

Study opportunities with the LOHENGRIN fission fragment separator at ILL

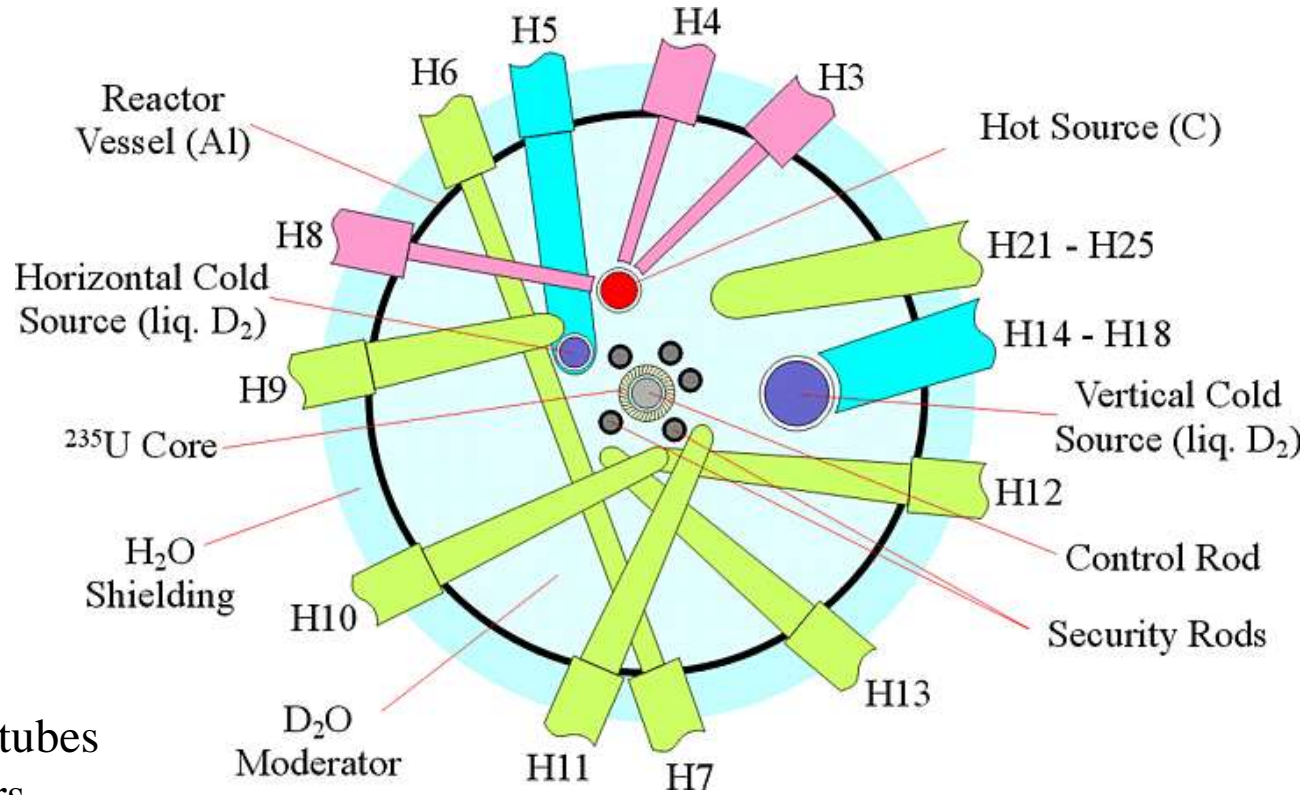
J.M.Daugas

ILL, 71 avenue des Martyrs CS 20156, 38042 Grenoble cedex 9, France



ILL Horizontal guides

Cold
Thermal
Hot
neutrons



Change of beam tubes
every 10 years

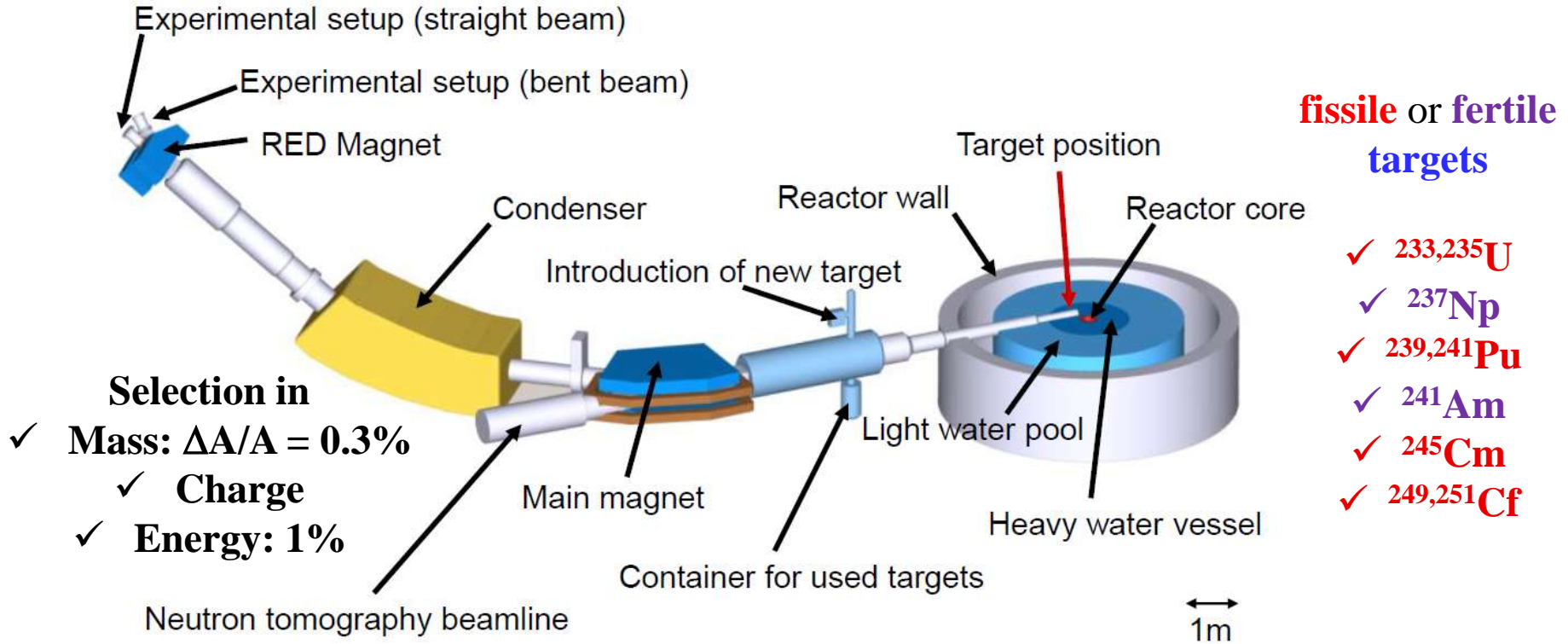
► continuation rejuvenation of the reactor

H9 – PN1 - Lohengrin Spectrometer

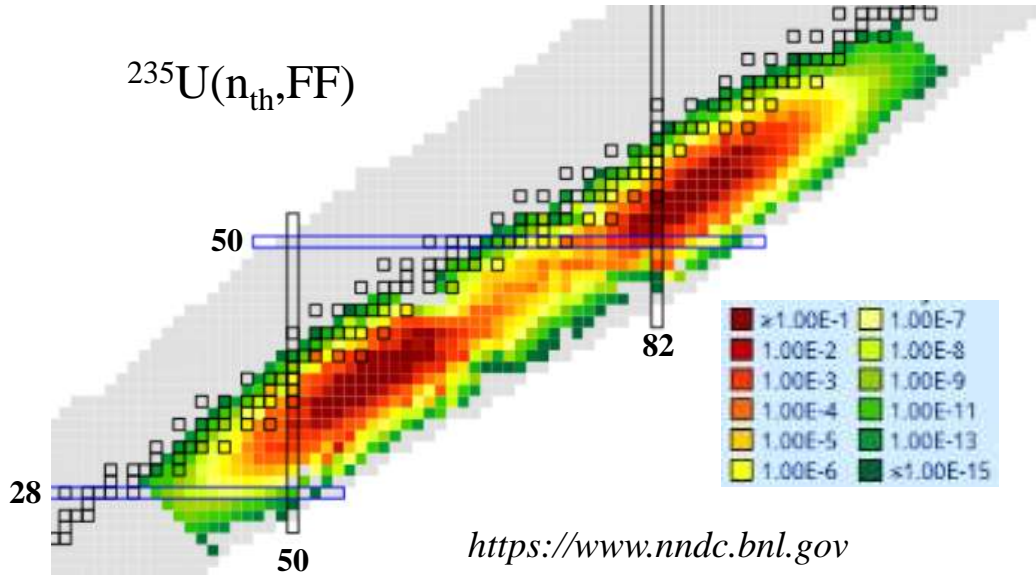
Recoil mass spectrometer for fission fragments

- ✓ Few mg of target in-pile
 - ✓ 5×10^{14} n/cm²/s
 - ✓ 10^{12} fissions per second
-
- ✓ Solid angle $\leq 3.2 \times 10^{-5}$ sr
 - ✓ Time Of Flight $\sim 2 \mu$ s

Lohengrin Spectrometer



Thermal neutron-induced reactions



$$^{235}\text{U} \sigma_f = 585 \text{ b} - ^{245}\text{Cm} \sigma_f = 2141 \text{ b}$$

- ✓ **Fission process** – yields, delayed neutrons
- ✓ **Structure of neutron-rich nuclei** – spectroscopic studies
- ✓ **Industrial applications and Detector characterisations**

Target preparation

Actinide on **Ti** backing

Size 7 x 1 cm² – Thickness 50 to 600 μg/cm²

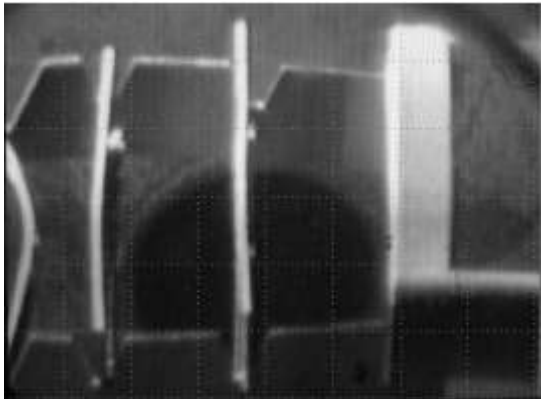
Spot welding
of target
on **target holder**



Target covered
with 0.25 μm **Ni** foil



Target holder and “diaphragm” positions on **target trolley** to **H9** neutron flux

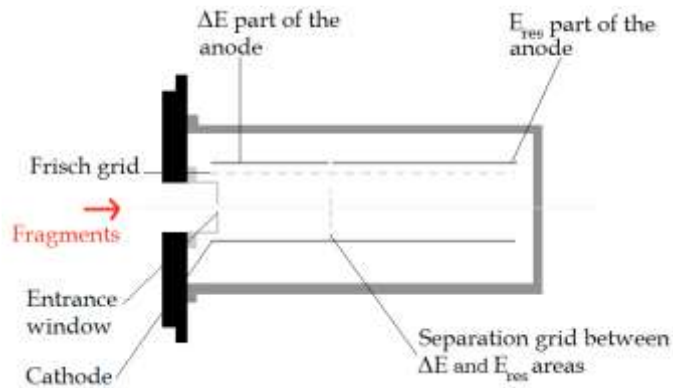


Hot target during **irradiation**
seen with periscope through magnet

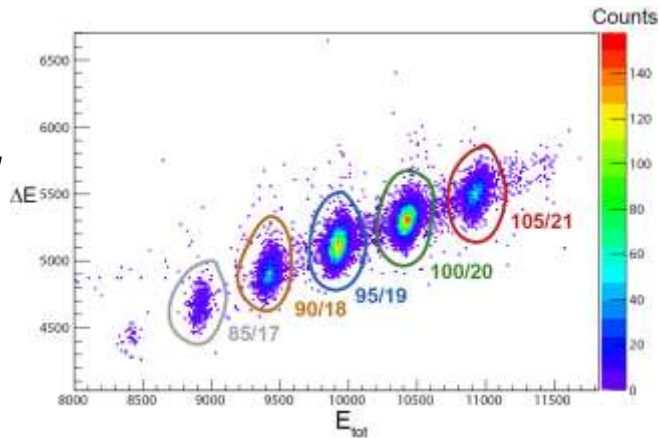


Fragment identification

Ionisation Chambers of different size

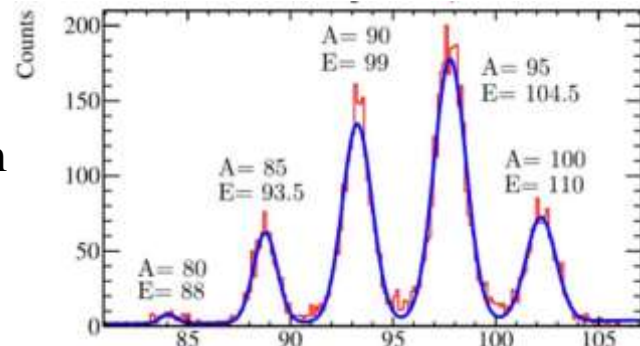


$\Delta E - E$
matrix

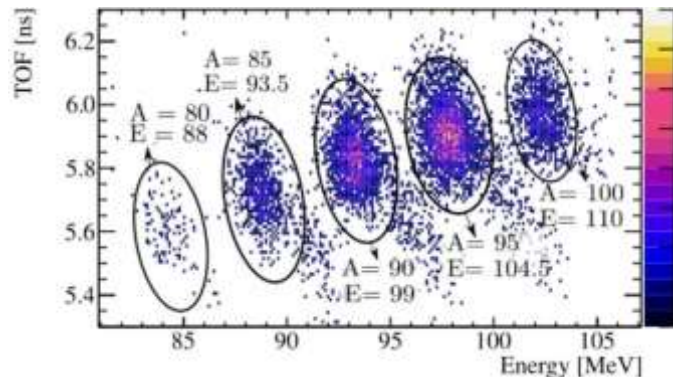


PIPS detector + MCP

E spectrum



$TOF-E$
matrix



A.M. Gómez L., A. Al Adili et al., *Eur. Phys. J. A* 61, 51 (2025)

Fission yields

Ionisation Chamber

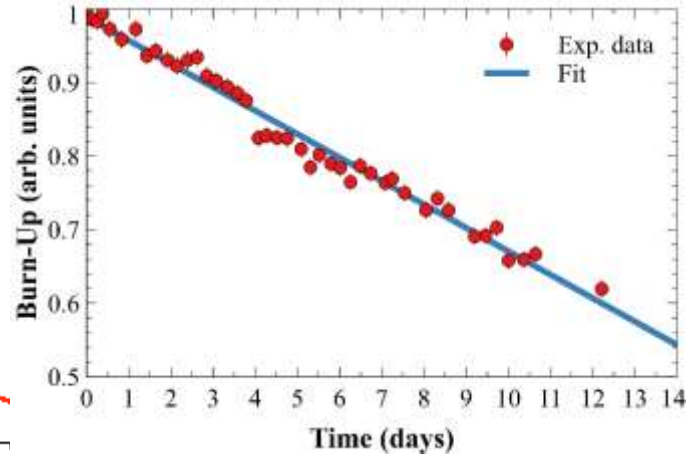
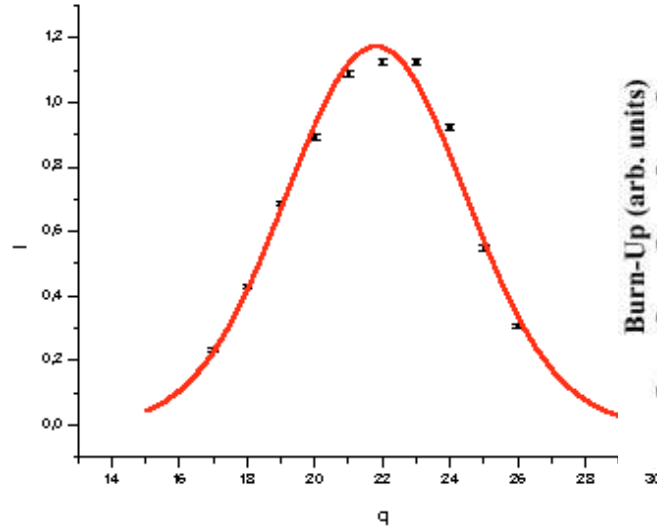
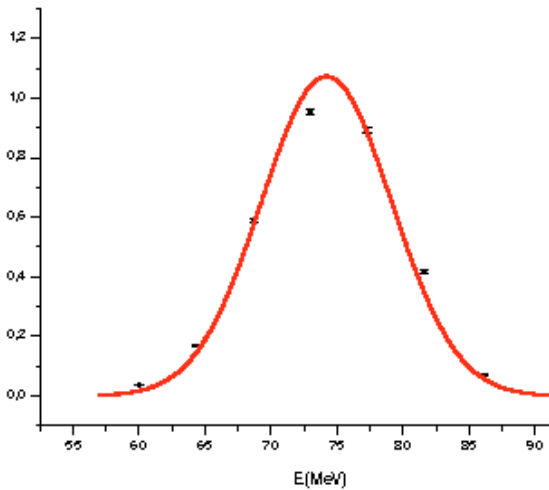
Mass yield measurements

See O. Serot talk

Energy distribution

Ionic charge distribution

Burn up



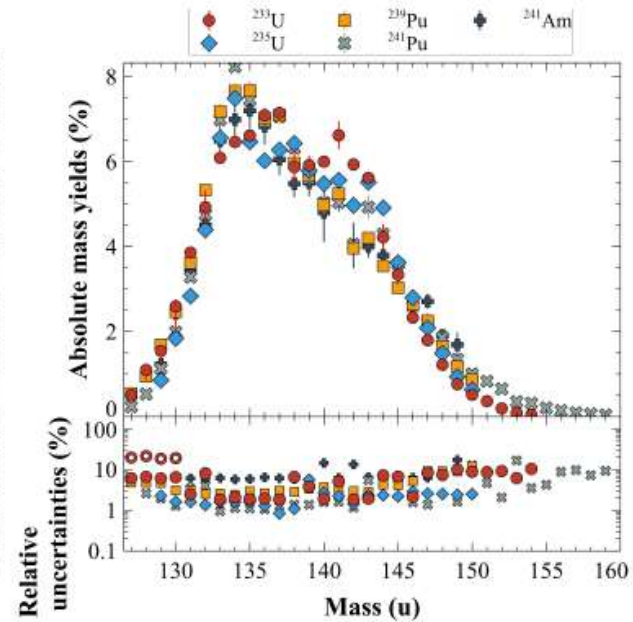
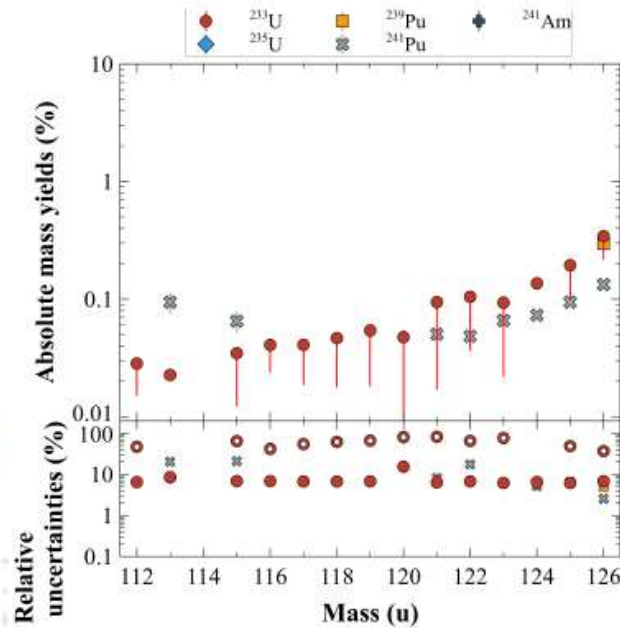
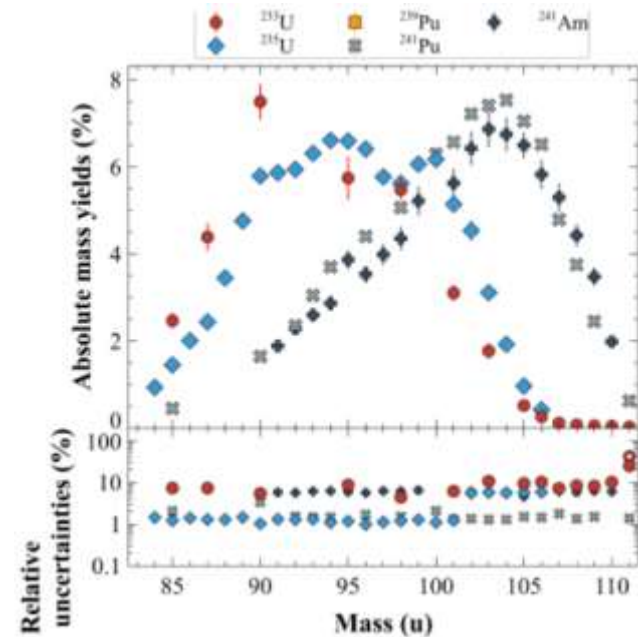
Fission yields

Courtesy A. Chebboubi et al., 'Fission Yields of Actinides', to be published in Eur. Phys. Journal A

Light mass region

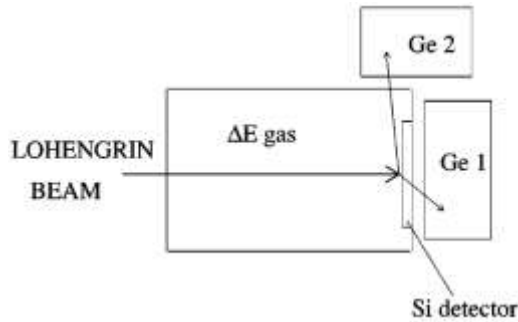
Symmetric mass region

Heavy mass region

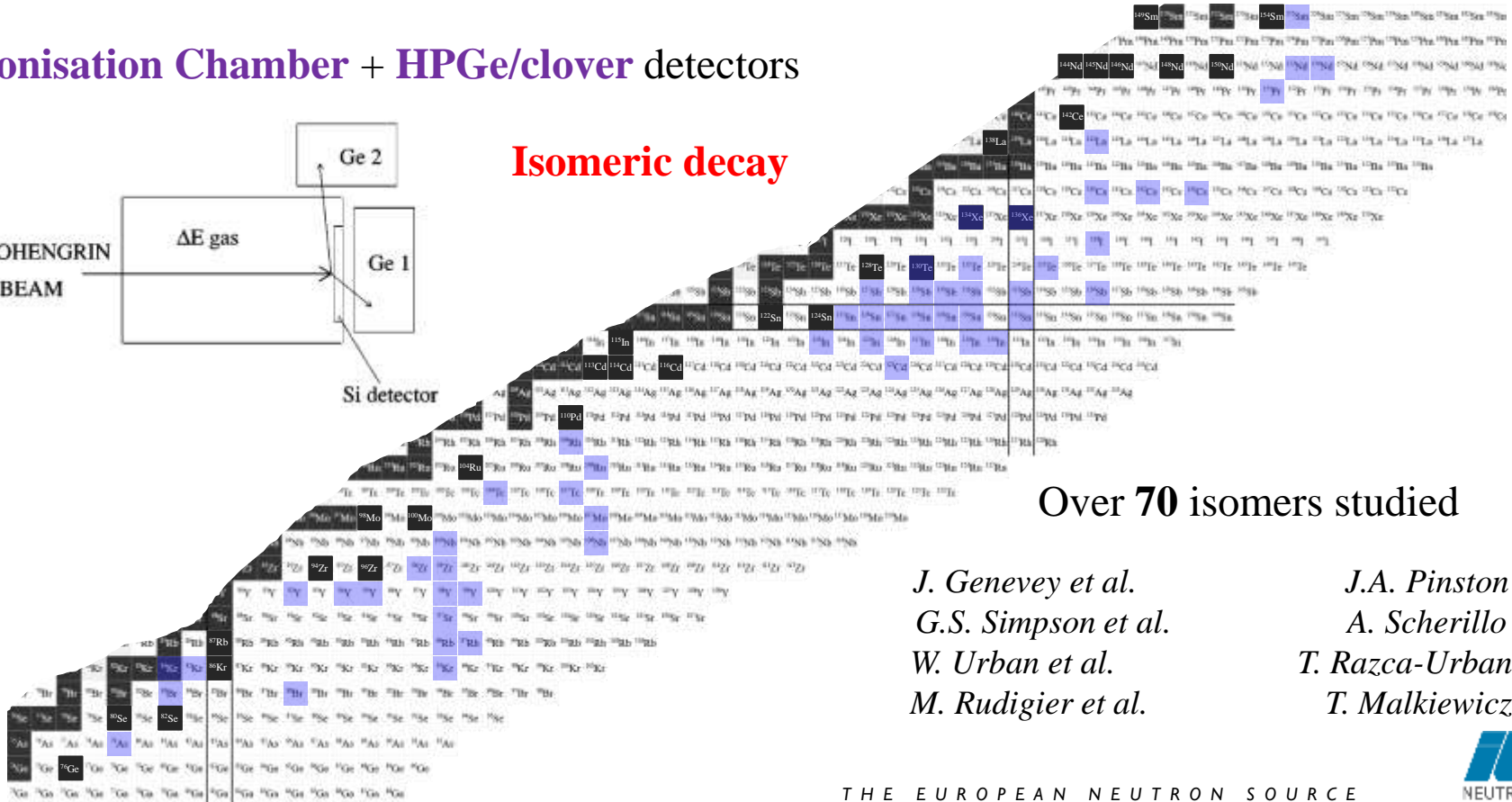


Discovery/study of μ s-isomers

Ionisation Chamber + HPGe/clover detectors



Isomeric decay



Over 70 isomers studied

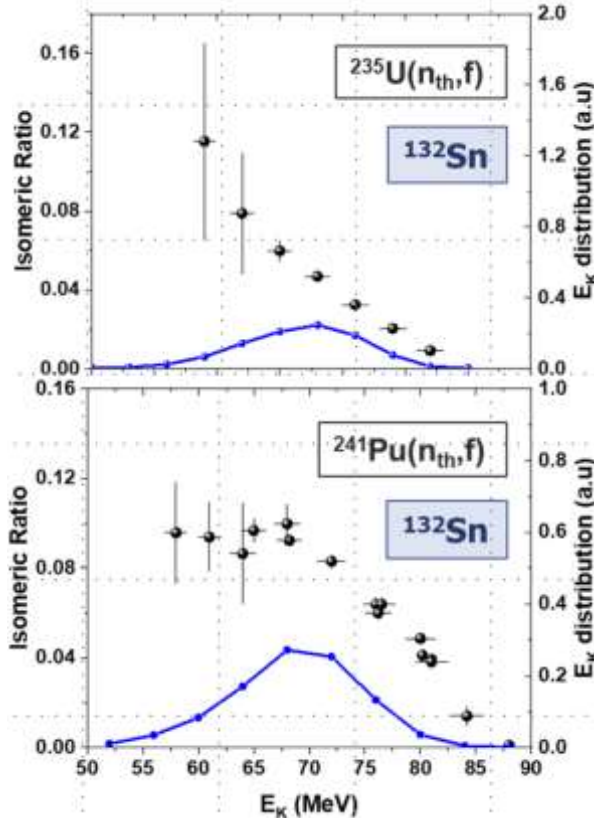
J. Genevey et al.
G.S. Simpson et al.
W. Urban et al.
M. Rudigier et al.

J.A. Pinston et al.
A. Scherillo et al.
T. Razca-Urban et al.
T. Malkiewicz et al.

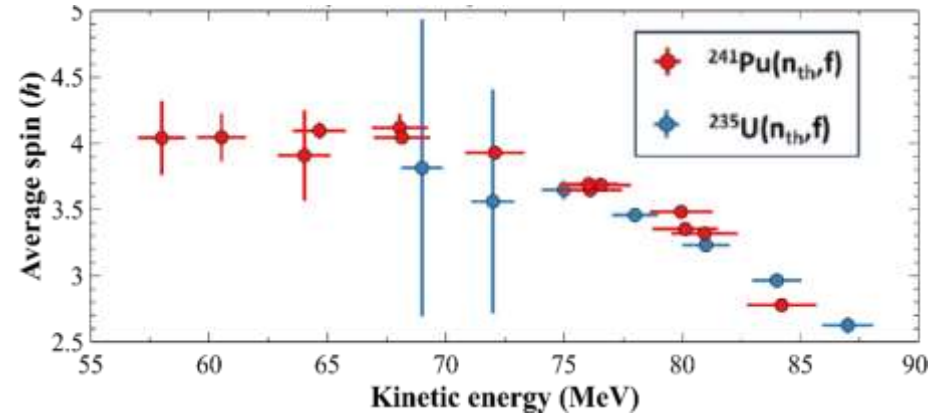
Isomeric ratio

Ionisation Chamber + HPGe/clover detectors

FY See O. Serot IR See A. Skouloudaki talks



From IR and thanks to the Monte Carlo FIFRELIN code
total angular momentum deduced

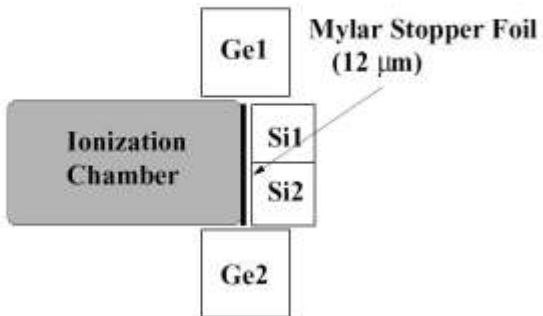


A. Chebboubi et al., EPJ web of Conference (2016)
A. Chebboubi et al., Phys. Lett. B775,190-195 (2017)
J. Nicholson, A. Chebboubi, O. Serot, et al.,
EPJ Web of Conferences 256, 00011 (2021)

Conversion electron spectroscopy

Ionisation Chamber + HPGe/clover + Si(Li) detectors

electron and X-ray



^{241}Pu target – selection $A = 97$

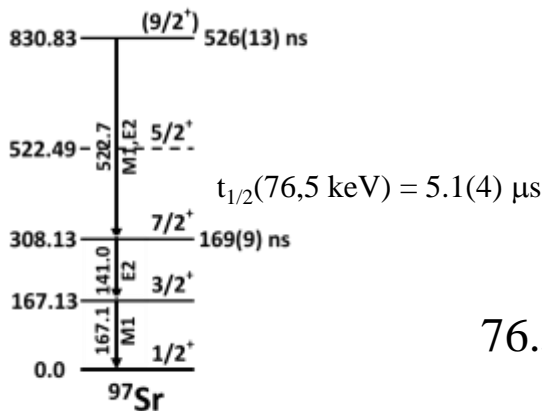
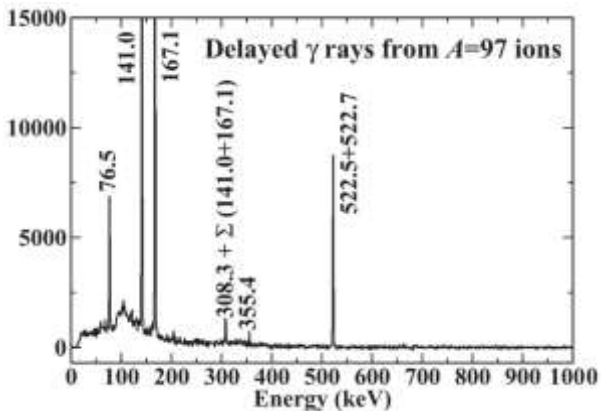
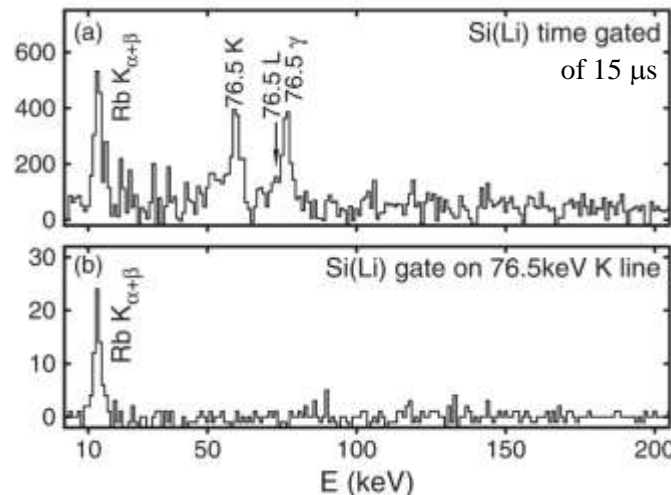
^{97}Rb 6.8×10^{-4}

^{97}Sr 1.5×10^{-2}

^{97}Y 4.4×10^{-3}

^{97}Zr 7.5×10^{-3}

^{97}Nb $8.8 + 2.0 \times 10^{-5}$



detection down to **10 keV**

76.5 keV unambiguously assign to ^{97}Rb

Fast-timing

HPGe/clover + LaBr₃ detectors + Plastic scintillator

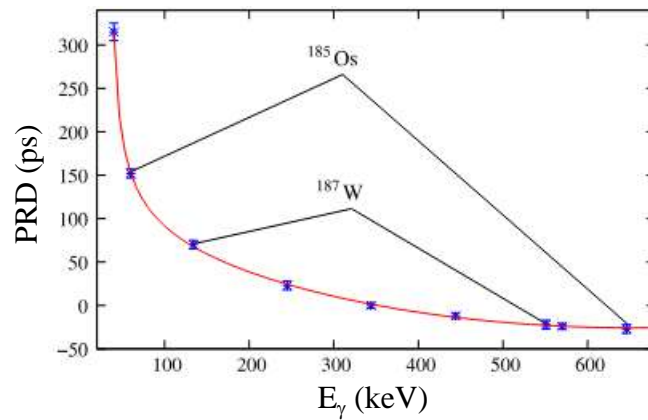
β , γ , τ in ps – ns range



See *J. Fisher talk*
L.L. Luperi talk

Use of ¹⁵²Eu, ¹³³Ba and ²⁰⁷Pb sources

²⁴Na (15 h), ¹⁴⁰La (1.7 d), ¹⁸⁵Os (93.6 d),
¹⁸⁷W (24 h), ¹⁹⁸Au (2.7 d) sources



Prompt Response Difference **PRD**

Non-linearity energy-dependent **time-walk**

Over **30** states studied

J.M. Regis et al.
S. Bottoni et al.
D. Kumar et al.

A. Pfeil et al.
A. Esmaylsadeh et al.
G.S. Simpson et al.

Nuclear moments

LaBr₃ detectors + SiPM

Time-Differential Perturbed Angular Correlation

TDPAC

g-factor

in non-perturbative crystal - \mathbf{B}_{ext}

in ferromagnetic crystal - \mathbf{B}_{hf}

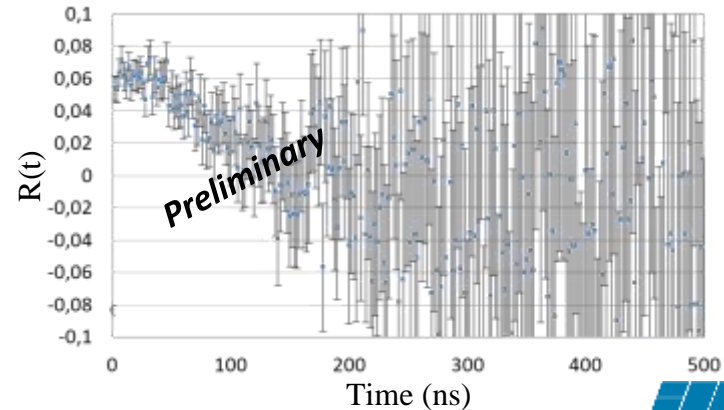
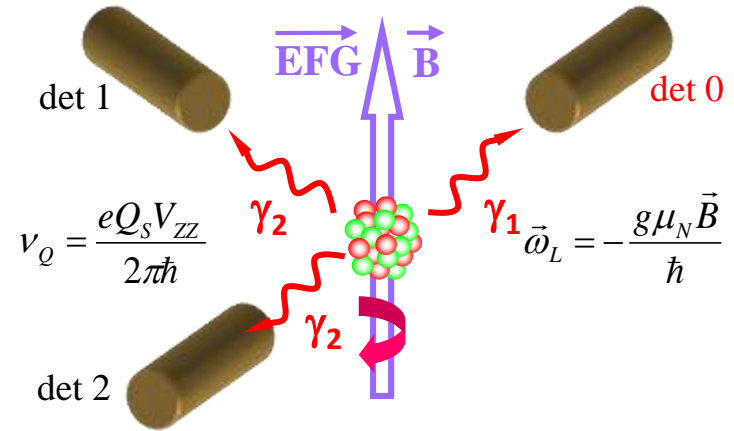
⁹⁸Y See D. Friant talk

¹³⁰Te and ¹³⁴Te analysis in progress

Q-moment

in poly or single crystal - V_{ZZ}

⁹⁸Y analysis in progress



Detector test

Particle detectors: **Ionisation chamber**, **Si**, **diamond**, etc...

From the **target holder**

$^{14}\text{N}(n,p)$ p, E = 0.58 MeV
 $^{59}\text{Ni}(n,p)$ p, E = 1.83 MeV
 $^{59}\text{Ni}(n,\alpha)$ α , E = 4.75 MeV
Ni recoils
Ti recoils
O recoils

From the **environment**

$^{10}\text{B}(n,\alpha)$ α , E = 1.47 MeV
 $^7\text{Li}^*$, E = 0.84 MeV
 $^{10}\text{B}(n,\alpha)$ α , E = 1.77 MeV
 ^7Li , E = 1.01 MeV
 $^6\text{Li}(n,\alpha)$ α , E = 2.05 MeV
 t, E = 2.73 MeV

From a **fissile target**

Fission fragments, E = 40 to 120 MeV

Ternary fission α , E = 6 to 13 MeV

Concluding remarks

High neutron flux ILL reactor

LOHENGRIN: world-unique **fission fragment separator**

- ✓ Study of **fission yields, isomeric ratios** and **dynamics**
 - Improvement of accuracy;
- Development of a TOF method to clean contaminated masses;
 - Testing of evaluation codes;
- ✓ Investigation of the structure of **neutron-rich nuclei** close and far from stability
 - Search of μ s-isomers, β -decay, and conversion electron spectroscopy,
 - Fast-timing and Nuclear moment measurements
 - ✓ Particle **detector** tests

Acknowledgements and contacts

Ulli Koester – Lohengrin responsible

Paolo Mutti – DAQ and detectors/electronics responsible

ILL staff

Spokespersons, users and collaborators

Proposal submissions **mid-February**
 mid-September

Do not hesitate to contact us

Thank you for your attention