On the systematic errors of the Th232(n,f) cross section measured with PPACs at CERN - nTOF

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Final Scientific EFNUDAT Workshop.

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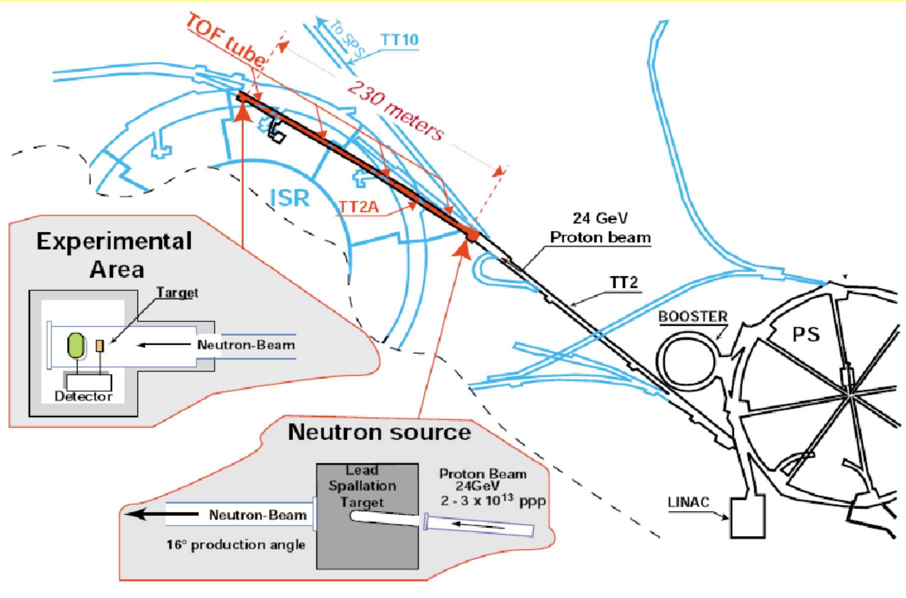
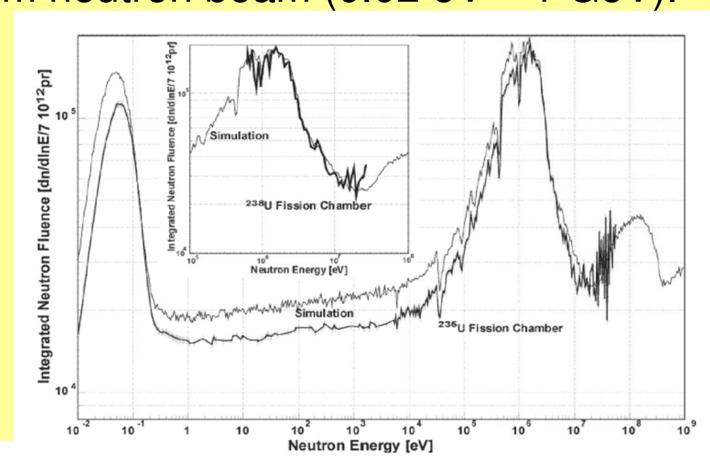
Introduction

- Th232(n,f) plays a key role in the development of Th/U reactors.
- The (n,f) cross section of Th232 has been measured at CERN-n_TOF (Phase 1).
  - Extended range from threshold up to 1 GeV.
- Systematic effects on the experiment will be discussed here, including the angular distribution of the fission fragments.
- Moreover, the angular distribution gives physical information on the dynamics of the fission process.
  - Qualitative results can be derived from that measurement.

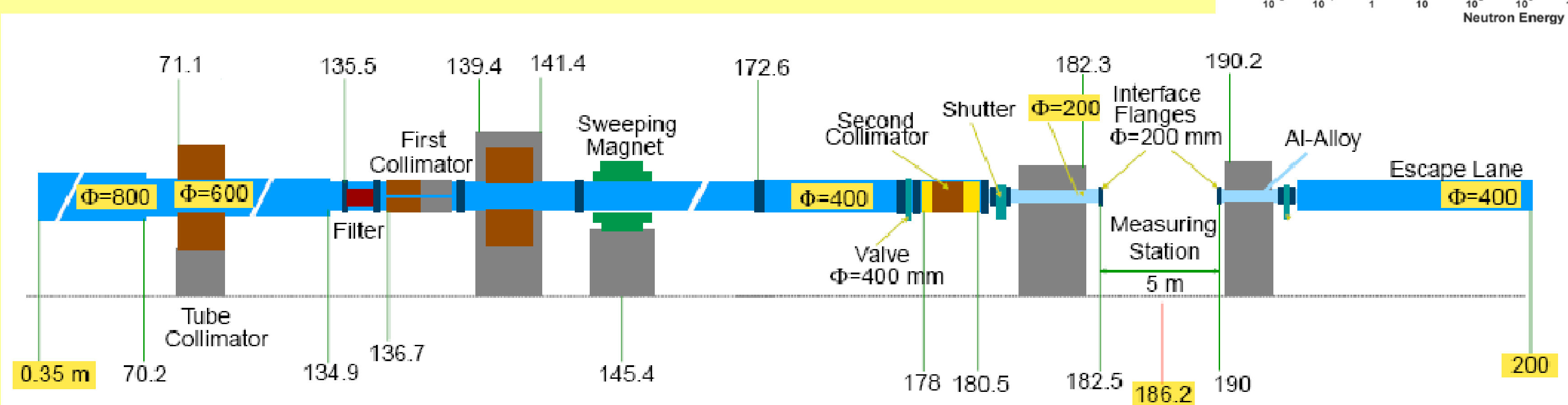
The n_TOF facility at CERN



- n_TOF (Neutron Time-Of-Flight) is a facility dedicated to the study of neutron-induced reactions: fission and radiative capture.
- The neutron beam is produced by spallation reactions of 20 GeV/c protons from the PS (Proton Synchrotron) on a lead target.
- White spectrum neutron beam (0.02 eV – 1 GeV).



- Around $9.6 \cdot 10^5$ neutrons per proton bunch.
- Long-flight path (185 m) → high-accuracy resolution in neutron energy using its time of flight (0.01% at 1 eV; 6% at 1 GeV).



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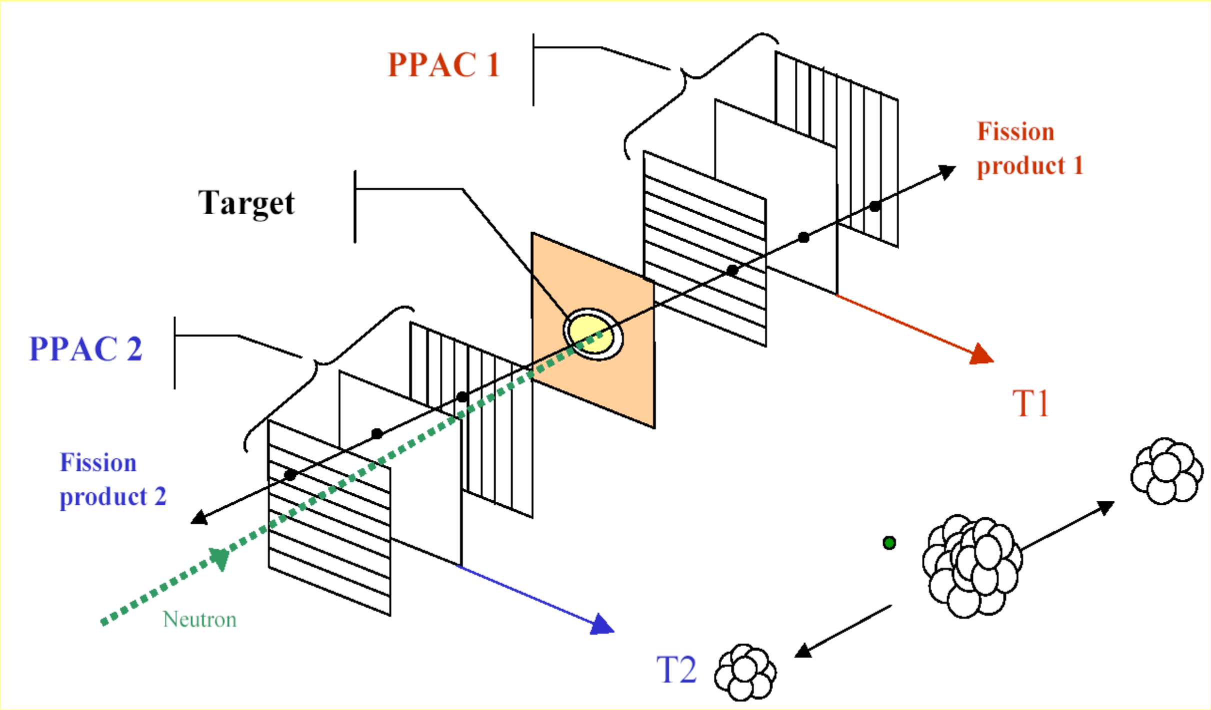
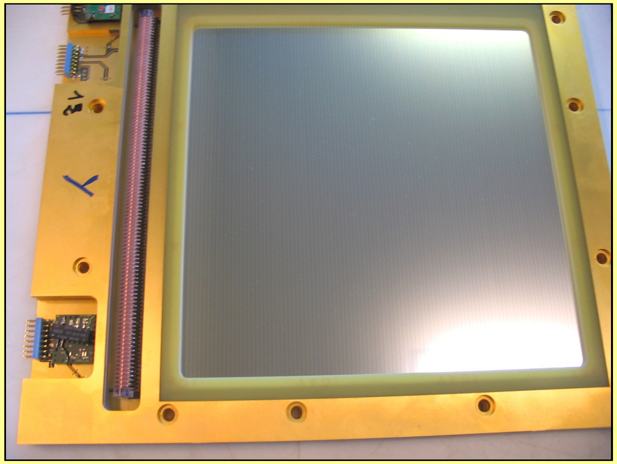
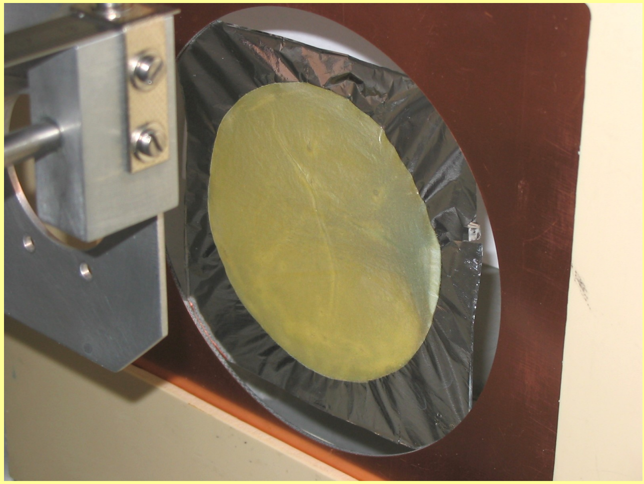
Experimental setup

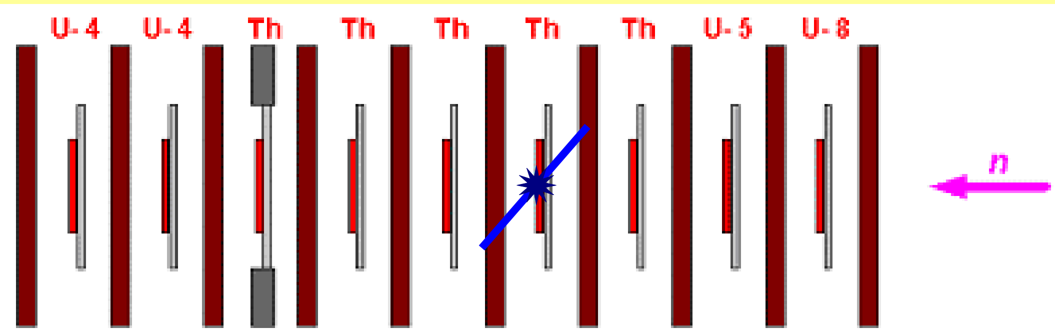






- Parallel Plate Avalanche Counter (PPAC) detectors.
- Central anode and two stripped cathodes.
  - Reconstruction of the trajectories of the fission fragments.
- **The fission fragments are detected in coincidence in two adjacent PPACs.**
  - Rejection of α-particles and light nuclei from other reactions.
- **Th-232 (5 targets), U-235** and **U-238** deposited over 2.5 μm of Aluminium (8 cm diameter).

Fission cross section measurements



- 10 PPACs and 9 targets.
- Reference targets: ^{235}U and ^{238}U.
- Neutron flux attenuation lower than 1%.

- Number of detected fission events: $C(E) = \Phi(E) \cdot m \cdot \sigma(E) \cdot \varepsilon(E)$
- Relative cross sections:

Three sources of systematics:

$$\frac{\sigma_i(E)}{\sigma_j(E)} = \frac{C_i(E)}{C_j(E)} \cdot \frac{\Phi_j(E)}{\Phi_i(E)} \cdot \frac{m_j}{m_i} \cdot \frac{\varepsilon_j(E)}{\varepsilon_i(E)}$$

(1) Independent of the neutron energy

(2) Equal to 1 if the targets are **geometrically identical (beam alignment)**

(3) Ratio of efficiencies:
- thickness of the samples and their backings
- angular distribution of the fission fragments

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IPN Orsay

Ratio of fission rates

$$\frac{\sigma_i(E)}{\sigma_j(E)} = \frac{C_i(E)}{C_j(E)} \cdot \frac{\Phi_j(E)}{\Phi_i(E)} \cdot \frac{m_j}{m_i} \frac{\varepsilon_j(E)}{\varepsilon_i(E)}$$

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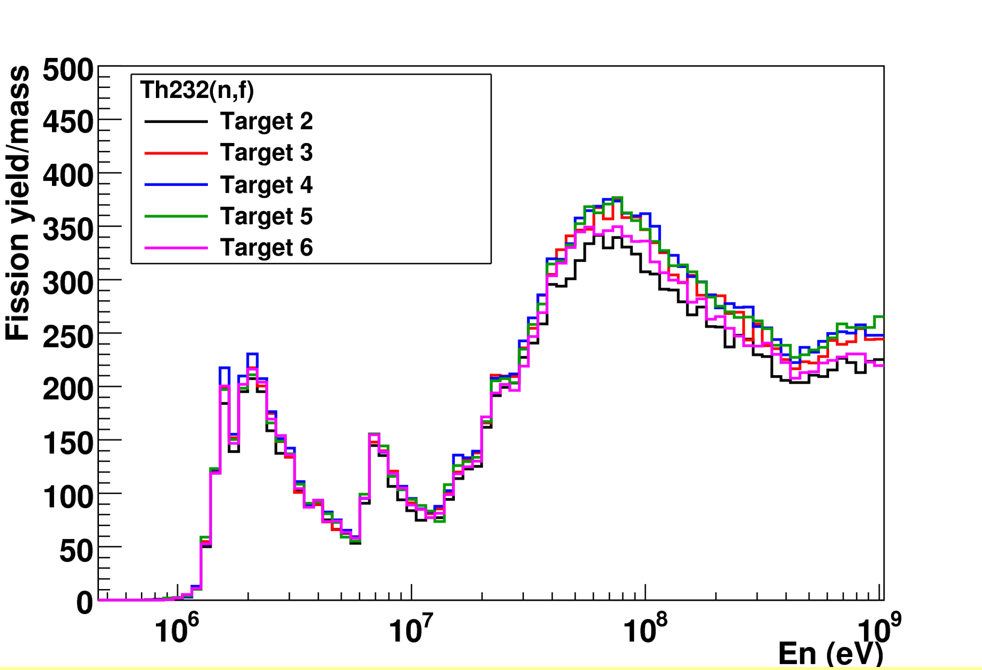
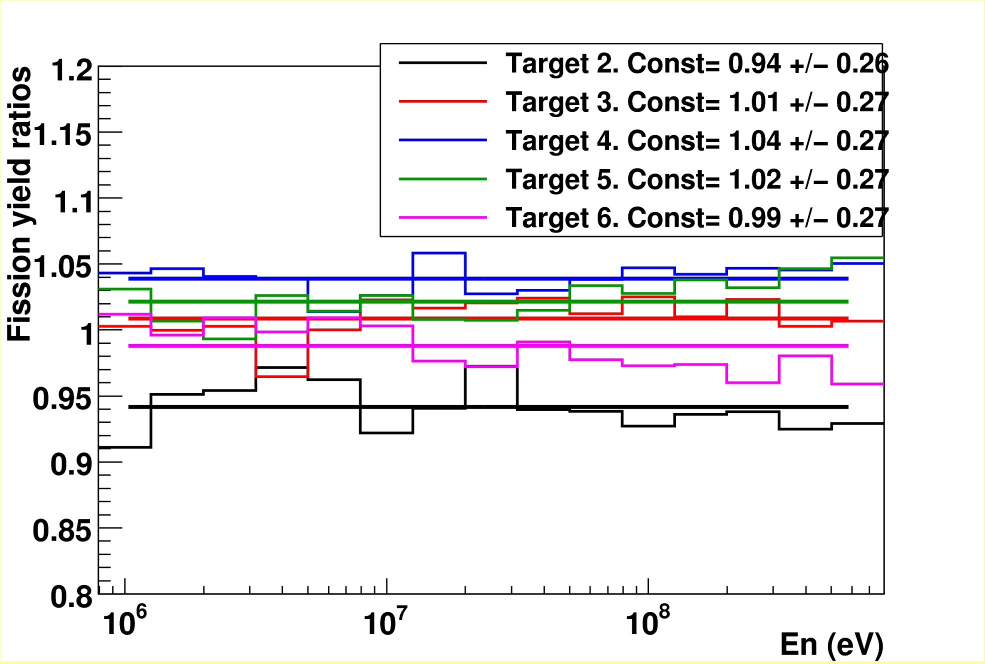
Ratio of fission rates

- All the fission rates (normalized to the mass of the target) should be equal:



- Ratio of each normalized fission rate over the mean value:



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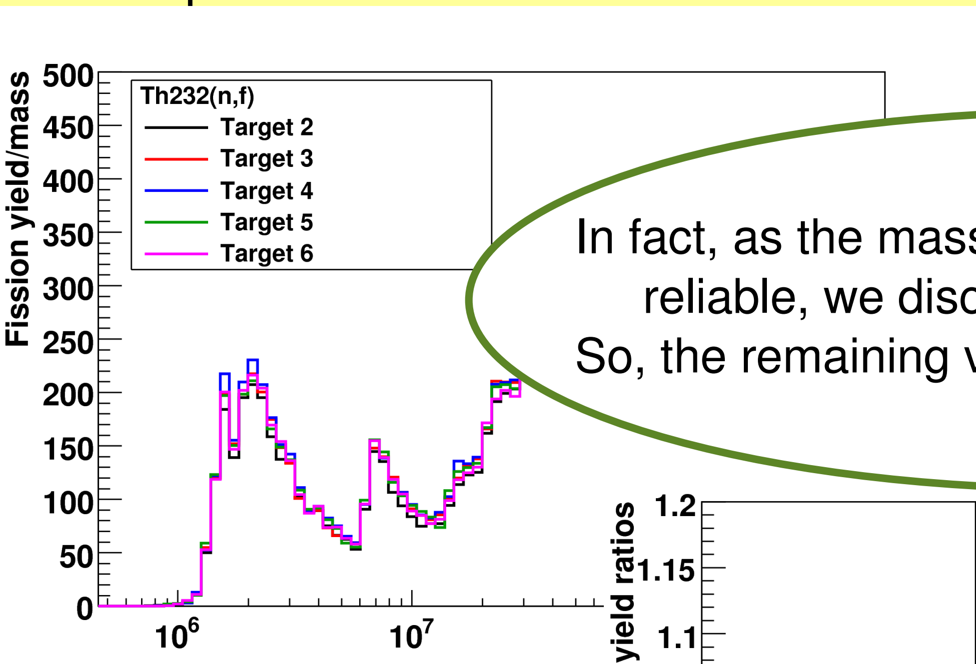
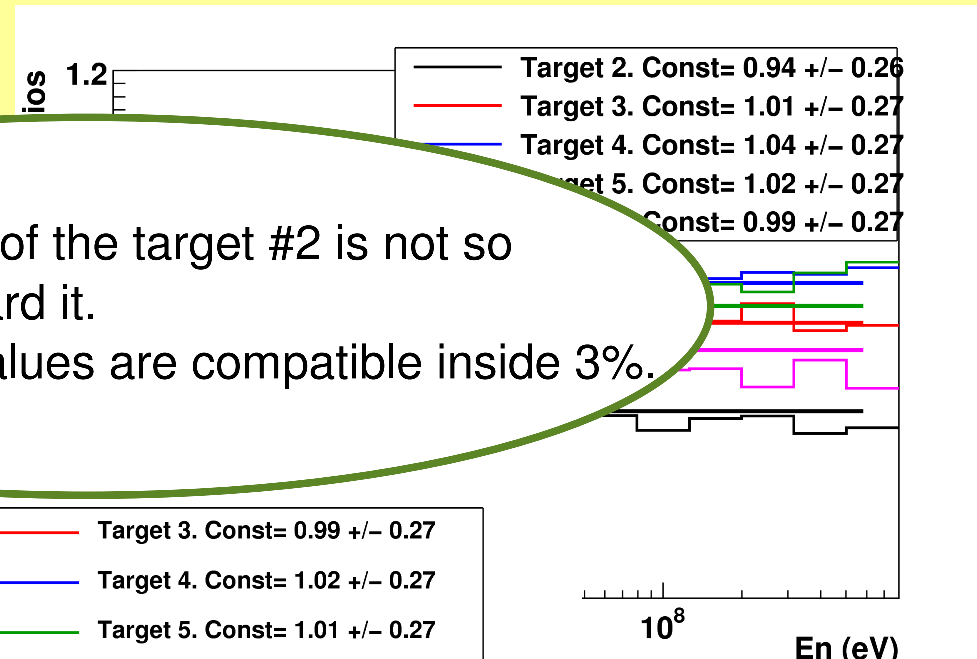
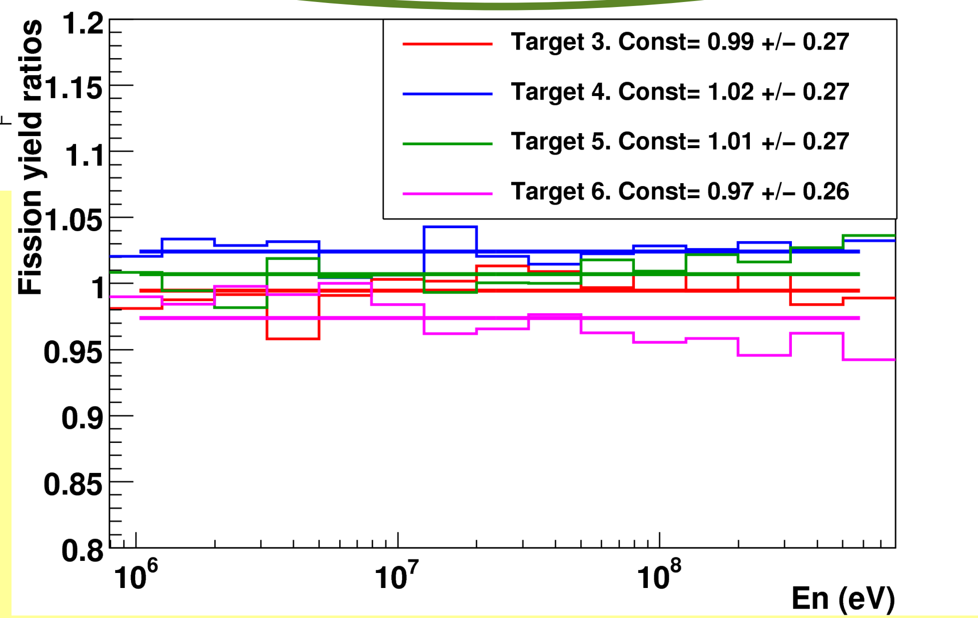


- Ratio of each normalized fission rate over the mean value:



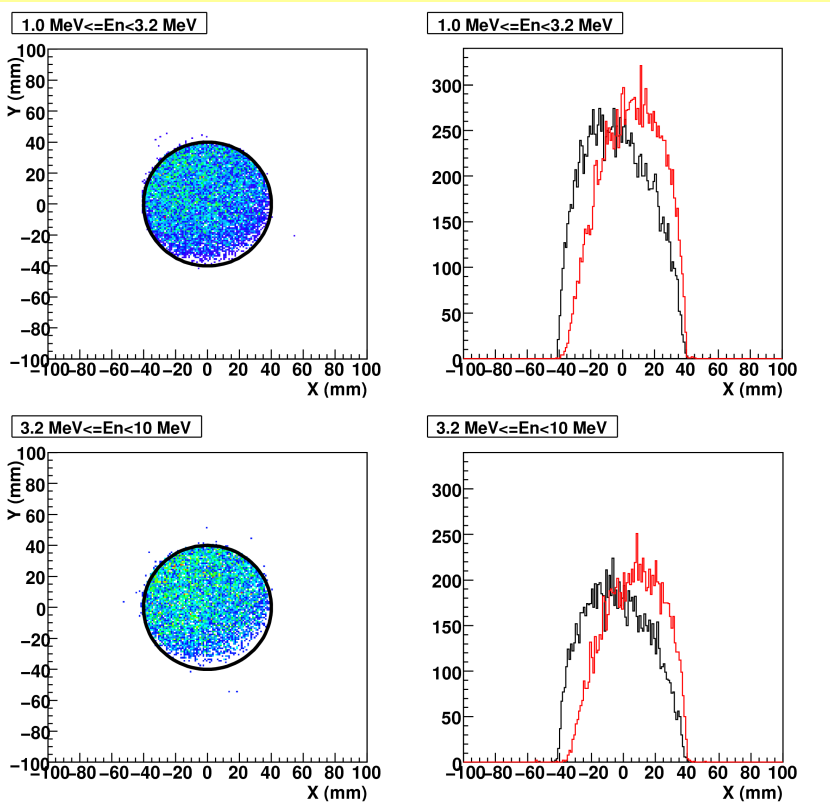
In fact, as the mass of the target #2 is not so reliable, we discard it.
So, the remaining values are compatible inside 3%.



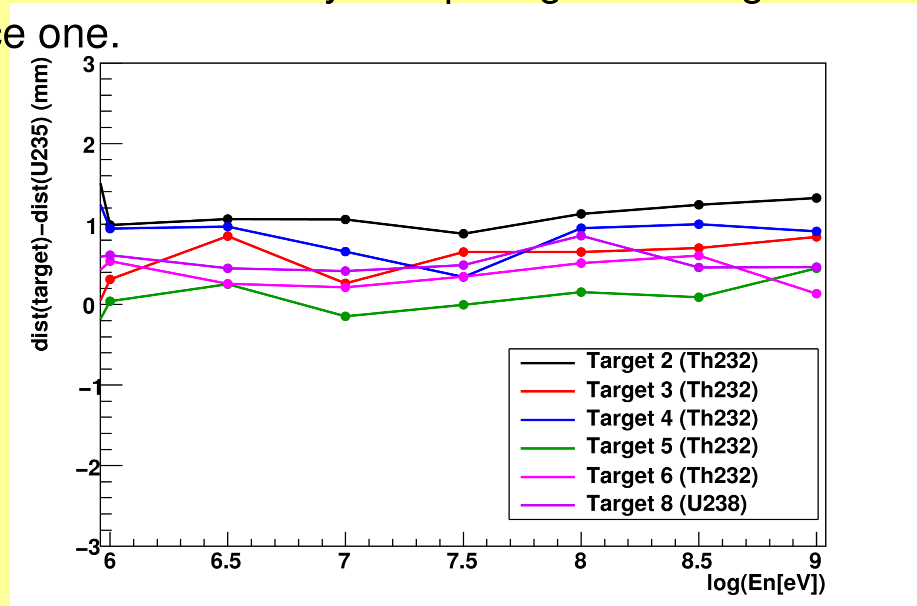
Beam alignment

$$\frac{\sigma_i(E)}{\sigma_j(E)} = \frac{C_i(E)}{C_j(E)} \boxed{\frac{\Phi_j(E)}{\Phi_i(E)}} \cdot \frac{m_j}{m_i} \cdot \frac{\varepsilon_j(E)}{\varepsilon_i(E)}$$

Neutron beam alignment



- The neutron beam spot should be equal for all the targets.
- Mapping of the positions of fission events. Sensitive to:
  - Mass distribution in the targets.
  - Beam profile and alignment.
- Distributions are not perfectly centered.
- The beam profile moves upwards slightly with the neutron energy (the same for all the targets, but affected by non-uniform mass distributions).
- We can correct this effect by comparing each target with the reference one.



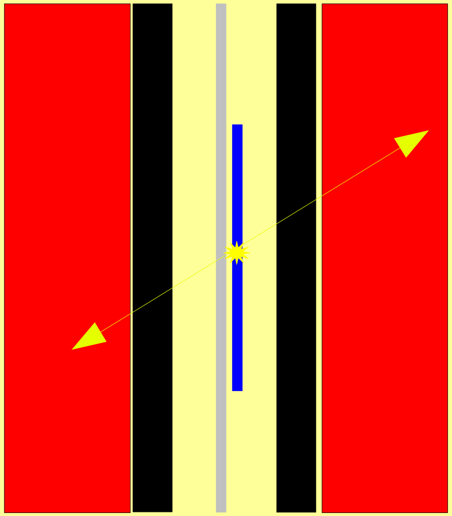
- Differences in the distance to the center with respect to the reference samples (U235 and U238) are smaller than 1 mm.
- The difference in the superimposed areas of two targets is 1.6% in the most unfavourable case.

Ratio of efficiencies

$$\frac{\sigma_i(E)}{\sigma_j(E)} = \frac{C_i(E)}{C_j(E)} \cdot \frac{\Phi_j(E)}{\Phi_i(E)} \cdot \frac{m_j}{m_i} \frac{\varepsilon_j(E)}{\varepsilon_i(E)}$$

- This ratio includes the differences between the thorium samples and the reference target.
- In particular, the specific anisotropy of each isotope (depending on neutron energy) will be discussed.

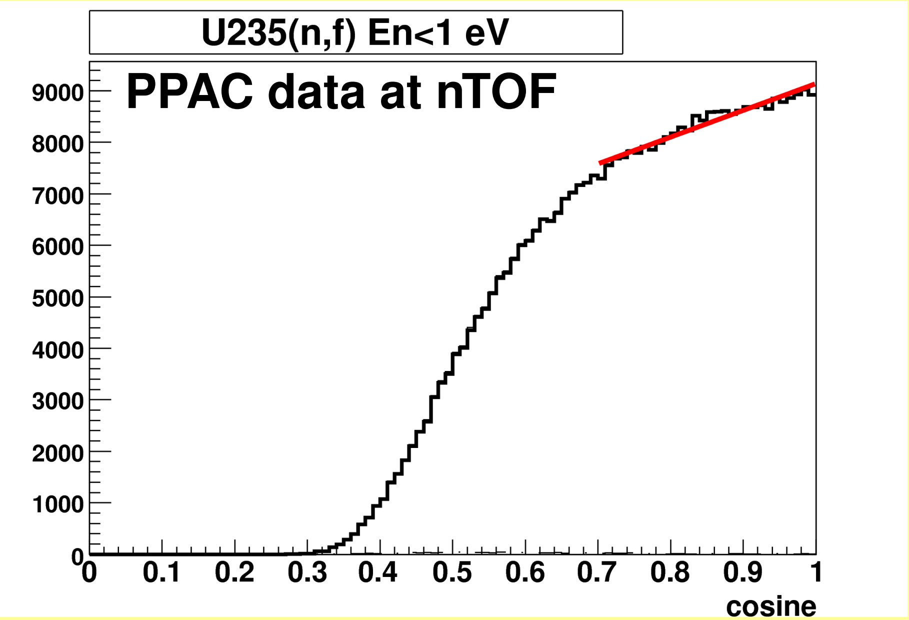
Ratio of geometrical effects



- The efficiency detection is given by the **maximum acceptance angle for the fission fragments (FF),** determined by its range (distribution on mass, charge and energy).
- Limited angular acceptance (solid angle << 4π).
- Moreover, the efficiency is proportional to cos θ.

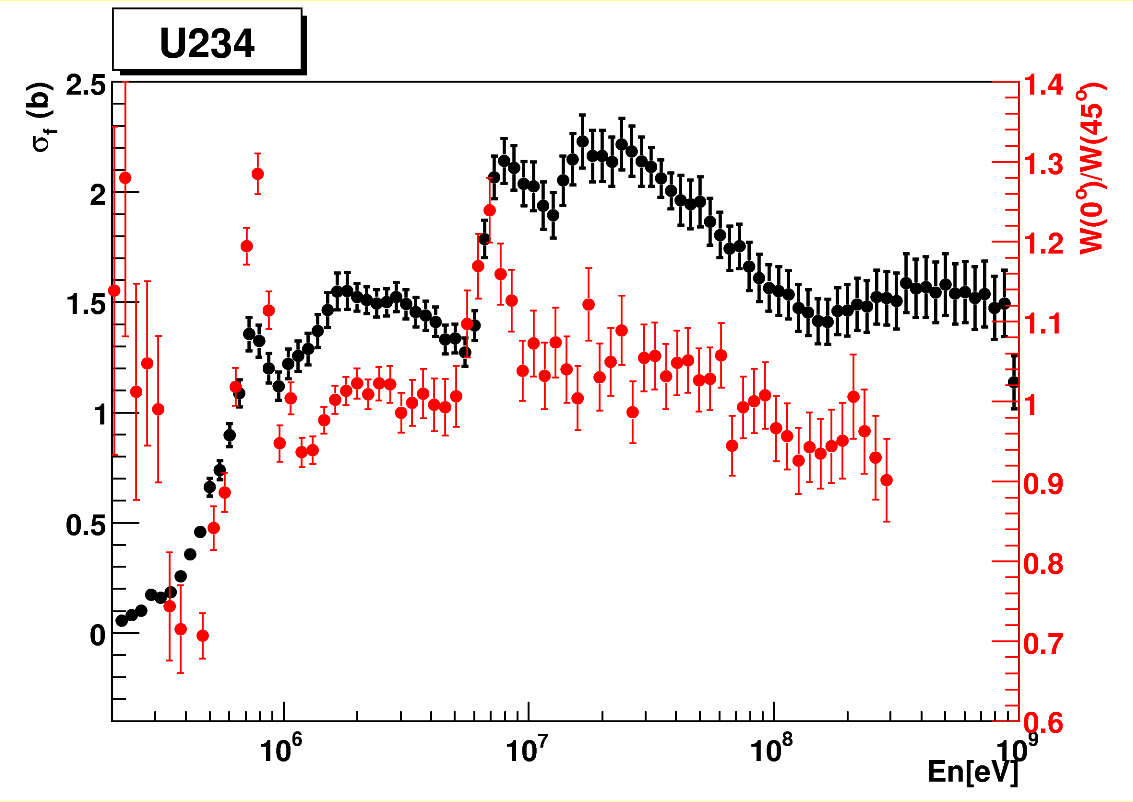
Bunemann et al., Can. J. Res. A27 (1949) 191

- To study the energy lost by the FF in the backing and in the detector walls, SRIM simulations have been perfomed.
- Assuming isotropy in the FFAD, these effects contribute with less than 1% to the fission cross section systematic uncertainties.



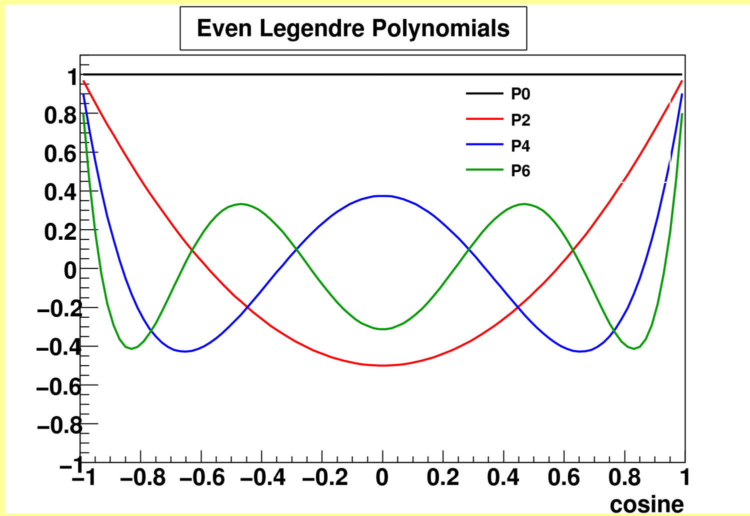
Anisotropy effects

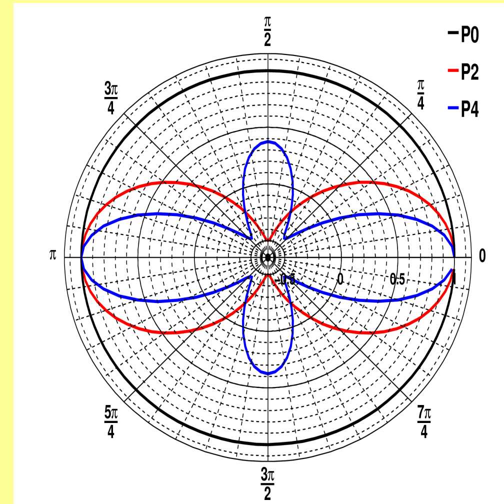
- The FFAD is not isotropic, mainly at neutron energies close to the thresholds of new fission chances.
  - Usually, the anisotropy parameter is defined as: $A = \frac{W(0^\circ)}{W(90^\circ)}$



FF Angular Distribution

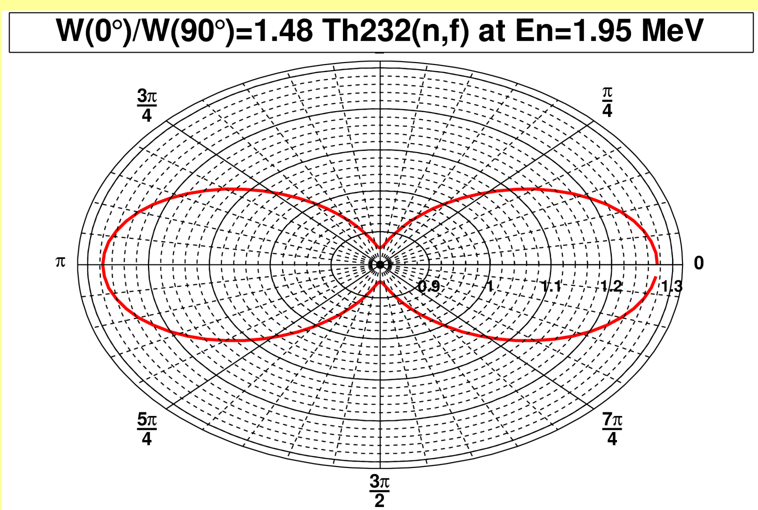
- The FFAD can be described using even Legendre polynomials:

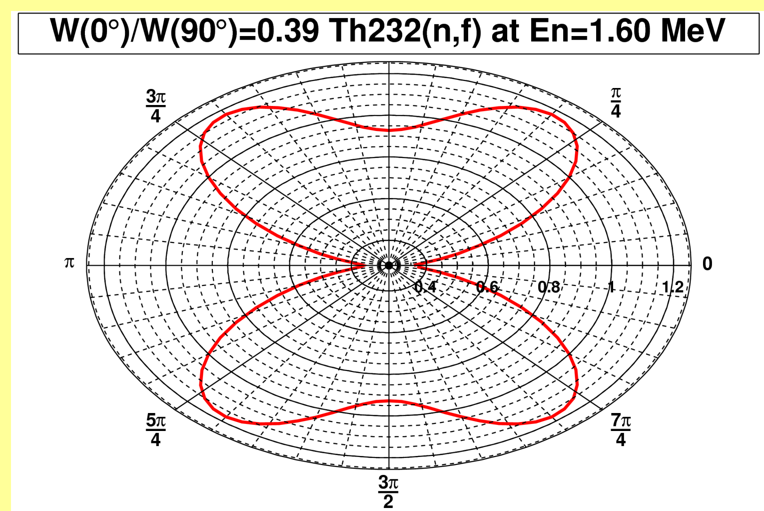




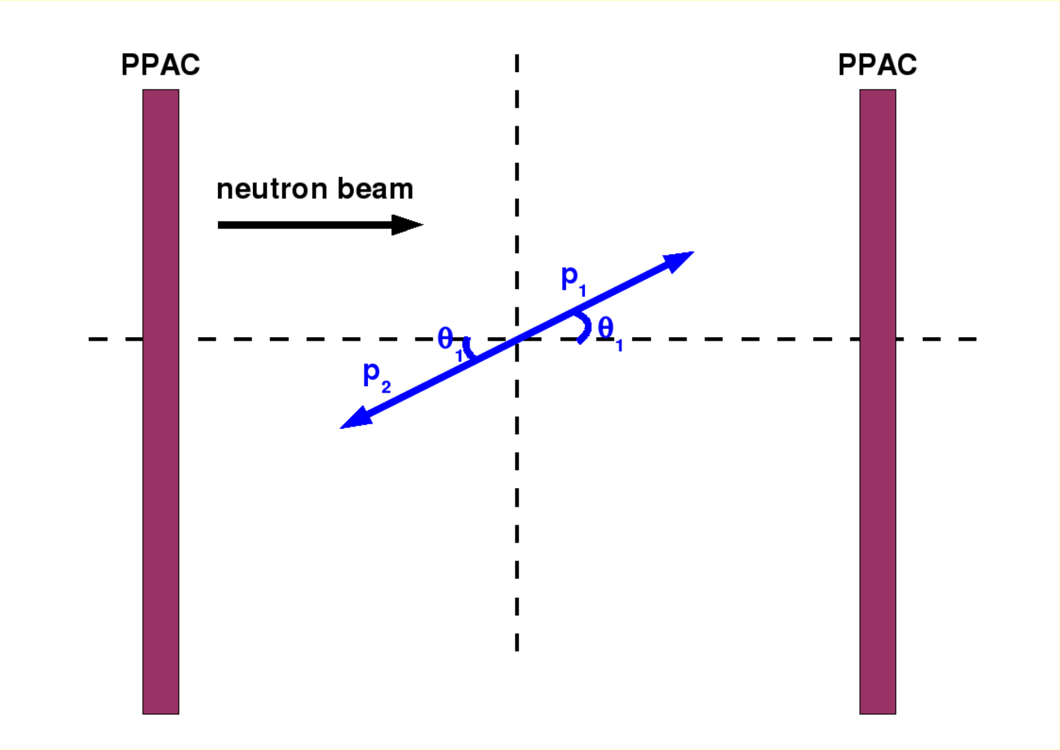
$$W(\theta) = \sum_L A_L P_L(\cos\theta) \qquad A = \frac{W(0^\circ)}{W(90^\circ)}$$

- For instance:



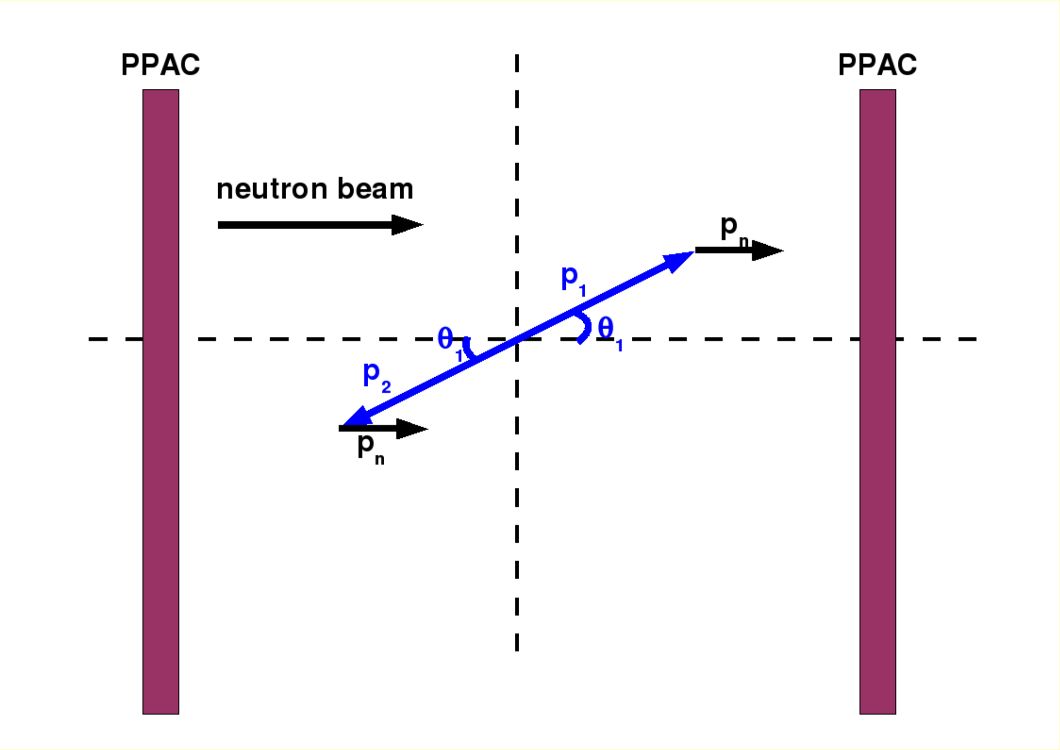


Linear momentum transfer (LMT)



p_1, p_2, θ_1, θ_2 → Momentum and outgoing angles of the fission fragments in C. M. frame.

Linear momentum transfer (LMT)



p_1, p_2, θ_1, θ_2 → Momentum and outgoing angles of the fission fragments in C. M. frame.

p_n → Momentum transferred by the neutron to the fissioning nucleus.

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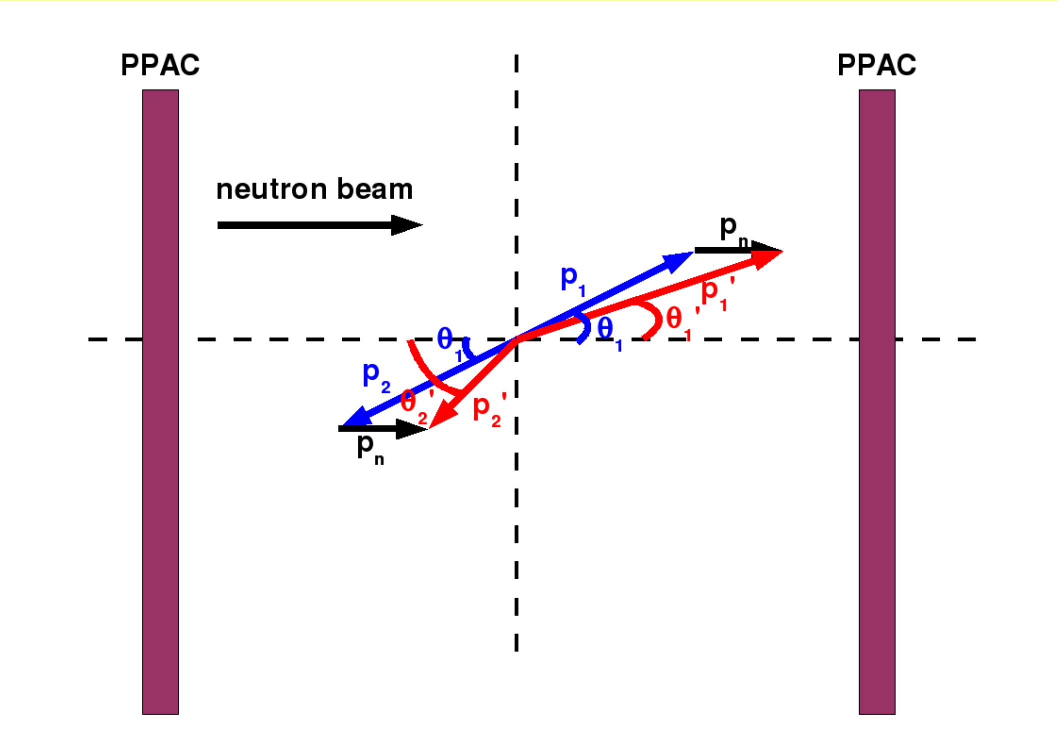

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$p'_1, p'_2, \theta'_1, \theta'_2$ → Momentum and outgoing angles of the fission fragments in Lab. frame.

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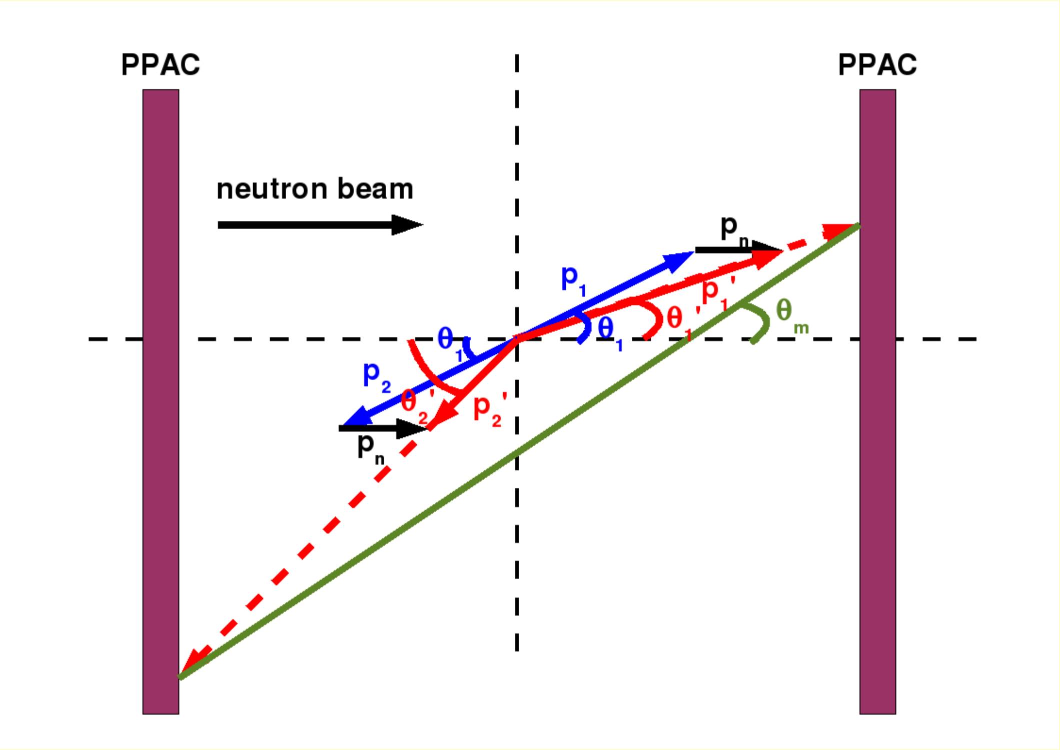

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θ_m → But the measured angle is θ_m **!**

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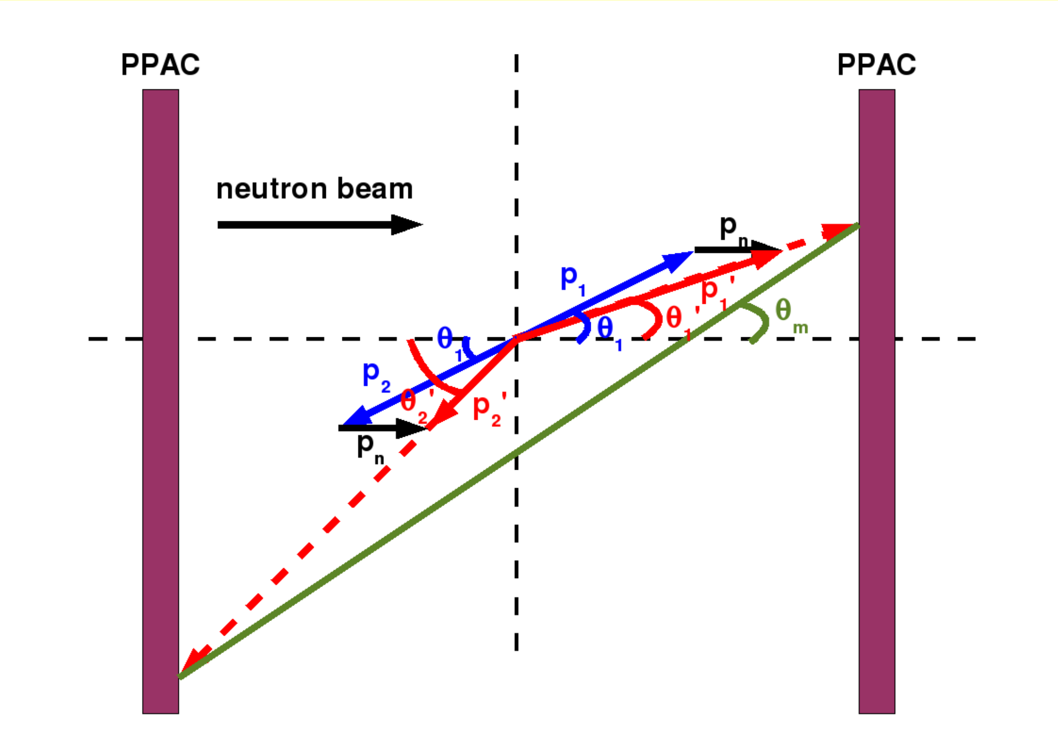

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θ_m → But the measured angle is θ_m !

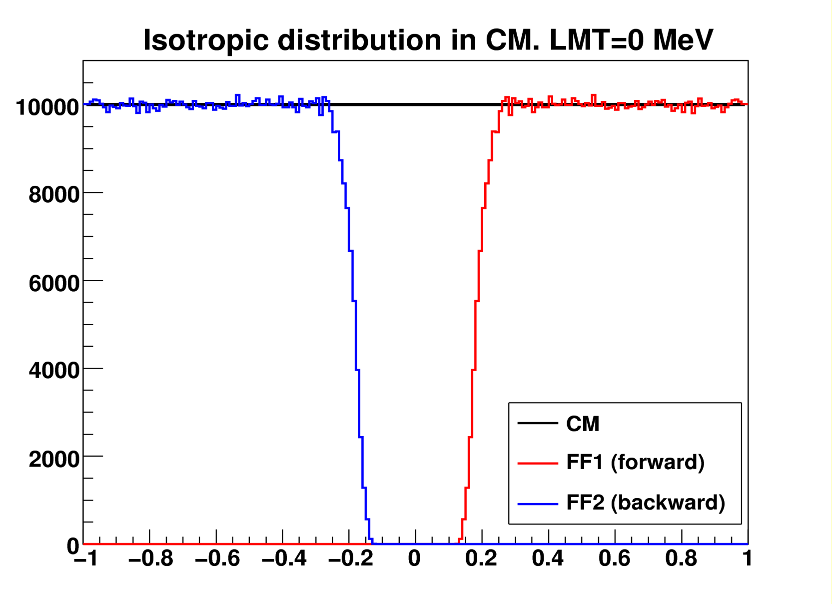
$$\tan\theta_{lab} = \frac{\sin\Theta_{CM}}{\gamma\left(\cos\Theta_{CM} + \frac{\beta}{\beta'_1}\right)}$$

- Several simulations have been performed to study how the measured angle looks like in different cases of anisotropy: A=W(0°)/W(90°).
  - Typical fission fragments. TKE given by Viola's systematics.
  - LMT in (N,f) reactions is not complete.
  - Energy losses calculated with SRIM.
  - A linear dependence of the detection efficiency with cos θ was included in the study.

Isotropic distribution of FF

- To study the behaviour of PPAC detectors, a simulation work has been performed, including geometrical features.
- First of all, an isotropic distribution of FF is produced, and cosine distribution of the outgoing angles of the FF and of the measured angle are shown:

Asymmetric-mass fission is assumed. A=131, Z=54, E=75 MeV (TKE given by Viola's systematic)



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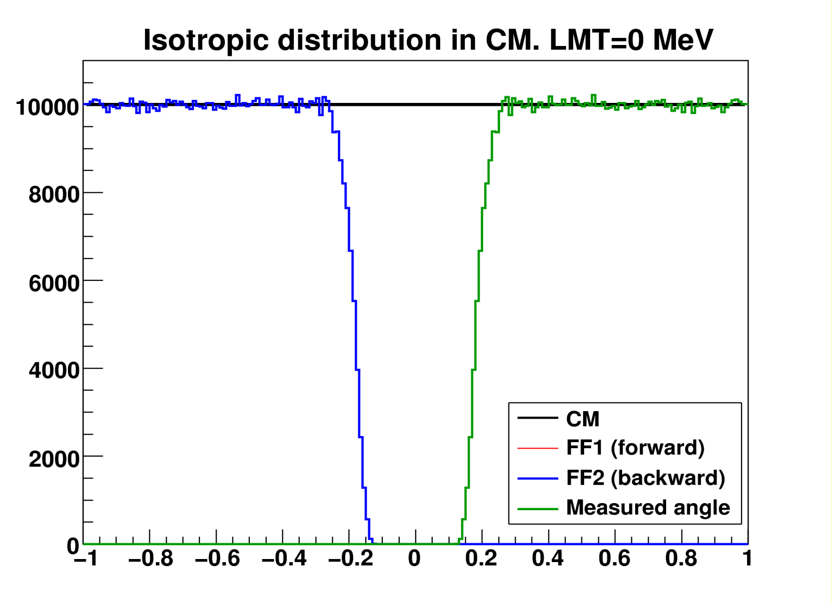

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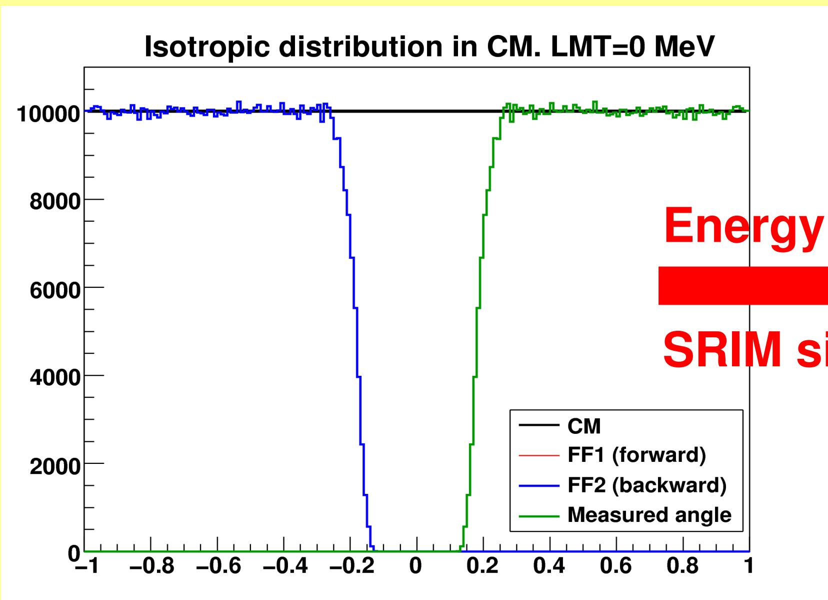
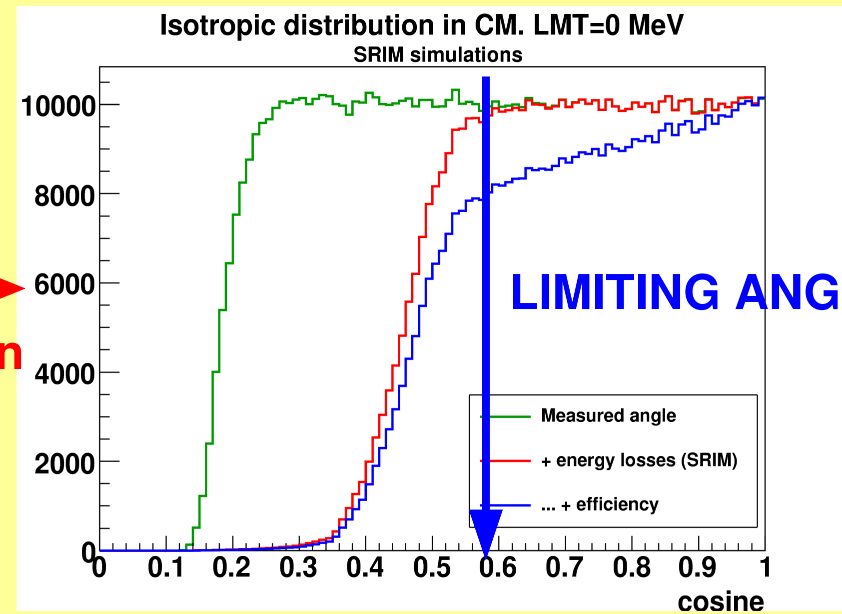
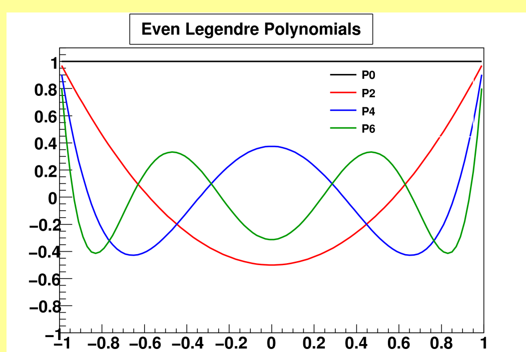


Energy losses

SRIM simulation



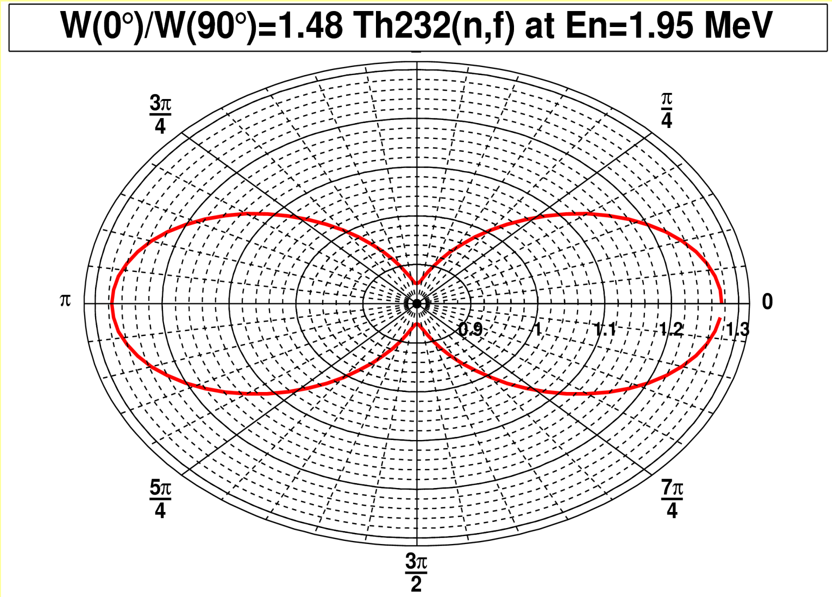
LIMITING ANGLE!!!

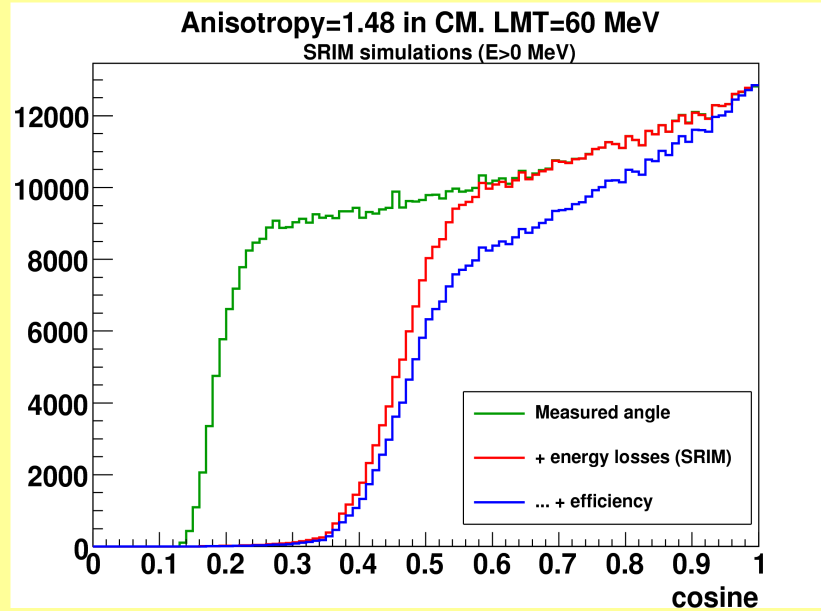


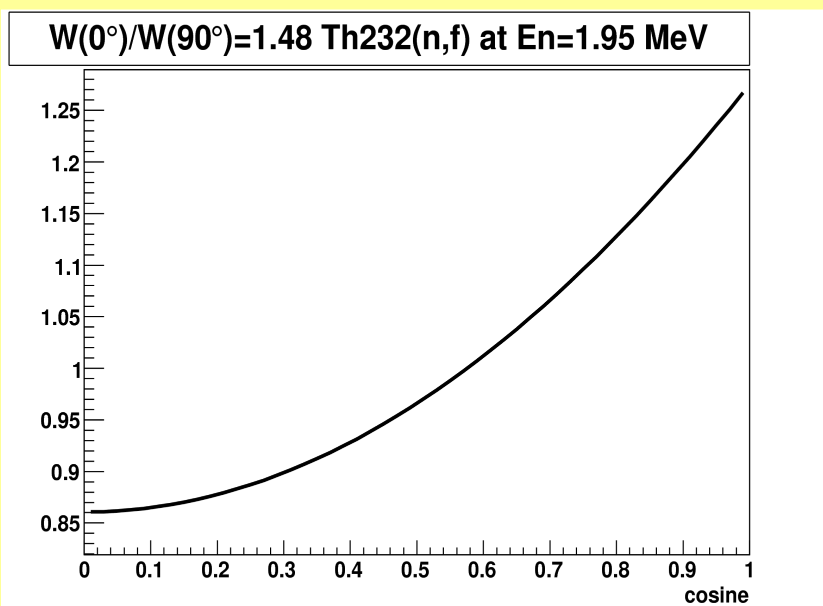
The efficiency decreases above 60°

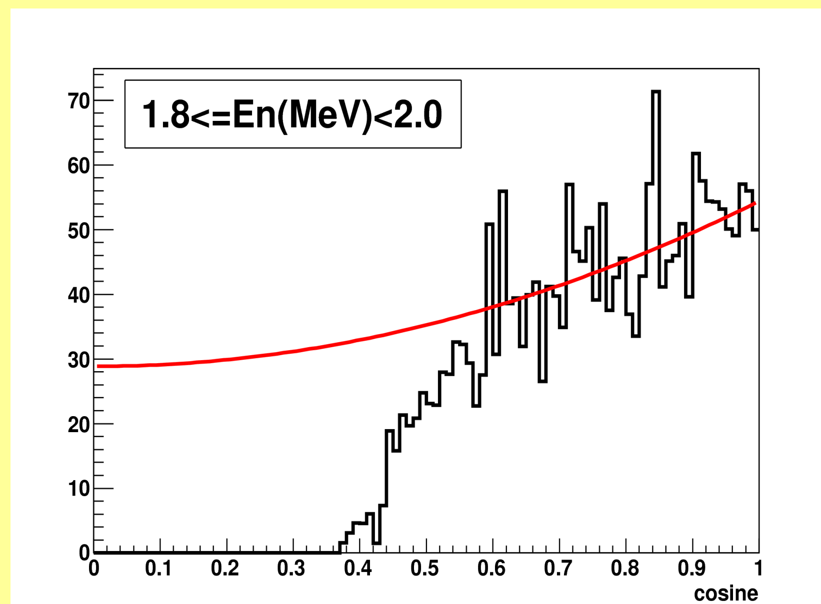
Having information limited to cos θ > 0.5 only makes sense to fit up to order L=2

Non-isotropic cases (A>1)



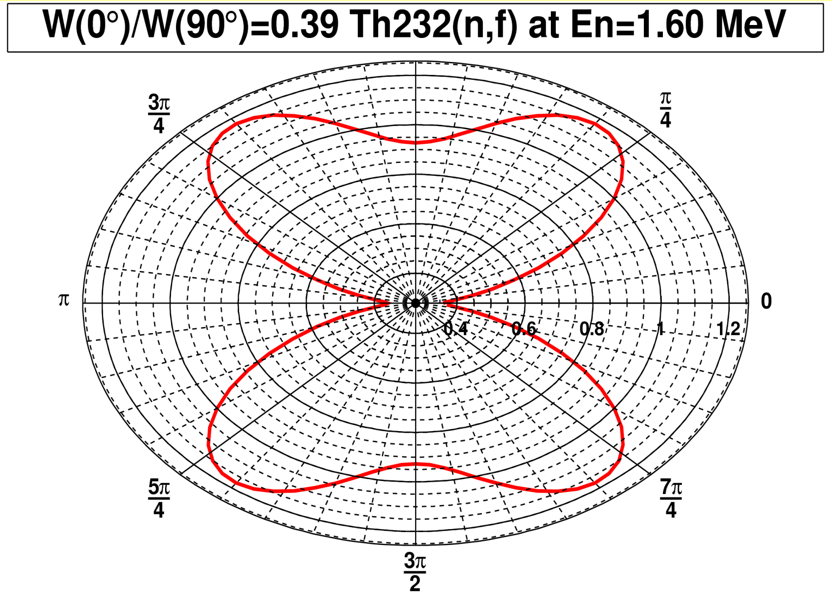


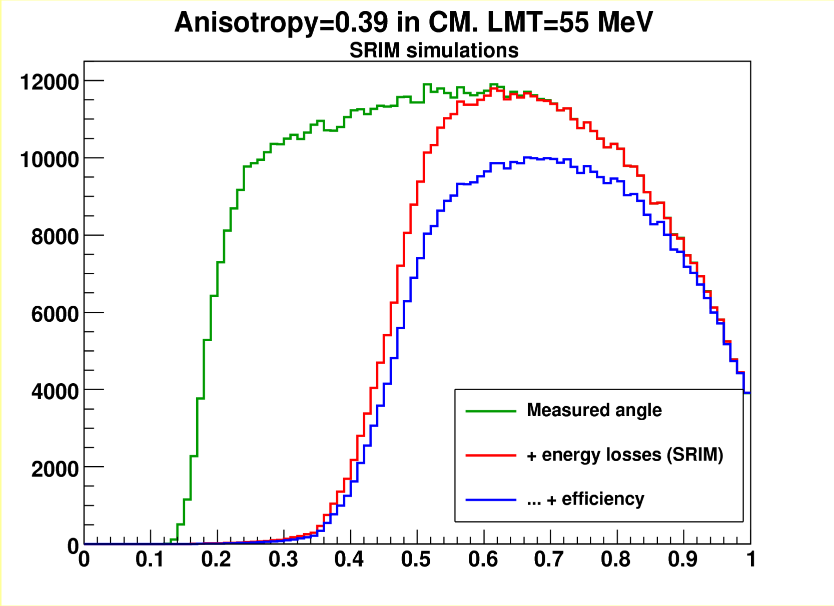


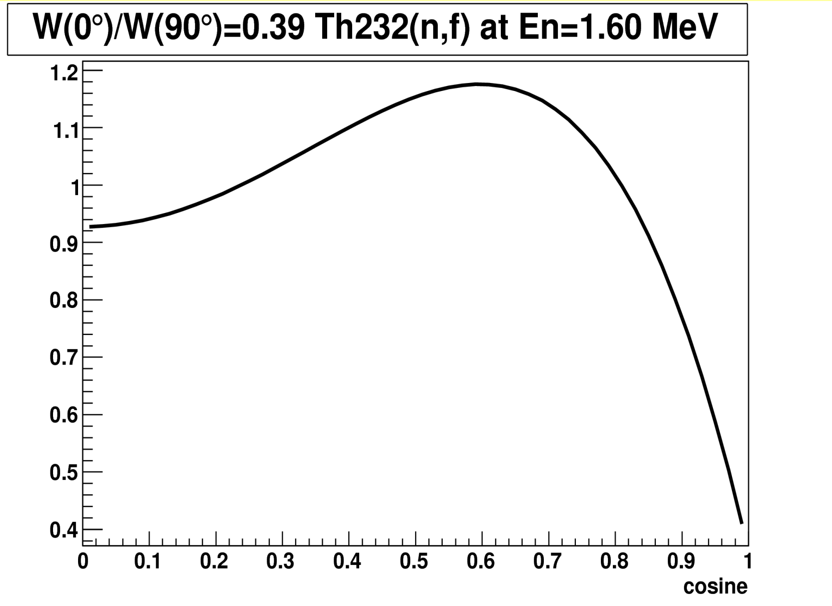


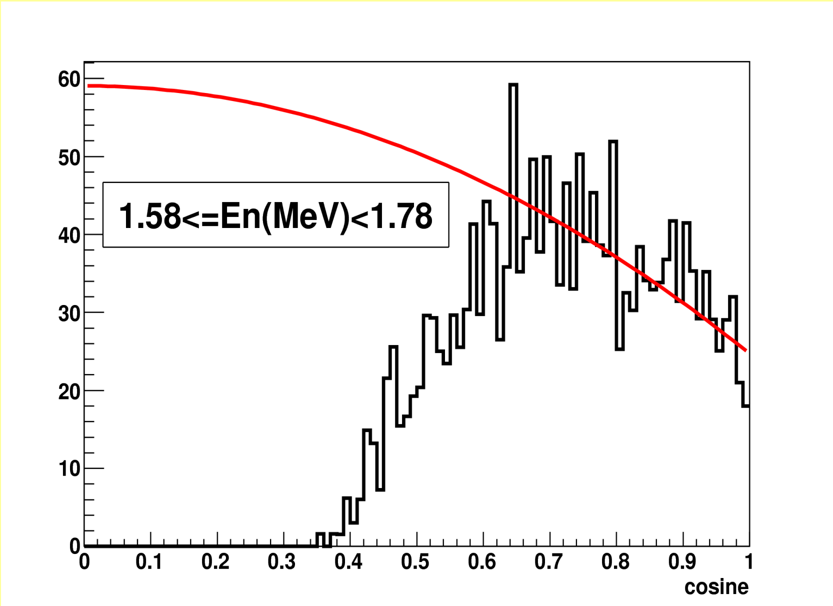
Caruana et al. Nucl. Phys. A285 (1977) 205

Non-isotropic cases (A<1)



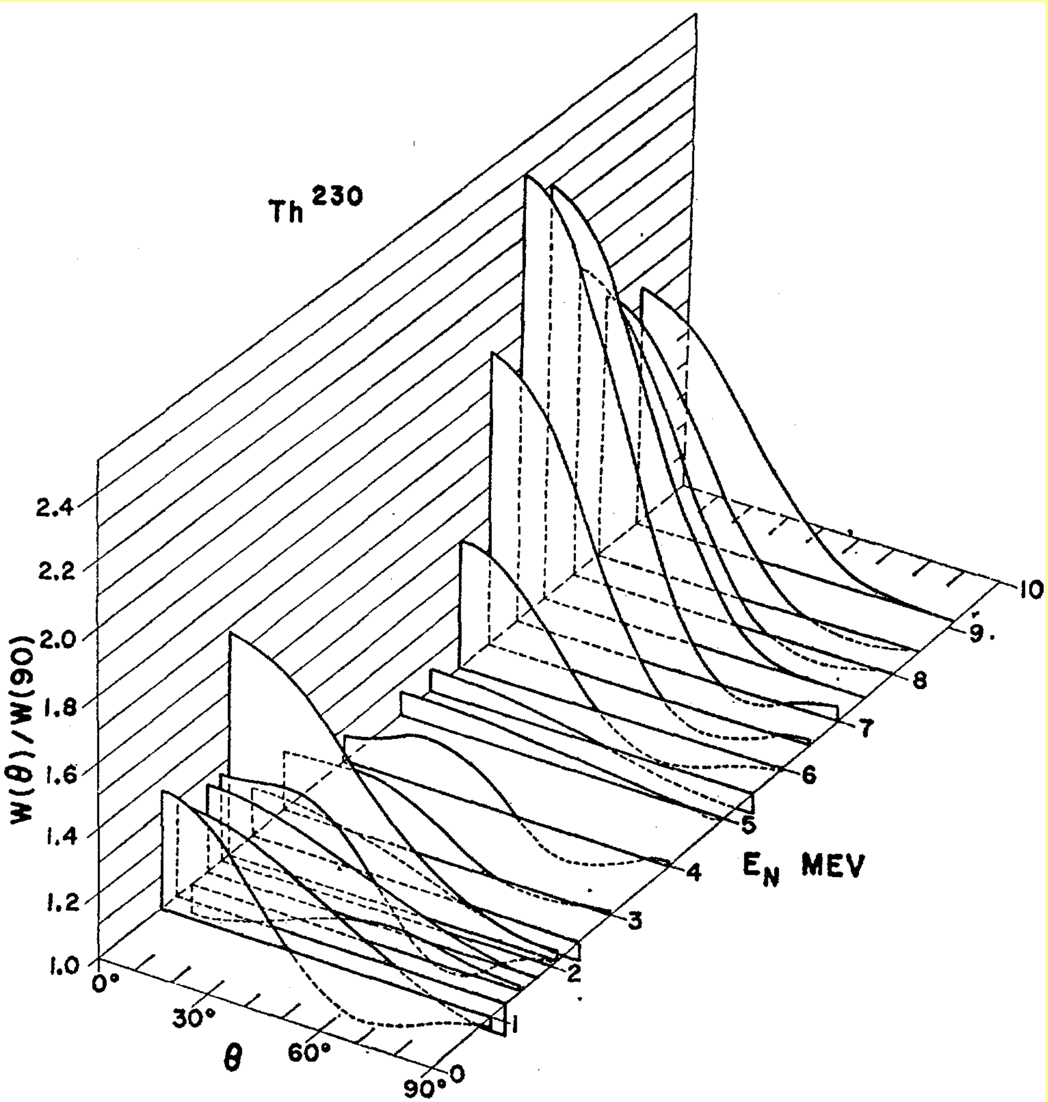






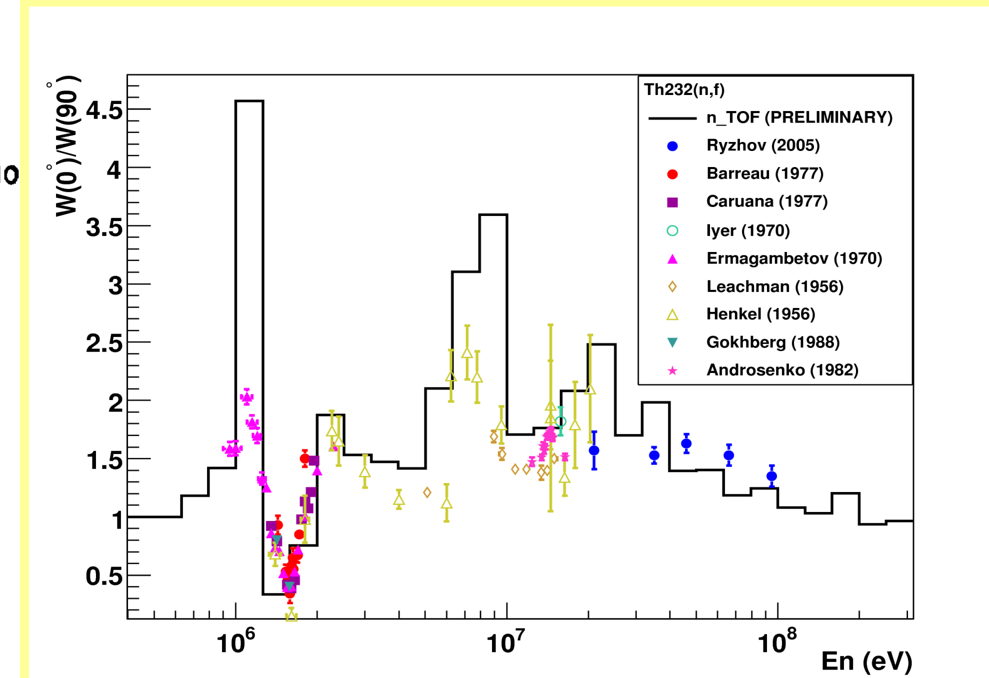
Caruana et al. Nucl. Phys. A285 (1977) 205

More general cases

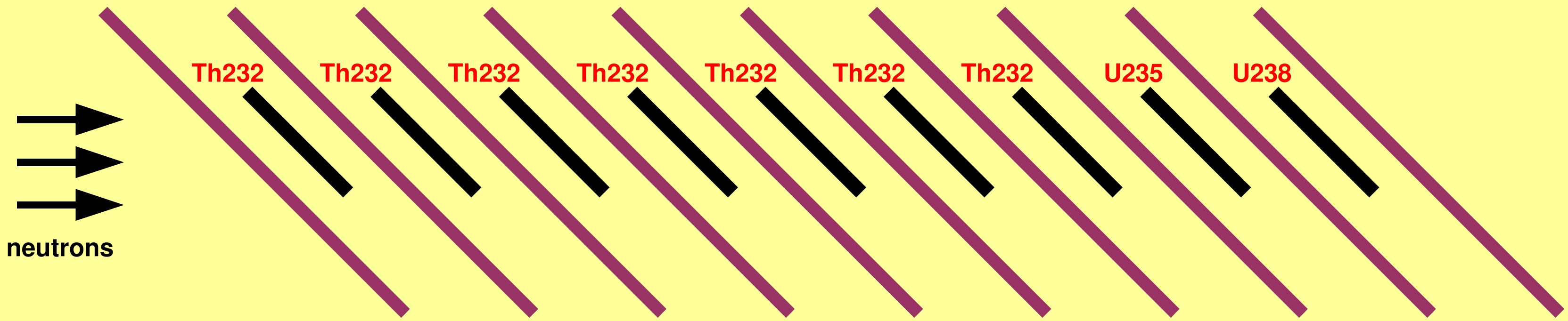


J. E. Simmons and R. L. Henkel, Phys. Rev. 120 (1960) 198

- Real fission angular distributions show maxima and minima at different angles, requiring 4th order Legendre polynomial fit.
- With the n_TOF Phase 1 setup, this was not possible → Only a qualitative measurement of the anisotropy can be extracted.



The next experiment



- A new fission chamber with PPACs and targets tilted 45° has been built at IPN-Orsay in order to cover from 0° to 90°.
- The Fission Fragment Angular Distribution will be completely described, without the present limitations.
  - The fission cross section measurements will be improved.
- **Experiment to be done at CERN – nTOF in this 2010 campaign.**

Conclusions

- The main systematic uncertainties in the measurement of the (n,f) cross sections with PPACs have been studied in depth.
- The angular distribution have been measured, but only in a limited angular range.
- The new chamber has been designed and tested at IPN-Orsay, and it will cover from 0° to 90°, allowing to reproduce the complete fission fragment angular distributions.

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- **I AM EAGERLY AWAITING FOR THE DATA-TAKING!!!!**