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# Measurements of capture cross-section of Minor Actinides with a Total Absorption Calorimeter at n_TOF.

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# Measurements of capture cross-section of Minor Actinides with a Total Absorption Calorimeter at n_TOF

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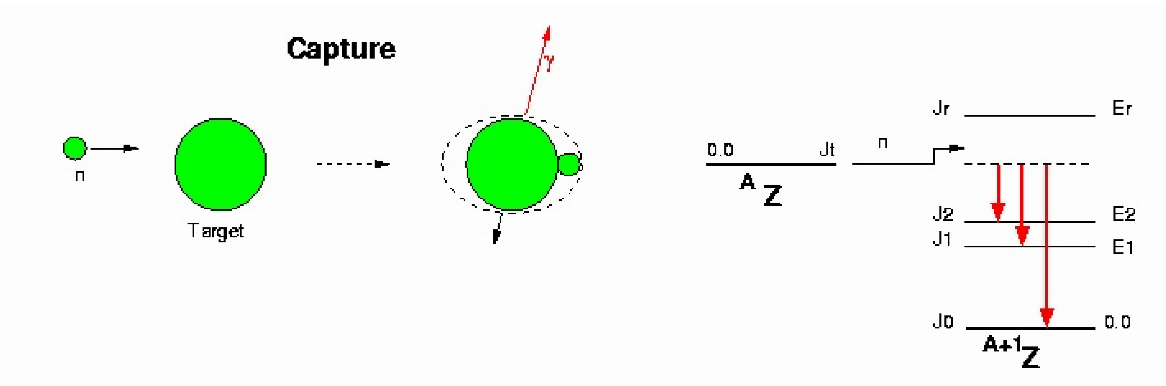
ICTP-IAEA, Trieste, 19-28 May, 2008

# Outline

- What is a Total Absorption Calorimeter (and how does it work)
- The n_TOF Calorimeter
- Some preliminary results

# The capture reactions




In a neutron capture reaction, excited compound nucleus is formed with $E_X=E_n+S_n$, (neutron energy and neutron separation energy, $5<S_n<10$ MeV).

Measurements of neutron capture cross-sections are performed by detecting γ-rays emitted from deexcitation of compound nucleus formed in the capture.

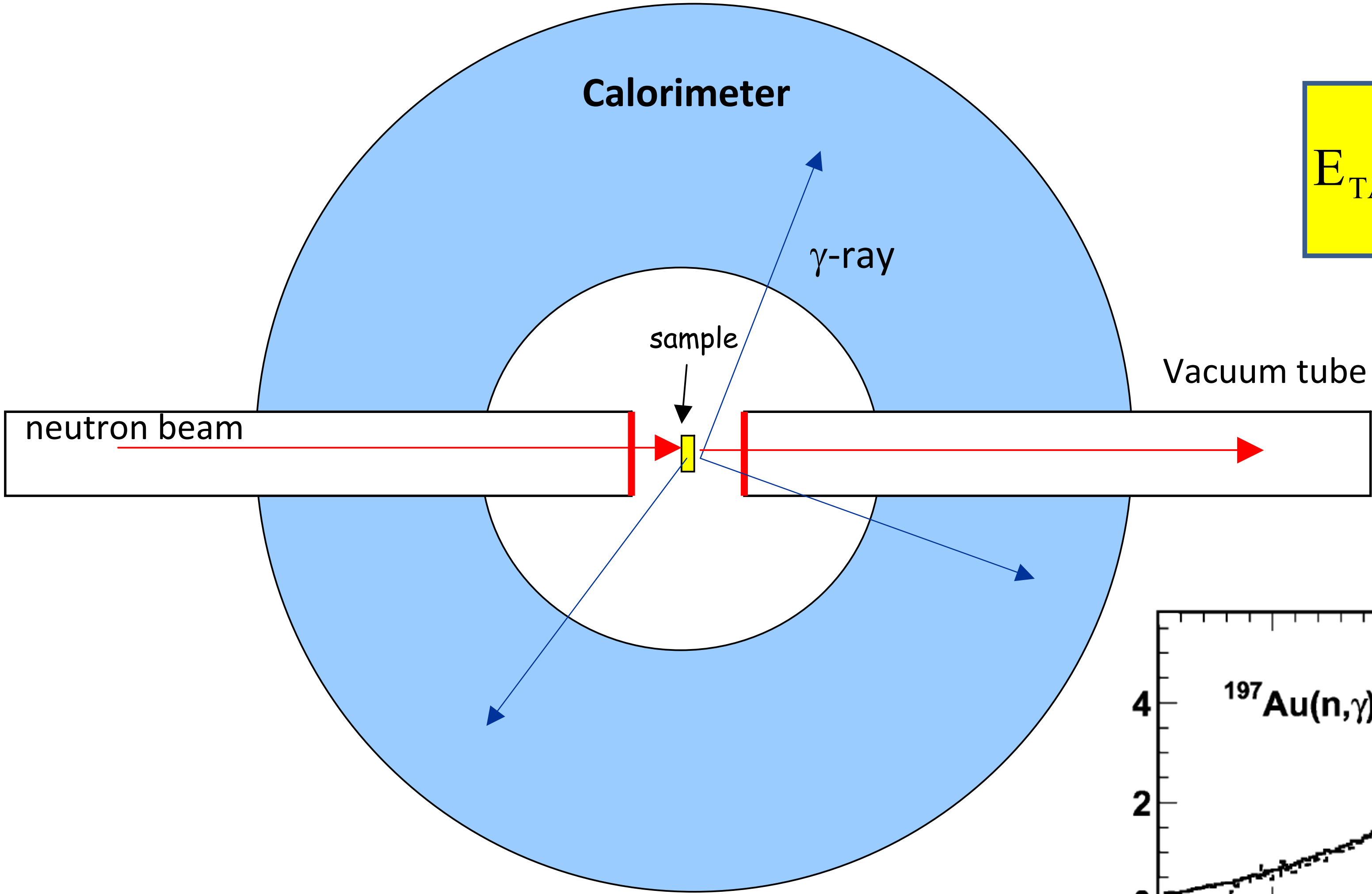
Two methods:

- Single γ-ray detection (shown before) ……………… low efficiency, need to correct for efficiency
- Detection of the entire cascade ……………………….. better, but more complicated (and expensive)

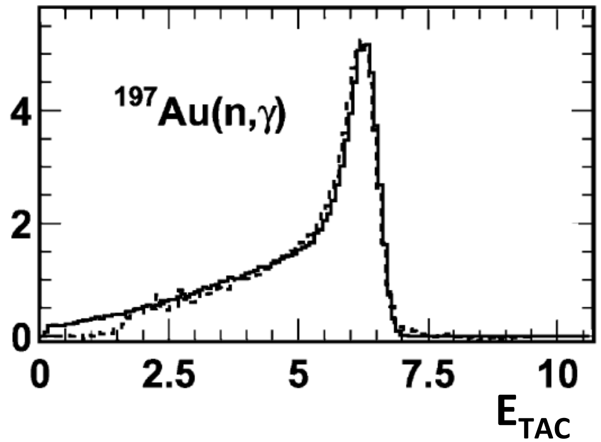
**Calorimetric method**: identify neutron capture reaction on the basis of the total energy of the cascade ($E_{tot} = E_n+S_n$ ) and on the **multiplicity** of the cascade.

In order to detect the whole cascade, it is necessary to have a detector that covers the **whole solid angle** (4π detector), and with very **high detection efficiency**.

# The calorimetric method




$$E_{TAC} = \sum_{i=1}^{M} E_{\gamma}$$



# Calorimeter vs single $\gamma$-ray detection

## Single $\gamma$-ray detection

- Choose detectors with **low neutron sensitivity**
- low-cost (few detectors)
- efficiency to capture $\gamma$-rays **low and dependent** on cascade
- requires **Pulse Height Weighting Technique** for "efficiency corrections"
- **Difficult to distinguish** between capture and background $\gamma$-rays

## Calorimetric method

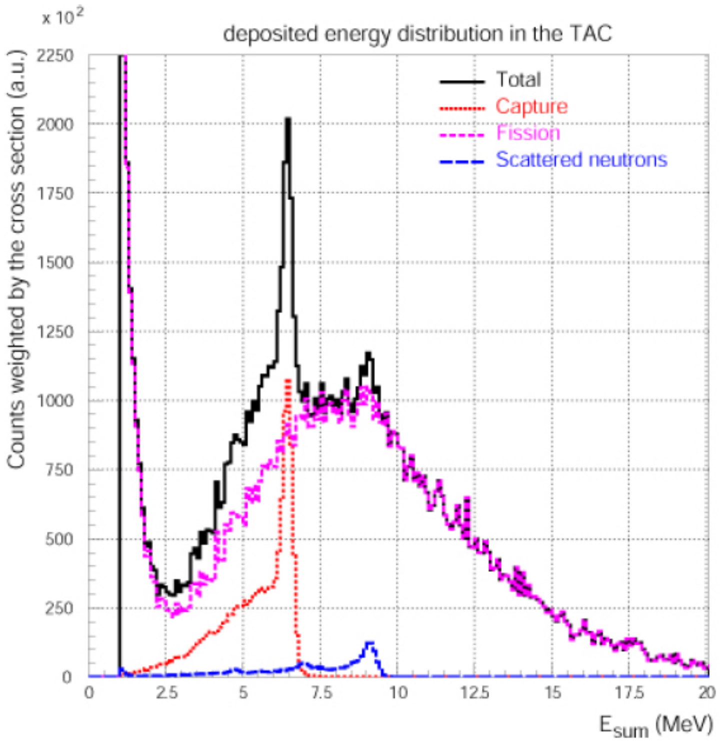
- **high** efficiency
- good **background rejection** capability
- Possibility to distinguish competing reactions (fission)
- poor neutron sensitivity
- many detectors
- high costs and complexity (many detectors)

For radioactive isotopes , calorimetric method is better since it allows better **rejection of $\gamma$-ray background** related to natural radioactivity:

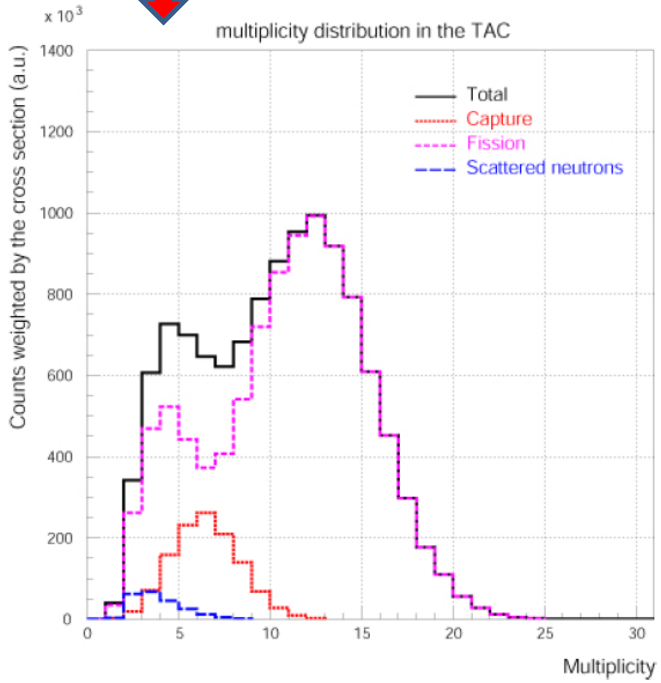
- energy of background $\gamma$-rays typically few MeV, well below capture energy;
- multiplicity of background $\gamma$-rays M=1, while for capture M~3

# Calorimeter vs single $\gamma$-ray detection

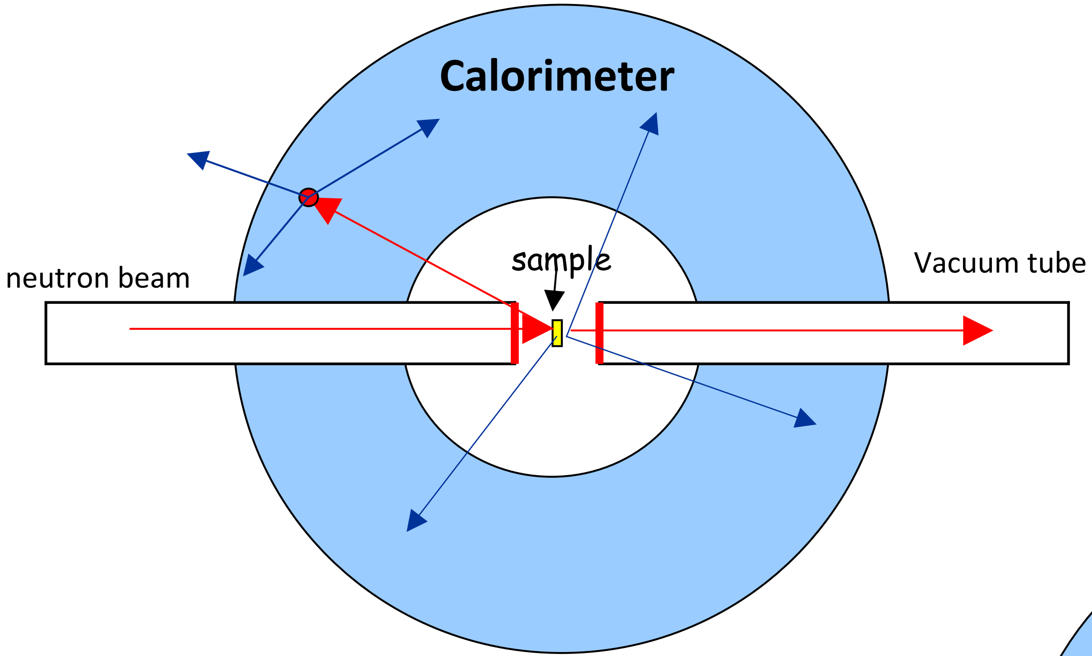
**A very important consideration**: a calorimeter allows to distinguish capture from other competing reactions that produce $\gamma$-rays (for example fission). Very powerful method for measurements of capture cross-sections of **fissile isotopes** (minor actinides)




Simulations of the calorimeter response for the fissile $^{245}$Cm



# The problem of neutron sensitivity



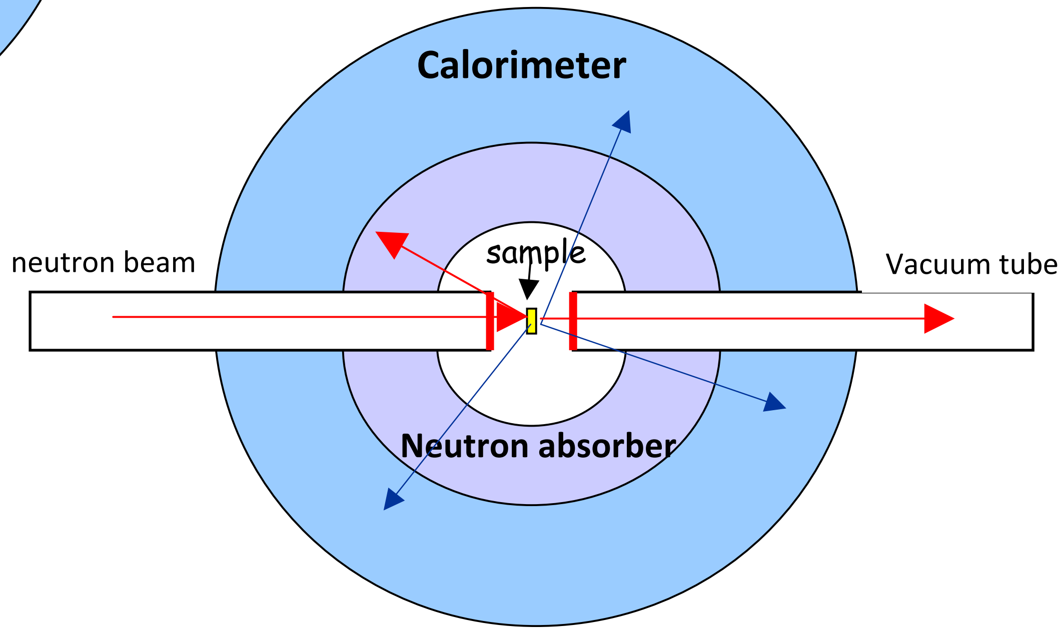

A neutron scattered in the sample can be captured inside the detector.

Cannot be easily distinguished from "capture" events in sample.

Important source of background (depends on elastic cross-section).

A solution consists in using an internal sphere of **neutron moderating and absorbing material**.

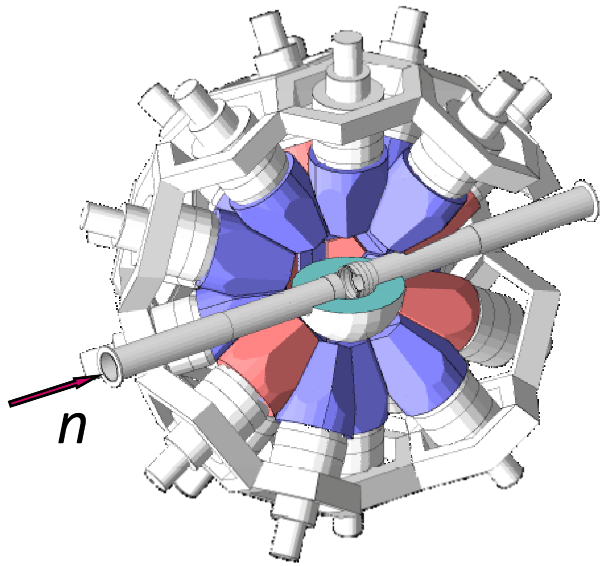
Also **"shield"** detectors from thermal neutrons.



# A real calorimeter

**How should a calorimeter be made:**

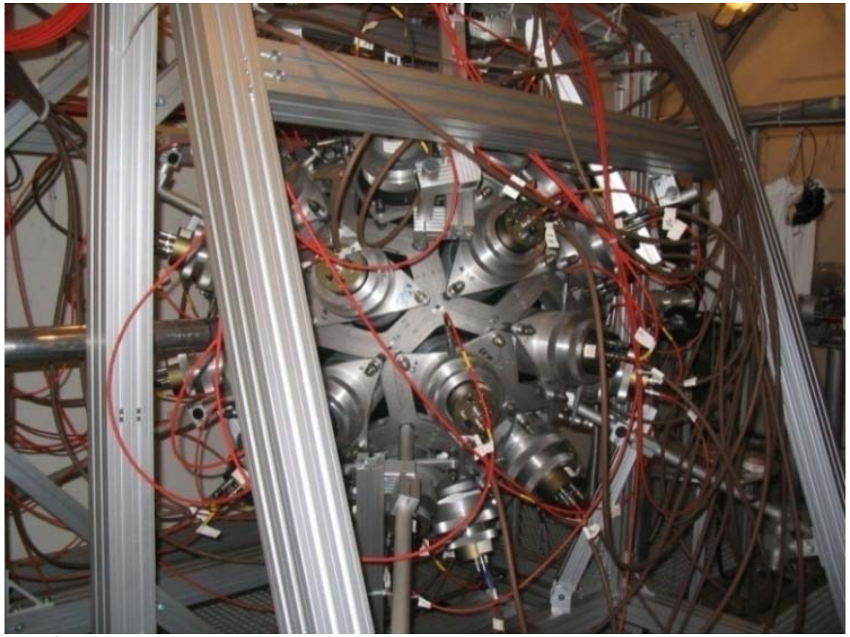
- large number of detectors (for multiplicity reconstruction)
- high-Z material (for high detection efficiency)
- big thickness (for high efficiency)
- fast response (for good timing properties)
- low neutron sensitivity



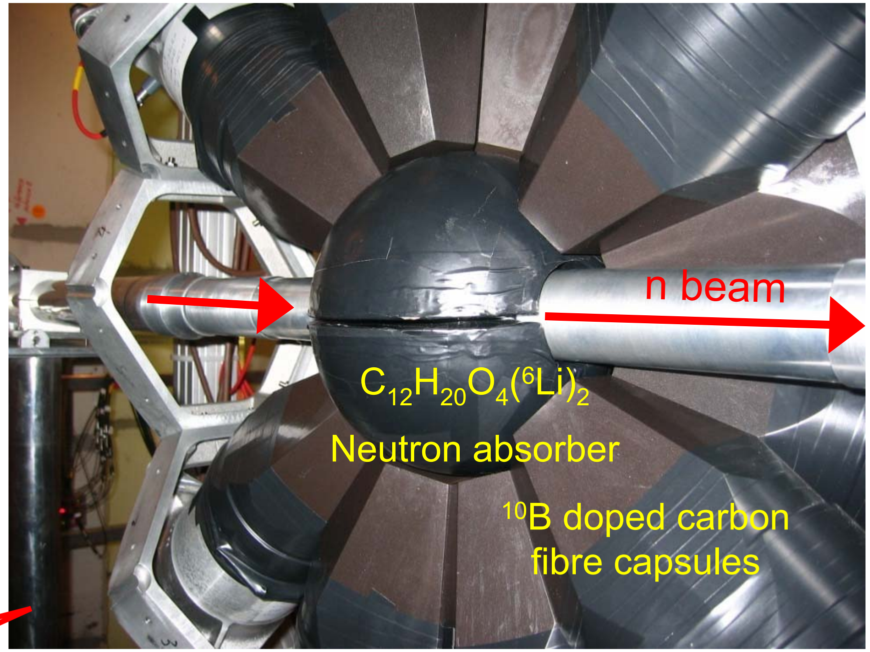

**The n_TOF Total Absorption Calorimeter (TAC):**

- 40 crystals of **$BaF_2$**, covering 95 % of $4\pi$
- **15 cm** thickness (98 % efficiency to 5 MeV $\gamma$-rays)
- Internal sphere of **$^{6}$Li-carbonate,** to moderate and absorbe neutrons scattered from the sample
- capsules in carbon fibre loaded with **$^{10}$B** to minimize neutron sensitivity

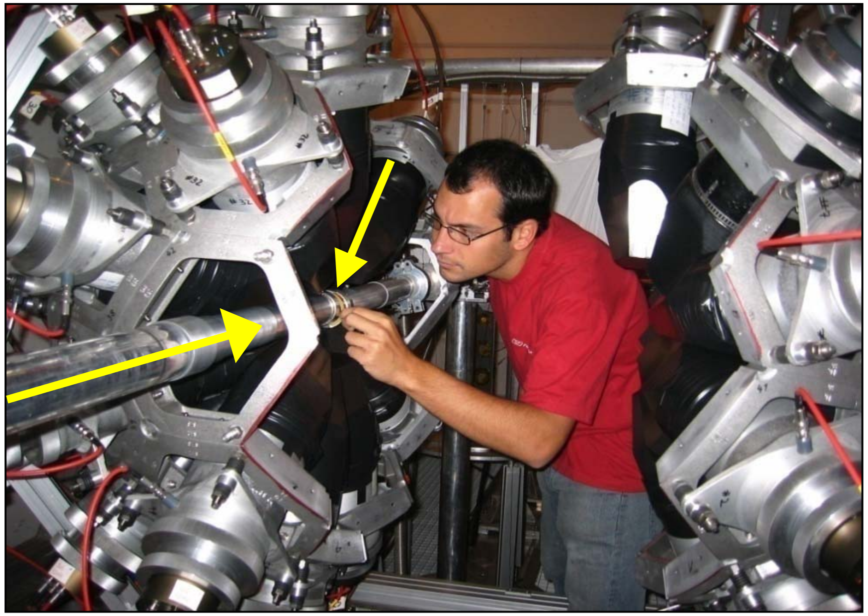
Very high efficiency to a single capture event (close to 100 %)



Calorimeter from the outside (closed)




Inner view of the calorimeter



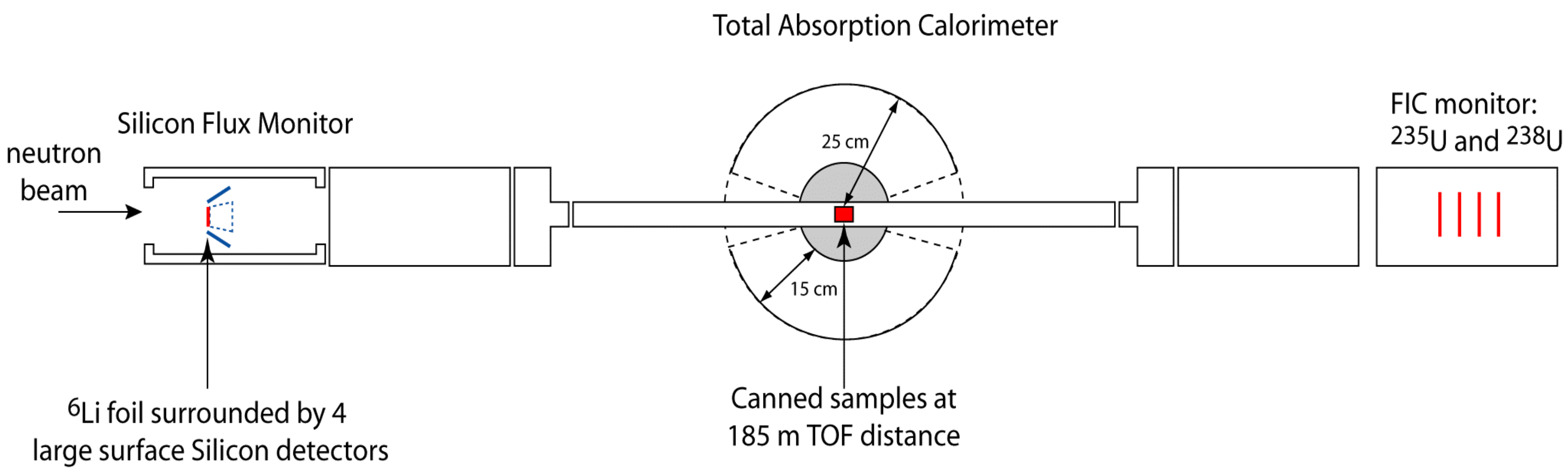
Mounting of a sample

# The n_TOF TAC

N.B.: The n_TOF calorimeter is not the only one used in the world:

- TAC at FZK operated since long time
- TAC at LANSCE constructed at the same time of n_TOF

However, better neutron sensitivity, characterization, analysis procedure, etc…

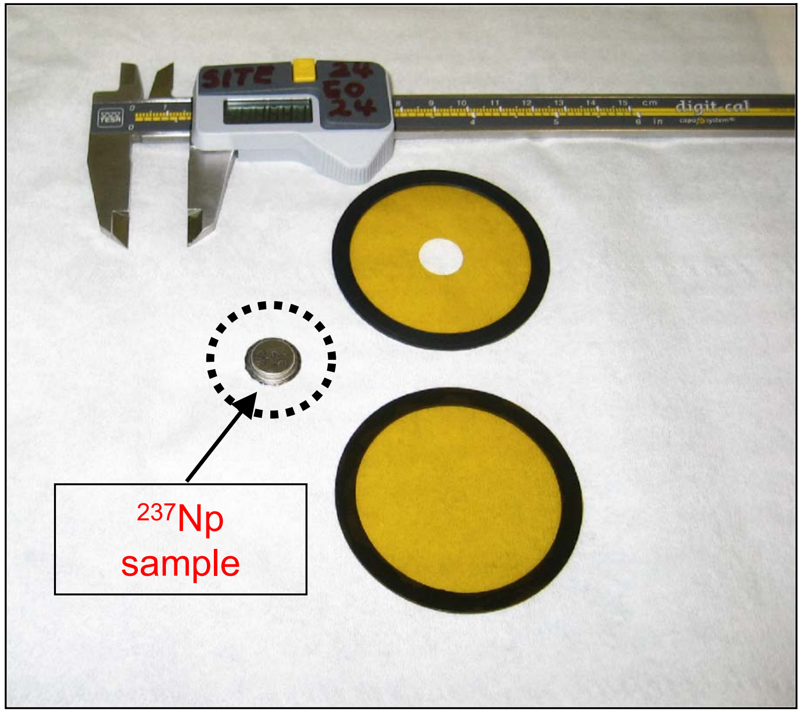



n_TOF TAC mounted inside the experimental area, in conjunction with a flux monitor (need to know the flux in capture measurements) !!

# The capture measurements with the TAC at n_TOF

Sample preparation:

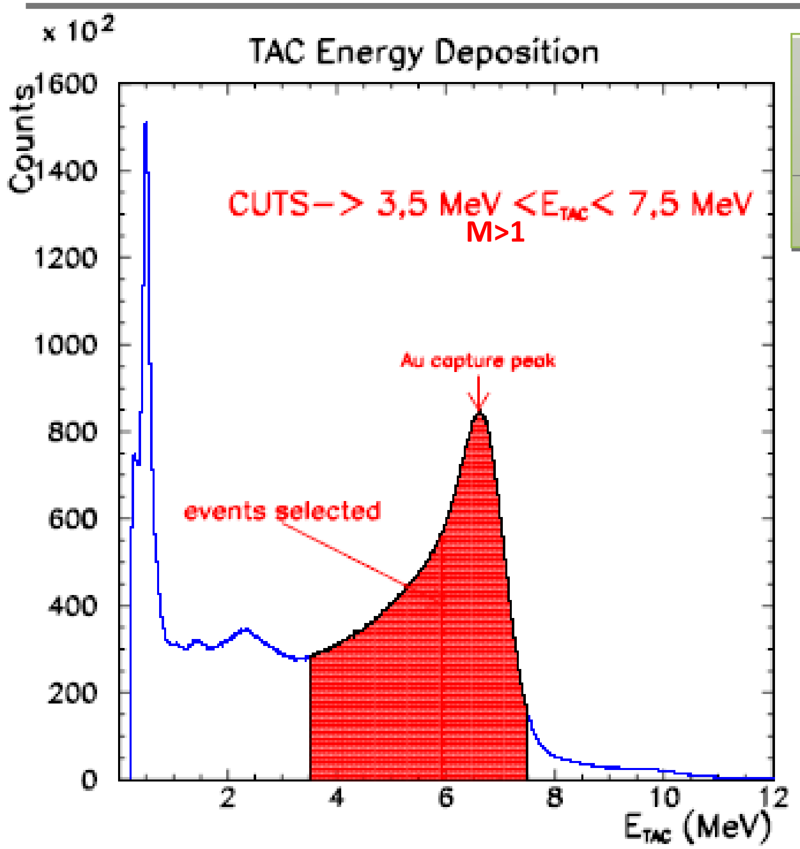
- 1 cm diameter
- sealed in Ti can (for safety reasons)
- precisely alligned in the beam




**Measured isotopes (2004):**

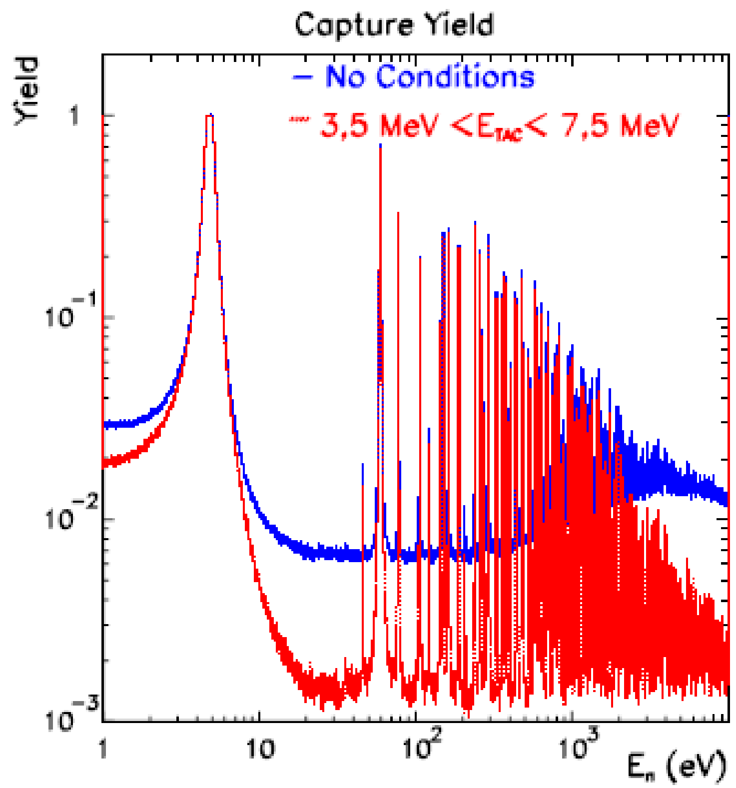
| | | |
|---|---|---|
| **$^{197}$Au** | ……………………… | paper in preparation |
| **$^{234}$U** | ……………………… | in preparation |
| **$^{233}$U** | ……………………… | data analysis |
| **$^{237}$Np** | …………………… | first draft |
| **$^{240}$Pu** | …………………… | first draft |
| **$^{243}$Am** | …………………… | data analysis |

# Data analysis: the Au(n,γ) cross-sections




The Au(n,γ) reaction is well known (capture standard):

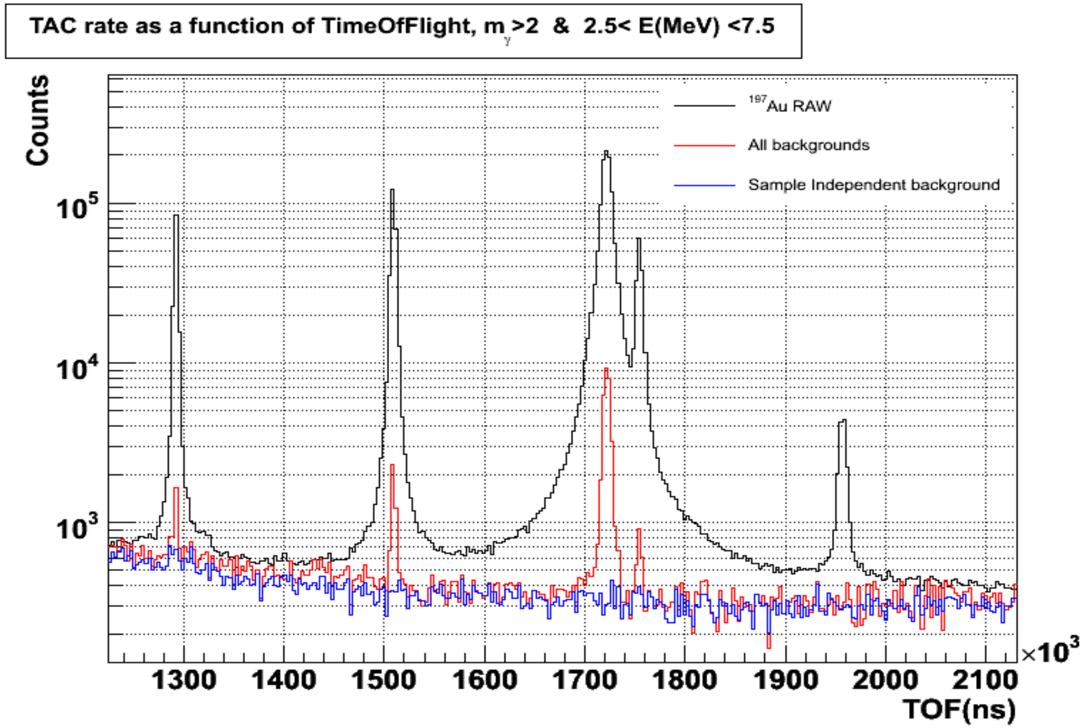
- useful to understand how the calorimeter work
- can be used for checking Monte Carlo simulations




P.S.: The energy deposition for a capture event does not produce a sharp peak at 6.5 MeV because of resolution of detectors.

The condition on the Total Energy in TAC s**uppresses drastically** the background

# Data analysis: the Au(n,$\gamma$) cross-sections



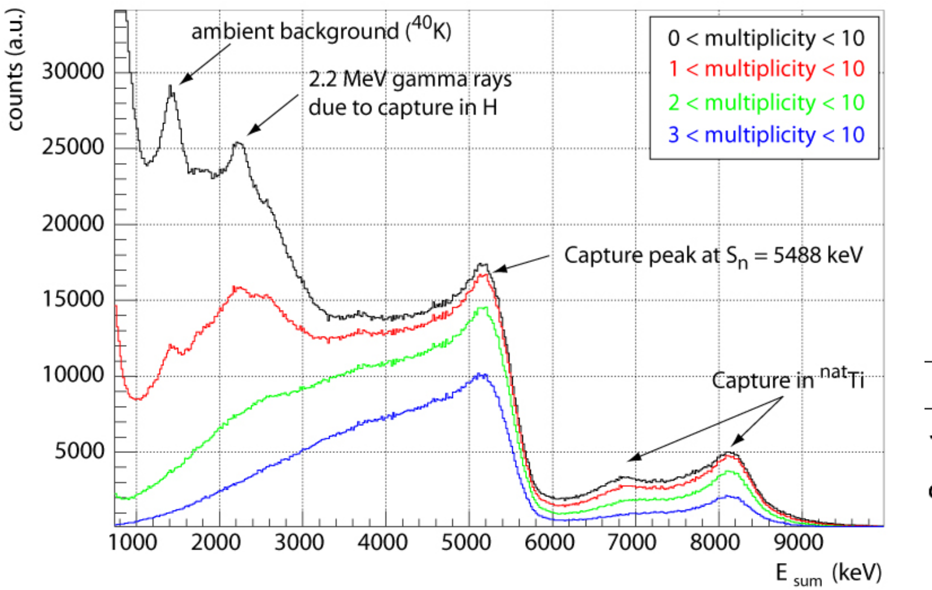

Attention: some neutron sensitivity survives in the calorimeter.

However, contribution of the background caused by neutron scattering is < 1 %.

N.B.: The background due to neutron scattering (neutron sensitivity is estimated with a C sample

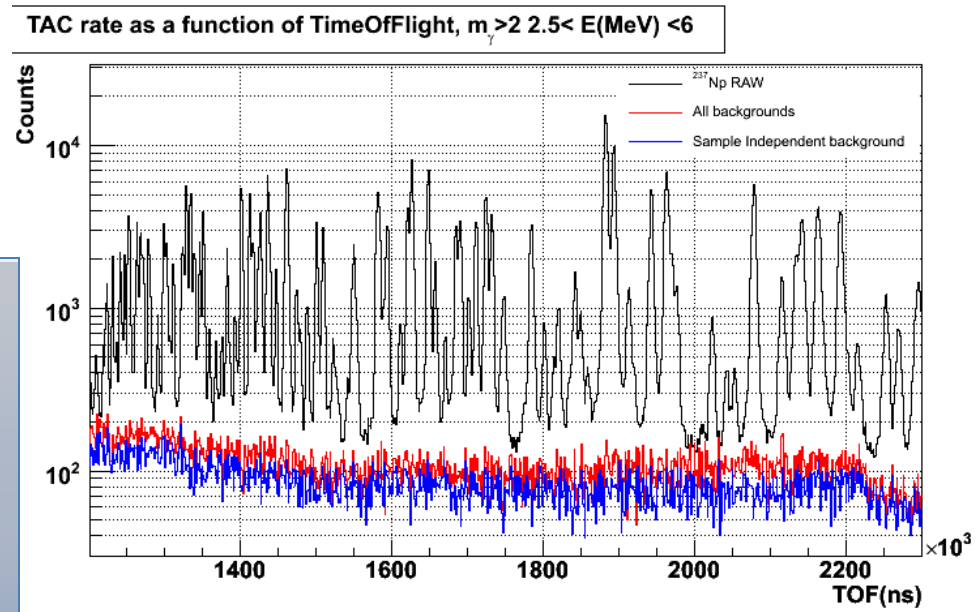
# Data analysis: the $^{237}Np(n,\gamma)$ cross-sections

Energy deposition spectrum for $^{237}Np$ in the neutron energy range 1 eV - 10 eV




The background can be rejected in two ways:

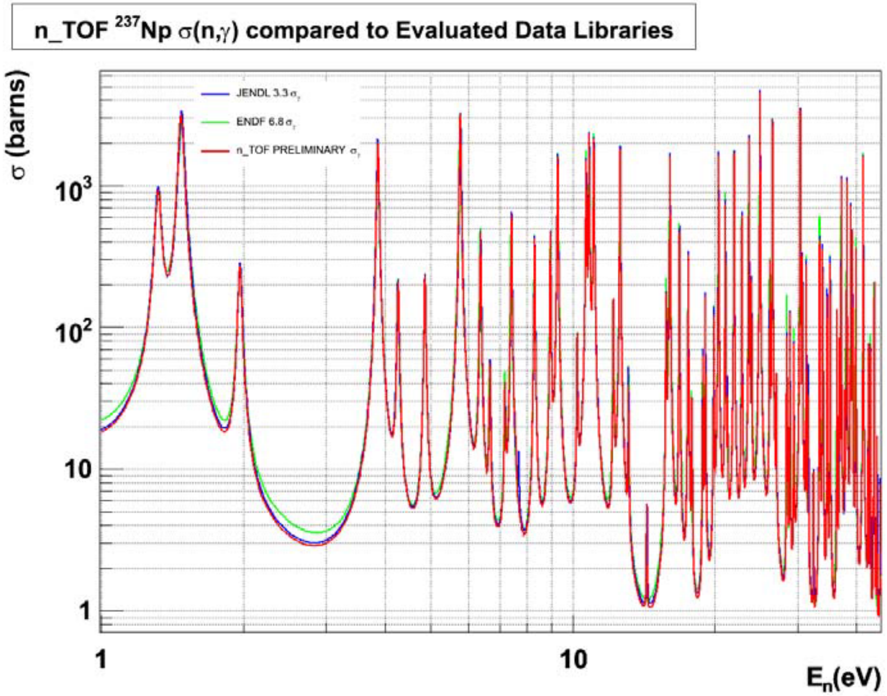
- condition on the deposited energy
- condition on the multiplicity of $\gamma$-rays



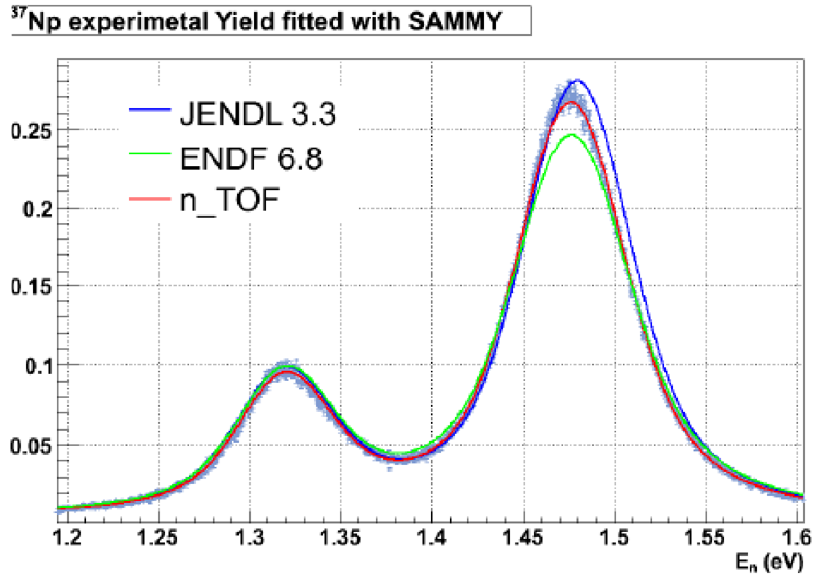

The condition on the multiplicity suppresses the background, but also changes the efficiency (decreases).

Efficiency corrections require extensive Monte Carlo simulations: Geant 4, MCNP-X, Fluka, etc…

# Resonance analysis of $^{237}$NP(n,$\gamma$)




The measured resonances have to be "fitted" (R-matrix analysis) to extract accurate resonance parameters.

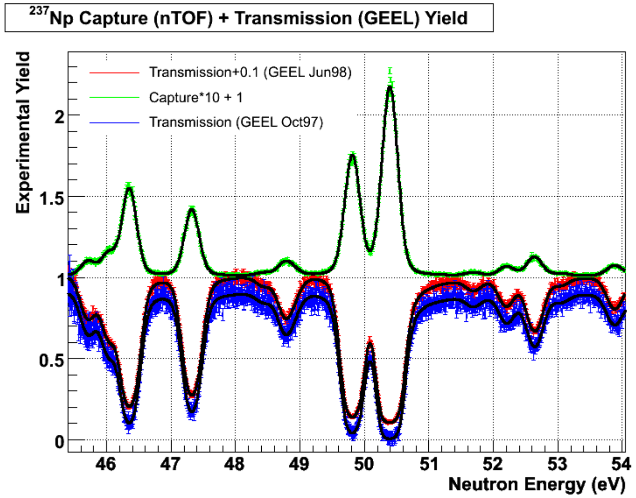


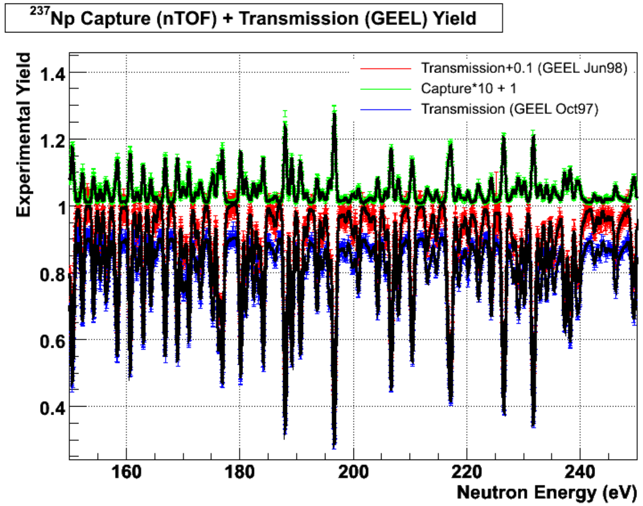

Typically done with the code SAMMY (see talk and exercises by S. Marrone)

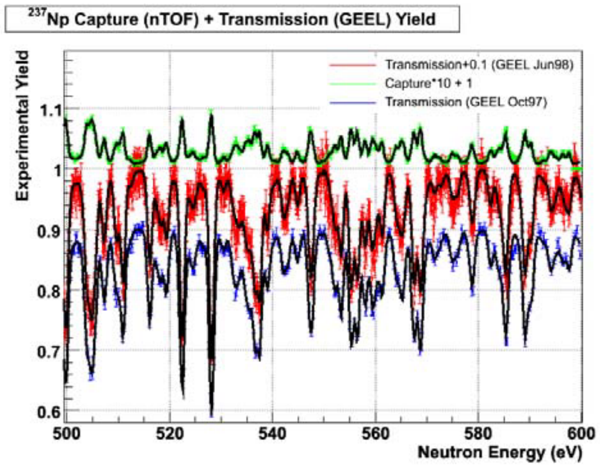
As discussed by P. Schillenbeecks, accurate resonance parameters (partial widths $\Gamma_n$ ad $\Gamma_\gamma$) can be obtained by combining capture and transmission measurements.

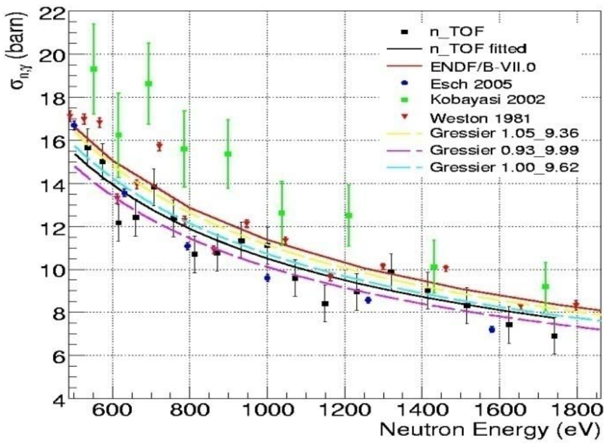
# $^{237}Np$ (n,γ) measurement with the TAC

43.3 mg, 1.29 MBq



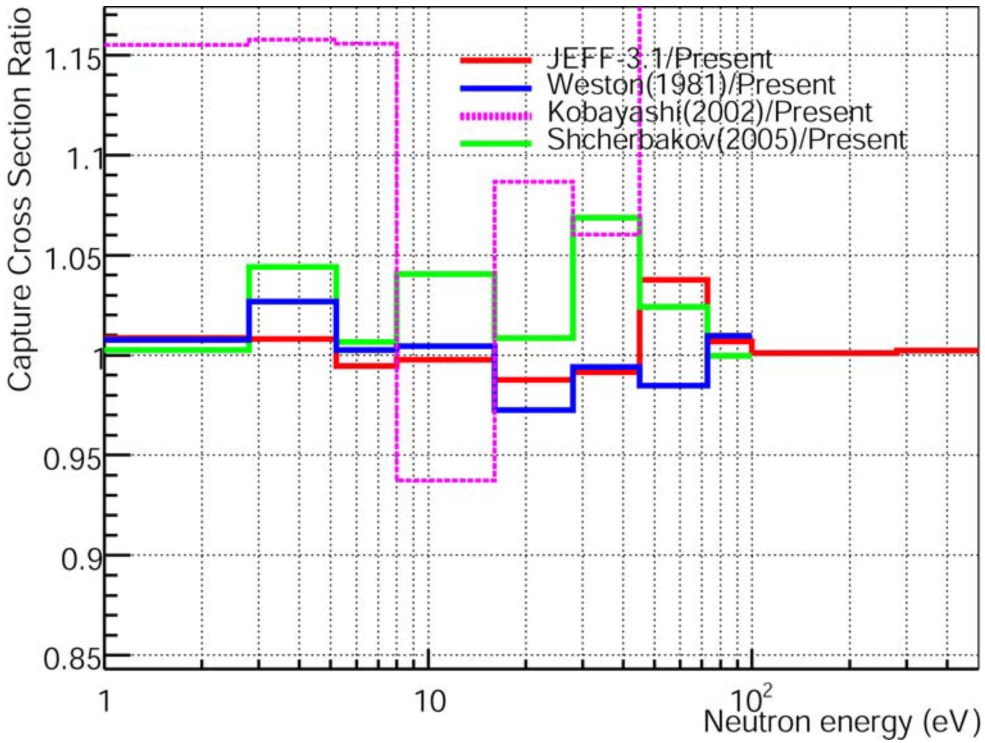



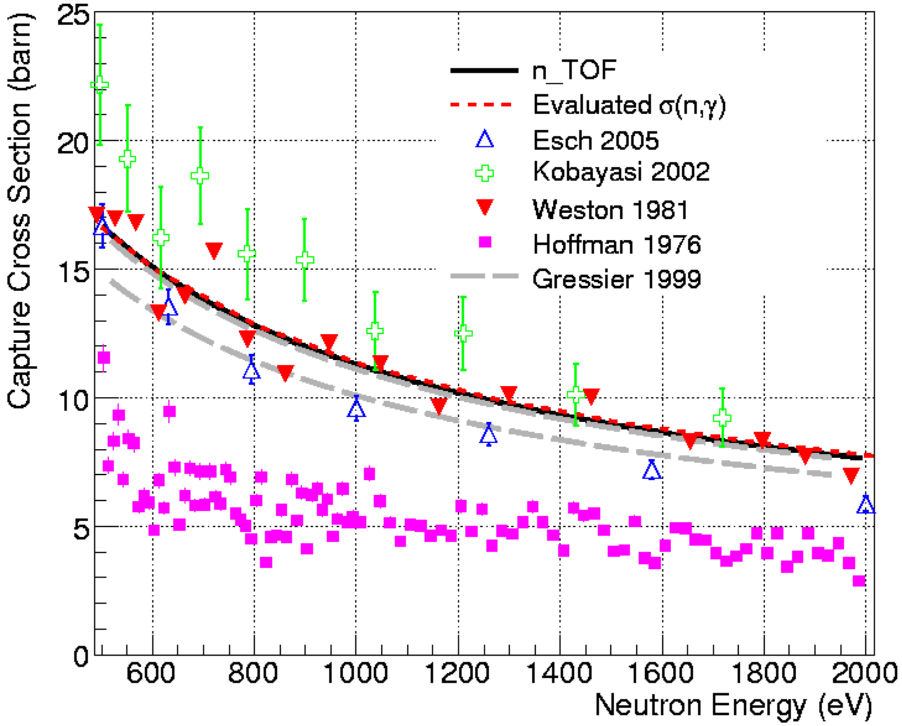




C. Guerrero et al. (n_TOF Collaboration), Proc. Int. Conf. Nuc. Data for Sci. and Tech. 2007, Nice.

# The $^{237}Np(n,\gamma)$ in the URR

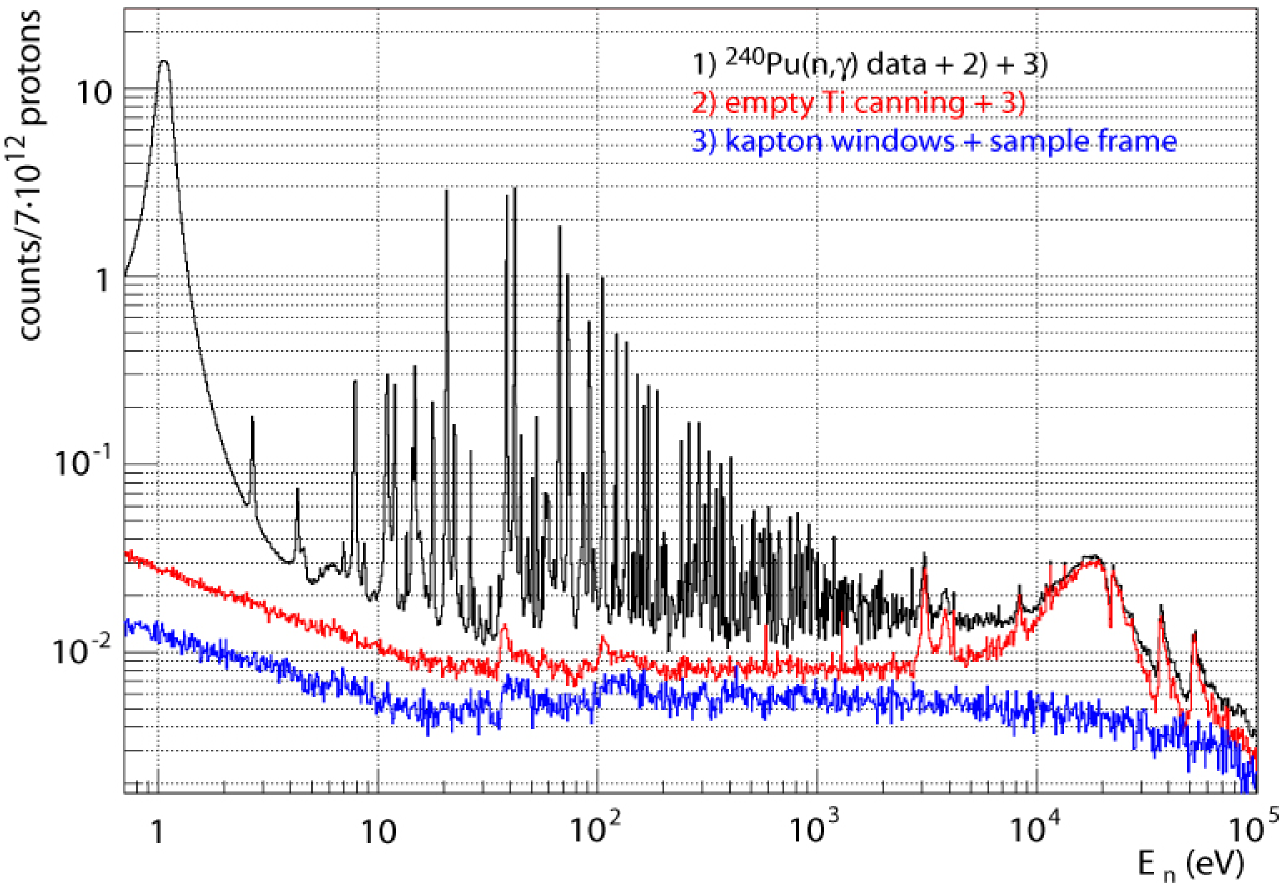



**JEFF-3.1 = JENDL-3.3 = ENDF/B-VII from (n,tot) at GELINA (V. Gressier et al.)**

The new data with high accuracy (5 %), help solve discrepancies between databases

# Data analysis: the $^{240}Pu(n,\gamma)$ cross-sections

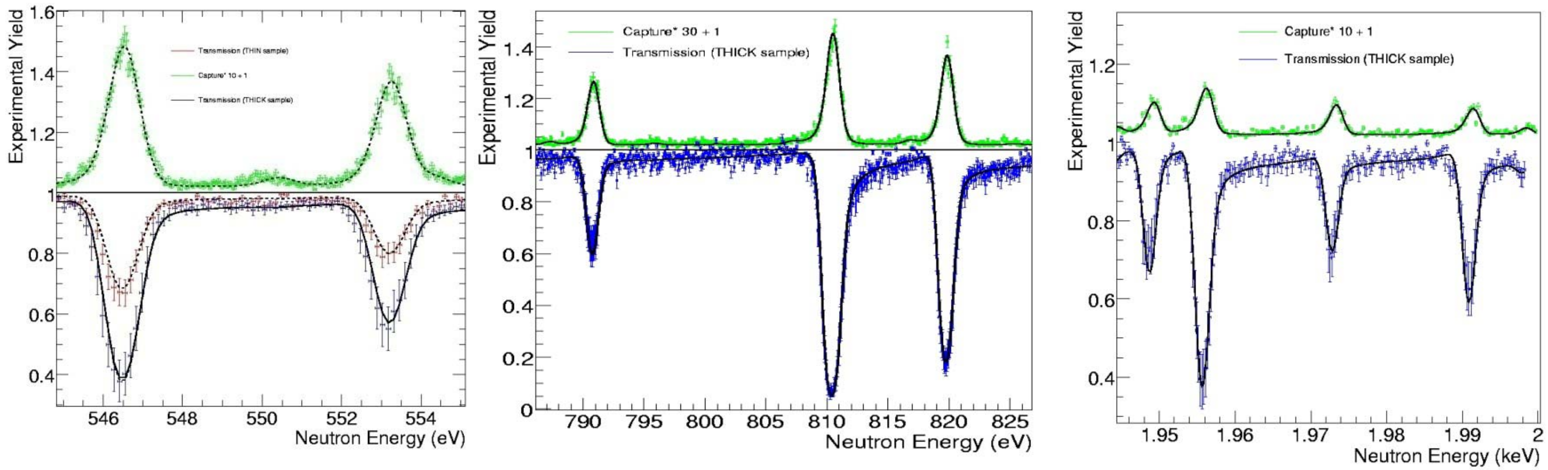



Below 10 keV, low background. Accurate measurement of the Resolved Resonance Region.

Above 10 keV, background dominated by neutron capture in … Ti !!

# $^{240}Pu$ (n,γ) measurement

51.2 mg, 458 MBq

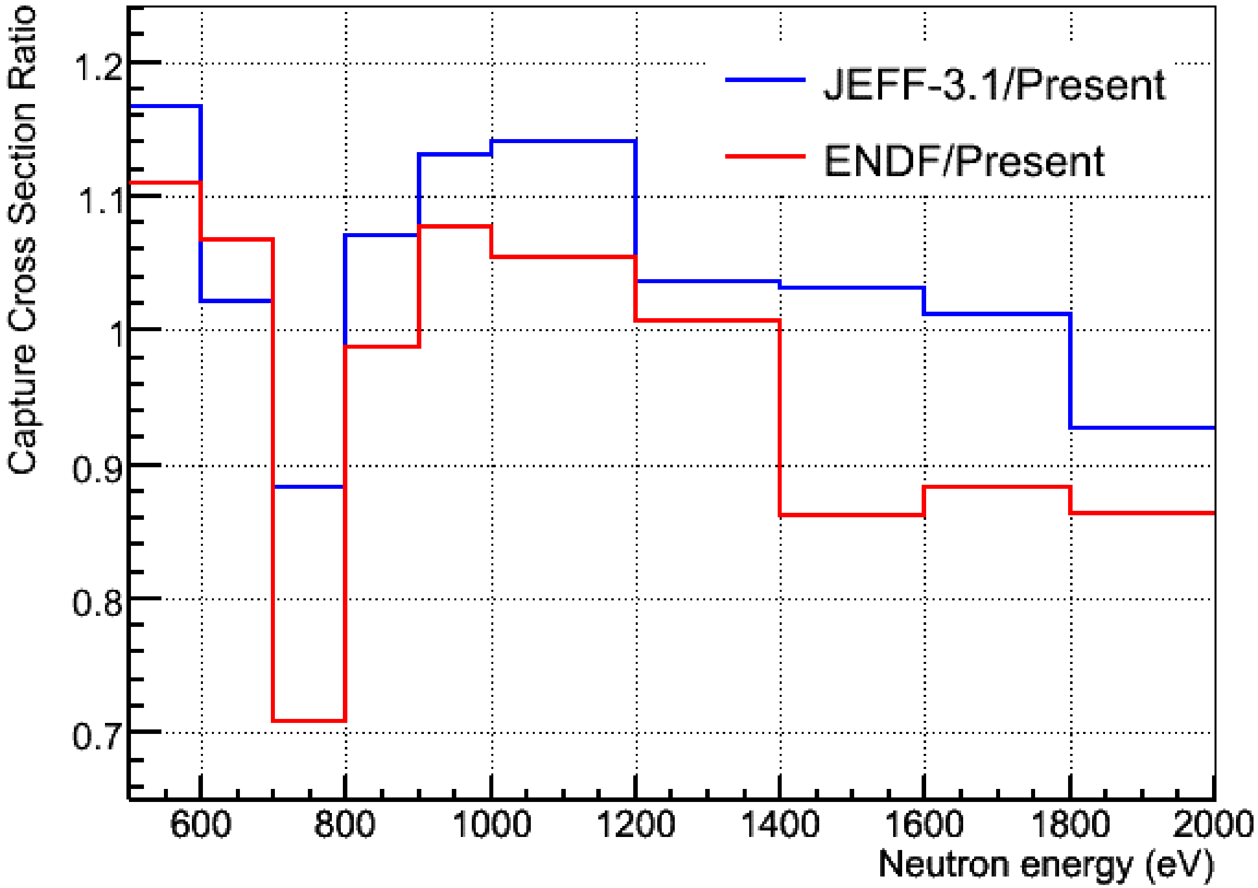



| | ENDF/B-VII | n_TOF | Bouland et al. |
|---|---|---|---|
| **‹$D_0$› (eV)** | 12.1 | **12.1±0.1** | 12.06 |
| **‹$\Gamma_\gamma$›(meV)** | 30.6 | **32.4±0.8** | 31.9 |
| **$S_0(10^{-4})$** | 1.13 | **1.04±0.08** | 1.07 |

C. Guerrero et al. (n_TOF Collaboration), Proc. Int. Conf. Nuc. Data for Sci. and Tech. 2007, Nice.

# The $^{240}Pu(n,\gamma)$ reaction

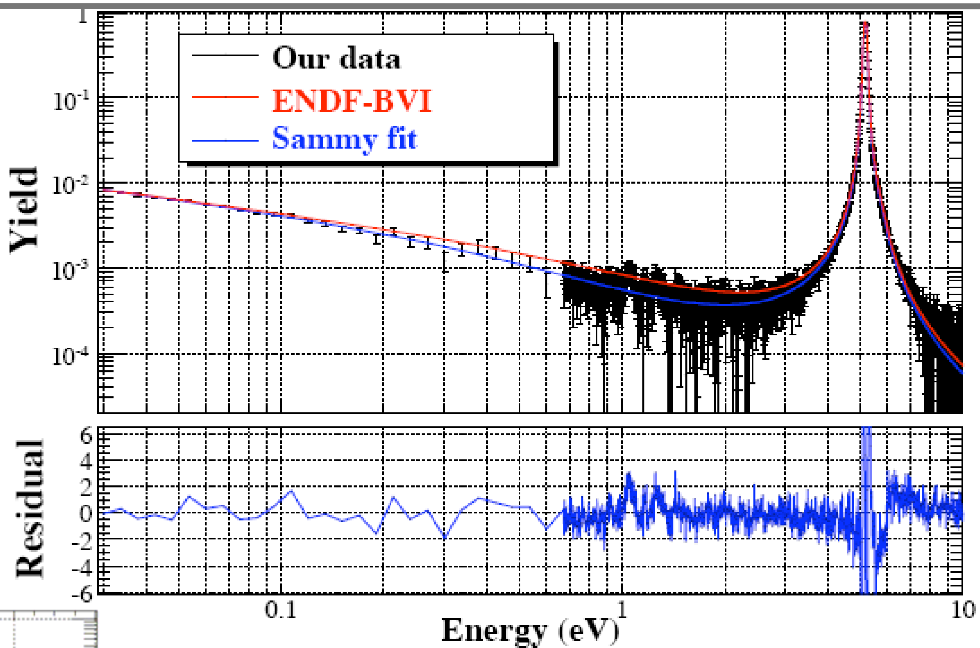
*Salvatores at al., Nucl. Sci. Eng. 146 (2004)* → **UNC($\sigma_\gamma$) = 10%**




**ENDF/B-VII based on (n,tot) at GELINA by Kölar et al. (1968)**

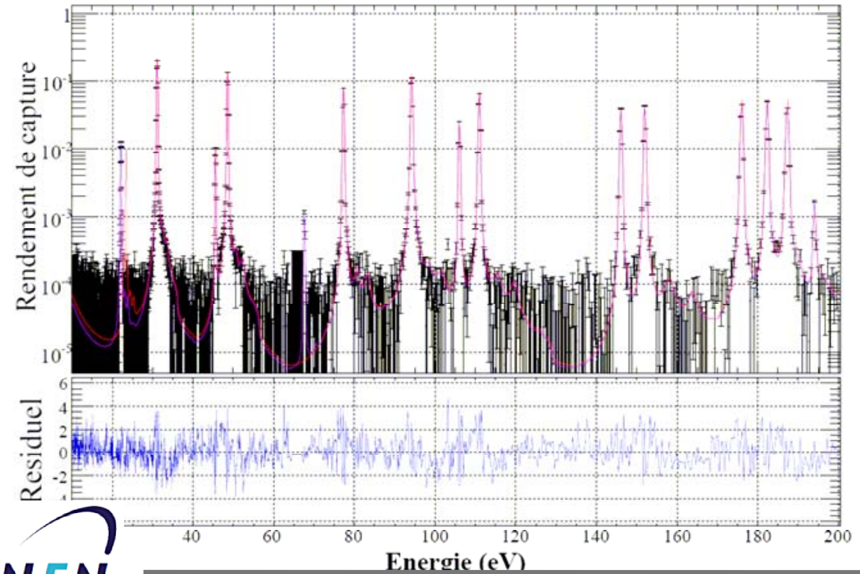
**JEFF-3.1 = JENDL-3.3 based on (n,tot) at GELINA by Kölar (*Bouland et al. 1998*)**

# The $^{234}U(n,\gamma)$ reaction




33 mg, 0.2 MBq

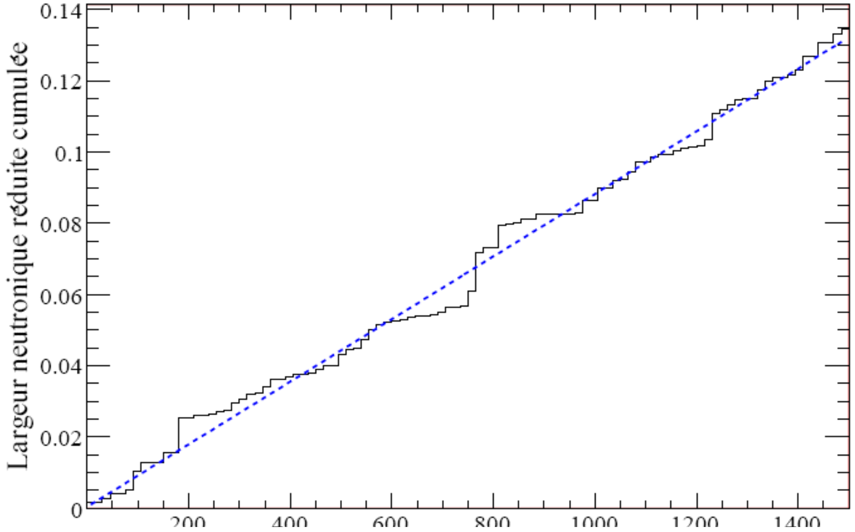
(piece of cake)

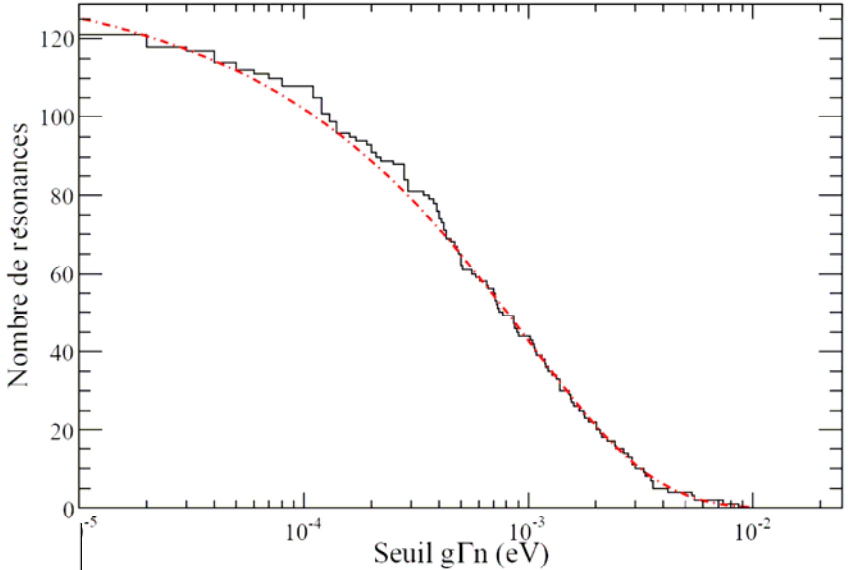


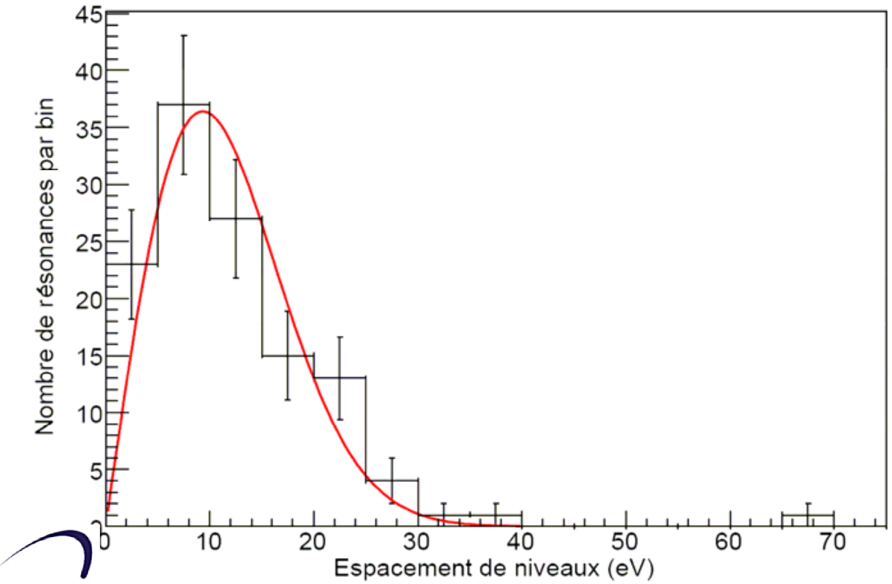

High quality data (very accurate)
Waiting only to be published

W. Dridi, E. Berthomieux et al., Phys. Rev. C, in preparation

# Statistical analysis of $^{234}U(n,\gamma)$



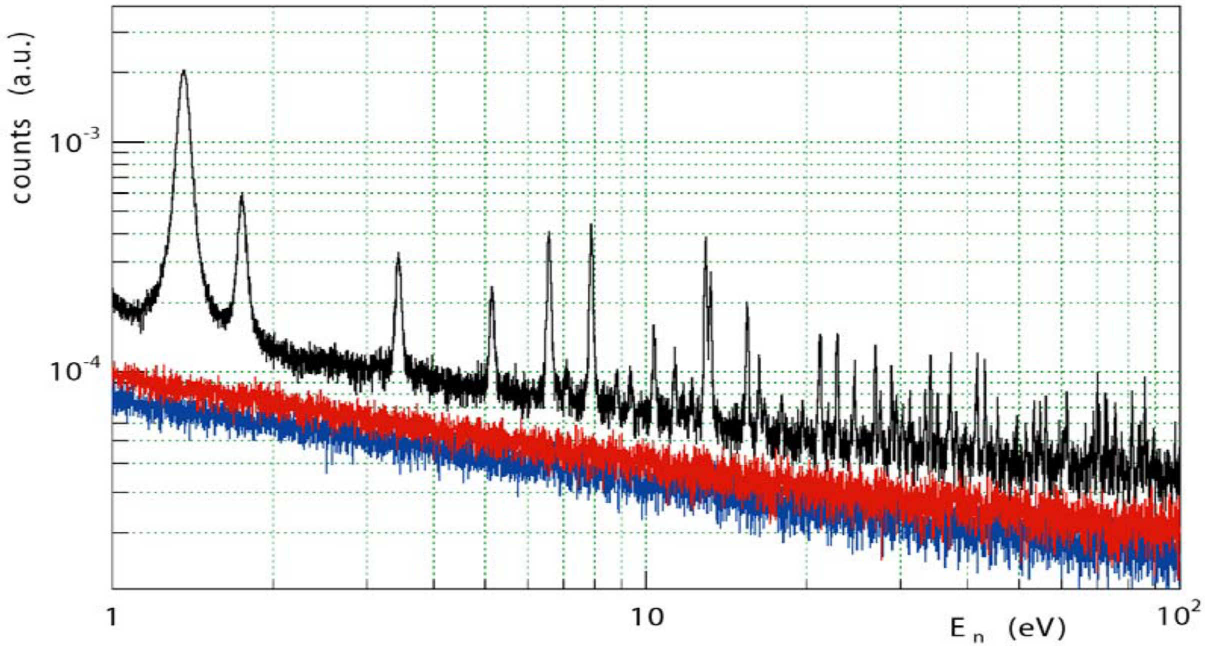




Allows to obtain information on average level spacing, neutron strength function, and other nuclear properties

Very important for model calculations

# $^{243}$Am (n,γ) measurement with the TAC




First (n,γ) measurement EVER. 10 mg, 75 MBq

D. Cano-Ott et al. (n_TOF Collaboration), Proc. Int. Conf. Capture Gamma-Ray Spec. 2005, Santa Fe.

# Conclusions

The detection of the entire γ-ray cascade allows to discriminate capture events from background (in particular the onerelated to natural radioactivity of the sample or to competing reactions).

Background rejection based on multiplicity and total energy reconstructed.

A fundamental device for measuring capture cross-sections of fissile elements (fission reactions rejected on the basis of total energy of γ-rays)

Thanks to its features, the TAC allows to measure with high accuracy capture cross-sections for Pu isotopes and minor actinides involved in advanced nuclear reactors.