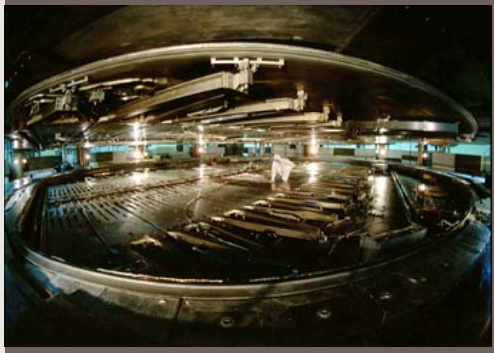
TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

TRIUMF Accelerators and the ARIEL Project



Lia Merminga | Accelerator Division | TRIUMF

EUROPEAN SPALLATION SOURCE

ESS Accelerator Division Seminar
Lund, Sweden
July 3, 2013

Outline

- TRIUMF Accelerators
- ARIEL: The Advanced Rare IsotopE Laboratory
  - ARIEL Construction
  - ARIEL Electron Linac
  - ARIEL Completion: ARIEL Science Phases
- Accelerator Science Research & Education
- Summary

TRIUMF
Canada's National Laboratory for Particle and Nuclear Physics

TRIUMF: A National Science Laboratory

Members

University of Alberta
University of BC
Carleton University
University of Guelph
University of Manitoba
Université de Montréal
Queen's University
Simon Fraser University
University of Toronto
University of Victoria
York University

Associate Members

University of Calgary
McGill University
McMaster University
University of Northern BC
University of Regina
Saint Mary's University
University of Winnipeg

Research focus:

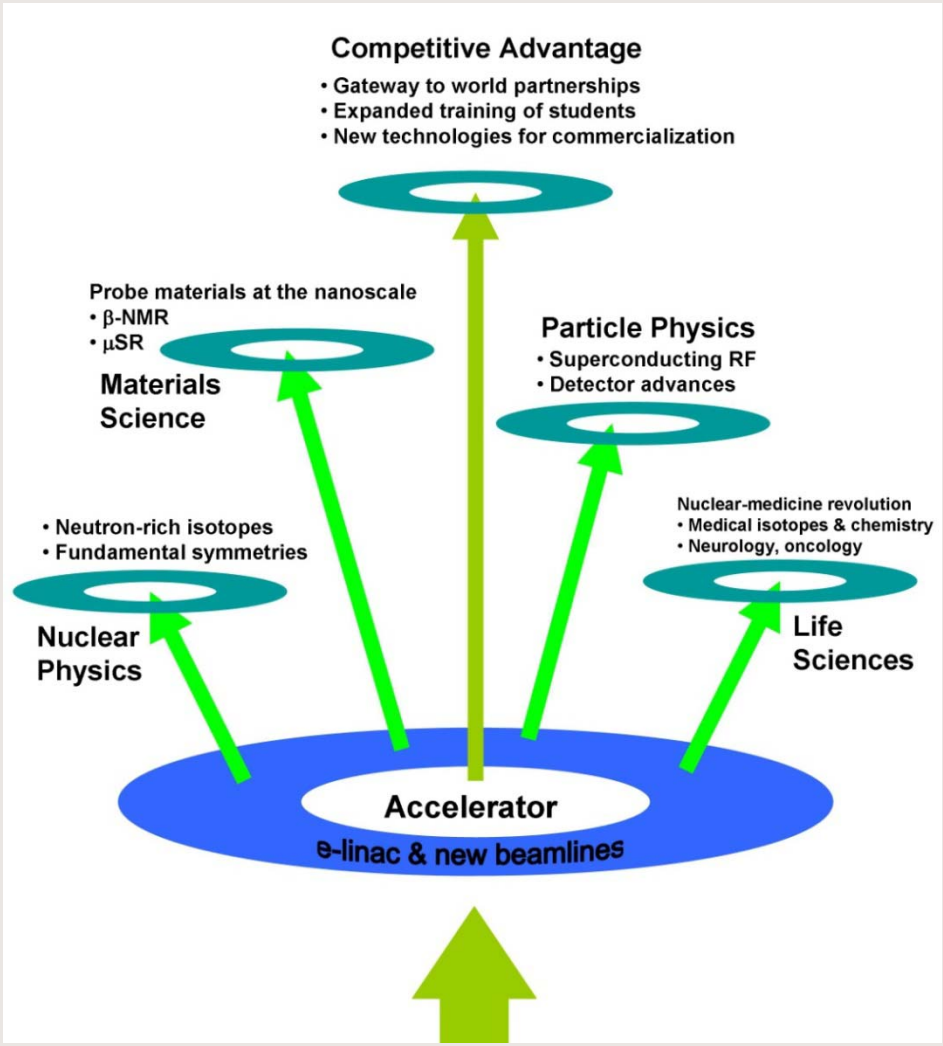
- Advancing isotopes for science & medicine
- Probing the structure & origins of matter

TRIUMF is owned & operated by a consortium of 18 universities

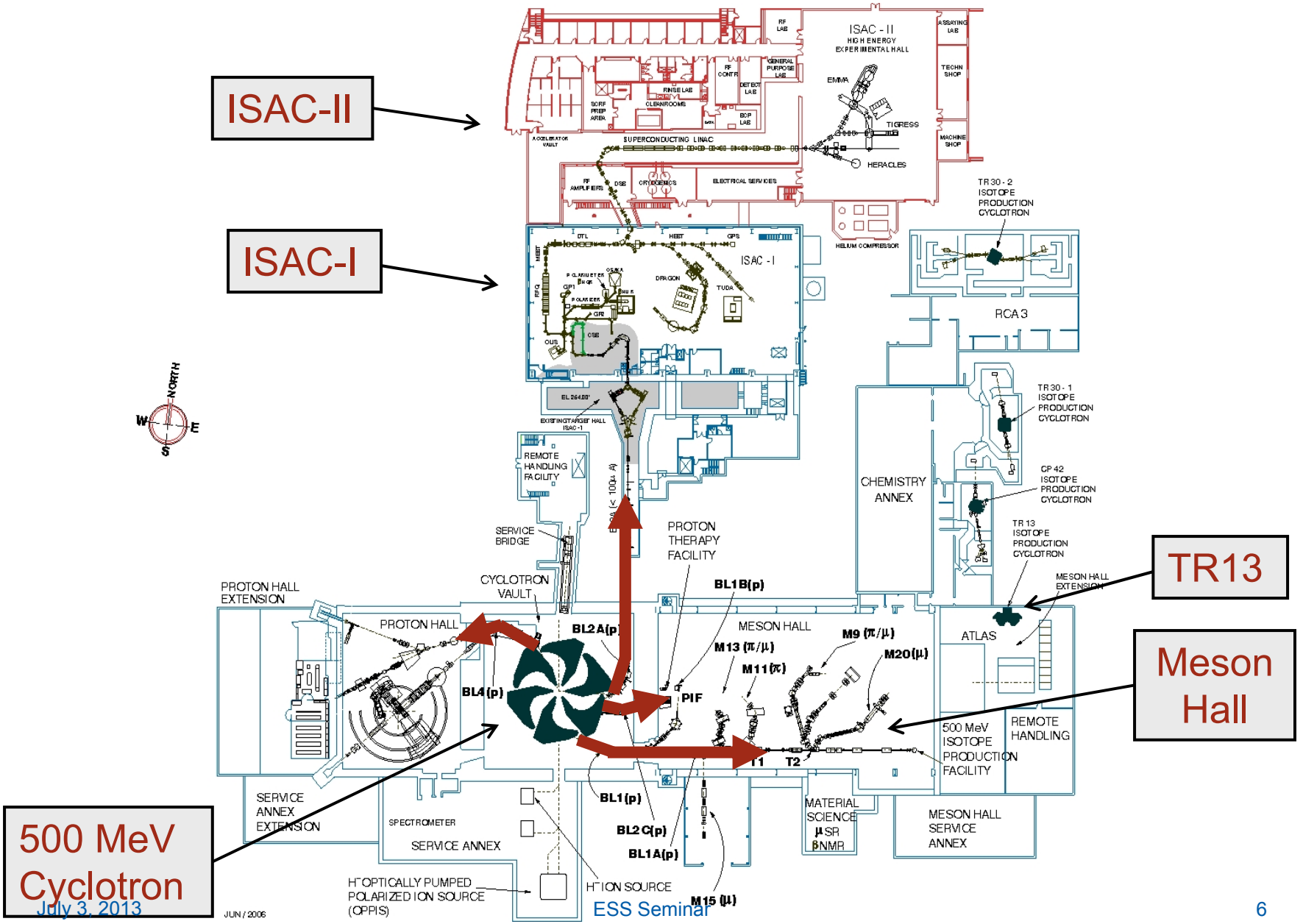
Founded 45 years ago in Vancouver

Unique Resource for Canada

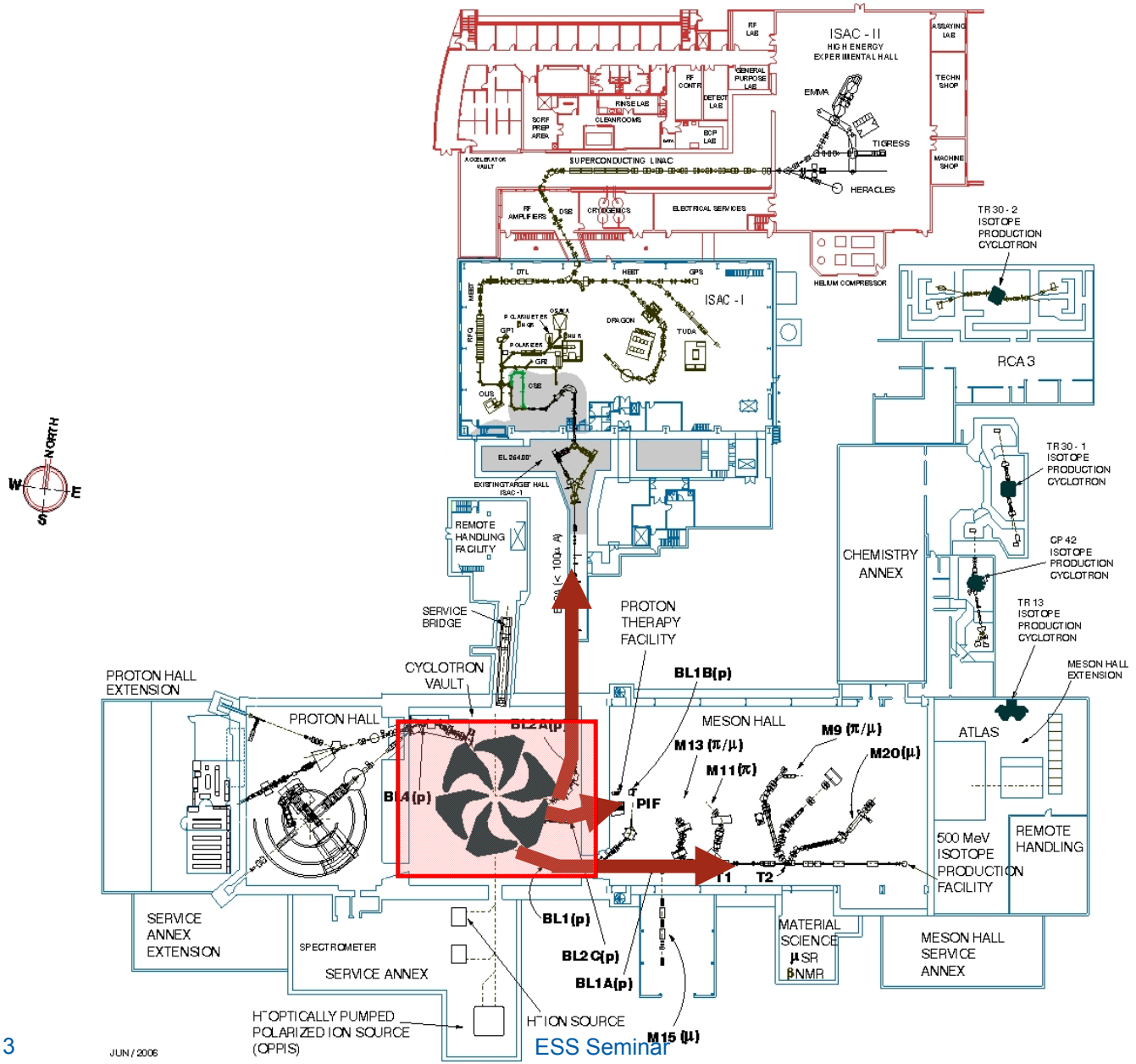
- People
  - ~450 scientists and staff on campus
  - ~80 (45+35) staff w/Nordion
  - largest engineering resource for fundamental research projects
    - ➔ enables university research on-site and off-site
- Knowledge
  - >1100 peer reviewed journal articles in the past 5 years
  - >80% of NSERC SAP funding involves TRIUMF
- Entrepreneurial
  - $1B in economic activity in last decade.
- International
  - 50+ international agreements/partnerships
- Visitors > 3,000 per year



TRIUMF Accelerators

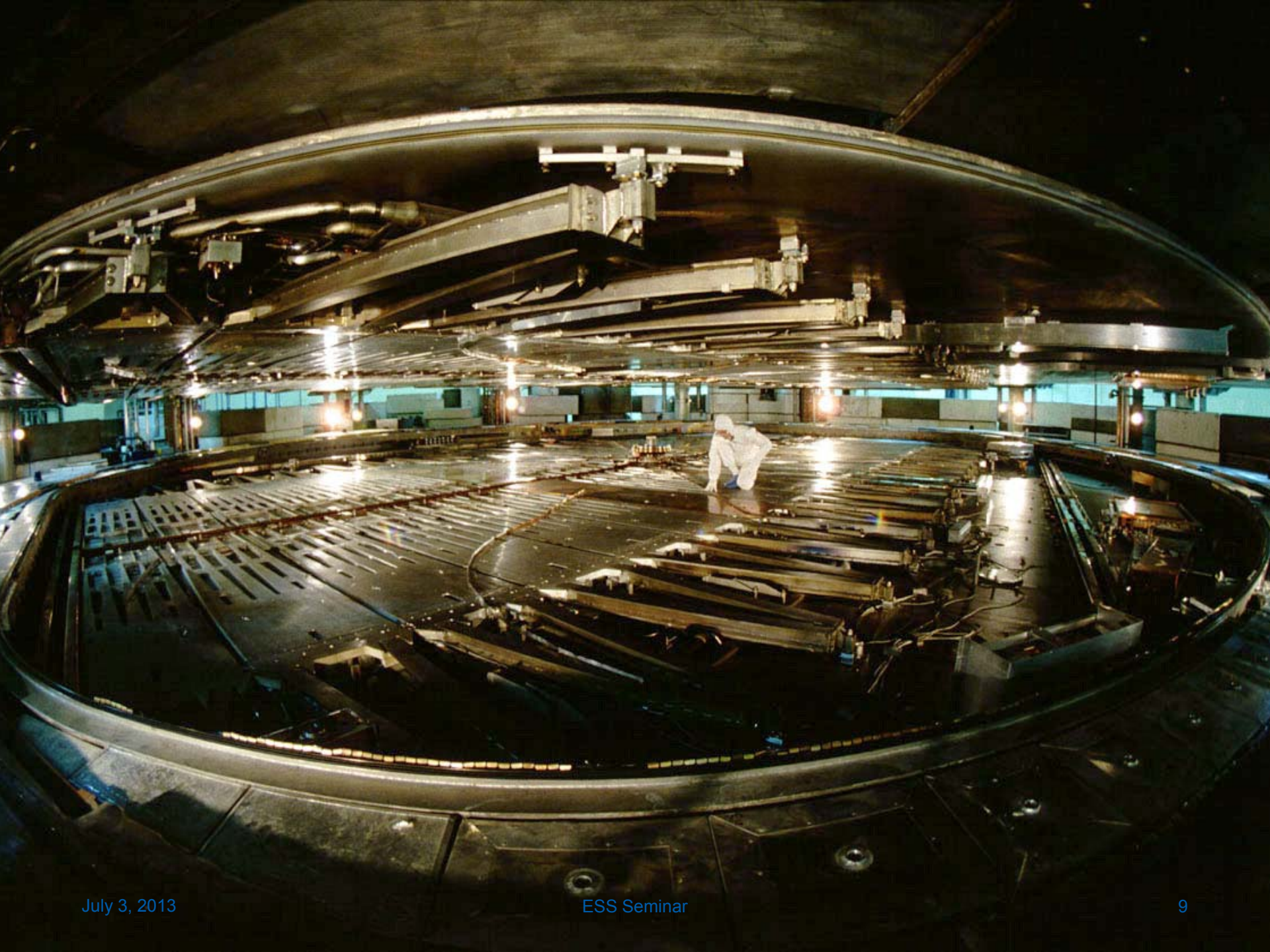


The 500 MeV Cyclotron



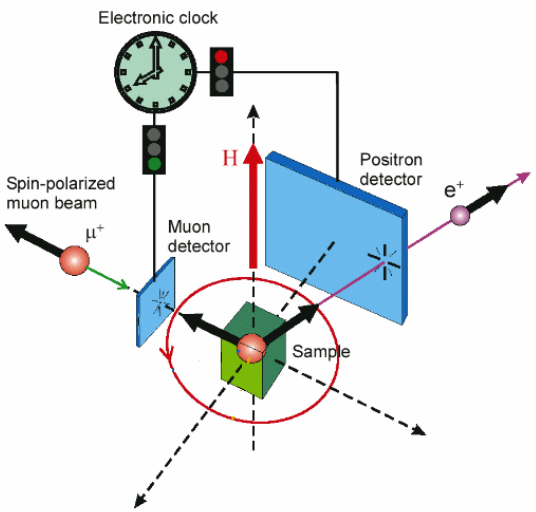
The 500 MeV Cyclotron at TRIUMF: The World's Largest Cyclotron

1972 TRIUMF, Vancouver, BC



Muon Spin Relaxation (μSR) Facility

The principle

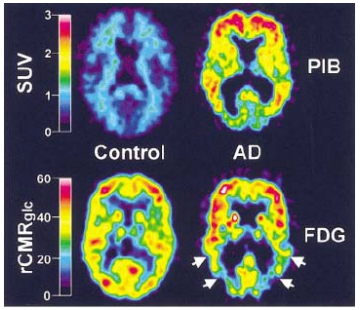


Muon-based Molecular and Materials Science

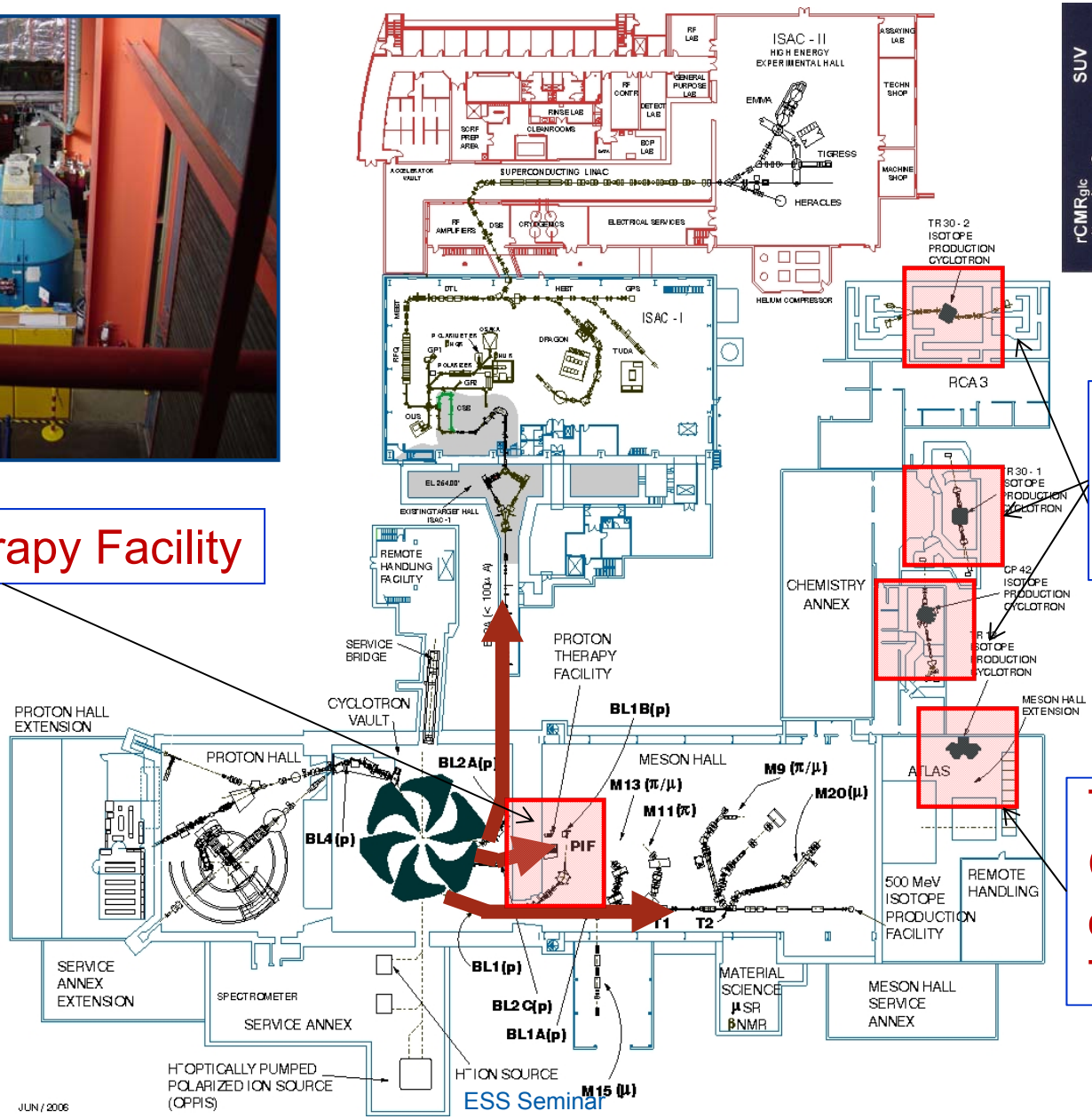
μSR uses the muon's spin to examine structural and dynamical processes in bulk materials on an atomic scale.

Only facility in the Americas.

Nuclear Medicine Facilities



Proton Therapy Facility



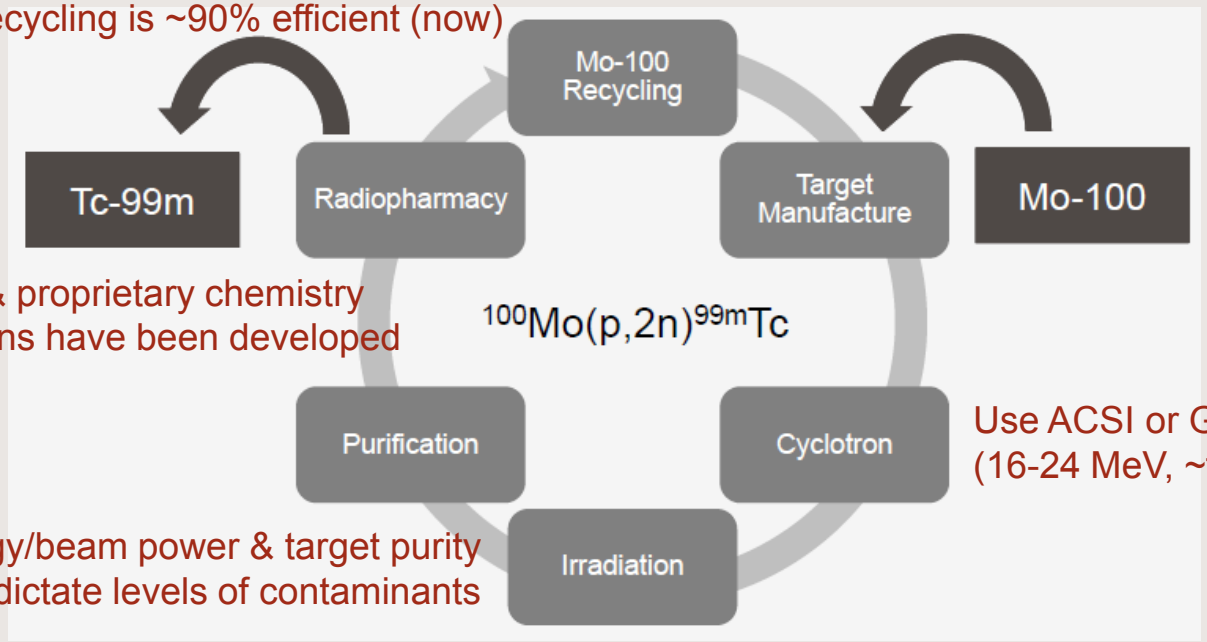
Cyclotrons owned by Nordion

TR13 Cyclotron owned by TRIUMF

Cyclotron production of Tc-99m

- TRIUMF-led consortium is developing target & chemistry technology to allow direct production of Tc-99m on existing medical cyclotrons
- New Milestone: ~10 Ci produced in downtown Vancouver in 6 hrs (enough for a full day of SPECT/CT scans in major urban area)

Recycling is ~90% efficient (now)



Thermal dissipation & fast dissolution constrain target

Std & proprietary chemistry options have been developed

Use ACSI or GE PETtrace cyclotrons (16-24 MeV, ~few 100 μA)

Energy/beam power & target purity dictate levels of contaminants

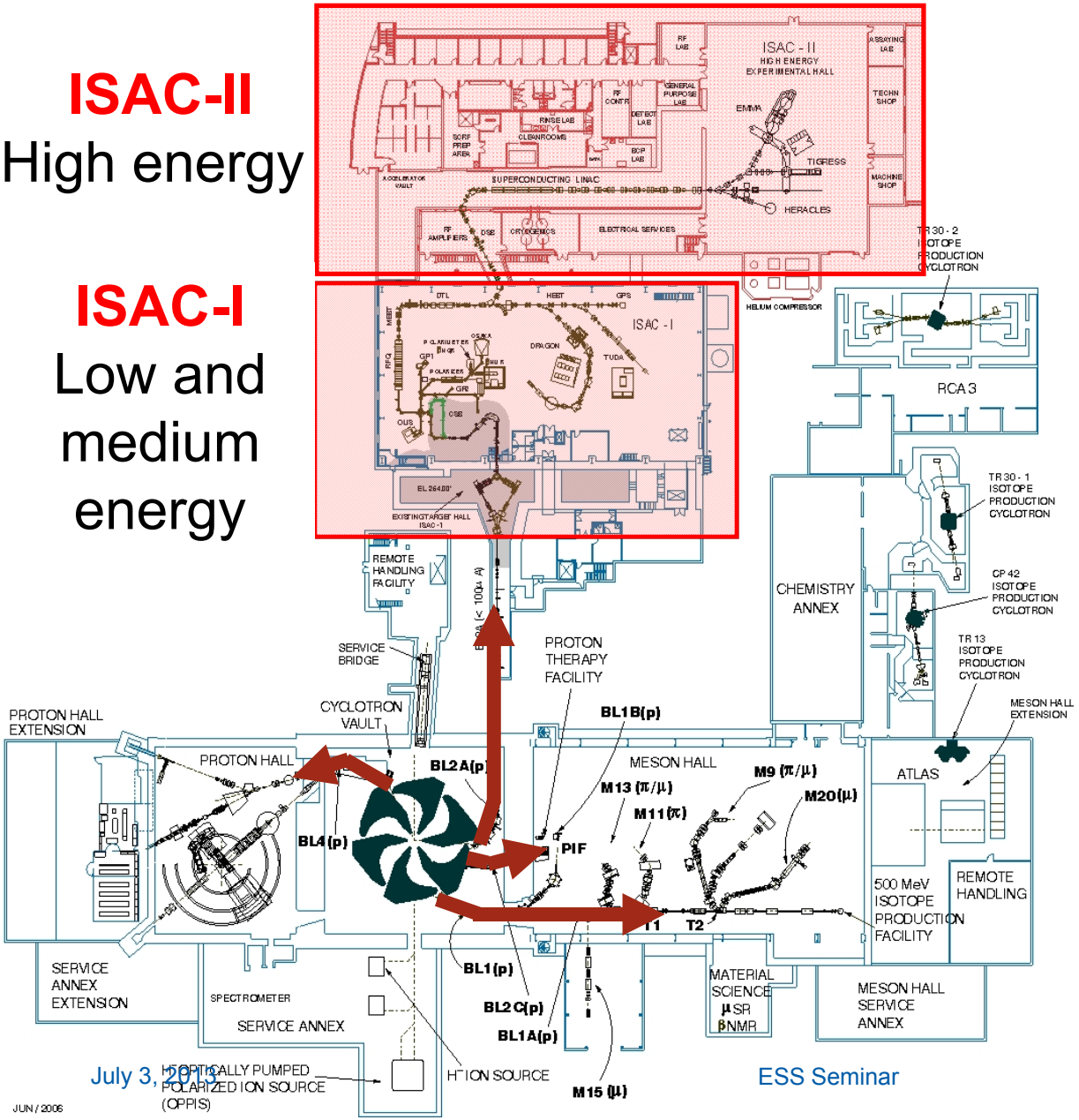
- Next Steps: Optimize QA/QC; Regulatory Approval; (Commercialize)

Labs: TRIUMF, BC Cancer Agency, CPDC/McMaster, Lawson
Federal agencies: Natural Resources, NSERC + CIHR, NRC

ISAC Rare Isotope Beam Facility

ISAC-II
High energy

ISAC-I
Low and medium energy

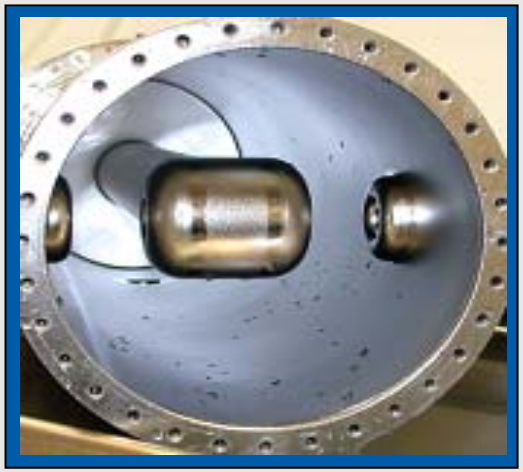


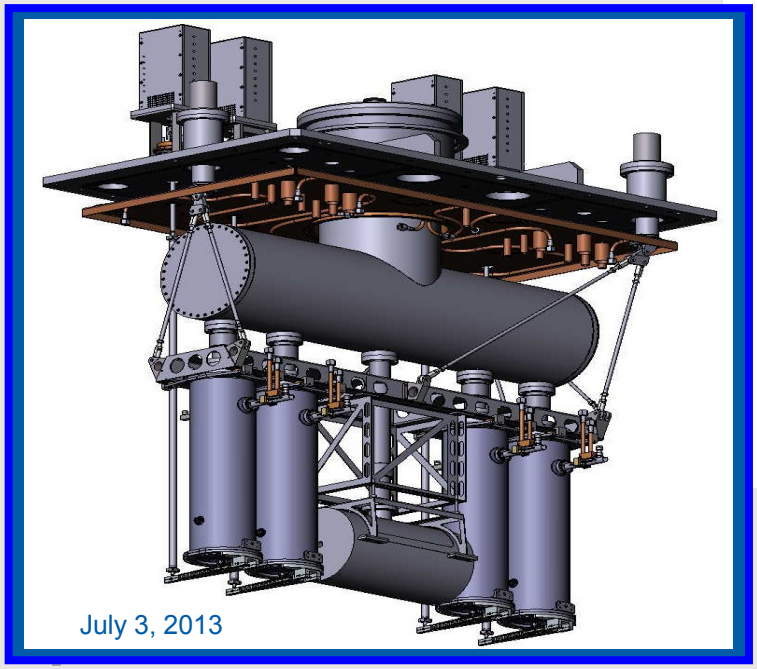
- World-class ISOL facility with highest power driver beam (50 kW)
- Most intense beams of certain species
- Seventeen world-class experiments on the floor in three areas:

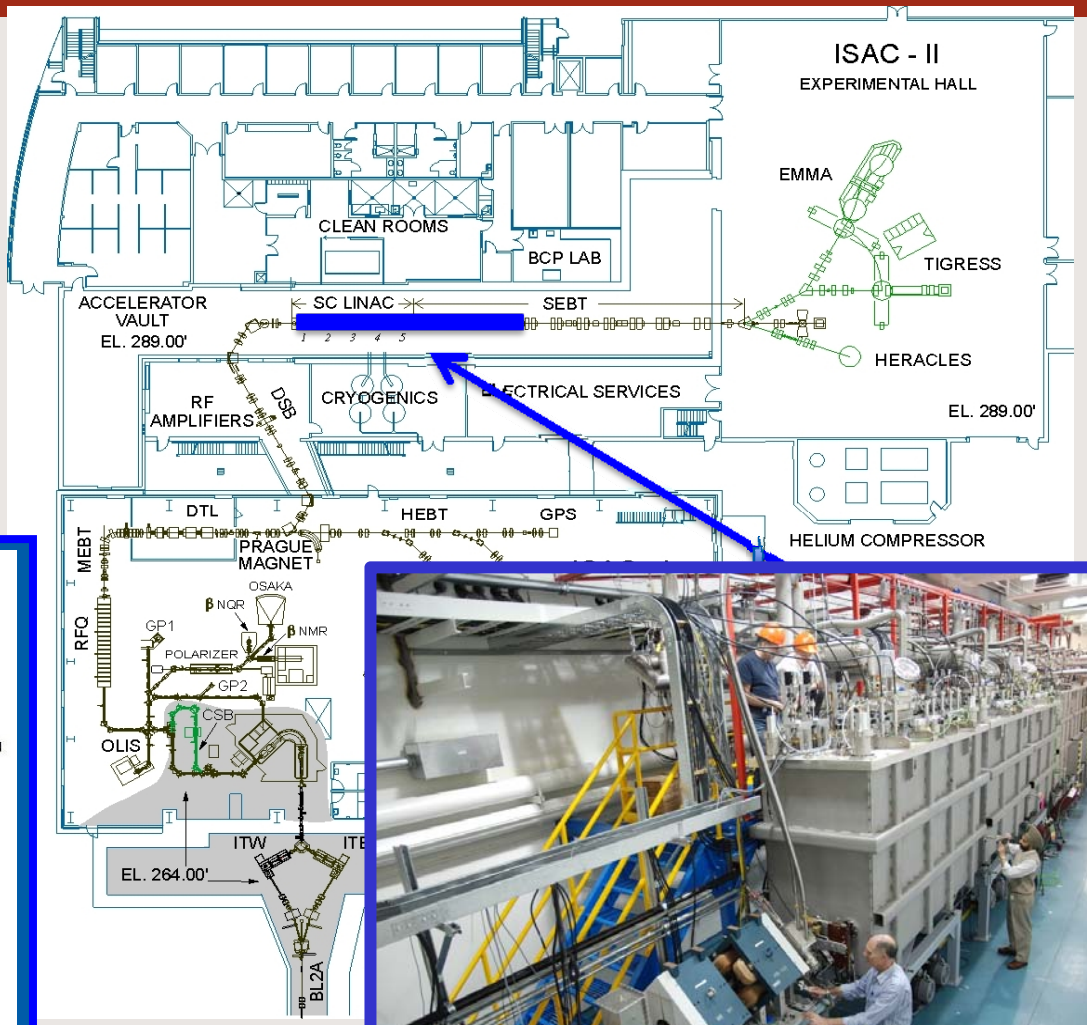
  low, medium, high energy
- Single user facility

  (single driver, two target stations)

ISAC II SRF Heavy Ion Linear Accelerator - Tech Transfer to PAVAC





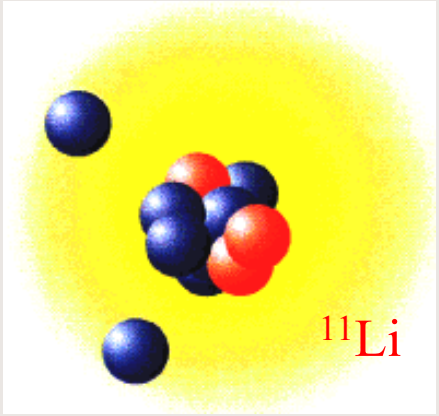


Cavities made by local fabricator PAVAC.

ISAC Science Program

Nuclear Structure and Reactions

- TUDA
- TIGRESS
- TITAN
- 8pi
- EMMA
- MAYA
- DENEX
- TOPLIS



Materials Science

- β-NMR
- β-NQR

Nuclear Astrophysics

- DRAGON
- TACTIC
- TIGRESS
- TUDA
- EMMA

Classical Nova

Most Intense ^{18}F Beam?

Fundamental Symmetries

- 8pi
- EDM
- GPS
- TITAN
- TRINAT

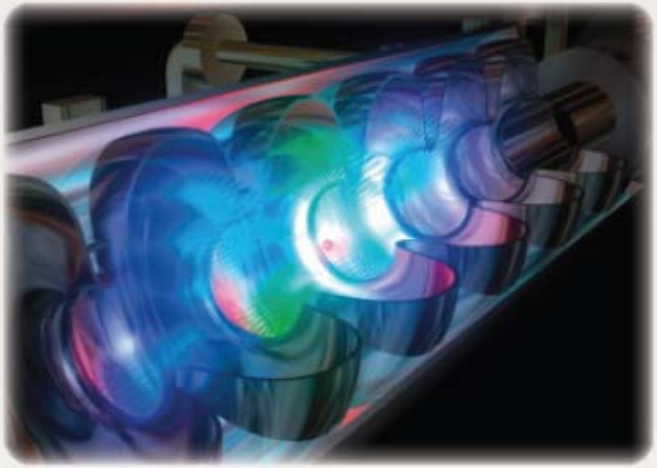
ARIEL:

The Advanced Rare IsotopE Laboratory

ARIEL

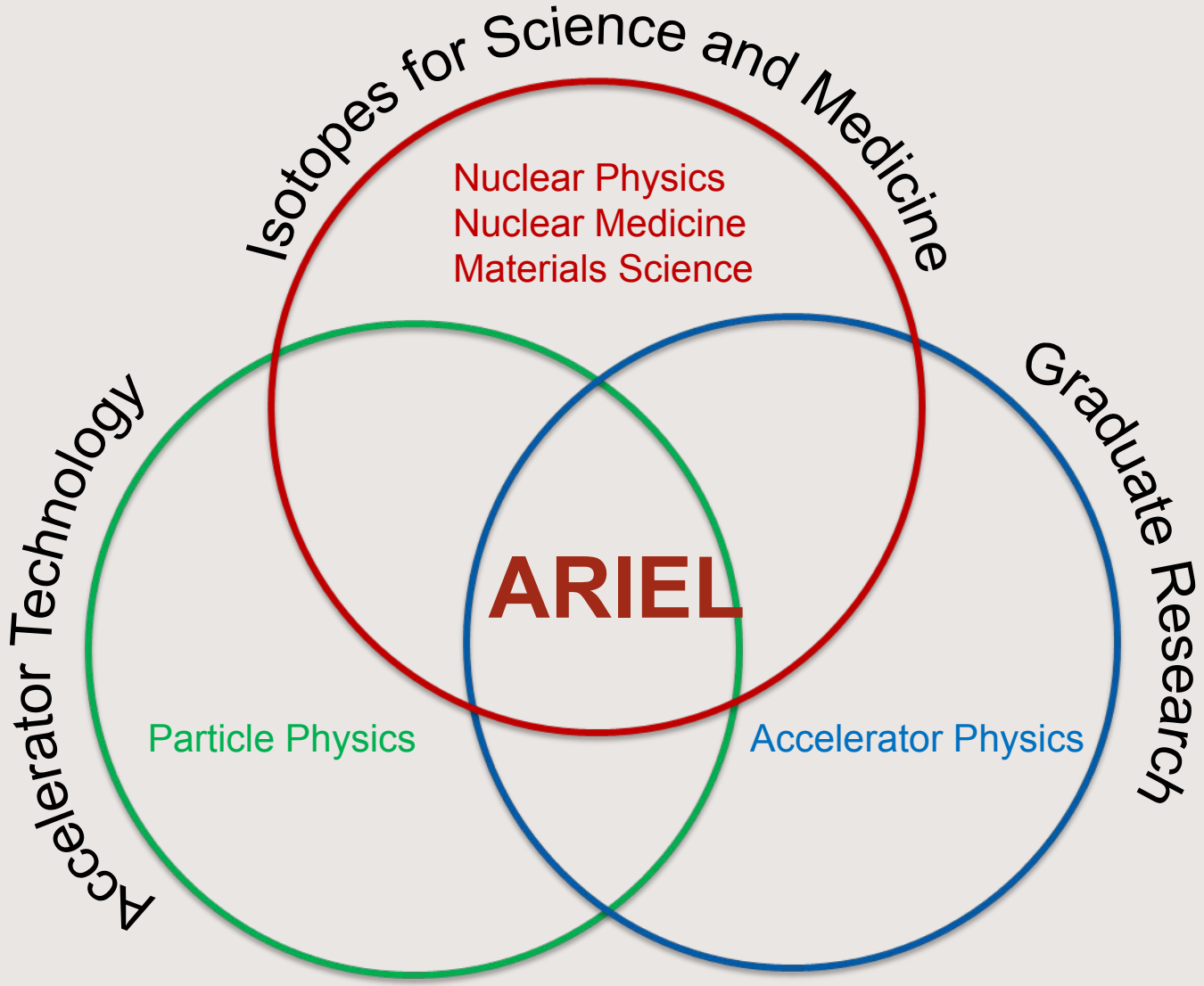
TRIUMF ARIEL

ADVANCED RARE ISOTOPE LABORATORY

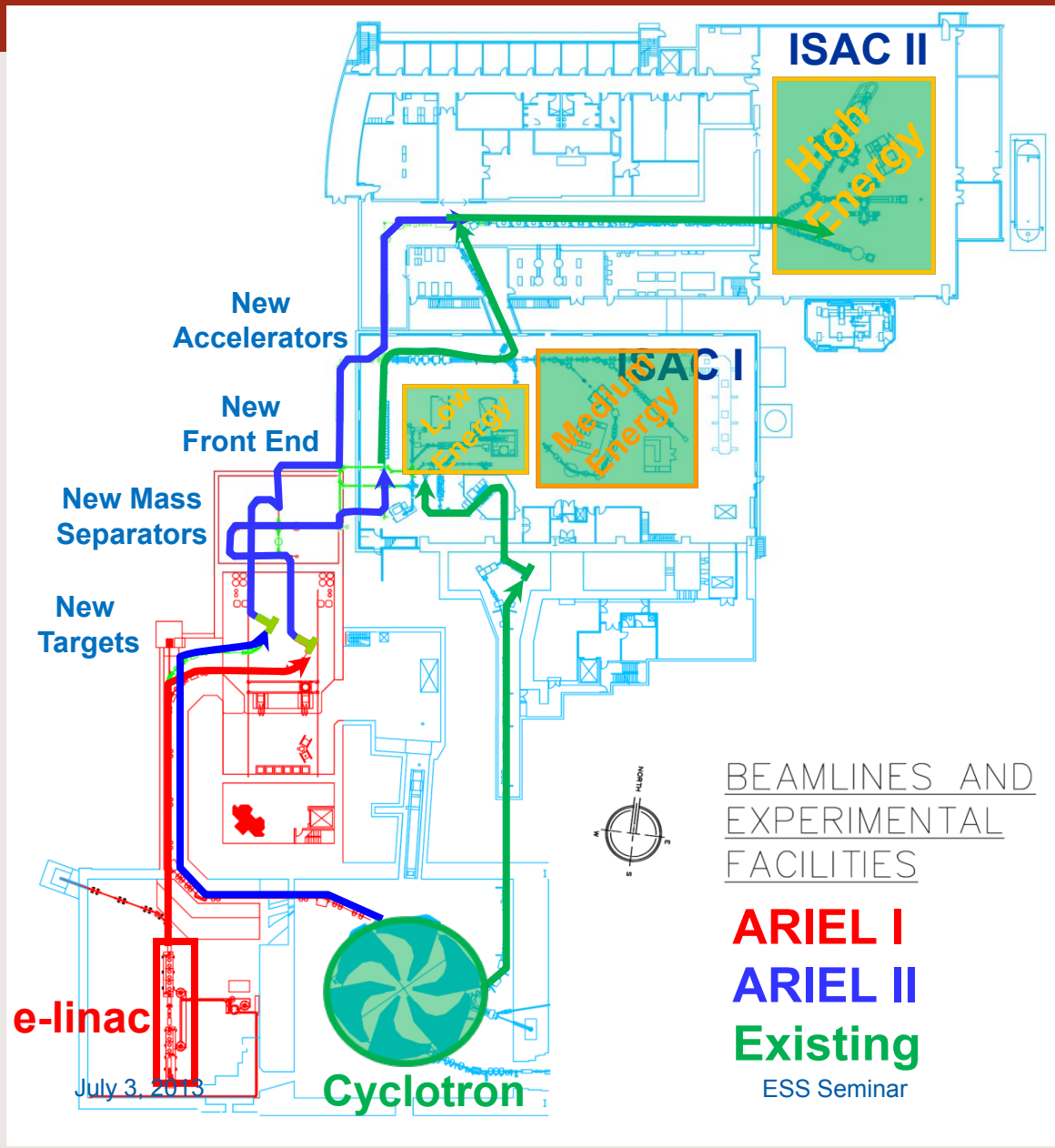


ARIEL will be TRIUMF's flagship Rare Isotope Beam facility for the production of isotopes for physics and medicine. ARIEL uses proton-induced spallation and electron-driven photo-fission of ISOL targets for the production of short-lived, rare isotopes that are delivered to multiple experiments simultaneously at the ISAC facility.

ARIEL: Synergies & Connections



ARIEL Project: 10-Year Vision



Substantially expand RIB program with:

- three simultaneous beams
- increased number of hours delivered per year
- new beam species
- increased beam development capabilities

Implementation:

- Complementary electron linac driver for photo-fission
- New target stations and front end
- New proton beamline
- Staged installation

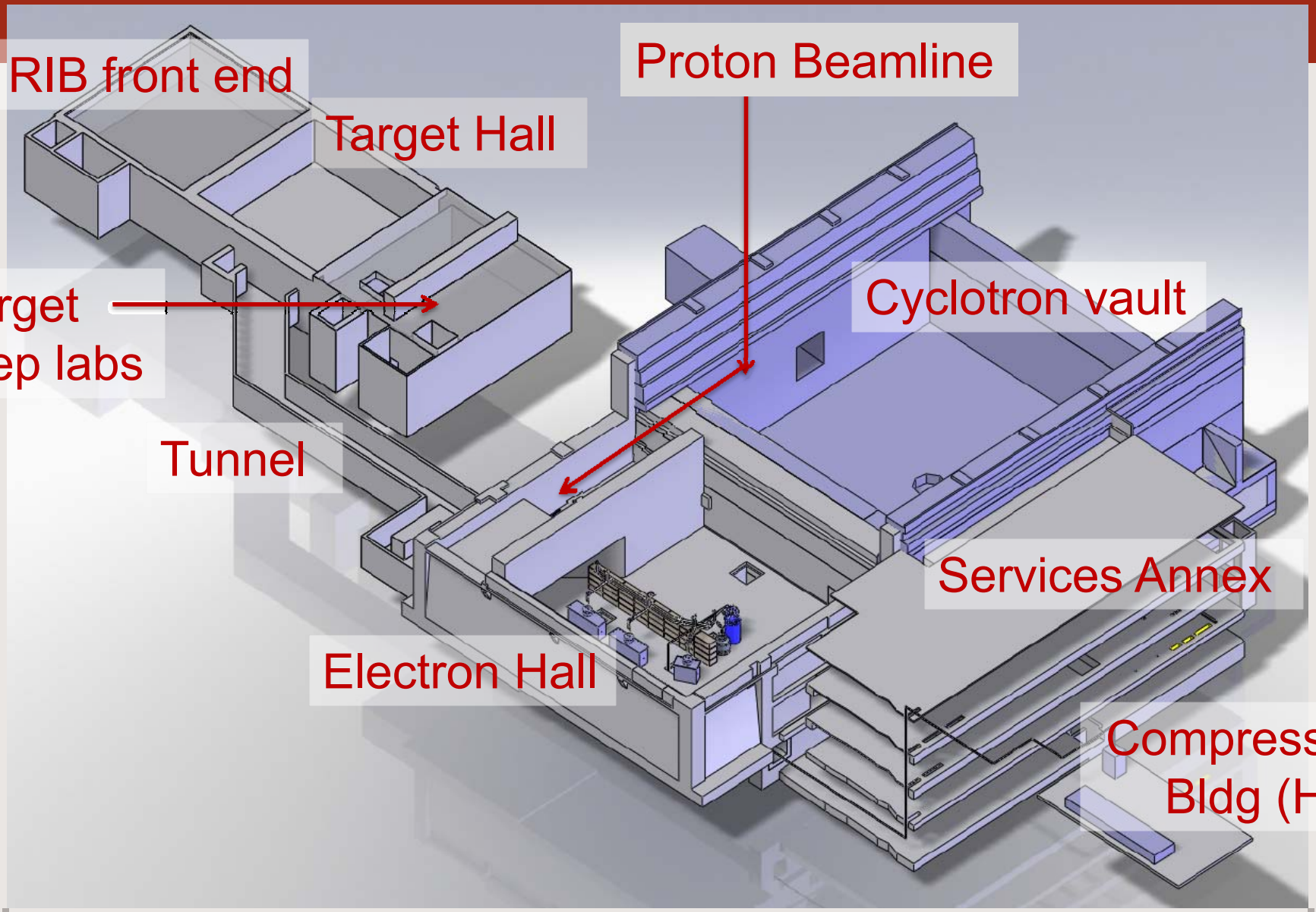
Time line (funding)

- Funded now ARIEL I (to be implemented until 2015):
  - Electron beam at 30 MeV, 100 kW from SRF linac
  - Civil construction to encompass objectives of both ARIEL Phase I & Completion
- Partial funding to initiate in this 5YP (2010-2015):
  - Electron Target Station
  - ARIEL Front-end for ISAC
- Next five-year plan – ARIEL Completion (2015-2020):
  - Electron beam at 50 MeV, 500 kW
  - Proton beam at >400 MeV, 100 μA from the H- cyclotron using new proton beamline
  - Proton target station
  - 2nd ARIEL Front-end for ISAC

ARIEL

Civil Construction

ARIEL layout



TRIUMF

Electron Hall - Now

Helium Compressor Building

ARIEL Building Construction

ARIEL Building

ARIEL Target Hall – Proton BL – RIB

Target Hall

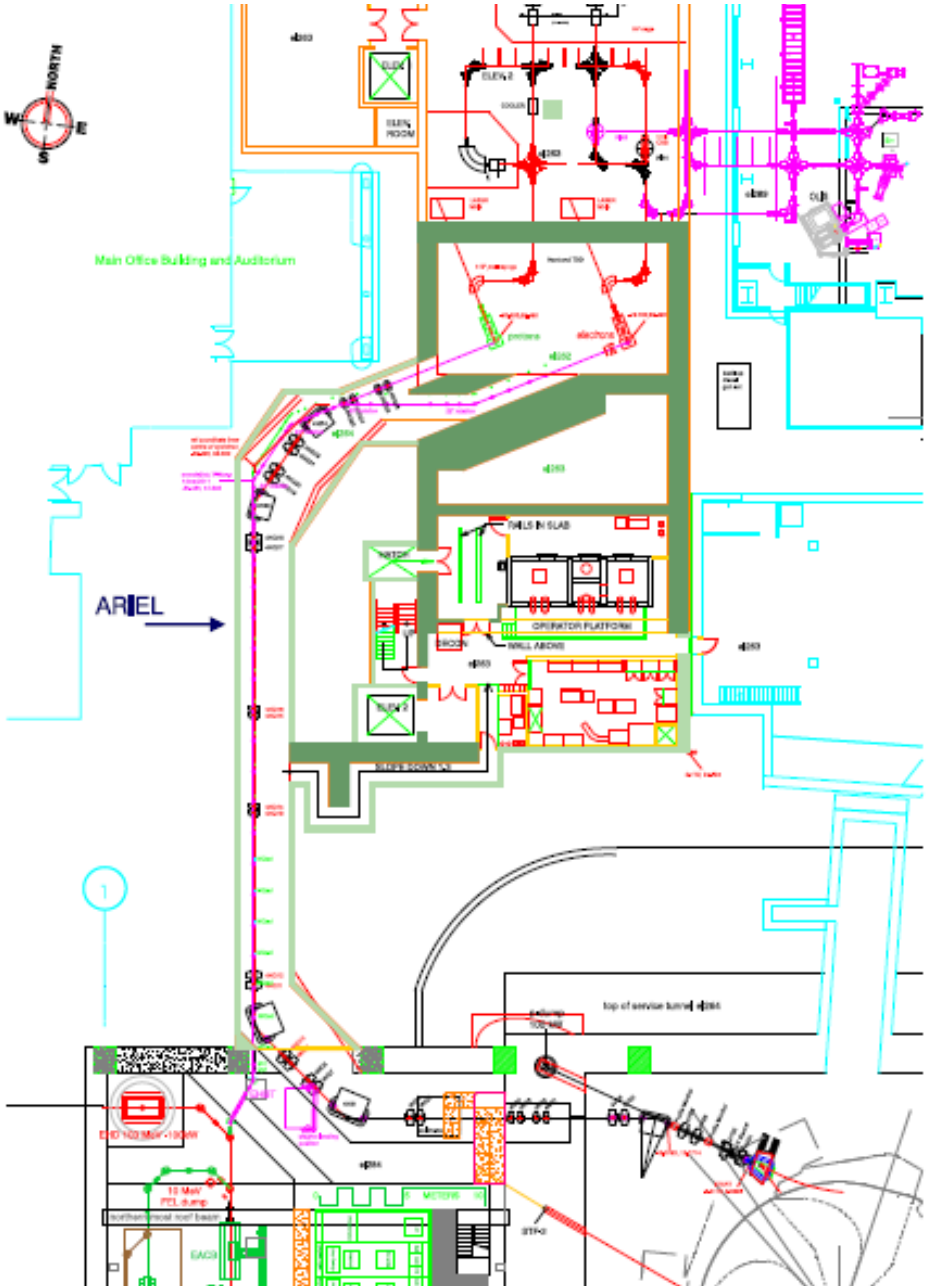
- Two target stations
- Hot cell facility
- Actinide & conventional labs
- Target Assembly Lab

Mass separator Room

- Two laser tables
- Dedicated pre-separators
- Ground level switch yard allows 3 simultaneous RIBs

Proton Beamline

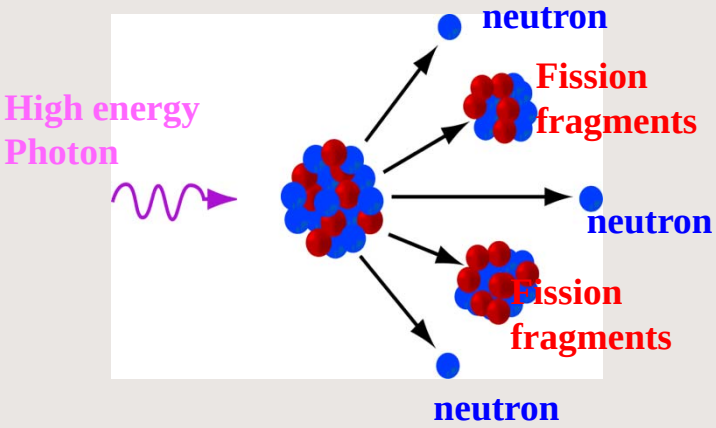
- Energy: 450-500 MeV
- Intensity: 1-100 μA
- Specs and optics design with many novel features complete

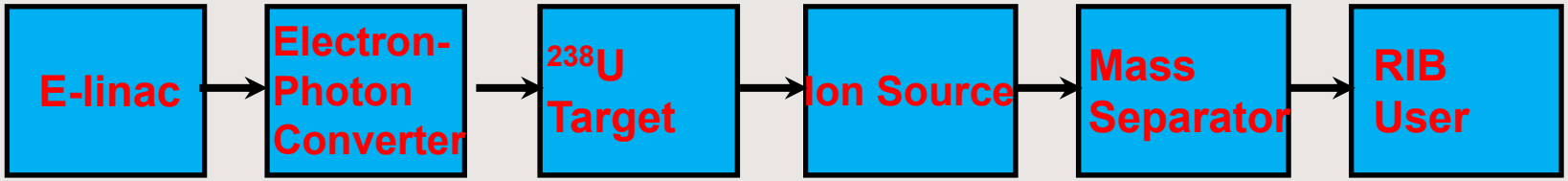


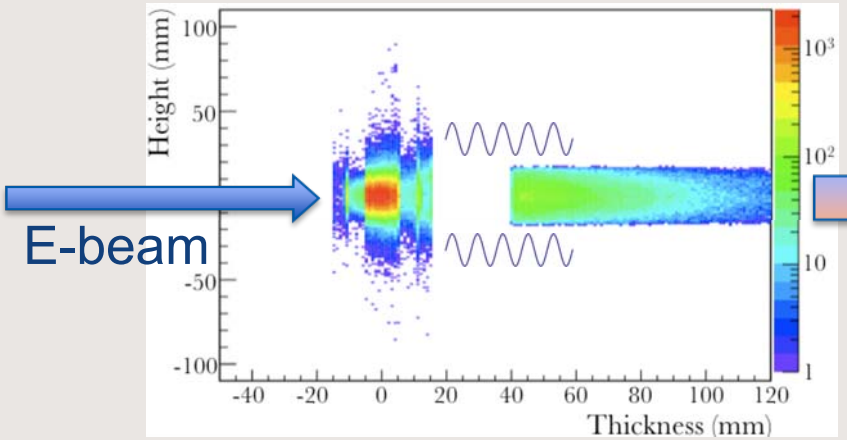
ARIEL e-Linac

Photo-fission production of Rare Isotope Beams

Photofission of ^{238}U was proposed by W. T. Diamond (Chalk River) in 1999 as an alternative production method for RIB.

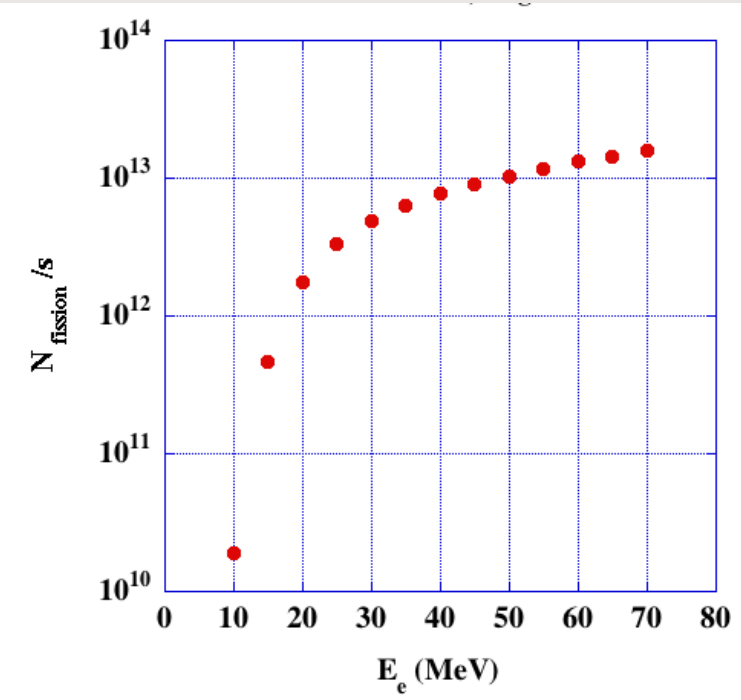






RIB & neutrons, γs

e-Linac Physics Requirements



Number of photo-fission/s vs. electron energy for 100 kW e-beam on Ta convertor and U target.

For up to 10^{14} fissions/s

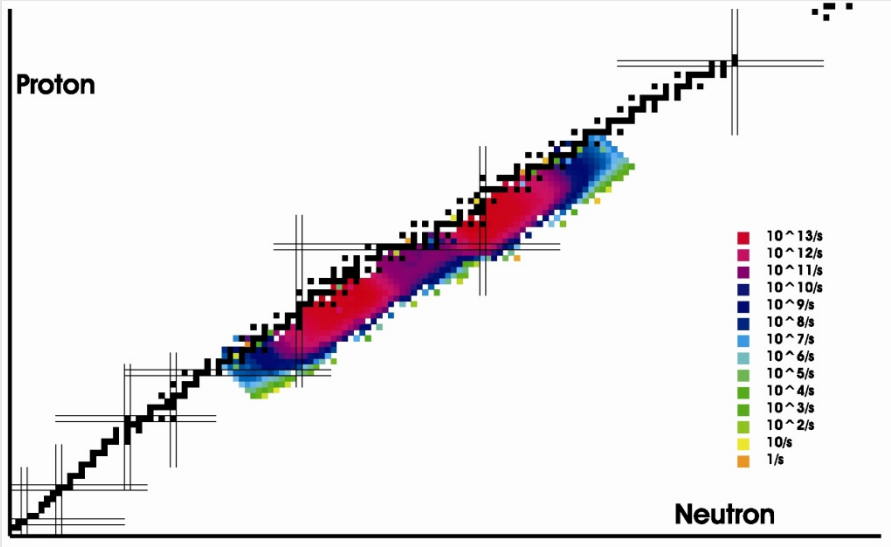
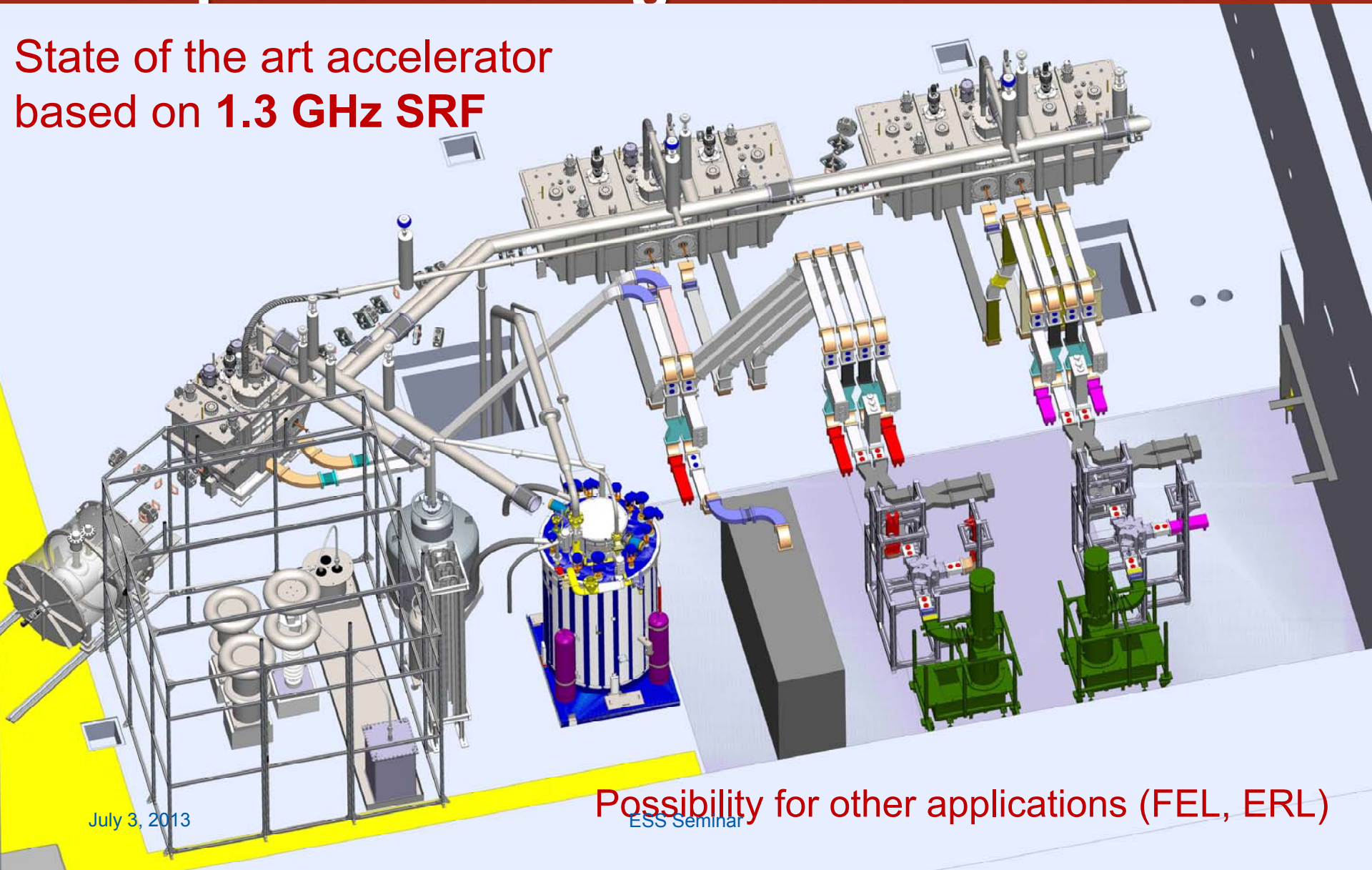


Photo-fission products using 50 MeV 10 mA electrons on to Hg convertor & UC_x target.

Kinetic energy (MeV)	50
Average current (mA)	10
Duty Factor	100%
Beam Power (MW)	0.5

ARIEL e-Linac : MW-class Superconducting Electron Accelerator

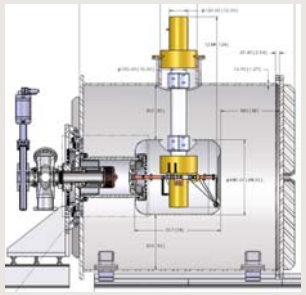
State of the art accelerator based on **1.3 GHz SRF**

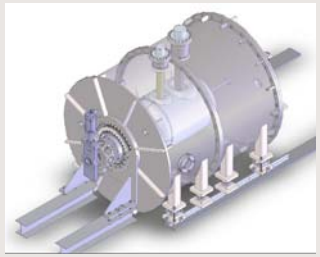


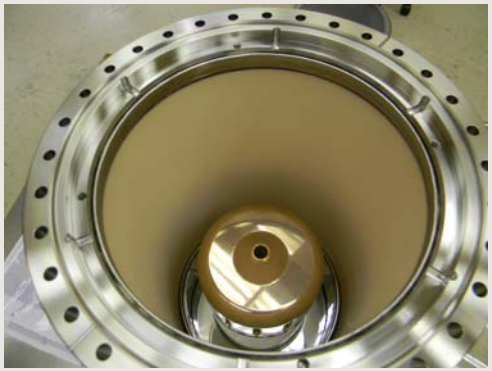
Possibility for other applications (FEL, ERL)

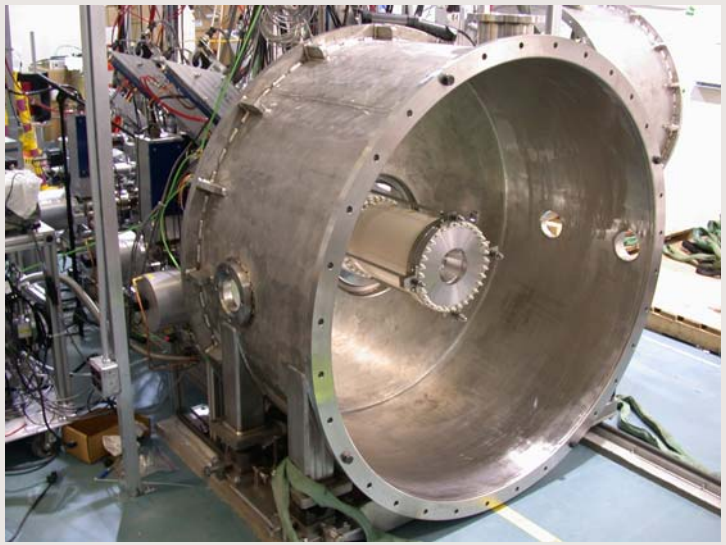
300 kV Electron Source

- 10 mA thermionic gridded gun, emittance 5 μm rms
- RF modulated grid at 650 MHz
- Use of dielectric waveguide to transmit modulation from ground potential to gun
- Gun commissioning July 2013







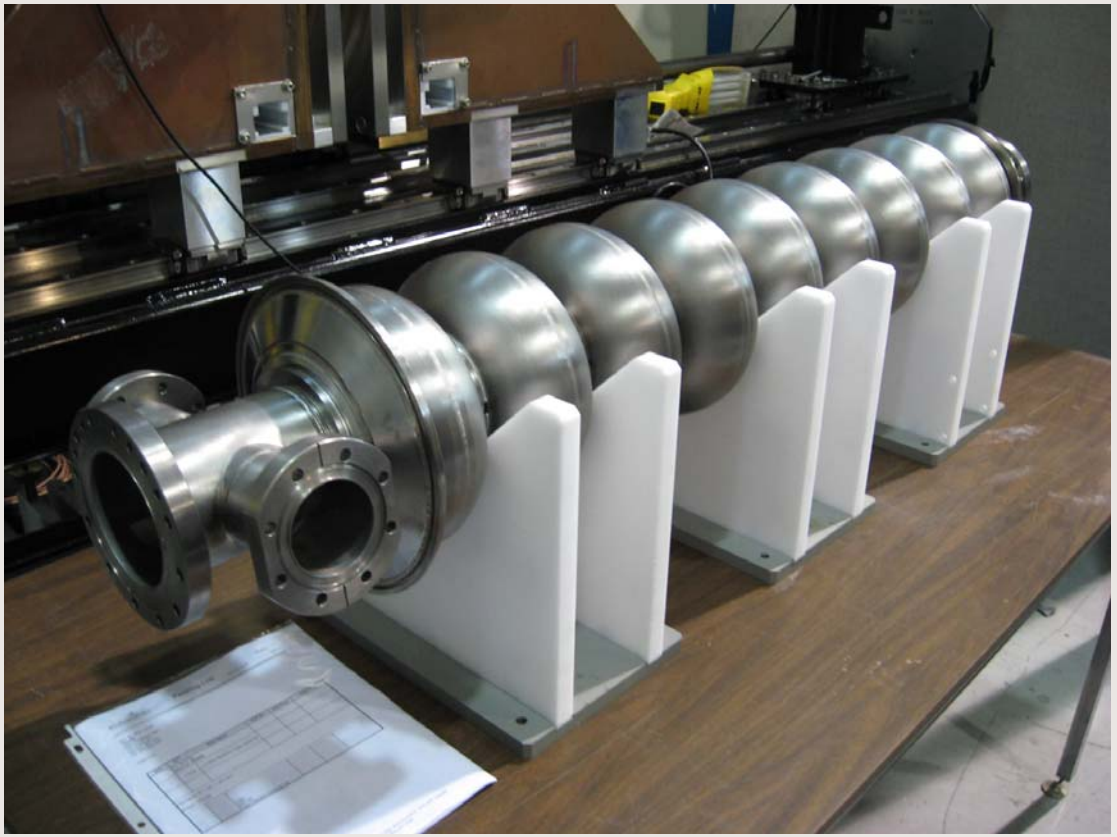


"Made in Canada" Superconducting RF Cavities

E_{acc}=10 MV/m at $Q_0 = 10^{10}$

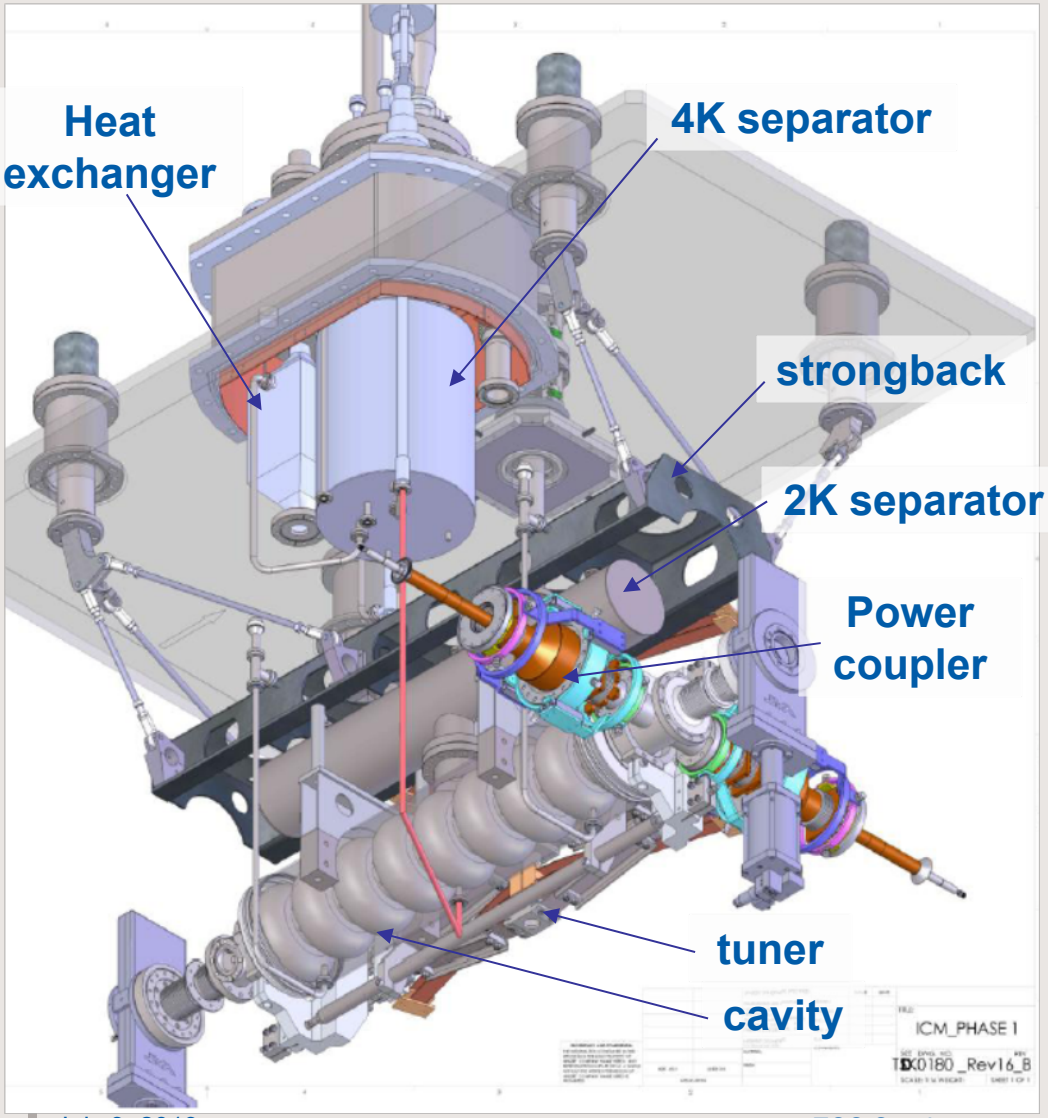
Single-cell cavity status:
Dec 2011: 7 out of 7
PAVAC/TRIUMF single-cells meet Q_0 requirement
Sept 2012: Gradient 25 MV/m

Multi-cell cavity fabrication by PAVAC (BC):
7-cell Cu cavity delivered Feb 2012
9-cell Nb cavity delivered May 2013



All modes $(R/Q)\times Q_L < 2\times10^6$ ohm for BBU $I_{th} > 20$ mA

Cryomodules



Cryomodule concept borrows significantly from ISAC-II.

Top loading box concept with cavity mounted to strongback that is suspended from struts.

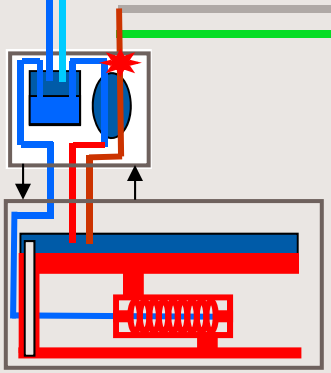
Box gives headroom for on-board 2K/4K insert.

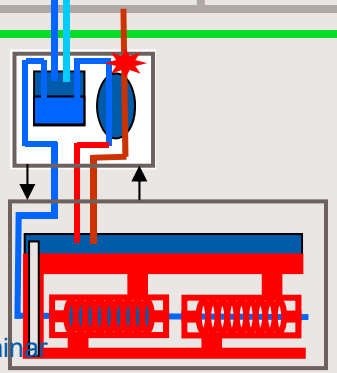
- Fab/assembly underway
- Injector CM beam commissioning fall 2013

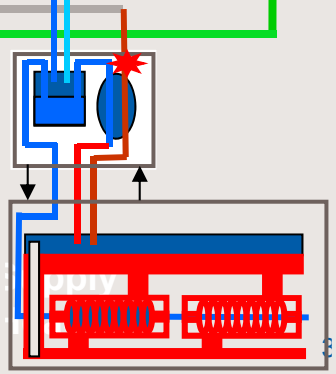
e-Linac Cryogenic System

800 W LHe at 4K
Sept 2013:
system commissioning

4K – 1.4Bara

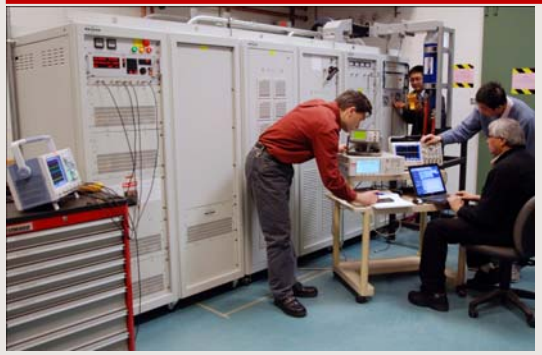


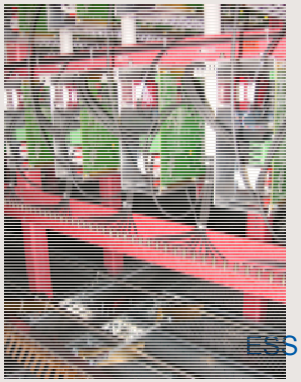




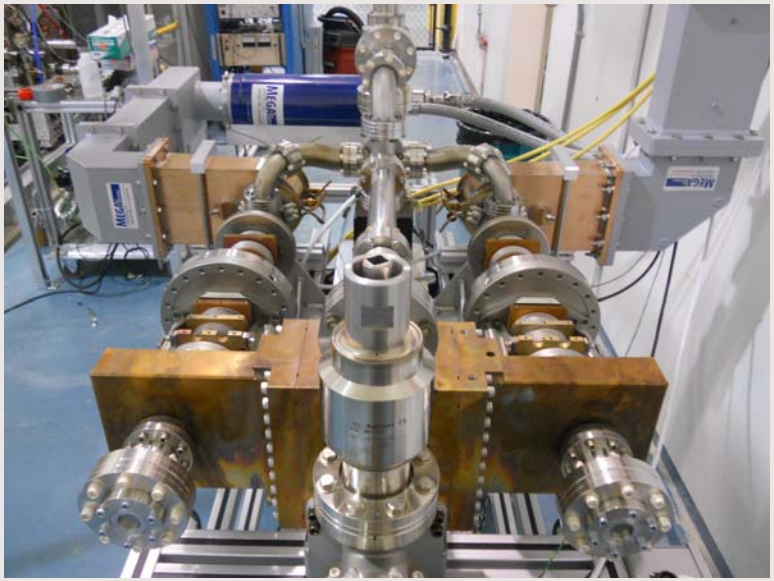
High Power RF Systems

IOT transmitter at 30 kW cw RF input





HP Coupler Conditioning Station: reached 8 kW cw, 10kW pk 500µs



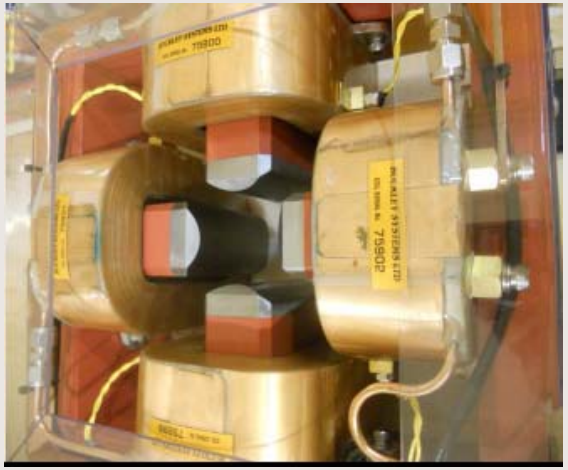
1.3 GHz 300 kW klystron purchase from CPI in coordination w/ HZB.
Delivered 3/2013

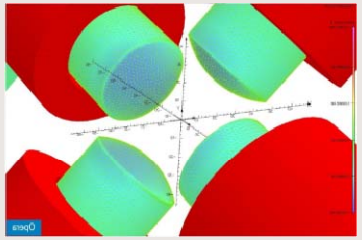
600kW 65kV HVPS awarded to Thomson Broadcast.
Delivery 7/2013

Beam lines: Magnets

Innovative Short Quad pole shape specified for minimum aberrations*
Three types of quadrupole magnets:

Type	Weak	Medium	Strong
K value (Tesla)	≤0.2	0.2≤K≤0.7	0.9≤K≤1.3



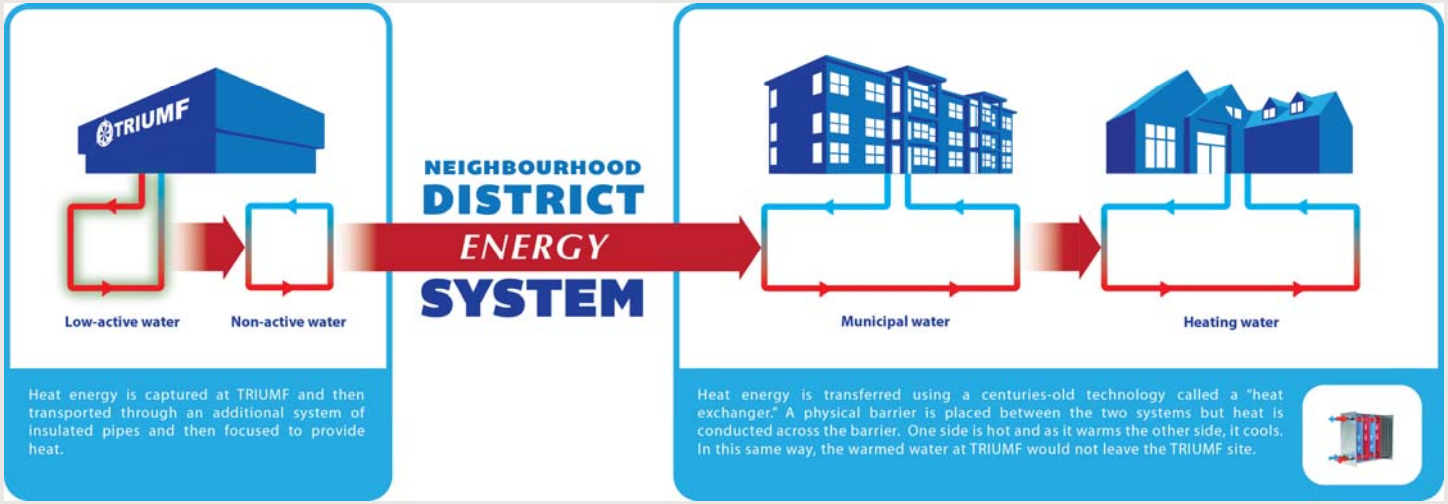


Quadrupole tender awarded to Buckley Systems in August 2012
Jan - March 2013: deliveries

* R. Baartman, "Quadrupole shapes," Phys. Rev. ST – AB 15, 074002 (2012)

Neighbourhood District Energy System

- Recover waste heat from cooling the cyclotron and later ARIEL
- Aim at “greening” all TRIUMF accelerators
- Working with UBC Sustainability Office

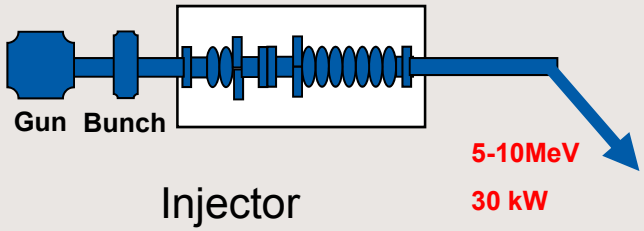


Cyclotron: 5 MW
ISAC: 1.5 MW
ARIEL: 3.3 MW

} ~10 MW heat generated

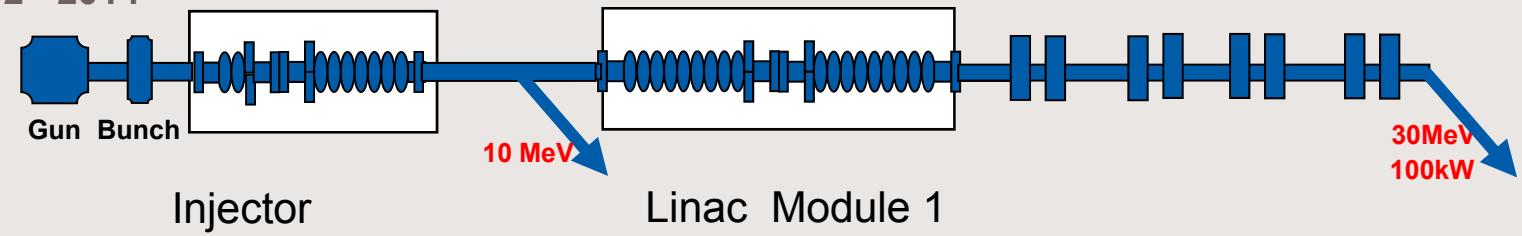
e-Linac Staging

Stage 1 - 2013

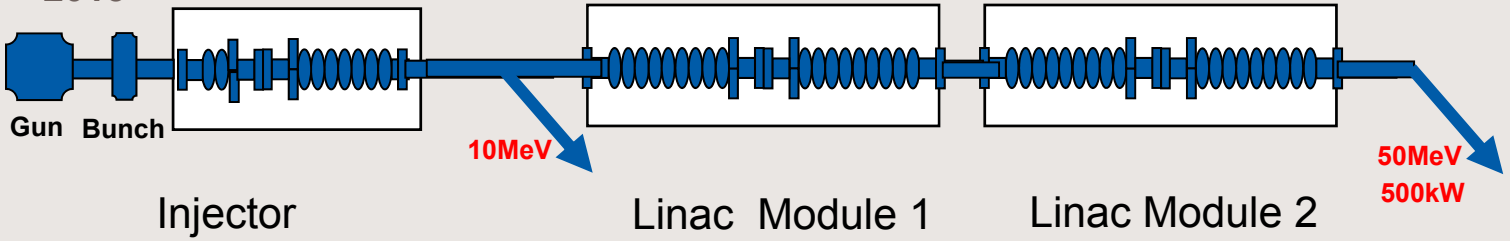


VECC Collaboration

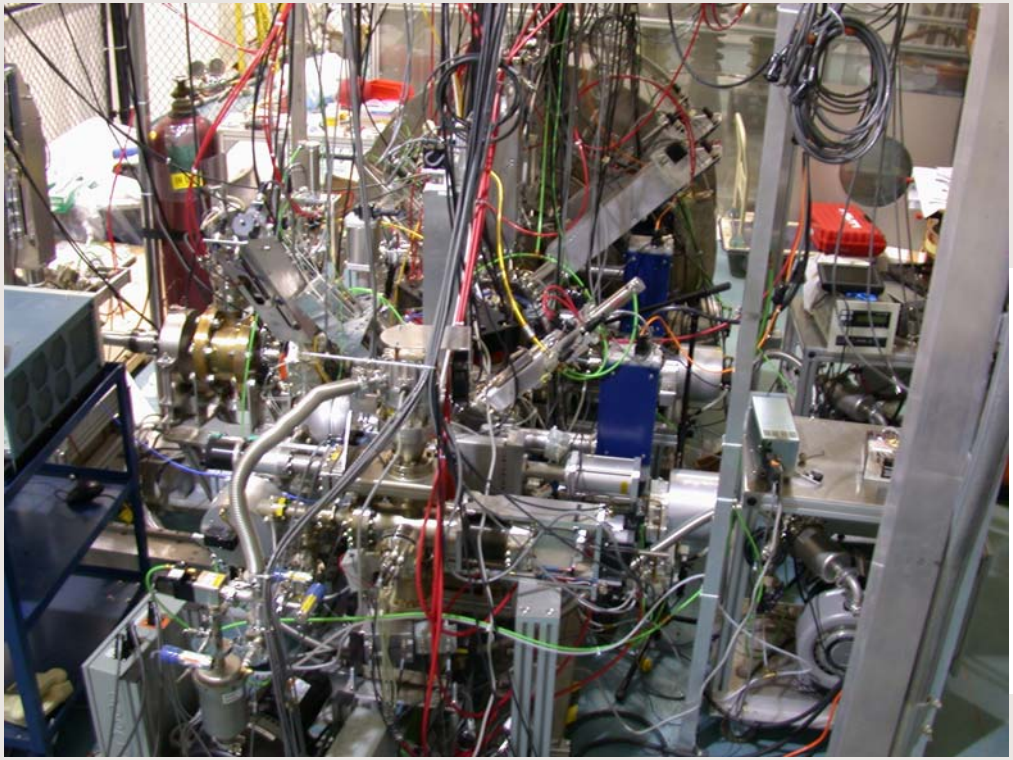
Stage 2 - 2014

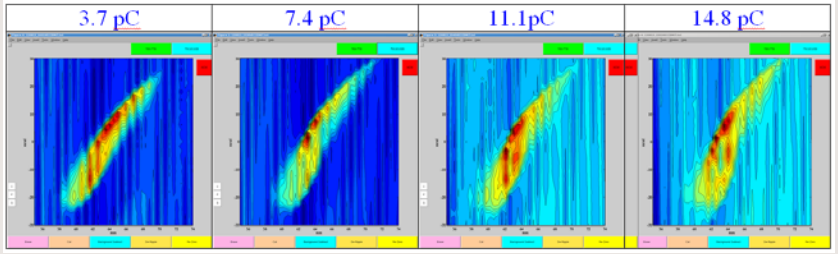


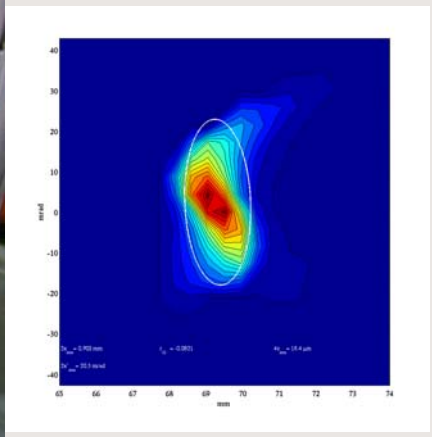
Stage 3 > 2015

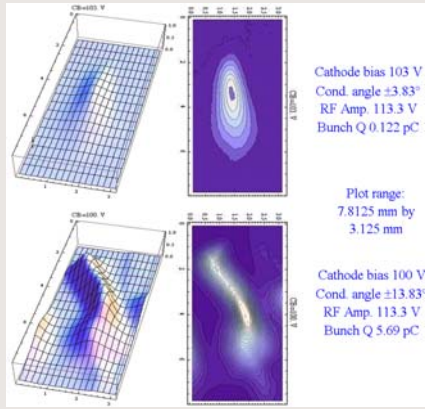


The VECC-TRIUMF Test Facility: front-end of the e-linac









Goals

- Commission VECC beam line
- Validate e-Linac Design
- Resolve e-Linac design questions
- Identify problems and solutions

Highlights

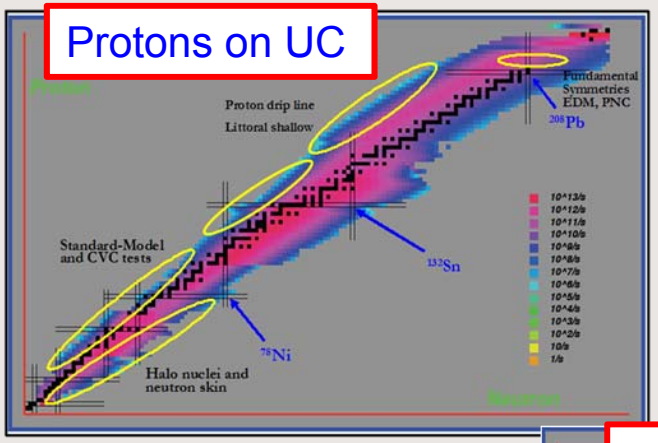
- *Measurements and detailed characterization of transverse and longitudinal phase space of 100 keV beam, as a function of charge per bunch, bunch length.*

Towards ARIEL Science:

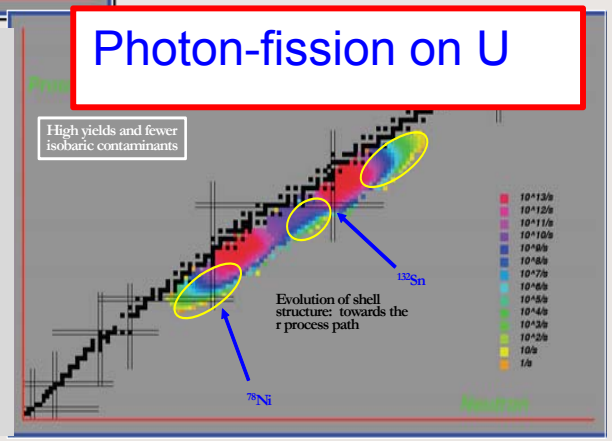
ARIEL Completion Project

Production rates with 500 kW electrons

In-target production rates (nuclei/sec) of key nuclei with 500 kW electron beam (50 MeV, 10 mA) on liquid lead converter and UCx target (1.2e13 f/s)



High intensity, "clean", n-rich isotopes, complementary to p-production



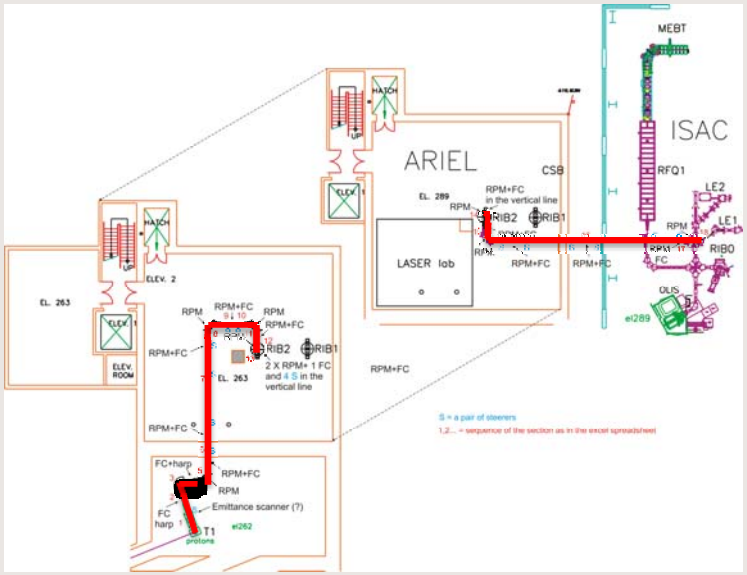
Nuclei	500 kW electrons
Ni-72	2.0E+08
Zn-78	3.4E+09
Kr-91	2.3E+11
Kr-94	1.3E+11
Rb-97	1.1E+11
Sn-132	2.5E+10
Sn-134	2.4E+09
Xe-142	5.2E+10
Xe-144	7.9E+09
Cs-144	6.0E+10
Cs-146	9.2E+08

ARIEL Completion Phase 1: Materials Science at β-NMR

1. Aiming at β-NMR as first ARIEL science

Requires:

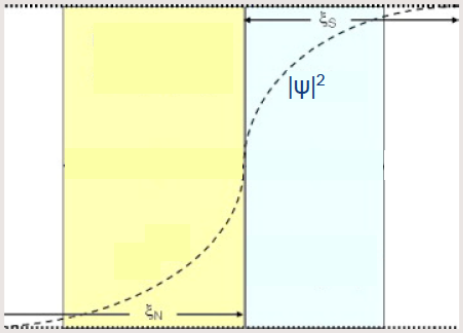
- ARIEL e-linac at 30 MeV 100 kW
- West Target station (non actinides)
- Pre-separator & beamline to β-NMR



Science:

Characterizing surfaces, interfaces and soft condensed matter physics

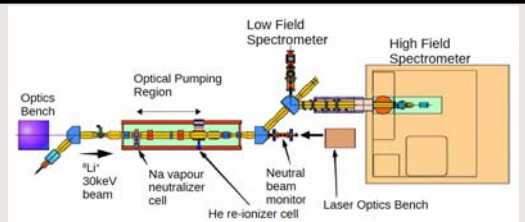
- Ginzburg-Landau SC order parameter is non-zero in the normal metal.
- Normal metal becomes superconducting.
- This can be detected directly with βNMR.



Silver - 29 nm
Normal metal

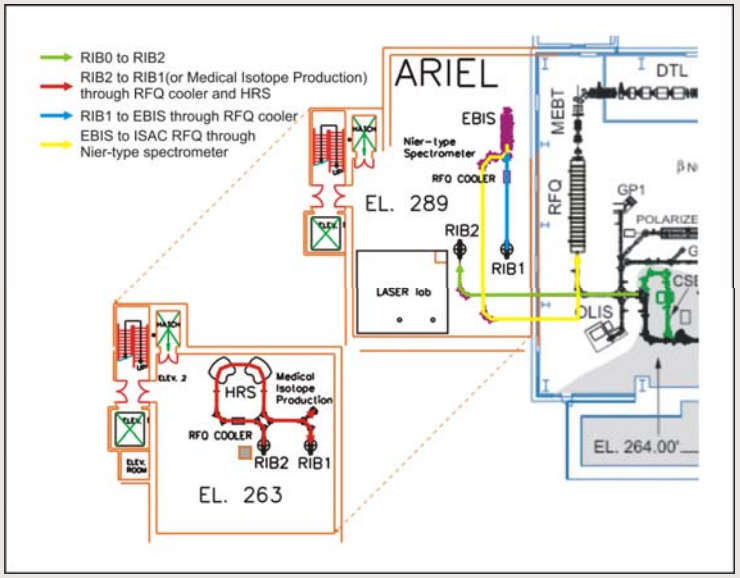
Niobium - 252 nm
Superconductor
T_c = 9.3 K

In β-NMR ^{8}Li is used to probe depth-dependent magnetic properties on nm scale, to obtain direct information on the penetration of magnetic flux near surface of a SC



ARIEL Completion Phase 2: Heavy Ion accelerated beams

2. Heavy Ion accelerated beams (using ISAC actinide target module) with ARIEL EBIS and high resolution mass separator and front-end

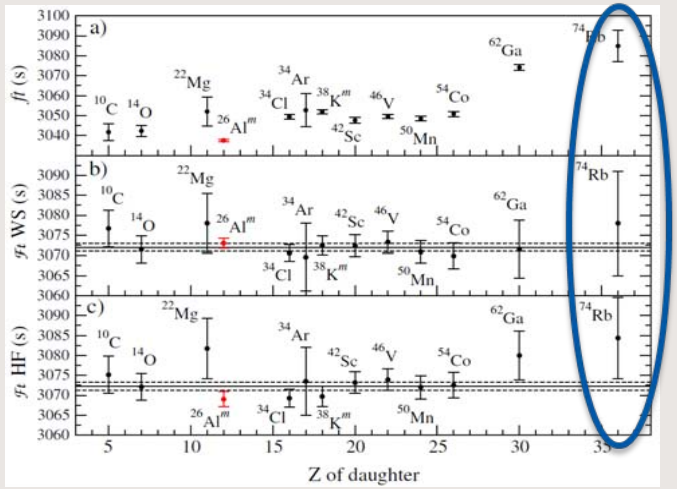


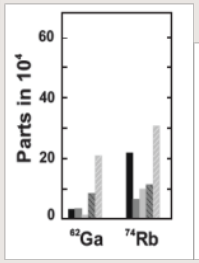
Requires:

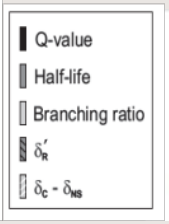
CANREB (EBIS and HRS) & beamlines

Science example:

Unitarity tests of CKM matrix: Test of CVC using superallowed Fermi decays







CANREB will provide clean beams of ^{74}Rb for Coulomb excitation to provide structure information to constrain isospin breaking corrections

$$Ft = ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R)} = \text{constant}$$

Experiment

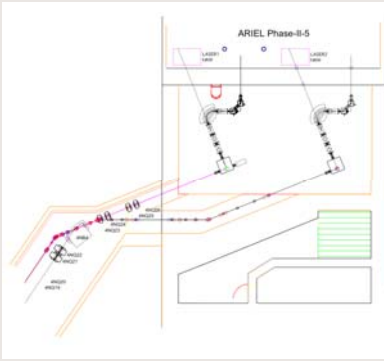
Calculated corrections (~1%) (nucleus dependent)

Inner radiative correction (~2.4%) (nucleus independent)

CVC Hypothesis

ARIEL Completion Phase 3: Physics of photo-fission

3. Physics of photo-fission



Requires:

- West Target station w/actinides, hot cell, labs
- East Target station, 2nd pre-separator, BL, MRS

Milestone: Two simultaneous electron-produced RIBs to users

Science: Fission fragments for r-process studies

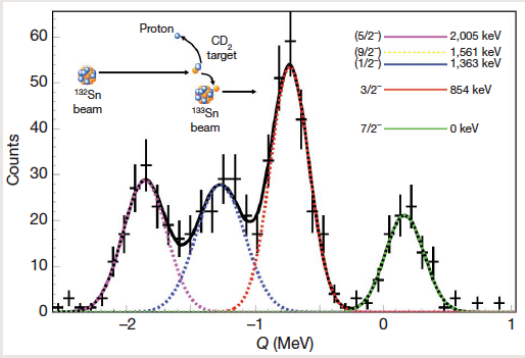
R. SURMAN, J. BEUN, G. C. MCLAUGHLIN, AND W. R. HIX

Z \ N	78	79	80	81	82	83	84	85	86	87
52	^{130}Te	^{131}Te	^{132}Te	^{133}Te	^{134}Te	^{135}Te	^{136}Te	^{137}Te	^{138}Te	^{139}Te
51	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb	^{135}Sb	^{136}Sb	^{137}Sb	^{138}Sb
50	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn	^{137}Sn
49	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In	^{133}In	^{134}In	^{135}In	^{136}In
48	^{126}Cd	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd	^{132}Cd	^{133}Cd	^{134}Cd	^{135}Cd

Nuclei for which uncertainties in neutron capture rates have large impact on final r-process abundance

Fission fragment rates from ARIEL enable studies of surrogate (d,p) reactions to obtain information on (n,γ) rates.

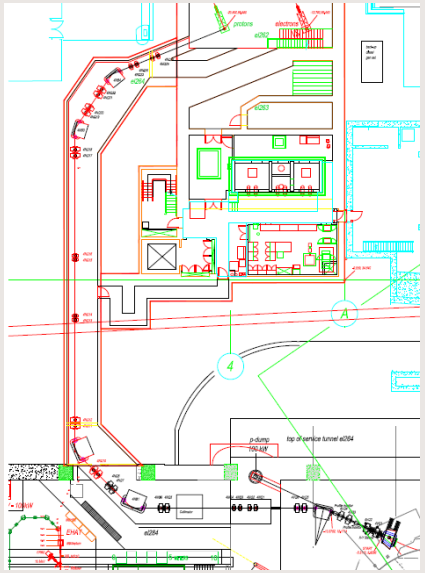
Studies of shell evolution in n-rich nuclei possible.



Jones et al., Nature 465 (2010)

ARIEL Completion Phase 4: Fundamental symmetries

4. New proton beam line for "long running" fundamental symmetry measurements



Requires: Proton beamline

Science: Electroweak precision experiments

Francium Parity Non-Conservation program started!

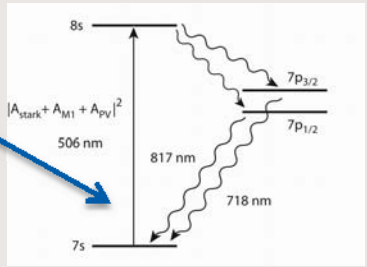
- Successful Francium trapping of ^{207,209,221}Fr in new Magneto Optical Trap (MOT)

Heavy nucleus, simple atomic structure

- excellent candidate for low-energy tests of hadronic weak interaction
- search for physics beyond the Standard Model ➔ **needs months of beamtime**

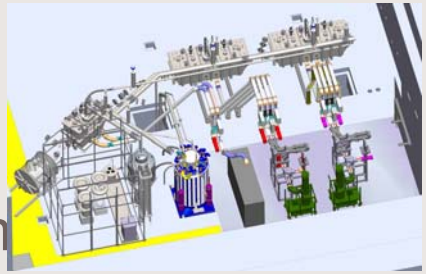
Parity-non-conserving (PNC) atomic transition (8s →7s)

➔ Probes strength of the weak neutral current between electron and quarks at very low momentum transfer



ARIEL Completion Phase 5: Full exploitation of photo-fission

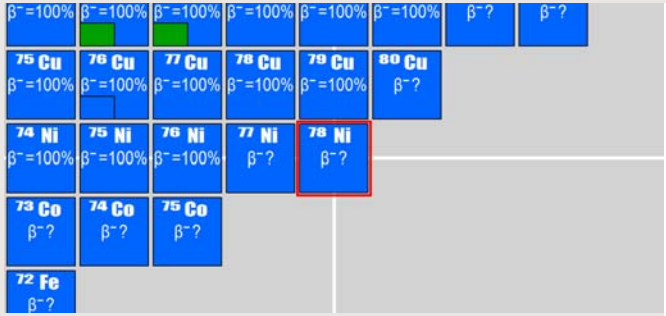
5. Full exploitation of photo-fission with high power e-linac

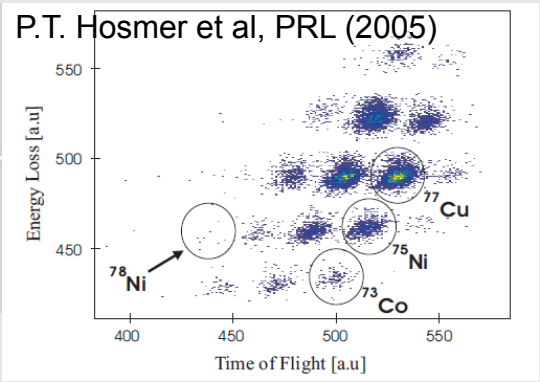


Requires: ARIEL e-Linac at 50 MeV, 500 kW

Science:

- Delineating the r-process path with fission fragm
- Masses, charge radii, decay properties
- Transfer reactions mapping shell structure
- Indirect studies of neutron capture and photo-dissociation rates





Doubly magic nucleus (p=28, n=50)
Properties of ^{78}Ni are important for the understanding of r-process.
Half-life (MSU meas) changed resulting element abundances dramatically.
Nuclear structure defines behavior of N=50 nuclei.

ARIEL will reach into this region and enable:

- Mass meas. (Q-values), Half life, Decay spectroscopy

Accelerator Science Research & Education at TRIUMF

Graduate Student Program in Accelerator Physics and Engineering

- **Goal is to establish a strong graduate student program in Accelerator Physics at TRIUMF in collaboration with Canadian and international universities**
- Components of the program - a multi-pronged approach:
  - **Graduate courses** offered to local universities e.g. UBC, UVic, and to remote locations via videoconferencing – lectures are now taped.
  - **Graduate students** conduct their thesis research at TRIUMF under the mentorship of TRIUMF scientists (11 students).
  - Apply for **NSERC grants** for research and graduate student training.
  - Increase number of **adjunct professors** at Canadian universities.
  - *Establish **Accelerator Physics & Engineering faculty** at Canadian universities – **discussions with UVic.***

Accelerator Science NSERC Grants

- A critical element of establishing a graduate student program in Accelerator Science and Engineering in Canada.

- ***Under a new initiative for TRIUMF and Canada, NSERC is now supporting accelerator science research and graduate student training. Accelerator Division scientists supervise and mentor students for their thesis projects.***

- *Seven accelerator proposals* were submitted in last three years to the subatomic-physics evaluation section. All funded at some level. New requests will be submitted this year.

Accelerator NSERC Grants

Proposal	Pis	Duration [years]	Competition year
Diagnostics, machine protect, controls for e-linac	Karlen, Chao Koscielniak Mattison	3	2011
Optimization platform for accelerator & transport design	Chao, Baartman	3	2011
Resonance Ionization Mass Spectroscopy	Lassen	5	2011
Cyclotron Physics	Baartman, Rao	3	2012
Fundamental Studies in SRF	Laxdal	5	2012
A Programme of Research and Development on the Improvement of SRF Cavities for Future Accelerators	Merminga, Orr, Laxdal, Baartman	3	2013
Développement de l'ensemble cibles et sources d'ions pour le projet ARIEL à TRIUMF	Bricault	3	2013

Summary

- TRIUMF accelerators enable a world-class, multi-disciplinary science program.
- With ARIEL, TRIUMF is poised to be a unique, world-leading RIB facility.
  - ARIEL will substantially expand the TRIUMF RIB with increased number of hours delivered, multiple simultaneous beams and new species, and increased beam development capabilities.
  - The 0.5 MW e-linac is a state-of-the-art facility which promises to advance nuclear physics, materials science and nuclear medicine. Represents a path to a linac-based light source in Canada.
- Steady, significant progress towards realizing ARIEL. On track for:

  Buildings construction completion – August 2013

  Injector Cryomodule beam test – November 2013

  25 MeV, 100 kW beam power – Sept 2014: e-Linac Project Complete

Thank you!
Merci!

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The ARIEL Team

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At UVic: Karlen, Abernathy, Birney, Langstaff, Storey.

VECC Tests Contributors:

J. Abernathy, F. Ames, Y. Chao, D. Dale, S. Dechoudhury, D. Dutta, K. Fong, C. Gong, P. Harmer, J. Holek, D. Karlen, A. Laxdal, R. Laxdal, A. Leung, D. Lang, D. Louie, A. Miller, A. Mitra, D. Morris, V. Naik, W. Rawnsley, J. Richards, S. Saminathan, C. Schaub, R. Shanks, D. Storey, V. Verzilov, P. Vincent, A. Vrielink, G. Waters, Q. Zheng