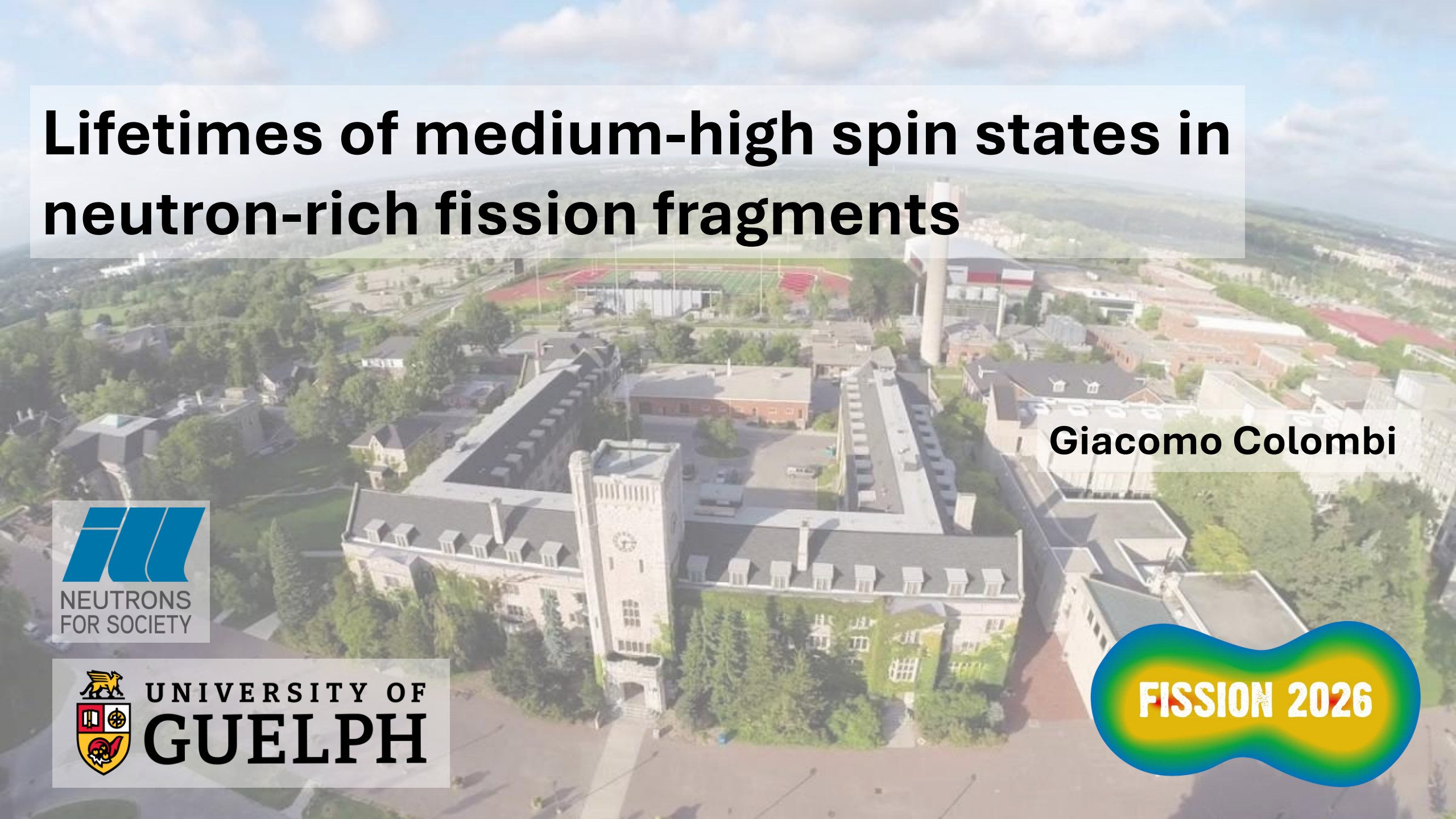
Lifetimes of medium-high spin states in neutron-rich fission fragments



Giacomo Colombi

NEUTRONS FOR SOCIETY

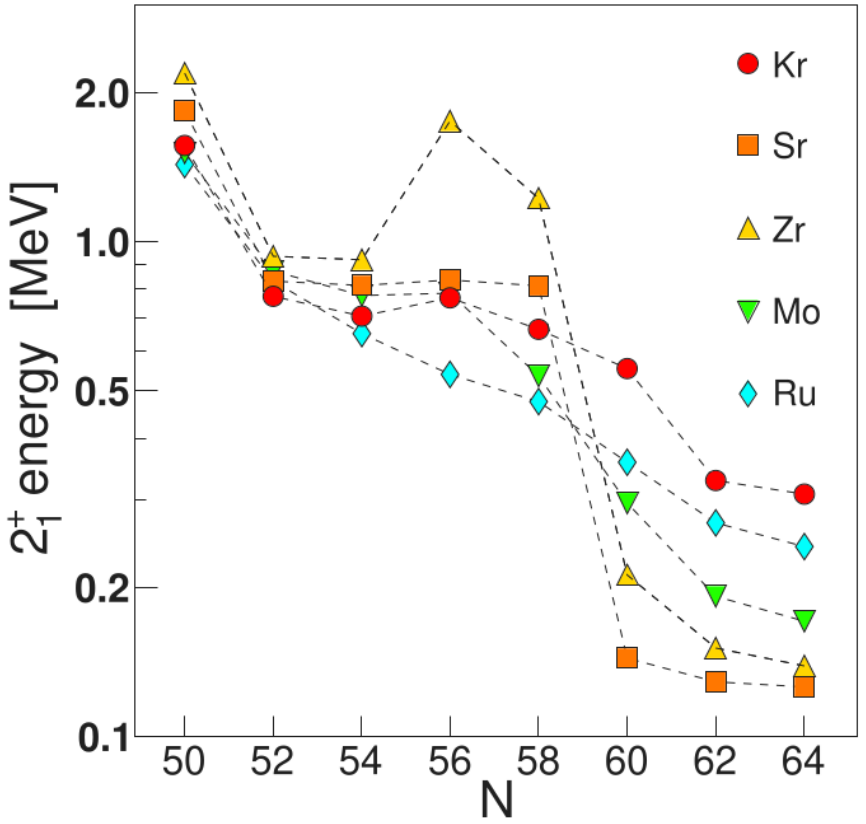
UNIVERSITY OF GUELPH

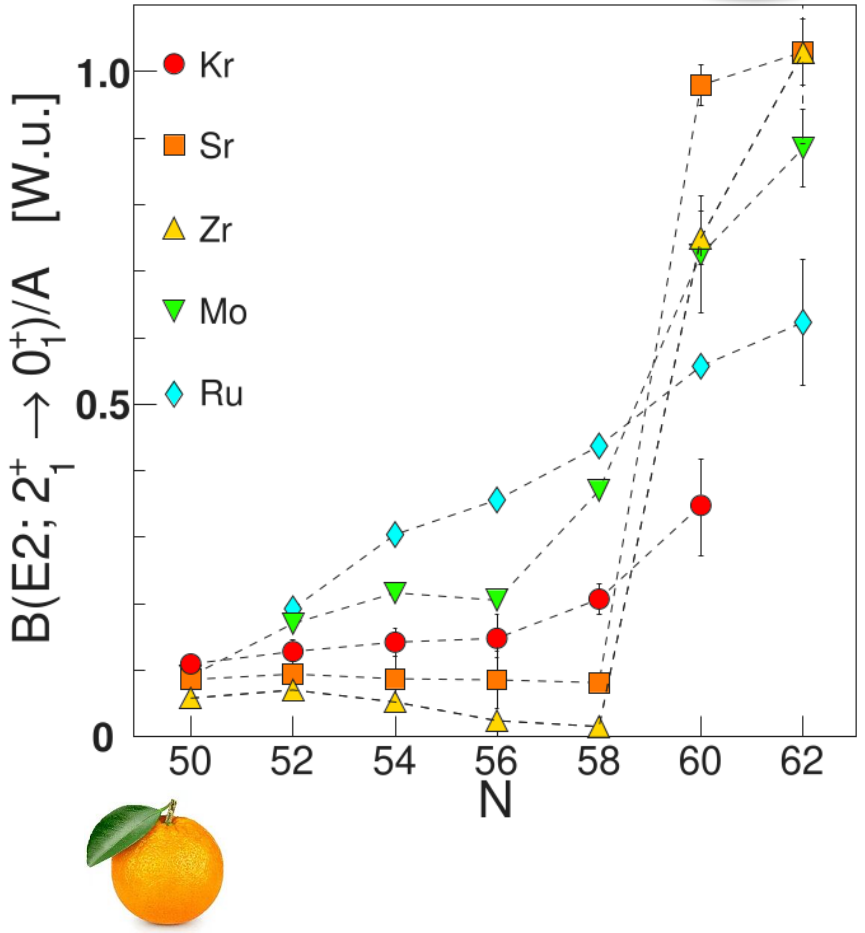
FISSION 2026

Shape transition at N=60

Dramatic change of the ground state structure observed at N = 58, 60 for Rb, Sr, Y, Zr isotopes

Inversion of coexisting regular and “intruder” configurations





P. Garrett, M. Zielińska and E. Clément, PPNP ***124*** *(2022), 103931*

Shape transition at N=60

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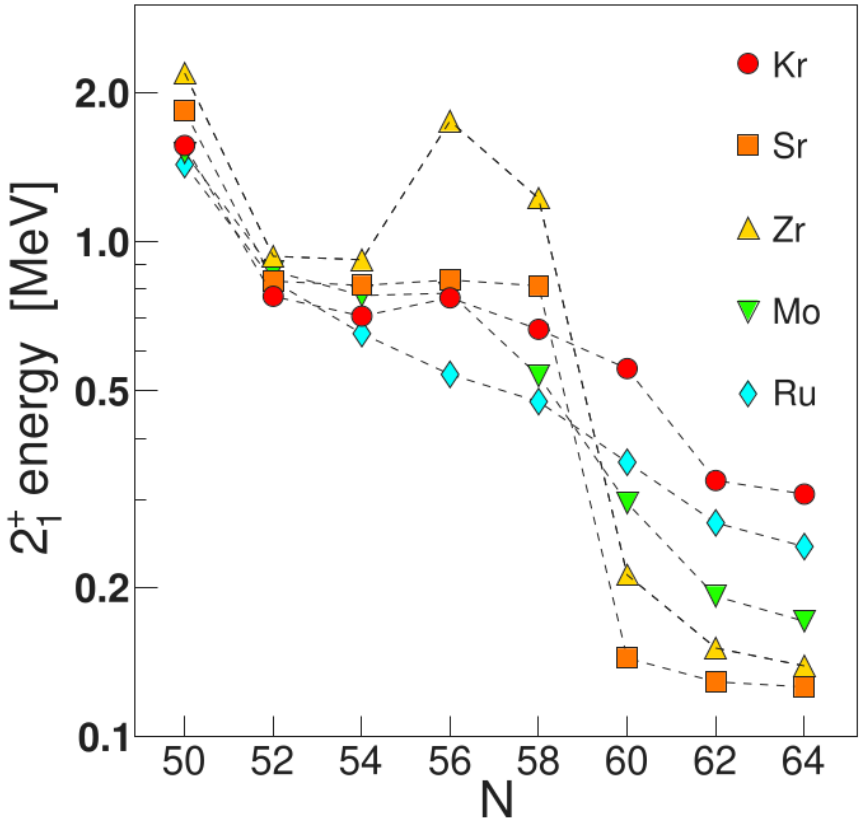
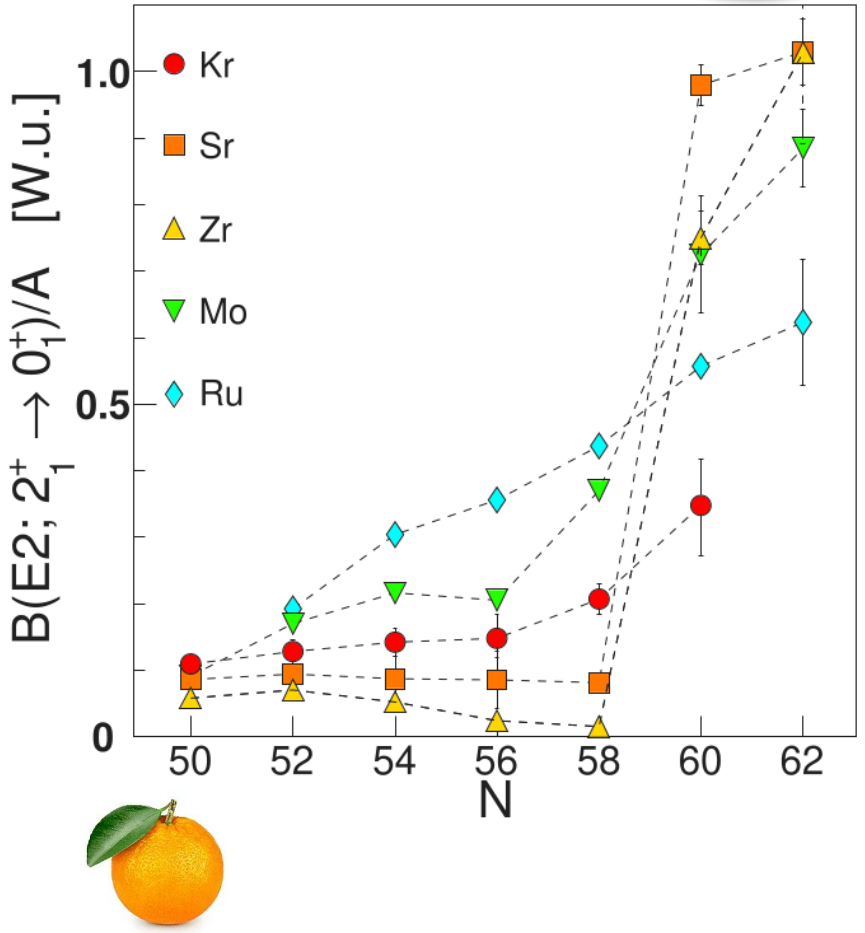
What is the behavior at medium-high spins?





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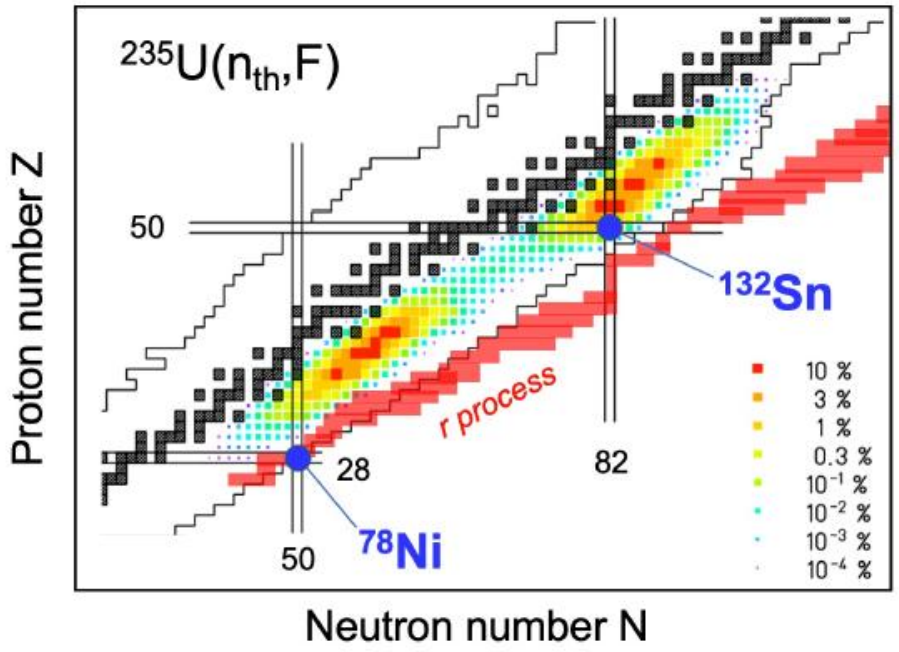
Neutron-induced fission

Neutron-rich nuclei at N=60
produced in nuclear fission



Neutron-induced fission: the active fission target

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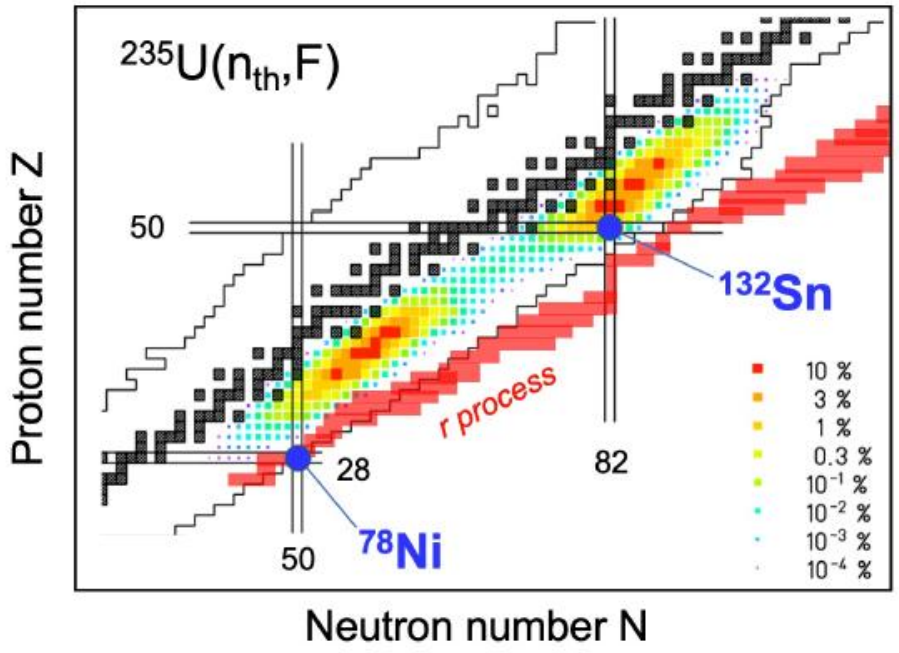
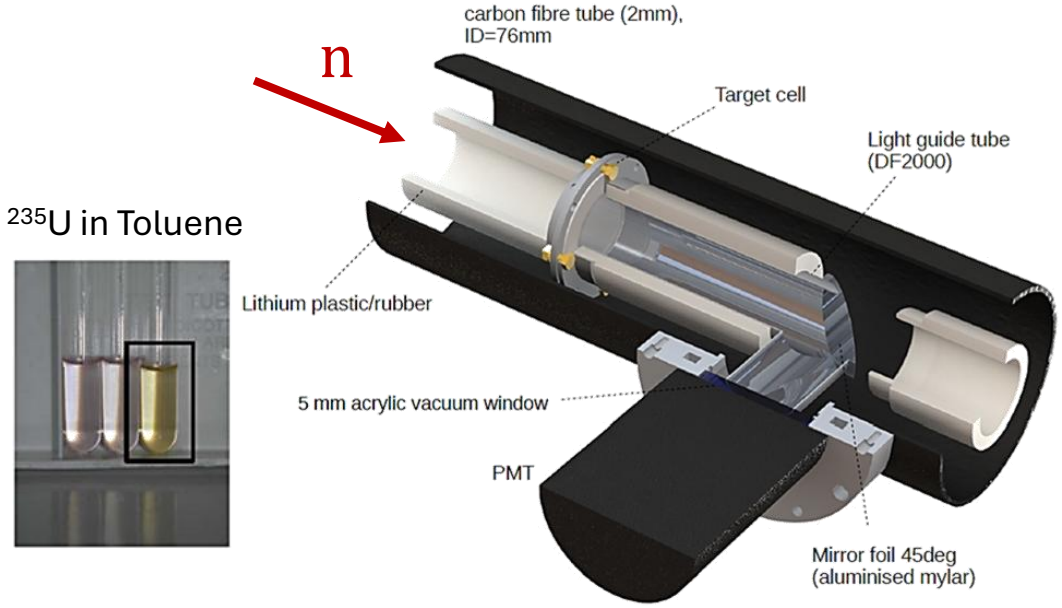


^{235}U dissolved in liquid scintillator

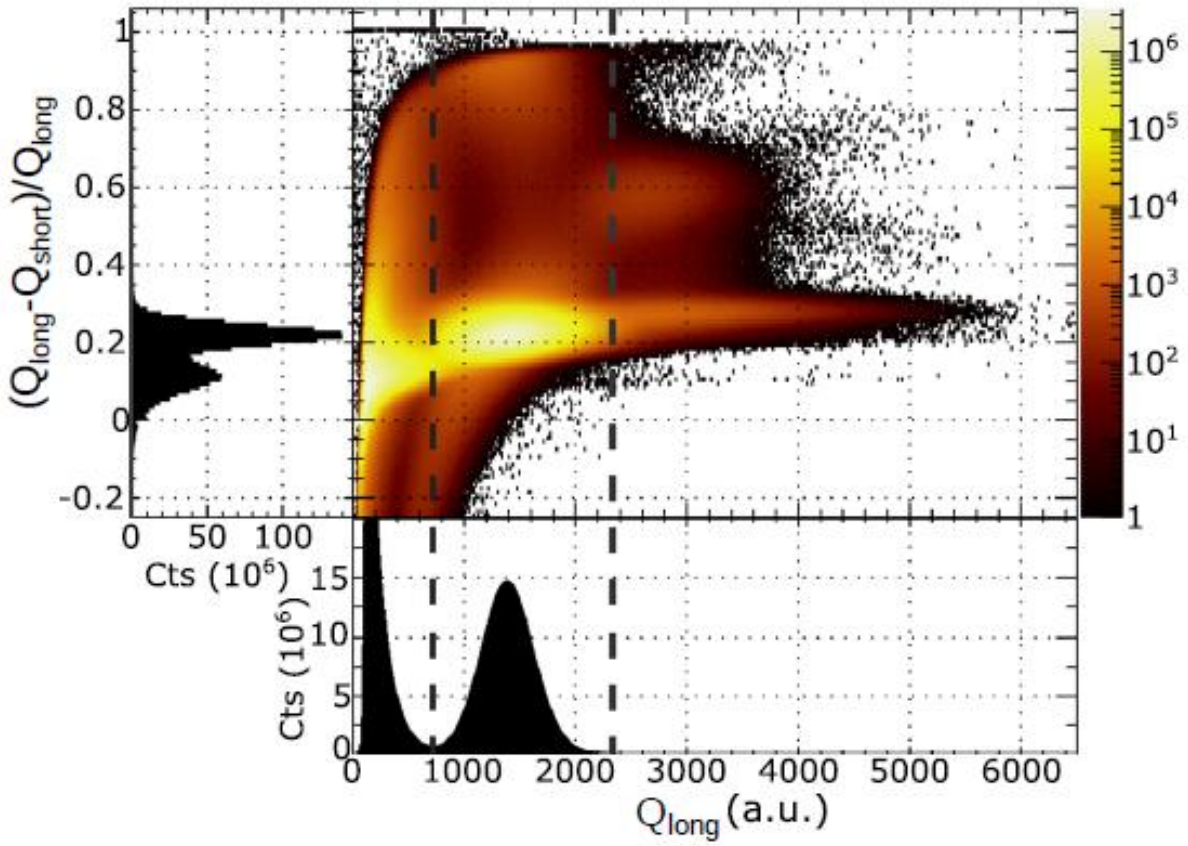
Suppression of the gamma rays from the beta decay



F. Kandzia *et al.*, Eur. Phys. J A **56**, 207 (2020)

Neutron-induced fission: the active fission target

Pulse shape discrimination



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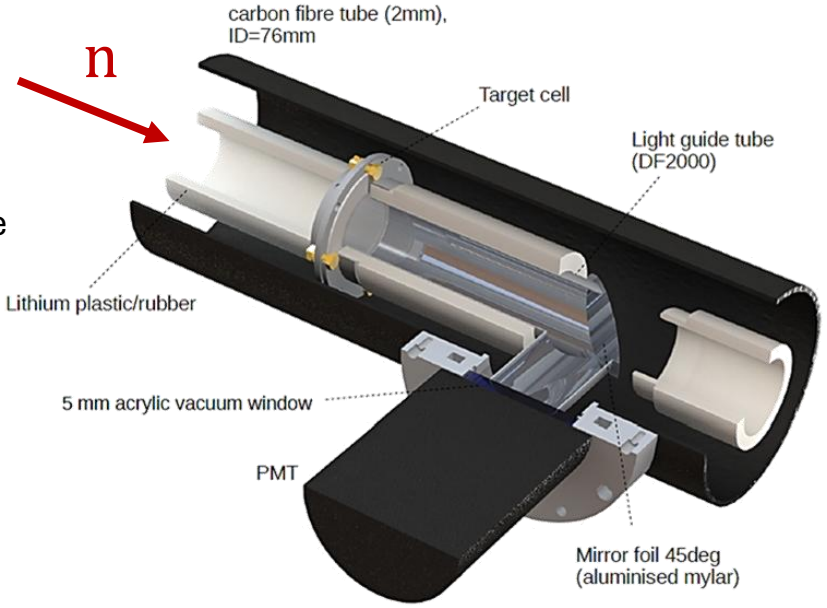
Suppression of the gamma rays from the beta decay

^{235}U in Toluene



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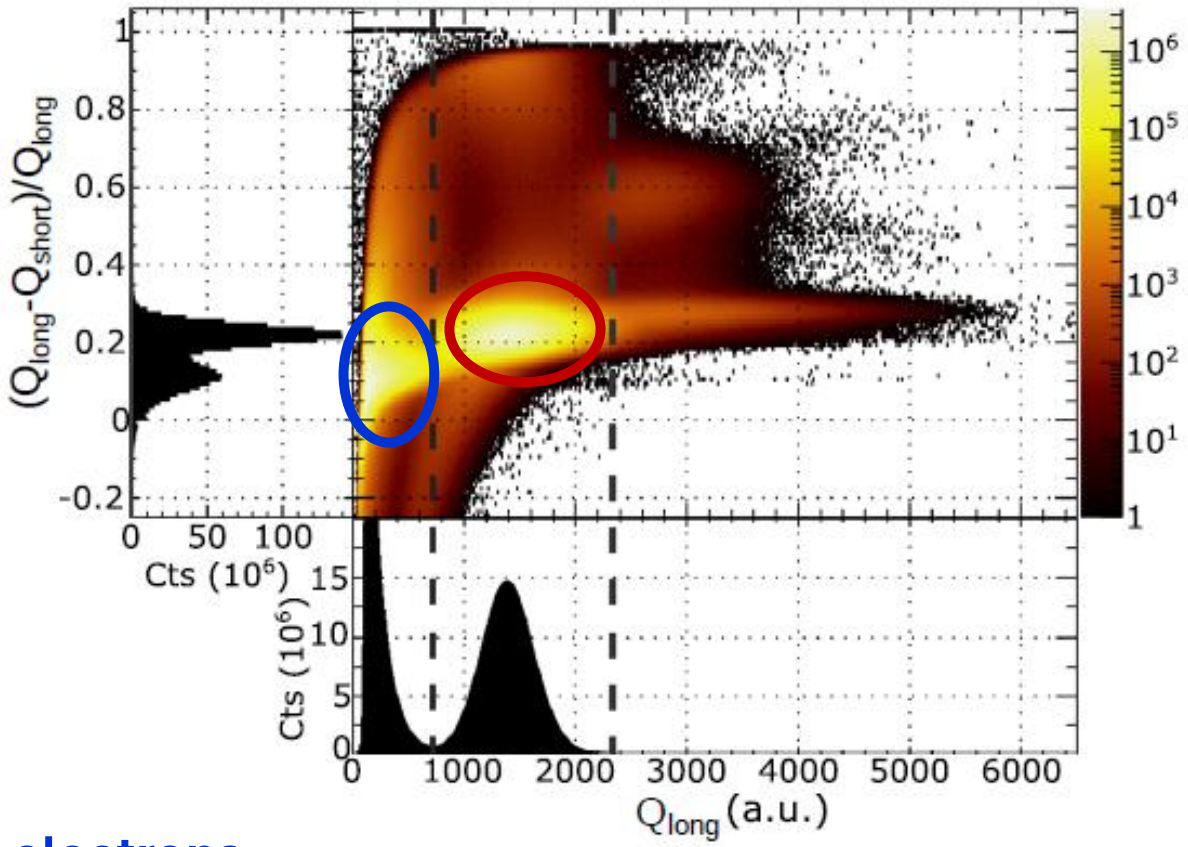
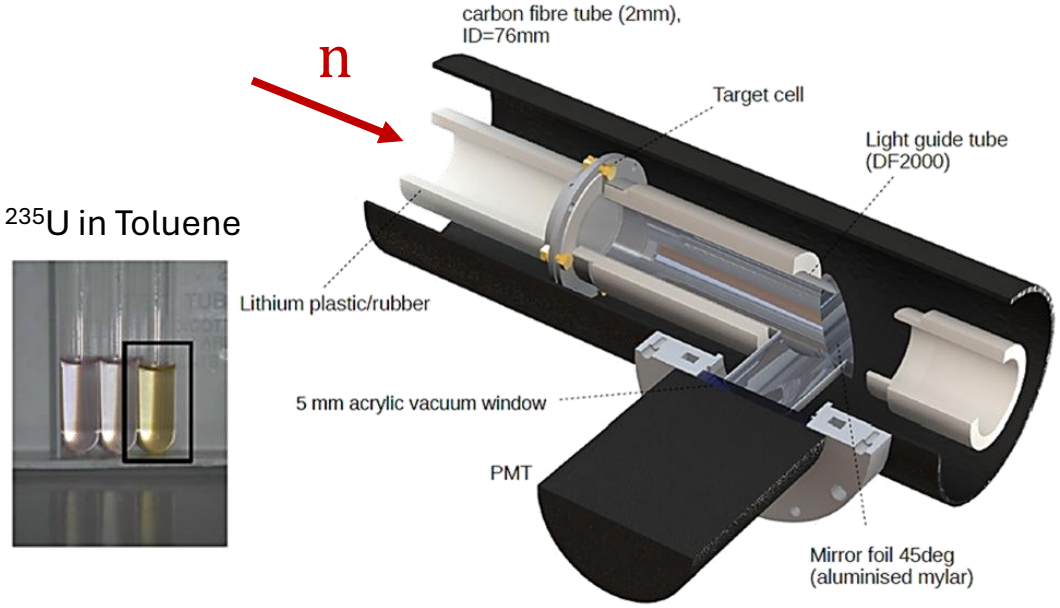


β electrons

Fission fragments

^{235}U dissolved in liquid scintillator

Suppression of the gamma rays from the beta decay

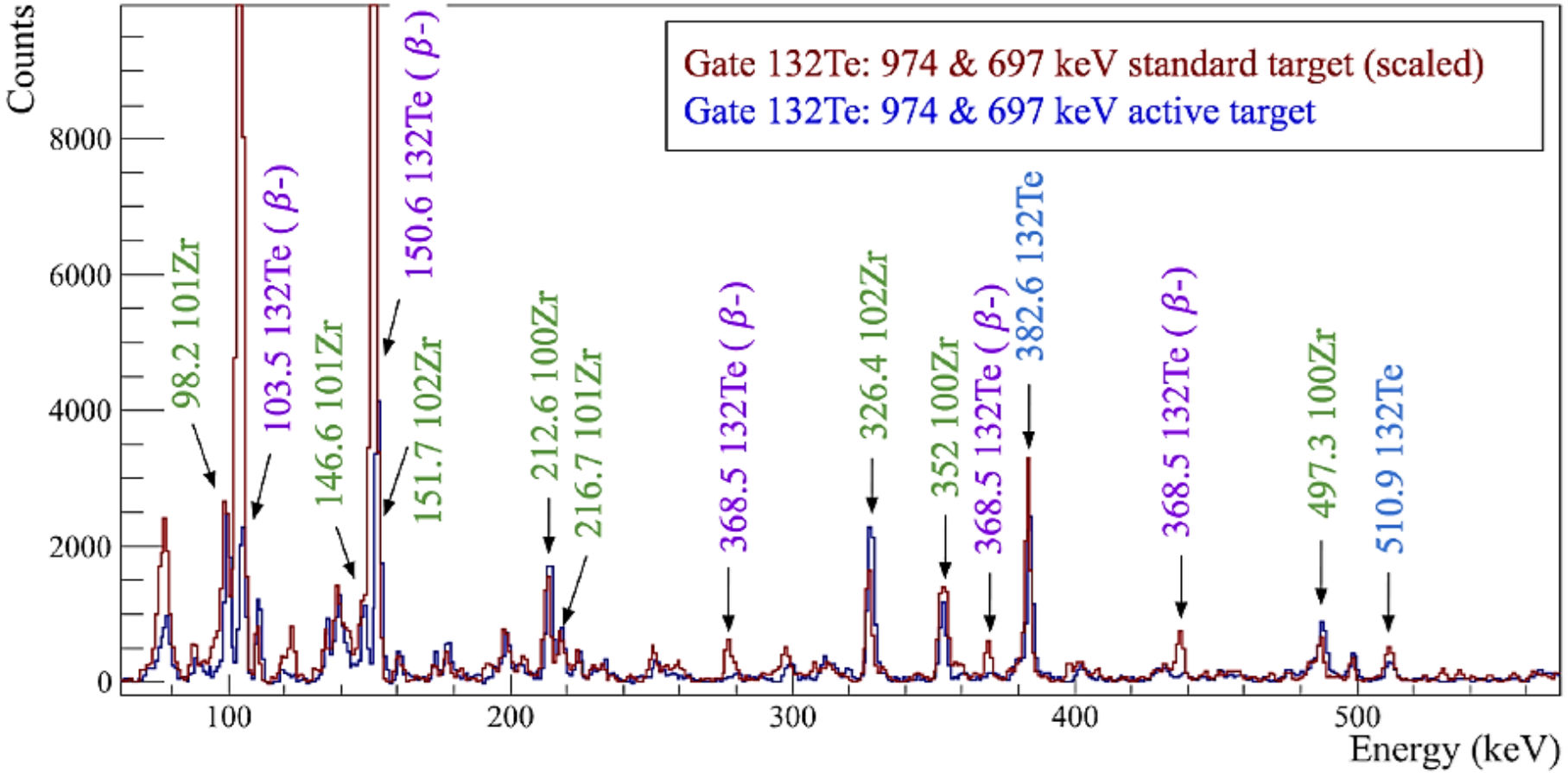


^{235}U in Toluene

F. Kandzia *et al.*, Eur. Phys. J A **56**, 207 (2020)

Performance of the active fission target

Triple coincidence spectra



- "Standard" 235-U metallic target at FIPPS
- Scintillator-based active target

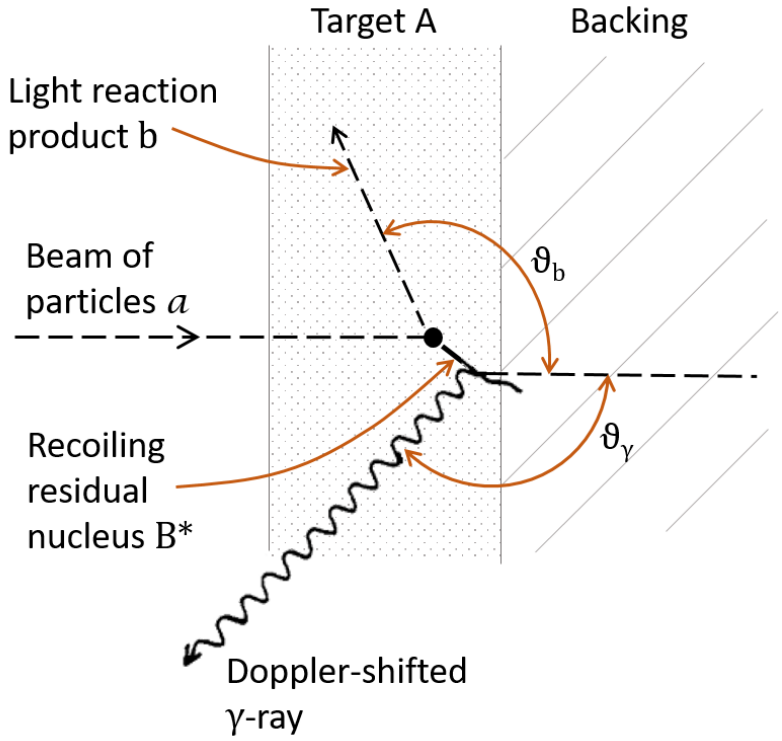
D. Reygadas, PhD Thesis,
Université Grenoble-Alpes, 2021

Lifetime measurements with Doppler shift technique

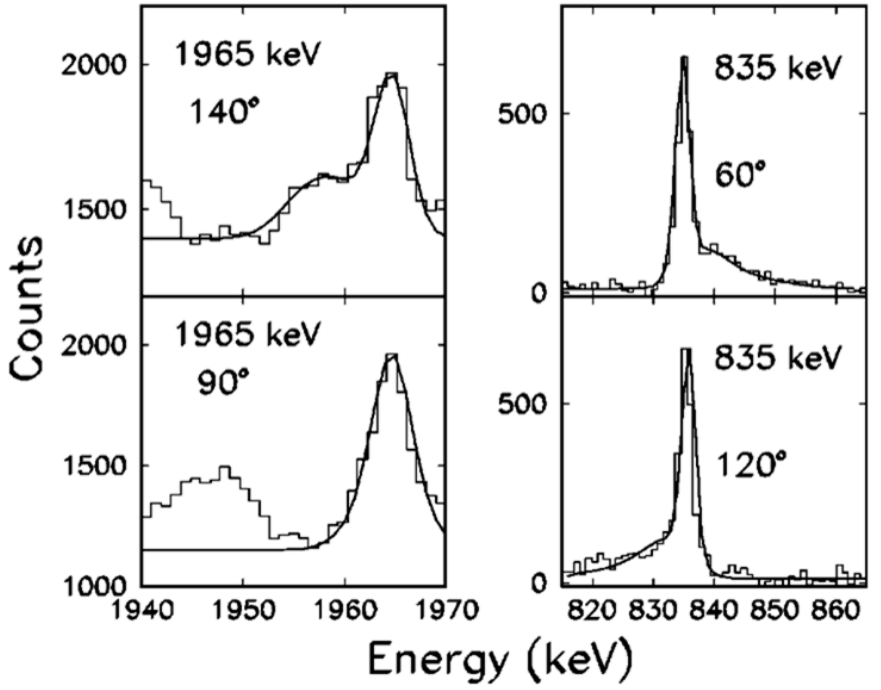
Doppler Shift Attenuation Method (DSAM)

- Slowing down of nuclei in the target
- Lifetimes from ≈fs to ≈ps

A(a,b)B*

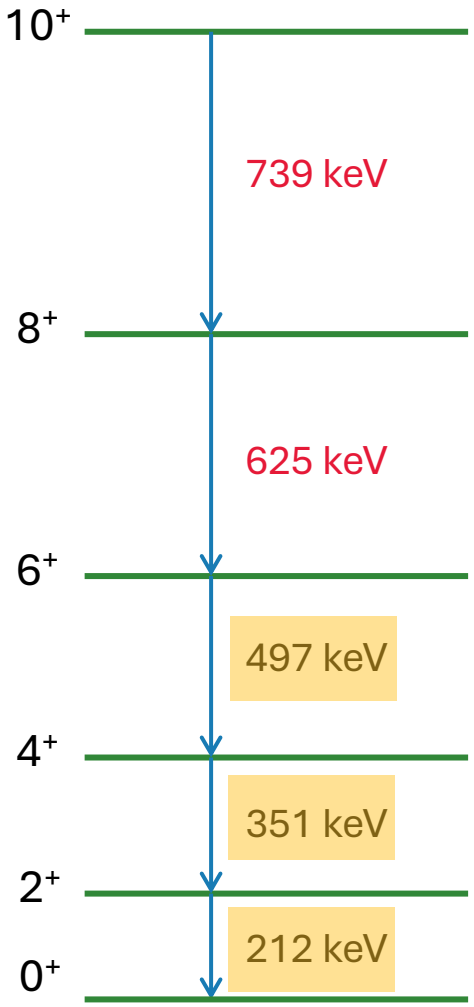


$$E'_\gamma = E_\gamma \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

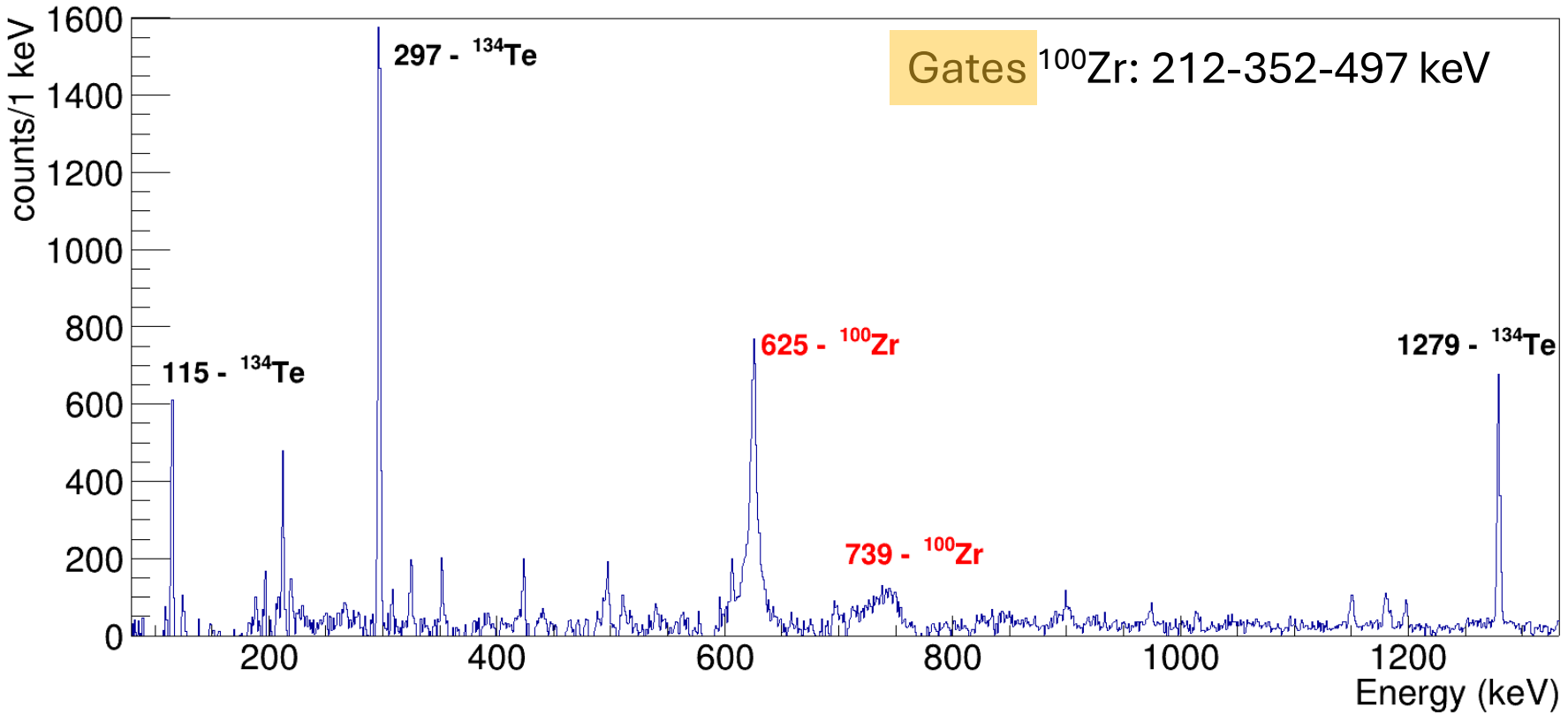


F. Brandolini *et al.*, Phys. Rev. C **60**, 041305 (1999)

Doppler broadened gamma-ray peaks



Triple coincidence spectrum



Lineshape analysis to determine the lifetimes of medium-high spin states

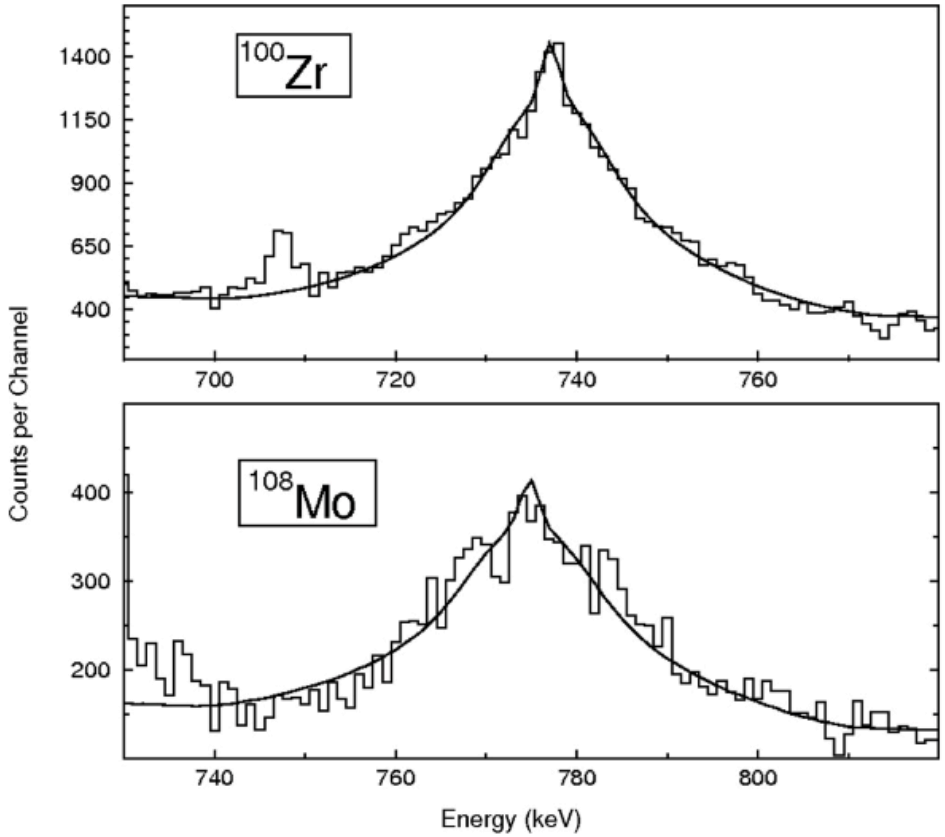
Existing literature

PHYSICAL REVIEW C **86**, 014321 (2012)

Lifetime measurements and nuclear deformation in the $A \approx 100$ region

A. G. Smith, J. L. Durell, W. R. Phillips, and W. Urban*
School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom

- Doppler-broadened peaks detected by the EUROGAM array
- ^{248}Cm spontaneous fission source in KCl pellet
- Lifetimes in neutron-rich Sr, Zr, Mo, Ru and Pd at spin I≈10
- Stopping power of the fission fragments from SRIM
- Gaussian kinetic energy distribution
- Assumption of constant quadrupole moment along the bands



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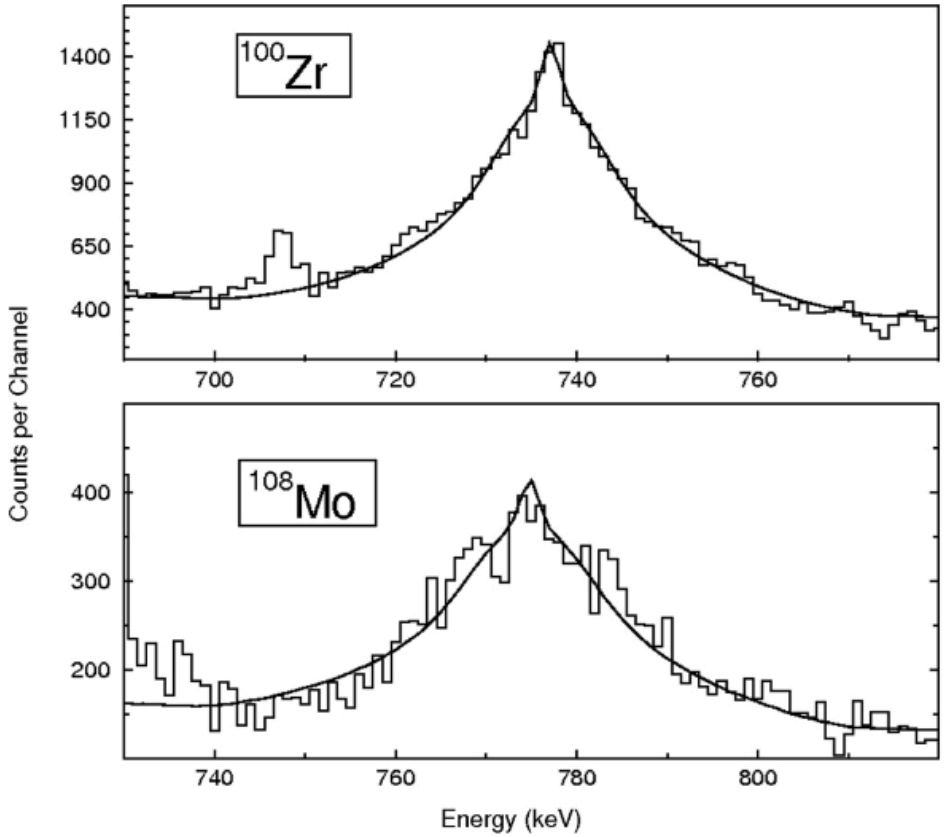
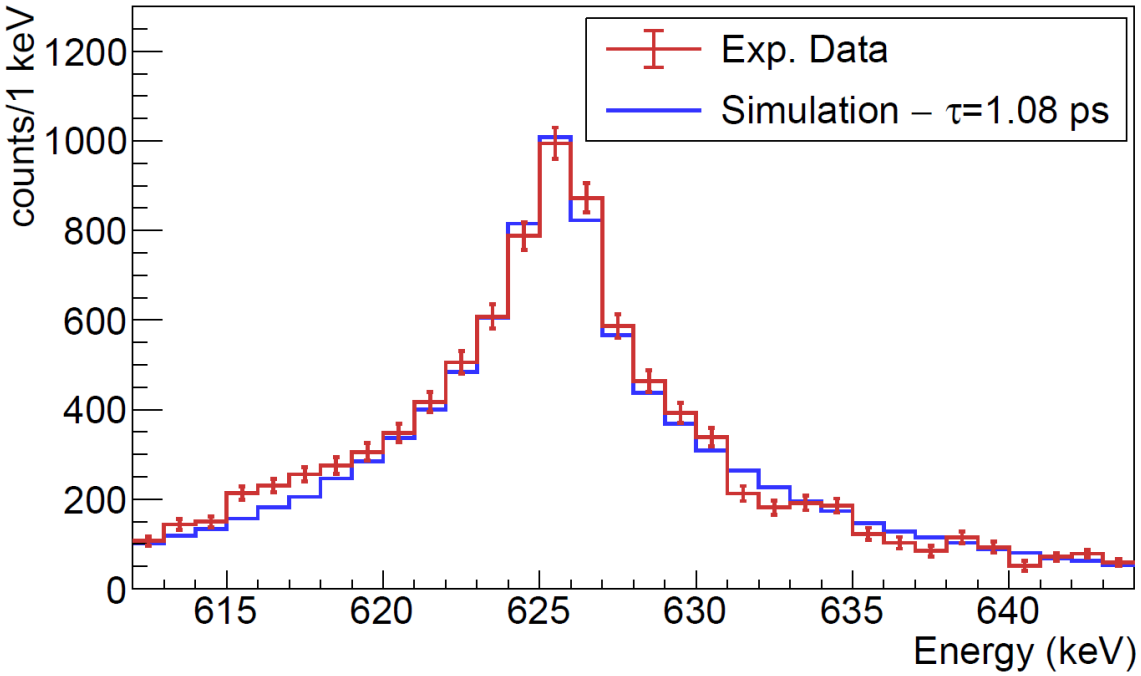
→ Recent publication by G. Pasqualato *et al.* in EPJ A (2023) 59:276 with AGATA-VAMOS-Plunger data

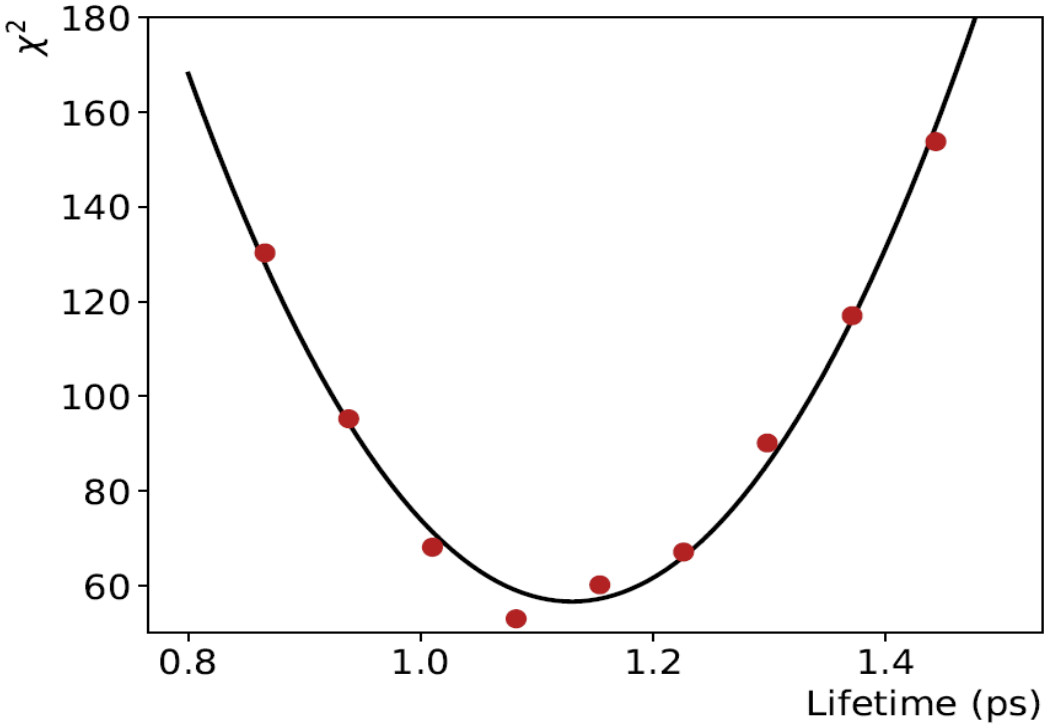


Lineshape analysis technique using the active target

^{100}Zr: $8^+ \rightarrow 6^+$ transition

"Discrete sampling" of the lifetime in the simulations





→ See Basile's talk for more details

Evaluation of systematic errors

- Detection response function
- Stopping power of fission fragments
- The “feeding history” of the state of interest
- The normalization of the simulated data
- Dependence with the gamma-ray energy
- Dependence with the number of simulated events

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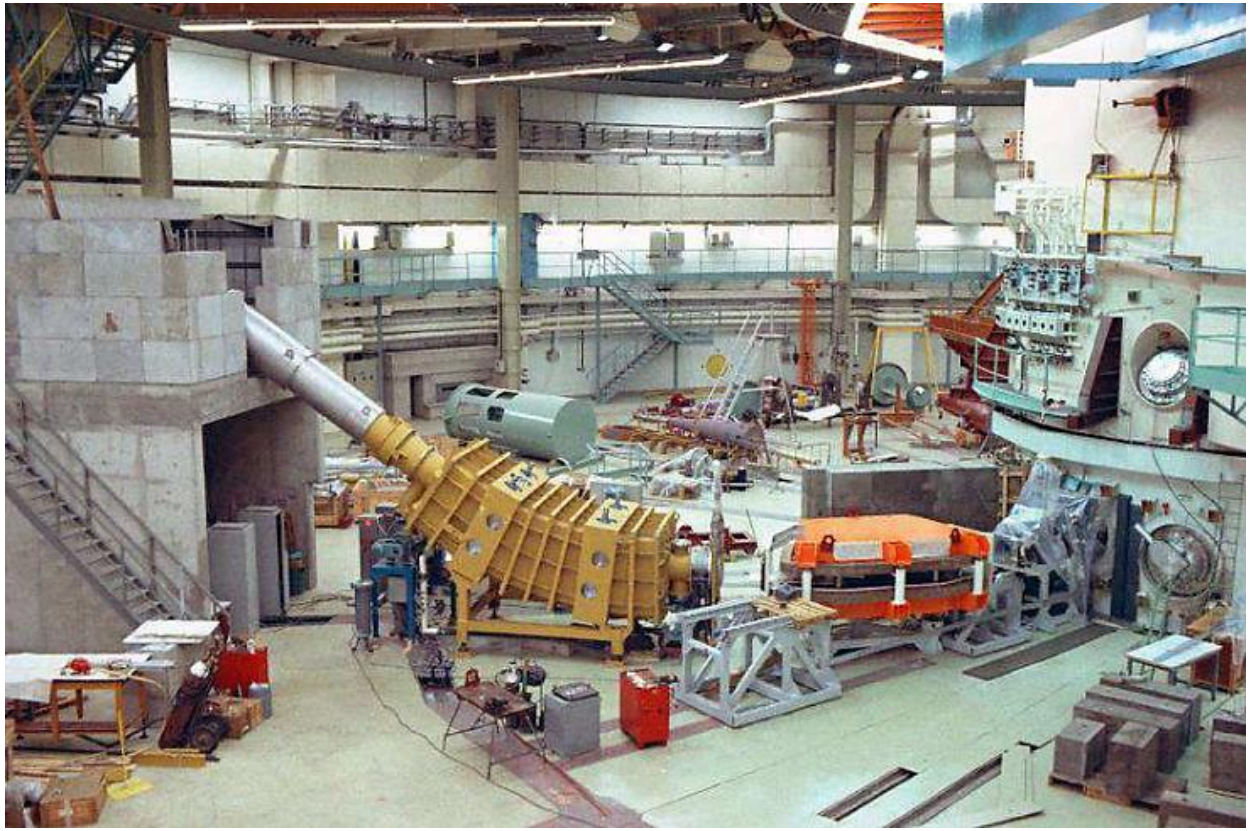
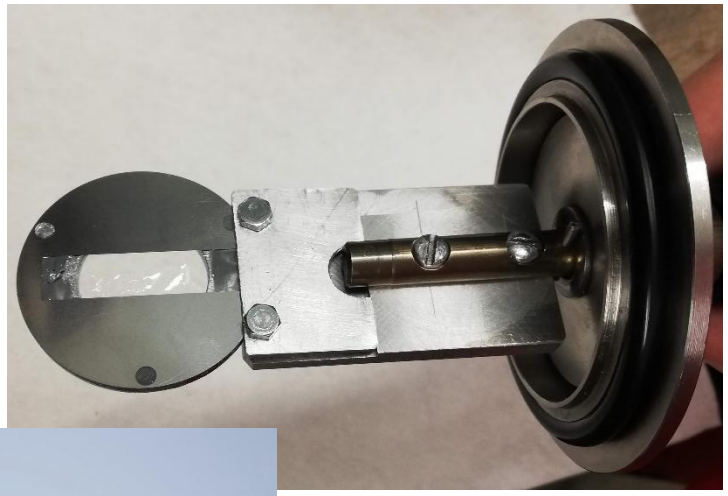
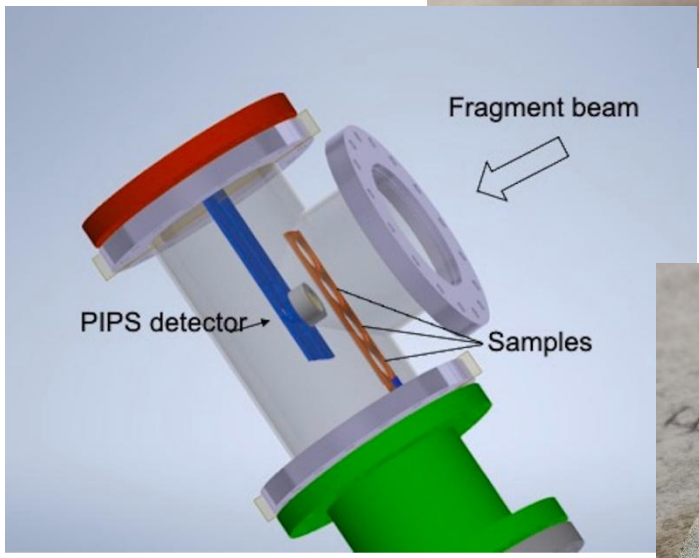
Energy loss of fission fragments

Measurement at the LOHENGRIN spectrometer with 2.5 µm PS foil



LOHENGRIN under construction in the 70s





T. Materna *et al.*, NIM B, **505** (2021) 1-16

Energy loss of fission fragments

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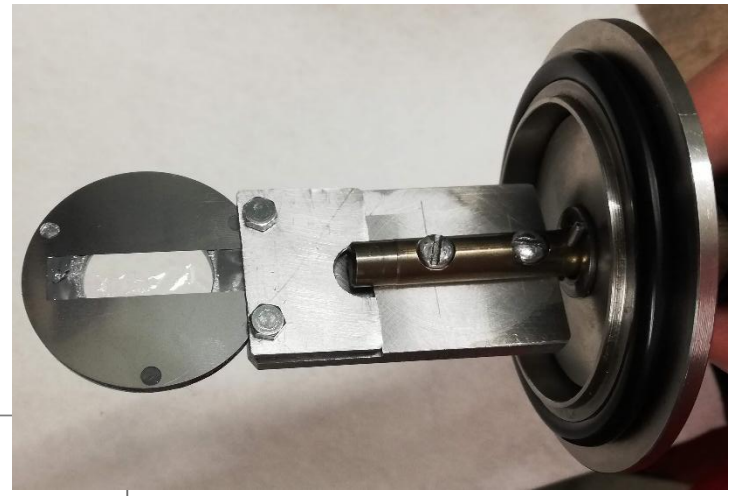
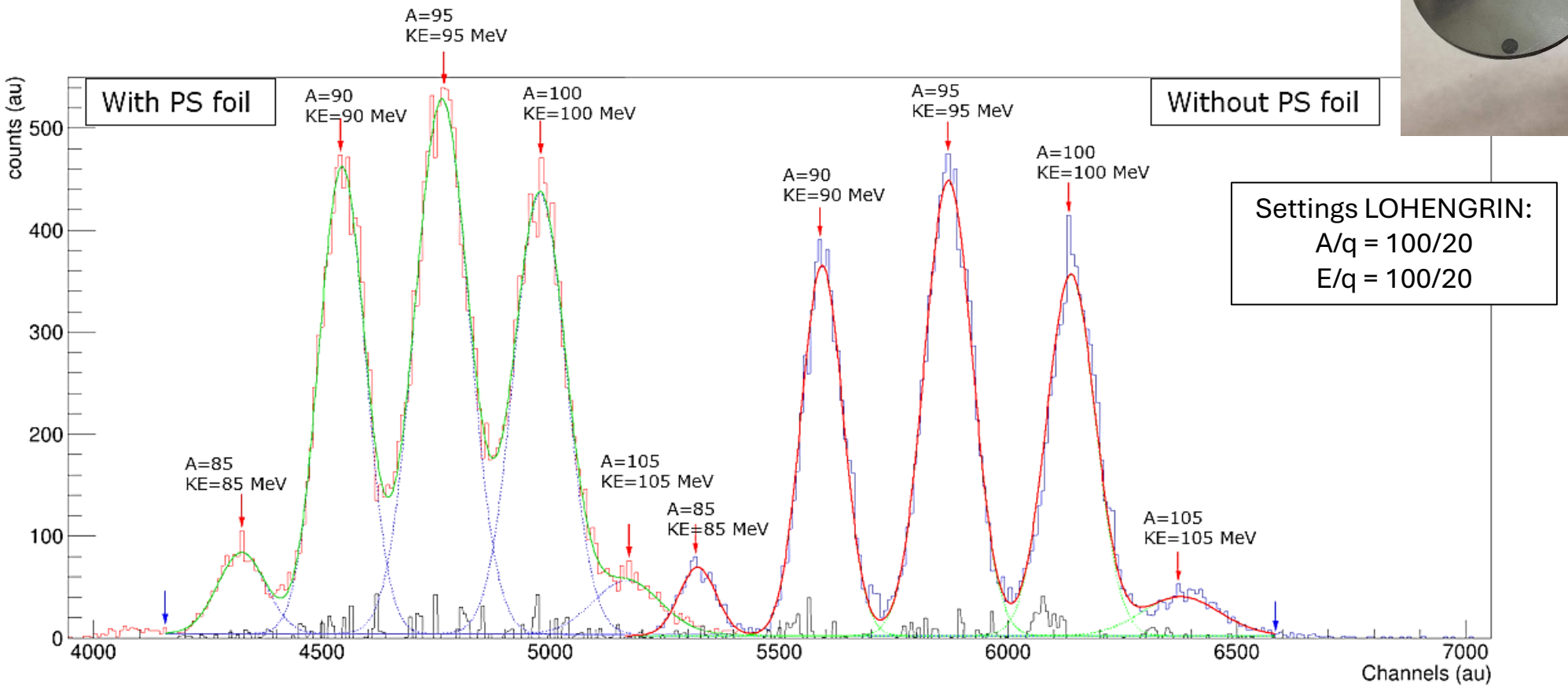




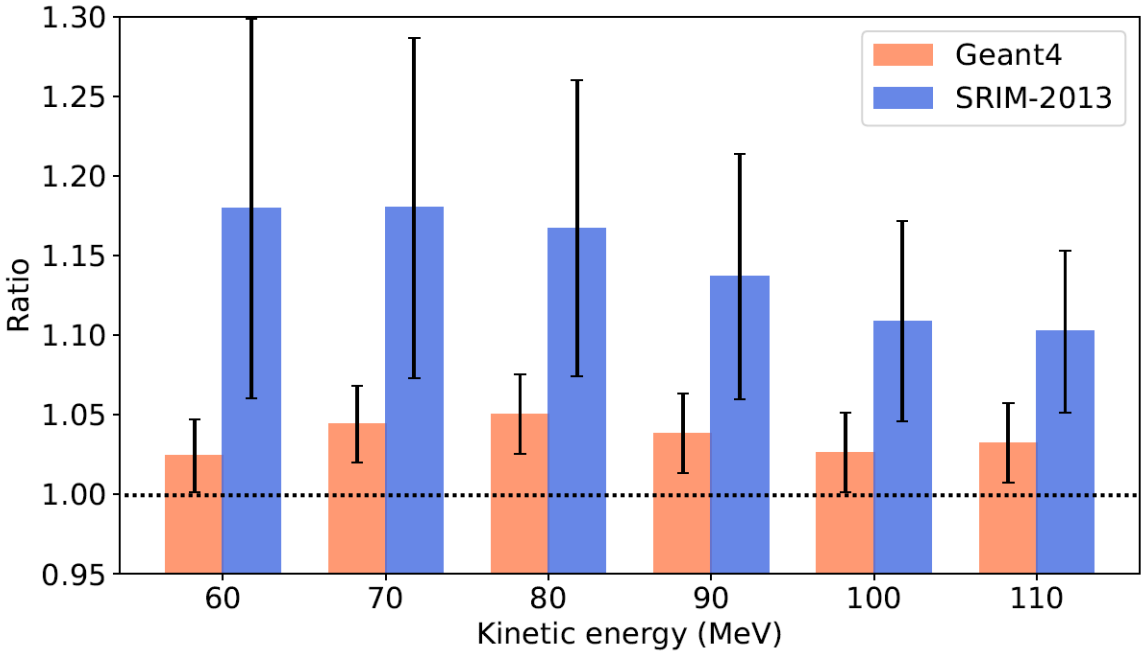
Settings LOHENGRIN:
A/q = 100/20
E/q = 100/20

Energy loss of fission fragments

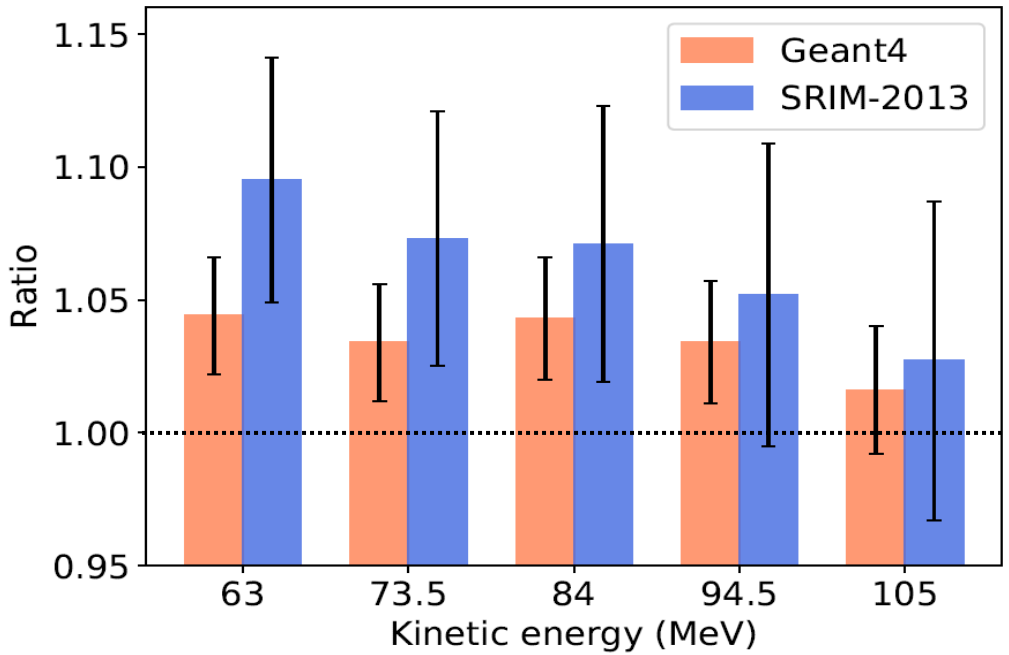
Comparison with Geant4 and SRIM-2013 calculations

→ Add 5% systematic error to the final result

^{100}Zr



^{105}Mo



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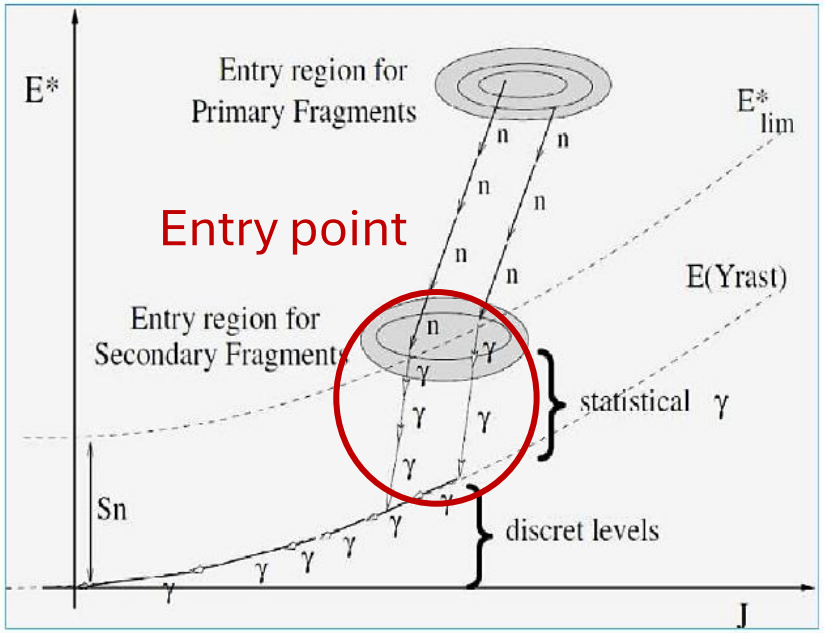
Correlation of excitation and kinetic energies

FIFRELIN simulation code:

- Inputs: mass and K.E. distribution before neutron emission
- Evaluation of the repartition of the energy between the fragments
- Fission fragment database with (A, Z, K.E., E*, J, π)



O. Litaize, O. Serot, and L. Berge,
Eur. Phys. J A (2015) **51**: 177

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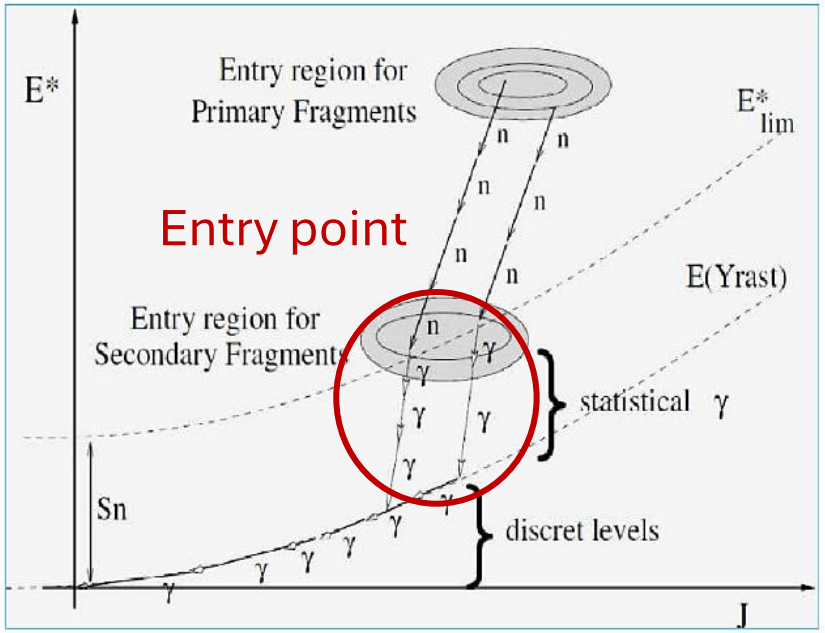

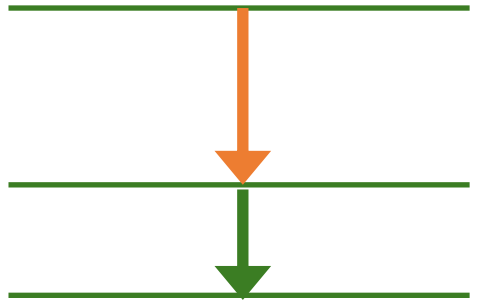

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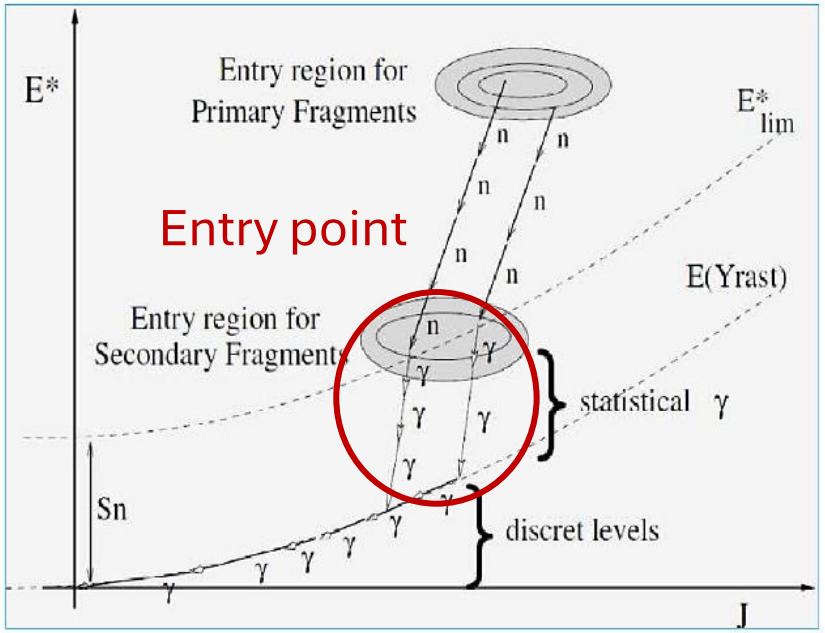

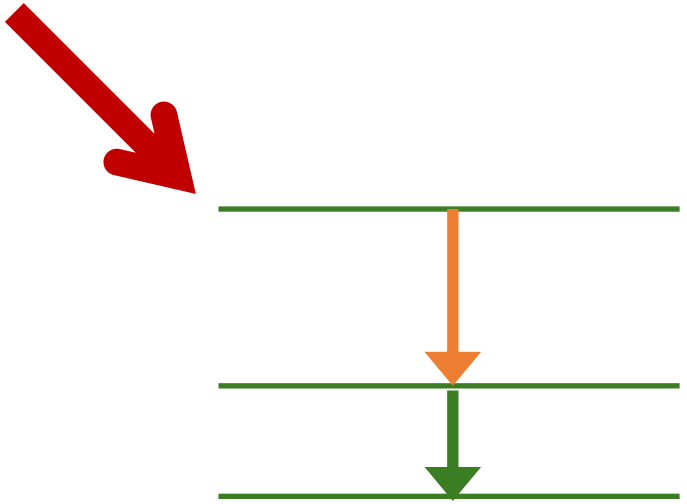

Feeding scenarios:

1. Direct population

O. Litaize, O. Serot, and L. Berge,
Eur. Phys. J A (2015) **51**: 177

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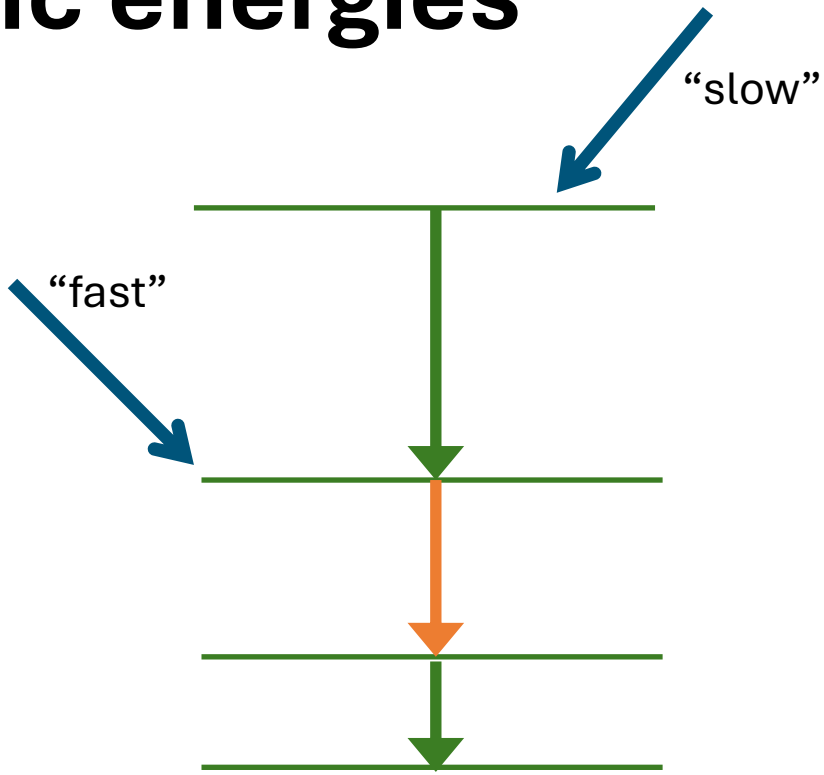

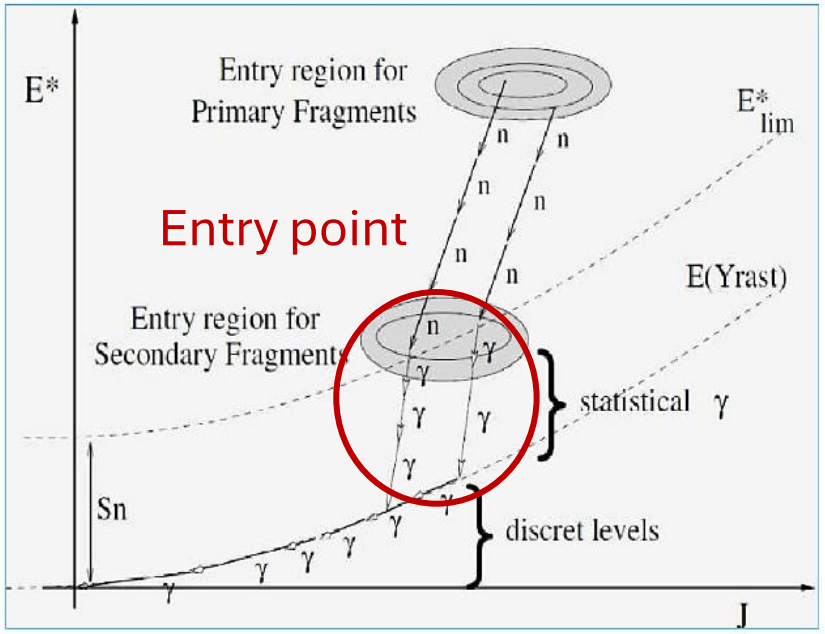

Feeding scenarios:

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2. Mixed population

O. Litaize, O. Serot, and L. Berge,
Eur. Phys. J A (2015) **51**: 177

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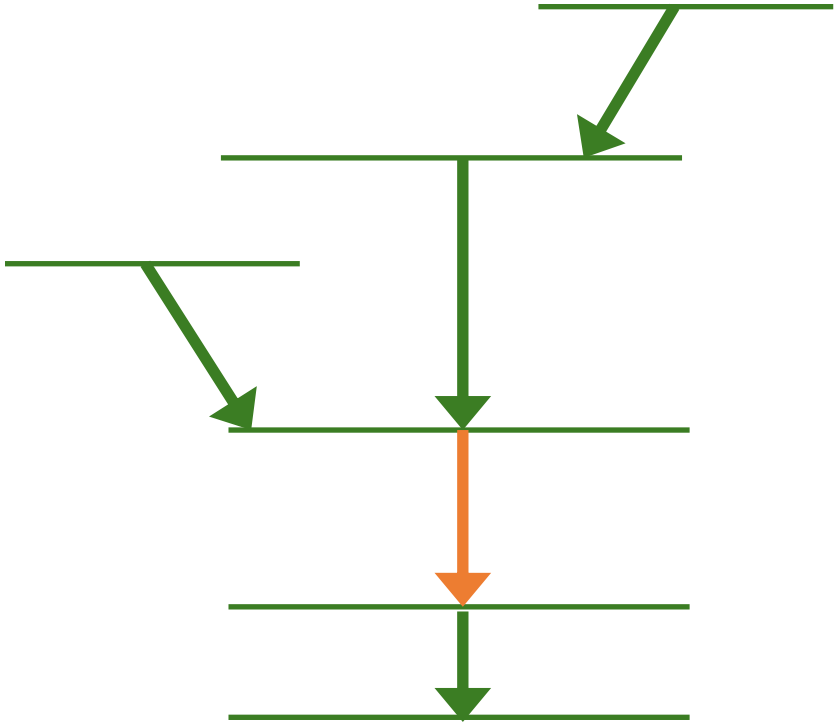
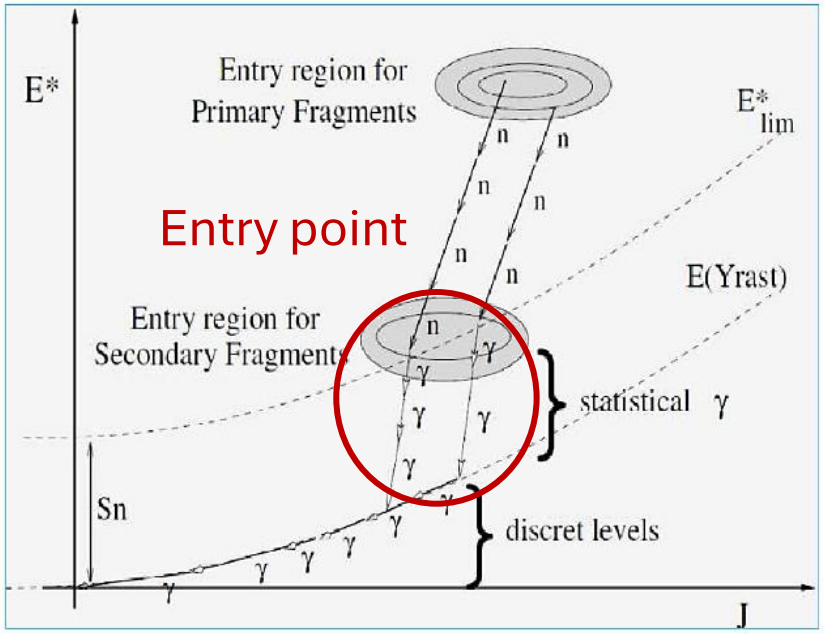




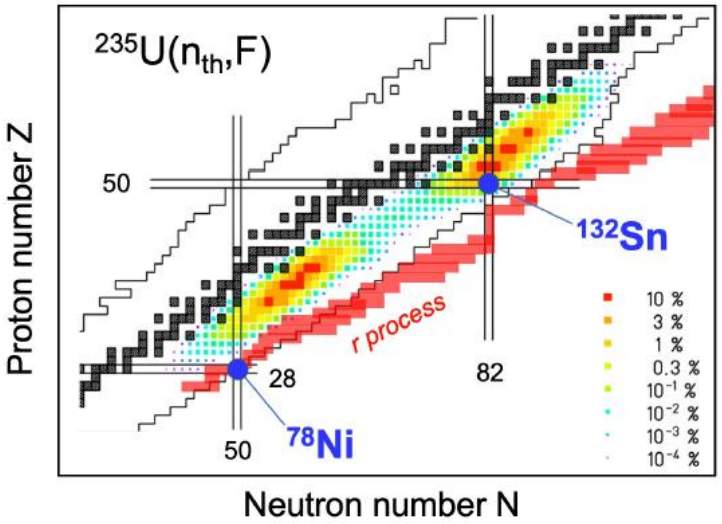
Feeding scenarios:

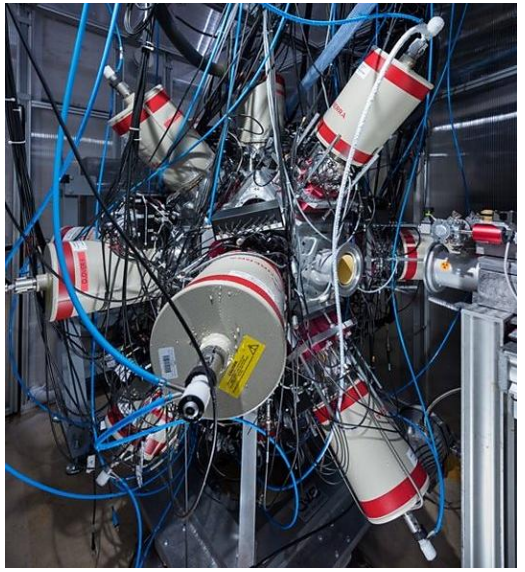
1. Direct population
2. Mixed population
3. FIFRELIN “full”

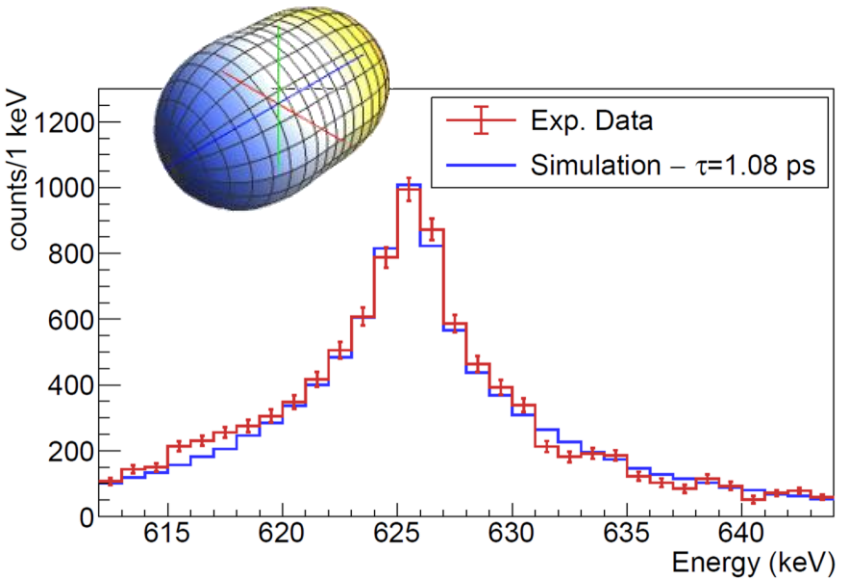
O. Litaize, O. Serot, and L. Berge,
Eur. Phys. J A (2015) **51**: 177

Conclusions

- The evolution of deformation as a function of angular momentum has been investigated in neutron-rich nuclei with A≈100 with gamma-ray spectroscopy techniques
- A novel implementation of Doppler shift lifetime measurement techniques has been developed
  - Realistic distributions of the kinetic and excitation energies of the fission fragments (FIFRELIN) have been used for the first time
- An enhancement of the deformation has been observed at medium-high spins for the first time
- Ongoing Shell Model calculations







Thank you for the attention

C. Michelagnoli, B. Massimino, J. Dudouet, S. Leoni,
J. Ljungvall, O. Serot, F. Nowacki and D. D. Dao