Development of a device for *ps* lifetime measurements at FIPPS phase 2

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Ecole PhyNuBE - 7th December 2021

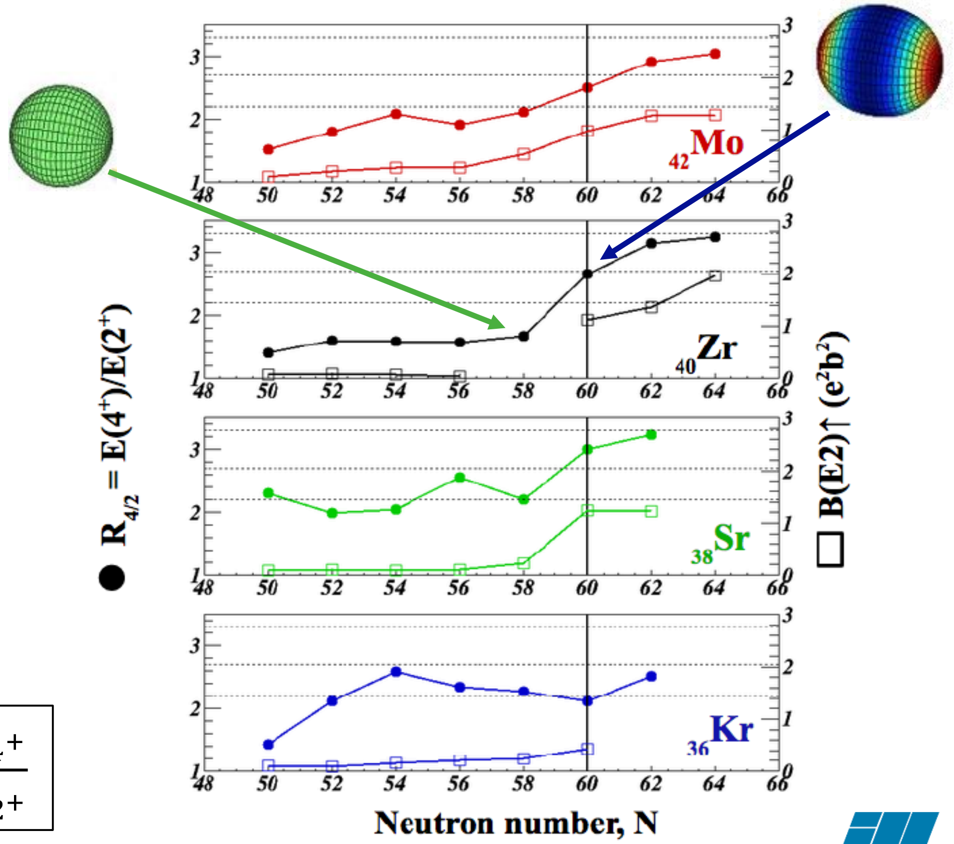
The A~100 island of deformation

- Neutron rich nuclei with A~100 (Z~45, N~60) exhibit drastic shape changes
- First observed for Zr (1970)

- Lifetimes measurements give access to the transition strengths which are needed to test and constrain theoretical models

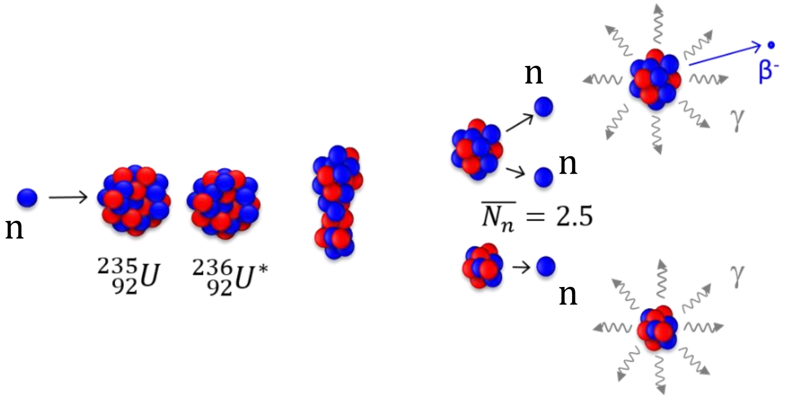
$$B(E2) = \frac{0.081642\ B_i}{\tau[ps]\ (E_\gamma[MeV])^5\ (1+\alpha)}$$

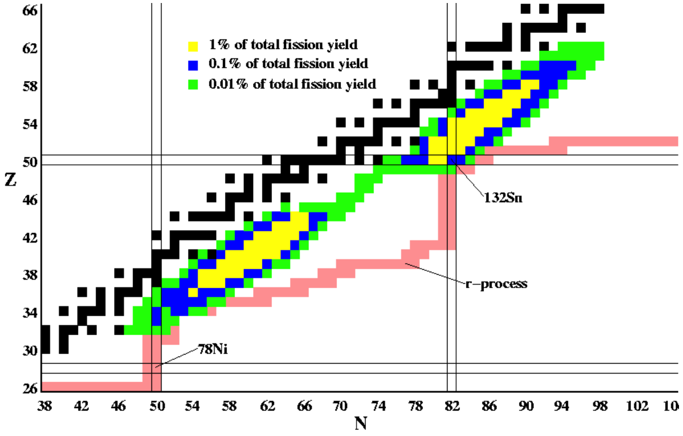
$$R_{4/2} = \frac{E_{4^+}}{E_{2^+}}$$



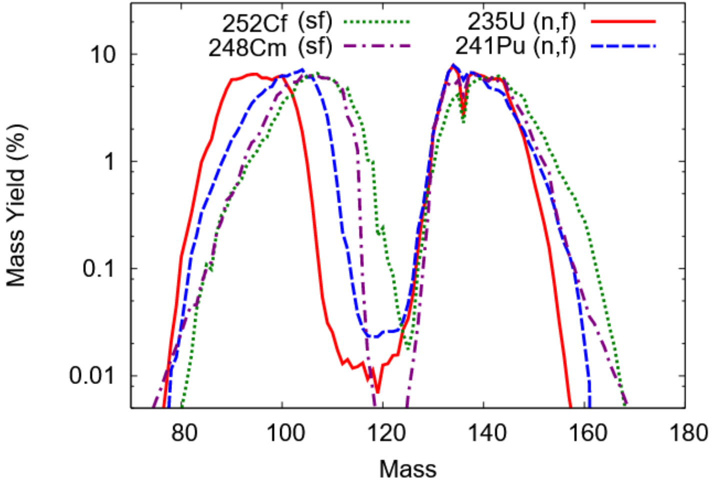
J. Dudouet *et al.*,
PRL 118 (2017) 162501

Production of neutron-rich nuclei via fission





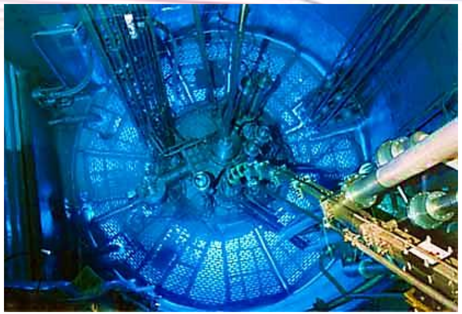
Mass region A~100 strongly populated via nuclear fission reactions



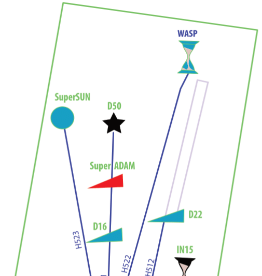
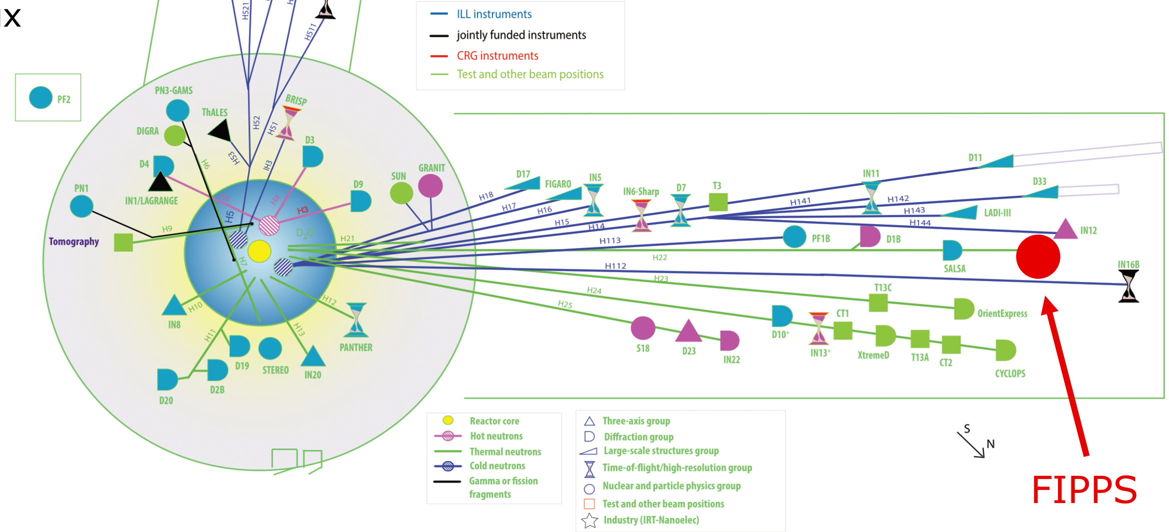
M. Jentschel *et al.*,
2017 JINST 12 P11003

Institut Laue-Langevin (ILL)

Grenoble, France



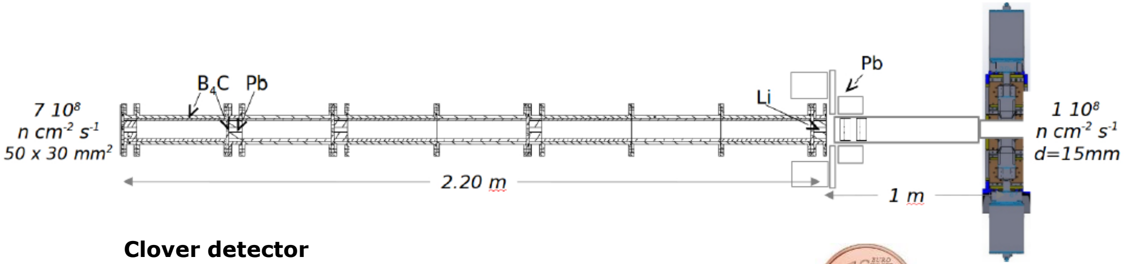
- European research facility specialised in neutron science
- Nuclear reactor with 58.3 MW thermal power
- Most intense continuous neutron flux in the world – 1.5×10^{15} n s^{-1} cm^{-2}

The FIPPS instrument at ILL

FIssion Product Prompt gamma-ray Spectrometer

- 8 Compton suppressed HPGe clover detectors
- Pencil-like (d=15mm) thermal neutron beam, with a flux of 10^8 n s^{-1} cm^{-2} at target position
- Possibility to add ancillary devices ($LaBr_3$, HPGe clovers...)
- (n,γ) and (n,F) reactions on stable and radioactive targets



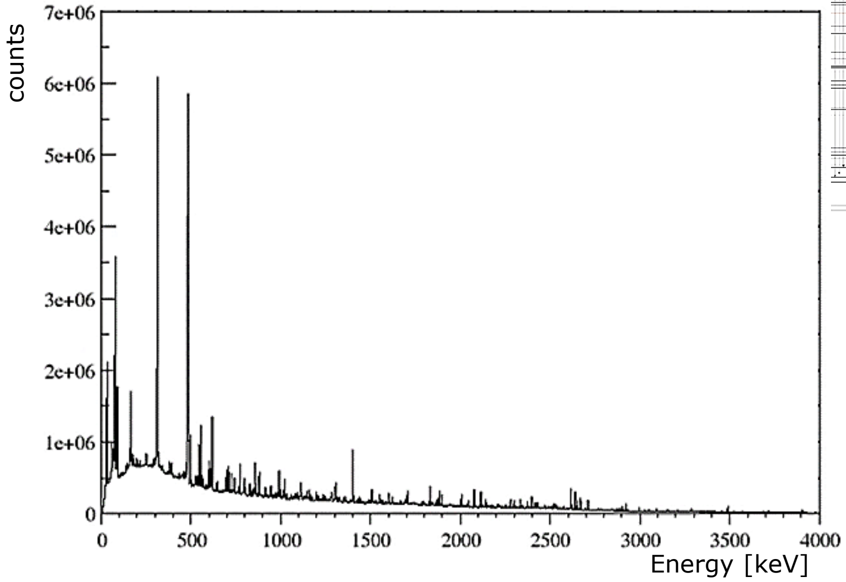
Clover detector

C. Michelagnoli *et al.*,
EPJ Web Conf., 193 (2018) 04009

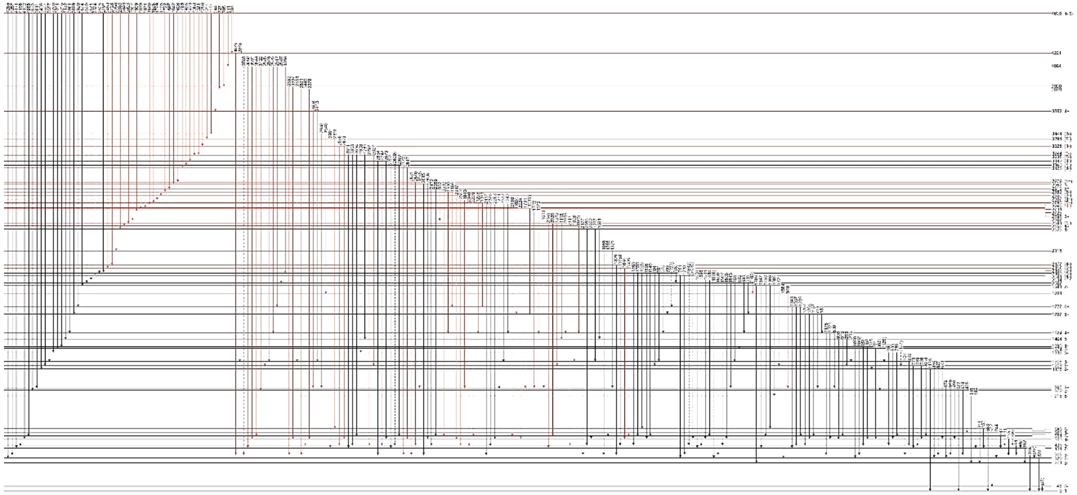
Complex level scheme

High energy resolution and efficiency are essential

What we measure

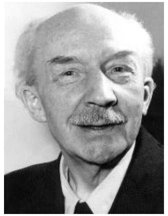


What we want to know

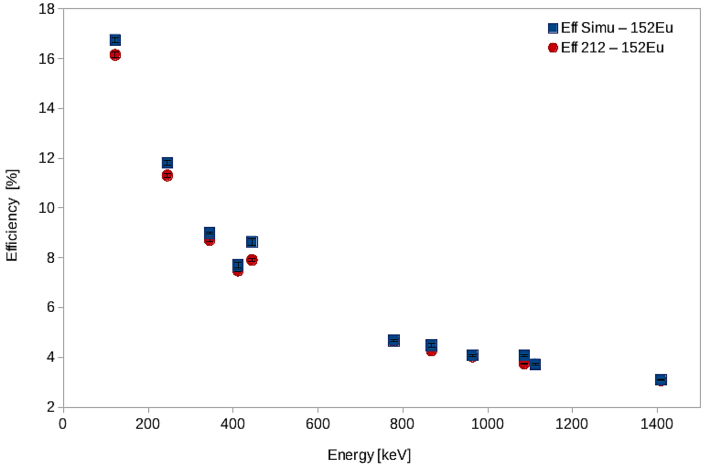


^{210}Bi level scheme

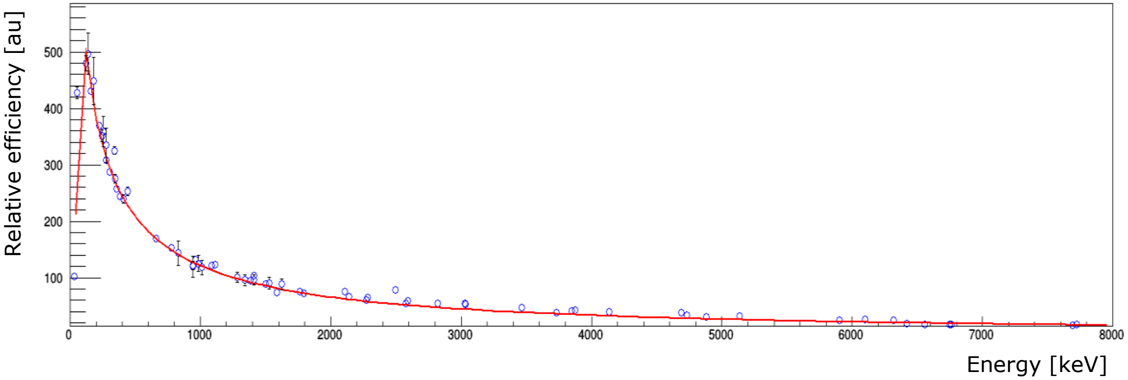
Coincidence method
Walter Bothe
Nobel prize 1954

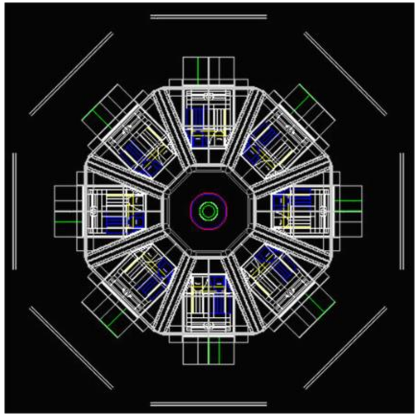


Geant4 Monte Carlo simulations and FIPPS efficiency



- Geant4 simulations to reproduce experimental campaigns and study the feasibility of future experiments
- Validated with the ^{152}Eu efficiency curve
- Efficiency curve up to 8 MeV thanks to (n,γ) reactions

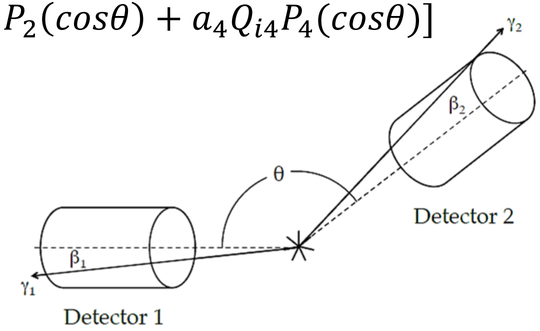


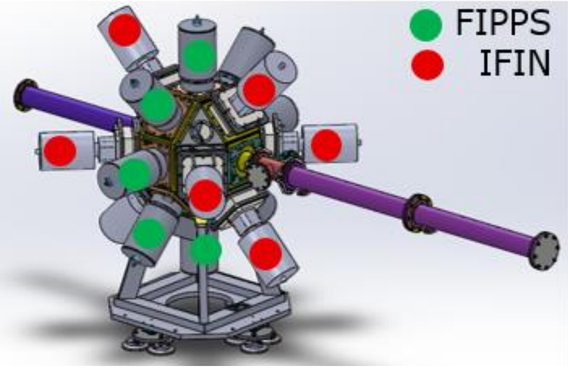


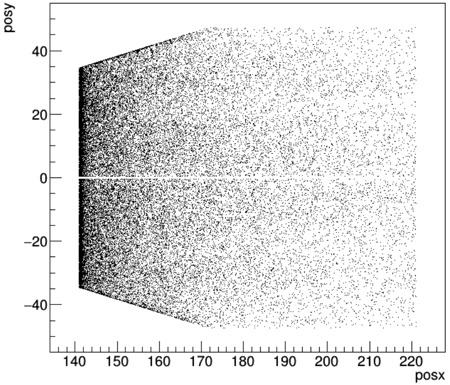
Angular correlation measurements at FIPPS+IFIN array

γ-γ angular correlations in a γ-ray cascade: evaluation of the coincidence intensity variation as a function of the detection angle

$$W(\theta) = A_0[1 + a_2 Q_{i2} P_2(cos\theta) + a_4 Q_{i4} P_4(cos\theta)]$$







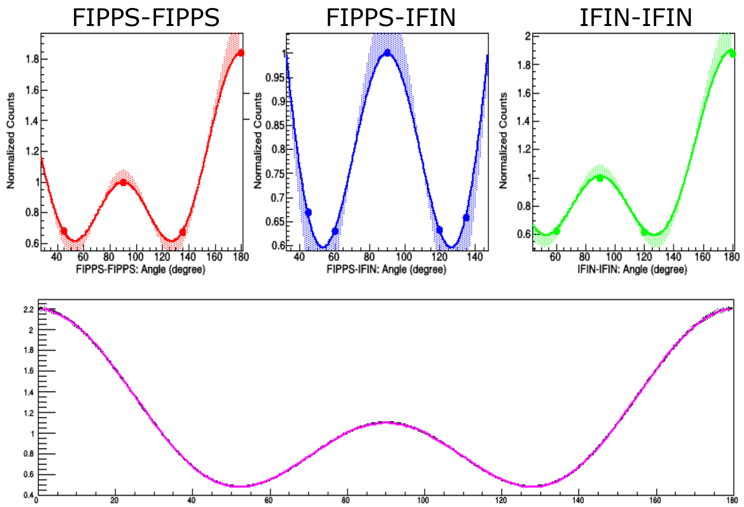
Determination of the average interaction point in a clover detector with a ^{152}Eu Geant4 simulation

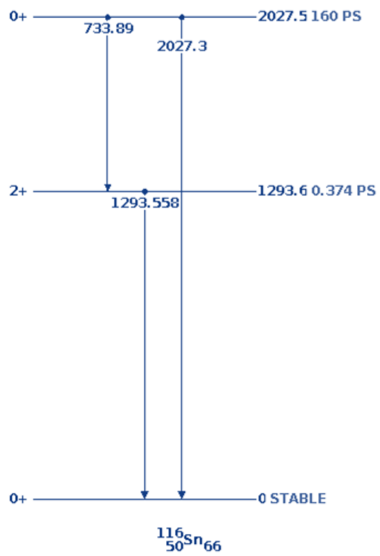
G. Colombi *et al.*,
Paper in preparation

Angular correlation measurements at FIPPS+IFIN array

Geometrical correction factors (Q_i) found thanks to Geant4 Monte Carlo simulations and compared with experimental ones

$$W(\theta) = A_0[1 + a_2 Q_{i2} P_2(cos\theta) + a_4 Q_{i4} P_4(cos\theta)]$$



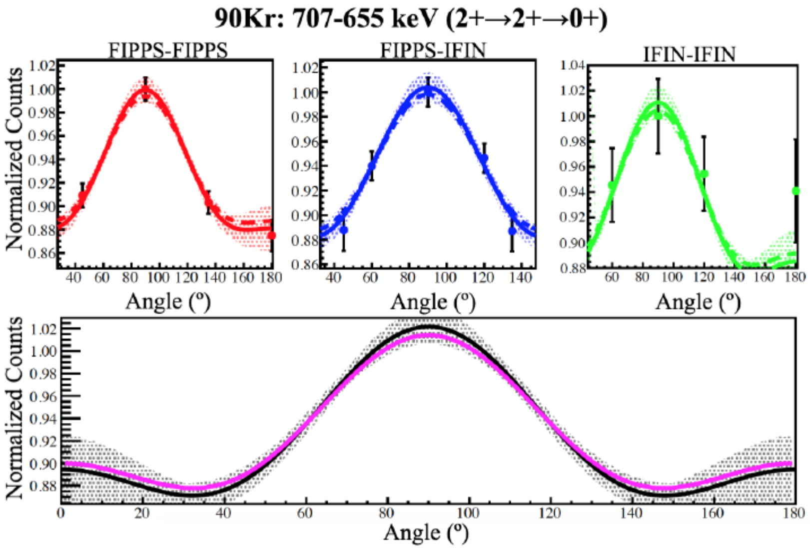


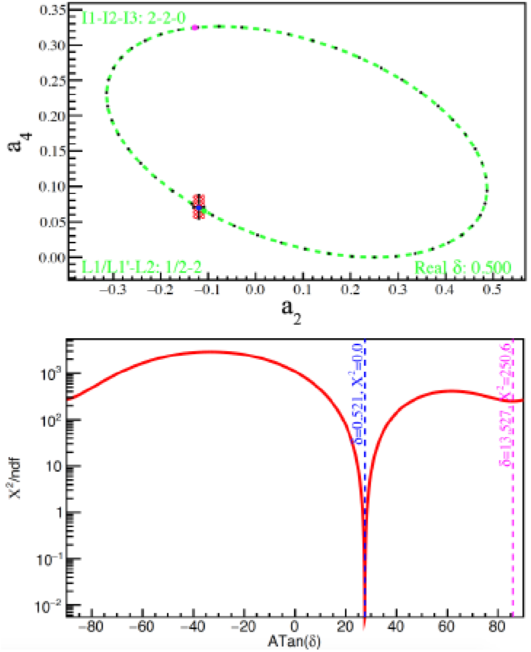
	Q_2 F-F	Q_4 F-F	Q_2 F-I	Q_4 F-I	Q_2 I-I	Q_4 I-I
Exp. data	0.856(12)	0.68(3)	0.89(2)	0.66(4)	0.84(3)	0.75(8)
Simulations	0.883(8)	0.677(4)	0.91(2)	0.725(6)	0.96(3)	0.724(12)

G. Colombi *et al.*,
Paper in preparation

Angular correlation measurements at FIPPS+IFIN array

Application of the method to analyze the neutron induced fission data from the ^{235}U *active target* campaign





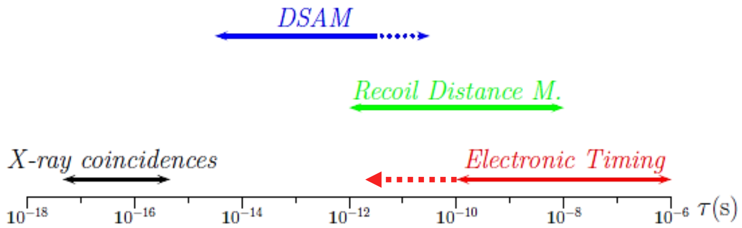
D. Reygadas, PhD Thesis,
Univ. Grenoble Alpes, 2021

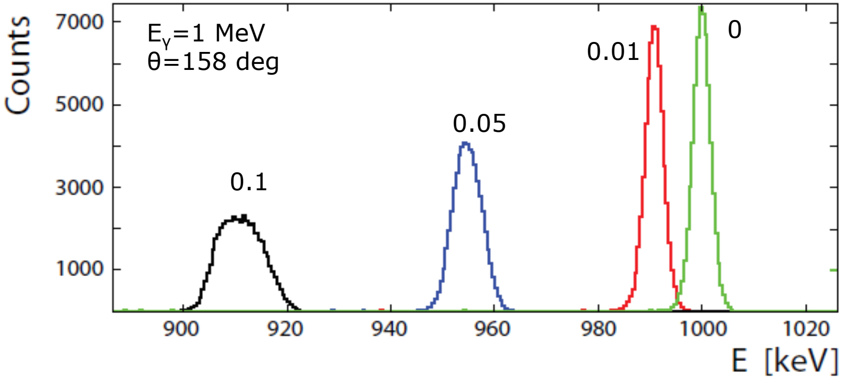
Lifetime measurements at FIPPS

- The measurement of the lifetime allows the determination of the transition strength, sensitive on the details of nuclear wave functions

- The timescale of interest defines the measurement method

$$B(E2) = \frac{0.081642\ B_i}{\tau[ps]\ (E_\gamma[MeV])^5\ (1+\alpha)}$$

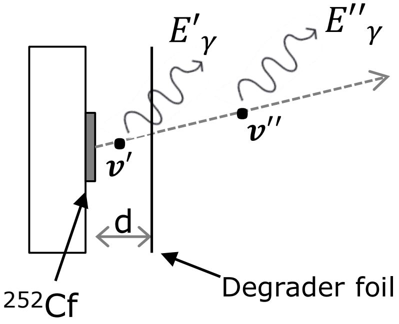


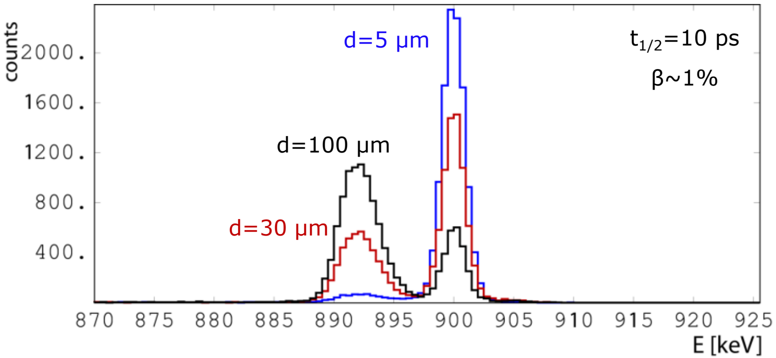


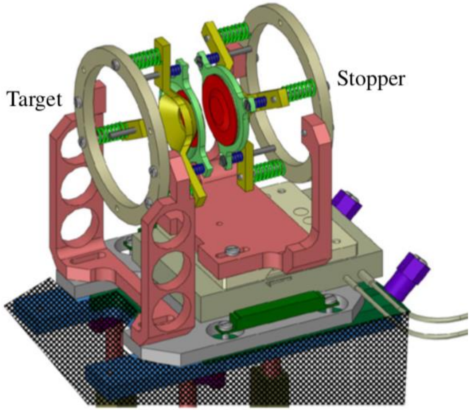
Doppler Relation:

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

The *plunger* device



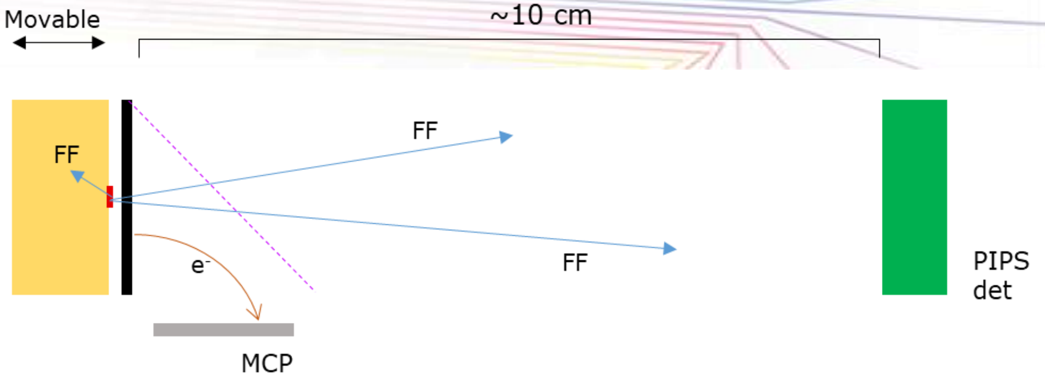




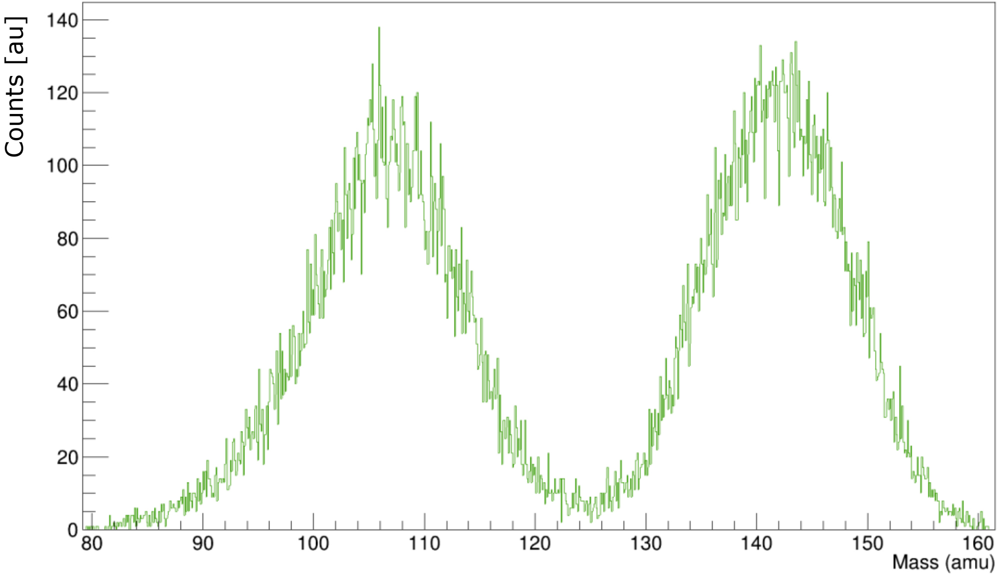
J. Ljungvall *et al.*,
NIMA 679 (2012) 61

- The intensities of the two peaks in the gamma spectrum change as a function of the target-to-degrader distance
- Ongoing development of the **first** prototype of plunger device to be used at a neutron beam in n-induced fission reaction

The *plunger* device at a neutron beam



Reconstructed fission fragments mass distribution from simulated ^{252}Cf source



Design and simulation of the fission fragment detection system which allows to have a mass resolution of 3-5 amu

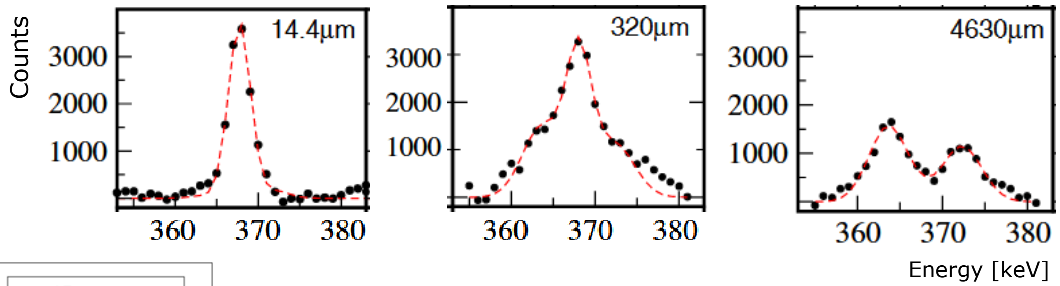
→ Study of already existing fission fragment spectrometers (VERDI, FALSTAFF, SPIDER…)

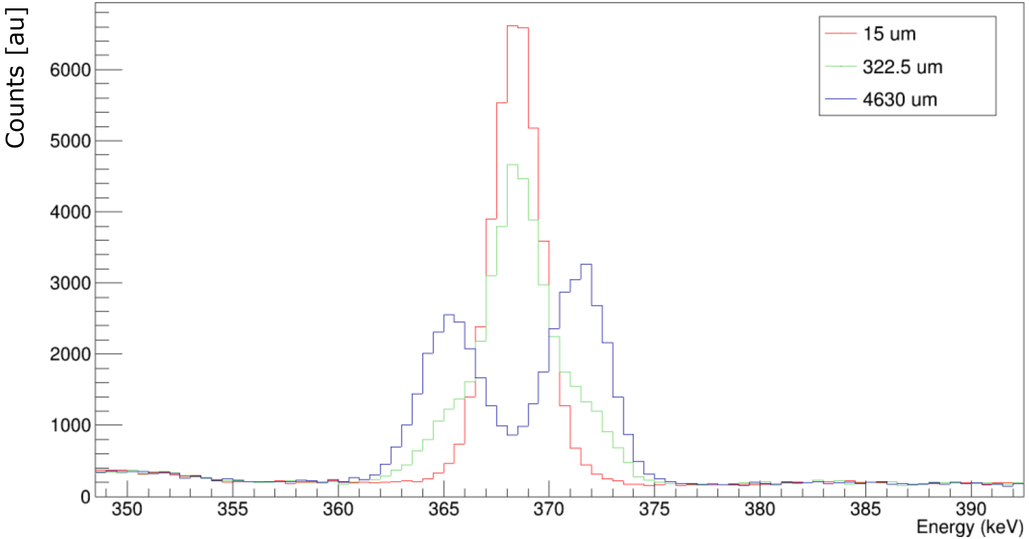
The *plunger* device at a neutron beam

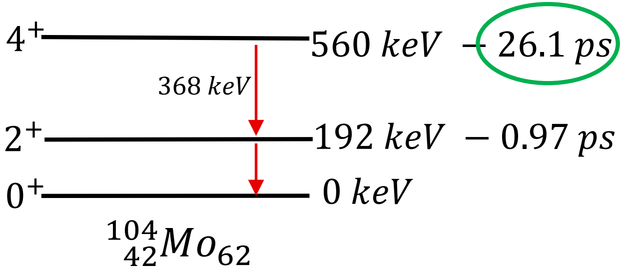
A.G. Smith *et al.* 2002,
J. Phys. G: Nucl. Part. Phys. 28 2307

Simulation of ^{104}Mo de-excitation in flight with a degrader foil at 15, 322.5 and 4630 μm

→ Doppler corrected spectra in forward and backward detectors





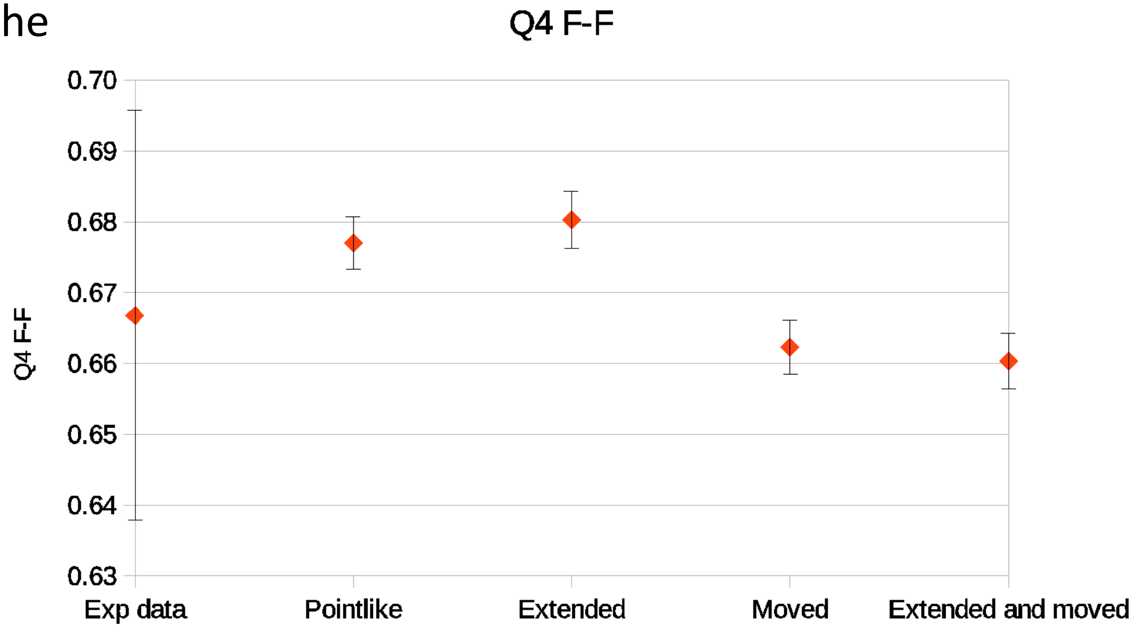


Conclusions and perspectives

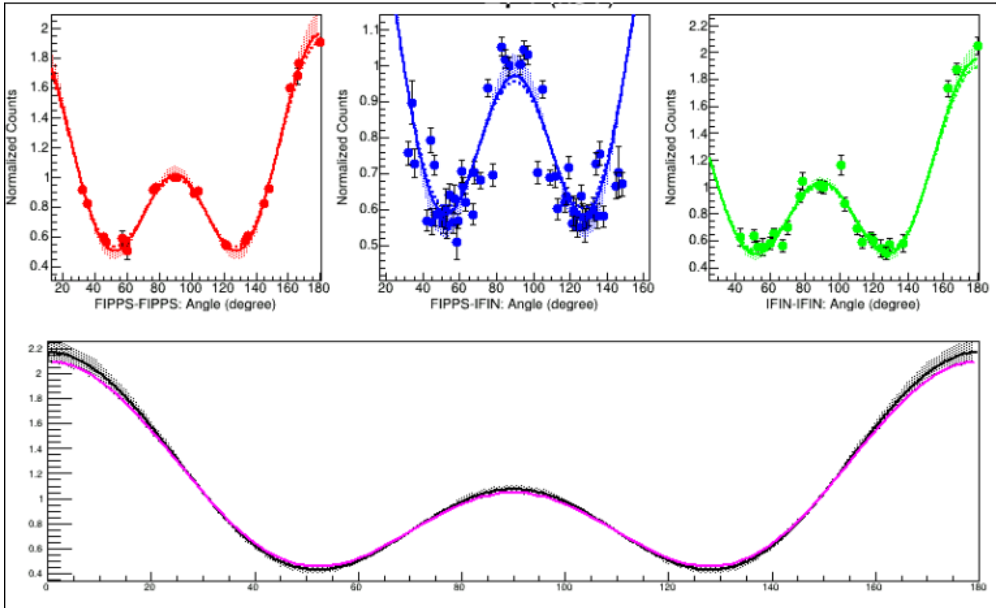
- The FIPPS gamma-ray spectrometer at ILL has been introduced, used for high-resolution spectroscopy after neutron induced reactions
- Different FIPPS setups can be described by Geant4 simulations (code developed during my 1st year of PhD)
- My PhD work focuses on the measurement of ps nuclear level lifetimes using the recoil distance Doppler shift technique with the plunger device → first application at a neutron beam
- I am presently designing a plunger setup to be used with a ^{252}Cf spontaneous fission source to explore the A=100-110 nuclear region
- The commissioning and following experiments are foreseen for the end of 2022 (soon a call for Letters of Intent will be sent out)


Thank you for listening!

Variation of Q_4 geometrical correction factor changing the dimensions and position of the source in the simulation



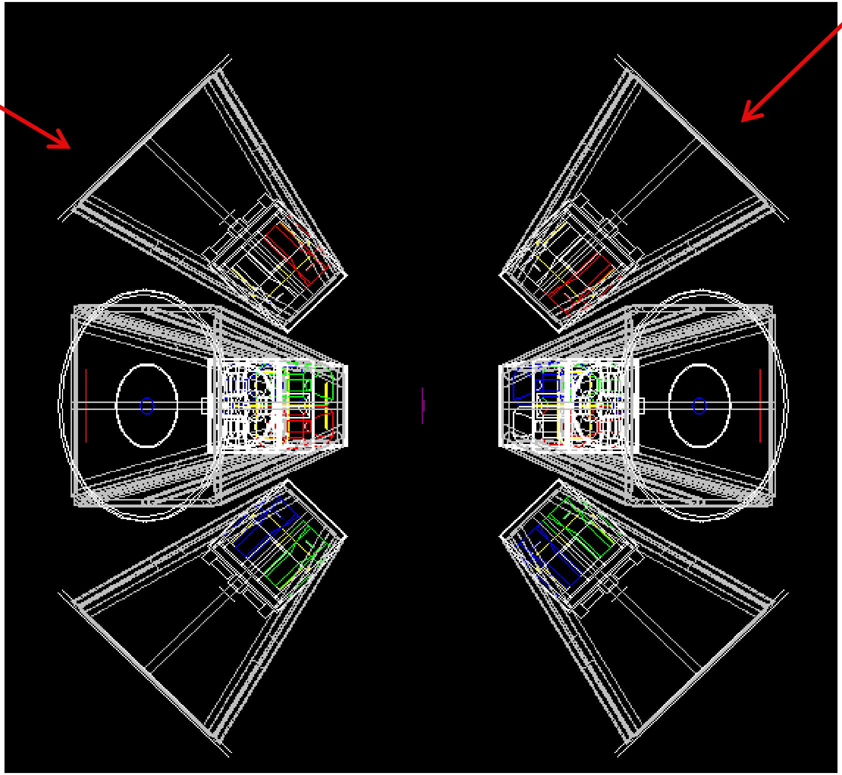
Angular correlation done with the crystal position instead of the clover position



IFIN backwards
[angles 120-150 deg]

FIPPS ring (not plotted)
[angles 75-105 deg]

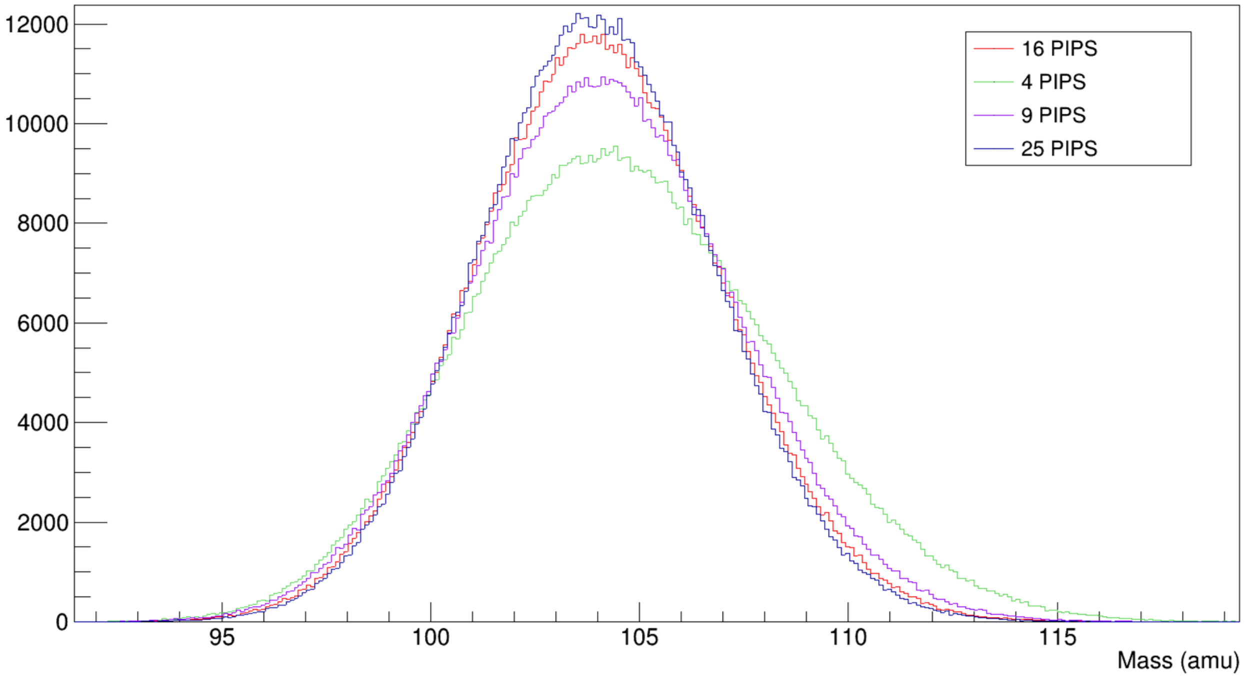
IFIN forwards
[angles 30-60 deg]



Fission fragments direction

Reconstructed mass distribution of simulated ^{104}Mo fission fragments

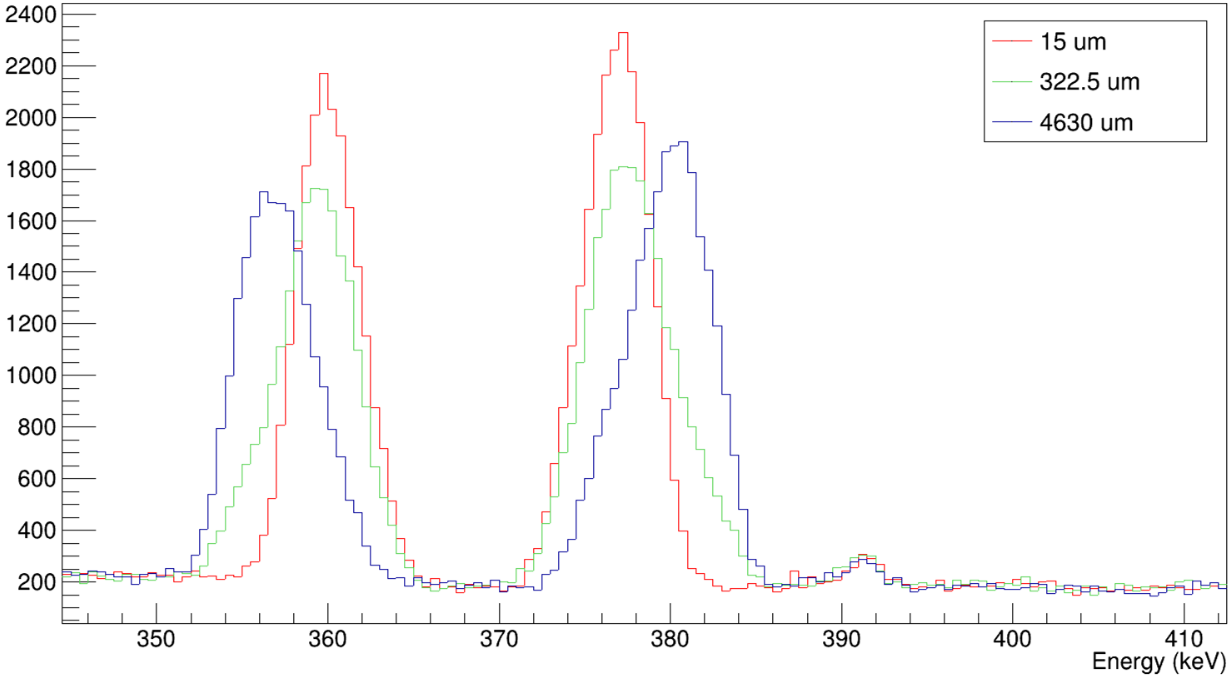
→ Division of the PIPS detector in segments to see the granularity needed



NEUTRONS FOR SOCIETY

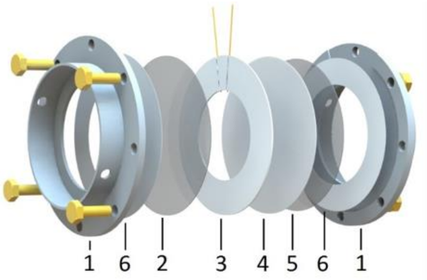
Simulation of ^{104}Mo de-excitation in flight with a degrader foil at 15, 322.5 and 4630 µm

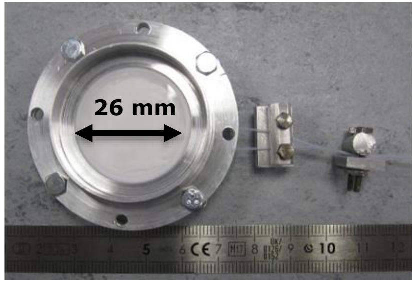
→ Not Doppler corrected spectra in forward and backward detectors

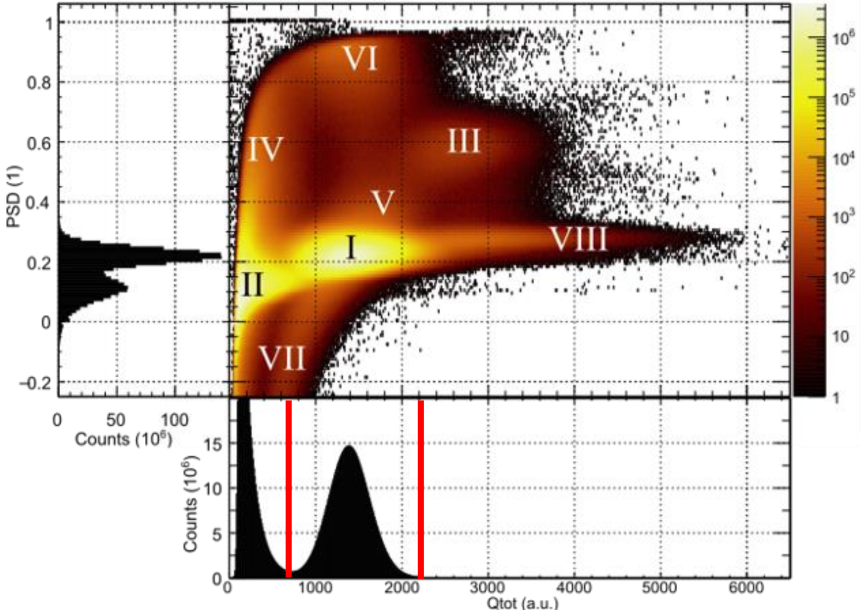


Active target

- Suppress γ-ray induced β background
- Actinide material dissolved in liquid scintillator
- Campaign at FIPPS in 2018
- 97.8(25)% fission tagging efficiency





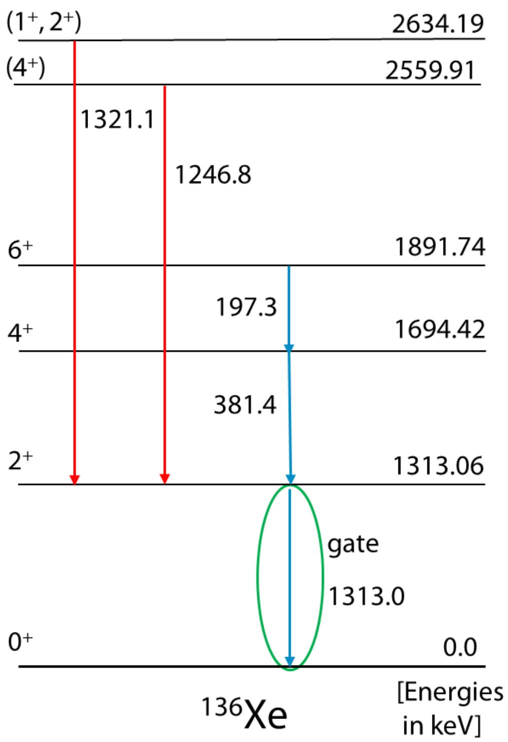


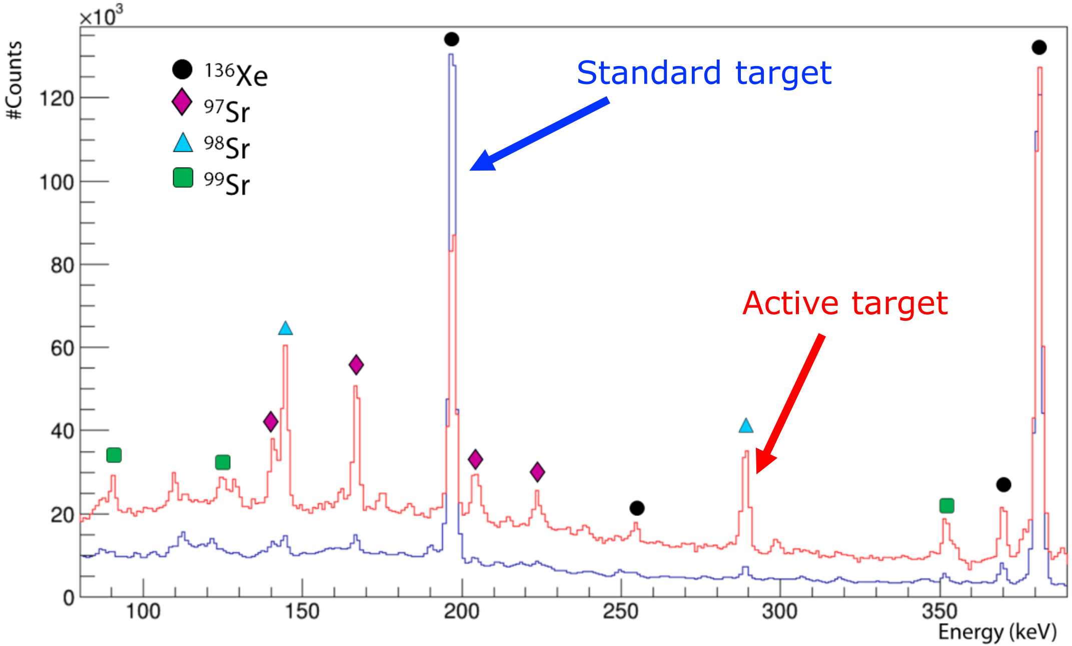
1 - Aluminium frame
2&5 - Sapphire windows (0.2 mm)
3 - Teflon spacer (0.5 mm) with capillaries
4 - Teflon backing with reflective foil
6 - Teflon washer

I – Fission events, II – Electron events

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

Active target

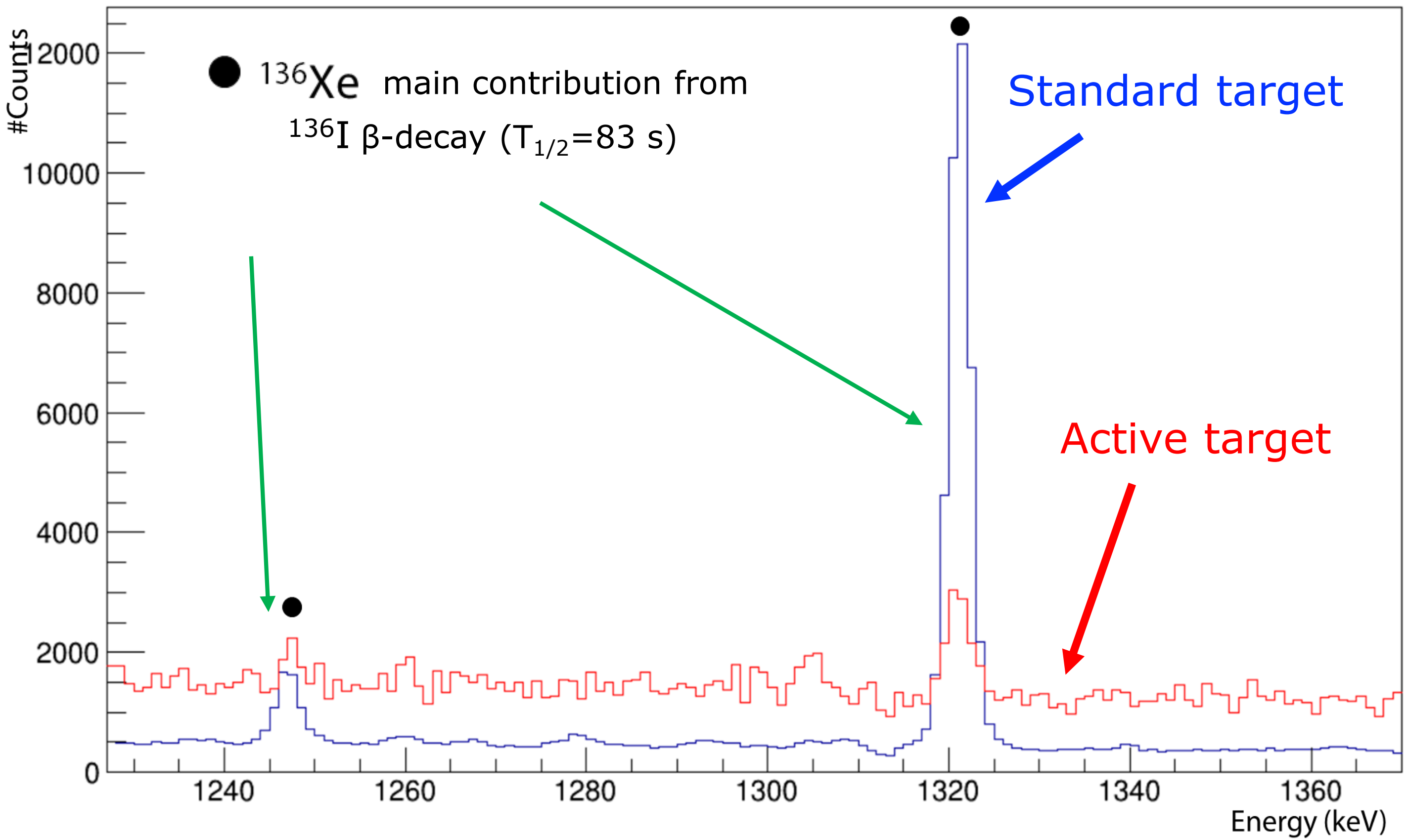




Gate 1313 keV transition ($2^+ \rightarrow 0^+$) in ^{136}Xe

Fission partners: ^{97}Sr, ^{98}Sr and ^{99}Sr

Active target



SOURCE

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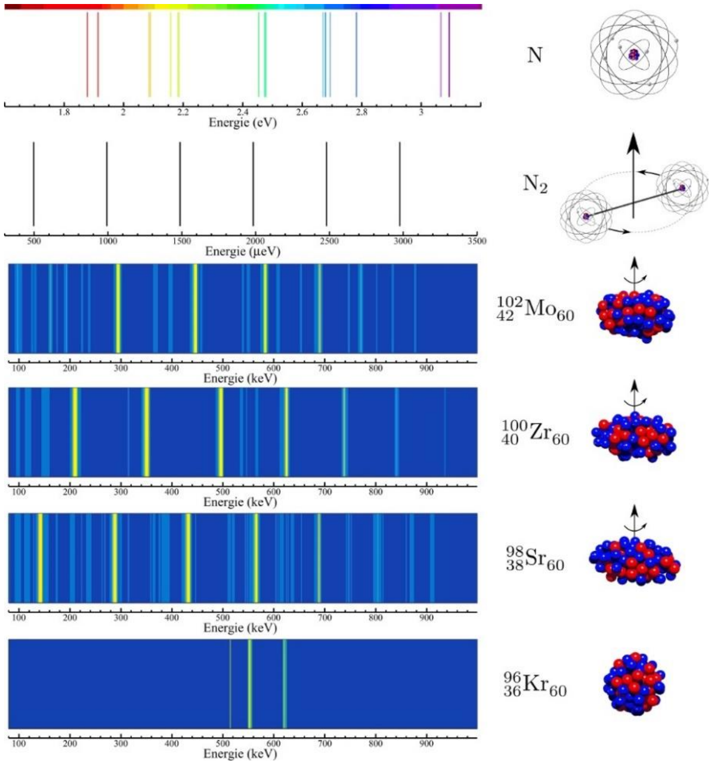
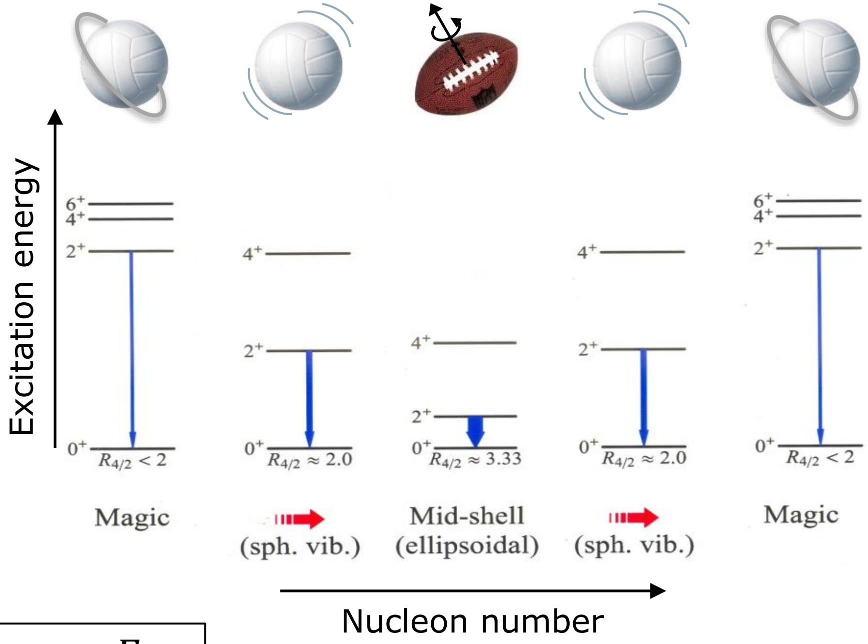
Collective excitations and nuclear shapes



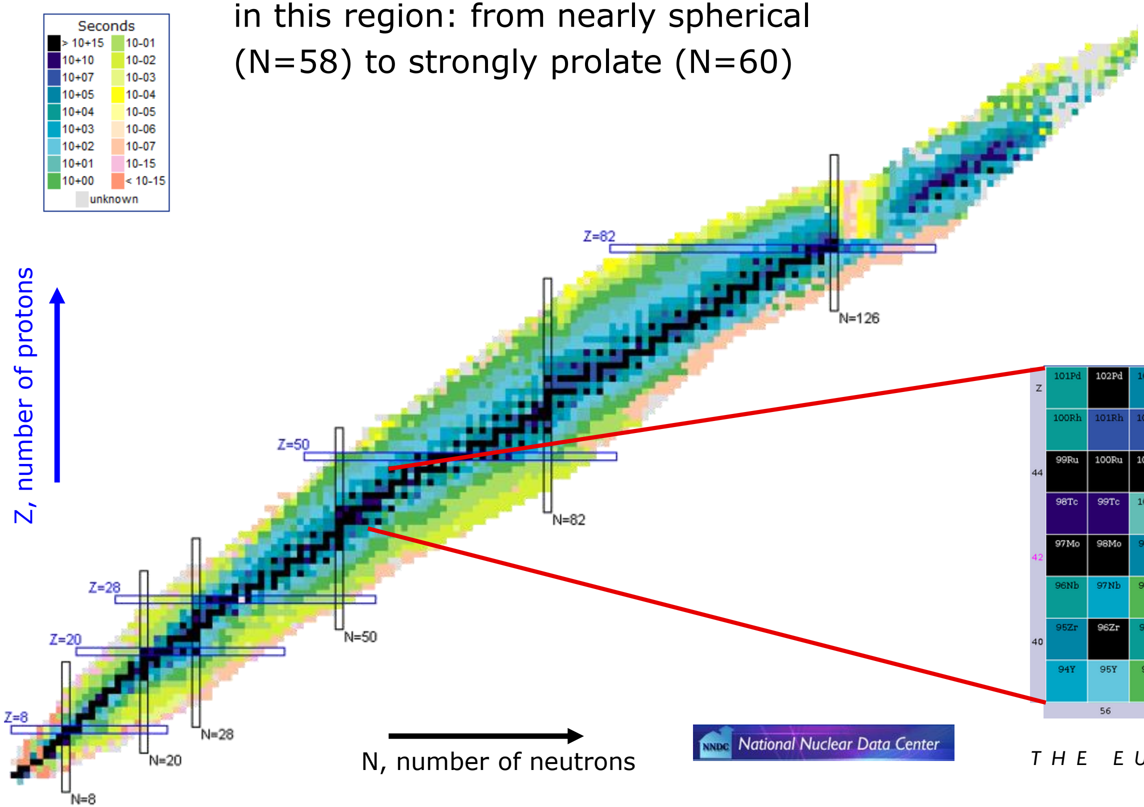


$$R_{4/2} = \frac{E_{4^+}}{E_{2^+}}$$

J. Dudouet *et al.*,
PRL 118 (2017) 162501

Shape changes in nuclei with A=100-110

Evidence of drastic shape transitions in this region: from nearly spherical (N=58) to strongly prolate (N=60)



National Nuclear Data Center