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Progress in development of ISOL RIB ion sources and targets for high power

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XVIII International Conference on Cyclotrons and their Applications 2007,
Giardini Naxos, Sicilia, Italia

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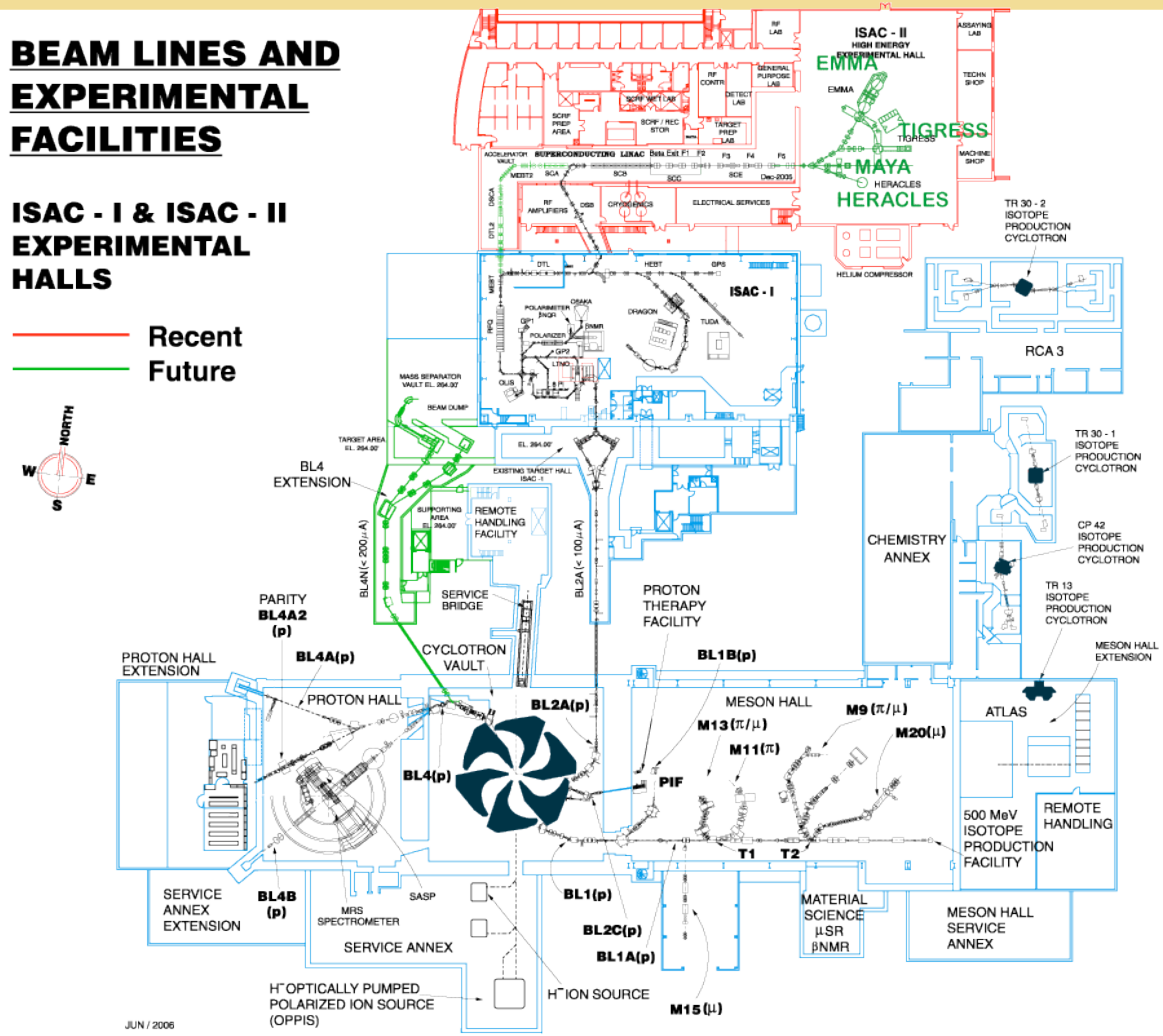
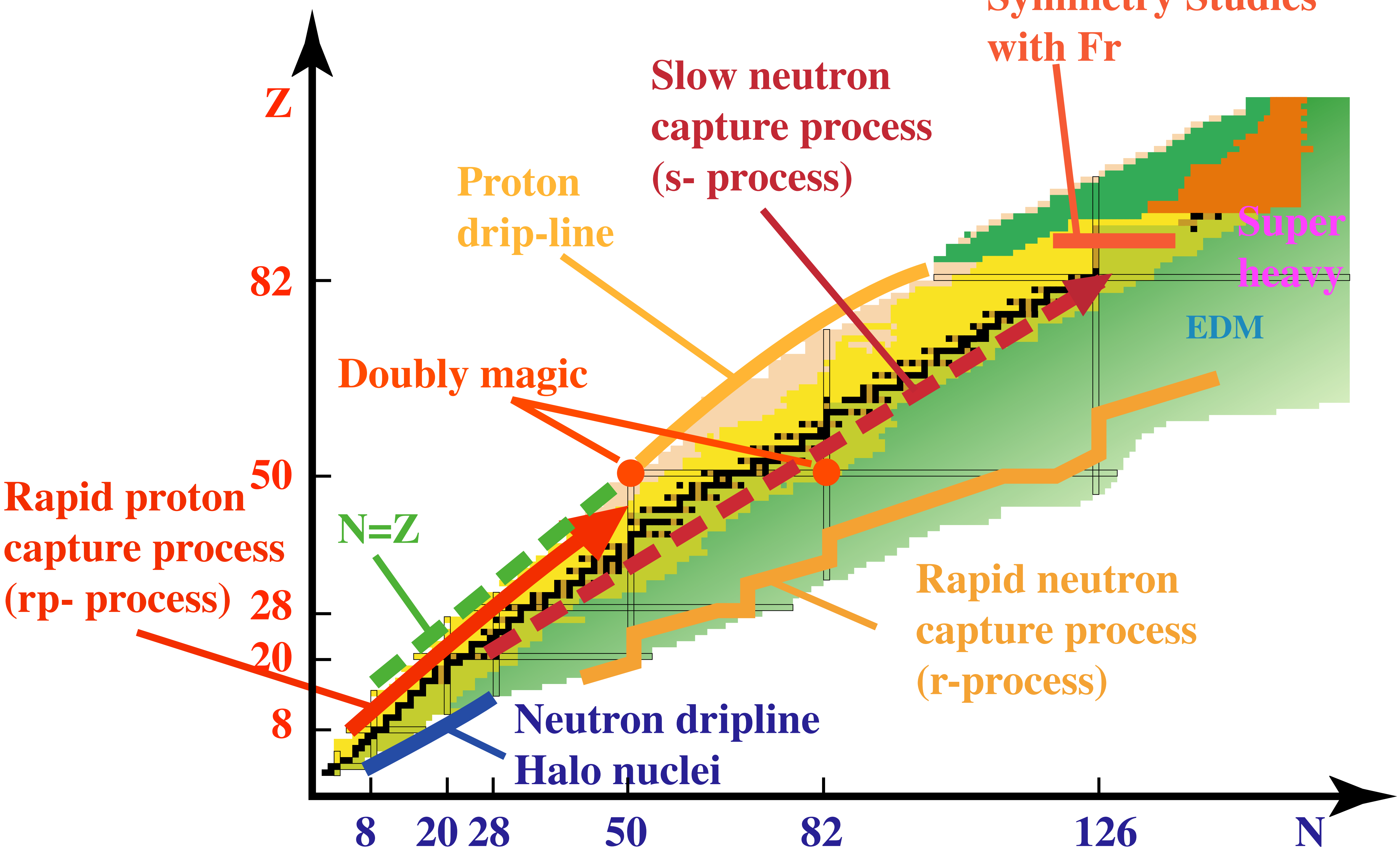


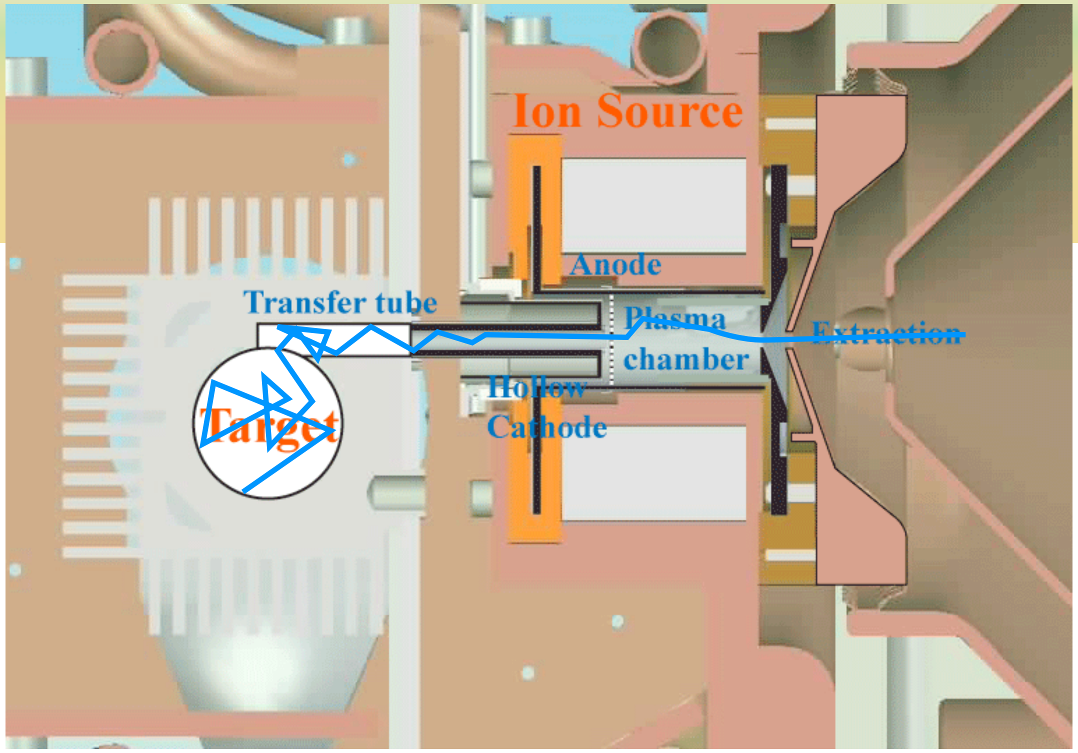
Outline

- Introduction to RIB production using ISOL method
- Target Development
  - Composite targets
  - High Power Targets
- On-Line ion source development
  - Resonant Laser Ion Source
  - FEBIAD Ion Source
  - ECR Ion Source
- Future plans for TRIUMF RIB facility
- Summary

Physics with RIB



ISOL Method



This method involves the interaction of light ion beam onto a thick high-Z target.

The fragments produced are stopped into the bulk of the target material

The radioactive atoms diffuse out of the target material matrix. => Diffusion process.

Then the radioactive atoms effuse out of the oven to the ion source . => Effusion process.

The radioactive atom is ionized => Ionization process.

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ISOL method: Yield

The yield depends on the following parameters:

$$Y = \Phi\ \sigma\ \chi\ \varepsilon_R \varepsilon_E \varepsilon_i,$$

Φ = Incident beam intensity,

σ = Cross section,

χ = Target thickness,

ε_R = Diffusion efficiency, f(D_0, E_A, T)

ε_E = Effusion efficiency, f(χ, ΔHa, T)

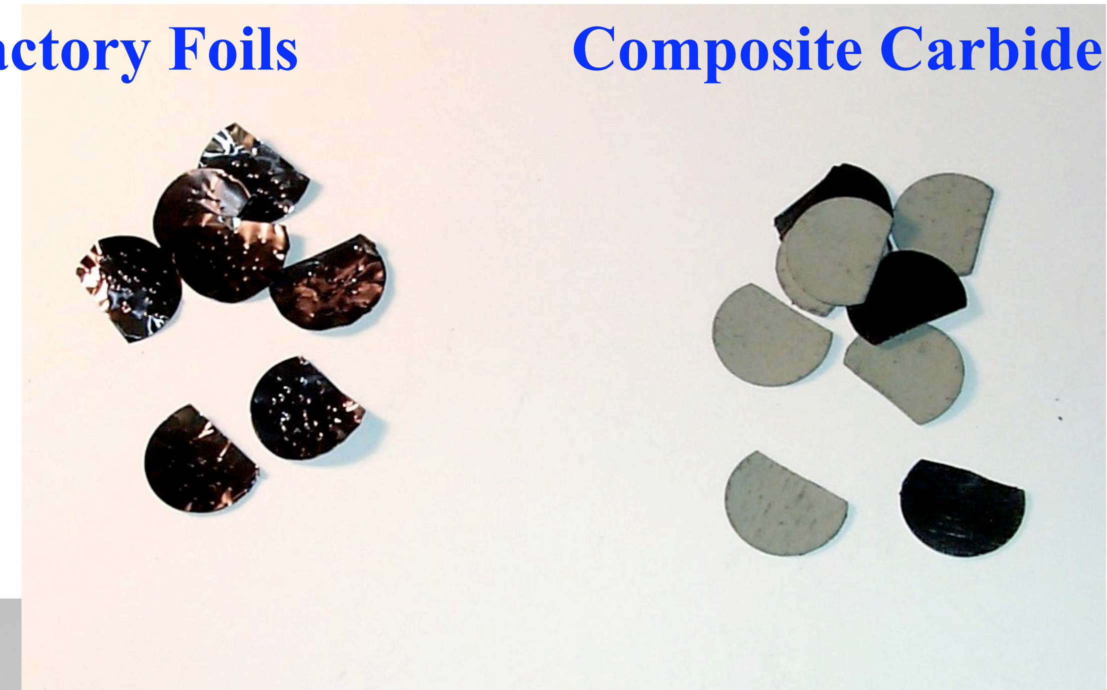
ε_i = Ionization efficiency.

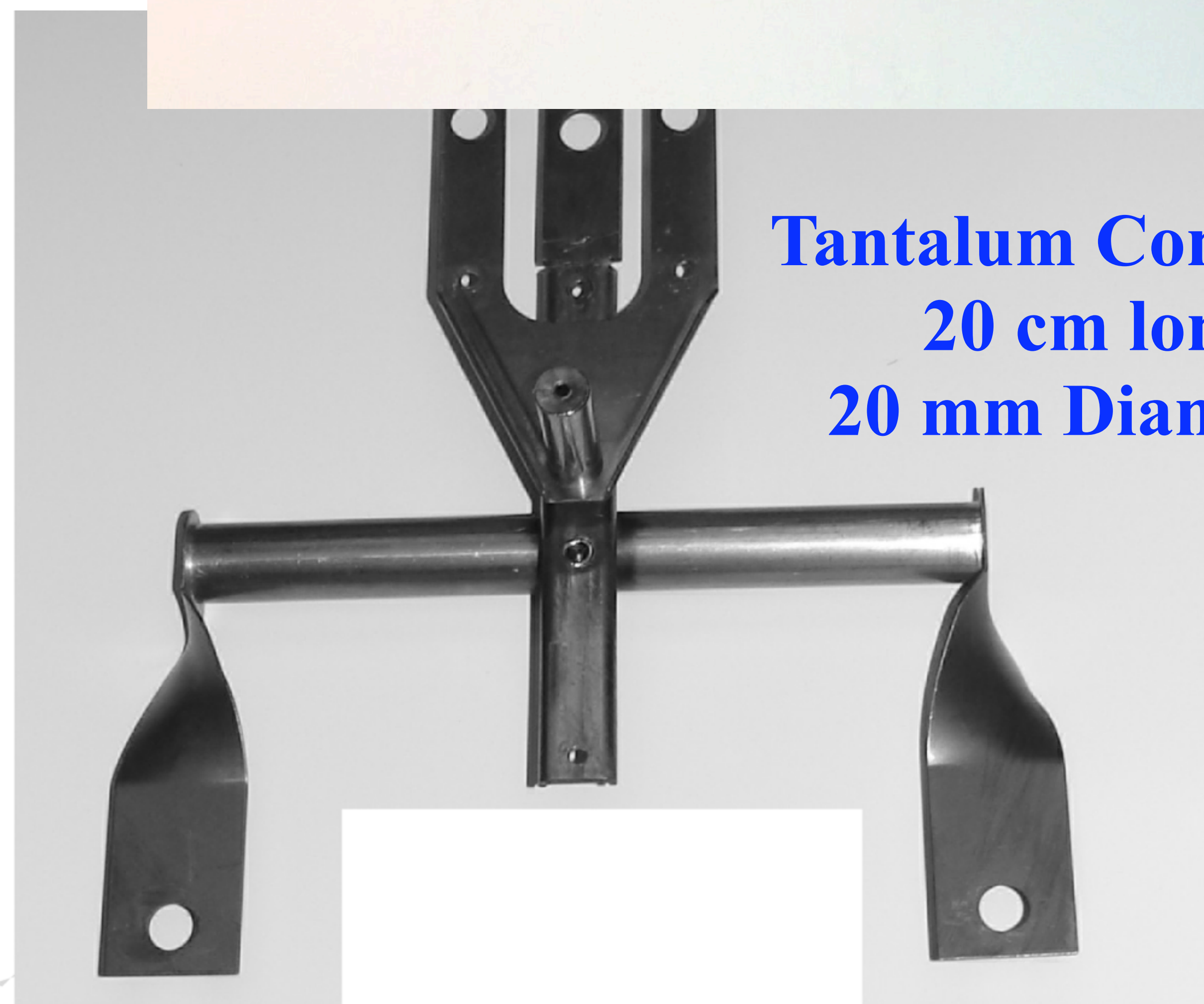
ISOL Target Development

- Target used at ISAC, refractory metals, Ta, Nb, ...
- Foils of thin layers of refractory carbides (SiC, TiC, ZrC, LaC_2 ~ 0.1 mm thick) deposited on flexible exfoliated graphite sheet
- Development of the composite foil technique has allowed carbide target operation with up to 70 μA proton beam.

Refractory Foils

Composite Carbide Foils



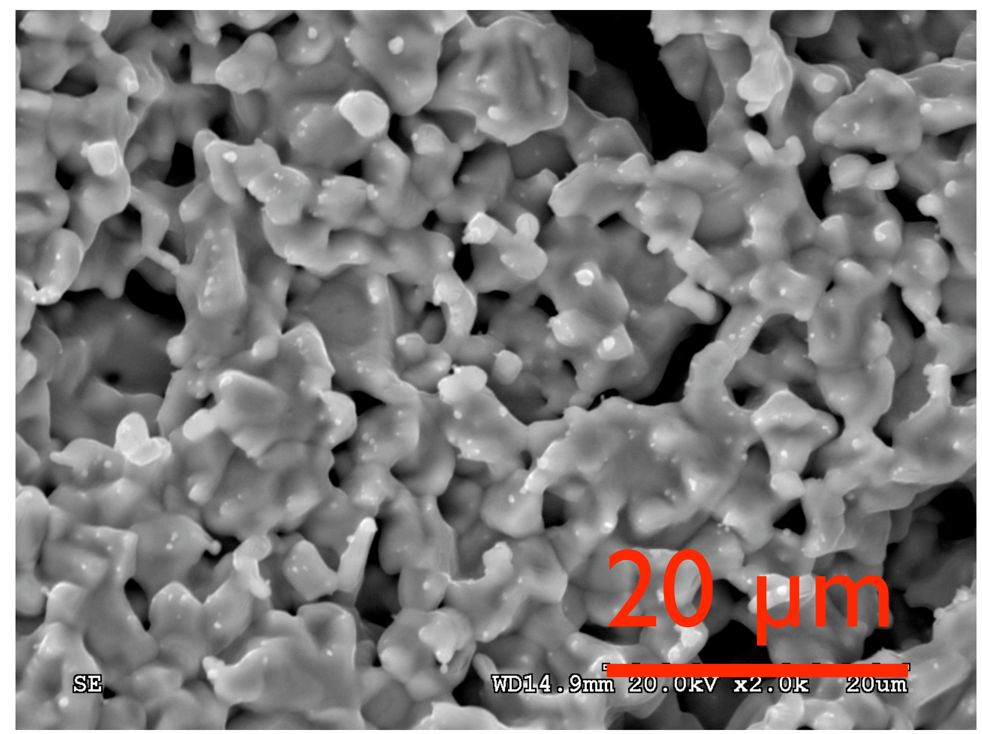


Tantalum Container
20 cm long
20 mm Diameter

Composite Targets

- To dissipate the power for the composite carbide target we developed a new technique. Using a slip cast method, the carbide target material is bounded onto an exfoliated graphite foil(0,13 mm thick).
- The target is then cut out of the cast and inserted into the Tantalum target container.

Slip cast onto exfoliated graphite foil (0.13 mm thick)



Electron Scan of the LaC_2 after slip cast and sintering at 1600 ºC.

High Power Target

1986	Eaton & Ravn, CERN/ISOLDE: 100 µA, 550 MeV, proton	Longitudinal fins on the Ta container
1991	Talbert et al., 100 µA, 600 to 1200 MeV, proton	Cooling design consisting of an annular solid thermal conductor encasing the target with an outer He-filled gap separating the conductor from a water-cooled outer jacket
1991-1996	Nitchke, LBNL: 100 µA, 800 MeV, proton Talbert et al., 100 µA, 600 to 1200 MeV, proton Bennett, RAL: 100 µA, 800 MeV, proton	Active conductive cooling using He gas flow. Active conductive cooling with thermal barrier Passive radiative cooling approach.
1998	Talbert et al., 100 µA, 500 MeV, proton	Active conductive cooling using water channels. Test at TRIUMF at 100 µA, 500 MeV, proton
1999	Bennett, RAL: 100 µA, 800 MeV, proton Rutherford Ion Source Test, RIST project	Built a diffusion bounded Ta target, off-line test shows that emissivity ~ 0,7-0,8.

RIST target

Target difficult to fabricate.

Very expensive target ≈ £50 k!

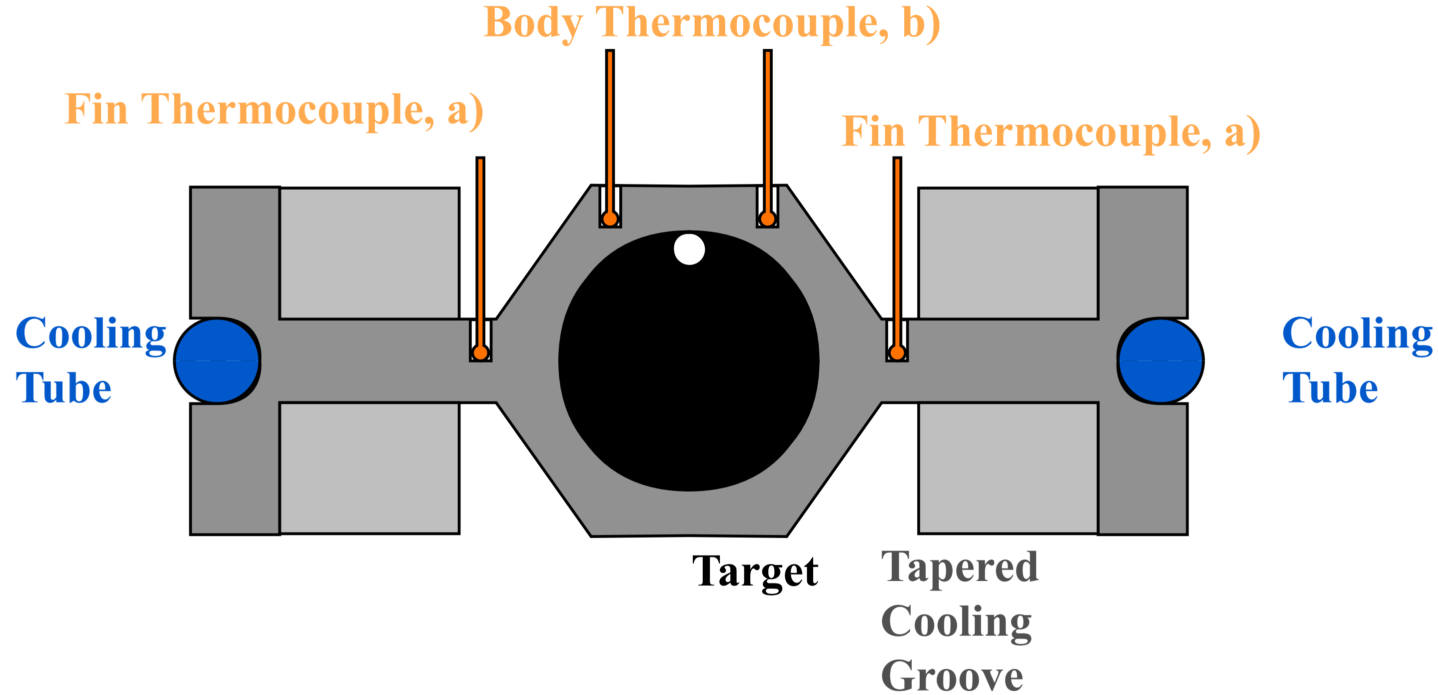
Photo Courtesy of Roger Bennet, RAL.

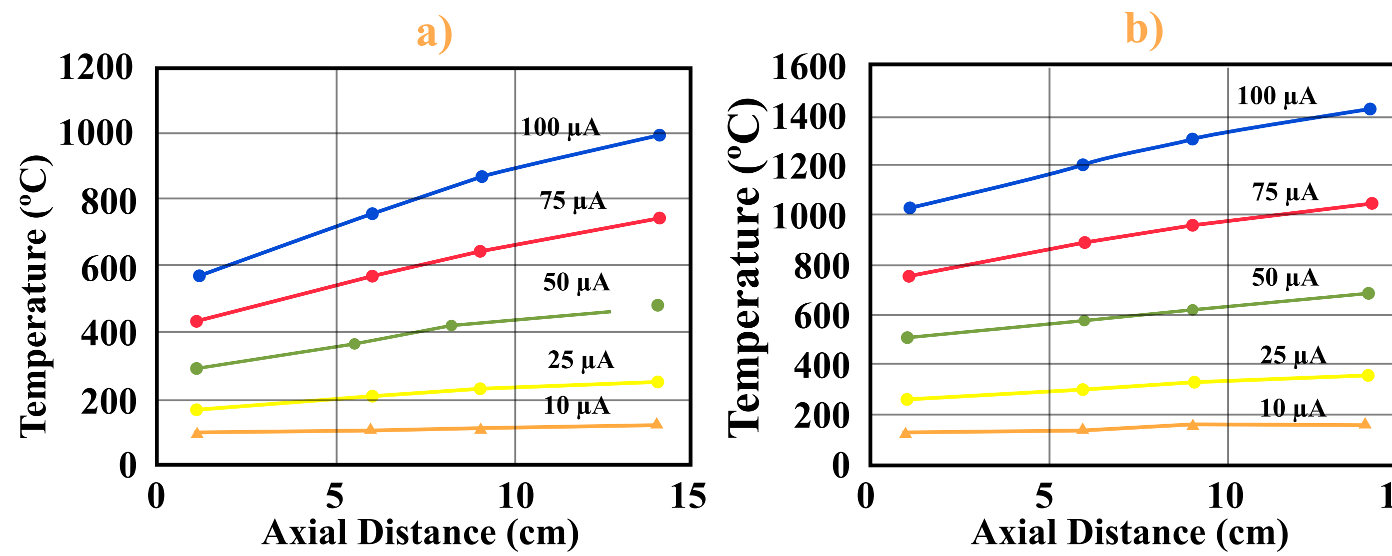
- **The RIST target was never put into practice, the test was never approved and further research on the subject abandoned.**
- **This design allows only target made from refractory metals, Ta, Mo, ... Limiting the production of RIB species.**

Talbert et al., HPT

Diffusion bounded Mo target

W. L. Talbert *et al*. Nucl. Phys. A 701 (2002) 303.



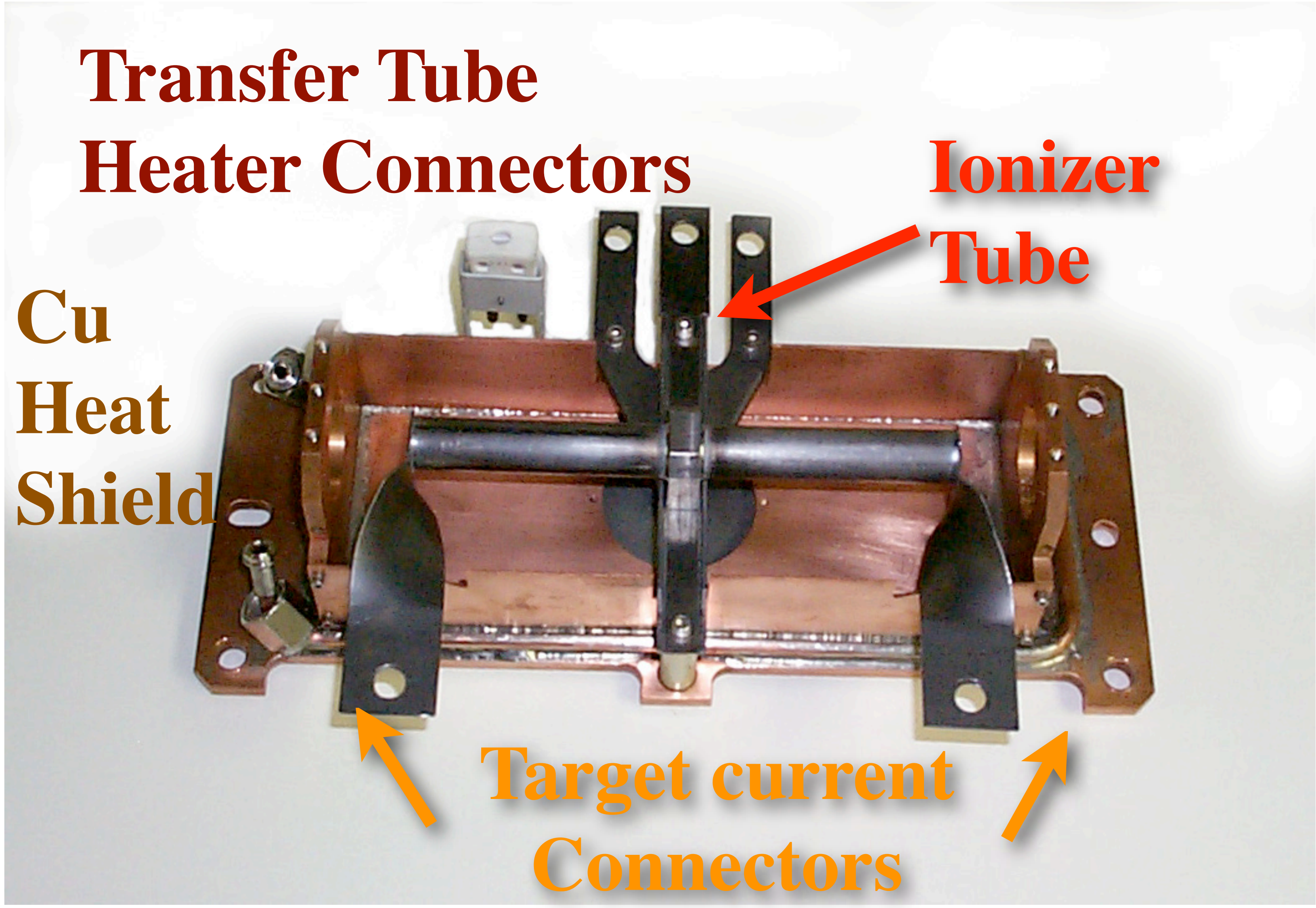


- The target temperature lower than the requested operating temperature, 2000 °C
- This design allows only target made from refractory metals, Ta, Mo, ...
  - This is somehow limits the production of RIB species.

HPT development

- Even though the ISAC facility has been designed for 100 µA, at the beginning (1998) it was not possible to operate the target with more than 1-3 µA.
- In 1999 a Nb foil target was operated with 10 µA.
- In 2000 both the Ta and Nb target were operated with 20 µA, and a SiC made from pressed powder into pellets was operated with 10 µA.
- In 2001 the proton beam intensity was raised to 40 µA on Ta and SiC/graphite composite target. This was obtained by removing all the thermal heat shield around the target and by reducing the target heating, while maintaining the target central temperature at the same value.

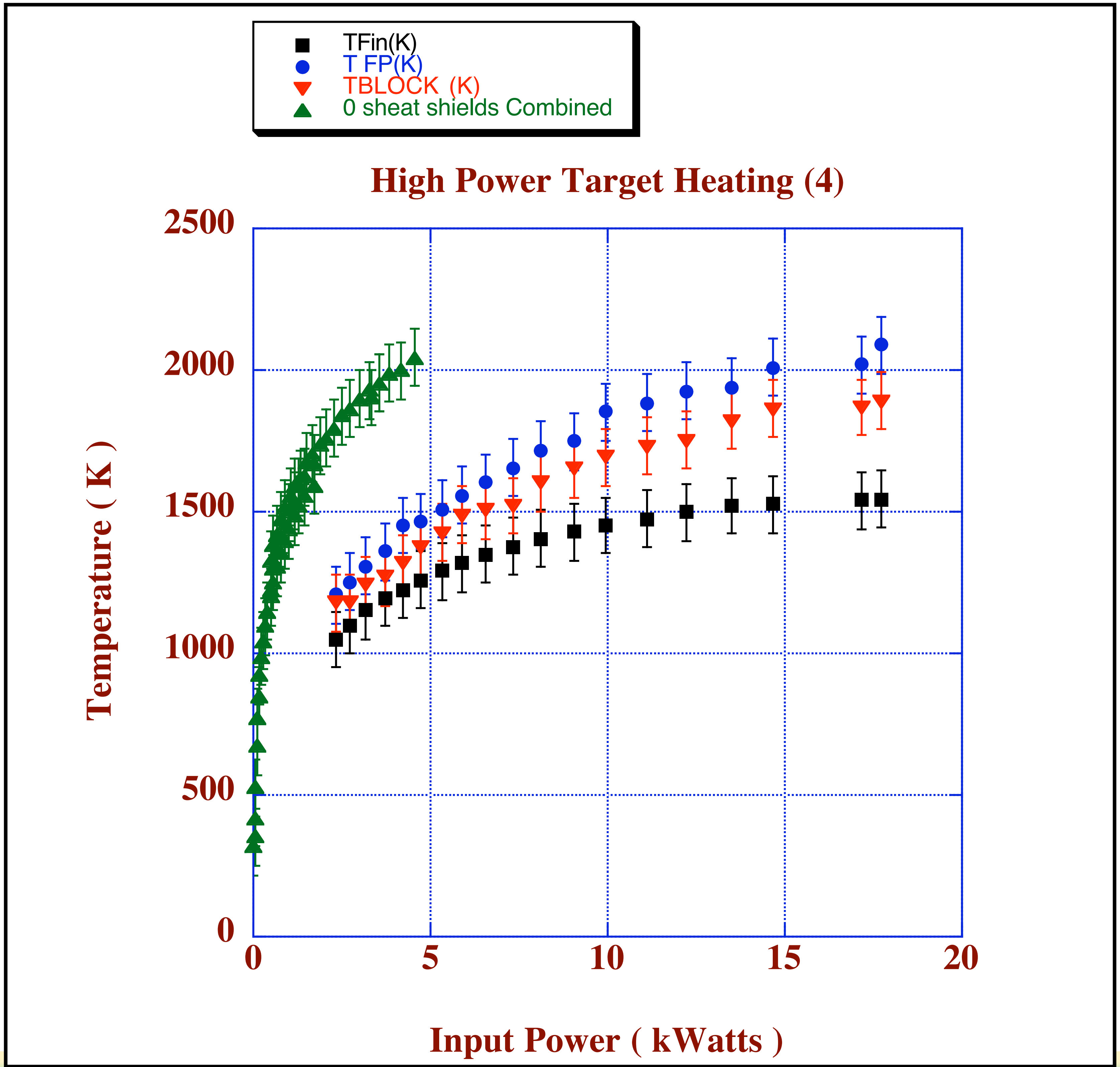
ISAC Target



Initial Design can only dissipate 4-7 kW in the target.

- **With this target design we can go as high as 40 μA.**
- **To go beyond this limit we have to add more effective cooling.**
- **We developed our own radiative cooling target by adding fins to the tantalum target container.**

High Power Target



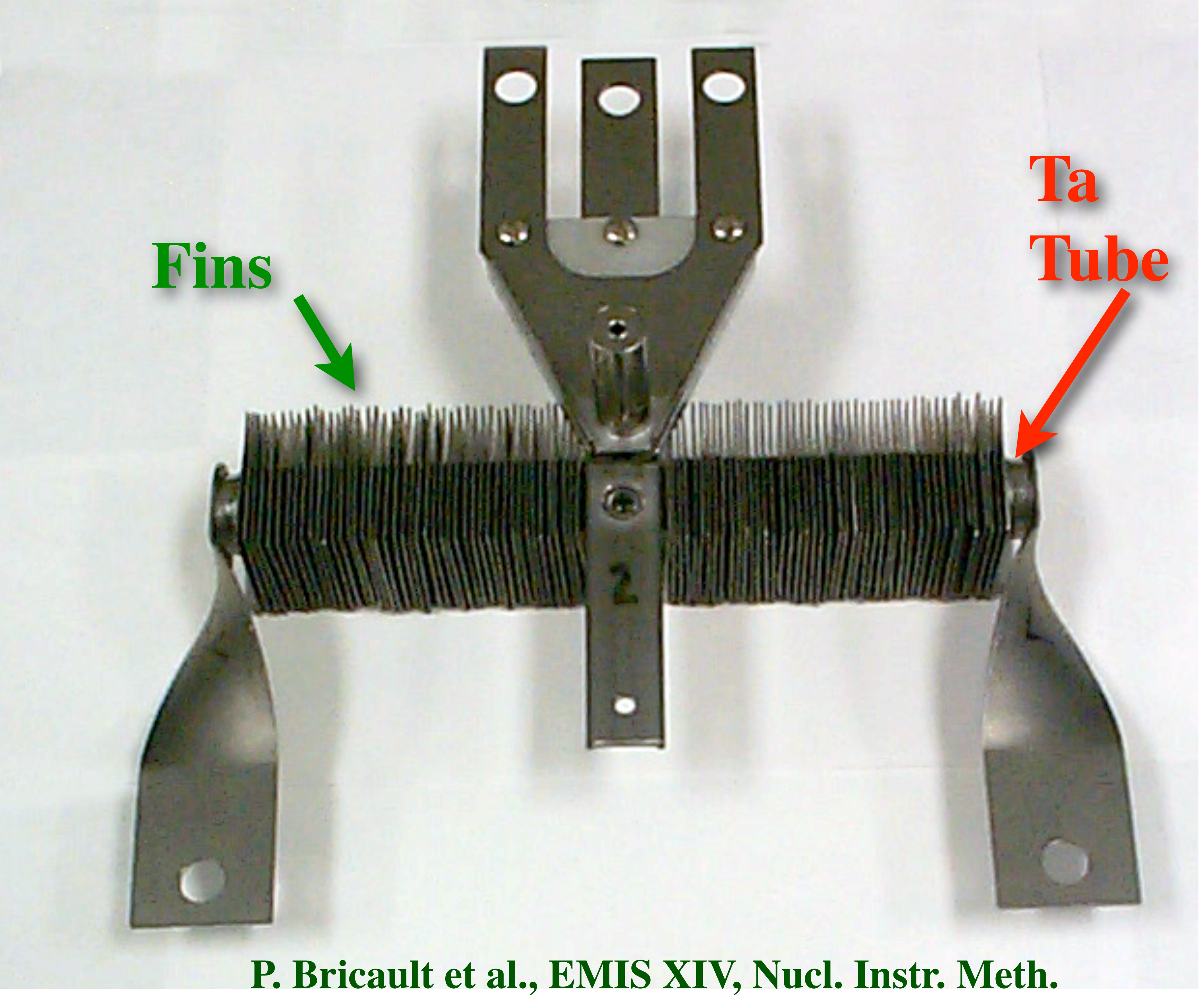
Improve the cooling by adding fins onto the target container. Emissivity: 0,92.

We demonstrated that a target equipped with fins can dissipate up to 17.5 kW.

High Power Target

Contrary to other designs we can use any target material, refractory metals or composite carbides or oxides, inside the Ta target container.

We demonstrated the operation of our HPT at 100μA level for a 500 MeV proton beam.



P. Bricault et al., EMIS XIV, Nucl. Instr. Meth.

Ion Sources

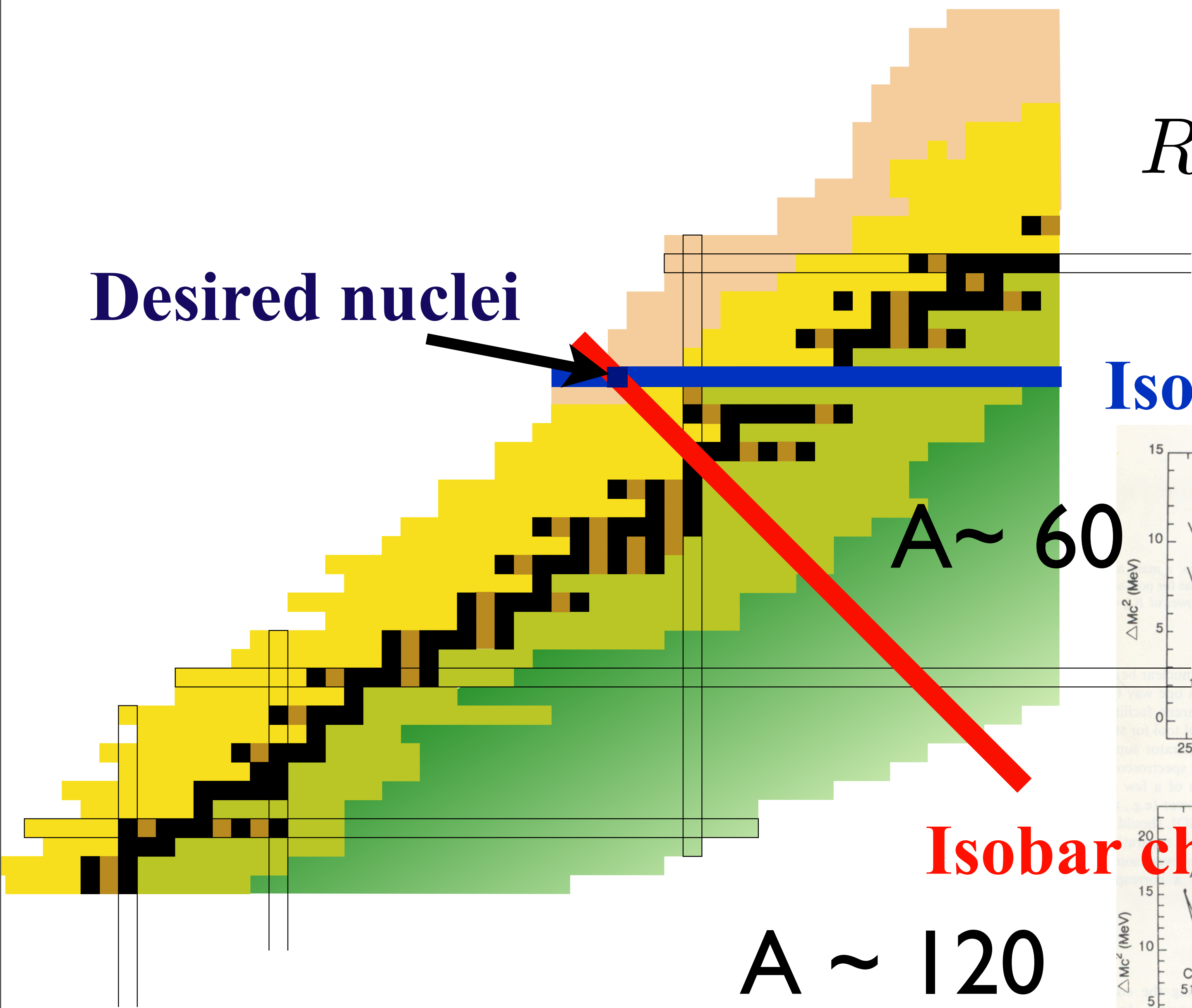
- The requirement for an ISOL ion source diverge from to a certain degree from the ones for an off-line ion source;
  - Because the production rate is somehow limited, We need highly efficient ion source,
  - Ionization efficiency most be independent of the pressure fluctuation,
  - Ion source free of instabilities in order to prevent reduction of the mass resolving power,
  - Has to operate in high radiation field and at high temperature to avoid condensable element to stick on the walls,
  - Maintenance free and long life-time,
  - Small size to avoid large nuclear waste inventory.

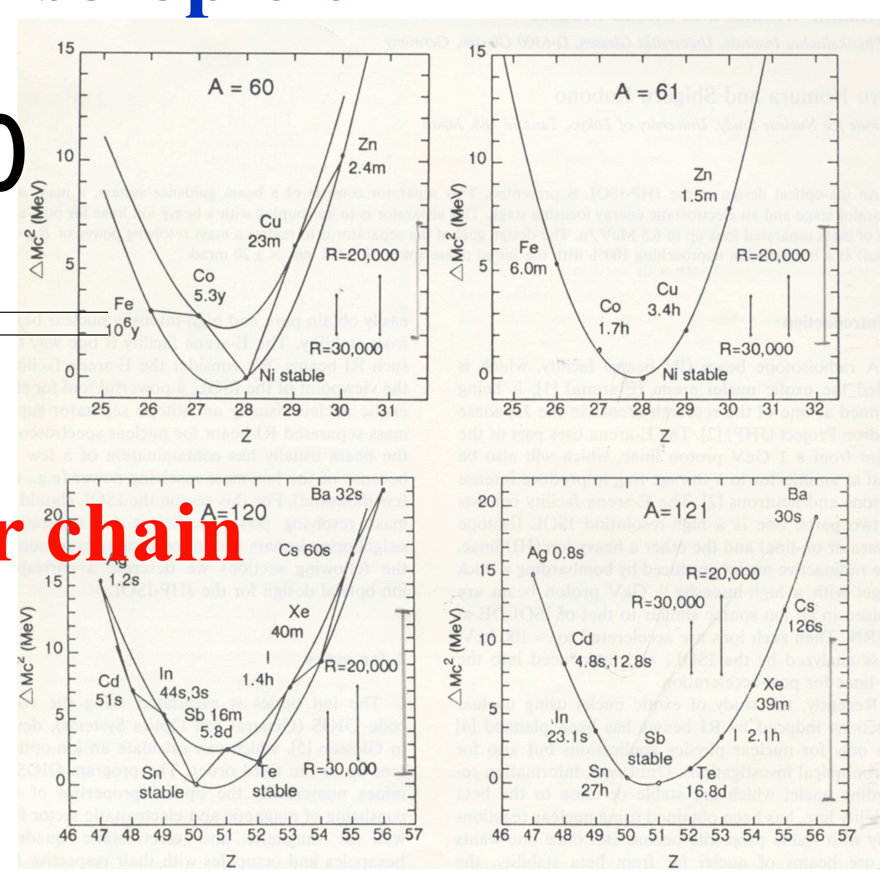
Laser Ion Source

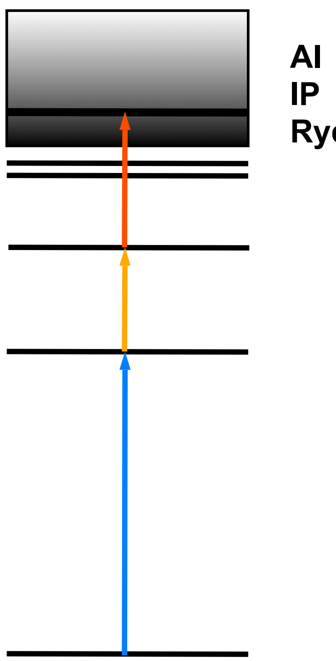
Advantage in RIB production using Resonant Laser Ion Source (RLIS)

Resonant Ionization LIS
-> element selective
-> isobar free beams

$$R = \frac{m}{\delta m} = \frac{A}{1}$$







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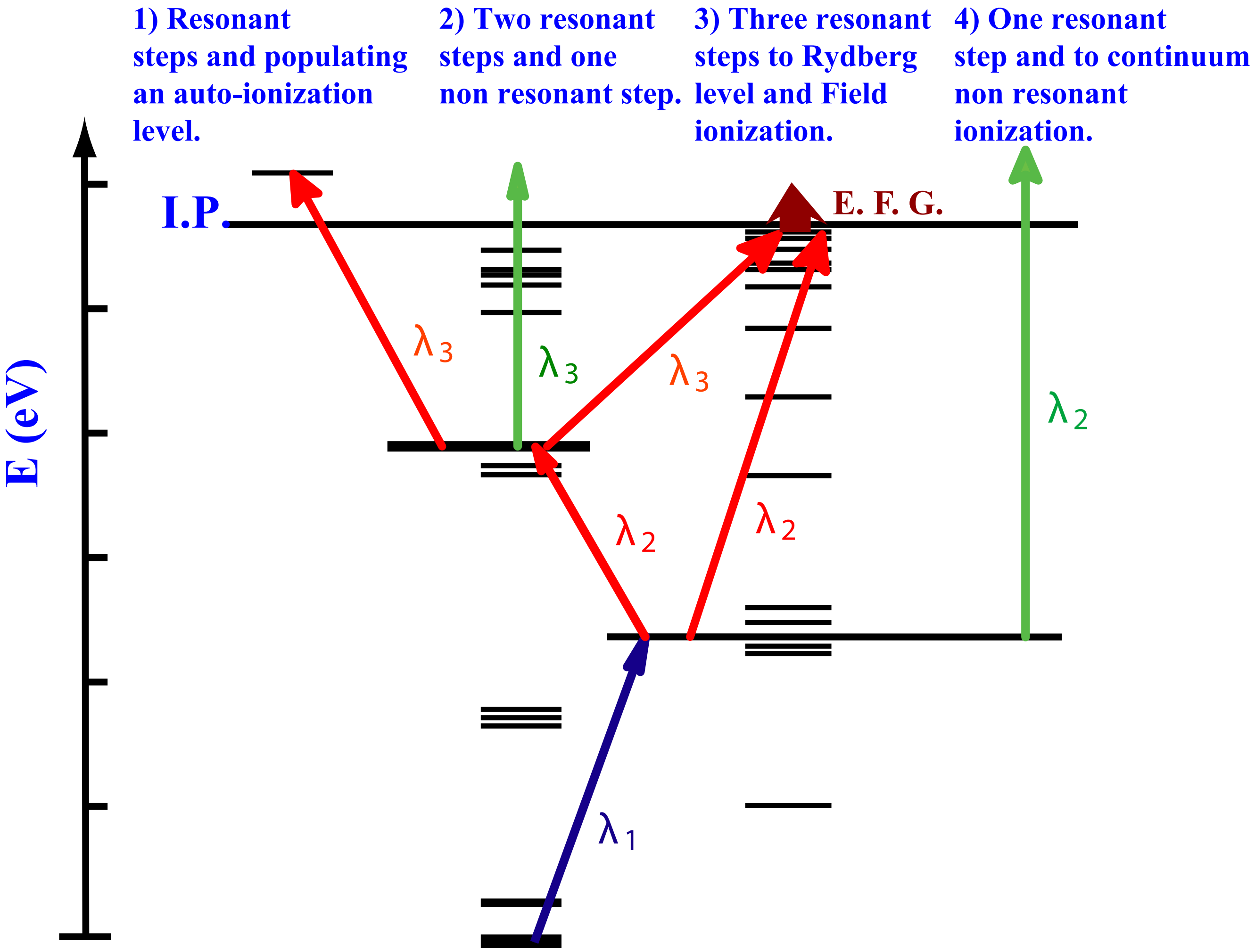
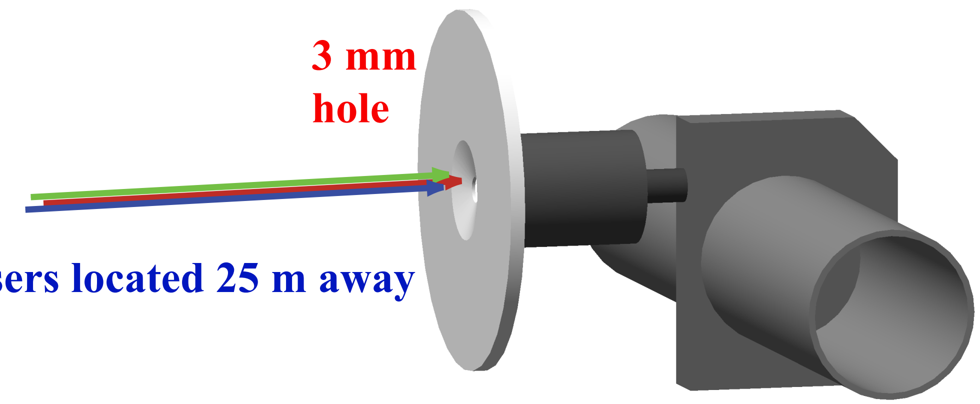
Resonant Laser Ion Source

Principle of the Resonance Laser Ion Source (RLIS)

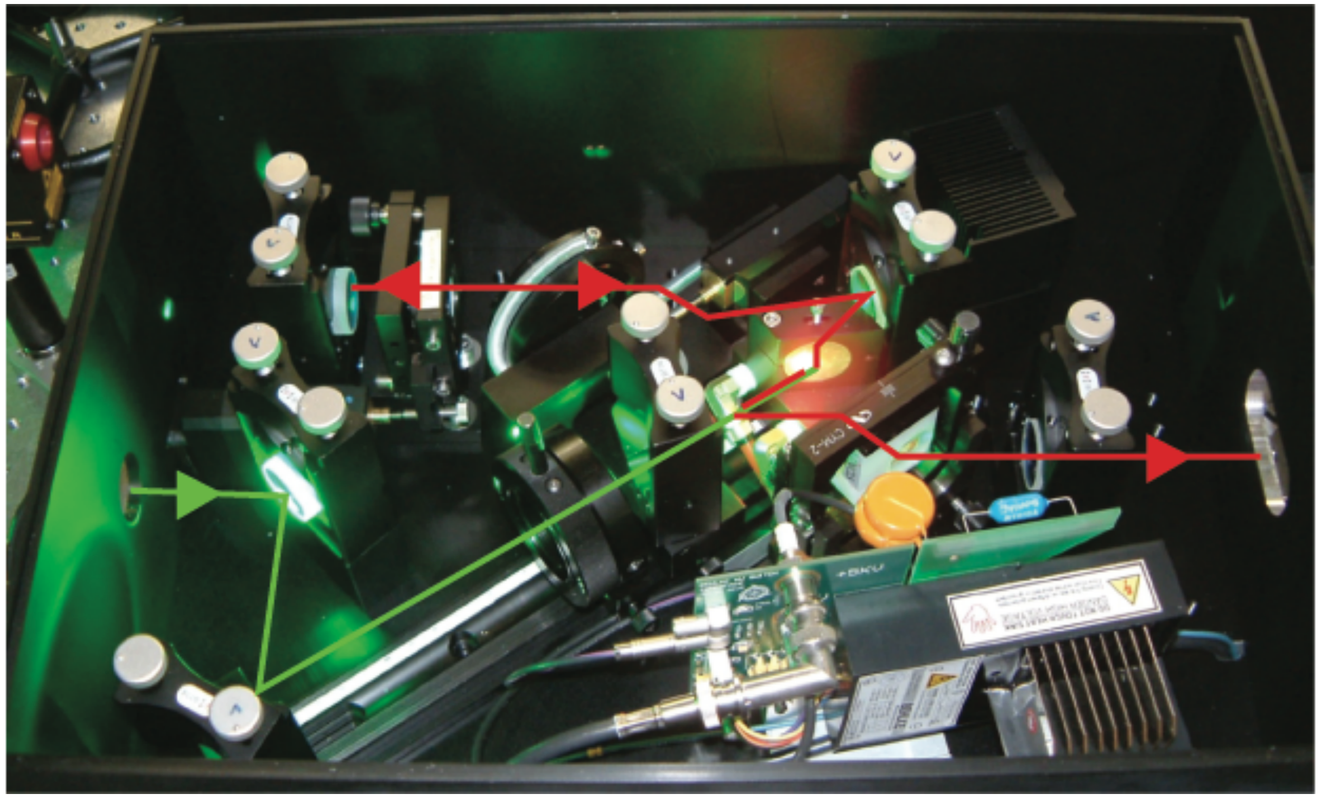


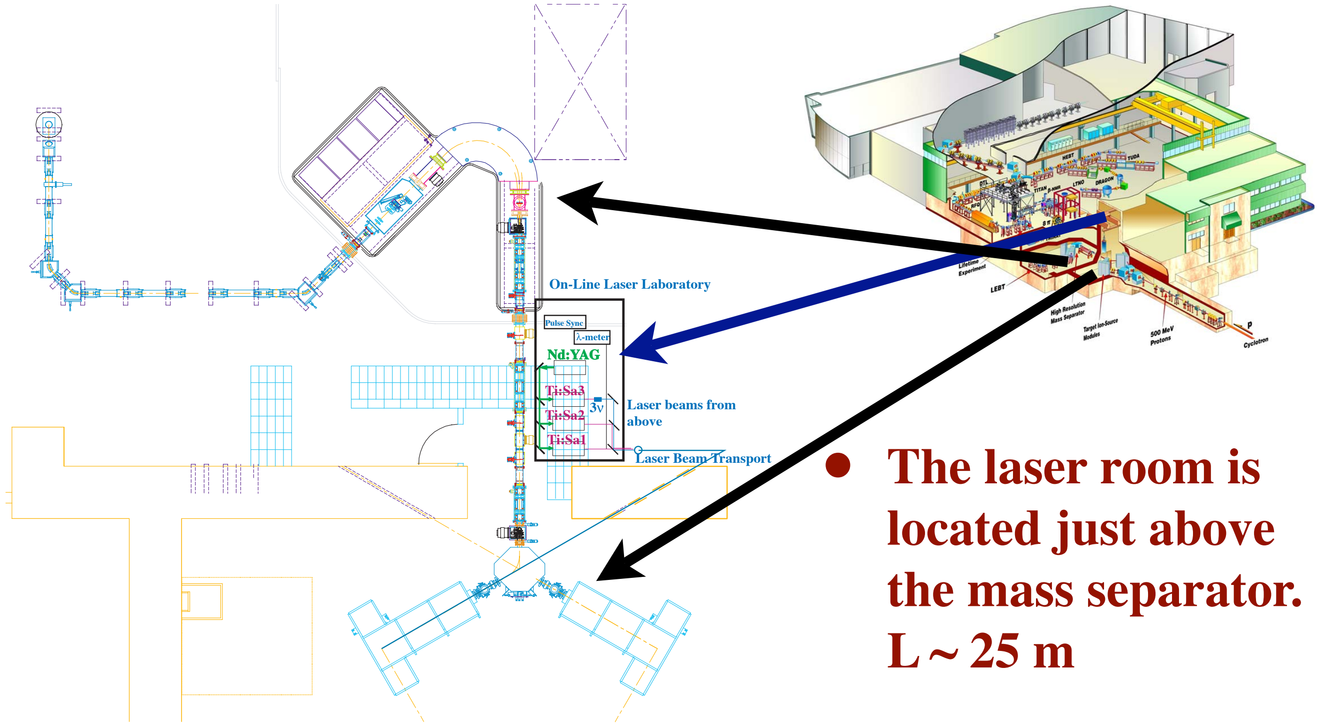


- **Laser requirements**
- **Laser must be applicable to a wide range of elements**
- **For selectivity at least two resonant steps are required and third one is even better.**
- **High repetition rate to ensure that the atom sees at least one laser pulse while traveling inside the transfer tube.**
- **Need to focus the laser beams into a 3 mm diameter hole, ~ 25 m away**
  - **Good laser beams quality is required.**
  - **Large optics elements.**
- **Need to synchronize the laser pulse such they arrive at the same time inside the transfer tube.**

TRIUMF Ti:Sa Laser

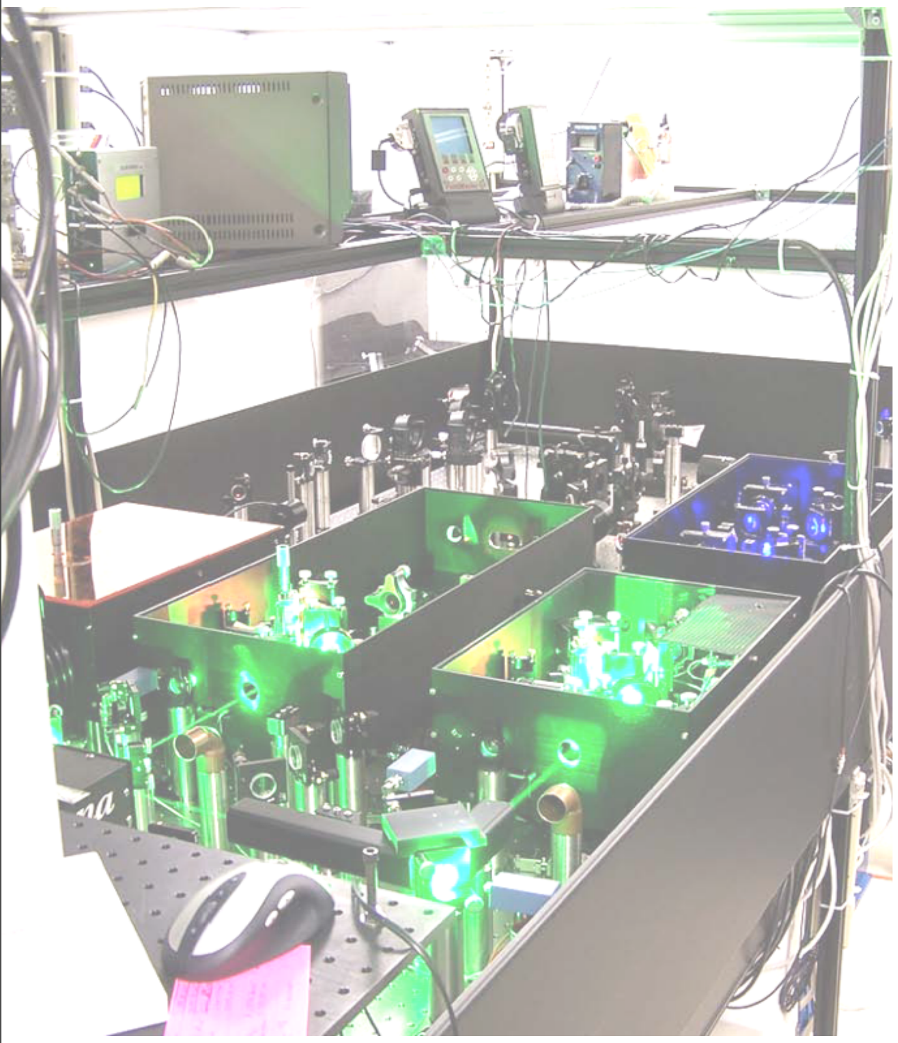
- **We built our Ti:Sa laser using U. Mainz design.** J.H. Yi et al, Japanese Journal of Applied Physics Part 1, Vol 42, Issue 8, p. 5066-5070 (2003)
  - **We simplify the design to make fabrication more cost effective using CNC machining.**
  - **Improve cooling, better thermal stability**
- **We upgrade the laser system by double side pumping.**
  - **More than double the output power.**

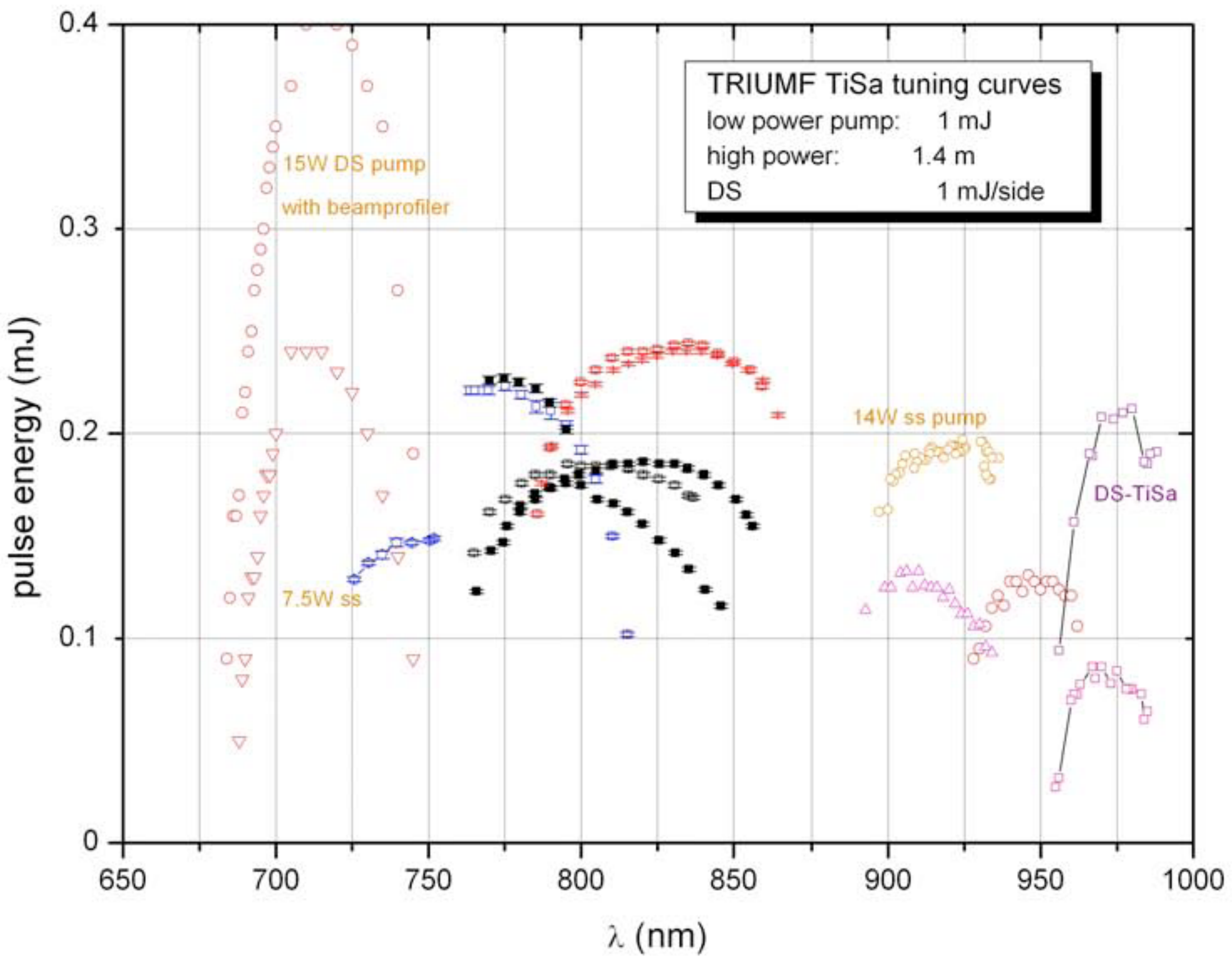




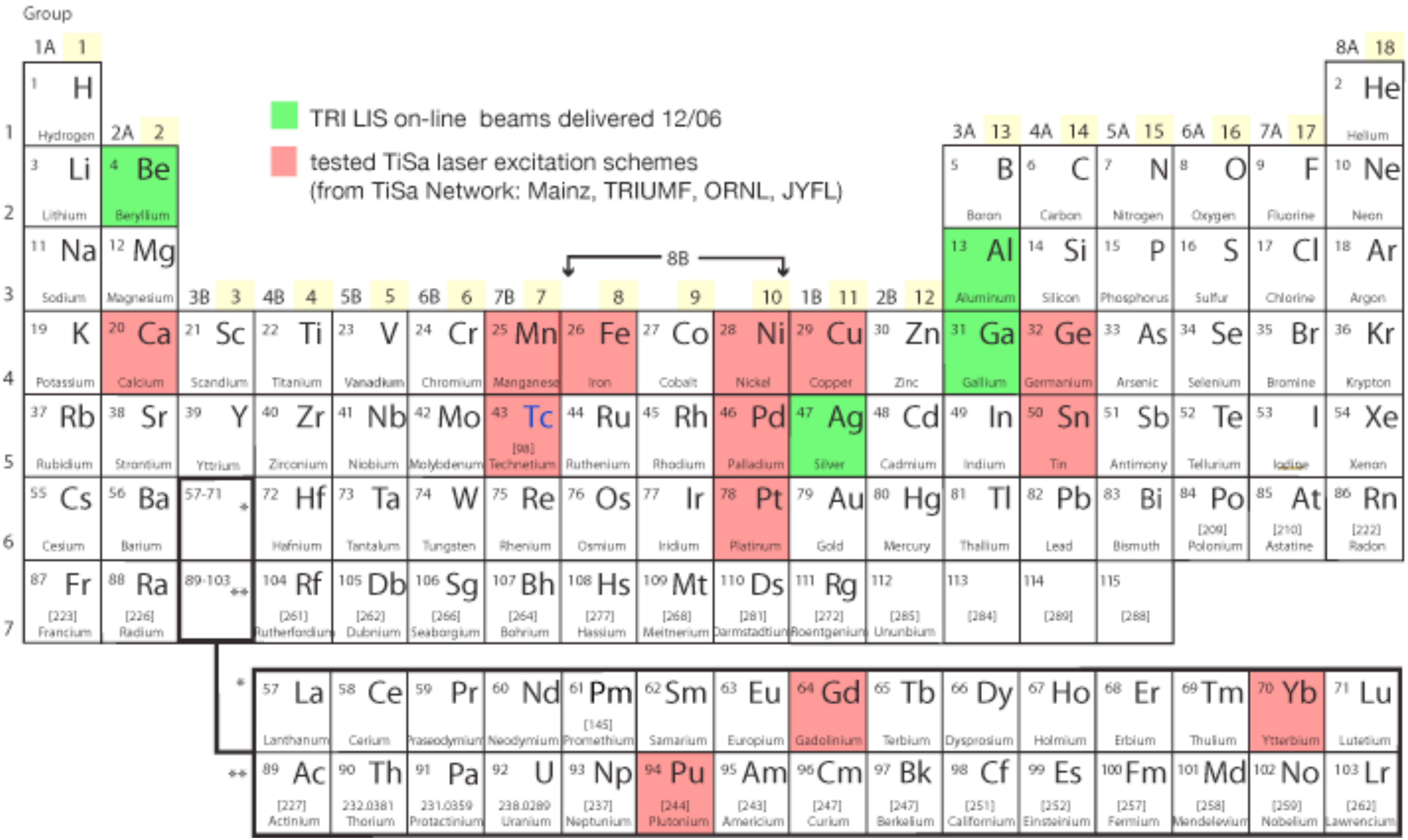
- **The laser room is located just above the mass separator. L ~ 25 m**

Ti:Sa tuning range



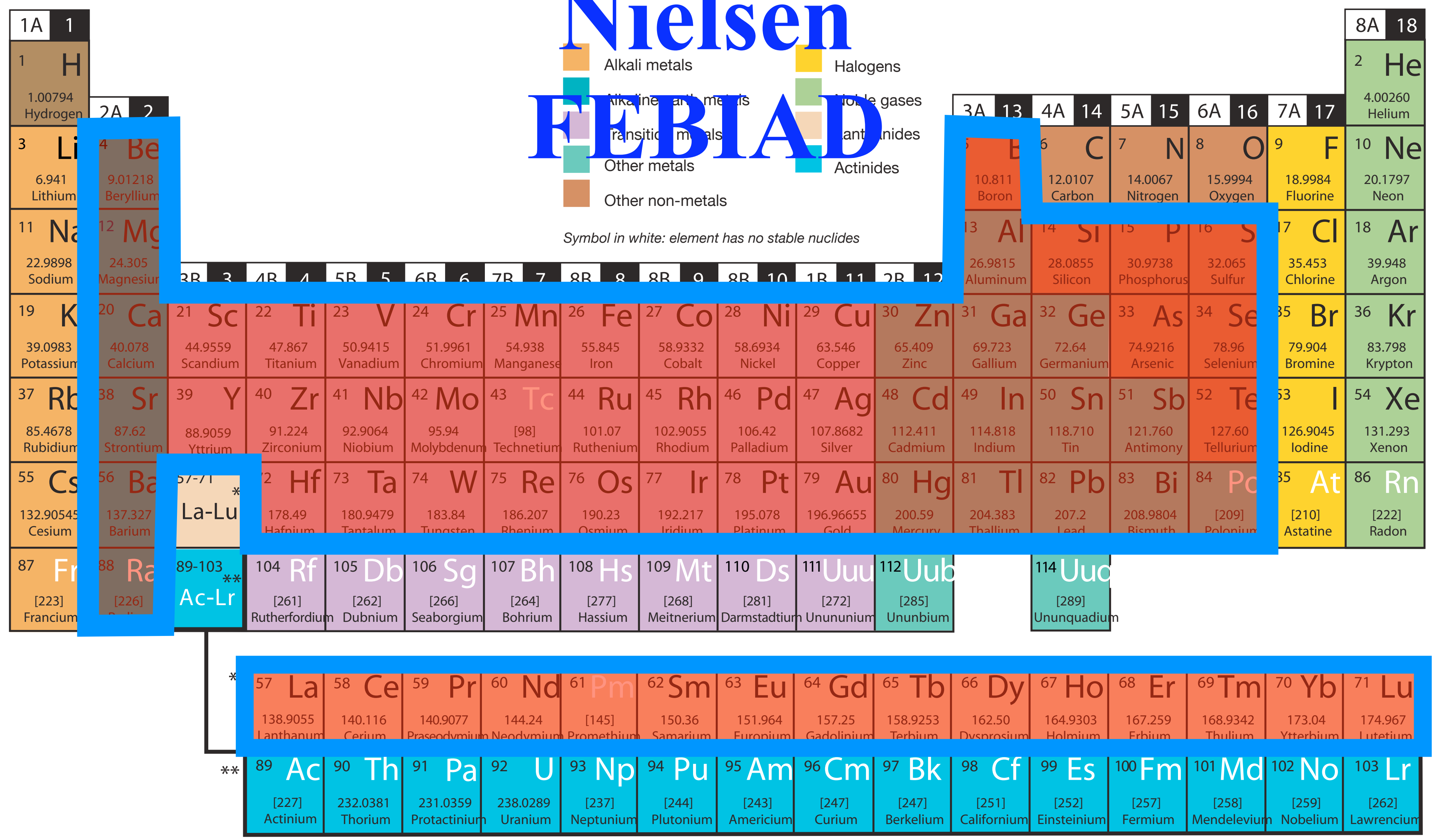


Laser Ion Source



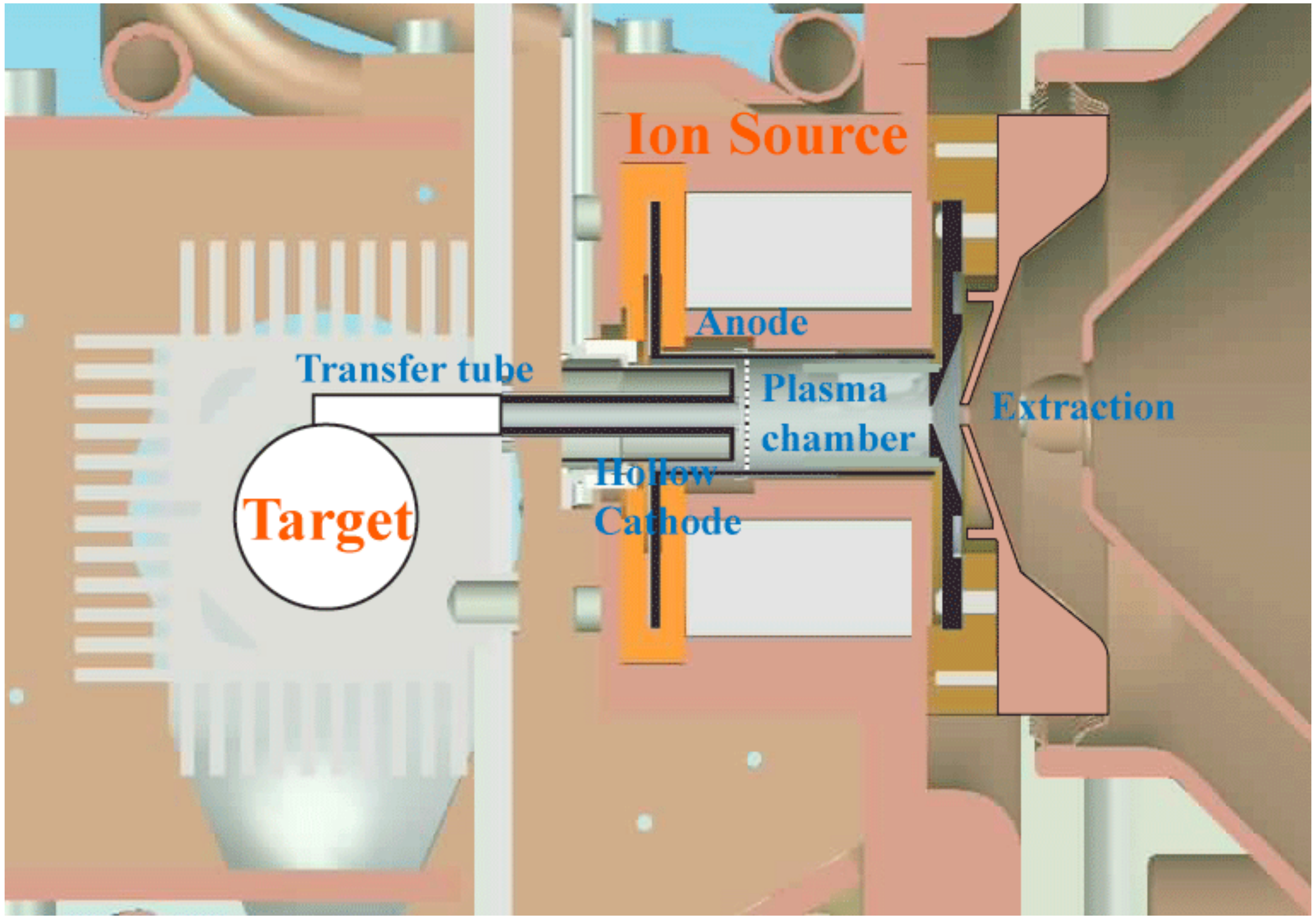
RIB Development

Plasma Ion Source
Bernas-Nier
Nielsen
FEBIAD



FEBIAD Ion Source

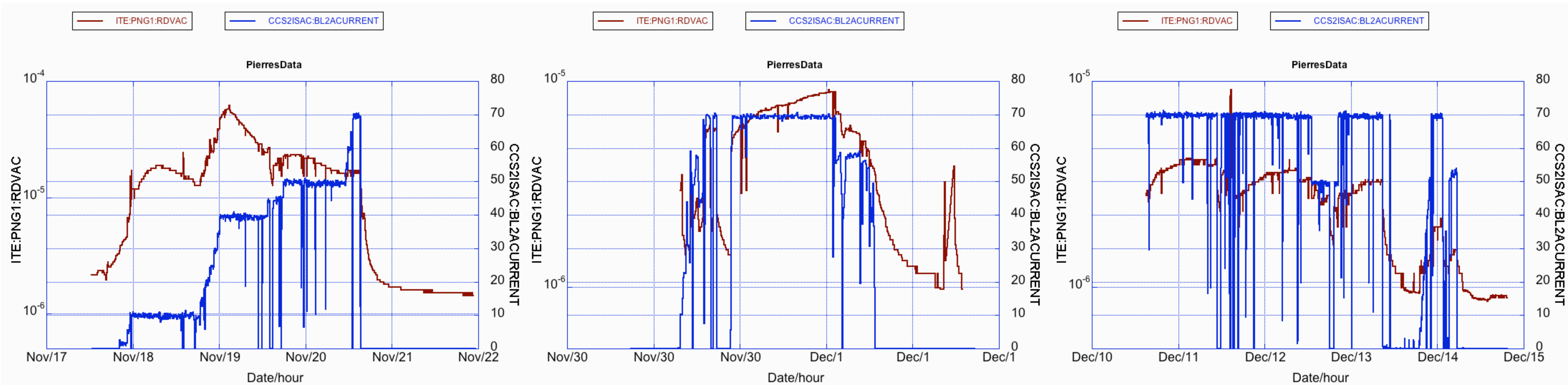
FEBIAD invented by
R. Kirchner and E. Roeckl, Nucl. Instr. and Method 133 (1976) 187-204.

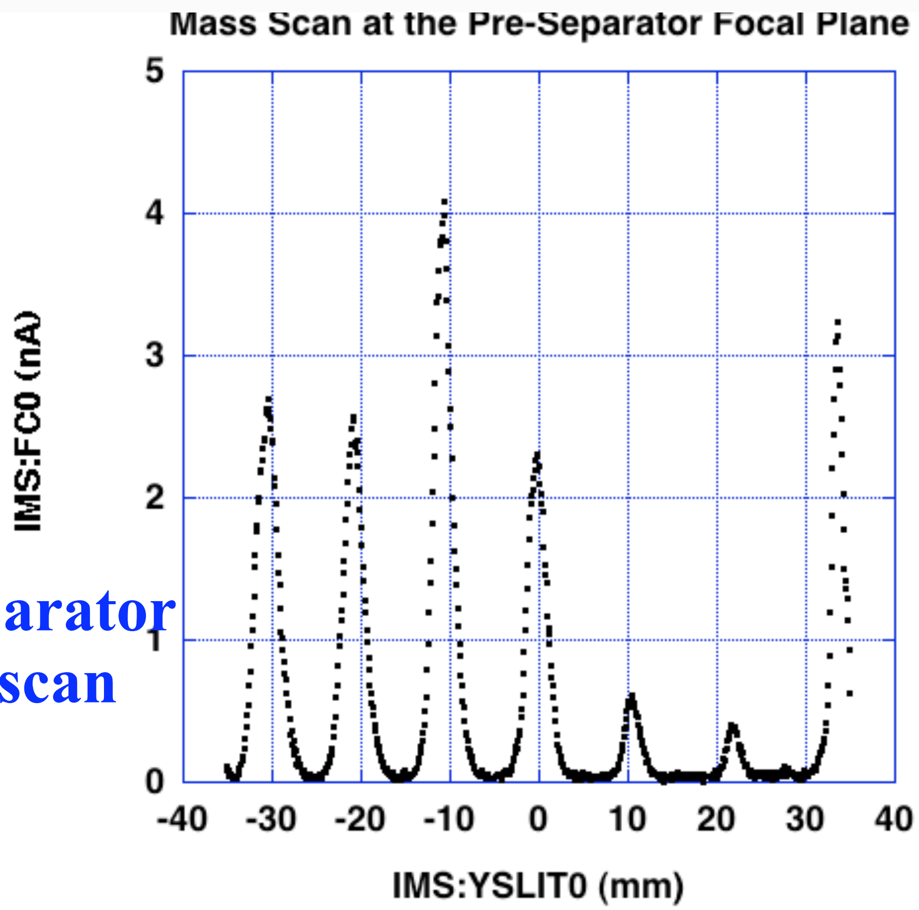


- Our FEBIAD is similar to the ISOLDE hollow cathode design.
- On-line tests of the FEBIAD (Forced Electron Beam Induced Arc Discharge) Fall 2006 with a TiC/C_{gr} for $^{34}Ar>^{34}C+\beta^{+}+\nu$ experiment
- and June 2007 for ^{18}F experiment.

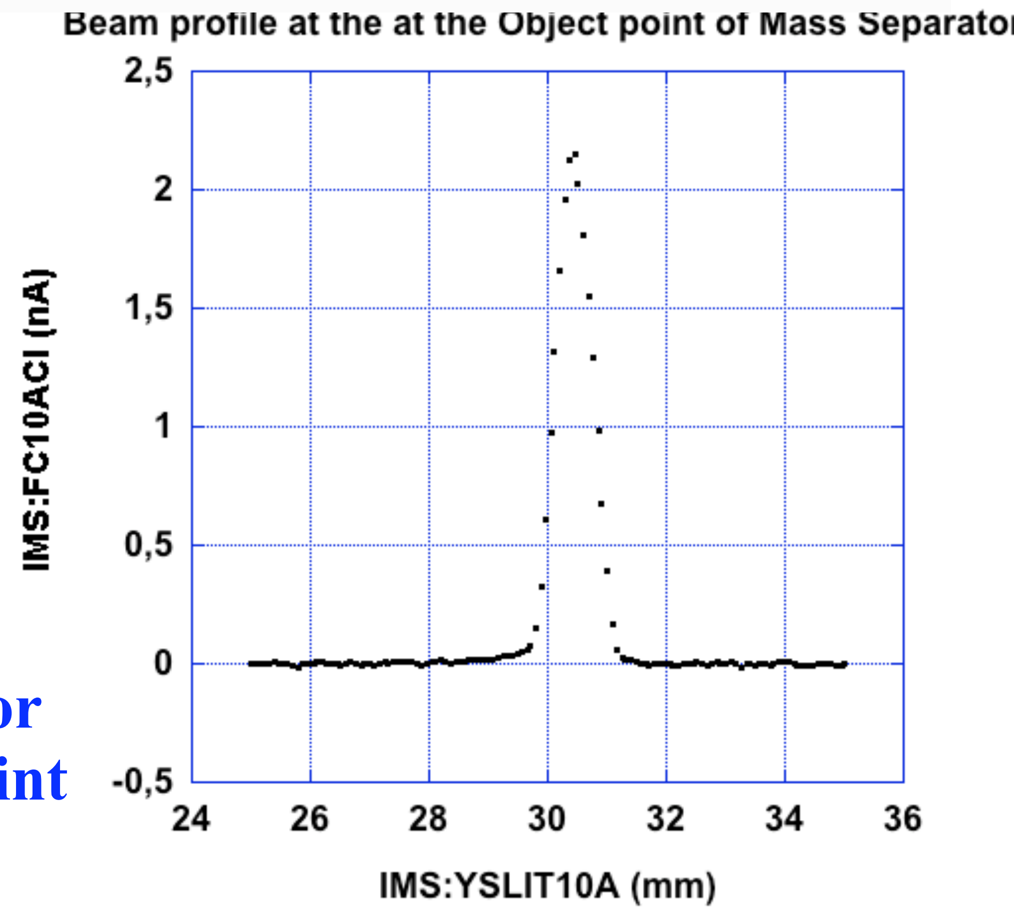
FEBIAD first run

FEBIAD first run



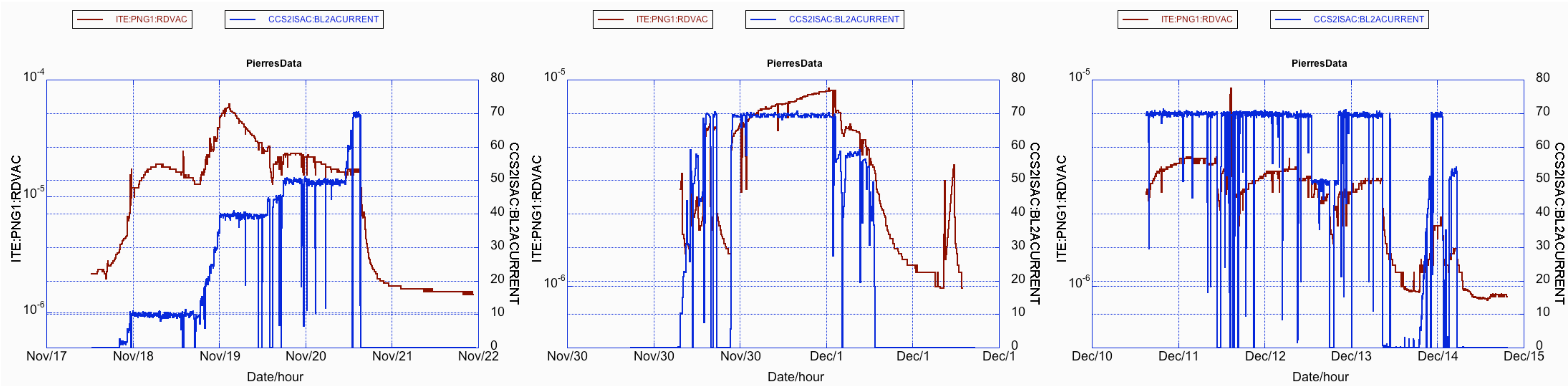


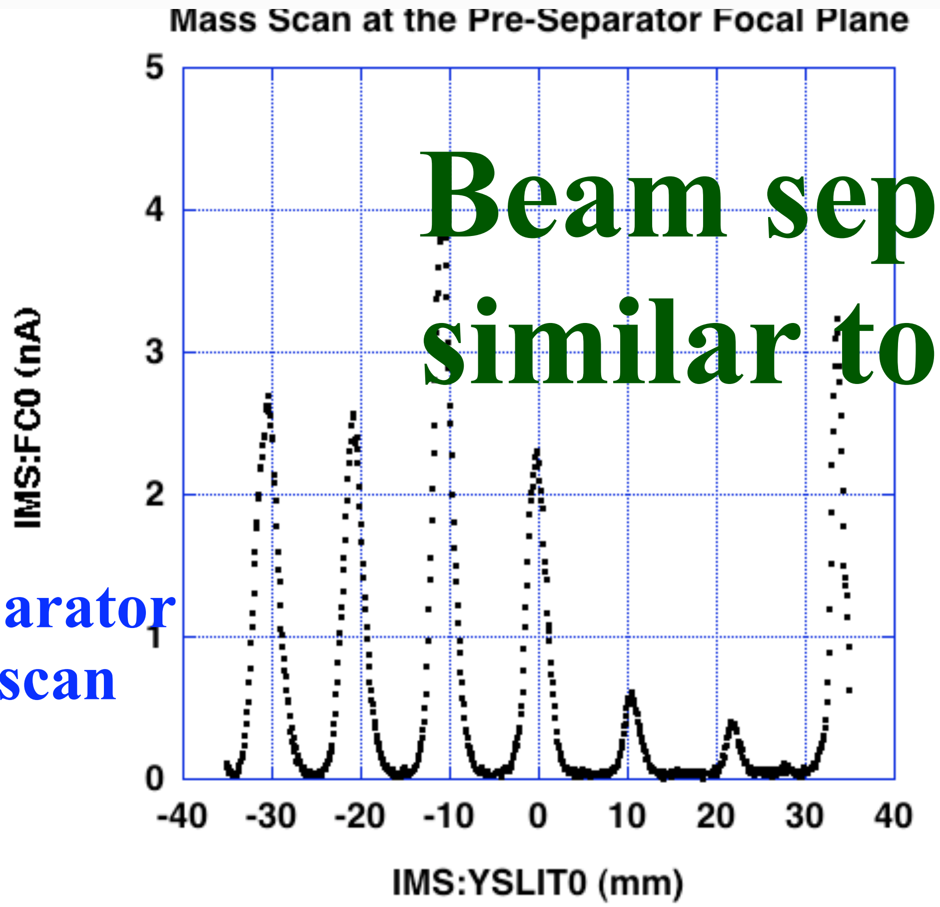
Pre-Separator mass scan

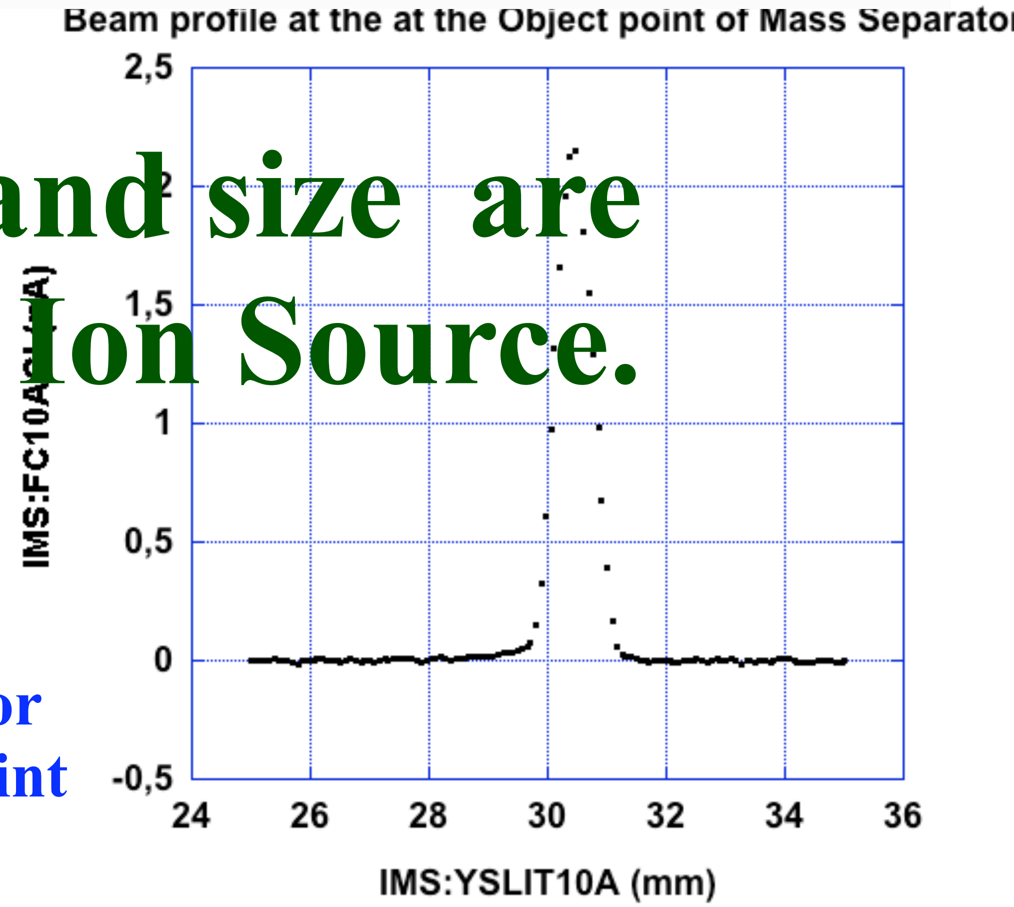


Mass Separator object point

FEBIAD first run







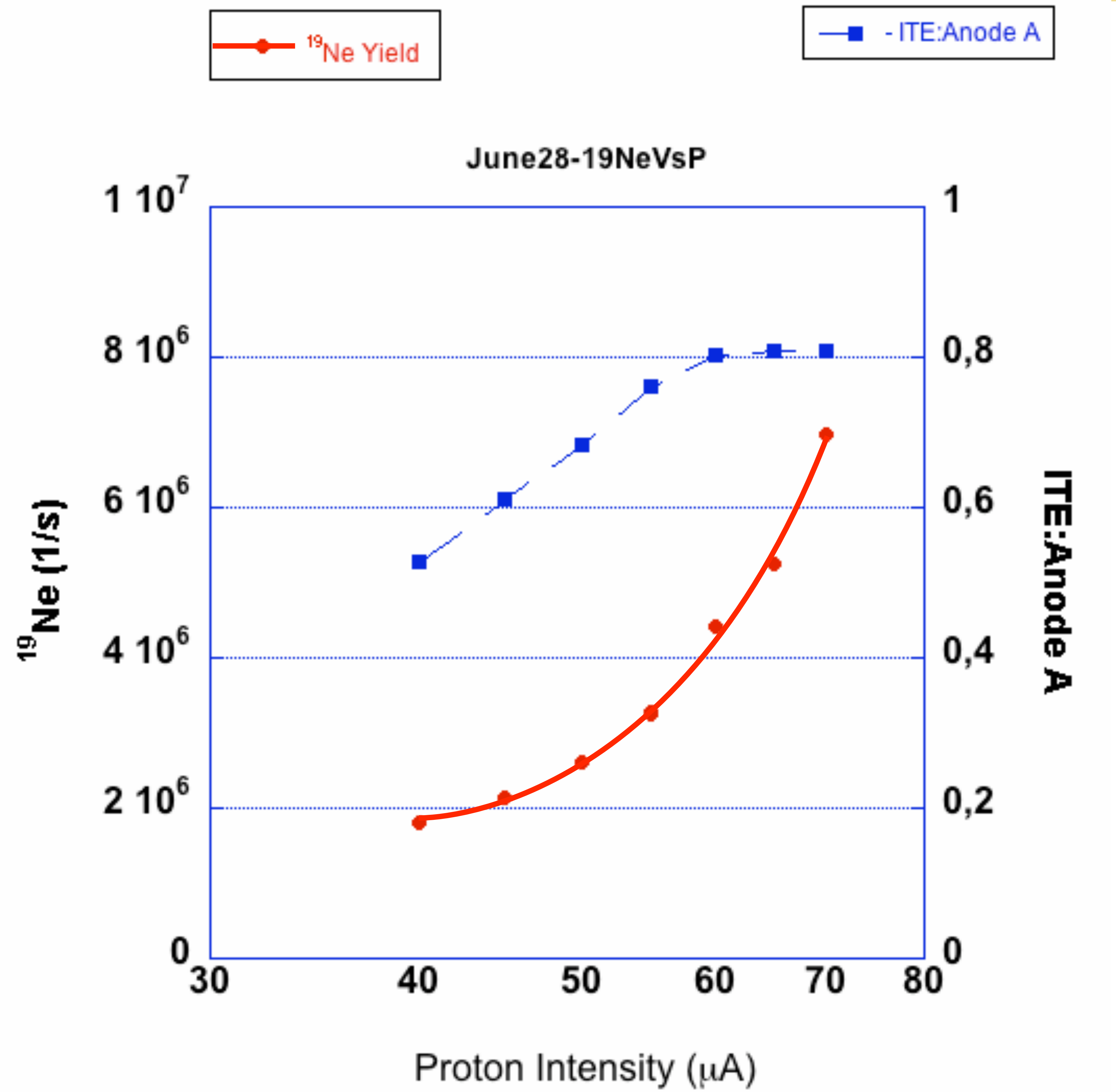
Beam separation and size are similar to Surface Ion Source.

Pre-Separator mass scan

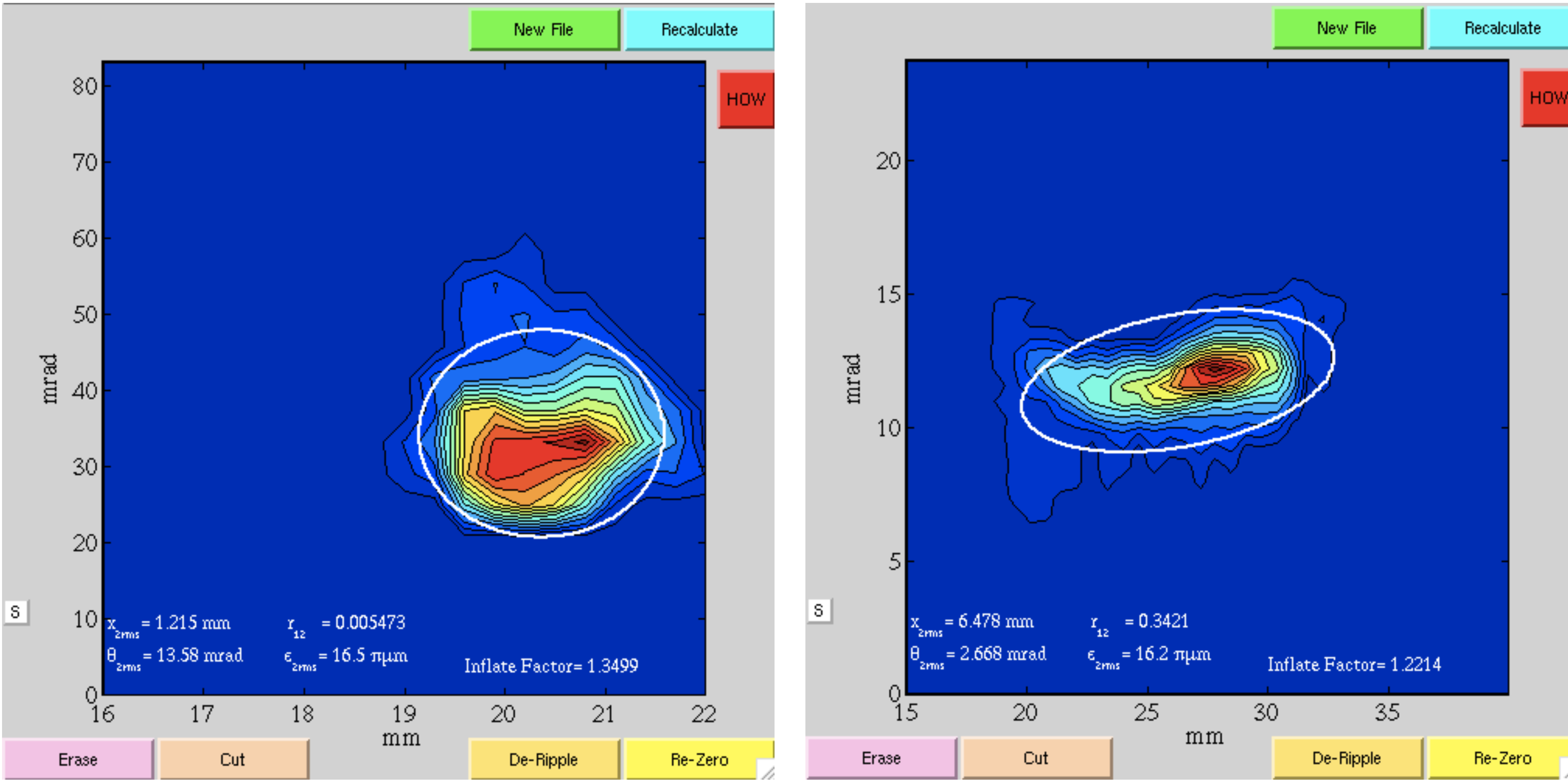
Mass Separator object point

FEBIAD run#2

- **ISOLDE SC ^{19}Ne ~ 3e7/s MgO target**



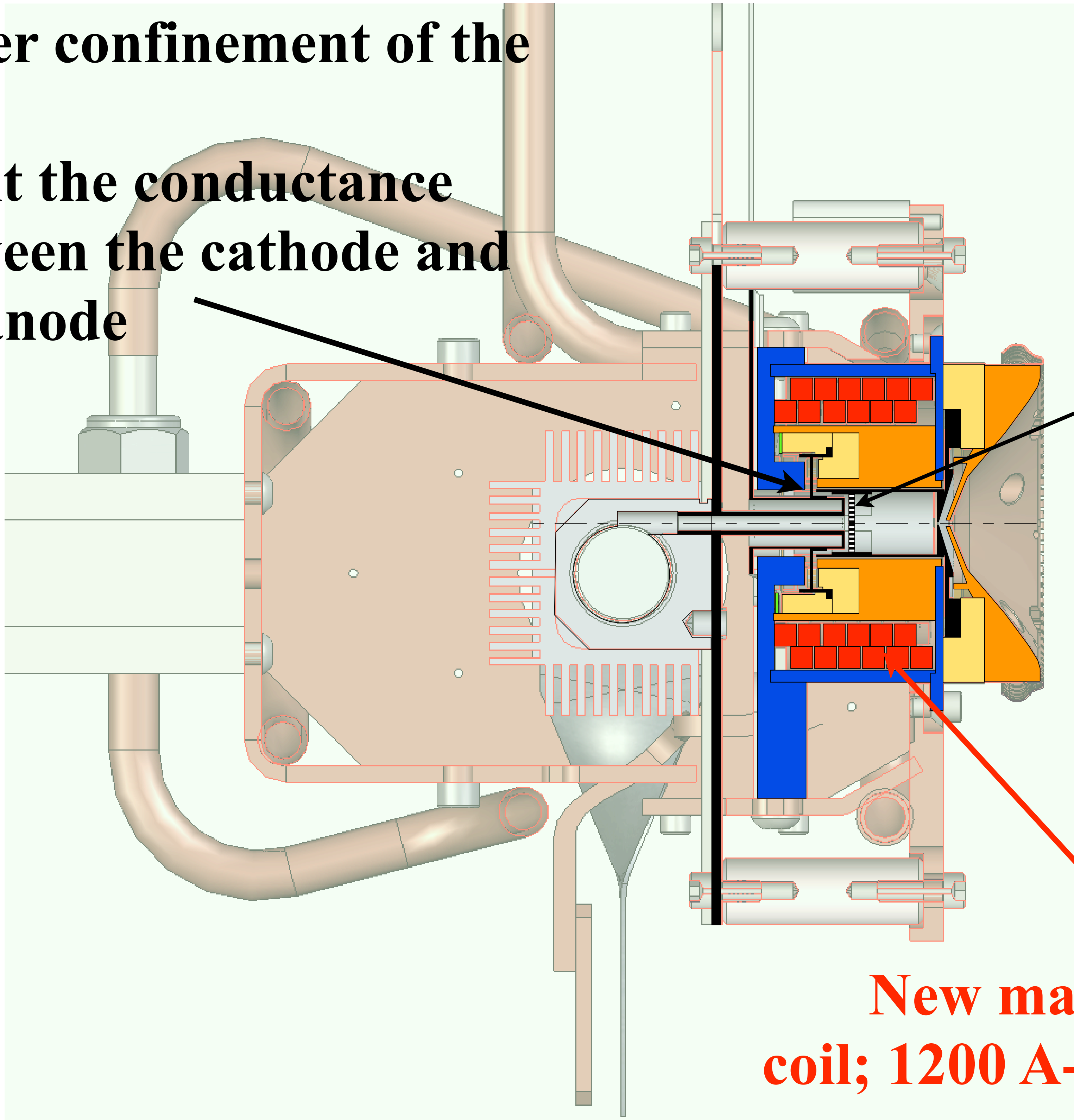
Measured H & V Emittances



$$\varepsilon_{V,H} = 16\ \pi\ \mu m$$

FEBIAD-Mk-XI

- **Better confinement of the gas.**
- **Limit the conductance between the cathode and the anode**



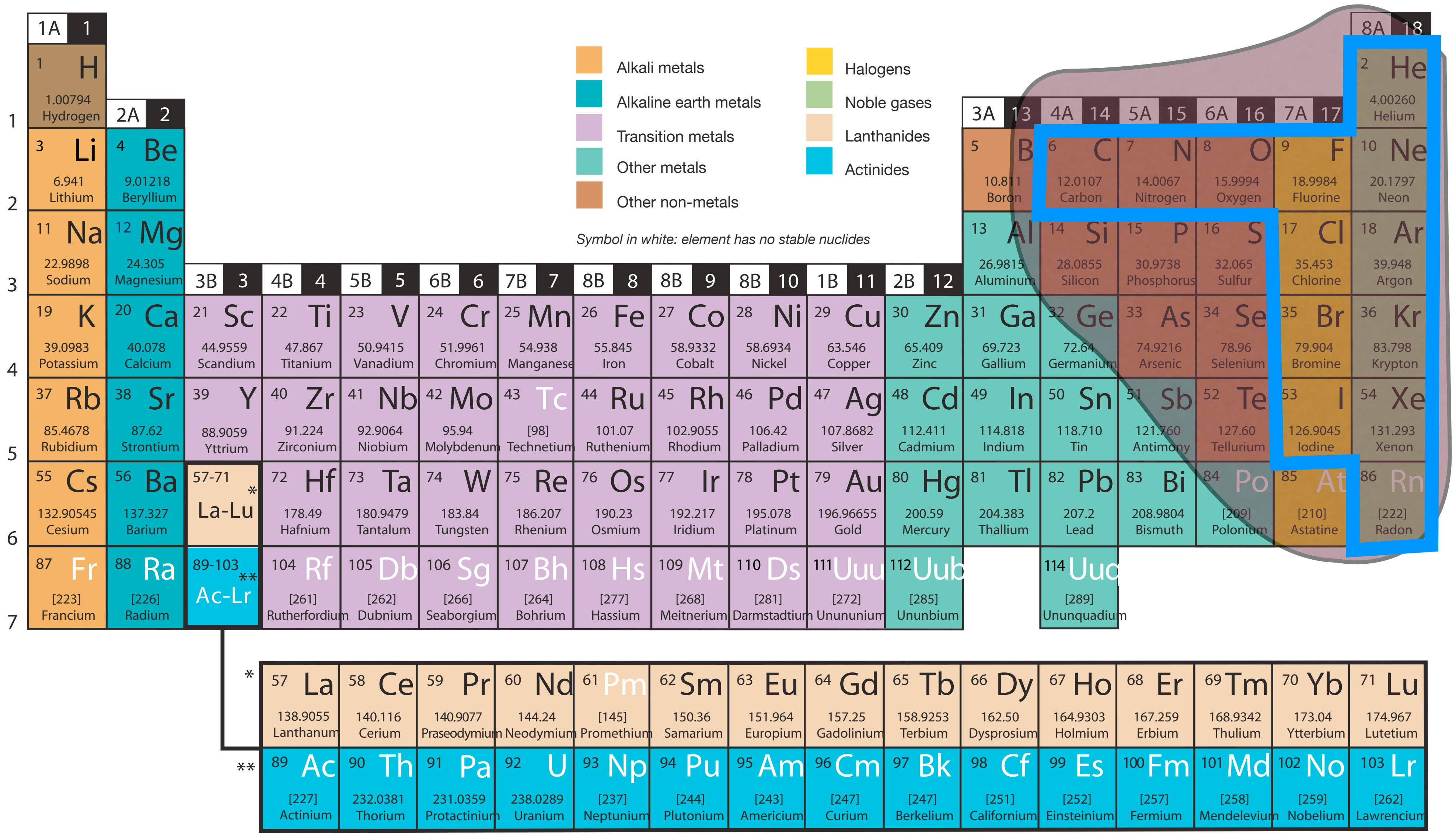
New grid

12,7 mm diameter Ta, 1 mm thick

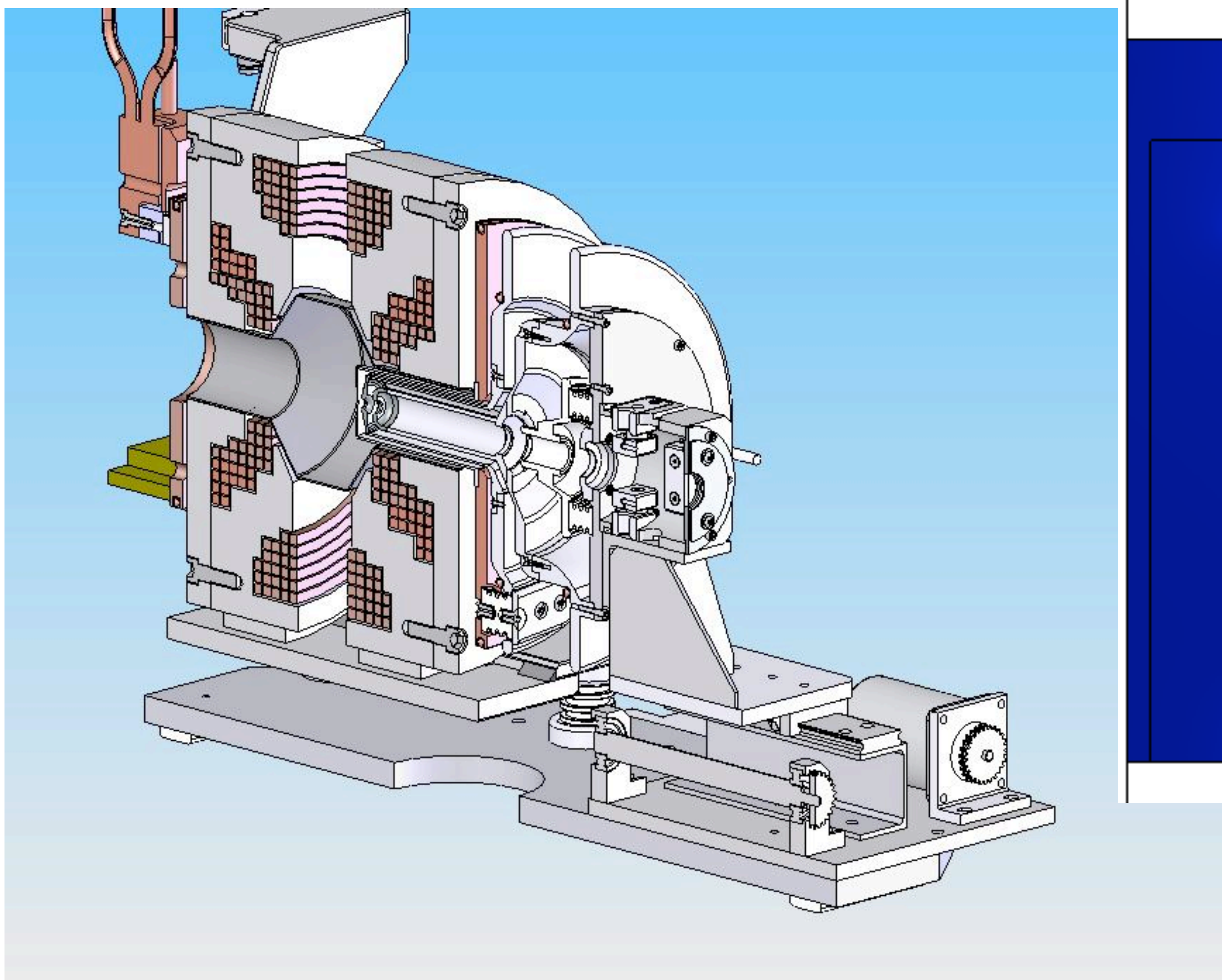
New magnetic coil; 1200 A-t=> 500 G

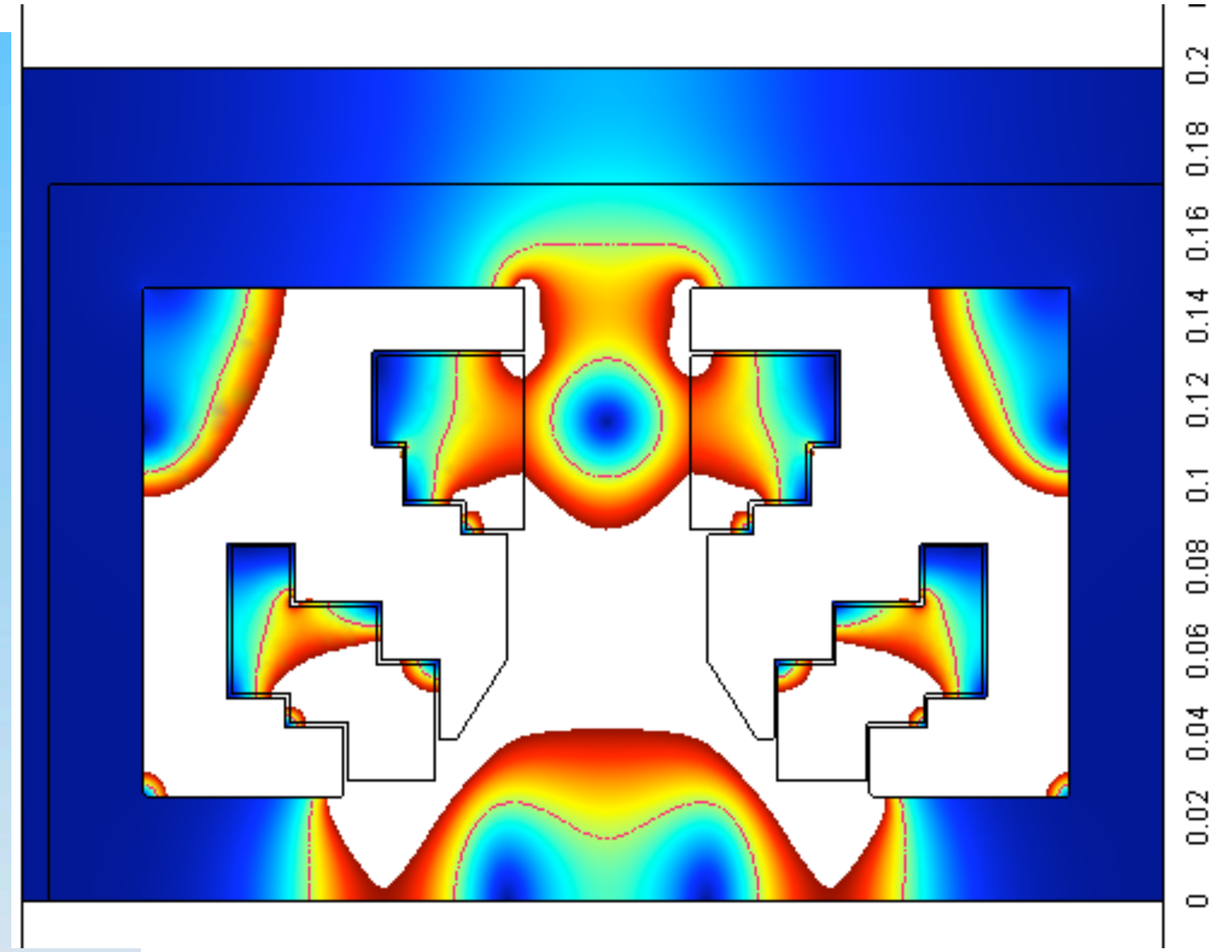
RIB Development

Electron Cyclotron Resonance Ion Source



New ECR Ion Source





- **MISTIC new ECR ion source, Collaboration between GANIL and TRIUMF,**
- **ECR with longitudinal and radial magnetic confinement.**
- **Operates at 3 - 6 GHz,** **N. Lecesne, P. Bricault-TRI-DN-05-23.**

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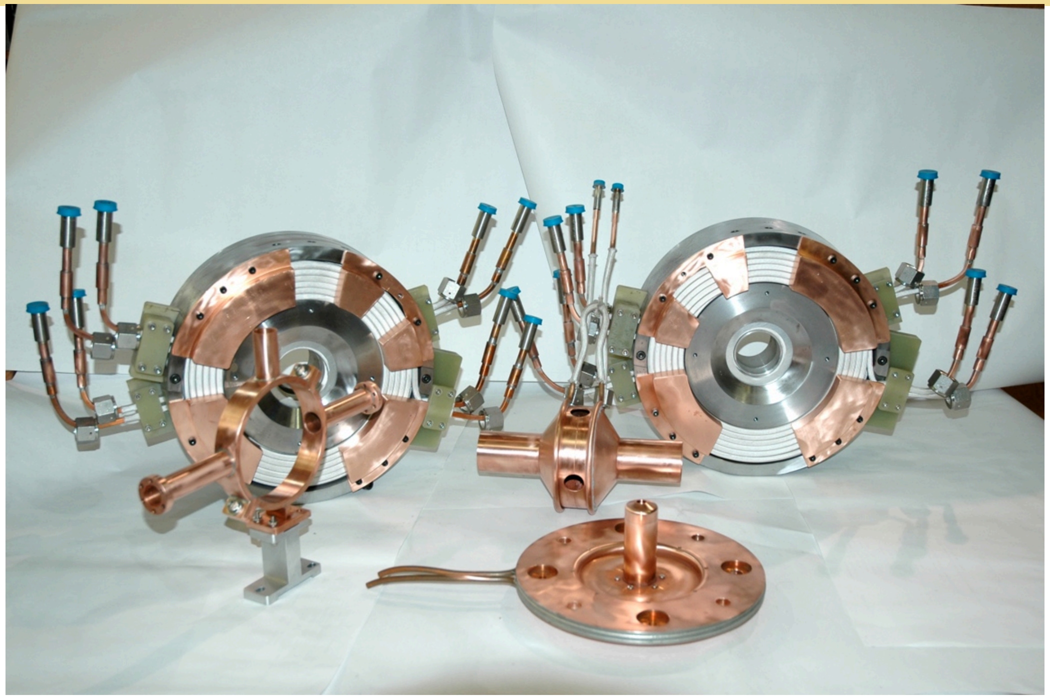
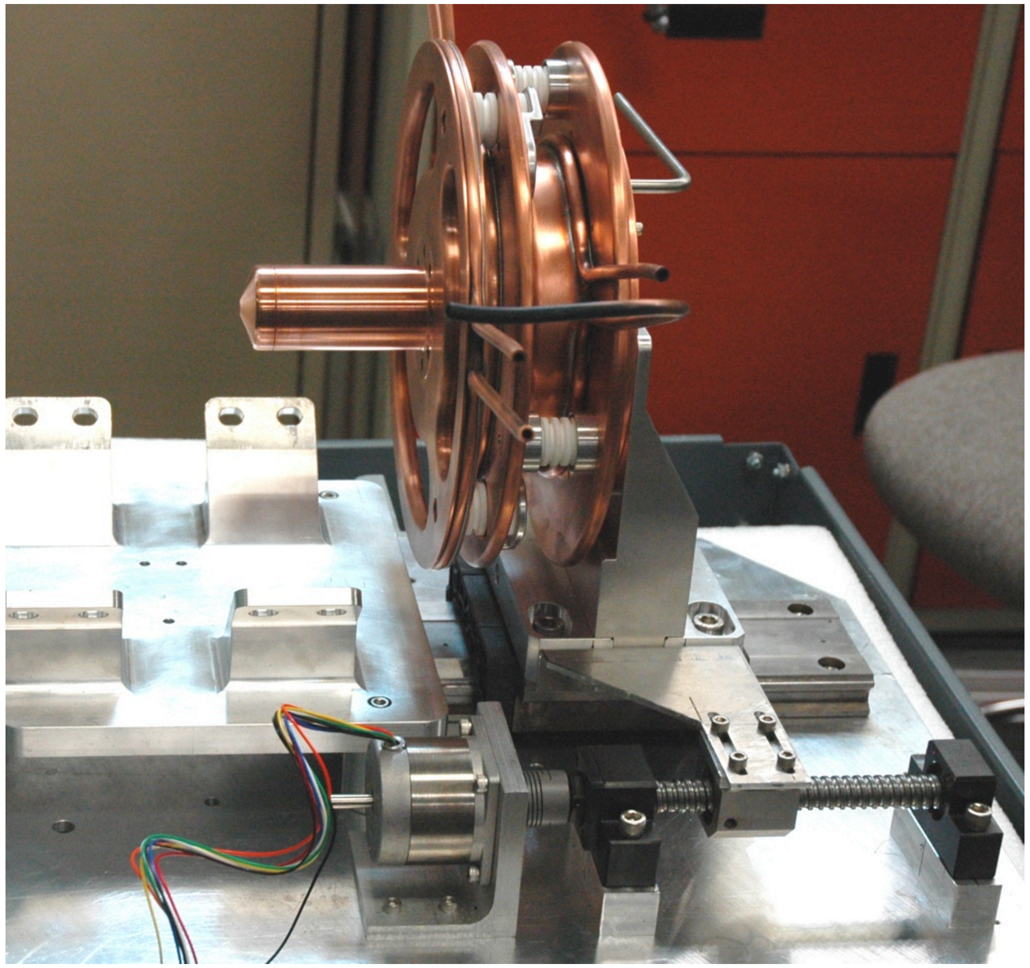
MISTIC



MISTIC fabrication is completed

Quartz plasma chamber

Ion source equipped with a movable 2 gap extraction electrodes



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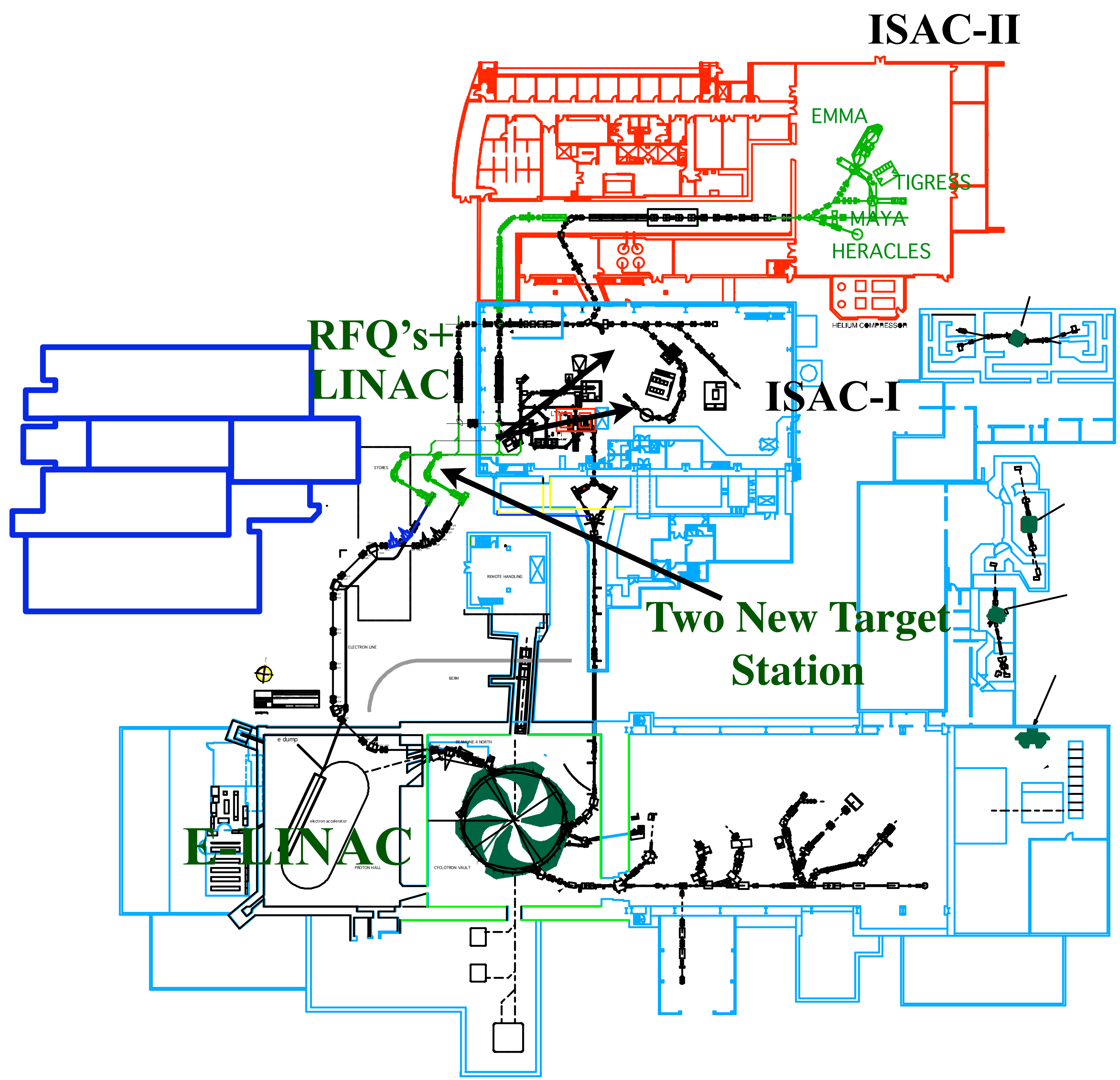
Future plans

- Presently 1/4 of the ISAC beam time is devoted to T/IS Dev.
- Request for beam time for approved High priority experiments > 4 years
- Use of BL4 can provide up to 200 μA proton at 450 MeV,
  - Two new target stations will allow;
    - RIB development,
    - Simultaneous RIB to two or three experiments simultaneously



Summary

- ISAC High Power target operates at 100 μA level, => BL2A A/C steerer: October 2007.
- Composite carbide targets (SiC, TiC and ZrC) operate up to 70 μA routinely.

Target	Target composition	Target Thickness	I_{Proton} μA	RIB
Ta #14 HP	Ta foils	21,8 g/cm^2	70	^{38m}K
Ta #15	Ta foils	21,8 g/cm^2	35	^{8}Li
Ta #16 HP	Ta foils	21,8 g/cm^2	100	^{9,11}Li, $^{51\text{-}53}$K
Ta #17	Ta foils	21,8 g/cm^2	35	^{8}Li, ^{156}Ho, ^{160}Lu
SiC #13 HP	SiC/C_{gr} foils	28 g/cm^2	65	^{8,9}Li, ^{20,21}Na
Ta #18	Ta foils	21,8 g/cm^2	35	^{8}Li, ^{11}Li
TiC #2 HP	TiC/C_{gr}	24,1 g/cm^2	70	^{34}Ar

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Summary

- Since 1998, the vast majority of the Radioactive Ion Beams has been produces using a hot surface ion source.
- A large program to equip the TRIUMF-ISAC RIB facility with ion sources that can efficiently ionize nearly all elements is underway
  - Resonant Laser Ion Source is quite advanced,
    - New generation of Ti:Sa solid state lasers.
  - FEBIAD ion source is being developed on-line. New design will incorporate a new radiation hard coil.
  - ECR (MISTIC) prototype is ready for tests,
    - Goal is to finalize the tests for next spring and start specifications for a new target module. On-line tests end 2009.
- Future 5-year plan to equip ISAC facility with new target stations to allow 2 to 3 simultaneous RIB to experiments.

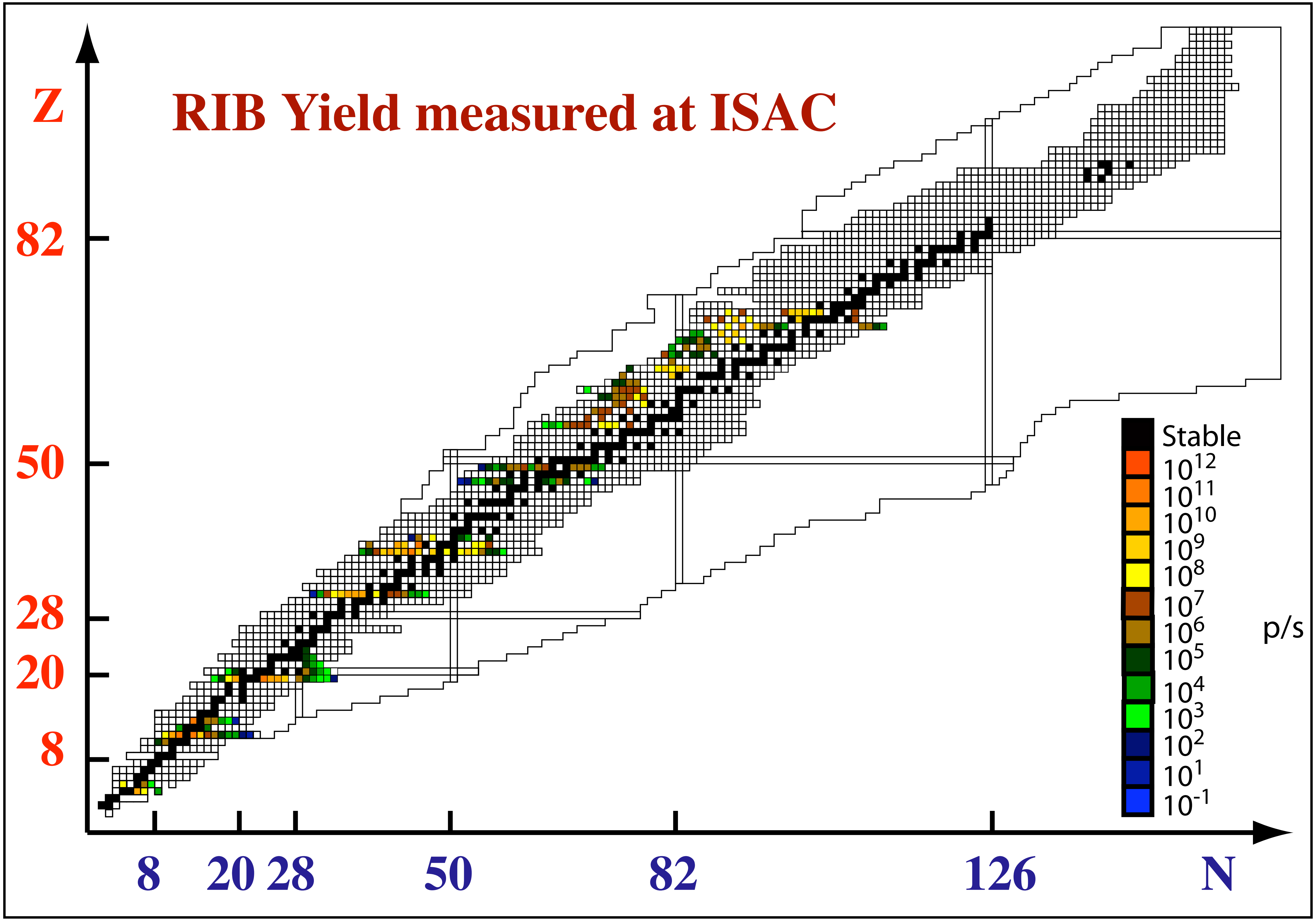
Thank you.

New RIB at ISAC

Target	Ion Source	Proton intensity (μA)	New RIB
Ta#15	TRILIS	35	$^{9-12}$Be and $^{104-114,116-119}$In
Ta#17HPT	TRILIS	65	^{84,86,87,89,90}Y and $^{99-113,116-117}$Ag
TiC#2HPT, SiC#14HPT	FEBIAD	70	^{6,8}He
TiC#2HPT	FEBIAD	70	^{19,20}O
TiC#2HPT, SiC#14HPT	FEBIAD	70	$^{17-19,23-25}$Ne
TiC#2HPT	FEBIAD	70	$^{27-29}$Mg
TiC#2HPT	FEBIAD	70	$^{32,34,38-45}$Cl
TiC#2HPT	FEBIAD	70	$^{33-35,41-45}$Ar
SiC#14HPT	FEBIAD	70	^{23}Mg
SiC#14HPT	FEBIAD	70	$^{17-18}$F

http://www.triumf.info/facility/research_fac/yield.php

ISAC RIB


RIB Yield measured at ISAC
Z
82
50
28
20
8
8
20
28
50
82
126
N
Stable
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^-1
p/s

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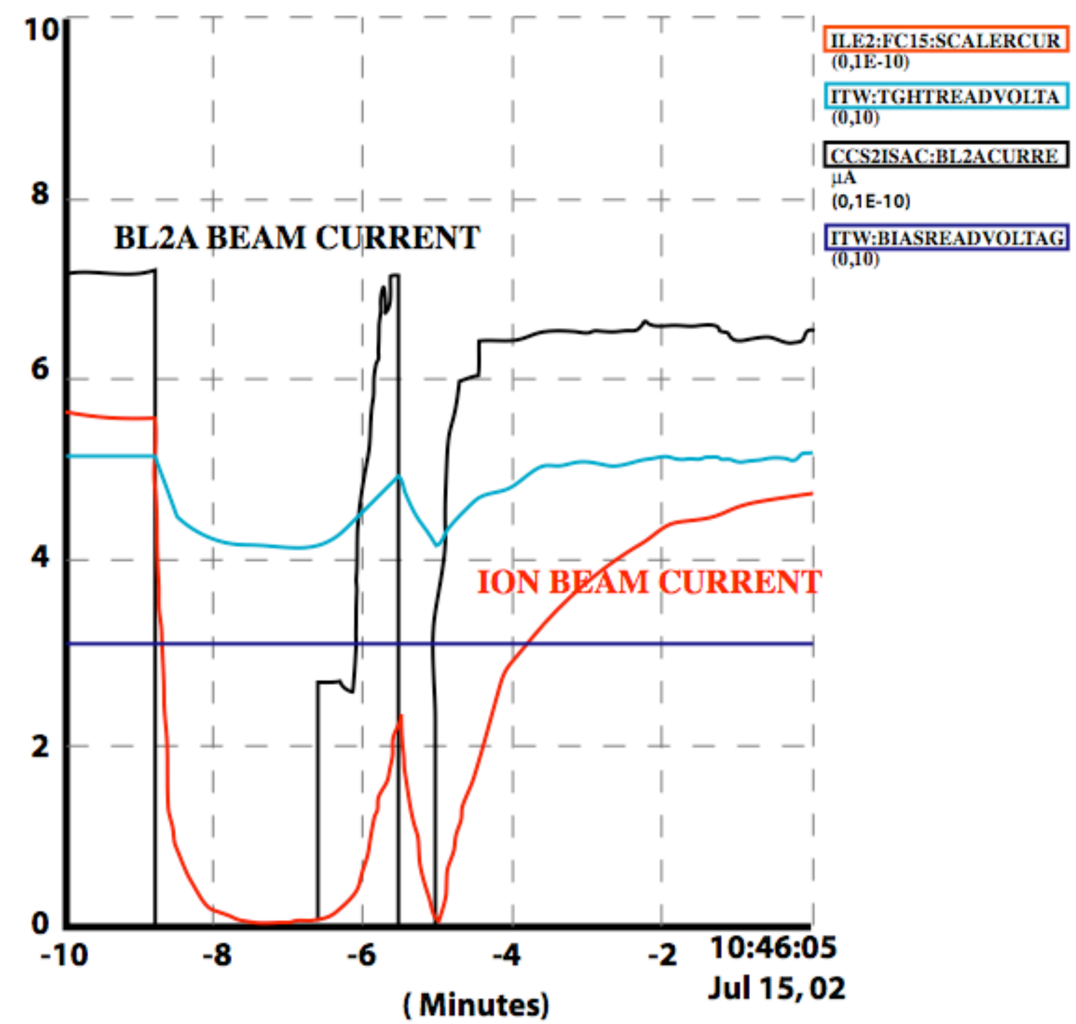
Cyclotron Stability

- Above 20 μA we are relying on the proton beam to heat the target,
- When the proton beam goes off the target cooling occurs within seconds. It takes several minutes before the target reaches optimum temperature,
- We improved the proton beam stability to avoid disturbance in RIB delivery.



Now we can run for several hours without any beam interruption.