TRIUMF

A Canadian Accelerator Contribution to the Electron Ion Collider

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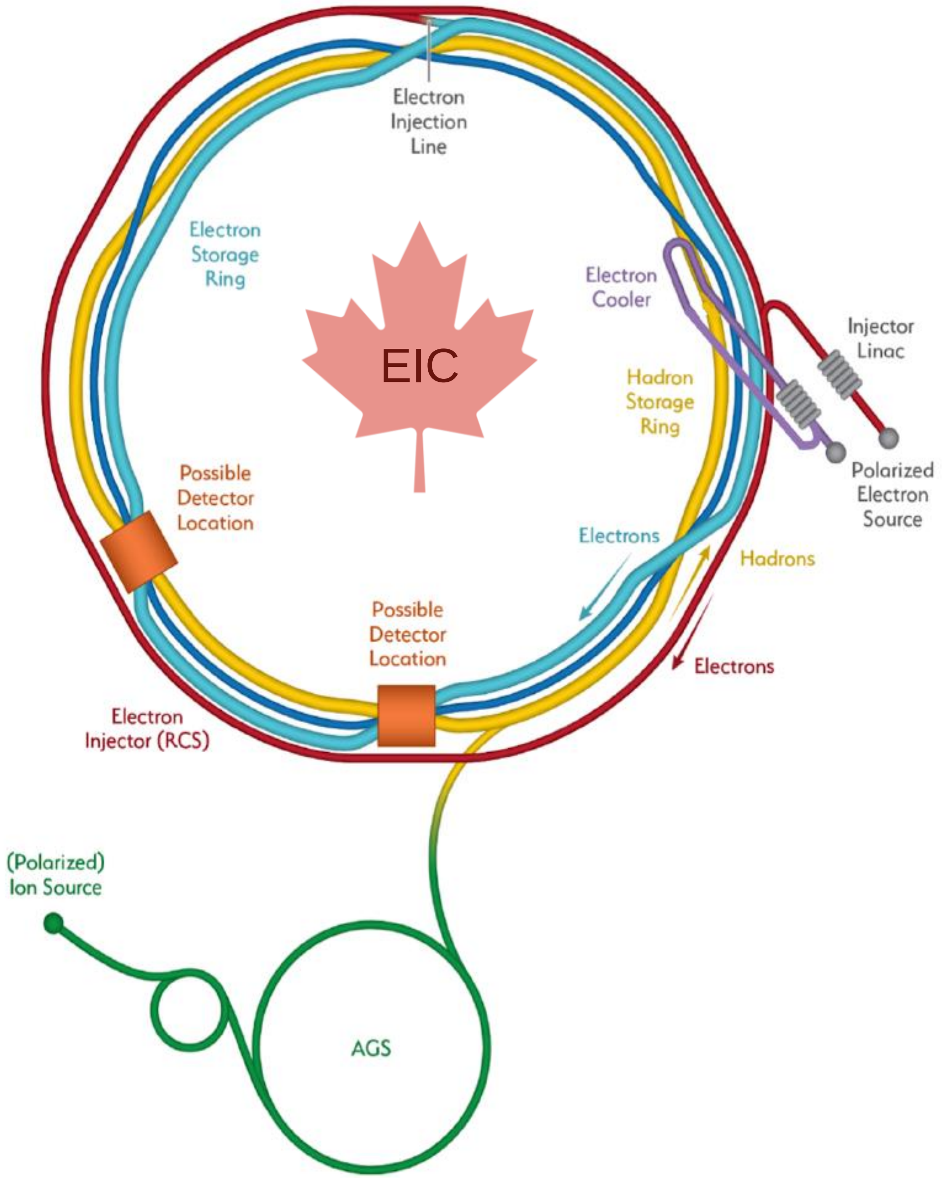

Collaborators:

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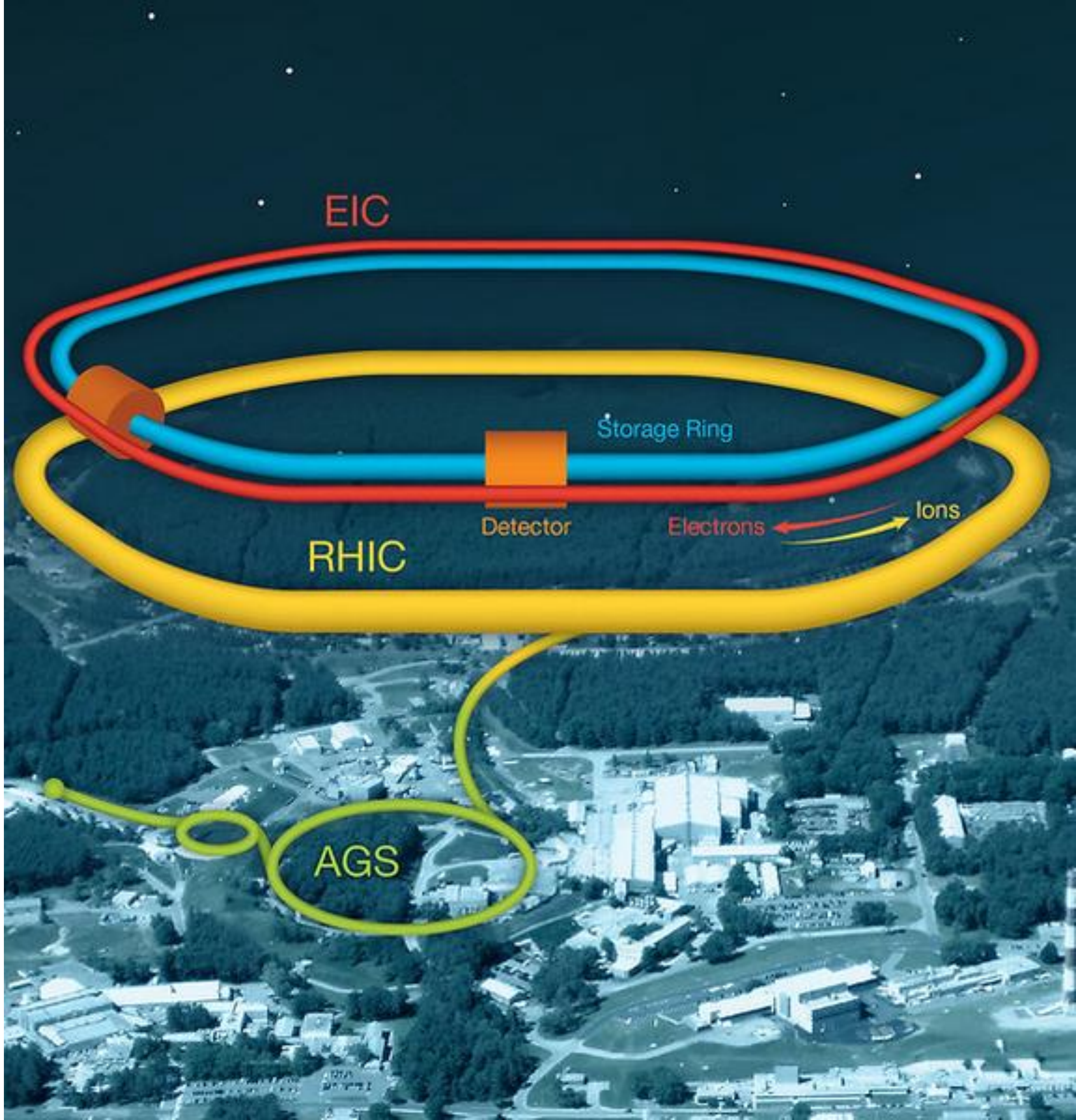
Electron Ion Collider

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

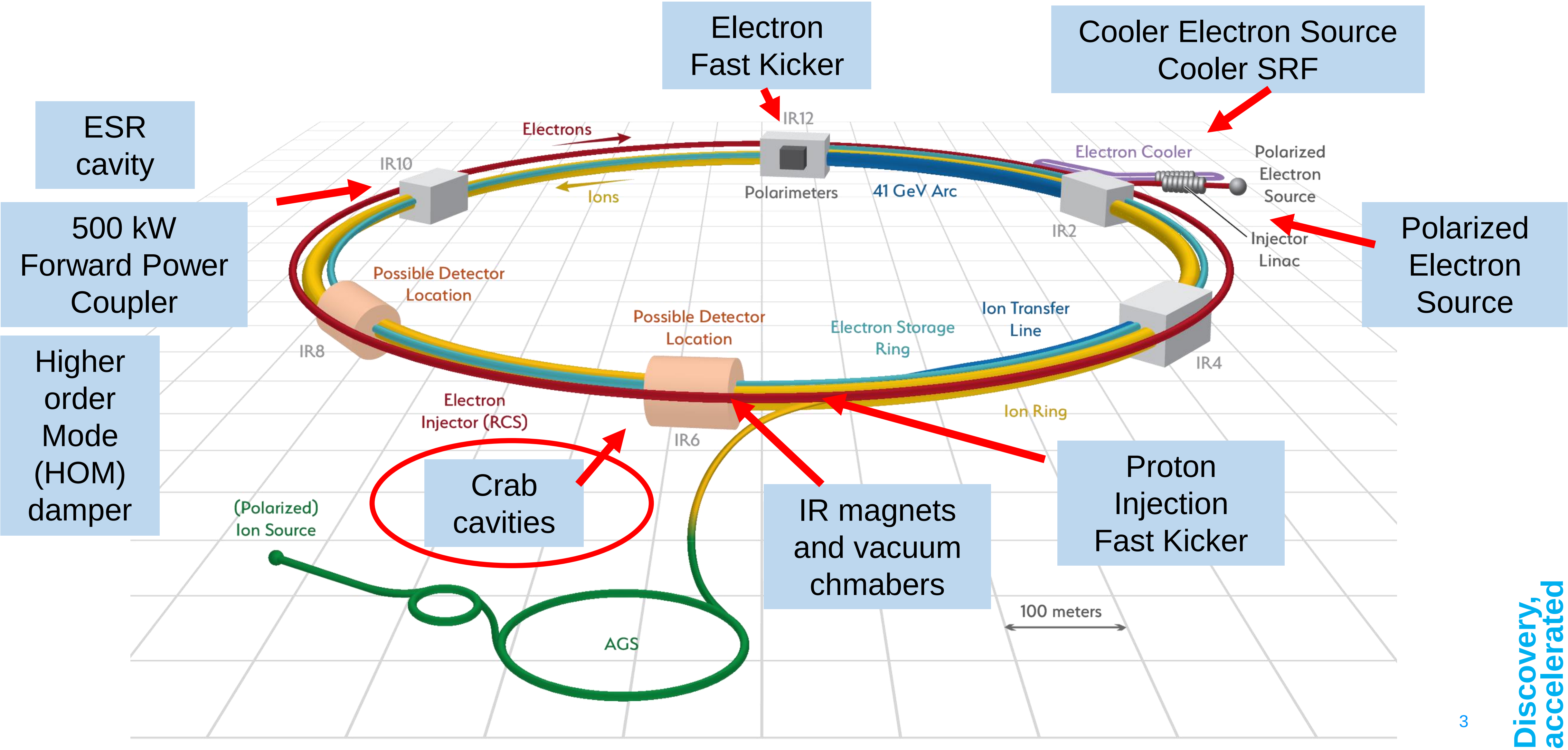
The EIC accelerator design is based on the existing RHIC Complex

- Hadron storage ring 40-275 GeV (based on existing RHIC)
- Electron rapid cycling synchrotron 0.4- 18 GeV new in RHIC tunnel
- Electron storage ring 2.5–18 GeV new ring in RHIC tunnel
- High luminosity interaction region



EIC Accelerator R&D scope overview

- The EIC offers significant challenges in accelerator technology

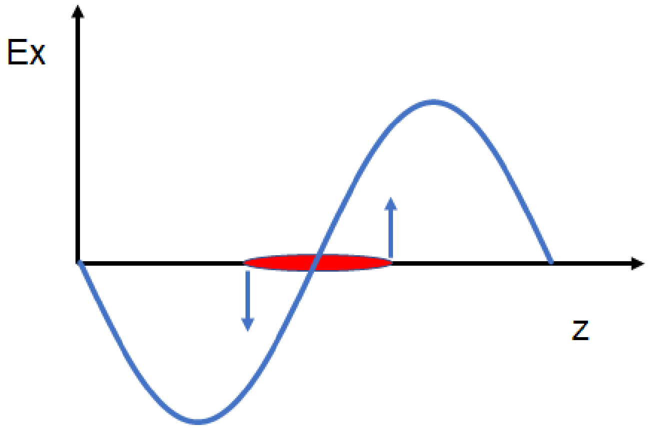


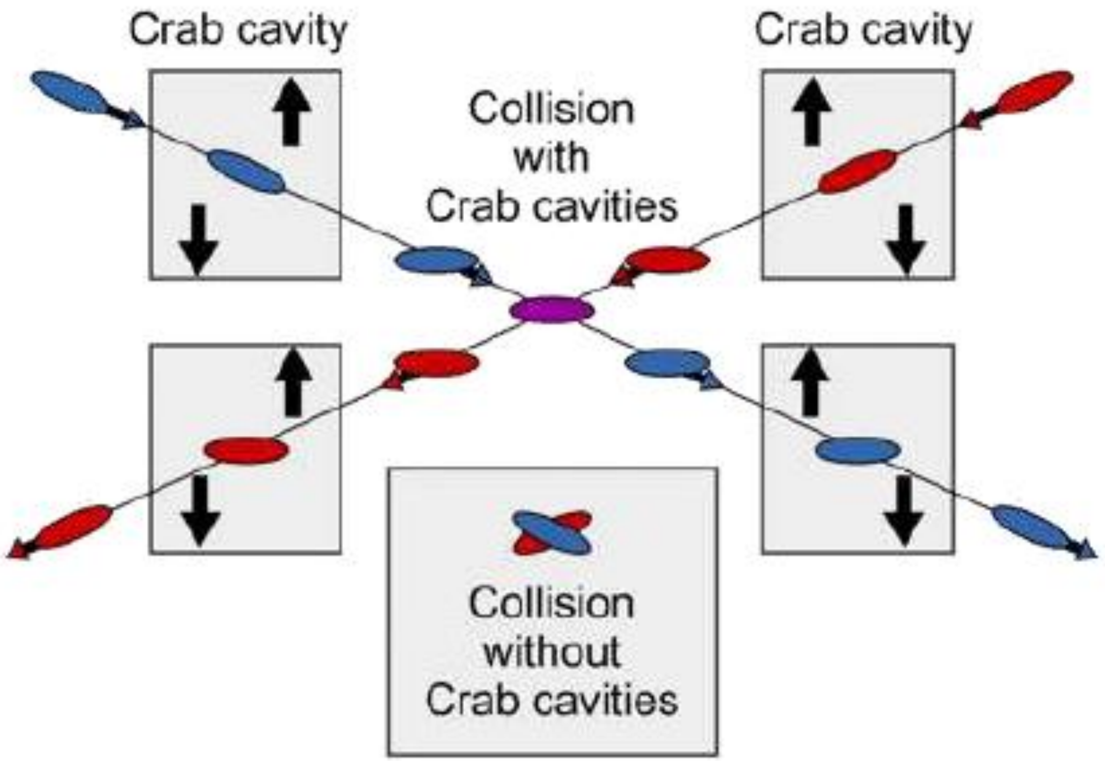
TRIUMF and the EIC accelerator

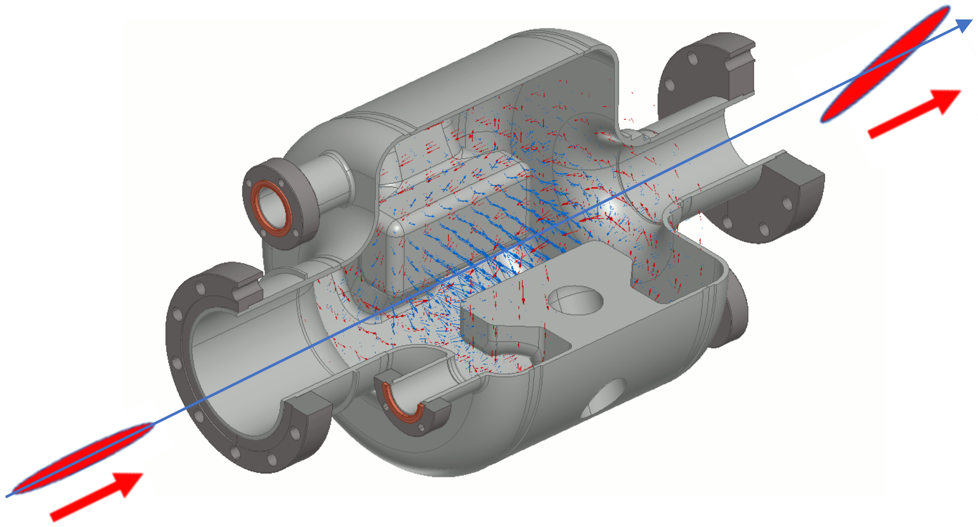
- Accelerator science at TRIUMF provides Canada with a world-class platform in beam physics and instrumentation, secondary particle production, and Superconducting RF (SRF) technologies.
- Together with the Canadian subatomic physics community we are developing a five-year plan informed by 20-year vision that includes support for international projects like the EIC.
- Discussions with EIC have identified the crab cavities as a possible in kind contribution from Canada

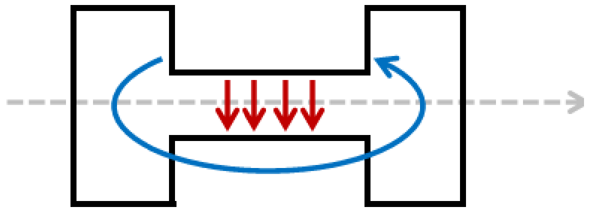
What is a crab cavity?

- 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)





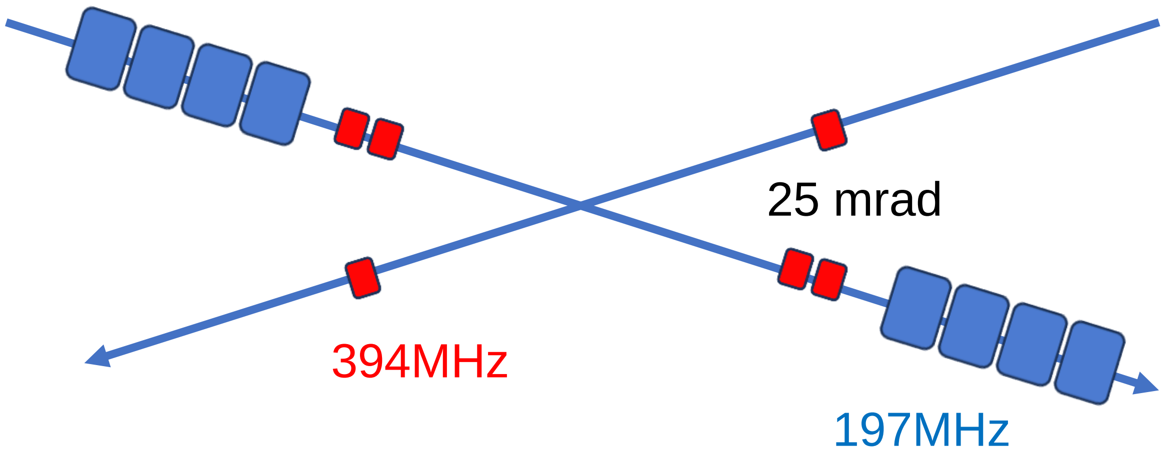




EIC CRAB Cavities

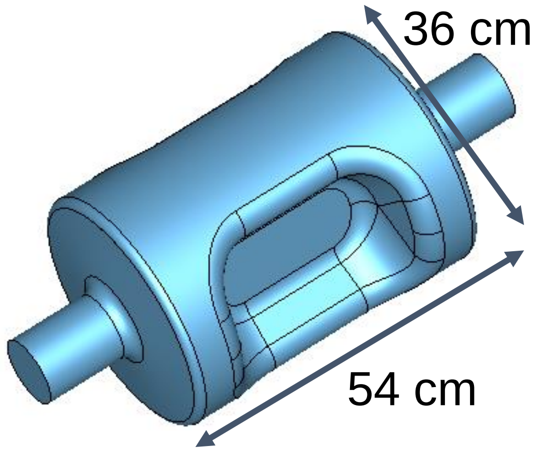
- The EIC requires crab cavities on both the hadron storage ring (HSR) and the electron storage ring (ESR)
- HSR – long bunch, high rigidity
  - requires eight 197MHz crab cavities and four 394MHz cavities to linearize the deflection
- ESR – short bunch, low rigidity
  - requires two 394 MHz cavities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

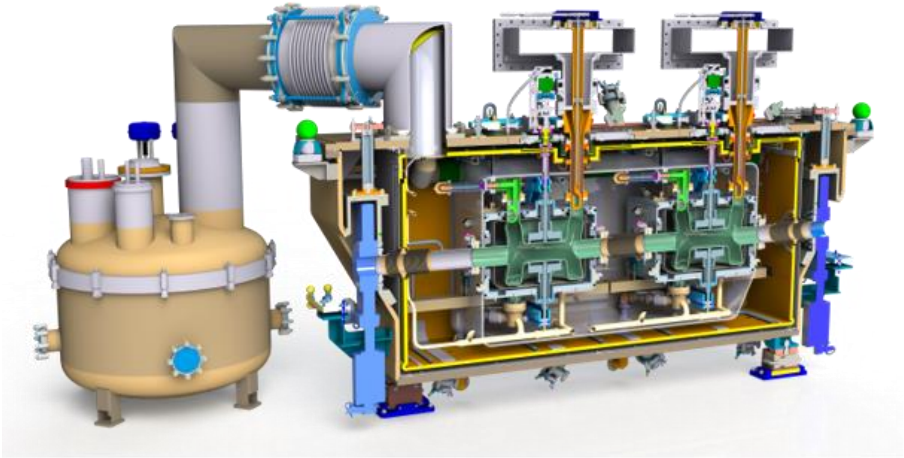
	Voltage/cavity Vt (MV)		**No. of cavities**	
System	HSR	ESR	HSR	ESR
197 MHz	8.5	-	8	-
394 MHz	2.4	2.9	4	2



Challenge 1: Large crossing angle -> high voltage -> SRF technology

- Given the high crossing angle (25mrad) and limited space strong deflecting voltages are required
- This precludes the use of normal conducting structures as the dissipated power would be too high (~1 MW for RT vs a few Watts for SRF)
- The cavities will be made from Niobium (Tc=9.2K) and operated at 2K
- The cavities will be housed in cryomodules for thermal isolation



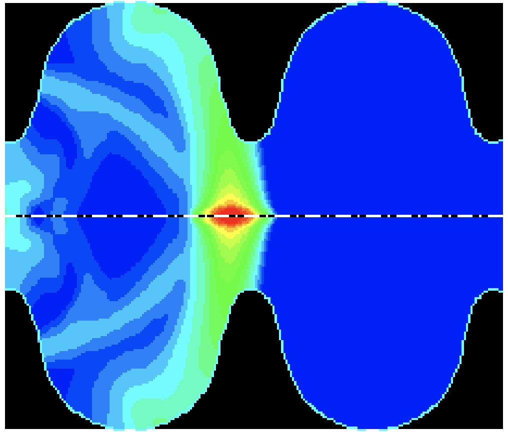


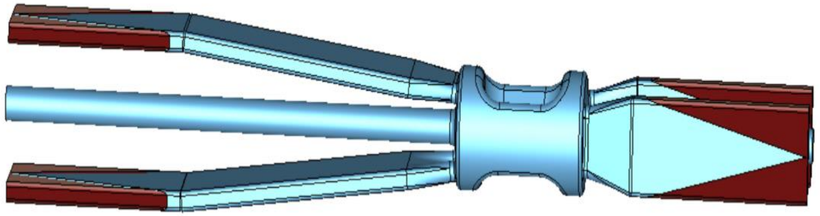
Discovery, accelerated

Challenge 2: High beam current and short bunches -> HOM excitation

- High intensity charged particles passing through an rf cavity can excite additional rf field modes in addition to the fundamental crabbing mode

- In EIC these higher order modes (HOMs) represent considerable power (10s of kW in e-ring) that must be removed from the cavity and delivered to an external load – under study at TRIUMF

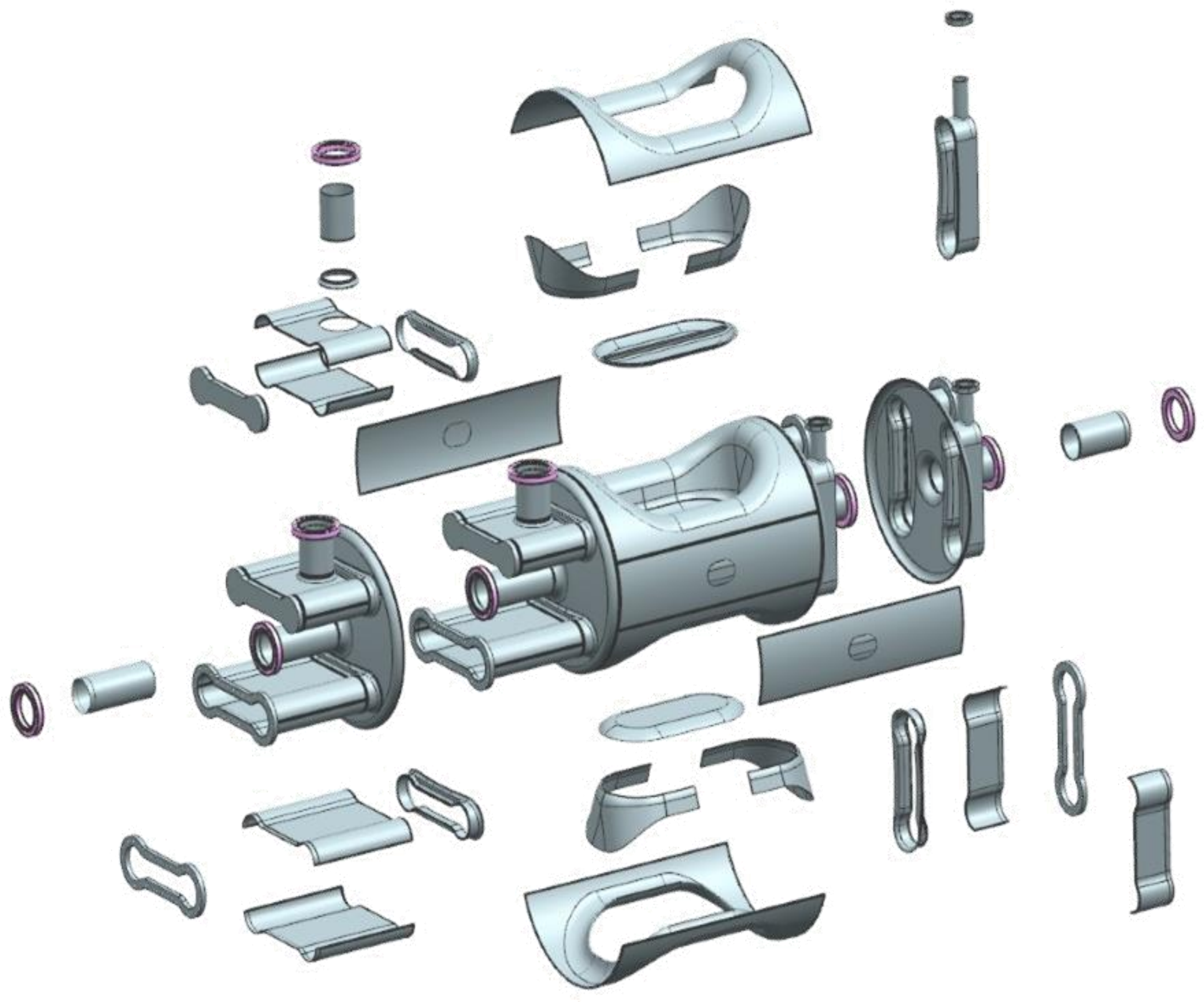




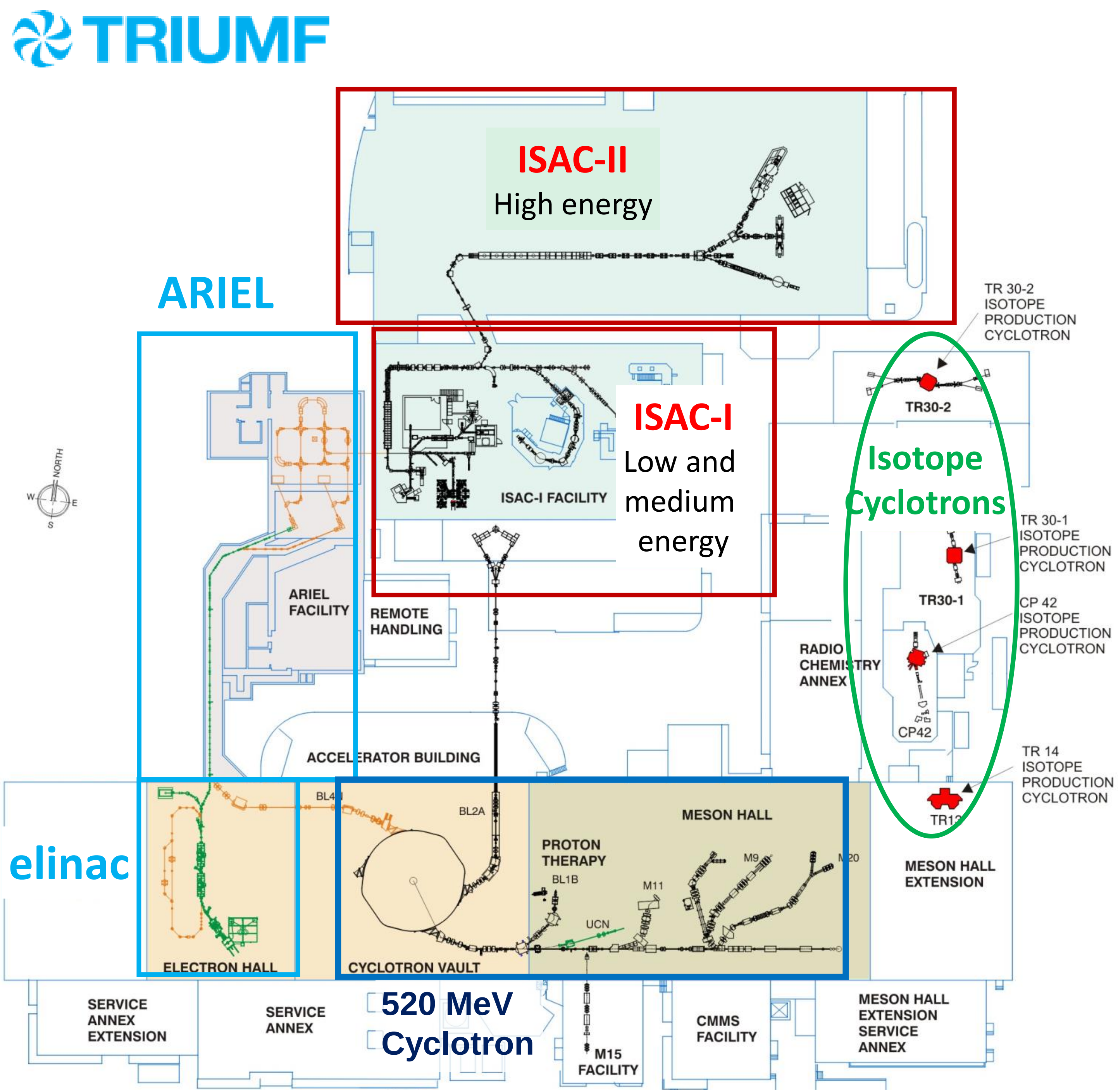
394 MHz Crab Cavity with waveguide HOM extraction to damped loads

Challenge 3: Complex cavity shape

- Crab cavities have complex shapes further complicated by additional ports and waveguides for HOM extraction
- Requires many unique forming/machining and electron beam welding steps



TRIUMF's SRF Capabilities



TRIUMF is Canada's particle accelerator centre.

A wide variety of accelerator technologies populate the campus.

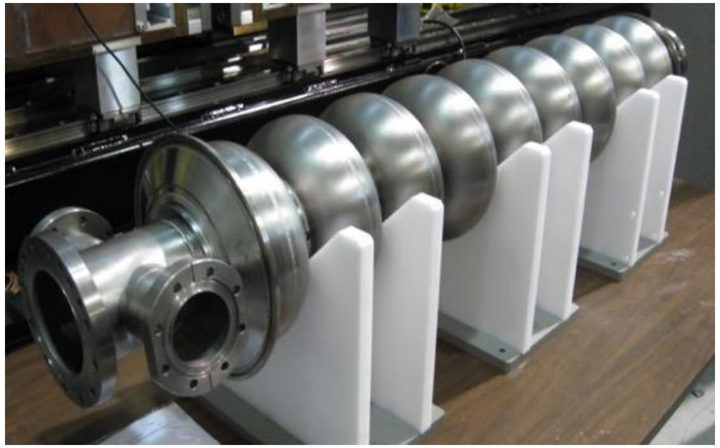
Our strategy is to use internal projects and external collaborations as springboards to expand core competencies or gain new ones.

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

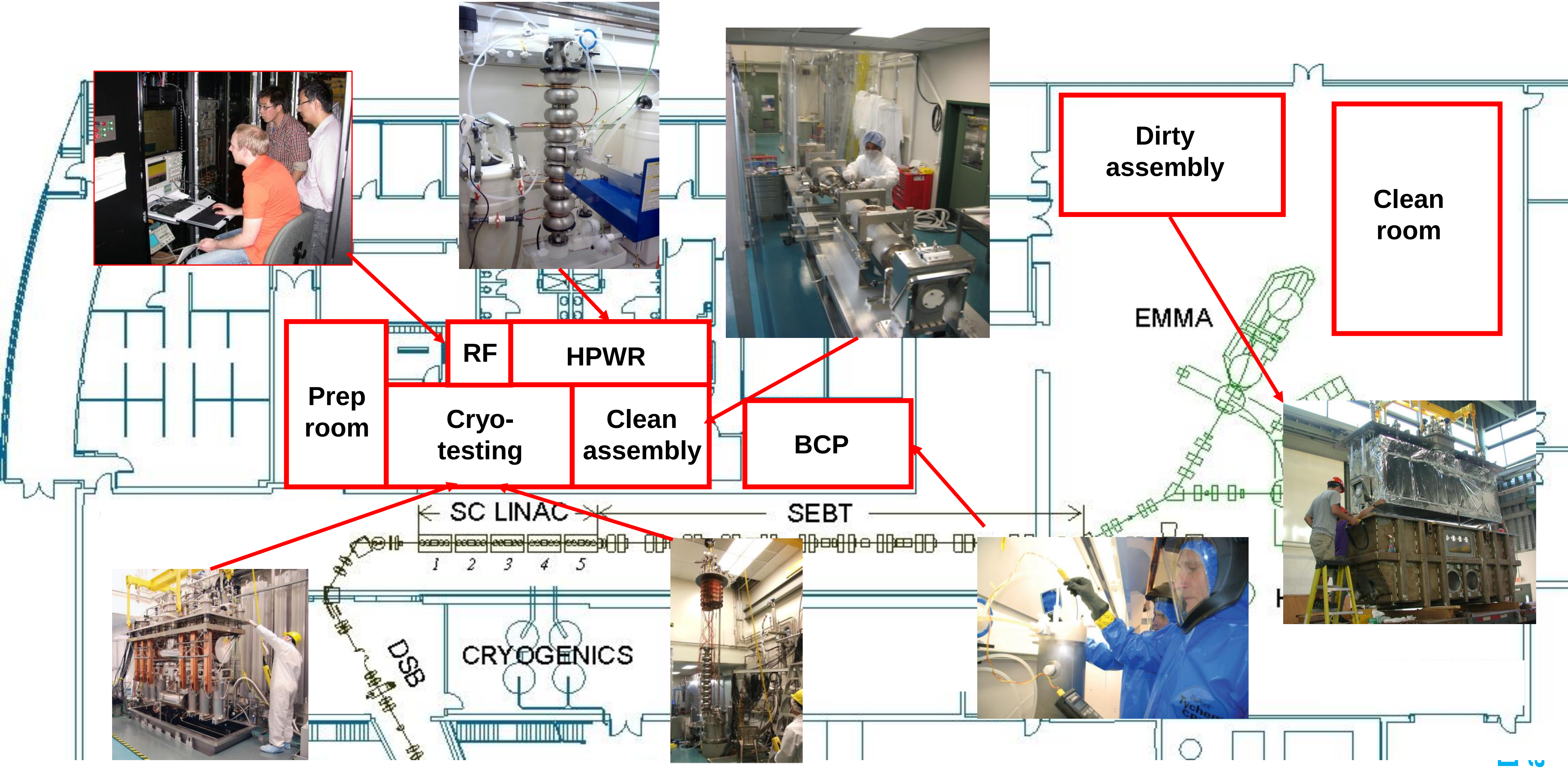


30MV ARIEL SRF 10mA electron linac
@ 1.3 GHz
first beam 2014



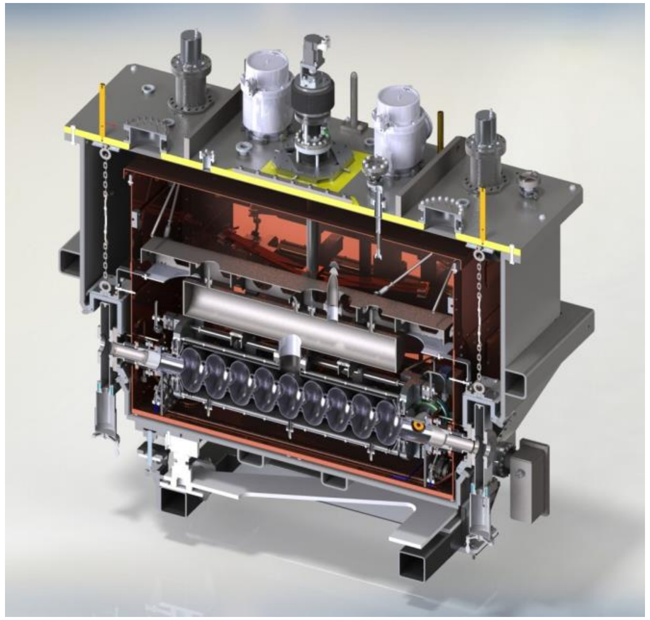
SRF Facilities

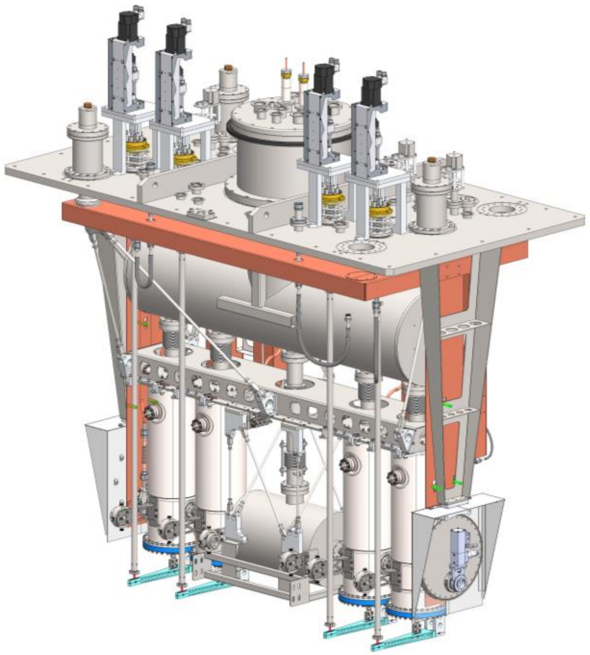
The SRF lab supports the in-house accelerator program, SRF research and external collaborations



TRIUMF and VECC (India)

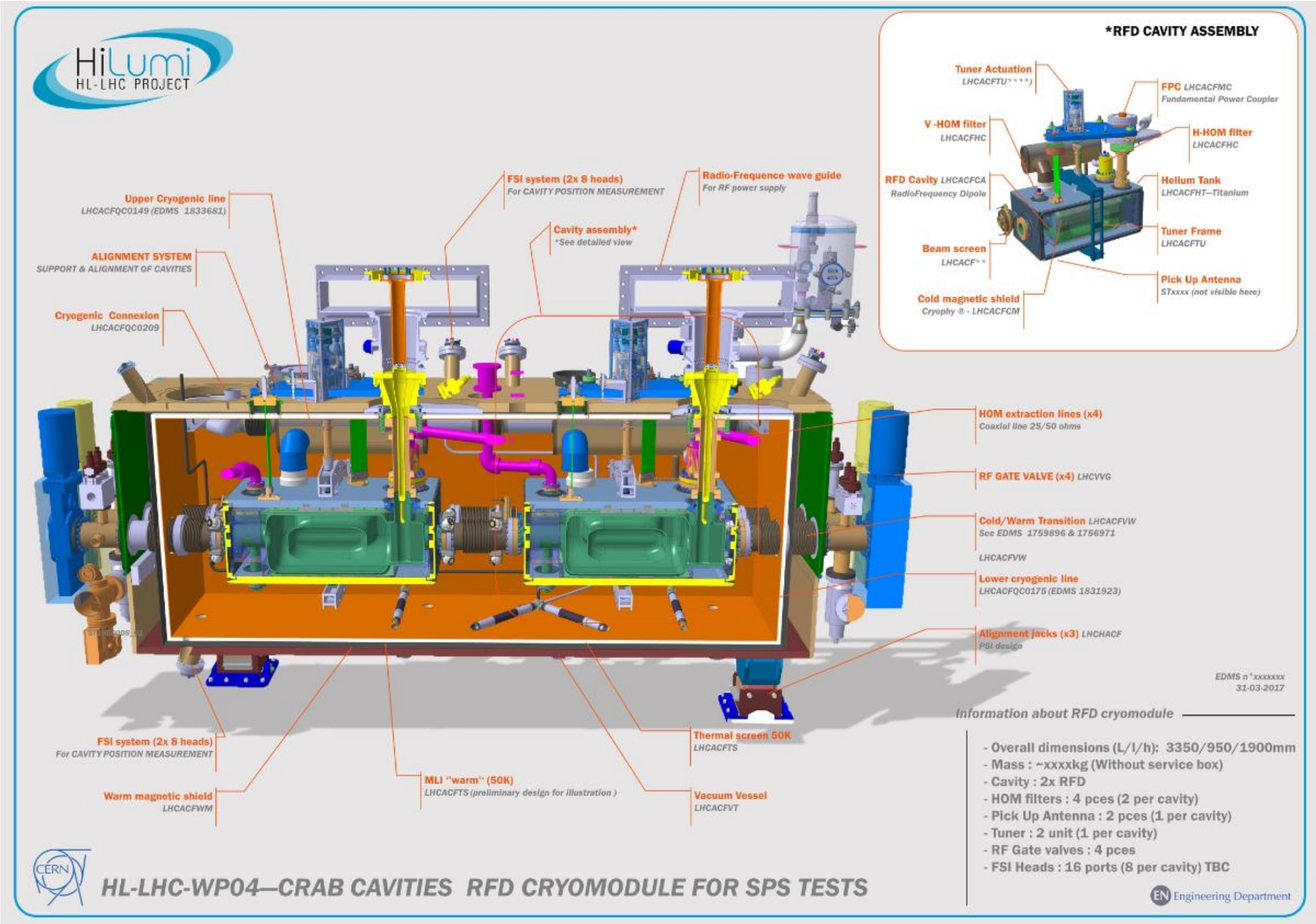
- An electron cryomodule was designed and fabricated at TRIUMF and shipped to VECC in 2018
- A heavy ion cryomodule was designed and fabricated at TRIUMF and shipped to VECC in 2022



TRIUMF and CERN

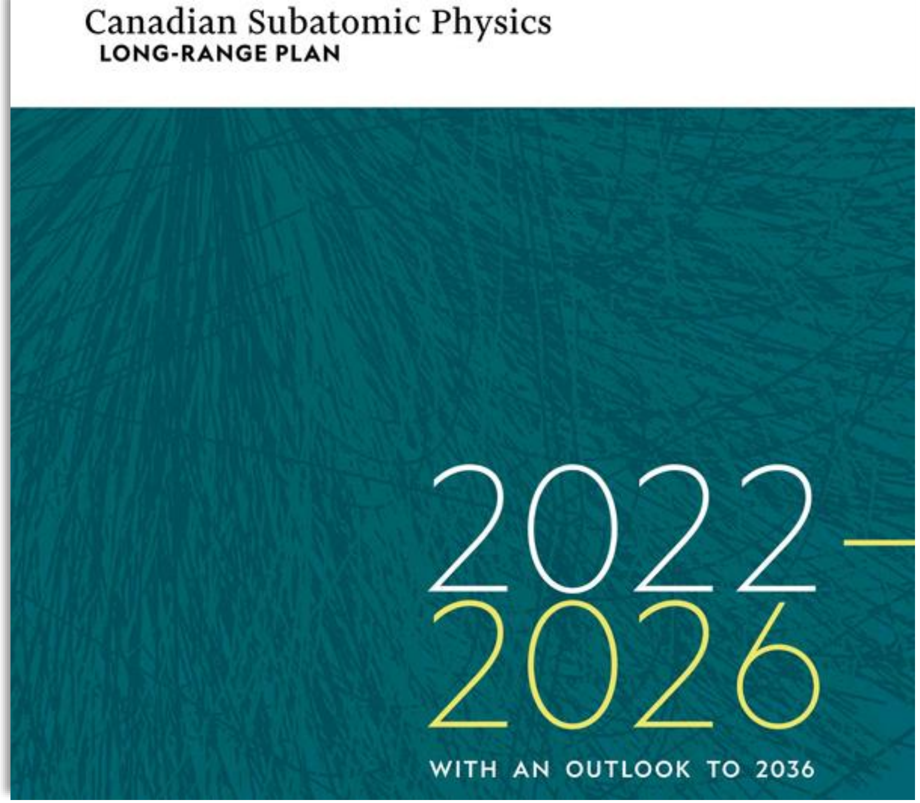
- As a Canadian contribution to the Hi-Luminosity upgrade project at CERN, TRIUMF will fabricate, qualify and ship five crab cavity cryomodules to CERN (2025-27)
  - Ten 400MHz crab cavities will be received from US collaborators starting later this year
- The project supplies critical infrastructure to CERN, supporting both the HL-LHC and the Canadian particle physics community



The Proposal

Canadian contribution to EIC

- The Canadian subatomic physics community is strongly supporting participation in the EIC program. In the 2022–2026 Canadian Subatomic Physics Long Range Plan, the community named the EIC as a “flagship program with broad outcomes.”
- A Canadian collaboration with EIC Canada, TRIUMF and University partners is pursuing a CFI proposal in the 2025 IF competition.
- The proposal leverages technical know-how at TRIUMF, engages Canadian industry in cutting edge accelerator technology while training next generation HQP.



Discovery, accelerated

Scope for EIC contribution

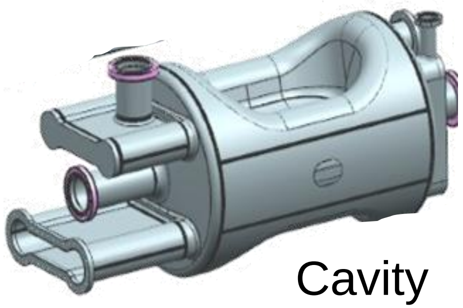
We propose to deliver scope on the 394 MHz crab cavity system for the HSR and ESR.

SRF Cavity package: (6)

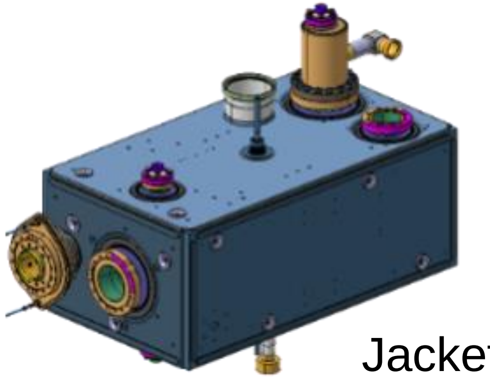
- Design including HOM mitigation schemes
- Niobium cavity fabrication plus jacket and cold magnetic shield
- Fundamental Power Couplers (FPC) and HOM mitigation schemes (waveguide or coupler).
- Rf tuner

Cryomodule package: (4)

- Outer vacuum chamber (OVC)
- thermal shield, mu-metal
- cryogenic piping
- fabricated in industry
- assembled and qualified at TRIUMF.

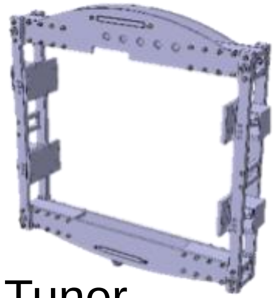


Cavity

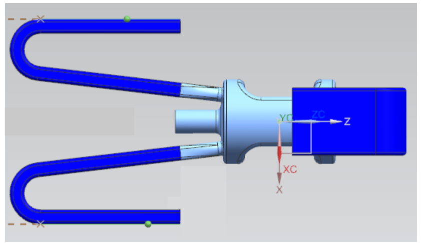


Jacketing

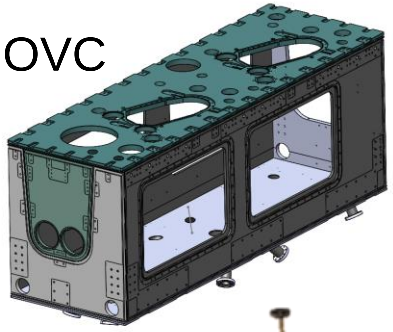
FPC



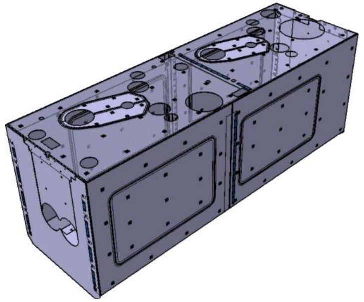
Tuner



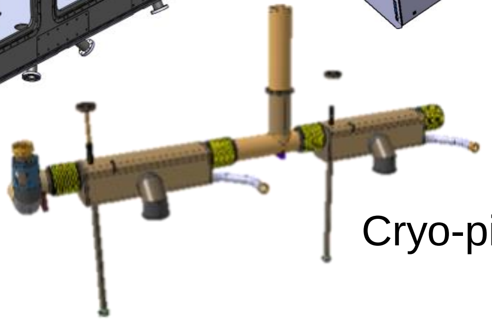
HOM mitigation



OVC



Thermal screen and mu metal



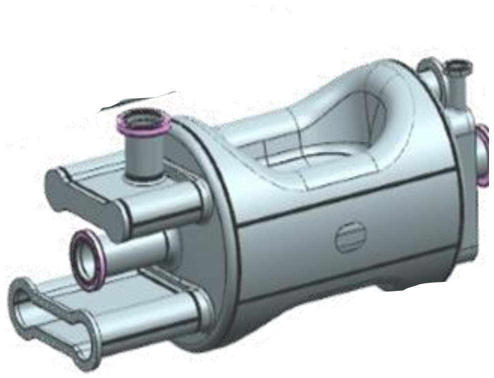
Cryo-piping

Assembly

Budget

The total project cost is estimated to be ~14M$ with capital costs of about 5M$ for cavity systems, 5M$ for cryostating and 1M$ for infrastructure upgrades at TRIUMF.

Cavity package components	Unit cost	No.	Sub-total
Bare cavities	400,000	6	2,400,000
Helium jacket	75,000	6	450,000
fundamental power coupler	75,000	6	450,000
HOM couplers	25,000	24	600,000
tuner	120,000	6	720,000
cold magnetic shield	20,000	6	120,000
qualification	5,000	24	120,000
Sub-total			**4,860,000**



Summary table	Capital	Labour	In kind	Total
Cavities	4,860,000	250,000	1,000,000	6,110,000
HSR CMs	2,868,000	150,000	1,000,000	4,018,000
ESR CMs	2,202,000	100,000	600,000	2,902,000
Infrastructure upgrade	1,000,000	150,000	100,000	1,250,000
Travel	120,000	0	0	120,000
Sub-total	**11,050,000**	**650,000**	**2,700,000**	**14,400,000**

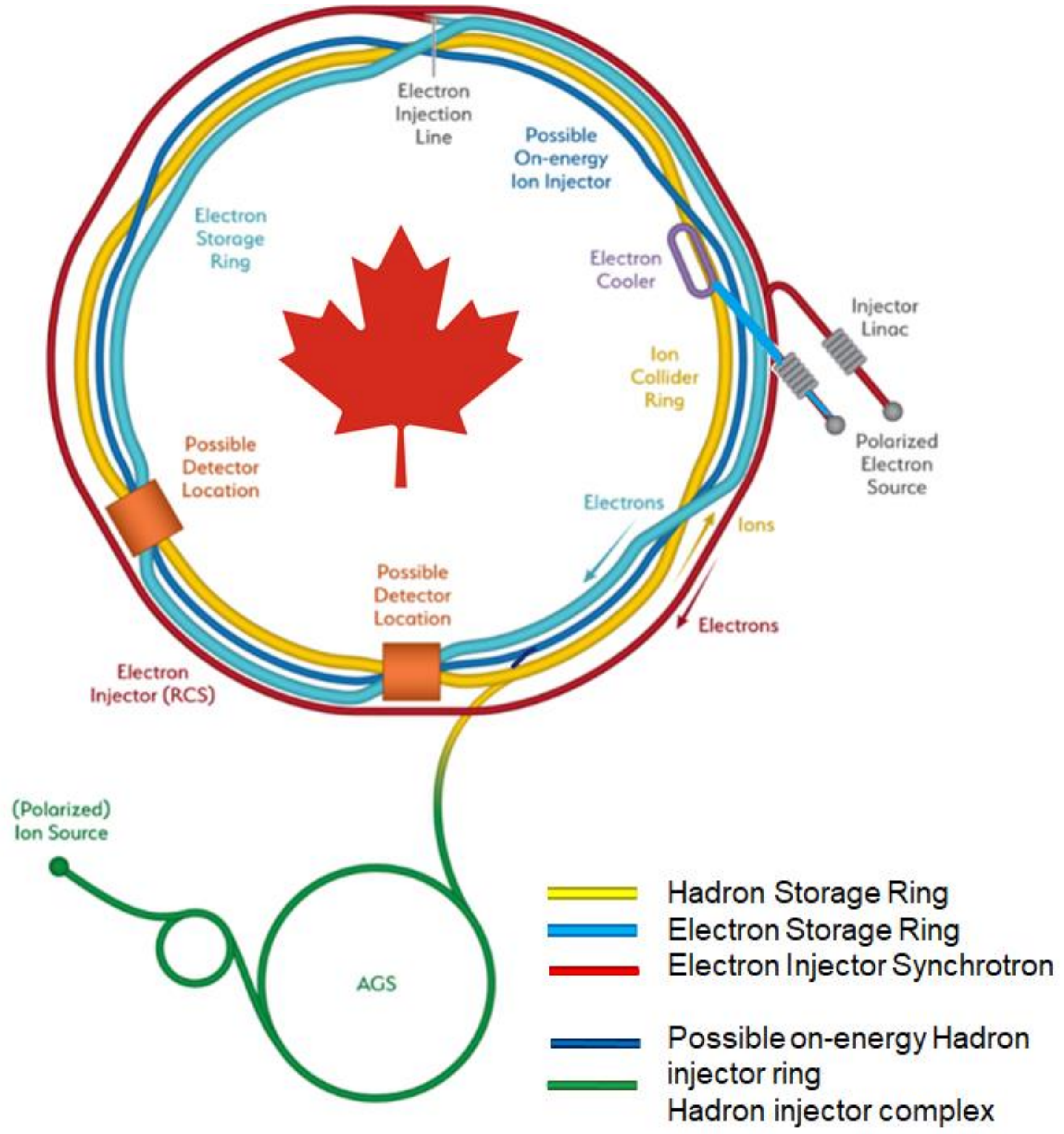
Funding and Timeline

The timeline would be framed by the CFI funding process with deliverables to EIC in 2029-2030.

Milestones		CY2025	CY2026	CY2027	CY2028	CY2029	CY2030	CY2
Proposal sent to CFI	April 2025							
Funds awarded	March 2026							
Cavity contract awarded	July 2026							
Prototype bare cavity received and qualified	Dec 2027							
Jacketed cavity received and qualified	Jul. 2028							
Fully dressed cavity test	Oct. 2028							
Series cavities received	May--2029							
Prototype ESR CM completed	May--2029							
ESR CMs completed and qualified	Dec 2029							
HSR CMs completed and qualified	Dec 2030							
Project complete	March 2031							

Summary

- ✓ The crab cavities are critical elements that offer a ten-fold increase in the EIC luminosity
- ✓ The technical scope offers unique challenges in design, fabrication, assembly and testing across rf modeling, superconducting rf, custom manufacture and cryogenics.
- ✓ The project supports both the EIC and the CINP community while leveraging and augmenting TRIUMF’s core competence in cutting edge accelerator technology and offering opportunity to Canadian industry in advanced accelerator technology.
- ✓ Collaborators welcome!



Thank you!

Merci!