NEUTRONS FOR SOCIETY

Probing nuclear structure with slow neutrons at ILL

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Caterina Michelagnoli | 5 July 2023

Institut Laue-Langevin

Outline

NEUTRONS FOR SOCIETY

Thermal neutrons: how and why?

An introduction to a *complementary* probe for nuclear structure, astrophysics and fission

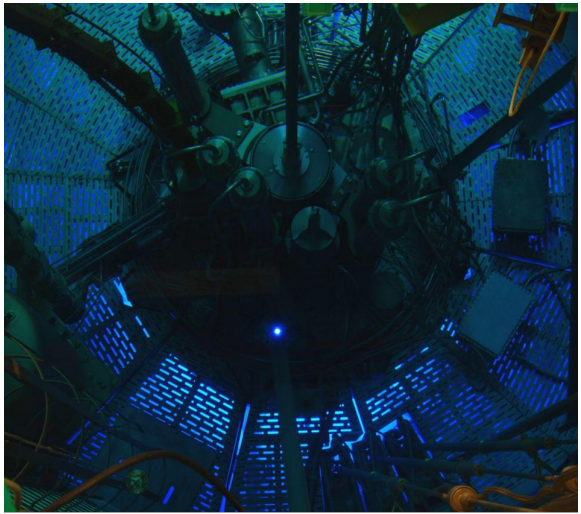
High resolution γ-ray spectroscopy after thermal neutron induced reactions

(n,fission) using a *fission tag* -systematic investigations in neutron-rich nuclei

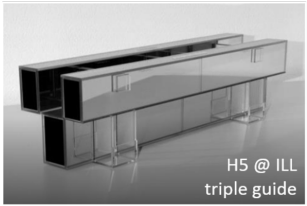
Concluding remarks and future possibilities

“The future” for high-resolution prompt γ spectroscopy after thermal neutron induced fission

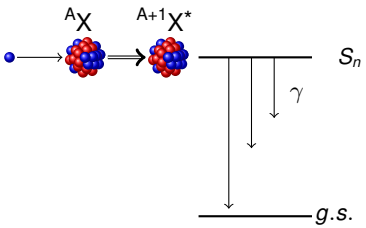
World's highest neutron flux for in-beam experiments



- ✓ up to 1.5 10^{15} n/s/cm^2
- ✓ in-pile irradiation of radioisotopes
- ✓ "slow" neutrons delivered to $\approx$ 40 instruments
- ✓ guided with little losses over hundreds of meters

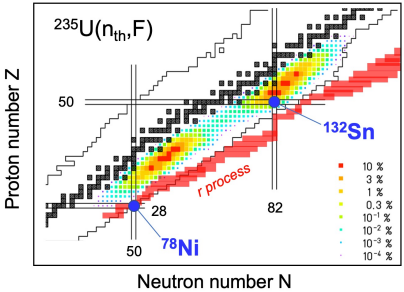


Neutron-induced reactions



Thermal neutron capture reactions

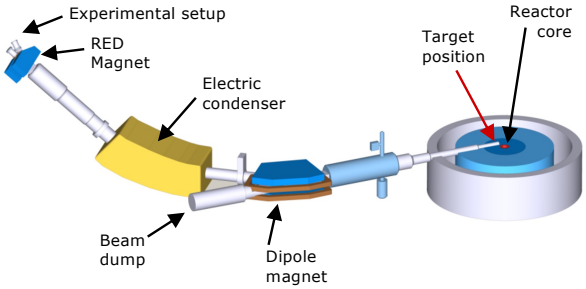
- Structure of nuclei close to stability
- Structure at low spin (below S_n)
- Cross-sections (applications)
- ^{27}Al(n,γ): σ=0.2 b; ^{157}Gd: 2.5 10^5b

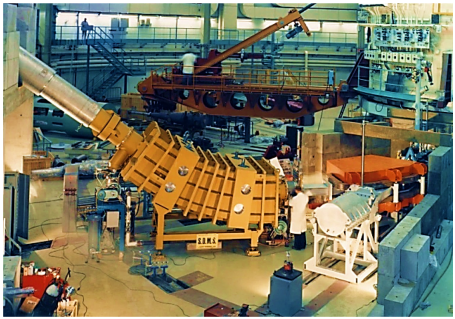


Neutron-induced fission

- Structure of n-rich nuclei (far from stability)
- Fission yields and dynamics
- ^{235}U: σ_f=585 b; ^{245}Cm: σ_f=2141 b

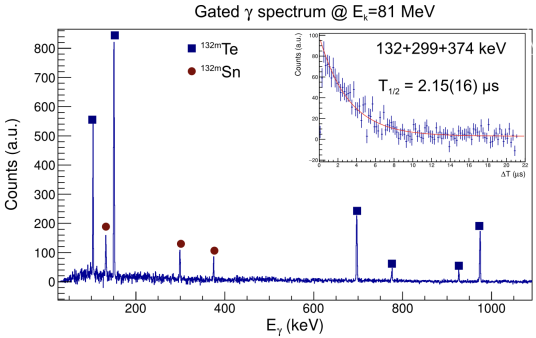
The Lohengrin (PN1) fission fragment separator

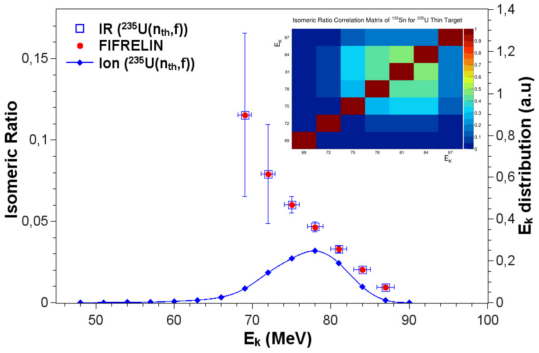




- ✓ Target in-pile, few mg (^{235}U, ^{241}Pu, ^{245}Cm ...)
- ✓ 10^{12} fissions/s $\Rightarrow$ mass-separated fission fragments, up to 10^5 per second, $t_{1/2} \geq \mu s$
- ✓ Up to $A/\Delta A > 1000$, $E/\Delta E > 1000$
- ✓ Detection of γ rays, conversion electrons, and β rays

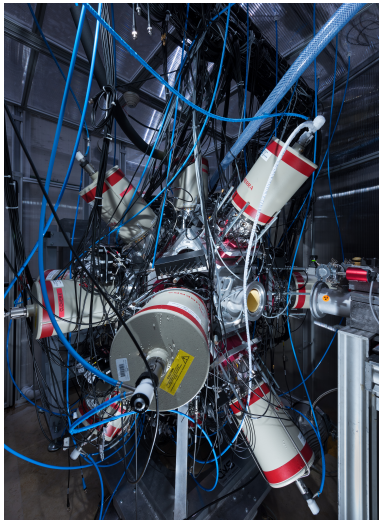
Kinetic energy dependence of fission fragment isomeric ratios for spherical nuclei ^{132}Sn





A. Chebboubi et al., Phys. Lett. B 775 (2017) 190

The FIPPS instrument at ILL



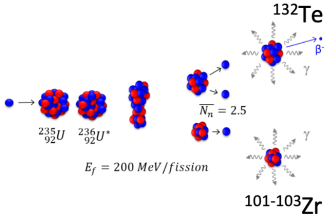
Fission Product Prompt γ-ray Spectrometer

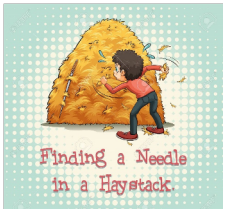
- ✓ 8HPGe clovers+Anti-Comptons (segmented)
- ✓ “pencil-like” thermal neutron beam (1.5cm diam., 5 10^7 n/s/cm^2)
- ✓ digital electronics
- ✓ list mode
- ✓ tight polycarbonate casemate (radioactive targets)
- ✓ possibility to add ancillary detectors: $LaBr_3$, additional clovers from IFIN-HH, ...

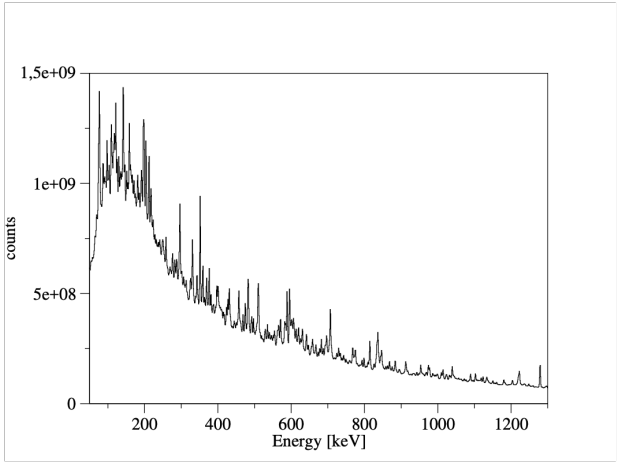
C. Michelagnoli et al., EPJ Web Conf., 193 (2018) 04009; many Master/PhD theses

G. Colombi et al., in preparation

γ-ray spectroscopy of fission fragments

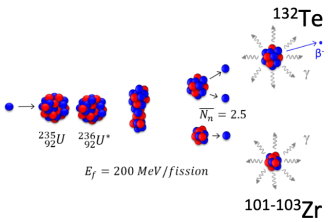


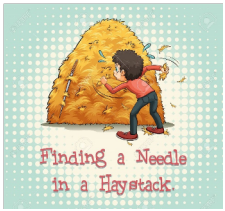


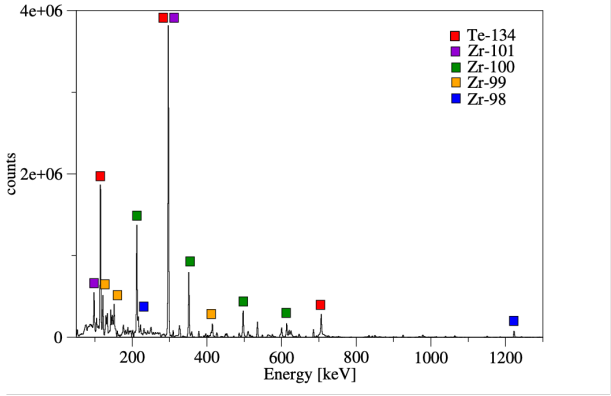


S. Leoni, C. Michelagnoli and J. Wilson, Riv. Nuovo Cim. 45 (2022) 461

γ-ray spectroscopy of fission fragments







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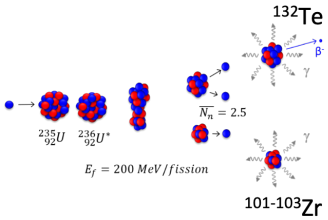

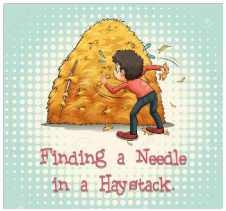

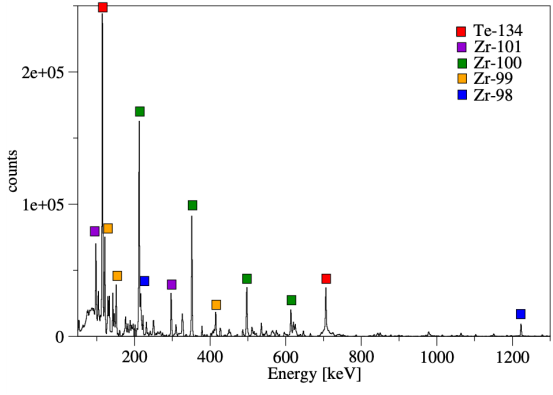

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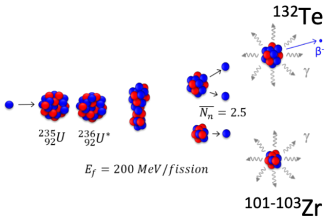

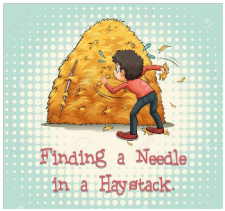

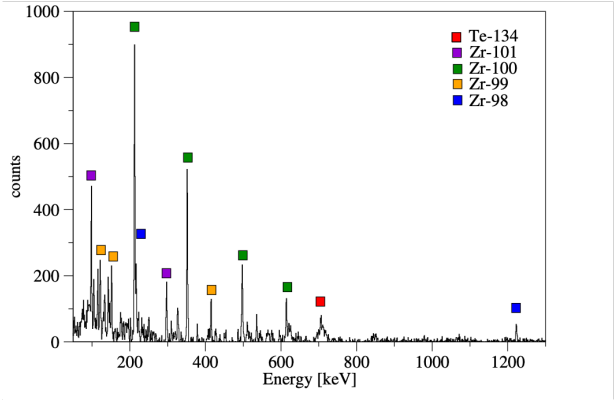

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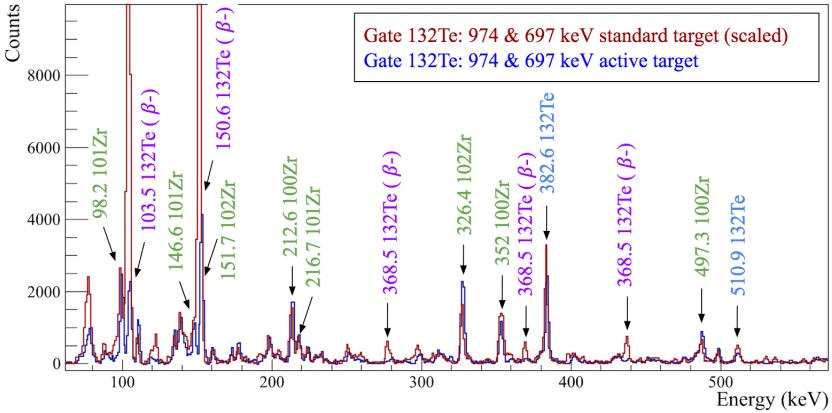
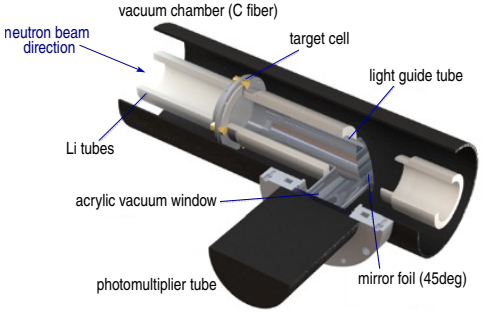
Suppression of β-decay induced background

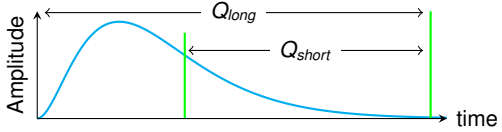


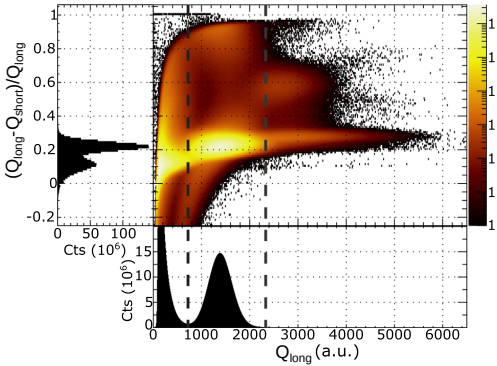
tag of fission events using ^{235}U diluted in liquid scintillator

D. Reygadas et al., PhD Thesis Univ. Grenoble-Alpes and ILL

Tag of fission events: Pulse Shape Discrimination







Adapted from Eur. Phys. J A 56 (2020) 207

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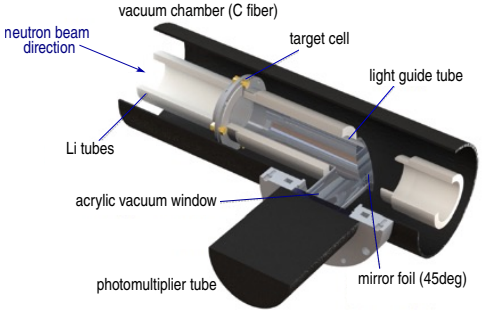

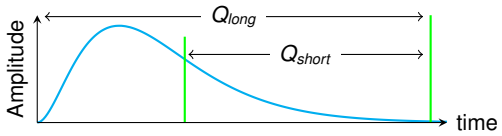

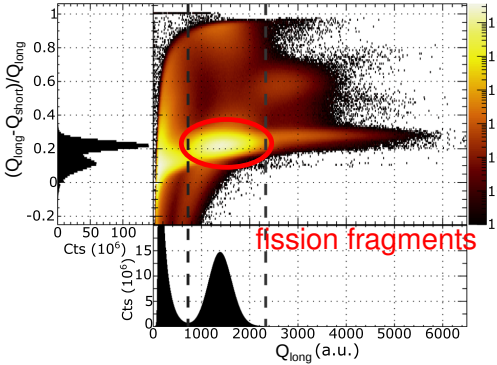

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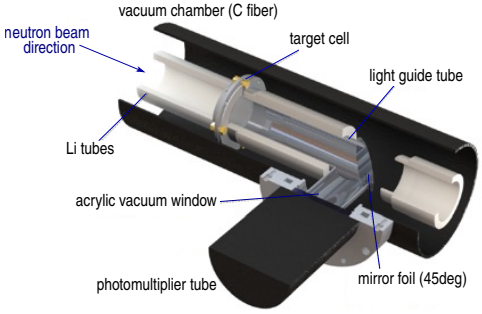
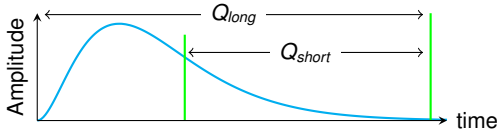
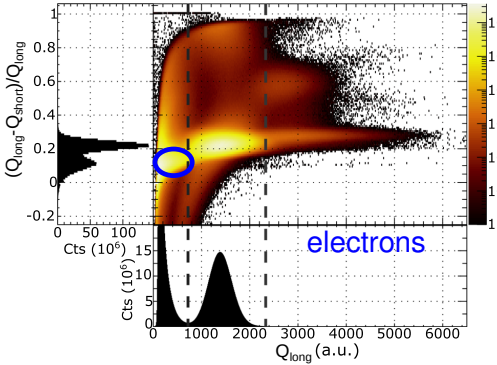


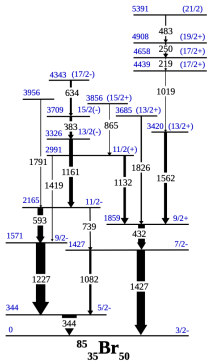


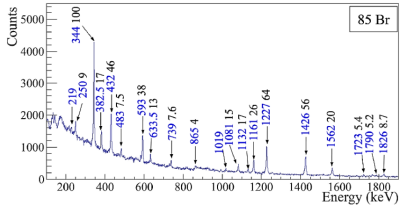


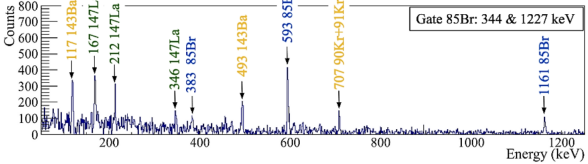
Adapted from Eur. Phys. J A 56 (2020) 207

Systematics of n-rich Br isotopes: combined analysis of FIPPS and AGATA+VAMOS data

New SM interaction, DNO+SM calculations (F. Nowacki, D. Dao, IPHC Strasbourg). New spectroscopic info up to ^{93}Br. Stay tuned!

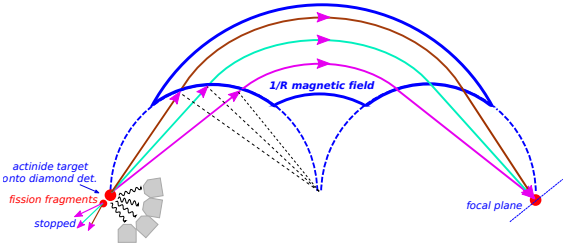


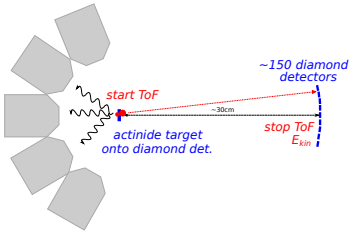




G. Colombi et al., proceedings INPC2022, in press; D. Reygadas, PhD Thesis, Univ. Grenoble-Alpes and ILL, 2021. J. Dudouet, D. Reygadas, G. Colombi et al., to be submitted to PRC

High-sensitivity fission experiments at FIPPS





Y.H. Kim et al. NIM B 463 (2020) 269

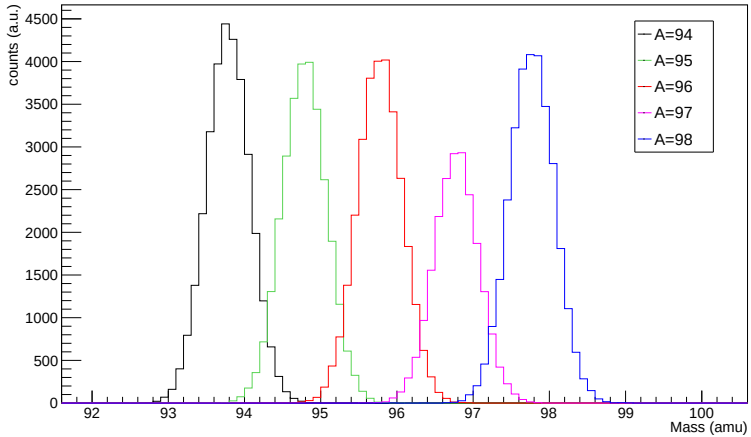
Gas-Filled-Magnet separator

- 1/R field (B_{max} <1.7 T)
- Y focusing ⇒ large acceptance
- same Bρ for all trajectories
- horizontal focusing (Thales circles)

Diamond Array for Fission Fragment Identification (DAFFI)

- Fission fragment id via time-of-flight
- Technical development in collaboration with CEA (Cadarache and Saclay), CNRS Lyon and Grenoble

DAFFI performance



Approved test experiments at FIPPS and Lohengrin

G. Colombi

Concluding remarks and future perspectives

- The slow neutrons produced by the ILL high flux reactor can be used for investigating nuclear structure, fission and astrophysics (complementary to other facilities)
  - structure of neutron-rich fission fragments (shape coexistence, structure at large N/Z asymmetry, ...); lifetime measurements

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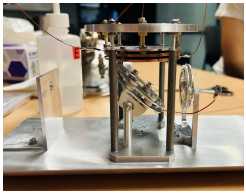
  - structure of neutron-rich fission fragments (shape coexistence, structure at large N/Z asymmetry, ...); lifetime measurements
- A fission fragment selection setup at a neutron beam will allow for high-sensitivity prompt spectroscopy of fission fragments (excellent performance expected, diamond technology)
- Many projects/possibilities:
  - plunger setup for fission
  - fission data open for LoI
  - diamond-based fission tag test
  - possibility for ^{245}Cm(n,fission)
  - other ideas ??



Acknowledgements

G. Colombi, L. Domenichetti, R. Pommier, E. Ruiz-Martinez, M. Jenstchel, U. Köster, H. Faust, Y.H. Kim, J.-M. Daugas and other ILL colleagues and services

J. Dudouet et al. IP2I Lyon

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B. Fornal, N. Cieplicka et al., PAN Krakow

J.M. Regis, L. Knafla et al., IKP Cologne

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