University of Victoria

TRIUMF

Accelerator Physics and ARIEL

Tobias Junginger
Assistant Professor UVic
in a joint appointment with TRIUMF

TRIUMF/UVic Accelerator Research

- UVic is the lead University of the ARIEL project – PI D. Karlen
- Through ARIEL we received NSERC funding for student support which allowed us to grow the accelerator research and education program
  - Currently 14 UVic graduate students in accelerator physics based at TRIUMF (11), UVic (2), D-Pace (1)
  - One graduate lecture course taught by the adjunct faculty each year at TRIUMF and broadcasted nationwide
  - Undergraduate lecture course, graduate + undergraduate projects offered at UVic
  - Special topics classes offered on demand (Ion sources, synchrotrons, SRF)

RESEARCH FOCUS at TRIUMF

- **Beam physics and instrumentation** (R. Baartman, T. Planche, O. Kester)
- **Superconducting RF** (R. Laxdal)
- **Ion Sources and Targets for secondary particle production** (A. Gottberg, T. Day Goodacre, O. Kester)

Projects at UVic

- Cryocooler based fundamental SRF studies
- Surface and Materiel Science Studies at the Electron Microscopy Facility (A. Blackburn)
- Application of SRF technology to quantum computing (R. de Sousa)
- Beam Dynamics studies for SuperKEKB (M. Roney)

Today my focus will be on graduate students projects which are directly relevant to ARIEL and science opportunities available through ARIEL

Content

- Availability and reliability of ARIEL e-linac
  - Plasma cleaning
  - Dust migration and mitigation
- Development of high power ISOL targets
- Future science opportunities enabled through ARIEL
  - TRISR - Storage Ring
  - Material Science with betaNMR for SRF research

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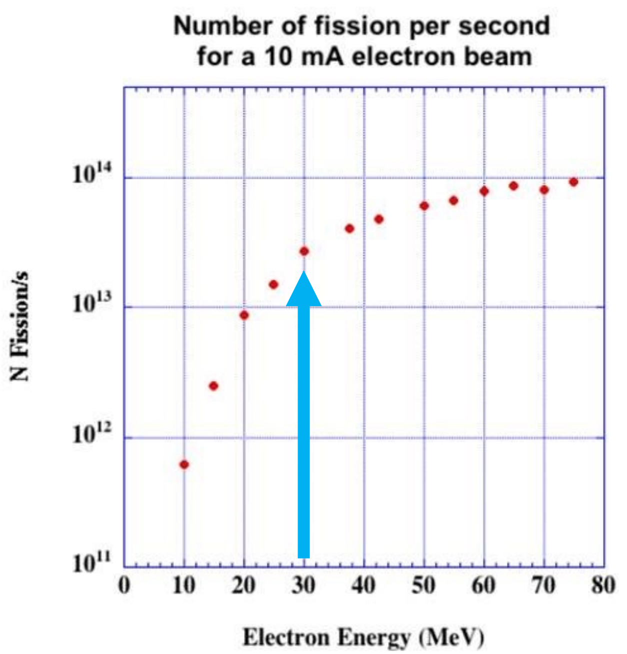
eLINAC: Reliable 30MeV Operation

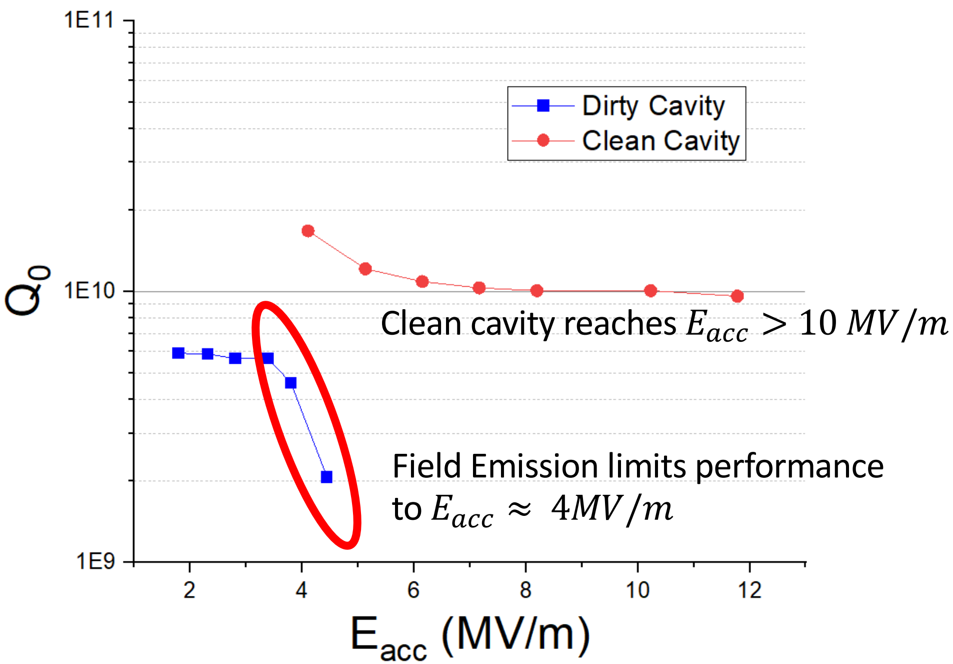
Stable 30MeV operation is critical for RIB production:

- RIB yield is strongly dependent on beam energy
- We're operating at 30MeV – at the lower end of the yield curve



Field emissions from contaminants in the SRF cavity limit RF performance to lower E_{acc}

- Prevention and mitigation critical to keeping performance high, to keep RIB yield high
- Sources of field emission can be dust and hydrocarbons

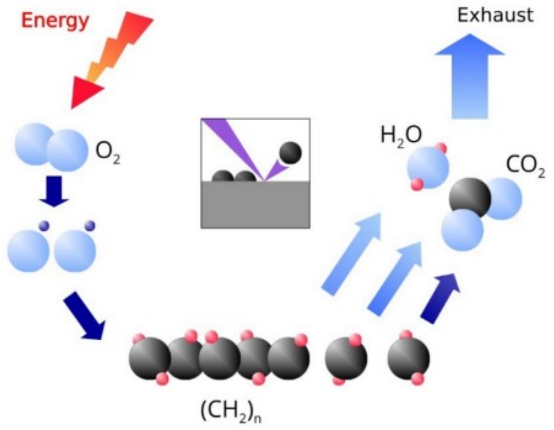


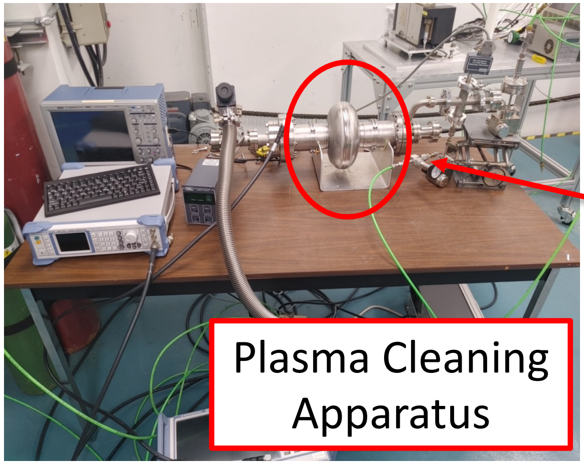
As presented by Philipp on Monday

Plasma Cleaning

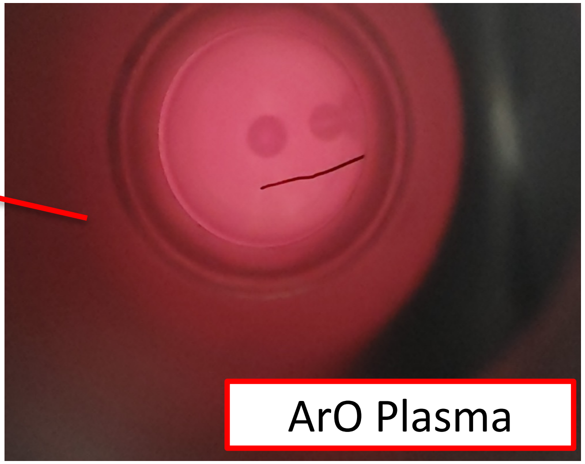
- Adsorbate gasses in the form of hydrocarbons are one facilitator of field emission within Superconducting RadioFrequency (SRF) cavities.
- Currently, cavity cleaning procedures are done *ex-situ* and are time-exhaustive (2-3 months).
- Plasma cleaning allows for an *in-situ* cleaning of surface hydrocarbons using an ArO plasma mixture, which reduces cleaning time to ~1 week.
- Once plasma cleaning has been optimized on uninstalled cavities, the technique will be rolled out onto ARIEL's e-linac.

MSc. D. Hedji
P.I. R.E. Laxdal





Plasma Cleaning Apparatus

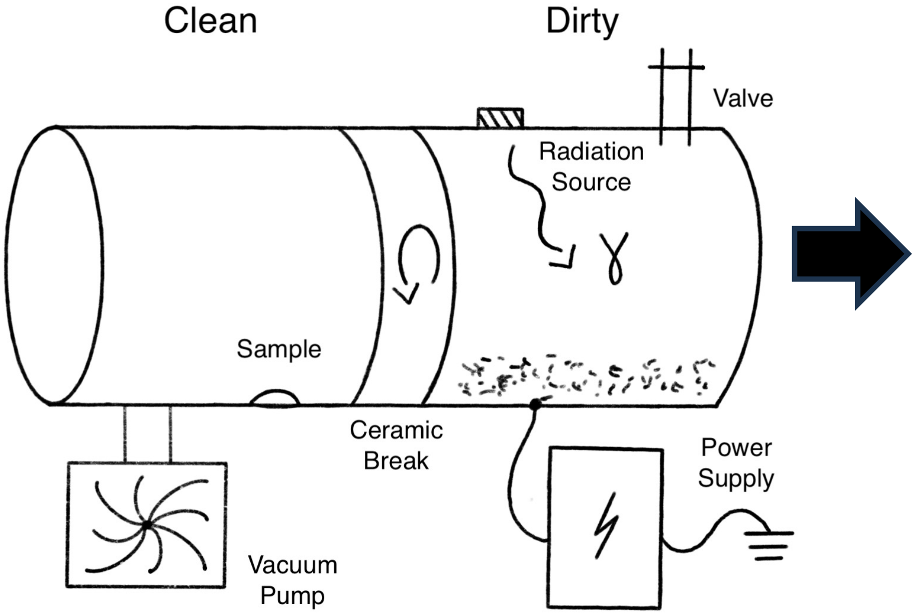


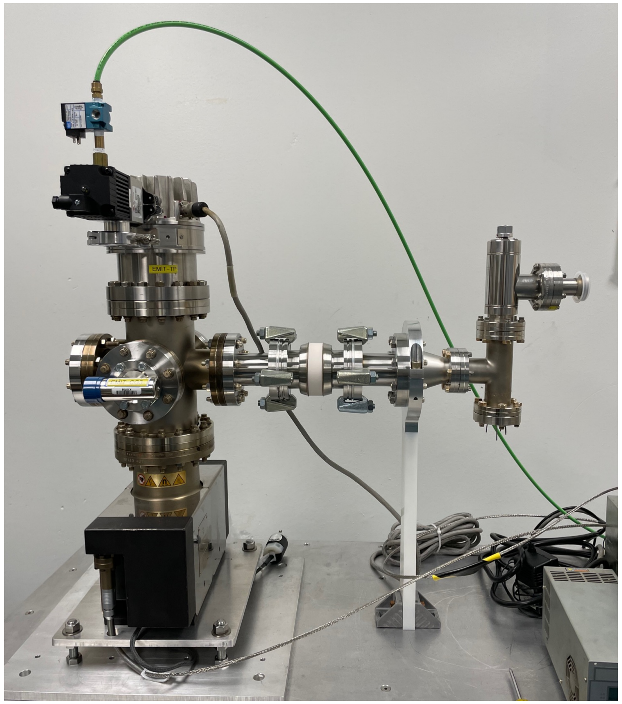
ArO Plasma

Dust migration

- Most common cause of beam loss in e-linac is currently field emission.
- Emitters are µm to sub µm sized contaminants → dust
- Previous studies indicate that dust migrates and is charged:
  - A potential barrier could therefore suppress dust migration and tackle field emission problem at its source.
- Status: Proof of principle experiment has been designed and assembled. Awaiting final components. Detailed experimental plan in development.

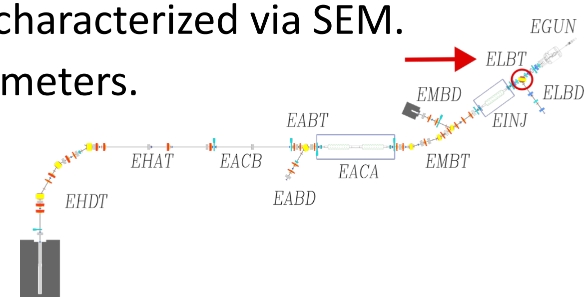
PhD A. Mahon
PI T. Planche



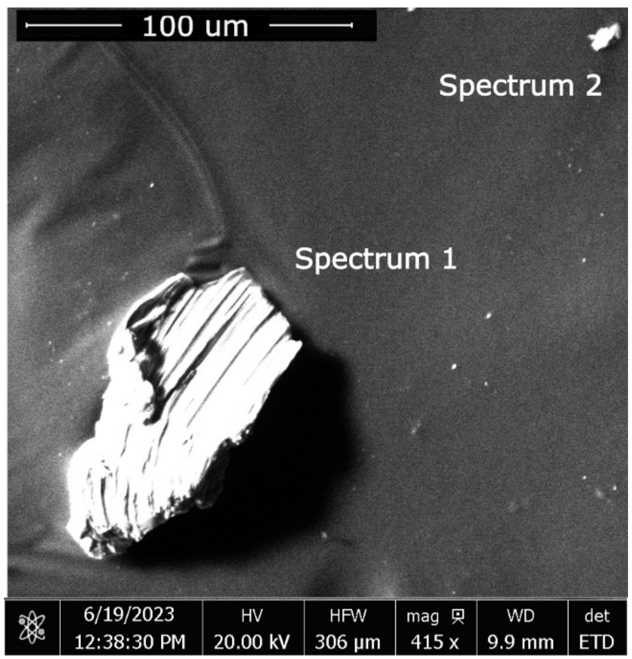


Dust migration

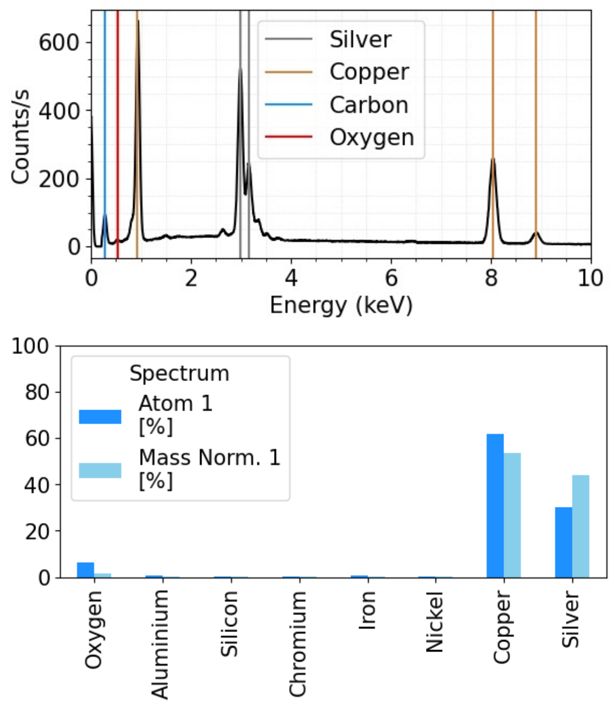
- Dust samples were collected from the low energy section (ELBT) of the e-linac early 2023.
- Preliminary results for collected dust grains were analyzed and characterized via SEM.
- Sizes range from a few micrometers to a few hundreds of micrometers.
- Elemental composition determined via EDX:
  - Copper, Silver, Chromium, Iron, Nickel, Oxygen, Silicon, Calcium, Sodium, etc.
- Conclusions on origin of dust contamination still pending.



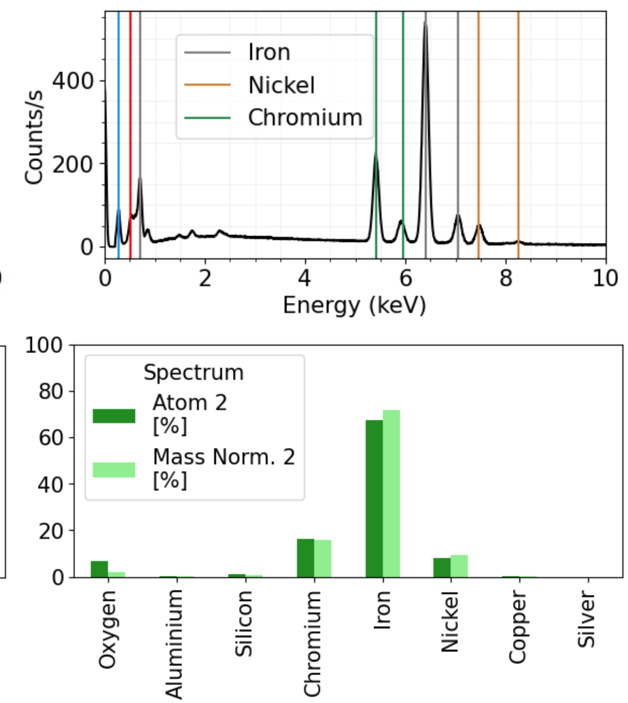
Example sample



Spectrum 1:



Spectrum 2:



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Development of high power ISOL targets

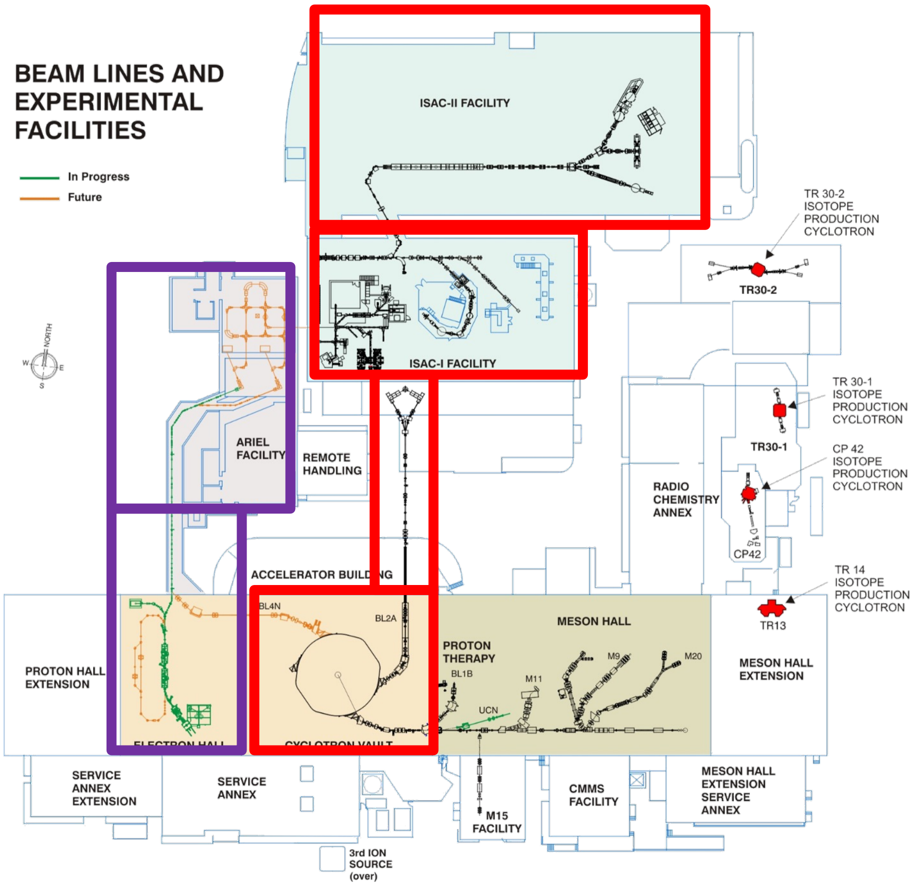
- At ARIEL two high power drivers will be available for RIB production
  - Proton beam (50 kW)
  - Electron beam (35 MeV x 2800 µA = 100 kW
- Maximizing output requires the development of Isol targets which can handle high power and to optimize the overall efficiency ε which can be as low as 10^{-6}

Equation of yield

$$I_{RIB} = \sigma_i(E).N_{Target}.I.\epsilon$$

To meet these requirements, we need a target material with

- very high melting point
- low vapor pressure
- high effective thermal conductivity
- Extremely efficient target container to dissipate very high beam power



Target Material and Target ion sources

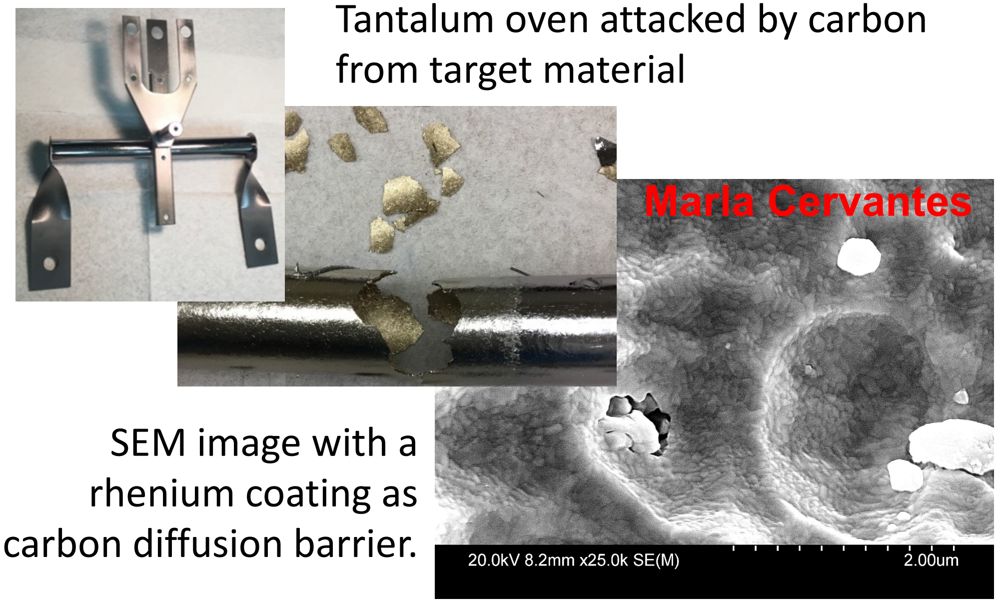
Several UVic students have made significant contributions to TIS developments for ARIEL

Novel Target Materials for Increased Radioisotope Intensities
Ph.D. Project Marla Cervantes

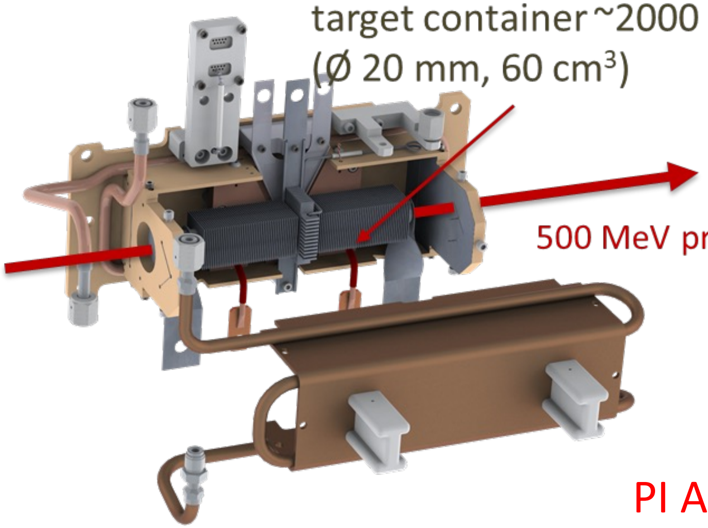
Fundamental studies on Ion Sources for High-Intensity Radioactive Beams
Ph.D. Project Fernando Maldonado (graduated in 2022)

Material damage dissipation for accelerator components in high radiation fields
Ph.D. Project Ferran Boix Pamies

Tantalum oven attacked by carbon from target material



SEM image with a rhenium coating as carbon diffusion barrier.



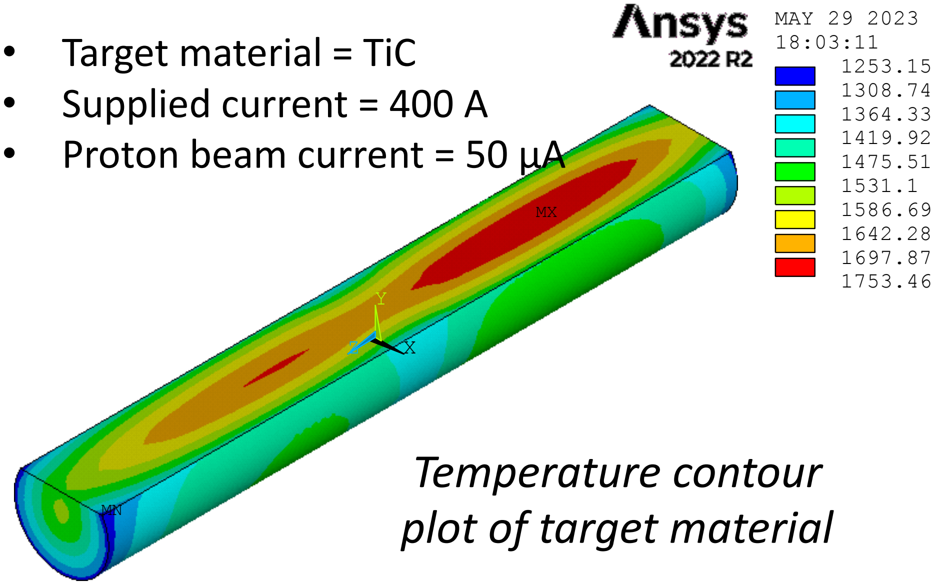
PI A. Gottberg

Development of high power ISOL targets

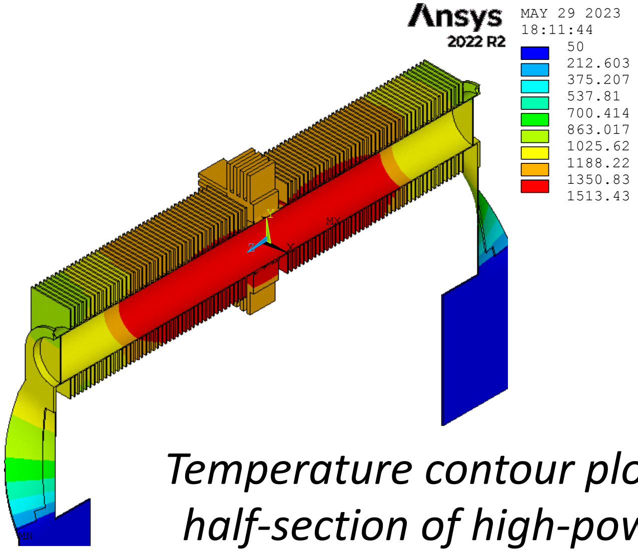
- Goal: Development of high-power target container to ramp up the existing beam power handling capacity at TRIUMF by a factor of 5
- Finite Element Simulation of target system under proton beam and resistive heating
- Heat generation in target material by proton current is obtained from FLUKA simulation and fed as an input into ANSYS.

PhD S. Ghosh
PI A. Gottberg

- Target material = TiC
- Supplied current = 400 A
- Proton beam current = 50 μA

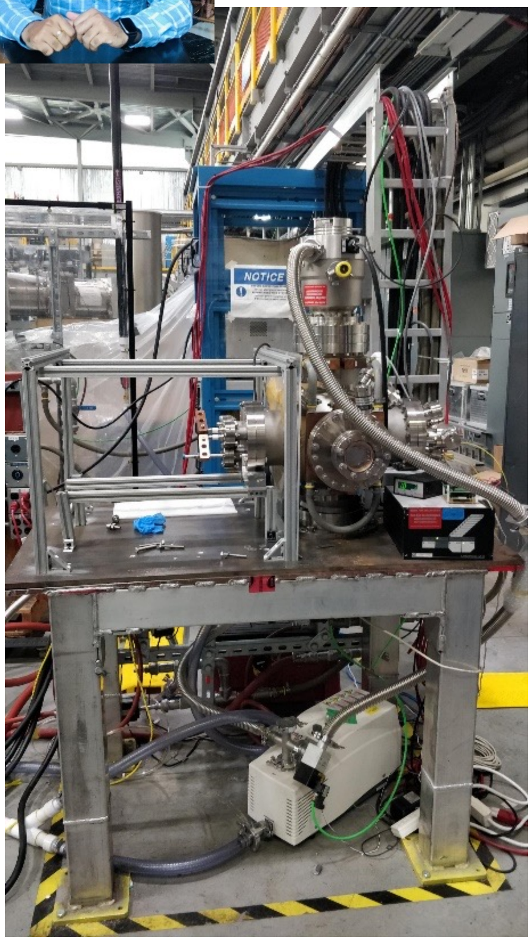


Temperature contour plot of target material



Temperature contour plot of half-section of high-power target container

Study of high-power target material properties



Chamber for heating investigations (CHI)

Experimental set-up to investigate thermal properties (thermal conductivity, etc.) of existing and future R&D ISOL target materials

ISAC Offline Test Stand

- *Will be used for investigating heat transfer through bulk material housed inside actual target container (thermal conductivity, contact resistance, etc.)*
- *Design of an electron bombardment heating setup on the test stand is in progress to simulate online proton heating.*

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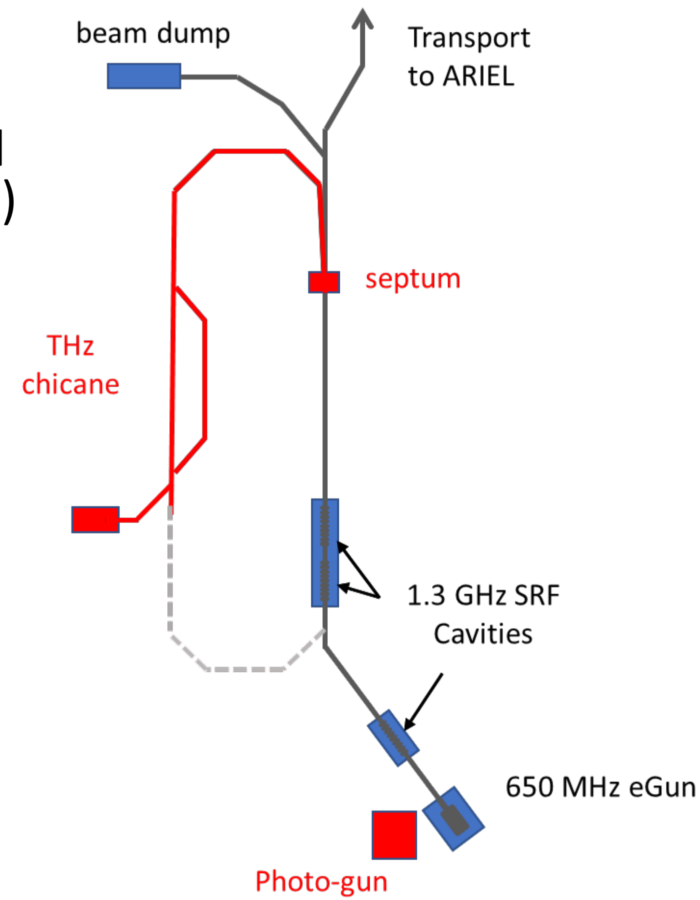
Future science opportunities enabled through ARIEL

- The ARIEL e-linac enables unique science opportunities
  - FLASH-MRT - Reducing side effects in radiotherapy by a combination of two novel treatment techniques, the ultra-fast (FLASH) radiotherapy with spatially fractionated microbeam therapy (MRT) – First beam delivered to experiment in February 2022
  - DarkLight project - Electron scattering experiment to search for particles beyond the standard model – Target chamber installed December 2021
  - CFI funded project: Terahertz radiation project
- ARIEL will triple TRIUMF's RIB output which provides more beam to current and future experiments such as
  - TRISR - Storage Ring
  - Material Science with betaNMR for SRF research



THz radiation project

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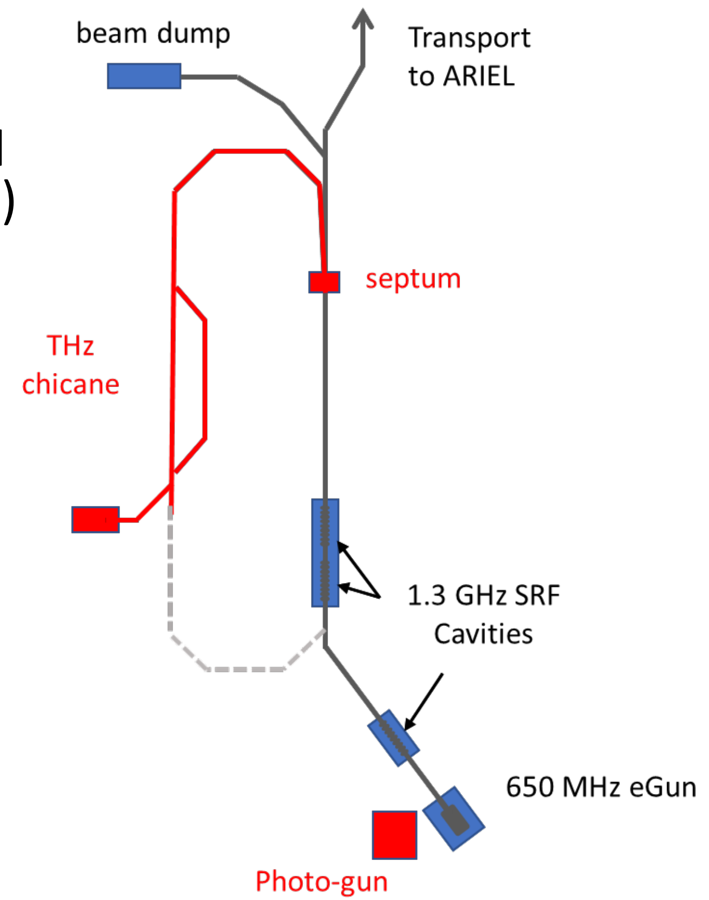


THz radiation project

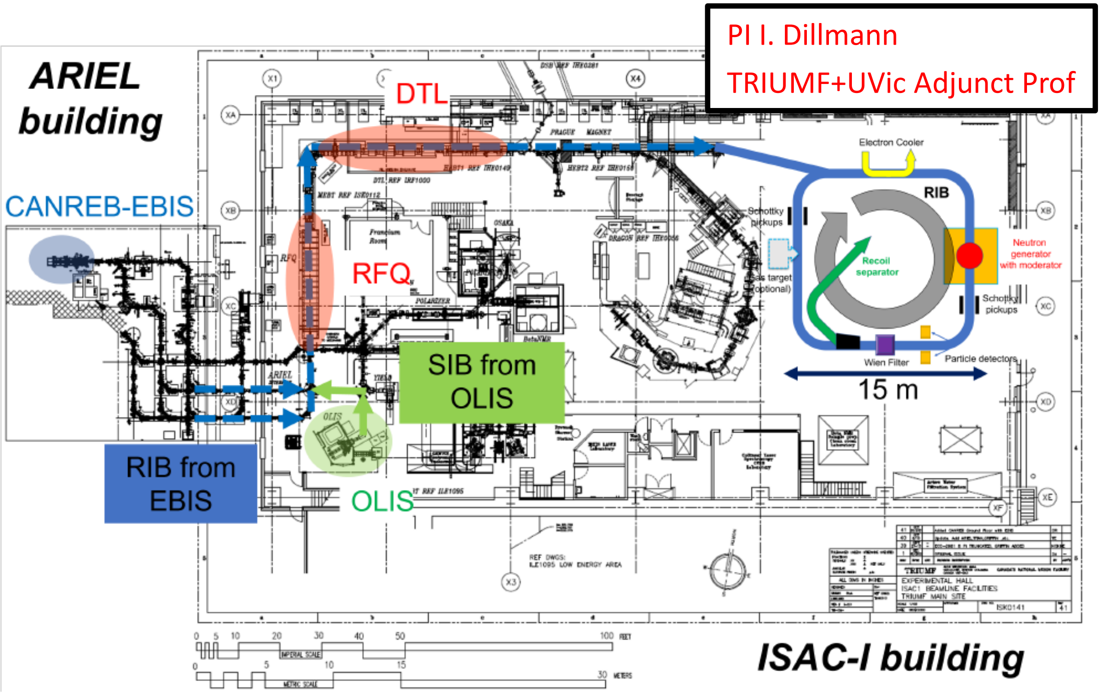
The TRIUMF Storage Ring (TRISR) Project

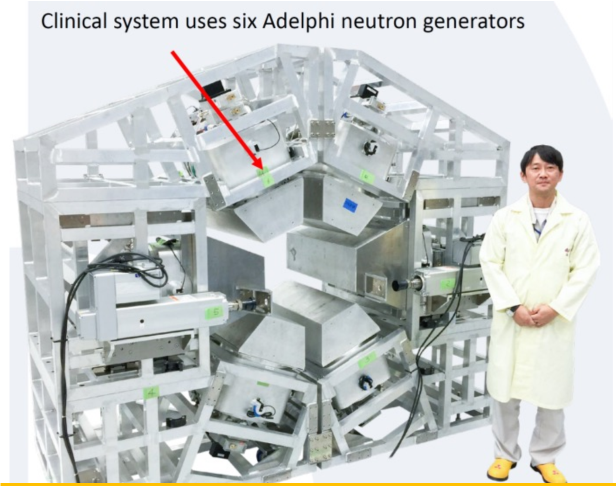
Motivation: Direct measurement of neutron capture cross sections of short-lived radionuclides down to seconds of half-lives.

Requirement: ISOL Facility + Storage Ring + Free Neutron "Target"

- Several proposal exist – no facility world-wide
- Others have considered using a reactor (safety issues) or a spallation source (costly) as targets. We consider using a commercial neutron generator as target.

Timeline: Feasibility studies towards TDR in 2026 – First experiments in 2031





Example of an existing system (for Boron Neutron Capture Therapy) in Japan

The TRIUMF Storage Ring (TRISR) Project

- **Mini-Workshop at TRIUMF (July 18-21)** with European colleagues and a presentation from neutron generator company *Adelphi Technologies Inc.*
  - Potential design: "star-like" design with 4-6 neutron generators (DT/DD) around moderator and beamline
  - Mobile setup:
    Step 1 (2025-2030): Installation and first measurements planned at GSI Darmstadt (CRYRING)
    Step 2 (>2030): Then move to TRIUMF once TRISR is constructed
- Funding applications this year
  - ERC Synergy Grant (up to 14 MEuro)
  - NSERC project discovery grant
- First TRISR paper has been published and two papers on extraction of circulating beam via Wien filter into recoil separator and neutron target design are in progress

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https://doi.org/10.1140/epja/s10050-023-01012-9
THE EUROPEAN PHYSICAL JOURNAL A
Check for updates
Regular Article - Experimental Physics

Measuring neutron capture cross sections of radioactive nuclei

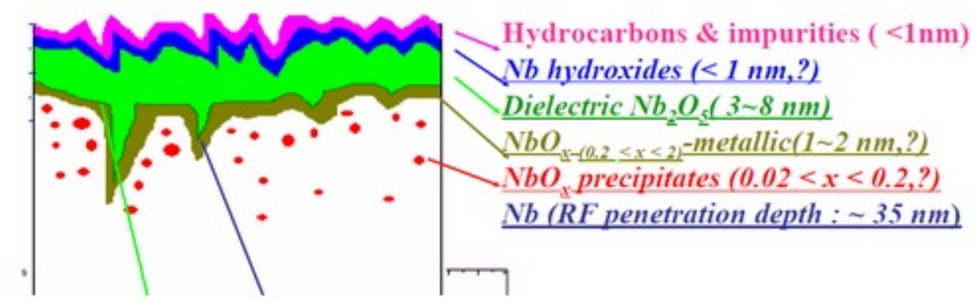
From activations at the FZK Van de Graaff to direct neutron captures in inverse kinematics with a storage ring at TRIUMF

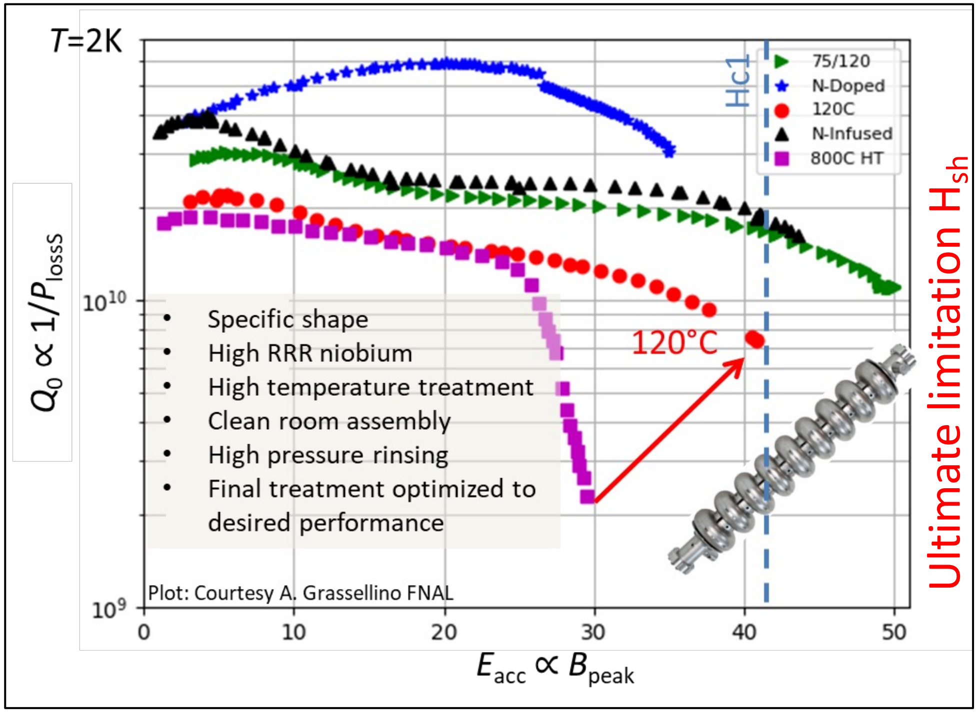
Iris Dillmann[1,2,a], Oliver Kester[1,2], Richard Baartman[1,2], Alan Chen[3], Tobias Junginger[1,2], Falk Herwig[2], Dobrin Kaltchev[1], Annika Lennarz[1,3], Thomas Planche[1,2], Chris Ruiz[1,2], Nicole Vassh[1]
[1] TRIUMF, Vancouver, BC V6T 2A3, Canada
[2] Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada
[3] Department of Physics and Astronomy, McMaster University, Hamilton, ON L8S 4M1, Canada

Motivation for fundamental SRF research

SRF is highly efficient but complex technology

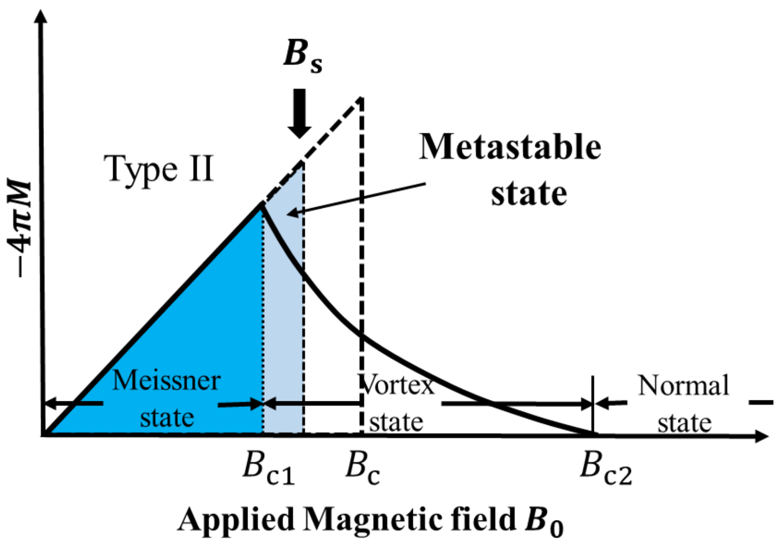
- Supercurrents only flow within a few tens of nanometres
  - Performance is very sensitive to near surface material properties which can be engineered by heat treatments in vacuum or low pressure gas atmosphere
- Current material of choice niobium is reaching fundamental limitations → Further improvements require new materials potentially as multilayers



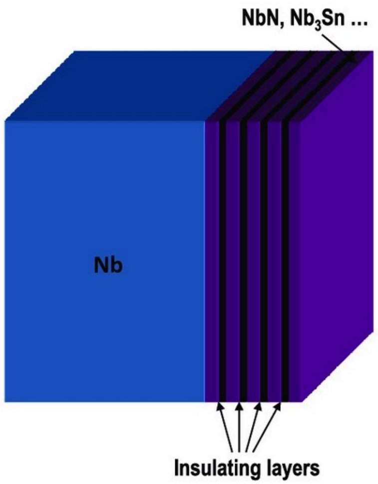


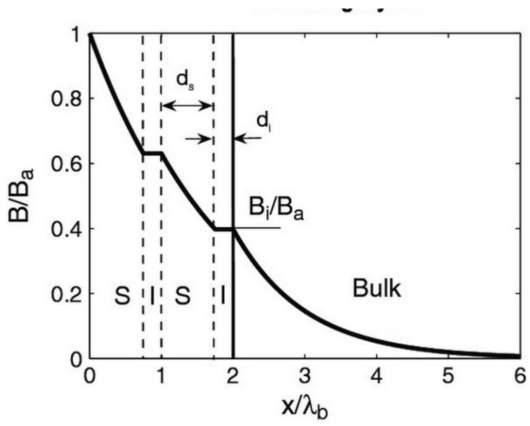
Hetero Structures for higher accelerating gradients

Superconducting radiofrequency (SRF) cavities need to be operated in the Meissner state to avoid strong dissipation from vortices.



For a defect free superconductor the maximum attainable field is set by the superheating field, which directly depends on the RF current.



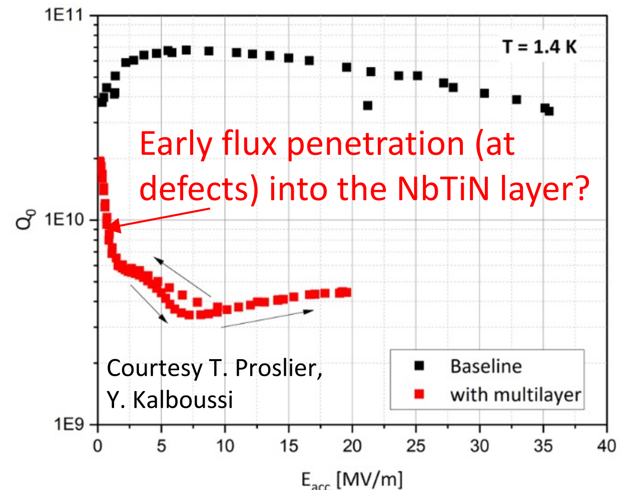


Nanometer thin multilayerd structures can potentially reach fields beyond Nb limitations. The current in each layer is influenced by all other layers →The exact current distribution in all layers needs to be known to predict the maximum E_{acc}

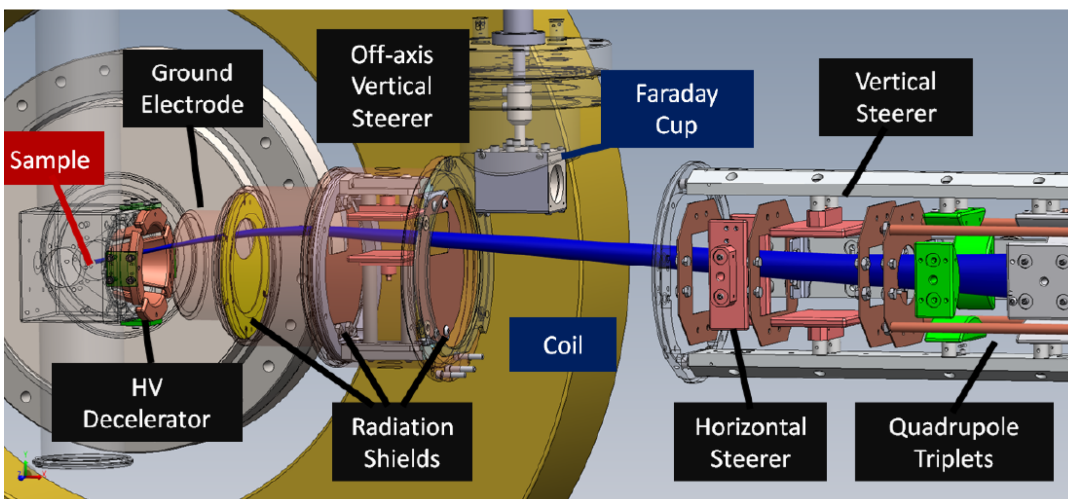
β-NMR + SRF @ TRIUMF

R. Laxdal, R. McFadden, PhD E. Thoeng (UBC), PhD Md Assaduzzaman

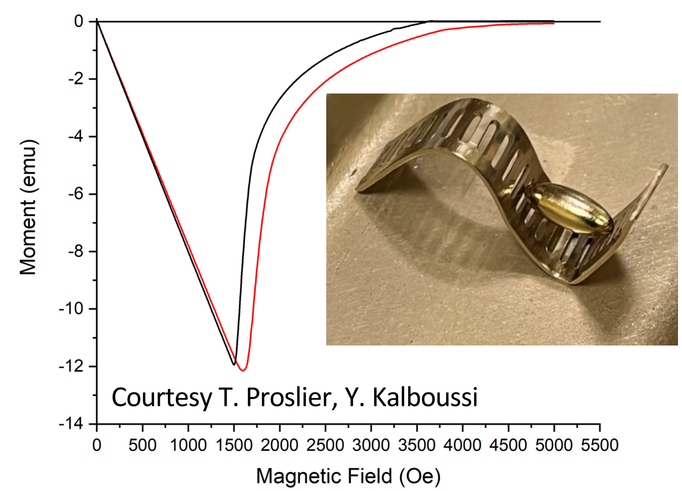
- RF performance of heterostructures generally lags behind Nb cavities
  - Early flux penetration into overlayer?
- With β-SRF we are able to detect penetration of magnetic flux with nanometer depth resolution at relevant fields for accelerator application
- A niobium ellipsoid has been coated using atomic layer deposition with 8nm of AlN and 46nm of NbTiN and will be tested in September
- ARIEL will enable more beta-NMR beam time



NbTiN/ALN/Nb coating shows weakened performance compared to uncoated cavity



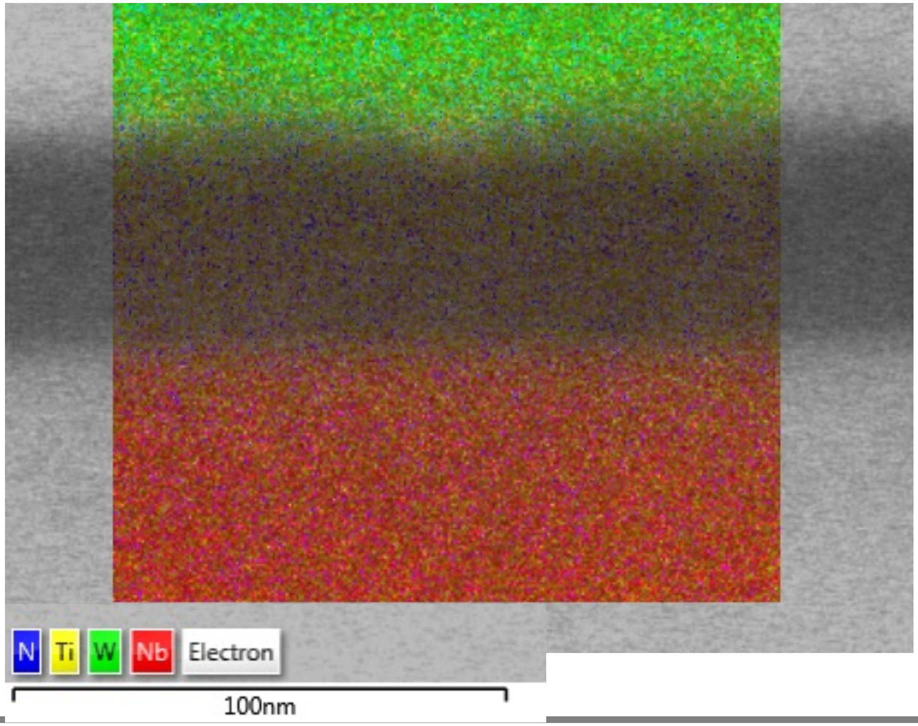
β-SRF: High parallel field extension of the β-NMR facility



NbTiN/AlN coating increased field of first vortex penetration

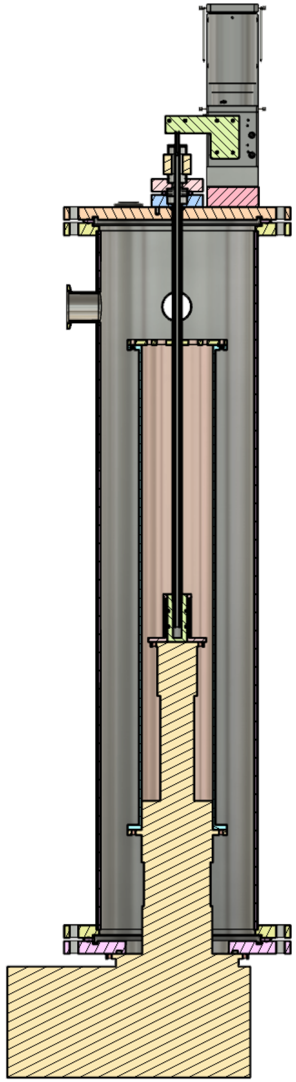
Measurement of the vortex penetration field

- β-NMR studies will be coupled with measurements of superconducting bulk and material properties at UVic
- Vibrating sample magnetometry can be used to measure the bulk vortex penetration field
  - Instruments are commercially available but the SRF parameter range (relatively low field at low temperature) favor a dedicated design which can be realized at a fraction of the cost
  - Status: Design finalized, construction started (MSc Lucas Wallace)



TEM/EDX map of a NbTiN on Nb sample

BSc Will Stokes



Summary

- Through ARIEL TRIUMF extended its expertise in
  - Beam physics and instrumentation
  - Superconducting RF
  - Ion Sources and Targets for secondary particle production
- Field emission mitigation in the e-linac and high power targets are key for high yield RIB delivery in the ARIEL area
- ARIEL will enable more beam time for current and future experiments such as β-NMR and TRISR