^{197}Au(n,γ) – towards a standard for stellar nucleosynthesis

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universität wien

PTB Physikalisch Technische Bundesanstalt
Braunschweig und Berlin

n_TOF

EFNUDAT
European Facilities for Nuclear Data Measurements

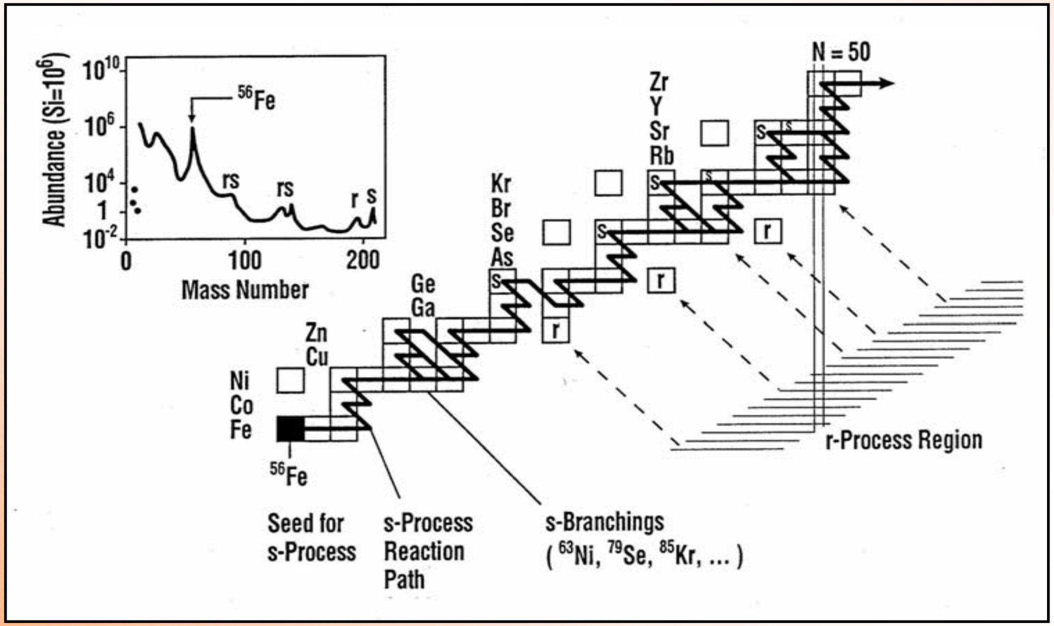
Outline

- Introduction
- Experiments
    1) at PTB
    2) at n_TOF
- Results and Conclusions

Introduction: nucleosynthesis beyond Fe

- Dominantly via neutron capture reactions

slow neutron capture (s-process) rapid neutron capture (r-process)



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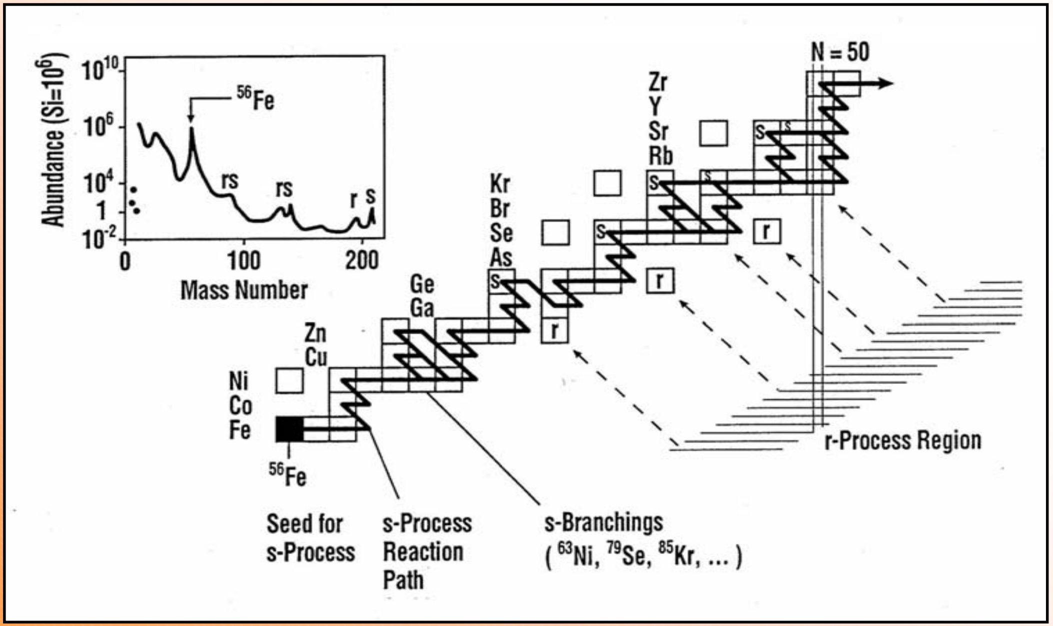


Nuclear physics input s-process:

- β half lives
- Maxwellian averaged cross section (MACS):

$$<\sigma>_{kT} = \frac{2}{\sqrt{\pi}} \frac{\int \sigma(E_n) E_n \exp(-E_n / kT) dE_n}{\int E_n \exp(-E_n / kT) dE_n}$$

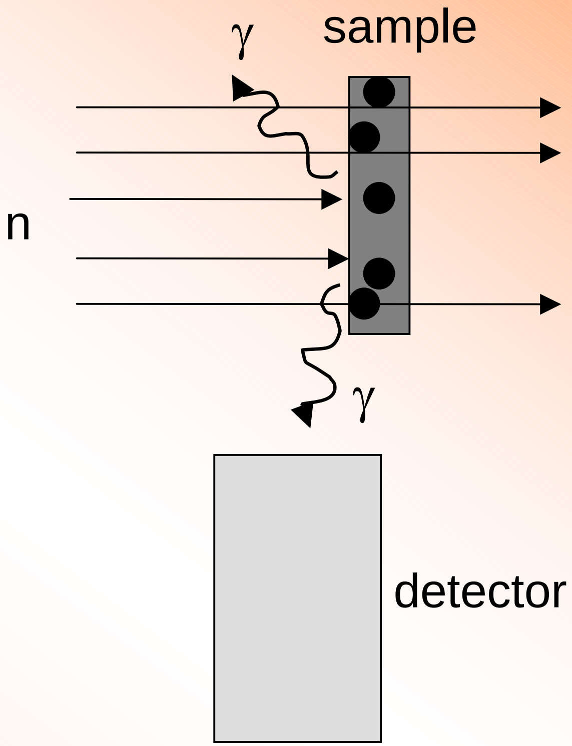
Introduction: measuring (n,γ) cross sections

- **Time-of-flight technique**

pulsed, white neutron beam

measure energy dependent cross section

calculate MACS



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- **Activation technique**

create quasi Maxwellian spectrum

measure MACS

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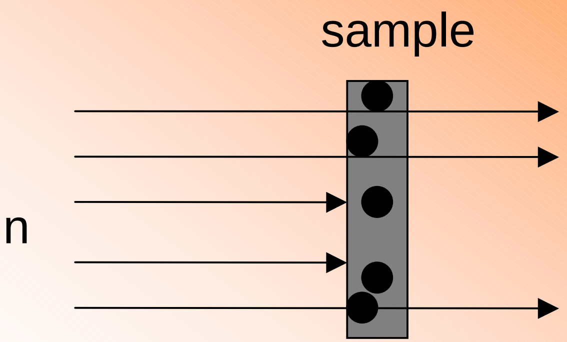

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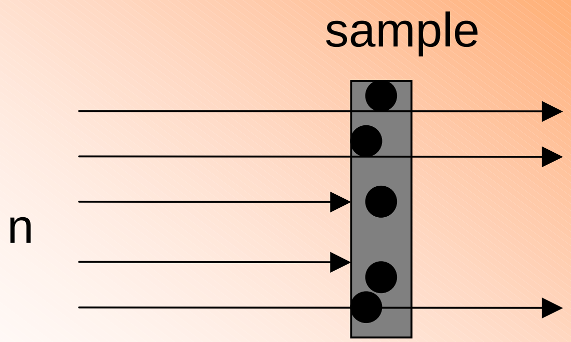

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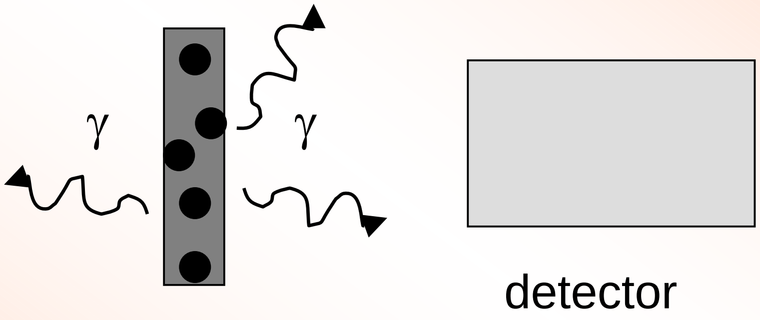
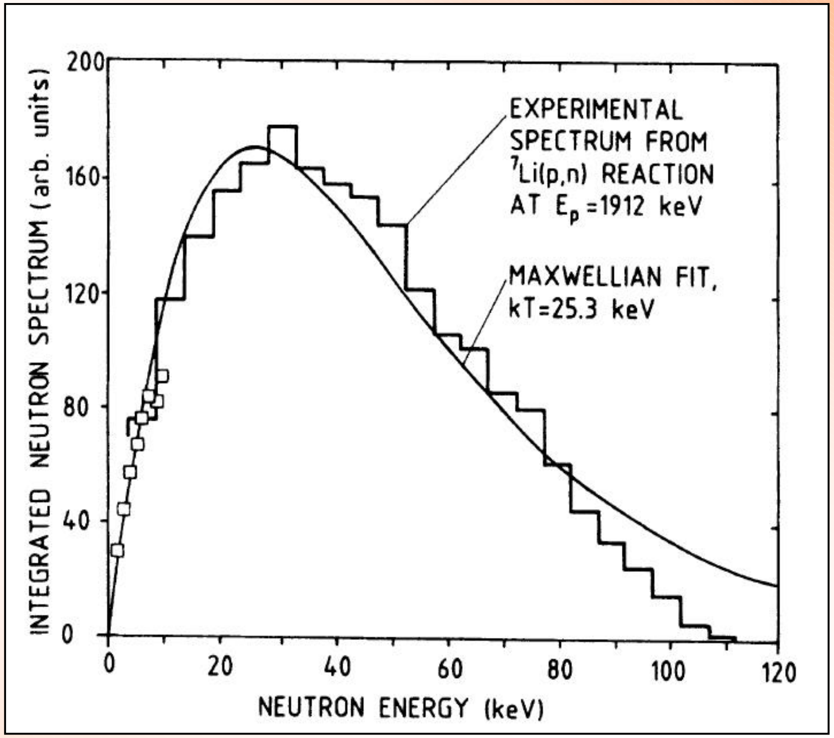


Introduction: the story of Au(n,γ)

- Measurement of Au(n,γ) MACS at KIT (*Ratynski and Käppeler, Phys. Rev. C **37**, 1988*)
- Quasi-maxwellian neutron spectrum at kT=25 keV produced by ^{7}Li(p,n)^{7}Be at E_p=1912 keV



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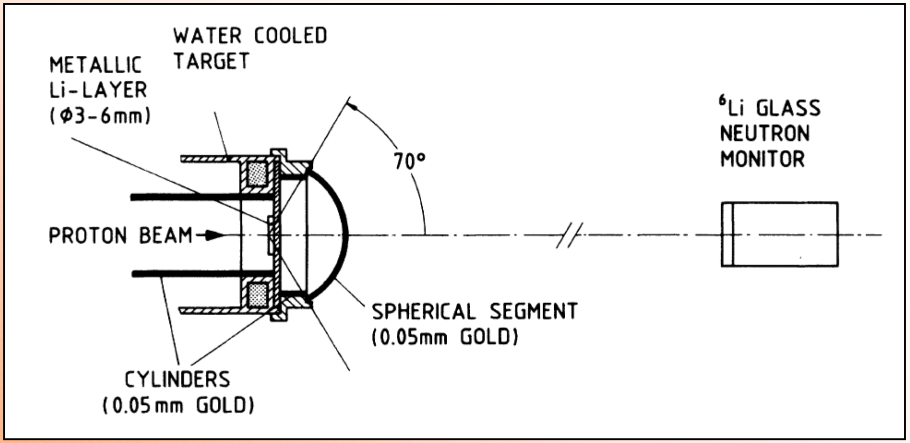
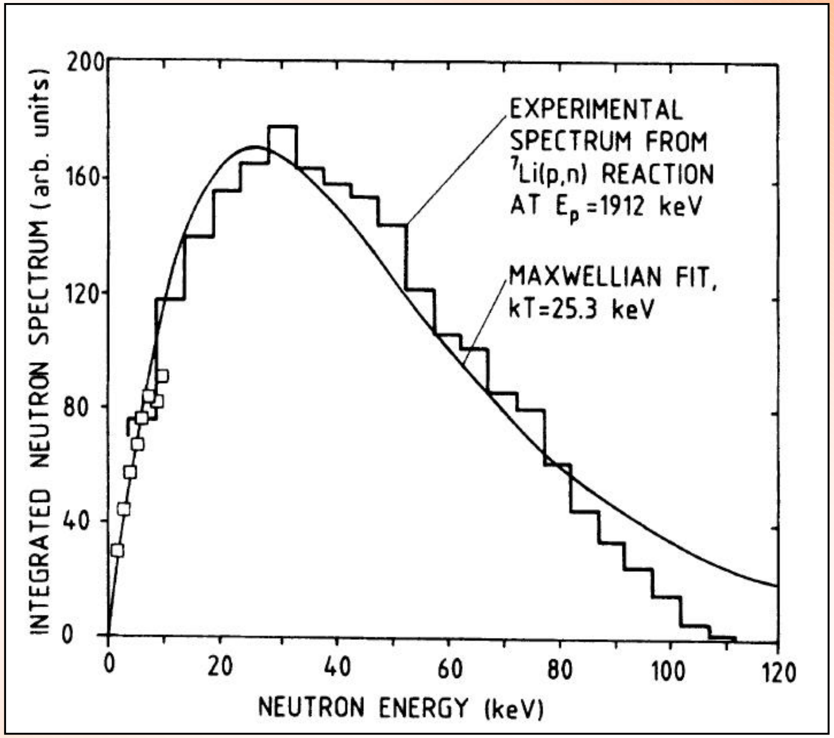


- Neutron emission forward peaked
- Neutron fluence determination by measuring ^{7}Be activity



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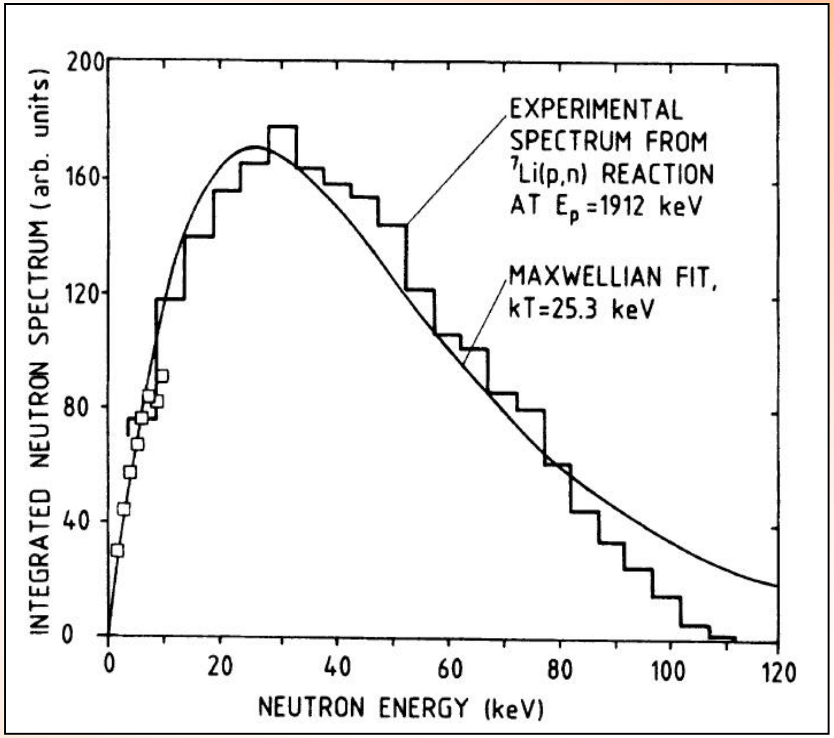
Input for transforming experimental cross section to MACS:

- energy dependence of cross section (from Macklin *et al.* 1982)
- neutron spectrum



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Input for transforming
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MACS

$$\sigma_{MACS}(30\text{keV}) = 582\ \text{mb} \pm 1.5\%$$

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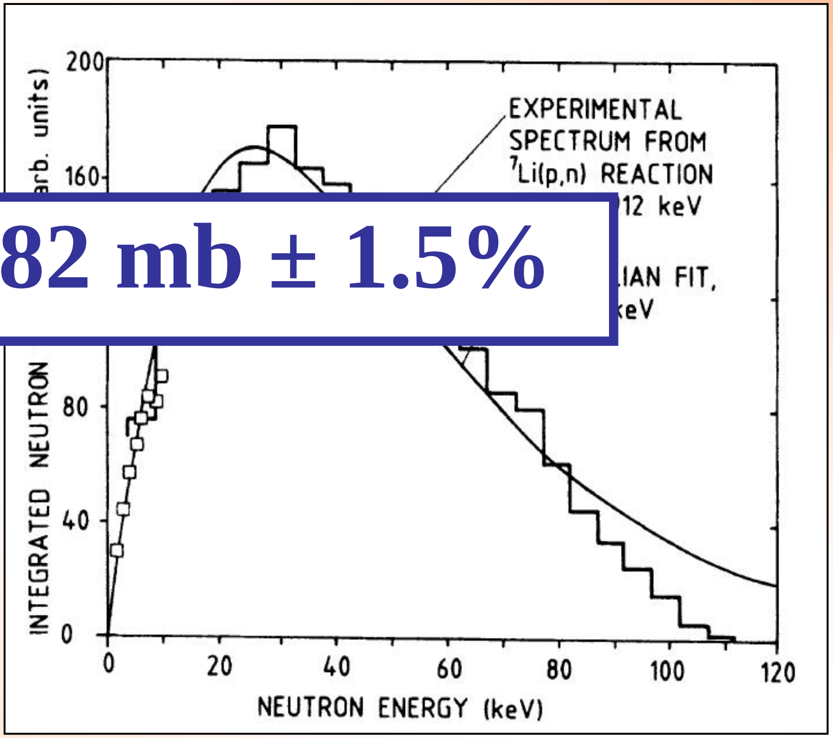
• neutron spectrum



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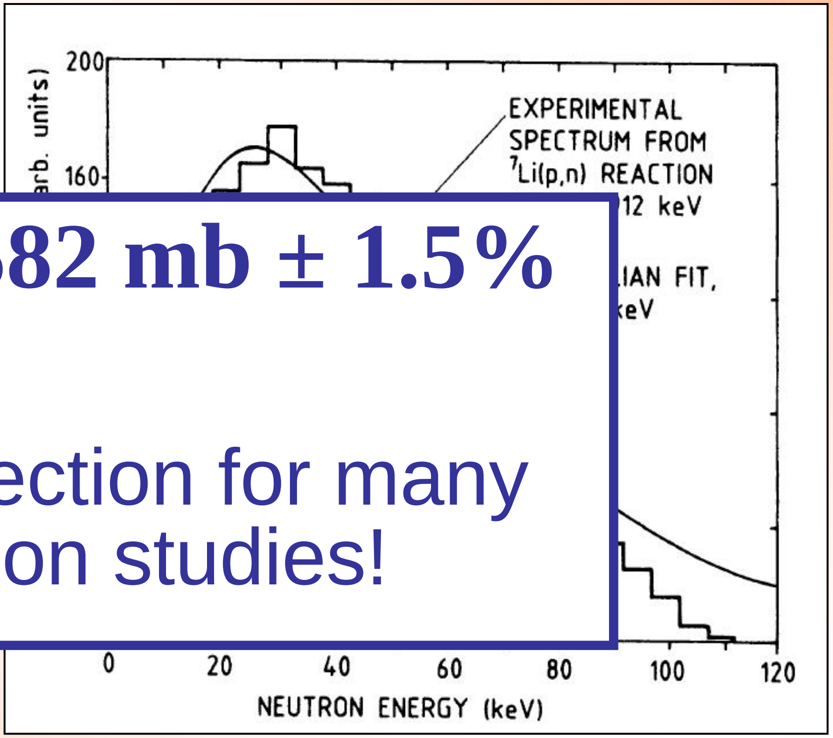
• neutr



σ_{MACS}(30keV) = 582 mb ± 1.5%

Reference cross section for many other activation studies!

Introduction: the story of Au(n,γ)

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- recommended standard for thermal and from 200 keV – 2.8 MeV, standard evaluation starts at 5 keV

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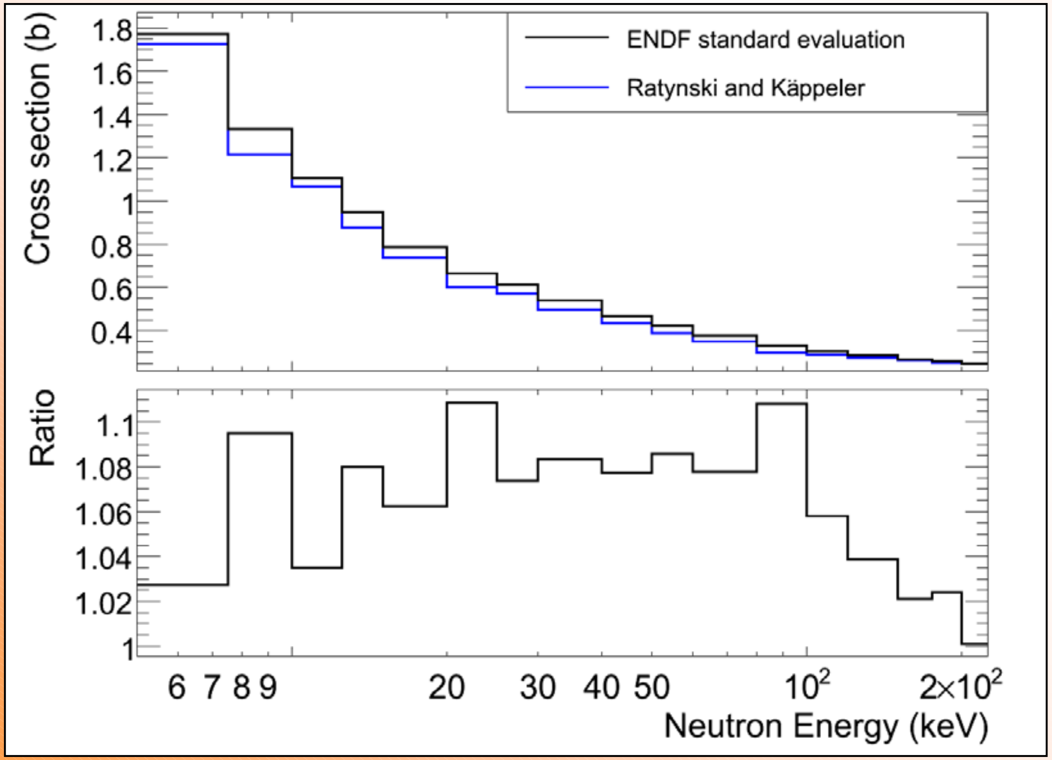

Discrepancy up to ~10% between IAEA standard evaluation (ENDF) and Ratynski evaluation based on KIT measurement!!!

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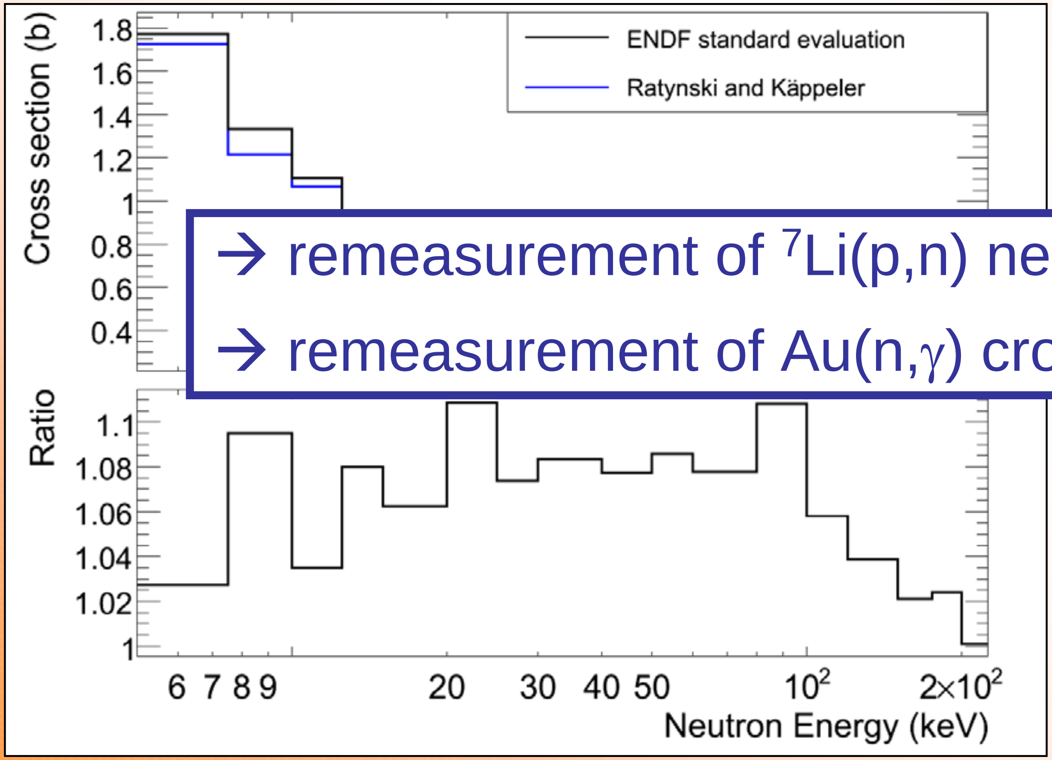


→ remeasurement of ^{7}Li(p,n) neutron spectrum at PTB

→ remeasurement of Au(n,γ) cross section at n_TOF

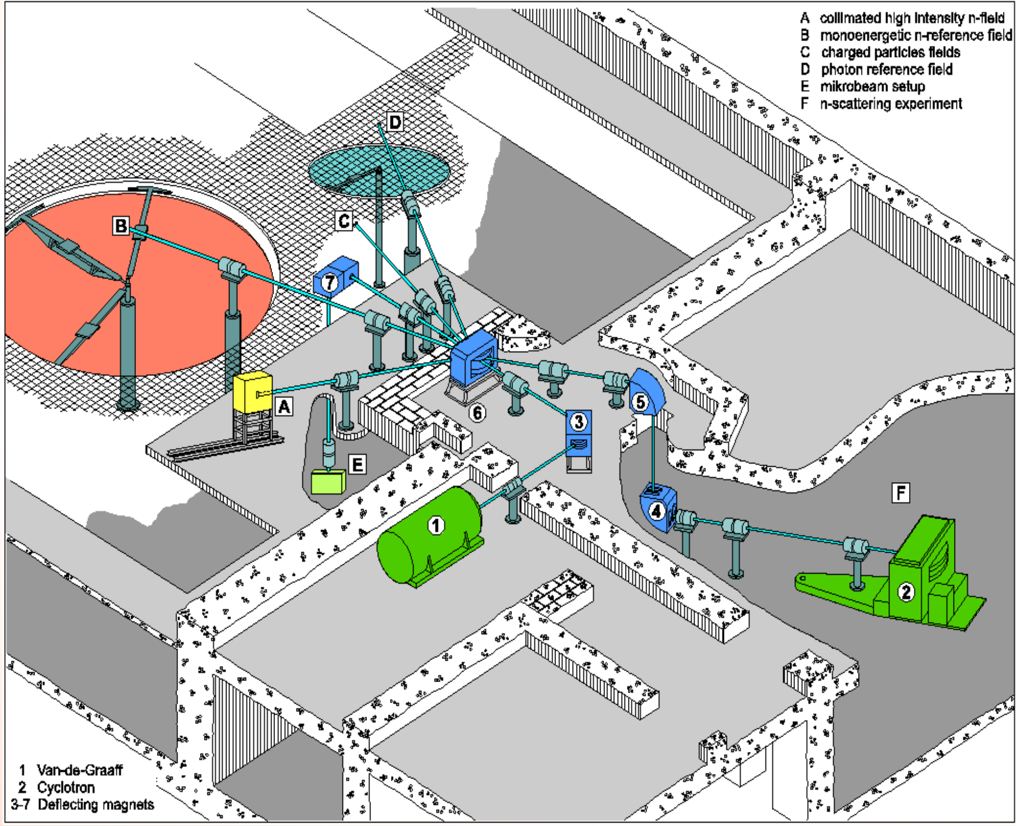
Discrepancy up to ~10% between IAEA standard

measurement!!!

Part I: Measurement of the ^{7}Li(p,n) neutron spectrum at PTB

^{7}Li(p,n) at PTB: experimental Setup

- 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): 3 ns
- average proton current: 0.5-0.8 μA



^{7}Li(p,n) at PTB: experimental Setup

Target:

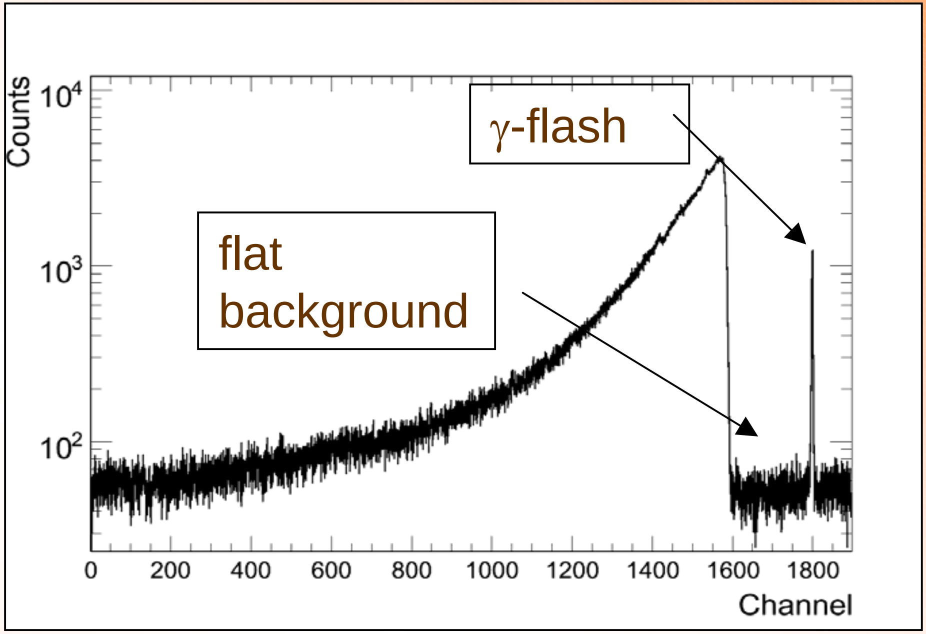
- metallic Li evaporated on Ta
- 10 μm thickness (565 μg/cm²)

Positions:

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

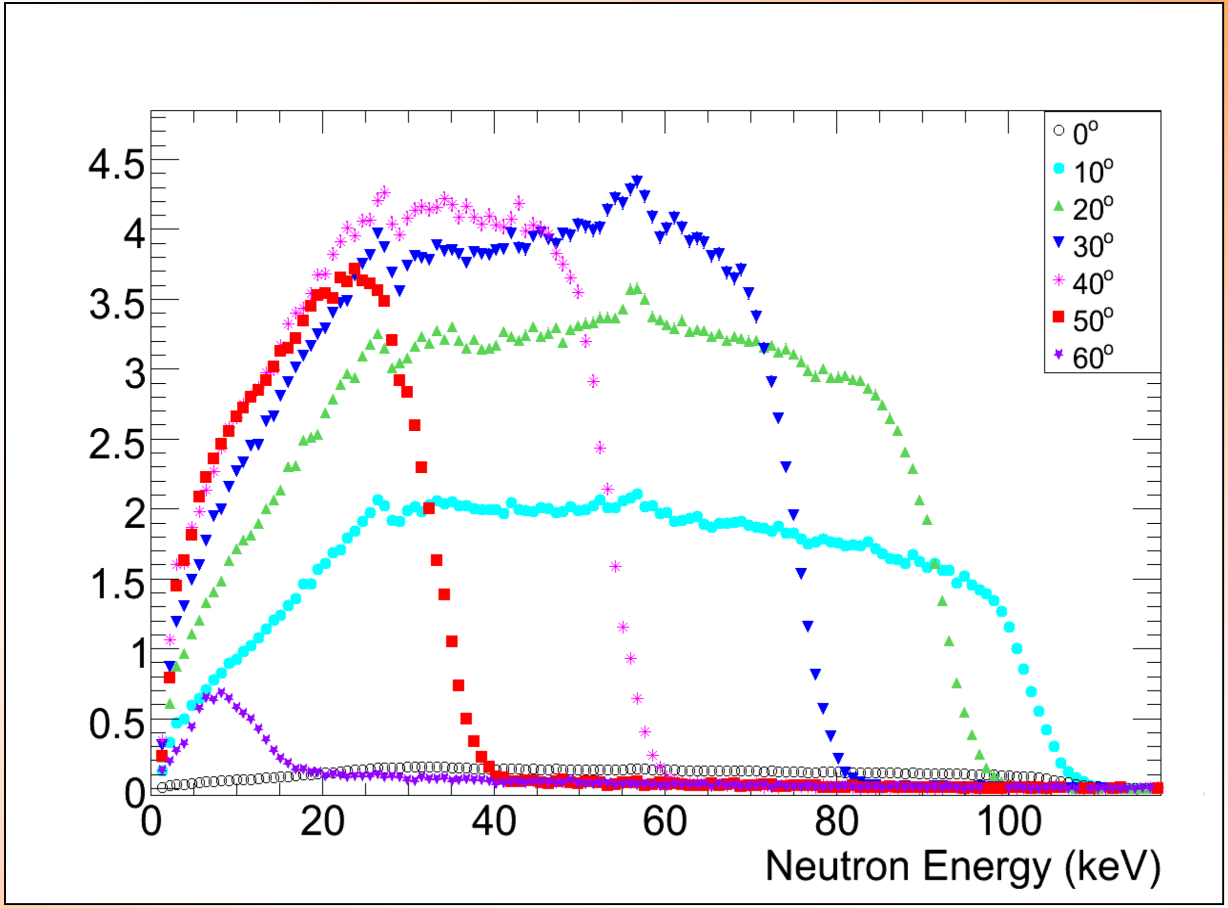
Detectors:

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

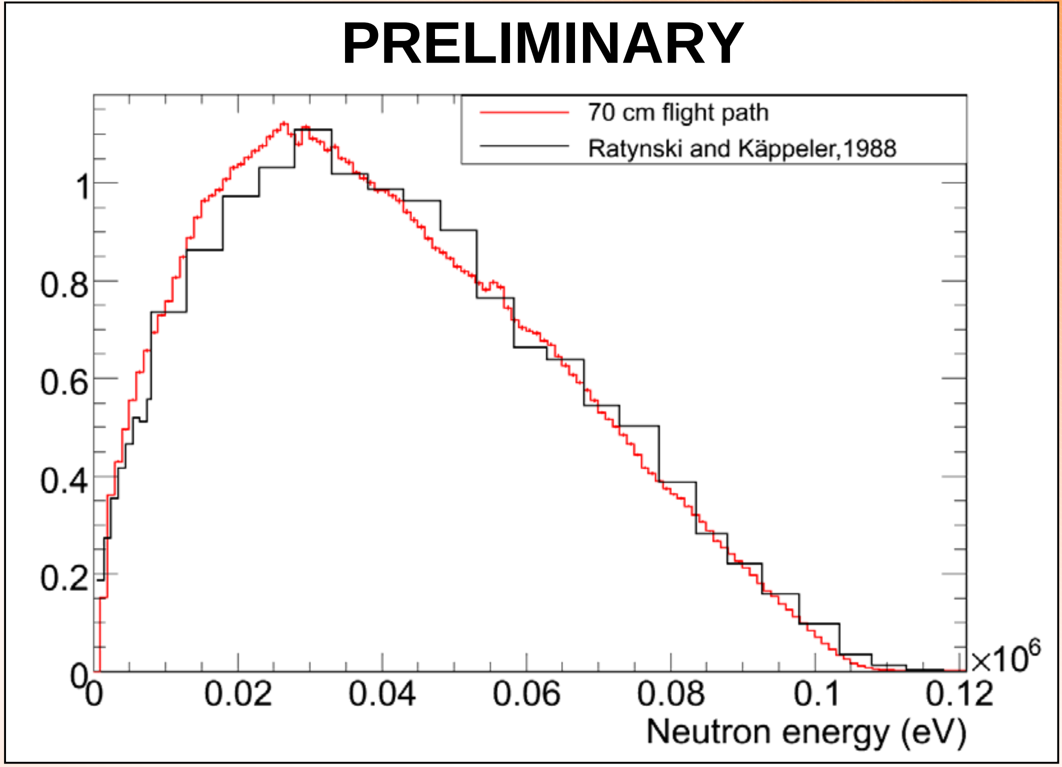


^{7}Li(p,n) at PTB: angular spectra

- angular spectra, 70 cm flight-path (weighted for solid angle)
- structures due to Si resonance (~60 keV) and Fe resonance (~30 keV, canning)



^{7}Li(p,n) at PTB: integrated spectra

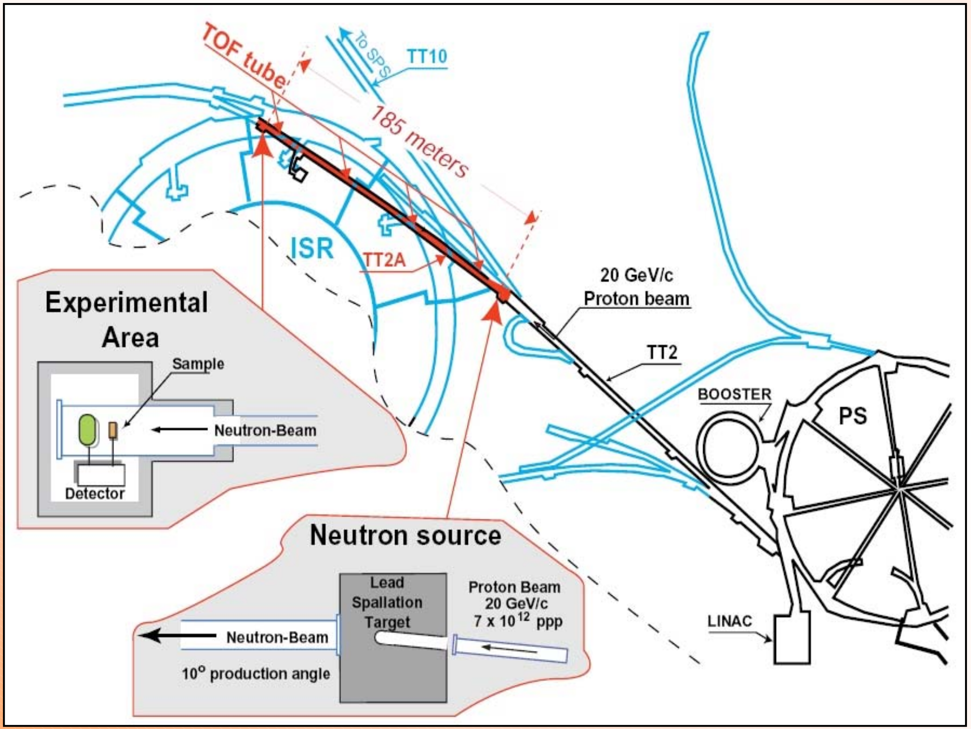


- 70 cm vs. Ratynski and Käppeler → small differences but they cannot explain discrepancies to ENDF

- underway: detailed MC simulations of experimental setup

Part II: Measurement of the Au(n,γ) cross section at n_TOF/CERN

Au(n,γ) at n_TOF: the n_TOF/CERN facility



20 GeV/c protons on Pb-target

Pulse width: 7 ns

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

→ 1.2×10^{6} neutrons/pulse @ 185 m

Flight path: 185 m

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

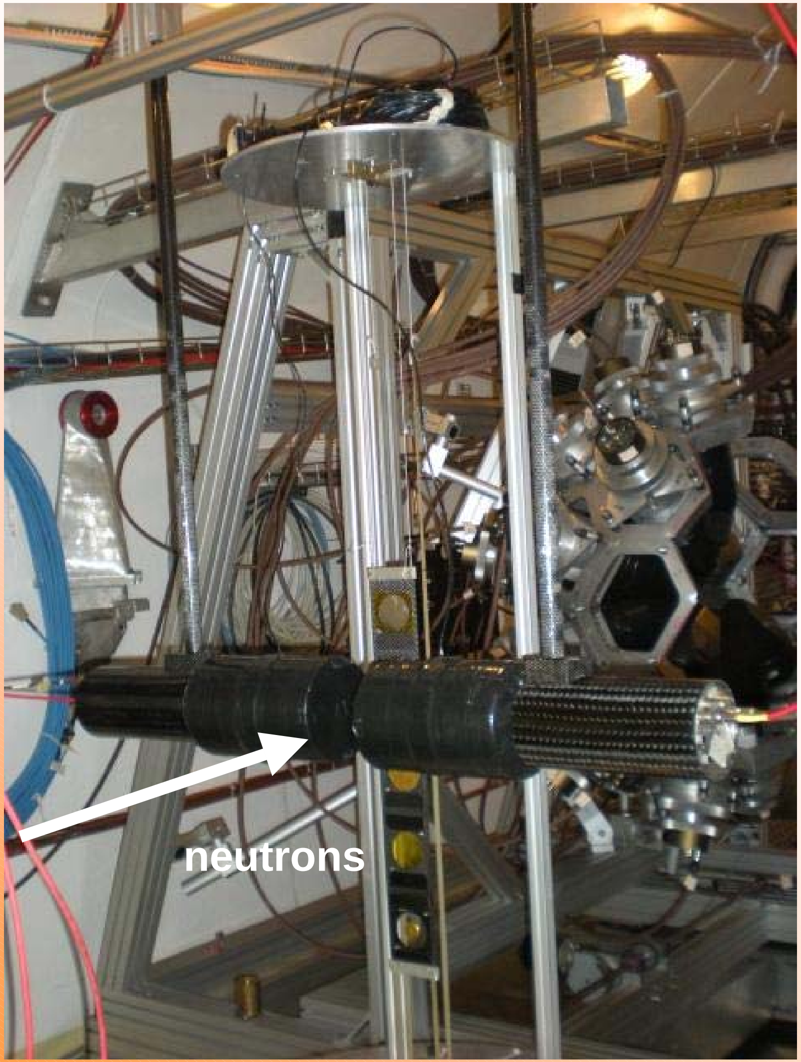
Beam size at capture setup: Ø~4 cm

Energy resolution $\Delta E/E$:

3×10^{-4} @ 1 eV – 4.2×10^{-3} @ 1 MeV

www.cern.ch/ntof

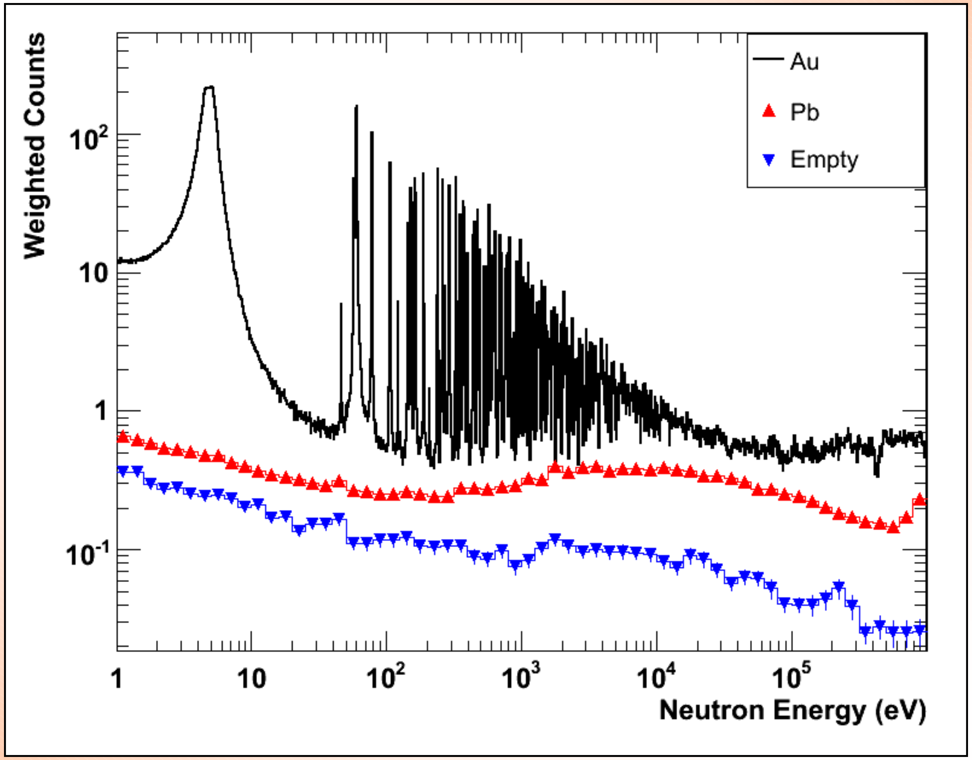
Au(n,γ) at n_TOF: the n_TOF/CERN facility



2 setups for capture measurements:

- total absorption calorimeter: 4π geometry (ε~100%)
- **two C_6D_6 detectors** (optimized for low neutron sensitivity [$\varepsilon_n/\varepsilon_\gamma<4\cdot10^{-5}$])

Au(n,γ) at n_TOF



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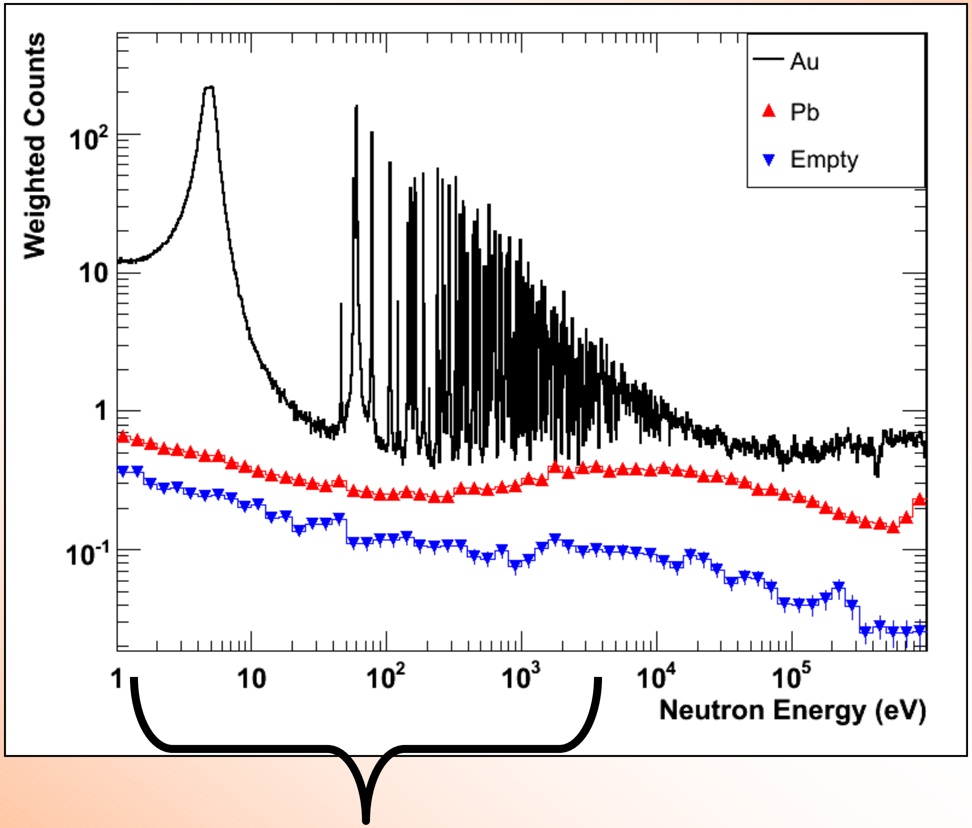

C. Massimi, and the n_TOF collaboration, Phys Rev C81 (2010)

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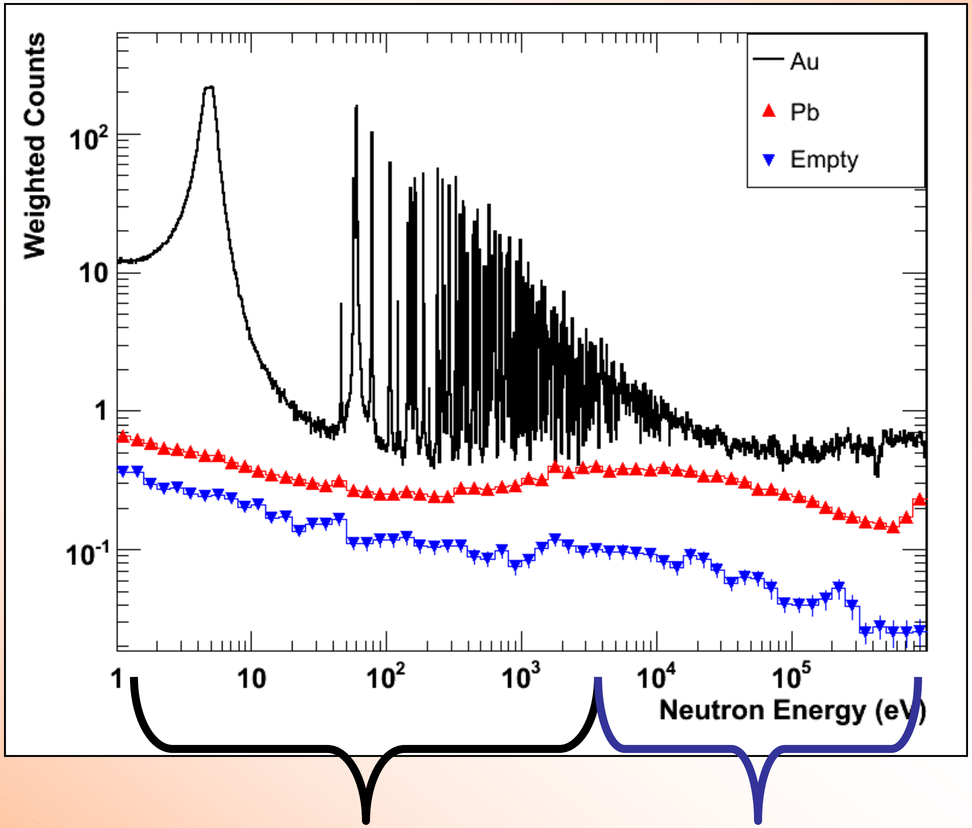

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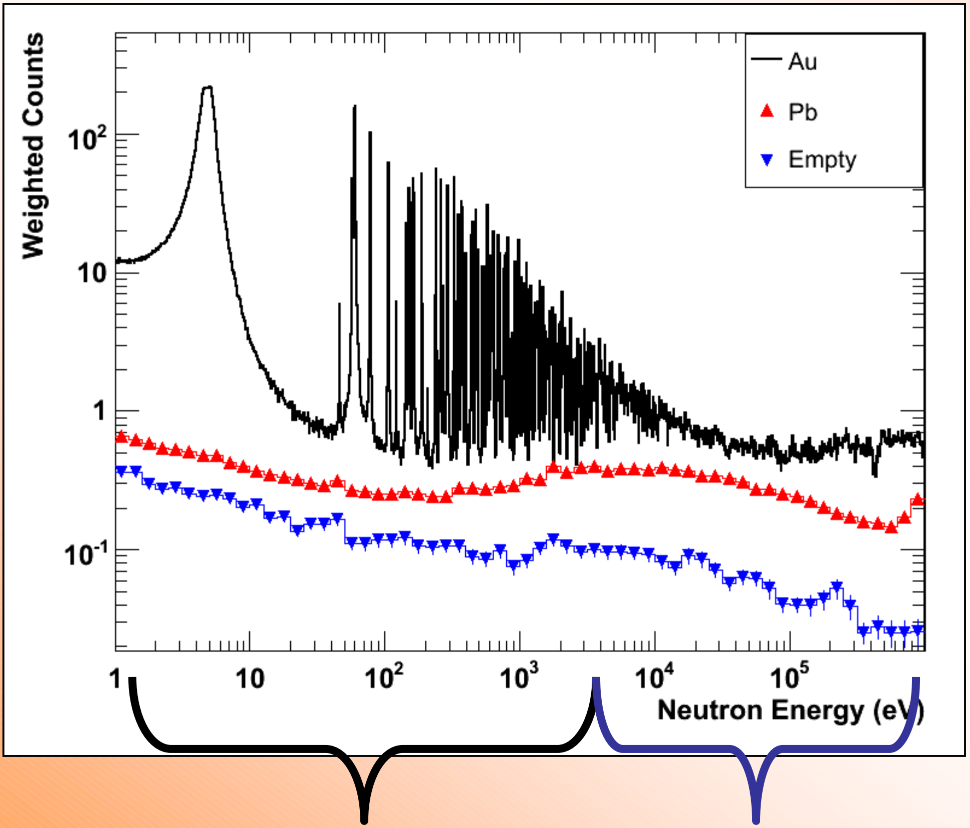
THIS TALK

Au(n,γ) at n_TOF: data reduction



C. Massimi, and the n_TOF collaboration, Phys Rev C81 (2010)

THIS TALK

From counts to capture yield:

$$Y_R = \frac{C-B}{\varepsilon \cdot f \cdot \Phi}$$

C... countrate

B....background

ε.....efficiency (low efficiency systems: pulse height weighting technique)

Φ....neutron flux (^{235}U fission chamber)

f.....corrections for sample size (e.g. multiple scattering, beam interception....)

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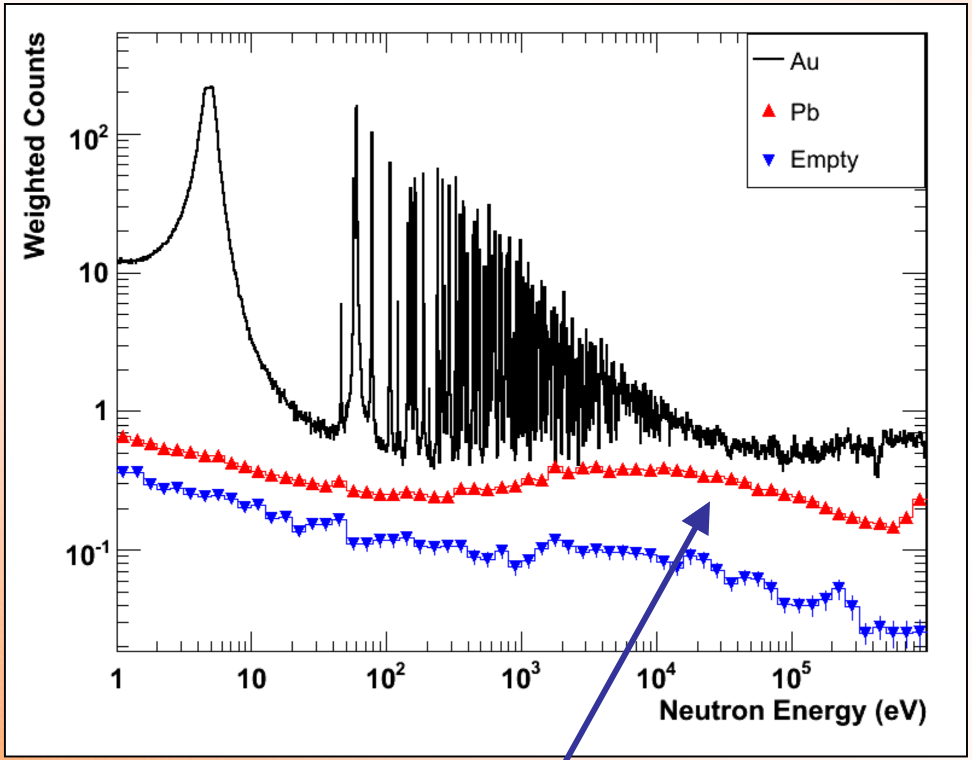

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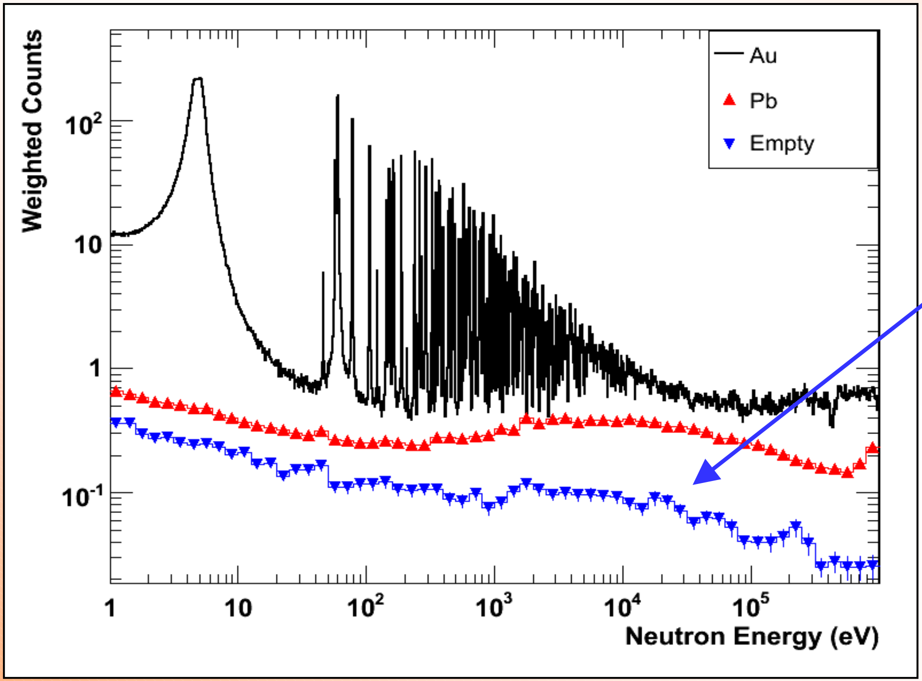
low countrate → proper background subtraction essential!

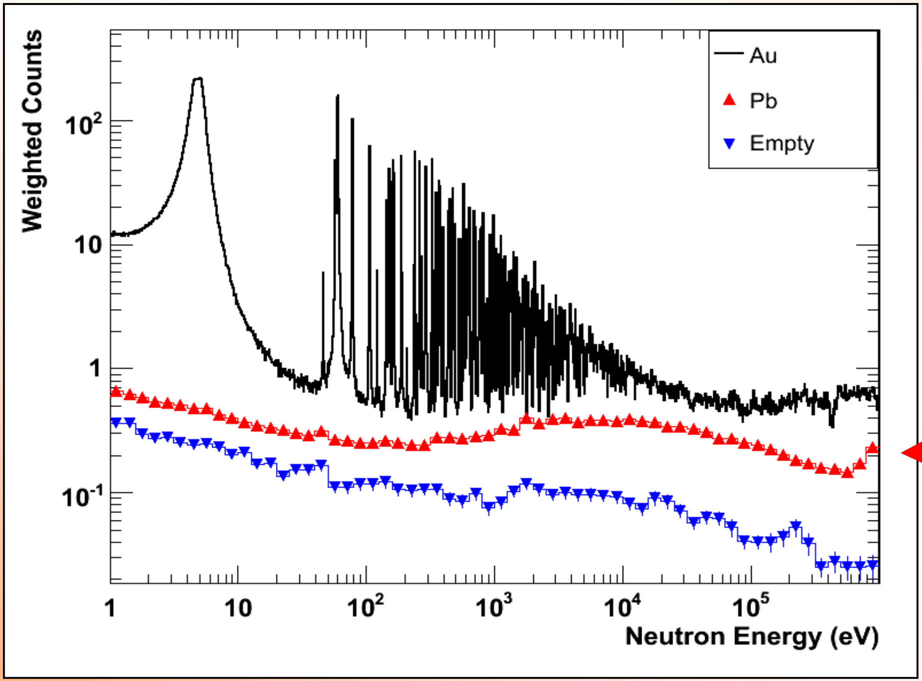
Au(n,γ) at n_TOF: background



Sample independent:

- empty sample holder

Au(n,γ) at n_TOF: background



Sample independent:

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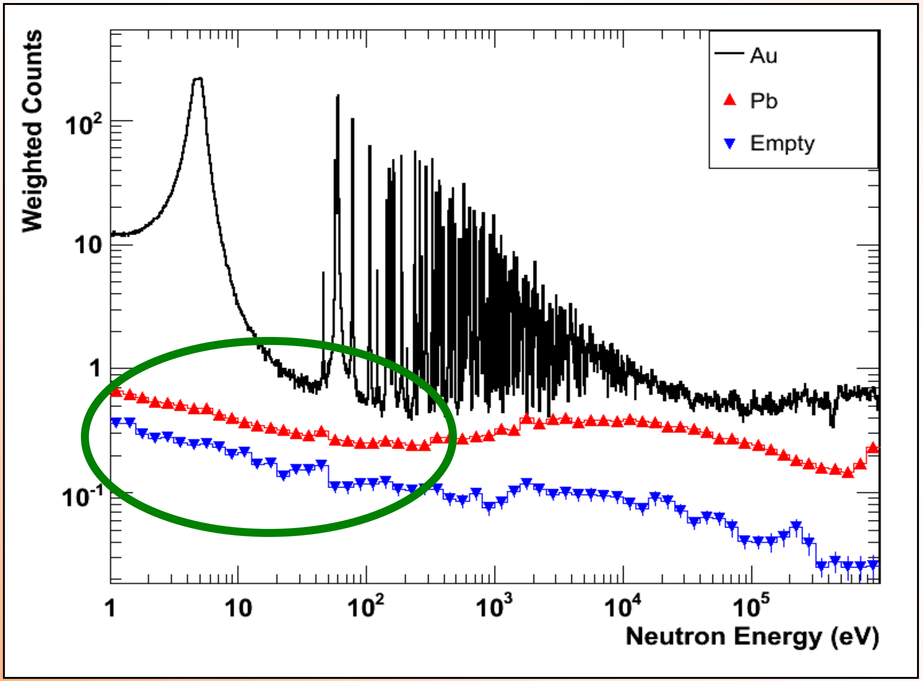
Sample dependent:

- obtain shape with **Pb** measurement
- neutron induced (E_n < 200 eV)
- γ – induced (200 eV<E_n<500 keV)

Au(n,γ) at n_TOF: background



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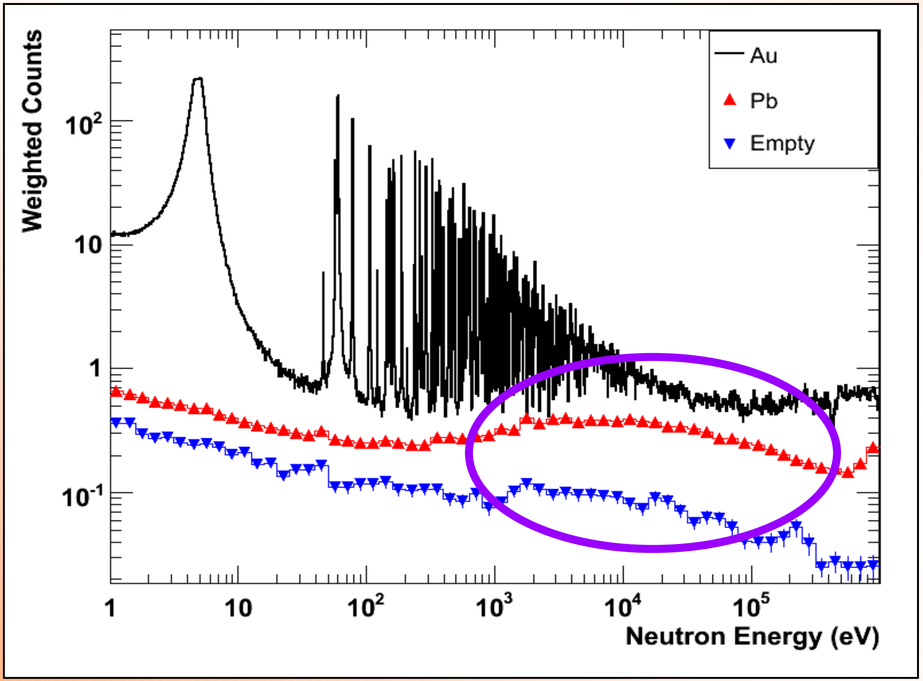

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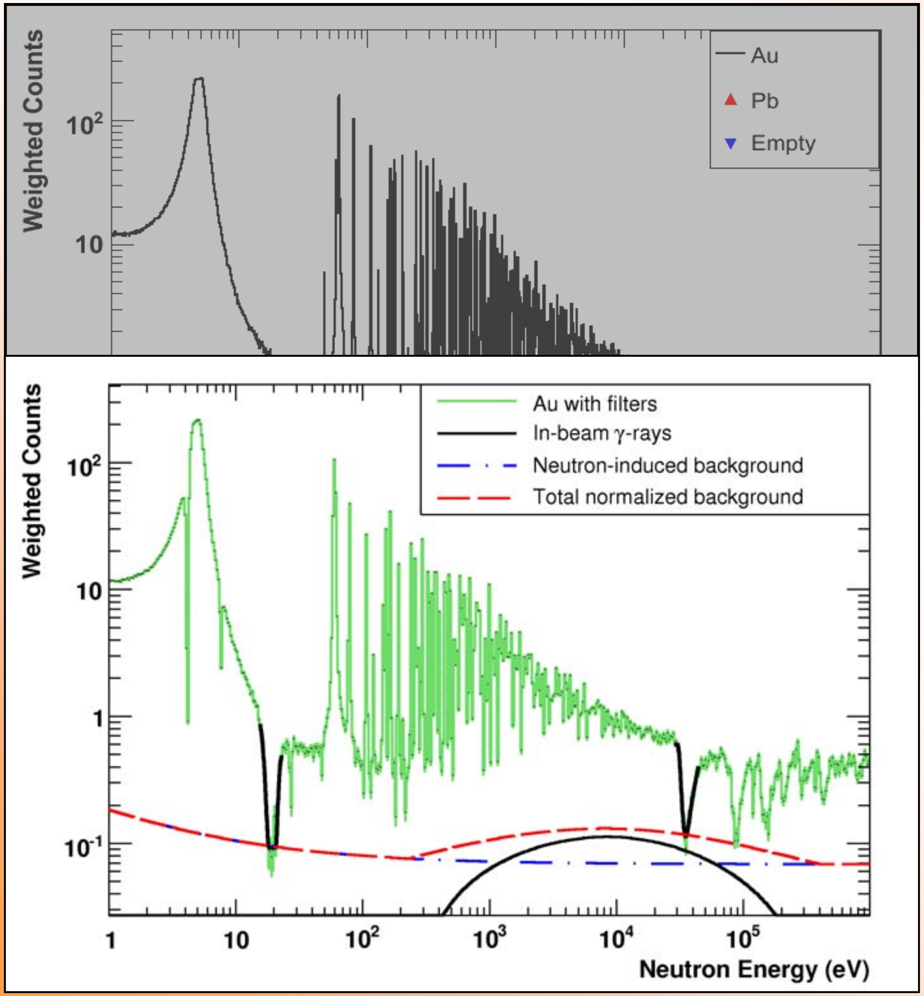

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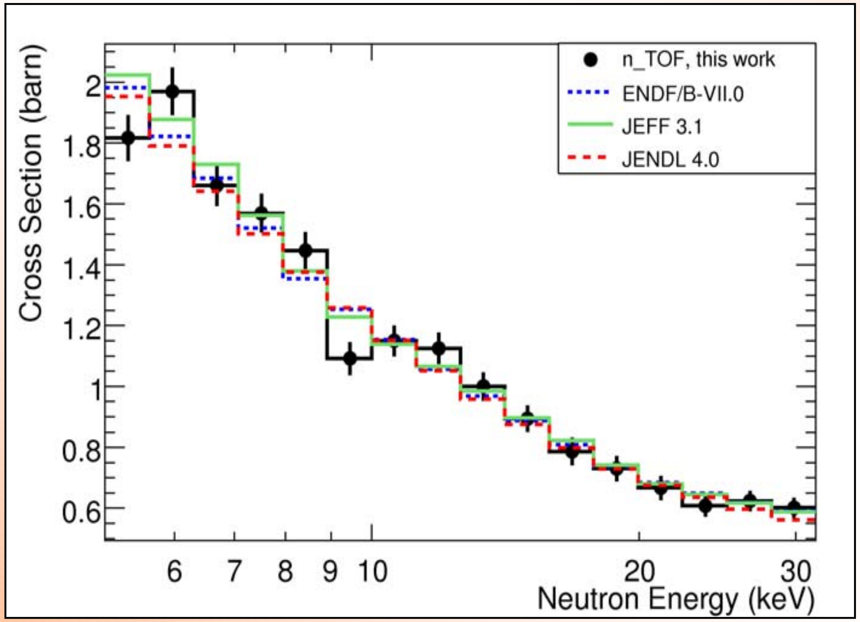
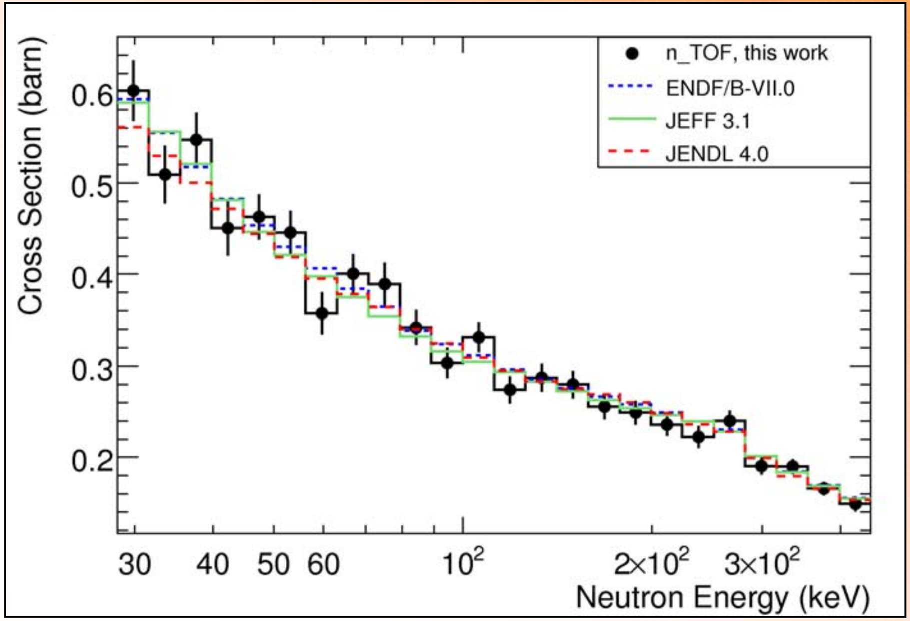
- obtain level by

1) measurement of Au with neutron filters
2) MC - simulations

Au(n,γ) at n_TOF: results

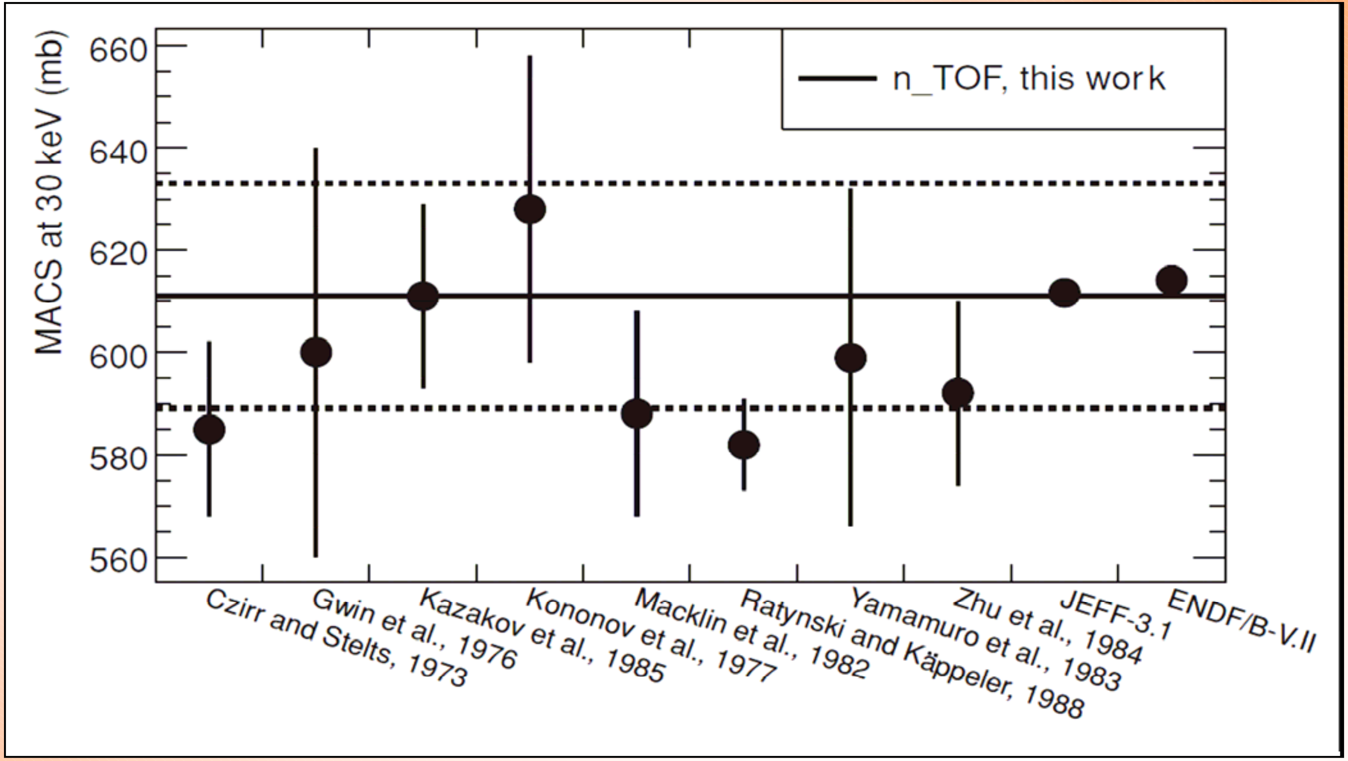




- analyzed from 5 keV – 400 keV
- total uncertainties 3.9-6.7 % (resolution of 20 bins per decade)
- MACS calculated from 5 keV – 100 keV
- 200-400 keV: agreement with standard cross section 2.1 %

C. Lederer, *et al.,* Phys. Rev. C **83**, 034608 (2011)

Au(n,γ) at n_TOF: results – MACS @ 30 keV



- **n_TOF: 611±22 mb (±3.6%)**
- **ENDF/B-VII (std. evaluation): 614.1 mb**
- **Ratynski and Käppeler: 582±9 mb**

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- further efforts for resolving this problem are underway

„Energy-broadened proton beam for production of quasi-stellar neutrons from the ^{7}Li(p,n)^{7}Be reaction“, **next talk by G. Feinberg**

Measurement of Au(n,γ) at GELINA/IRMM, C. Lampoudis *et al.*

Thank you for your attention!

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EFNUDAT
European Facilities for Nuclear Data Measurements

n_TOF