Measurement of (n,xnγ) reactions of interest for the new nuclear reactors

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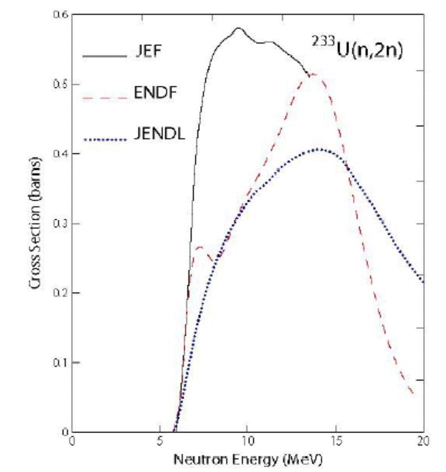
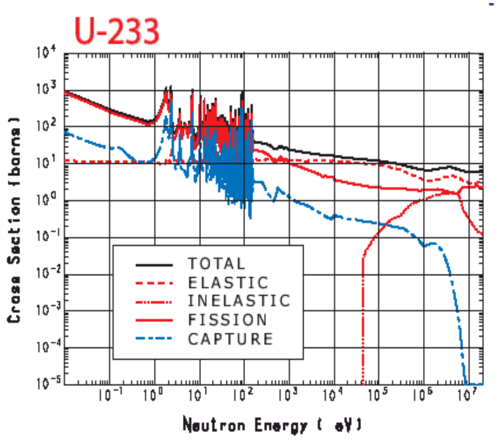
Motivation

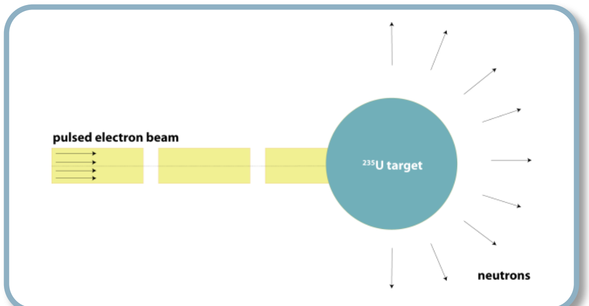
- New reactor generation based on fast neutron reactions:
  - neutron induced reactions in these regions not known or not precisely
- Importance of (n,xn) reactions
  - neutron slow down
  - neutron multiplication
  - production of other nuclei
- Measurements on ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{232}Th have been made. Current work: ^{235}U, ^{nat}W





Experimental setup

- Experiments are performed using a white pulsed neutron beam from Gelina (IRMM, Geel, Belgium)
- A ^{235}U target is bombarded by a pulsed electron beam: γ radiation is created by *Bremsstrahlung,* neutrons are created by *photofission.*



- Neutron energy is determined using the TOF technique

$$E_n = (\gamma - 1) m_n c^2 \quad , \quad \gamma = \sqrt{\frac{1}{1 - \frac{v^2}{c^2}}} \quad , \quad v = \frac{d}{t}$$

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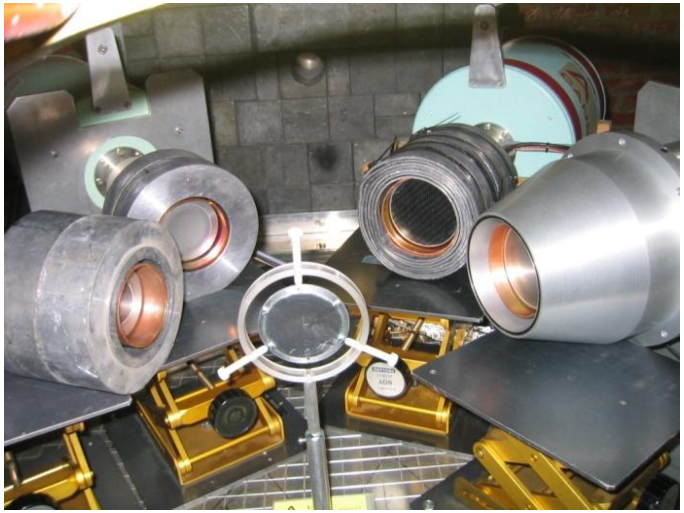
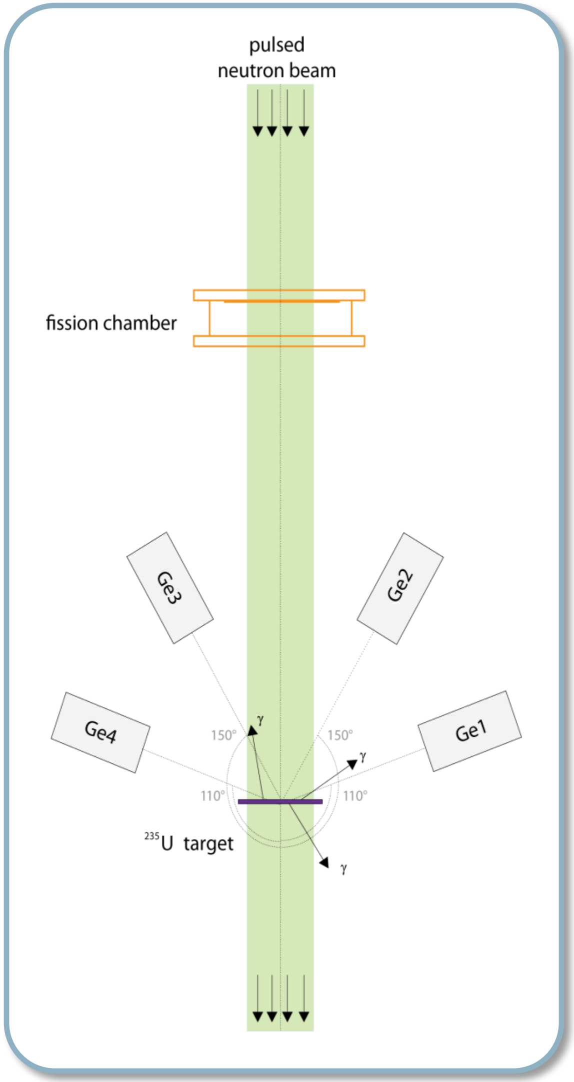
Experimental setup

- Experiments are performed at FP16/30m
- Method: Prompt γ ray spectroscopy
  - Ex: $^{235}U(n,n')^{235}U^*$
    $^{235}U(n,2n)^{234}U^*$

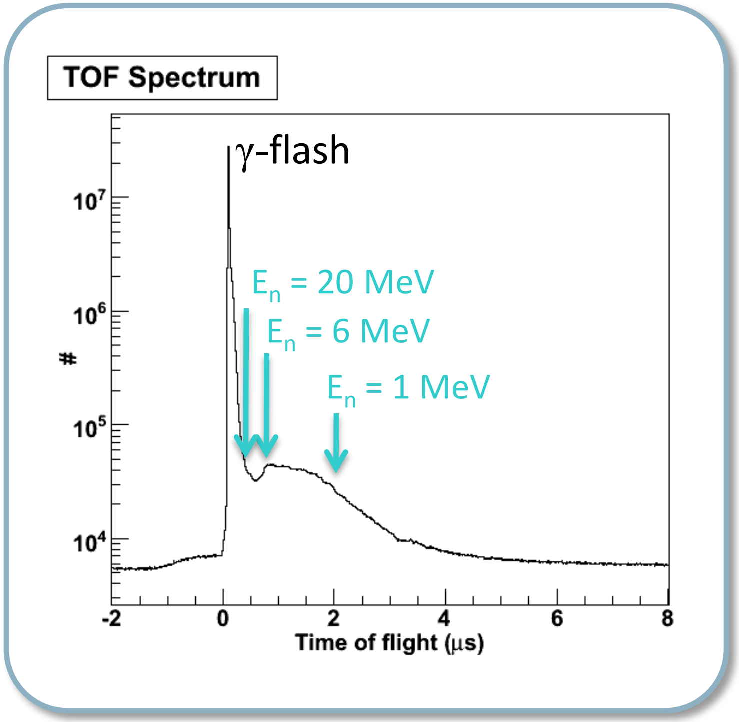


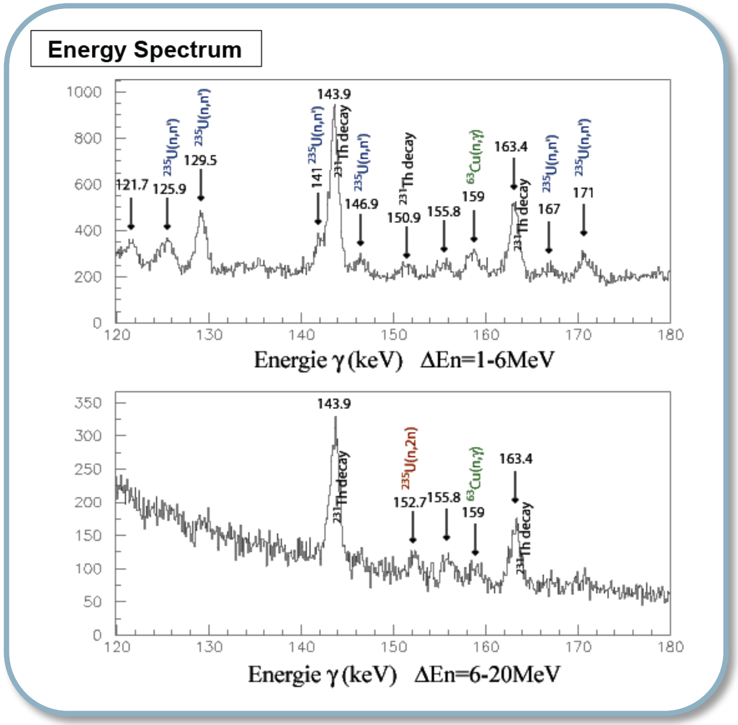


- DAQ: Digital TNT2 cards developed at IPHC

HPGe detectors

- Time of flight and energy spectra





Cross sections

- The cross section of a γ transition can be expressed as:

$$\sigma = \frac{n_{det}}{\varsigma\, s\, \Phi\, \varepsilon\, t}$$

Detected hits in a given ray:
- Good statistics
- Low background

Cross section of a given γ ray transition [b]

Acquisition time [s]

Areal density of atoms in target [cm^{-2}]

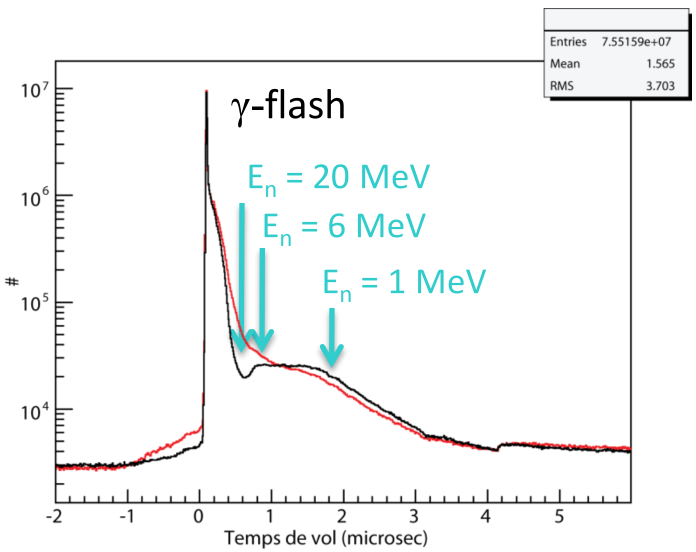
Detection efficiency
- Measurements
- Simulations

Target surface [cm^2]

Incident neutron flux [$s^{-1}\cdot cm^{-2}$]
- Fission chamber precision

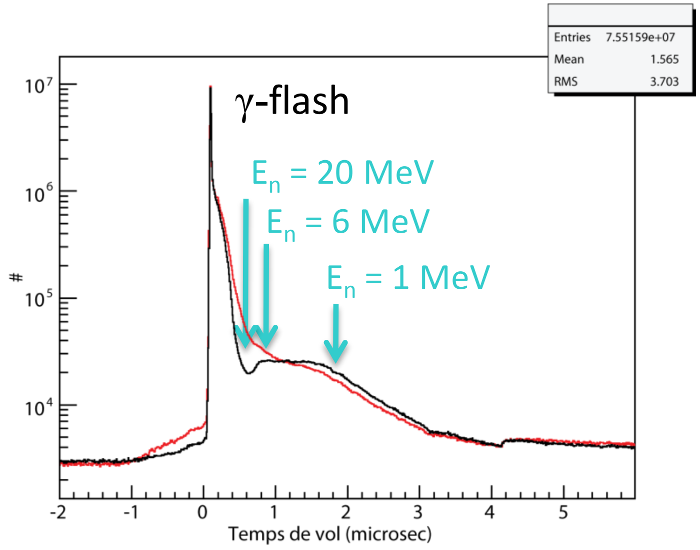
Background reduction in Ge spectra

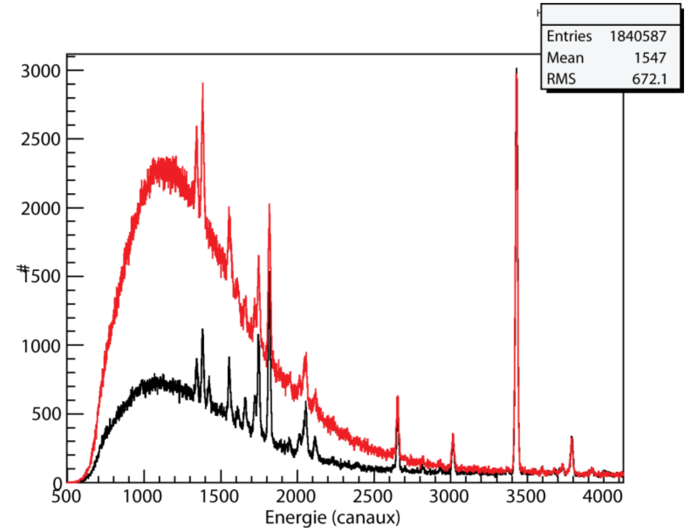
- Time of flight and energy spectra



Background reduction in Ge spectra

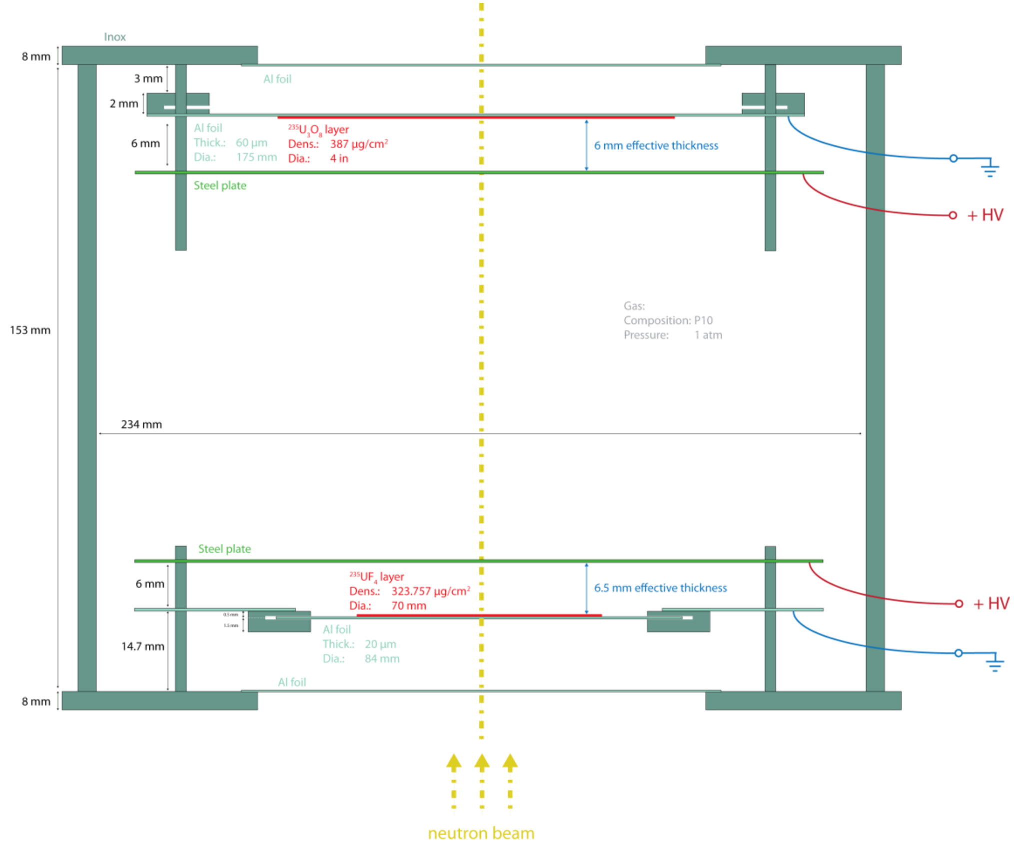
- Time of flight and energy spectra





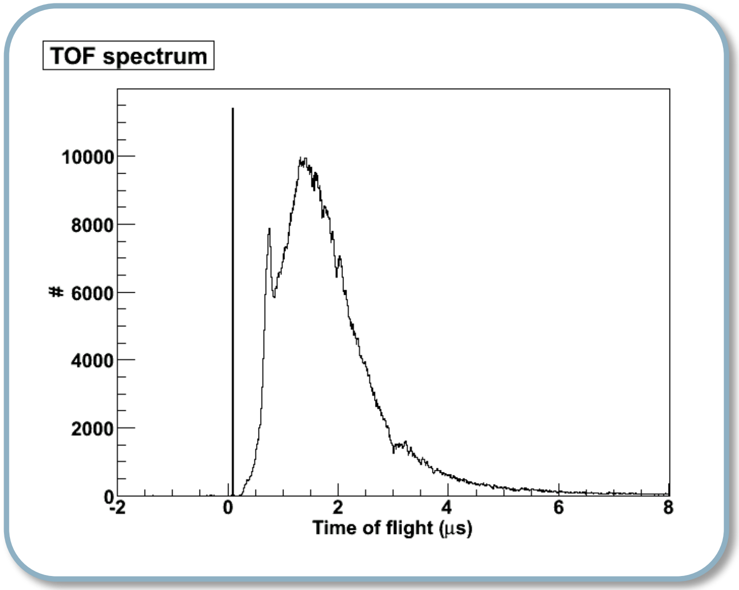
Flux monitoring

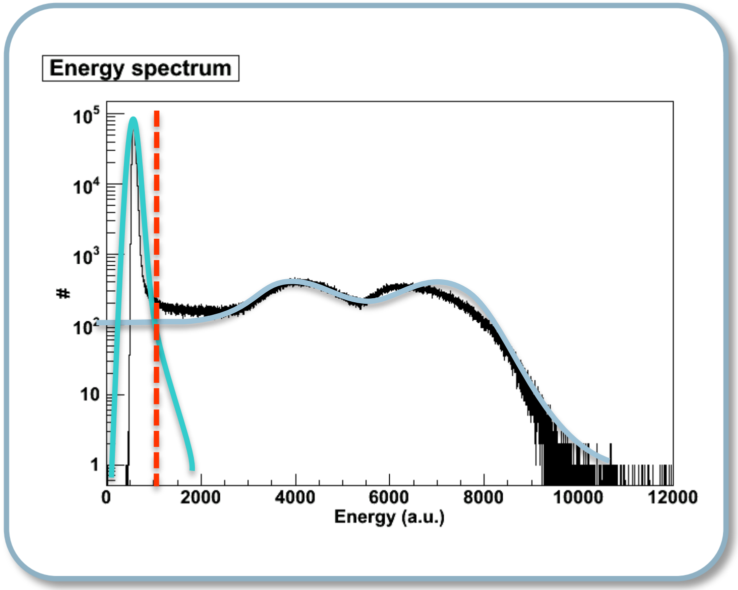
- To get accurate results it is of upmost importance to know precisely the incident neutron flux
  - Flux monitored using a fission chamber



Fission chamber

- Time of flight and energy spectra

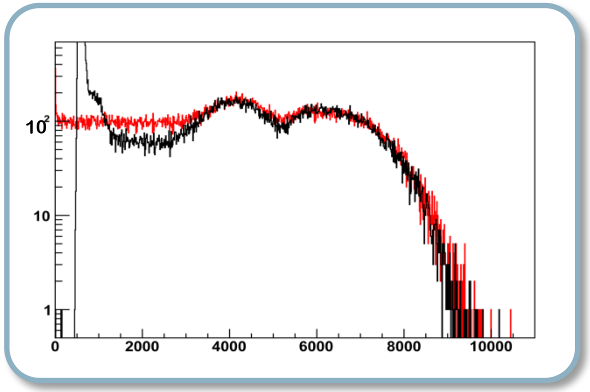




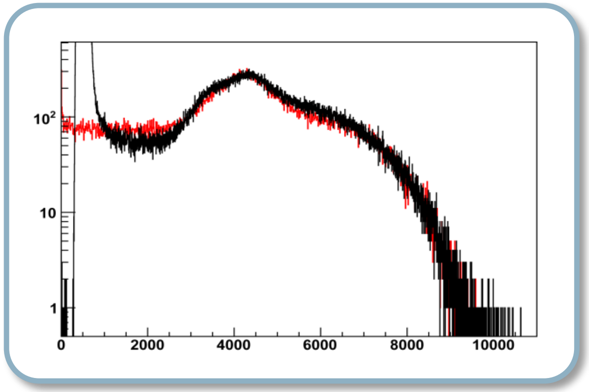
Simulating the fission chamber

- On one hand some of the created fission products don't have sufficient energy to get out of the $^{235}UF_4$ foil
  - They don't generate a detectable pulse
- On the other hand, weak signals are lost by performing a straight cut at a certain energy level
- To take these facts into account, simulations have been made using the Geant4 code

- The energies of the fission products are too weak (below the Bragg peak) for correct Geant4 simulations
- Calibration measurements will have to be performed: current estimated efficiency of ≈85%



Simulated energy spectrum for a FC thickness of 8 mm



Simulated energy spectrum for a FC thickness of 5.5 mm

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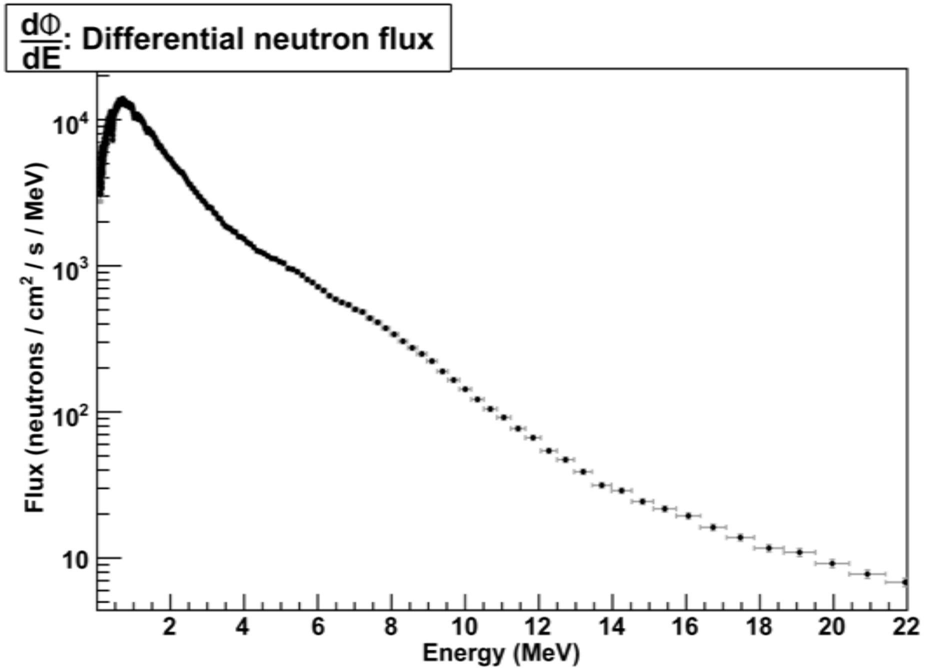
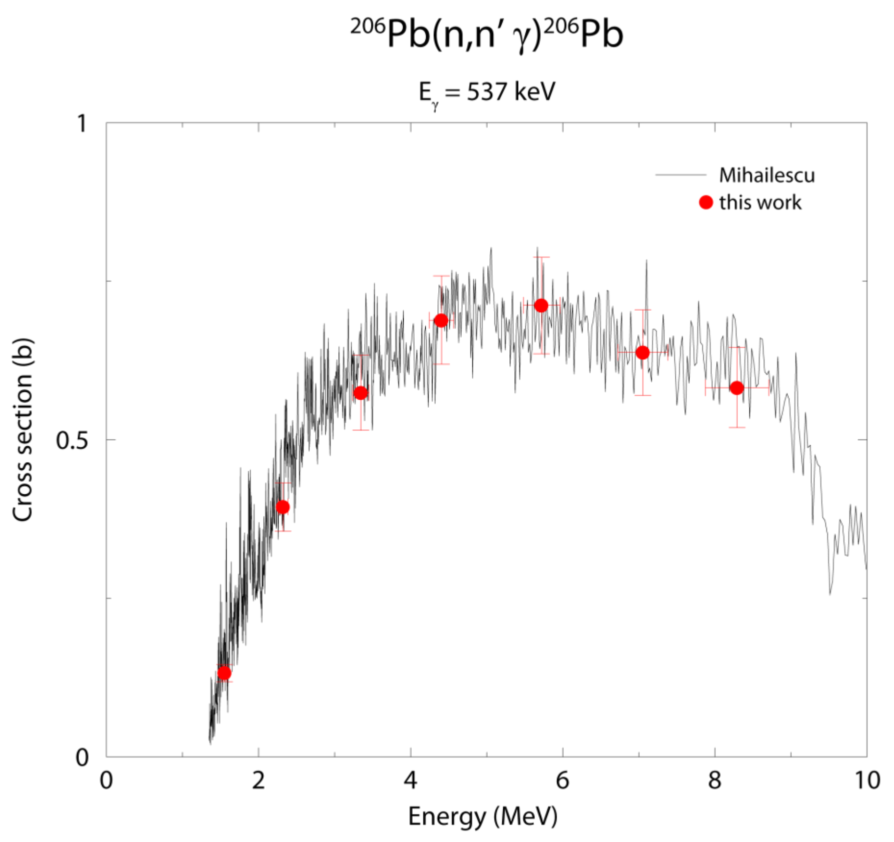
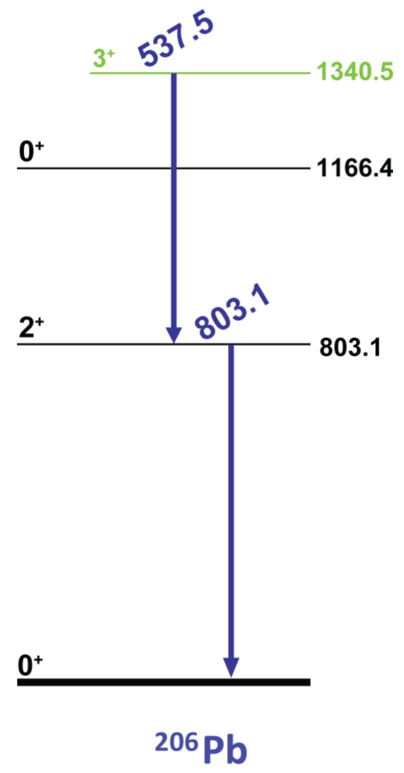
Neutron flux at Gelina

- The given neutron flux is highest at 1 MeV
- Uncertainties currently range from 8 to 10 %

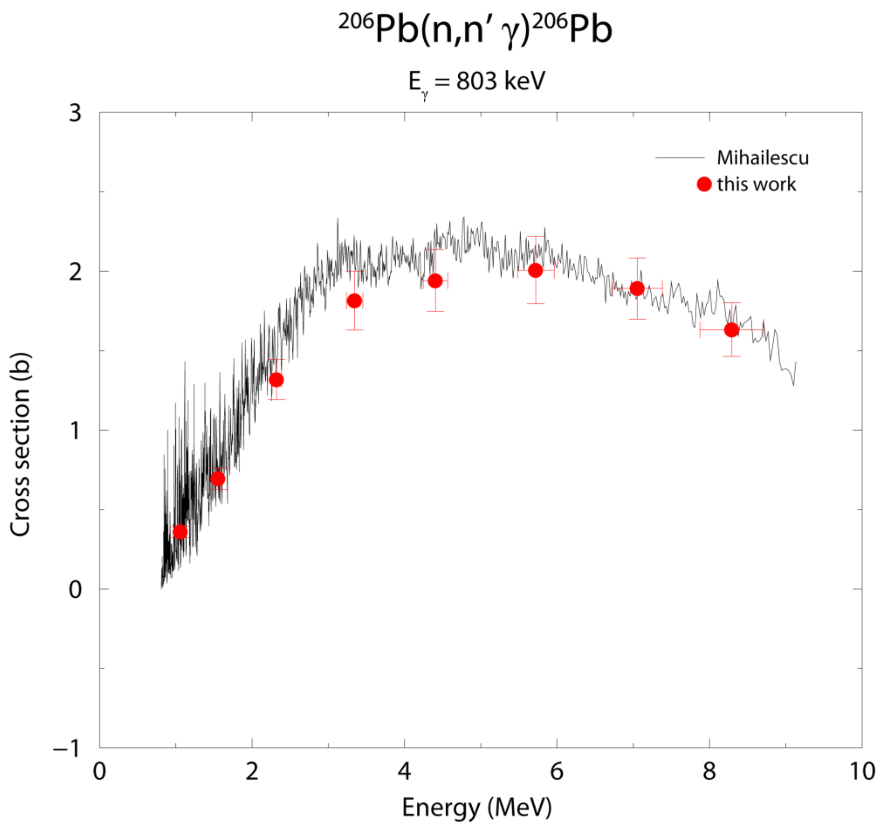


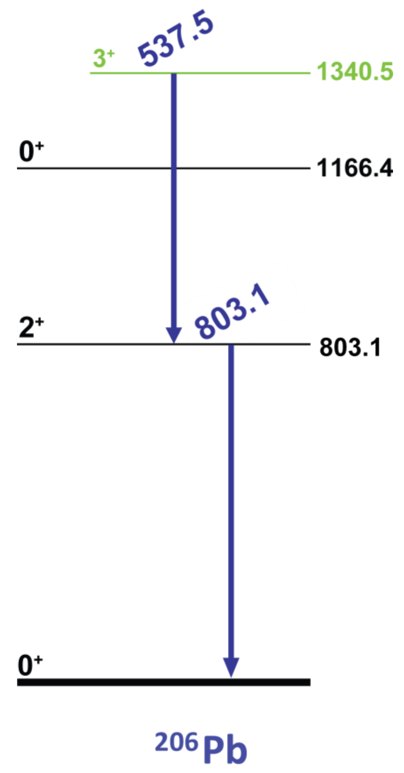
Results: $^{206}Pb(n,n'\gamma)\,^{206}Pb$





Results: $^{206}Pb(n,n'\gamma)^{206}Pb$





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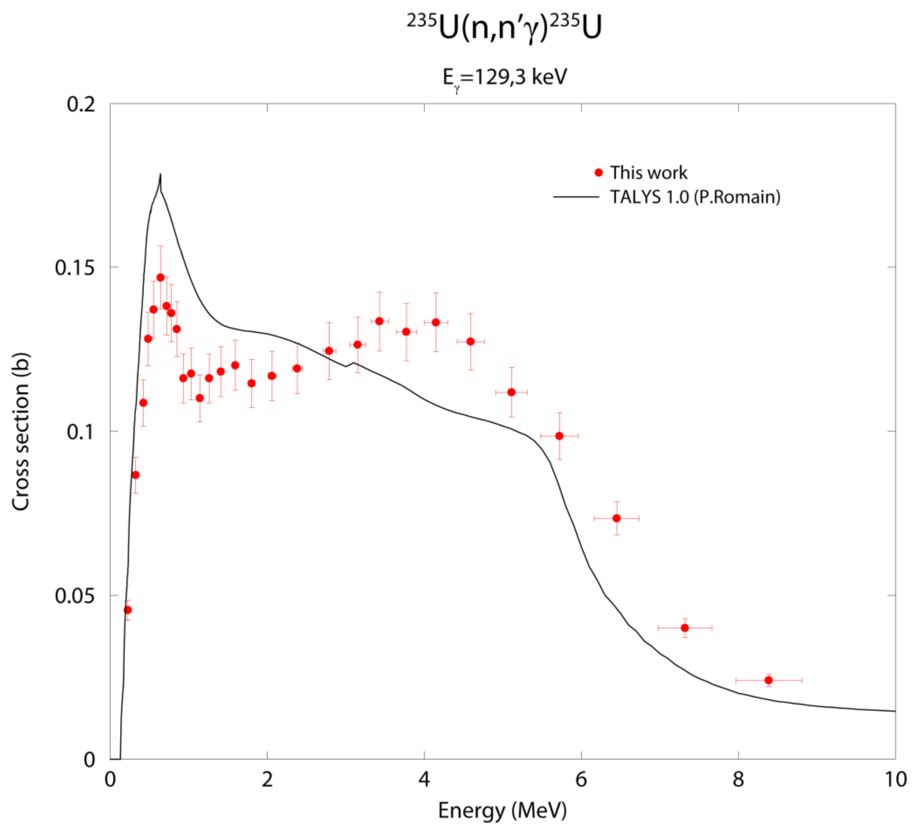
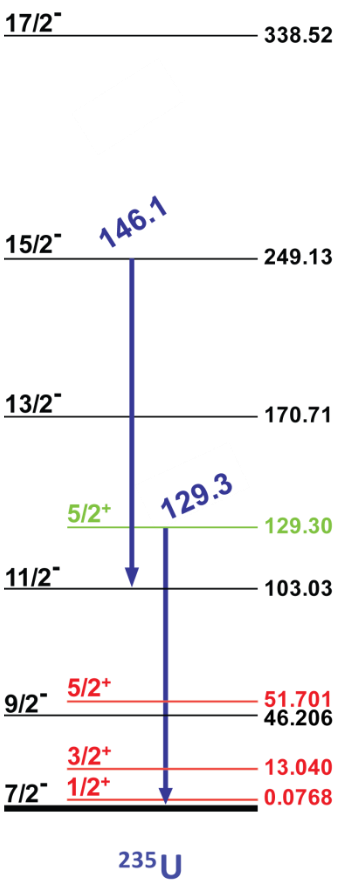
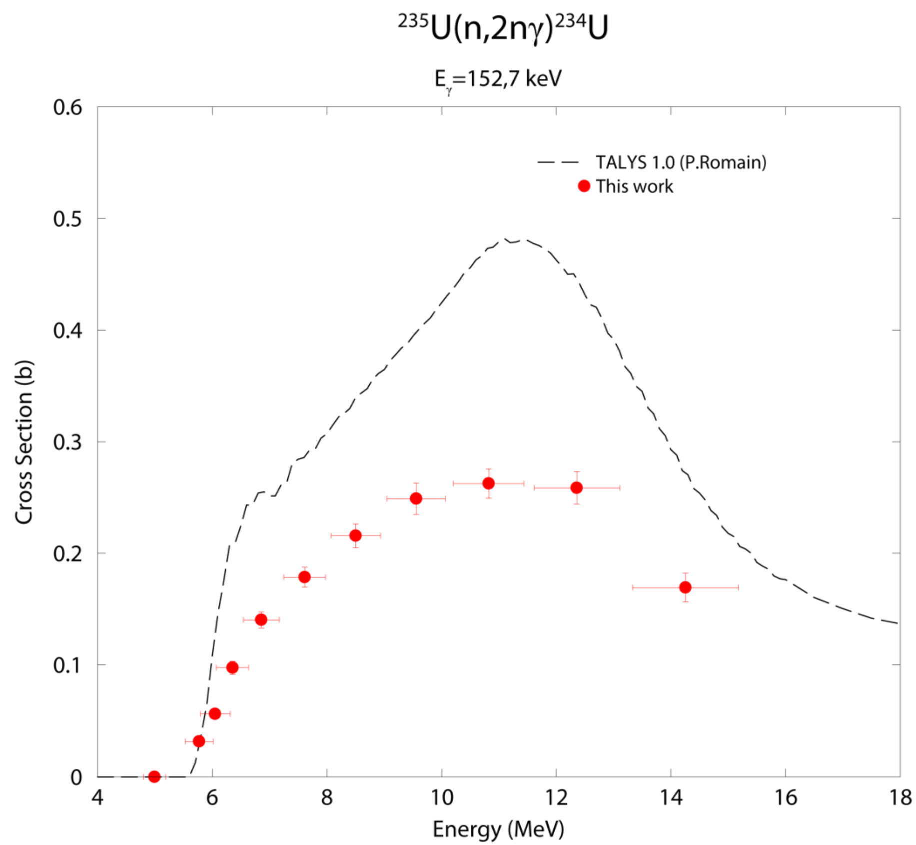
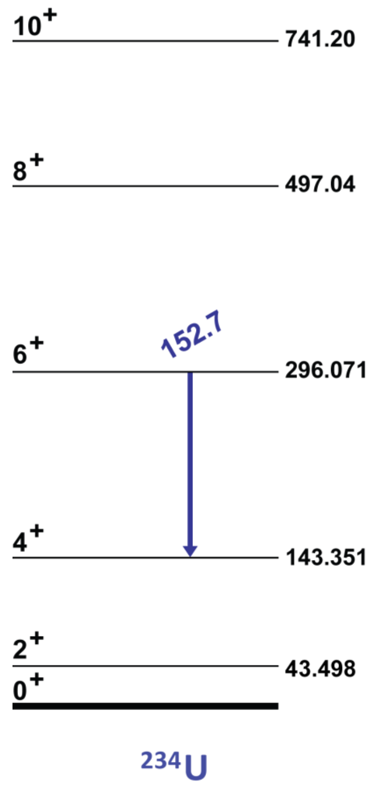
Results: $^{235}U(n,n'\gamma)^{235}U$





Results: $^{235}U(n,2n\gamma)^{234}U$





Conclusions & Perspectives

- Promising results for Pb and ^{235}U
- Further investigation on TALYS parameterization

- Perspectives:
  - Calibration measurements of the fission chamber
  - Development of a segmented planar HPGe detector, to reduce pile up rates
  - Measuring (n,xnγ) reactions on actinides:
    - ^{232}Th: (n,n'γ), (n,3nγ)
    - ^{238}U: (n,n'γ)
    - ^{233}U: (n,n'γ), (n,2nγ)

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Angle integration

- One can show that the differential cross section can be expressed as a finite sum over even degree Legendre polynomials:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta_i, E_i) = \frac{\sigma}{4\pi}\sum_{k=0}^{[j_i]} c_{2k} P_{2k}(\cos\theta_i)$$

- where $[j_i]$ is the largest integer smaller than or equal to the spin of the decaying state j_i. Gaussian quadrature specialized to even degree polynomials [4] can be used: for a given number *n* of detectors, we need the best angles ($x_j = \cos\vartheta_j$) and weights w_i to verify:

$$\sigma = 2\pi\int_{-1}^{1}\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(x)\,dx = 2\pi\sum_{i=1}^{n} w_i \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(x_i)$$

- This is achieved for x_i being the *n* positive zeroes of the Legendre polynomial P_{2n} and

$$w_i = \frac{1}{\sum_{m=0}^{n-1}((4m+1)/2)P_{2m}^2(x_i)}$$

- For the two detector configuration, the following results are found:
  w = 0.69571 for ϑ = 30.56°, 149.44° and w = 1.30429 for ϑ = 70.12°, 109.88°

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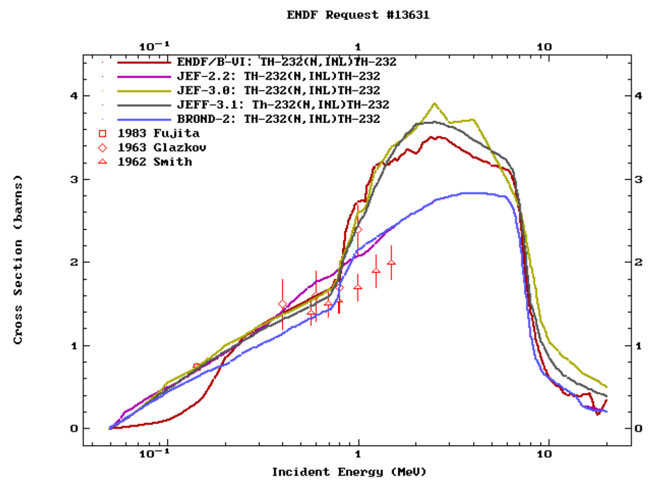
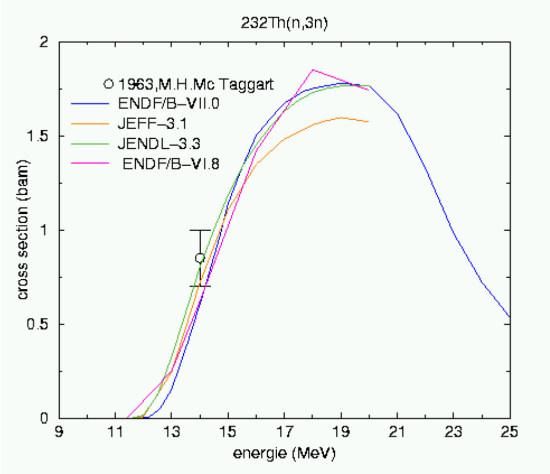
Currently known ^{232}Th data



^{232}Th(n,INL)



^{232}Th(n,3n)