# The $^{197}$Au(n,$\gamma$) cross-section in the unresolved resonance region

Claudia Lederer

IAEA consultants meeting on cross-section standards
Vienna, 13-15 October 2010

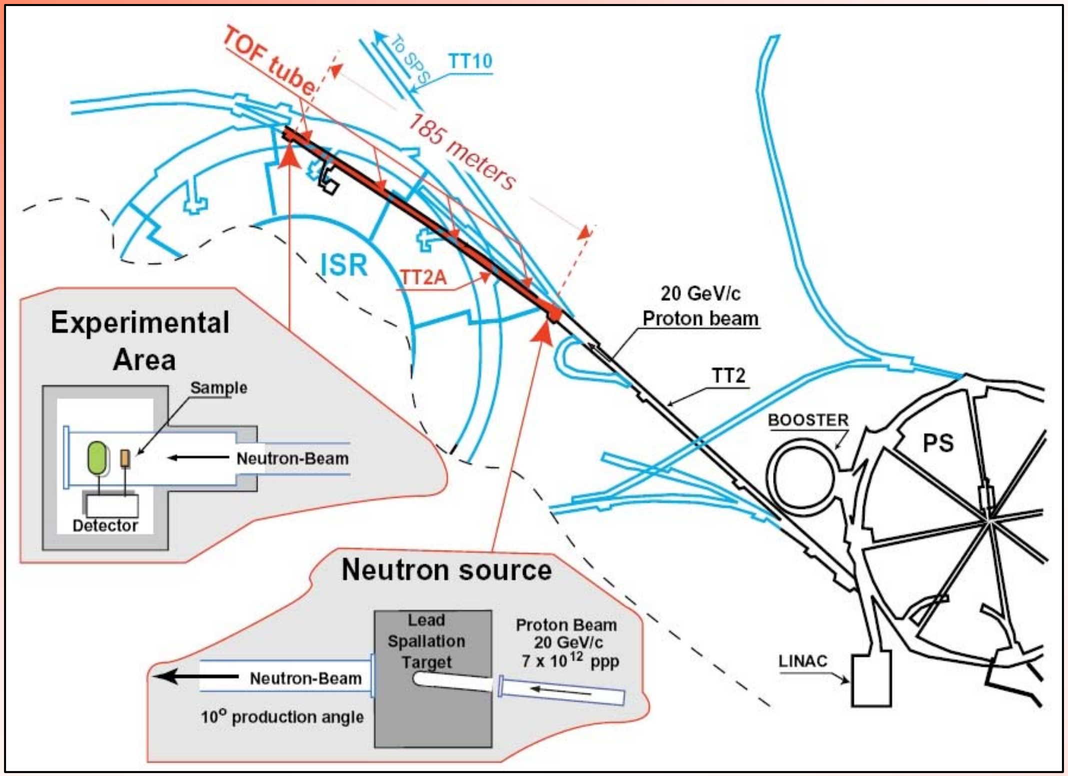
# Discrepancies standard evaluation – MACS by Ratynski and Käppeler →

- new measurement of Au(n,γ) at GELINA (P. Schillebeeckx) and n_TOF
- measurement of $^{7}$Li(p,n) quasi-maxwellian neutron spectrum at PTB

# Measurement at n_TOF

In collaboration with: N. Colonna, C. Domingo-Pardo, F. Gunsing, F. Käppeler, C. Massimi, A. Mengoni, A. Wallner, the n_TOF Collaboration

# n_TOF (neutron time-of-flight) facility at CERN




20 GeV/c protons on Pb-target

Pulse width: 7 ns

Intensity: 7 $\cdot 10^{12}$ protons per pulse

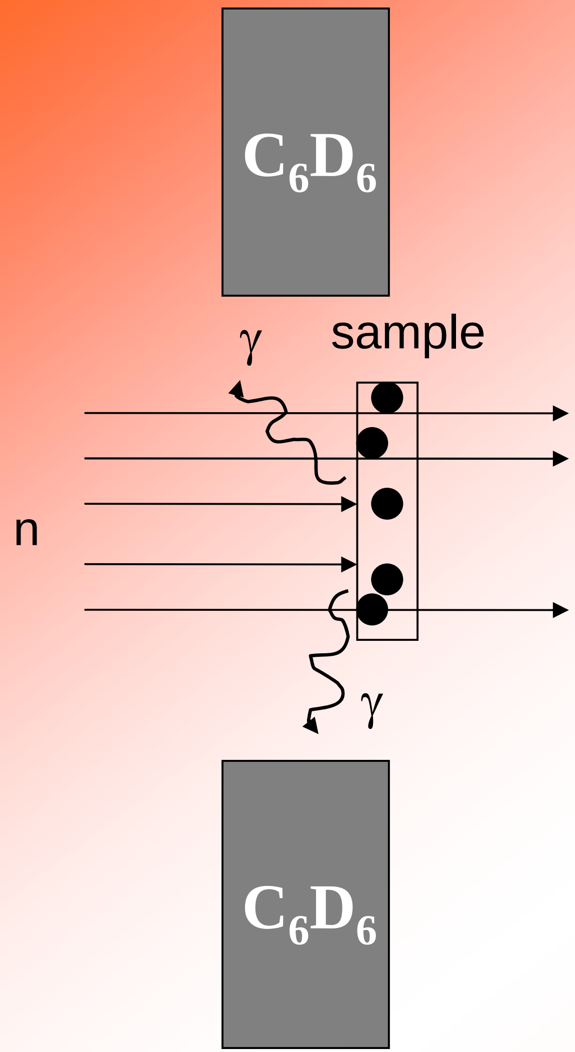
Flight path: 185 m

Neutron energy: $10^{-3}$-$10^{10}$ eV

Beam size at capture setup: Ø~4 cm

2 setups for capture measurements:

- total absorption calorimeter: 4$\pi$ geometry ($\varepsilon$~100%)
- **two $C_6D_6$ detectors**



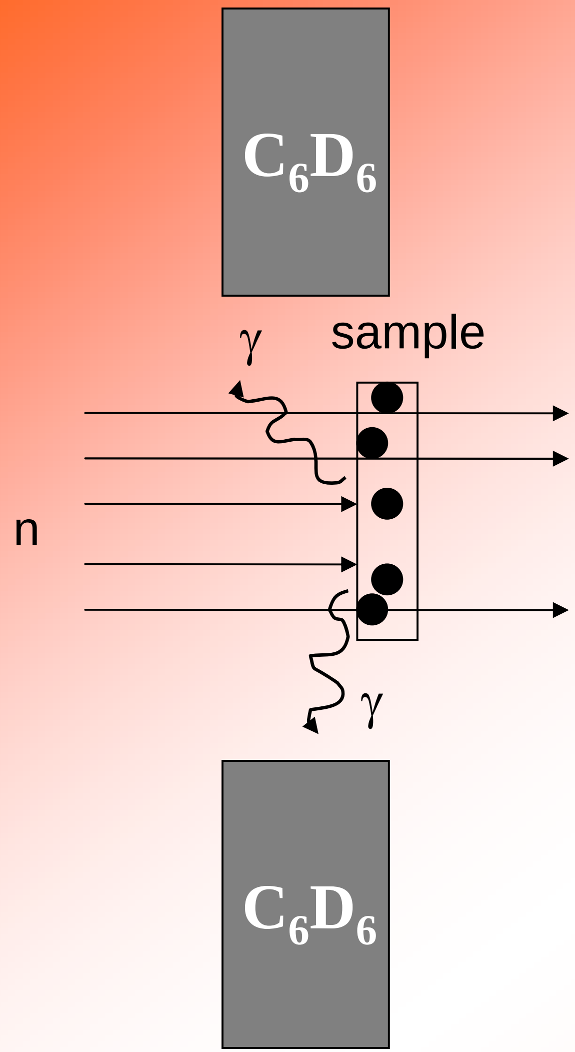

$^{197}Au+n \rightarrow {}^{198}Au^* \rightarrow {}^{198}Au + \gamma$

**Detection technique:**

- 2 $C_6D_6$ detectors
- about 20% efficiency for detecting a capture event

**Sample**

- 15 mm diameter
- 1299 mg mass
- $2.241 \cdot 10^{-3}$ atoms/barn
- 0.37 mm thickness

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$$Y_R = f_{corr} \cdot f_N \frac{C-B}{\varepsilon \cdot \Phi}$$

B.. background

ε....efficiency

$f_N$....normalization

ϕ...neutron flux

$f_{corr}$...other experimental effects

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# Efficiency

• Pulse height weighting technique

• apply pulse-height dependent weight to recorded signal to achieve:

$$\varepsilon_c = k \bullet (S_n + E_n)$$

• uncertainty for weighting: 2%

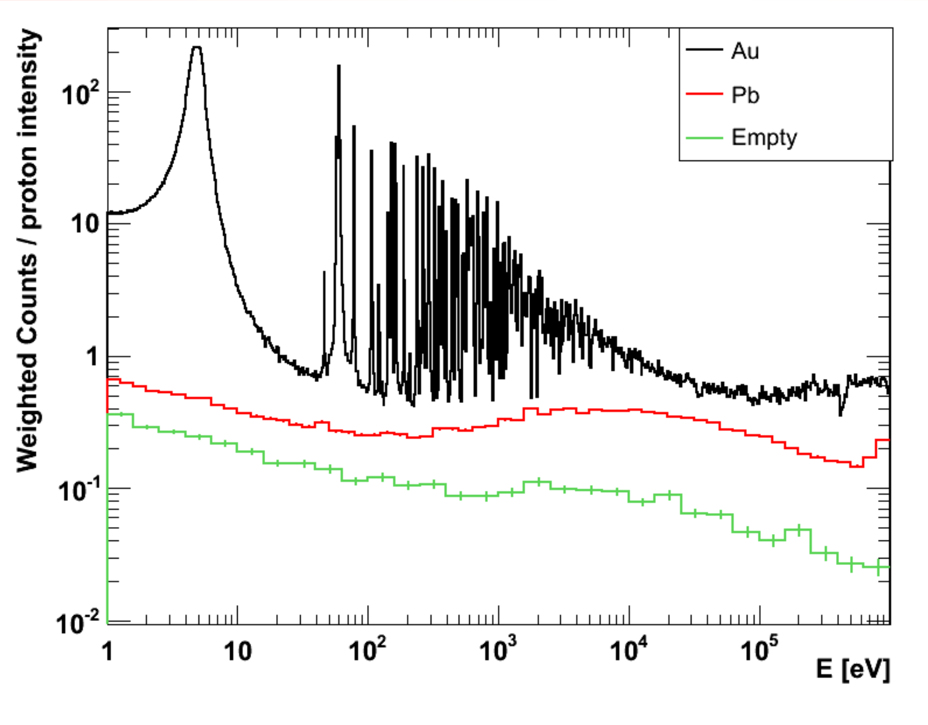
• WF validity >99.4% for different neutron absorption in sample

• for details see: C. Massimi, C. Domingo-Pardo *et al.*, Phys. Rev. C **81**, 044616 (2010)

# Background

Components:

- neutron induced bg (energies <200 eV)
- in-beam-gamma-rays (200 eV-400 keV)
- (n,n'γ) reactions (first inelastic channel Au: 77.4 keV)



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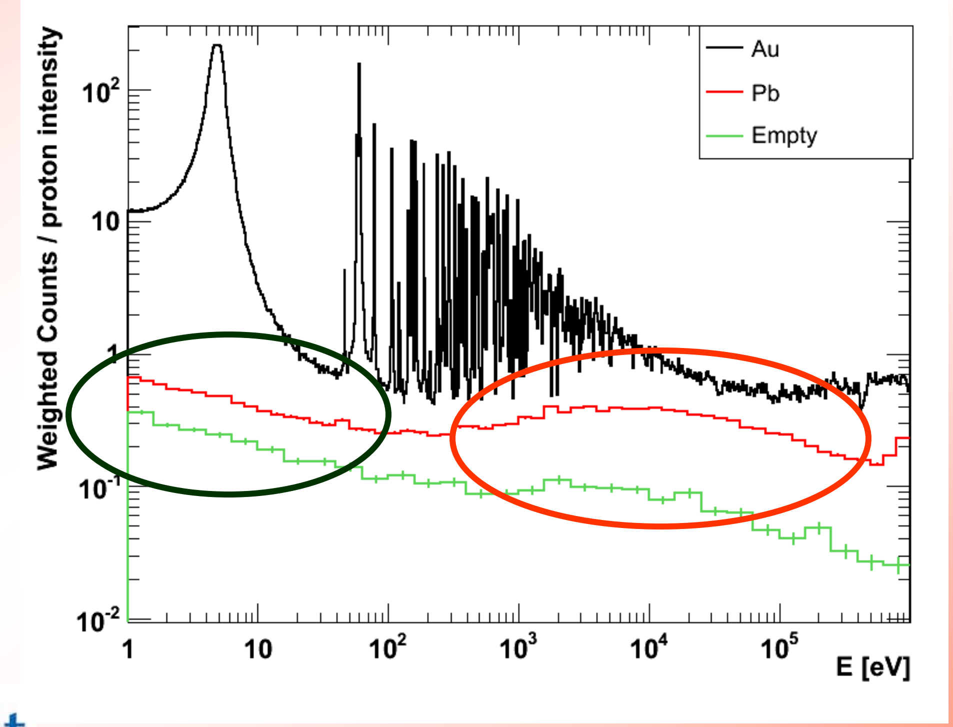




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n_TOF

# Background

Total background:

$$B_{tot} = f_n \bullet B_n + f_\gamma \bullet B_\gamma + B_{ambient}$$

# Background - shape

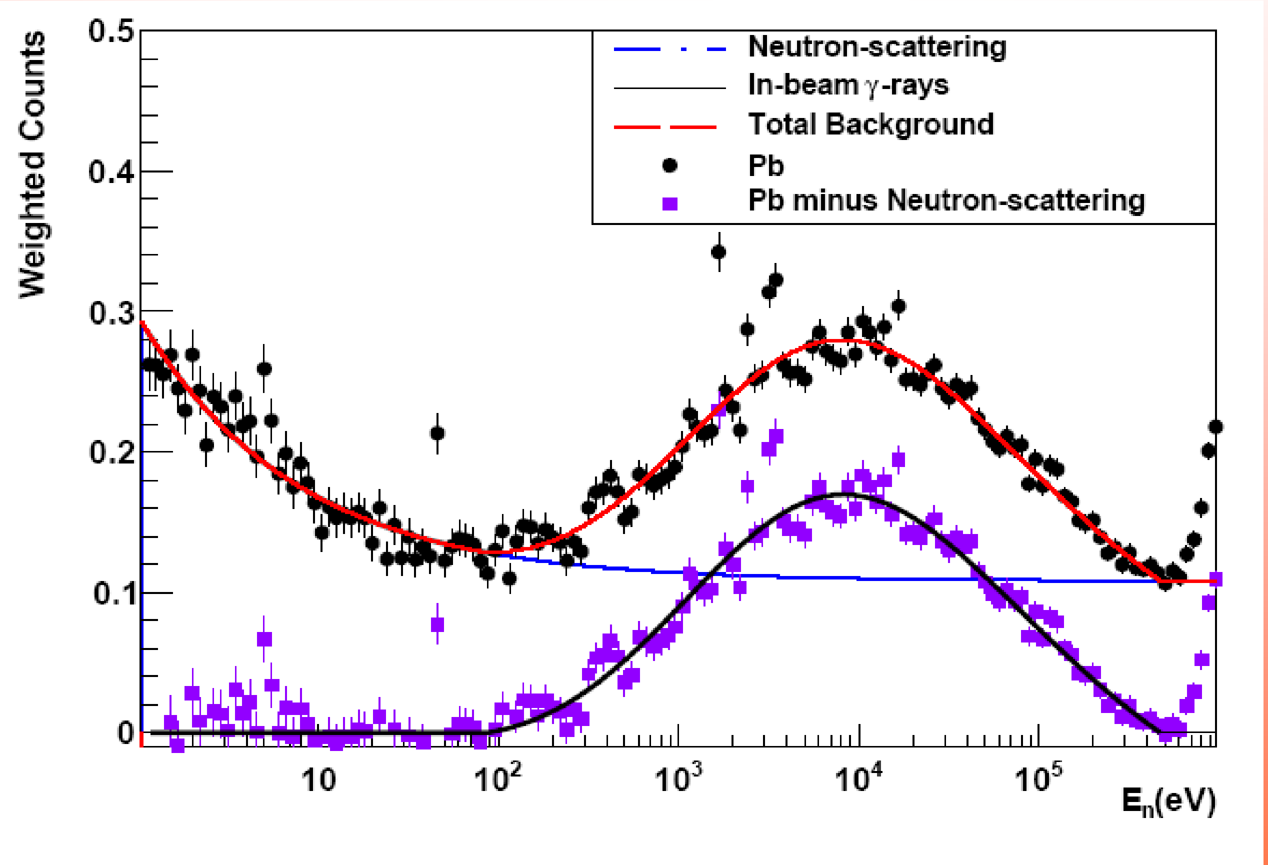
Total background:

$$B_{tot} = f_n \bullet \mathbf{B_{n,el}} + f_\gamma \bullet \mathbf{B_\gamma} + B_{ambient}$$

$\mathbf{B_n = a + b \bullet E^{-0.5}}$

$\mathbf{B_\gamma = c + d \bullet exp(-e \bullet E^{-0.5}) + f \bullet exp(g \bullet E^{-0.5})}$

Pb:



# Background - normalization

Total background:

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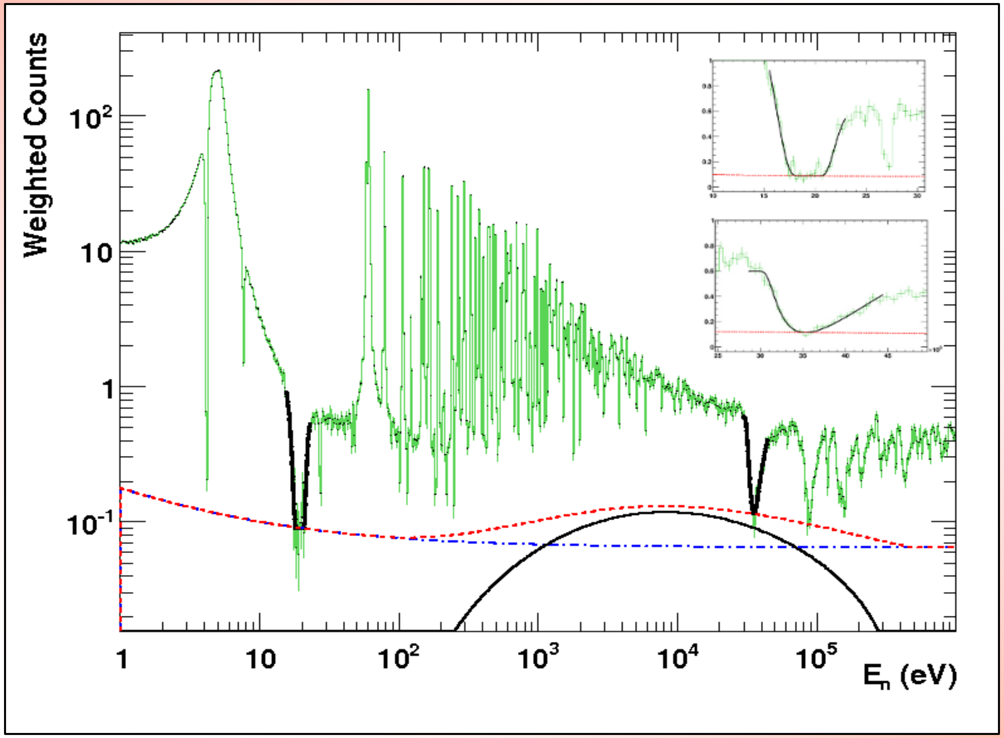
- Method 1: neutron filters in beam*

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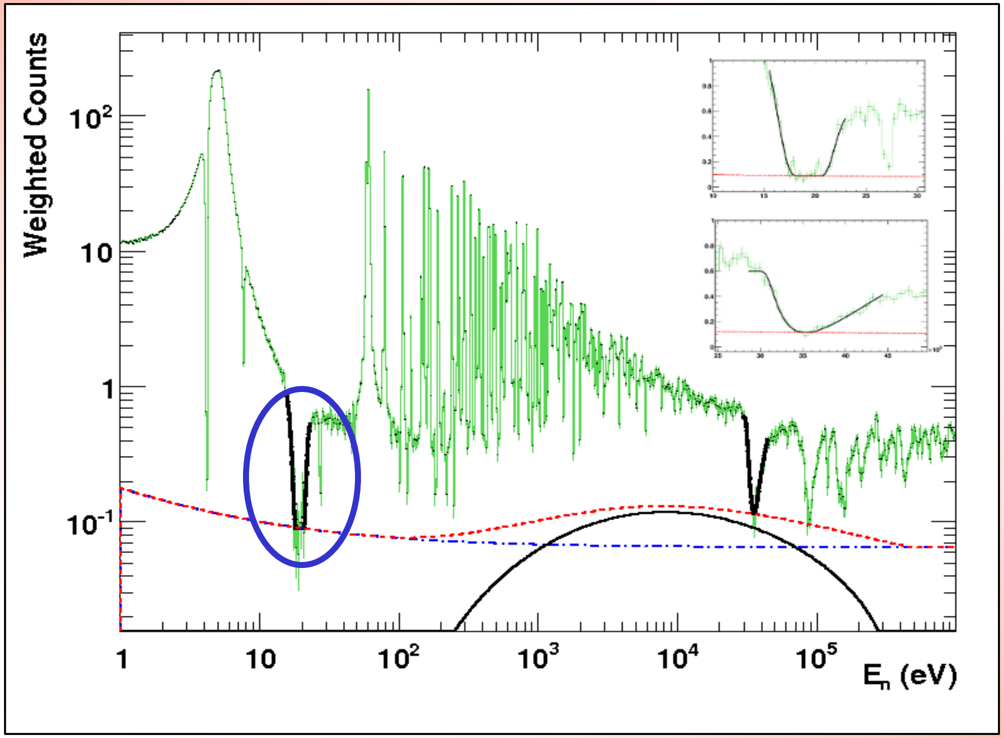


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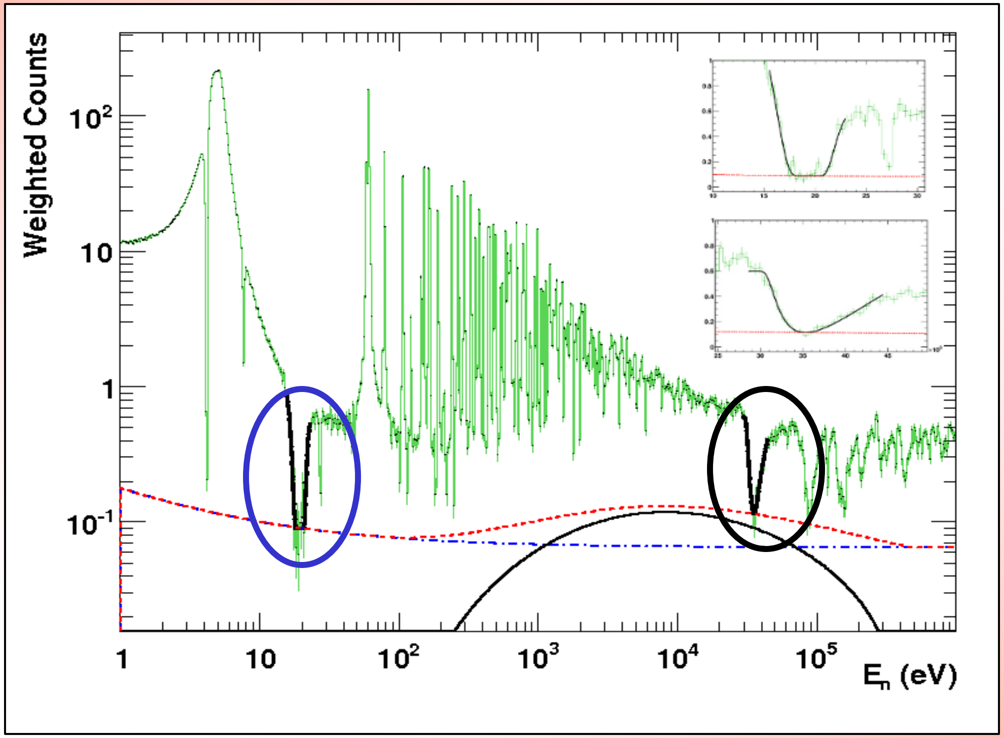


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$$\cdot f_\gamma = f_f \cdot f_{att}$$

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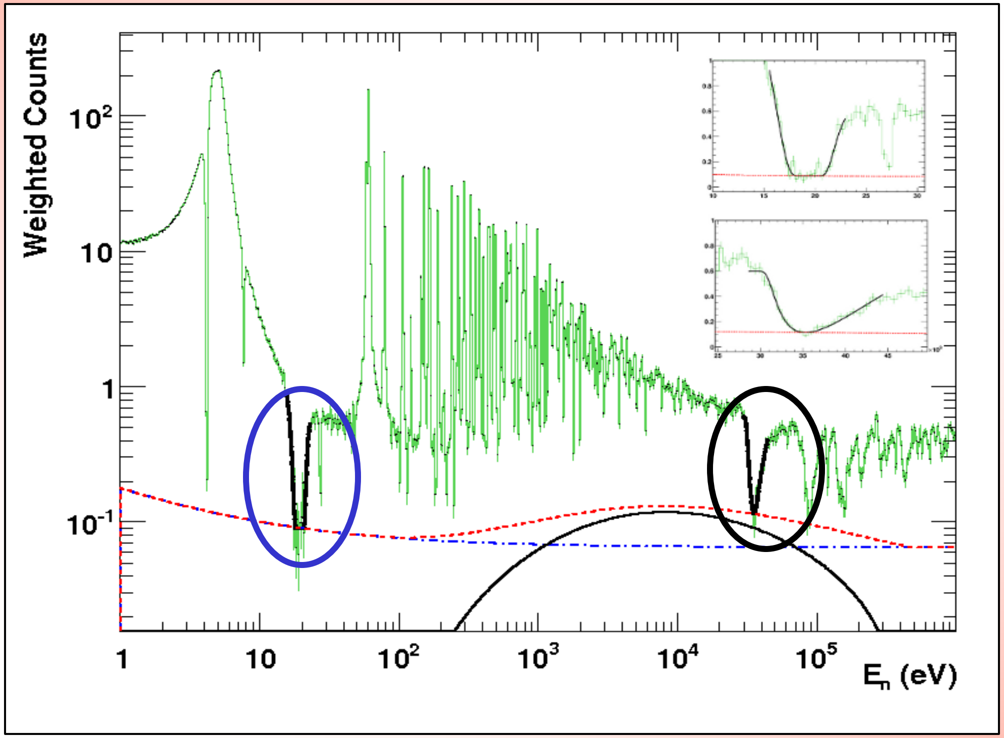


- W (20.06 eV) and Al (34.7 keV)
- $\mathbf{f_n = 0.556 \pm 5\%}$
- $\mathbf{f_f = 0.354 \pm 7\%}$
- $\mathbf{f_{att,sim} = 1.83 \pm 8\%}$

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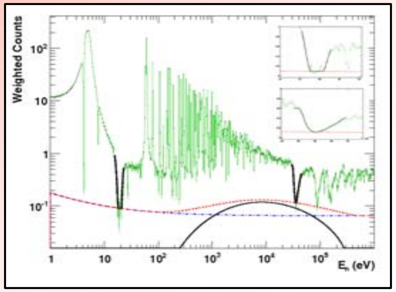


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- Method 2: simulations of $f_\gamma$

- GEANT3: $f_\gamma = 0.625$
- MCNPX: $f_\gamma = 0.669$

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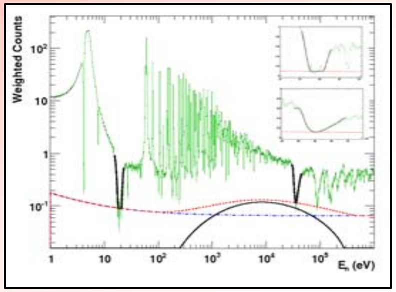

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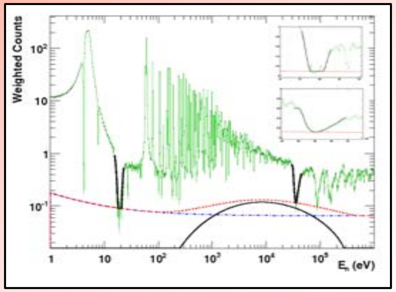


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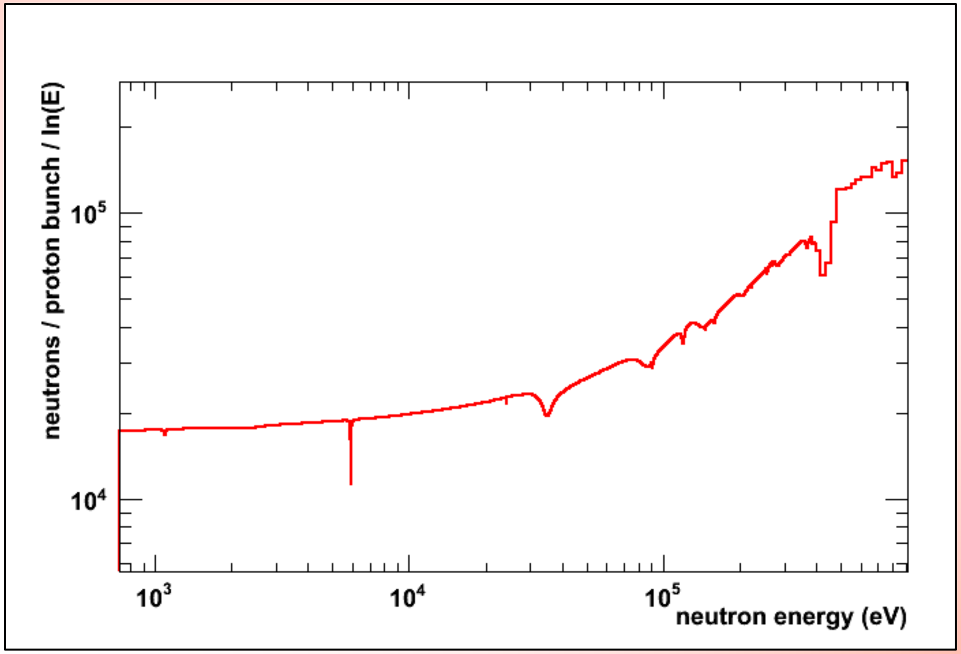
→ uncertainty in cross-section around 1.6 % !

# Neutron flux

- Parallel plate fission chamber loaded with $^{235}U$
- Uncertainty: 2% (apart from the dips)




# Normalization

- Saturated resonance technique
- 4.9 eV resonance in Au: no neutrons transmitted
- Fit top of resonance
- Uncertainty : 1%

# Further Corrections/Checks

- energy dependence of neutron beam profile max. 4.5%
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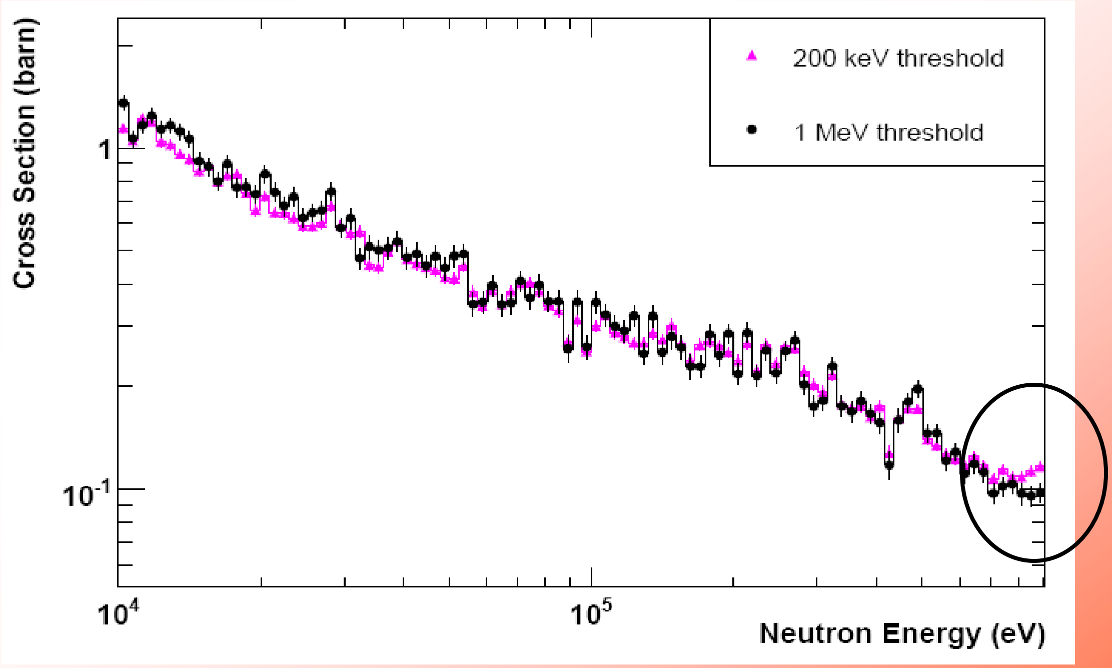
- Background due to inelastic channels:

  compare spectra with 200 keV and 1MeV threshold:



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- energy dependence of neutron beam profile max. 4.5%
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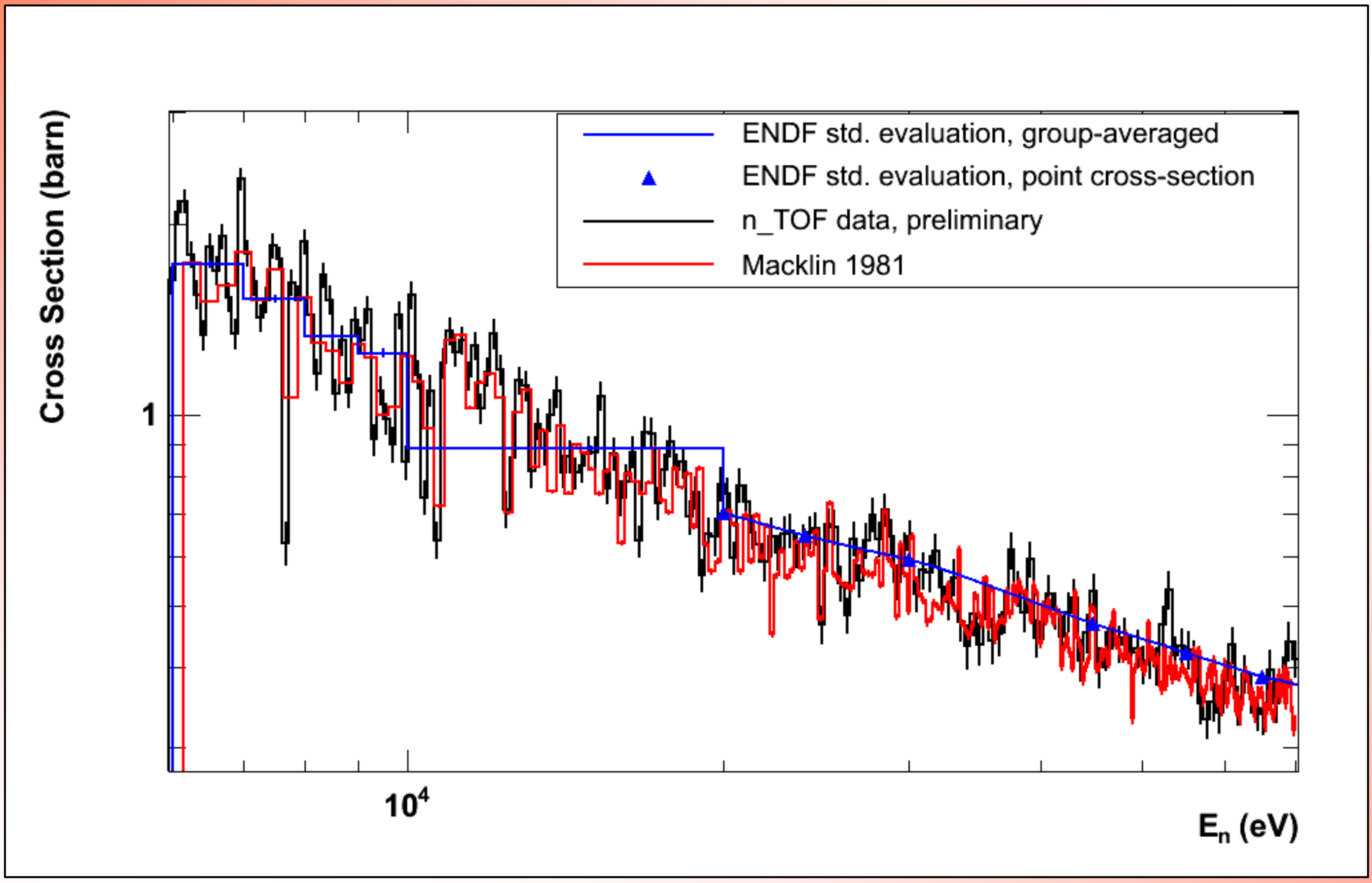
- Missing: comparison of capture yield using different thresholds

  → can reduce the 2% uncertatinty in PWHT!
- expected final uncertainty: 4-5%

# Results: structures in cross-section



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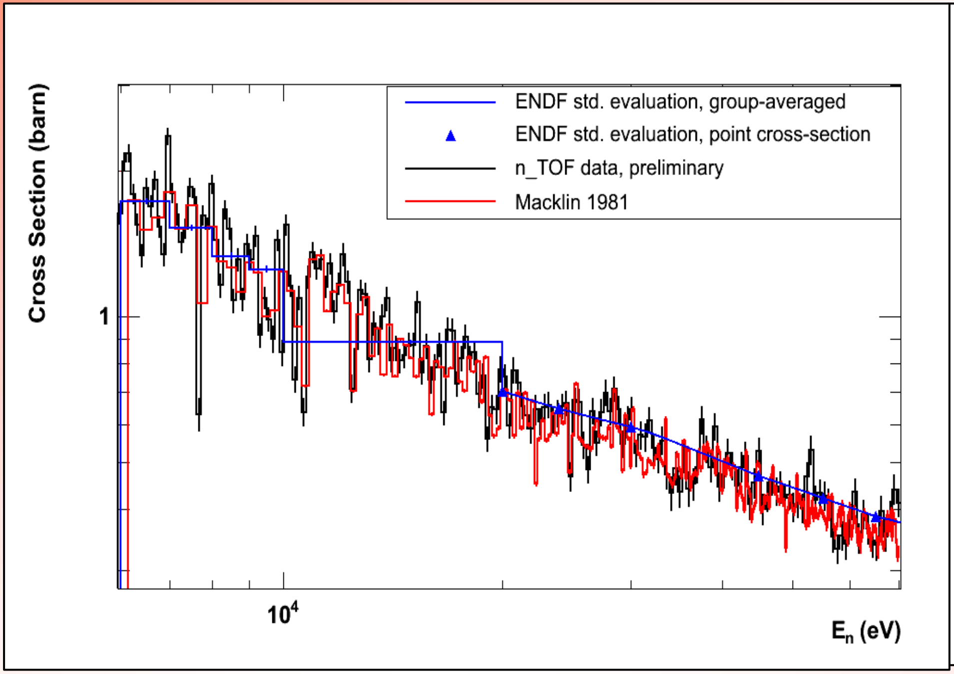


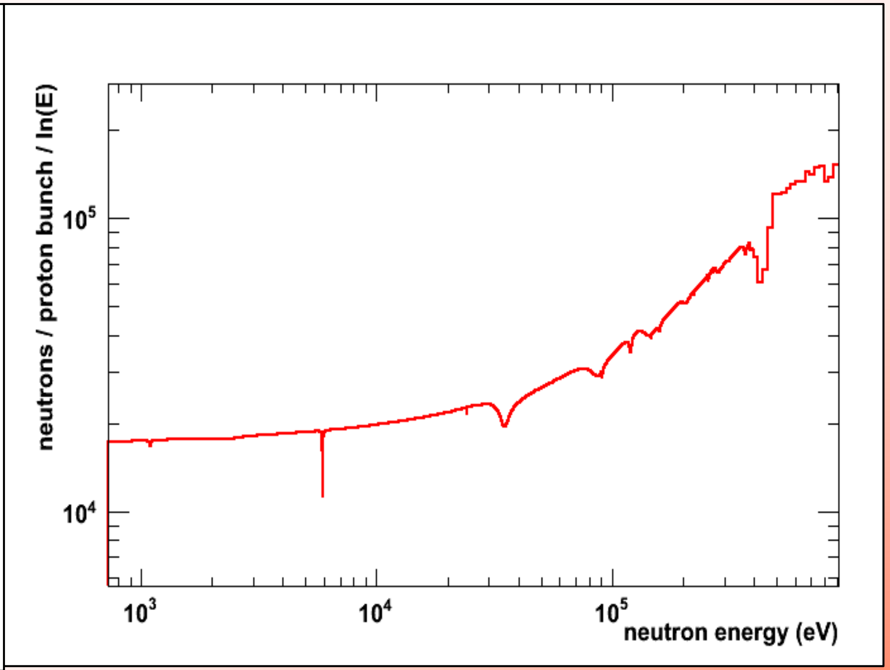

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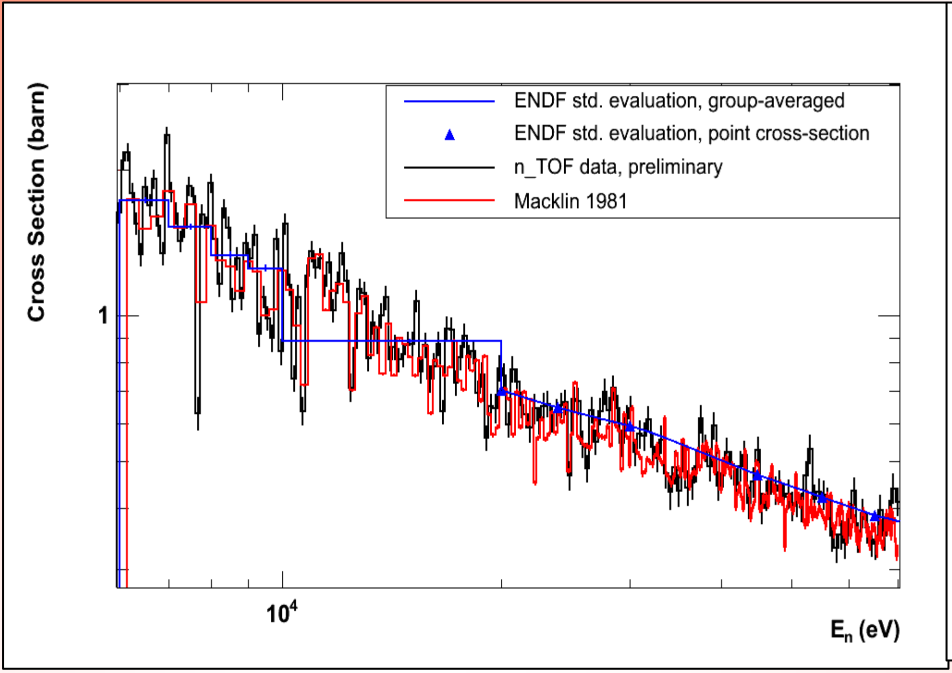


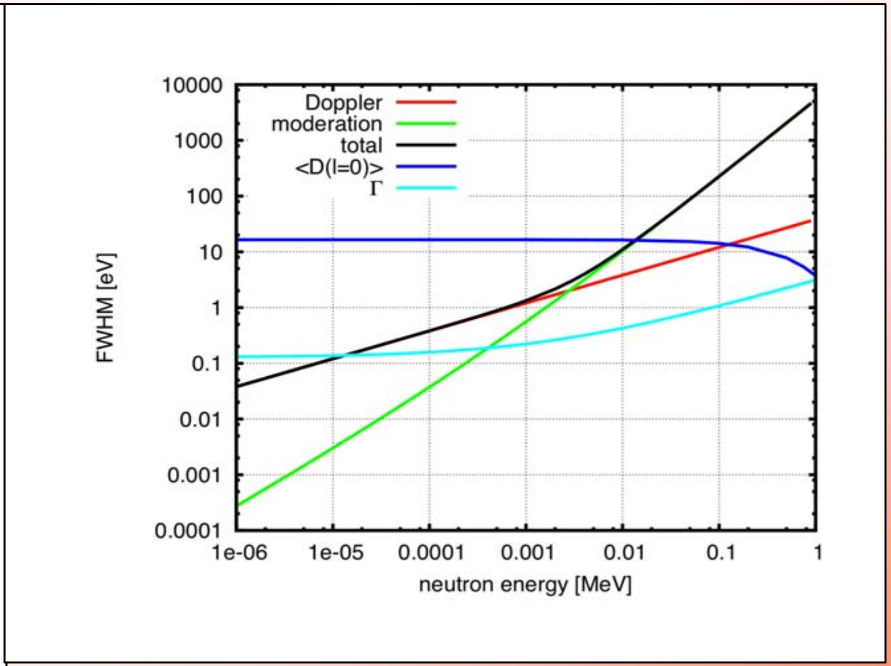

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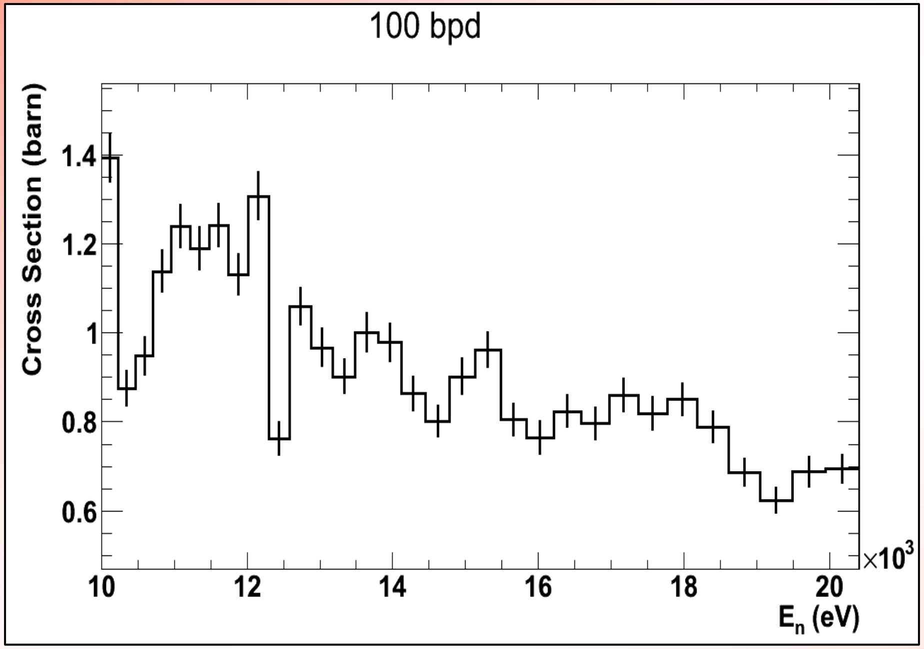


experimental

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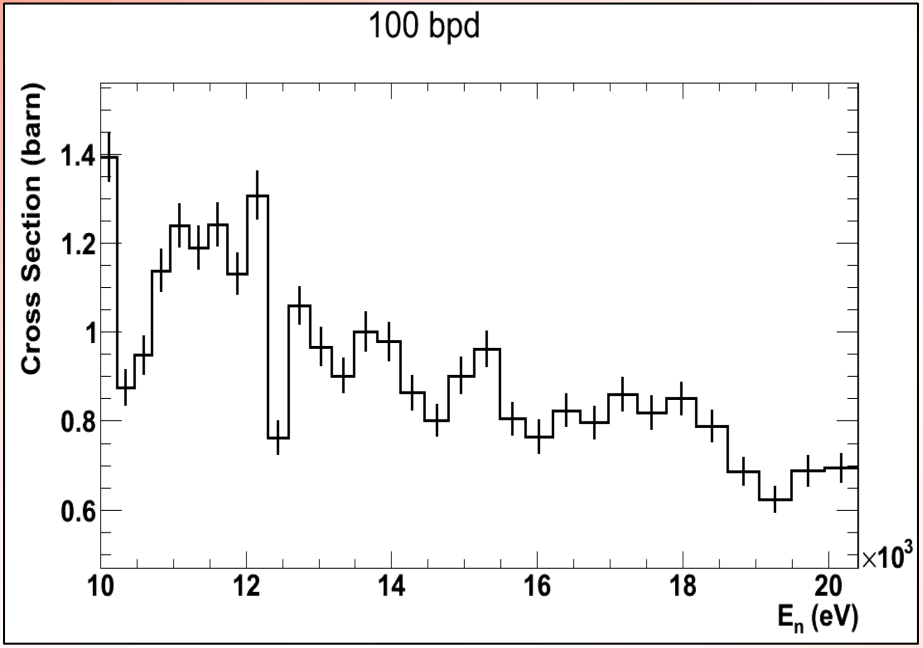


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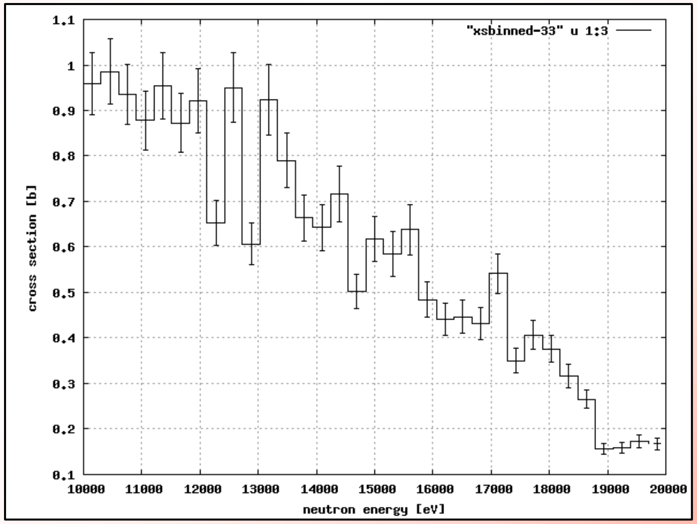


trial 1

simulation

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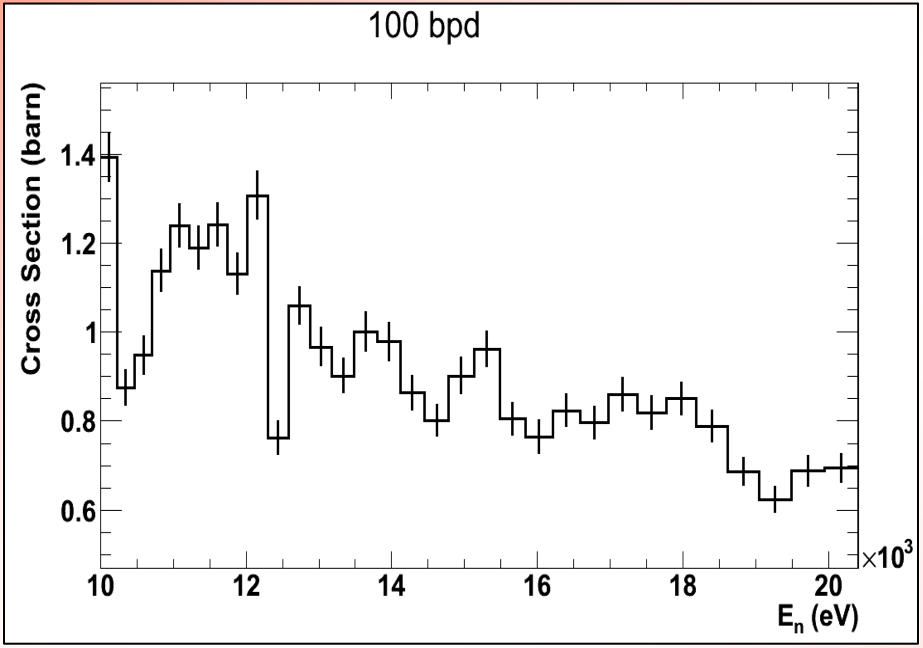
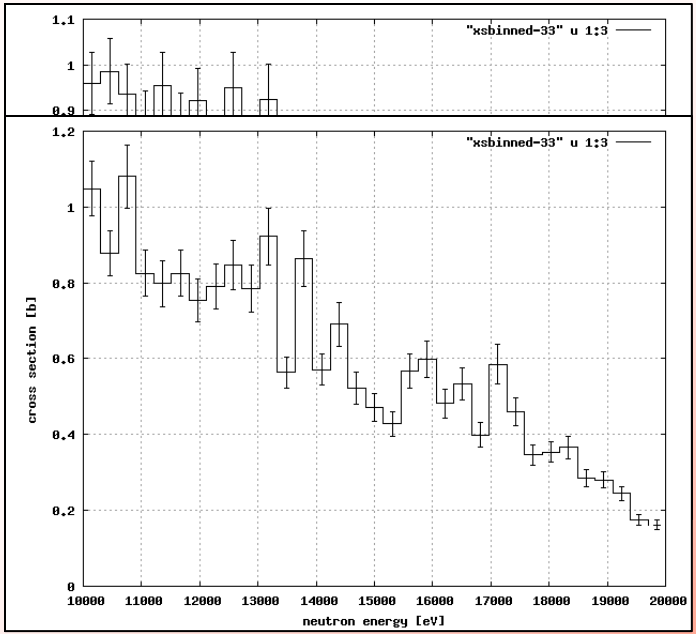



experimental




simulation

trial 2

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# Results: structures in cross-section

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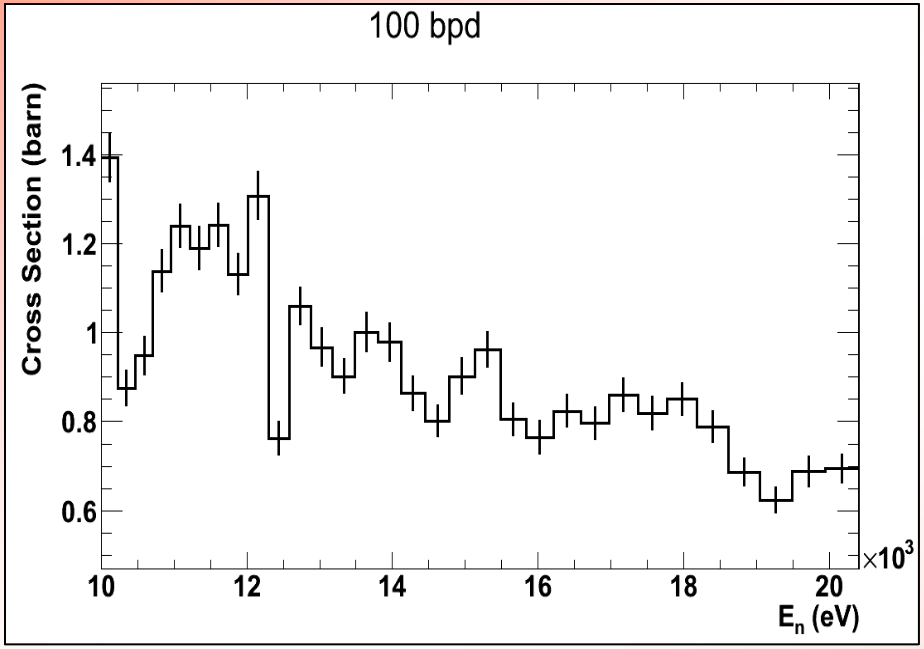
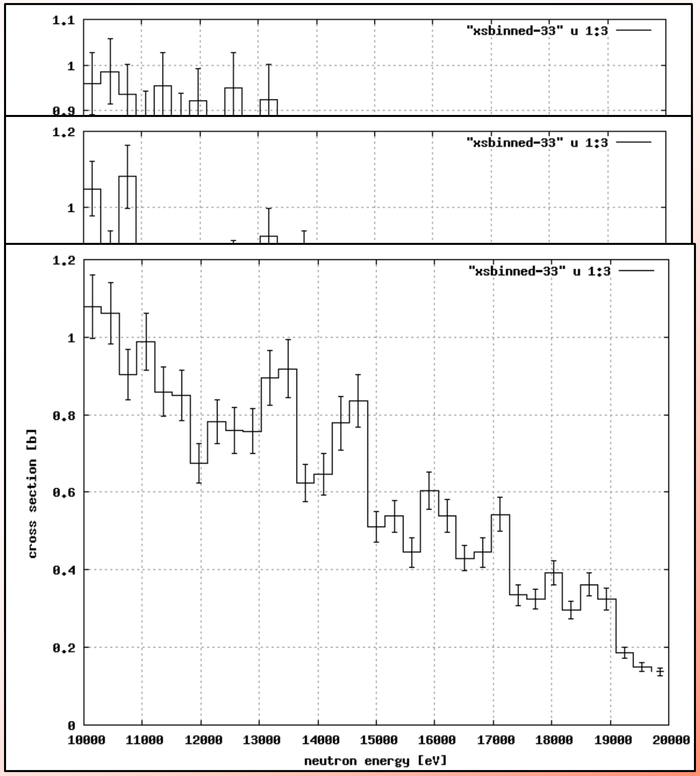


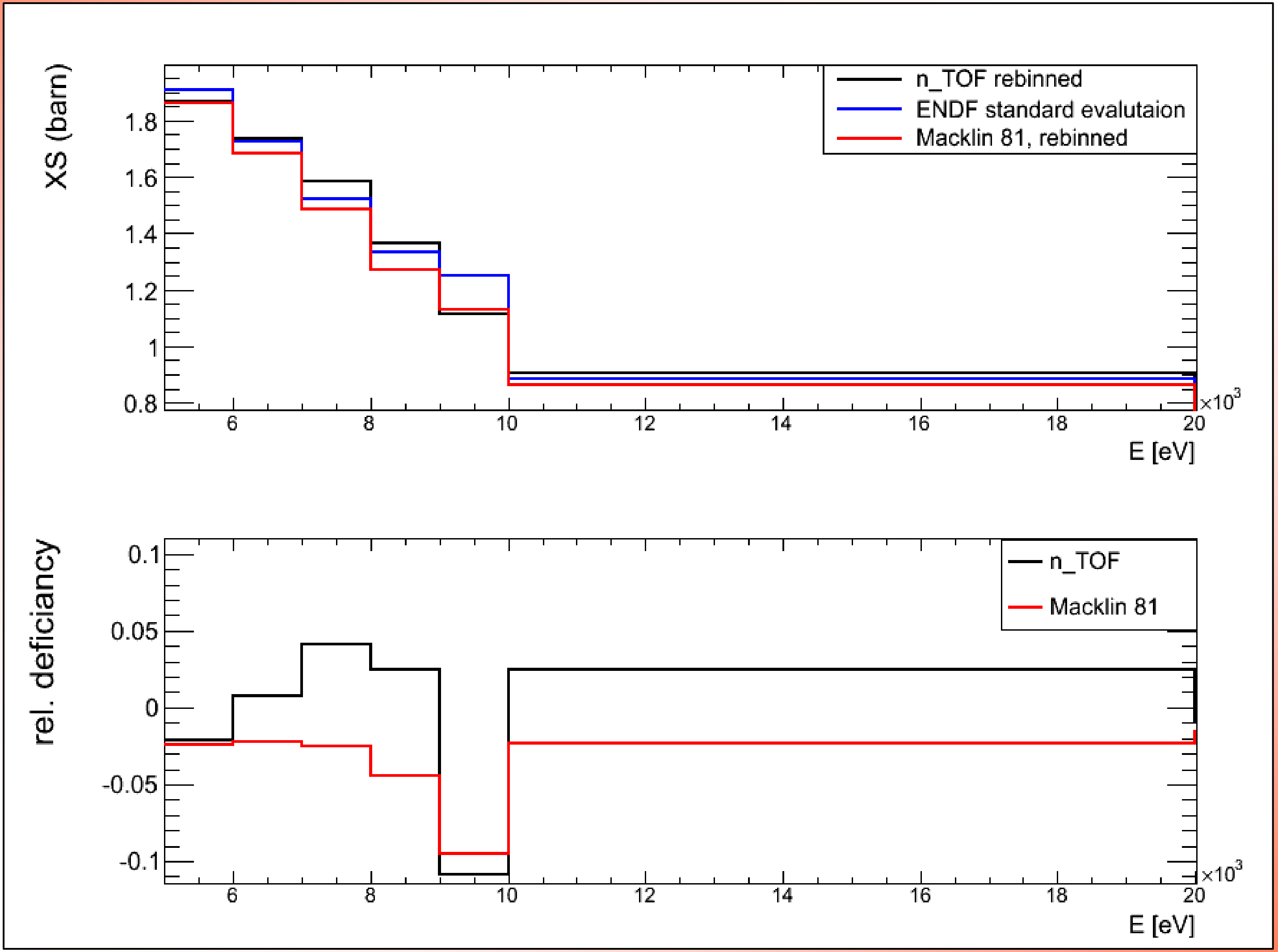

experimental




simulation

trial 3

# Results:



XS (barn)
1.8
1.6
1.4
1.2
1
0.8
n_TOF rebinned
ENDF standard evalutaion
Macklin 81, rebinned
6
8
10
12
14
16
18
20
$\times 10^3$
E [eV]
rel. deficiancy
0.1
0.05
0
-0.05
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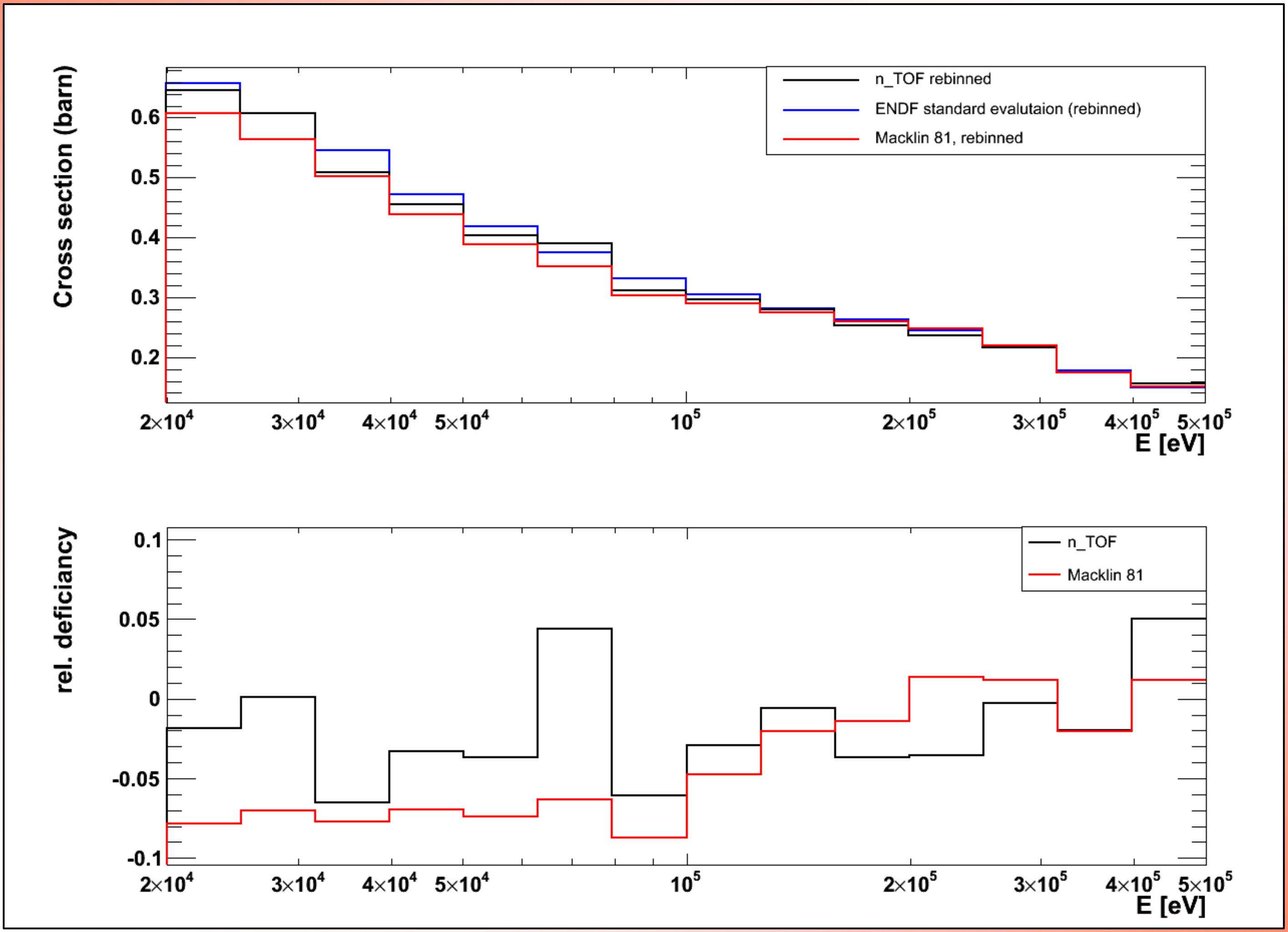
10 bpd



# Cross-sections folded with Ratynski Käppeler spectrum:

- neutron energy from 5 keV

| | |
|---|---|
| Macklin, 1981: | 537 mb |
| ENDF/B-VII: | 571 mb |
| ENDF std. eval.: | 575 mb |
| n_TOF (preliminary): | 564 ± 23 mb → 2% to ENDF std |
| | → 4.7% to Macklin |

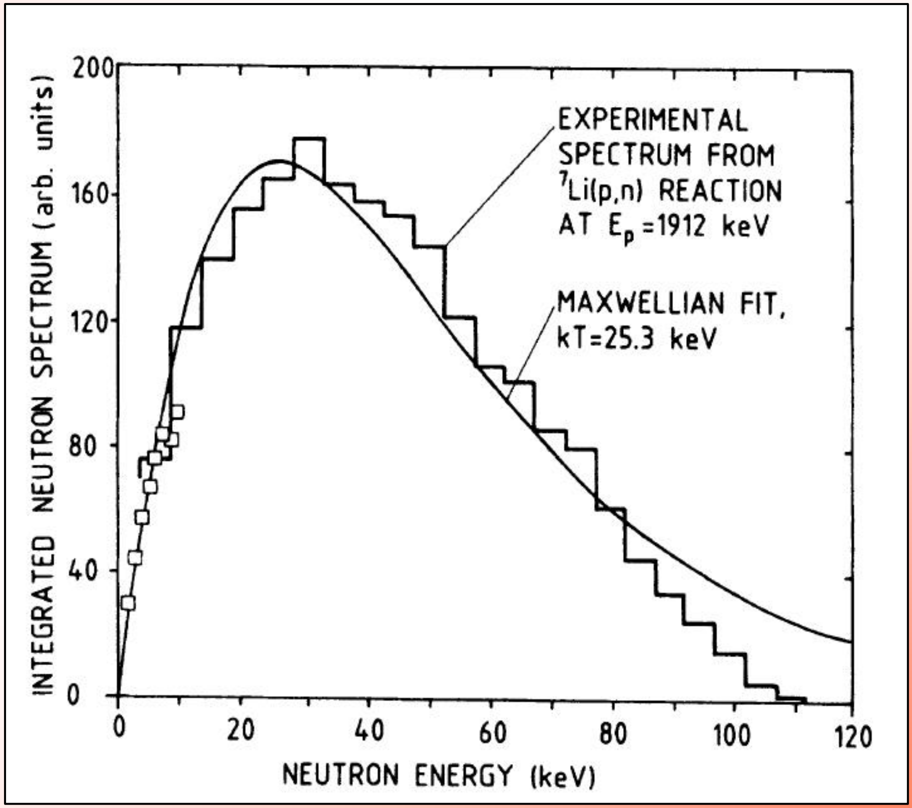
# Measurement of the $^{7}Li(p,n)$ neutron spectrum with $E_p$=1912 keV at PTB

Physikalisch Technische Bundesanstalt
Braunschweig und Berlin

In collaboration with: I. Dillmann, U. Giesen, F. Käppeler,
A. Mengoni, M. Mosconi, R. Nolte, A. Wallner

# $^7$Li(p,n)$^7$Be as neutron source

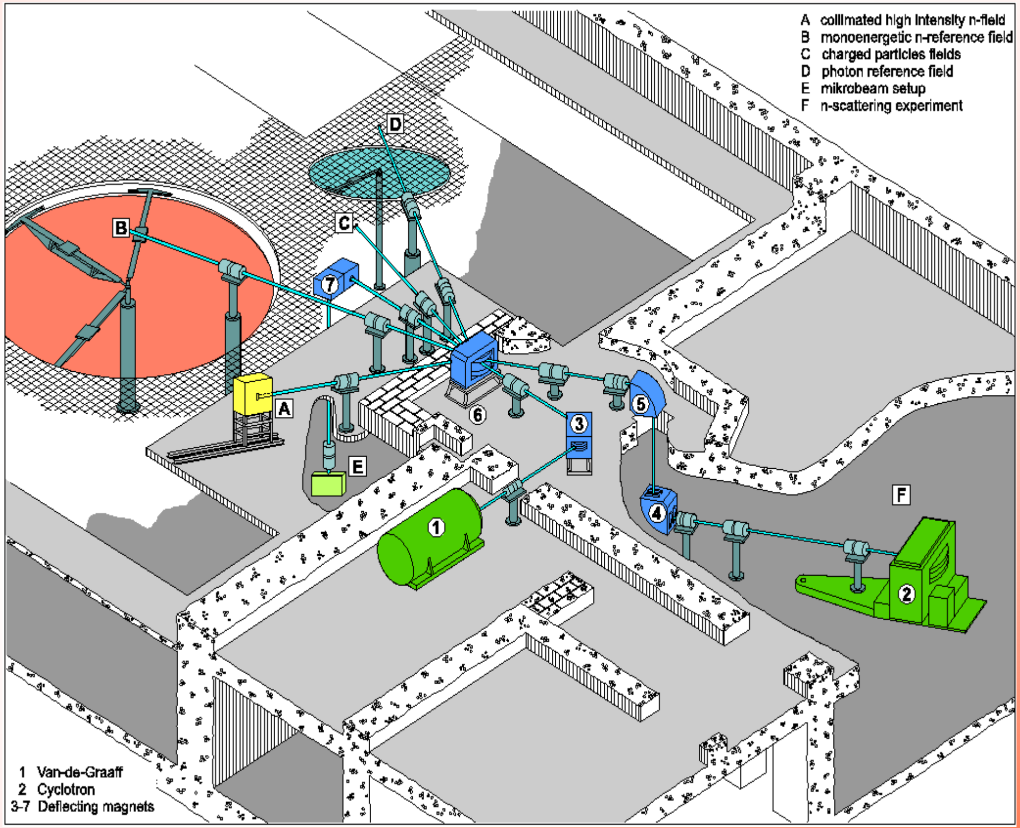
- for $E_p$=1912 keV → quasi-maxwellian energy distribution with kT=25 keV
- neutron emission: forward peaked with 120° opening angle
- Au(n,γ) cross section measured at KIT using this spectrum with 1.4% uncertainty




Ratynski and Käppeler, Phys. Rev. C **37** (1988)

# Experimental setup at PTB

- calibrated setup for angular distribution measurements
- Proton source: 3.75 MV Van de Graaff
- $E_p$=1912±1 keV
- Repetition Rate: 0.625 MHz
- Pulse width (FWHM): 3ns
- Average proton current: 0.5-0.8 μA



# Experimental setup at PTB

**Target**:

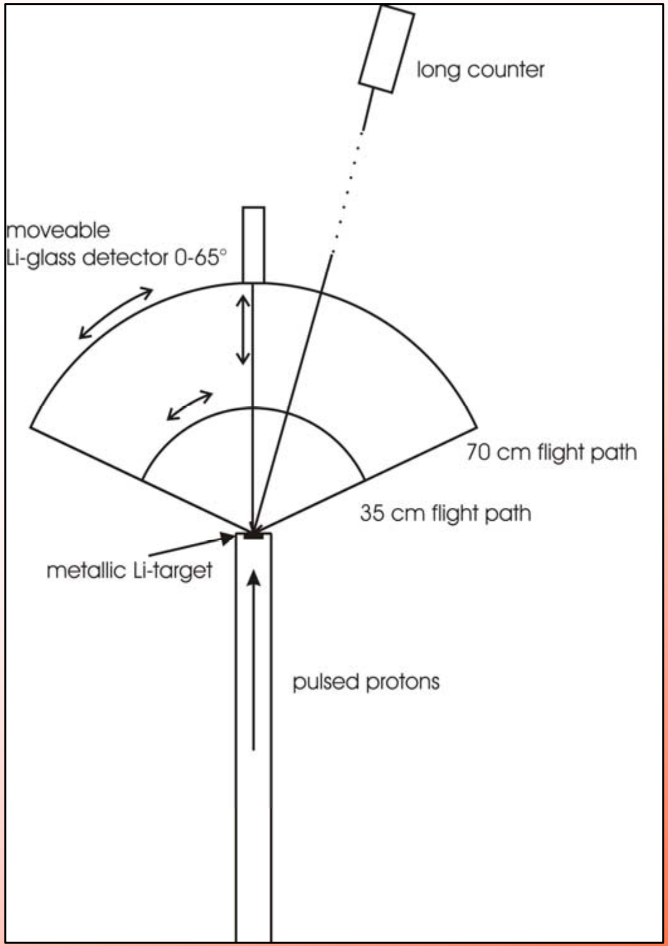
- Metallic Li evaporated on Ta
- 10 μm thickness (565 μg/cm²) → protons slowed down below reaction threshold ($E_{thres}$=1881 keV)

**Positions:**

- two flight paths: 35 cm and 70 cm
- angles: 0-65 deg, steps of 5 deg

**Detectors:**

- moveable Li-glass
- Long counter (fluence determination)



# Data reduction

- dead-time correction and background subtraction
- time-of-flight to neutron energy conversion
- detection efficiency: $^{6}Li(n,t)^{4}He$ cross-section – standard (simulation underway)
- neutron fluence: long-counter
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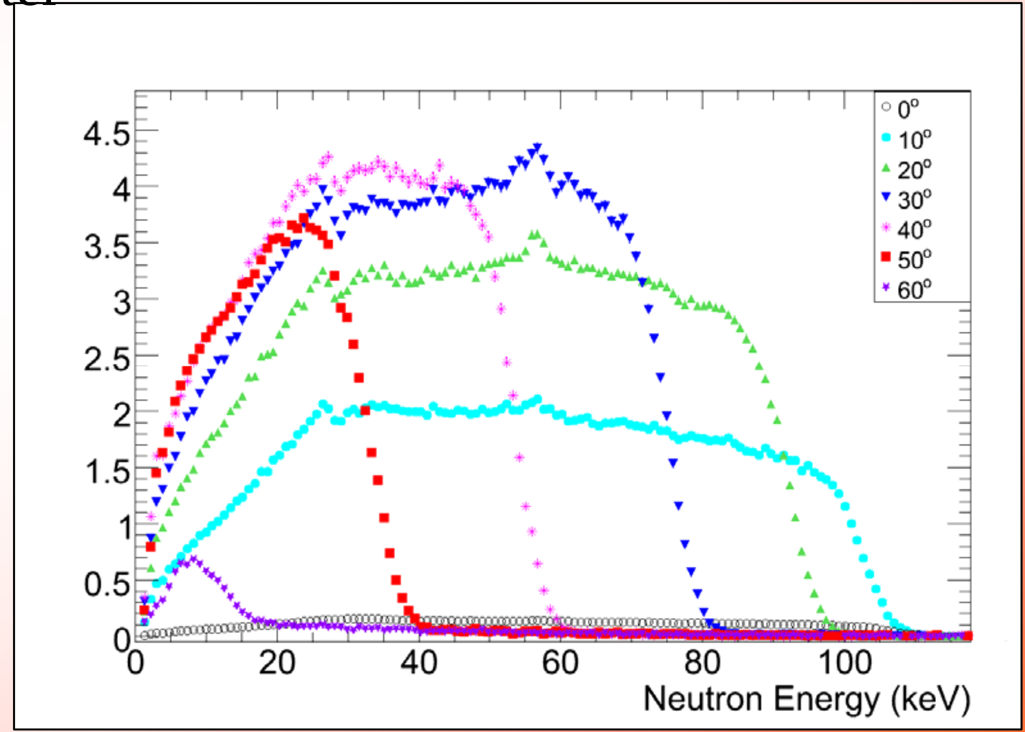


70 cm flight path

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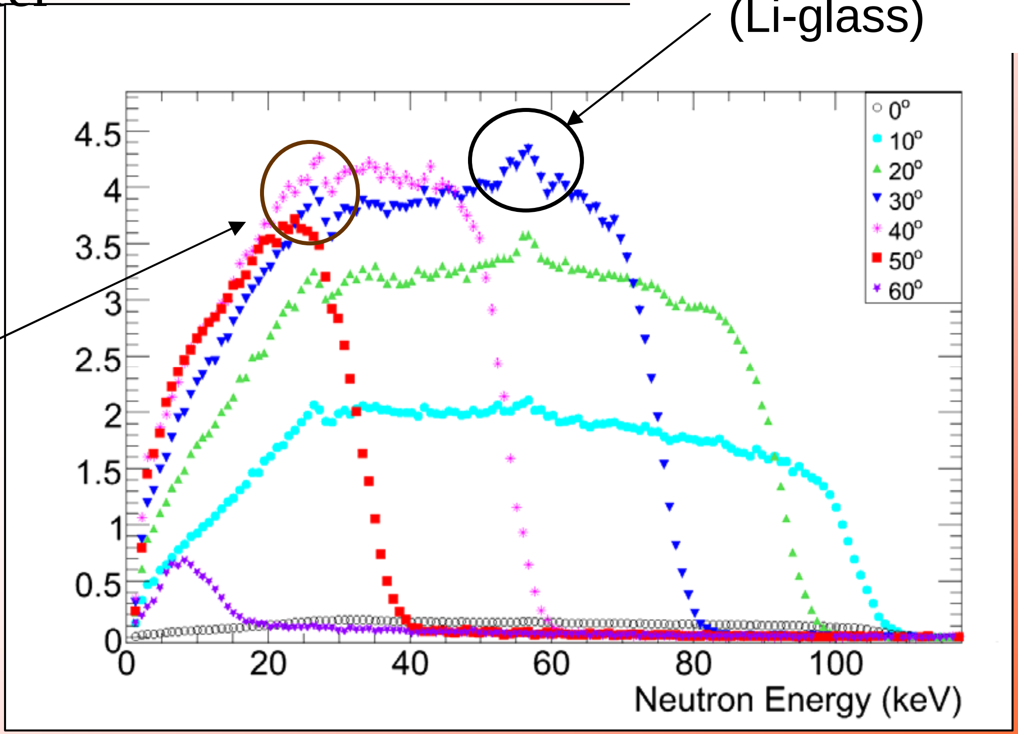
$^{28}Si$-resonance (Li-glass)

$^{56}Fe$-resonance (detector cover)




70 cm flight path

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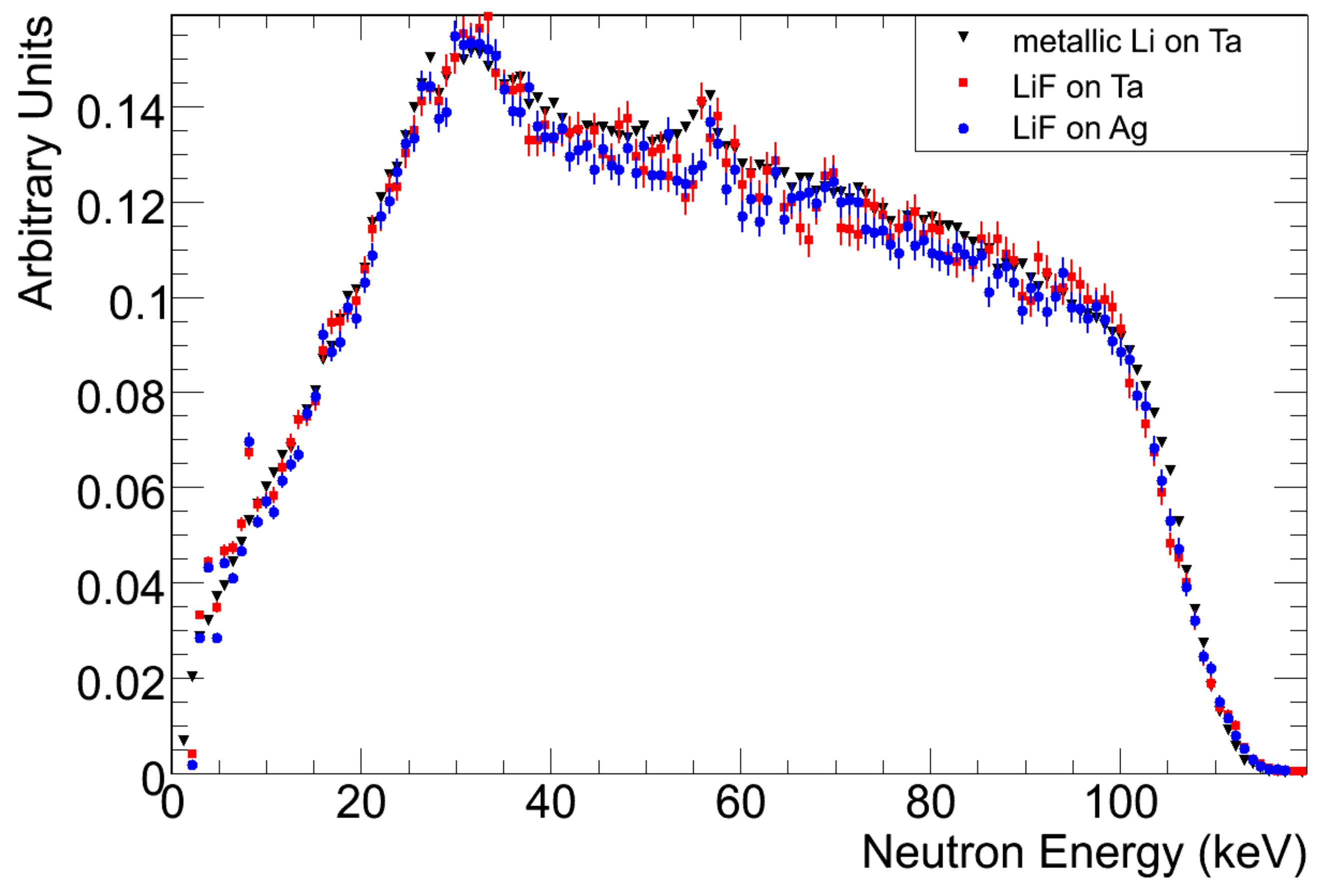
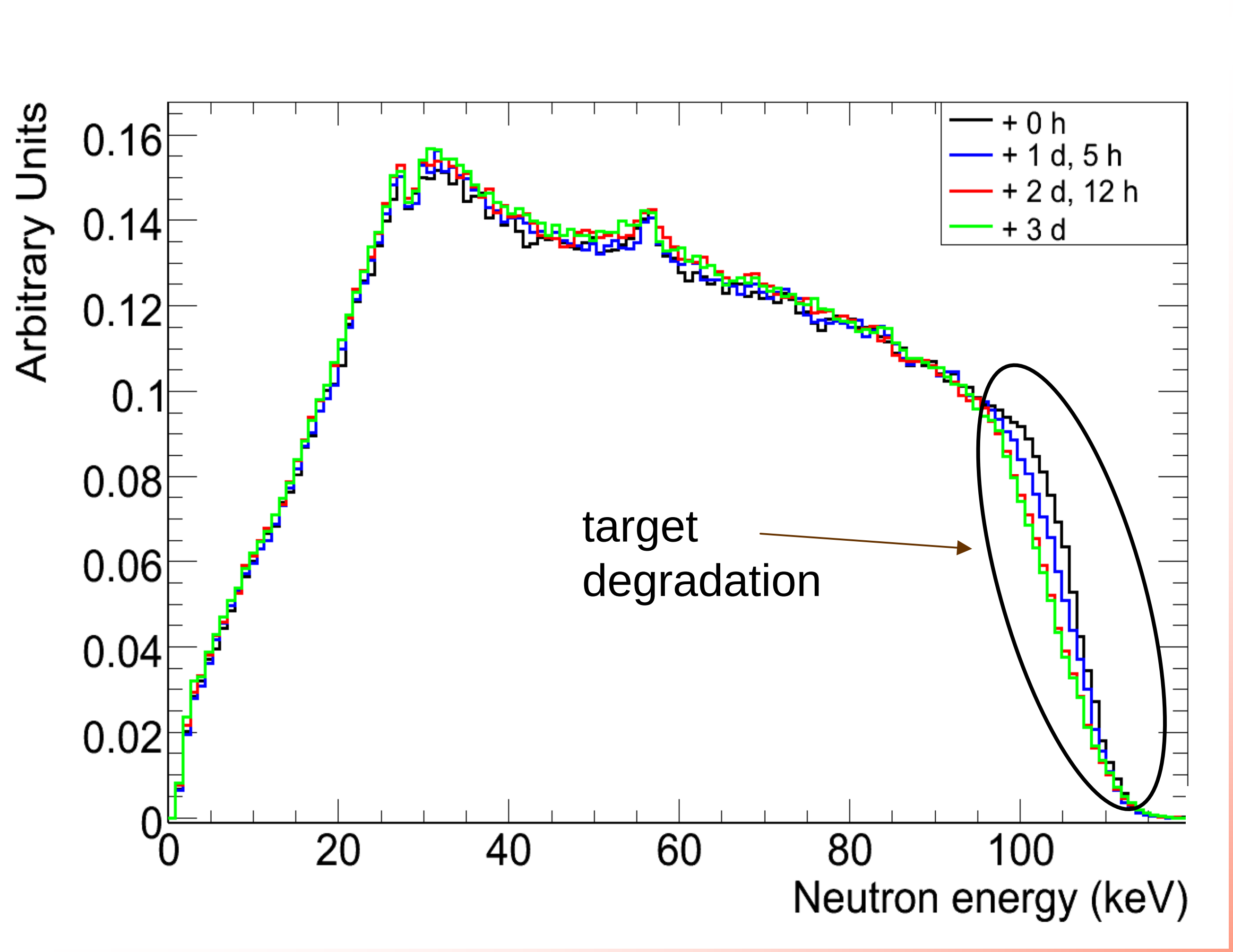
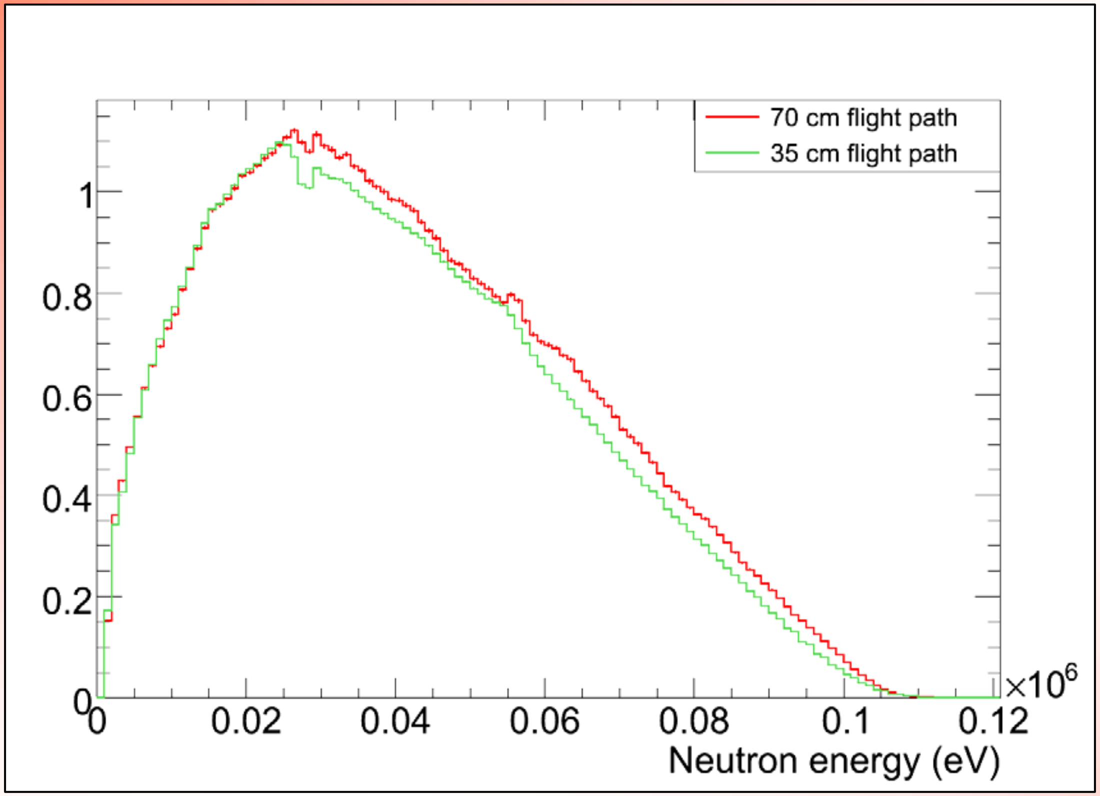
# Reference Runs: different targets



# Reference Runs: target stability



# Summed spectra




- less high energy neutrons for 35 cm flight path
- reason still unclear, simulations of setup underway
- effect also visible at consecutive runs (→ probably not target degradation)
- overlap in solid angle for 35 cm

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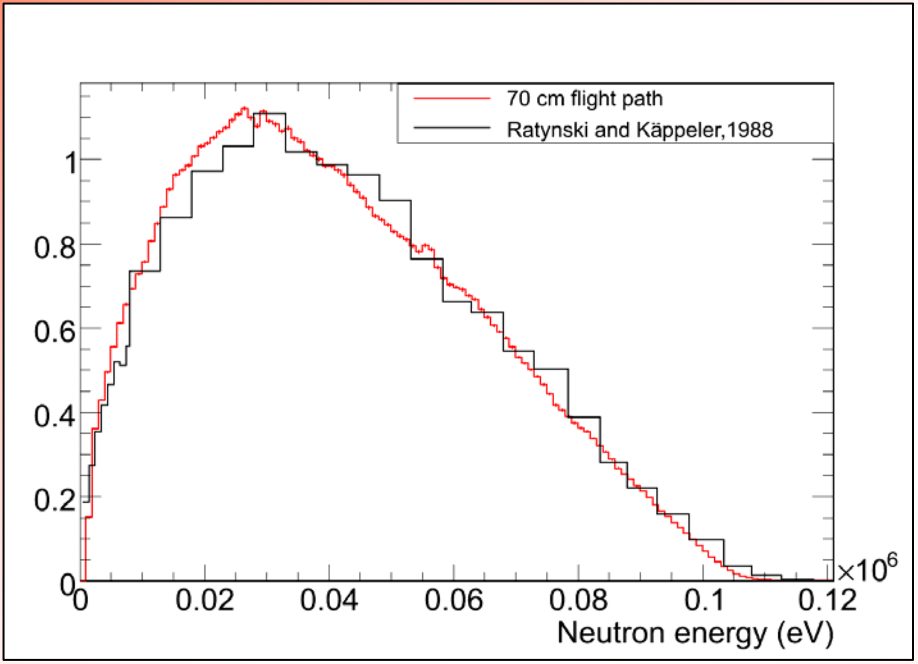


• W. Ratynski and F. Käppeler, Phys. Rev. C **37**, 595 (1988)

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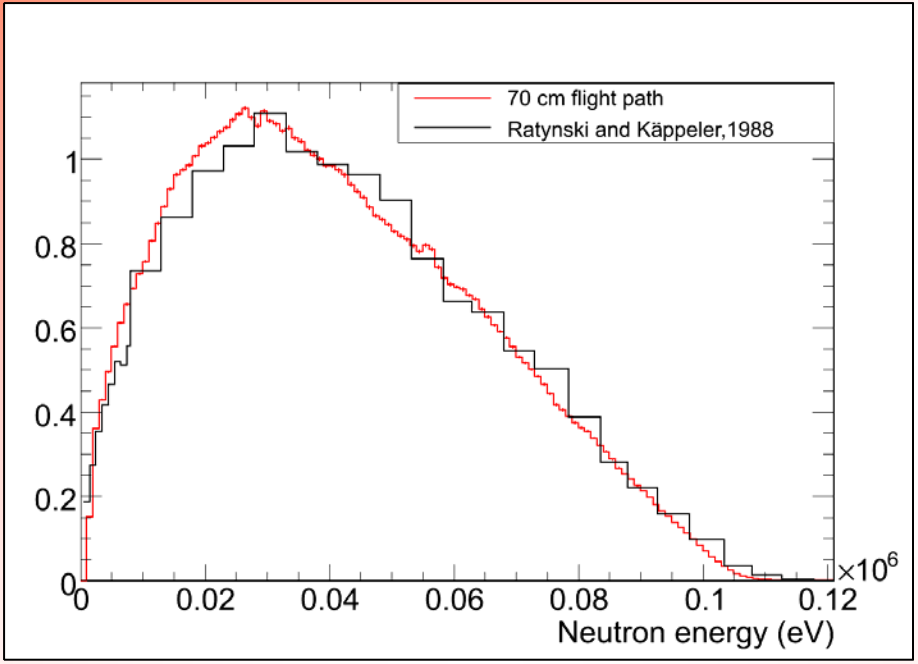
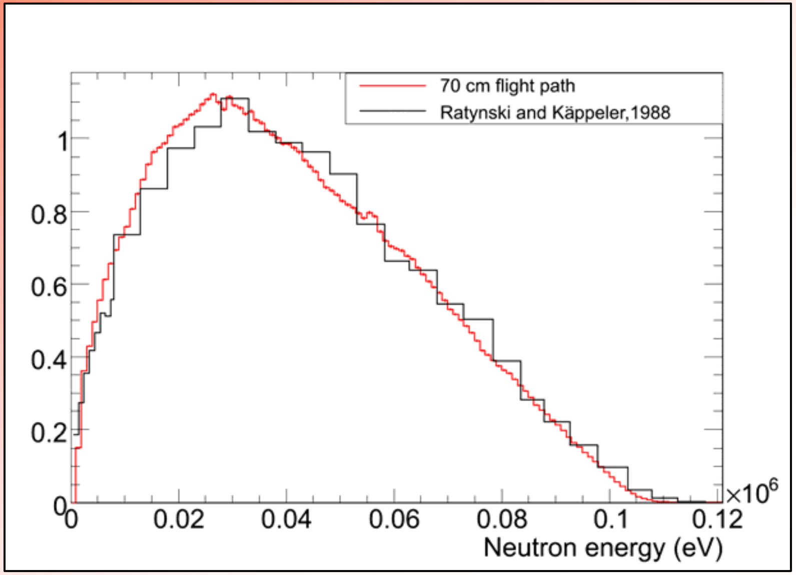
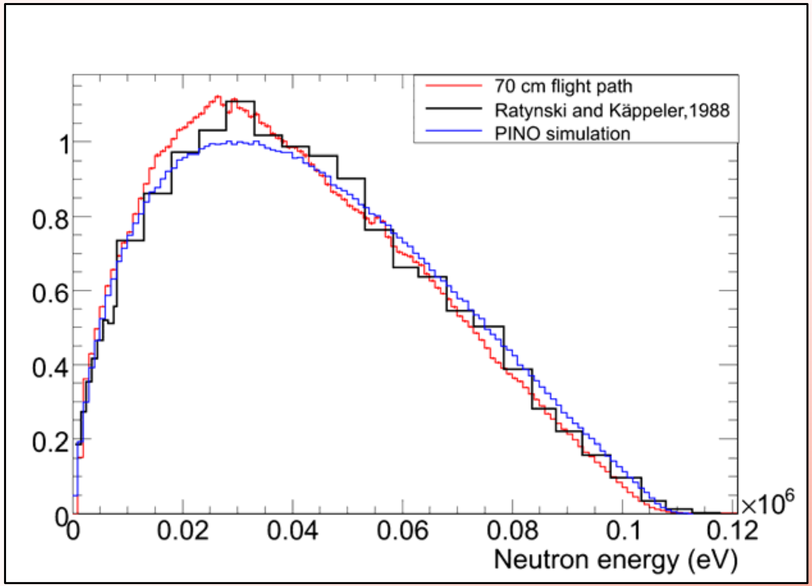



- $^{197}$Au(n,γ) (ENDF-B7 library)
- 633 mb for Ratynski and Käppeler spectrum
- 630 mb for PTB spectrum
- only 0.5 % difference !

- W. Ratynski and F. Käppeler, Phys. Rev. C **37**, 595 (1988)

# Summed spectra




- W. Ratynski and F. Käppeler, Phys. Rev. C **37**, 595 (1988)

- PINO- a tool for simulating neutron spectra resulting from the $^{7}Li(p,n)$ reaction, R. Reifarth et al. , Nucl. Instr. Meth. A 608, 139 (2009)

# Conclusions

**n_TOF measurement**

- preliminary results of Au(n,γ) cross section measured at n_TOF more in favour of the ENDF standard evaluation,
- Uncertainty in n_TOF measurement of 5% could be reduced (check with different detection thresholds)

**PTB measurement**

- $^{7}$Li(p,n) spectrum measured at PTB shows small differences, but effect on averaged Au cross section only 0.5%, since cross section is very smooth in this energy region.
- MC simulations of exp. setup at PTB underway → changes in results are still possible