热中子能区天然硼全截面与$^{10}B(n,\alpha)$截面实验测量

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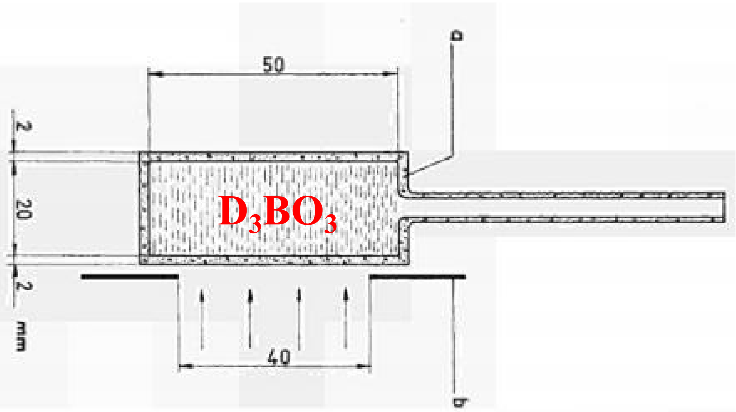
Outline

Motivation

- Neutron reaction cross sections are always measured relative to neutron cross-section standards (σ_{std}). Relative measurement avoids measuring the neutron energy spectrum but is limited by the precision of the σ_{std}.
- The ^{10}B(n,α) cross-section is one of the commonly used σ_{std}.

Advantages of ^{10}B(n,α) as a cross section standard

- ✓ Few isotopes
- ✓ non-radioactive
- ✓ High $\sigma_{(n,\alpha)}$ in thermal



Prosdocimi A, Deruytter A J. Journal of Nuclear Energy. Parts A/B. Reactor Science and Technology, 1963, 17(2): 83-87.

Only one dataset (1963) exists for the ^{10}B(n,α) cross section at thermal, calling for more precise measurements. Therefore, we are proposing an absolute transmission measurement of ^{10}B at CSNS Back-n to obtain new data in a high-precision level.

Comparison of Two Experiments

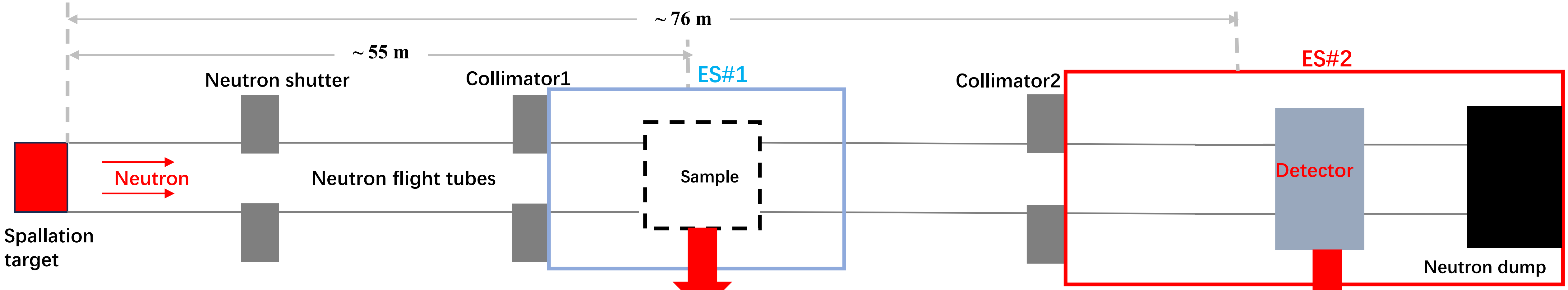
	Previous Experiment	Back-n Experiment
Sample:	D_3BO_3 solution	BN sheet
Neutron Source:	Reactor Neutron Source	Spallation Neutron Source

Advantages of our Experiment setup

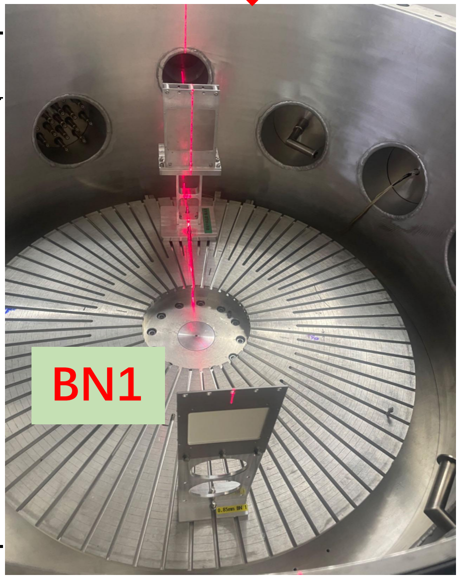
- Less affected by impurities
- Higher neutron energy resolution

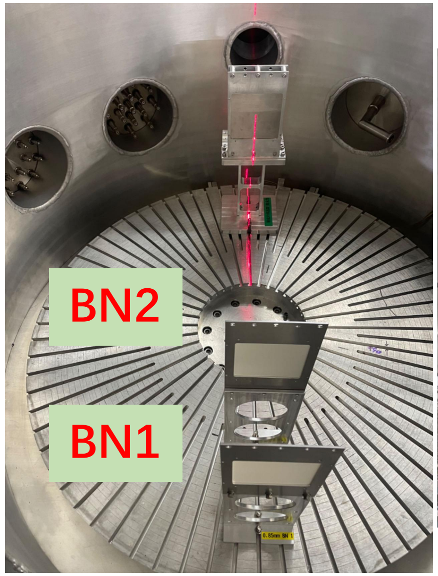
Experimental setup

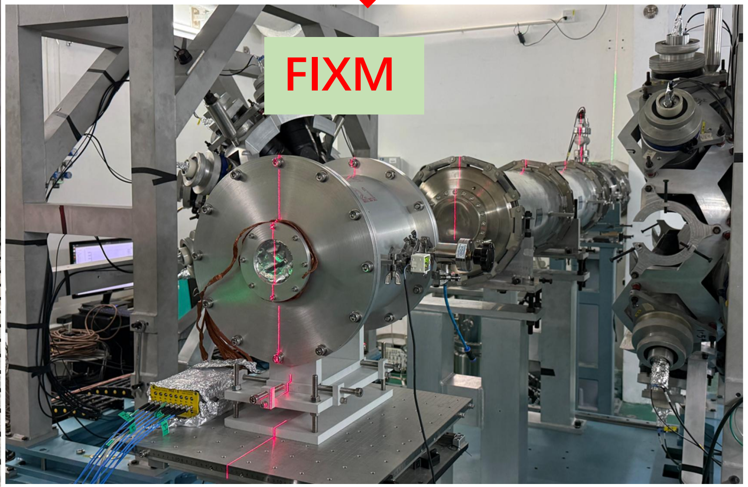
This work presents the first thermal neutron measurement ever conducted at the Back-n facility. A Cd filter previously placed in the beam absorbed neutrons below **0.3 eV**. With the removal of the Cd filter and the assessment of cold neutron background for TOF greater than **40 ms**, the accessible energy range has now been successfully extended down to **0.02 eV.**



	BN1	BN2
m (g)	13.031±0.00025	12.9485±0.00033
S (cm^2)	64.3204	64.3236±0.0113
Thickness (um)	875	874
Isotopic $^{10}B/B$	0.199	0.199







Experimental Advantages

BACK-N CSNS-WHITE NEUTRON SOURCE

Advantages of total cross-section measurement

^{10}B(n, tot):
- ^{10}B(n, el) — **~2.1937 b (0.0253 eV)**
- ^{10}B(n, γ) — **~ 0.7 b (0.0253 eV)**
- ^{10}B(n, α_0)^{7}Li and ^{10}B(n, $\alpha_1\gamma$)^{7}Li — **~ 3844 b (0.0253 eV)**

The ^{10}B(n,el) and (n,γ) cross sections contribute less than **0.1‰** to the total cross section at thermal energies. Thus, by measuring ^{10}B(n,tot) precisely, the ^{10}B(n,α)^{6}Li cross section can be accurately obtained via:

$$(n,\alpha) = (n,tot) - (n,el) - (n,\gamma)$$

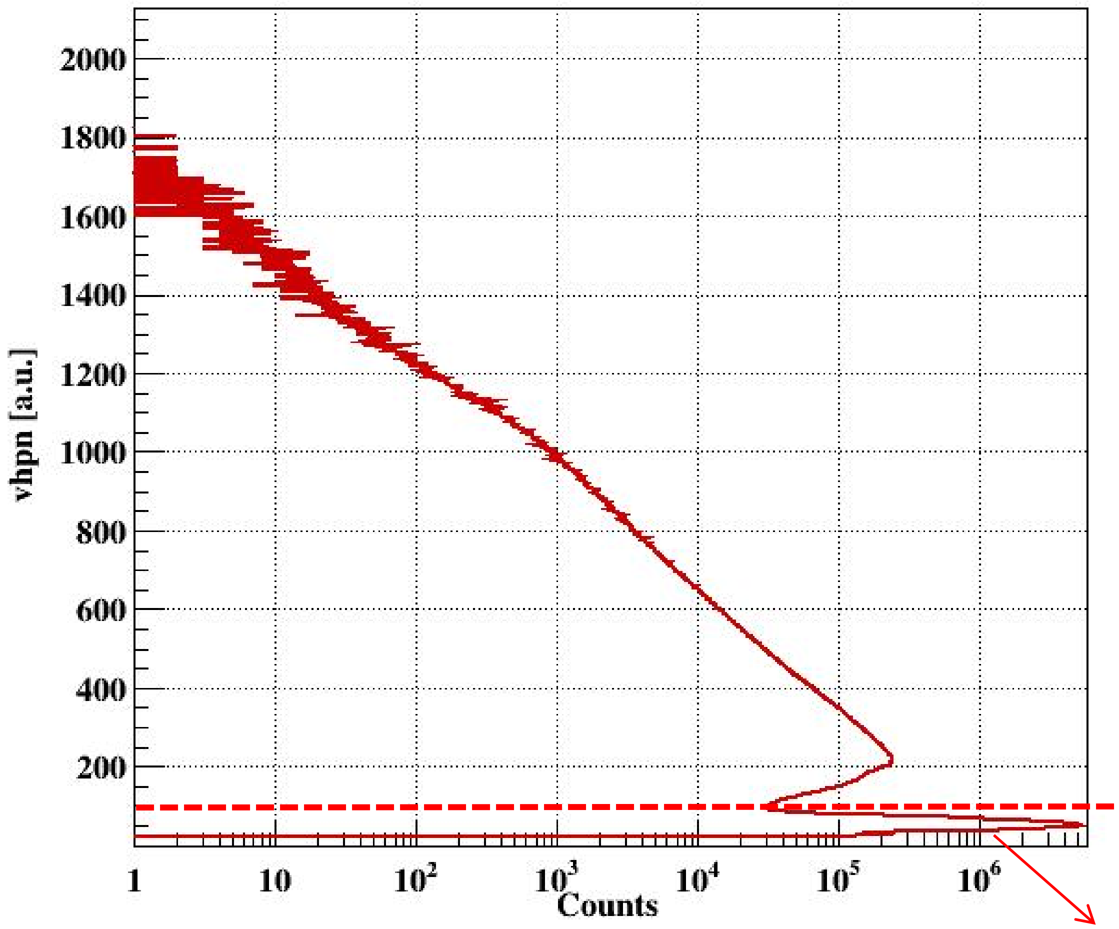
Advantages of Transmission

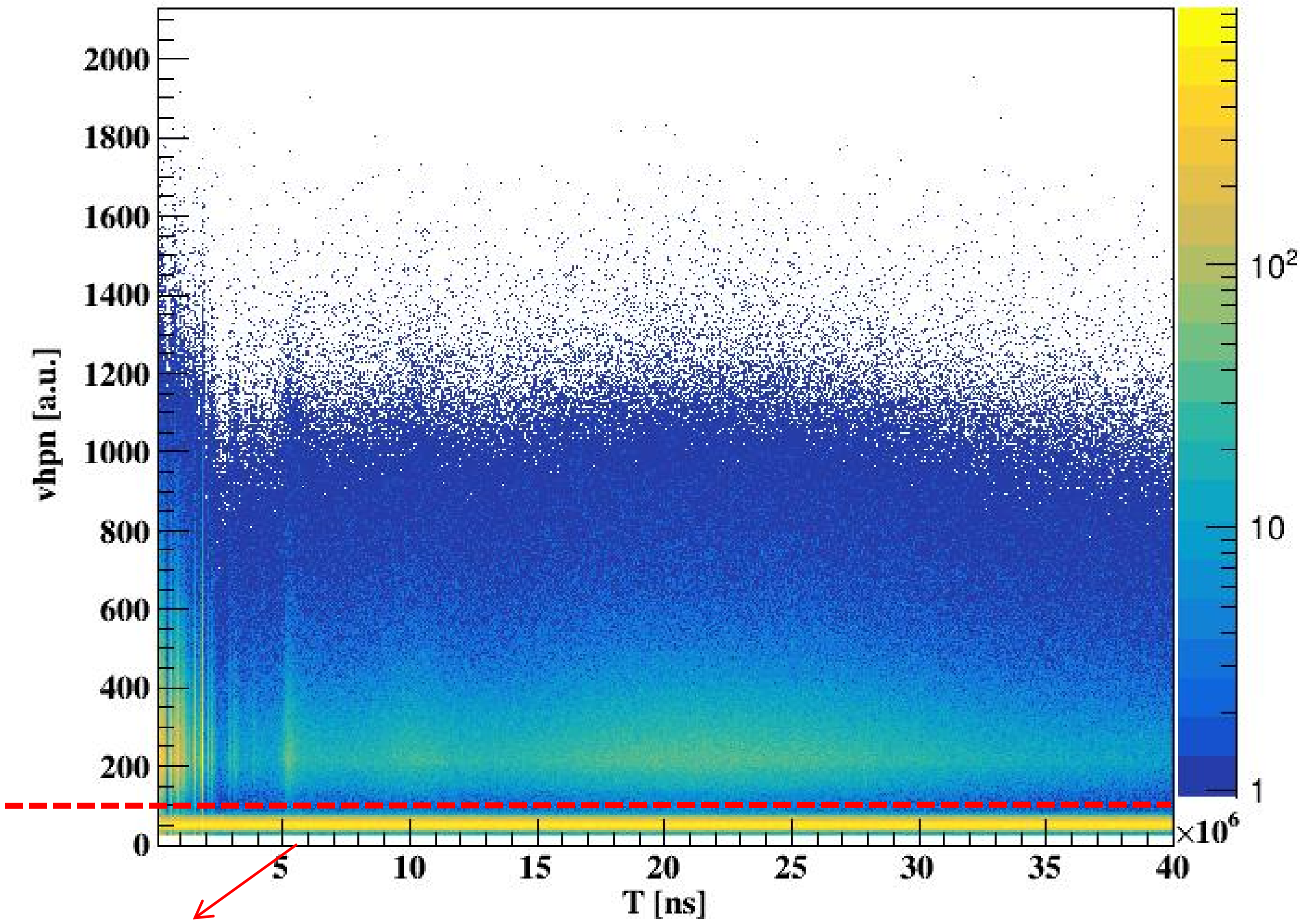
The neutron transmission method is absolute and spectrum-independent, enabling high-precision determination of the σ_{std}.

Advantages of BN sample

The thermal neutron cross sections of ^{14}N (~12.17 b, 99.625%) and ^{15}N (~4.5 b, 0.375%) are significantly smaller than that of ^{10}B(n,α) (~3844 b).

➢ Using the pulse amplitude to cut the alpa background



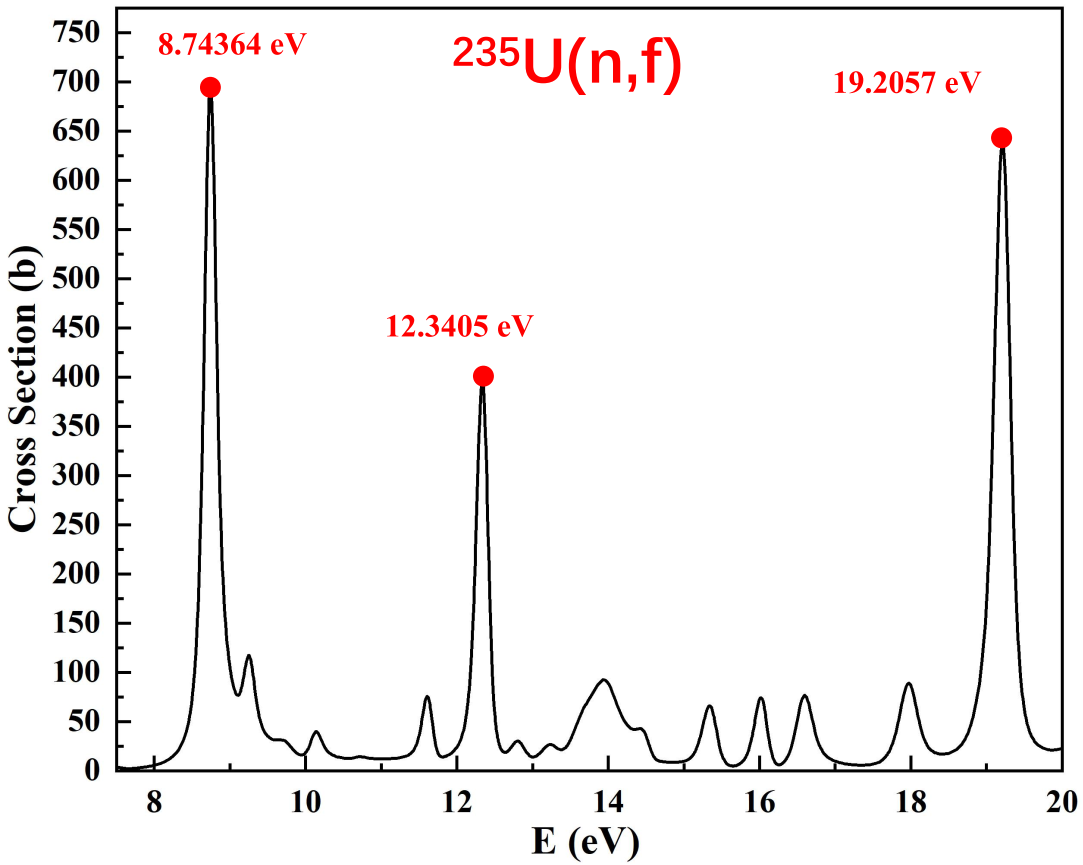


α background

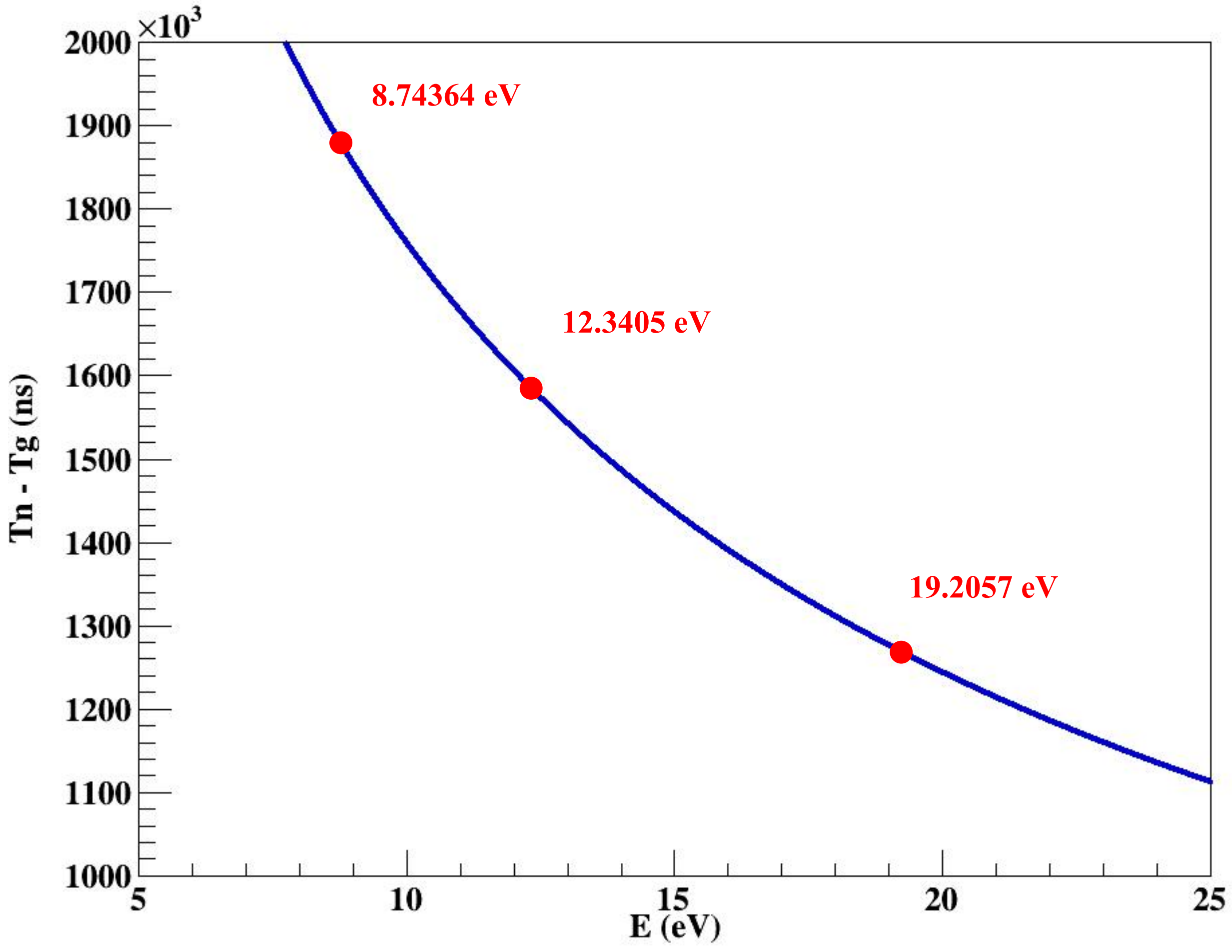
Flight distance calibration

➢ The $^{235}U(n, f)$ resonances are used for calibrating the neutron flight distance

$$T_n - T_g = \frac{L}{c}\left[\frac{1}{\sqrt{1-\frac{1}{\left(\frac{E_n}{m_n c^2}-1\right)^2}}} - 1\right]$$



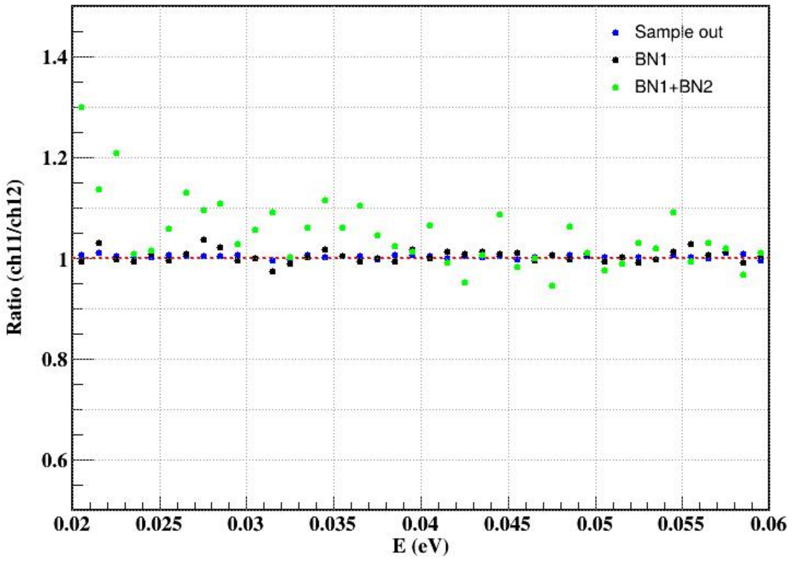
➢ Flight Distance Fitting



ch	11(U5-1)	12(U5-9)	13(U5-4)	14(U5-5)
L (m)	76.9589	76.9777	76.9968	77.0207

Data Quality (0.02 eV-0.06 eV)

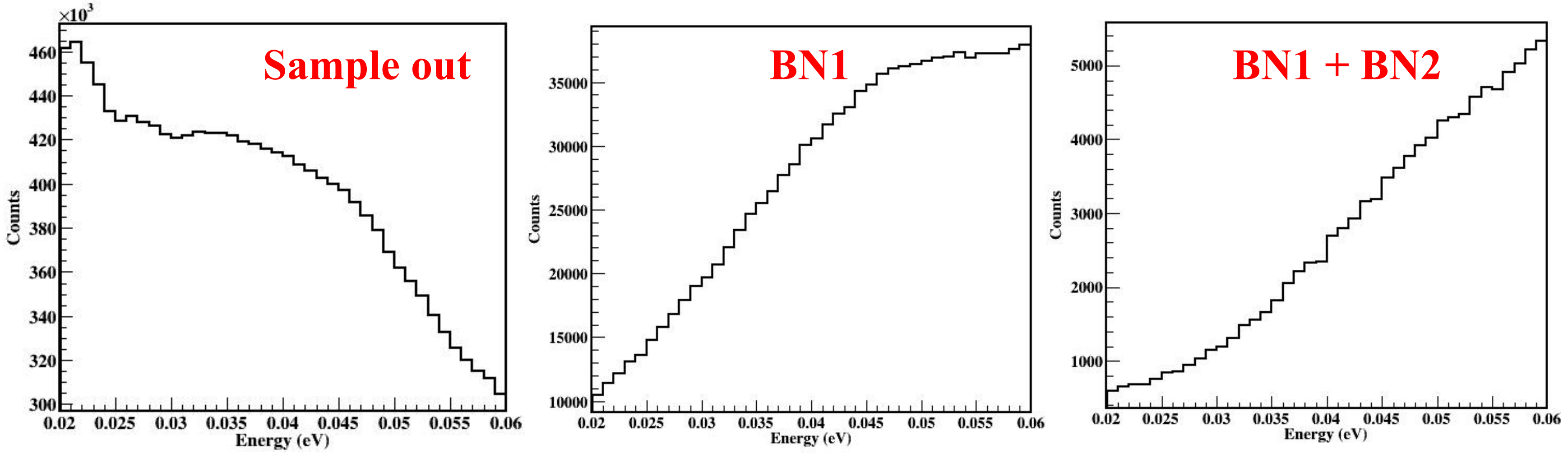
➢Consistency verification (ch11/ch12)



For the **Sample out**, channel 11 and 12 agree within **1.2%**.

Therefore, data from channels 11 and 12 are directly combined in the subsequent analysis.

➢ Fission rate



Energy VS Counts

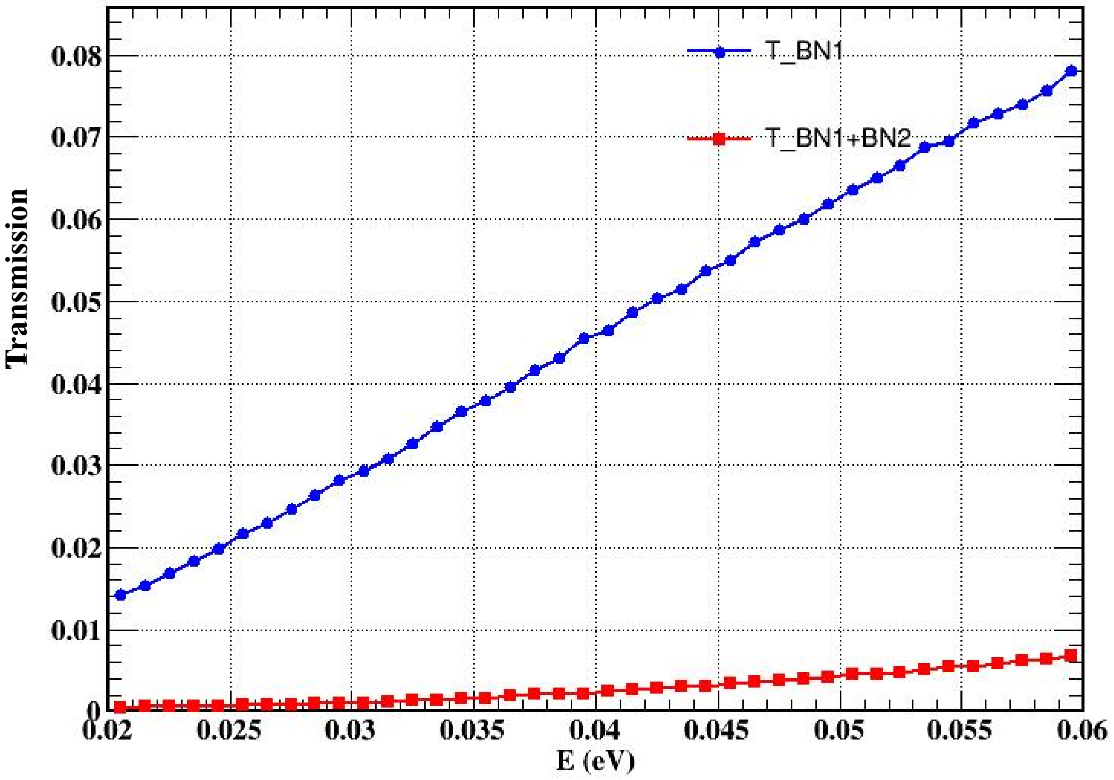
BN1 recorded over **10,000** counts per bin in the thermal region, with statistical uncertainty below **1%**, while BN1+BN2 showed lower statistics. Thus, the analysis is based on **BN1 and Sample out.**

Transmission

$$T_{BN1} = \frac{N_{BN1}}{N_{Sample\ out}} \cdot \frac{P_{Sample\ out}}{P_{BN1}}$$

$$T_{BN1+BN2} = \frac{N_{BN1+BN2}}{N_{Sample\ out}} \cdot \frac{P_{Sample\ out}}{P_{BN1+BN2}}$$

T denotes **transmission**, N denotes neutron counts. P denotes the proton number impinging the spallation target.

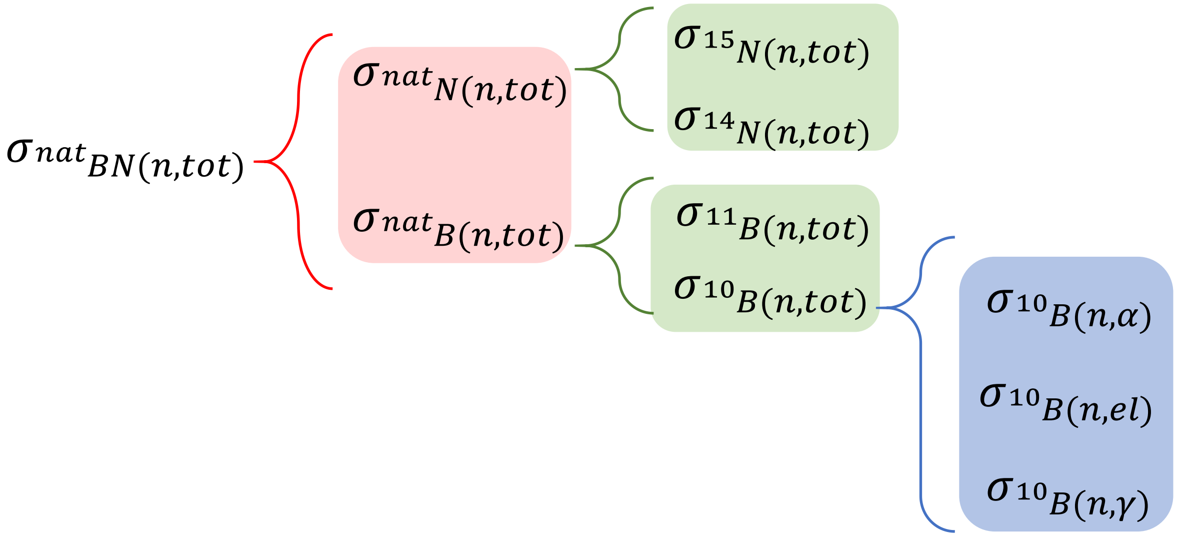


Total Cross Section and Correction

$$\sigma_{{}^{nat}B(n,tot)} = \frac{-lnT}{N_s} - C_{{}^{15}N}\sigma_{{}^{15}N(n,tot)} - C_{{}^{14}N}\sigma_{{}^{14}N(n,tot)}$$

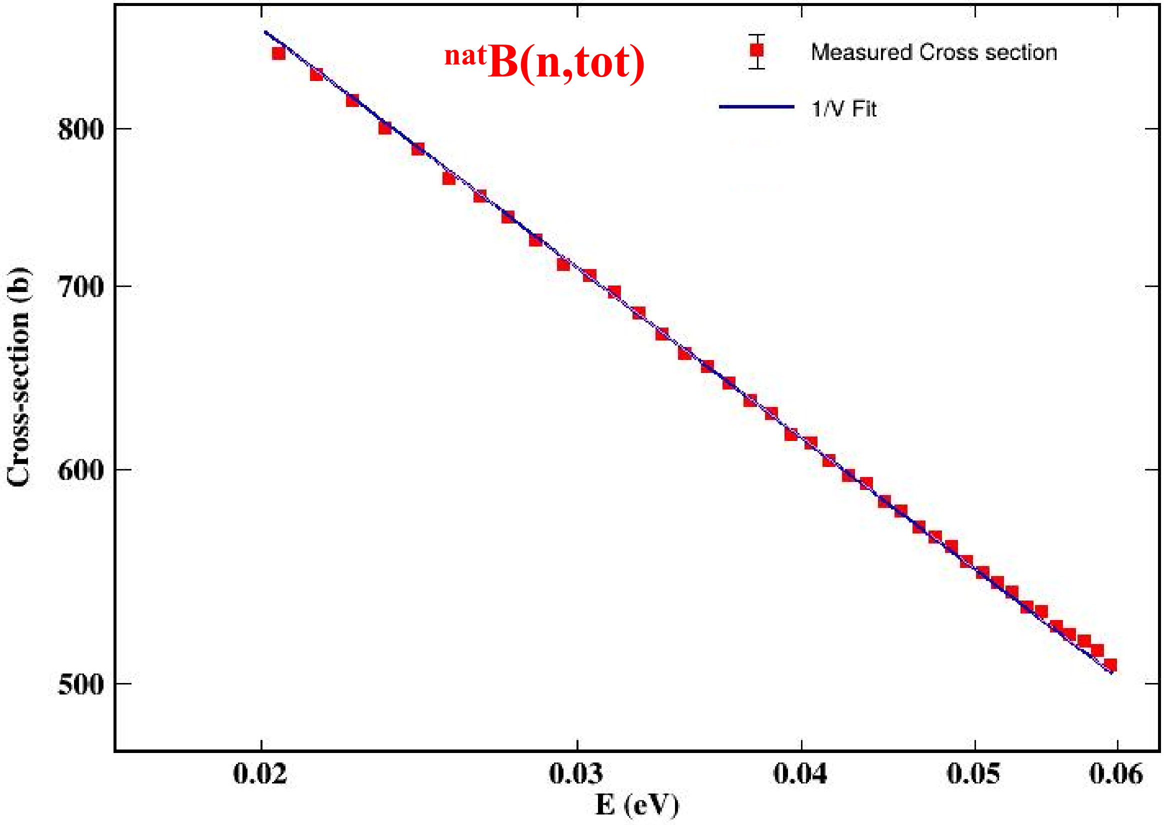
$$\sigma_{{}^{10}B(n,\alpha)} = (\sigma_{{}^{nat}B(n,tot)} - C_{{}^{11}B}\sigma_{{}^{11}B(n,tot)})/C_{{}^{10}B} - \sigma_{{}^{10}B(n,el)} - \sigma_{{}^{10}B(n,\gamma)}$$

N_s denotes the **areal density** of the BN. C_i denotes the abundance of the i-th nuclide.

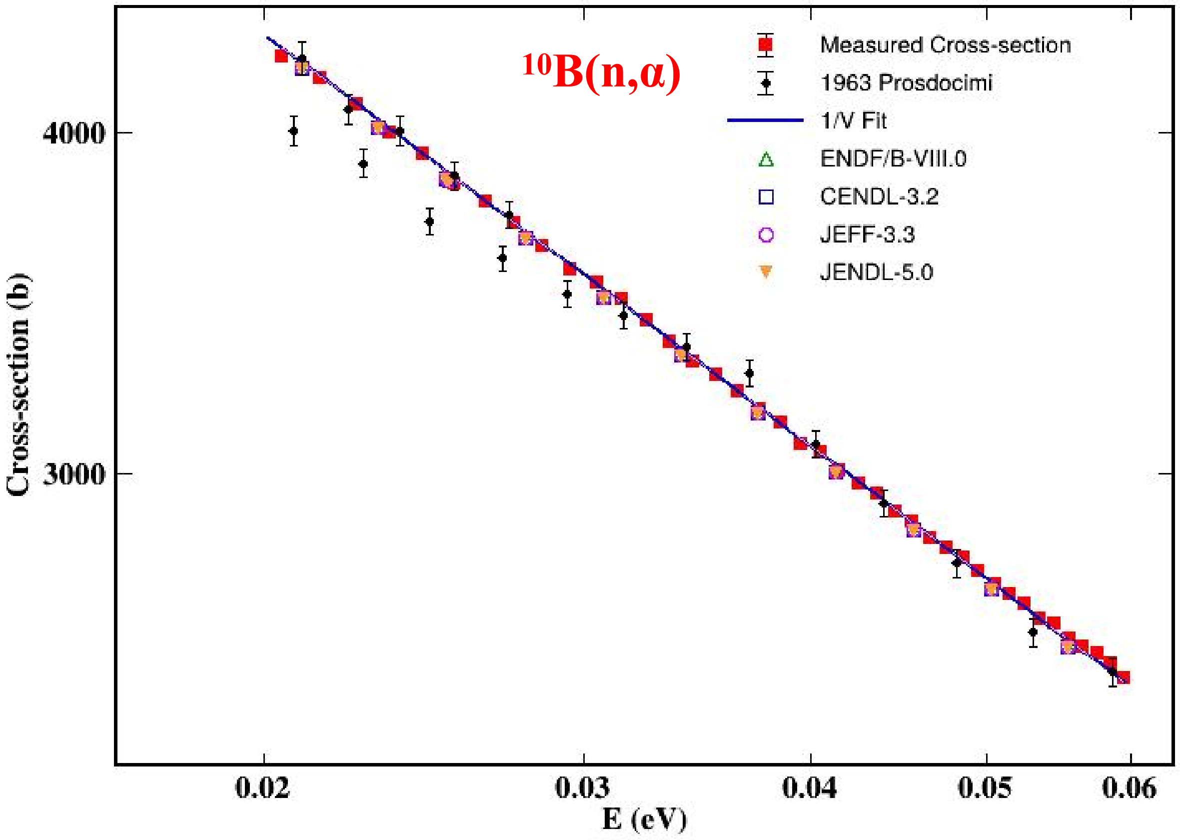


Cross-section (Preliminary)

- ^{nat}B total cross section



- ^{10}B(n,α) cross section

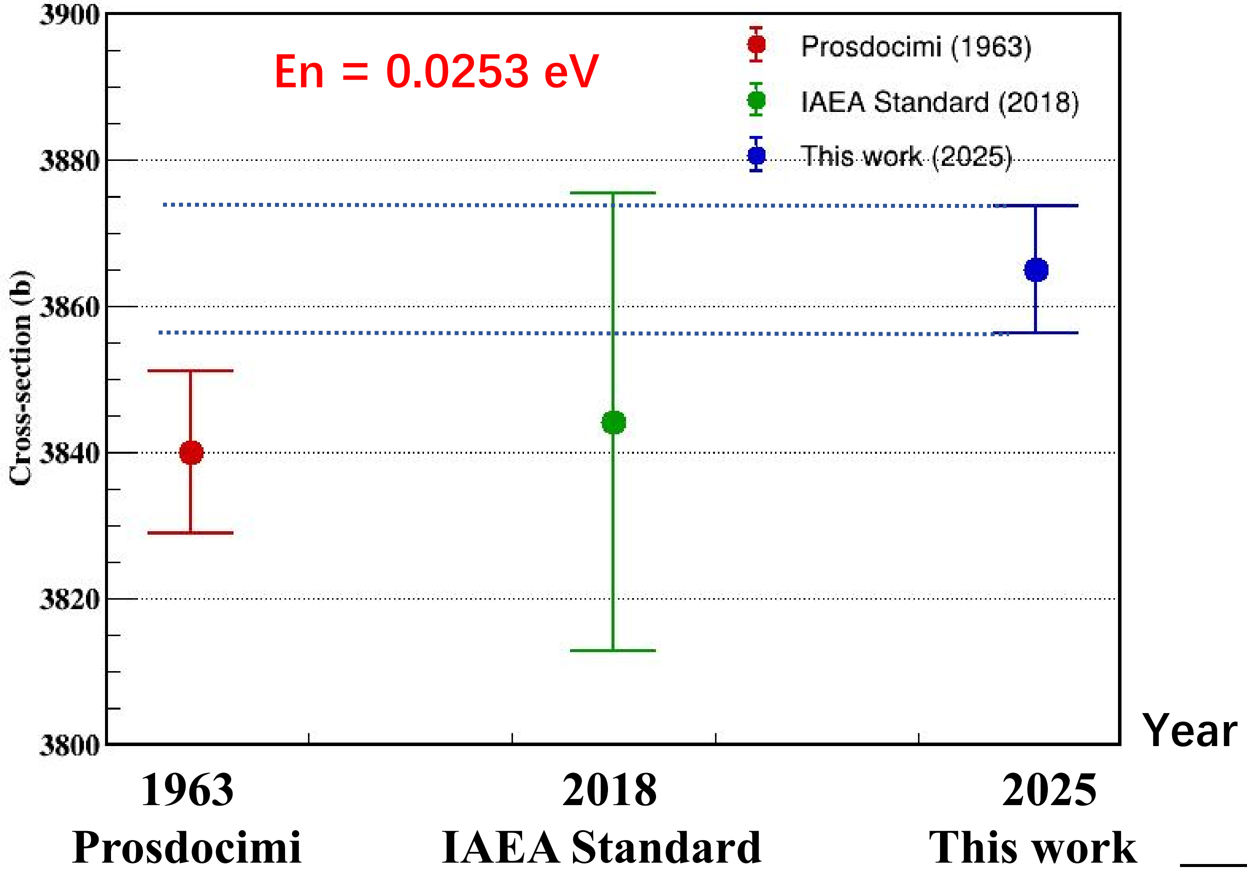


^{nat}B tot (0.0253 eV)	1963 Prosdocimi	This work (1/v Fit)
Cross-section (b)	760.8±1.9	**774.77±1.69**

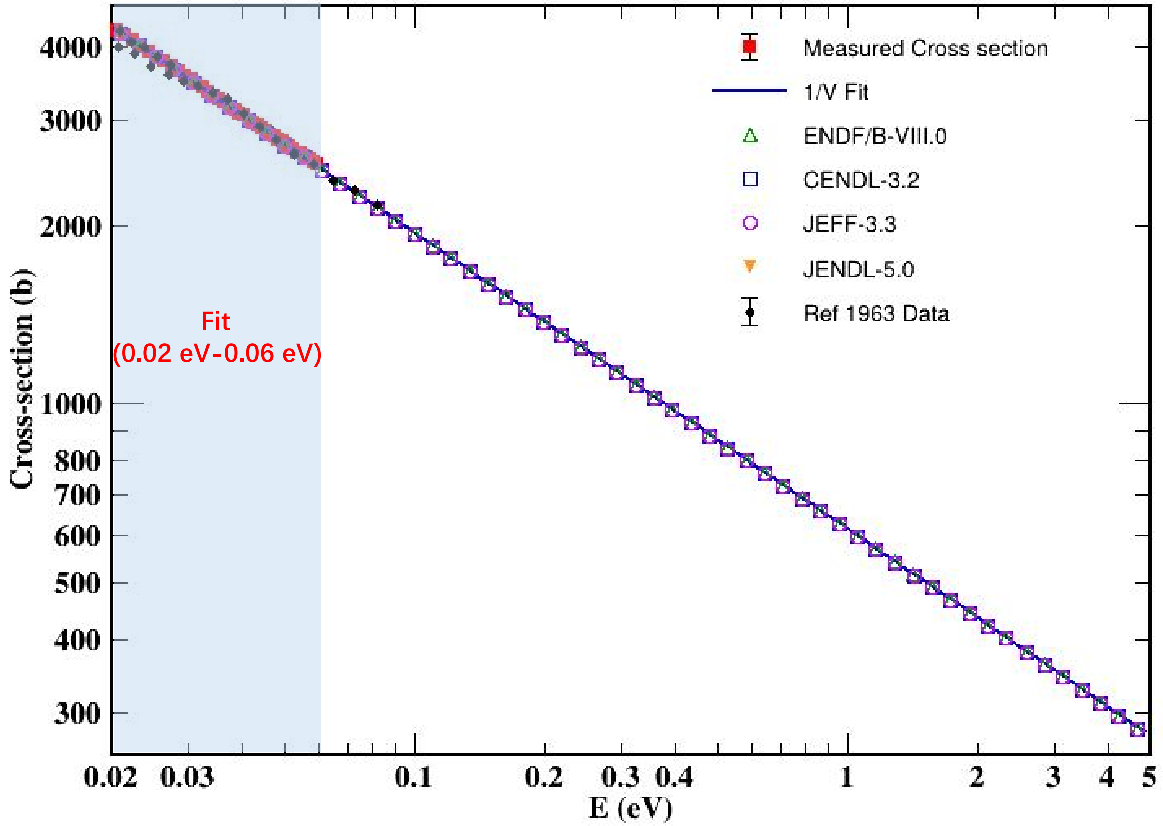
^{10}B(n,α) (0.0253 eV)	IAEA Standard	ENDF/B-VIII.0	CENDL-3.2	JEFF-3.3	JENDL-5.0	1963 Prosdocimi	This work (1/v Fit)
Cross-section (b)	3844.121±31.5	3844.16	3842.37	3842.37	3836.98	3840±11	**3864.99±8.44**

Cross-section (Preliminary)

- ^{10}B(n, a) cross section at thermal point



- $^{10}B(n,\alpha)$ cross-section (0.02 eV-5 eV)



$^{10}B(n,\alpha)$ (5.0 eV)	This work (1/v Fit)	ENDF/B-VIII.0	CENDL-3.2	JEFF-3.3	JENDL-5.0
Cross-section (b)	**274.931**	273.507	271.46	271.46	272.447

Error analysis

Uncertainty estimation

$$\frac{\Delta\sigma_{BN(n,tot)}}{\sigma_{BN(n,tot)}} = \frac{1}{\ln T}\sqrt{\left(\frac{\Delta T}{T}\right)^2 + \left(\ln T \cdot \frac{\Delta N_s}{N_s}\right)^2}$$

$$\frac{\Delta\sigma_{natB(n,tot)}}{\sigma_{natB(n,tot)}} = \frac{\sqrt{\Delta\sigma_{BN(n,tot)}{}^2 + \Delta\sigma_{natN(n,tot)}{}^2}}{\sigma_{natB(n,tot)}}$$

$$\frac{\Delta\sigma_{10B(n,tot)}}{\sigma_{10B(n,tot)}} = \frac{\sqrt{\Delta\sigma_{natB(n,tot)}{}^2 + (\Delta\sigma_{B11}\cdot C_{B11})^2}}{\sigma_{10B(n,tot)}\cdot C_{B10}}$$

$$\frac{\Delta\sigma_{10B(n,\alpha)}}{\sigma_{10B(n,\alpha)}} = \frac{\sqrt{\Delta\sigma_{10B(n,tot)}{}^2 + \Delta\sigma_{10B(n,el)}{}^2 + \Delta\sigma_{10B(n,\gamma)}{}^2}}{\sigma_{10B(n,\alpha)}}$$

Sources of uncertainty

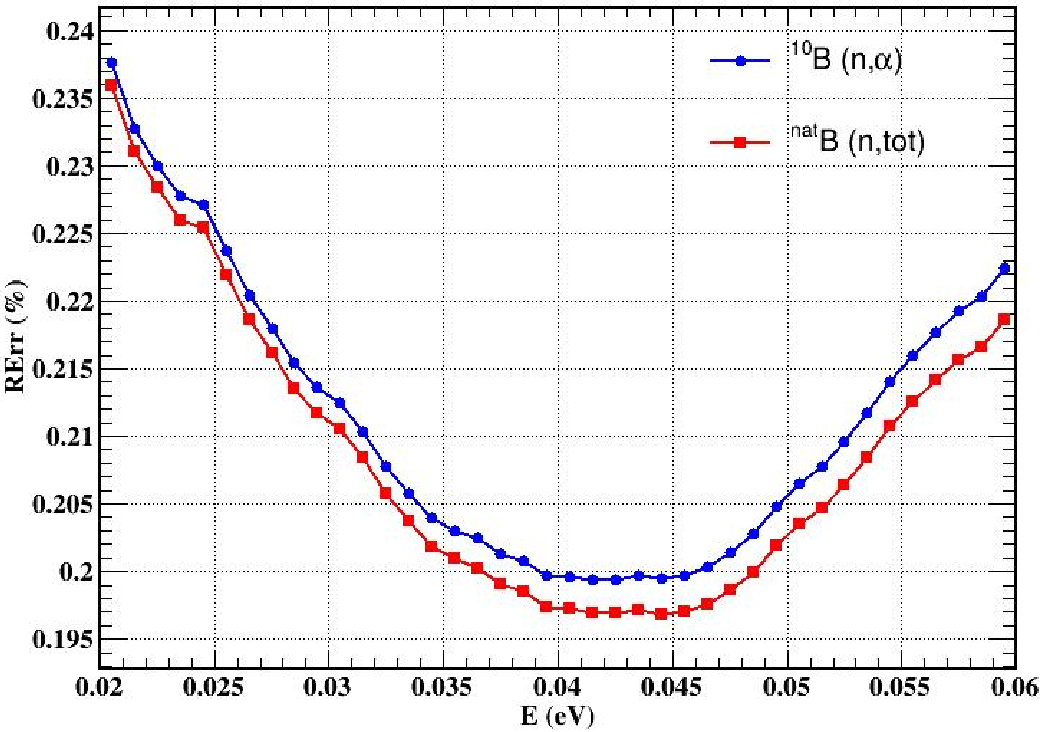
1. Statistics → Primary
2. Sample mass
3. Sample surface area
4. Cross-section library data

(2–4) → Minor

5. Flight distance calibration
6. Flight time
7. Sample impurity
8. Isotopic abundance

(5–8) → Negligible

Relative Error vs Energy



Summary

➢ Conclusions

1.In the thermal neutron region, our measured cross section deviates from the IAEA standard by 20.87 b (0.54%), suggesting a possible need for refinement of the existing IAEA reference data.

2.The maximum uncertainty in this measurement is only 0.238%, demonstrating a high-precision determination of the $^{10}B(n, \alpha)$ cross-section at thermal region. It is lower than the uncertainties reported in both IAEA and 1963 (Prosdocimi) data.

3. This work reports the first physics measurement at thermal region at CSNS Back-n, extending the facility's capability to the thermal region.

➢ Future works

1. Investigate the potential impact of sample and beam inhomogeneities.

2.Refined background and uncertainty analysis to improve $^{10}B(n,\alpha)$ cross-section accuracy

中国散裂中子源
China Spallation Neutron Source

Thank you！

恳请各位专家批评指正

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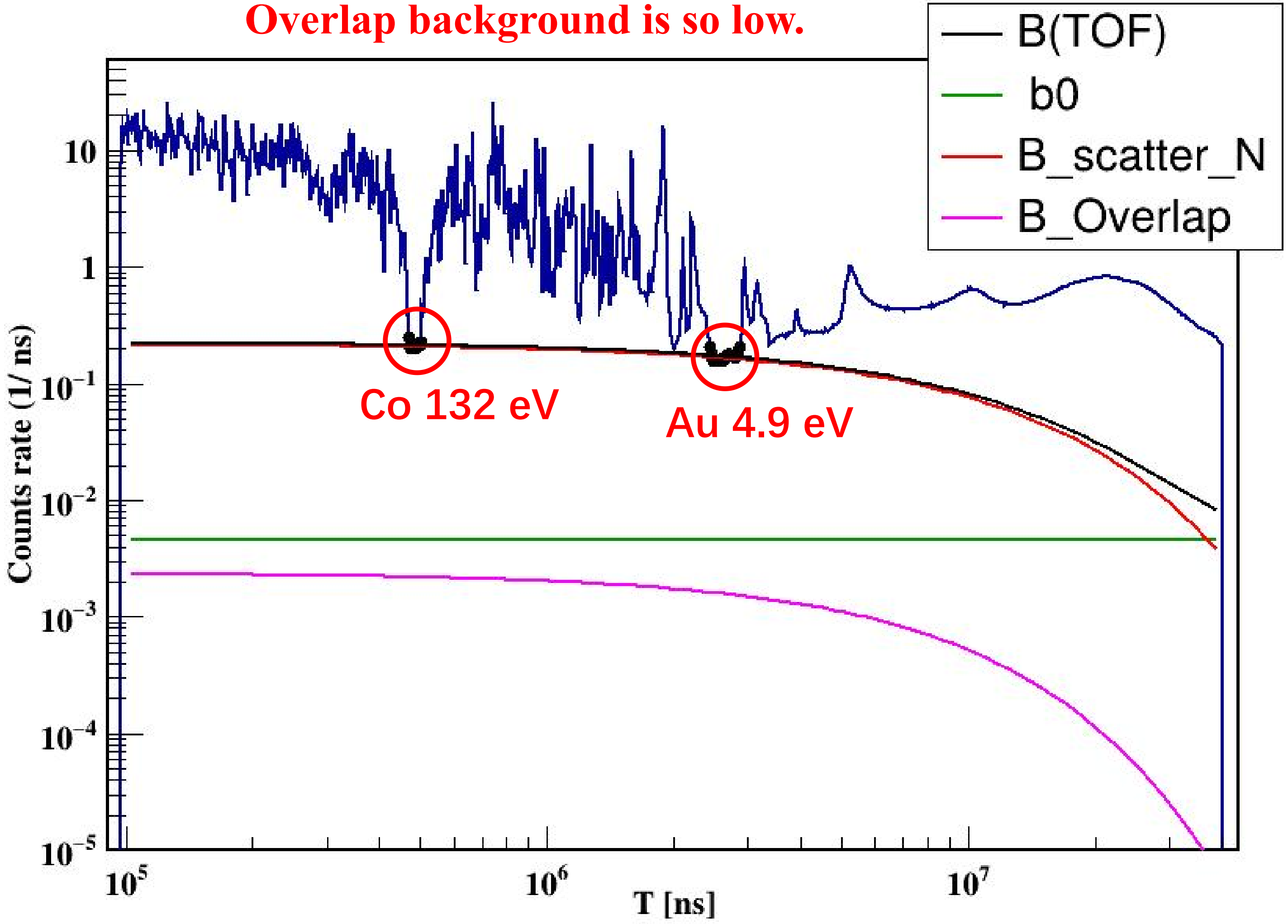
$$B = B_0 + B_{scatter} + B_{overlap} = b_0 + b_1 * e^{-\lambda_1 t} + b_2 * e^{-\lambda_2 (t+4E6)}$$

$$B = 0.00457497 + 0.218313 * e^{(-1.04298E-7)*t} + 1.00009 * e^{-1.51174E-7*(t+4E6)}$$

Overlap background is so low.



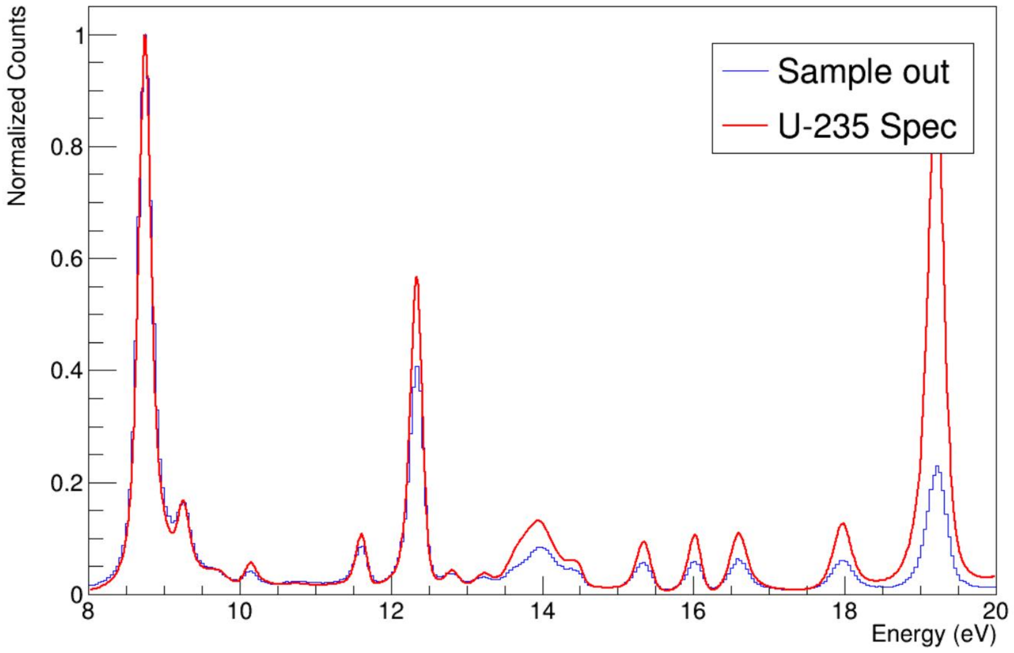
Neutron energy resolution (0.0253 eV)

$$\frac{dv}{v} = \sqrt{(\frac{\Delta L}{L})^2 + (\frac{\Delta T}{T})^2} = 0.0623\%$$

$$\frac{dE}{E} = \gamma(\gamma + 1)\sqrt{(\frac{\Delta L}{L})^2 + (\frac{\Delta T}{T})^2} = 0.1247\%$$

ΔL = 4.8 cm，ΔT = 205 ns，
L = 76.9589 m，T = 34980813 ns

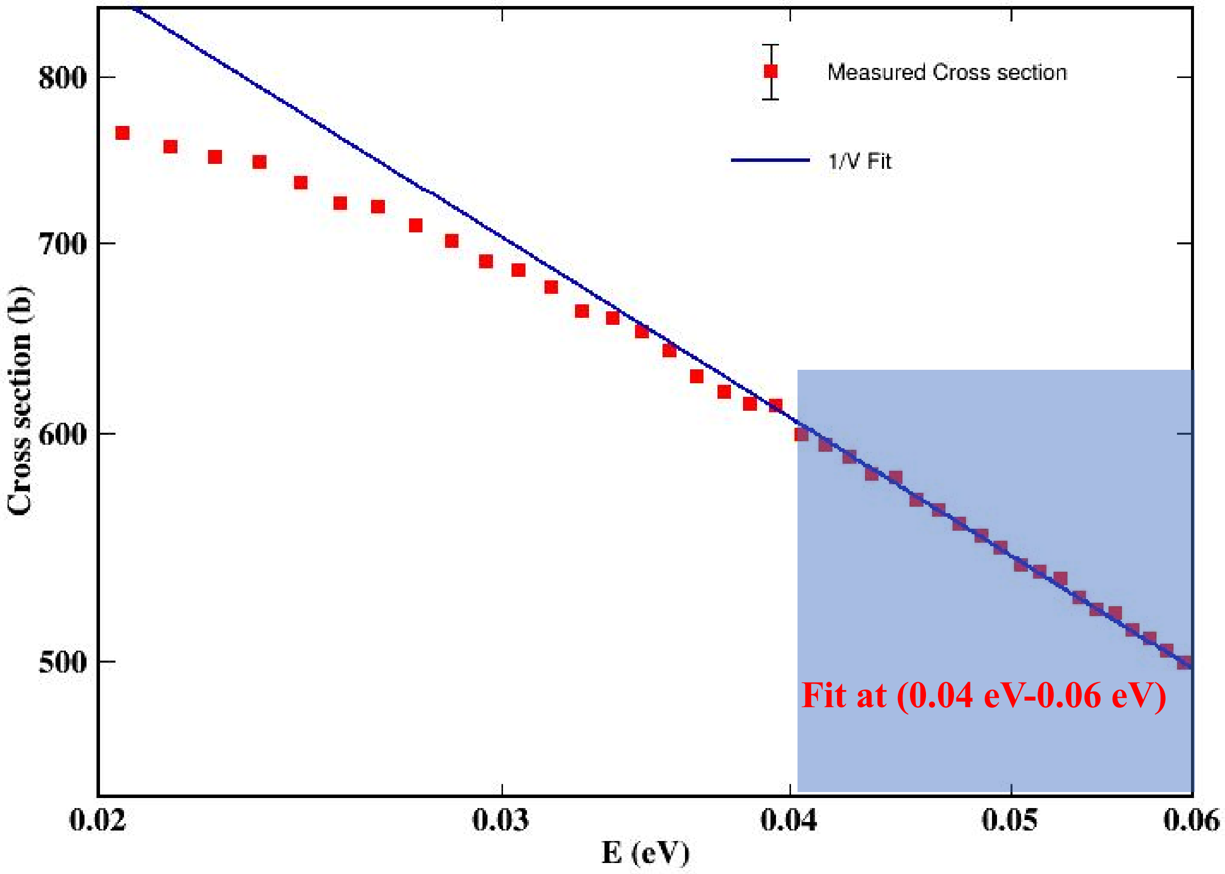
Verify flight distance



[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20192003	1963	A. Prosdoci	3896	45	0. 15	0. 006	0. 5	0. 0227
20192003	1963	A. Prosdoci	4004	48	0. 15	0. 006	0. 5	0. 0238
20192003	1963	A. Prosdoci	3711	41	0. 15	0. 006	0. 5	0. 0247
20192003	1963	A. Prosdoci	3856	46	0. 15	0. 006	0. 5	0. 0255
20192003	1963	A. Prosdoci	3597	39	0. 15	0. 006	0. 5	0. 0271
20192003	1963	A. Prosdoci	3732	43	0. 15	0. 006	0. 5	0. 0273
20192003	1963	A. Prosdoci	3491	40	0. 15	0. 006	0. 5	0. 0294

- ^{nat}B total（BN1+BN2 and Sample out）

764.895 b (0.0253 eV)



- $^{10}B(n,\alpha)$ cross section （BN1+BN2 and Sample out）

3815.61 b (0.0253 eV)