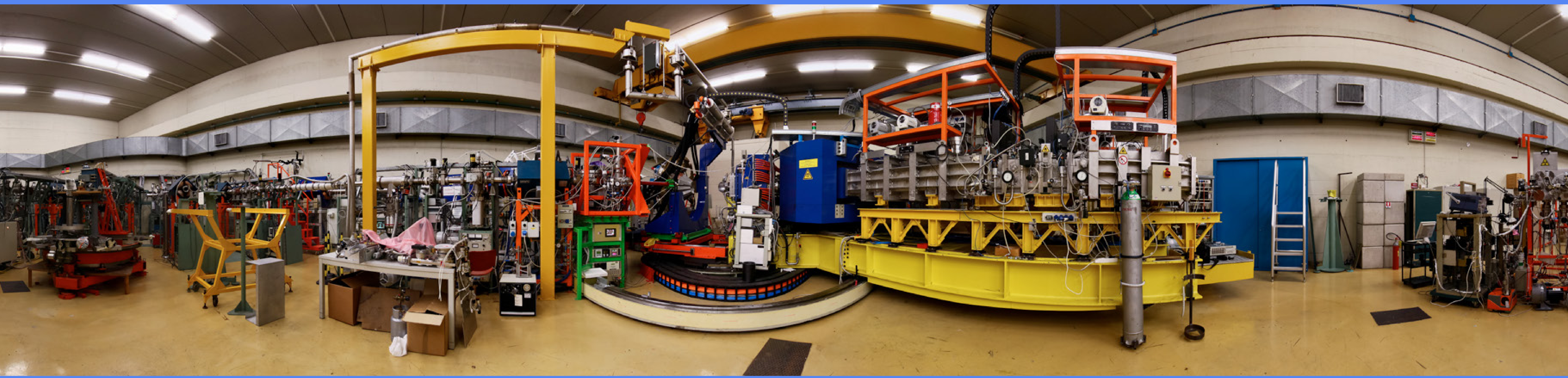


Spectroscopy of Neutron-Rich Nuclei in the Actinide and Te-Ba Region with Multi-Nucleon Transfer Reactions

DPG-Frühjahrstagung Hadronen und Kerne: HK 11.1

Andreas Vogt

Institute for Nuclear Physics | University of Cologne

17 March 2014

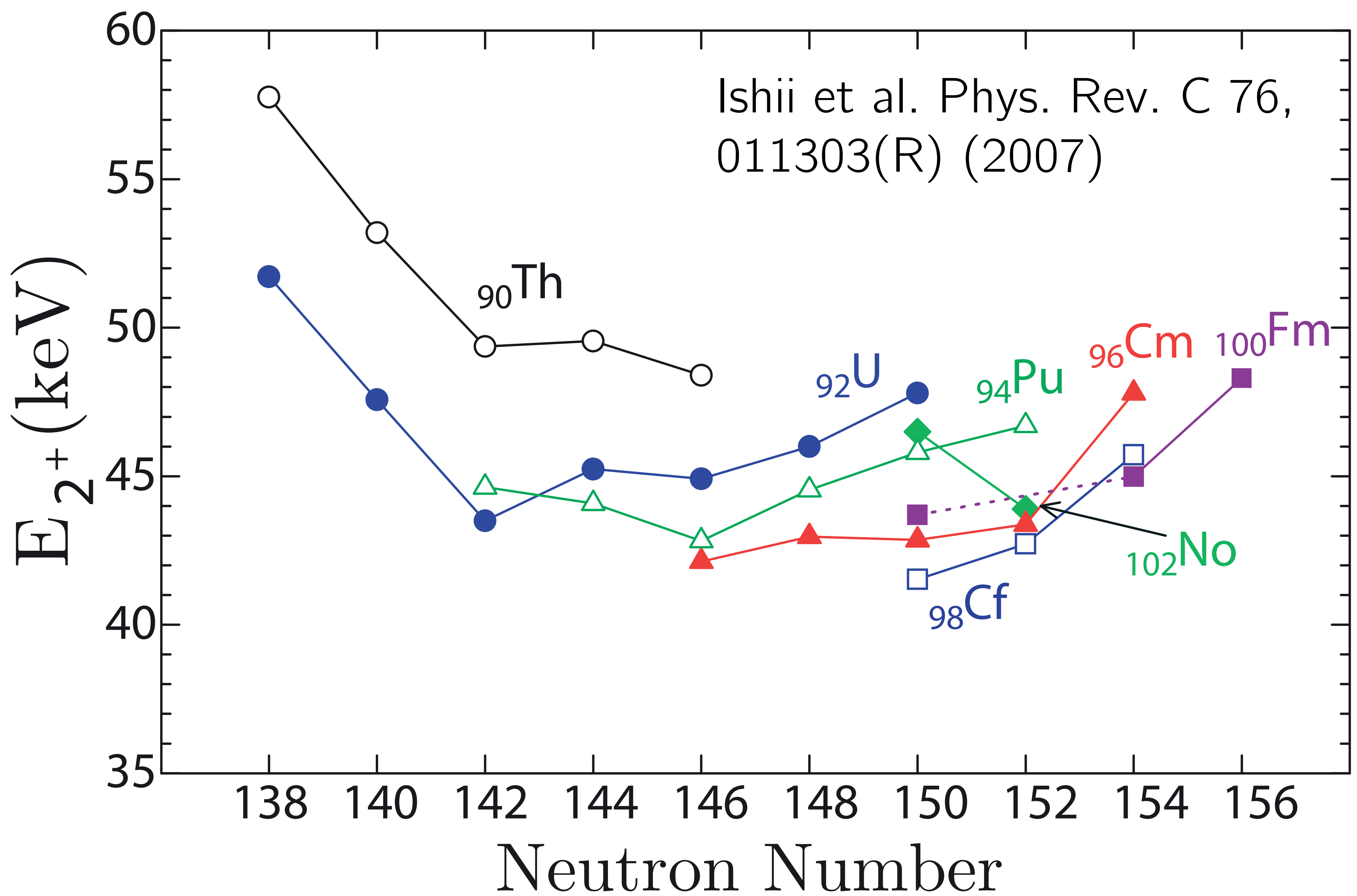
GEFÖRDERT VOM

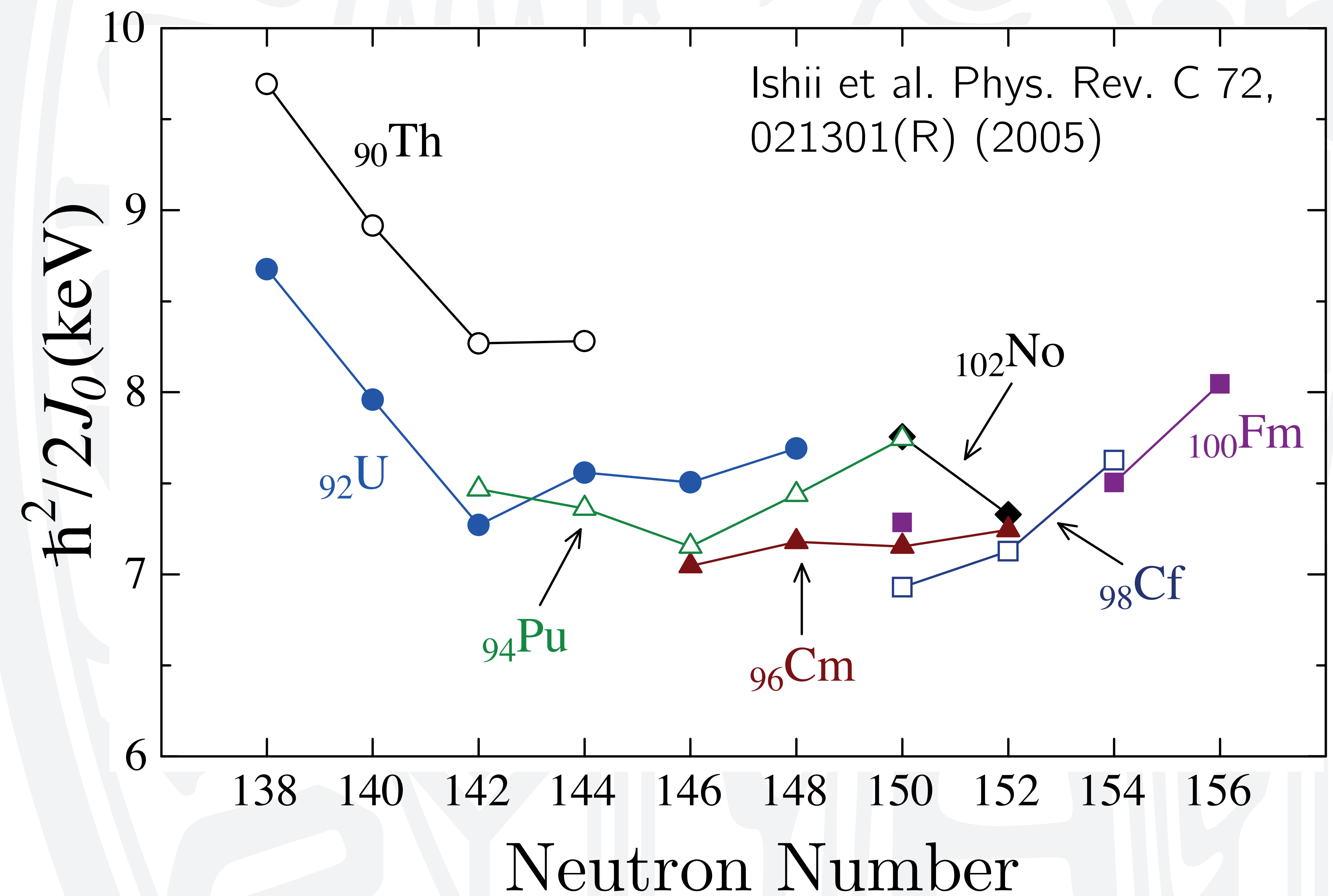
Bundesministerium für Bildung und Forschung

Motivation: Spectroscopy of neutron-rich Z=90-92 actinides

Recent theoretical investigations of the neutron rich actinide nuclei

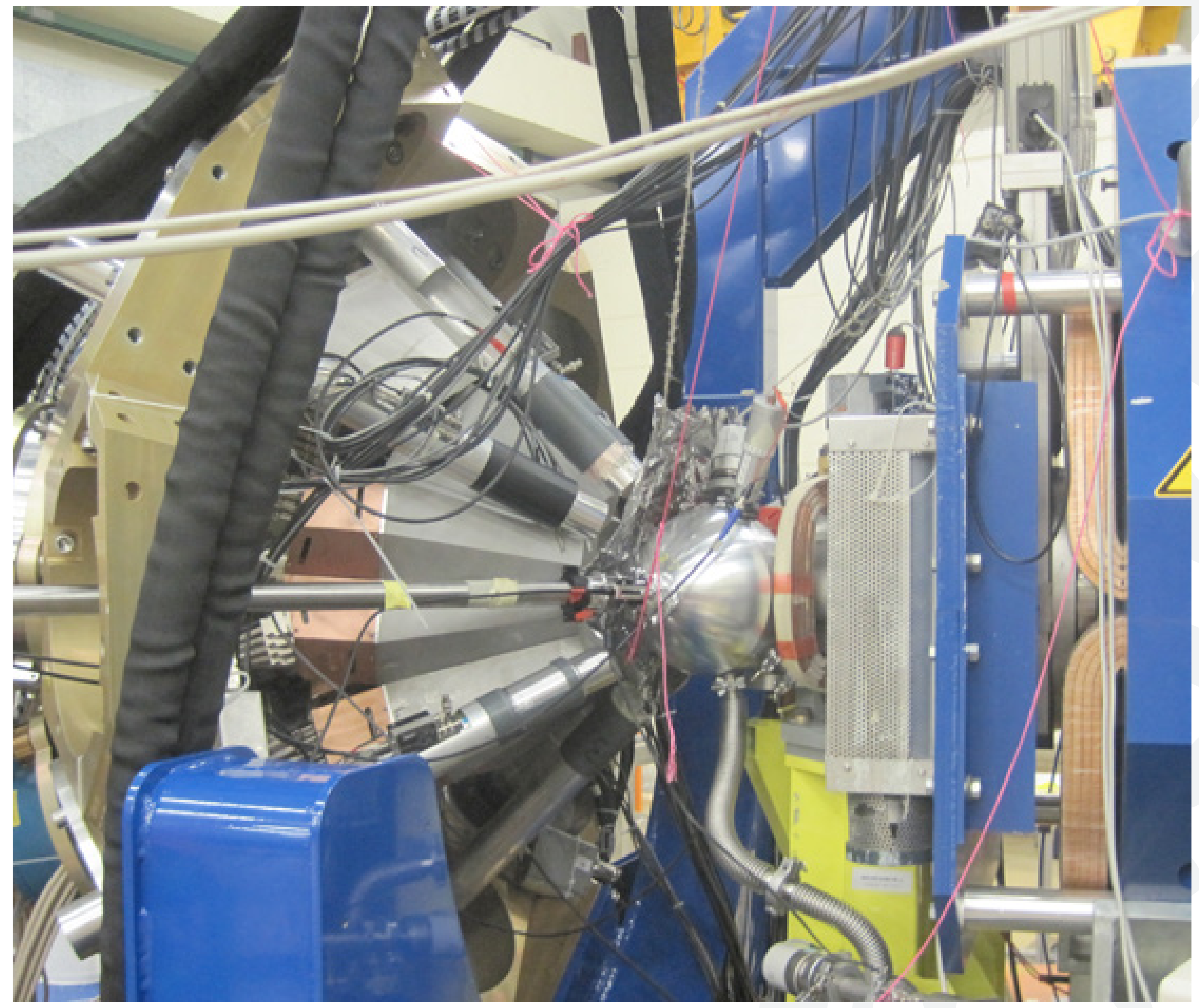
Shell Correction Energy	Alternative Parity States	MF and beyond-MF methods, Gogny force	Relativistic nuclear energy density functionals
A.Sobiczewski, I. Muntian, Z. Patyk, Phys. Rev. C, 63 (2001) 034306	Shneidman, et al. Phys. Rev. C 74, 034316 (2006)	J.-P. Delaroche et al. Nuclear Physics A 771 (2006) 103–168	D. Vretenar, et al., Int. Journal of modern Physics E (2010)

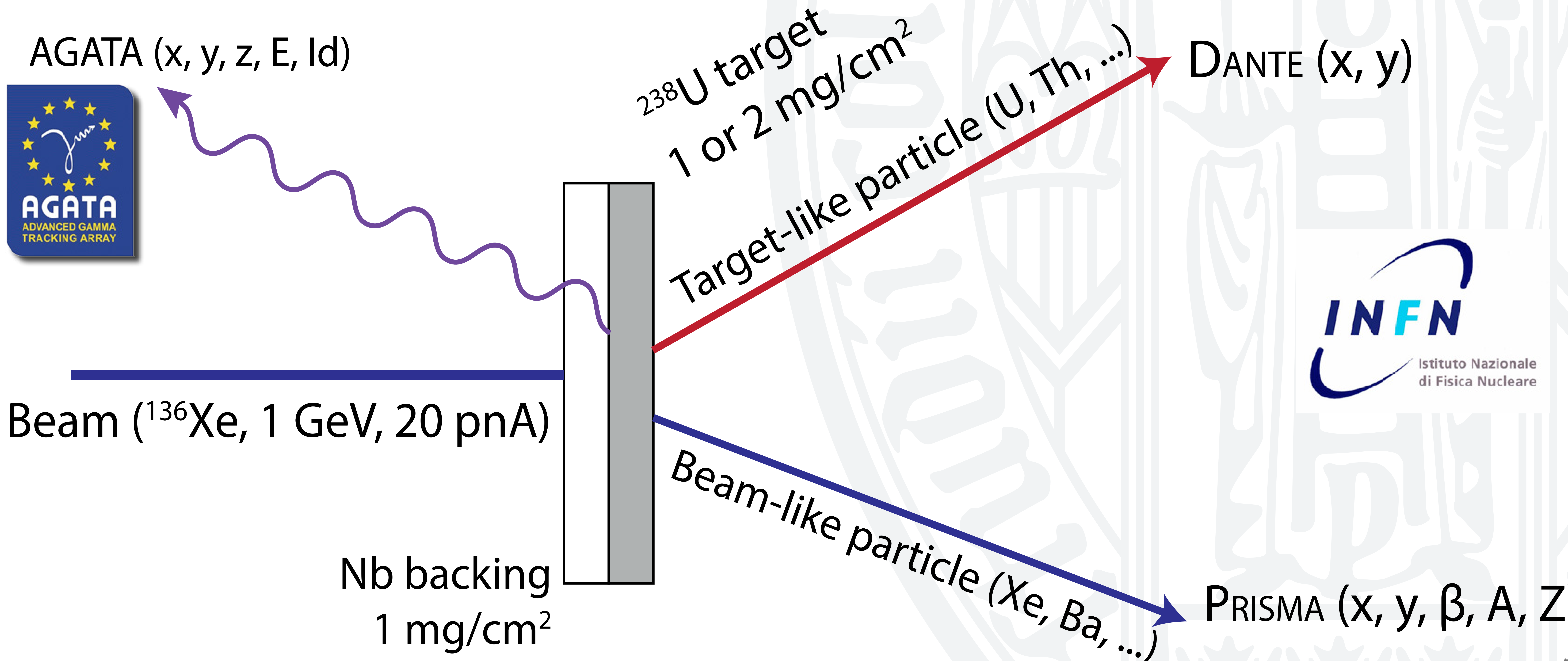




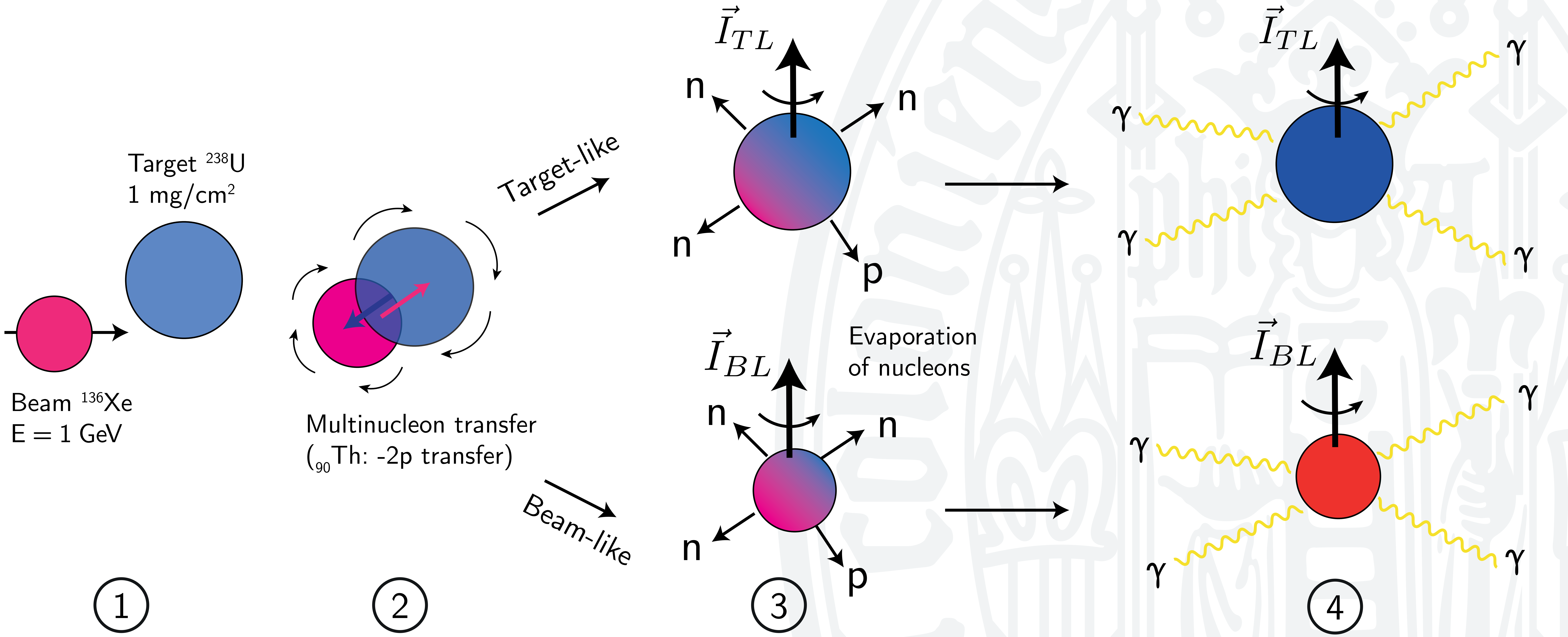
- Explore hardly accessible neutron rich actinide region
  - » Lack of target and beam combinations
  - » Cross sections of the reactions compared to fission background are very small

Multinucleon transfer reactions can produce neutron-rich actinide nuclei!





Multi nucleon transfer reactions

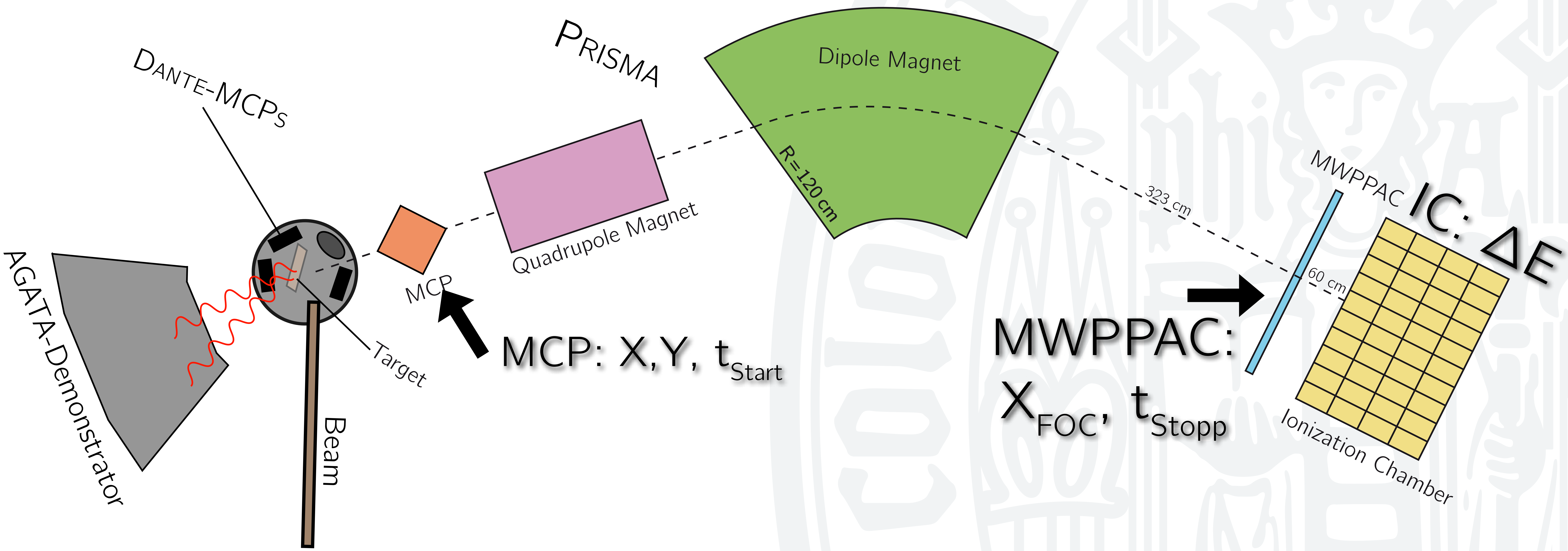


Z in beam	Correspondence in target
$Z = 51$: Antimon $_{51}$Sb	Americium $_{95}$Am
$Z = 52$: Tellurium $_{52}$Te	Plutonium $_{94}$Pu
$Z = 53$: Iodine $_{53}$I	Neptunium $_{93}$Np
$Z = 54$: **Xenon** $_{54}$Xe	**Uran** $_{92}$U
$Z = 55$: Cesium $_{55}$Cs	Protactinium $_{91}$Pa
$Z = 56$: Barium $_{56}$Ba	Thorium $_{90}$Th

→ **Doppler correction to be applied for both beam- and target-like spectra**

PRISMA Spectrometer

$\theta_{grazing} = 50\,^\circ$



- E_{cal}, ΔE_{cal} from IC
- TOF
- X_{MCP}, Y_{MCP}, X_{FOC}

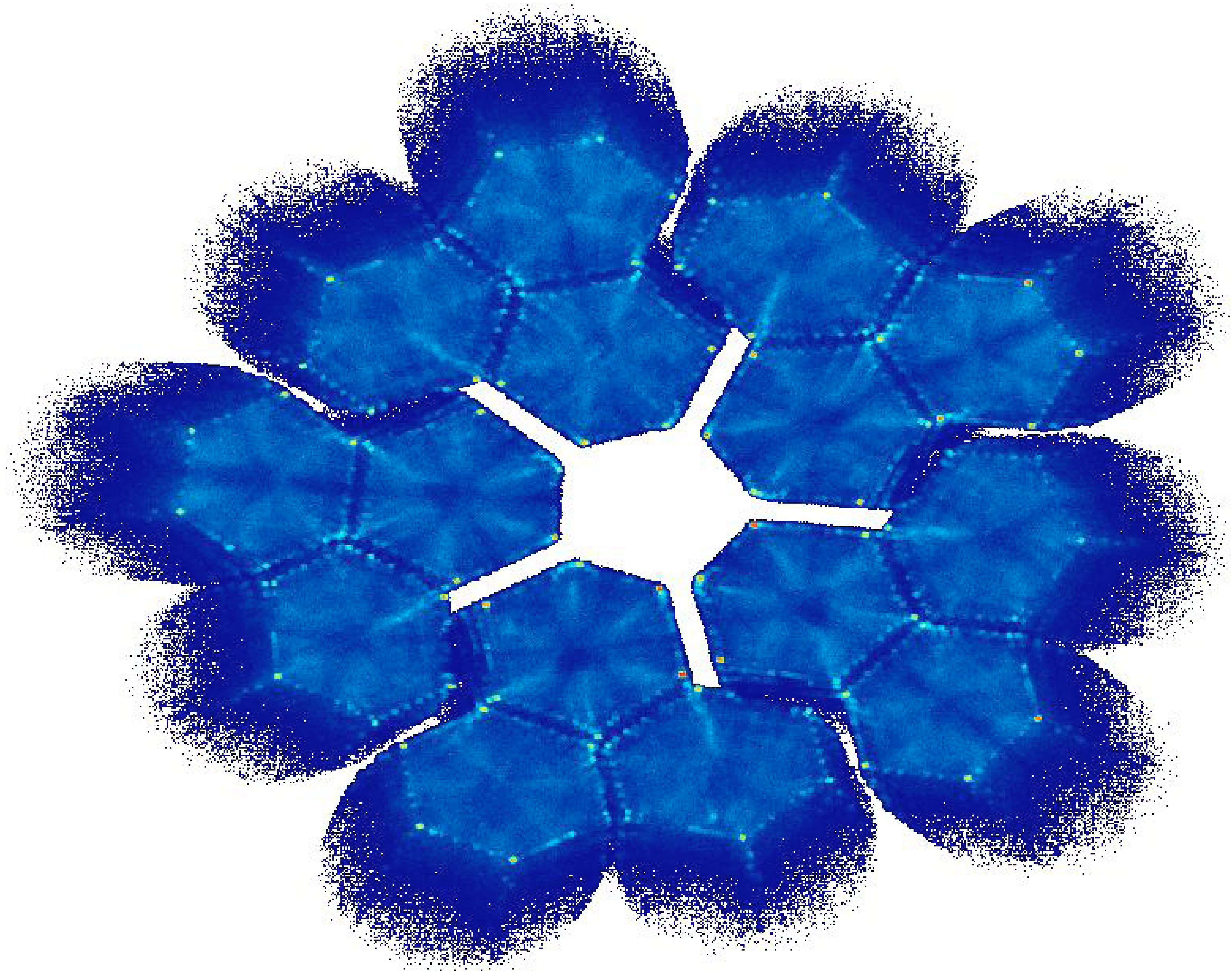
- Bending radius R
- eff. path length L
- $\beta = v/c$

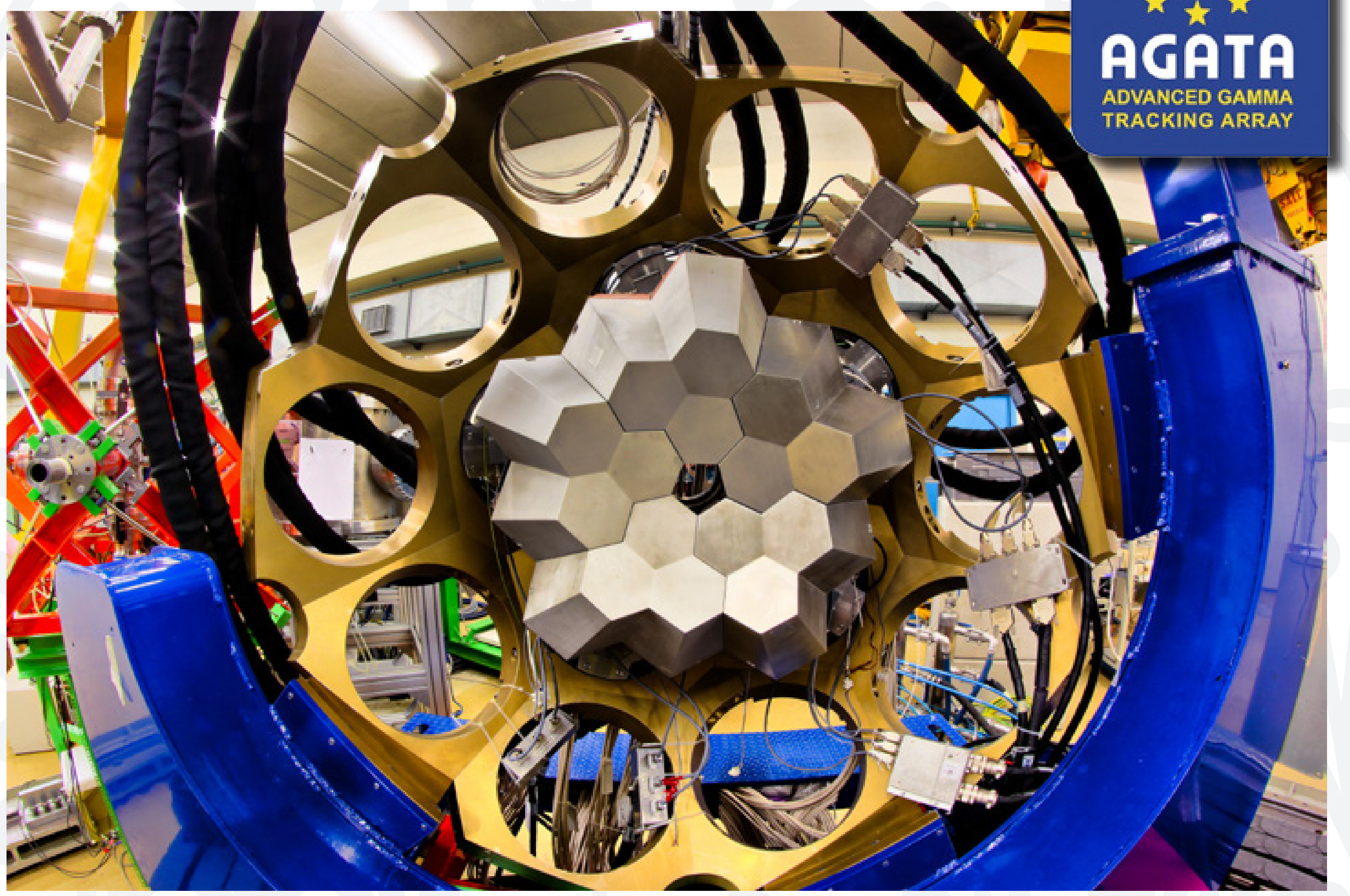
Angular acceptance	$\Delta\theta \approx 12^\circ$
Solid angle	$\Delta\Omega \approx 80\,\mathrm{msr}$
Dispersion	$\approx 4\,\mathrm{cm}/\%$

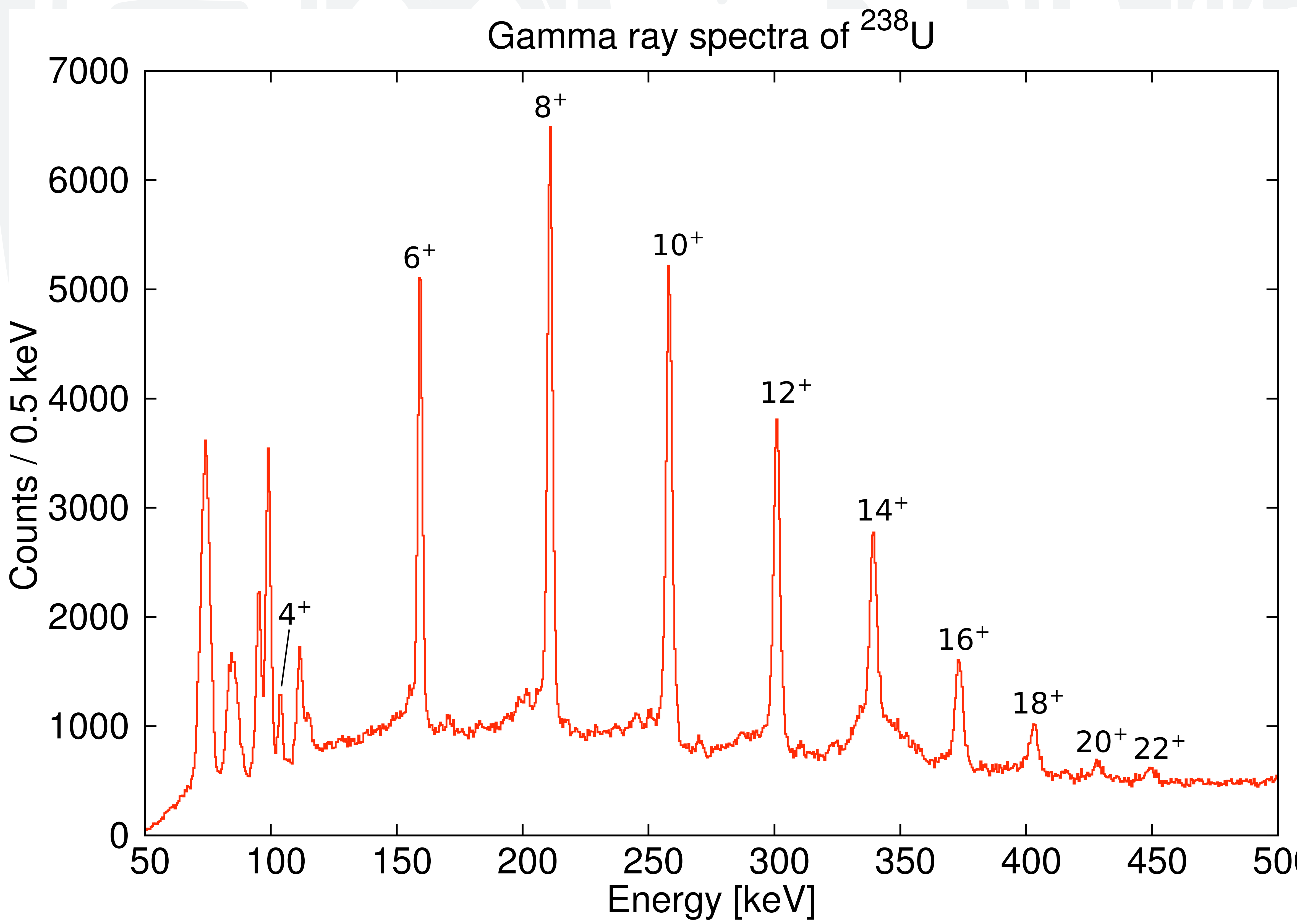
Trajectories reconstructed through iterative procedure depending only on ratio of fields in dipole and quadrupole providing trajectory length L and curvature radius R

AGATA Gamma Spectrometer

Position of first interaction after PSA and tracking







5 asymmetric triple-clusters

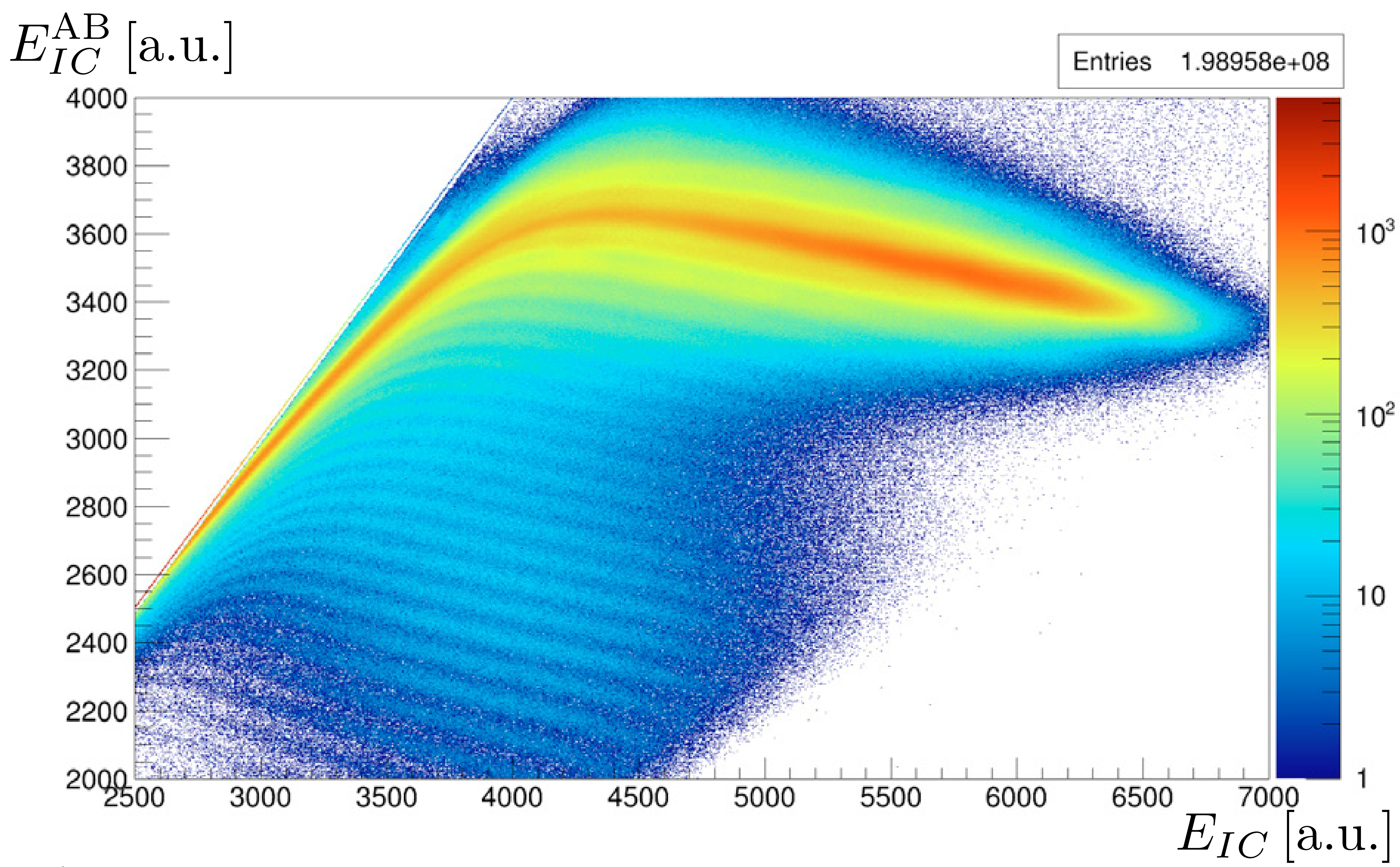
15 36-fold segmented crystals
540 segments
555 high-resolution digital-channels

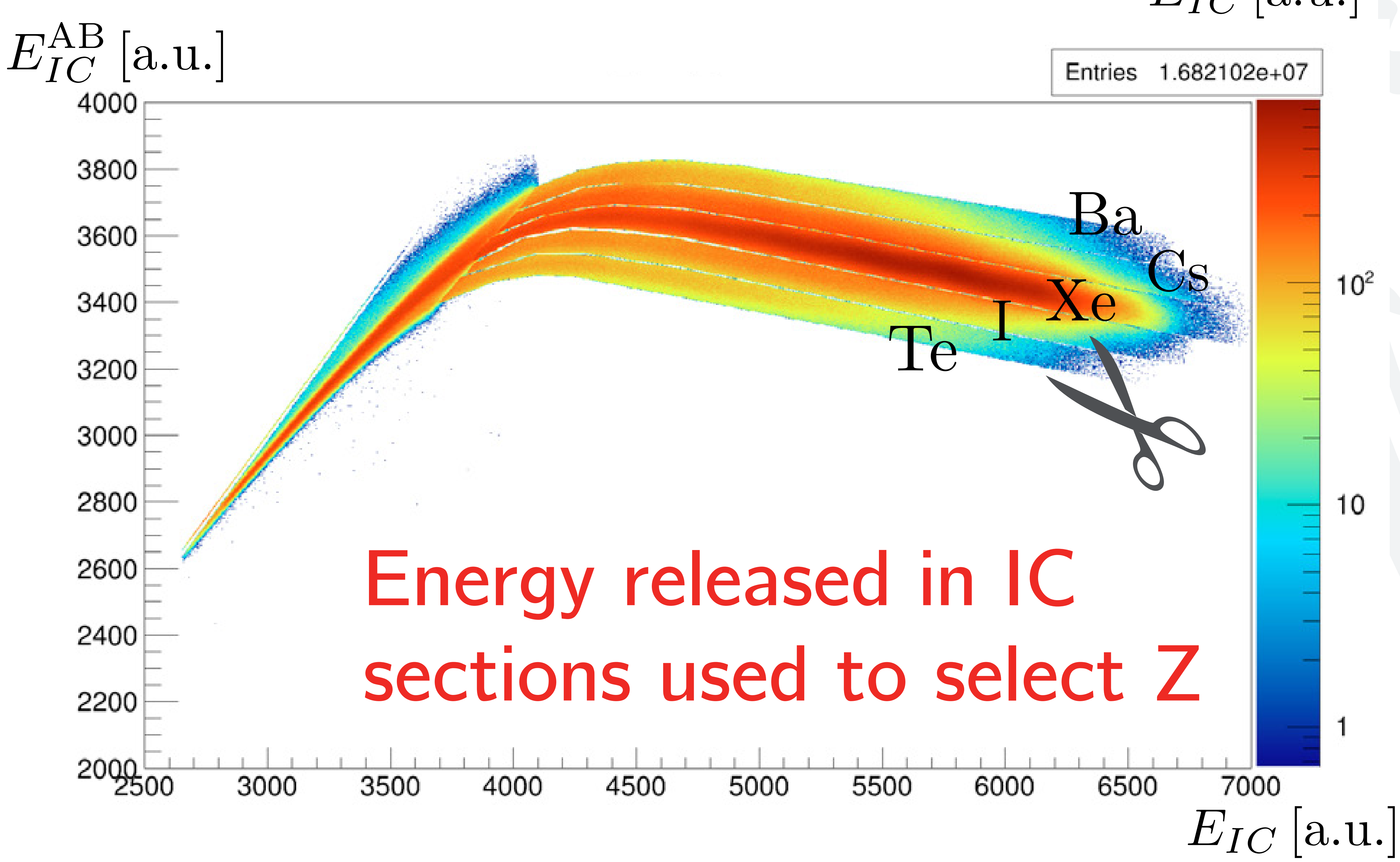
→ B. Birkenbach HK 58.8
"Gamma-Ray Tracking with the AGATA Demonstrator"

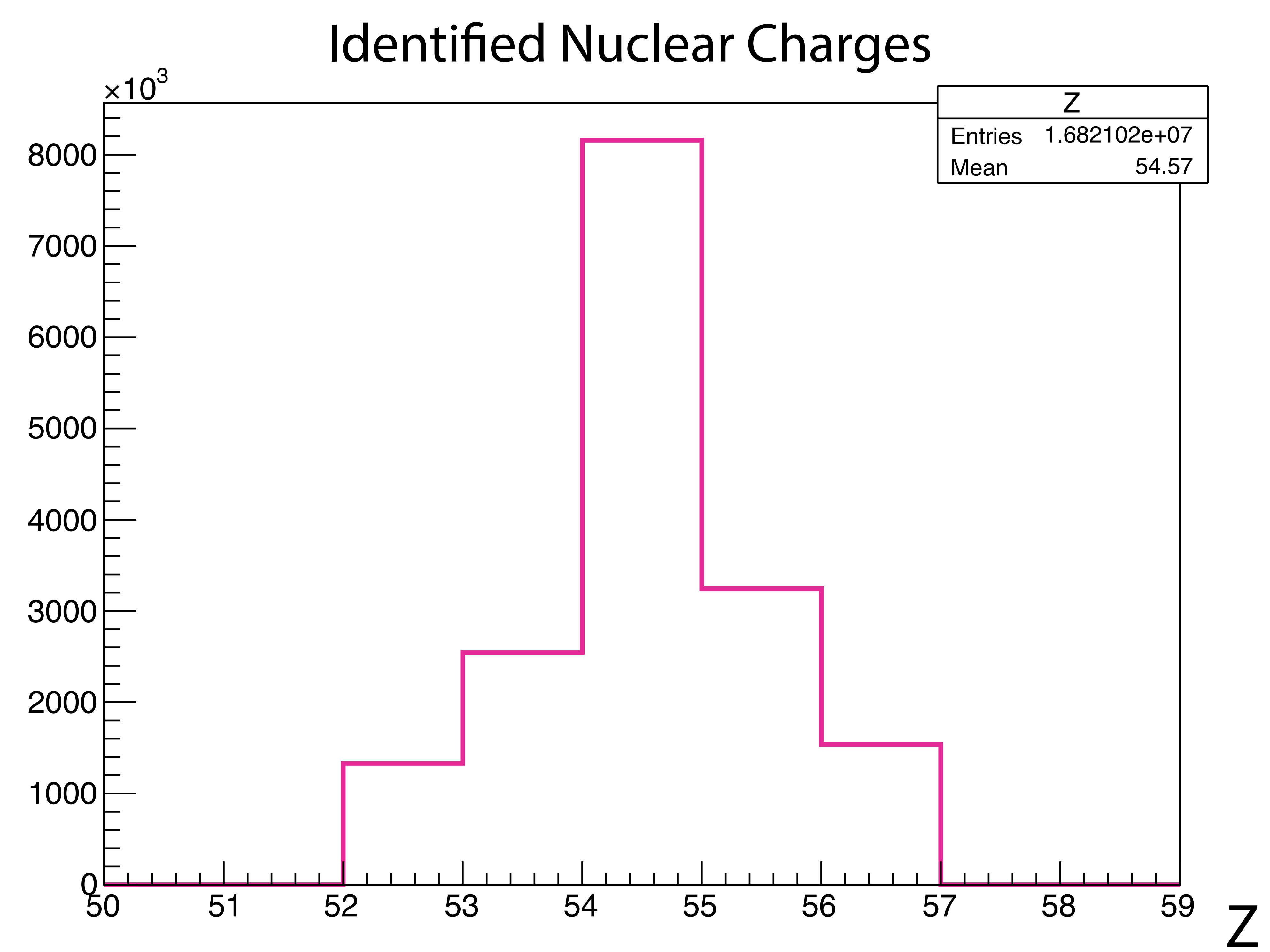
Z selection via energy loss in IC

$$-\frac{\mathrm{d}E}{\mathrm{d}x} \propto \frac{Z^2}{E}$$

$^{A}_{Z}X^{q+}$





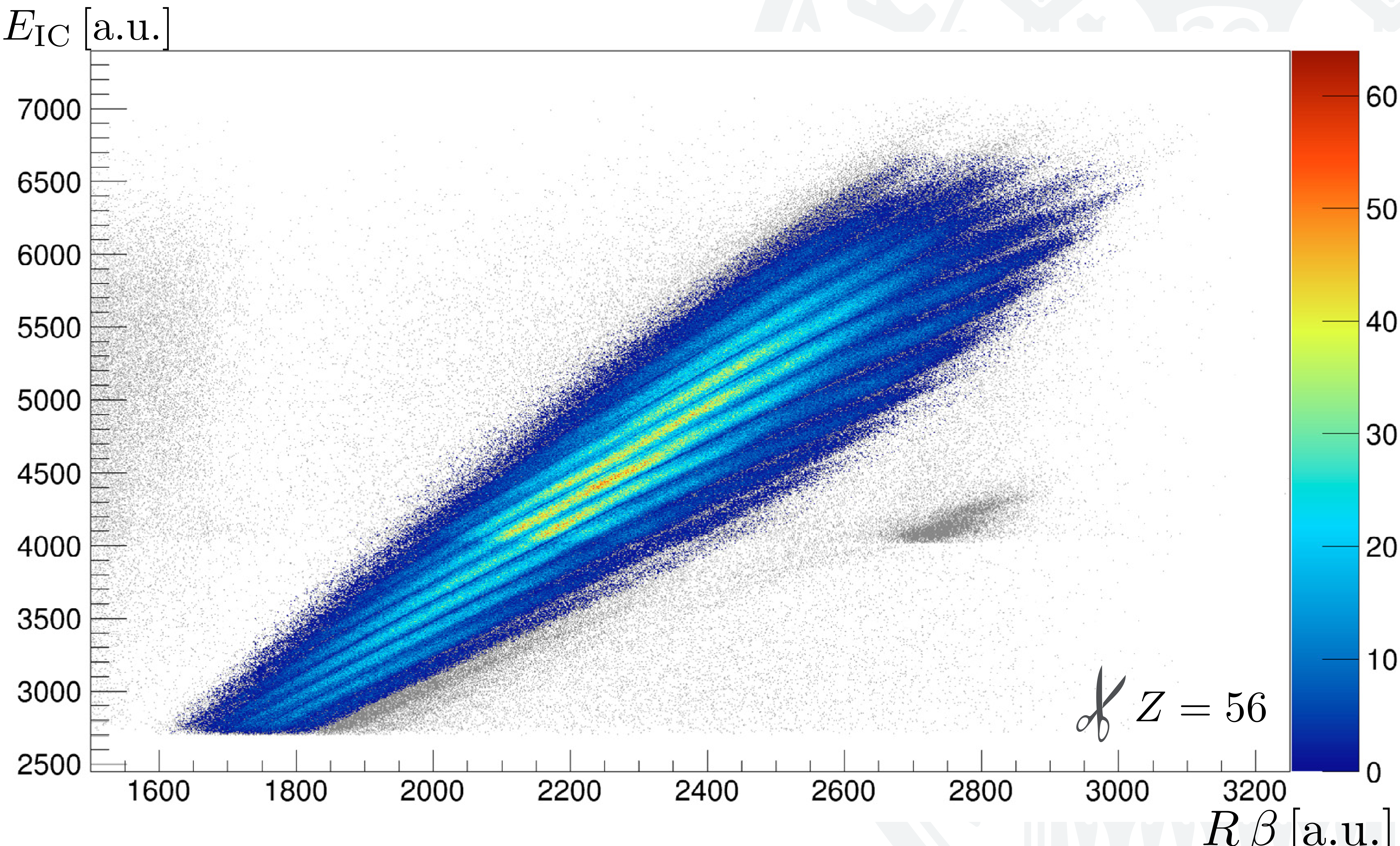


Barium	1.79×10^6	16.0%
Caesium	3.71×10^6	33.2%
Xenon	11.17×10^6	100%
Iodine	4.10×10^6	36.7%
Tellurium	2.07×10^6	18.5%

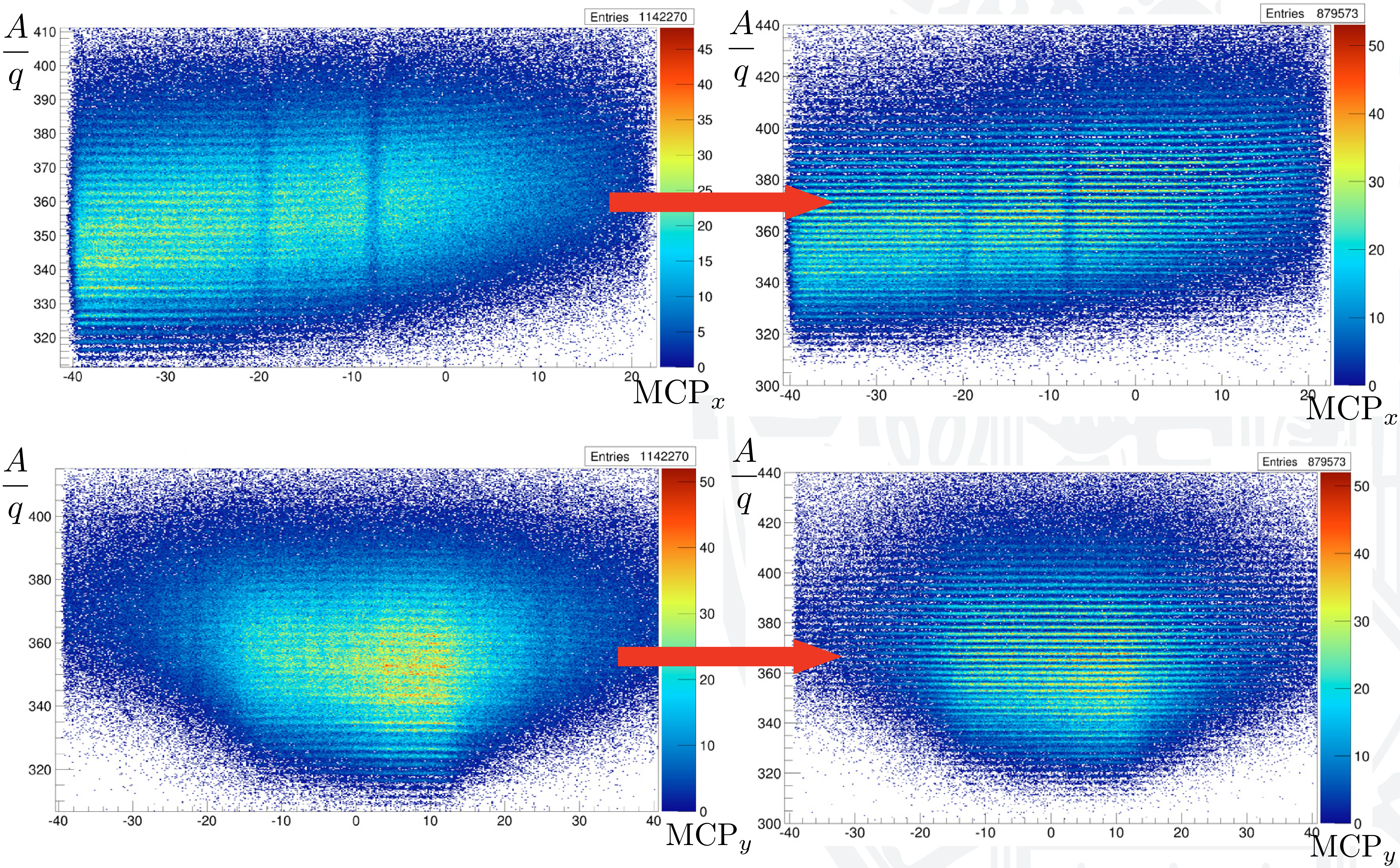
Charge state selection

via total kinetic energy and particle's Lorentz motion $\frac{E_{\mathrm{IC}}}{R\beta} \propto q$

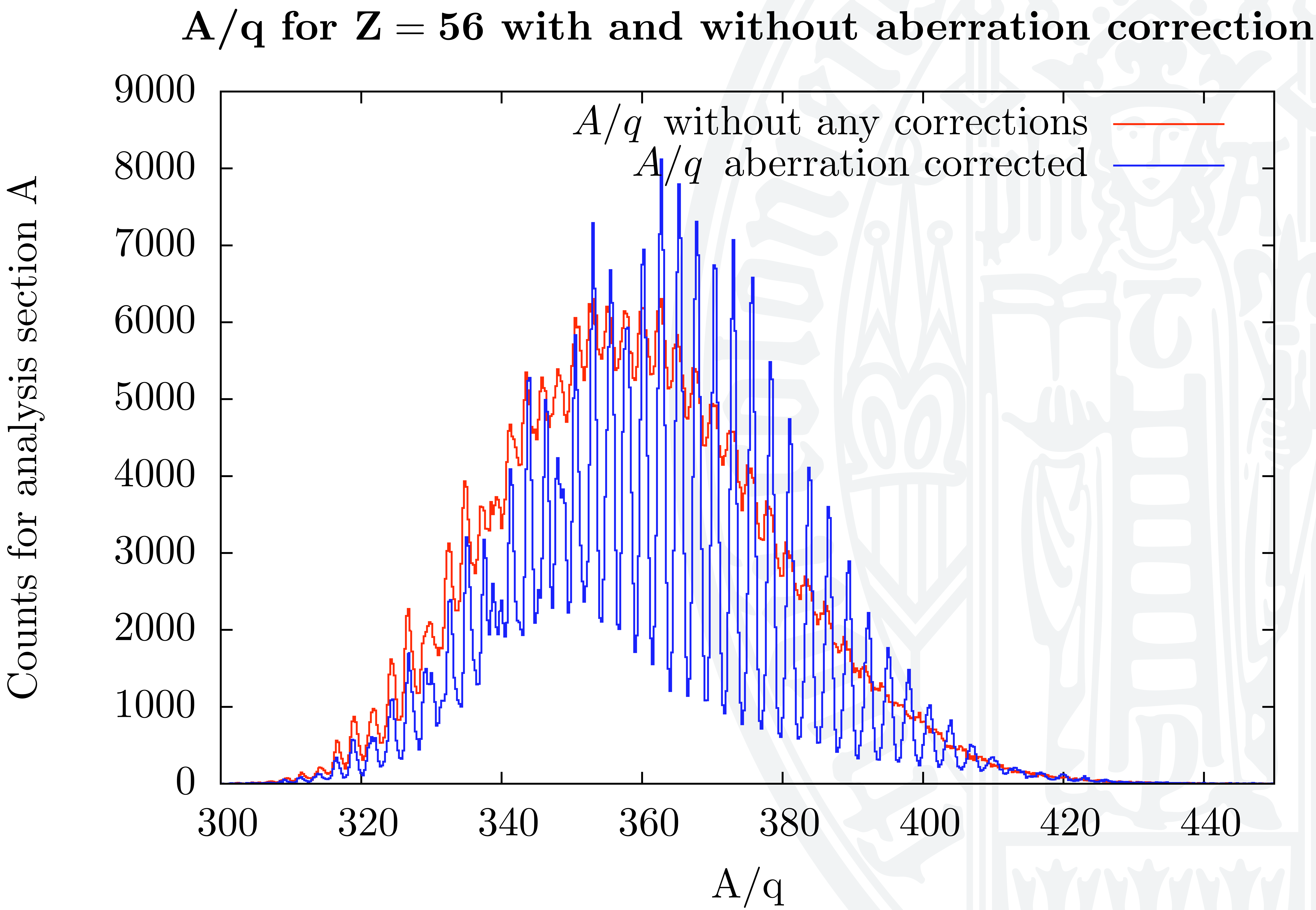
$^{A}_{Z}X^{q+}$



Aberration corrections via polynomial straightening



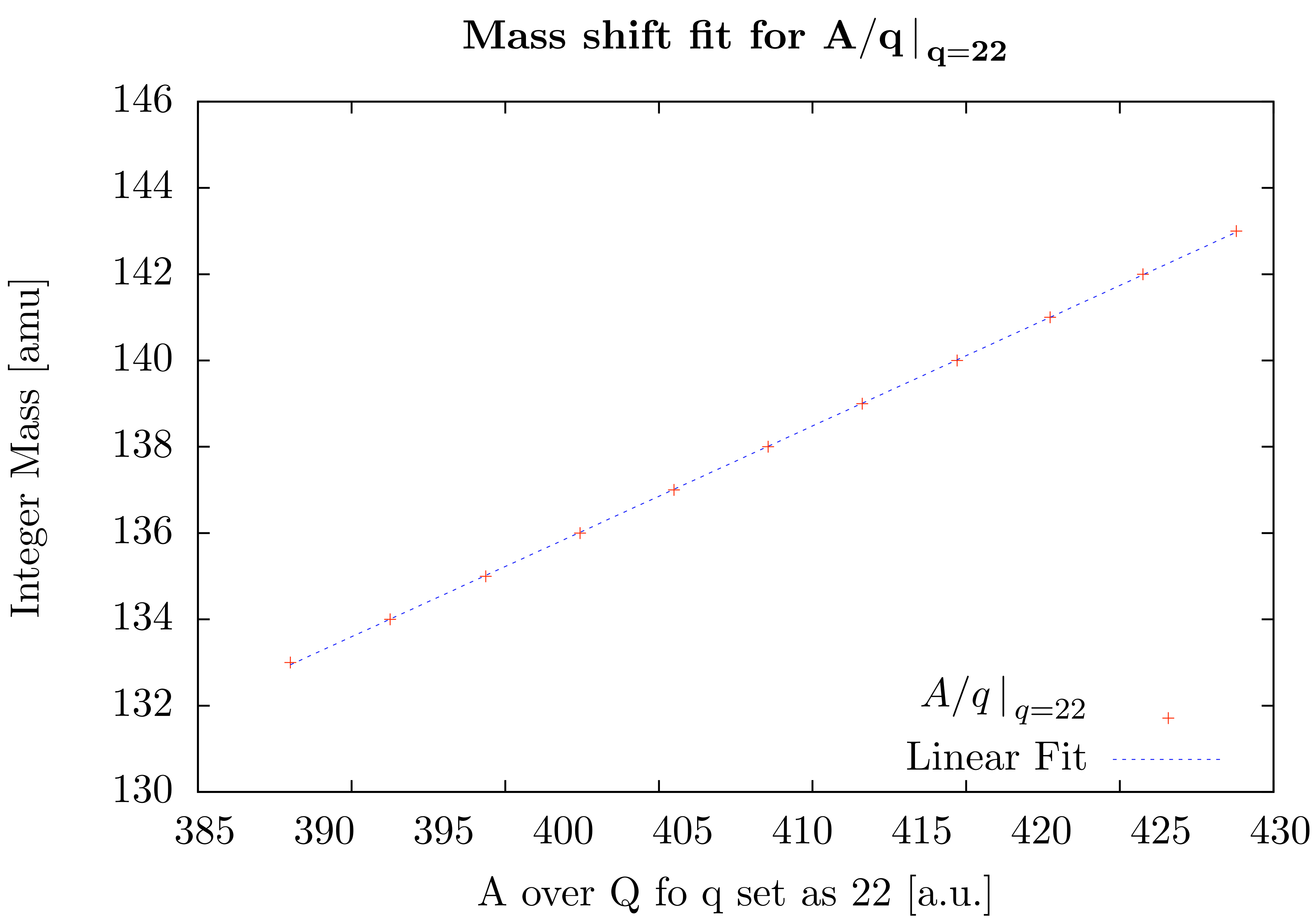
Results of aberration corrections

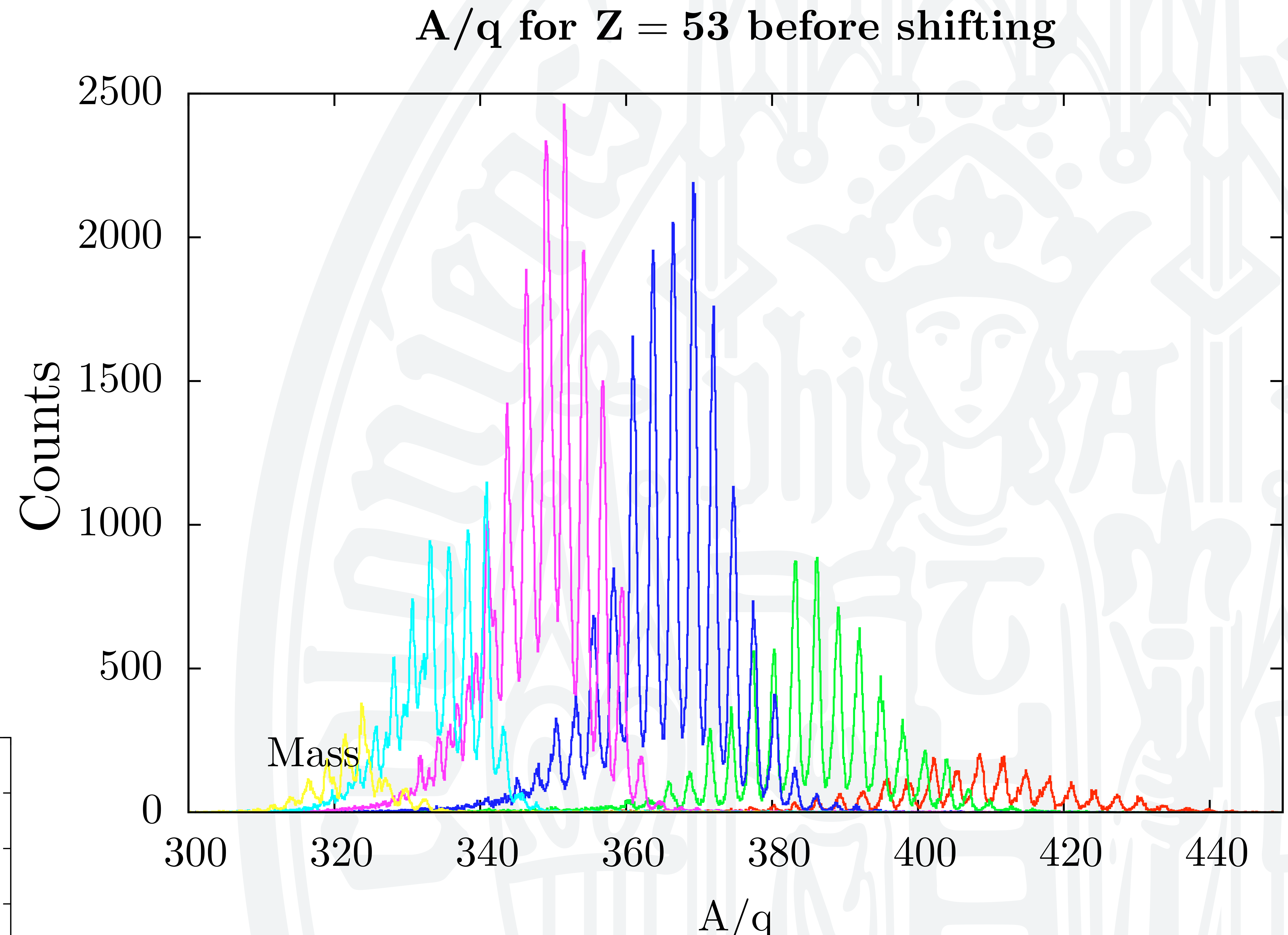


Mass calculation

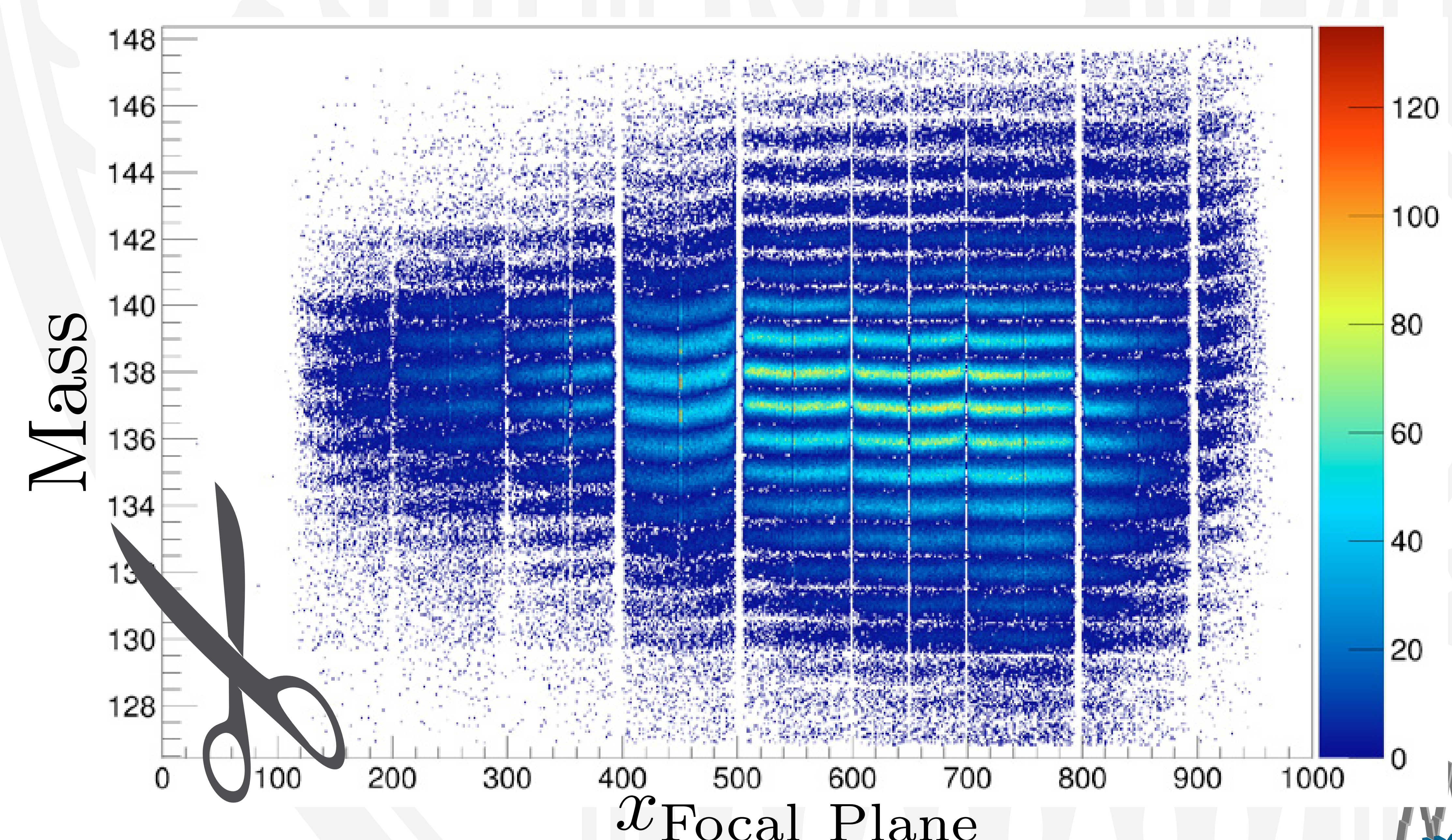
Align all A/q spectra by shifting for given charged states q_i and construct A:

$$A = a_i \cdot \frac{A}{q}\bigg|_{q_i} + b_i$$





Set mass gates in 2D mass histogram

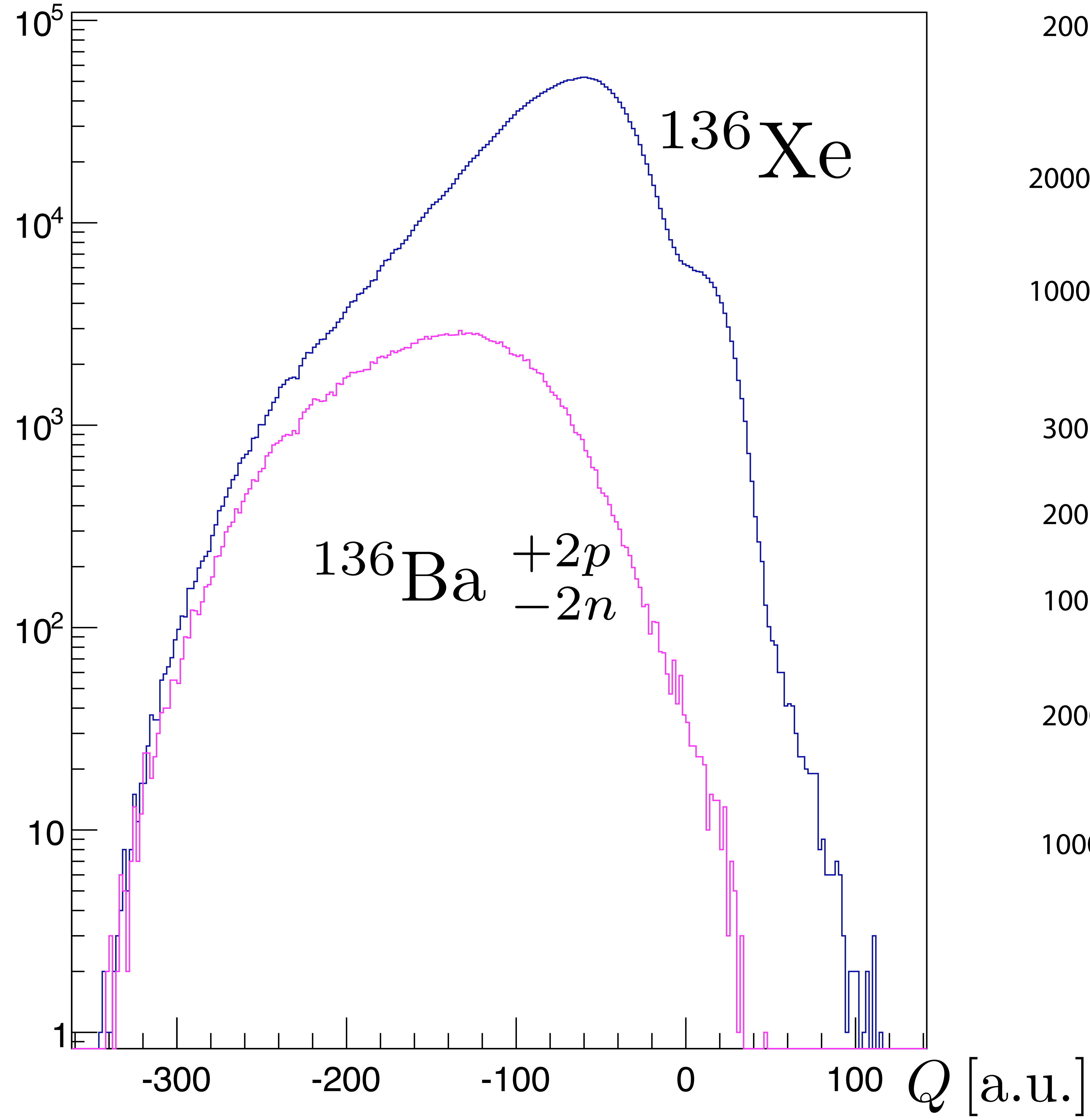


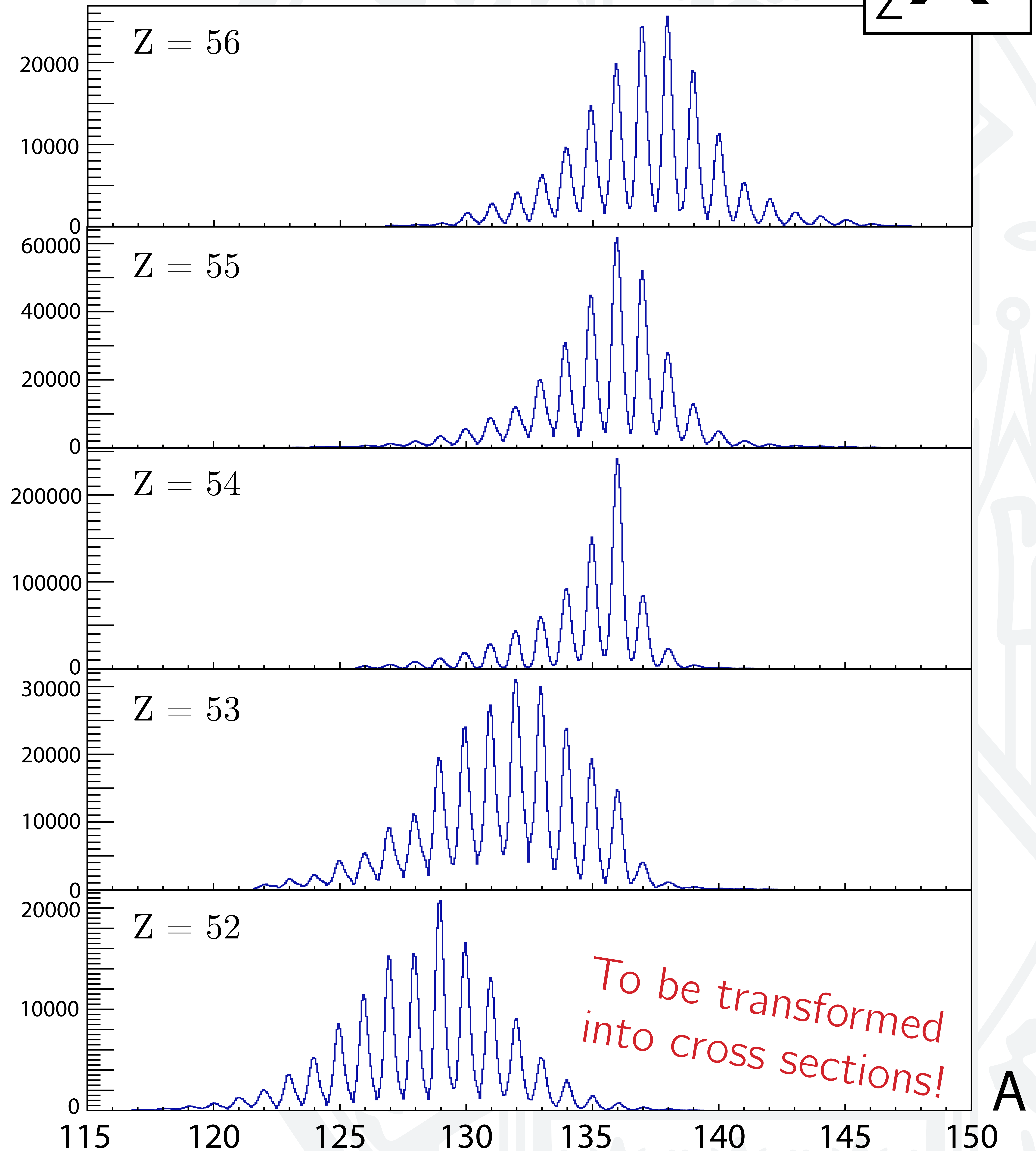
Yields of beam-like particles

Mass resolving power for studied high-mass regime:

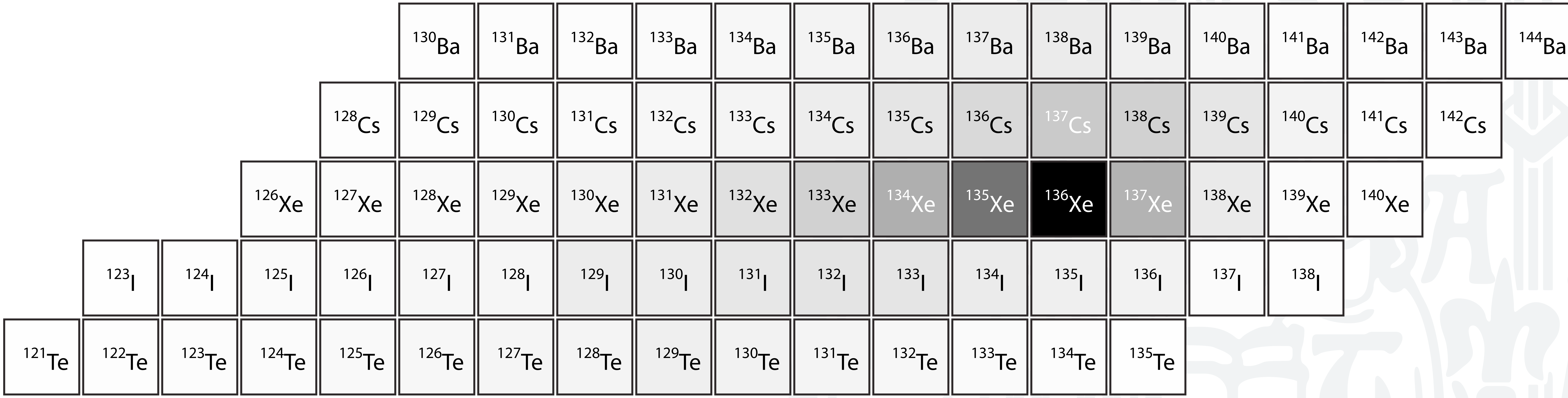
$$\frac{m}{\Delta m} = 324 \pm 3$$

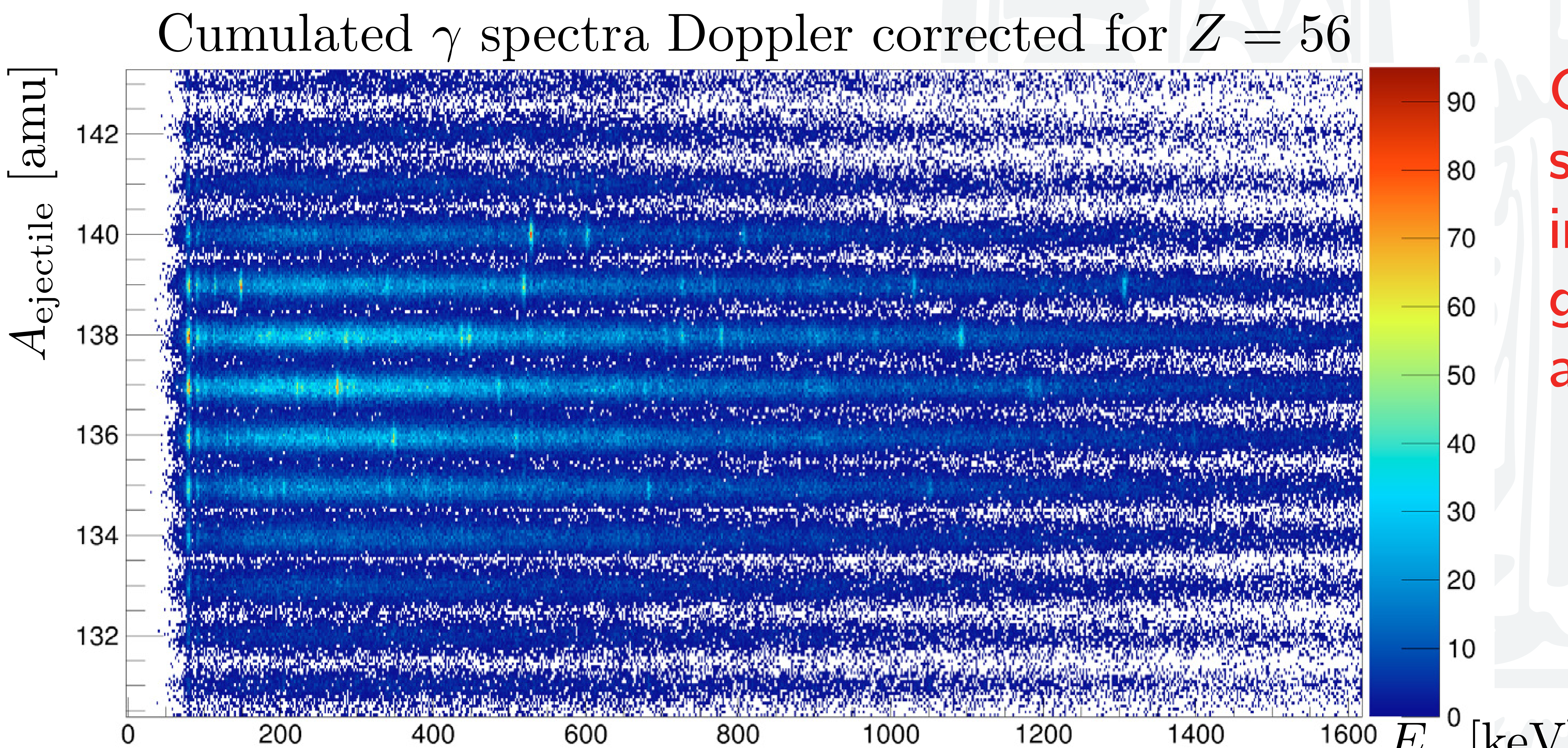
Q-value distribution





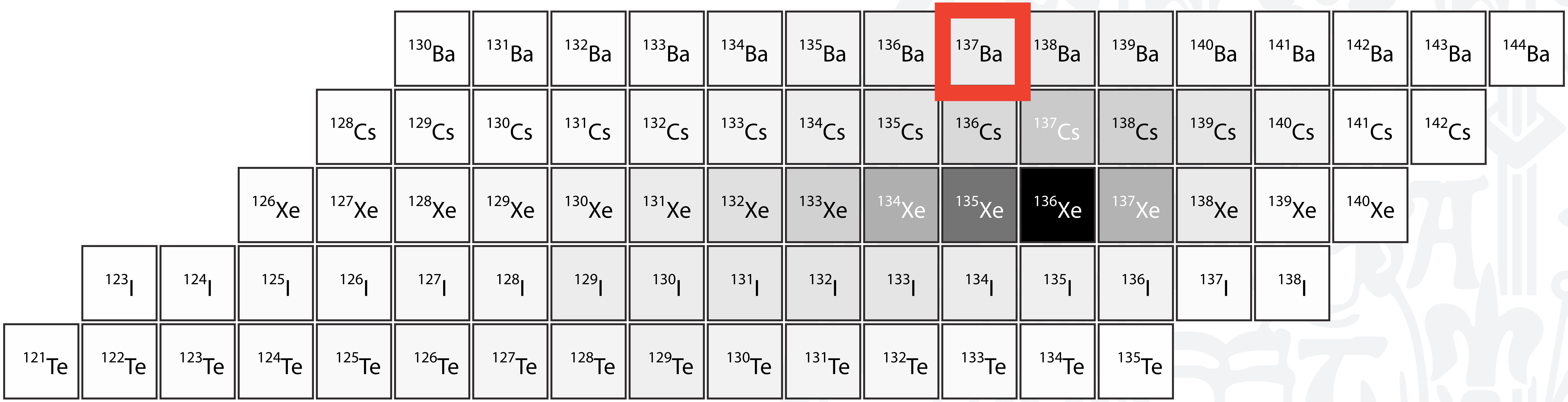
Yields of beam-like particles

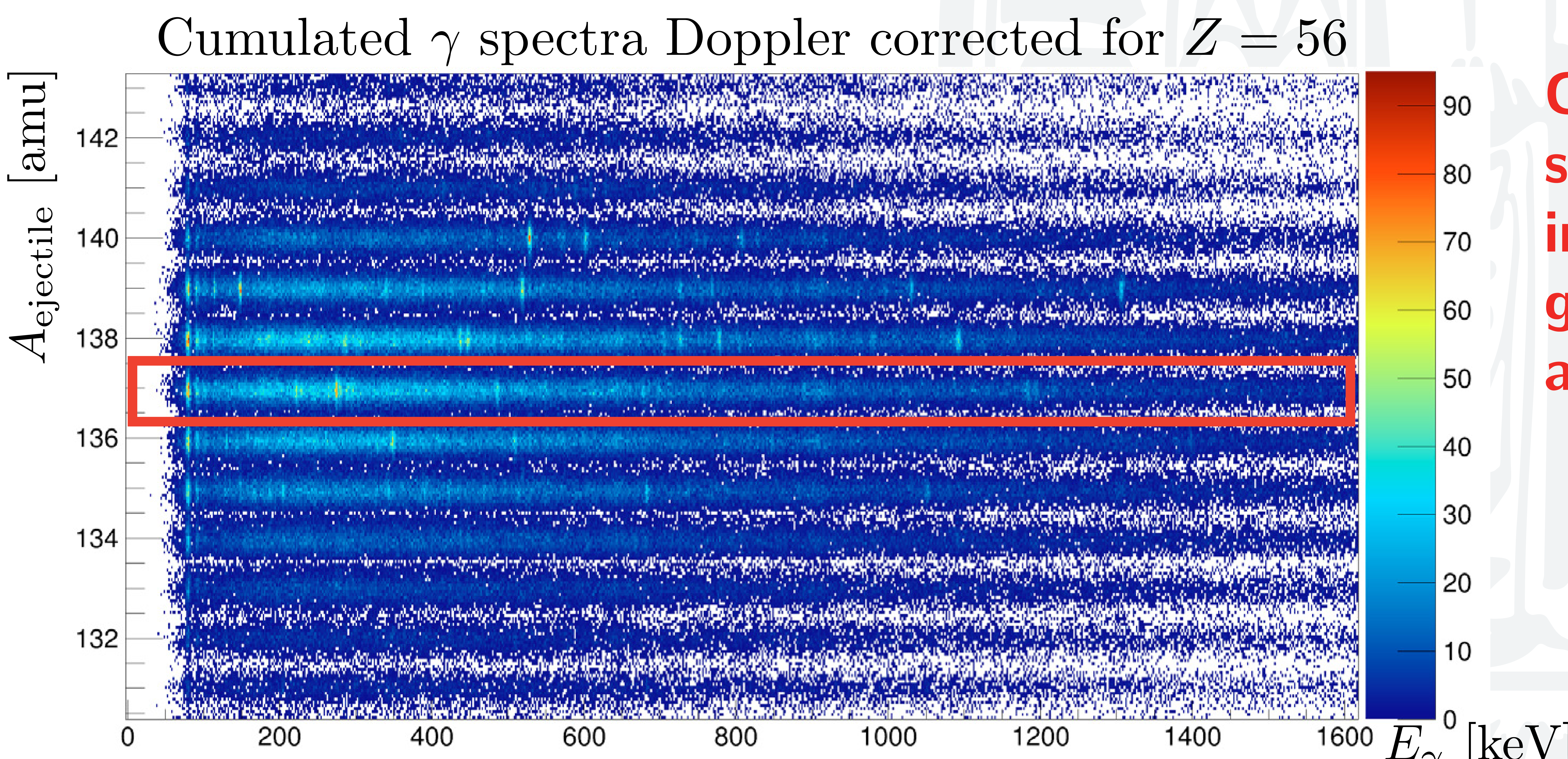




Clean separation in terms of gamma analysis!

Yields of beam-like particles



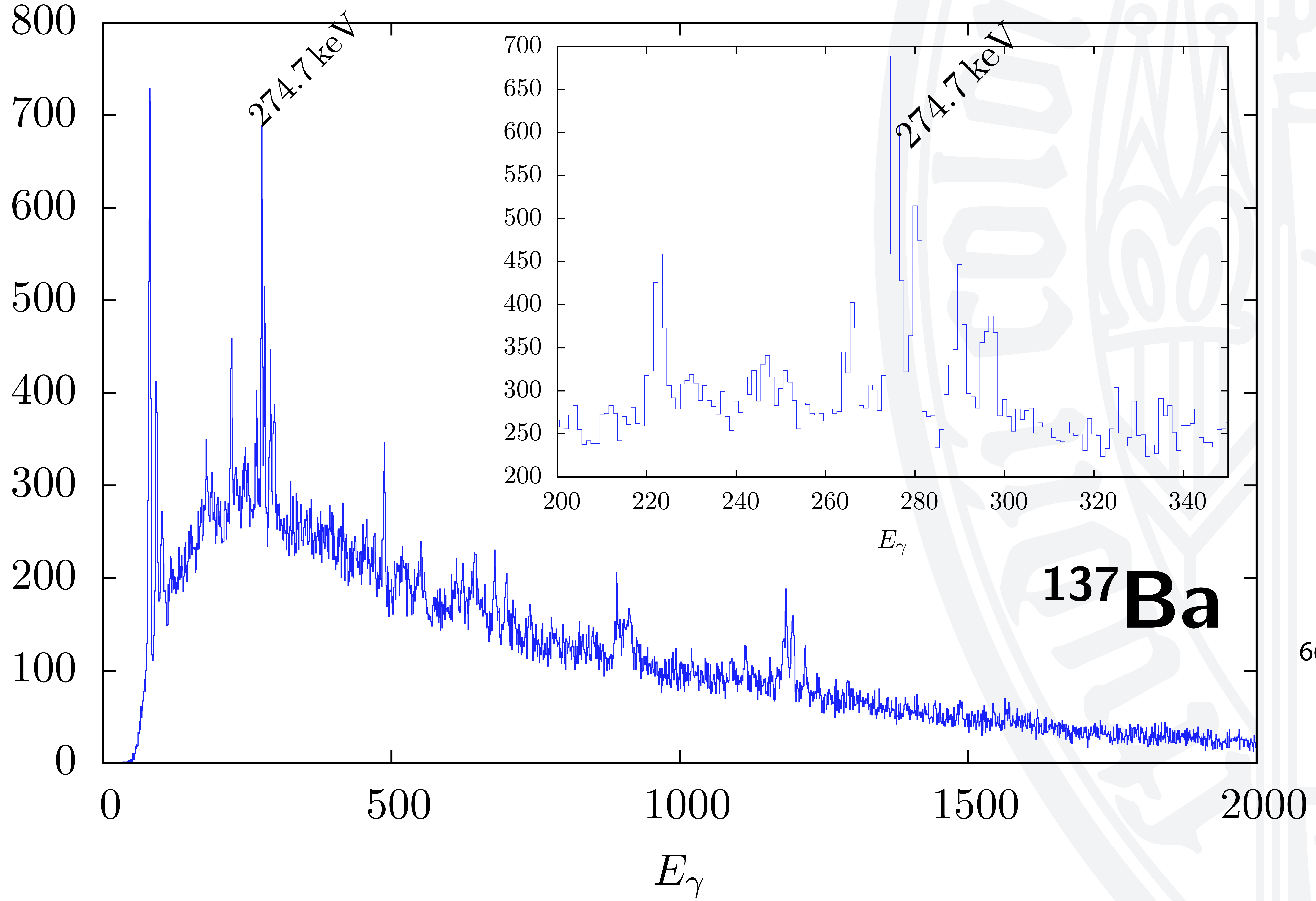


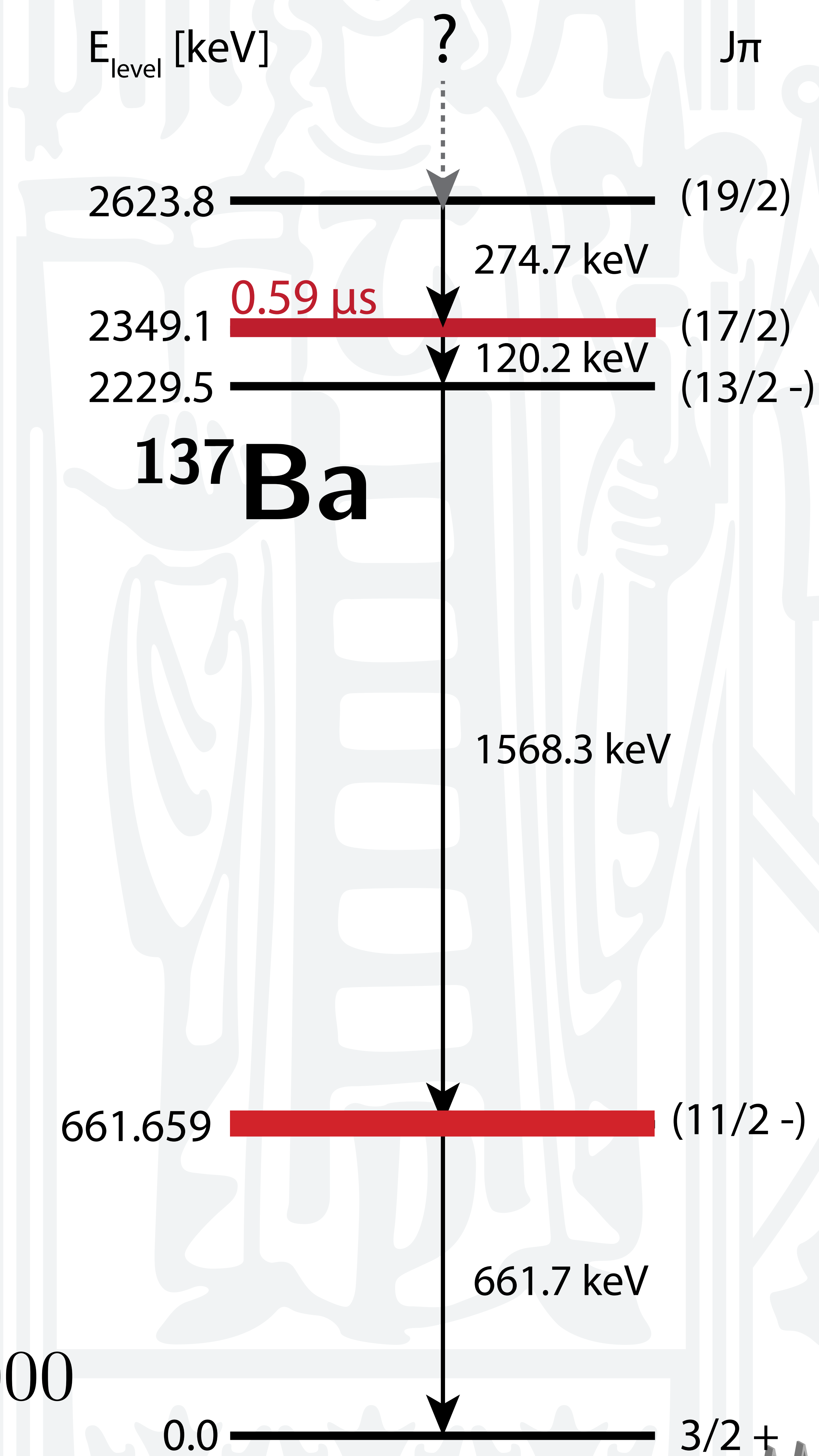
Clean separation in terms of gamma analysis!

New high-spin transitions in Ba and Te

Several candidates for new transitions in Ba and Te γ spectra found

Ongoing γγ analysis challenging due to low statistics and high fission background





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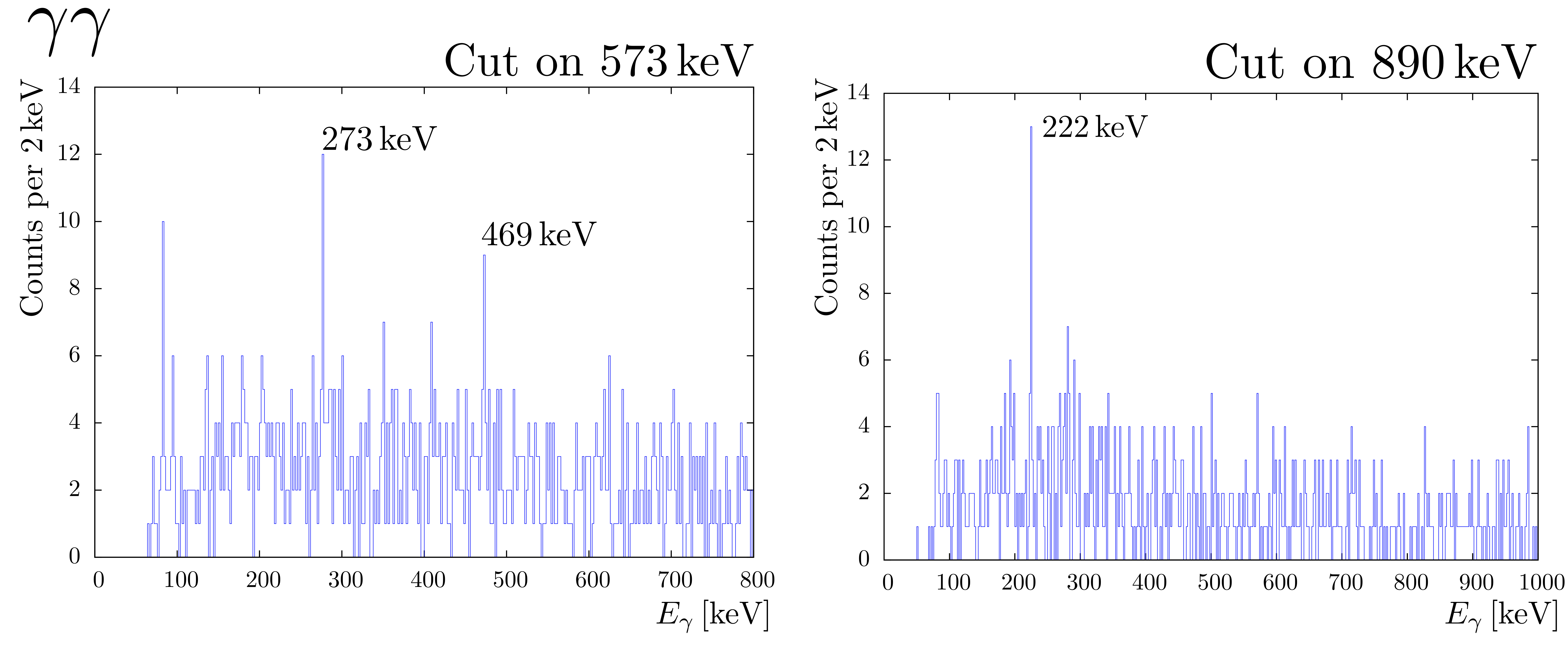
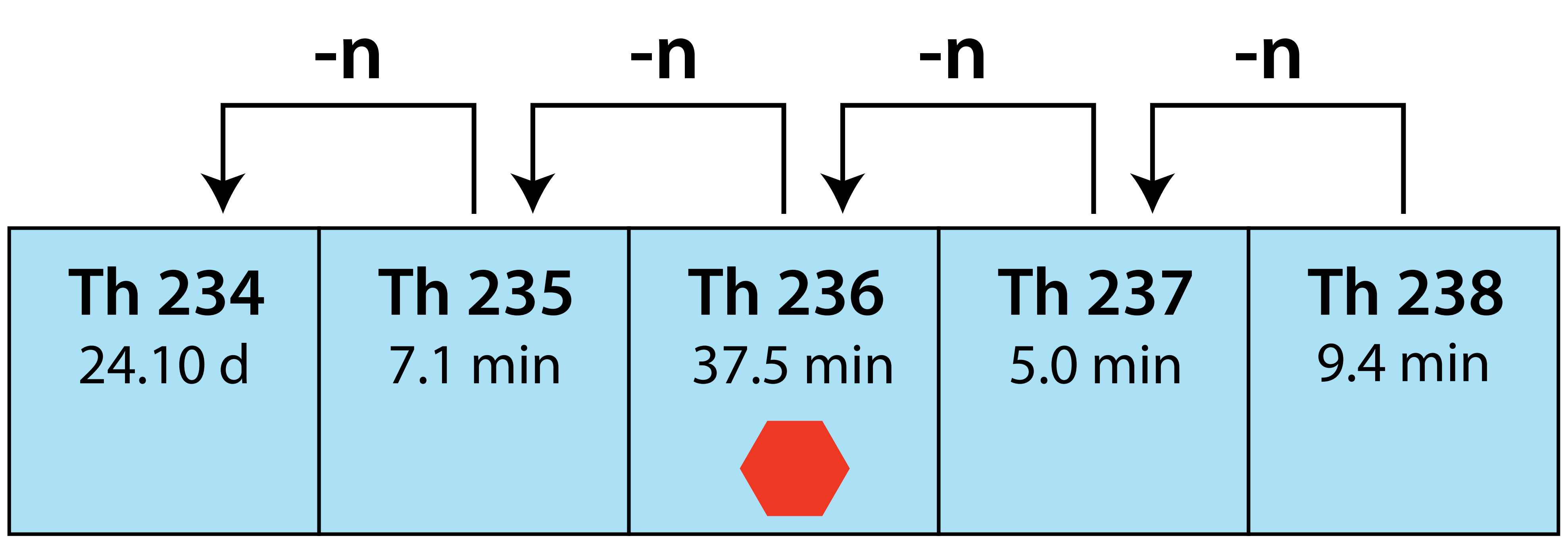
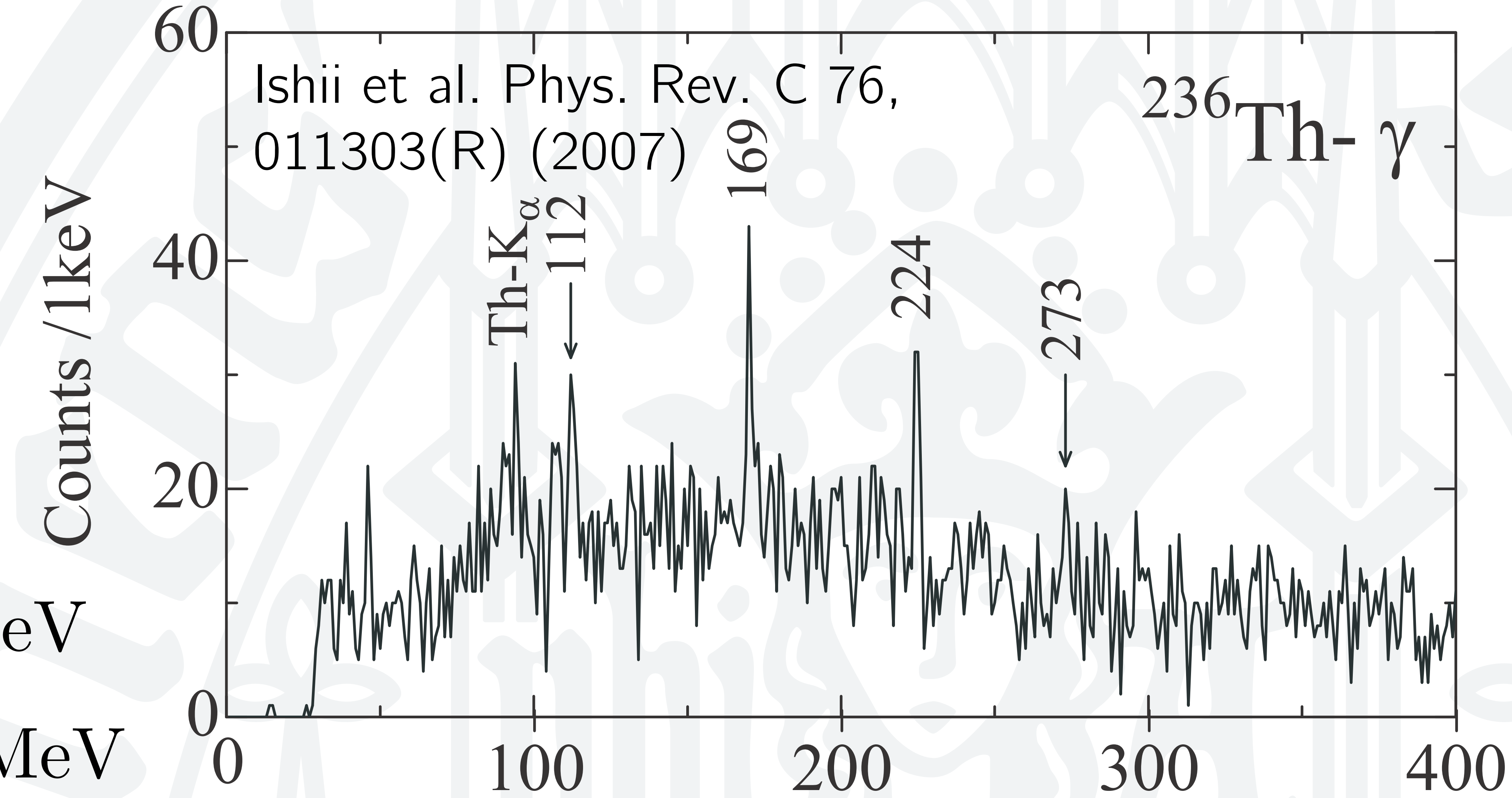


Preliminary!

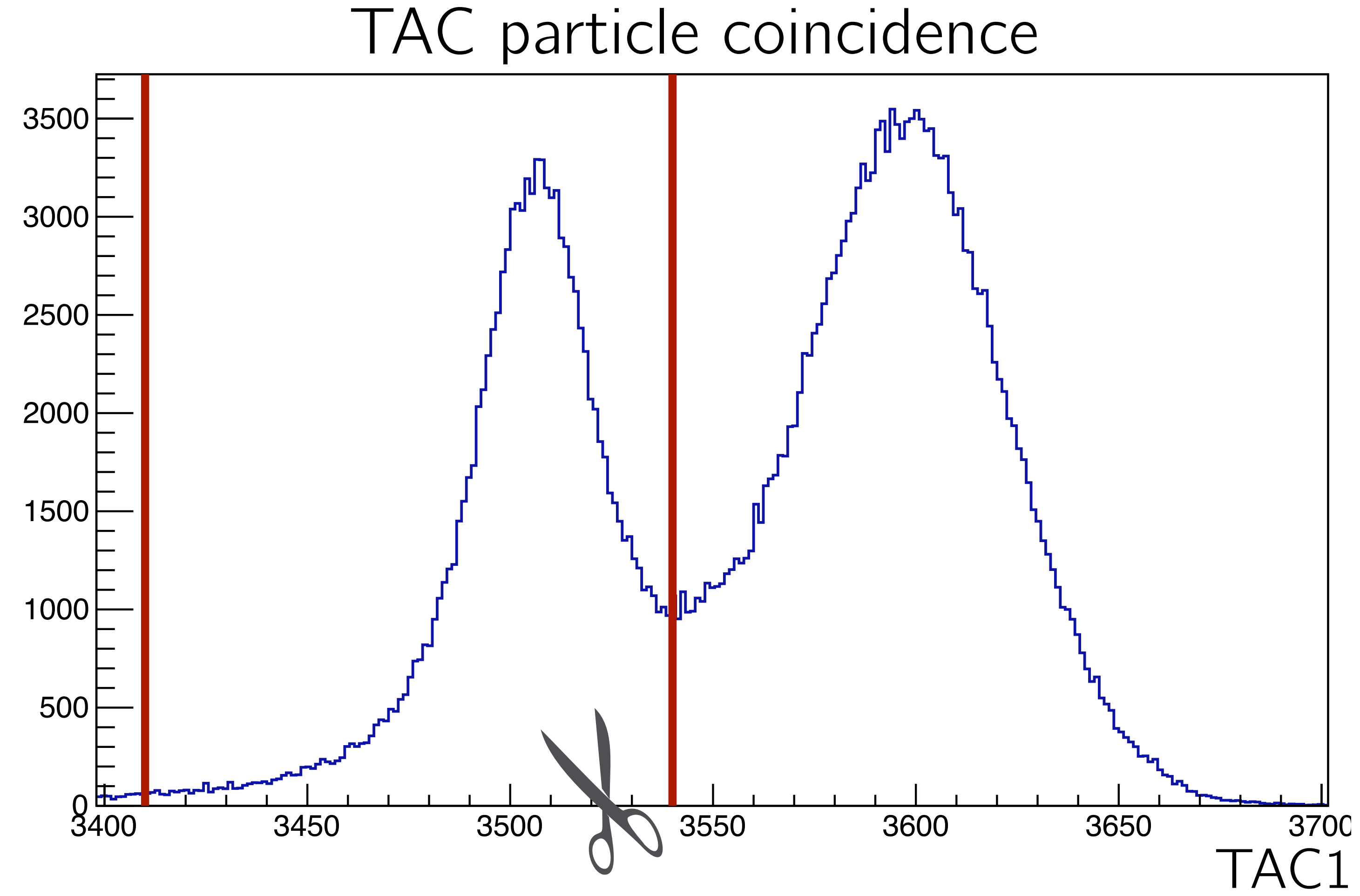
γ-spectrum for ^{138}Ba, Doppler corrected for target-like $^{236\text{-}xn}$Th

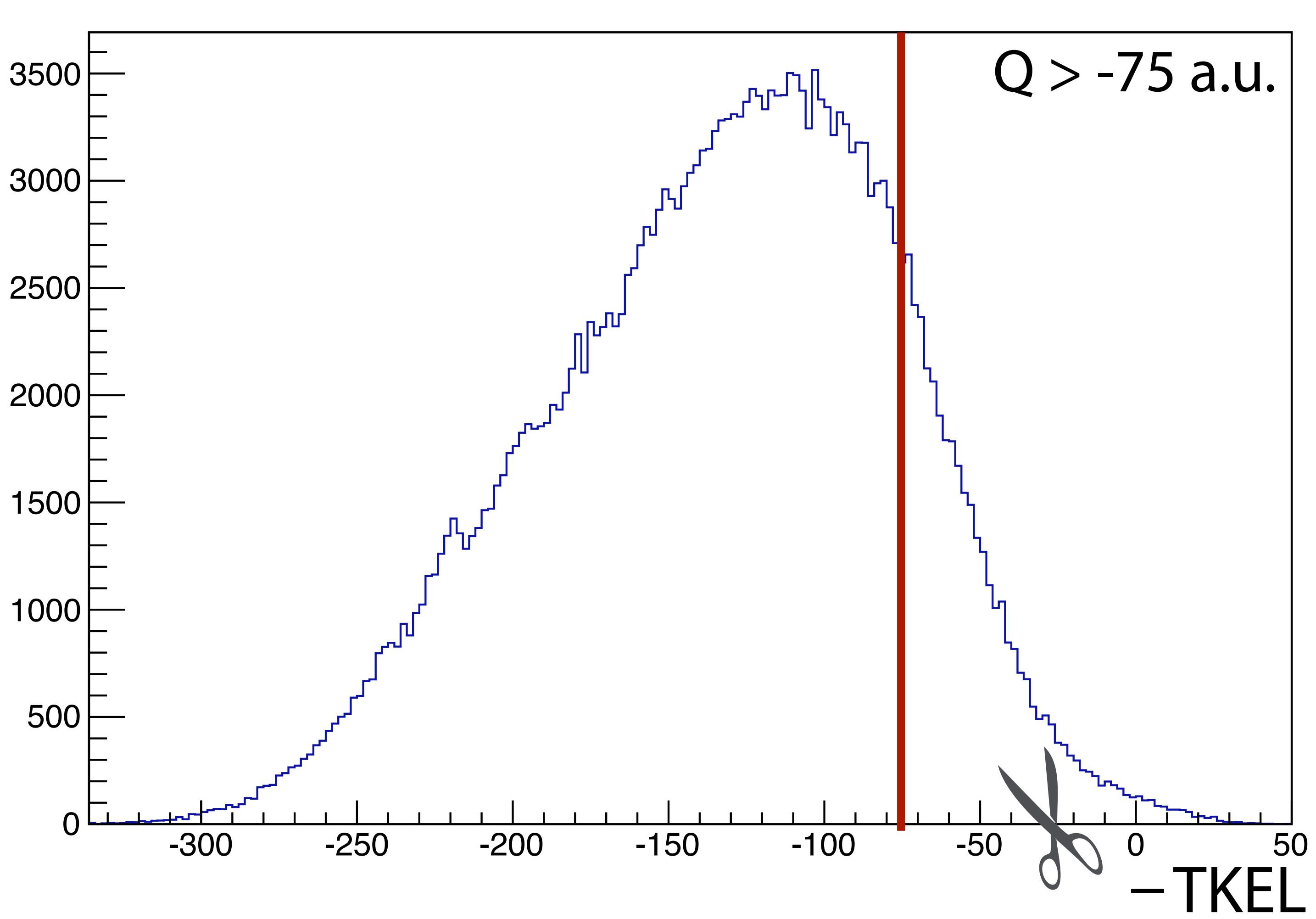


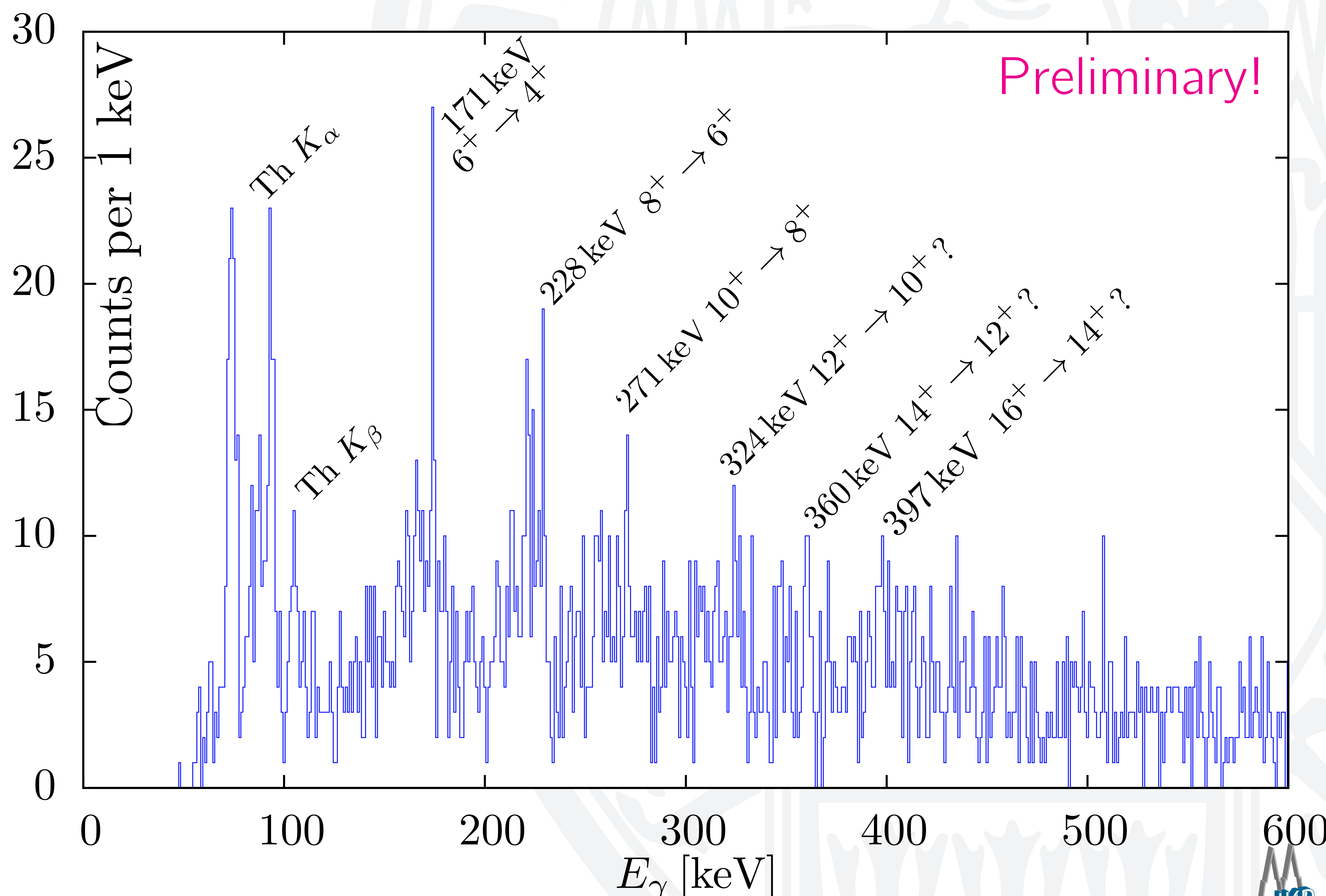
$$S_n^{^{236}\mathrm{Th}} = -5.834\,\mathrm{MeV}$$
$$S_{2n}^{^{236}\mathrm{Th}} = -10.502\,\mathrm{MeV}$$



Applied cuts







Summary

- Successful experiment with AGATA-Prisma setup
- Identification of beam-like particles in the Ba-Te region
- Isotopic yields for $^{136}\mathrm{Xe} + {}^{238}\mathrm{U}$ multinucleon transfer reactions
- Doppler-corrected spectra for ejectile and recoil particles in kinematic coincidence

Outlook

- Determination of levels, transitions and moments of intertia in neutron-rich Th and Pu isotopes
- Analysis of high-spin levels in Ba and Te
- Conversion of yields into cross sections
- Neutron-rich nuclei in the Sb region are within range

Personæ

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GEFÖRDERT VOM

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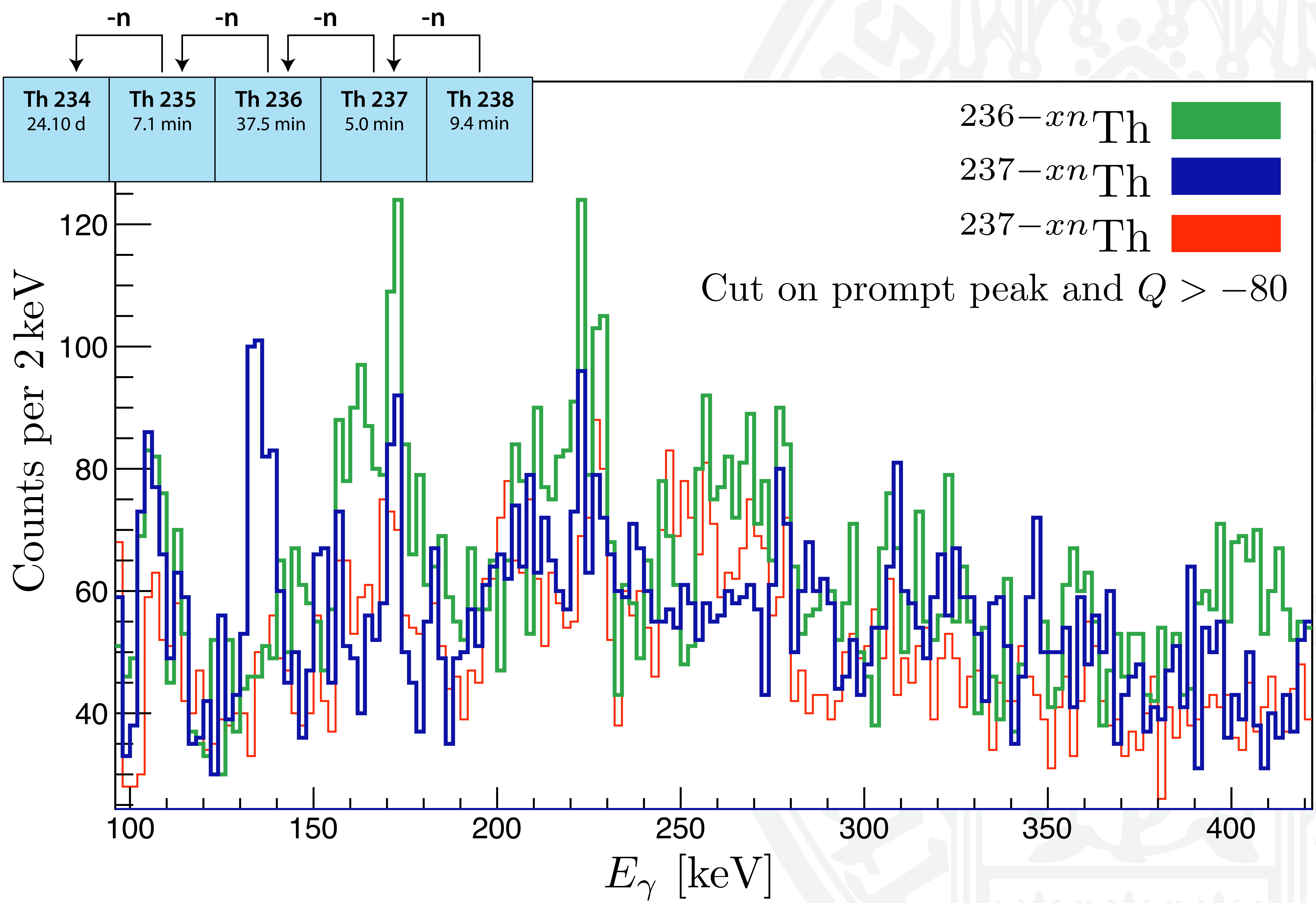
ENSAR

INFN Istituto Nazionale di Fisica Nucleare

bcgs Bonn-Cologne Graduate School of Physics and Astronomy

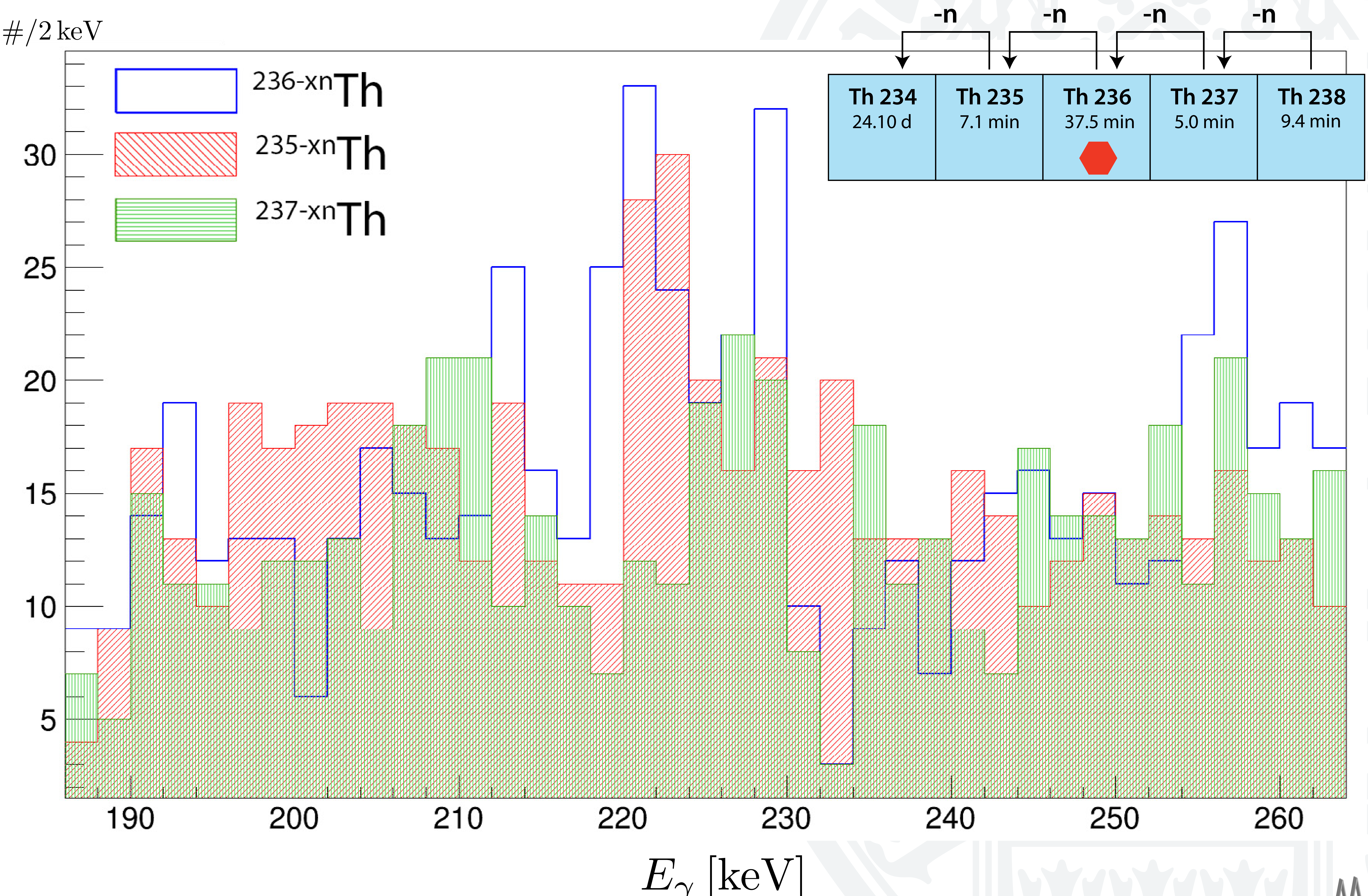
IKP Universität zu Köln

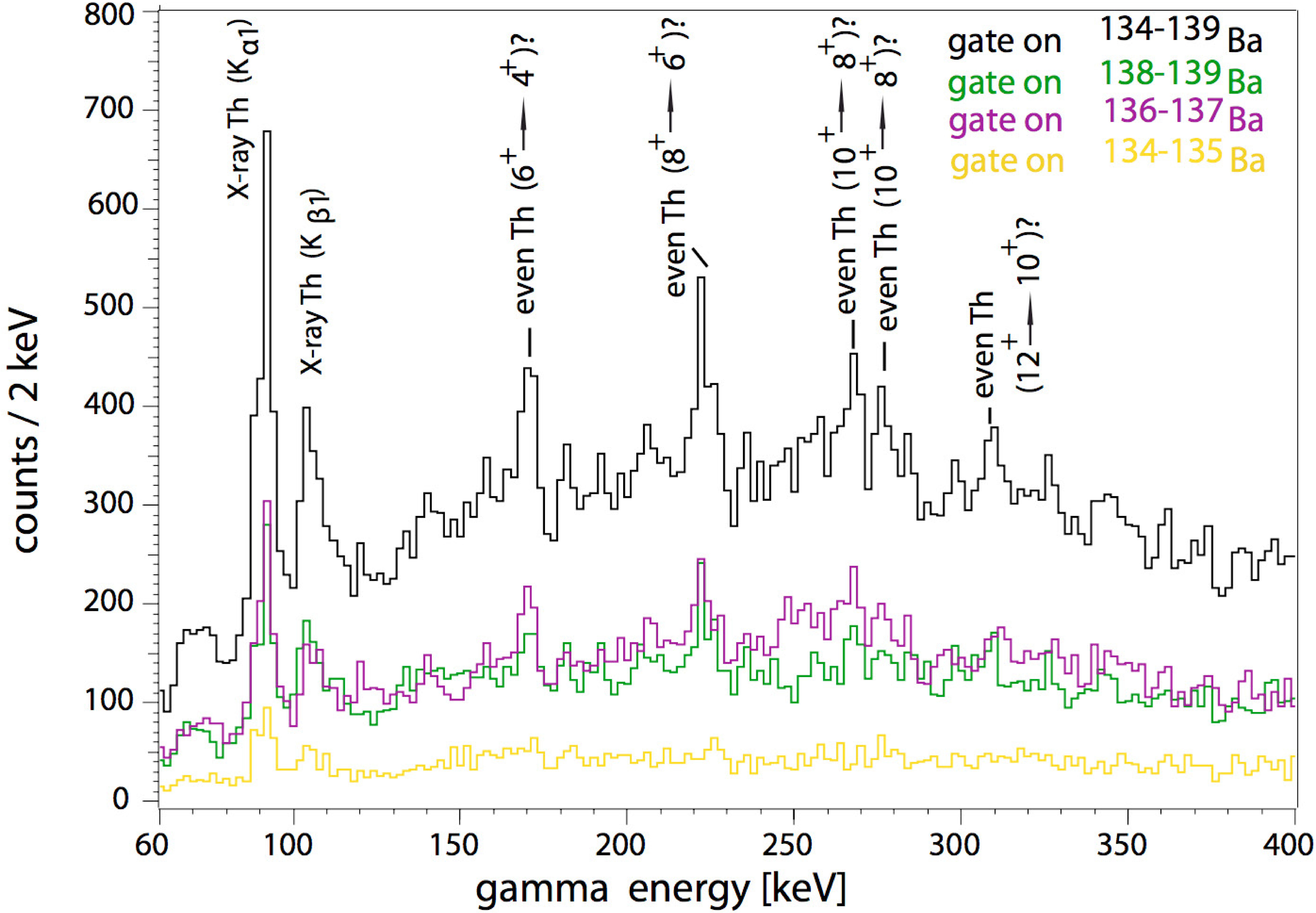
Appendix



-n
-n
-n
-n
Th 234
24.10 d
Th 235
7.1 min
Th 236
37.5 min
Th 237
5.0 min
Th 238
9.4 min
236−xnTh
237−xnTh
237−xnTh
Cut on prompt peak and Q > −80
Counts per 2 keV
120
100
80
60
40
100
150
200
250
300
350
400
Eγ [keV]

223 keV vs 228 keV for 8+ state in ^{236}Th





Kerstin Geibel: *Search for Proton Emission in* ^{54}*Ni and Multi-Nucleon Transfer Reactions in the Actinide Region.* Inaugural-Dissertation. Köln 2012.

Cross section determination

$$\frac{d\sigma}{d\Omega} = \frac{N_s}{N_b\ \rho_t\ l_t\ (d\Omega)_d}$$

requires measurement of beam and elastic channel intensities

$$\frac{d\sigma}{d\Omega_{\mathrm{lab}}} = \frac{N \times f(\theta_{\mathrm{lab}}, E)}{C}$$

PRISMA transport function correction factor

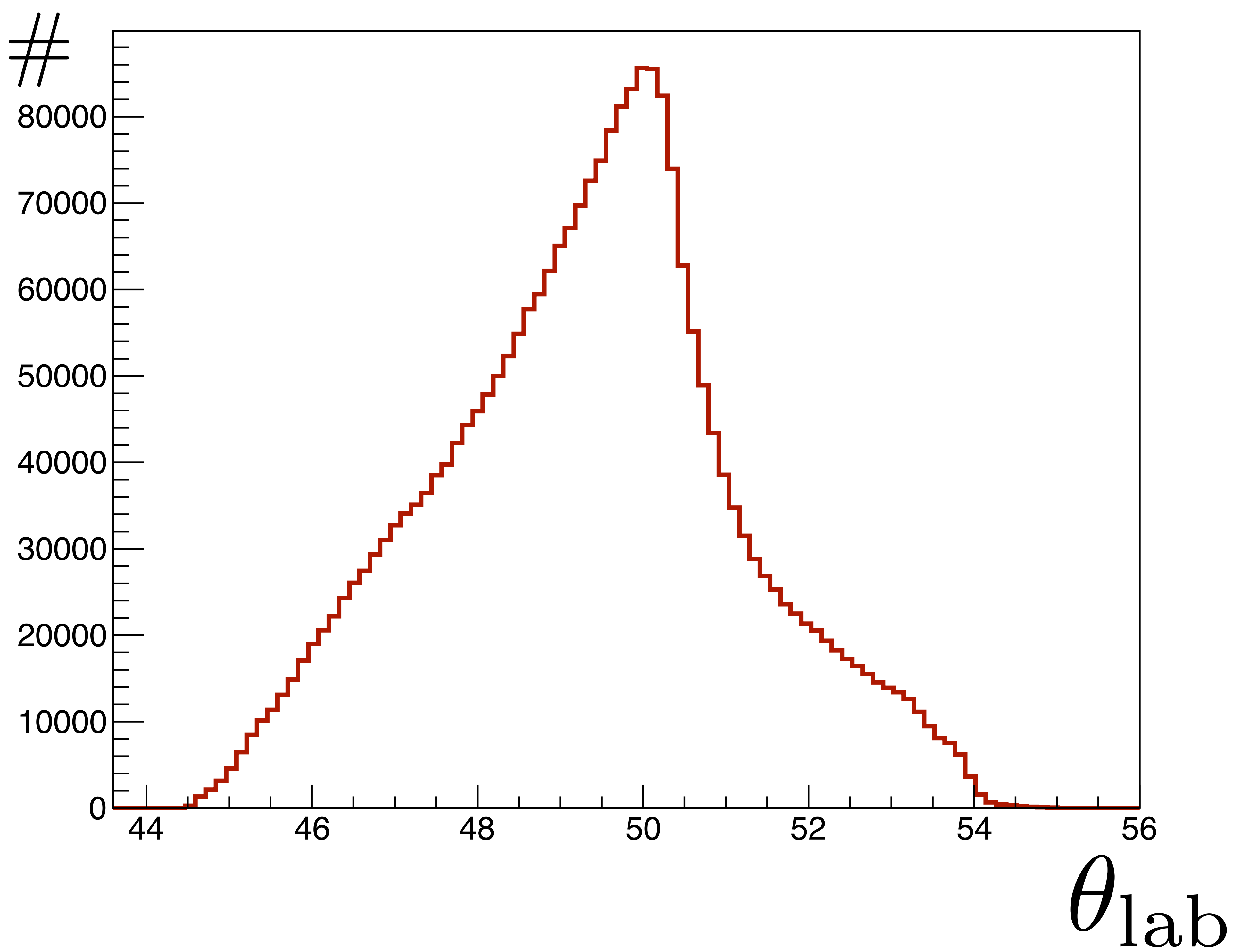
counts to mb/sr conversion factor

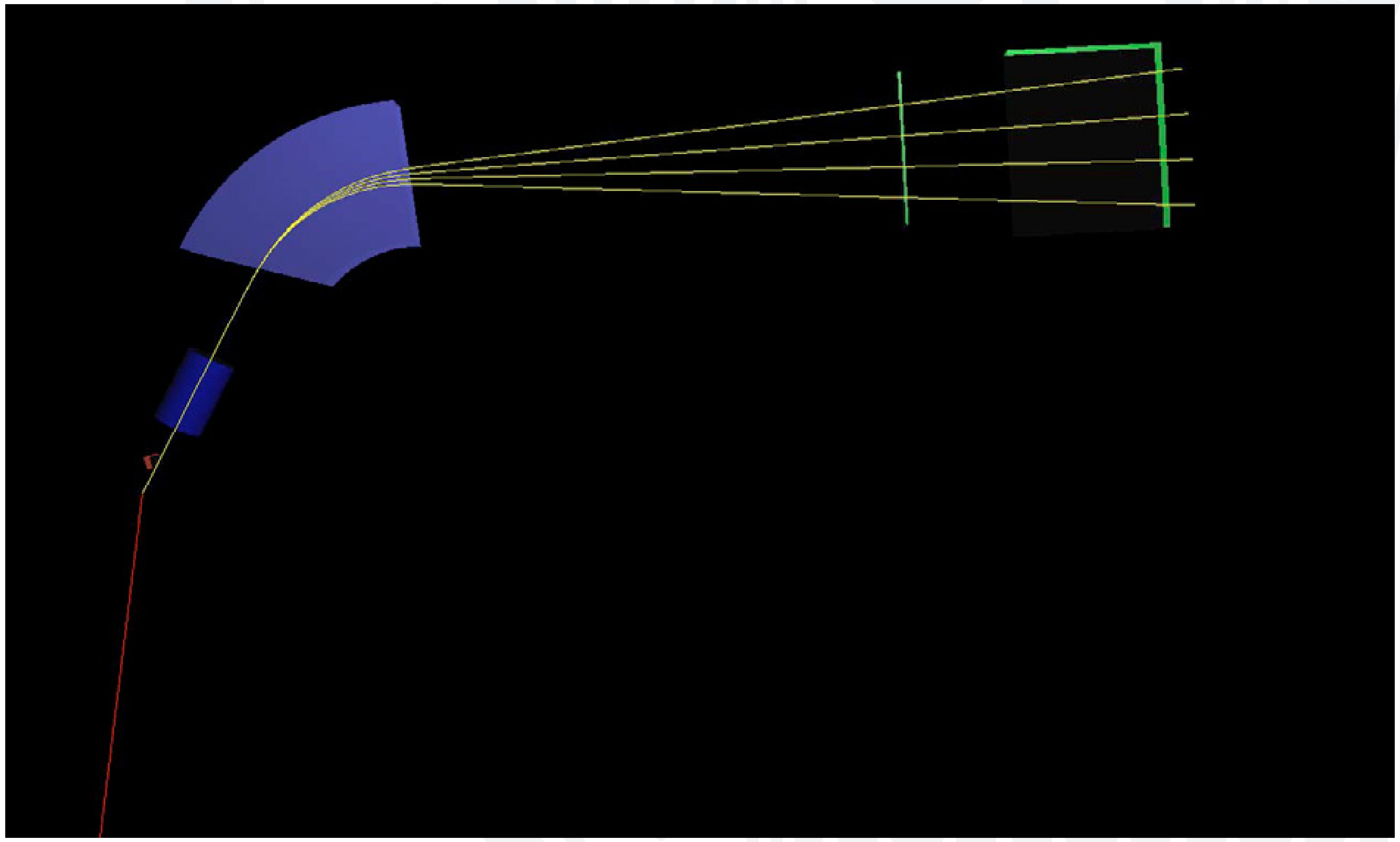
elastically scattered events

$$f(E,\theta,\phi) = \frac{\#\,\mathrm{INPUT\ Events:\ at\ MCP}(E,\theta,\phi)}{\#\,\mathrm{OUTPUT\ Events:\ at\ Focal\ Plane}(E,\theta,\phi)}$$

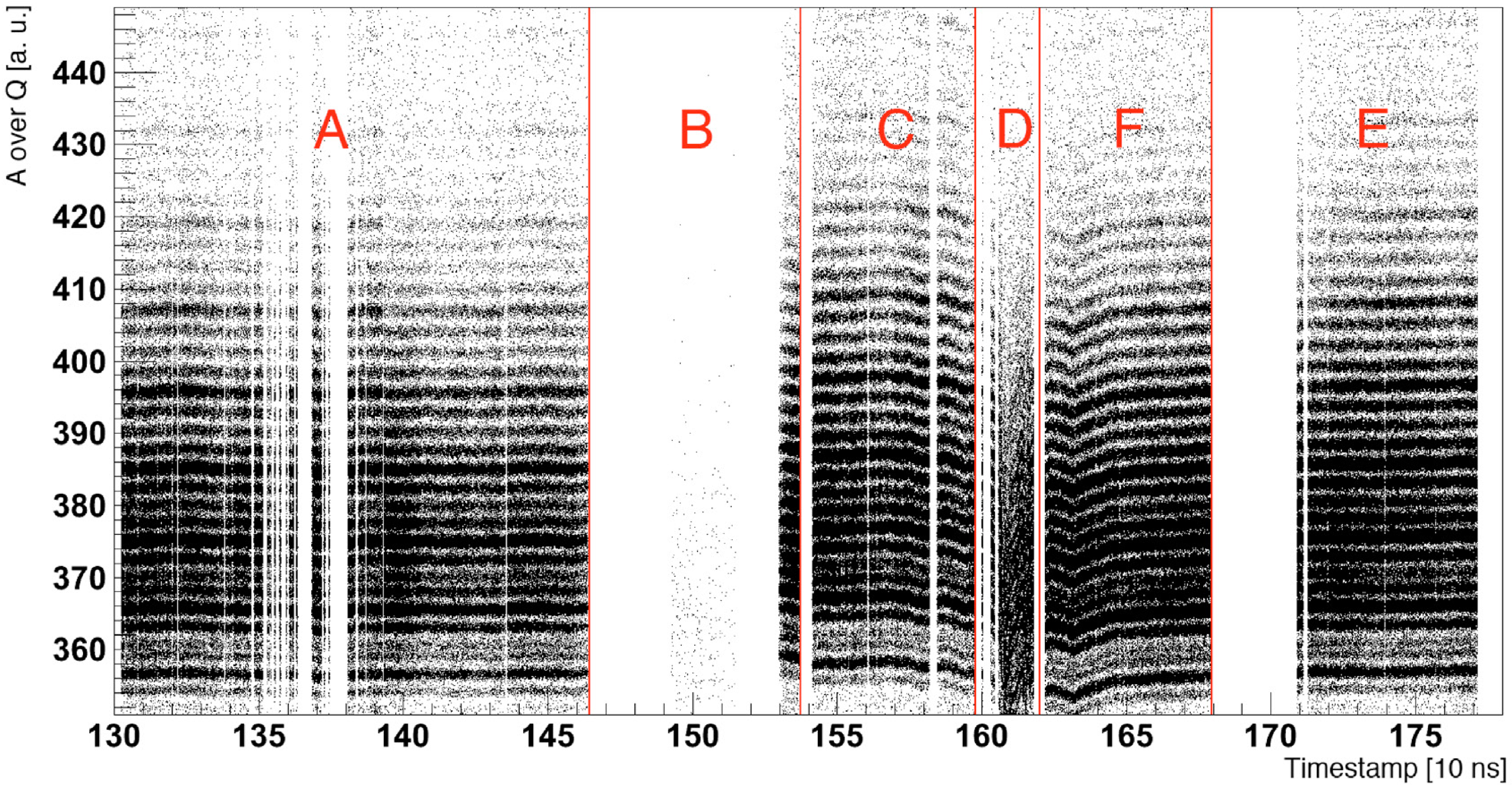
obtained by Monte-Carlo simulation based on PRISMA ray-tracing code

$$\frac{d\sigma}{d\Omega}_{\mathrm{GRAZING}} = f(E,\theta,\phi) \times \frac{d\sigma}{d\Omega}_{\mathrm{measured}}$$



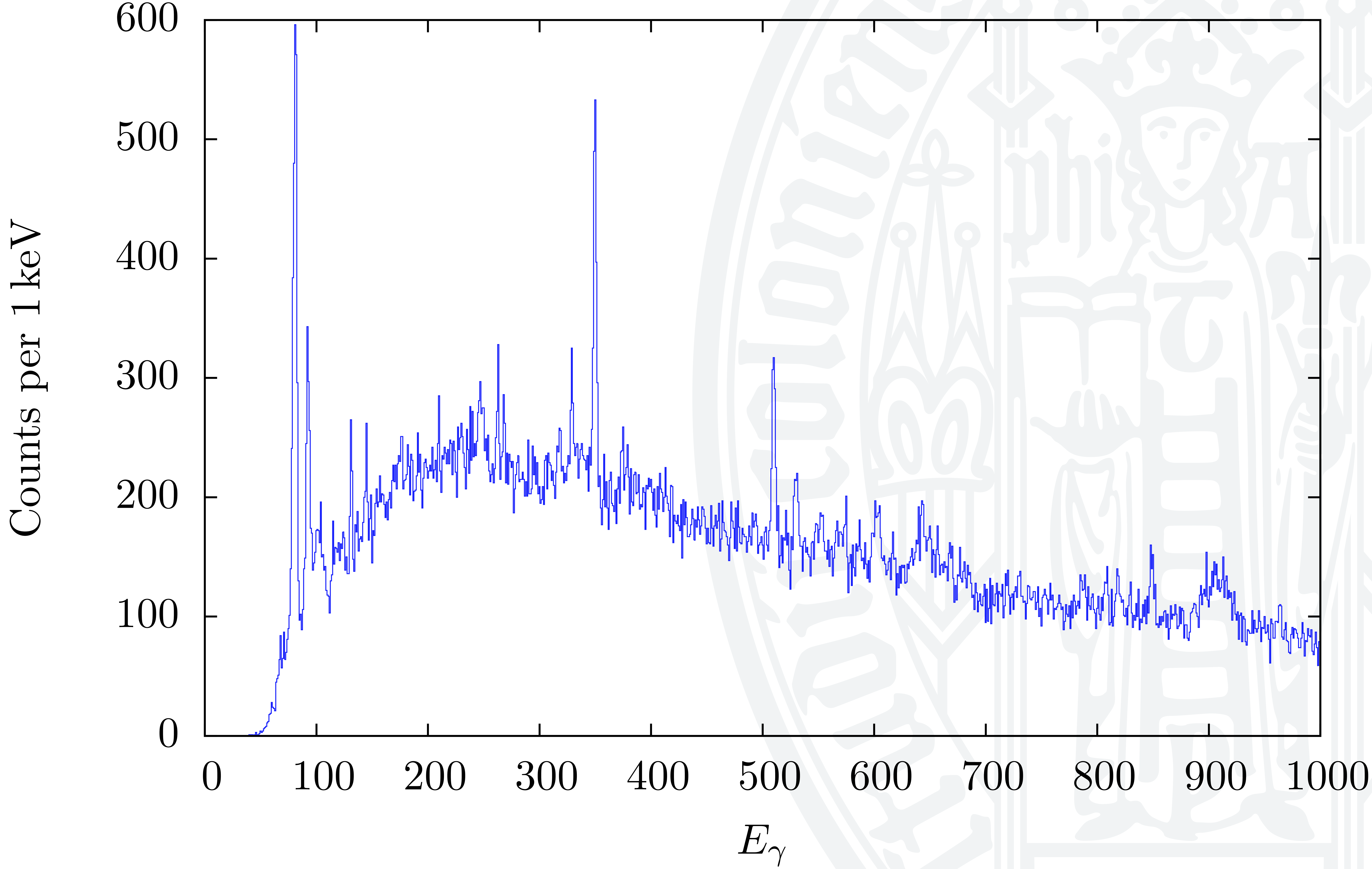


Time dependence of analysis

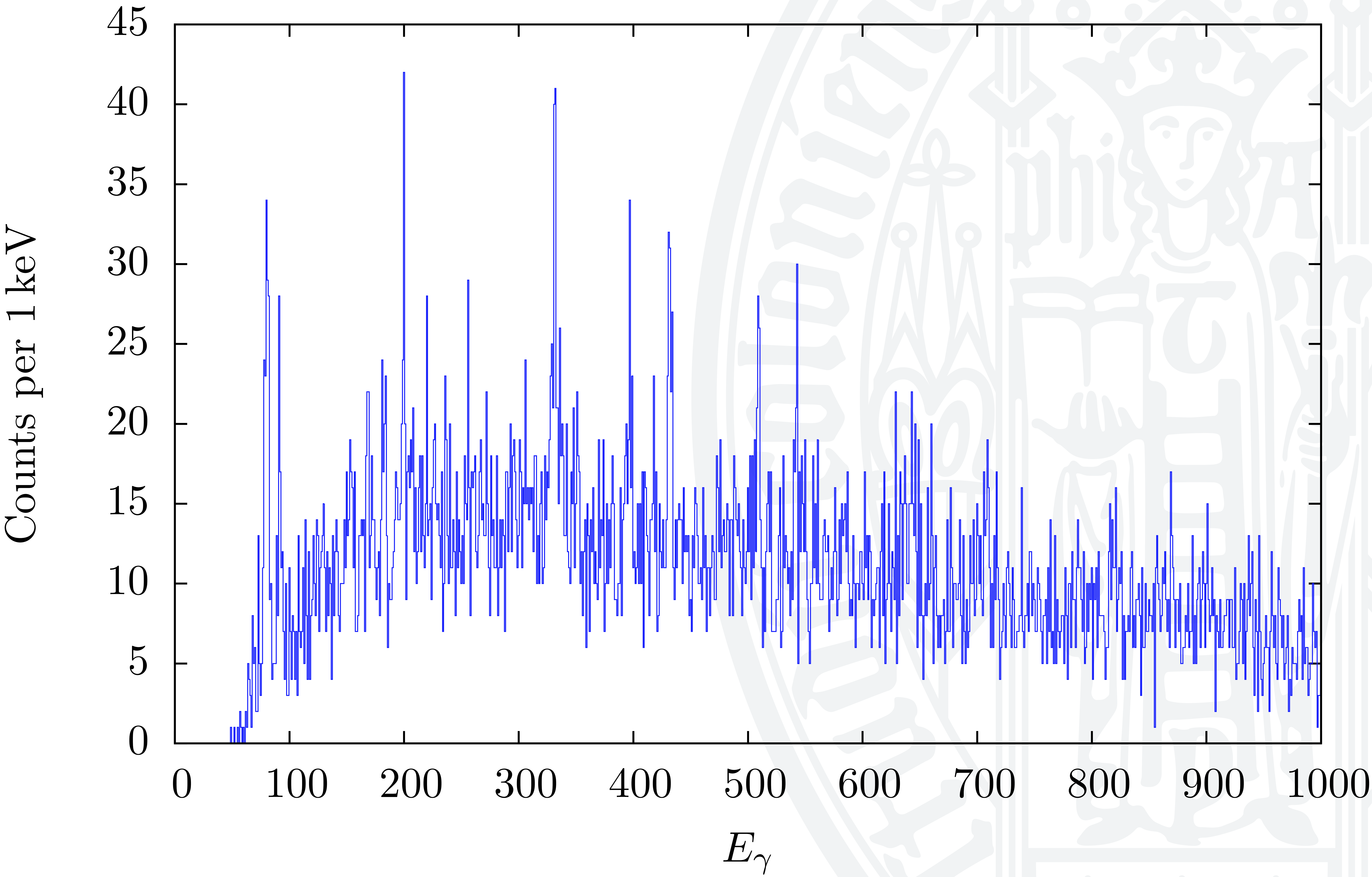


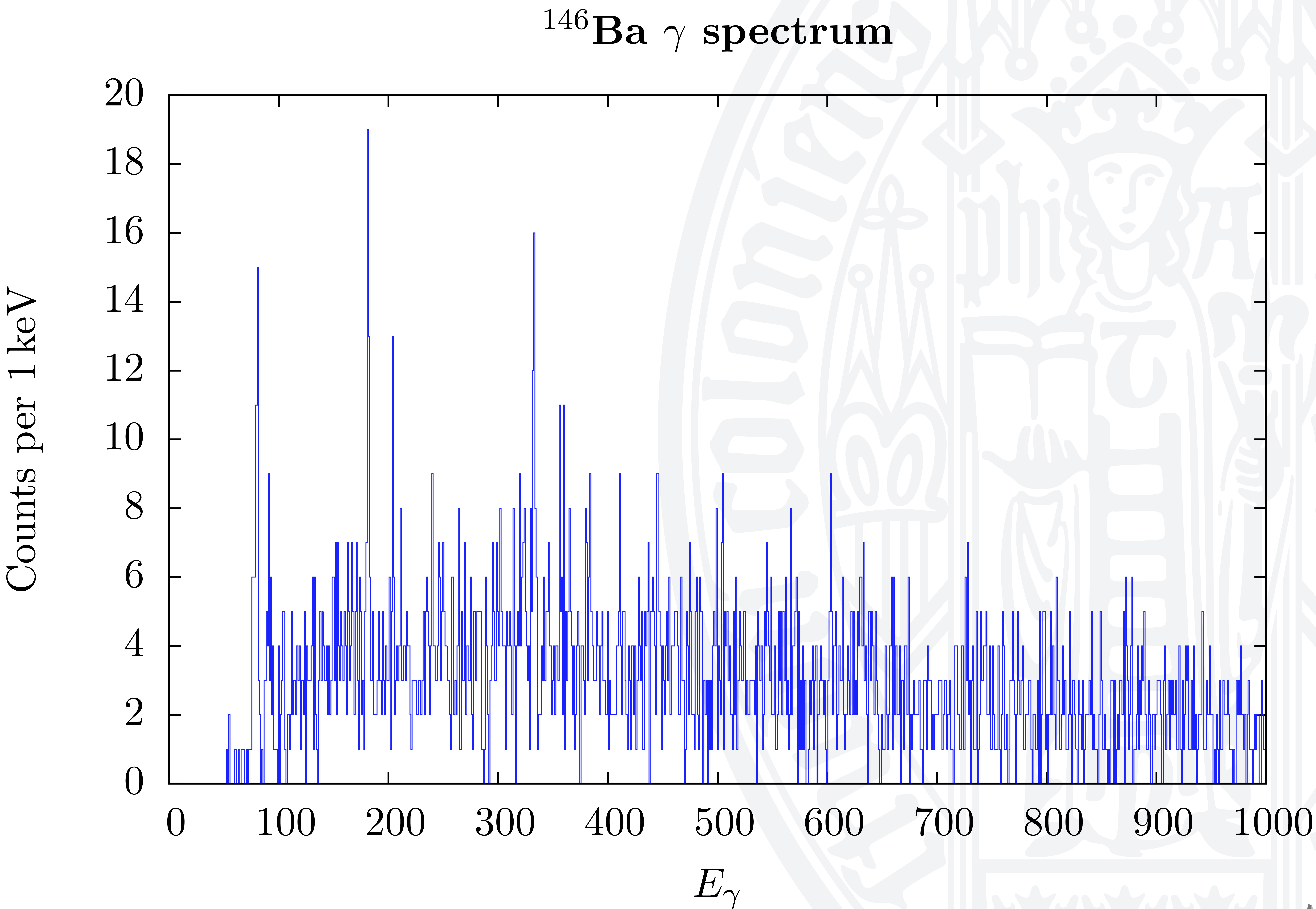
A / Q for one TAC of the MWPPAC against Ancillary Time Stamp

^{136}Ba γ spectrum



^{144}Ba γ spectrum





^{146}Ba γ spectrum
Counts per 1 keV
E_γ
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
900
1000