Fission Yields Measurements at LOHENGRIN

Subtask 2.5.1 : Fission yield studies in (n,f) reactions
Subtask 4.2.1 : Evaluation of fission yields

SANDA Final Meeting 3-5 July 2024, Madrid

S. Julien-Laferrière[1,2], C. Sage[1], O. Méplan[1], M. Ramdhane[1]

A. Chebboubi[2], G. Kessedjian[2], O. Serot[2], O. Litaize[2], D. Bernard[2], J. Nicholson[2]

U. Köster[3], Y.H. Kim[3], A. Blanc[3], H. Faust[3], P. Mutti[3]

A. Letourneau[4], T. Materna[4] , M. Rapala[4]

1 LPSC, Université Grenoble-Alpes, CNRS/IN2P3, F-38026 Grenoble Cedex, France
2 CEA-Cadarache, DES, IRESNE, DER, SPRC, LEPh, F-13108 Saint Paul lez Durance, France
3 Institut Laue-Langevin, F-38042 Grenoble Cedex 9, France
4 CEA-Saclay, DRF, IRFU, DPhN, LEARN, Orme des merisiers, F-91191 Gif-sur-Yvette, France

SANDA

Supplying Accurate Nuclear Data for energy and non-energy Applications

HORIZON2020

Summary

- Context – Motivations
- The LOHENGRIN spectrometer : facility and detectors setup description
- Subtask 2.5.1 : Fission yield studies in (n,f) reactions
  - Isotopic yield measurement as a function of the kinetic energy for the $^{241}Pu(n_{th},f)$ reaction : analysis and results
  - ^{132}Sn Isomeric ratio measurement as a function of the kinetic energy
- Subtask 4.2.1 : Evaluation of fission yields
  - Observables used to test some model assumptions implemented in the Monte-Carlo code FIFRELIN used for fission yield evaluations
- Conclusion and perspectives

Context - Motivations

Around fission yields measurements :

- Despite a real effort on fission yields measurements, current evaluated data still need some improvements :
  - Uncertainties reduction
  - Experimental Variance-covariance matrices
  - Discrepancies between models/evaluations and measurements in the heavy and symmetric regions

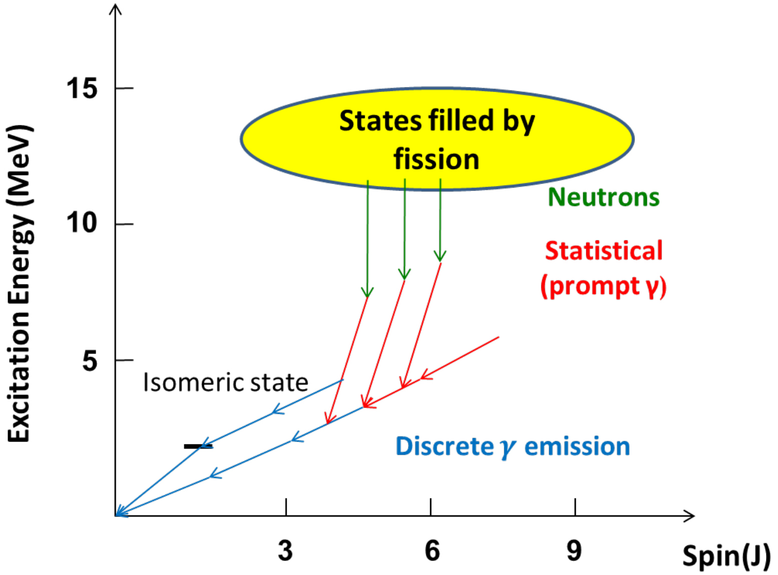
- Study of the fission process :
  - Exhaustive set of isotopic yields per mass enables the local odd-even effect estimation, which can be seen as a local test for the mean neutron emission
  - Symmetric and very asymmetric regions : test validity of models for evaluations
  - Parity effect and kinetic energy dependence to test excitation energy repartition
  - Isomeric ratios = indirect information on spin distribution and excitation energy available at scission

Context - Motivations

- In this context, different measurements have been carried out by our collaboration to measure the fission yields with a special focus in specific observables (isotopic and isomeric productions, dependency with kinetic energy)

- **Theoretical description :**

$$Y(A,Z,E^*,J^\pi) = Y(A,Z) \times P(E^*,J^\pi)$$



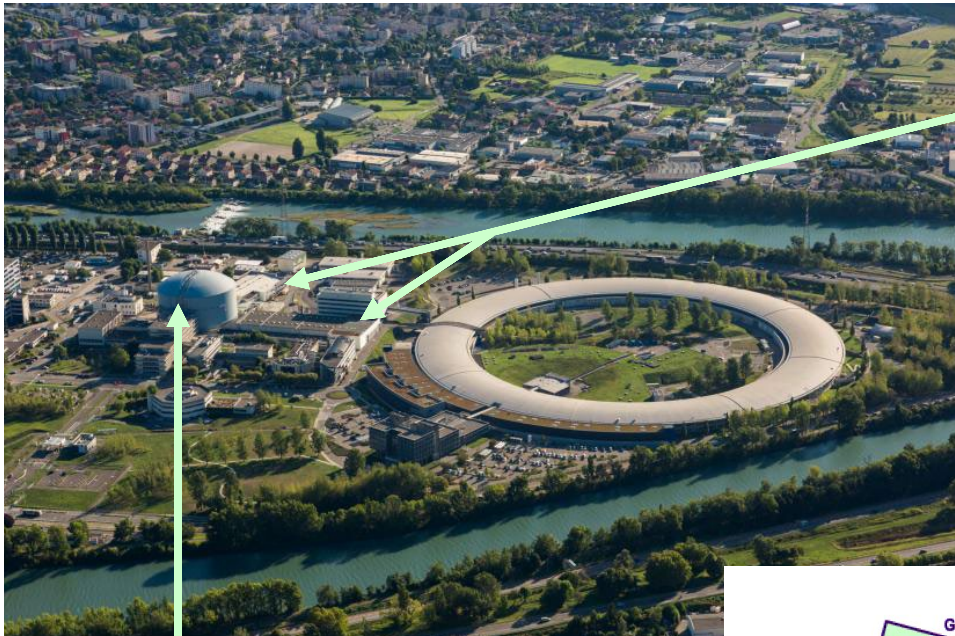
(Z, I) Kinetic energy dependence :

- $P(E^*,J^\pi)$ excitation energy sharing and spin distributions
- modeling prompt particle emission (n/γ) - cascade – competition (n/γ)
- foreseen material damage/heating in the reactor studies

- **Observables** $Y(A,Z,E_k,J,\pi) = Y(A) \cdot P(Z|A) \cdot P(E_k|A,Z) \cdot P(IR,n,\gamma|A,Z,E_k)$

Mass — Charge — Kinetic energy — Isomers Prompt particles

ILL and the Lohengrin spectrometer



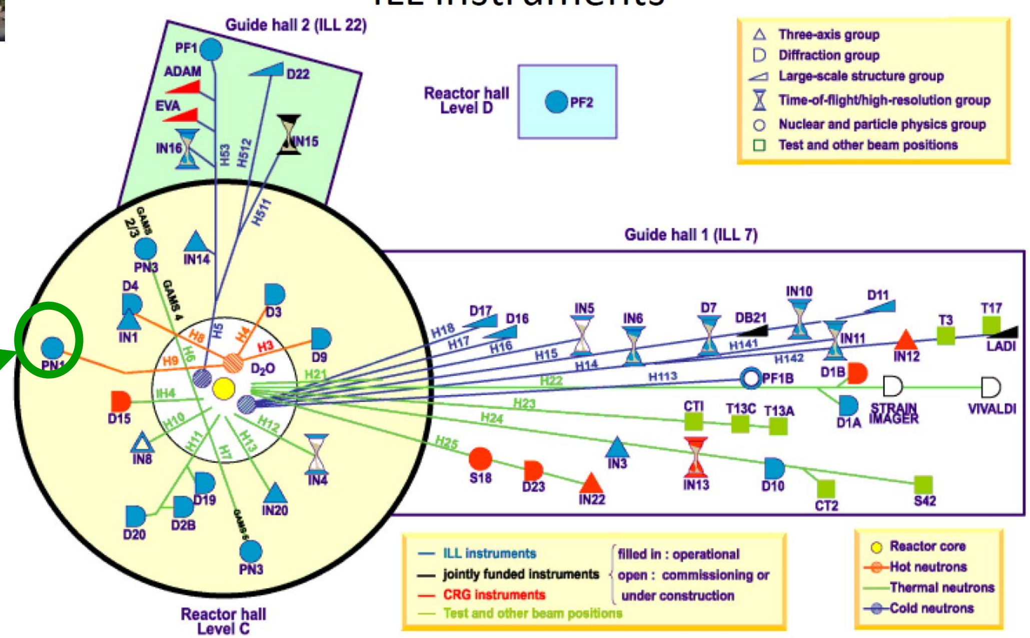
Experiment halls

ILL reactor
Grenoble, France

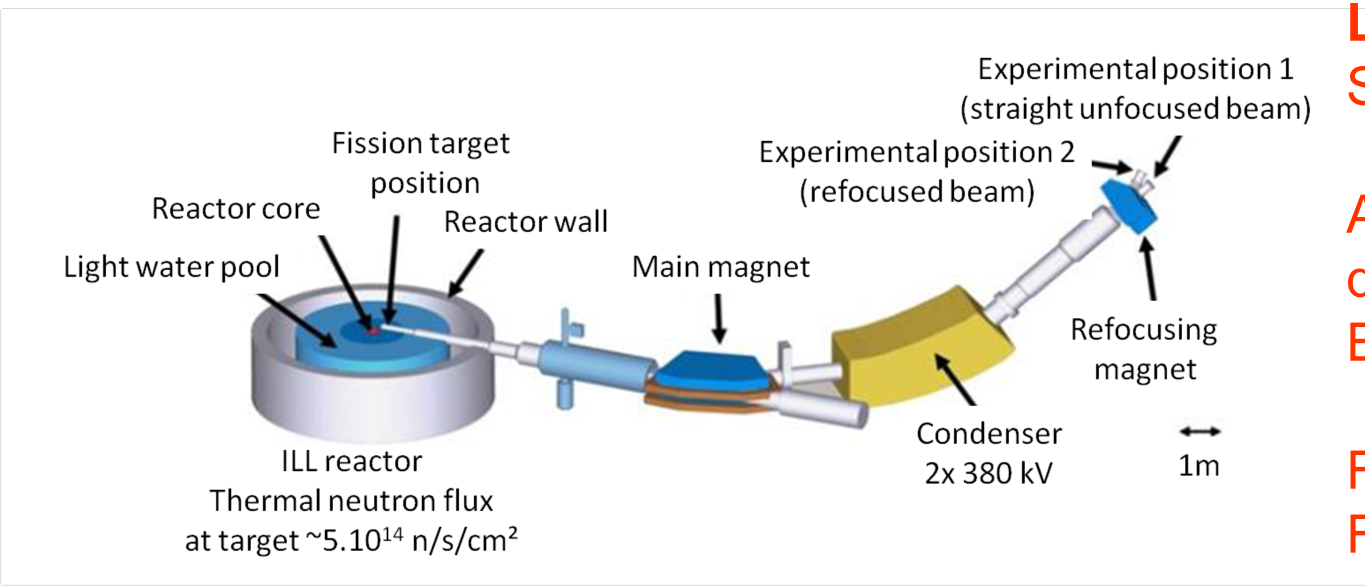
ILL features :
40 instruments
High flux reactor : 58 MW thermal
At target : 5.10^{14} n/s/cm^2

LOHENGRIN fission product spectrometer

ILL instruments



ILL and the Lohengrin spectrometer

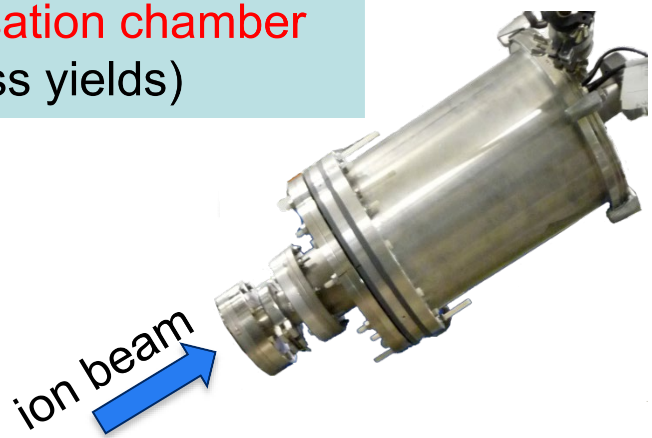


Lohengrin :
Selection in A/q & E/q

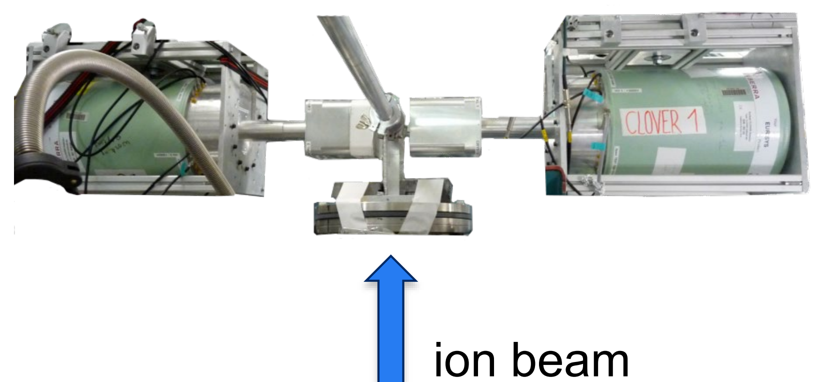
A : mass
q : ionic charge
E : kinetic energy

Flight path : 23 m
Flight time ~ µs

Measurements with
Ionisation chamber
(mass yields)



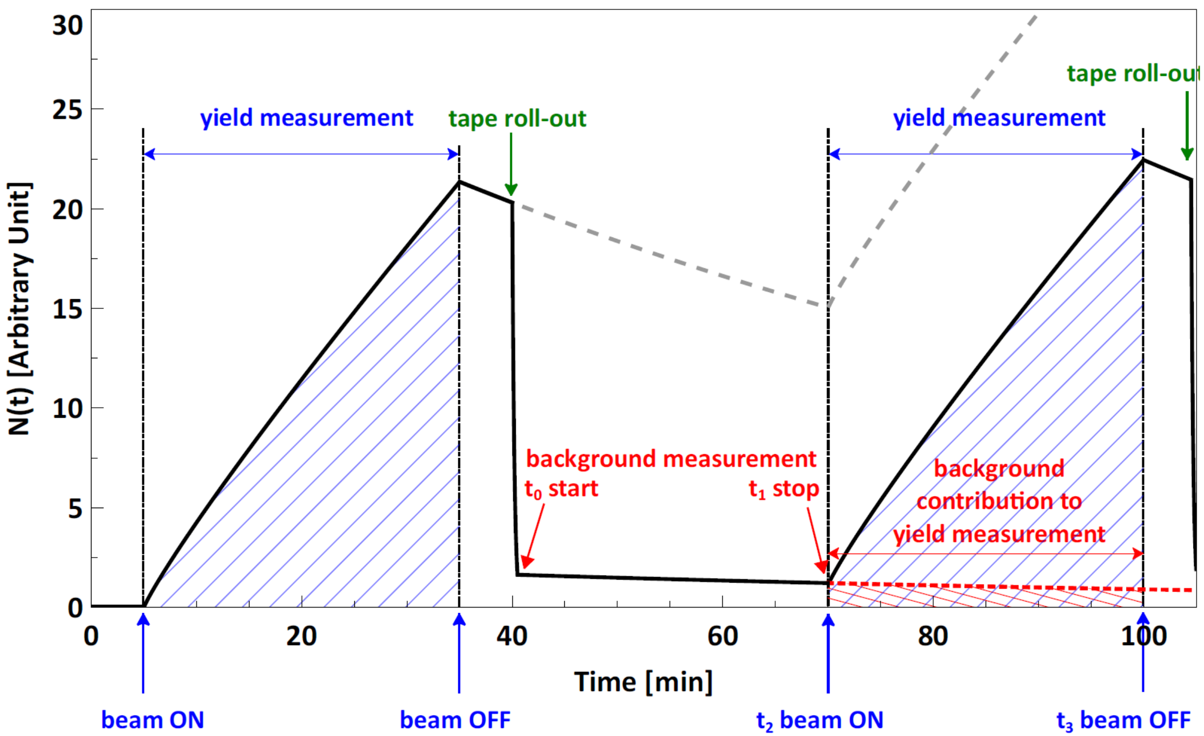
Or with HPGe detectors
(isotopic yields, isomeric ratios)



Isotopic yields measurement

Measurement steps :

- Ion beam deposited on a moving tape inside a vacuum chamber
- 2 Ge clovers with 4 crystals detect the gamma rays from the FP β decays
- The tape moves at the end of the measurement to clean the environment and start a new measurement



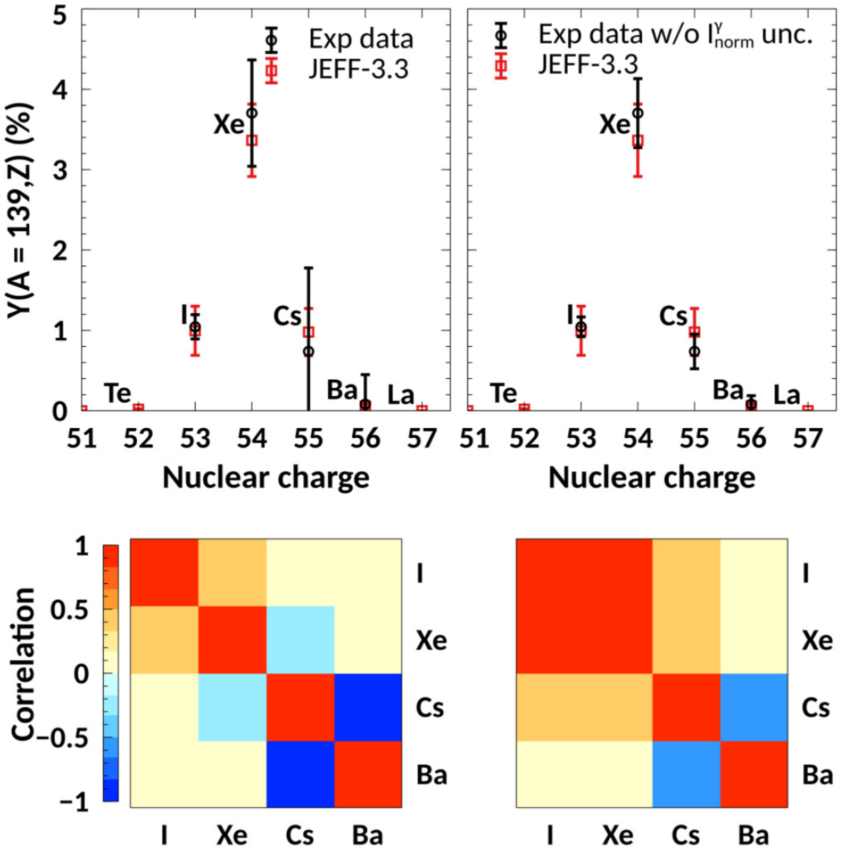
We measure :
The isotopes decays on the tape and on the surrounding frame

Matrix solving of the Bateman equations

Contribution of the isotopes from the tape only

Kinetic energy dependency of isotopic distributions

- Absolute isotopic yields for $^{241}Pu(n_{th},f)$
  - New measurement and analysis protocol
  - Evaluation of the systematics of the setup (correlations E-q, target burnup…) and computation of the experimental variance-covariance matrices
  - Development of an analysis method independent from any external normalization



Mass A = 139:

- All the uncertainties propagated (left)
- Case where the uncertainty of the normalization the normalization intensity I^{γ}_{Norm} is equal to zero

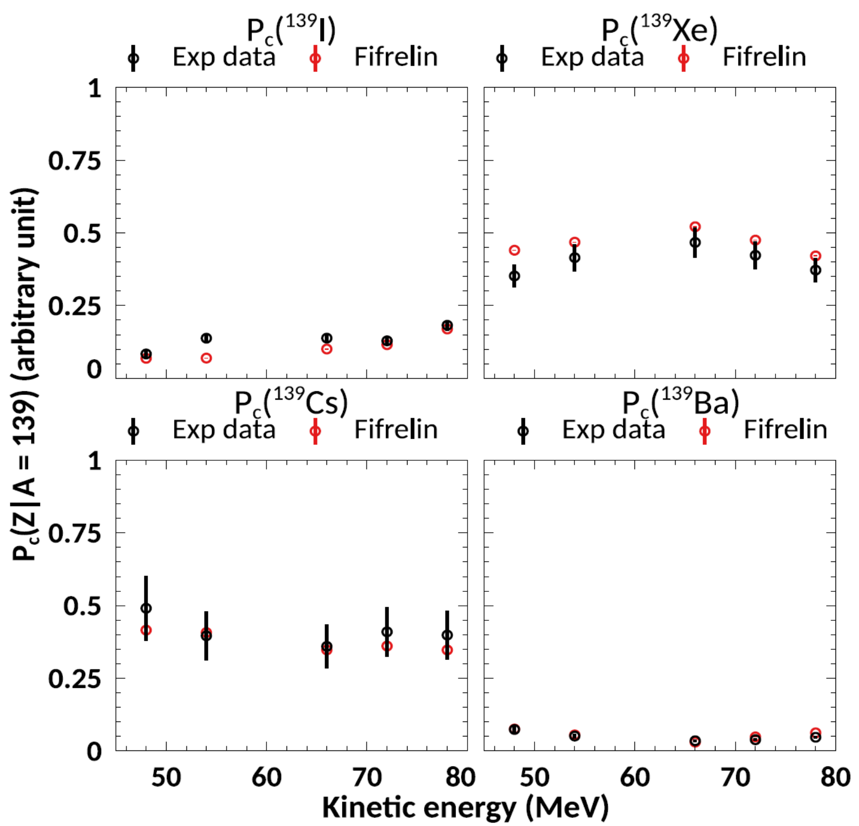
→ uncertainties mainly coming from nuclear decay data

*S. Julien-Laferrière et al., Phy. Rev. C **102**, 034602 (2020)*

Kinetic energy dependency of isotopic distributions

➢ Absolute isotopic yields for $^{241}Pu(n_{th},f)$

- FIFRELIN can compute isotopic yields as a function of kinetic energy through an event-by-event analysis, after correction for the energy loss inside the target.
- FIFRELIN kinetic energy distributions convoluted by a Landau distribution to model the energy loss



<u>Mass A = 139</u>:

- Agreement with FIFRELIN satisfactory
- Slight overestimation for Xe

→ FIFRELIN validated for the kinetic energy dependency of the mass 139.

*S. Julien-Laferrière et al., Phy. Rev. C **102**, 034602 (2020)*

Kinetic energy dependency of isotopic distributions

- Absolute isotopic yields for $^{241}Pu(n_{th},f)$

Local odd-even effect : with Z_e and Z_o the even and odd nuclear charges

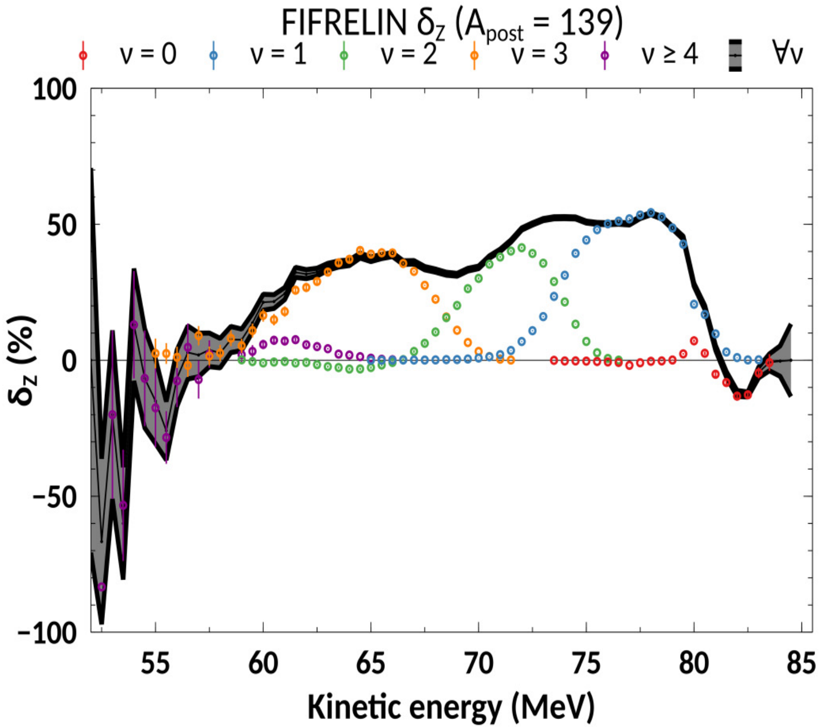
$$\delta_Z(A) = \frac{\sum_e Y(A,Z_e) - \sum_o Y(A,Z_o)}{Y(A)}$$

- Structures can be interpreted as due to the prompt neutron emission as suggested by the contributions from the different numbers of emitted neutrons

- LOHENGRIN measurements are a probe to the local prompt neutron emission through all the de-excitation path assumptions used in FIFRELIN

- Other mass regions are planned to be investigated in a near future

Case of the mass A = 139

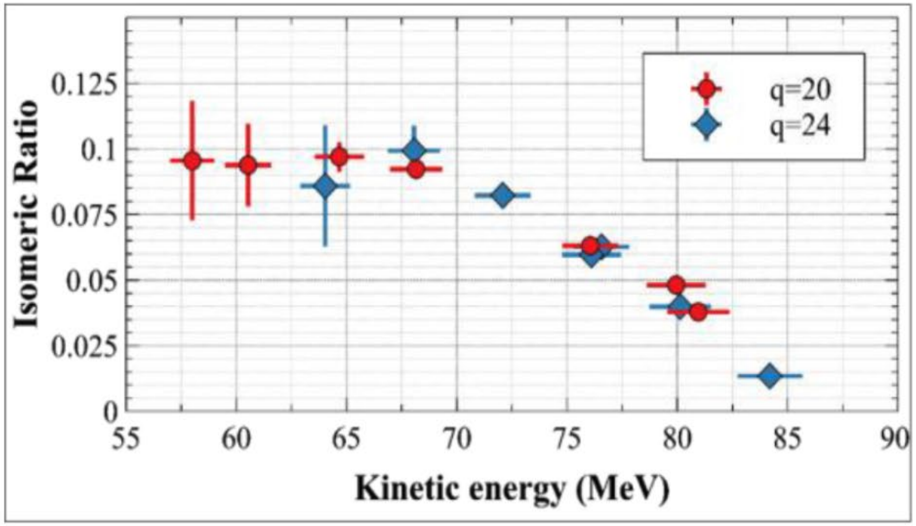


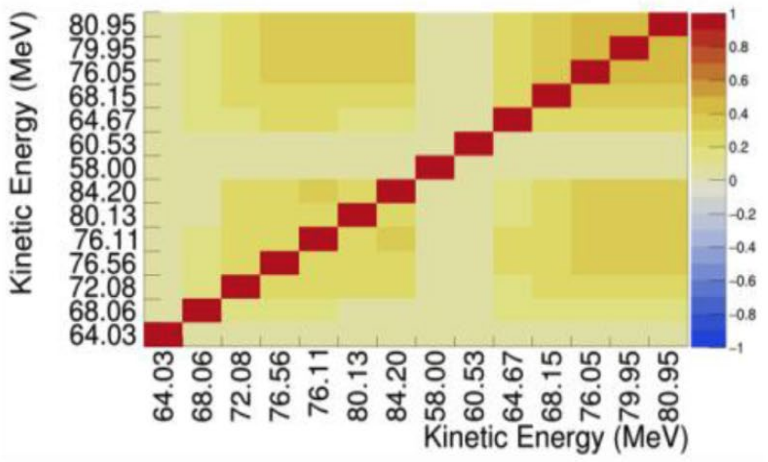
S. Julien-Laferrière et al., Phy. Rev. C ***102****, 034602 (2020)*

^{132}Sn Isomeric Ratio as a function of kinetic energy

- Experimental campaign on LOHENGRIN related to the kinetic energy dependency of ^{132}Sn fission product isomeric ratio (IR) measured for thermal neutron induced fission of ^{241}Pu.
- IRs are deduced using gamma ray spectrometry in coincidence with the signals of the ionization chamber.
- The isomeric ratio is defined as the ratio of the production rate of one isomeric state to the sum of the production rates of all the isomeric states and the ground state.

Results obtained for $^{241}Pu(n_{th},f)$:



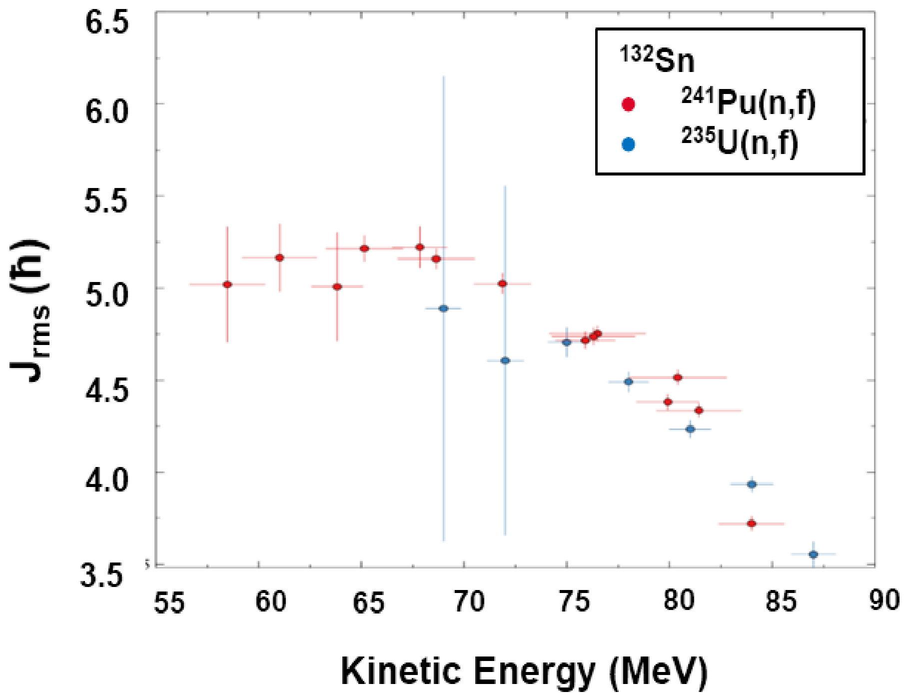


11

^{132}Sn Isomeric Ratio as a function of kinetic energy

- Data interpreted using the FIFRELIN Monte-Carlo code. Combining the measured IRs with the FIFRELIN calculations, the angular momentum distribution characterized by a free parameter J_{rms} (spin cut-off parameter) can be deduced:

$$P(J) \propto (2J+1)\exp\left(-\frac{\left(J+\frac{1}{2}\right)^2}{J_{rms}^2}\right)$$



- Evolution of the J_{rms} with kinetic energy of the doubly magic nucleus of ^{132}Sn.
- The J_{rms} value obtained from both $^{235}U(n_{th},f)$ and $^{241}Pu(n_{th},f)$ reactions are quite similar.
- Experimental and computed results have been also compared with the calculations using the Madland-England model

→. Weak agreement obtained ! Assumption oversimplified: the isomeric ratio does not depend only on the angular momentum of the ground state and the isomeric state

Conclusion and Perspectives

- Several successful measurements campaigns performed in the frame of subtasks 2.5.1 and 4.2.1 of the Sanda project

- Subtask 2.5.1 : New isotopic and isomeric yields measured as a function of the kinetic energy for the $^{241}Pu(n_{th},f)$ reaction. Final results published and deliverable D2.12 submitted

- Subtask 4.2.1 : promising new observables used to test some model assumptions implemented in FIFRELIN. Results published and deliverable D4.3 submitted

- Prospectives : Need for further measurements, especially other experimental IR in order to validate the models used in FIFRELIN for the determination of fission product spin!

- Continuation of fission studies at LOHENGRIN : focus on the challenging symmetry region with a new detection system (APRENDE !)