Measurement of the neutron flux with small collimator of Back-n #ES1 at CSNS

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28-th International on Nuclear Data for Science and Technology. May 24-28, 2021.

Outline

1. CSNS and Back-n facility
2. Experimental setup
3. Analysis and results
4. Conclusions and outlooks

1. CSNS and Back-n facility

- Where are we (**C**hina **S**pallation **N**eutron **S**ource)?

1. Back-n facility at CSNS

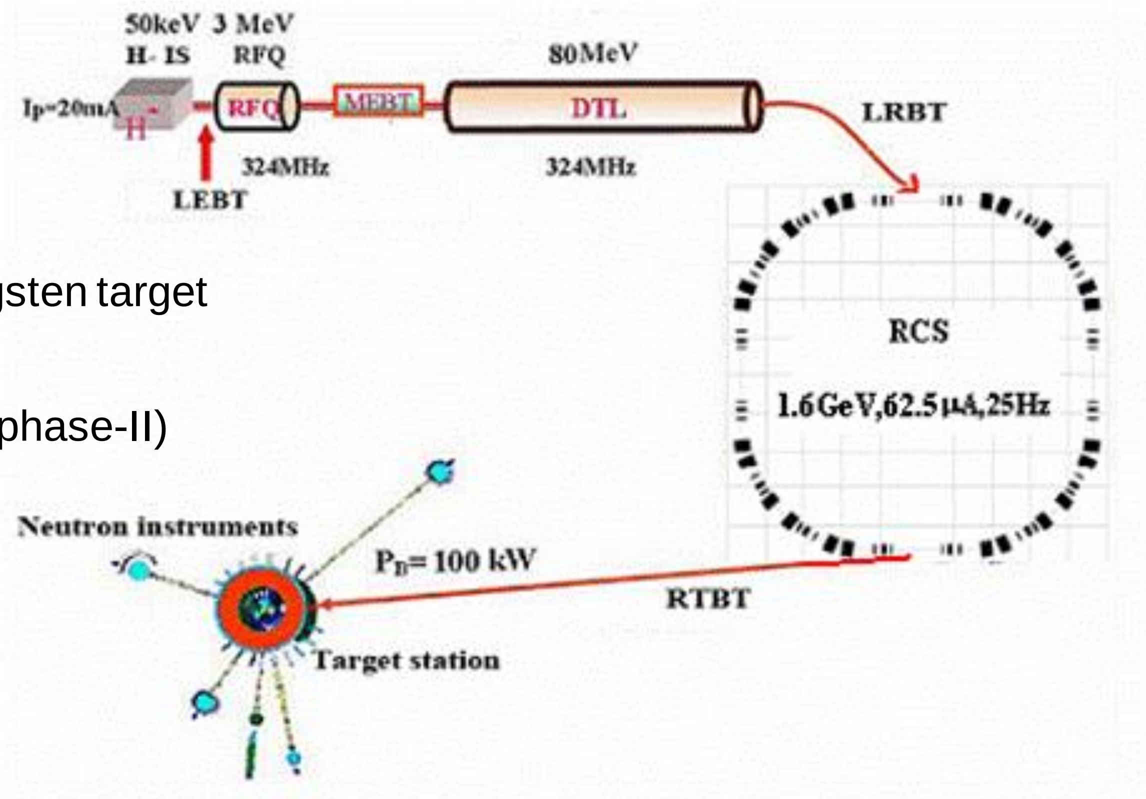
- CSNS is located in Guangdong-Hong Kong-Macao Greater Bay Area

1. CSNS and Back-n facility

- CSNS campus

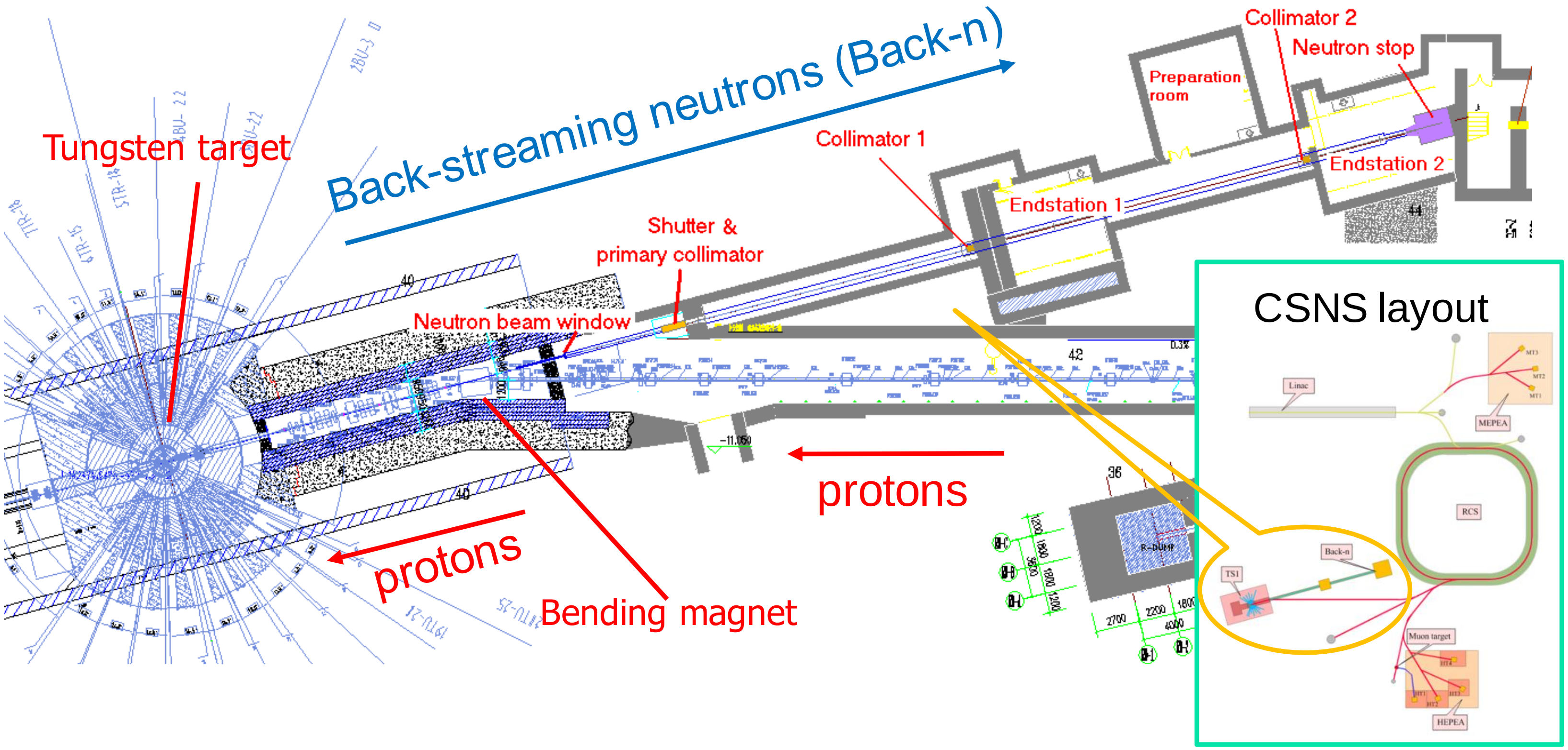
Layout of CSNS accelerators

- Started running since 2018
- 1.6 GeV protons bombarding tungsten target
- 25 Hz repetition frequency
- Beam power: 100 kW (500 kW in phase-II)



Layout of the Back-n WNS beam line

- Two ends tations: #ES1 with flight path ~55 m, #ES2 with ~76 m
- Wide neutron energy range (from ~0.5 eV to ~200 MeV)
- Weak γ-flash compared with forward direction due to back-streaming design



1. CSNS and Back-n facility

- Beam characterization is important for newly built Back-n facility
- Knowledge of the flux is crucial for feasibility study and data analysis

1. CSNS and Back-n facility

- Beam characterization is important for newly built Back-n facility
- Knowledge of the flux is crucial for feasibility study and data analysis

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

- J.Y. TANG, et al, Nucl. Sci. Tech. (2021) 32:11 (Above data are from simulation)

This work reports the first measurement of the flux with small collimator at #ES1

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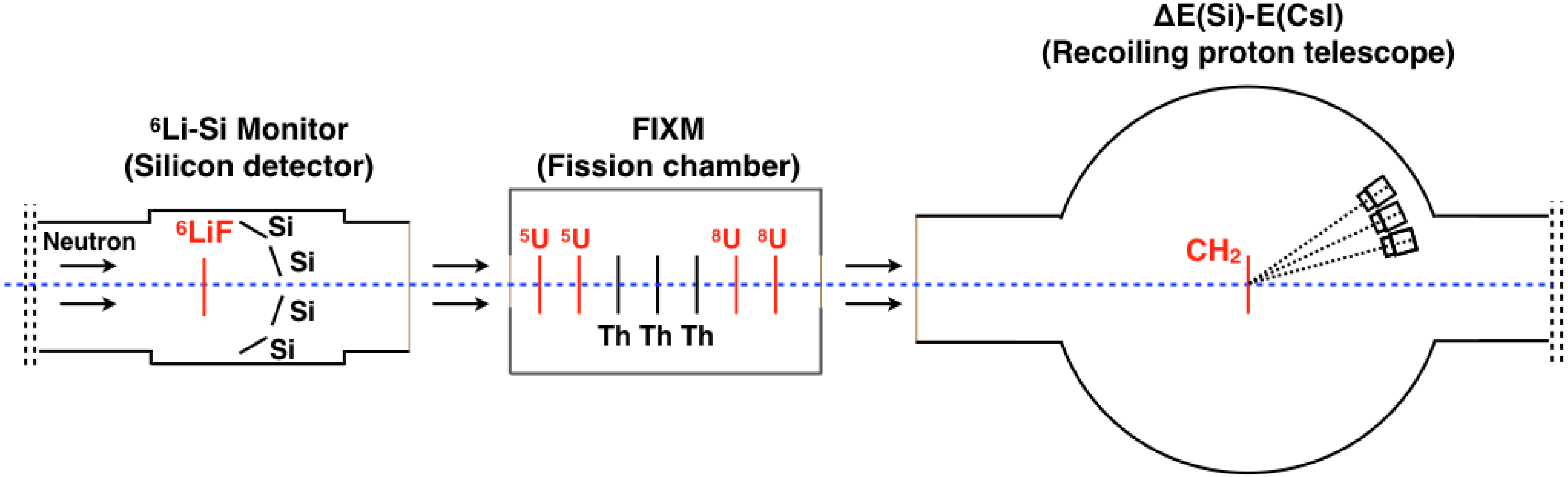
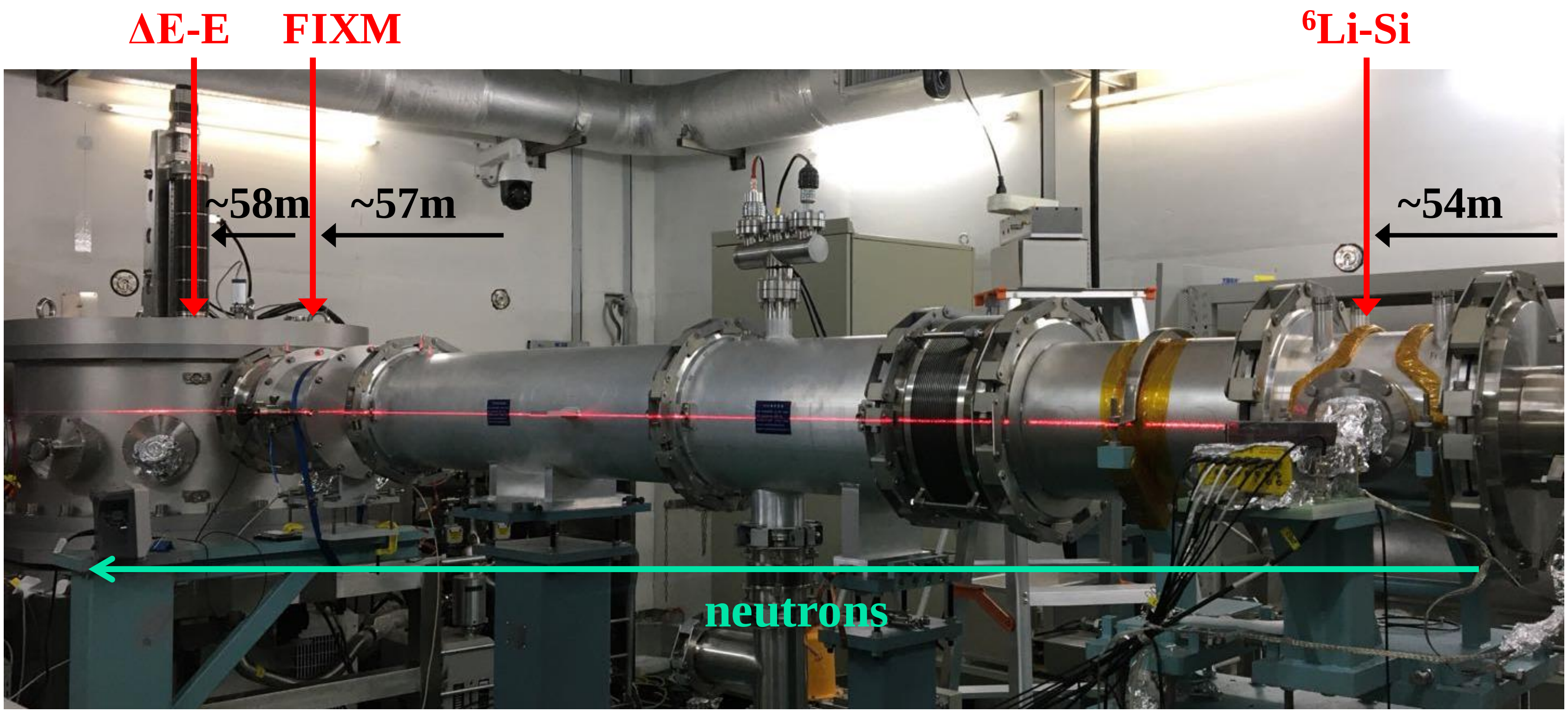
2. Experimental setup

- 3 detection system are used synchronously to characterize the neutron flux



Detector	Neutron converter	Measurement energy range
^{6}Li-Si	^{6}LiF / ^{6}Li(n, t)	~1 eV-10 keV
FIXM	^{235}U/ ^{235}U(n, f)	~1 eV-~100 MeV
ΔE-E (Si-CsI)	Polythene / H(n, n)H	~10 MeV-~100 MeV

2. Experimental setup



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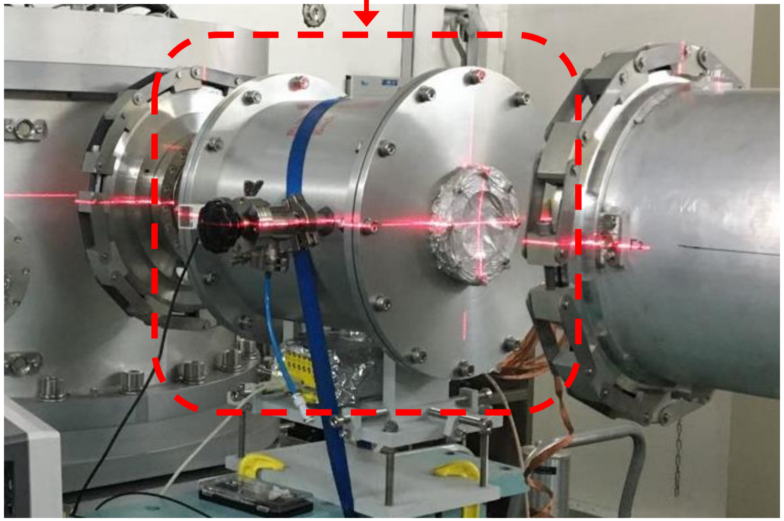
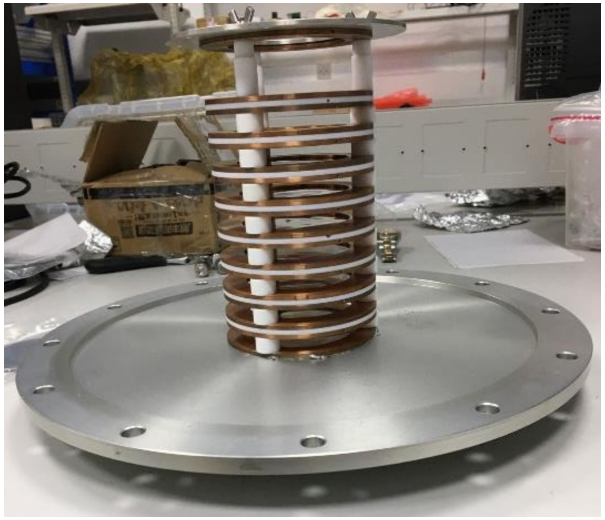
3. Analysis and results: FIXM

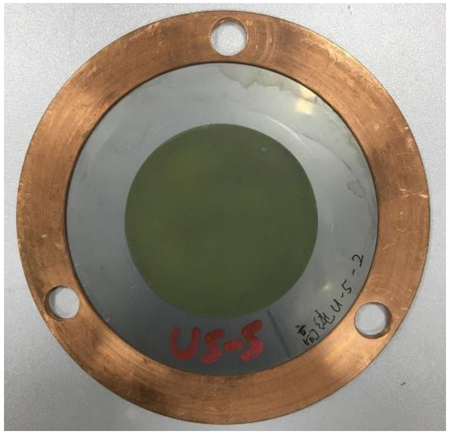
FIXM



Open chamber



^{235}U sample



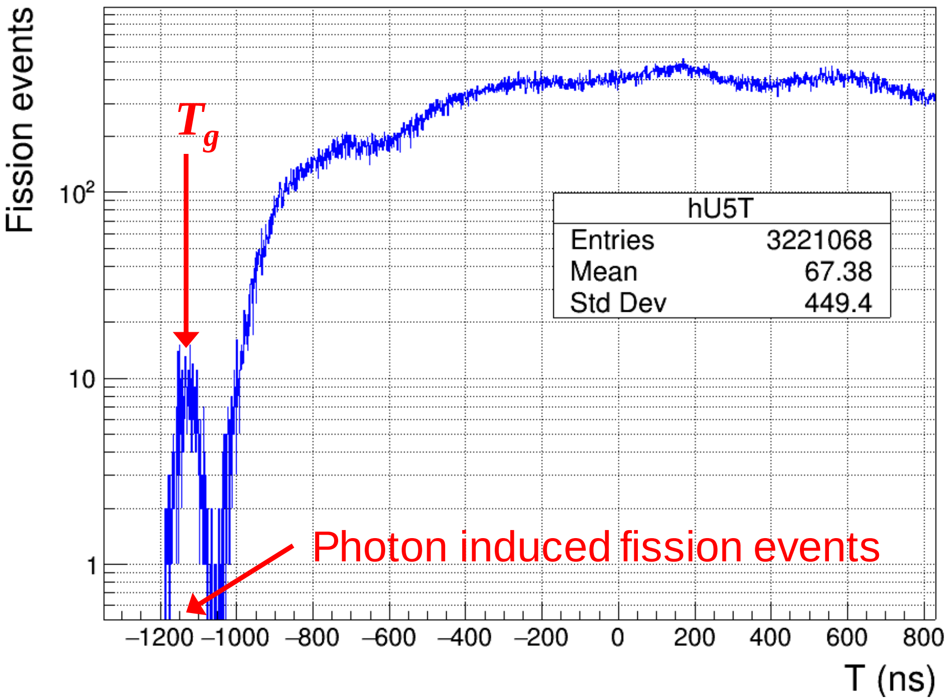
- ^{235}U Thickness: 323.44 ug/cm^2

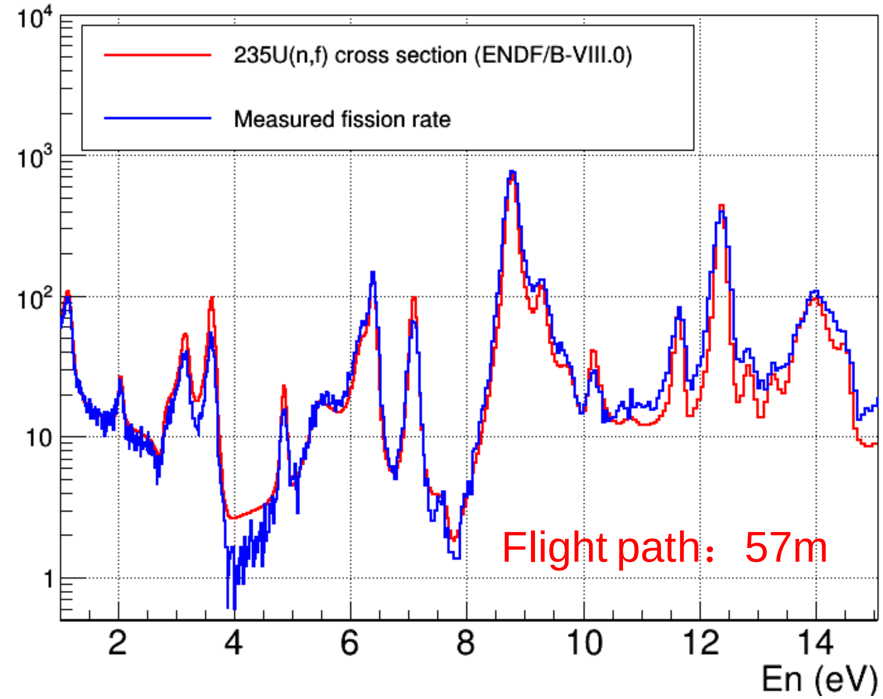
3. Analysis and results: FIXM

(1) Time-of-flight (TOF) method to determine neutron energy

$$v = \frac{L}{TOF} = \frac{L}{T - T_0}$$

- T_0 is calibrated by the Y-induced events
- Flight path L is calibrated by the resonance peaks of ^{235}U

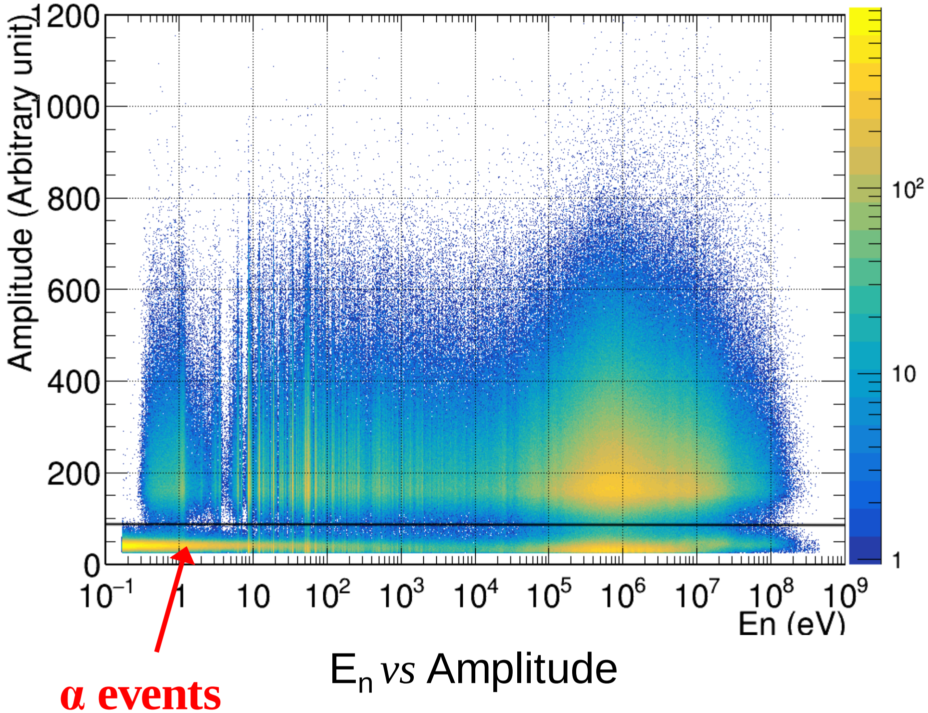




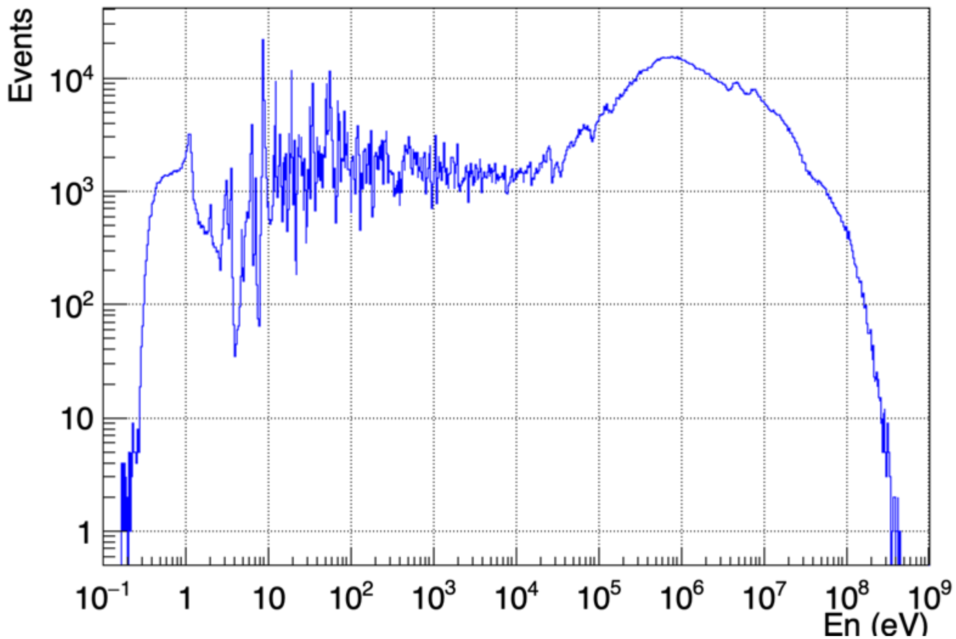
Yonghao CHEN, "*Measurement of the neutron flux with small collimator of Back-n #ES1 at CSNS*". ISINN-28, May 24-28, 2021.

3. Analysis and results: FIXM

(2) Fission rate determination



E_n *vs* Amplitude

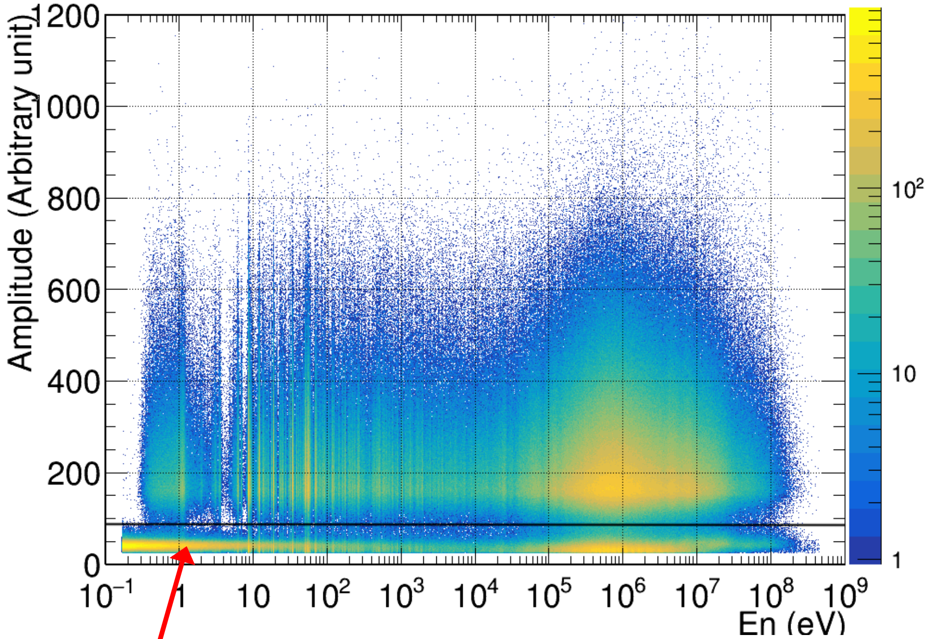


Fission rate as a function of neutron energy

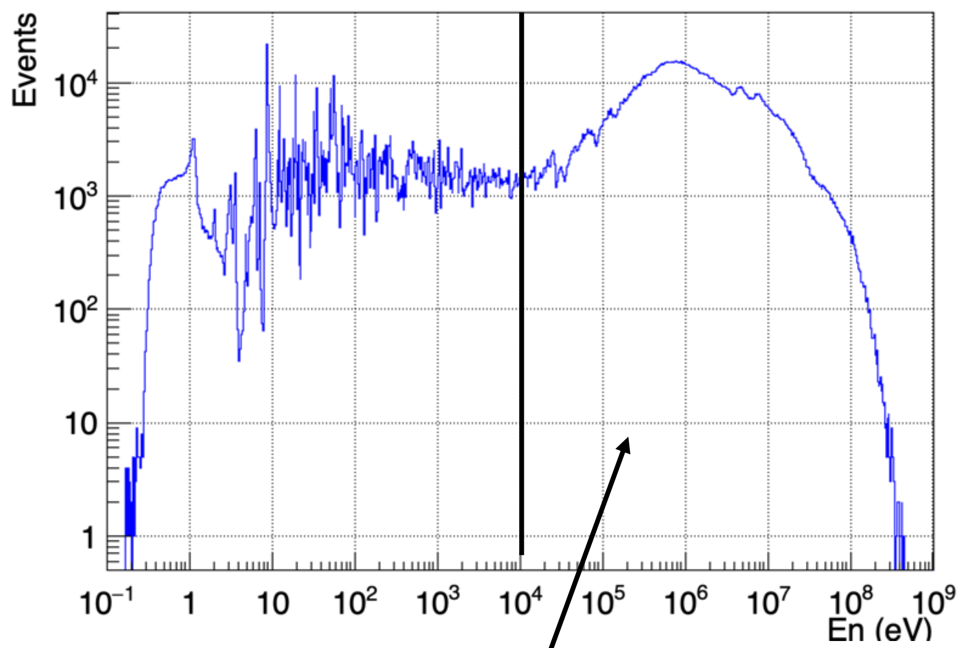
3. Analysis and results: FIXM

(2) Fission rate determination

Measured in double-bunch mode of accelerator:
2 identical proton bunches with fixed time interval (410 ns) in one pulse



E_n *vs* Amplitude



Fission rate as a function of neutron energy

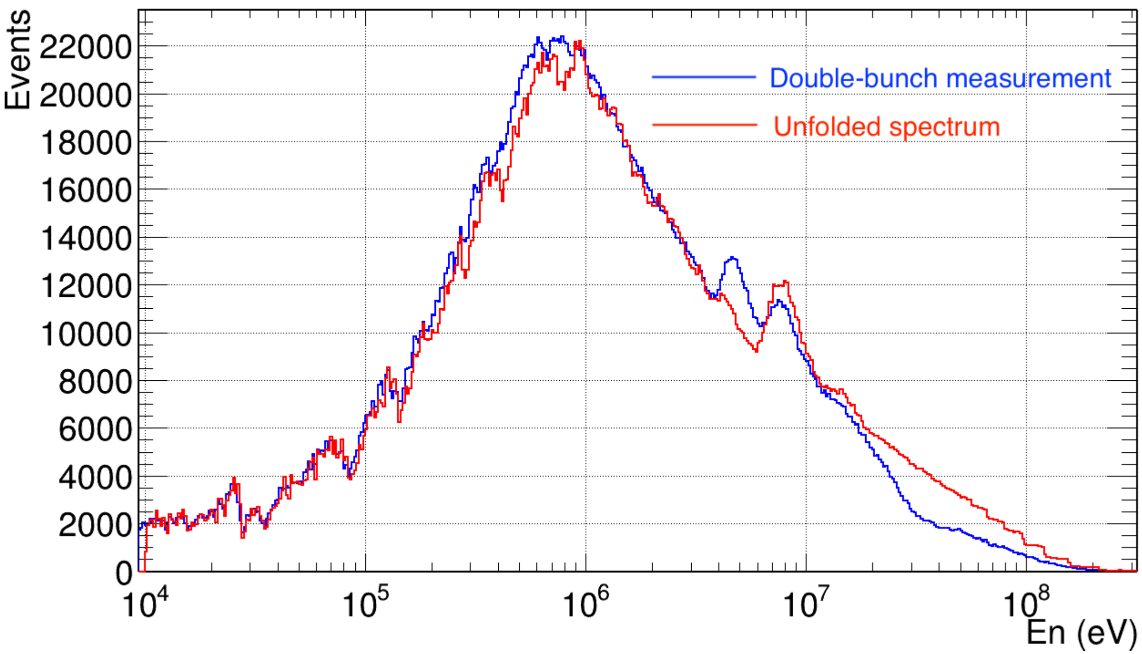
Double-bunch unfolding is applied for neutrons above 10 keV

(3) double-bunch unfolding

- An iterative algorithm is developed for unfolding based on the Bayes' theorem

H. Yi et al, *JINST* 14 (2019): 02011

$$C_i^{(k+1)} = E_i \frac{C_i^{(k)}}{C_{i-\Delta}^{(k)} + C_i^{(k)}} + E_{i+\Delta} \frac{C_i^{(k)}}{C_i^{(k)} + C_{i+\Delta}^{(k)}}$$



3. Analysis and results: FIXM

(4) Neutron flux determination

$$\Phi(E_n) = \frac{N(E_n)}{\sigma(E_n)\varepsilon(E_n)N_V}$$

Φ	Neutron flux
E_n	Neutron energy
N	Reaction rate
ε	Detection efficiency(~95%)
σ	Cross section
N_v	Sample quantity

(4) Neutron flux determination

$$F(E_n) = \frac{N(E_n)}{\sigma(E_n)\varepsilon(E_n)N_V}$$

Φ	Neutron flux
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ε	Detection efficiency(~95%)
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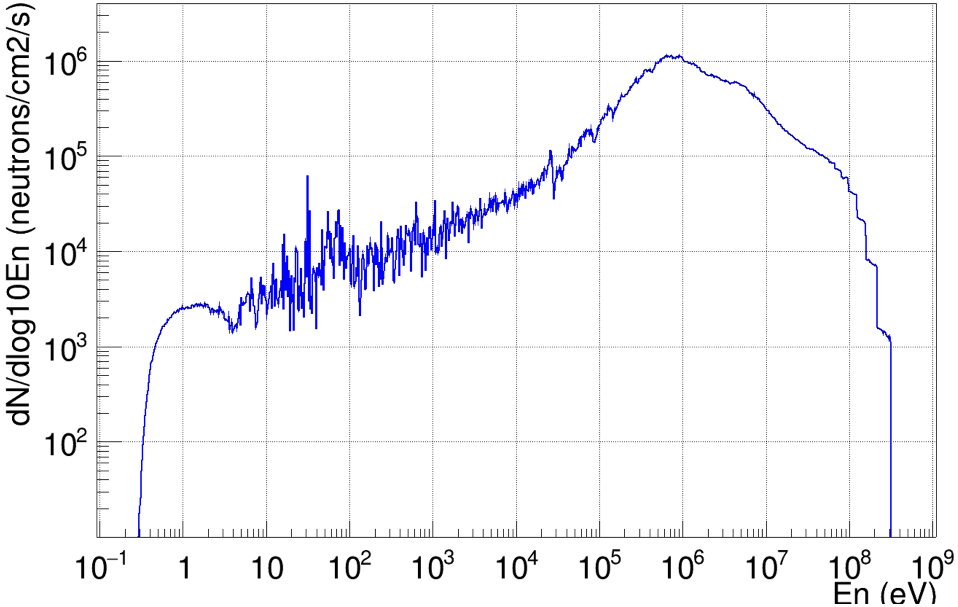
Neutron flux measured by FIXM with 100 bins per decade (bpd)
Integral flux: 1.63×10^6 n/cm^2/s (small collimator)



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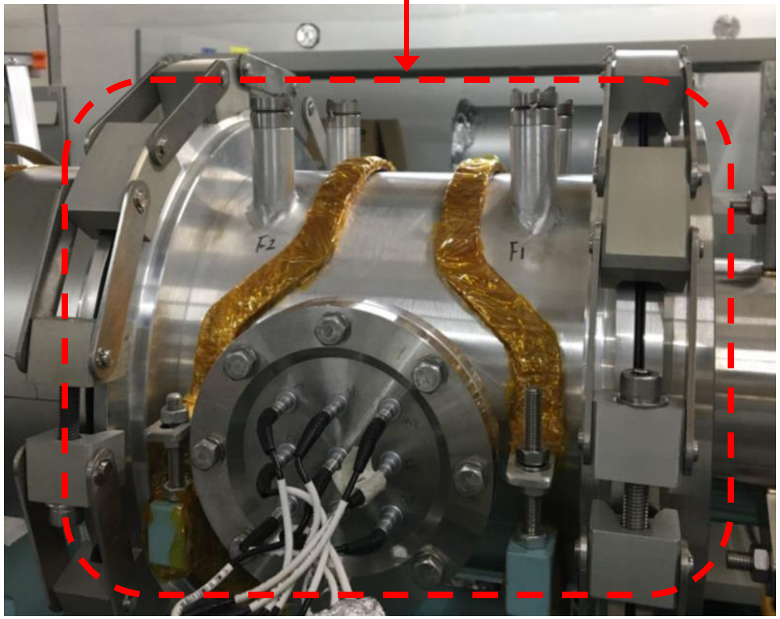
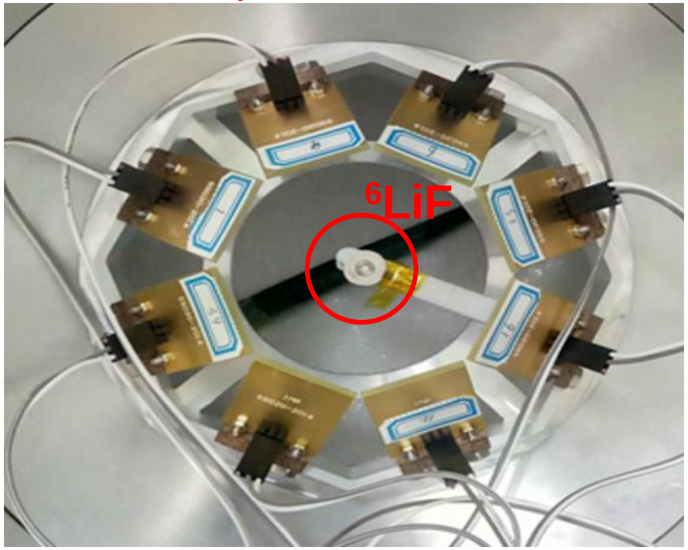
3. Analysis and results: ^{6}Li-Si monitor

^{6}Li-Si



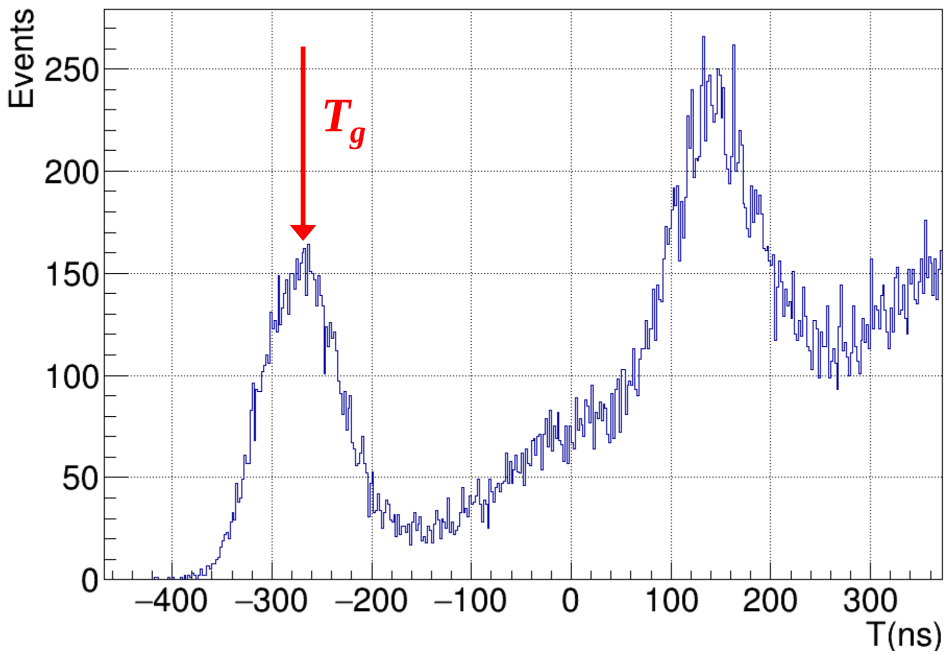
Open chamber

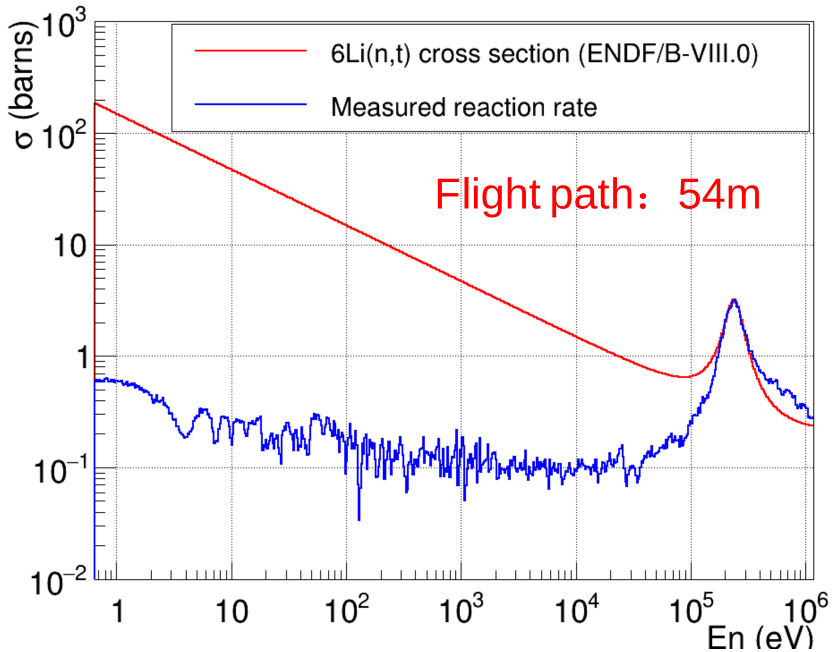


3. Analysis and results: ^{6}Li-Si monitor

(1) TOF method

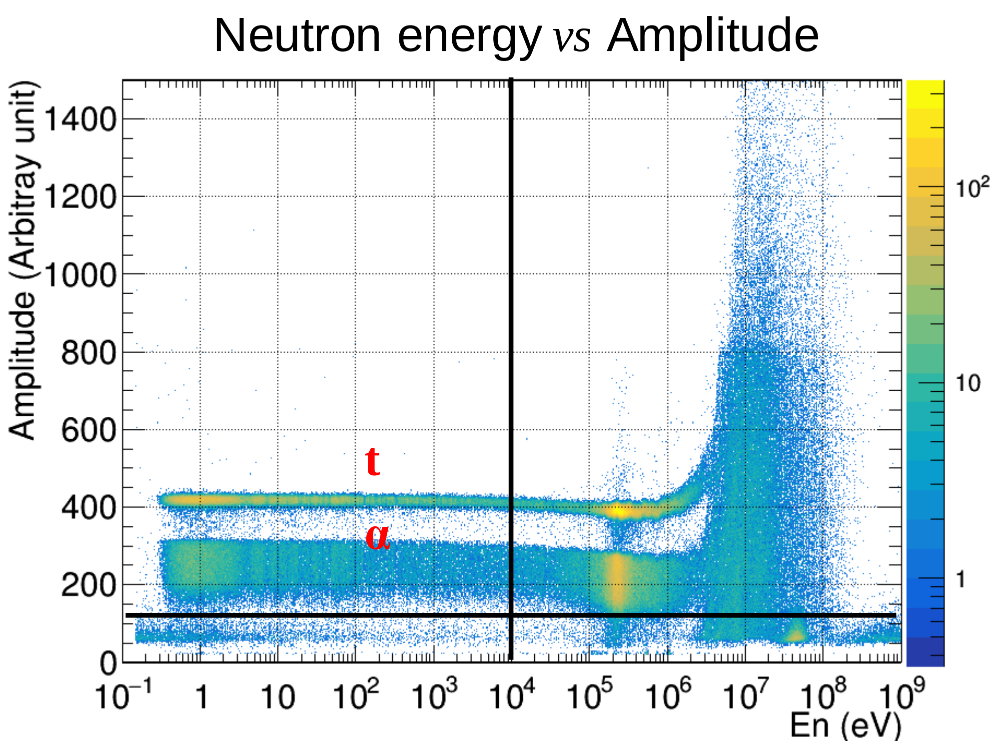
- T_0 is calibrated by the Y-rays
- *L* is calibrated by the resonance peaks of ^{6}Li





3. Analysis and results: ^{6}Li-Si monitor

(2) Reaction rate

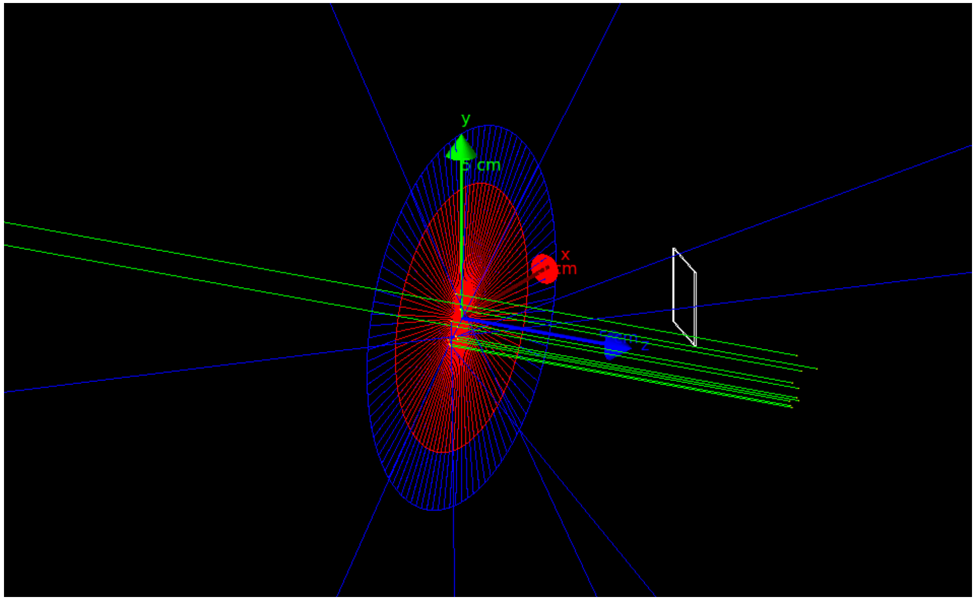


Double-bunch unfolding is not needed for low energy neutrons (<10 keV)

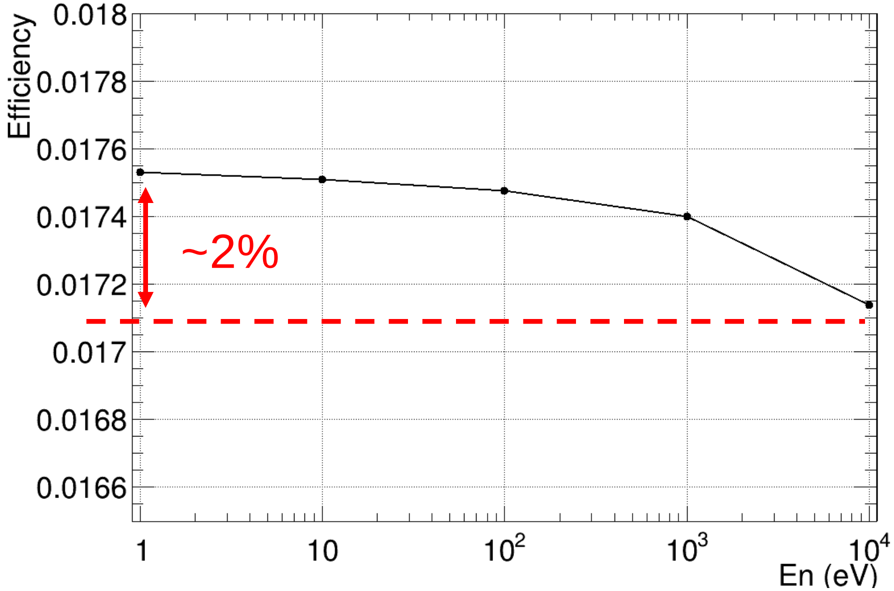
3. Analysis and results: ^{6}Li-Si monitor

(3) Efficiency simulation (Geant4)

G4 detector geometry



Efficiency curve

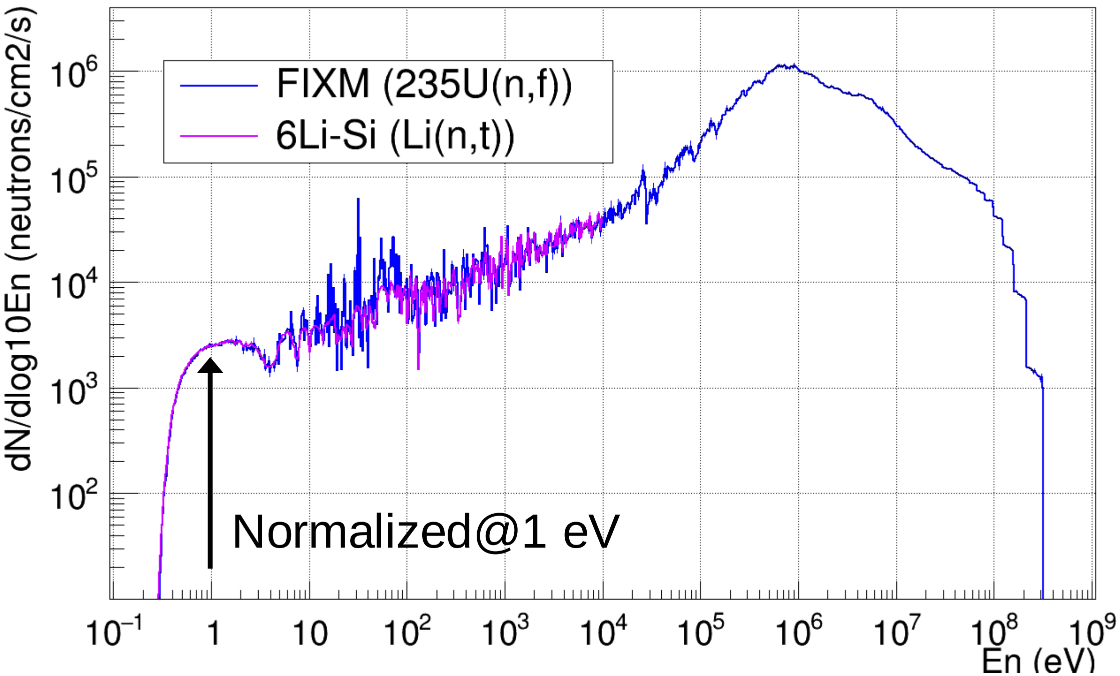


- Efficiency correction is slight when include both triton and alpha in the reaction rate (compensation)

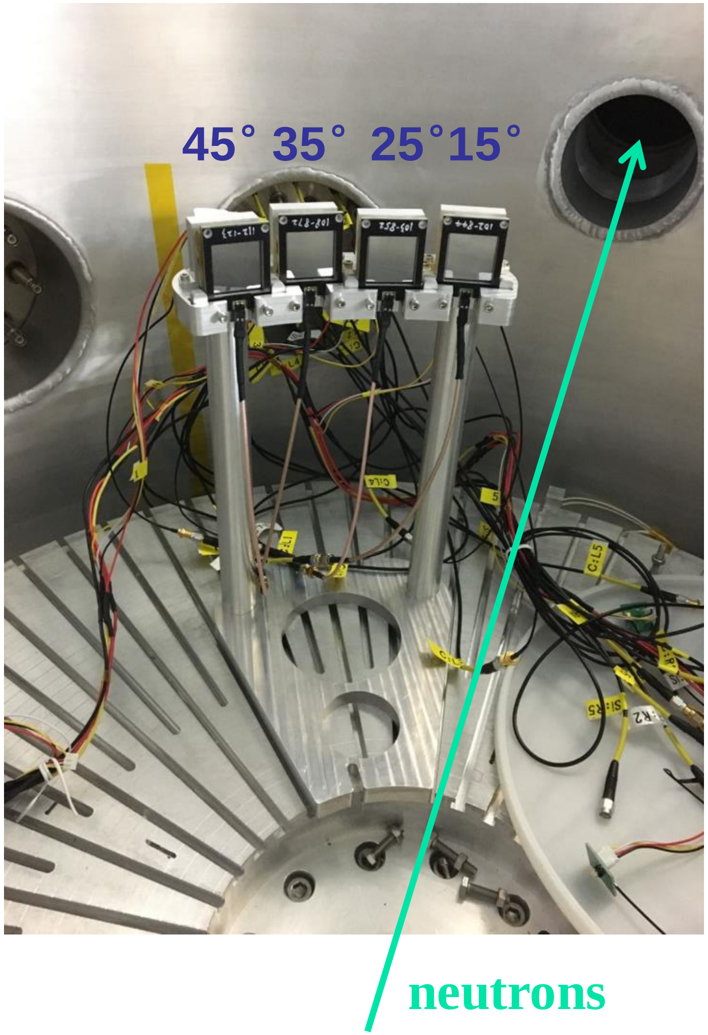
3. Analysis and results: ^{6}Li-Si monitor

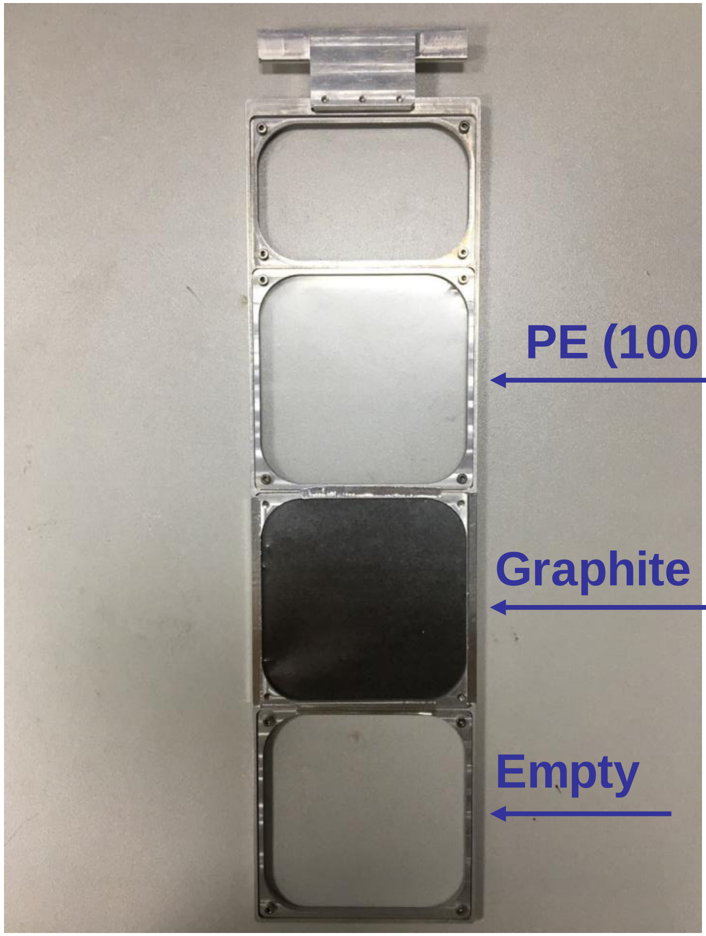
(4) Neutron flux

- ^{6}Li-Si measurement is normalized to FIXM measurement at 1 eV



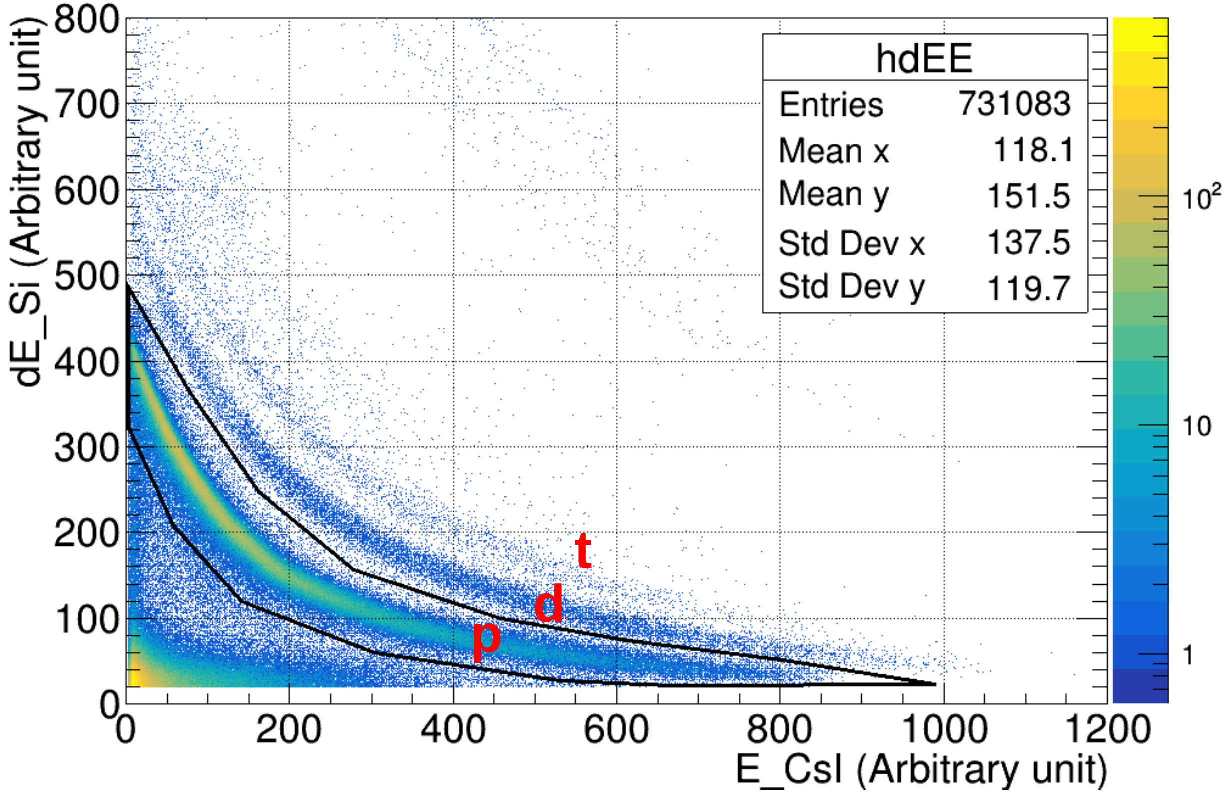
3. Analysis and results: ΔE-E detector





3. Analysis and results: ΔE-E detector

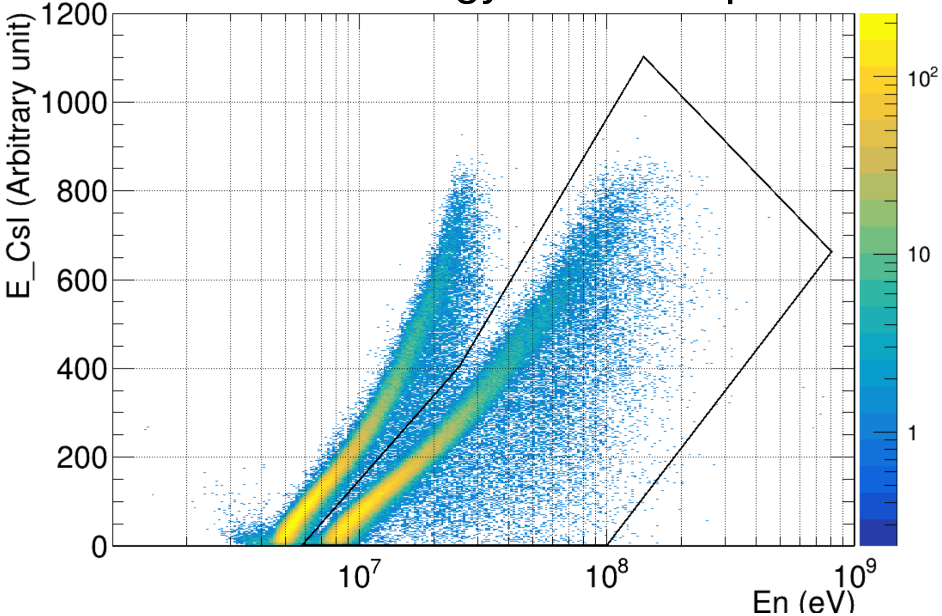
(1) ΔE-E particle identification - 25 °



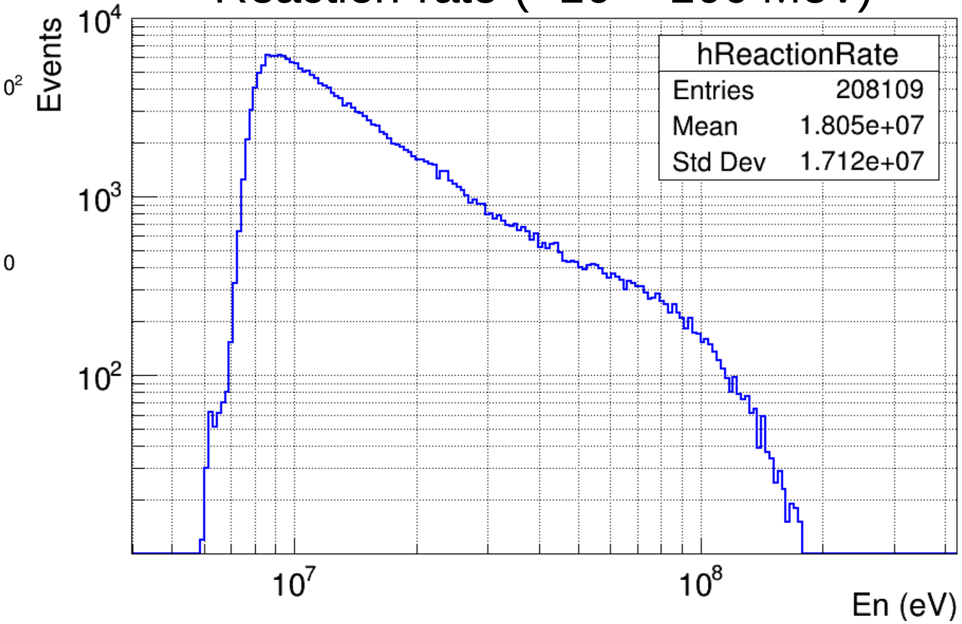
3. Analysis and results: ΔE-E detector

(2) n-p reaction rate - 25 °

Neutron energy *vs* CsI amplitude



Reaction rate (~10- ~100 MeV)

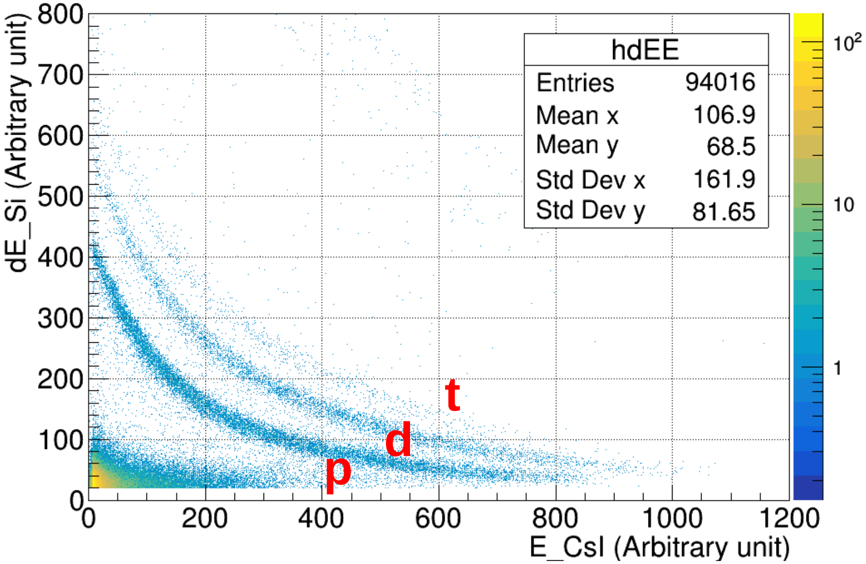


- Double-bunch effect (unfolding is not needed)

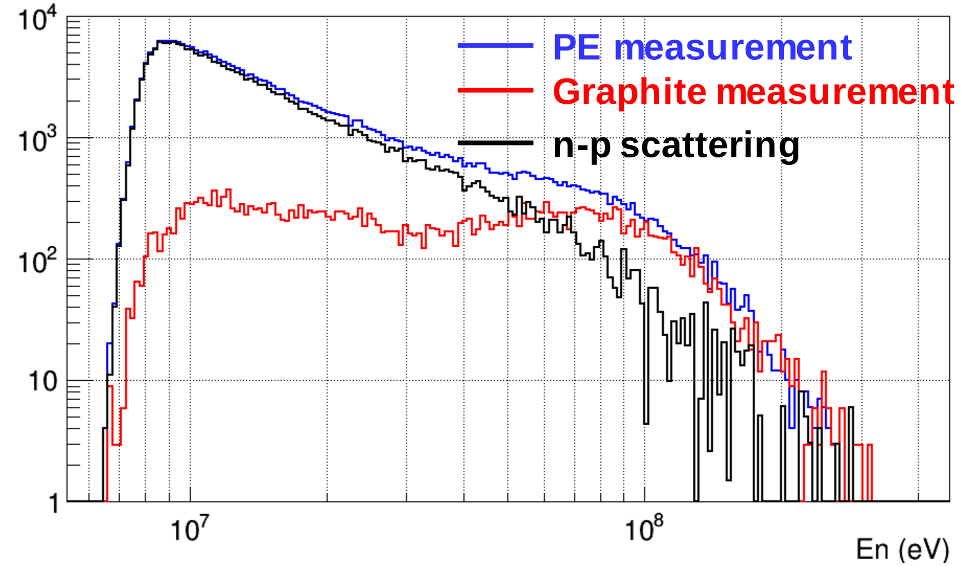
3. Analysis and results: ΔE-E detector

(3) Carbon background correction - 25 °

ΔE-E identification of graphite sample



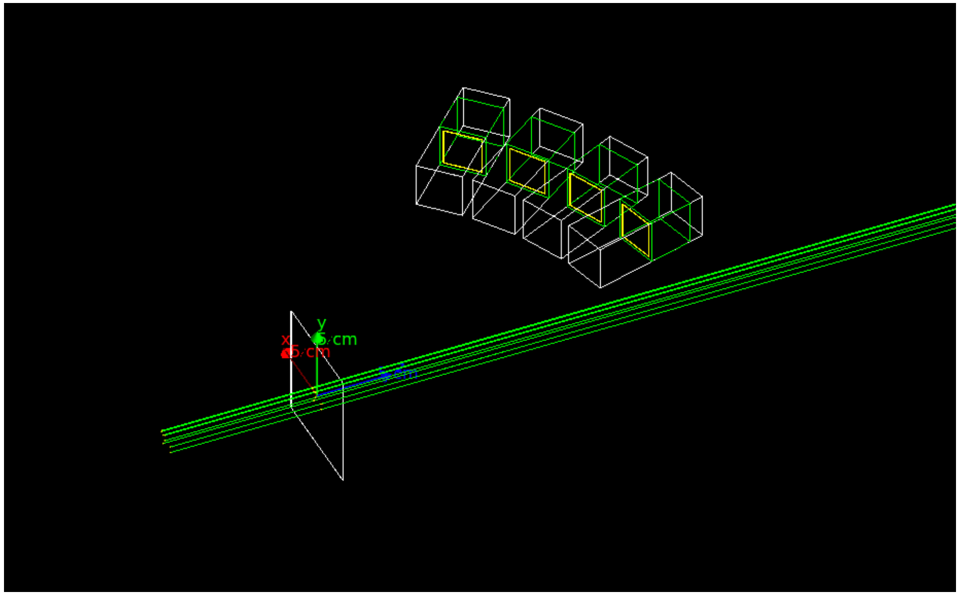
Reaction rate correction



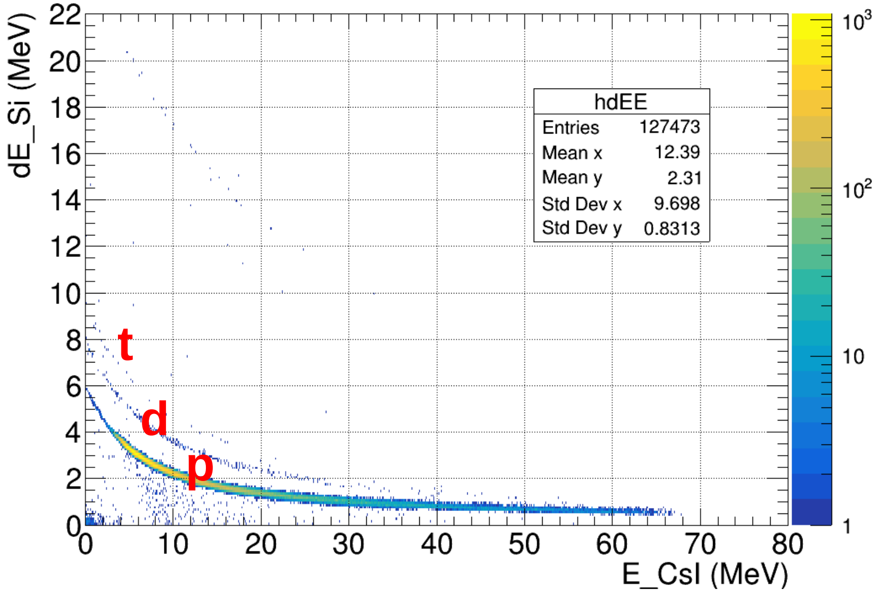
3. Analysis and results: ΔE-E detector

(4) Efficiency simulation (Geant4)

G4 detector geometry

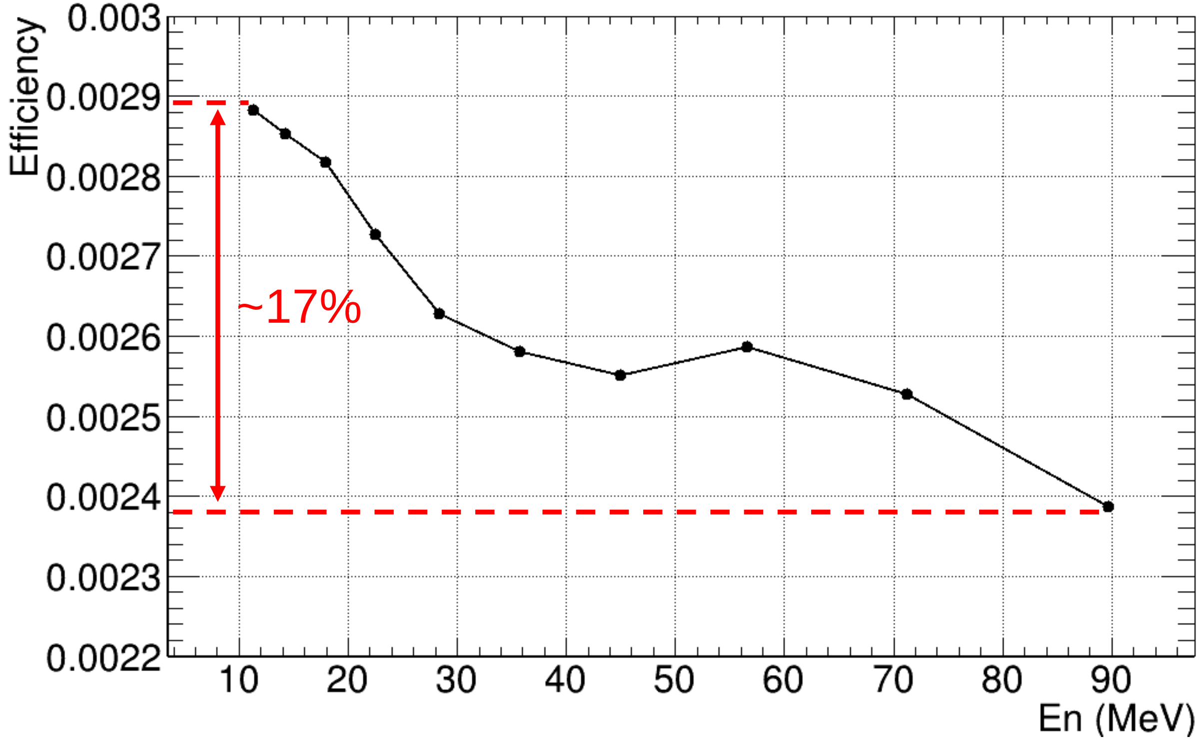


Simulated ΔE-E distribution of PE sample



3. Analysis and results: ΔE-E detector

(4) Efficiency simulation (Geant4)- 25 °



- The energy dependency of the efficiency is not negligible

(5) Neutron flux

$$\Phi(E_n) = \frac{N(E_n)}{\sigma(E_n)\varepsilon(E_n)N_V}$$

Φ	Neutron flux
E_n	Neutron energy
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3. Analysis and results: ΔE-E detector

(5) Neutron flux

$$F(E_n)=\frac{N(E_n)}{s(E_n)e(E_n)N_V}$$

Φ	Neutron flux
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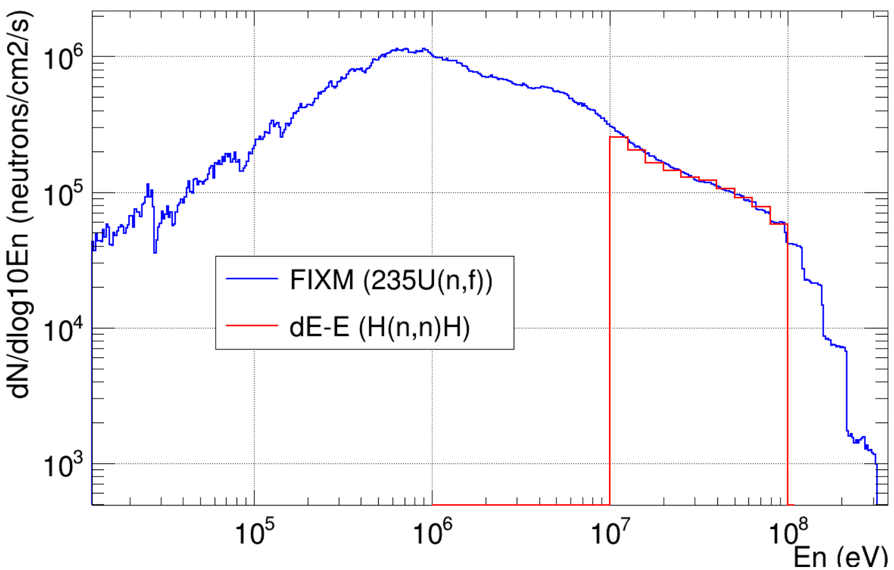
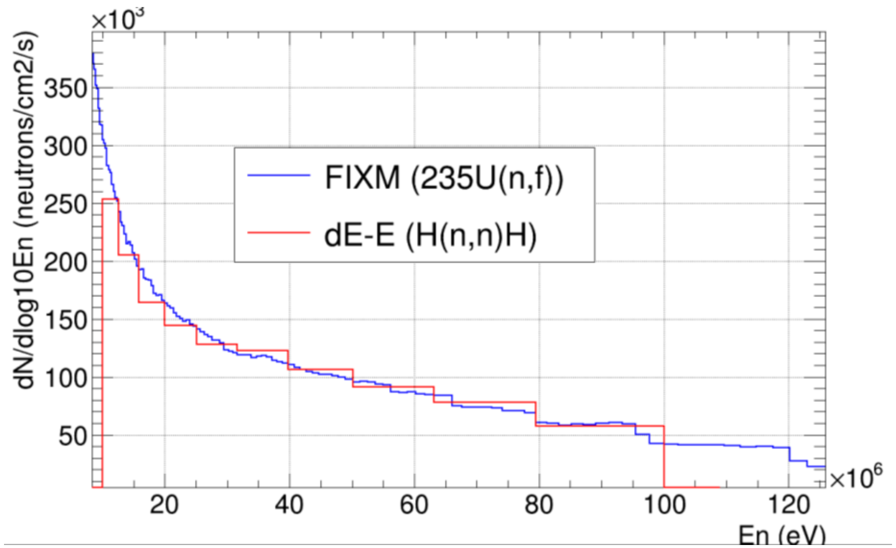
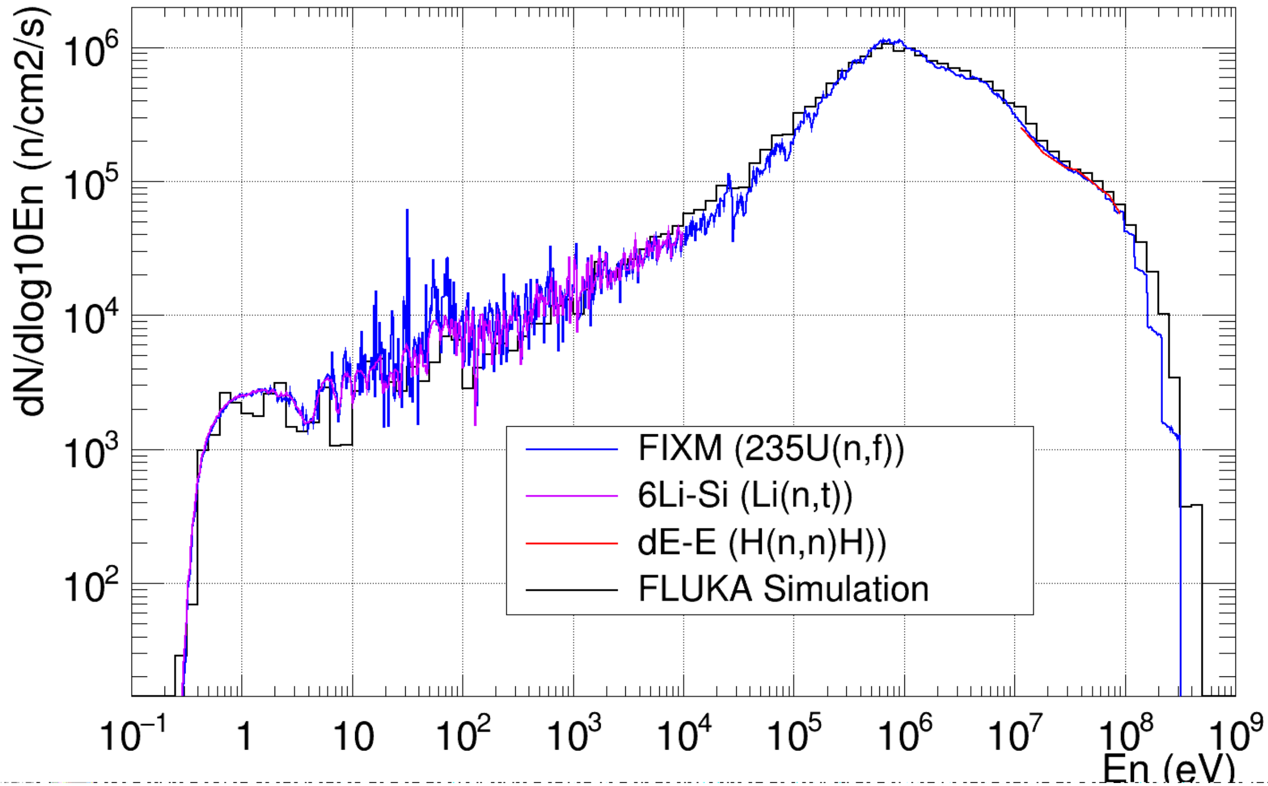




CSNS Back-n #ES1 neutron flux with small collimators

- Measured neutron flux: 1.63×10^6 n/cm^2/s
- Simulated neutron flux: 1.67×10^6 n/cm^2/s



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Conclusions:

1. First measurement of the neutron flux of Back-n #ES1 with small collimator was successfully campaigned and preliminary results are obtained
2. 3 detection systems demonstrate a consistency
3. Measurement and simulation have an general agreement both in shape and flux

Outlooks:

1. Good consistency between the FIXM and ΔE-E measurements is motivating us to perform the absolute measurement (cross section measurement relative to n-p scattering)
2. Simulation will be studied in more details and need to be validated
3. The uncertainty will be estimated and the flux will be finalized

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