Measurement of fission cross section and fission-fragment angular distribution of ^{231}Pa

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ISOLDE and Neutron Time-of-Flight Experiments Committee 28/06/2017

^{231}Pa(n,f) measurement motivation

Some of the new reactors concepts are based on the Th/U cycle:

^{232}Th(n, ɣ) → ^{233}Th(β) → ^{233}Pa(β) → ^{233}U

In this cycle, ^{231}Pa is a relevant isotope produced in (n,2n) reactions and in radioactive capture

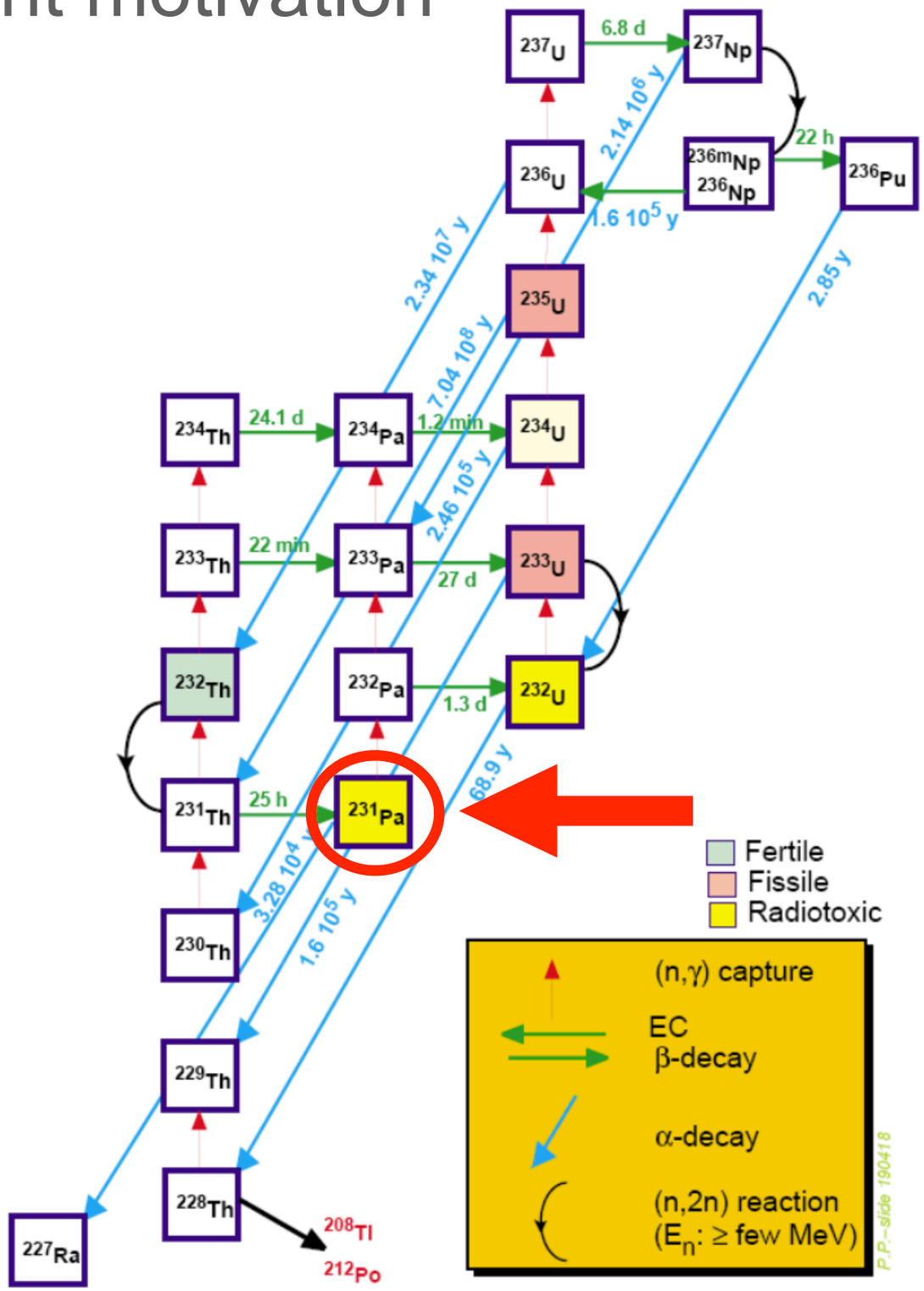
^{232}Th(n, 2n) → ^{231}Th(β) → ^{231}Pa

^{230}Th(n, ɣ) → ^{231}Th(β) → ^{231}Pa

^{231}Pa would be considered for incineration in fast reactors because of its relatively short half-life of $32 \cdot 10^3$ years

- very radiotoxic waste.
- heat generator.

Its neutronic properties should be known with a suitable accuracy, in particular its fission cross section



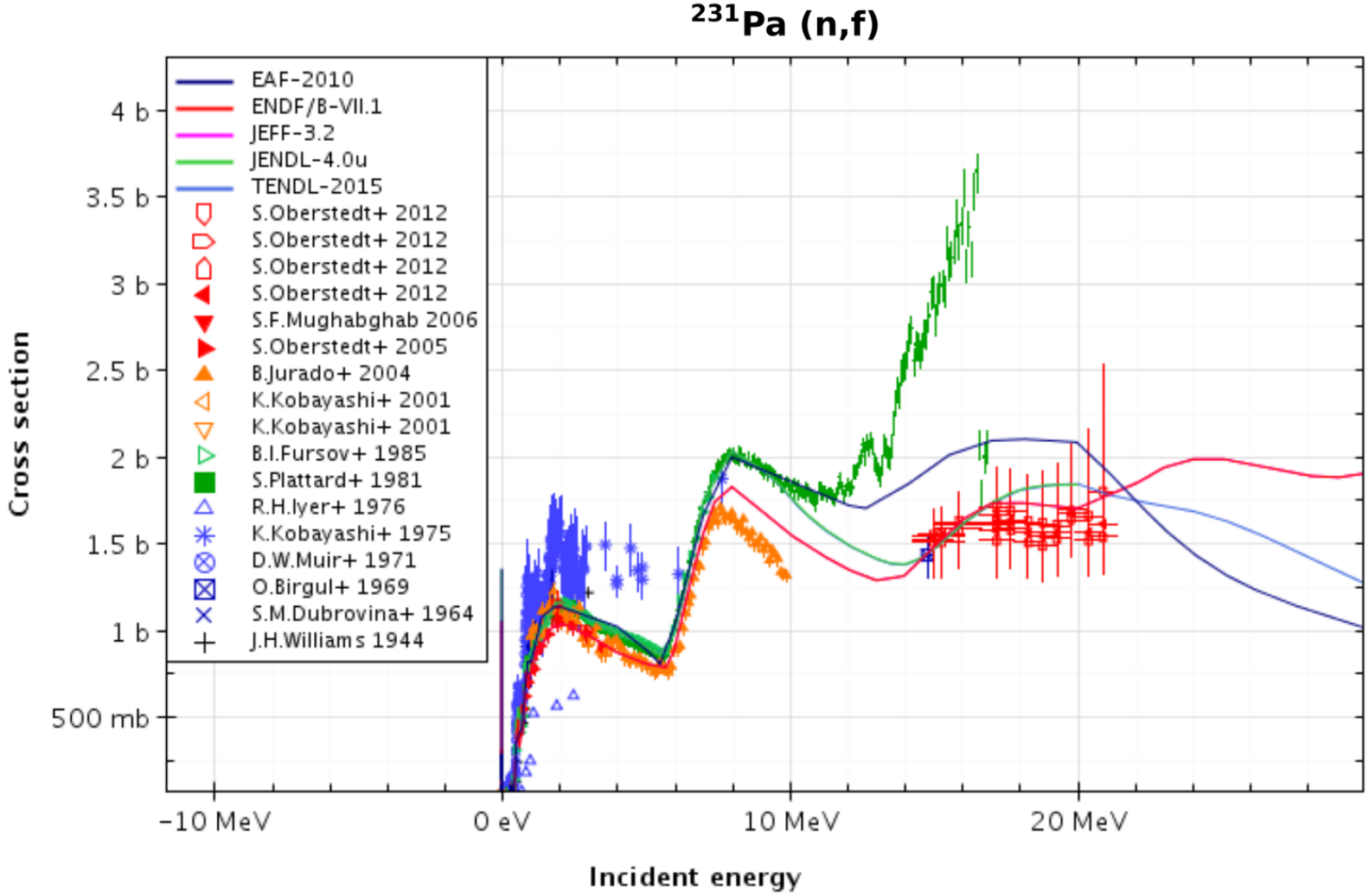
U. Abbondanno et al. CERN/INTC 2001-025

^{231}Pa(n,f) measurement motivation

Information on n-induced fission cross section of ^{231}Pa is scarce:

- only 4 measurements extend over a significant energy range
- and they present large discrepancies

Platard et al. and Fursov et al. depart from Oberstedt et al. up to 50% at 14 MeV
This last in better agreement with the surrogate data.



- The evaluations present discrepancies up to 30%
- They cover a energy range not supported by any data.

Additional direct measurement would constrain the evaluations

Also it would be a **good test of the surrogate method** in order to extend its validity to the region of ^{233}Pa.

^{231}Pa(n,f) measurement motivation

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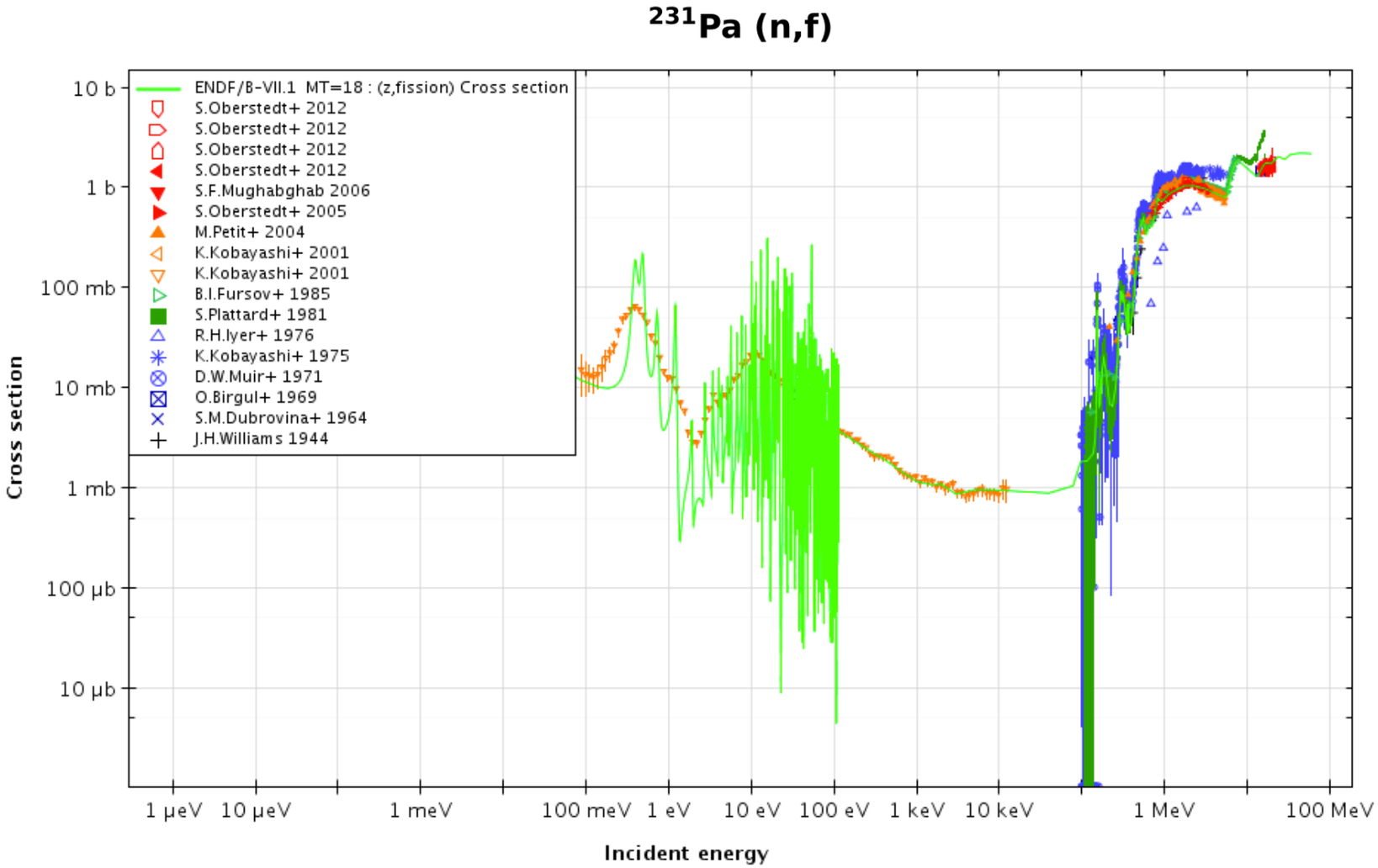

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Additional direct measurement would constrain the evaluations

At low energy : only one set of data with poor resolution is available

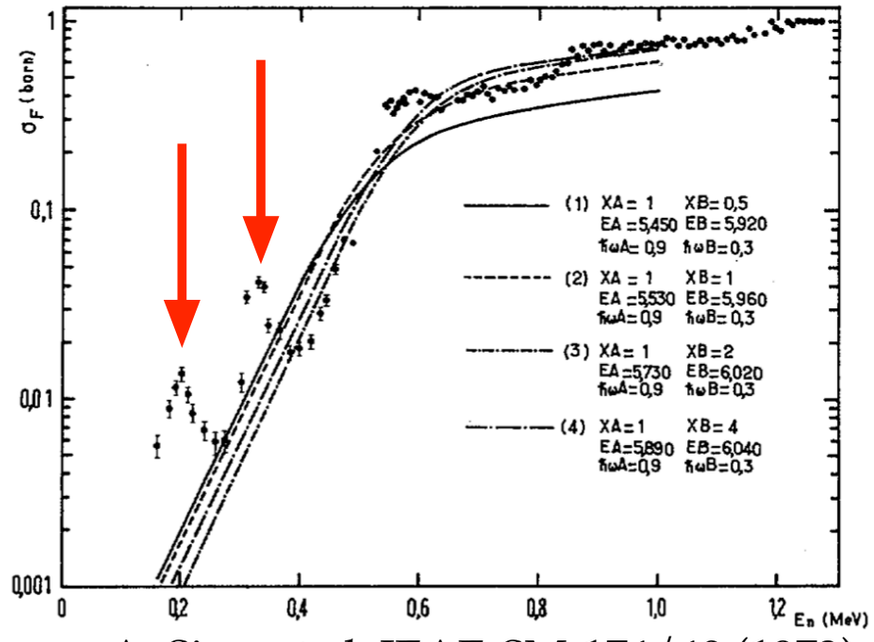
^{231}Pa(n,f) measurement motivation

^{231}Pa shows strong **vibrational resonances in the threshold**

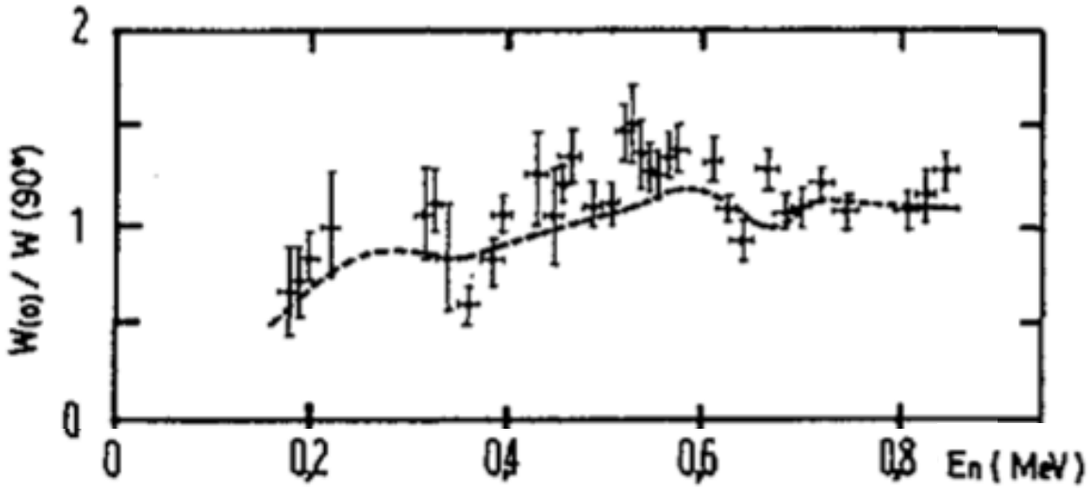
- Surrogate reaction ^{231}Pa(d,pf) suggests an hiperdeformed scenario
- Not confirmed due to the lack of angular distribution measurements

Only two measurements of the fission-fragment angular distribution are reported:

- Performed with mono-energetic neutron beams
- Both sets of data are not consistent in the resonance region



A. Sicre et al. IEAE-SM-174/40 (1973)



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P.E. Vorotnikov Sov. J. Nucl. 5, 415 (1971)

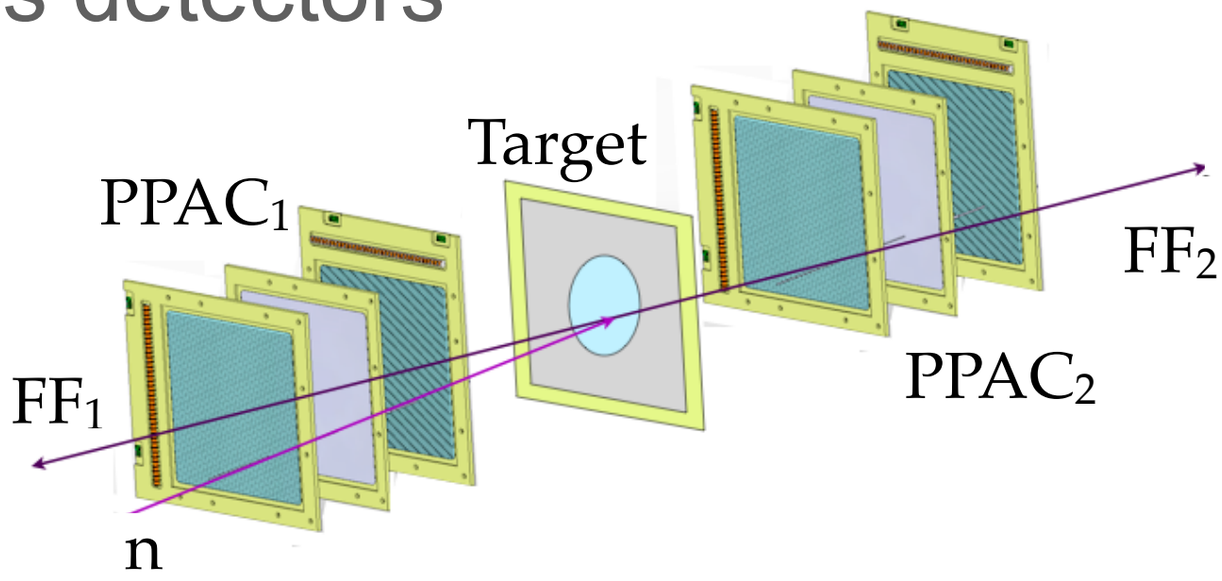
More robust and accurate data in order to improve the information on the vibrational resonances is required.

The measurement of n_TOF would fulfill such a requirement, extending, in addition, the data to higher energies.

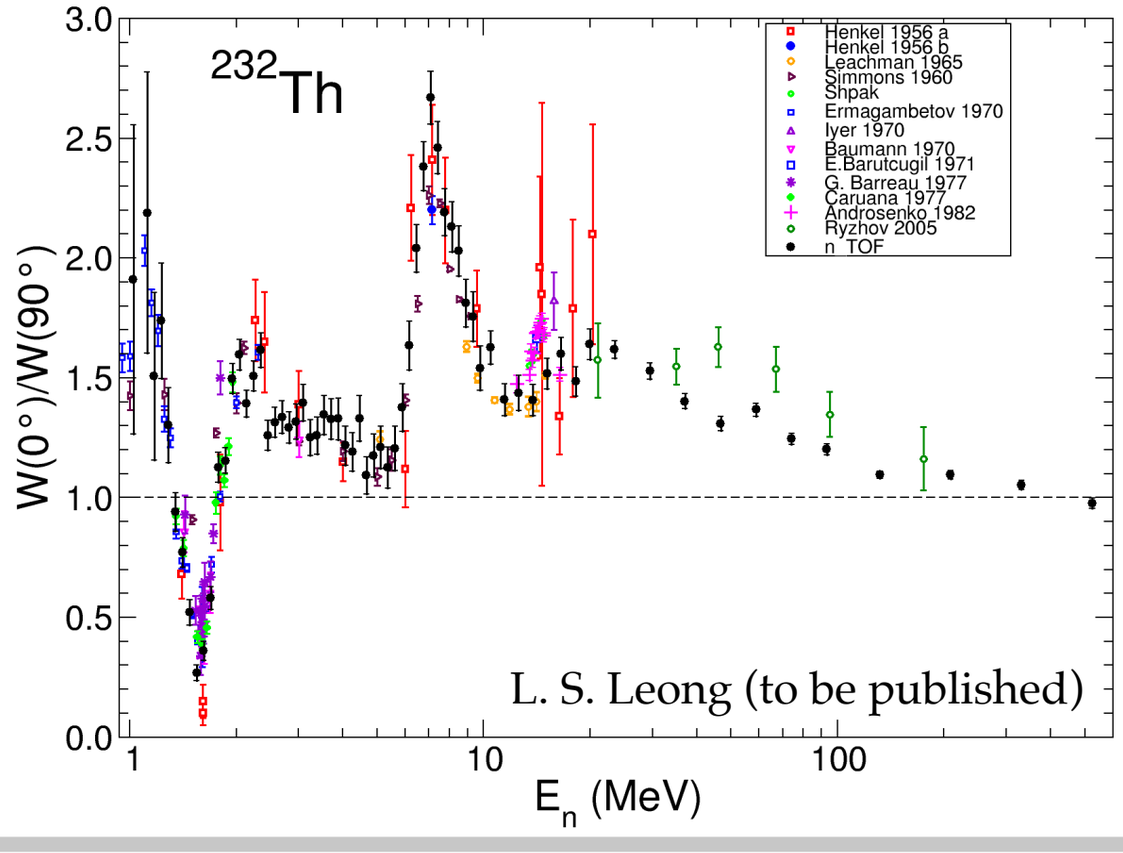
The PPACs detectors

The Parallel Plate Avalanche Counters:

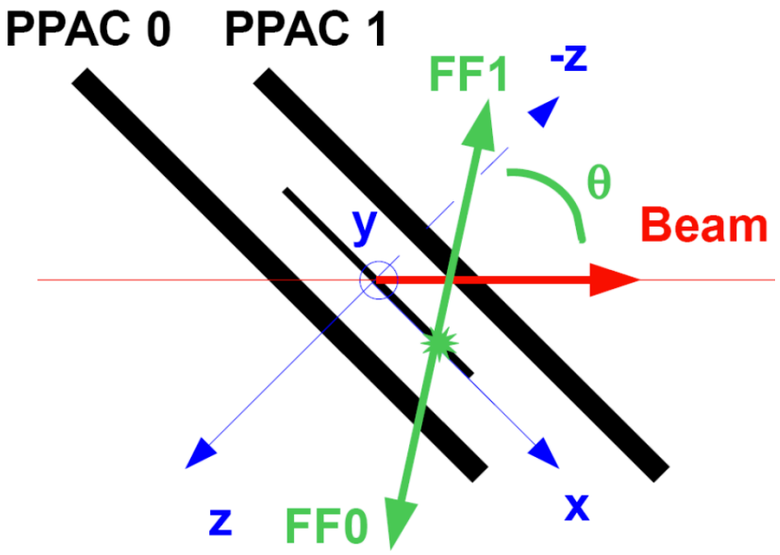
- both fission fragments detected:
  - efficient background rejection
- energies higher than 100 MeV for a 20 m flight-path
- fragment position tracking with 2mm of resolution:
  - emission angle, measured event by event
- compact and transparent to neutron beams:
  - 10 detectors with 9 interleaved targets



This experimental setup provided successful measurements of ^{232}Th, ^{234}U, and ^{237}Np

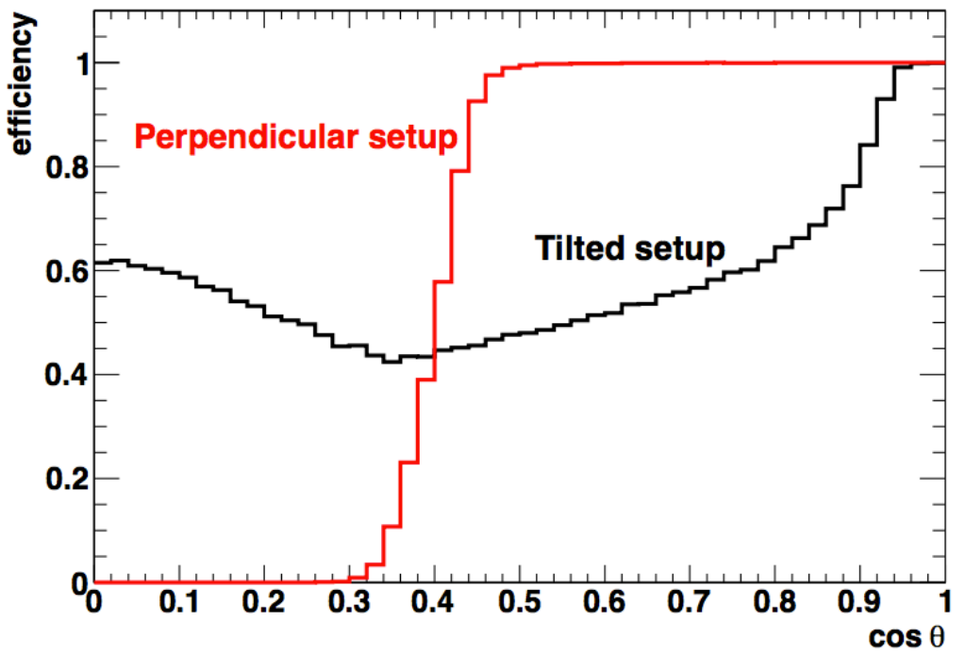


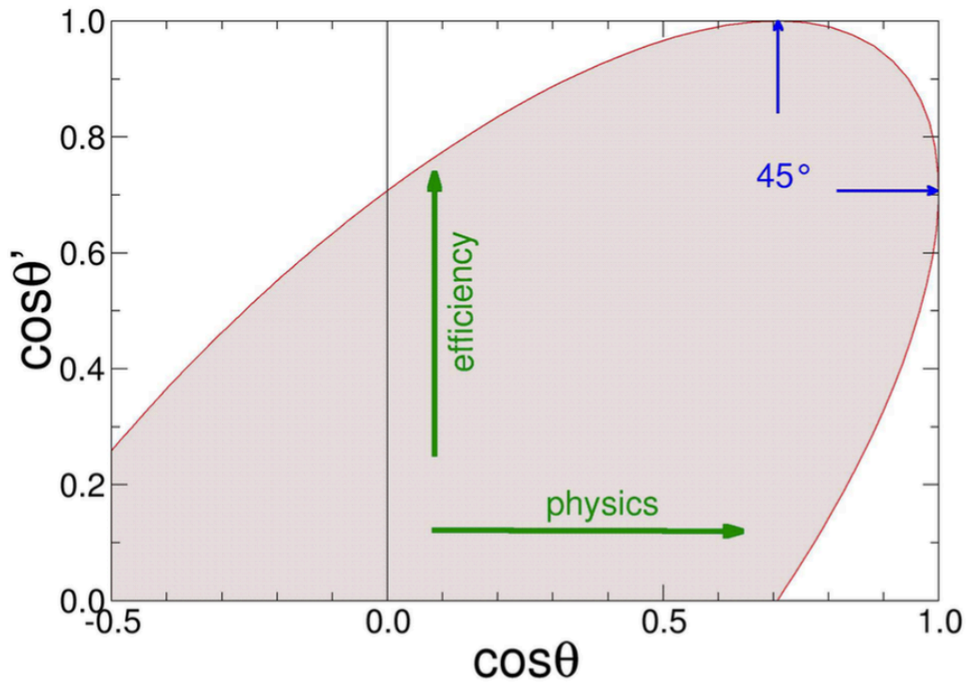
The PPACs detectors



Every detector and target are tilted 45º-respect to the beam axis, with a separation of 2.5 cm between each other in their orthogonal direction.

This configuration permits a full angular coverage of fission fragments, compared with the limited θ<66º perpendicular setup.





In addition, the tilted setup provides a self-consistent efficiency calculation:

- efficiency depends on the angle respect to the detector surface and not to the n-beam
- this setup provides two different angles accounting, separately, for the efficiency and the anisotropy.

Beam requirement

The radioprotection rules limits the amount of ^{231}Pa to 1 mg per batch (1.8 MBq/mg):
- The higher flux of EAR2, compared to EAR1, is required.

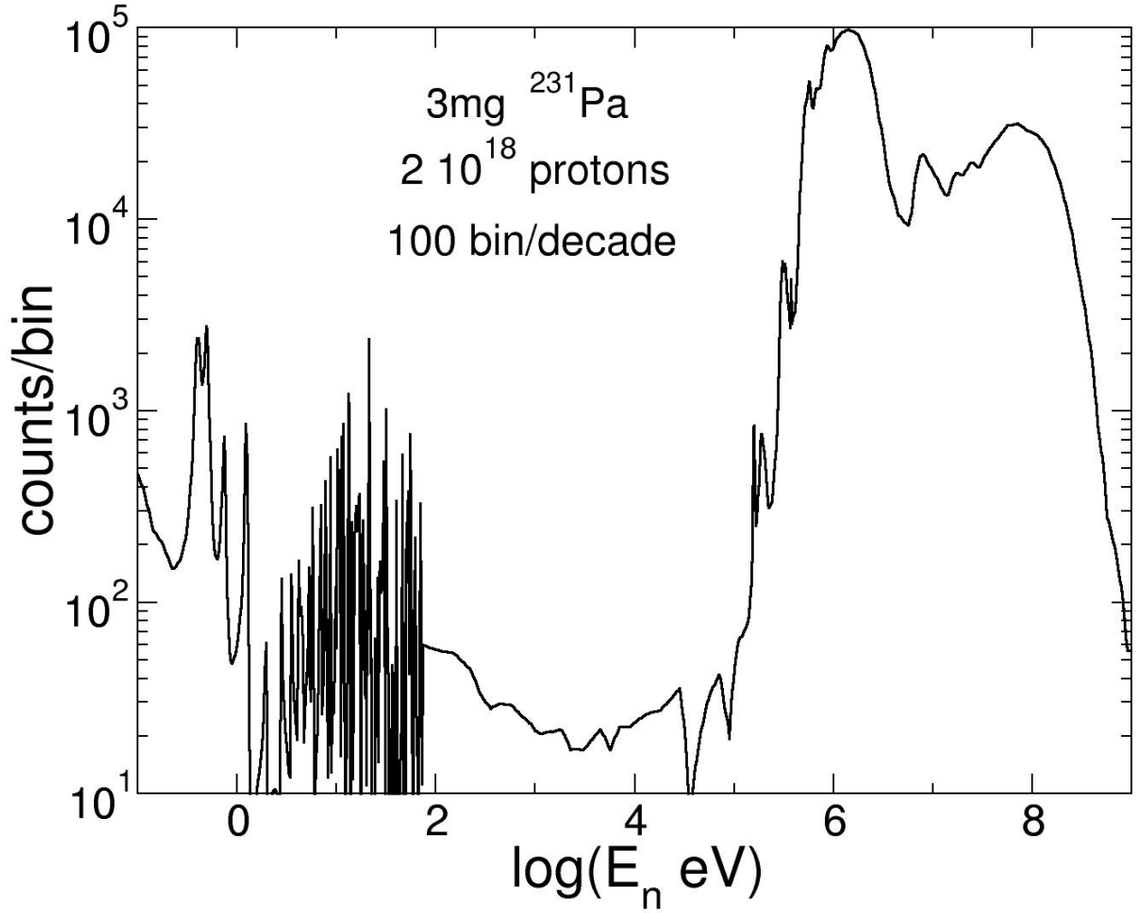
- **5 target slots will be filled by 200 μg/cm^2-thickness ^{231}Pa** for the measurement,
- 4 target slots will be filled by 2 targets of ^{238}U and 2 of ^{235}U as a reference for the time and position calibration and the normalization.

The resolution requirements are:

- **100 bins/decade** in order to have a good energy resolution, manly in the resonance region
- **1000 counts/bin** in order to reach ± 0.1 in the anisotropy uncertainty

The estimation of the statistics for **3 mg of ^{231}Pa** (conservative), using the evaluated cross section from ENDF/BVII-1 and an overall detection efficiency of 50%, indicates that we need:

$2 \cdot 10^{18}$ protons



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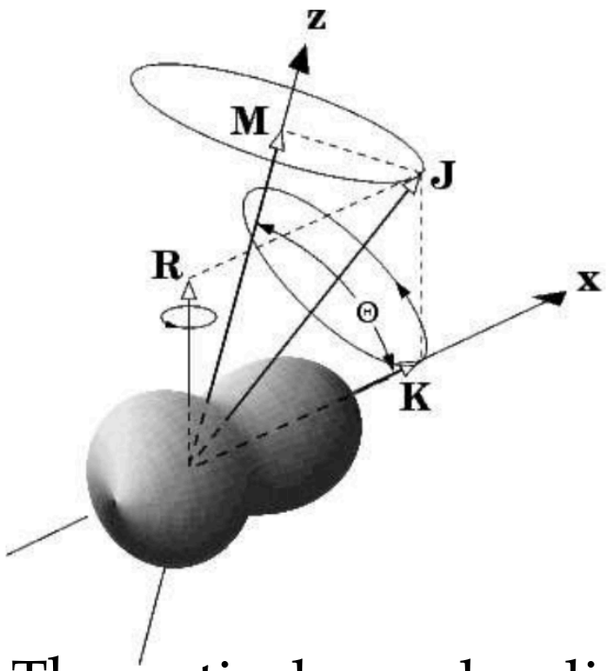
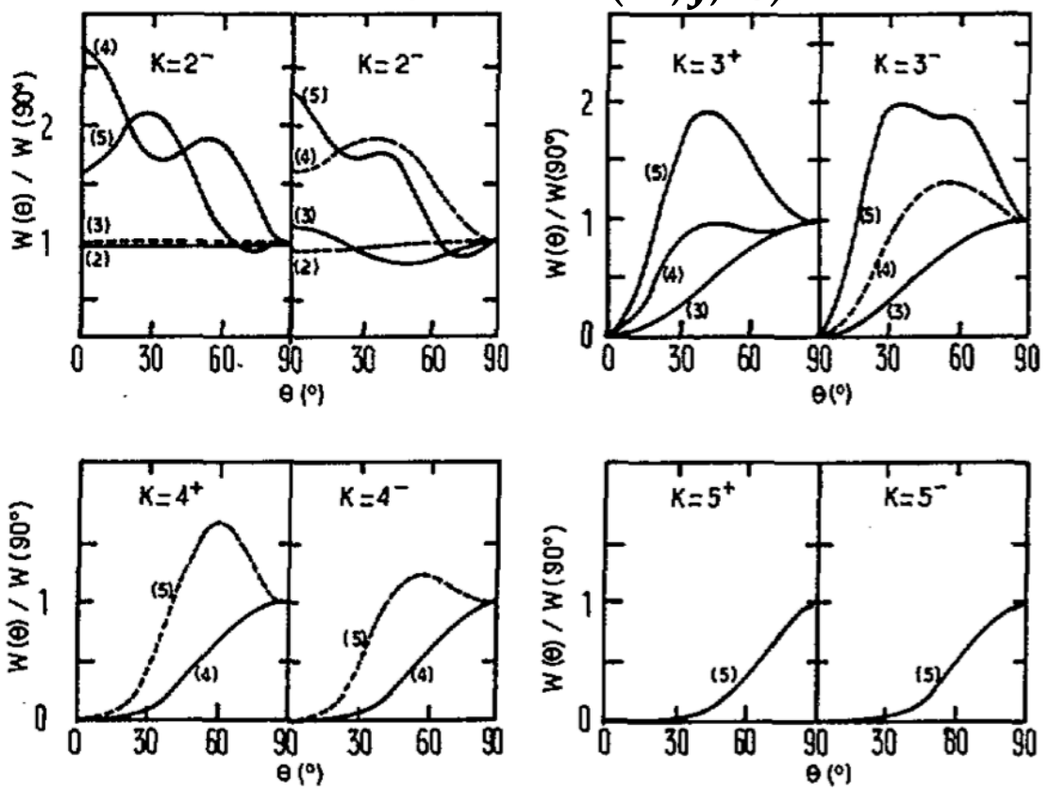
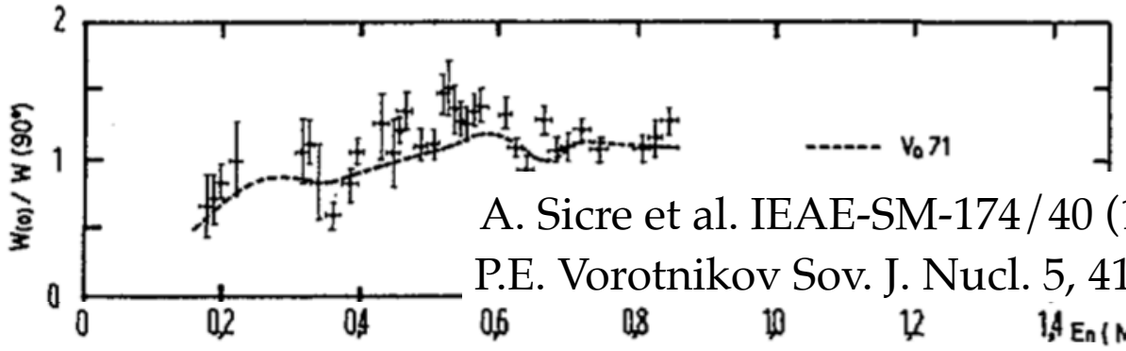


K quantum number (projection of **J** over the deformation axis)

Theoretical angular distributions for each (**K**,**J**,π)



Discrepancies between both sets of data



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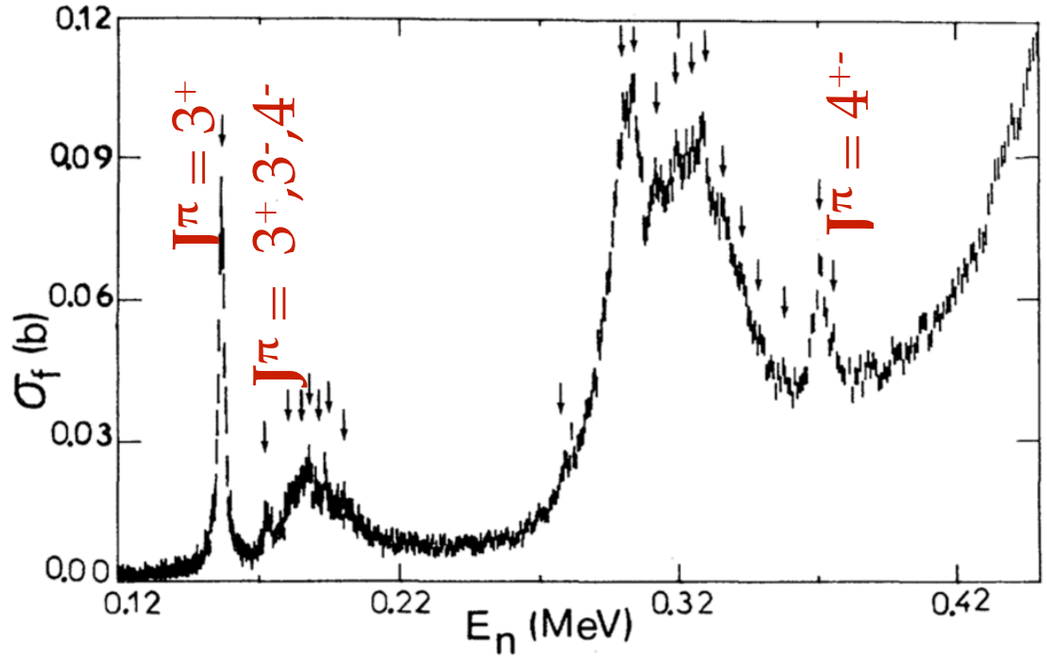

The poor resolution of the angular distribution prevents a clear state assignment

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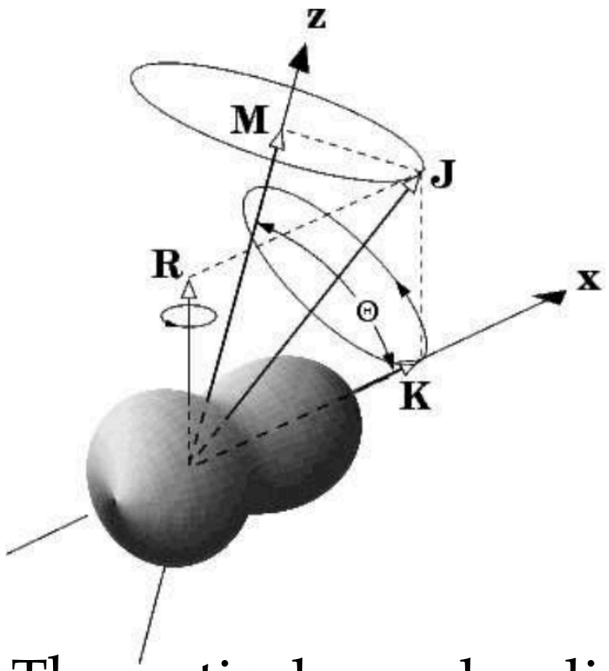

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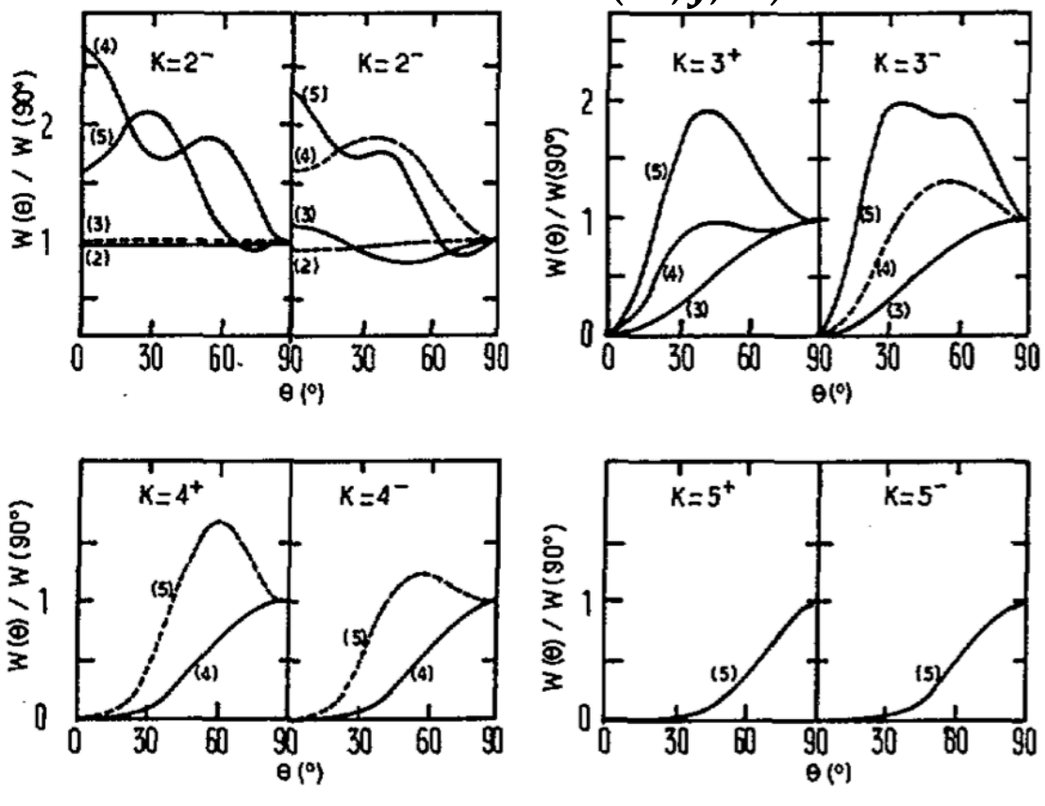
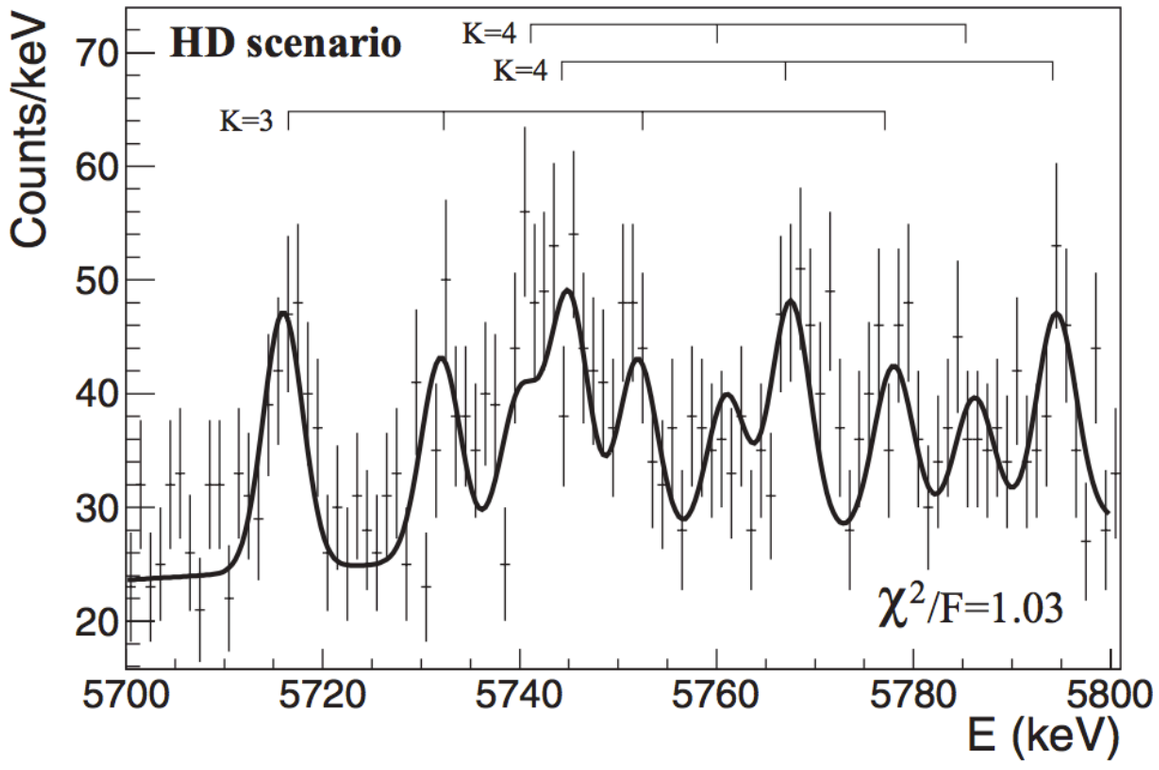


^{231}Pa(d,pf) L. Csige et al. PRC 85,054306 (2012)

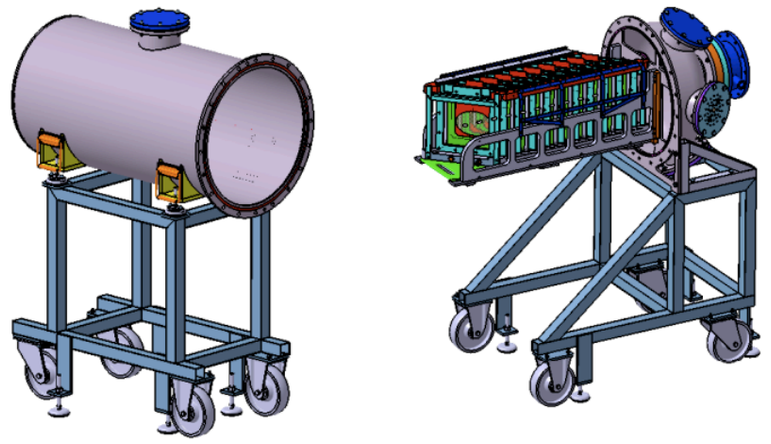


HIPERDEFORMED SCENARIO based on the fit to the accurate fission barrier measurement, **no angular distribution**

Present Status

5 new PPACS under construction at the IPN

- Conductive foils of gold instead of aluminium
- New preamplifiers under design in order to reduce the cathodes signal width
- Shorter delay lines under construction

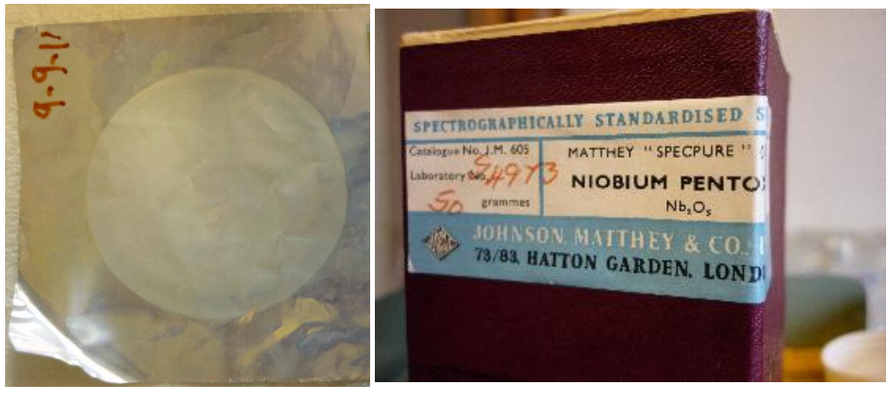


PPACs chamber transportation

- Transportation accepted as UN2911 instead of class A
- A rotation setup is under preparation by the mechanics division of IPN in order to put the chamber in vertical

^{231}Pa target under preparation by Claire Le Naour at IPN

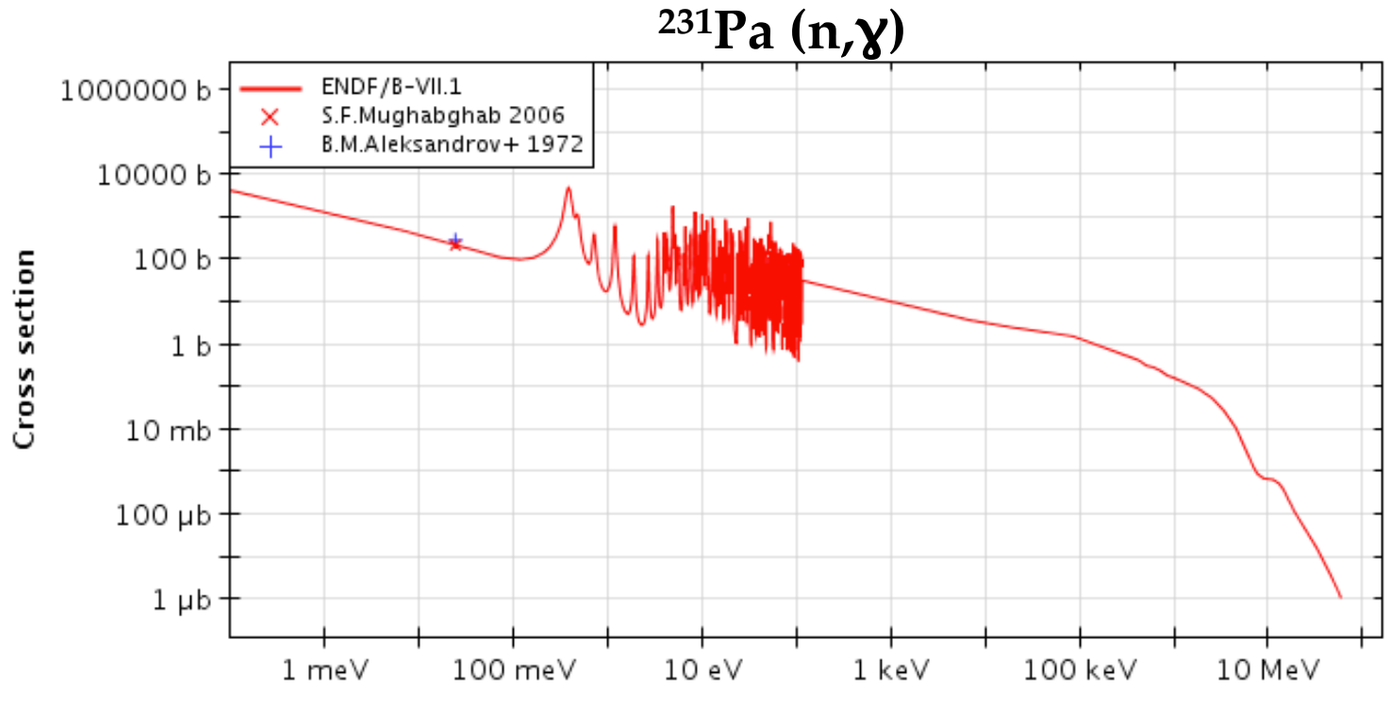
- Successful electrodeposition of Nb (chemical substitute of Pa) on a 1 mm Al foil
- Purification of the Pa samples done



^{231}Pa(n,ɣ) status

Only two single experimental points are reported so far from ^{231}Pa (n,ɣ)

Measurement would be done in EAR1 with the TAC detector with an detection efficiency ~50%



New specific targets are needed:

- Point-like targets
- Following the radioprotection rules