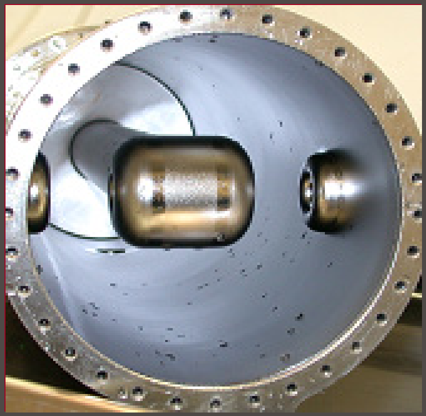
The ISAC-II Linac Performance

Marco Marchetto | ISAC High Energy Facility Coordinator | TRIUMF



Outline

- Introduction
  - TRIUMF
  - ISAC-I
- ISAC-II
- Operational experience
  - Hardware issue
  - Acceleration performance
  - Future perspective
- ARIEL and ISAC
- Conclusions

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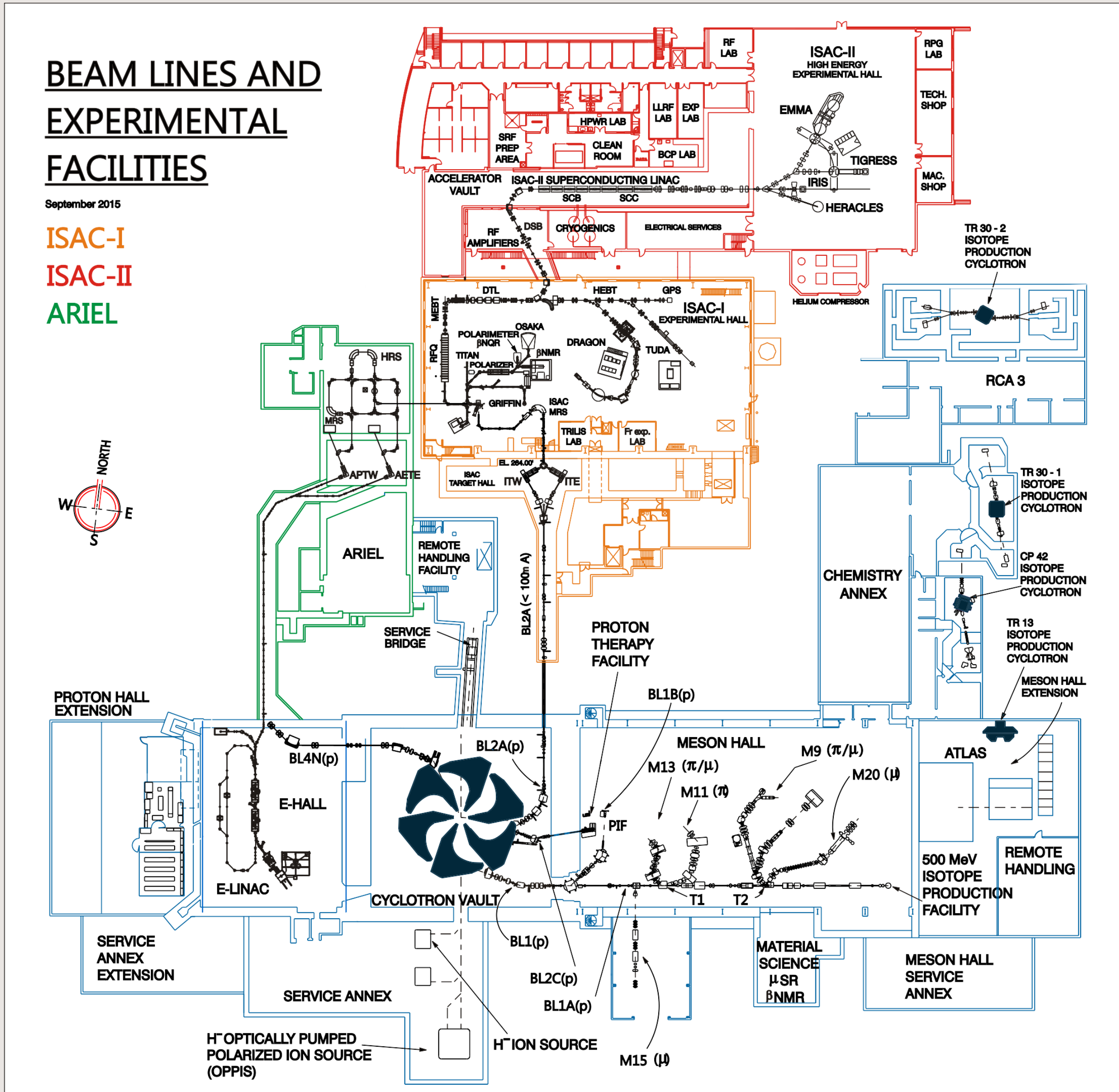
TRIUMF

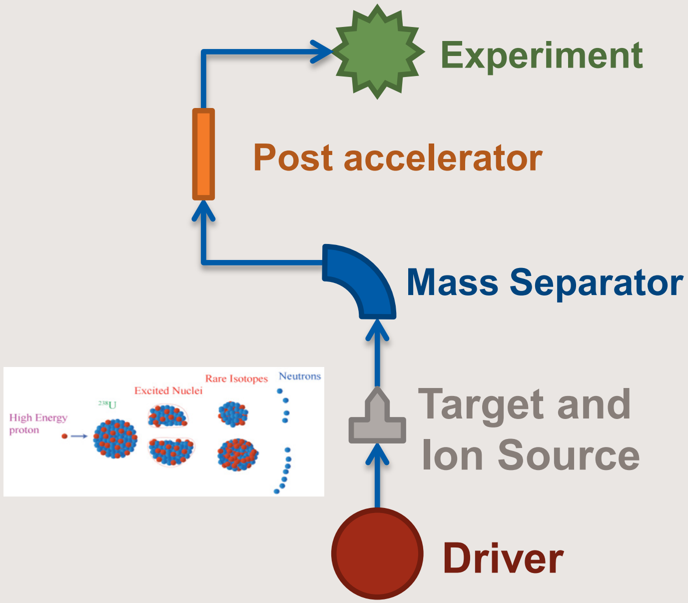
Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

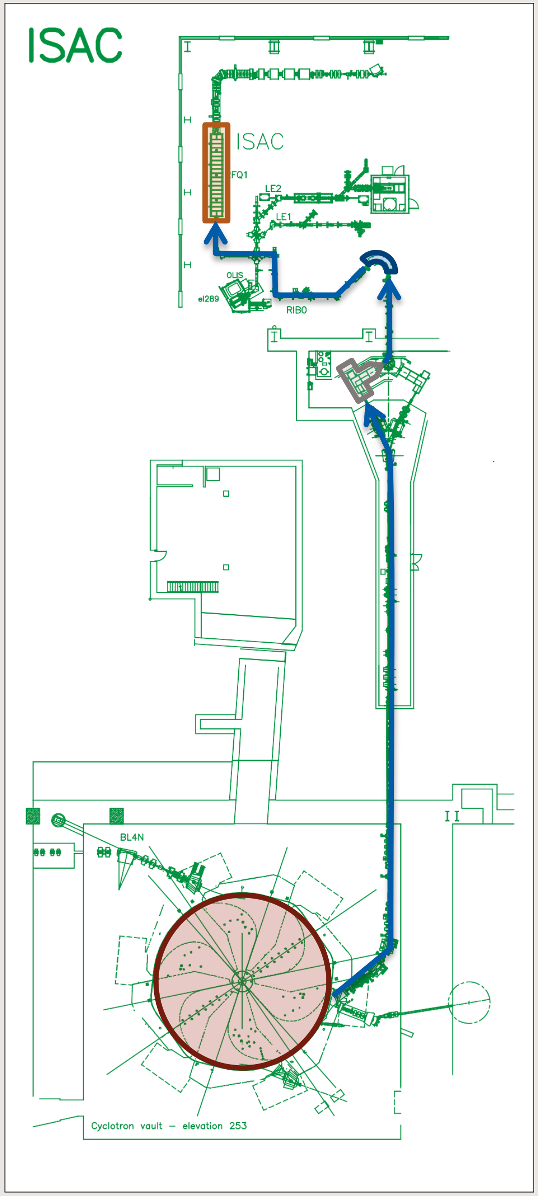


Vancouver, BC
UBC campus

ISAC at TRIUMF

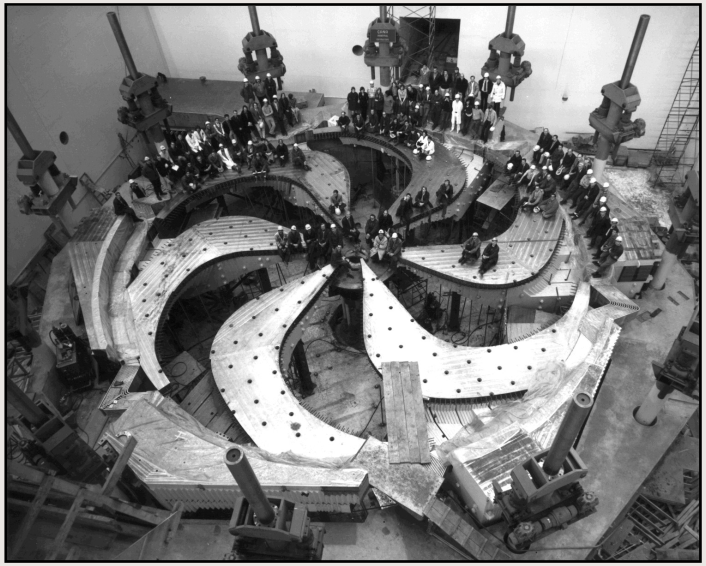
- Isotope Separation and ACceleration (ISAC)
- Isotope Separation On Line (ISOL) facility for rare isotope beam (RIB) production
- Highest power driver beam (50 kW)
- Most intense radioactive beam of certain species: ^{11}Li yield at $2.2 \cdot 10^4$ ions/s with 65 μA (April 2015)



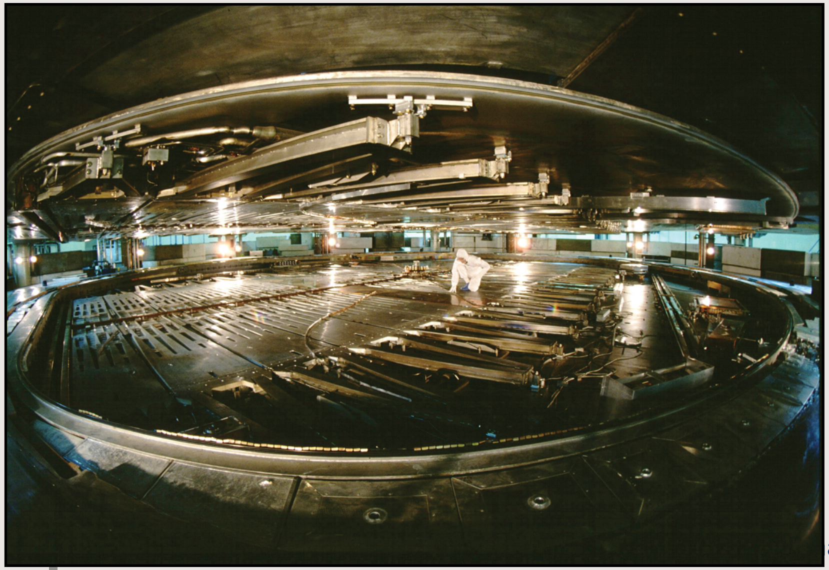


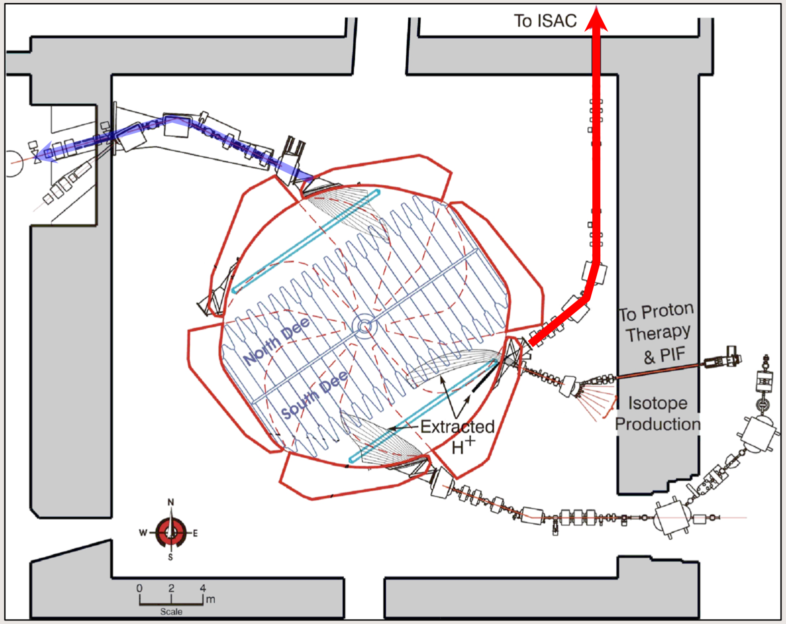
ISAC driver

https://www.youtube.com/watch?v=L1Orq4zBFLI&feature=em-share_video_user



- H$^-$ cyclotron as proton driver (multiple extraction at different energies) for RIB production
- Proton at 500 MeV up to 100 mA (50 kW)
- Two production lines:
  - ISAC BL2A existing
  - ARIEL-II BL4N expected 2020





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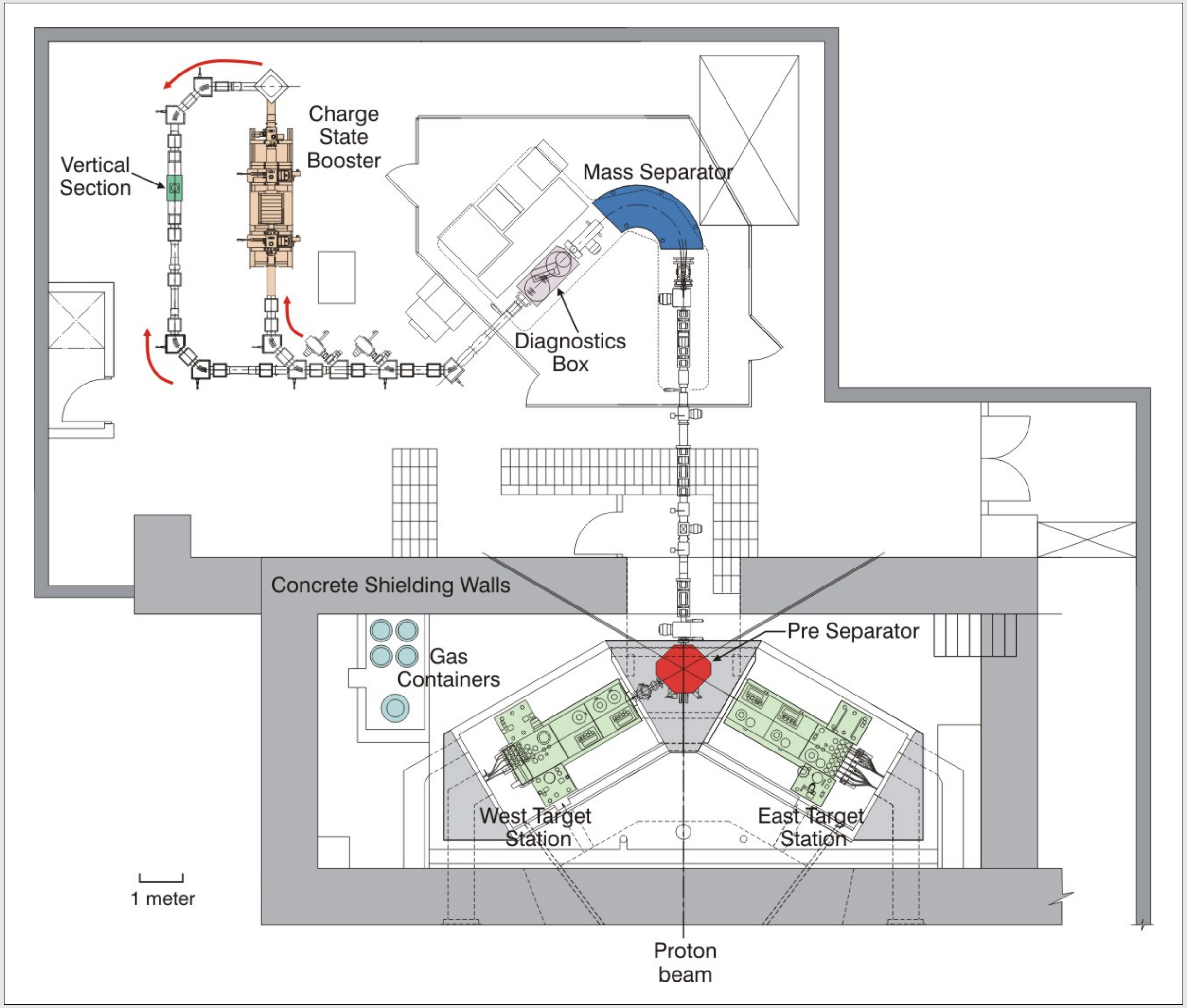
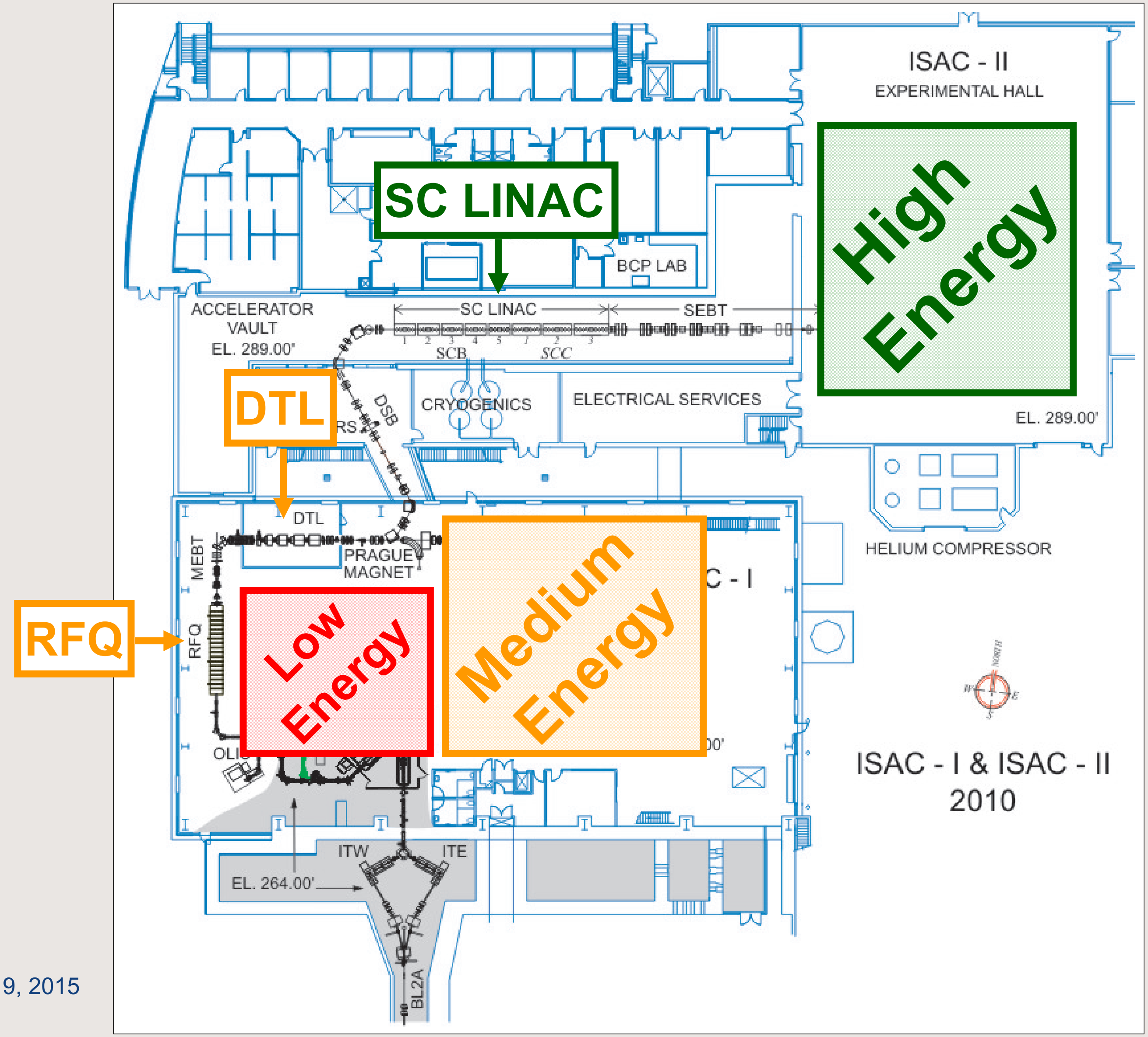
Target stations and Mass separator

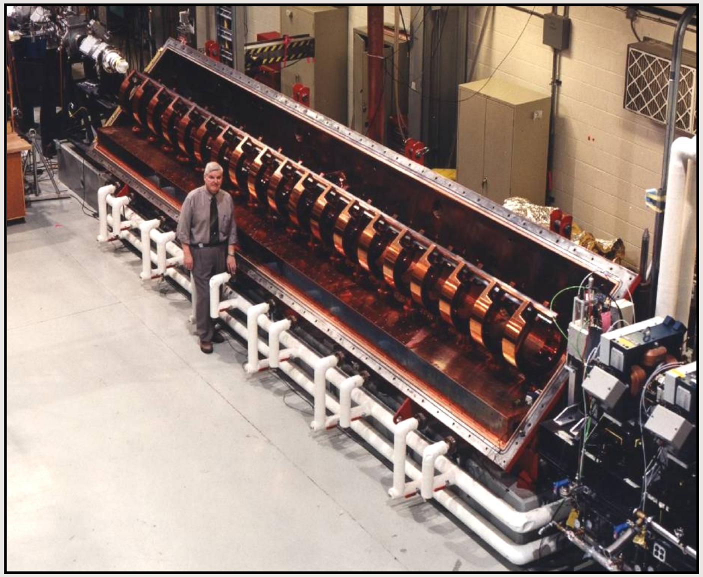


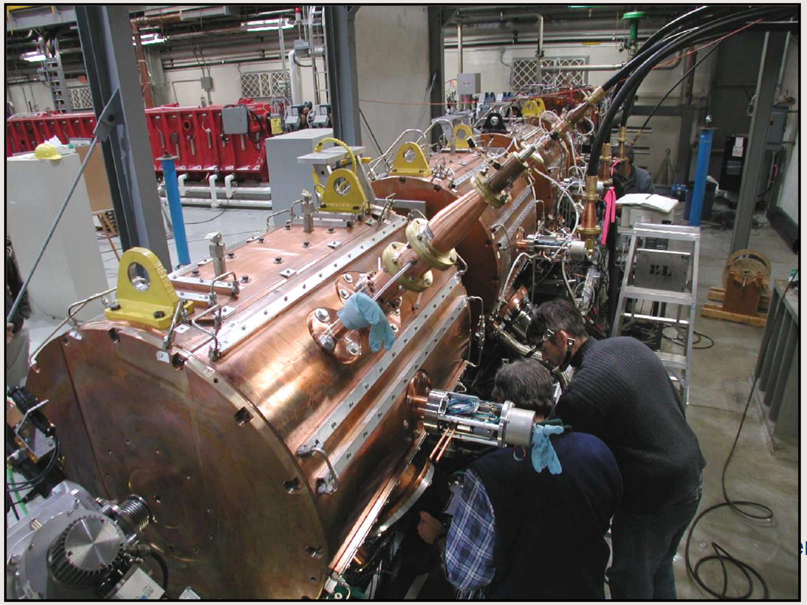
- Two underground target stations with extraction voltage up to 60 kV
- Proton beam sent to one of the target station at the time
- Common pre-separator inside the shielded area
- Mass separator on high voltage platform (typical operation resolving power 3000)
- Charge breeder (ECR type) for post acceleration

Experimental facilities



ISAC-I accelerators





- RFQ normal conducting at 35.36 MHz:
  - 8m long CW machine
  - 150 keV/u, 3≤A/q≤30
  - high quality transverse and longitudinal emittance: 0.2 μm and 1.5 kev/u·ns
- DTL normal conducting at 106.08 MHz:
  - Separated functions
  - Five IH interdigital RF cavities
  - Three split-ring bunchers
  - Variable energy machine
  - 150 keV/u ≤ E ≤ 1.8 MeV/u,   2≤A/q≤7
  - ISAC-II SCinac injector 1.5 MeV/u

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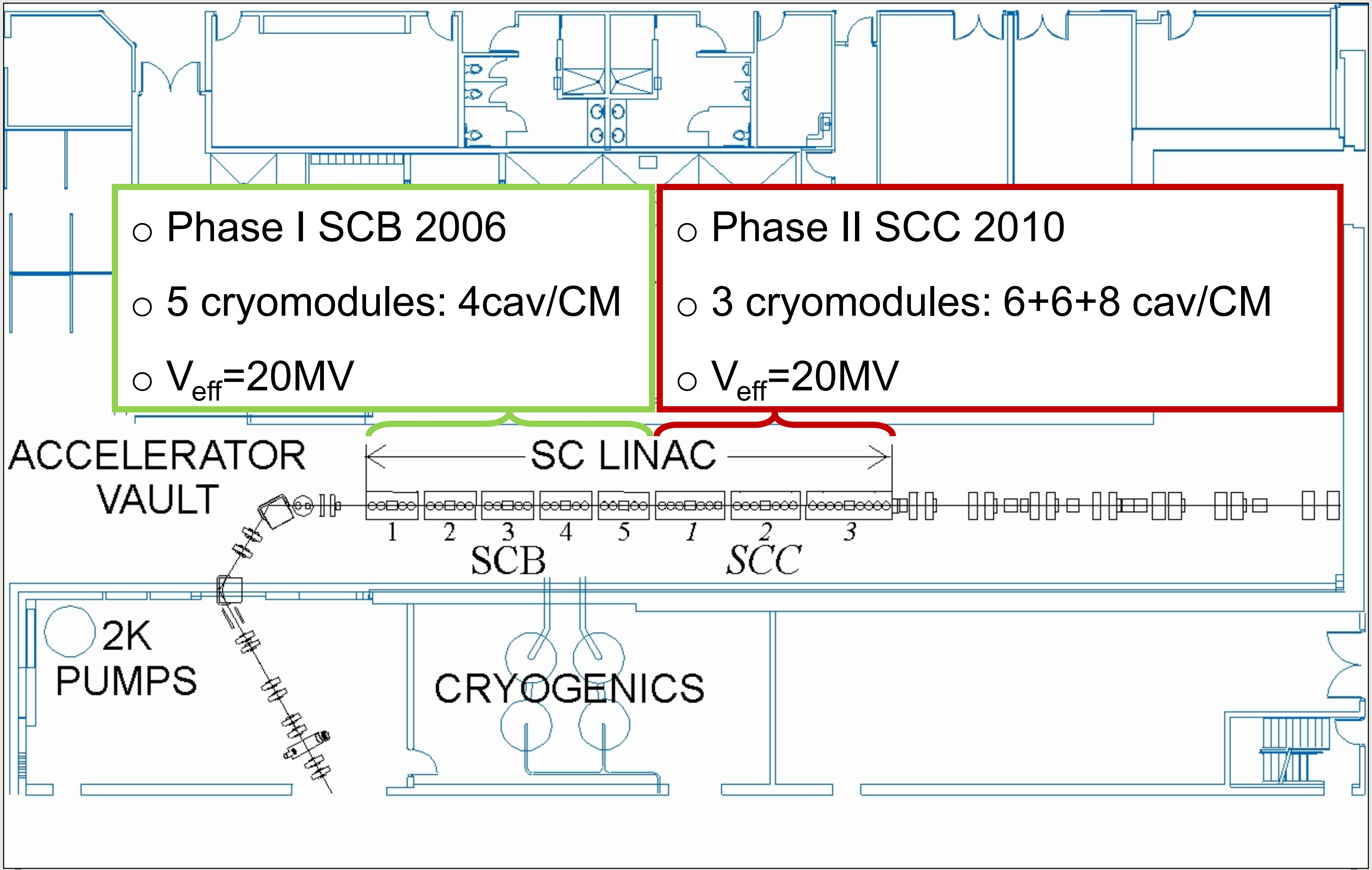
ISAC-II

- The idea (late 1990's) was to expand ISAC-I capabilities
- Requirements:
  - higher energies to support Nuclear Physics studies at and above the Coulomb barrier: energy E≥6.5MeV/u for A/q=6 (≥30MV of effective accelerating voltage) with full energy variability
  - broader mass range: up to A~150
- Design:
  - Superconducting heavy ion linac of 40MV
  - ECR charge state breeder (CSB) to increase the charge state for A>30 to meet the RFQ A/q acceptance

ISAC-II linac installation



- Phase I SCB 2006
- 5 cryomodules: 4cav/CM
- V_{eff}=20MV

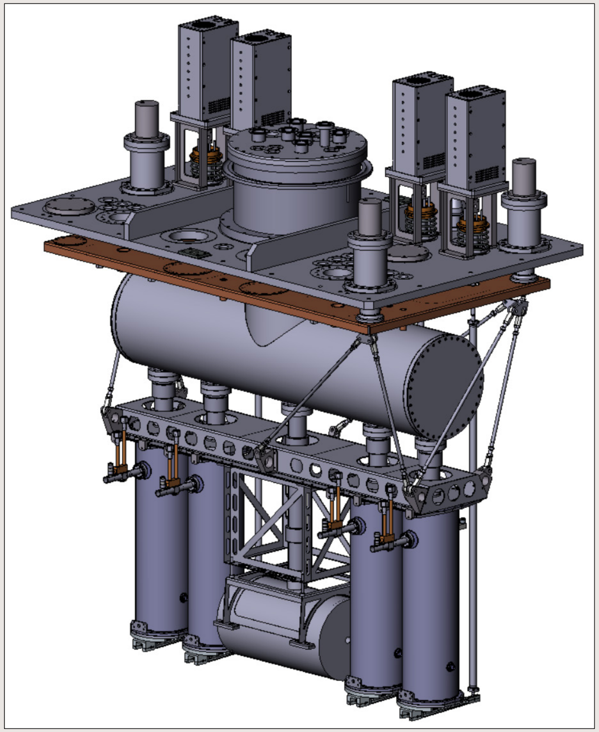
- Phase II SCC 2010
- 3 cryomodules: 6+6+8 cav/CM
- V_{eff}=20MV

Project highlights

- Linac budget of 15M$ project: cryogenics (refrigerators and distribution system), cavities, solenoids, cryomodules, RF amplifiers, power supplies
- SCB cavities manufactured by E. Zanon
- SCC cavities manufactured by PAVAC Industries (Vancouver area): part of a development plan to qualify a Canadian vendor of bulk niobium SRF resonators
- The project was completed on time and on budget

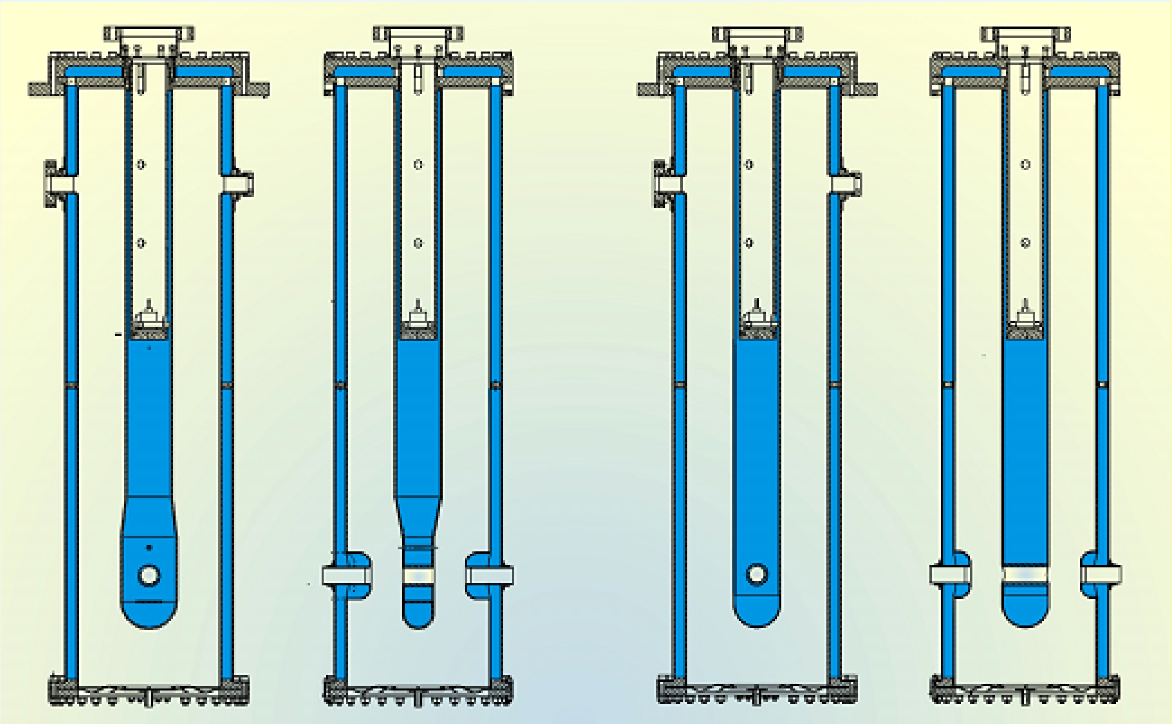
Cryomodule characteristics

- Quarter wave bulk niobium resonator
  - Tuner for helium pressure fluctuation 20Hz bandwidth: slotted niobium plate actuated by an external linear motor
  - Liquid nitrogen cooled coupling loop
- Single superconducting solenoid (9T) halfway though the module
- Single vacuum
- Liquid helium reservoir (4 K)
- Liquid nitrogen heat shield
- Strongback to support cavities and solenoid with three (SCB) and four (SCC) suspension points



ISAC-II QWR Cavities

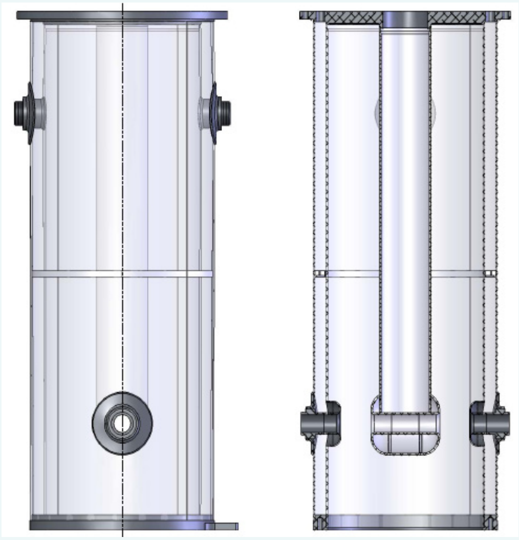
Phase I



106.1 MHz β=5.7%
SCB(1-8)

106.1 MHz β=7.1%
SCB(9-20)

Phase II

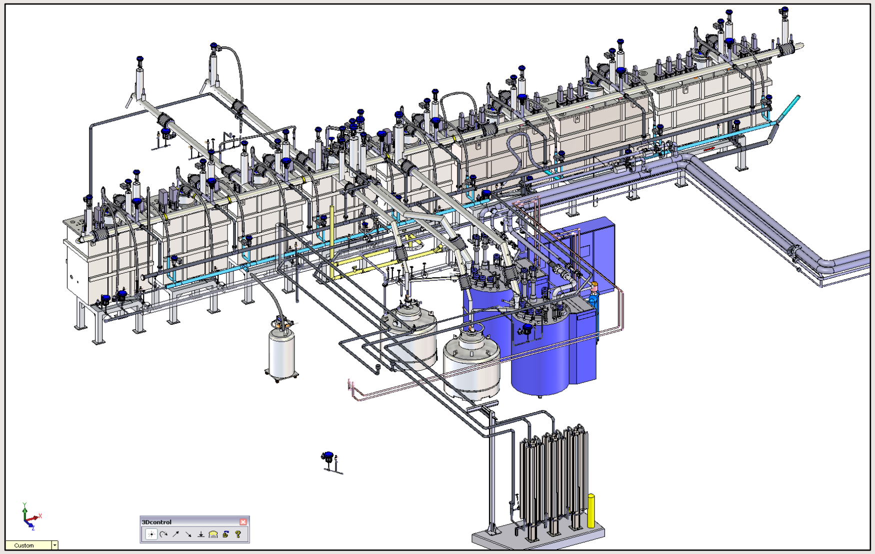


141.4 MHz β=11%
SCC

ISAC-II design values: V_{eff}=1.1MV, P_{cav}=7W, E_p=30MV/m, H_p=60mT

Cryogenic

- 2 Linde TC50 600W refrigerator system
- 2 1000 l dewars
- 2 Keiser compressor (both compressor motors failed and have been replaced)
- 1 Keiser recovery compressor
- 2 high pressure buffer tanks
- Distribution systems:
    - 4k Liquid Helium supply
    - He cold return gas to compressor through refrigerator
    - He warm return gas to compressor
    - LN2 supply



Cryomodule assembly

- Clean room assembly
- Cold test prior to delivery to the vault
- Establish warm off-sets for cold alignment using WPM and optical targets
- Check cavities and RF systems
- Measured cryogenic static load
- Establish vacuum integrity
- Check solenoid operation

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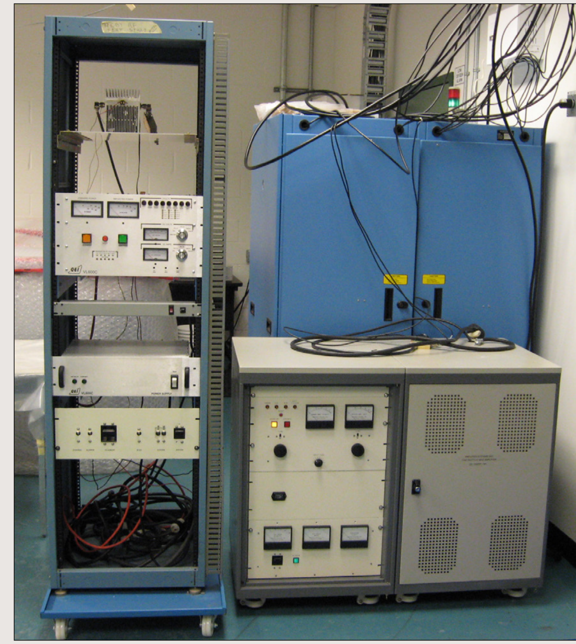
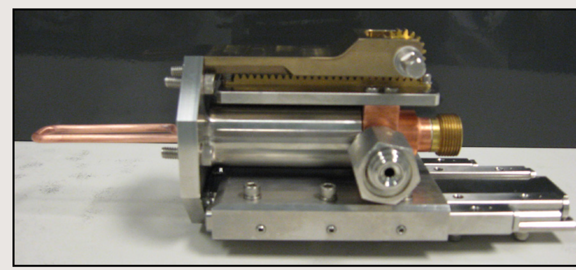
Operational Experience

- Some cavities require extensive multipacting conditioning. Use of an external signal generator reduces conditioning time
- Solid state amplifiers of Phase II more stable than tube amplifiers of Phase I that need to be tuned as tubes age
- Experienced “sticky” couplers in SCB. Developed new coupling loop with improved mechanical drive for SCC cavities
- Some RF cables have developed in vacuum shorts
- SCC3 He vacuum leak
- SCB4 had a significant vacuum accident





SCB4 vacuum accident

- SCB4 suffered a catastrophic failure of the Varian 550 turbo pump in 2009
- Debris were cleaned in situ with no treatment for the cavity
- Not immediate degradation of performances

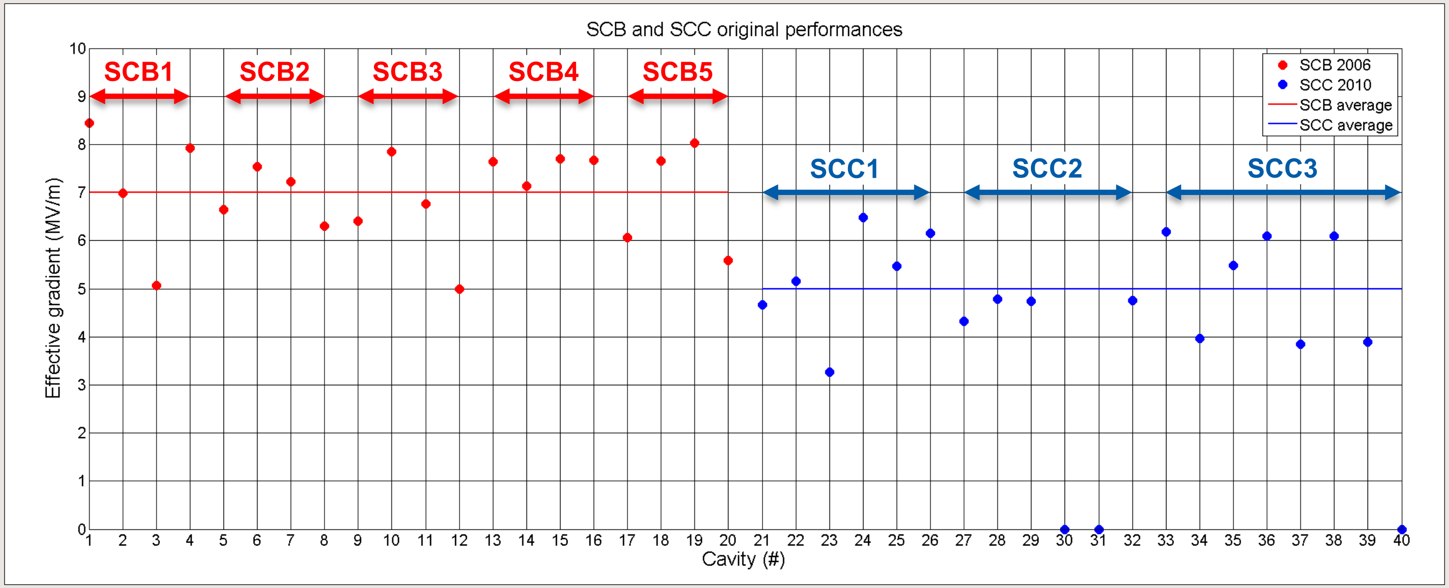
SCC3 HELIUM leak

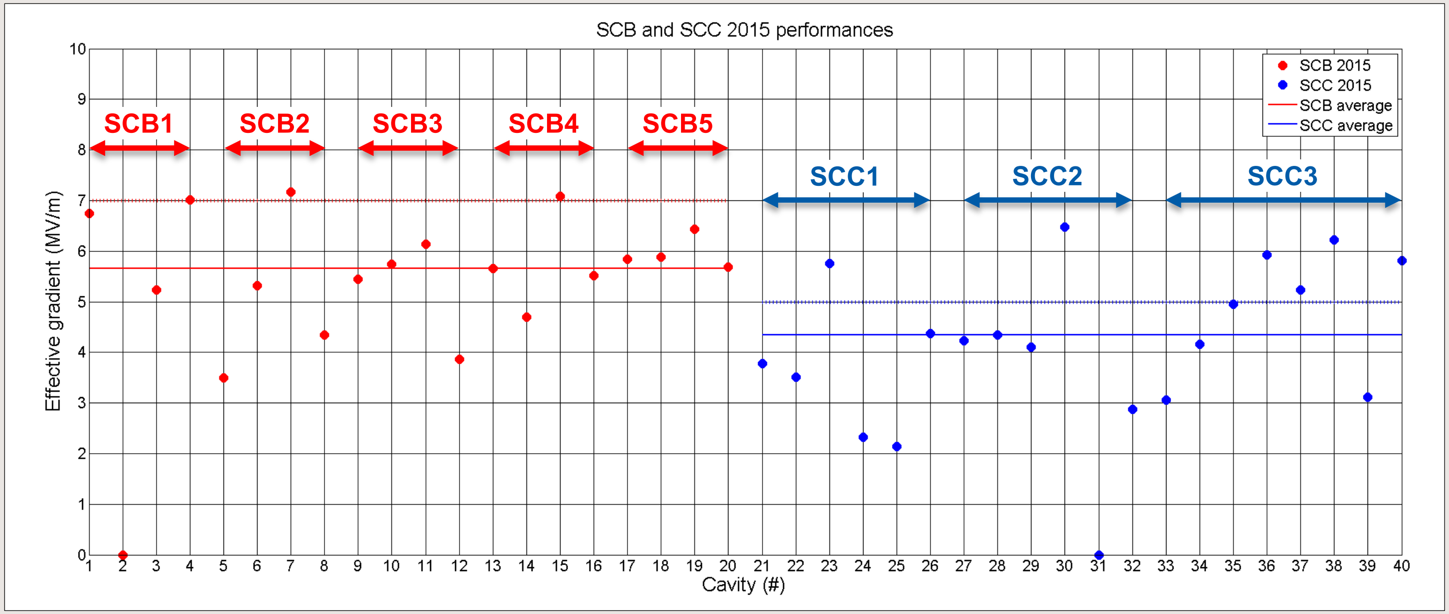
- Vacuum leak present since 2012 (cryomodule pressure high 10^{-5} torr)
- Lowest average cavity performance (not leak related)
- One cavity was not in operation due to cable issue
- 2015 winter shutdown
  - Leak check and redo indium seal on cavities
  - 15μm Buffer Chemical Polishing (BCP) and High Pressure Water Rinsing (HPWR)
  - Replace 3/8" ANDREW FSJ2-50 RF cable with drilled connectors and RF feedthrough on cryomodule lid

RF cable issue

- Some RF cables have developed in vacuum shorts
- Tested 3/8" cables with 200W forward power for full reflection:
  - Burnt cable
  - Melted connector isolation material
- Observed glow discharge at the interface of cable and connector due to trapped air or vapor from isolation material (regular cable in vacuum environment)
- Selected ANDREW 1/2" FSJ4-50 RF cable instead of 3/8" FSJ2-50
- Drill vent holes on cable connectors and RF feedthrough to release low pressure gas

Performance 2006-2015





$^{20}Ne^{5+}$ @ 9 MeV/u (August 2015) equivalent to 30MV of effective accelerating voltage. Still meet ISAC-II original specification

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Future perspective

- Beam delivery requirements (accelerator point of view):
  - Provide the requested energy (highest so far 15 MeV/u)
  - Stable operation (minimize downtime in order to deliver >75% of scheduled beam time)
- Restore/improve the cavity gradient
  - Degassing
  - Reprocessing: BCP and HPWR
  - RF cable retrofitting
  - SCC style coupling loop for SCB cavities
- Challenge: schedule maintenance activity without significantly impacting the beam availability to experiments

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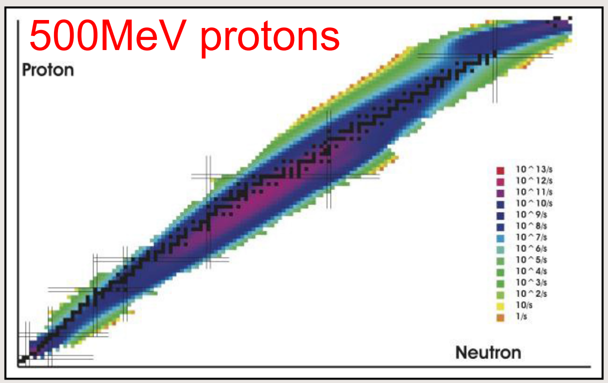
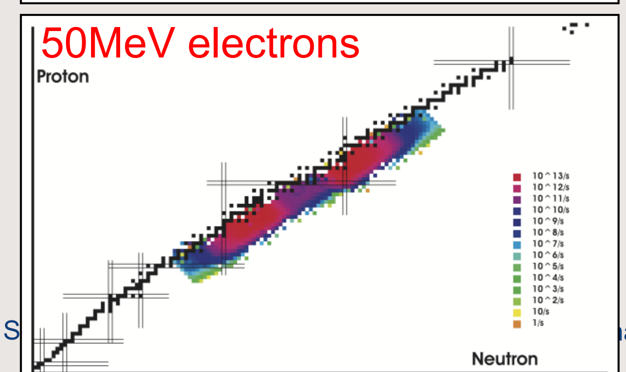
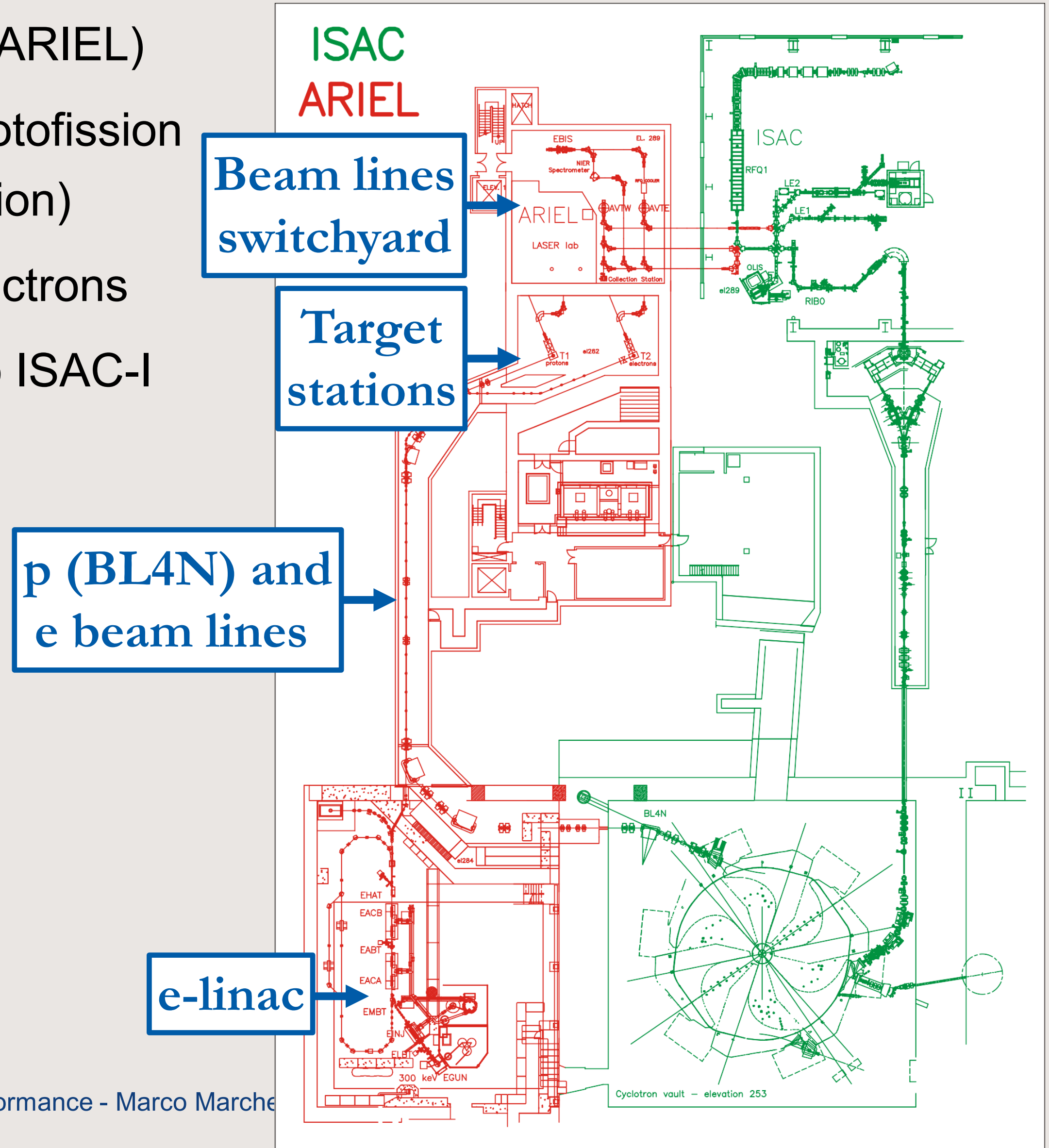
ARIEL

- Advance Rare IsotopE Laboratory (ARIEL)
- Electron linac (e-linac) driver for photofission production (low isobaric contamination)
- Two target stations: protons and electrons
- Electrostatic switchyard connects to ISAC-I

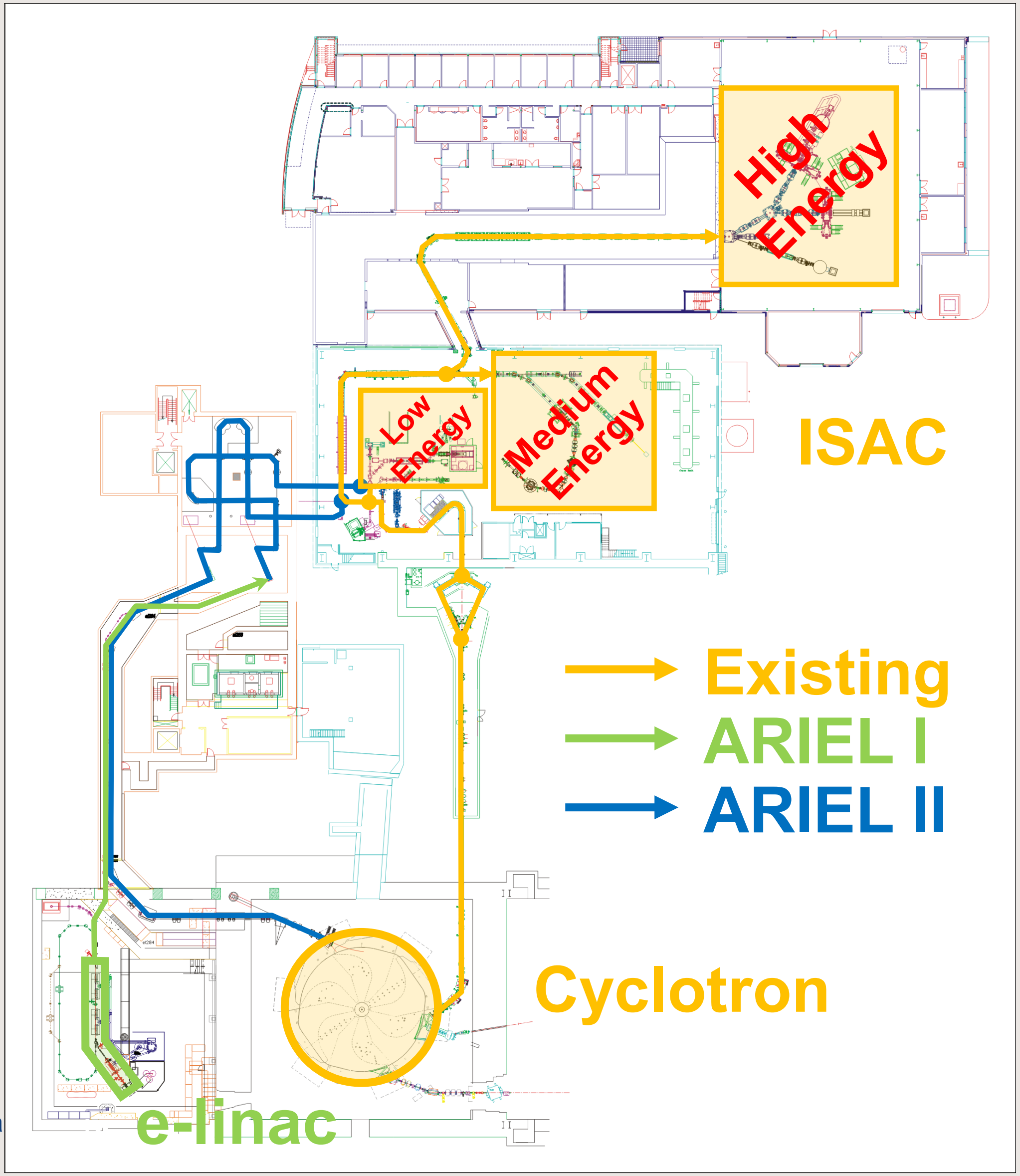






ARIEL goal

- RIB multi-users facility: three simultaneous radioactive beams instead of one
- Increase the number of RIB hours available in particular to the high energy experiments
- ISAC-II linac is the post accelerator for the future ARIEL facility as well
- ISAC-II linac reliability becomes critical



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ARIEL and ISAC

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Conclusions

- ISAC-II superconducting linac is in operation for almost a decade and still met the ISAC-II original specification even though a degradation in the cavity gradient occurred
- A maintenance plan needs to be implemented for the years to come to avoid further degradation and keep meeting experimental requirements
- ISAC-II linac reliability becomes even more critical when the dedicated RIB beam will be available from ARIEL

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Merci!

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