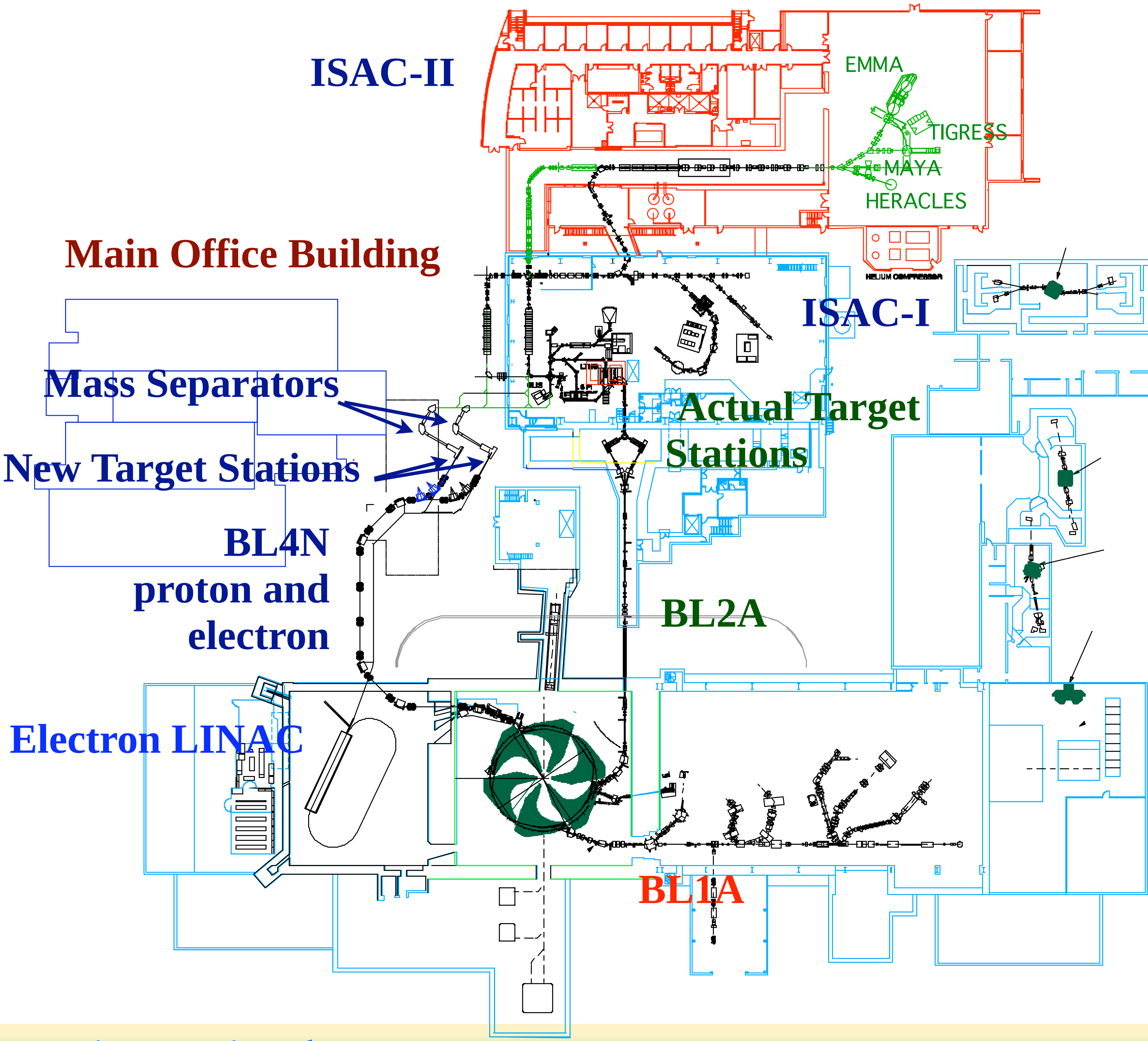
TRIUMF

Actinide Target Station & ^{238}U Photofission Yield

Pierre Bricault

SEEC, 25-26 March 2008

TRIUMF Layout



- Next 5-YP
- Three RIB to users
  - One RIB from actual ISAC
  - Proton Beam line (< 200 µA; 475 MeV)
  - Electron Beam producing photofission (10 mA ; 50 MeV)

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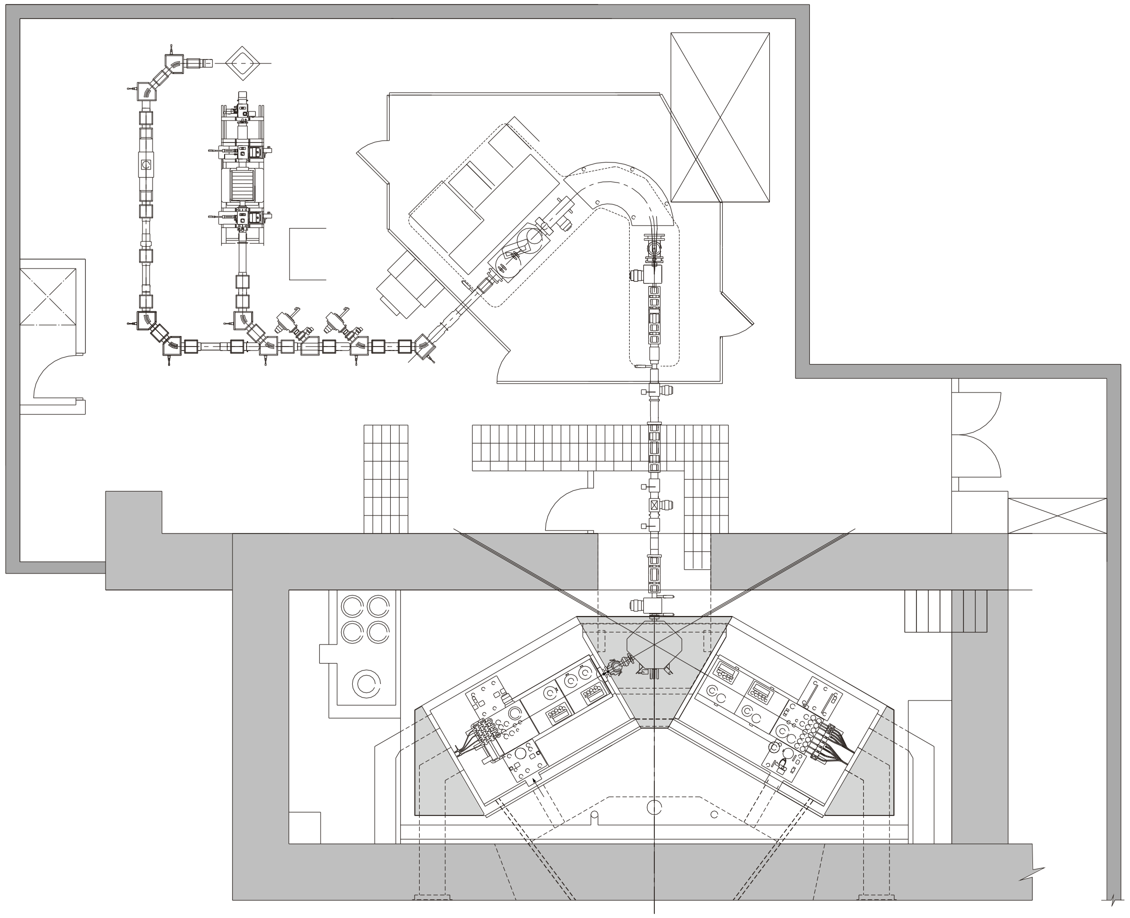
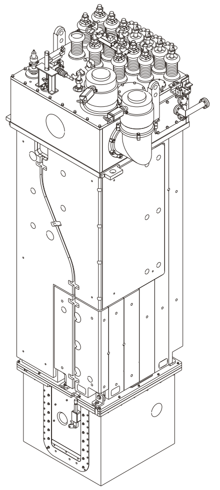
ISAC-III

- More RIB to USers
- New Target Station Compatible with Actinide Target Material
- New High Intensity Beam Dump: at least 200 µA
- We are proposing a solution to deliver Three RIB to Users
  - One RIB from actual ISAC
  - Proton Beam line (< 200 µA; 475 MeV)
  - Electron Beam producing photofission (10 mA ; 50 MeV)
- First of all, new target stations has to 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.**



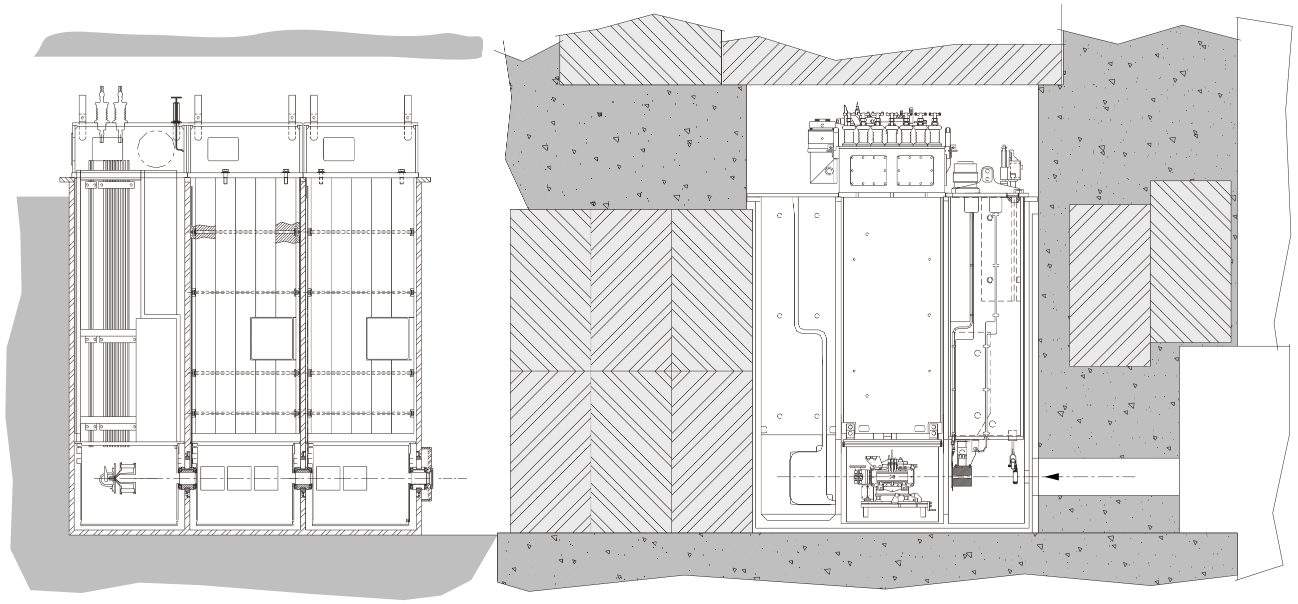


Advantages of the ISAC target station concept

1. The modular approach permits use of high intensity (up to 100 µA) proton beam on target.

2. Non-hard radiation material are located in a zone where the radiation fields are low enough.

3. Front end optics can be exchanged as well as the target.



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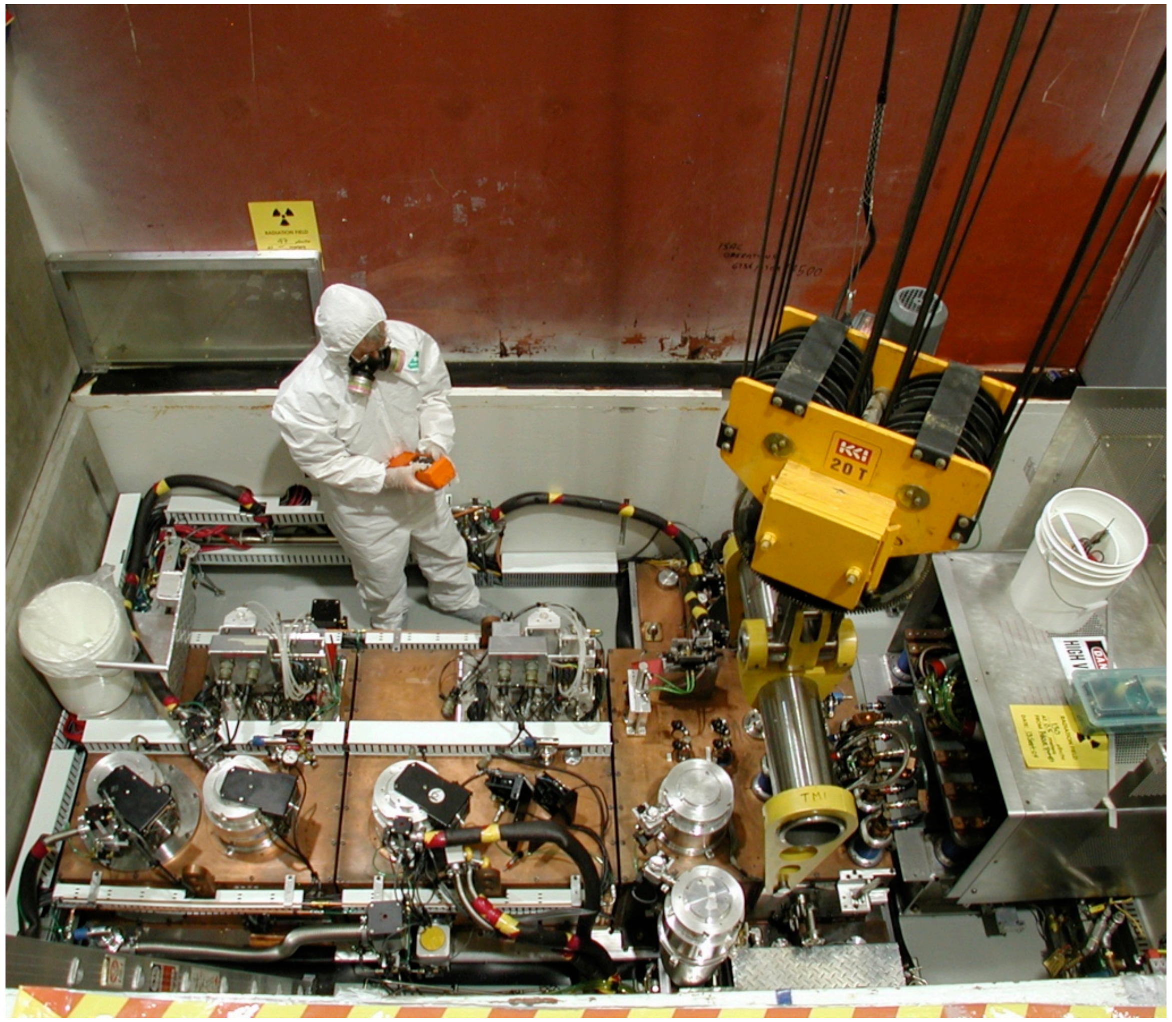
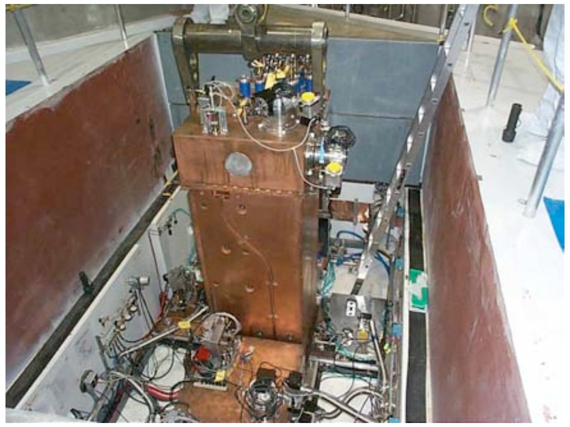
EVALUATION OF THE ISAC TECHNOLOGY

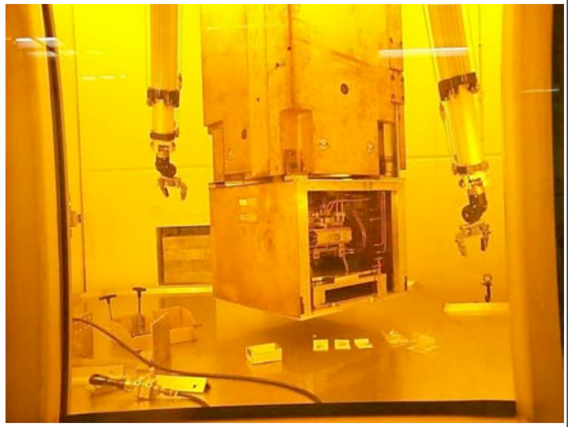
- **Disadvantages of the ISAC target station concept**

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



Target module





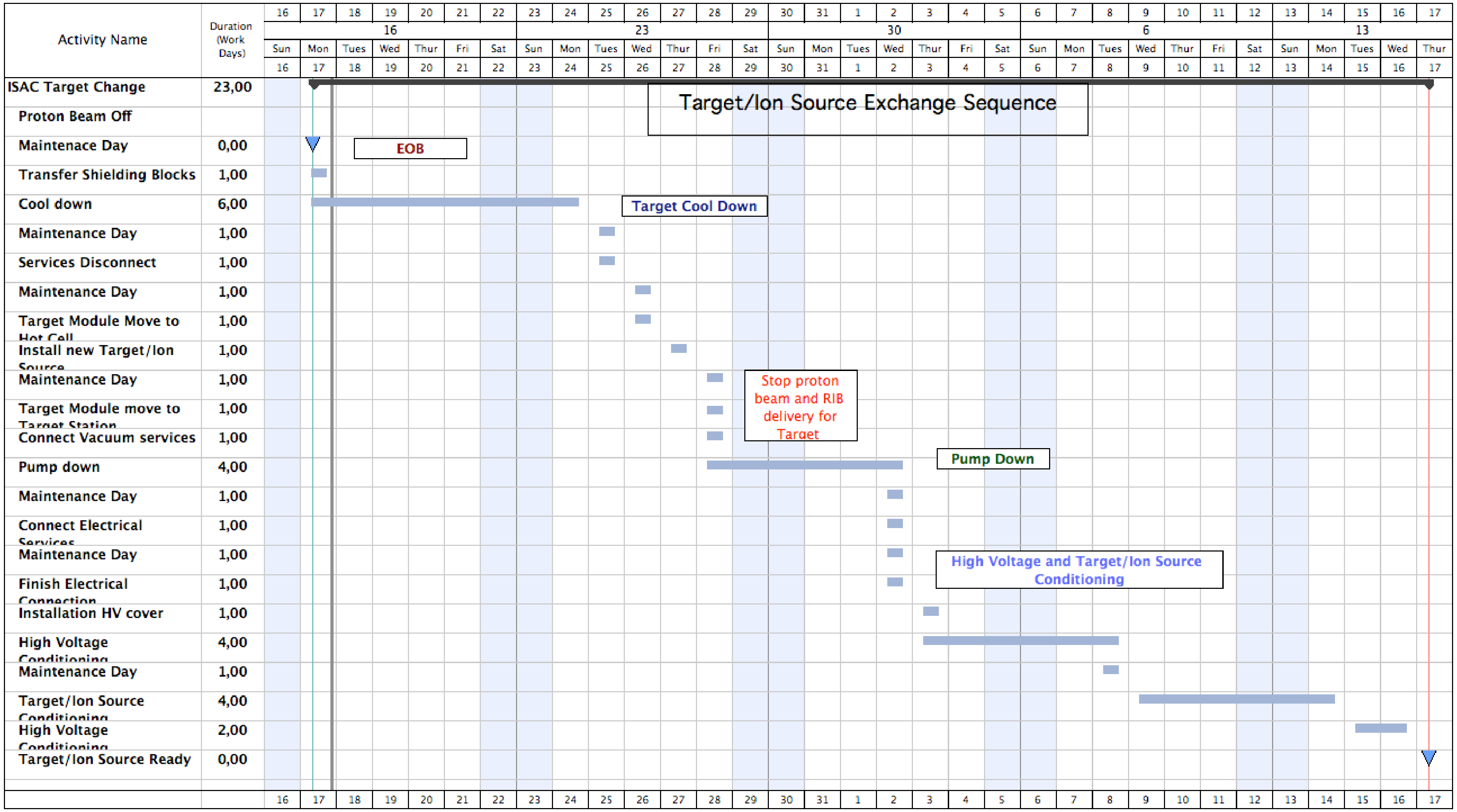
Other Findings

- **In the present situation we have the possibility to deliver only one RIB at the time for physics.**
  - **Our two target stations are sharing the same mass separator.**
  - **Maintenance in the target hall is using approximately 25-30% of the time.**
  - **RIB development is also taking 25% of the time.**
  - **These effects reduce beam time for experiments.**
- **Need more beams deliver to ISAC users.**

Solutions

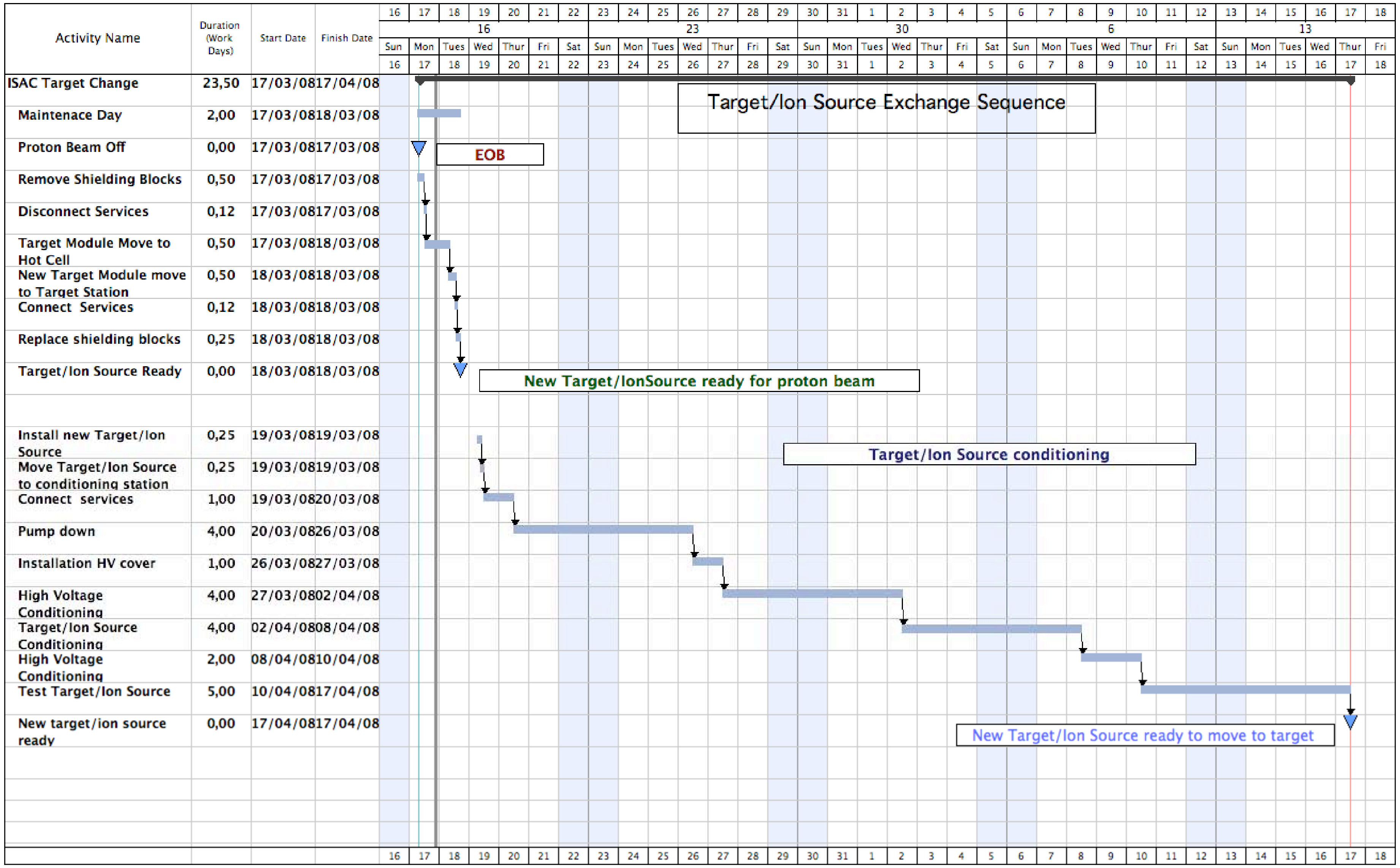
- Target has to be inside a completely sealed containment box,
  - Handling,
  - conditioning before use,
- Target/ion source services has to be connected remotely,
- One Hot-cells dedicated to target/ion source exchange only,
- Two target stations has to work completely independently of each other,
  - Independent mass separator,
  - Independent cooling water,
  - Independent nuclear ventilation,
- We must be able to service one target station while the other one is delivering RIB to experiment or beam R&D.

Target exchange



- To exchange the target its takes from 3 (need two shifts without proton beam) to 5 weeks,
- Its forces us to run our target much longer than we should,
  - Low yield because of the radiation damage.

Target exchange

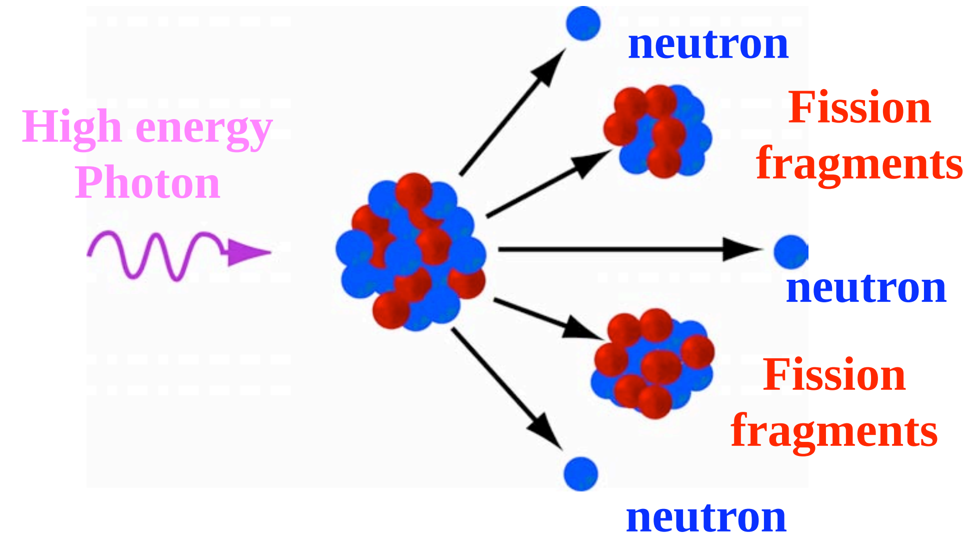


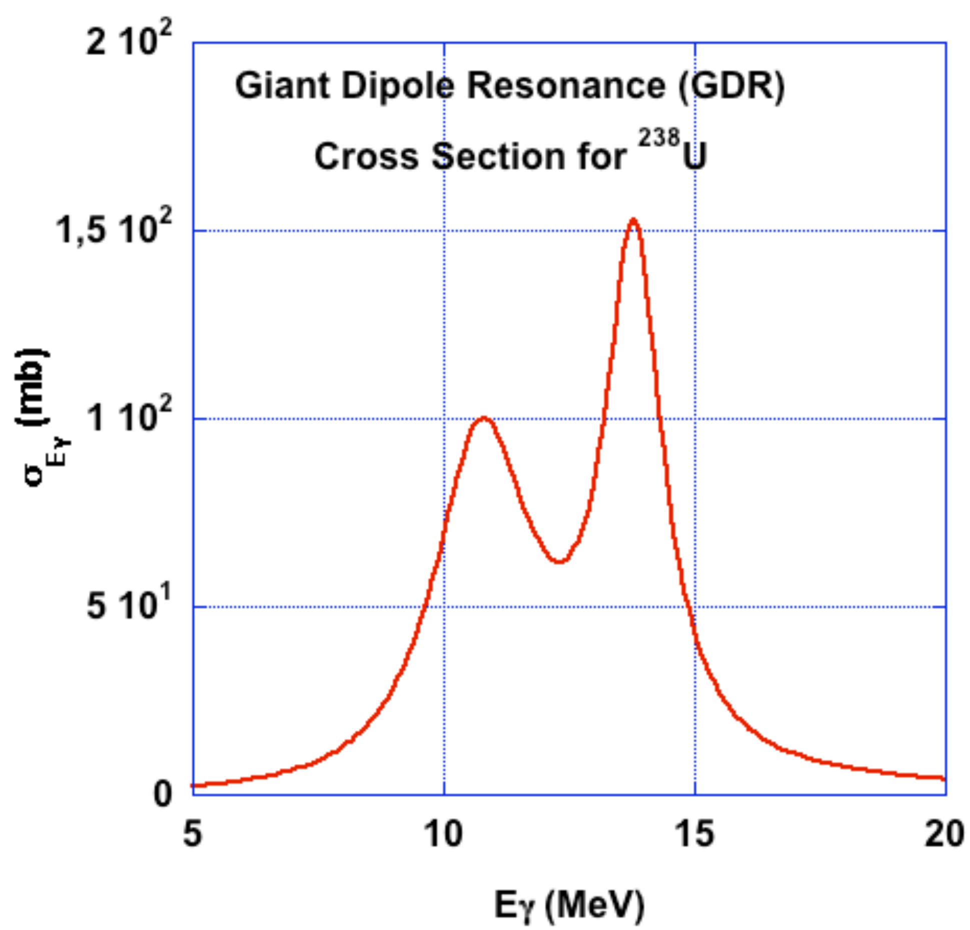
Activity Name	Duration (Work Days)	Start Date	Finish Date
ISAC Target Change	23,50	17/03/08	17/04/08
Maintenace Day	2,00	17/03/08	18/03/08
Proton Beam Off	0,00	17/03/08	17/03/08
Remove Shielding Blocks	0,50	17/03/08	17/03/08
Disconnect Services	0,12	17/03/08	17/03/08
Target Module Move to Hot Cell	0,50	17/03/08	18/03/08
New Target Module move to Target Station	0,50	18/03/08	18/03/08
Connect Services	0,12	18/03/08	18/03/08
Replace shielding blocks	0,25	18/03/08	18/03/08
Target/Ion Source Ready	0,00	18/03/08	18/03/08
Install new Target/Ion Source	0,25	19/03/08	19/03/08
Move Target/Ion Source to conditioning station	0,25	19/03/08	19/03/08
Connect services	1,00	19/03/08	20/03/08
Pump down	4,00	20/03/08	26/03/08
Installation HV cover	1,00	26/03/08	27/03/08
High Voltage Conditioning	4,00	27/03/08	02/04/08
Target/Ion Source Conditioning	4,00	02/04/08	08/04/08
High Voltage Conditioning	2,00	08/04/08	10/04/08
Test Target/Ion Source	5,00	10/04/08	17/04/08
New target/ion source ready	0,00	17/04/08	17/04/08

- We are proposing to exchange the target within two days,
- We will have a dedicated hot-cell to exchange the target. The new target will be conditioned and ready for on-line operation before it is installed in the target station.

Photofission

- Photofission of ^{238}U has been proposed in 1999 by W. T. Diamond [NIM, v 432, (1999)p471] as an alternative to produce RIB in Chalk River.
- The idea was later push a little further by Y. T. Oganessian in 2000 [RNB2000, Nucl. Phys. A 701 (2002) p 87],
- The continuous gamma spectrum produce by electron is utilized to excite the giant dipole resonance (GDR) in ^{238}U.





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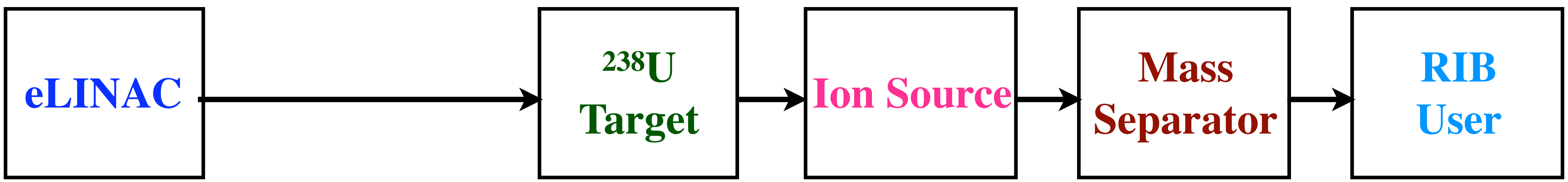
Basic Parameters

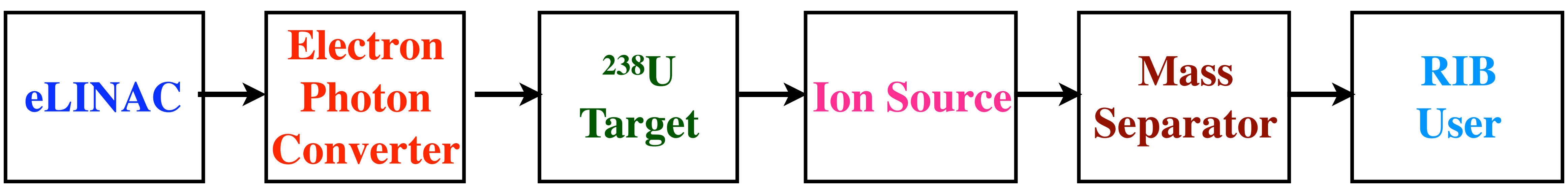
Item	Value	Units
Electron energy	50	MeV
Total power	0,5	MW
Electron current	0,01	Ampère
Target, UC_2	15	g/cm^2

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

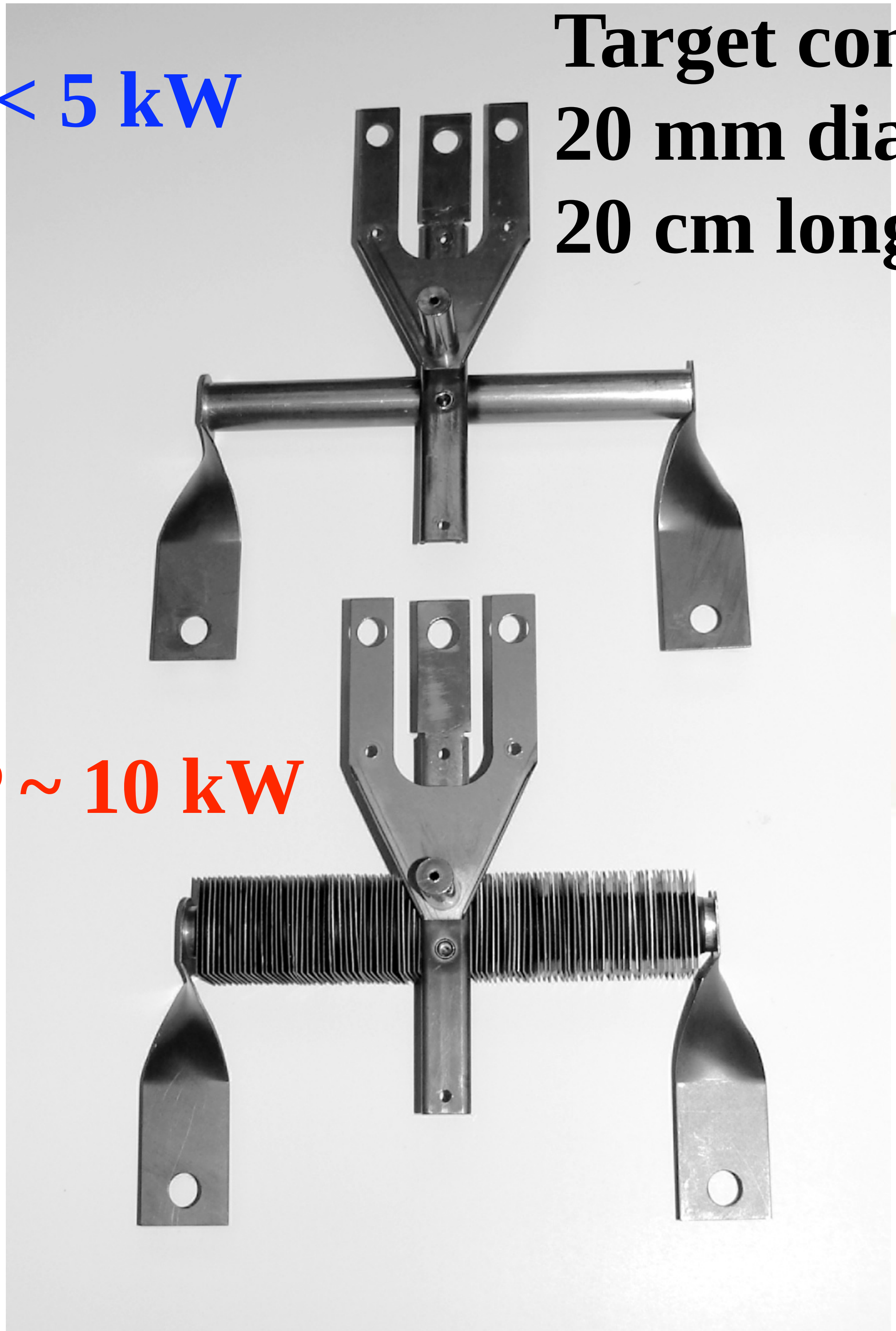
Low electron beam power < 25 kW

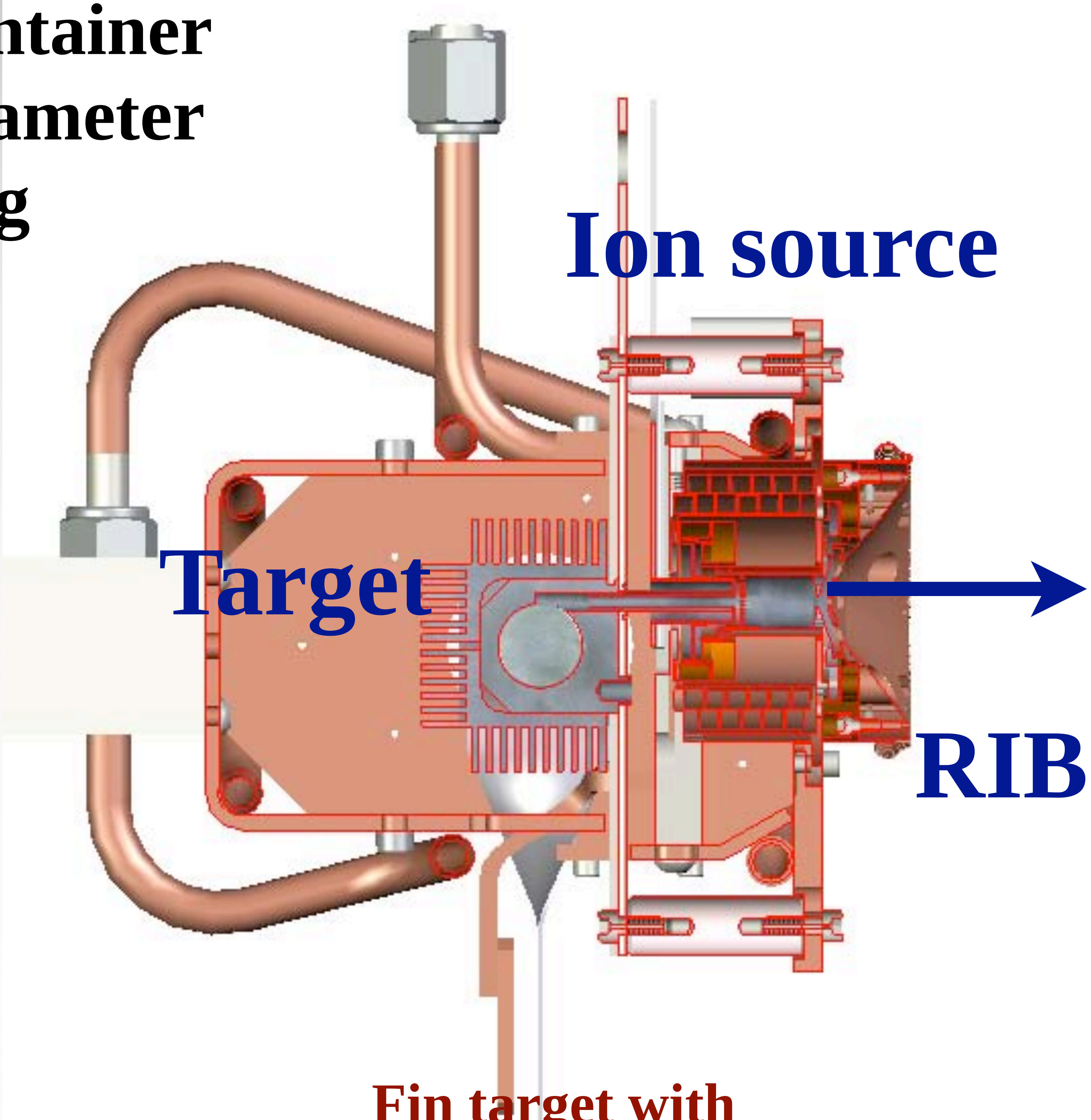


High electron beam power > 25 kW



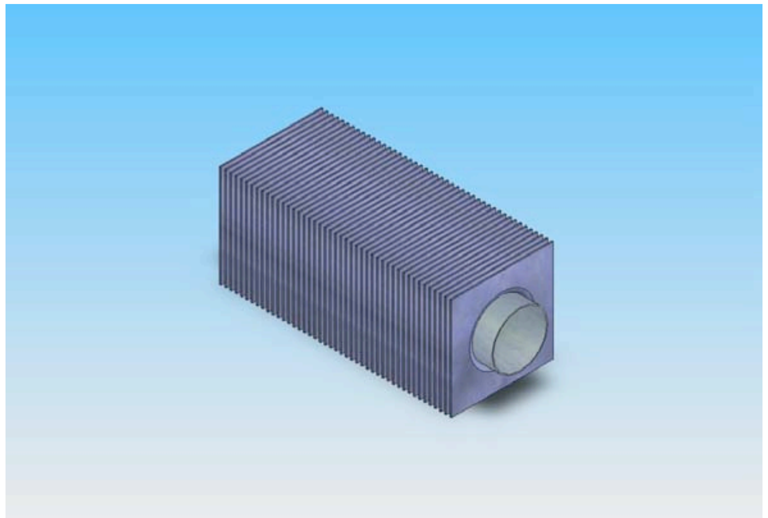
ISAC Target/Ion Source

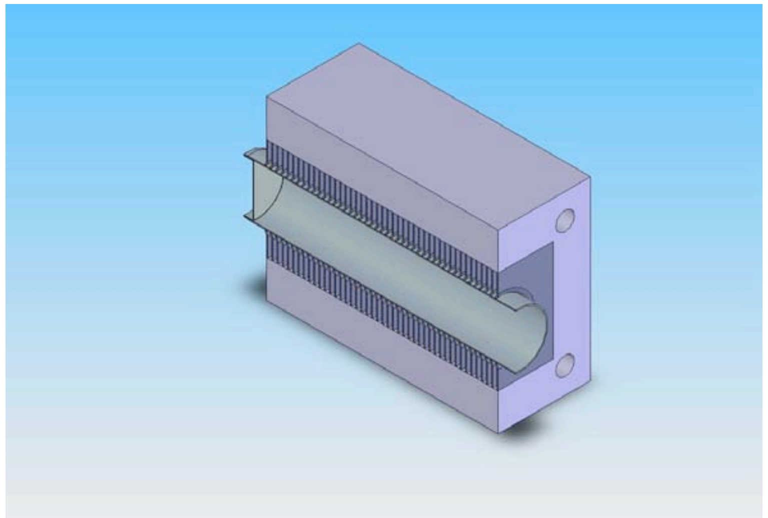


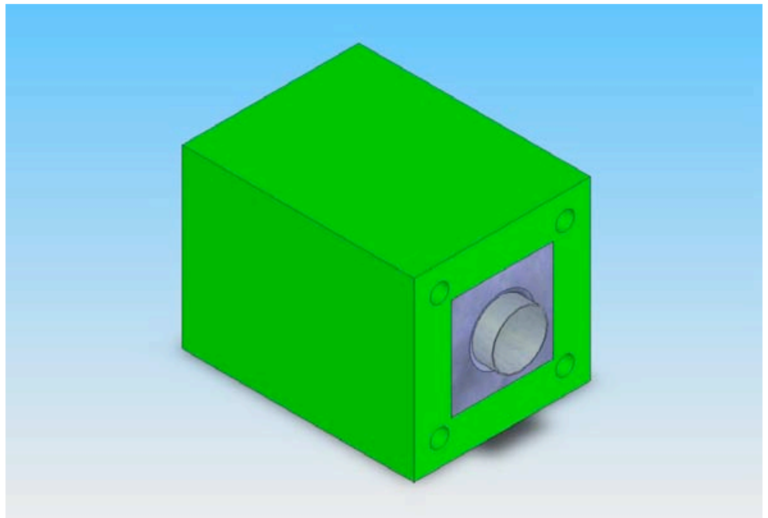


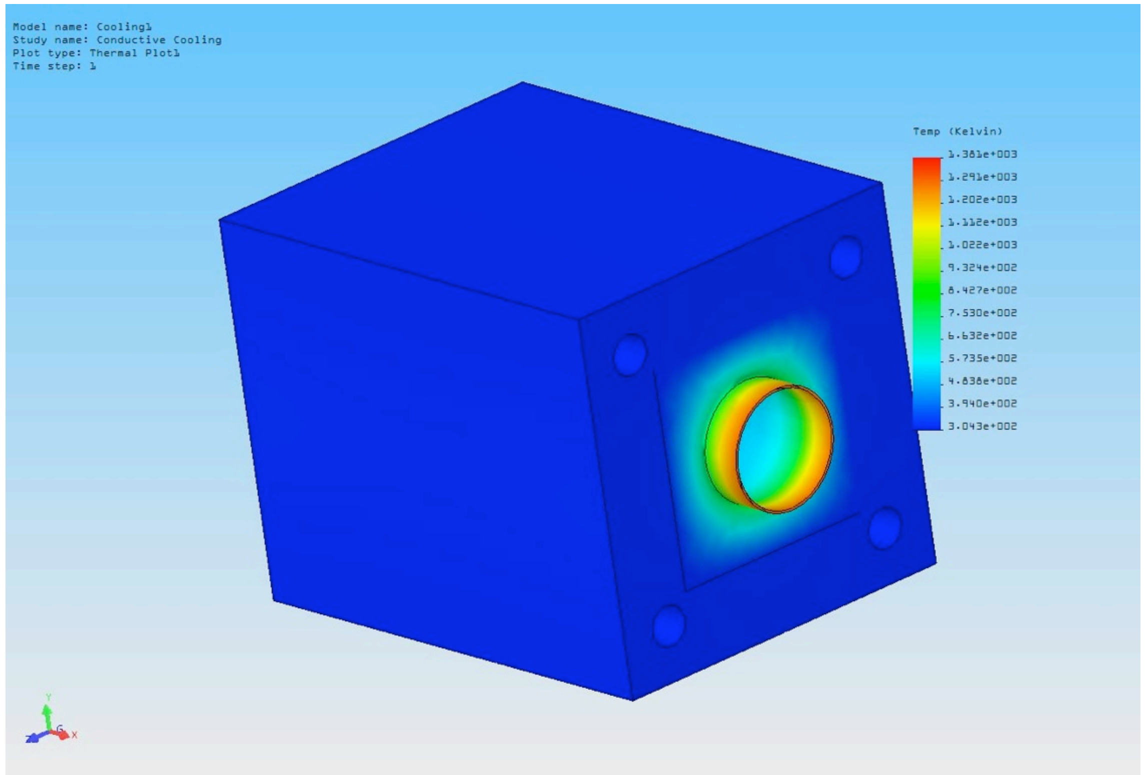
ISAC Target/Ion Source

- **Cooling concept for P ~ 20 - 30 kW**









Electron Energy & Radiation

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

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

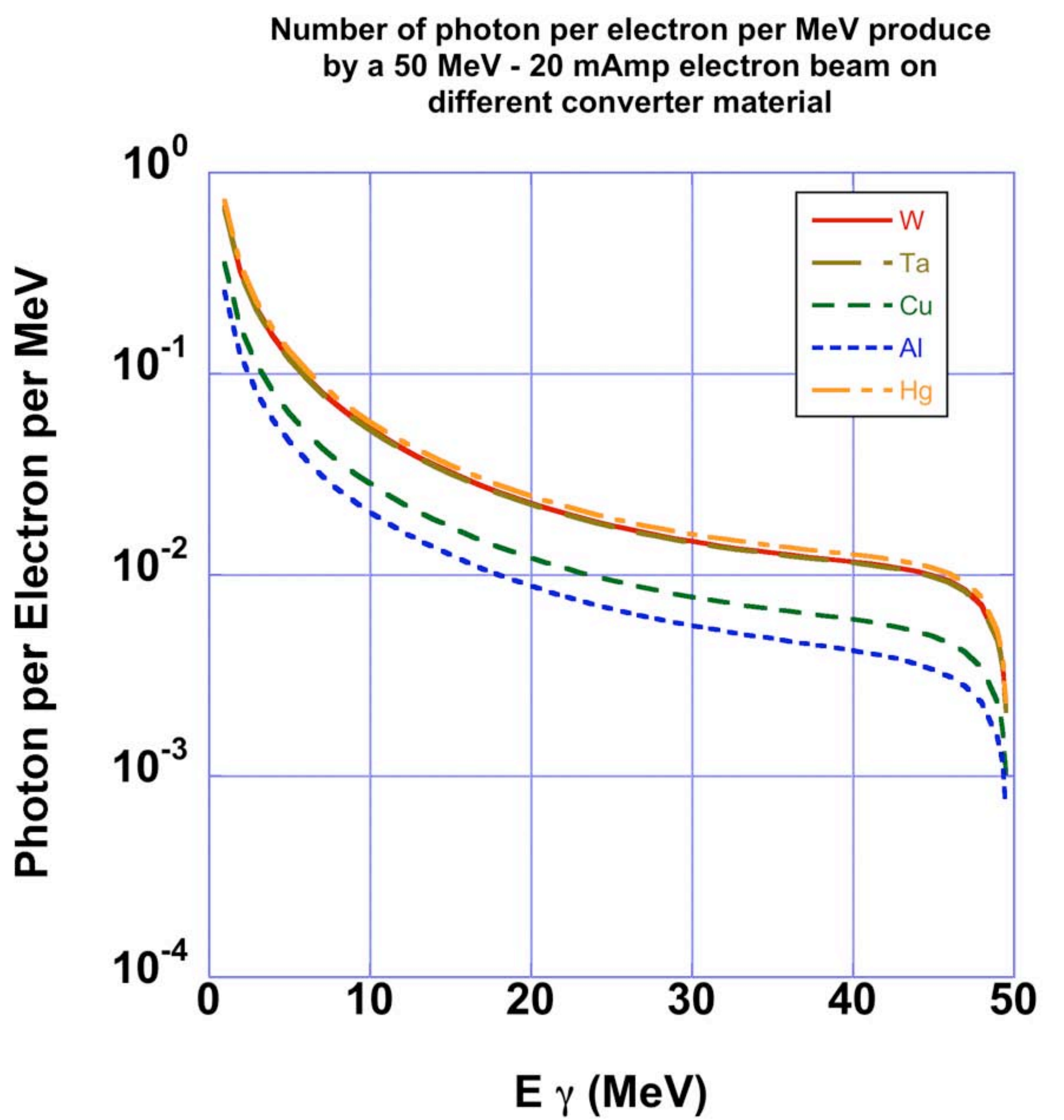
$$\overline{E} \simeq E_0 exp(-\frac{\rho \Delta x}{X_0})$$

- E is the electron energy
- α ~ 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/cm³)	$1/X_0$	X_0 (g/cm²)	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 Distribution

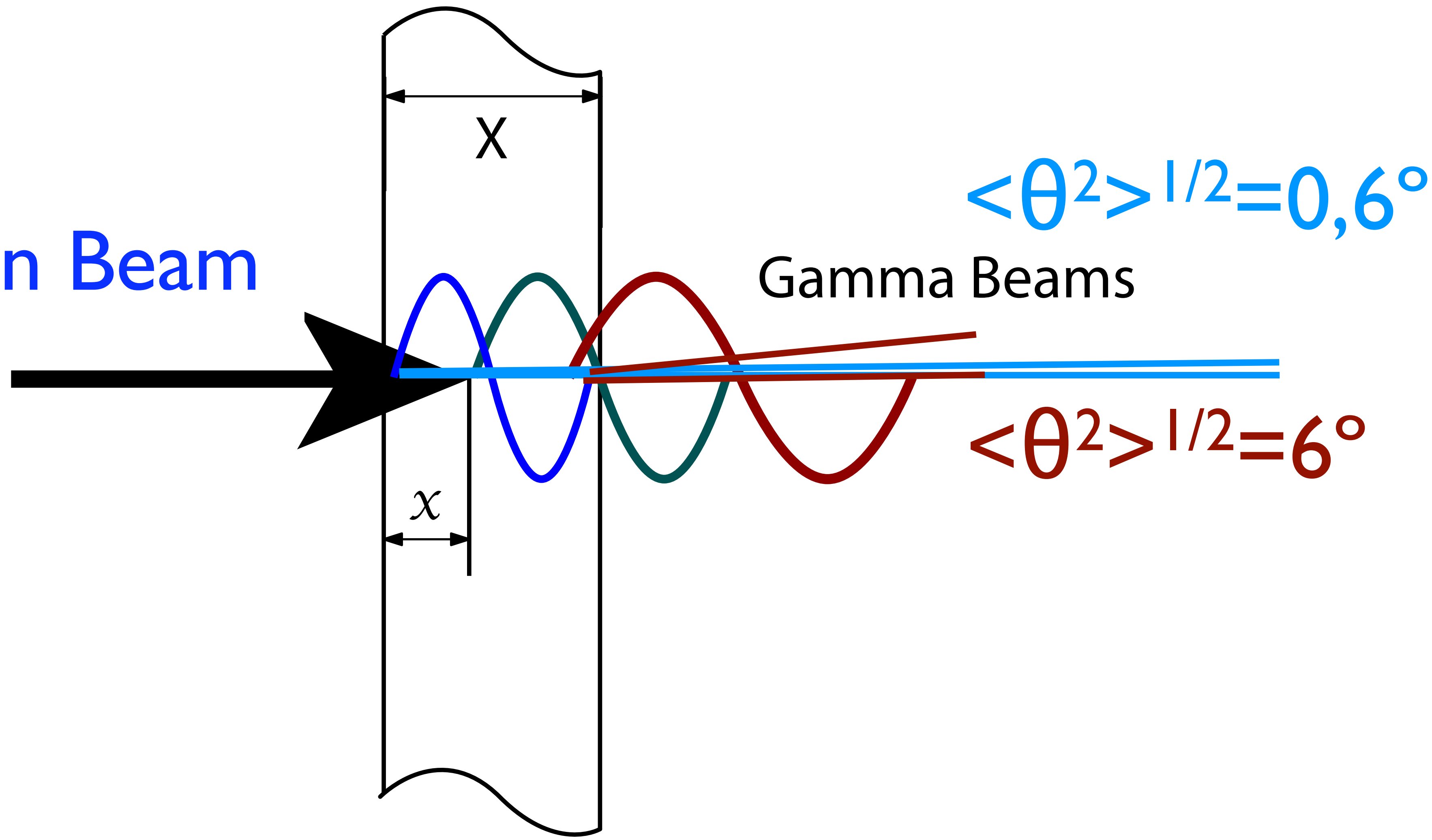
- **Using the Born approximation, Bethe, Heitler, Sauter and Racah developed an expression that gives the photo energy distribution**



$$d\sigma_k = 2\alpha Z^2 r_0^2 \frac{dk}{k}\left[\left(1+\left(\frac{E}{E_0}\right)^2 - \frac{2}{3}\frac{E}{E_0}\right)\left(lnM(0)+1-\frac{2}{b}tan^{-1}b\right)\right.$$
$$\left.+\frac{E}{E_0}\left[\frac{2}{b^2}ln(1+b^2)+\frac{4(2-b^2)}{3b^2}tan^{-1}b-\frac{8}{3b^2}+\frac{2}{9}\right]\right]$$

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

Photon cone angle



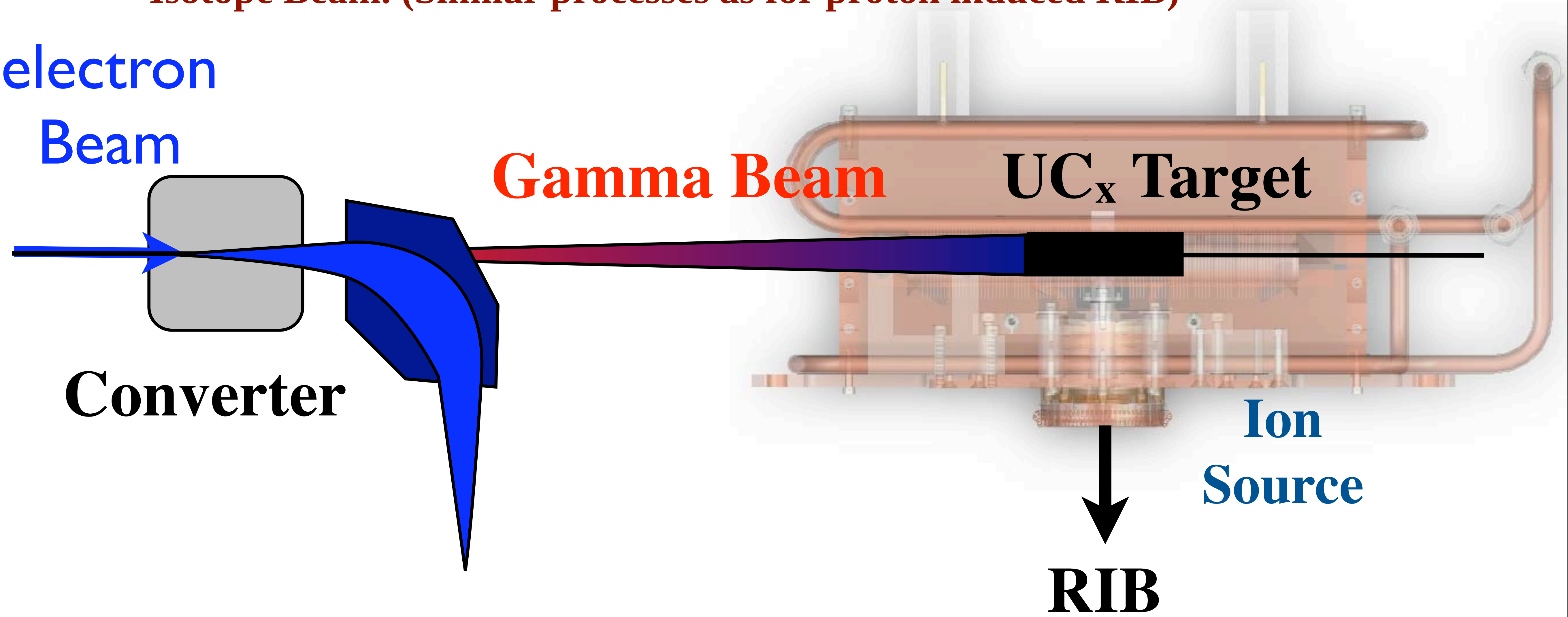
- **The photon cone from the interaction of the electron with the heavy nucleus is given by;**

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

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

Schematic Layout

- The electron beam impinges into the Hg converter and the resulting gamma beam interact with the ^{238}U target nuclei to produce photofission.
- The fission recoils stop in the target material.
- The atoms diffuse to the surface and effuse to the ion source to produce a Rare Isotope Beam. (Similar processes as for proton induced RIB)

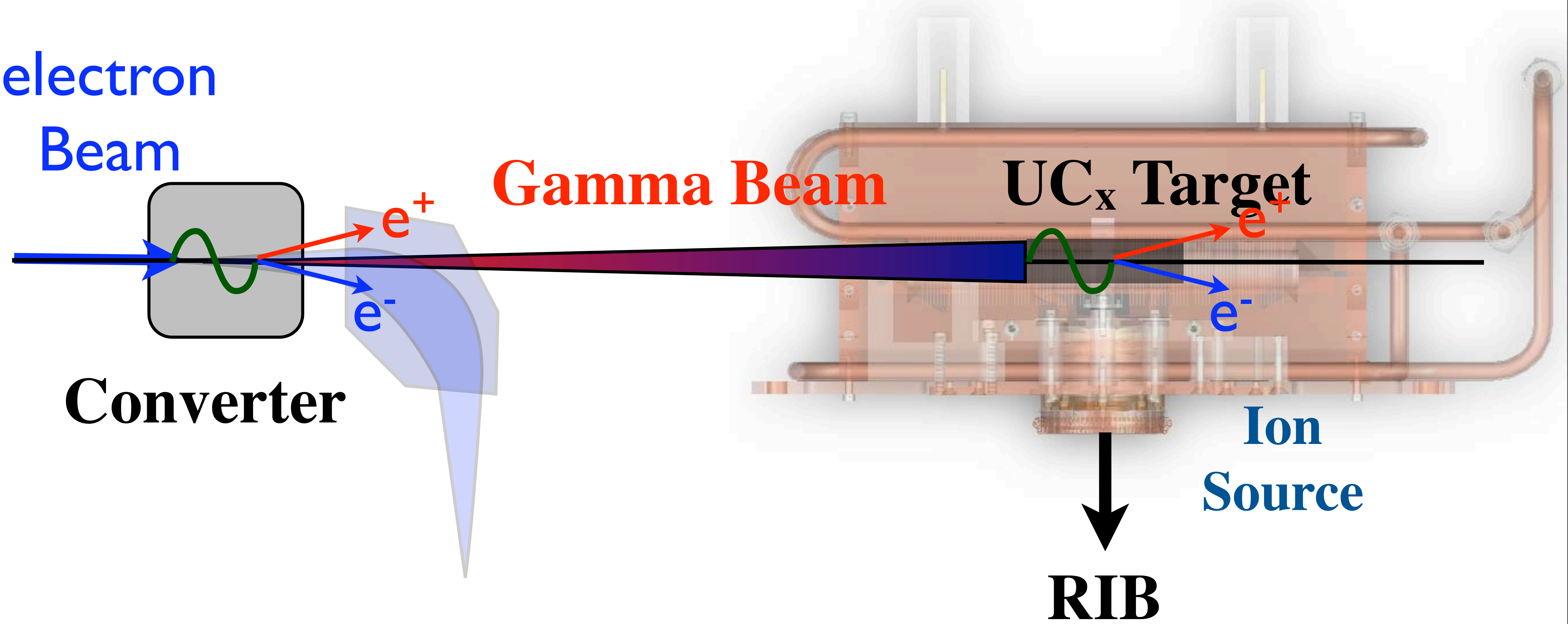


Photon Interaction

- There is three processes by which a photon can interact with matter. The relative importance depends on the photon energy.
  - At low energy the photon < 0,1 MeV the photon will interact via the photoelectric effect. The cross section for this process fall very rapidly with photon energy,
  - At photon energy up to 5 MeV the Compton scattering is the dominant process.
  - At higher energy the photon converts into an electron-positron pair in the electrical field of a nucleus.
- The result of these processes is that the photon intensity is attenuated.

Gamma Attenuation

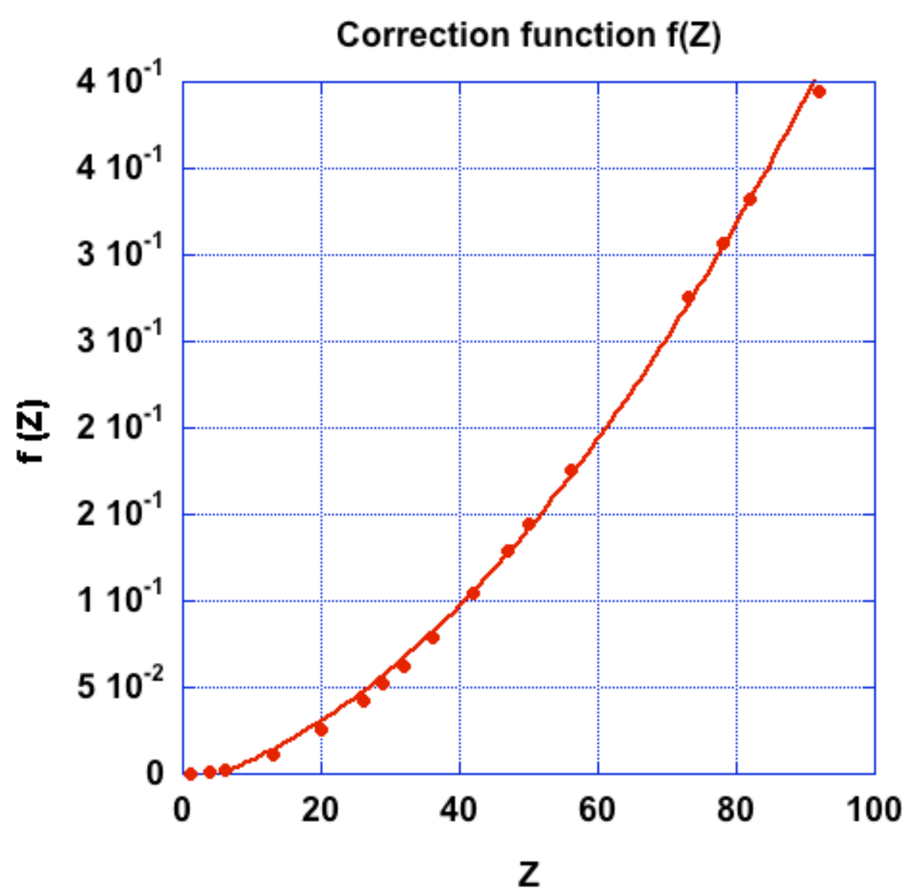
- Once the gamma rays are produced in the converter there is a probability that the gamma ray produces an electron-positron pair,
- It is the same when the gamma rays enter the target material.

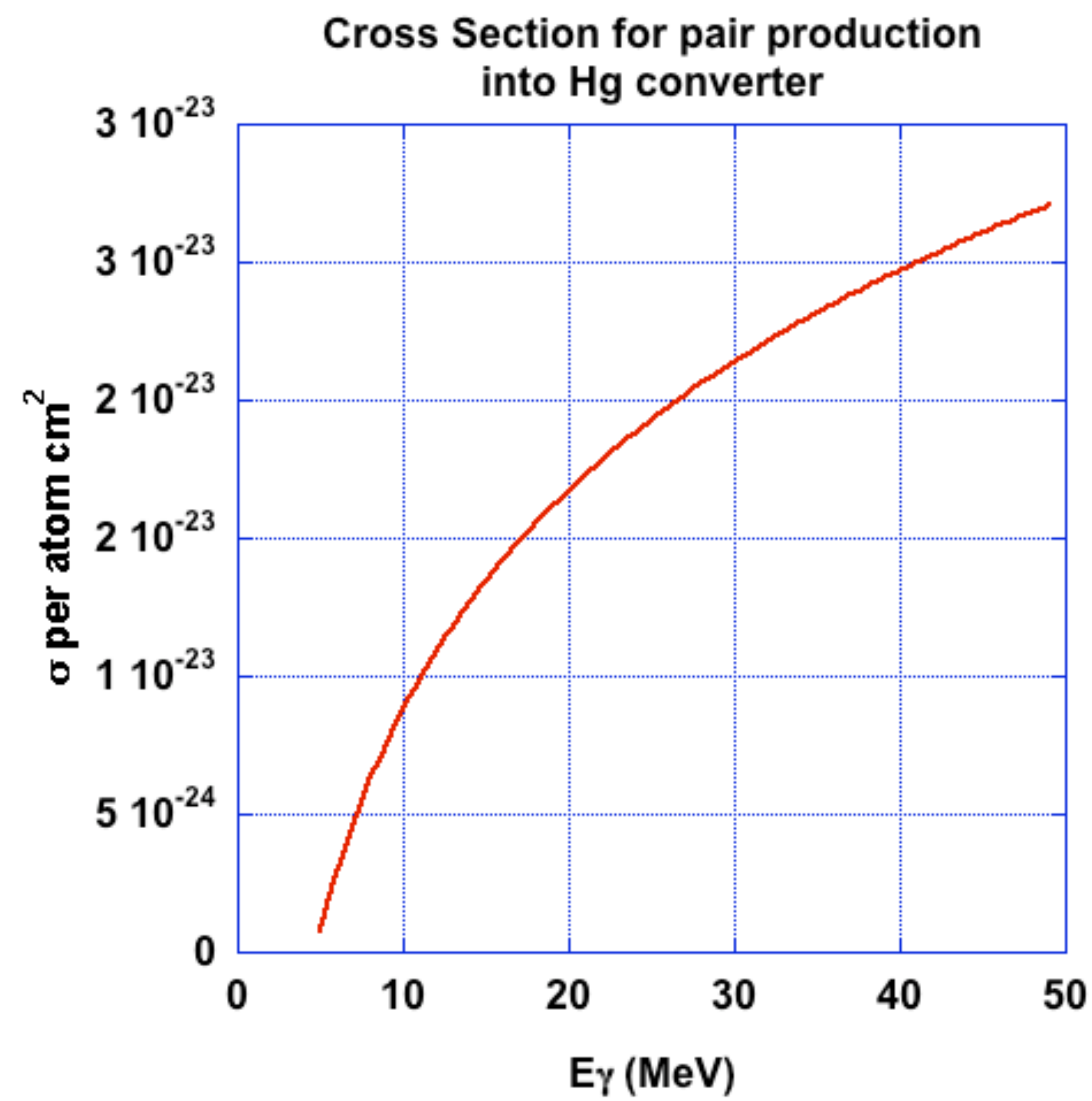


e^+e^- pair production

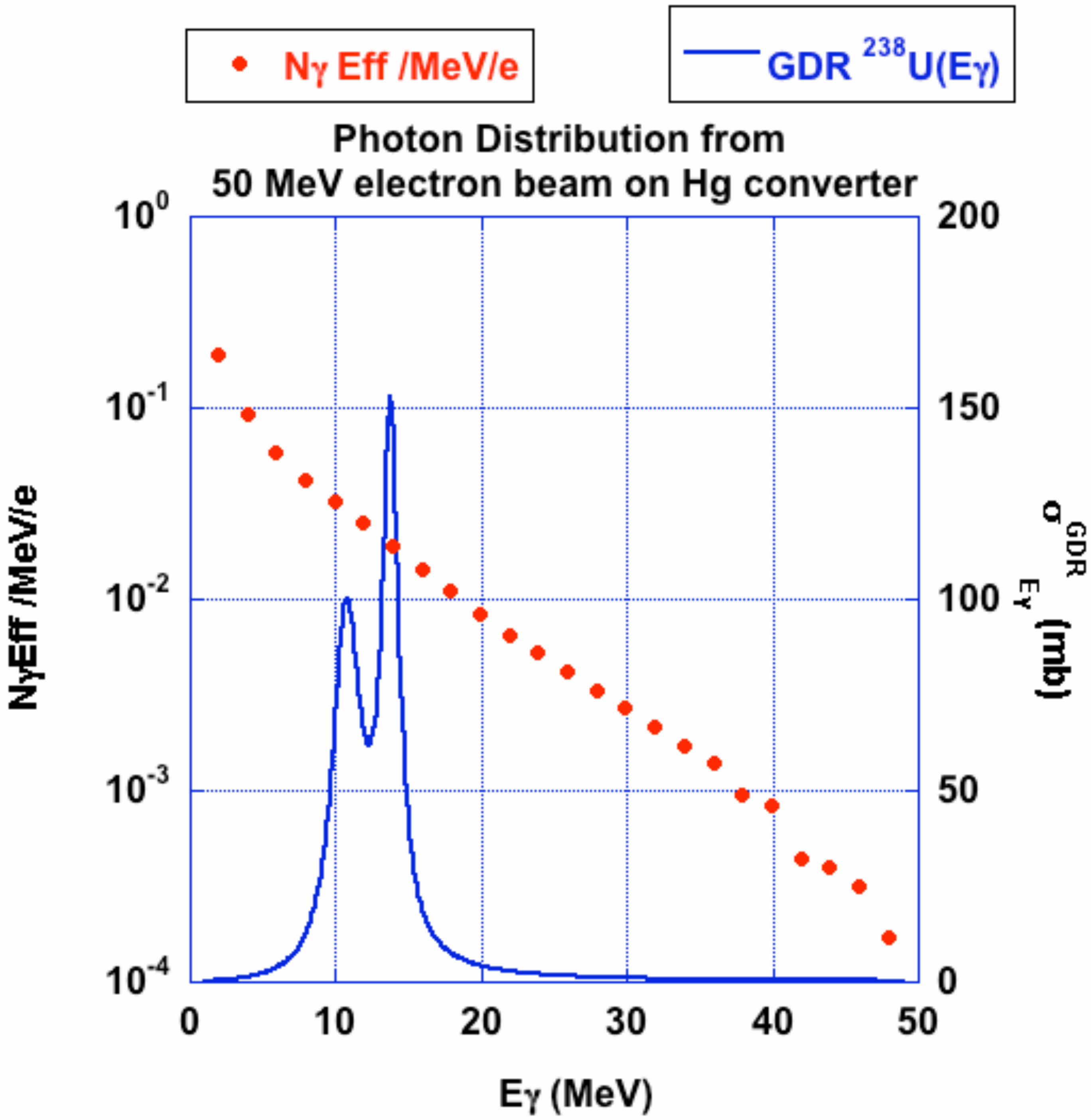
$$\sigma_{e^+e^-} = \alpha Z^2 r_e^2 \left[\frac{28}{9} ln(2k) - \frac{28}{9} f(Z) - \frac{218}{27}\right]$$

$$k = \frac{E_\gamma}{m_0 c^2}$$





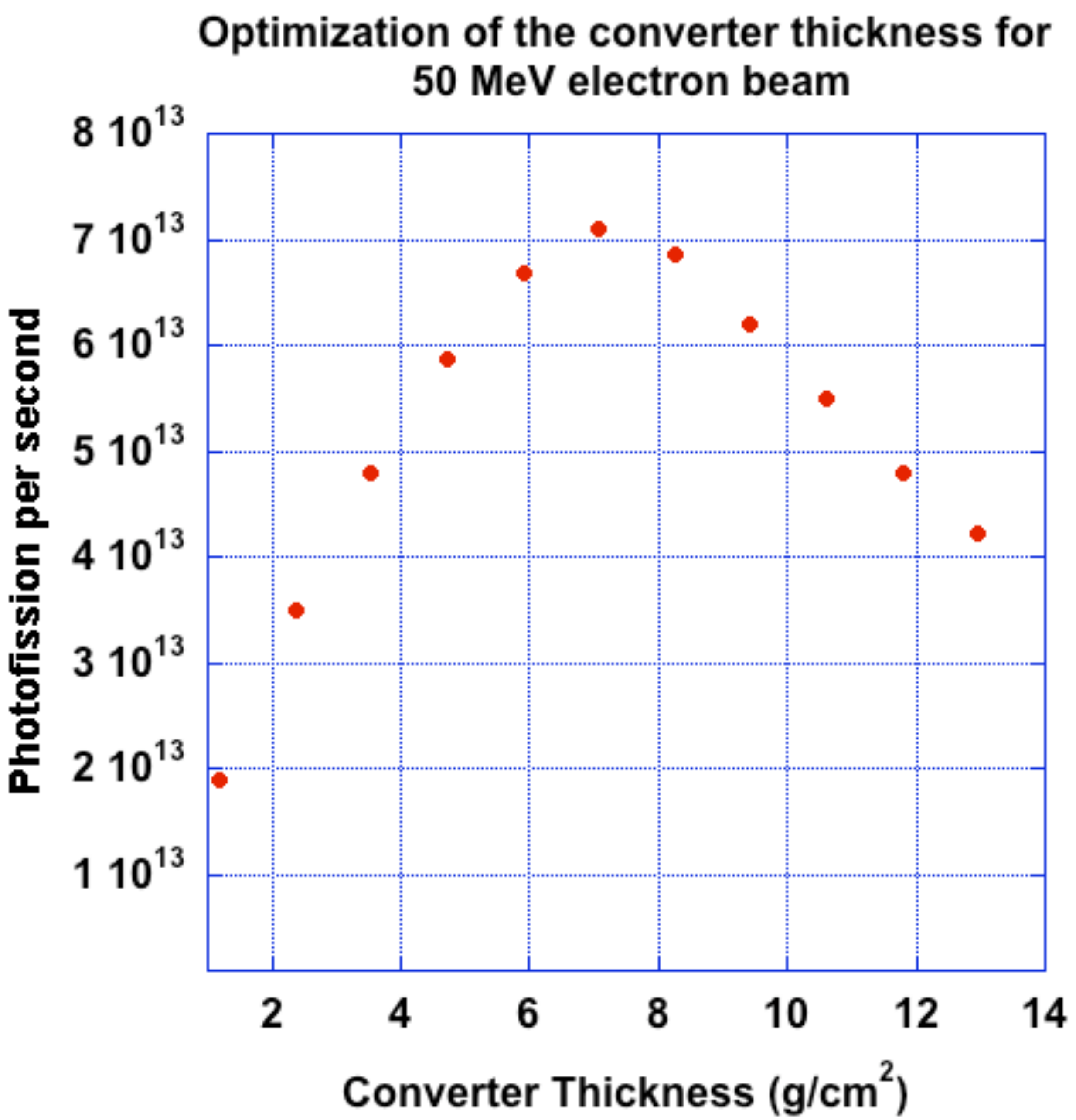
Residual Photon distribution



- **To estimate the number of fission induced by photon interaction with ^{238}U we have to integrate the residual photon spectrum with the GDR differential cross section.**

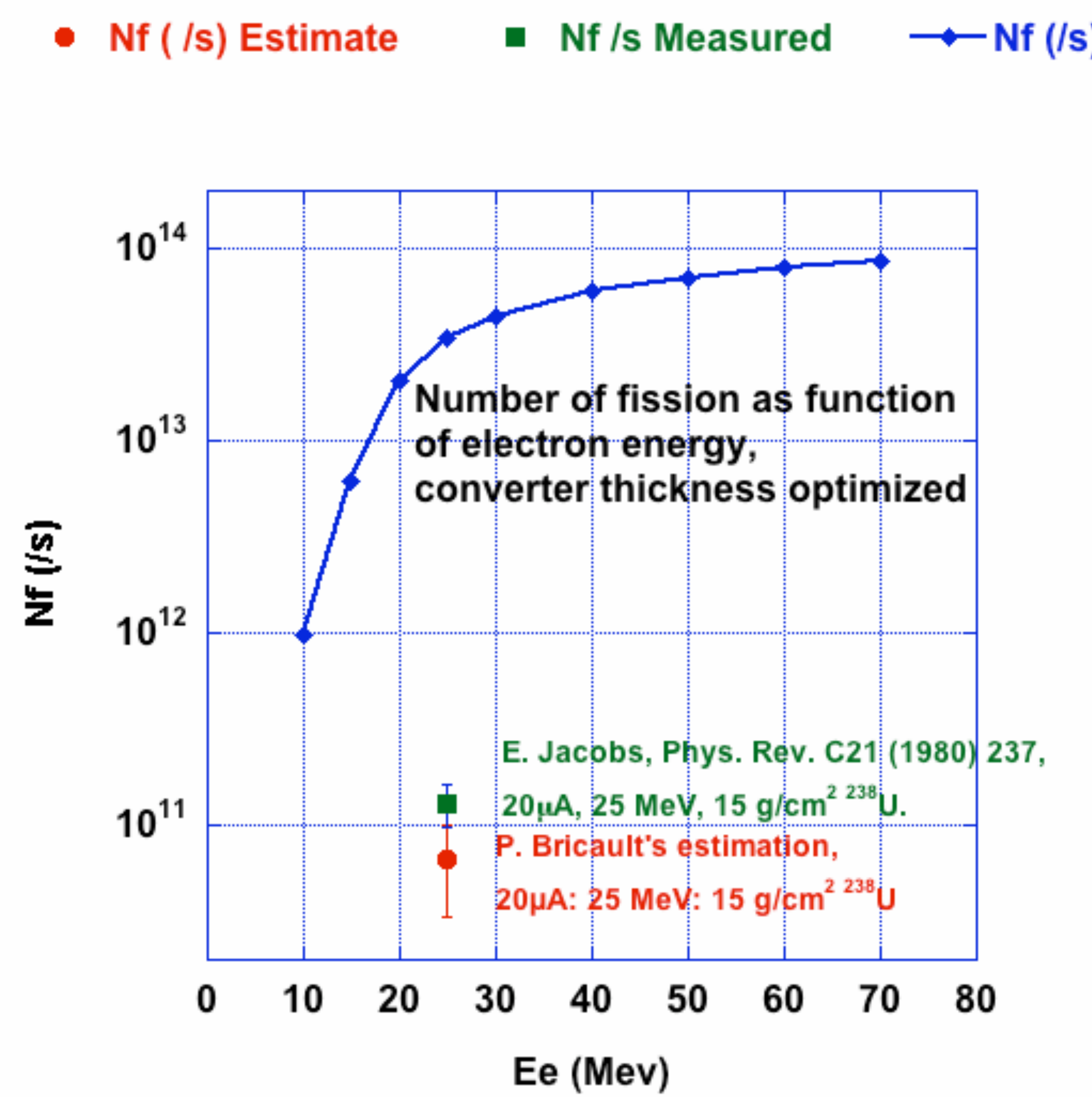
Optimization

- **Specifications:**
  - **Electron initial energy: 50 MeV,**
  - **Electron beam intensity: 10 mA,**
  - **Converter material: Hg,**
  - **^{238}U thickness: 15 g/cm^2, E. Jacobs *et al.*, Phys. Rev. C21 (1980) 237, used the same target thickness.**
- **Optimum is 1,2 X^{Hg}_0.**

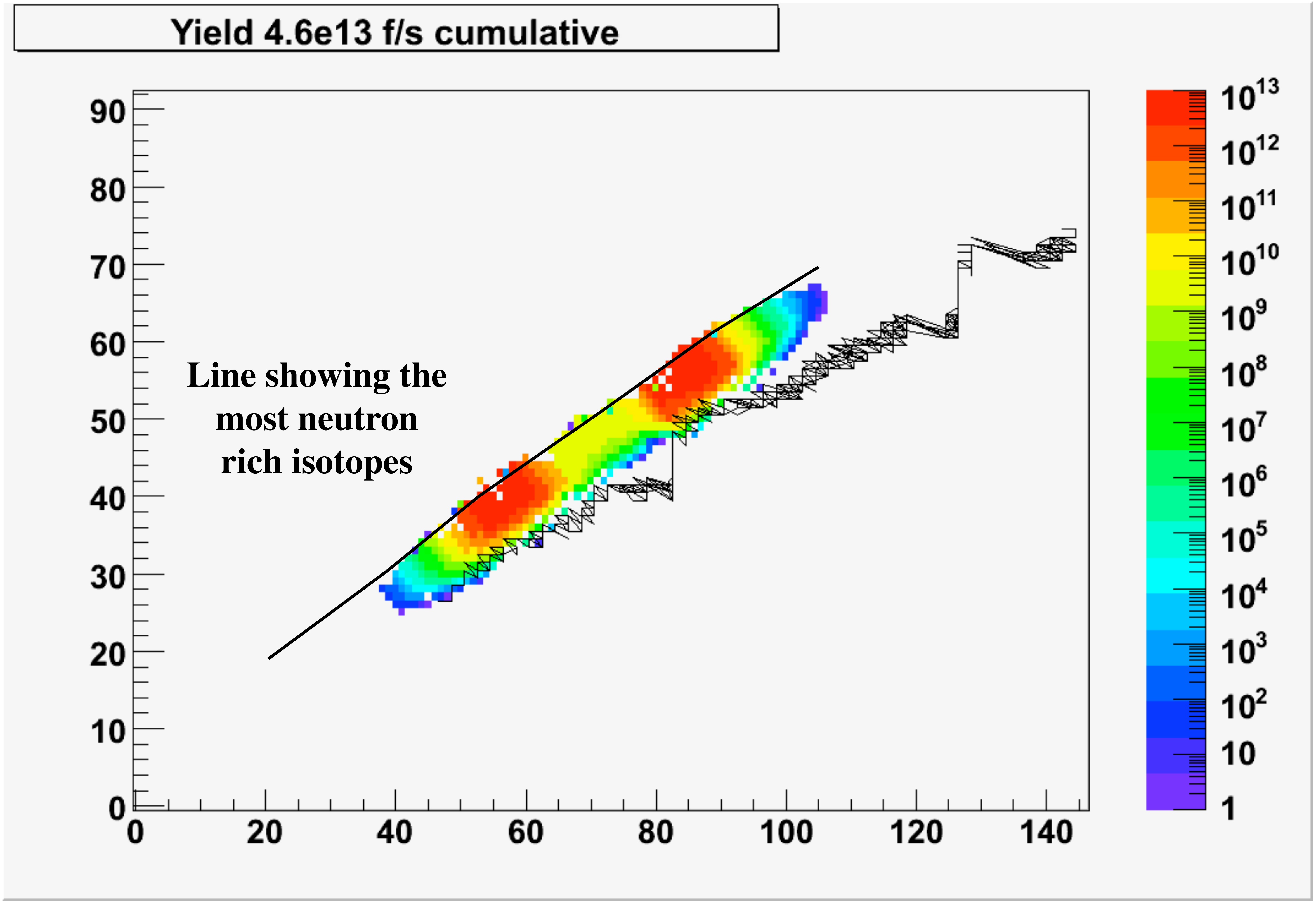


Optimization, electron energy

- Optimization of the electron energy, the following plot shows the number of induced fissions as a function of the primary electron beam energy.
- Calculation compared to measurements.

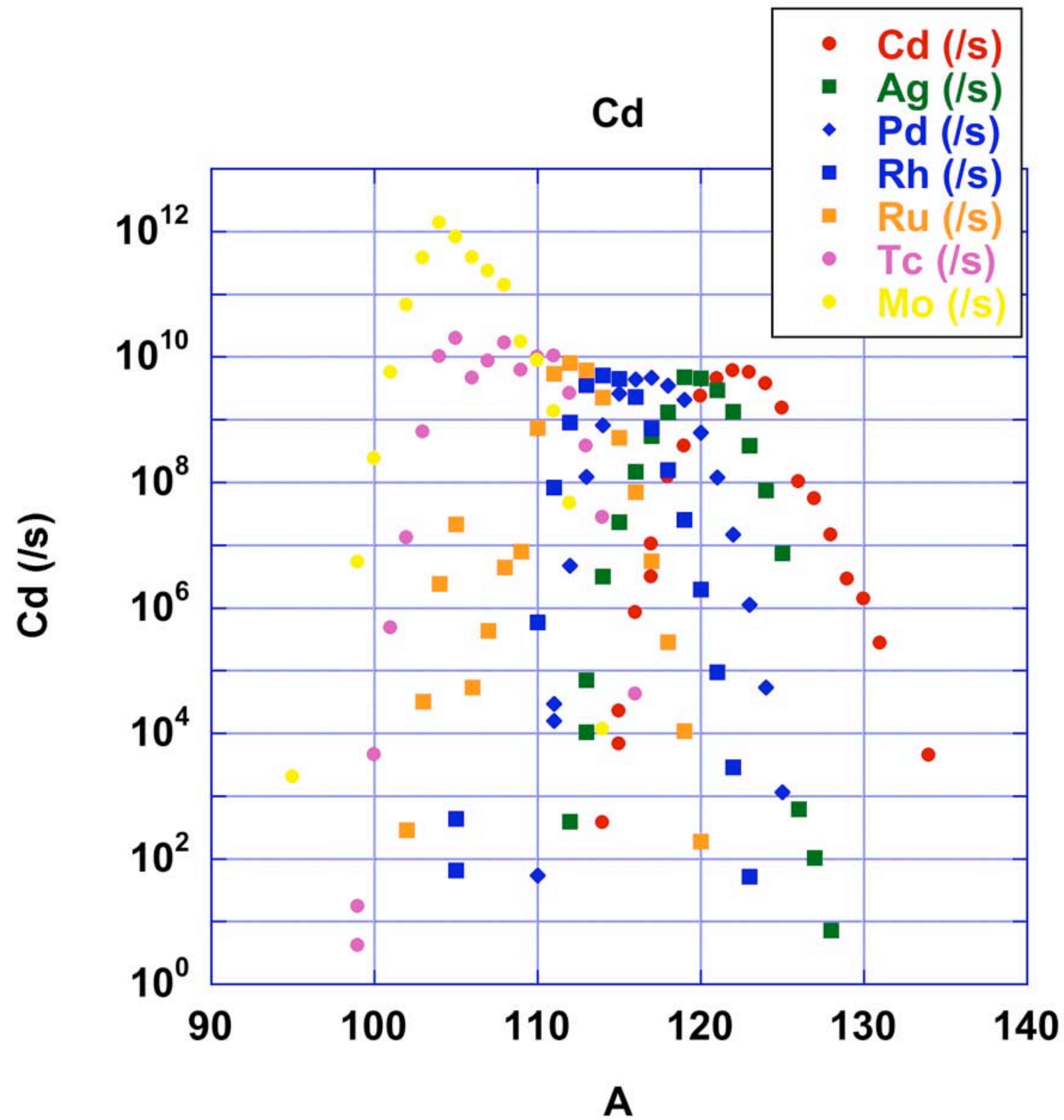


Yield Distribution

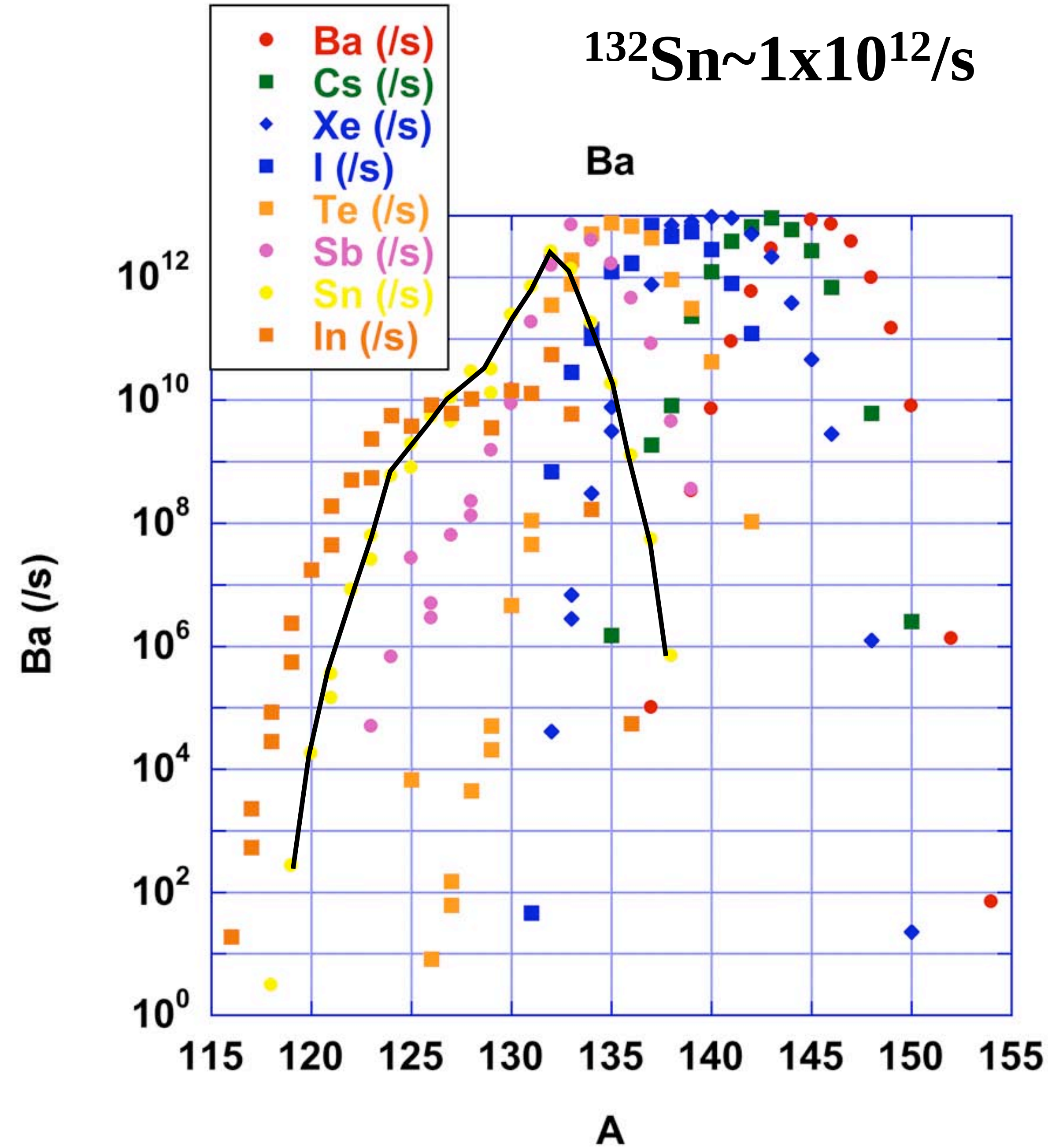


Yield distribution

- **Yield of rare isotopes, using the fission yield distribution for 7×10^{13} f/s.**

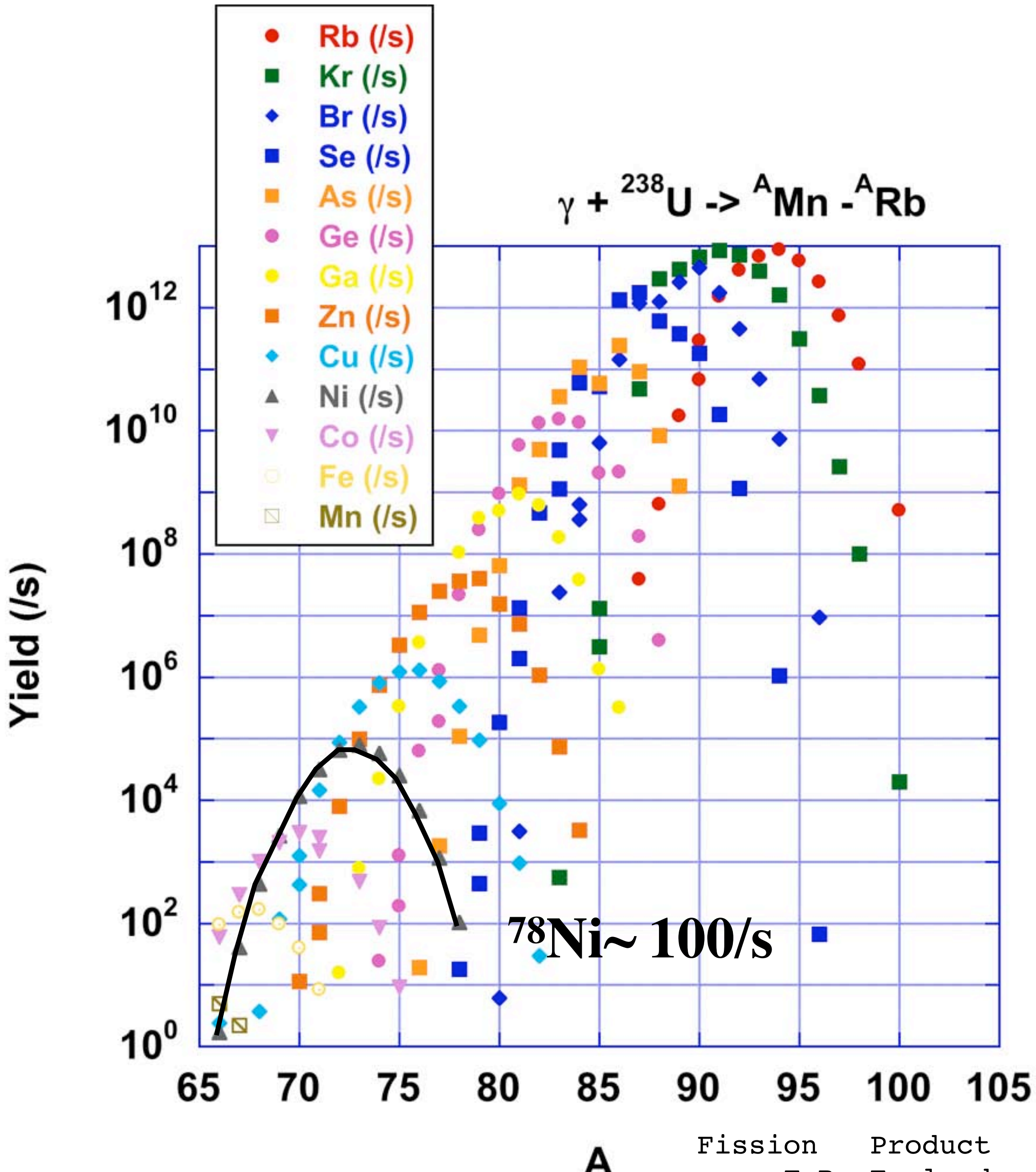


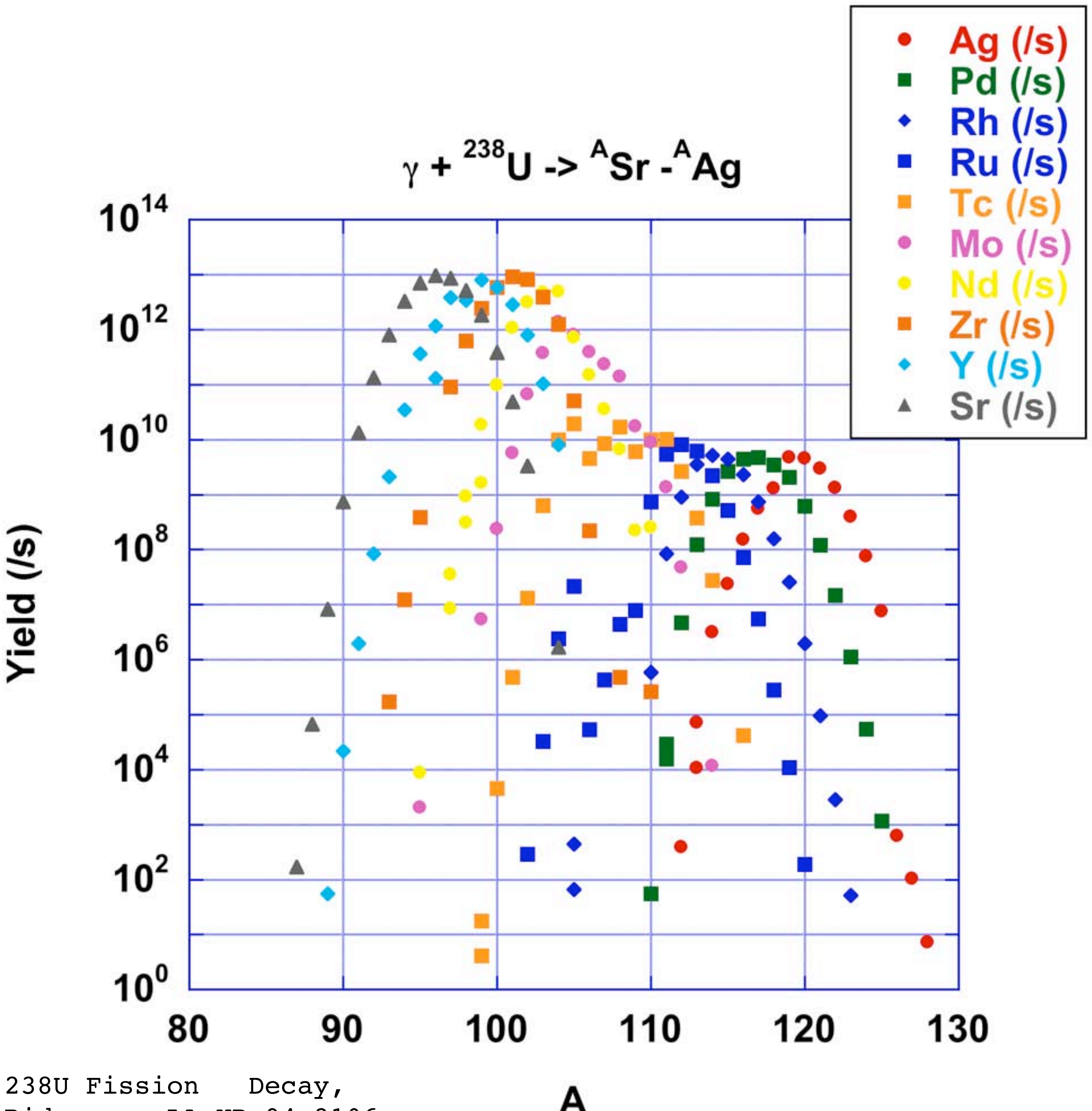
$^{132}Sn \sim 1 \times 10^{12}/s$



Yield distribution

- Yield of rare isotopes, using the fission yield distribution for $7x10^{13}$ f/s.





Fission Product Yields of 238U Fission Decay, T.R. England and B.F. Rider, LA-UR-94-3106,

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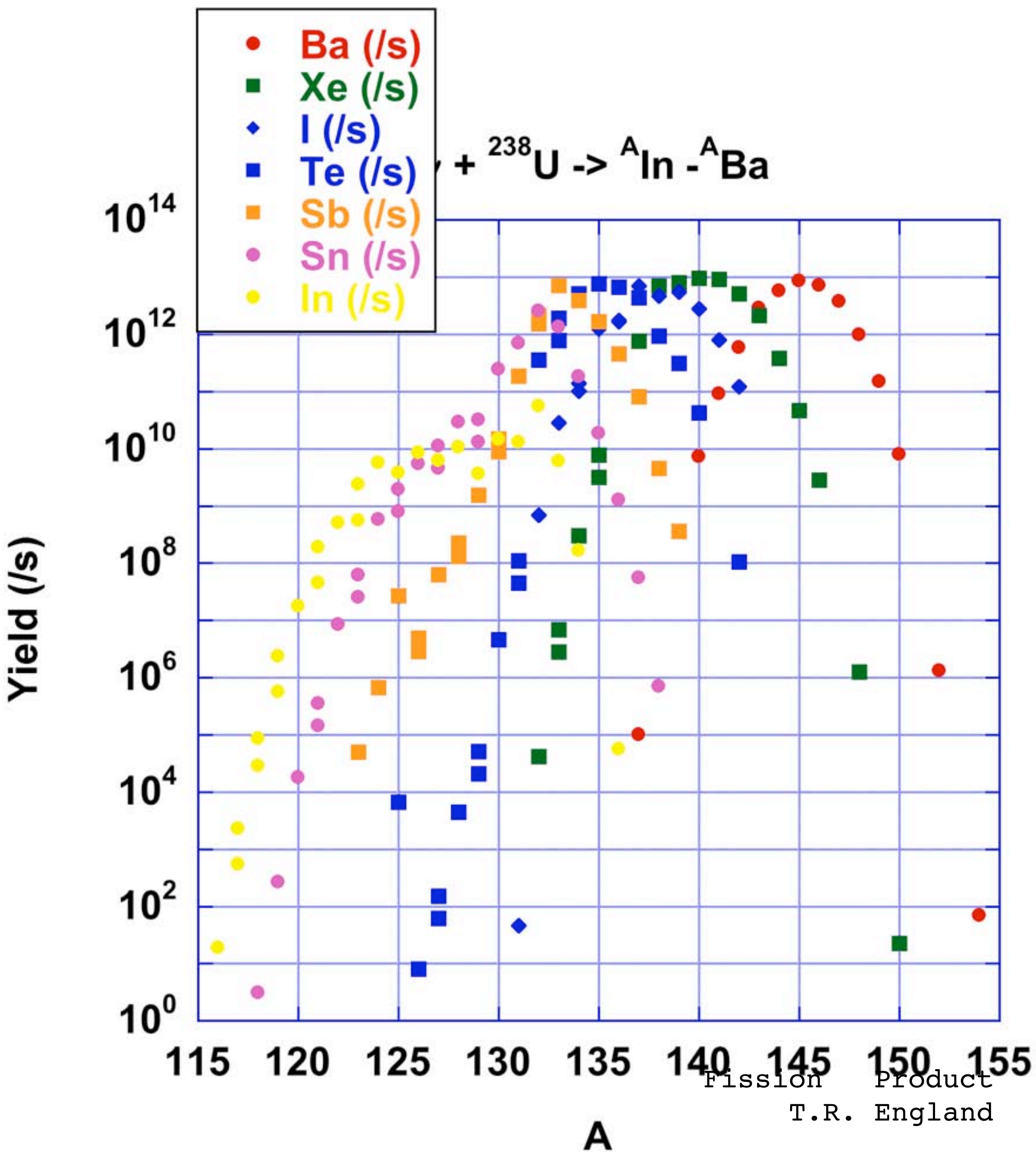
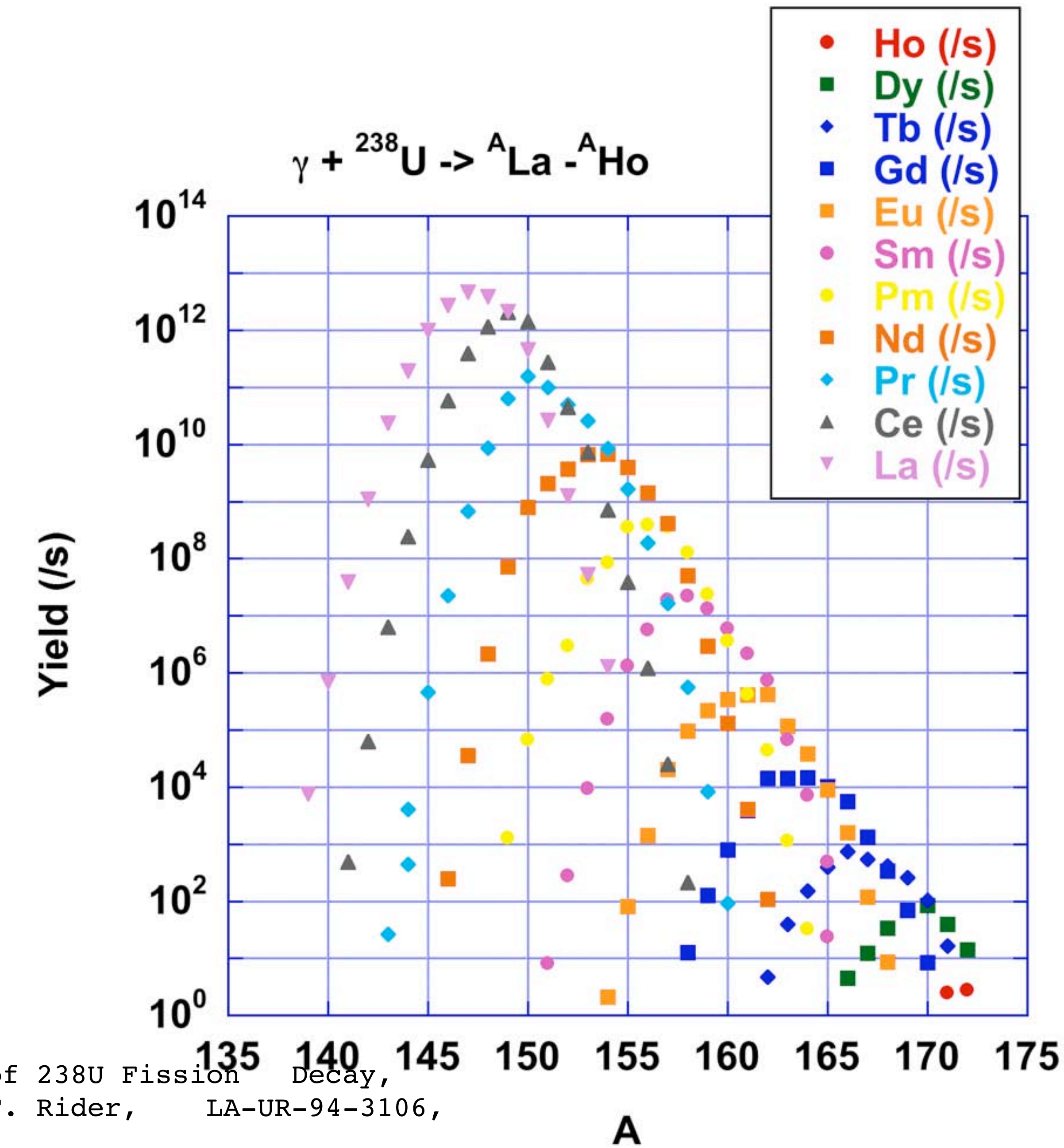




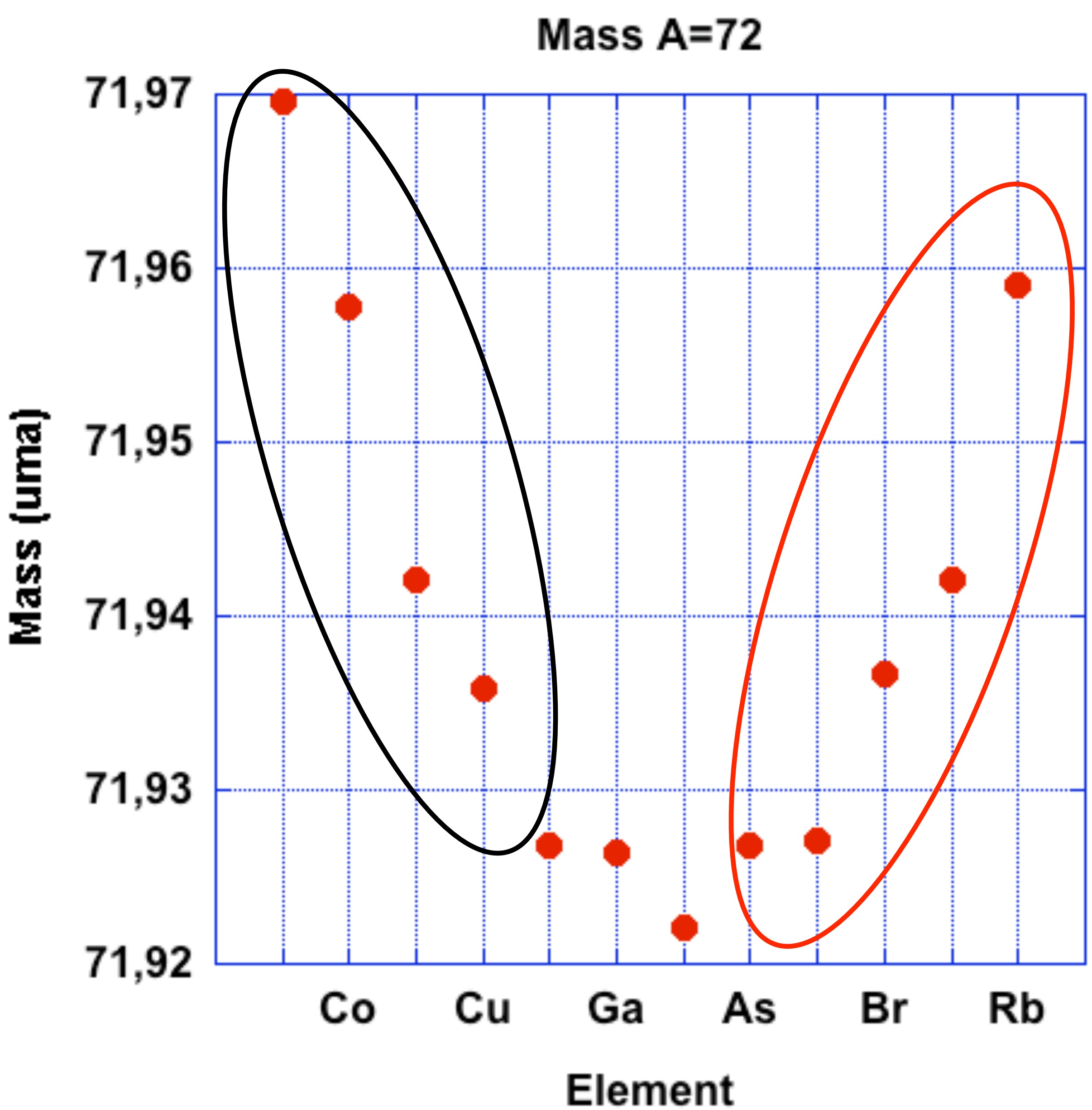
Fission Product Yields of 238U Fission Decay,
T.R. England and B.F. Rider, LA-UR-94-3106,

Conclusion

- New Target Stations design will allow us to exchange target much faster. The goal is to have a new target/ion source assembly ready within 2 days instead of ~ 4 weeks
  - To accomplish this we will have the target/ion source into a true containment box.
  - It will allow us to operate air sensitive target material, without having the risk spreading contamination during transport between target-station and hot-cell.
- eLINAC can provide clean neutron rich beams.

Neutron Rich Beams

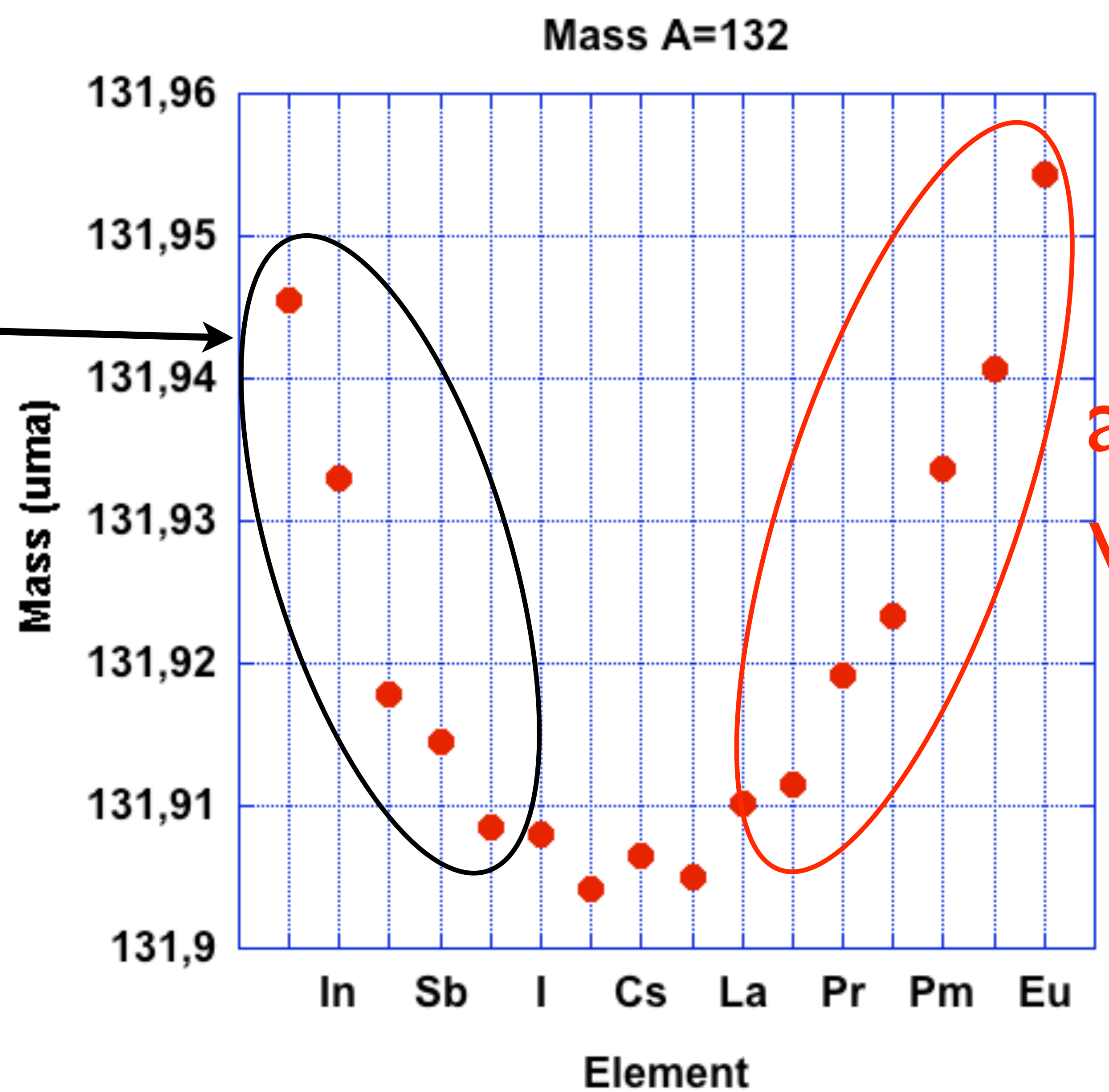
Neutron rich beams



These beams are not produced with photofission

Neutron Rich Beams

Neutron rich beams



These beams are not produced with photofission

Conclusion

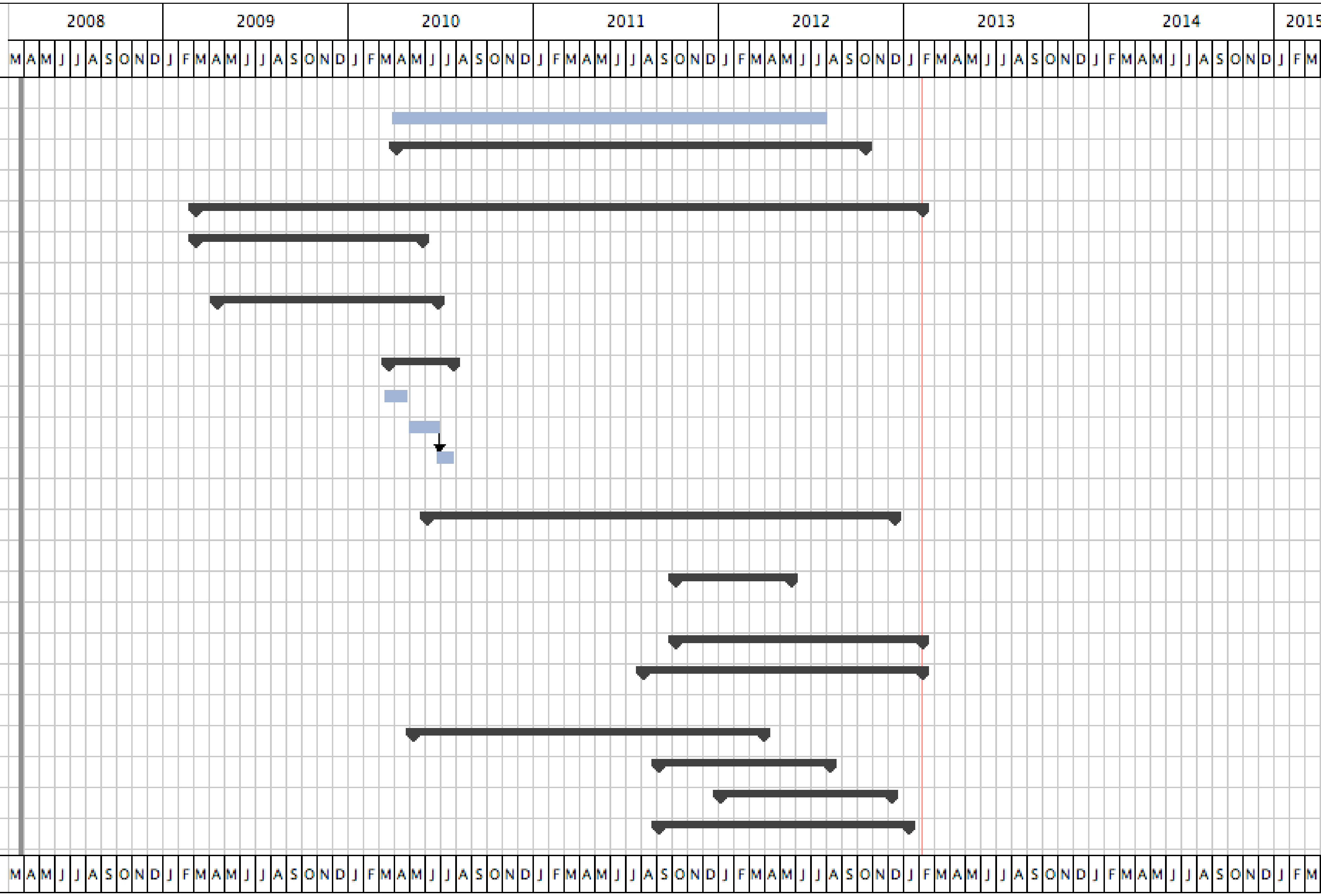
- eLINAC can provide clean neutron rich beams.
- eLINAC can produce photofission at a rate ~ 10^{14}/s, allowing a third RIB delivery simultaneously to ISAC users.
- eLINAC can provide ^{8}Li beam to ß-NMR, $^{9}Be(\gamma,p)^{8}Li$.
- One of the new target station will allow RIB development, => new beams to ISAC users.

- **Thank you.**

TRIUMF

Schedule

Activity Name	Duration (Work Days)	Start Date	Finish Date
Building ready	609,23	01/04/10	01/08/12
Proton Beam Line...	675,08	01/04/10	17/10/12
Target Station	1 028,35	02/03/09	07/02/13
Entrance Module...	325,86	02/03/09	24/05/10
Target Module...	318,28	13/04/09	24/06/10
Dump Module	95,92	15/03/10	26/07/10
Specifications	30,46	15/03/10	26/04/10
Design	40,61	03/05/10	28/06/10
Review	20,31	28/06/10	26/07/10
Exit Modules...	671,87	01/06/10	12/12/12
Rail system...	168,40	03/10/11	21/05/12
Vacuum system...	358,79	03/10/11	07/02/13
Control...	403,12	01/08/11	06/02/13
Remote Handling Crane...	505,19	03/05/10	28/03/12
Hot-Cell Tgt Change...	247,44	01/09/11	07/08/12
Hot-Cell Maintenance...	247,44	02/01/12	06/12/12
T/IS Conditioning Station...	360,85	01/09/11	10/01/13



- + 13 FTE, 6 Technicians, 5 Scientists, 2 Engineers.