collaboration and contribution
A key will be high performance – new treatments and new materials – higher Tc

Summary

- Accelerator science at TRIUMF provides Canada with a world-class platform in beam physics and instrumentation, secondary particle production, and SRF technologies.
- TRIUMF has a long tradition of international collaboration in support of Canadian contributions to large particle physics projects.
- Collaborations contribute to Canadian and International projects with critical components and expertise while maintaining and developing national resilience in cutting edge technologies

TRIUMF

Thank you,
Merci

2026-06-24

Discovery, accelerated