Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

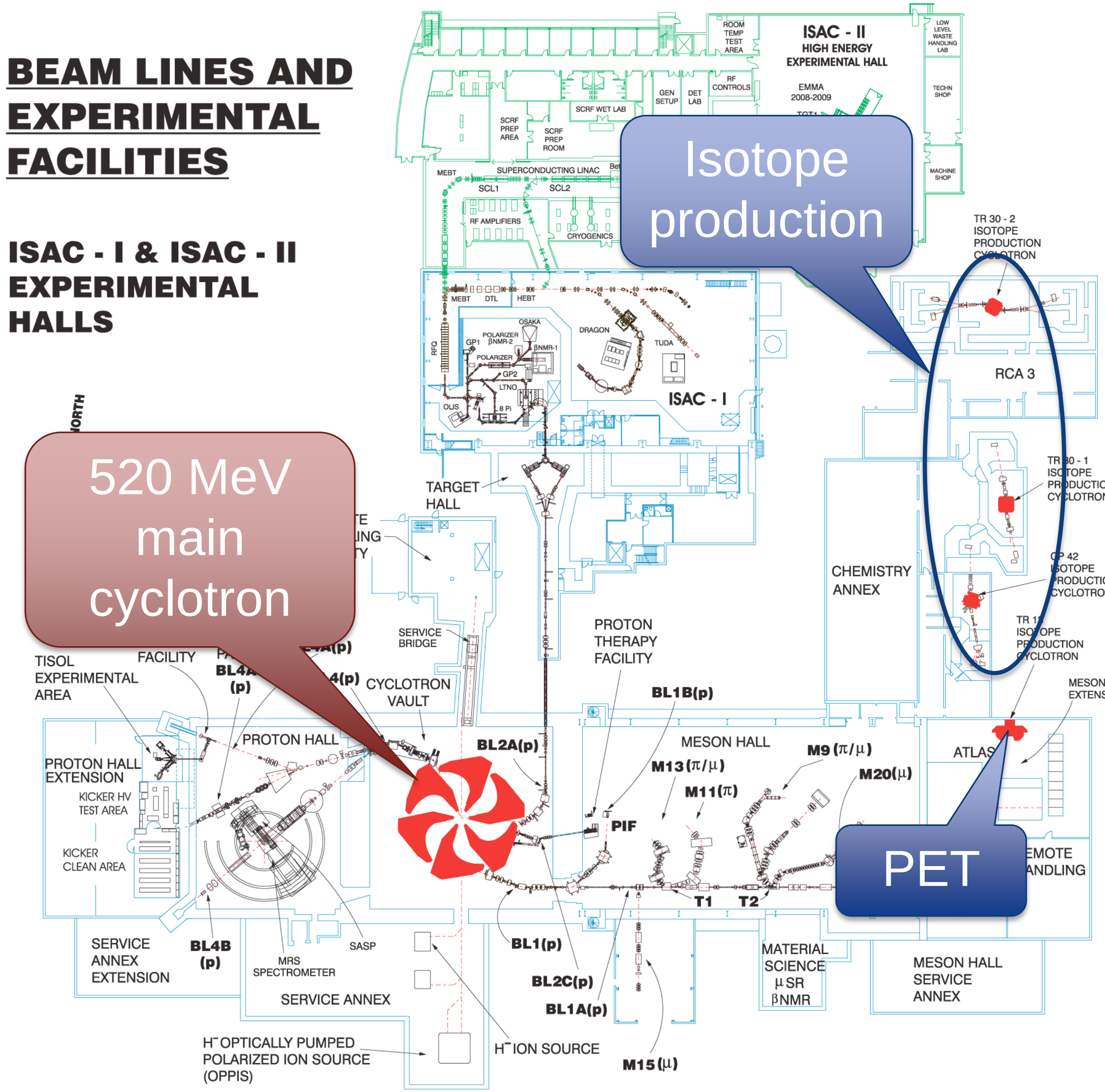
RIB at TRIUMF: From ISAC to ARIEL

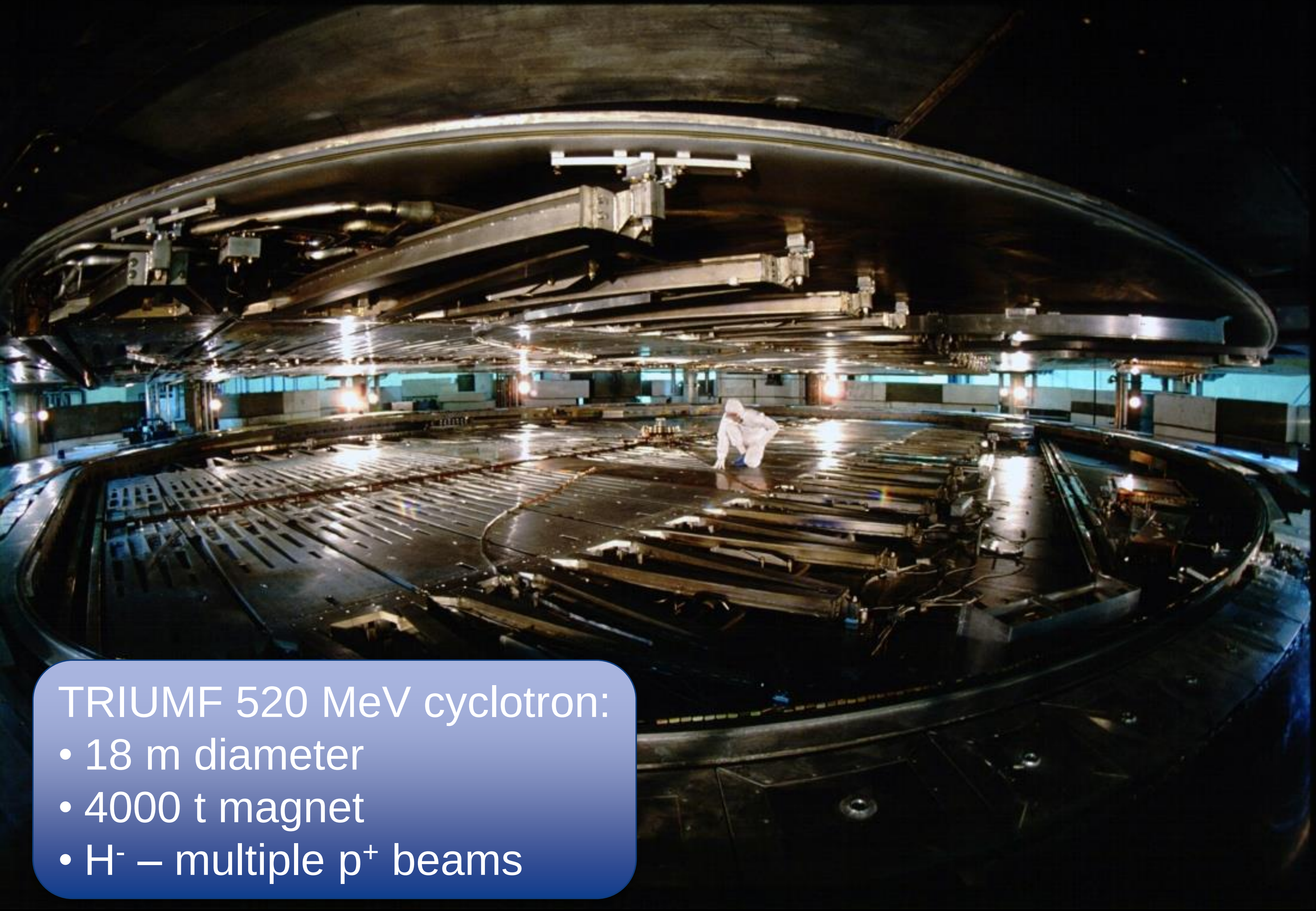
Colin Morton | Beam Delivery Group Liaison/Coordinator | TRIUMF

Accelerating Science for Canada
Un accélérateur de la démarche scientifique canadienne

What is TRIUMF?

- Canada's national laboratory for particle and nuclear physics
- Programs in nuclear medicine and materials science
- Accelerators and accelerator-based research


BEAM LINES AND EXPERIMENTAL FACILITIES
ISAC - I & ISAC - II EXPERIMENTAL HALLS
Isotope production
520 MeV main cyclotron
PET
ISAC - II HIGH ENERGY EXPERIMENTAL HALL
ROOM TEMP TEST AREA
LOW LEVEL WASTE HANDLING LAB
EMMA 2008-2009
GEN SETUP
DET LAB
RF CONTROLS
TECHN SHOP
MACHINE SHOP
SCRF WET LAB
SCRF PREP AREA
SCRF PREP ROOM
MEBT
SUPERCONDUCTING LINAC
SCL1
SCL2
RF AMPLIFIERS
CRYOGENICS
MEBT
DTL
HEBT
RFQ
OSAKA
POLARIZER
βNMR-2
βNMR-1
GP1
GP2
LTNO
OLIS
8 Pi
DRAGON
TUDA
ISAC - I
TR 30 - 2 ISOTOPE PRODUCTION CYCLOTRON
RCA 3
TR 30 - 1 ISOTOPE PRODUCTION CYCLOTRON
CP 42 ISOTOPE PRODUCTION CYCLOTRON
TR 13 ISOTOPE PRODUCTION CYCLOTRON
CHEMISTRY ANNEX
TARGET HALL
SERVICE BRIDGE
PROTON THERAPY FACILITY
CYCLOTRON VAULT
TISOL EXPERIMENTAL AREA
FACILITY
BL4A (p)
BL1B(p)
MESON HALL EXTENSION
PROTON HALL
PROTON HALL EXTENSION
KICKER HV TEST AREA
KICKER CLEAN AREA
BL2A(p)
MESON HALL
M13(π/μ)
M9(π/μ)
M11(π)
M20(μ)
ATLAS
PIF
T1
T2
SERVICE ANNEX EXTENSION
BL4B (p)
MRS SPECTROMETER
SASP
BL1(p)
BL2C(p)
BL1A(p)
MATERIAL SCIENCE μSR βNMR
MESON HALL SERVICE ANNEX
SERVICE ANNEX
H⁻ OPTICALLY PUMPED POLARIZED ION SOURCE (OPPIS)
H⁻ ION SOURCE
M15(μ)
NORTH

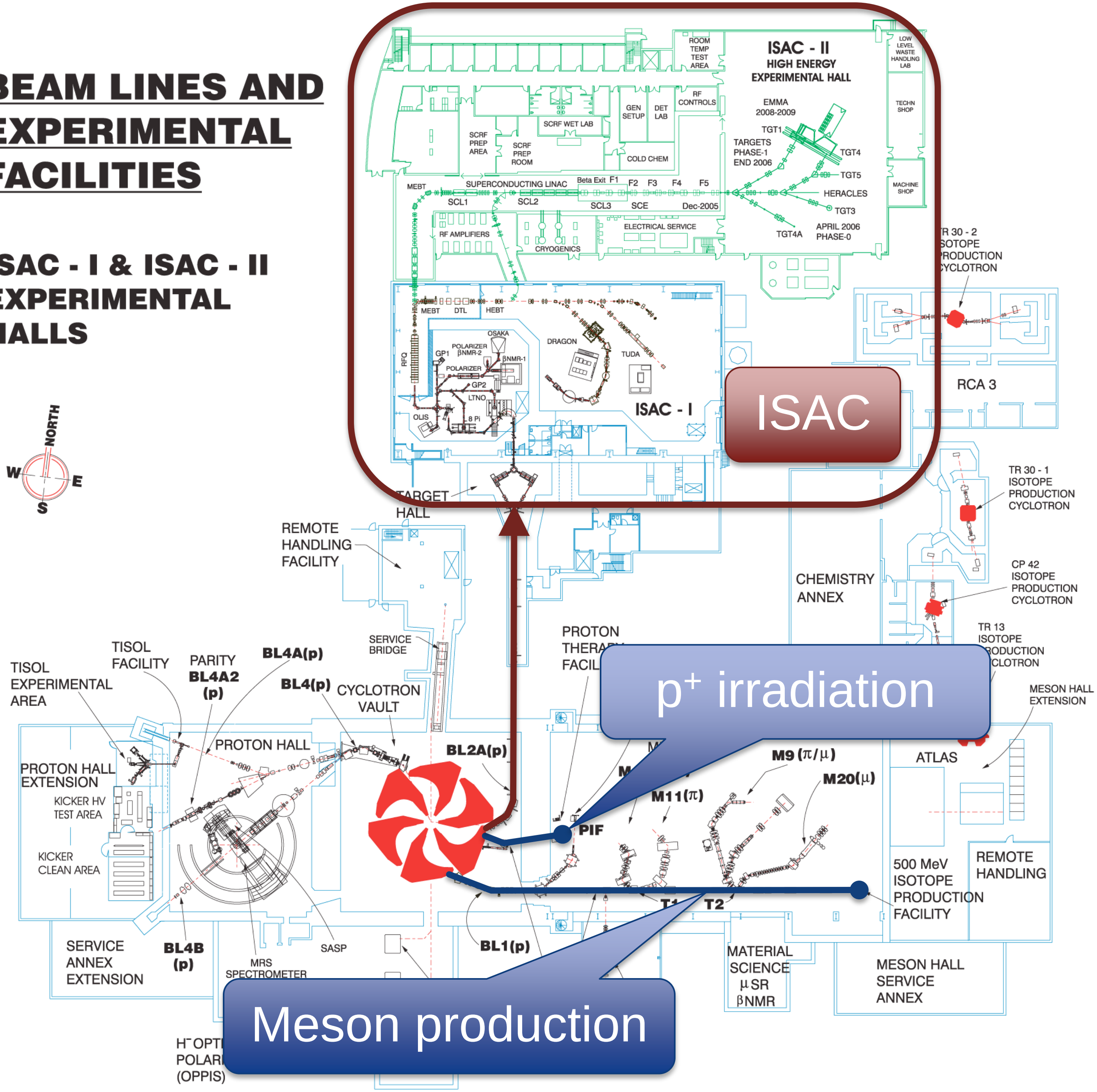


TRIUMF 520 MeV cyclotron:

- 18 m diameter
- 4000 t magnet
- H^- – multiple p^+ beams

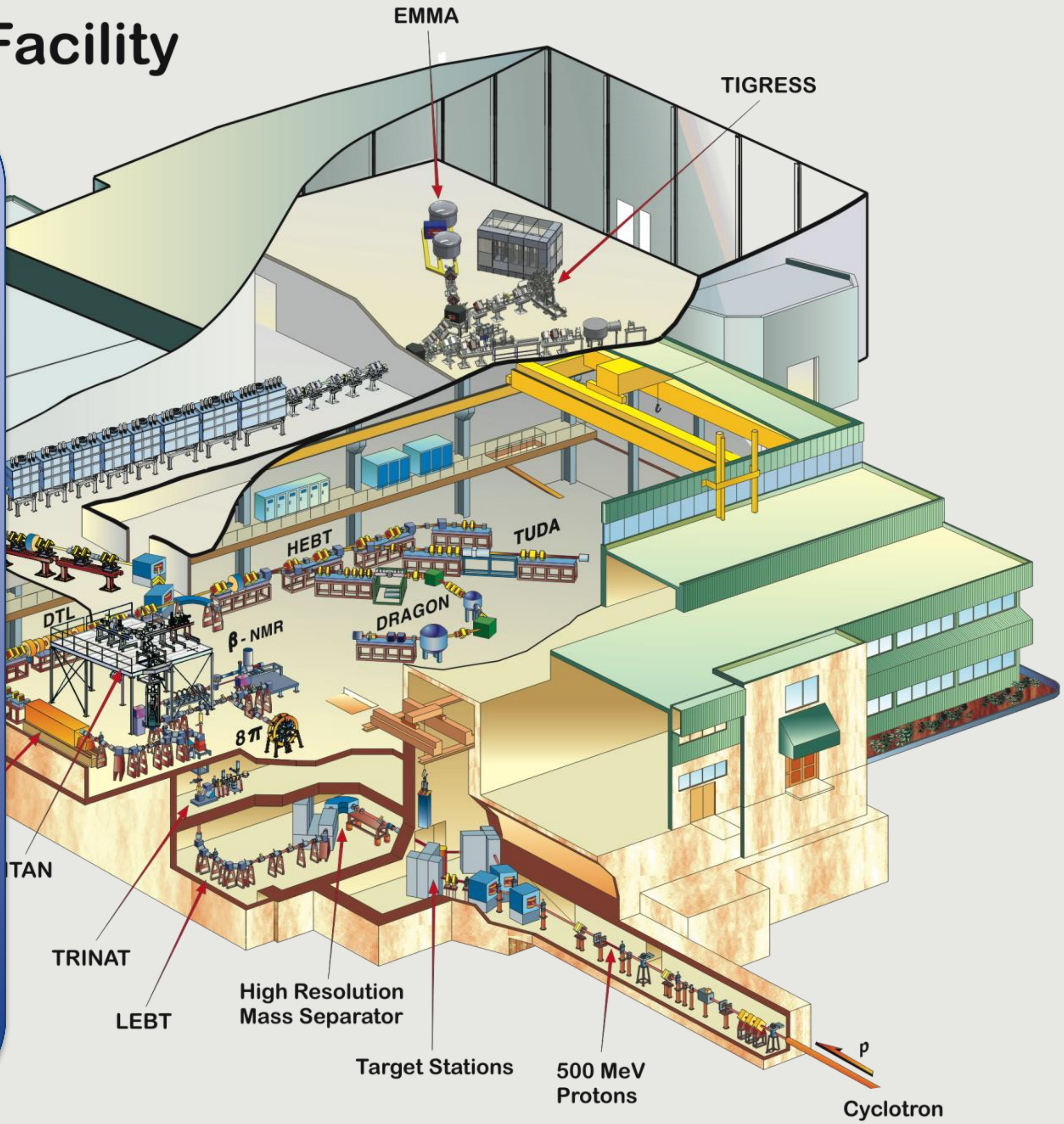
BEAM LINES AND EXPERIMENTAL FACILITIES

ISAC - I & ISAC - II EXPERIMENTAL HALLS



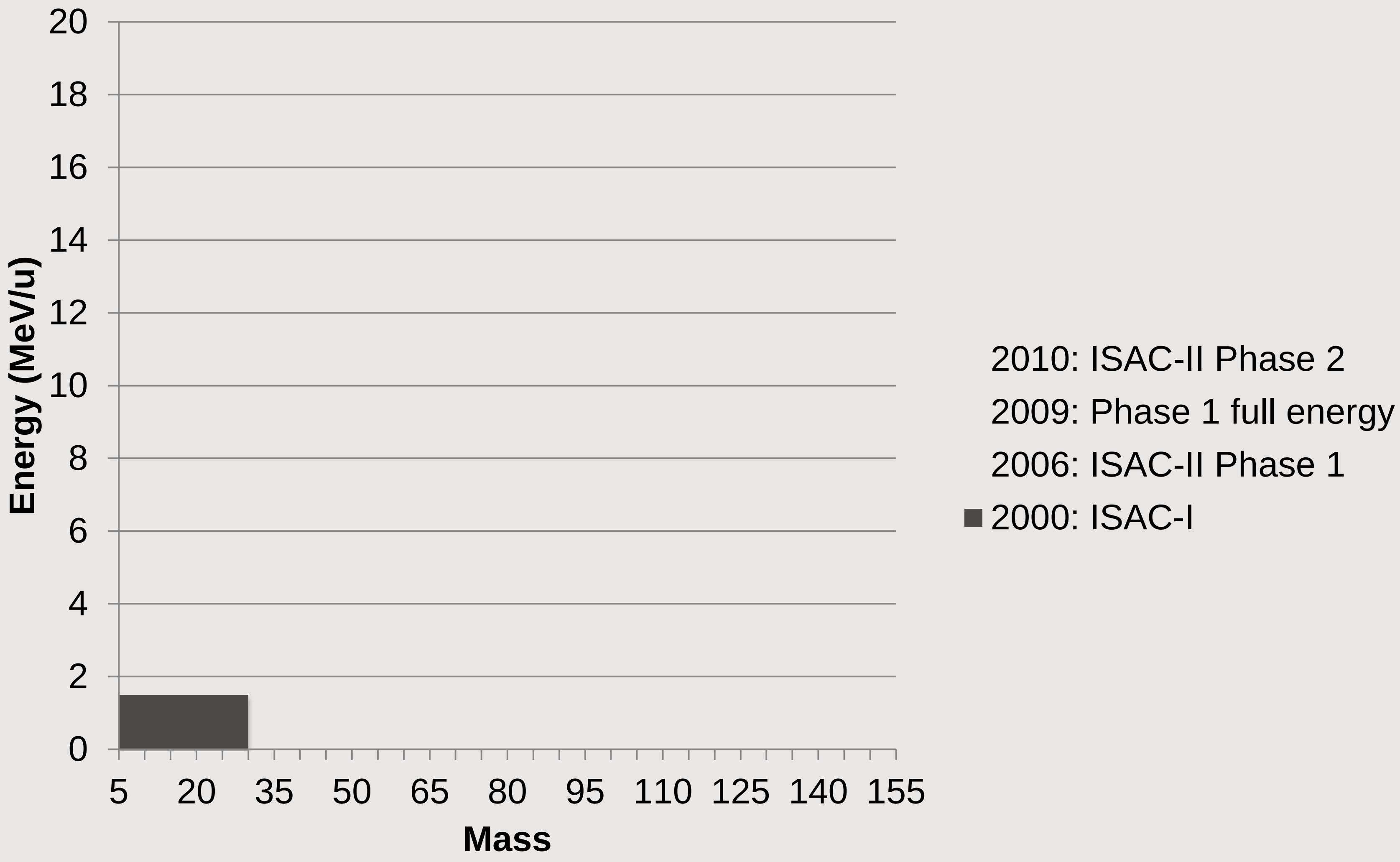
ISAC-I and ISAC-II Facility

- Targets:
  - Ta, Nb foils
  - SiC, TiC, ZrC
  - NiO
  - Actinides: UO_2, UC_x, ThO (this fall)
- Ion sources:
  - Surface
  - FEBIAD
  - RILIS
  - IG-LIS (RILIS + RF ion guide)
- 480–520 MeV p^+
- Up to 100 μA
- **~50 kW beam power on target**

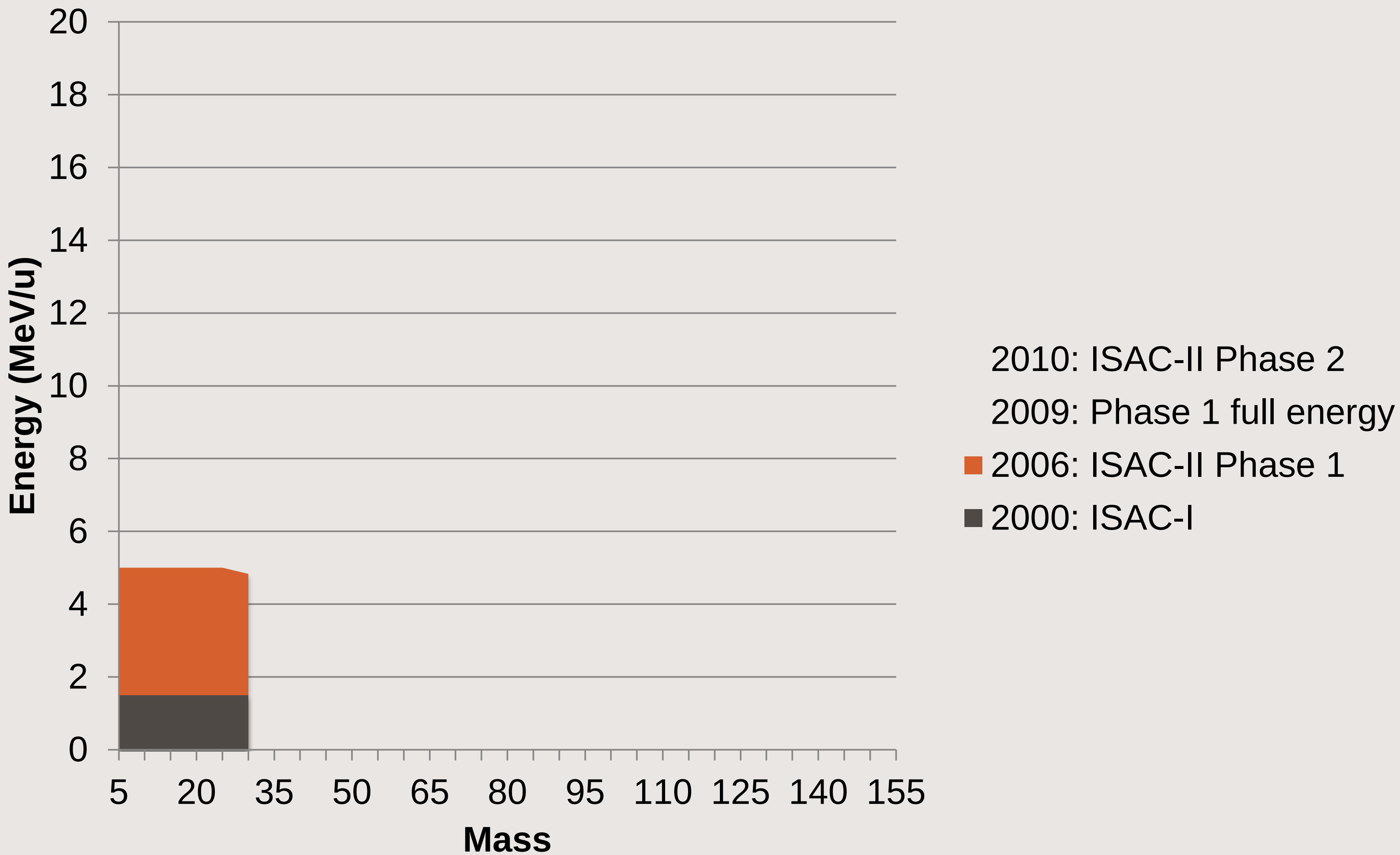


TRIUMF

ISAC operating envelope, 2000–2010

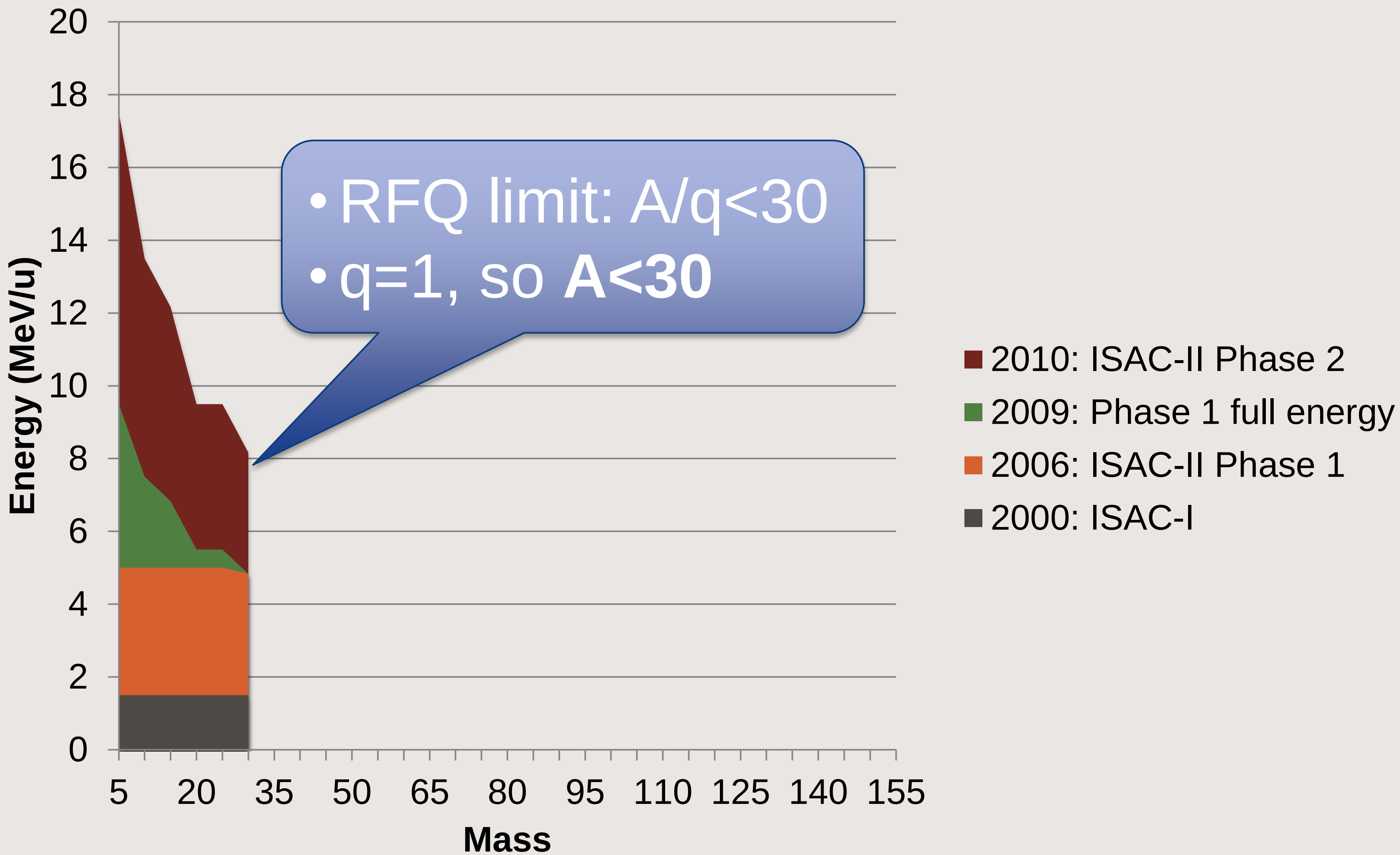


ISAC operating envelope, 2000–2010



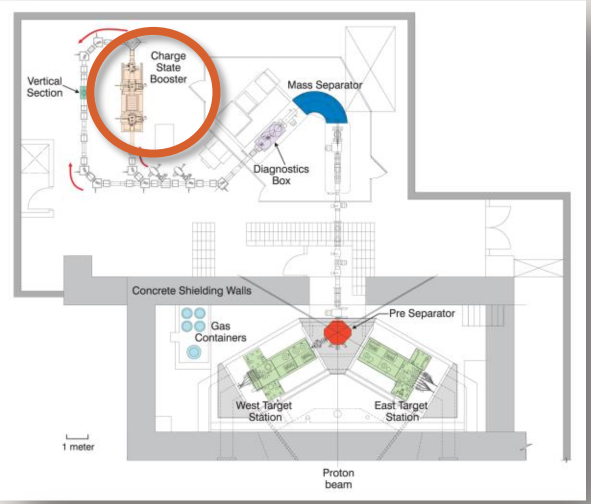
ISAC operating envelope, 2000–2010

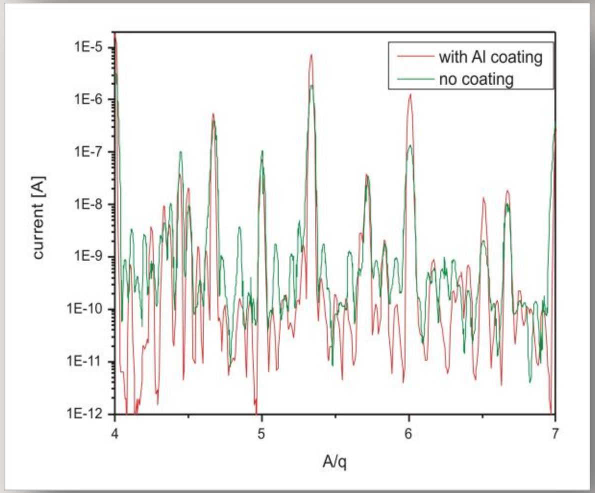
ISAC operating envelope, 2000–2010



Beyond A=30…

- Need to increase q, lower A/q before acceleration
- Charge State Booster (CSB)
  - Pantechnik PHOENIX ECRIS charge breeder
  - Boosts RIB to high charge states, A/q < 7
  - **10s to 1000s of pA of stable-beam background**

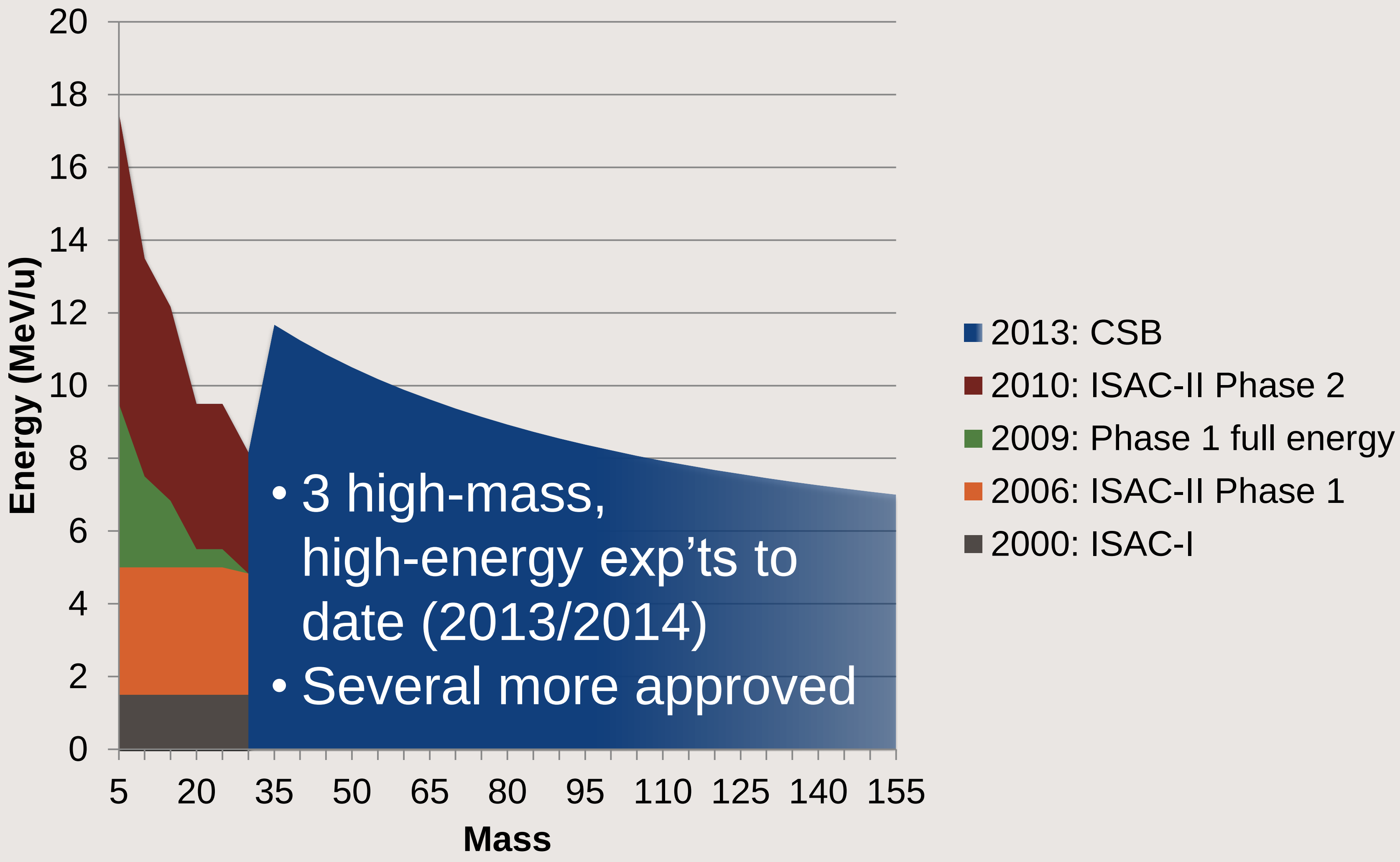




…to high-mass beam delivery

- New equipment:
  - Al liner for CSB plasma chamber
  - Bragg detector for particle ID and beam setup
- New techniques:
  - Time-of-flight separation using the low-energy prebuncher and RFQ
  - A/q separation using the beamline magnets between the DTL and ISAC-II
  - Stripping at 1.5 MeV/u to select charge states with favourable signal/noise ratios
- New tools:
  - Tune scaling utilities
  - Web-based tools for planning high-mass delivery

ISAC operating envelope, 2014



TRIUMF

ISAC to date

- 1996: ISAC construction begins
- 1998: first RIB at ISAC
- 2000: first accelerated RIB at ISAC-I
- 2007: first RIB with ISAC-II SC-LINAC
- Now: **3000+ hours/year** of RIB to users
  - ~32–36 weeks, 8–10 targets, 15–20 experiments + development
  - Broad range of isotopes
  - Low-energy beams from ~10–60 keV; high-energy beams from 150 keV/u to >6.5 MeV/u (A/q=6)

Top-notch science

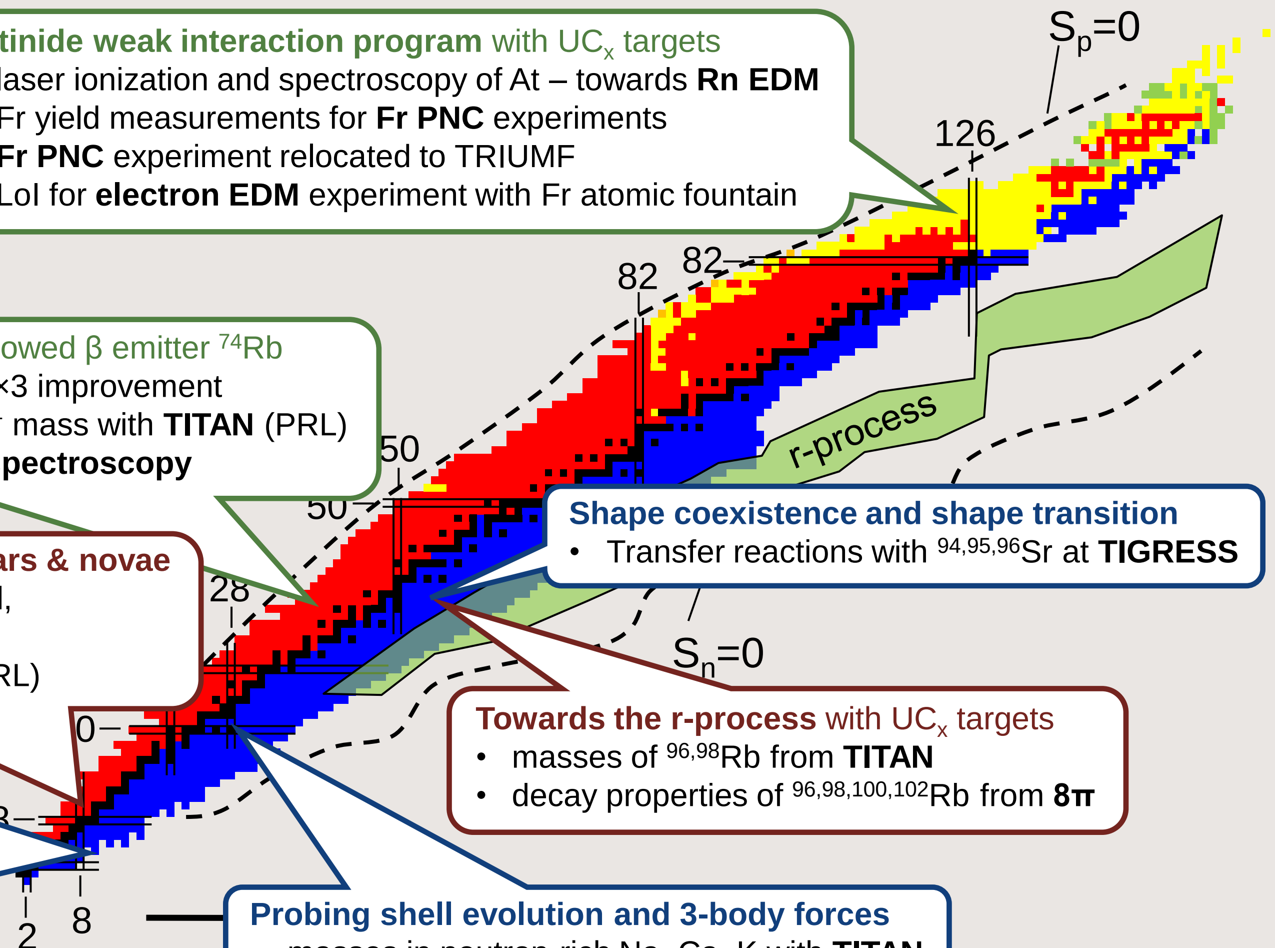
Nuclear structure
Nuclear astrophysics
Fundamental symmetries

Actinide weak interaction program with UC_x targets
- laser ionization and spectroscopy of At – towards **Rn EDM**
- Fr yield measurements for **Fr PNC** experiments
- **Fr PNC** experiment relocated to TRIUMF
- LoI for **electron EDM** experiment with Fr atomic fountain

Unitarity test of CKM matrix: superallowed β emitter ^{74}Rb
- precision branching ratio from **8π** – ×3 improvement
- precision measurement of the $^{74}Rb^{8+}$ mass with **TITAN** (PRL)
- charge radius from **collinear laser spectroscopy**

Nuclear reactions in Sun, ancient stars & novae
- **DRAGON:** $^{18}F(p,\gamma)^{19}Ne$, $^{33}S(p,\gamma)^{34}Cl$, $^{17}O(p,\gamma)^{18}F$, $^{3}He(\alpha,\gamma)^{7}Be$
- **TUDA :** $^{18}F(p,\alpha)^{15}O$, $^{18}F(\alpha,p)^{21}Ne$ (PRL)

Tests of *ab initio* nuclear theory
- reaction studies of halo nuclei ^{11}Li & ^{10,11}Be with **TUDA** and **TIGRESS**
- ^{6}He, ^{8}He mass measurements with **TITAN**



Shape coexistence and shape transition
- Transfer reactions with ^{94,95,96}Sr at **TIGRESS**

Towards the r-process with UC_x targets
- masses of ^{96,98}Rb from **TITAN**
- decay properties of ^{96,98,100,102}Rb from **8π**

Probing shell evolution and 3-body forces
- masses in neutron-rich Na, Ca, K with **TITAN**

Reiner Kruecken, TRIUMF Science Division

The challenge? Meeting demand

- Two-year backlog of experiments
- Huge specific demand for ^{8}Li (β-NMR)
- Beam delivery improvements:
  - Improved scheduling to minimize interruptions
  - Better coordination with experimenters
  - Finding overlooked sources of downtime
- However:
  - Efficiency gets you 30–50% more beamtime – not factors of two or three
  - **We need something more.**

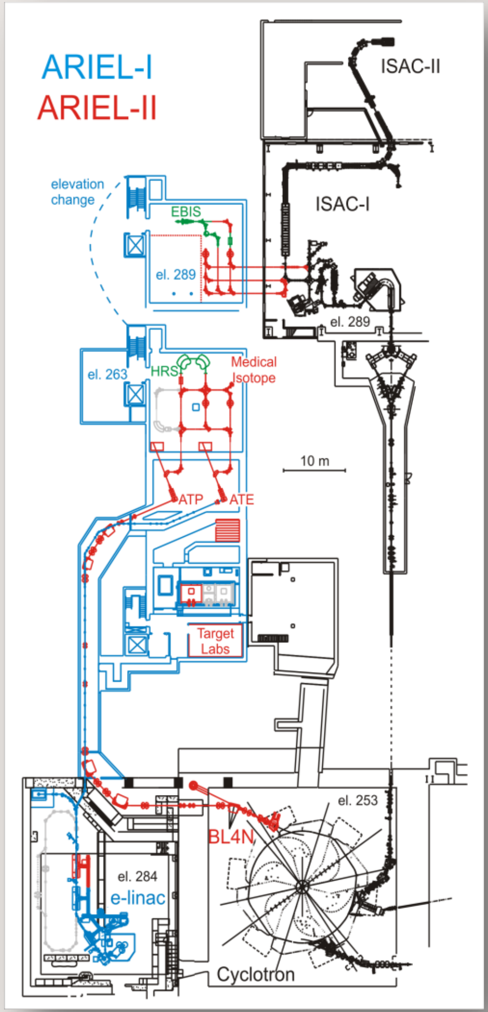
TRIUMF ARIEL

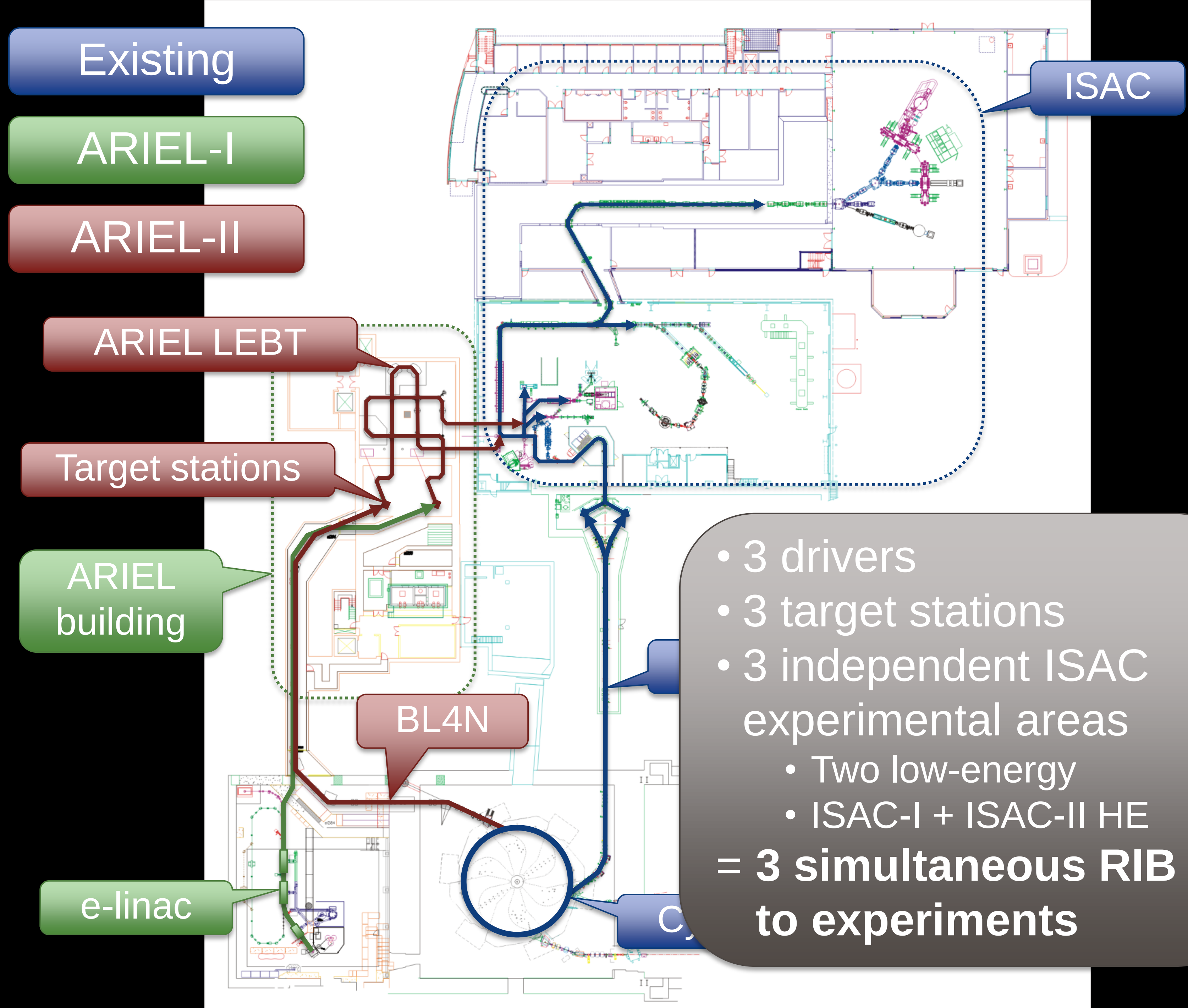
ADVANCED RARE ISOTOPE LABORATORY

- New ISOL infrastructure to build on past success
- **TRIUMF’s flagship facility**
- Focus of both the 2010–2015 and 2015–2020 five-year plans
- Goal: to **more than triple the amount of RIB available at ISAC**

ARIEL: A facility in two acts

- ARIEL-I (2010–2015)
  - Civil construction for both ARIEL-I and ARIEL-II facilities
  - Electron linac up to 25 MeV, 100 kW – centrepiece of the project
- ARIEL-II (2015–2020)
  - Completion and use of the entire facility





- 3 drivers
- 3 target stations
- 3 independent ISAC experimental areas
  - Two low-energy
  - ISAC-I + ISAC-II HE

= 3 simultaneous RIB to experiments

ARIEL-I: Civil construction

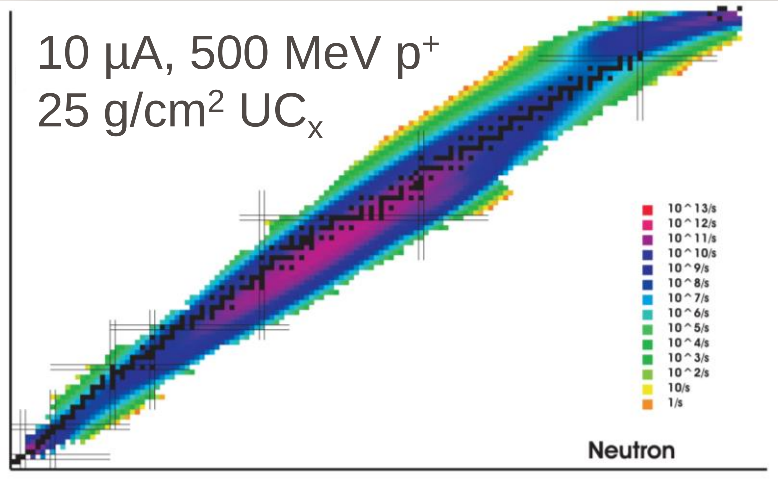


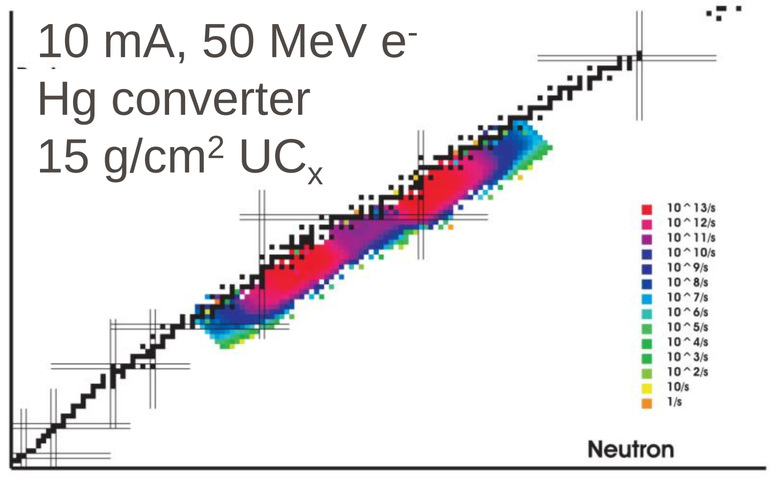



- Building finished Sept. 2013
- Also:
  - Cryogenics building
  - Conversion of Proton Hall for e-linac (e-Hall)

ARIEL-I: e-linac

- State-of-the art SC linac
  - TESLA (ILC) technology
  - 25 MeV, 100 kW now
  - 50 MeV, 500 kW later
- Why electrons?
  - RIB production by photofission – high production of neutron-rich species with less isobaric contamination, no spallation products





ARIEL-I: e-linac status

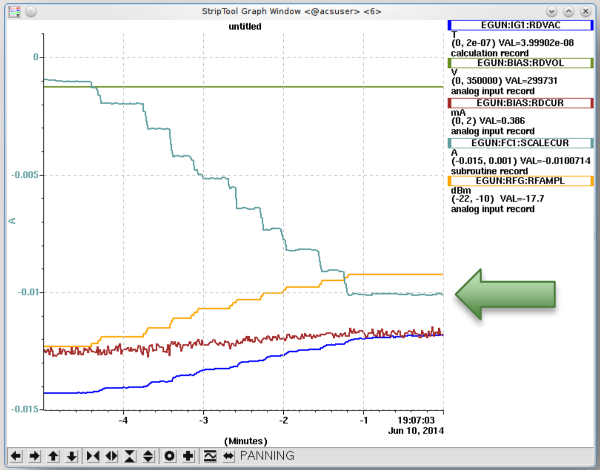
- In the last year:
  - Cryogenics acceptance testing completed
  - e-gun and LEBT installed and commissioned
  - MEBT installed
  - 2 klystrons and HV supplies installed and commissioned
  - Injector and accelerator cryomodules assembled, installed, and commissioned

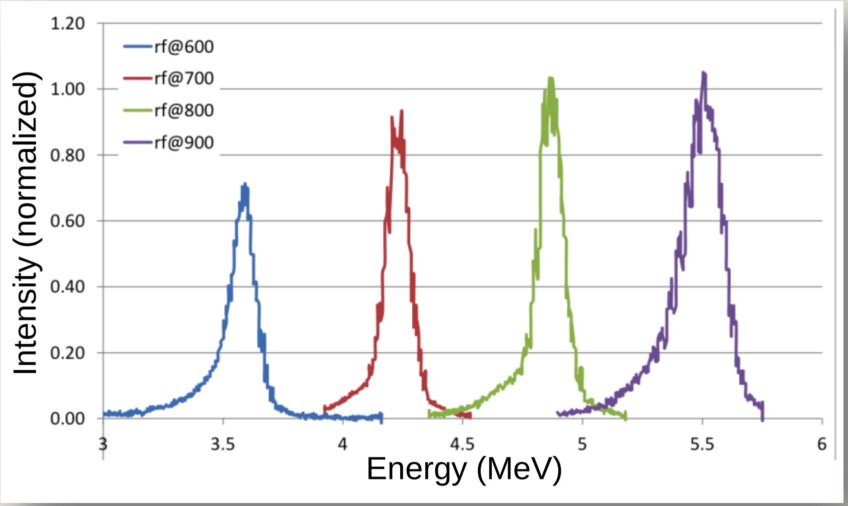

January, 2014


September, 2014

ARIEL-I: e-linac status

- Commissioning underway
- e-gun operated up to 10 mA peak current





- Beam accelerated to 10 MeV beam dump
- 20 MeV test planned for next week

L. Merminga (NS2014)

ARIEL-II: Overview

- Overall goal:
  - Delivery of three simultaneous RIB to users
- Technical objectives:
  - High-intensity photoconverter/target development
    - Solid converter for beam power below ~100 kW
    - Liquid converter for beam power above ~100 kW
  - Expanded expertise in SRF, targets, etc.
- Project structure:
  - Five phases with timing determined by scientific priority, technical readiness, resource availability

TRIUMF

ARIEL-II scientific deliverables

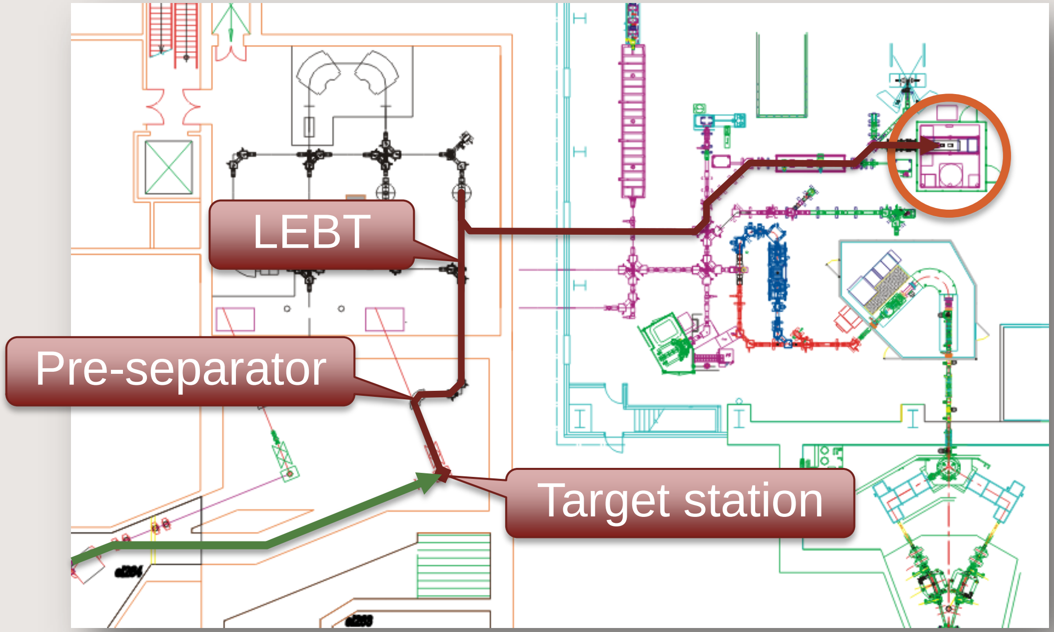
Phase	Will deliver isotopes…
1	…as probes of magnetism at interfaces and surfaces of new functional materials using β-NMR.
2	…to elucidate our fundamental understanding of atomic nuclei by enabling studies of the evolution of structure and dynamics of very neutron-rich nuclei approaching the r-process path.
3	…for molecular imaging of diseases and treatment of cancer in the ARIEL collection station and isotopes for developing a standard model for nuclear physics.
4	…to search for new forces in nature. **It will also mark the milestone of three simultaneous rare isotope beams delivered to users.**
5	…to determine how the heavy elements from iron to uranium were produced in the universe.

Why a phased approach?

- Phasing ARIEL-II allows construction and science to alternate during the project
  - Fastest way to new science
  - Extends TRIUMF's scientific reach with each phase
  - Delivers continuous stream of results, discoveries, and papers through the duration of the project
- ARIEL-II has been planned to minimize disruption to ISAC operation and beam delivery

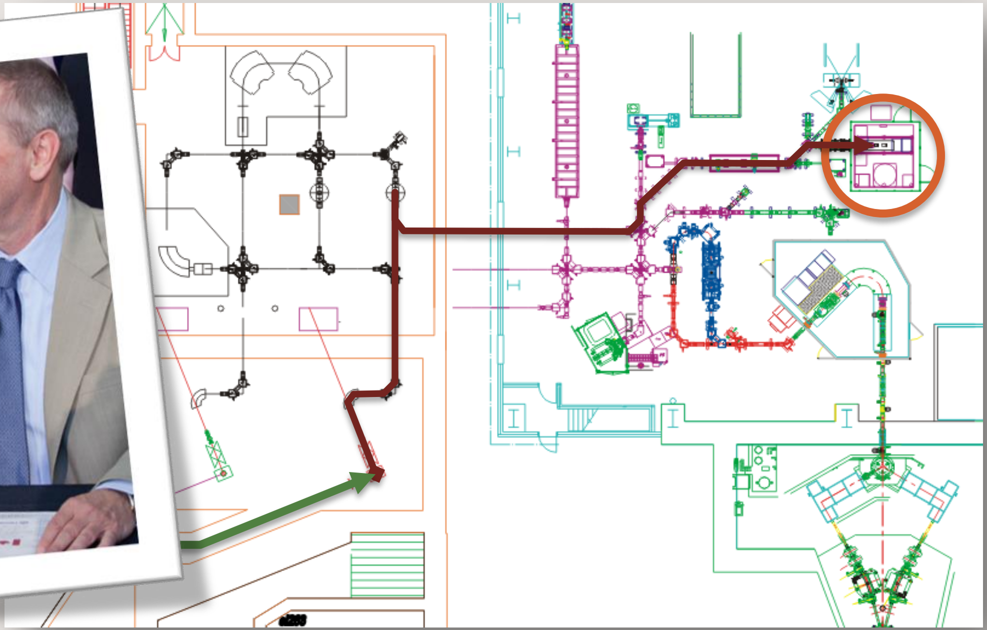
ARIEL-II Phase 1: Materials science with β-NMR

- Goal:
  - Photo-production of ^{8}Li in BeO using bremsstrahlung photons from stopping a 100 kW electron beam in a solid target, and delivery to β-NMR at ISAC
- Requirements:
  - ARIEL e-linac – 25 MeV, 100 kW
  - Electron target station (ATE)
  - Pre-separator and LEBT



ARIEL-II Phase 1: Materials science with β-NMR

- Collaboration with VECC (Kolkata)
  - MoU signed August 2013
  - \$10.4M – includes two ARIEL target modules (to be tested at ARIEL) and front-end beamlines

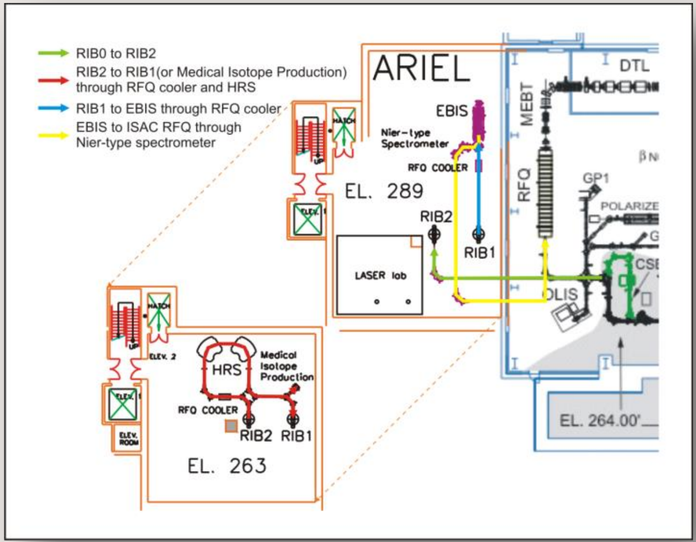


ARIEL-II Phase 2: Photofission for r-process studies

- Goal:
  - Production and delivery of neutron-rich fission fragments using actinide targets with a solid photoconverter
- Requirements:
  - Electron target station (ATE) with actinide target
  - Actinide chemistry lab
  - RILIS source
- Phase 2 greatly extends the range of RIB available

ARIEL-II Phase 3: Purified high-mass, high-energy RIB

- Goals:
  - Transport of high-mass RIB from ISAC to ARIEL and purification and charge-breeding of ISAC and ATE beams for delivery to high-energy experimental areas
  - A collection station for medical isotopes
- Requirements:
  - CANREB – CFI-funded project including EBIS, HRS, RFQ coolers, etc.
  - Low-energy beam transport through ARIEL

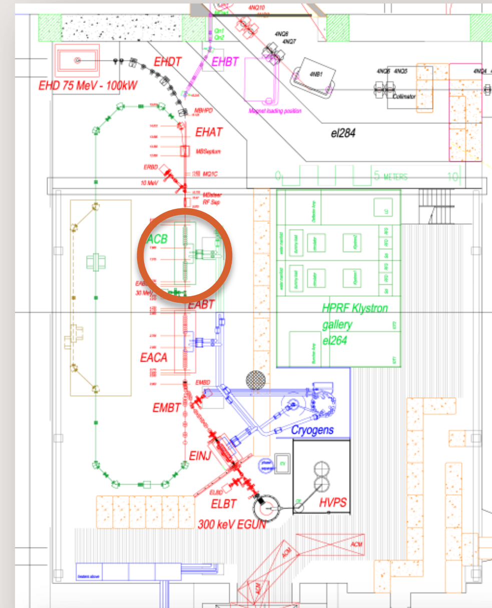


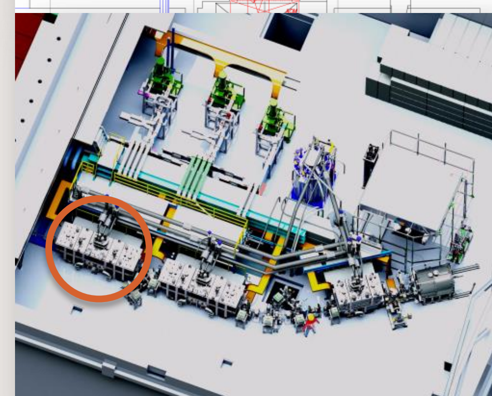
ARIEL-II Phase 4: Actinide production for fundamental symmetries

- Goal:
  - RIB production using a new proton beamline (BL4N) delivering up to 100 µA of ~500 MeV protons to a dedicated actinide target station
- Requirements:
  - Proton beamline
  - Proton target station (ATP) and actinide target
  - Low-energy beam transport from ATP
- **Three simultaneous RIB delivered to users**

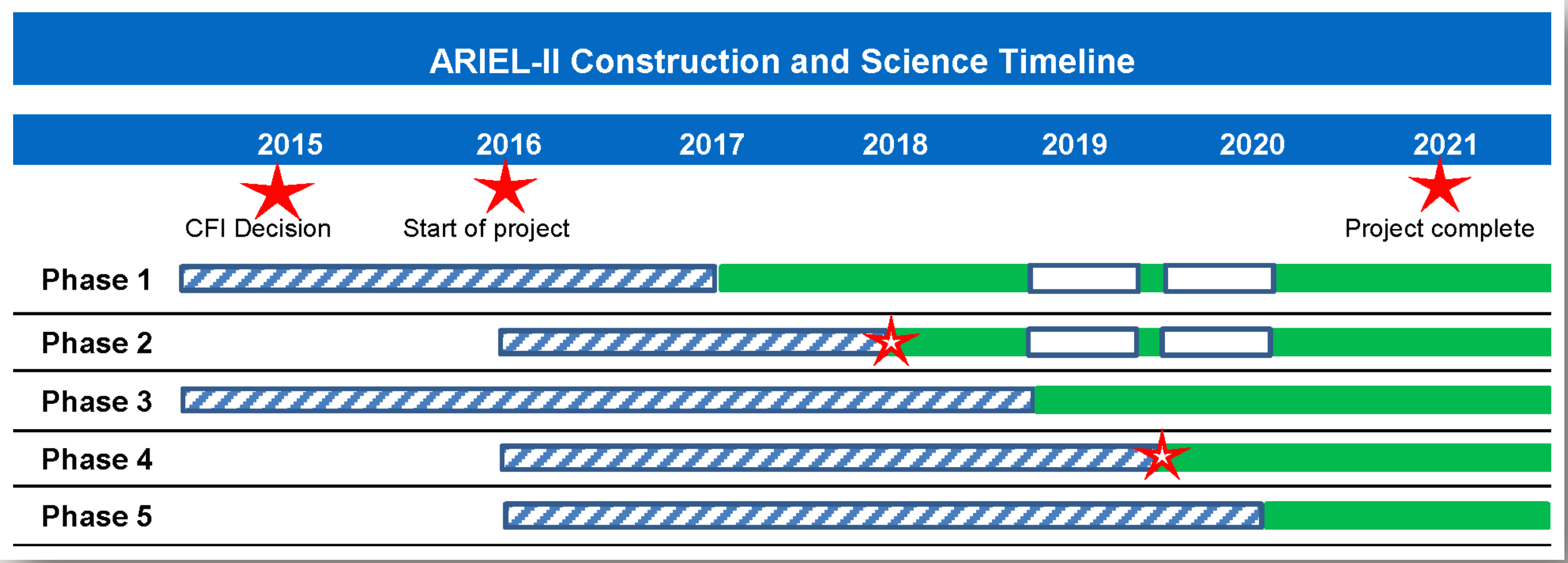
ARIEL-II Phase 5: Full-power e-linac

- Goal:
  - The full e-linac design specification of 50 MeV and 500 kW beam power for RIB production by photofission – 2×10^{13} fissions/second
- Requirements:
  - Second accelerator cryomodule
- Opens up research into r-process nucleosynthesis with very neutron-rich isotopes





ARIEL-II schedule: Science at every phase



- Phase 1: Materials science with β-NMR
- Phase 2: Photofission
- Phase 3: Medical imaging and treatment; high-mass beams
- Phase 4: Fundamental symmetries
- Phase 5: Full power of e-linac; r-process astrophysics

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

Project number **33351**
Innovation Fund
Proposal

Project information

Project title	ARIEL-II: Driving Scientific Discovery and Health Science with TRIUMF's Advanced Rare Isotope Laboratory
Applicant institution	University of Victoria
Collaborating institutions	Carleton University, McGill University, McMaster University, Queen's University, Saint Mary's University, Simon Fraser University, The University of British Columbia, The University of Western Ontario, The University of Winnipeg, University of Alberta, University of Calgary, University of Guelph, University of Manitoba, University of Northern British Columbia, University of Regina, University of Toronto, Université de Montréal, York University

Project leader

Name	Dean Karlen
Title/position	R.M. Pearce Professor of Physics

Project funding

Total project cost	$33,890,000
Amount requested from the CFI	$13,556,000
Percentage of the total project cost requested from the CFI (maximum 40%)	40%

CFI proposal submitted – decision in October

ARIEL-II Collaborators: 19 Canadian universities + TRIUMF

(from the ARIEL-II CFI proposal)

Summary

- ISAC:
  - 3000+ hrs/year of RIB for users
  - High-energy, high-mass program underway
  - **More demand than available beam time**
- ARIEL:
  - Expanded ISOL capabilities – builds on ISAC success
  - New drivers (electron and proton), targets, front ends; new EBIS (CANREB)
  - Phased approach designed to maximize science output during construction
  - **2019: 3 simultaneous RIB to users**

Acknowledgements

- ISAC:
  - TRIUMF Operations and technical support groups
  - TRIUMF's Beam Delivery group (F. Ames, J. Lassen, P. Kunz, M. Marchetto, R.E. Laxdal)
  - High Mass Task Force (F. Ames, M. Marchetto, R.E. Laxdal, A. Garnsworthy*, G. Hackman*, P. Bender*, B. Davids*) *(* = Science Division)*
  - ISAC's experimental community
- ARIEL:
  - ARIEL, CANREB, and associated collaborations
- This talk:
  - R. Kruecken, L. Merminga, R.E. Laxdal, J. Lassen, M. Marchetto, TRIUMF's Communications group

Thank you!
Merci!

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