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Measurement of ^{169}Tm(n, tot) cross section at Back-n

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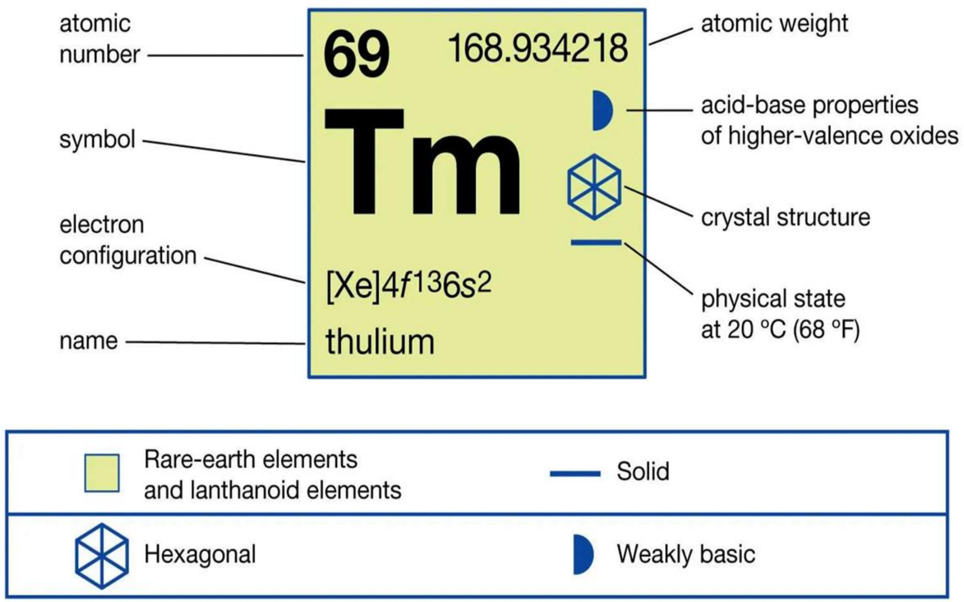
CONTENTS

01 Motivation

Thulium (Tm)

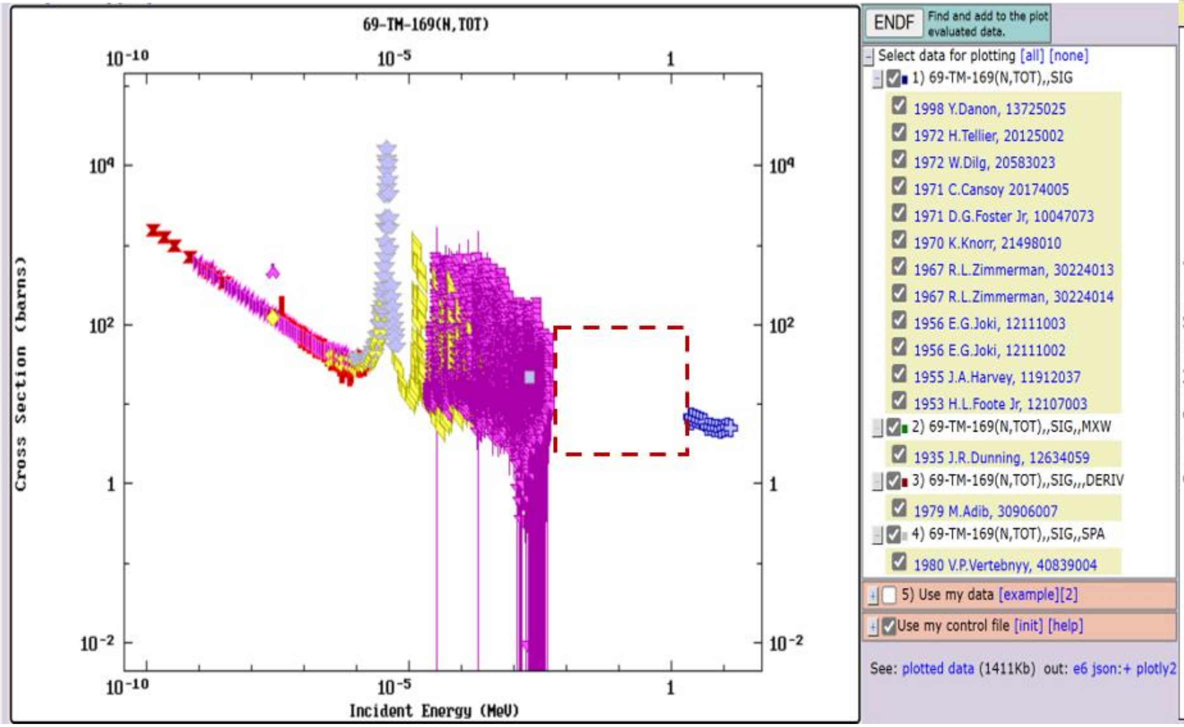
- One of the rarest of the rare-earth elements.
- Natural abundance: 100% ^{169}Tm.
- Laser material.
- X-ray sources (^{170}Tm)
- Superconducting material.
- Fission product.
- High neutron absorption cross section.

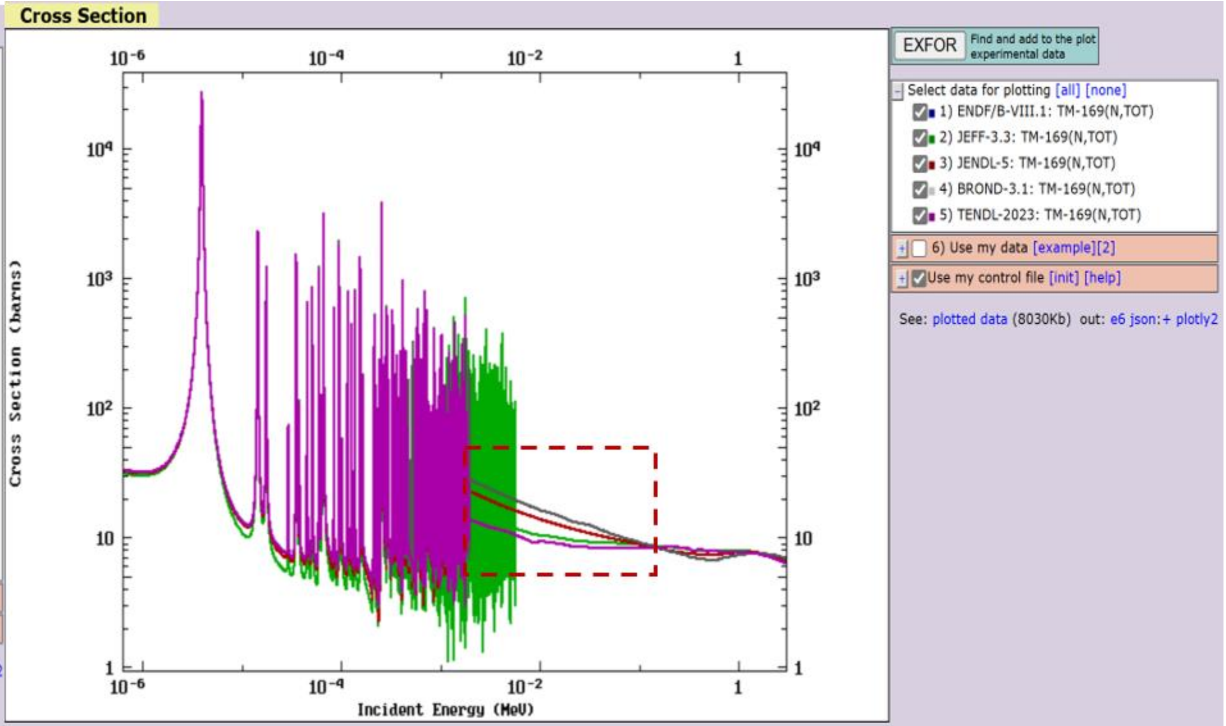


Motivation

The neutron total cross section of ^{169}Tm

- ✓ Few experimental data exist in EXFOR, with missing data between 5 keV and 1 MeV.
- ✓ Significant discrepancies among evaluated data in ENDF between 1 keV and 100 keV.
- ✓ No evaluated data exist in CENDL 3.2.



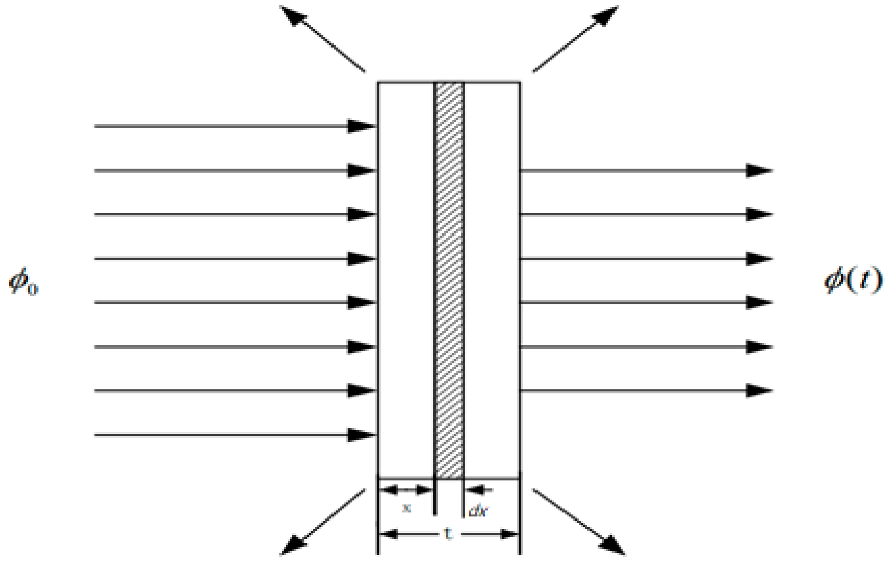


02

Experiment

Principle and method

- ✓ Transmission method is the most commonly used technique for neutron total cross-section measurement.
- ✓ The absolute neutron flux and detection efficiency are not required.
- ✓ Time-of-flight method can be used to determine incident neutron energy at a pulsed neutron facility.

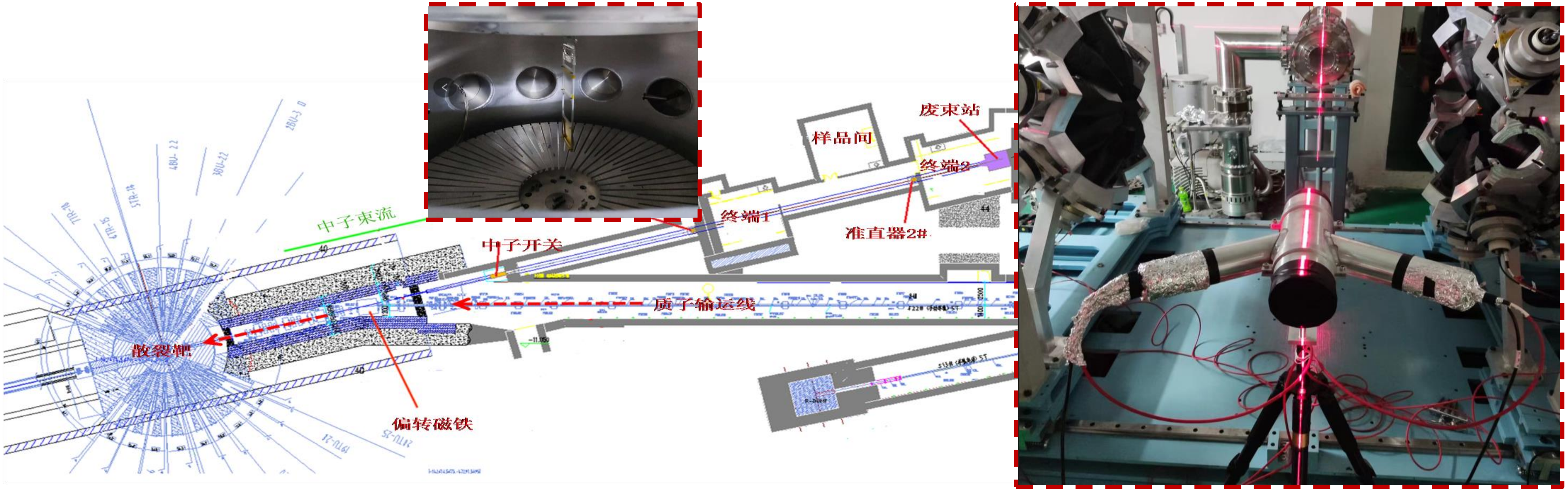


$$\int \frac{d\phi}{\phi} = -N\sigma_t \int dx \qquad T = \frac{\phi}{\phi_0} = e^{-N\sigma_t x}$$

$$\ln\phi = -N\sigma_t x + c \qquad \sigma_T = -\frac{\ln(T)}{Nx}$$

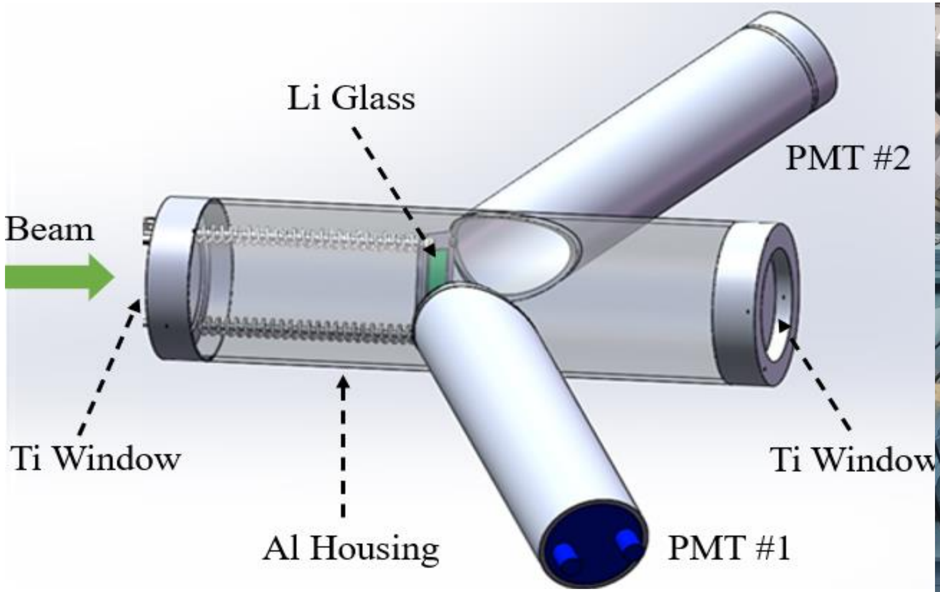
The experimental setup

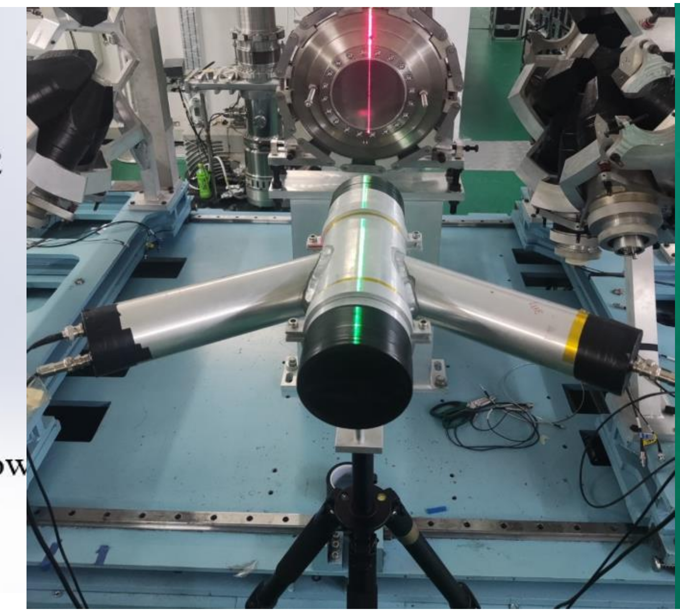
- ✓ Back-n facility, with Thulium samples installed in ES#1 (~57 m) and a wing-shaped lithium glass scintillation detector installed in ES#2 (~ 77 m).
- ✓ Two-Bunch mode @ 160 kW, with ϕ 3-15-40 mm collimators.



Wing-shaped lithium glass detector

- ✓ Li-6 glass was used for its smooth shape of the detection efficiency curve.
- ✓ The wing shape was designed to protect the PMTs from being blinded by the γ-flash.
- ✓ A Li-7 glass was used to evaluate the background of the Li-6 glass induced by the γ rays.
- ✓ Coincidence measurement was used to reduce the counts of dark noise of the PMTs.





The detection efficiency of the wing-shaped detector and the response of Li-6 and Li-7 glasses to the Back-n neutron beam were simulated with the Geant4 toolkit.

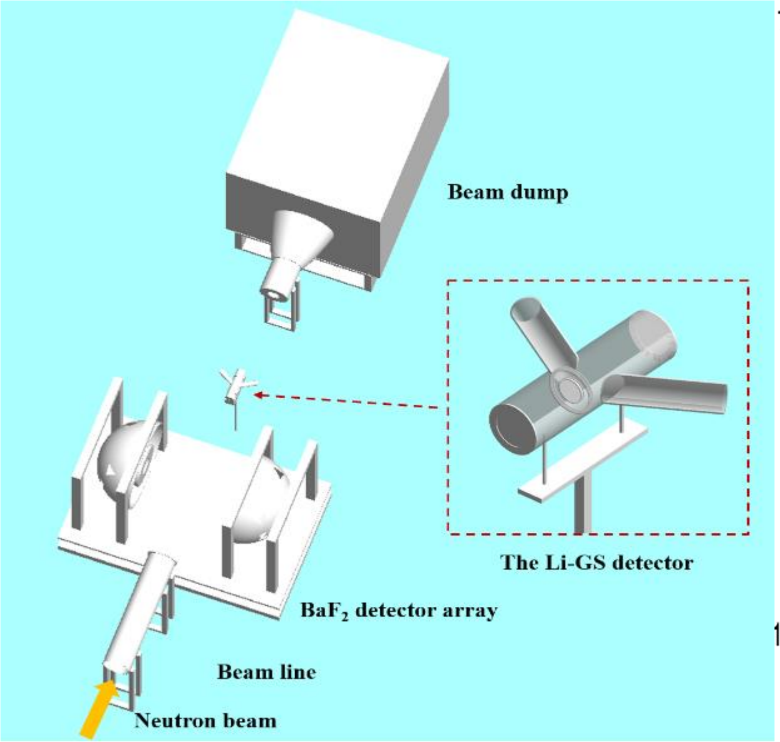


Fig. The geometric model

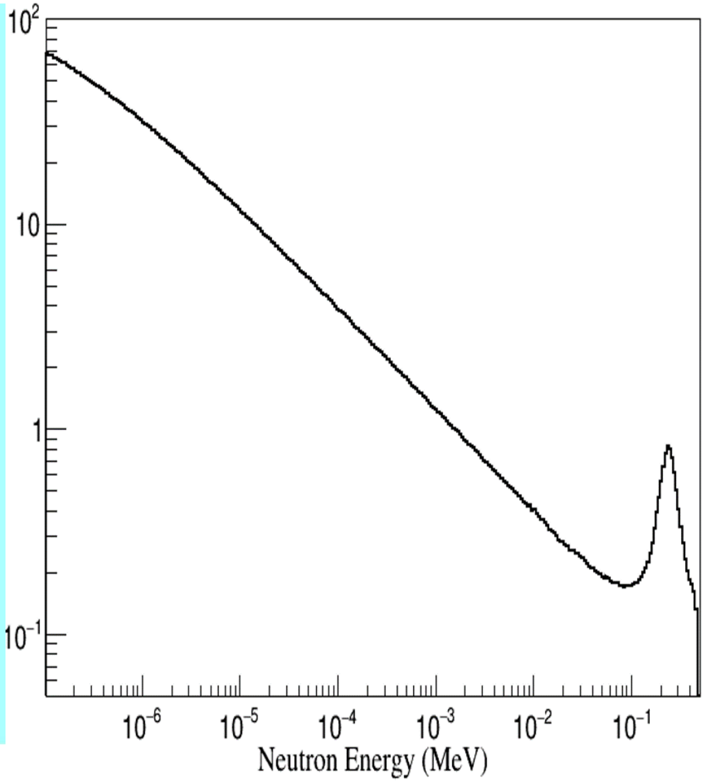


Fig. The detection efficiency

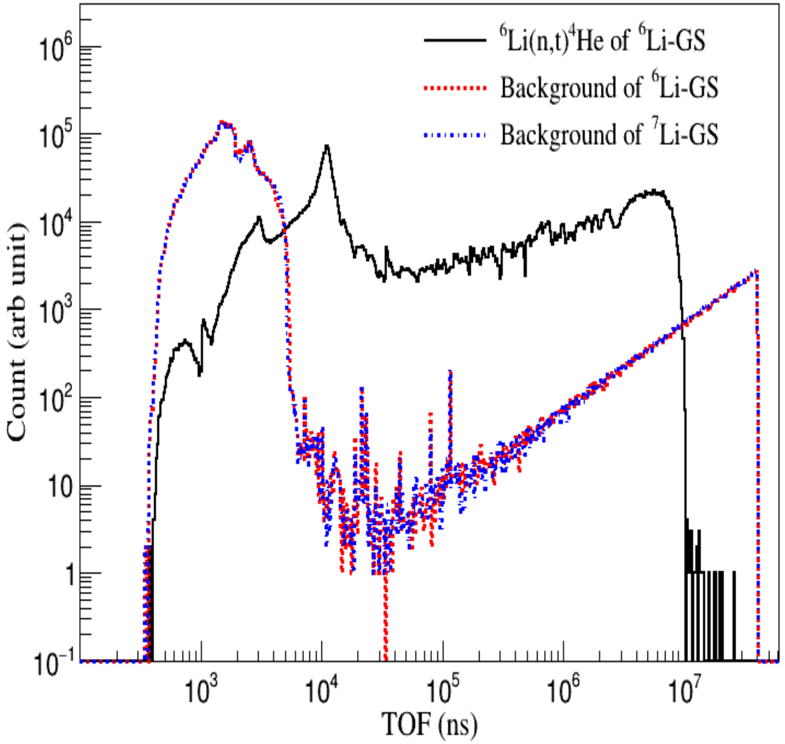


Fig. The response spectra of Li-6 and Li-7

Experiment

The Pu-C neutron source and gamma-ray source were used to test wing-shaped lithium detector and determine its response to neutrons and γ-rays.

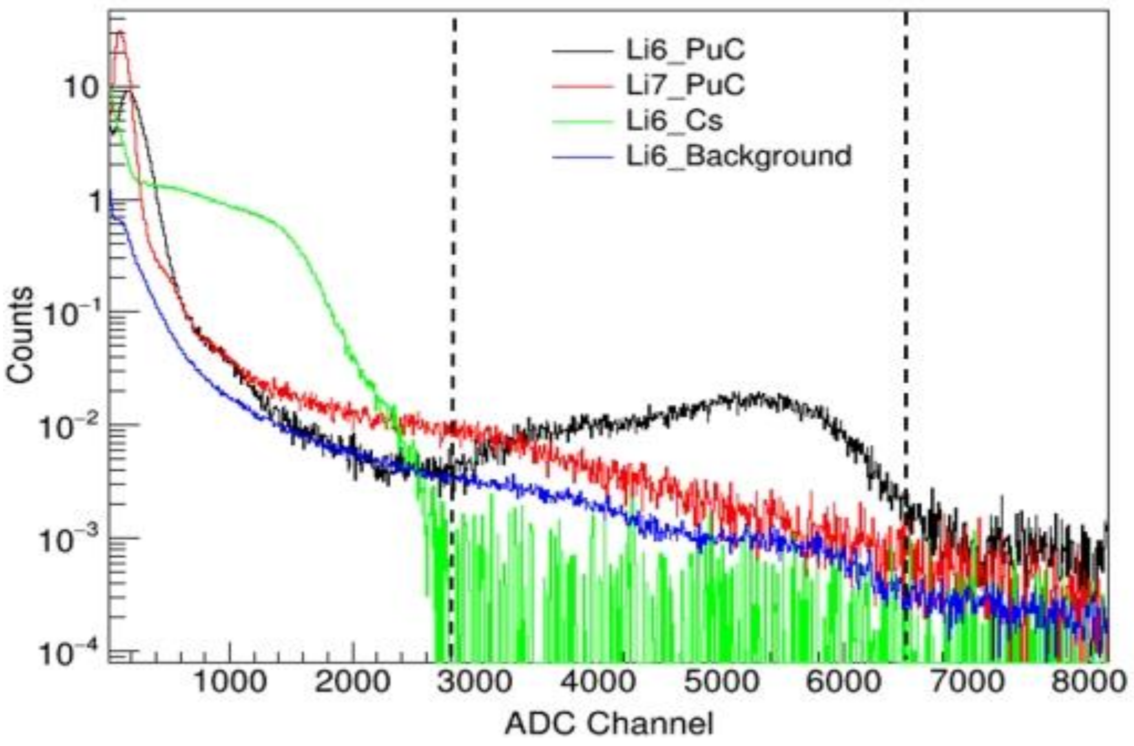


Fig. The energy response spectra

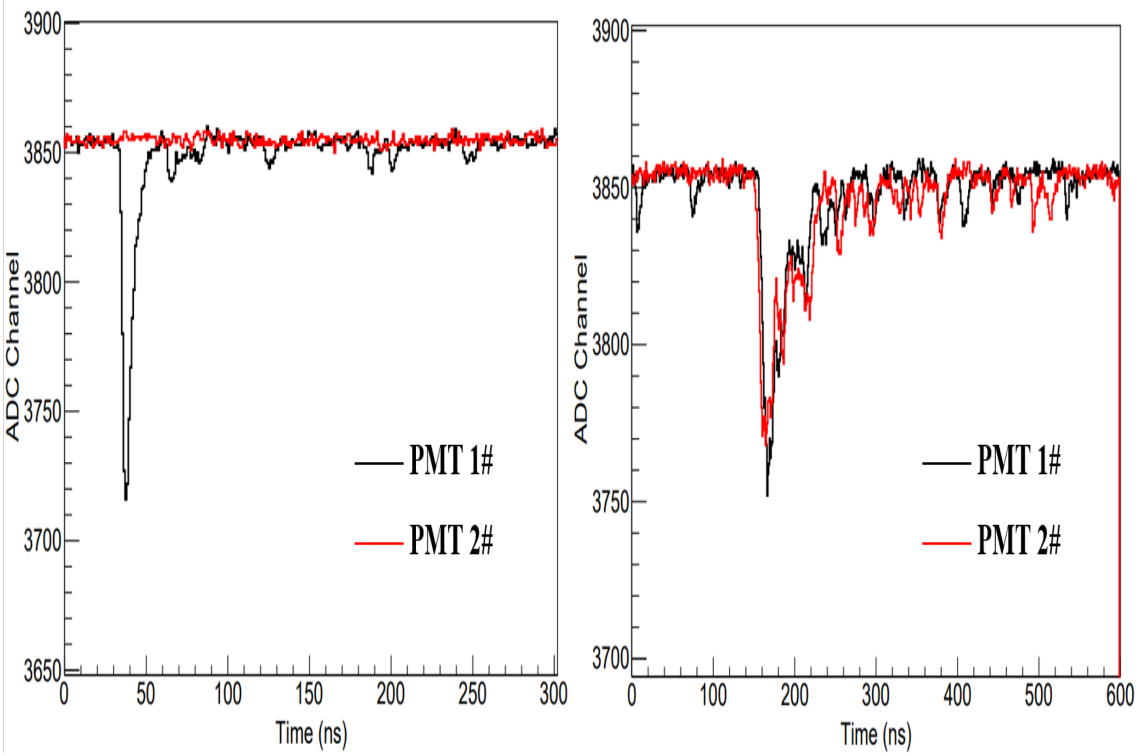
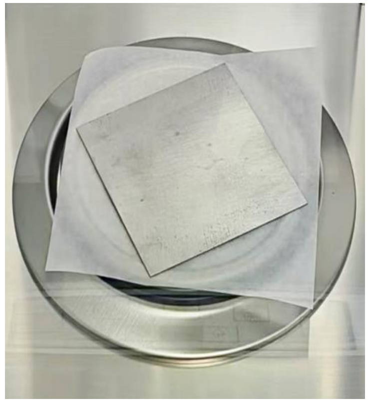
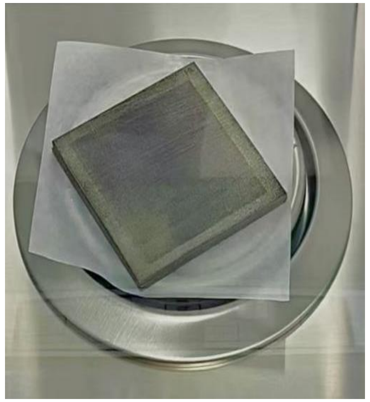


Fig. Coincidence measurement waveforms

Samples and filters

- ✓ Two ^{169}Tm samples with different thickness were used in this work.
- ✓ The ^{169}Tm samples were installed in the LPDA chamber and can be inserted into and withdrawn from the neutron beam remotely.
- ✓ A Cd filter was used to absorb neutrons with energy below 0.3 eV.
- ✓ Ta and Co filters were used to evaluate background with “saturated resonance method”.

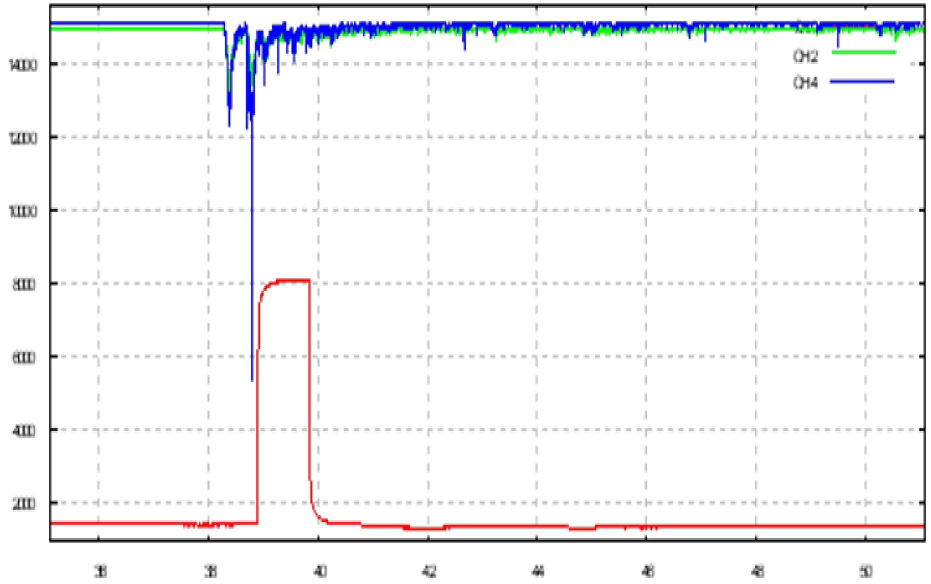

1#Tm


2#Tm

Material	Diameter/Lenth (mm)	Thickness (mm)	Purity (%)
^{169}Tm 1#	60.34±0.05	0.51±0.003	≥99.95
^{169}Tm 2#	60.37±0.11	4.43±0.022	≥99.95
^{181}Ta	100±0.5	1.0±0.05	≥99.90
^{59}Co	100±0.5	1.0±0.05	≥99.90
^{nat}Cd	80±0.5	1.0±0.05	≥99.90

Data acquisition

- ✓ DT5730B (CEAN s.p.a) with 500 MS/s sampling rate and 14-bit resolution was used in this work.
- ✓ Three signals were sent to the DT5730B: T0 trigger, anode signals of the two PMTs.
- ✓ The waveform code was used to record all the signals above threshold, which was 10 mV in this measurement.

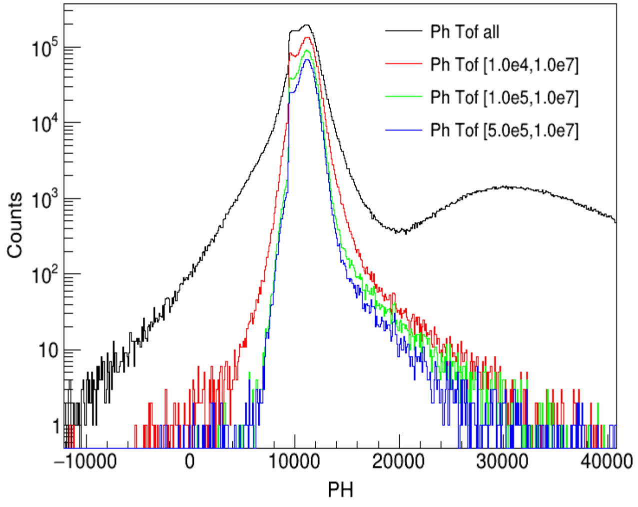


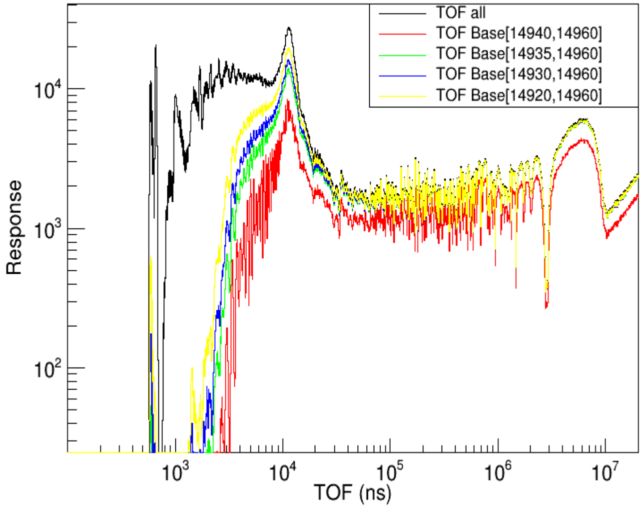
03

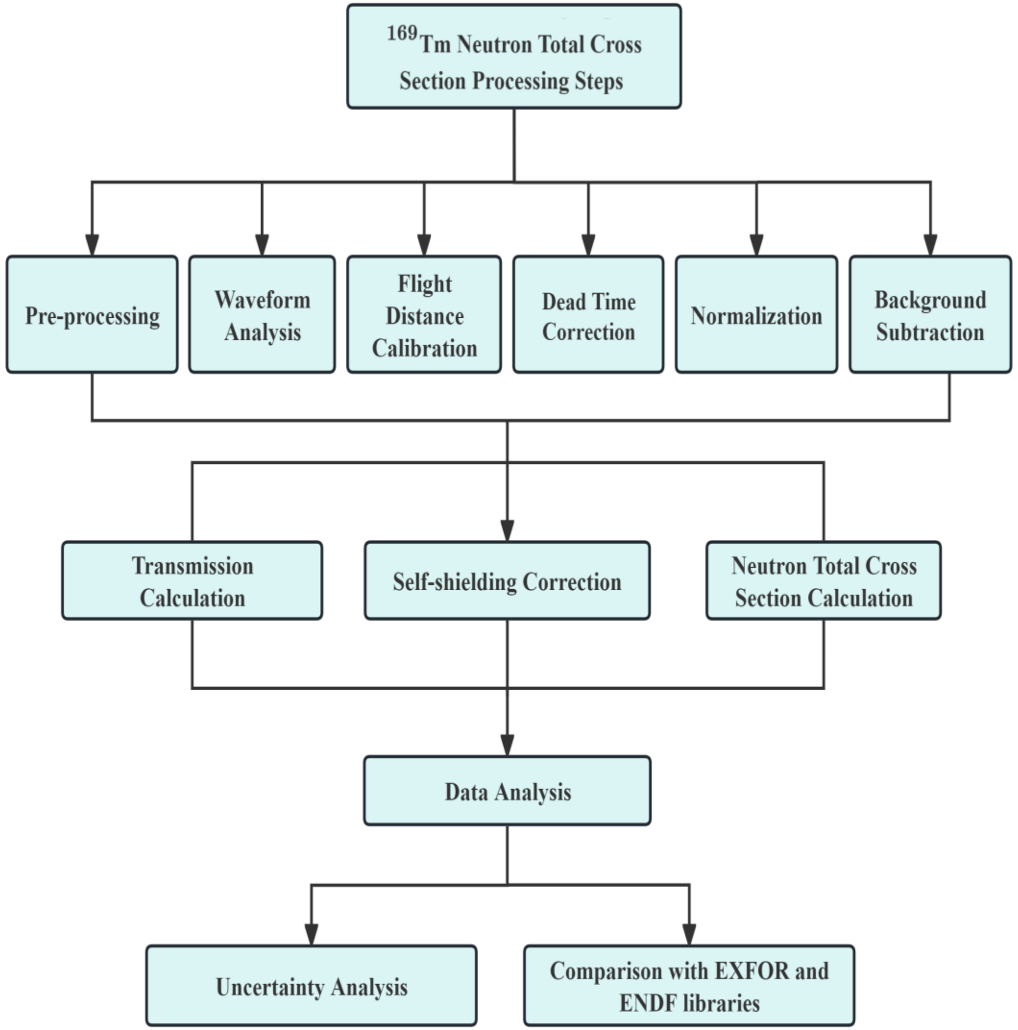
Data Analysis

Data reduction

- ✓ Extract energy and time from waveforms；
- ✓ Normalization；
- ✓ Dead time correction;
- ✓ Background subtraction.







Background

- There is always background in the measurement, more or less.

$$T = \frac{\phi}{\phi_0} = e^{-N\sigma_t x}$$

$$T_{exp} = N_T \frac{C_{in} - B_{in}}{C_{out} - B_{out}}$$

- Li-7 glass and Ta/Co resonance filters were used to determined the background.

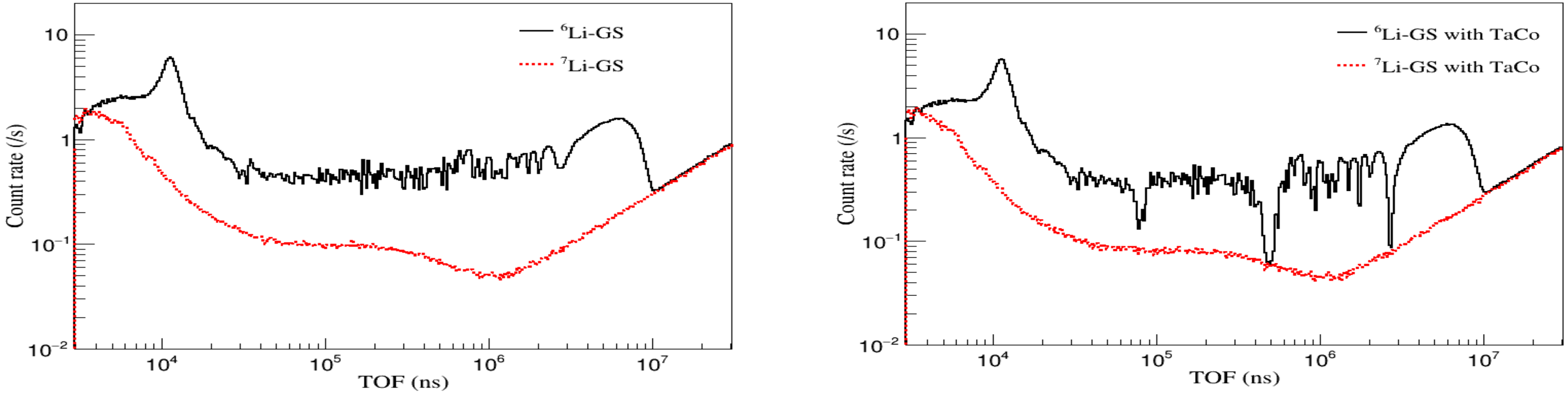
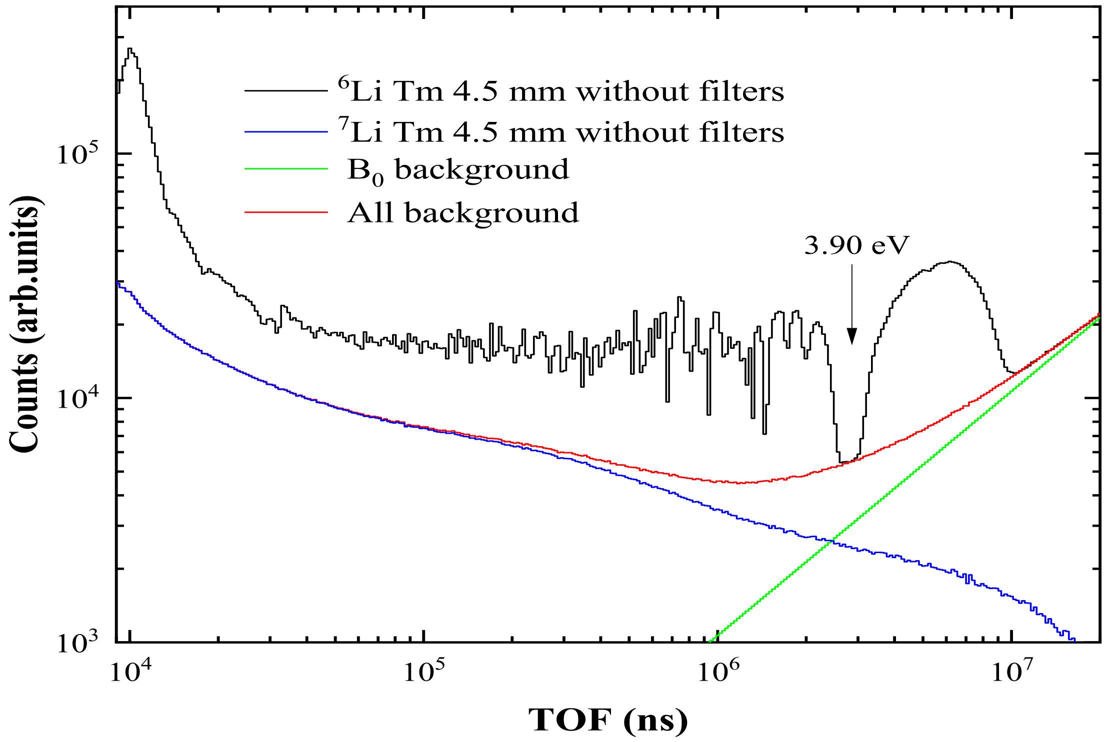


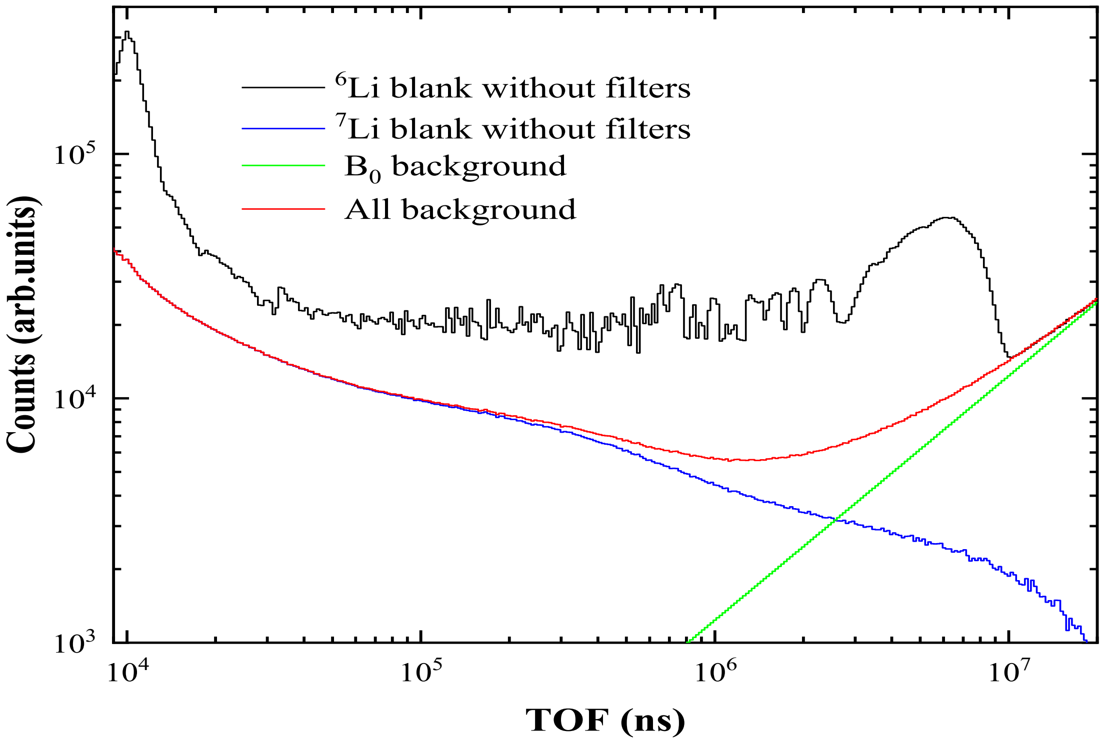
Fig. The Tof spectra with and without the filters

There were mainly two kinds of backgrounds in this measurement: **activation** and **in-beam γ-rays**.

$$B_{in(Li6)} = B_{0in(Li6)} + [C_{in(Li7)} - B_{0in(Li7)}] \times k_{Tm}$$

$$B_{out(Li6)} = B_{0out(Li6)} + [C_{out(Li7)} - B_{0out(Li7)}] \times k_f / k_s$$





Transmission

- Neutron energy was determined via:

$$E_n = \frac{1}{2} m_n v_n^2 = \left(72.3 \times \frac{L}{TOF - t_0}\right)^2$$

- Transmission was determined via:

$$T(E_n) = F_T \frac{C_{in}(E_n) - B_{in}(E_n)}{C_{out}(E_n) - B_{out}(E_n)}$$

- Self-shielding factor (F_T) was corrected via:

$$\langle T_{exp} \rangle \neq e^{-n\langle \sigma t \rangle} \qquad F_T = \frac{\overline{T}_{\exp}}{e^{-n\overline{\sigma}_t}} \approx 1 + \frac{1}{2} n^2 \operatorname{var}(\sigma_t) + \ldots$$

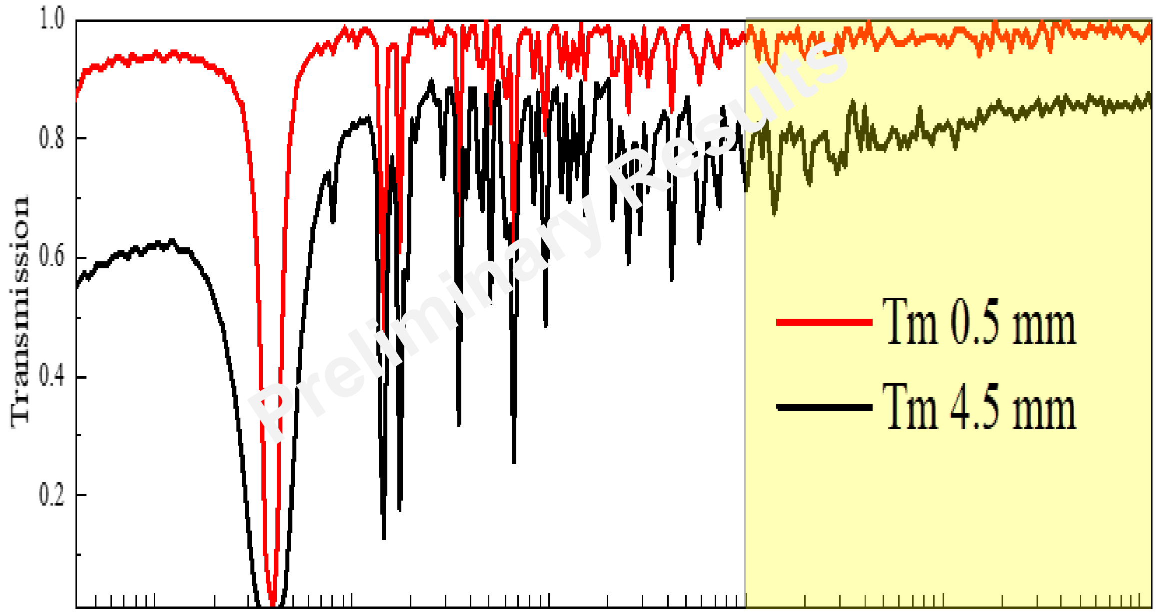


Fig. The transmission spectra of 169Tm samples

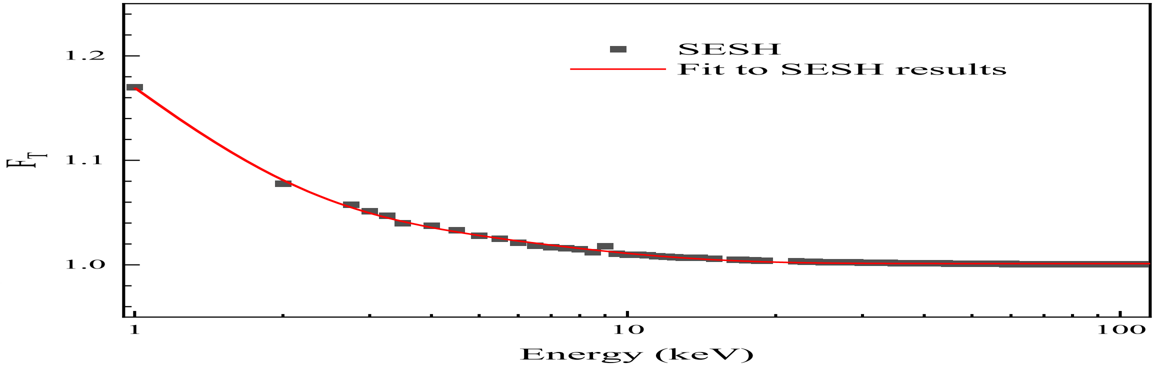
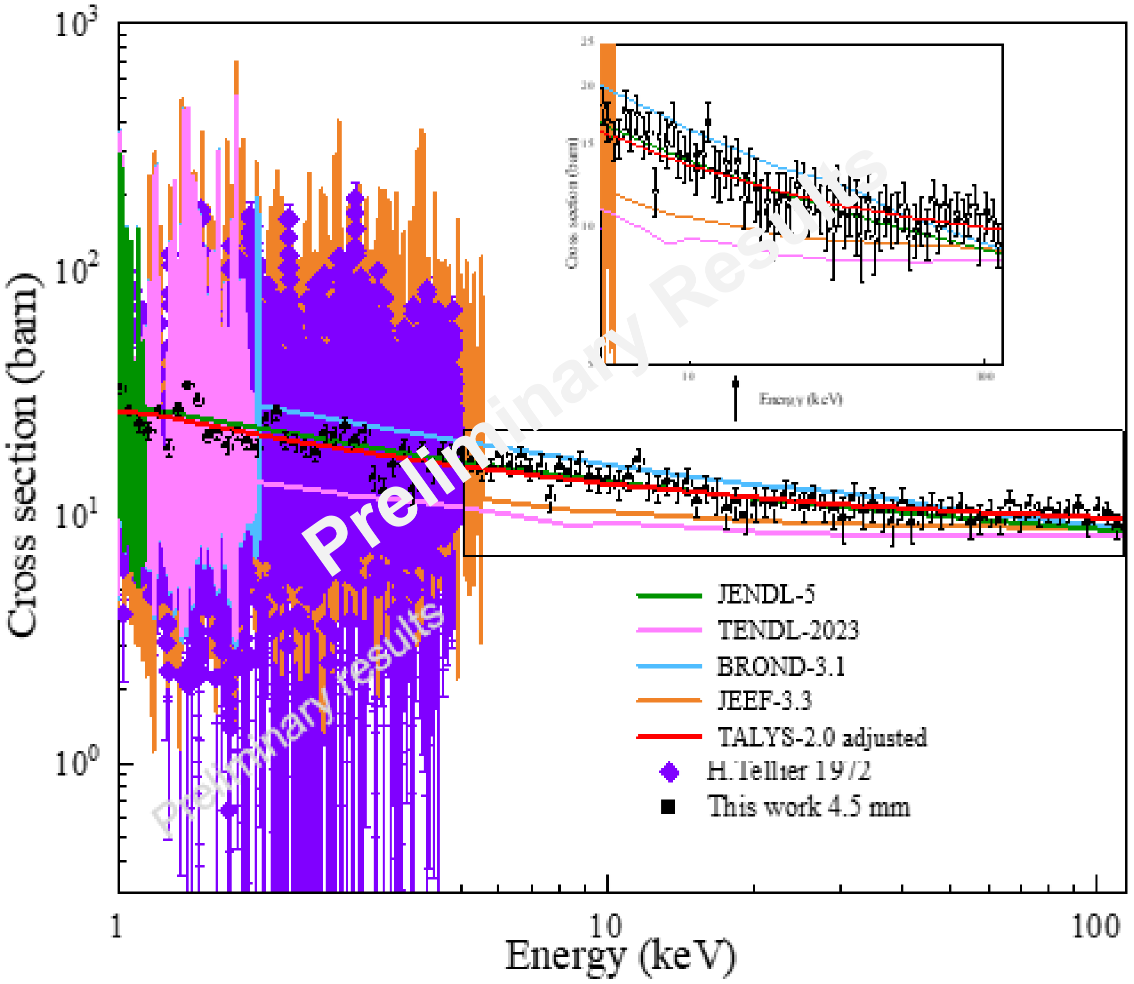


Fig. The self-shielding correction factor

04 Results

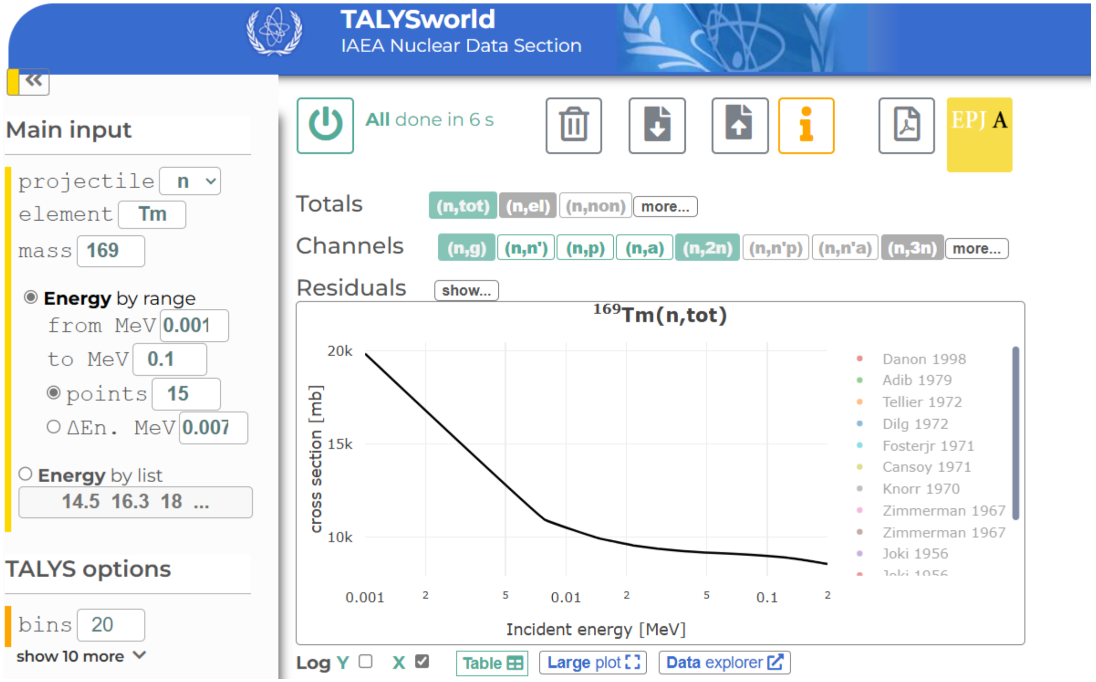
The measured cross section of ^{169}Tm(n, tot)

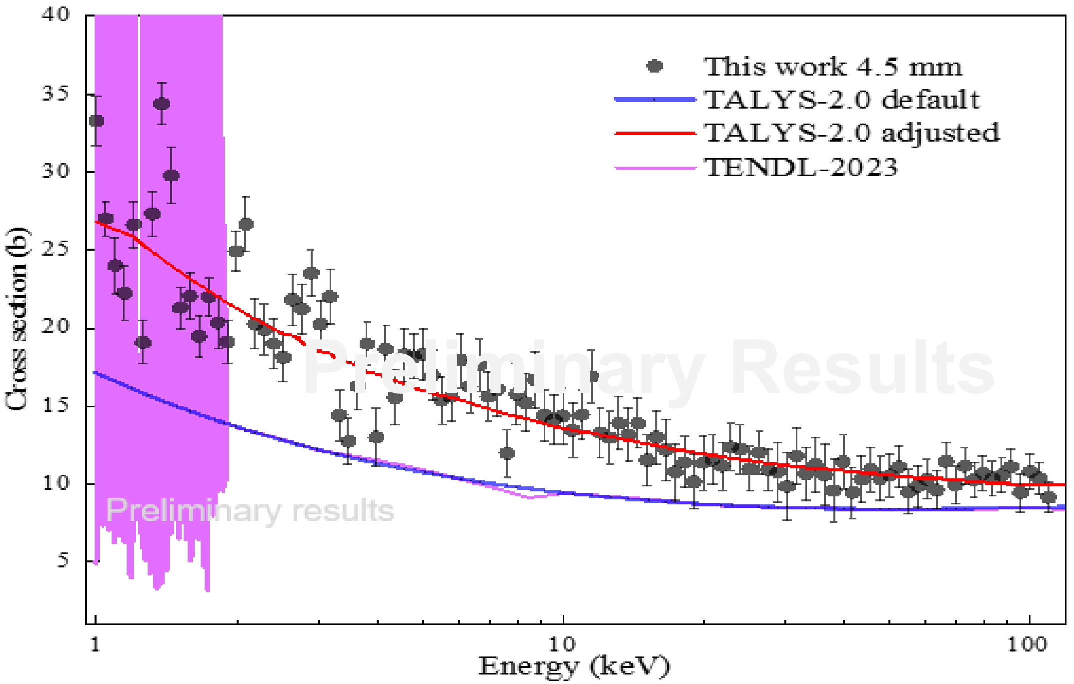
- ✓ The average total cross sections of ^{169}Tm were obtained in the energy region between (**1-110**) keV.
- ✓ The uncertainties in the transmission are less than **3%**.
- ✓ The uncertainties in the neutron energy are less than **0.5%**.
- ✓ This result agrees well with the evaluated data of **JENDL-5**.



The theoretical cross section of ^{169}Tm(n, tot)

TALYS-2.0 was used to calculate the neutron total cross section of ^{169}Tm. With some minor adjustments of the default optical parameters, the calculated cross sections were in good agreement with the experimental data.





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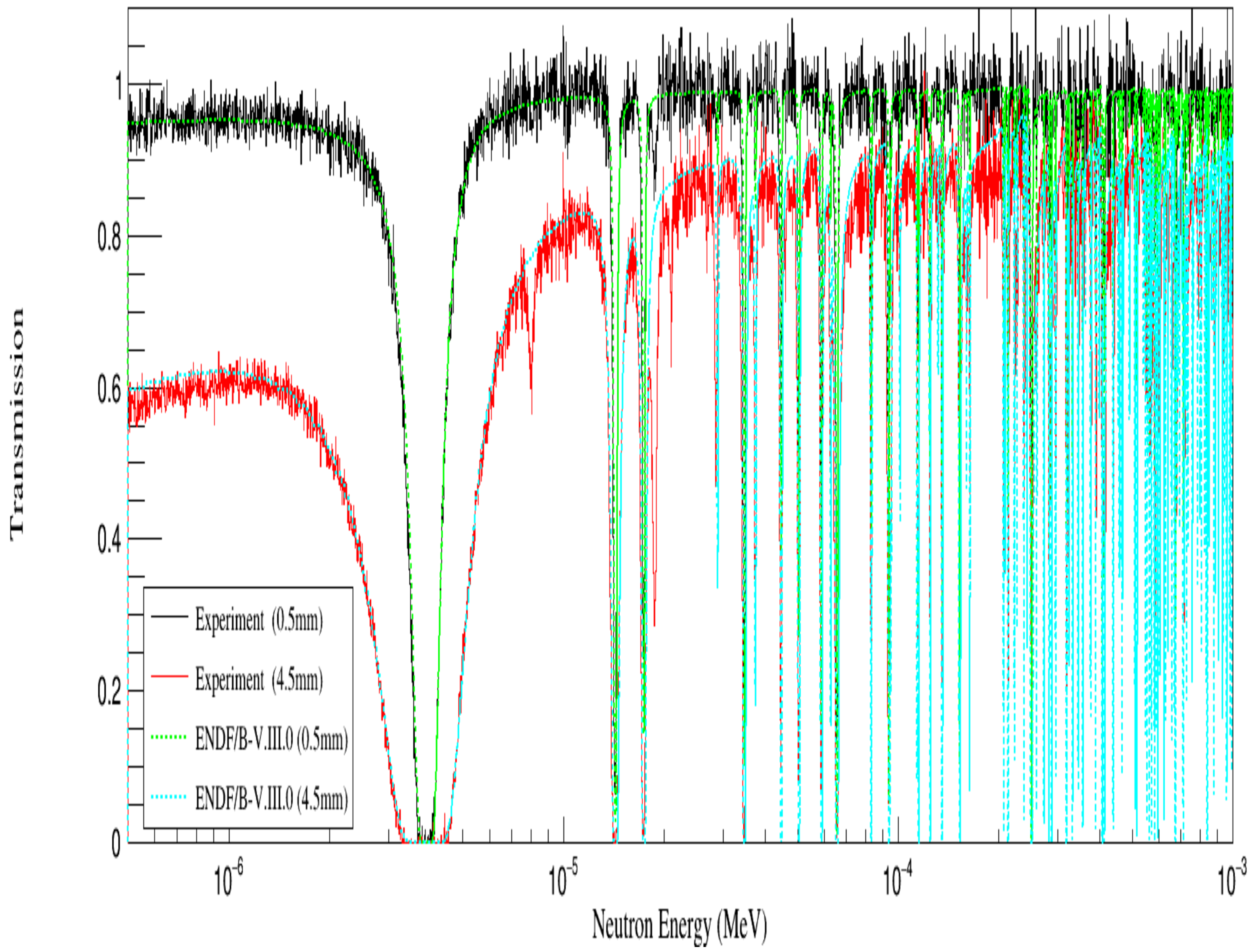
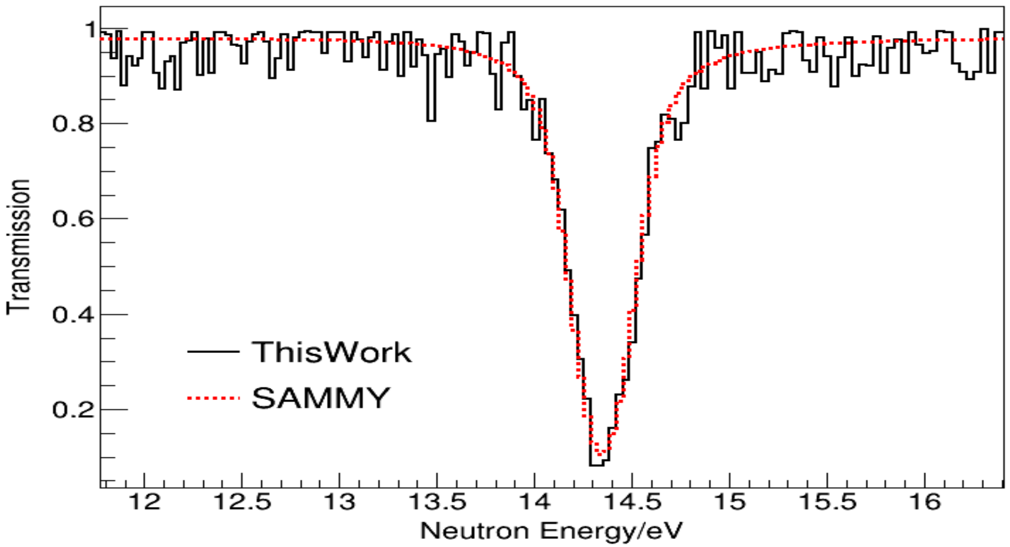
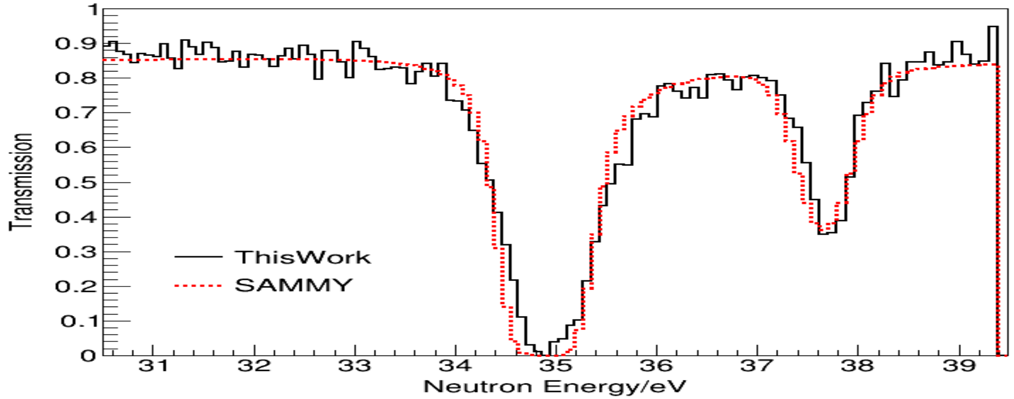
The resonance parameters analysis is still in progress







Acknowledgment：

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Thanks for your listening!