Nuclear fission research at JRC GEEL

or

Fission Observables from Direct Kinematics

Stephan Oberstedt

European Commission, Joint Research Centre, G.6, 2440 Geel (BE)

WONDER 2026: 7th edition of the International Workshop On Nuclear Data Evaluation for Reactor Applications

Aix-en-Provence (FR), June 29 – July 3, 2026

European Commission

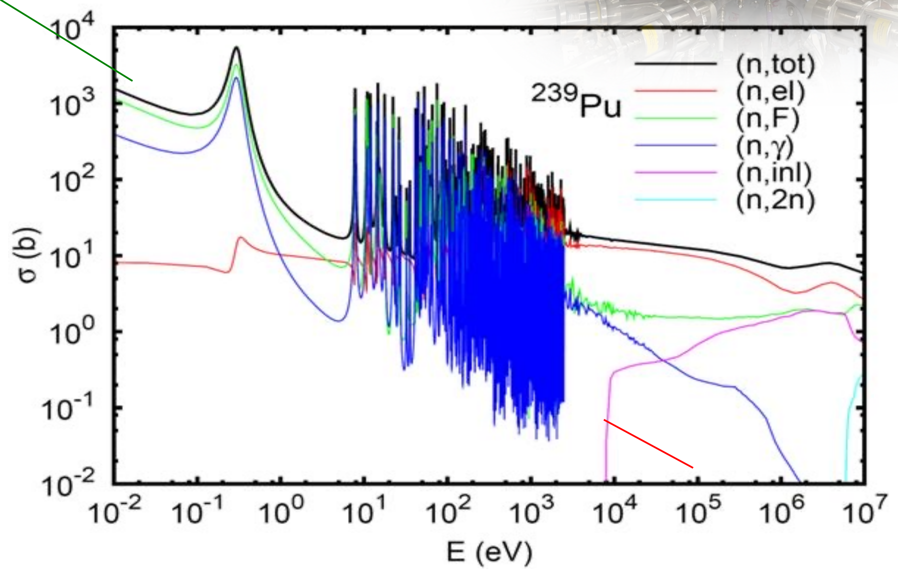
To start with …

- Just a bit about our research facilities at JRC
- Cross-section measurements at JRC
- Fission-fragment yield measurements
- A little bit of ternary fission?
- Is there an (n, γf) process in $^{235}U(n_{RR}, f)$ and $^{239}Pu(n_{RR}, f)$
- Systematic PFGS characterisation
- Isomer-to-prompt yield ratios
- The shape isomer in ^{237}U

The JRC G.6 neutron facilities (Geel, BE)

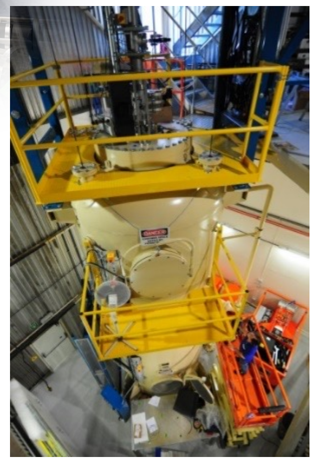
Time-of-flight measurements

GELINA



VESPA++ @MONNET

MONNET



Mono-energetic higly-intense neutron beams

Cross section measurements @ JRC

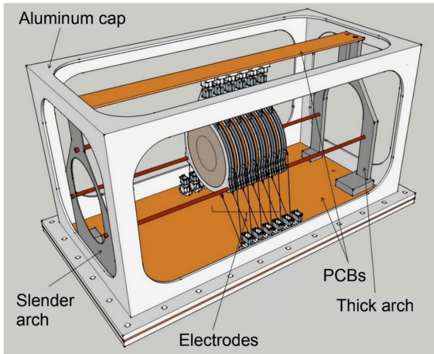
- **CHARPU : ^{239}Pu cross section complementing n_TOF capture and fission experiments, 36225/2/2021-1-RD- EUFRAT-GELINA (for more details, listen to** Adrian Sanchez Caballero **later today)**

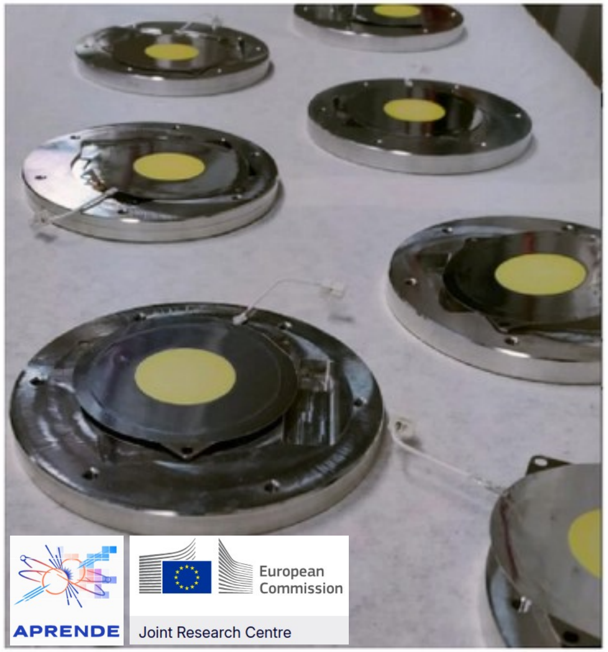
- **^{241}Pu capture and fission cross sections @GELINA (for more details, listen to** Aline Cahuzac **following Adrian's talk)**

- **MENPHIS** #1 & **#2: ^{240,242}Pu(n,f) cross-section measurement in the threshold region, 37362/1/2026-1-RD- EUFRAT-MONNET (for more details about the ^{242}Pu campaign, listen to** Salma El Hessak, **high noon on Thursday)**

Cross section measurements @ JRC

- EPIC : 238, 242,240Pu fission cross section measurements 700 keV up to 25 MeV (3%)
- Sample preparation at large numbers by our TP-group





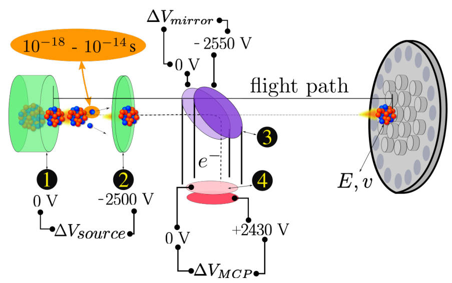
stolen from: A. Chatillon et al., P(ND)^2-3 : Perspectives on Nuclear Data for the Next Decade (2026)

- Test beam-time at FP16@7m reported to Sep.'26 due to malfunctioning of GELINA

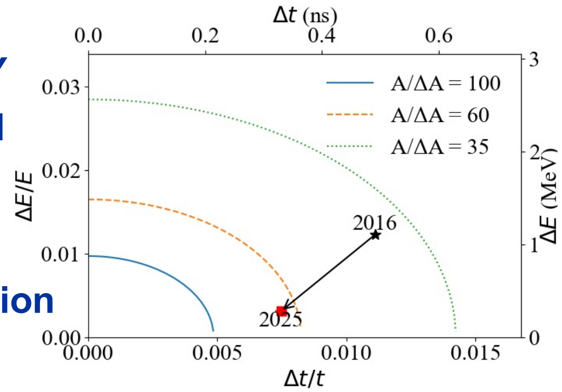
VERDI and ^{248}Cm(sf) post-neutron FF yields

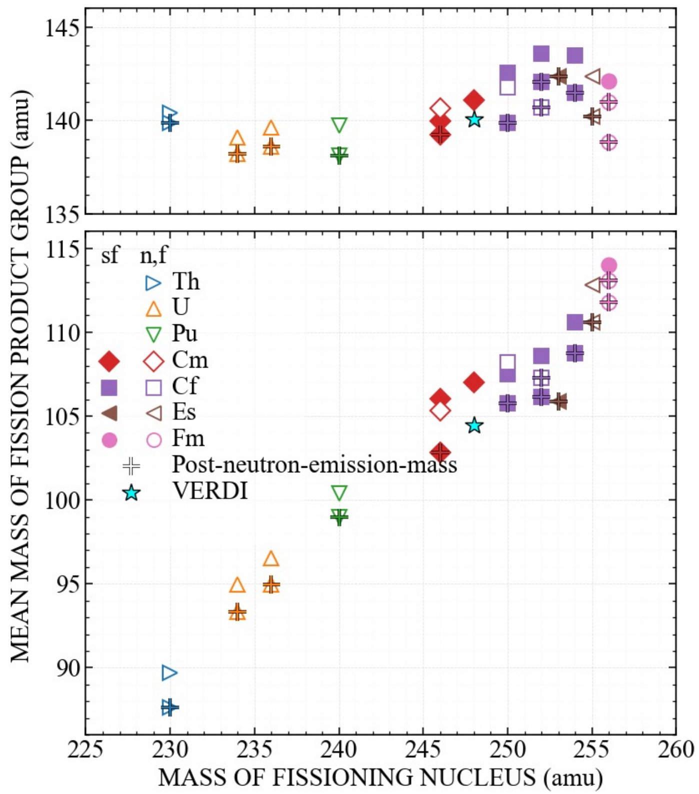
Optimization of the fission-fragment TOF spectrometer VERDI 2.0

- transition to digital DAQ (ADQ36)
- optimization: PA and waveform analysis
- calibration of 32 time & energy channels



- ^{248}Cm(sf): direct measurement of IFY
- ^{248}Cm(sf): ternary fission with VERDI

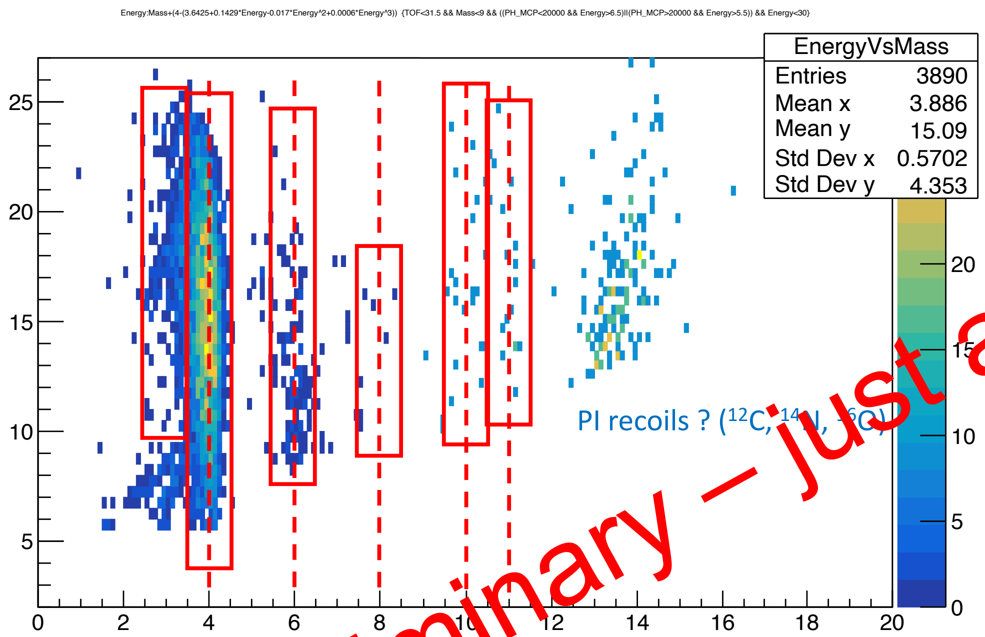


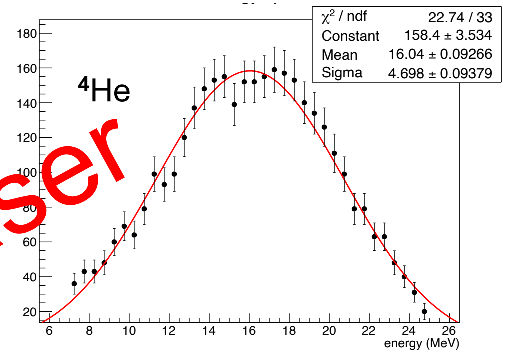


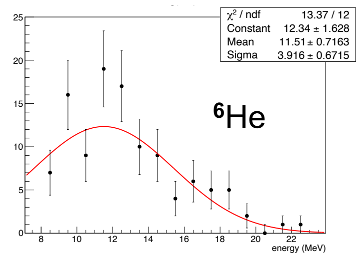
- more details just after this presentation
- PhD thesis of Ana M. Gomez L. (UU)

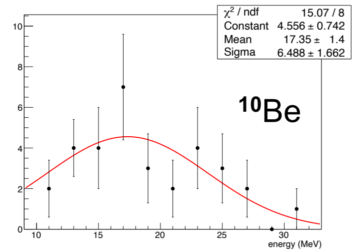
Ana M. Gomez L., A. Al-Adili, …, S. Oberstedt, Eur. Phys. J A (2025) 61:51
Ana M. Gomez L., S. Oberstedt …, A. Al-Adili, 1083 (2026) 171061
Ana M. Gomez L., S. Oberstedt, …, A. Al-Adili, Phys. Rev C (submitted)

VERDI, ^{248}Cm(sf) and some ternaries





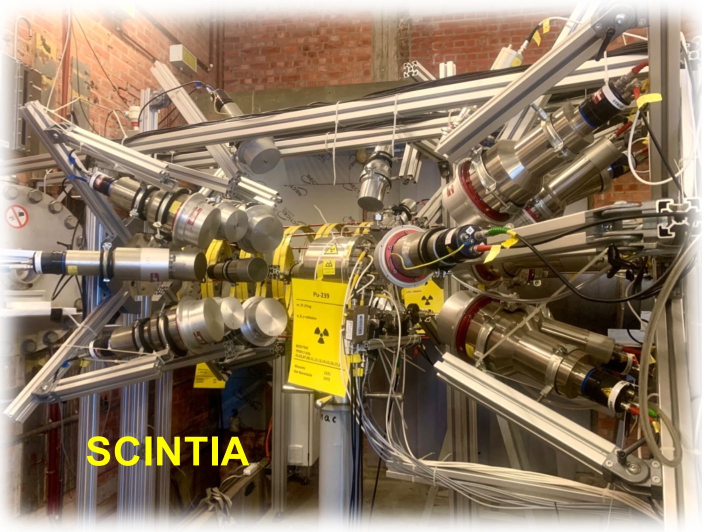




Ana M. Gomez L., S. Oberstedt, A. Oberstedt …, A. Al-Adili, confirmation of experimental results pending

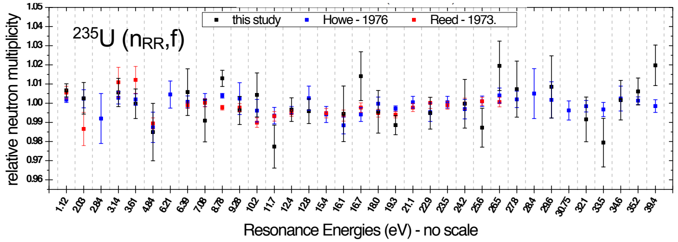
ν_p fluctuations and the (n, γf) process

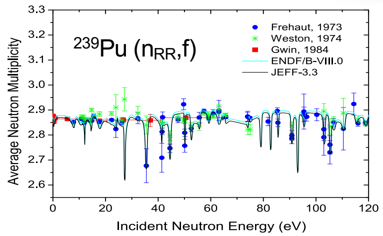
- ⤇ ν_p fluctuations observed in ^{235}U and ^{239}Pu
- ⤇ suspected that this could be due to the (n, γf) process



- ➢ 1st step: Y(A*, TKE; ν_p)
- ➢ 2nd fission mode analysis to quantify impact of Y(A*, TKE) changes
- ➢ 3rd obtain ν_p and spectrum

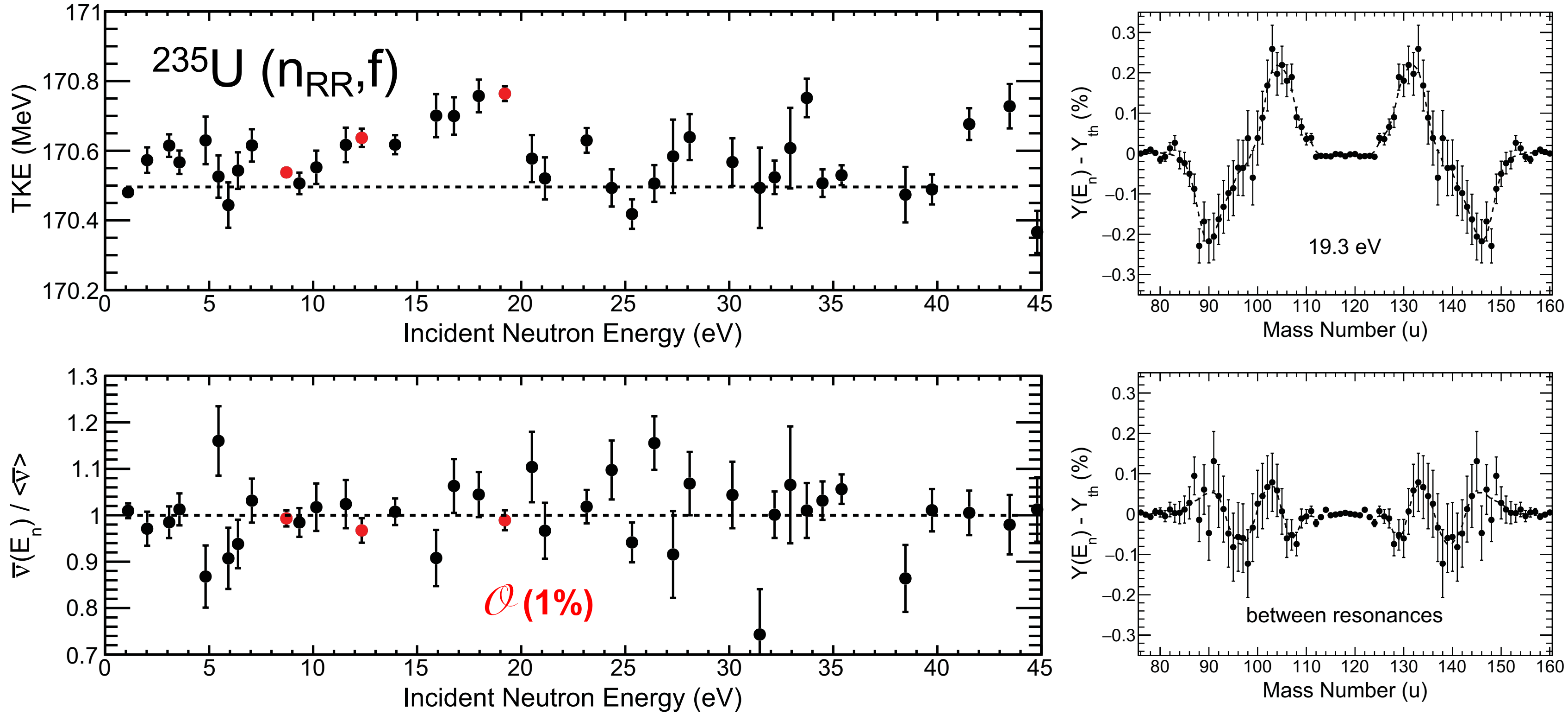
- ➢ HPRL-ID 99 (ν_p, E_n < 5 eV) and HPRL-ID 9 (PFGS, $E_{n,RR}$)
- ➢ experimental part of Candisse Daire's PhD thesis





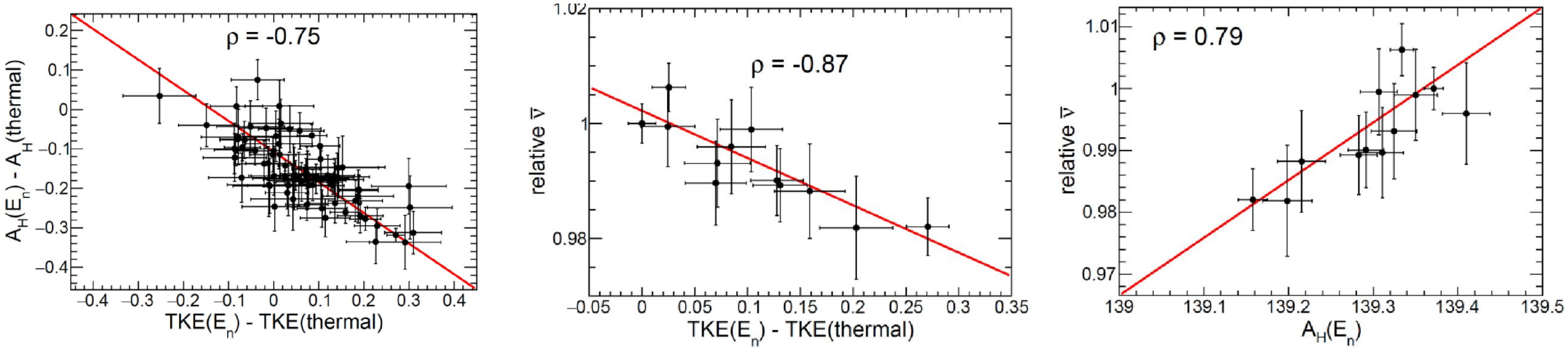
APRENDE: REsonance neutron **MU**ltiplicity in Fi**S**sion, **WP 2, Task 2.2, SUBTASK 2.2.3**

ν_p fluctuations and the (n, γf) process



ν_p fluctuations and the (n, γf) process

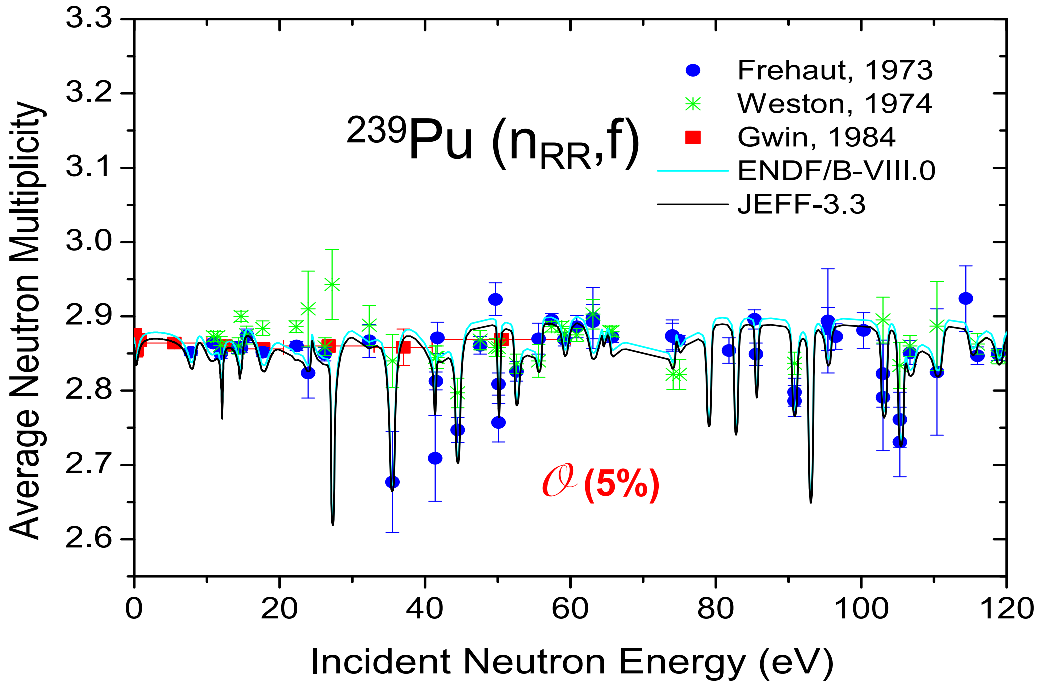
$^{235}U(n_{RR},f; I^{\pi} = 3^-,4^-)$



- **In $^{235}U(n,f)$ the $\nu_p(E_{n,RR},f)$ fluctuations are essentially due to fluctuations in Y(A*, TKE)**

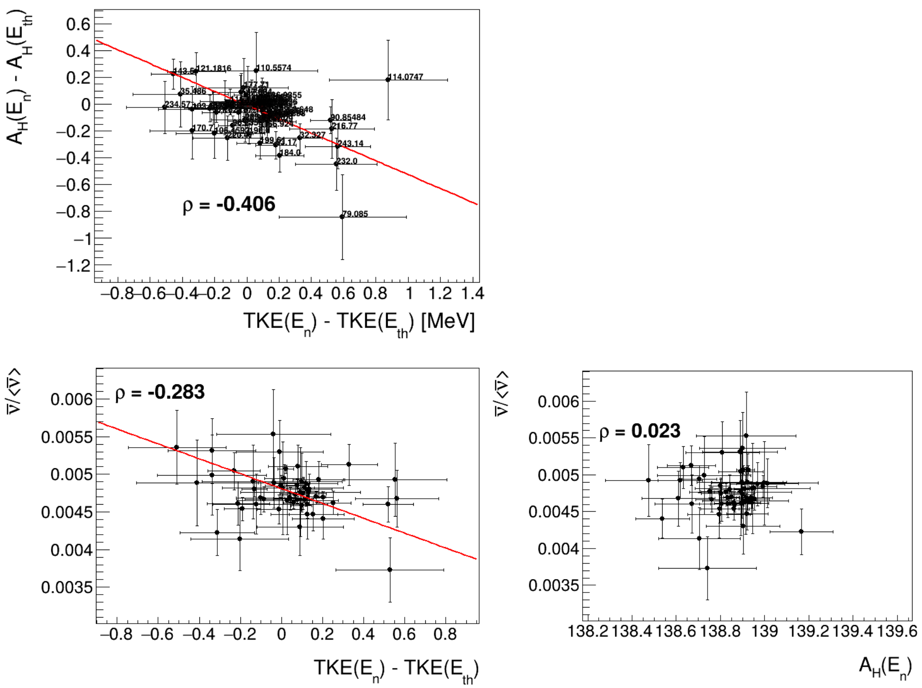
ν_p fluctuations and the (n, γf) process

$^{239}Pu(n_{RR},f;\ I^{\pi} = 0^+,1^+)$

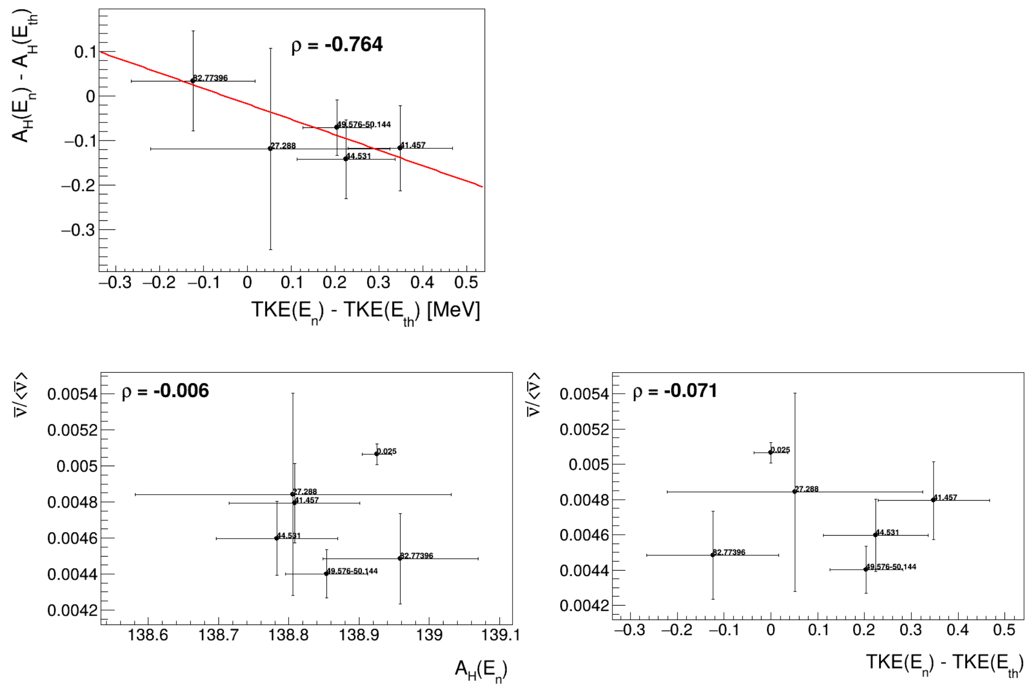


ν_p fluctuations and the (n, γf) process

^{239}Pu(n_{RR},f; I^{π} = 0^{+})



^{239}Pu(n_{RR},f; I^{π} = 1^{+})



ν_p fluctuations and the (n, γf) process

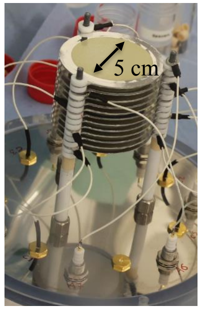
- Competition between (n,f) and (n,γf) reaction
- (n,γf) => emission of a γ ray before the saddle point is passed
- γ-ray energy of the order of 800 keV (≈ 0.1 n)
- 1^+ resonances possess small Γ_f !

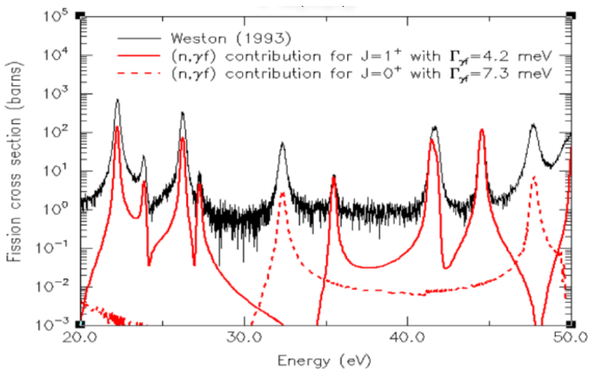
J. E. Lynn, P. Talou and O. Bouland, Phys. Rev. C97 (2018) 064601

E. Leal-Cidoncha, G. Noguere, O. Bouland and O. Serot, EPJ Web of Conferences 211 (2019) 02004

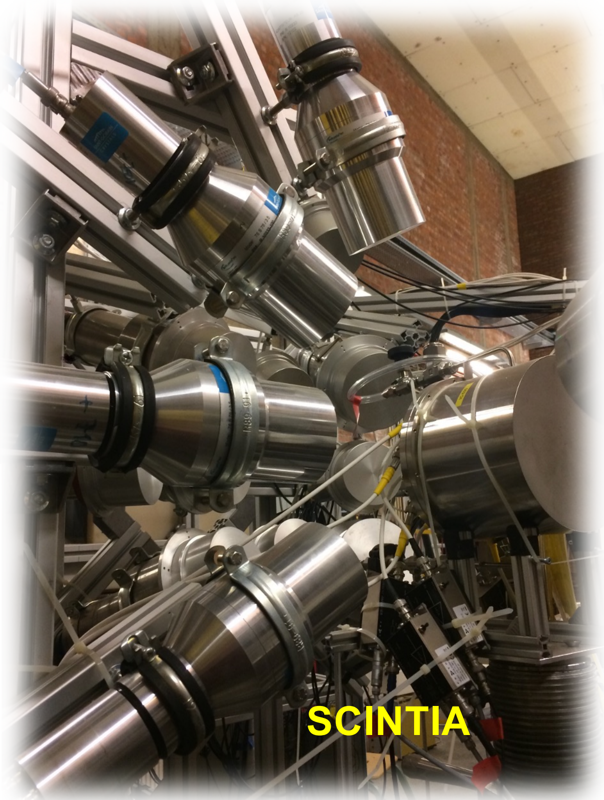
C. De Saint Jean, R. McKnight, NEA/WPEC, Report NEA/NSC/WPEC/DOC(2014)34(2014)

- 12 ^{239}Pu layers (≈ 28 mg)
- GELINA @ 400Hz, L = 8.81 m



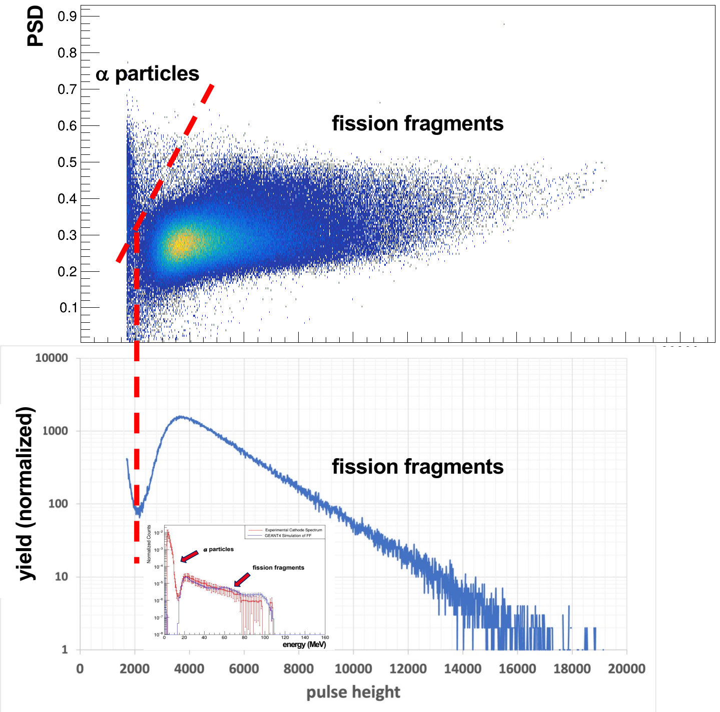


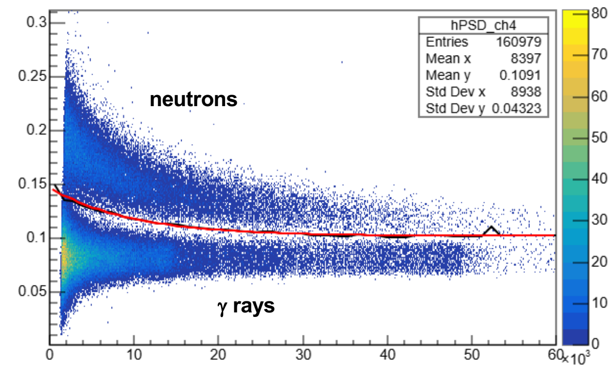
E_{res} (eV)	Γ_f (meV)	Exp. stat. Unc (%)
27.29	2.8	5
35.49	3.5	2.3
41.46	6.4	0.9
44.53	4.4	0.9
50.14	5.0	0.6
82.77	5.2	1.1

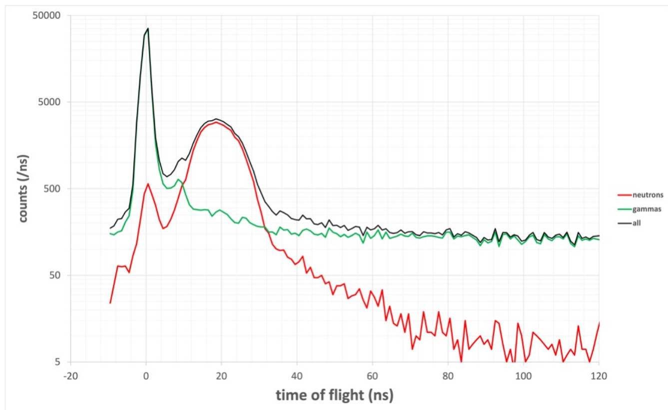


ν_p fluctuations and the (n, γf) process

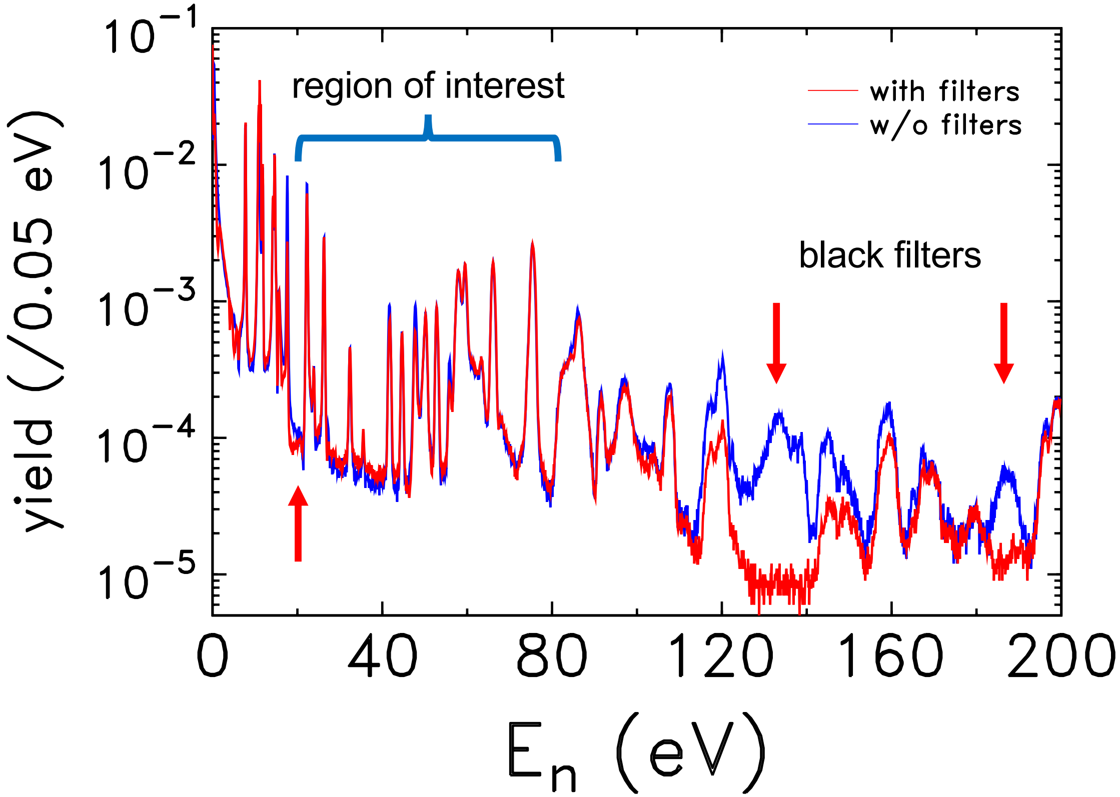
- 22 fast-neutron detectors (EJ301, stilbene, …
- 4 $LaBr_3$ detectors (76 mm × 76 mm)



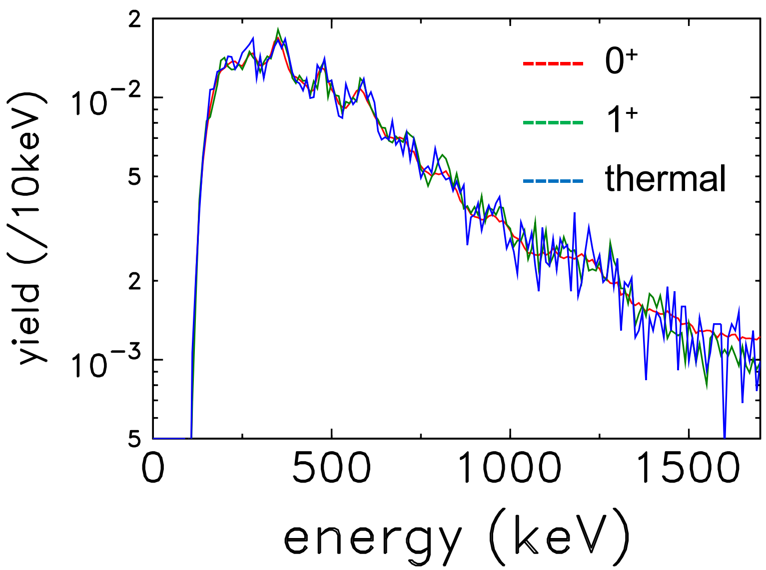


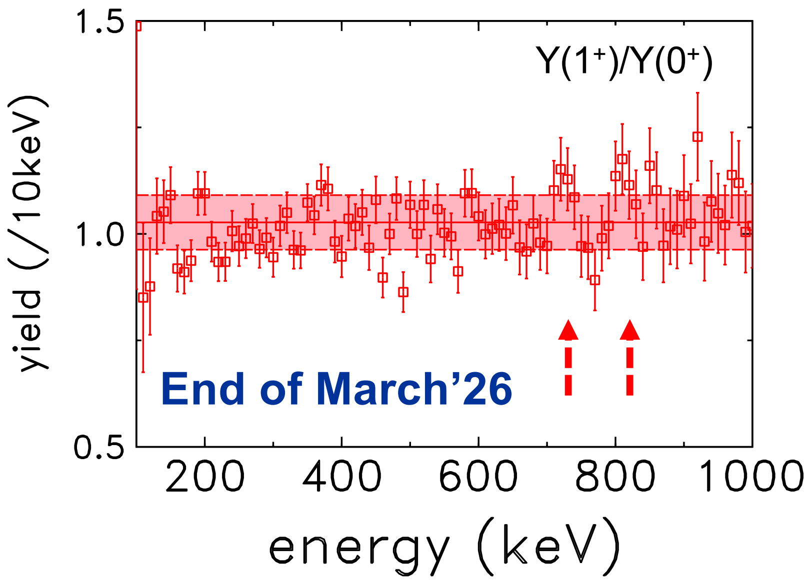


ν_p fluctuations and the (n, γf) process



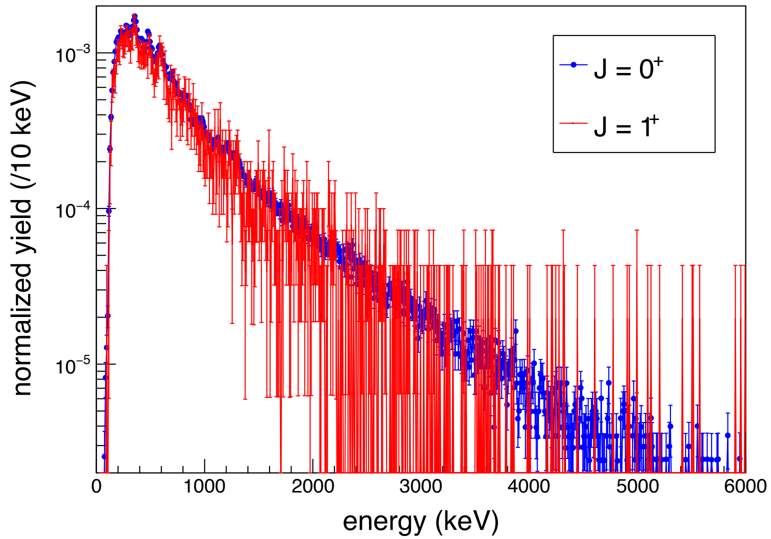
ν_p fluctuations and the (n, γf) process

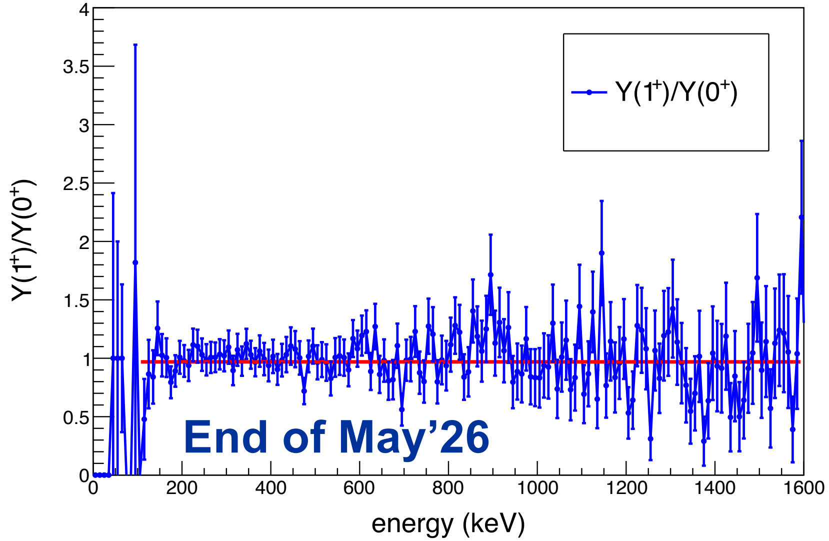




- γ-ray energy of the order of about 800 keV (≈ 0.1 n)

ν_p fluctuations and the (n, γf) process





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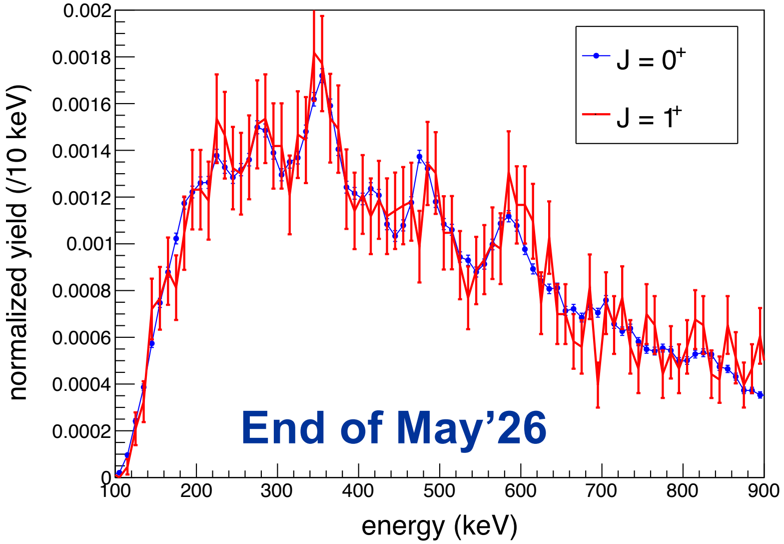
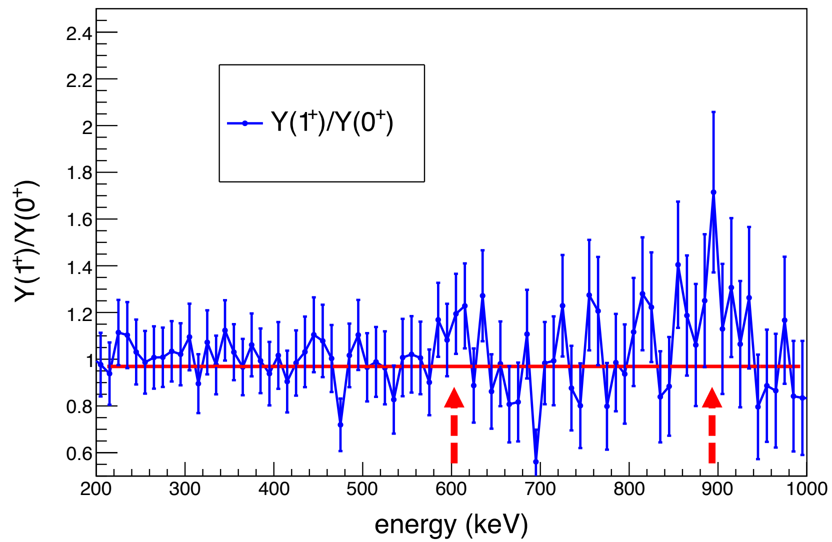
ν_p fluctuations and the (n, γf) process





- **γ-ray energy of the order of about 800 keV (≈ 0.1 n)**

- **Data taking needs to continue until end of 2026, at least, depending on GELINA's performance**
- **(n,γf) => the inclusion of γ-ray detectors into SCINTIA turns out to be a successful approach**

Prompt and isomeric γ-rays in fission

- ✓ Research initiated from HPRL (2011): observed excess γ-heating for ^{235}U, ^{239}Pu

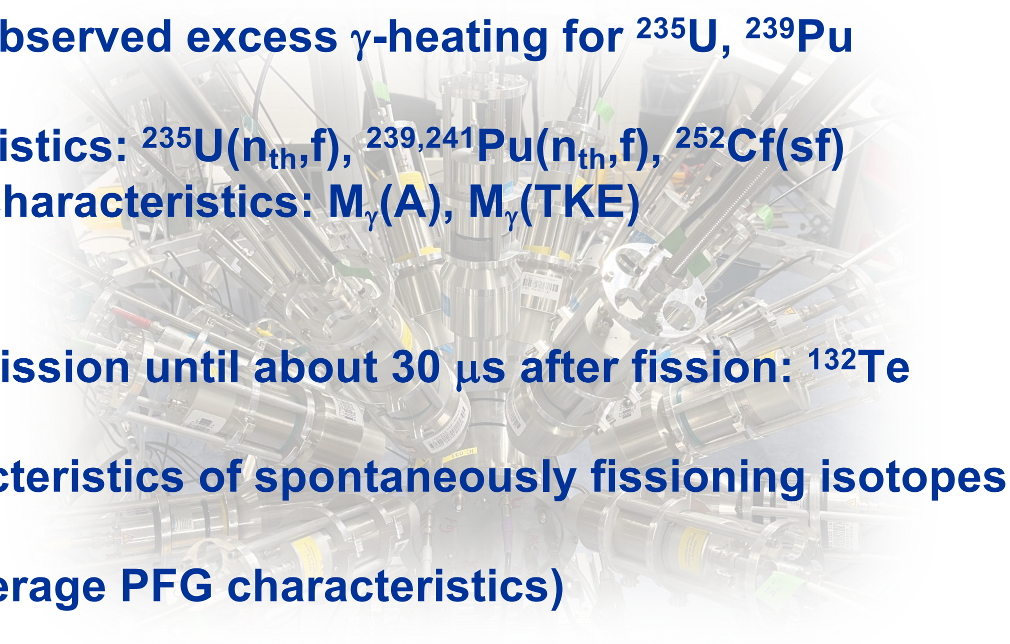
- ✓ Average prompt fission γ-ray characteristics: ^{235}U(n_{th},f), ^{239,241}Pu(n_{th},f), ^{252}Cf(sf)
- ✓ ^{252}Cf(sf) – fission-fragment correlated characteristics: M_γ(A), M_γ(TKE)
- ✓ ^{252}Cf(sf) – isomeric γ-ray decays ($T_{1/2}$)

- ✓ ^{252}Cf(sf) – time-dependence of γ-ray emission until about 30 μs after fission: ^{132}Te

⇨ Systematic investigation of PFG characteristics of spontaneously fissioning isotopes

- ➢ ^{242,}~~^{244,}~~^{246,248}Cm, ^{250,252}Cf, ^{242,244}Pu (average PFG characteristics)
- ➢ time-dependent γ-ray emission
- ➢ Isotopic fission-fragment identification => isomer-to-prompt ratio

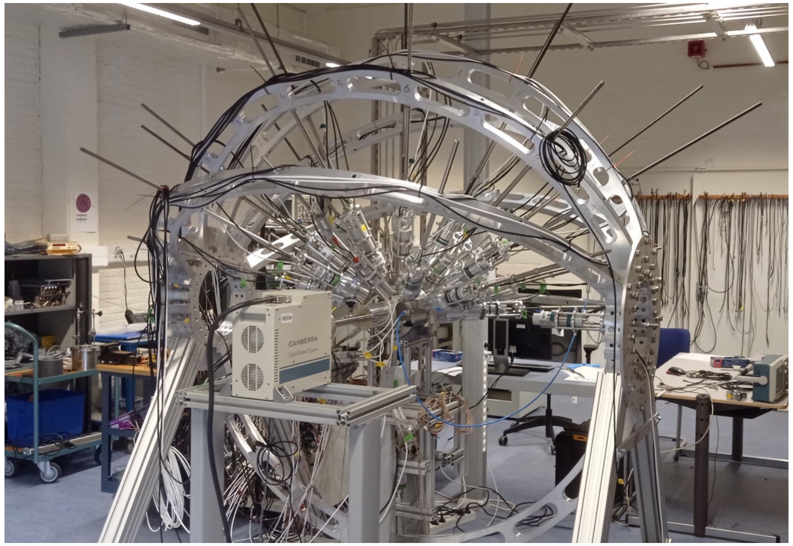
⇨ Part of this large programme is subject to Alan Danilo's PhD thesis !



Prompt and isomeric γ-rays in fission

⇰ **upgrade to VESPA 2.0**

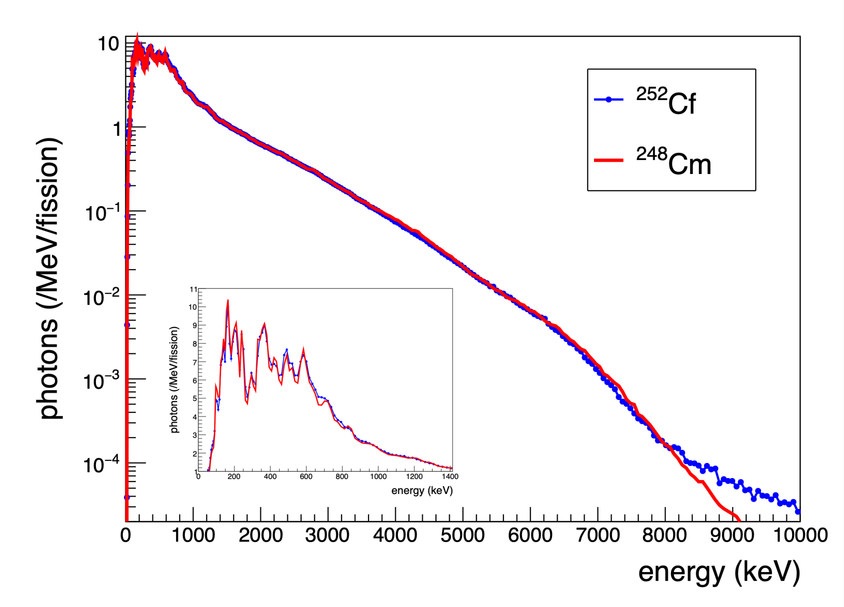
- **new detector frame**
- **variable detector configuration**
- **28+ γ-ray detectors**
- **DAQ (1GS, 2Vpp)**
- **clean FGIC for calibration at sample position**
- **γ-energy calibration range (32 keV – 9 MeV)**

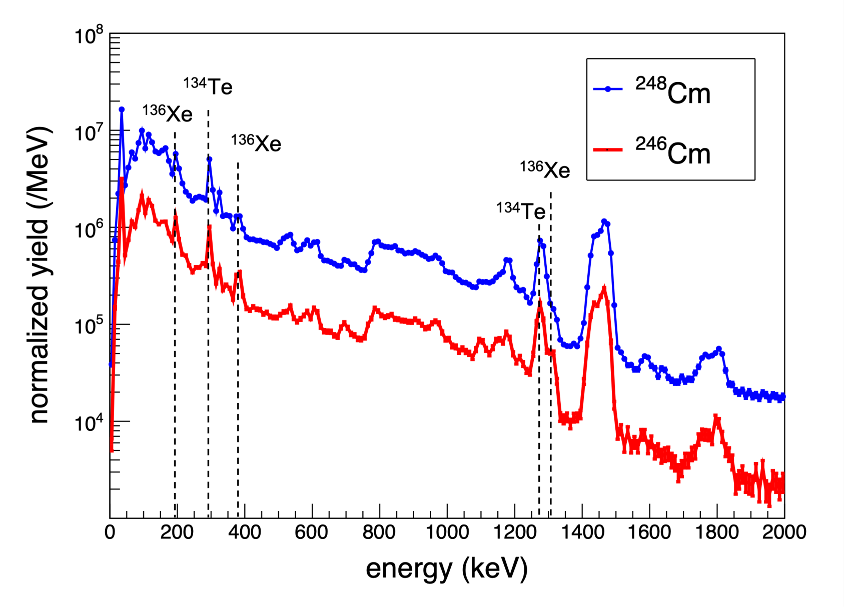


type	quantity	diameter (mm)	length (mm)	distance to sample (mm)
$LaBr_3$(Ce+Sr)	2	50.8	76.2	170
$LaBr_3$(Ce)	2	76.2	76.2	170
$LaBr_3$(Ce)	10	50.8	50.8	170
$LaBr_3$(Ce)	1	88.9	203.2	245
$CeBr_3$	13	50.8	50.8	170
CLLBC	1	38.1	38.1	530

Prompt and isomeric γ-rays in fission

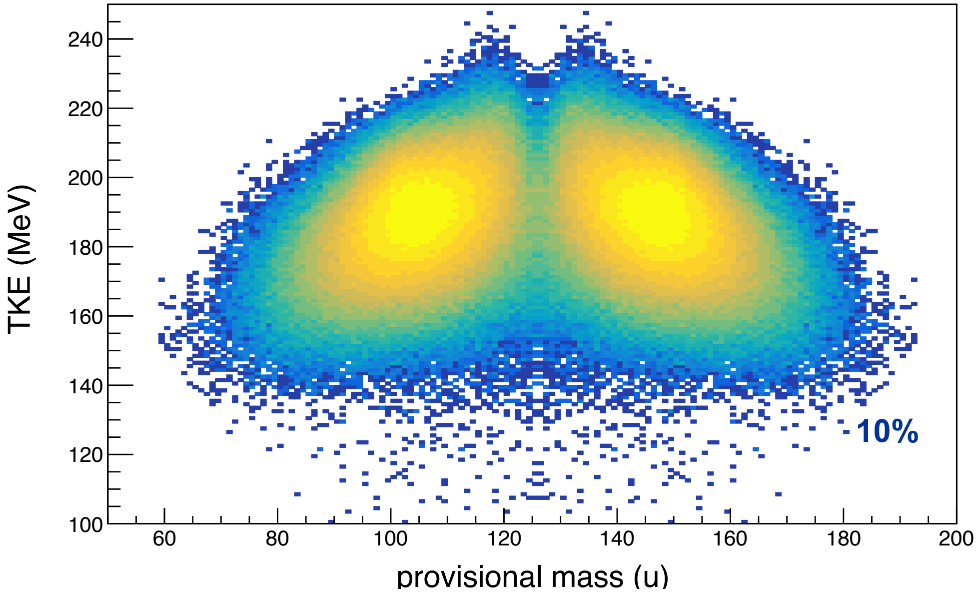
- ✓ Measurements finalized: $^{242,246,248}Cm$ (non-spec), ^{248}Cm(spec), ^{252}Cf (spec)
- ✓ First emission spectra obtained for $^{246,248}Cm$
- ✓ Emission spectra for ^{242}Cm and ^{252}Cf (as reference) due
- ✓ Principle isomers (^{134}Te, ^{136}Xe) identified

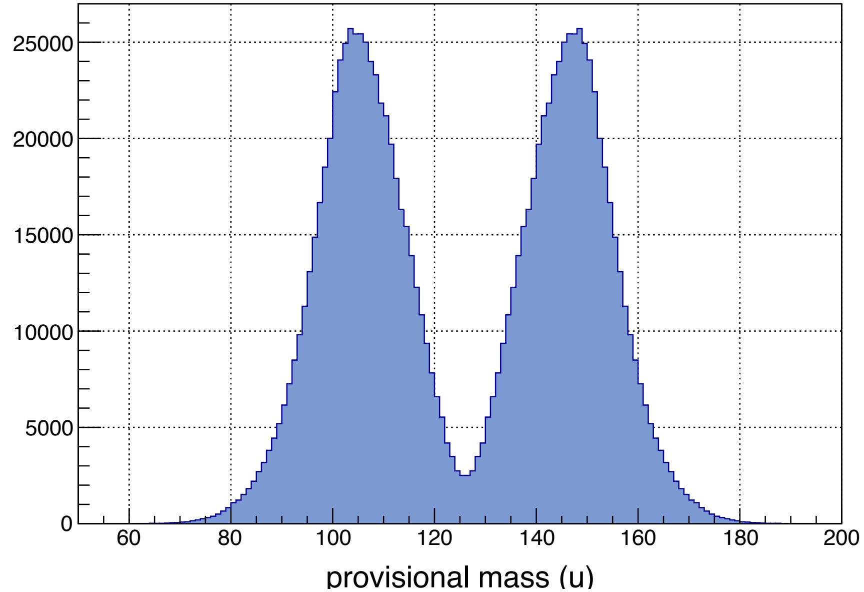




Prompt and isomeric γ-rays in fission

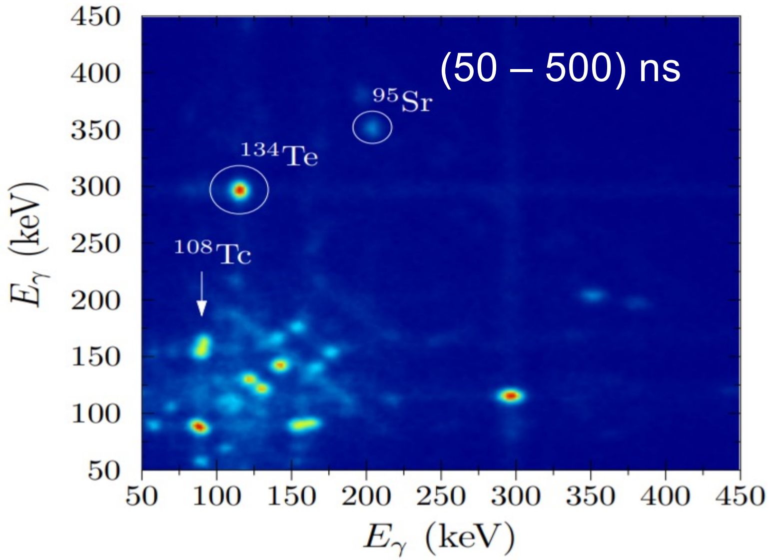
- ✓ Data taking with ^{252}Cf (spec) ongoing
- ✓ Mass reconstruction started

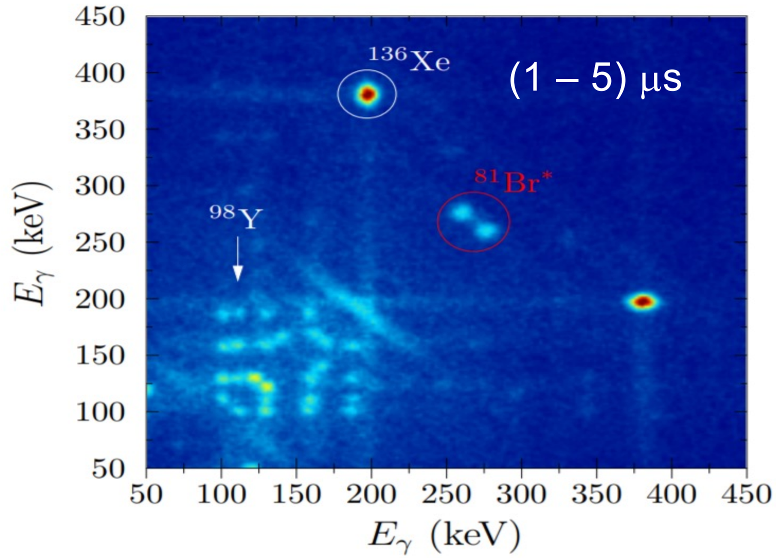




Prompt and isomeric γ-rays in fission

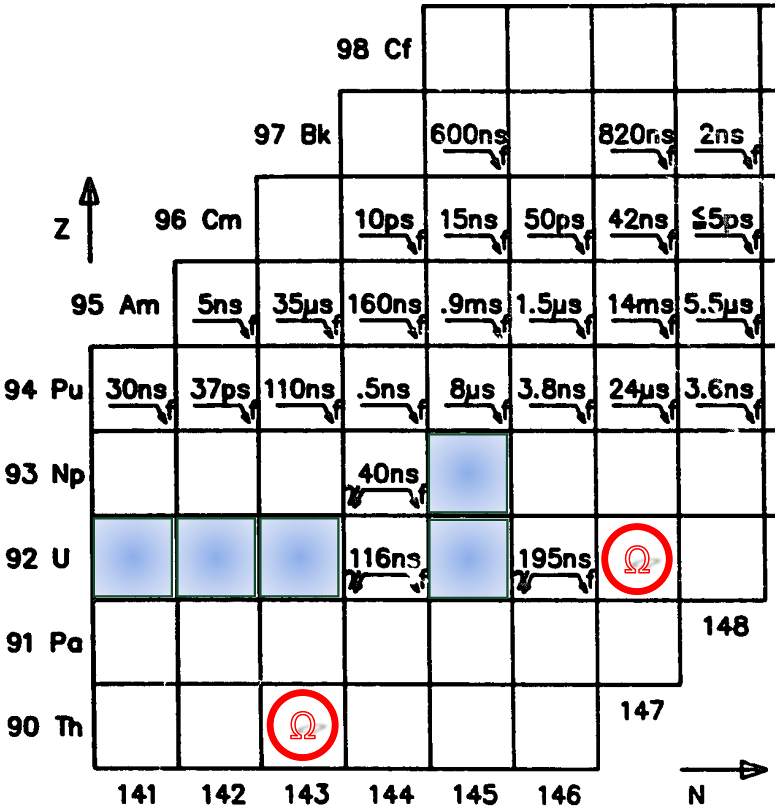
✓ **Correlation with γ-rays following (➔ isomeric yield ratios)**





PhD thesis of Valentin Piau (CEA Cadarache), 19 Oct'22

Landscape of shape isomers



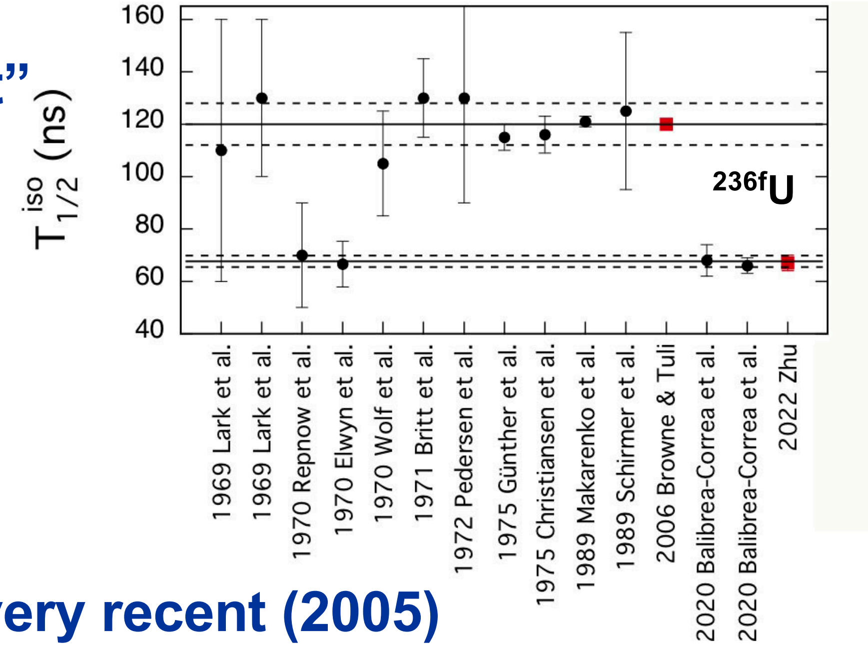
- Decay half-life, $T_{1/2,SI}$
- Branching ratio, $\Gamma_{SI,f}/\Gamma_{SI,\gamma}$
- Intermediate structure in sub-threshold fission, E_{II} (and E_{III})
- $Y(A^*, TKE)_{SI}$
- Together with barrier parameters from cross section data
- ➠ Image of the potential energy landscape between GS and saddle point

S. Oberstedt, J.P. Theobald et al., Nuclear Physics A 573 (1994) 467-485
S. Oberstedt, J.P. Theobald et al., Nuclear Physics A 578 (1994) 31-44

“Odd” uranium isotopes …

- Experimental half-lives “quite discrepant”

  - ^{236f}U: either ≈120 ns or ≈ 70 ns
  - ^{238f}U: ≲ 200 ns and ≈ 280 ns

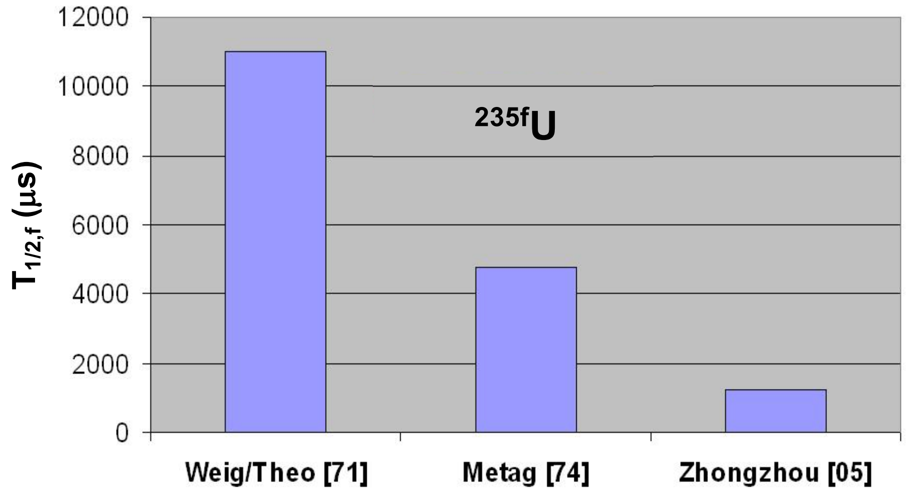


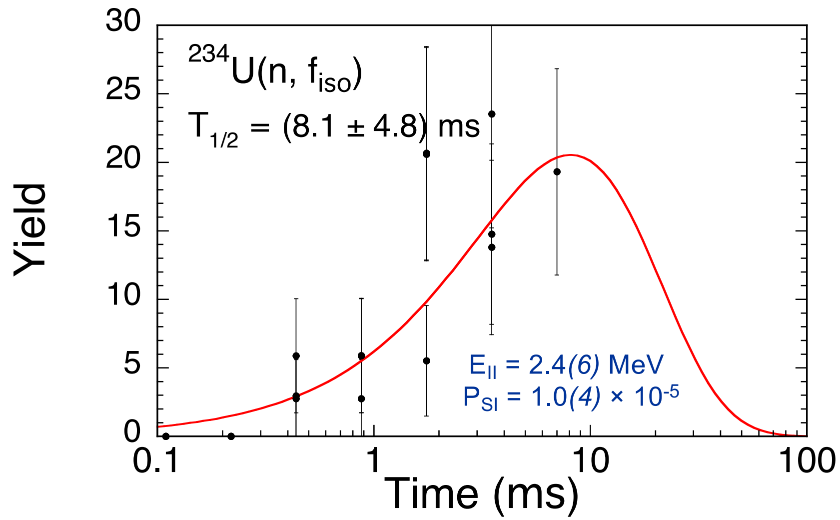
- Discovery of first odd-U shape isomers very recent (2005)

- Extreme range of half-life estimates for odd (and odd-odd) isotopes

“Odd” uranium isotopes …

- Extreme range of half-life estimates for odd(-N) isotopes
- most favourable case is ^{235f}U: $T_{1/2}$ = (1 – 11) ms

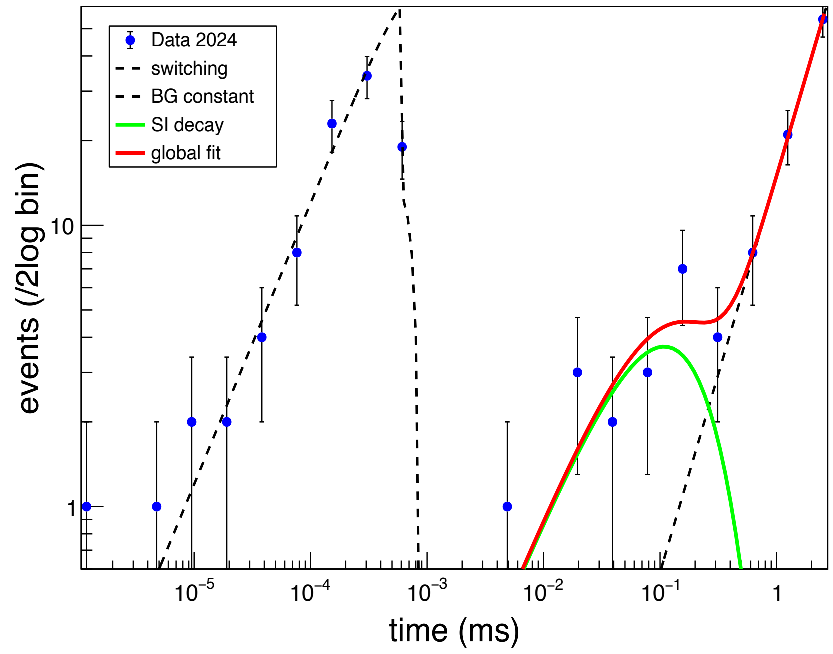




- ^{238f}Np : $T_{1/2}$ = 1 µs – 10 s

^{237f}U : recent achievement

- NEPTUNE@100Hz: $T_{1/2,f}$ = 1 μs – 5 ms
- highly-enriched ^{236}U sample: 99.973%
- level density ratio: E_{II} = 2.2*(2)* MeV
- $T_{1/2,\gamma}/T_{1/2,f}$ = 9.9 (Wagemans 1990)

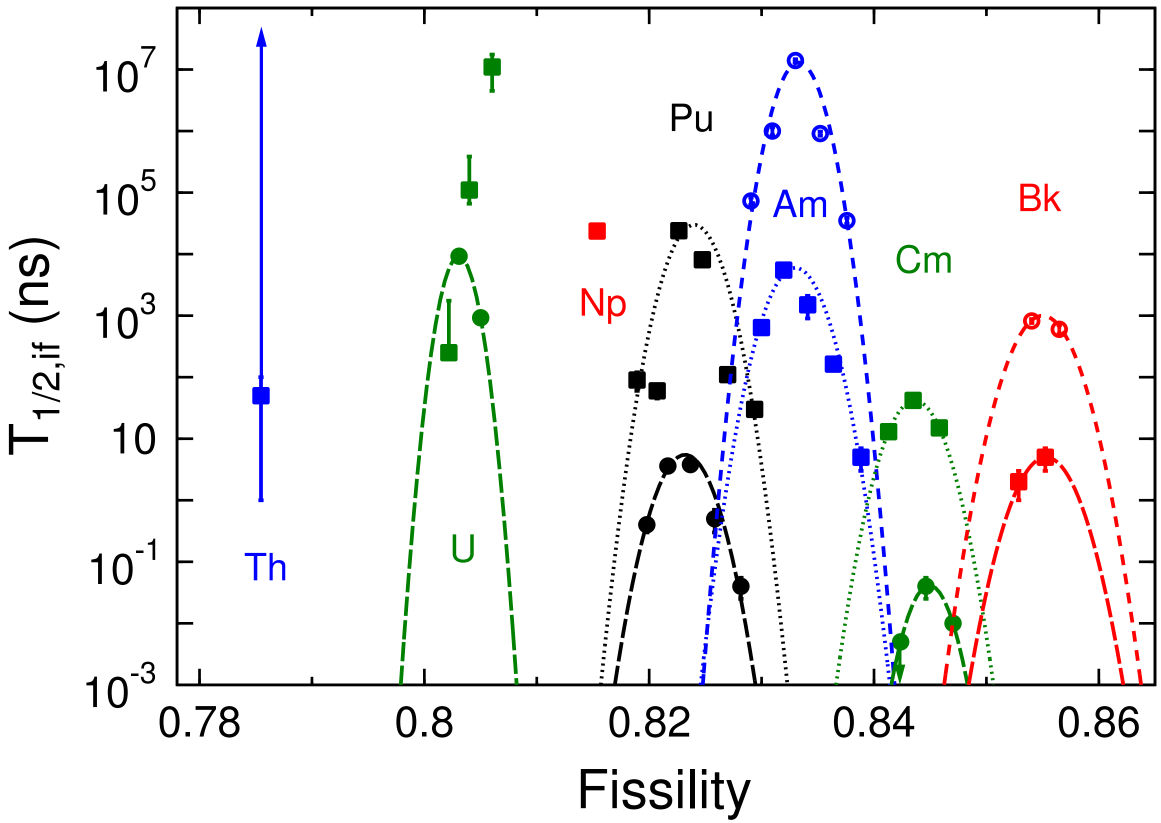


✓ $T_{1/2} \approx (0.11 \pm 0.06)$ ms

✓ $P_{SI} < (1.8 \pm 0.7) \times 10^{-7}$

✓ set of consistent barrier parameters for ^{237}U deduced (manuscript due to submission)

SI landscape a bit different …



Future projects and activities

Available facilities @ JRC

GELINA (ELISA, GAINS, …

MONNET (now with HIBL and fast Rabbit)

VESPA++ 2.0

SCINTIA

VERDI

Shape isomer research (MONNET)

- ^{238}U(n,n’) method qualification (data analysis)
- ^{236}U(n,n’) shape isomer T1/2 verification (target soon on its way back from n-TOF)
- ^{233}U(n,n’) odd-A isotope (target available)

SCINTIA

- Continuation of data-taking until end of 2026, at least!
- Unfolding of measured γ-ray spectra
- Analysis of the neutron spectra for 0^+ and 1^+ resonances
- ^{233}U(n_{RR},f; $I^\pi = 2^+,3^+$), what about ν_p (E_{RR})
- high fission cross section
- Y(A, TKE) available?
- high-quality spectroscopic targets achievable?

VESPA++

- ^{250}Cf(sf), ^{242,244}Pu(sf)
- average PFGS characteristics

⤇ finalizing PFGS systematics

- DoD spectroscopic target characterization
- VESPA@MONNET (next generation)

VERDI

- whatever will require a PhD student for extended period

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Andreas Oberstedt
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CEA, DES, IRESNE, DER, SPRC, LEPh, Cadarache center (FR)

Valentin Piau
Subatech, CNRS/IN2P3, IMT-Atlantique, Nantes University (FR)

~~**Alf Göök**~~
Department of Physics and Astronomy, Uppsala University, Box 516, 751 20 Uppsala, Sweden

Ana M. Gomez L., Ali Al-Adili
Department of Physics and Astronomy, Uppsala University (SE)
Norwegian Nuclear Research Centre (NNRC)

Dennis Renisch, Christoph Düllmann, Christoph(er) Sirleaf
Department of Chemistry - TRIGA Site, Johannes Gutenberg University Mainz (DE)

C. Fontana, ~~W. Geerts~~, ~~D. Lewis~~, C. Paradela D., ~~G. Sibbens~~, D. Vanleeuw, M. Vidali,
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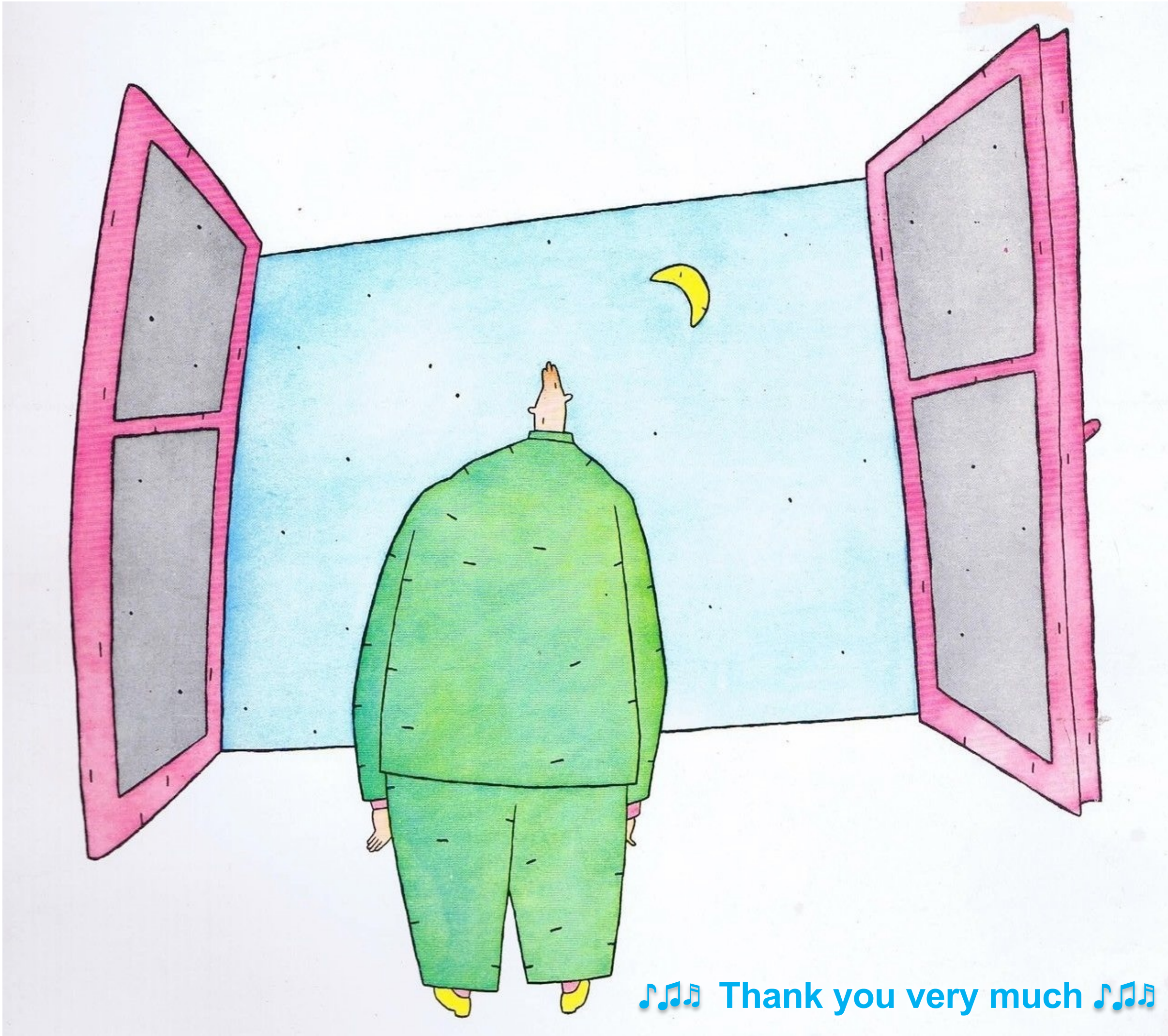
♪♫♬ Thank you very much ♪♫♬

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