Inelastic neutron scattering studies of ^{132,134}Xe: Elucidating structure in a transitional region and possible interferences for $0\nu\beta\beta$ searches

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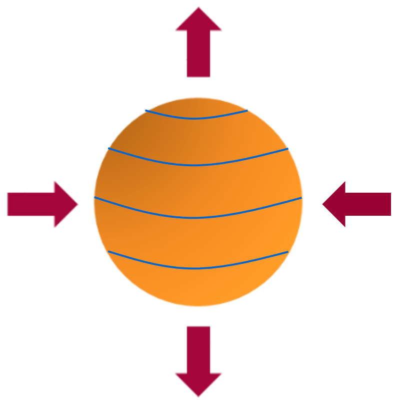
ARUNA

NSF

University of Kentucky Accelerator Laboratory 50 years 1964-2014 UK

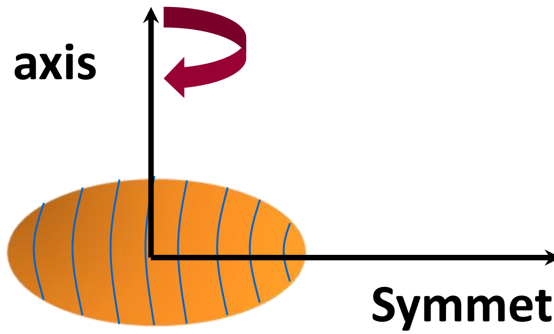
Nuclear Shape Transitions



spherical
vibrator

critical
point?

E(5)



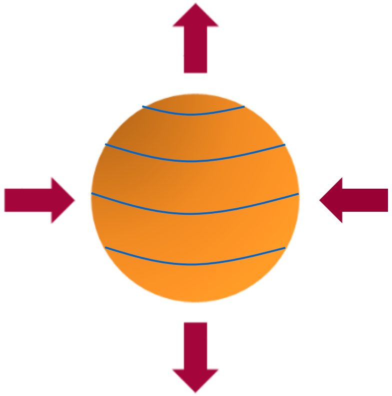
γ-soft
deformed rotor

1st proposed example: ^{134}Ba

F. Iachello, Phys. Rev. Lett. 85, 3580 (2000).

R. F. Casten and N. V. Zamfir, Phys. Rev. Lett. 85, 3584 (2000).

Nuclear Shape Transitions



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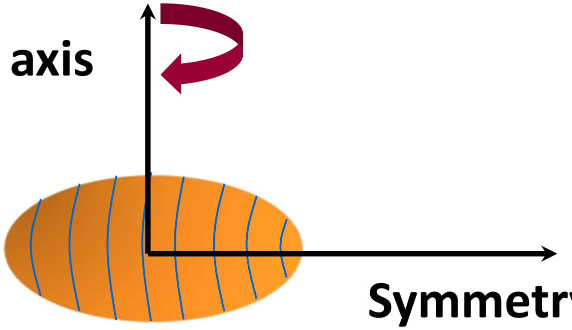
E(5)

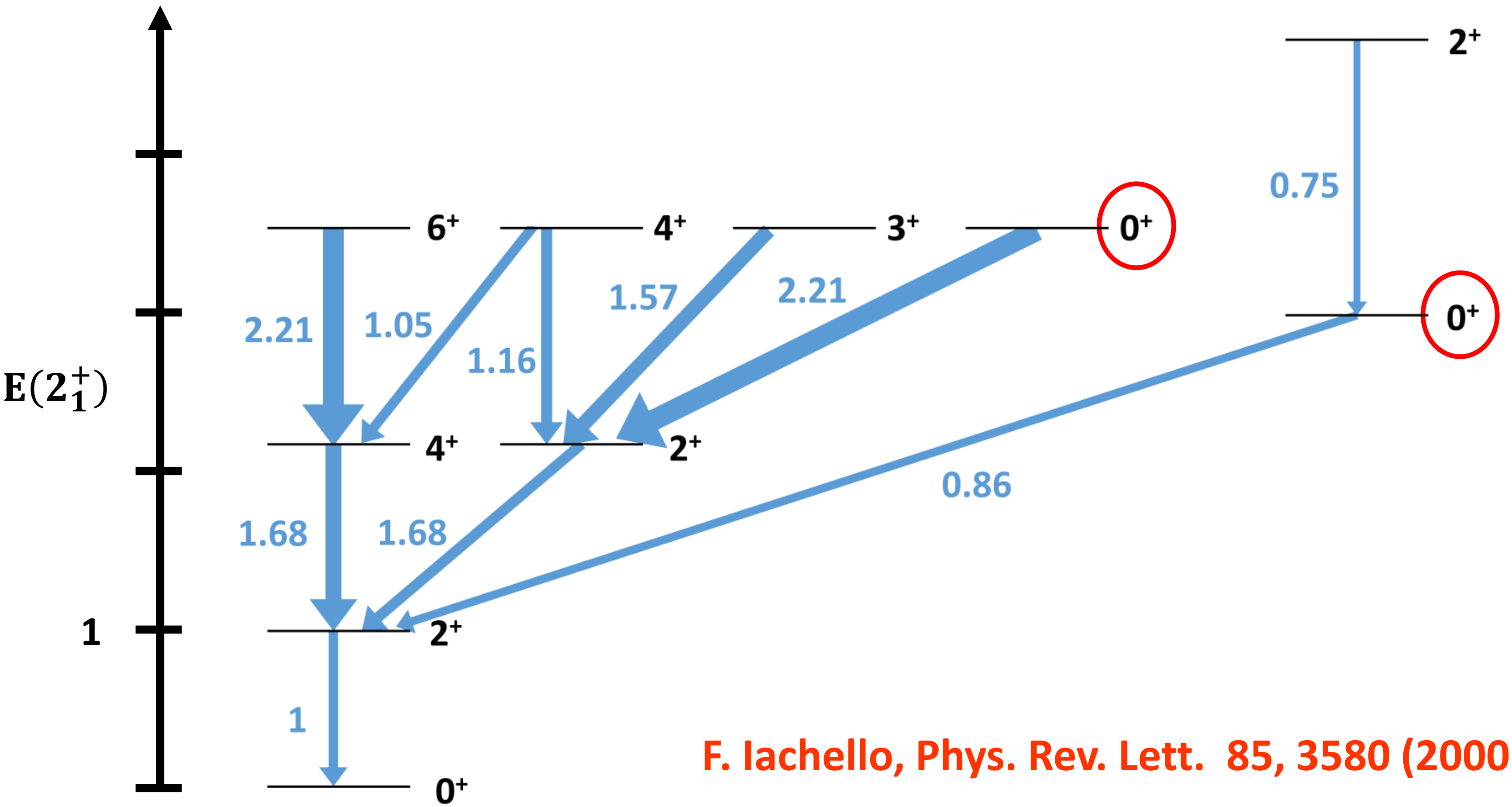


γ-soft
deformed rotor

136, 134, 132, 131, 130, 129, 128, 126, 124 Xe

Identifying E(5)

- Predicted level scheme, relative B(E2)s



F. Iachello, Phys. Rev. Lett. 85, 3580 (2000).

Do the Xe nuclei exhibit E(5) behavior?

- $E(4_1^+)/E(2_1^+)$=2.0-2.5
- 2 0⁺ states $E(0^+)/E(2_1^+)$= 3-4
- $0_2^+ \rightarrow 2_1^+$ and $0_3^+ \rightarrow 2_2^+$

Nucleus	$E(4_1^+)/E(2_1^+)$	$E(0_2^+)/E(2_1^+)$	$E(0_3^+)/E(2_1^+)$
^{128}Xe	2.33	3.57	4.24
^{130}Xe	2.25	(3.35)	(3.76)
^{132}Xe	2.16		
^{134}Xe	2.04		

R. M. Clark, *et al.* Phys. Rev. C 69, 064322 (2004).

PHYSICAL REVIEW C **80**, 061304(R) (2009)

Robust test of E(5) symmetry in ^{128}Xe

L. Coquard,[1] N. Pietralla,[1] T. Ahn,[1,2] G. Rainovski,[3] L. Bettermann,[4] M. P. Carpenter,[5] R. V. F. Janssens,[5] J. Leske,[1] C. J. Lister,[5] O. Möller,[1] W. Rother,[4] V. Werner,[2] and S. Zhu[5]

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[2] *Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA*
[3] *Faculty of Physics, St. Kliment Ohridski University of Sofia, 1164 Sofia, Bulgaria*
[4] *Institut für Kernphysik, Universität Köln, Zülpicher Str. 77, D-50937 Köln, Germany*
[5] *Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*

(Received 16 November 2009; published 23 December 2009)

Low-lying collectively excited states of ^{128}Xe were investigated by γ-ray spectroscopy following the ^{12}C(^{128}Xe,^{128}Xe*)^{12}C projectile Coulomb excitation reaction. Nineteen absolute $E2$ transition strengths were obtained including the first measurement of the critical $B(E2)$ decays from the second and third $J^\pi = 0^+$ states. These data are compared with the theoretical predictions of the critical point symmetry E(5) and allow us to conclude that ^{128}Xe is not an E(5) nucleus as previously suggested, leaving ^{130}Xe as the most likely candidate among the Xe isotopes.

$$0_2^+ \rightarrow 2_1^+ \text{ and } 0_3^+ \rightarrow 2_2^+$$

$$0_3^+ \rightarrow 2_1^+ \text{ and } 0_2^+ \rightarrow 2_2^+$$

PHYSICAL REVIEW C **82**, 024317 (2010)

Evolution of the mixed-symmetry $2^+_{1,\mathrm{ms}}$ quadrupole-phonon excitation from spherical to γ-soft Xe nuclei

L. Coquard,[1] N. Pietralla,[1] G. Rainovski,[1,2] T. Ahn,[1,3] L. Bettermann,[4] M. P. Carpenter,[5] R. V. F. Janssens,[5] J. Leske,[1] C. J. Lister,[5] O. Möller,[1] W. Rother,[4] V. Werner,[3] and S. Zhu[5]

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[2]*Faculty of Physics, St. Kliment Ohridski University of Sofia, BG-1164 Sofia, Bulgaria*
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[5]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

(Received 23 June 2010; published 23 August 2010)

Low-lying collective states of ^{130,132}Xe have been investigated by γ-ray spectroscopy following ^{12}C(Xe,Xe*)^{12}C projectile Coulomb excitation. The one-phonon $2^+_{1,\mathrm{ms}}$ states have been identified: the 2^+_4 state at 2150 keV with $B(M1; 2^+_4 \rightarrow 2^+_1) = 0.15(4)\mu_N^2$ in ^{130}Xe and the 2^+_3 state at 1985 keV with $B(M1; 2^+_3 \rightarrow 2^+_1) = 0.22(6)\mu_N^2$ in ^{132}Xe. The evolution of the one-phonon $2^+_{1,\mathrm{ms}}$ states in the even-even stable xenon isotopic chain from the vibrators near $N = 82$ to the γ-soft nuclei toward midshell is discussed.

E(5)?

University of Kentucky Experiments

- Inelastic neutron scattering — (n,n'γ)
  - Monoenergetic neutrons via $^{3}H(p,n)^{3}He$
  - Allows determination of:
    - Level scheme
    - Transition multipolarities
    - Multipole mixing ratios
    - Level lifetimes by DSAM
    - Transition probabilities
    - Cross sections
- Solid XeF_2 samples of >99.9% ^{132}Xe, ^{134}Xe
  - Highly enriched, solid targets not used previously

XeF_2 in Teflon® vial

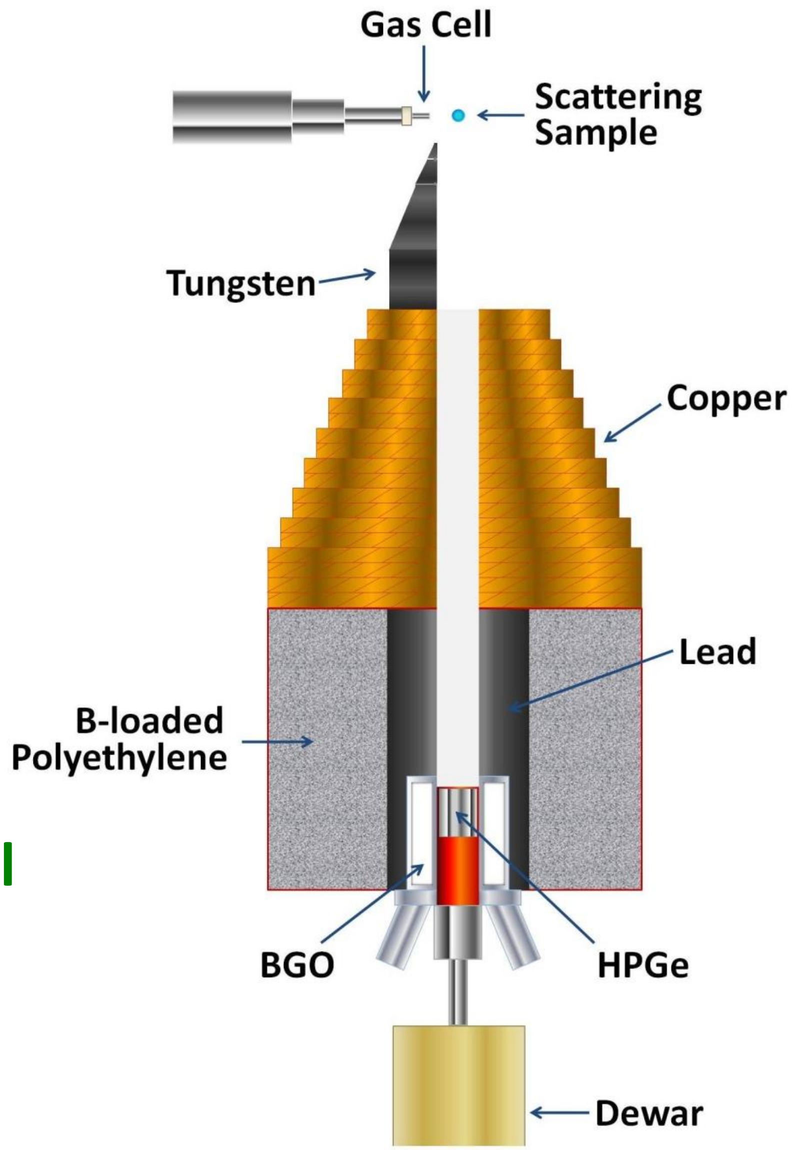
Experimental Setup

Excitation functions

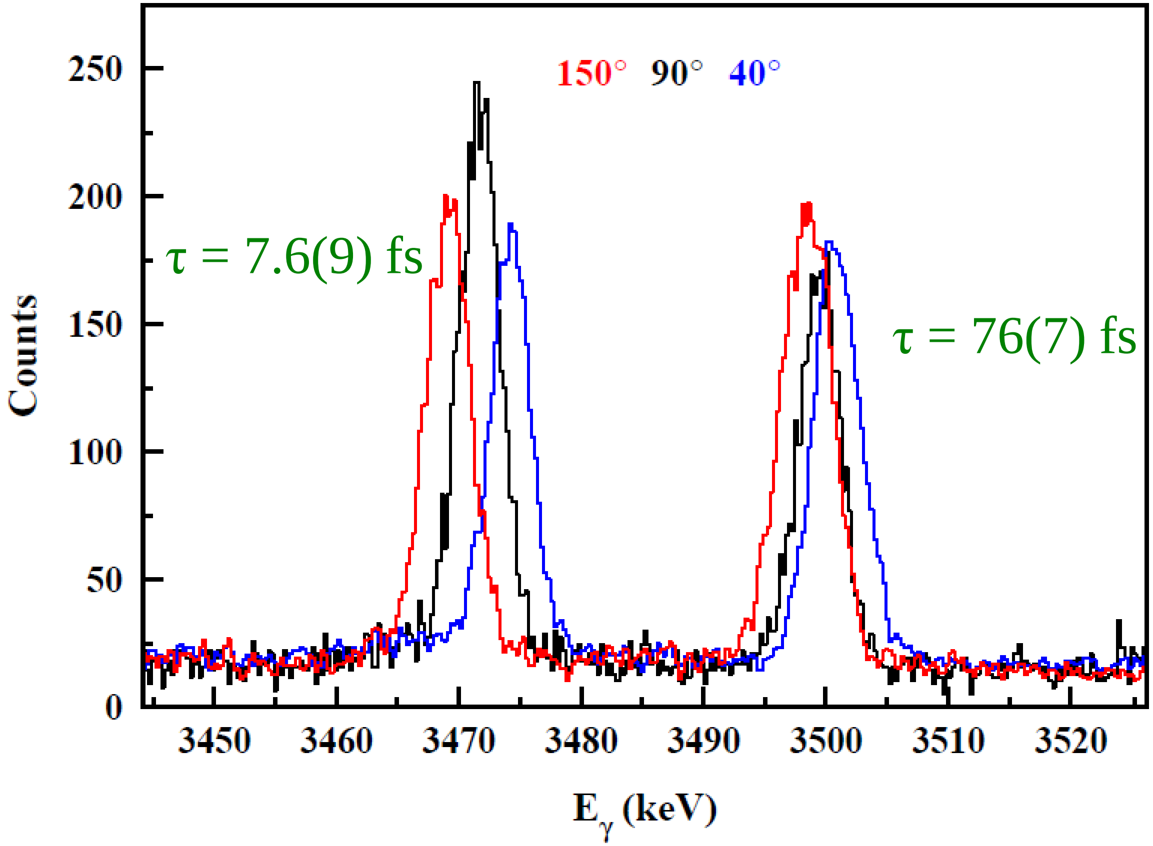
- Vary neutron energy
- Detection angle constant
- Build level scheme
- Cross sections

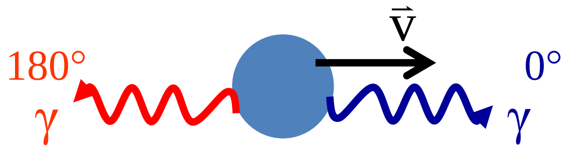
Angular distributions

- Constant neutron energy
- Detection angle varied from 40°-150°
- Transition multipolarities, multipole mixing ratios, level lifetimes, transition probabilities



Level Lifetimes: Doppler-Shift Attenuation Method (DSAM)





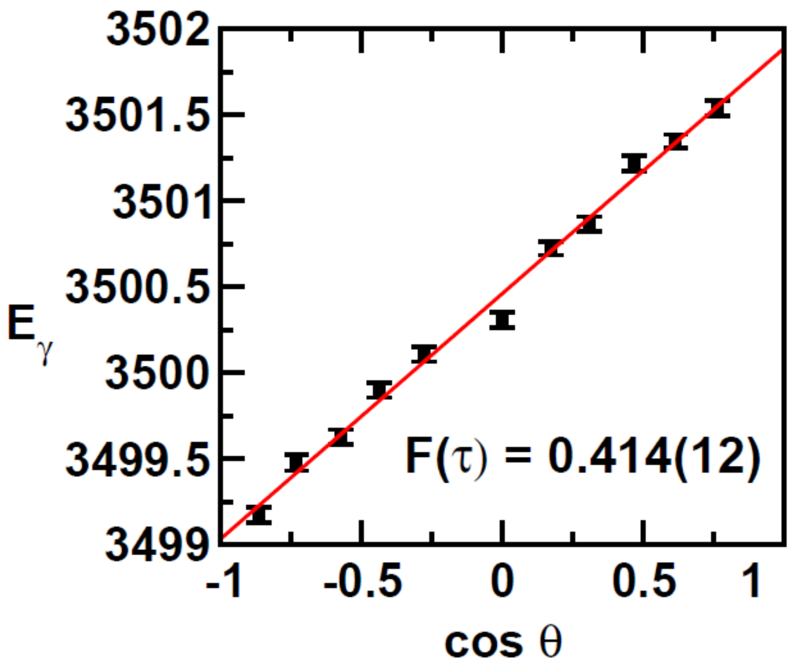
Scattered neutron causes the nucleus to recoil.

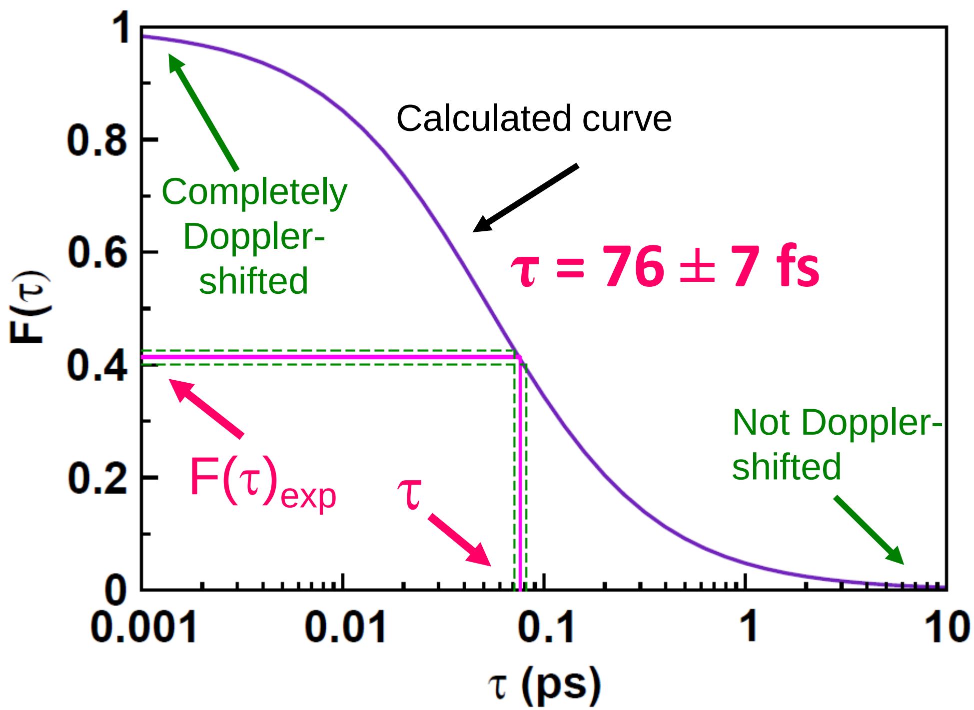
Emitted γ rays experience a Doppler shift.

Level lifetimes in the femtosecond region can be determined.

T. Belgya, G. Molnár, and S.W. Yates, Nucl. Phys. A607, 43 (1996).
E.E. Peters *et al*., Phys. Rev. C 88, 024317 (2013).

DSAM



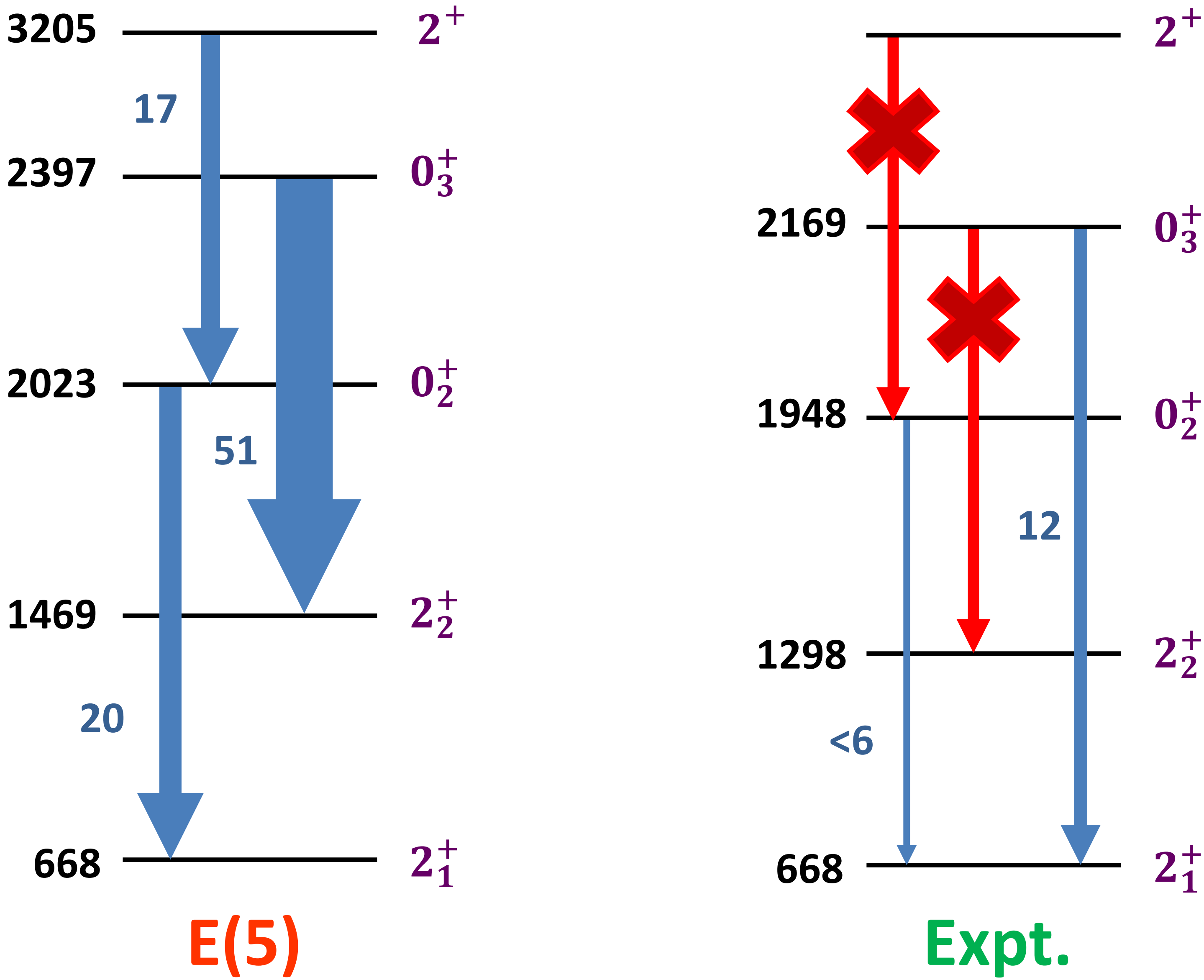


$$E_\gamma(\theta) = E_\gamma\left[1 + F_{exp}(\tau)\frac{v_{cm}}{c}\cos\theta\right]$$

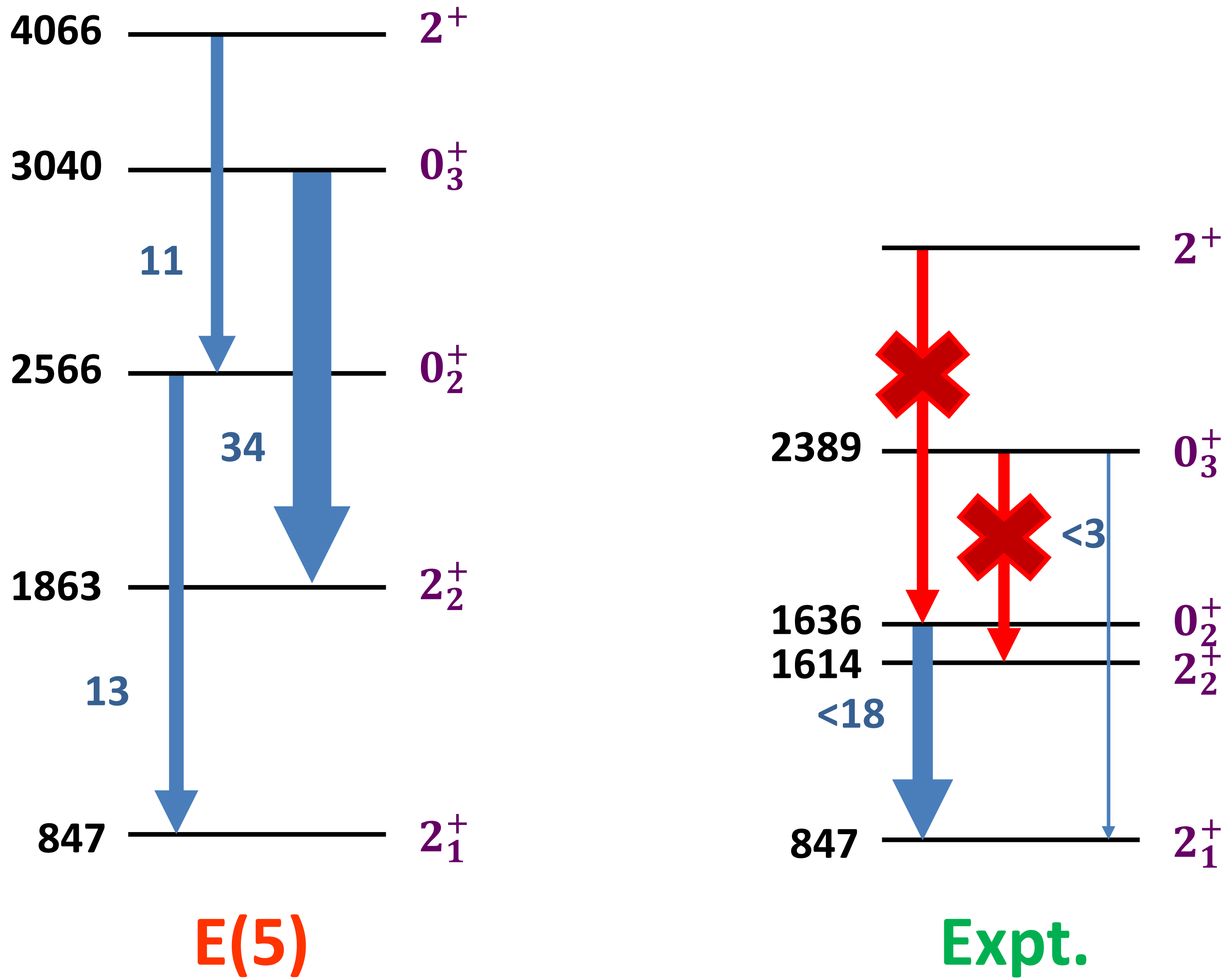
K.B. Winterbon, Nucl. Phys. A246, 293 (1975).

T. Belgya, G. Molnár, and S. W. Yates, Nucl. Phys. A607, 43 (1996).

^{132}Xe 0^+ States



^{134}Xe 0^+ States



Do the Xe nuclei exhibit E(5) behavior?

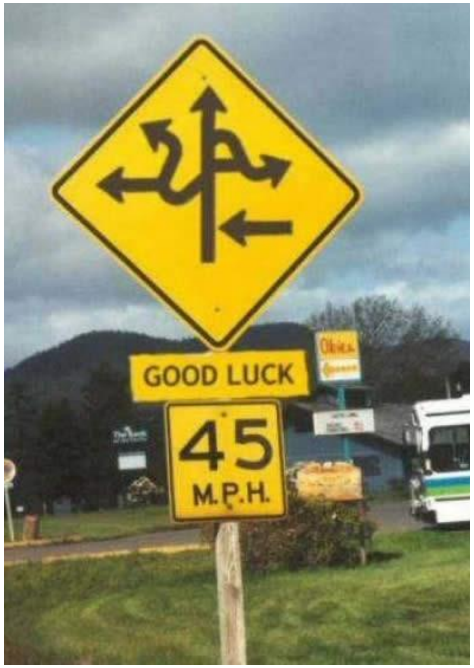
- $E(4_1^+)/E(2_1^+)$=2.00-2.50
- 2 0^+ states 3-4 times $E(2_1^+)$
- $0_2^+ \rightarrow 2_1^+$ and $0_3^+ \rightarrow 2_2^+$ ✖

Nucleus	$E(4_1^+)/E(2_1^+)$	$E(0_2^+)/E(2_1^+)$	$E(0_3^+)/E(2_1^+)$
^{128}Xe	2.33	3.57	4.24
^{130}Xe	2.25	(3.35)	(3.76)
^{132}Xe	2.16	**2.92**	**3.25**
^{134}Xe	2.04	**1.93**	**2.82**

R. M. Clark, *et al.* Phys. Rev. C 69, 064322 (2004).

Structure Summary

- Neither ^{132}Xe nor ^{134}Xe fits the E(5) description.
- Transitional nuclei continue to be difficult to describe.



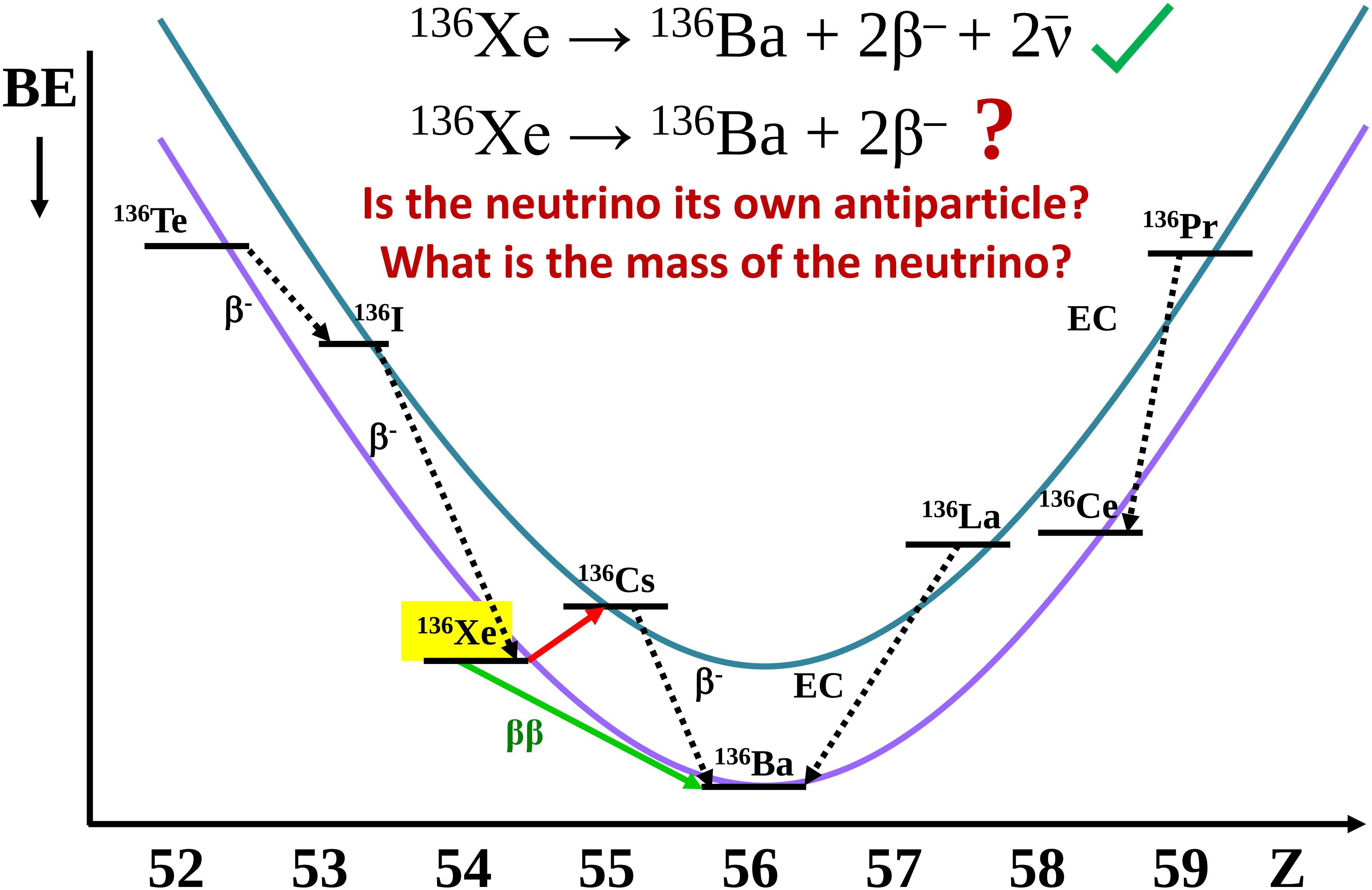
Double-β Decay

$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2\beta^{-} + 2\bar{\nu}$$ ✓

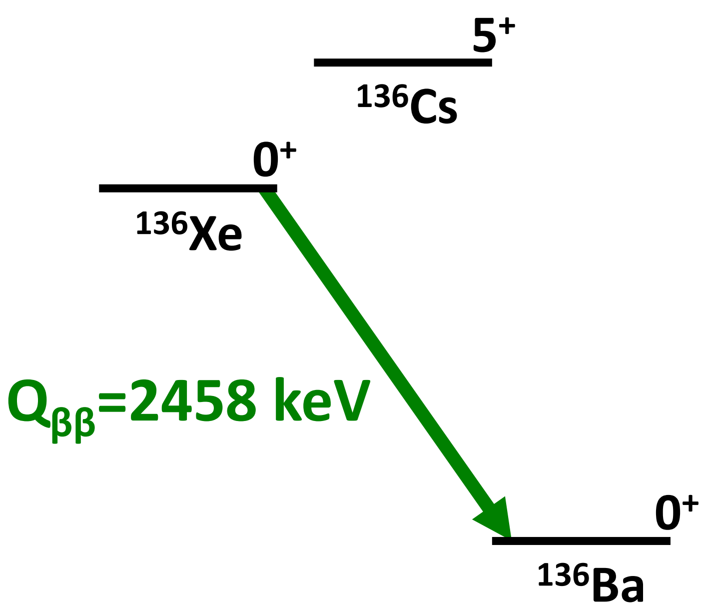
$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2\beta^{-}$$?

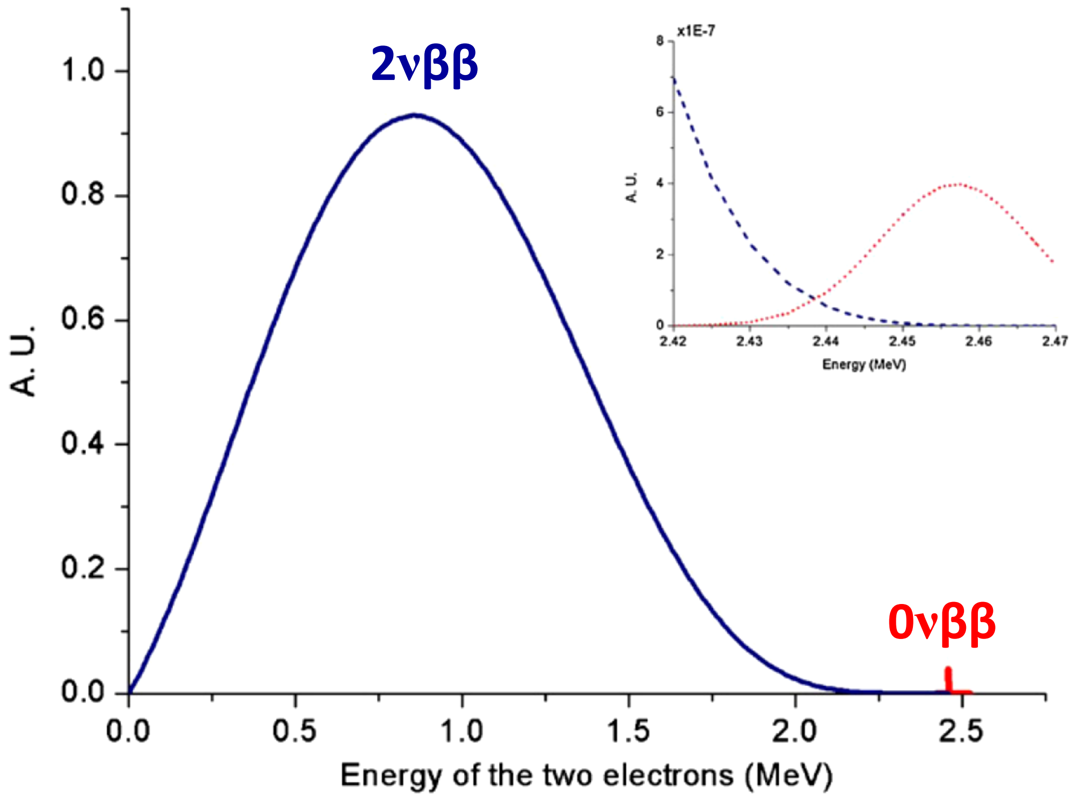
Is the neutrino its own antiparticle?

What is the mass of the neutrino?



Experimental Signature of 0νββ

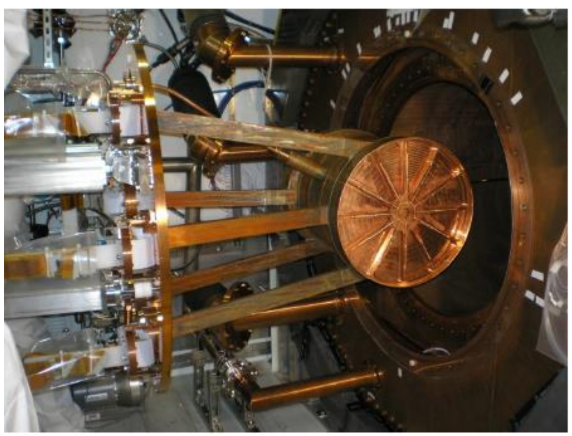


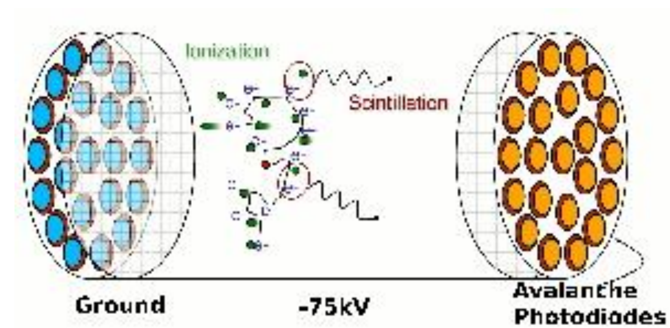


S. Cebrián et al., J. Phys. G: Nucl. Part. Phys. 40 (2013) 125203

EXO Enriched Xenon Observatory

- **EXO-200:**
  - 200 kg of Xe (*l*)
    - 80.6% enriched in ^{136}Xe (remaining 19.4% is ^{134}Xe)
  - Q-value: 2457.83 ± 0.37 keV

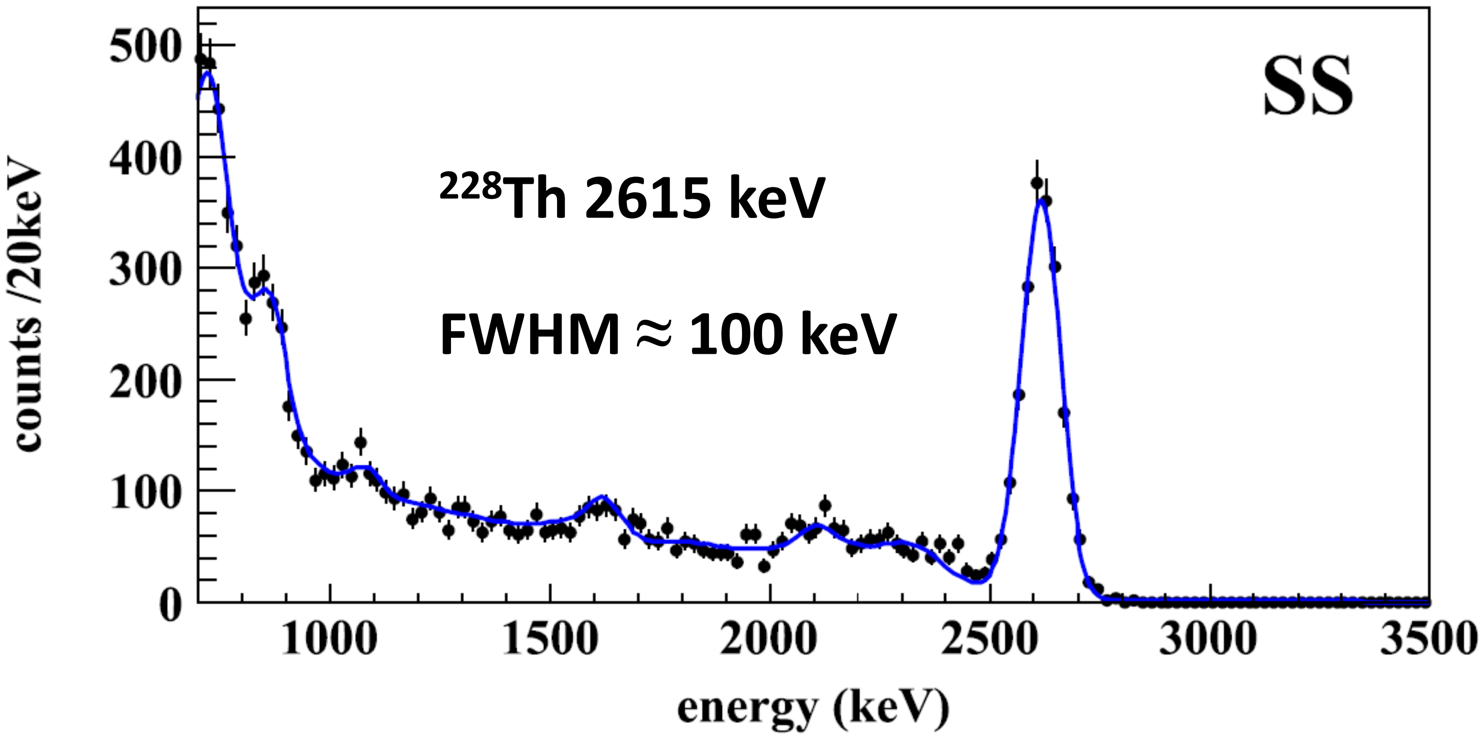




2012 JINST 7 P05010 PRL 109, 032505 (2012)

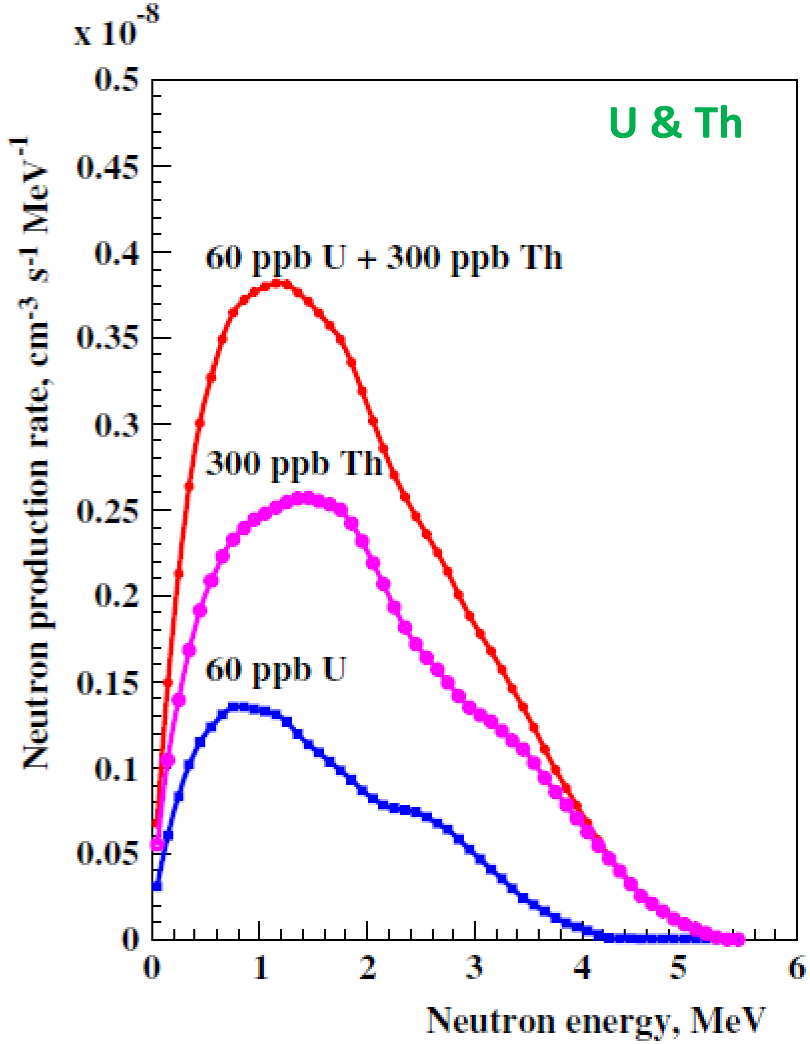
Pictures from R. Neilson TIPP 2011 and http://www-project.slac.stanford.edu/exo/

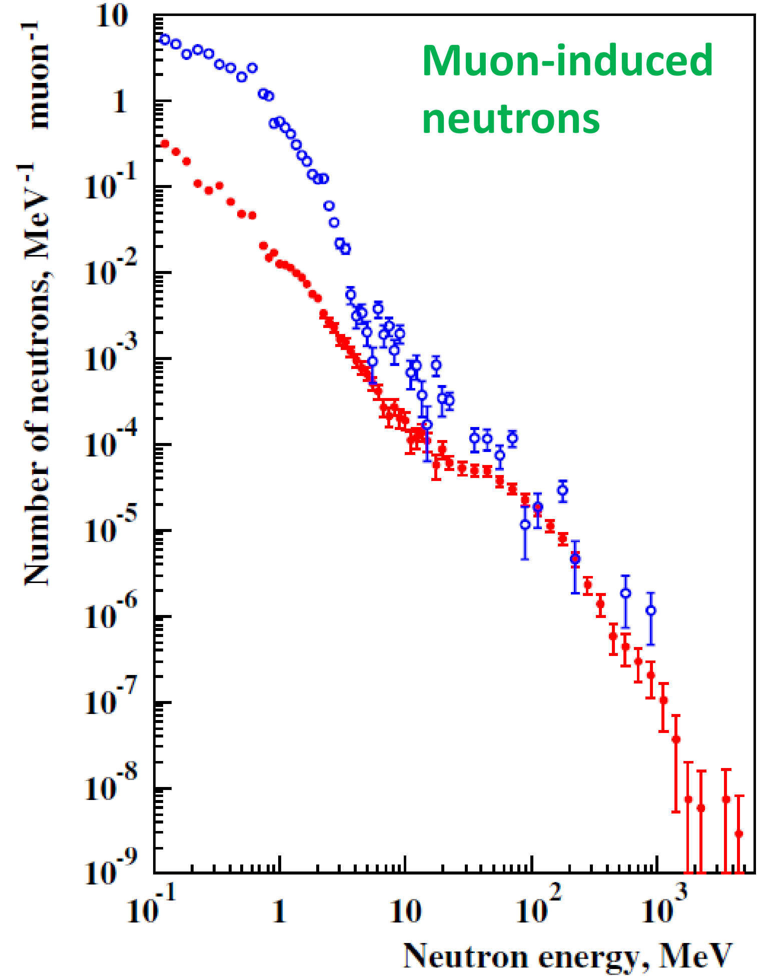
EXO Resolution



PRL 109, 032505 (2012)

Calculated Neutron Backgrounds



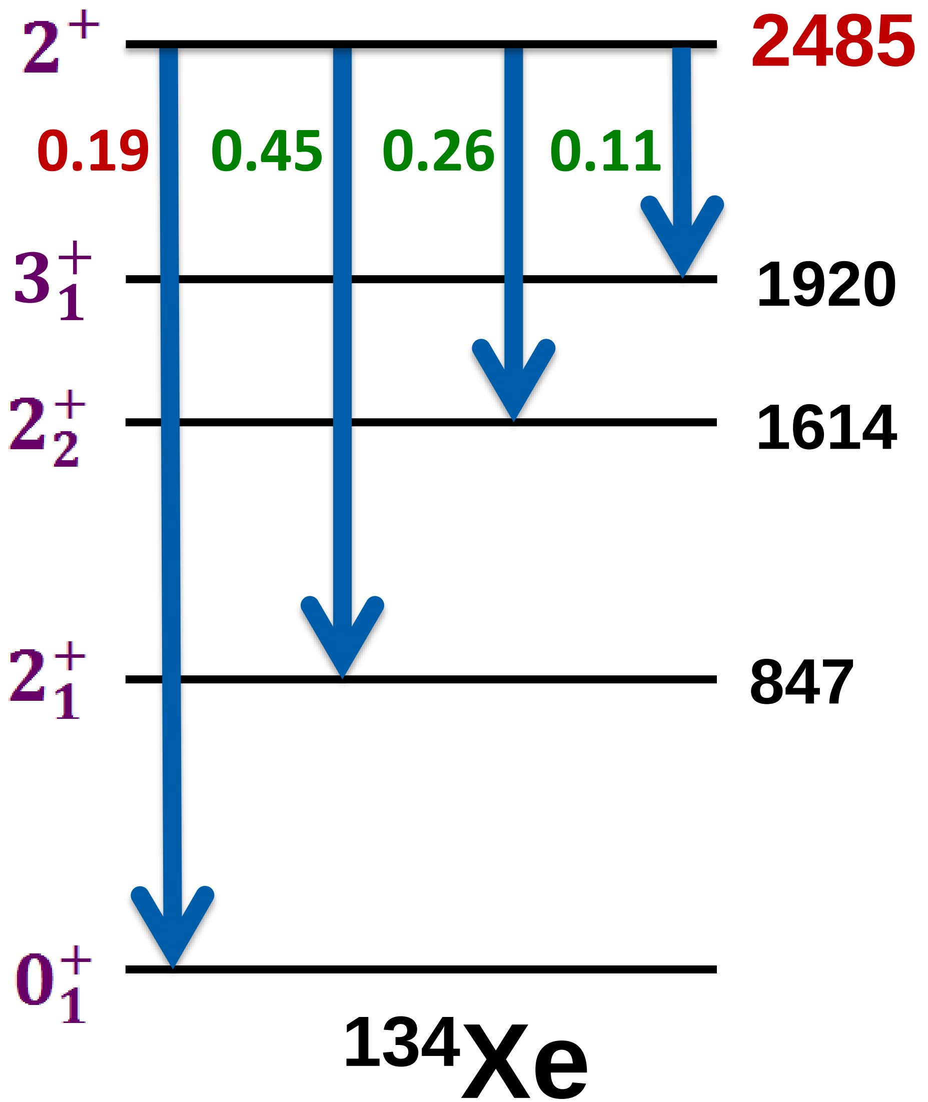


M.J. Carson et al. Astroparticle Physics 21 (2004) 667–687

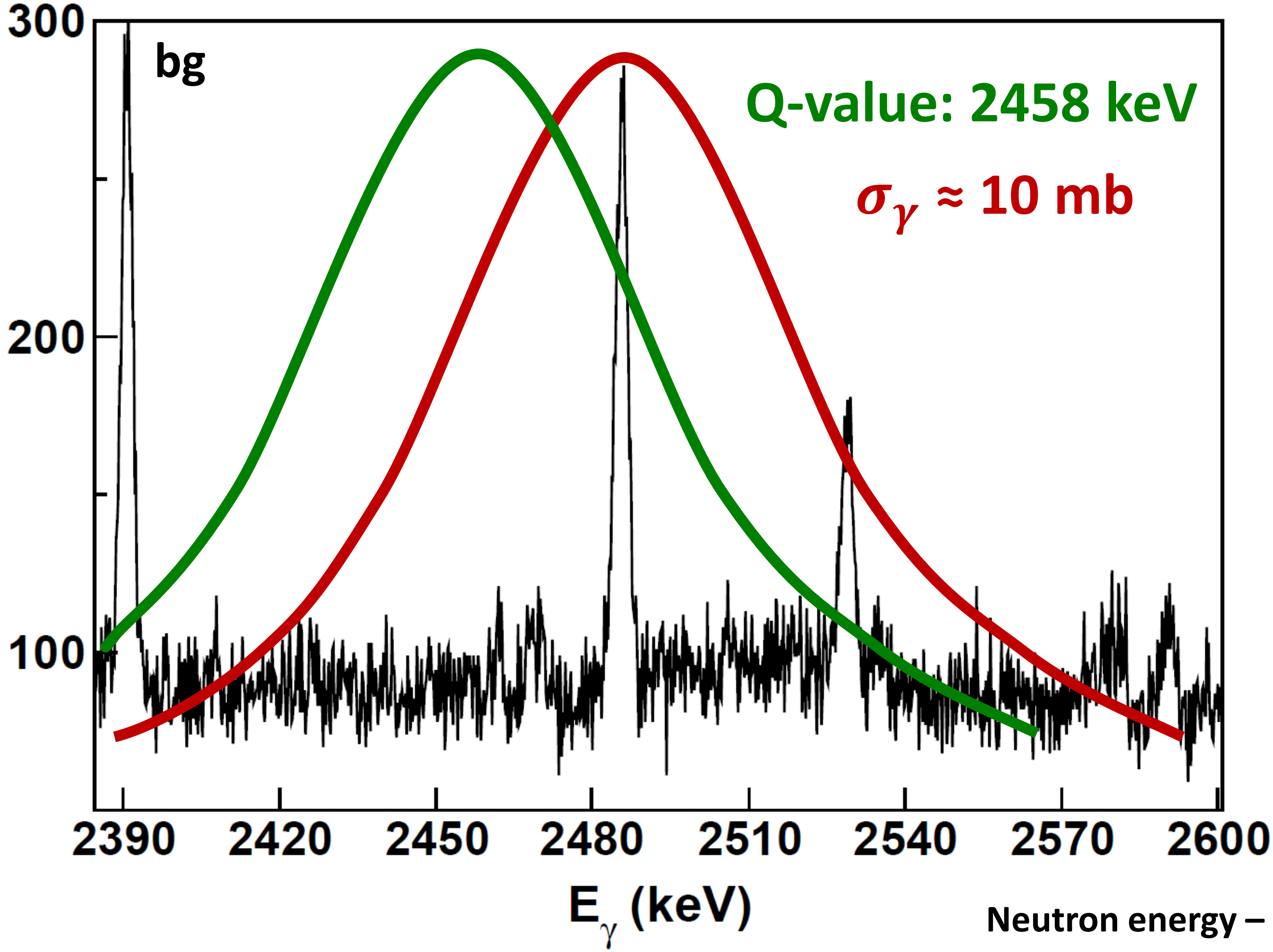
^{134}Xe(n,n'γ) Background?

$\tau = 331^{+60}_{-46}$ fs

New Level!

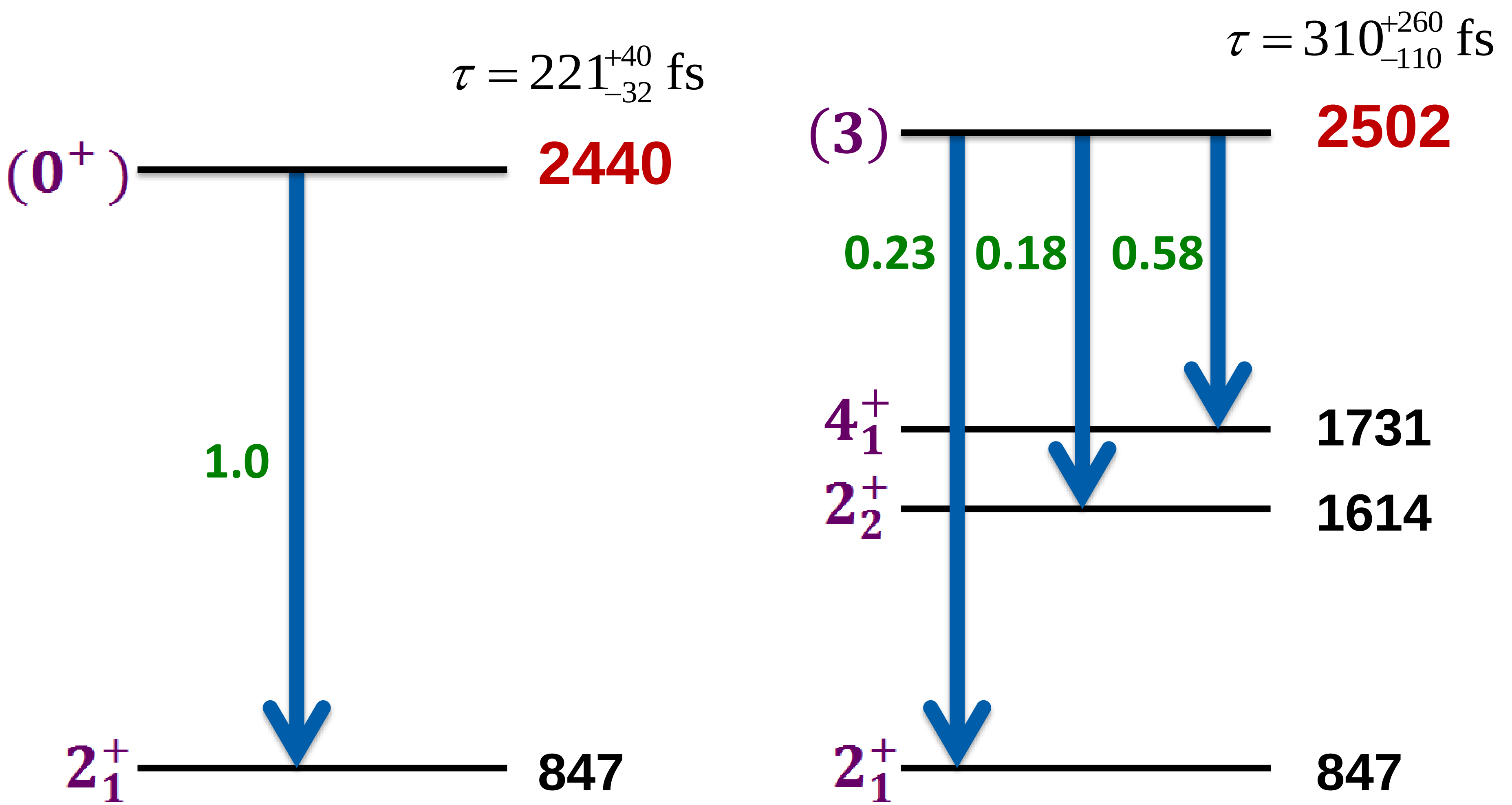


2485-keV Gamma Ray

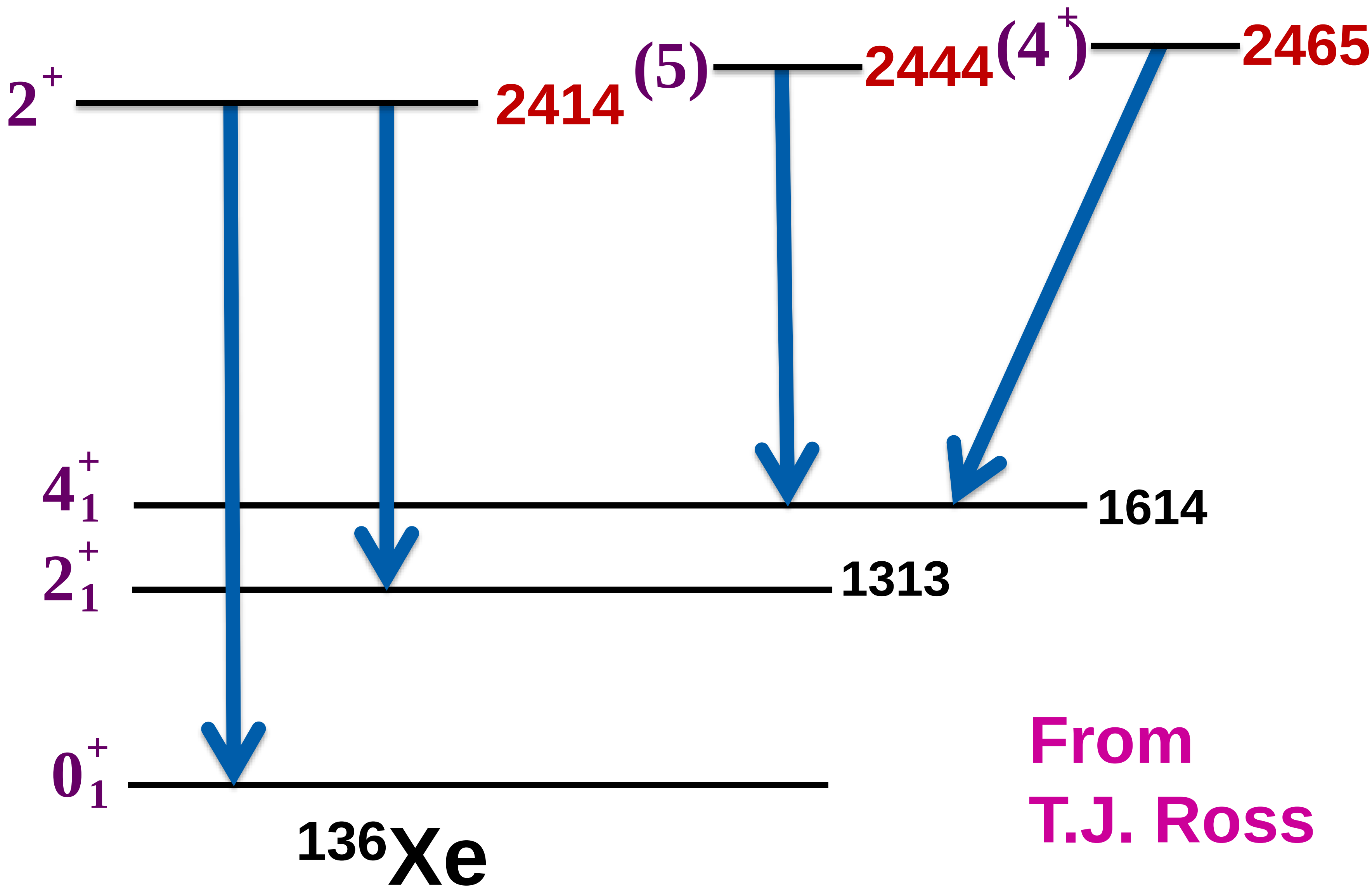


Neutron energy – 2.7 MeV

Other New Levels of Interest

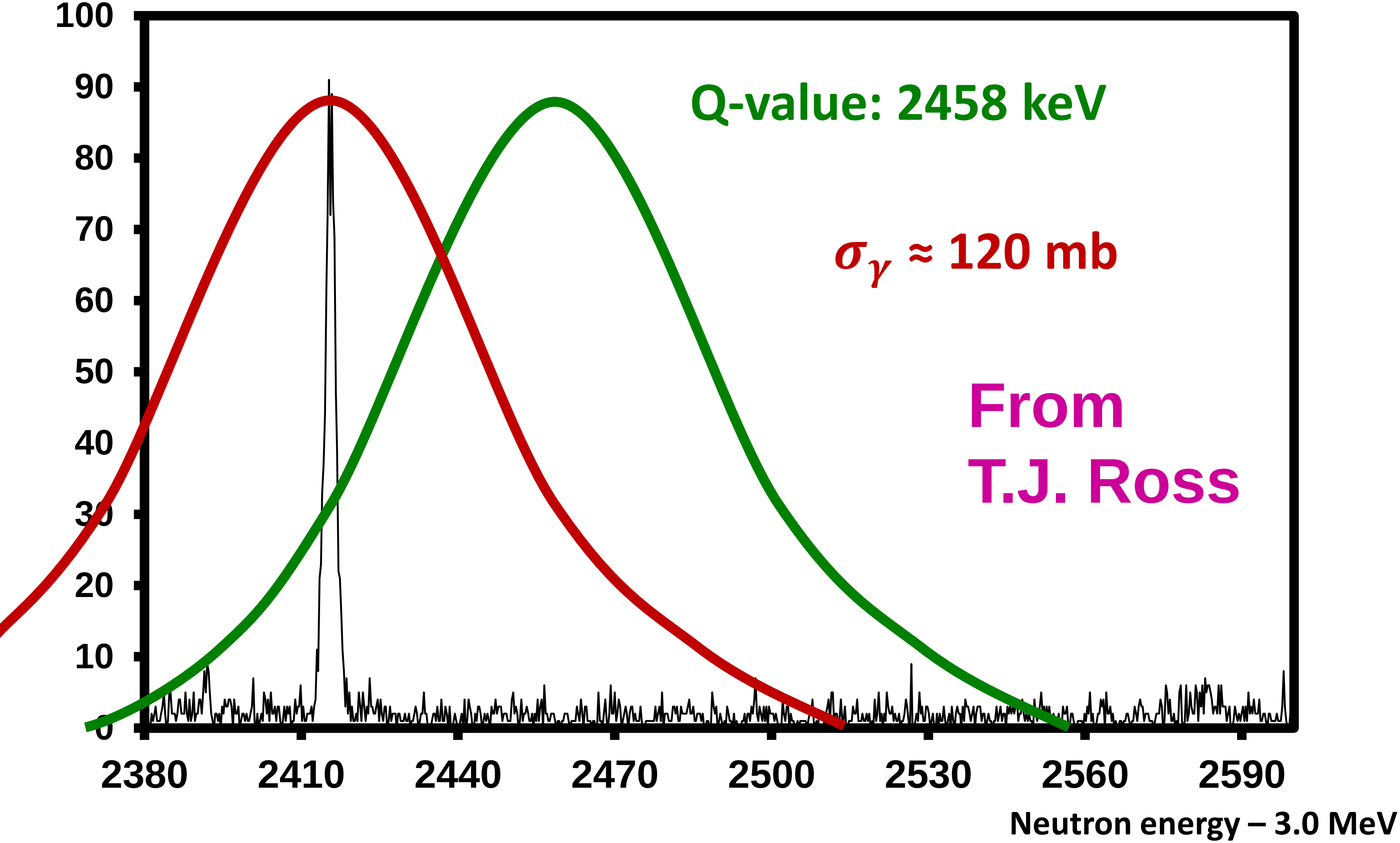


^{136}Xe: Three levels in the region



From
T.J. Ross

^{136}Xe 2414-keV Gamma Ray



Acknowledgments

Xe conversion:

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Thank You!