

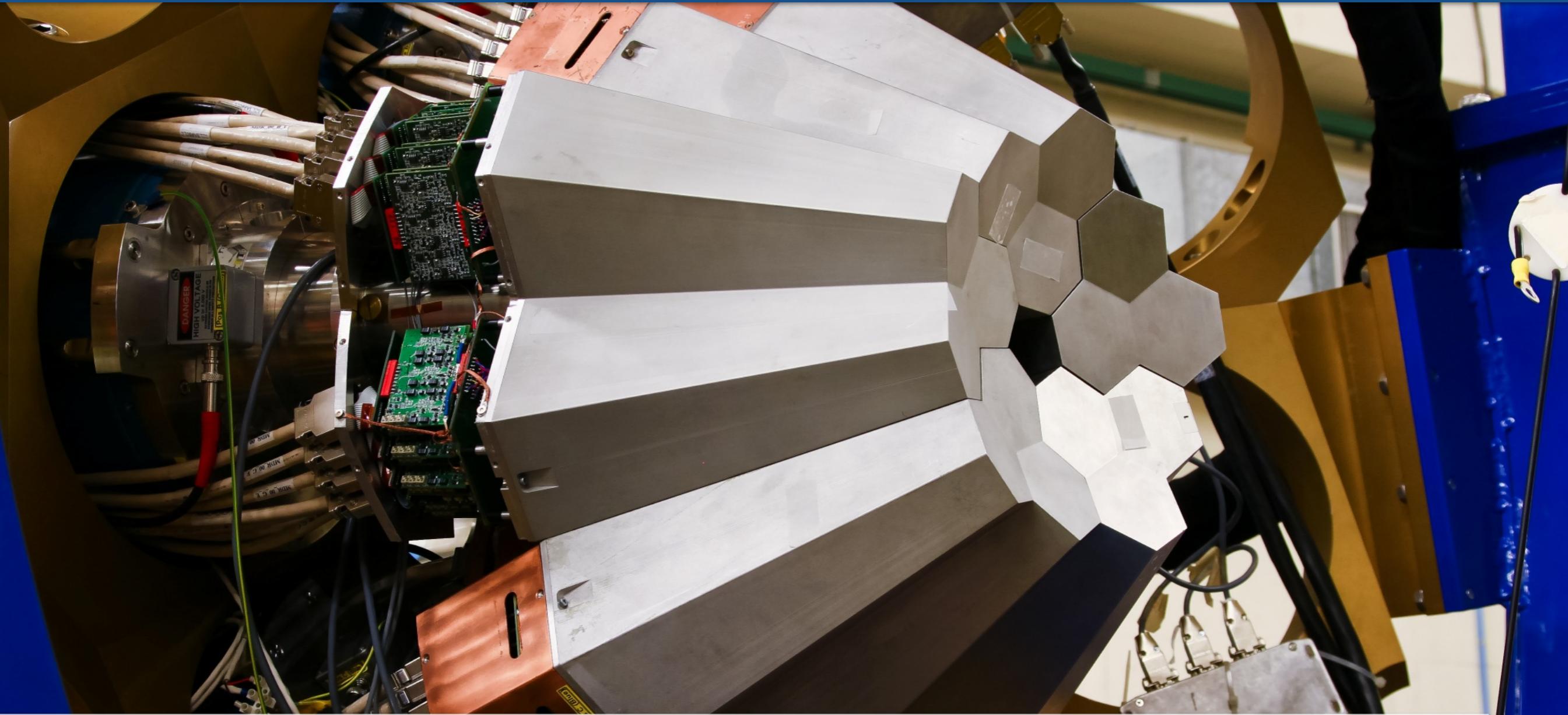
# Spectroscopy of Light and Heavy Transfer Products in Multinucleon-Transfer Reactions

Andreas Vogt

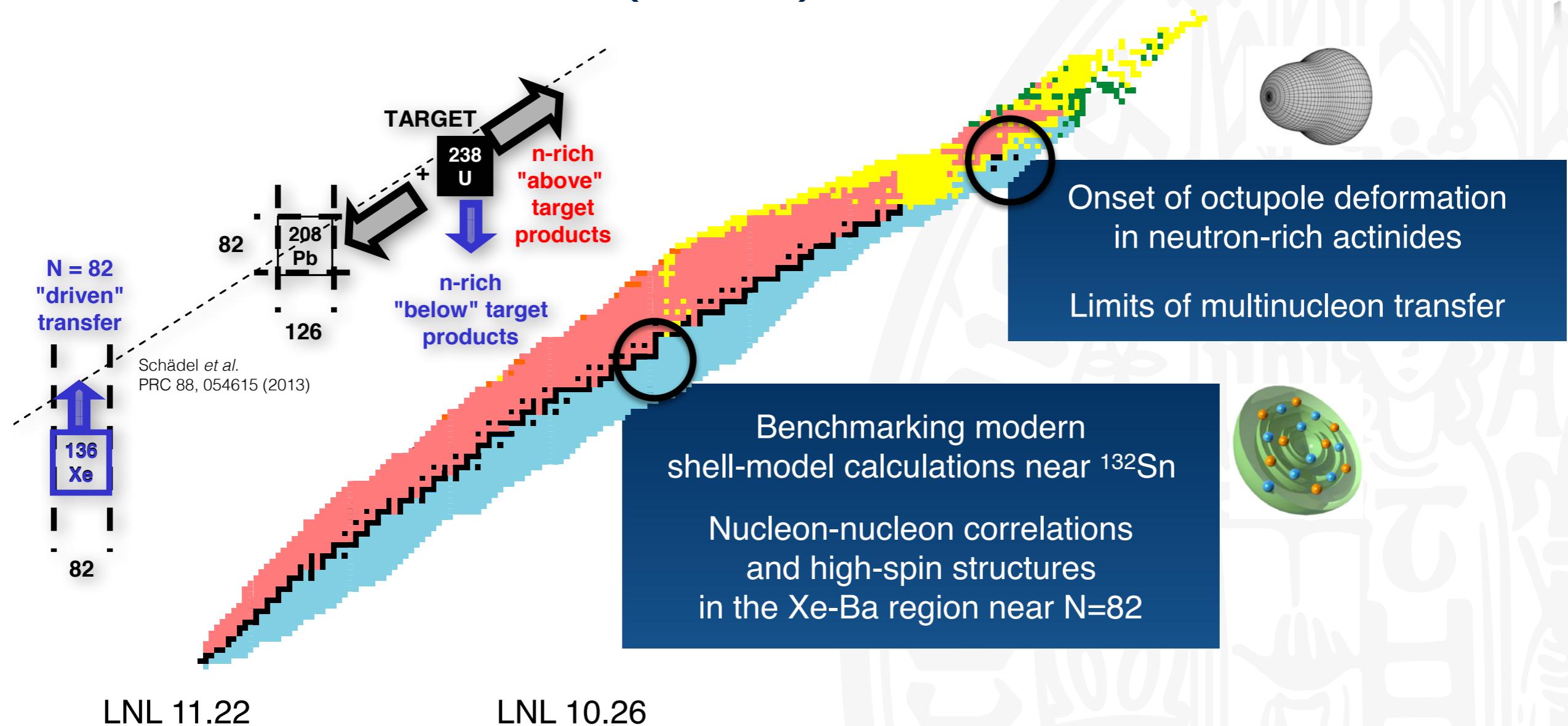


NUSPIN 2016 Kick-off Workshop and AGATA Physics Workshop  
San Servolo - 29 June 2016

Institute for Nuclear Physics  
University of Cologne



# M multinucleon Transfer (MNT) in the Actinide Region



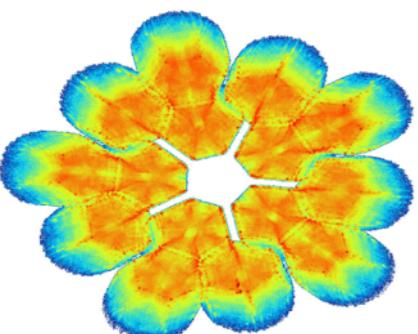
$^{136}\text{Xe} + ^{238}\text{U}$  @ 1 GeV  
full AGATA demonstrator  
+ PRISMA

$^{136}\text{Xe} + ^{208}\text{Pb}$  @ 930 MeV  
three triple clusters  
+ PRISMA

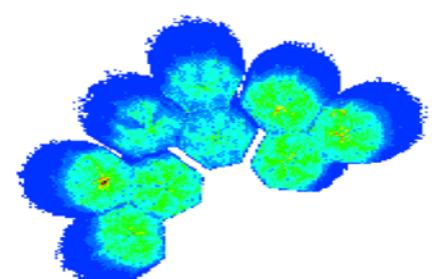
+

$^{70}\text{Zn} + ^{238}\text{U}$  @ 860 MeV  
CLARA  
+ PRISMA

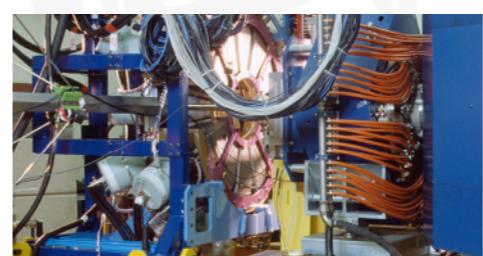
$^{136}\text{Xe} + ^{198}\text{Pt}$  @ 850 MeV  
GAMMASPHERE  
+ CHICO



M. Siciliano et al. INFN-LNL Rep. 241 63 (2015)

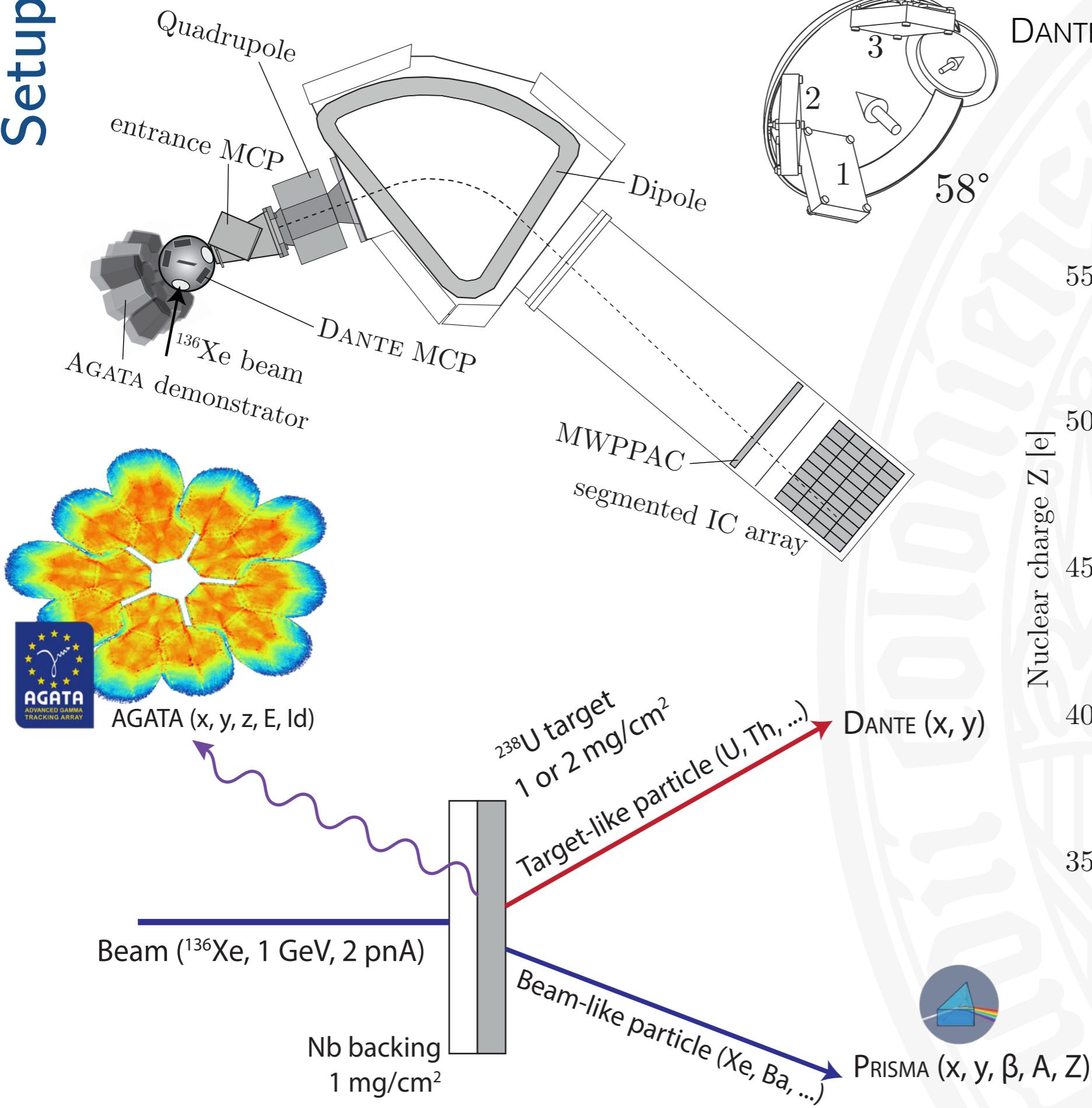


K. Geibel. PhD thesis. Univ. Köln (2012)

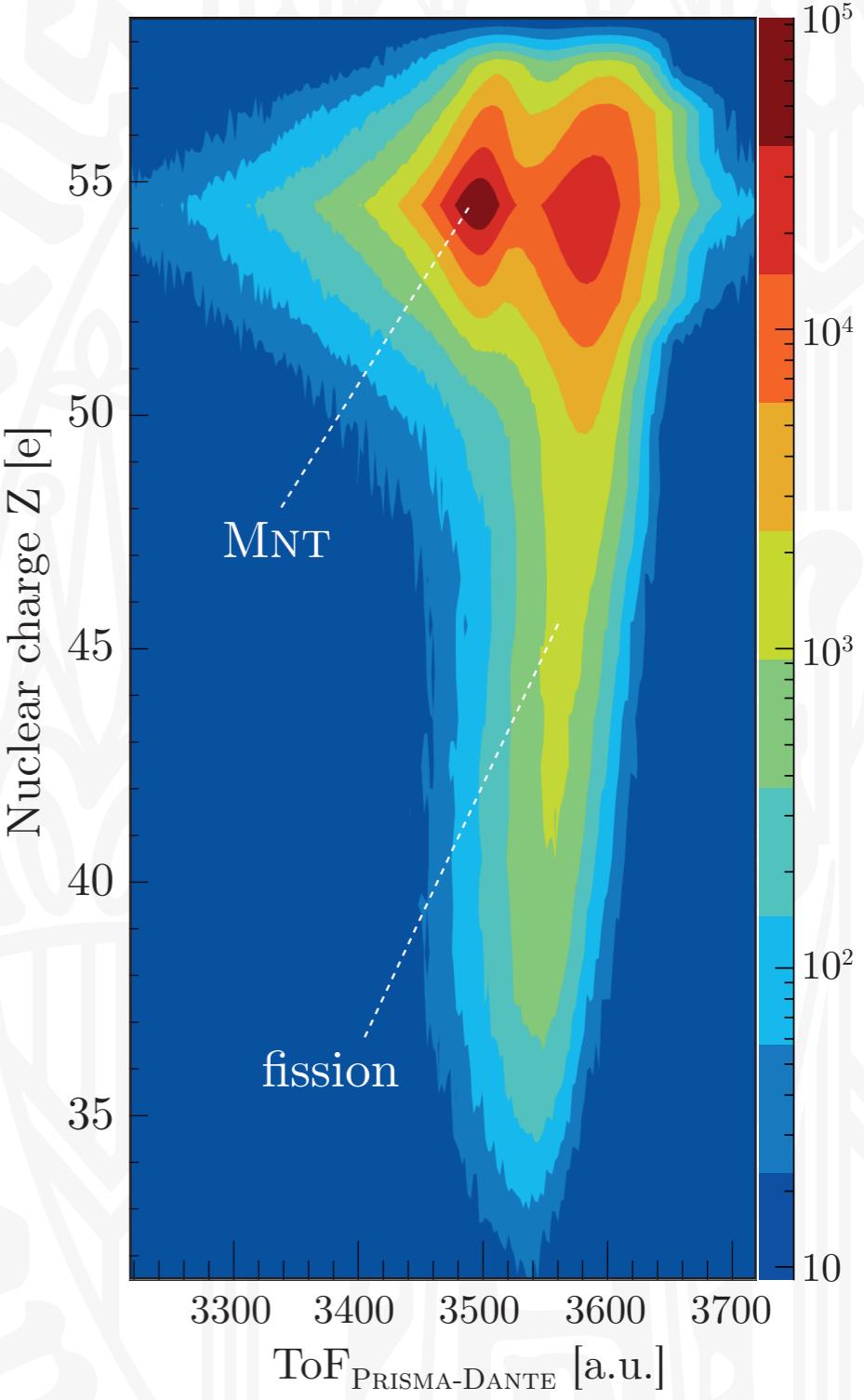


J.J. Valiente-Dobón et al.  
PRC 69, 024316 (2004)

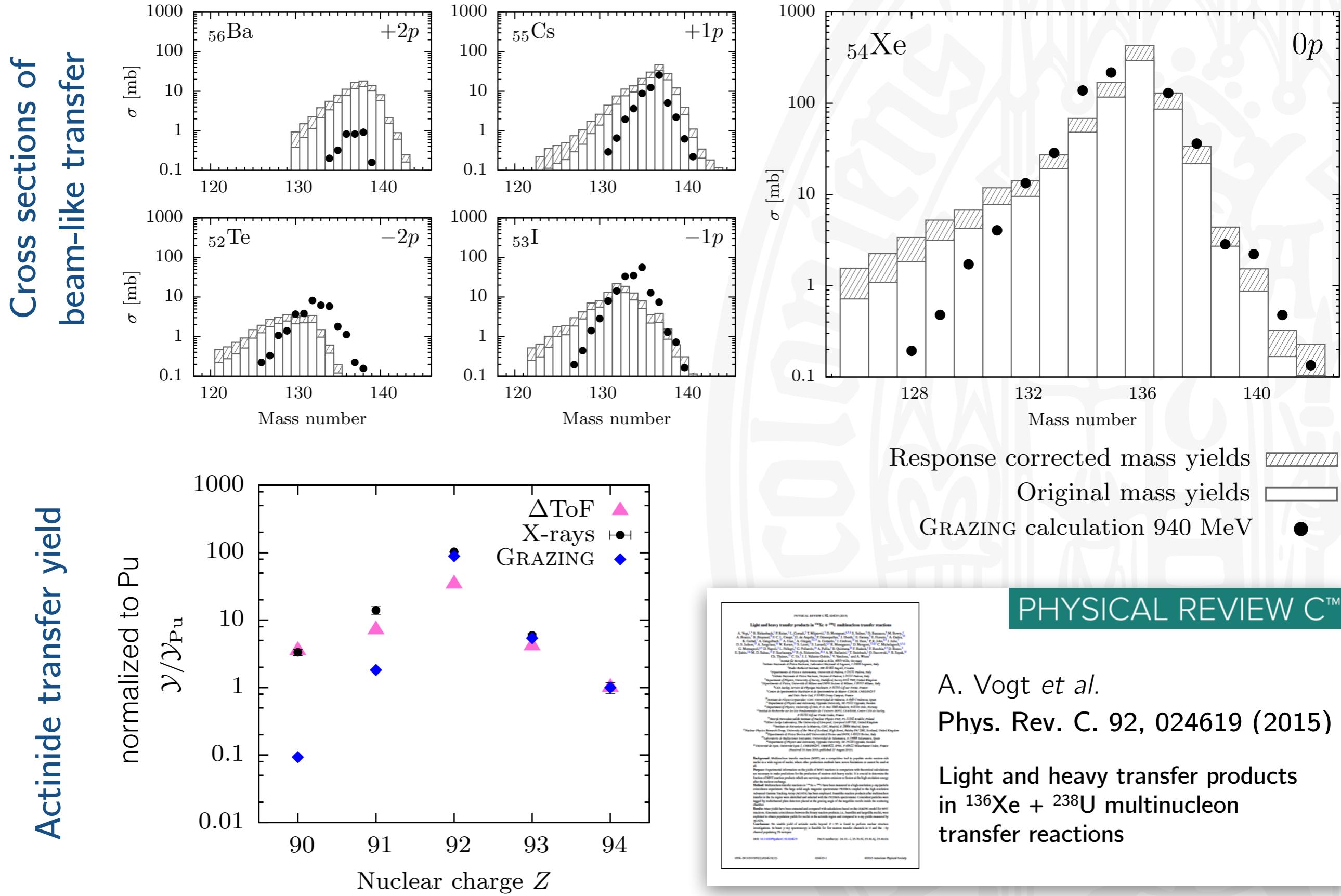
# Setup



DANTE MCPs



# Features of Multinucleon Transfer



# Theoretical Predictions for the Actinide Region

## Mean Field Calculations

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

## Macroscopic Microscopic

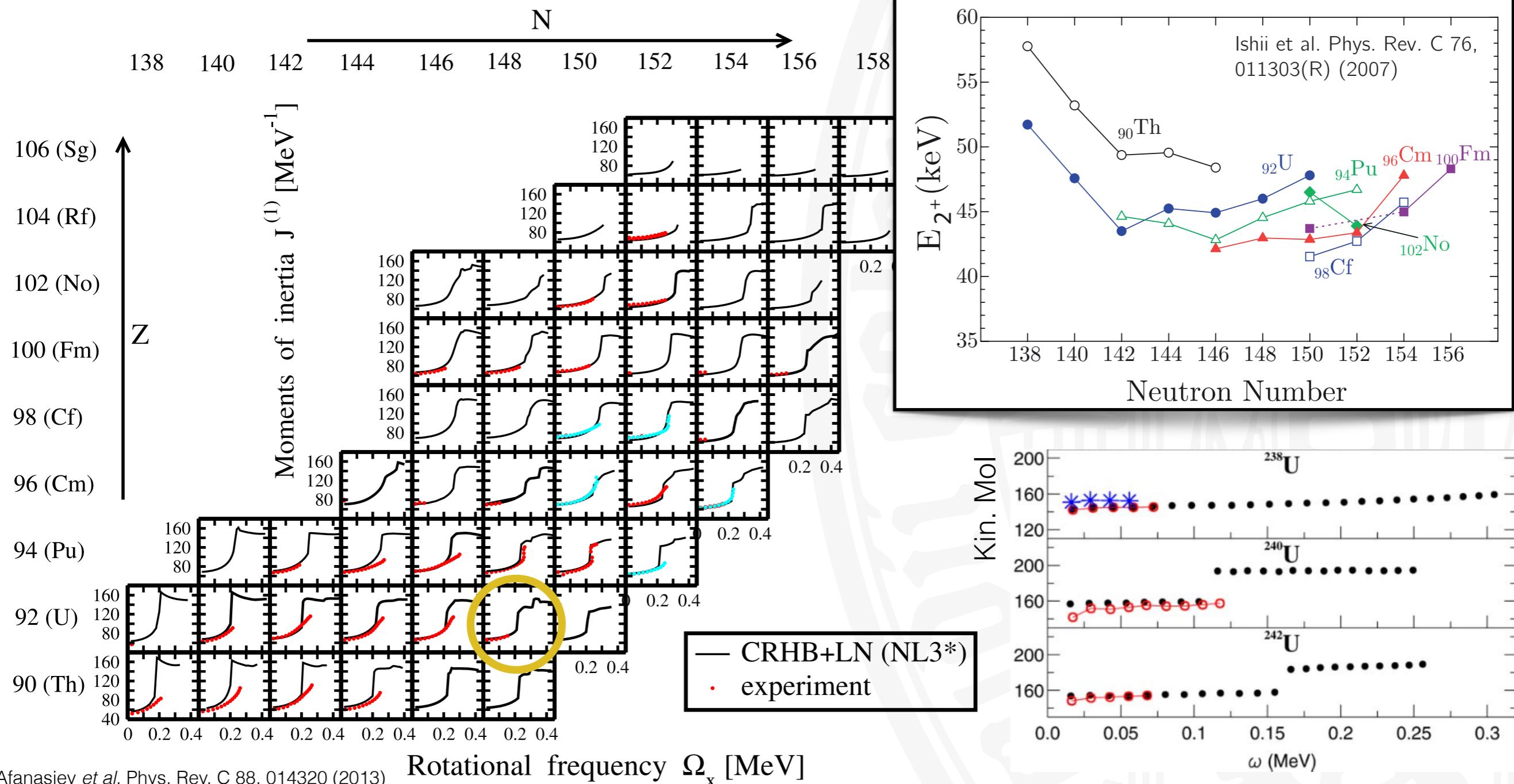
Nerlo-Pomorska *et al.*  
Phys. Rev. C 84, 044310 (2011)

## Cluster Model

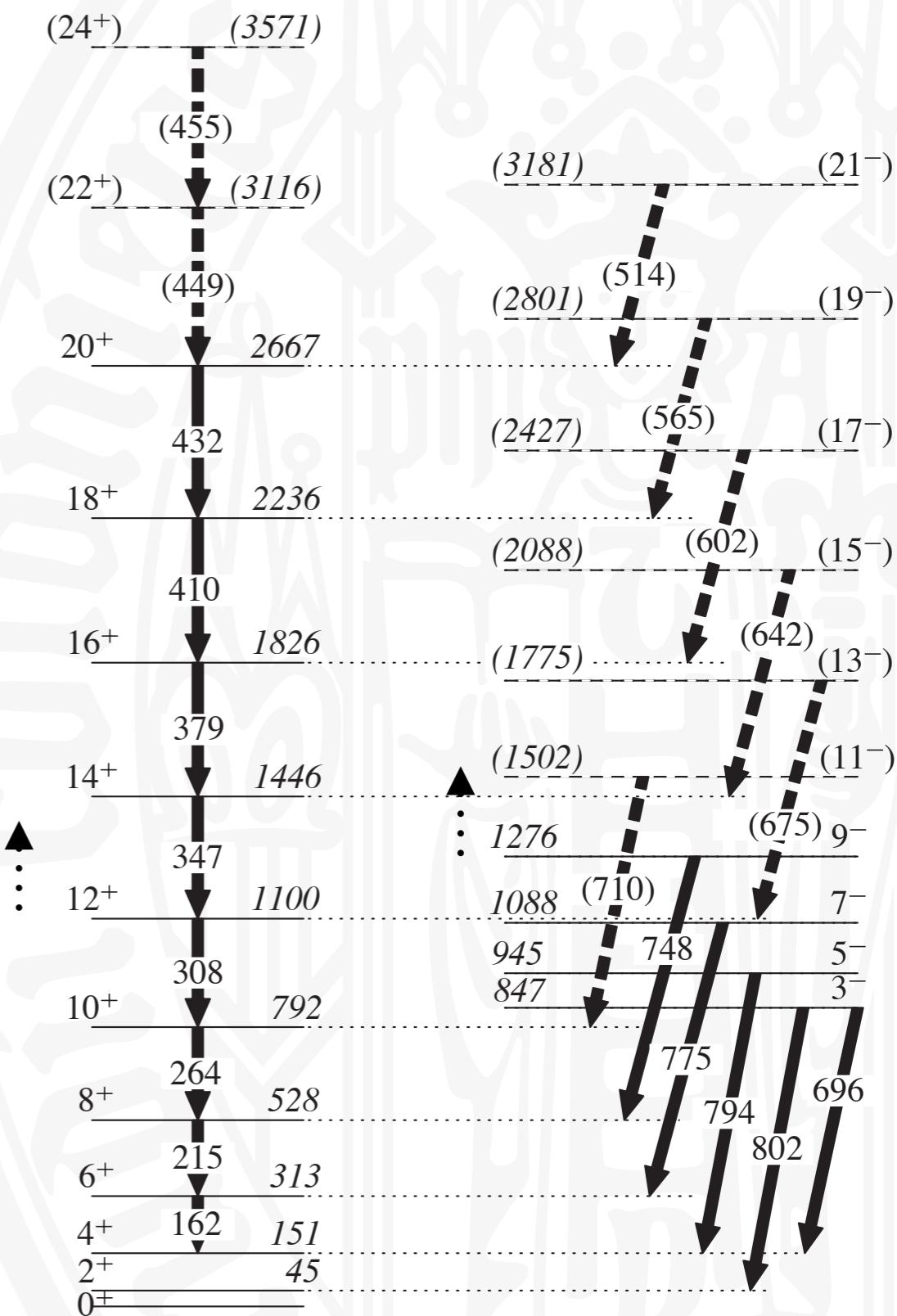
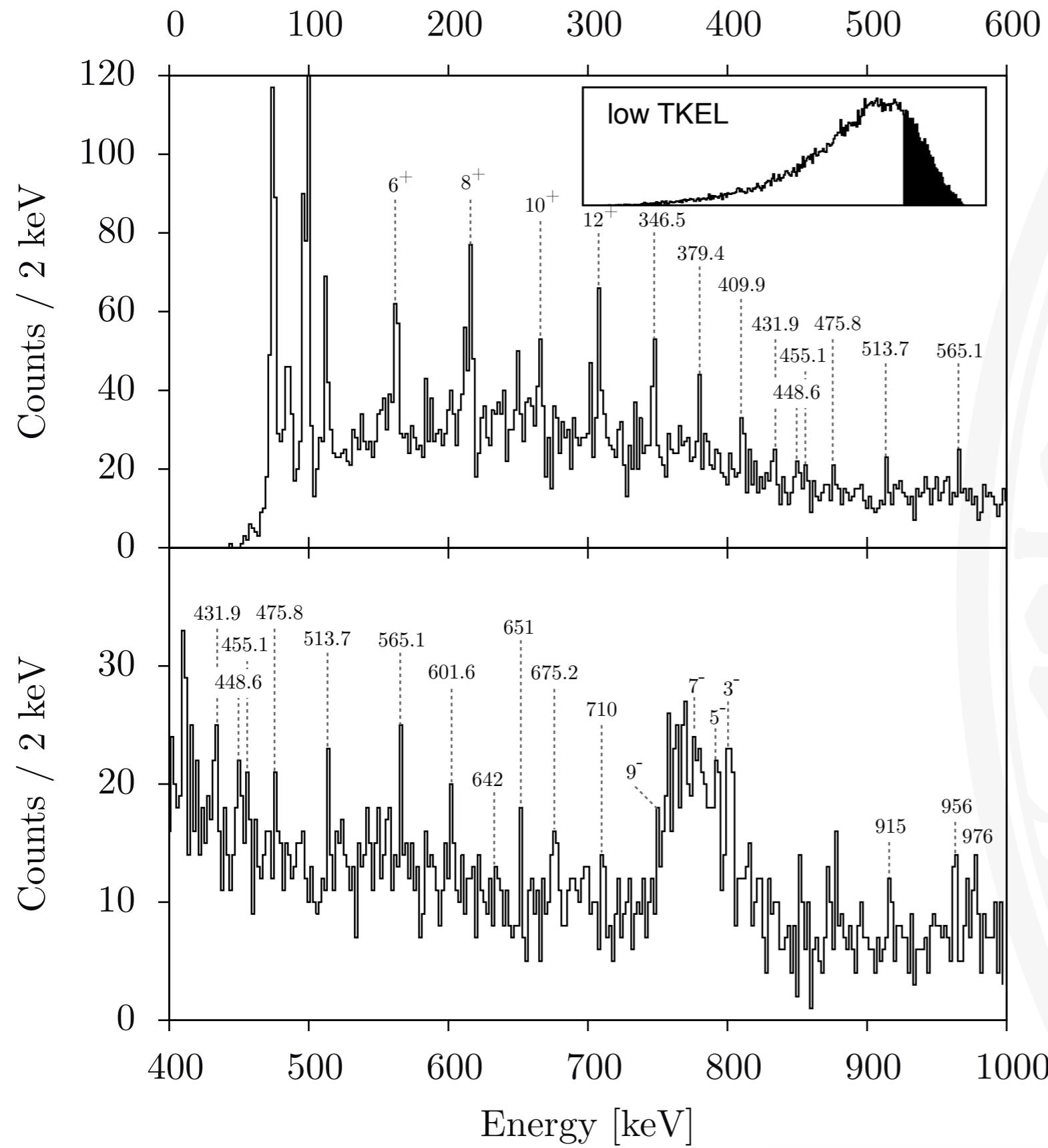
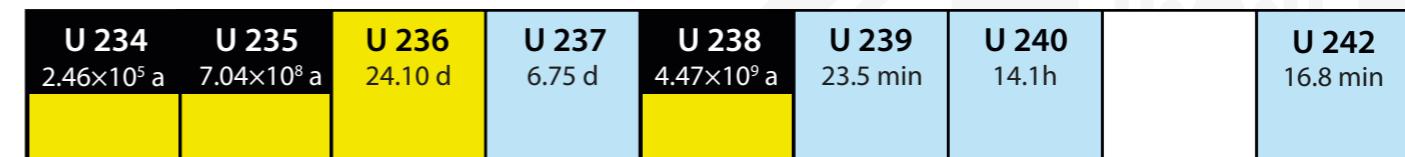
Shneidman *et al.*  
Phys. Rev. C 74, 034316 (2006)

## Density Functionals

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

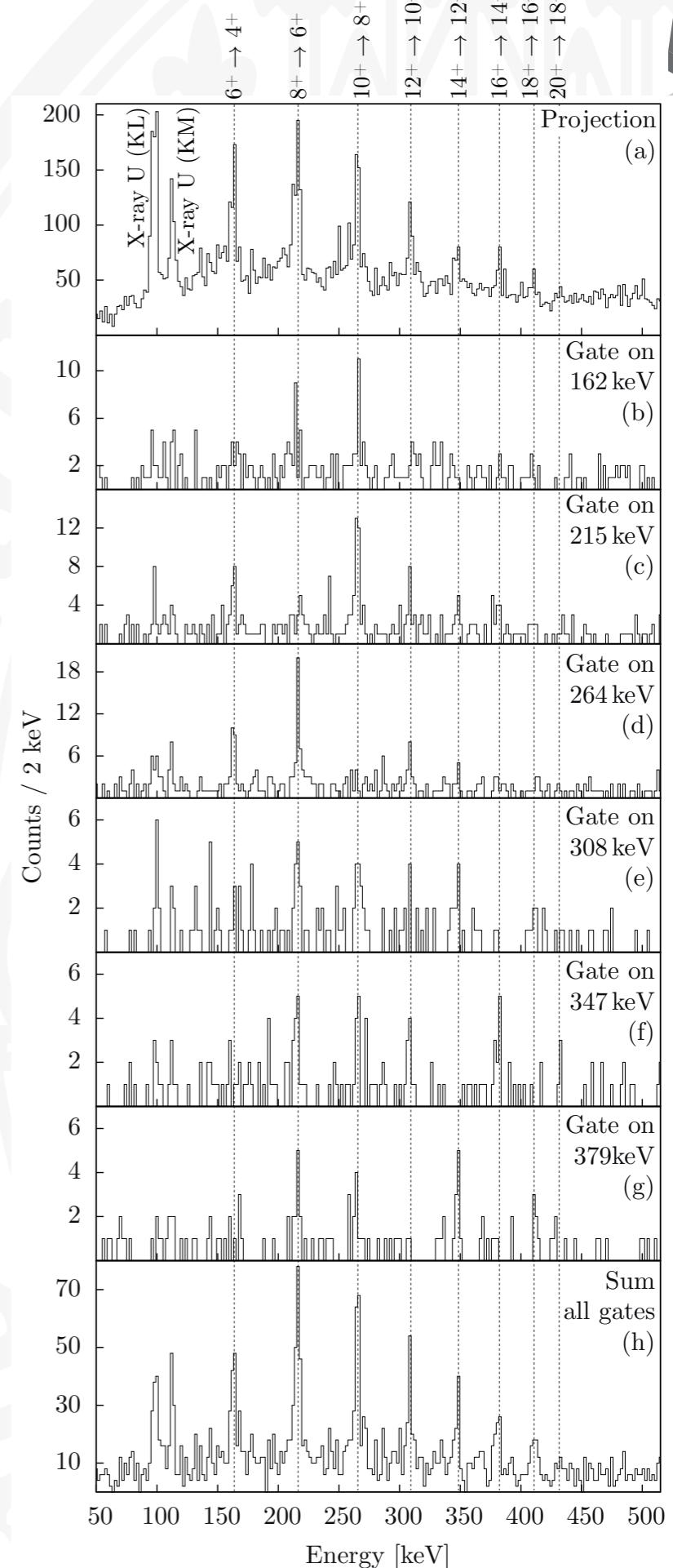
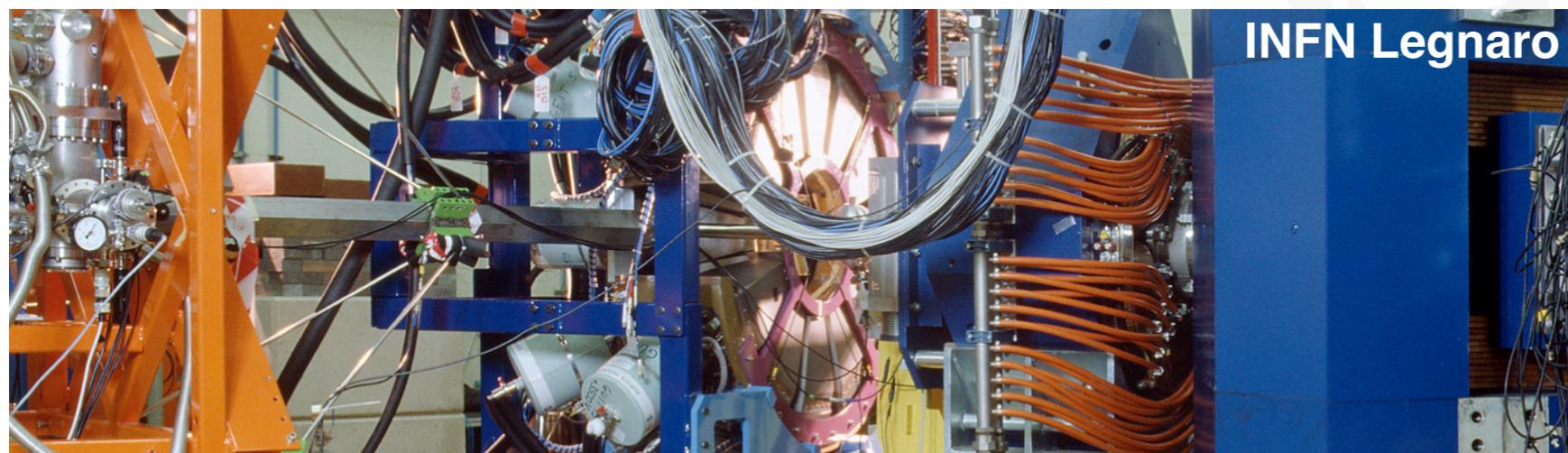
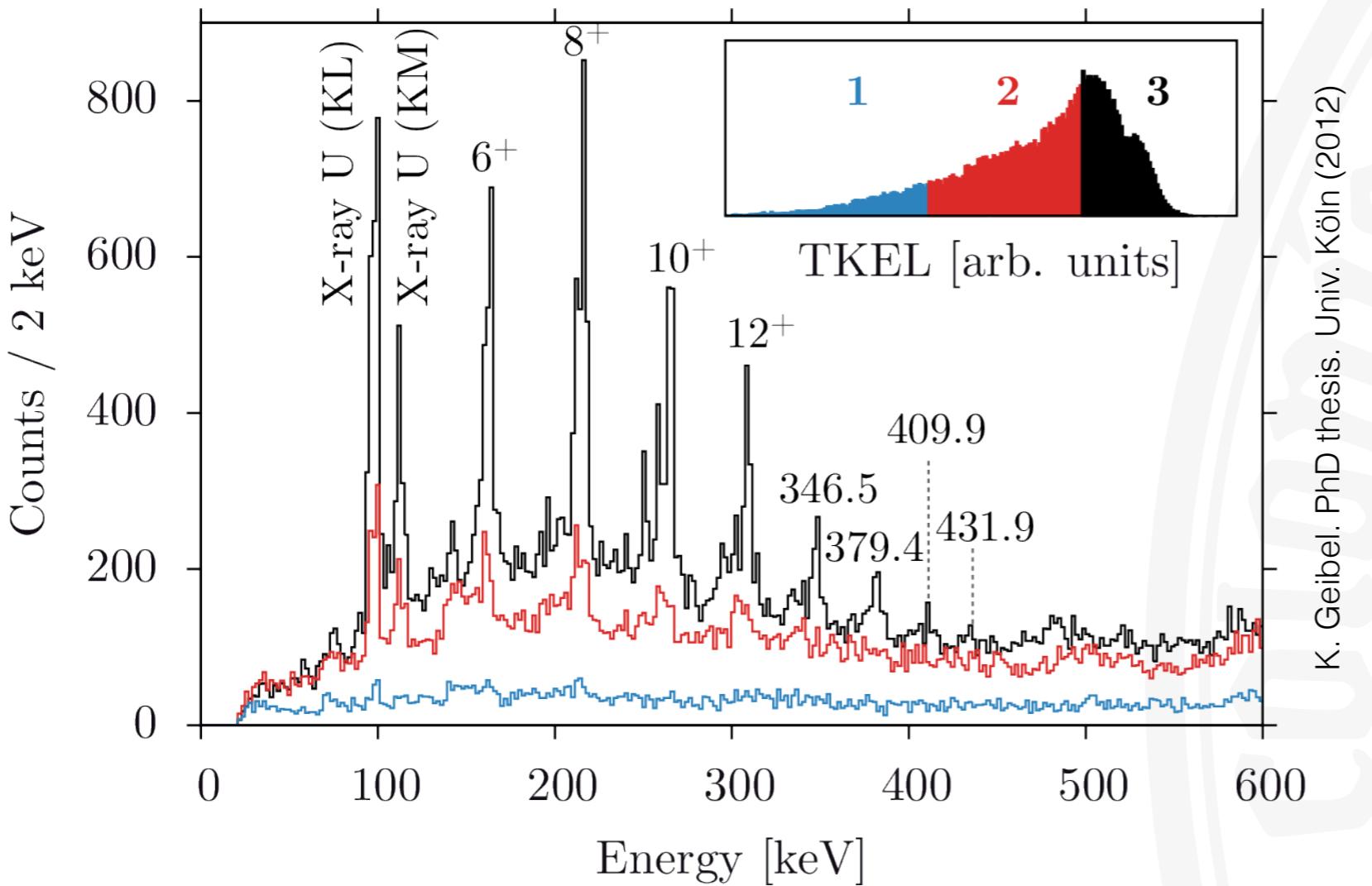


# Spectroscopy of $^{240}\text{U}$

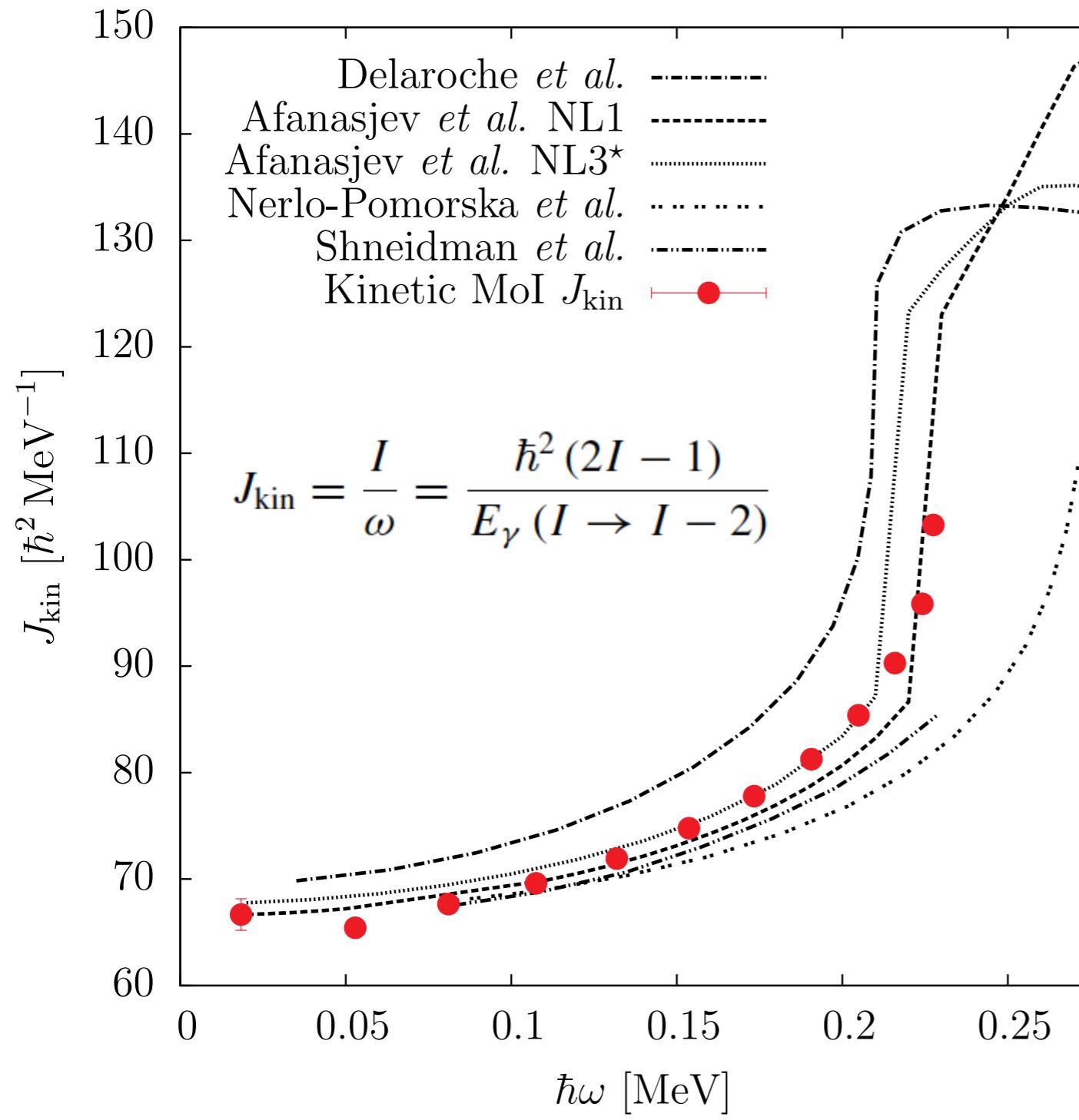


# Spectroscopy of $^{240}\text{U}$ with CLARA+PRISMA

$^{70}\text{Zn} + ^{238}\text{U}$  @ 860 MeV



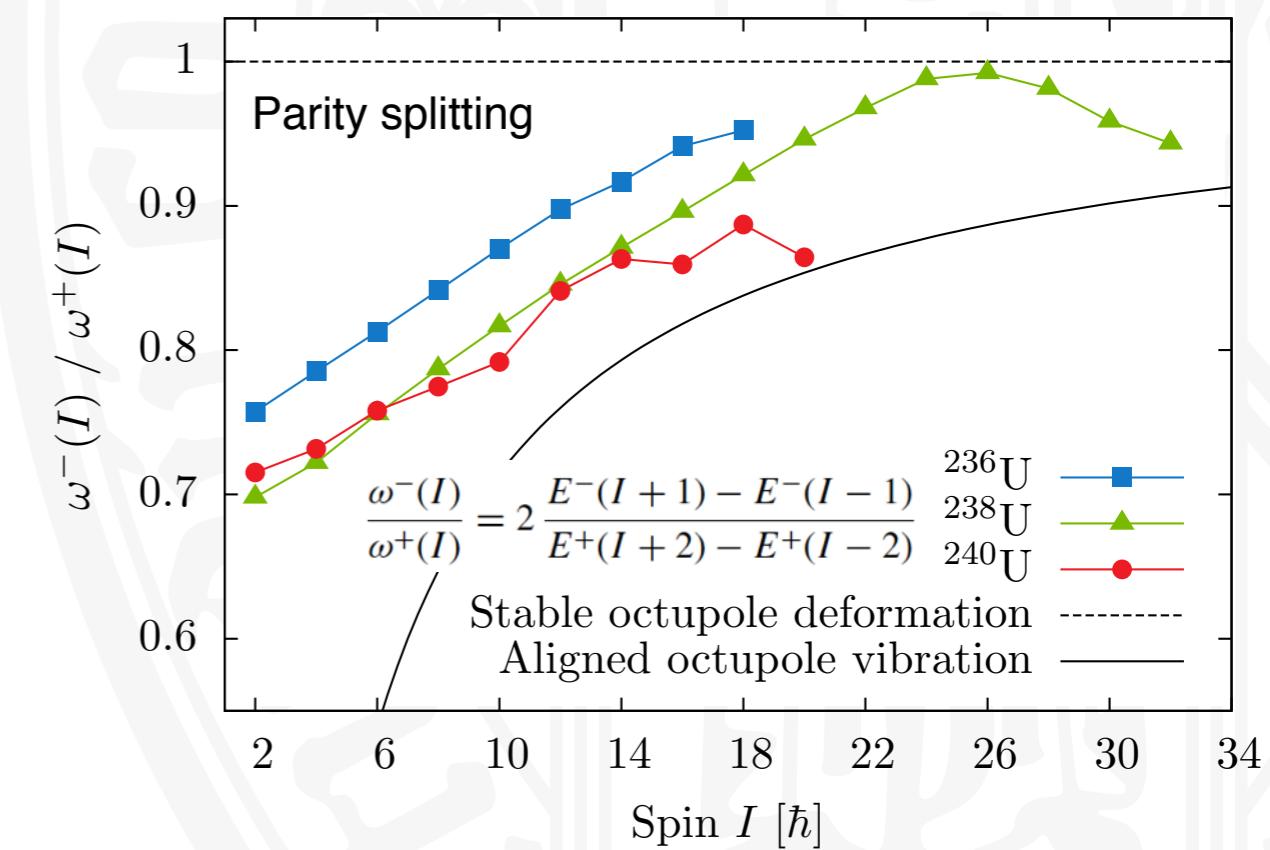
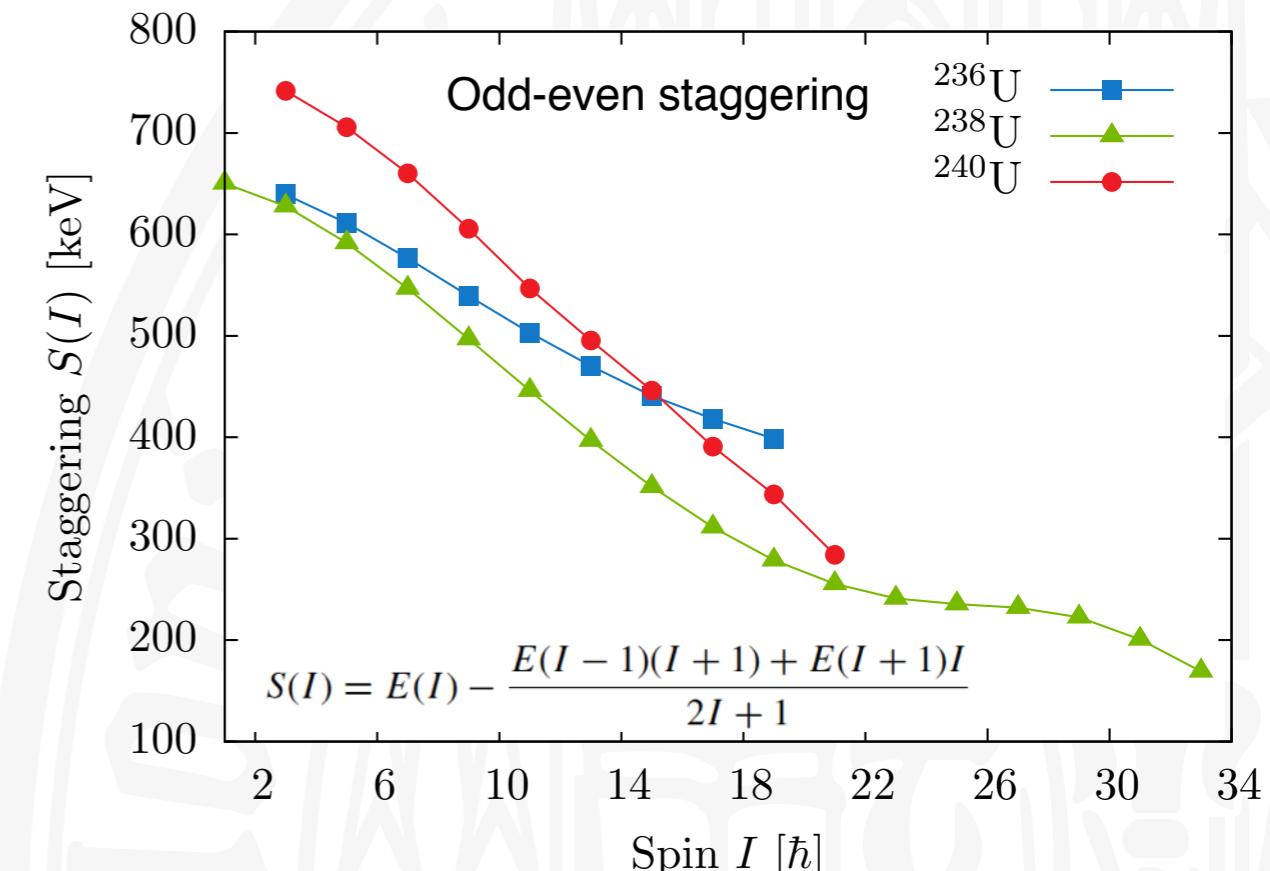
# $^{240}\text{U}$ : Moment of Inertia



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

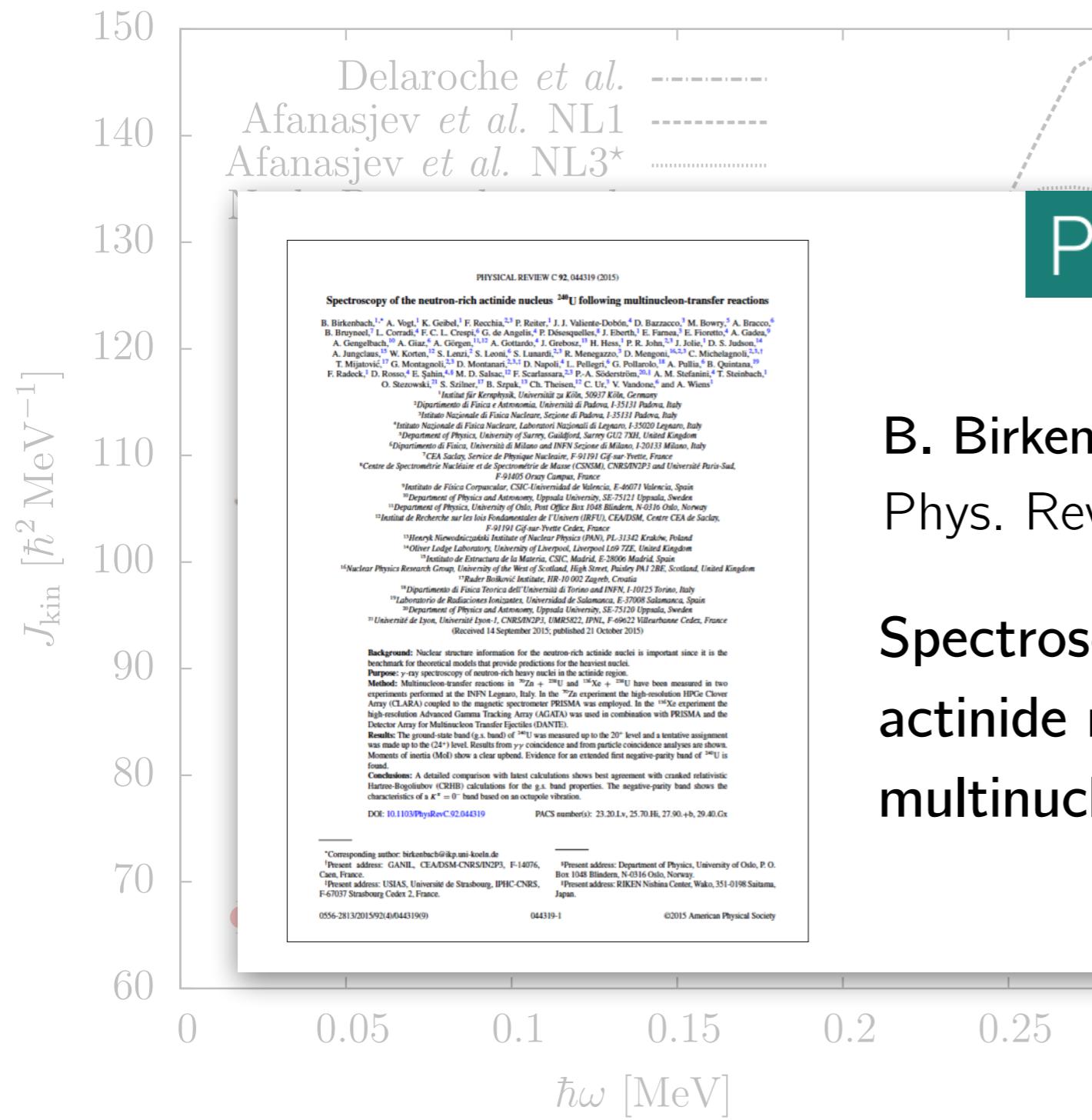
Afanasjev *et al.* Phys. Rev. C 88, 014320 (2013)

# Negative-parity band signatures



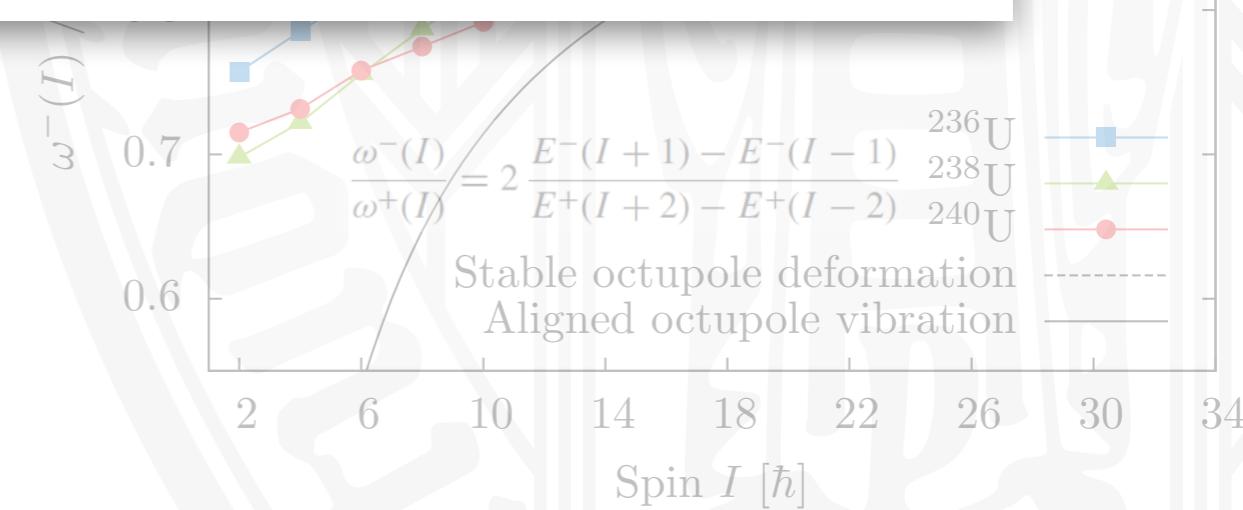
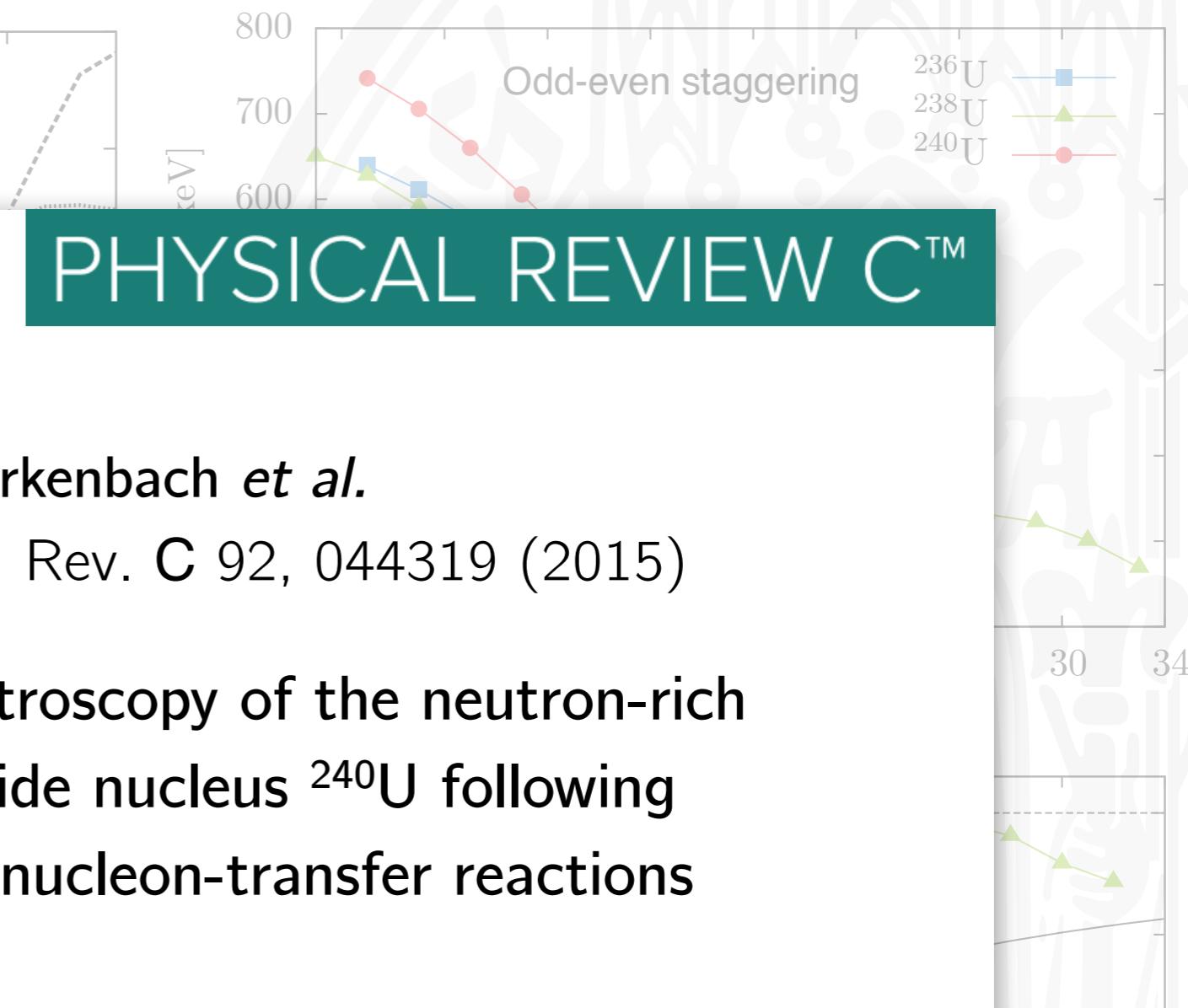
# $^{240}\text{U}$ : Moment of Inertia

# Negative-parity band signatures

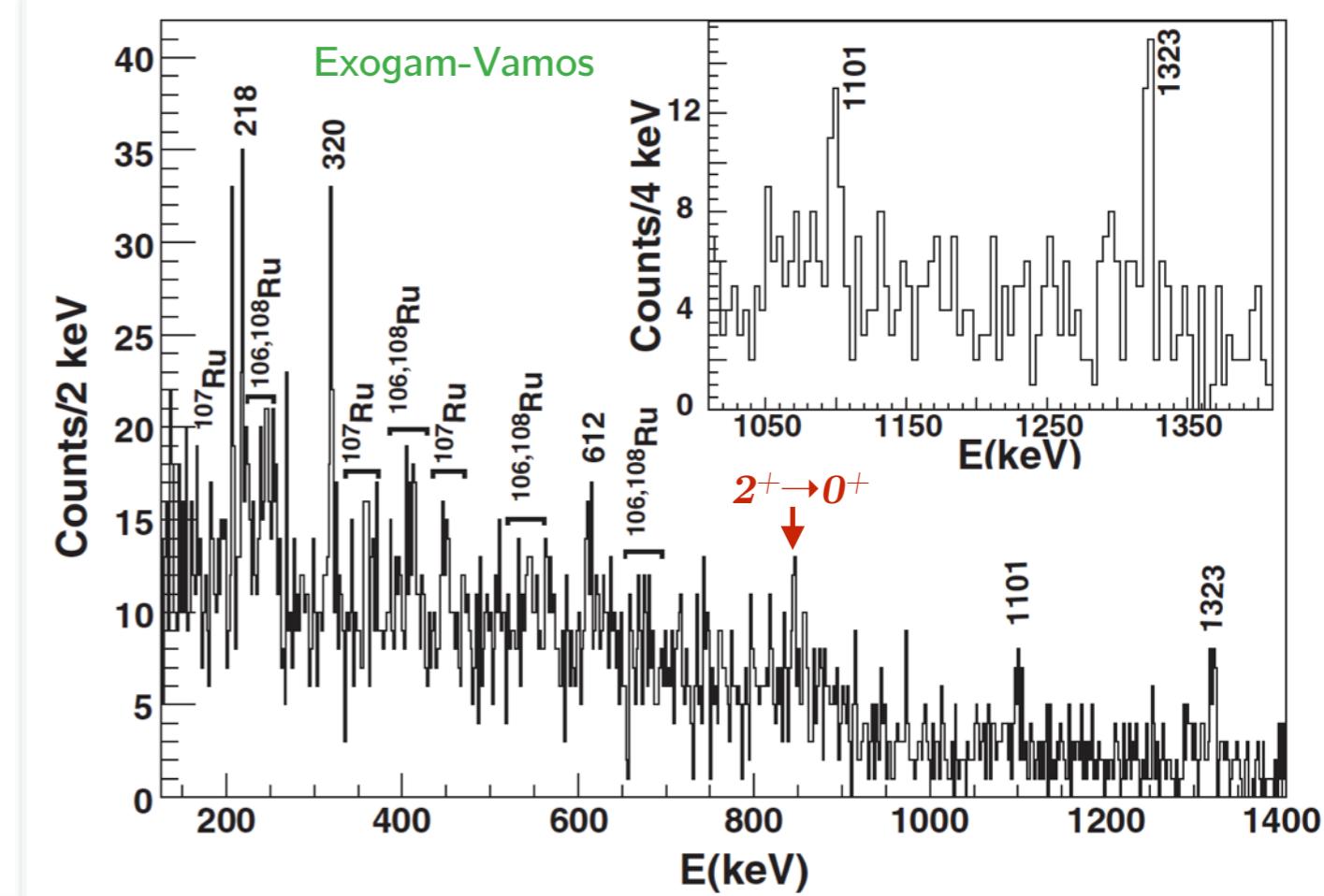
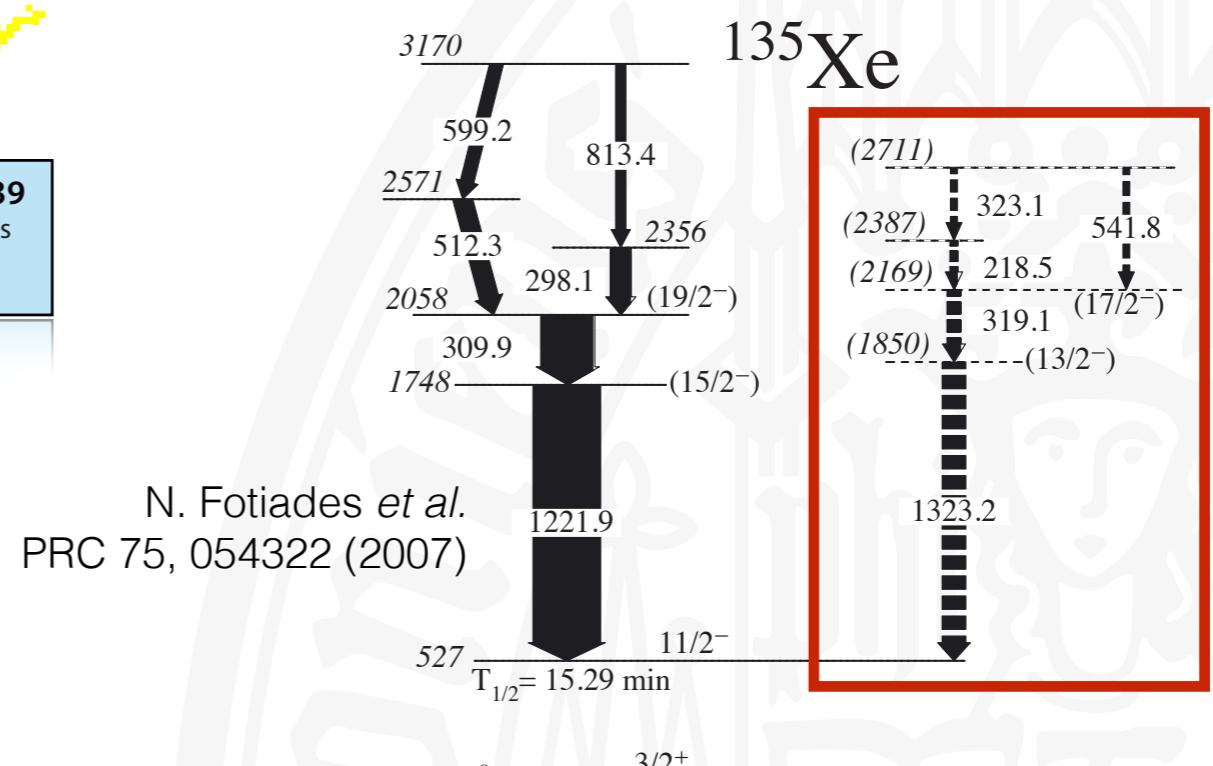
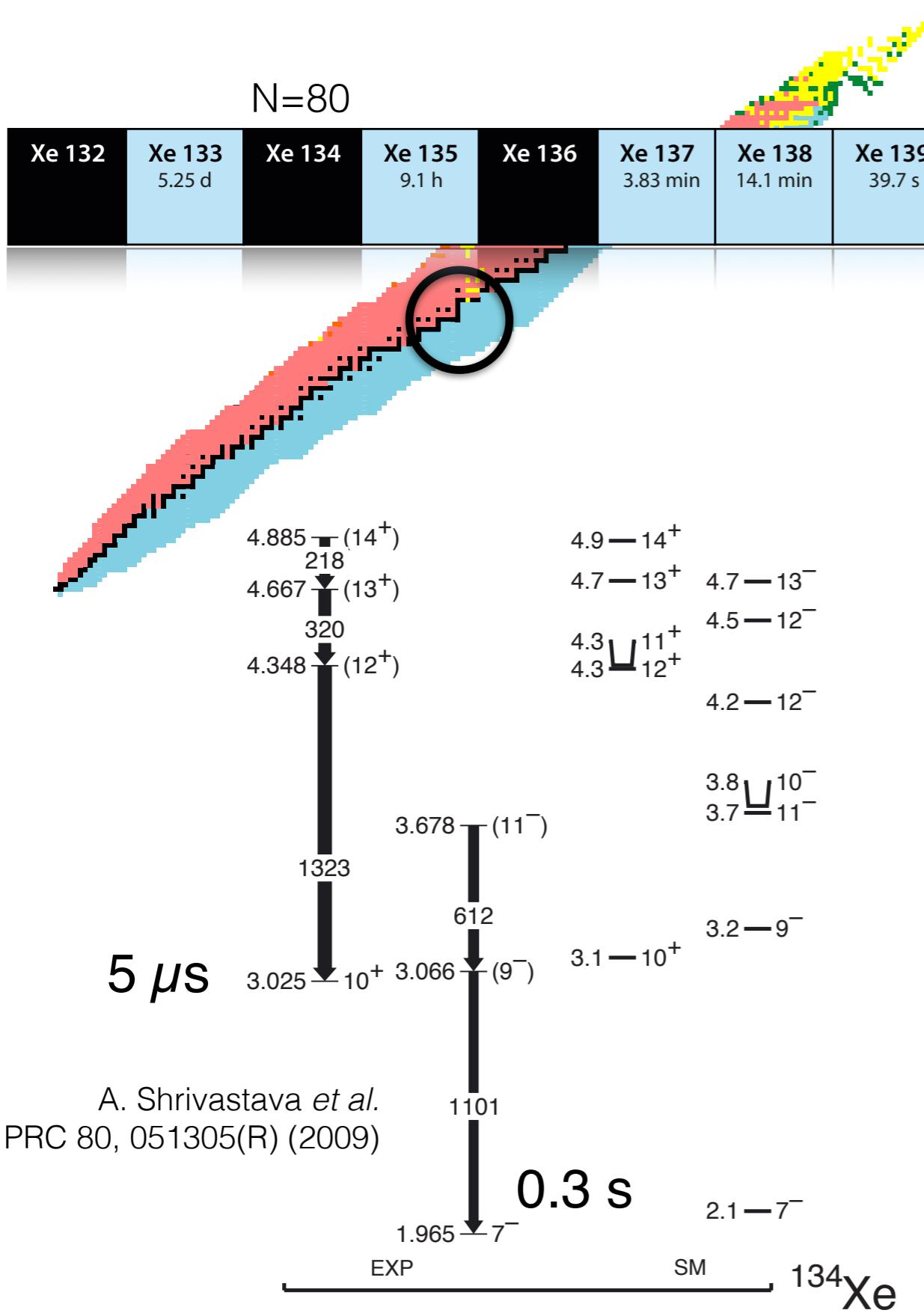


GSB and up-bend are best described by CDFT frameworks in NL1 and NL3\* parametrization

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

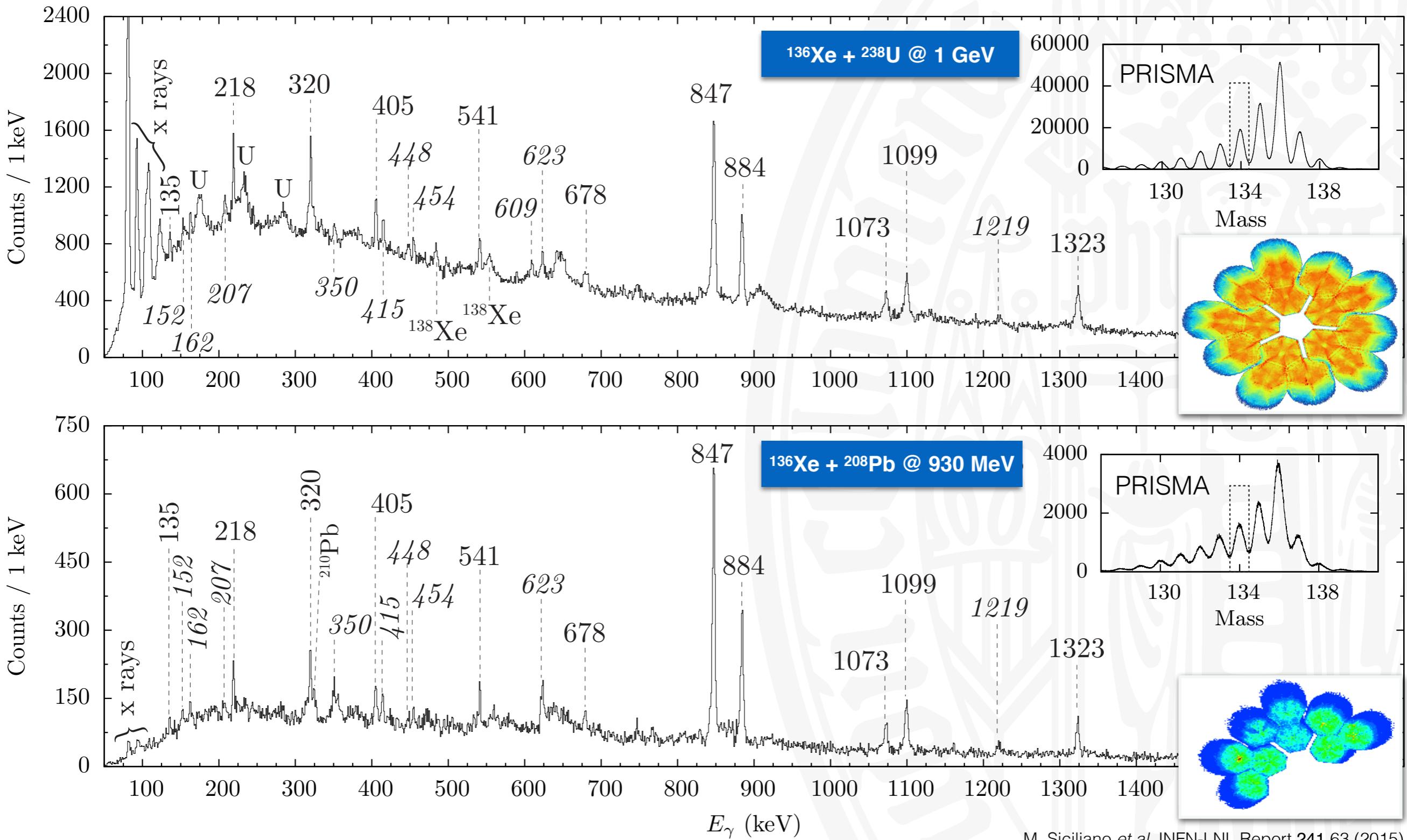


# High-Spin Spectroscopy of Xe Isotopes

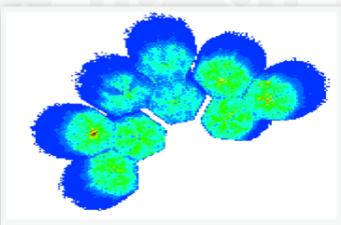


# High-Spin Spectroscopy of $^{134}\text{Xe}$

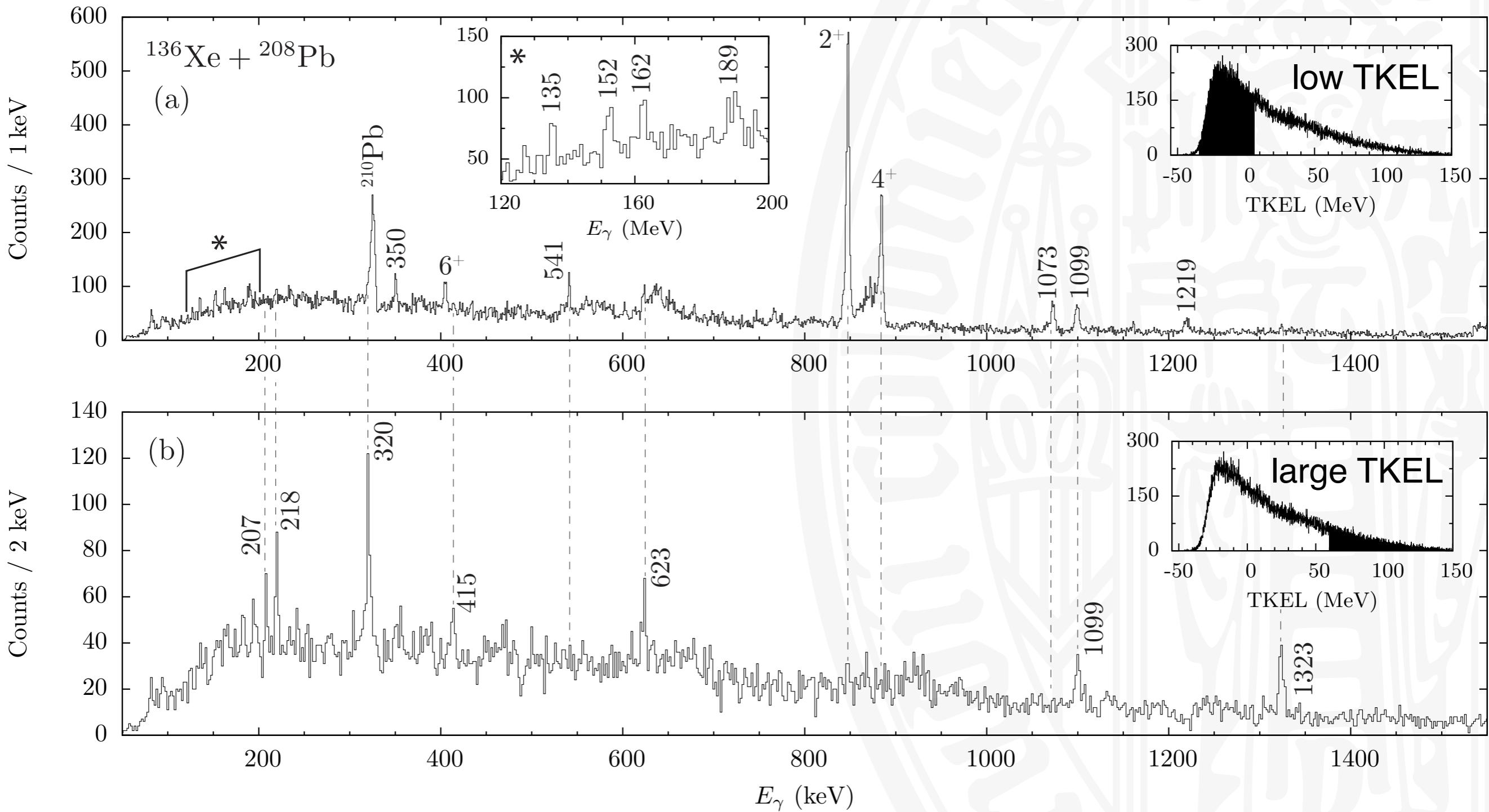
$^{134}\text{Xe}$



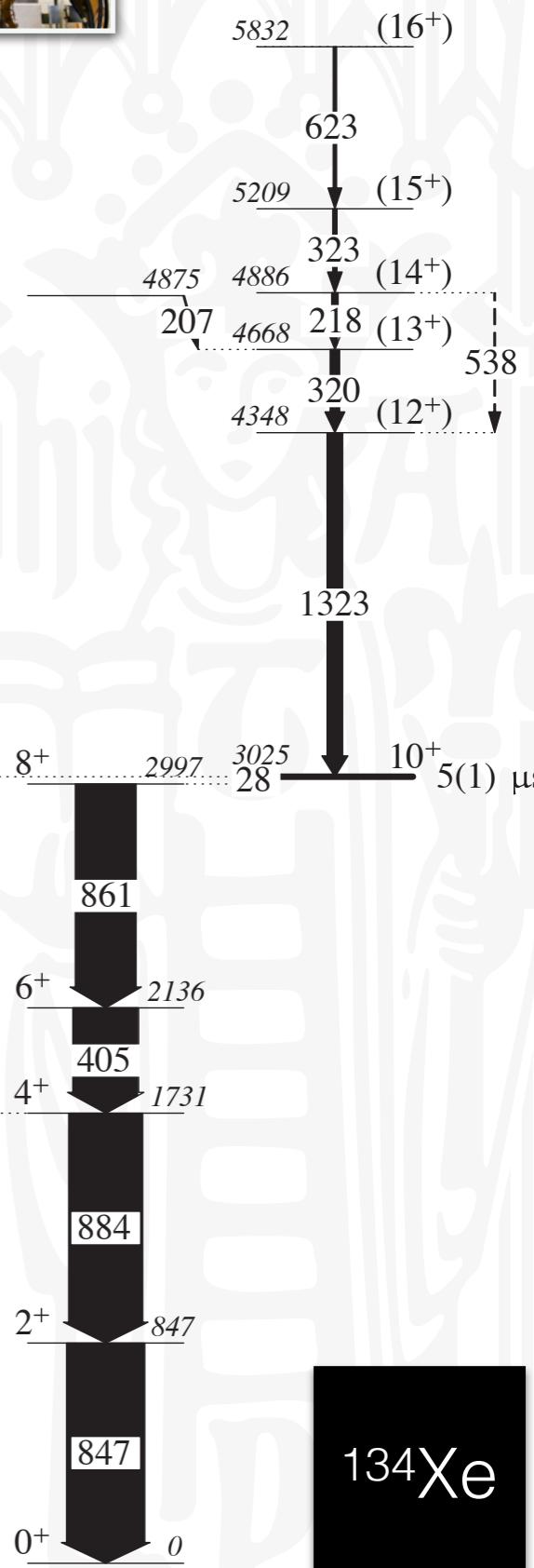
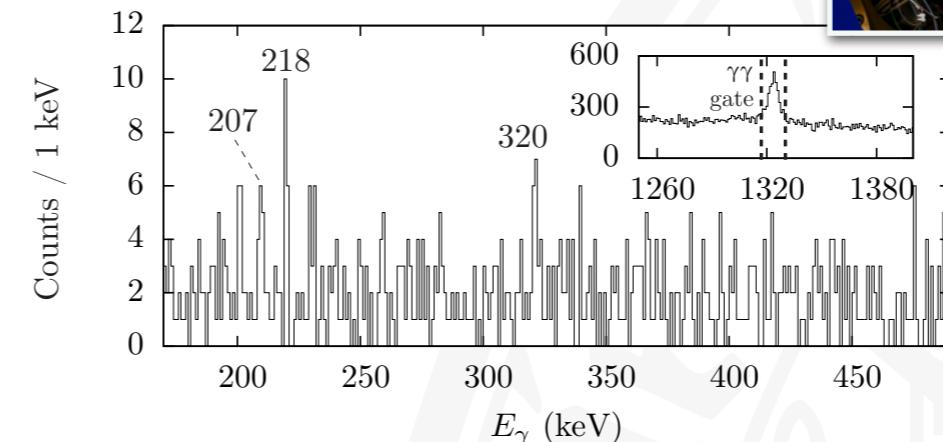
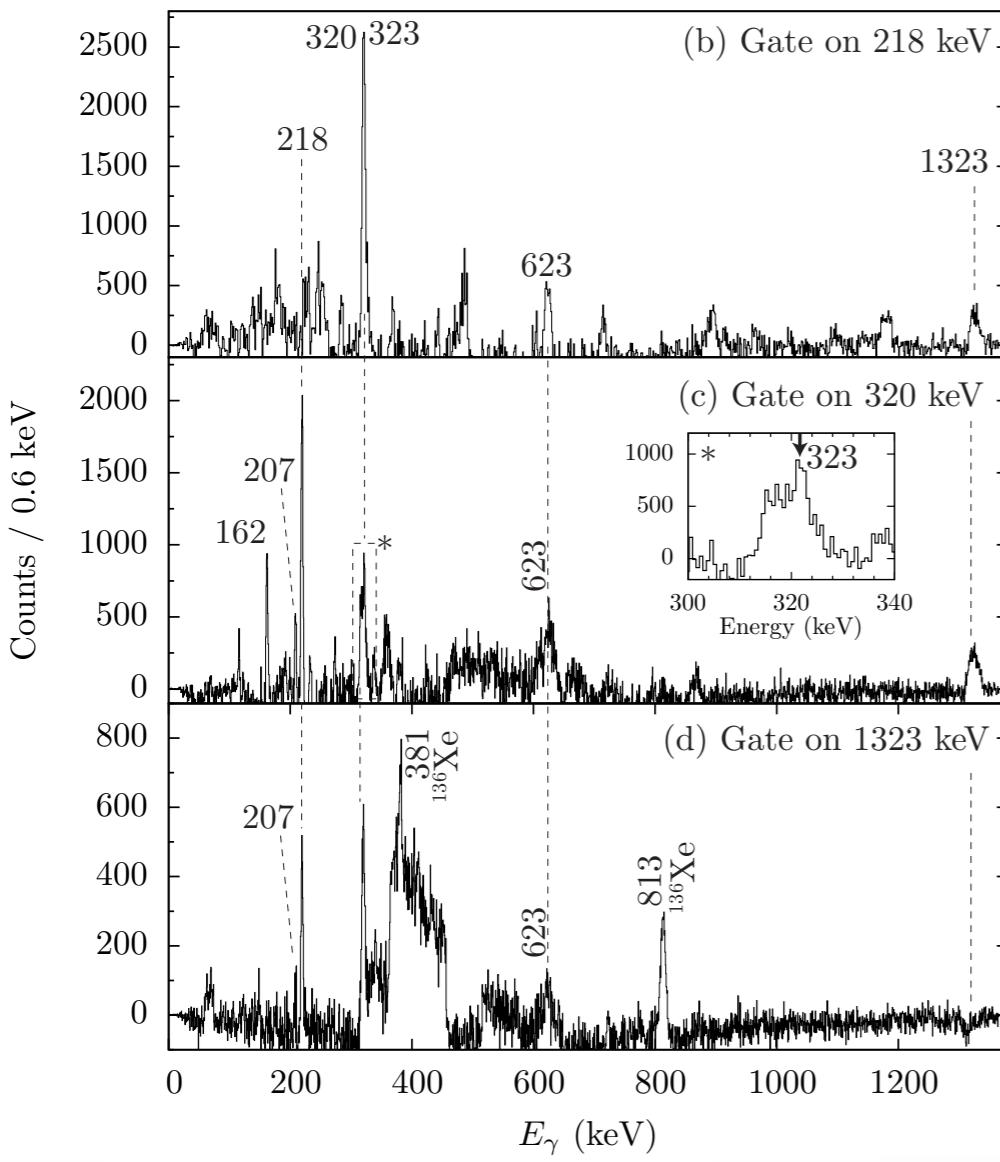
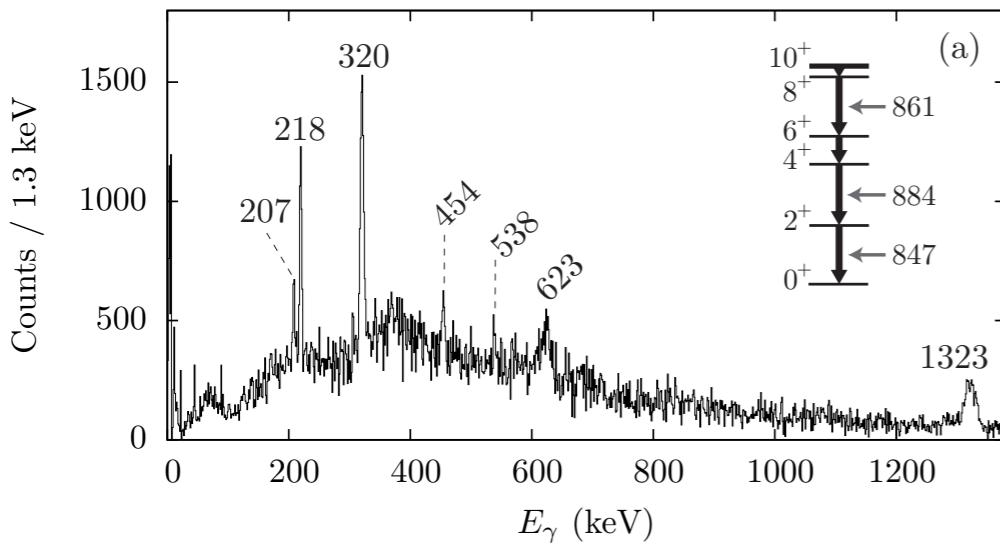
# High-Spin Spectroscopy of $^{134}\text{Xe}$



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



# High-Spin Spectroscopy of $^{134}\text{Xe}$

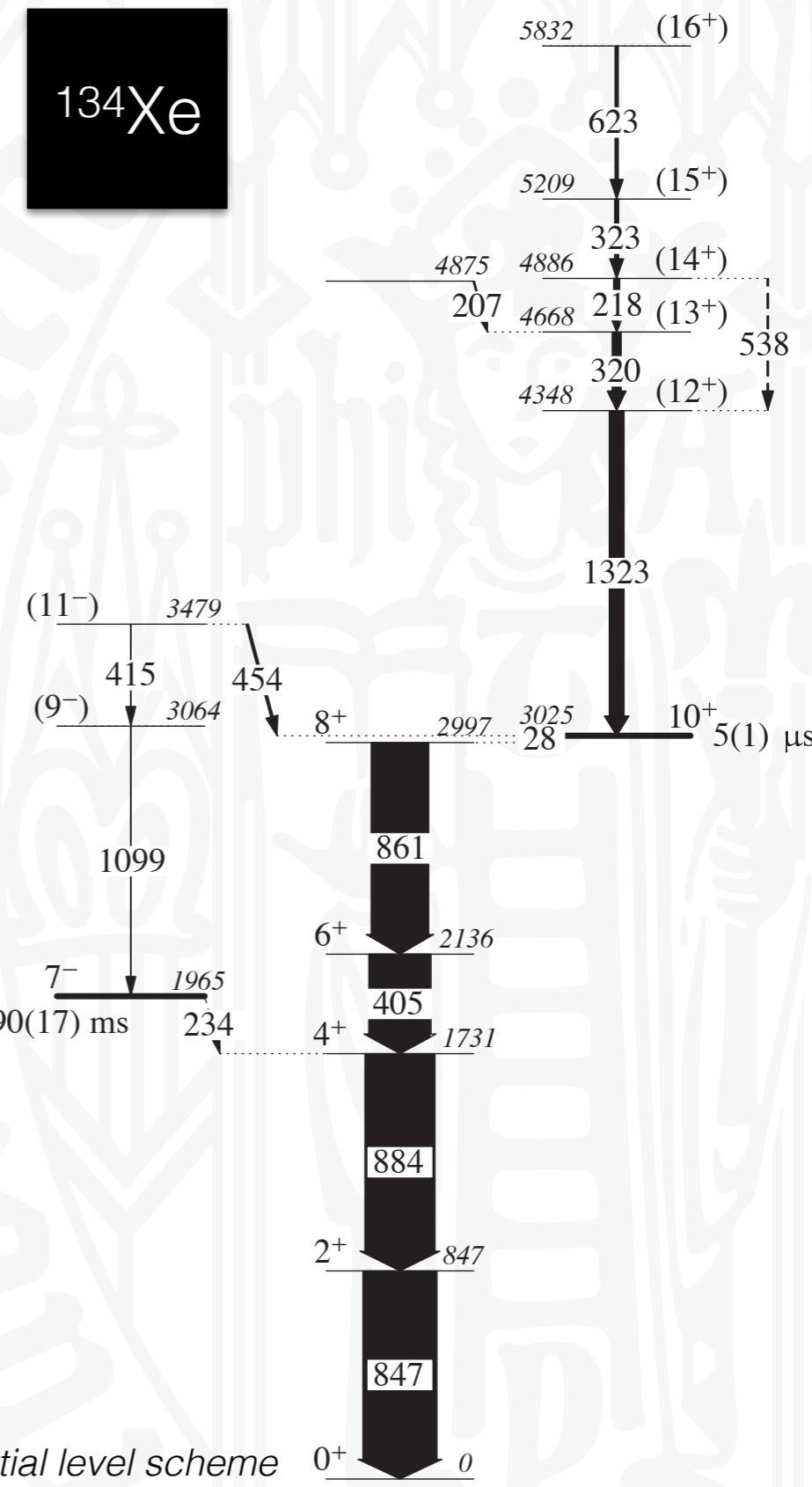
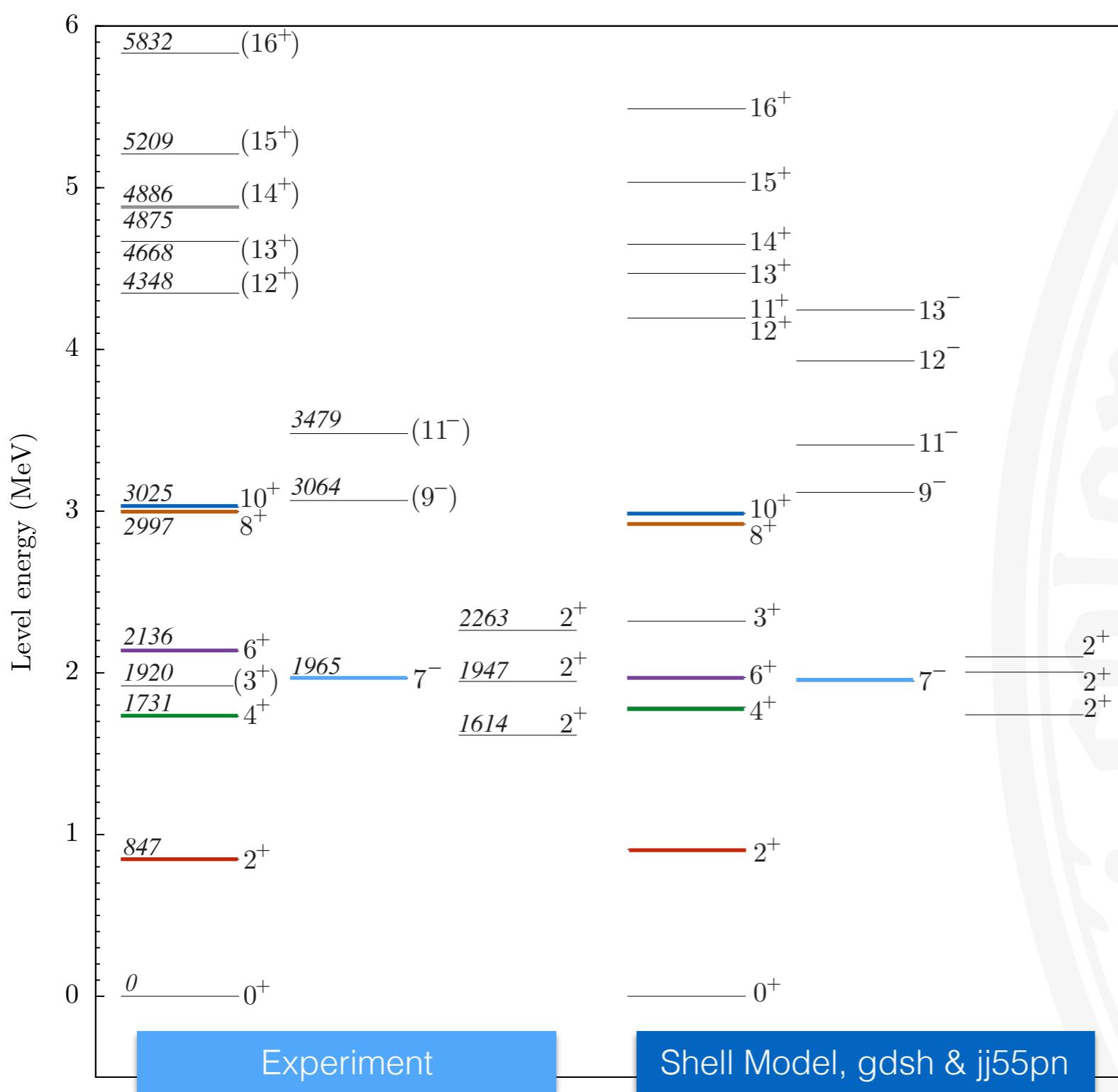


GAMMASPHERE+CHICO

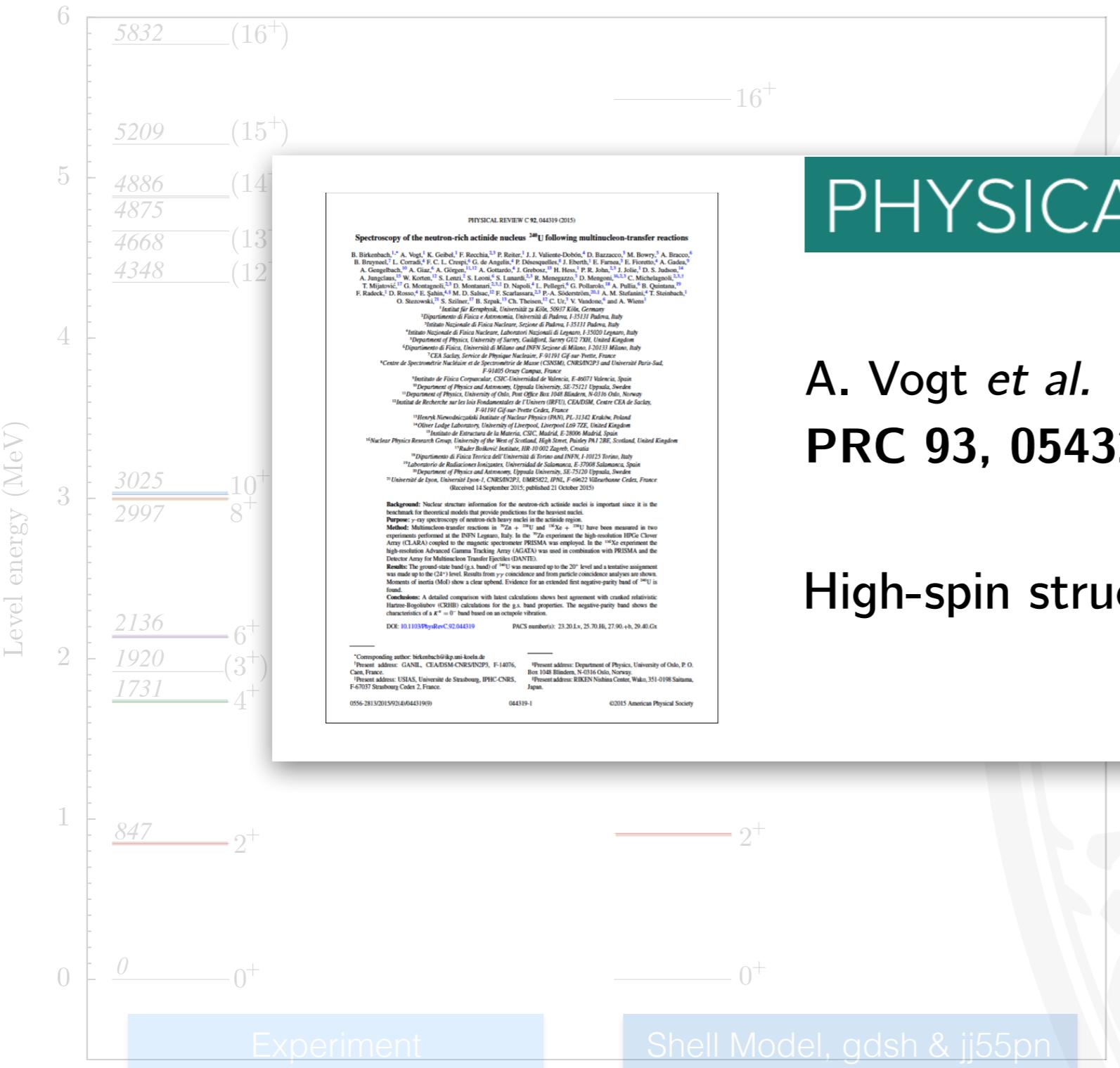
$^{136}\text{Xe} + ^{198}\text{Pt} @ 850 \text{ MeV}$

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

# High-Spin Spectroscopy of $^{134}\text{Xe}$



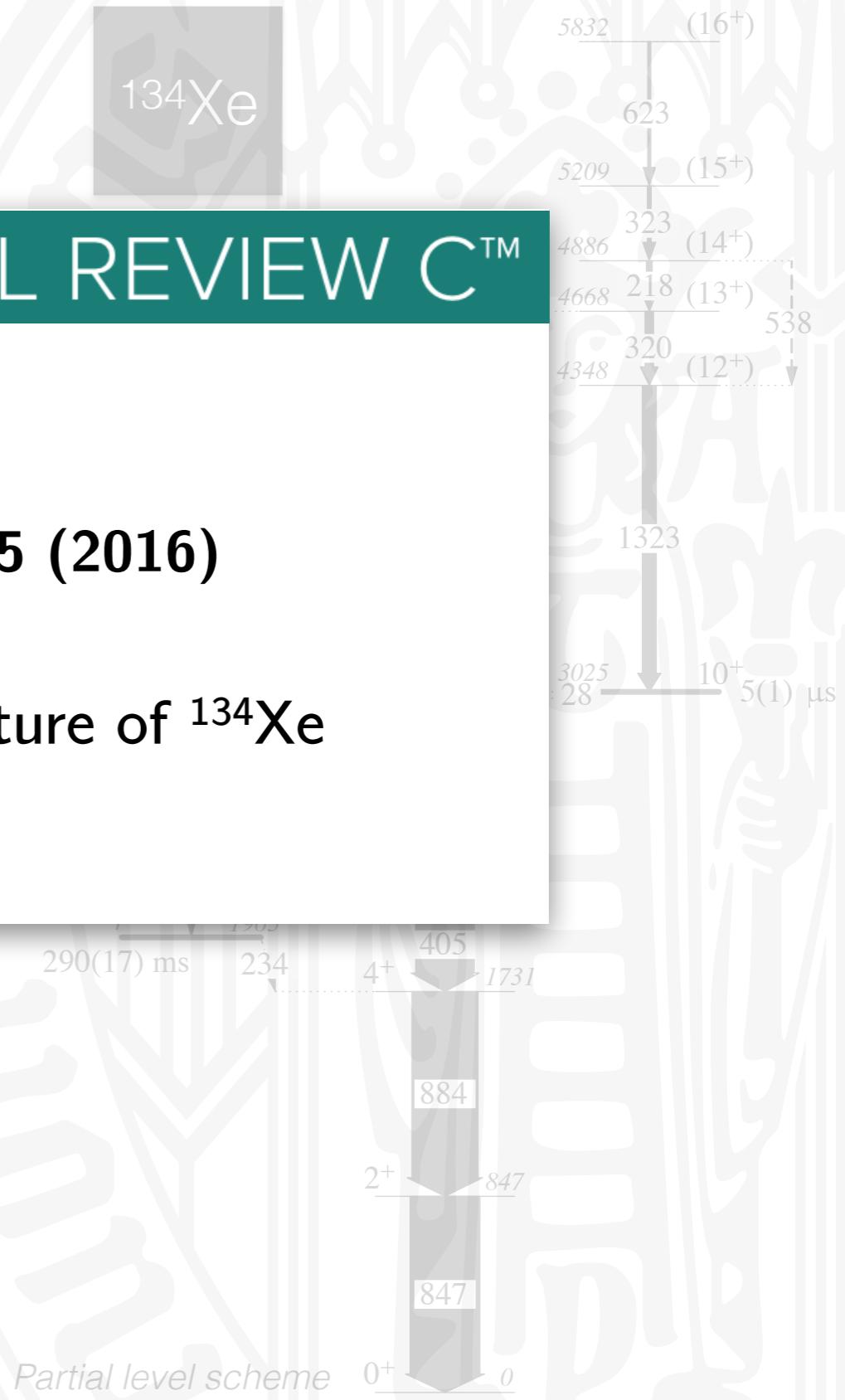
# High-Spin Spectroscopy of $^{134}\text{Xe}$



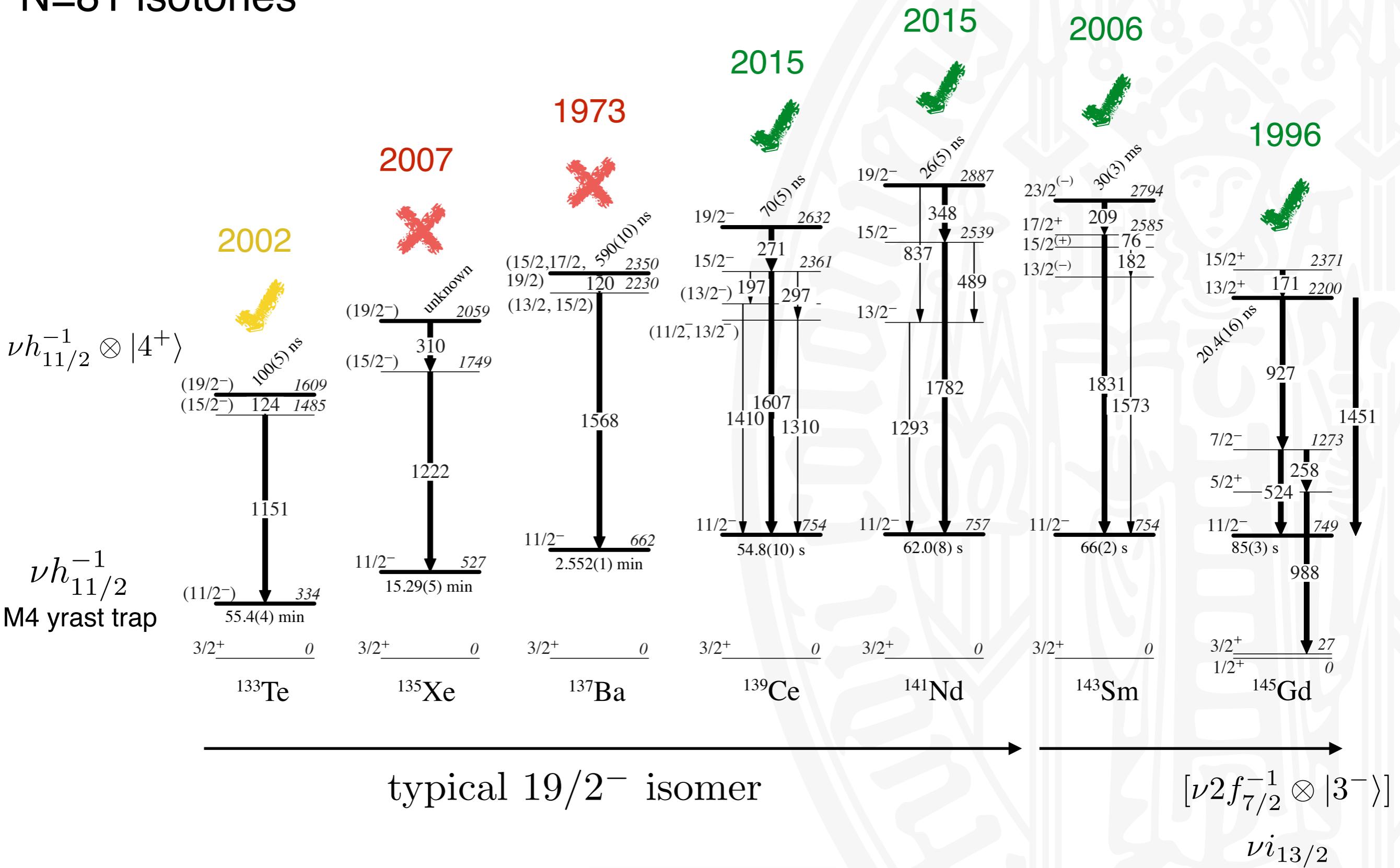
PHYSICAL REVIEW C™

A. Vogt *et al.*  
PRC 93, 054325 (2016)

High-spin structure of  $^{134}\text{Xe}$

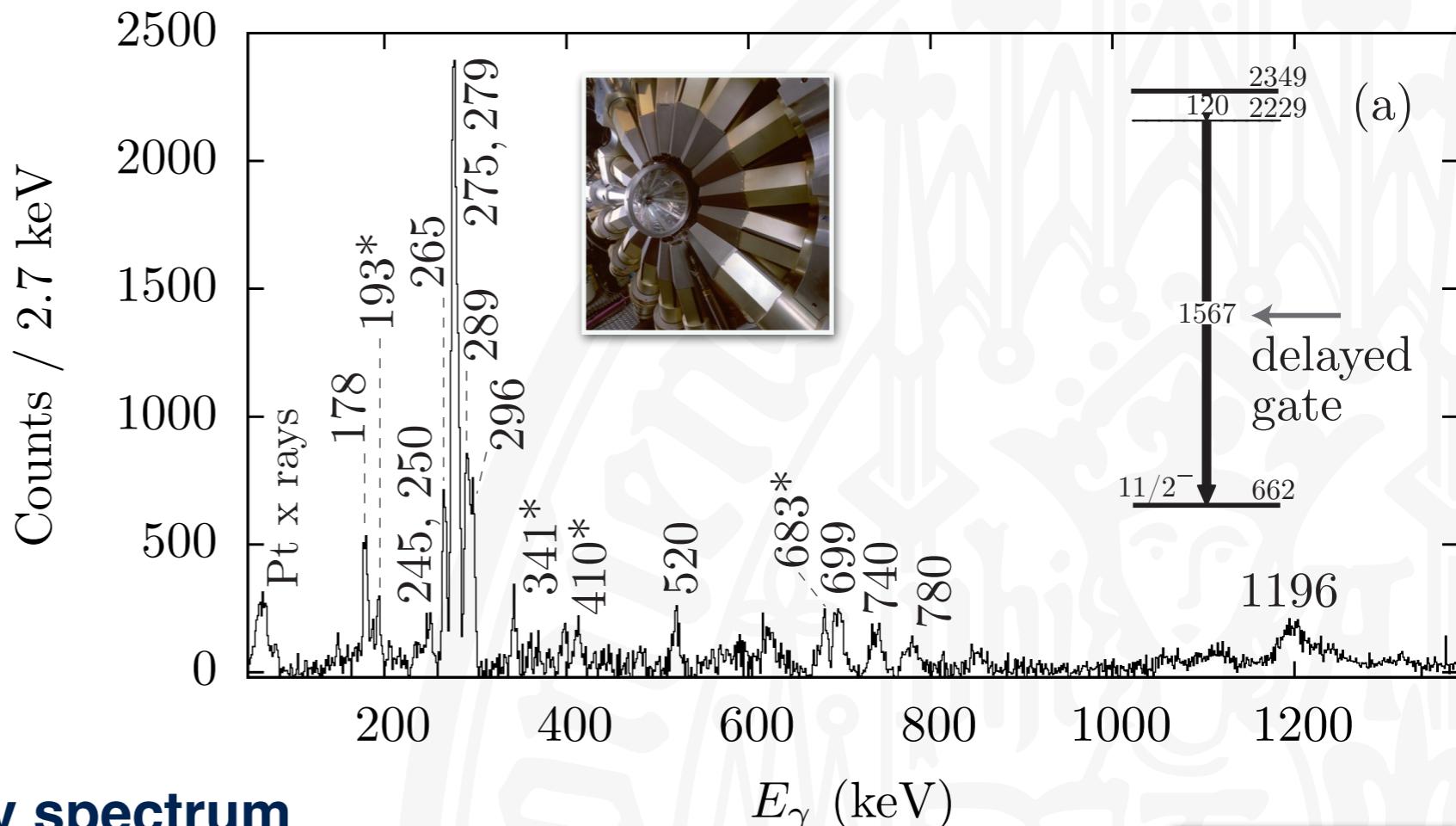


# High-spin data available near N=82 shell closure

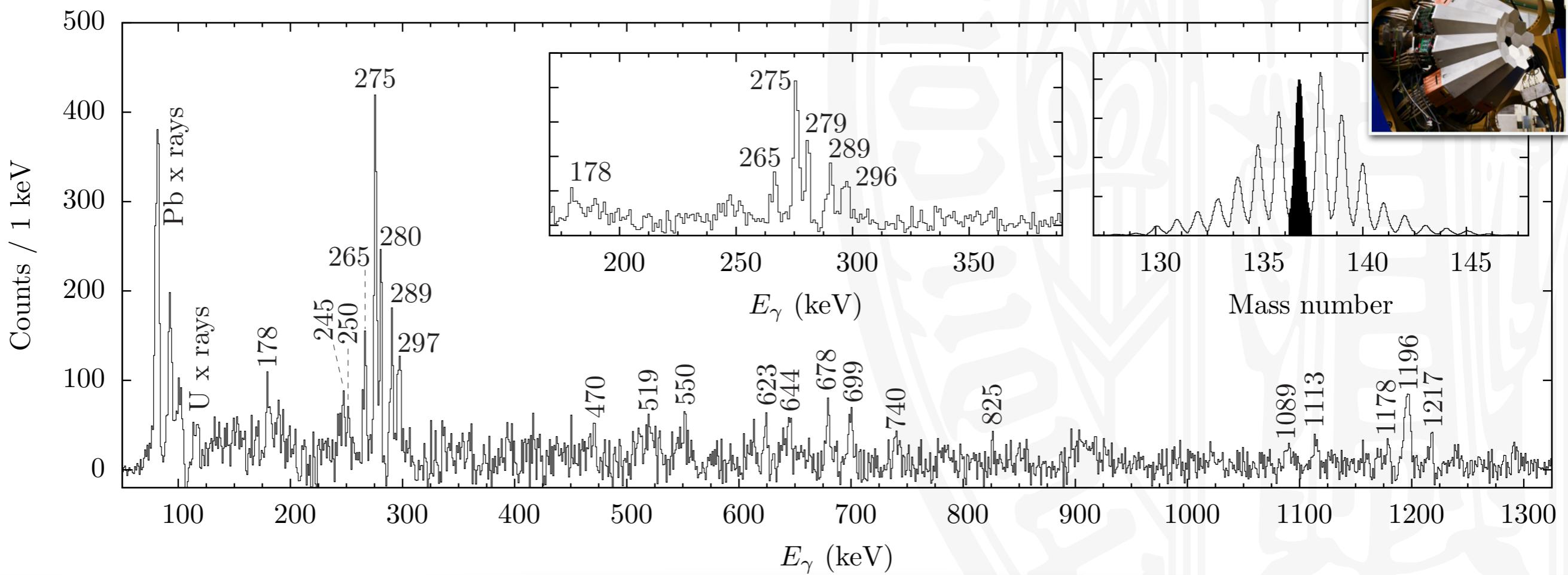


<sup>137</sup>Ba

## GAMMASPHERE delayed-prompt $\gamma\gamma$ coincidences

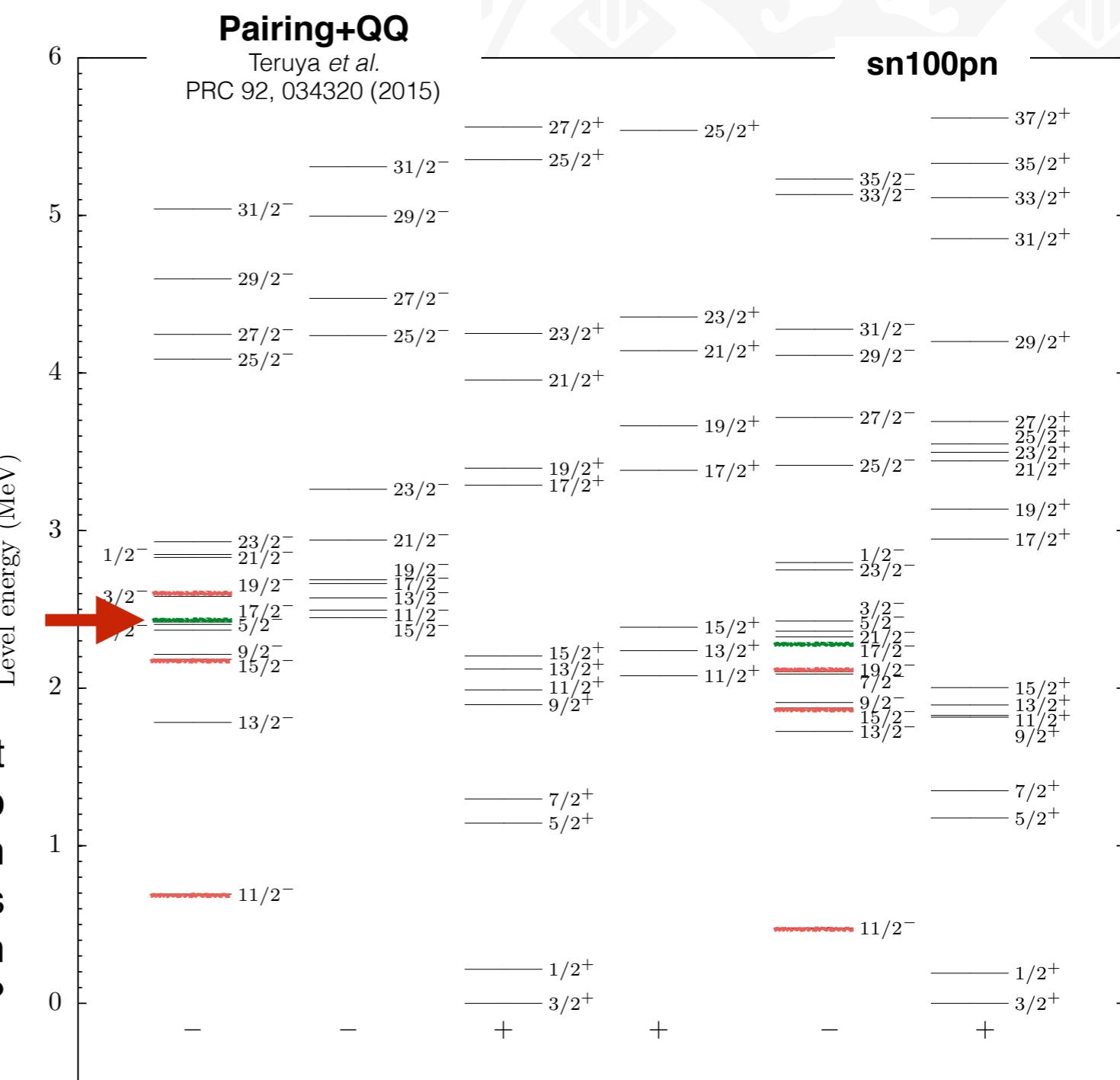
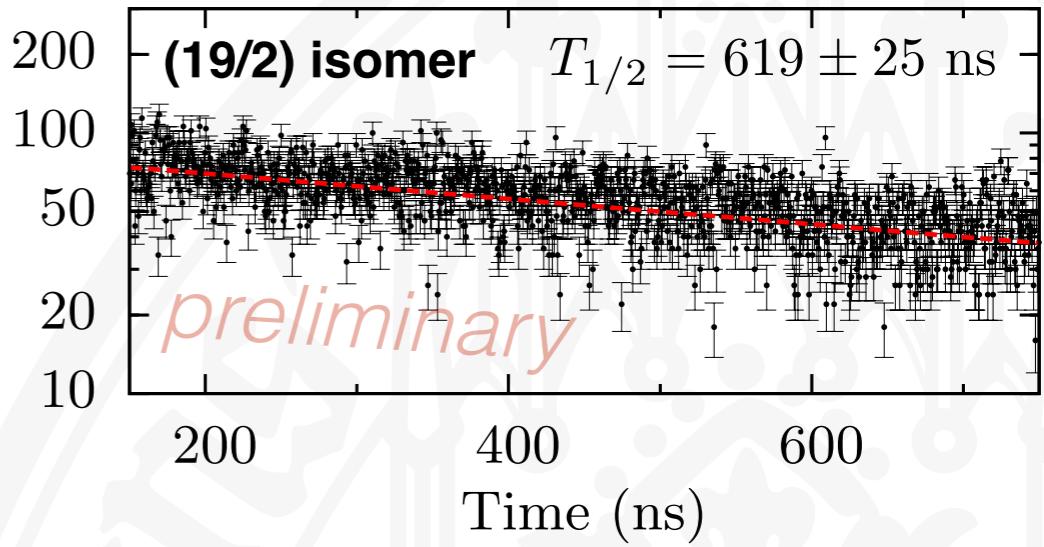
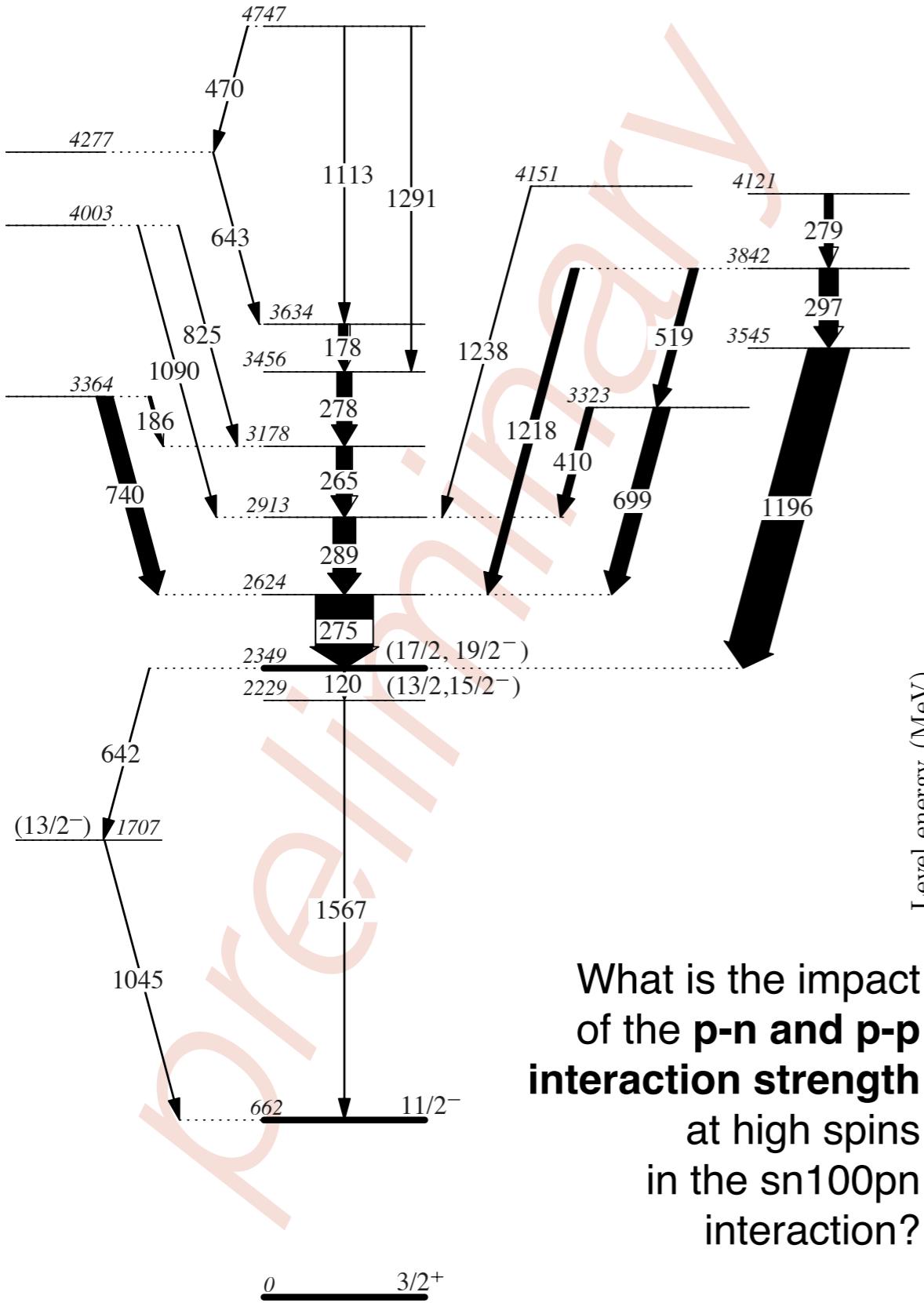


## AGATA+PRISMA singles $\gamma$ -ray spectrum



# Preliminary results

to be submitted to PRC



# Publications

## Summary

- ▶ Study of multinucleon transfer and fission properties of  $^{136}\text{Xe} + ^{238}\text{U}$
- ▶ Discrimination of fission and transfer
- ▶ Actinide survivability against fission

- ▶ Gamma-ray spectroscopy of neutron-rich  $^{240}\text{U}$  after MNT

- ▶ Nuclear structure on top of isomers in  $^{134}\text{Xe}$

- ▶ High-spin states in  $^{137}\text{Ba}$  and  $^{135}\text{Xe}$
- ▶ p-n correlations near the N=82 shell closure



### MNT reaction study

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

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### $^{240}\text{U}$ spectroscopy

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

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### High-spin structure of $^{134}\text{Xe}$

A. Vogt *et al.*  
**PRC 93, 054325 (2016)**

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und Forschung



# Summary

## ► Study of multinucleon transfer and

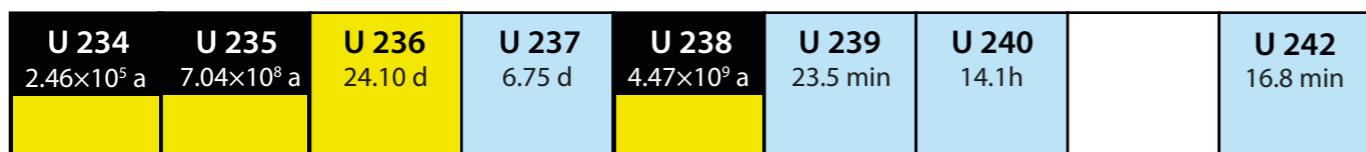
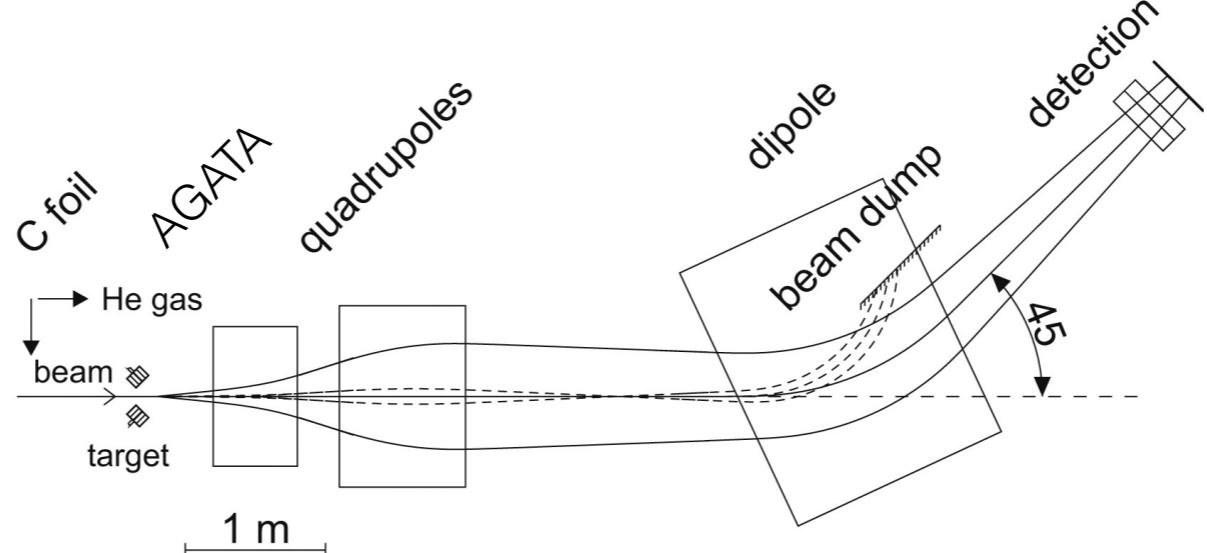


## MNT reaction study

A. Vogt *et al.*

# Outlook

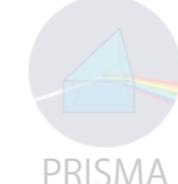
- Now: AGATA@GANIL with 32 crystals
- VAMOS in **gas-filled mode** and tagging station 2018+



Nuclear structure on top of  
isomers in <sup>137</sup>Ba and <sup>135</sup>Xe

PRC 93, 054325 (2016)

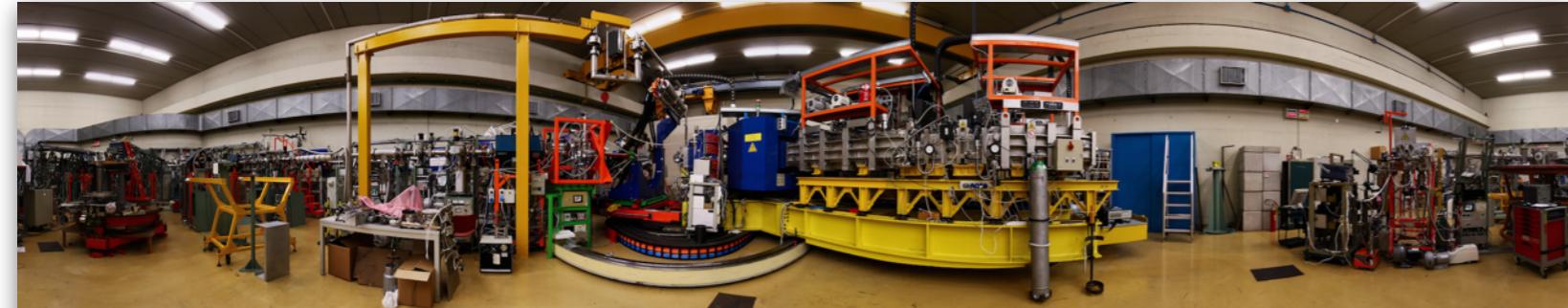
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# Publications



Thank you for your attention!

A. Vogt,<sup>1,\*</sup> B. Birkenbach,<sup>1</sup> P. Reiter,<sup>1</sup> A. Blazhev,<sup>1</sup> M. Siciliano,<sup>2,3</sup> J. J. Valiente-Dobón,<sup>3</sup> C. Wheldon,<sup>4</sup> D. Bazzacco,<sup>5</sup> M. Bowry,<sup>6</sup> A. Bracco,<sup>7</sup> B. Bruyneel,<sup>8</sup> R. S. Chakrawarthy,<sup>9</sup> R. Chapman,<sup>10</sup> D. Cline,<sup>11</sup> L. Corradi,<sup>3</sup> F. C. L. Crespi,<sup>7</sup> M. Cromaz,<sup>12</sup> G. de Angelis,<sup>3</sup> J. Eberth,<sup>1</sup> P. Fallon,<sup>12</sup> E. Fioretto,<sup>3</sup> S. J. Freeman,<sup>9</sup> A. Gadea,<sup>13</sup> K. Geibel,<sup>1</sup> W. Gelletly,<sup>6</sup> A. Gengelbach,<sup>14</sup> A. Giaz,<sup>7</sup> A. Görgen,<sup>15,16,12</sup> A. Gottardo,<sup>3</sup> A. B. Hayes,<sup>11</sup> H. Hess,<sup>1</sup> H. Hua,<sup>11</sup> P. R. John,<sup>2,5</sup> J. Jolie,<sup>1</sup> A. Jungclaus,<sup>17</sup> W. Korten,<sup>16</sup> I. Y. Lee,<sup>12</sup> S. Leoni,<sup>7</sup> X. Liang,<sup>18</sup> S. Lunardi,<sup>2,5</sup> A. O. Macchiavelli,<sup>12</sup> R. Menegazzo,<sup>5</sup> D. Mengoni,<sup>18,2,5</sup> C. Michelagnoli,<sup>2,5,‡</sup> T. Mijatović,<sup>19</sup> G. Montagnoli,<sup>2,5</sup> D. Montanari,<sup>2,5,§</sup> D. Napoli,<sup>3</sup> C. J. Pearson,<sup>6,||</sup> L. Pellegri,<sup>7</sup> Zs. Podolyák,<sup>6</sup> G. Pollaro,<sup>20</sup> A. Pullia,<sup>7</sup> F. Radeck,<sup>1</sup> F. Recchia,<sup>2,5</sup> P. H. Regan,<sup>6,21</sup> E. Şahin,<sup>3,¶</sup> F. Scarlassara,<sup>2,5</sup> G. Sletten,<sup>22</sup> J. F. Smith,<sup>18</sup> P.-A. Söderström,<sup>14,#</sup> A. M. Stefanini,<sup>3</sup> T. Steinbach,<sup>1</sup> O. Stezowski,<sup>23</sup> S. Szilner,<sup>19</sup> B. Szpak,<sup>24</sup> R. Teng,<sup>11</sup> C. Ur,<sup>5</sup> V. Vandone,<sup>7</sup> D. Ward,<sup>12</sup> D. D. Warner,<sup>25,†</sup> A. Wiens,<sup>1</sup> and C. Y. Wu<sup>11,\*\*</sup>

<sup>1</sup>Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany

<sup>2</sup>Dipartimento di Fisica e Astronomia, Università di Padova, I-35131 Padova, Italy

<sup>3</sup>Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy

<sup>4</sup>School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

<sup>5</sup>Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy

<sup>6</sup>Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom

<sup>7</sup>Dipartimento di Fisica, Università di Milano and INFN Sezione di Milano, I-20133 Milano, Italy

<sup>8</sup>CEA Saclay, Service de Physique Nucléaire, F-91191 Gif-sur-Yvette, France

<sup>9</sup>Department of Physics and Astronomy, Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom

<sup>10</sup>SUPA, School of Engineering and Computing, University of the West of Scotland, Paisley PA1 2BE, United Kingdom

<sup>11</sup>Department of Physics, University of Rochester, Rochester, New York 14627, USA

<sup>12</sup>Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

<sup>13</sup>Instituto de Física Corpuscular, CSIC-Universidad de Valencia, E-46071 Valencia, Spain

<sup>14</sup>Department of Physics and Astronomy, Uppsala University, SE-75121 Uppsala, Sweden

<sup>15</sup>Department of Physics, University of Oslo, Post Office Box 1048 Blindern, N-0316 Oslo, Norway

<sup>16</sup>Institut de Recherche sur les lois Fondamentales de l'Univers (IRFU), CEA/DSM, Centre CEA de Saclay, F-91191 Gif-sur-Yvette Cedex, France

<sup>17</sup>Instituto de Estructura de la Materia, CSIC, Madrid, E-28006 Madrid, Spain

<sup>18</sup>Nuclear Physics Research Group, University of the West of Scotland, High Street, Paisley PA1 2BE, Scotland, United Kingdom

<sup>19</sup>Ruder Bošković Institute, HR-10 002 Zagreb, Croatia

<sup>20</sup>Dipartimento di Fisica Teorica dell'Università di Torino and INFN, I-10125 Torino, Italy

<sup>21</sup>Radioactivity Group, National Physical Laboratory, Teddington, Middlesex, TW11 0LW, United Kingdom

<sup>22</sup>Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark

<sup>23</sup>Université de Lyon, Université Lyon-1, CNRS/IN2P3, UMR5822, IPNL, F-69622 Villeurbanne Cedex, France

<sup>24</sup>Henryk Niewodniczański Institute of Nuclear Physics PAN, PL-31342 Kraków, Poland

<sup>25</sup>CCLRC Daresbury Laboratory, Warrington WA4 4AD, United Kingdom



## MNT reaction study

A. Vogt *et al.*

PRC 92, 024619 (2015)

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## $^{240}\text{U}$ spectroscopy

B. Birkenbach *et al.*

PRC 92, 044319 (2015)

PHYSICAL REVIEW C™



## High-spin structure of $^{134}\text{Xe}$

A. Vogt *et al.*

PRC 93, 054325 (2016)

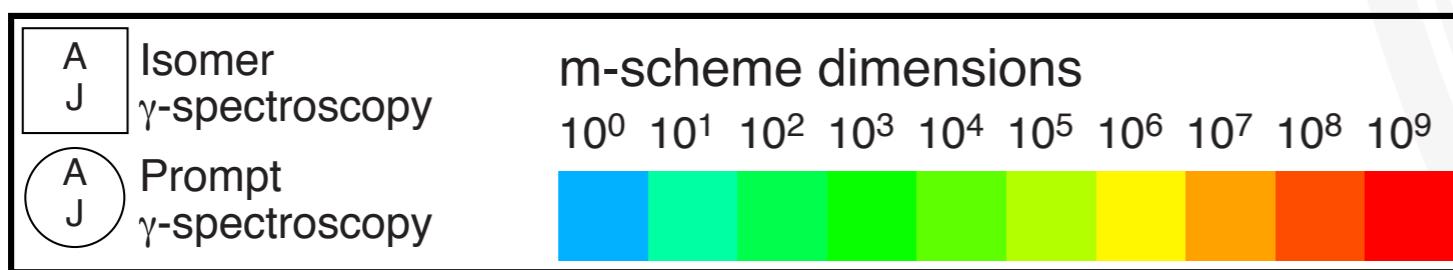
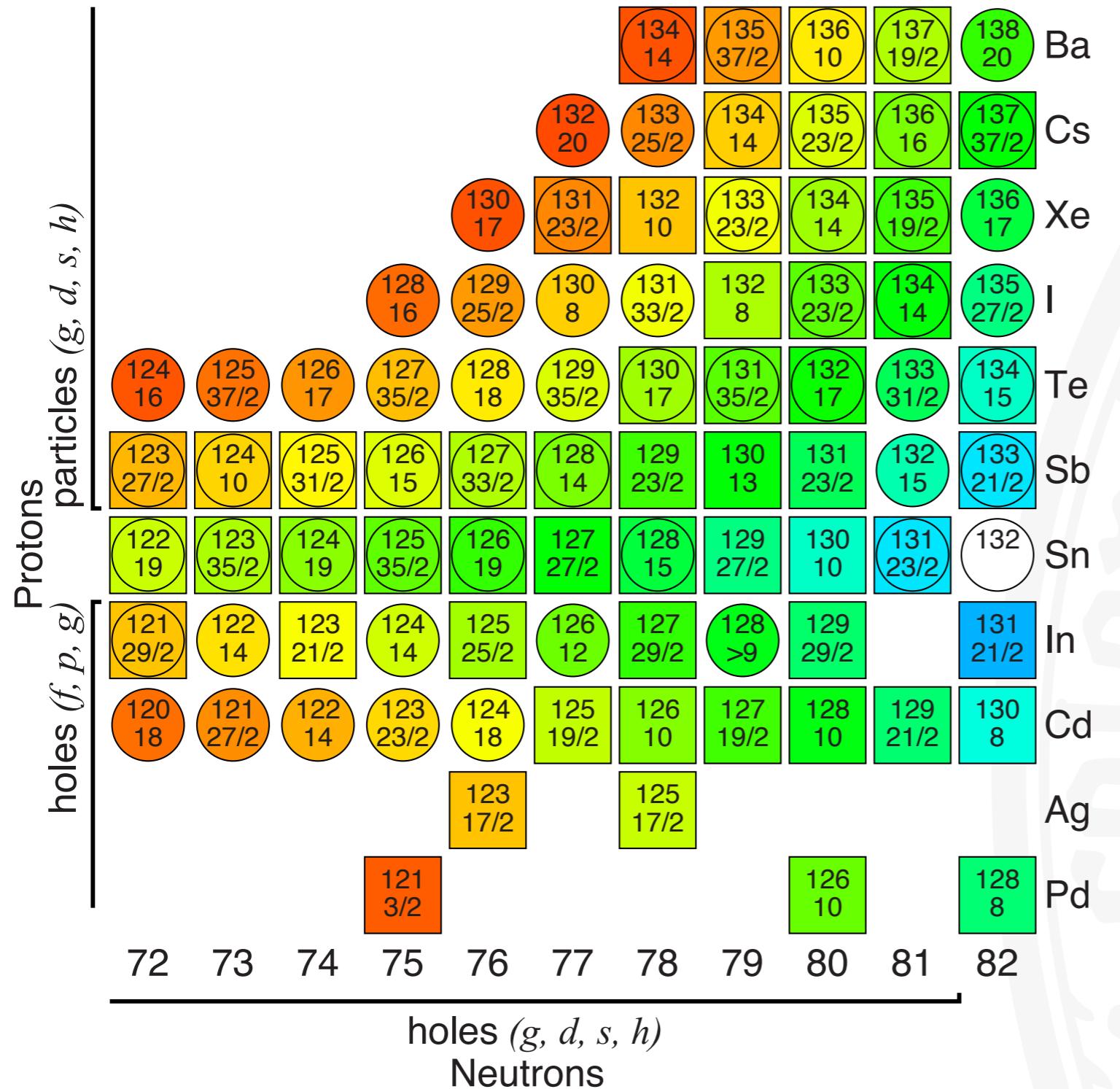
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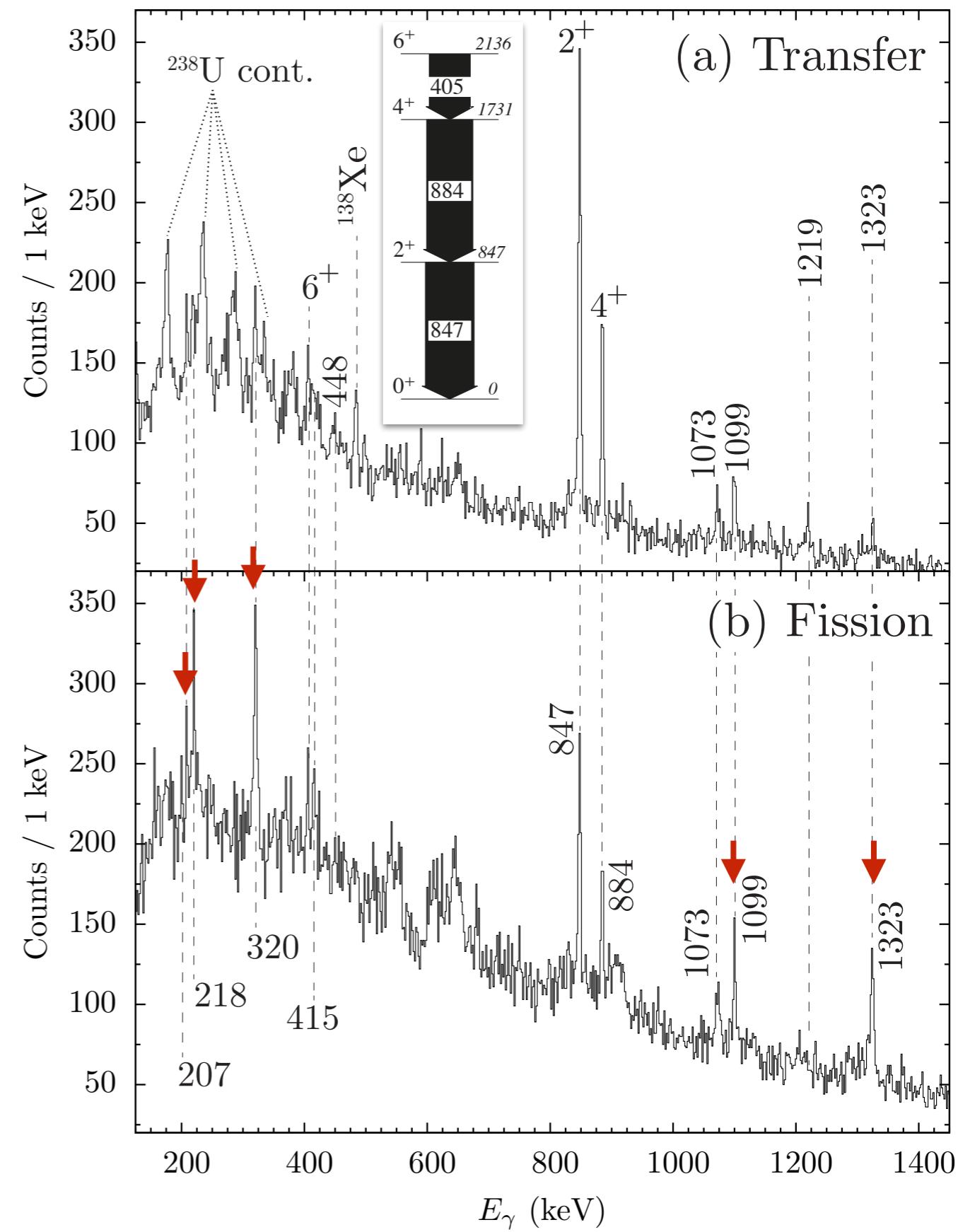
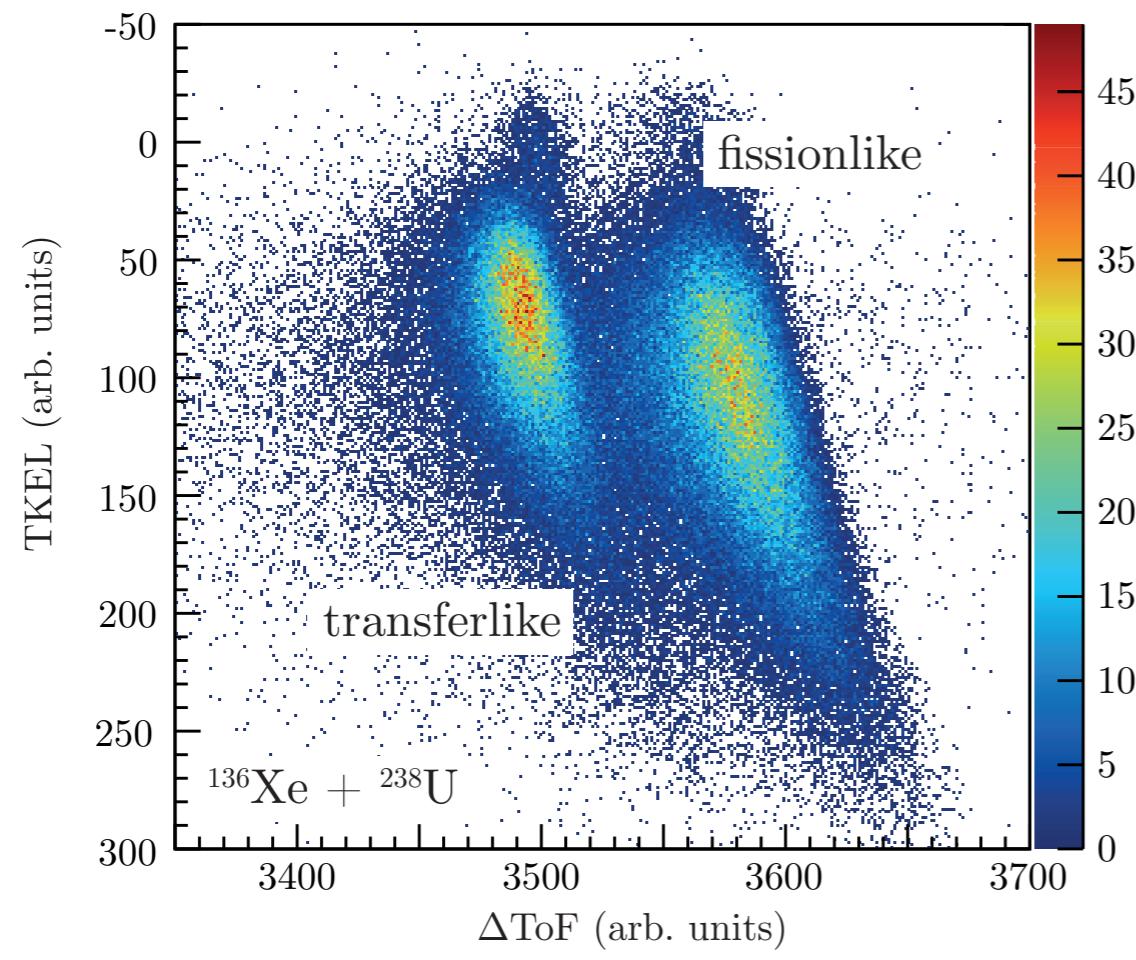
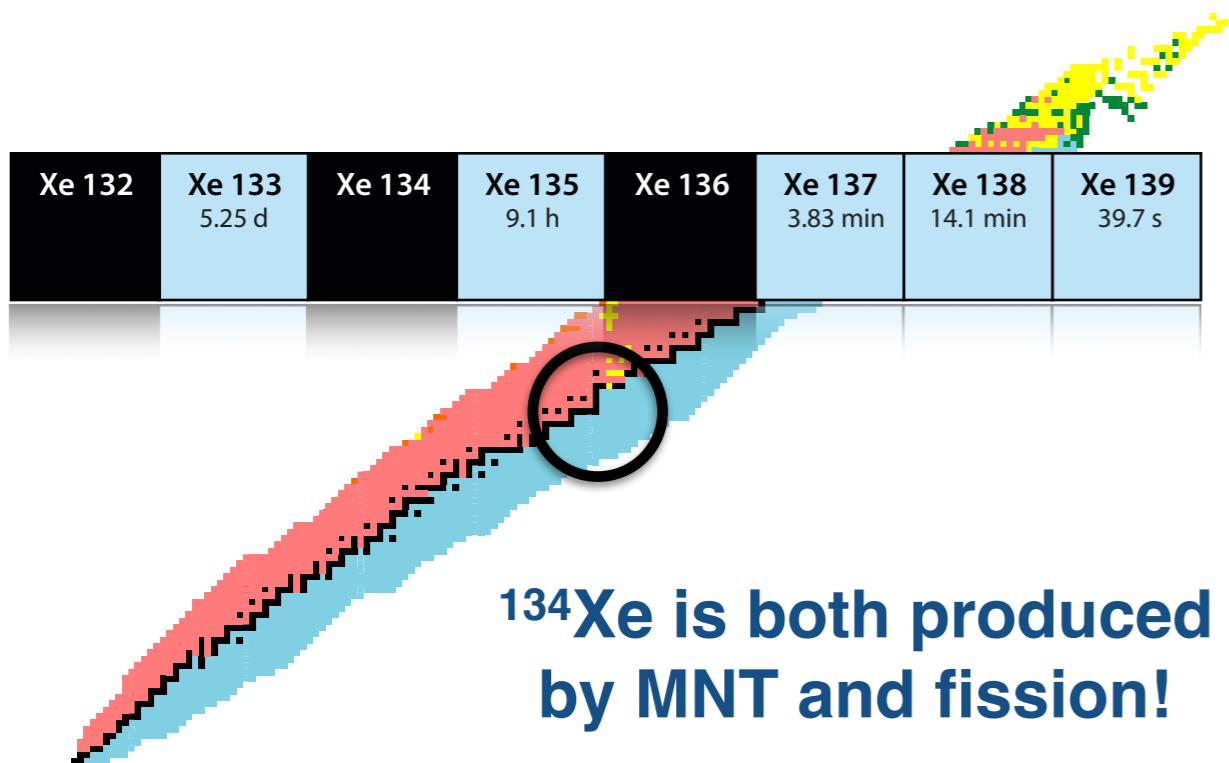




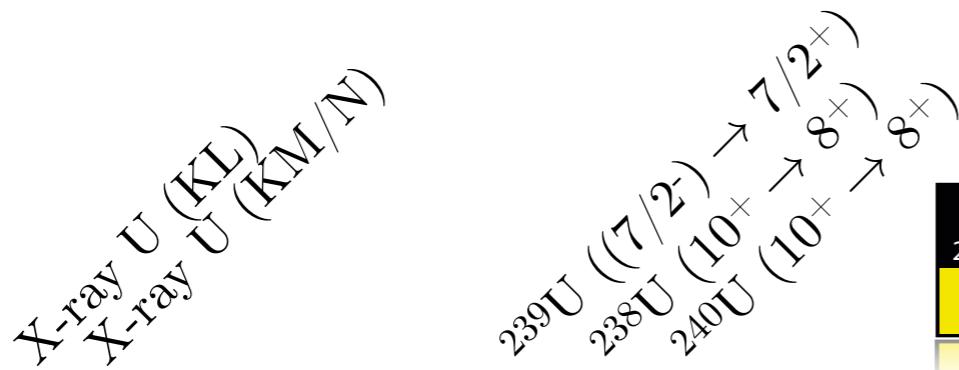
M. REJMUND *et al.*

PHYSICAL REVIEW C 93, 024312 (2016)

# High-Spin Spectroscopy of $^{134}\text{Xe}$



# Spectroscopy of $^{240}\text{U}$



U 234 $2.46 \times 10^5 \text{ a}$	U 235 $7.04 \times 10^8 \text{ a}$	U 236 24.10 d	U 237 6.75 d	U 238 $4.47 \times 10^9 \text{ a}$	U 239 23.5 min	U 240 14.1 h		U 242 16.8 min
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