# TRIUMF in the ARIEL Era

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NACB2019 - Vancouver,
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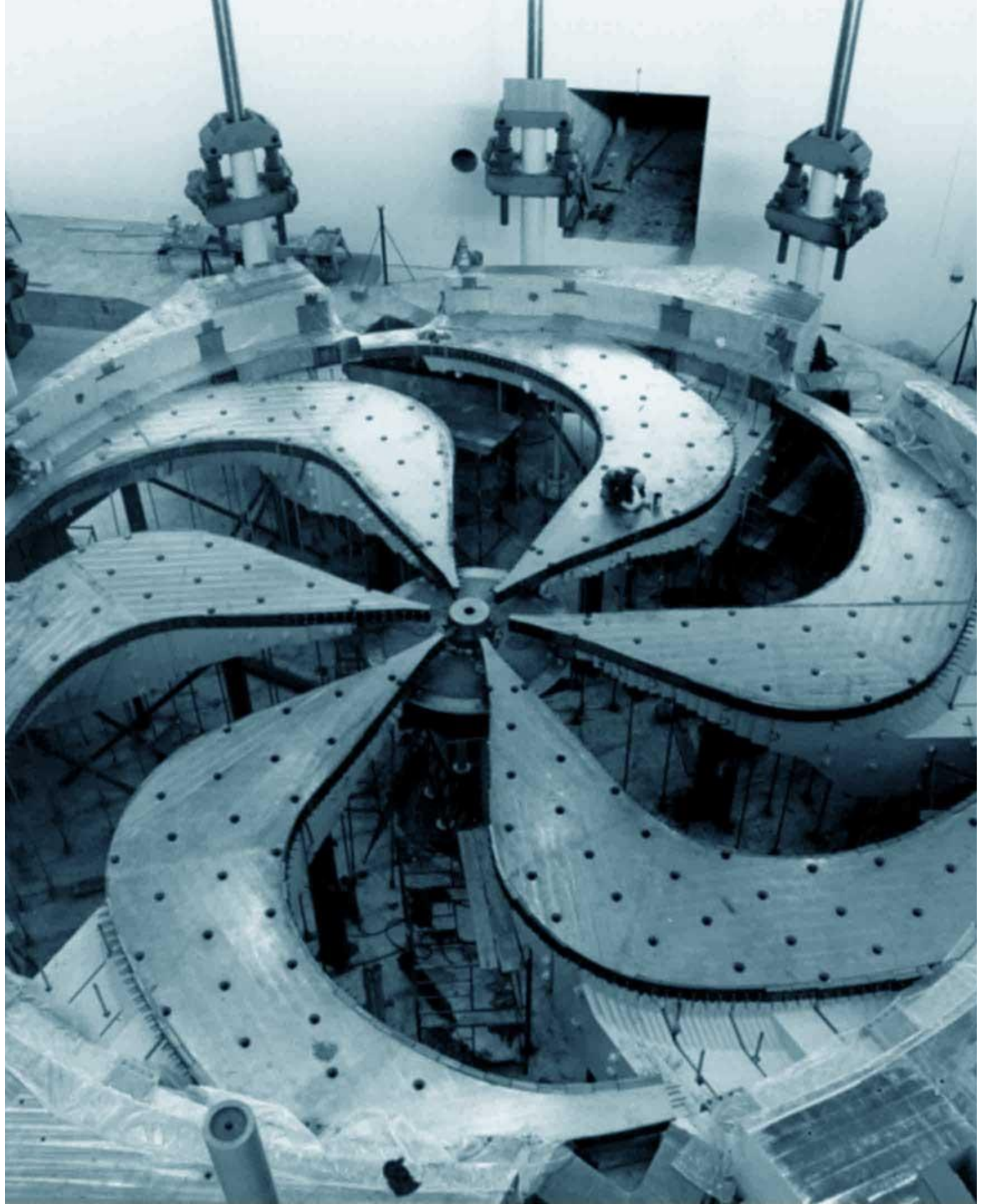


2019-06-10

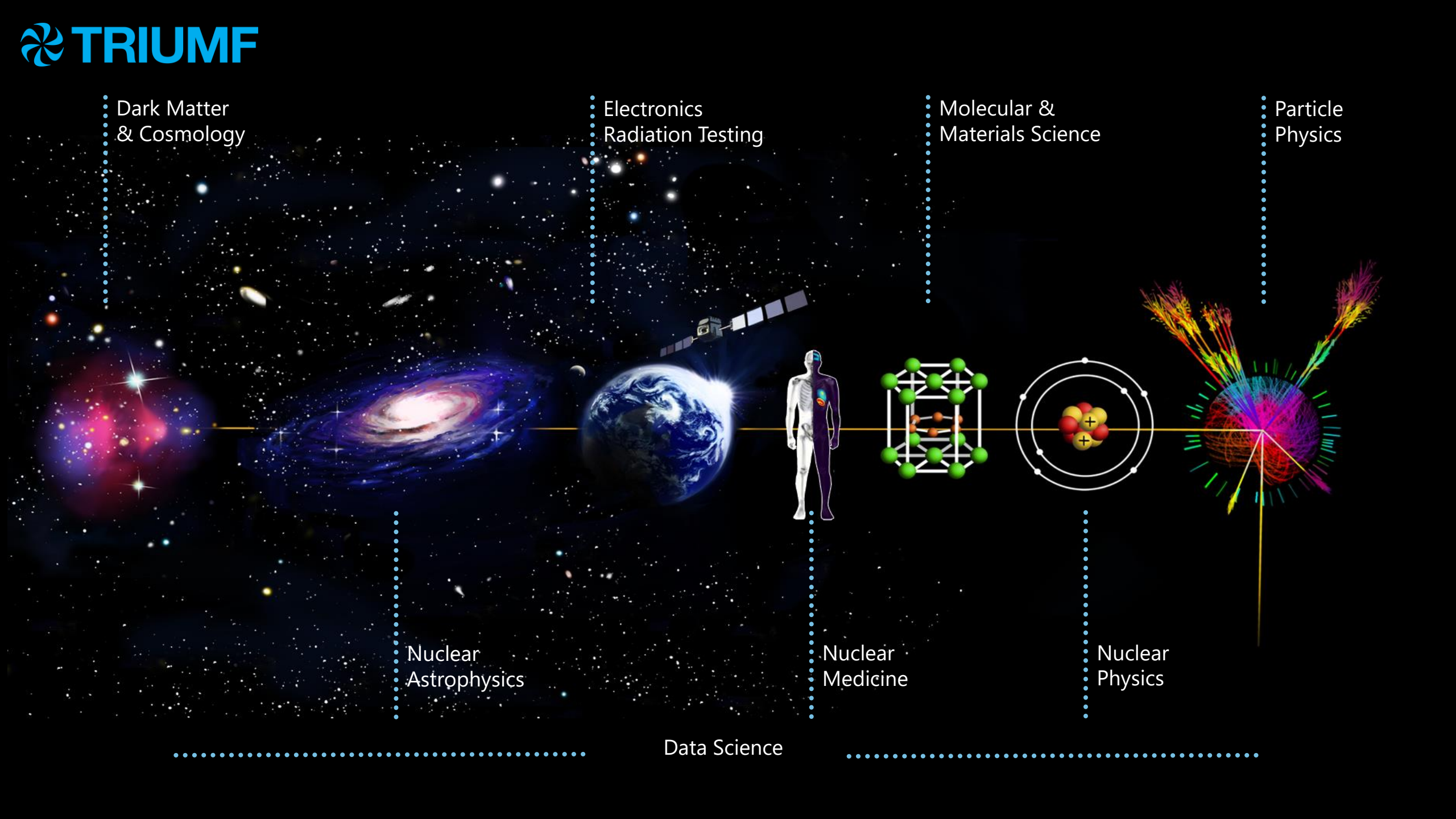
Discovery, accelerated


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

Our laboratory is one of Canada's major investments in large-scale research infrastructure

with >500 staff and >200 students & post-doctoral researchers

TRIUMF


Dark Matter
& Cosmology
Electronics
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Molecular &
Materials Science
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Astrophysics
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Medicine
Nuclear
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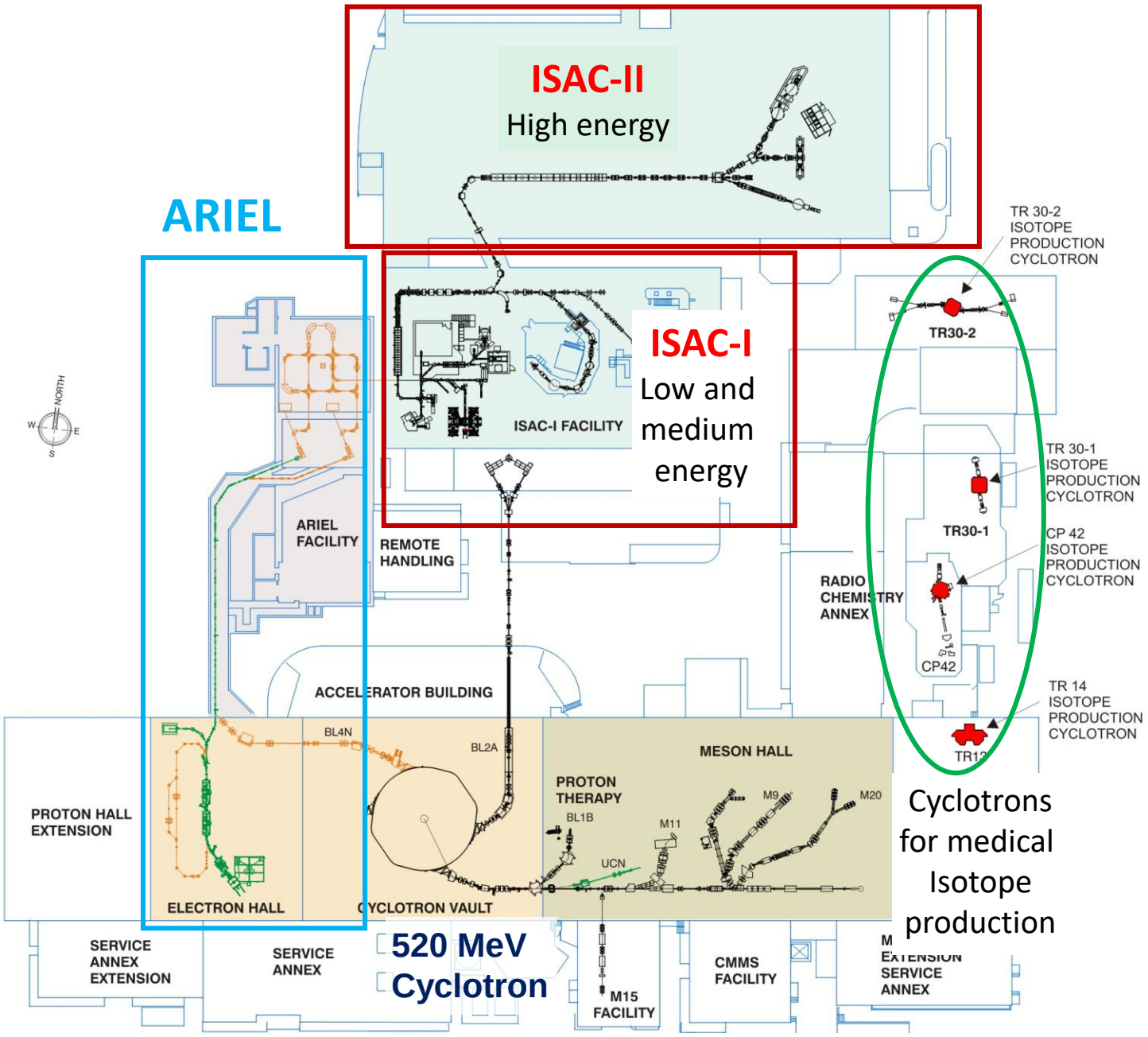
Data Science


TRIUMF has five decades of experience in building a rich particle accelerator infrastructure that nurtures cutting-edge research.

# TRIUMF accelerator complex




## Primary beam driver:

Cyclotron, 520 MeV, $H^-$

Produces rare isotopes, neutrons and muons!

## Isotope Separator and Accelerator facility - ISAC

Isotope Separator Online (ISOL) facility

ISAC-I: Normal conducting-linac, 0.15-1.8 MeV/u

ISAC-II: Superconducting-linac, 1.5-16.5 MeV/u

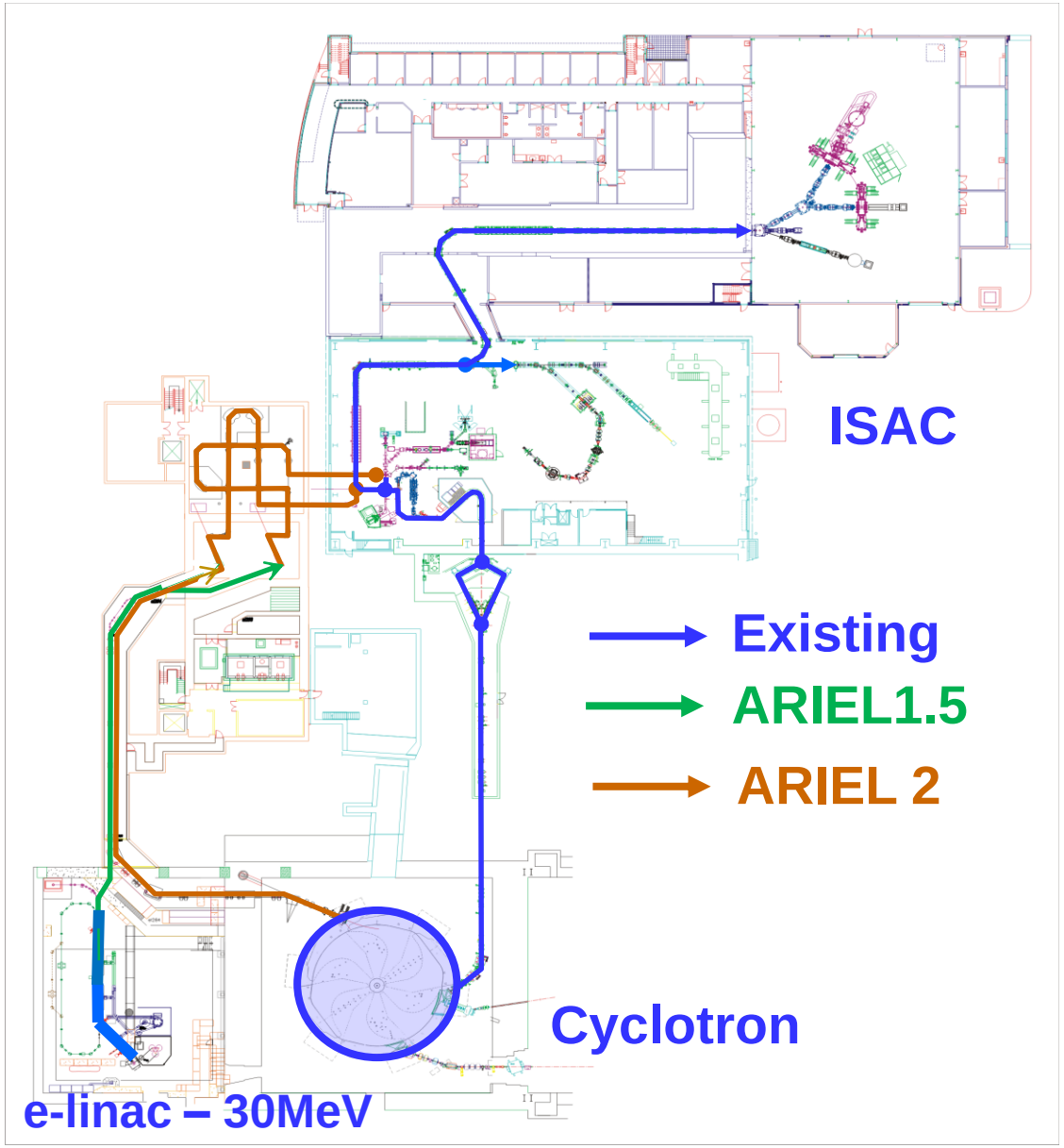
## Advanced Rare Isotope Laboratory - ARIEL

Superconducting electron linac

30 MeV, 10 mA, cw

## 4 Cyclotrons for medical isotope production

# Advanced Rare Isotope Laboratory - ARIEL



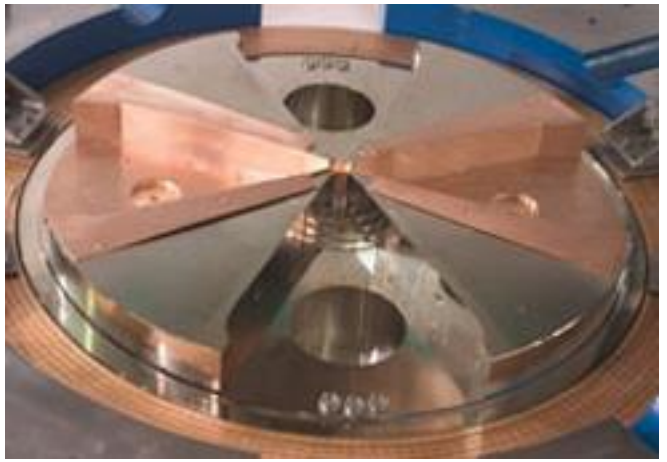

## TRIUMF will transition into ARIEL:

- Multi-user, multi-disciplinary RIB Facility
- Intense, clean RIB beams for ISAC experiments:
  - New 35 MeV superconducting electron linac
  - New 100 kW electron beamline and target station
  - New 50 kW proton beamline and target station

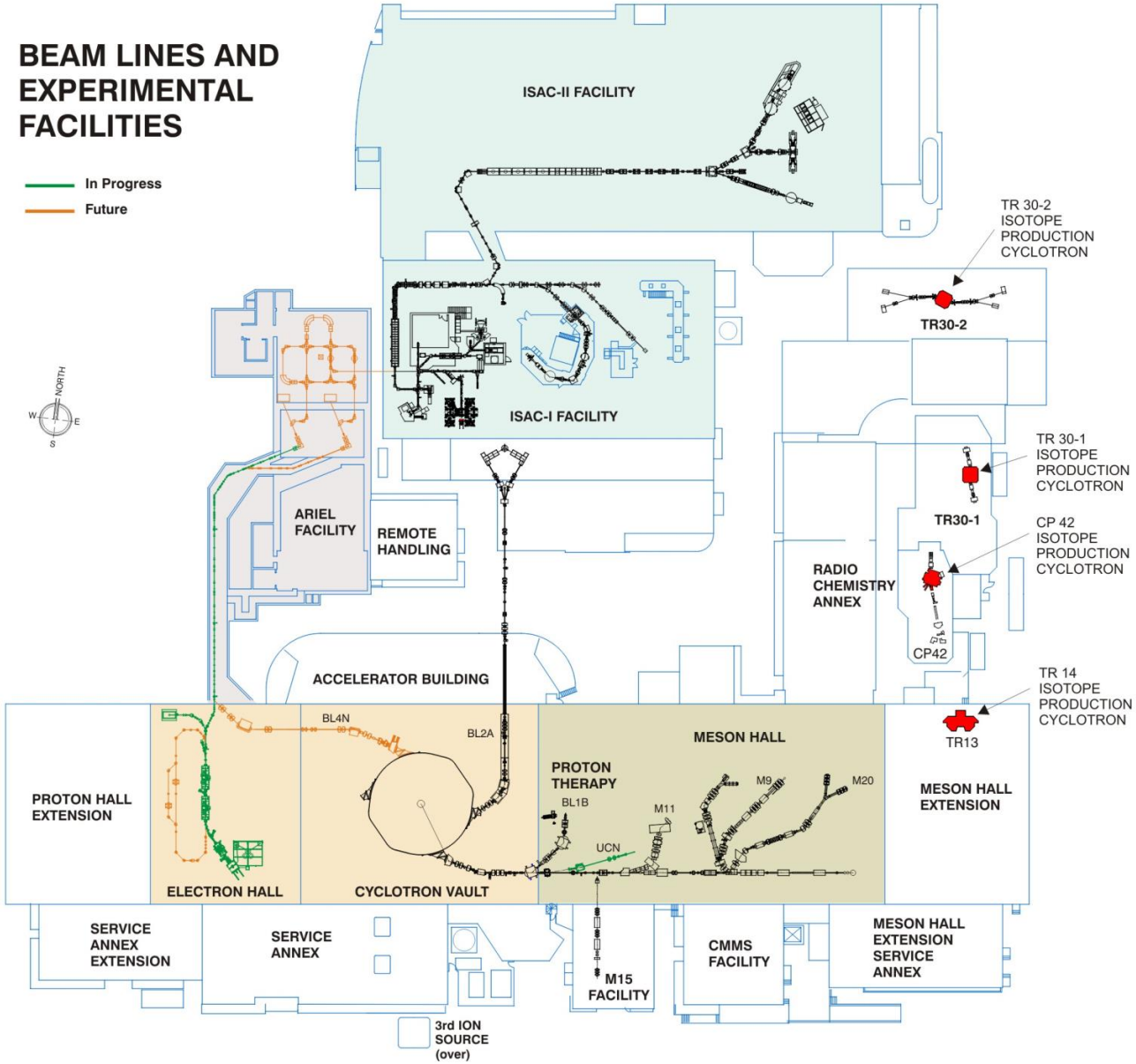
TRIUMF currently uses its TR-13 cyclotron to deliver high-intensity 13-MeV $H^-$ ion beams for PET radioisotope production.

In addition to the common $^{18}F$ and $^{11}C$ isotopes, TRIUMF also produces $^{68}Ga$, $^{64}Cu$, $^{89}Zr$, $^{44}Sc$, $^{86}Y$, $^{119}Sb$, with capabilities to produce many others

Moving forward, TRIUMF is doing the construction of a new facility – the Institute for Advanced Medical Isotopes – that will be centered around a new TR-24 medical cyclotron. This new facility will greatly expand TRIUMF capabilities in the life sciences.



# Production, preparation and post acceleration of rare isotope beams

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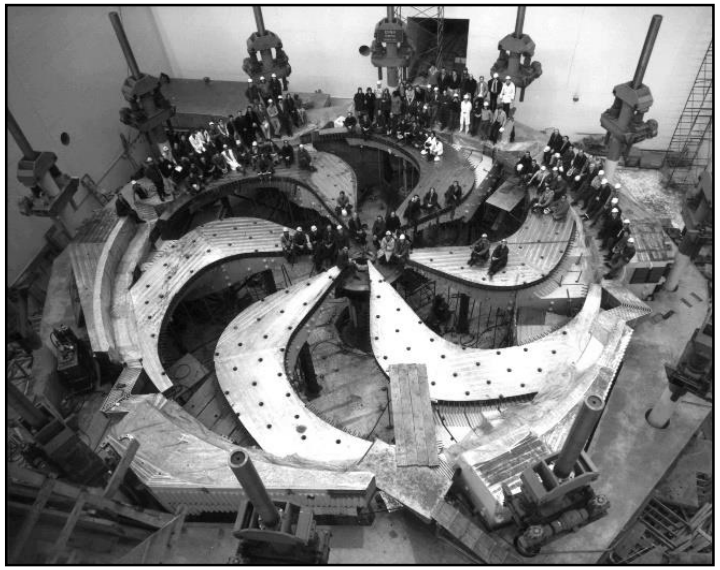
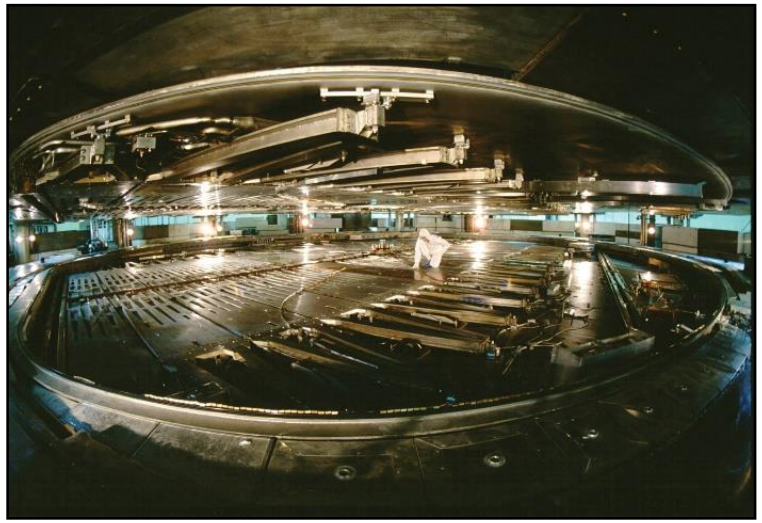
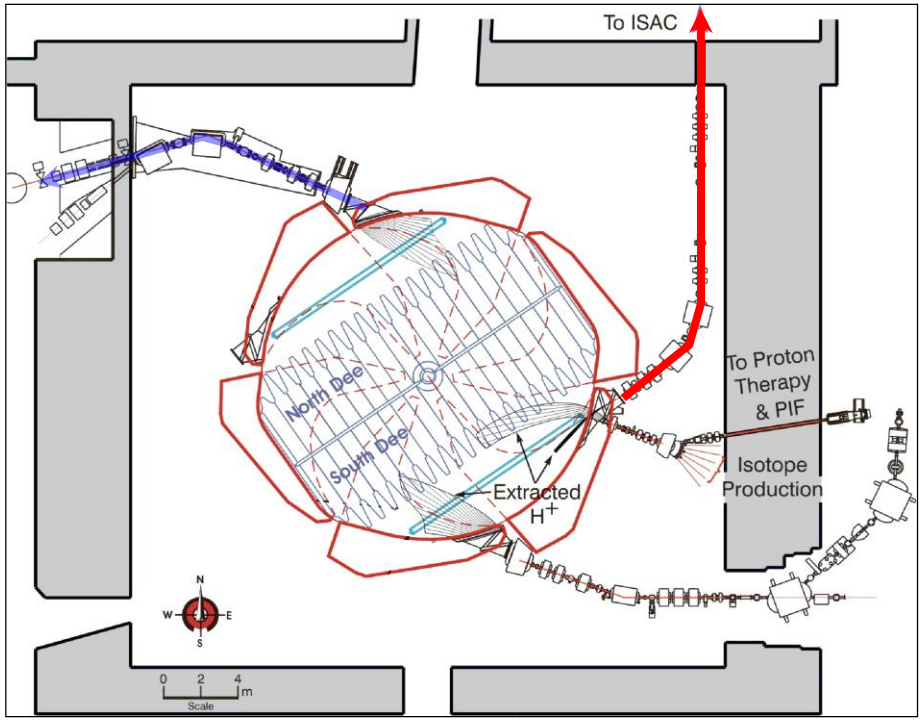
# The 520 MeV $H^-$-cyclotron





- $H^-$ cyclotron as proton driver (multiple extraction at different energies) for RIB production
- Proton at 500 MeV up to 100 μA (50 kW)
- Two production lines:
  - ISAC BL2A existing
  - ARIEL-II BL4N expected 2023




Largest Cyclotron in the world:
D = 18 m

Magnet weight
4000 t

Coil current:
18500 A



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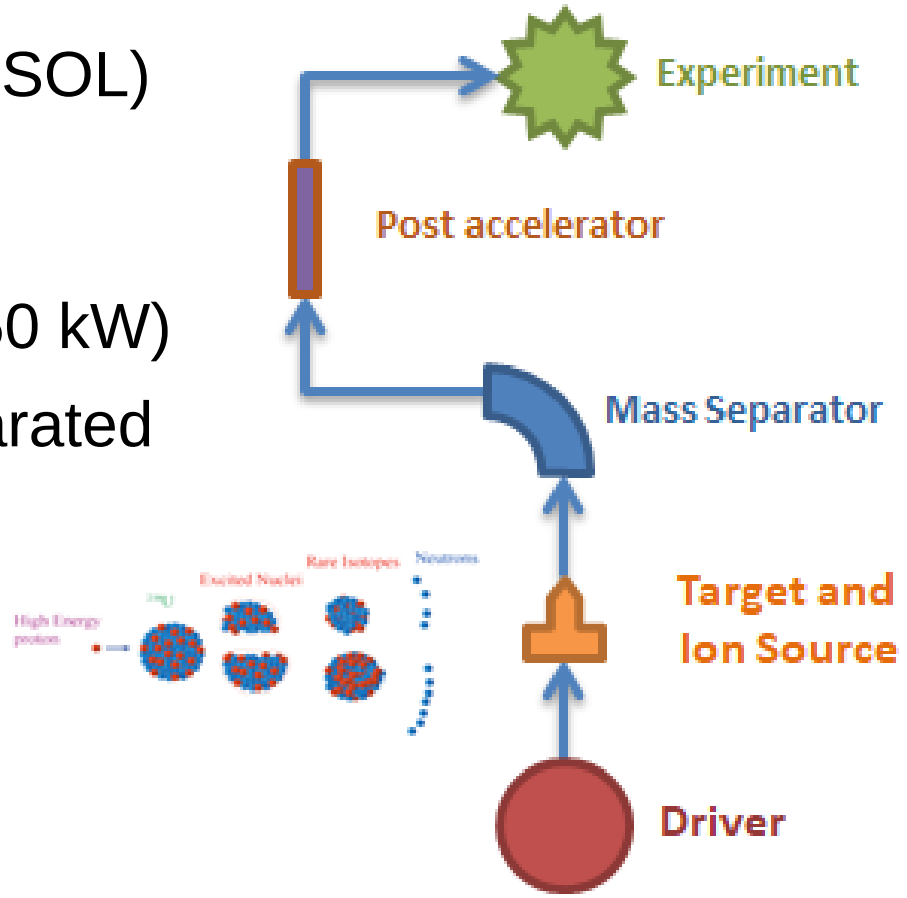
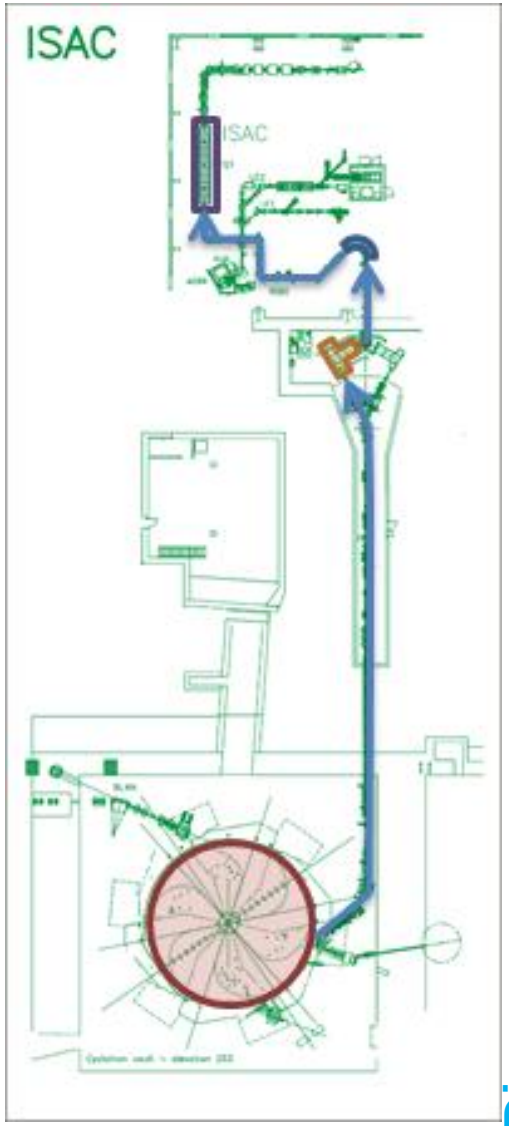
# ISAC at TRIUMF

## Isotope Separator and Accelerator facility (ISAC)

- Isotope Separation On Line (ISOL) facility for rare isotope beam (RIB) production
- Highest power driver beam (50 kW)
- Extracted ions are mass separated and either post-accelerated or delivered to low energy experiments directly.

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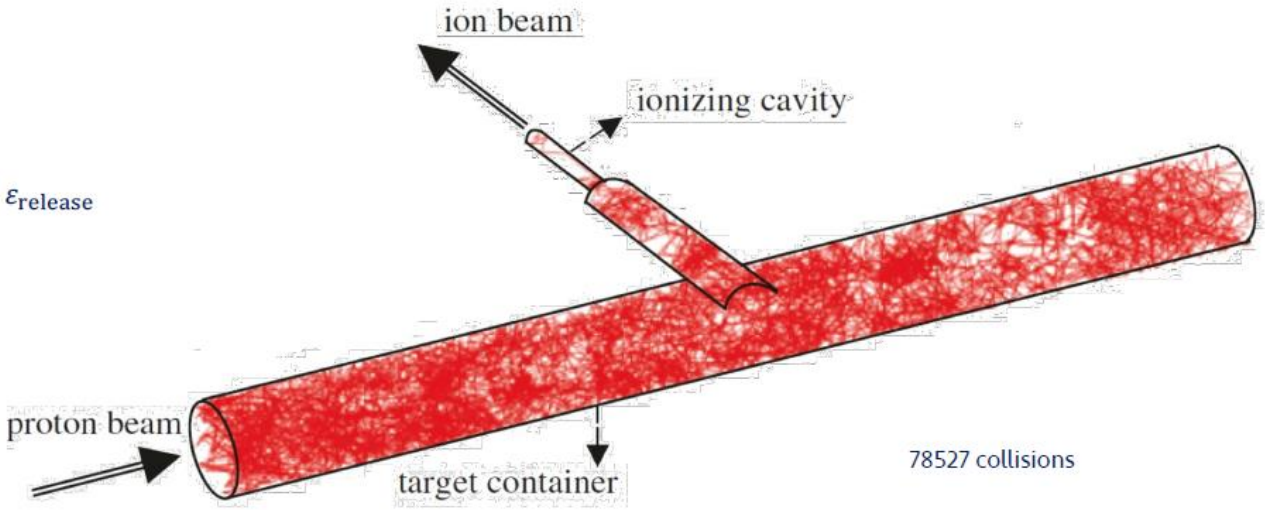
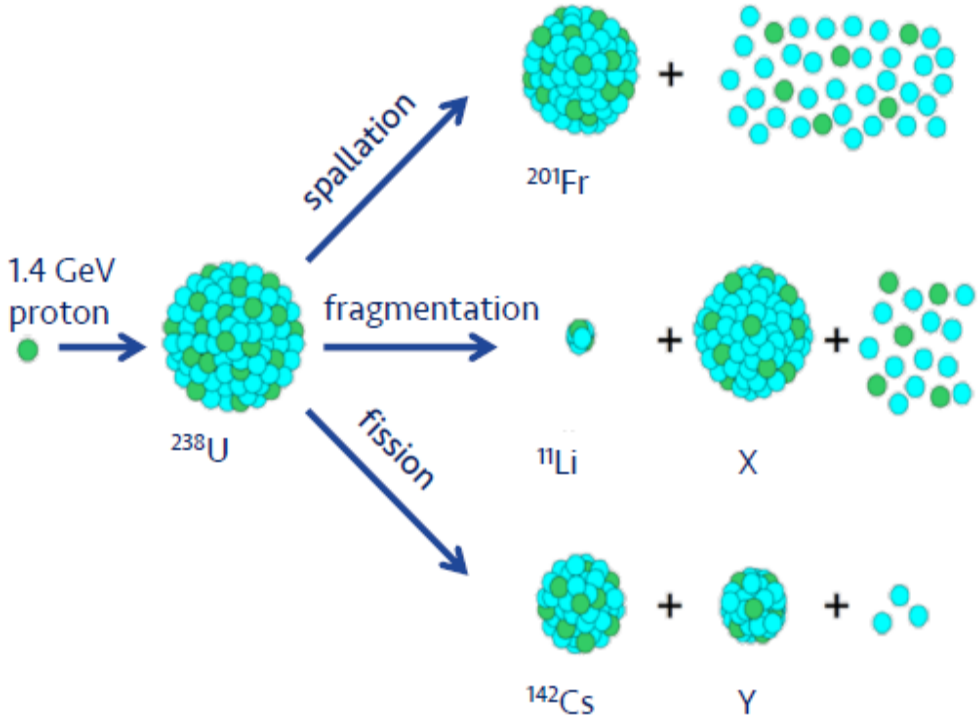
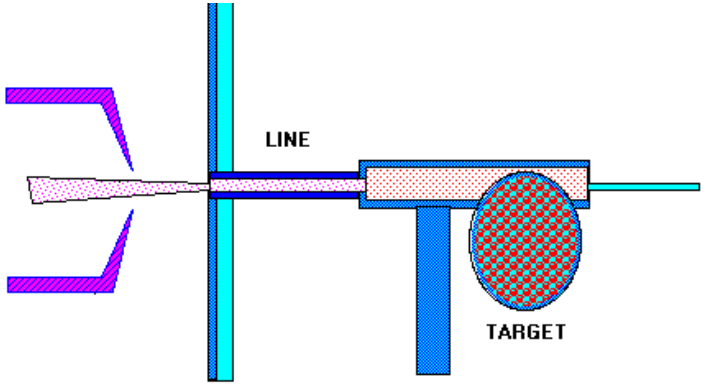
# Target ion sources

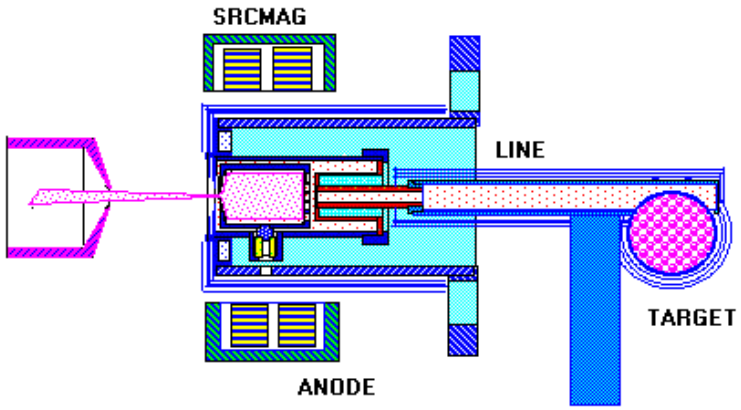



Surface ionisation




Plasma ion source

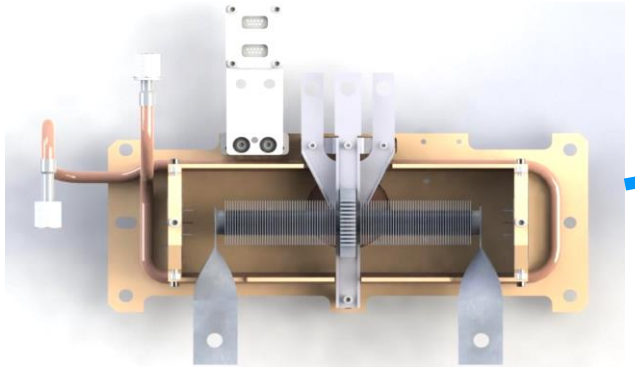


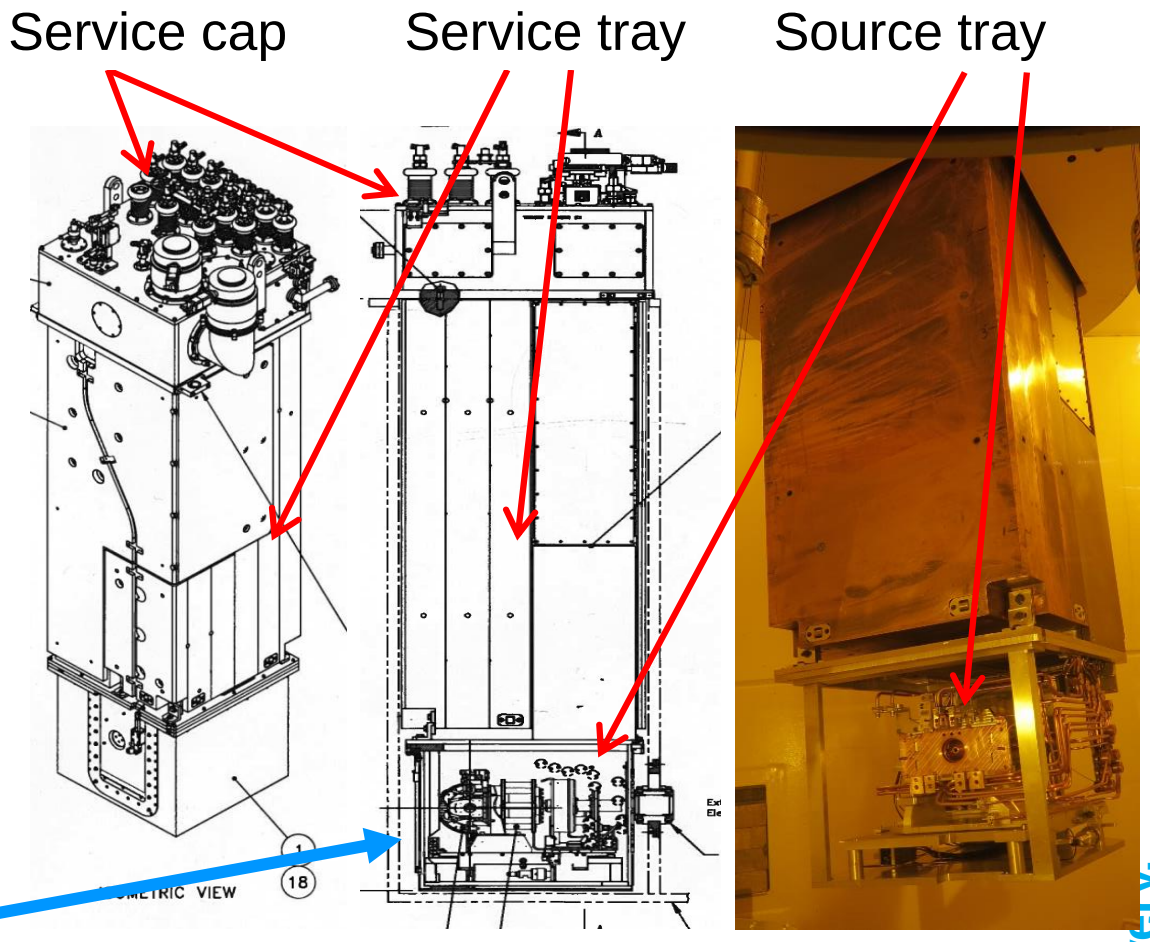

- Target and ion sources units, common is surface ionisation, laser ionisation and plasma ionisation.
- Targets are heated up to high temperatures to support diffusion of isotopes into the ionisation region.

# ISAC Target Modules (TM)

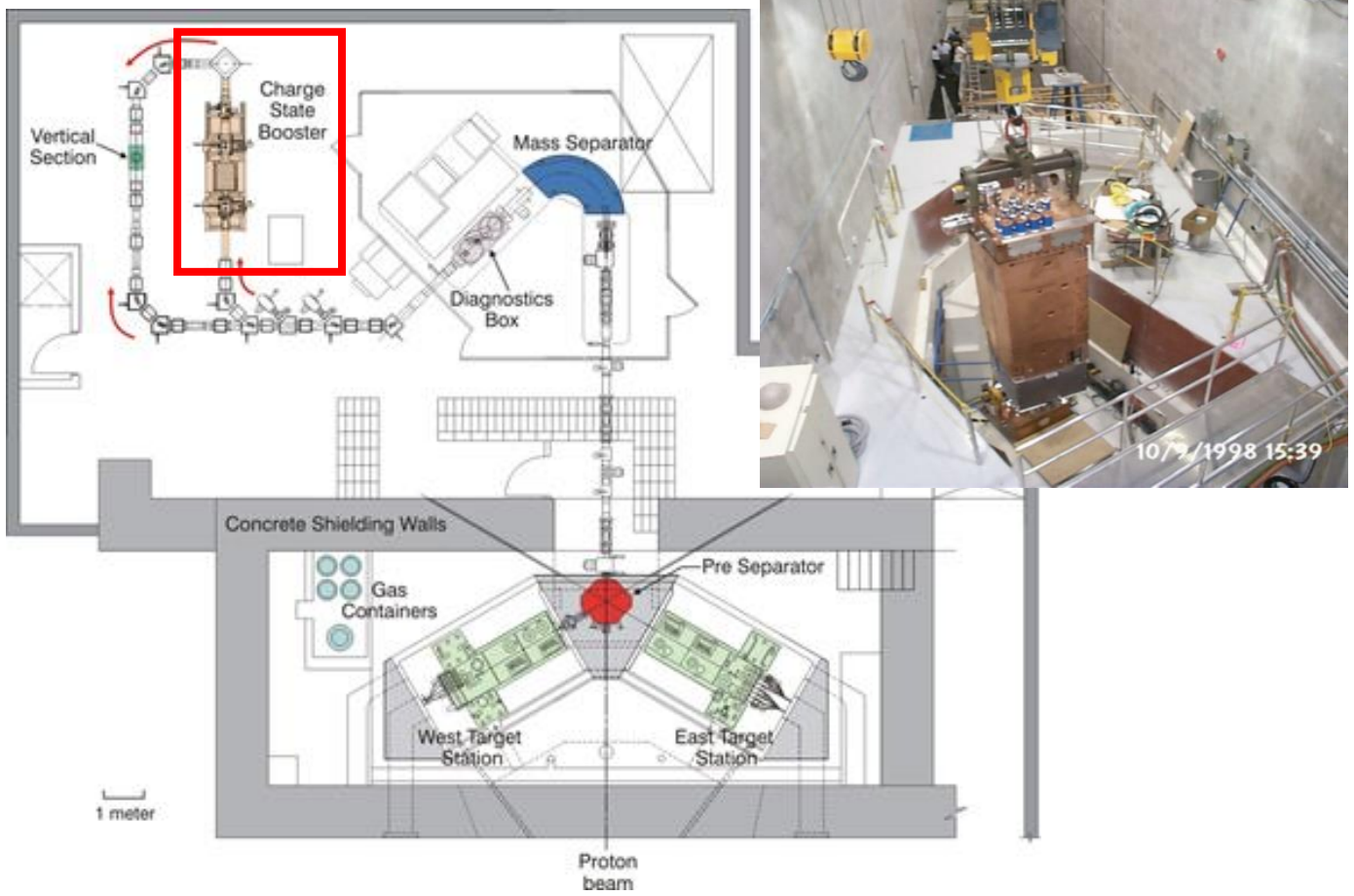
TRIUMF employs so-called Target Modules (TMs).

- Common are the different section of the module, the service cap, service tray and sources tray.
- TM is moved from the target station to the hot cell for target exchange
- Target/Ion sources unit mounted on the sources tray





# ISAC target stations and mass separator





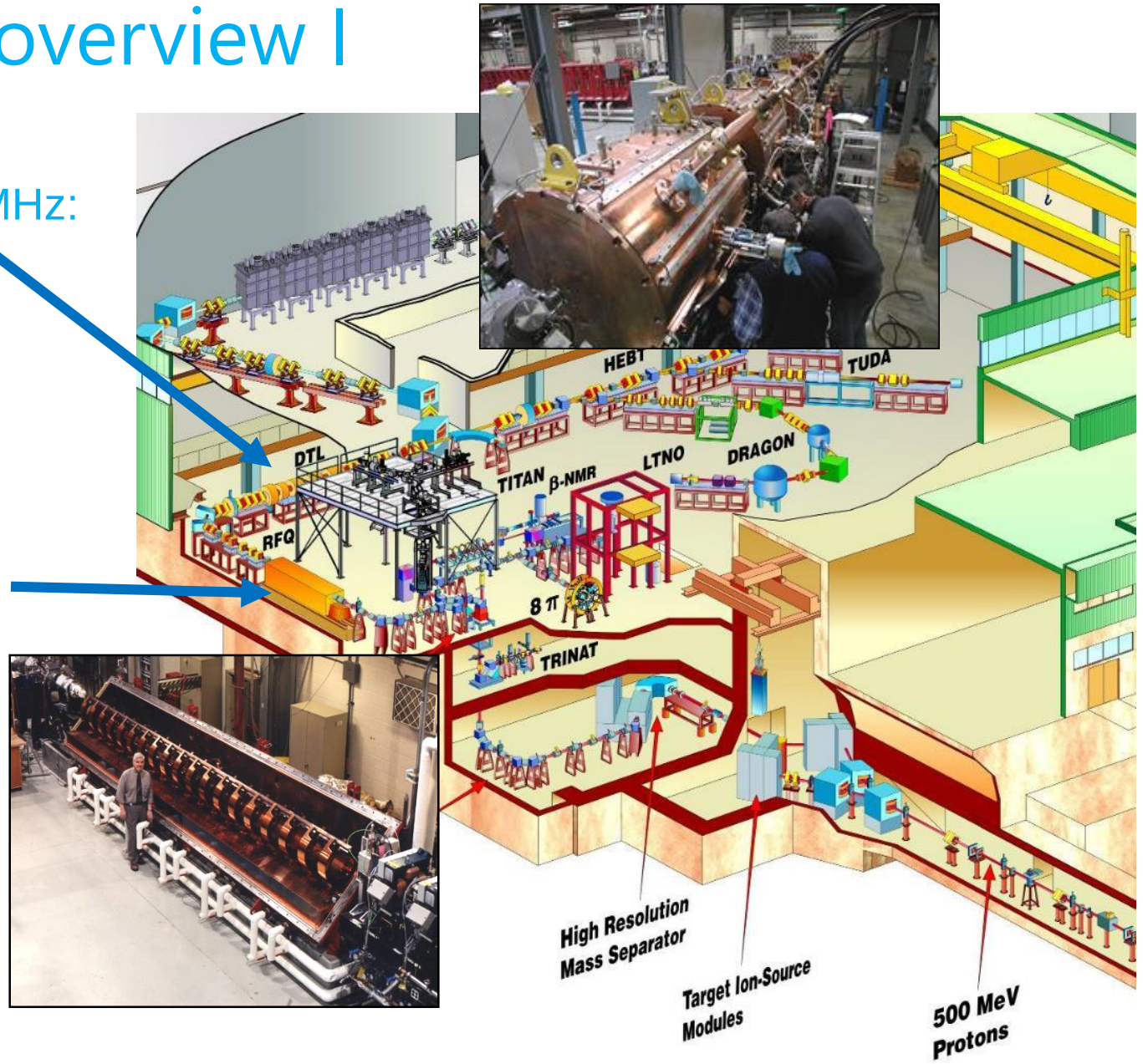


- Two underground target stations with extraction voltage up to 60 kV
  Target module sits in a big vacuum tank!
- Proton beam sent to one of the target stations at the time
- Common pre-separator inside the shielded area
- Mass separator on high voltage platform (typical operation resolving power  3000)
- Charge breeder (ECR type) for post acceleration

# ISAC linacs overview I

## ISAC-I:

- DTL normal conducting at 106.08 MHz:
  - Separated functions
  - Variable energy machine
  - 150 keV/u ≤ E ≤ 1.8 MeV/u
  - 2 ≤ A/q ≤ 7
- Radio Frequency Quadrupol (RFQ) normal conducting at 35.36 MHz:
  - 8m long split ring structure
  - 153 keV/u, 3≤A/q≤30



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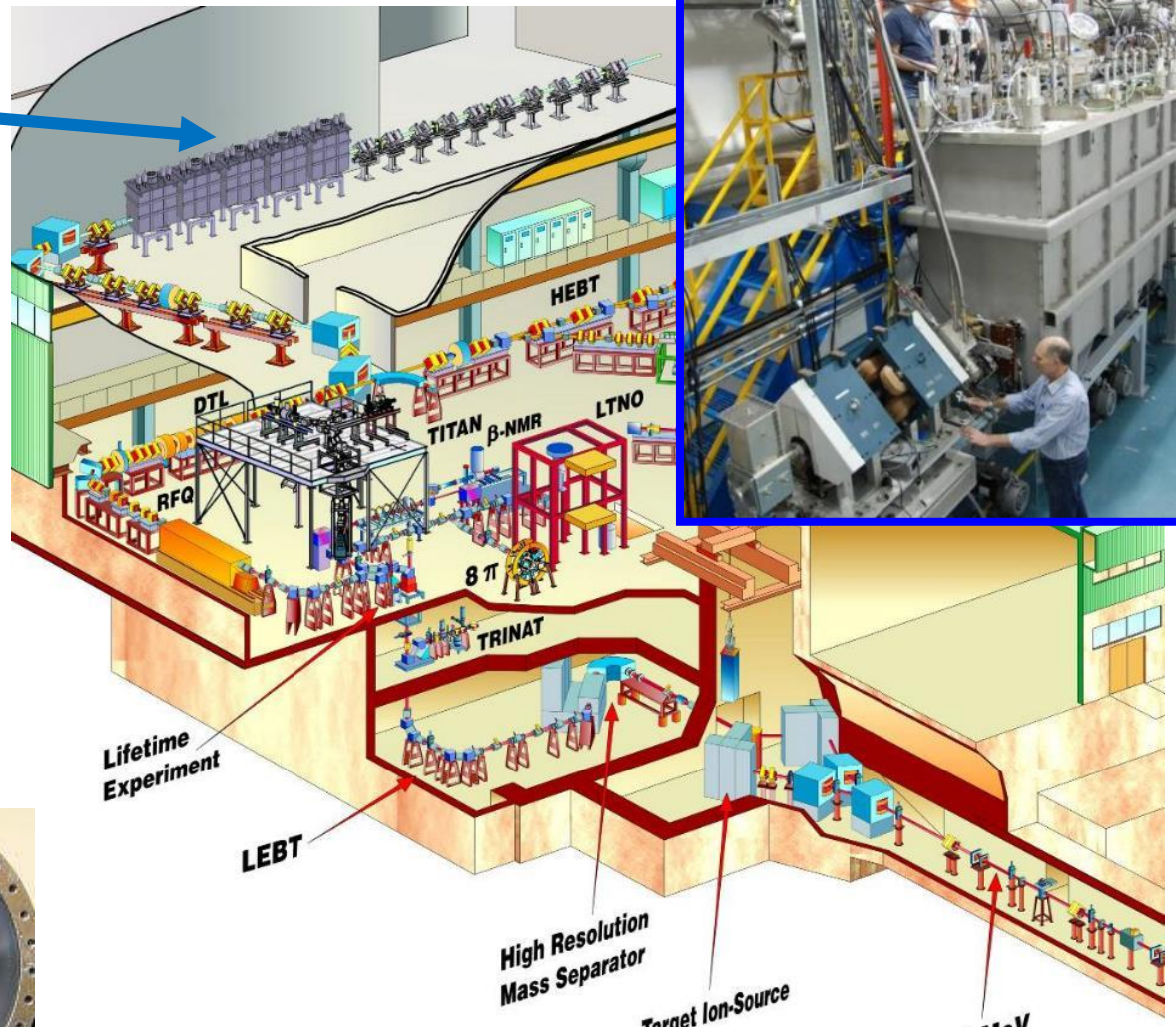
# ISAC linacs overview II

## ISAC-II: Superconducting linac at 106.08 MHz:

- SC-Linac using quarter wave resonators (QWR) with $\beta$ = 0.057, 0.071, 0.11
- Max. energy range
  6.5 MeV/u (A/q=6)
  16.5 MeV/u (A/q=2)
- Cryomodules with 4, 6 and 8 QWR and one SC solenoid 9T



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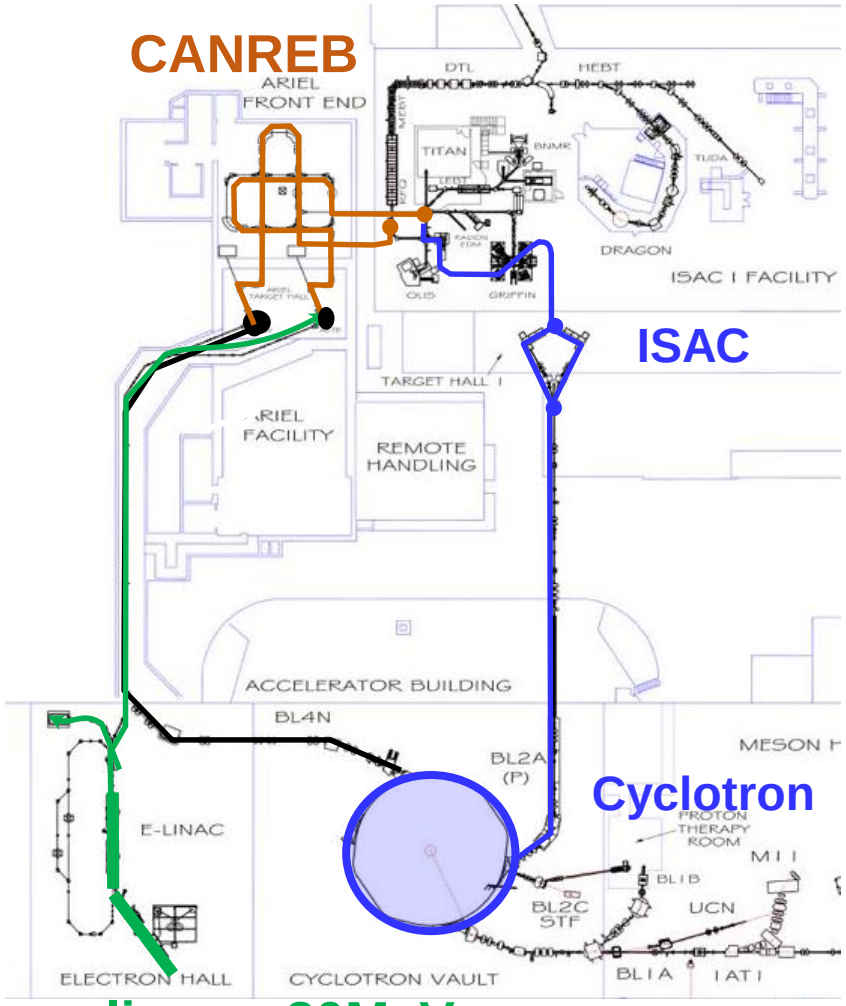
# Adding new capabilities – ARIEL

# How do we add new capabilities?

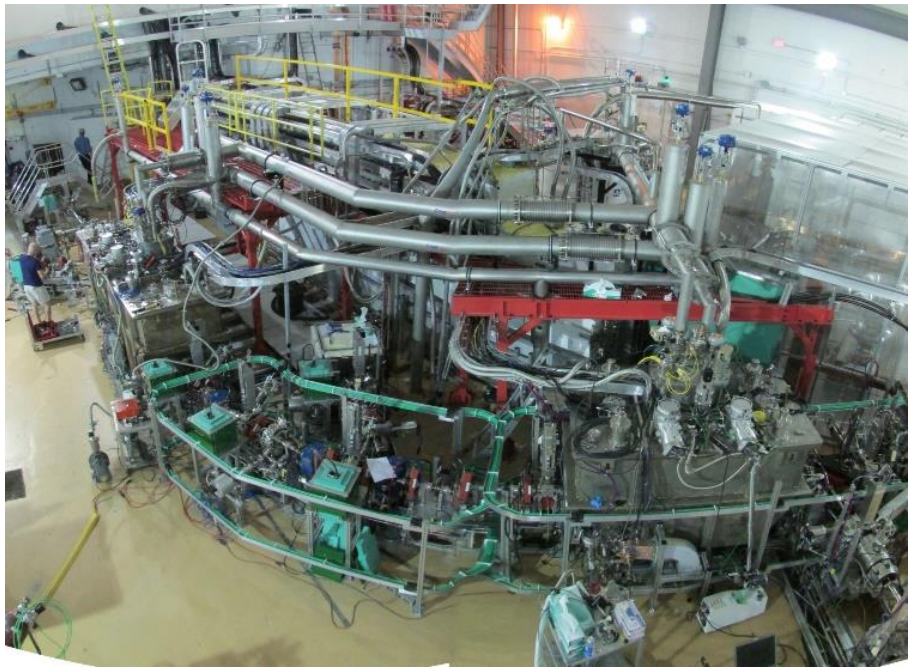


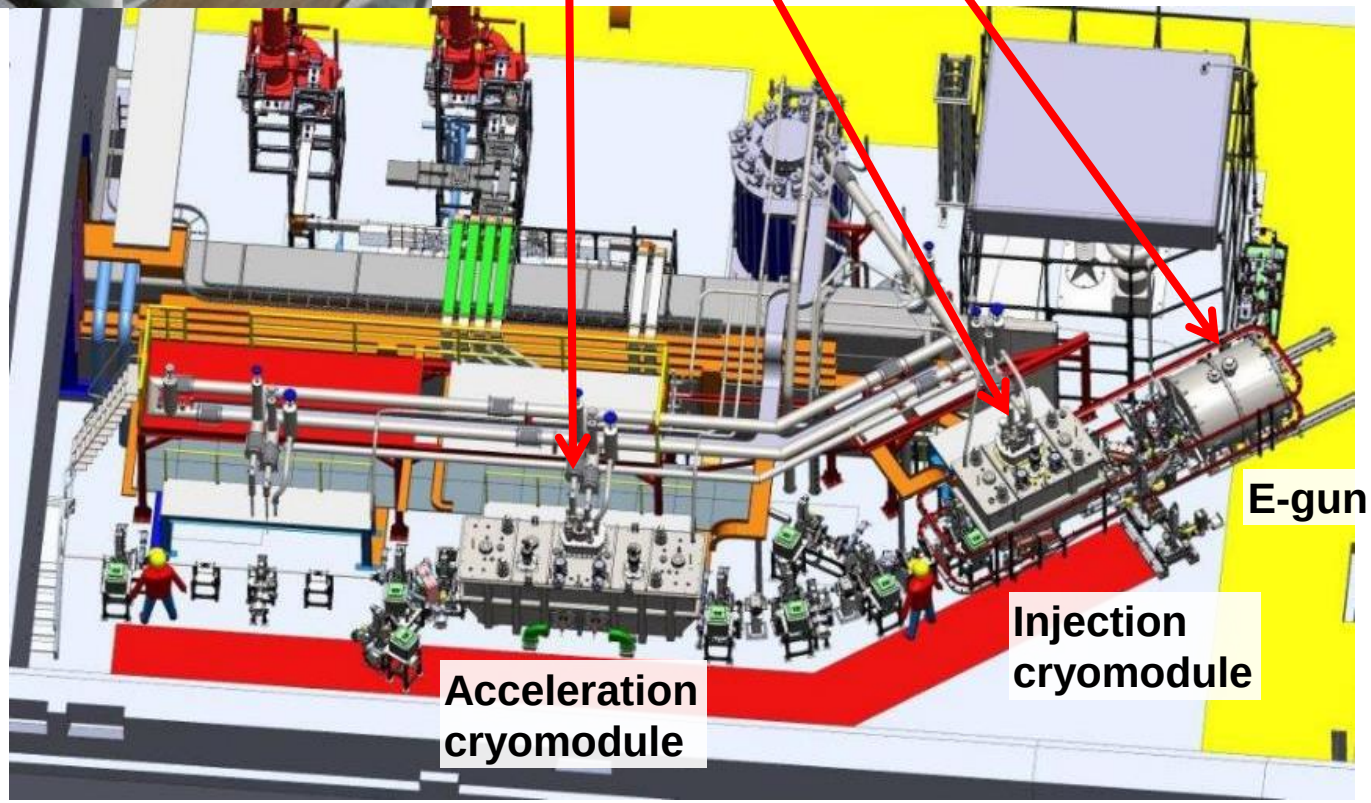

- A 30 MeV superconducting electron linac
  300 kW beam power cw, highest power in this energy range
- Two new high power rare isotope target stations
  - New 100 kW convertor target station
  - 50 kW proton target station (with symbiotic target for medical isotope production)
- Unique beam preparation and transport system (CANadian Rare isotope facility with Electron Beam ion source - CANREB)
  - High resolution separator
  - Beam preparation with RFQ and EBIS
- ARIEL will triple ISAC's present rare isotope capabilities.

# ARIEL – superconducting electron-Linac

- SRF – Cavity from TESLA collaboration, modified for cw and high beam loading operations
- Two cavities are driven by a single klystron – challenge for the low level RF-control

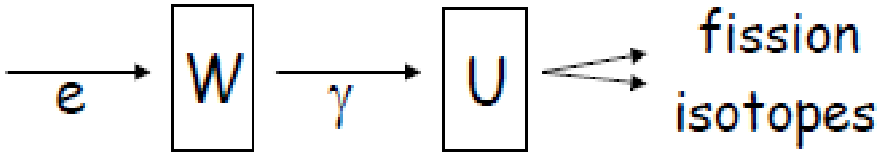
- E-gun delivers max. 10 mA at 300 keV beam
- The injector cryomodule accelerates to 5-10 MeV
- The accelerator cryomodule is equipped with two cavities and reaches max. 30 MeV.

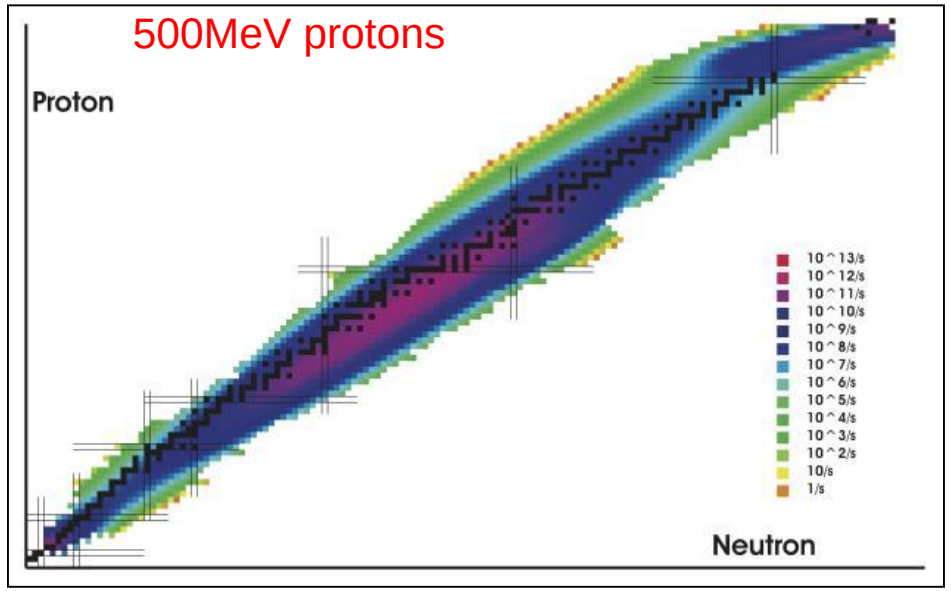


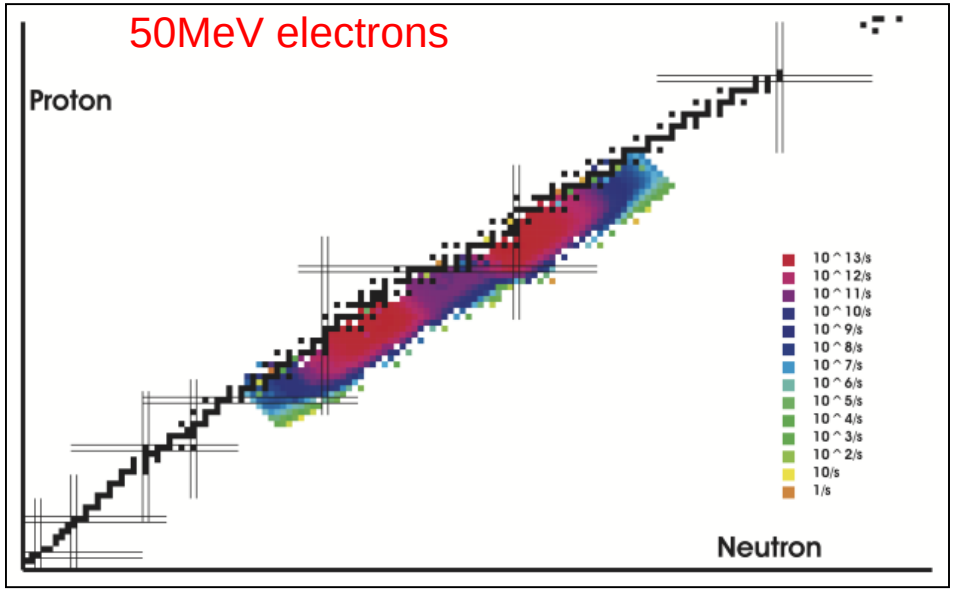


# Production of RIBs with electron beams

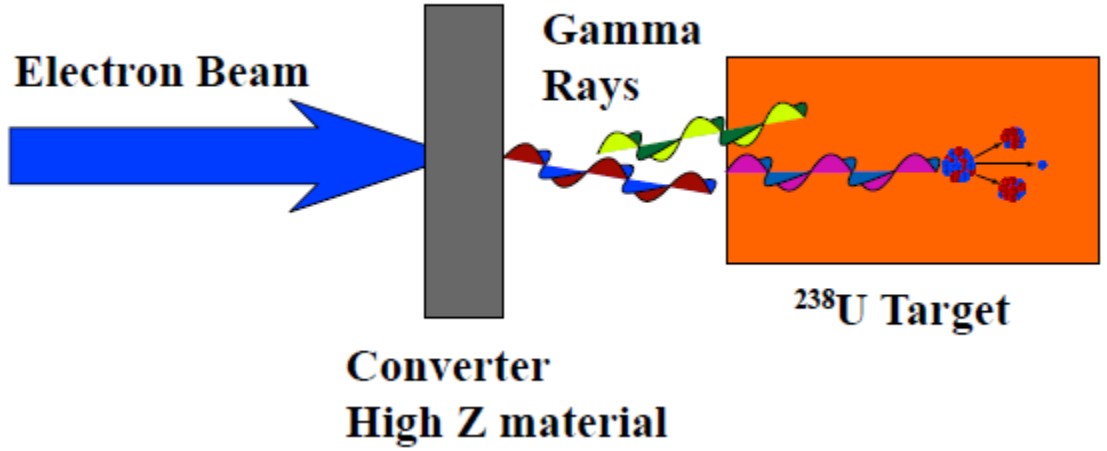
10 mA of 30-50 MeV electrons from the superconducting e-linac (via the photo fission process) yielding a range of isotopes not available from proton reactions and higher beam purity.

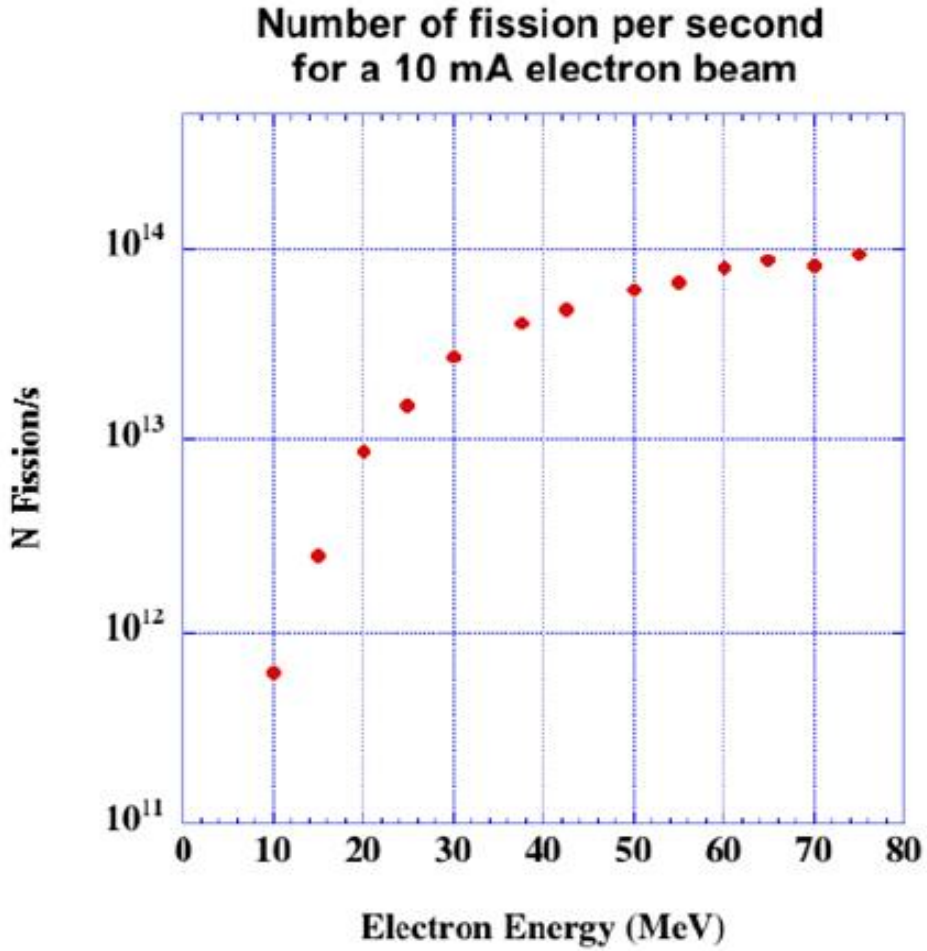


# Required electron beam energy




- Converter made of high Z material, Au, W, Ta. Thickness ~ 3.5 mm.
- Electrons MUST be stopped in low Z material Al.

- The number of fissions per second saturates beyond 35 - 40 MeV beam energy.

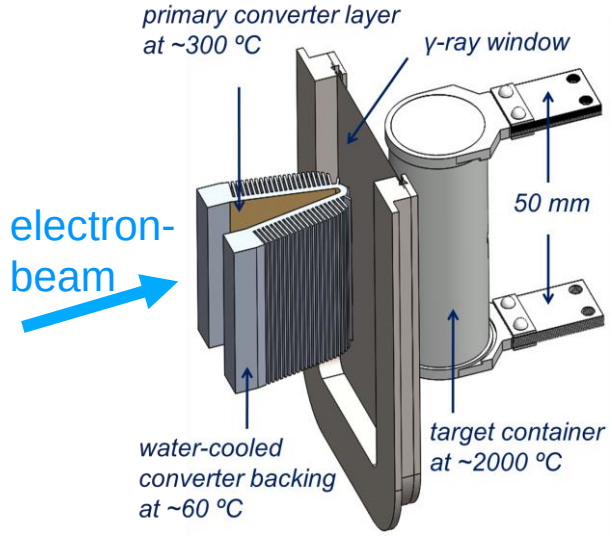
# ARIEL high power target stations



## First ever high power electron-gamma convertor RIB production!

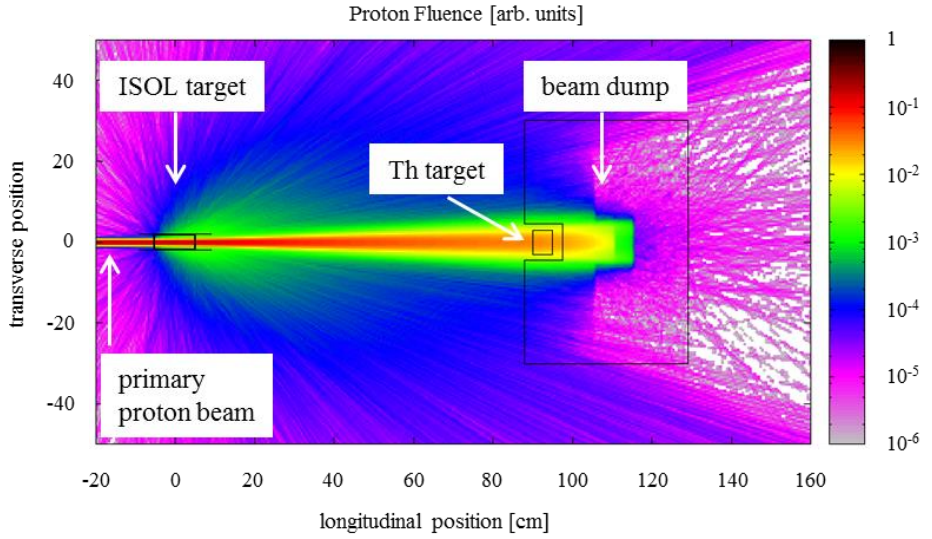
- Electron-to-gamma converter
  → direct beam power deposition would melt the target
- Converter target material tests with Ta and Au performed and feasibility demonstrated with Ta.

A high risk of the ARIEL project has been retired!



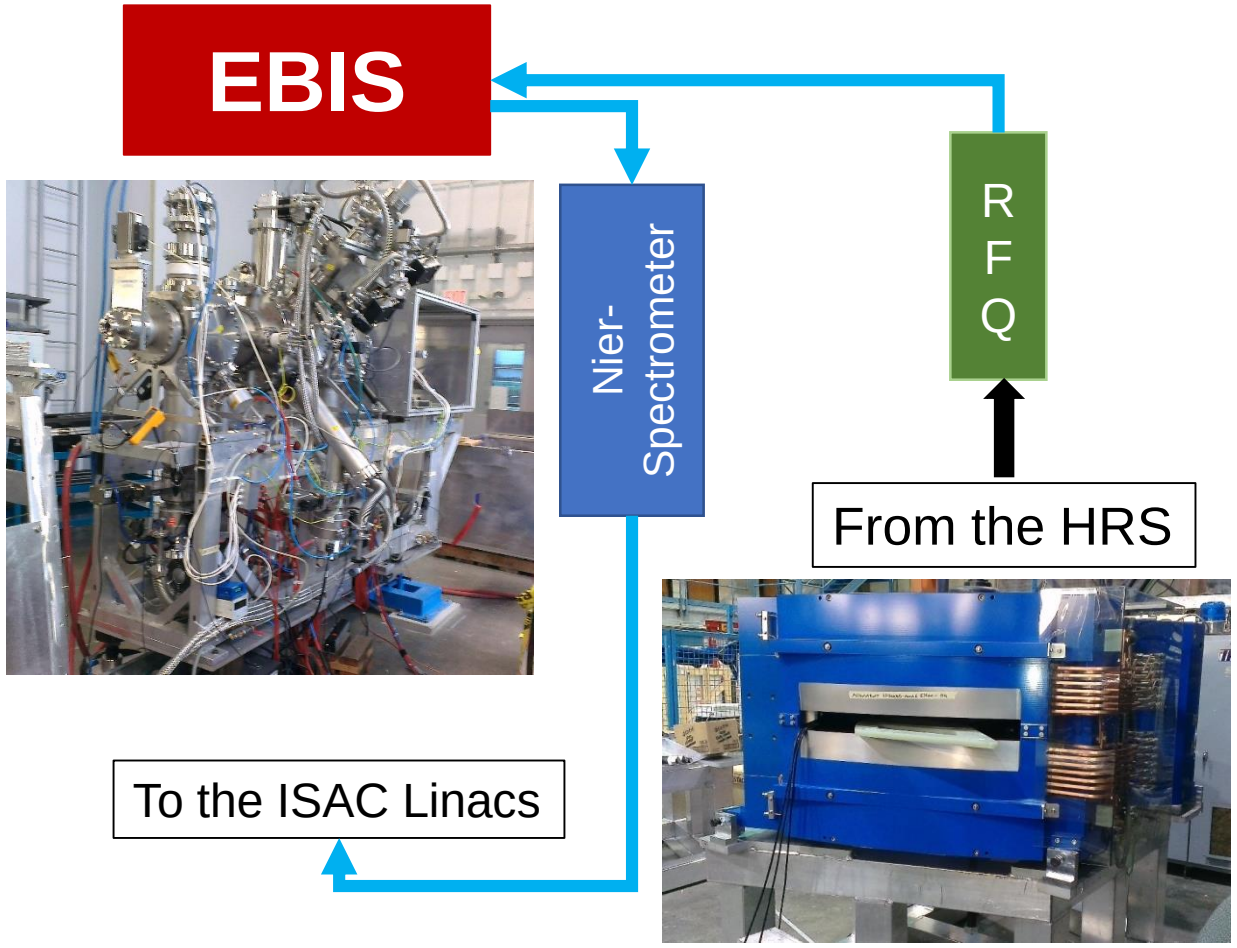

## Unique Proton target station

- Utilizing Neutron Converter Targets
- Comprising a symbiotic target for medical isotope production in the beam dump.



# CANadian Rare isotope facility with Electron Beam ion source

L. Graham




CANREB (funded CFI project, SMU) is the unique beam preparation system for high quality ARIEL beams:

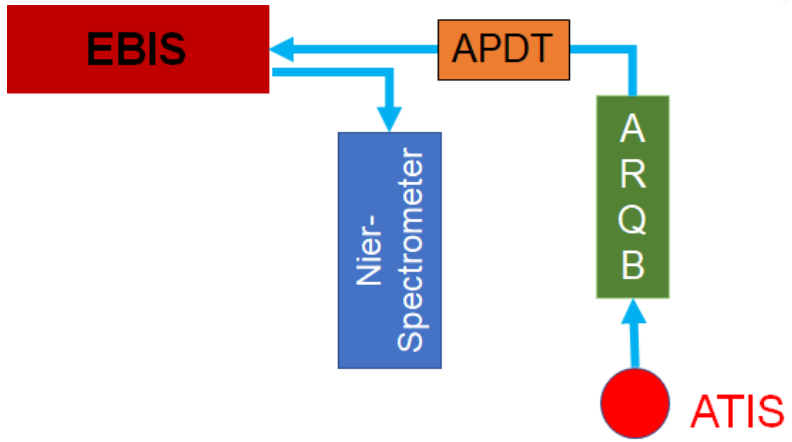
- High Resolution mass Separator (HRS) M/ΔM = 20,000 for RIB beams
- Electron beam ion source (EBIS) charge state breeder.
  Shortest breeding time (10 ms) and highest rep rate (100 Hz)!

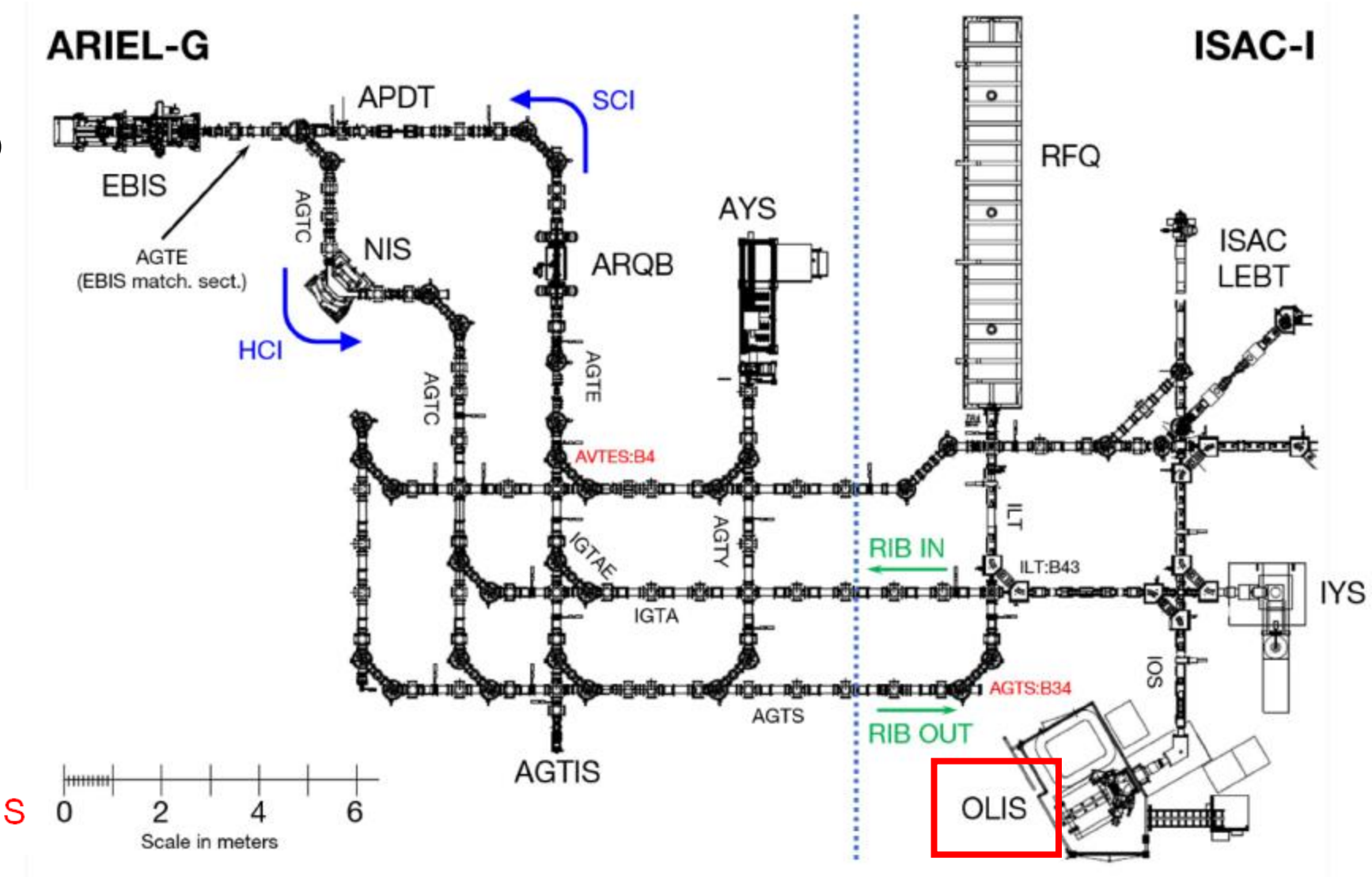
Will enable high mass acceleration and less background!

# ARIEL: Phase 3 / CANREB status



- Ground floor installation completed, beam being tuned from the ISAC offline ion source (OLIS) to CANREB
- Beam commissioning of RFQ and PDT continued and provided a better under-standing of the beam tunes.
- EBIS beam injection in early June, means now!



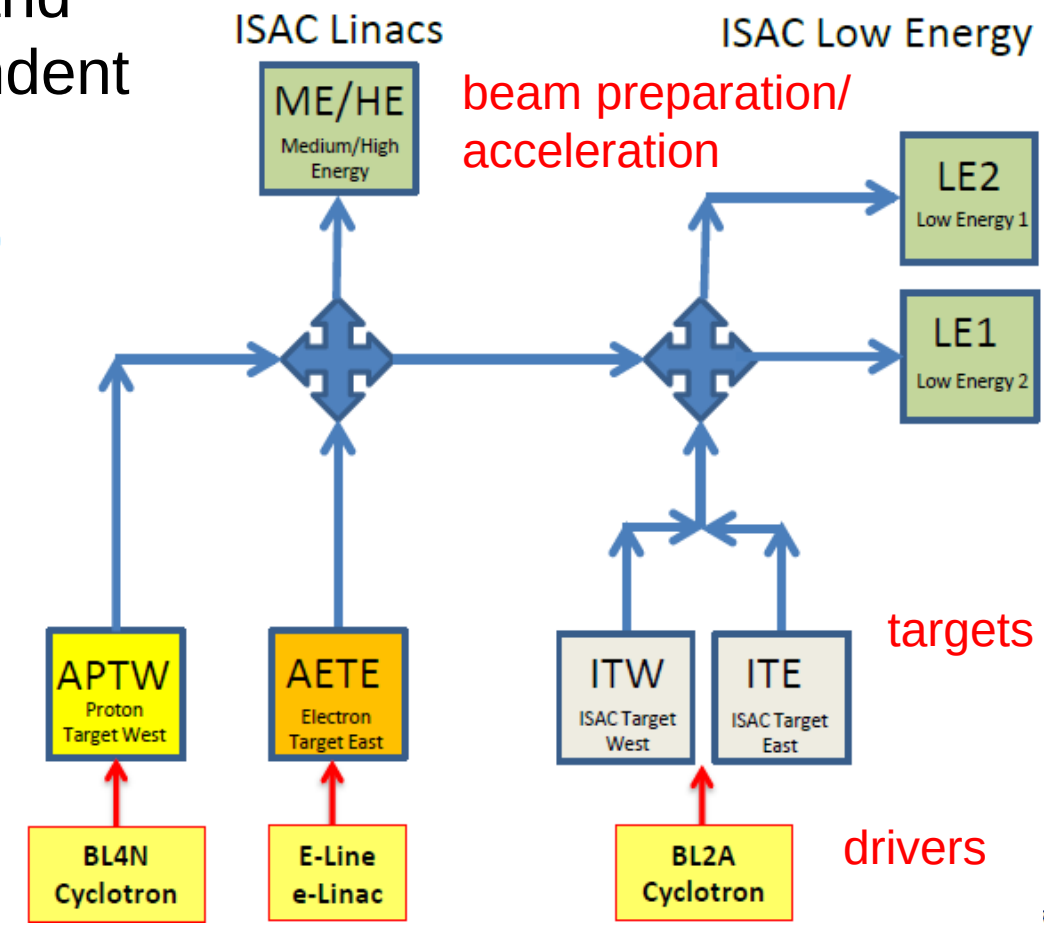
# To transition into the ARIEL operation

Three target areas:

One in ISAC with ITW/ITE as a single source and two in ARIEL with APTW and AETE as independent sources.

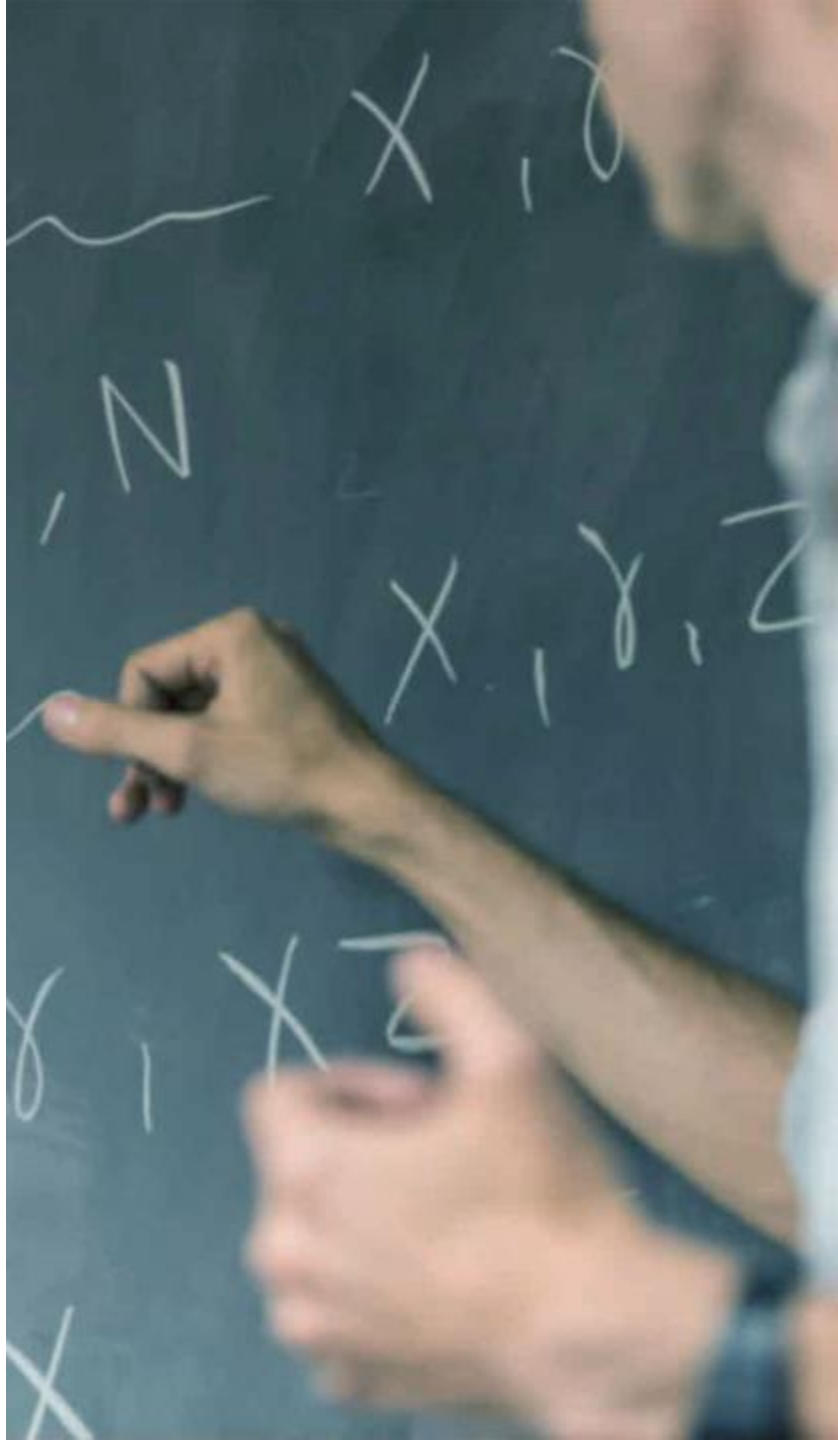
- `RIB Factory' is a requirement to reach 9000 hours of RIB beam delivery.
  → a standard weekly rhythm maximizes efficiency while minimizing resources.
- Increased target production is required.

The ARIEL reliability metric is
> 90% for drivers and > 80%/75% (LE/HE) for RIBS
> 94% target reliability



# The Accelerator research program

- 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.



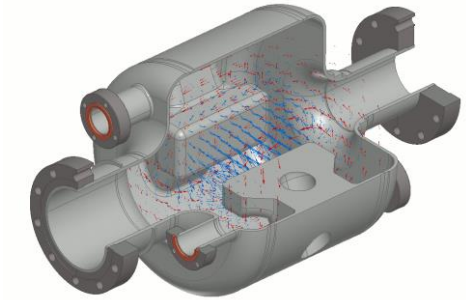
# TRIUMF Accelerator division

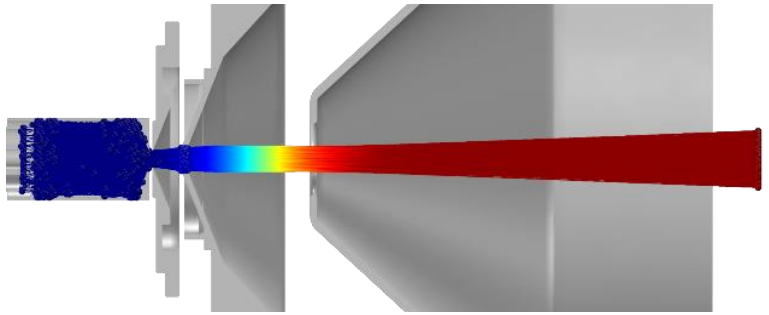
- 140 staff members, 4 Post Doctoral Fellows (PDF), 14 graduate students Supervision of about 20 Coop students / year
- Among the staff there are 14 faculty members of which 9 have an adjunct professor status at one of TRIUMF's member universities.
- Accelerator division at TRIUMF provides a world-class platform in accelerator sciences.

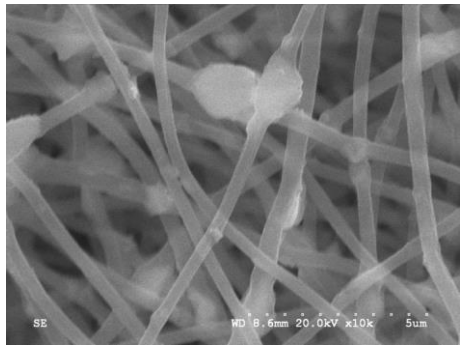
PDF Ramona Leewe and staff member Bhalwinder Waraich
in discussion with minister Kirsty Duncan at the HL-LHC announcement

# The Accelerator science research program

- **Beam physics and instrumentation**
  - Intense beams, modeling - space charge effects, beam-beam effects (HL-LHC)
  - Particle sources, beam diagnostics (AWAKE)
- **Superconducting RF and RF**
  - SRF cavity development – RF-separator
    new balloon type single spoke resonator
  - New processes and material investigation with μSR and βNMR.
- **Target Material and Target ion sources**
  - Target materials and convertor technology
  - Optimization of beam extraction
  - Laser ionization schemes
- **Engineering Research and Development**
  - Beam line maintenance in high radiation fields
  - Target station technology – first ever online high power target transfer
  - High power target handling
  - Cryogenics-, vacuum-, RF-technology







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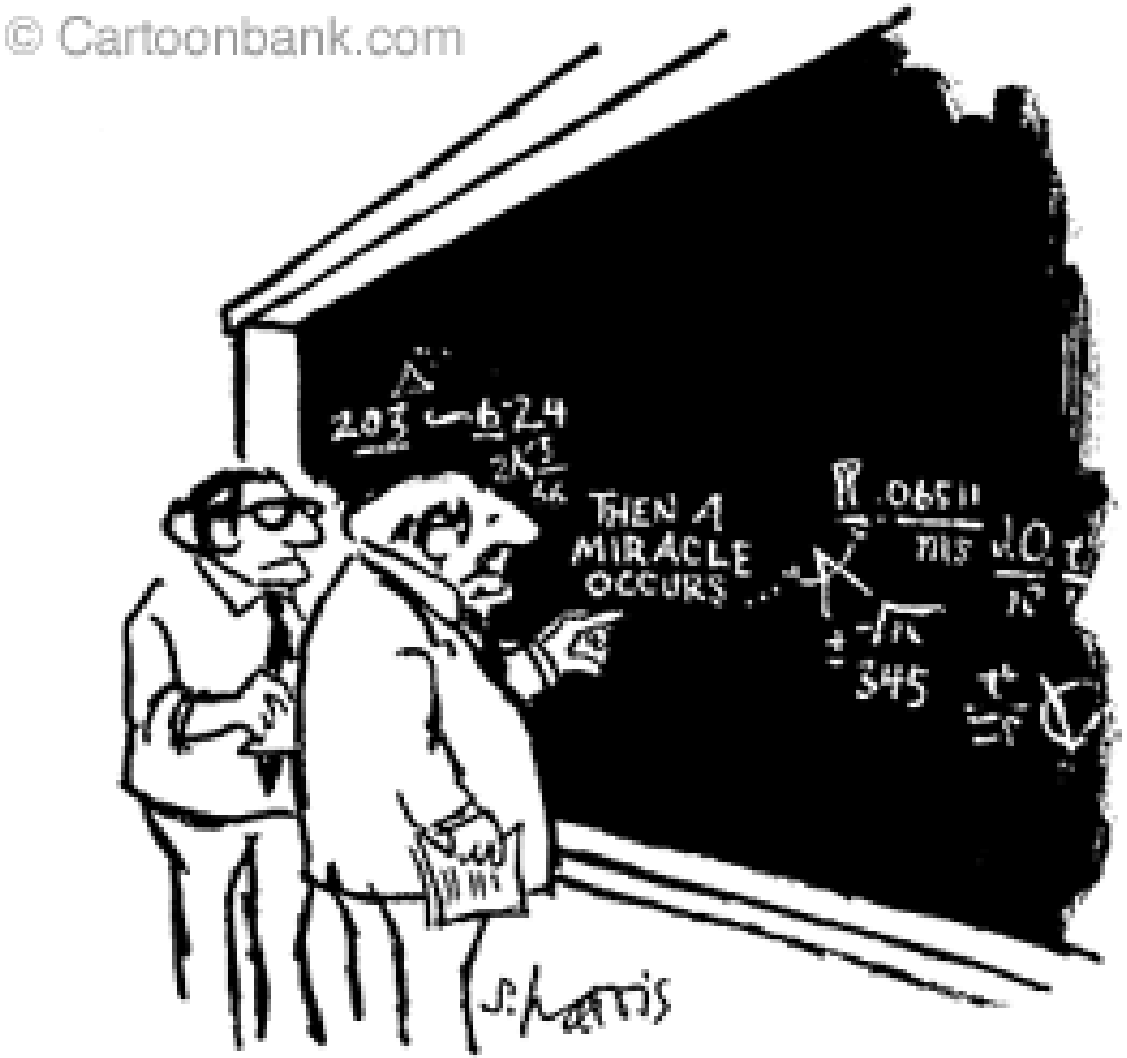
# Welcome to the North American Charge Breeder workshop – NACB2019

- ECR and EBIS charge state breeder developments
- Charge breeding of stable and radioactive isotopes: review of recent work
- Beam transport, diagnostics, and simulations
- Machine operation and experience with Rare Isotope Beams
- Sub-systems of ECR and EBIS/T devices

TRIUMF

Charge state breeders are no miracles, but require a profound know-how and new technologies!



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# Thank you
# Merci

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