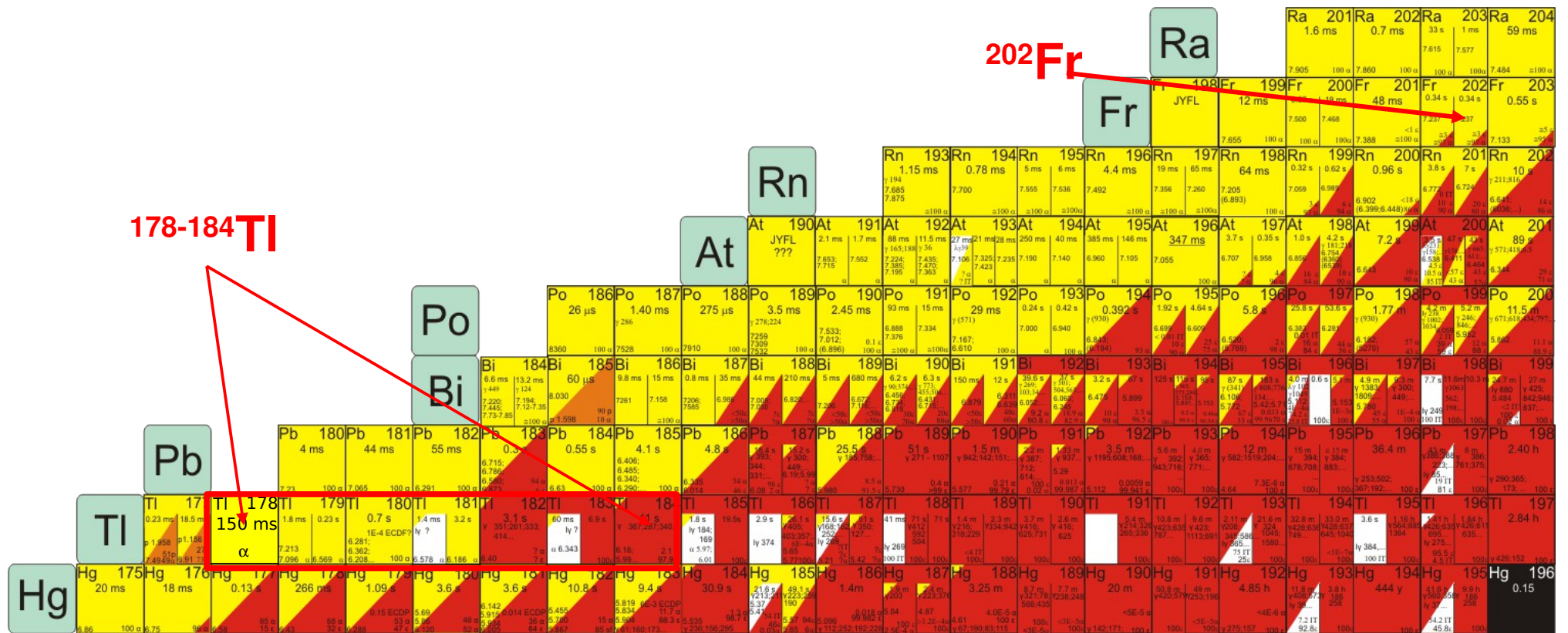


On behalf of IS466 Collaboration and the ISOLDE collaboration

β delayed fission studies of the neutron deficient $^{180-184}\text{Tl}$ and ^{202}Fr nuclei @ISOLDE facility



Collaboration ..



Andrei Andreyev
Valentina Liberati
Joseph Lane



Nick Bree
Thomas Cocolios
Jan Diriken
Jytte Elseviers
Mark Huyse
Paul Van den Bergh
Piet Van Duppen
Martin Venhart
D. Radulov
Hilde De Witte
I. Darby



P. Möller, A. Sierk

RIKEN

Takatoshi Ichikawa



Katsuhisa Nishio
Akira Iwamoto

I. Tsekhanovich
(CENBG, France)



RILIS & ISOLDE



Stanislav Antalic
Zdenka Kalaninova



Robert Page

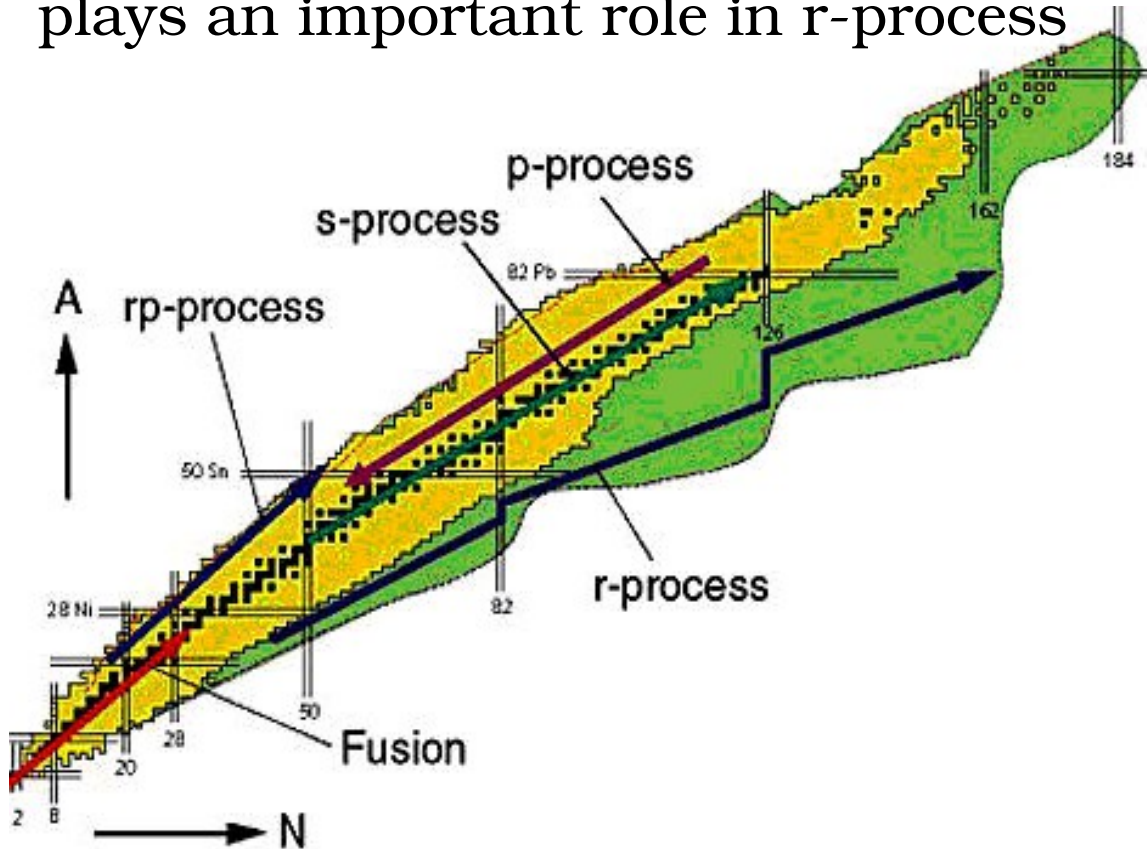
U. Koster (*ILL, Grenoble, France*)
S. Franchoo (*IPN, Orsay, France*)
S. Vermote, C. Wagemans (*University of Gent, Belgium*)
M. Veselský (*Slovak Academy of Sciences, Bratislava, Slovakia*)

- ***Motivation – fission and r-process***
- ***B delayed fission – general properties***
- ***IS466 experiment -***
 - ***^{178}Tl***
 - ***^{202}Fr***
- ***Conclusion***

Fission and r-process ..

■ Fission

(spontaneous fission, n-induced fission and β delayed fission)
plays an important role in r-process

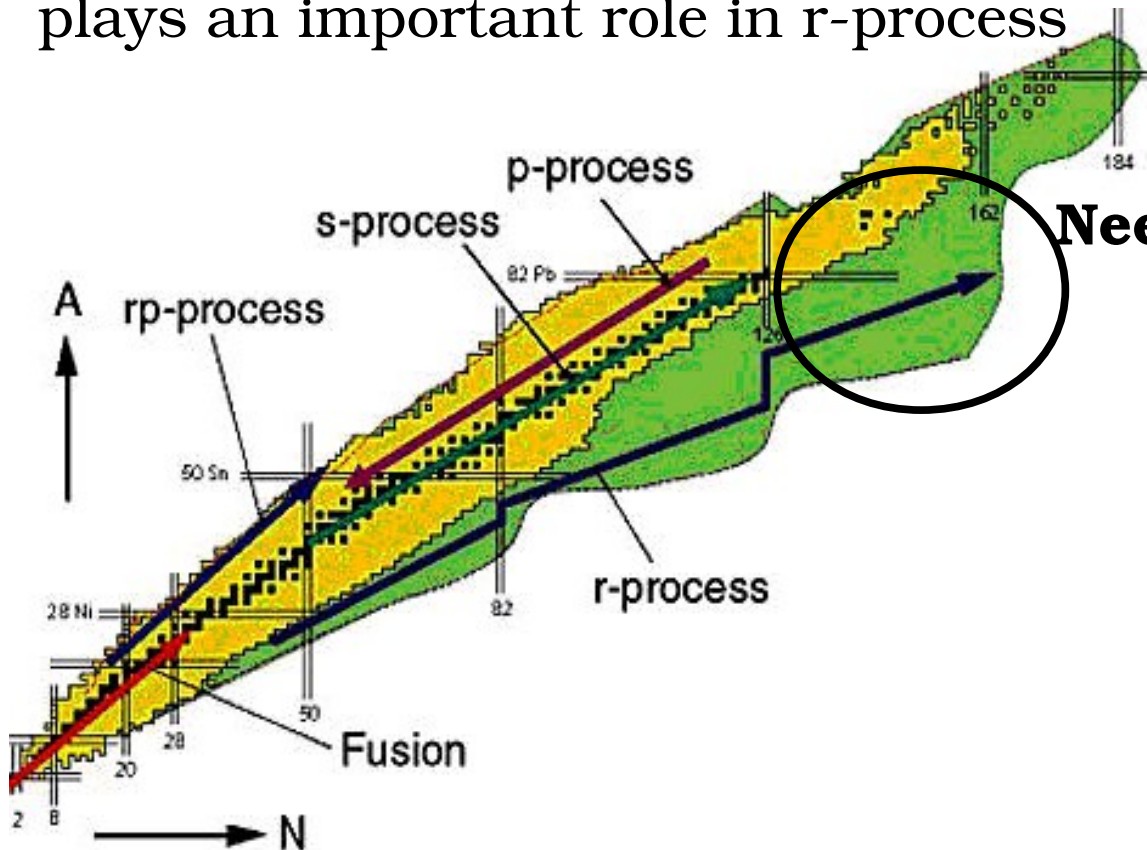


Fission and r-process ..

■ Fission

(spontaneous fission, n-induced fission and β delayed fission)

plays an important role in r-process

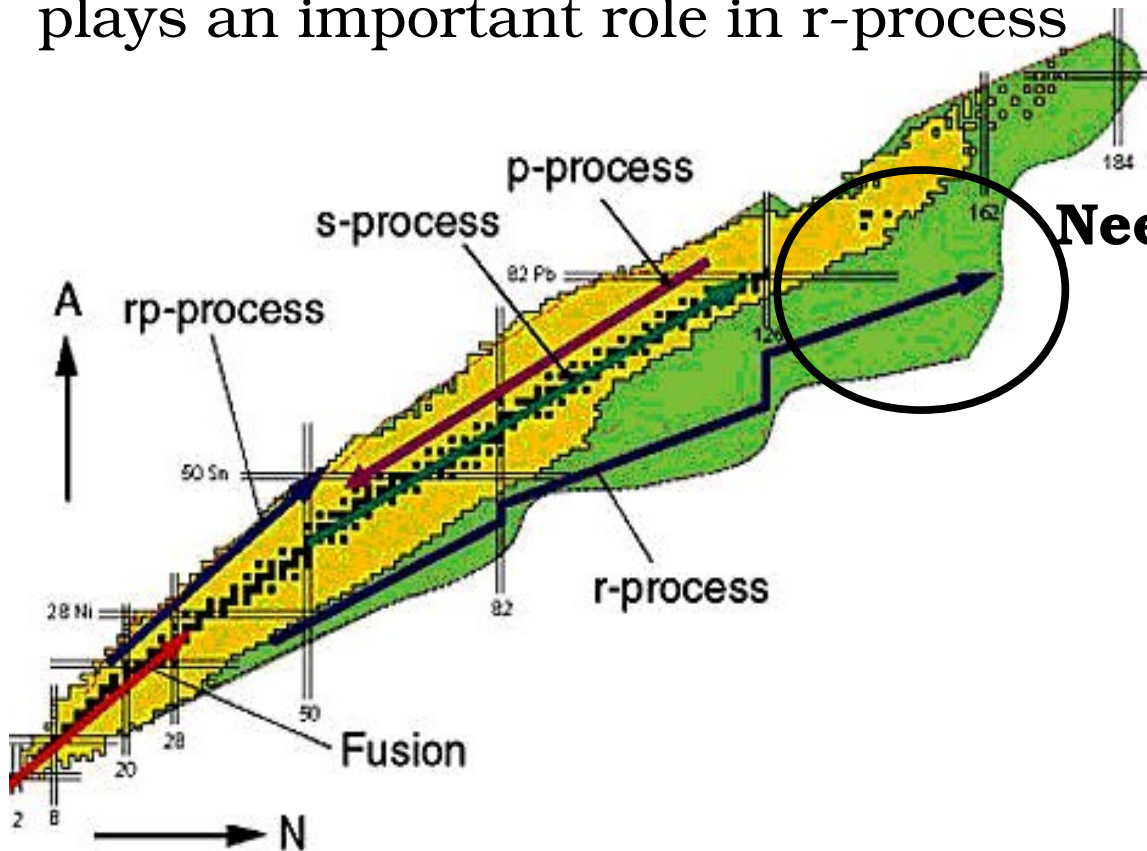


Need data for very exotic nuclei

Fission and r-process ..

■ Fission

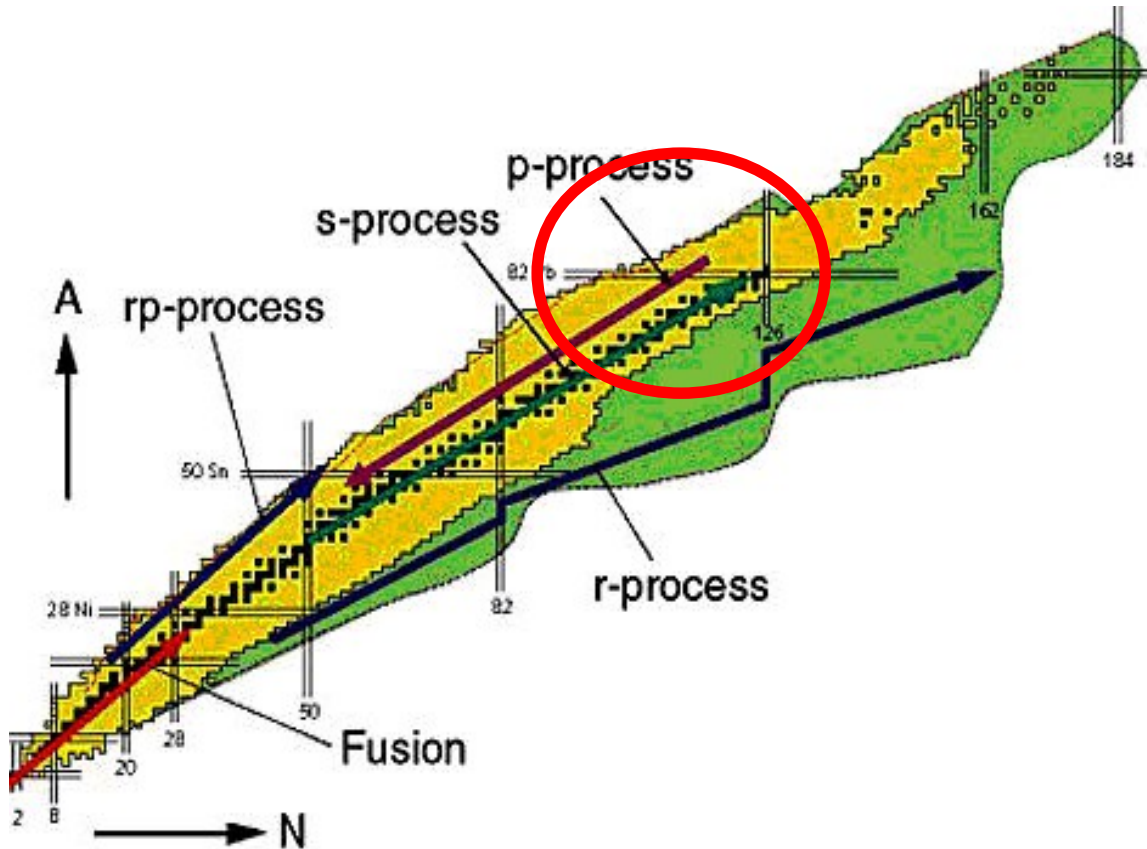
(spontaneous fission, n-induced fission and β delayed fission)
plays an important role in r-process



Need data for very exotic nuclei

Unfortunately, so exotic nuclei are not presently accessible by available techniques!

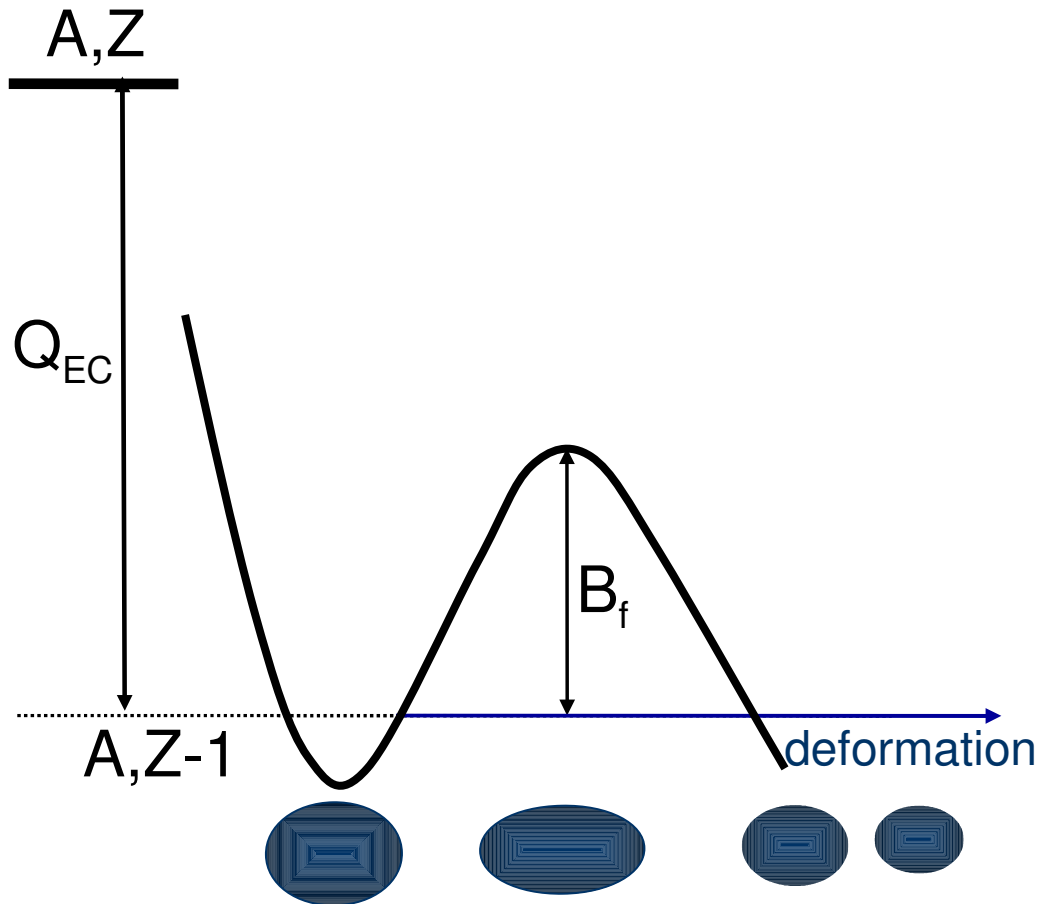
Fission and r-process ..



■ That is why the underlying mechanisms and properties of beta-delayed fission (and of low-energy fission in general) have to be investigated by using alternative approaches and in other regions of the Nuclear Chart.

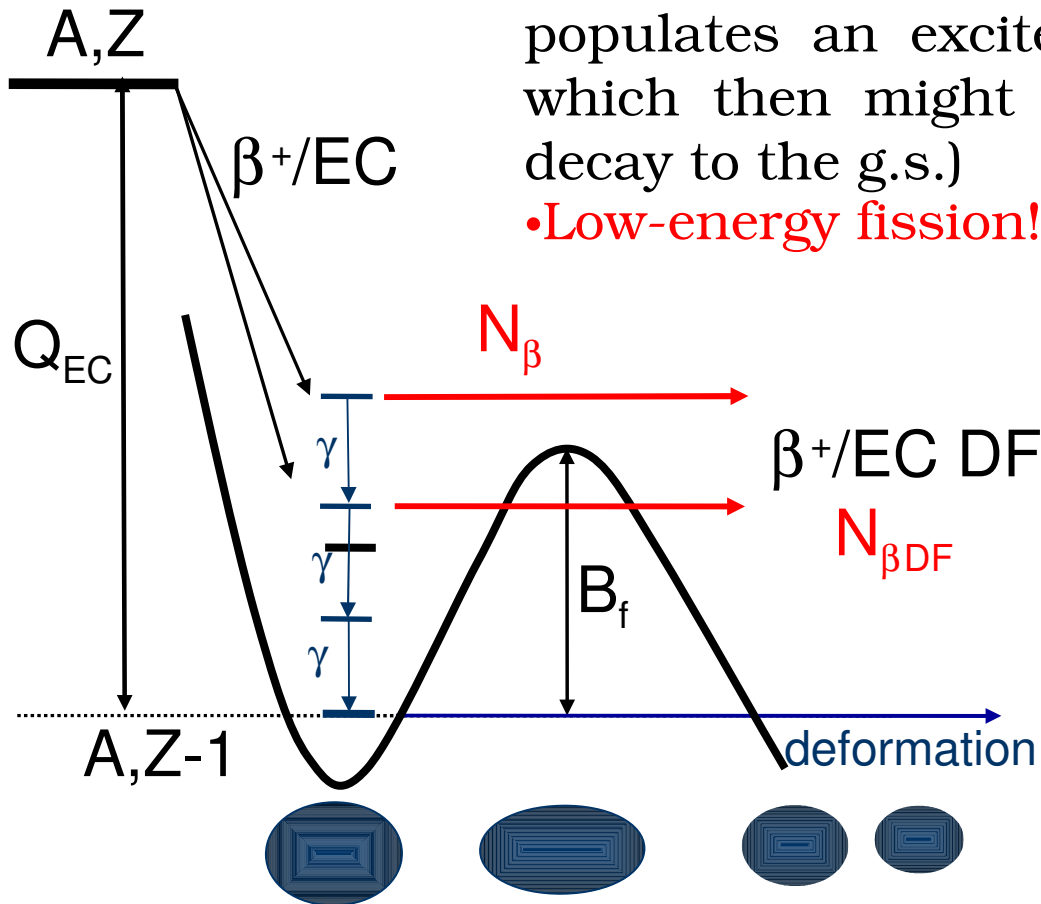
■ According to semi-empirical estimates, the neutron-deficient nuclei in the U and Pb regions provide such a possibility via the beta-delayed fission decay

β delayed fission..



β delayed fission..

- Discovered in 1966 @Dubna $^{232,234}\text{Am}$
- 2 step process: β^+ /EC decay of a parent (A,Z) nucleus populates an excited state in the (A,Z-1) daughter, which then might fission (in competition with the γ decay to the g.s.)
- **Low-energy fission!** ($E^* \leq Q_{\text{EC}}$)



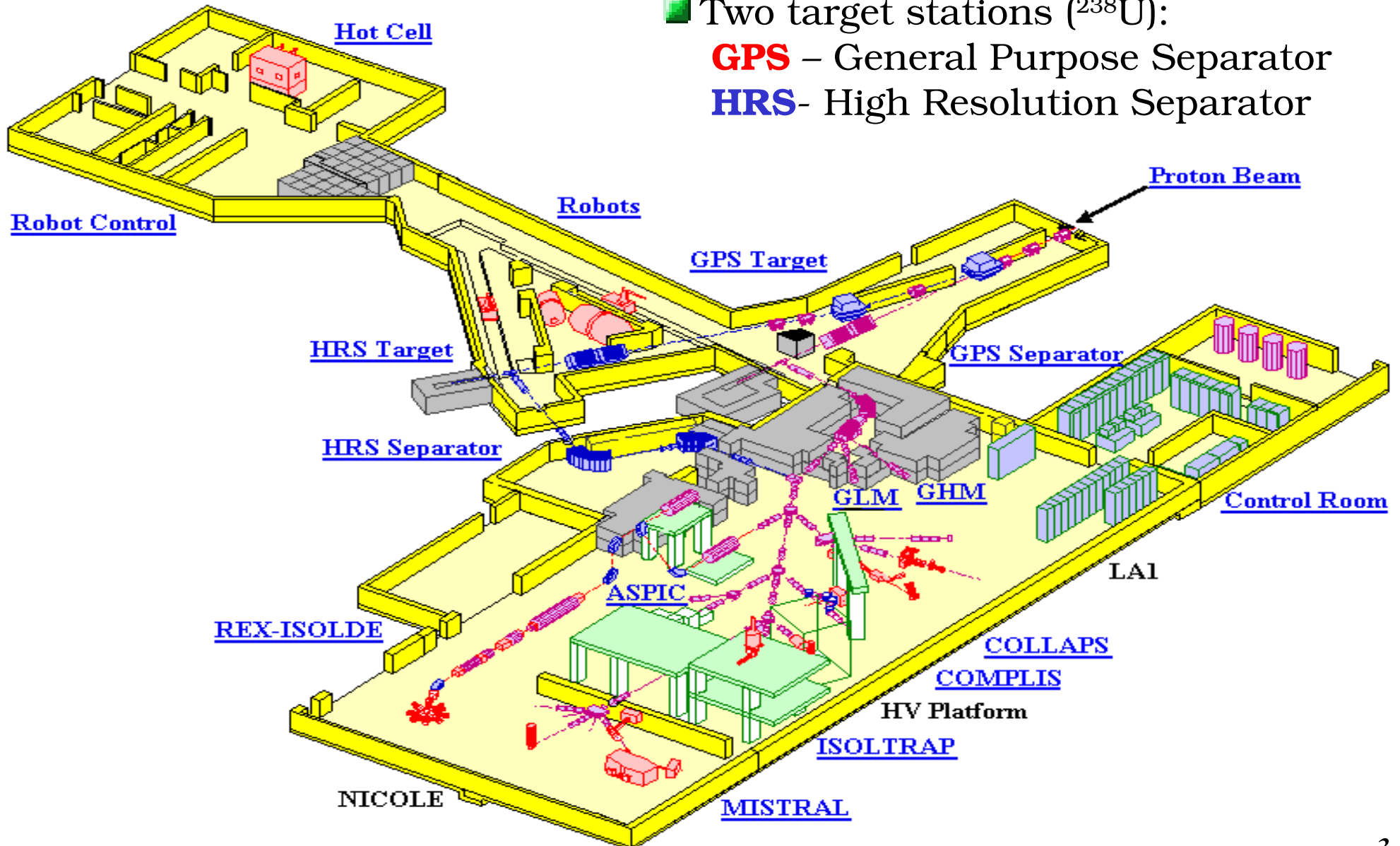
β DF branch

$$P_{\beta\text{DF}} = \frac{N_{\beta\text{DF}}}{N_{\beta}}$$

$P_{\beta\text{DF}}$ depends strongly on:

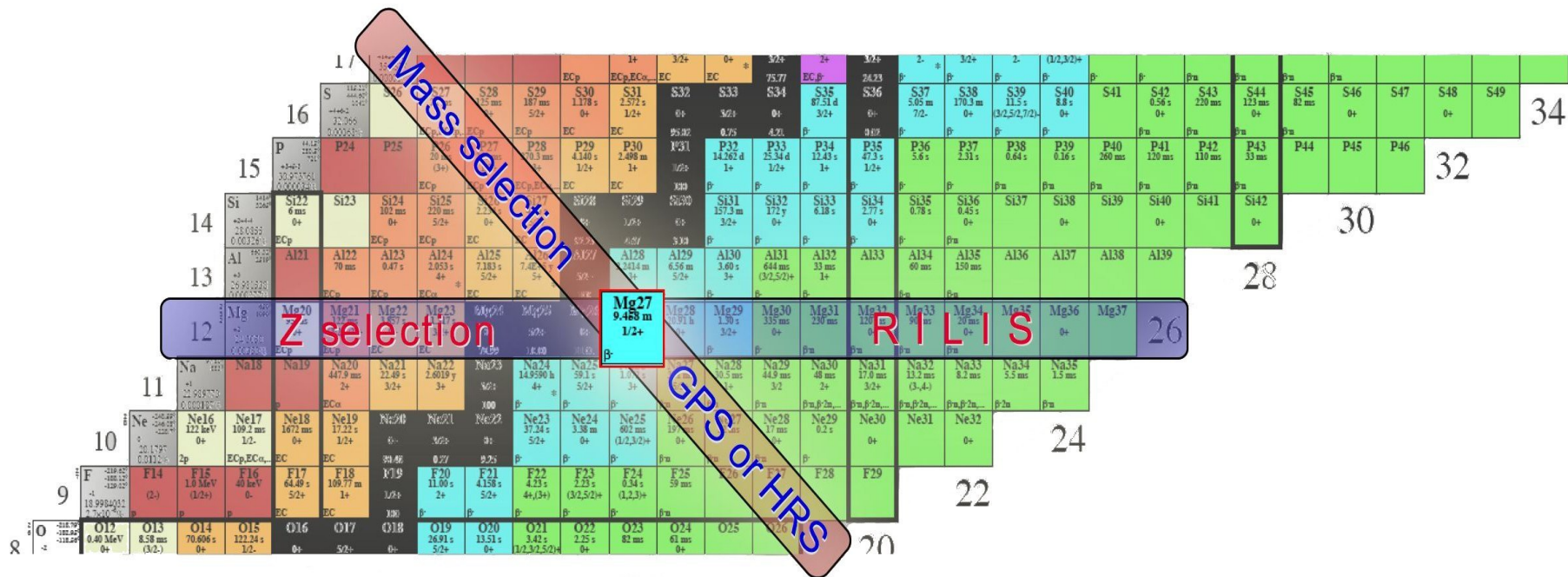
- Q_{EC} of the parent
- B_f of the daughter
- Actually, $Q_{\text{EC}} - B_f$ is important

- Proton beam 1.4 μA , 1.4 GeV from PSB
- Two target stations (^{238}U):
 - GPS** – General Purpose Separator
 - HRS** – High Resolution Separator



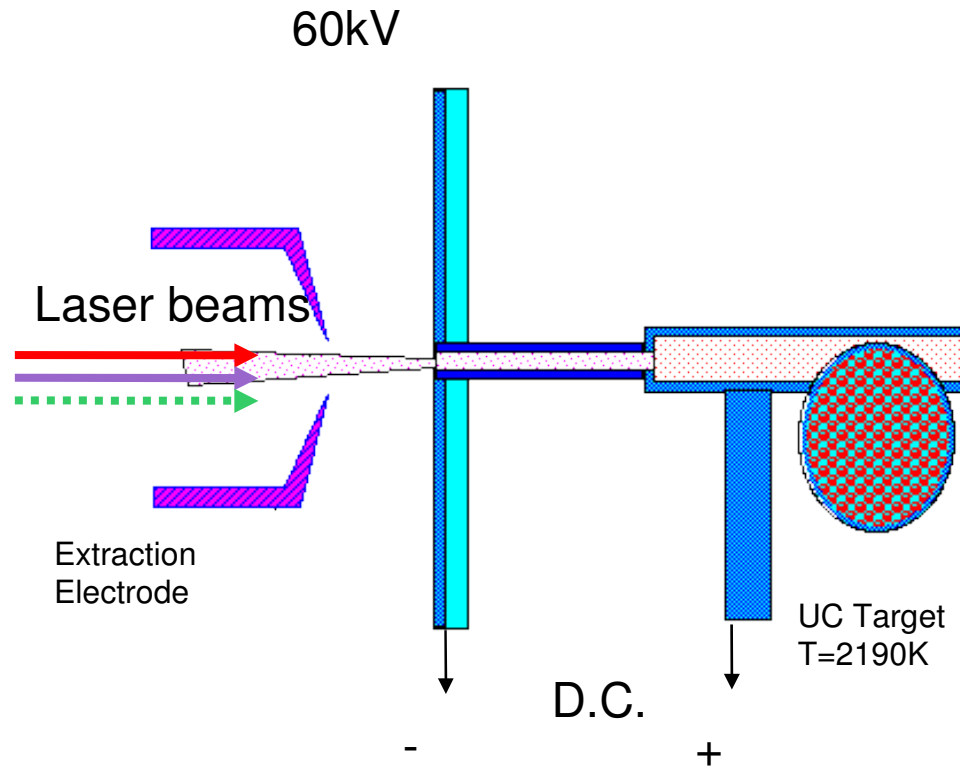
Isotope Selection..

- Hundreds of different isotopes are produced.
- A highly selective method is required to achieve a pure beam**

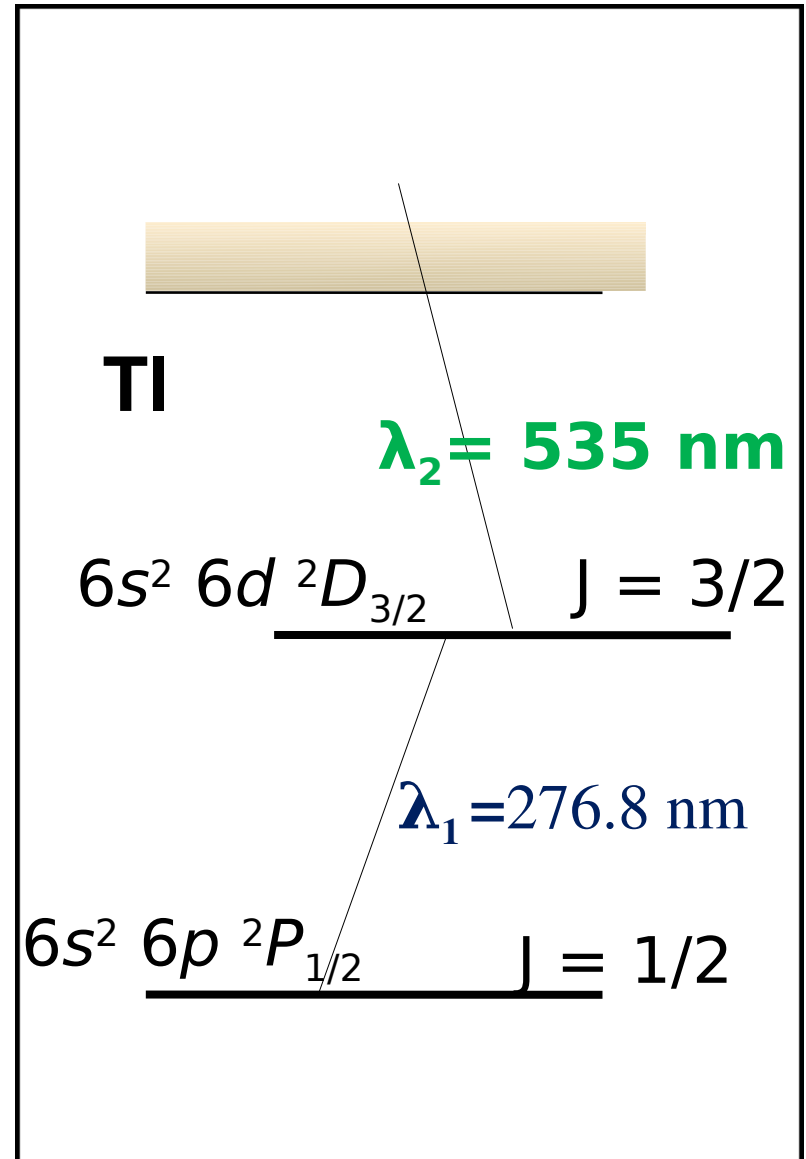


Use mass separator to select mass A: => ISOLDE
Use laser Ion Source to select Z: =>RILIS

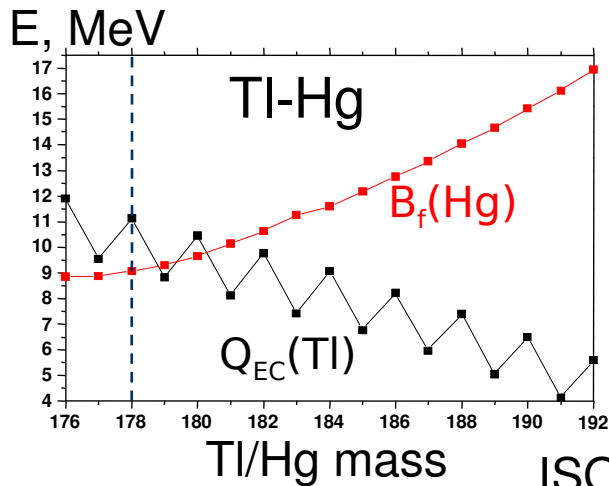
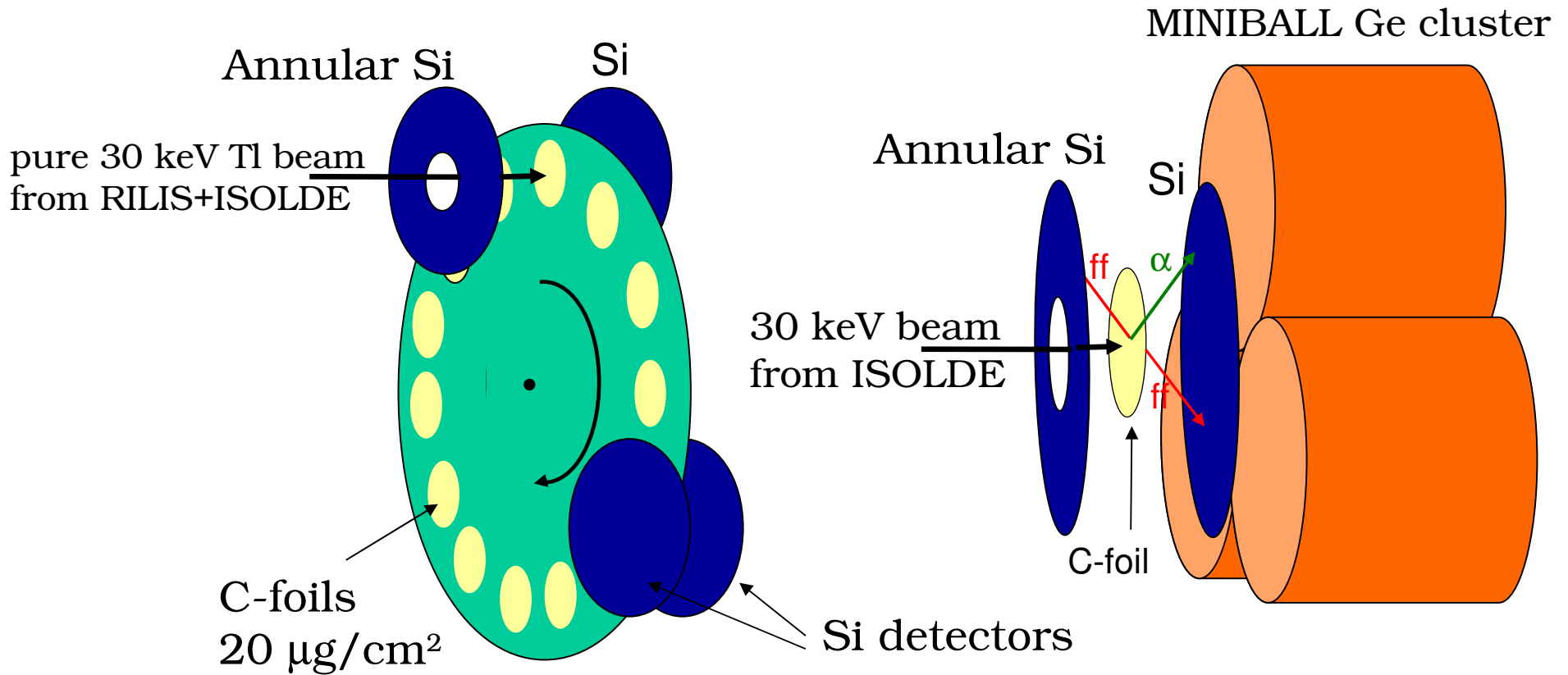
RILIS&ISOLDE can provide a unique A and Z identification



- Highly selective process, $\epsilon = 2\%-19\%$
- It uses lasers of different wavelength to stepwise ionize a specific element



Experiment IS466-* Setup ..



Setup: Si detectors from both sides of the C-foil

- Simple setup & DAQ: 4 PIPS (1 of them – annular)
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-gamma coincidences
- Digital electronics (5 DGF modules)

A New Type of Asymmetric Fission in Proton-Rich Nuclei

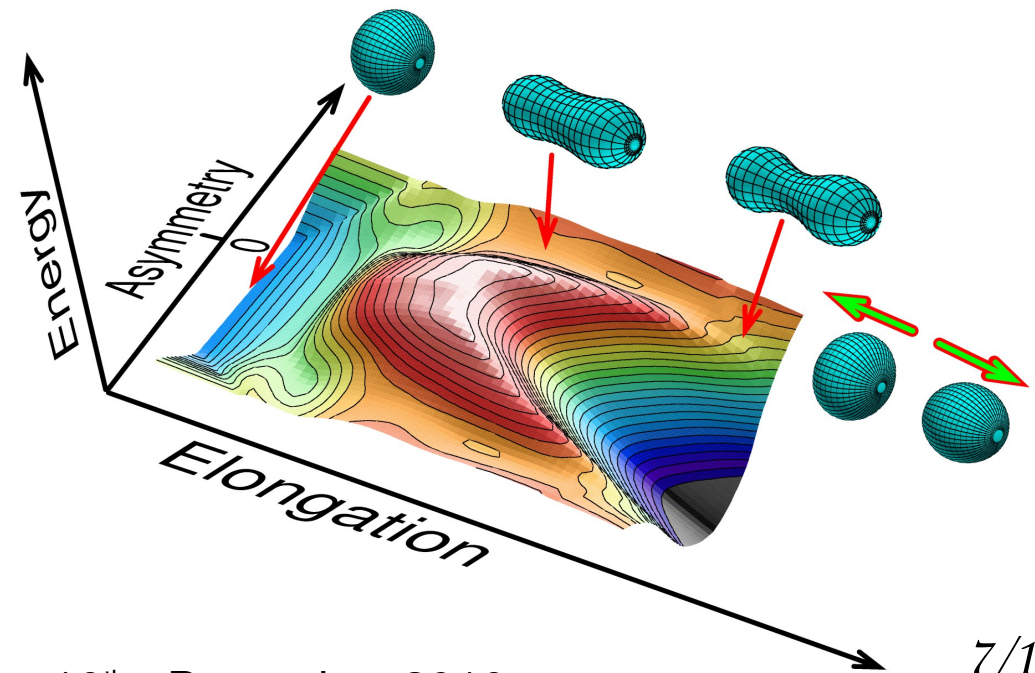
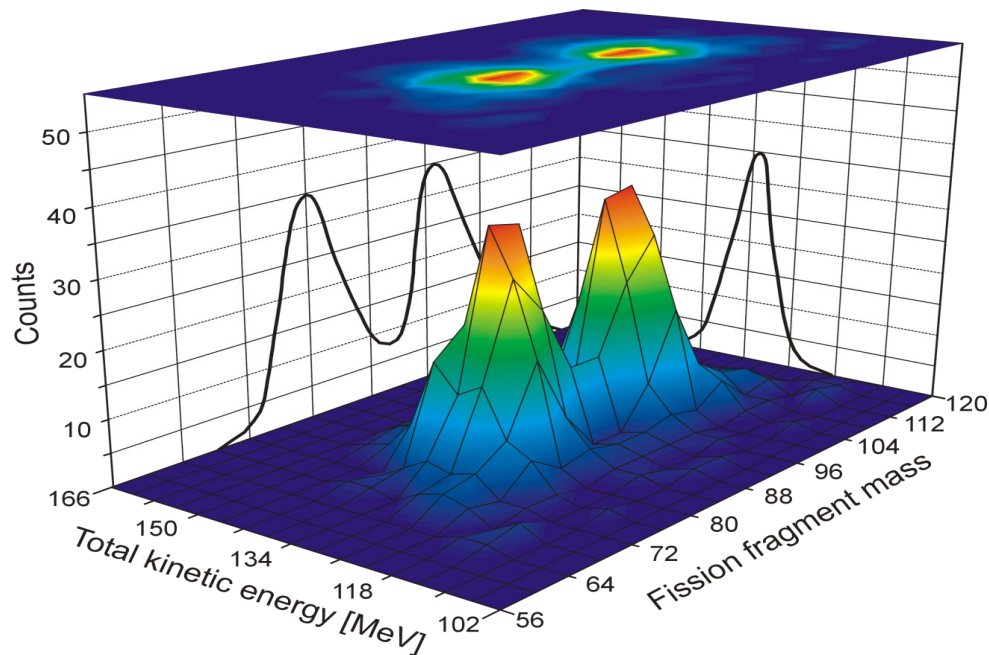
A.N. Andreyev^{1,2}, J. Elseviers¹, M. Huyse¹, P. Van Duppen¹, S. Antalic³, A. Barzakh⁴, N. Bree¹, T.E. Cocolios¹, V. F. Comas⁵, J. Diriken¹, D. Fedorov⁴, V. Fedosseev⁶, S. Franchoo⁷, J.A. Heredia⁵, O. Ivanov¹, U. Köster⁸, B. A. Marsh⁶, K. Nishio⁹, R.D. Page¹⁰, N. Patronis^{1,11}, M. Seliverstov^{1,6}, I. Tsekhanovich^{12,17}, P. Van den Bergh¹, J. Van De Walle⁶, M. Venhart^{1,3}, S. Vermote¹³, M. Veselsky¹⁴, C. Wagemans¹³, T. Ichikawa¹⁵, A. Iwamoto⁹, P. Möller¹⁶, A.J. Sierk¹⁶

¹*Instituut voor Kern- en Stralingsfysica, K.U. Leuven, University of Leuven, B-3001 Leuven, Belgium*

²*School of Engineering, University of the West of Scotland, Paisley, PA1 2BE, UK and the Scottish Universities Physics Alliance (SUPA)*

<http://www.nature.com/news/2010/101201/full/news.2010.642.html>

“Mercury serves up a nuclear surprise”(Eugenie Samuel Reich)



Experiment IS466-II ..

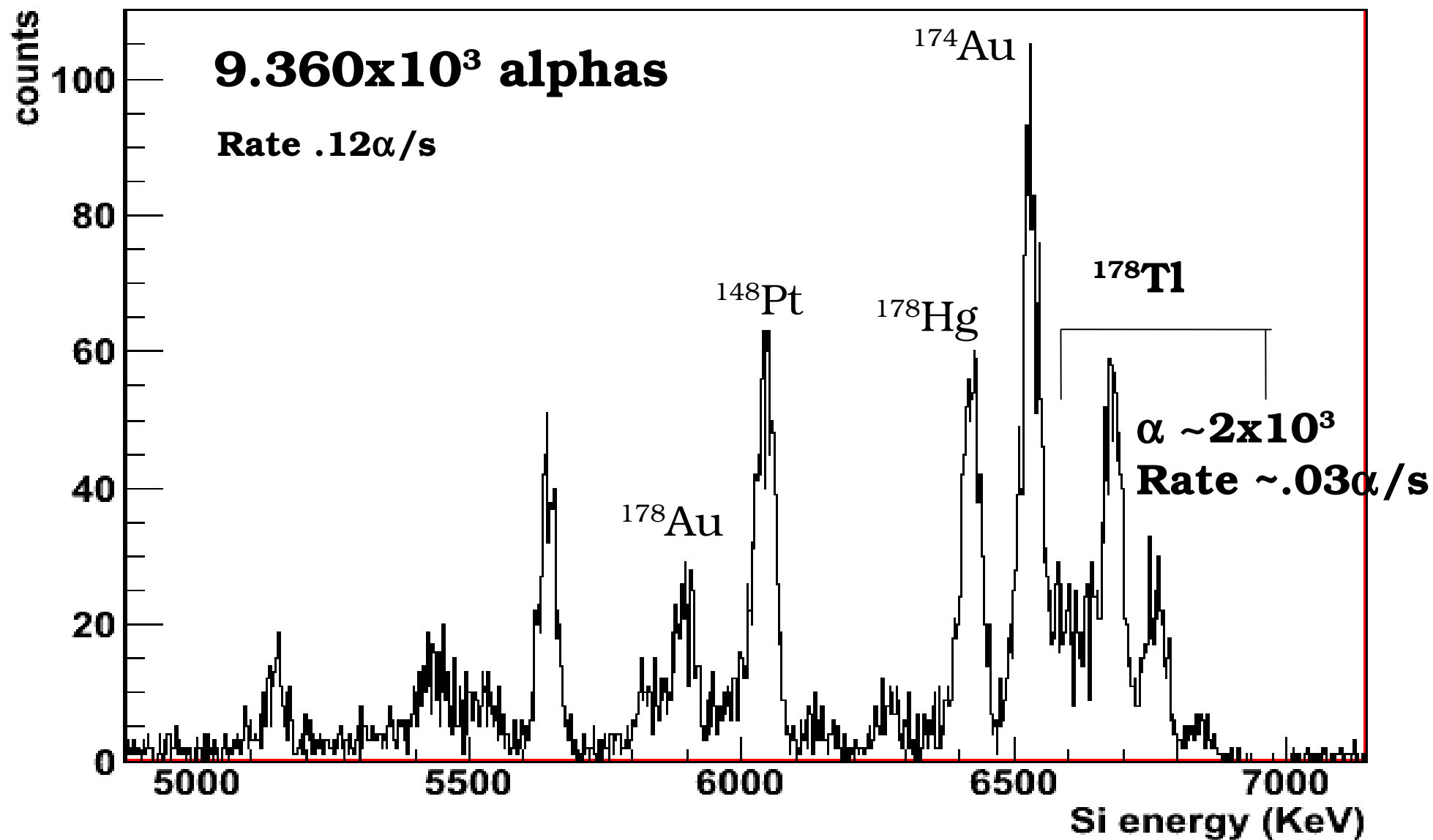
In view of the very successful IS466 run : research extended to **lighter and heavier neighbors of ^{180}Tl** .

^{178}Tl	^{182}Tl
^{180}Tl	^{183}Tl
^{181}Tl	^{184}Tl
^{202}Fr	

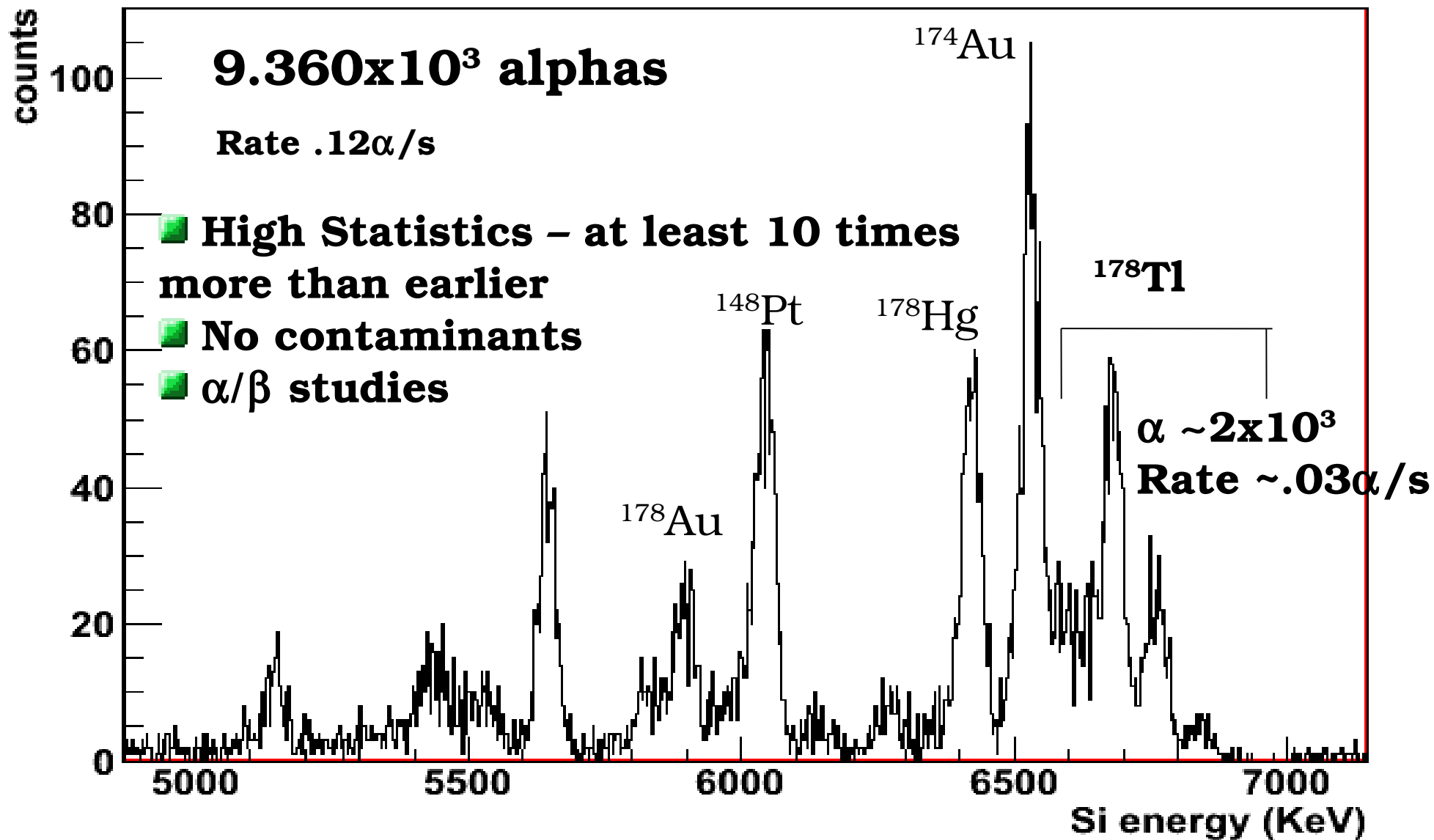
- **ISOTOPE SHIFT** and **HYPERFINE STRUCTURE** measurement performed for the **red** nuclei
This will allow deducing properties of the nuclei, i.e, radius, moments,..

(Relative data currently under analysis)

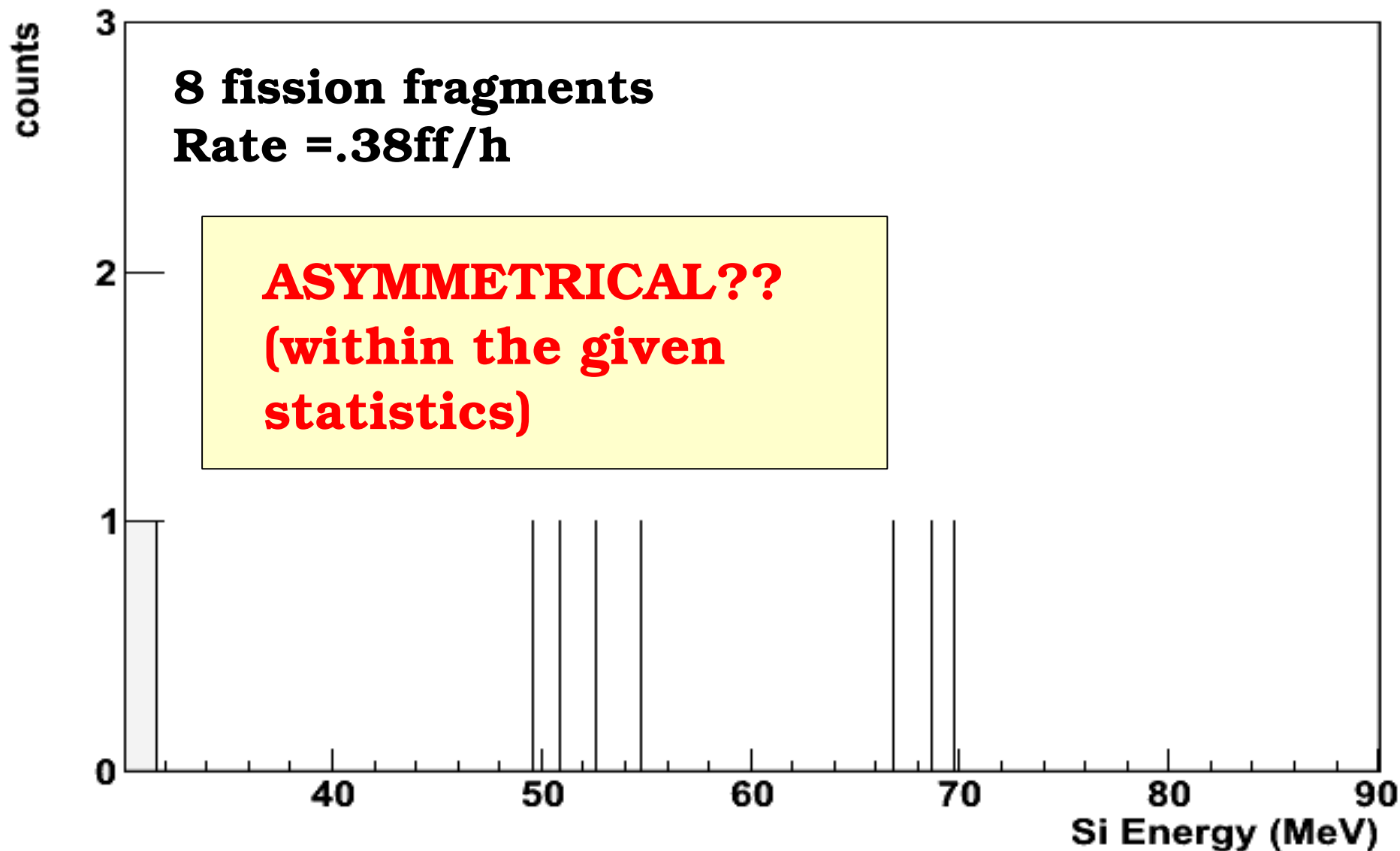
^{178}Tl - alpha spectrum



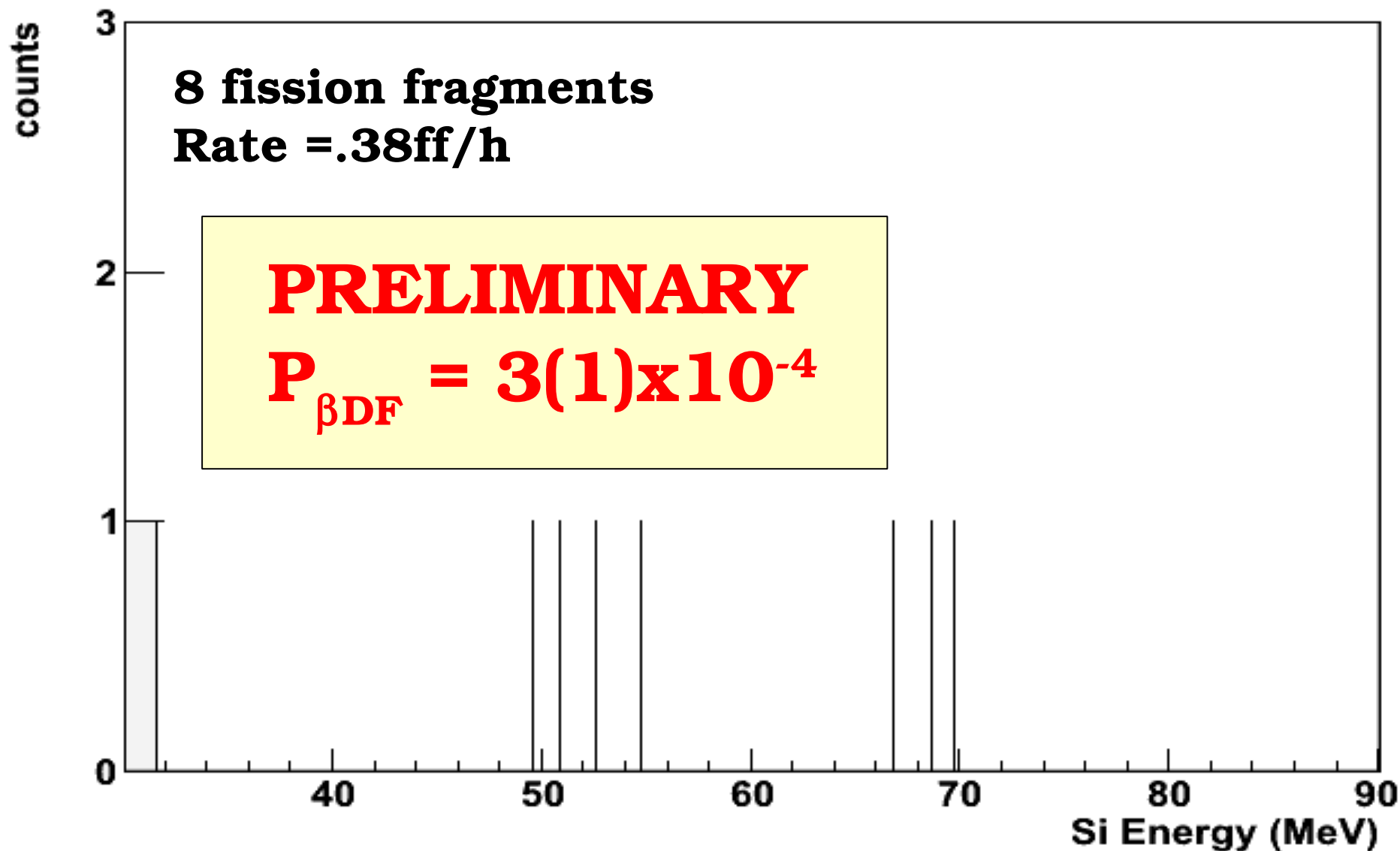
178Tl - alpha spectrum



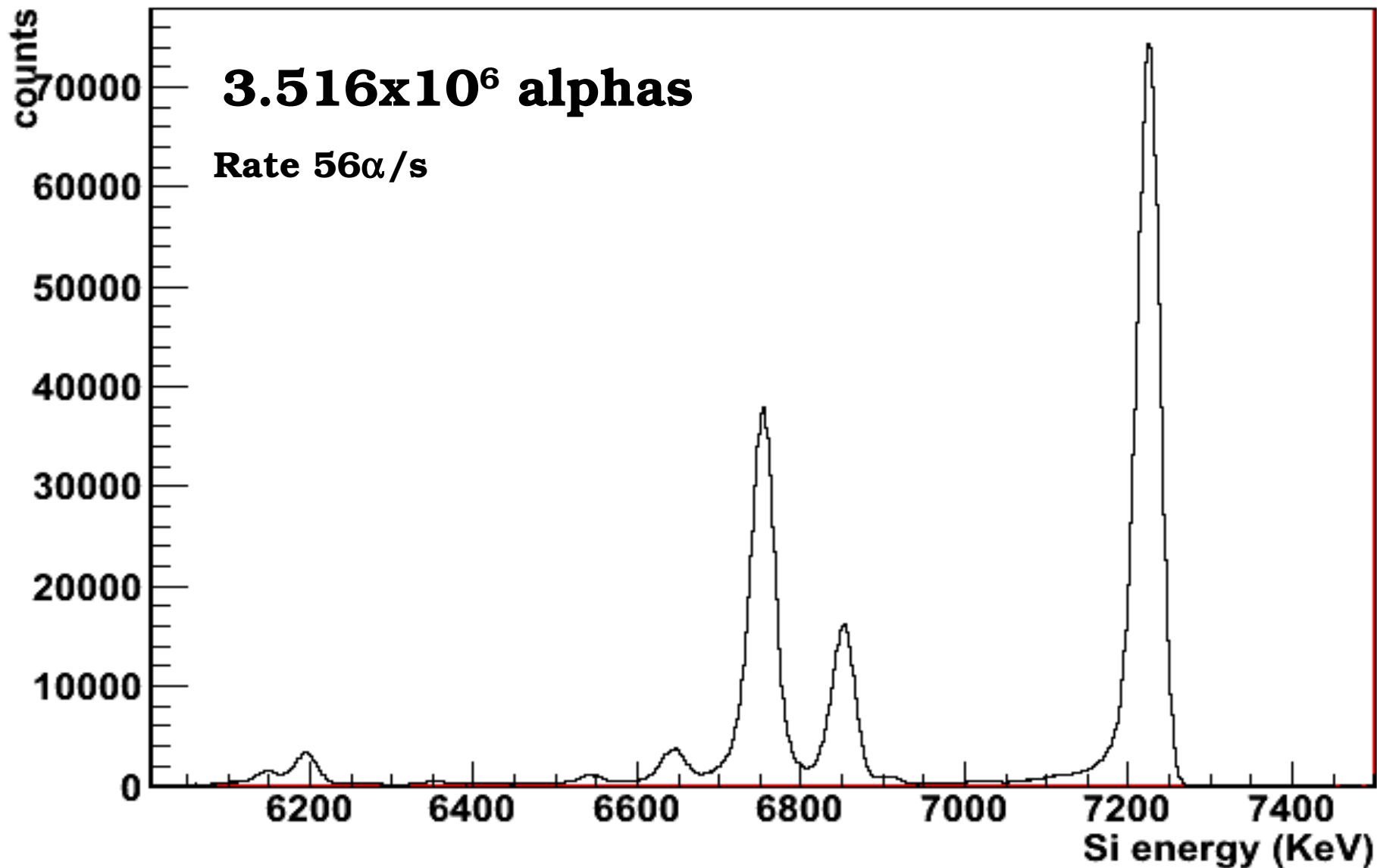
178Tl - Fission Events



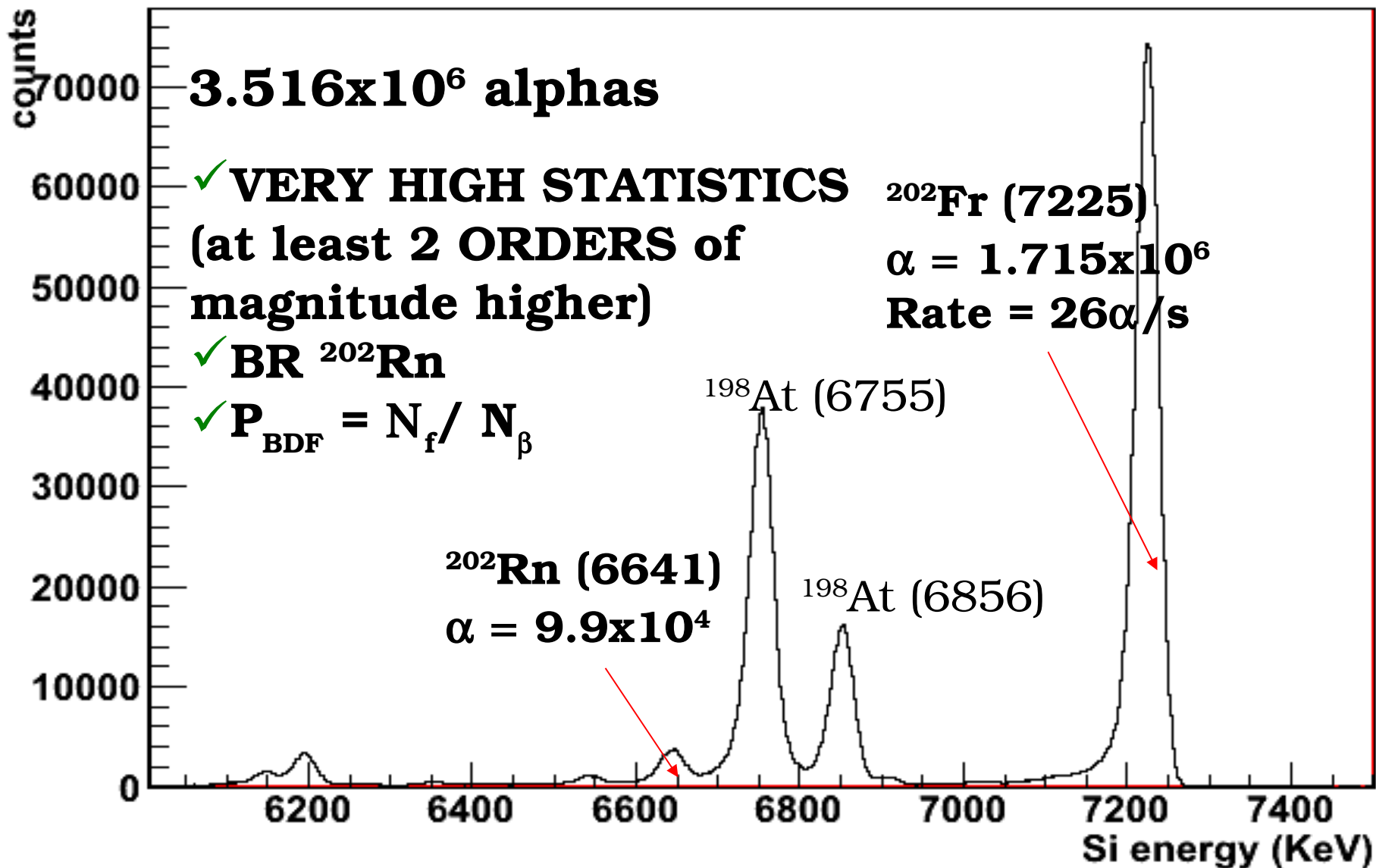
178Tl - Fission Events

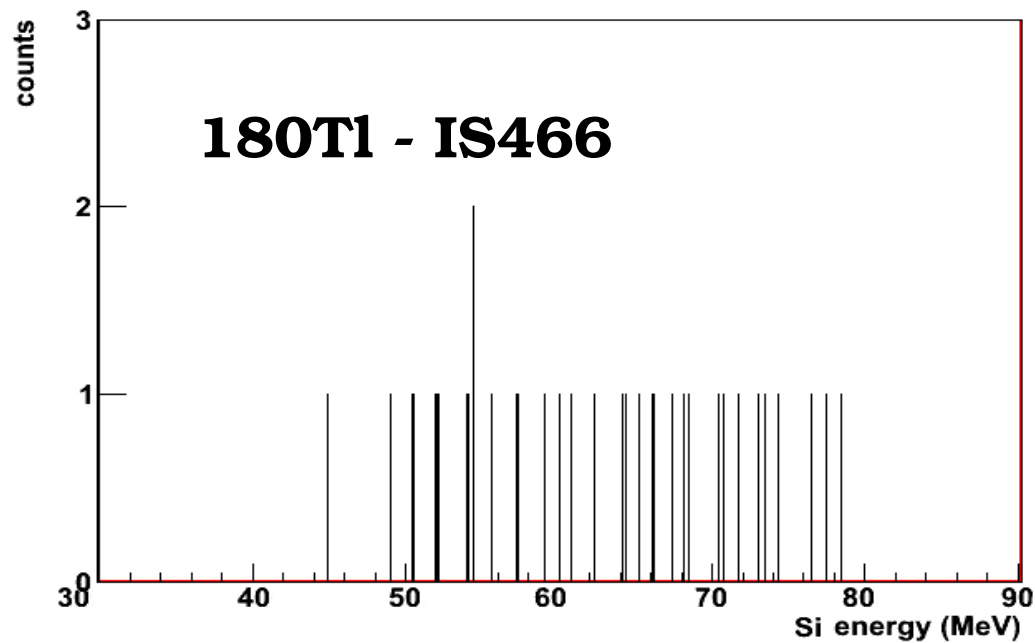
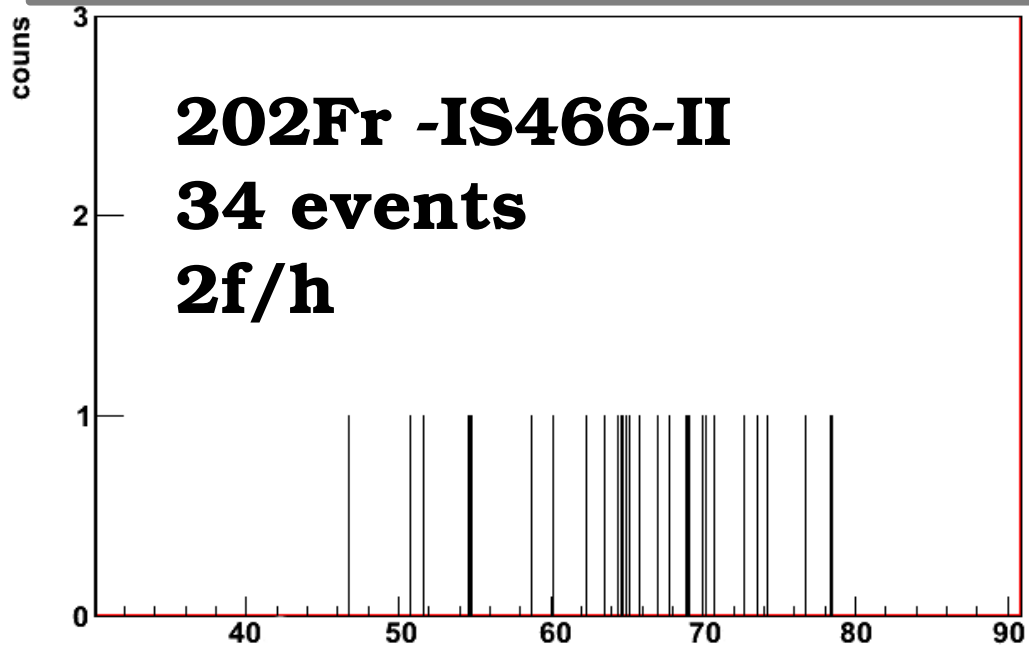


202Fr - alpha spectrum

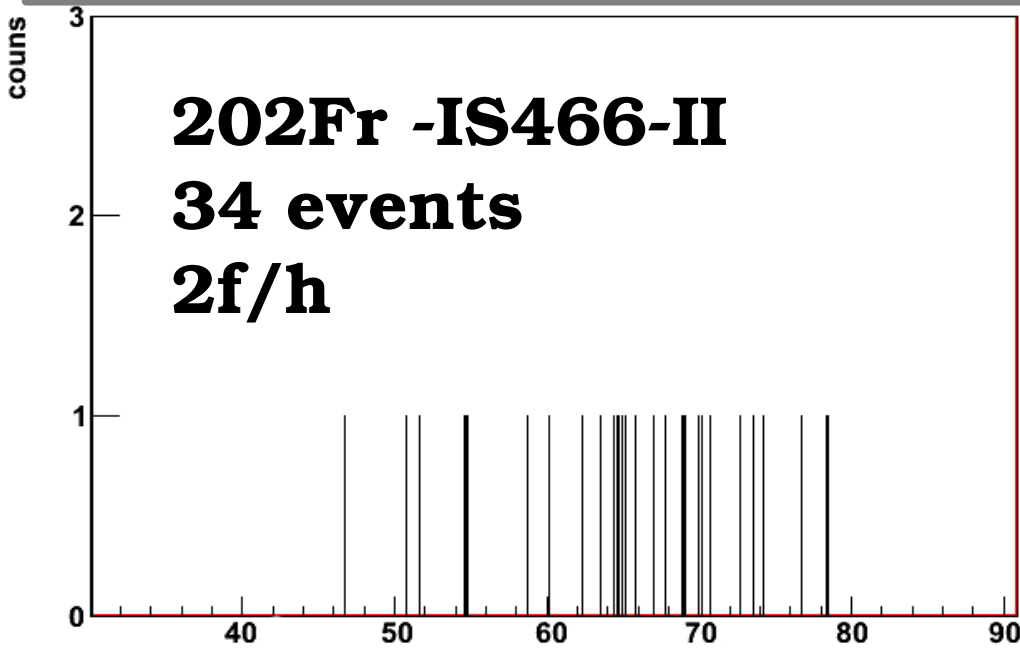


202Fr - alpha spectrum

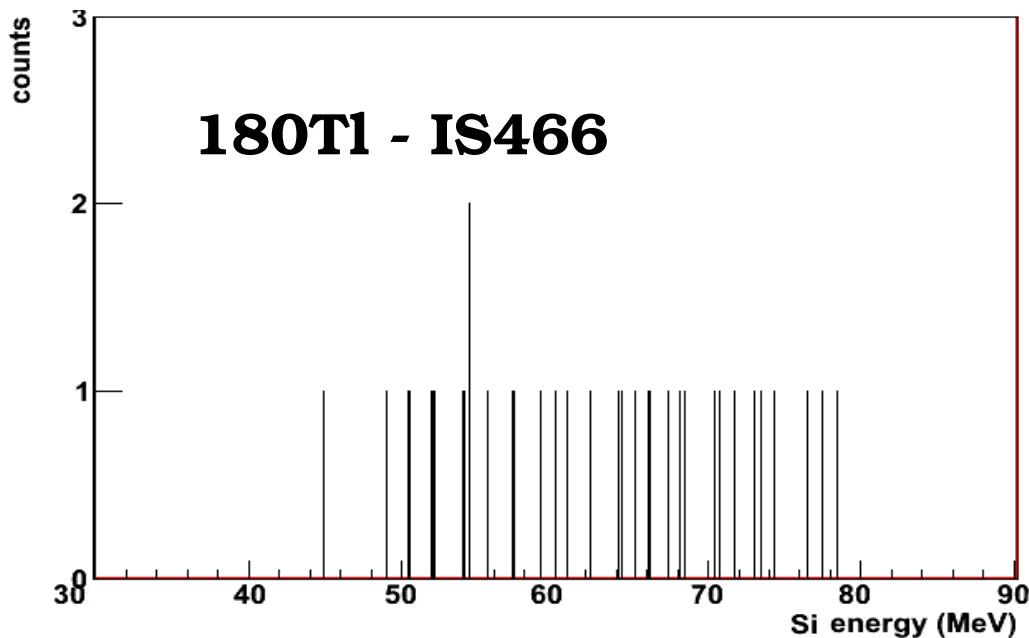




^{202}Fr - IS466-II
34 events
2f/h



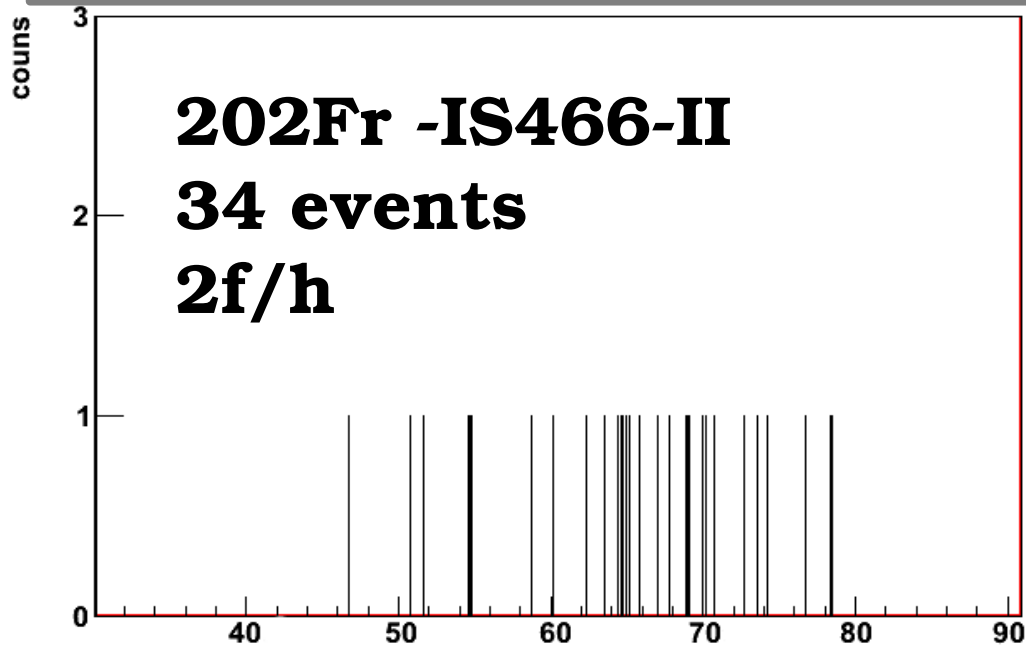
^{180}Tl - IS466



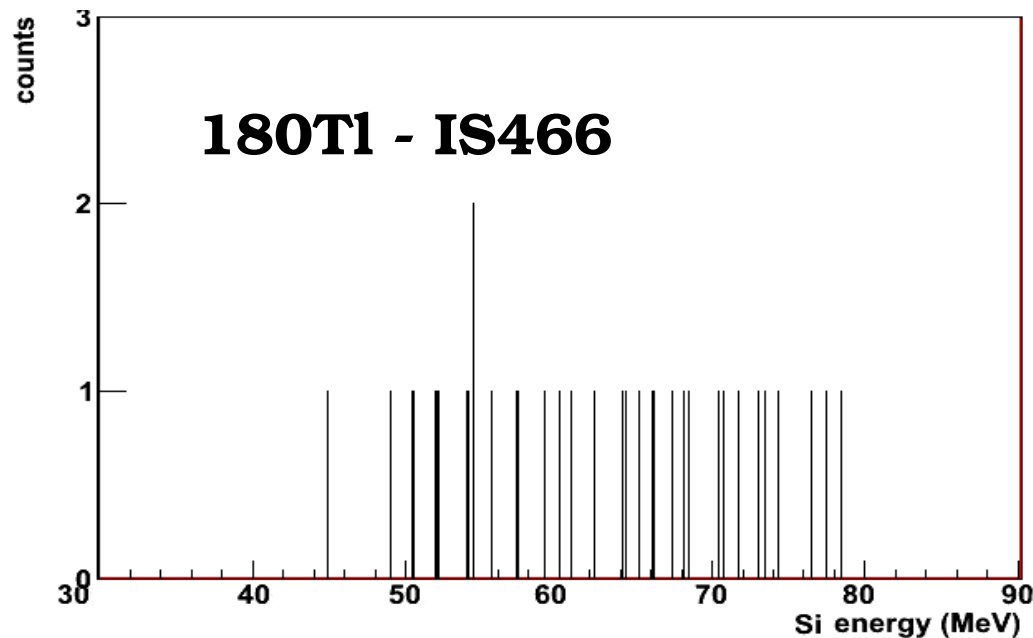
■ Apparently, comparable mean width, but could be also symmetrical -

■ Larger density in the middle of ^{202}Fr in comparison with ^{180}Tl .

■ Thus, need more singles (and also need coincidences).



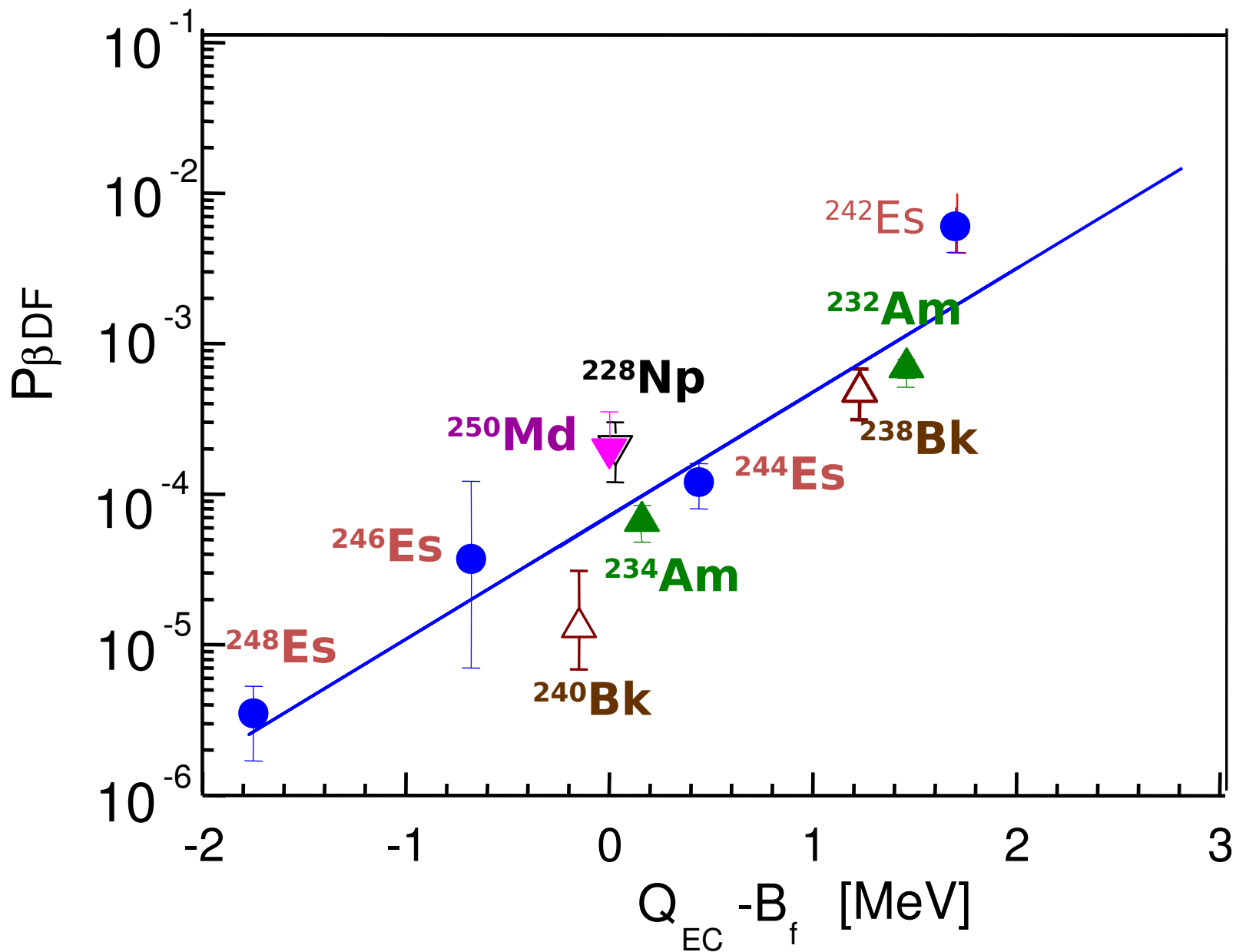
■ **We need coincidence data for ^{202}Fr OR 4-5 times more statistics in singles(which is achievable)!!!**



PRELIMINARY

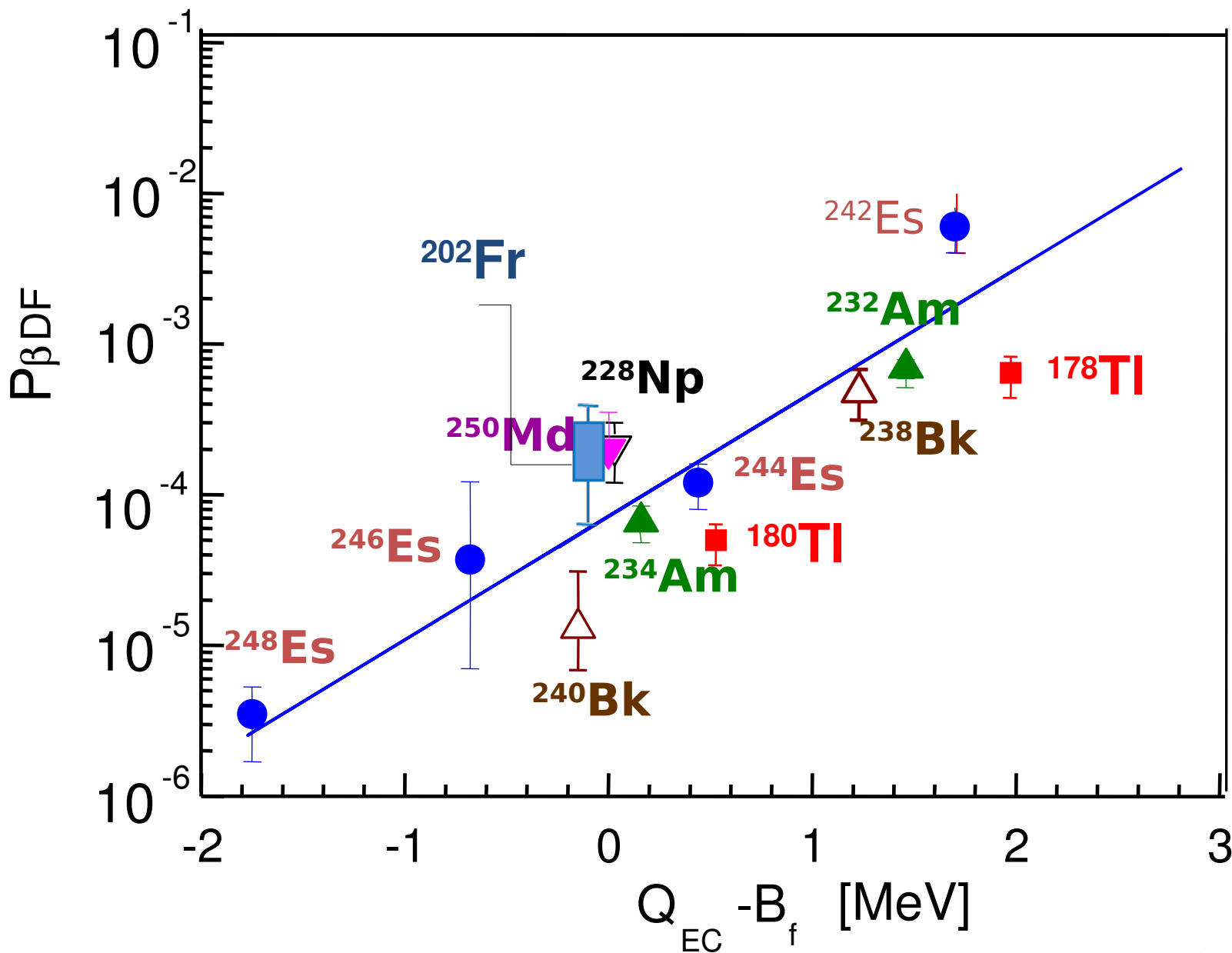
$$P_{\beta\text{DF}} = 3(1) \times 10^{-4}$$

*(Two isomers in ^{202}Fr
Which one do fission?)*



- 10 known βDF cases in trans-U region
- Relatively low Q_{EC} and B_f values (3-5 MeV)
- Linear dependence**

- Pb-region data fit in the general trend.
- Before IS466 two different behaviours were expected for $P_{\beta DF}$ in the U- and Pb- regions (different Q and B_f)
- SAME behaviour observed!!**



Future Work and Analysis in the Pb region ..

Identification of new bDF nuclei and detailed studies (e.g. Bf, TKE, mass..)

ISOLDE:

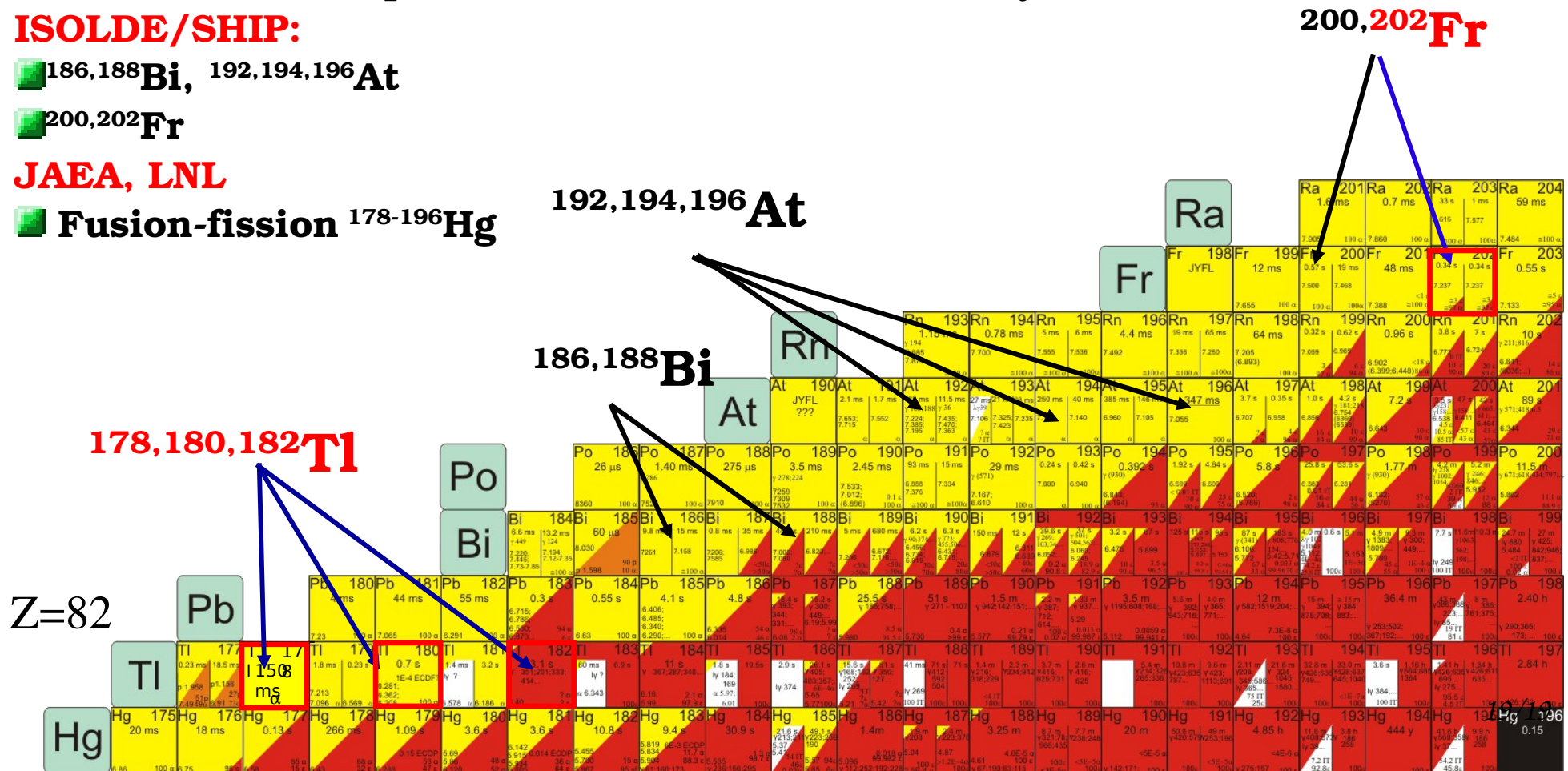
- ^{180}Tl – HFS scan with RILIS : search for 2 isomeric states
- ^{180}Tl – mass measurement at ISOLTRAP
- $^{178,182}\text{Tl}$ – bDF experiments at ISOLDE (done, July 2010)

ISOLDE/SHIP:

- $^{186,188}\text{Bi}$, $^{192,194,196}\text{At}$
- $^{200,202}\text{Fr}$

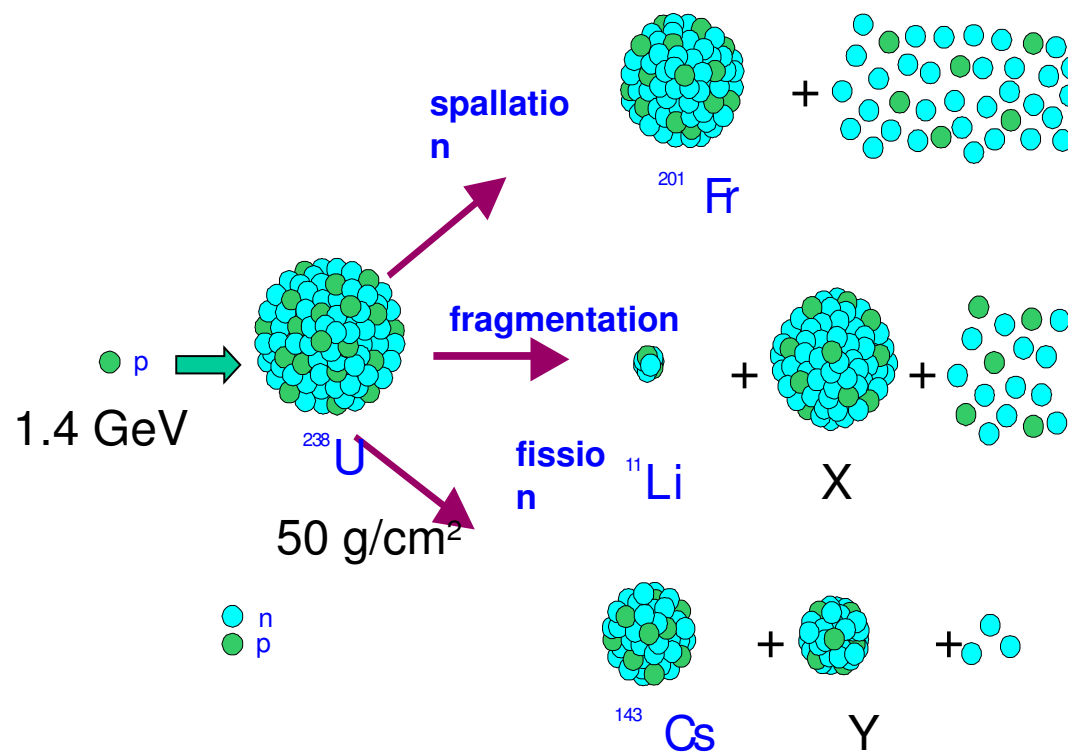
JAEA, LNL

- Fusion-fission $^{178-196}\text{Hg}$

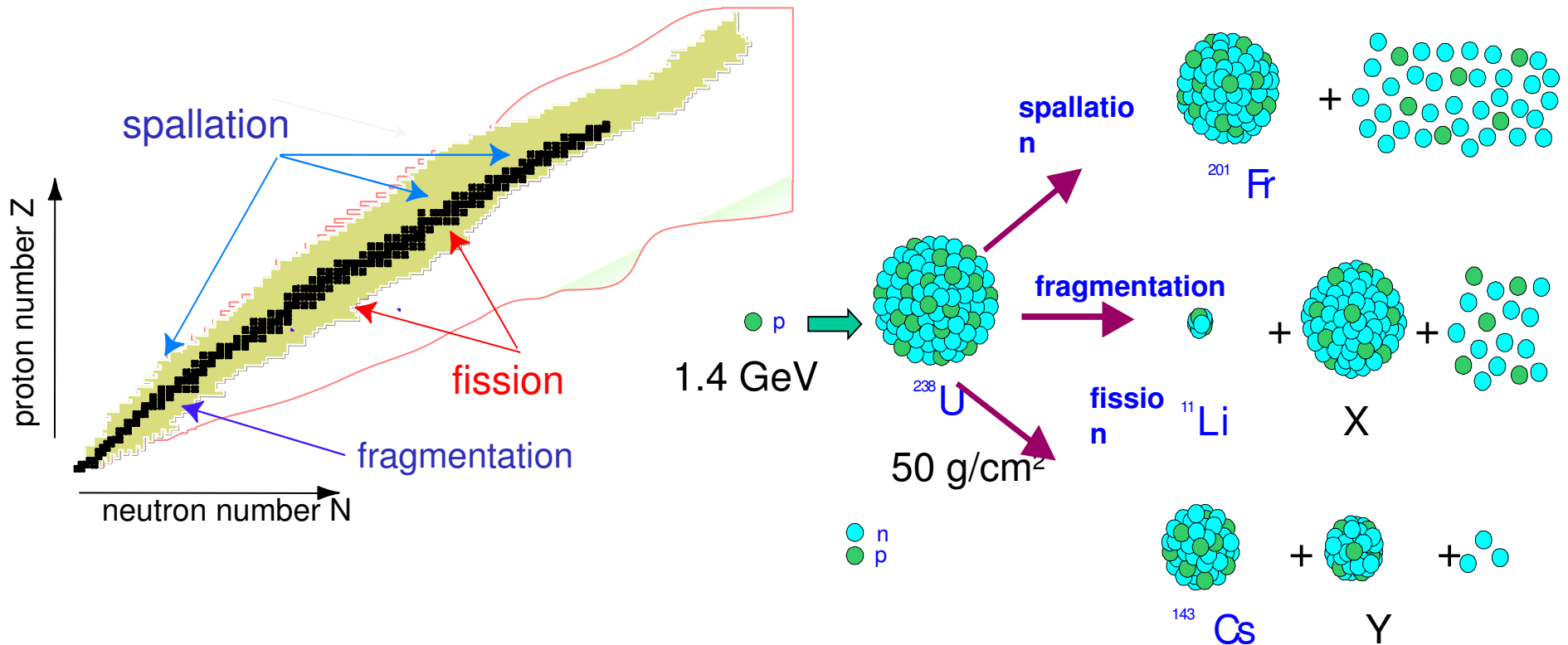


*Thank you
For the attention*

Radioactive Isotope production..



Radioactive Isotope production..



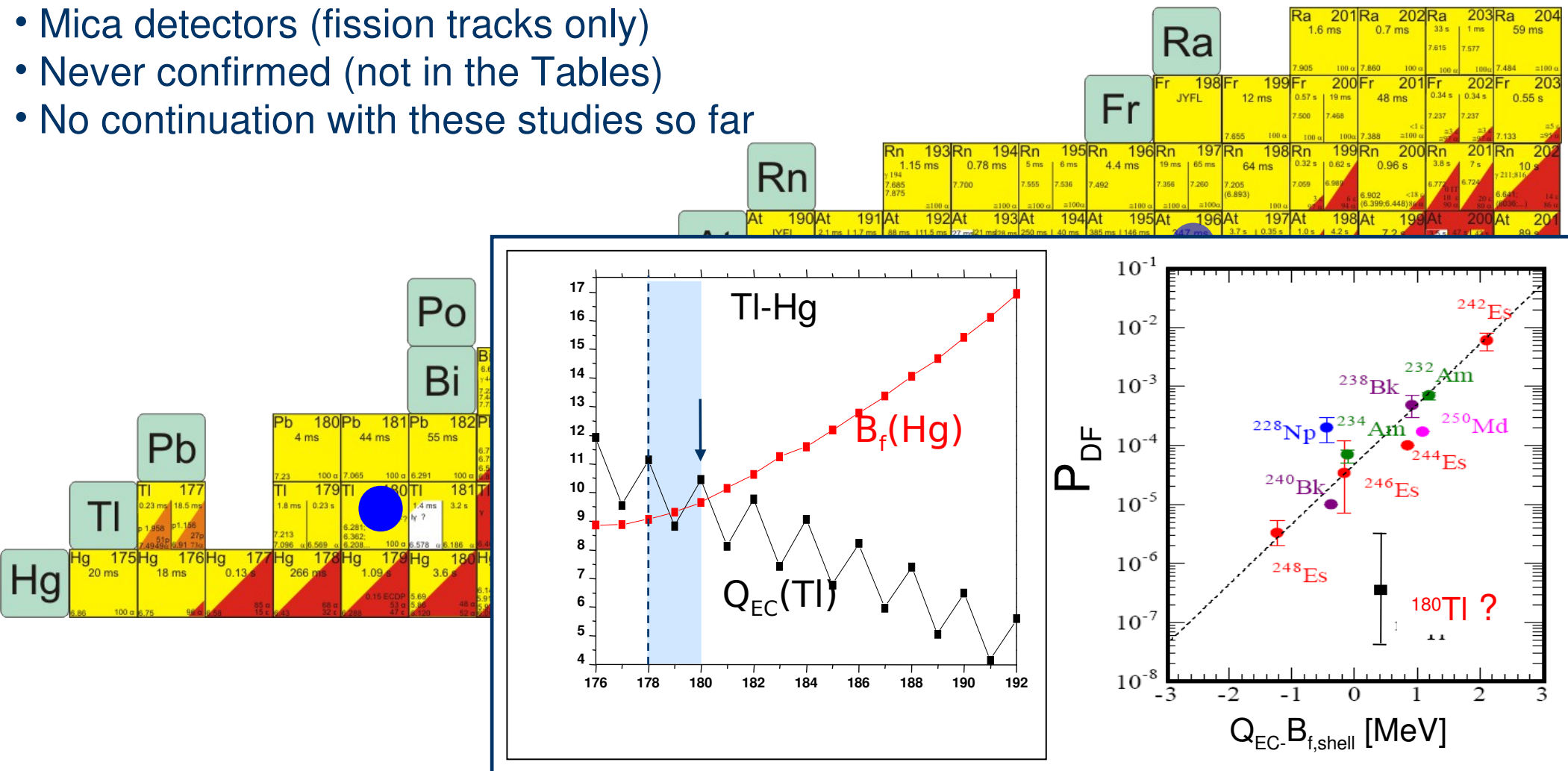
The target material is chosen to maximise the desired isotope production

Previous Studies in the Pb region (Dubna)

Yu. A. Lazarev et al. Europhys. Lett. 4 (1987) 893; and Inst. Phys. Conf. Ser. No132 (1992) 739

“Most probable” candidates: ^{180}Tl ($P_{\text{ECDF}}=3 \times 10^{-(7 \pm 1)}$), ^{188}Bi , ^{196}At (no P_{ECDF} data)

- Irradiations inside the cyclotron (no A,Z selection for products)
- Rotating wheel system, thick effective targets (2 mg/cm²)
- Cross-irradiations, apparent $\sigma_{\text{fis}} \sim 15\text{-}50$ pb
- Mica detectors (fission tracks only)
- Never confirmed (not in the Tables)
- No continuation with these studies so far



A bit of IS ..

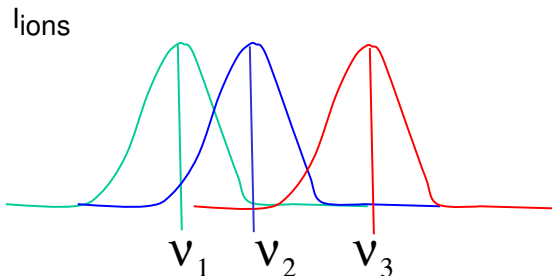
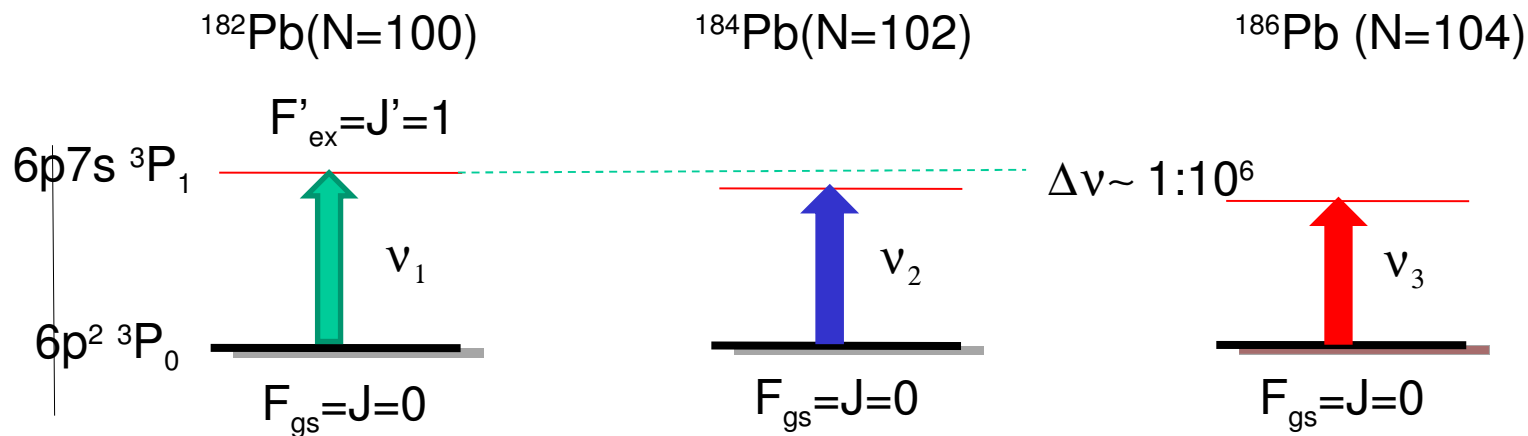
$$\Delta v = v_1 - v_2 \text{ Isotope Shift (IS)}$$

Total Angular Momentum of an Atom

$$F_{\text{atom}} = I_{\text{nuclear}} + J_{\text{electron}}$$

(for an even-even isotope $I=0$, thus, $F=J$)

Let's consider, e.g. even-even Pb ($Z=82$) isotopes



IS proportional to the charge radius!