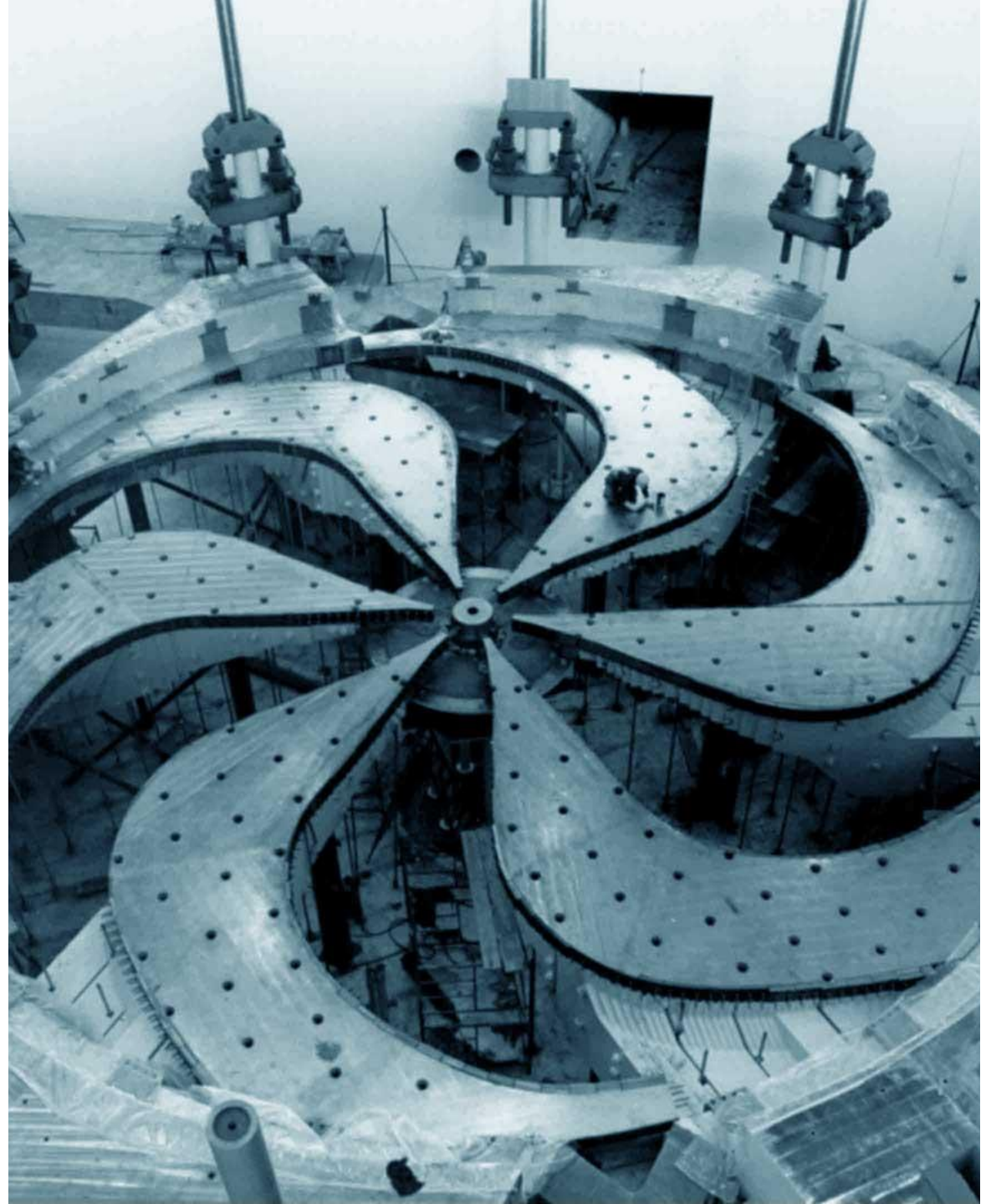


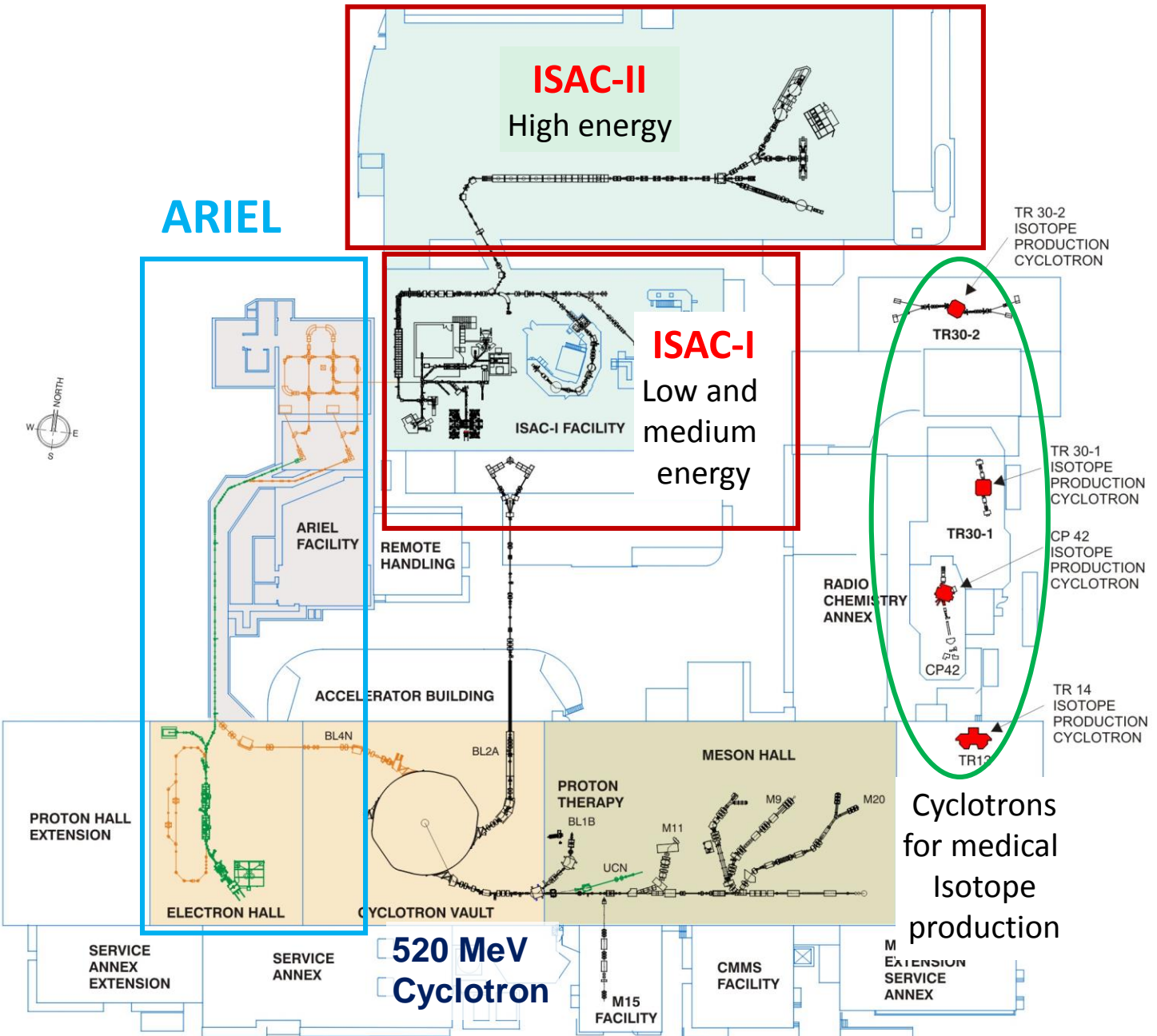
TRIUMF accelerator expertise in international projects

Bob Laxdal (for Accelerator Division)
TRIUMF Science Week Aug. 17, 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.



This mission is reflected in the wide variety of accelerator technologies that populate the campus.

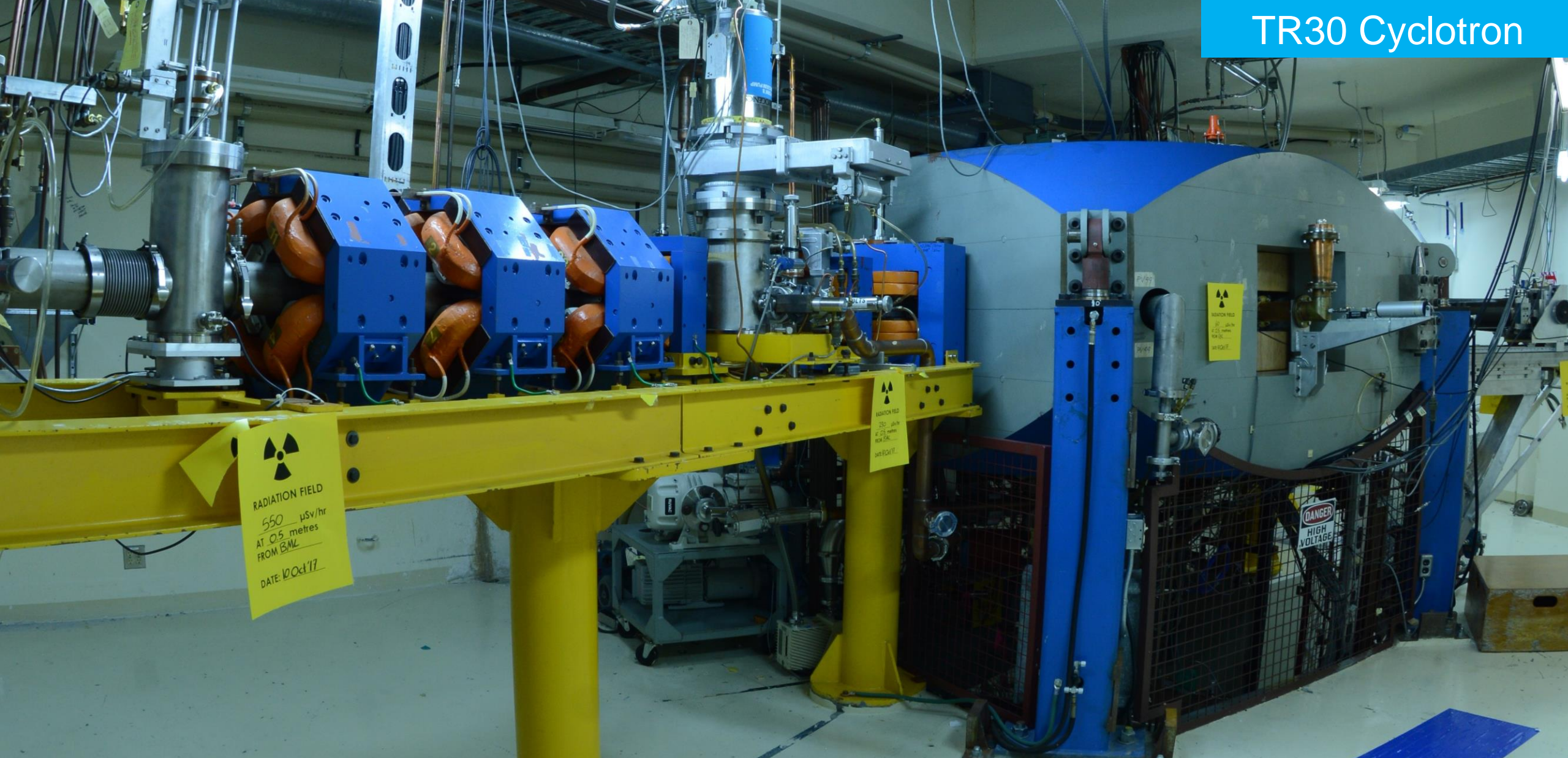
Our strategy is to use internal projects and external collaborations as springboards to expand core competencies or gain new ones.

Rather than import technology, we typically develop it, accumulating a broad expertise within a relatively small lab.

H- Cyclotrons – our first major core competence – also gave us experience in high power rf, high power targets, electrostatic and magnetic beamlines, remote handling, high intensity sources, physics of space charge dominated proton beams

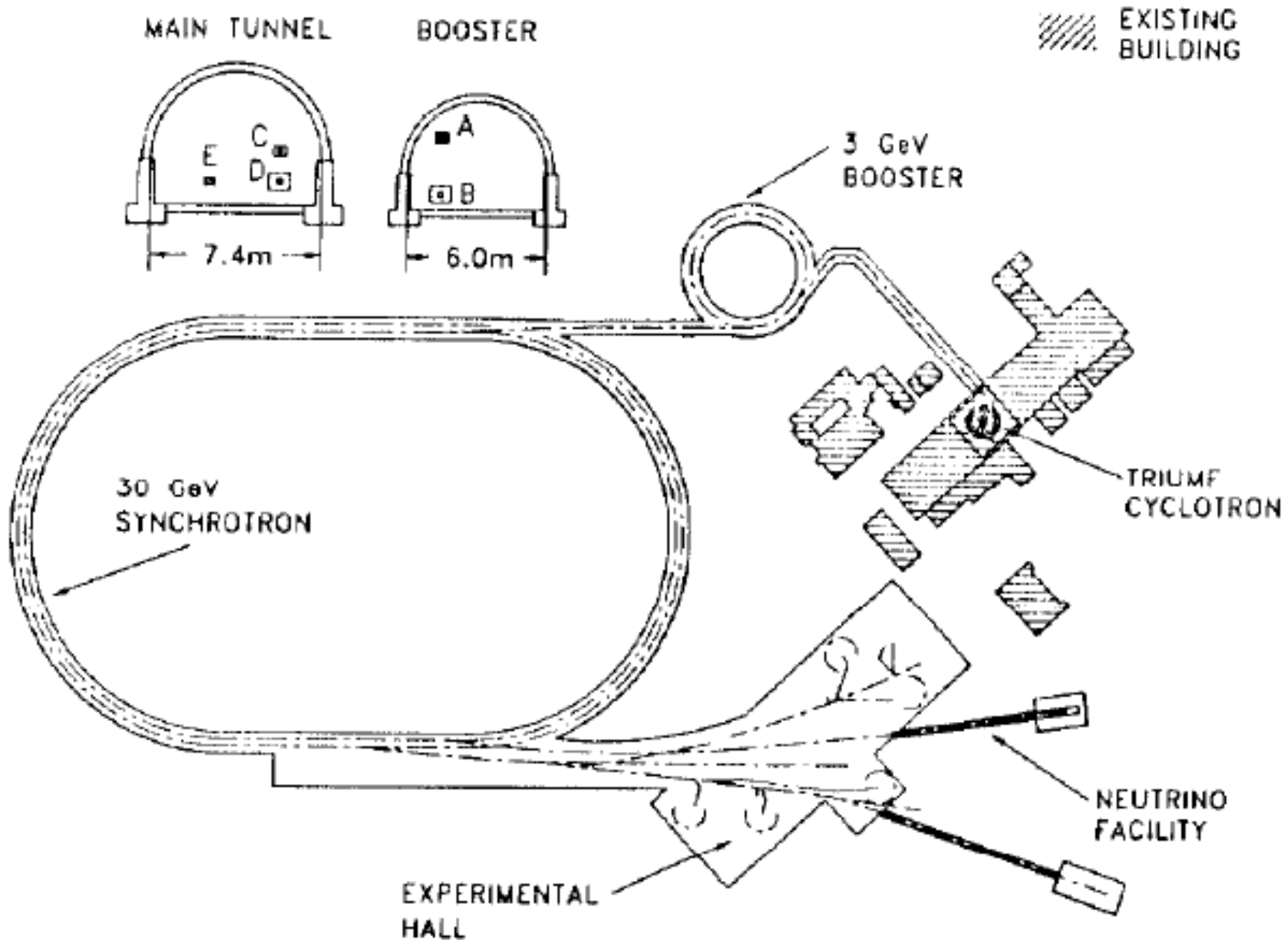


TRIUMF - INSIDE THE 500 MeV CYCLOTRON



H- Cyclotrons – this core competence was enhanced in the late 80s with the decision to develop the TR30 and TR13 industrial cyclotrons with EBCO (now ACSI)

KAON Factory Proposal (1985-1995) – significantly enhanced our skill set – synchrotron design, high intensity beam dynamics, pulsed HV systems





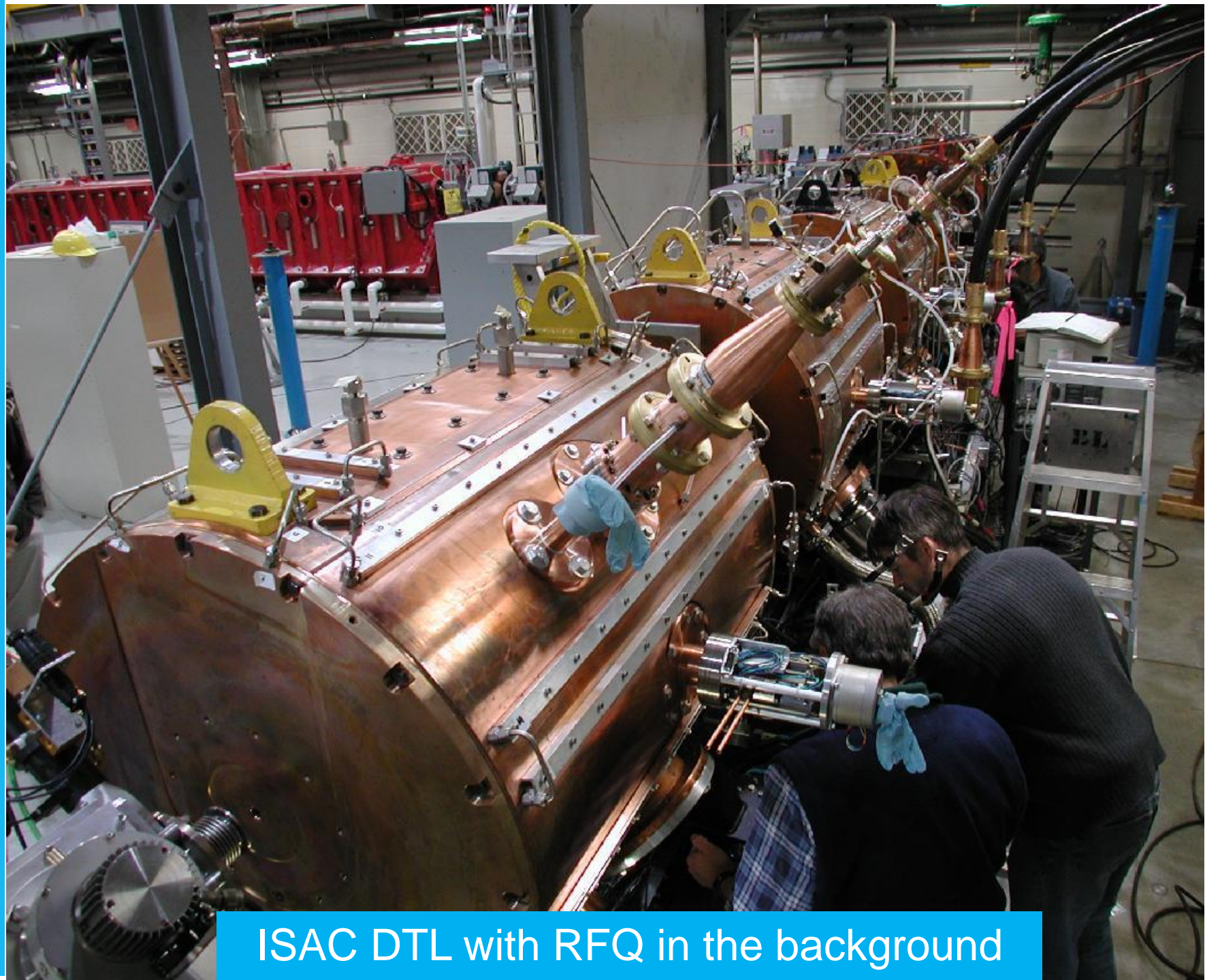
ISAC (1995 - present)

ISAC marked a renaissance for Accelerator physics and technology at TRIUMF

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

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 breeders



ISAC-II Cryomodule

ARIEL e-Linac (2008-2014)

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



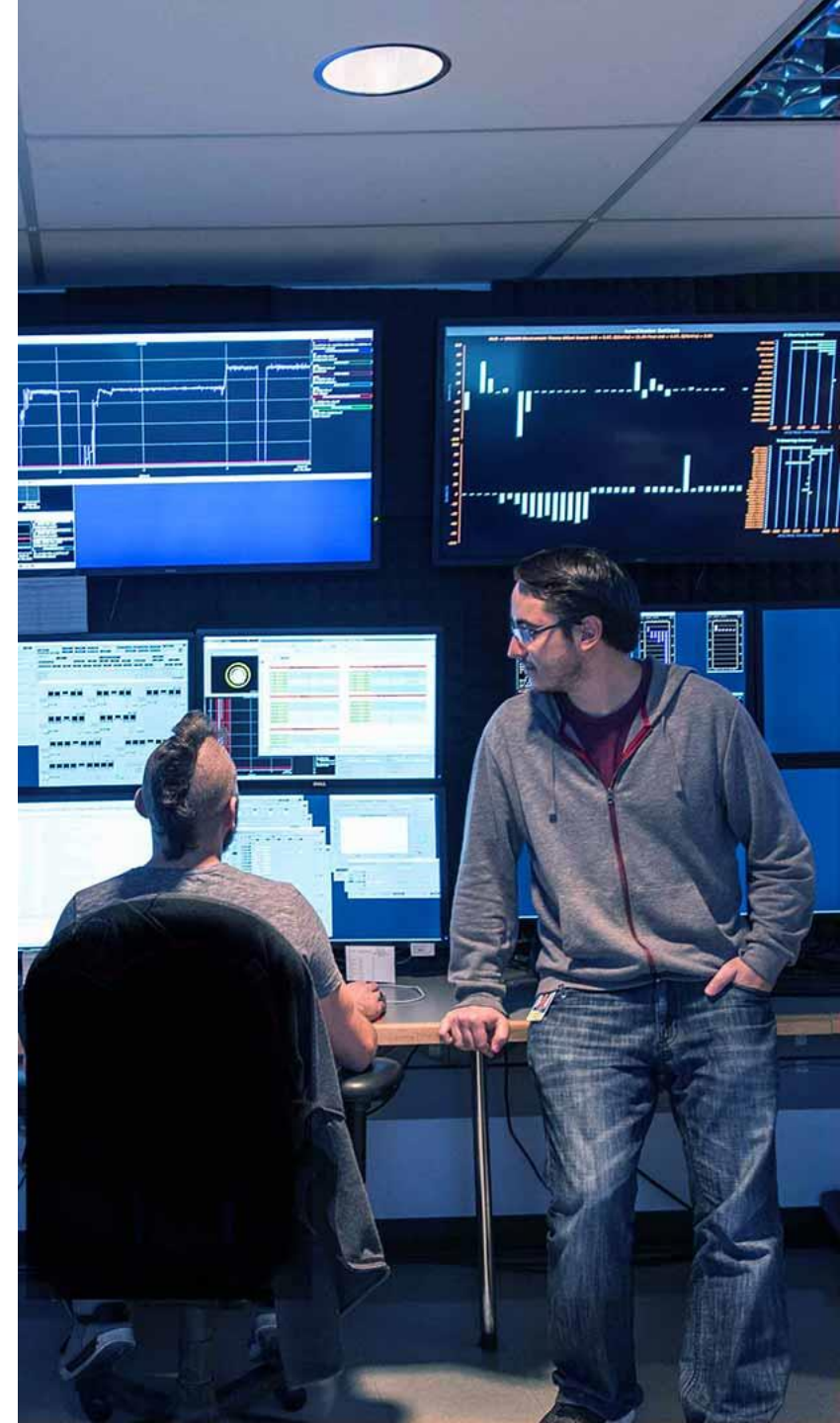
ARIEL Phase II (2014-present)

- High power target design for electrons
- ISOL systems
- EBIS Charge breeding
- Remote handling
- High resolution spectrometers
- Machine protection systems



Accelerator research at TRIUMF

- 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, new projects like ARIEL, the training of HQP, and international projects and collaborations.



Collaboration map

TRIUMF accelerator scientists are engaged in a number of international collaborations. The international projects aid the community but also nurture our internal expertise while training HQP.

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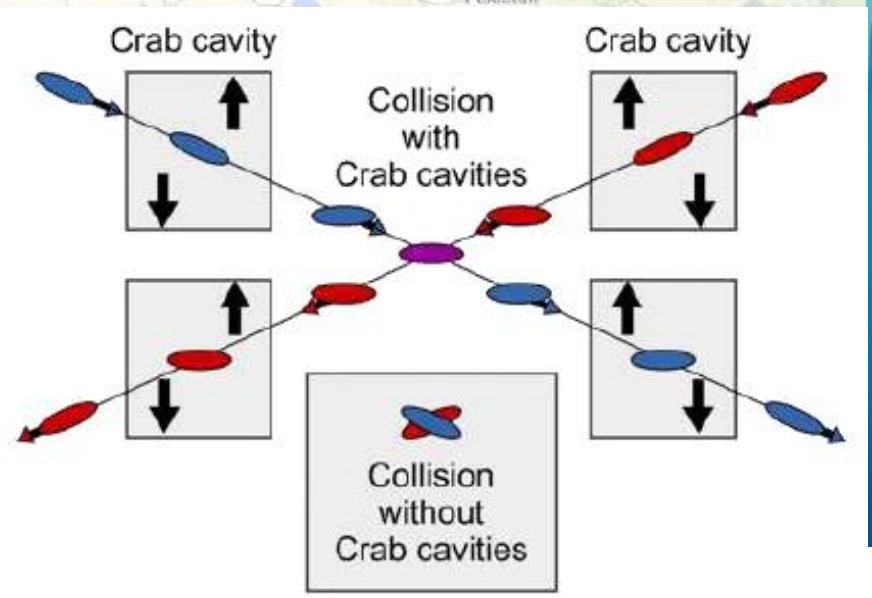


TRIUMF has had an active engagement with CERN historically with important contributions to LEP, the LHC and ISOLDE.

This continues in the FYP through collaborations and contributions towards LHC, Hi-Lumi , ISOLDE and AWAKE:

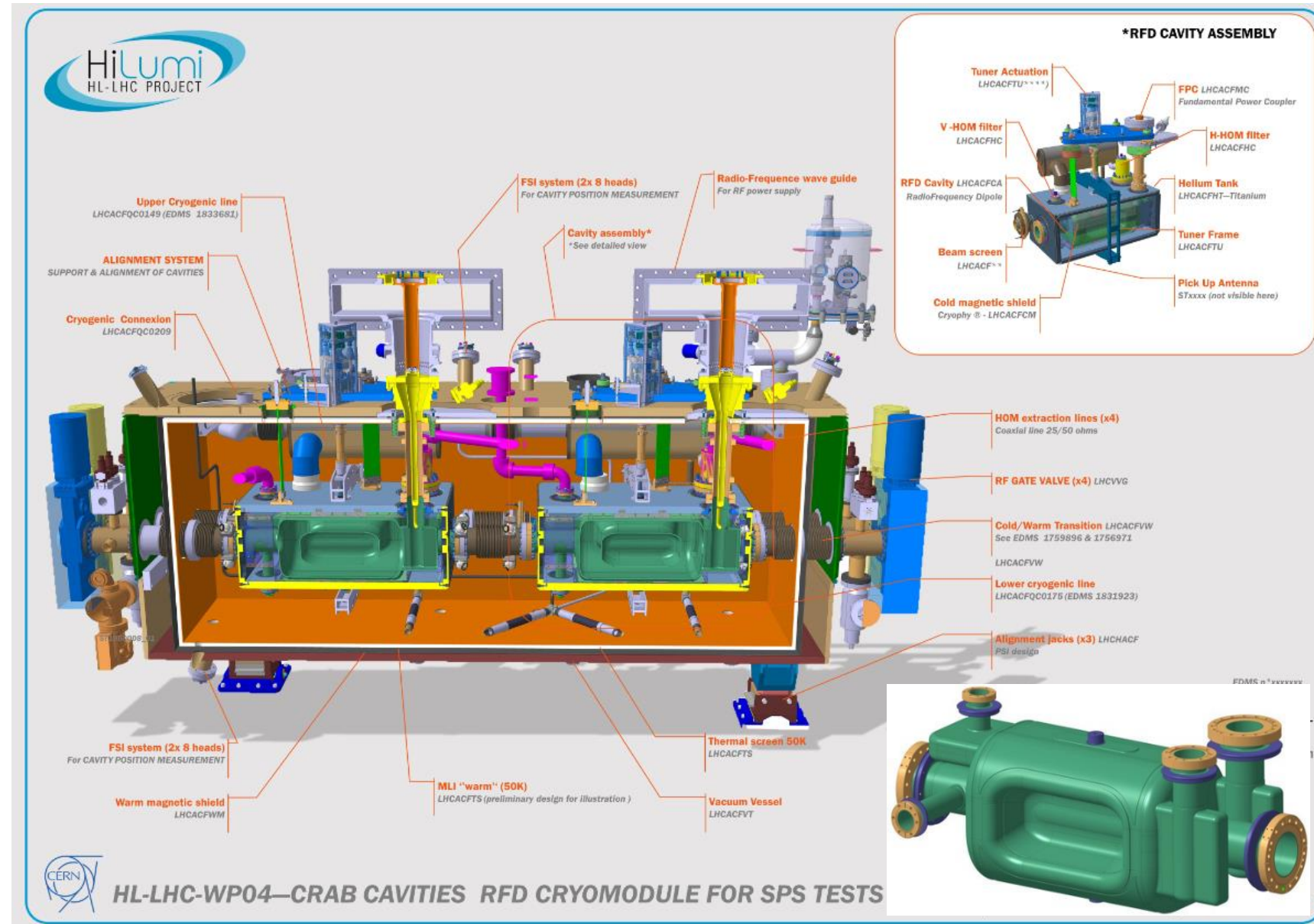
- Crab cavity cryomodules,
- Beam physics,
- RIB technology
- Beam diagnostics

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

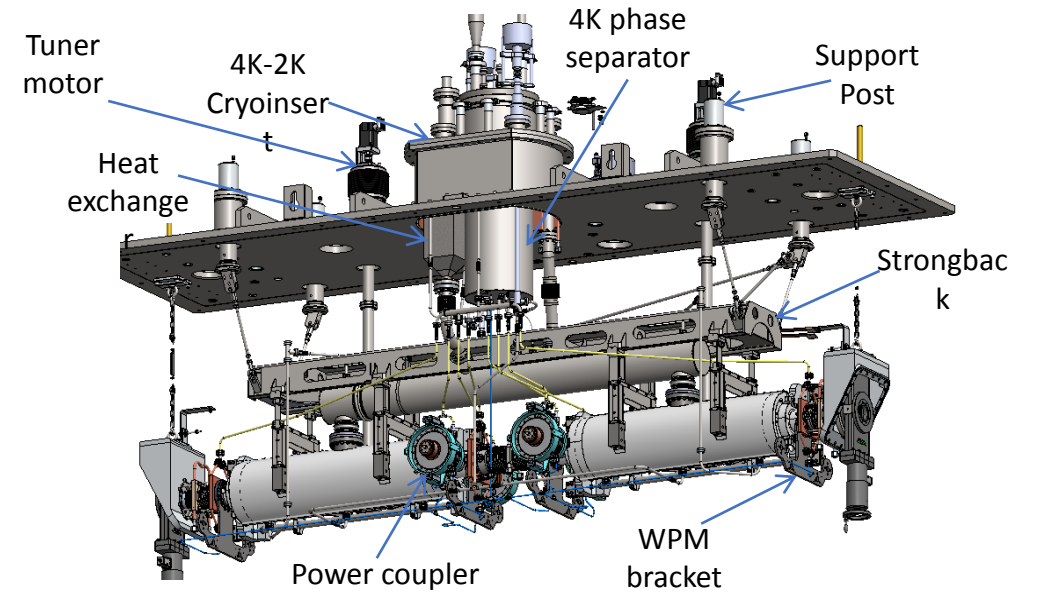
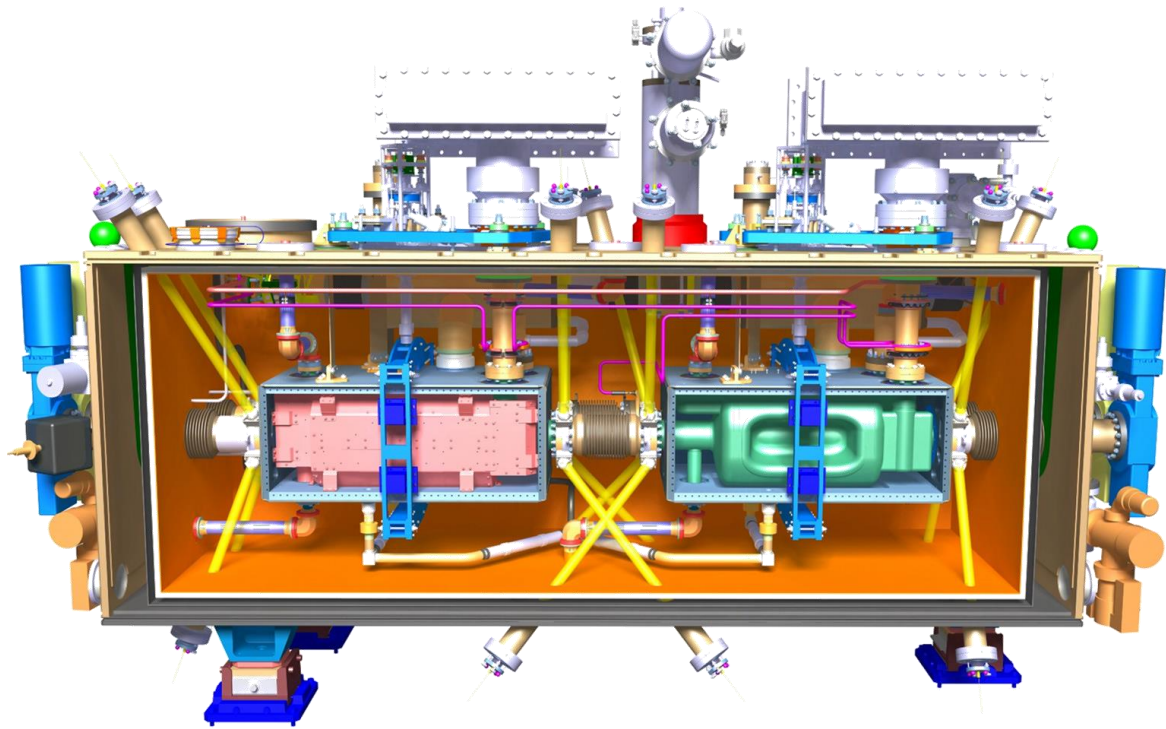


HL-LHC Crab Cavity Cryomodules – TRIUMF scope

- TRIUMF is funded to supply five crab cavity cryomodules to the Hi-Lumi upgrade at CERN
- The design is a collaboration between **CERN, UK** and TRIUMF
- TRIUMF will receive 10 RF Dipole cavities from **US** collaboration
- TRIUMF will produce and qualify the cryomodules before shipping to CERN
- The project advances Canadian core competencies in superconducting rf technologies and supplies critical infrastructure to CERN, supporting both the HL-LHC and the Canadian IPP community



Hi-Lumi Cryomodule vs ARIEL



The Hi-Lumi cryomodule design borrows from the ARIEL e-Linac module developed and fabricated at TRIUMF.

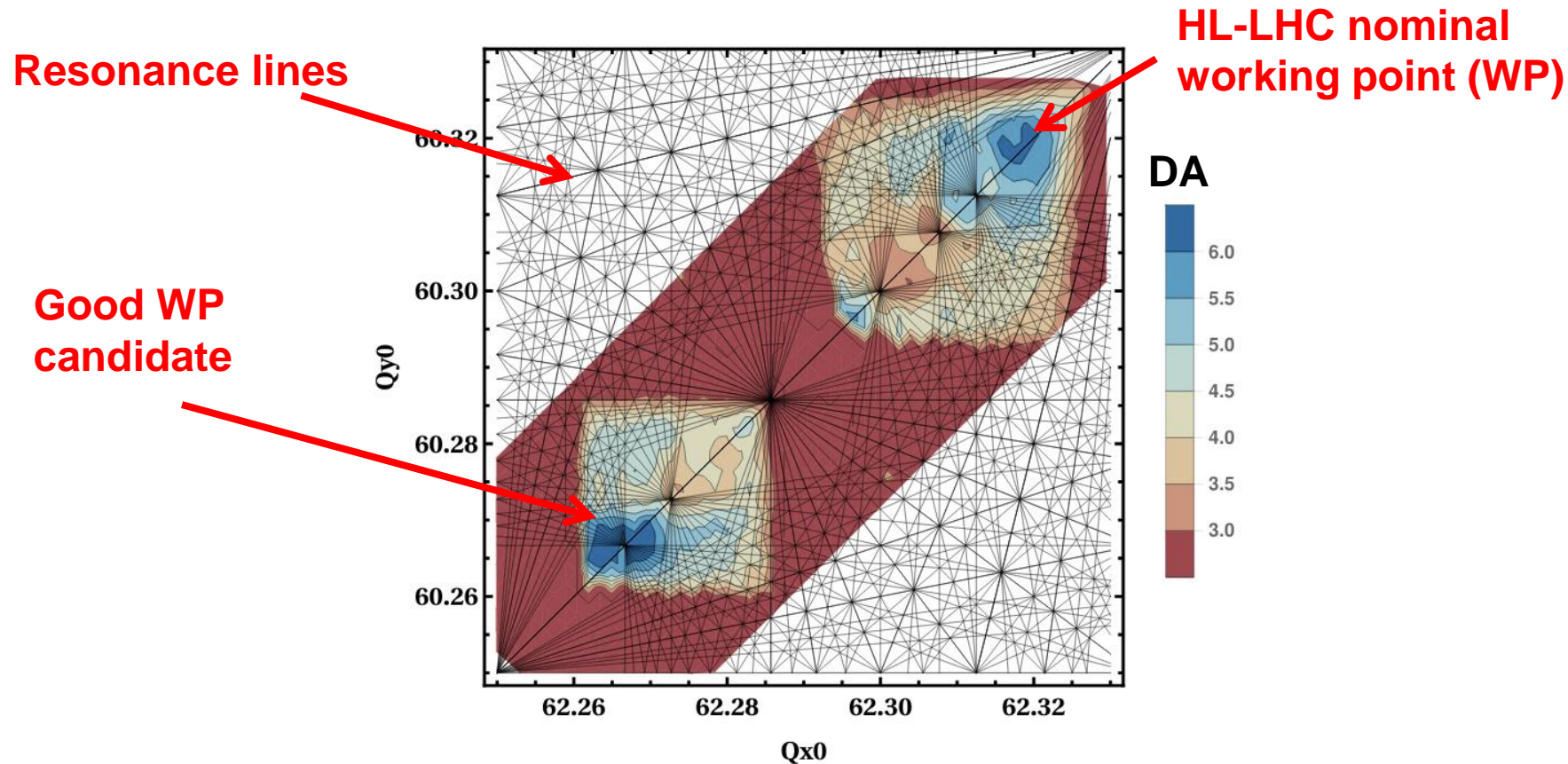
A prototype will be assembled in 2021 and series production at TRIUMF will span 2022-24



ARIEL Cryomodule

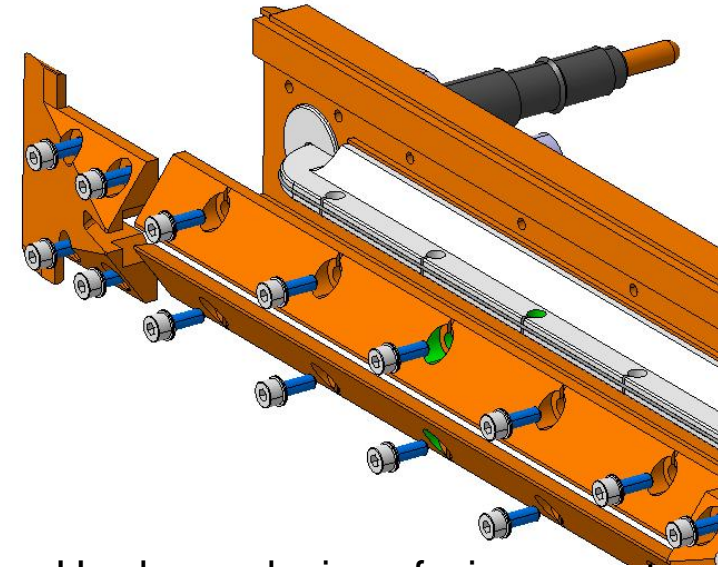
Beam physics studies focus on the general understanding of the impact of resonances to the choice of the optimal working point at collision.

- **Tune-scans:** look for dependencies of the dynamic aperture of HL-LHC on the tune working point (WP) as part of a detailed tracking campaign aimed at luminosity optimization

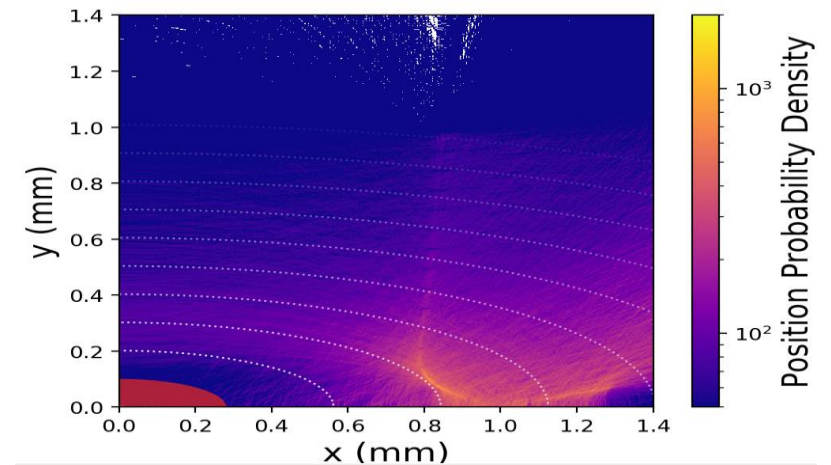


Additional beam physics and potential hardware contribution to HL-LHC

- An issue with Hi-Lumi LHC is Beam-Beam Long-Range effects at the interaction regions
- TRIUMF (D. Kaltchev) has developed a Hamiltonian based beam physics model of these effects
- The effect can be mitigated (confirmed in LHC tests) with the addition of **physical wires**, running high currents, → TRIUMF's model helps explain and optimize the wire compensation
- Canada via TRIUMF could provide the final wire correctors for HL-LHC
- In a separate study, student P. Belanger is using beam loss data from falling particulate (UFOs) in LHC to predict the sources of the contamination



Hardware design of wire corrector

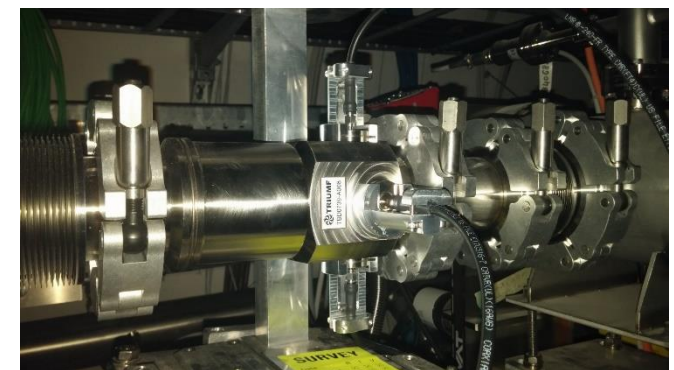
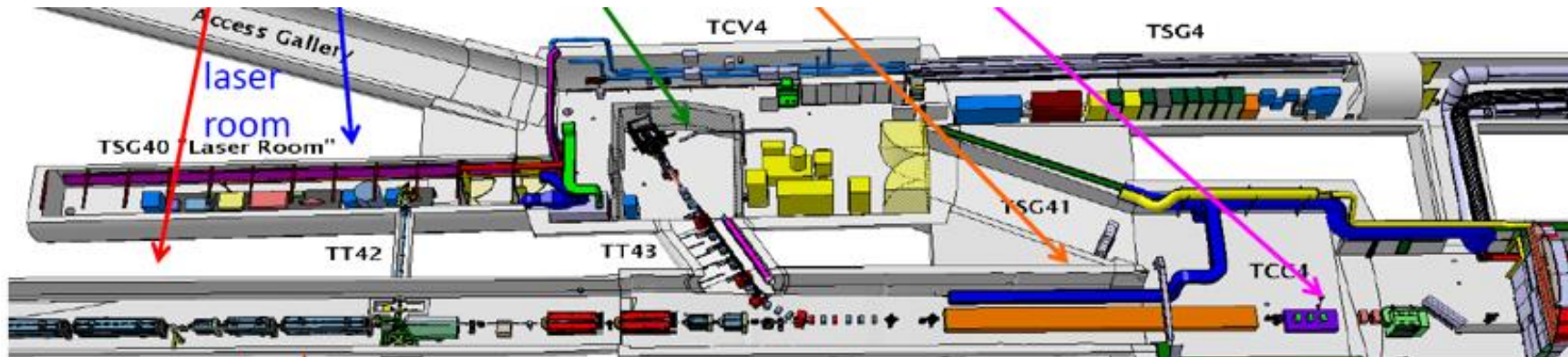
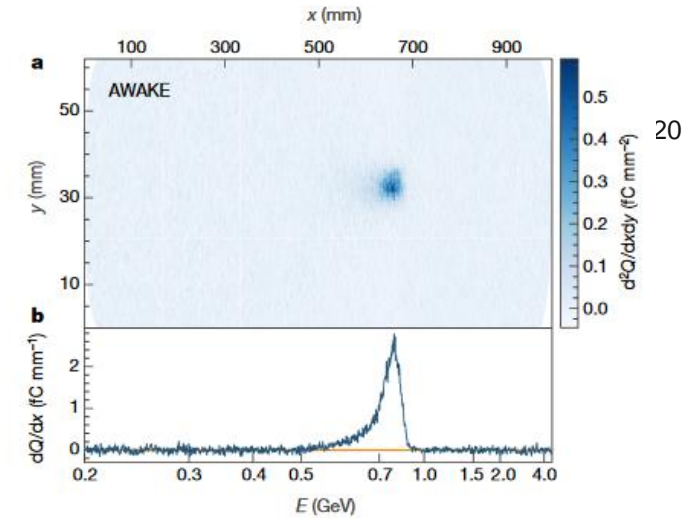


Reconstructed probability density function for the dust position around the beam (0,0).

TRIUMF and AWAKE experiment



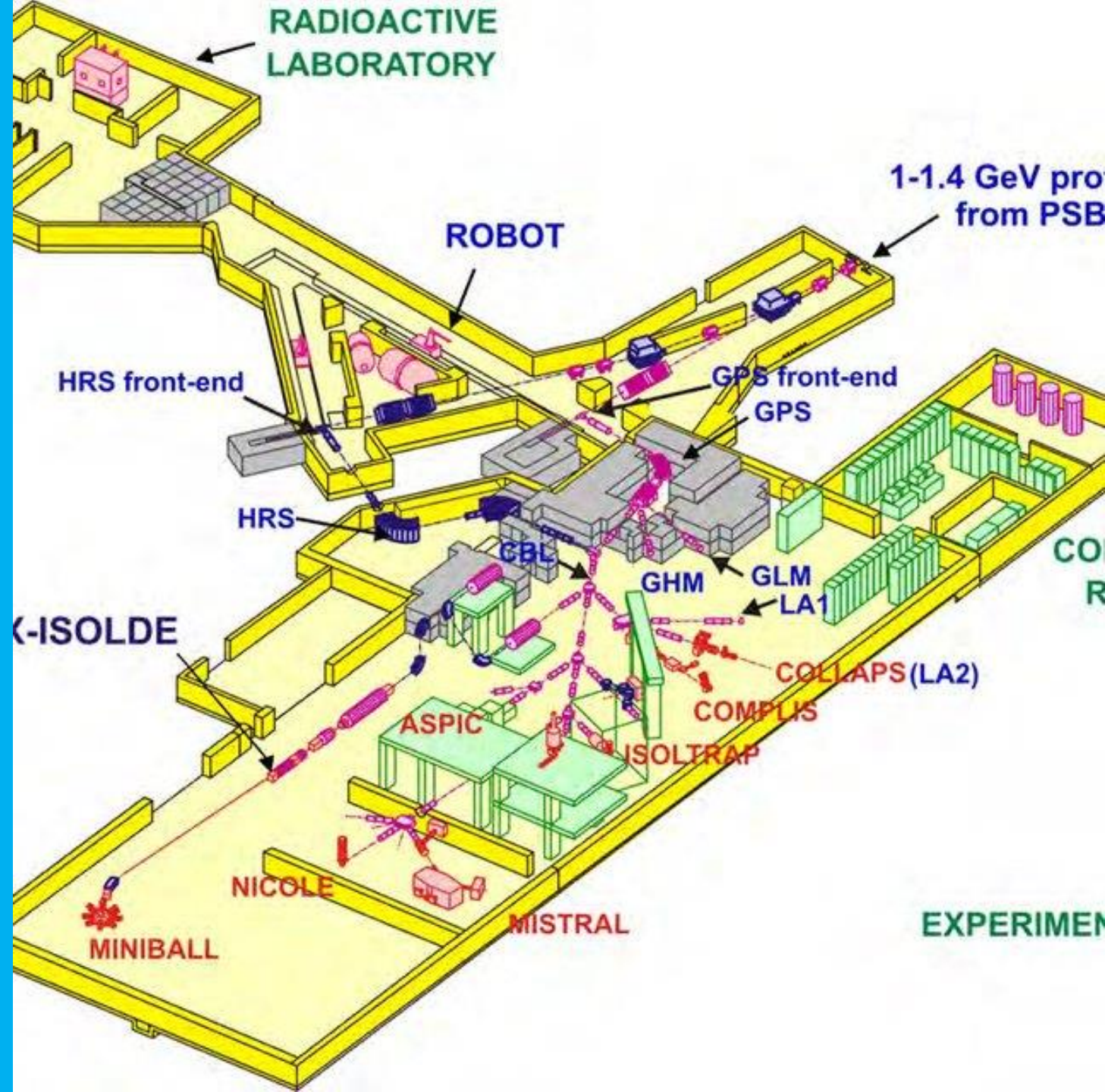
- AWAKE is an R&D experiment at **CERN** towards developing novel accelerator technologies for future accelerators
- Exploits acceleration of electrons by plasma waves driven by high energy protons from SPS
- TRIUMF scope (NSERC funded)
 - Design and construction of diagnostics (stripline beam position monitors, Faraday cup and associated electronics for electron and common beam lines
 - Student funding
- Now preparing for AWAKE Run 2



ISOLDE and TRIUMF

Close collaborations on ISOL target and ion source technology, RIB diagnostics and SRF science and technology

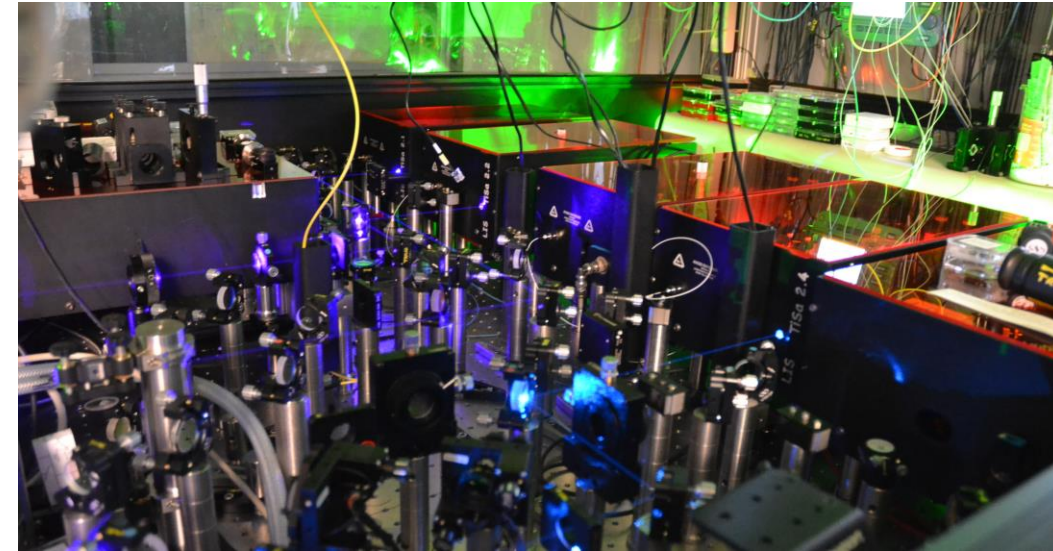
- Technical collaborations on p2n (proton to neutron converter), FEBIAD ion source, target components longevity, beam diagnostics
- co-applicants on a EU Marie-Curie Fellowship program and student exchange
- Exchange of technical equipment



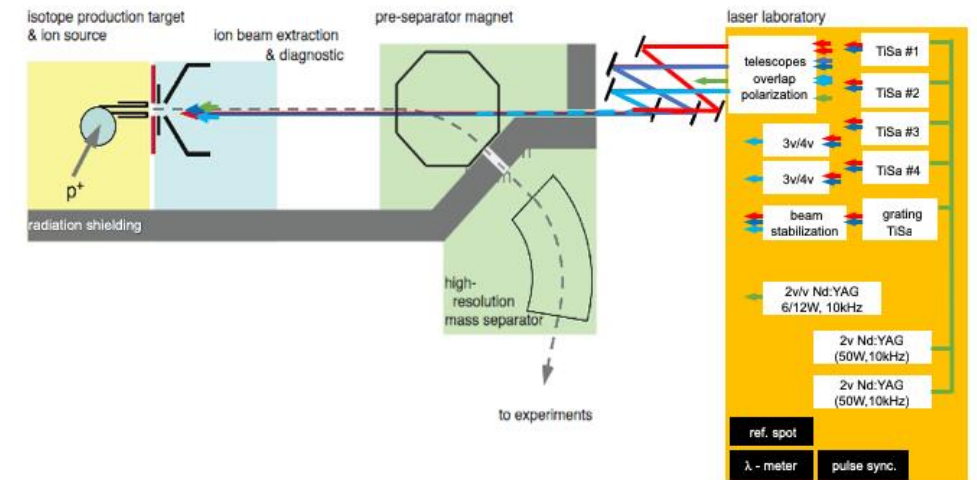
Laser Ion Source R&D

international collaborations

- In-source spectroscopy of Actinides – U Mainz, GSI-HMI Mainz
- Laser Resonance Ionization Spectroscopy – FRIB, RIKEN
- next generation all solid state laser ion source – U Mainz, GANIL
- TiSa laser dev. network – U Mainz, GSI / HMI Mainz, JYFL, CERN-ISOLDE, KU Leuven, GANIL, U Nagoya
- CLS laser spectroscopy & polarizer facility project - RAON
- EU Marie-Curie training network LISA (Laser ionization spectroscopy of Actinides) – U Mainz, GSI / HMI Mainz, JYFL, CERN-ISOLDE, KU Leuven, GANIL, U Nagoya & industry partners
- student exchange – U Oldenburg, TU Darmstadt



all solid state laser ion source -TRI LIS (2019)



TRIUMF Remote Handling

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

TRIUMF remote handling and target technologies as well as the know-how of HQP are valued by international collaborations (**T2K**, **MYRRHA**, **RISP**)

RH robotics development



TRIUMF RH specialists assisting in T2K target repair



Examples of international designs based on TRIUMF RH:

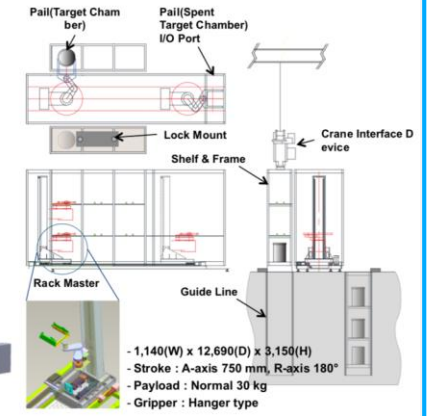
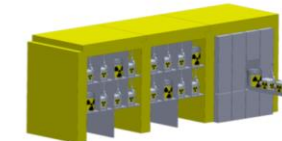
Proton Target Facility concept @ SCK•CEN 23

Target module handling similar to ISAC facility @ TRIUMF

SCK•CEN/2002/21/9 SIC Approved 10/11/18 15:39

This block contains architectural drawings and a photograph. On the left is a detailed floor plan of a facility with various rooms and corridors. On the right is a 3D perspective rendering of a large, rectangular industrial structure with a green base. Below these is a photograph of a target module handling system in operation, showing a large, cylindrical component being moved by a robotic arm.

Spent Target Storage

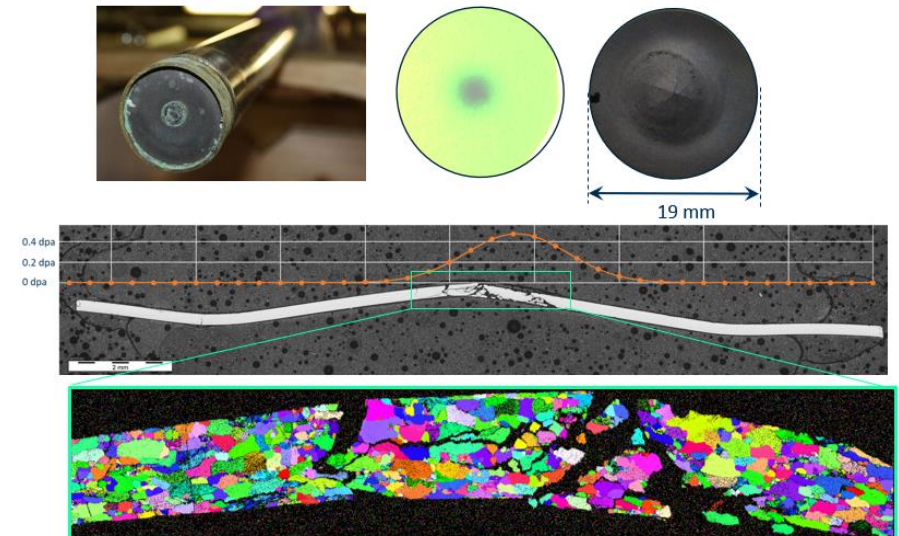


Fundamental TRIUMF R&D for neutrino production e.g. Dune, J-Parc

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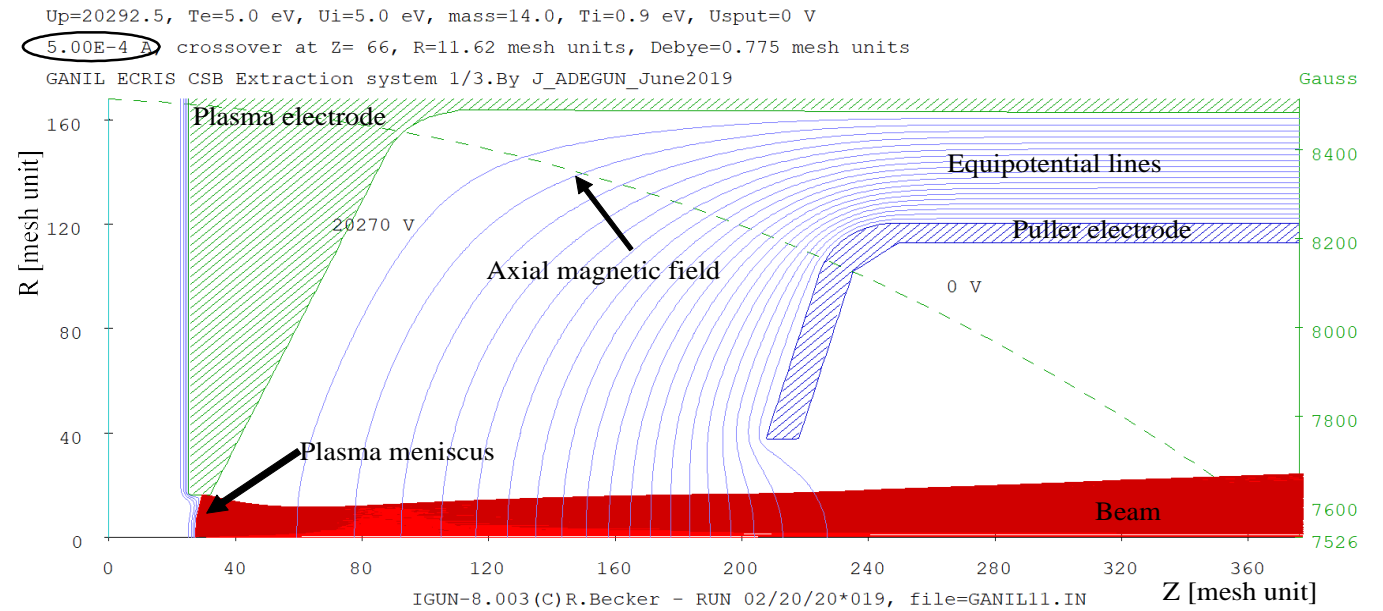
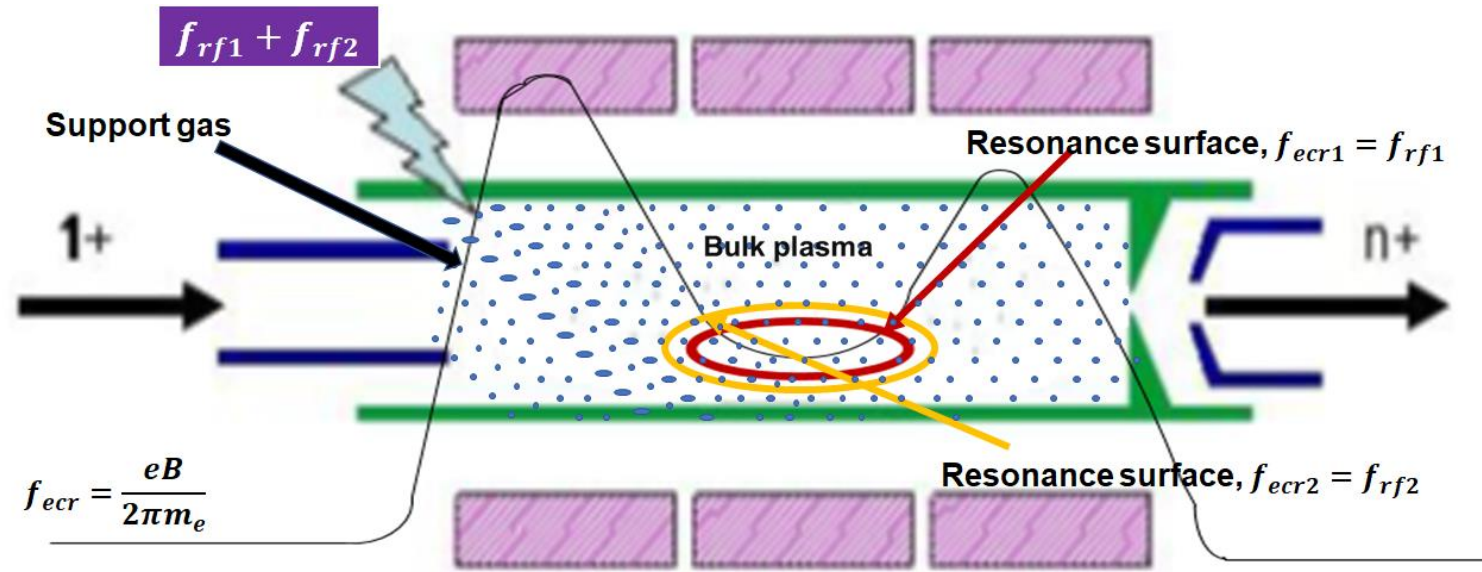
- Based on TRIUMF's previous contributions to T2K TRIUMF is well positioned to make contributions to **LBNF** and **J-Parc** in
 - beam diagnostics and remote handling
 - high power target technology
- TRIUMF is an active member of the **RaDIATE** global collaboration
 - Hosted meeting at TRIUMF in Dec. 2019
 - Planning a material aging test centre at TRIUMF coupled with simulations to feed global data base

Beam window failure investigations



GANIL and TRIUMF employ a 14.5 GHz PHOENIX ECRIS for charge state breeding.

- Increase of charge breeding efficiency by implementing
 - two-frequency heating technique that provides two resonance zones
- Improving the beam properties by optimizing the extraction system
 - Simulations with the code IGUN©
 - Benchmarking with beam emittance measurements



- **UHV RF induction oven** (NSERC) used to explore various **heating/doping** recipes
 - Program is coupled with fundamental studies using μ SR and β -NMR with collaborators from **JLab, Cornell, FNAL, Temple U., Lancaster U., HZB, PSI and UVic**
- Developing **vertical electropolishing** with Teflon stirrers to augment doping effort
 - Collaboration with **KEK**
- Exploring low cost fabrication techniques using reactor grade Nb and TIG welding (NSERC)
- High performance cryomodule development with a **FNAL** led collaboration



Induction Furnace



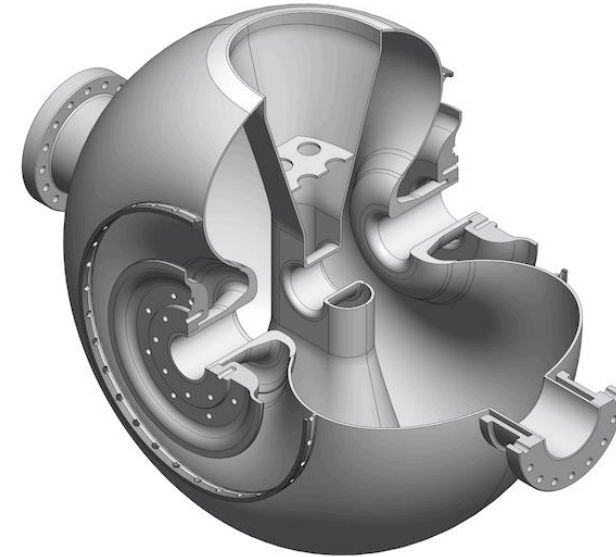
Vertical EP



Low cost SRF cavity (TRIUMF)

SSR Balloon resonator (TRIUMF, RISP)

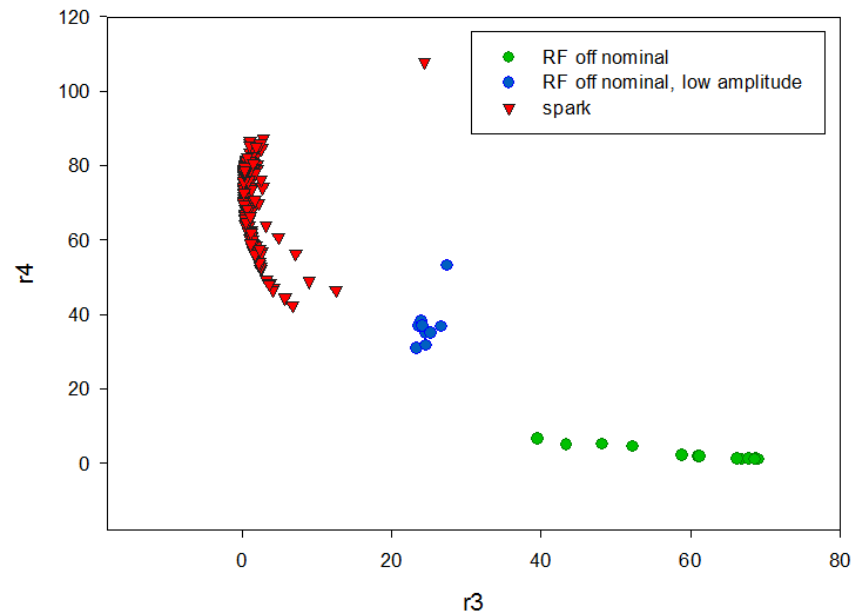
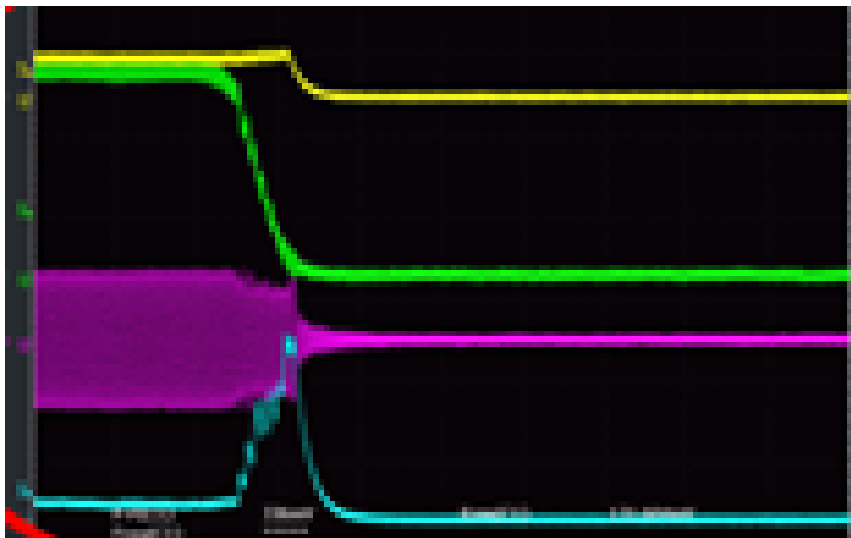
- TRIUMF has developed and successfully tested a new variant (**balloon geometry**) of a single spoke resonator for Hadron acceleration
- The cavity shape virtually eliminates the high level multipacting that plagues standard geometries
- The cavity design and prototyping was sponsored by **RISP (Korea)** and is being used in their heavy ion driver linac
- TRIUMF is also collaborating with **FNAL** and **Euclid** on further advancements



TRIUMF Low Level RF collaborations

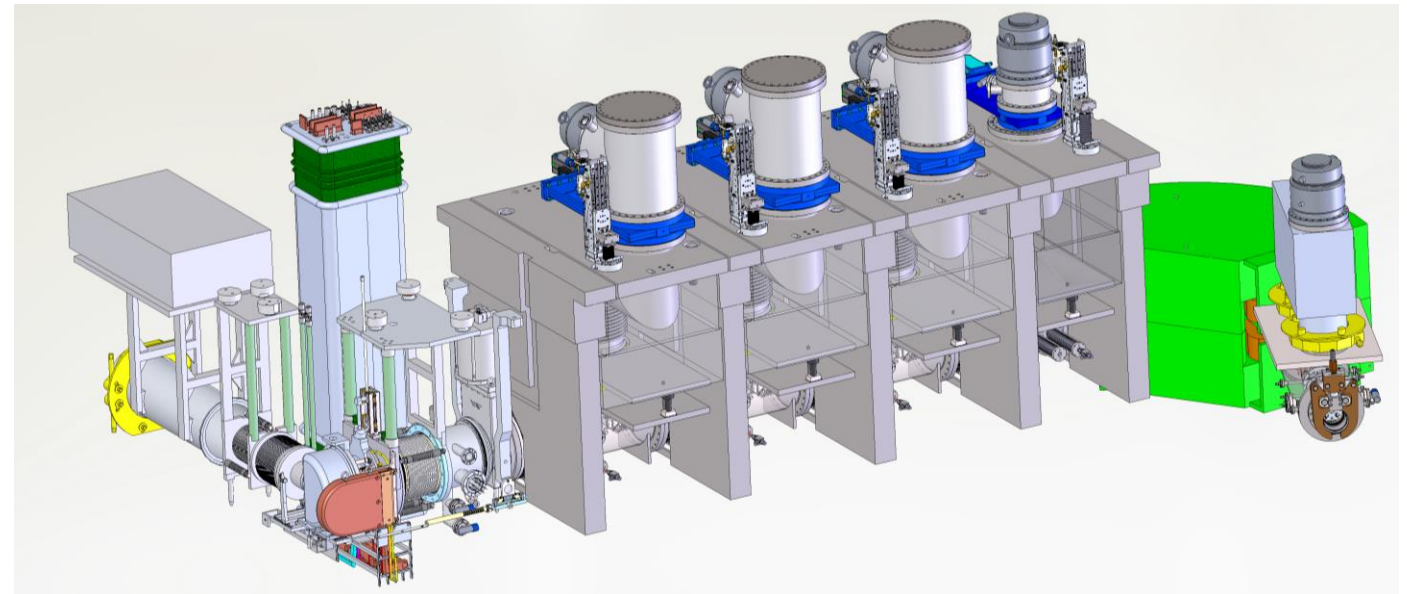
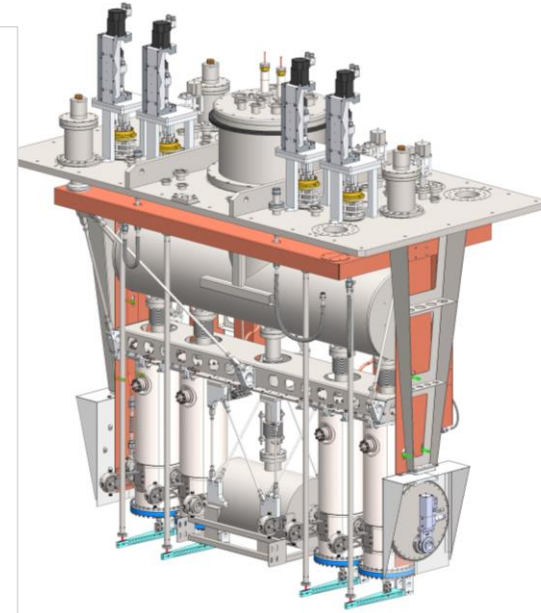
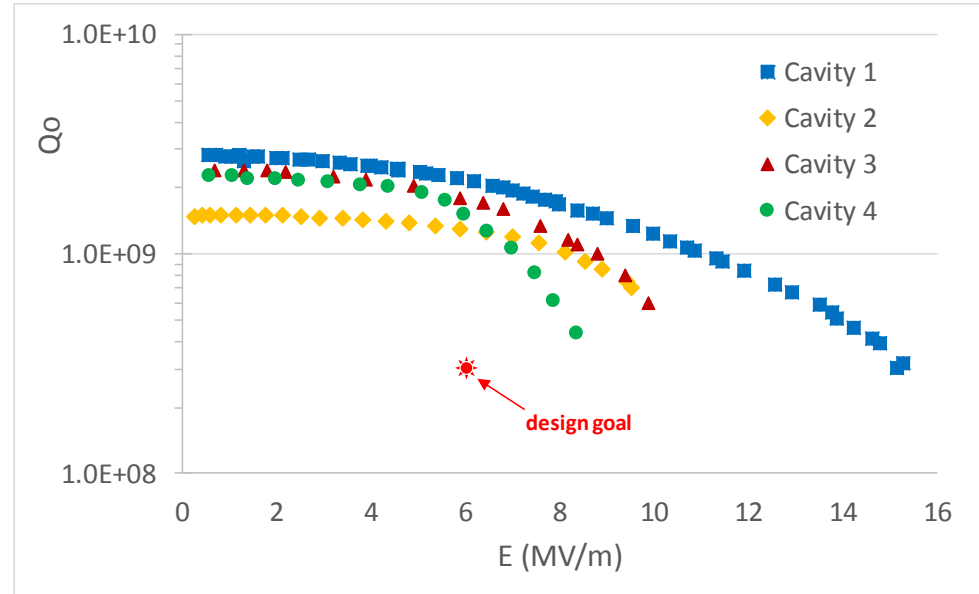
- TRIUMF's LLRF group manages the stabilization of all rf systems at TRIUMF and are sought after for collaboration and work for others (**IMPCAS, RISP, CIAE**)
- Spark detection and reaction system within TRIUMF's cyclotron through fault diagnostic and machine learning
 - In collaboration with Prof. Dr. Gerwald Lichtenberg from the **University of Applied Science in Hamburg**, Germany
 - 500MeV cyclotron rf spark events are accumulated based on an oscilloscope image then characterized to form a data base for machine learning to guide machine protection

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TRIUMF and VECC (Kolkata)

- TRIUMF and **VECC** have been collaborating on mutually aligned projects since 2008 – ANURIB in Kolkata and ARIEL in Vancouver
- The latest agreement includes a heavy ion cryomodule and an ARIEL target module and RIB extraction line
- The cryomodule will be completed this year (all cavities are now qualified)
- The RIB target module and beamline will be delivered in 2022.



General ACC projects

- TRIUMF scientists are part of proposals in a broad range of topics to support the Canadian community
 - Polarized beams in ring accelerators, spin dynamic (**SUPER KEKB, EIC**)
 - E-linac related FEL research for production of IR and THz radiation
 - High intensity proton driver linacs – neutron sources, medical accelerators

Summary

- TRIUMF Accelerator Science has an active program in International collaborations through the next five year plan
- The collaborations strengthen our core competences, engage students and support the Canadian science community



Thank you
Merci

www.triumf.ca

Follow us @TRIUMFLab



RADRIS Collaboration

Laser spectroscopy on trans-fermium elements **at SHIP/GSI** using **Radiation Detected Resonance Ionization Spectroscopy**

nature

Published: 28 September 2016

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

Mustapha Laatiaoui , Werner Lauth, Hartmut Backe, Michael Block, Dieter Ackermann, Bradley Cheal, Premaditya Chhetri, Christoph Emanuel Düllmann, Piet van Duppen, Julia Even, Rafael Ferrer, Francesca Giacoppo, Stefan Götz, Fritz Peter Heßberger, Mark Huysse, Oliver Kaleja, Jadambaa Khuyagbaatar, Peter Kunz, Felix Lautenschläger, Andrew Kishor Mistry, Sebastian Raeder, Enrique Minaya Ramirez, Thomas Walther, Calvin Wraith & Alexander Yakushev

Nature **538**, 495–498(2016)



Raeder, S., et. al. Probing Sizes and Shapes of Nobelium Isotopes by Laser Spectroscopy. *Phys. Rev. Lett.* 120, 232503 (2018).

Chhetri, P., et. al. Precision Measurement of the First Ionization Potential of Nobelium. *Phys. Rev. Lett.* 120, 263003 (2018).

- TRIUMF's LLRF group manages the stabilization of all rf systems at TRIUMF and are sought after for collaboration and work for others
- **IMPCAS** (China) – 24 LLRF controllers for SRF linac.
- **RISP** (KOREA) – 1 LLRF controller for SRF test area.
- **CIAE** (China) – MOU between TRIUMF and CIAE for continual cooperation.
 - Cooperation on RF structure and LLRF control for cyclotrons.
 - Exchange of researchers and students.

