Spectroscopy of Light and Heavy Transfer Products in Multinucleon-Transfer Reactions

DPG-Frühjahrstagung Hadronen und Kerne - 14. März 2016

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IKP
Universität zu Köln
INFN
AGATA ADVANCED GAMMA TRACKING ARRAY
PRISMA
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Bundesministerium für Bildung und Forschung
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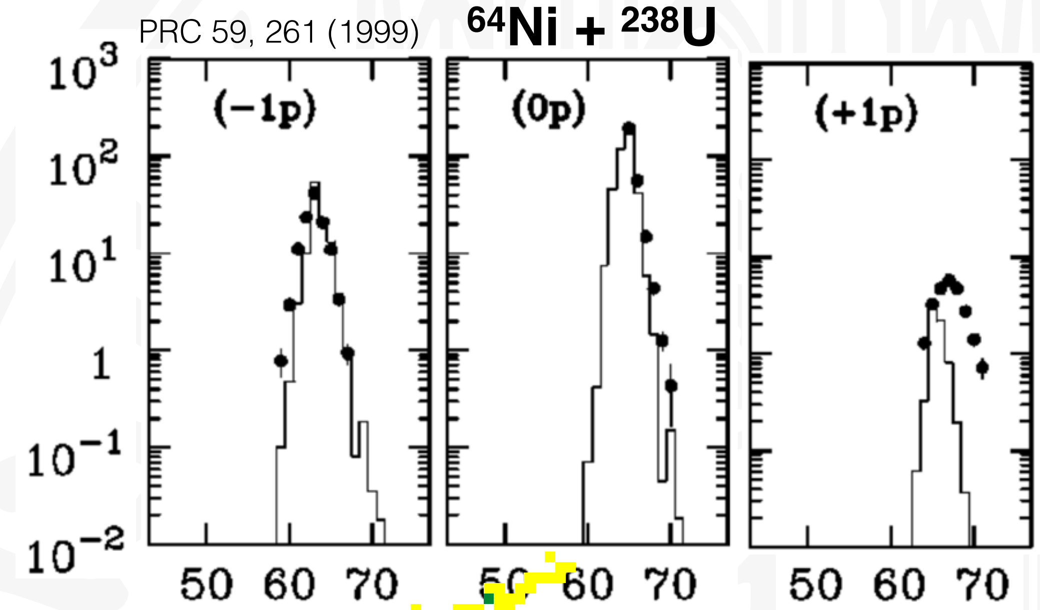
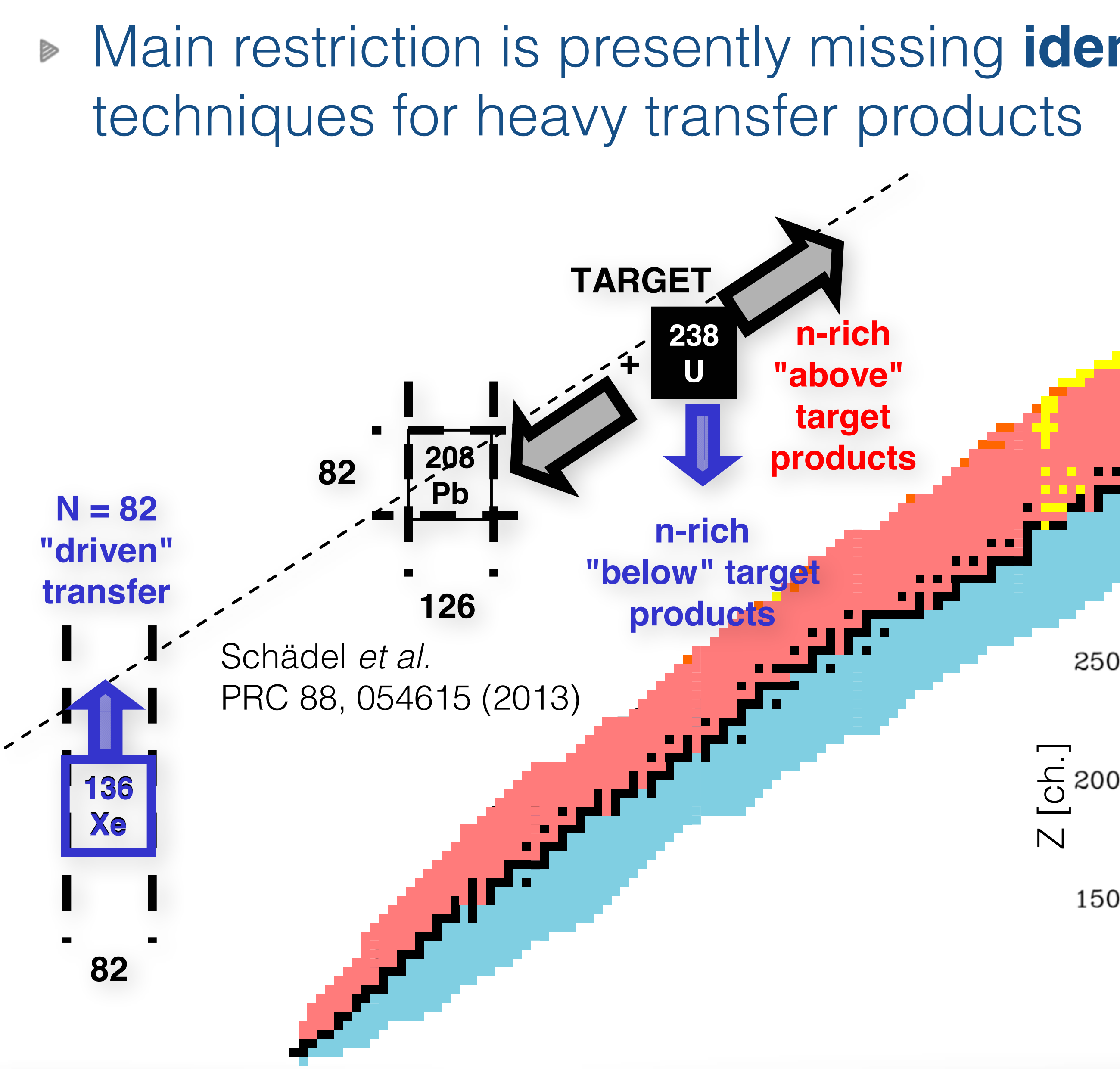
Multinucleon Transfer (MNT) in the Actinide Region

- MNT reactions are a competitive tool to populate **exotic neutron-rich nuclei**
- For each transferred neutron, cross section drops by a constant factor, ***μ*b to mb cross sections**
- **Evaporation** may strongly influence the isotopic distribution of the final fragments
- Main restriction is presently missing **identification** techniques for heavy transfer products

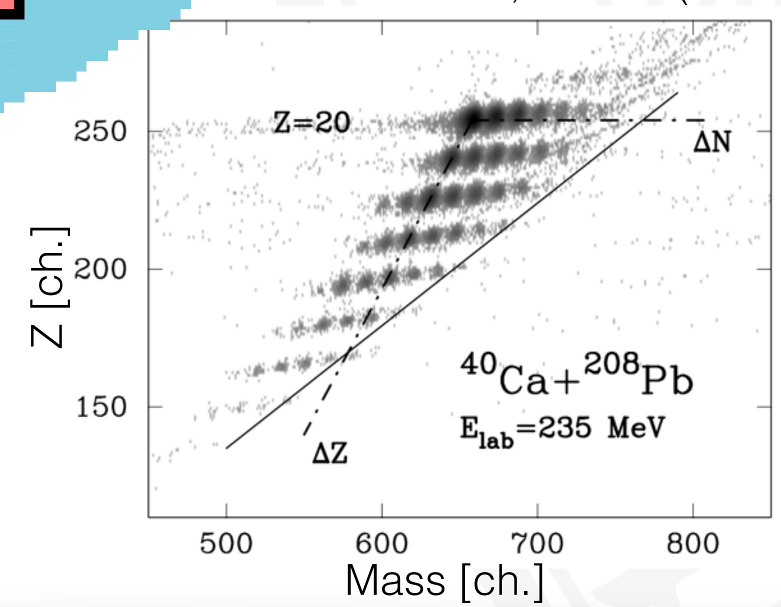




Binary character with characteristic grazing angles.

Population in the (N,Z) plane is dictated by the Q_{opt}

Szilner *et al.* PRC 71, 044610 (2005)



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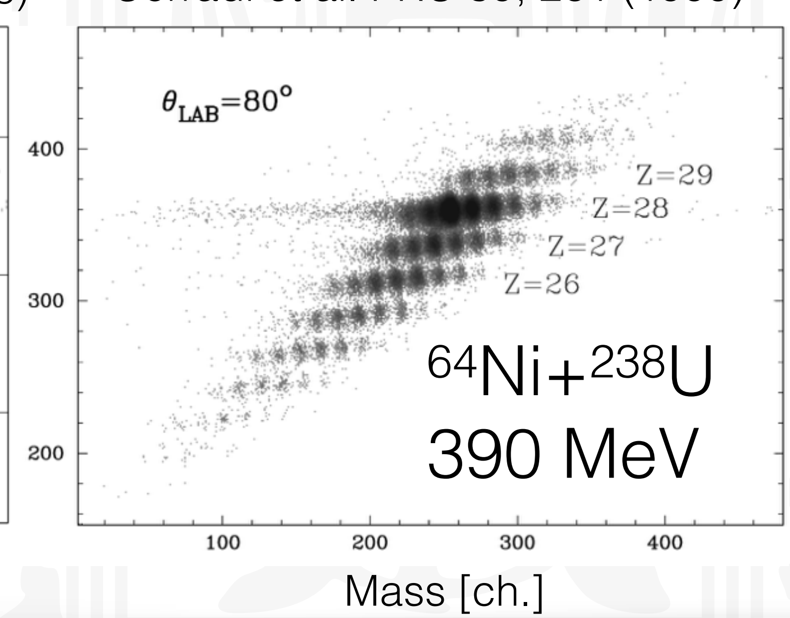

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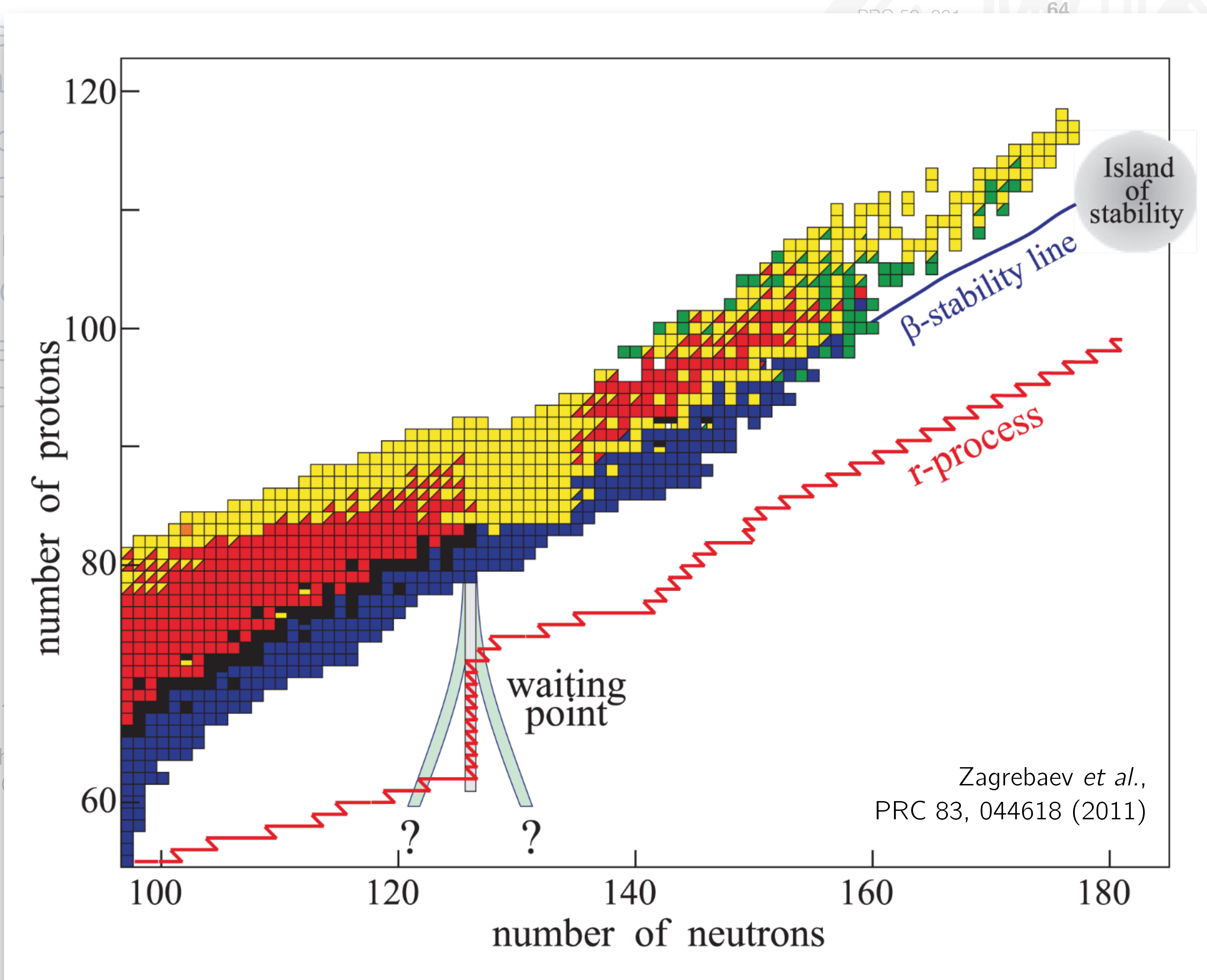

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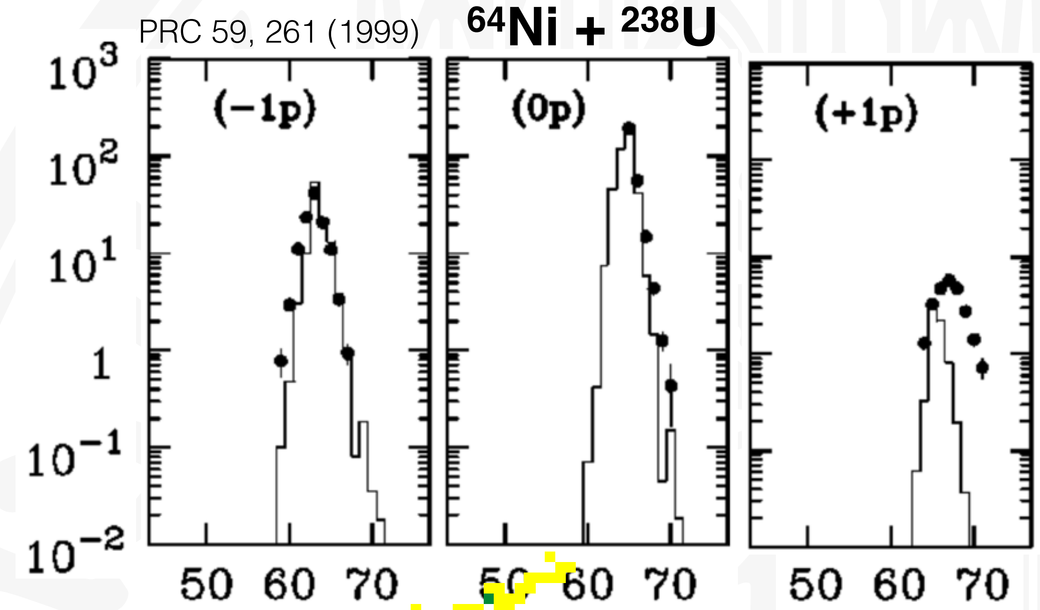

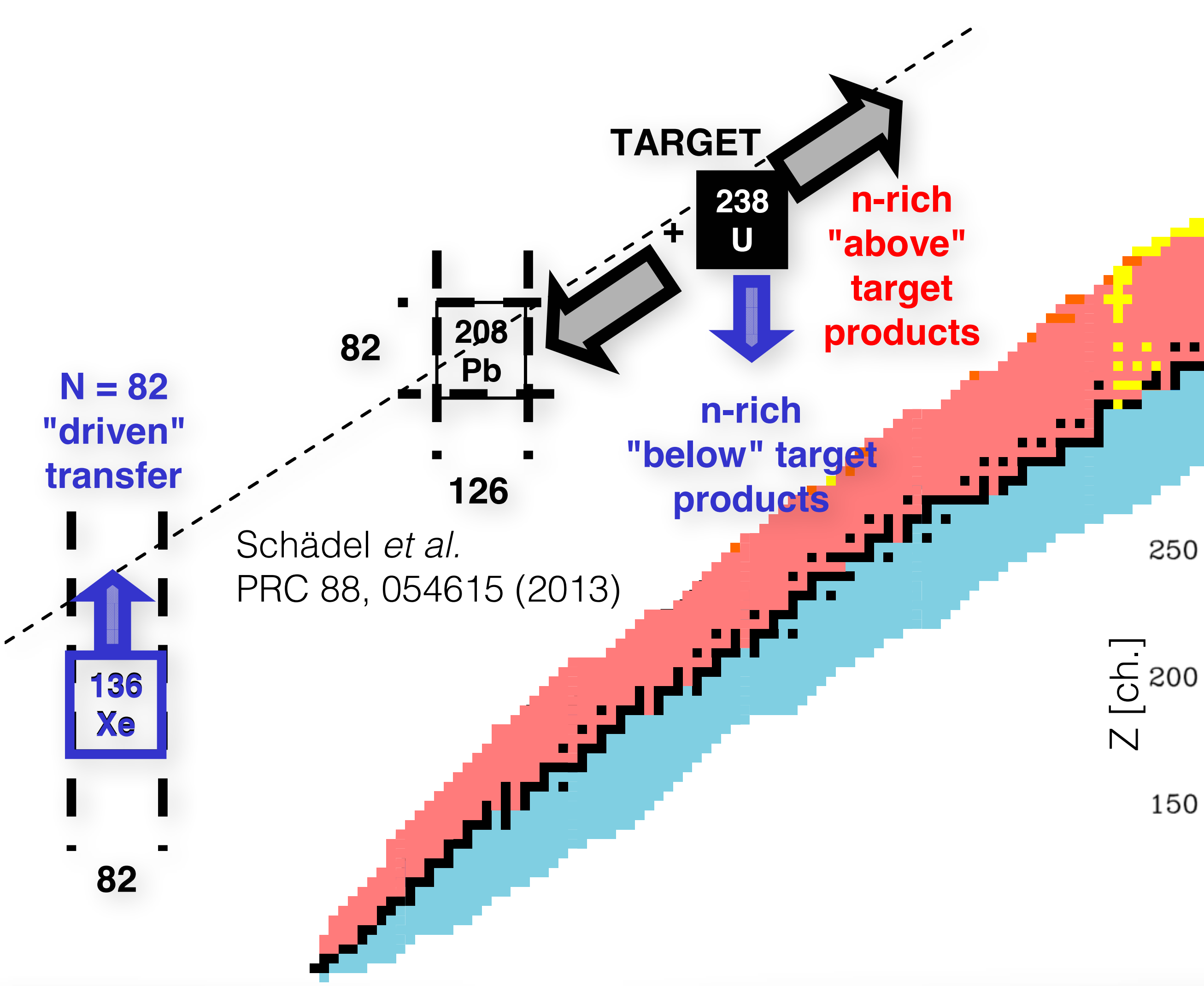

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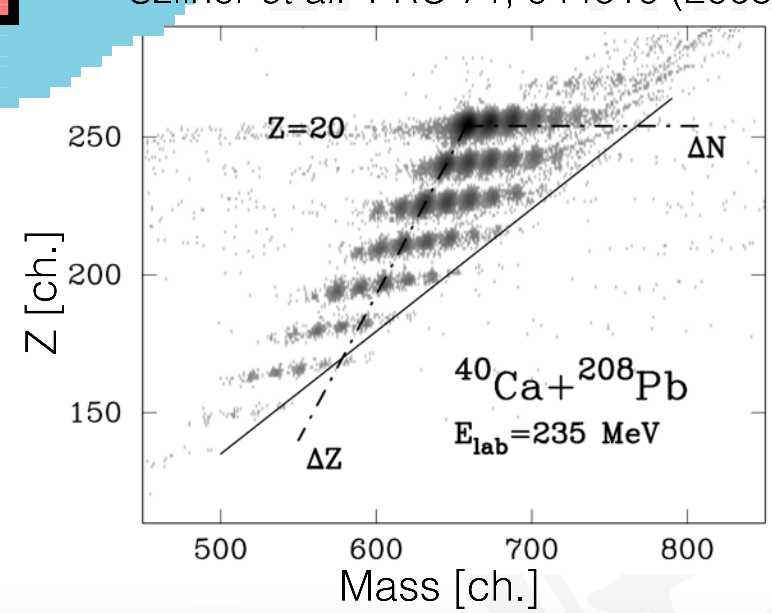

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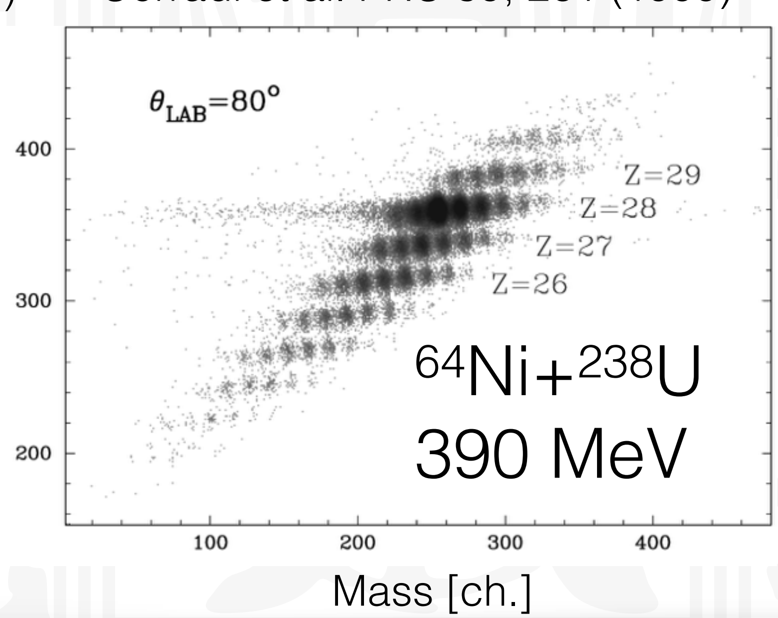


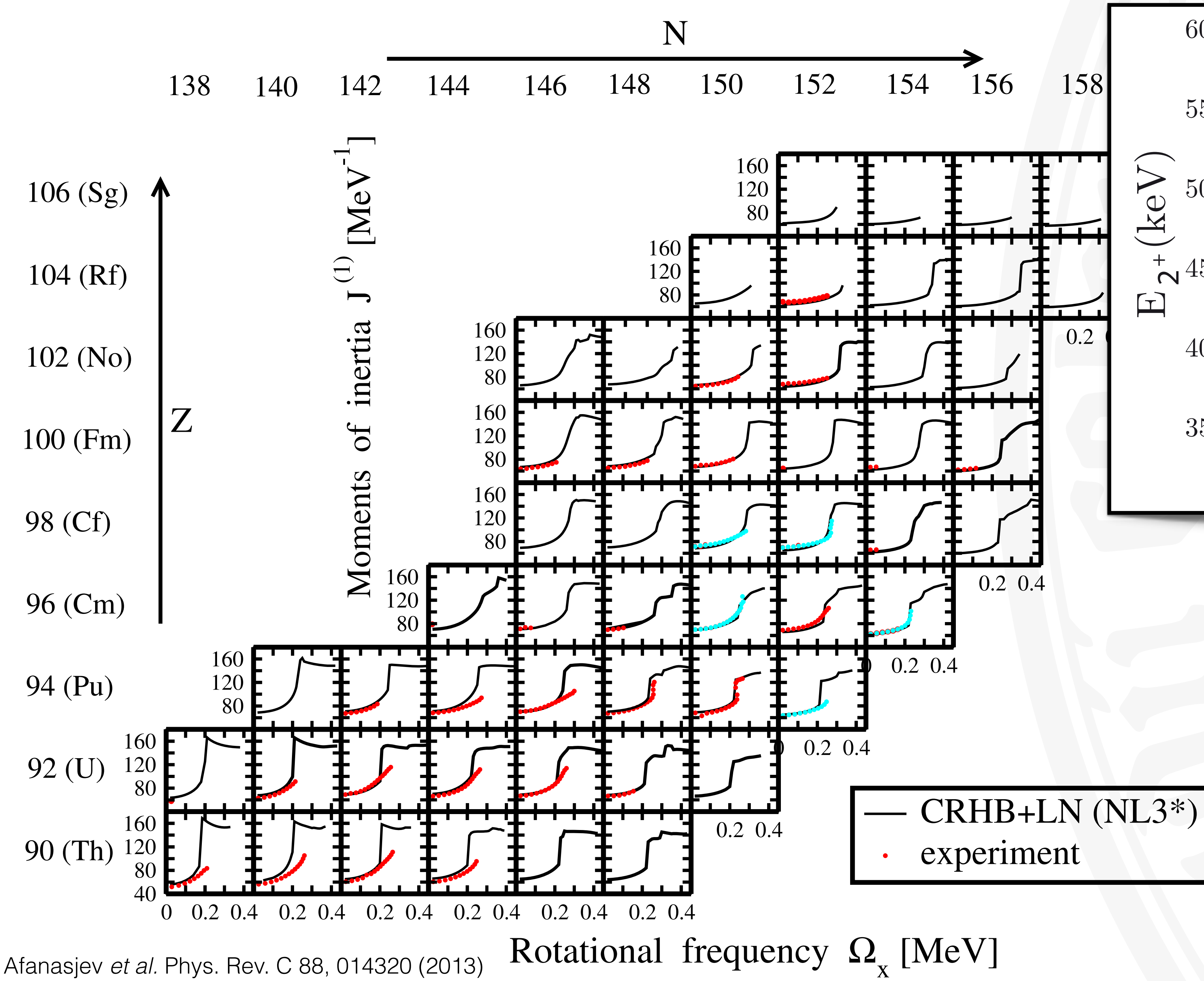
Theoretical Predictions for the Actinide Region

Mean Field Calculations
Delaroche *et al.*
Nucl. Phys. A 771 (2006)

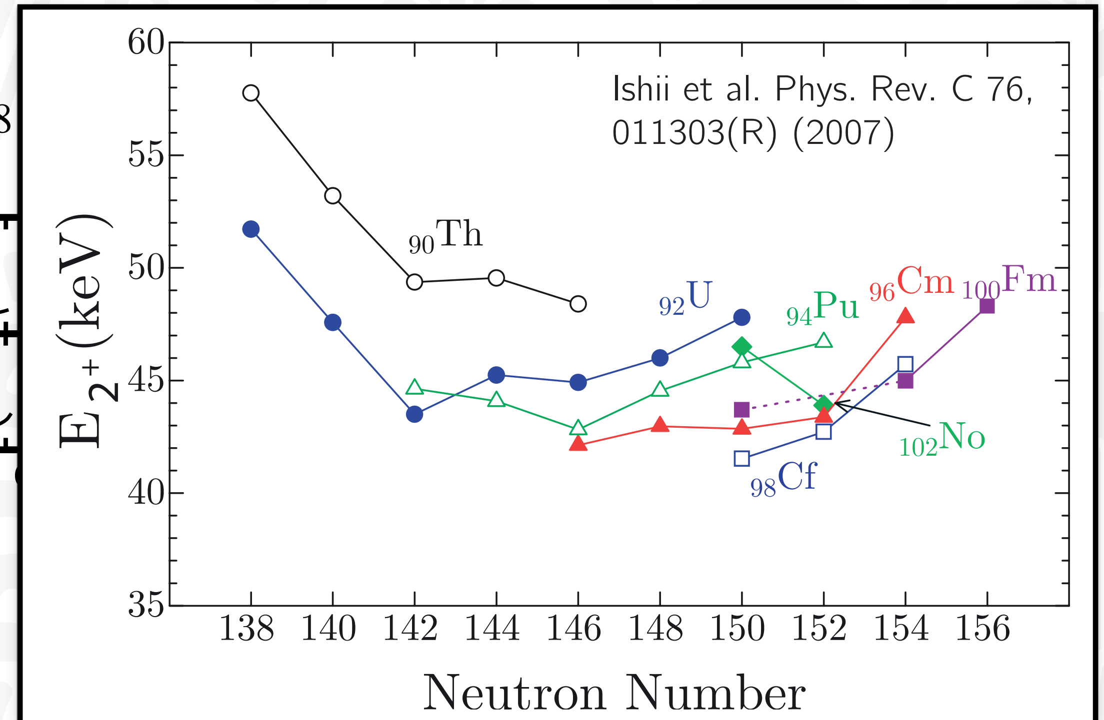
Macroscopic Microscopic
Nerlo-Pomorska *et al.*
Phys. Rev. C 84, 044310 (2011)

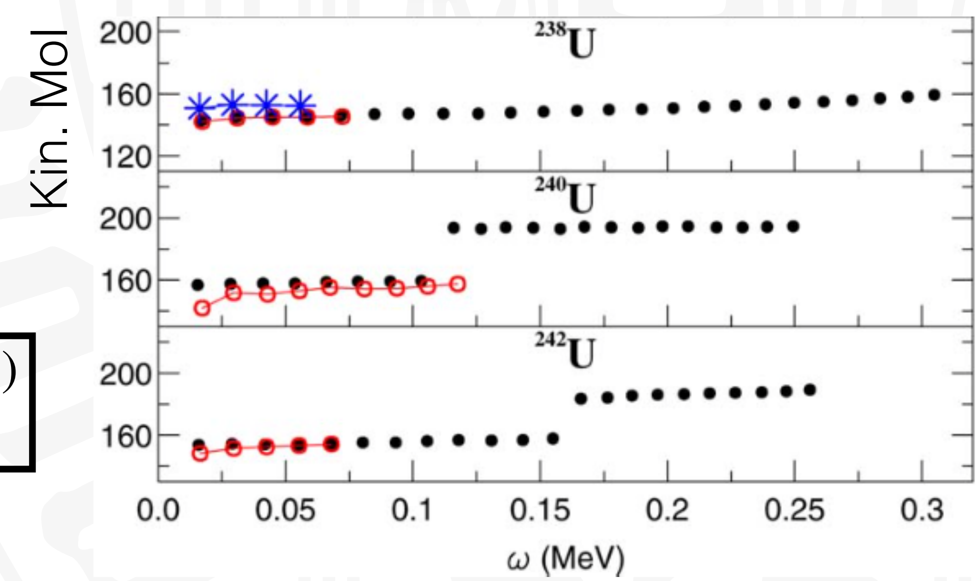
Cluster Model
Shneidman *et al.*
Phys. Rev. C 74, 034316 (2006)

Density Functionals
Afanasjev *et al.*
Phys. Rev. C 88, 014320 (2013)

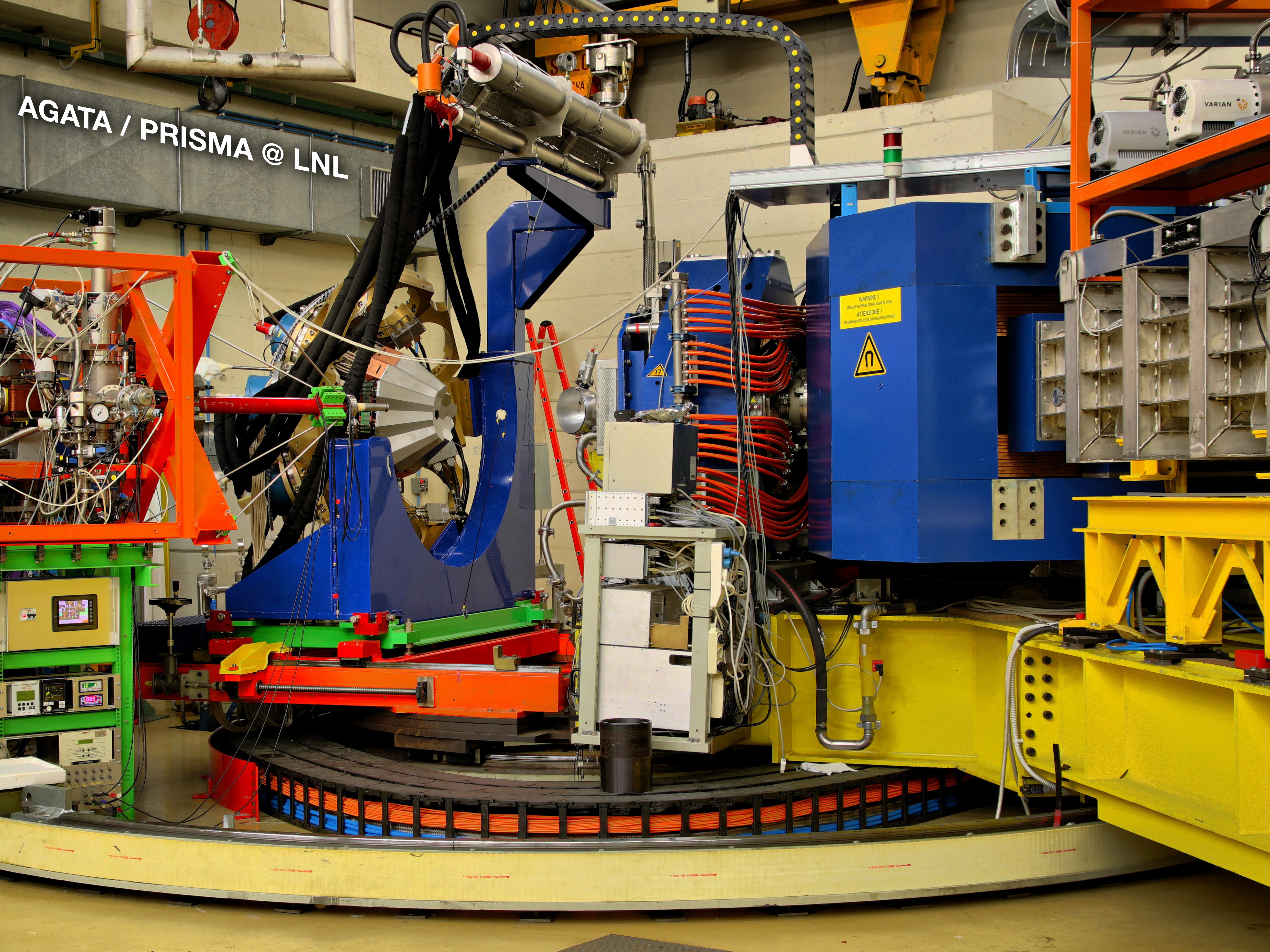


Afanasjev *et al.* Phys. Rev. C 88, 014320 (2013)

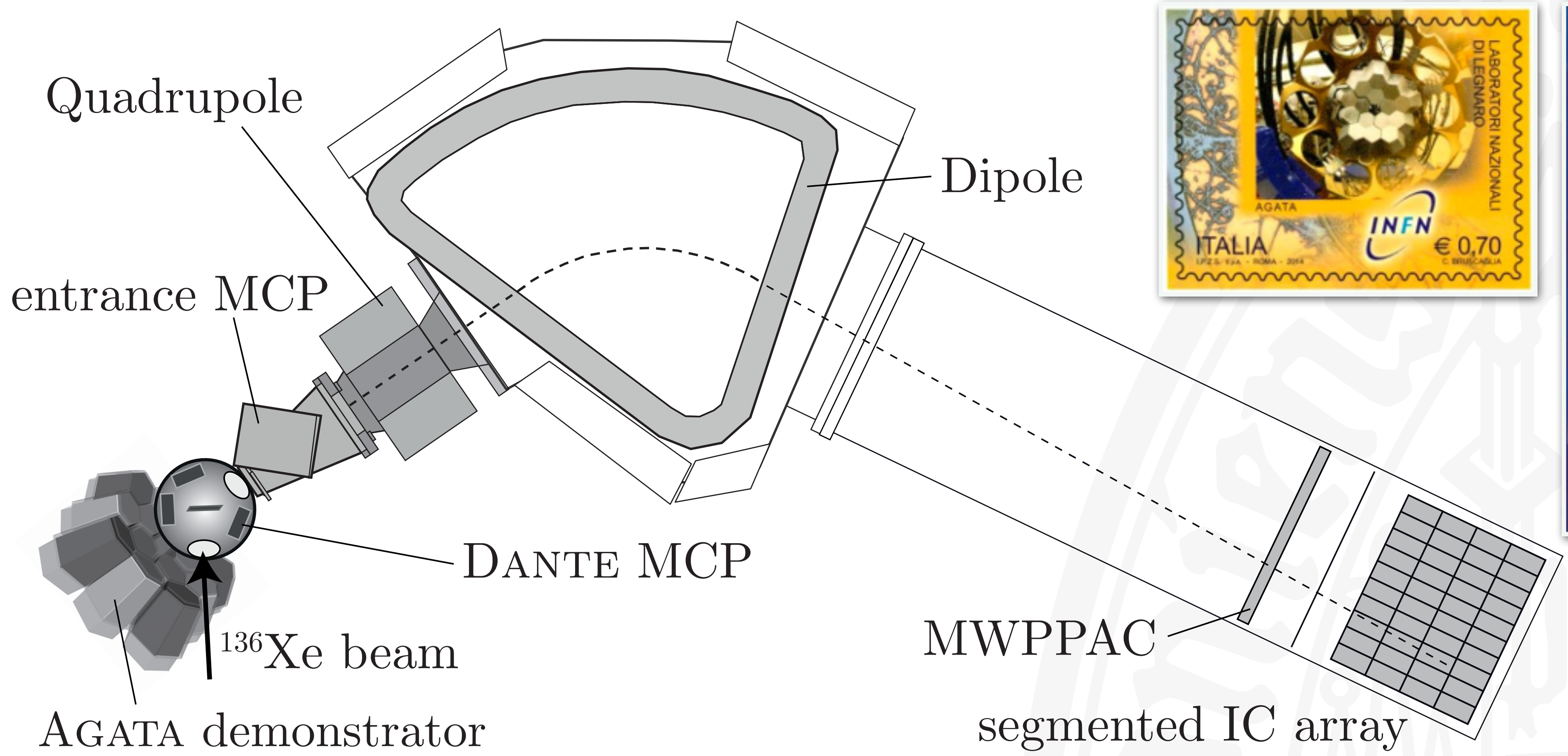


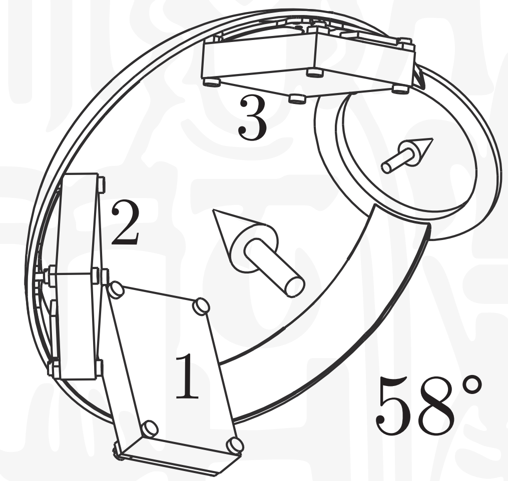


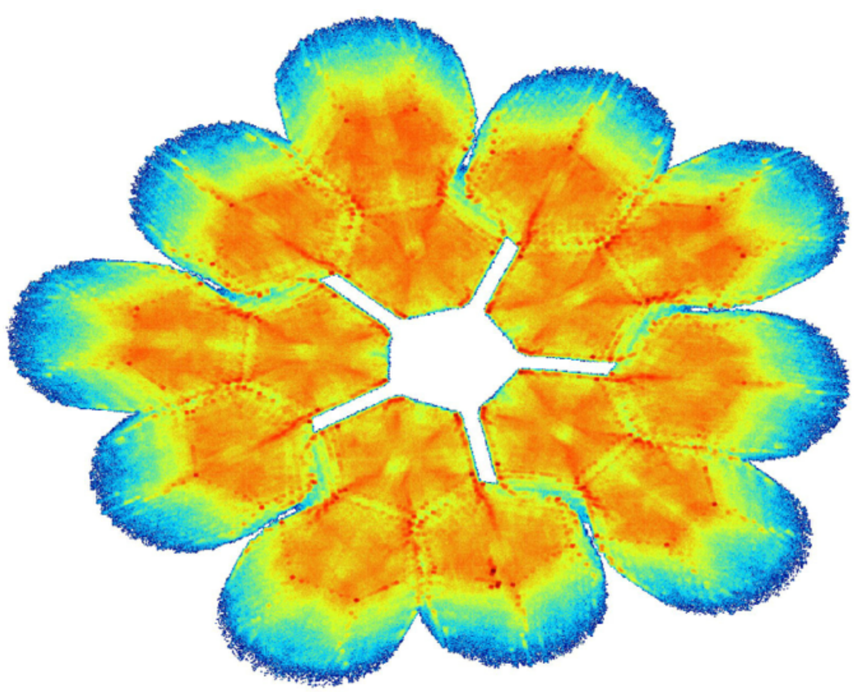
Delaroche *et al.* Nucl. Phys. A 771 (2006)

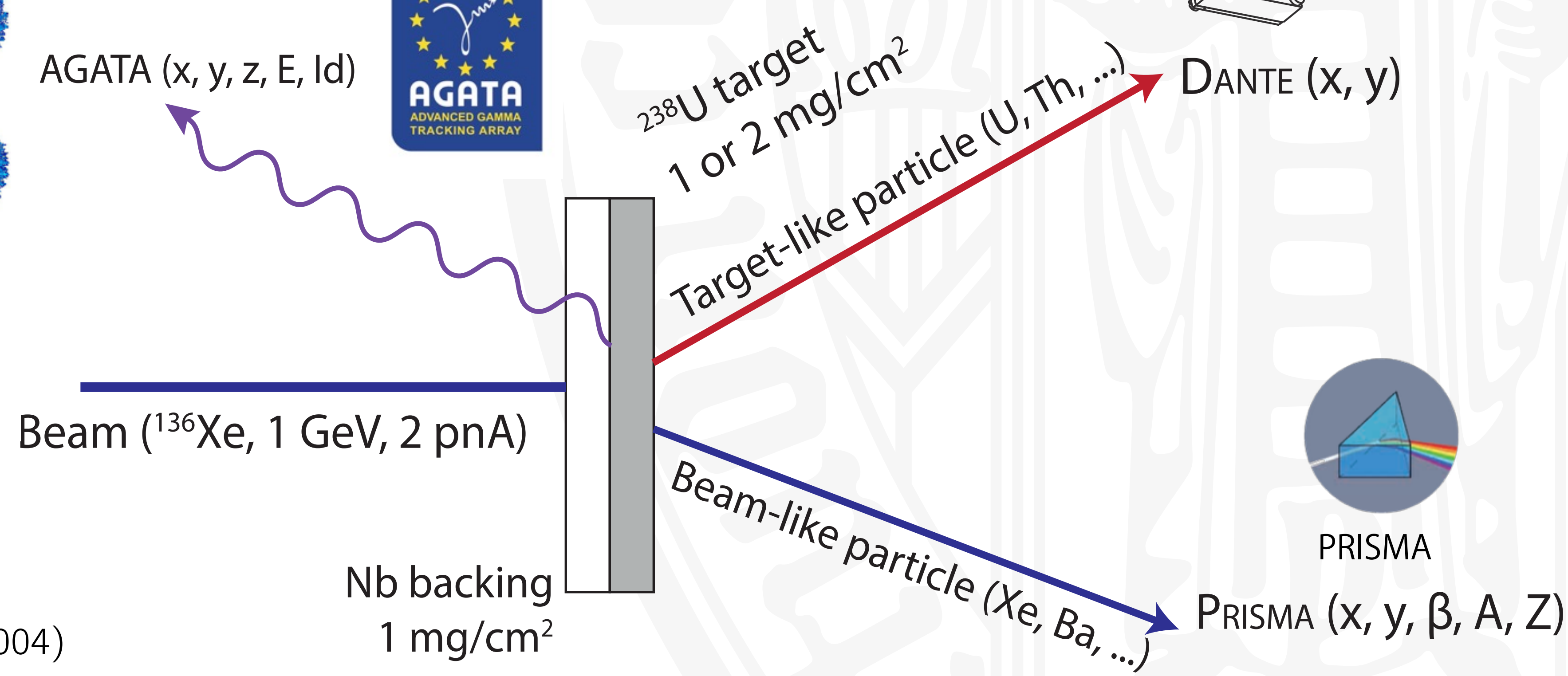

AGATA / PRISMA @ LNL
VARIAN

Setup







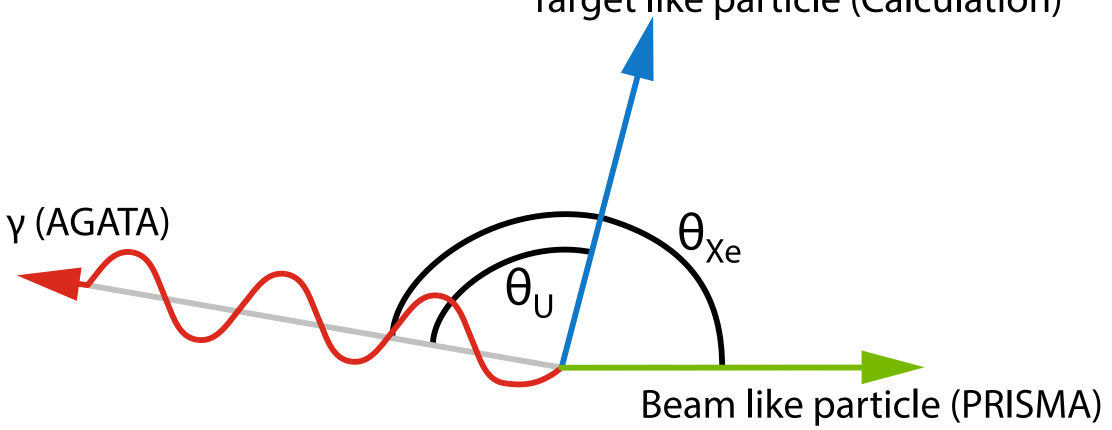


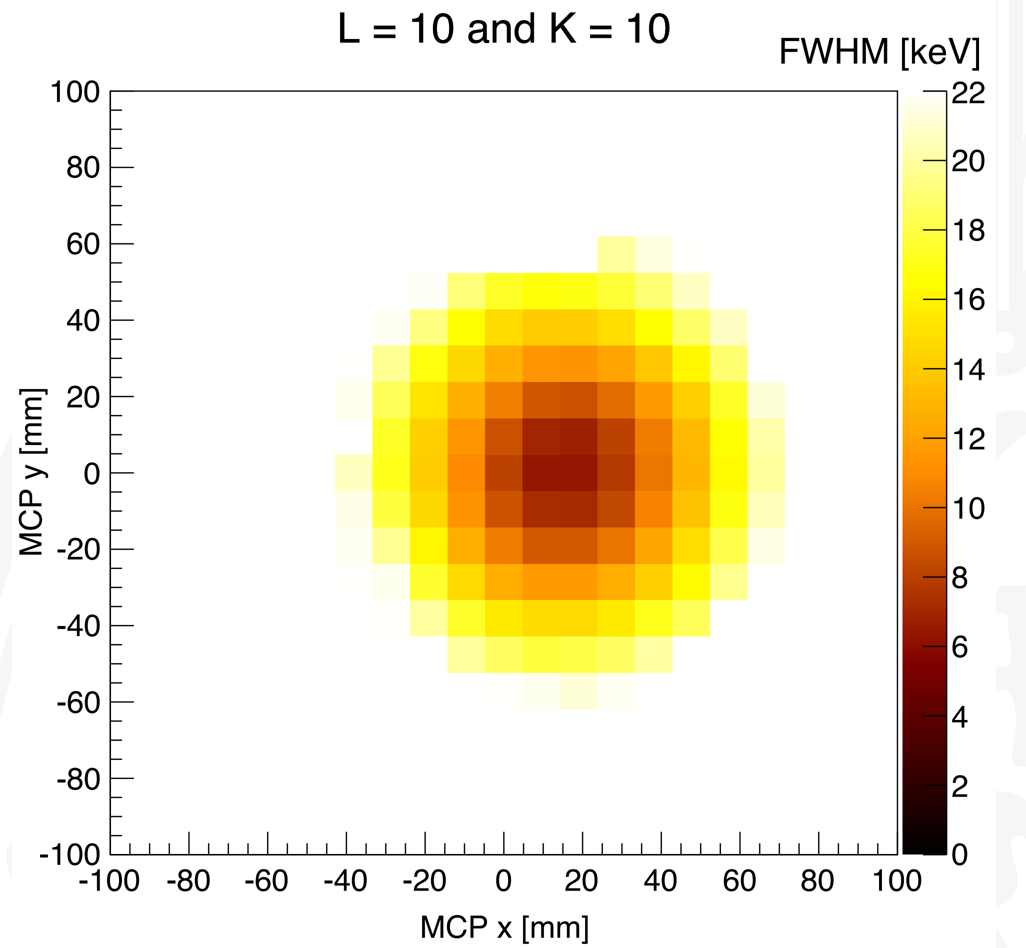
S. Akkoyun *et al.*, NIM A 668 (2012)
A. Lopez-Martens *et al.*, NIM A 533, 454 (2004)

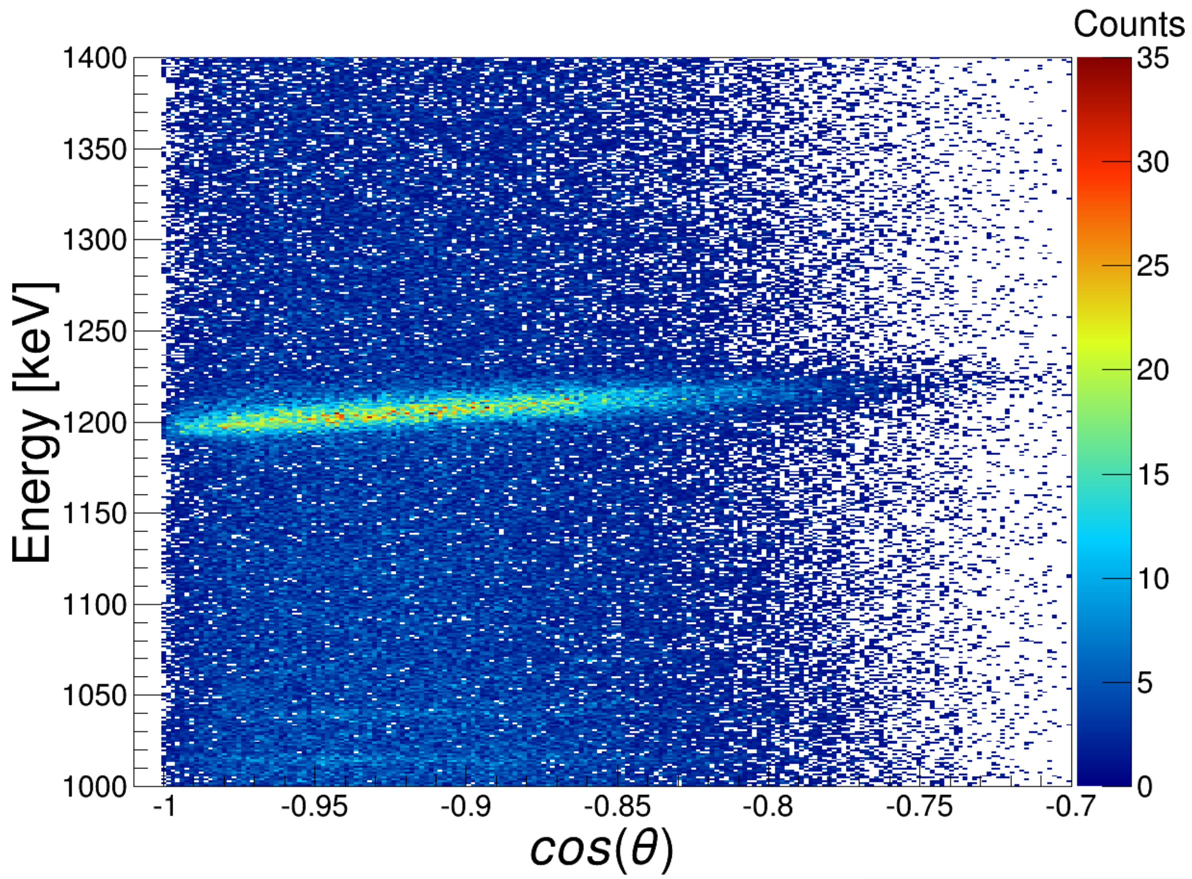
AGATA Doppler Correction

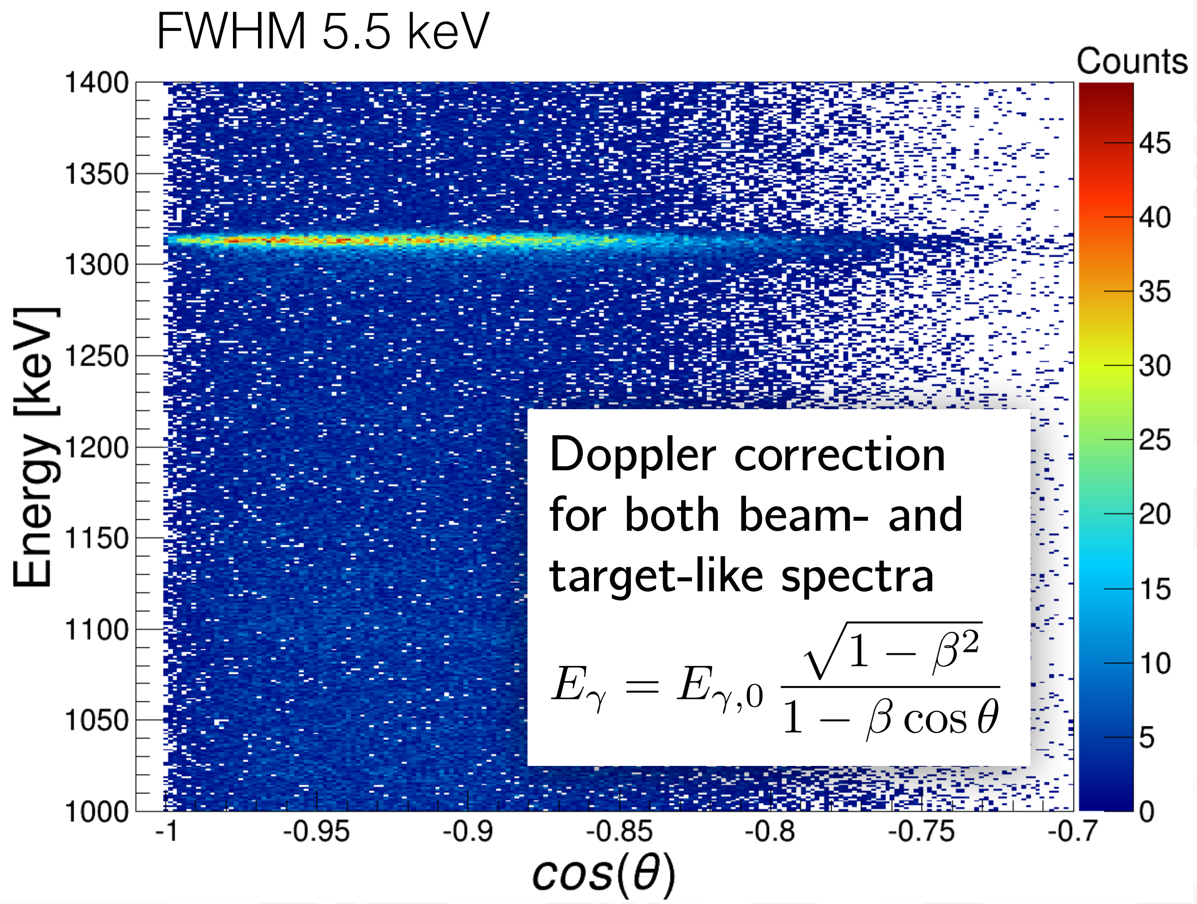
Optimization with four parameters:

- Ejectile velocity
- PRISMA (x,y) position on the entrance detector
- AGATA distance



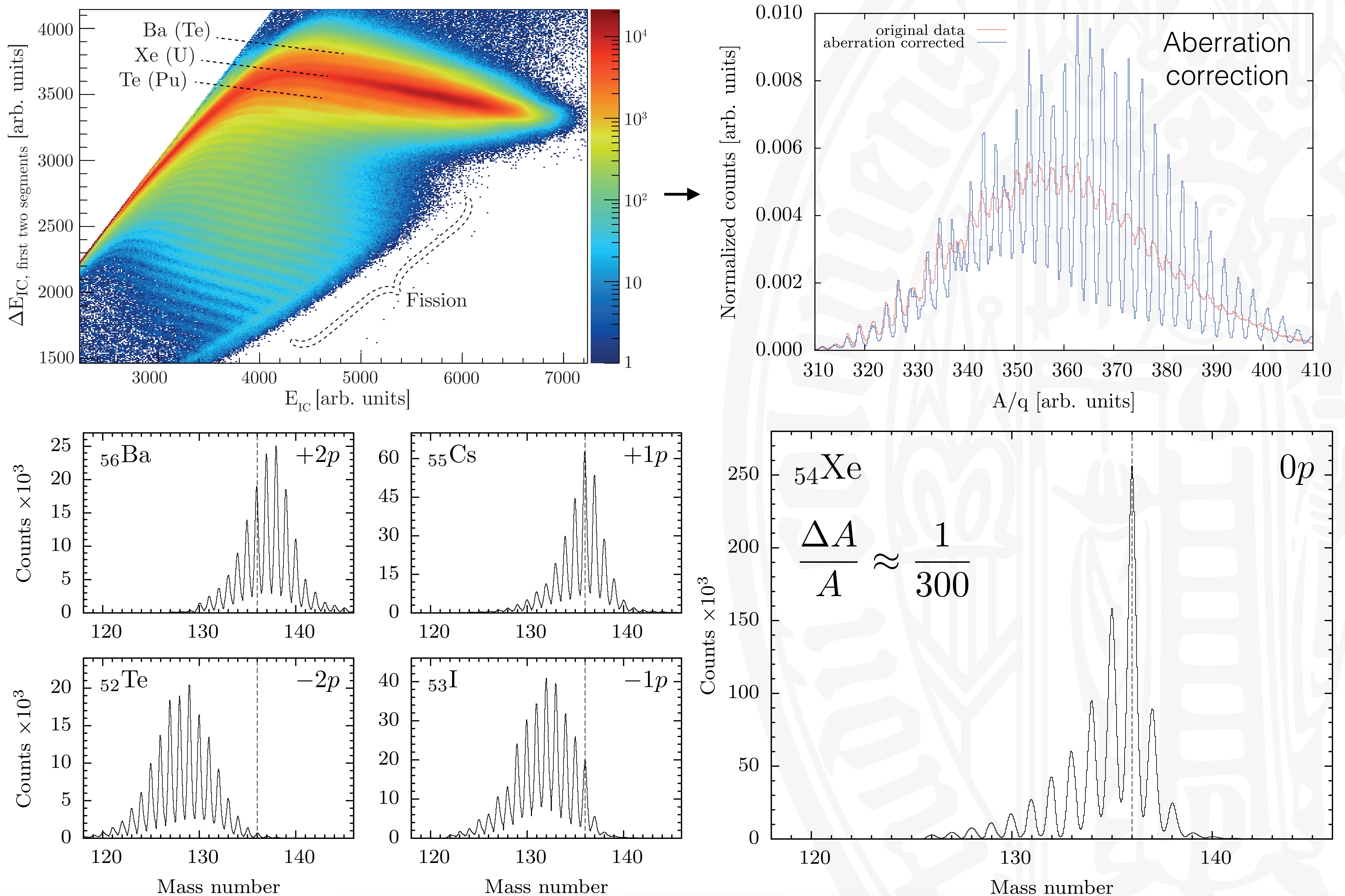




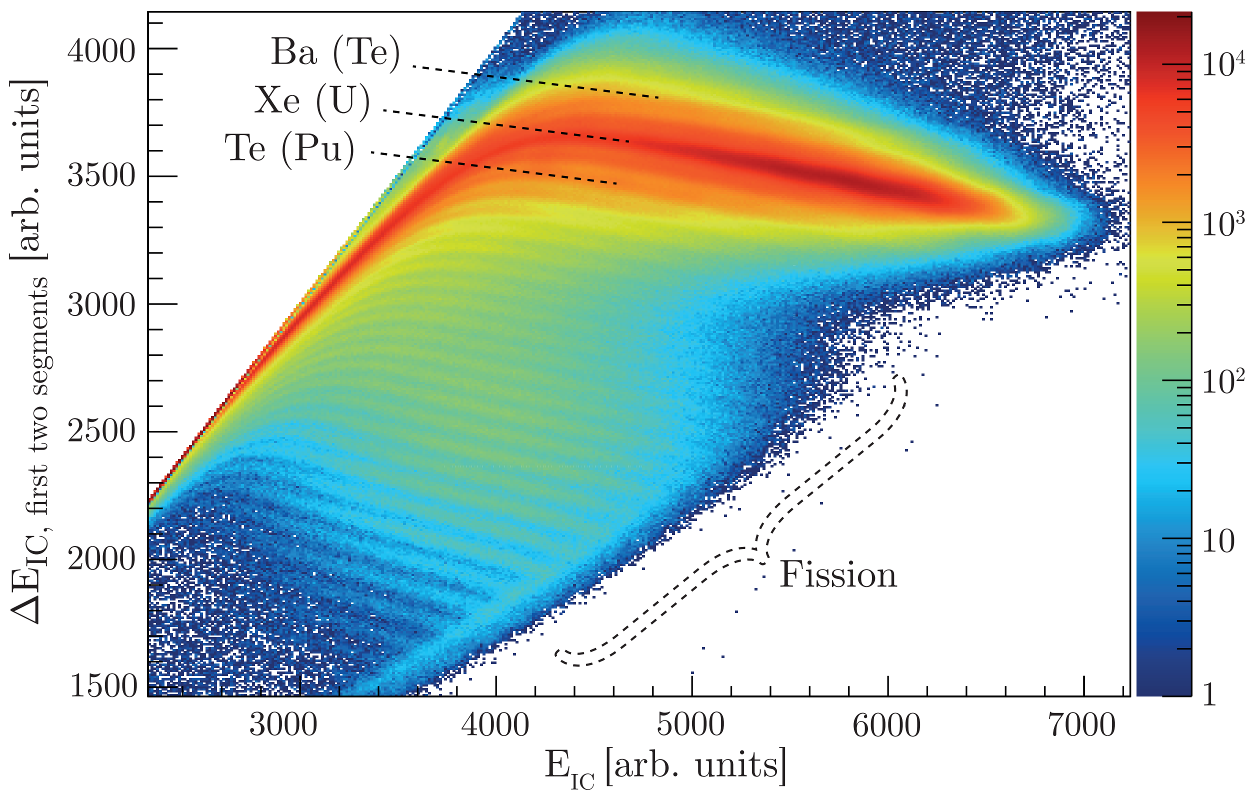


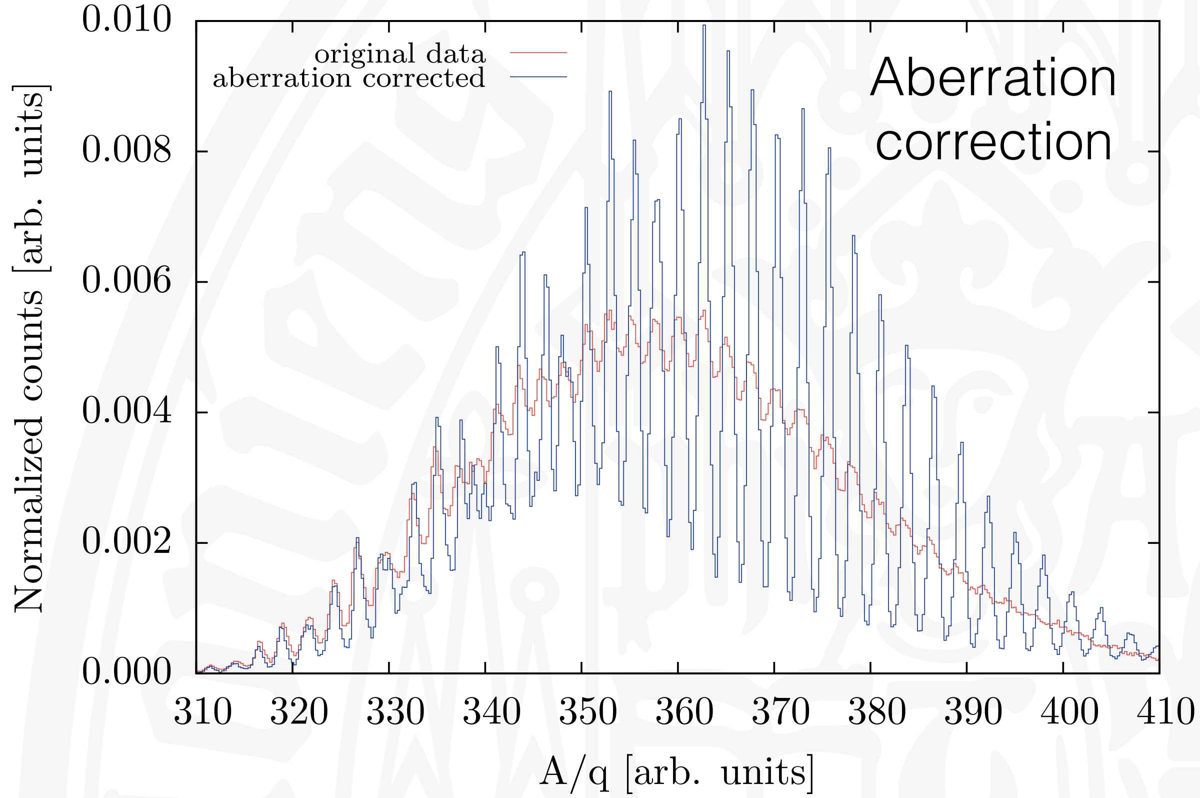
$$E_\gamma = E_{\gamma,0} \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

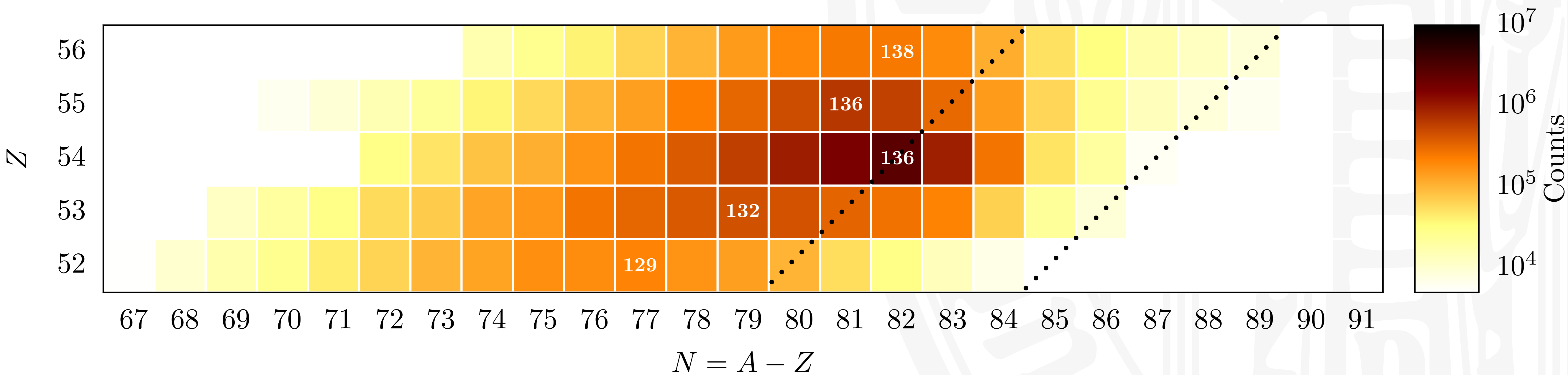
PRISMA Analysis Procedure



PRISMA Analysis Procedure



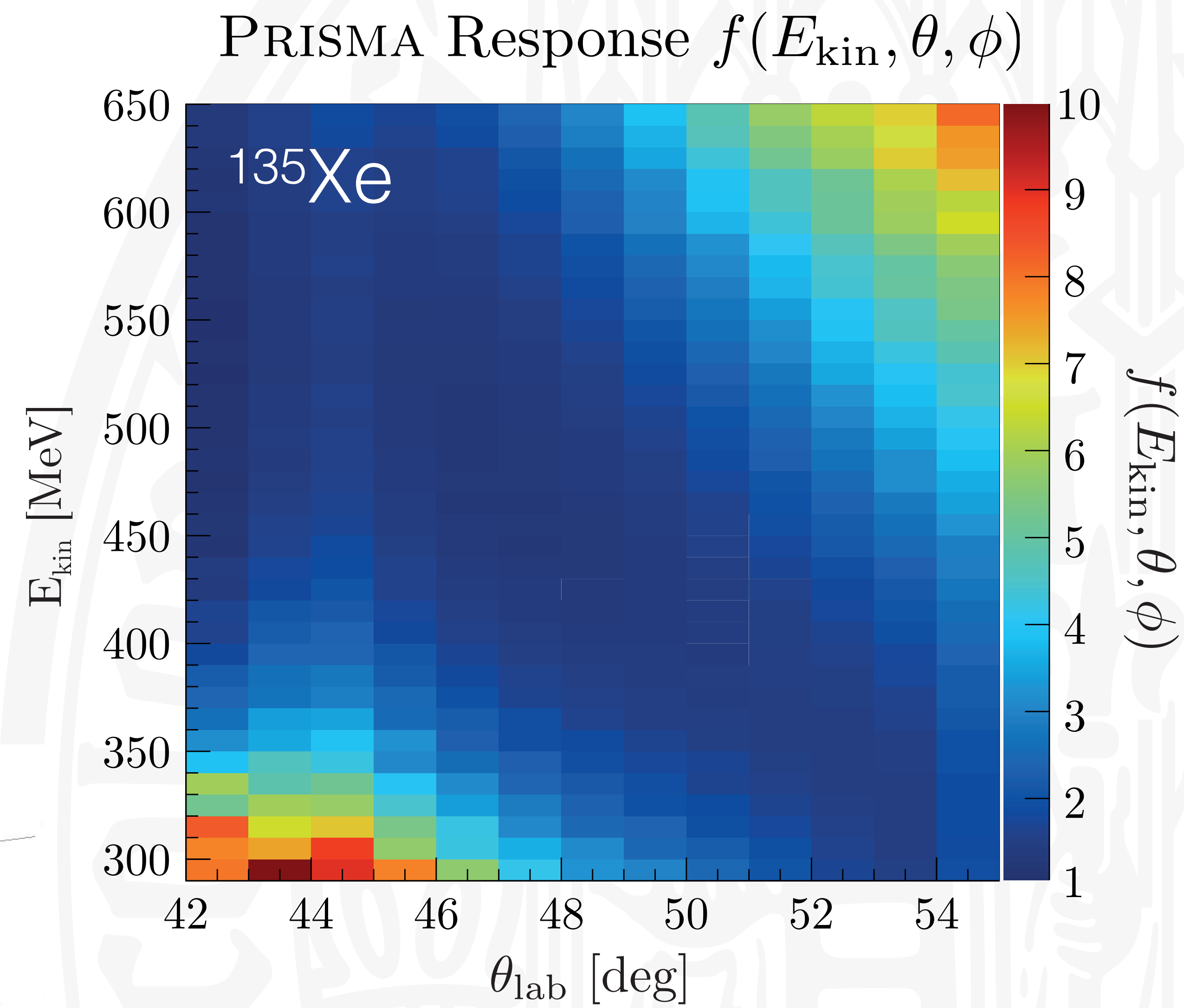


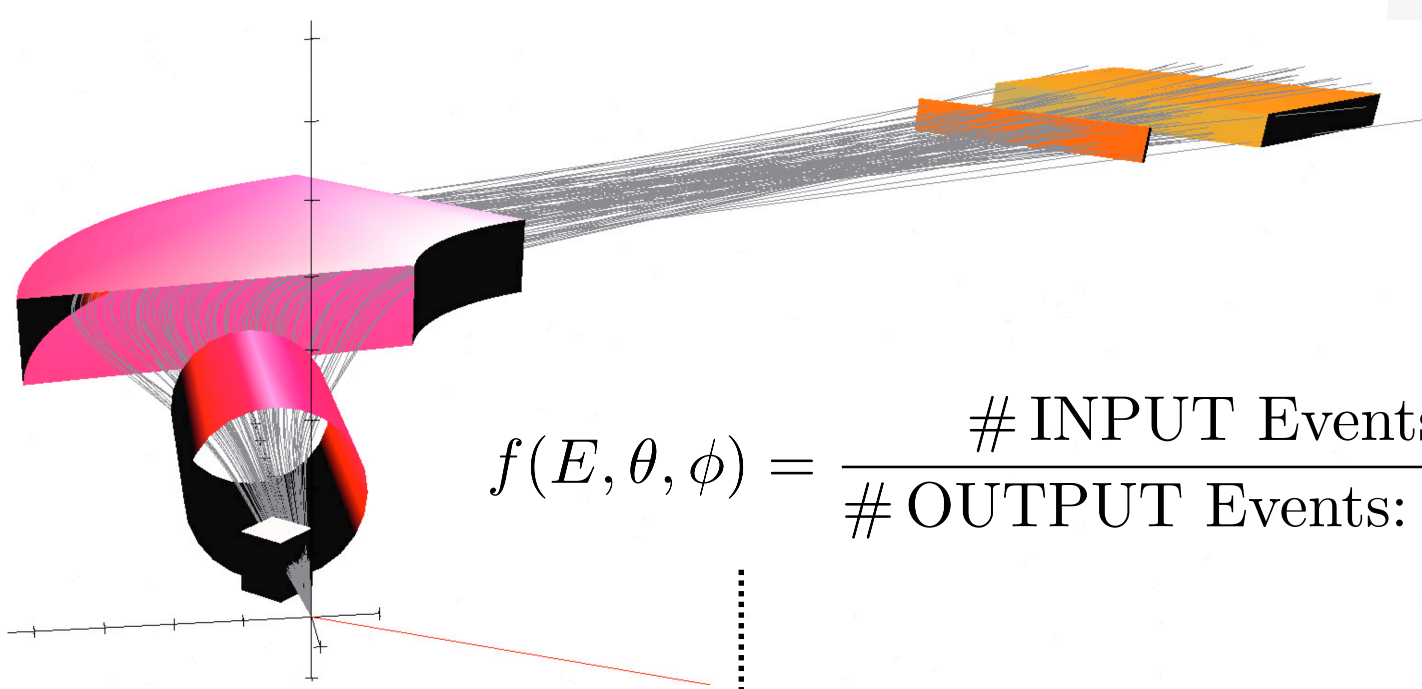


PRISMA Response Function

Transport event distribution uniform in [E,ϑ,ϕ] with Monte Carlo simulation

- ray-tracing code of PrismaLibrary
- adjust dipole and quadrupole fields to align experimental event distribution with simulation





MCP input

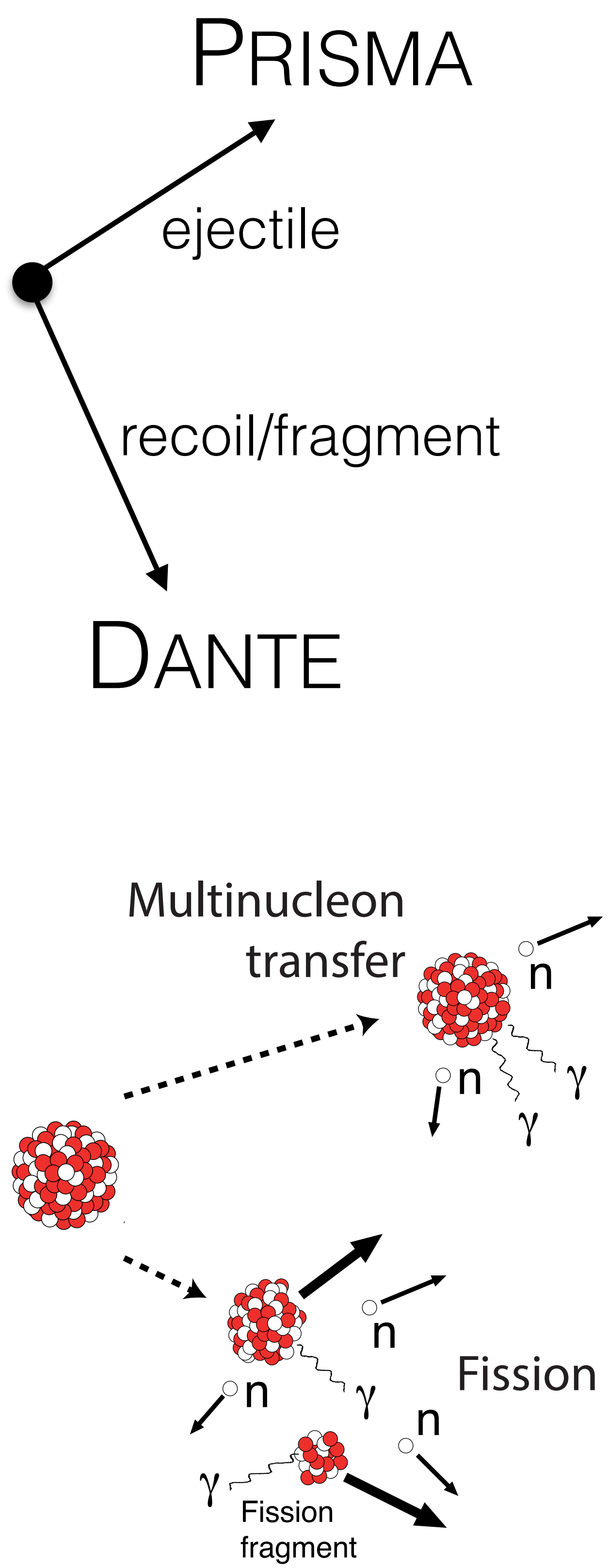
$$f(E,\theta,\phi) = \frac{\#\,\text{INPUT Events: at MCP}(E,\theta,\phi)}{\#\,\text{OUTPUT Events: at Focal Plane}(E,\theta,\phi)}$$

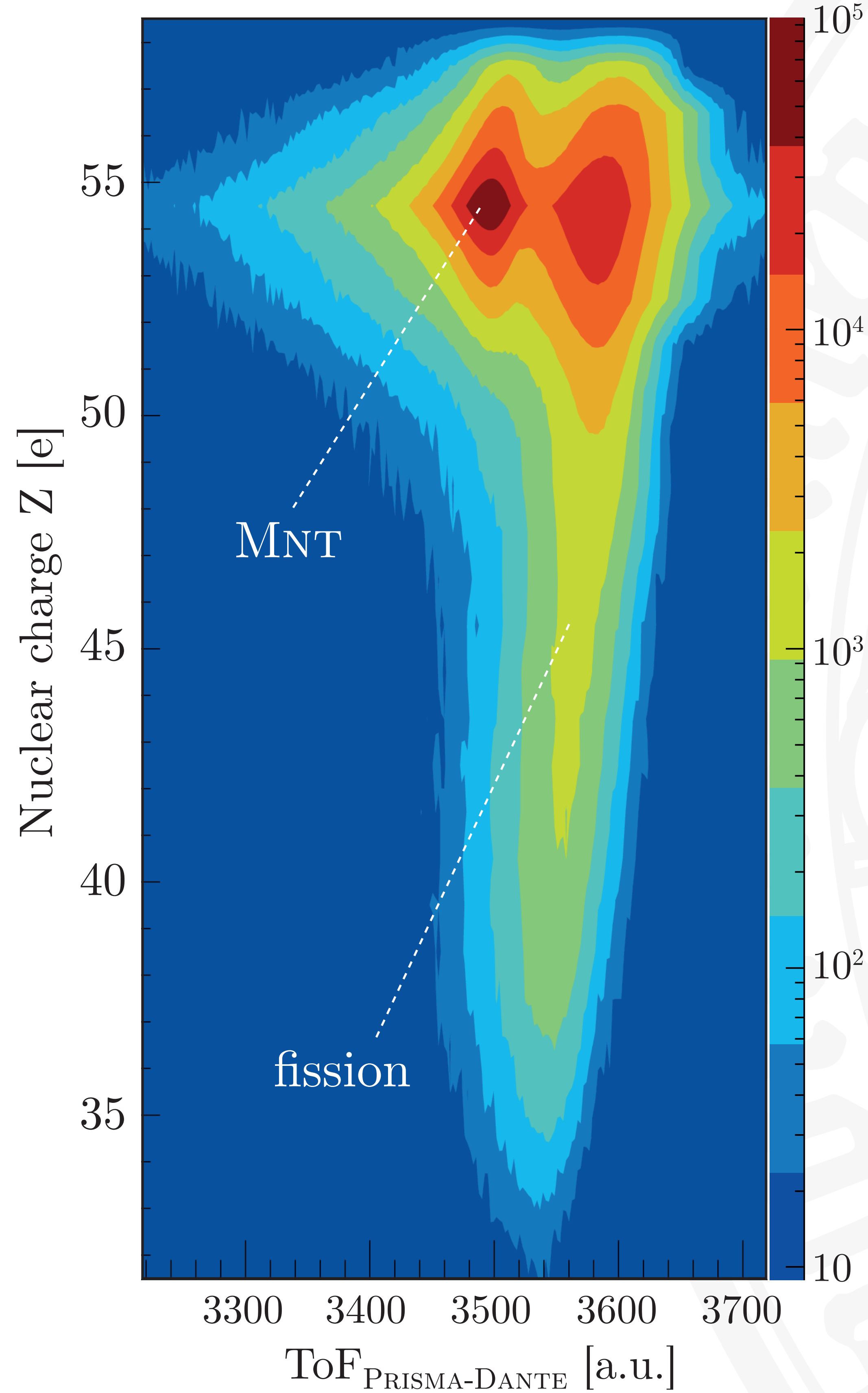
transported to PPAC,
signal in IC,
no IC veto

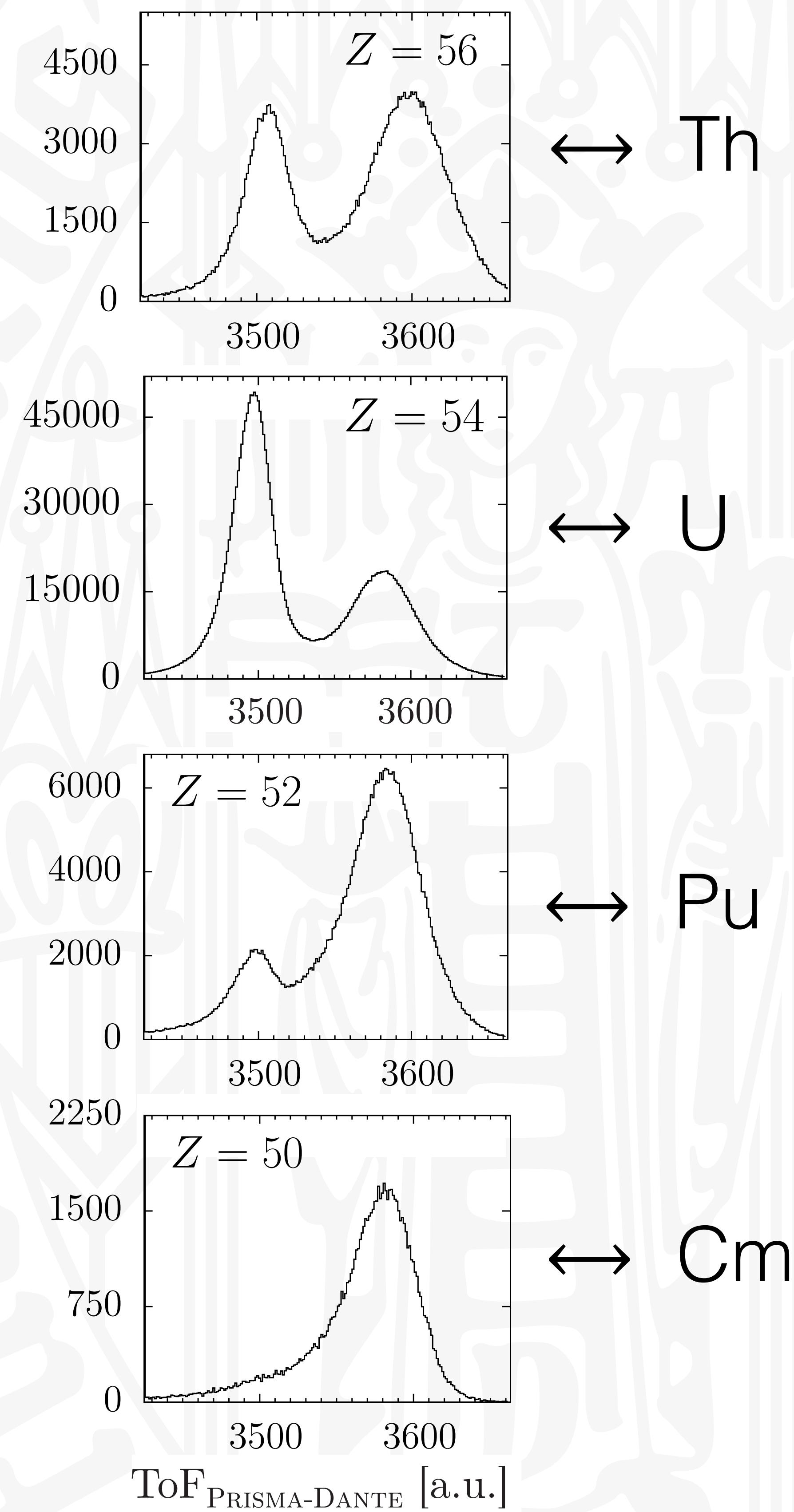
$$Y = f(E_{\mathrm{kin}},\theta,\phi) \times Y_{\mathrm{measured}}$$

D. Montanari *et al.* Eur. Phys. J. A 47, 11004-9, 2011

Discriminating Fission & Transfer







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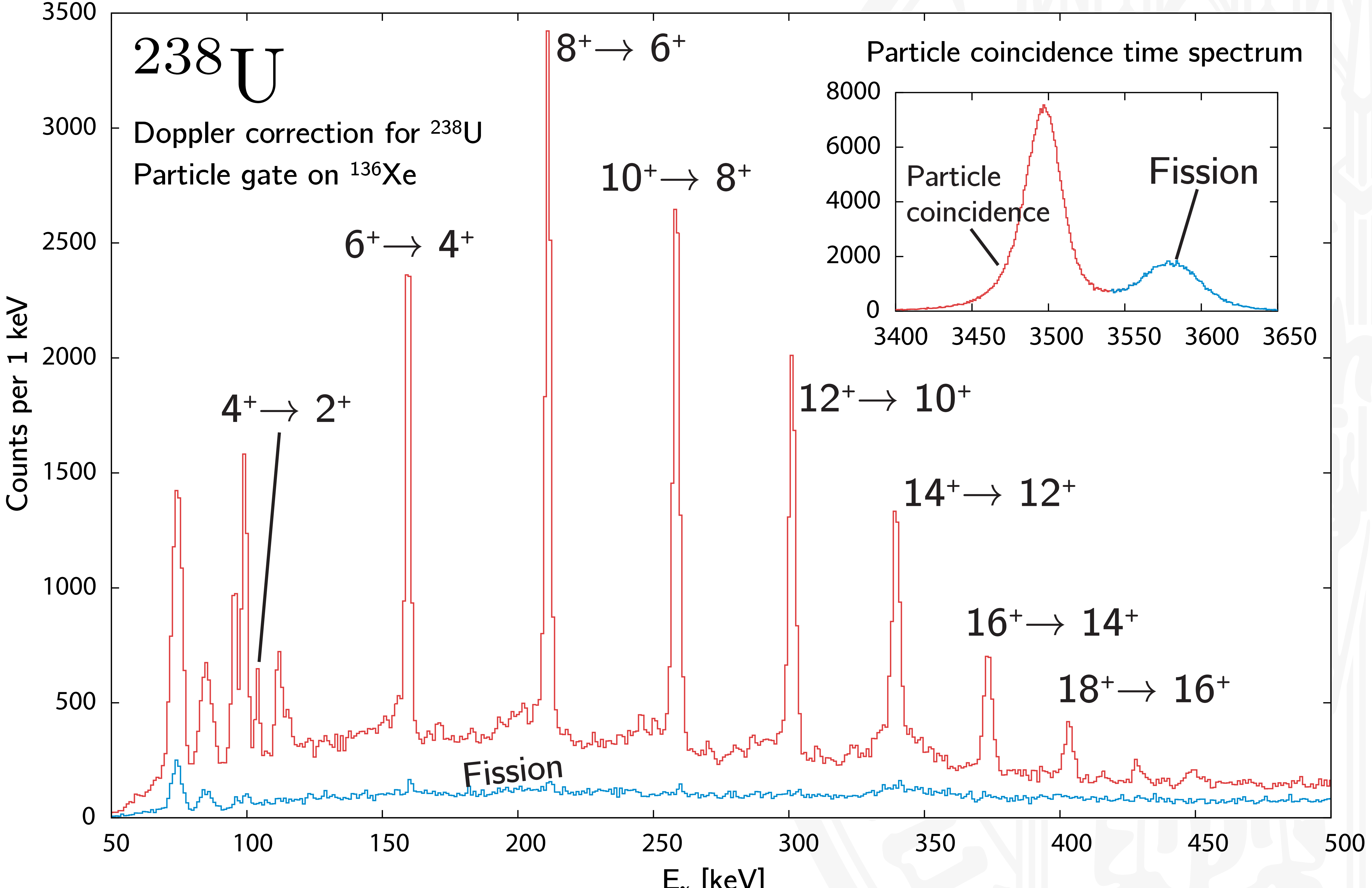

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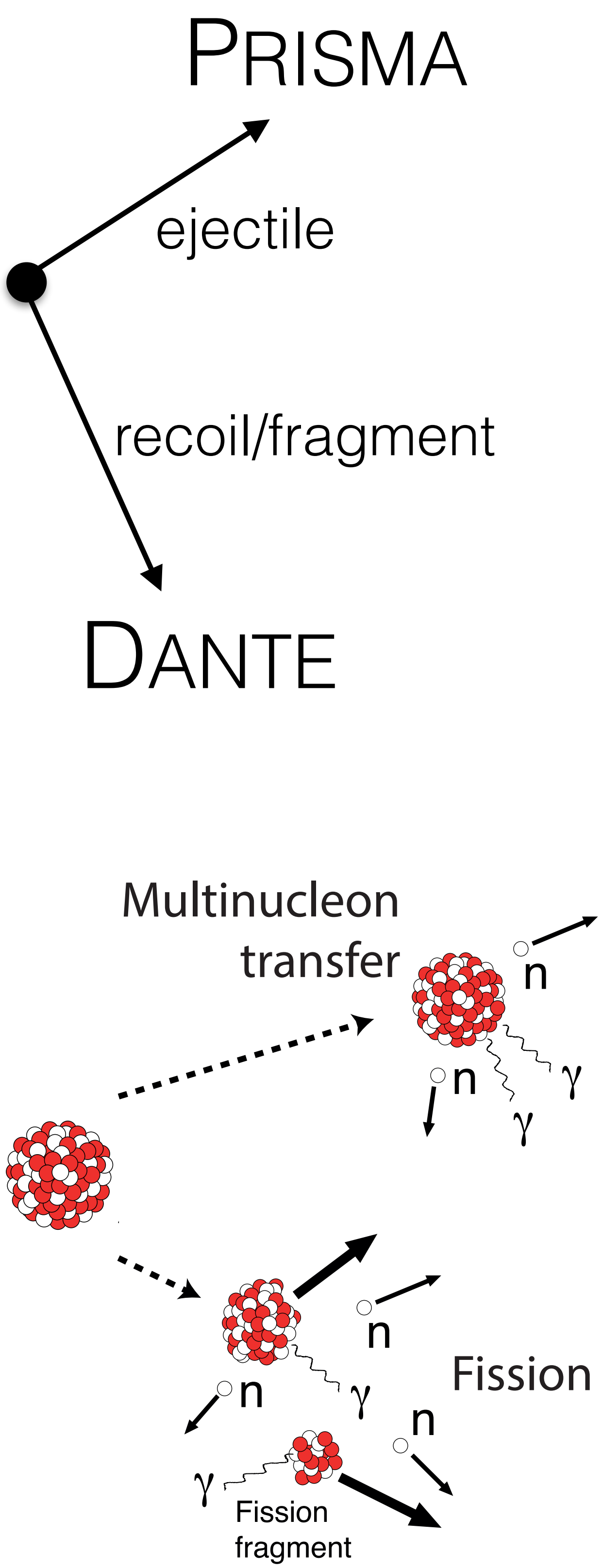
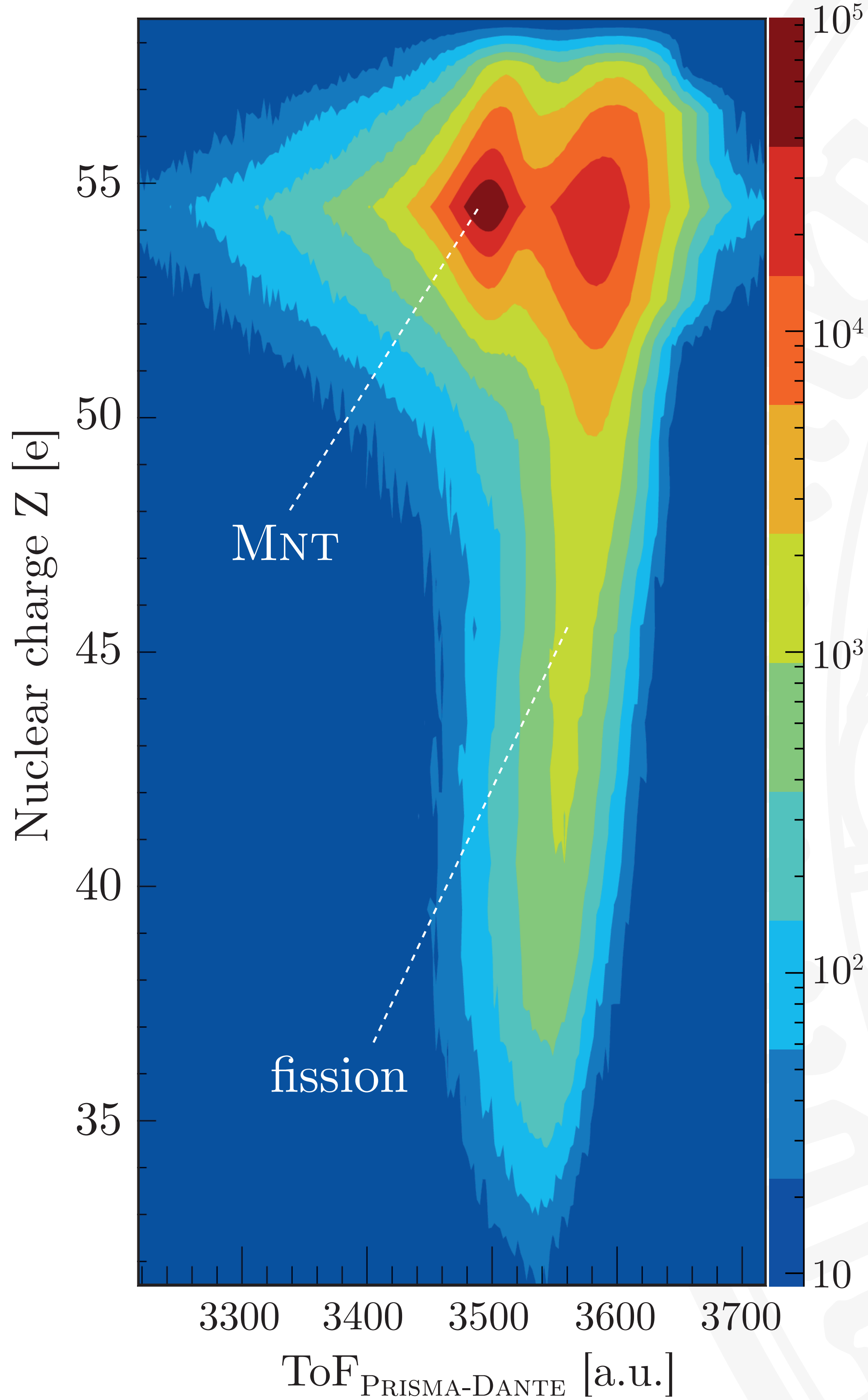
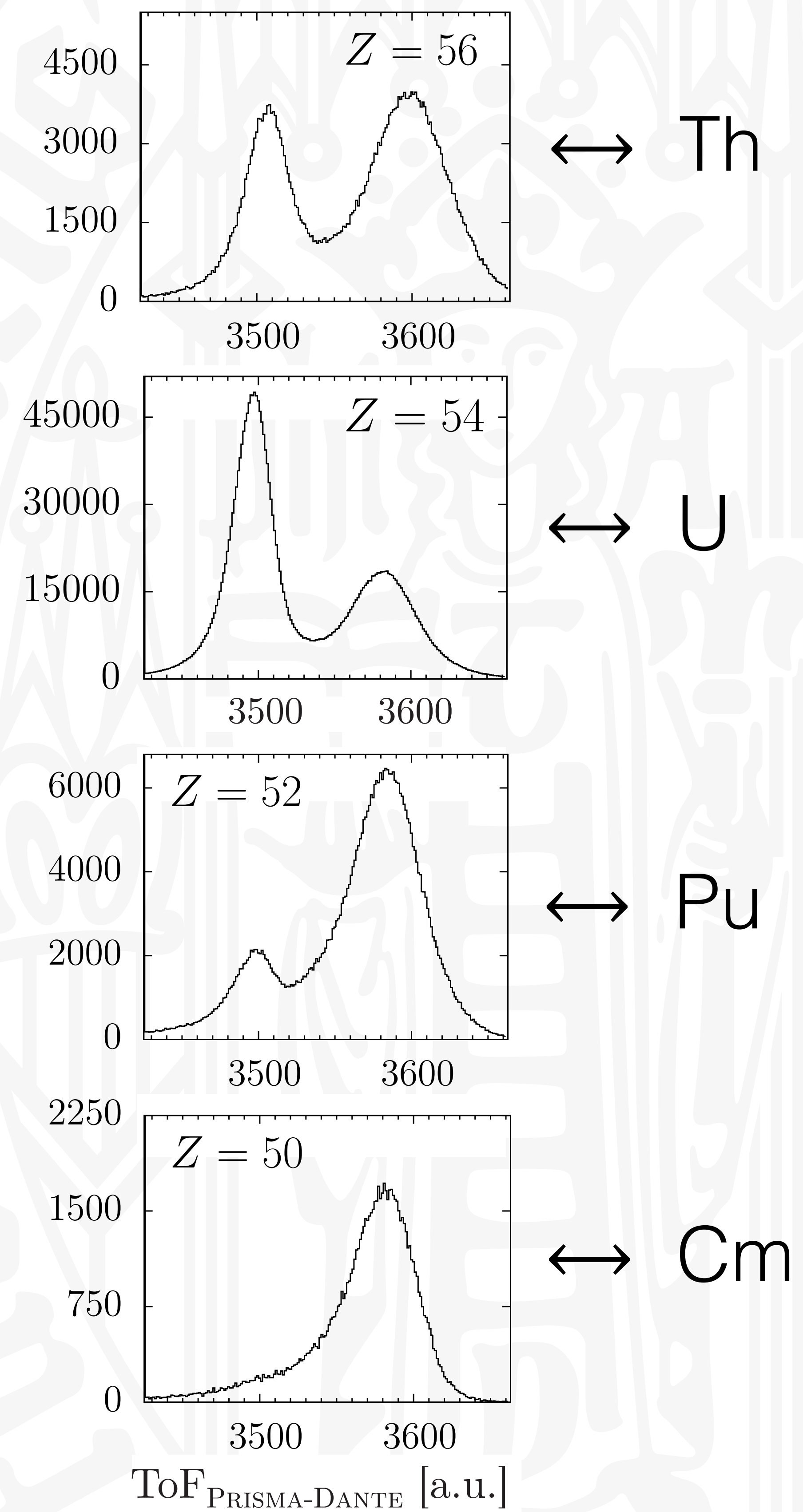
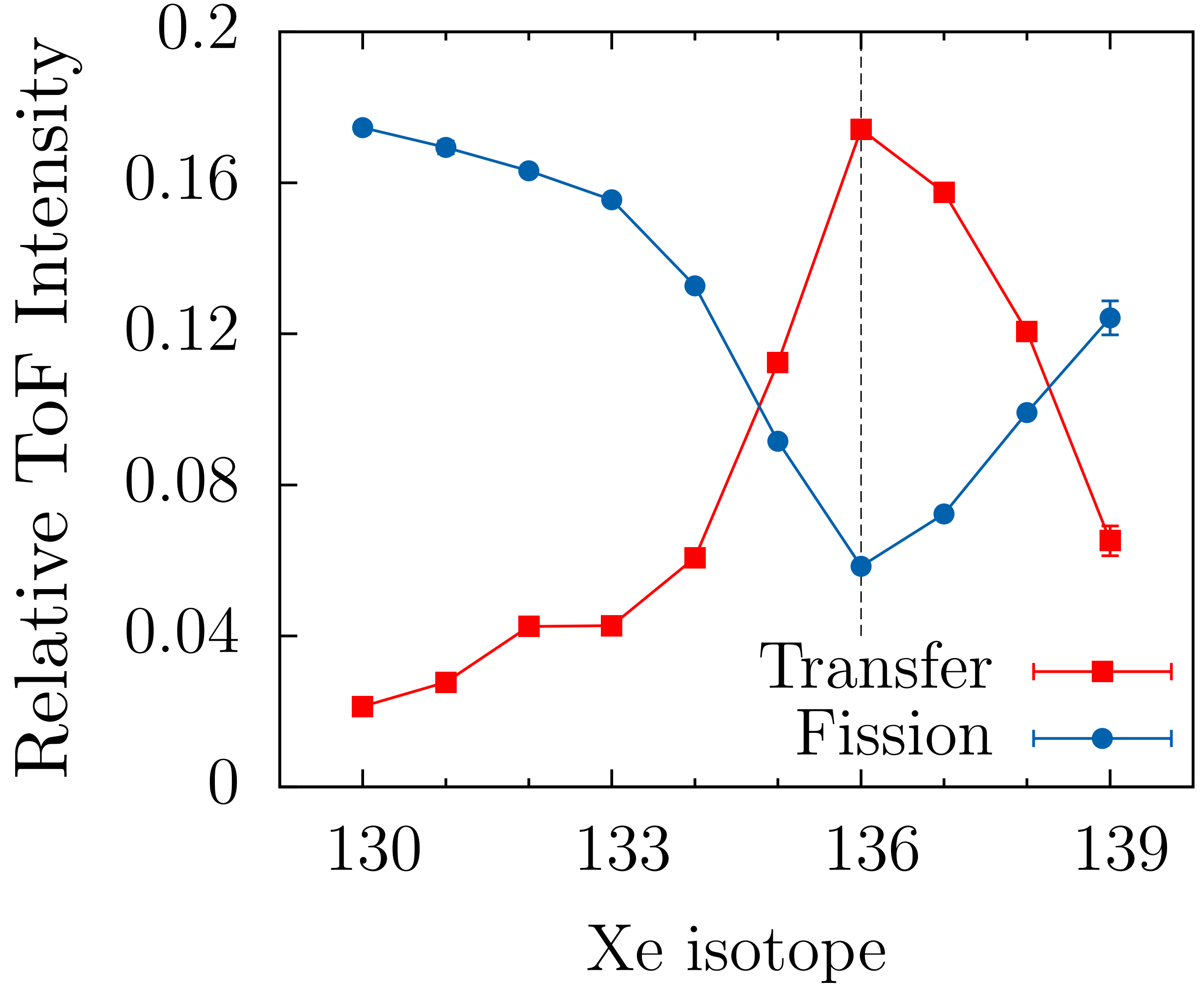






Discriminating Fission & Transfer

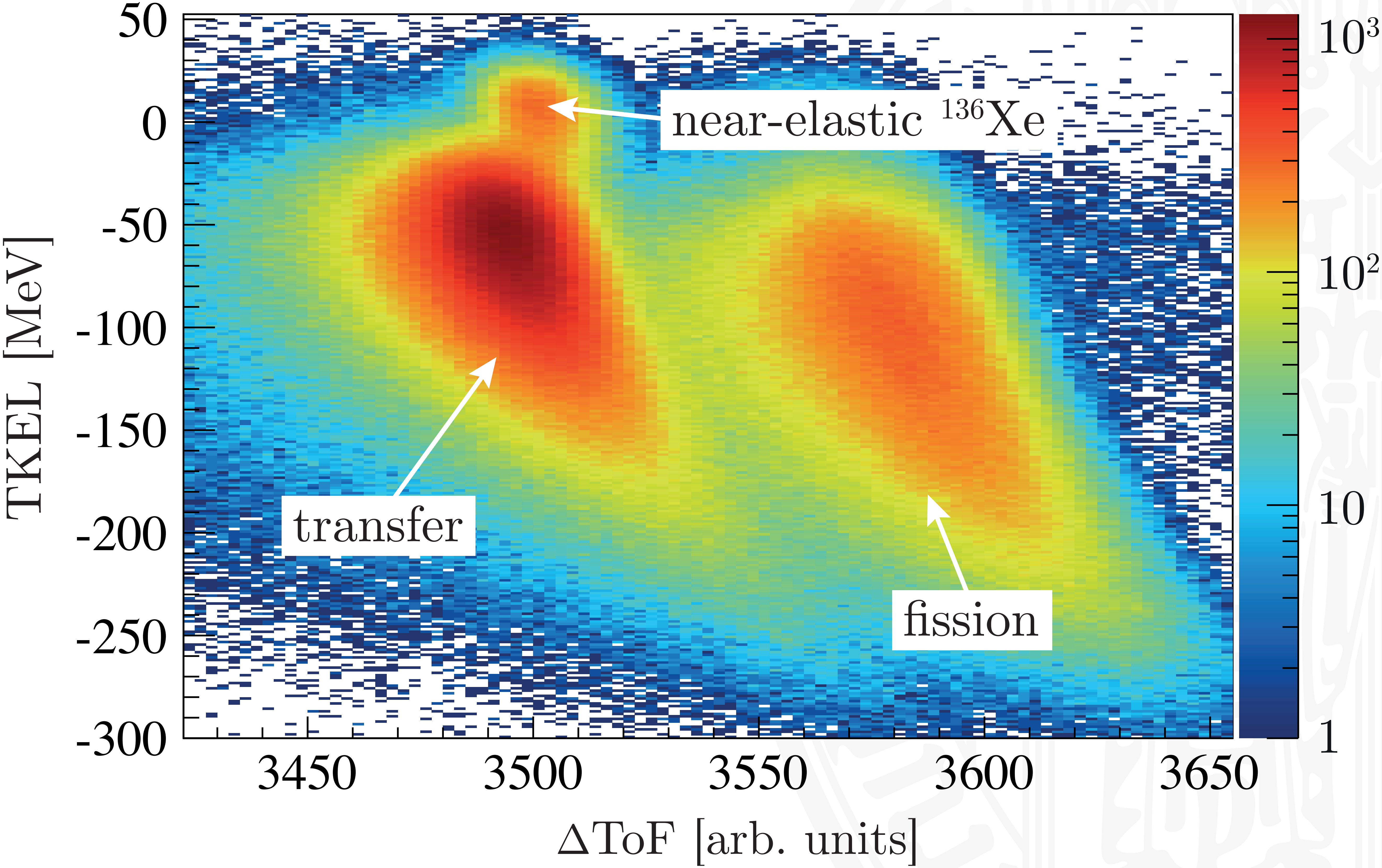
To what extend can exotic or n-rich nuclei be produced via MNT?



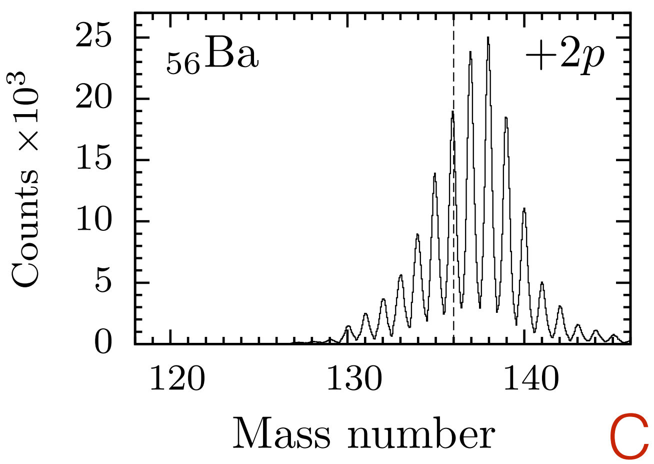
Neutron transfer most probable for up to two neutrons

P
ejectil
recoil/fr
D
Multinuc
tra
n
γ
Fissi
fragm
ToF PRISMA-DANTE [a.u.]
ToF PRISMA-DANTE [a.u.]

Selecting Transfer Events



Comparison to GRAZING

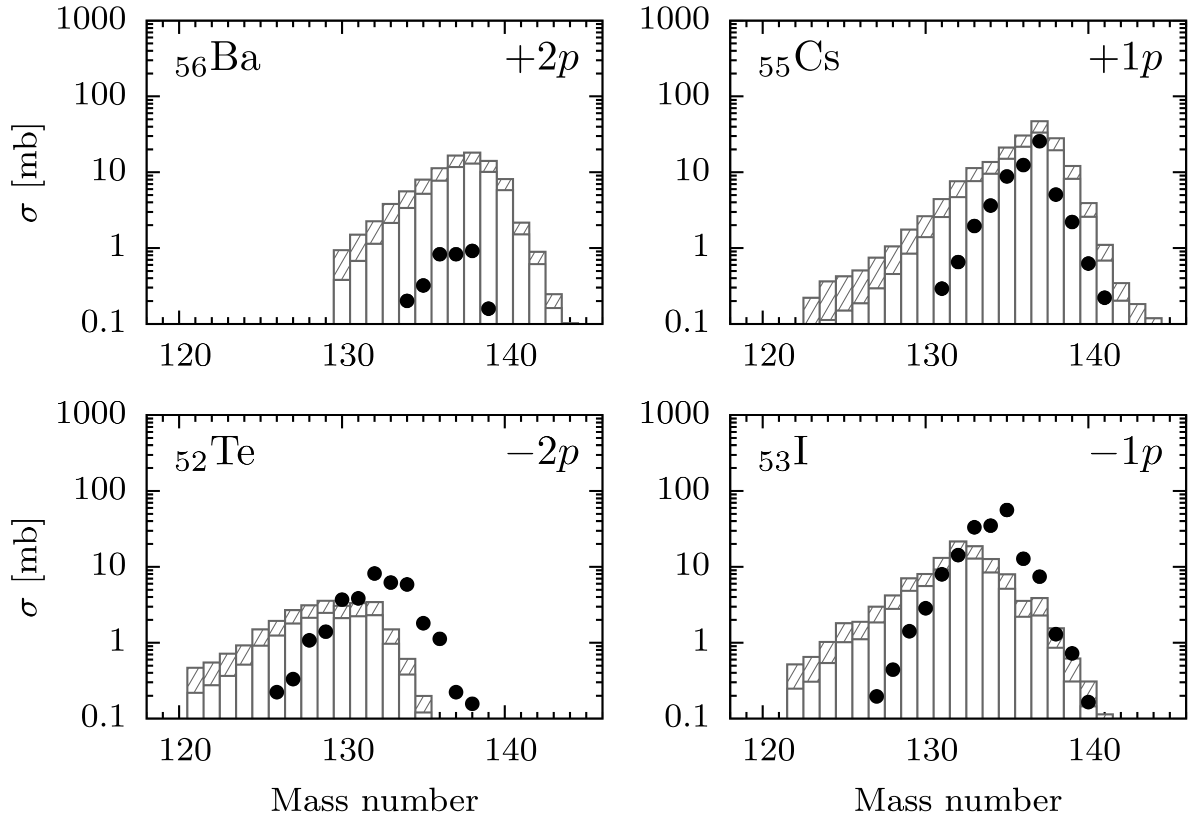


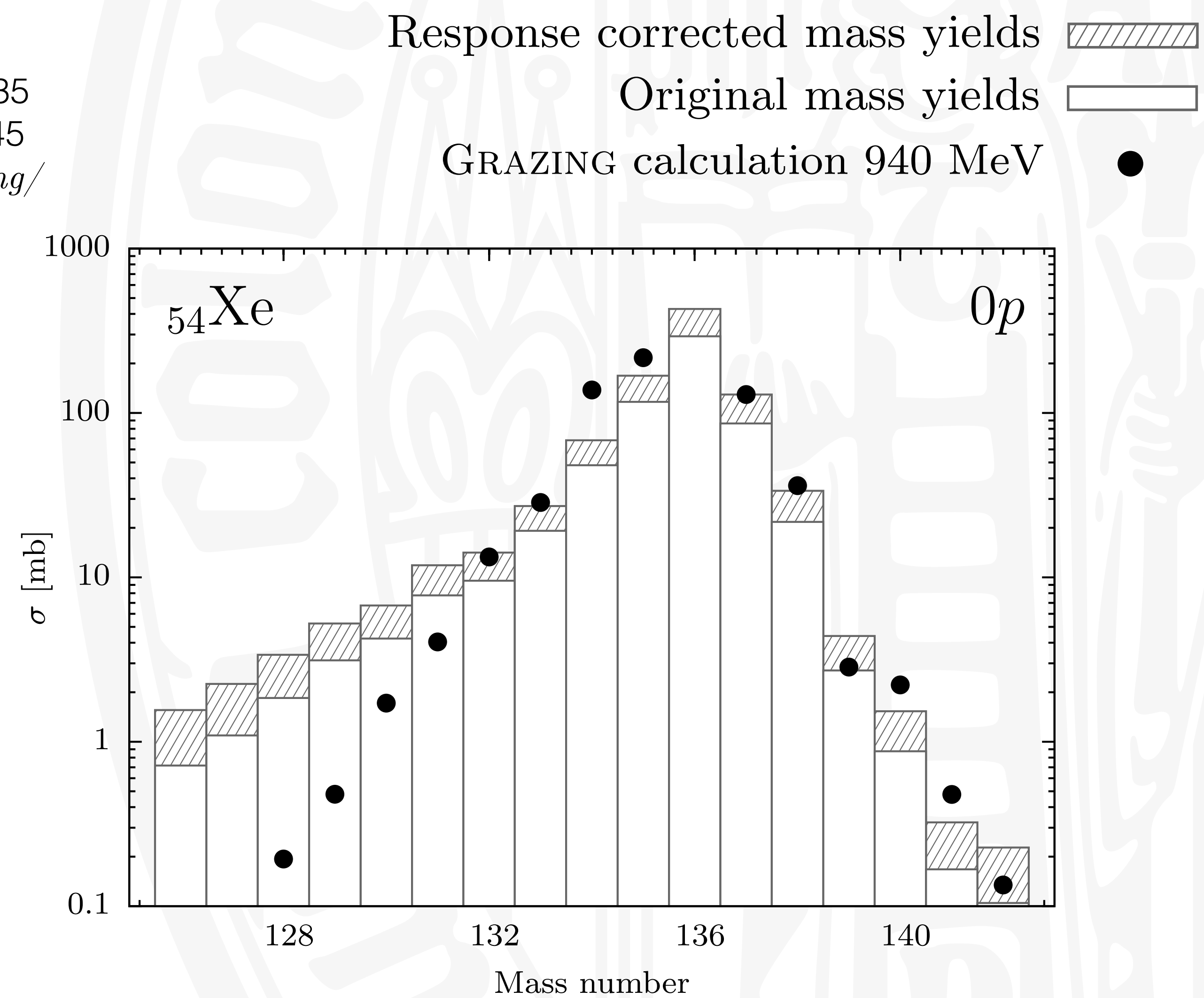
Corrected data normalized to +1n channel calculated by GRAZING model

A. Winther. Nucl. Phys. A 572 (1994) 191-235
A. Winther. Nucl. Phys. A594 (1995) 203-245
http://personalpages.to.infn.it/~nanni/grazing/

Semiclassical microscopic approach

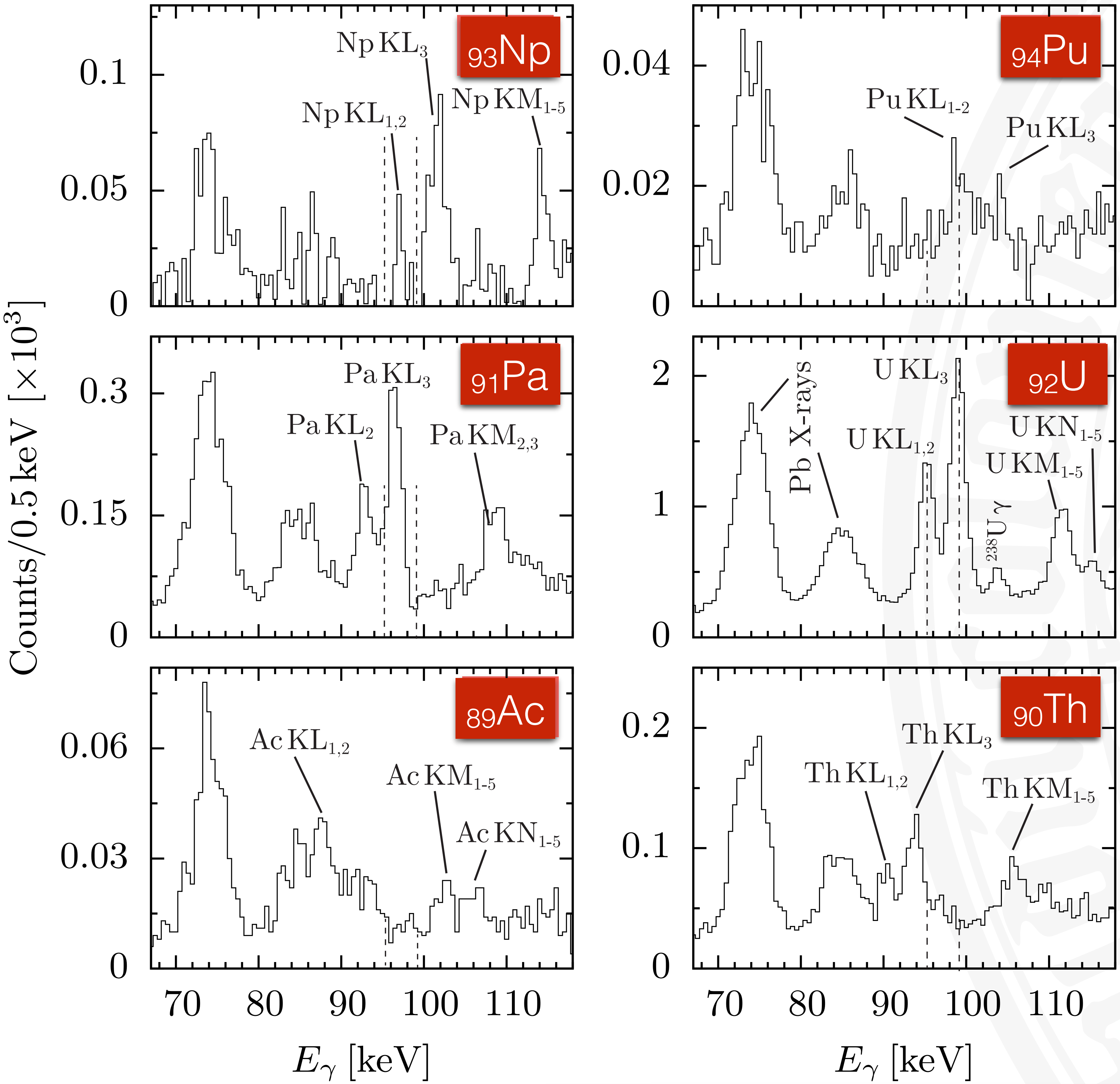
- calculates evolution of reaction by using intrinsic degrees of freedom of two colliding nuclei:
  - surface modes
    low-lying modes
    high-lying modes
  - microscopic formfactor for transfer
  - transfer described via a multistep mechanism

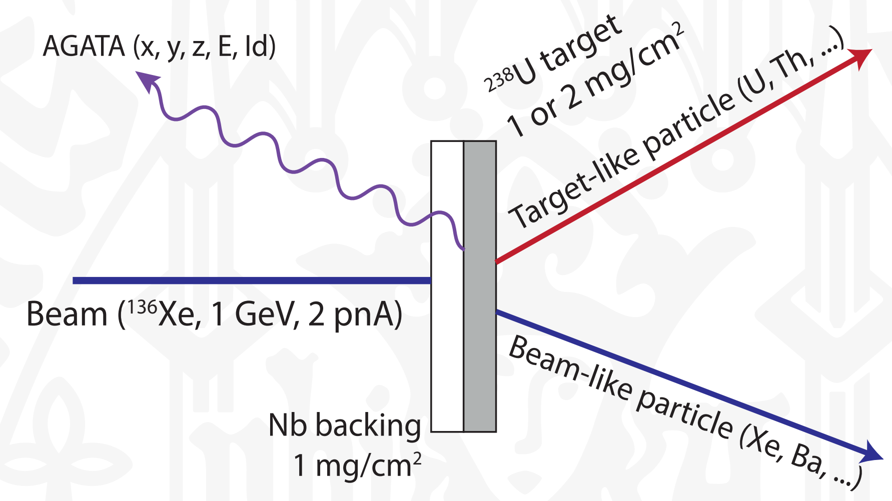


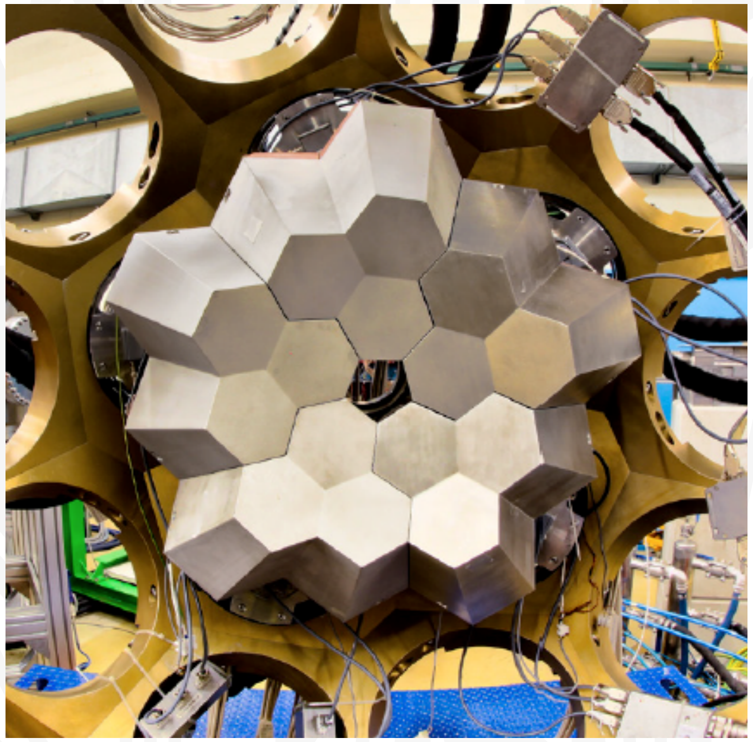


Future: GRAZING-F model including fission competition: R. Yanez, W. Loveland. Phys. Rev. C 91, 044608

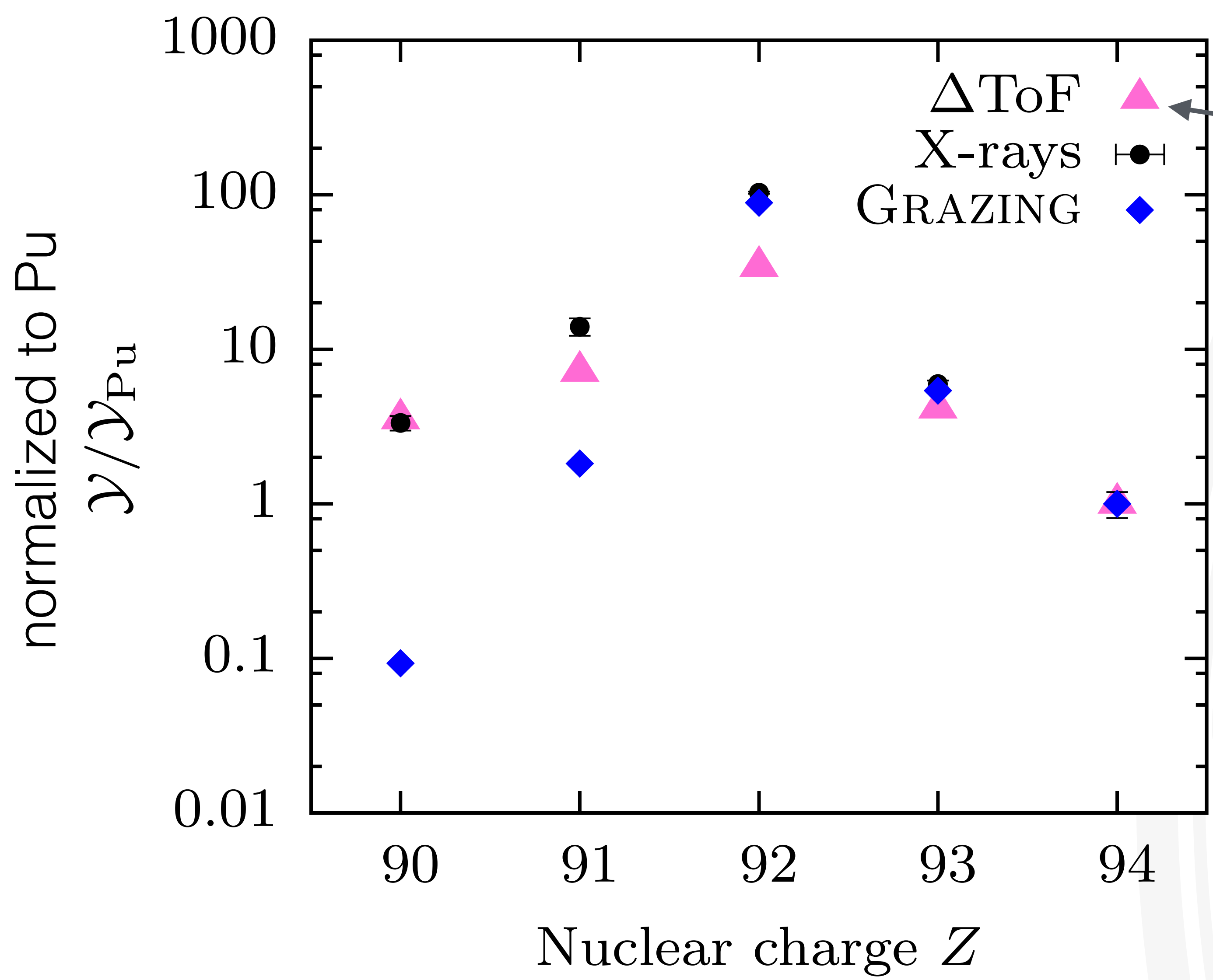
Actinide Yields via X-ray Spectra

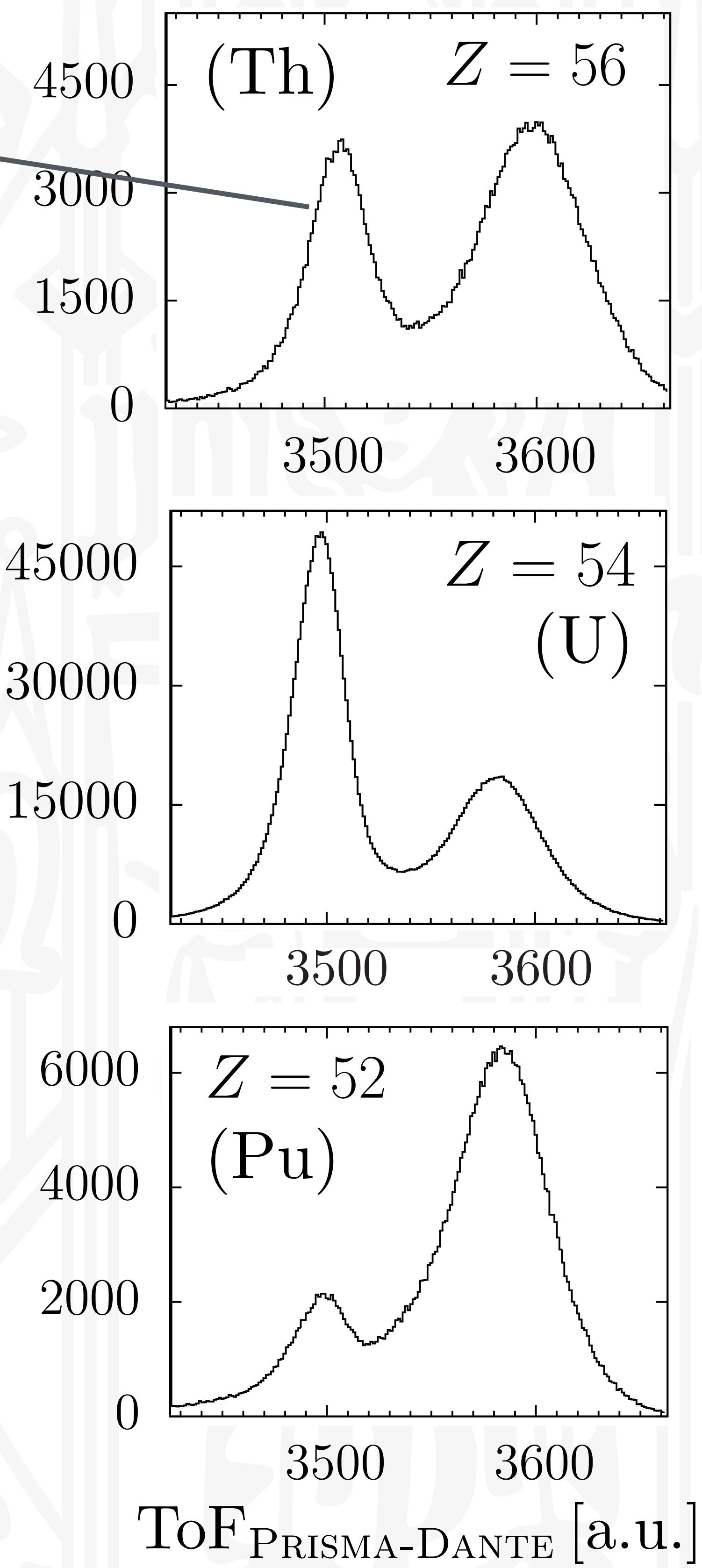






Actinide Yields via X-rays and ΔToF



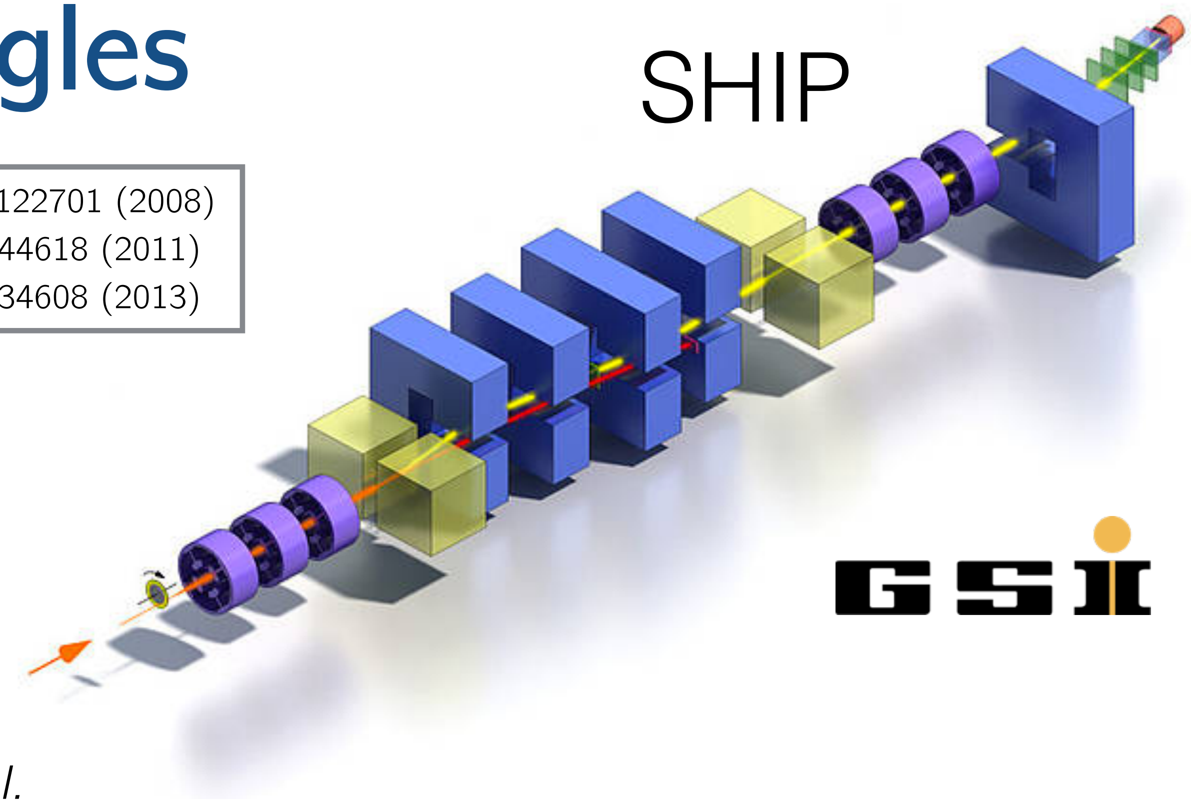


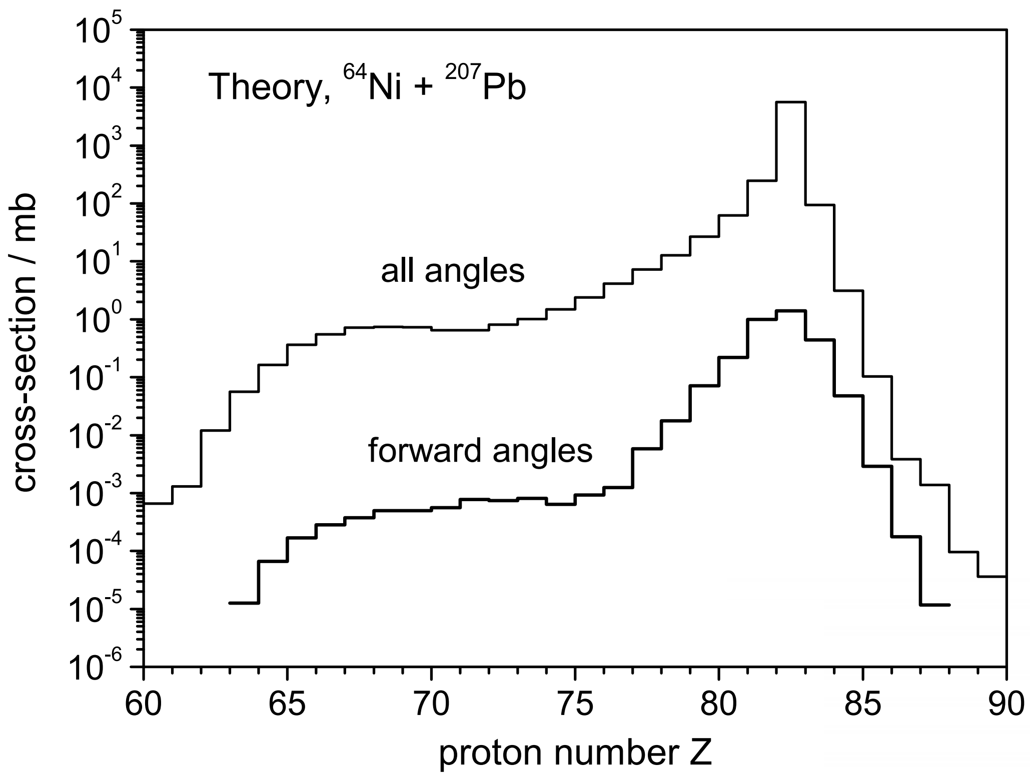
- For actinide binary partners, **proton-stripping reactions are favored** over proton pickup
- GRAZING **underestimates proton-deficient actinides**
- Population of actinide nuclei with **high Z is disfavored**

MNT at non-grazing angles

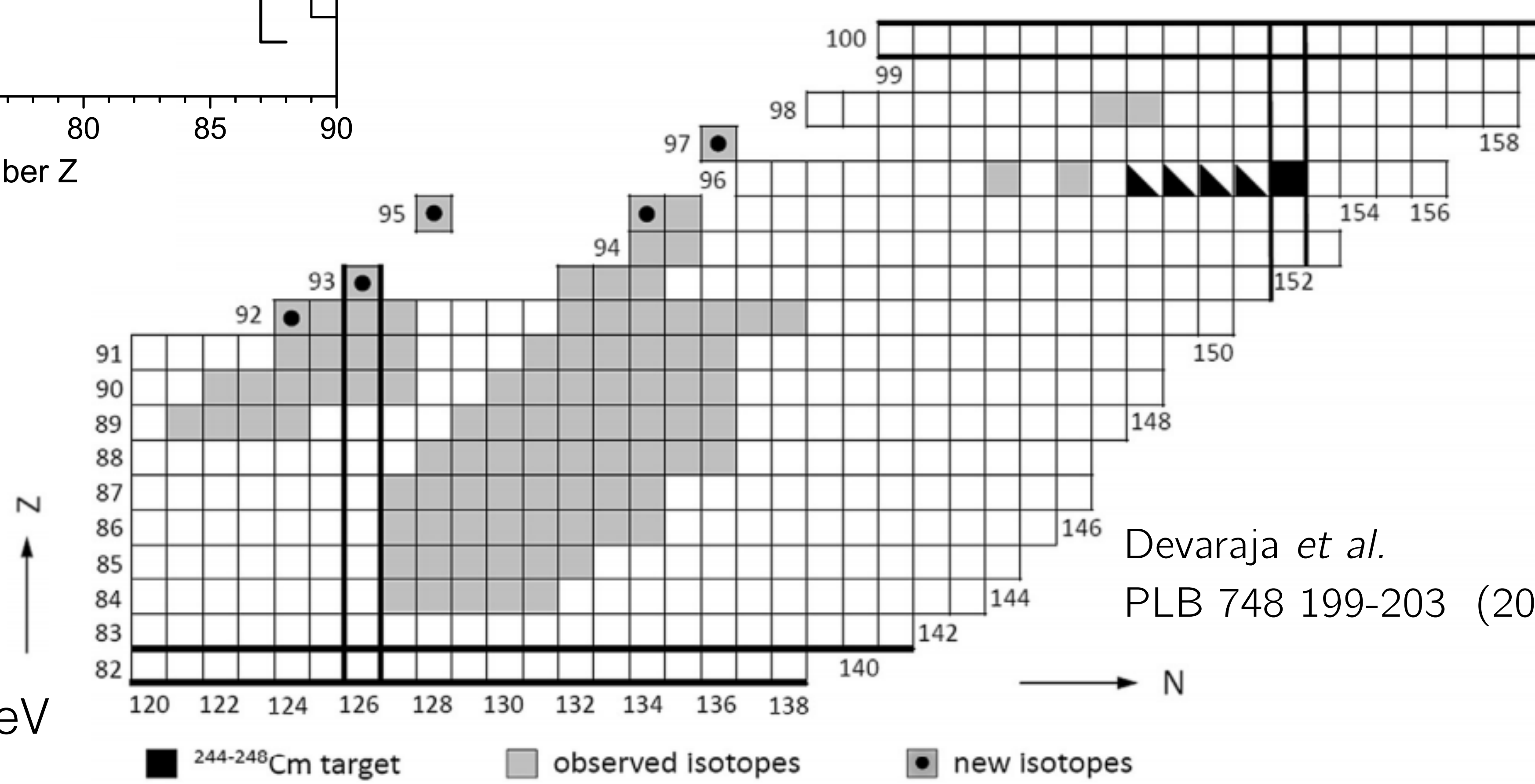
Predictions for the production of new isotopes:

Zagrebaev and Greiner, PRL 101, 122701 (2008)
Zagrebaev and Greiner, PRC 83, 044618 (2011)
Zagrebaev and Greiner, PRC 87, 034608 (2013)





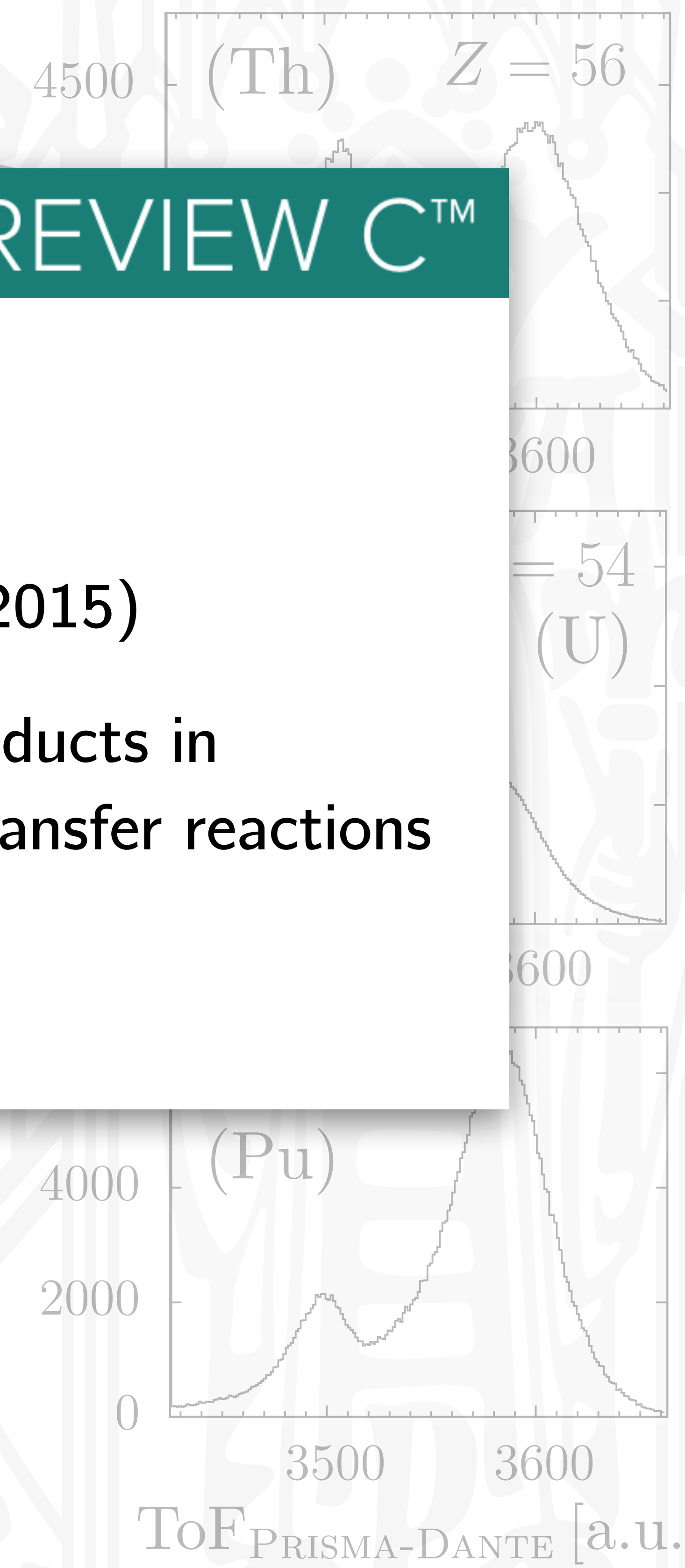
Comas *et al.*
EPJ A 49 112 (2013)



Devaraja *et al.*
PLB 748 199-203 (2015)

^{48}Ca + ^{248}Cm @ 270 MeV

Actinide Yields via X-rays and




PHYSICAL REVIEW C 92, 024619 (2015)

Light and heavy transfer products in $^{136}Xe + ^{238}U$ multinucleon transfer reactions

DOI: 10.1103/PhysRevC.92.024619 PACS number(s): 24.10.−i, 25.70.Hi, 29.30.Aj, 29.40.Gx

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PHYSICAL REVIEW C™

A. Vogt *et al.*

Phys. Rev. C. 92, 024619 (2015)

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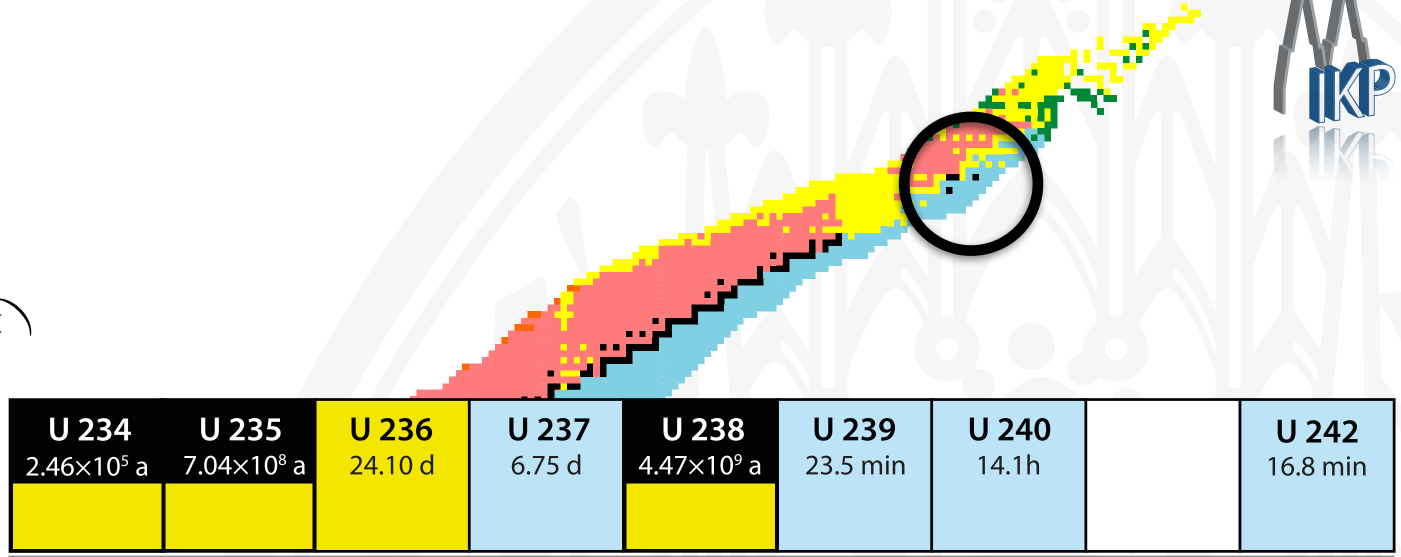
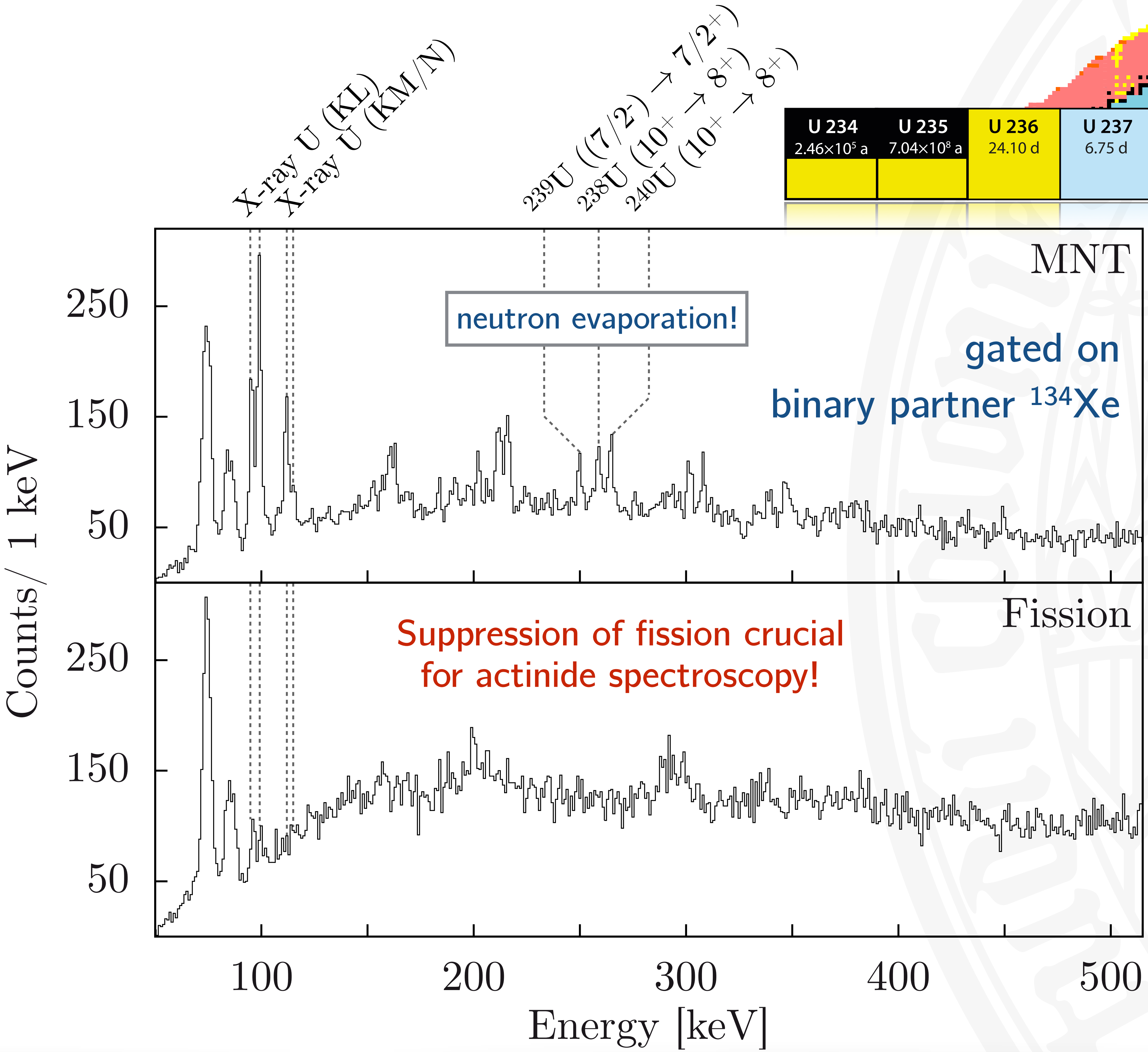
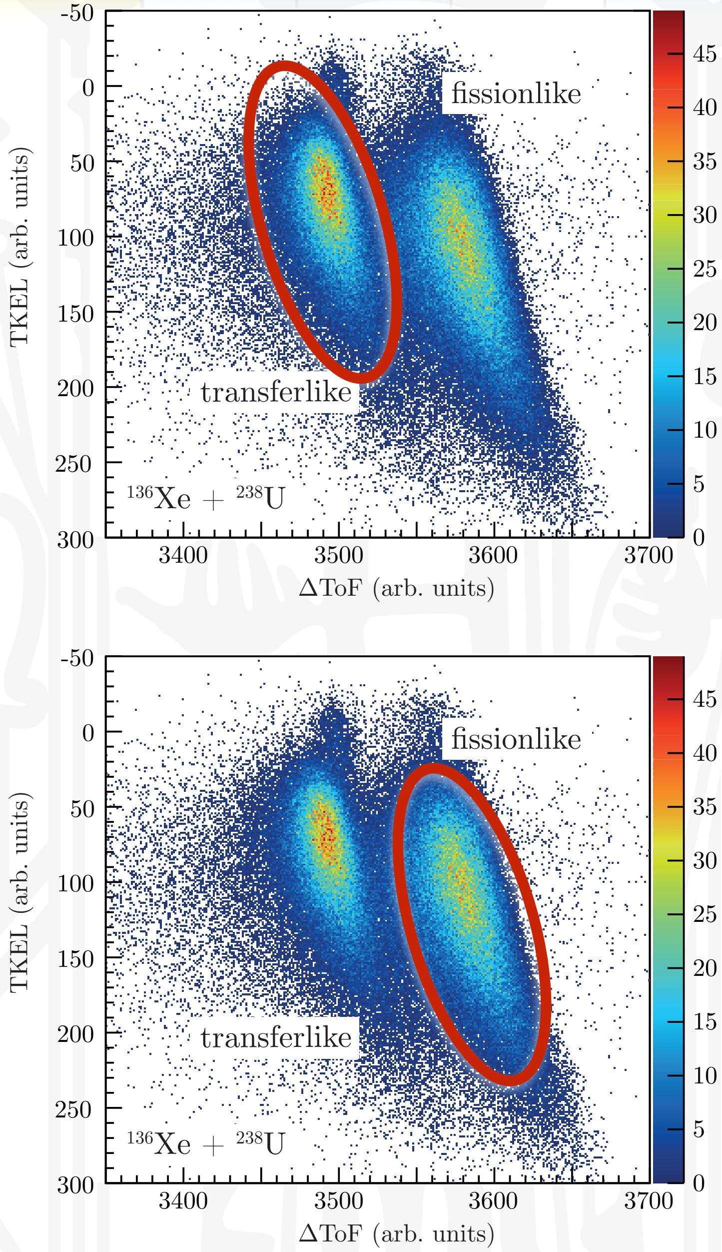
- **GRAZING underestimates proton-deficient actinides**
- Population of actinide nuclei with

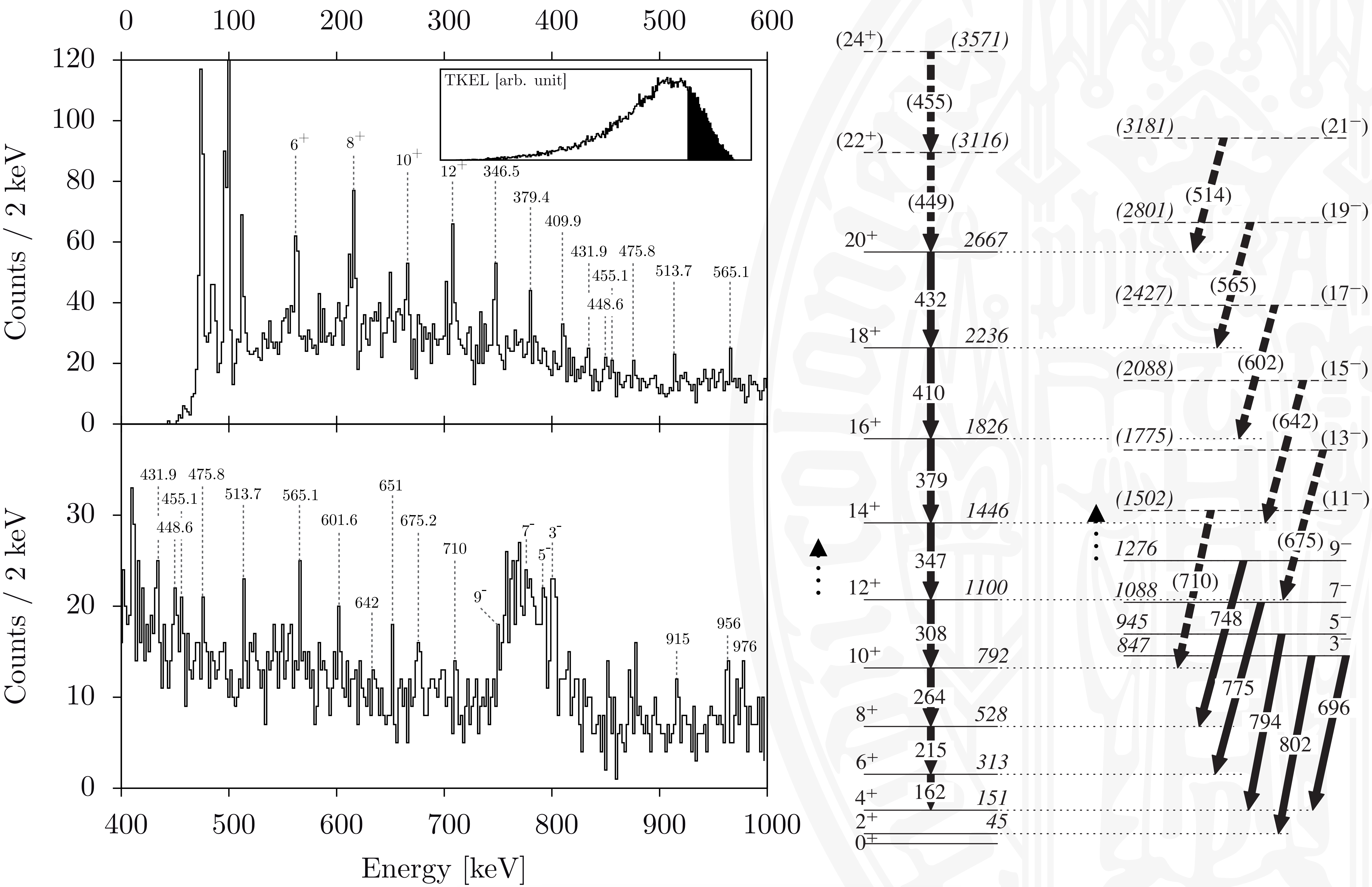
Spectroscopy of ^{240}U





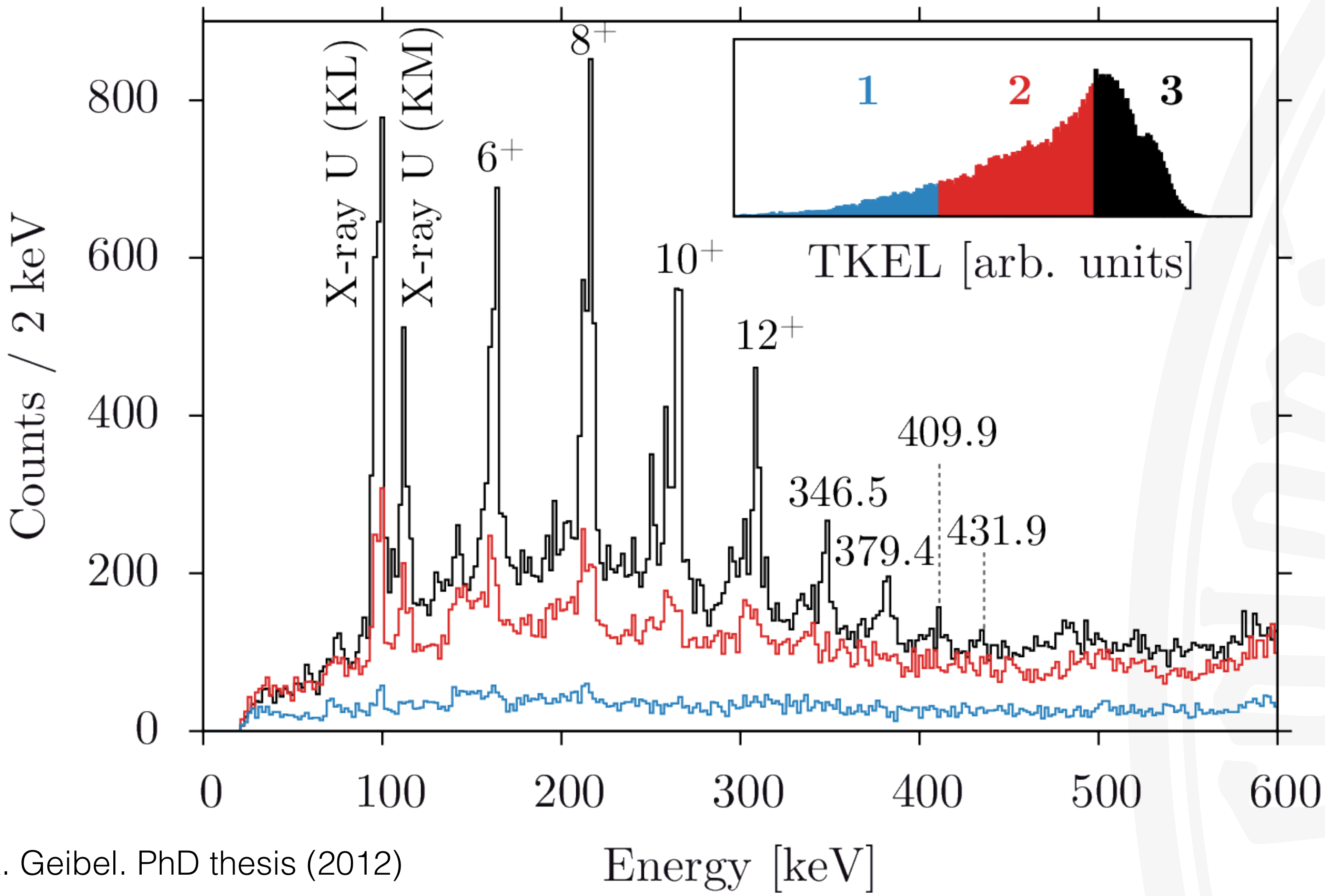


Spectroscopy of ^{240}U with AGATA+PRISMA

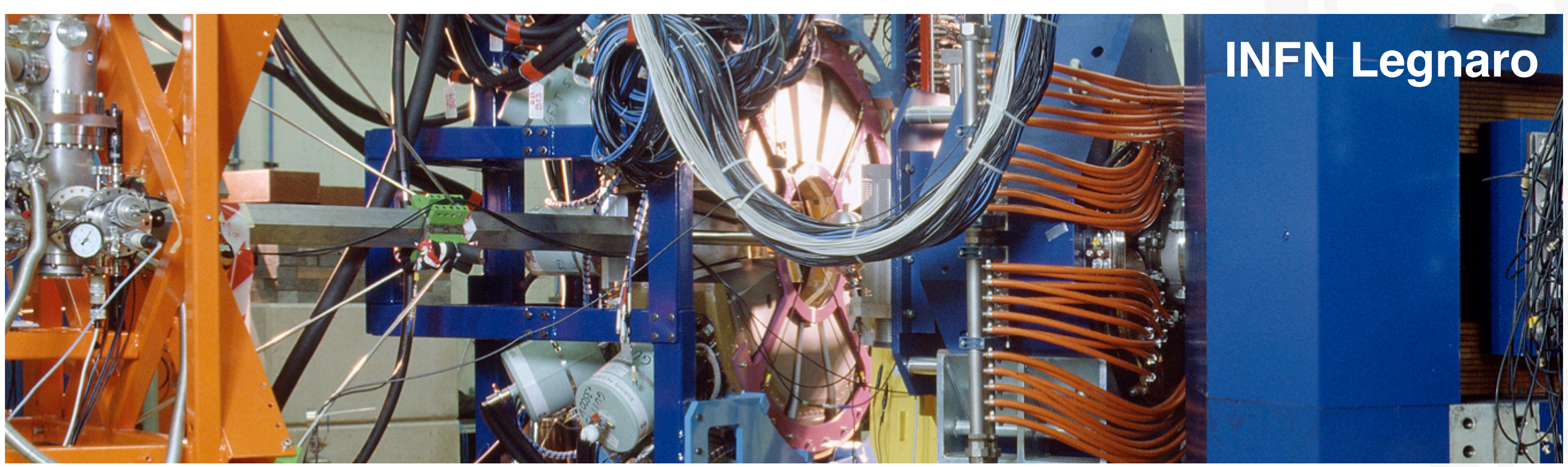


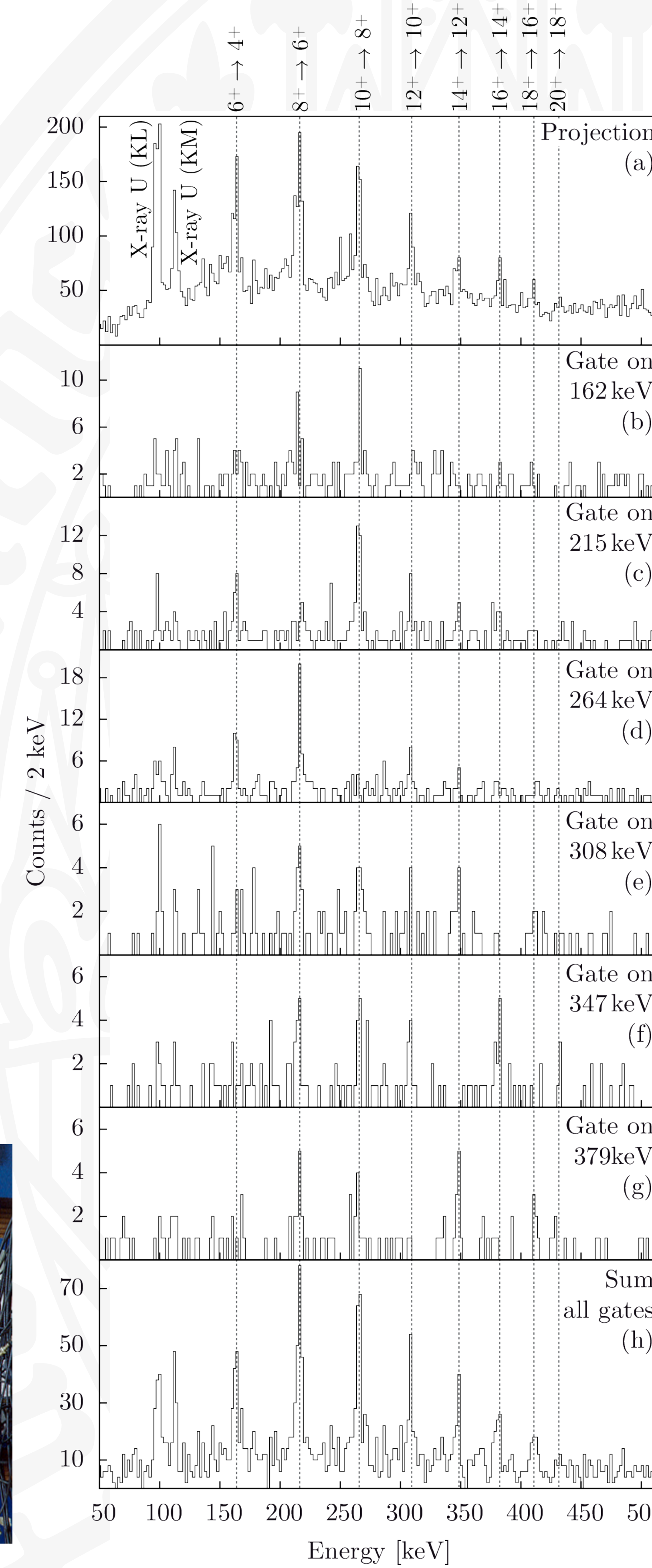
Spectroscopy of ^{240}U with CLARA+PRISMA

$^{70}Zn + ^{238}U$ @ 460 MeV

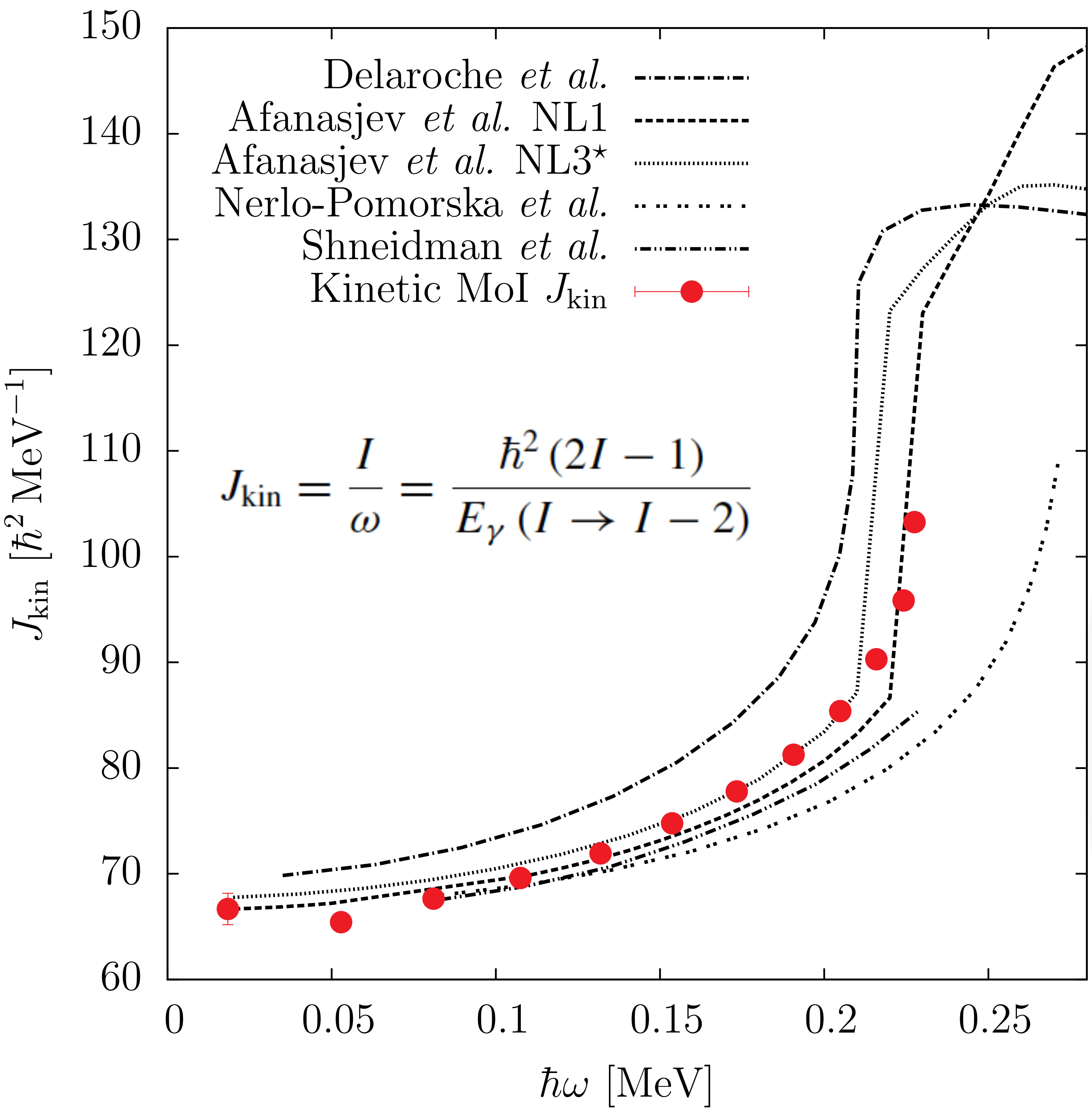


K. Geibel. PhD thesis (2012)





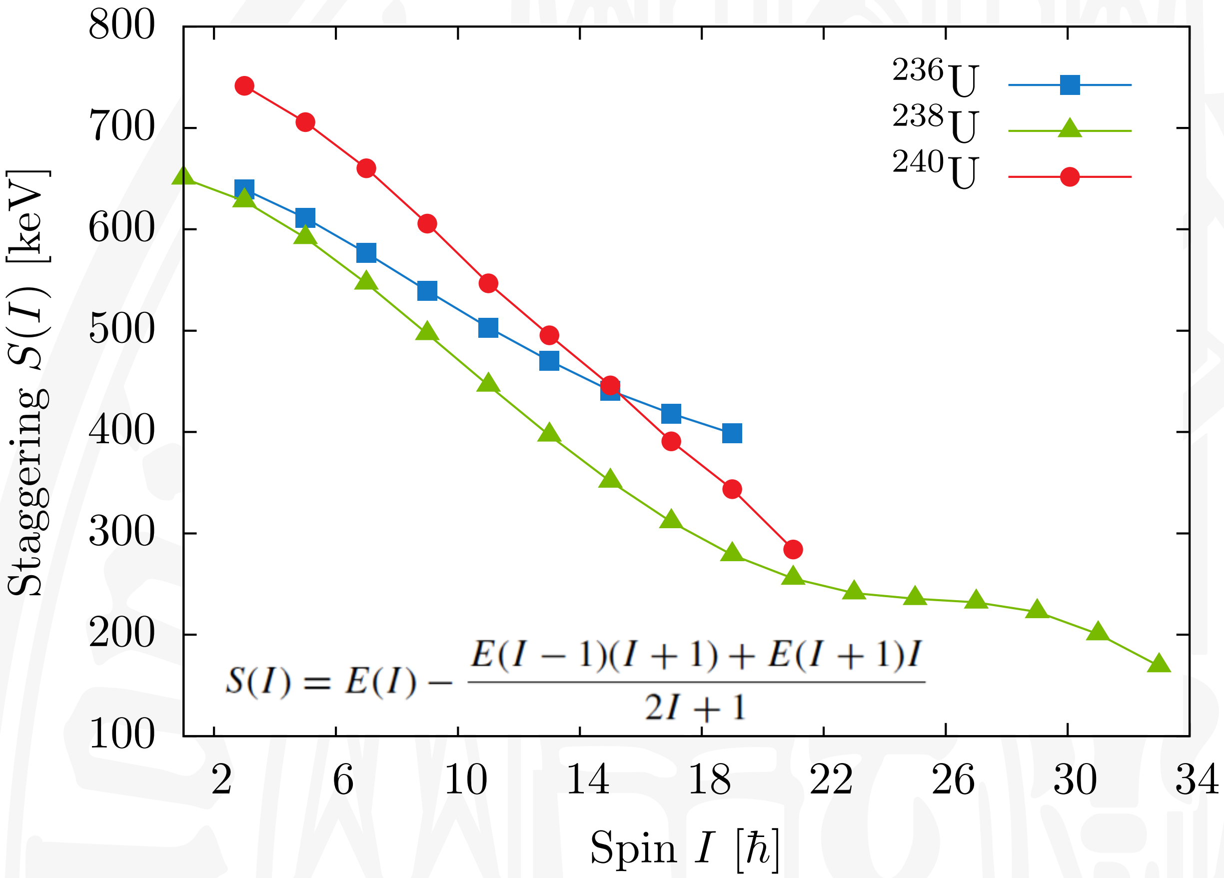
^{240}U: Moment of Inertia

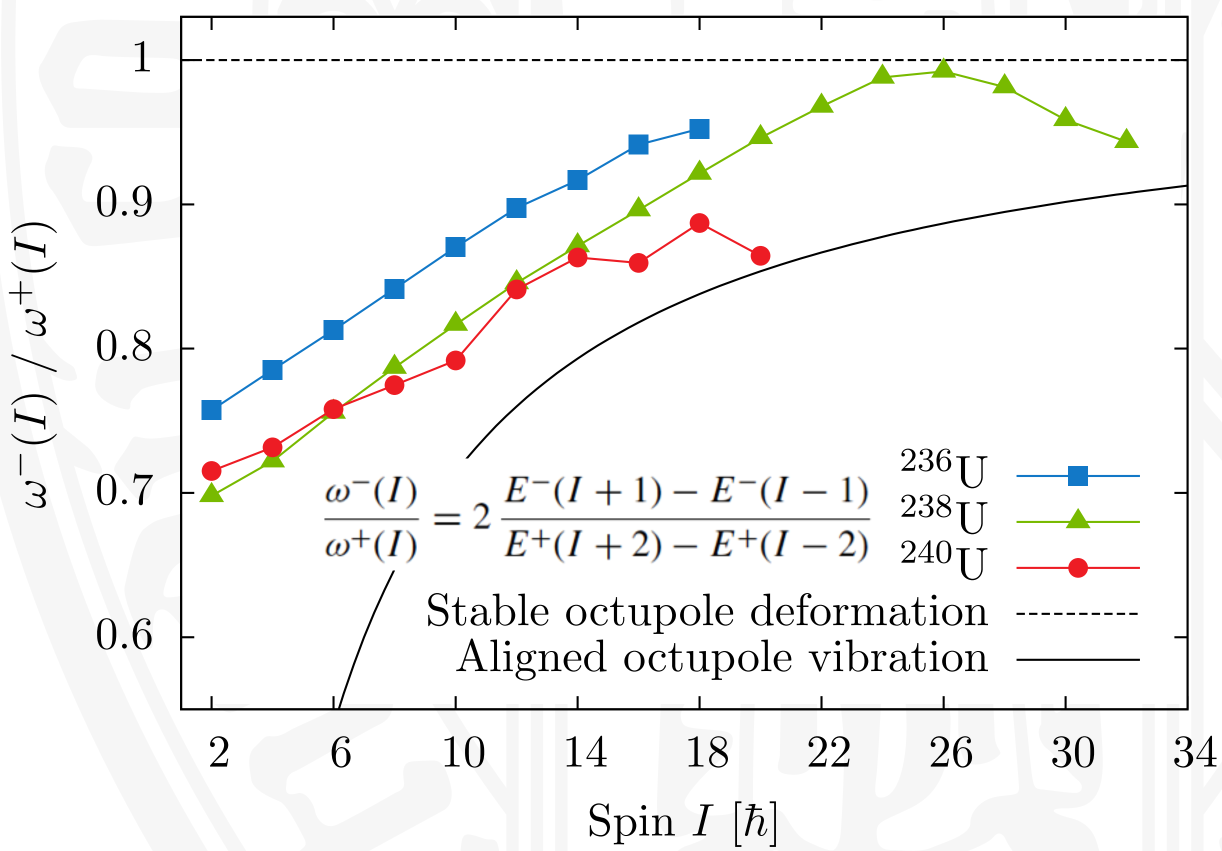


GSB and up-bend are best described by CDFT frameworks in NL1 and NL3* parametrization

Afanasjev *et al.* Phys. Rev. C 88, 014320 (2013)

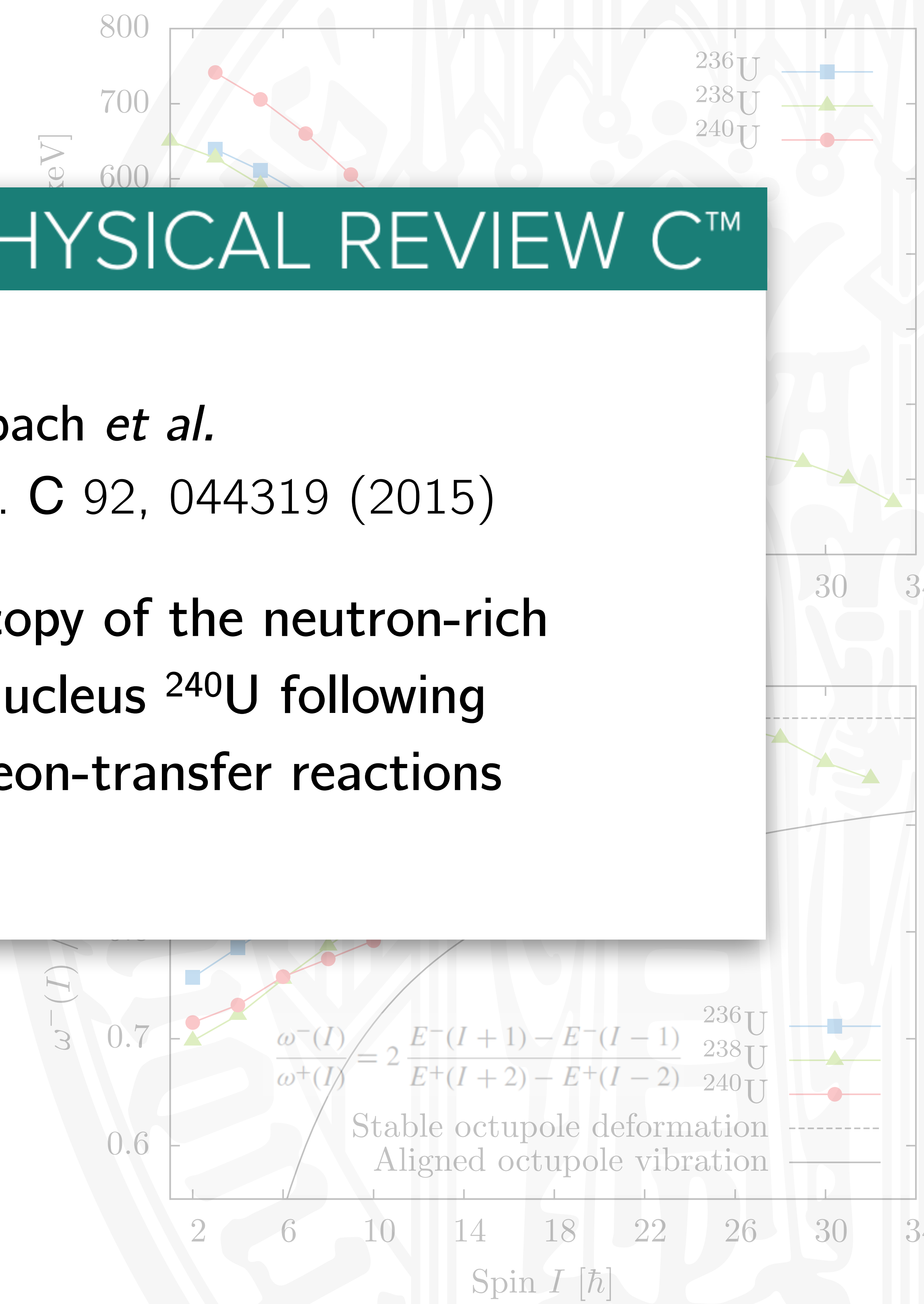
Parity Splitting





240

Parity Splitting



PHYSICAL REVIEW C™

PHYSICAL REVIEW C **92**, 044319 (2015)

Spectroscopy of the neutron-rich actinide nucleus ^{240}U following multinucleon-transfer reactions

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Background: Nuclear structure information for the neutron-rich actinide nuclei is important since it is the benchmark for theoretical models that provide predictions for the heaviest nuclei.
Purpose: γ-ray spectroscopy of neutron-rich heavy nuclei in the actinide region.
Method: Multinucleon-transfer reactions in ^{70}Zn + ^{238}U and ^{136}Xe + ^{238}U have been measured in two experiments performed at the INFN Legnaro, Italy. In the ^{70}Zn experiment the high-resolution HPGe Clover Array (CLARA) coupled to the magnetic spectrometer PRISMA was employed. In the ^{136}Xe experiment the high-resolution Advanced Gamma Tracking Array (AGATA) was used in combination with PRISMA and the Detector Array for Multinucleon Transfer Ejectiles (DANTE).
Results: The ground-state band (g.s. band) of ^{240}U was measured up to the 20^+ level and a tentative assignment was made up to the (24^+) level. Results from $\gamma\gamma$ coincidence and from particle coincidence analyses are shown. Moments of inertia (MoI) show a clear upbend. Evidence for an extended first negative-parity band of ^{240}U is found.
Conclusions: A detailed comparison with latest calculations shows best agreement with cranked relativistic Hartree-Bogoliubov (CRHB) calculations for the g.s. band properties. The negative-parity band shows the characteristics of a $K^\pi = 0^-$ band based on an octupole vibration.

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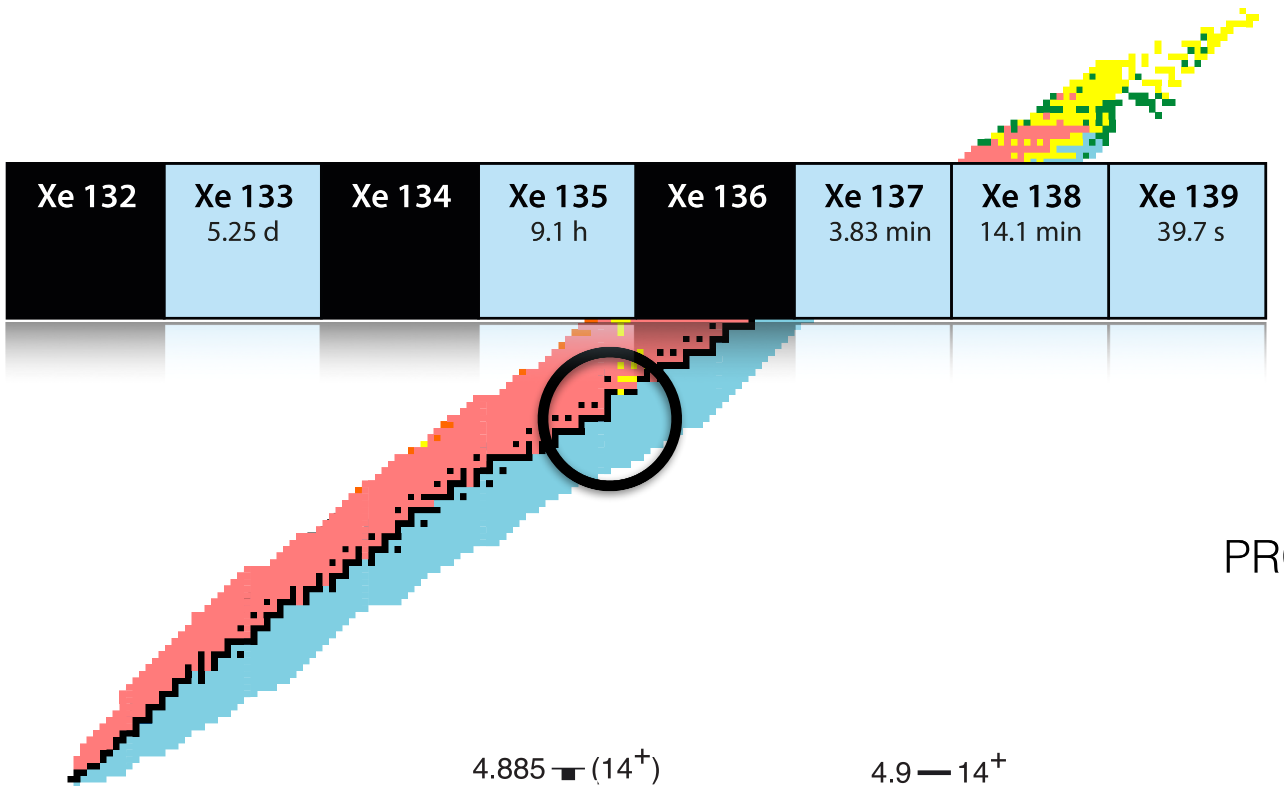
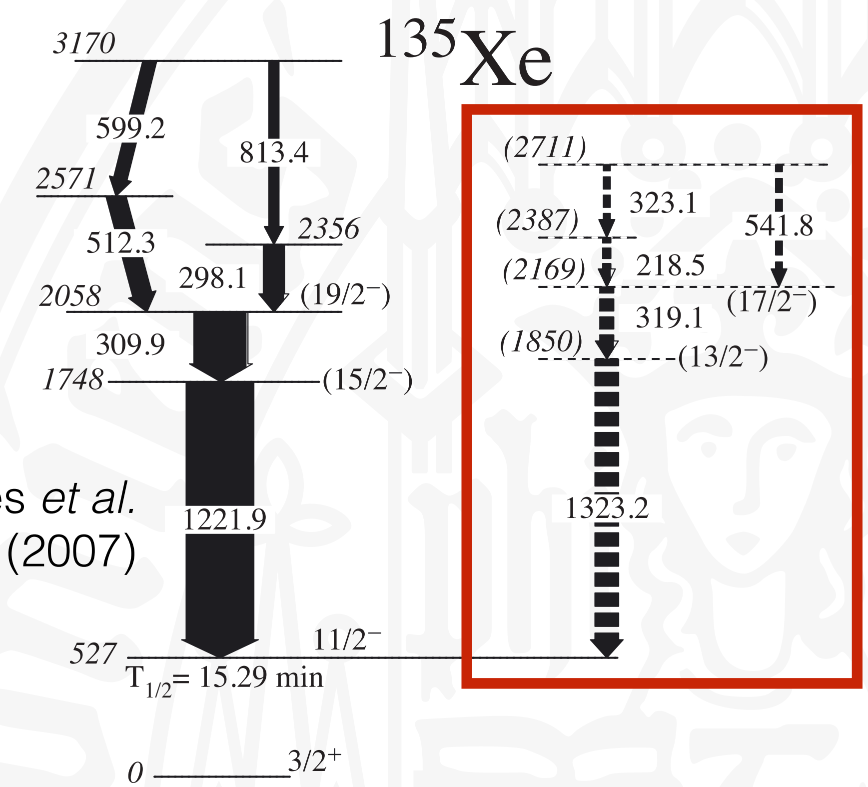
B. Birkenbach *et al.*
Phys. Rev. **C** 92, 044319 (2015)

Spectroscopy of the neutron-rich actinide nucleus ^{240}U following multinucleon-transfer reactions

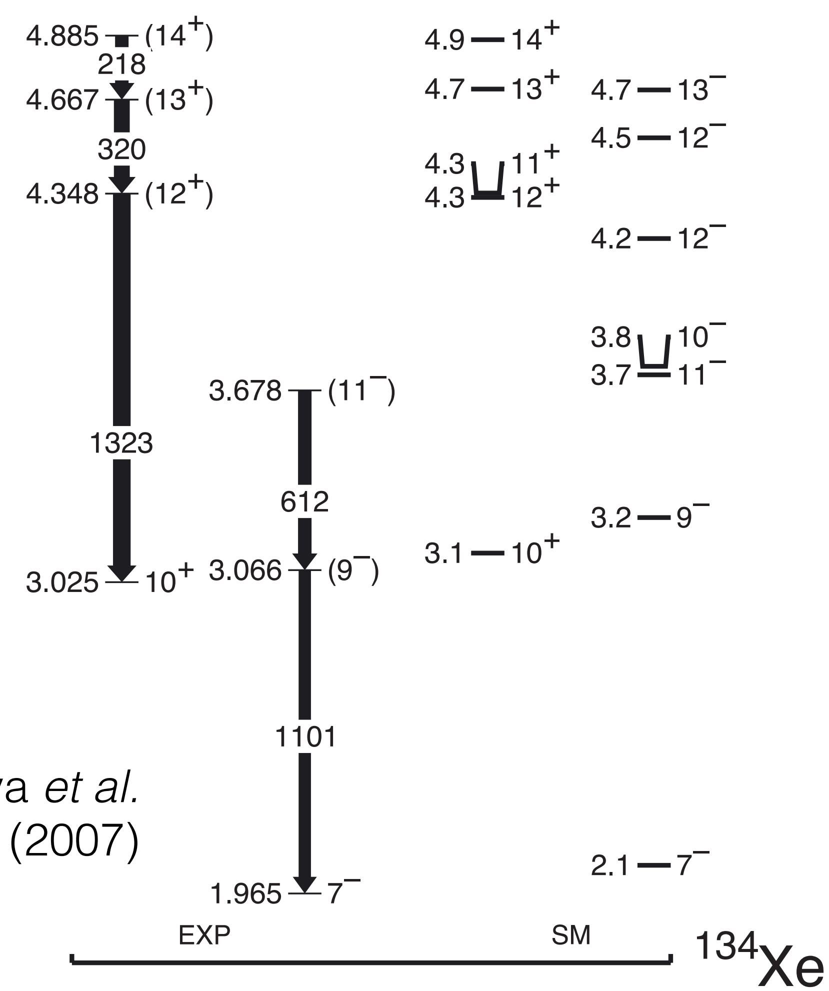
GSB and up-bend are best described by CDFT frameworks in NL1 and NL3* parametrization Afanasjev

High-Spin Spectroscopy of the Xe Isotopes

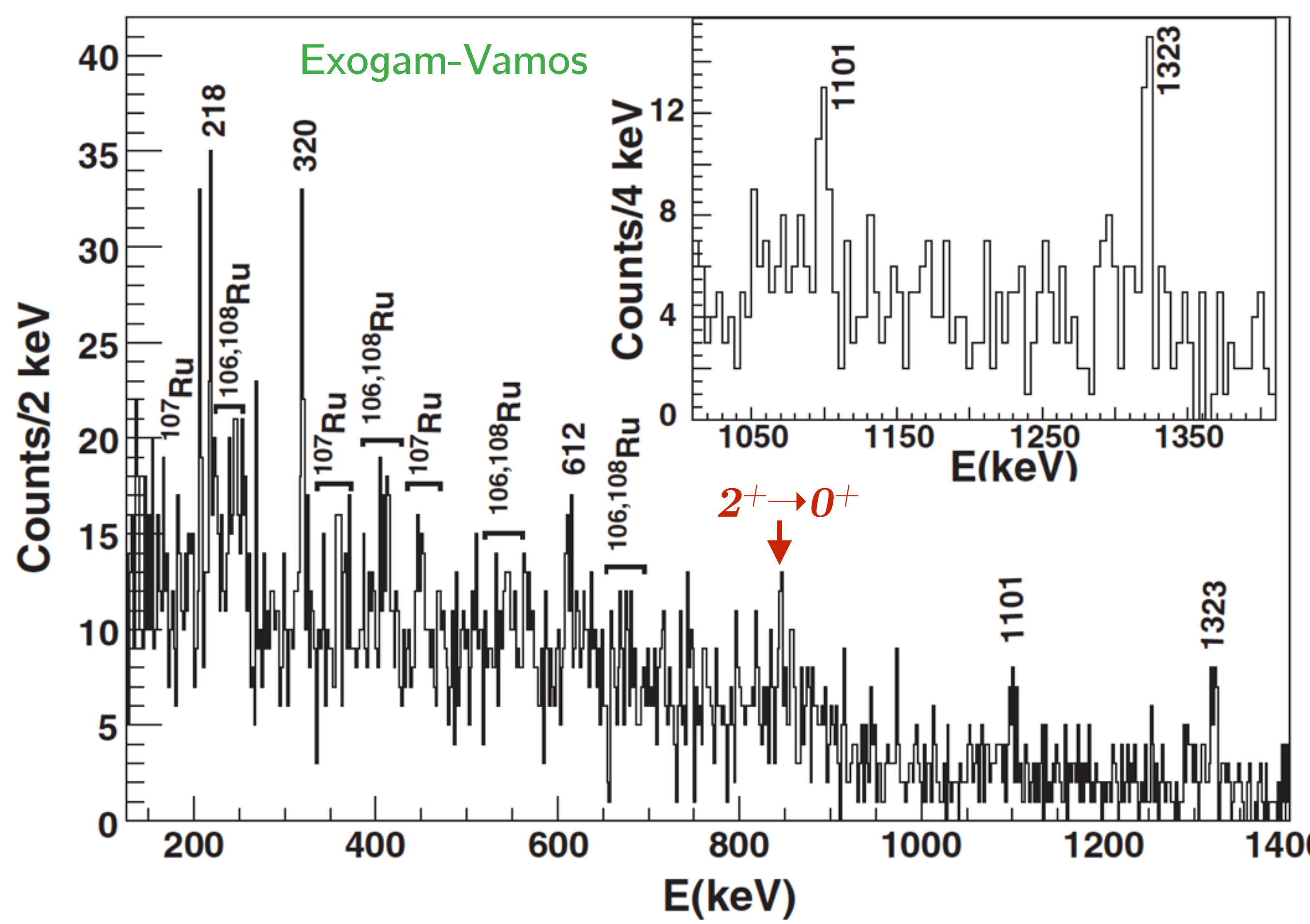




N. Fotiades *et al.*
PRC 75, 054322 (2007)

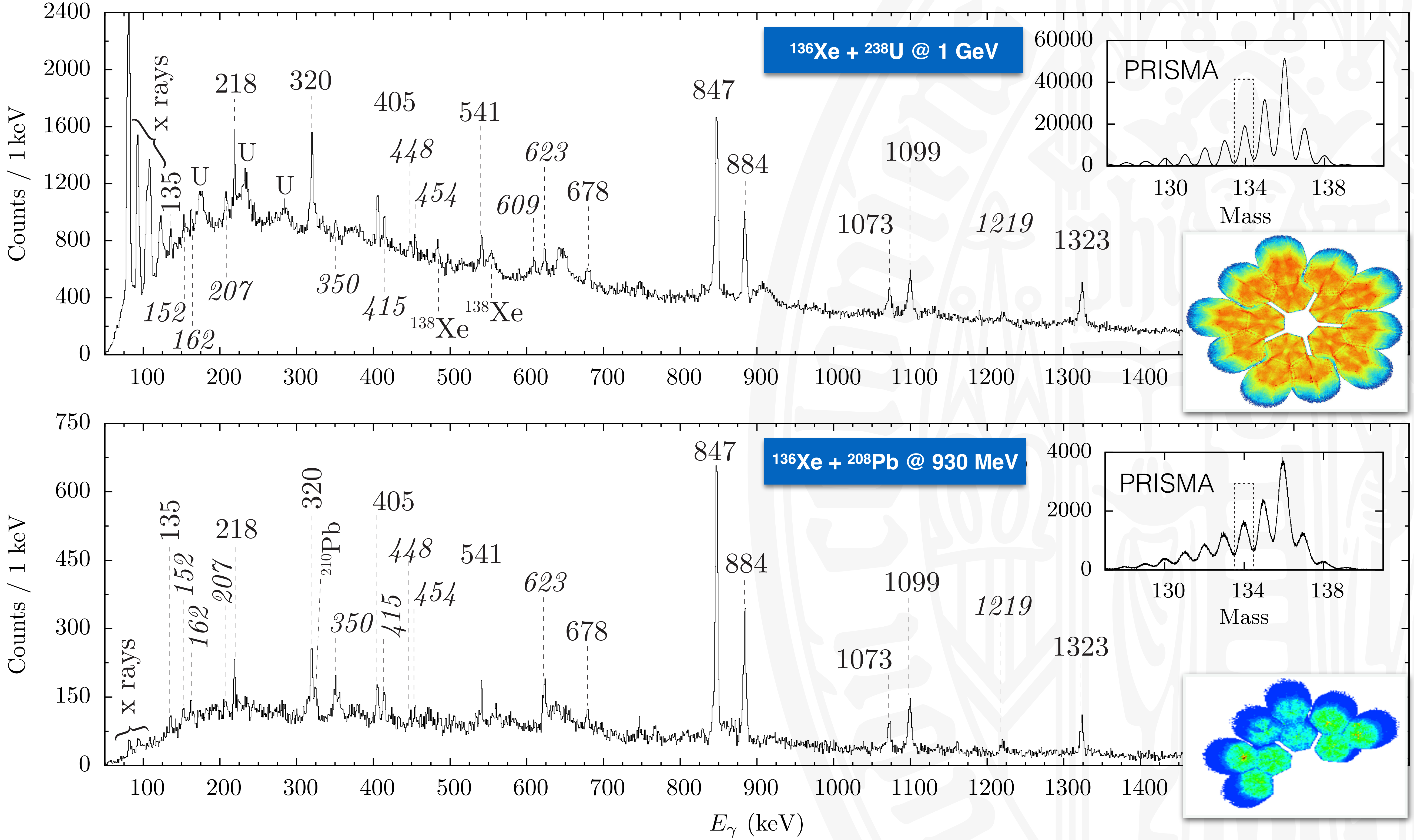


A. Shrivastava *et al.*
PRC 80, 051305(R) (2007)

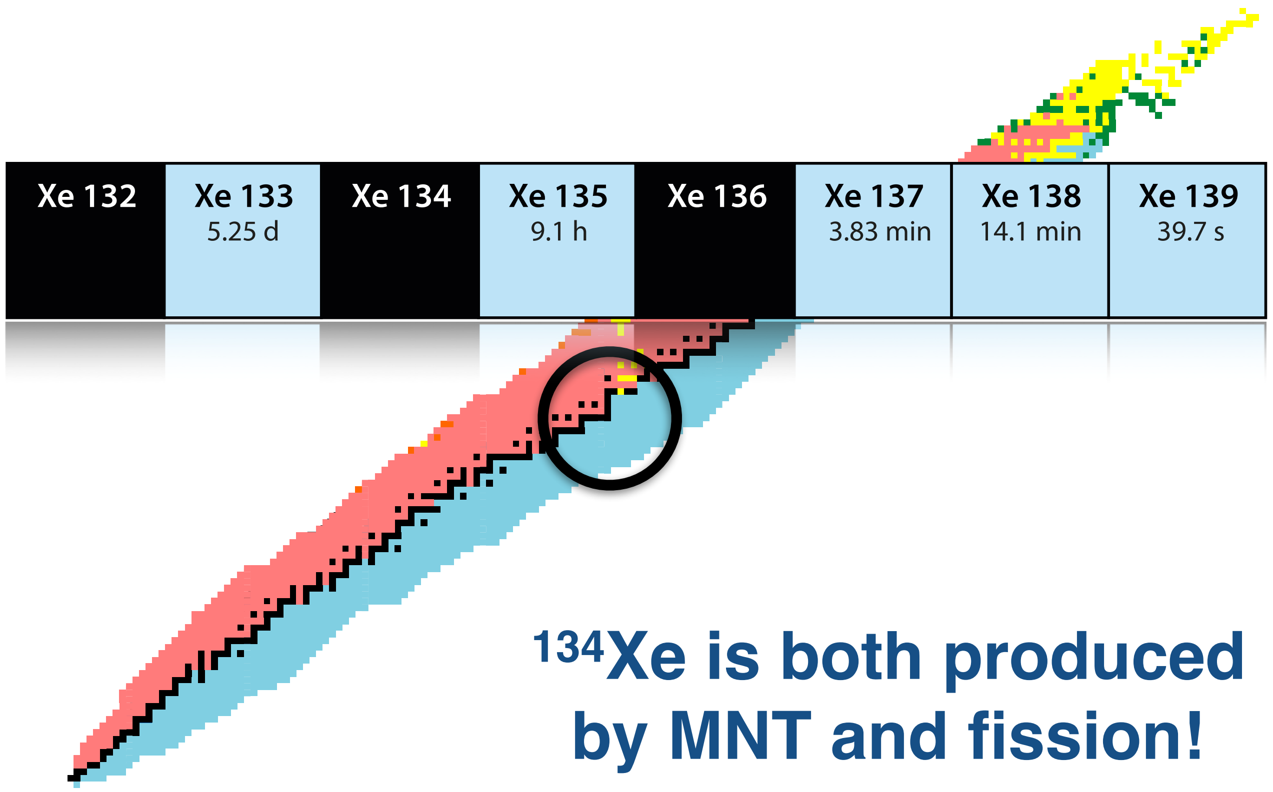


High-Spin Spectroscopy of ^{134}Xe

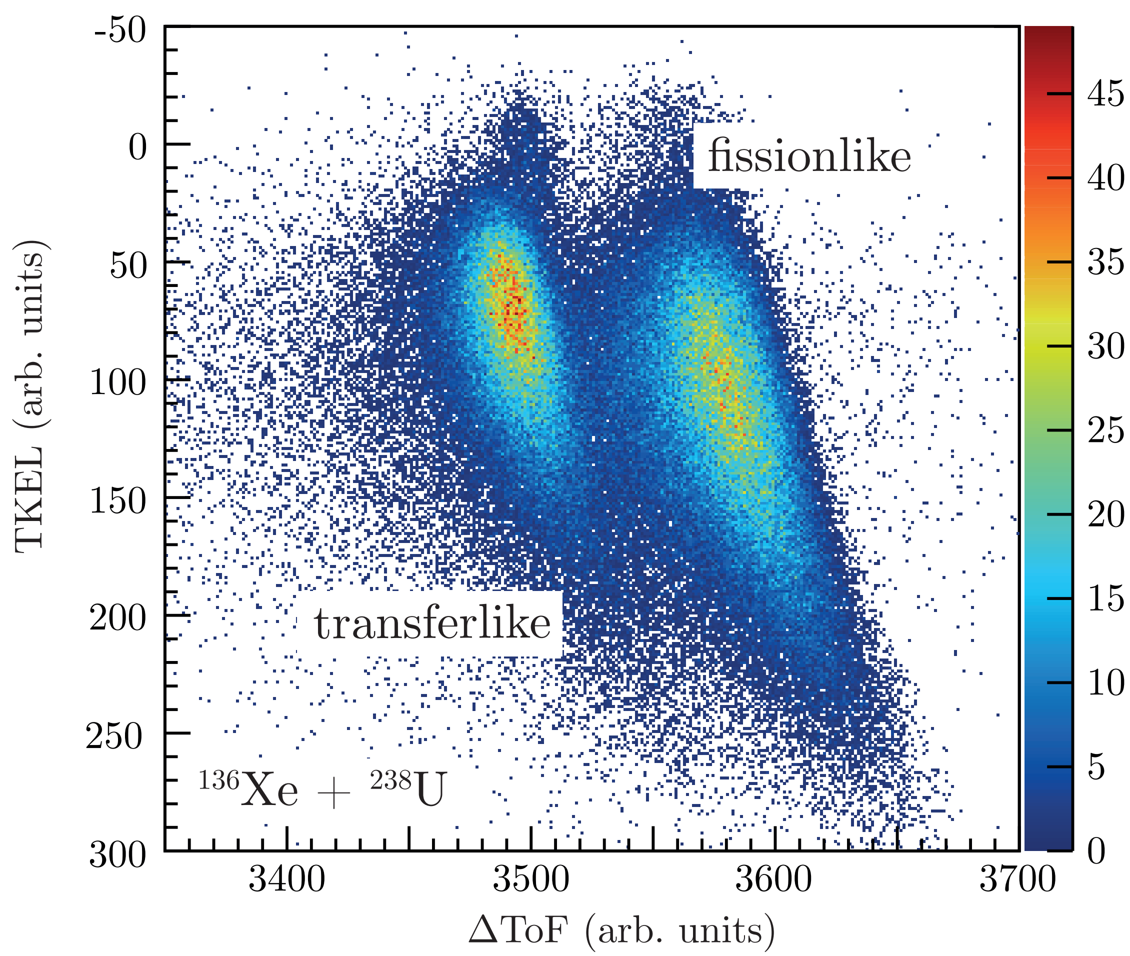
^{134}Xe

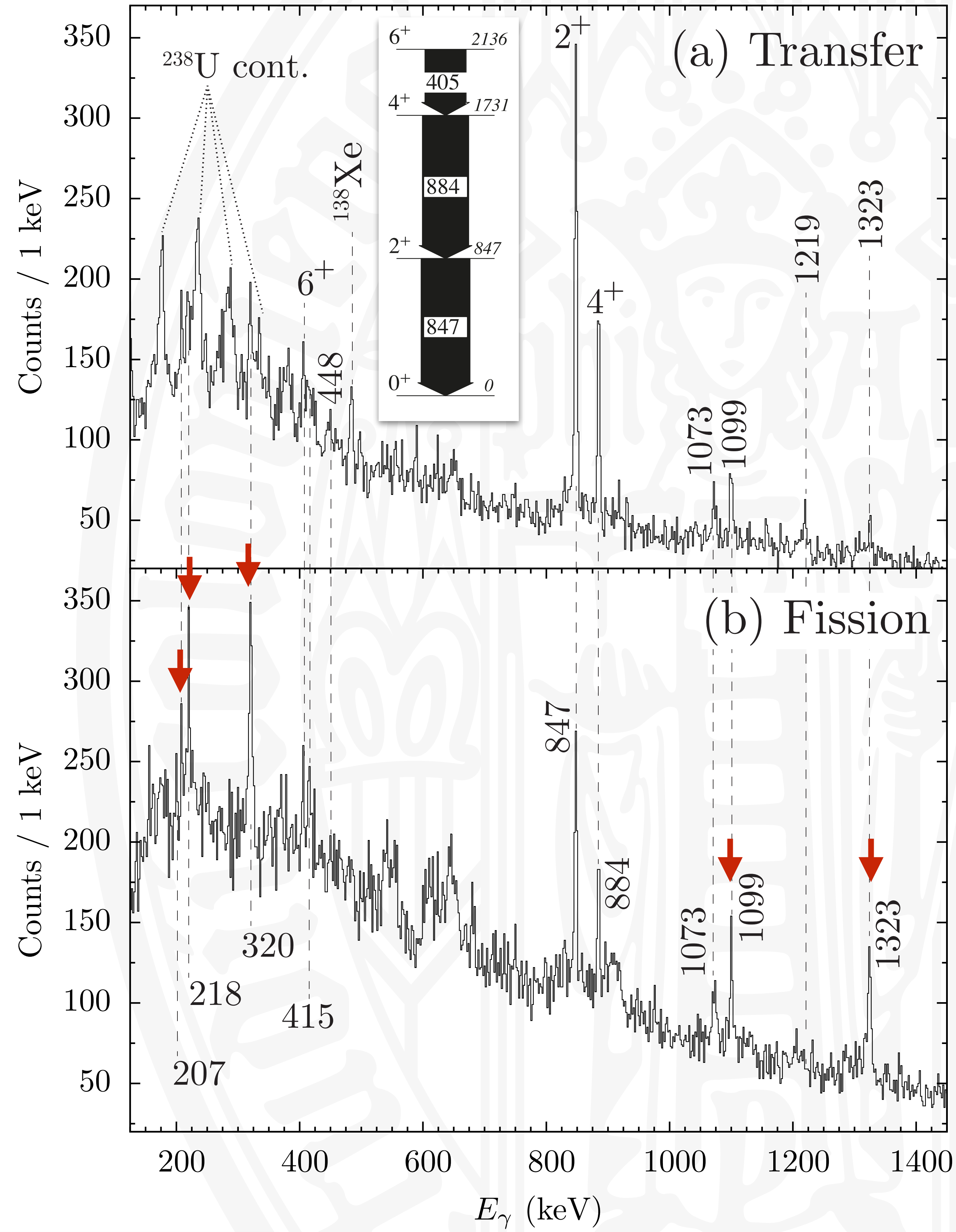


High-Spin Spectroscopy of ^{134}Xe

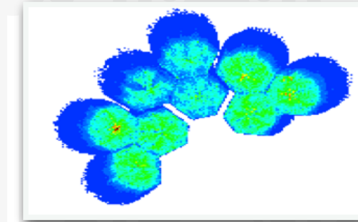


^{134}Xe is both produced by MNT and fission!

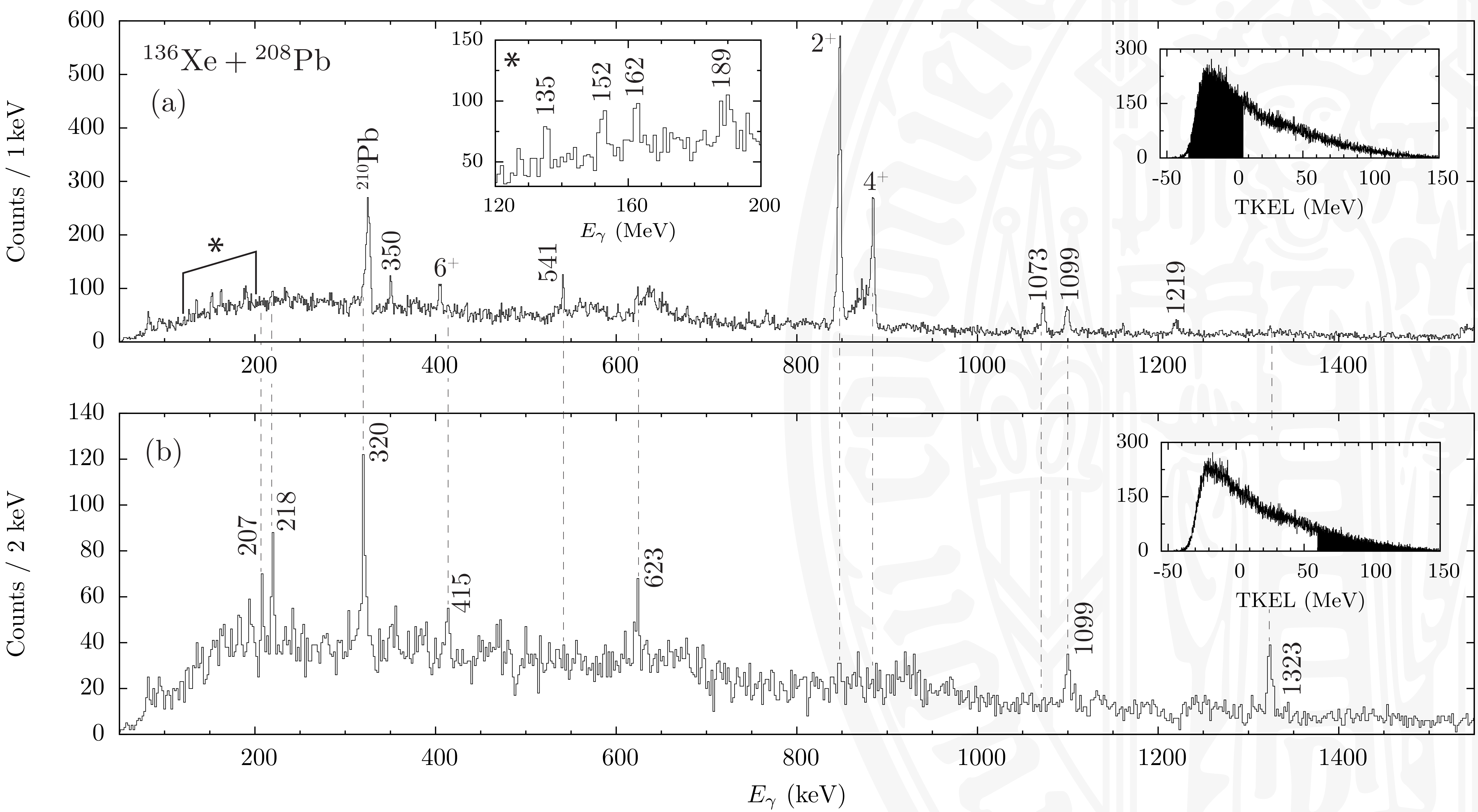




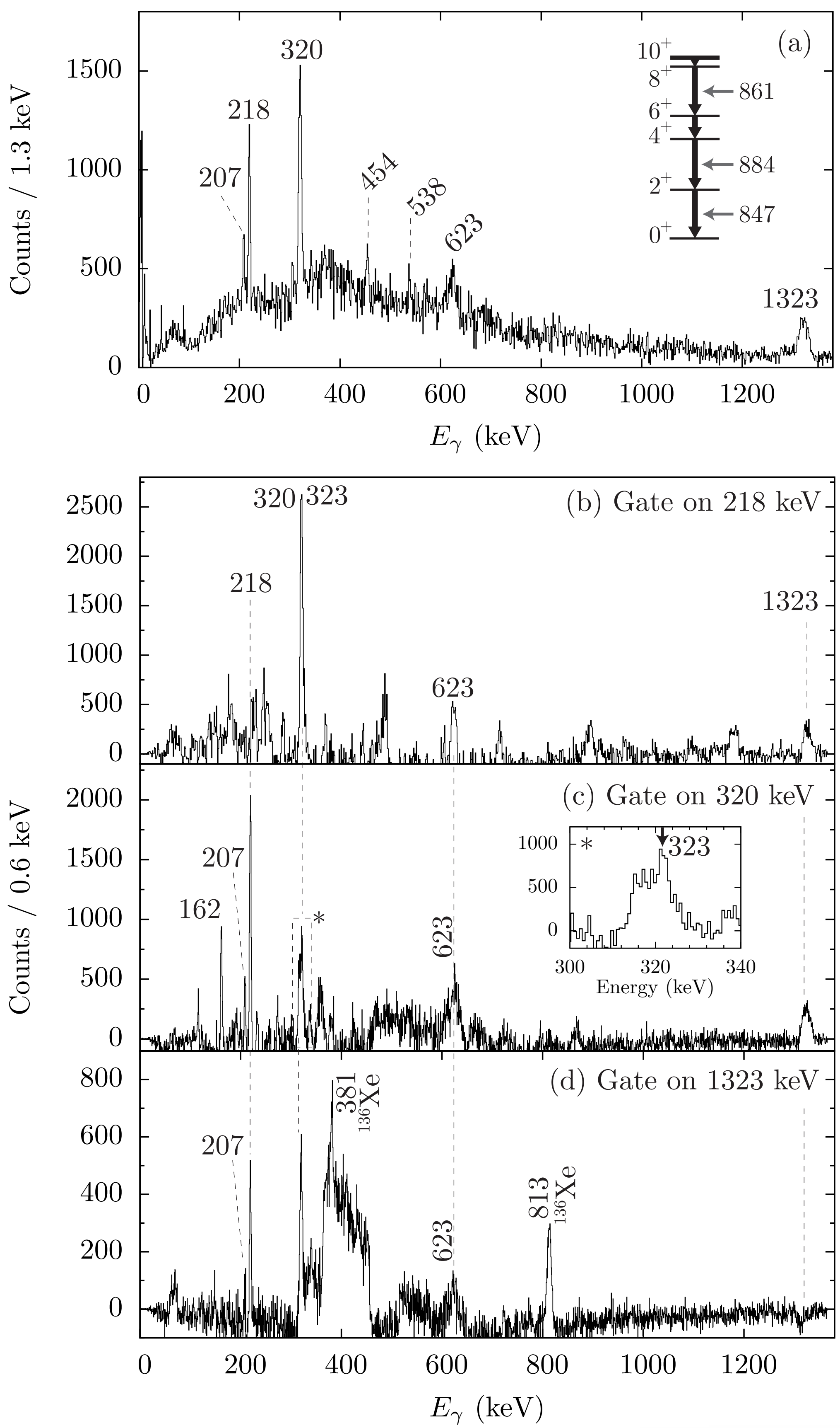
High-Spin Spectroscopy of ^{134}Xe

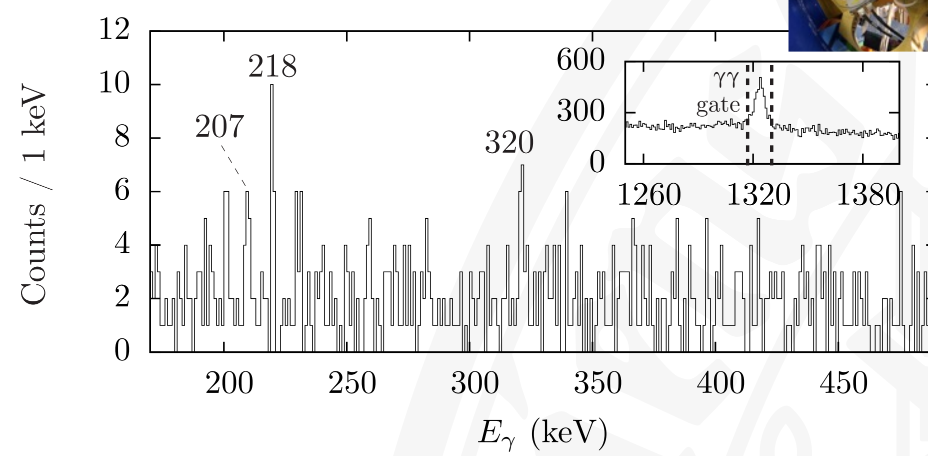


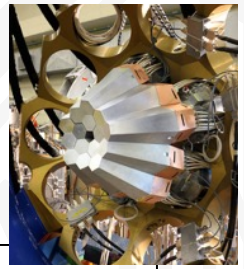
- Contrain excitation energies via Total Kinetic Energy Loss (TKEL)

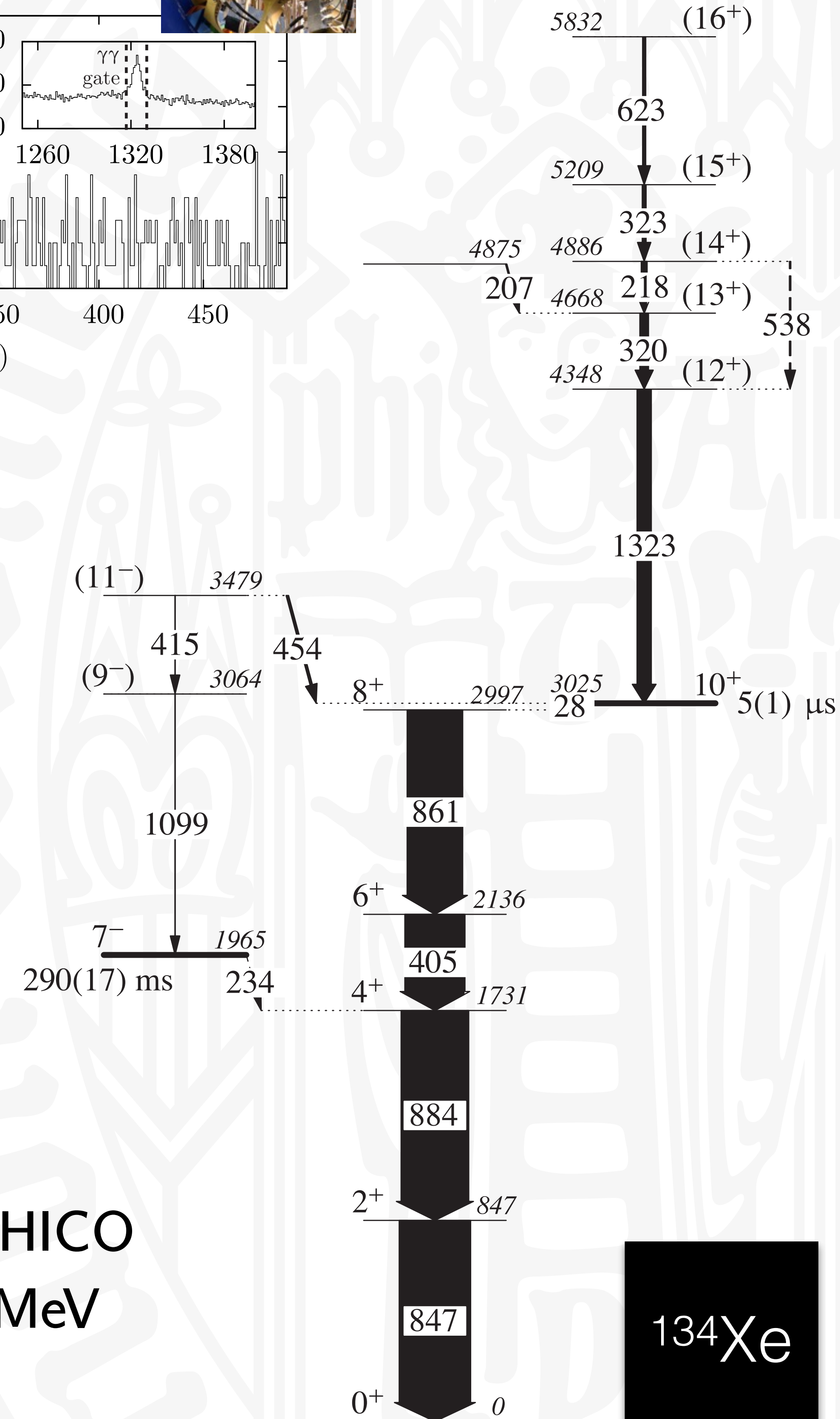


High-Spin Spectroscopy of ^{134}Xe









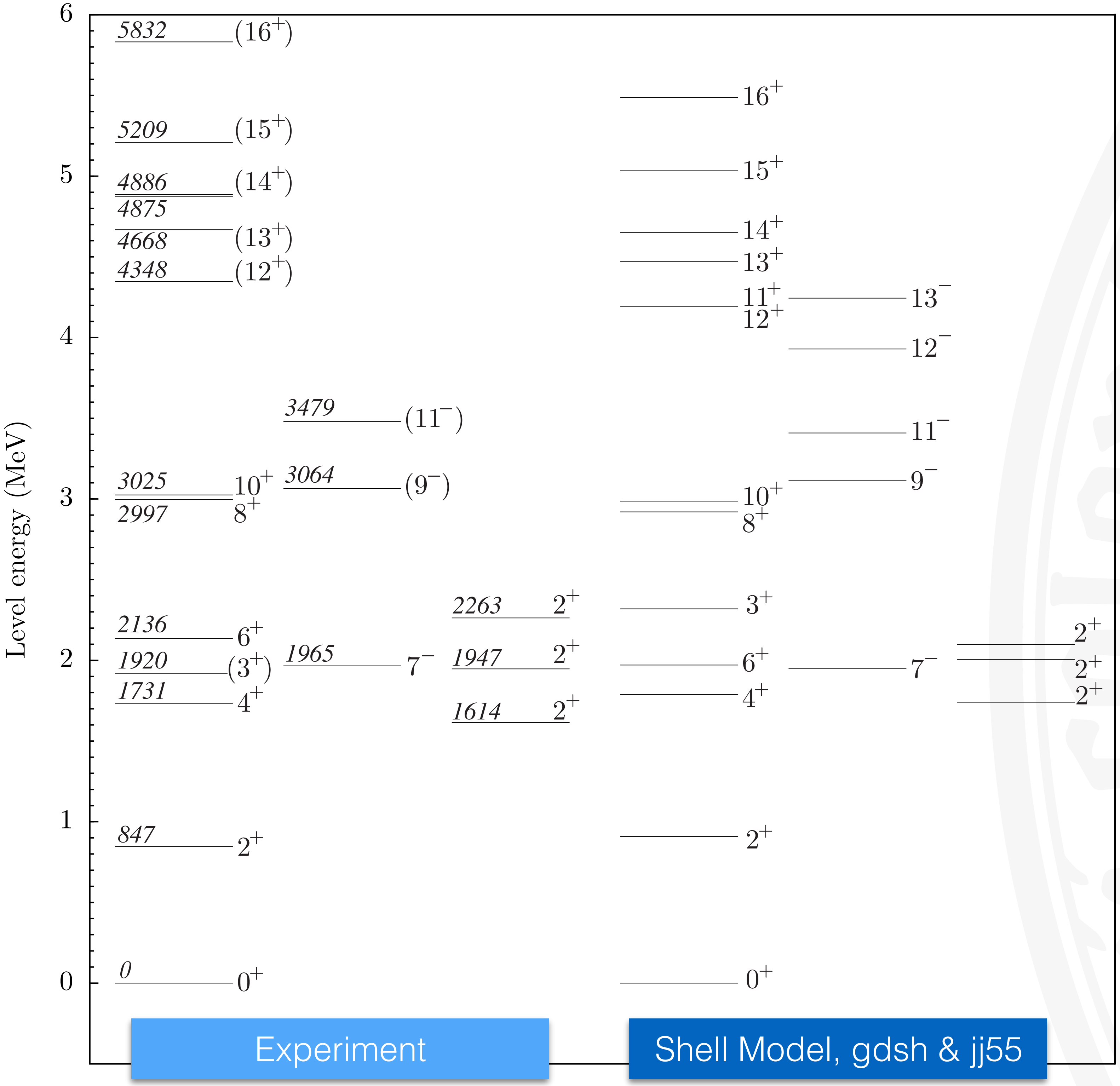
GAMMASPHERE+CHICO

^{136}Xe + ^{198}Pt @ 460 MeV

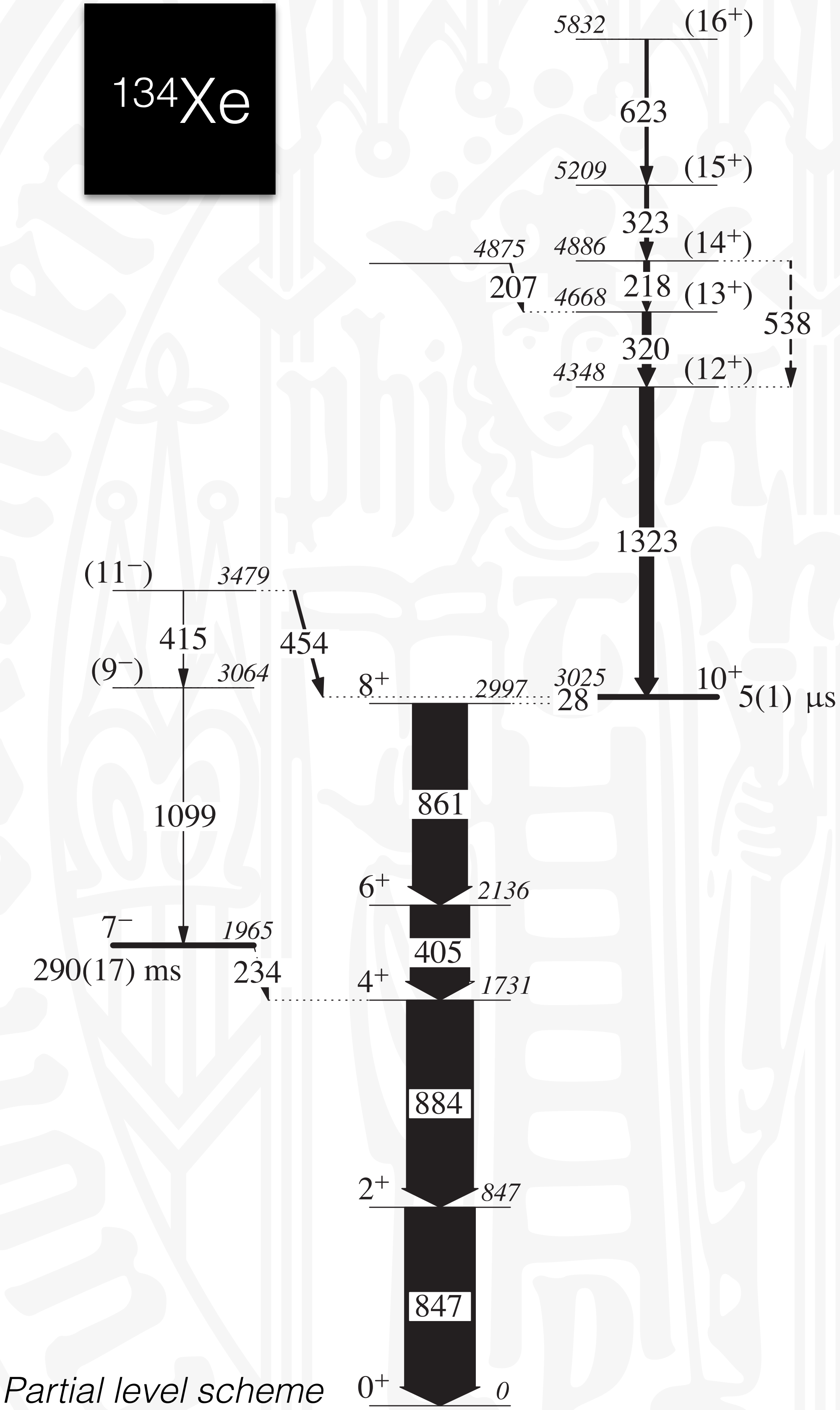
J.J. Valiente-Dobón *et al.*
PRC 69, 024316 (2004)

^{134}Xe

High-Spin Spectroscopy of ^{134}Xe



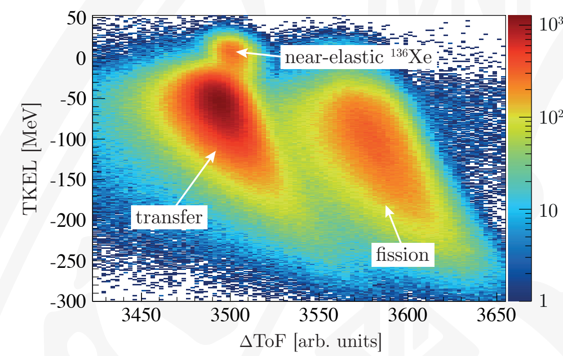
^{134}Xe

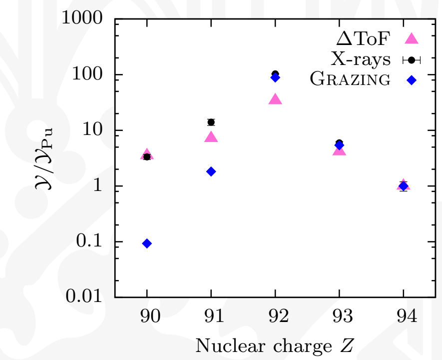


A. Vogt *et al.* Submitted to PRC. (2016)

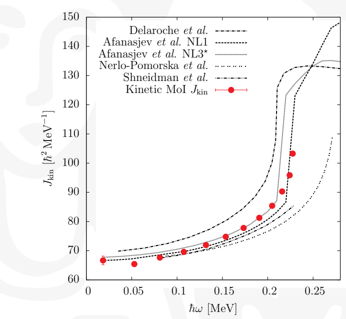
Summary

- Study of multinucleon transfer and fission properties of ^{136}Xe + ^{238}U
- Discrimination of fission and transfer





- Actinide survivability against fission
- Gamma-ray spectroscopy of neutron-rich ^{240}U after MNT

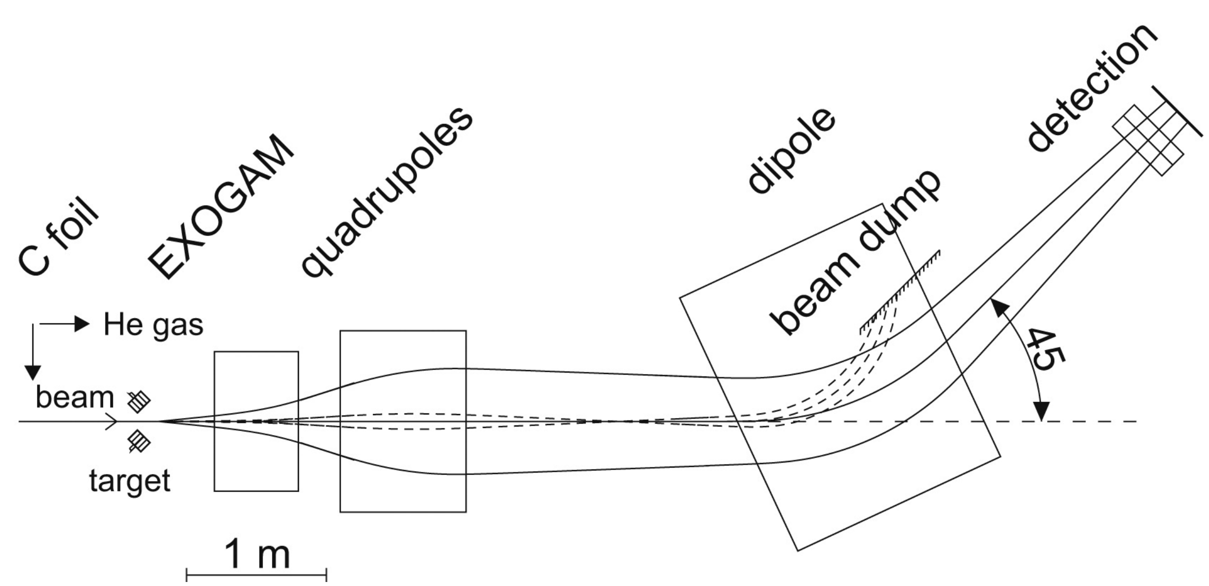


- Nuclear structure on top of isomers in ^{134}Xe

Xe 132	Xe 133	Xe 134	Xe 135	Xe 136	Xe 137	Xe 138	Xe 139
	5.25 d		9.1 h		3.83 min	14.1 min	39.7 s

Outlook

- Now: AGATA@GANIL with 32 crystals
- VAMOS in gas-filled mode and tagging station 2018+



Summary

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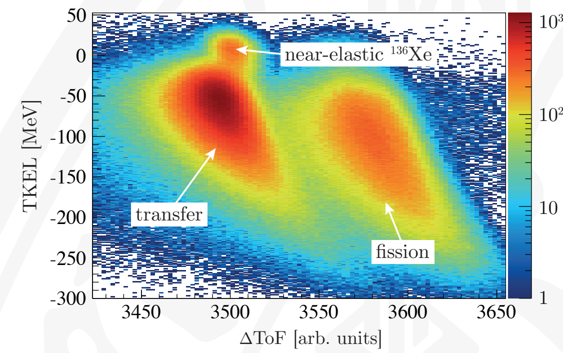

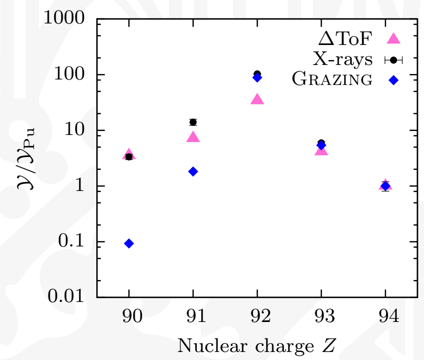

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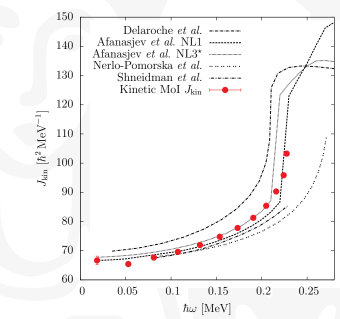


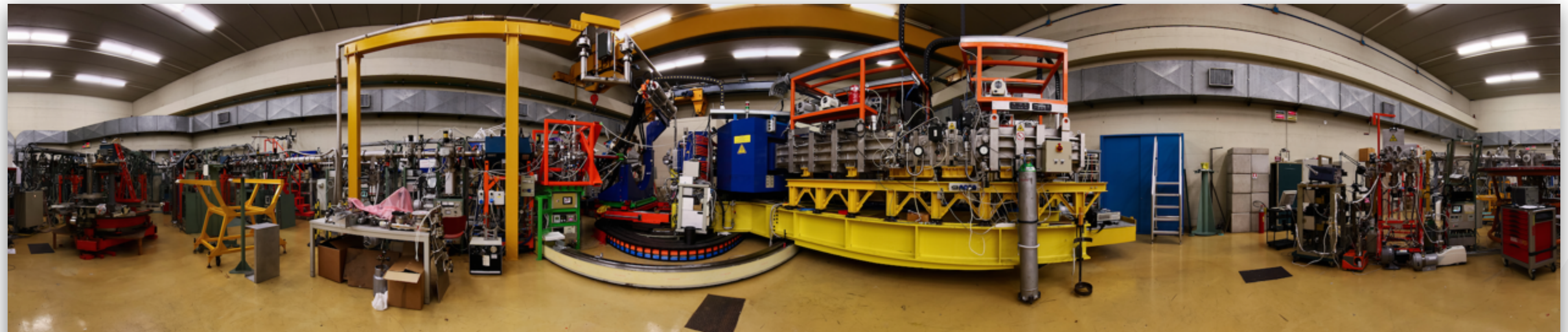
- Nuclear structure on top of isomers in ^{134}Xe

Xe 132	Xe 133	Xe 134	Xe 135	Xe 136	Xe 137	Xe 138	Xe 139
	5.25 d		9.1 h		3.83 min	14.1 min	39.7 s

Towards HISPEC@FAIR:
Opportunities and first results with AGATA

Christian Stahl — Institut für Kernphysik, TU Darmstadt

HK 46.3 12:00 — 12:30 S1/01 A1



Thank you for your attention!

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Publications

MNT reaction study

A. Vogt *et al.*
PRC. 92, 024619 (2015)

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^{240}U spectroscopy

B. Birkenbach *et al.*
PRC. 92, 044319 (2015)

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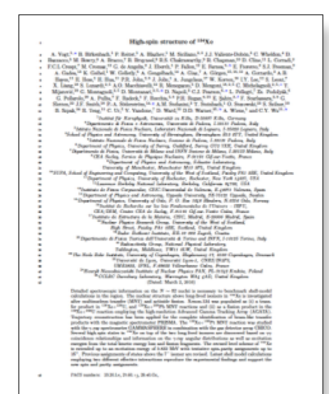

High-spin structure of ^{134}Xe

A. Vogt *et al.*
submitted to PRC

Universität zu Köln

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AGATA ADVANCED GAMMA TRACKING ARRAY

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