cea irfu

Results on $^{235}U(n_{th},f)$ isotopic fission yields using prompt and delayed gamma rays at the FIPPS spectrometer of the ILL

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Collaboration

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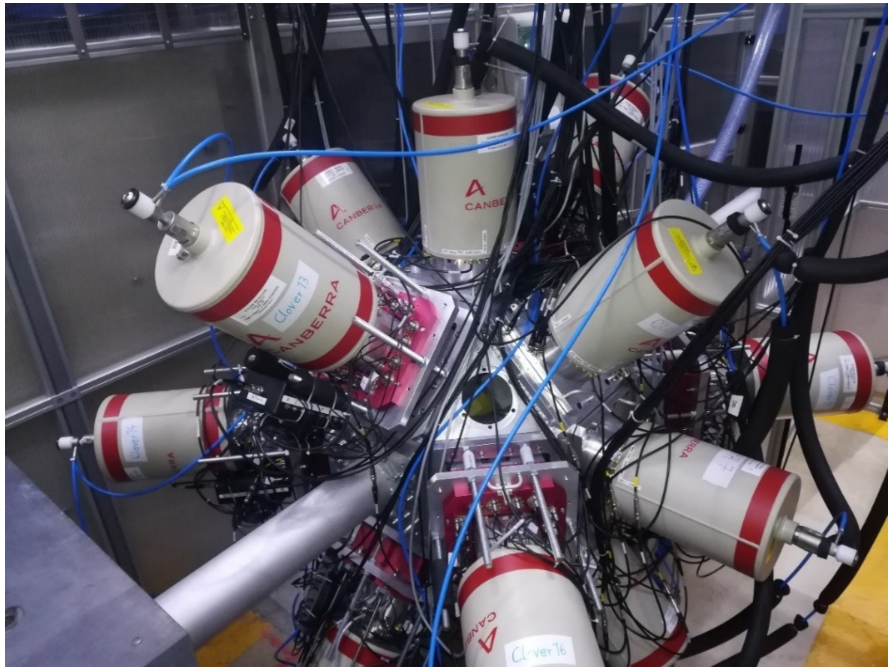
Outline

1. Experimental campaign at FIPPS with a ^{235}U active target
2. Prompt gamma data : motivations and first results on fission yields
3. Delayed gamma data : motivations and first results
4. Conclusions and Perspectives

1. Experimental campaign at FIPPS with a ^{235}U active target

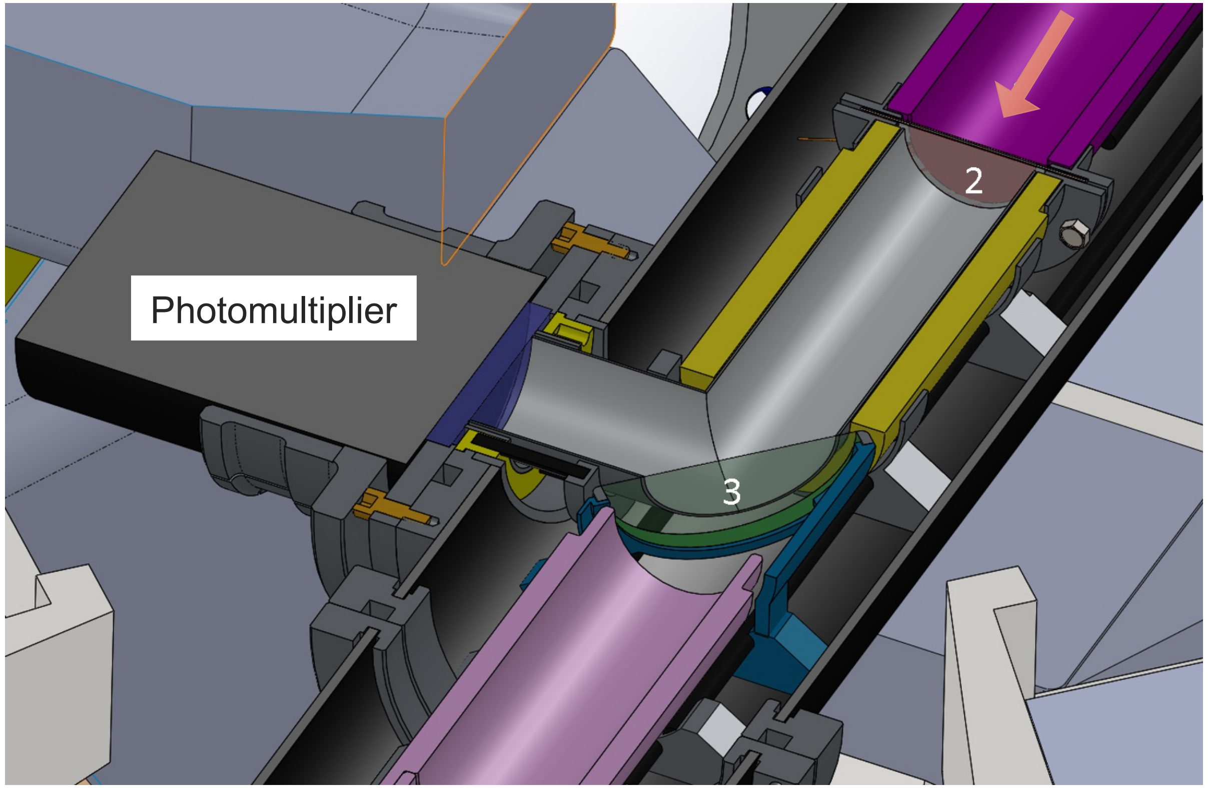
FIPPS spectrometer at ILL



First experiment with an active target at FIPPS

- Gamma–ray spectrometer made of 16 HPGe clover detectors
- with BGO shielding around IFIN HPGe detectors
- 10^8 neutrons/s/cm^2
- Collimation : 1.5 cm diameter beam

^{235}U Active target



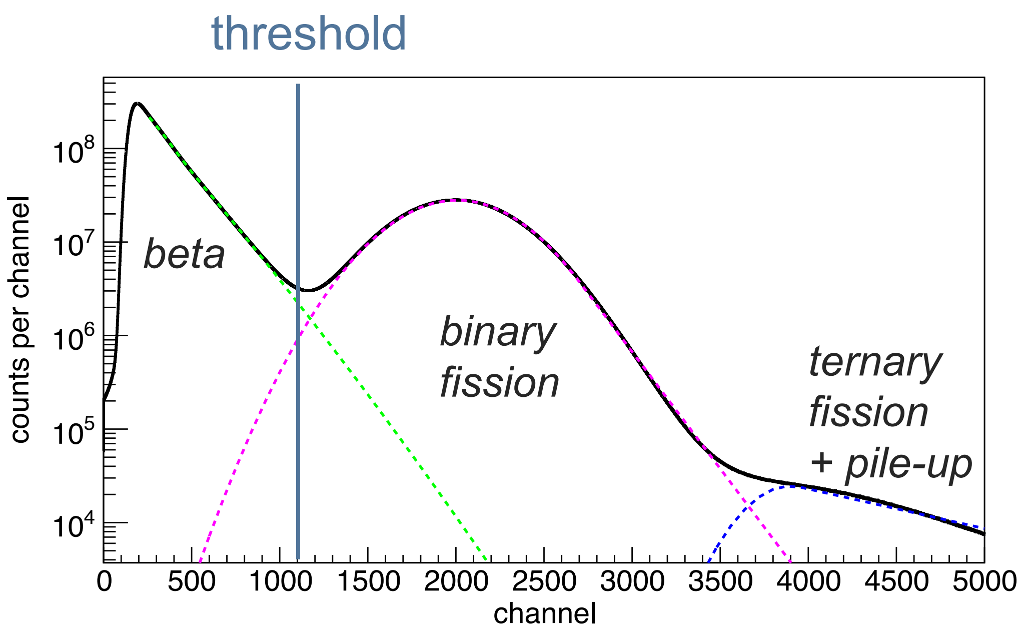
U-235 dissolved in a liquid scintillator

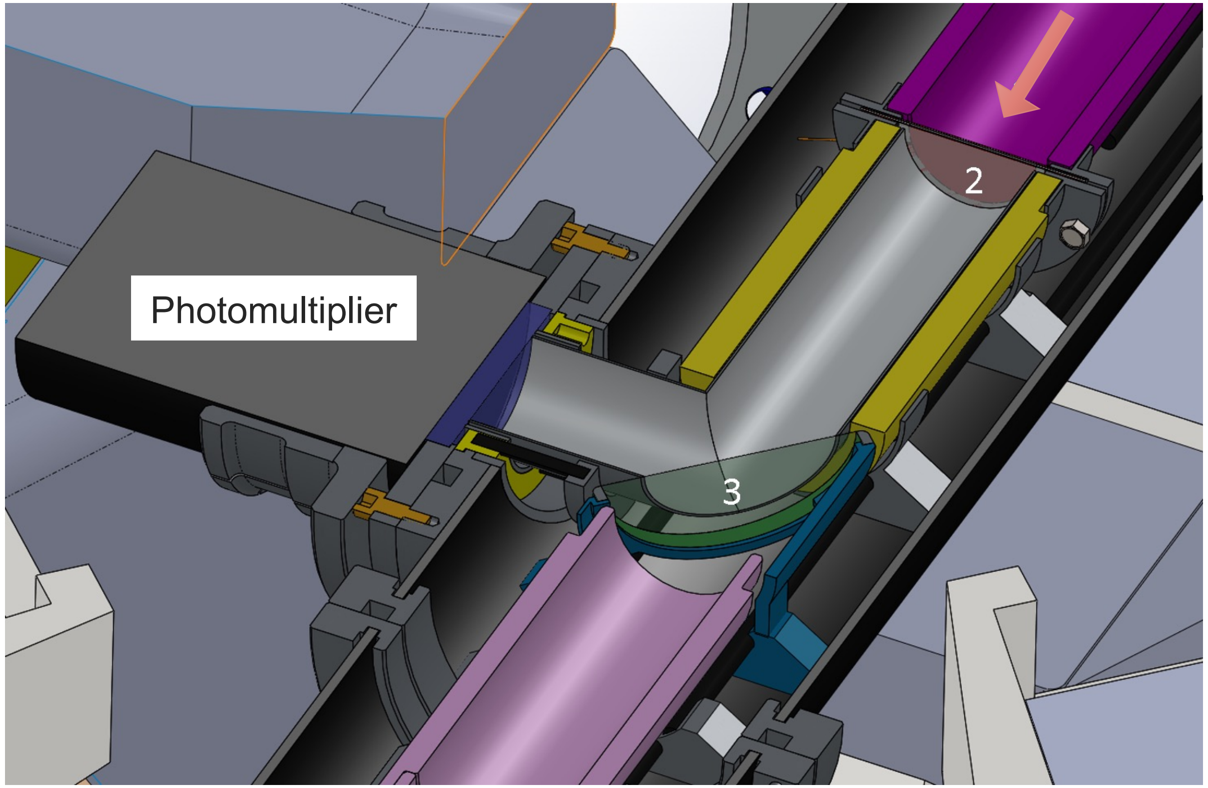
(deuterated toluene, naphthalene, PBBO, HDEHB)

Fission fragments stopped in liquid
Light signal used to tag fission events

F. Kandzia et al. EPJA 2020

^{235}U Active target





2.44 10^{10} fission events

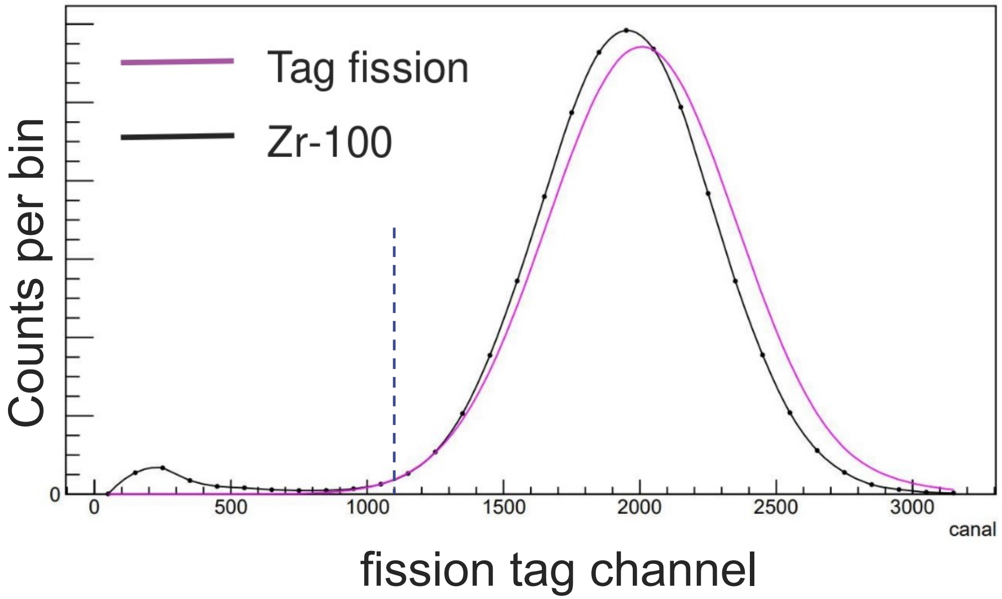
97.8 % of the events > threshold are fission events

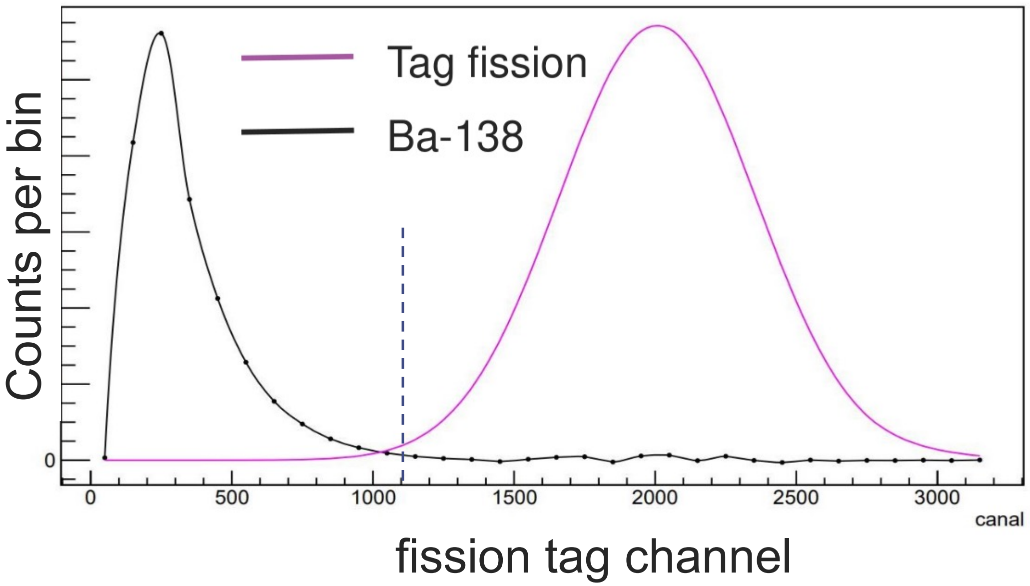
F. Kandzia et al. EPJA 2020

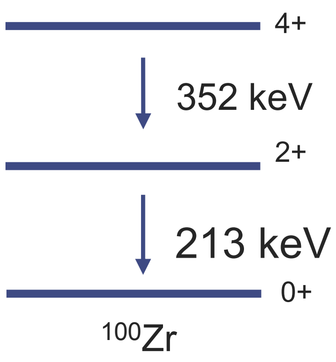
Data from the experimental campaign on FIPPS

- 39 days – 9095 runs of 5 minutes
- 2.44 x 10^{10} fission events
- Data from 60 (54) HPGe crystals (no addback) – BGO signals not used
- Gamma-ray Spectra, Coincidence $\gamma\gamma$ Matrices, $\gamma\gamma\gamma$ cubes
  - in coincidence with fission (fission tag > 1100) → “Prompt” data
  - in veto with fission (no fission tag or fission tag < 1100) → “Delayed” data
- Calibration : ^{152}Eu source + ^{27}Al(n,g) from target support

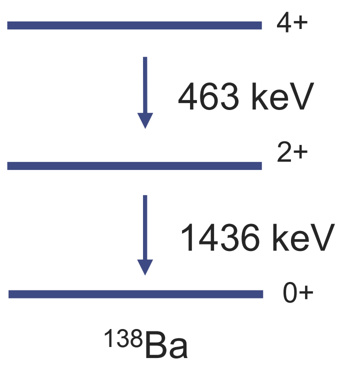
^{235}U Active target performances





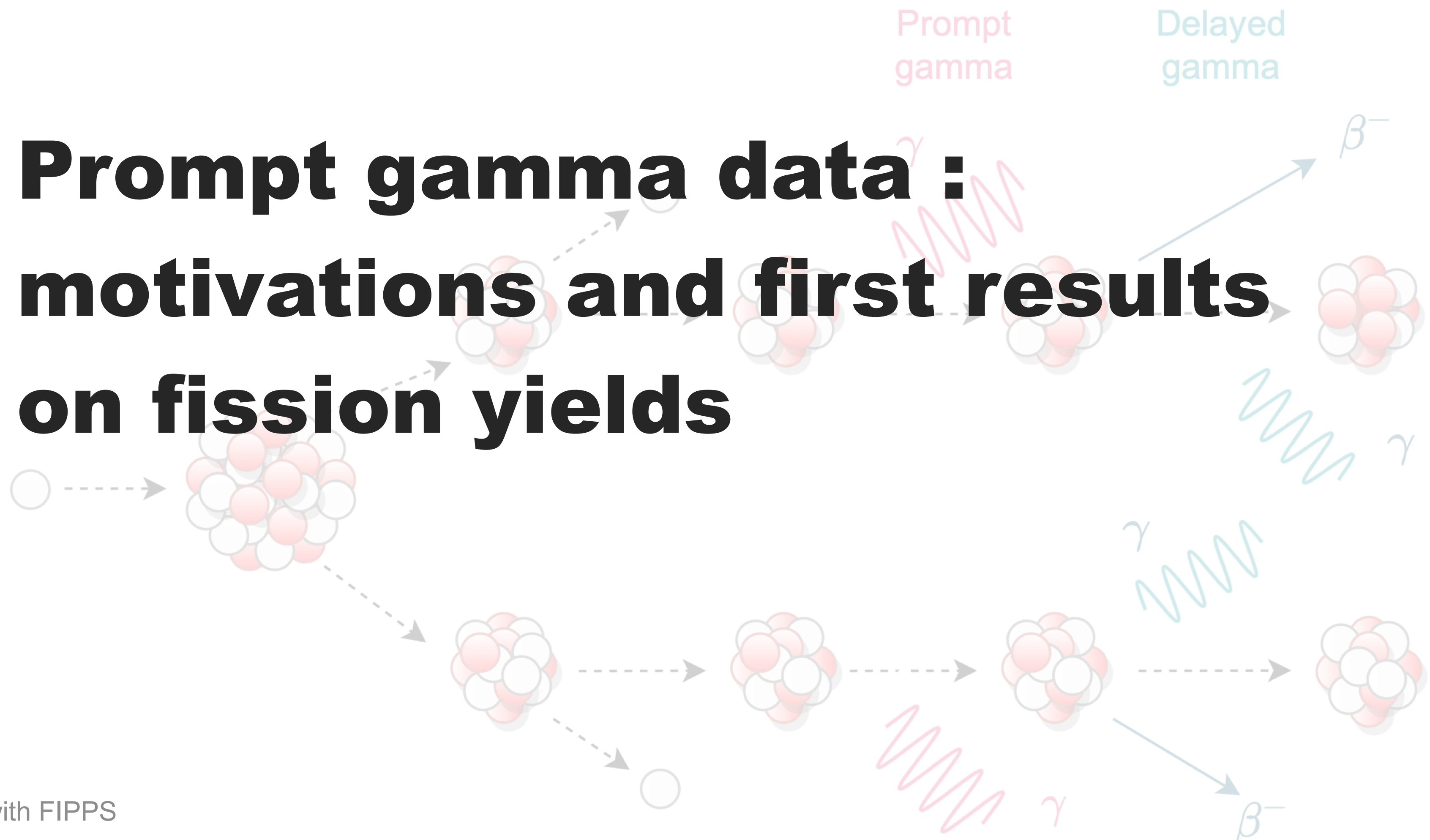


Mainly produced by fission



Produced by beta-decay of ^{138}Cs

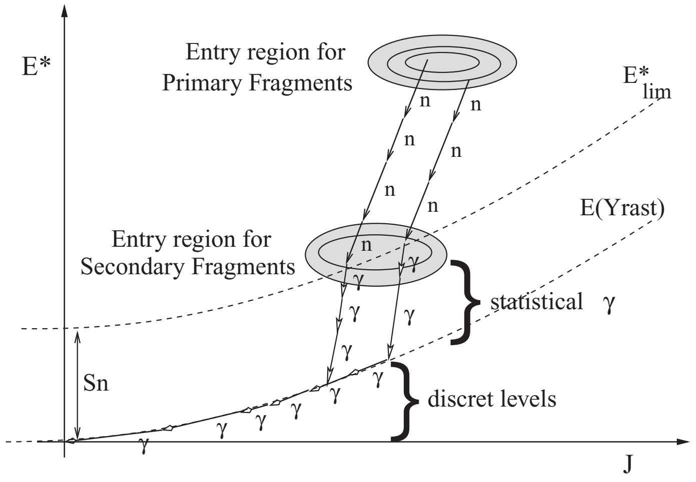
2. Prompt gamma data : motivations and first results on fission yields



Motivations for prompt gamma analysis

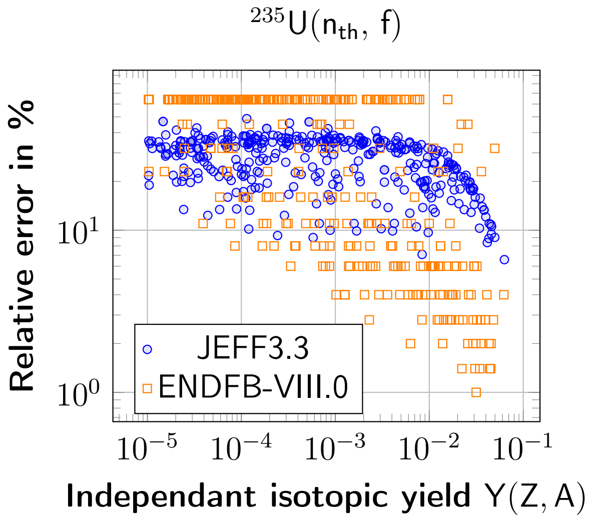
Study of the fission process via the cascade of prompt gamma-rays

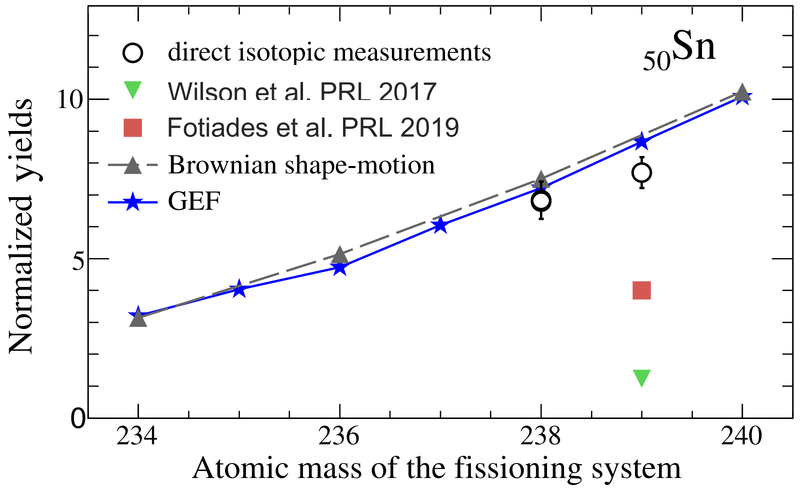
- find the spin distribution of the fragments
- understand the sharing of the total excitation energy
- comparison to FF de-excitation code FIFRELIN



Evaluate the possibility of extracting absolute independent Y(A,Z)

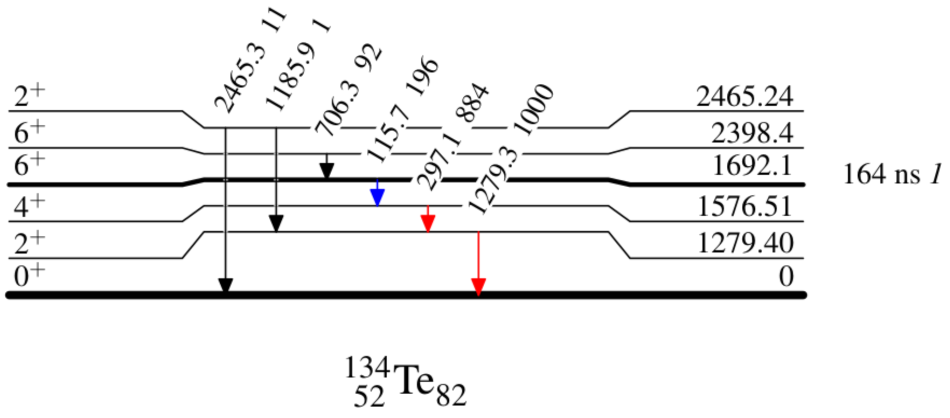
- access to heavy fragments
- yield of ^{132}Sn





Ramos et al., PRL 123, 092503 (2019)

Method for extracting fission yields

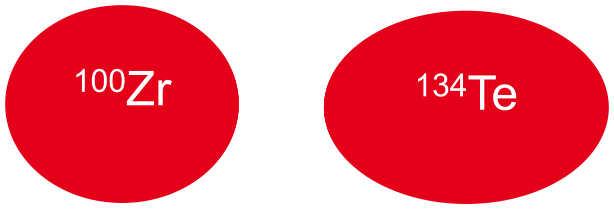


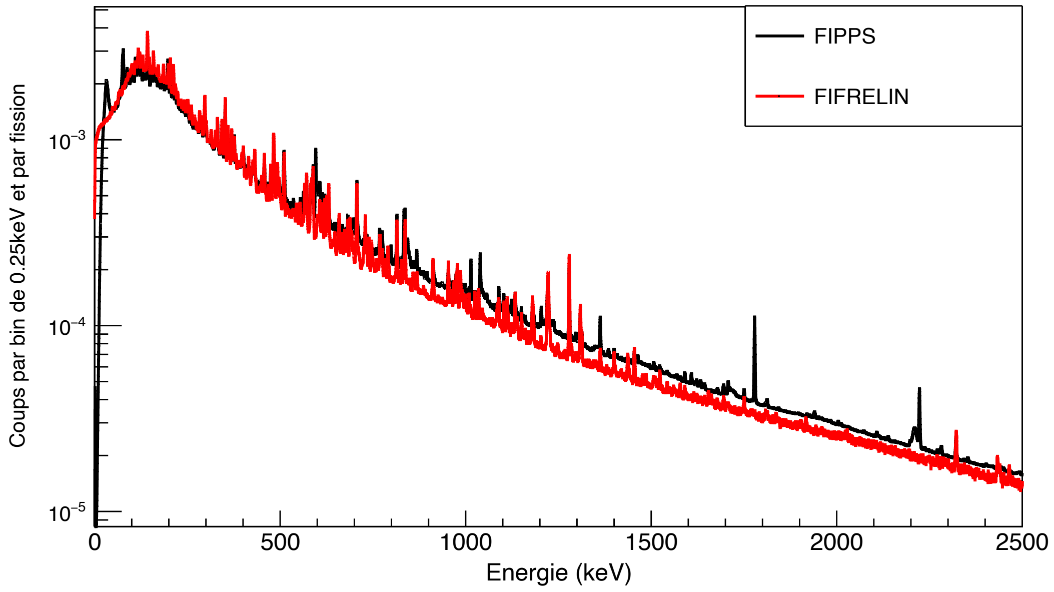
Partial level scheme from ENSDF for ^{248}Cm(sf) with intensities from PRC 65, 017302

$$Y = \frac{\sum N_\gamma(E_i)}{N_{fissions}} = \frac{1}{N_{fissions}} \left\{ N_{\gamma\gamma}(1279{,}297) \times \frac{N_\gamma(1279)}{N_\gamma(297)} \right\} \left\{ 1 + \frac{N_\gamma(2465)}{N_\gamma(1279)} + \dots \right\}$$

from $\gamma\gamma$ matrix

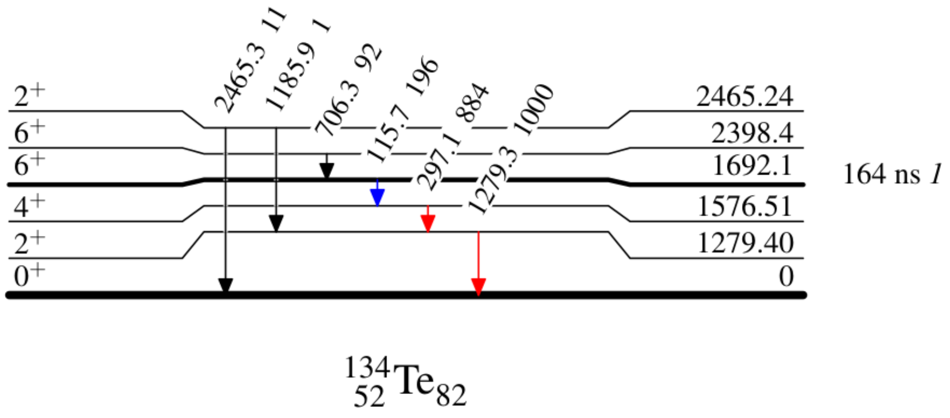
from $\gamma\gamma\gamma$ cube





Prompt gamma-ray spectrum measured with FIPPS vs obtained with FIFRELIN + G4

Method for extracting fission yields



$$Y = \frac{\sum N_\gamma(E_i)}{N_{fissions}} = \frac{1}{N_{fissions}} \left\{ N_{\gamma\gamma}(1279{,}297) \times \frac{N_\gamma(1279)}{N_\gamma(297)} \right\} \left\{ 1 + \frac{N_\gamma(2465)}{N_\gamma(1279)} + \ \dots \right\}$$

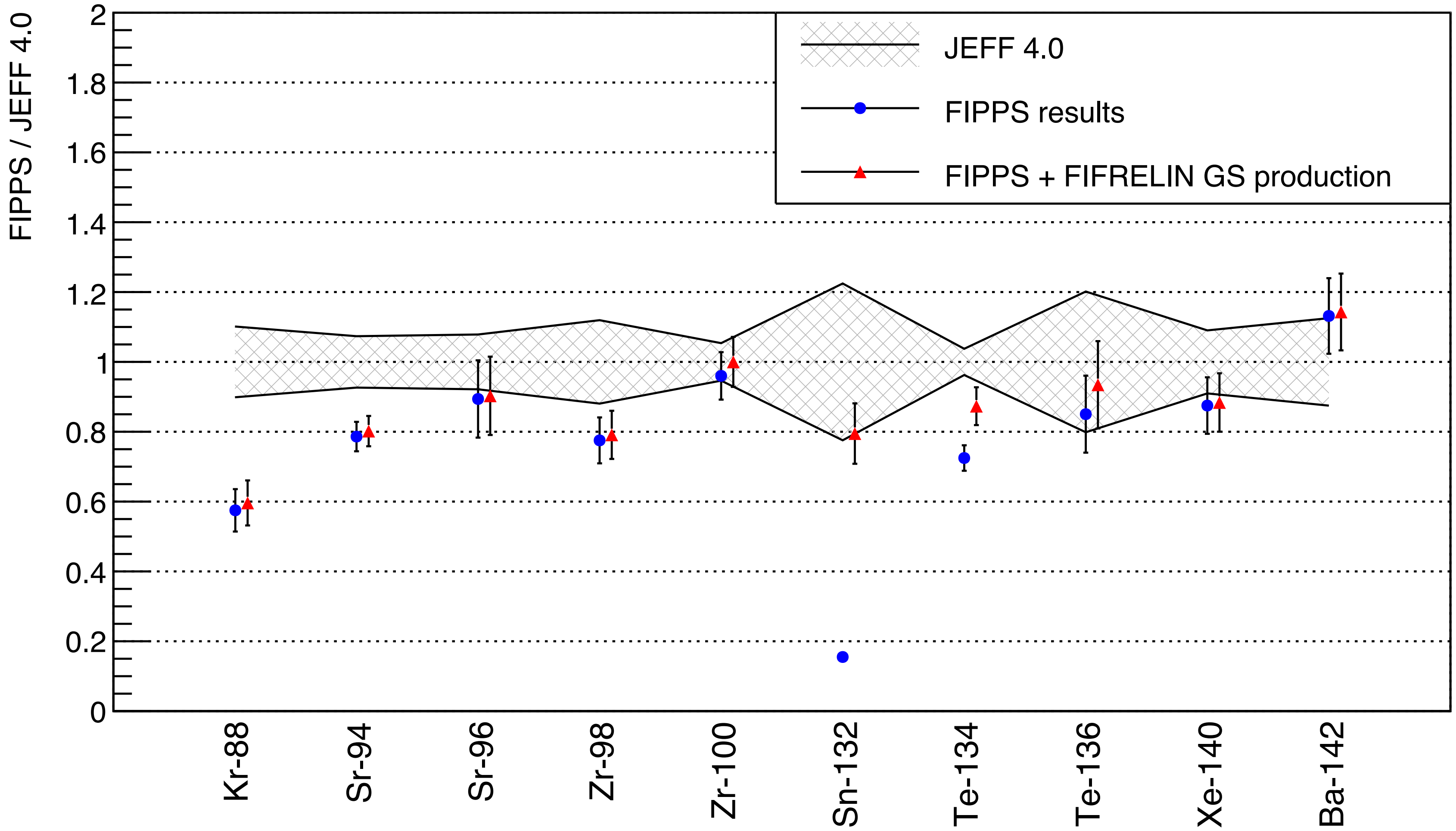
from γγ matrix

from γγγ cube

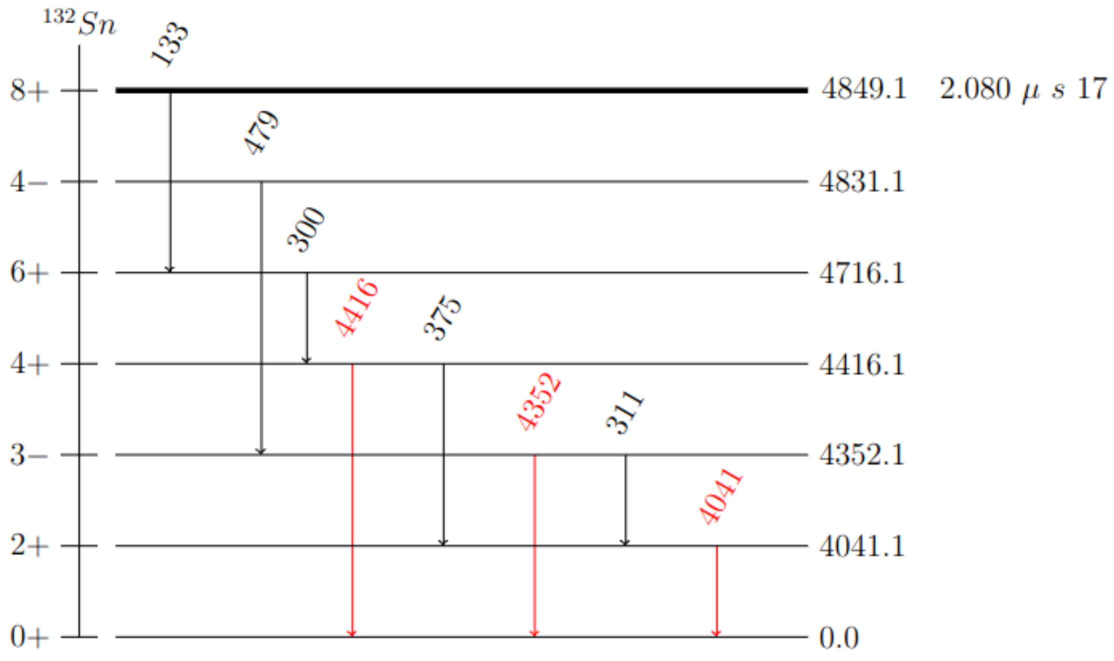
- Hypothesis : the cascade in one fragment does not depend on the other fragment
- Absolute efficiency of the spectrometer : ^{152}Eu + $^{27}Al(n,g)$
- **Corrections for**
  - dead time : 2.3 %
  - internal conversion : BRICC
  - summing effect : FIFRELIN + GEANT4 : 13 – 18 %
  - possible contaminations of the peaks : FIFRELIN
  - direct production of the ground state : FIFRELIN
  - isomeric state (if lifetime > coincidence time window)
- Main difficulty : fitting precisely the peaks !

Result for independent Y(A,Z)

Pierre Herran PhD result



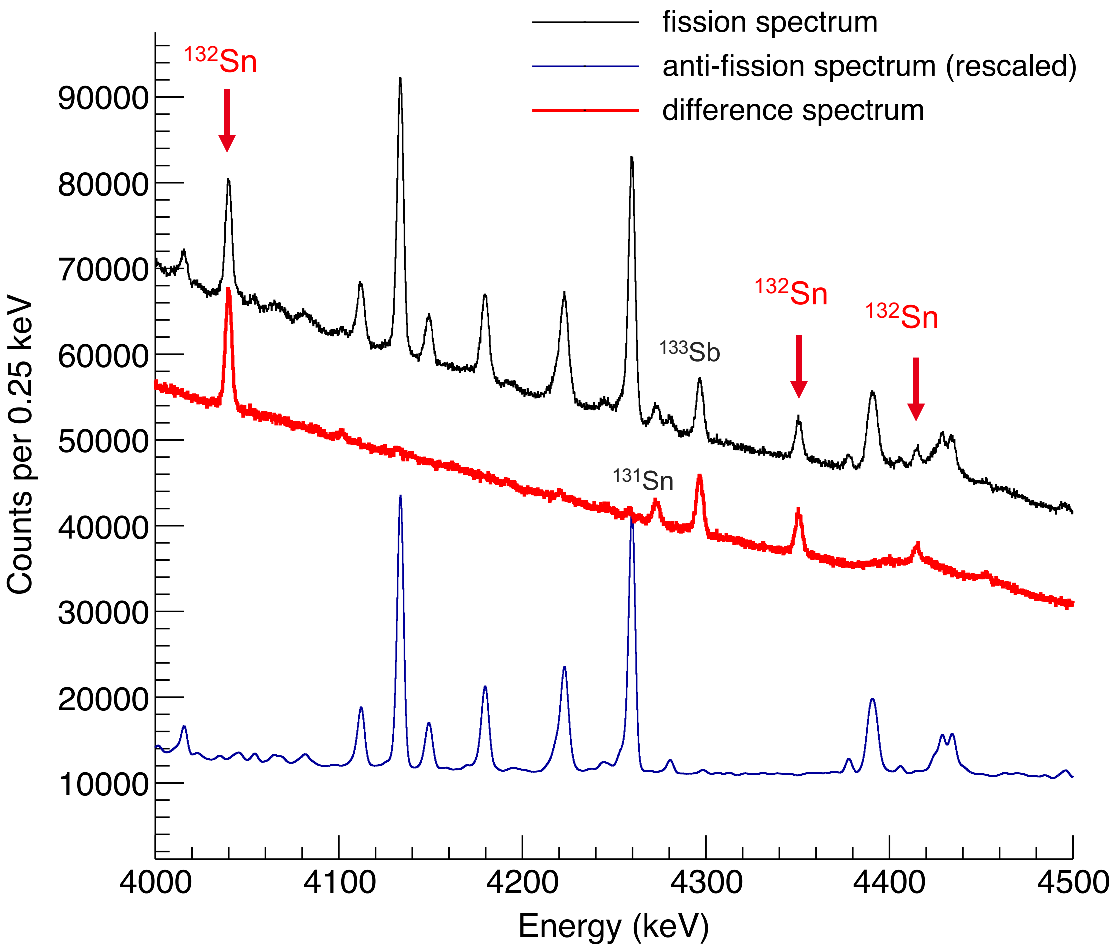
^{132}Sn



$$Y = \frac{N_\gamma(4041) + N_\gamma(4416) + N_\gamma(4352)}{N_{fissions}}$$

^{132}Sn

Pierre Herran PhD result



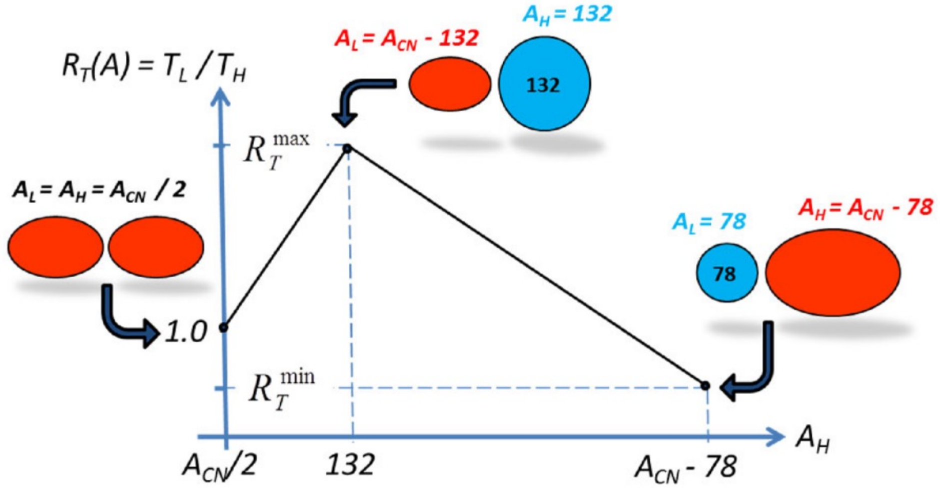
$$Y = \frac{N_\gamma(4041) + N_\gamma(4416) + N_\gamma(4352)}{N_{fissions}}$$

Y = 0.107 (5) % with FIPPS

~ 5 - 7 times smaller
than ENDF/B-VIII : Y = 0.59 (2) %
or JEFF 4.0 : Y = 0.73 (16) %

^{132}Sn

Pierre Herran PhD result



$$Y = \frac{N_\gamma(4041) + N_\gamma(4416) + N_\gamma(4352)}{N_{fissions}}$$

Y = 0.107 (5) % with FIPPS

~ 5 - 7 times smaller
than ENDF/B-VIII : Y = 0.59 (2) %
or JEFF 4.0 : Y = 0.73 (16) %

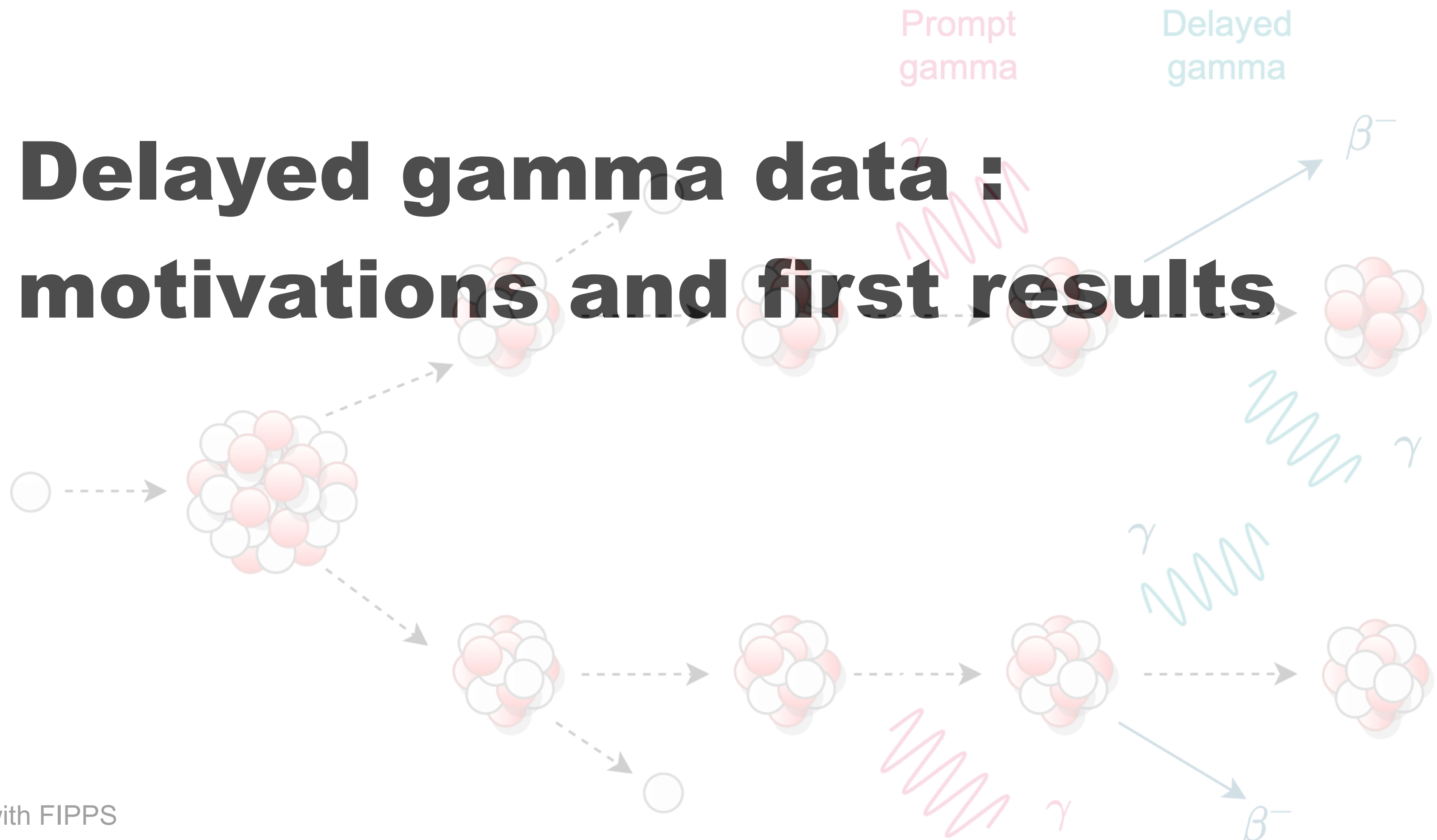
Most of the excitation energy goes to the fission partner of ^{132}Sn because ^{132}Sn is doubly magic and there is no excited level below 4 MeV in ^{132}Sn
→ ^{132}Sn produced mostly in its ground state at fission

FIFRELIN simulation (CGCM + BSFGM + EGLO)

66 % of the GS directly populated by fission
14 % of the GS populated directly after neutron emission

-> 80 % with no emission of gamma

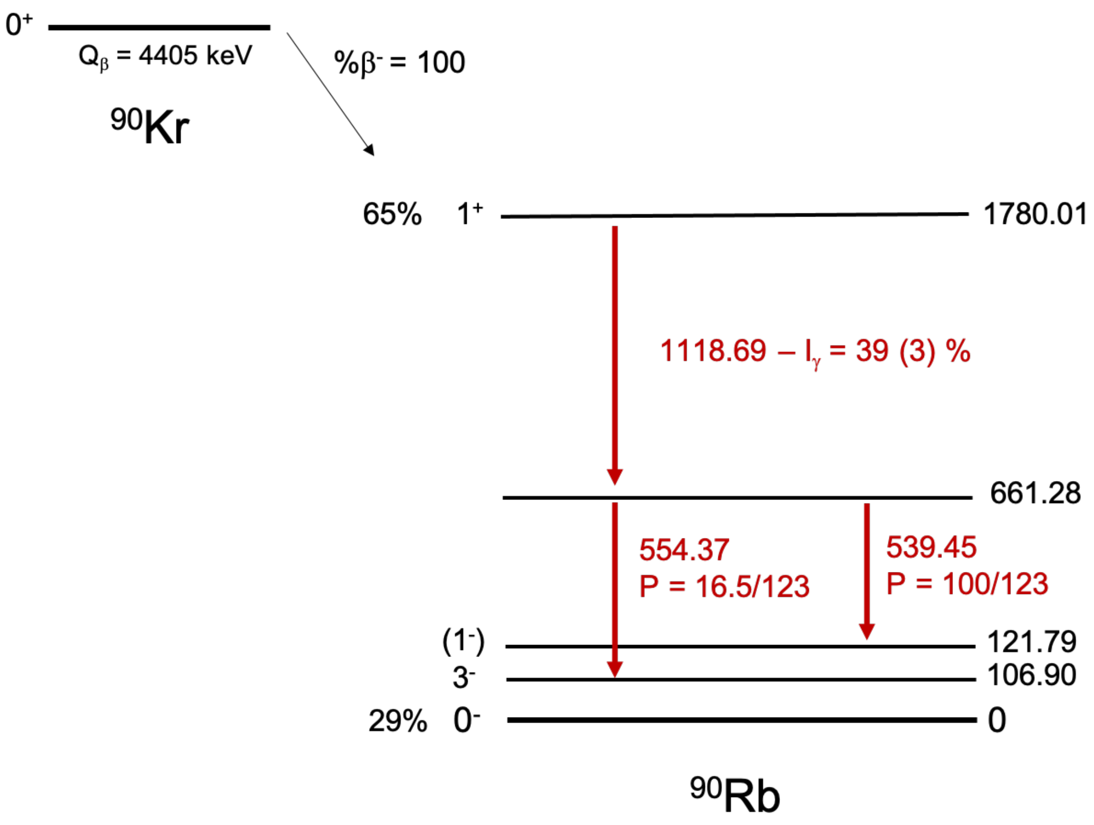
3. Delayed gamma data : motivations and first results



Motivations

- Context of the reactor antineutrino anomaly
- Detection of anomalies in the beta decay intensities or in fission yields
- Test of a phenomenological model of the beta strength function able to correct Pandemonium effect

Method on ^{90}Kr decay



Expected $\gamma\gamma$ coïncidences per fission

$$= Y_{cum}(^{90}Kr) \,.\, I_\gamma(E_1) \,.\, P_\gamma(E_2)$$

$$= 0.0472 * 0.39 * 100/123$$

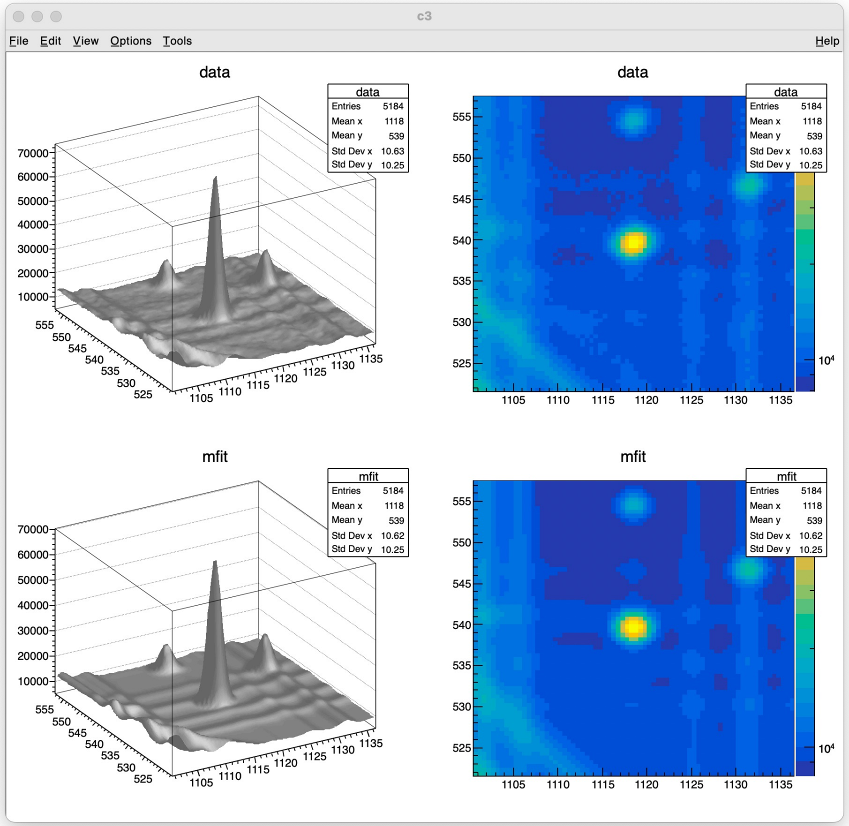
$$= 0.0149\ (12)$$

Method on ^{90}Kr decay

Mattéo Ballu PhD results

Data

2D fit



Expected $\gamma\gamma$ coïncidences per fission

$= Y_{cum}(^{90}Kr) . I_{\gamma}(E_1) . P_{\gamma}(E_2)$

$= 0.0472 * 0.39 * 100/123$

$= 0.0149$ (12)

Measured $\gamma\gamma$ coïncidences per fission

$= N_{\gamma\gamma}(E_1, E_2) / N_{fissions}$

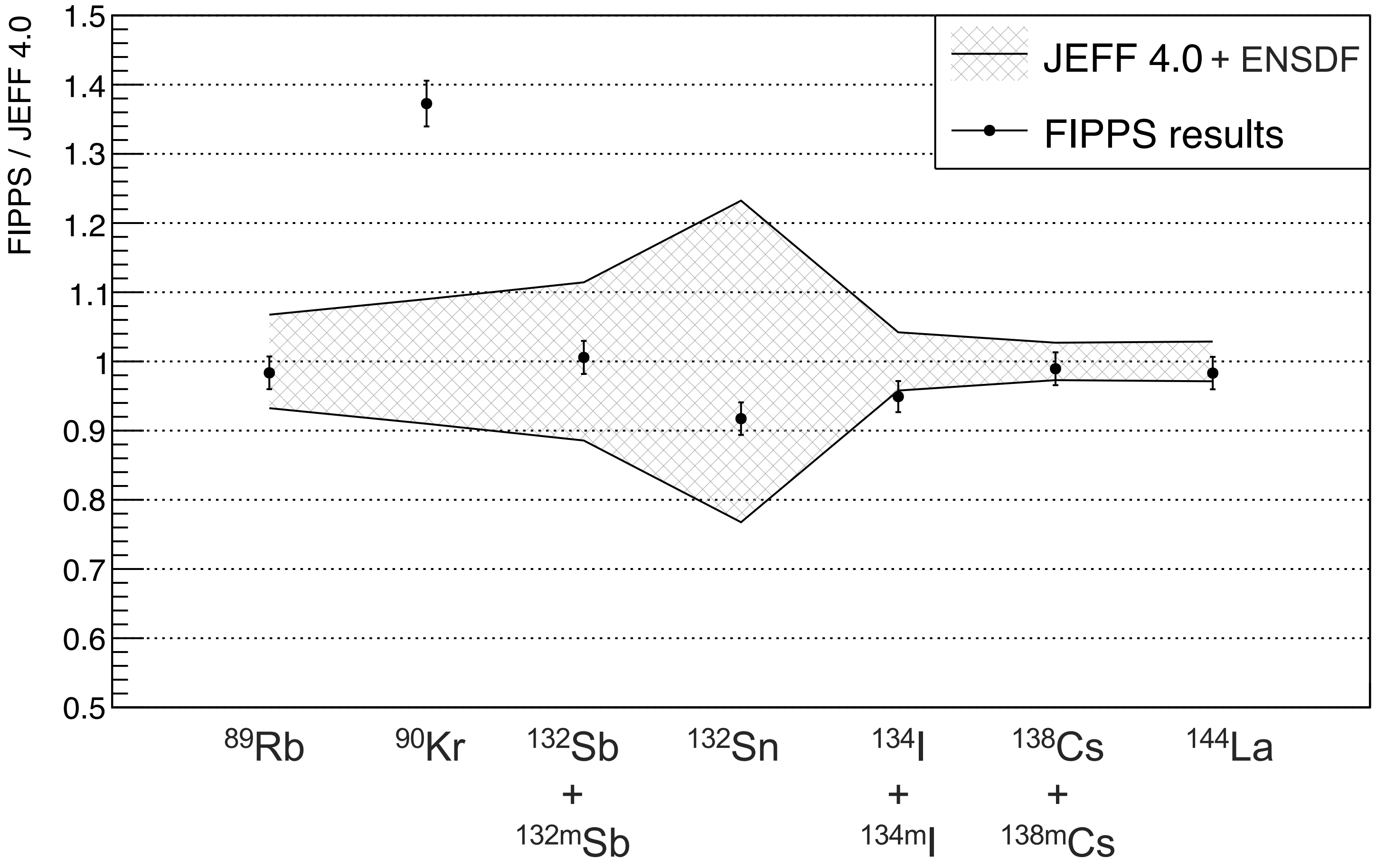
$= 0.0210$ (5)

→ Ratio $\frac{measured}{expected} = 1.4$

Delayed gamma-ray results

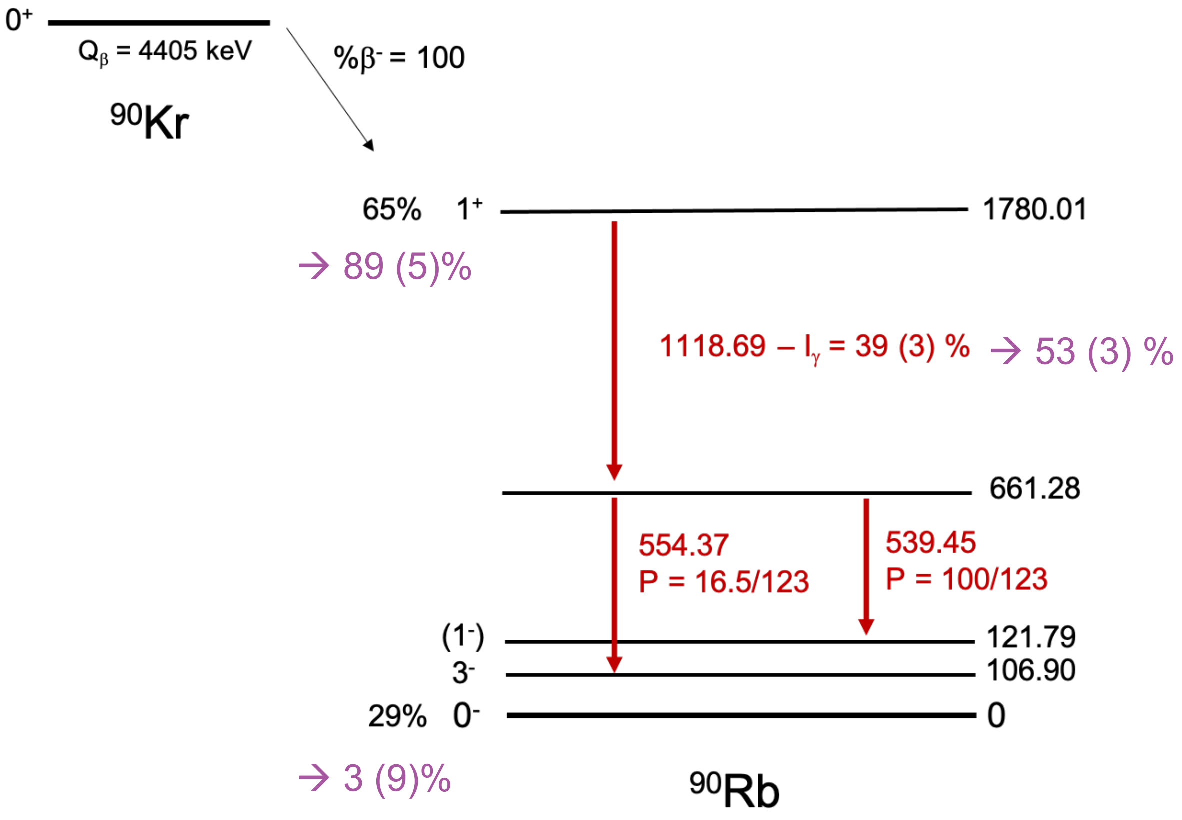
Mattéo Ballu PhD results

$$\frac{N_{\gamma\gamma}(E_1, E_2) / N_{fissions}}{Y_{cum} \cdot I_\gamma(E_1) \cdot P_\gamma(E_2)}$$



Result for ^{90}Kr decay

Mattéo Ballu PhD results



Expected $\gamma\gamma$ coïncidences per fission

$= Y_{cum}(^{90}Kr) \,.\, I_\gamma(E_1) \,.\, P_\gamma(E_2)$

$= 0.0484 * 0.39 * 100/123$

$= 0.0153\ (14)$

Measured $\gamma\gamma$ coïncidences per fission

$= N_{\gamma\gamma}(E_1, E_2) \,/\, N_{fissions}$

$= 0.0210\ (5)$

→ Ratio $\frac{measured}{expected} = 1.4\ (1)$

→ GS feeding $\simeq$ 3 (9) %

Compatible with MTAS measurement at HRIBF by A. Fijałkowska et al., PRL 119,052503 (2017) found GS feeding of 7(1) % instead of 29(4) %

4. Conclusions and Perspectives

Conclusions & Perspectives

Absolute Independent Fission Yields with prompt gamma

- Possible but not applicable for all the nuclei
- Many corrections

Sn-132 mostly produced at ground state in agreement to FIFRELIN assumptions for the sharing of excitation energy

Delayed gamma-ray coincidences are promising to find anomalies in the cumulative fission yields or delayed gamma intensities

- Need cleaner data : another active target with no sapphire, no electronic problems
- Automatize the analysis : ML methods for 2D fitting

Collaboration

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