

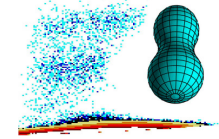
Information on the super-deformed ground state in $^{235}\text{U}^*$

A. Oberstedt

Outline:

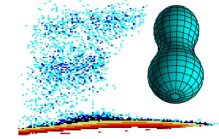
- Motivation
- Difficulties
- The NEPTUNE experiment
- Results
- The GELINA experiment
- Results
- Summary

Motivation



- Safety of present and future nuclear power devices relies on precise knowledge of the nuclear potential energy landscape
- Energy as function of nuclear deformation exhibits (at least) double-humped barrier
- **Shape isomers** provide information about the height and width of the outer barrier
- Lack of information in particular for **odd-A uranium isotopes**

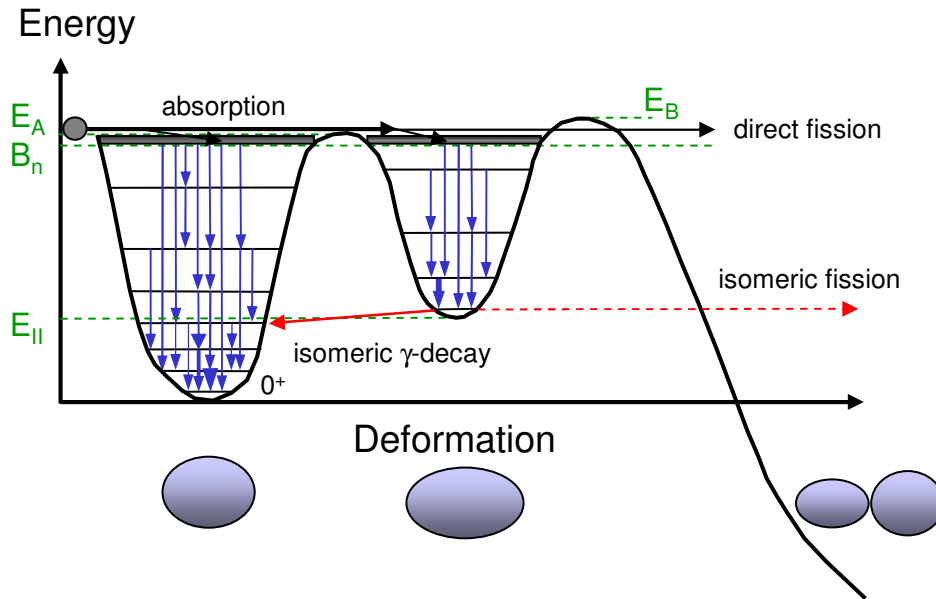
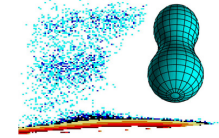
Shape isomerism



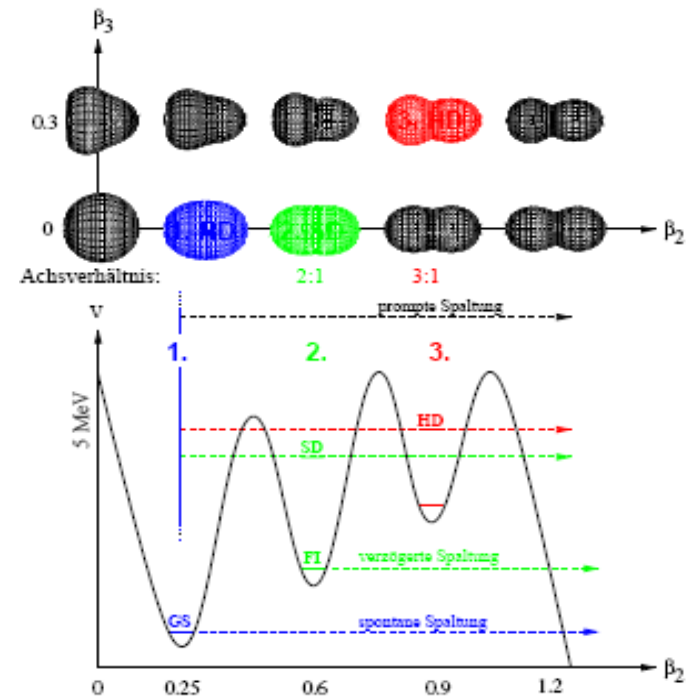
What can we learn?

- The decay mode of the shape isomer contains information on
 - barrier parameters such as height and penetrability, transmission coefficients
 - is the barrier double- or triple-humped?
 - shape-isomeric half-life characterises inertia and viscosity of nuclear matter
- Essential input parameters for nuclear reaction models
- Precise knowledge about the nuclear potential energy landscape

The fission barrier



Double-humped,
like in ^{238}U ...

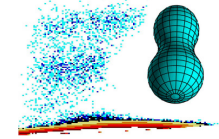


... or triple-humped, as found in ^{230}Th at $E_n = 720$ keV?

Today still not clear:

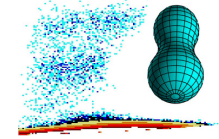
- “real” deep minimum?
- more or less developed shoulder?

Difficulties

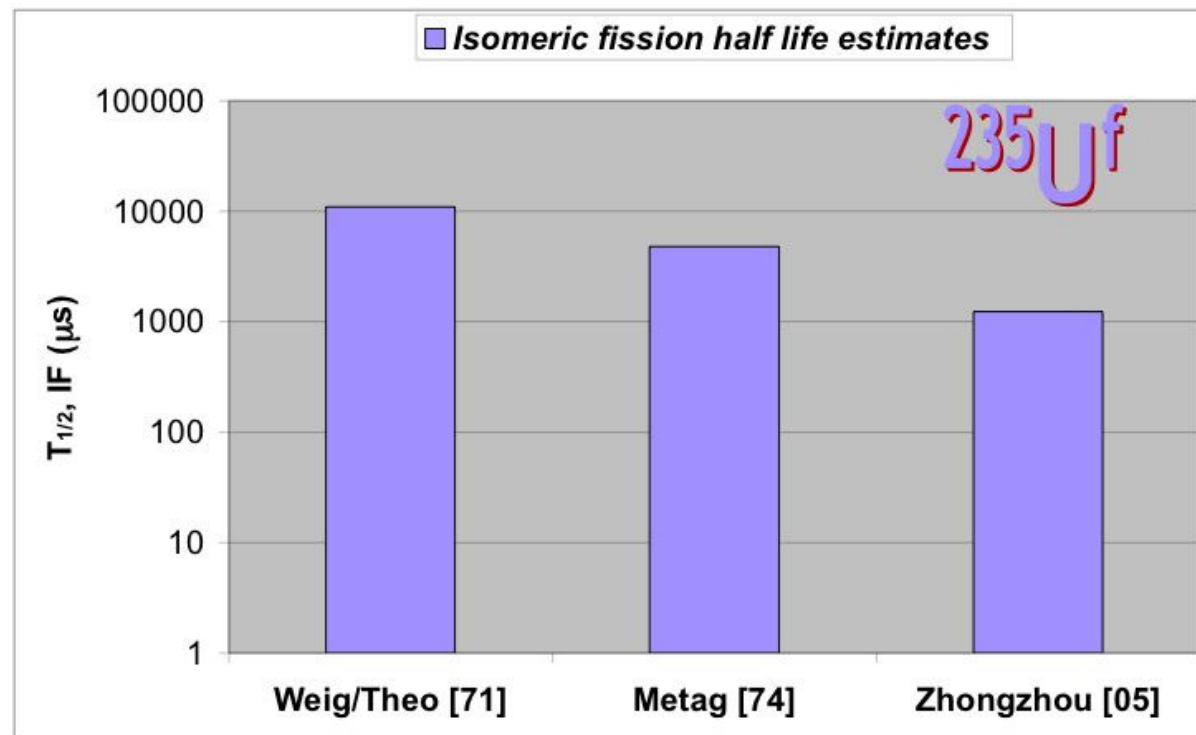


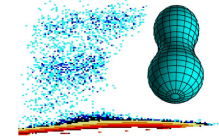
- The measurement of **half-lives** from **several μs to some s** is **extremely difficult** in neutron-induced reactions due to a strong background component
- Population probability of a shape isomer is typically **$\leq 10^{-5}$**
- Theoretical **predictions won't help**, e.g.
 $10 \mu\text{s} < T_{1/2} < 10 \text{ s}$ in case of ^{237}Np
- Not feasible with standard pulsed particle accelerators

Most favourable case?



- Half-life predictions for isomeric fission of ^{235}U vary by only **one** order of magnitude
-> **1.2, 4.8 and 11 ms!**





7 MV Van-de-Graaff accelerator @ EC-JRC IRMM & NEPTUNE

Incident neutron energies:

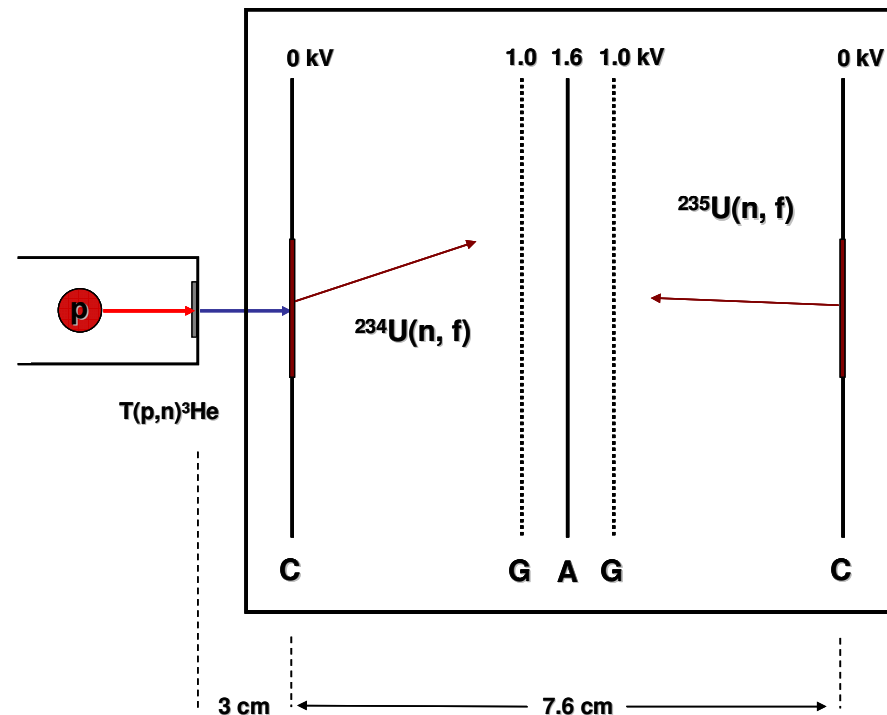
- $E_n = 0.95$ and 1.27 MeV
- production reaction $T(p, n)^3\text{He}$

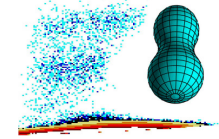
Fission fragments:

- twin Frisch-grid ionisation chamber
- common anode
- ^{234}U sample ($m = 1.364$ mg)
 - $N_4 = 3.51 \times 10^{18}$ atoms
 - $N_5 = 2.93 \times 10^{15}$ atoms
- ^{235}U sample ($m = 2.380$ mg)
 - $N_5 = 6.10 \times 10^{18}$ atoms ($\times 2082$)

Neutron monitoring:

- liquid scintillator (NE213 type)
- n- γ discrimination
- ^{235}U sample (thermal neutrons)

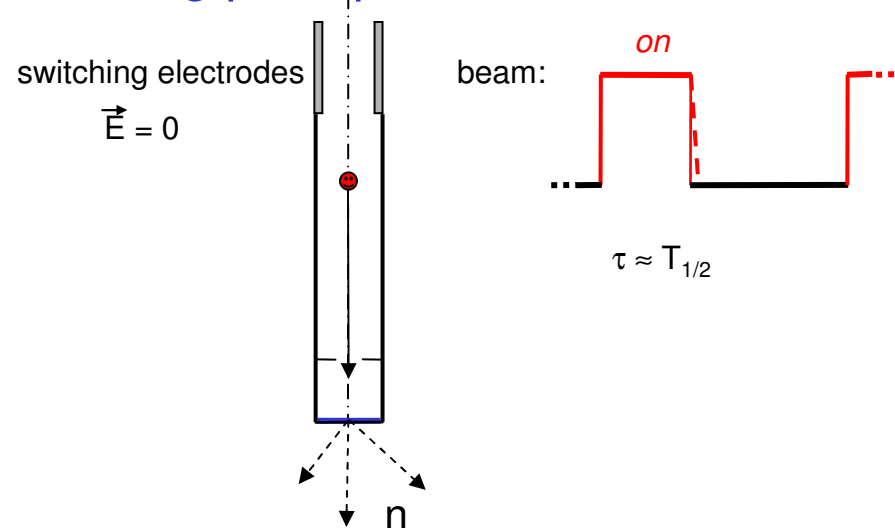




= **NEw Pulsed and TUneable NEutron** source

- electrostatic deflection of the charged-particle beam
- variable pulse repetition frequency and precisely adjustable width of the neutron pulse

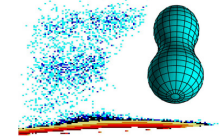
Working principle:



NEPTUNE settings in this work:

- 50, 100 and 150 Hz
@ $E_n = 1.27$ MeV
- 100 Hz @ $E_n = 0.95$ MeV
- 30% duty cycle

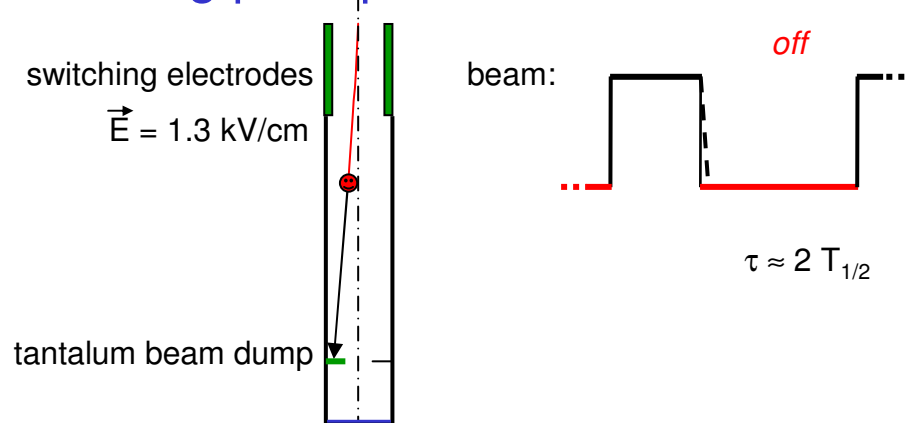
2 weeks of beam time!



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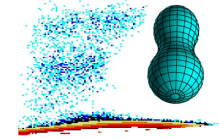


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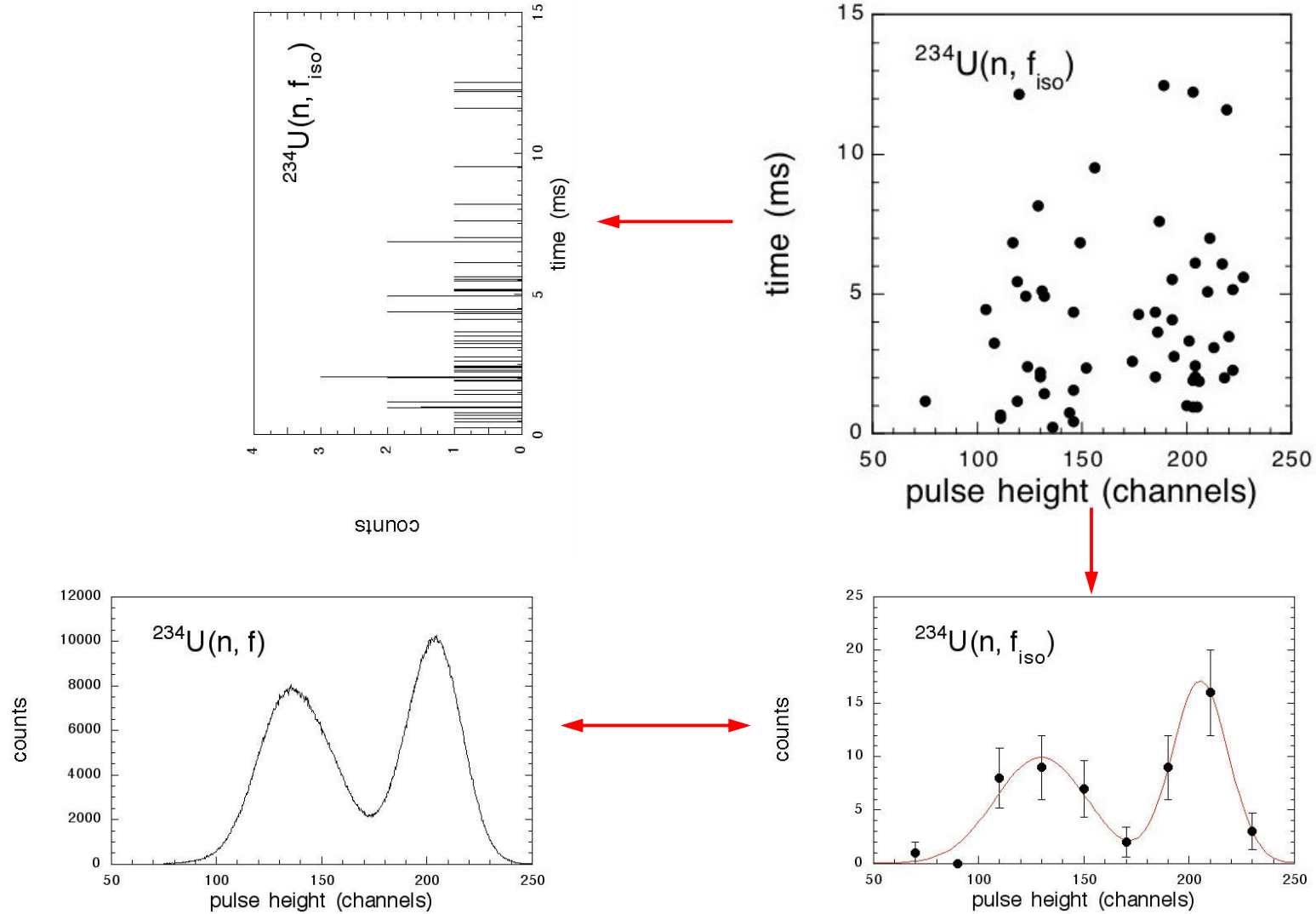
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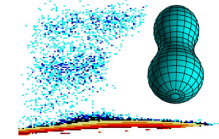
2 weeks of beam time!

“Raw” data

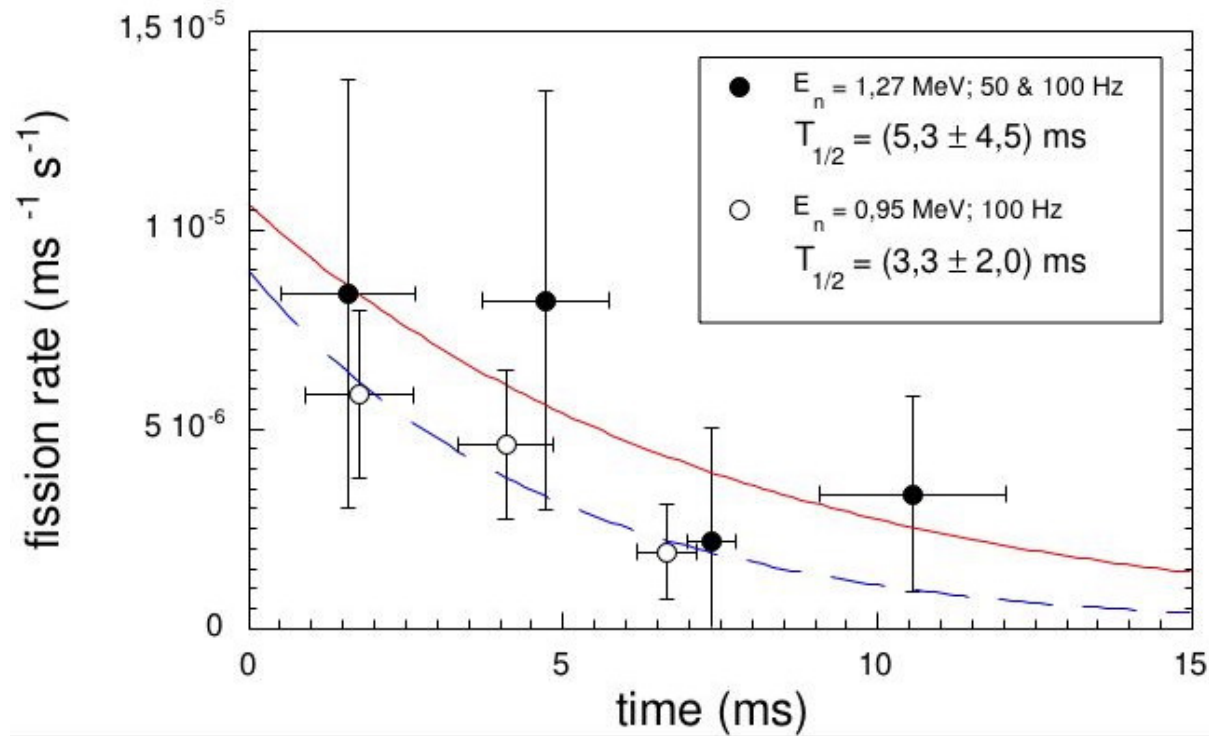


-> 55 delayed fission events from the reaction $^{234}\text{U} + n$



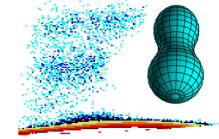


Background-subtracted delayed fission events from $^{234}\text{U} + n$, collected in time bins of 3 ms width



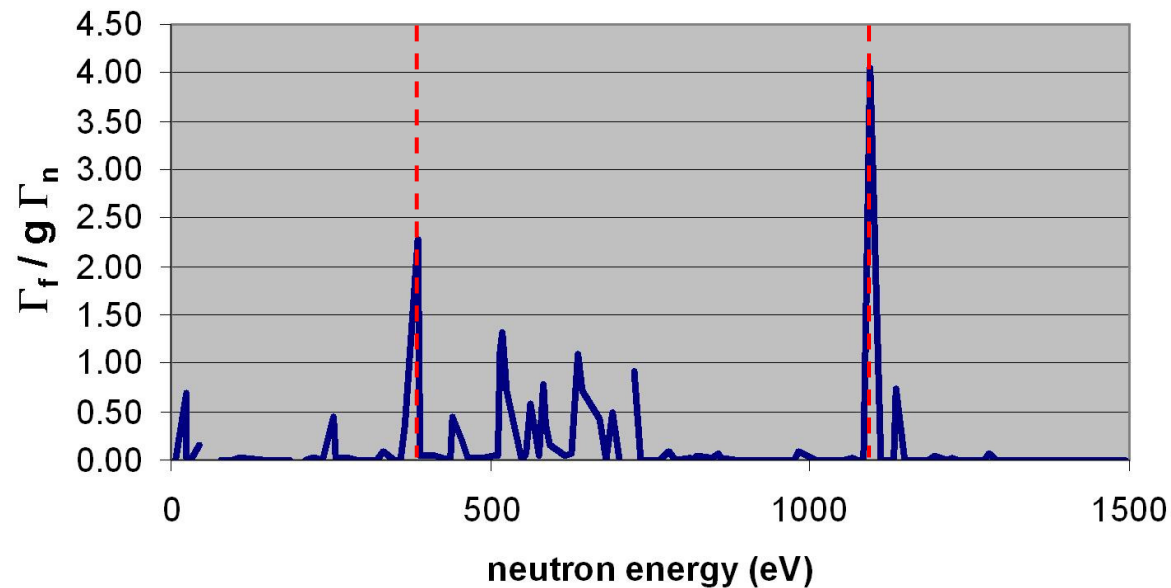
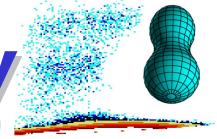
-> Isomeric fission half-life: $T_{1/2} = (3.6 \pm 1.8) \text{ ms}$

Experimental approach



- Population of resonance in the energy region of the intermediate structure (IS) by low-energy (i.e. s-wave) neutron capture
- Observable resonances contain contributions from class-I and class-II states of about same energy to fission cross section
- Choosing resonance with largest class-II contribution: quasi class-II state
- Low neutron width and high fission width: $\Gamma_f > \Gamma_n$!
- γ -rays appearing exclusively from resonances belonging to an IS: candidates for decay to super-deformed (SD) minimum
- Coincident measurement of γ -rays from the decay of the resonances: energy of SD ground state E_{II} !

The reaction $^{234}\text{U} + n \rightarrow ^{235}\text{U}^f + \gamma$

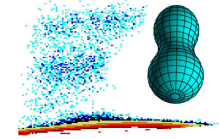


Possible resonances with considerable class-II contributions at

- $E_n = 387.6 \text{ eV}$ and $E_n = 1092.5 \text{ eV}$



GELINA neutron tof facility

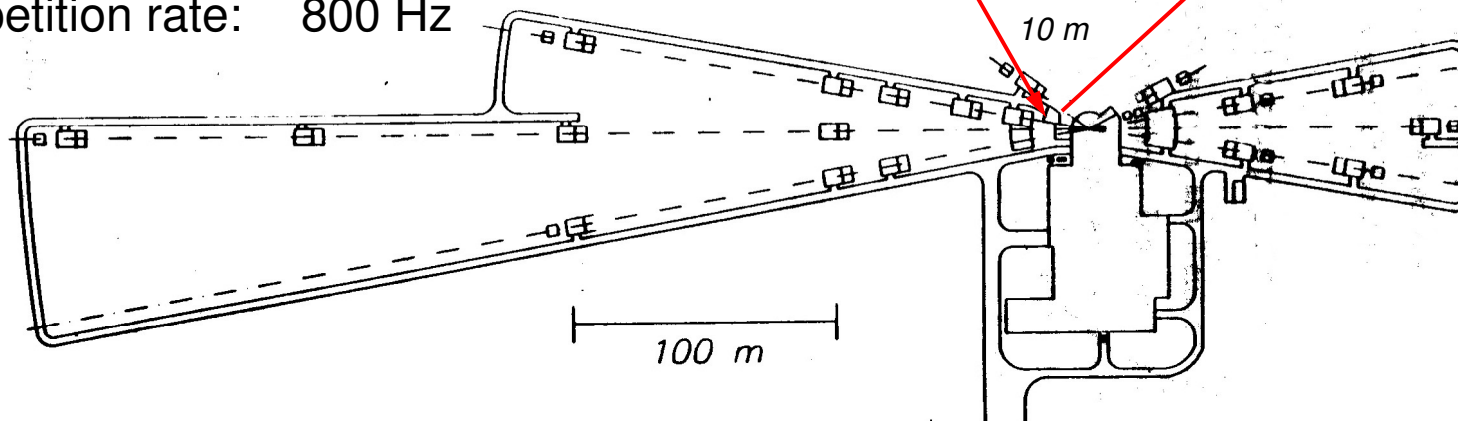


150 MeV electron linear
accelerator producing
white neutron spectrum
($E_n = E_{n,th}$ to 15 MeV)

Pulse length: 1 ns

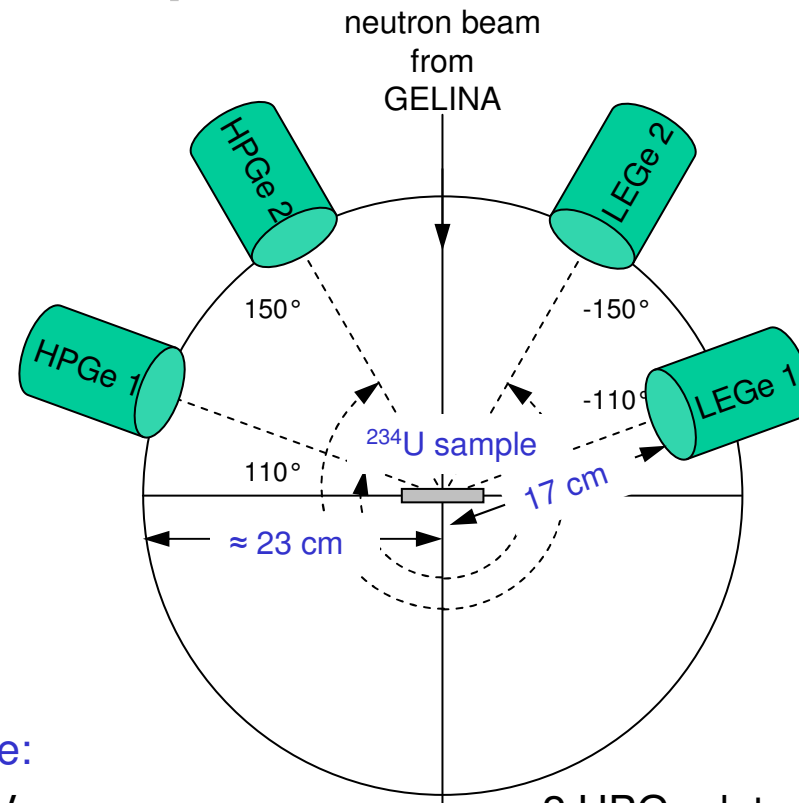
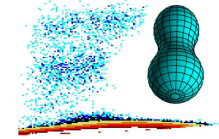
Repetition rate: 800 Hz

GELINA FP5 (10 m)



- Neutron flight paths from 10 to 400 m length
- Average neutron flux $3.4 \cdot 10^{13} \text{ s}^{-1}$

Experimental set-up



Neutron energy range:

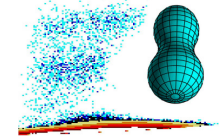
- $E_n = 5$ to 1500 eV

Sample:

- ^{234}U sample ($m = 2.12$ g)
 - $N_4 = 5.45 \cdot 10^{21}$ atoms
 - diameter 3.0 cm

Detectors

- 2 HPGe detectors (ORTEC, n-type)
 - 45% relative efficiency
 - X-coolers
 - distance ca. 23 cm
- 2 LEGe detectors (Canberra, n-type)
 - 7% relative efficiency
 - distance ca. 23 and 17 cm



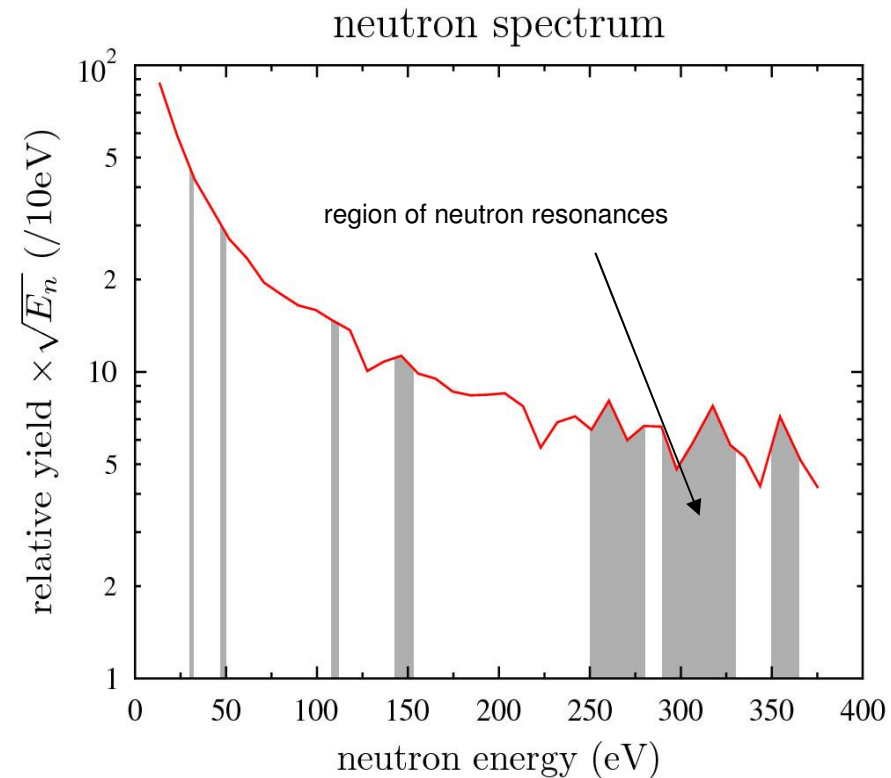
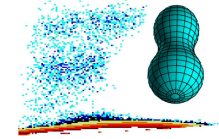
Problems:

- Extremely high γ -count rates due to
 - highly radioactive sample ($A_{\alpha} \approx 4.9 \cdot 10^8$ Bq)
 - short distance between source and detectors (limited space due to lead wall at FP5)

Solutions:

- 5 mm lead shielding in front of detectors
- One detector (LEGe 1) had to be switched off
- Additional coincidence condition was necessary, which is, however, reducing the count rate even for events of our interest ... but **increasing signal-to-background ratio** due to high neutron capture γ -multiplicity
- Shaping time reduced from 4 to 2 μ s
- Energy resolution still very good: $\Delta E/E \sim 0.5\%$ @ 1.33 MeV

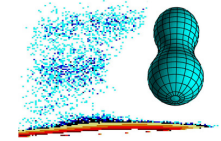
Results II



- Conversion from tof to energy spectrum
- Grey-shaded areas indicate regions of resonances with largest Γ_n (Mughabghab, 2006)



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