Cross-section measurement of $^{14}N(n, p)^{14}C$ reaction

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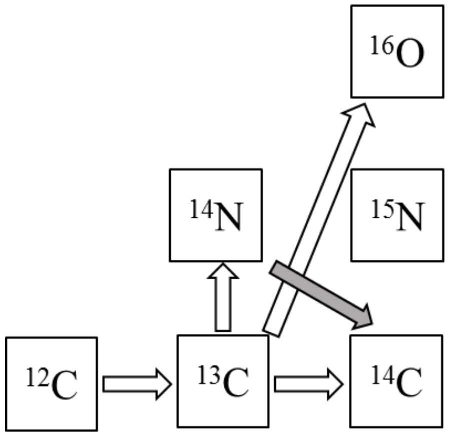
Outline

- Background
- Experimental setup
- Data analysis
- Cross sections
- Summary

Background

1、$^{14}N(n, p)^{14}C$ reaction is the most important poison reaction of the main neutron source of the s-process.



2、$^{14}N(n, p)^{14}C$ reaction is an important link in the reaction chain for the formation of ^{19}F

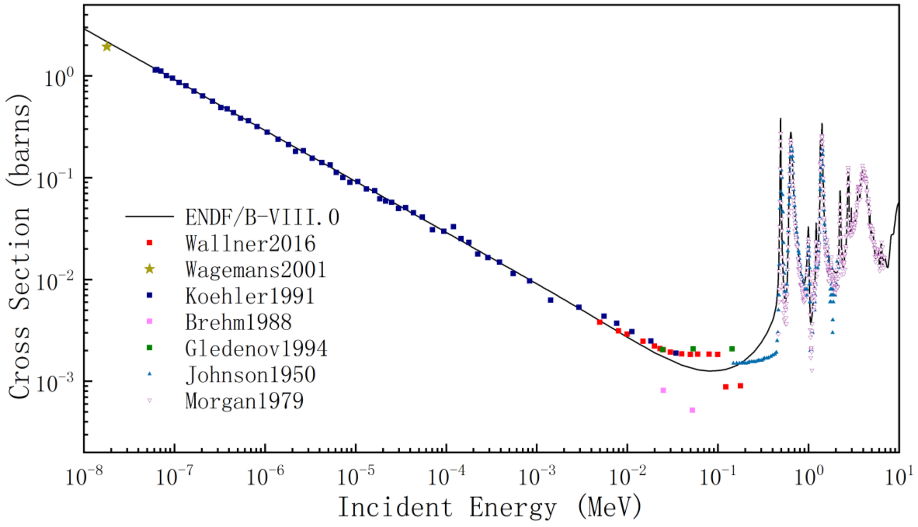
$^{14}N(n, p)^{14}C(\alpha, \gamma)^{18}O(p, \alpha)^{15}N(\alpha, \gamma)^{19}F$

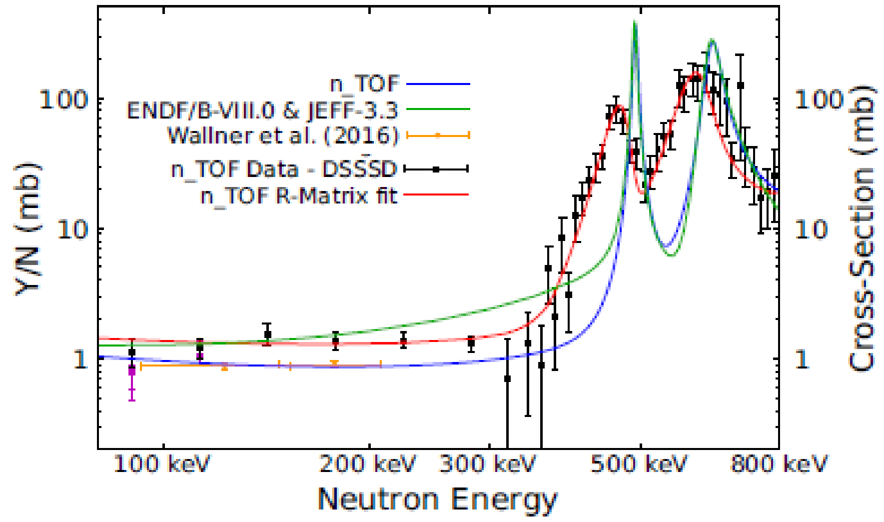
3、In medical treatment research using neutron, due to the high proportion of ^{14}N content in human's body, $^{14}N(n, p)^{14}C$ reaction cross sections also needed.

Background: Research Status

Cross sections of $^{14}N(n,p)^{14}C$ reaction have been measured from meV to 10 MeV.

- Based on the cross sections measured at 123 and 178 keV, Wallner et al.(in 2016) suggest the resonance peak at 493 keV was 3.3 times smaller than that of Morgan.
- Measurement at n-TOF(published in 2023) shows that the cross sections of the resonance at 493 keV is consistent with that given by the ENDF/B-VIII.0 database.
- The low energy tailing (100-450 keV) of the first resonance peak given by the measurement at n-TOF is lower than in the ENDF/B-VIII.0 database.
- At present, there is no differential cross-section data of $^{14}N(n,p)^{14}C$ reaction in the whole energy region.
- Reaction channels' J^{π}



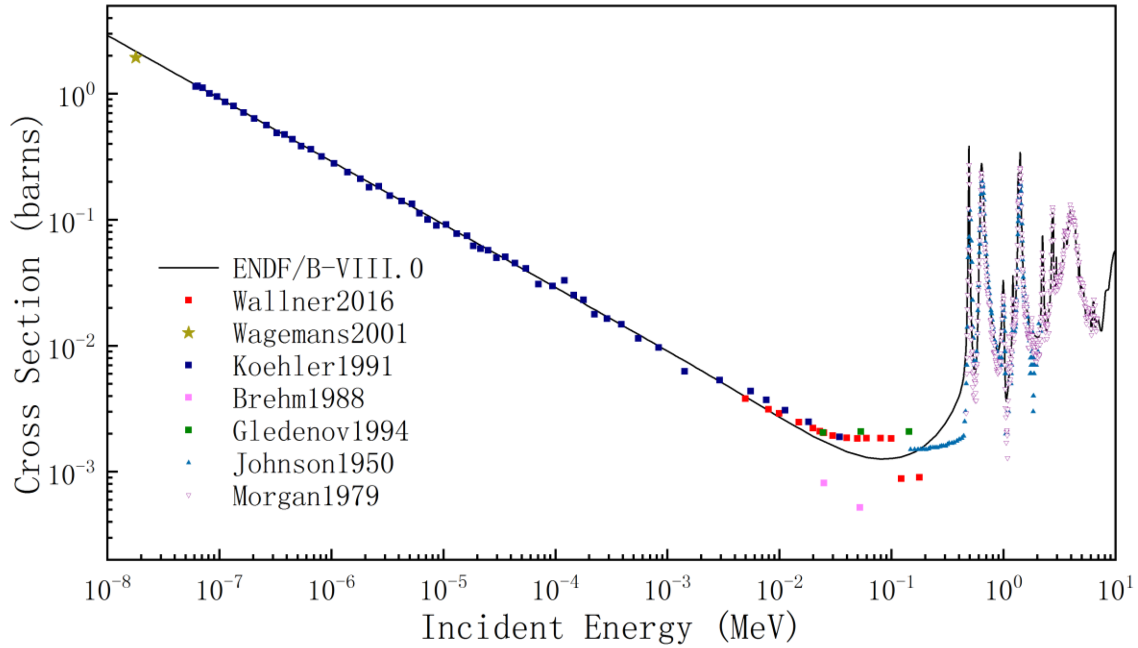


Wallner, et al, Phys. Rev. C 93 (2016) :045803;
Pablo Torres-Sánchez, et al, Phys. Rev. C 107 (2023) : 064617;

Background: Research Status

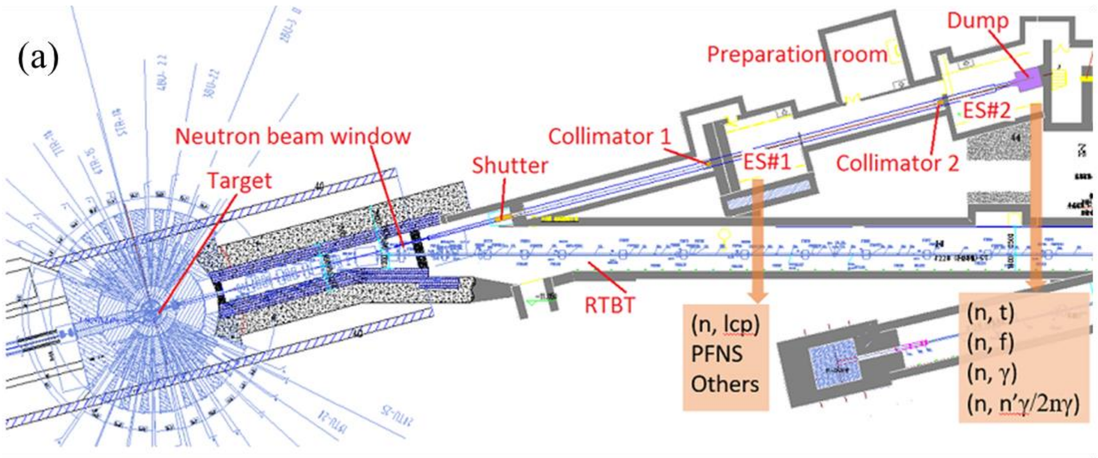
Recent researches focus on:

- Cross sections in the keV energy region
- Reaction channels' J^{π}
- Differential cross sections
- Resonance peaks in MeV region

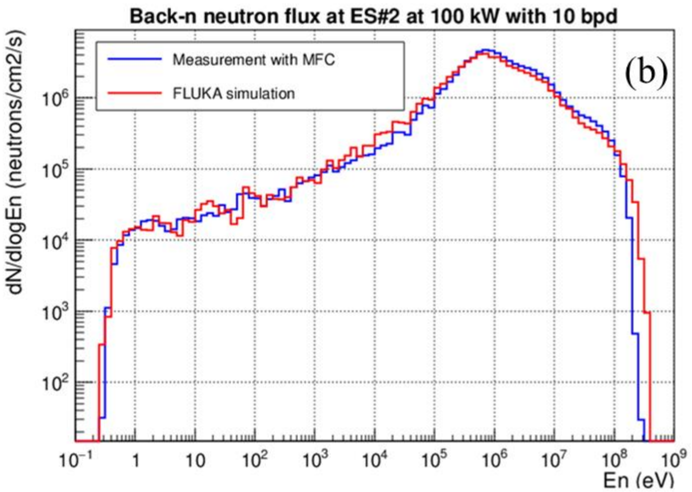


Back-n white neutron facility

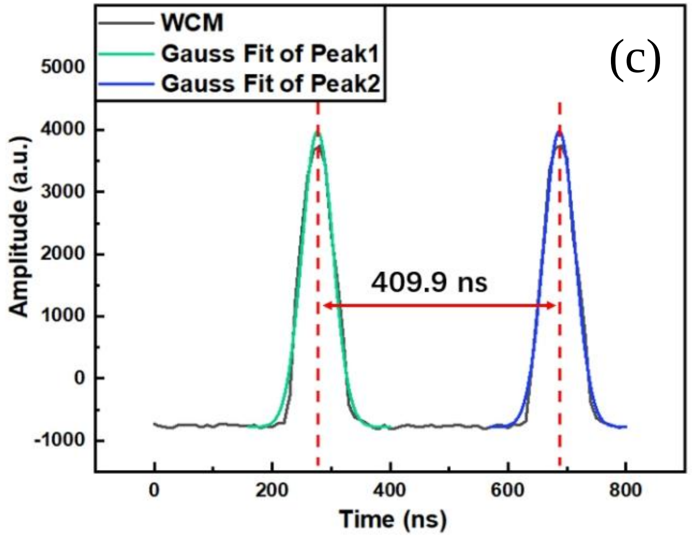
- The CSNS Back-n white neutron facility in DongGuan, south China
- Pulse neutron beam; Energy range: 0.3 eV-300 MeV(with Gd absorber in the beamline)
- Time interval between two pulses: 40 ms (25 Hz)
- Double bunches; Pulse width: 60 ns(FWHM).



CSNS Back-n white neutron facility



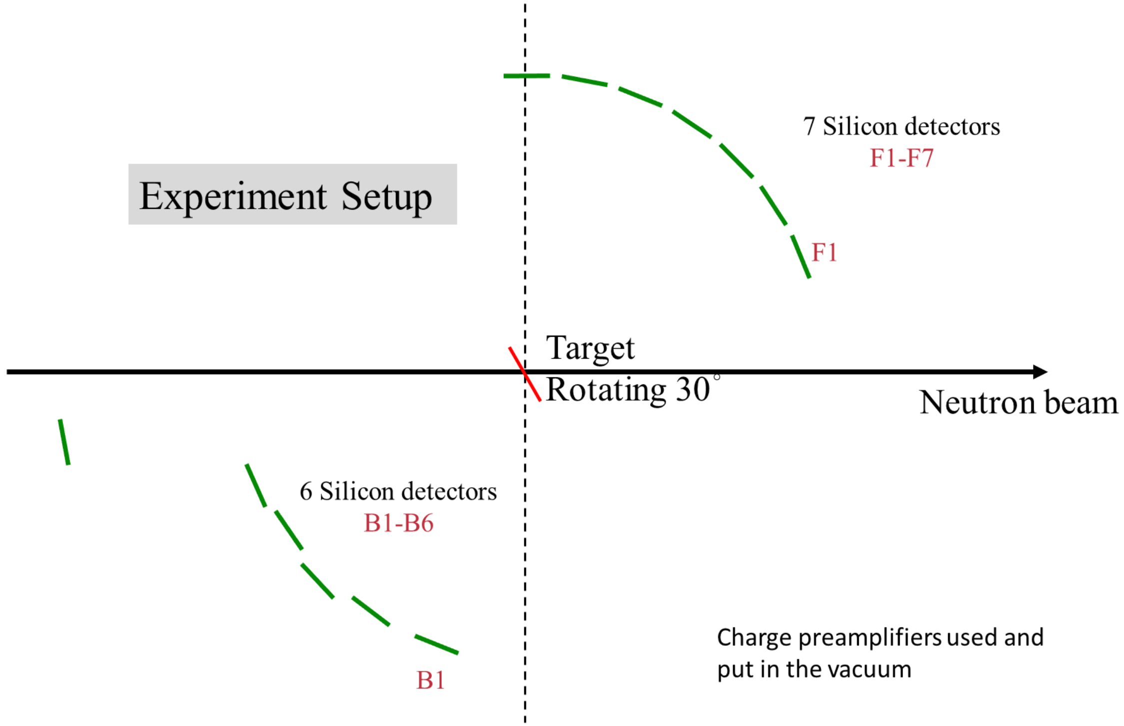
Back-n's energy spectrum



Double bunches structure

Experiment setup

- 13 silicon PIN detectors; Charge preamplifiers in vacuum to keep noise as low as possible
- December 2nd to 22th (2022) (beam time about 400 hours)



	F1	F2	F3	F4	F5	F6	F7	B1	B2	B3	B4	B5	B6
Angle(°):	21.4	32.86	44.29	55.71	67.14	78.57	90	105	121.32	133.88	146.41	158.74	170
D/mm	189.5	189.5	189.5	189.5	189.5	189.5	189.5	193	195.61	202.73	193.75	204.64	

Targets

- ^{14}N target: 200 μg/cm^2 $C_3H_6N_6$ (Melamine) in each side, on 10.8 μg/cm^2 Al substrate, **double-sided target;**

Measurement relative to ^{6}Li(n, t) reaction

- ^{6}LiF: 360 μg/cm^2, single-sided target, on 10 μg/cm^2 Al substrate;
- Al foil for background subtraction;

✓ During experiment, targets were rotated 30° to reduce the energy loss of the products in large angle.

✓ Beam spot: neutron beam's diameter about 20mm (neutron switch φ50+collimator 1 φ15);

✓ Waveform recorded by digitizer;

Target:
1: ^{6}LiF+Al
2: $C_3H_6N_6$ + Al
3: Al
4: α source

Data analysis

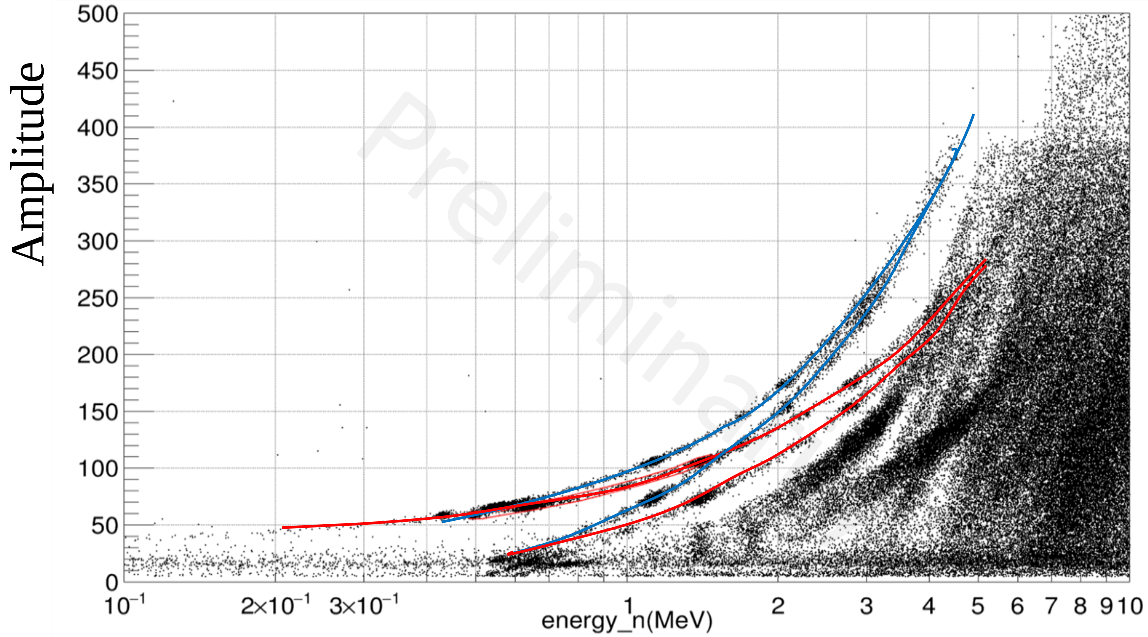
- Detectors' energy calibration & TOF calibration
- Amplitude vs TOF spectra: $^{14}N(n, p)^{14}C$ & $^{6}Li(n, t)$ identification
- Unfolding of the double-bunched beam
- Statistics of each neutron energy bin
- Considering Back-n's energy spectrum
- Normalize differential cross sections of $^{6}Li(n, t)$ reaction at 0.2 MeV
- Relative to the $^{6}Li(n, t)$ reaction, differential cross sections of the $^{14}N(n, p)^{14}C$ reaction
- R-Matrix analysis

Protons from $^{14}N(n, p)^{14}C$

- 0.1-0.5 MeV: protons from $^{14}N(n, p)^{14}C$ are rare
- **4 proton event bands** of $^{14}N(n, p)^{14}C$ reaction in MeV region:

  Double bunches : 410 ns interval. E_n is based on the first bunch, with **red** for the first bunch and **blue** for the second.

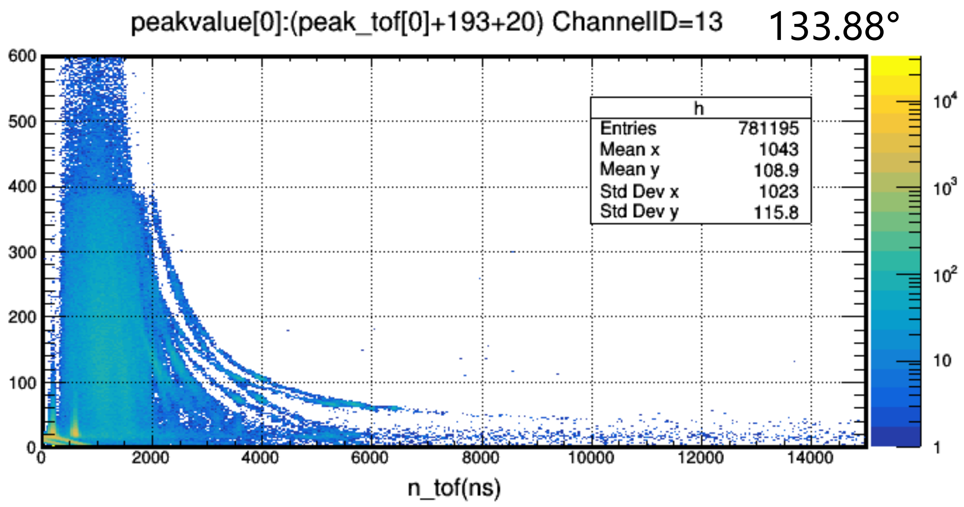
  Double-sided target: double-sided $C_3H_6N_6$ on Al substrate, events from each neutron bunch **split into 2** bands.
- Background: $^{14}N(n, \alpha)$, np scattering (seriously affected at small angles), Al(n, α)……



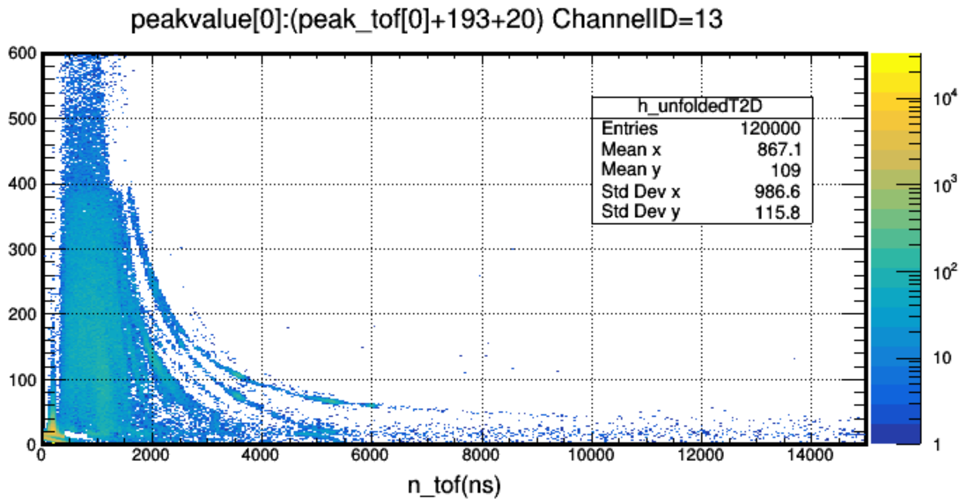
Amplitude vs E_n (TOF) spectrum (133.88°)

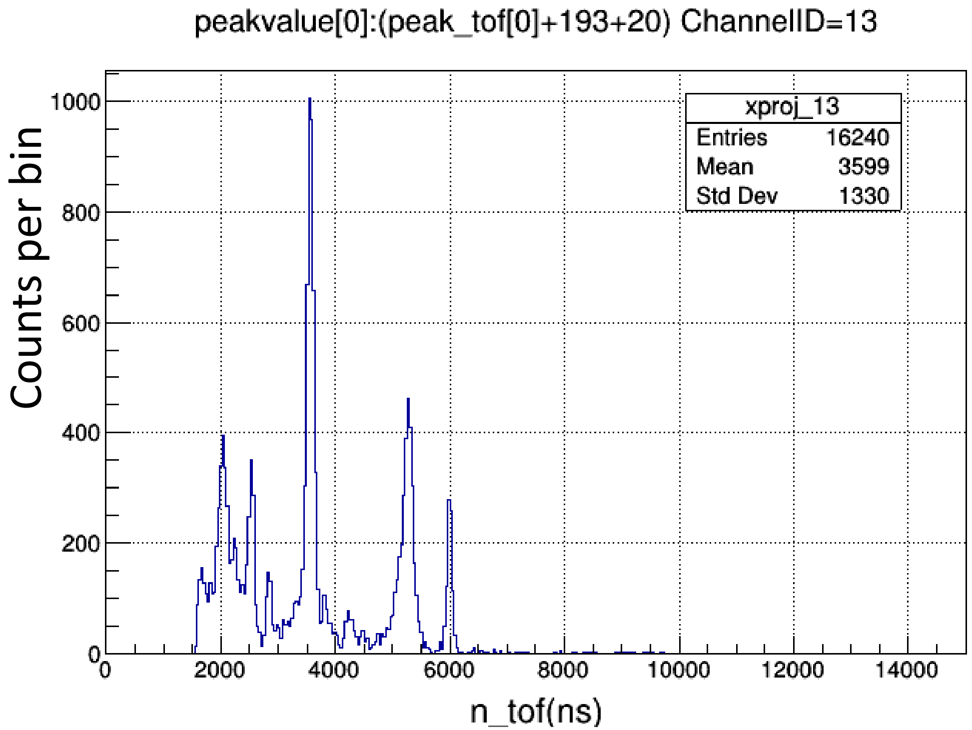
Unfolding of the double-bunched beam

133.88°



After unfolding



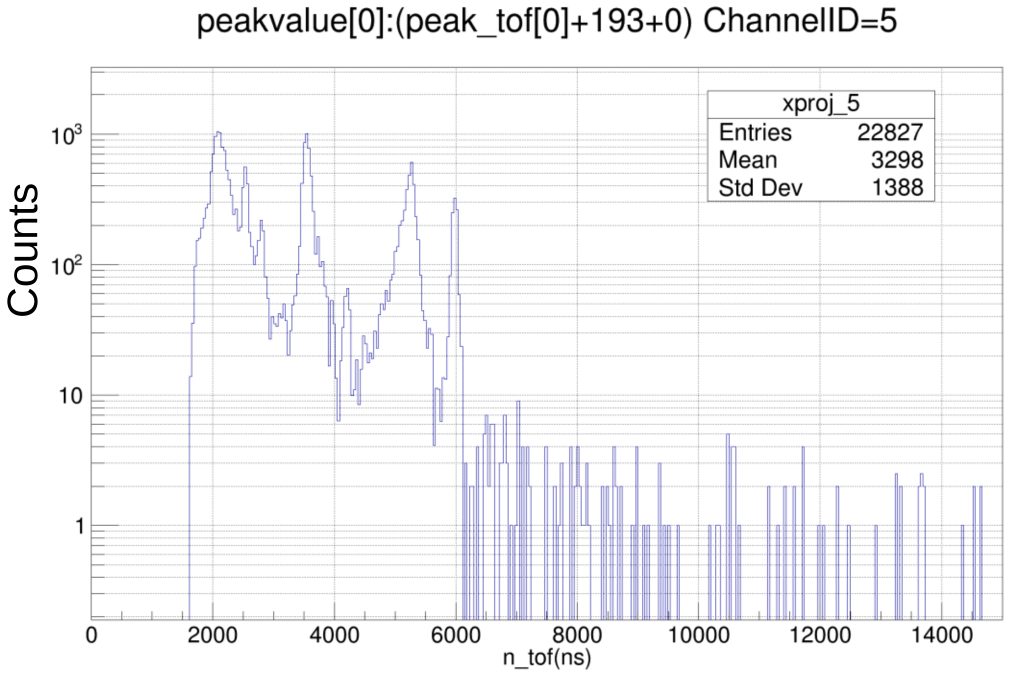


Projection on TOF of neutrons

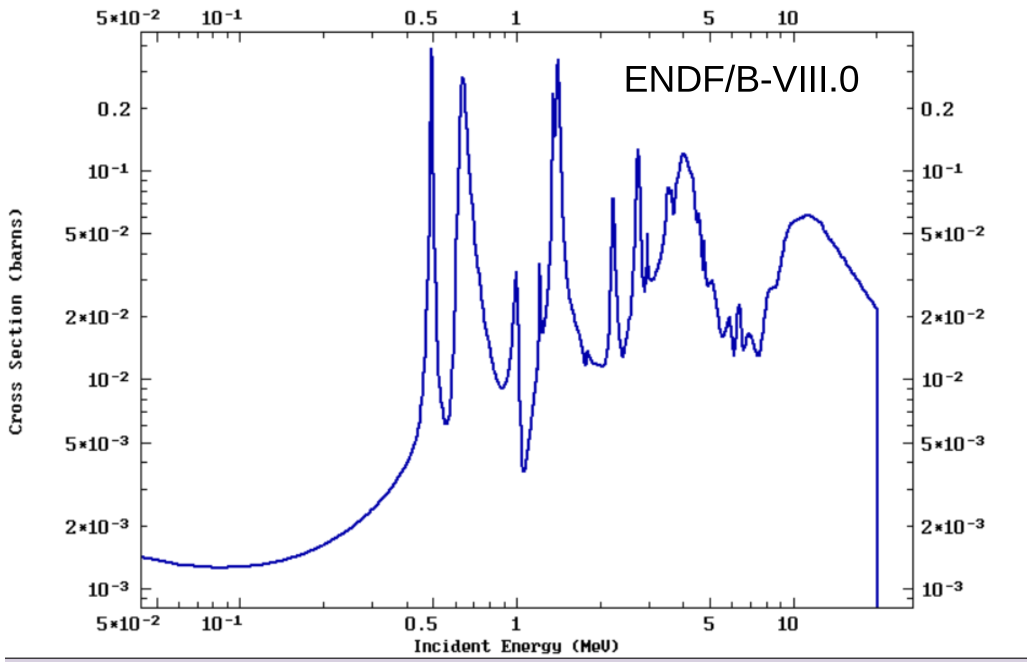
- ✓ When the neutron energy is relatively low, the proton emitted from the other side of ^{14}N(n, p) can’t penetrate the Al substrate;
- ✓ When the neutron’s TOF is less than 4500 ns, the proton on the other side can penetrate, and the two lines tend to merge with the increase of energy (double the statistics).

Counts

- In 0.1-0.45 MeV neutron energy region, the cross-section is about 1-5 mb, and the differential cross-section is as low as 0.1mb.
- Resonances' peak-to-valley is ideal.



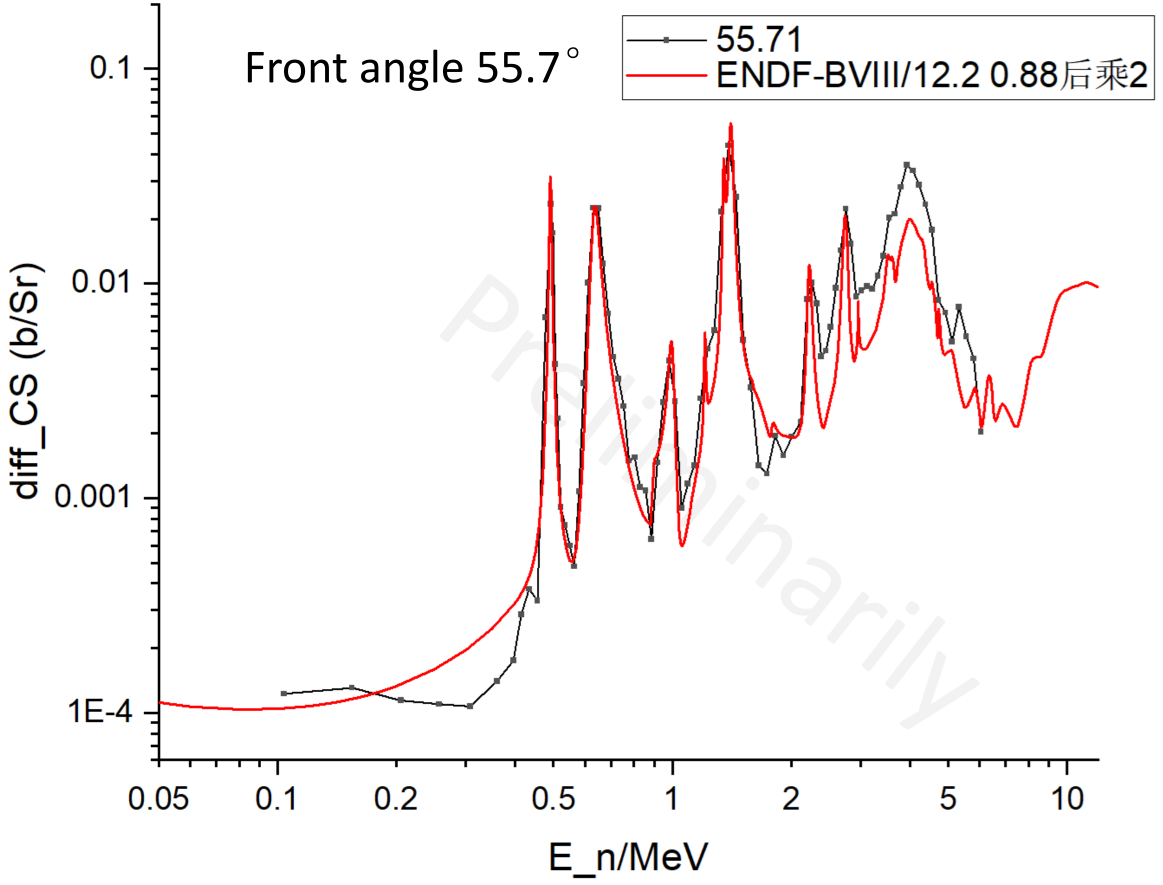
Counts varies with the neutron flight time(40 ns per bin)

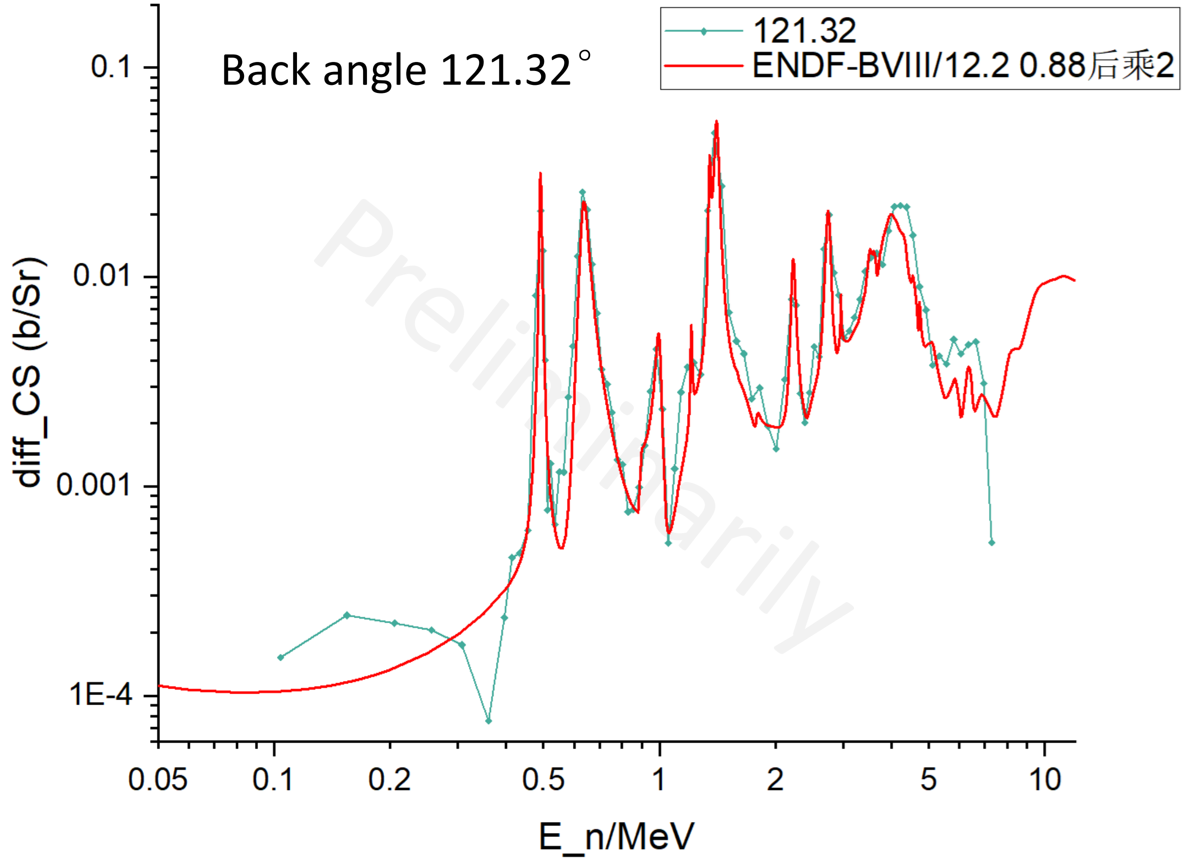


Cross-section evaluation data of $^{14}N(n, p)$ reaction

Differential cross sections of $^{14}N(n, p)^{14}C$

- Differential cross sections of $^{14}N(n, p)^{14}C$ relative to $^{6}Li(n, t)$ reaction (E_n=0.5 MeV).
- $^{6}Li(n, t)$ reaction's cross sections are also deduced.

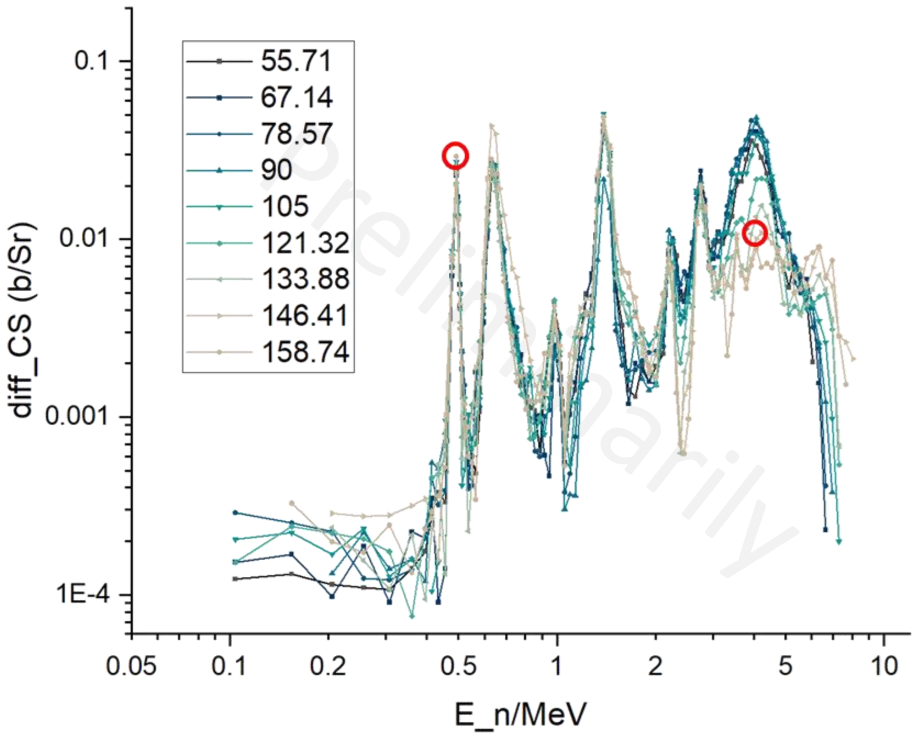


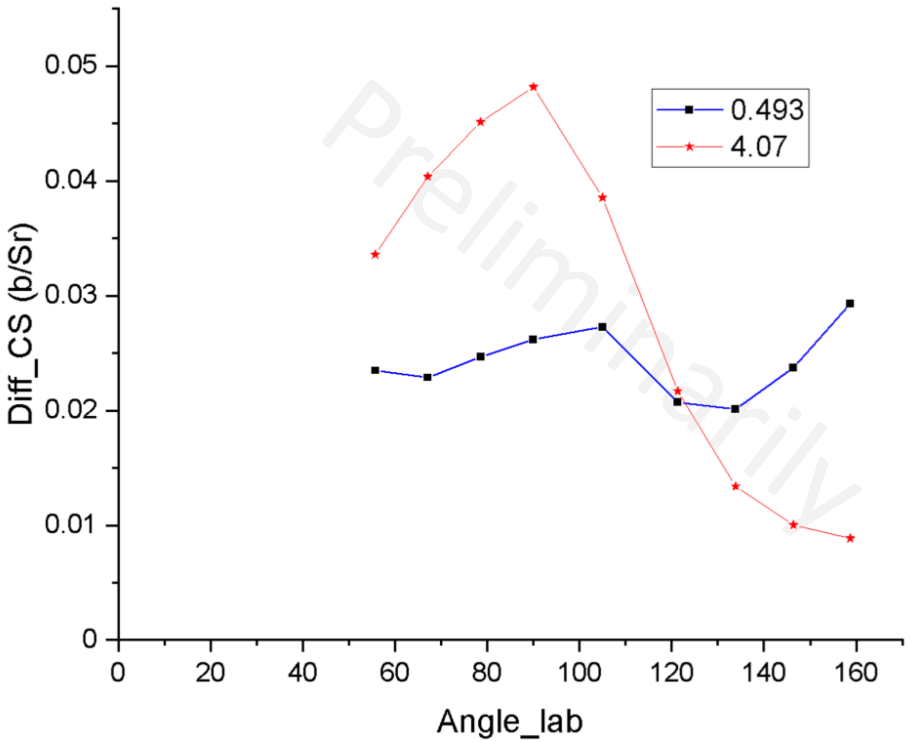


The preliminary experimental results without error analysis at present

Differential cross sections of $^{14}N(n, p)^{14}C$

- $E_n \leq 2$ MeV, differential cross sections varies little in the θ_{lab}(55º-158º).
- Differential cross sections in the E_n region of 100-450 keV is ~0.1mb, as the uncertainty is large.
- $E_n > 2$ MeV, there is a very obvious angular distribution and the resonance peaks are relatively dense, needs to be further explained with R-Matrix analysis.





0.493 MeV
& 4.07 MeV

Summary

- Differential cross-section measurement of $^{14}N(n, p)\,^{14}C$ reaction was carried out.
- Preliminary differential cross sections in 0.1 - 6 MeV E_n region have been obtained.
- Angular distribution of the $^{14}N(n, p)$ reaction at some neutron energy shows anisotropies.
- Preliminary result at E_n ~493 keV resonance supports the results of n-TOF(2023), while the cross sections of the 100-450 keV region needs to be further analyzed.
- R-Matrix analysis still is ongoing.

Thanks for your attention!

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