



The diagram shows a portion of the periodic table with three isotopes of Terbium (Tb) highlighted in colored boxes. The boxes are labeled with the isotope, its half-life, and its decay modes and daughter products.

- Tb 149** (yellow box): 4.1 h. Decay modes: ϵ , α 3.97, β^+ 1.4..., γ 352; 165...
- Tb 152** (pink box): 17.5 h. Decay modes: ϵ , β^+ 3.0; 2.6; 2.0..., γ 344; 271; 586...
- Tb 155** (red box): 5.23 d. Decay modes: ϵ , γ 87; 105; 180..., e^-

A blue caduceus symbol is positioned above the highlighted boxes. The periodic table shows elements from H to Og, with some elements missing in the original image.

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



ISOLTRAP MR-ToF-MS

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DARMSTADT



This project has received funding from the European Union under grant agreements No 262010 (ENSAR), 654002 (ENSAR2) and 101008571 (PRISMAP).

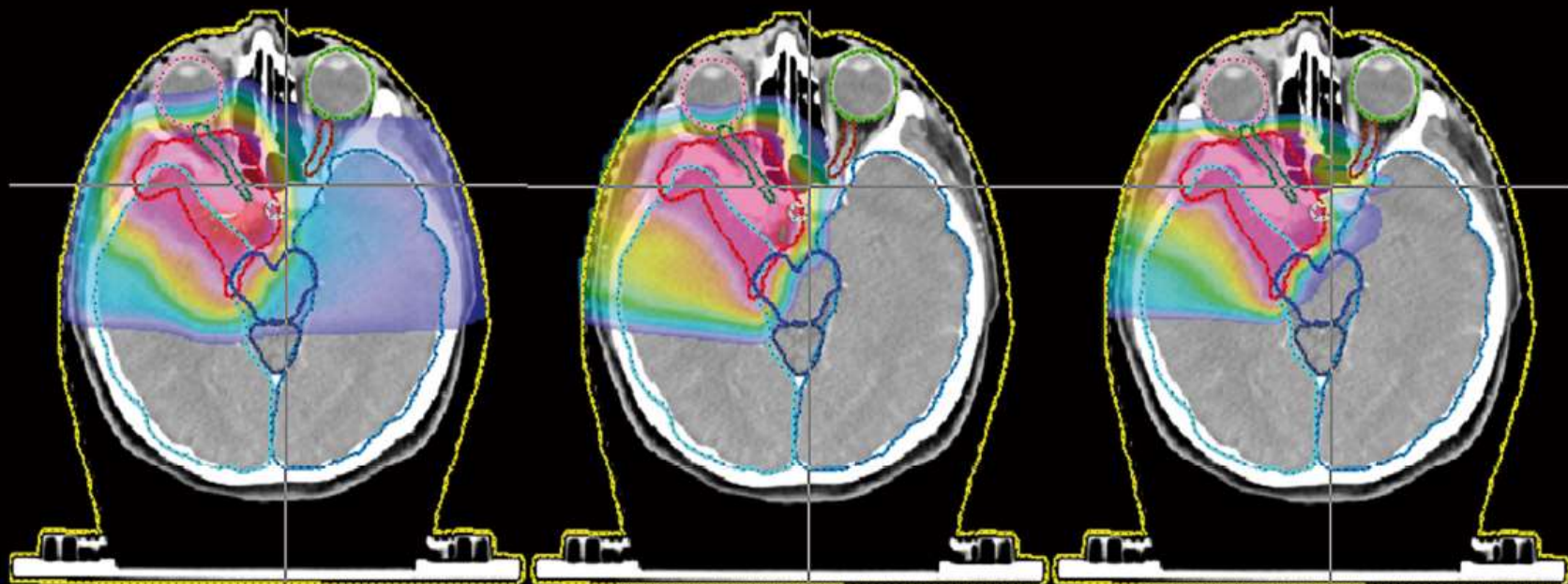
Progress in cancer treatment



IMXT

protons

carbon ions



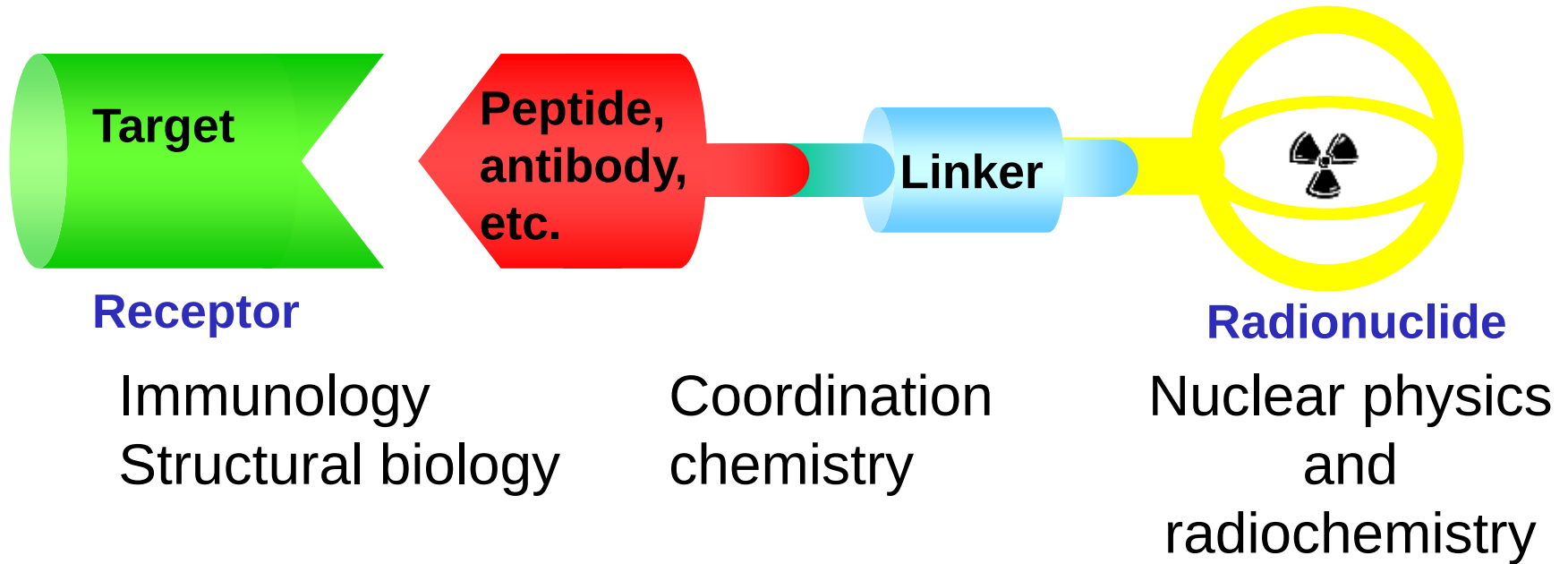
52.5
GyE

5.0
GyE

How to treat such patients?

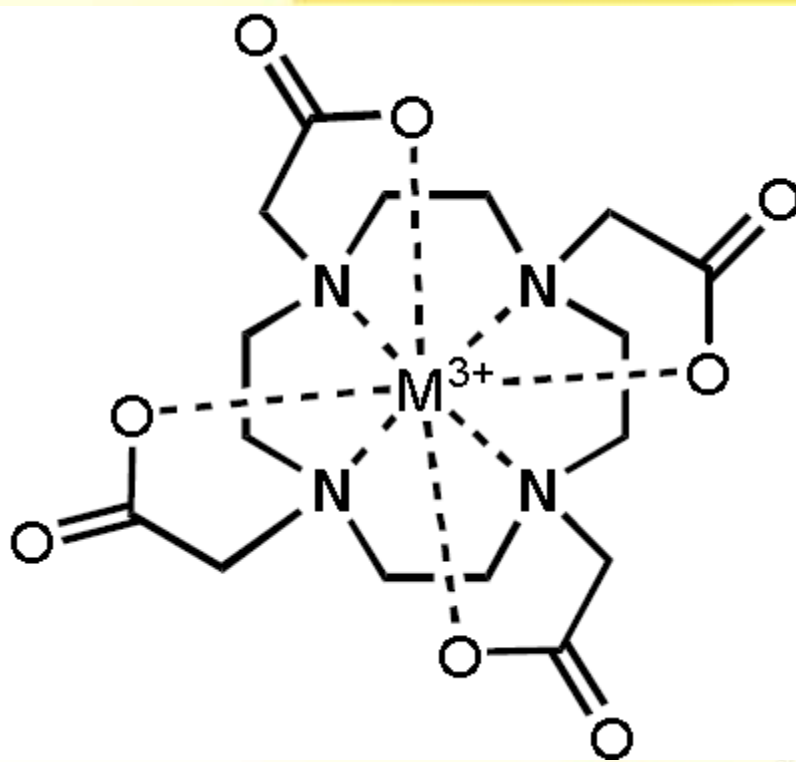


Multidisciplinary collaboration to fight cancer

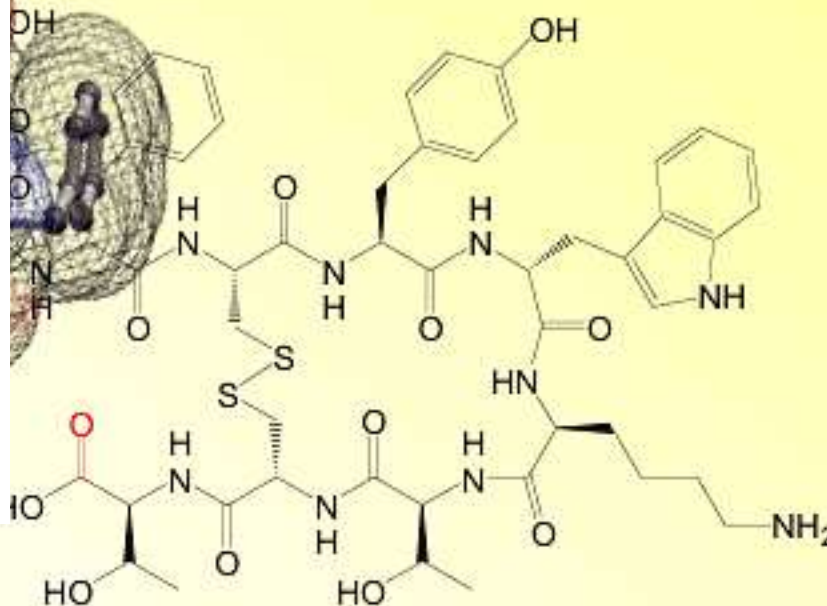


Nuclear medicine and medical physics

Structural Formula of DOTA-TOC/TATE



DOTA-TATE



1,4,7,10-tetraazacyclododecantetraacetate

^{111}In

^{90}Y

^{67}Ga

^{177}Lu

^{68}Ga

^{213}Bi

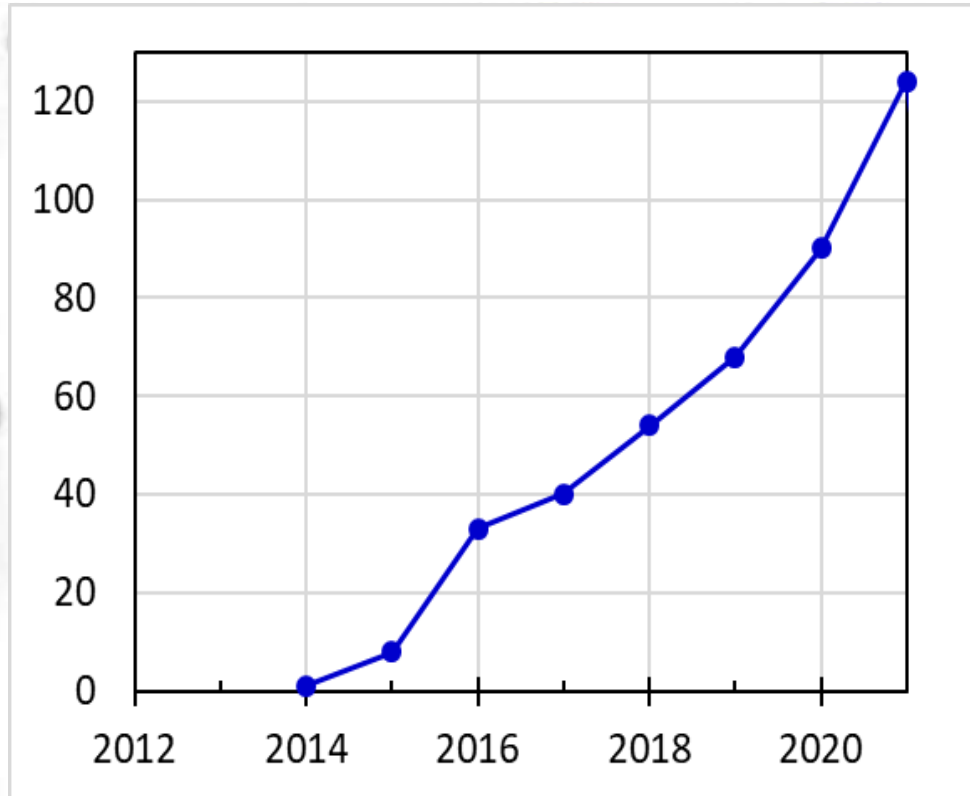
$$\text{IC}_{50} (\text{Y}^{\text{III}}) = 1.6 \pm 0.4 \text{ nM}$$

Helmut Maecke, EANM-2007.



^{177}Lu -radioligand therapy of advanced prostate cancer

A



C. Kratochwil et al., Eur J Nucl Med Mol Imaging 2015;42:987.

R.P. Baum et al., J Nucl Med 2016;57:1006.

C. Kratochwil et al., J Nucl Med 2016;57:1170.

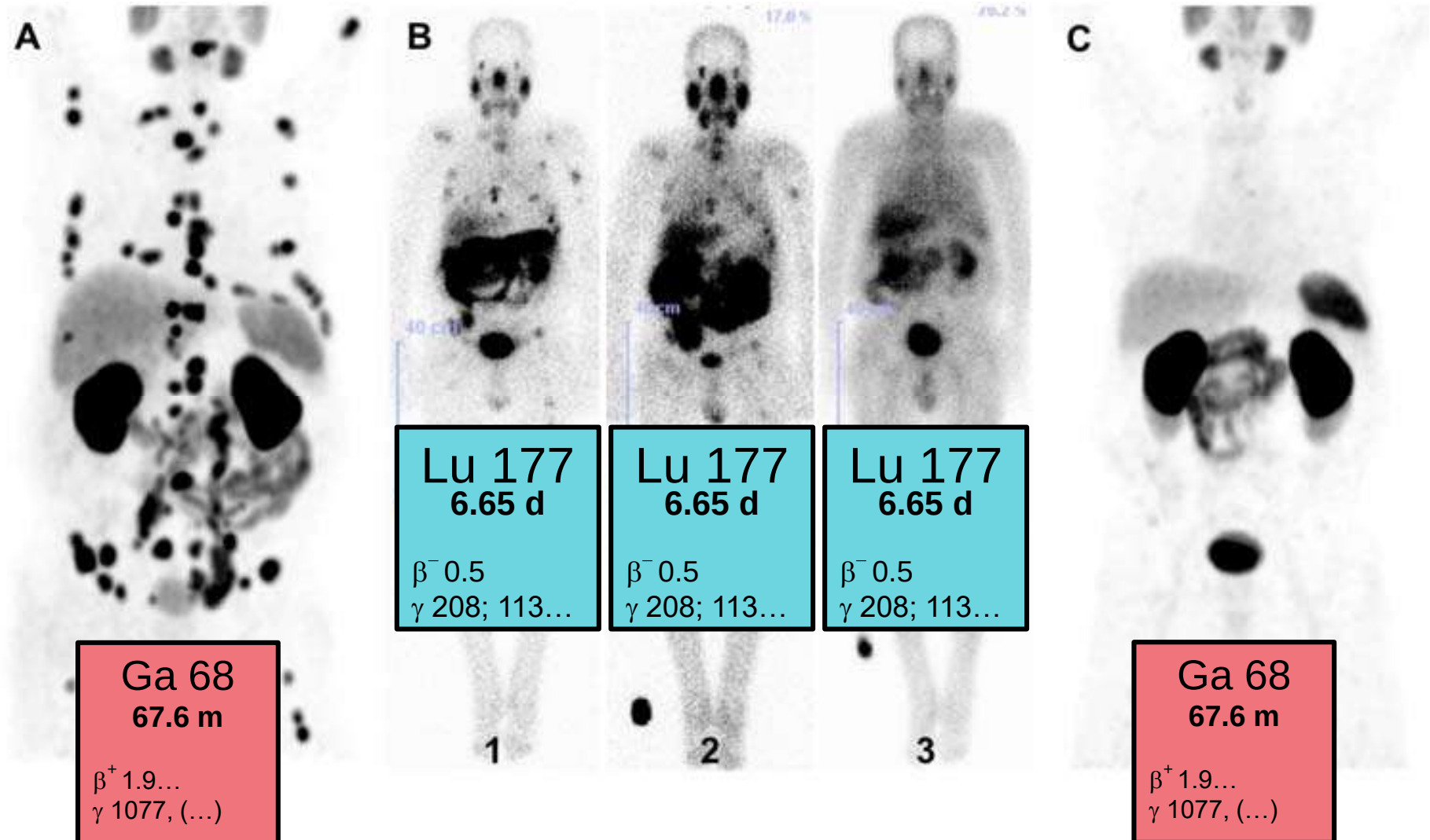
K. Rahbar et al., J Nucl Med 2017;58:85.

M.S. Hofman et al., Lancet Oncol 2018;19:825.

O. Sartor et al., N Engl J Med 2021;385:1091.

23 March 2022: Pluvicto® approved by FDA

^{177}Lu -radioligand therapy of advanced prostate cancer

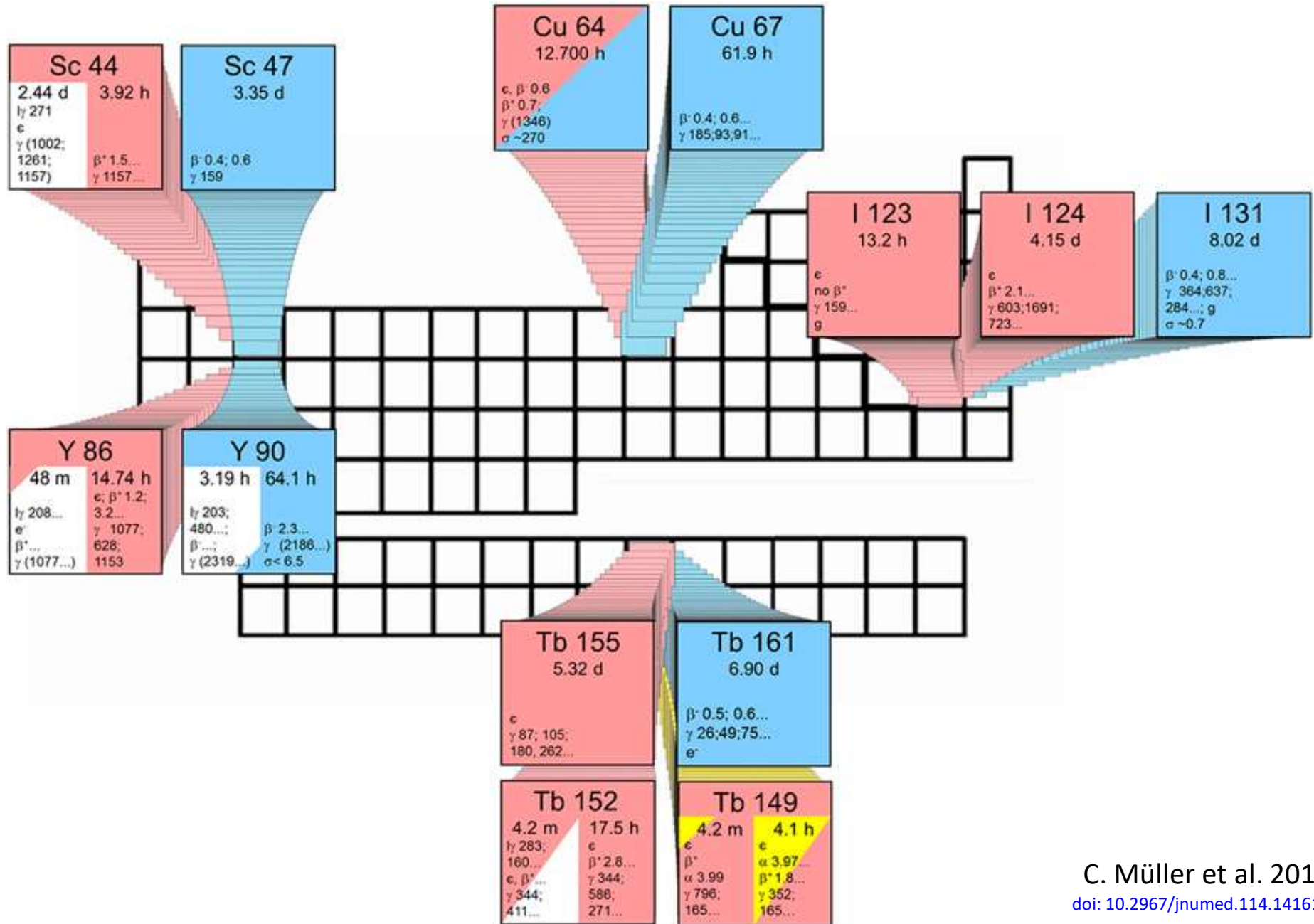


Matching of in-vivo behaviour ?

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Matched pairs for theranostics



The ideal beta emitter ?

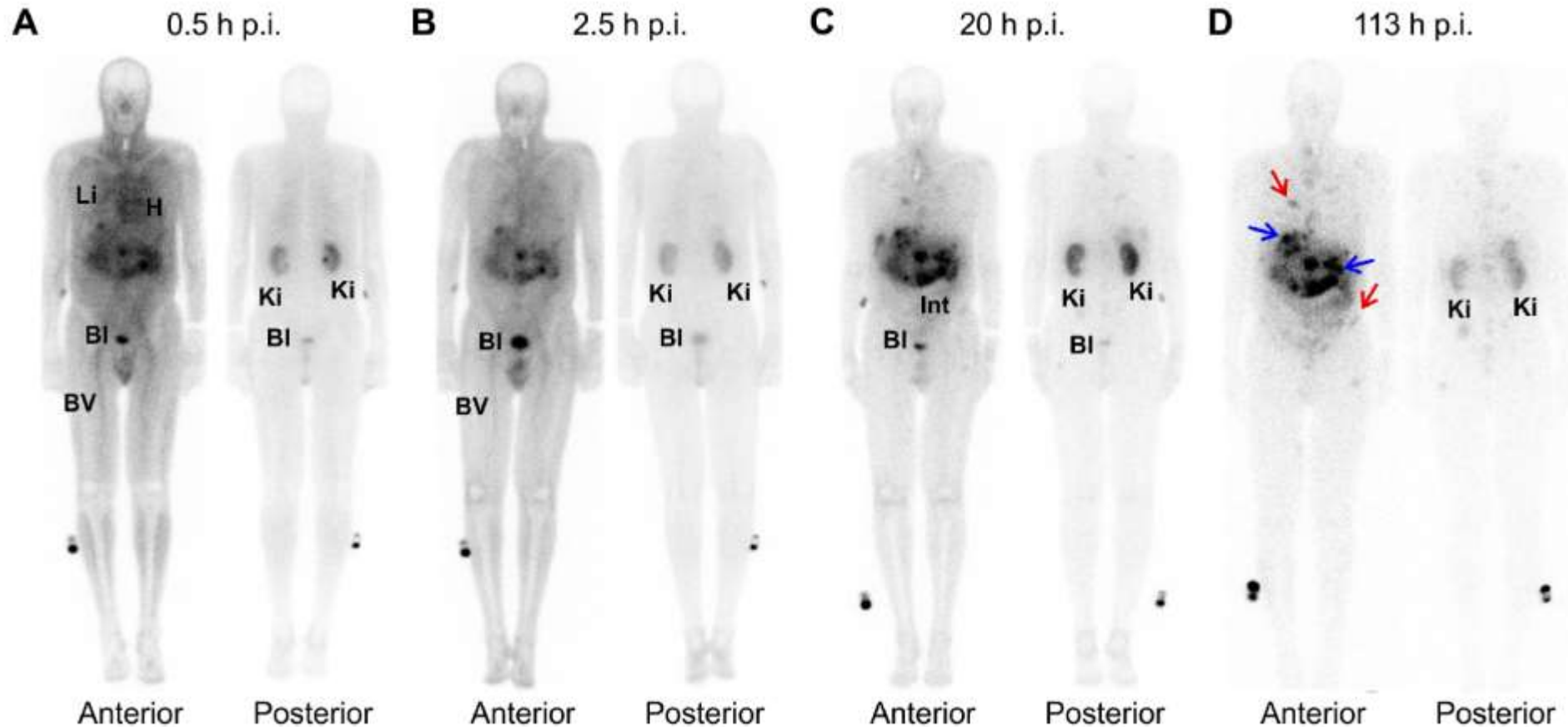
Tb 161

6.96 d

β^- 0.5; 0.6

γ 26; 49; 75...

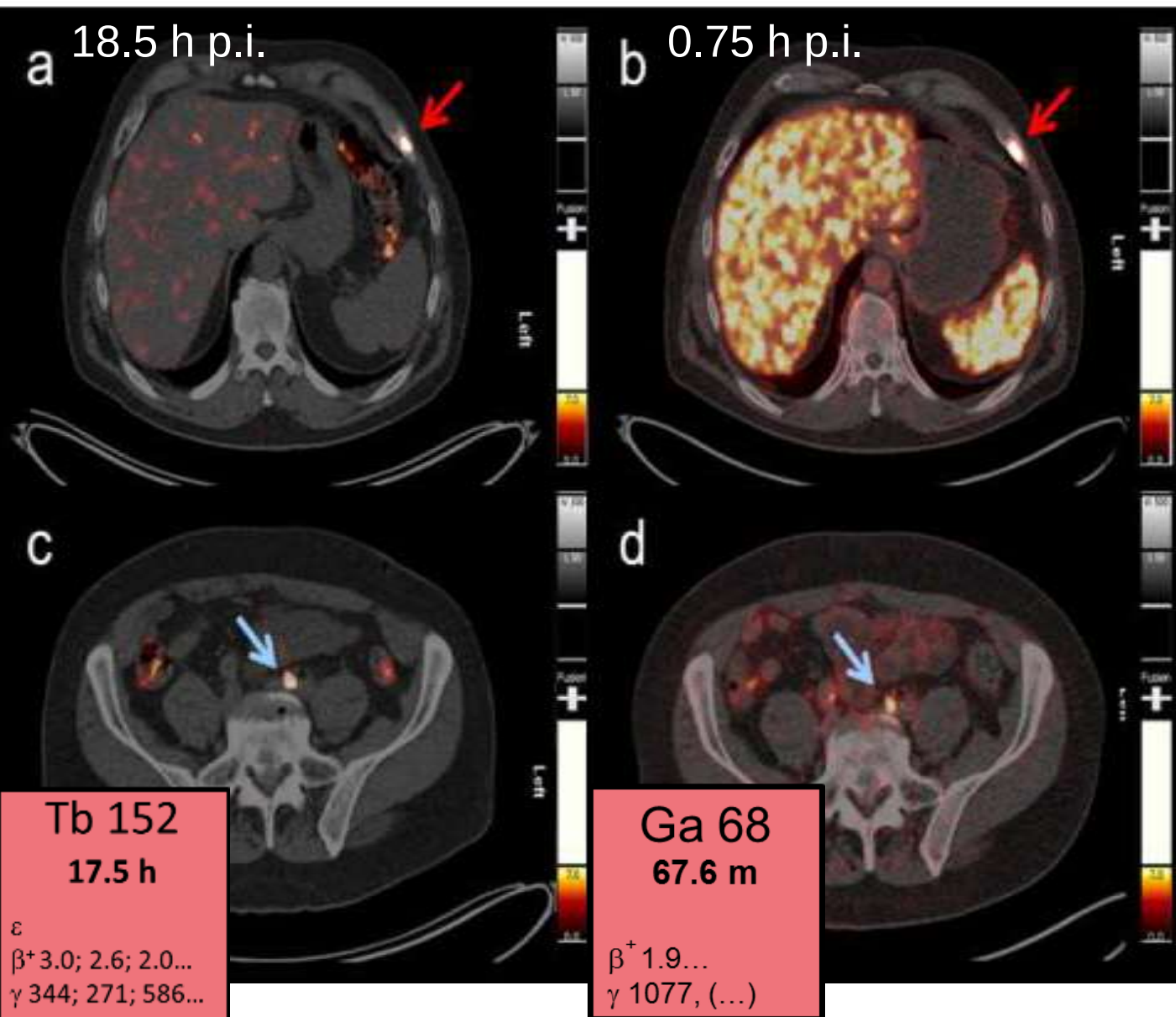
e^-



R.P. Baum et al. 2021

[doi: 10.2967/jnumed.120.258376](https://doi.org/10.2967/jnumed.120.258376)

First-in-human study with ^{152}Tb -PSMA-617



Zentralklinik Bad Berka

PAUL SCHERRER INSTITUT
PSI

ETH zürich

IOOLDE

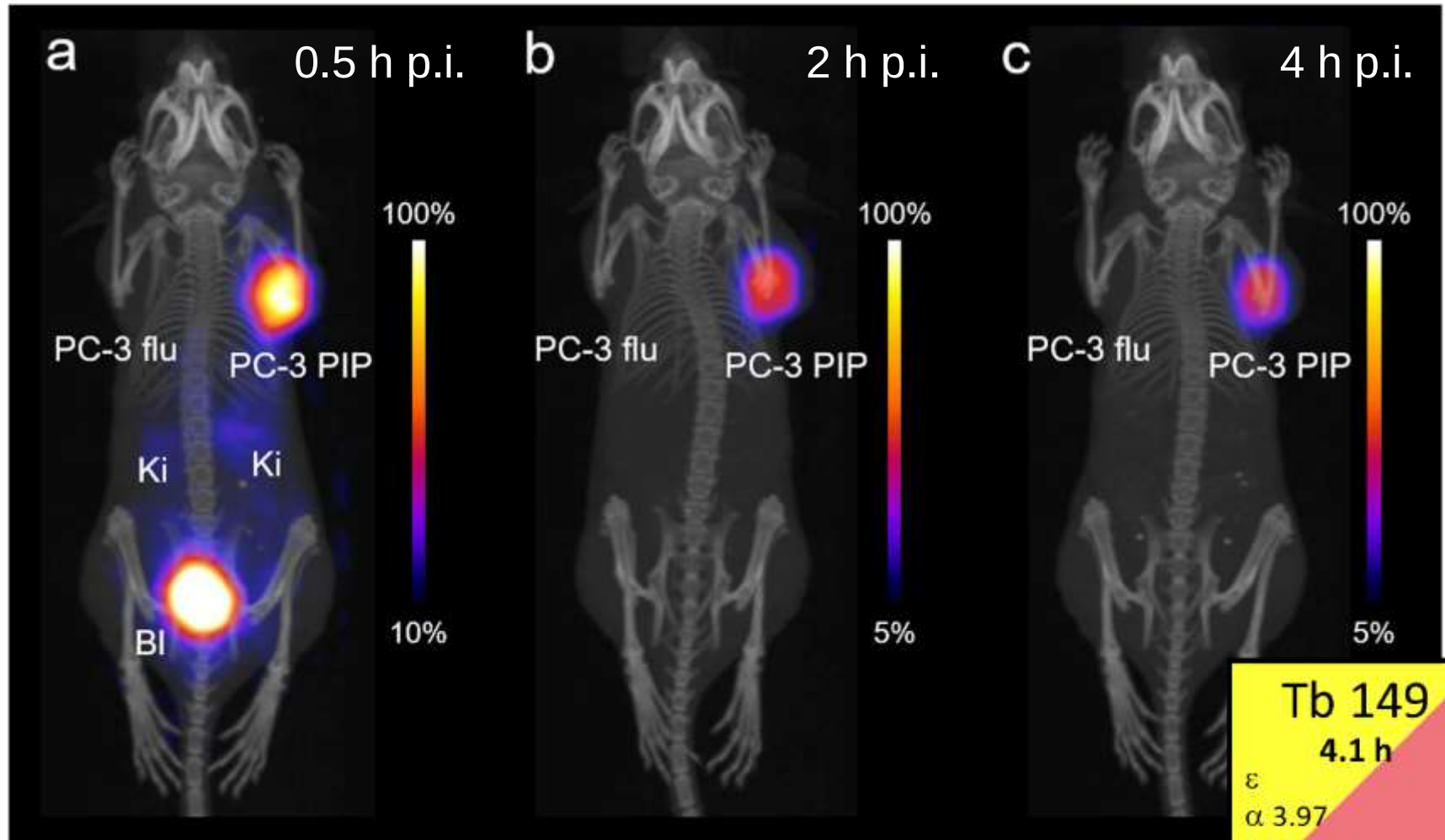
ILL
NEUTRONS
FOR SOCIETY

ENSAR2

150 MBq ^{152}Tb -PSMA-617

C. Müller et al. *EJNMMI Research* 2019;9:68.

Alpha-PET with ^{149}Tb



5 MBq ^{149}Tb -PSMA-617

Tb 149
4.1 h
ϵ
α 3.97
β^+ 1.4...
γ 352; 165...

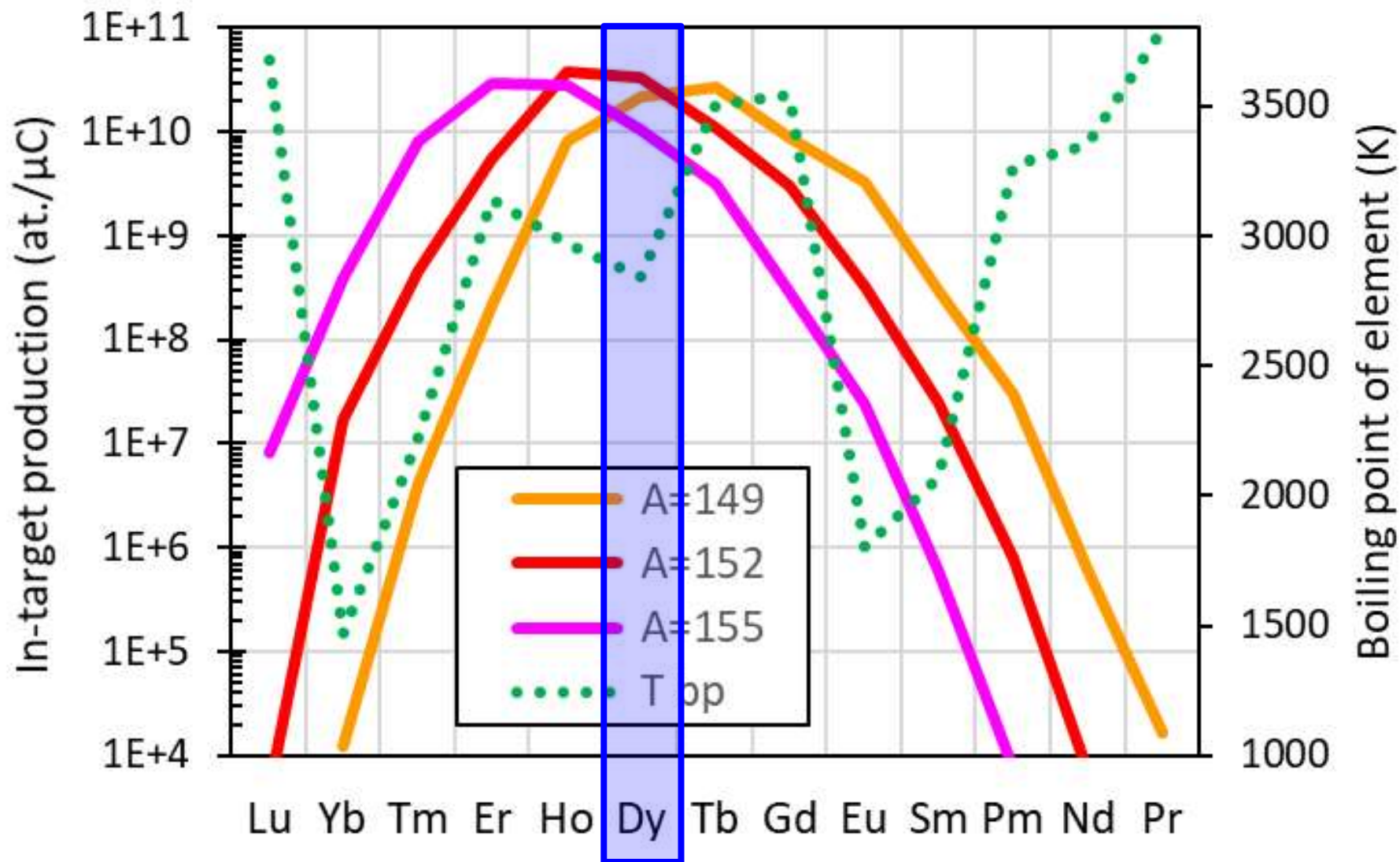
Terbium: a unique element for nuclear medicine



Dy 150 7.2 m ε; β ⁺ ... α 4.23 γ 397 e ⁻	Dy 151 17 m ε; α 4.07 γ 386; 49; 546; 176... g; m	Dy 152 2.4 h ε α 3.63 γ 257 g	Dy 153 6.29 h ε; β ⁺ ... α 3.46... γ 81; 214; 100; 264	Dy 154 3.0 · 10 ⁶ a α 2.67	Dy 155 10.0 h ε β ⁺ 0.9; 1.1... γ 227...	Dy 156 0.056 α 33 α _{n, α} < 0.009	Dy 157 8.1 h ε γ 326...	Dy 158 0.095 α 33 α _{n, α} < 0.006	Dy 159 144.4 d ε γ 58; e ⁻ α 8000	Dy 160 2.329 α 60 α _{n, α} < 0.0003	Dy 161 18.889 α 600 α _{n, α} < 1E-6	Dy 162 25.475 α 170
Tb 149 4.2 m ε β ⁺ 3.99 γ 796; 165...	Tb 150 4.1 h ε β ⁺ 3.97... α 3.49 γ 352; 266...	Tb 151 5.8 m ε; β ⁺ 3.1; α 3.41 γ 252; 287; 496...	Tb 152 17.5 h ε; β ⁺ 2.8; α 3.44; γ 344; 411...	Tb 153 2.34 d ε; β ⁺ 2.8; α 3.44; γ 344; 411...	Tb 154 23 h ε; β ⁺ 2.8; α 3.44; γ 344; 411...	Tb 155 5.32 d ε γ 87; 105; 160; 262...	Tb 156 5.4 h ε γ 58; 199; 1222...	Tb 157 99 a ε γ (54) e ⁻	Tb 158 10.5 s ε β ⁺ 0.9 γ 844; 962; 80...	Tb 159 100 α 23.2	Tb 160 72.3 d β ⁻ 0.6; 1.7... γ 879; 299; 966... α 570	Tb 161 6.90 d β ⁻ 0.5; 0.6... γ 26; 49; 75... e ⁻
Gd 148 74.6 a α 3.183 α 14000	Gd 149 9.28 d ε; α 3.016 γ 150; 299; 347...	Gd 150 1.8 · 10 ⁶ a α 2.72	Gd 151 120 d ε; α 2.60 γ 154; 243; 175...	Gd 152 0.20 1.1 · 10 ¹⁴ a α 2.14; α 700 α _{n, α} < 0.007	Gd 153 239.47 d ε γ 97; 103; 70... α 20000 α _{n, α} 0.03	Gd 154 2.18 α 60	Gd 155 14.80 α 51000 α _{n, α} 0.00008	Gd 156 20.47 α 2.0	Gd 157 15.65 α 254000 α _{n, α} < 0.05	Gd 158 24.84 α 2.3	Gd 159 18.48 h β ⁻ 1.0... γ 364; 59...	Gd 160 21.86 α 1.5



Predicted production rates



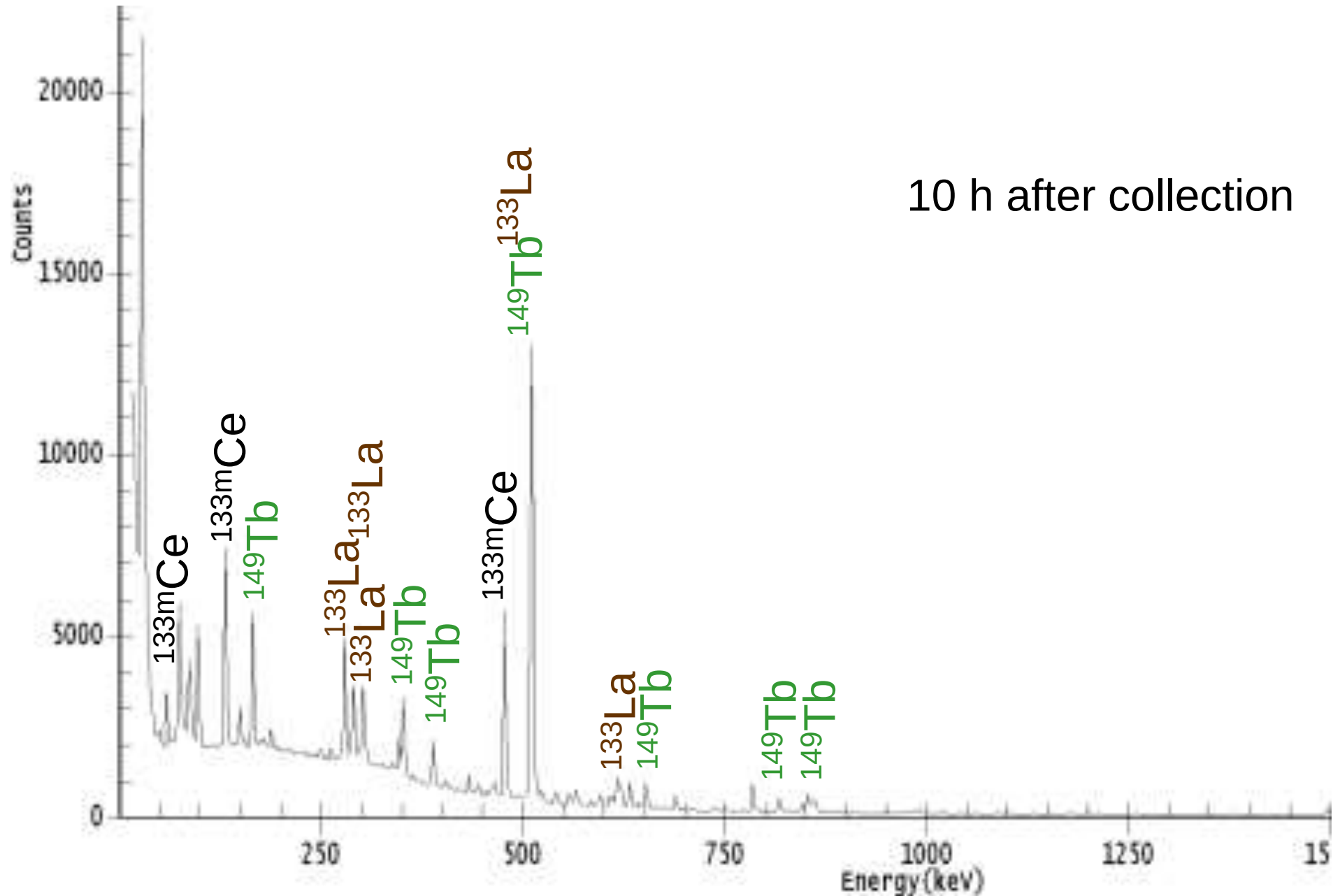
Off-line gamma ray spectroscopy



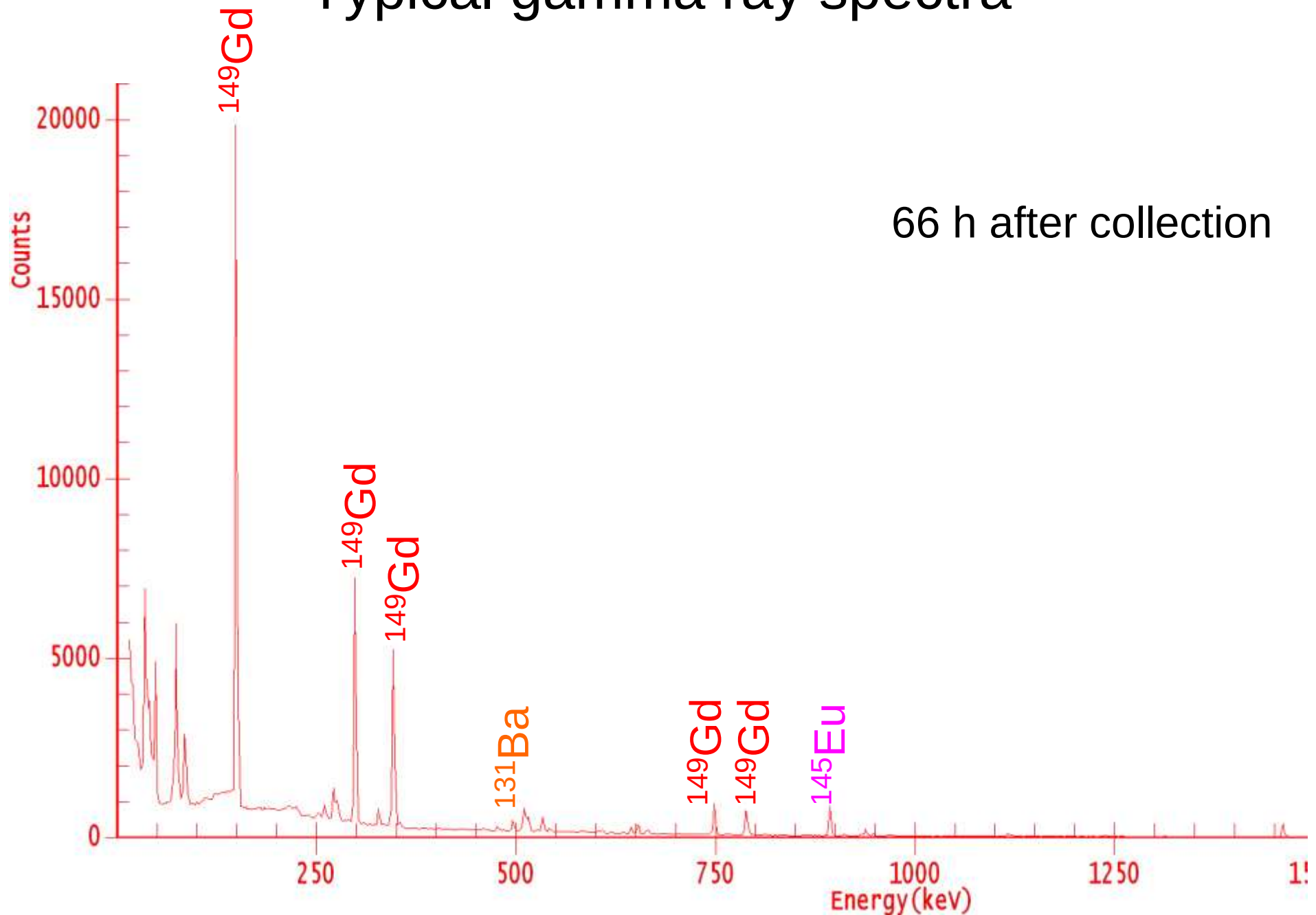
Implant test samples



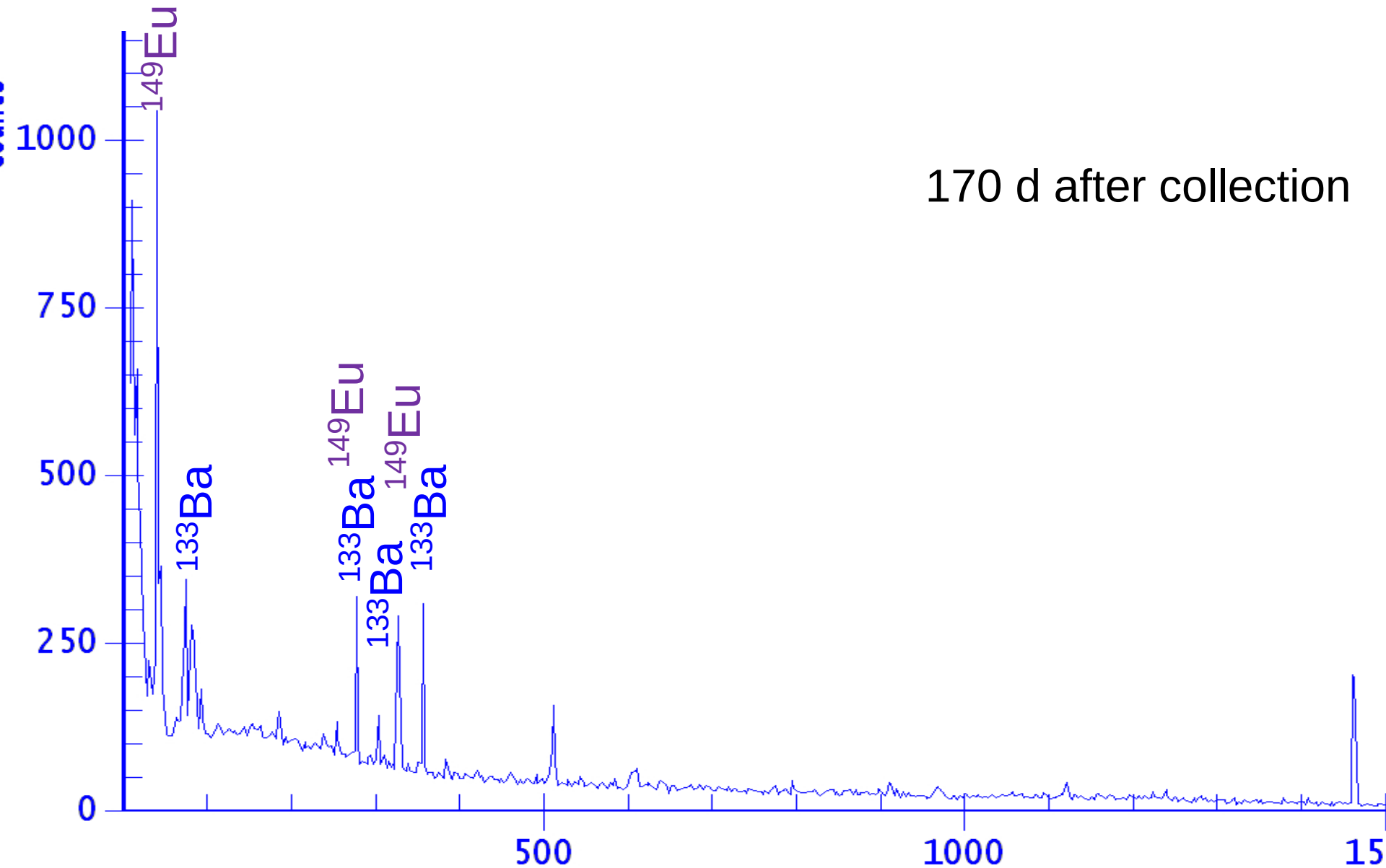
Typical gamma ray spectra



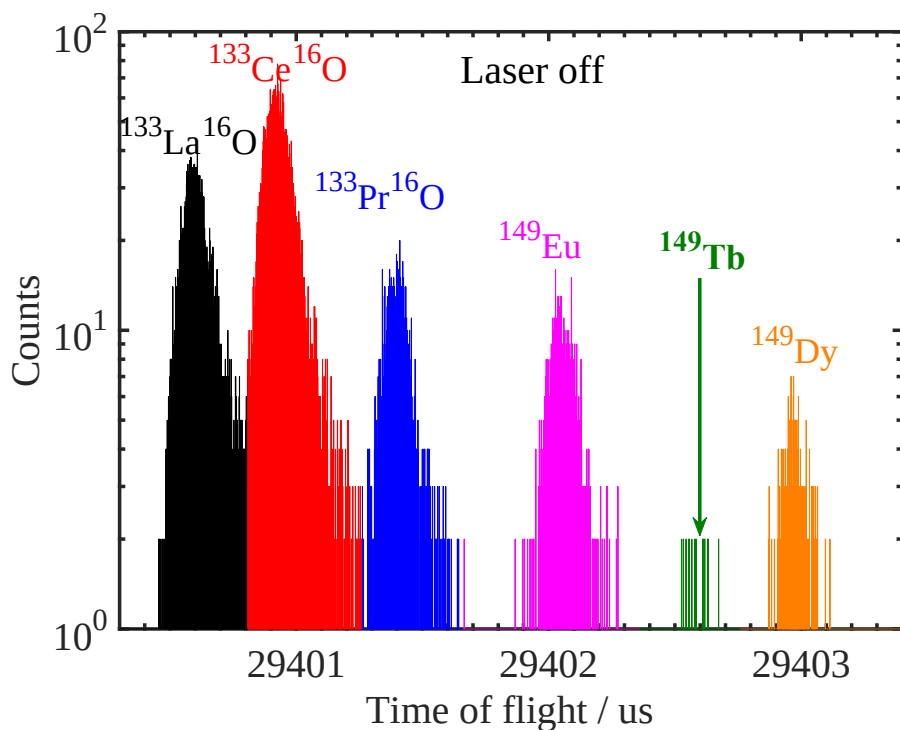
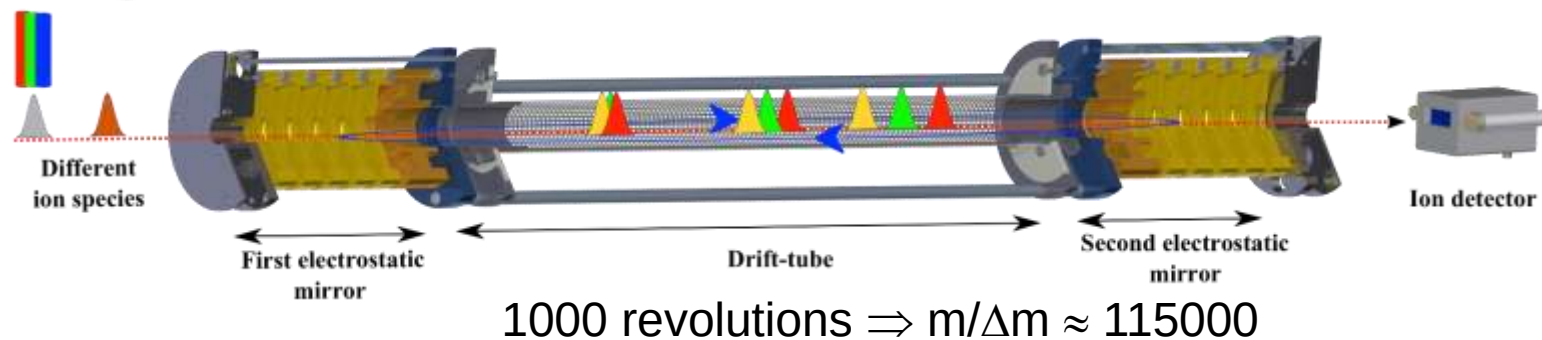
Typical gamma ray spectra



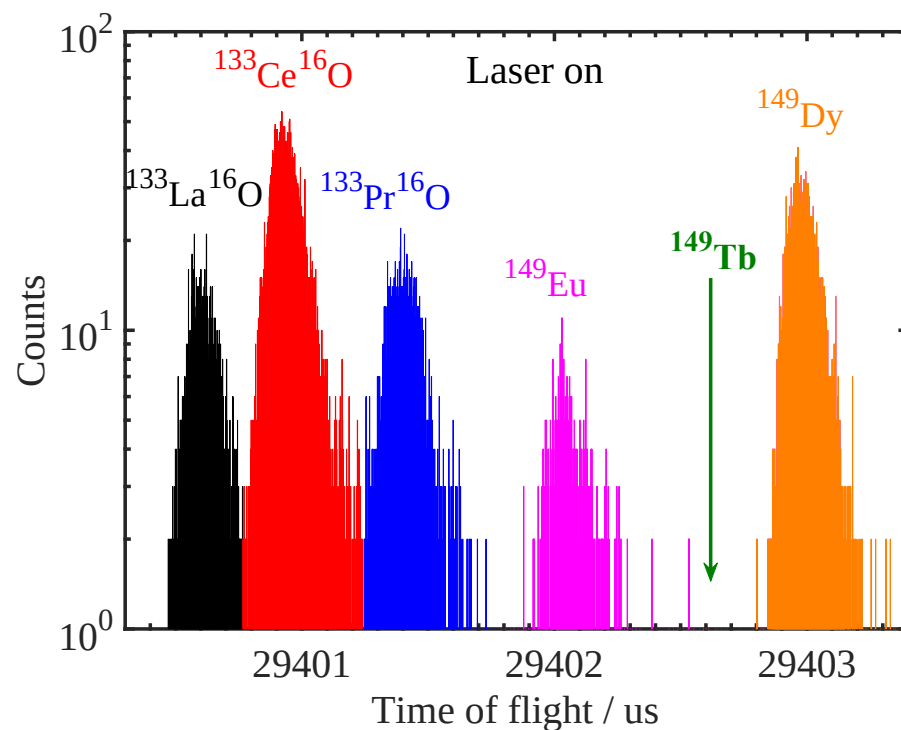
Typical gamma ray spectra



Beam optimization with ISOLTRAP's MR-ToF-MS

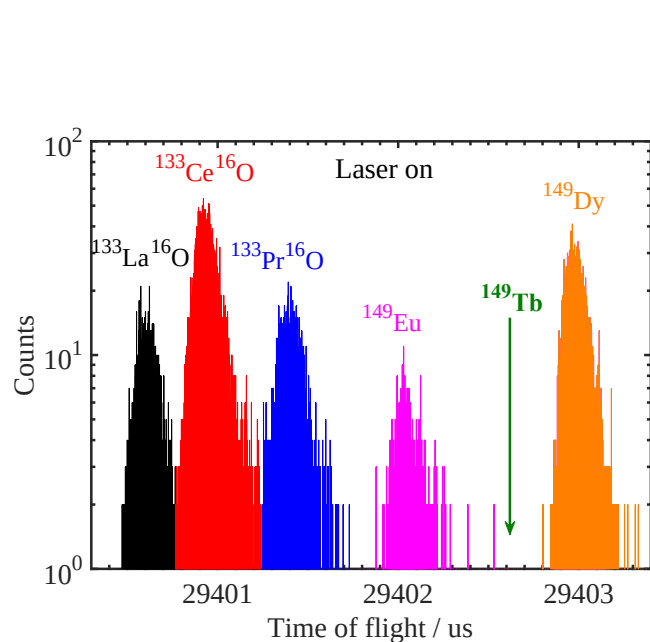
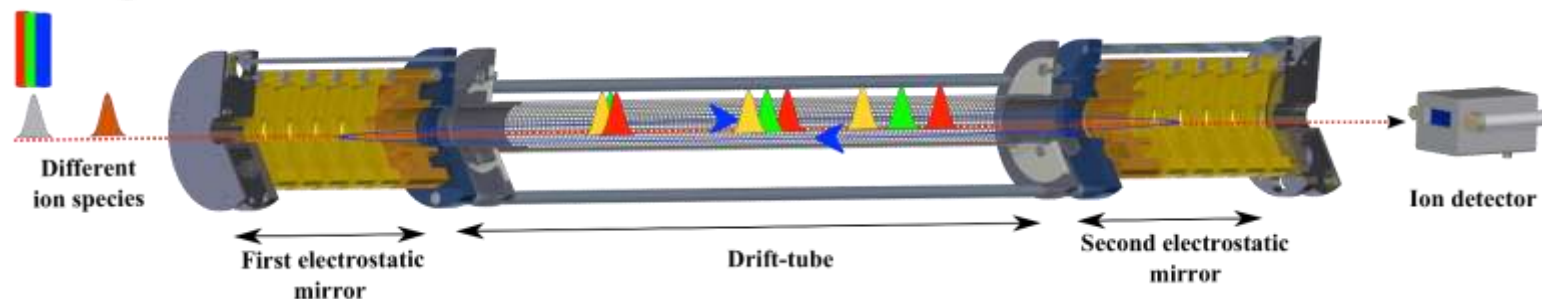


Much more Dy than Tb



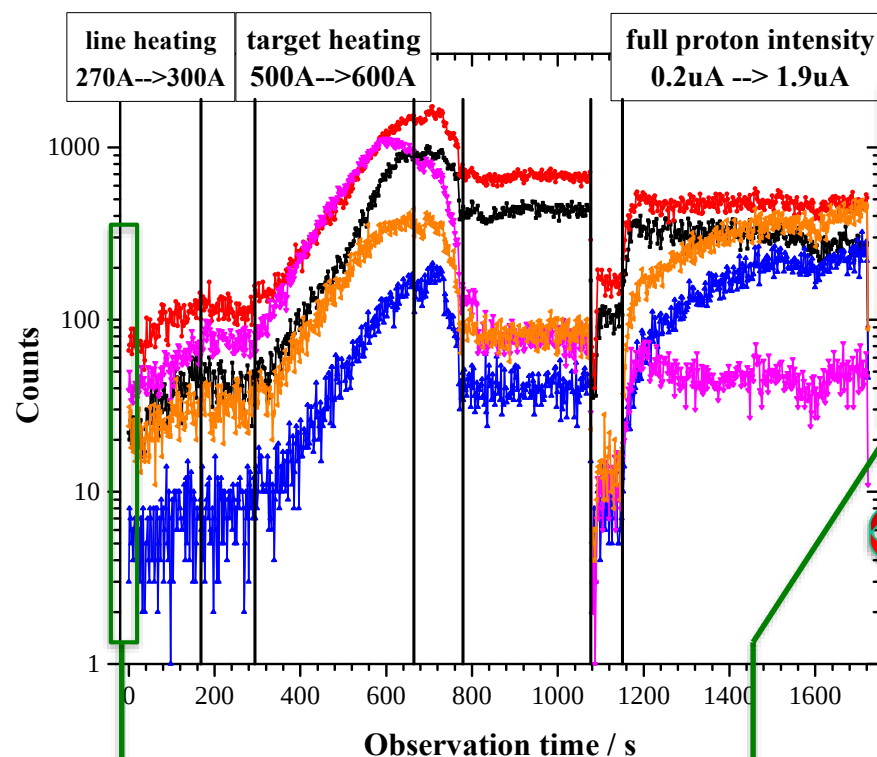
Laser on/off ratio ≈ 10

Beam optimization with ISOLTRAP's MR-ToF-MS



^{149}Dy release-limited

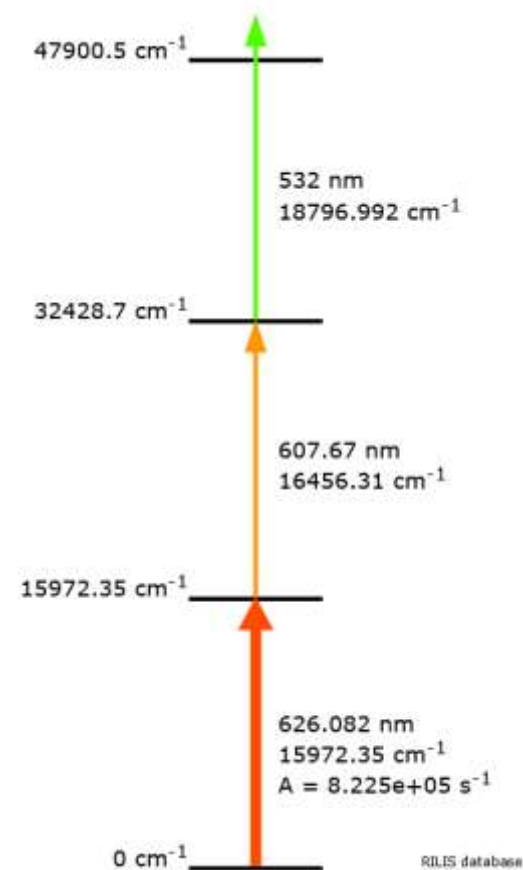
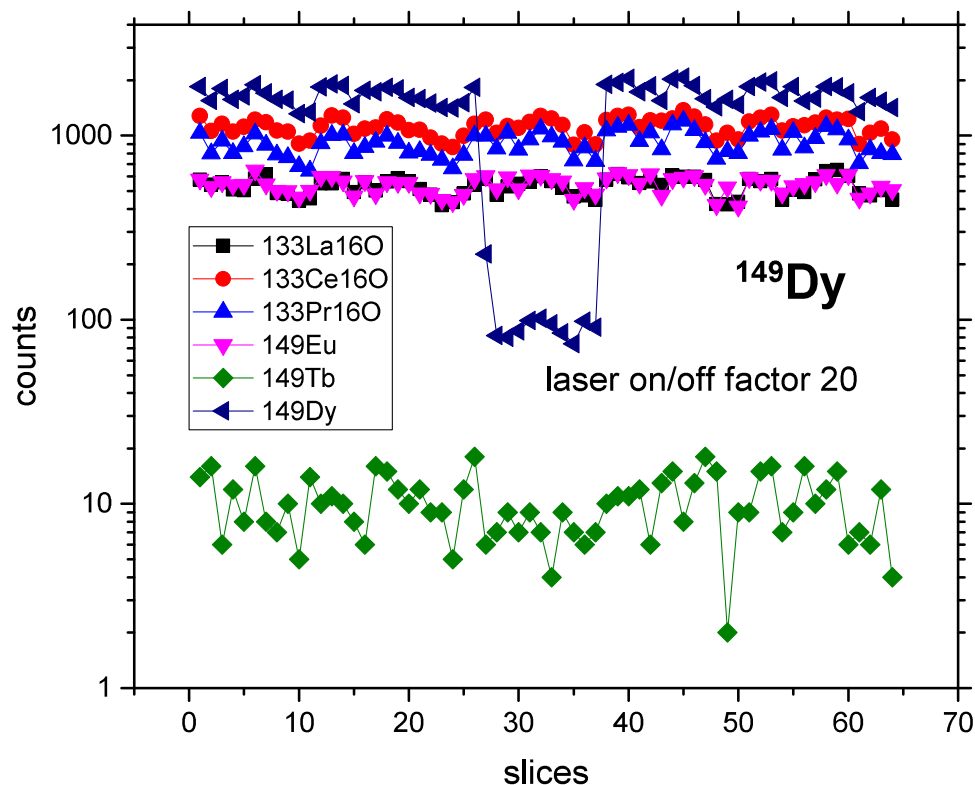
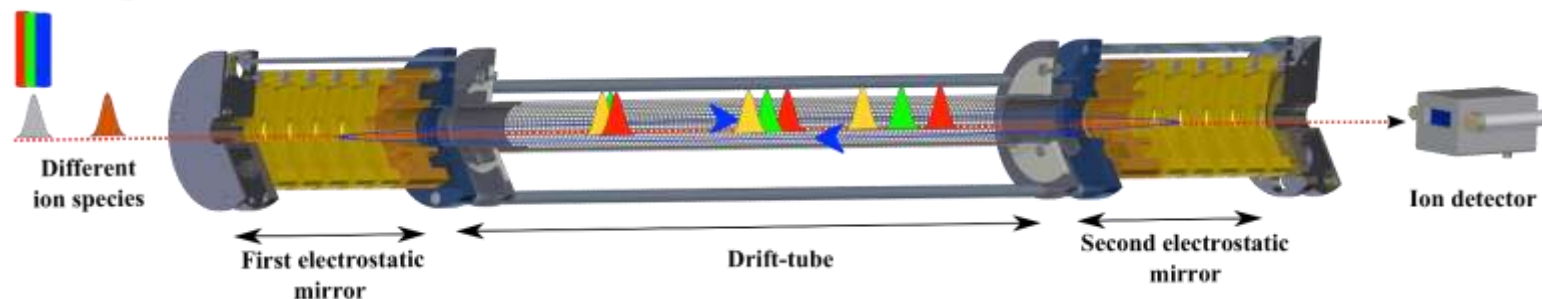
⇒ Improves significantly
with hotter target



Isotope	Half life
^{133}La	3.9 h
^{133}Ce	97 m
$^{133\text{m}}\text{Ce}$	5.1 h
^{133}Pr	6.5 m
^{149}Eu	93 d
^{149}Dy	4.2 m
^{149}Tb	4.1 h

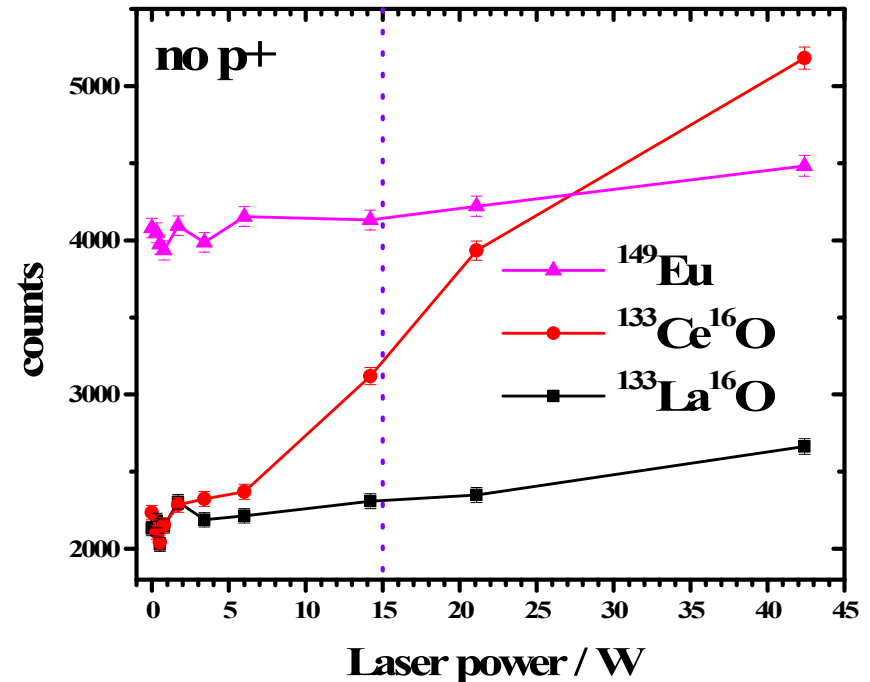
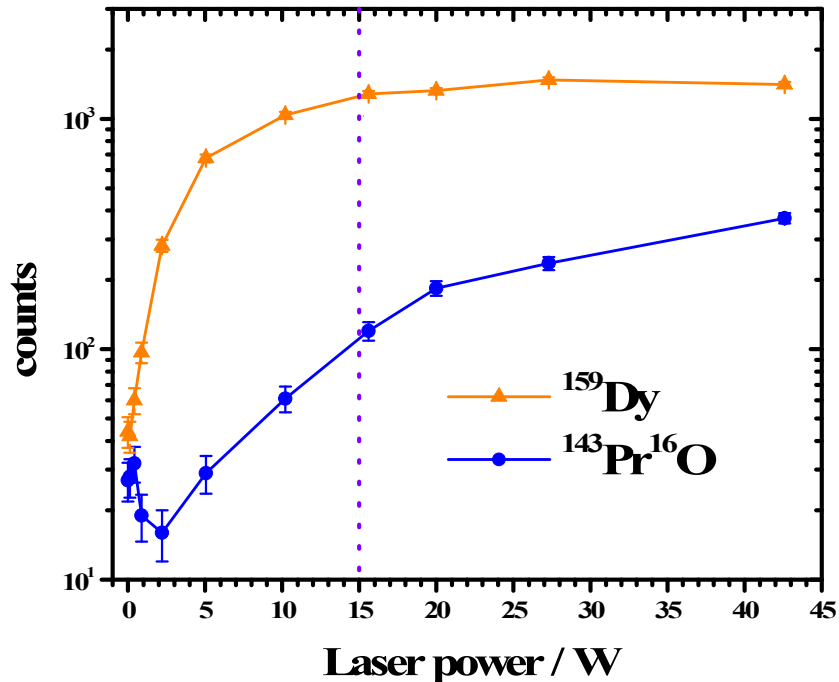
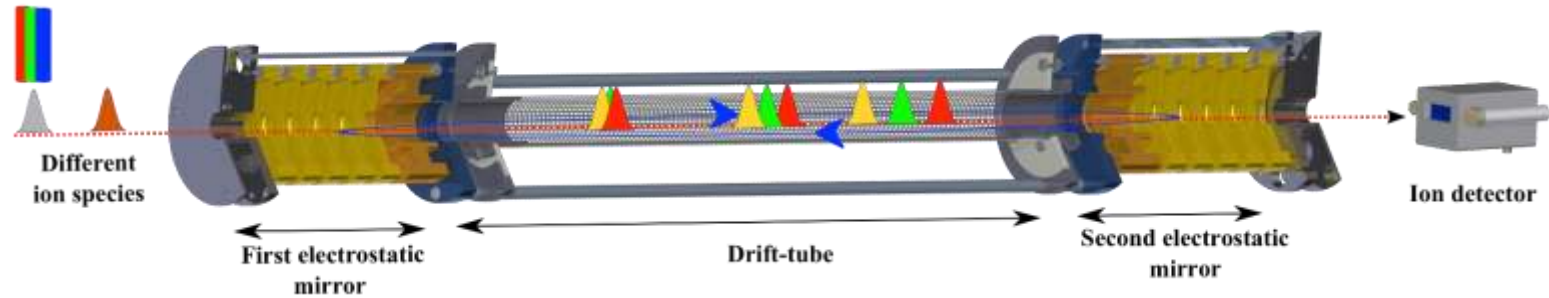
Before optimization: 6.3/1 After optimization: 2.3/1
Tb / contaminants → factor ≈ 3 improvement!

Beam optimization with ISOLTRAP's MR-ToF-MS



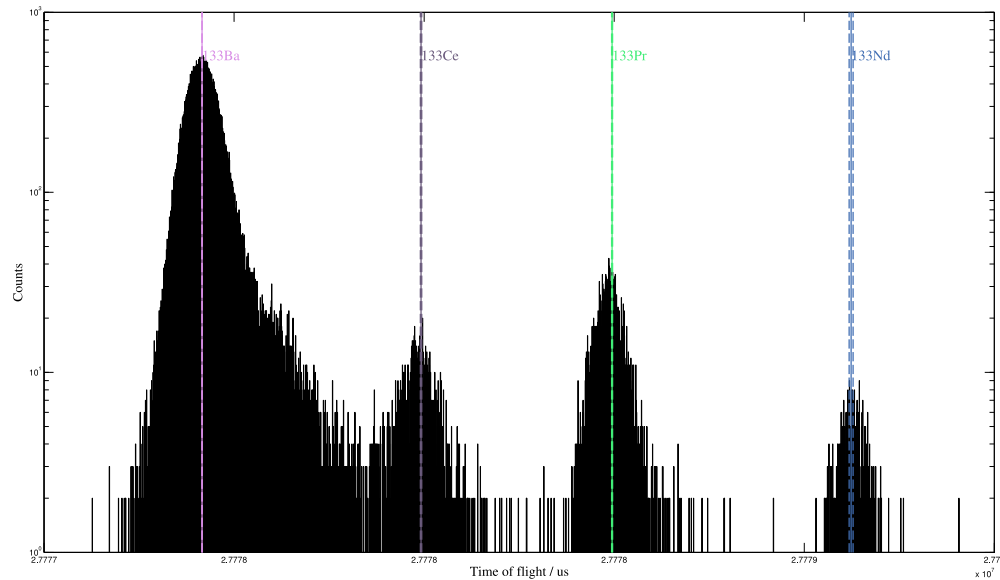
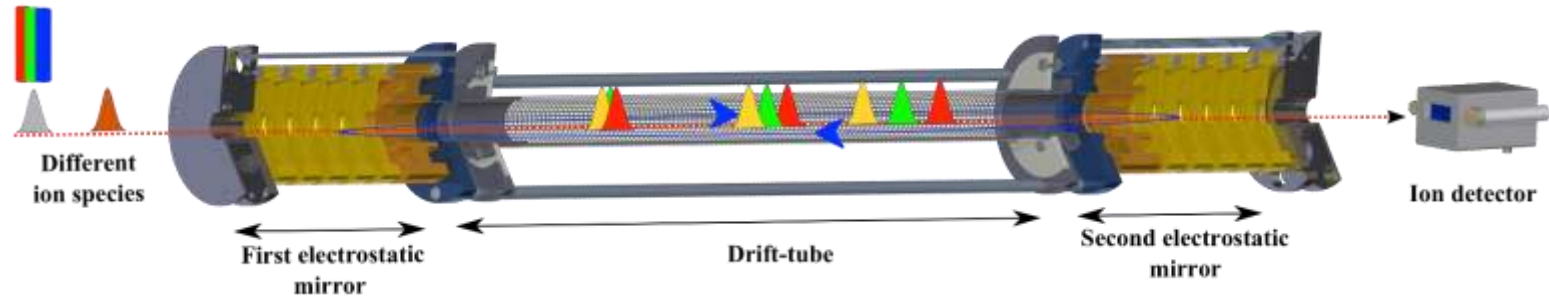
1st step (626 nm) affects only Dy

Beam optimization with ISOLTRAP's MR-ToF-MS



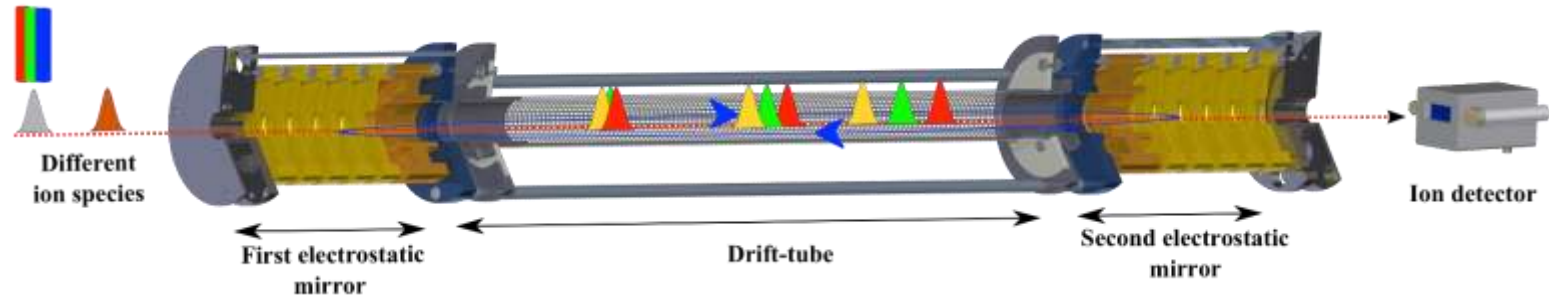
3rd step (532 nm high power) enhances also PrO^+ and CeO^+
 $\Rightarrow$ reduction to ≈ 15 W improves $^{149}\text{Tb}/\text{contaminants}$ factor ≈ 3

Beam optimization with ISOLTRAP's MR-ToF-MS

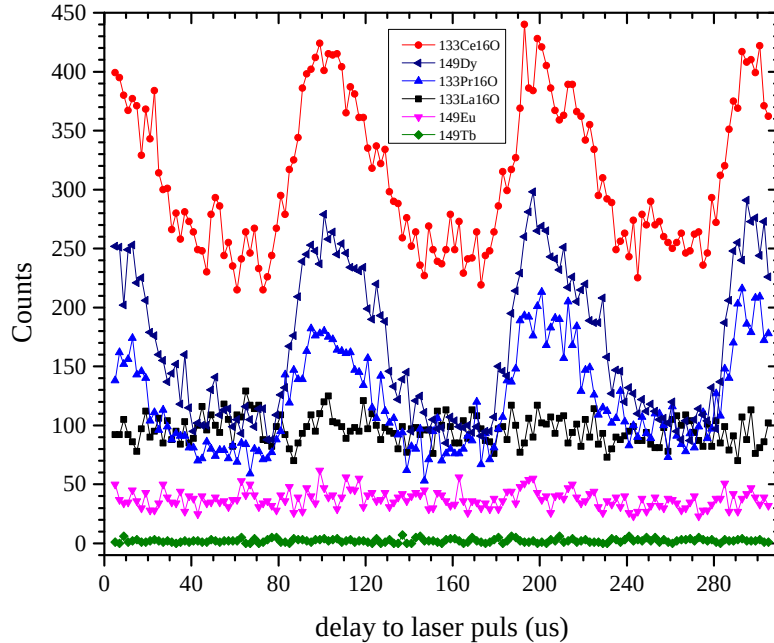


No laser effect on atomic Ba, La, Ce, Pr and Nd,
but on PrO and CeO

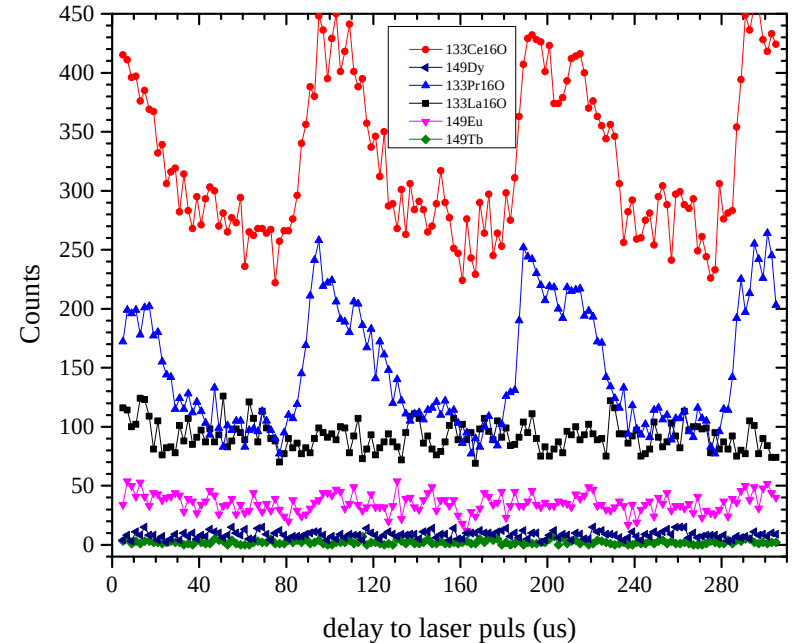
Beam optimization with ISOLTRAP's MR-ToF-MS



All lasers on

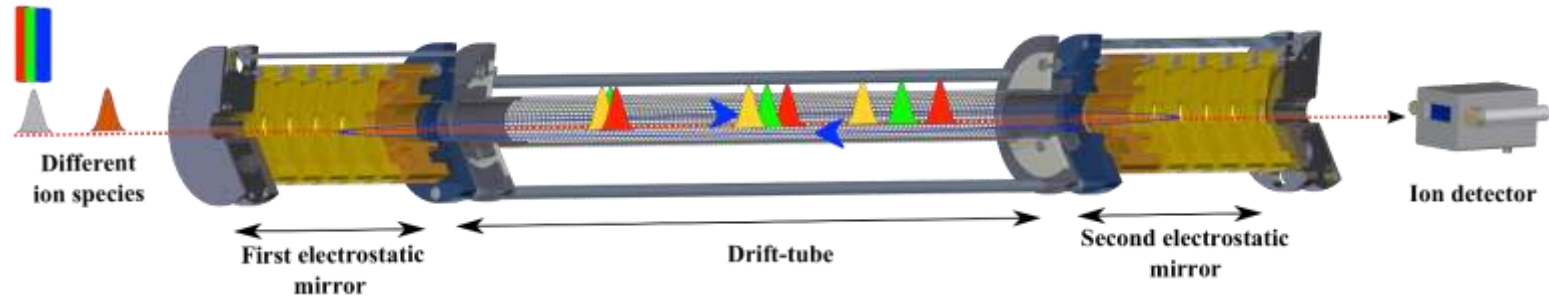


1st step blocked

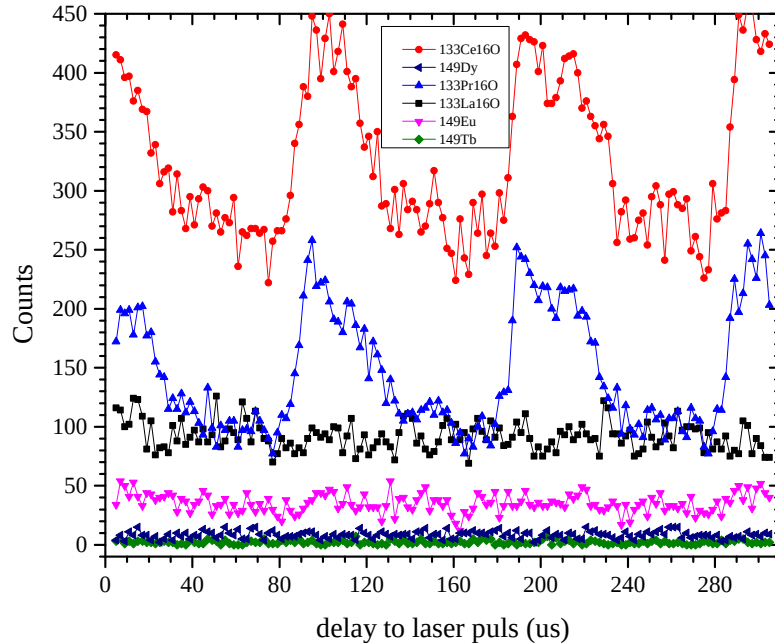


PrO^+ , CeO^+ pulsed $\Rightarrow$ photo-ionized, not only thermo-ionized

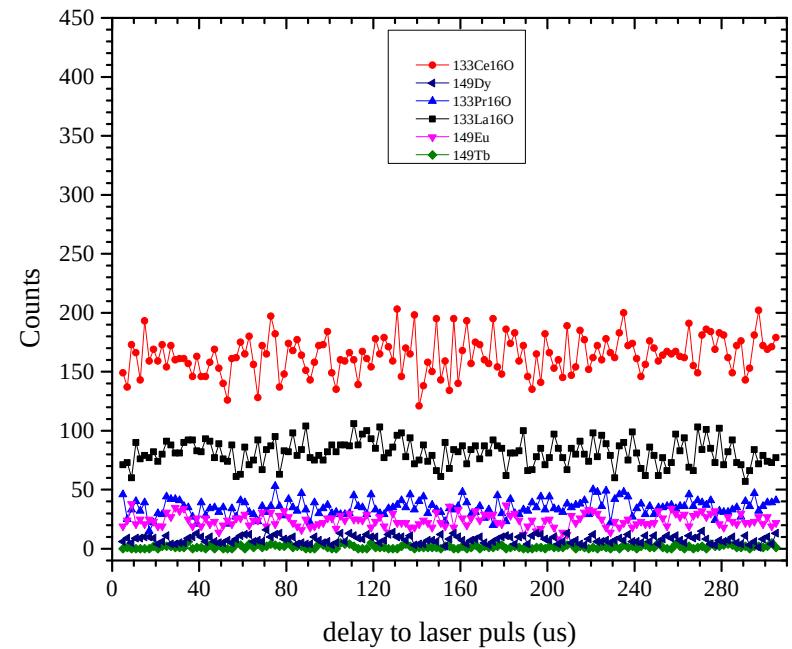
Beam optimization with ISOLTRAP's MR-ToF-MS



1st step blocked

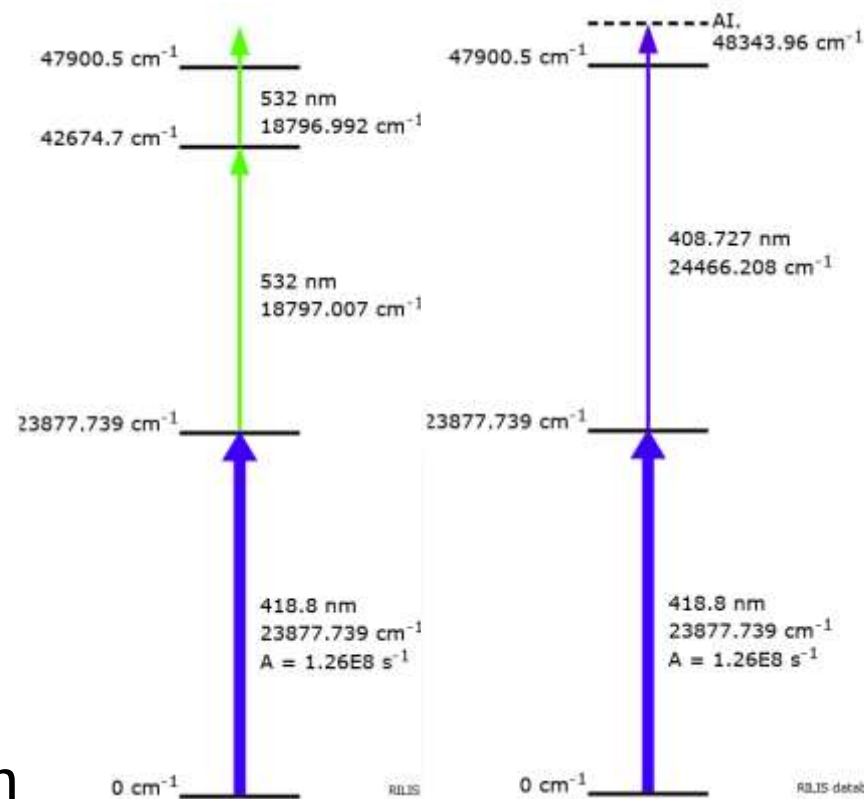
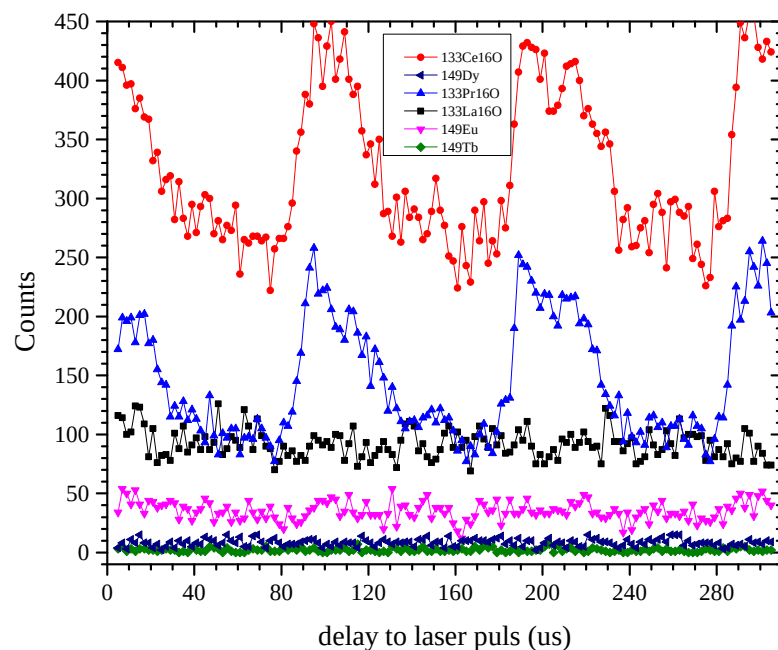
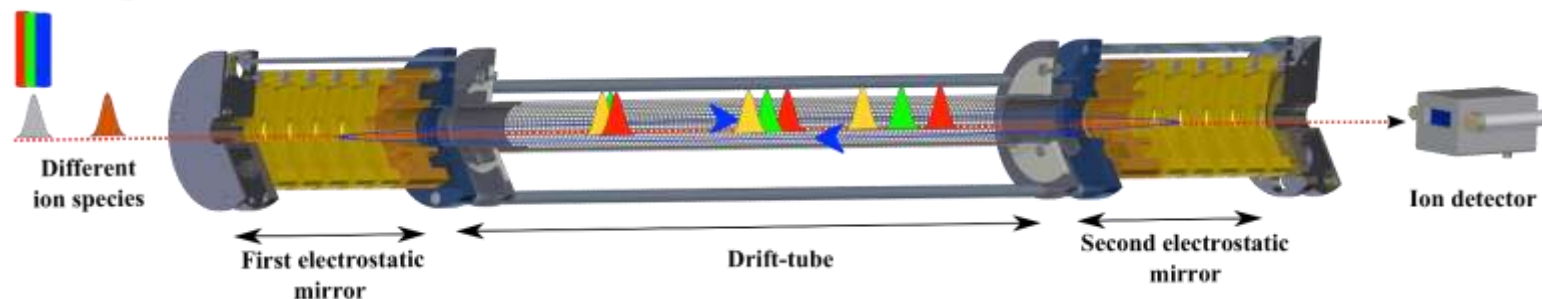


2nd step blocked



PrO^+ and CeO^+ pulsed $\Rightarrow$ 608 nm has resonant effect

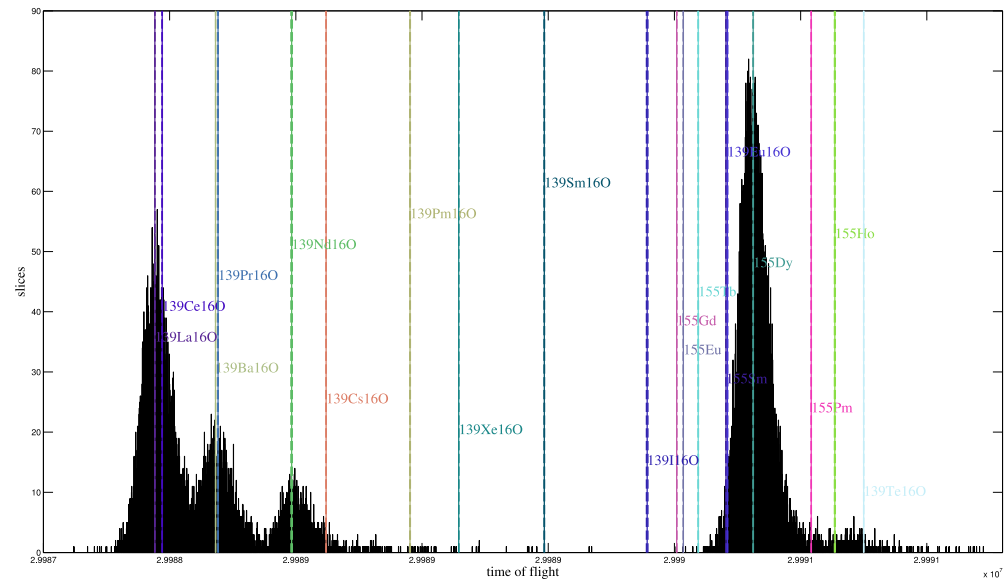
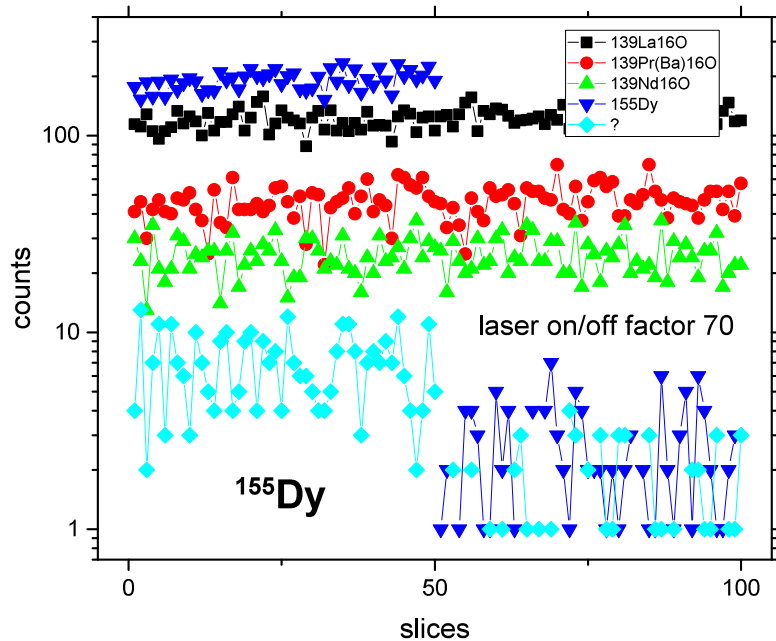
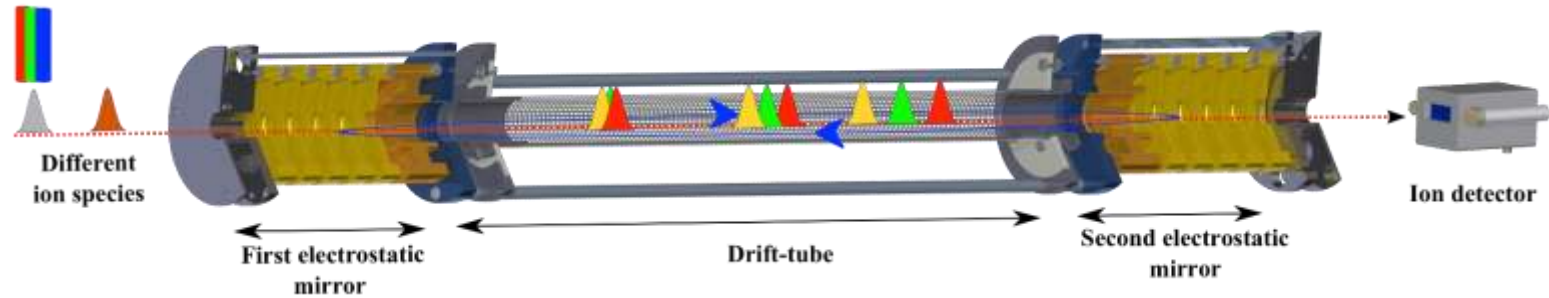
Beam optimization with ISOLTRAP's MR-ToF-MS



New RILIS schemes avoid 608 nm

(probably) no PrO^+ and CeO^+ enhancement

Beam optimization with ISOLTRAP's MR-ToF-MS

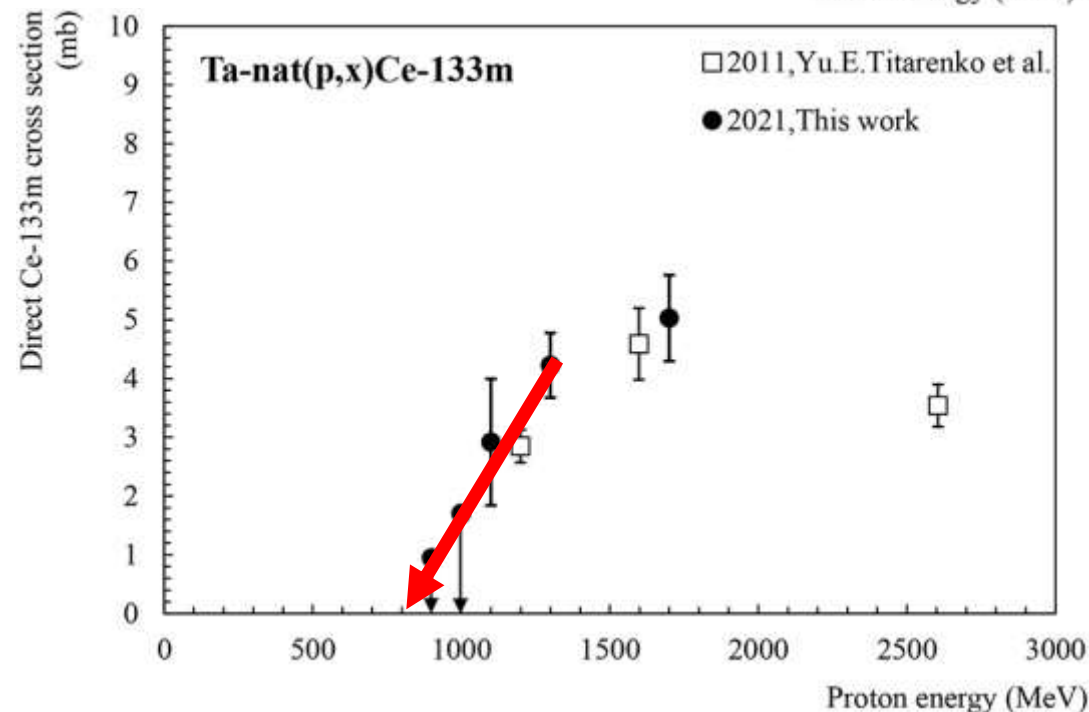
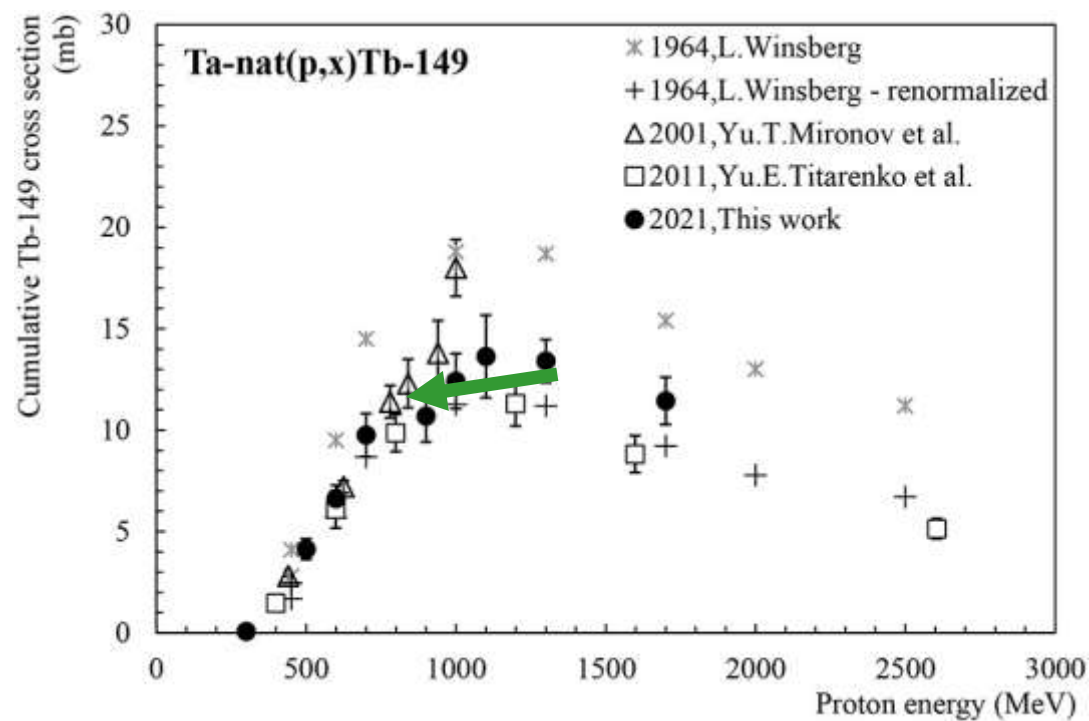


Also for $A=155$ and $A=152$ Dy is the dominant isobar

(cf. PS-1-3)

Future improvement of Tb / CeO ratio ?

(cf. Simon Stegemann)



Summary

- MR-ToF-MS is extremely useful for on-line beam optimization
- on-line production of $^{149,152,155}\text{Tb}$ best via Dy precursors
- ^{149}Dy yield release limited, $\approx 2\%$ overall efficiency
 $\Rightarrow$ hotter target & thinner foils could help
- no laser effect on atomic Pr^+ , Nd^+ , Ce^+
- PrO^+ and CeO^+ laser-ionized with 608 nm + 532 nm
- RILIS schemes with 1st step 419 nm produce cleaner Dy
- *^{149}Dy laser enhancement smaller than for other Dy isotopes*
- $\approx 800\text{-}1000$ MeV p would produce significantly less ^{133}Ce
- off-line production of $^{149,152,155}\text{Tb}$ would be different
 (cf. next talk)