Target Stations Design for eLINAC + Actinides

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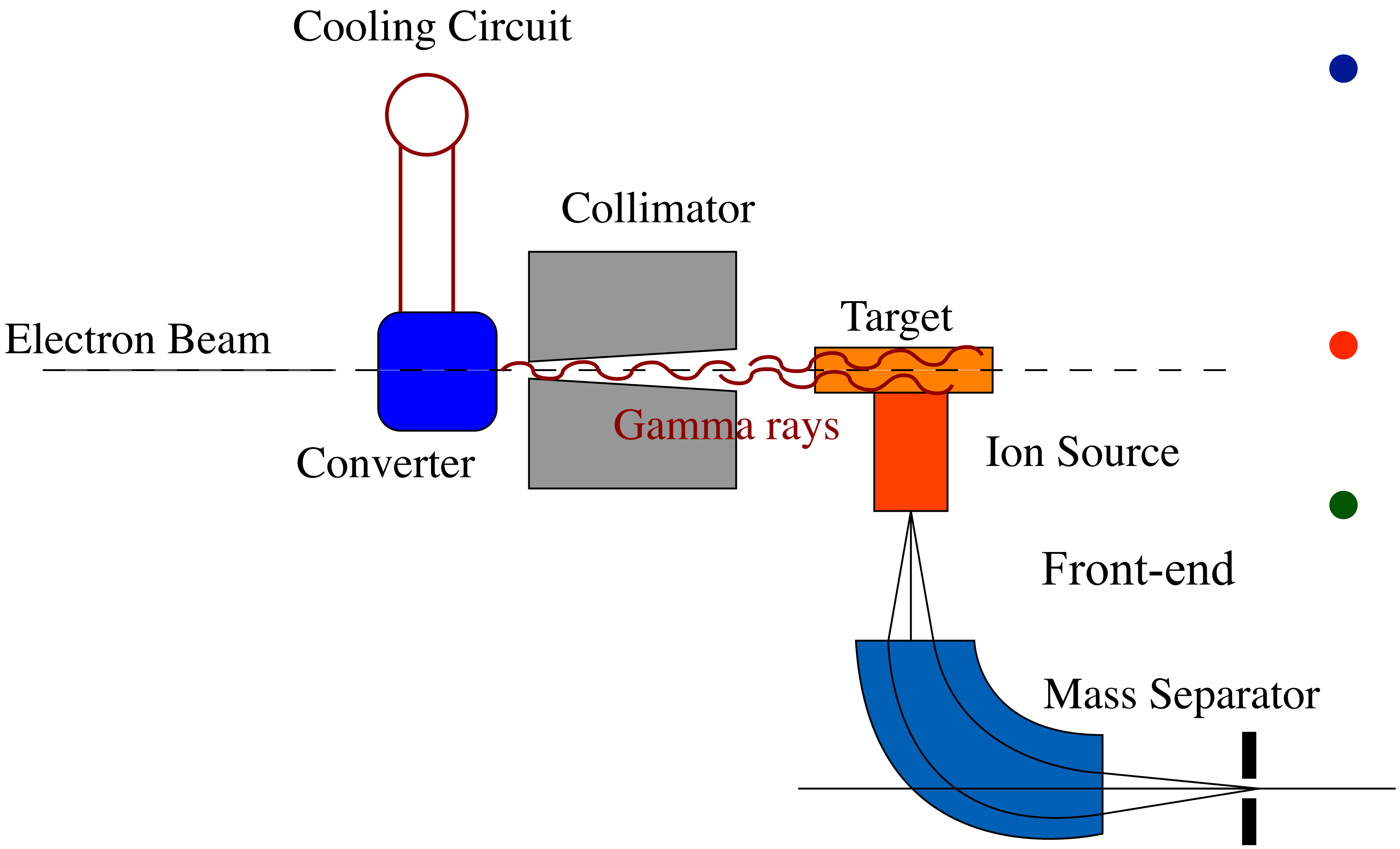
TRIUMF
ACOT, Nov 2007

Basic Parameters

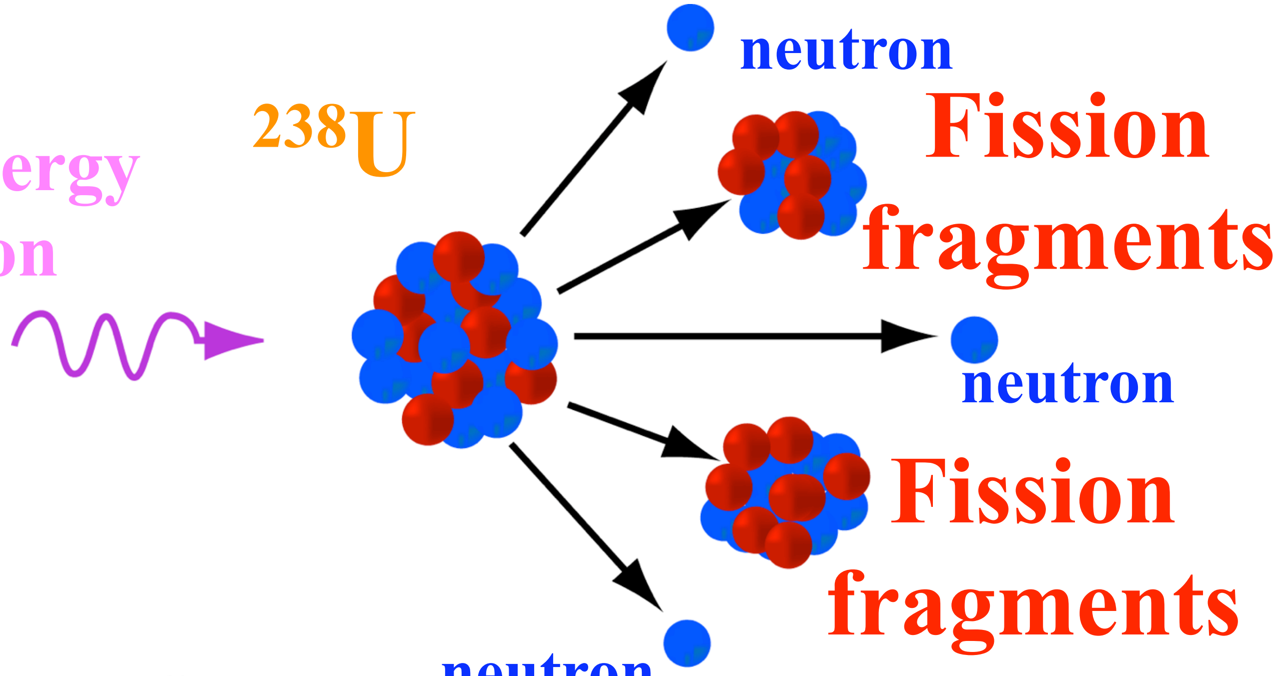


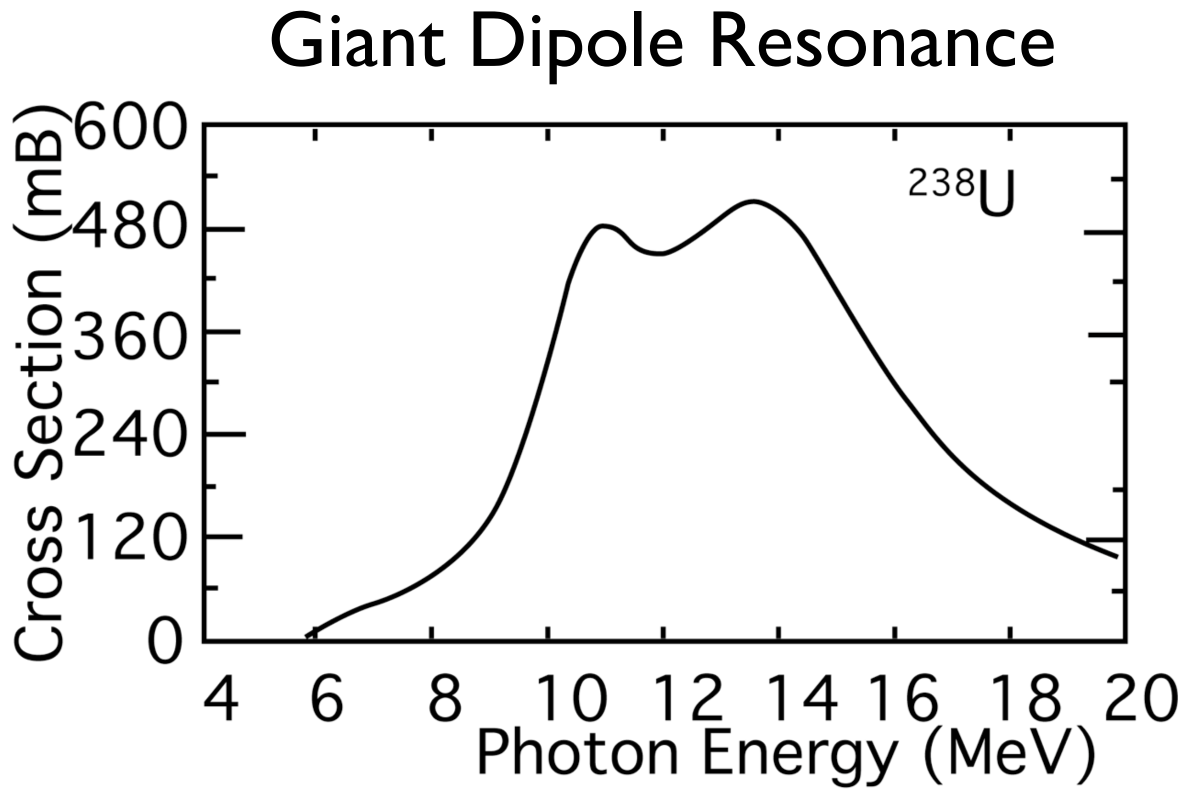
- **Basic**
  - **Photofission,**
  - **Braking radiation,**
- **Concept for the converter,**
- **Target station concept for actinides target**

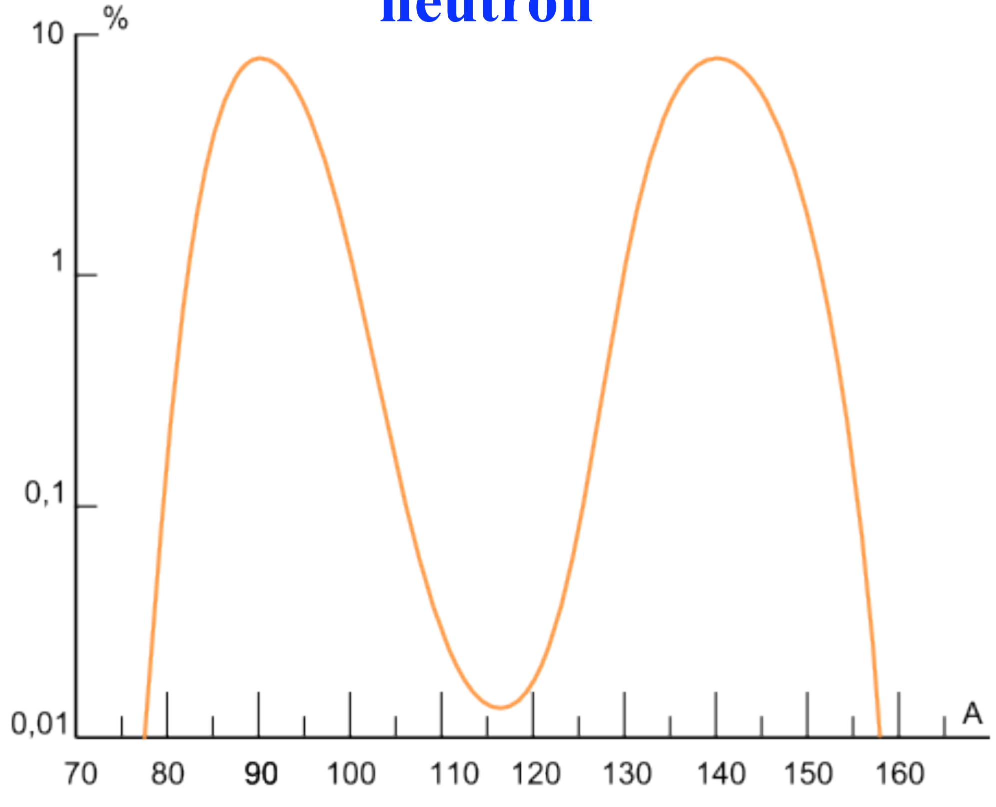
RIB to users

Photo-Fission

- **Induced fission using photons was first observed in Westinghouse laboratory in 1940,**
  - **R. 0. Haxby, W. E. Shoupp, W. E. Stephens, and R. H. Wells, Phys. Rev. 58, 92 (1940); 59, 57 (1941).**
- **Fission can be induced by photons exciting the giant dipolar resonance (GDR) of the nucleus. This process is called photo-fission.**





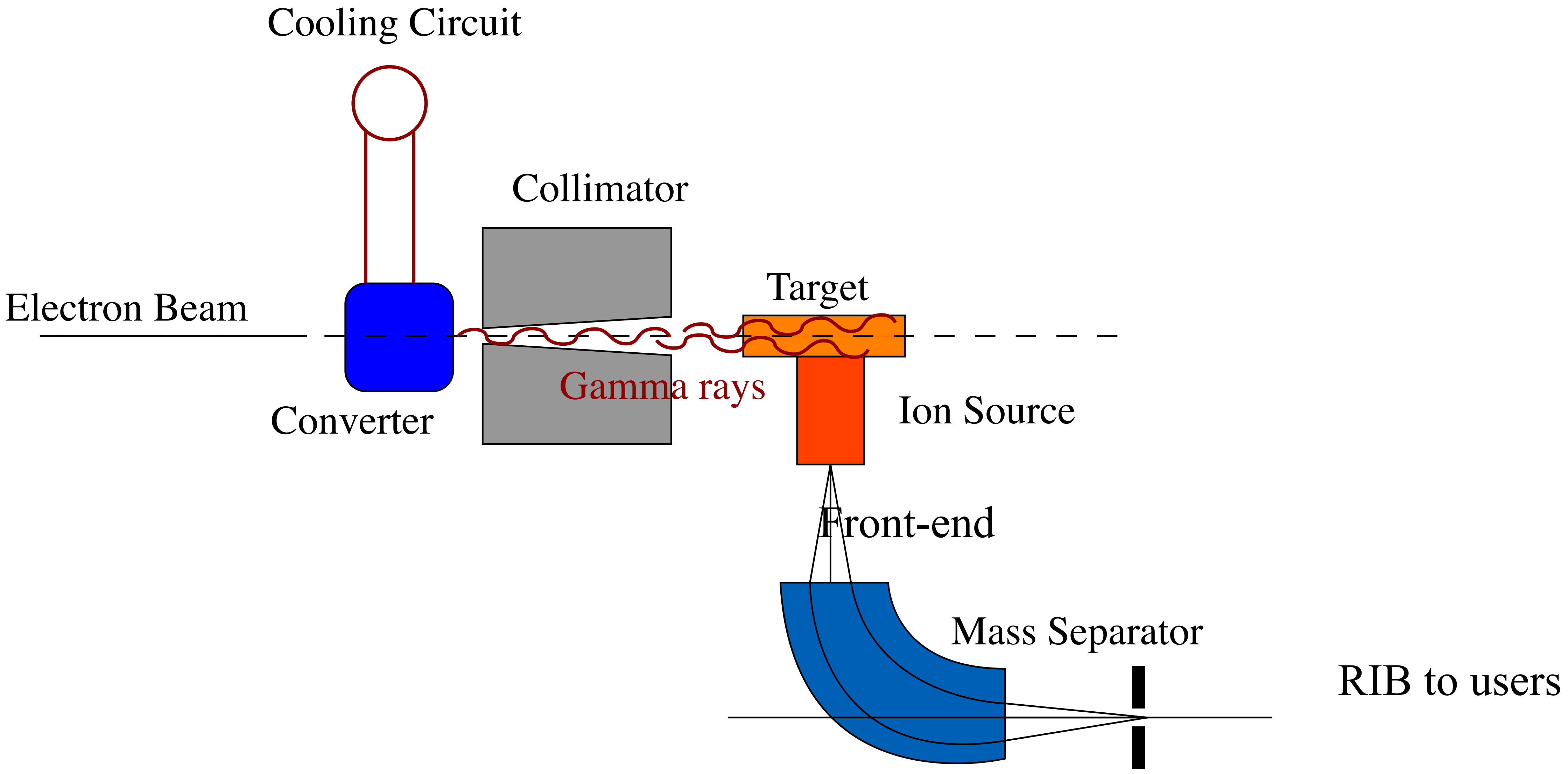


Fission Fragment

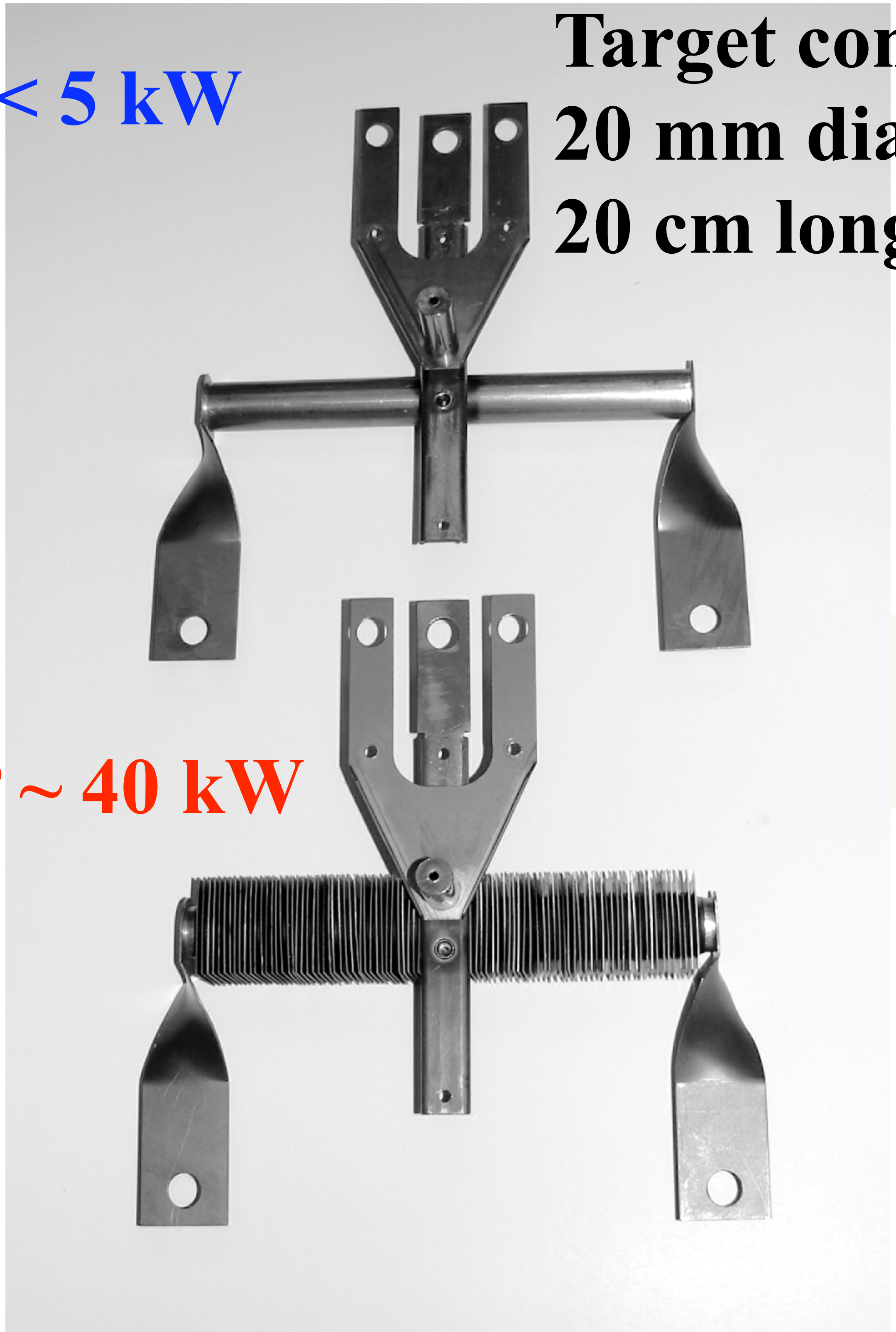
Basic Parameters

Item	Value	Units
Electron energy	**50**	**MeV**
Total power	**0,5**	**MW**
Electron current	**0,01**	**Ampère**
Target, UC_2	**50**	**g/cm^2**

- **Assuming same target/ ion source design in use at ISAC**



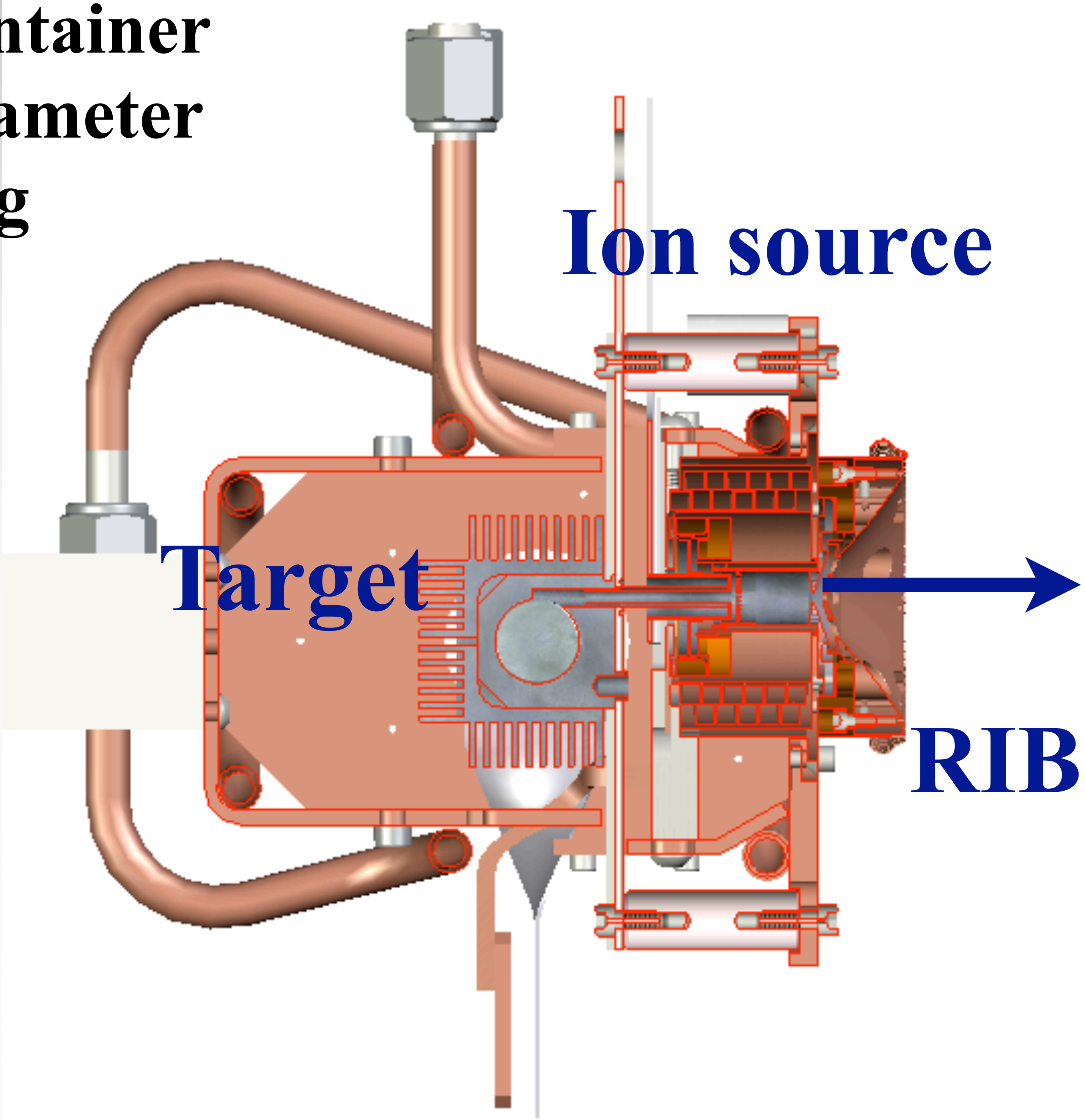
ISAC Target/Ion Source



Target container
20 mm diameter
20 cm long

P < 5 kW

P ~ 40 kW



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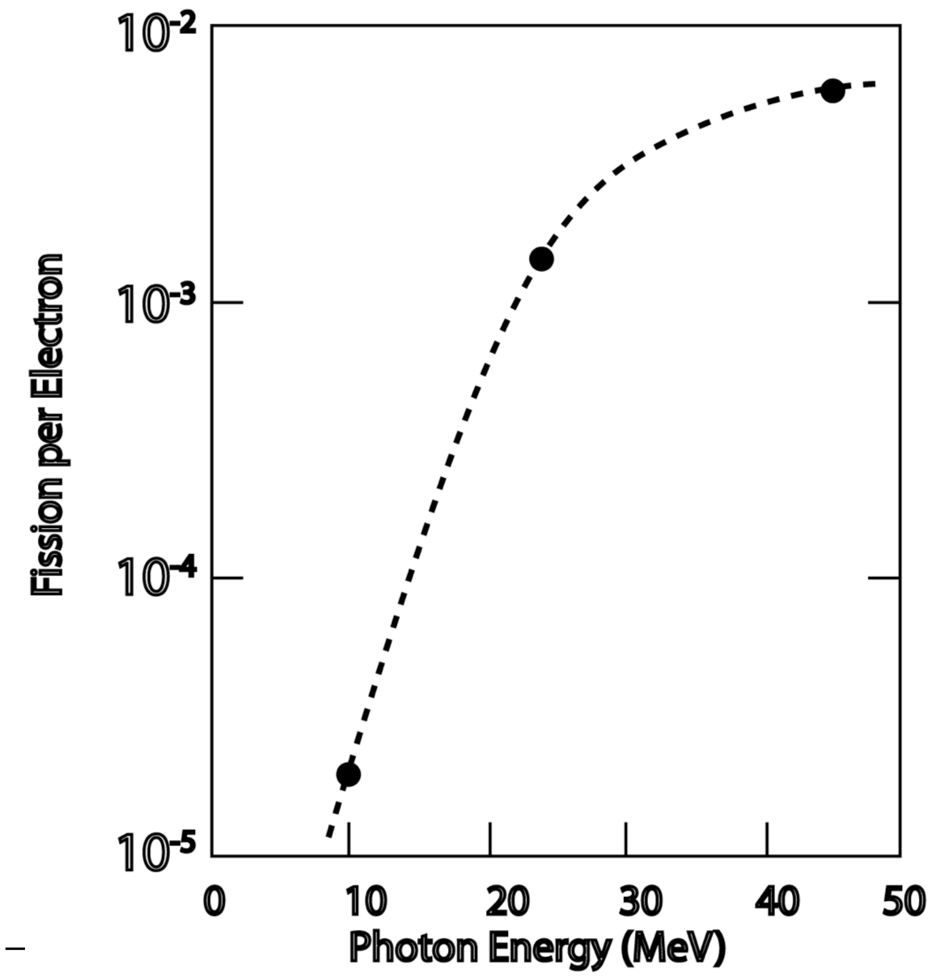
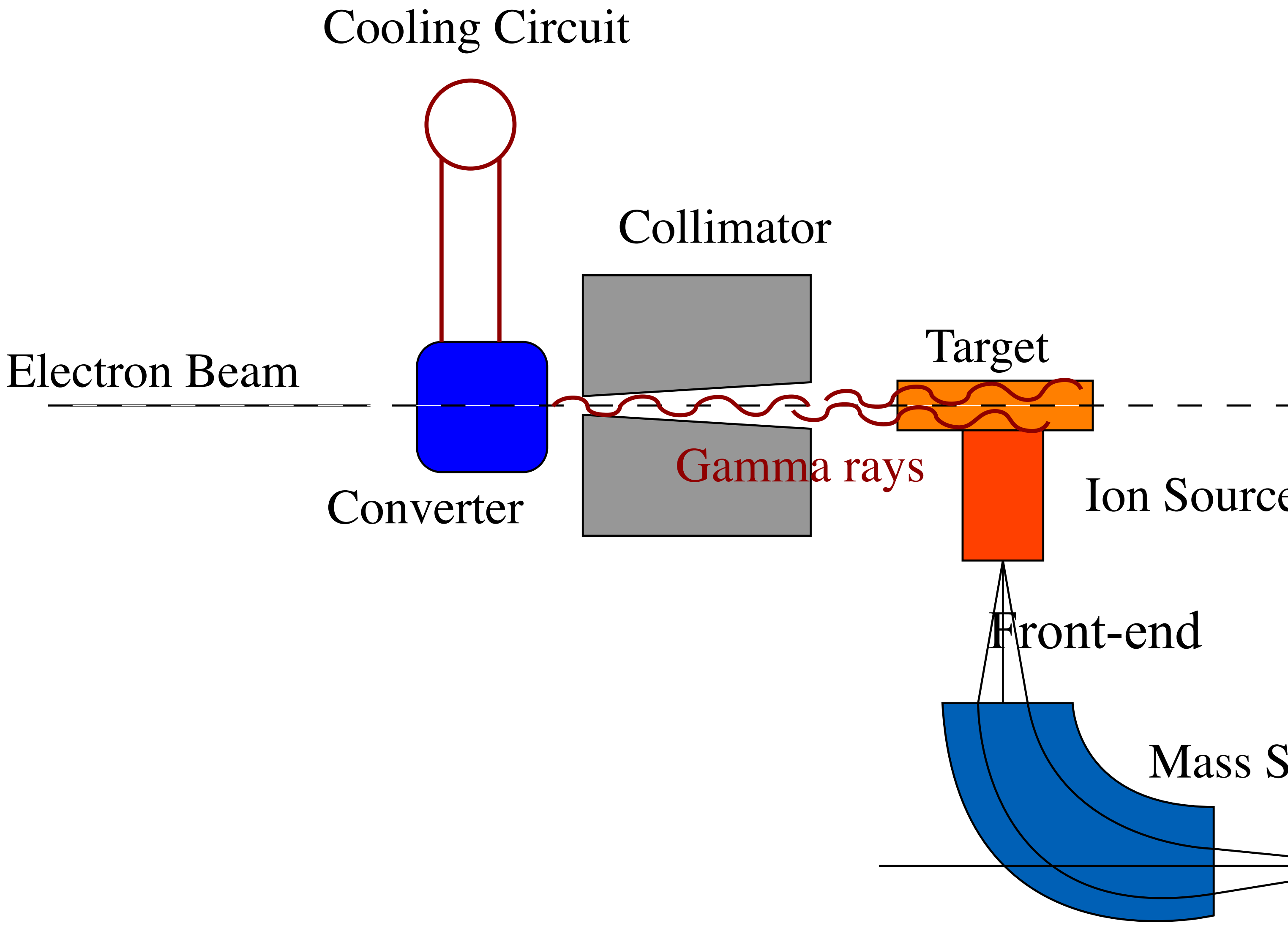




Braking Radiation

$$\frac{dE_{Rad}}{\rho dx} \simeq -\frac{E}{X_0}$$

$$\frac{1}{X_0} = \frac{4\alpha N_A Z(Z+1) r_e^2 log(183 Z^{-1/3})}{A}$$

$$\overline{E} \simeq E_0 exp(-\frac{\rho \Delta x}{X_0})$$

- E is the electron energy
- $\alpha \sim 1/137$
- N_A is the Avogadro number, 6,023e23 at/mole
- Z is the material atomic number
- r_e is the classical electron radius ~ 2,818e-13 cm
- A is the molar mass of the material

Element	Z	A	ρ (g/cm^3)	1/X$_0$	X$_0$ (g/cm^2)	τ (cm)
Al	13	27	2,3	0,0178	56,17	24,42
Cu	29	63,5	8,92	0,0340	29,45	3,30
Ta	73	181	16,65	0,0684	14,62	0,88
W	74	184	19,25	0,0691	14,48	0,75
Hg	80	202	13,58	0,0729	13,71	1,01
Pb	82	208	11,34	0,0742	13,47	1,19

Photon Energy

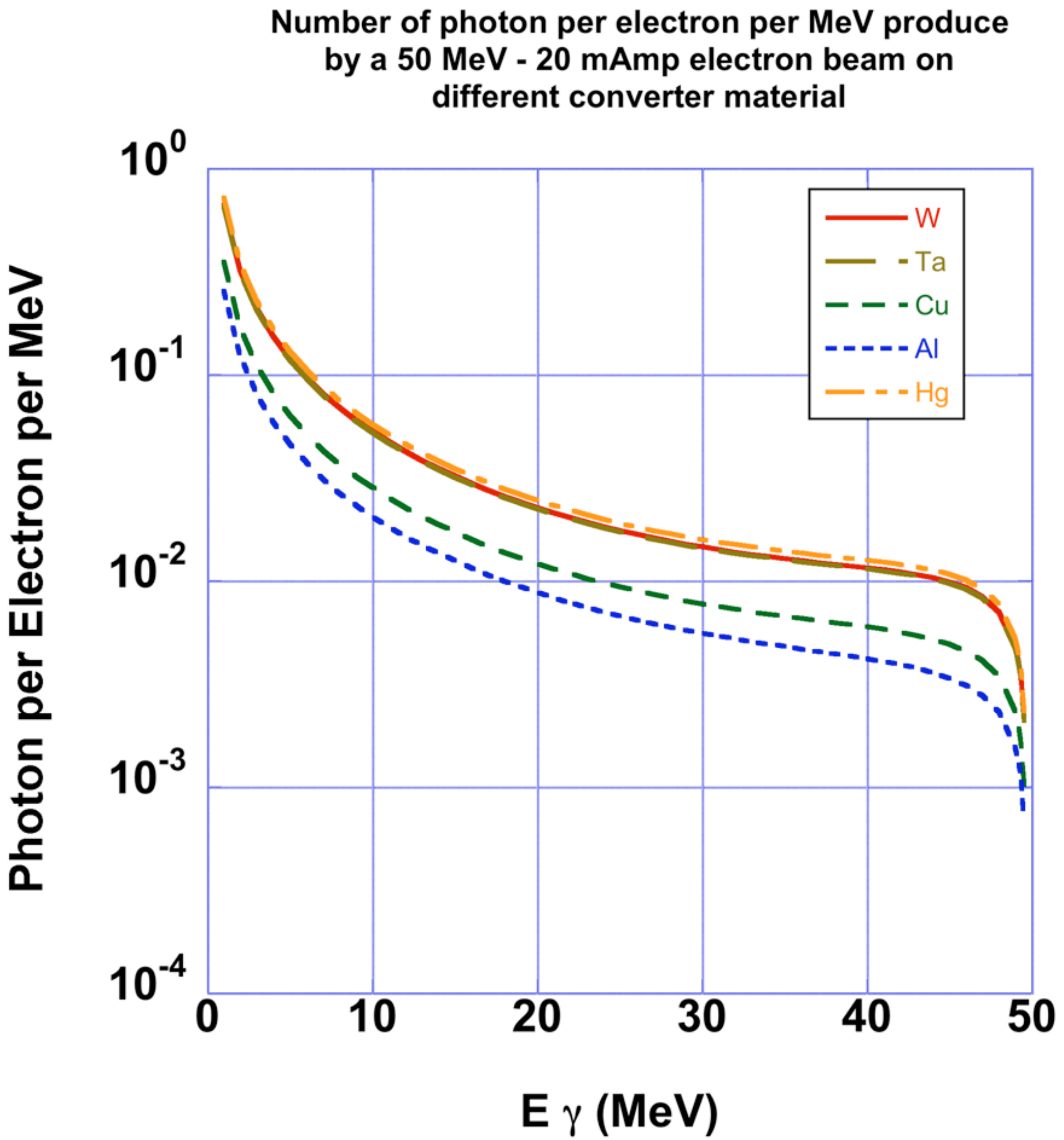
- **Using the Born approximation, Bethe, Heitler, Sauter and Racah [1] developed an expression for the low energy electron beam, E< 100 MeV;**

$$d\sigma_k = 2\alpha Z^2 r_0^2 \frac{dk}{k}\left[\left(1+\left(\frac{E}{E_0}\right)^2-\frac{2}{3}\frac{E}{E_0}\right)\left(lnM(0)+1-\frac{2}{b}tan^{-1}b\right)\right.$$

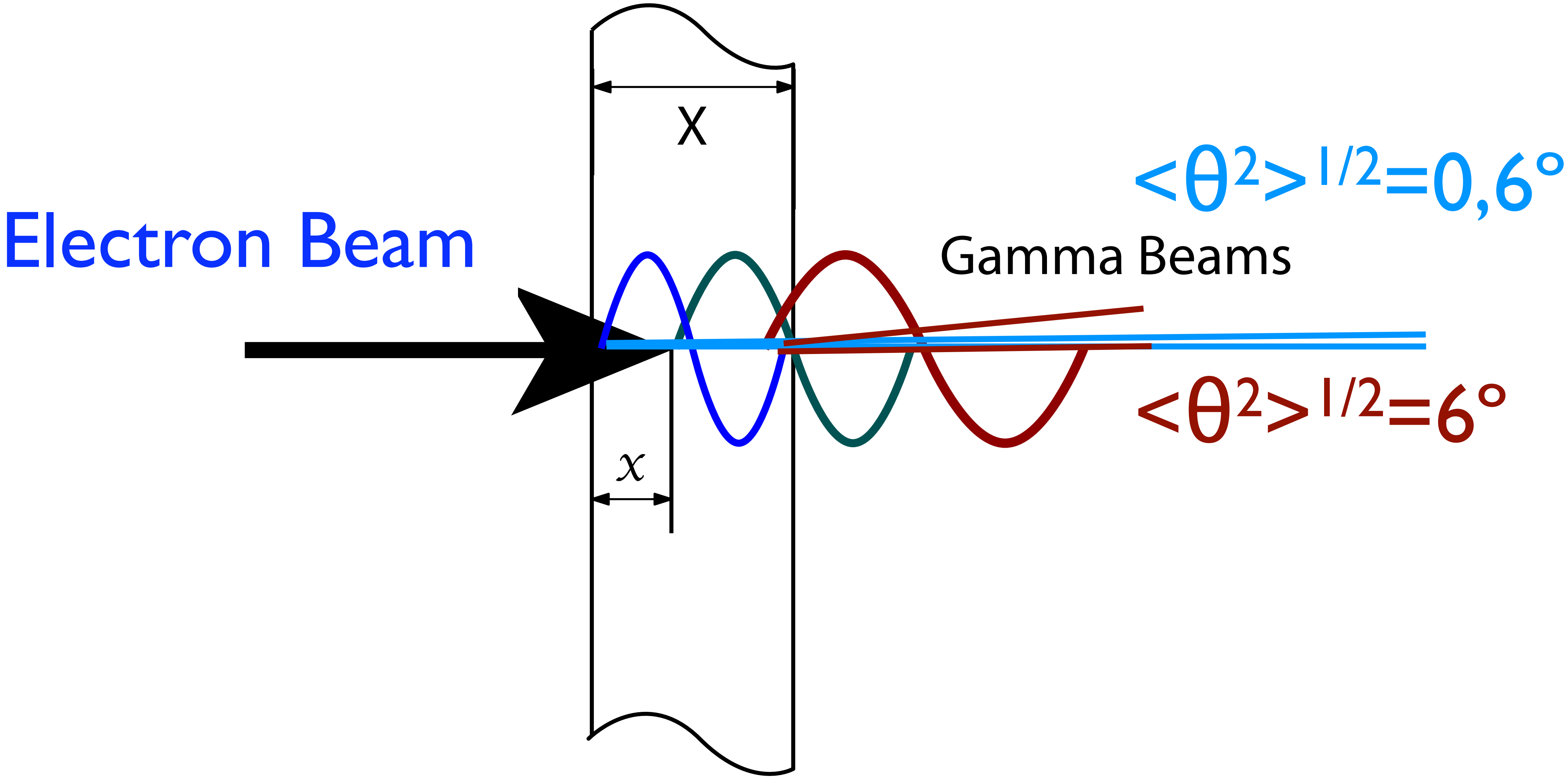
$$\left.+\frac{E}{E_0}\left[\frac{2}{b^2}ln(1+b^2)+\frac{4(2-b^2)}{3b^2}tan^{-1}b-\frac{8}{3b^2}+\frac{2}{9}\right]\right]$$

$$b = \left(\frac{2E_0 E Z^{1/3}}{111\ k}\right) \qquad \frac{1}{M(0)} = \left(\frac{k}{2E_0 E}\right)^2 + \left(\frac{Z^{1/3}}{111}\right)^2$$

Photon Distribution



Photon cone angle



- The photon cone from the interaction of the electron with the heavy nucleus is given by;

$$\langle\Theta^2\rangle^{1/2} \approx 1/\gamma = m_e c^2/E$$

- For E = 50 MeV, $\langle\Theta^2\rangle^{1/2}$ is ~ 10 mRad and 100 mRad at 5 MeV.

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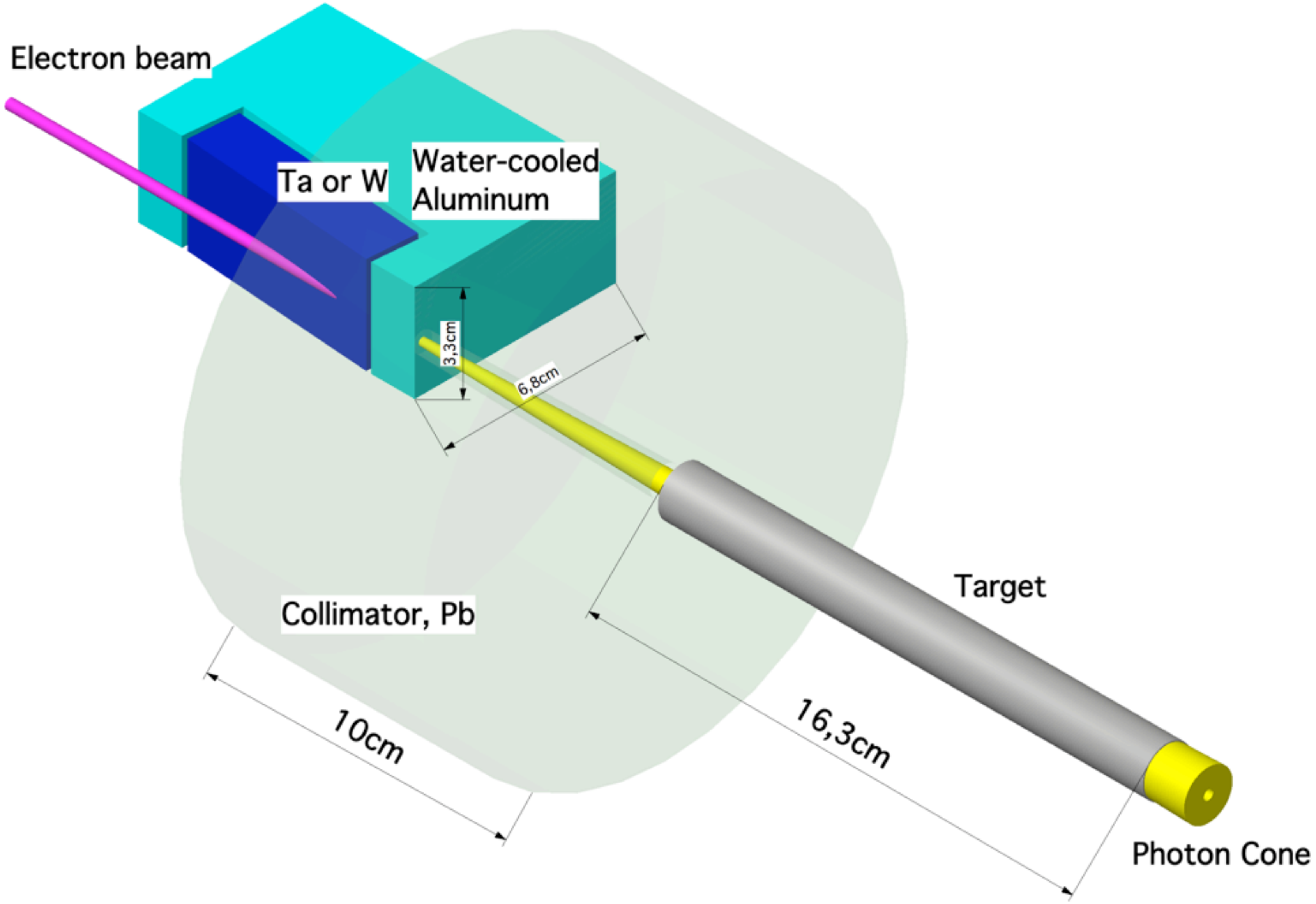
Converter, Option 1



- The converter is made of solid Ta or W block imbedded into an Aluminum
- The converter is tilted to allow the maximum surface area where the beam interact with the converter

Cooling; option 1

- The integral of the photon distribution gives approximately 1 photon for every electron. Assuming no contribution from the photon; the amount of power we have to remove is 1/2 of the total electron beam power ~ 500 kW.

$$P[kW] = c_{coolant} \Delta T[K] \, Q[kg/s]$$

Material	Density (g/cm^3)	c (J/gK)	ΔT (K)	Q (l/m)
H_2O	1	4,18	30	240
Na	0,97	1,23	300	84
Hg	13	0,14	300	53
Pb	11,34	0,16	500	33

- Because of the required beam size on the converter this option is impractical.
- The power density is extremely large.
- Cannot see how to bring that much coolant close to the hot spot.

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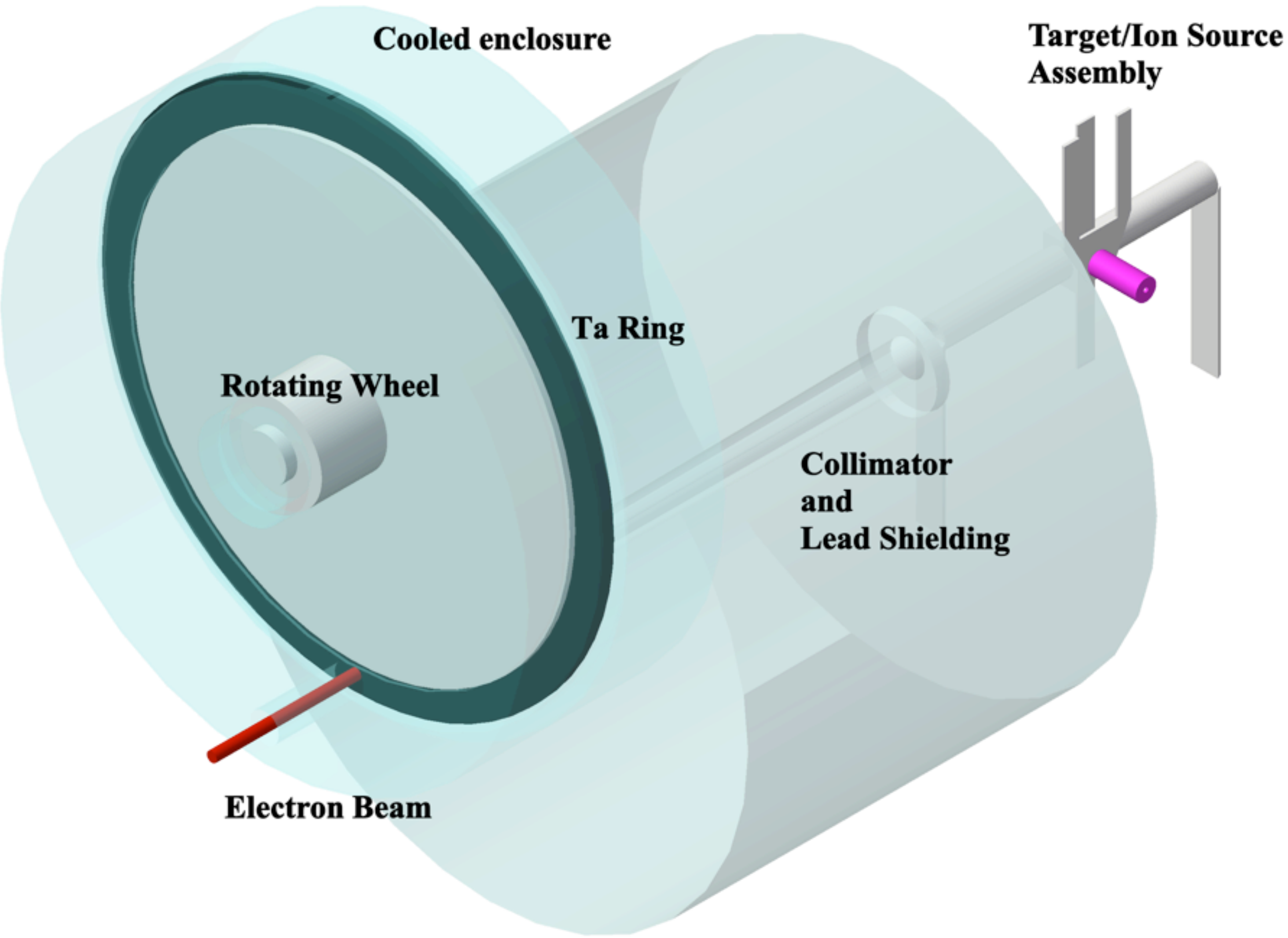
Converter, Wheel



- The converter is made of rotating Ta or W ring.
- The electron beam heats the refractory metal to ~ 2000º C.
- The wheel rotates and the hot spot cool down by radiative cooling.
- The wheel is embedded into a cooled Al or Cu casing to remove the power.

Converter, Wheel

- Estimation of the cooling time for the rotating wheel,

$$P = \frac{dE}{dt} = \epsilon\sigma A\left(T_f^4 - T_{ambient}^4\right)$$

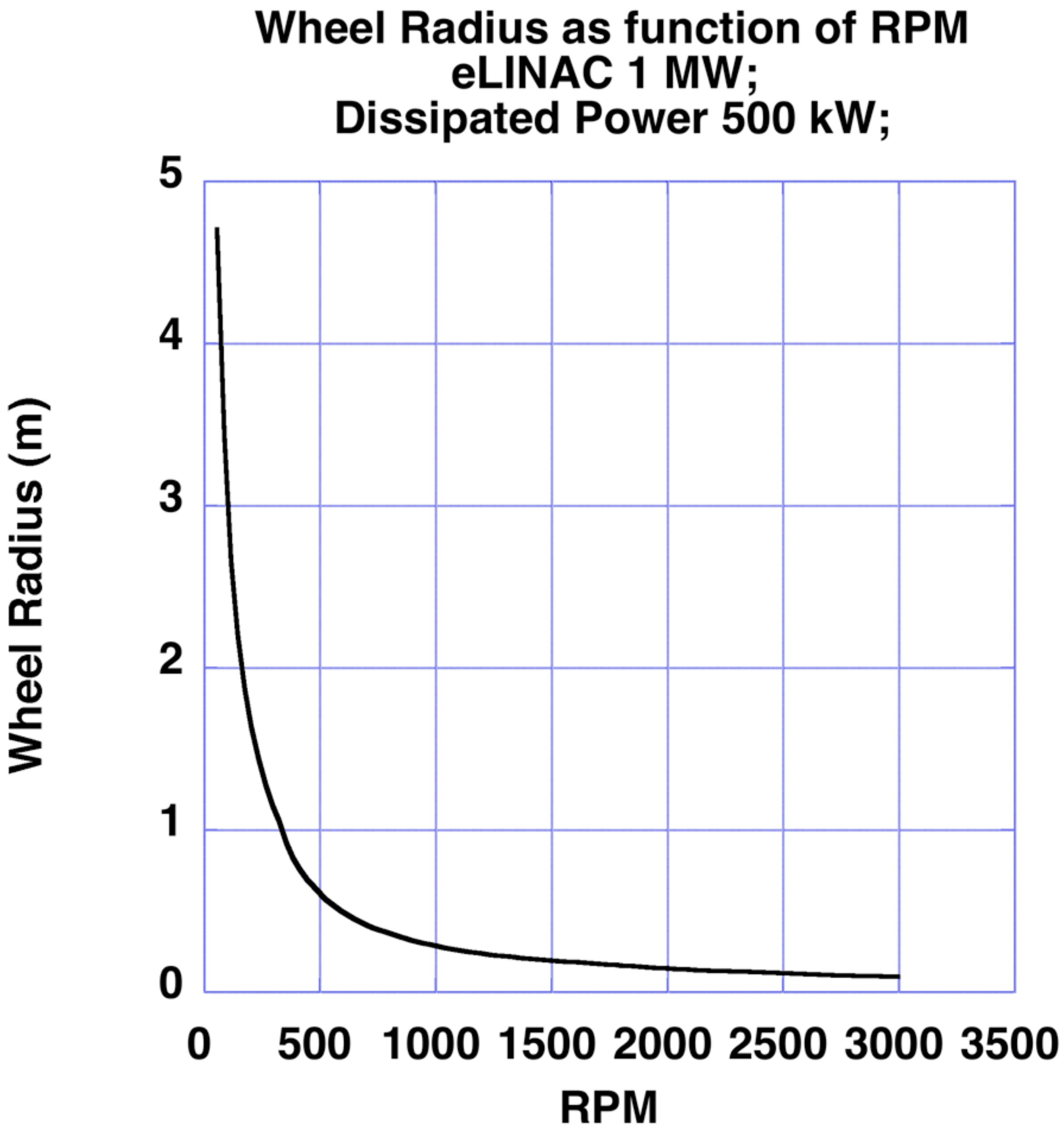
If T_f is << than $T_{ambient}$ we can consider only the following equation

$$P = \frac{dE}{dt} \approx \epsilon\sigma A T_f^4$$

$$t_f \approx \frac{M_{Rad}\,N_{Avogadro}\,k}{4A_{mole}\sigma\epsilon A_{Rad}}\left[\frac{1}{T_f^3} - \frac{1}{T_i^3}\right]$$

Converter, Wheel

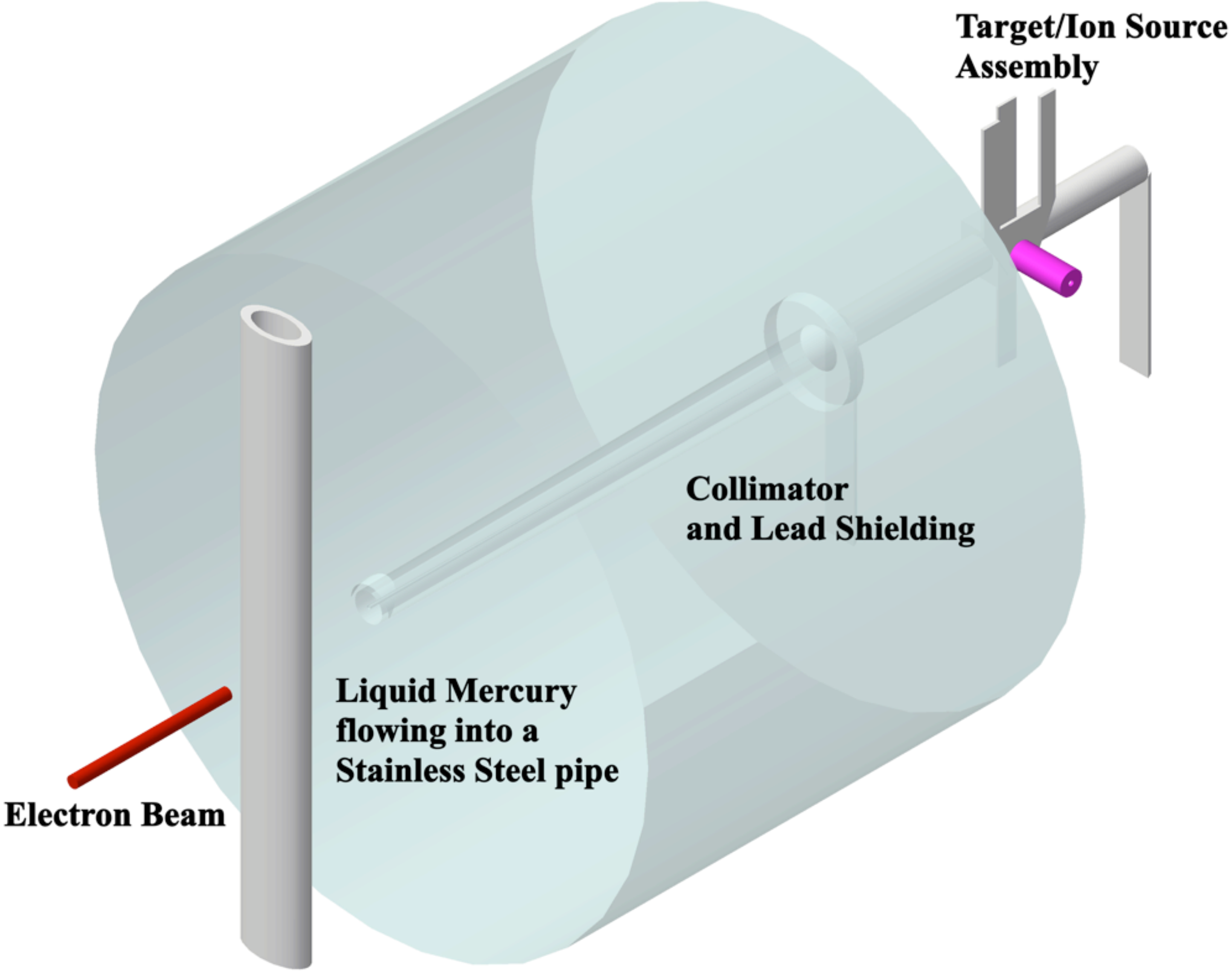
- **Figure giving the Wheel rotating frequency for different radius.**



- **500 kW,**
- **$\Delta T = 1000^{o}C$,**
- **Tantalum**

- **THINGS TO DO**
- **Evaluate the practicality of this solution;**
  - **Size of the wheel is quite large, Large size of the wheel means a large vacuum volume.**
  - **Estimation of the stored energy,**
- **Cooling of the casing, how practical it will be,**
  - **Depends on the size the casing,**
  - **Size of the cooling pipe.**

Converter, Option 3

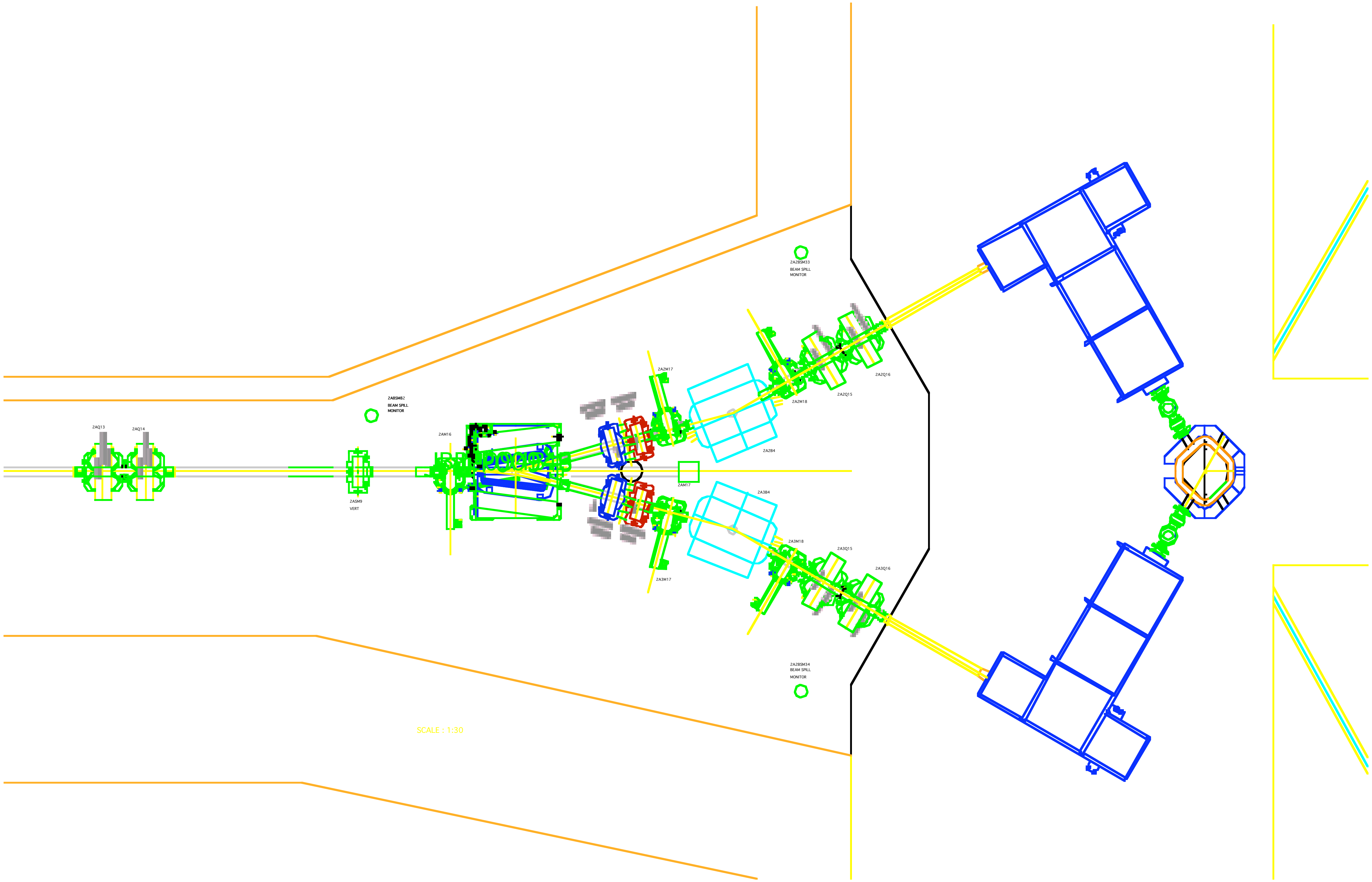


- Using a liquid Mercury converter allow to combine the converter and the coolant in one.
- For a $\Delta T = 300^{o}C$ we will need 51 l/m.

$$R = \frac{\rho v D}{\mu}$$

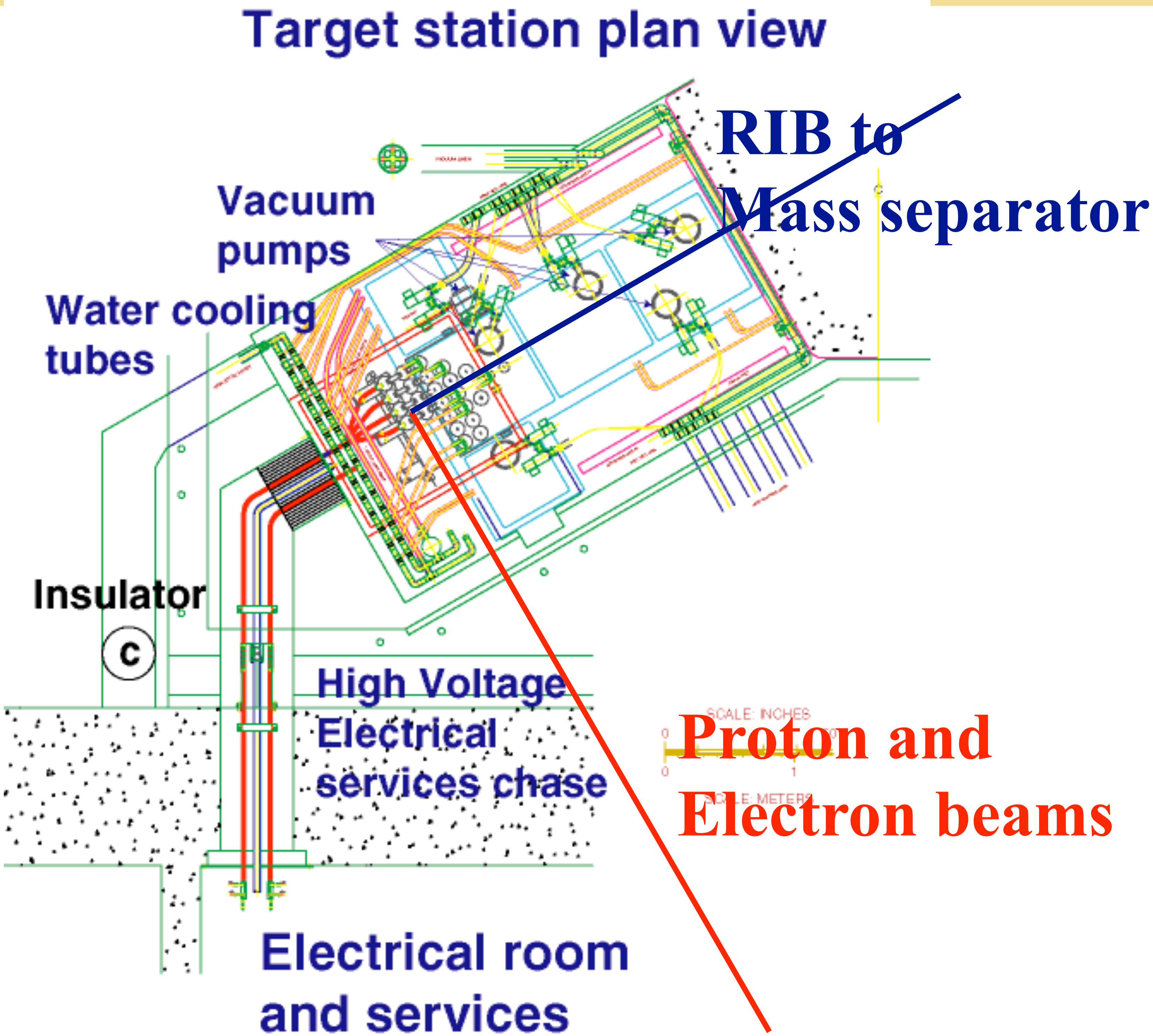
The Reynolds number is 4,7e5 using ρ = 13,6 kg/l, v= 1,3 m/s and a pipe of 4 cm.

Target Station



Target Station

- Target station is composed in five modules,
  - Entrance module
  - Target module
  - Proton beam dump
  - Two modules for heavy ions beam optics
- New design must be compatible with actinide target.



EVALUATION OF THE ISAC TECHNOLOGY

The target station is an assembly of 5 modules, entrance, target and beam dump, plus two exit modules containing the heavy ion optics elements for beam preparation to the mass separator.

Advantages of the ISAC target station concept

1. **The modular approach permits use of high intensity beam on target since the non-hard radiation material are located in a zone where the radiation fields are low enough.**
2. **Front end can be exchanged as well as the target.**

Disadvantages of the ISAC target station concept

1. **Actual confinement box housing the target not hermetic.**
2. **Hand on connection and disconnection of the target services.**
3. **Target change takes 3 to 4 weeks,**
4. **The target can not be conditioned and ready for use,**
5. **Target module has to move from the target station to the hot-cell, ~ 30 m.**
6. **Air sensitive material such as LaC and UC creates extra difficulties.**

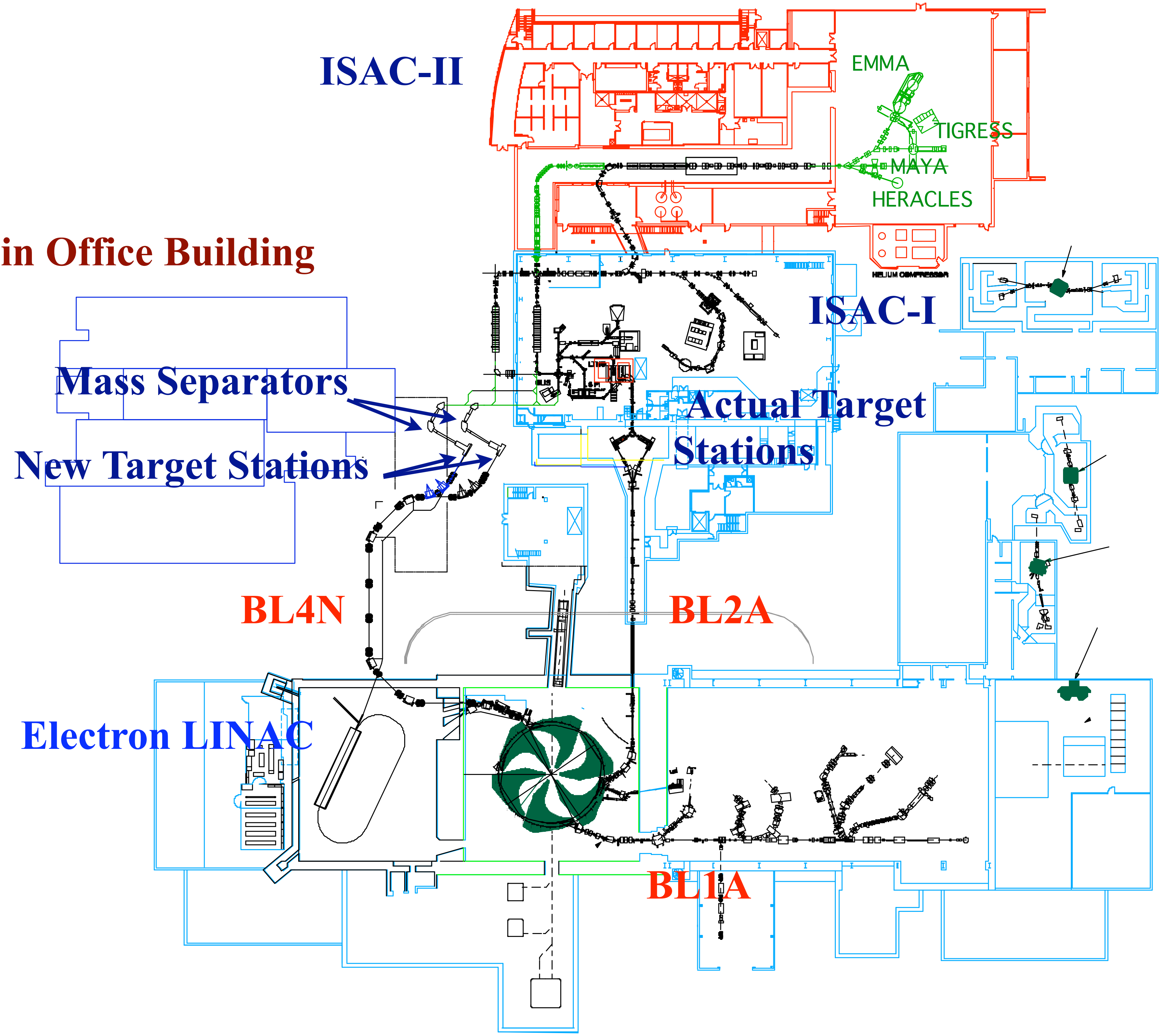
Findings

- In the present situation we have the possibility to deliver only one RIB at the time for physics.
  - Two target stations are sharing the same mass separator.
  - Maintenance in the target hall is taking 25-30% of the time.
  - RIB development is also taking 25% of the time.
- We can provide more RIB using a new BL4N, proton and electrons

Solutions

- Target has to be inside a completely sealed containment box,
- Target/ion source services has to be connected remotely,
- Hot cells located above the target station,
- Two target stations has to work completely independently of each other,
  - Independent mass separator,
  - Independent cooling water,
  - Independent nuclear ventilation,
- We must be able to work on one target stations while the other one is being serviced.

TRIUMF Layout



ISAC-II

Main Office Building

ISAC-I

Mass Separators

Actual Target Stations

New Target Stations

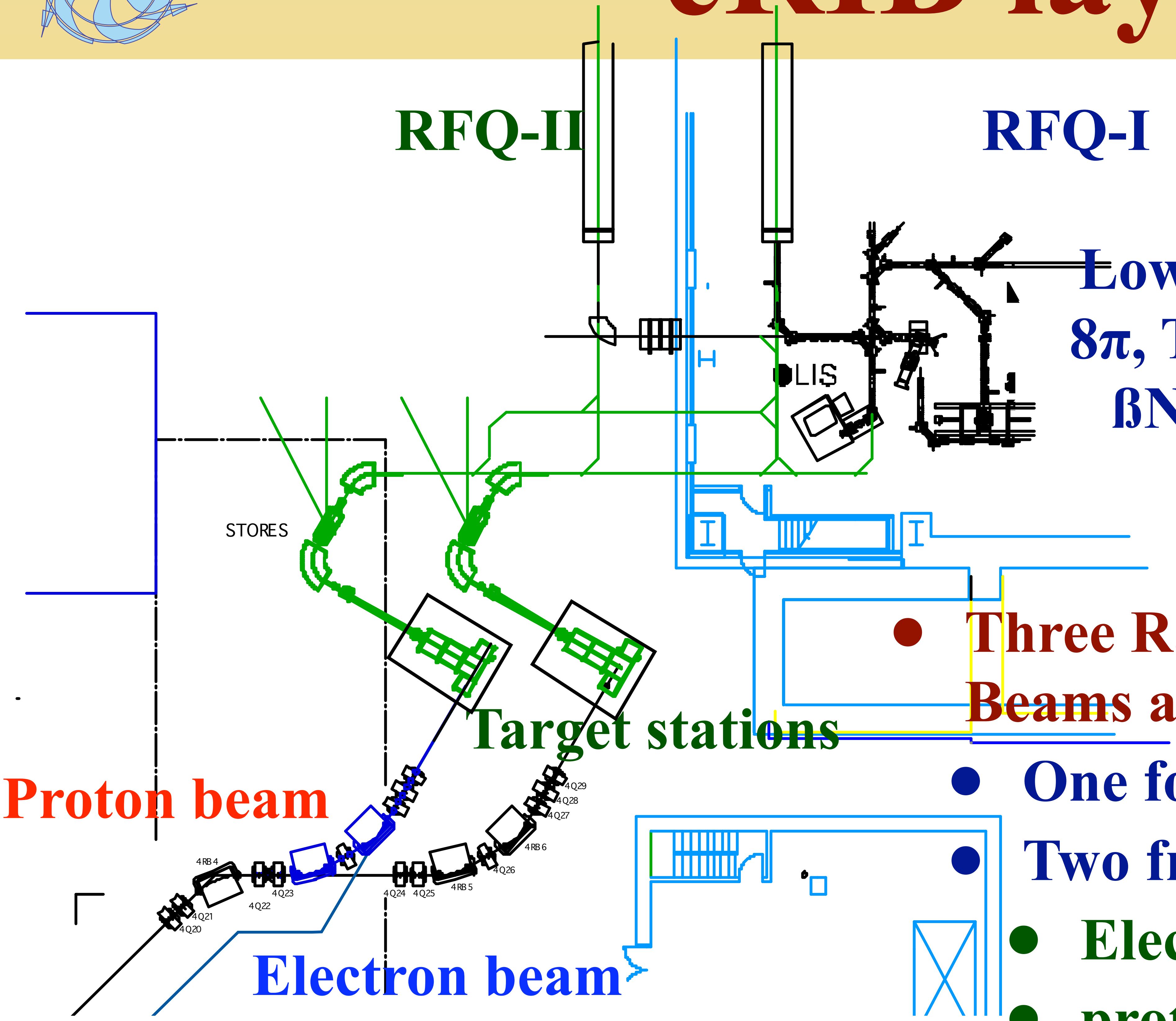
BL4N

BL2A

Electron LINAC

BL1A

eRIB layout



RFQ-II

RFQ-I

Low energy
8π, TRINAT
ßNMR,...

Target stations

Proton beam

Electron beam

- Three Radioactive Ion Beams at the same time
- One form BL2A
- Two from BL4N
  - Electron-photo-fission
  - proton up to 200 µA

Summary

- We have formed a design group for the new target stations;
  - TRIUMF, ISOLDE/CERN, GANIL
  - Report by Feb. 2008,
  - Target Station design,
    - New Front-end for mass separator including cooler,
      - better mass resolution
    - Two Entrance module designs;
      - one for electron
      - one for proton
- Step approach
  - 50 kW, electron directly into the target,
  - 100 kW, W converter,
  - 500 kW, Liquid mercury converter,
  - Complete study to provide detail specifications for engineering design, mid 2009.