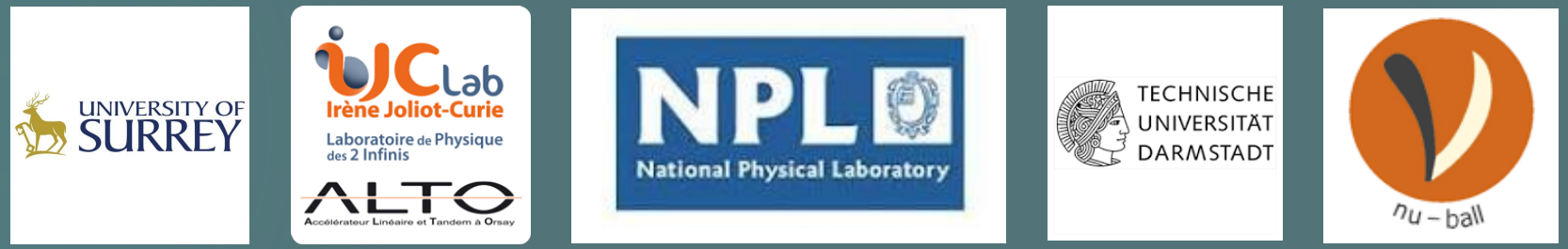
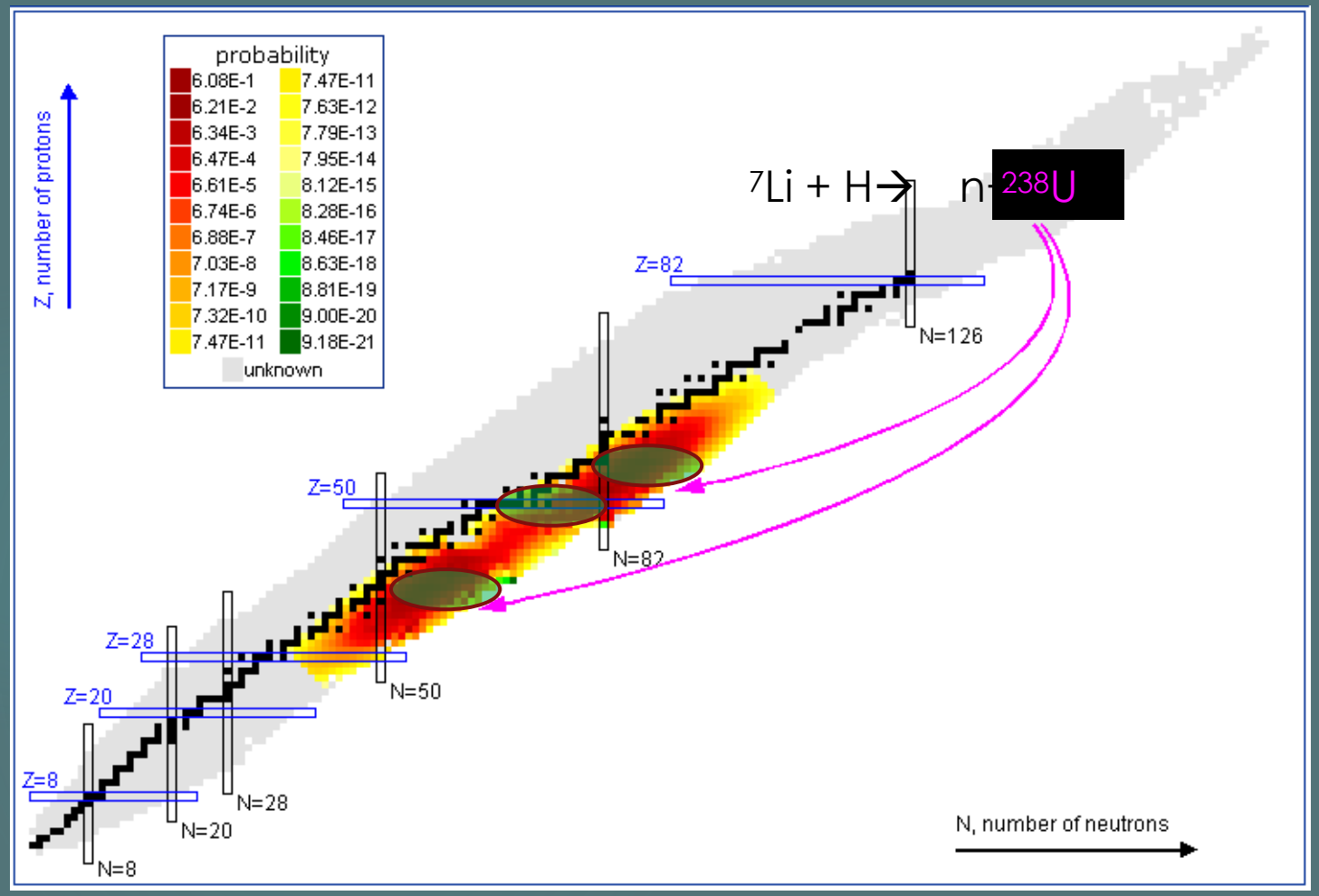
Fast-timing spectroscopy with the ν-ball2 spectrometer

S. Pascu, C. Hiver, Zs. Podolyak, P.H. Regan, Ma. Von Tresckow, J.N. Wilson, and the ν-ball2 N-SI-120 collaboration

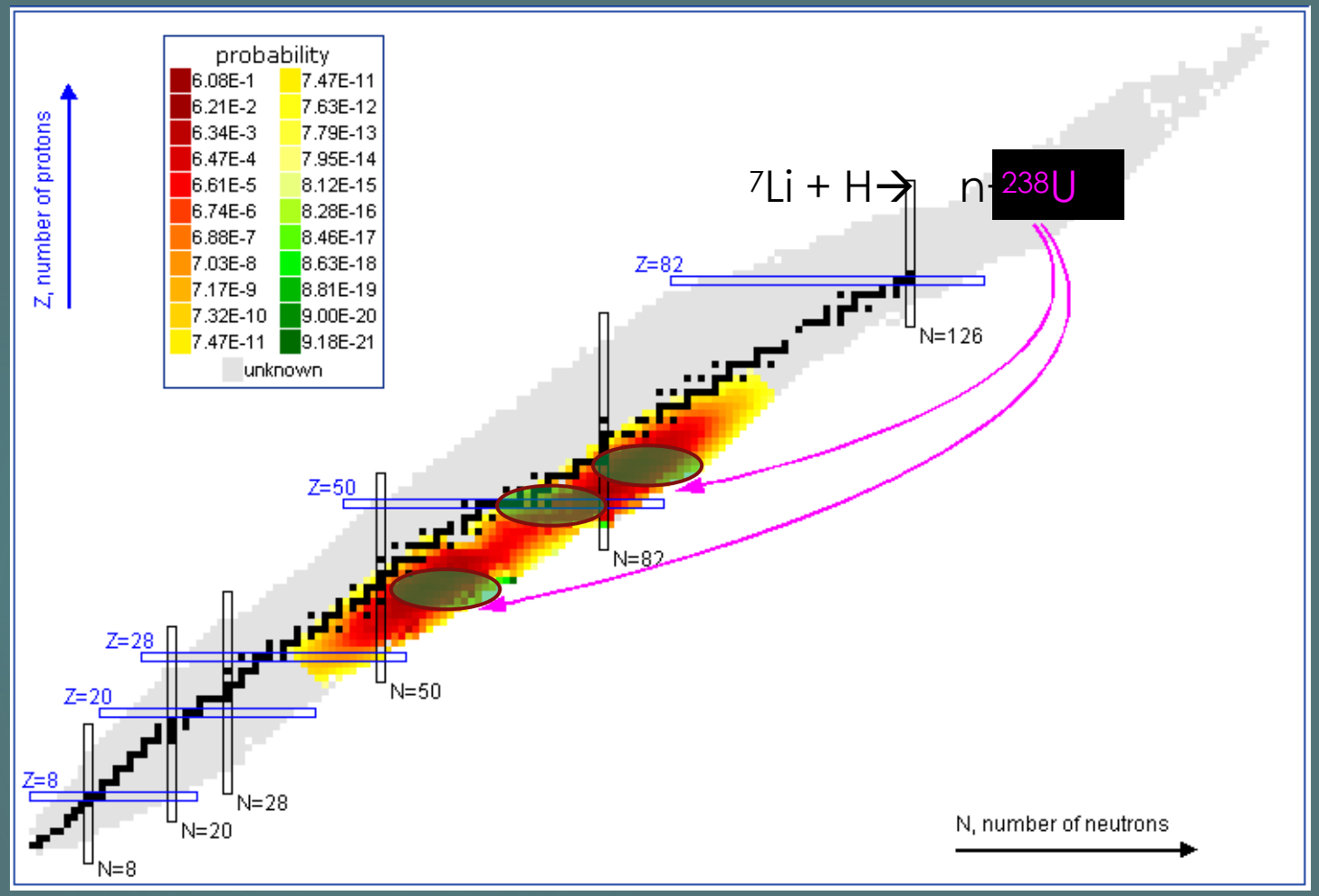


Capture Gamma-Ray Spectroscopy 2023 17-21 July 2023

Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)

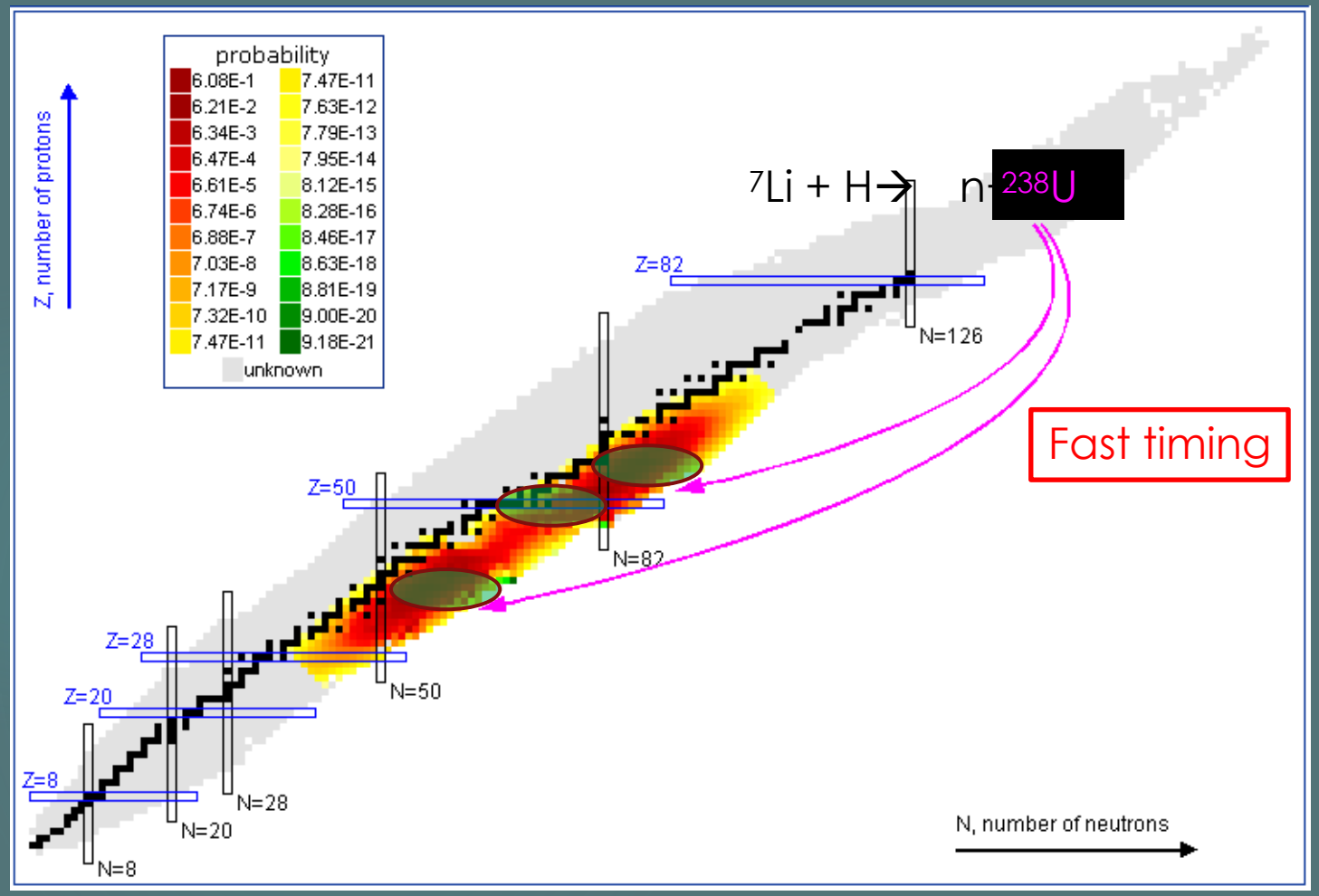


Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)



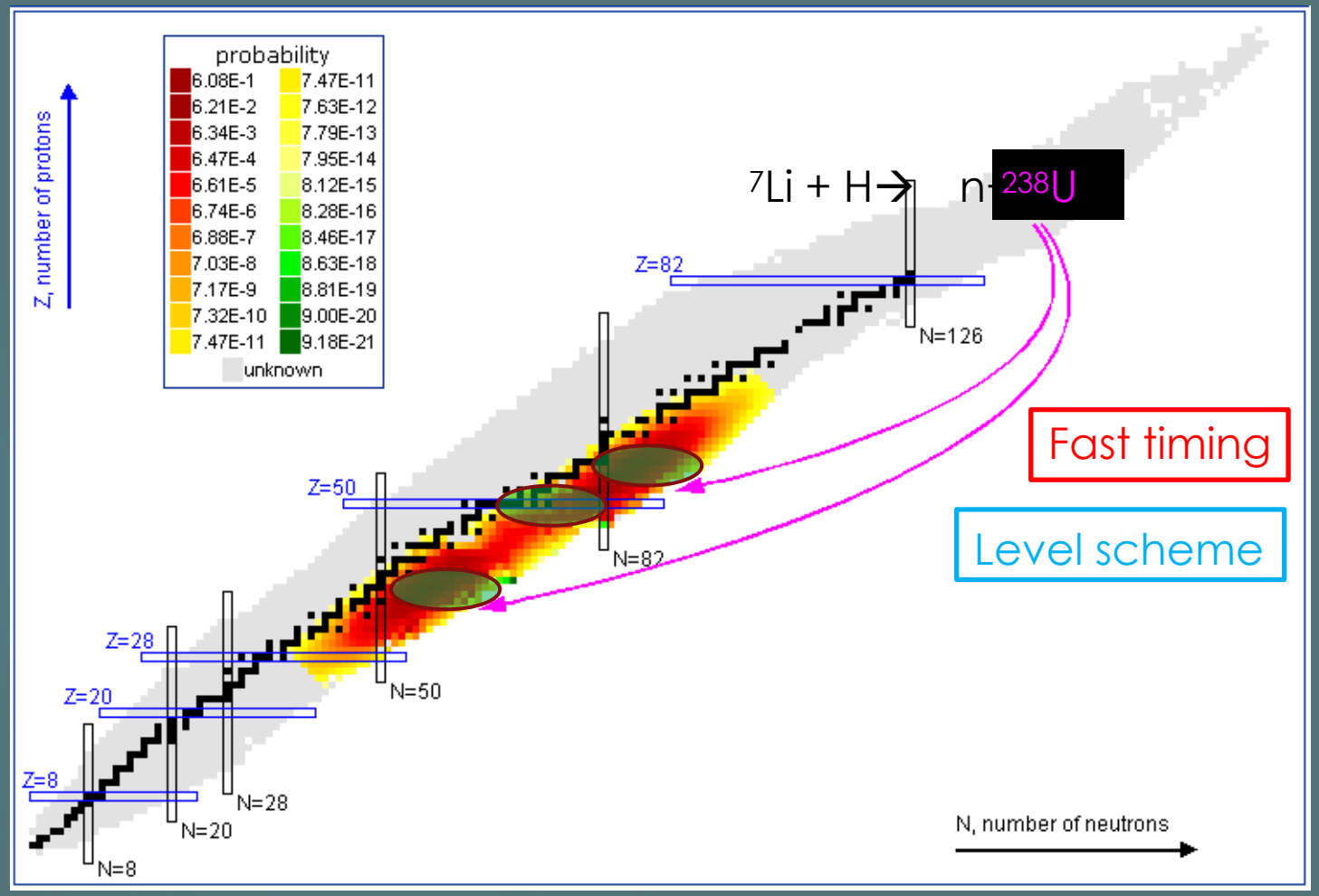
- ^{238}U nuclear structure study with ν-Ball 2 for nuclear energy application
  M. Kerveno et al.
- Evolution of the deformation across the yttrium isotopic chain in the neutron-rich nuclei around A =100
  L. W. Iskra, B. Fornal, S. Leoni et al.
- Spectroscopy of high-spin multiplets in few-valence-particle nuclei around ^{132}Sn
  N. Cieplicka-Orynczak, B. Fornal, S. Leoni et al.
- Gamma and fast-timing spectroscopy of Se and Ge isotopes populated in fission
  A. Korgul, L. M. Fraile, et al.
- Fast-timing investigation of single particle and collective states in Te isotopes
  L. M. Fraile, A. Korgul, et al.
- Investigation of Sn isotopes populated in fission
  L. M. Fraile, A. Korgul, et al.
- Gamma spectroscopy of neutron-rich $^{128-134}$In isotopes populated in fission of ^{238}U
  M. Stryjczyk, M. Piersa-Silkowska, et al.
- Probing the rapid shape transition in ^{100}Zr and ^{102}Zr by fast-timing lifetime measurements
  K. Rezynkina, S. Bottoni et al.
- Determination of level density and radiation strength function for fission fragments
  N. Jovancevic et al.
- Lifetime measurements around N=90
  M. Rudigier, Th. Kröll, M. von Tresckow, et al.
- Study of shape-coexistence and single-particle states in neutron-rich Kr isotopes
  A. Blazhev, R. Gerst
- Constraining isomeric fission yield ratios for ^{238}U(n,f) using ν-ball-2
  A. Algora et al.

Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)



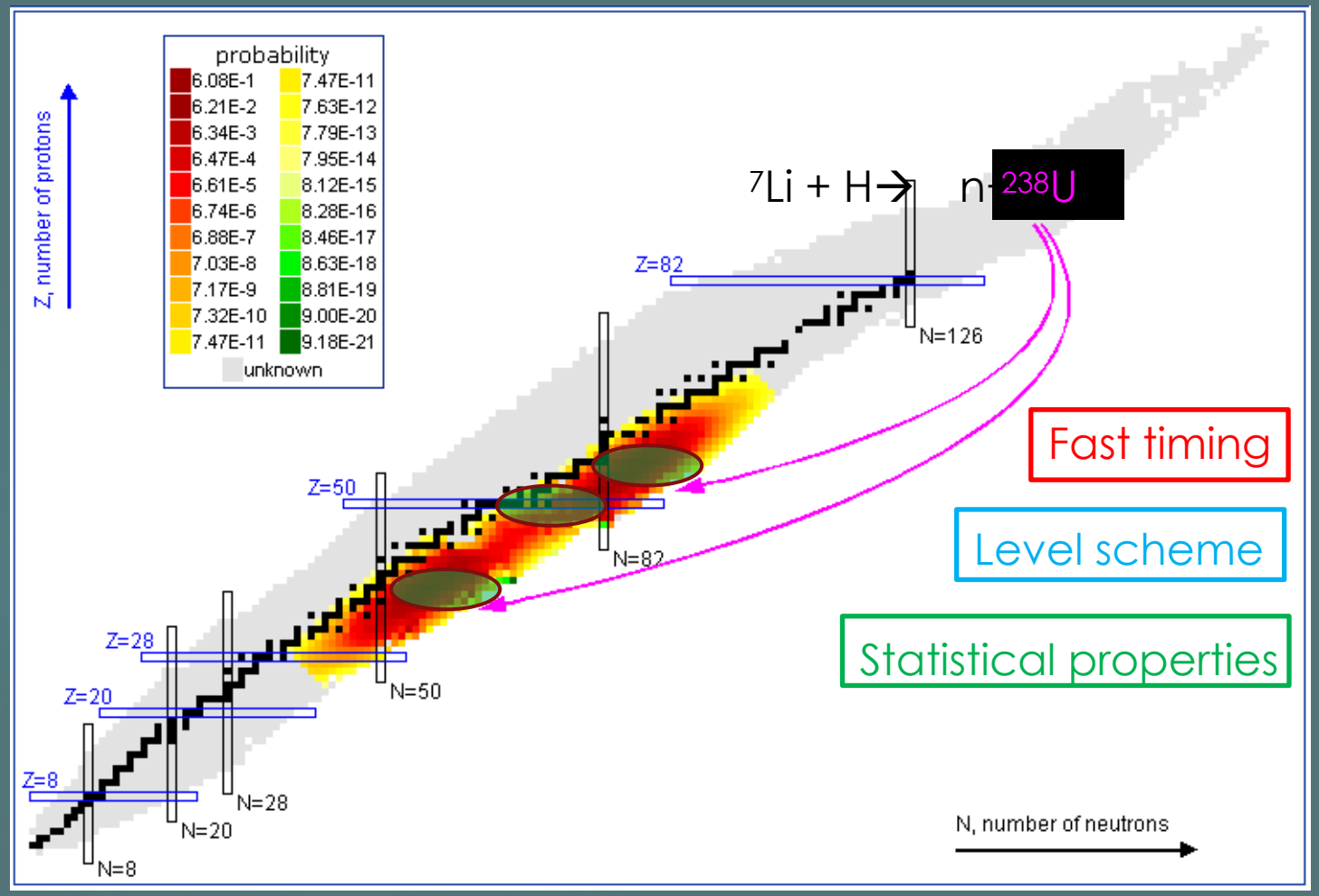
- ^{238}U nuclear structure study with ν-Ball 2 for nuclear energy application
  M. Kerveno et al.
- Evolution of the deformation across the yttrium isotopic chain in the neutron-rich nuclei around A =100
  L. W. Iskra, B. Fornal, S. Leoni et al.
- Spectroscopy of high-spin multiplets in few-valence-particle nuclei around ^{132}Sn
  N. Cieplicka-Orynczak, B. Fornal, S. Leoni et al.
- Gamma and fast-timing spectroscopy of Se and Ge isotopes populated in fission
  A. Korgul, L. M. Fraile, et al.
- Fast-timing investigation of single particle and collective states in Te isotopes
  L. M. Fraile, A. Korgul, et al.
- Investigation of Sn isotopes populated in fission
  L. M. Fraile, A. Korgul, et al.
- Gamma spectroscopy of neutron-rich $^{128-134}$In isotopes populated in fission of ^{238}U
  M. Stryjczyk, M. Piersa-Silkowska, et al.
- Probing the rapid shape transition in ^{100}Zr and ^{102}Zr by fast-timing lifetime measurements
  K. Rezynkina, S. Bottoni et al.
- Determination of level density and radiation strength function for fission fragments
  N. Jovancevic et al.
- Lifetime measurements around N=90
  M. Rudigier, Th. Kröll, M. von Tresckow, et al.
- Study of shape-coexistence and single-particle states in neutron-rich Kr isotopes
  A. Blazhev, R. Gerst
- Constraining isomeric fission yield ratios for ^{238}U(n,f) using ν-ball-2
  A. Algora et al.

Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)



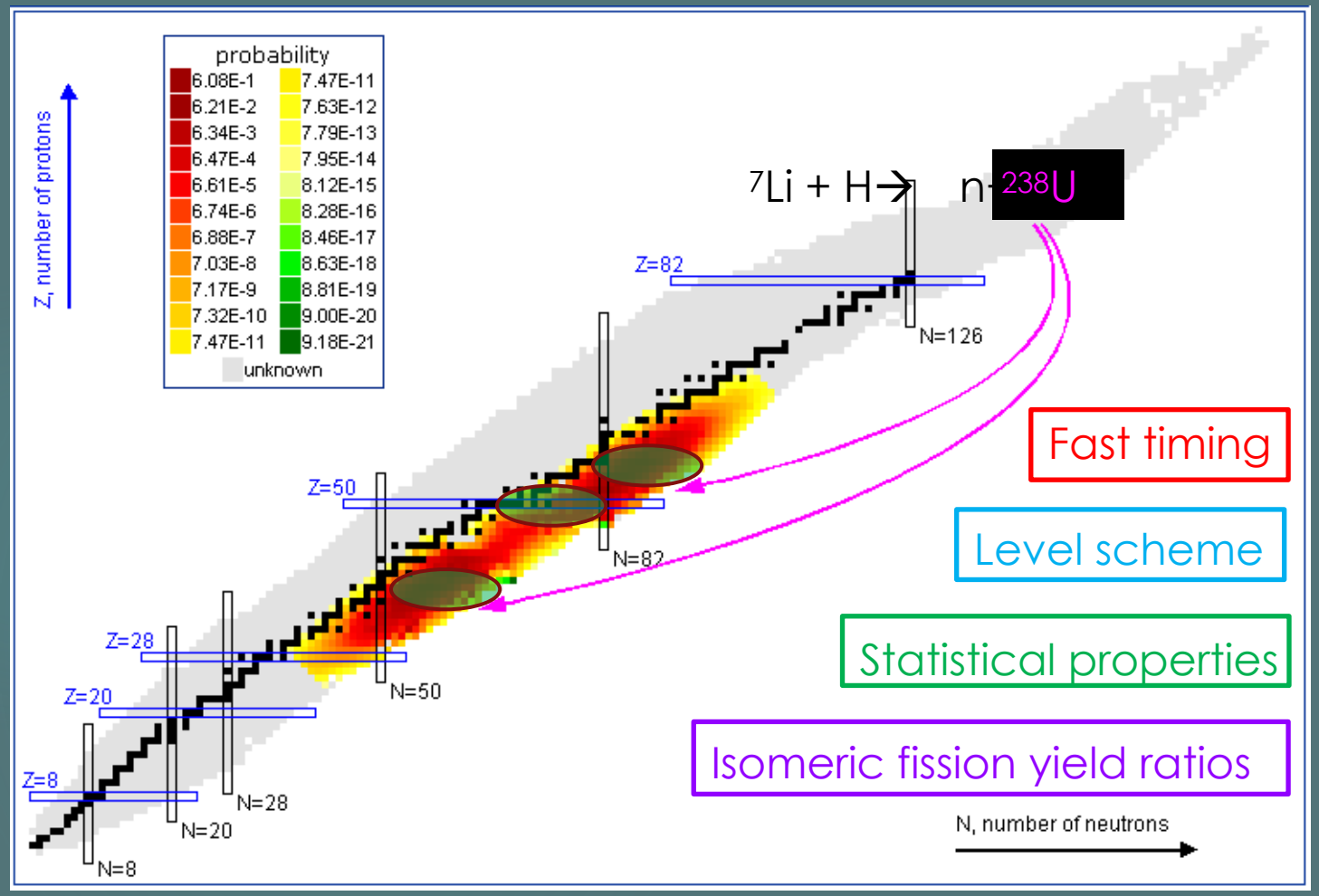
- ^{238}U nuclear structure study with ν-Ball 2 for nuclear energy application
  M. Kerveno et al.
- Evolution of the deformation across the yttrium isotopic chain in the neutron-rich nuclei around A =100
  L. W. Iskra, B. Fornal, S. Leoni et al.
- Spectroscopy of high-spin multiplets in few-valence-particle nuclei around ^{132}Sn
  N. Cieplicka-Orynczak, B. Fornal, S. Leoni et al.
- Gamma and fast-timing spectroscopy of Se and Ge isotopes populated in fission
  A. Korgul, L. M. Fraile, et al.
- Fast-timing investigation of single particle and collective states in Te isotopes
  L. M. Fraile, A. Korgul, et al.
- Investigation of Sn isotopes populated in fission
  L. M. Fraile, A. Korgul, et al.
- Gamma spectroscopy of neutron-rich $^{128-134}$In isotopes populated in fission of ^{238}U
  M. Stryjczyk, M. Piersa-Silkowska, et al.
- Probing the rapid shape transition in ^{100}Zr and ^{102}Zr by fast-timing lifetime measurements
  K. Rezynkina, S. Bottoni et al.
- Determination of level density and radiation strength function for fission fragments
  N. Jovancevic et al.
- Lifetime measurements around N=90
  M. Rudigier, Th. Kröll, M. von Tresckow, et al.
- Study of shape-coexistence and single-particle states in neutron-rich Kr isotopes
  A. Blazhev, R. Gerst
- Constraining isomeric fission yield ratios for ^{238}U(n,f) using ν-ball-2
  A. Algora et al.

Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)



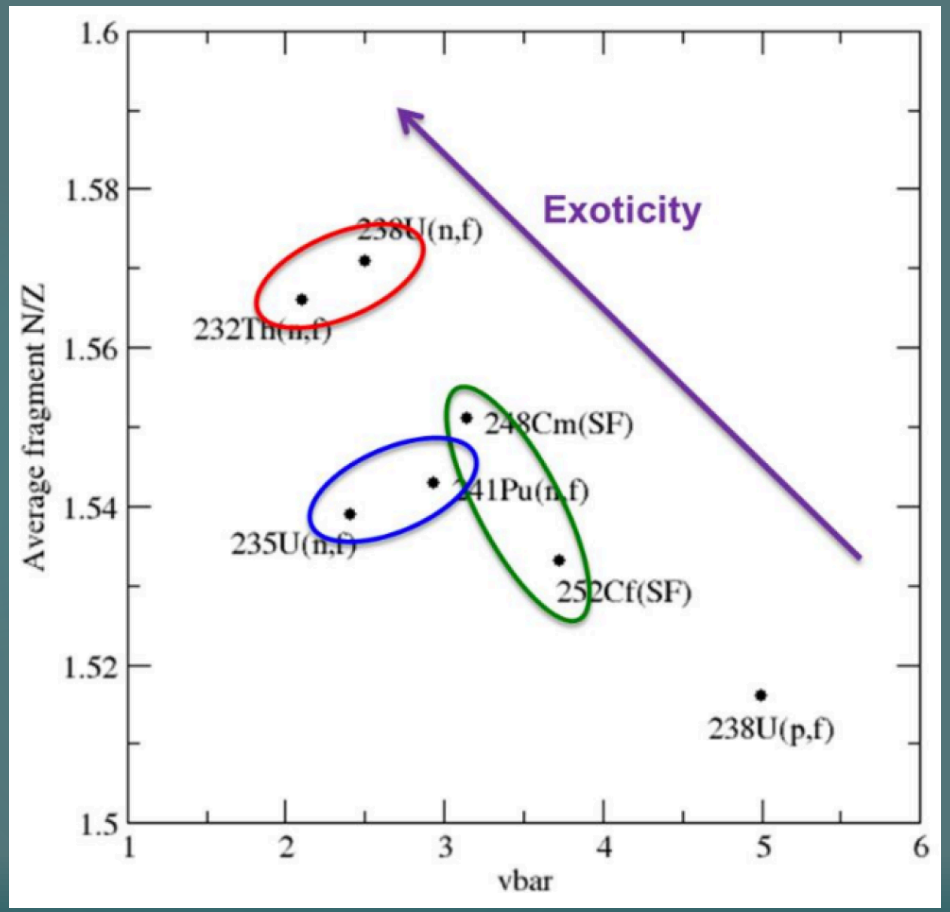
- ^{238}U nuclear structure study with ν-Ball 2 for nuclear energy application
  M. Kerveno et al.
- Evolution of the deformation across the yttrium isotopic chain in the neutron-rich nuclei around A =100
  L. W. Iskra, B. Fornal, S. Leoni et al.
- Spectroscopy of high-spin multiplets in few-valence-particle nuclei around ^{132}Sn
  N. Cieplicka-Orynczak, B. Fornal, S. Leoni et al.
- Gamma and fast-timing spectroscopy of Se and Ge isotopes populated in fission
  A. Korgul, L. M. Fraile, et al.
- Fast-timing investigation of single particle and collective states in Te isotopes
  L. M. Fraile, A. Korgul, et al.
- Investigation of Sn isotopes populated in fission
  L. M. Fraile, A. Korgul, et al.
- Gamma spectroscopy of neutron-rich $^{128-134}$In isotopes populated in fission of ^{238}U
  M. Stryjczyk, M. Piersa-Silkowska, et al.
- Probing the rapid shape transition in ^{100}Zr and ^{102}Zr by fast-timing lifetime measurements
  K. Rezynkina, S. Bottoni et al.
- Determination of level density and radiation strength function for fission fragments
  N. Jovancevic et al.
- Lifetime measurements around N=90
  M. Rudigier, Th. Kröll, M. von Tresckow, et al.
- Study of shape-coexistence and single-particle states in neutron-rich Kr isotopes
  A. Blazhev, R. Gerst
- Constraining isomeric fission yield ratios for ^{238}U(n,f) using ν-ball-2
  A. Algora et al.

Spectroscopy of neutron-rich fission fragments produced in the ^{238}U(n,f) reaction with ν-ball 2 (N-SI-120)

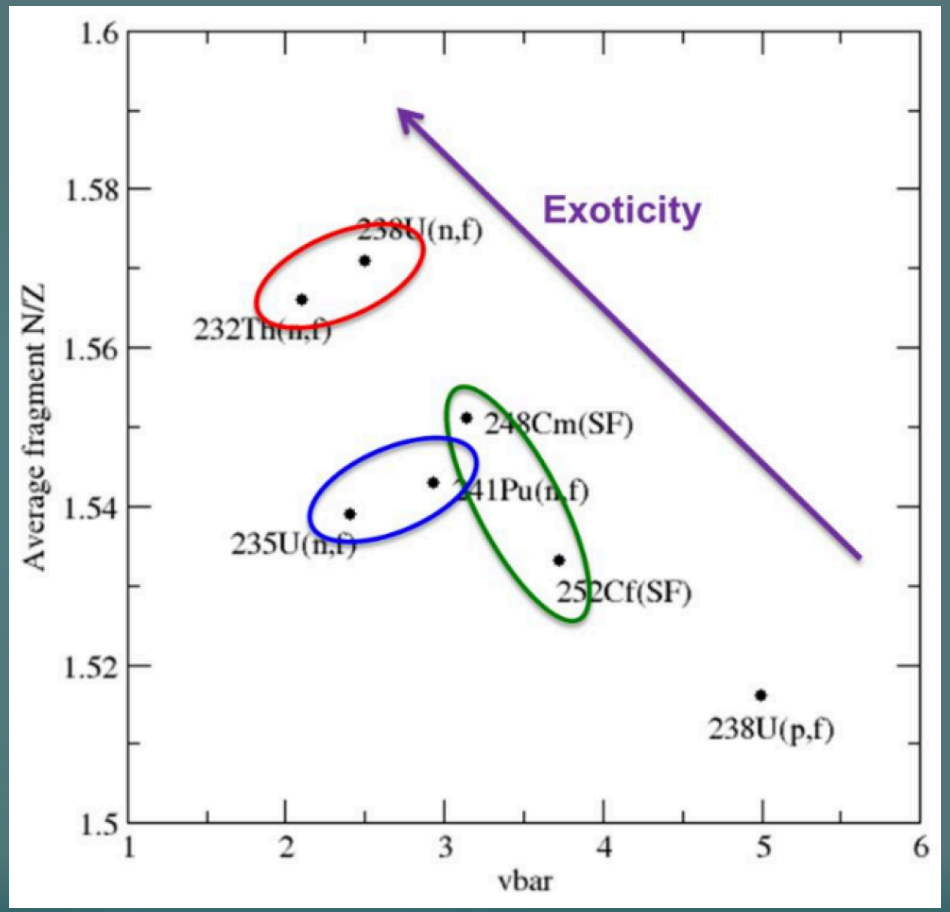


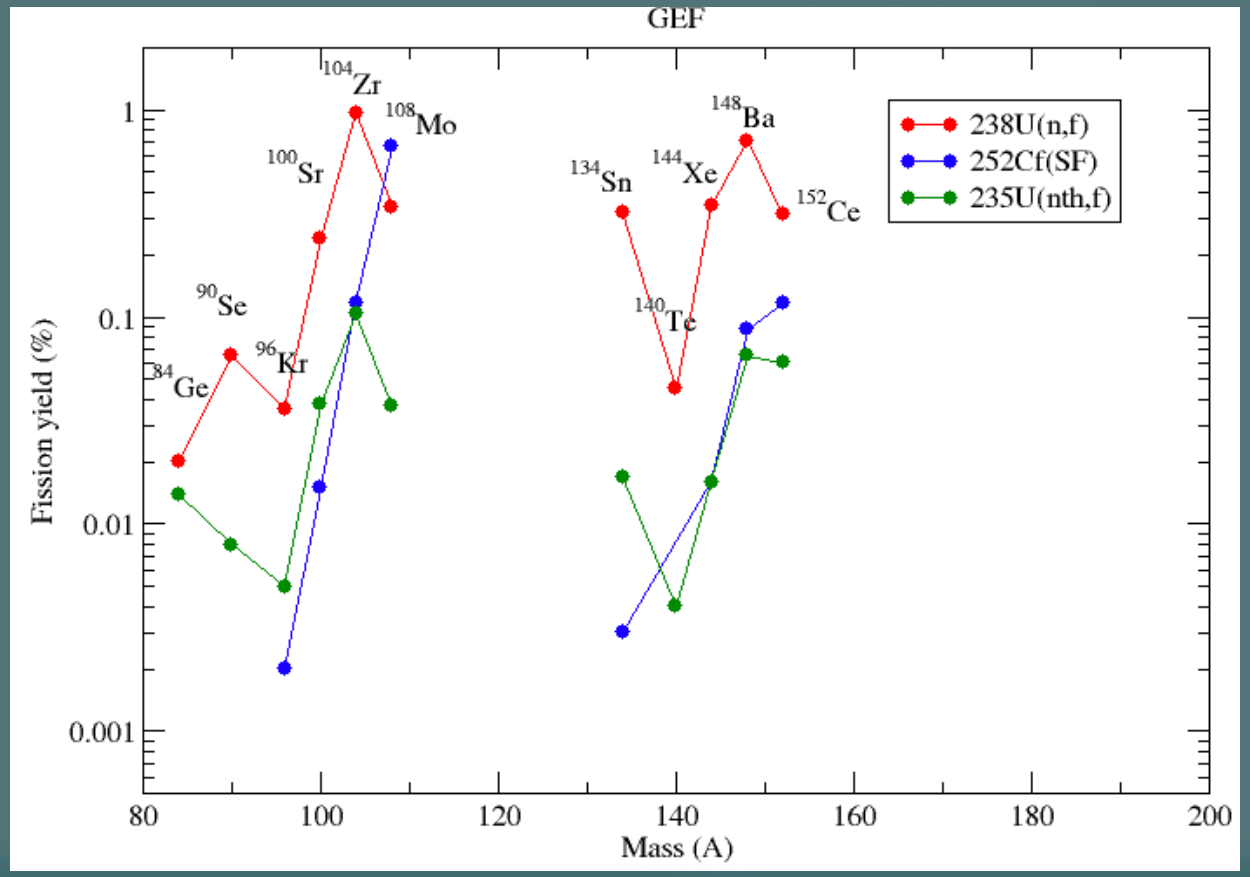
- ^{238}U nuclear structure study with ν-Ball 2 for nuclear energy application
  M. Kerveno et al.
- Evolution of the deformation across the yttrium isotopic chain in the neutron-rich nuclei around A =100
  L. W. Iskra, B. Fornal, S. Leoni et al.
- Spectroscopy of high-spin multiplets in few-valence-particle nuclei around ^{132}Sn
  N. Cieplicka-Orynczak, B. Fornal, S. Leoni et al.
- Gamma and fast-timing spectroscopy of Se and Ge isotopes populated in fission
  A. Korgul, L. M. Fraile, et al.
- Fast-timing investigation of single particle and collective states in Te isotopes
  L. M. Fraile, A. Korgul, et al.
- Investigation of Sn isotopes populated in fission
  L. M. Fraile, A. Korgul, et al.
- Gamma spectroscopy of neutron-rich $^{128-134}$In isotopes populated in fission of ^{238}U
  M. Stryjczyk, M. Piersa-Silkowska, et al.
- Probing the rapid shape transition in ^{100}Zr and ^{102}Zr by fast-timing lifetime measurements
  K. Rezynkina, S. Bottoni et al.
- Determination of level density and radiation strength function for fission fragments
  N. Jovancevic et al.
- Lifetime measurements around N=90
  M. Rudigier, Th. Kröll, M. von Tresckow, et al.
- Study of shape-coexistence and single-particle states in neutron-rich Kr isotopes
  A. Blazhev, R. Gerst
- Constraining isomeric fission yield ratios for ^{238}U(n,f) using ν-ball-2
  A. Algora et al.

^{238}U(n,f) reaction

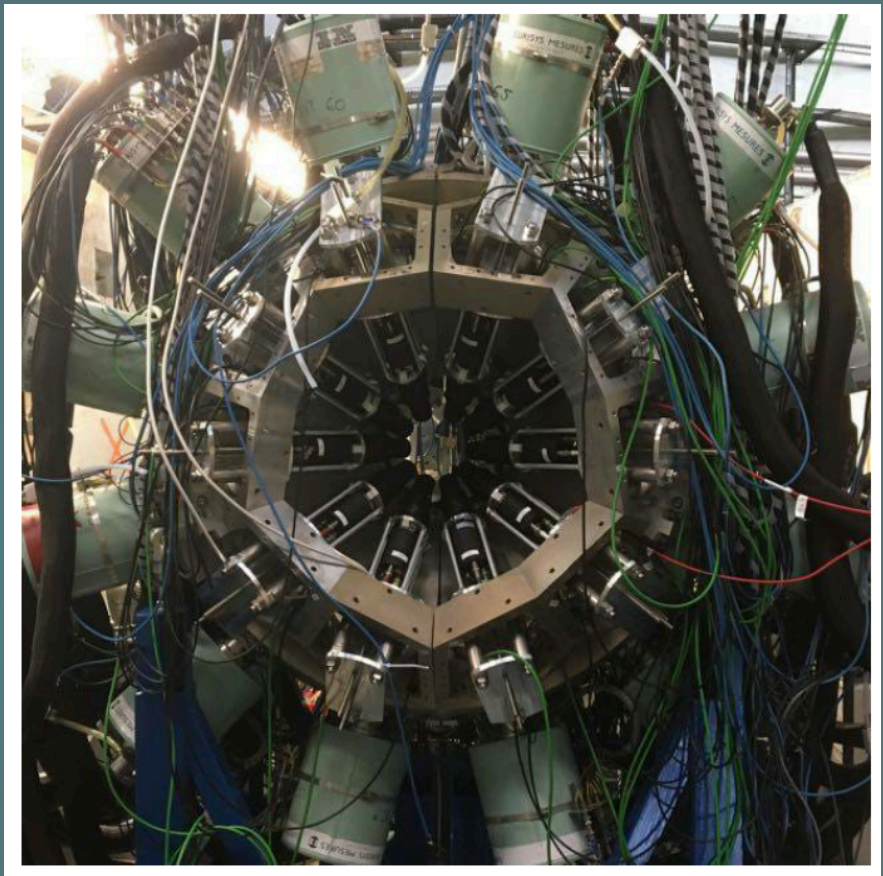


^{238}U(n,f) reaction

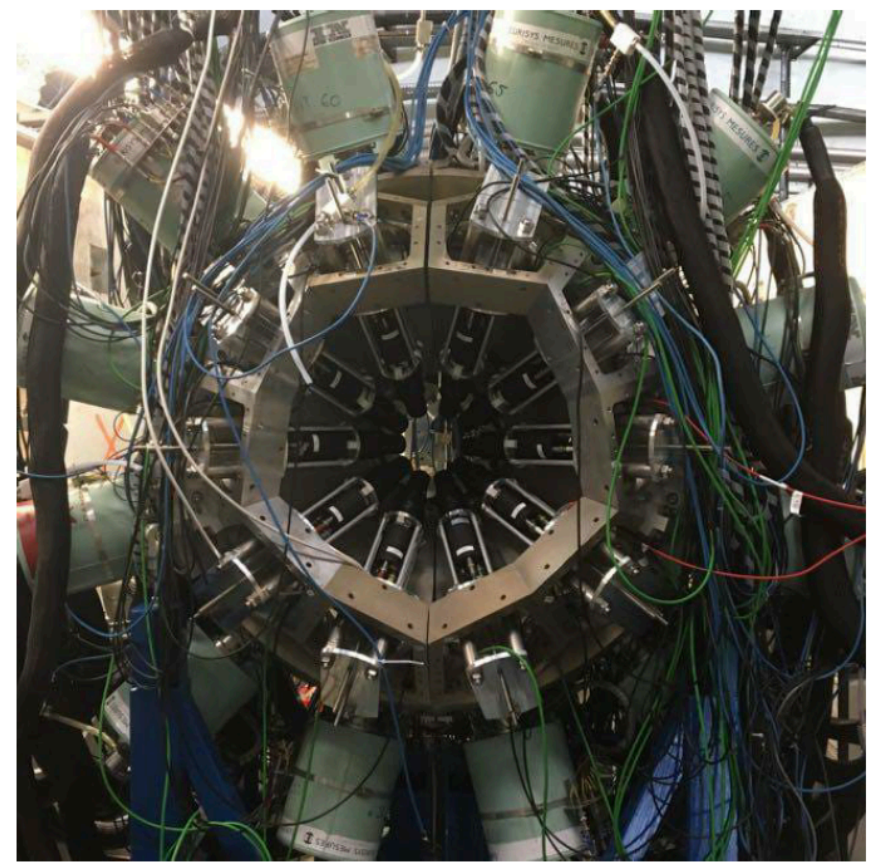


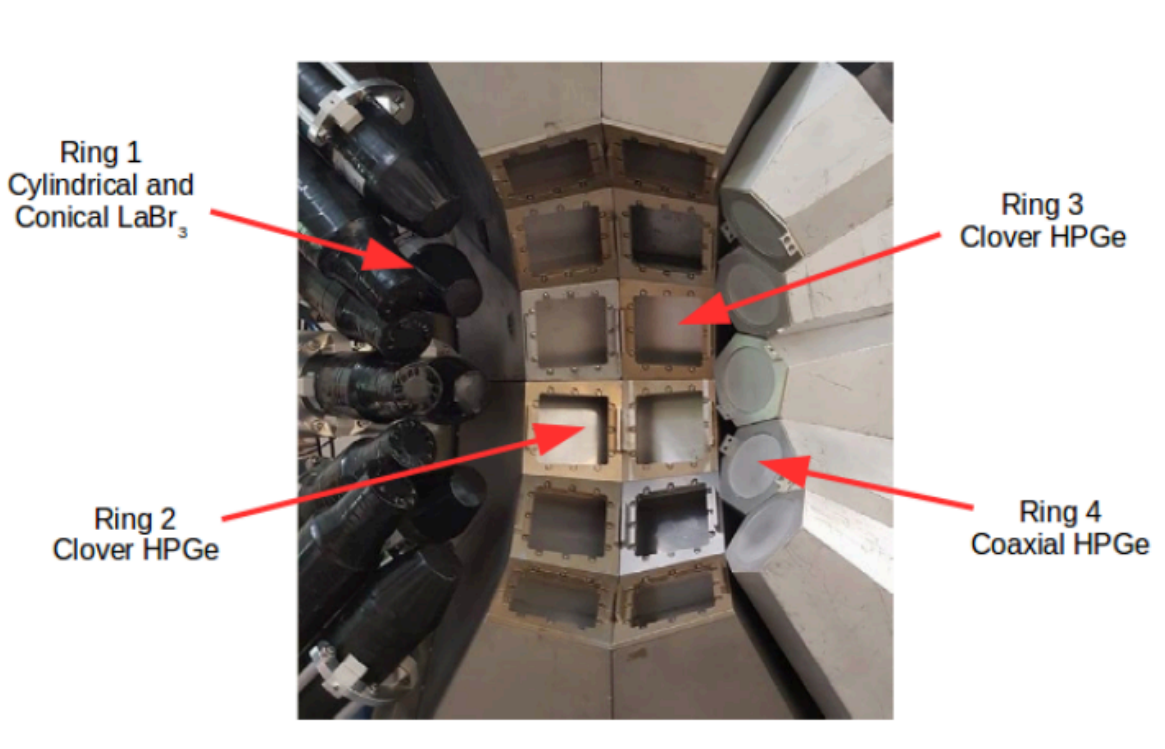


ν-ball1 array



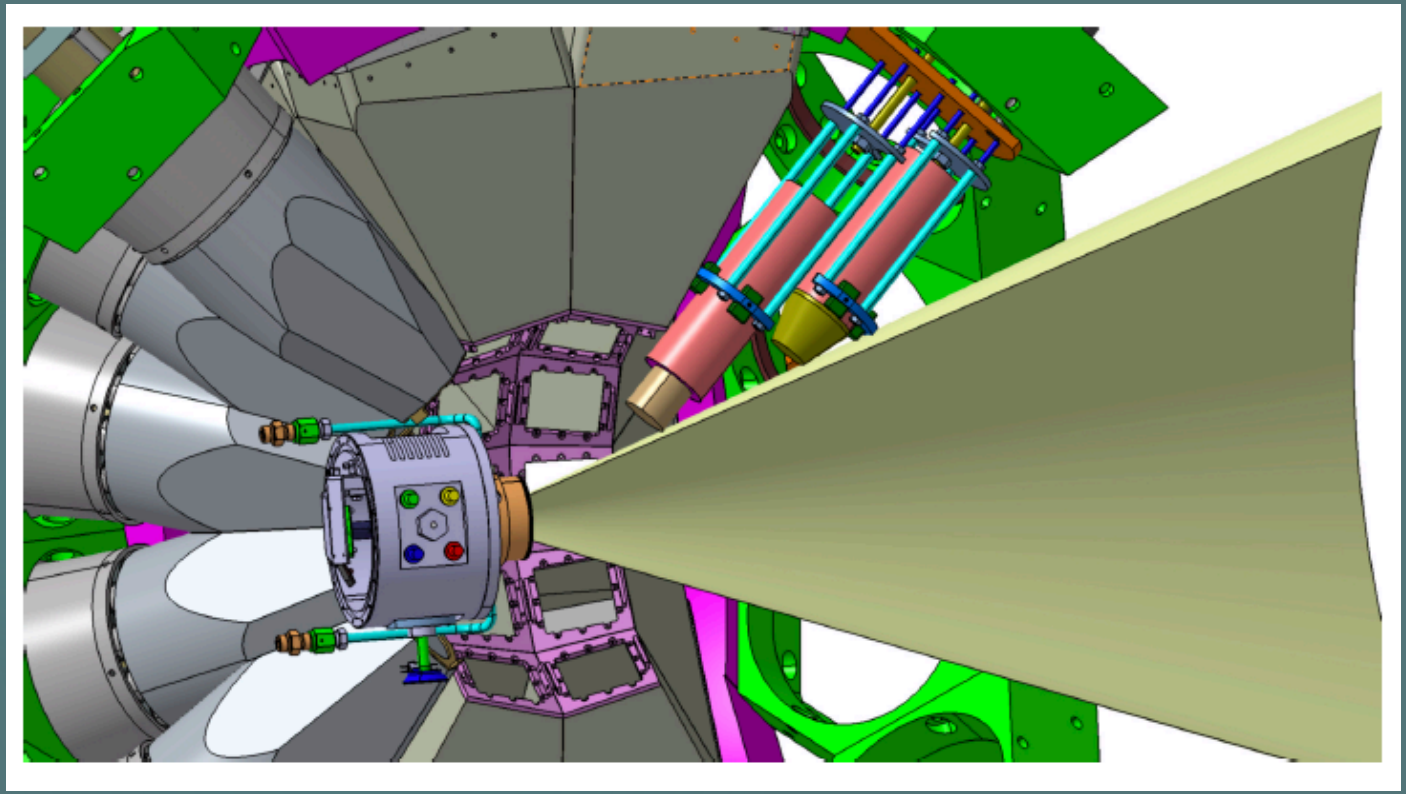
ν-ball1 array





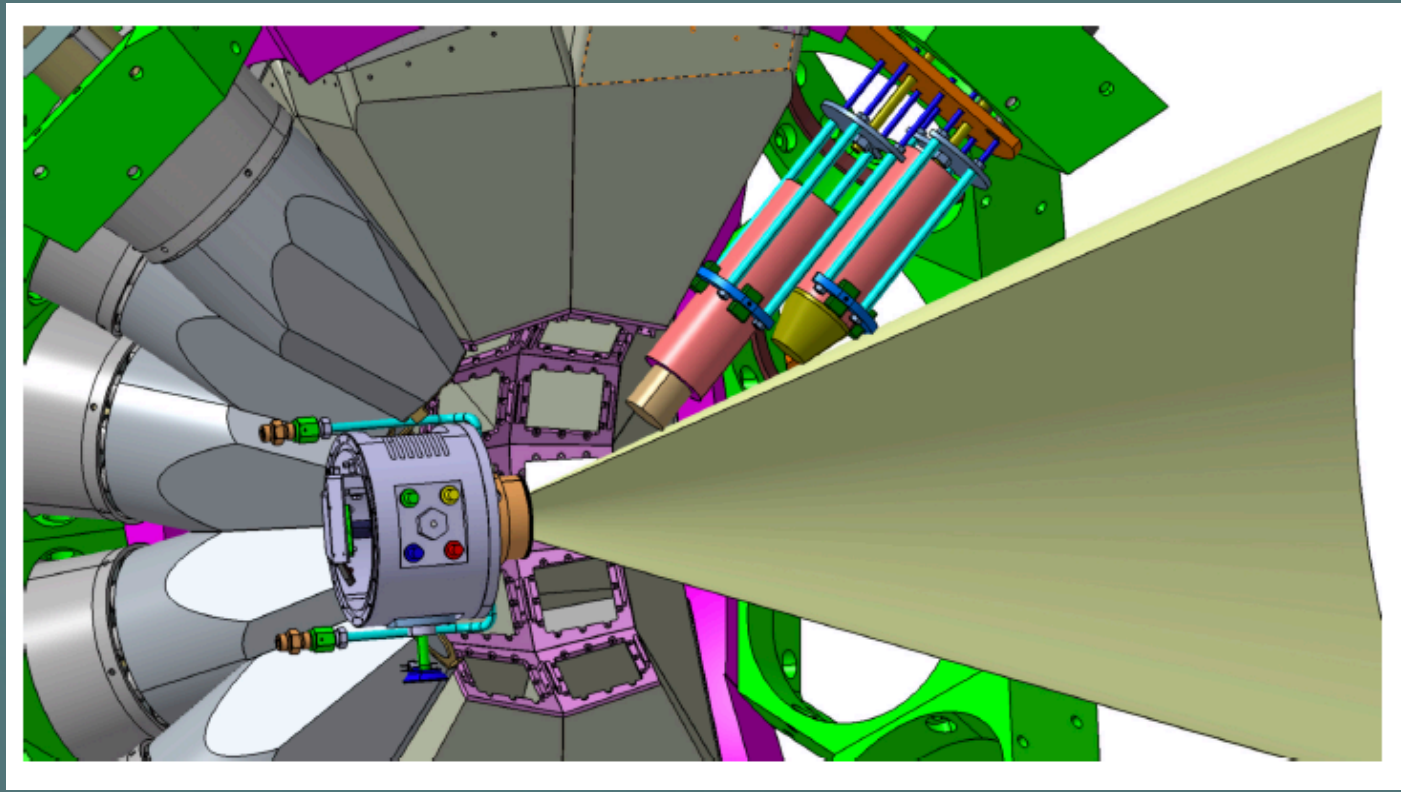
ν-ball1 array

Neutron cone

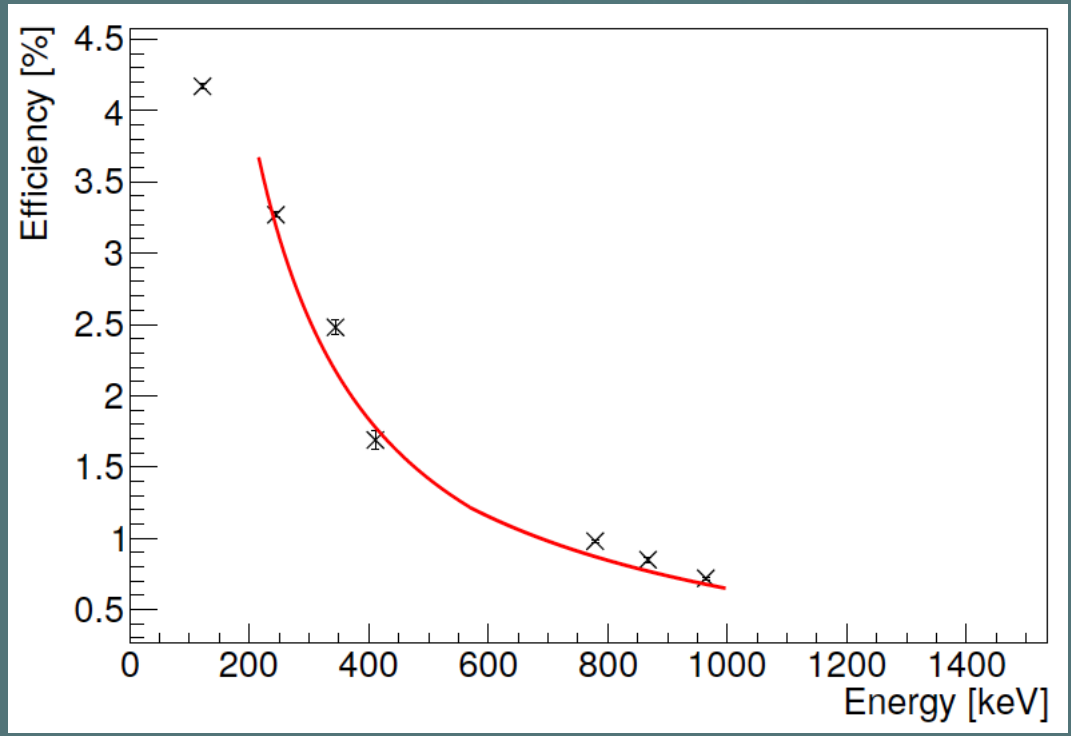


ν-ball1 array

Neutron cone

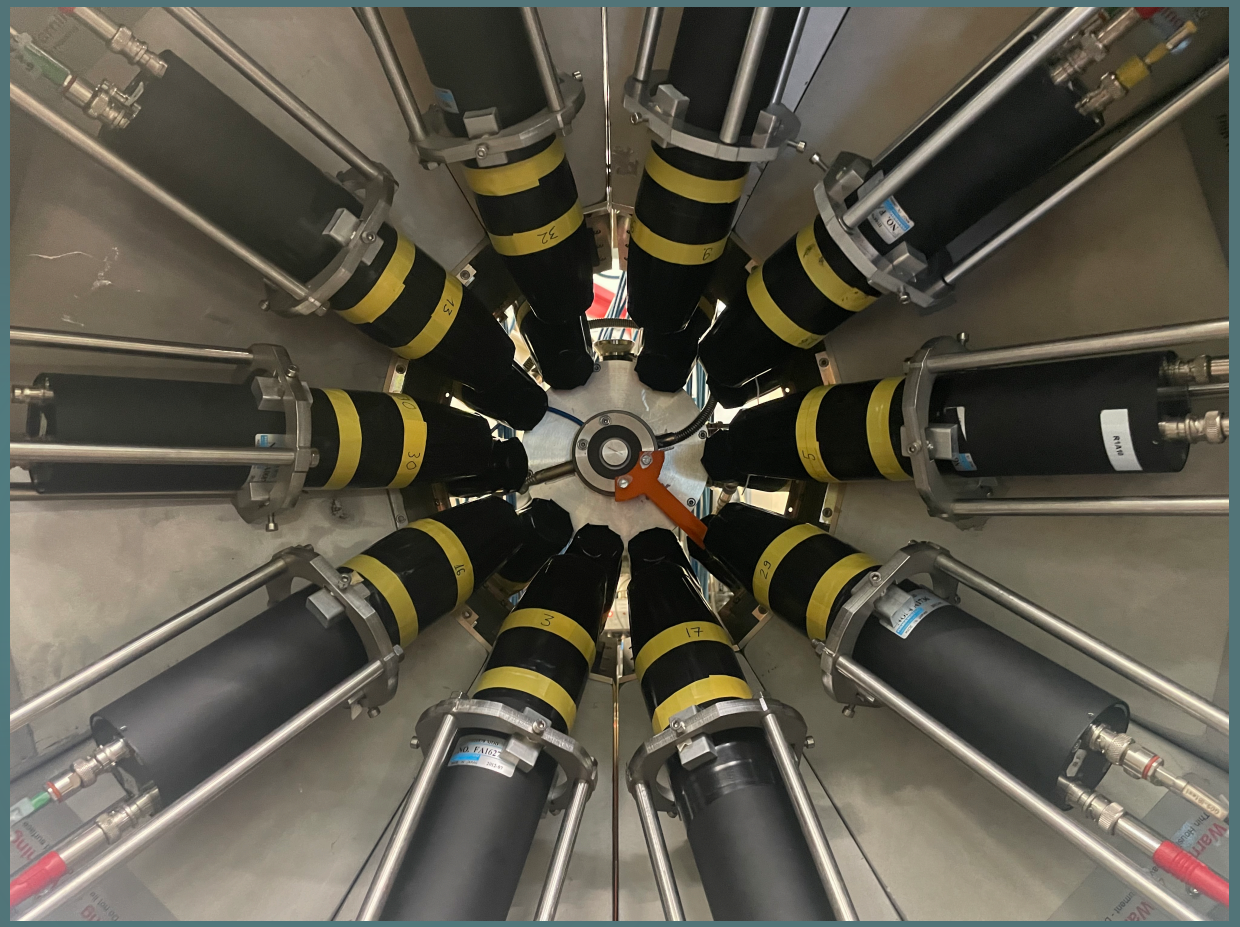


$LaBr_3$ efficiency curve

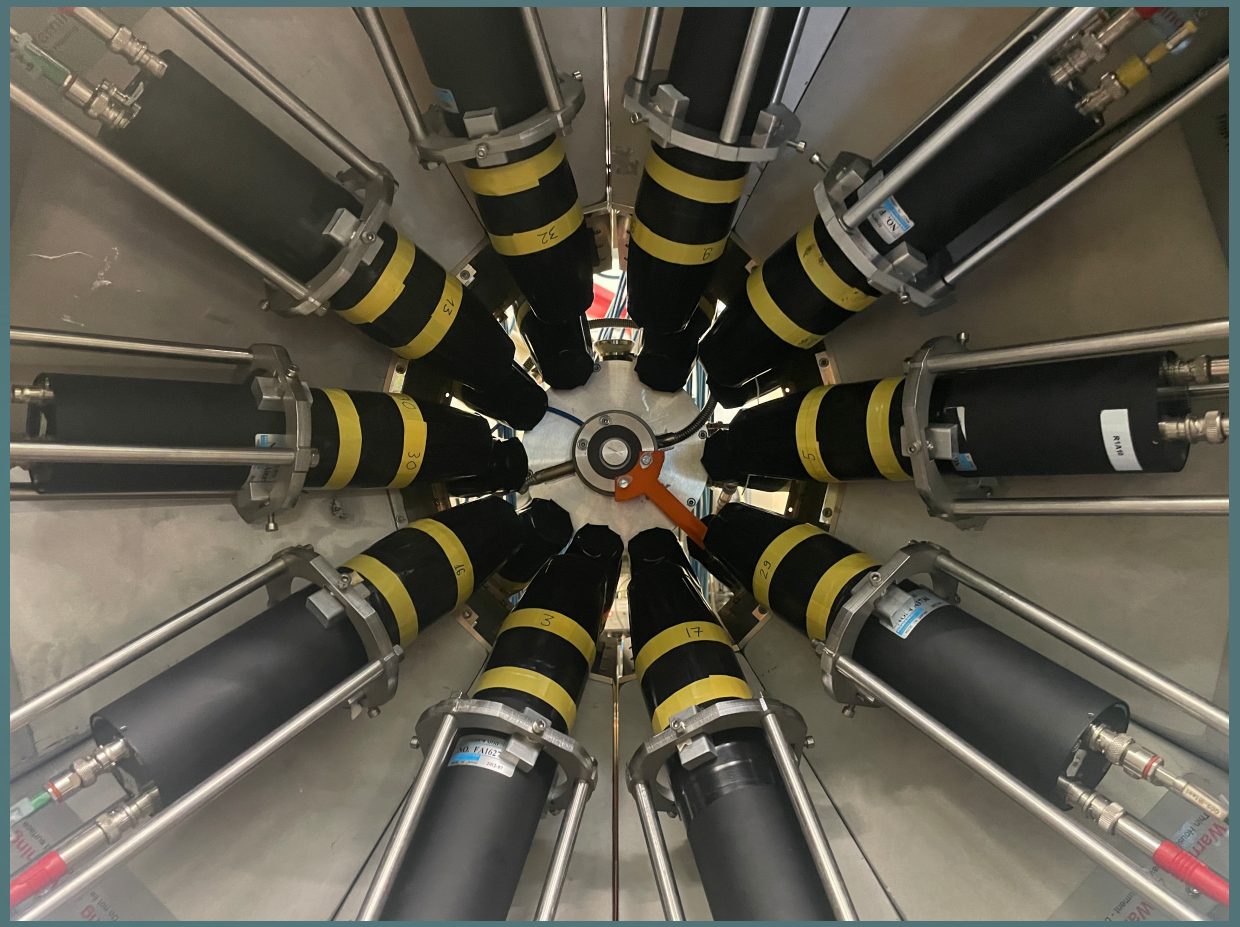


R. Canavan PhD thesis

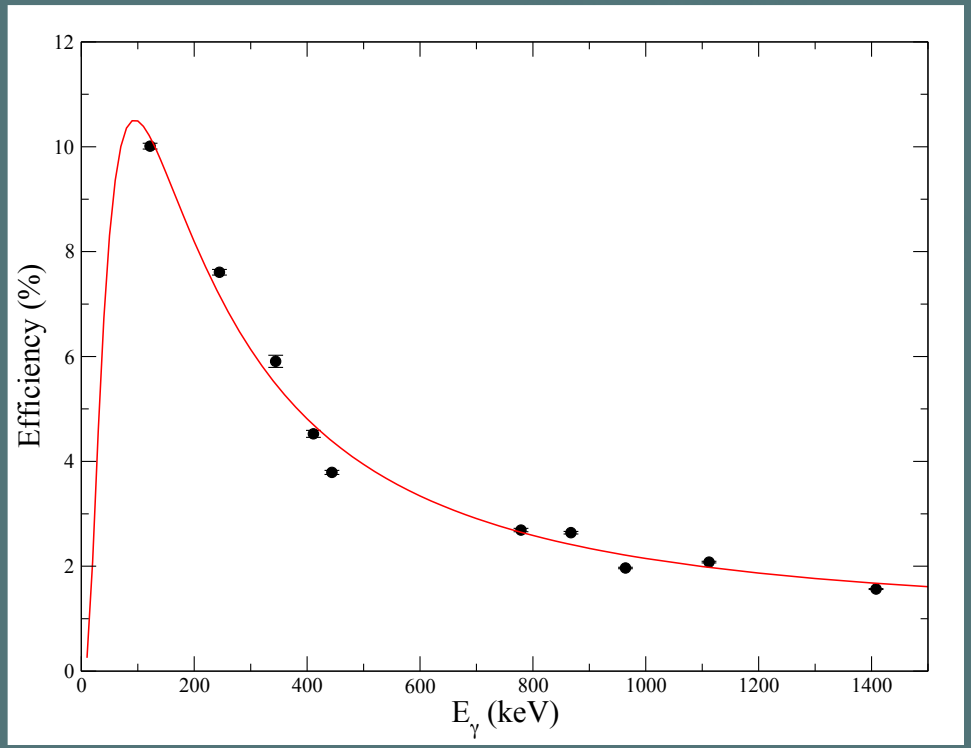
ν-ball2 array



ν-ball2 array



$LaBr_3$ efficiency curve



Energy resolution: 34 keV @ 1408 keV (2.4%)
Time resolution: ~350 ps @ 1173-1332 keV

ν-ball1 vs ν-ball2

ν-ball1

ν-ball2

ν-ball1 vs ν-ball2

ν-ball1

- Fast neutron source (LICORNE)

Clean spectra

ν-ball2

Fast neutron source (Improved LICORNE): Au stopper, W collimator

ν-ball1 vs ν-ball2

ν-ball1

- Fast neutron source (LICORNE)
- ^{7}Li beam: ~ 10 nA pulsed beam pulsed beam

Clean spectra

x 10

ν-ball2

Fast neutron source (Improved LICORNE): Au stopper, W collimator

High intensity ^{7}Li beam: ~ 100 nA

ν-ball1 vs ν-ball2

ν-ball1		**ν-ball2**
• Fast neutron source (LICORNE)	Clean spectra ⟷	Fast neutron source (Improved LICORNE): Au stopper, W collimator
• ^{7}Li beam: ~ 10 nA pulsed beam pulsed beam	x 10 ⟷	High intensity ^{7}Li beam: ~ 100 nA
• H gas cell: 1.3 atm	x 25% ⟷	H gas cell: 1.6 atm

ν-ball1 vs ν-ball2

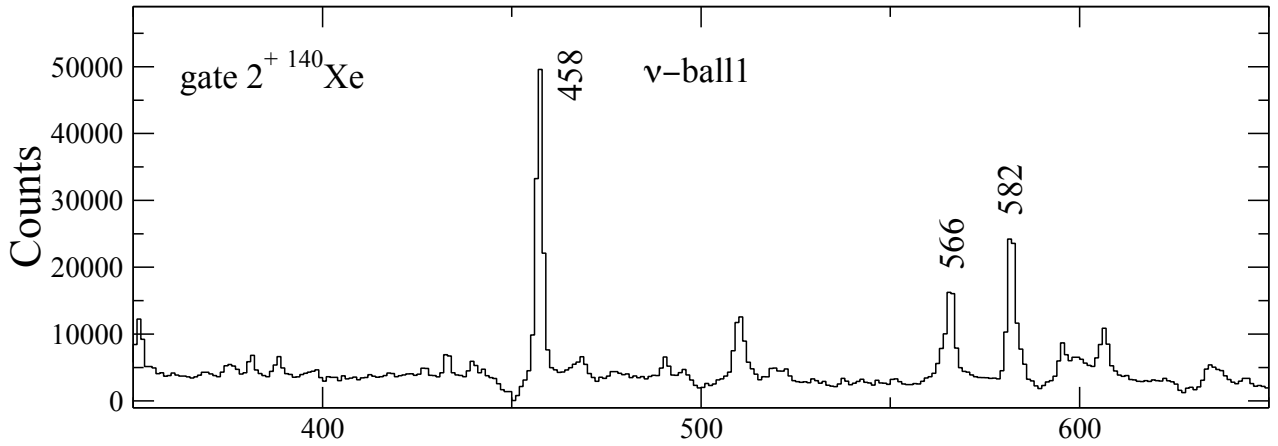
ν-ball1		**ν-ball2**
• Fast neutron source (LICORNE)	Clean spectra ⟷	Fast neutron source (Improved LICORNE): Au stopper, W collimator
• ^{7}Li beam: ~ 10 nA pulsed beam pulsed beam	x 10 ⟷	High intensity ^{7}Li beam: ~ 100 nA
• H gas cell: 1.3 atm	x 25% ⟷	H gas cell: 1.6 atm
• 24 clovers + 10 Coax HPGe + + 20 $LaBr_3$ detectors (2 types)	⟷	24 clovers + 20 UK FATIMA detectors (1.5''x2'' cylindrical crystals)

ν-ball1 vs ν-ball2

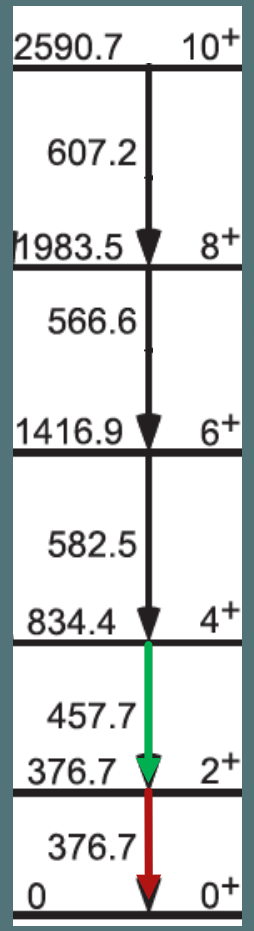
ν-ball1		**ν-ball2**
• Fast neutron source (LICORNE)	Clean spectra ⟷	Fast neutron source (Improved LICORNE): Au stopper, W collimator
• ^{7}Li beam: ~ 10 nA pulsed beam pulsed beam	x 10 ⟷	High intensity ^{7}Li beam: ~ 100 nA
• H gas cell: 1.3 atm	x 25% ⟷	H gas cell: 1.6 atm
• 24 clovers + 10 Coax HPGe + + 20 $LaBr_3$ detectors (2 types)	⟷	24 clovers + 20 UK FATIMA detectors (1.5''x2'' cylindrical crystals)
• Eff($LaBr_3$)~0.7% @ 1 MeV	x 3 ⟷	Eff($LaBr_3$)~2.1% @ 1 MeV

Spectra from ν-ball1 vs ν-ball2

^{140}Xe



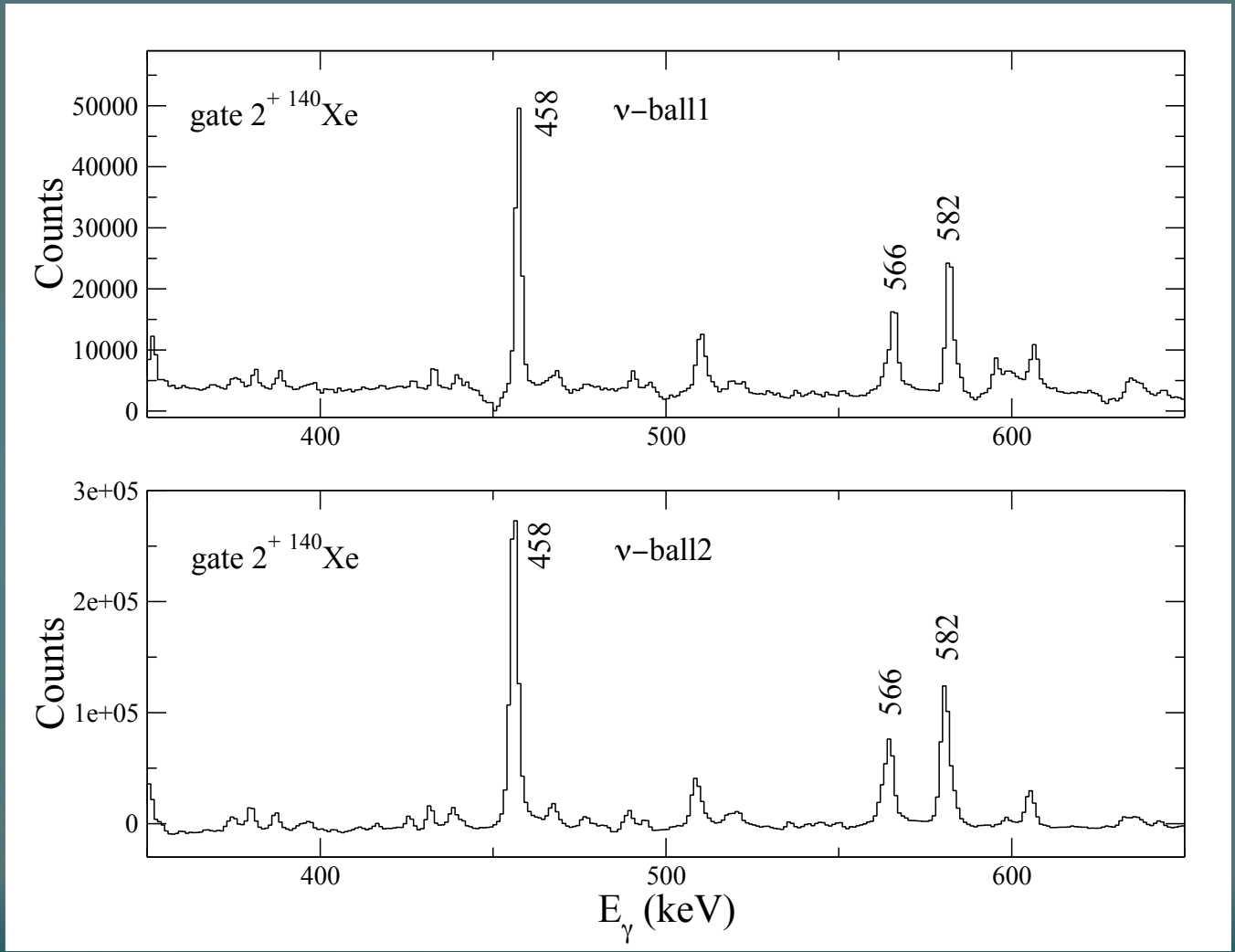
Y. Huang et al., PRC 93, 064321 (2016)



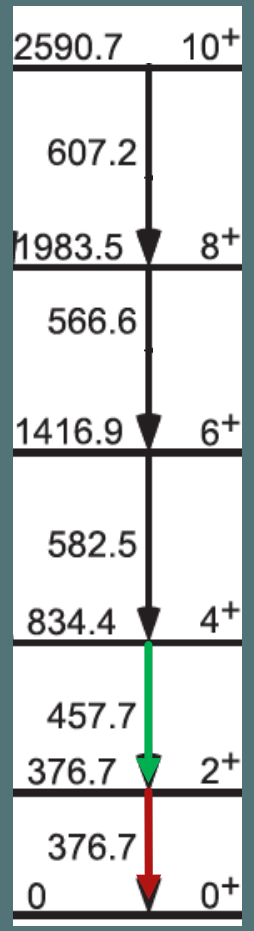
^{140}Xe

Spectra from ν-ball1 vs ν-ball2

^{140}Xe



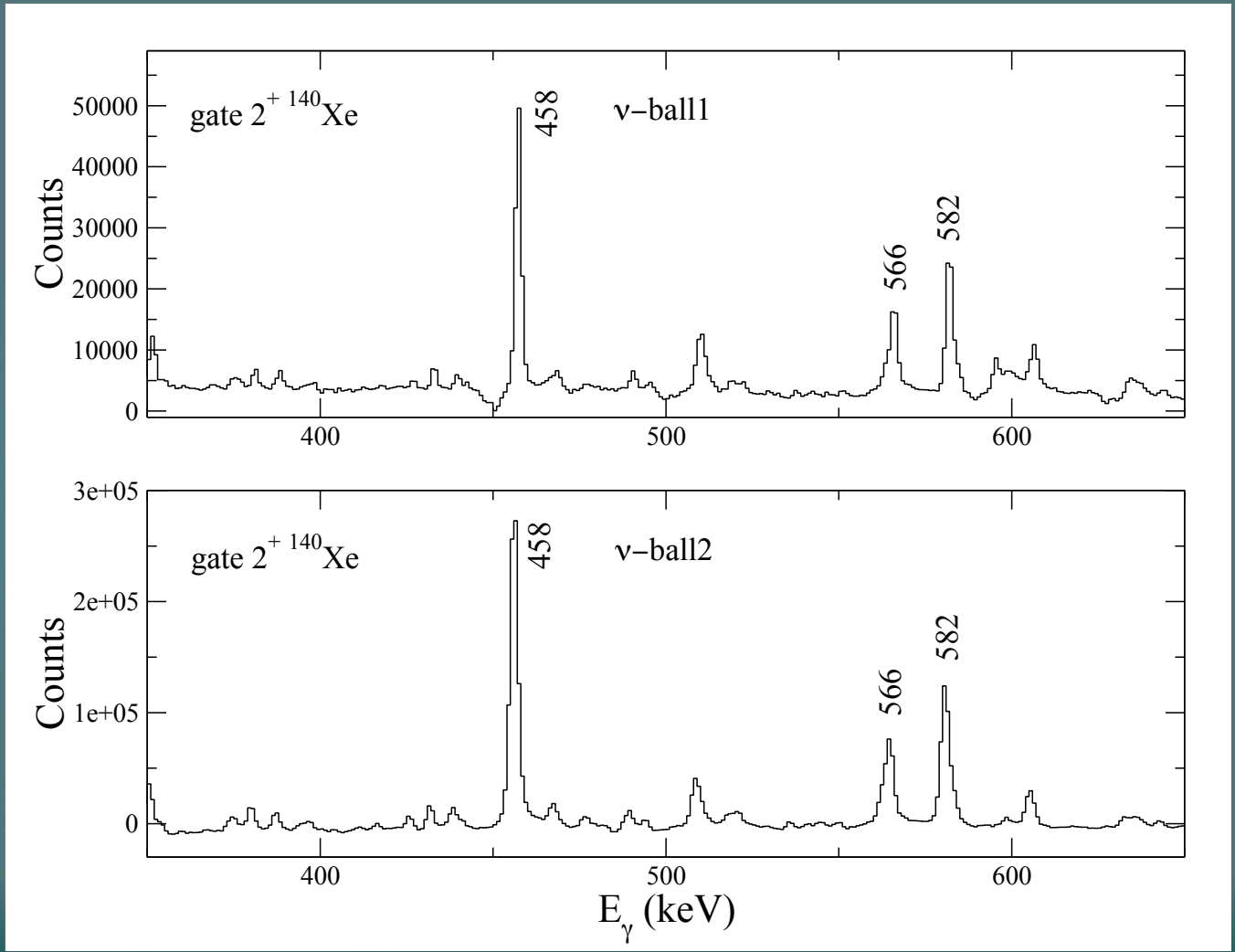
Y. Huang et al., PRC 93, 064321 (2016)



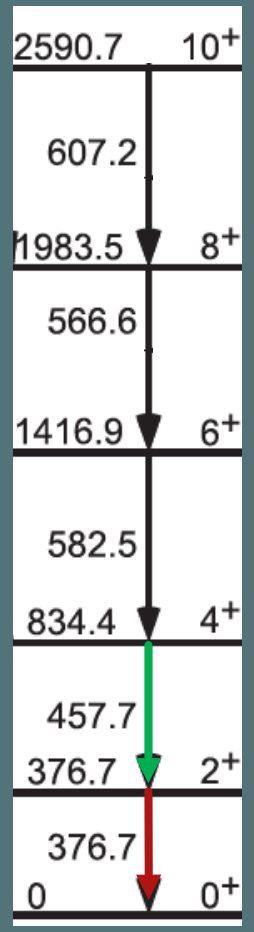
^{140}Xe

Spectra from ν-ball1 vs ν-ball2

^{140}Xe



Y. Huang et al., PRC 93, 064321 (2016)



^{140}Xe

458 keV peak:

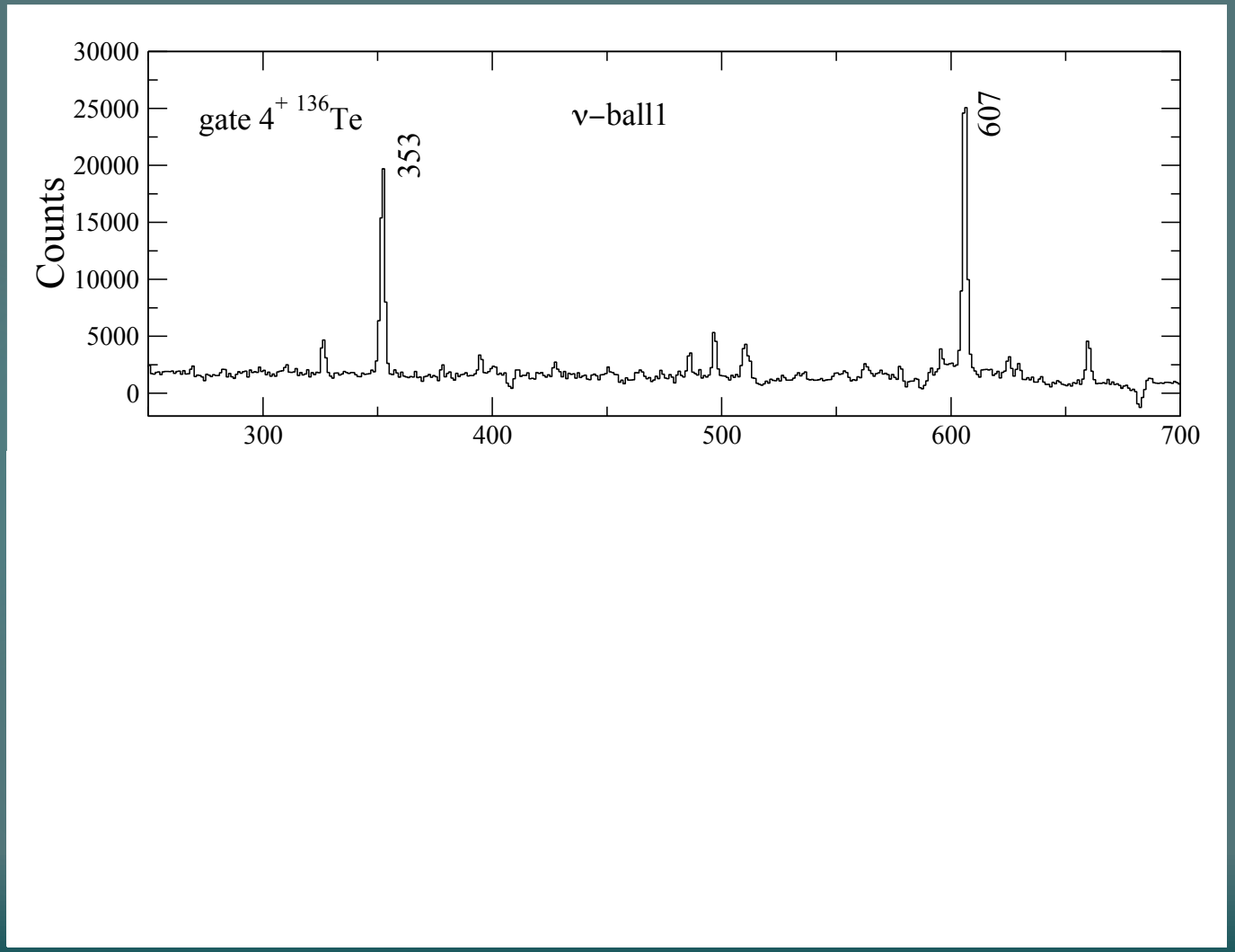
ν-ball1: 115000 counts

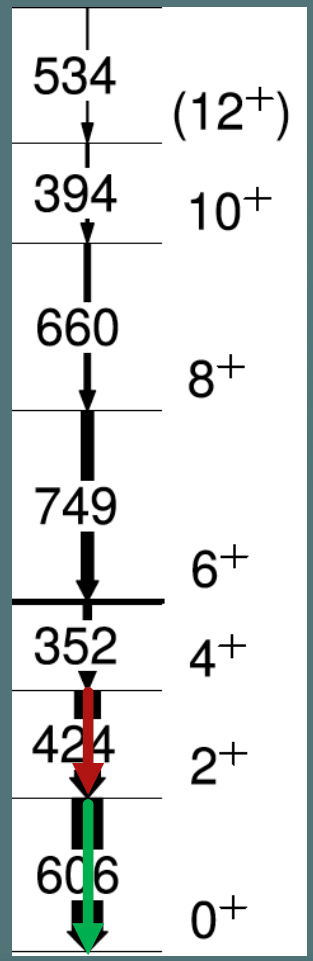
ν-ball2: 883000 counts

$$\frac{\nu\text{-ball2}}{\nu\text{-ball1}} \sim 7.7$$

Spectra from ν-ball1 vs ν-ball2

^{136}Te

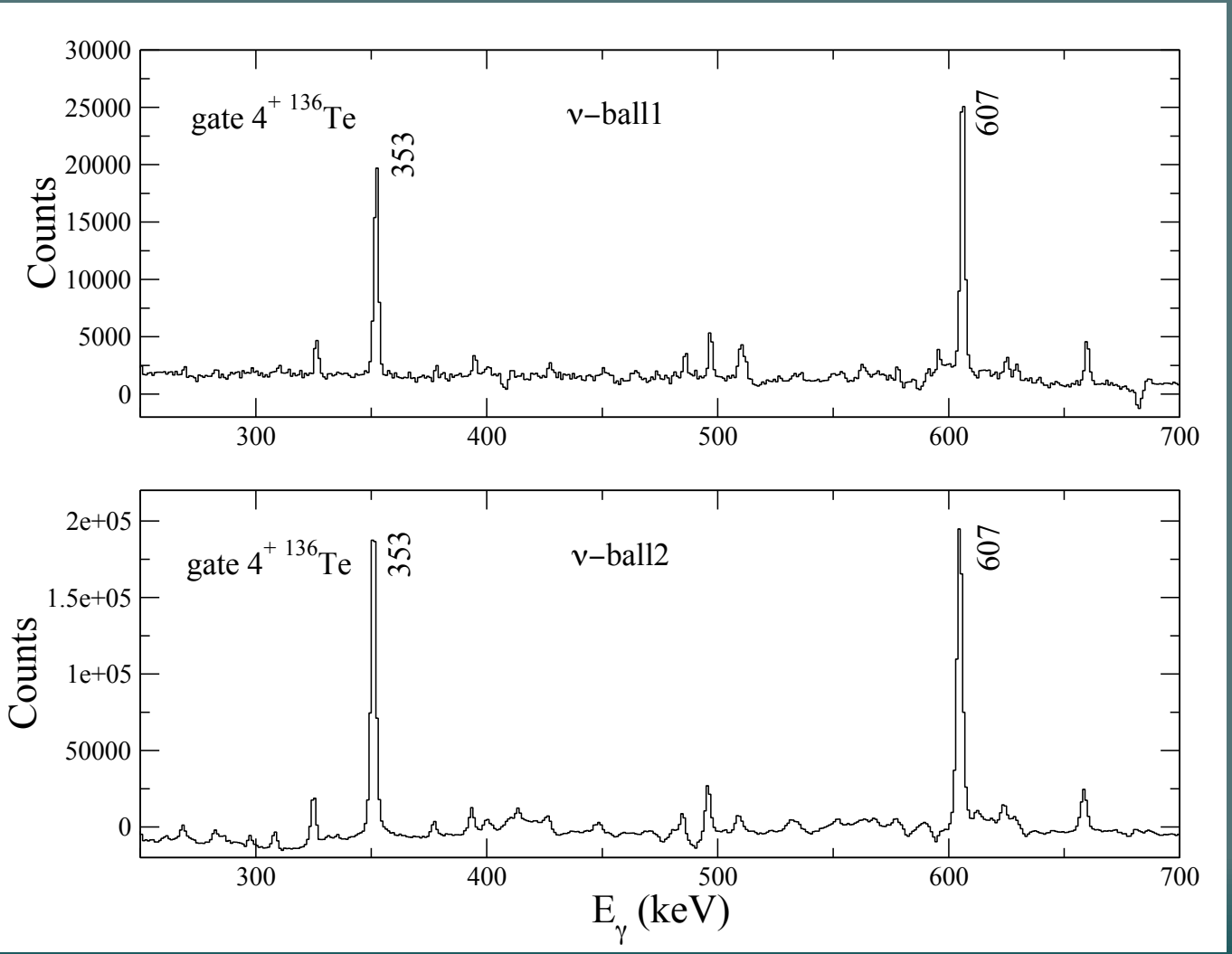


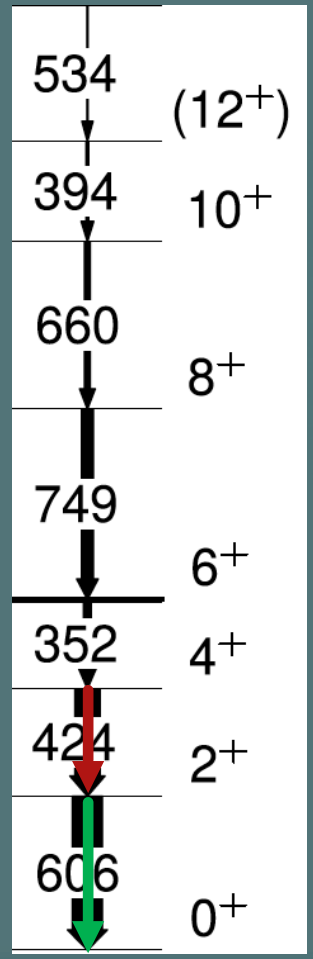


^{136}Te

Spectra from ν-ball1 vs ν-ball2

^{136}Te

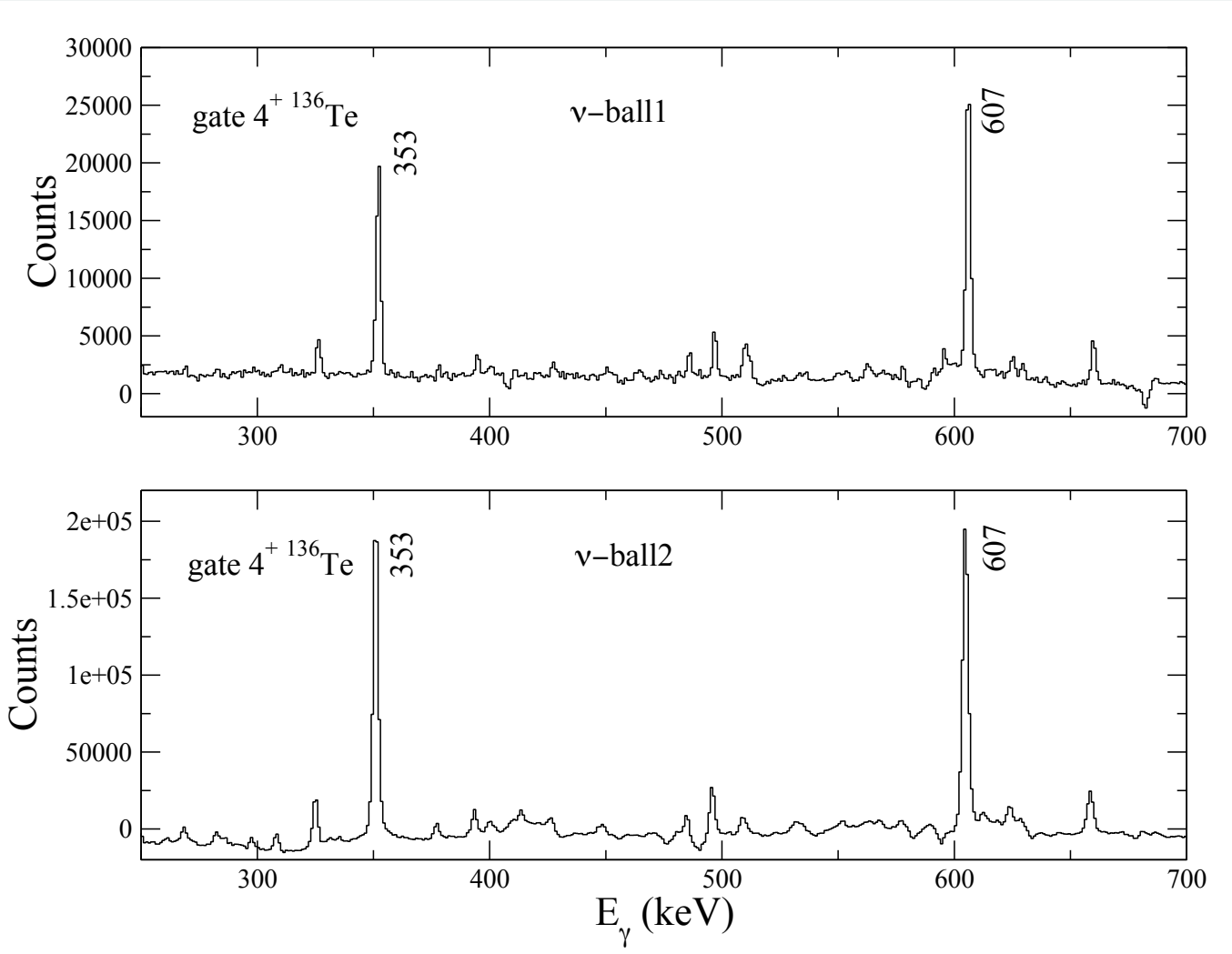


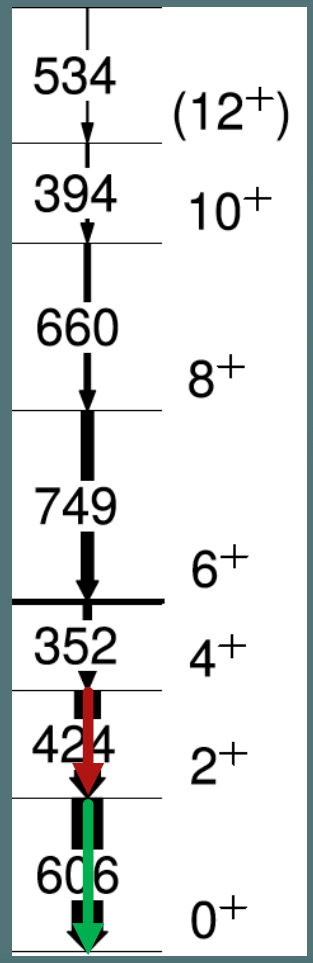


^{136}Te

Spectra from ν-ball1 vs ν-ball2

^{136}Te





^{136}Te

607 keV peak:

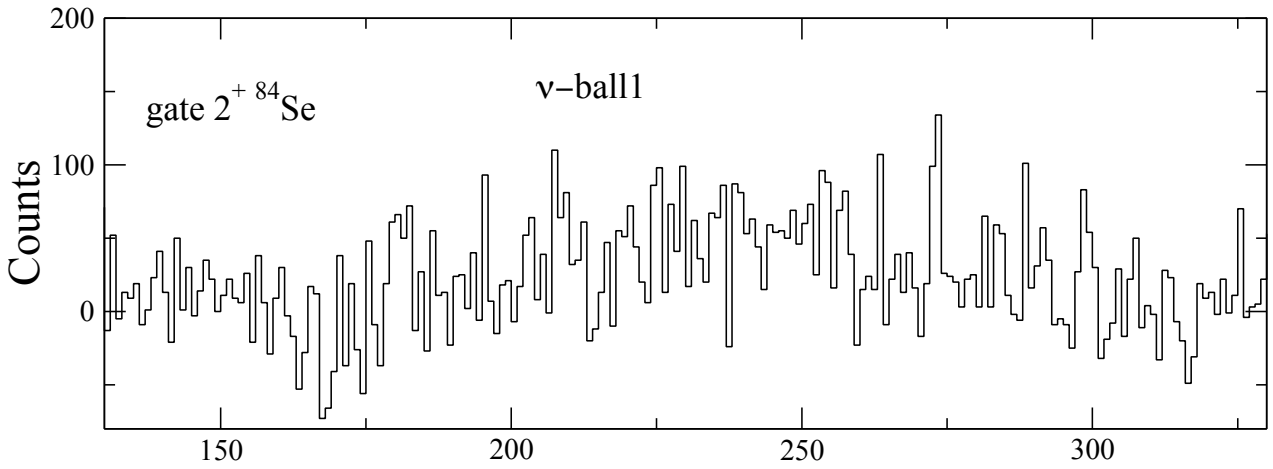
ν-ball1: 80000 counts

ν-ball2: 636500 counts

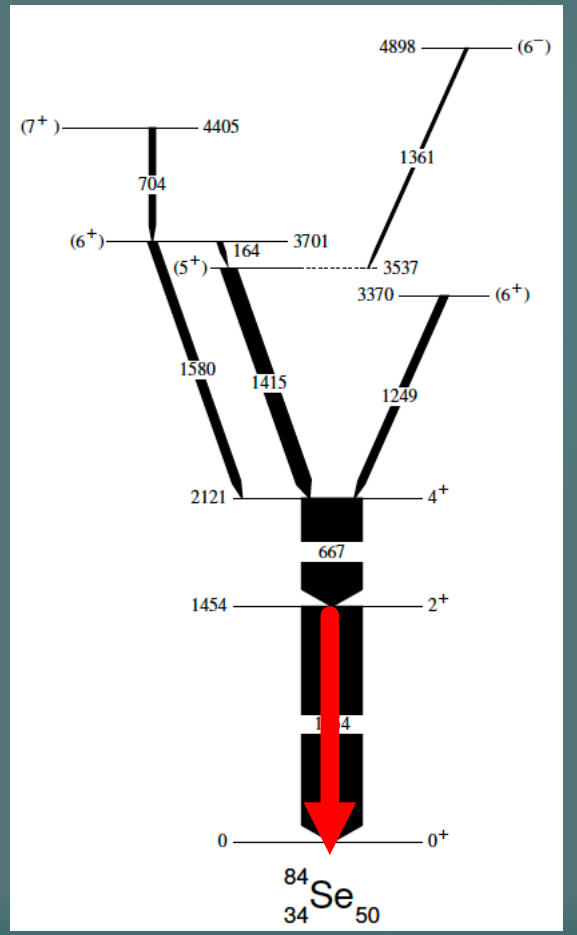
$$\frac{\nu\text{-ball2}}{\nu\text{-ball1}} \sim 8.0$$

Spectra from ν-ball1 vs ν-ball2

^{152}Ce

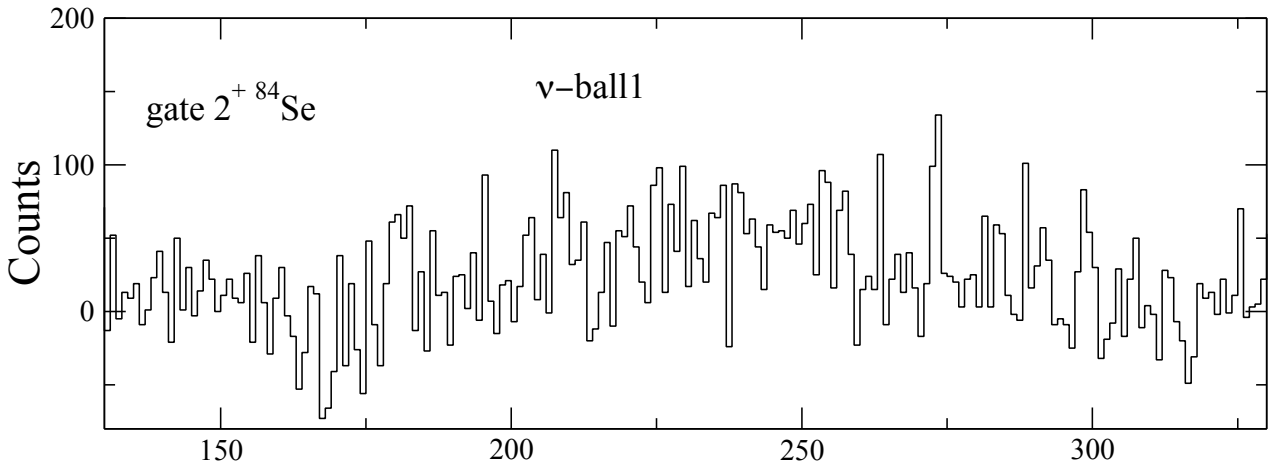


A. Prevost et al., EPJA 22, 391 (2004)

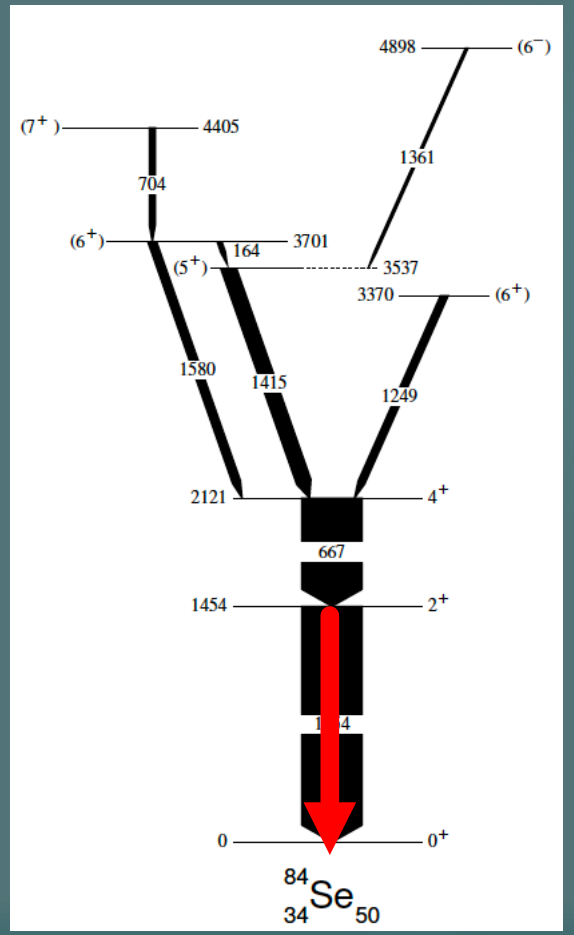


Spectra from ν-ball1 vs ν-ball2

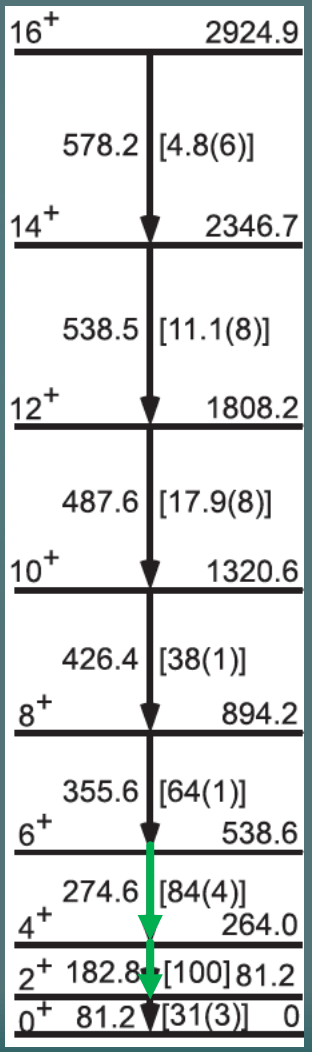
^{152}Ce



A. Prevost et al., EPJA 22, 391 (2004)



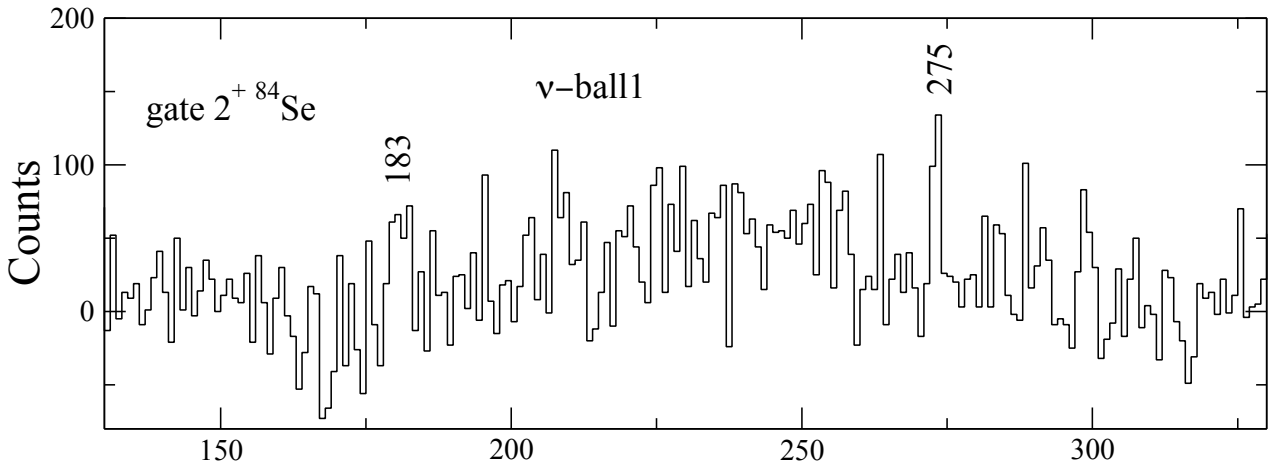
^{152}Ce



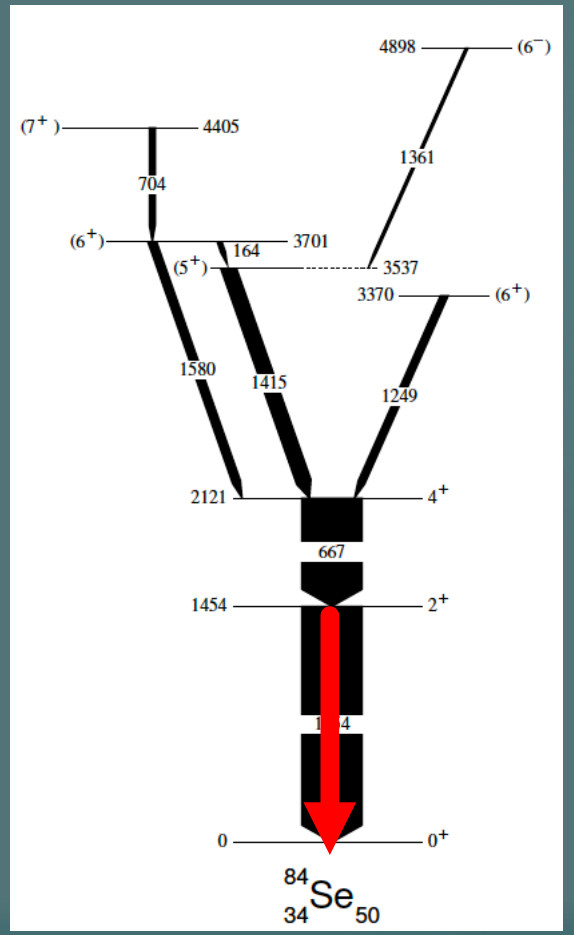
H.J. Li et al., PRC 86, 067302 (2012)

Spectra from ν-ball1 vs ν-ball2

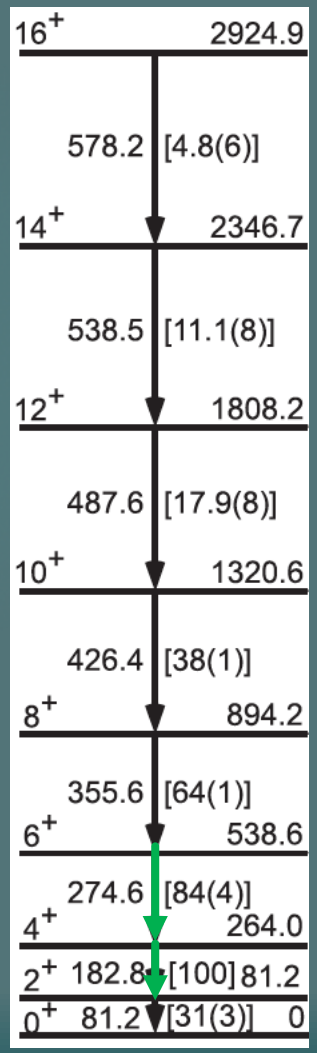
^{152}Ce



A. Prevost et al., EPJA 22, 391 (2004)



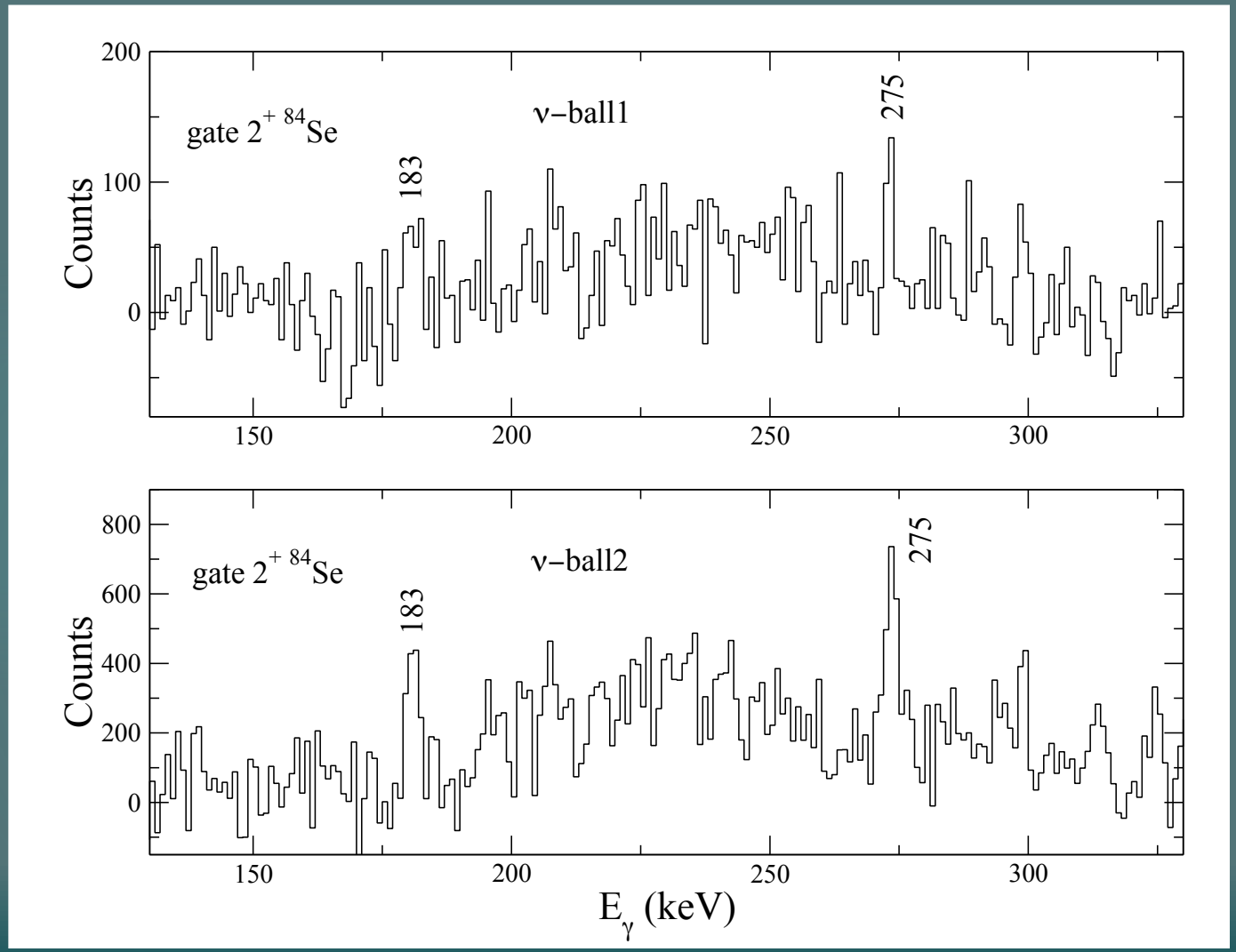
^{152}Ce



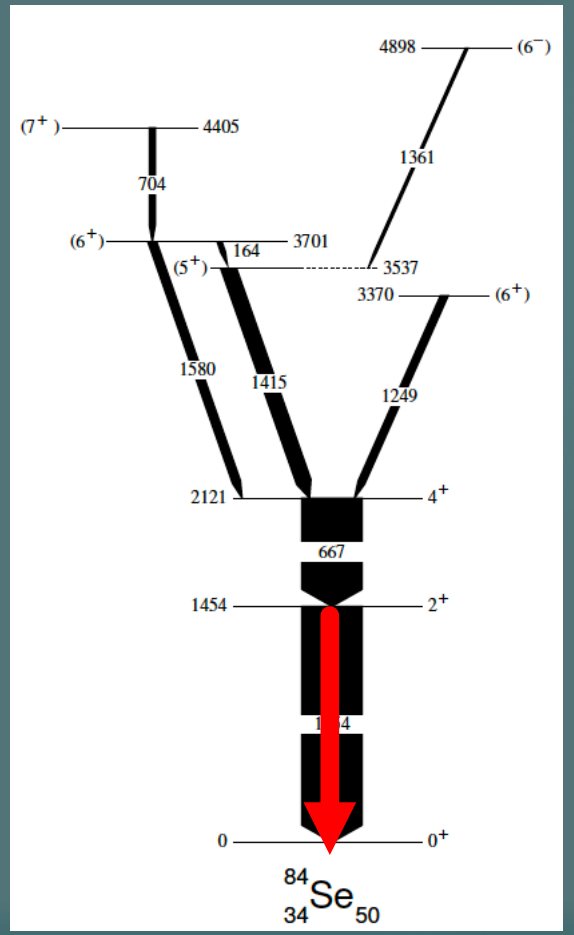
H.J. Li et al., PRC 86, 067302 (2012)

Spectra from ν-ball1 vs ν-ball2

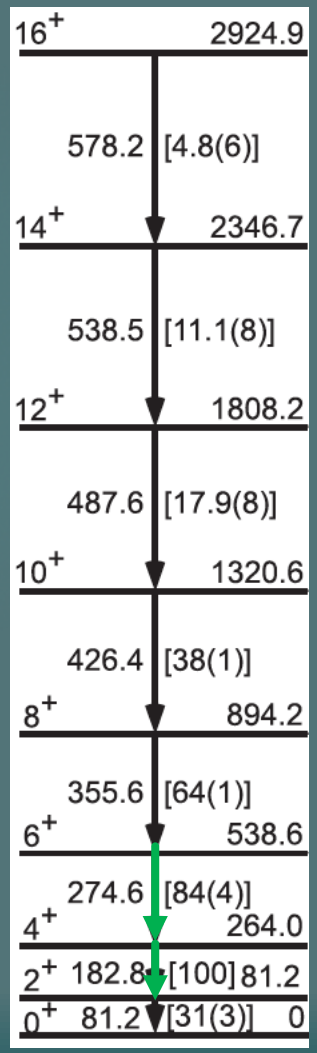
^{152}Ce



A. Prevost et al., EPJA 22, 391 (2004)



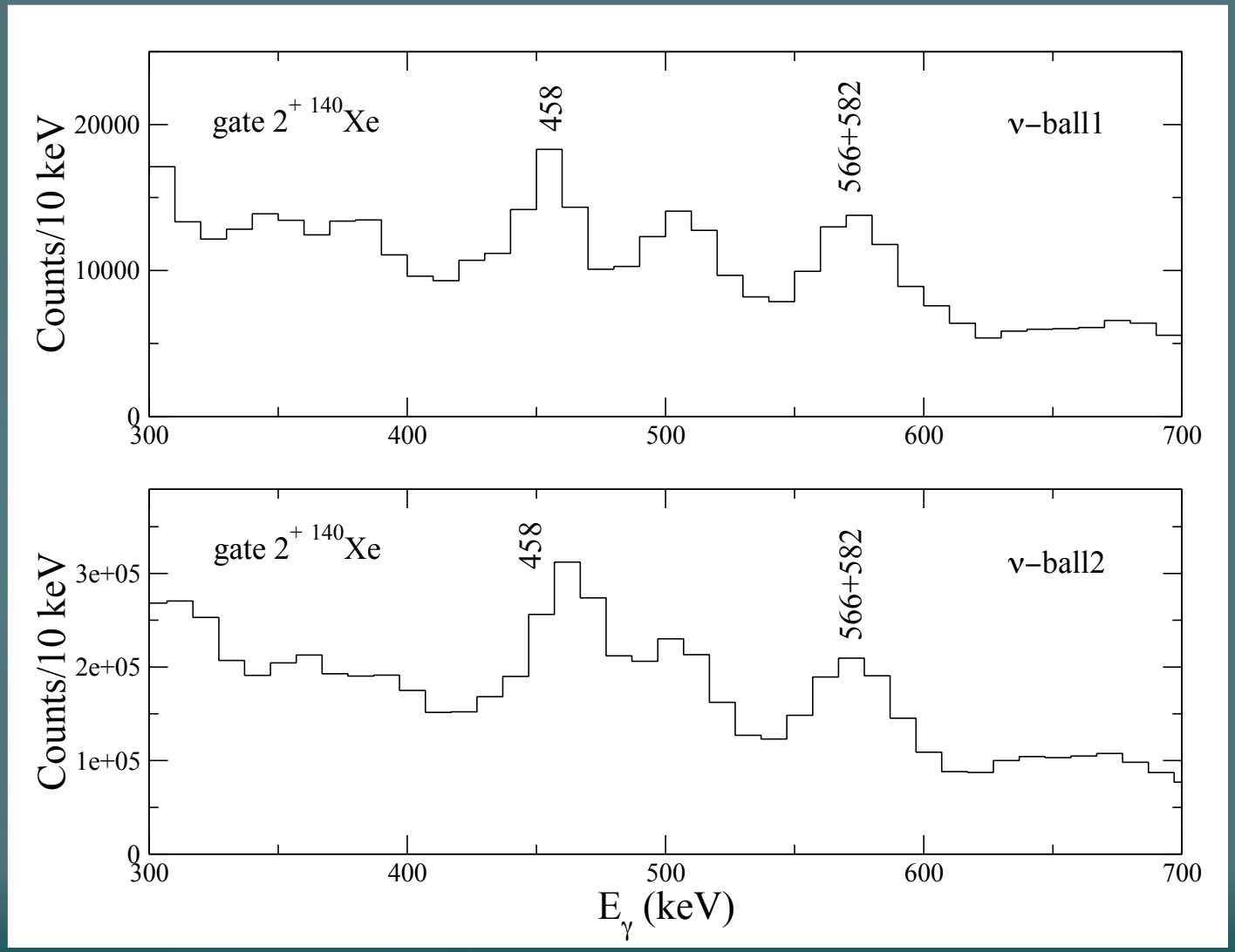
^{152}Ce



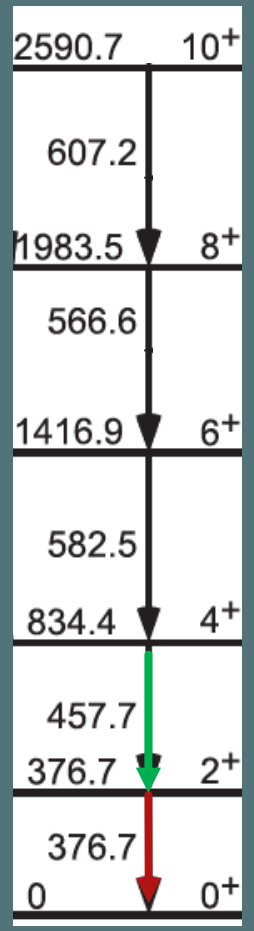
H.J. Li et al., PRC 86, 067302 (2012)

Spectra from ν-ball1 vs ν-ball2

^{140}Xe



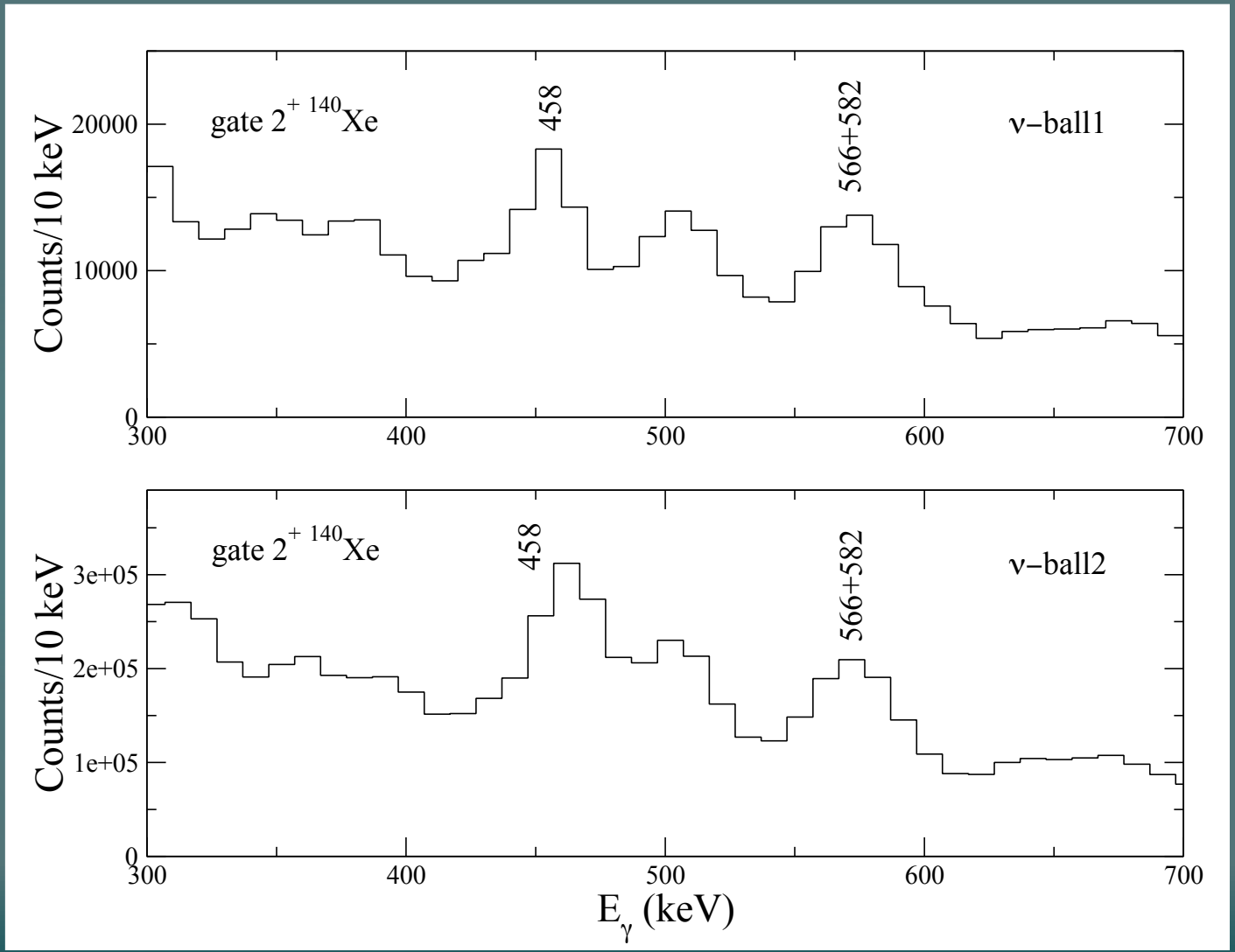
Y. Huang et al., PRC 93, 064321 (2016)



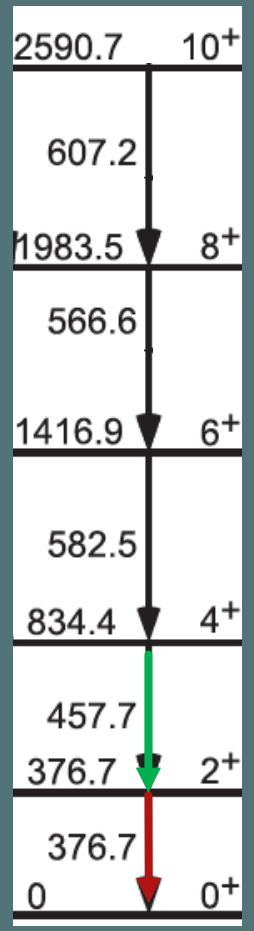
^{140}Xe

Spectra from ν-ball1 vs ν-ball2

^{140}Xe



Y. Huang et al., PRC 93, 064321 (2016)



^{140}Xe

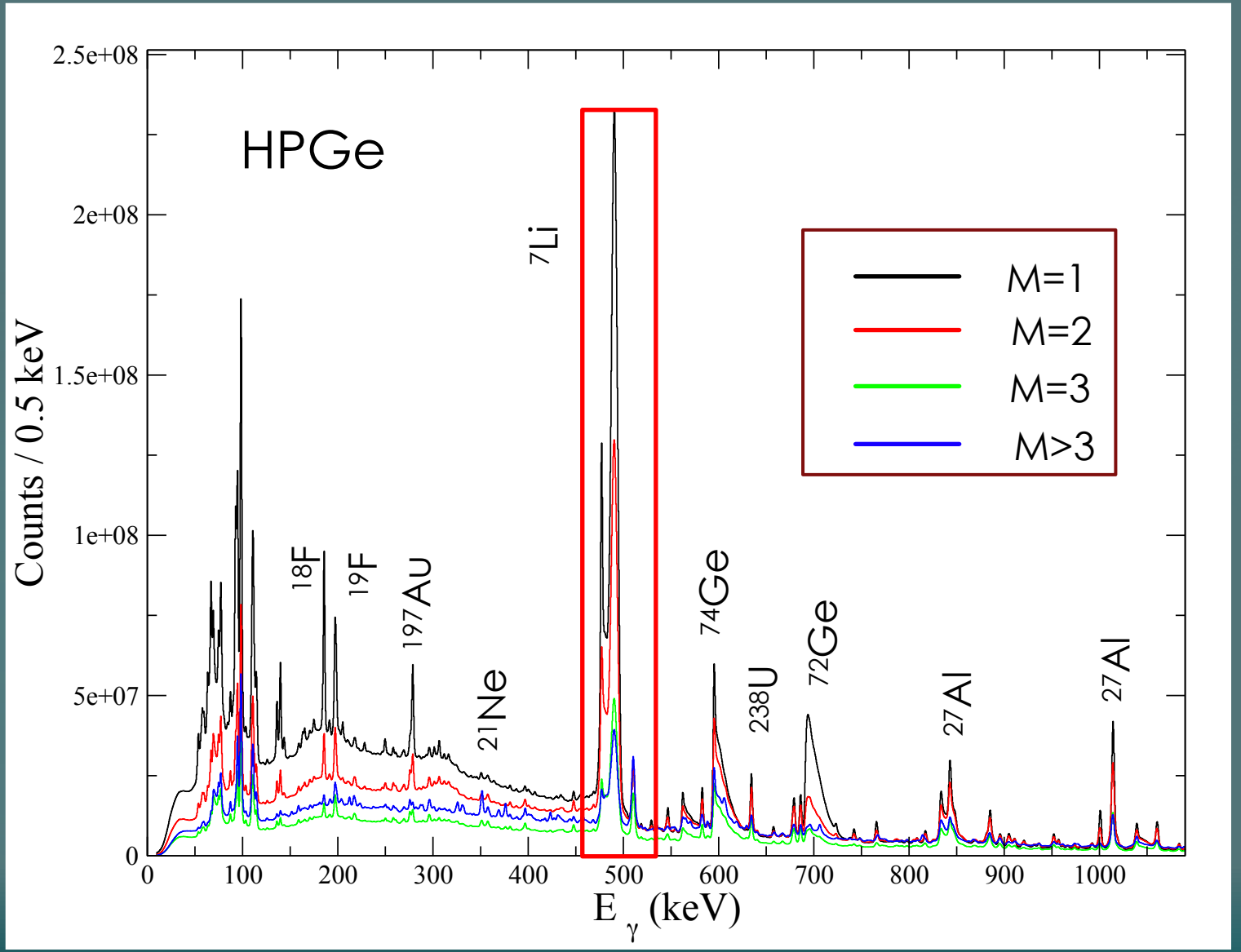
458 keV peak:

ν-ball1: 25000 counts

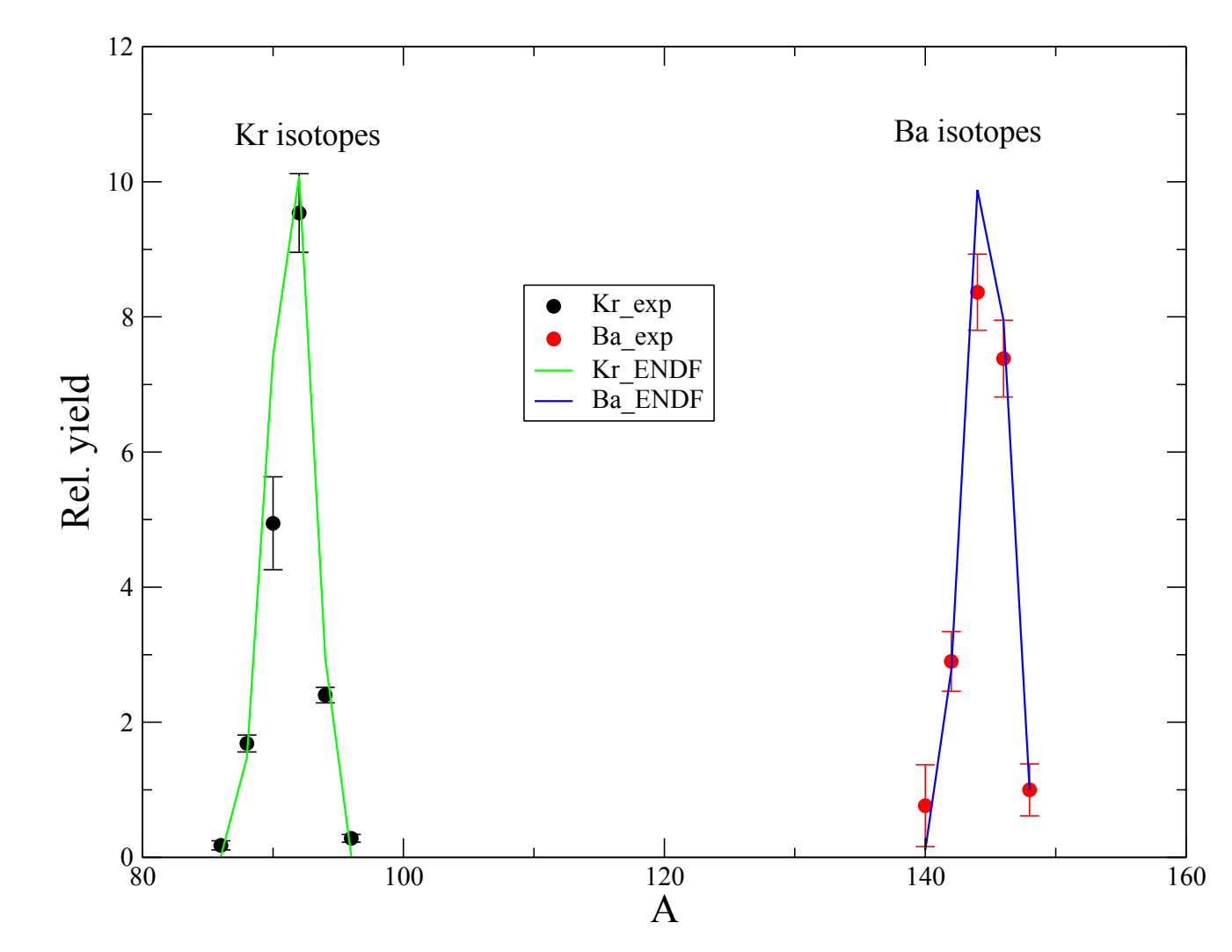
ν-ball2: 625000 counts

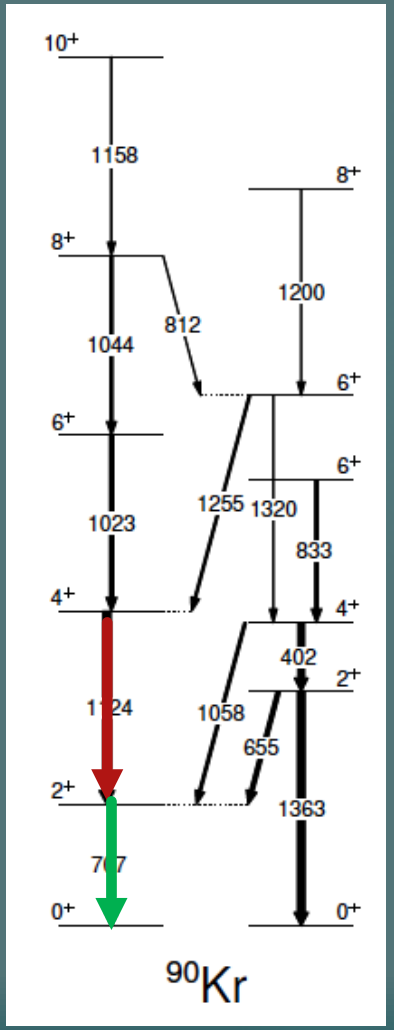
$$\frac{\nu\text{-ball2}}{\nu\text{-ball1}} \sim 25$$

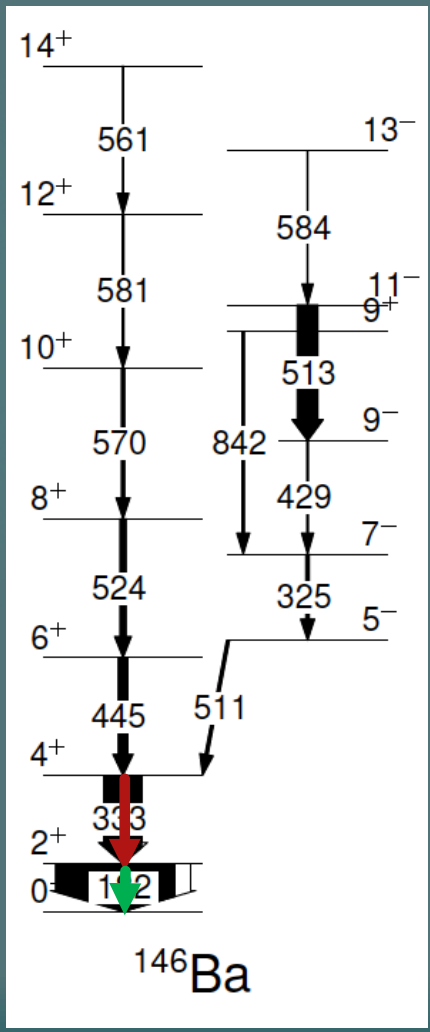
Spectra from the ν-ball2 fission experiment



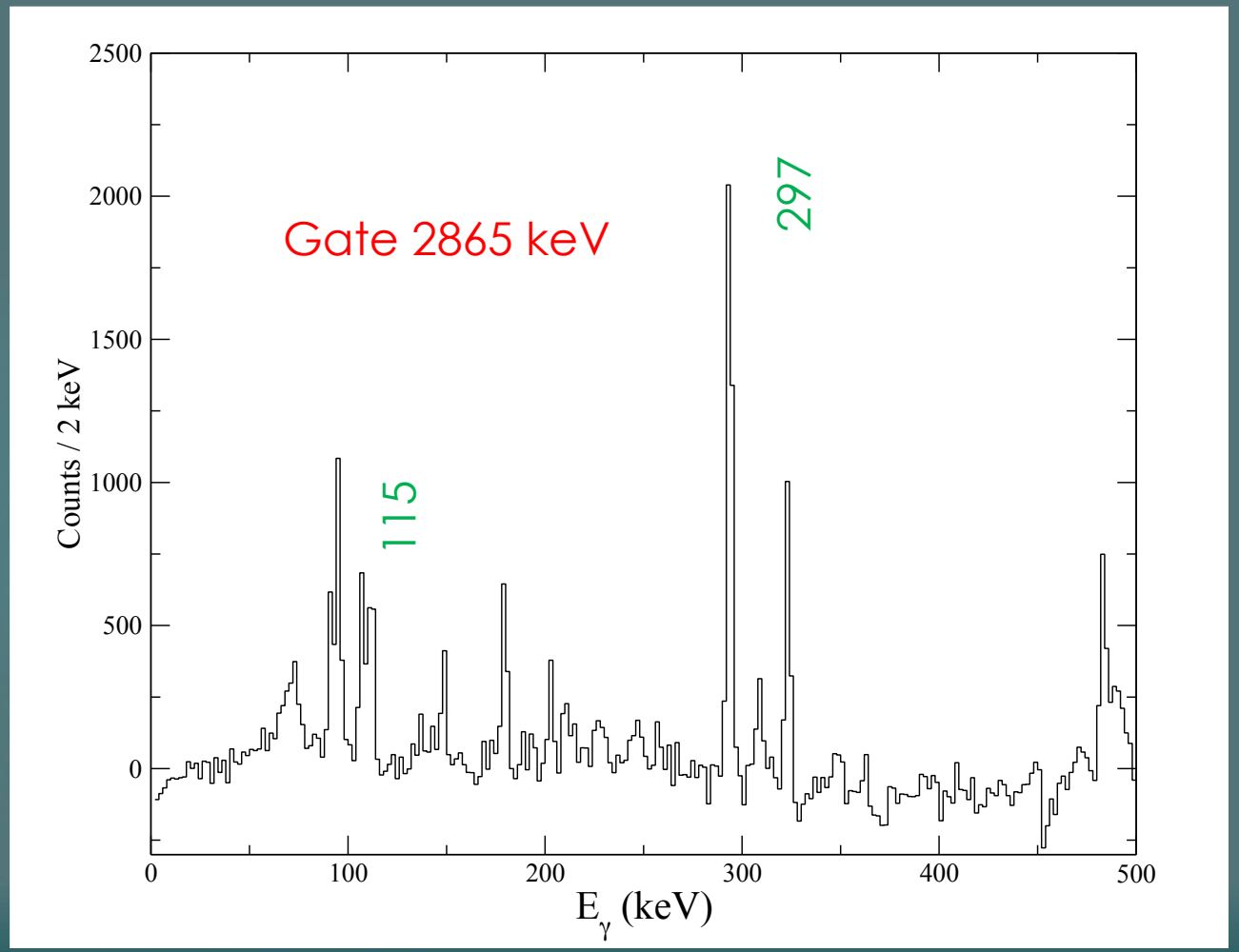
Fission product yields for Kr-Ba isotopes

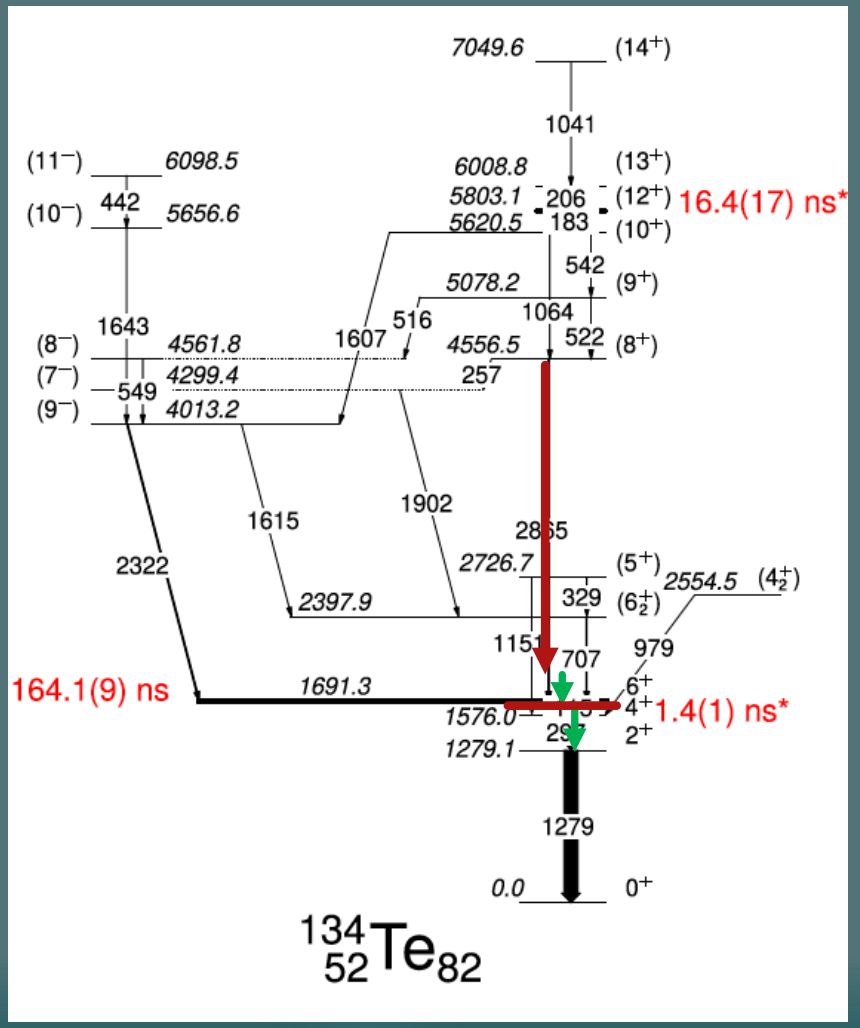




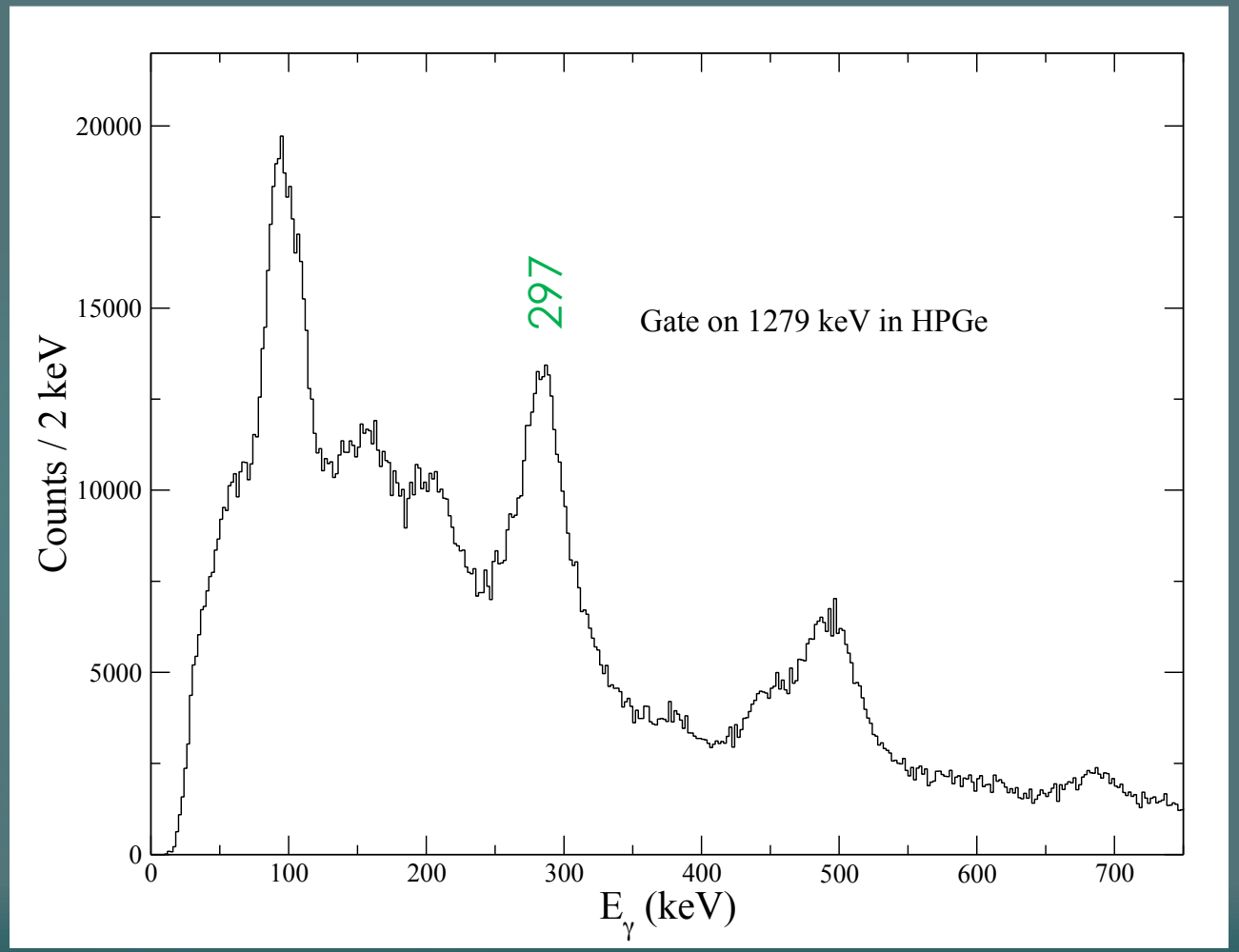


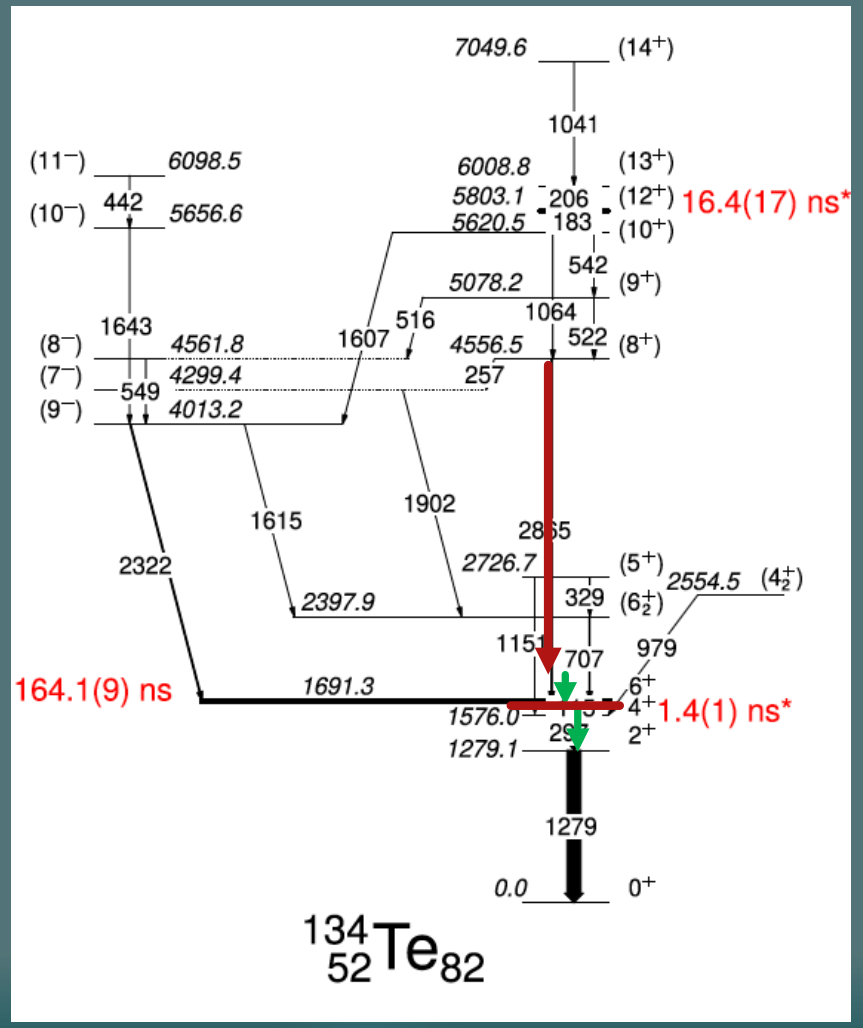
Fast-timing with ν-ball2



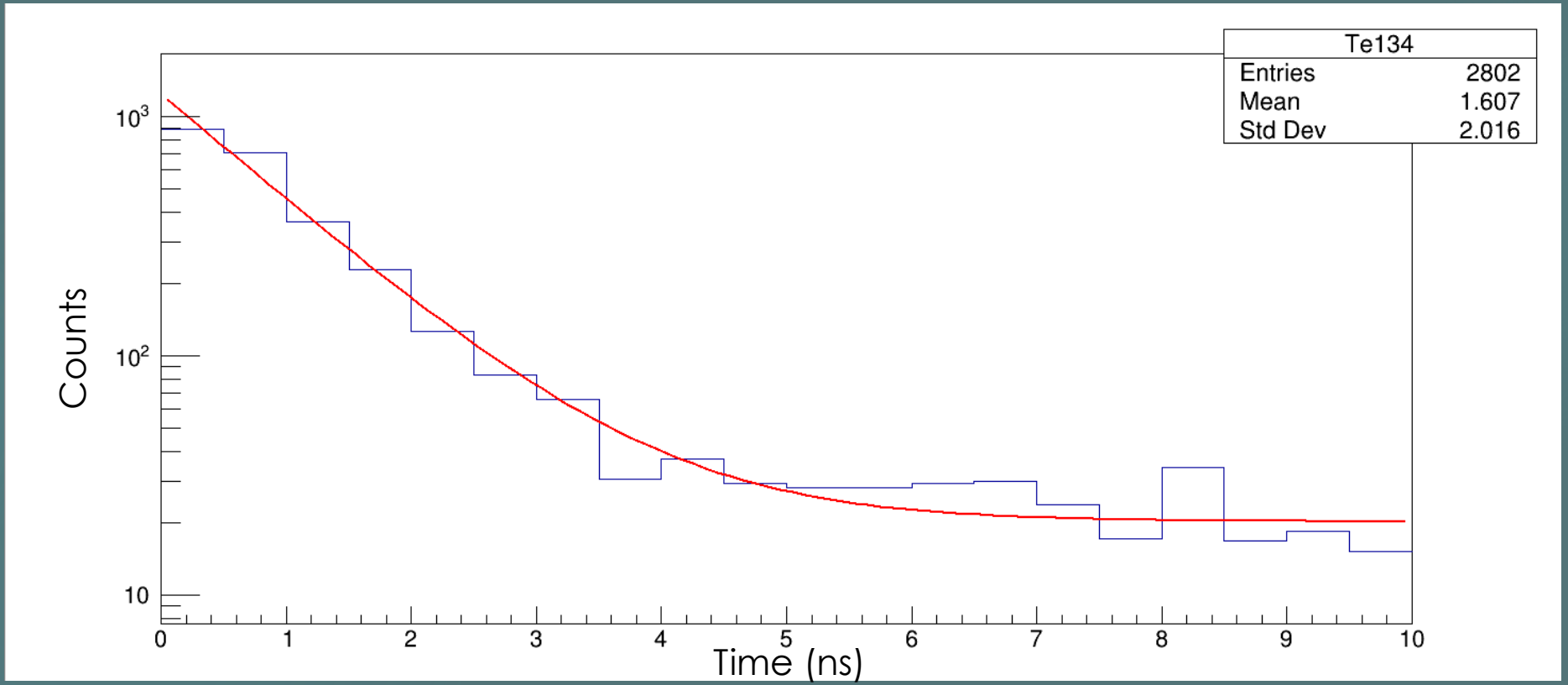


Fast-timing with ν-ball2

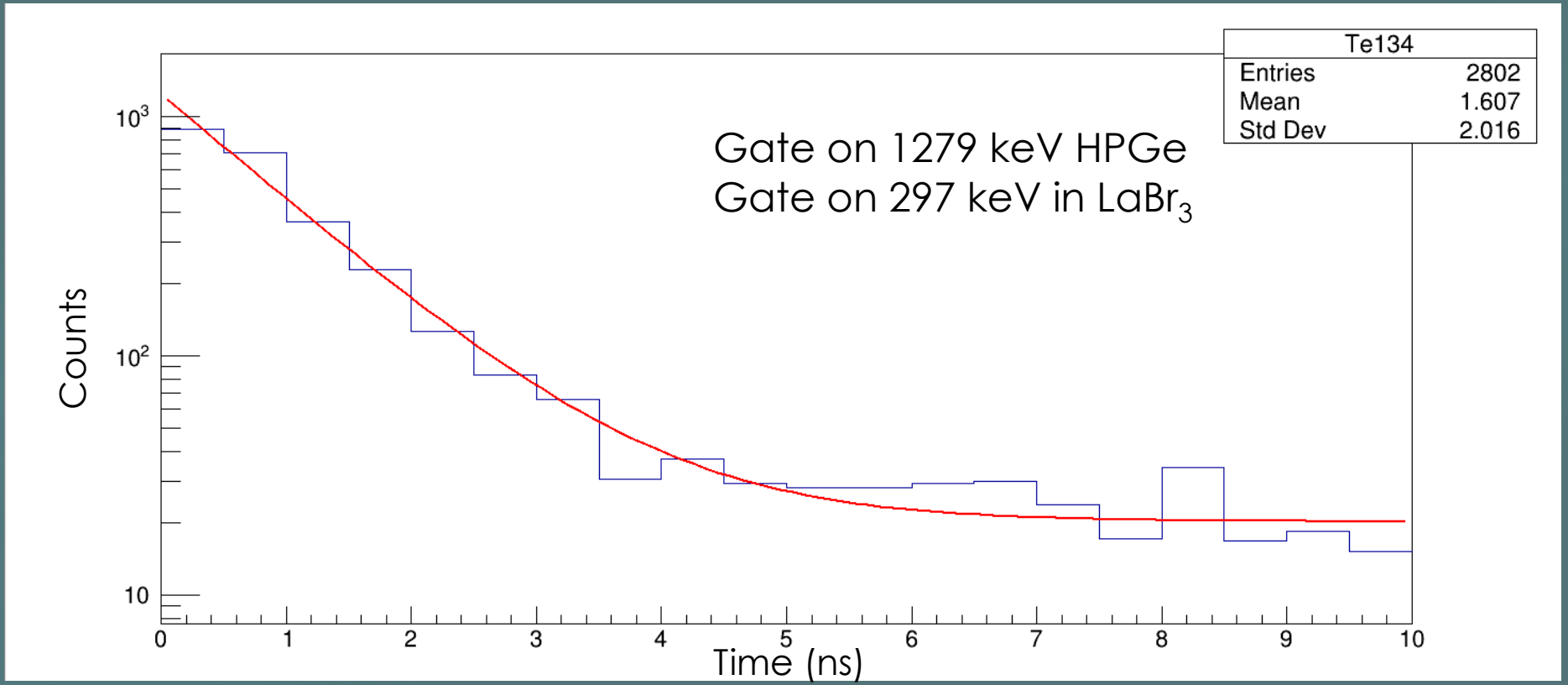




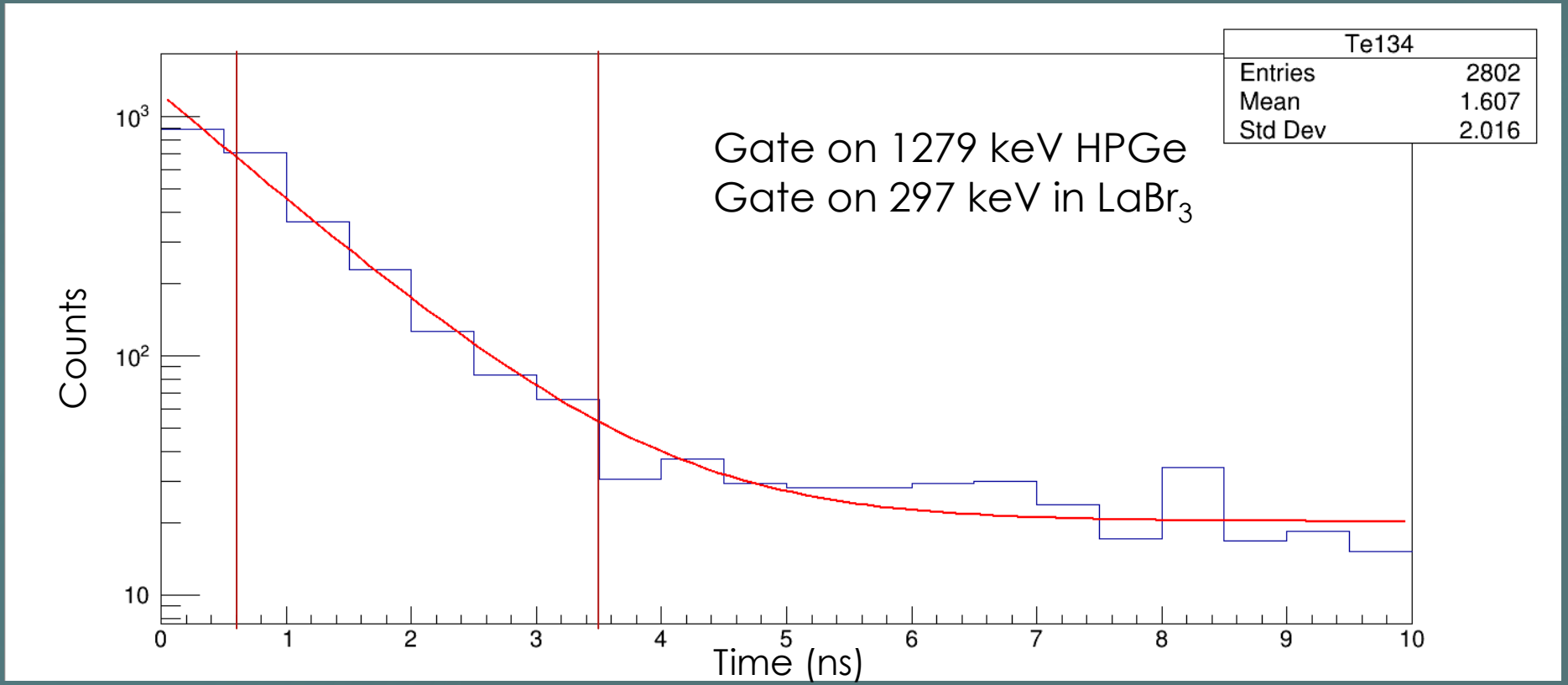
Fast-timing with ν-ball2



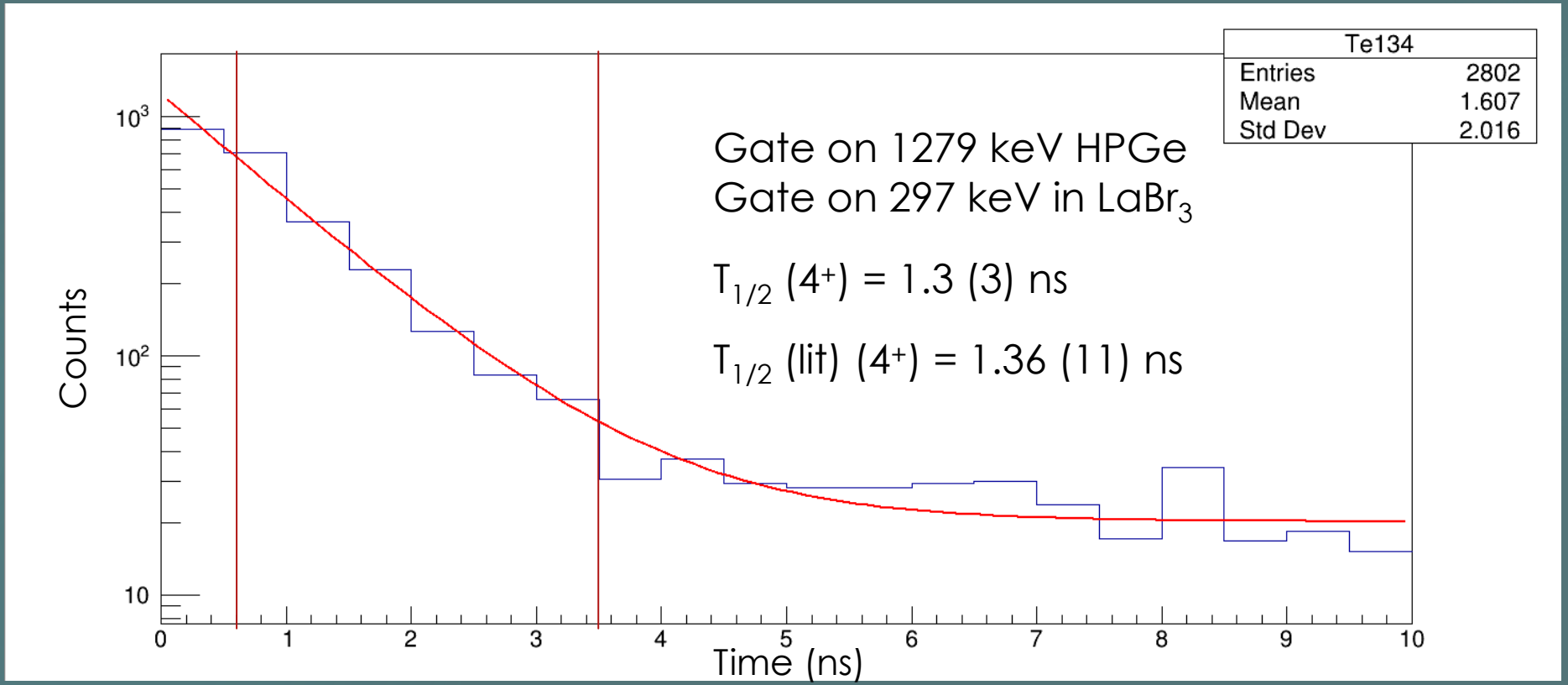
Fast-timing with ν-ball2



Fast-timing with ν-ball2



Fast-timing with ν-ball2



Conclusions

Conclusions

- Successful fast-neutron induced fission experiment

Conclusions

- Successful fast-neutron induced fission experiment
- ν-ball2: 24 clover HPGe + 20 $LaBr_3(Ce)$

Conclusions

- Successful fast-neutron induced fission experiment
- ν-ball2: 24 clover HPGe + 20 $LaBr_3(Ce)$
- Improved statistics

Conclusions

- Successful fast-neutron induced fission experiment
- ν-ball2: 24 clover HPGe + 20 $LaBr_3(Ce)$
- Improved statistics
- Preliminary analysis

Thanks to all the collaborators