ISAC RIB Production Systems and Target Development

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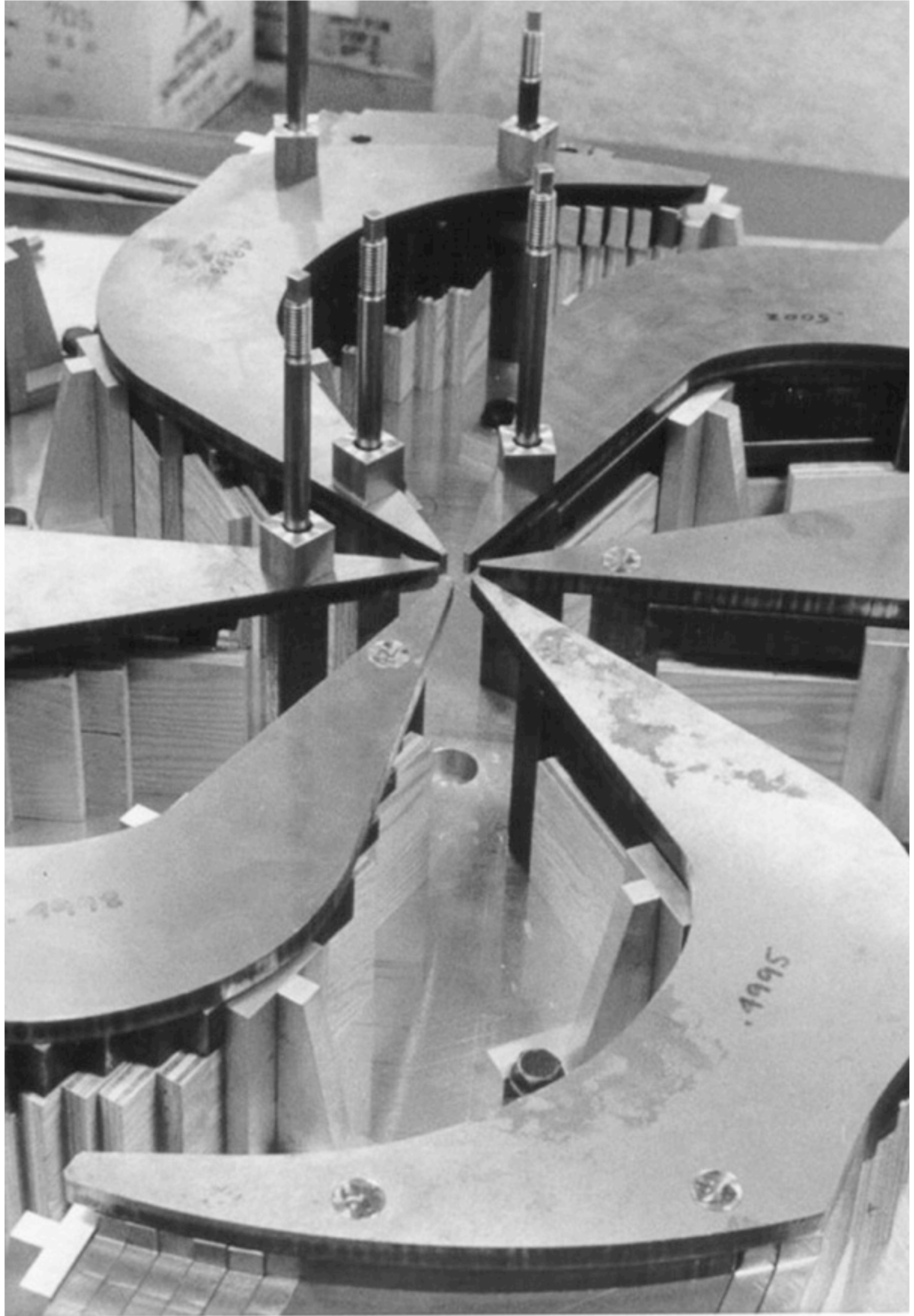
ISAC20
21 August 2019

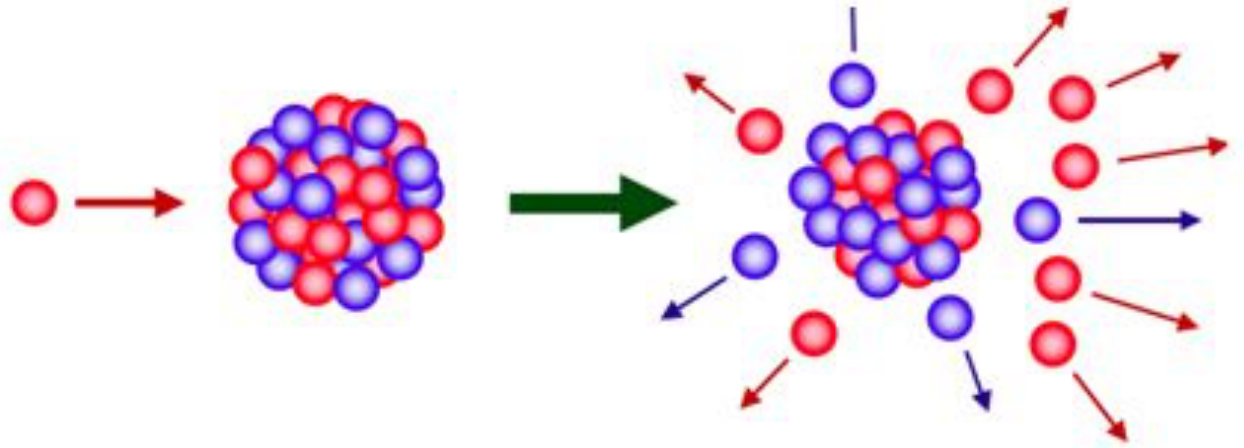


Discovery, accelerated

Techniques for RIB production

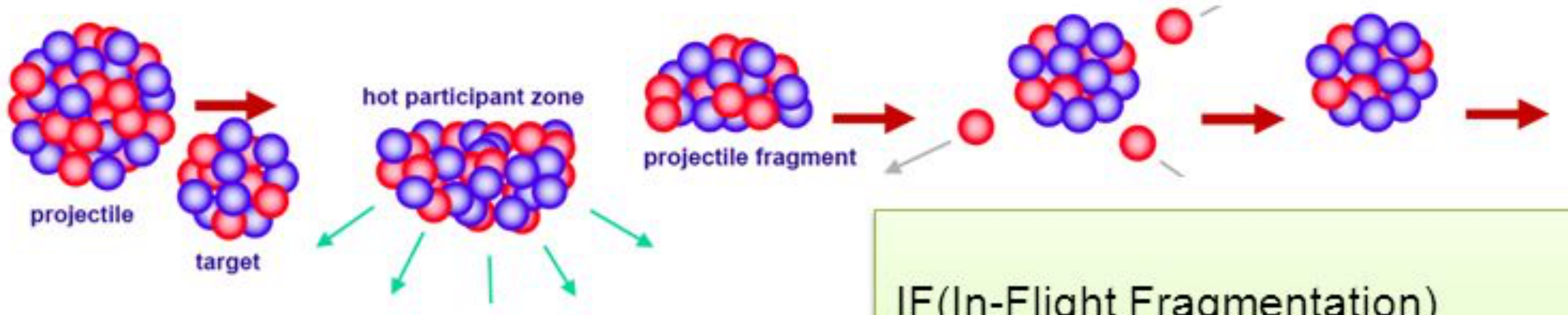
Making Rare Isotope Beam

Target spallation, fission by energetic light projectile



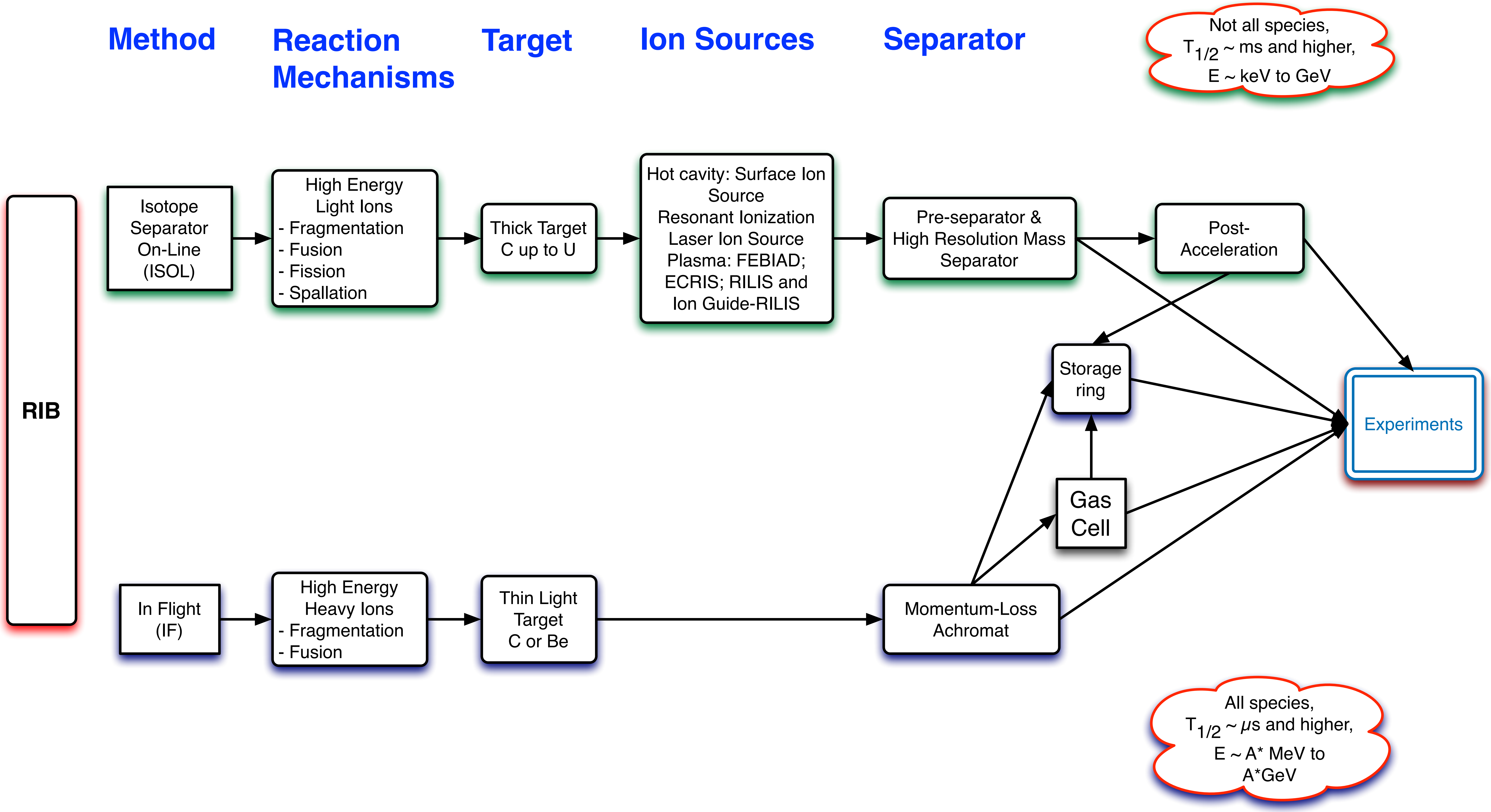
ISOL(Isotope Separator On-Line)
p → thick target (eg. Uranium Carbide)
fission fragments → rare isotopes

Projectile fragmentation

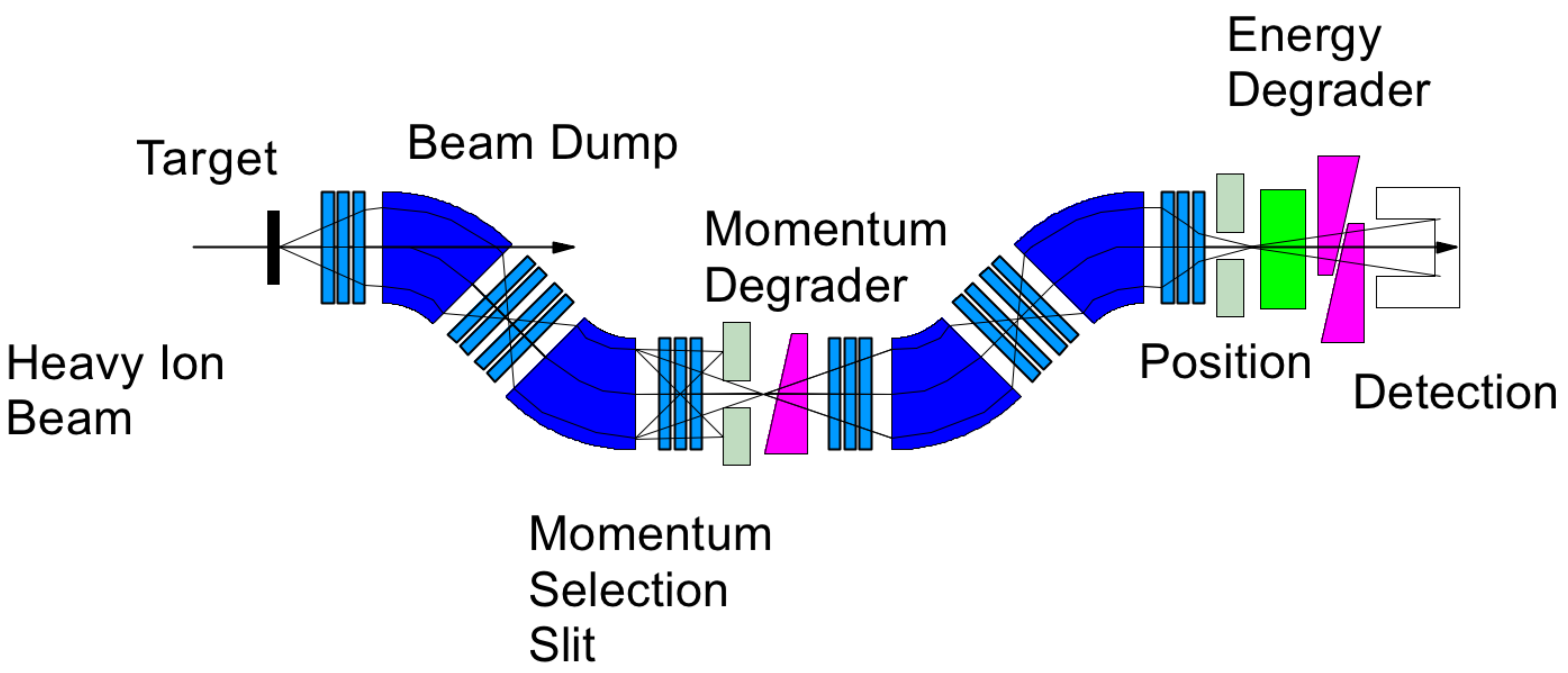


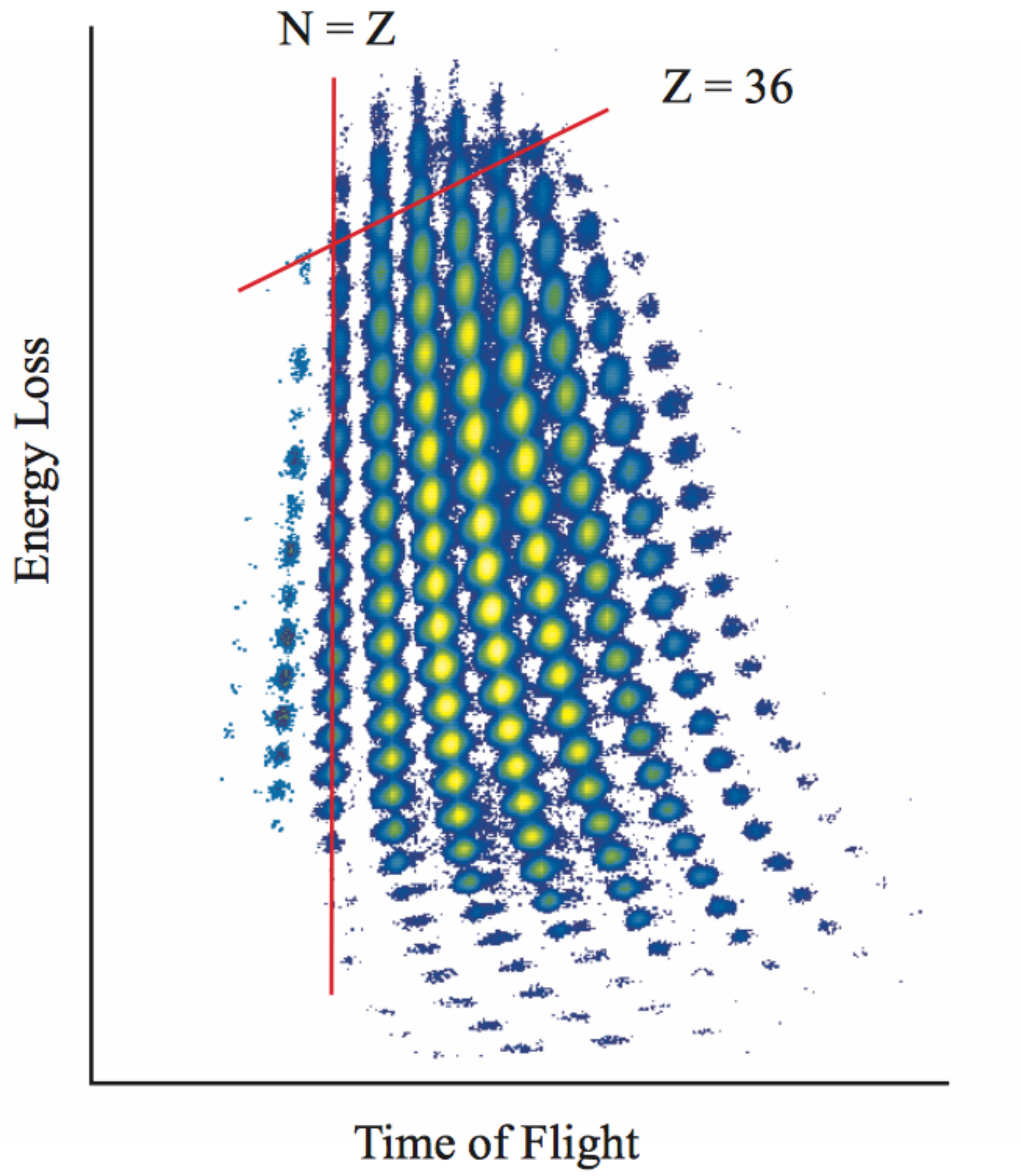
IF(In-Flight Fragmentation)
Heavy ion beam → thin target
projectile fragmentation
→ high energy RI beam or
→ stopping and reacceleration

Techniques for RIB production



Results of In Flight RIB production





ISAC Radioactive Ion Beams Production System

ISAC AND OTHER ISOL FACILITIES IN 1995

- When ISAC was funded in 1995 there were a few RIB facilities using the light ion beam on thick target
  - ISOLDE - CERN, 800 MeV proton Synchrotron, <2>μA, no post accelerator.
  - HRIBF, Oak-Ridge, USA. Small cyclotron (p, d ...) 40 MeV, <2-4>μA and an electrostatic tandem as post-accelerator.
  - Gatchina, 1GeV proton synchrotron, <1>μA, no post accelerator.
  - ISOCELE, Orsay, France

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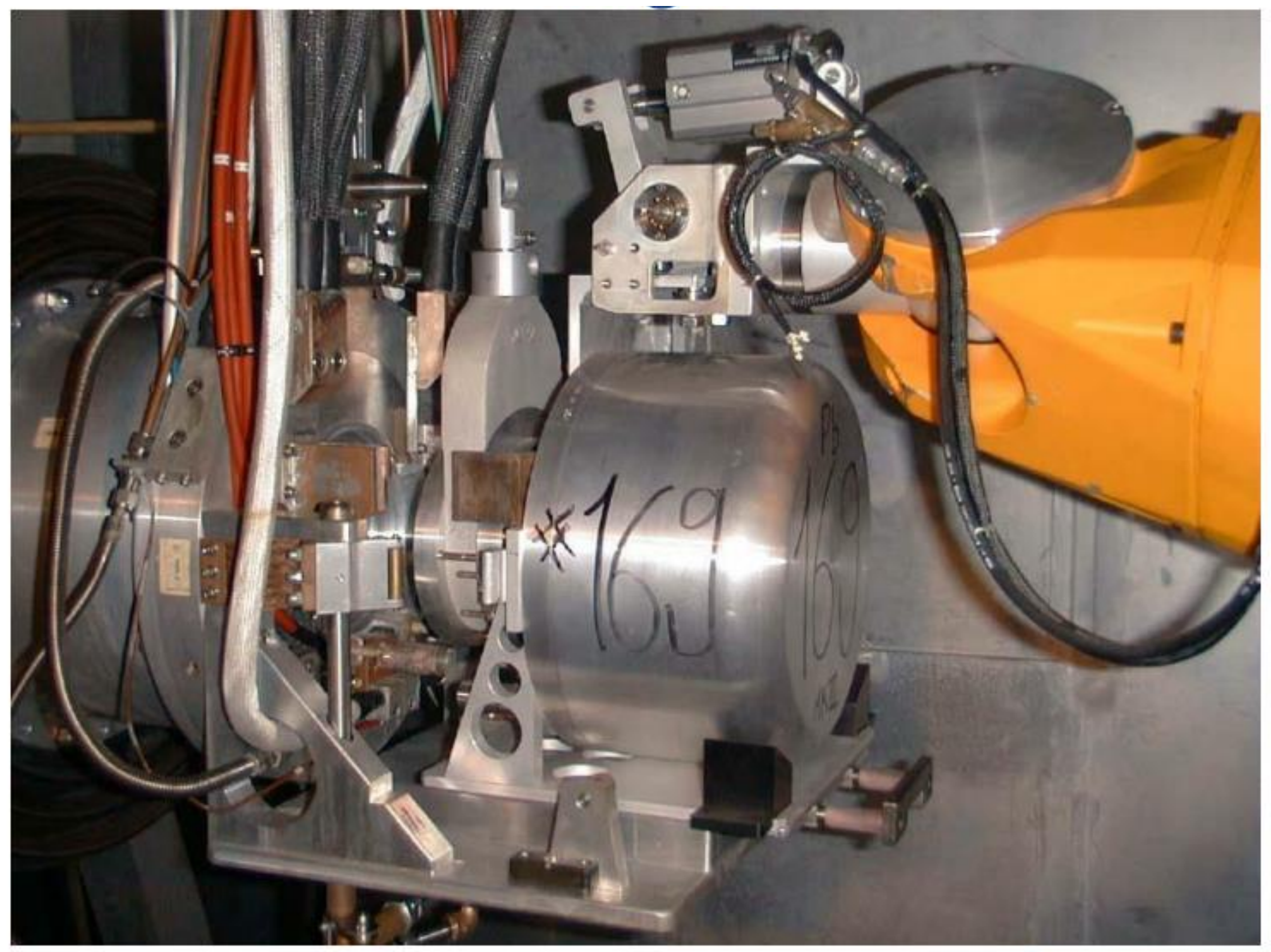
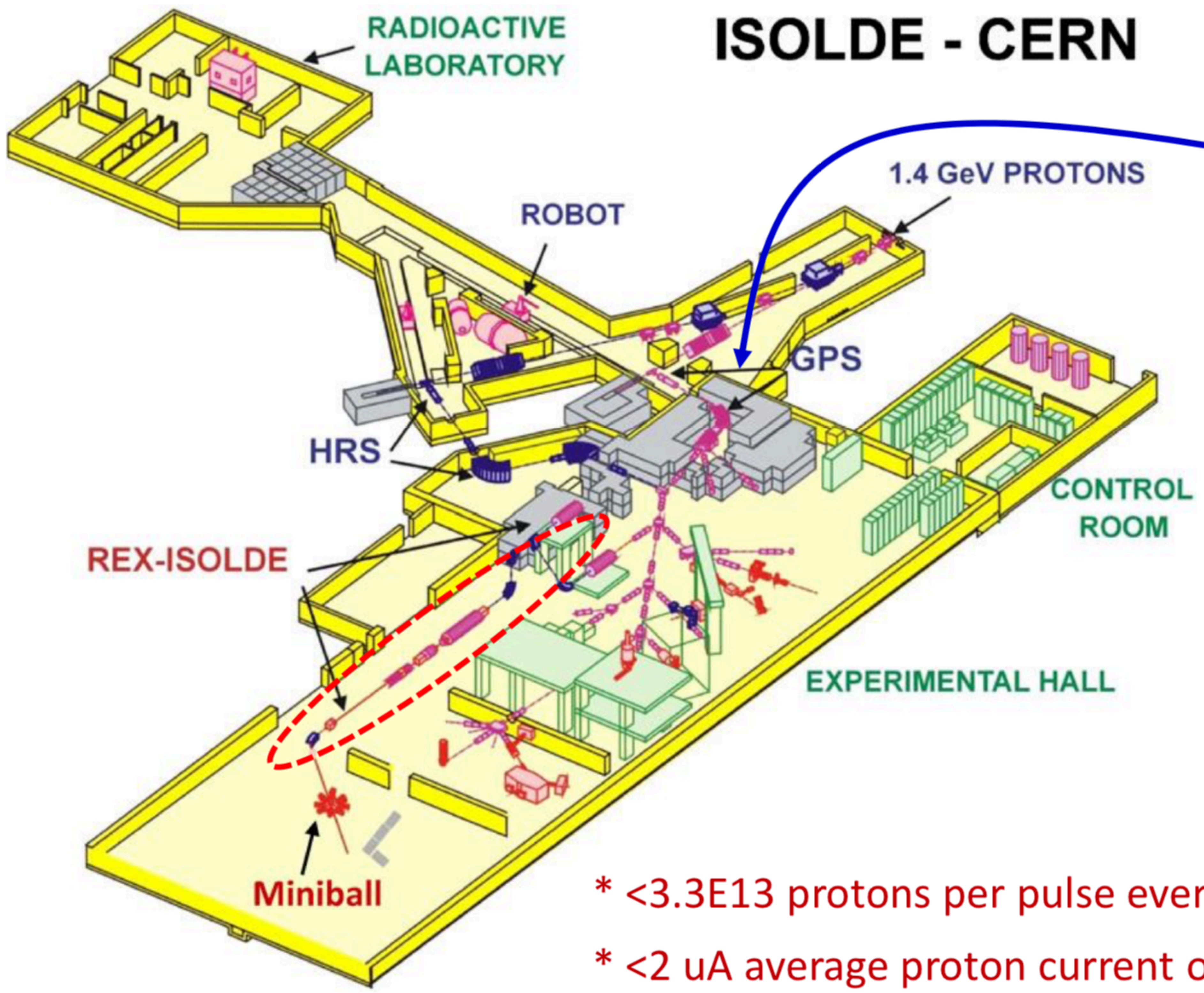
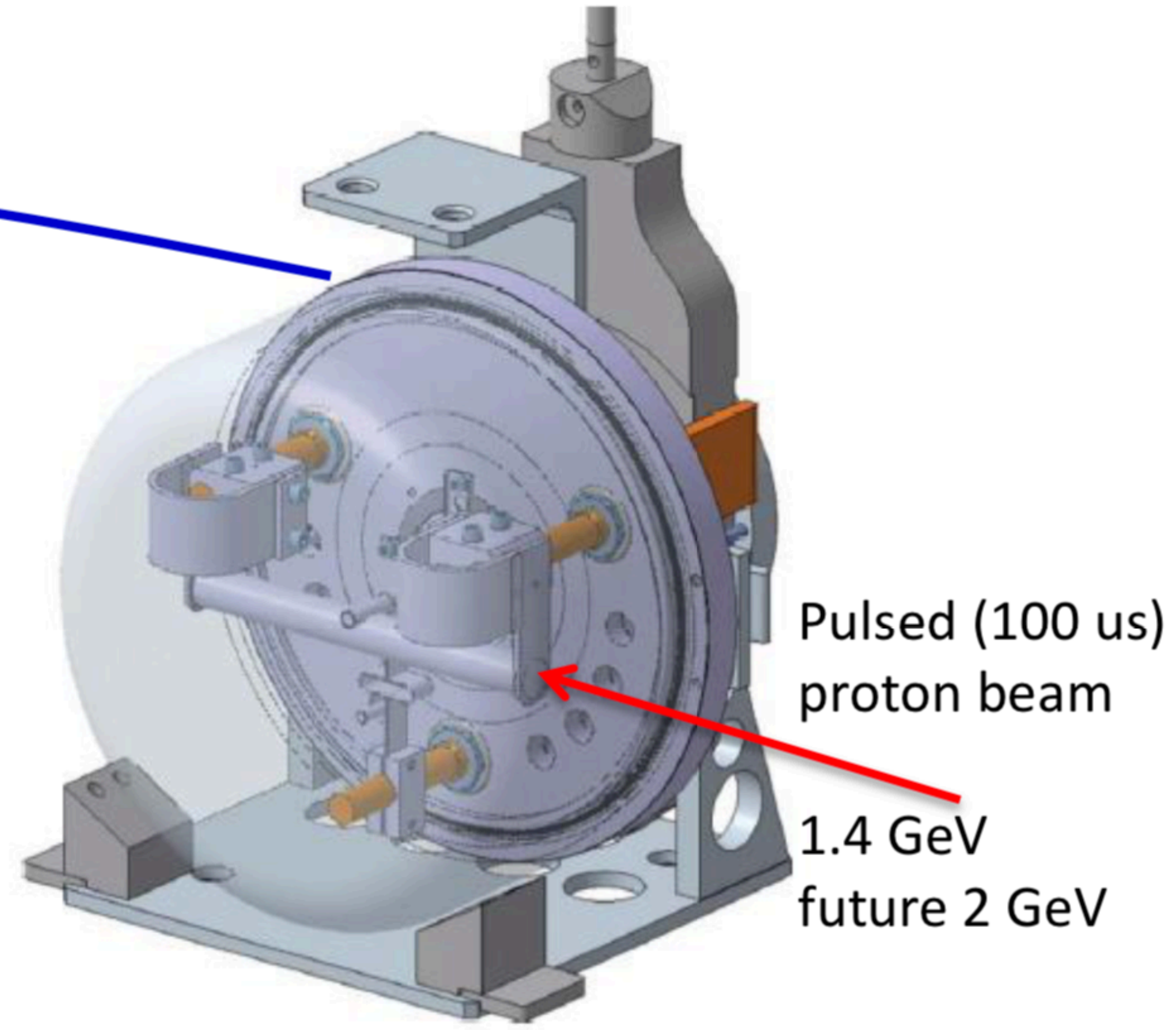
  - ISOCELE, Orsay, France
- Most of the ISOL facilities were based on the ISOLDE/CERN design, which began in 1967.



ISOLDE Layout





Standard ISOLDE target unit
(courtesy S. Marzari)

* <3.3E13 protons per pulse every N*1.2 s (N=1,2,3…)
* <2 uA average proton current on the target
* Target material: UCx, SiC, CaO, YO, molten Pb etc
* Material diffusion, effusion and sticking time govern the release time
* Magnetic separator

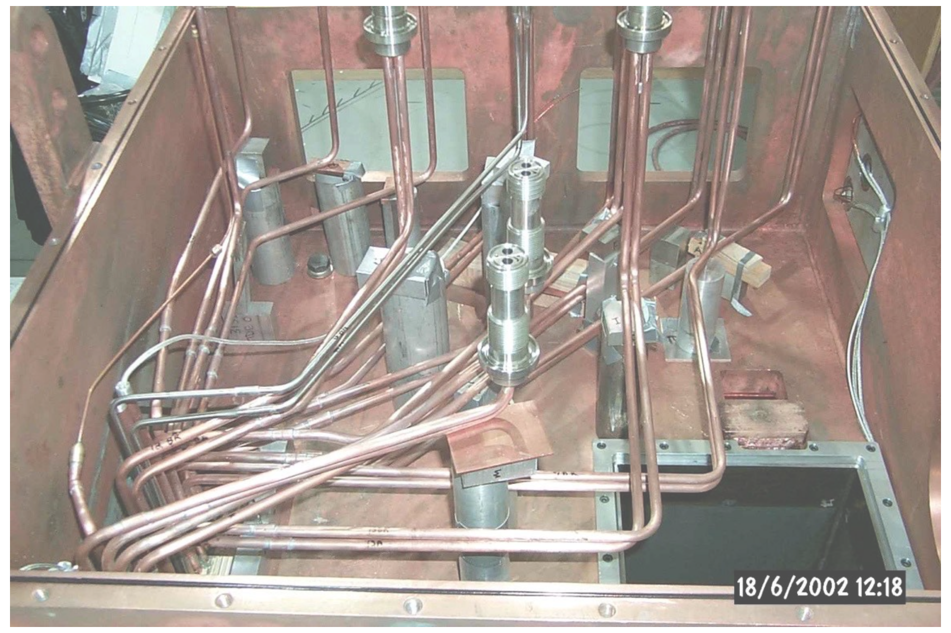
ISAC proposal

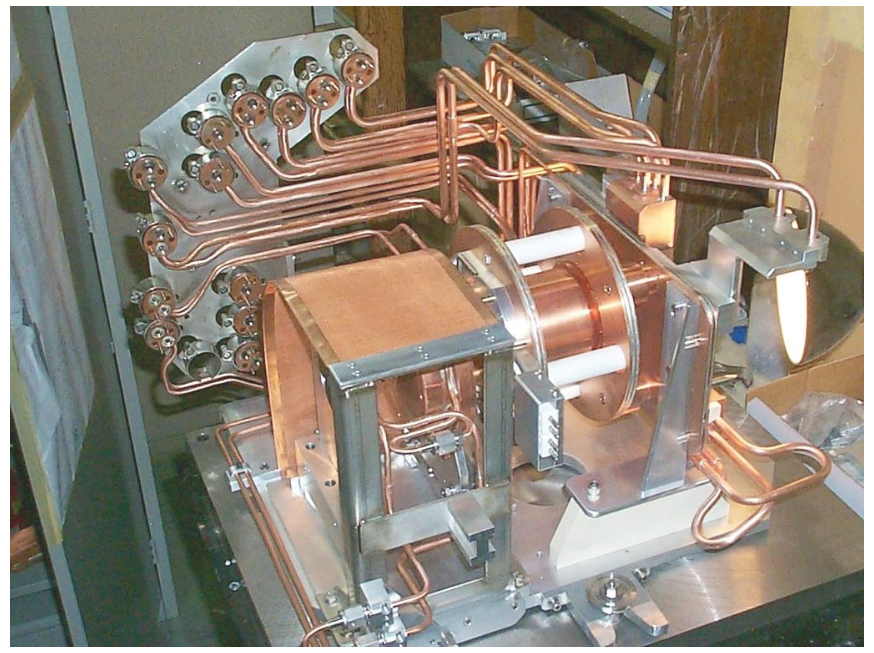
- The ISAC proposal was calling for much higher proton beam intensity on the ISOL target, 100-μA instead of the usual 2 μA average at most of the ISOL facilities.
- At the time the ISOLDE target technology was based on O-ring to seal the target box and the vacuum seal on the front-end beam line.
- There were major concerns using ISOLDE technology for high intensity driver (100 μA):
    - The longevity of the ISOLDE target vacuum seals at higher radiation dose rate.
    - Maintenance of the vacuum pumps in close proximity of the RIB production target.
    - Maintenance of the front-end beam line.

ISAC - meson facility (T1 and T2)

- At TRIUMF like most of the meson facilities, targets were routinely operated at 120 μA or more.
- The production targets are usually placed at the bottom of a shield plug that is inserted vertically into the driver beam line.
- Targets are thin enough to let most of the proton beam passes through.
- ISAC RIB production system has been based on these aspects:
  - Target will be placed at the end of a shield plug, horizontally in the first design and then vertically.
  - The optics front-end will also be installed at the end of a shield plug for ease of maintenance.
  - Diagnostics at the entrance of the target were then added on another shield plug and finally, a beam dump module has been added.

Target Station design

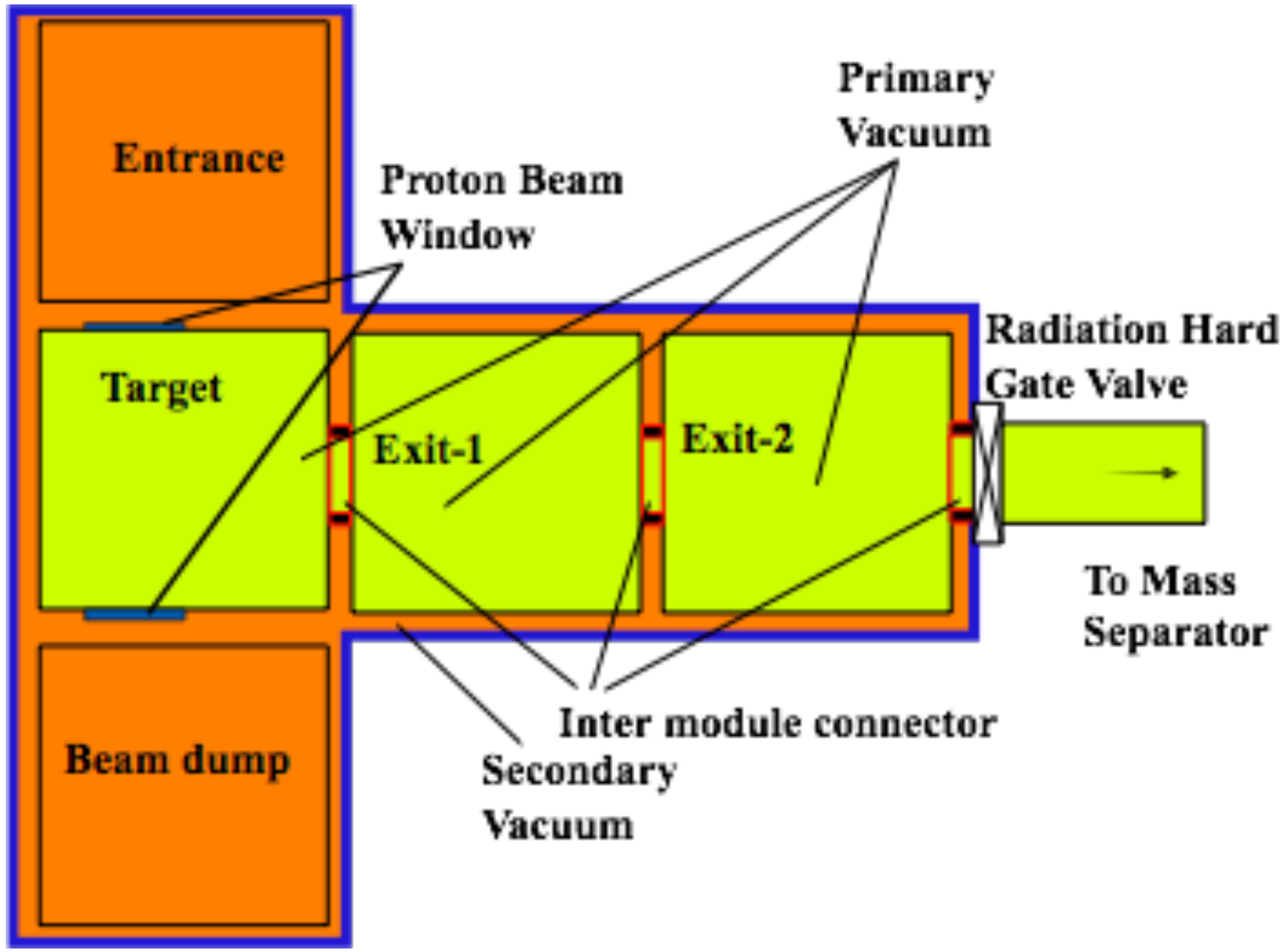




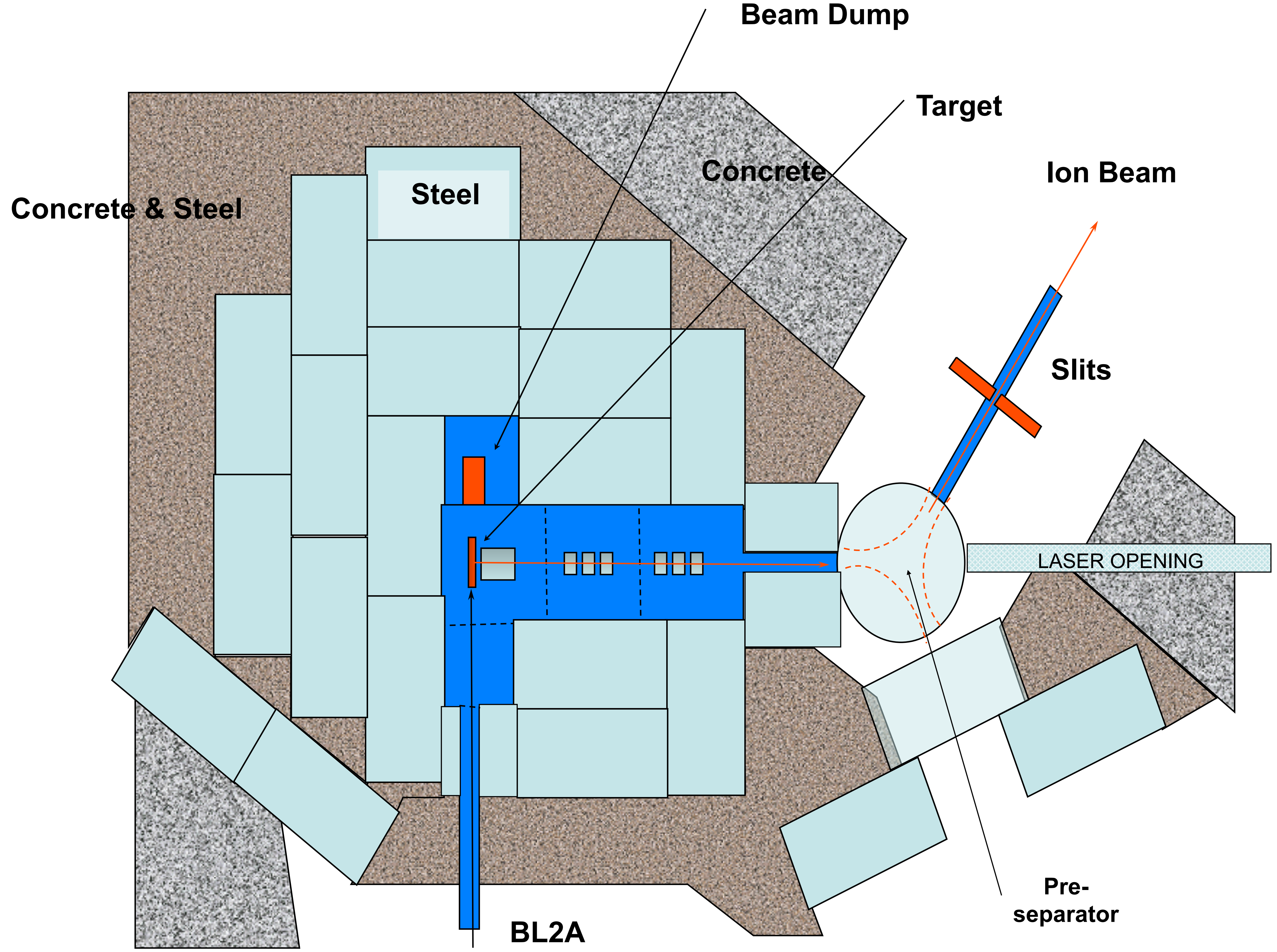
- Contrary to meson production targets which are sealed, the ISAC target has to be connected to an Ion Source without any ‘*window*’.
- This was a major concern for the Radiation Safety officier at the time and it drives the design of the target station and the target hall.
- The target station(s) to be housed in a seal target hall equipped with nuclear ventilation.
- All modules to be inserted into a T-shaped vacuum box.
- The production target and the electrostatic optics to be inserted into ‘*containment-boxes*’. This envelope defined the primary vacuum volume.
- Metal seals between the target module and the exit-modules to seal the primary vacuum from the secondary vacuum.

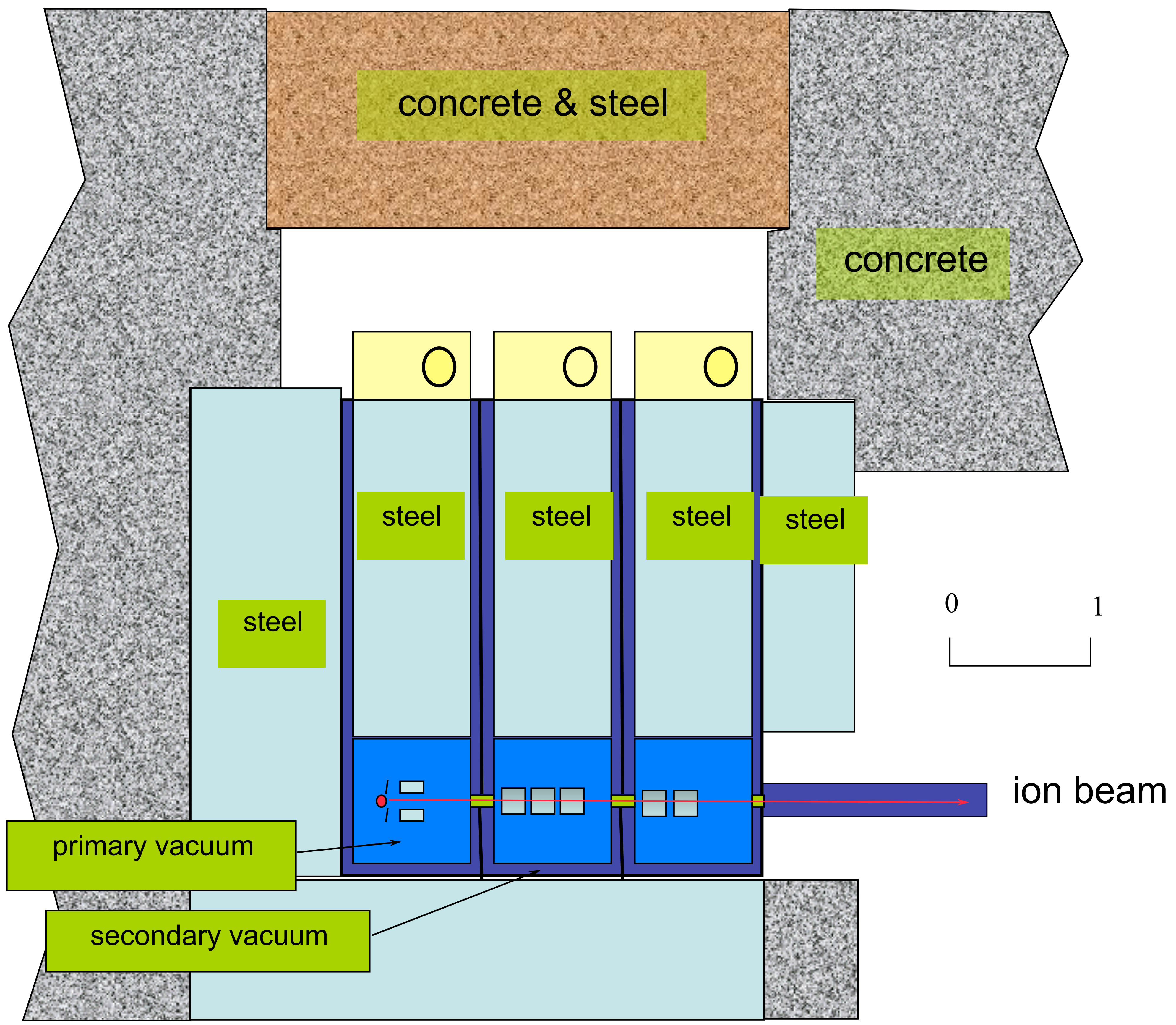
ISAC target station vacuum

- ISAC target station utilizes two vacuum envelopes:
  - Primary vacuum, target box, RIB beam line,
  - Secondary vacuum, Entrance module and Modules external vacuum volumes.
- Differential pumping to mitigate the propagation of contamination.

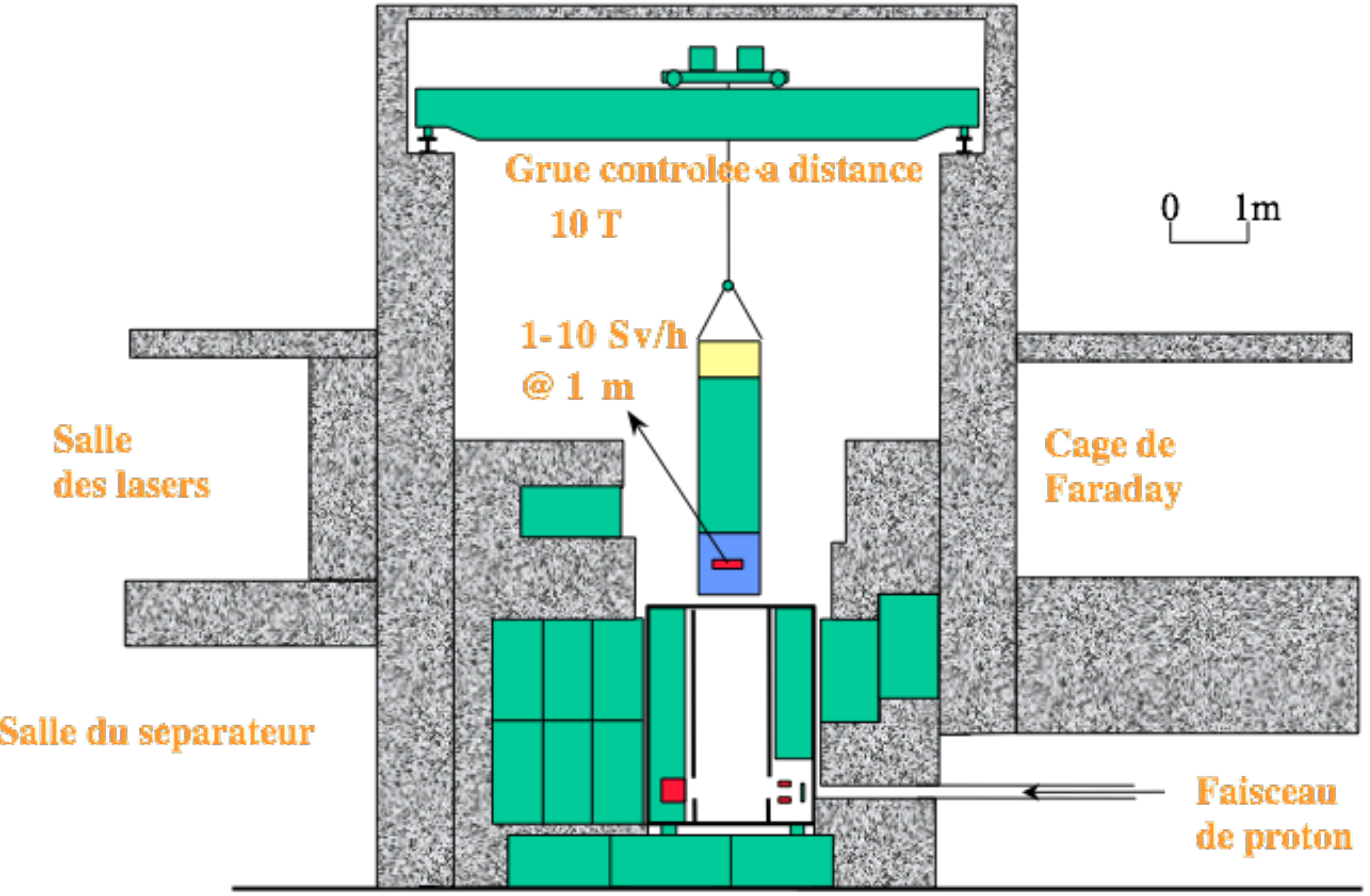


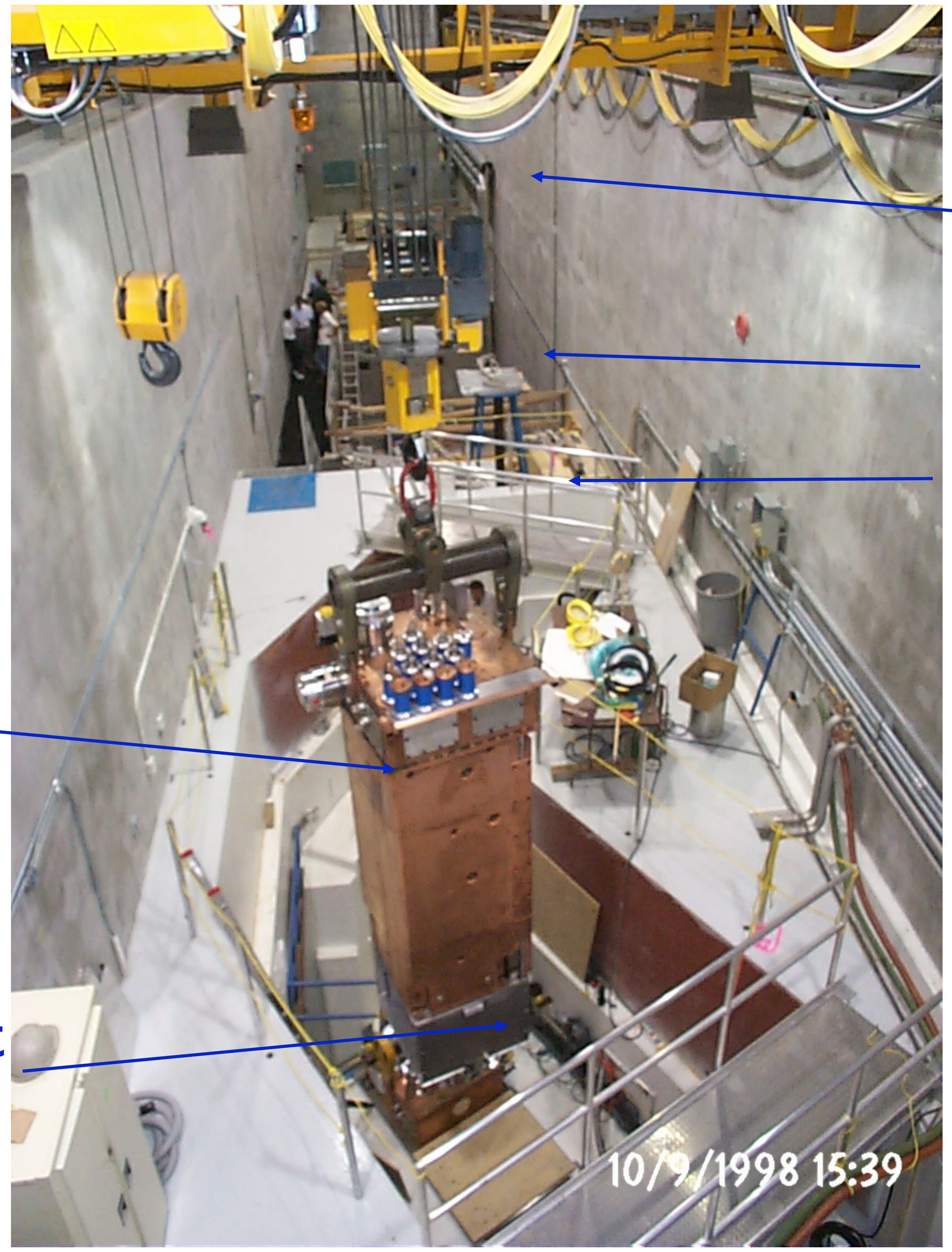
ISAC target station shielding





ISAC target station Operation





Remote
Overhead Crane

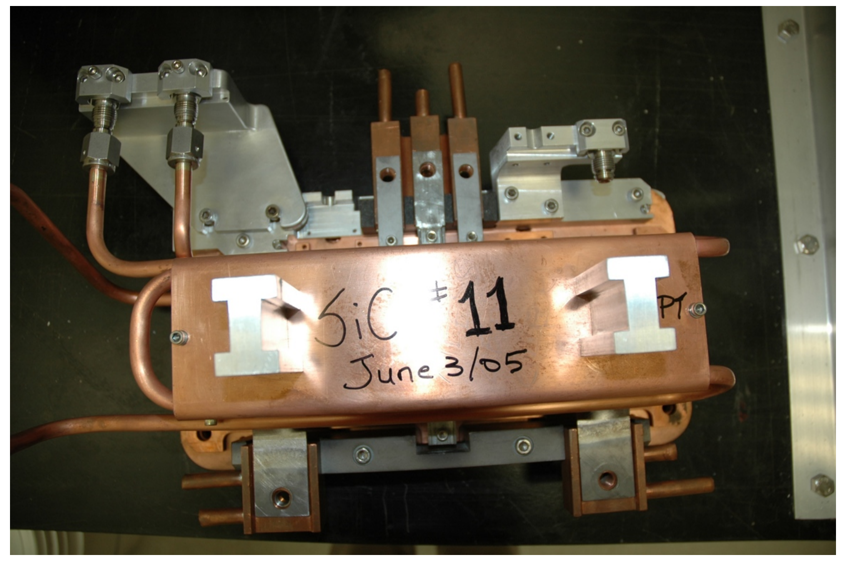
Hot-cells

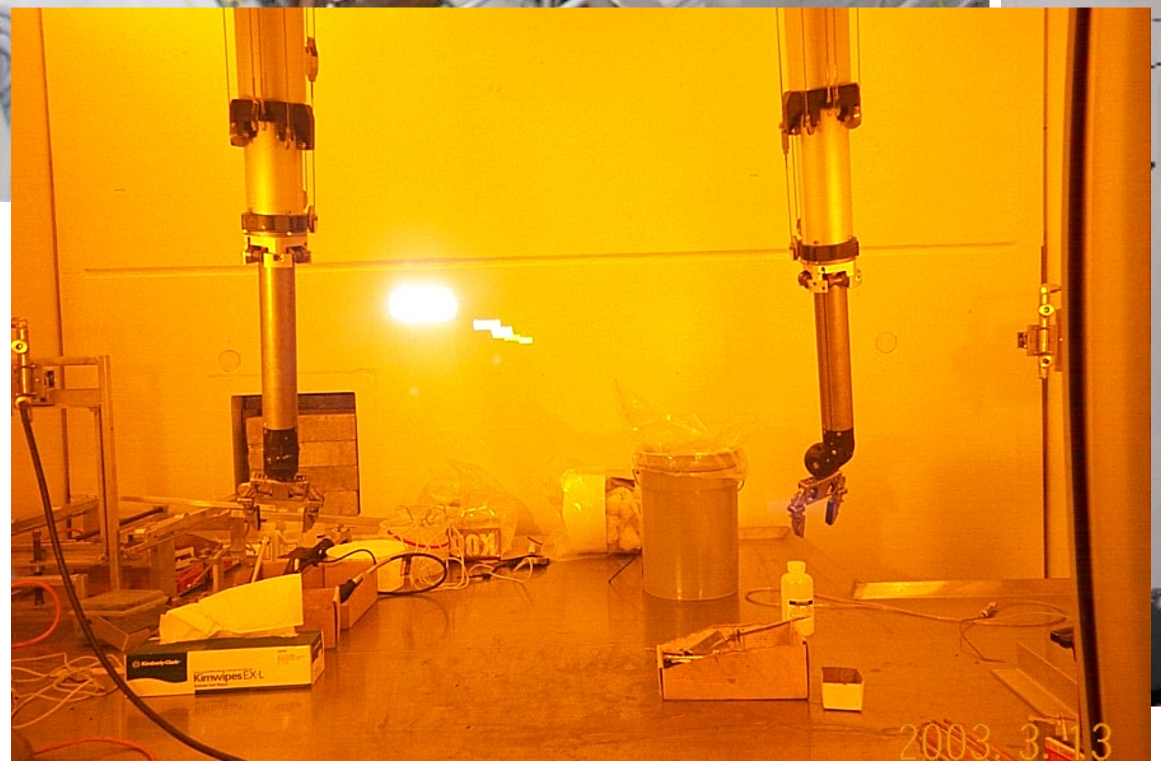
Spent Target
Storage Vault

Target
Module

Target Pit

ISAC target station Operation

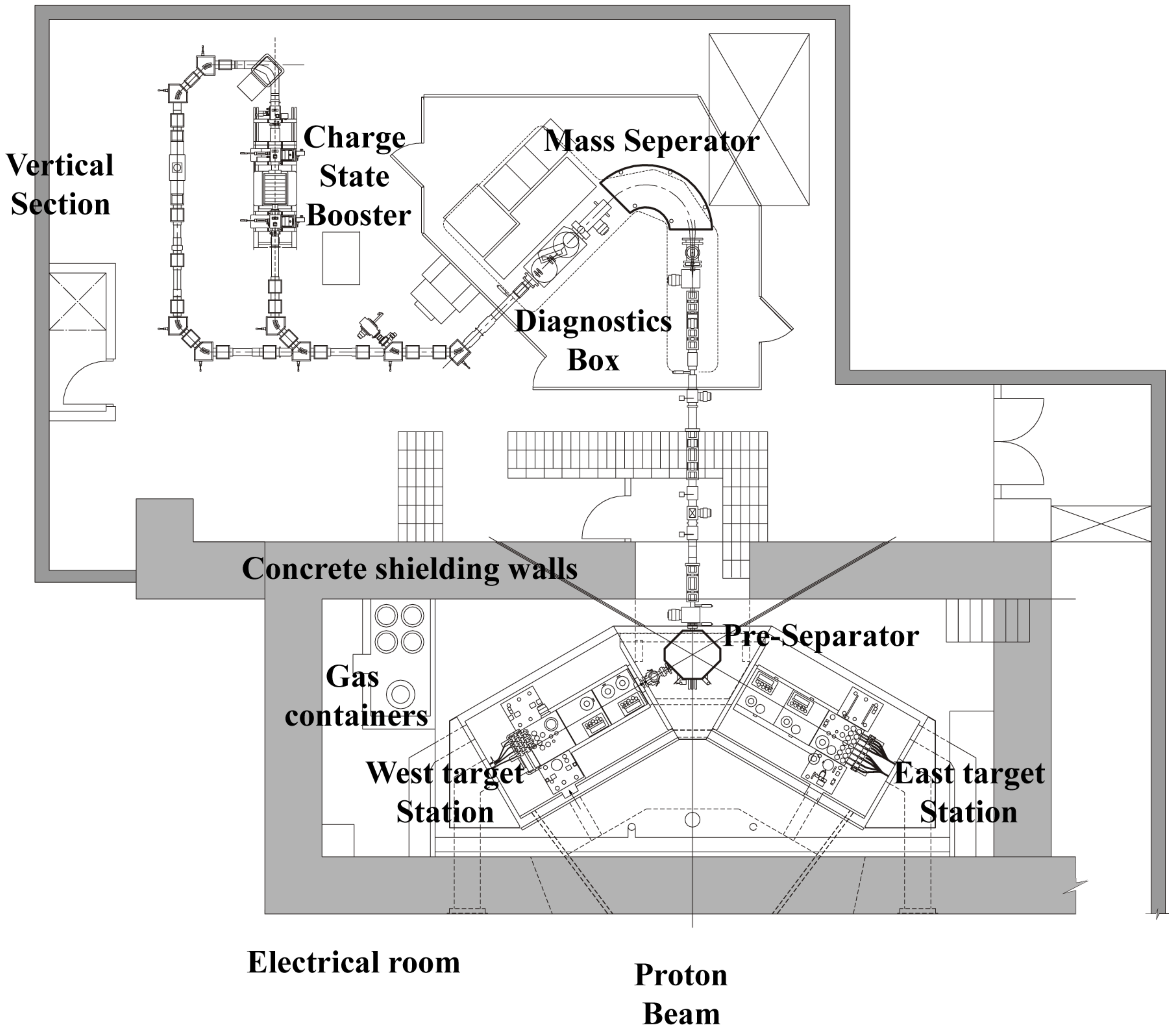




ISAC target station and Mass Separator

- Two target stations and pre-separator are inside the heavily shielded building.
  - The pre-separator filters most of the contamination.
  - Mass separator is on a high voltage platform to reduce potential background from ion-gas collision at extraction.

Plan view of the target stations and the Mass Separator

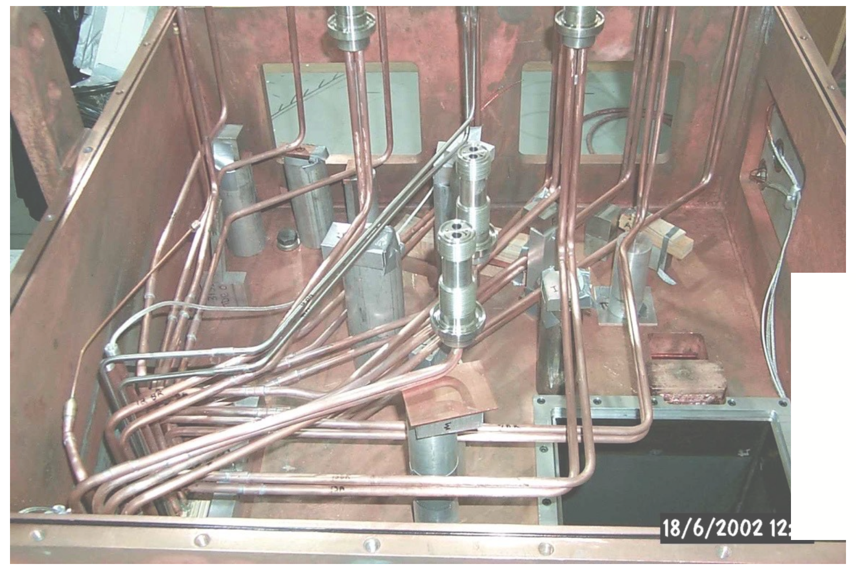


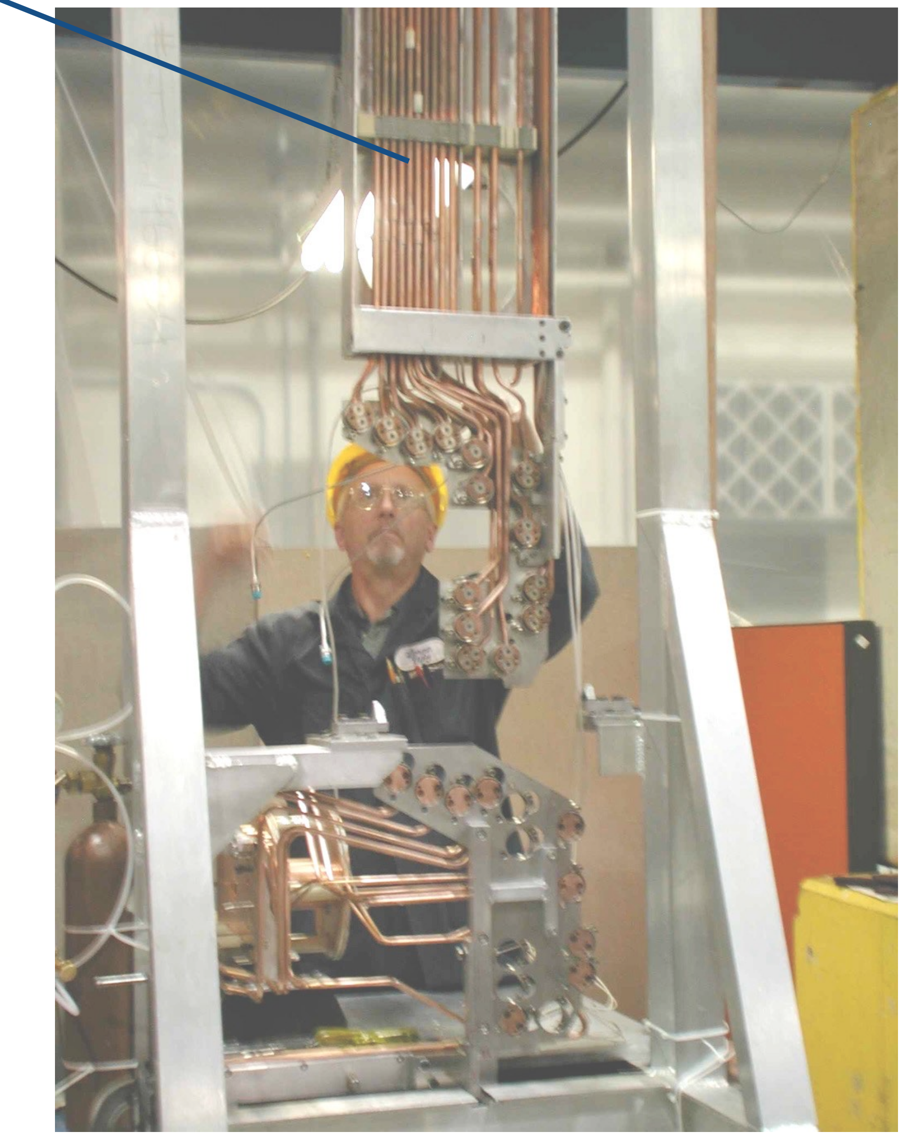
ISAC RIB system (+)

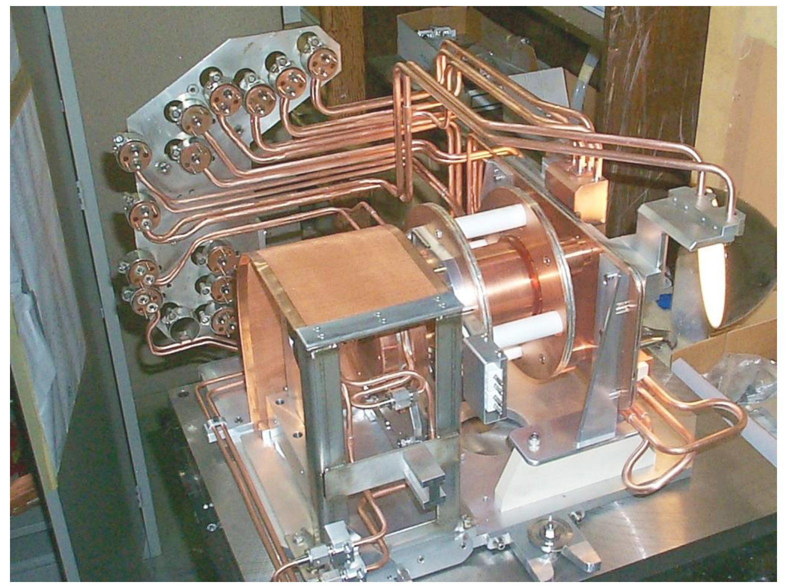
- The modular approach provides shielding to non-radiation resistant components allowing the operation of the ISAC facility with 500 MeV-100 μA proton beam.
- ISAC one of the most powerful ISOL facility in the world with its 50 kW beam power on target.
- Two-stage mass separator system prove to be very effective in:
  - Reducing contamination spread along beam line,
  - Highly active mass-selection slit-jaws are in the heavily shielded building reducing risk for spreading contamination.
- Electrostatic optics for RIB preparation in exit modules proved to be very robust,
  - We never had to replace any quadrupole during the 16 years of operation due to problem with high voltage or mechanical failure.
- Vacuum separation, primary and secondary volumes, works well.
  - Target and RIB beam line in primary,
  - Target module in secondary,
  - Double-bellow actuated seal separating the two volumes works well.

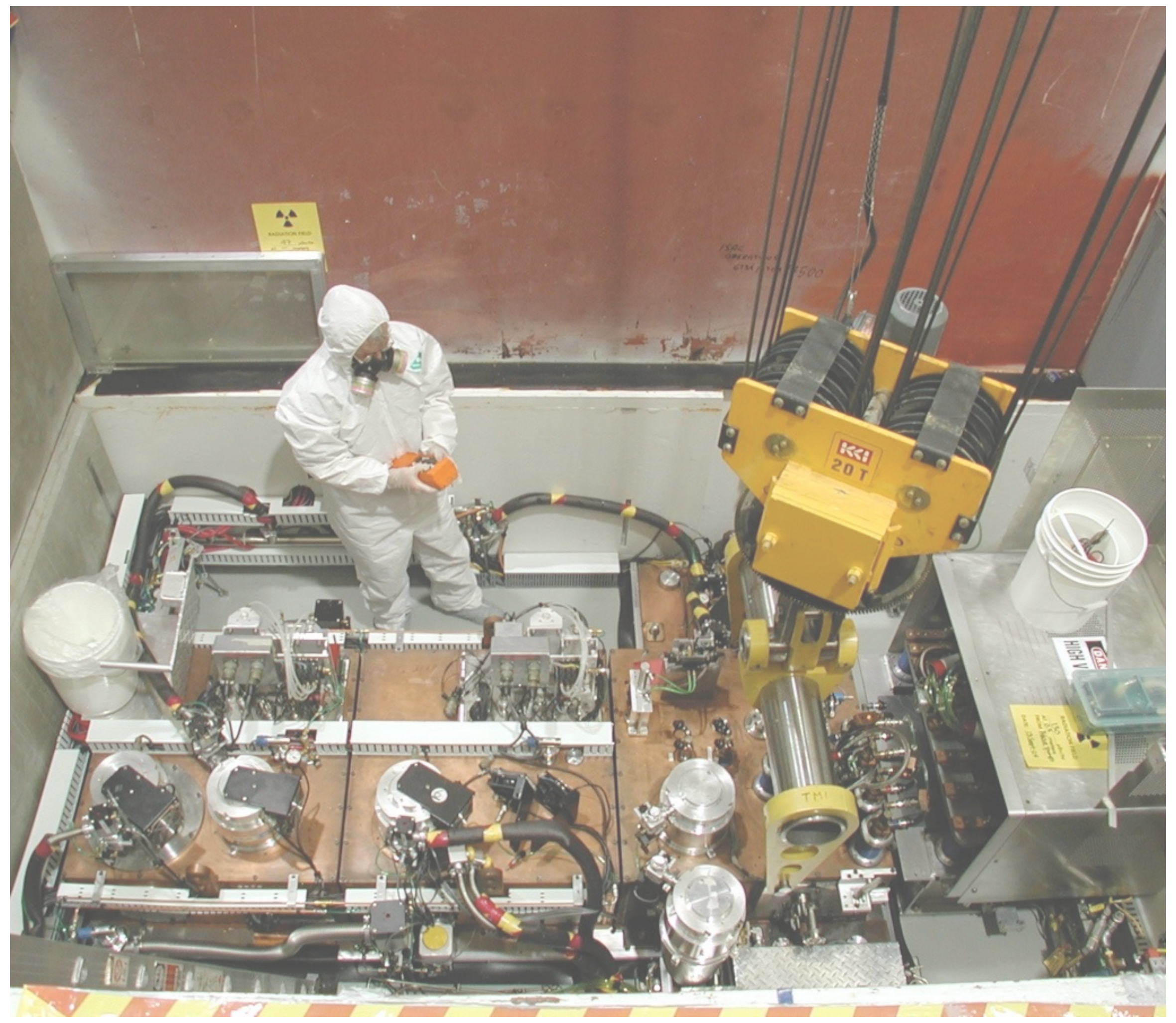
ISAC RIB system (-)

- Largest sources of downtime at ISAC are caused by Target Modules:
  - Water leaks inside vacuum.
  - More than 200 joints in the cooling-lines.
  - High voltage breakdown, the target module have difficulty to hold required voltage to accelerate ions at 2 keV per nucleon for the post-accelerator.
    - Too small gap between lines and ground plane,
    - Proton scattering showers onto high voltage lines.
    - Need a new design for high voltage FT.
- The ‘containment box’ is not hermetically sealed, which does not allow the use of air sensitive target materials.
- Manual services disconnection in the target hall cause delay for target rotation. Dose to personnel







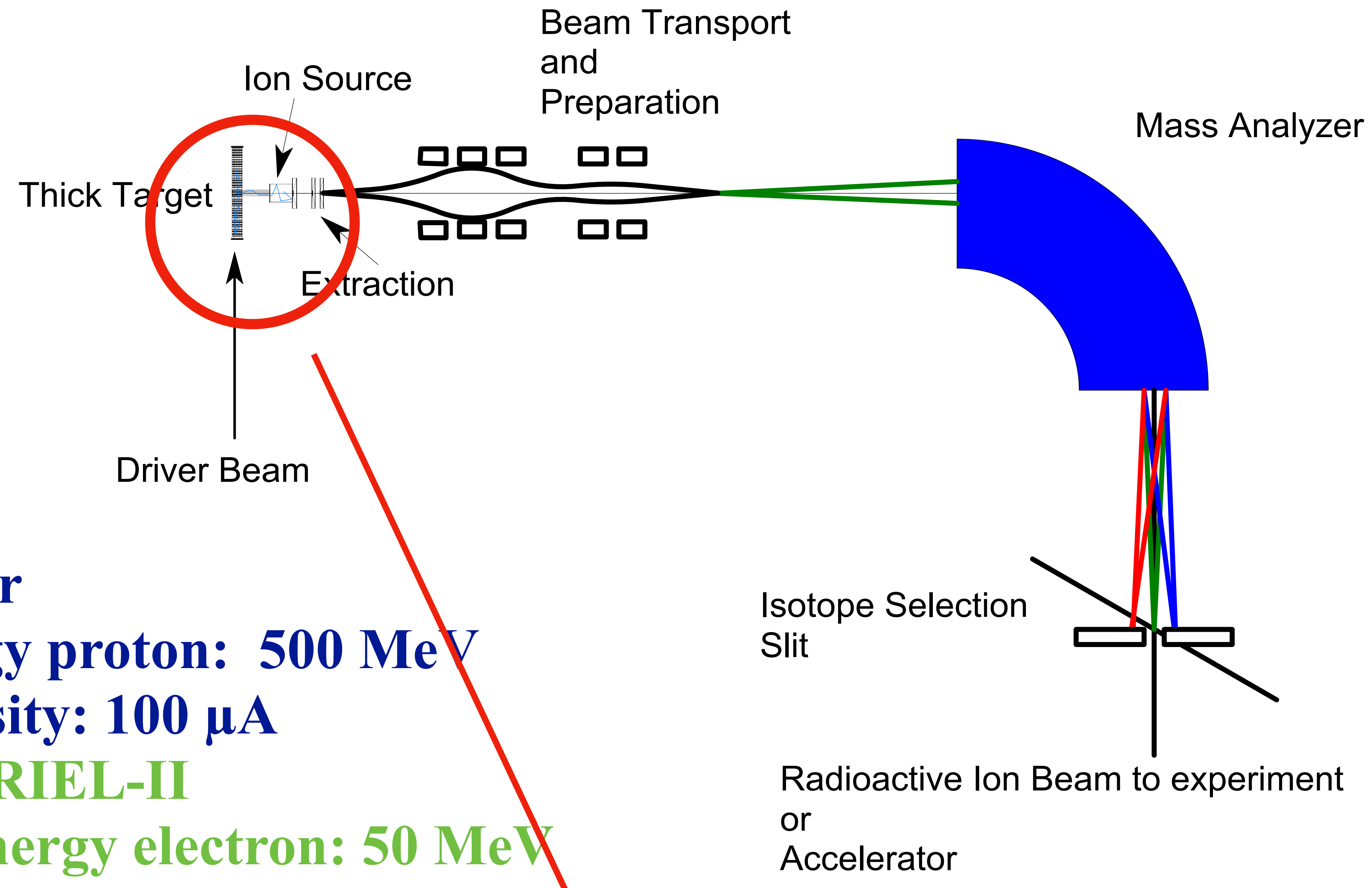


ISAC Target Development

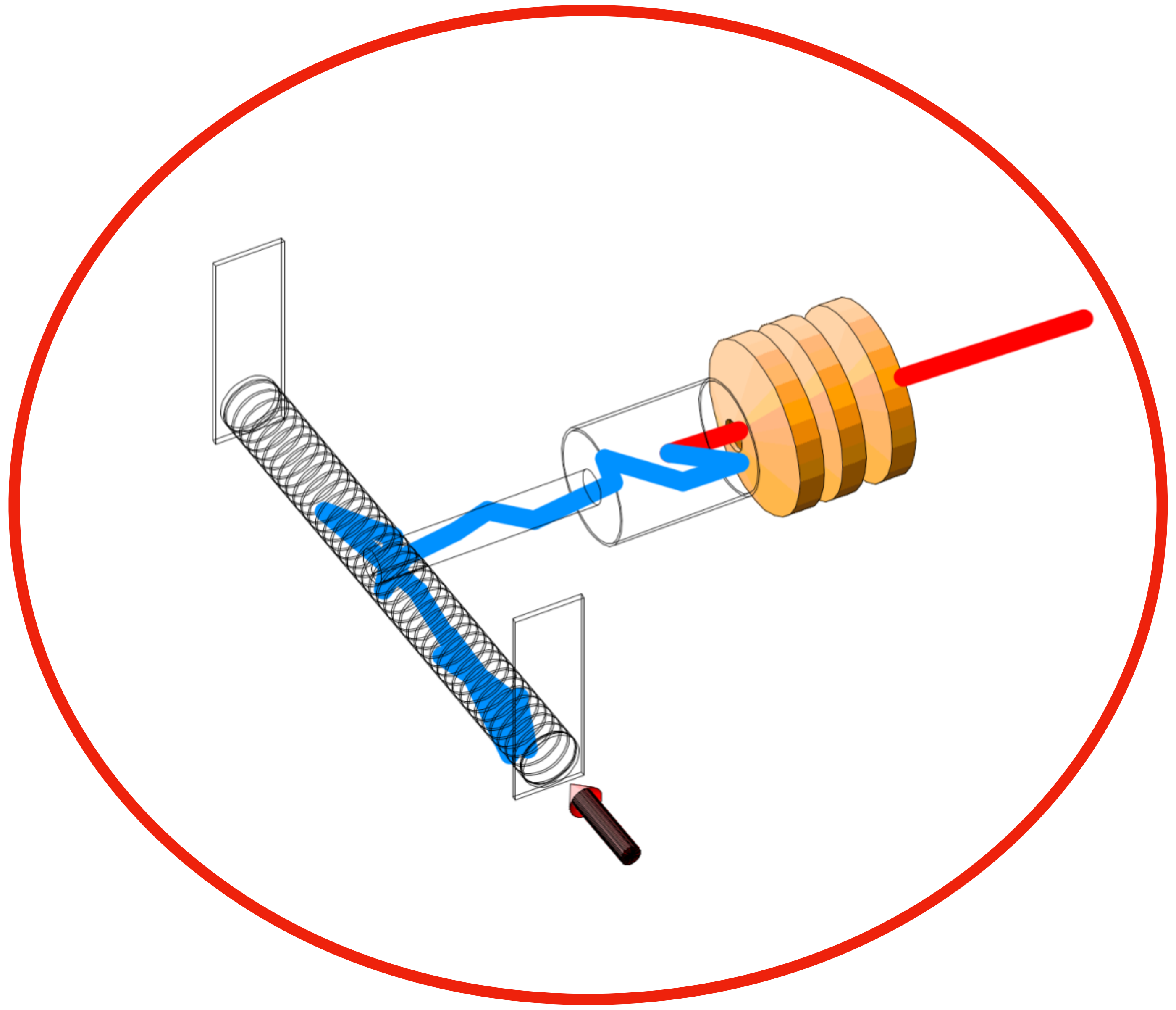
ISOL method

- This method involves the interaction of light ion beam onto a high Z thick target material
- The resulting fragments are stopped in the bulk of the target
- $Y = \Phi_p \, \sigma \, (N_a/A \, \tau) \, \varepsilon_D \, \varepsilon_E \, \varepsilon_I$
- $\varepsilon_D \Rightarrow D = D_0 \, e^{\frac{-E_A}{kT}}$, size of the grain and Activation energy and operating temperature,
- $\varepsilon_E \Rightarrow \Delta T = \chi \, (\tau_0 \, e^{\frac{-H_A}{kT}} + t_{ij})$, nb of collisions inside the target container, sticking time, enthalpy and operating temperature
- $\varepsilon_I = f(IP)$, ionization potential.

Schematic of the ISOL method



ISAC driver
High Energy proton: 500 MeV
High Intensity: 100 μA
and with ARIEL-II
Medium Energy electron: 50 MeV
High Intensity: 1 to 10 mA

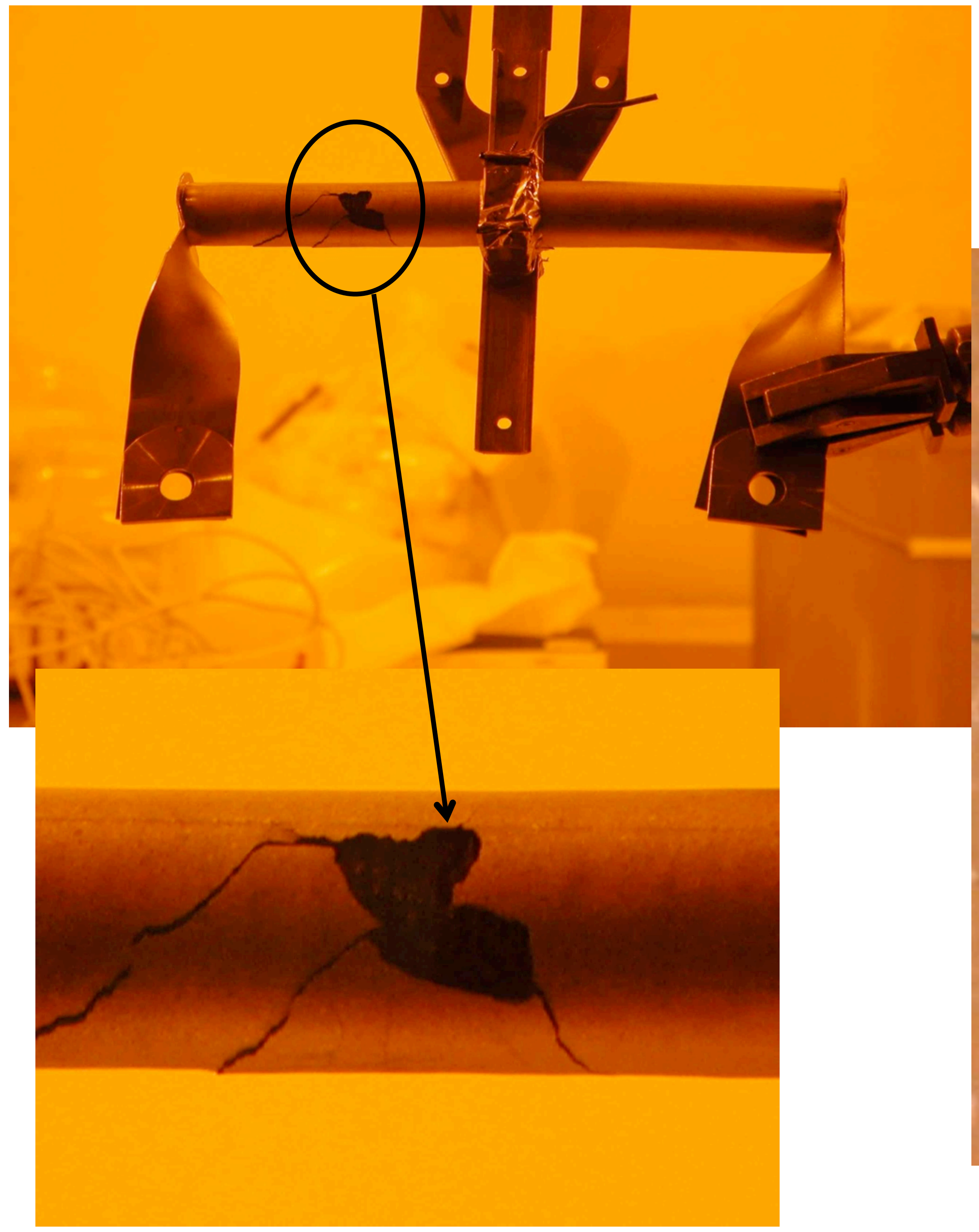


ISAC High Power Target Development

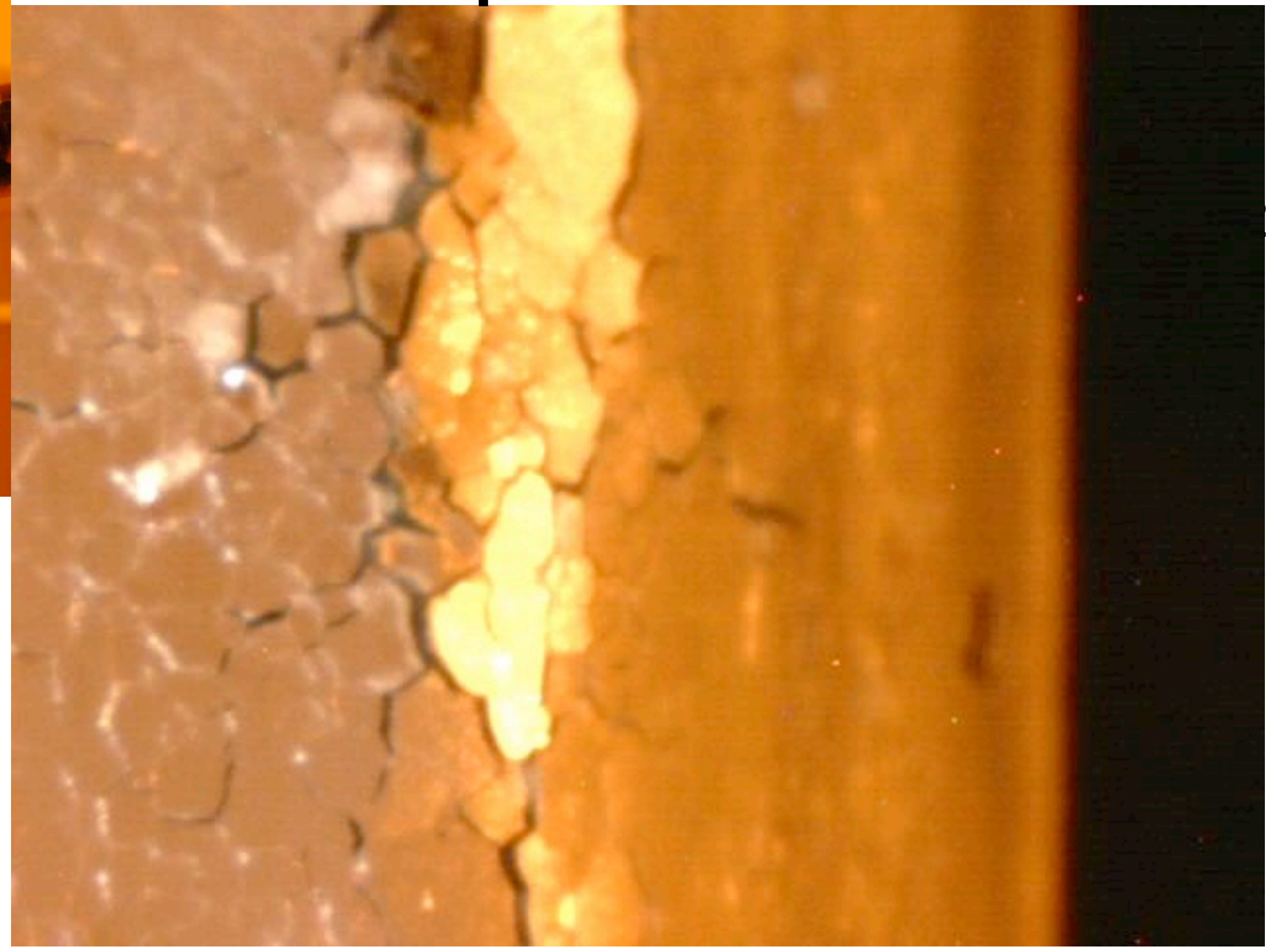
- When increasing the driver beam power onto a direct ISOL target we had to solve two major problems:
  - Target container has to be cooled,
  - Target material has to survive higher power density deposition,
    - Target material evaporation => high pressure, not good for ion source and high voltage extraction (sparking problems),
    - Target material sintering => large grain formation, not good for fast diffusion release.
- Best target material are:
  - Refractory metals, such as Ta, Nb, W,
  - Carbides,
  - Oxides, but they have lower operating temperature.
- Except for metal foils we had to improve the target material overall thermal conductivity in order to operate above <2> μA.

Target Failures

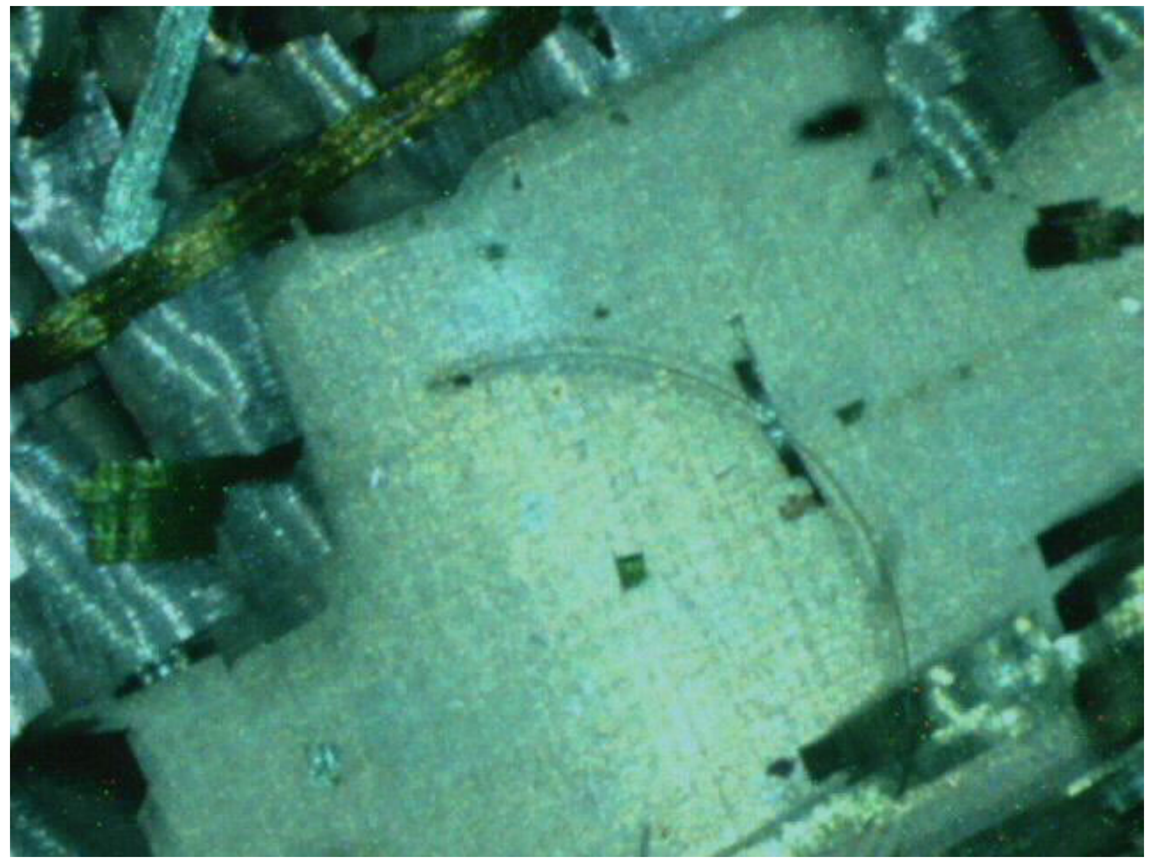
- When increasing proton beam from 2 to 30 μA we experienced target failures.
- Diagnostics of spent target was difficult.
- When we obtained the permission to open the target and see what was going on we were able to react and fix the problems.
  - Add a USB scope inside the hot-cell and use telescope to see the target. We discovered that:
    - Chemical reactions between target container and target material
    - Impurities going into interstitial boundary
- We solve the problem by coating the inner target container walls with TaC layer.
- Ramping up the proton beam too fast.
  - Evaporation of the Ta target



$N_p \sim 1E19$ protons



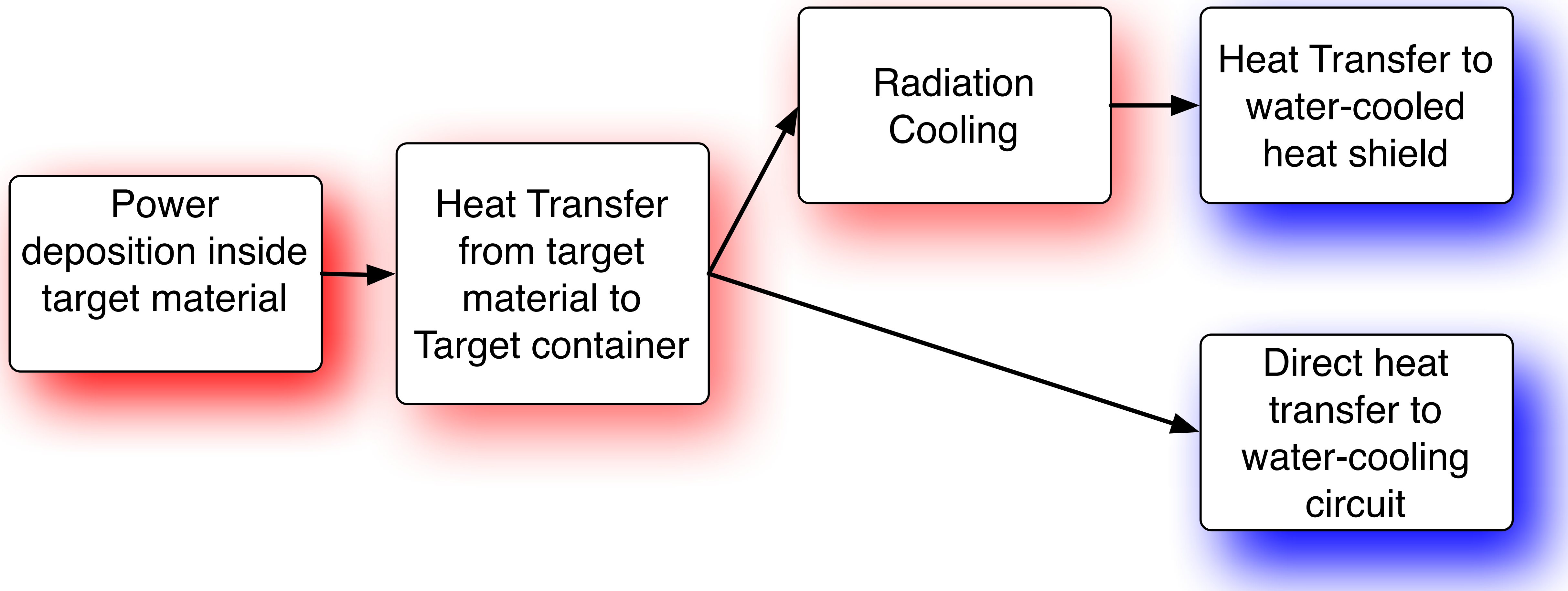
View from inside the hot-cell
Tantalum foil on cooled copper surface from target evaporation



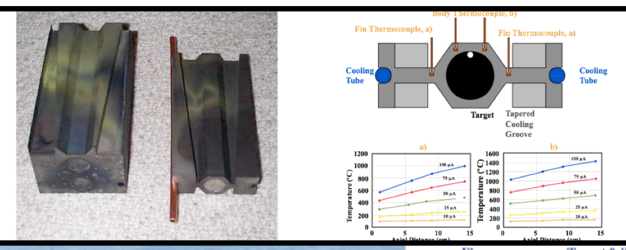
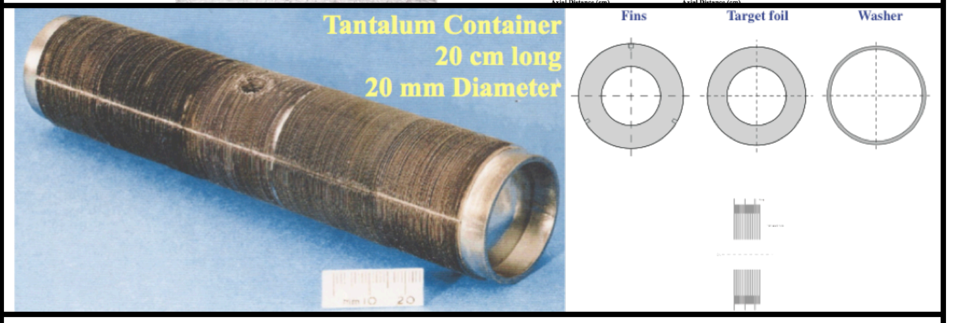
High Power Target Development

- Approaches to ISOL high power cooling
  - Radiation cooling
  - Heat sink

ISOL High Power Target



Brief history of the ISOL HPT

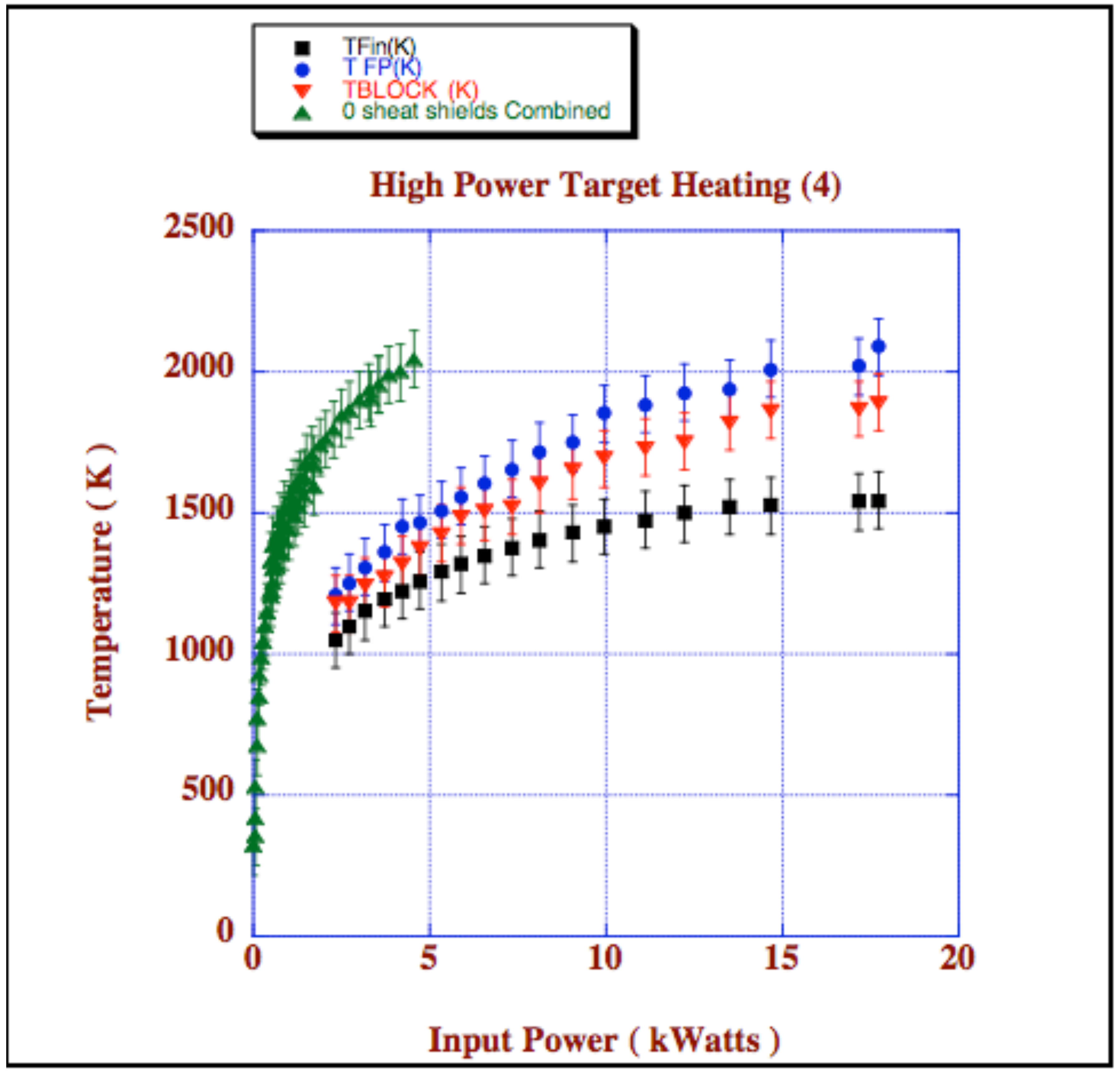
1986	Eaton & Ravn, CERN/ISOLDE: 100 µA, 550 MeV, proton	Longitudinal fins on the Ta container	
1991	Talbert et al., 100 µA, 600 to 1200 MeV, proton	Cooling design consisting of an annular solid thermal conductor encasing the target with an outer He-filled gap separating the conductor from a water-cooled outer jacket	
1991-1996	Nitchke, LBNL: 100 µA, 800 MeV, proton Talbert et al., 100 µA, 600 to 1200 MeV, proton Bennett, RAL: development of a HPT for 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: Rutherford Ion Source Test, RIST project Tested at ISOLDE: 3 µA, 1000 MeV, proton	Built a diffusion bounded Ta target, off-line test shows that emissivity ~ 0,7-0,8.	
2003	P. Bricault, M. Dombsky, A. Dowling and M. Lan, ISAC Test with high power electron impact,	Transversal fins diffusion bounded to Ta tube (target container), emissivity ~ 0,9.	
2004-2015	P. G. Bricault, M. Dombsky, P. W. Schmor and A. Dowling, first proton beam at 100 µA on thick target.	Transversal fins diffusion bounded to Ta tube With rotating proton beam on target, end of may 2015.	

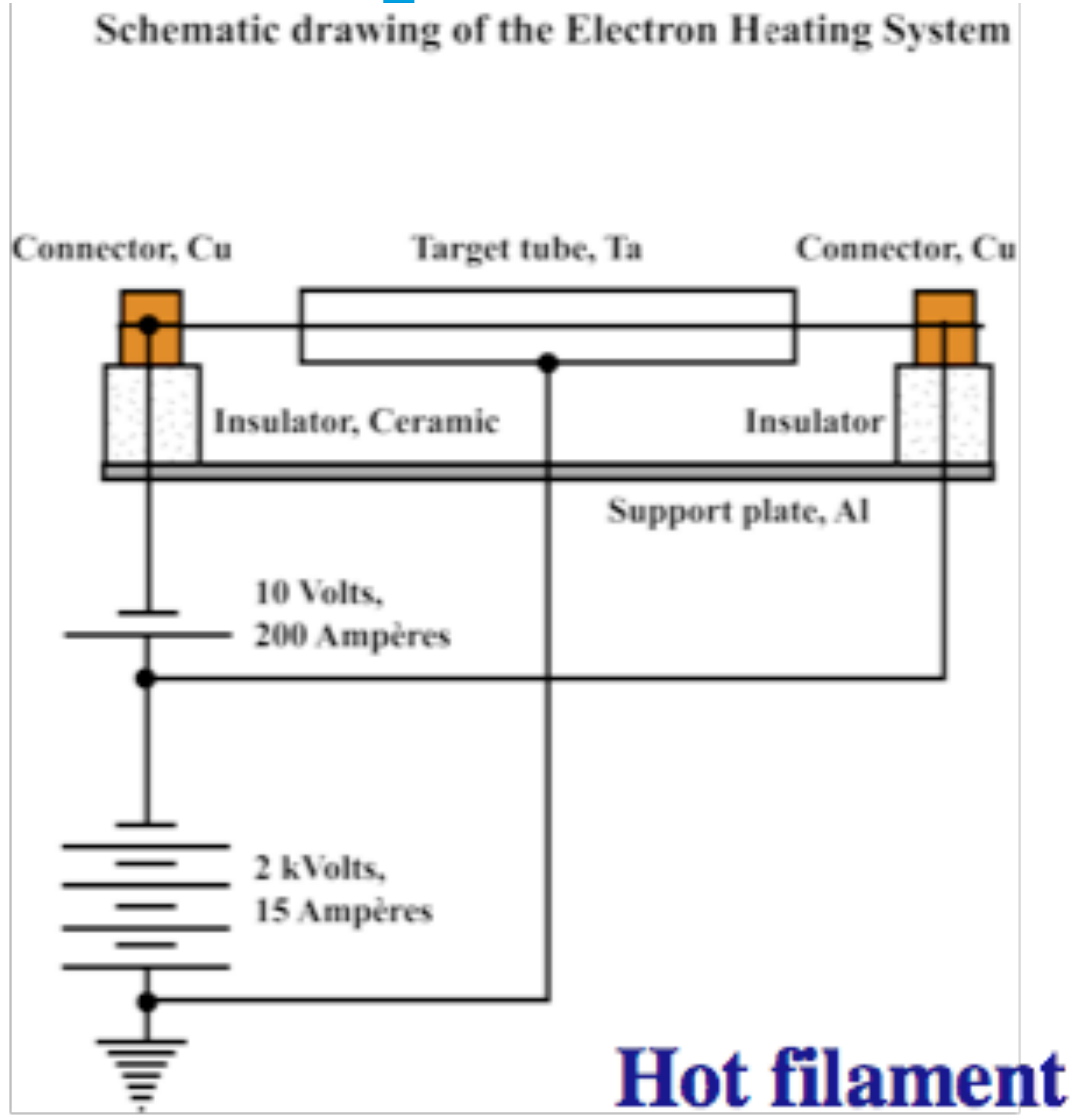
High Power Target (HPT) Development

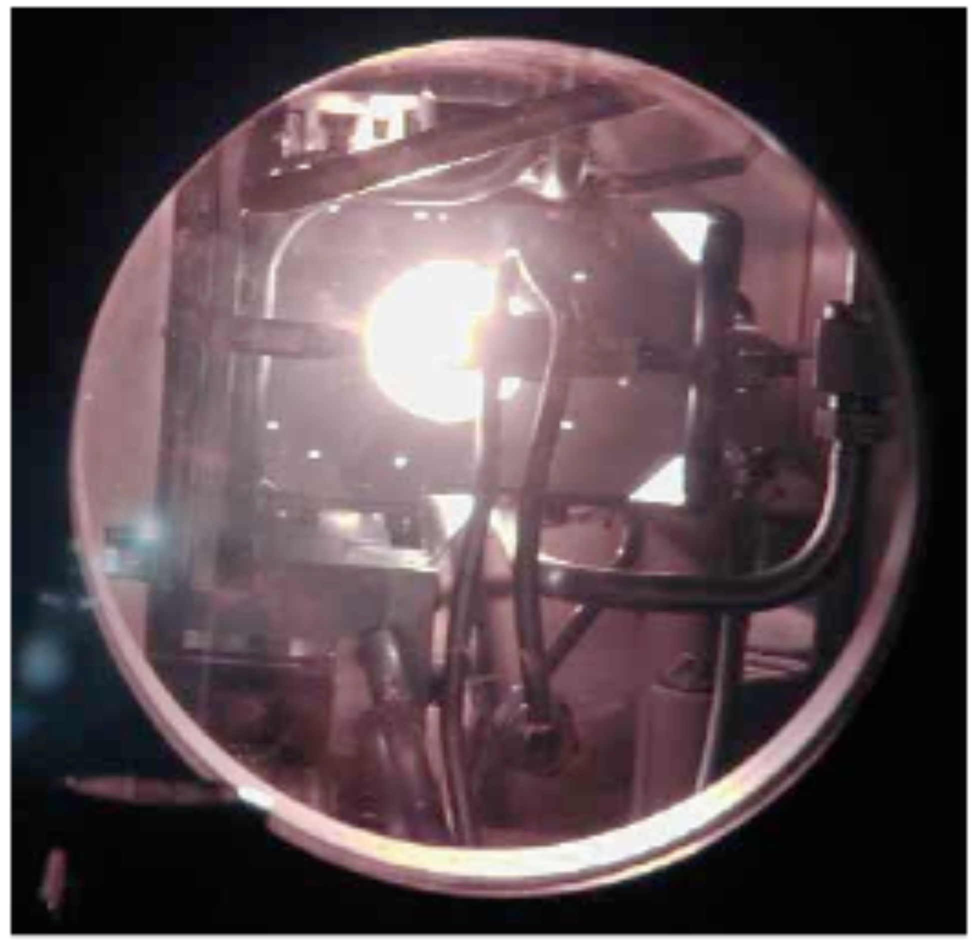
- Using an old KAON kicker magnet PS we build a test stand to heat the HPT using electrons emission from hot filament.

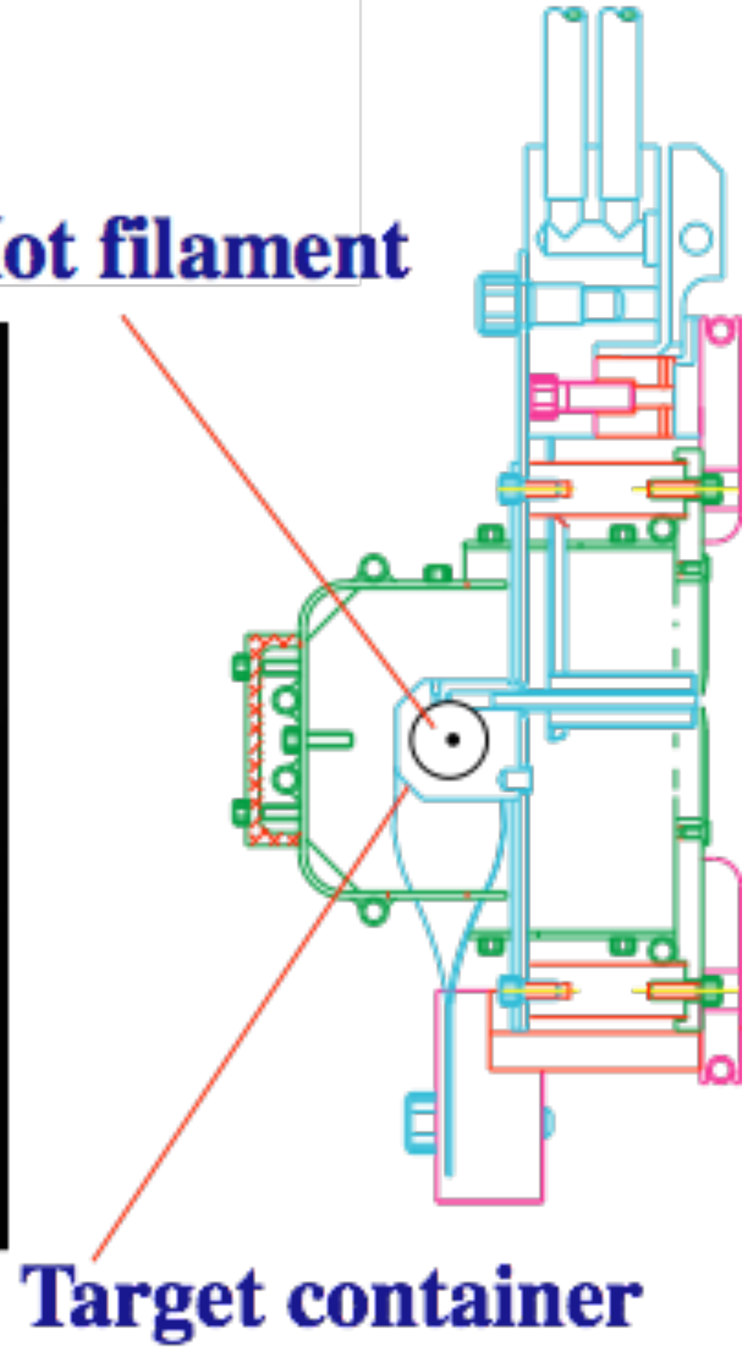
- Filament was made of a 3 mm diameter Ta tube biased at 2 kV delivering 15 A of electron beam.

Effective Emissivity ≈ 0.92!





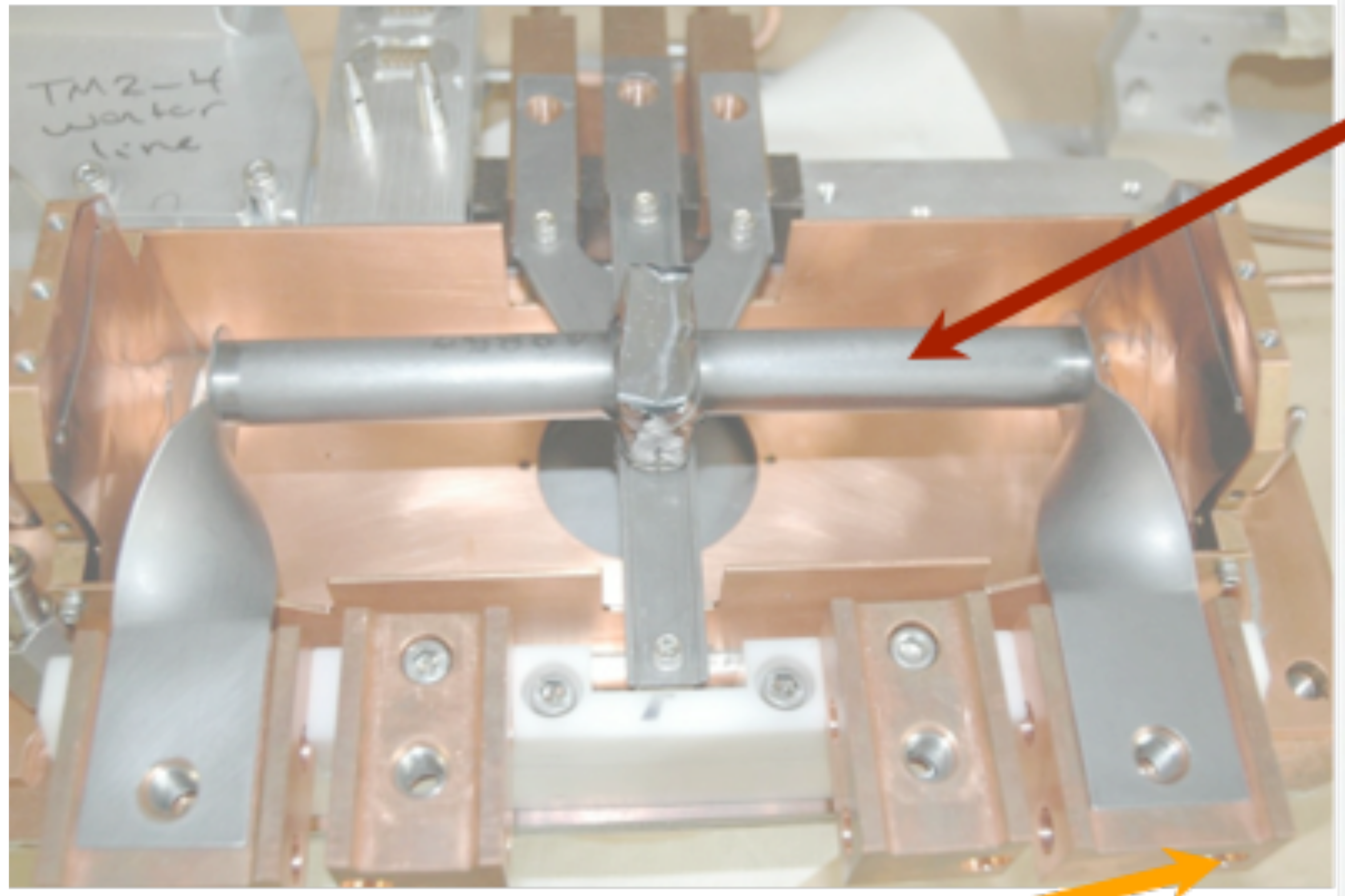




High Power Target Development

- Normal ISAC target on the left hand side.
- High power target using radiative cooling fins on the right hand side

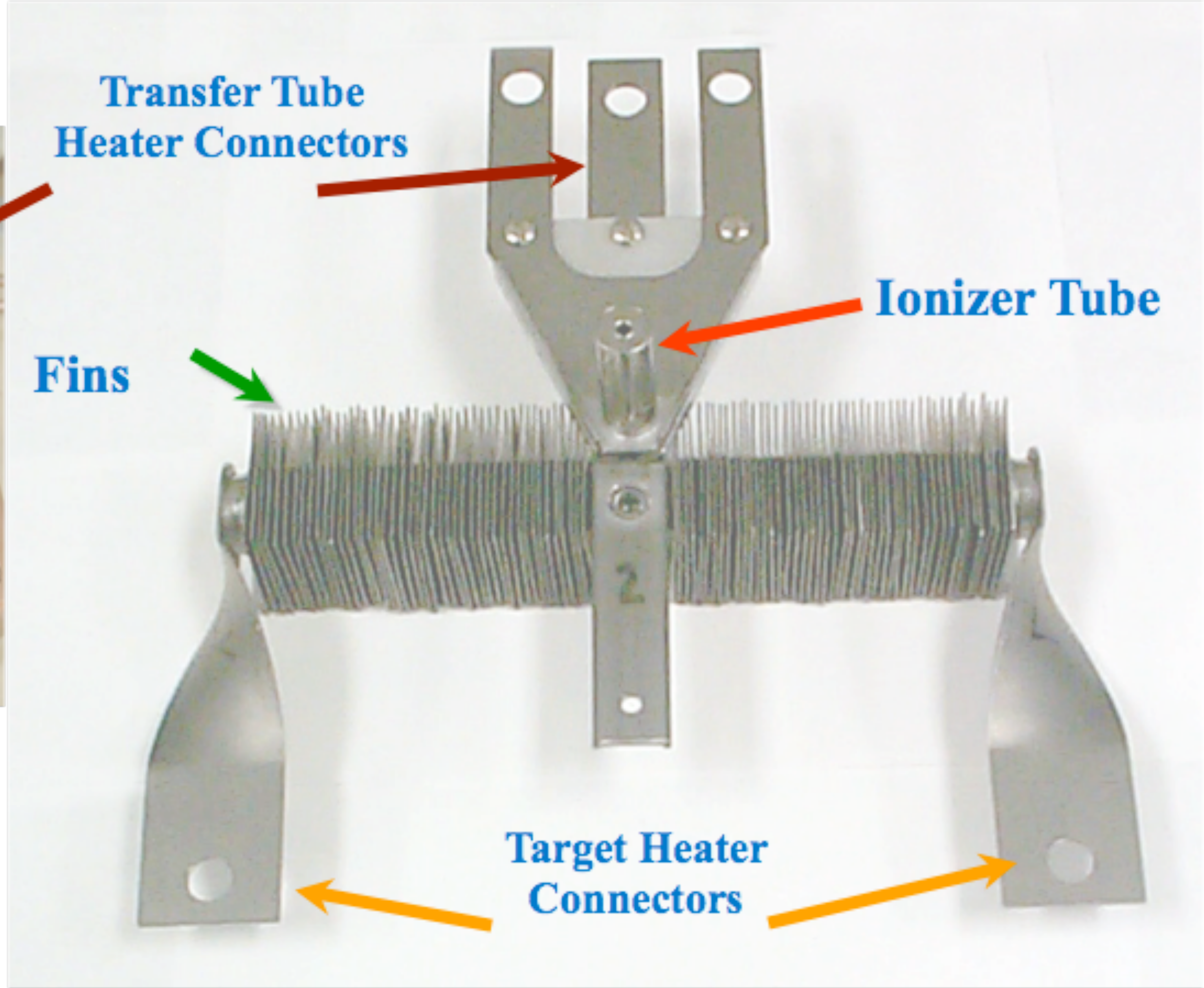
Normal Target



Target Heater Connectors

$I_{Proton} \leq 40\ \mu A$

High Power Target



$55 \leq I_{Proton} \leq 100\ \mu A$

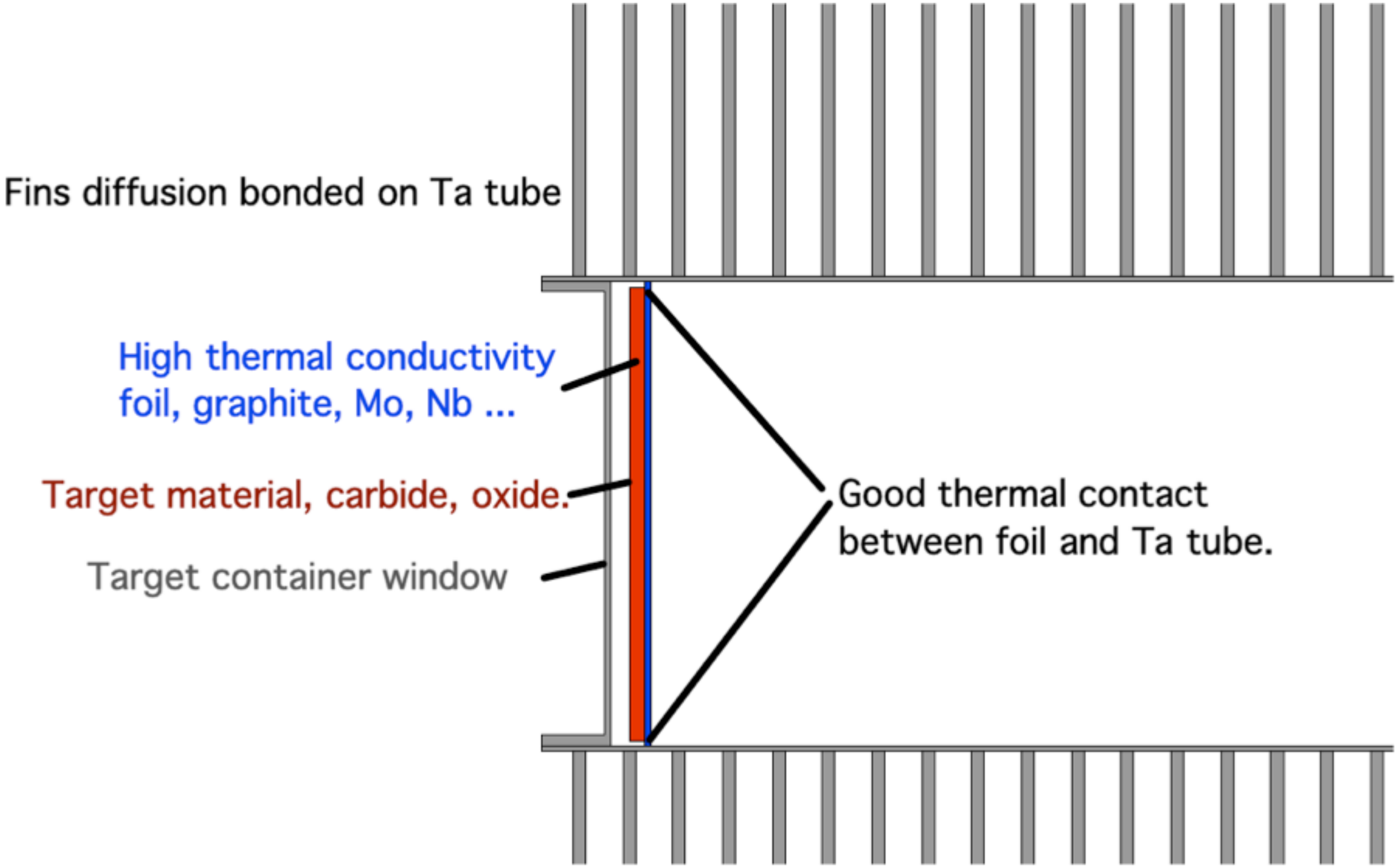
Composite High Power Target Development

- Very few target materials can sustain high power deposition,
  - Ta, Nb, Mo and W.
- Unfortunately, the chemistry inside the target material sometime prevent the desired nuclear species to efficiently escape the target container to reach the ion source. For example, short lived Ga isotopes were not observed in large quantity from Nb foils target, were observed from ZrC target.
- Efficient RIB production demands other type of target material,
  - Carbides or Oxides.

Composite target

- In order to dissipate more power from the target material to the radiative cooling fins we have developed a target made of two layers.

- An oxide or carbide layer on top of a high thermal conductivity backing.

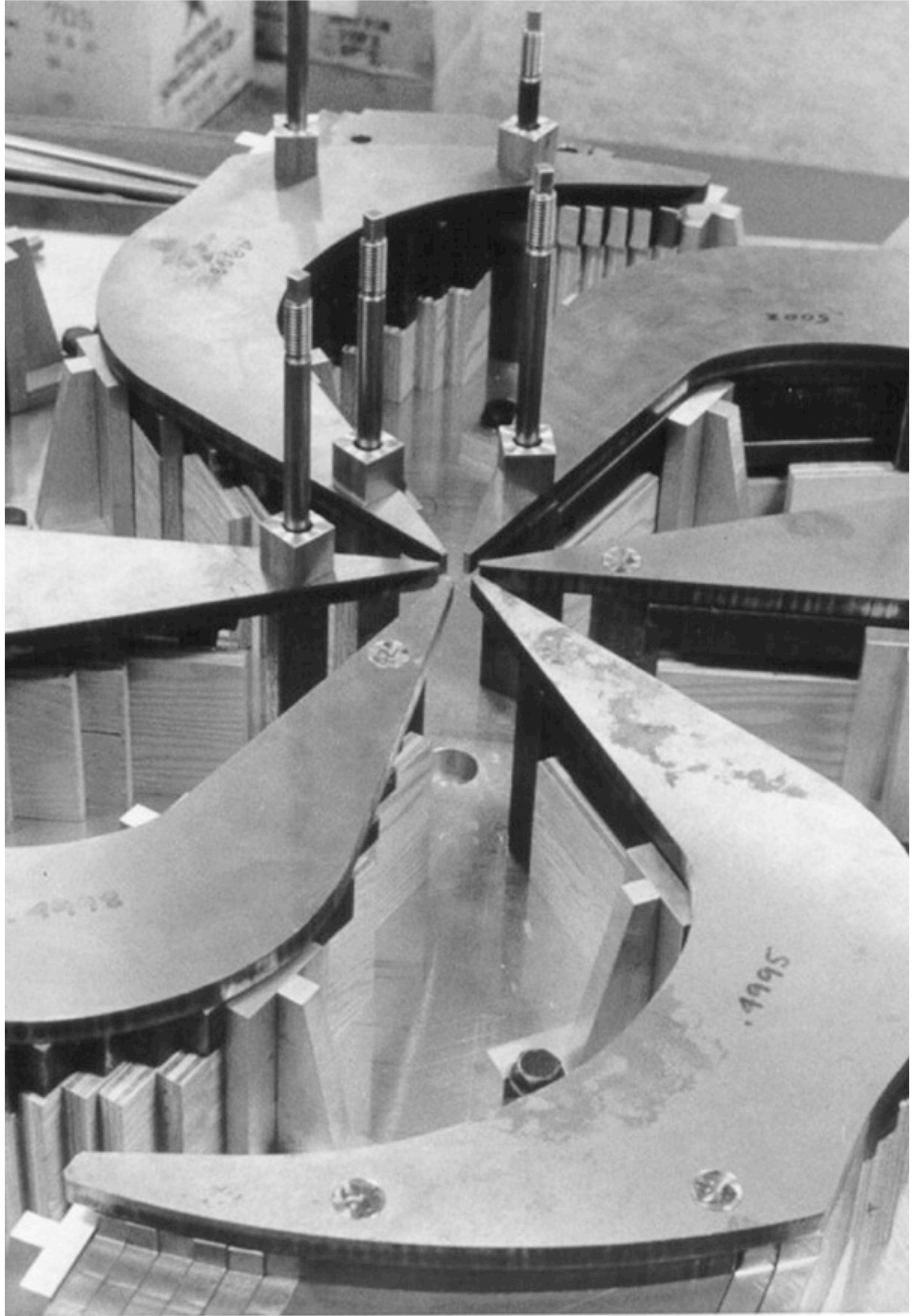


Composite Target

Target Material (RIB)	High Conductivity Support	Proton Beam Intensity (uA)
SiC (He, Li, Na, Mg, Al, F, Ne)	C (graphite foil, 0.1 mm thick)	70 - 85
TiC (K, Na, Ca, Ar, Cl ...)	C (graphite foil, 0.1 mm thick)	70 - 85
ZrC (Kr, Ga, Br, As ...)	C (graphite foil, 0.1 mm thick)	75 - 100
UC (At, Fr, Po, Ra, Rn, Pu, ...)	C (graphite foil, 0.1 mm thick)	Limited to 10 but capable of 65 - 100
NiO (C)	Ni (disk, 0.5 mm thick)	30
Nb5Si3 (Br, As)	Nb (foil, 0.025 mm thick)	15
Al2O3 (Ne) (EURISOL HPT)	Nb (disk, 0.5 mm thick)	30

TRIUMF

Thank you
Merci



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