TRIUMF

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

The Advanced Rare Isotope Laboratory
ARIEL

June 18, 2014

Isotopes for Science and Medicine

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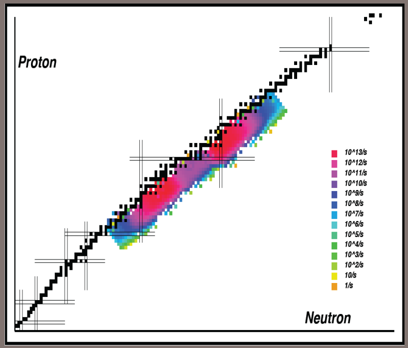
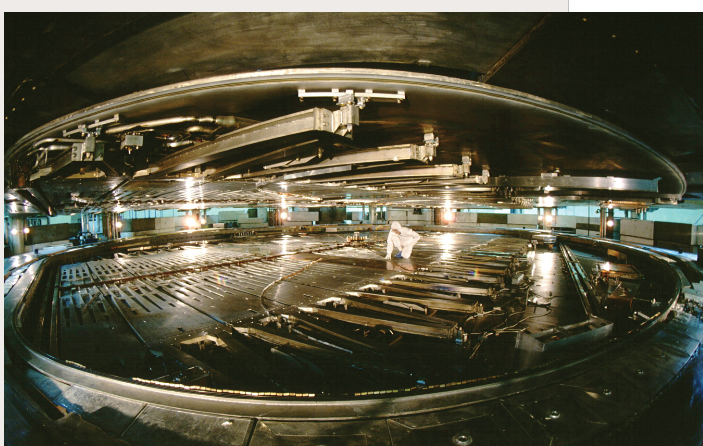
Professor of Physics | University of British Columbia

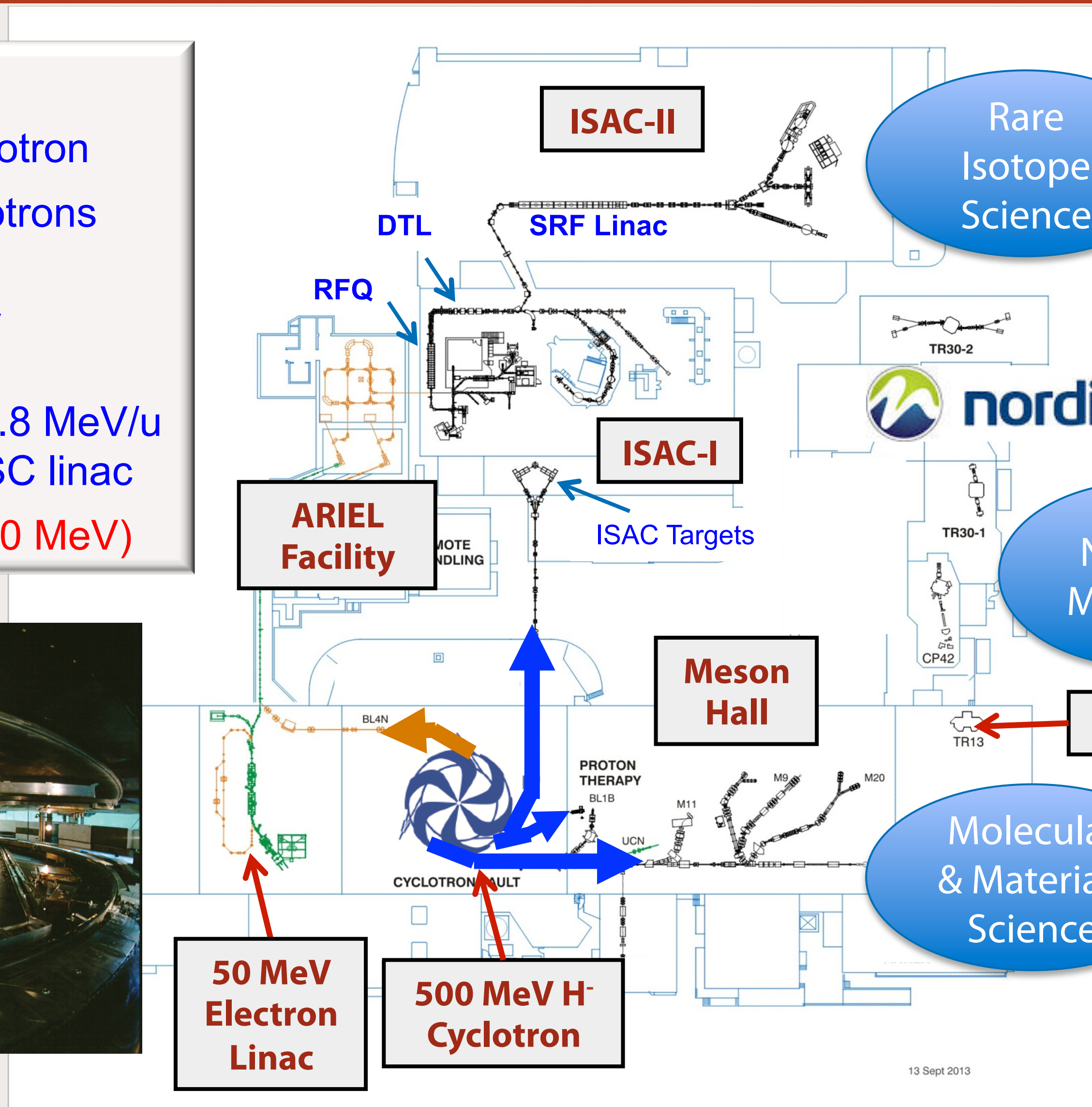


TRIUMF accelerator complex

TRIUMF Accelerators:

- 500 MeV, 350μA,H^- cyclotron
- 4 medical isotopes cyclotrons (TR13,CP42,TR30x2)
- ISAC 50kW ISOL facility
  - RFQ, 3 ≤ A/q < 30
  - DTL, A/q ≤ 7, 0.1-1.8 MeV/u
  - 40 MV Heavy Ion SC linac
- ARIEL e-linac (10mA, 50 MeV)

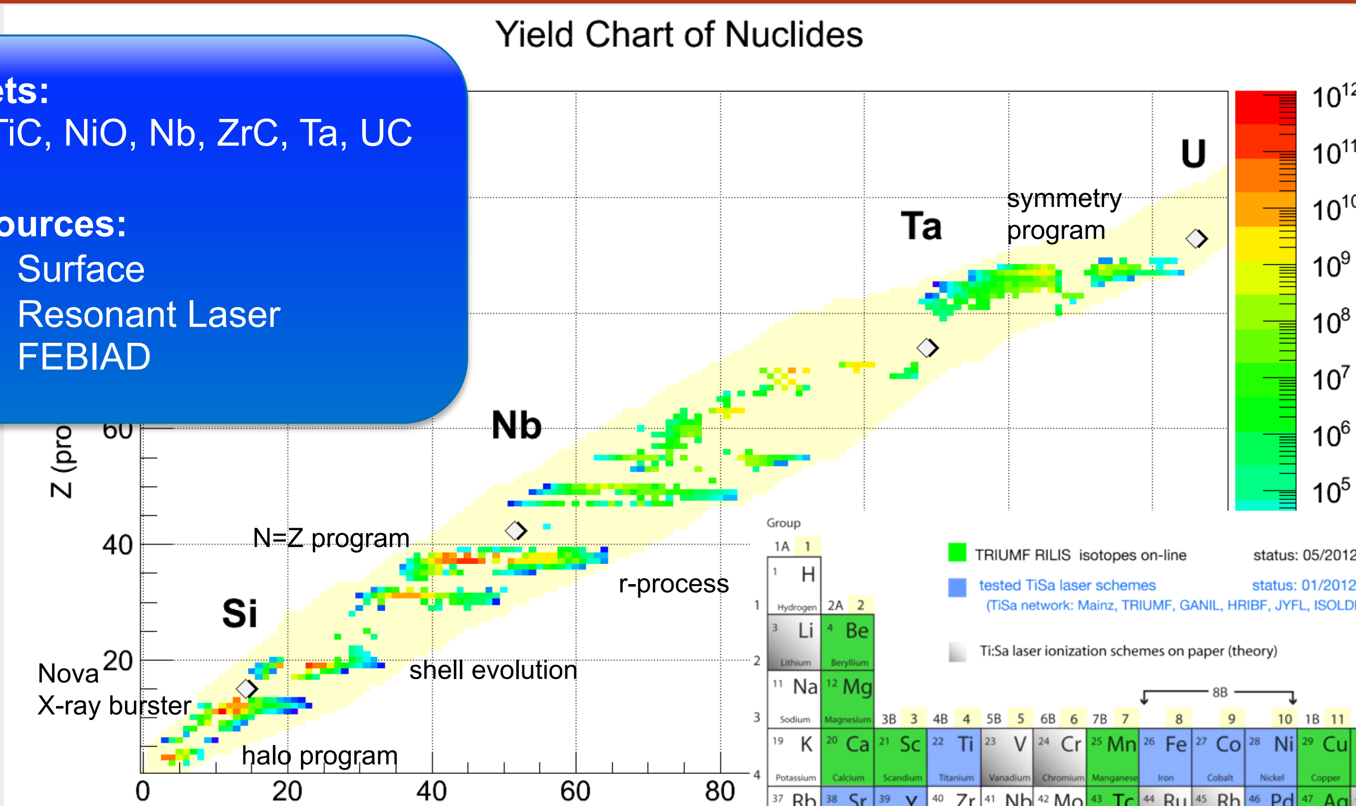




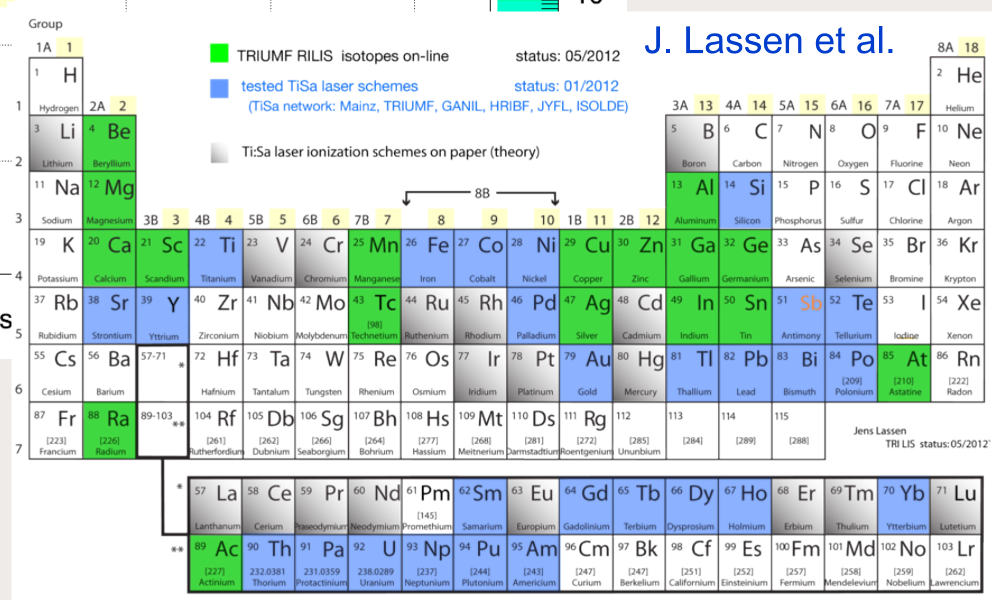
ISAC isotopes

Targets:
SiC, TiC, NiO, Nb, ZrC, Ta, UC

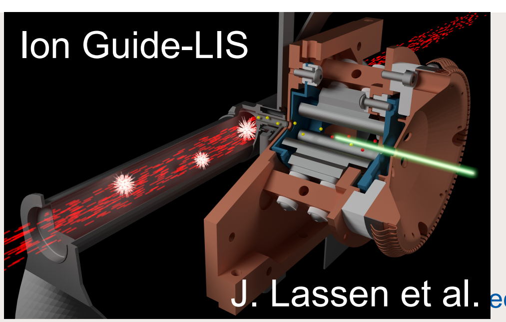
Ion sources:
- Surface
- Resonant Laser
- FEBIAD



P. Kunz et al.



J. Lassen et al.



J. Lassen et al.

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Isotopes for Science and Medicine

Isotopes for developing a standard model for nuclear physics:

Nuclear Structure

- probing ab-initio theory in light and medium-mass nuclei
- understanding the role of 3N forces in the shell evolution of nuclei

Isotopes as laboratories search for new forces in nature:

Fundam. Symmetries

- Setting world-leading limits on physics beyond the standard model
- Developing leading EDM experiments for the atom (RnEDM) and electron (FrEDM)

Isotopes to determine the origin of the heavy elements in the universe:

Nuclear Astrophysics

- Understanding the nucleosynthesis in nova and x-ray bursters
- Delineating the r-process path and identifying its astrophysical origin

Isotopes as probes of magnetism at interfaces and surfaces:

Materials Science

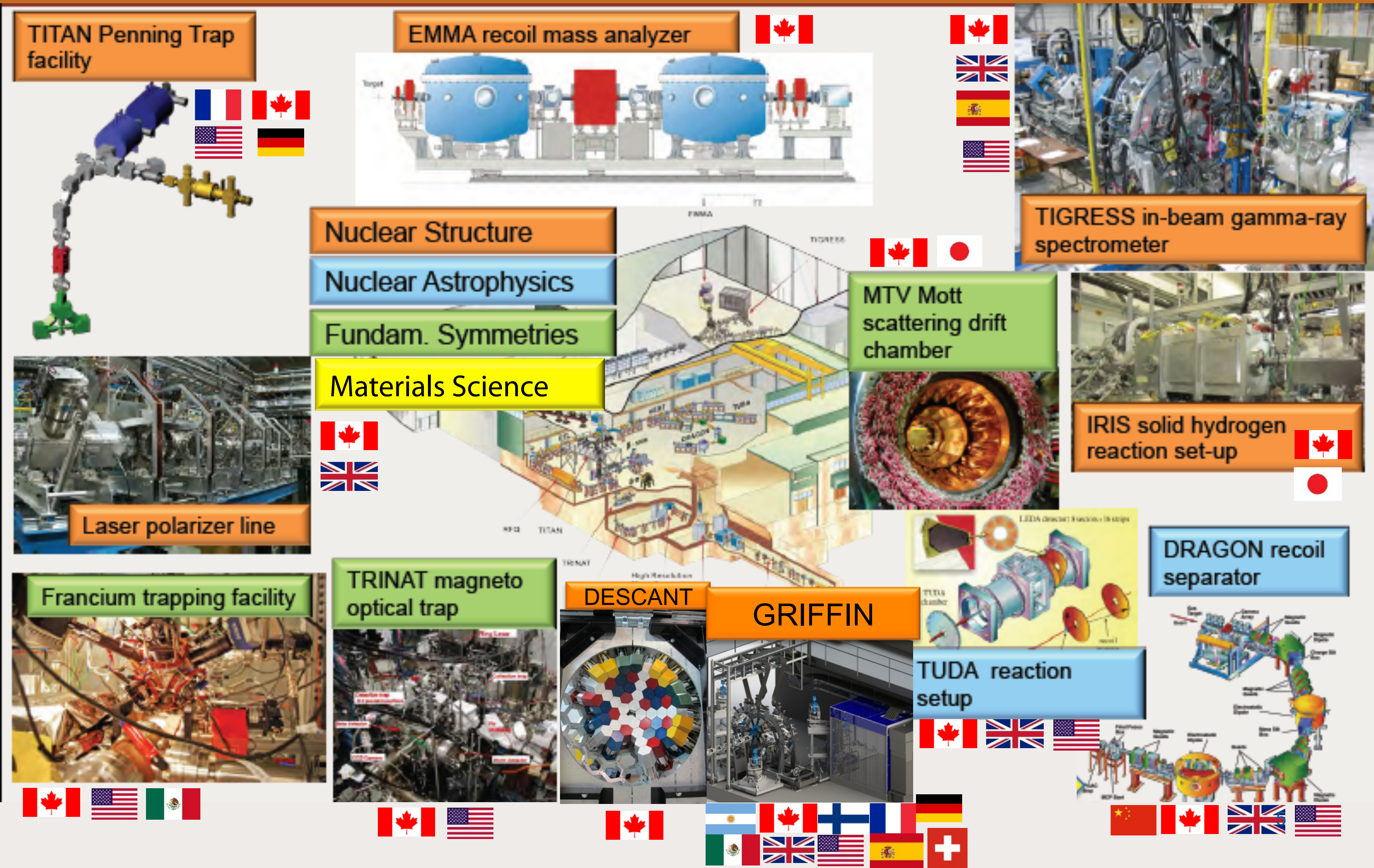
- Expanded user program in depth controlled β-NMR
- Understand magnetic and electronic properties of surfaces and interfaces
- Develop better battery materials

Nuclear Medicine

Isotopes for molecular imaging of diseases and treatment of cancer:

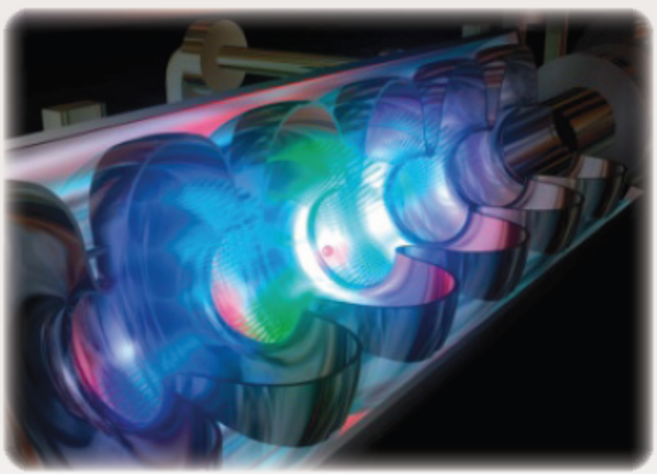
- Produce research quantities of alpha emitting isotopes for targeted alpha tumor therapy
- Develop new designer isotopes for diagnostics and treatment

ISAC Experimental facilities and programs



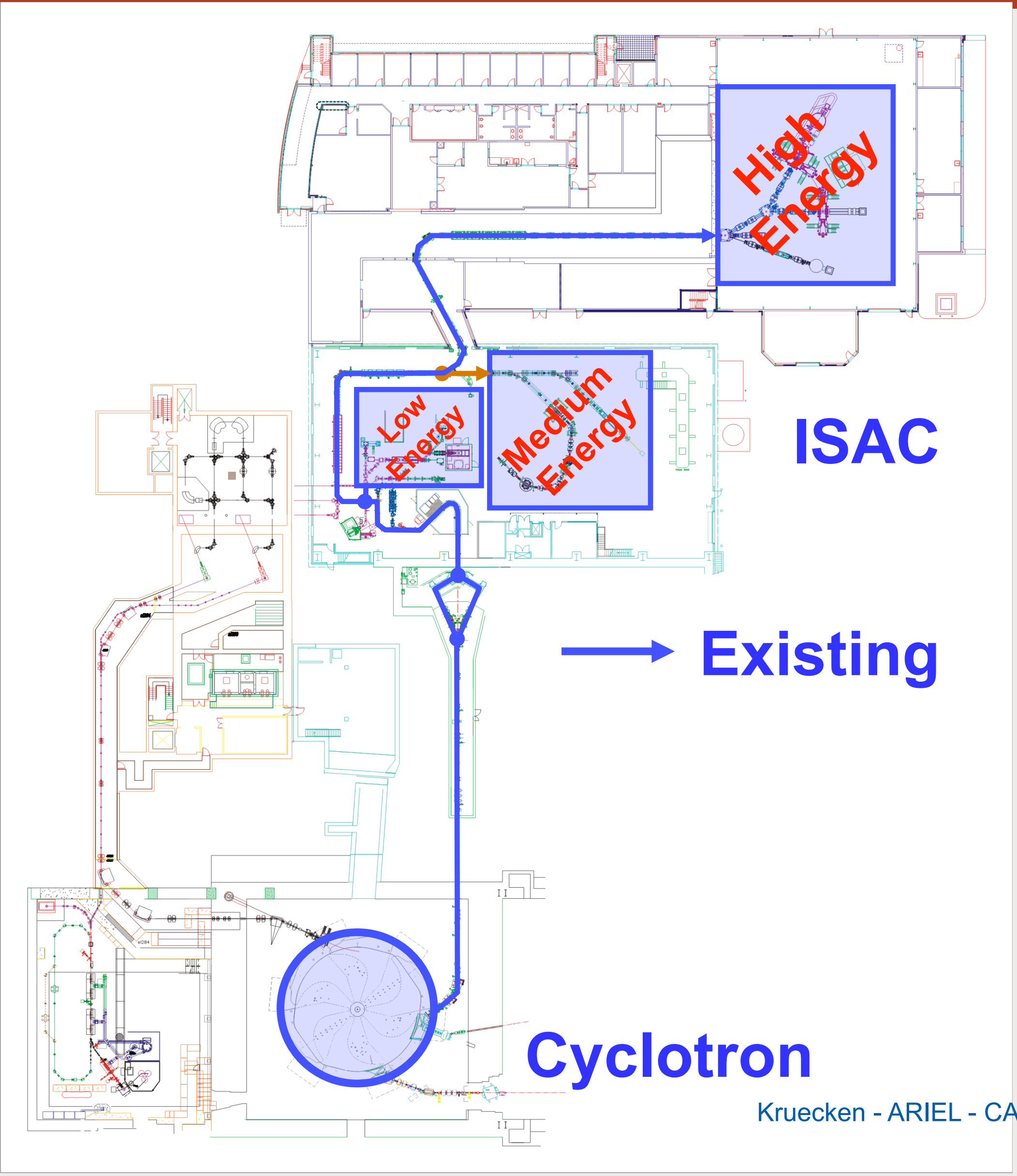
TRIUMF ARIEL

ADVANCED RARE ISOTOPE LABORATORY



ARIEL will be TRIUMF's flagship Rare Isotope Beam facility for the production of isotopes for science 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.

Advanced Rare IsotopE Laboratory



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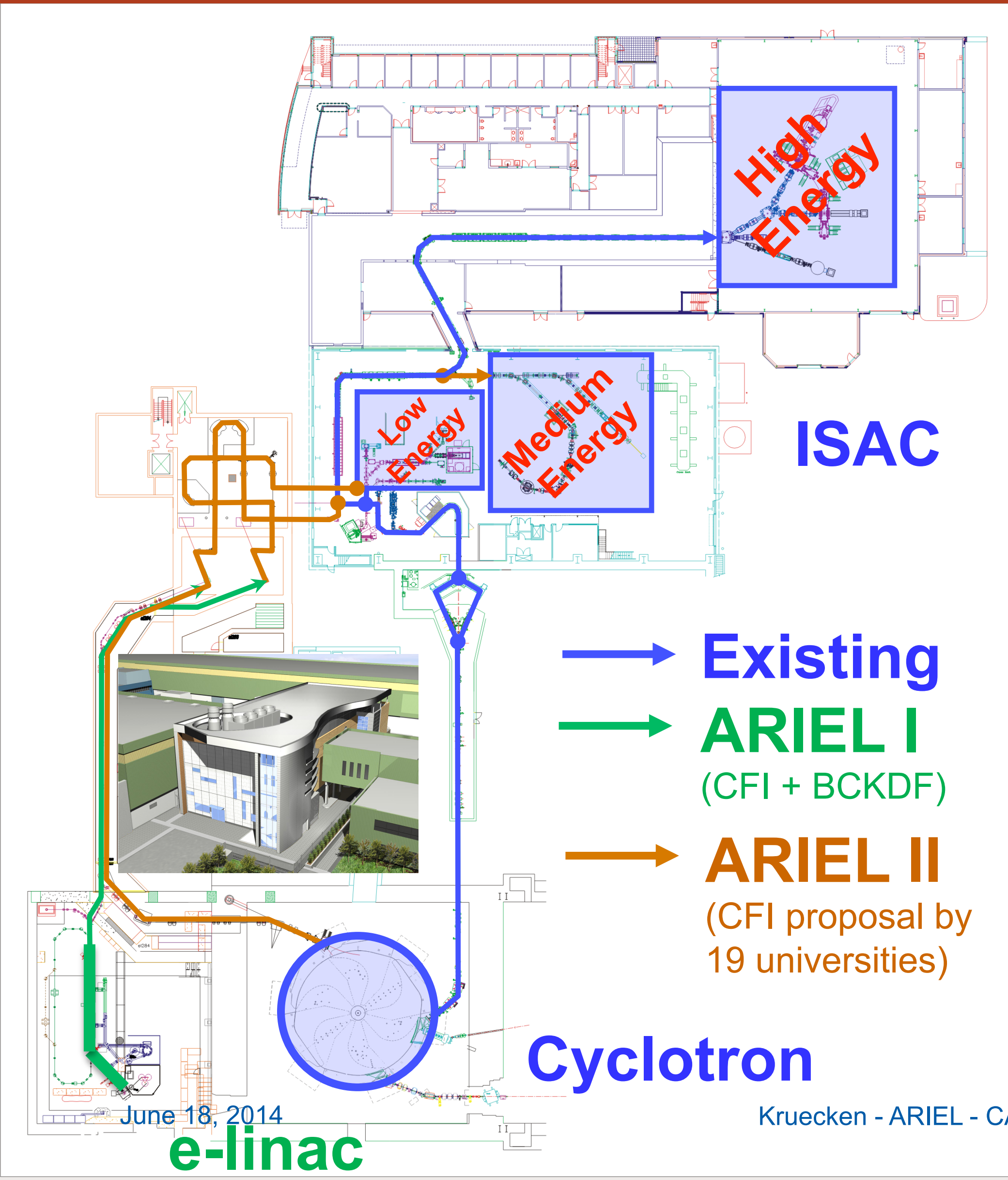
Advanced Rare IsotopE Laboratory



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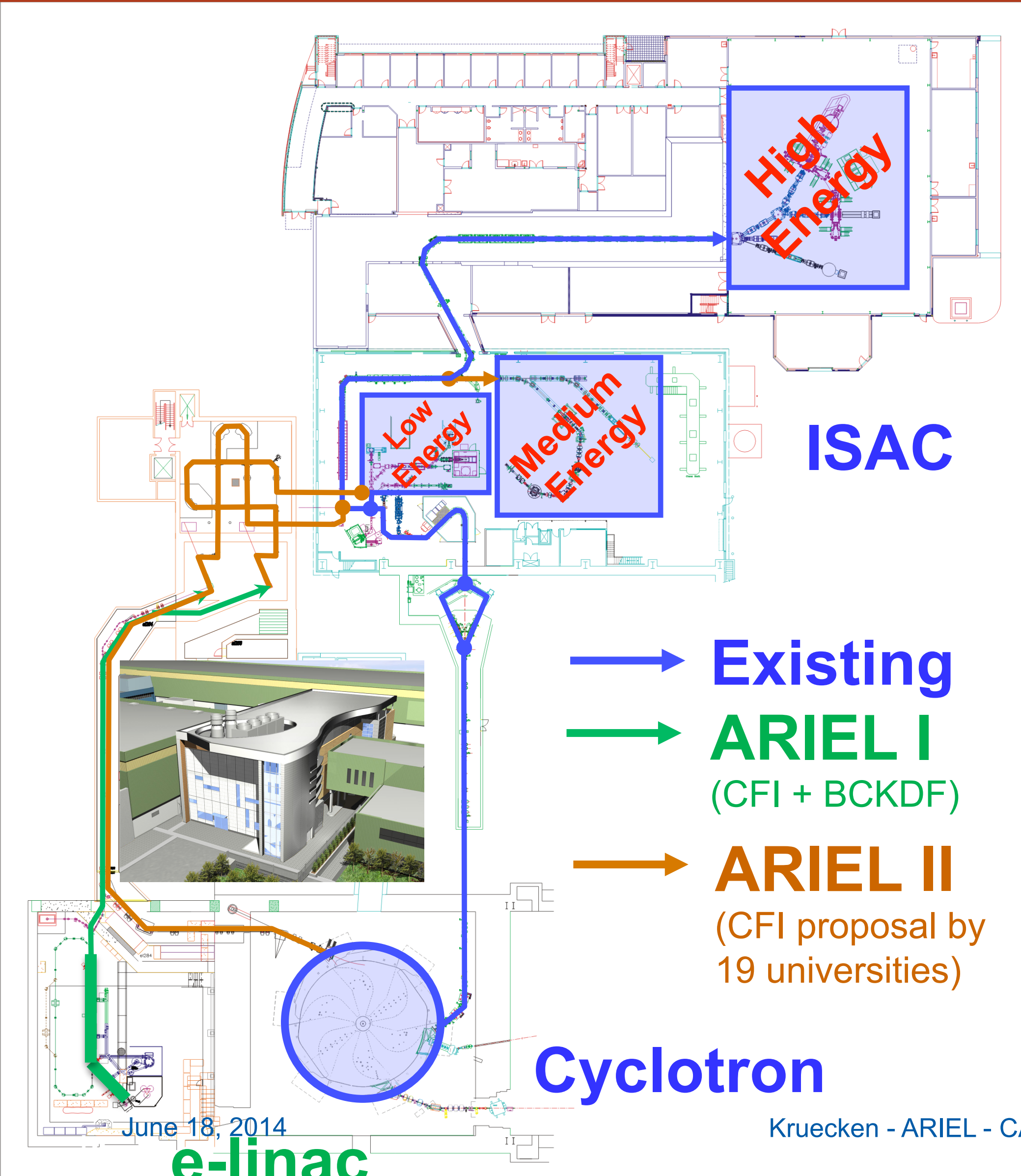
Advanced Rare IsotopE Laboratory



Completing & operating ARIEL absolutely central to realizing laboratory vision:

Global leadership for Canada in Isotopes for Science & Medicine

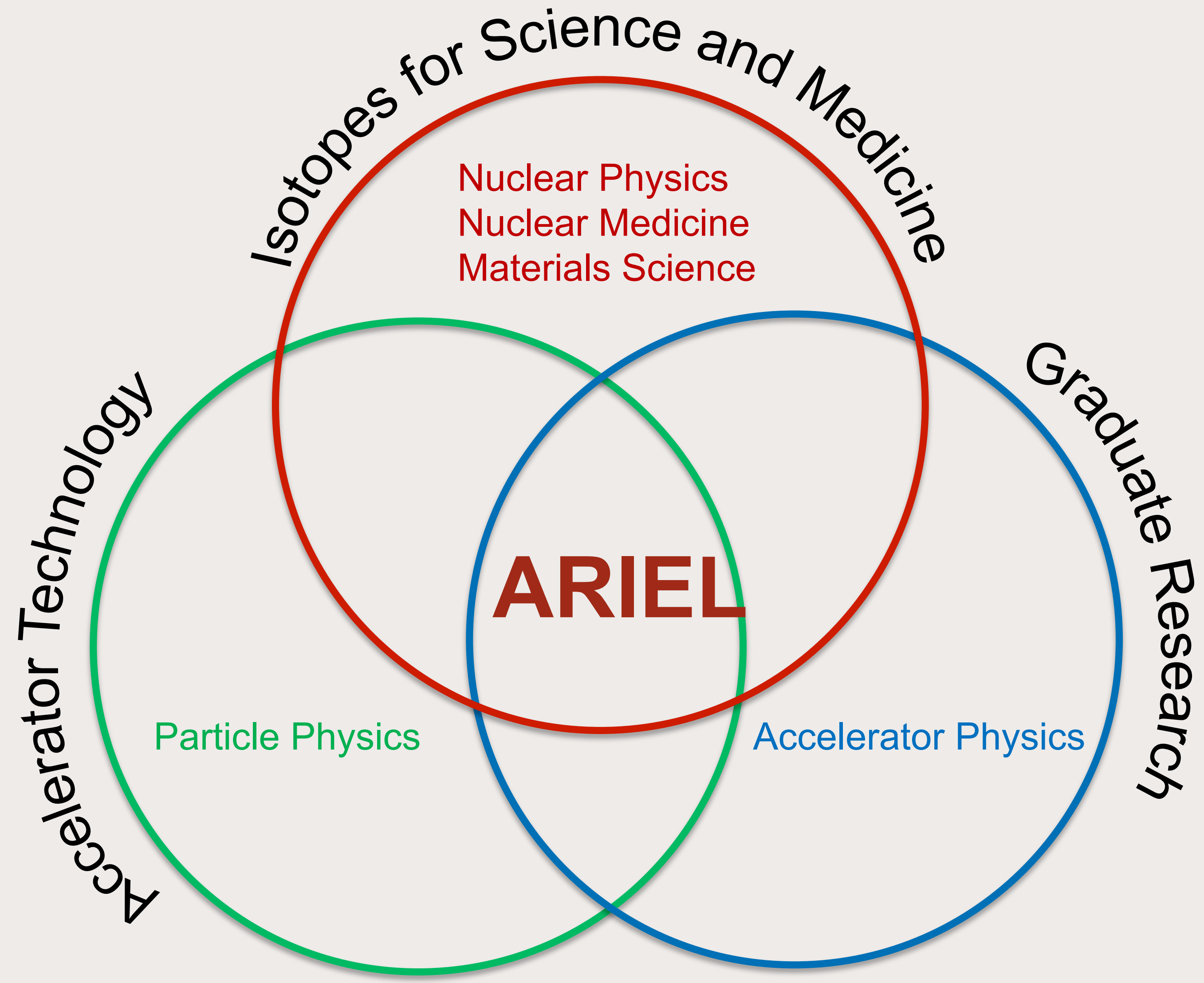
Substantially expands capabilities:

- Three simultaneous beams
- More and new isotopes
- Enables new experiments
- Expands national & international users
- International partnership w/ India
- World-leading capabilities
- Serves Canada and society

Implementation:

- Two new drivers: electron & proton
- Two new target stations and front end
- **Interleave science with construction**

ARIEL: Synergies & Connections



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ARIEL Buildings Occupancy

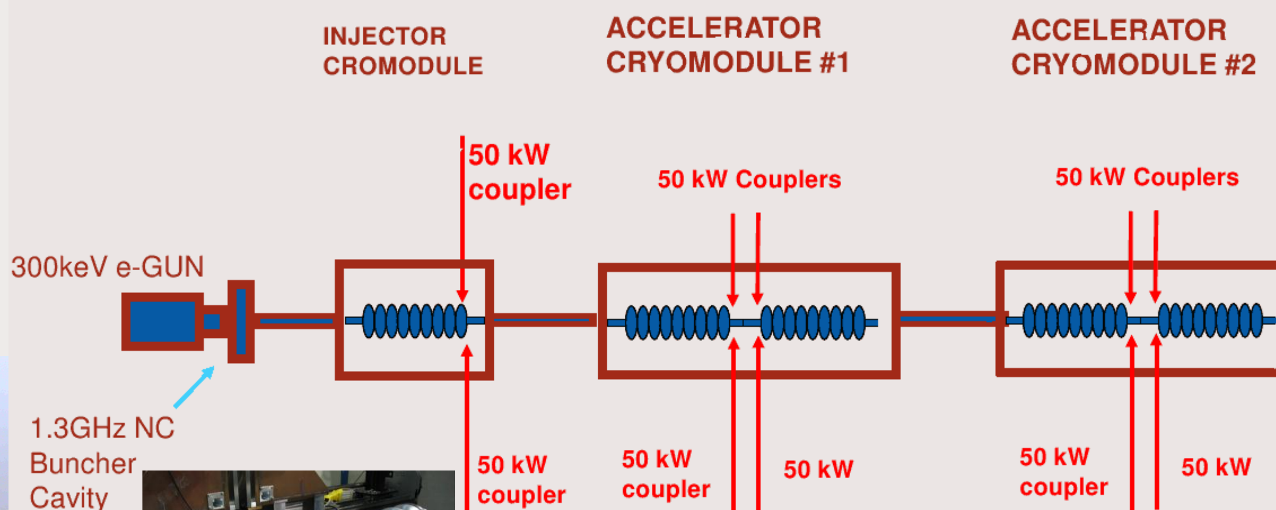
ACEC-BC* Award of Merit, 2014 April 11

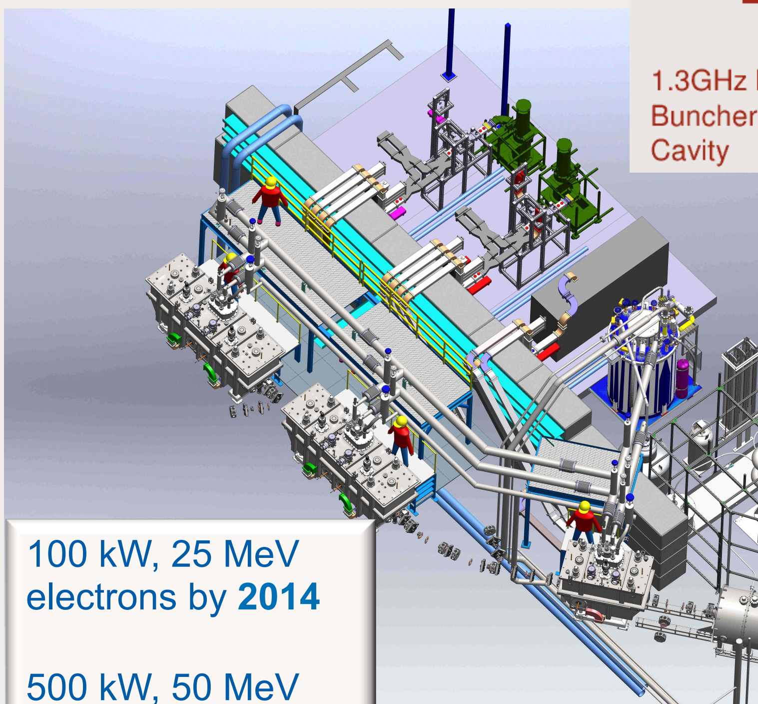
- **Culmination of 3 years work**
- **Meets needs of entire ARIEL scope**

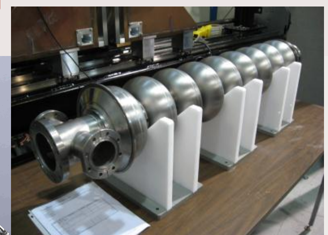
*Association of Consulting Engineering Companies of BC.

e-linac: MW-class Superconducting Electron Accelerator

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







100 kW, 25 MeV electrons by **2014**

500 kW, 50 MeV electrons by **~2020**

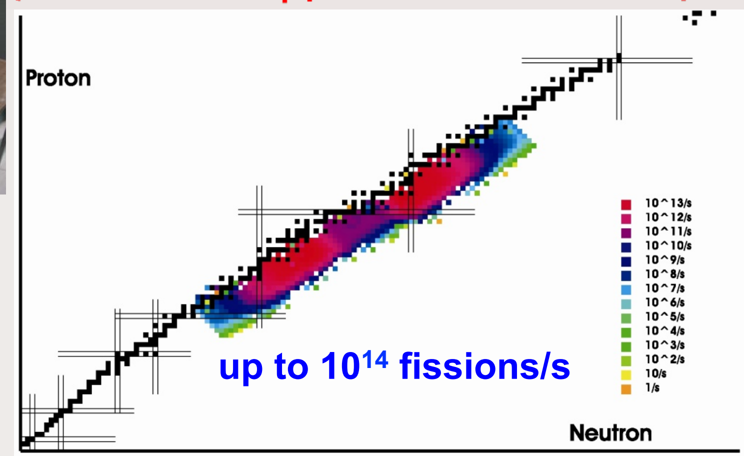


Photo-fission products using 50 MeV 10 mA electrons onto Hg convertor & UC_x target.

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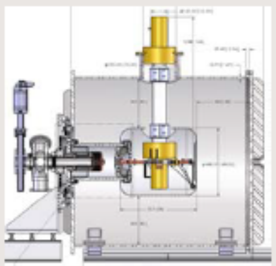
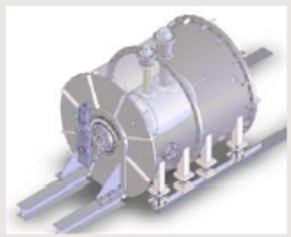
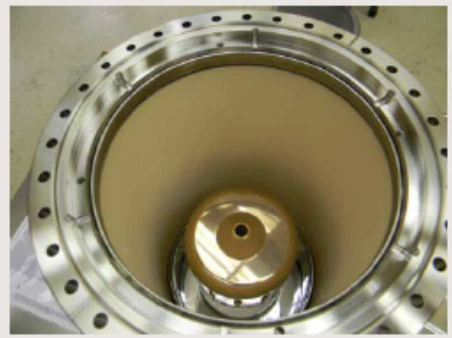
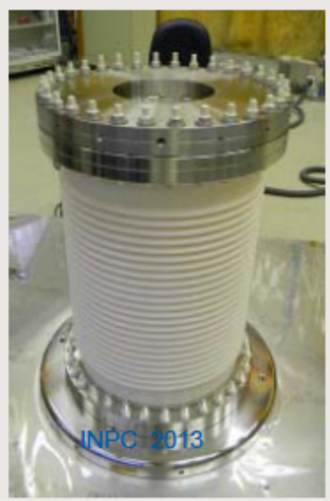
300 kV electron gun

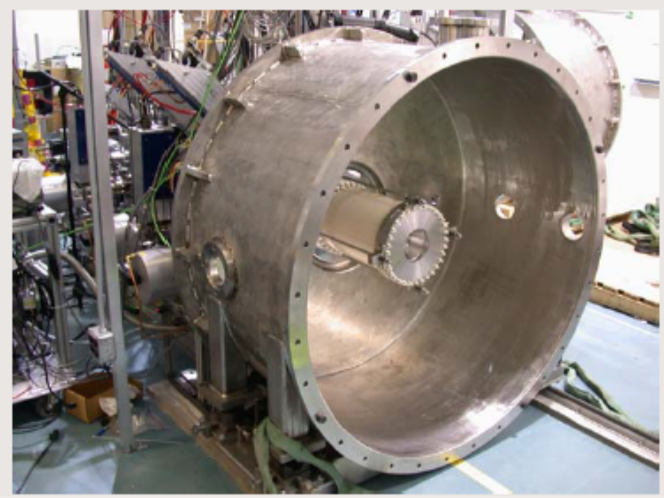
- 10 mA thermionic gridded gun, emittance 5 μm rms
- RF modulated grid at 650 MHz
- Use of dielectric waveguide to transmit modulation from ground potential to gun
- Gun commissioning June 2013







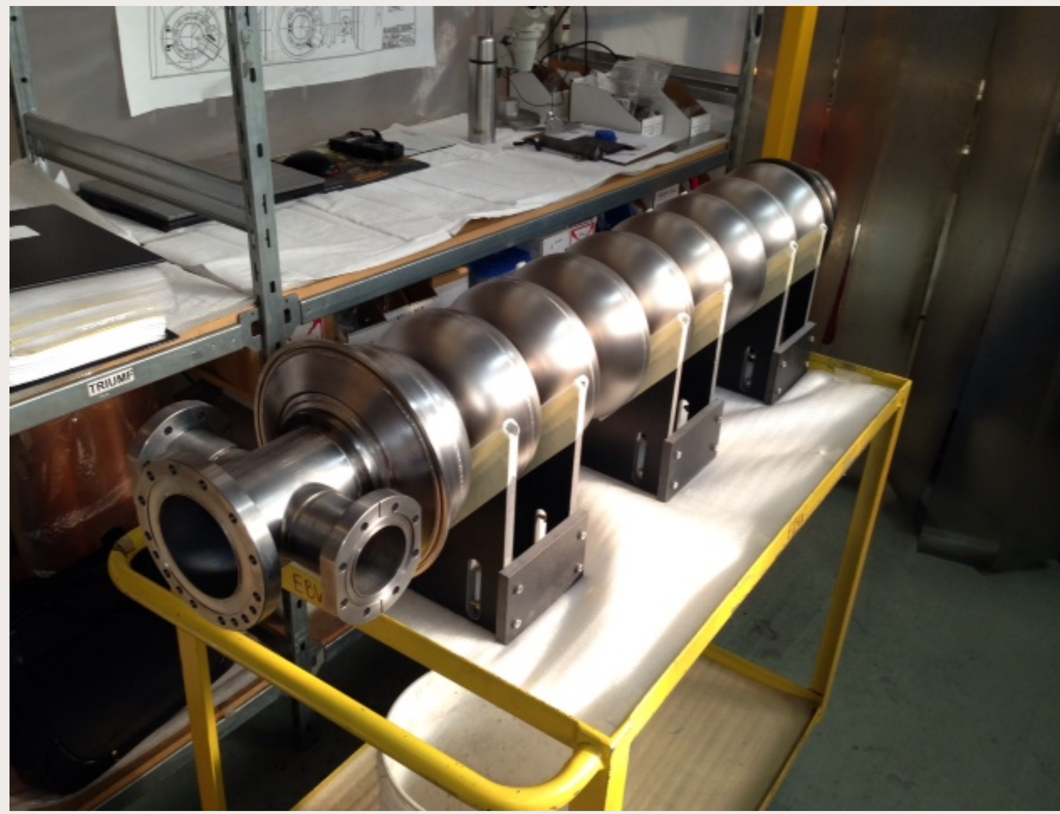




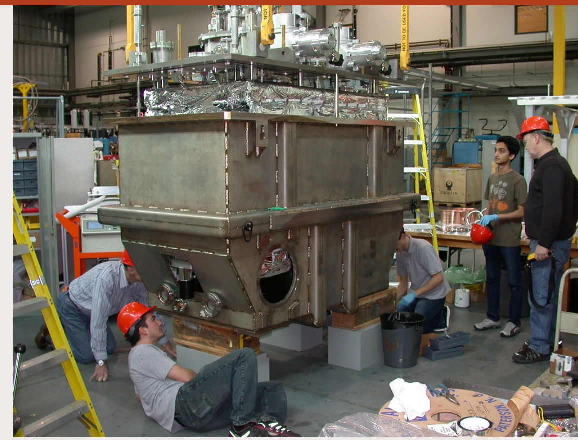
"Made in Canada" Superconducting RF Cavities

Multi-cell SRF cavity fabrication by PAVAC, Inc.

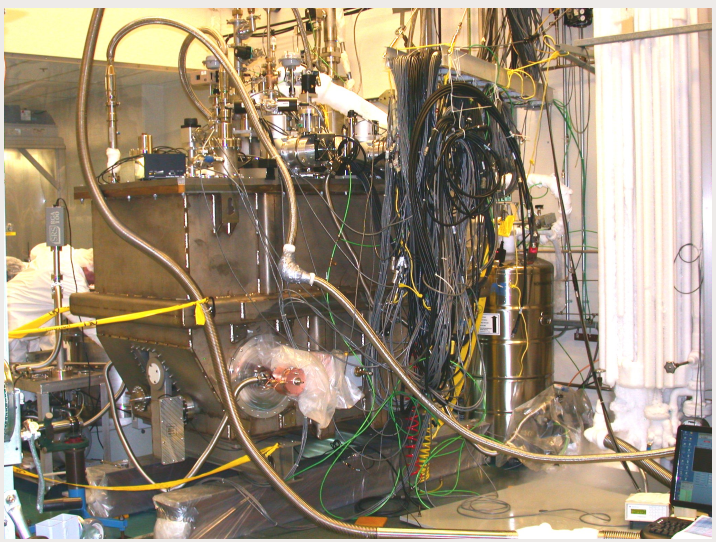
Status:
- Three cavities delivered
- One more in fabrication



Injector CM Final Assembly & Cold 2K Test



2014/04/07
Cold mass
in cryostat

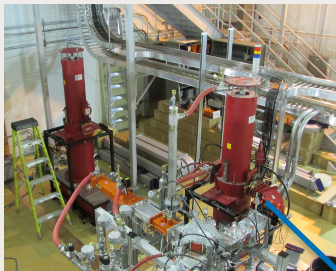


Cold test start 2014/04/17

2014/04/25 2K cold test complete.

e-linac progress

Klystrons

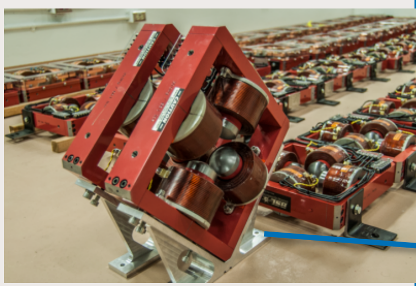


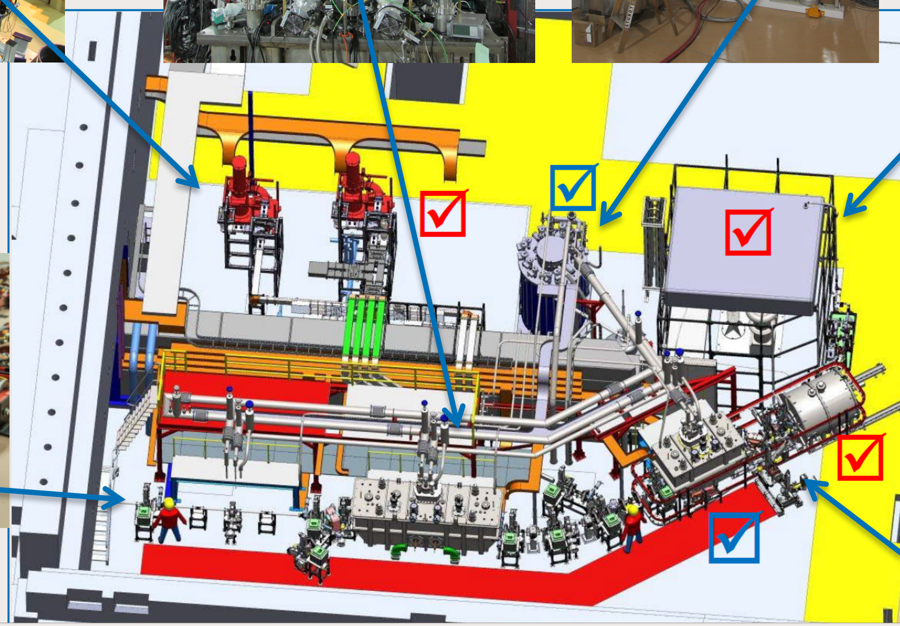
Cryogenics infrastructure

LHe cold box

e-Gun HV power supply

Beamline magnets



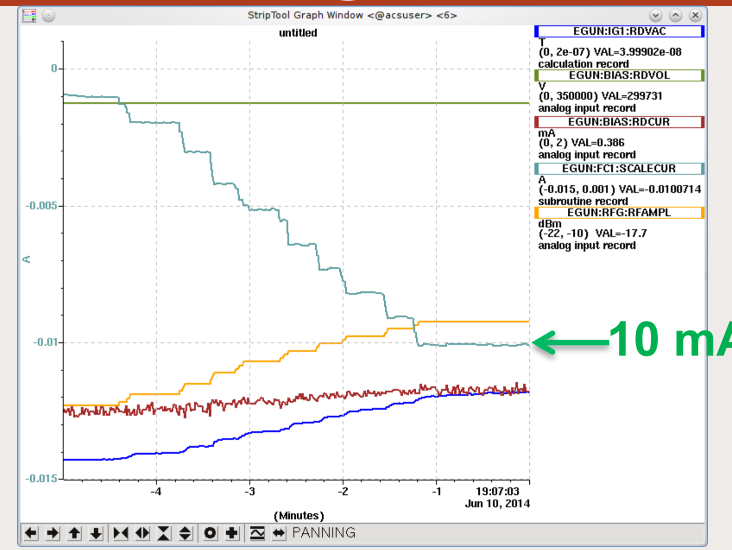


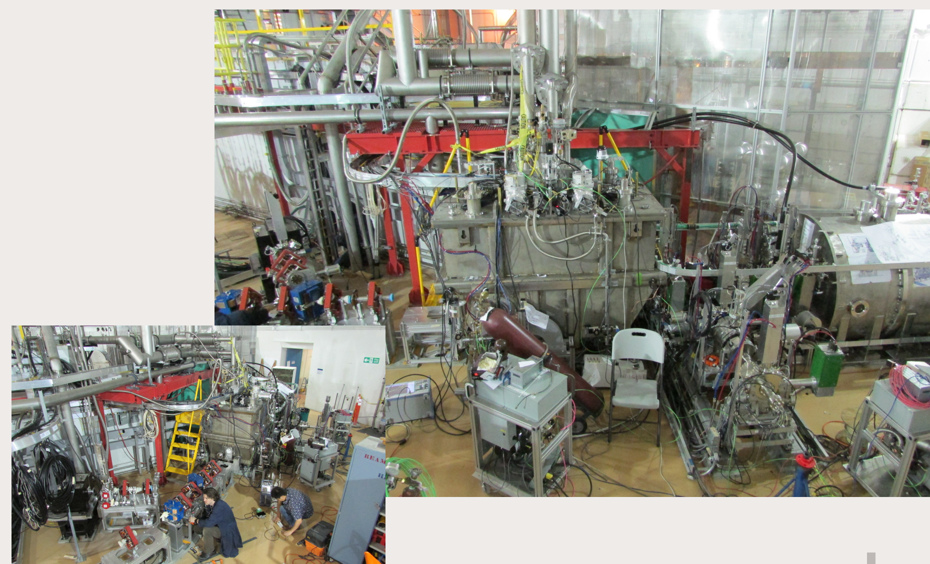
e-Gun and injector cryomodule

- E-gun and injector cryomodule installed in e-hall
- Commissioning started (CNSC license for 3kW, 10mA egun, 4K cooldown of ICM)
- On track for fall delivery of 25MeV, 100kW beam

ARIEL e-Linac: Installation & Commissioning Status

- Electron source operated at 300 kV, up to 10 mA peak current @ 1% duty factor
- Klystron integrated RF system test has been completed at 1kW level
- RF delivered to cavity on resonance at 4K
    - Cavity RF field sustained in self-excited loop in accelerating mode
- Next steps: lock the field in amplitude and phase, at 4 or 2K – increase gradient to 10MV/m





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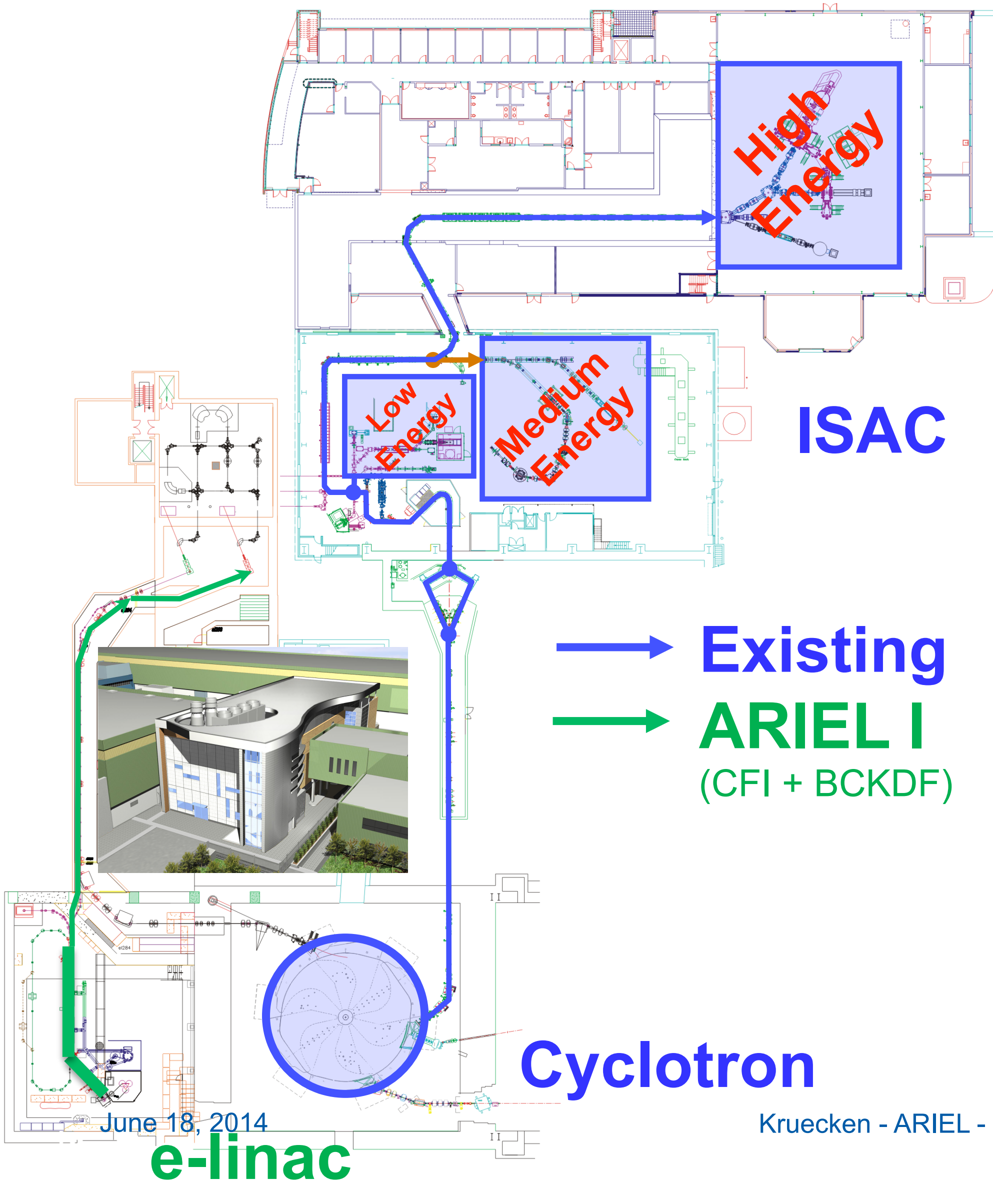

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Substantially expands capabilities:

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Implementation:

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- **Interleave science with construction**

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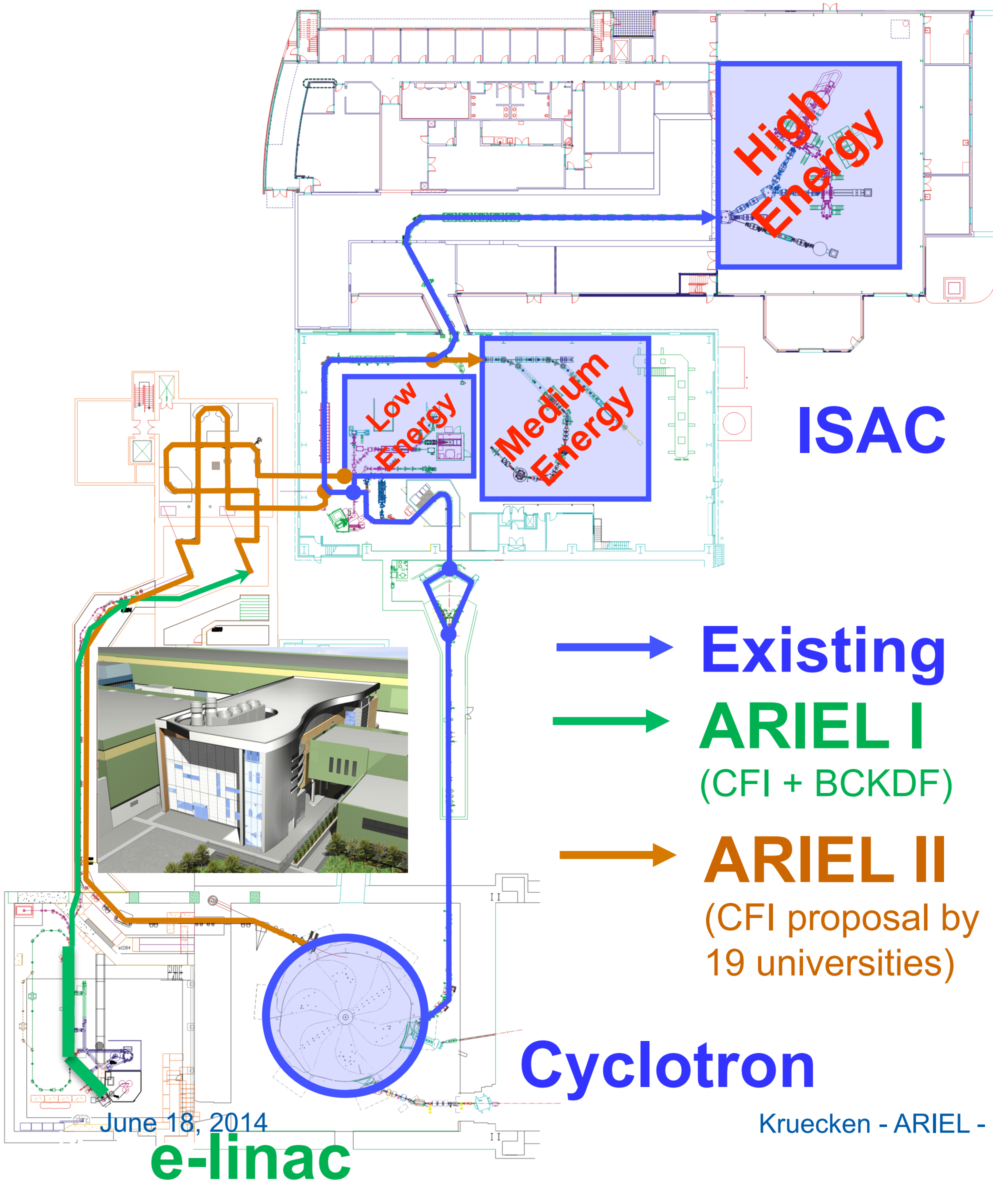

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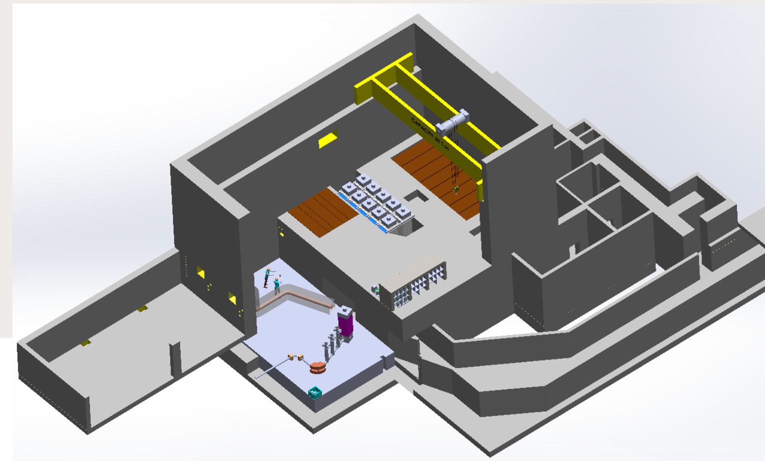
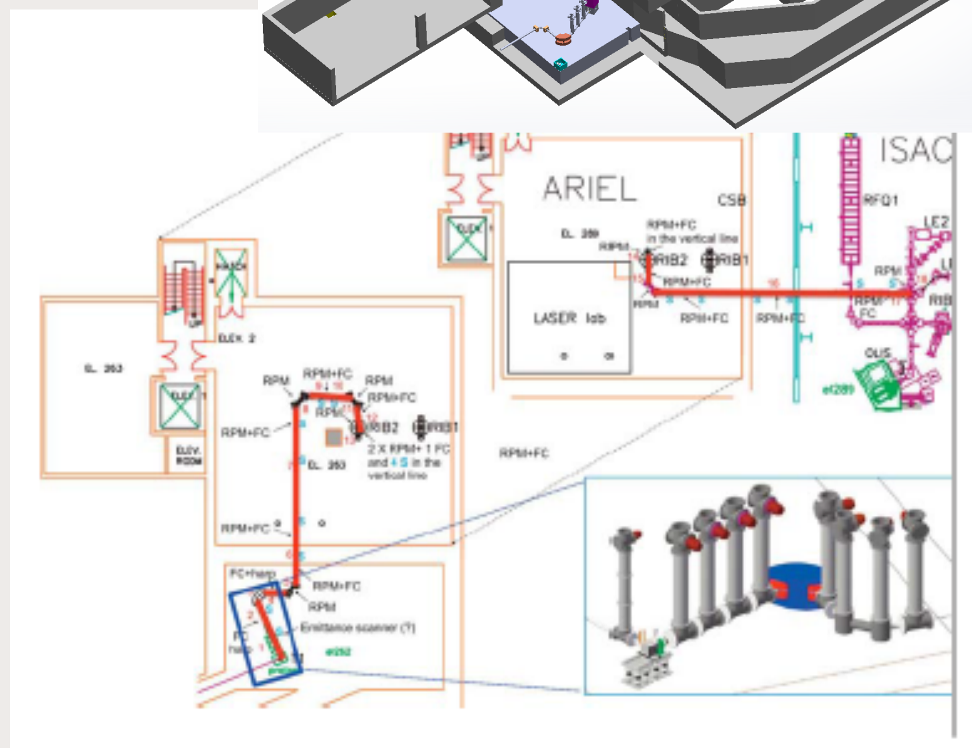
Phase 1: Li-8 for β-NMR

Goals:

- Photo-production of Li-8 in a Be-9 target using bremsstrahlung photons produced by stopping 100 kW electron beam in a solid metal target, and delivered to β-NMR.





Requires:

- ARIEL e-linac 30 MeV 100 kW
- Non-actinide target station with solid converter
- Pre-separator & beamline to β-NMR

ARIEL II Phase 1: VECC MoU ADD-3

Phase 1 will be done in collaboration with VECC - Kolkata:

- In August 2013 MoU Add-3 was signed
- Scope includes two ARIEL target modules, tested in ARIEL, and front-end beamlines

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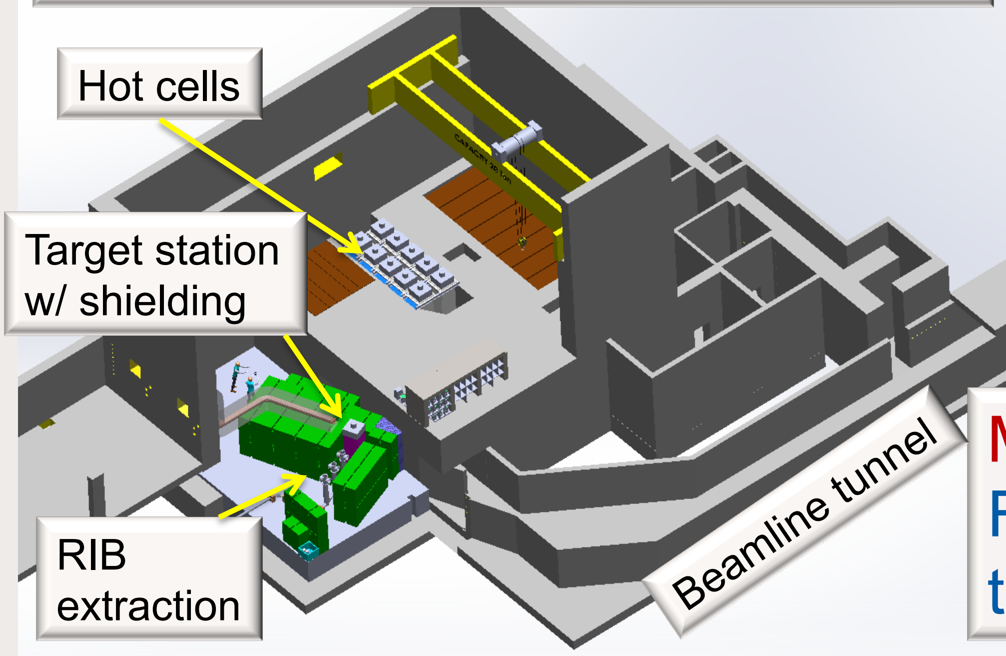
Phase 2: Photo-fission for r-process studies

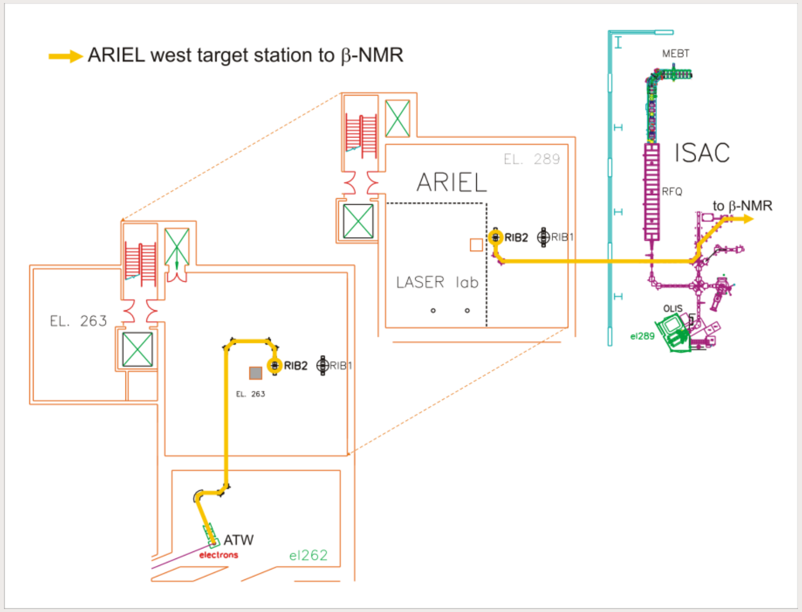
Goals:

- Production and delivery of neutron-rich fission fragments by implementing actinide targets in conjunction with the solid photo-converter.

Requires:

- east target station w/ actinides
- hotcell for work w/ actinides
- Medium Resolution Separator





Milestones:

First photofission beams from the e-linac to ISAC

Phase 3: Purified accelerated high mass RIBs

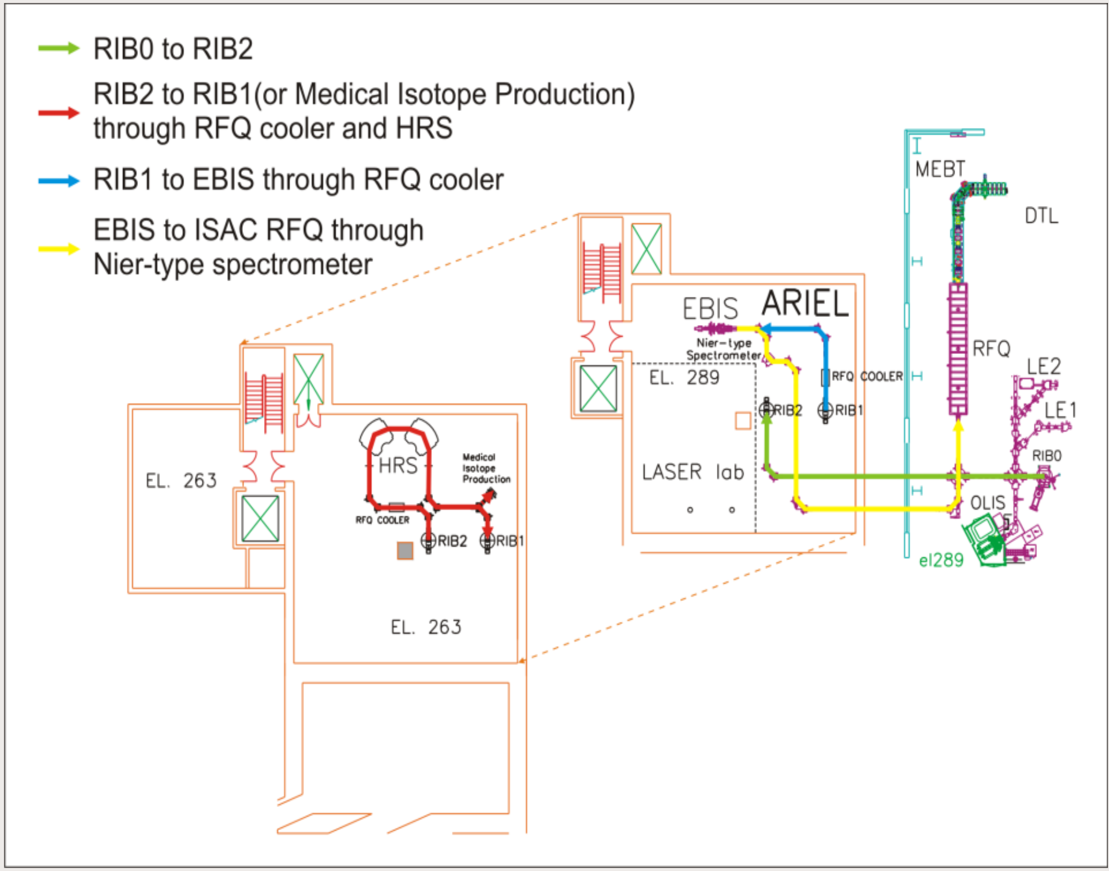
Goals:

- Transport ISAC RIBs with A>29 to the ARIEL building for advanced purification & charge breeding and deliver them to the ISAC energy experimental areas.
- A collection station for medical isotopes will be implemented.

CFI-funded CANREB project provides the essential components required for the ARIEL front-end: EBIS, HRS, RFQ cooler.

Requires (within ARIEL II):

- 60 m LEBT beamlines



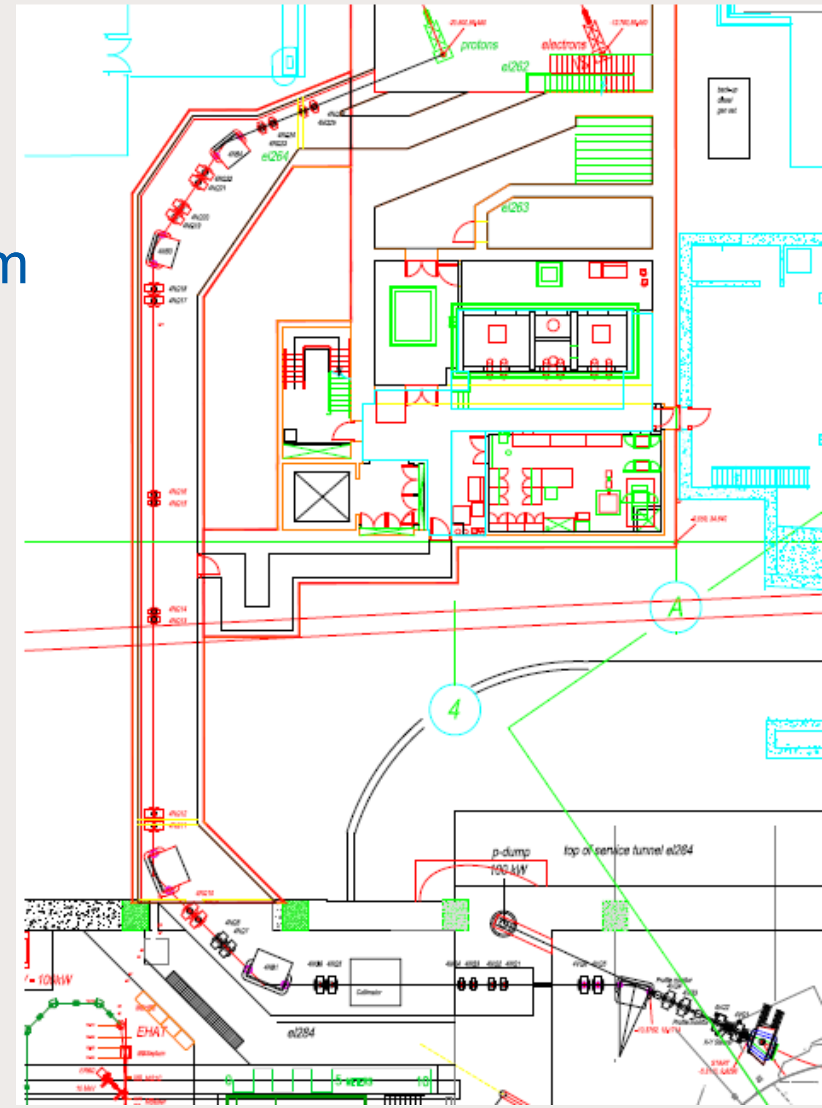
Phase 4: Actinide Production for Fundamental Symmetry Tests

Goals:

- Implement new proton beamline (BL4N) from cyclotron, delivering up to 100 µA at 500 MeV of proton beam to the West Target Station.

Requires:

- Proton beamline BL4N



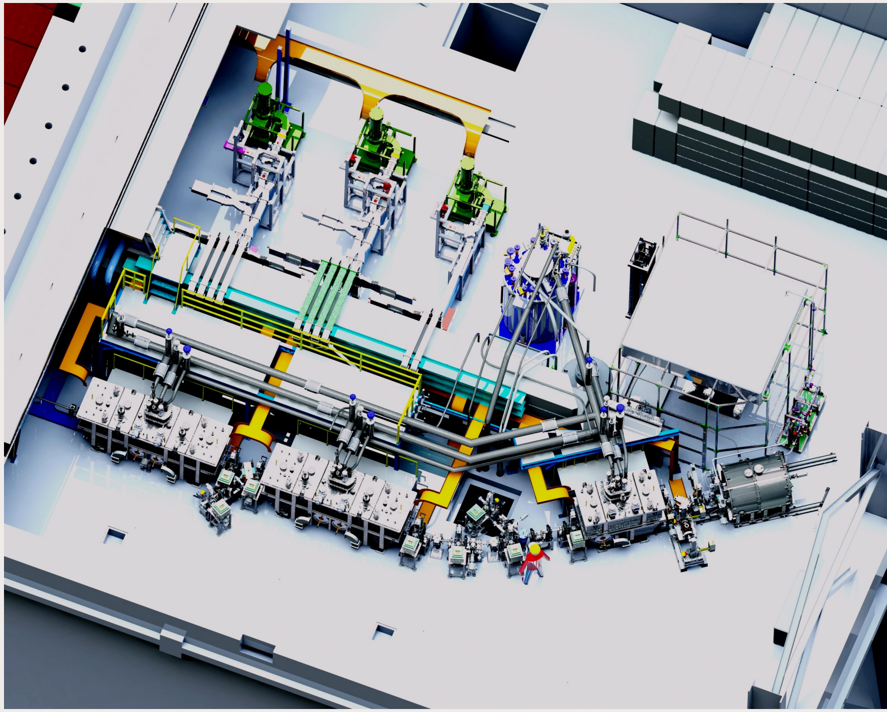
Phase 5: Full power e-linac to reach most exotic neutron rich nuclei

Goals:

- Increase the energy and power of the e- linac beam to full design specification 50 MeV, 500kW, producing up to 10^{14} fissions per second.

Requires:

- additional Accelerator Crymodule w/ 2 cavities
- additional klystron



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ARIEL-II Science Drivers & Implementation Criteria

Science Drivers

1. Increased beam time to β-NMR for full user program
2. Pure, heavy mass accelerated RIBs (from ISAC & ARIEL)
3. Reaching the r-process using photo-fission (w/ highest beam energy)
4. Enable long beam times for Fundamental Symmetries & Nuclear Astrophysics
5. Isotopes for Nuclear Medicine R&D

Technical and other Objectives

- Delivery of three simultaneous RIBs to users
- High intensity photo-converter development (to enable 500 kW operation)
- Extend TRIUMF's core competencies in SRF and high power targets

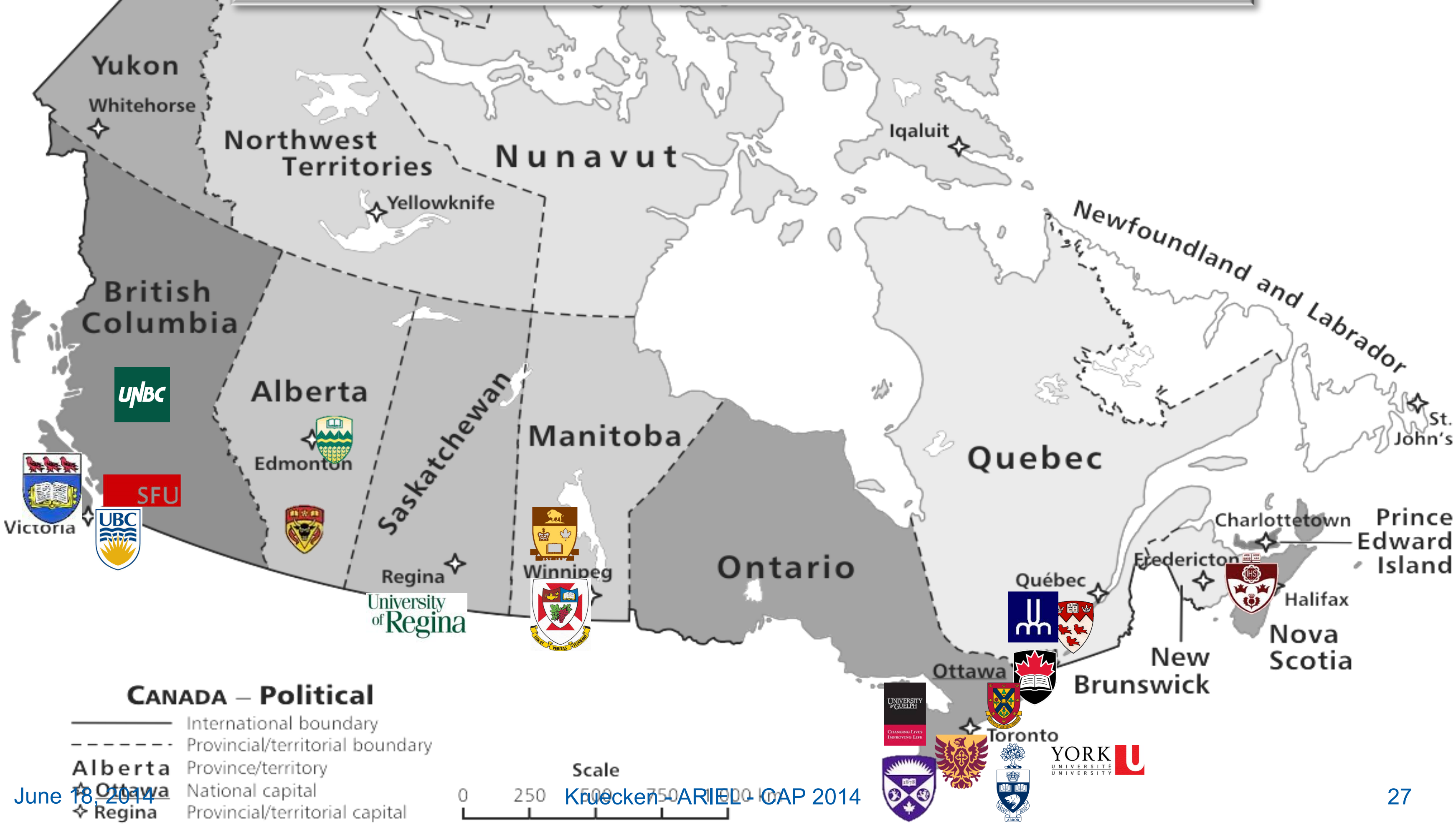
Phased Implementation

- Phased construction enables continuous stream of scientific results from ARIEL.

ARIEL-II: Completion to Science

$32.4M CFI application

19 participating universities (w/ envelope)



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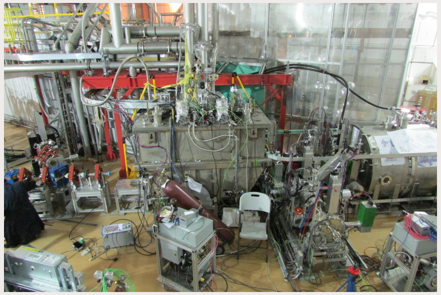
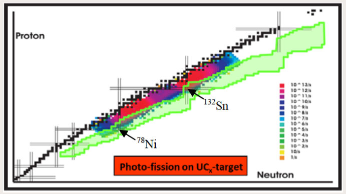
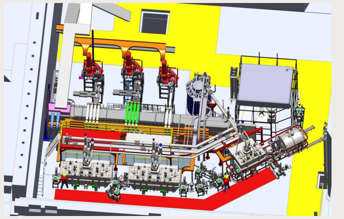
ARIEL Timeline





ARIEL-II Phase 2
Photofission ➔ r-process



ARIEL-II Phase 5
Extend r-process reach

June 2010
ARIEL Project begins

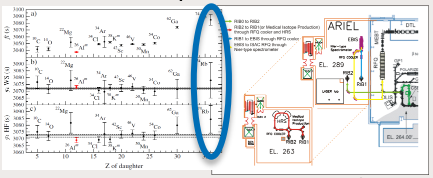
January 2013
CANREB CFI funding announcement

August 2013
ARIEL Building complete

September, 2014
e-linac Phase 1 Complete

March 2015
ARIEL-II CFI decision

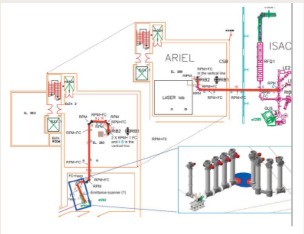
ARIEL-II Phase 3 (CANREB)
Pure High Mass accel. RIBs
Medical isotopes collection station



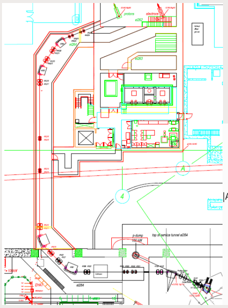
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020

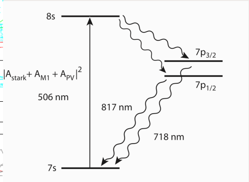
August 2013
TRIUMF-VECC MOU Add-3 signed

ARIEL-II Phase 1
Materials Science at β-NMR



ARIEL-II Phase 4 (BL4N)
Fundamental Symmetries
Two ARIEL beams

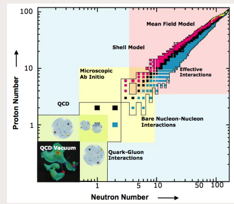




Complete ARIEL and tap its unique capabilities for isotope production.

Unified theory for all nuclei

- halo / dripline nuclei & ab-inito theory
    - ➔ high power proton beam
- shell evolution and 3N forces
    - ➔ high power electron beam



Origin of the heavy elements

- H & He burning
    - ➔ High power proton beam
    - ➔ Beam development time
    - ➔ Long beam times
- r-process in neutron-rich nuclei
    - ➔ High power electron beam

Fundamental Symmetries

- Francium and Radon EDMs and PNC
    - ➔ High power proton beam
    - ➔ Long beam times

➔ Need high-power proton and electron production in full multi-user operation w/ 3 production targets

TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY

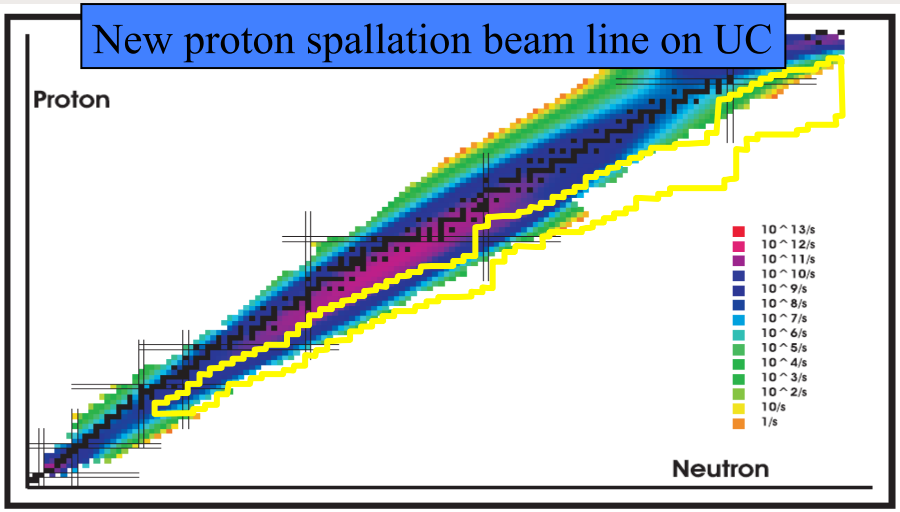


Figure 7: Production yield in target assuming a 10 μA proton beam onto a 25 g/cm² UC_x target using FLUKA.

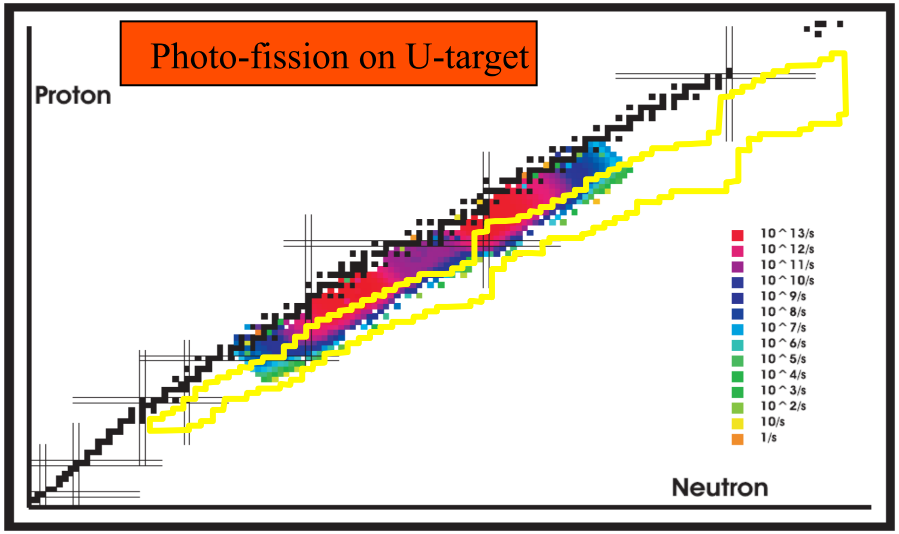


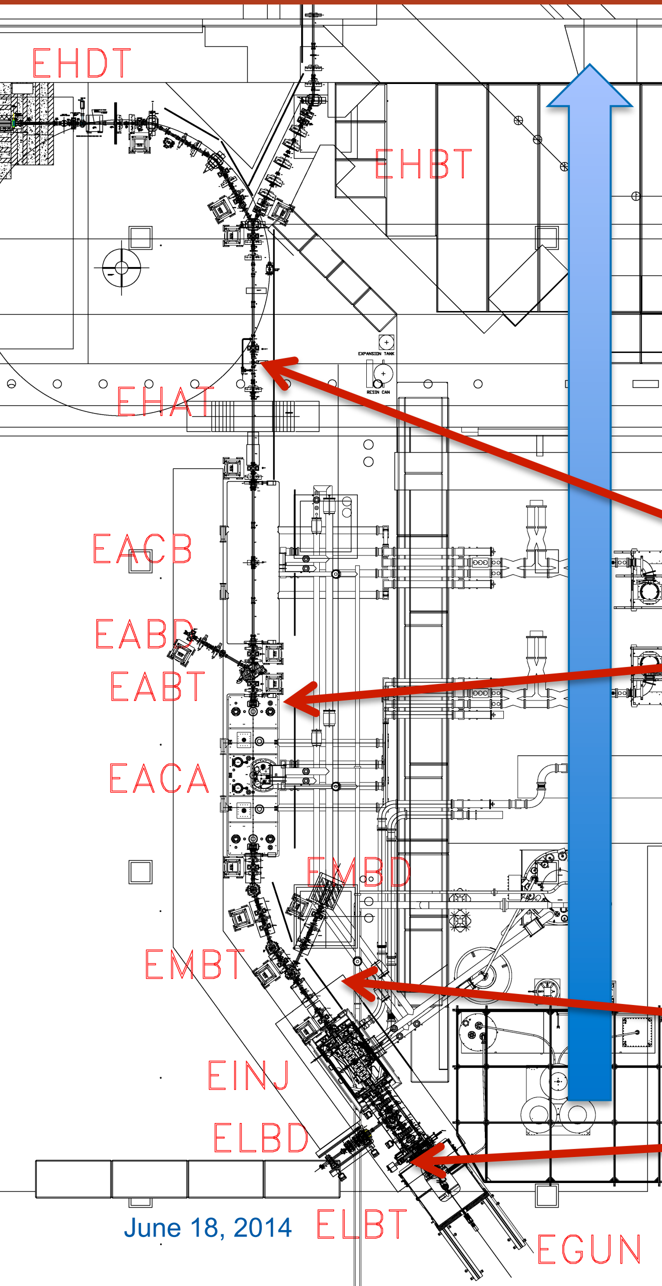
Figure 8: Production in target assuming 4.6x10¹³ photo-fission induced into a 15 g/cm² UC_x target.

Thank you!

Merci!

TRIUMF:
Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McMaster | McGill | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's Simon Fraser | Toronto | Victoria | Winnipeg | York

Campaign staged: follows build out of equipment & increase of beam power

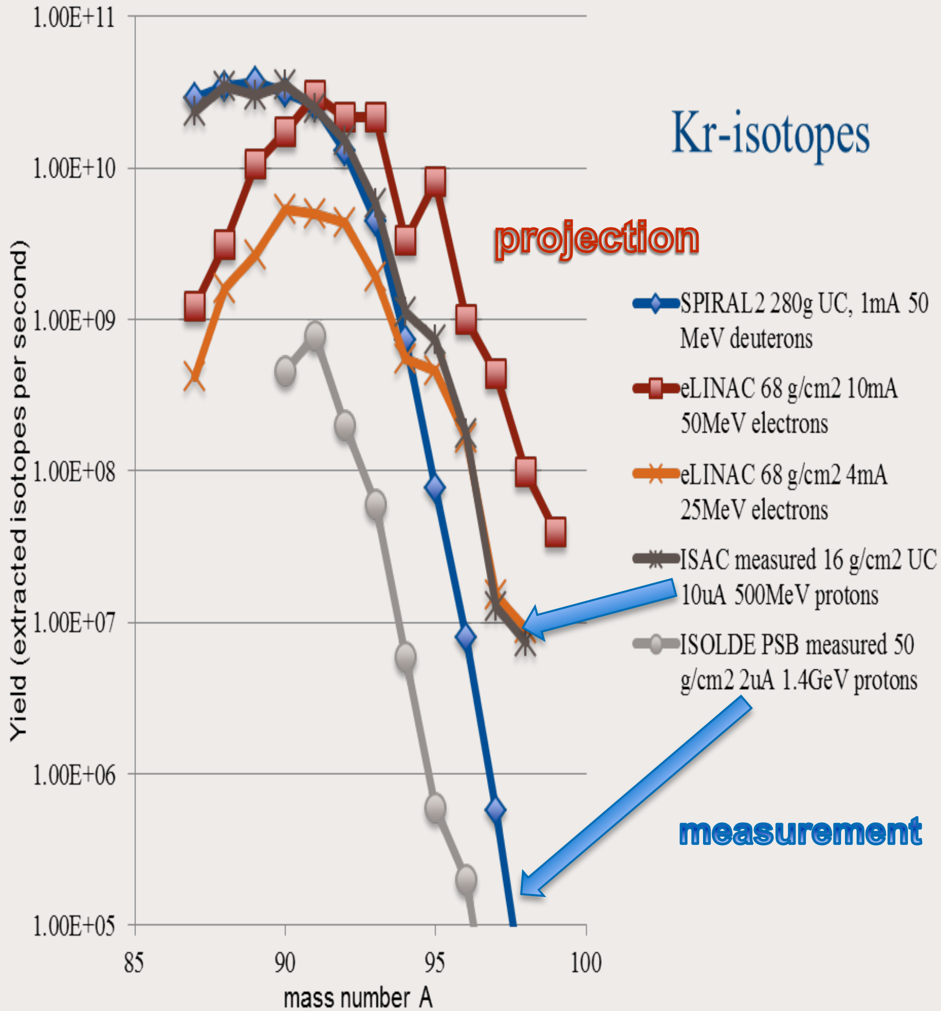


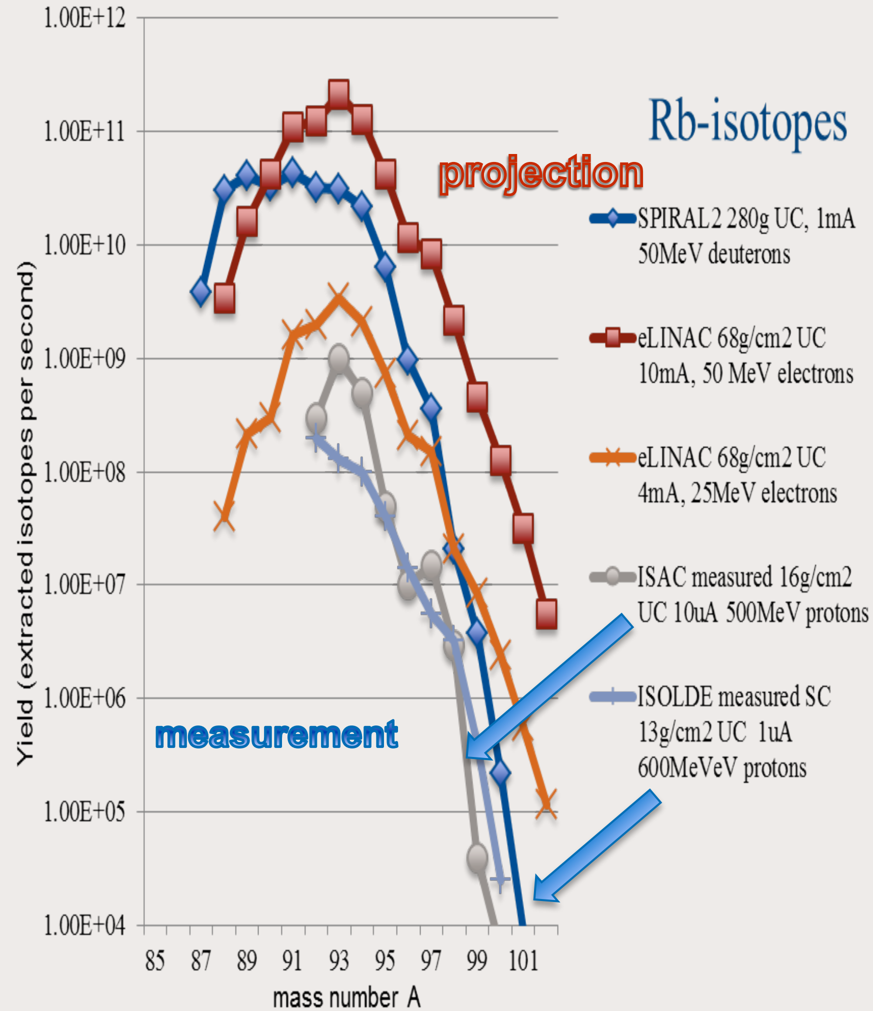
- **High Power Commissioning**, beam power up to 100kW.
- **Accelerator Commissioning**, beam energy up to 30 MeV
  - Part 4: beam average power progressively increased from 100W up to 30kW
  - Part 3: EACA second SRF cavity installed & commissioned; beam accelerated up to 30MeV at the EHD dump. Beam power limited to 100 W.
  - Part 2: EHAT and EHDT beamlines and EHD dump are added, and commissioned to 1kW beam power.
  - Part 1: EACA cryomodule (with a single SRF cavity), EABT and EABD are added; EACA equipment commissioned; beam accelerated to 20MeV at EABD dump.
- **Injector Commissioning**, beam energy up to 10 MeV
  - Part 3: beam average power progressively increased to 1kW at EMBD dump
  - Part 2: EINJ cryomodule, EMBT to EMBD are added; EINJ equipment commissioned; beam power < 100W, 10MeV.
  - Part 1: GUN, ELBT and ELBD commissioned to 300keV

Red denotes CFI subset

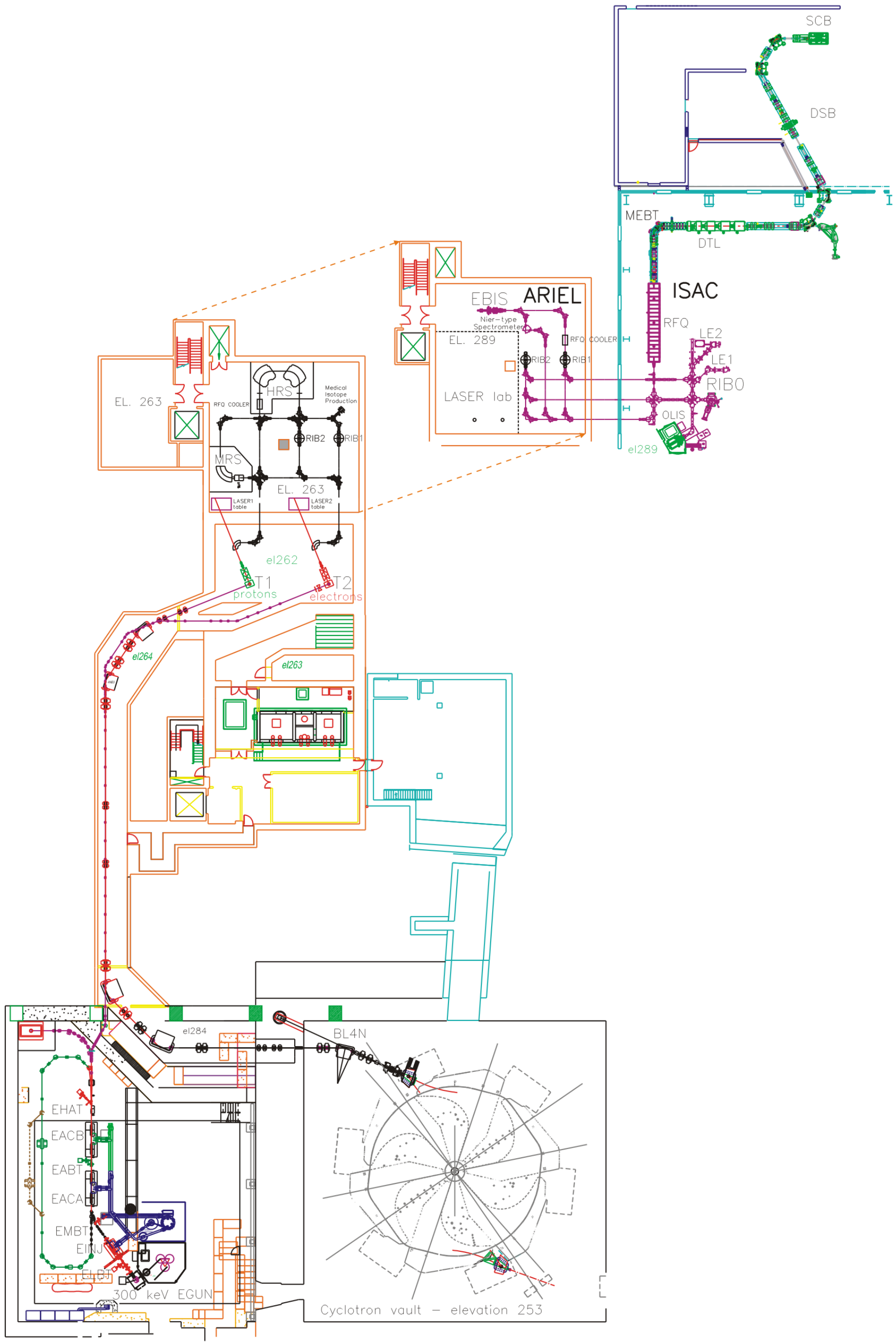
TRIUMF

Reaching the r-process path in the laboratory: competitive isotopes

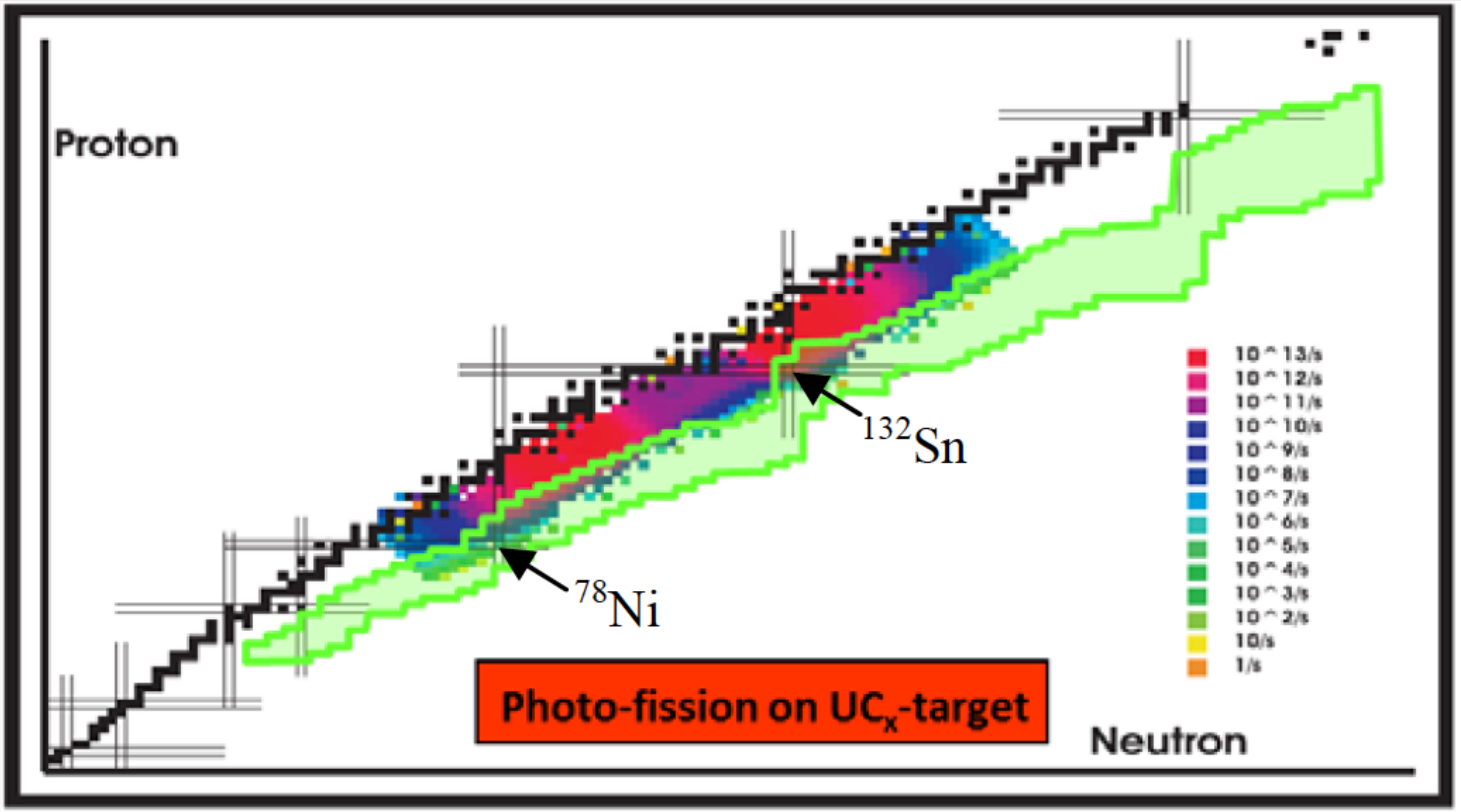




Projection ARIEL: FLUKA, using the converter-target geometry and experimental diffusion times, and extraction and ionization efficiencies from ISOLDE, overlaid with the isotope specific half-live. Uncertainty in projection: factor ~10. (TRIUMF 5YP page 422), SPIRAL: GANIL web site.



SCB
DSB
MEBT
DTL
ISAC
RFQ
LE2
LE1
RIB0
OLIS
el289
EBIS
ARIEL
Nier-type Spectrometer
EL. 289
RFQ COOLER
RIB2
RIB1
LASER lab
EL. 263
HRS
RFQ COOLER
Medical Isotope Production
RIB2
RIB1
MRS
EL. 263
LASER1 table
LASER2 table
el262
T1
protons
T2
electrons
el264
el263
el284
BL4N
EHAT
EACB
EABT
EACA
EMBT
EINJ
ELBT
300 keV EGUN
Cyclotron vault – elevation 253


Proton
^{132}Sn
^{78}Ni
10^13/s
10^12/s
10^11/s
10^10/s
10^9/s
10^8/s
10^7/s
10^6/s
10^5/s
10^4/s
10^3/s
10^2/s
10/s
1/s
Photo-fission on UC$_x$-target
Neutron