CANADA'S NATIONAL LABORATORY
FOR PARTICLE AND NUCLEAR
PHYSICS

Latest Performance Of The 500 Mev H^{-} Cyclotron And Recent Progress Towards Three Simultaneous RIB's At TRIUMF

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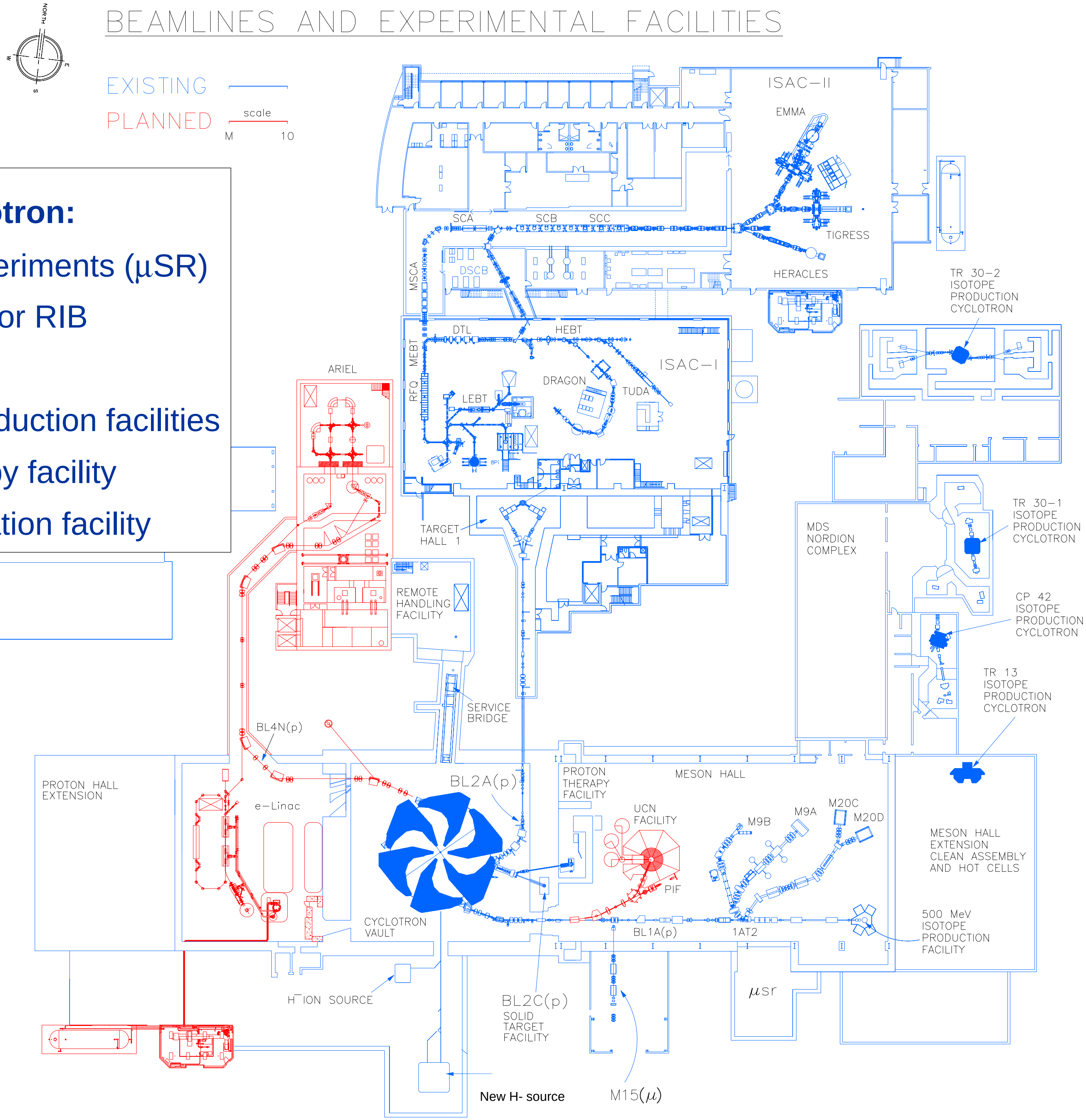
TRIUMF, Vancouver, Canada

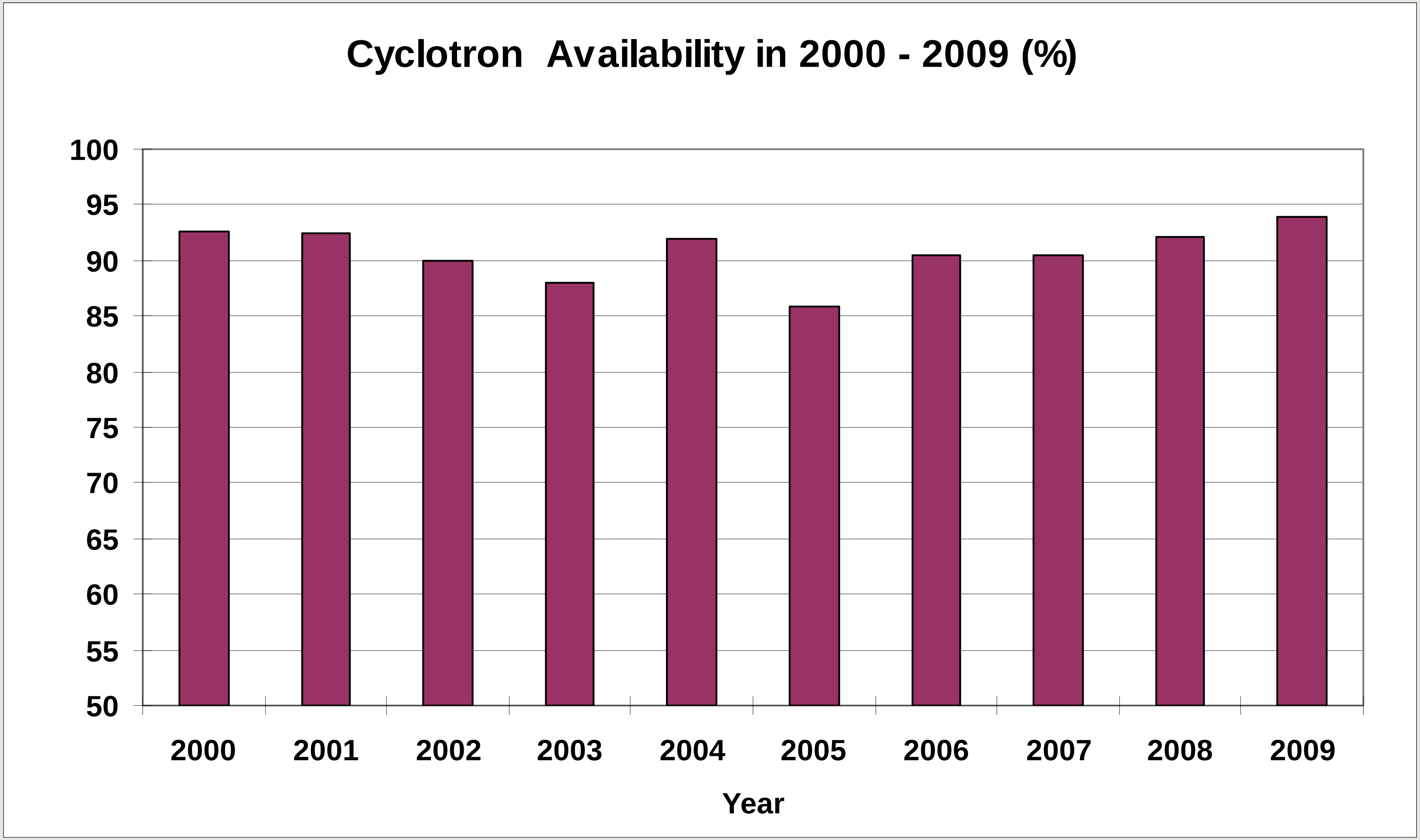
Outline

- Introduction
- Cyclotron operation statistic
- Cyclotron upgrade highlights
- Cyclotron beam development
- Recent achievements in ISAC
- ARIEL project highlights
- Summary

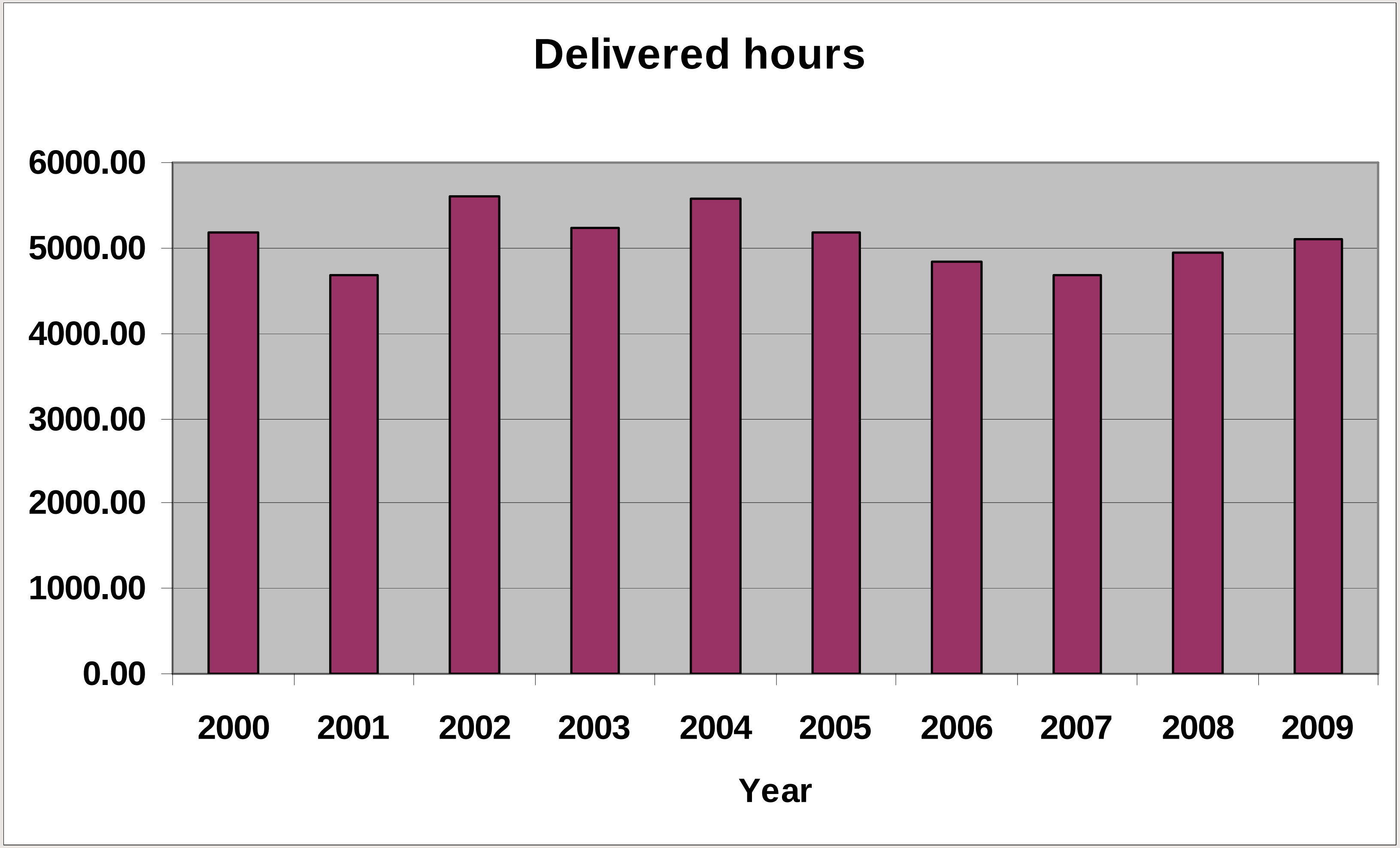
- **500 MeV Cyclotron:**
  - 5 meson experiments (μSR)
  - ISOL facility for RIB experiments
  - 2 isotope production facilities
  - Proton therapy facility
  - Proton irradiation facility



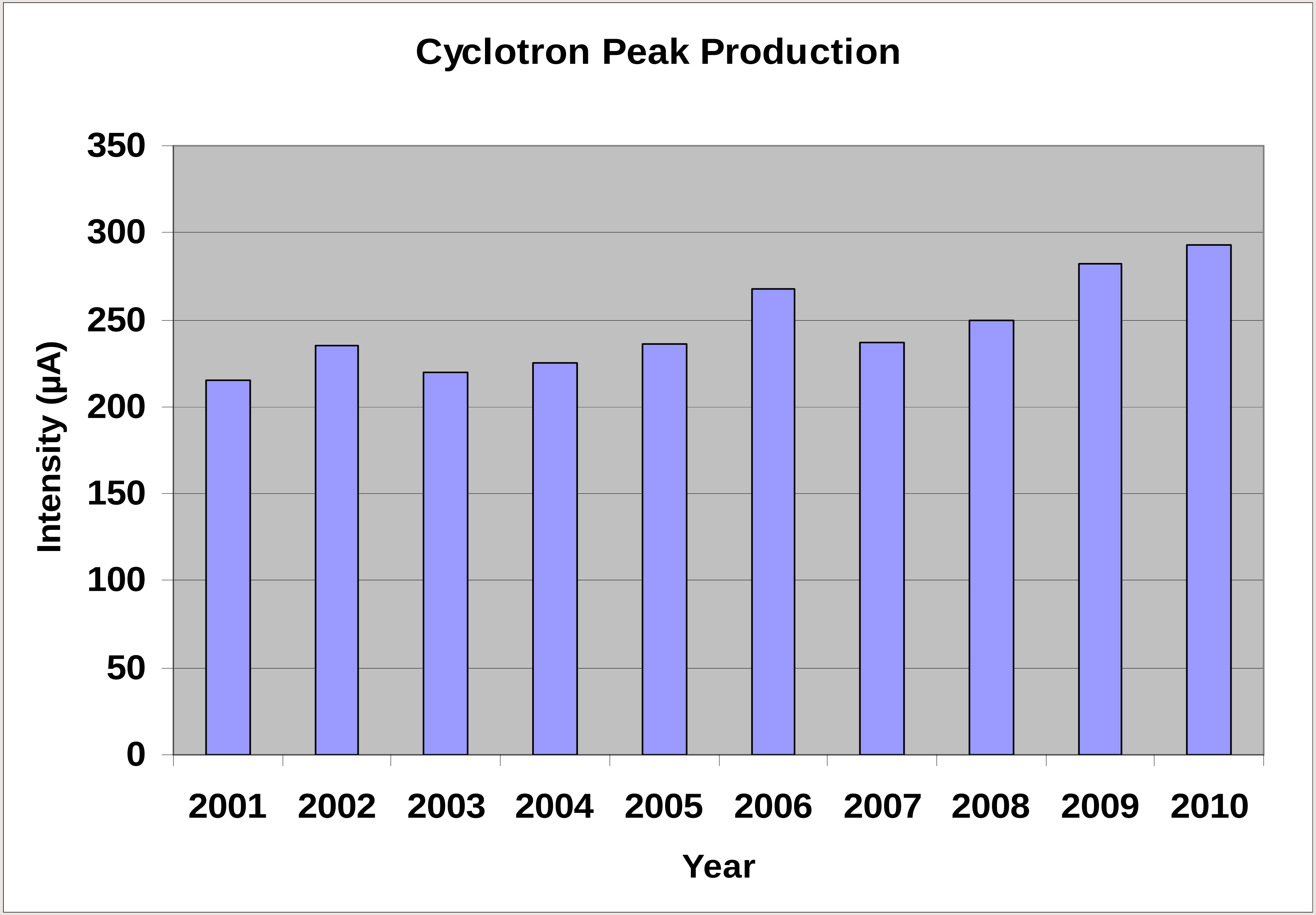
Cyclotron operation statistics



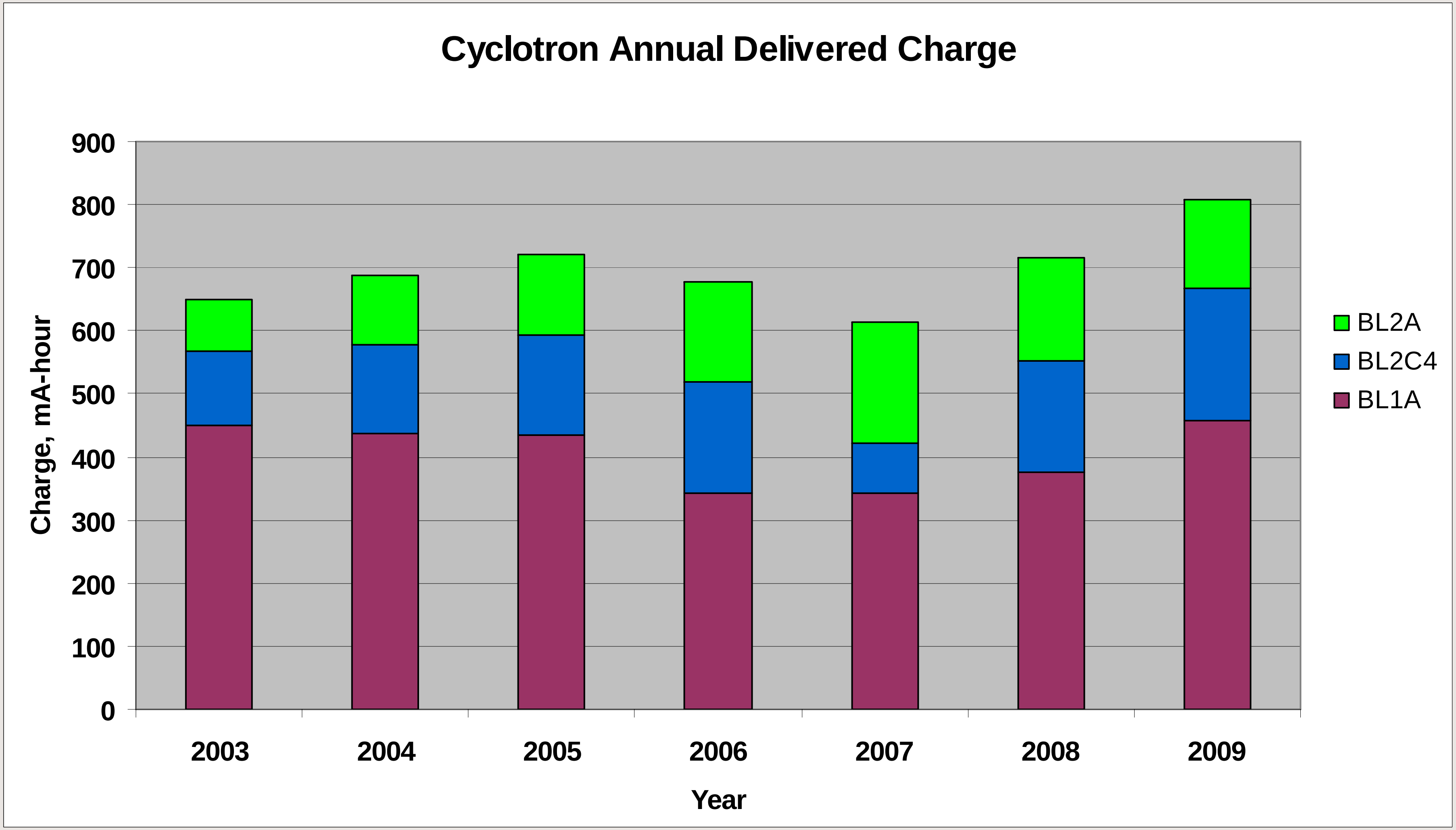
Cyclotron operation statistics (continued)



Cyclotron operation statistics (continued)

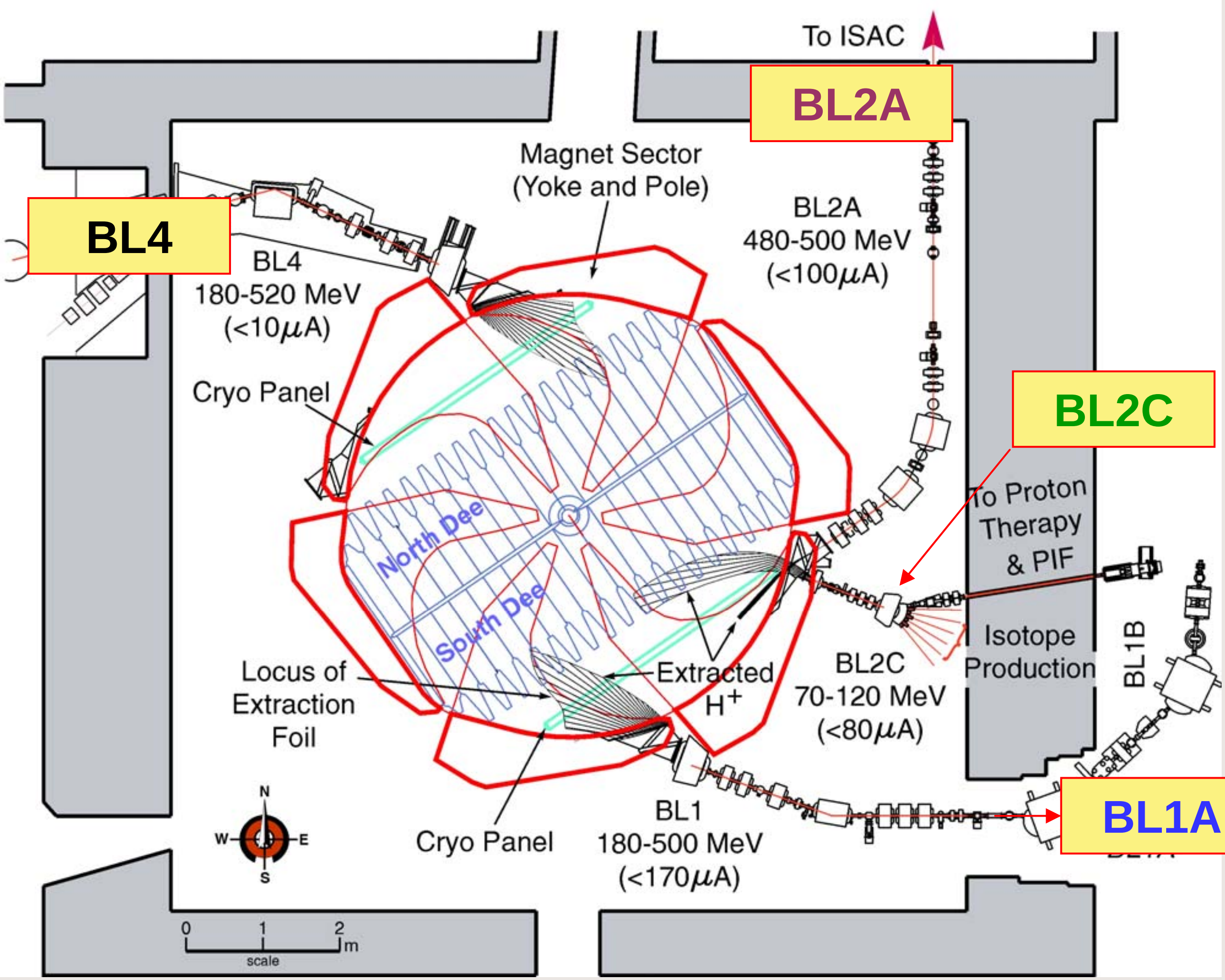


Cyclotron operation statistics (continued)



Cyclotron Capability

Last decade routine operation: 220-250 μ A extracted



Immediate needs:

MuSR program & 500 MeV isotopes: • BL1A (130 μ A)
ISAC program: • BL2A (75 μ A)
Sr production: • BL2C (75 μ A)
• **Total (280 μ A)**

5YP goal: 300 μ A

Long term plan: 400 μ A

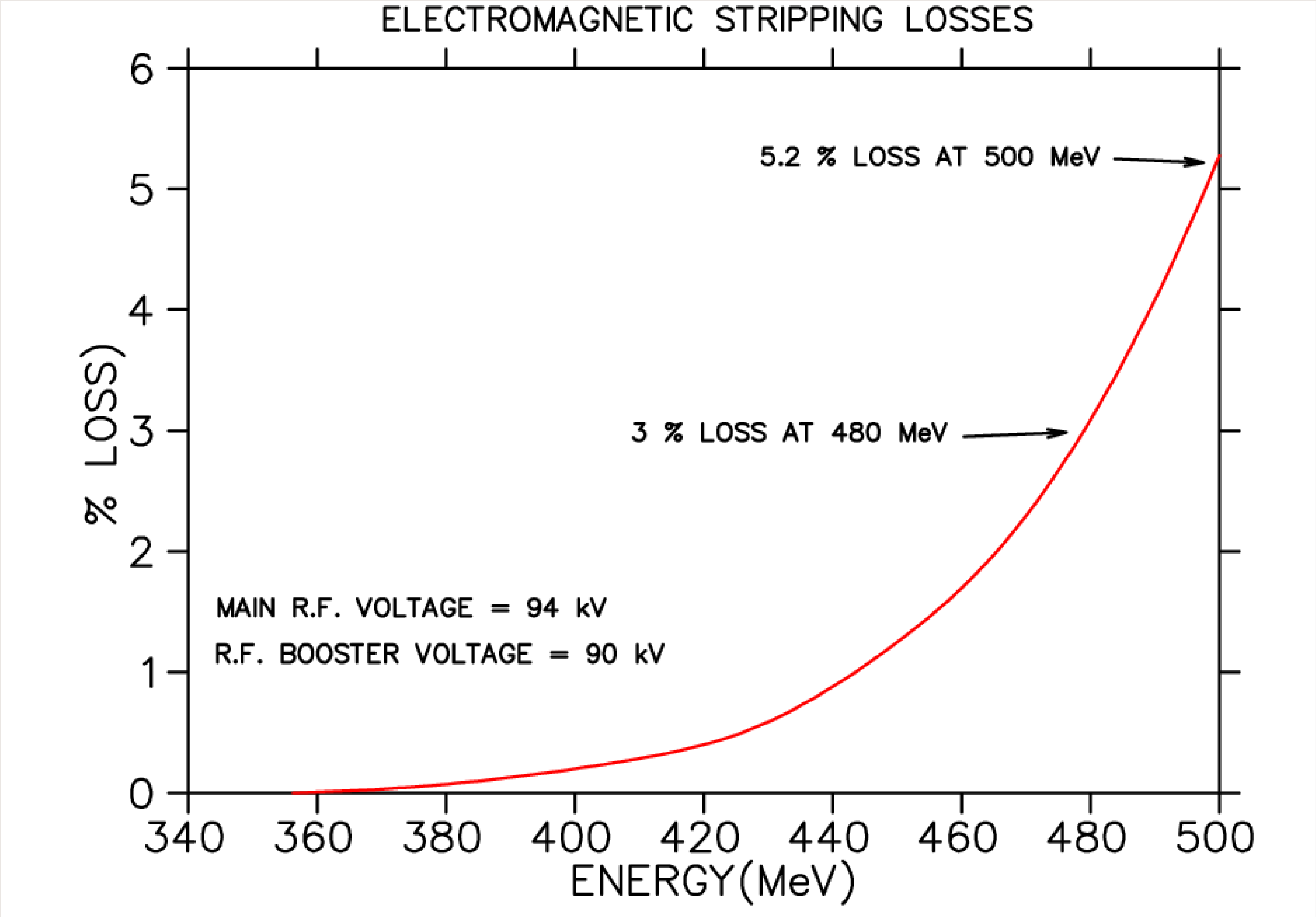
BL4=>100 μ A

Cyclotron Intensity Upgrade (400 μA) Path

- Dee voltage raise (90=>96 kV) to improve machine acceptance (95 kV now)
- Injection line fine tuning to improve matching into the cyclotron (new emittance scanner employed in 2010)
- Implement high brightness ion source (2012)
- Injection line upgrade to accommodate intense beams
- Centre region high power beam probes development
- Additional 200 μA beam dump construction to support machine development (2013)
- New BL4 extraction probe fabrication (2013)

Cyclotron Intensity Upgrade (400 μA) Constraints

- Two primary beams for ISAC have to be stable
- Maintenance requires regular access to the machine
  - Present activation levels are tolerable, but cannot be much exceeded
- Sources of the activation beam losses in the cyclotron:
  - Residual gas stripping (~2% @ $5*10^{-8}$ Torr)
  - Transmission losses in the vertical plane (~1%)
  - Lorenz stripping losses (~5% at 500 MeV)
- Extraction energy reduction from 500 to 480 MeV implemented in 2010 allowed 30% reduction of prompt radiation and residual activation (confirmed with H^0 online measurements and residual radiation monitors)
  - Energy reduction produced negligible impact on experiments and isotope production


ELECTROMAGNETIC STRIPPING LOSSES
5.2 % LOSS AT 500 MeV
3 % LOSS AT 480 MeV
MAIN R.F. VOLTAGE = 94 kV
R.F. BOOSTER VOLTAGE = 90 kV
% LOSS)
ENERGY(MeV)
0
1
2
3
4
5
6
340
360
380
400
420
440
460
480
500

Cyclotron refurbishing highlights

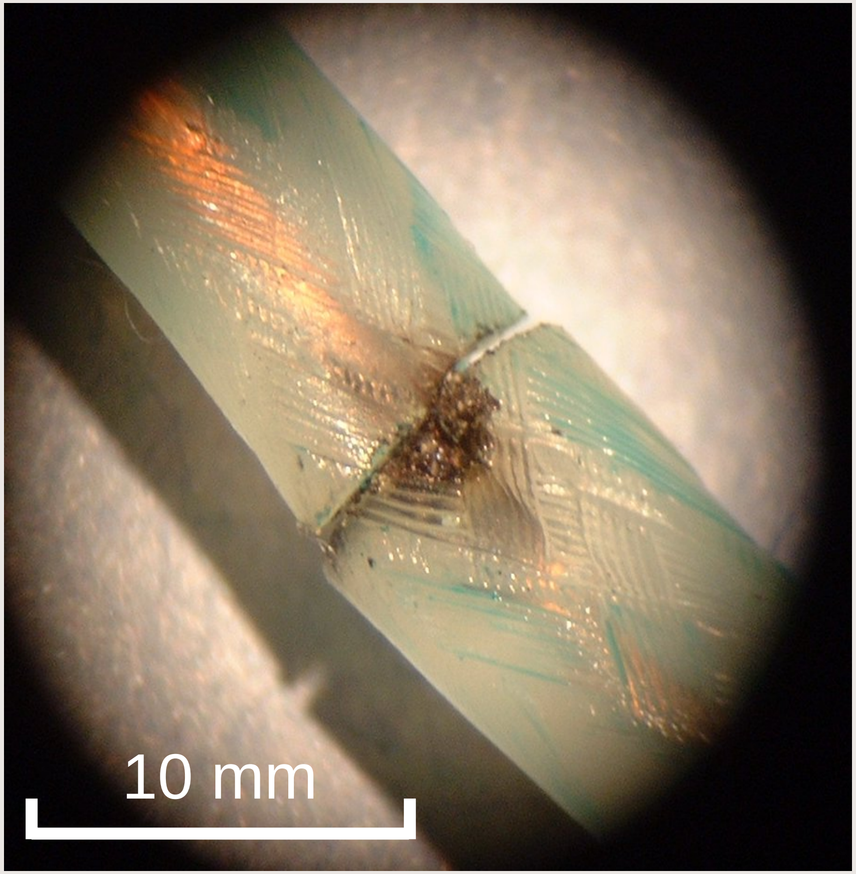
- **New helium refrigerator for vacuum cryopumping:**
  - Successfully employed in 2008
  - Improved vacuum ($2*10^{-8}$ Torr), low maintenance
- **Vault re-cabling:**
  - ~1300 cables to replace
  - 5 year project (dose driven)
  - Status: new cable tray infrastructure & 130 cables are done
- **New vertical section of the injection line:**
  - Ready for installation in winter 2011 shutdown
- **Trim & Harmonic coils power supplies replacement:**
  - 120 units of 10-20 kW
  - 5 year project, just started

Vault Re-cabling

Nature of the problem:

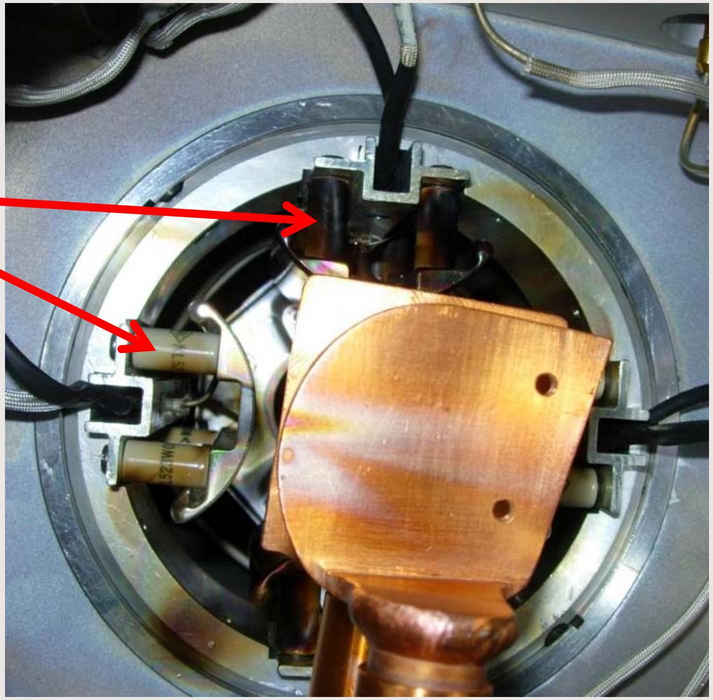
Cables got damaged due to

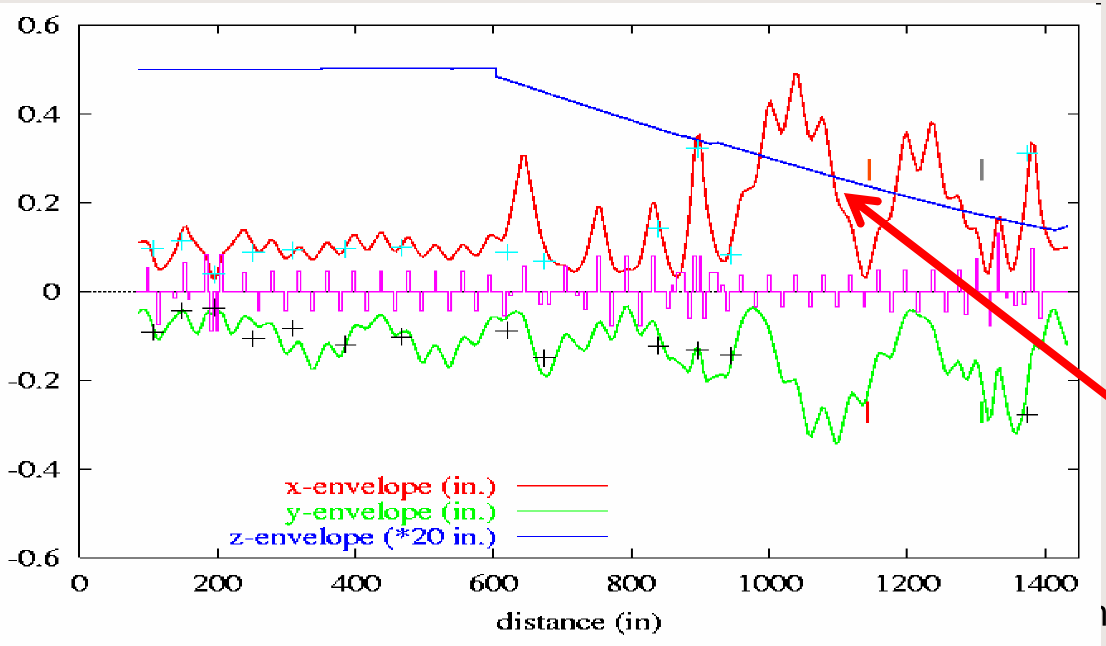
- **Radiation**
- **Elevated temperature**
- **Moisture**



Injection line vertical section: Old Beamline Issues

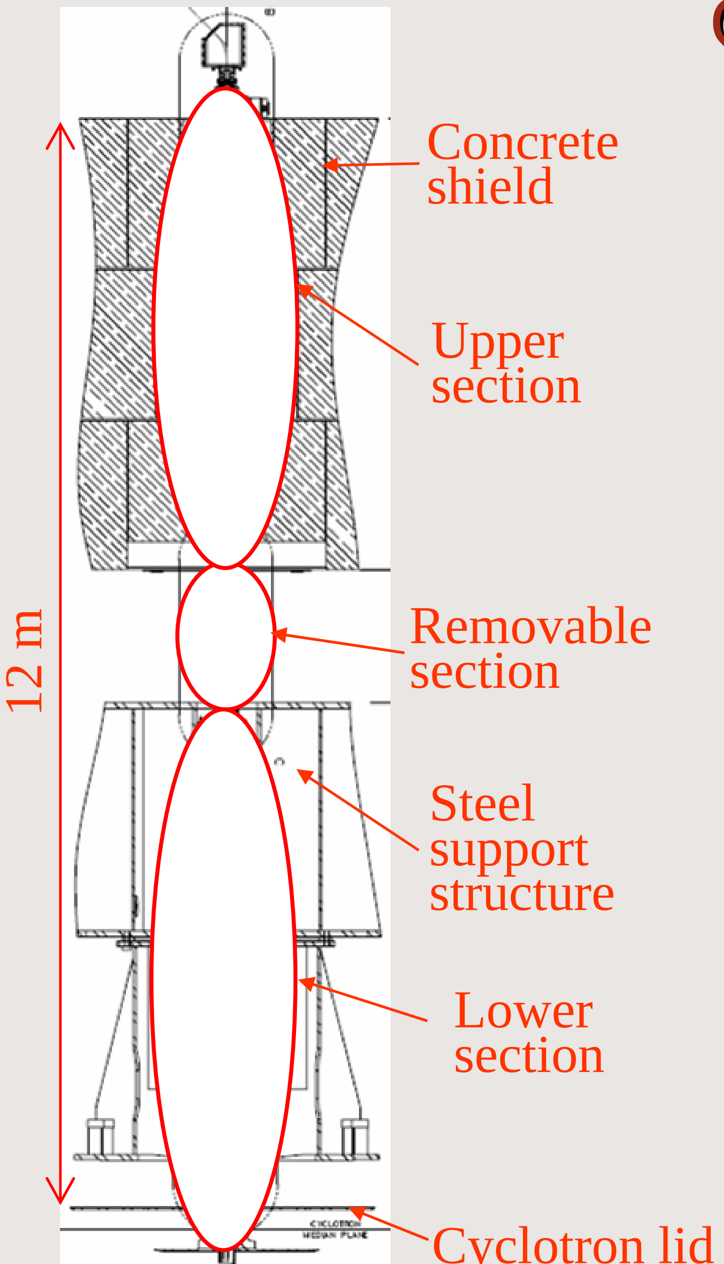
- Electrostatic quads insulators got coated after >20 years in operation
- Radiation environment (cables, plastic hoses)





- Congested space: limited access
- Limited diagnostics: poor beam matching

Injection line vertical section: Goals and Scope



Goals:

- New robust optics compatible with future intensity increase by factor ~10
- Improved vacuum
- Enhanced diagnostics
- Improved serviceability

Scope:

- 12 m electrostatic beamline
- 45 optics elements (quads, steerers, etc.)
- 19 diagnostics devices (5 types)

Beam Development Program

See Y. Rao's talk (TUMCCO03) today

Highlights:

- Machine intensity increase
- Beam stabilization in the cyclotron and on the ISAC target
- Study of extraction of 2 stable beams for ISAC
- Beam size and position control on all production targets
- Beam extraction at lower energy (480 MeV instead of 500 MeV)
- Extraction foil ^{7}Be contamination issue resolution
- Intensity stabilization for all users
  - Partial extraction
  - Split ratio regulation with harmonic coils
- Centre region beam dynamics study

New Ex1 / Ex2A Foil

- Highly oriented pyrolitic graphite foil
- Tantalum holder with a large radius corner
- Thin copper cushion
- Remained intact after 250 mAh

Tests with copper frame and diamond foil failed

Extraction Foils Properties

Foil type	Dimensions	Typical/max intensities	Lifetime
Pyrolitic Graphite Foil	4-5 mg/cm^2 16 x 32 mm	120/150 µA	65 mAh
Highly Oriented Pyrolitic Graphite Foil (+ new frame)	1.5-3 mg/cm^2 16 x 32 mm	120/150 µA	250 mAh, low statistics
Highly Oriented Pyrolitic Graphite Strip	3-5 mg/cm^2 Width: 0.25 -0.4 mm Height: 32 mm	50 µA	Being tested
Graphite Brush	6.4 mm wide curtain made of 0.025 mm Ø wires	70/80 µA	65 mAh
Graphite Filament	0.025 mm in diameter	< 1 nA	Never reached

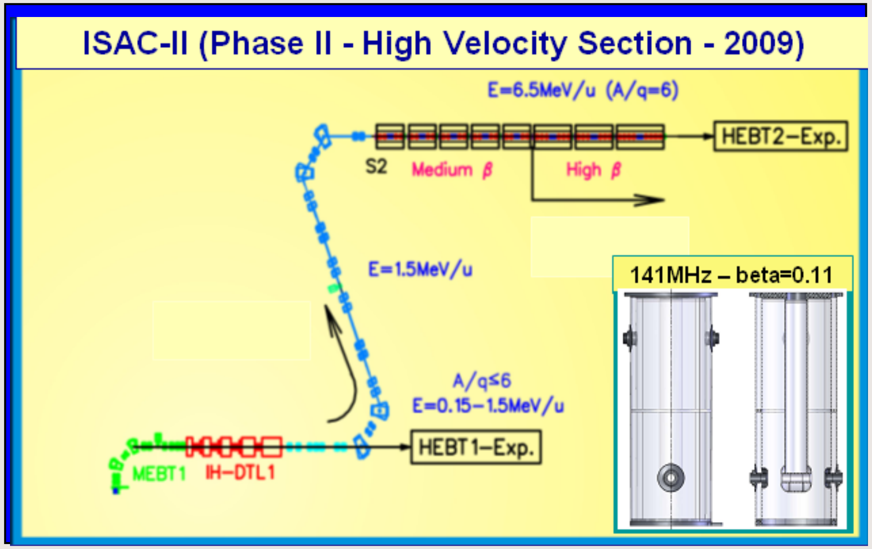
Recent achievements in ISAC

- ISAC-II Phase-II superconducting linac
  (B. Laxdal's talk on Thursday: THM1CIO02)
- Target development
- Ion sources
- Charge state booster

(P. Bricault's talk on Thursday: THM1CIO04)

ISAC-II Phase II SC-Linac Upgrade

- Five year R&D project completed on time and on budget
- Features three cryomodules with 20 niobium cavities
- First beam delivered to experiment April 2010



Actinide Target Tests

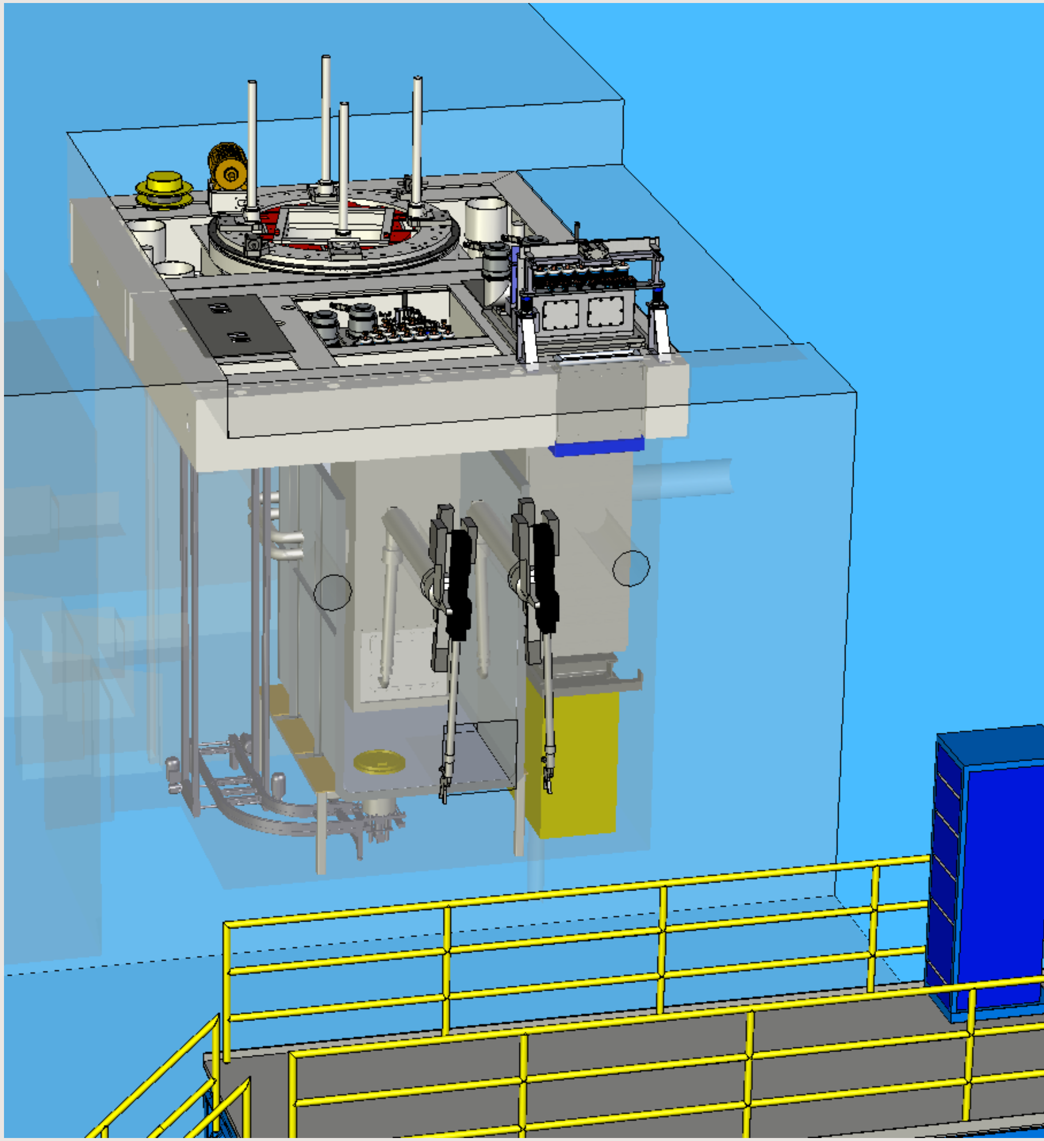
Sep 2008: Investigation of potential migration of activity through the actinide target and RIB beamline; review of upgraded ISAC radiation monitoring system and other infrastructure

Dec 2009: UO_2 target with FEBIAD ion source; investigation of noble gases Ar, Kr, Xe, Rn; RIB delivered to 8 π spectrometer

Based on the experience of the previous runs improved target material compounds (UCx) are currently being developed. The next actinide target run at ISAC is scheduled in **Dec 2010**

Target		Target Thickness	p+ Irradiation	max. Beam Current	Ion Source	Investigated Elements
UO2 #1	Sep 2008	22.1 g/cm3	296 μAh	2 μA	Surface	Na, K, Ga, Rb, In, Cs, Fr
UO2 #2	Dec 2009	20.9 g/cm3	426 μAh	2 μA	FEBIAD	Ar, Kr, Xe, Rn, Fr

Conditioning Station and North Hot Cell



Note: 50 KW beam on ISOL target

Motivation

- To prepare and test target/ion source assembly before on-line operation
  - Test cooling lines
  - Condition at HV
  - Prepare for on-line operation
- To prevent target module/hot cell cross contamination during actinide target handling, a new hot cell is being developed

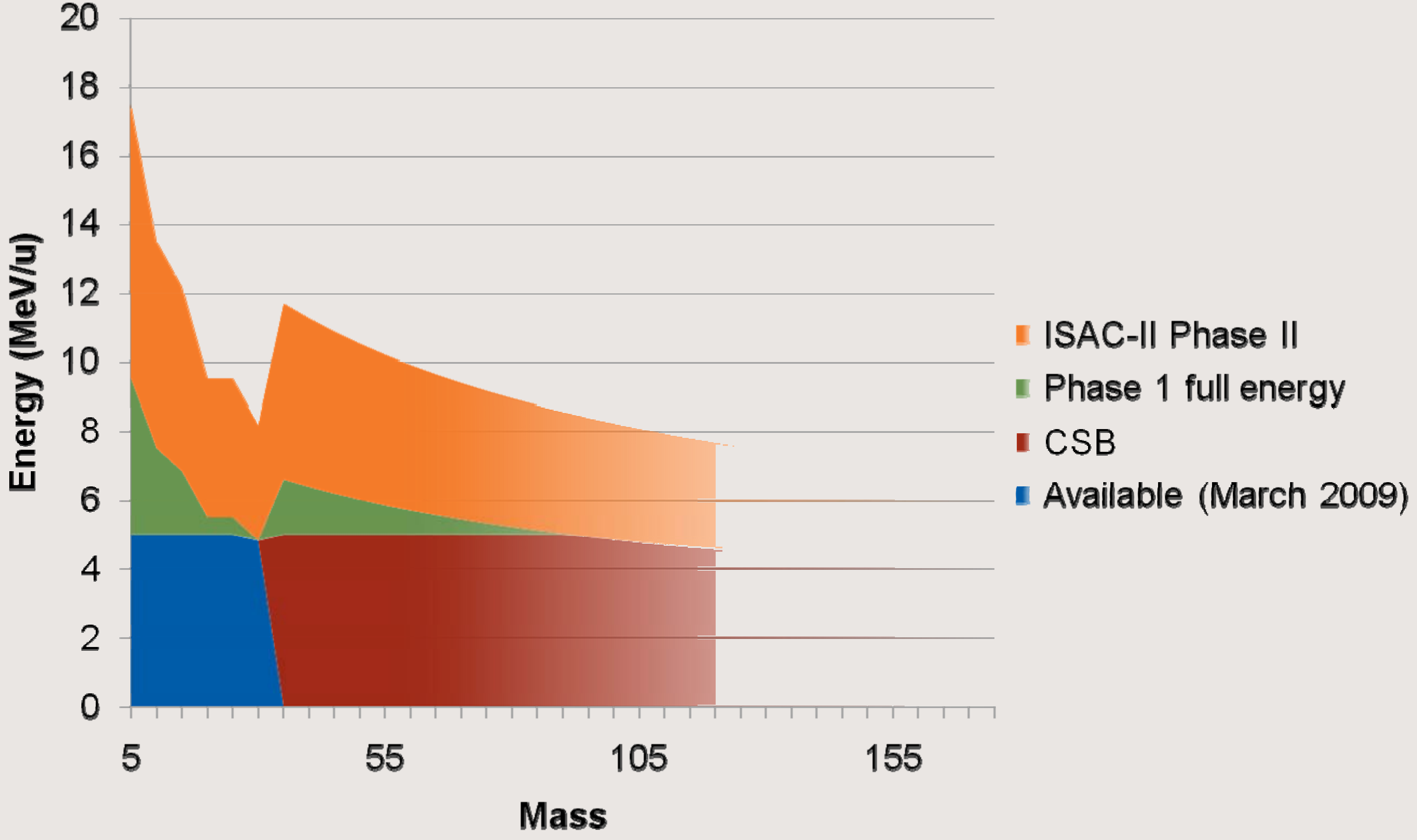
Status

- Conditioning station ready in 2011
- North hot cell ready in 2012

Charge State Booster

- ChargeState Breeder is based on PHEONIX ECR
- Installation and commissioning are completed
- Tests completed, demonstrated RIB acceleration
- Efficiency is 2-5%
  - Improvement of the vacuum will help
- First delivery to experiment happened in summer
- Program for purifying beam from contaminants during acceleration is in progress
- Continue development with RIB
  - Eff vs T1/2
  - Eff vs chemical properties
  - Test injection of molecular ions for better RIB purification
- Plan for future: develop EBIS or EBIT

Accelerated RIB at ISAC – Evolution

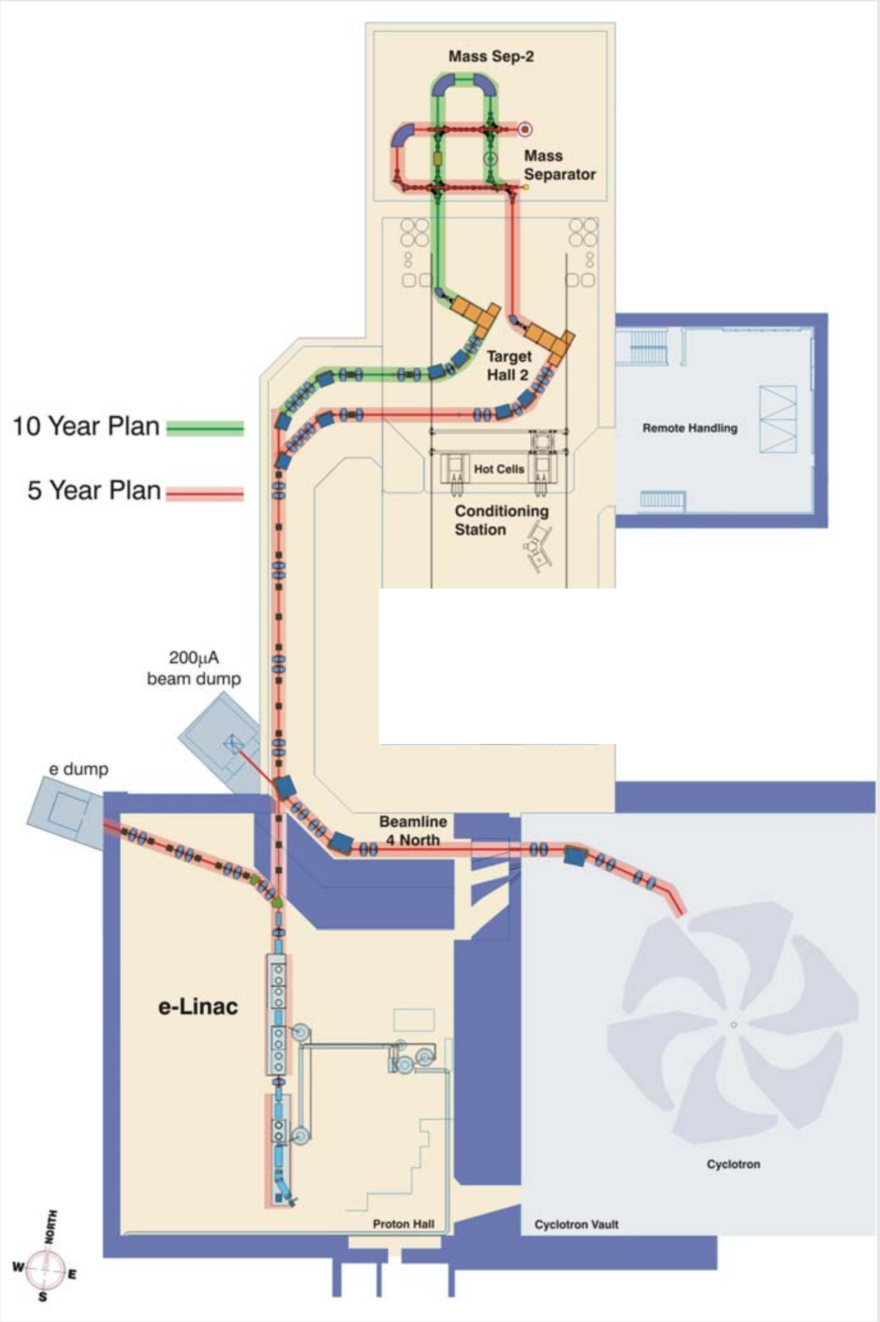


FIVE YEAR PLAN (2010-2015)

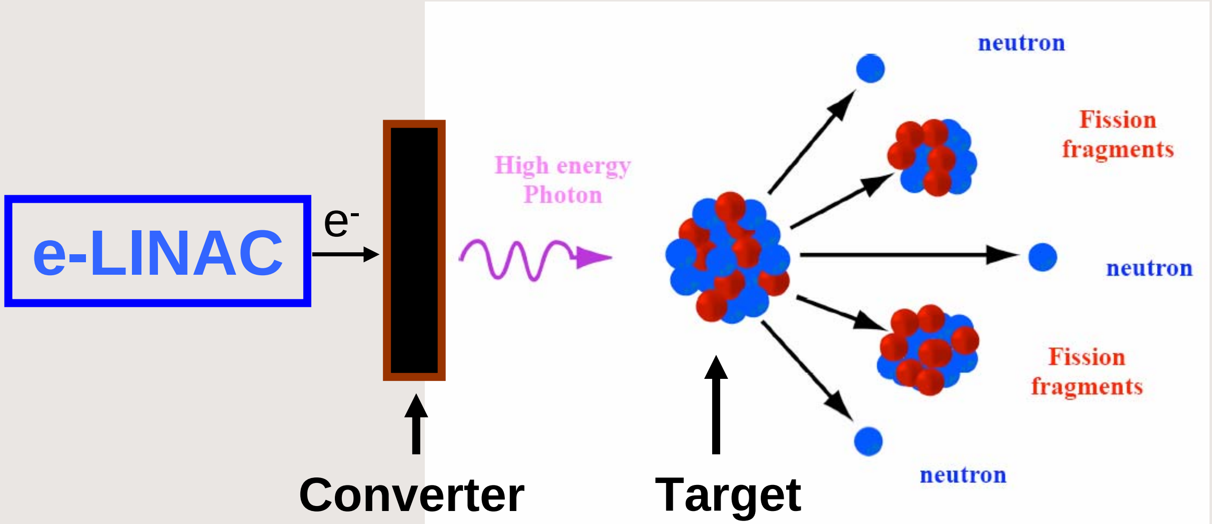
- **TRIUMF is set to further expand its strength: RIBs, nuclear medicine, isotope production, material science, technology transfer**
- **Accelerators Main Goal: More RIB's for users!**
- **Issues at ISAC:**
    - **Big overhead for target and beam switchover (~3000 hours RIB delivered over 4500 driver availability)**
    - **12 experimental stations and 1 available RIB at the time**
    - **Development of new RIB shares time with running experiments**
- **Solution: Three simultaneous RIB's: one for each experimental area**
- **Realization: ARIEL project**

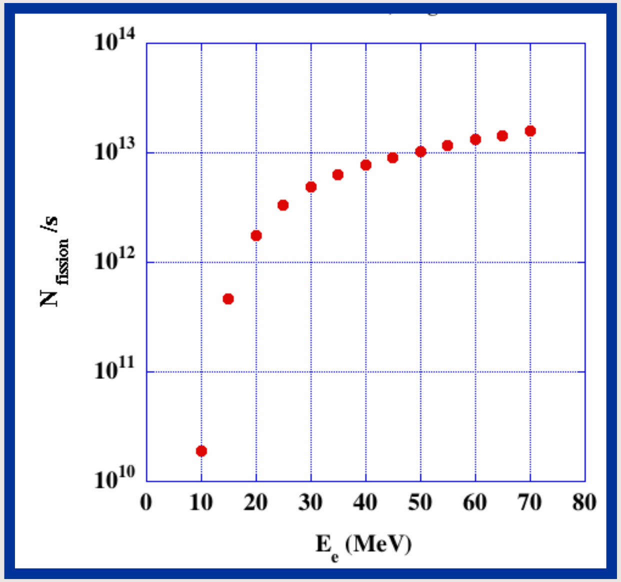
ARIEL Project

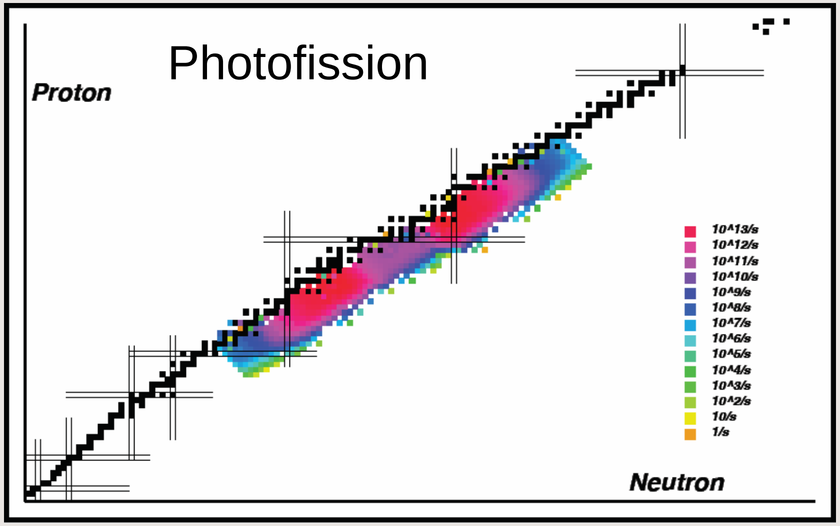
- 10-year project
- Started in 2010
- Key components:
  - Electron linac driver
  - New proton beam line
  - Two new target stations (actinide)
  - New mass separators & frontend
  - New ISAC postaccelerator
- Electron accelerator and beamlines are funded by CFI
- Buildings and infrastructure are funded by local government

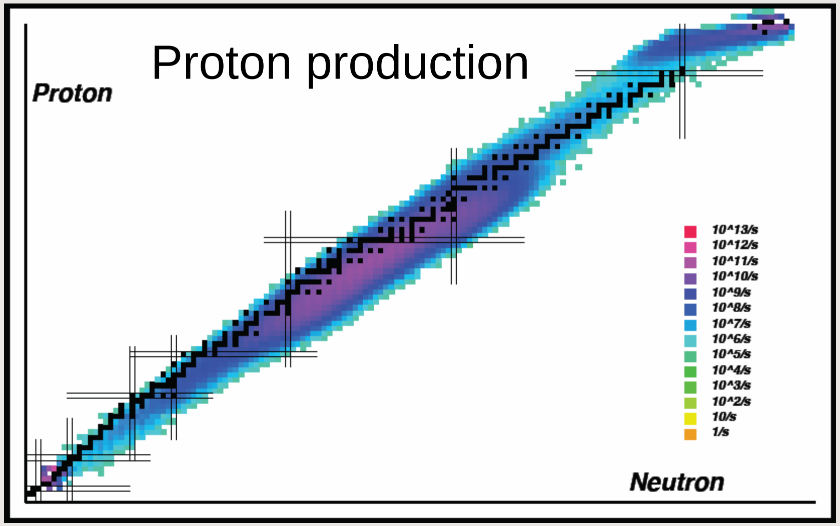


Photofission

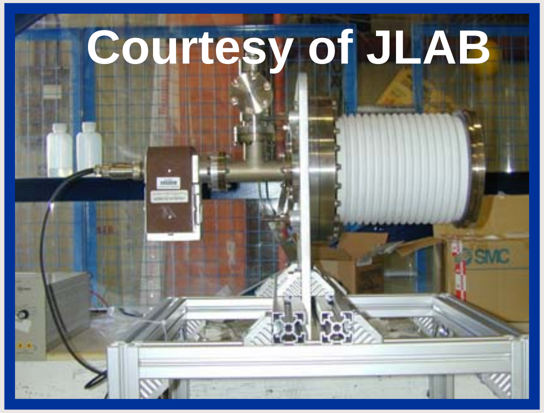




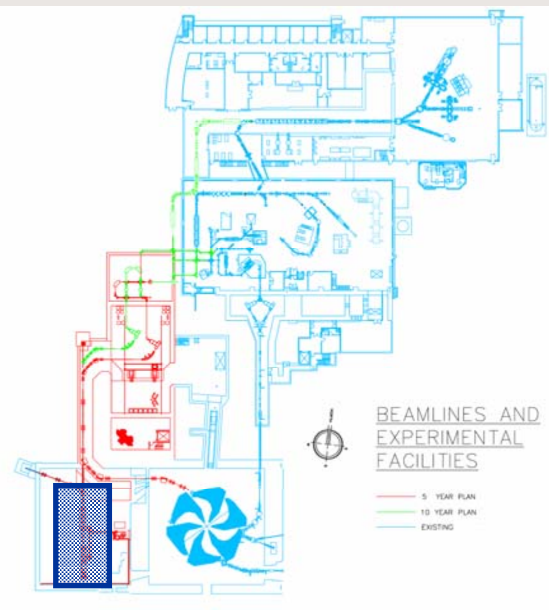


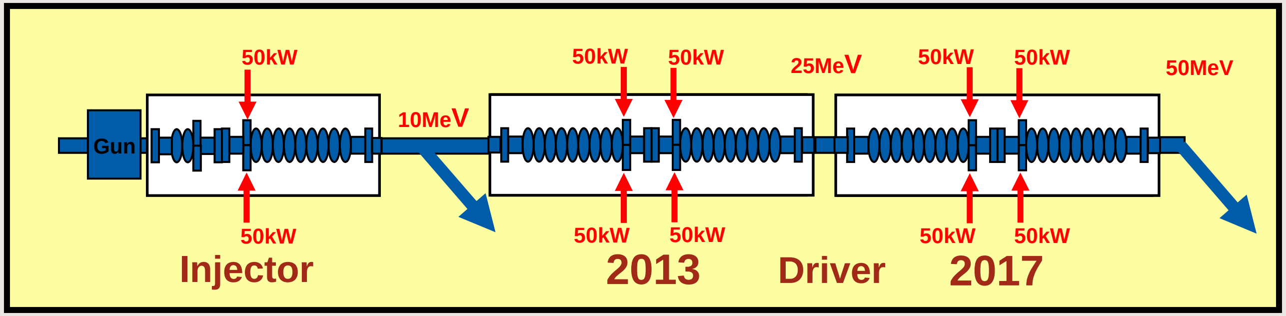


e-LINAC



- **Electron driver for photofission: independent and complementary**
- **Elliptical SC cavities at 1.3 GHz**
- **Operation mode CW**
- **Limited gradient at 10 MV/m**
- **Final energy 50 MeV**
- **Intensity 10 mA**
- **½ MW beam power**
- **100 kV gun is being tested**





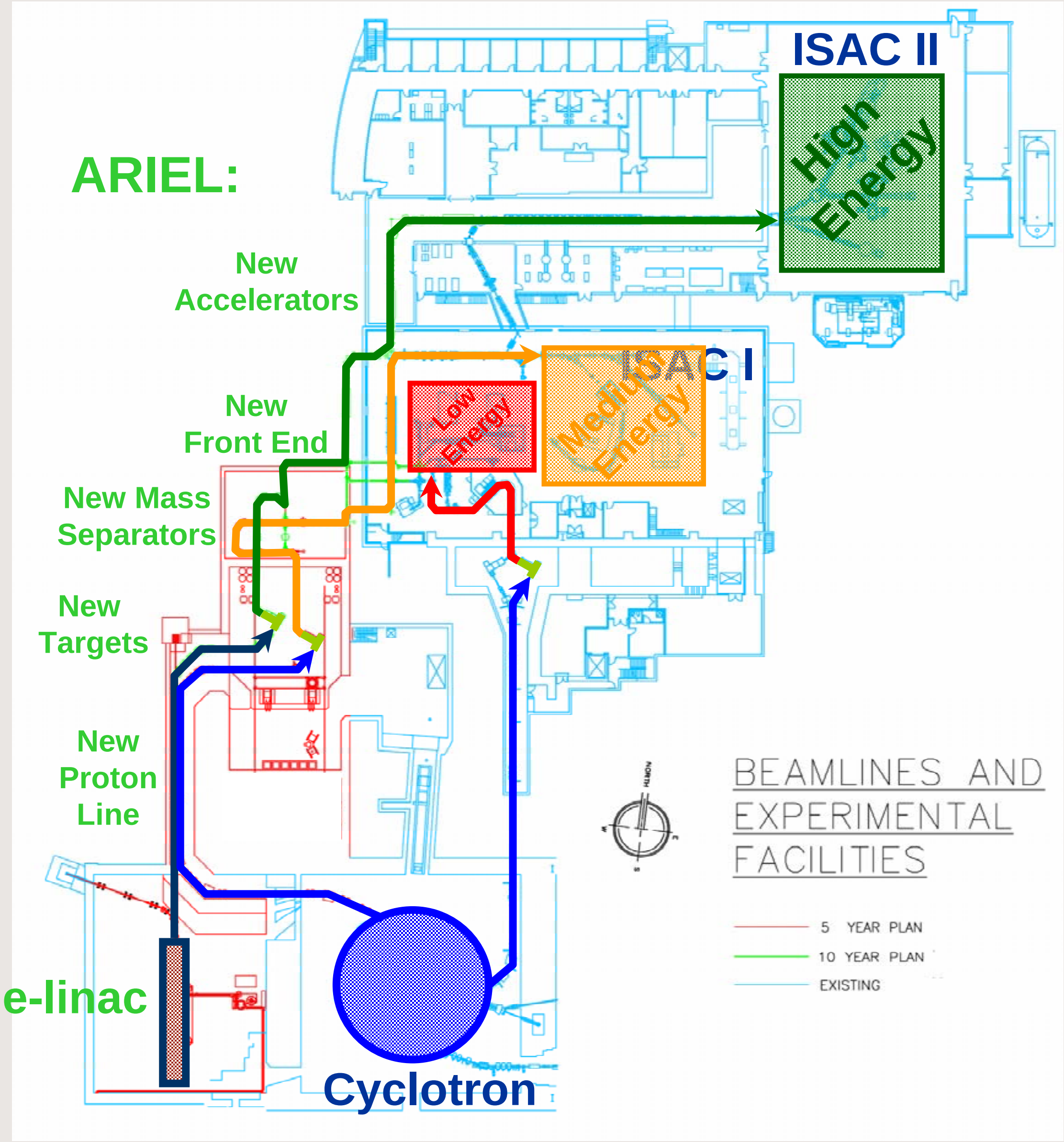
Collaboration with VECC (Kolcata, India)

- Same goal: electron linac for RIB
- Scope: build and test with beam two Injector Cryo-Modules (ICM) at 10MeV/50kW
- Share resources
- Supported early start of e-linac design

New Proton Beam Line (BL4N)

- Required beam: 10-100 μA
- Energy: 450-500 MeV
- Transport capacity: 200 μA
- Beam dump capacity: 200 μA
- Intensity instabilities: <1%
- Achromatic design & collimation: low loss
- 500 Hz beam rastering on the target

Future RIB delivery



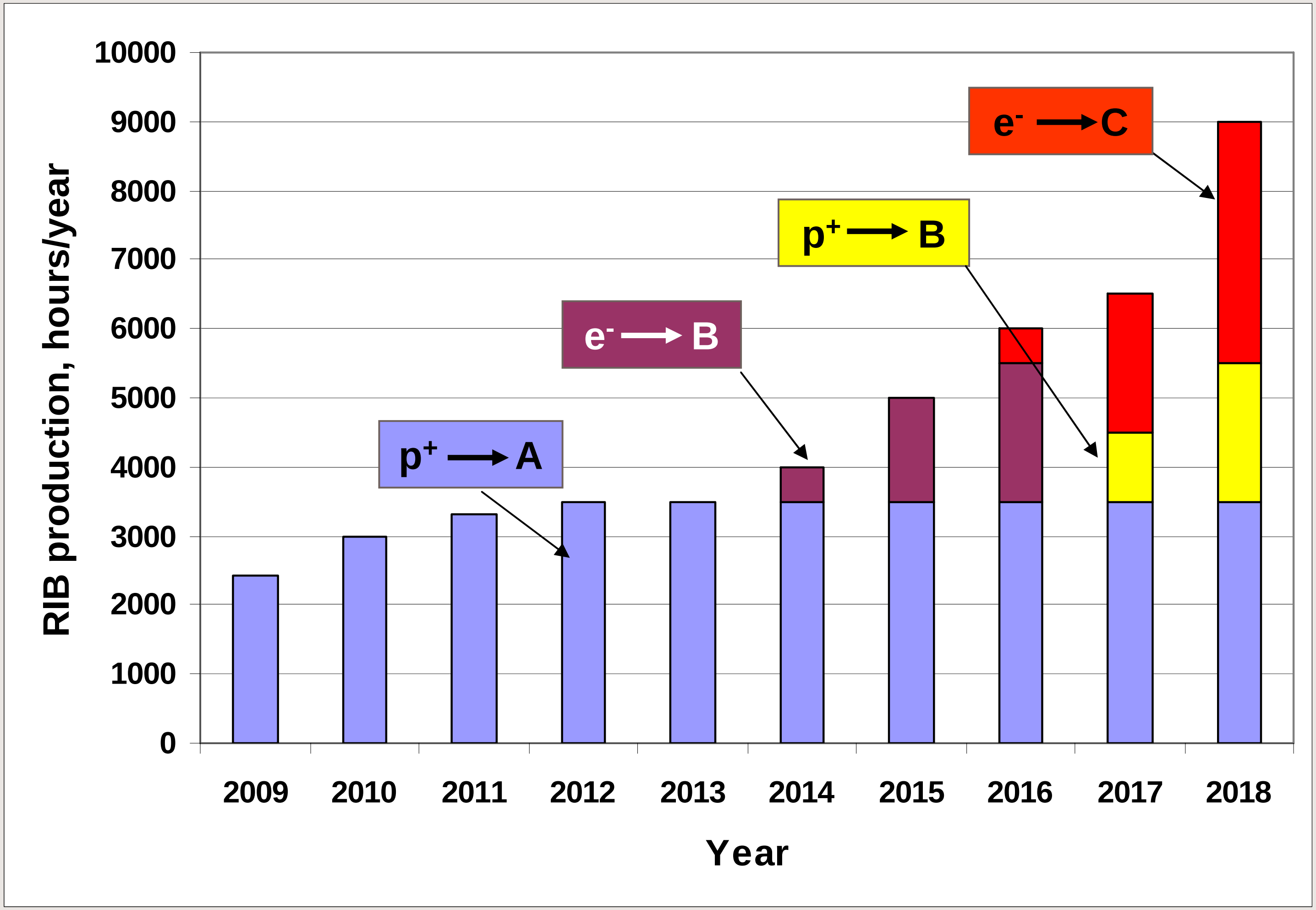
- Goal: three simultaneous radioactive beams
- New complementary driver (e-linac)
- New proton beamline
- New target stations and mass separators
- New front end and post accelerators
- Staged installation

RIB Production Potential

Target A – ISAC-I target

Target B – The e-linac – 2013, the new proton line – 2016: double RIB hours

Target C – high power electrons: triple RIB hours by 2018



Summary

- 500 MeV cyclotron remains the TRIUMF's workhorse and is capable of satisfying the increasing operational requirements in the future
- TRIUMF cyclotron intensity needs to be increased by > 30%
- One more high intensity stable beam have to be extracted
- Extraction energy reduction helped equipment activation issue
- TRIUMF provides one of the most intense ISOL facilities in the world and is expanding into actinide targets domain
- TRIUMF has proven its SRF expertise with operational SC heavy ion linac and is moving into L-band domain
- New electron linac driver for RIB's is funded and being developed