Superconducting Radio Frequency R&D

Long Term Vision

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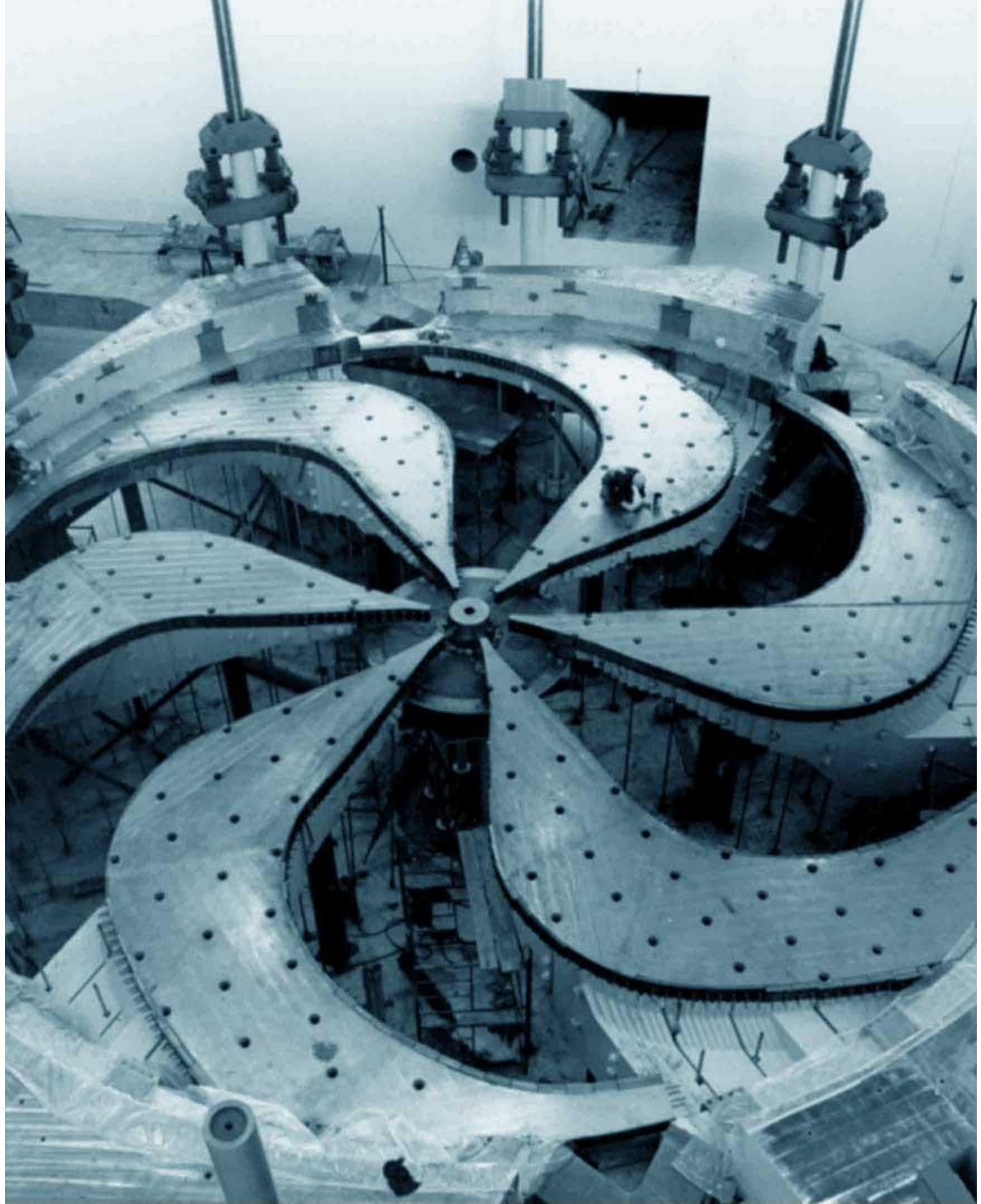
SRF/RF Department

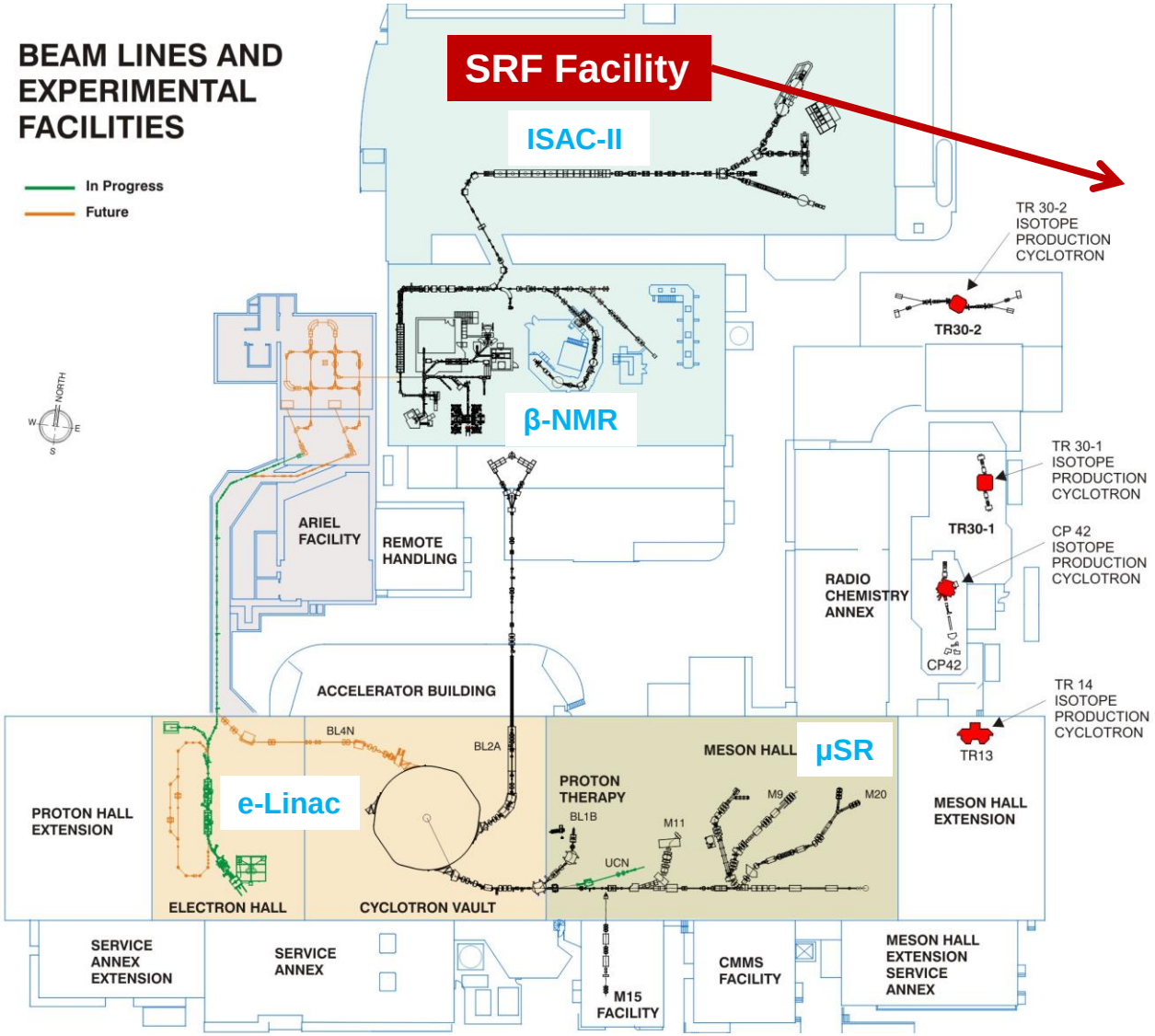
Science Week, Aug. 20, 2020

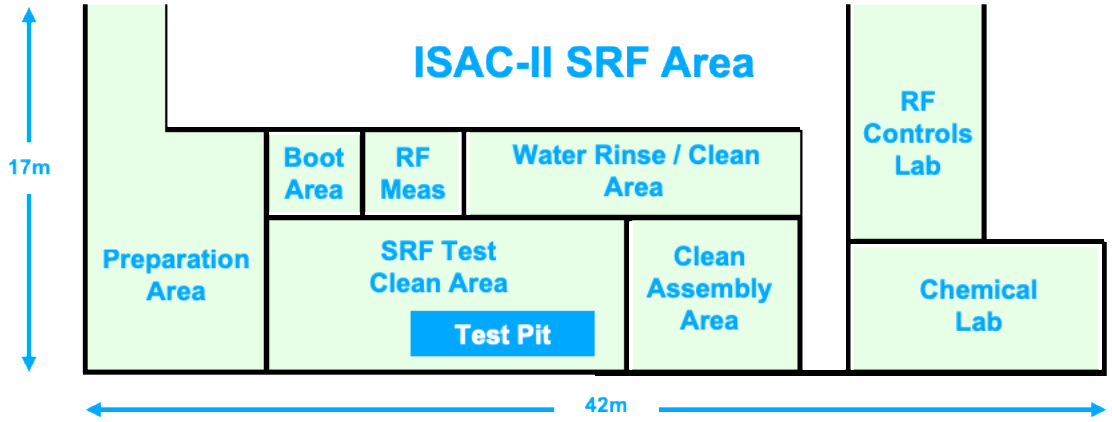


Outline

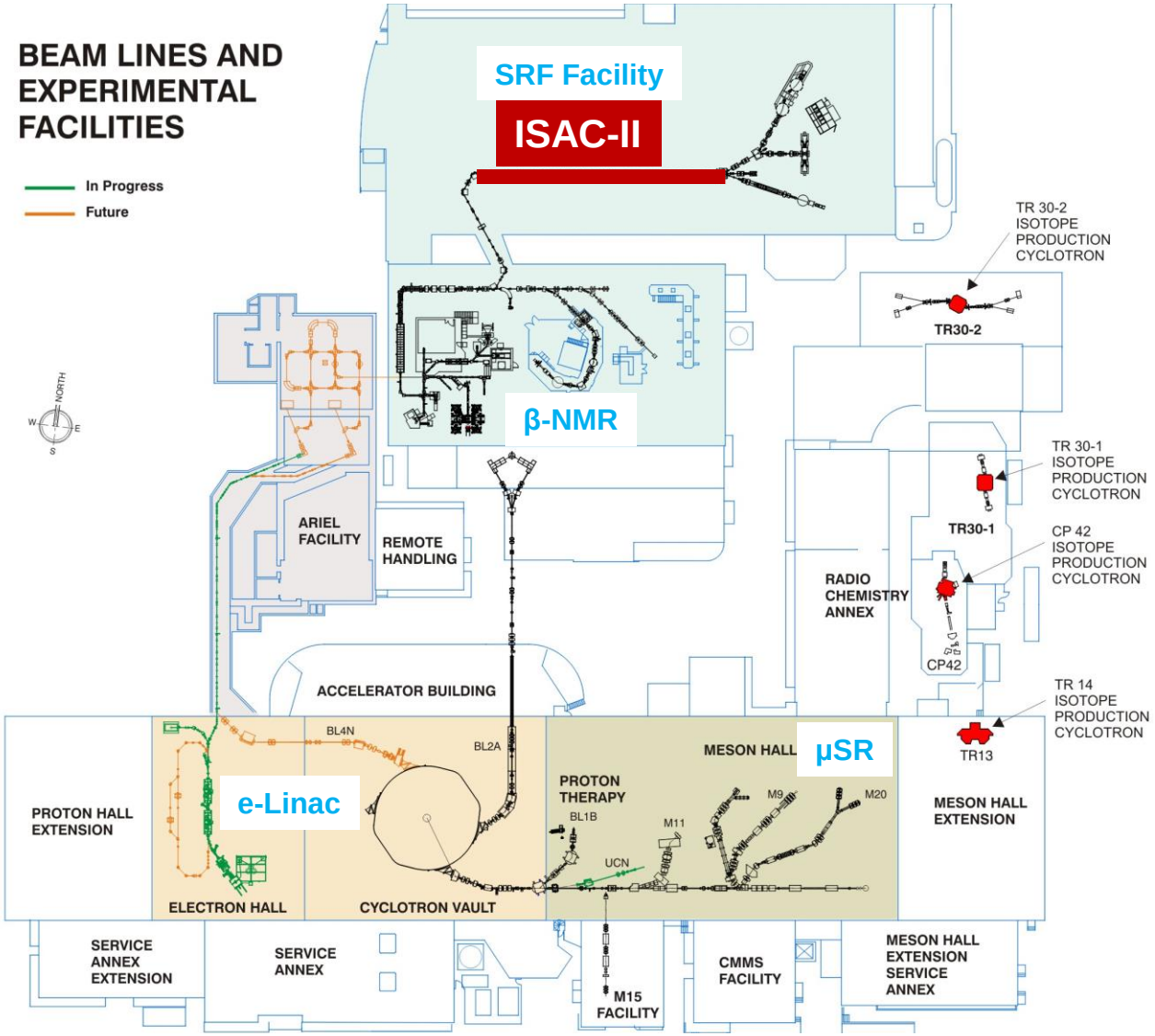
- **Existing SRF facilities at TRIUMF**
- Upgrade projects for SRF linacs
- SRF Work-for-Others
- SRF R&D supporting future global initiatives
- Summary

SRF Facilities at TRIUMF

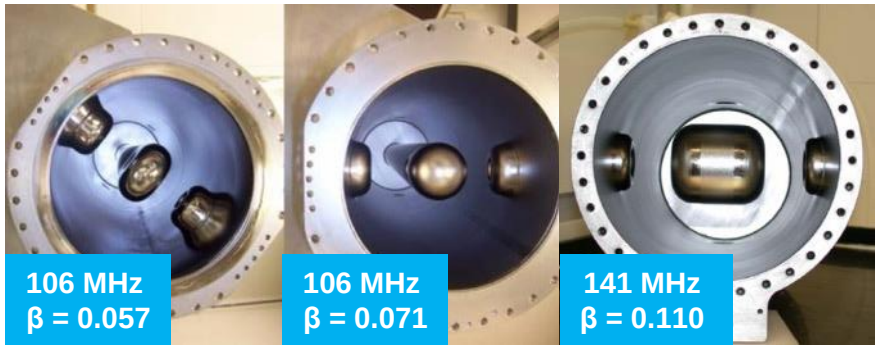




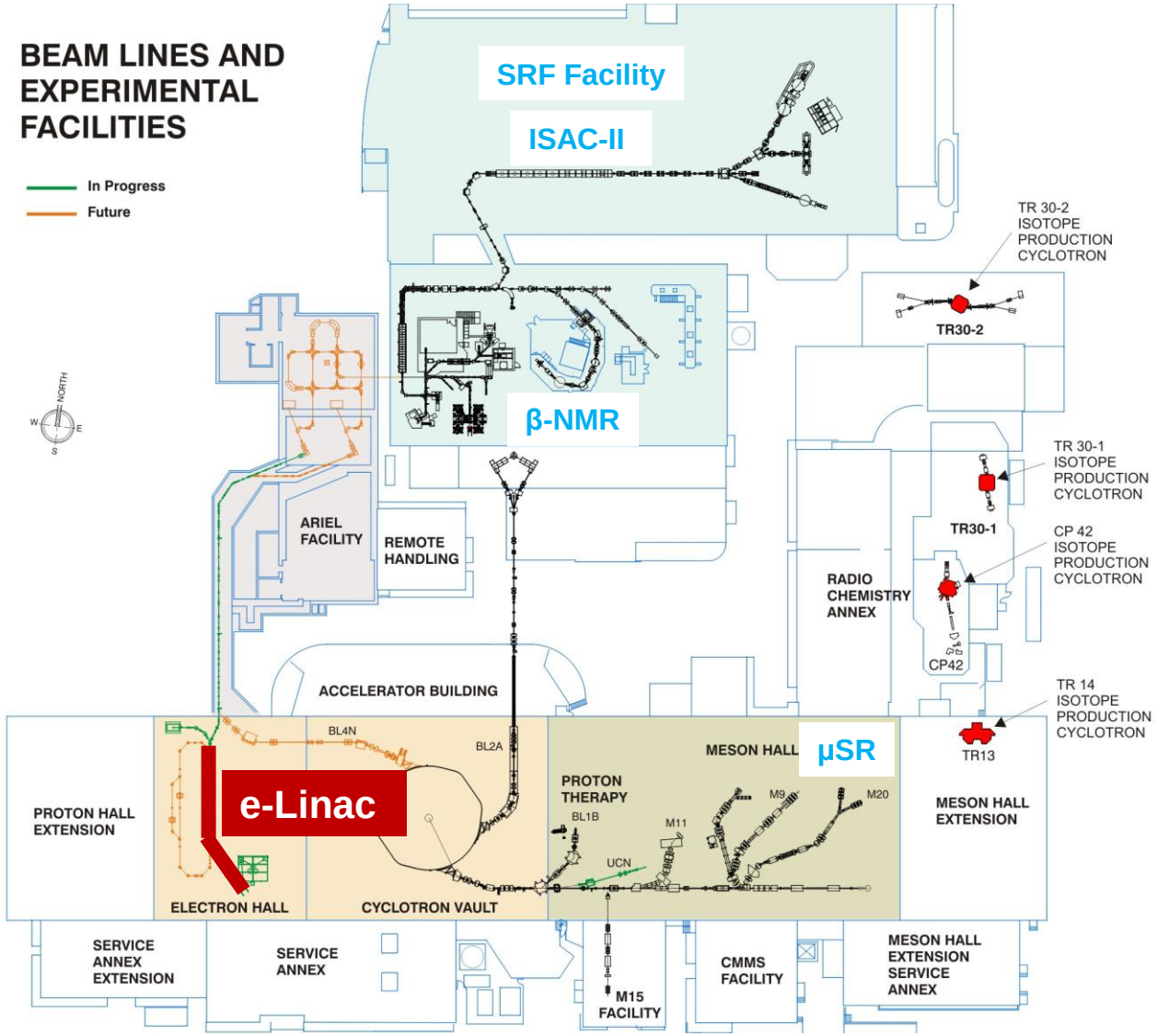
ISAC-II Linac



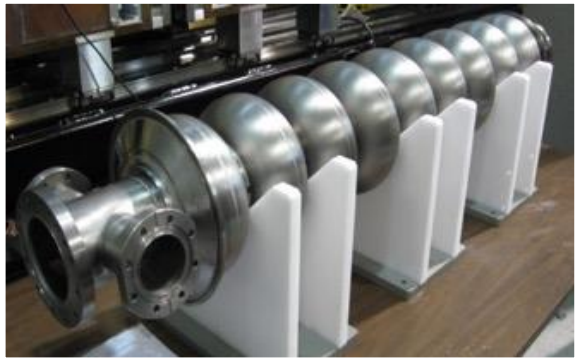
- **Superconducting heavy ion linac**
  - 40 QWRs in 8 CMs to provide 40 MV
  - Cavity frequency 106 / 141 MHz
  - Acceleration for heavy ion beam A/q<6
  - Operation since 2006

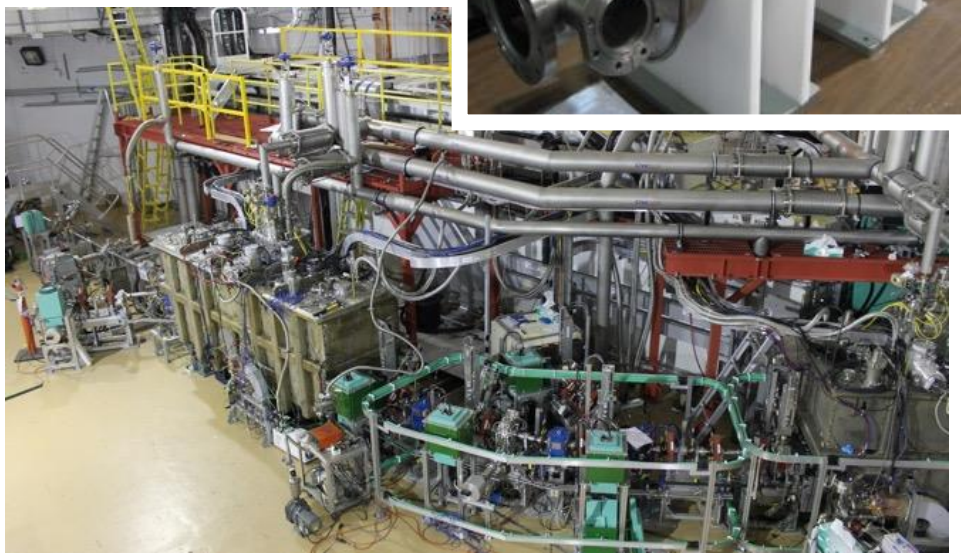


ARIEL e-Linac



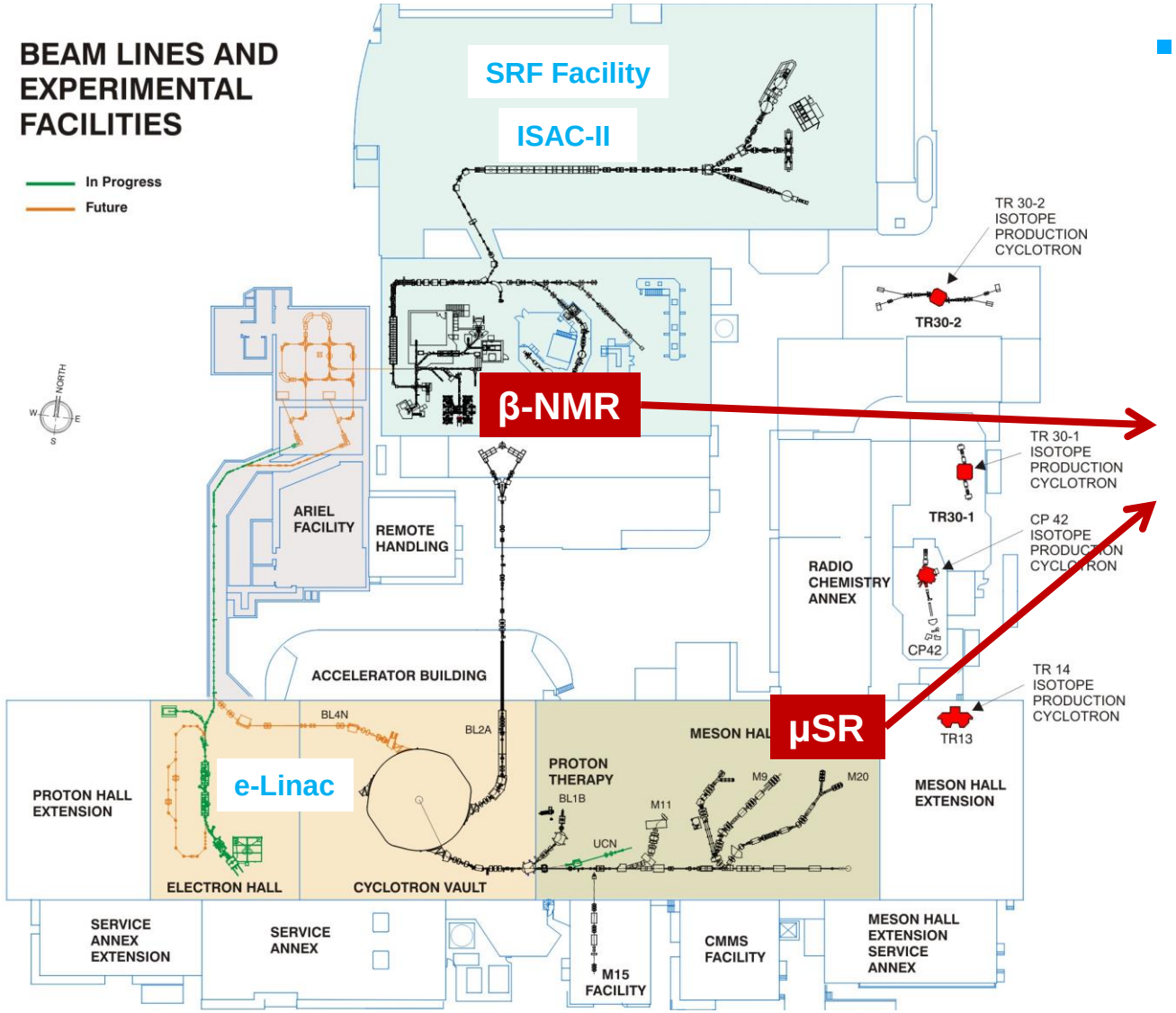
- **Superconducting electron linac – driver**
  - 30 MeV 10 mA CW electron beam
  - 1.3 GHz 9-cell elliptical cavity
  - Operating at 10 MV/m
  - Two 60 kW RF power coupler for one cavity
  - Achieved 31 MeV beam early this year



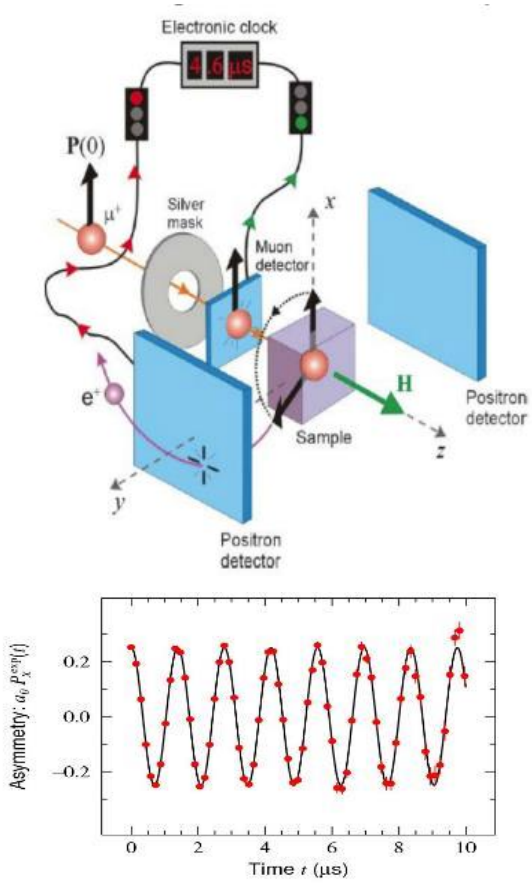


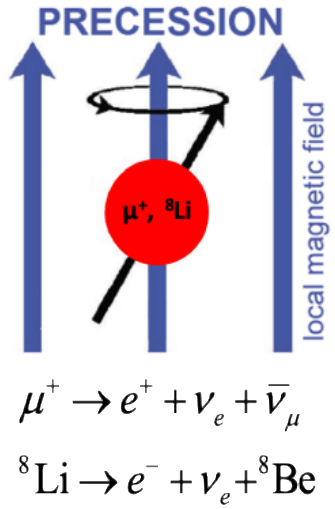
Discovery, accelerated

Material Science Facilities for SRF



- TRIUMF hosts two world class facilities for material science – **μSR and β-NMR**





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- Existing SRF facilities at TRIUMF
- **Upgrade projects for SRF linacs**
- SRF Work-for-Others
- SRF R&D supporting future global initiatives
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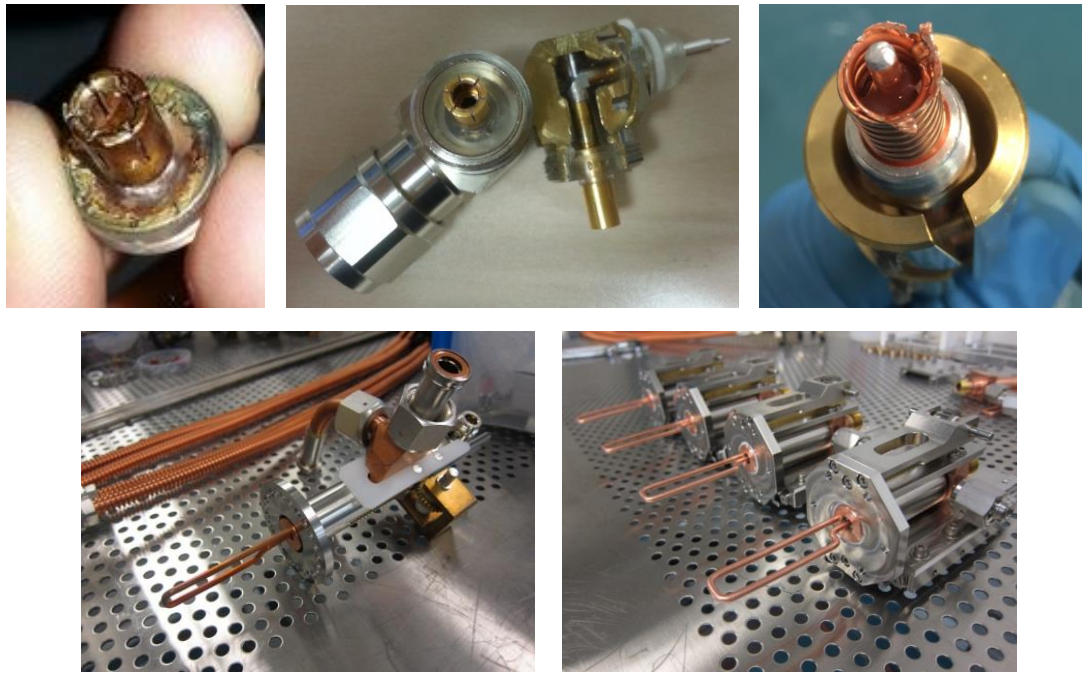
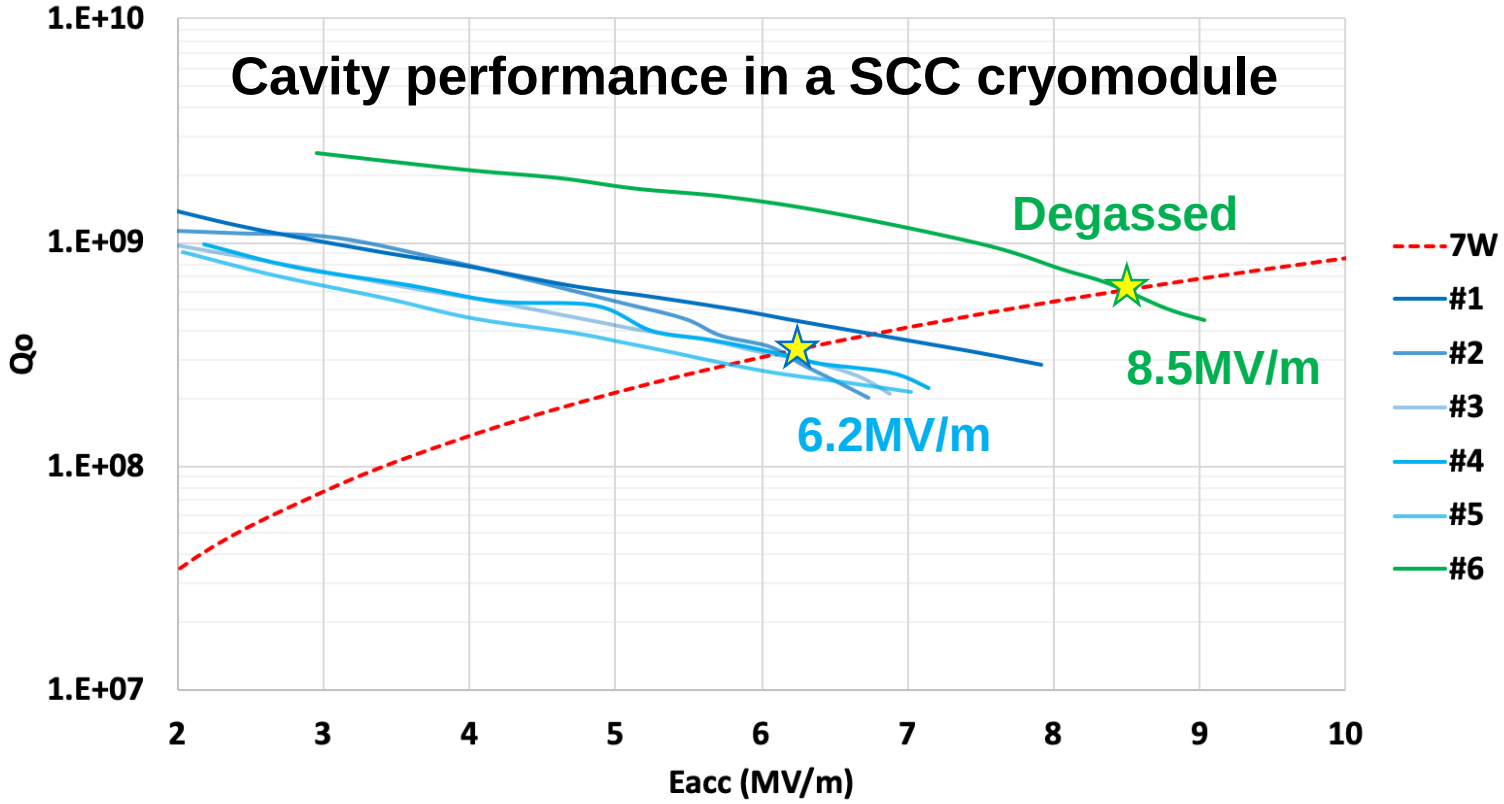
ISAC-II – Transmission Line Upgrade

- To provide more reliable operation
  - The major limit is the failures on internal RF transmission line
  - Lost 0.8 cavity/yr since operation
- In progress projects
  - Modify RF connector to prevent glow discharge
  - Replace standard RF cable by thicker cable to mitigate melted insulation material
  - Upgrade RF coupler for reliable mechanics
- In planned projects
  - Upgrade to silica hermetic sealed cable
  - Re-optimize standing wave distribution along transmission line



ISAC-II – Hydrogen Degassing

- Hydrogen degassing
  - To bake at 650~800 degC in high vacuum environment for several hours to release hydrogen
  - To provide higher Q at the same gradient or higher gradient at the same RF loss
  - Potentially ~30% performance improvement (from current data)
- High vacuum furnace dedicated for SRF application is required
- To refurbish 1 cryomodule per year – 8 years program

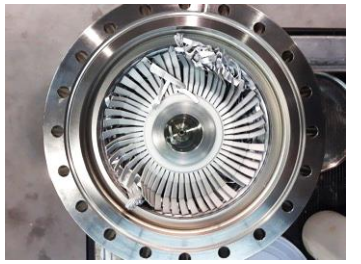


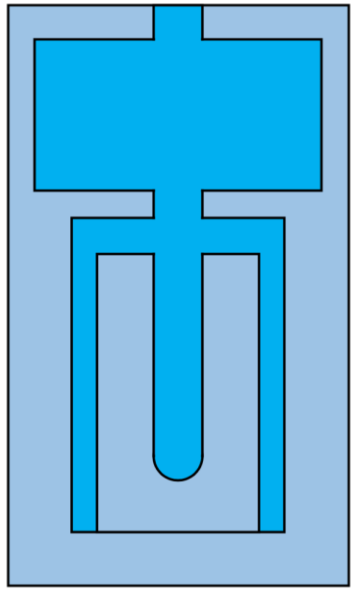
ISAC-II – Separated Vacuum Cryomodule

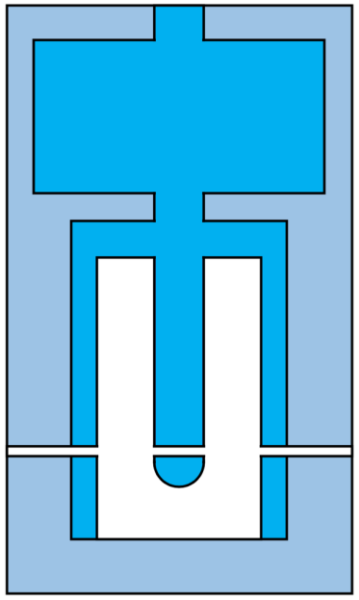
- TRIUMF has plan to upgrade post-accelerators
  - SCA cryomodules in low energy section
  - Booster cryomodule after SCC

See talk of R. Laxdal

- Lessons learned from ISAC-II operation
  - Field emission causes instability in operation and limits operating gradient
  - Emitters from cavity processing, assembly and operation
- Separated vacuum cryomodule
  - Achieves better cleanness for cavity string assembly and operation
  - Allows in-situ cryomodule refurbishment
  - Design and expertise exist



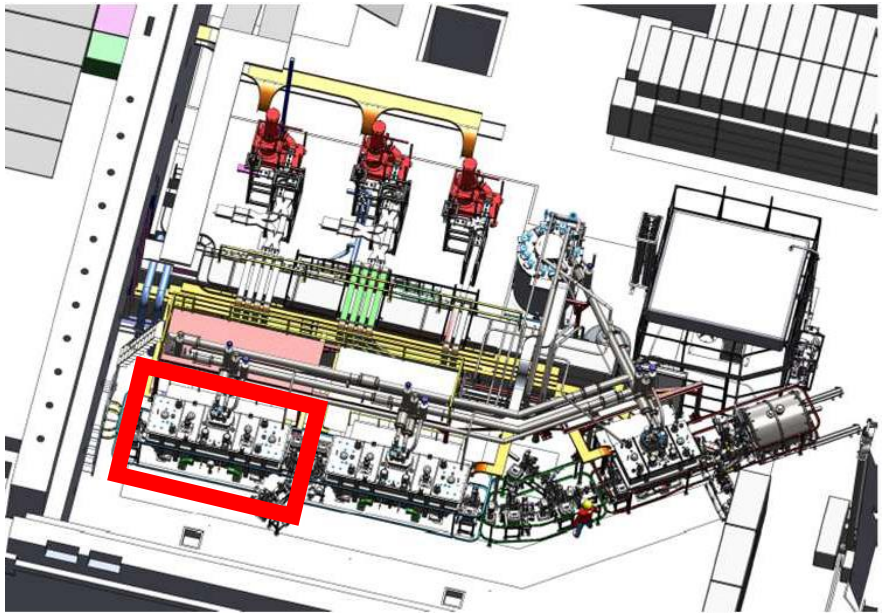




Common vacuum **Separated vacuum**

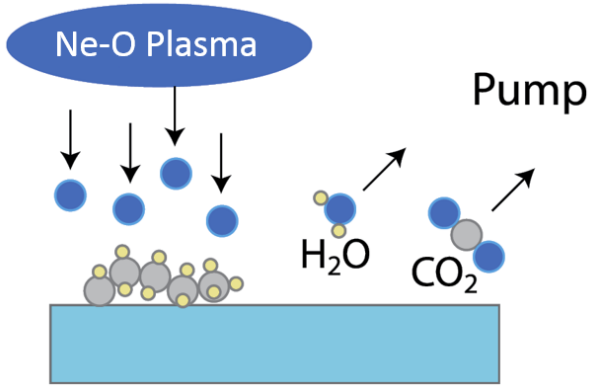
e-Linac – Second Accelerator Cryomodule

- Motivation
  - To meet the initial e-Linac design specifications
  - An on-line spare to increase long term availability and reliability of accelerator operation
  - Would operate more cavities at reduced performance as required
  - Capable to use energy as a variable to fine tune the delivery and production from the ARIEL AETE

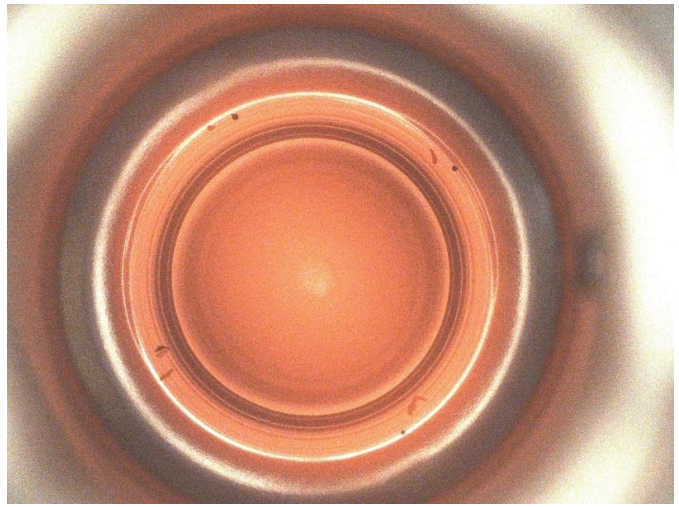


e-Linac – Plasma Cleaning

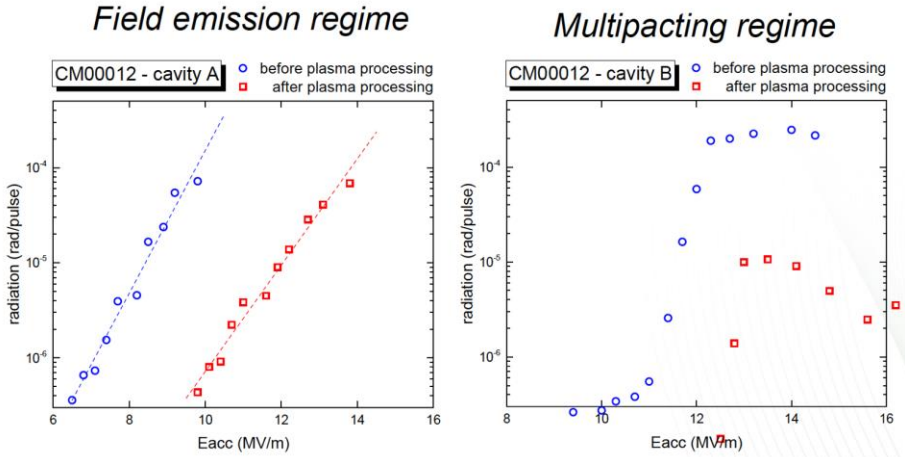
- Plasma cleaning
  - Remove hydrocarbons and absorbates
  - Reduce field emission by increasing work function of RF surface
- Worldwide developments
  - SNS demonstrated in-situ plasma cleaning on elliptical low beta cavities
  - FNAL proved principles on 1.3GHz single cell and 9-cell cavities recently
- Benefits for e-Linac
  - In-situ procedure to restore cavity performance due to field emission – significantly shorten refurbishment period
  - To reduce dark current from SRF cavities without taking off-line



M. Doleans et al. NIMA 812 (2016) 50-59



B. Giaccone et al. TTC2019



8 TTC Feb. 2017 S-H. Kim

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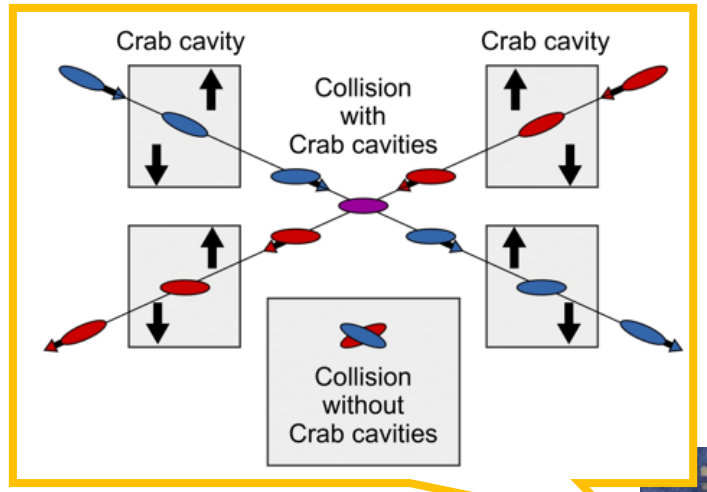
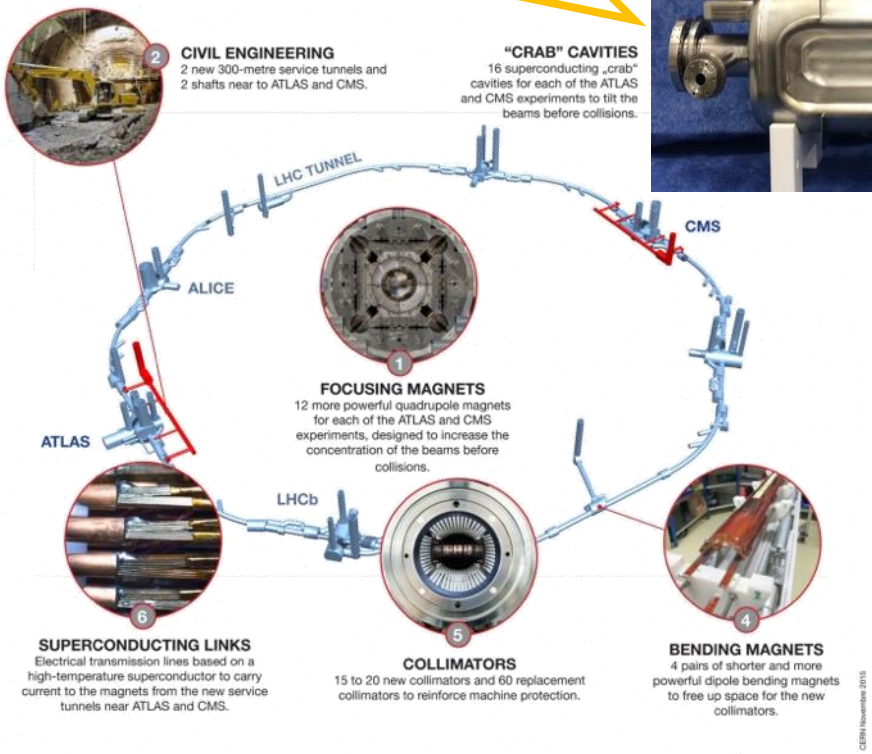
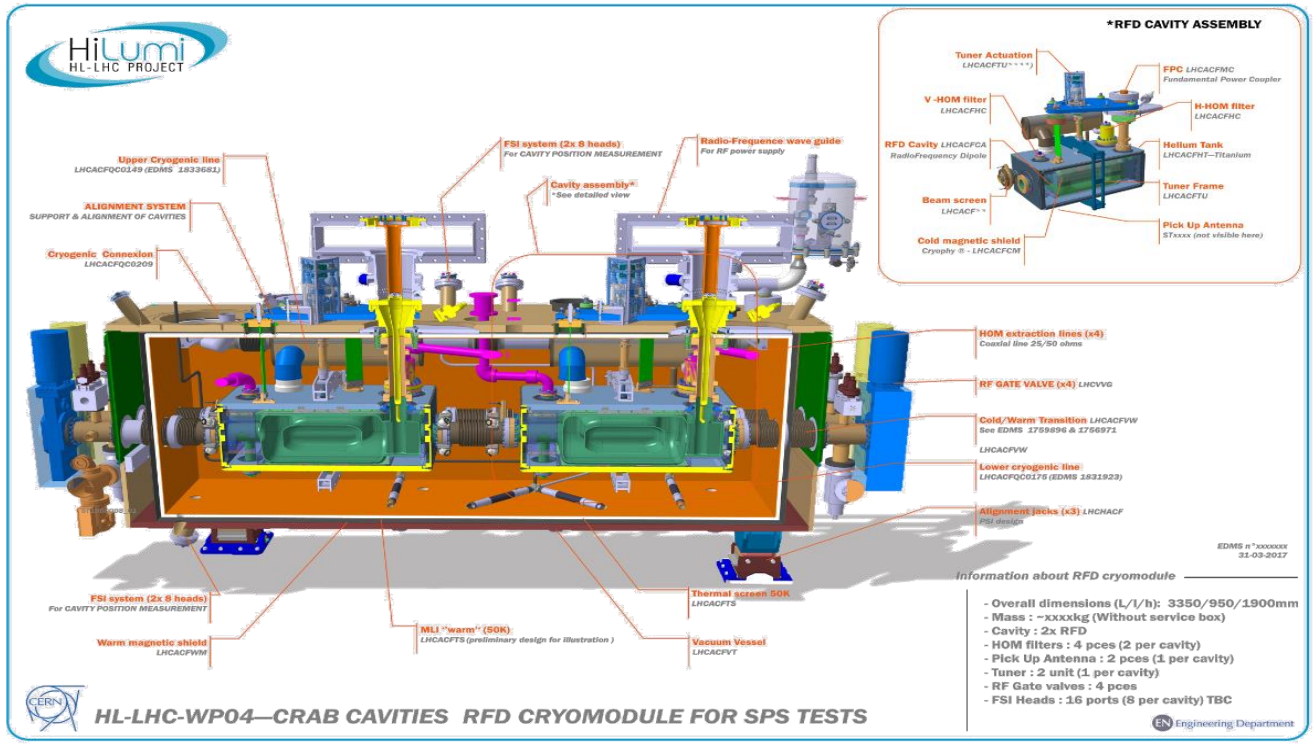
High-Luminosity LHC Upgrade (CERN)

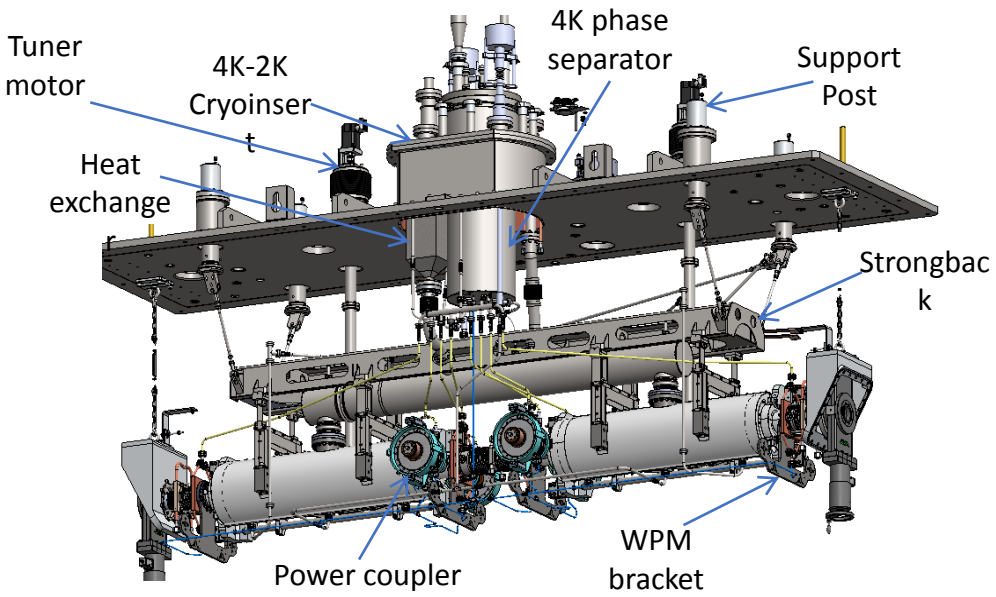
- HL-LHC upgrade project will increase the luminosity in LHC
  - Deflecting mode cavities (Crab cavities) are critical components
- TRIUMF has been funded to supply 5 crab cryomodules
  - The cryomodule design is a collaboration between CERN, UK and TRIUMF
  - To receive 10 dressed RFD resonators produced in AUP (US)
  - To produce and qualify the cryomodules before shipping to CERN
  - To advances Canadian competence in SRF technologies





Crab Cryomodule & ARIEL ACM

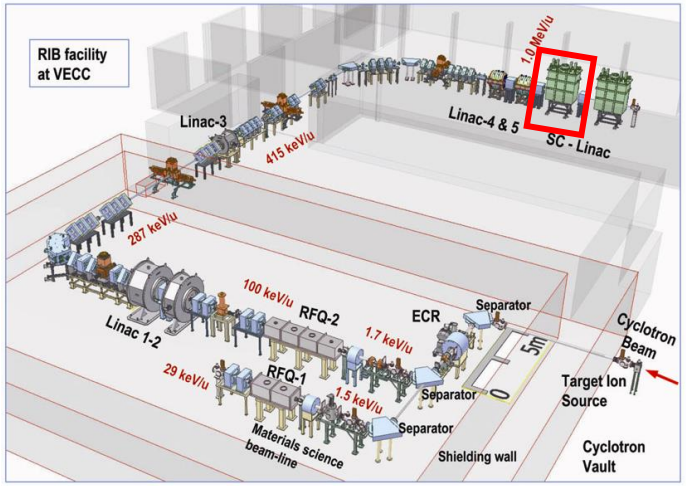


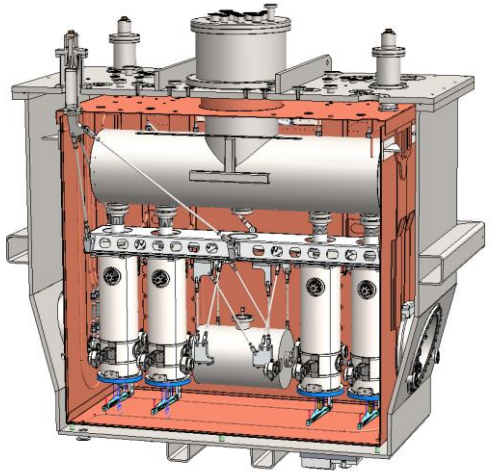


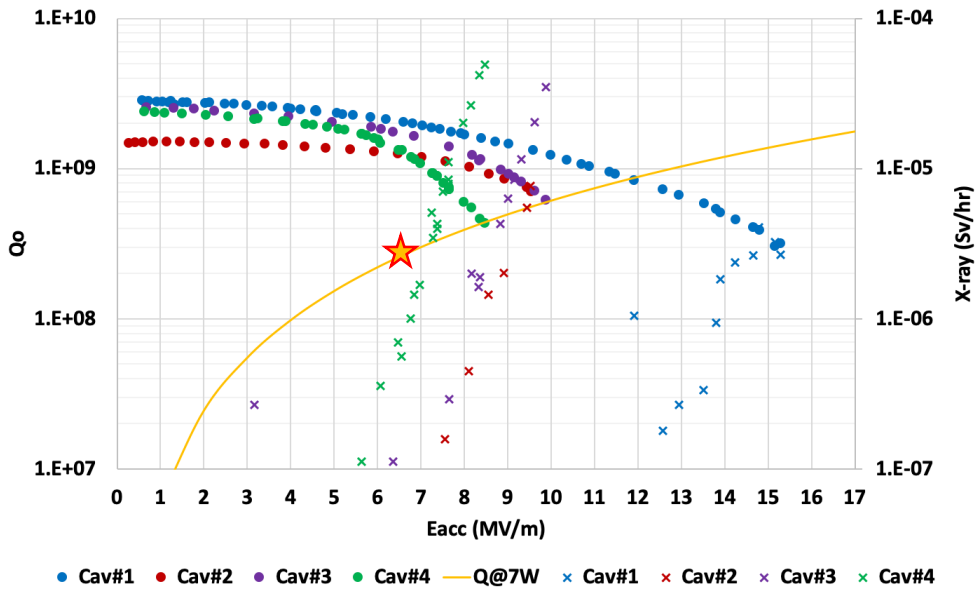
- The cryomodule design borrows from the ARIEL ACM developed and fabricated at TRIUMF.
- A prototype will be assembled in 2021 and series production will complete in 2024

QWR Heavy Ion Cryomodule (VECC)

- TRIUMF has active collaboration with VECC since 2008
  - Completed and delivered injector cryomodule
- SRF team has been developing a heavy ion cryomodule for VECC since 2018
  - The design based on ISAC-II cryomodules
  - Contains 4 QWRs and 1 solenoid
  - Separated vacuum system
  - Will complete this year
- SRF group is open to new collaborations after Hi-Lumi such as EIC crab cavity modules







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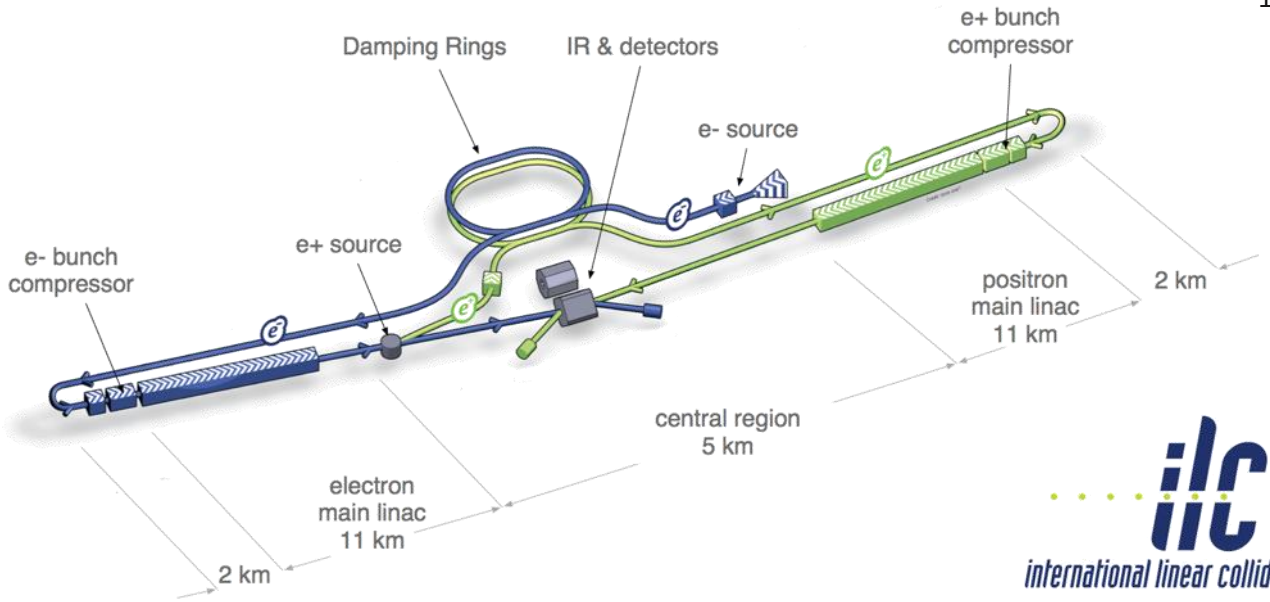
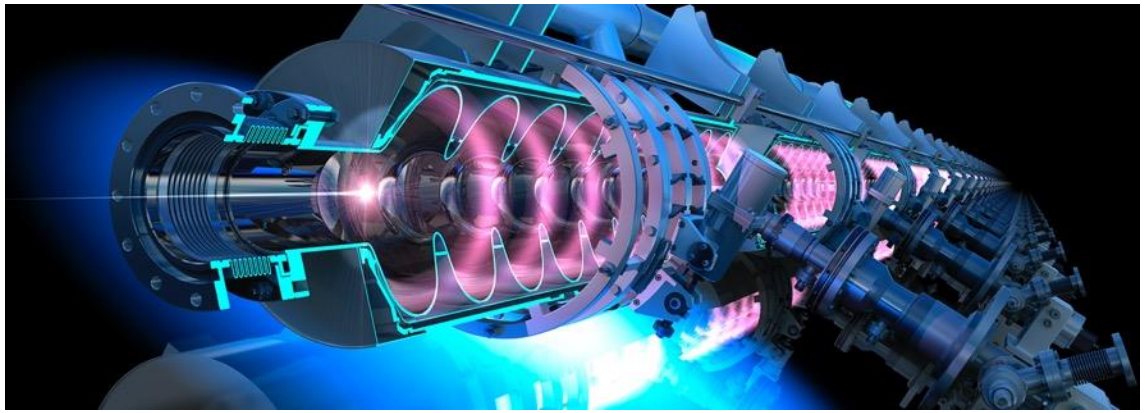
Potential Contributions to Future Machines

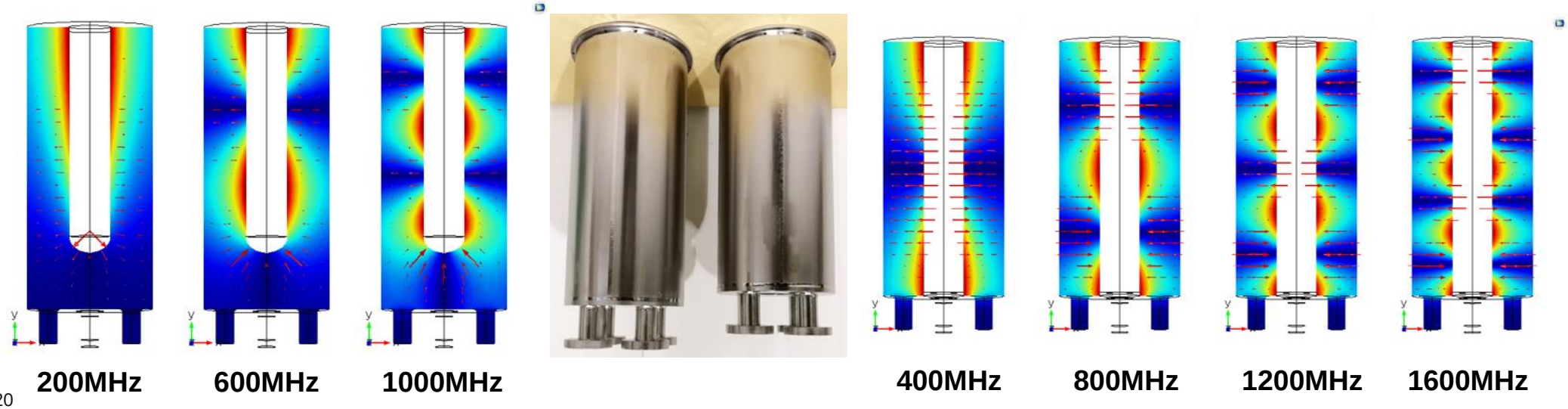
- Based on previous contributions to CERN, Canada via TRIUMF is well placed to contribute ‘in-kind’ to future large global installations like ILC or FCC.
- SRF Contributions from TRIUMF would come most naturally from
  - Developments towards high gradient and high Q
  - SRF material developments
  - New geometry and novel fabrication techniques





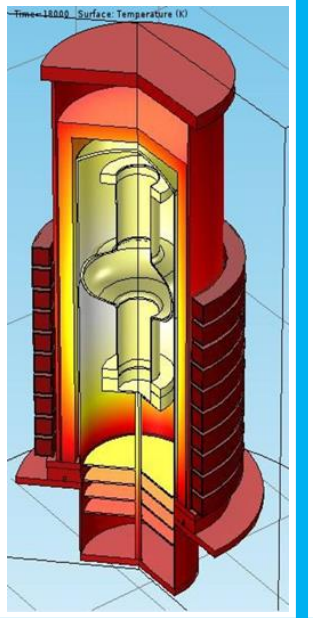
Multi-Frequency Coaxial Test Program

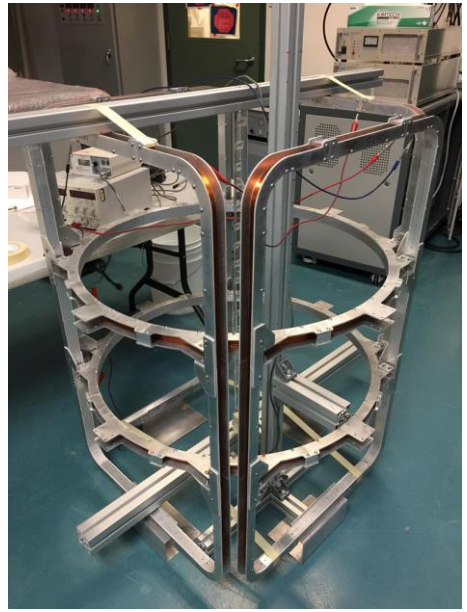
- Multi-frequency coaxial test resonators program – systemic optimization study
  - What is the role of frequency on field dependent surface resistance
  - What are the optimum treatments for low frequency cavities
  - How does flux trapping differ in TEM mode cavities
- Impacts for hadron or heavy ion linacs and cw linacs (**EIC, PIP-II**)
- Inform SRF fundamentals (combining with μSR and β-NMR makes strong contribution)
- Infrastructures developments to support novel cavity processing

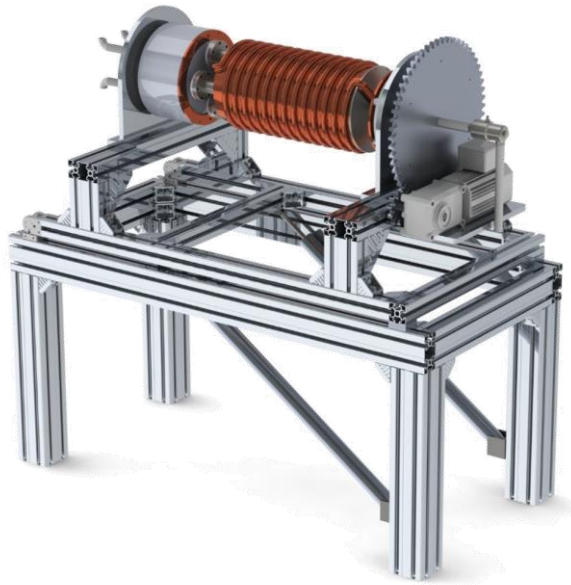


SRF R&D

- UHV RF Induction furnace
  - Designed to heat treat 1.3GHz single cell cavity and multi-frequency coaxial resonators
  - R&D to explore N_2 doping and new material coating (Nb_3Sn)
- Electropolishing
  - Developed vertical EP on single cell to augment doping effect
  - Conceptual design of new EP facility for coaxial cavities
- 3-axis Helmholtz coil
  - Commissioned to compensate external magnetic field and to study magnetic flux trapping and expulsion
- Mobile temperature mapping system
  - To investigate local RF heating and loss mechanisms

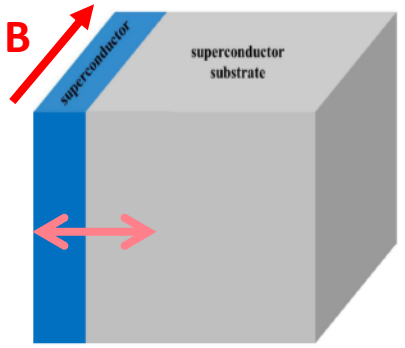




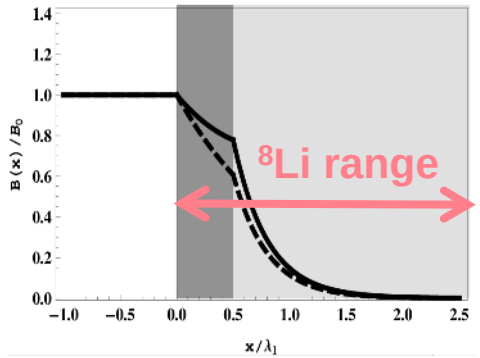


SRF Material Research

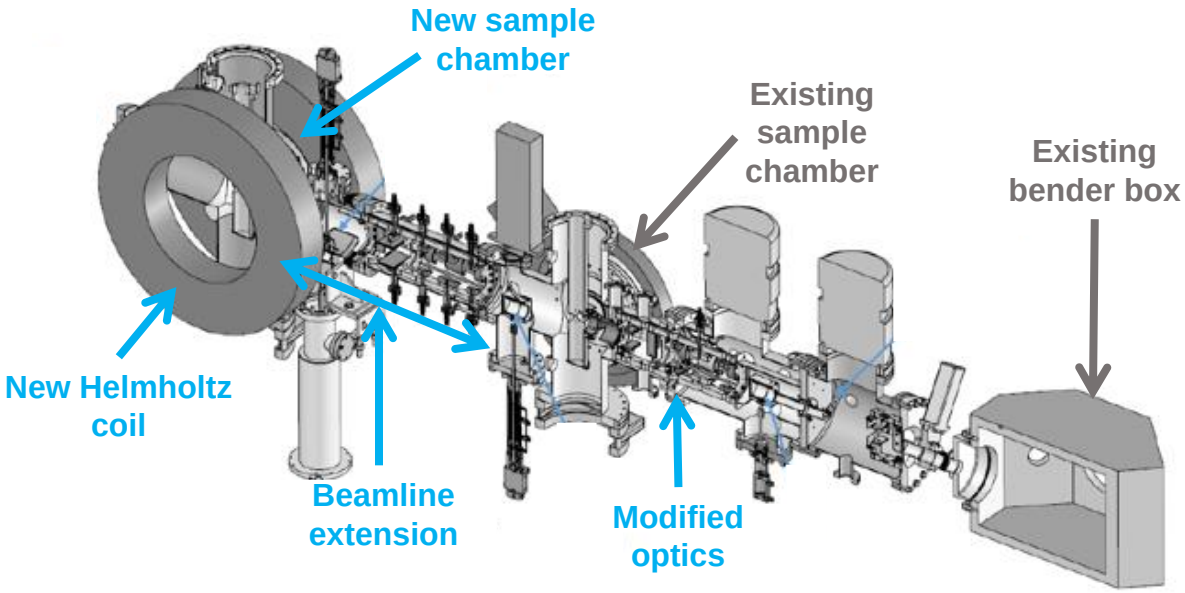
- TRIUMF hosts two world class facilities for material science – **μSR and β-NMR**
  - SRF group have used both to shed light on the breakdown fields for SRF application
  - New surface treatments aimed at engineering a ‘dirty’ Nb surface layer to shield bulk from high surface currents to extend peak field (**ILC**)
- New beamline and high field spectrometer in β-NMR
  - To diagnose samples with variable implantation depth and parallel magnetic field up to 200mT
  - To provide a unique facility in the world allows **testing doped Nb and new materials to push towards higher gradients**



Dirty layer **Clean Nb**

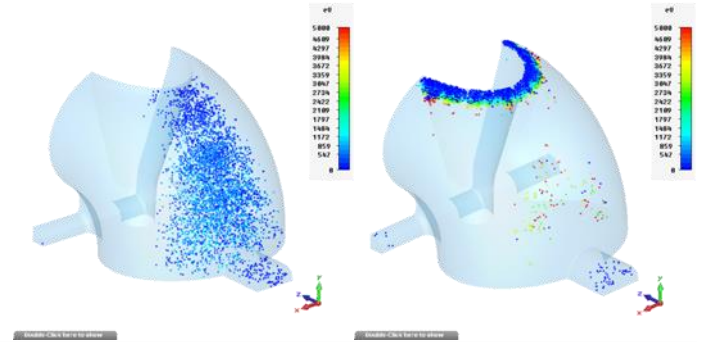


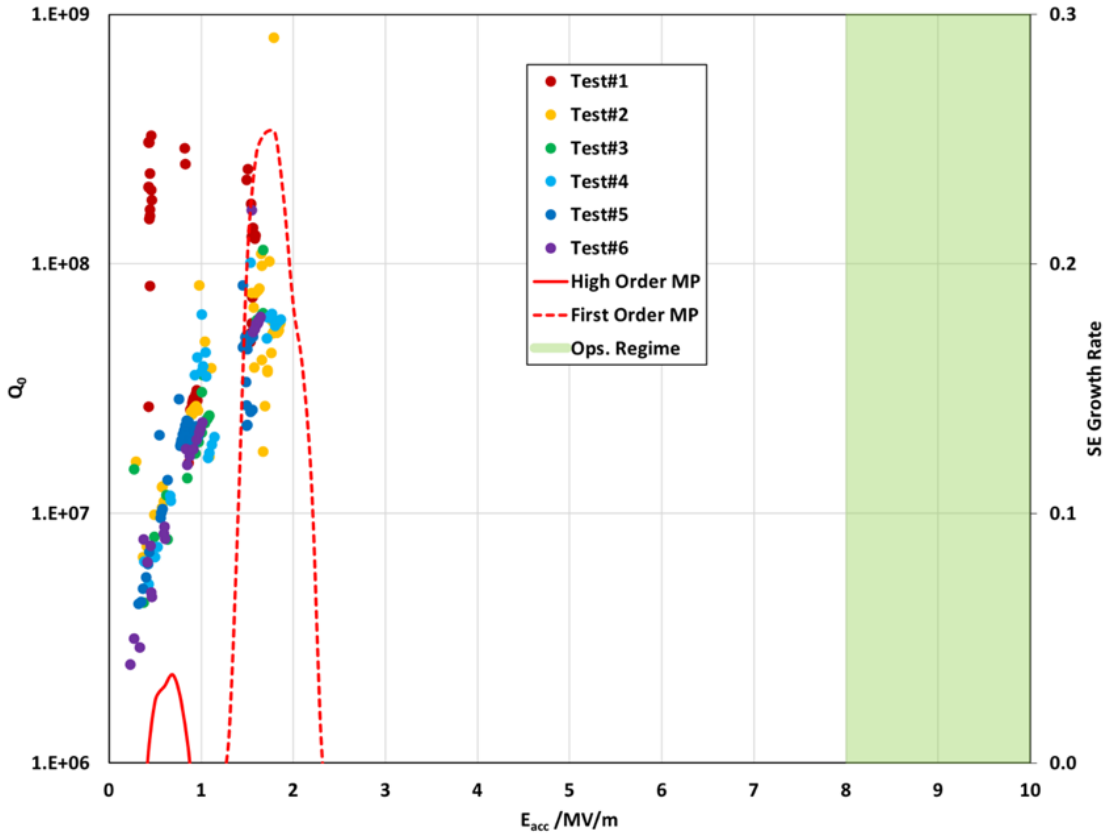
T. Kubo – TTC, Saclay



Balloon Single Spoke Resonator

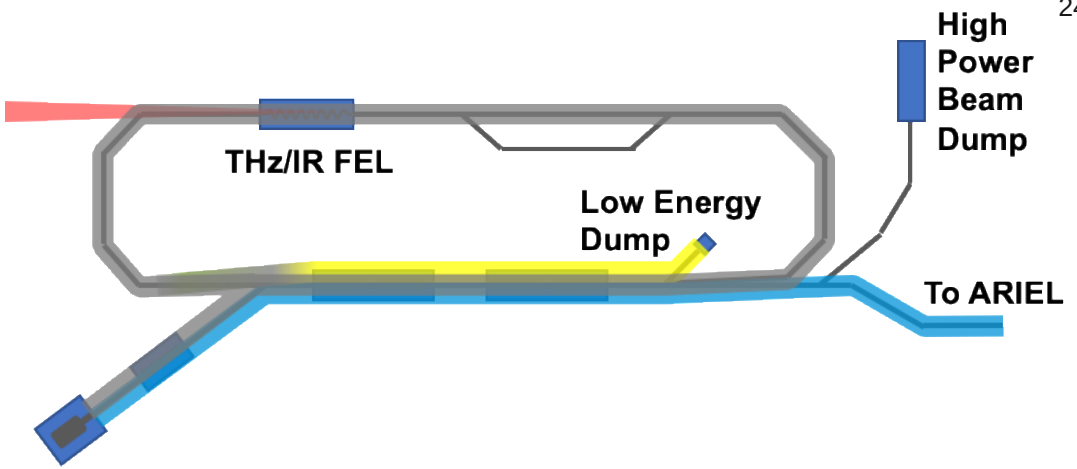
- TRIUMF has successfully developed and tested a new variant (balloon geometry) of a single spoke resonator for Hadron acceleration
- Cavity geometry was proposed to mitigate the significant multipacting issue in standard spoke resonators
- Prototyping was sponsored by **RISP (Korea)** and being used in their driver linac
- TRIUMF is also collaborating with **FNAL** and **Euclid** on further advancements

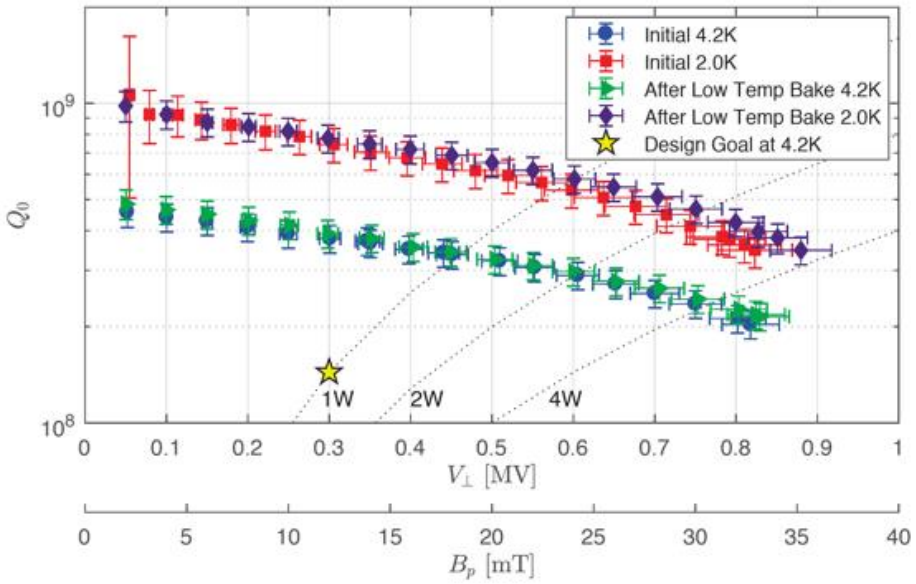


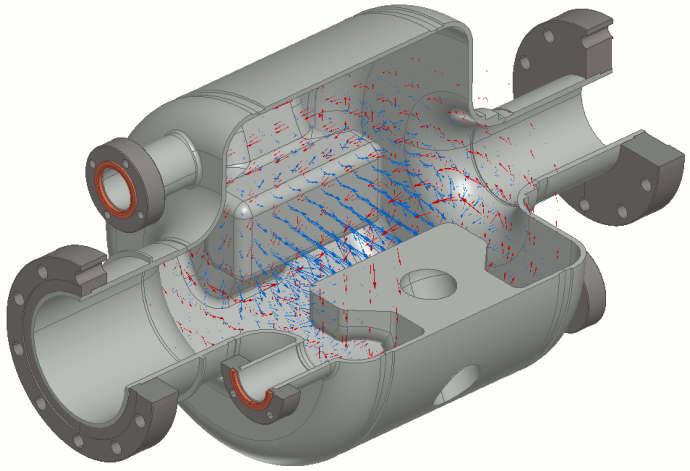


RF Separator Cavity

- 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**)







Vision of SRF R&D

- The goal of SRF R&D programs
  - Support the high performance and availability of ISAC-II operation
  - Support the commissioning of ARIEL e-Linac and the transition into the reliable operation
- TRIUMF keeps active global collaborations on cavity and cryomodule developments to support SRF community and expand our skill set
- The SRF infrastructures developments allow TRIUMF to
  - Deliver student based cutting edge researches on SRF fundamental and techniques
  - Advance Canadian competence to support future global initiatives

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Thank you
Merci

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