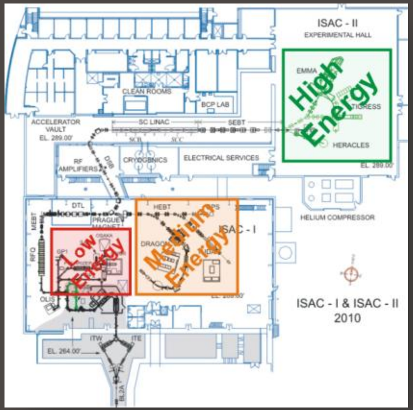
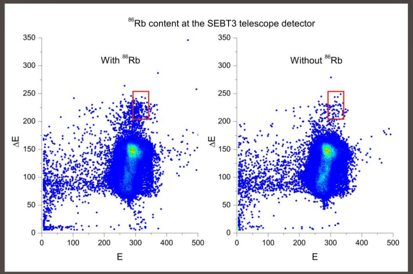
Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

# PROGRESS AND PLANS FOR THE HIGH MASS BEAM DELIVERY AT TRIUMF


**Marco Marchetto | TRIUMF**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# Summary

- Introduction
  - ISAC facility
- High Mass Beam Delivery
- The ”toolkit”
  - Accelerator filtration/selection
  - Software
  - Diagnostic
- $^{76}Rb$ beam development
- Future development
- Conclusion

# High Mass Task Force

- Accelerator division: Friedhelm Ames, Bob Laxdal , Marco Marchetto, Colin Morton (spoke-person)
- Science division: Barry Davids, Adam Garnsworthy, Greg Hackman
- Strong support from both the Accelerator and the Science division

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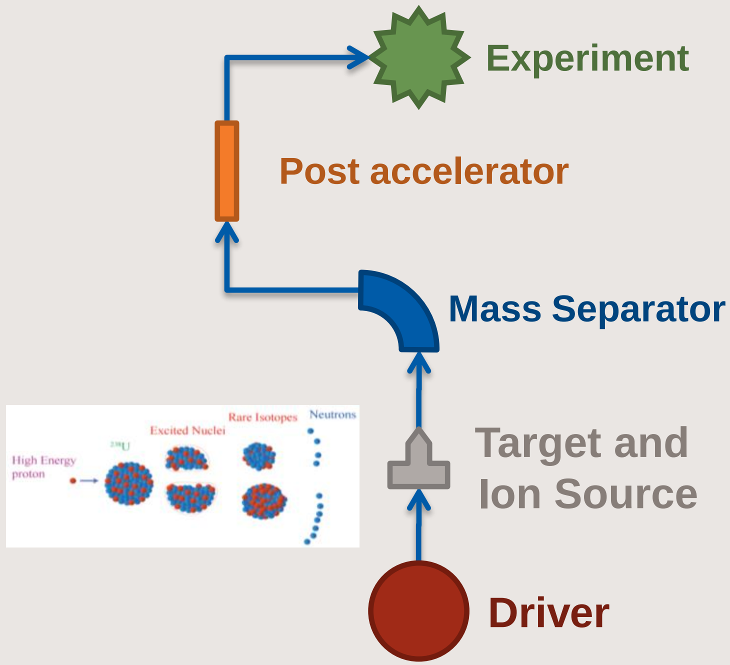
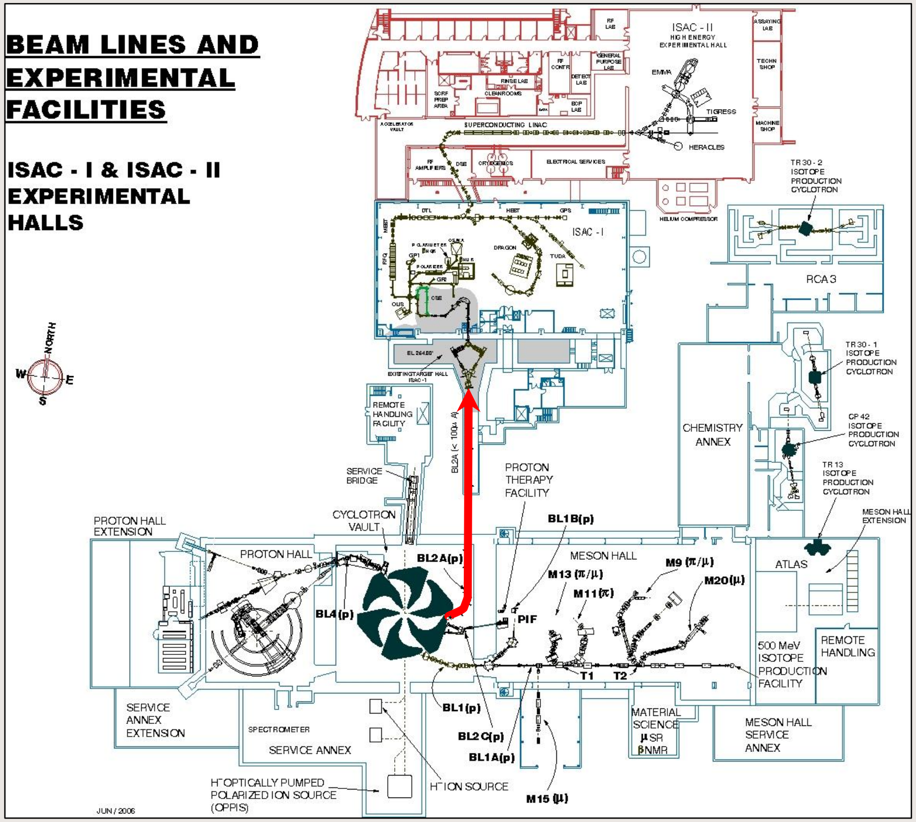
# ISAC at TRIUMF

- ISOL facility for rare isotope beam (RIB) production



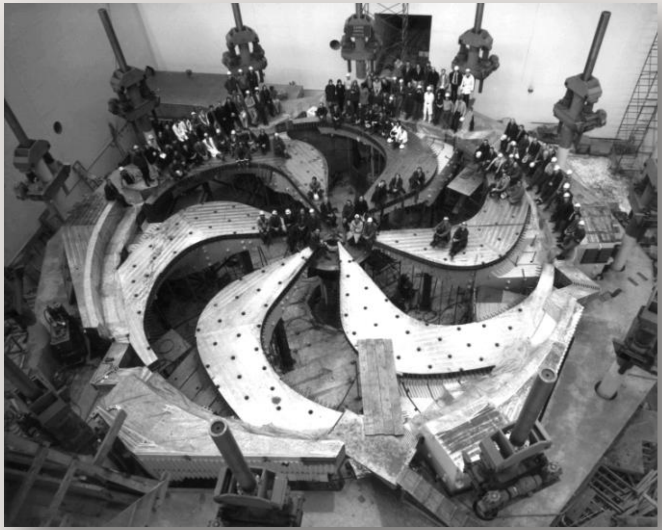




- <u>ISAC facility produce, post-accelerate and deliver RIB's (most intense of certain species) using the highest power driver beam (50 kW)</u>

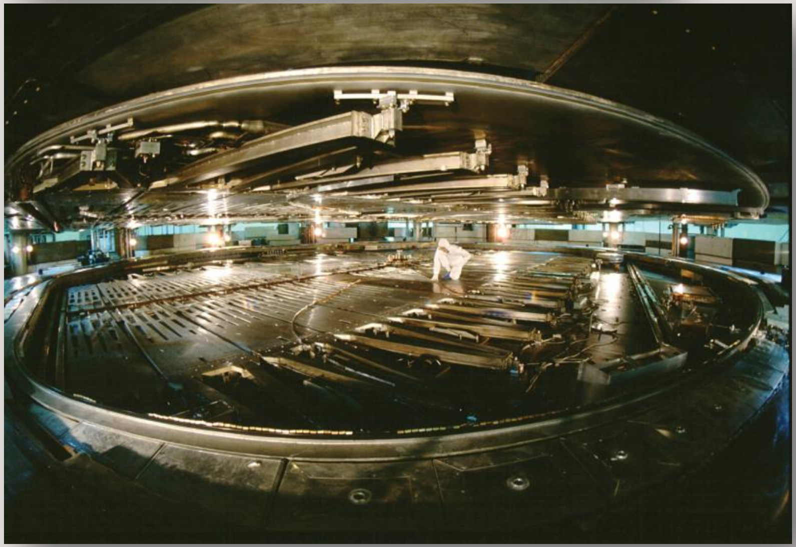
# ISAC in the world

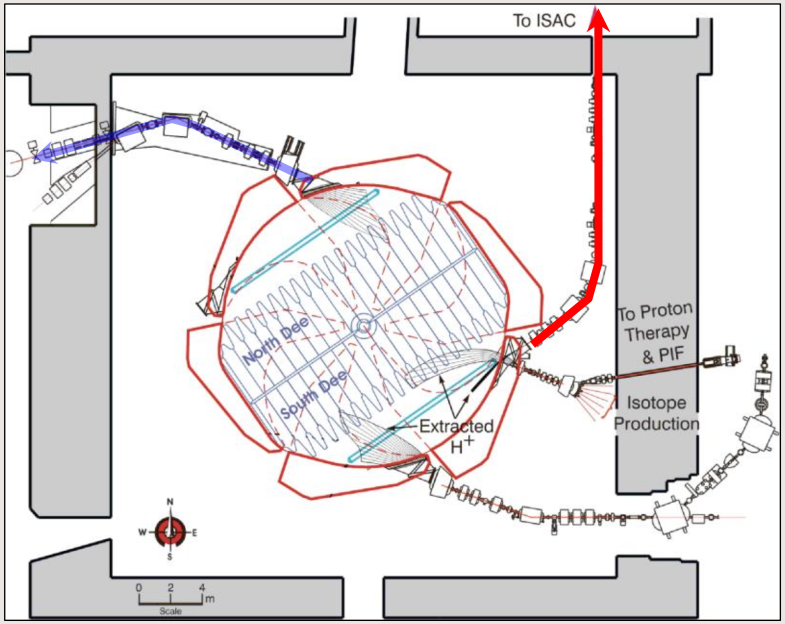
| Lab | Facility | Type | Driver | Post-accelerator | Voltage (MV) | Energy (MeV/u) |
|---|---|---|---|---|---|---|
| **Existing** | | | | | | |
| TRIUMF | ISAC | ISOL | 500MeV, 50kW p | RFQ, DTL, SCL | 52.5 | 6.5-18 |
| CERN | ISOLDE | ISOL | 1.4GeV, 2.8 kW, p | RFQ, DTL | 13 | 3 |
| GANIL | Spiral-I | ISOL | 3kW HI | cyclotron | | ~5-25 |
| ORNL | Holifield | ISOL | 50MeV, 500W p,d | tandem | 25 | |
| ANL | CARIBU | Gas-catcher | Radio-active source | ATLAS sc linac | 52 | ~7-17 |
| **Future** | | | | | | |
| CERN | HIE-Isolde | ISOL | 1.4, 2.8kW, p | SCL | 40 | 6.5-18 |
| MSU/ NSCL | FRIB | Gas-catcher | 400kW HI | RFQ, SCL | | 12-20 |
| GANIL | SPIRAL-II | ISOL | 200kW d | cyclotron | | 5-25 |

# ISAC driver



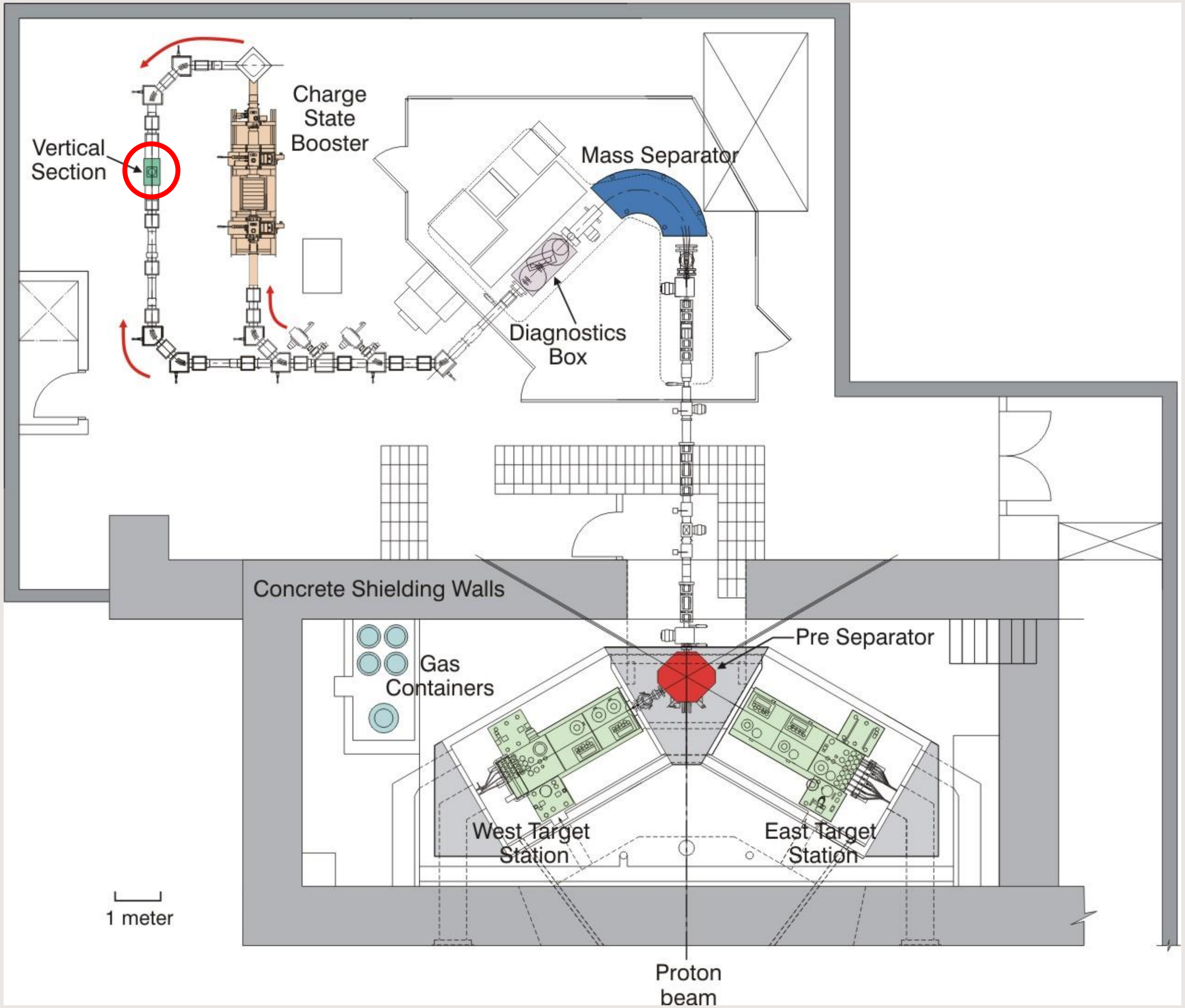
- H$^-$ cyclotron as proton driver;
- ISAC proton accelerated to 500 MeV up to 100 $\mu$A;
- Cyclotron can operate at 300 $\mu$A;
- In the future one more proton line for RIB production (ARIEL)



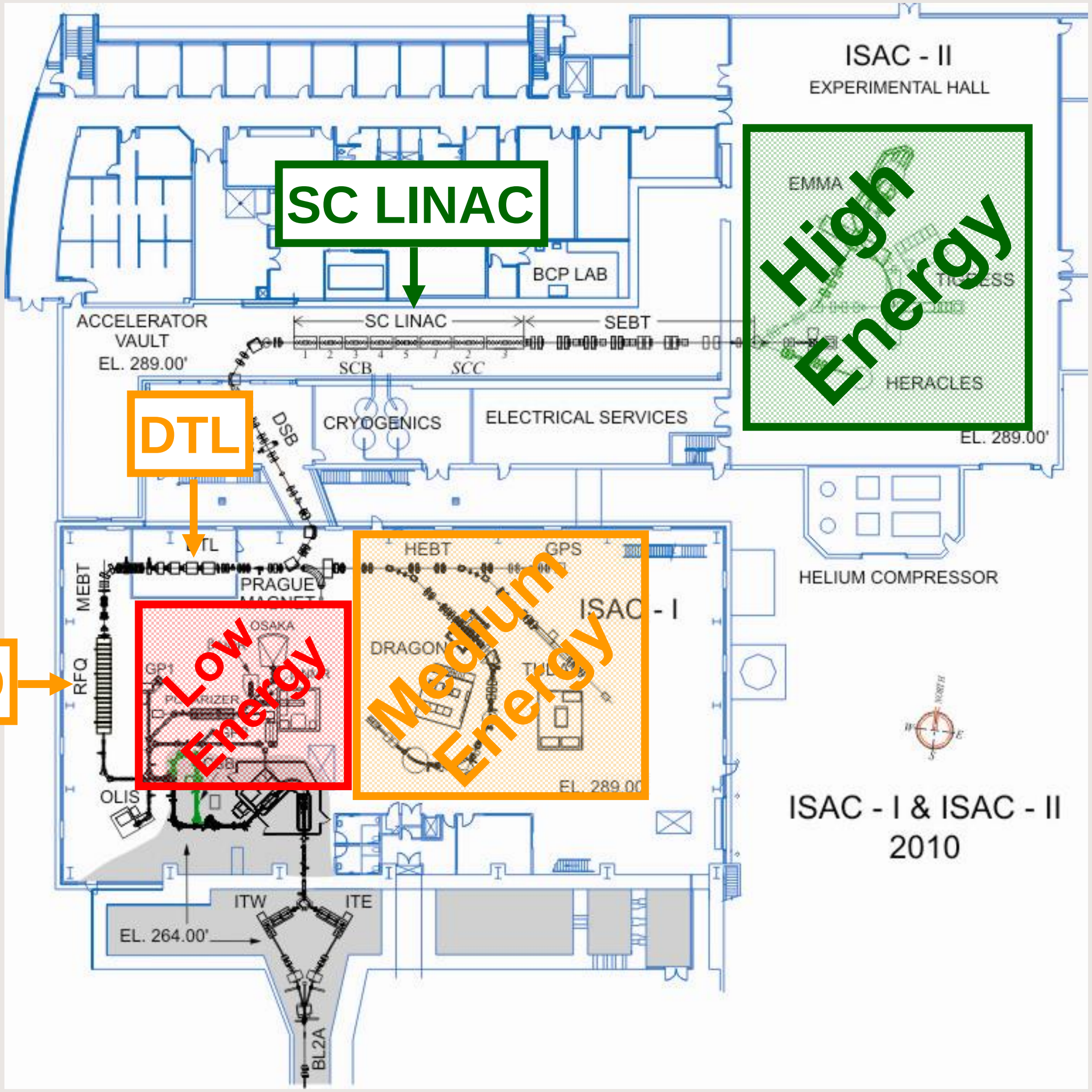


# Target stations and Mass separator

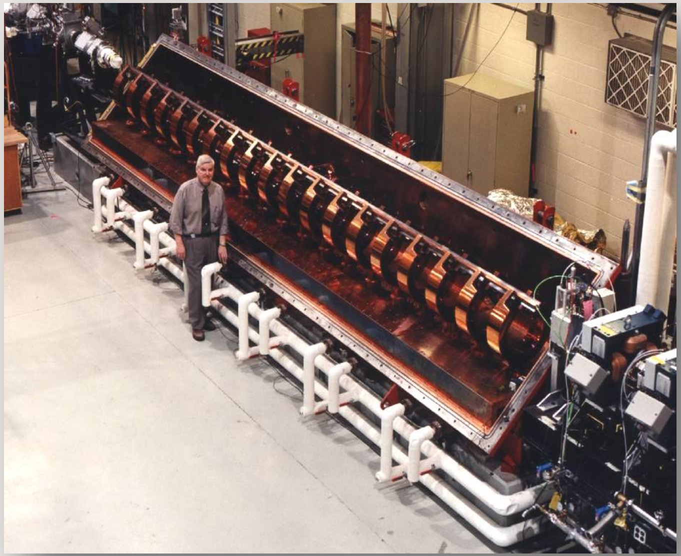
- Two underground target stations
- Proton beam sent to one of the target station at the time
- Pre-separator inside the shielded area to contain radiation
- Mass separator on high voltage platform to increase resolution
- Charge breeder ECR type

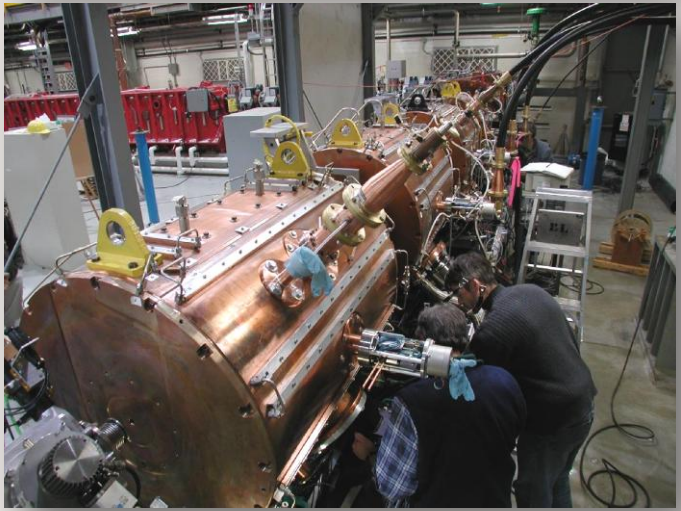


# Experimental facilities



# ISAC I Linac

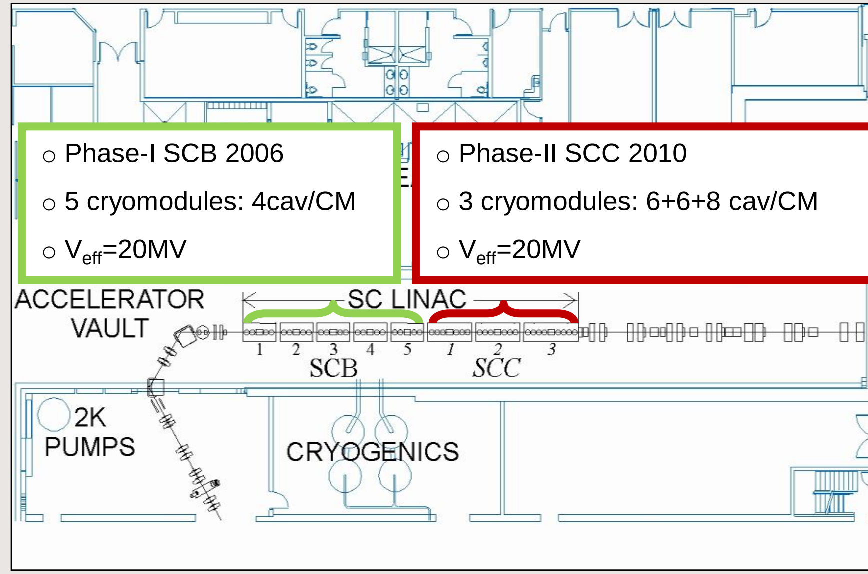


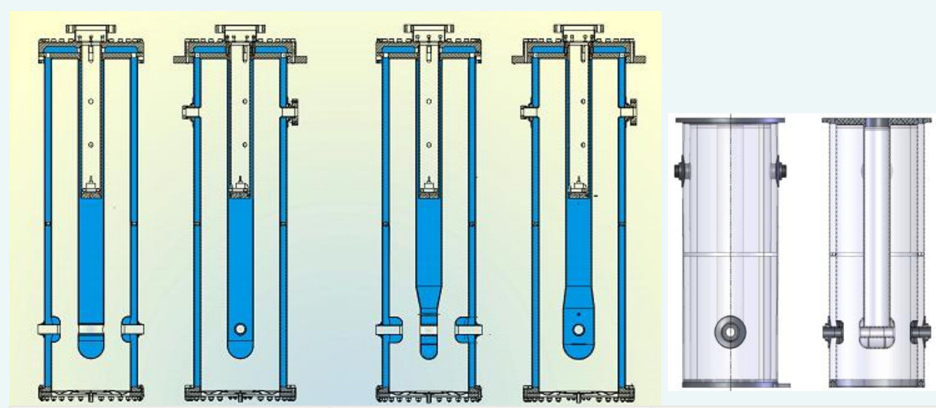


- RFQ
  - 8m long CW machine
  - Resonant frequency 35 MHz
  - Injection energy 2 keV/u
  - Final energy 150 keV/u, $3 \leq A/q \leq 30$
  - high quality transverse and longitudinal emittance: 0.2 $\pi$ $\mu$m and 1.5 $\pi$ kev/u·ns.
- DTL
  - Separated functions design
  - Five IH interdigital RF cavities
  - Three split-ring bunchers
  - Resonant frequency 106 MHz
  - Variable energy machine
  - 150 keV/u ≤ E ≤ 1.8 MeV/u, $2 \leq A/q \leq 7$
  - ISAC II injector 1.5 MeV/u

# ISAC-II linac

- 40 QWR in 8 cryomodules operating at 4K
- 3 QWR families with different design beta
- 106 MHz for phase-I SCB cavities
- 141 MHz for phase-II SCC cavities
- 40 MV of accelerating voltage
- Final energy is A/q dependent : 18MeV/u for A/q=2
- Average 30 MV/m peak field at 7W



106.1 MHz β=5.7% SCB(1-8)

106.1 MHz β=7.1% SCB(9-20)

141.4 MHz β=11% SCC (21-40)

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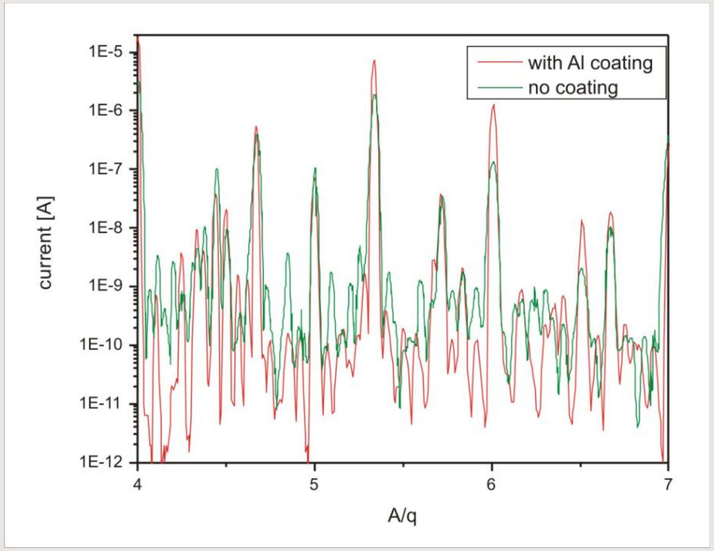
# RIB beam delivery

- ISAC at TRIUMF is one of the leading facility for production and delivery of RIB's and we plan to make it the leading ISOL facility (ARIEL)
- ISAC-II project has two goals: reaching higher energies (above the Coulomb barrier) and delivering high masses (beyond 30, ISAC-I limit)
- The Charge Breeder is instrumental to reach the mass goal by reducing the M/q of high mass beams within the ISAC-I accelerators acceptance
- The <u>fact</u> is that the ECR type breeder produces a background of stable species that can hide the RIB ($10^3$-$10^6$ particle/s)
- The <u>issue</u> is that the RIB need to be delivered relatively pure (free of contaminants)



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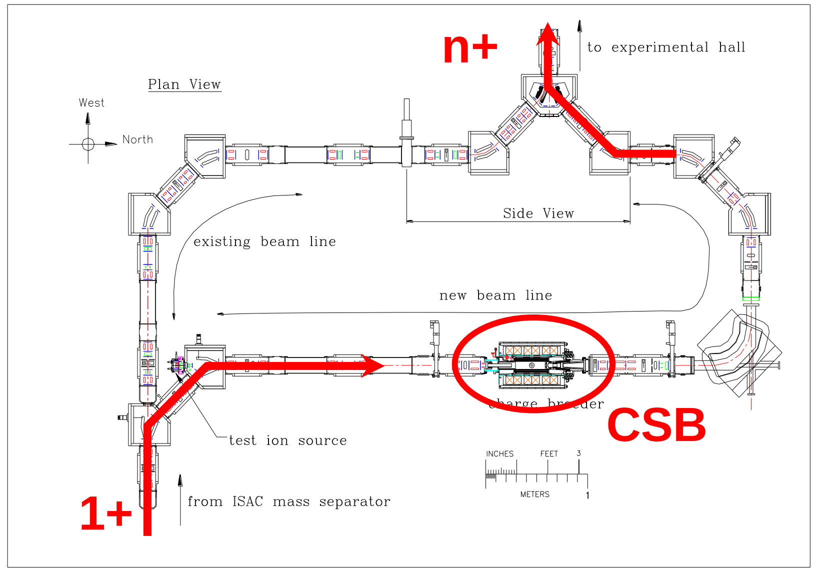
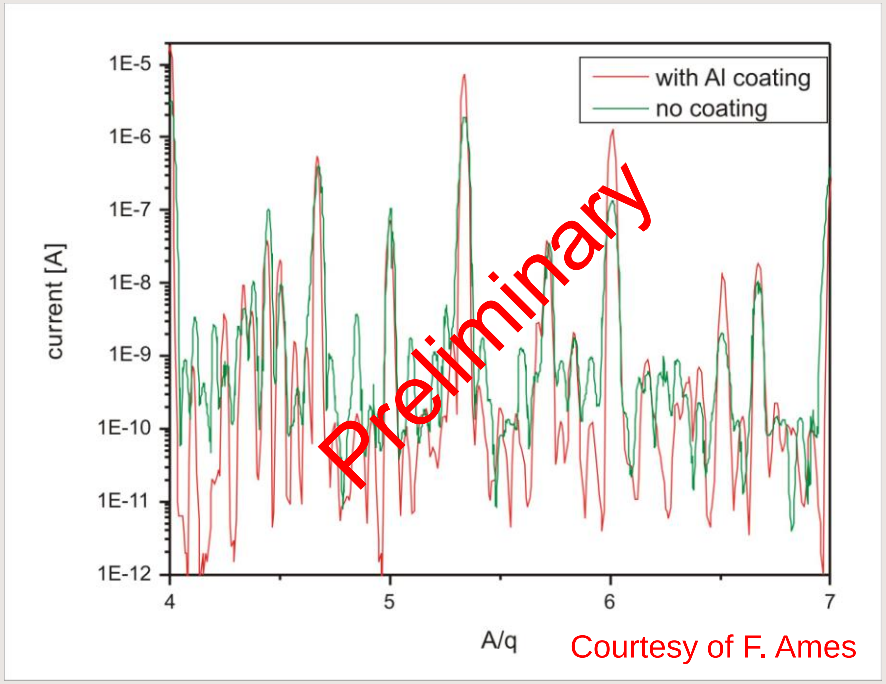
# ECR background improvement

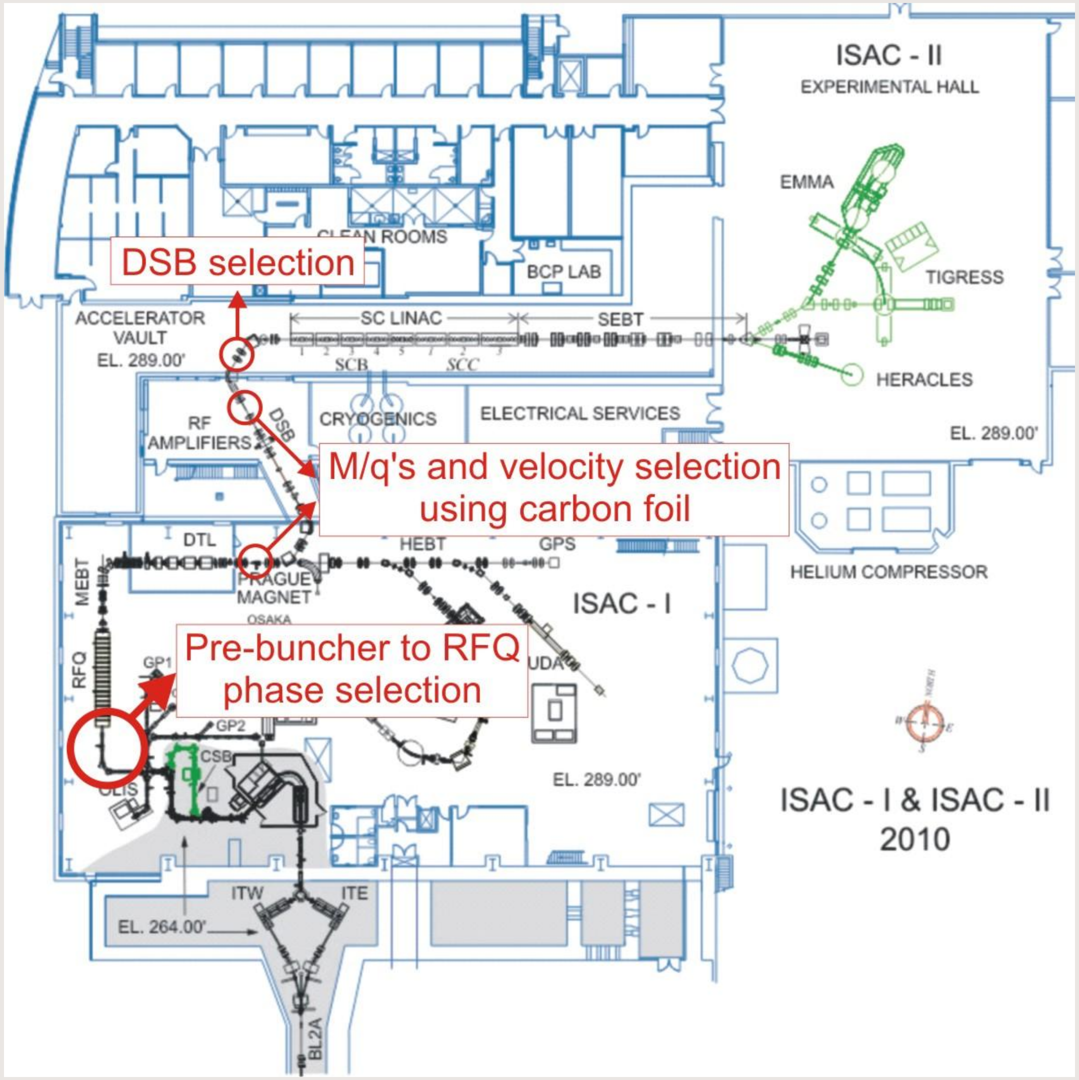
- 14GHz Phoenix ECR source from Pantechnik
- Breeding efficiency 2-5%
- All RIBs come with contaminants from the background gas and vacuum chamber materials
- Need to purify the beam at the source



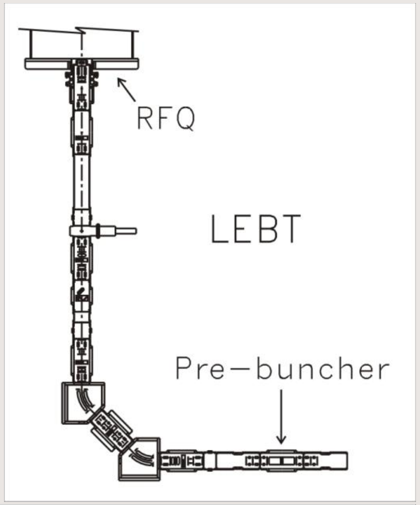

See Colin Morton presentation at the High Mass workshop

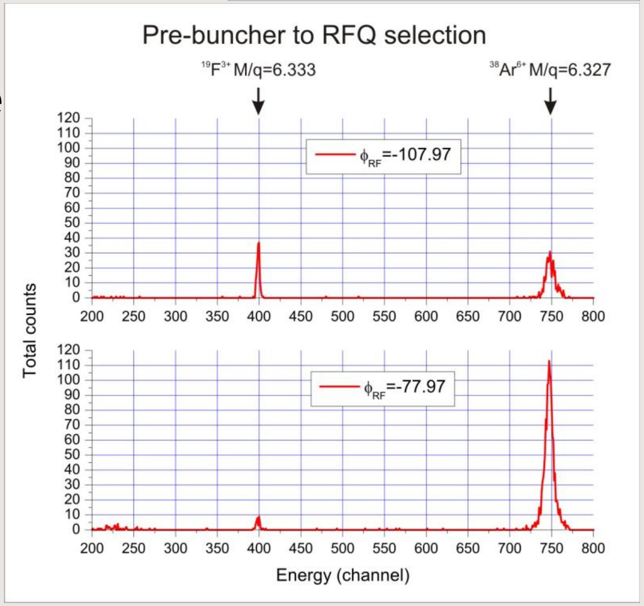
# Accelerator filtration overview



# Pre-buncher RFQ filtration

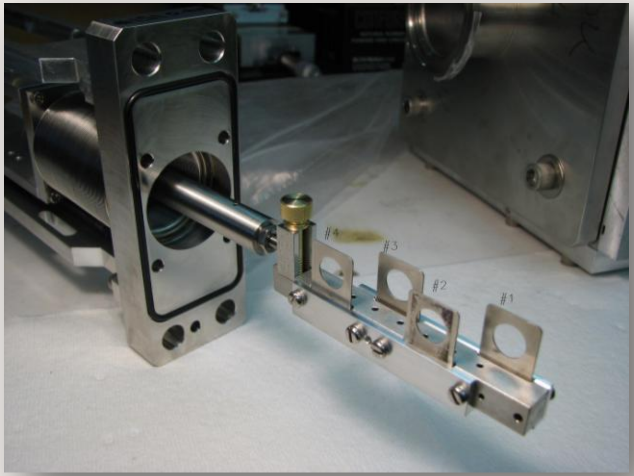
- The pre-buncher is located 5 m upstream of the RFQ
- Source extraction voltage is fixed: different M/q are extracted with different velocities $v=(2 \cdot q \cdot V_{ext}/M)^{1/2}$
- Different velocities generated different time of flights between the pre-buncher and the RFQ.
- RFQ phase acceptance is 40° or $\delta t = 3 \cdot 10^{-9}$ s
- So M/q's that are spaced more than $\delta t = 3 \cdot 10^{-9}$ s at the RFQ can be filtered by adjusting the pre-buncher phase (namely synchronizing one A/q with the RFQ bunckets)
- $^{19}F^{3+}$ and $^{38}Ar^{6+}$ arrive at the RFQ with a $\delta t=3.7 \cdot 10^{-9}$ s (equivalent to a resolution of $(M/q)/\Delta(M/q)=1115$)

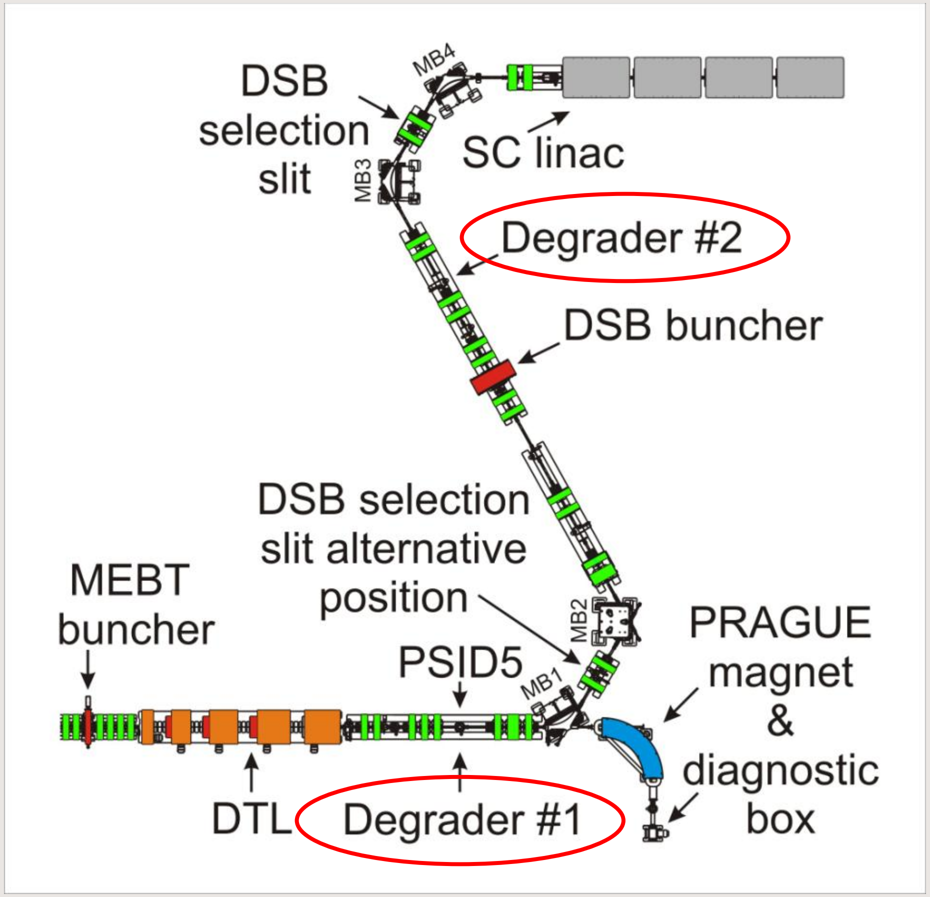


# Stripper-degrader

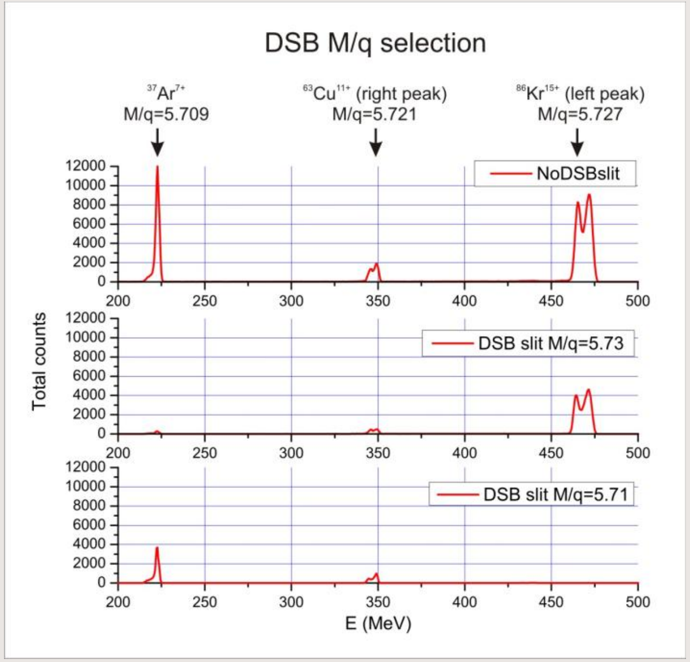
- Created velocity difference (degrader) to select around the bender
- Stripping to a different M/q to clean the beam from contaminants
- Two possible locations for carbon foils to be used as stripper and degrader (depending on the thickness)

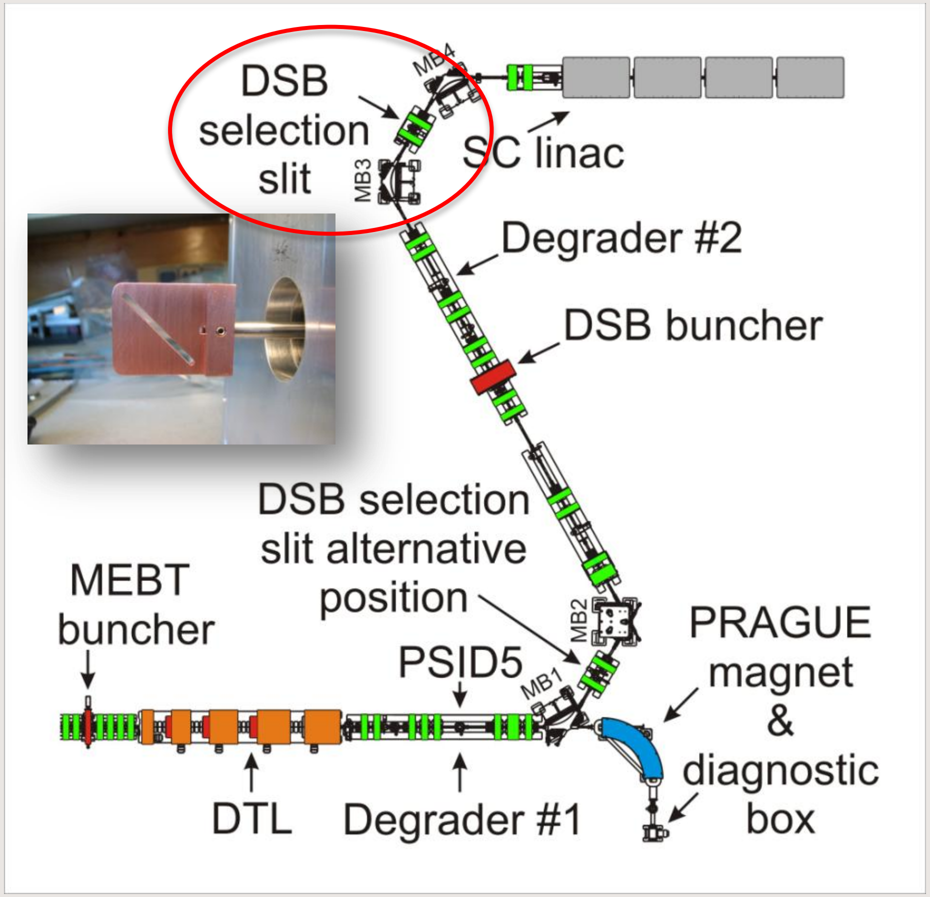




# DSB selection

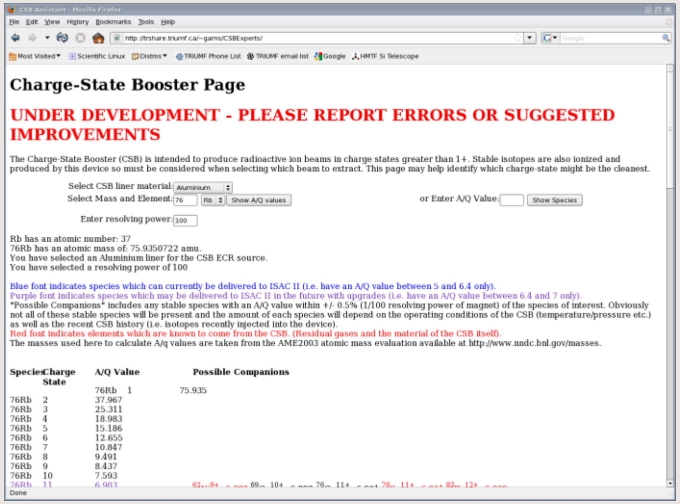
- DSB dipole MB3 has 1.6 m dispersion
- Movable 2 mm selection slit
- Resolution of (M/q)/Δ(M/q)=375
- $^{37}Ar^{7+}$ and $^{86}Kr^{15+}$ have (M/q)/Δ(M/q)=309
- $^{37}Ar^{7+}$ and $^{63}Cu^{11+}$ have (M/q)/Δ(M/q)=477



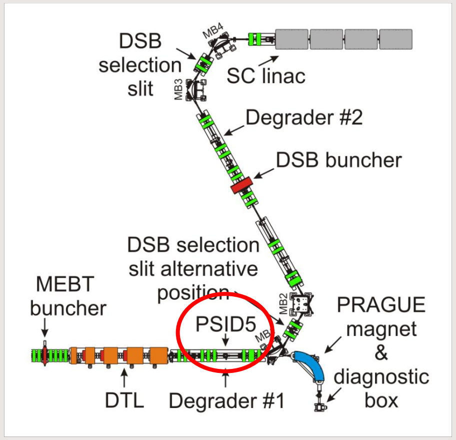
# Software applications

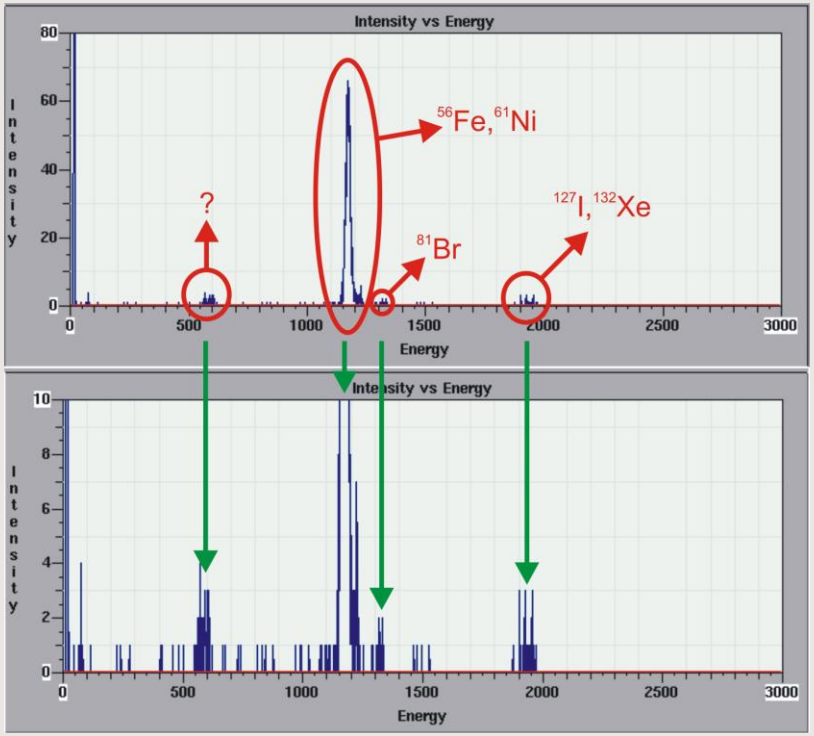
- *CSBassistant*: web based application to identify all possible contaminants before the run [http://trshare.triumf.ca/garns/CSBExperts/](http://trshare.triumf.ca/garns/CSBExperts/)
- Scaling routine: EPICS based application to scale the ISAC beam lines optics and RF
  - Voltages of the electrostatic quadrupoles and steerers
  - Currents of the magnetic quadrupoles and steerers
  - No hysteresis cycle around the final setpoint but approaching from the same side of the hysteresis curve
  - Hall probe measured magnetic field of the dipoles
  - RF amplitudes of all devices (pre-buncher, RFQ, DTL, SClinac…)

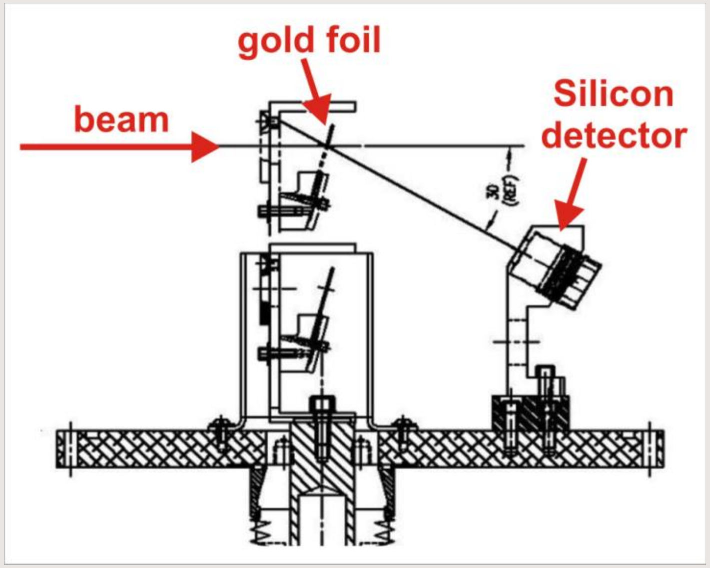



# Diagnostic: purity monitor

- Purity monitor (PSID5) downstream of the DTL:
  - Beam scattering through a gold foil to a silicon detector
  - Spectrum based on total energy (need to be calibrated)
  - Elements with same mass but different Z are indistinguishable
  - Stand high current (few enA)

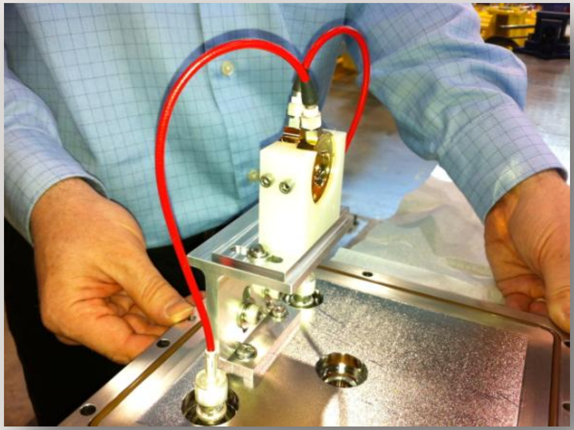


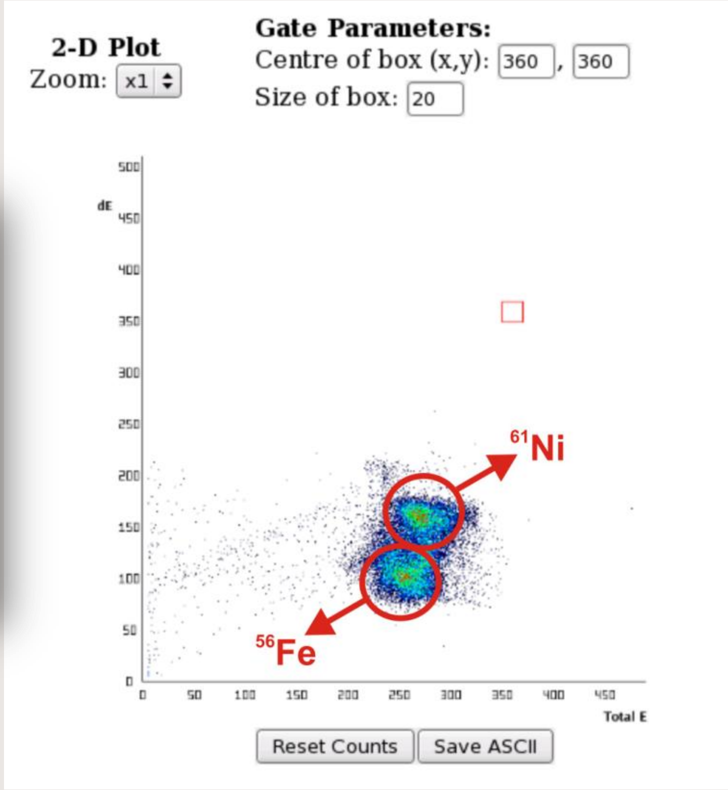



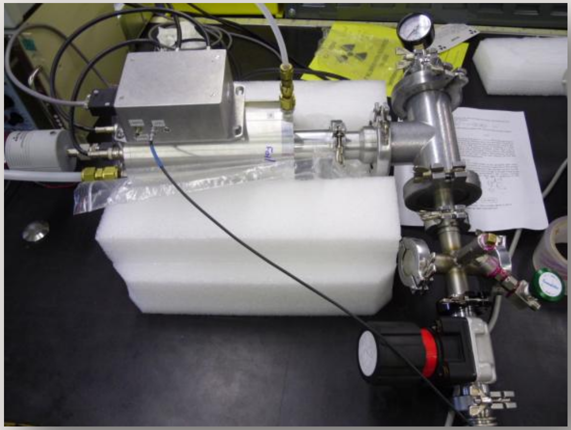



# Diagnostic: ΔE-E detector

- Silicon telescope downstream of the SC-linac:
  - Provides ΔE-E information: distinguished different mass and different Z
  - Current limited (few $10^3$ particle/s)
- Gas detector:
  - ΔE-E information
  - Not current limited





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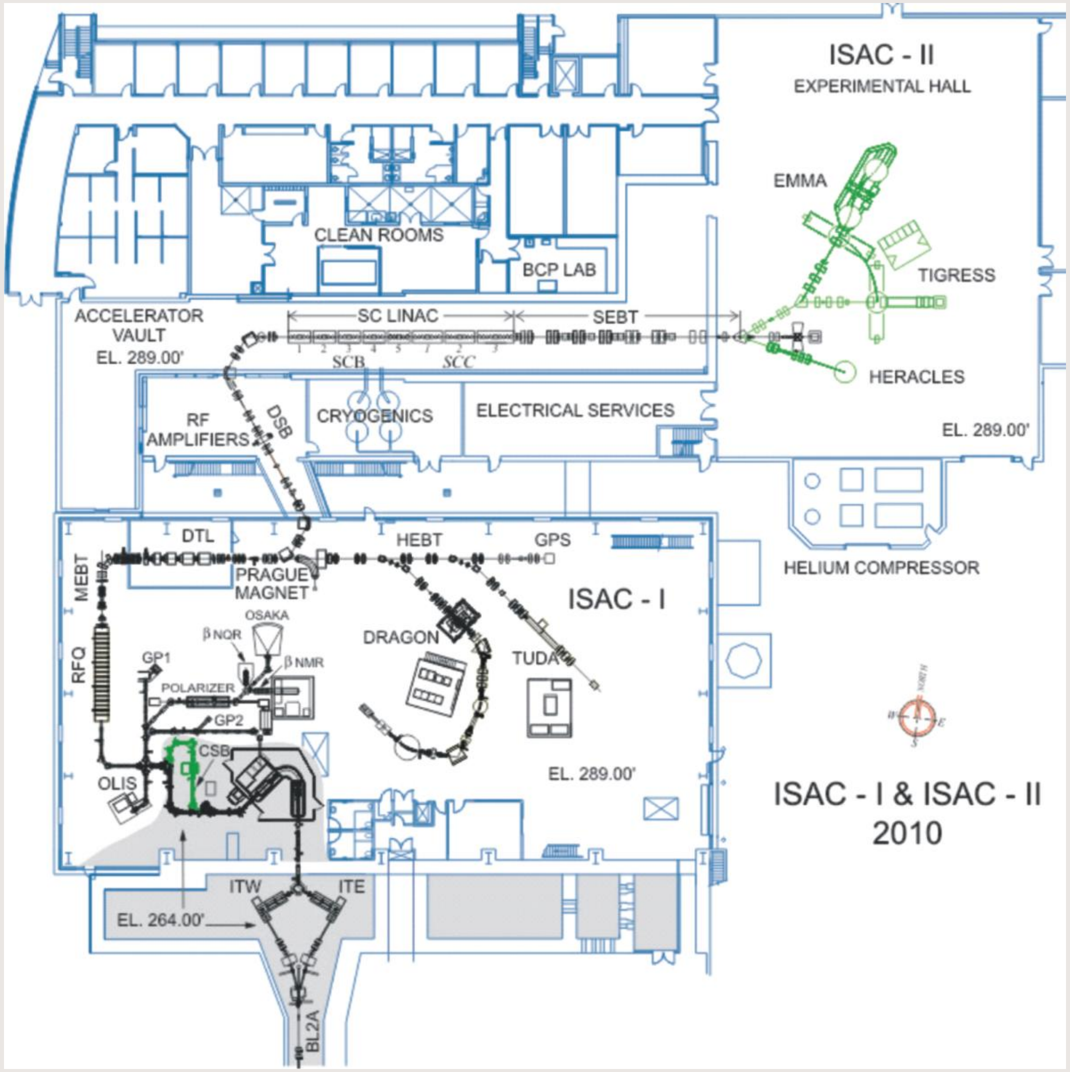
# Rb beam development

- The radioactive beam chosen is $^{76}$Rb based on future approved experiment
- Charge state selected ($^{76}Rb^{15+}$) based on accelerator acceptance and best purity calculated by the *CSBassistant*
- Tune the linac with $^{12}C^{2+}$ up to the DSB stripper-degrader then stripped to $^{12}C^{5+}$
- Scaling routine used to scale the linac in the 2-3 M/q range
- The scaling routine has been demonstrated to step precisely through M/q's
- The reference starting point (initial tune) must be defined



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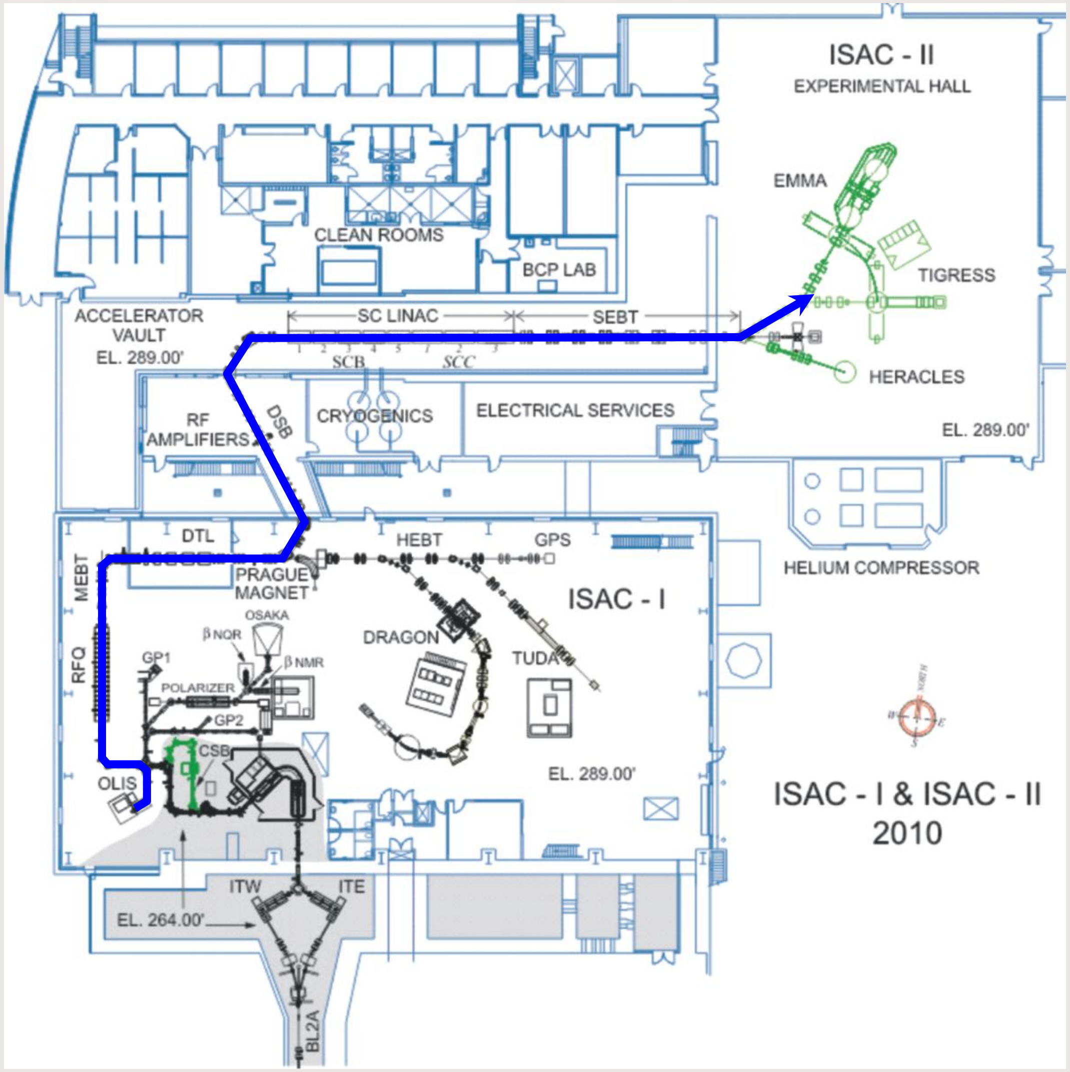

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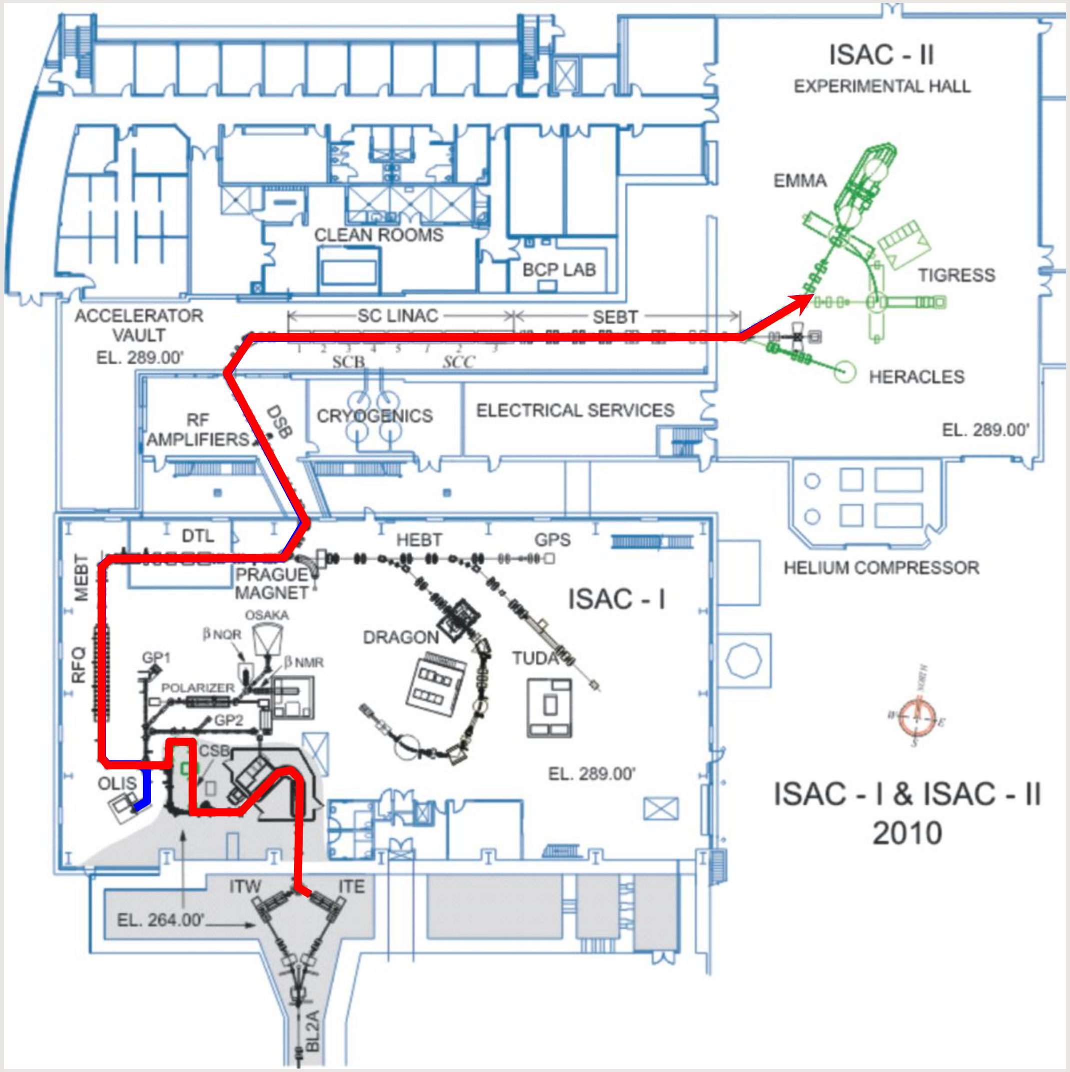
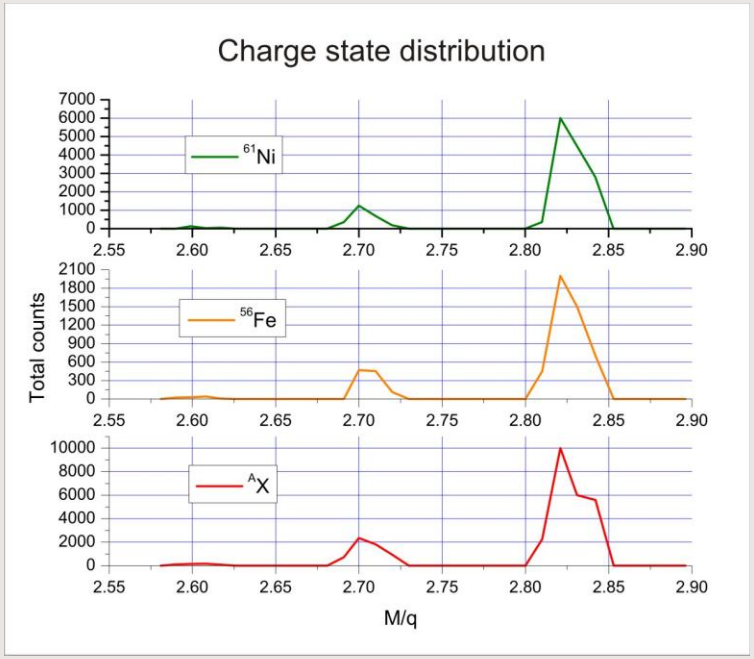
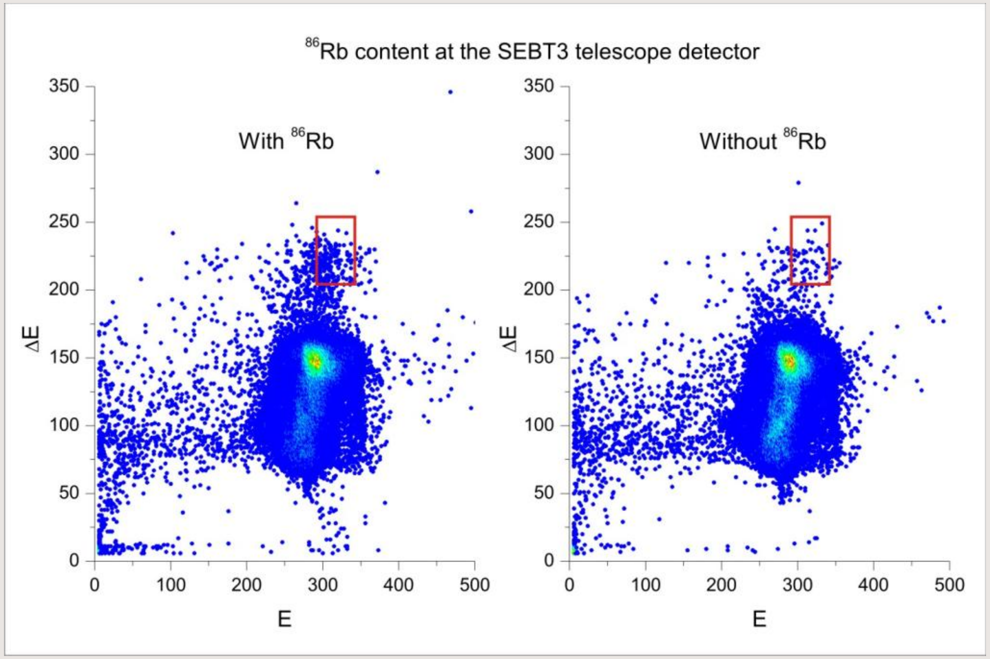


# Charge state distribution

- Measured the charge state distribution of the "cocktail" beam: $^{61}Ni$, $^{56}Fe$ and al.
- $^{76}Rb$ not present in the cocktail since it was stopped at the source
- Selected the measured M/q to use as starting point for scaling: $^{61}Ni^{21+}$ (M/q=2.902) peak was measured at M/q=2.821
- Scaled the linac chain from $^{61}Ni^{21+}$ to $^{76}Rb^{26+}$
- Introduced $^{76}Rb$ in the system



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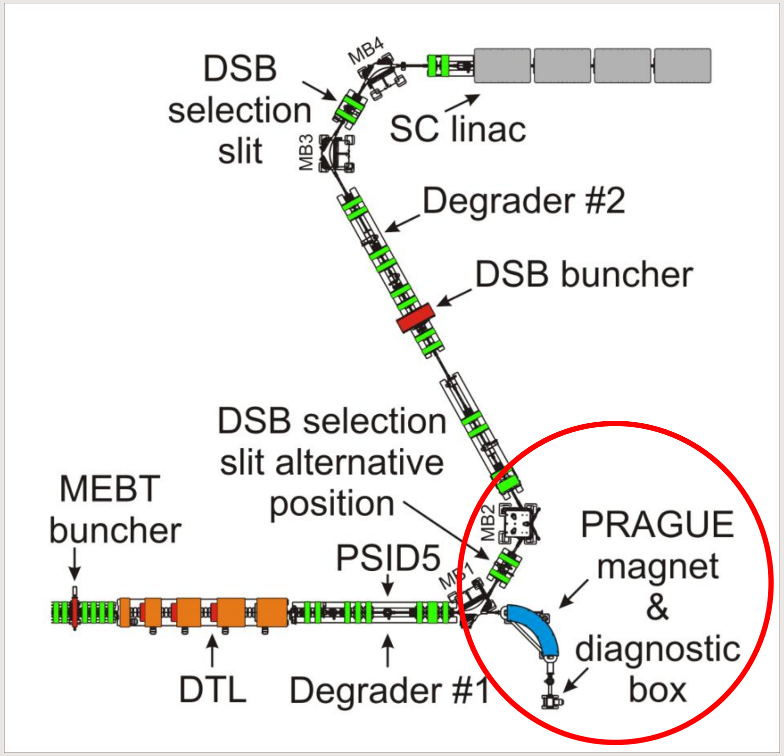
# “PRAGUE” diagnostic box

- The DSB buncher function is to match the beam into the SC linac
- With the stripper-degrader in the second location the DSB buncher is used to compensate for the energy loss moving away from the linear region
- As consequence the beam is not properly match into the linac leading to loss in transmission
- The first location is better for the foil
- The energy is going to be compensated with the DTL and the DSB buncher keep matching the beam properly into the SC linac




- The DTL analyzing magnet (PRAGUE) can be use as spectrometer for charge state distribution measurement (instead of the SClinac), energy loss and energy spread
- Adding a beta counter in the PRAGUE diagnostic box to detect the presence of RIB

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# Conclusion

- Phase selection in the accelerator chain can be use as M/q resolution
- Dedicated diagnostic is fundamental to tune RIB
- Precise scaling set the beam lines on the right M/q
- *CSBassistant* type of calculator is important to predict the contaminants
- The first results of delivering high masses at ISAC are promising
- Remains clear that the delivery of such beams is not going to be effortless
- Every new beam will required development time

# Thank you

# Merci