Research on Neutron Flux Measurement of CSNS Back-n

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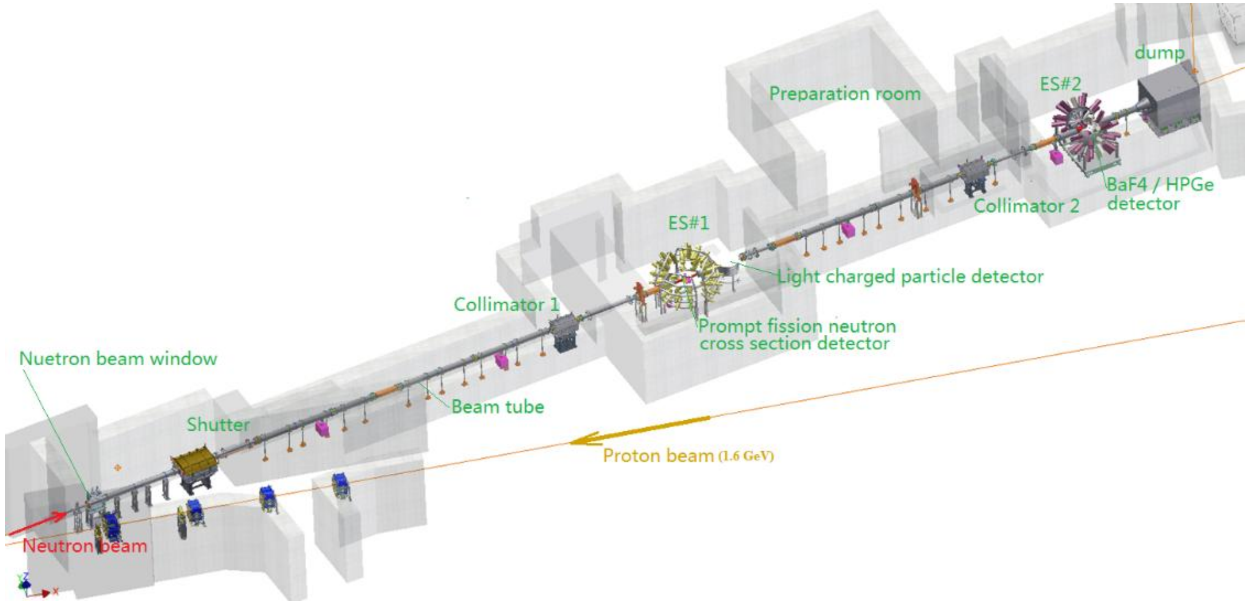
CONTENTS

CONTENTS

Motivation

China Spallation Neutron Source (CSNS) Back-streaming neutron beamline (Back-n) is suitable for various **scientific** and **technological** research.

- **Wide energy range (thermal to 300 MeV)**
- **High neutron flux (~10^7 n/s/cm^2)**
- **Good energy resolution (0.4%@1 eV, 4.9%@10 MeV)**



Motivation

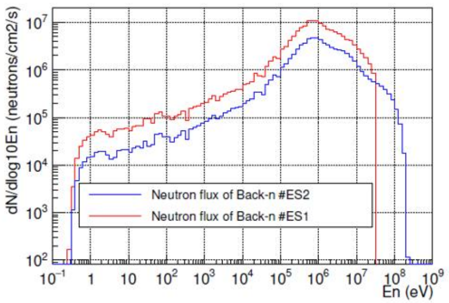
Importance of Neutron Flux

- Crucial and fundamental parameter of the facility
- Important guidance for planned measurements
- Prerequisite for the analysis of the measurements

At CSNS Back-n, continuous research efforts have been conducted to improve the reliability and precision of measurements

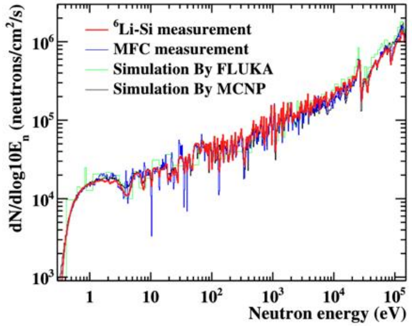
Yonghao Chen et al., EPJA (2019) 55: 115
Yonghao Chen et al., EPJ WC (2030) 239: 17018

2019-2020



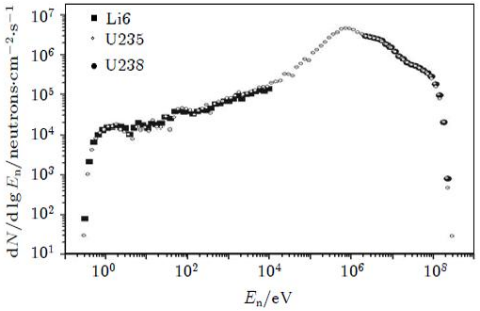
Yijia Qiu et al., NIMA (2025), 1075: 170383.

2025



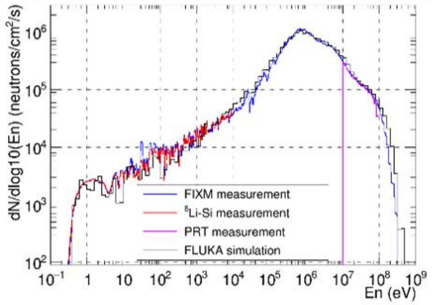
2018 → **2025**

2019



Bao Jie et al. Acta. Phys. Sin. (2019) 68(8): 080101.

2024



Yonghao Chen et al., EPJA (2024) 60: 63

Motivation

- Back-n has a very wide energy range spanning 10 orders of magnitude
- Back-n has 2 End Stations (ES#1/ES#2) and multiple beamline configurations (totaling 36 combinations)

Table 1 Four sets of standard beam spots and neutron fluxes with relevant collimator apertures at Back-n (100 kW)

Mode	Shutter (mm)	Coll#1 (mm)	ES#1 spot (mm)	ES#1 flux (n/cm^2/s)	Coll#2 (mm)	ES#2 spot (mm)	ES#2 flux (n/cm^2/s)
Low intensity	Φ3	Φ15	Φ15	1.3×10^5	Φ40	Φ20	4.6×10^4
Small spot	Φ12	Φ15	Φ20	1.6×10^6	Φ40	Φ30	6.1×10^5
Large spot	Φ50	Φ50	Φ50	1.8×10^7	Φ58	Φ60	6.9×10^6
Imaging	78 × 62	76 × 76	75 × 50	2.0×10^7	90 × 90	90 × 90	8.6×10^6

Jing-Yu Tang, et al. NST (2021) 32: 11

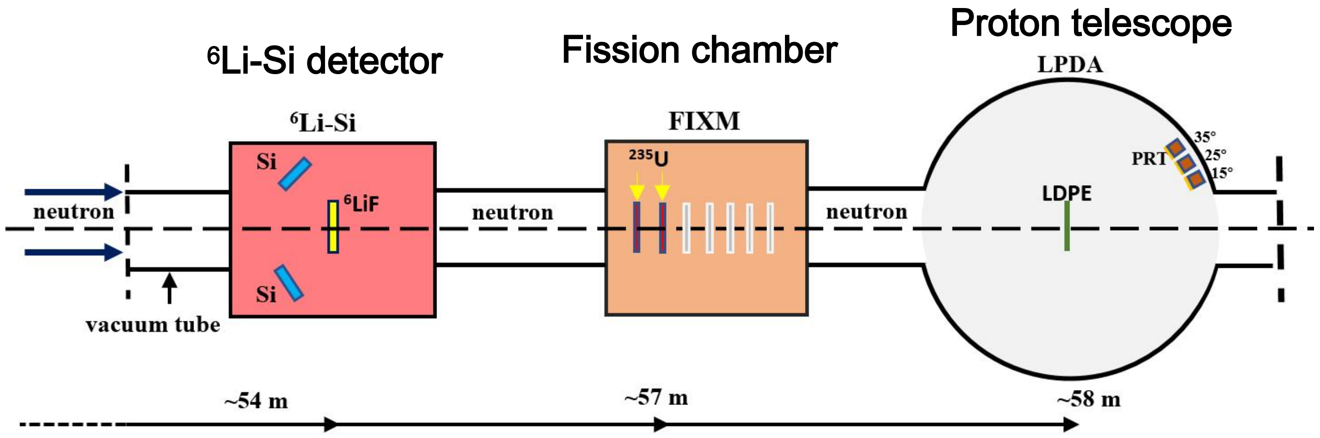
- **Measurement precision improvement**
- **Systematic research**

CONTENTS

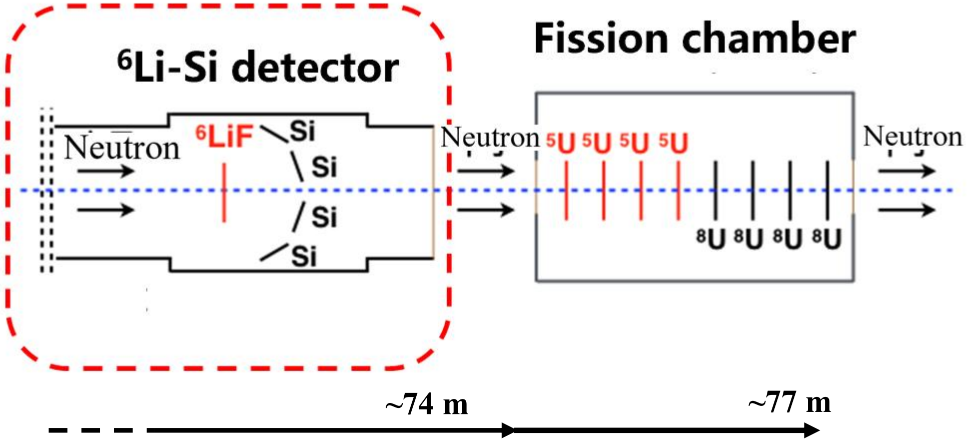
- Motivation
- Content
- Conclusion

Detectors

Flux measurement @ES#1



Flux measurement @ES#2



Detectors and induced reactions

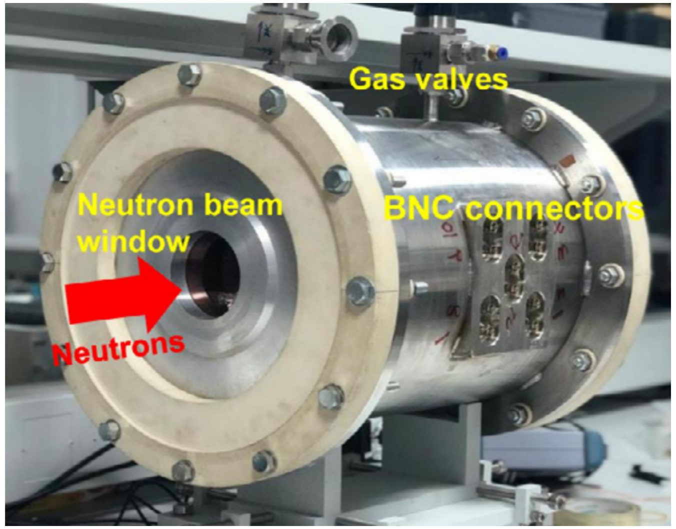
Detectors	Samples and reactions	Energy range
^{6}Li – Si	^{6}LiF/^{6}Li(n, t)	0.3eV – 150keV
FIXM	^{235}U/^{235}U(n, f)	0.3eV – 300MeV
PRT	LDPE/H(n, n)	10MeV – 70MeV

Experimental Setup

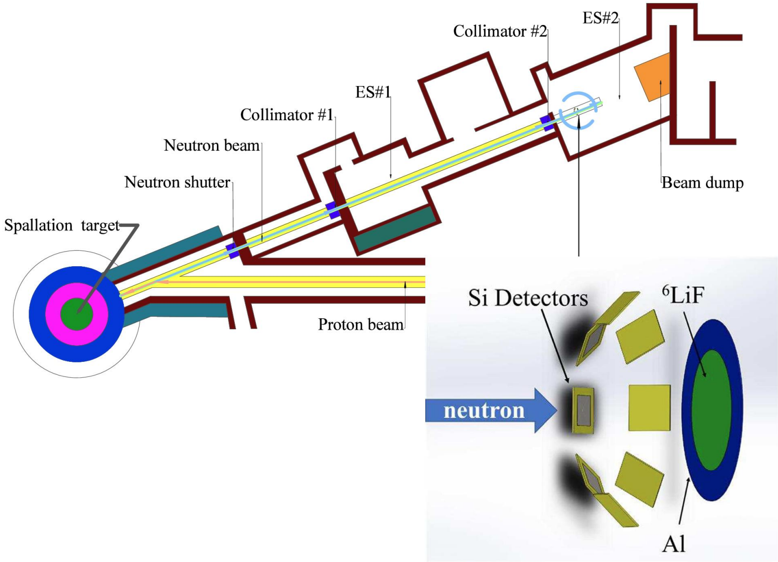
- The neutron flux at ES#2 was measured by a ^{6}Li -Si monitor and FIXM

Beamline Configurations @ES#2

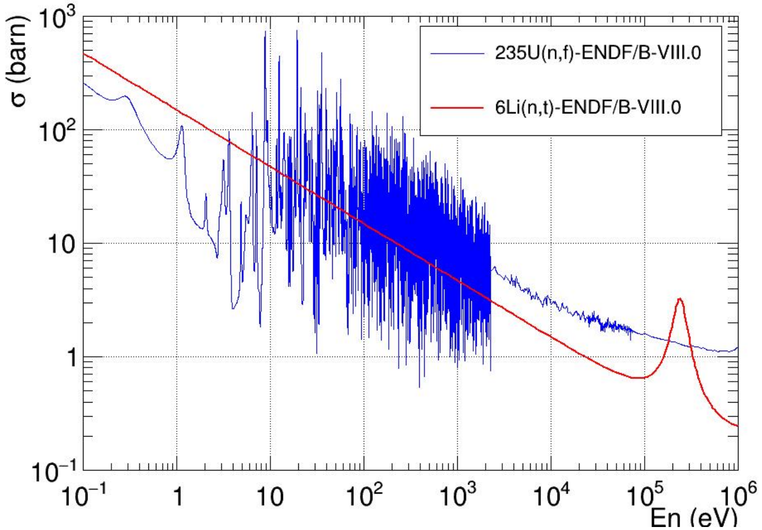
Shutter (mm)	Collimator 1 (mm)	Collimator 2 (mm)	Beam spot
50	50	58	Large beam spot Φ60
12	15	40	Small beam spot Φ30



FIXM (Fission Ionization chamber for Fission Cross-Section Measurements)
NIMA, 2019, 940: 486-491.



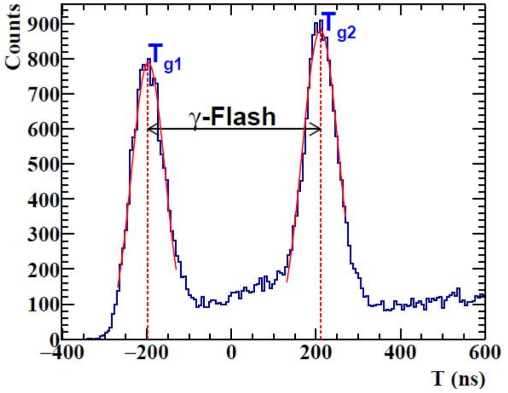
^{6}LiF conversion + 8 isotopically distributed Si detectors



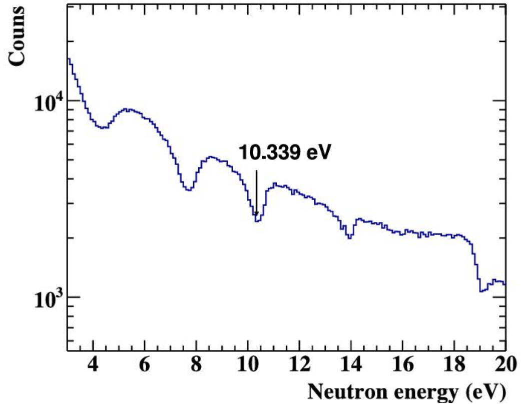
Li-Si Data Processing

- The neutron time-of-flight (TOF) method

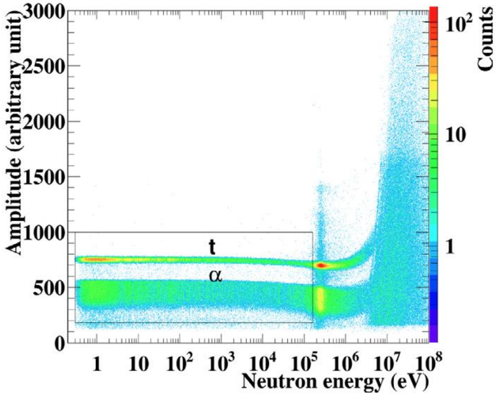
Calibration of T_0 using γ-flash



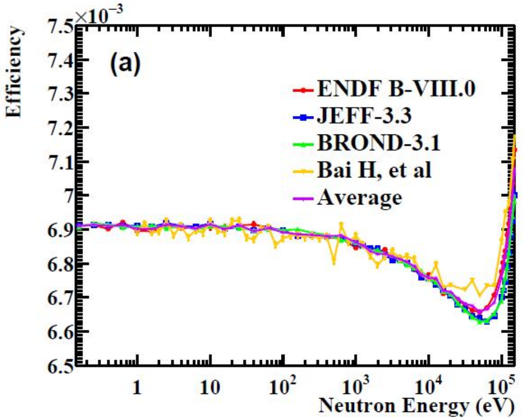
Calibration of the L using ^{181}Ta(n, tot) reaction

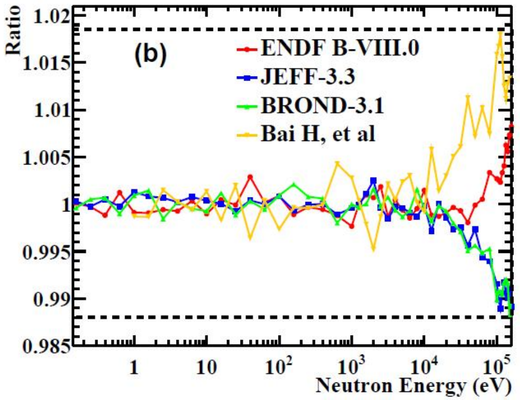


The two-dimensional distribution of neutron energy versus the signal amplitude.



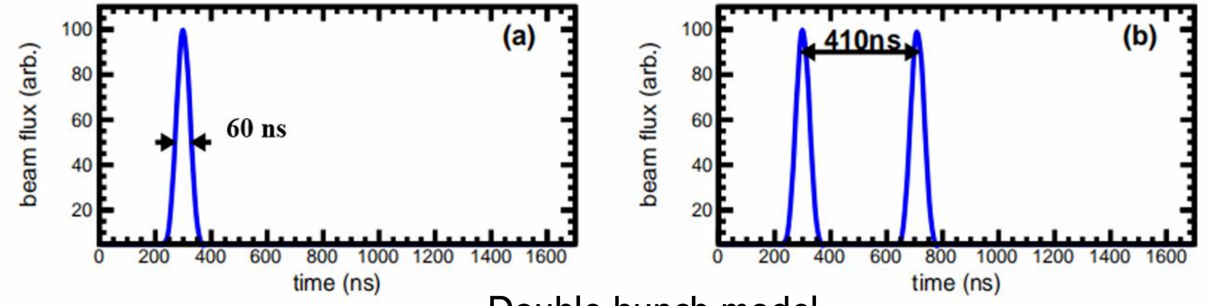
- Detection efficiency simulation
  - ✓ Simulation was based on different evaluation databases and experiment data(*CPC (2020) 44: 014003*) by Geant4
  - ✓ Detection efficiency above 1 keV is significantly affected by anisotropic angular distribution



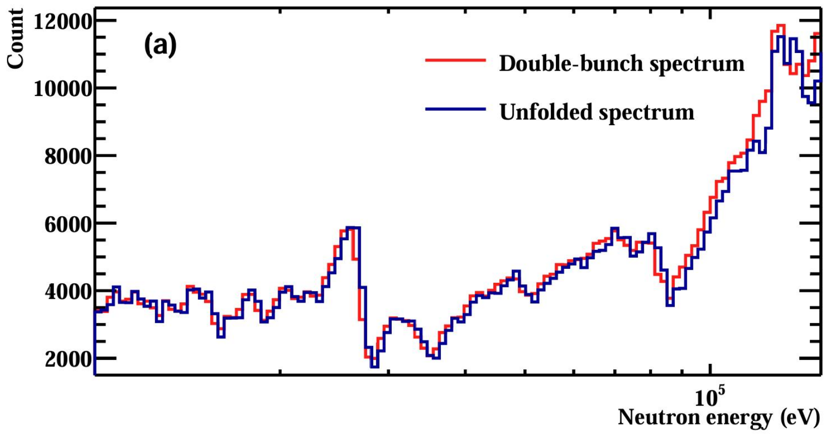


Li-Si Data Processing

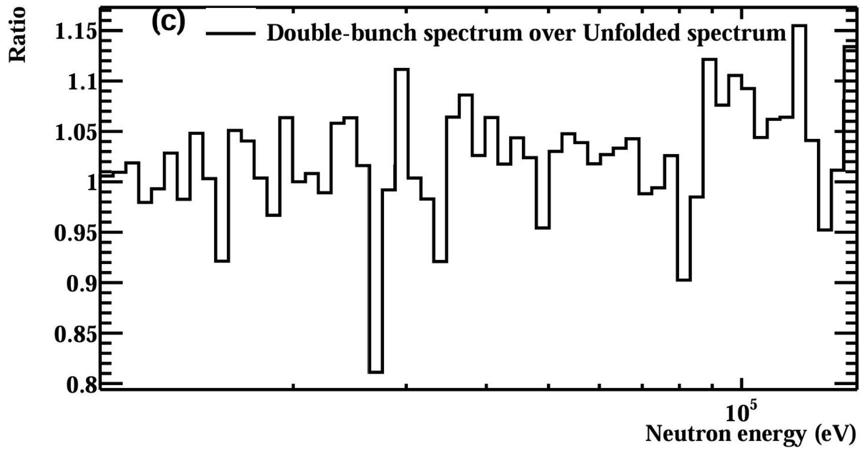
- Double bunch unfolding
  - ✓ The CSNS accelerator is usually operated in a double bunch mode, which means in each pulse there are two identical proton bunches with a 410 ns interval
  - ✓ **Double bunch unfolding program was based on Bayesian iteration method** (JINST 14 (2019): 02011)



Double bunch model



$$C_i^{k+1} = T_i \frac{C_i^{(k)}}{C_{i-\Delta}^{(k)} + C_i^{(k)}} + T_{i+\Delta} \frac{C_i^{(k)}}{C_i^{(k)} + C}$$

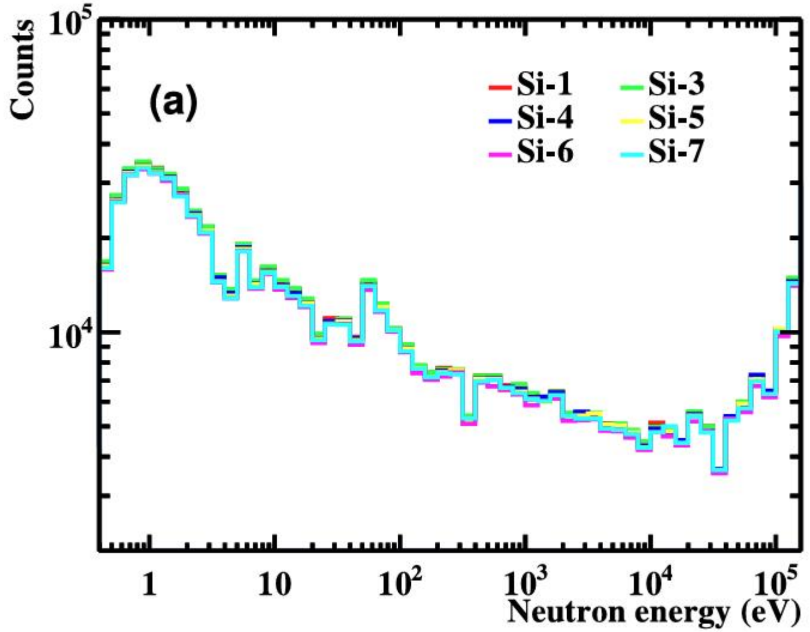


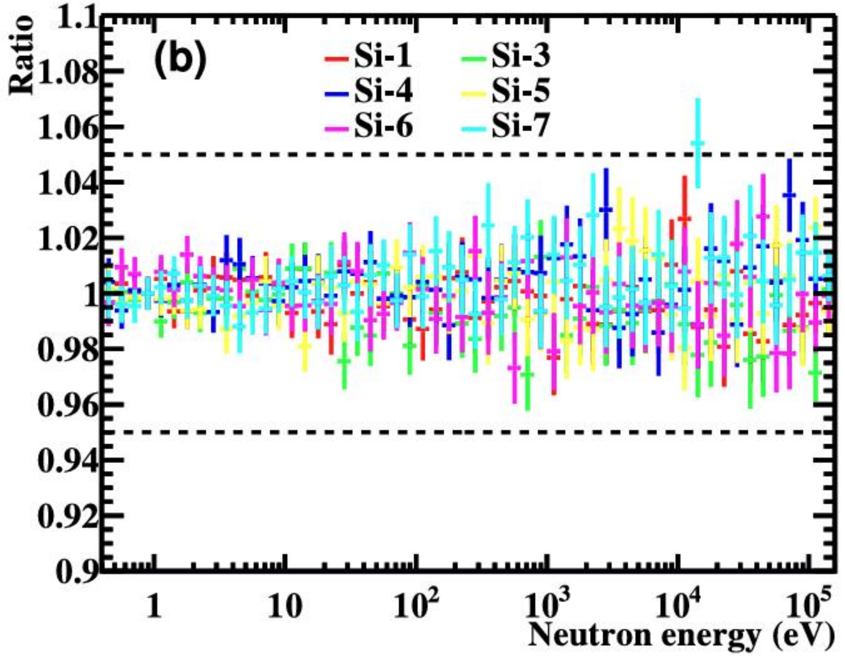
Li-Si Data Processing

- Measurement consistency

✓ To ensure measurement consistency, the reaction rates as a function of neutron energy was compared

✓ The coupling of the beam profile and the sample layer may result in the deviation

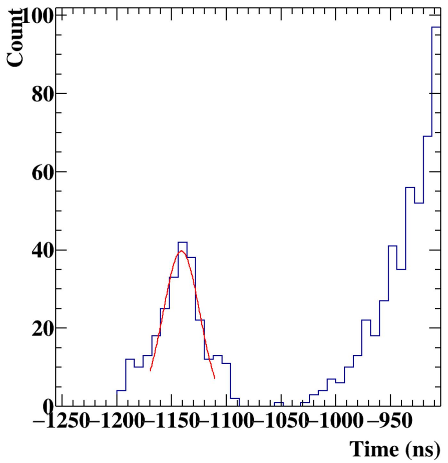




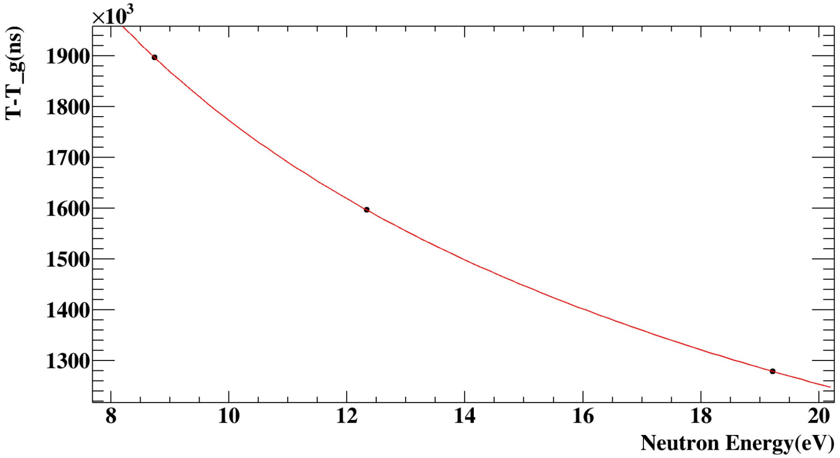
FIXM Data Processing

- The neutron time-of-flight (TOF) method was used

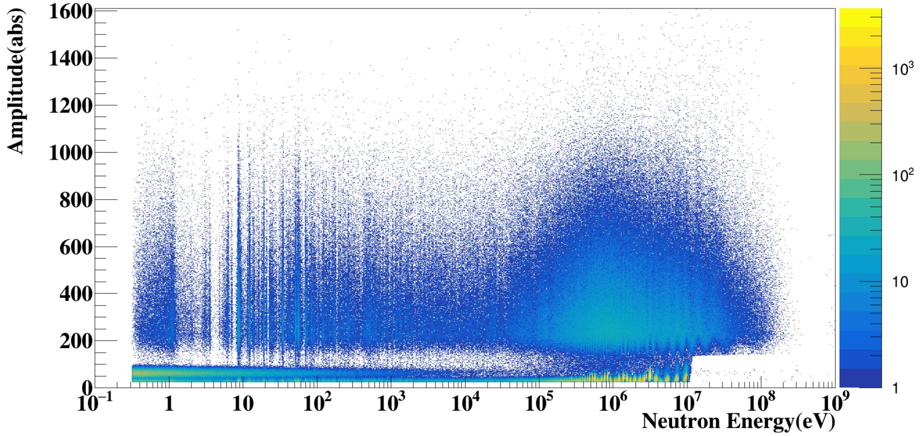
Calibration of T_0 using γ-flash



Calibration of the L using ^{235}U(n,f) reaction

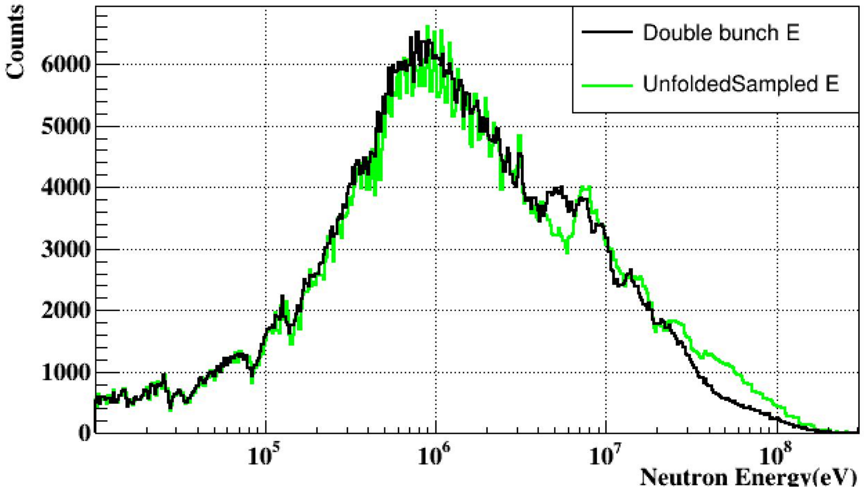


The two-dimensional distribution of neutron energy versus the signal amplitude.



- Double bunch unfolding

✓ **Double bunch unfolding program was based on Bayesian iteration method** (JINST 14 (2019): 02011)

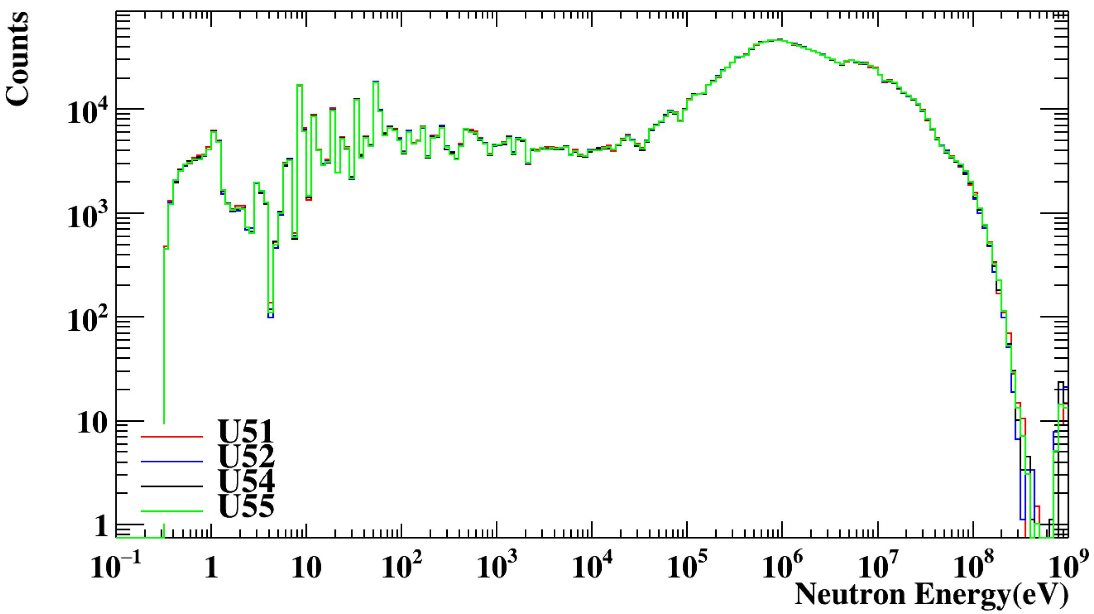


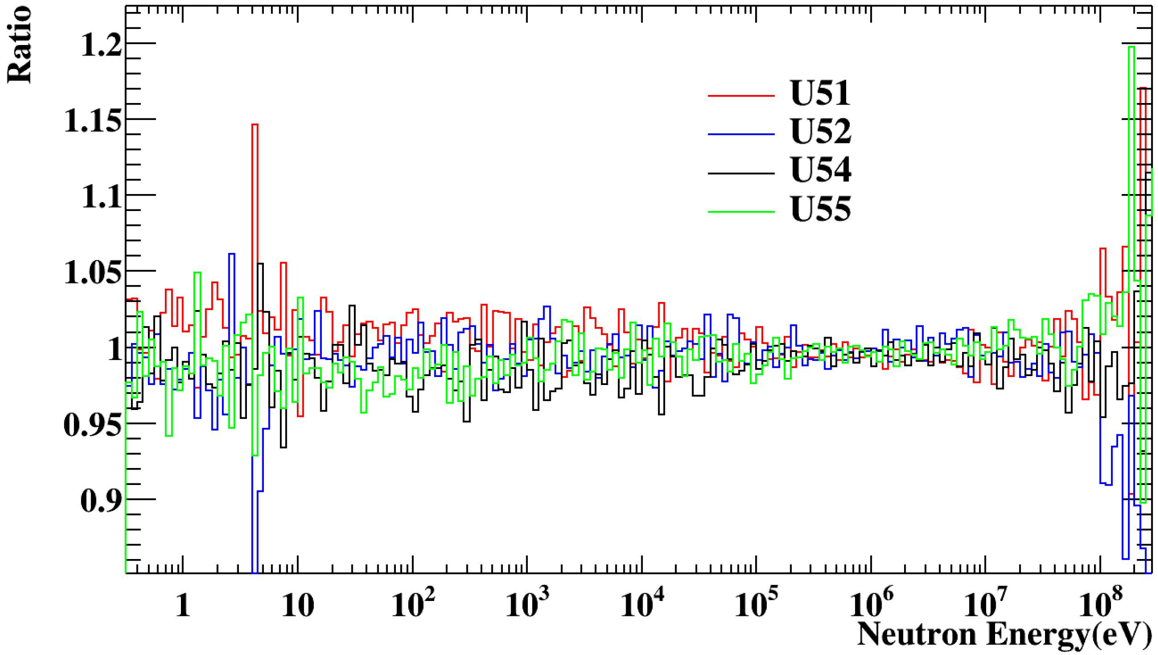
FIXM Data Processing

- Measurement consistency

✓ To ensure measurement consistency, the reaction rates as a function of neutron energy was compared

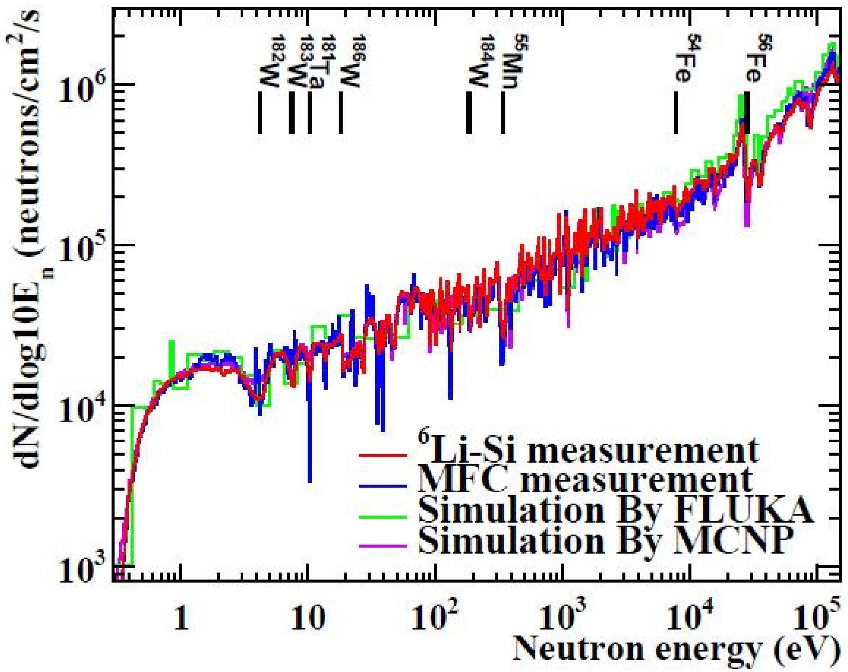
✓ The maximum deviation is less than 8% from 10 eV to 100MeV**(@ES#2 303030)**

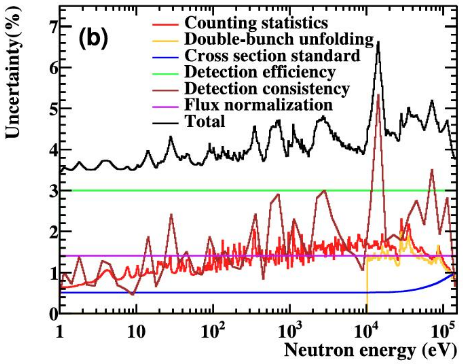


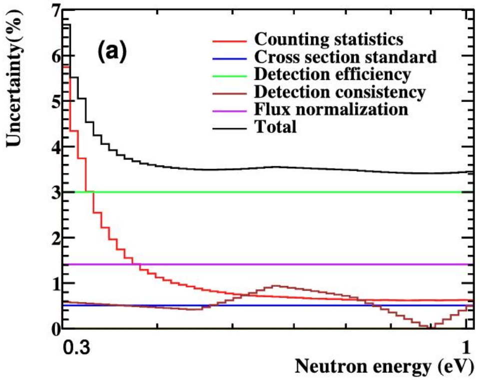


Large beam spot flux @ES#2

- The ^{6}Li-Si measurement in the low-energy range is significantly better than the fission chamber:
  - ✓ **Fewer oscillations， thereby offering a smoother flux shape**
- The ^{6}Li-Si measurement reflects the real structure of the beam：
  - ✓ **Consistent with MCNP simulation results, and dips due to absorption from the target system materials (W, Ta, Fe) can be observed clearly**
- The uncertainties are 3.4%-6.7% from 0.3 eV to 150keV measured by Li-Si monitor



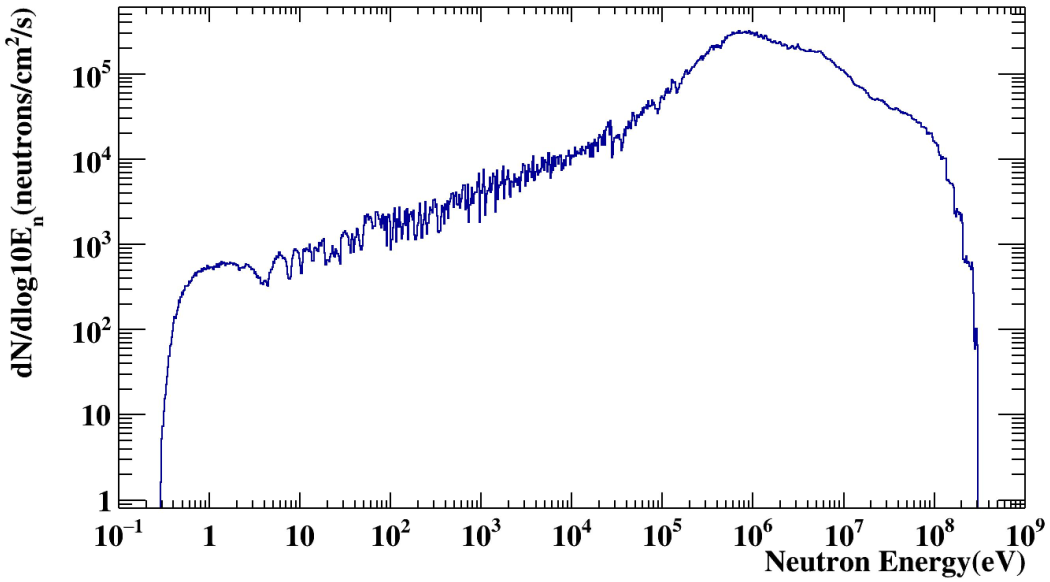


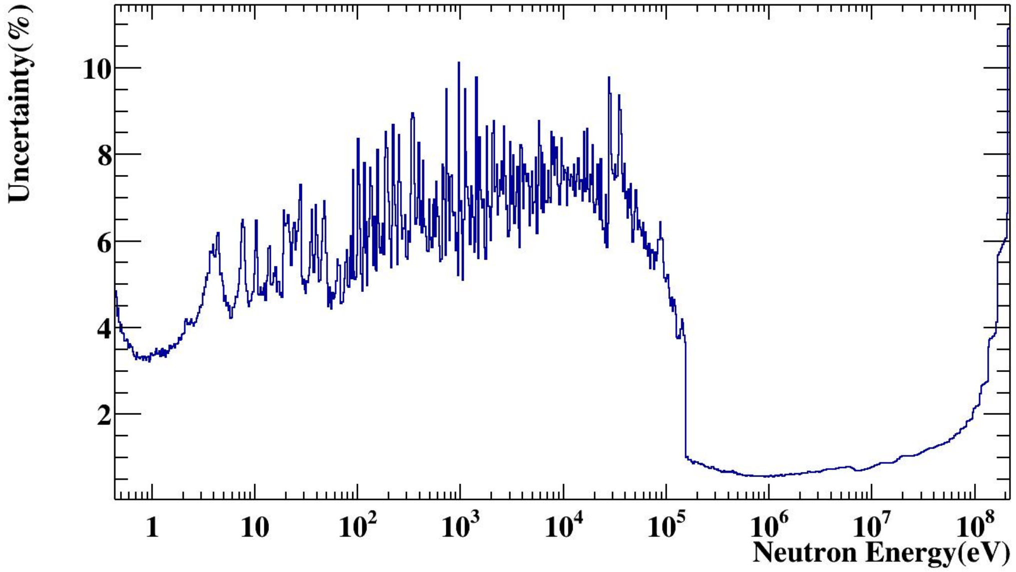


Source of uncertainty	Uncertainty
Counting statistics	0.6%–5.8%
Double-bunch unfolding	0.9%–2.0%
^{6}Li(n,t) cross-section	0.5%–1.0%
Detector efficiency	3.0%
Detector consistency	0%–5.3%
Flux normalization	1.4%
Total	3.4%–6.7%

Small beam spot flux @ES#2

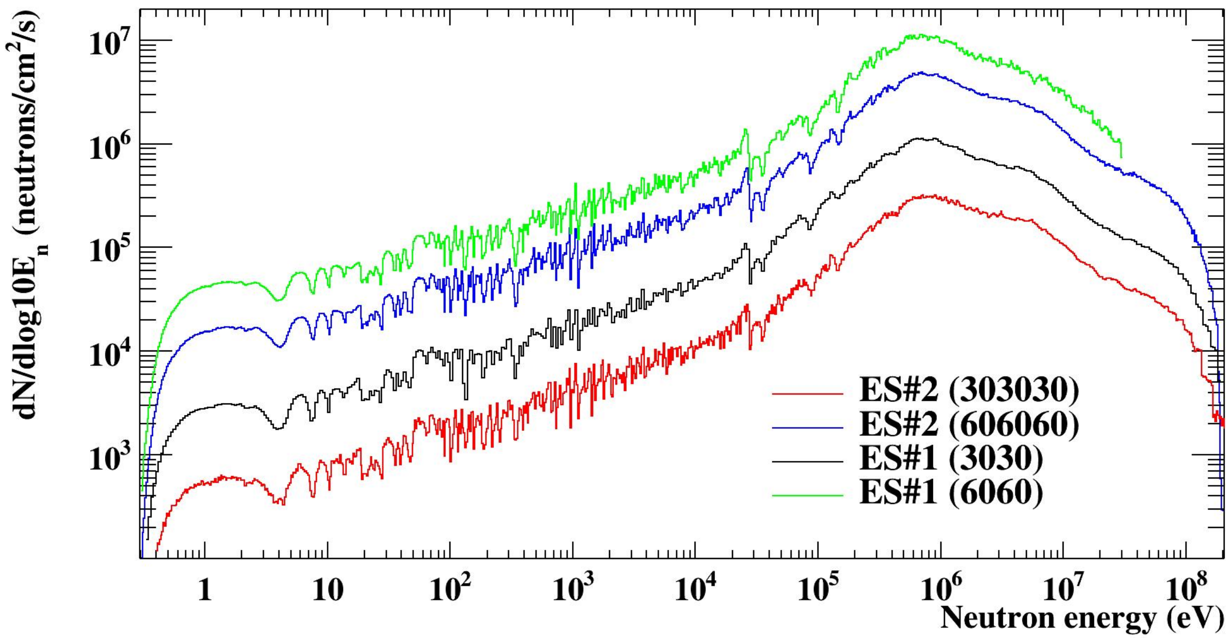
- The statistical uncertainties are less than 10% (0.3 eV – 150 keV measured by Li-Si monitor) and less than 6.5% (150keV – 200MeV measured by FIXM)

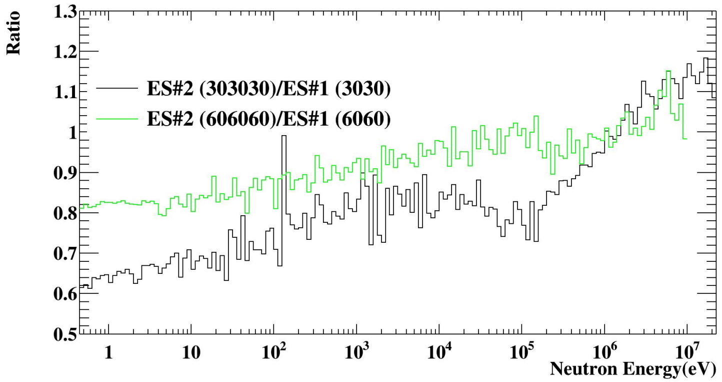


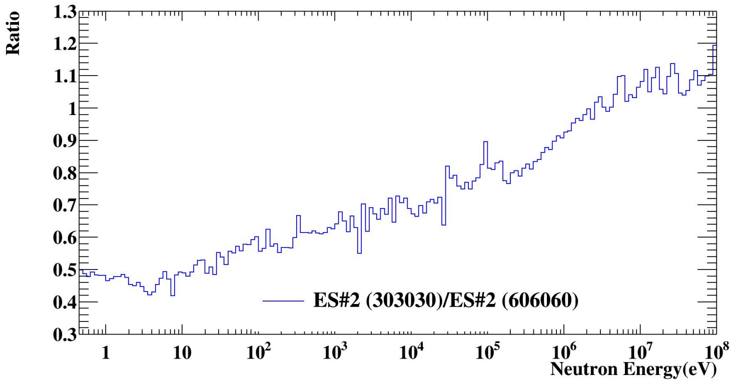


Flux under different configurations

- ✓ Comparison of flux under different configurations and different end stations
- ✓ Under the same beamline configuration, different end stations have different neutron flux
- ✓ At the same end station, different beamline configurations reshape the neutron flux
- ✓ Neutrons in the beamline are absorbed by materials such as Fe/Cu in the beam shutter and collimators







CONTENTS

Conclusion

1. The large beam spot flux of the Back-n ES#2 in the low-energy region (0.3 eV – 150 keV) with uncertainties range of 3.4-6.7%, was obtained relatively detailed and precise result
2. The small beam spot flux of the Back-n ES#2 (0.3 eV – 200 MeV) with statistical uncertainties range of 0.5-10.0%, was obtained
3. The flux is **influenced by the beamline configuration**, primarily due to neutron absorption by the shutter and collimator of the beamline

Measurement Flux Data URL

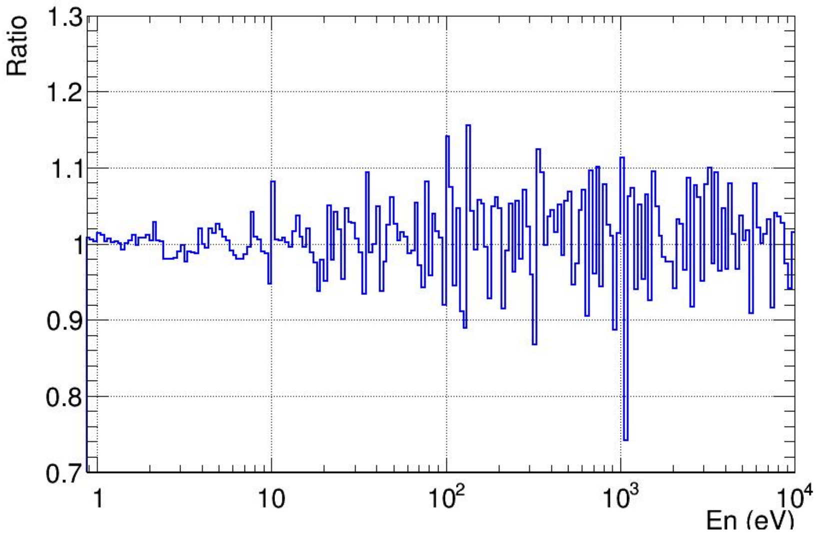
https://code.ihep.ac.cn/beag_csns/share/-/wikis/Back-n?redirected_from=Back%E2%80%90n

Thank you

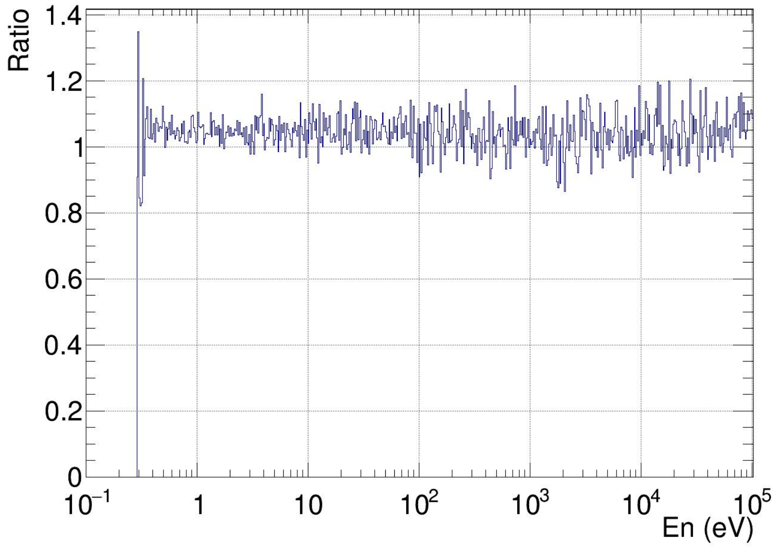
Back up

- Comparison of flux at different accelerator powers measured in different time
- ✓ The flux of Back-n does not change with the increase of CSNS accelerator power (20 kW→125 kW)

Comparison between 20 kW and 100 kW



Comparison between 100 kW and 125 kW



- 20 kW (February 2018)
- 100 kW (February 2020, December 2021)
- 125 kW (March 2022)

- Comparison of spectra under 2 beamline configurations of 2 end stations
- ✓ Under the same beamline configuration, the proportion of low-energy neutrons (1 eV-100 keV) in ES#2 is lower than that in ES#1
- ✓ In ES#2, the proportion of low-energy neutrons (1 eV-100 keV) in the small beam spot is lower than that in the large beam spot.
- ✓ Except for the small beam spot in ES#2, different beamline configurations have minimal impact on the shape of the fast neutron energy spectrum.
- ✓ Materials such as Fe/Cu in the neutron shutter and collimator absorb low-energy neutrons in the beamline. Additionally, when the collimator size is small, it can absorb/moderate fast neutrons.