Preliminary study of white neutron beamlines at the CSNS second target station

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Introduction & Motivation

CSNS as multiple research platforms

- **Capability** to support multiple platforms

  Neutron scattering, White neutrons, Medium/High-energy protons…

White neutrons at CSNS

- **Back-n:** Back-streaming neutrons

  Completed, Nuclear data measurements
- **High energy neutrons**: Forward 41° beamline

  Planned, Atmospheric neutron for single-event effect(SEE)
- CSNS second target station(TS2): possible a few beamlines

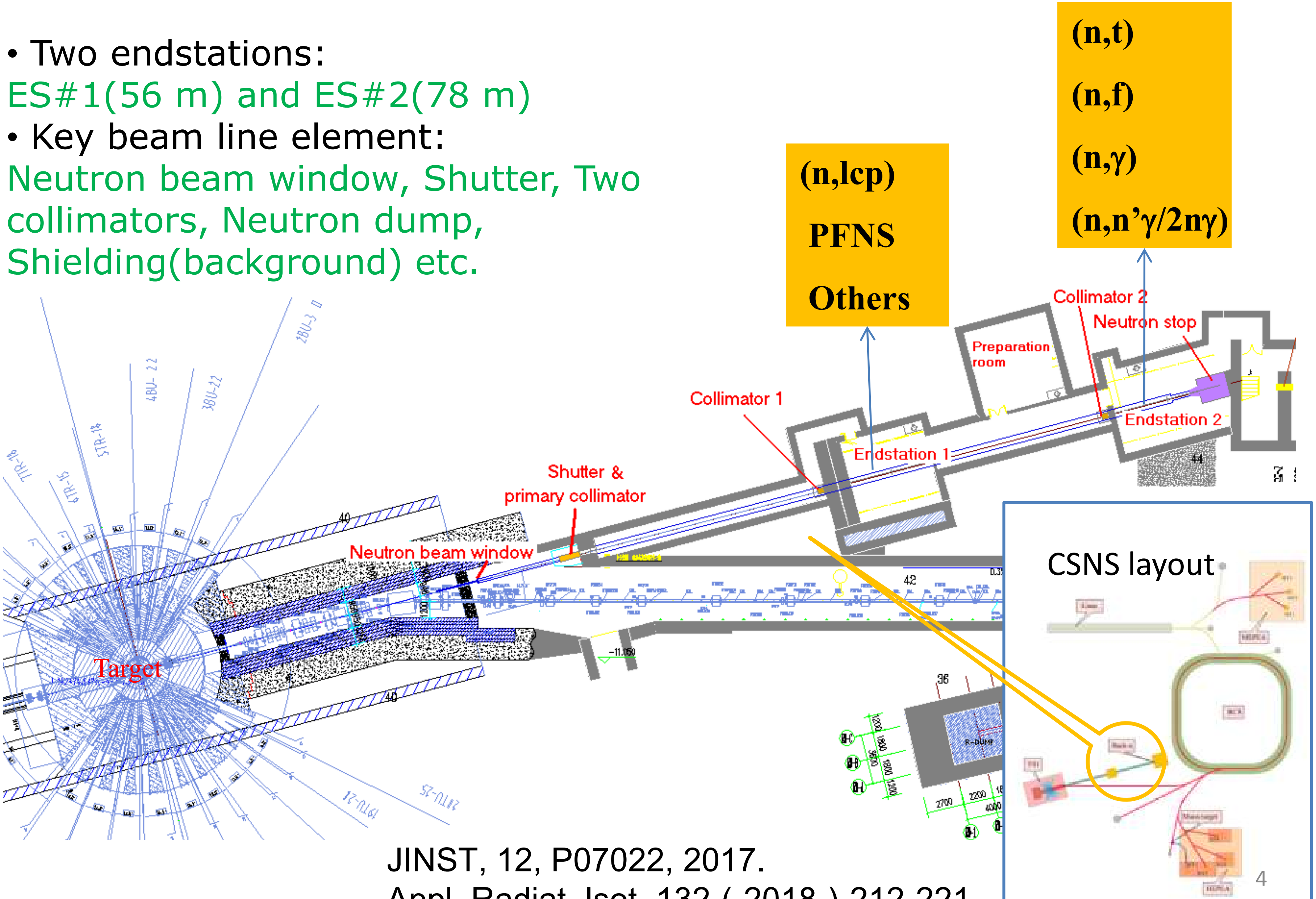
  Vision: combination of cold neutrons, white neutrons and muons; hybrid target structure

Key parameters for a WNS

Wide energy spectrum, High flux, Good time resolution, low background…

Layout of the Back-n white neutron beamline

- Two endstations:
  ES#1(56 m) and ES#2(78 m)
- Key beam line element:
  Neutron beam window, Shutter, Two collimators, Neutron dump, Shielding(background) etc.



JINST, 12, P07022, 2017.
Appl. Radiat. Isot. 132 (2018) 212-221.

The characteristics of Back-n

- Neutron energy：1 eV – 100 MeV
- Proton energy：1.6 GeV
- Proton beam intensity：~1.6×10^{13} p/pulse (@100 kW)
- Pulse repetition frequency：25 Hz
- Time resolution（1 eV -1 MeV）：0.2% ~ 0.9%
- Neutron flux（$n/cm^2/s$）：

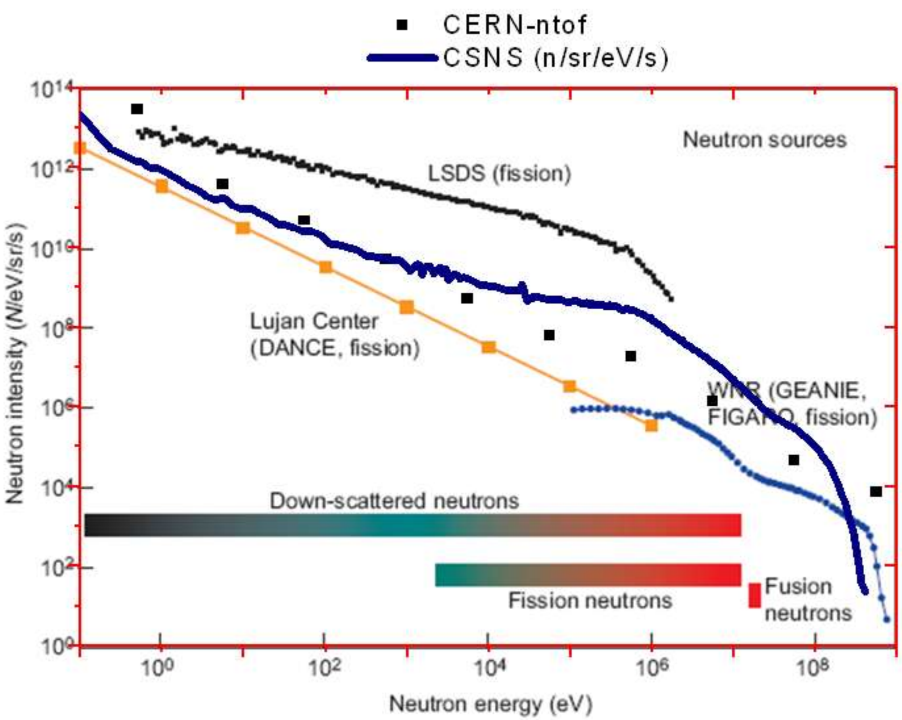
  4.33×10^{7} (Φ60 mm, ES#1)

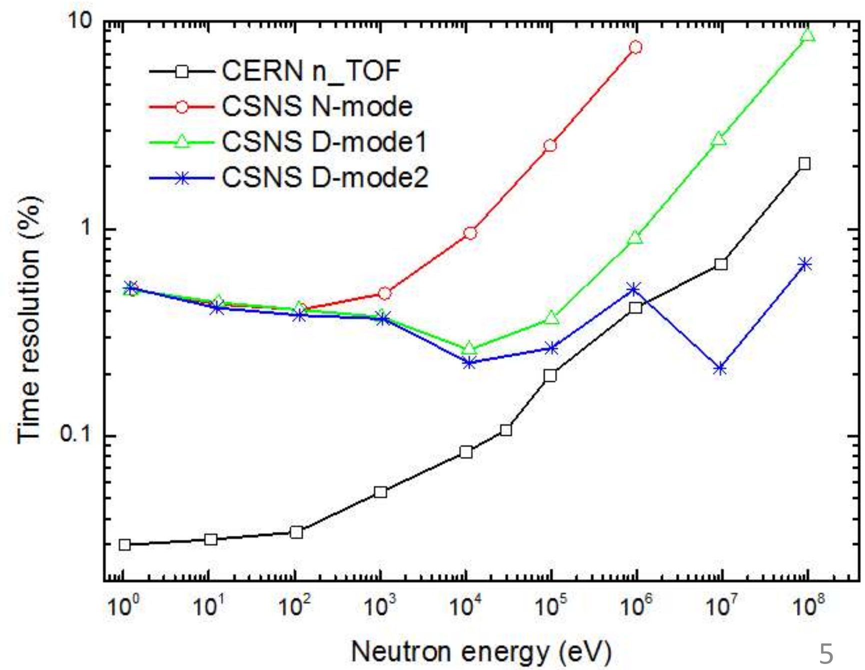
  1.36×10^{7} (Φ60 mm, ES#2)

✓ Perform well in terms of neutron intensity and available neutron energy regions; the most intense in neutron flux at target.

✓ Time resolution is not as good as CERN n_TOF; however, if dedicated mode 2 is used, it can exceed n_TOF above 1 MeV.

✓ A world-class white neutron source, greatly advance nuclear data measurement capabilities in China.





Motivation:

- Back-n is limited to only 80 meters away, and shares a thick target with neutron scattering, making relatively low time resolution for low energy neutrons.

- In addition, because there is only one beam line, which limits parallel experiments (at maximum, two experiments).

- For the CSNS TS2, beam repetition frequency can be 12.5 Hz, making it ideal for neutron scattering applications with long-wave neutrons (or cold neutrons). At the same time, a pulse has only one bunch which is also very beneficial to the fast neutron flight time measurement resolution of the white neutron source.

- Taking the advantage of a white paper for early planning at TS2, we can consider adding more white neutron beamlines to make the CSNS white neutron source the most powerful in the world.


Support buildings
RCS
LINAC
Back-n
RTBT
Target station
(TS1)
Test building#2
Service building
Test building#1
TS2
(reserved)
Office & Lab building#A2
Office & Lab building#A1

Design considerations for TS2

- A hybrid target station
Proposed to serve both neutron scattering applications and white neutron applications

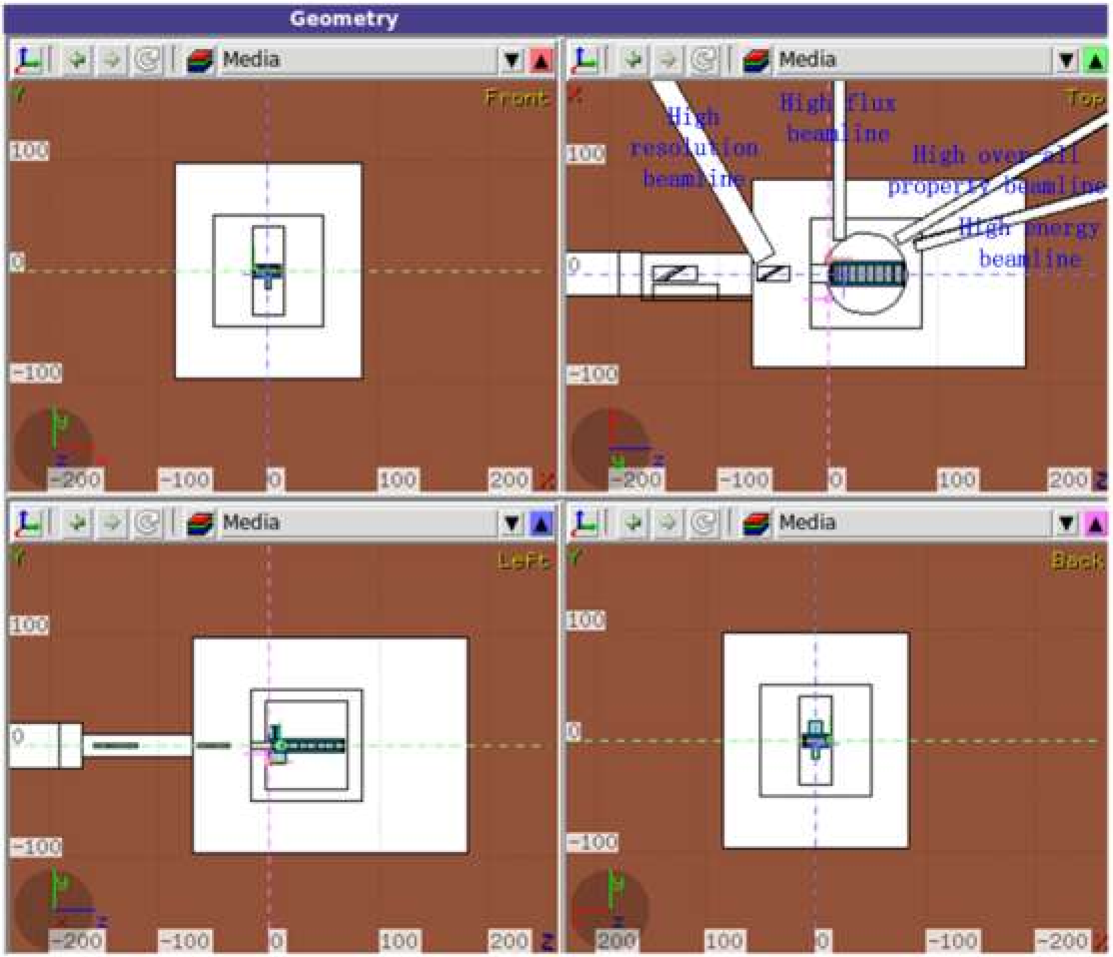
- The thick target material and size :17 cm × 7 cm × 65 cm, the thin target is tungsten, not too thick for high-resolution neutrons.

- Appropriate distance between the thin and thick targets

- Neutron beam tube divided into two types, providing white neutrons and moderated neutrons

Four white neutron beamlines

FLUKA model



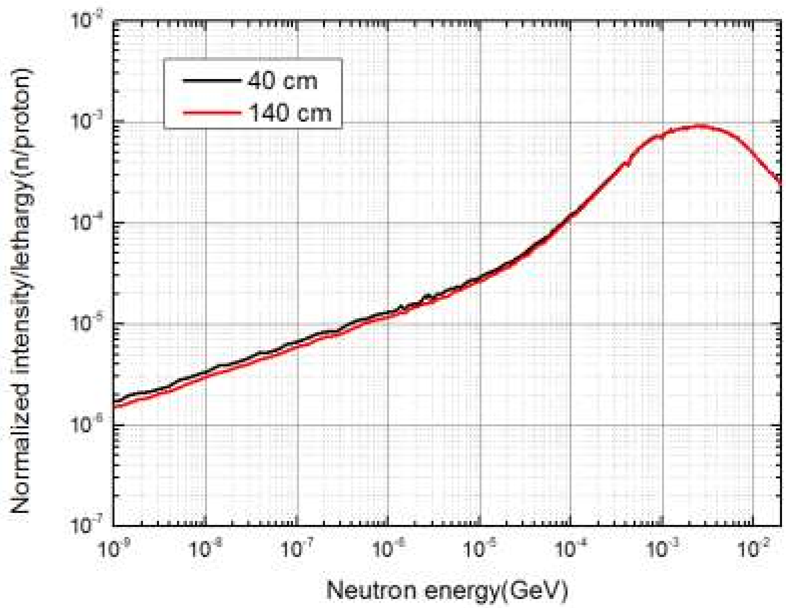
Note: the thin target tilts 30° along the direction of the incident proton.

- High resolution white neutron beamline
- High flux white neutron beamline
- High energy white neutron beamline
- High over-all property white neutron beamline

Distance selection between the thin and thick targets

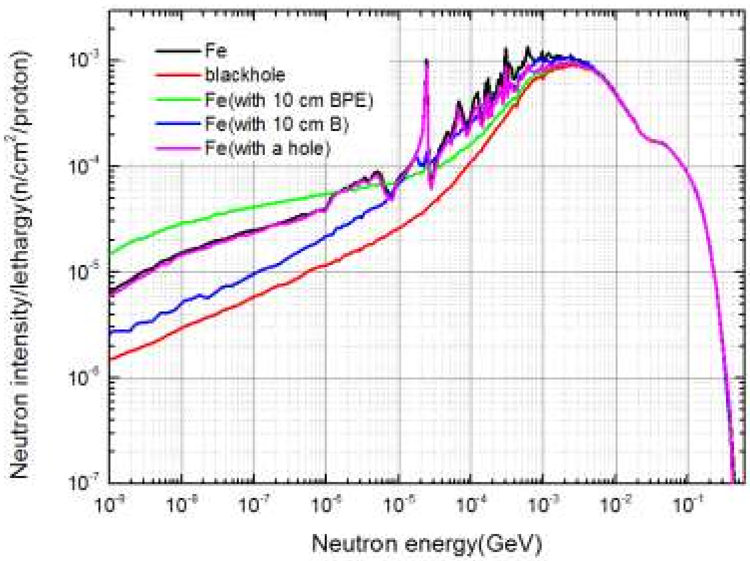
--to make high-resolution white neutron beamline evade neutrons from the thick target as much as possible

◆ Initial set: 40 cm
about 21% neutron influenced by the thick target



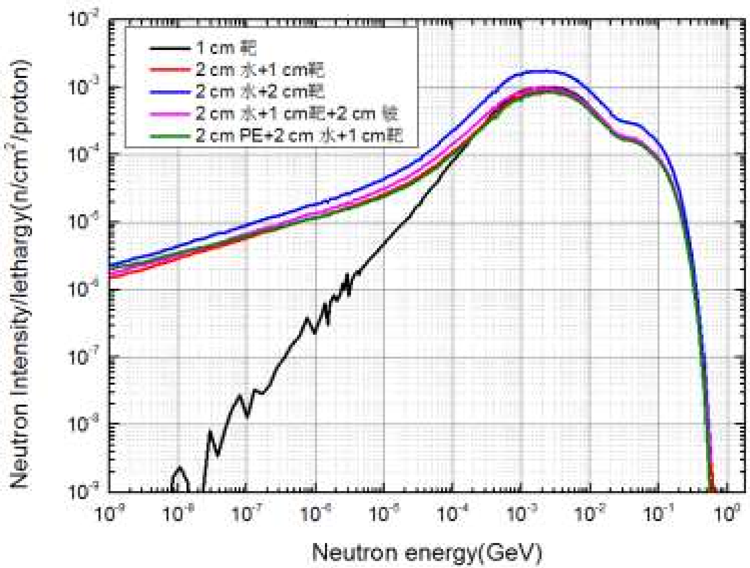
◆ Black-body (shielding material), almost the same under 40 cm and 140 cm cases

◆ Black-body is the ideal case, take actions on shielding body



◆ It may be possible to use the detector's response to remove effect from the thick target due to time delay

Simulation results --high resolution beamline



Extracted from the thin target along the incident proton direction 120°, flight length: 200 m

- Thin target thickness: 2 cm
- Water moderated layer: 2 cm

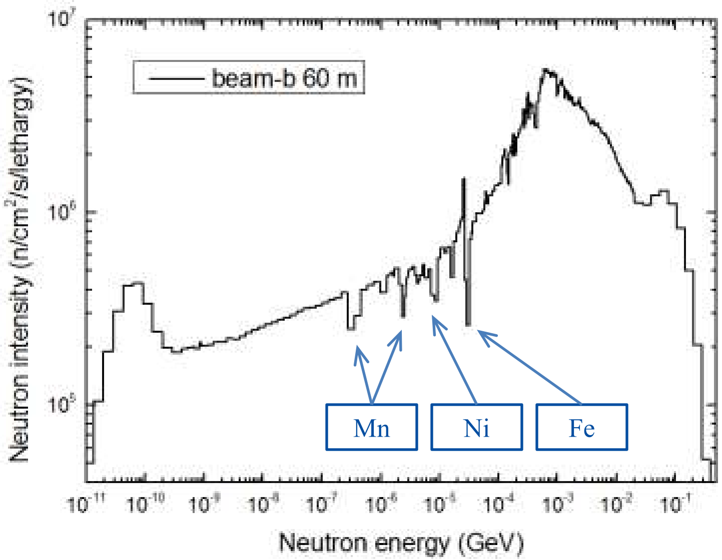
If there is no strict requirement on neutron flux, the thin target thickness can be adjusted to 1 cm, which can reduce the proton scattering effect and further improve the time resolution.

En (eV)	FWHM (μs)	Flight time (μs)	$\Delta t/T$(200 m)
1	1.44	14460	9.95×10^{-5}
10	0.392	4136	9.48×10^{-5}
10^2	0.134	1342	9.99×10^{-5}
10^3	0.0384	437	8.79×10^{-5}
10^4	0.0136	138	9.86×10^{-5}
10^5	0.0042	45.2	9.30×10^{-5}
10^6	0.0014	14.8	9.46×10^{-5}
10^7	0.00062	4.81	1.29×10^{-4}

✓ Without considering the proton pulse, neutron time resolution can reach 1/10000 at 1eV to 10 MeV.

✓It is perfectly suitable for nuclear data measurements that require high resolution.

Simulation results --high flux beamline



Extracted vertically from the longitudinal depth of the thick target about 10 cm, flight length: 60 m

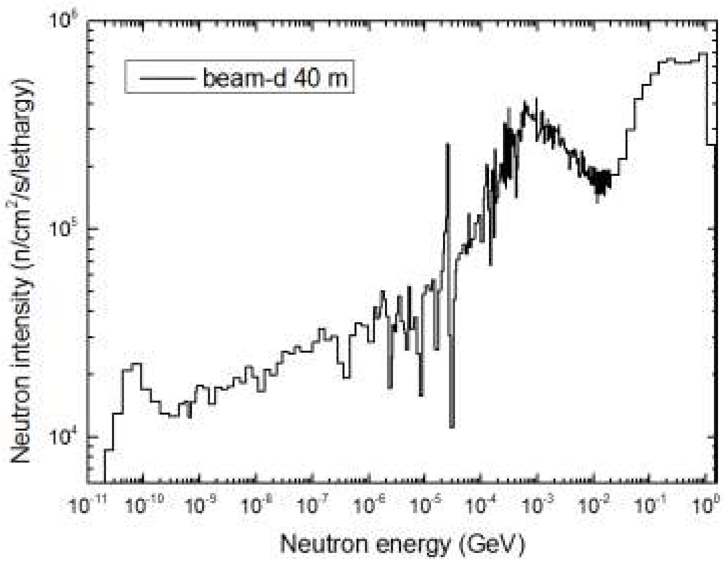
- ✓ Neutron energy: 0.03 eV-400 MeV
- ✓ The deep pit occur in the vicinity of tens of keV due to the resonant cross-section of Fe.
- ✓ Neutron flux is about 10^7 n/cm^2/s.

En (eV)	FWHM (μs)	Flight time (μs)	$\Delta t/T$(60 m)
1	1.76	4476	3.93×10^{-4}
10	0.430	1278	3.37×10^{-4}
10^2	0.176	410	4.30×10^{-4}
10^3	0.0740	136	5.44×10^{-4}
10^4	0.0332	43.2	7.68×10^{-4}
10^5	0.0220	14.2	1.55×10^{-3}
10^6	0.00700	4.76	1.47×10^{-3}
10^7	0.00214	1.54	1.39×10^{-3}

Neutron time resolution is less than 1/1000 at 1 eV~10 keV, which is also good.

This beamline is designed as a high-flux white neutron beamline, if just keep spectrum shape unaffected, when change the flight length to **20 m**, there will be **one order** magnitude growth on neutron flux.

Simulation results --high energy beamline



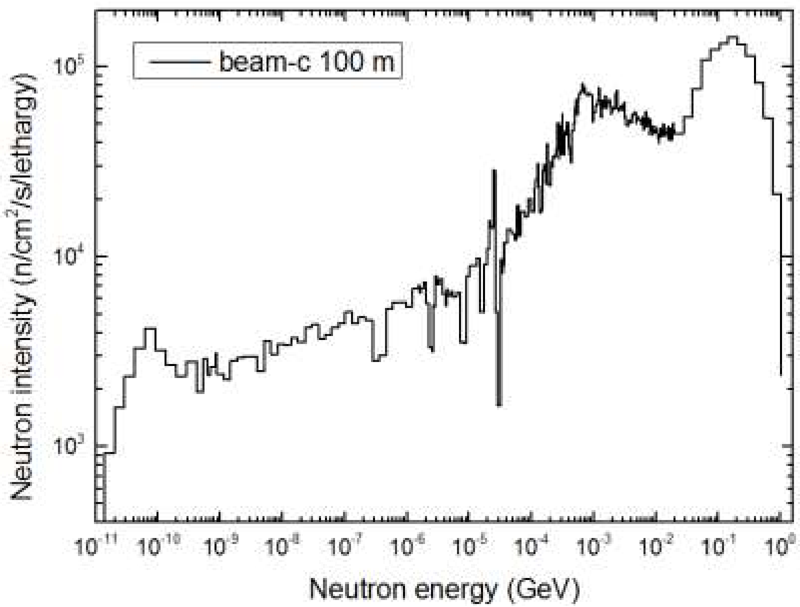
Extracted from the longitudinal depth of the thick target about 30 cm along the incident proton direction 15° ,flight length: 40 m

- Wide spectrum, from thermal neutron to GeV
- A higher peak near 200 MeV in addition to the peak near 1 MeV (forward behavior of spallation neutrons)
- The proportion of neutrons (>100 MeV) is close to 50%.

En (eV)	FWHM (μs)	Flight time (μs)	$\Delta t/T$(40 m)
1	4.40	3600	1.22×10^{-3}
10	1.25	1024	1.22×10^{-3}
10^2	0.380	333	1.14×10^{-3}
10^3	0.175	108	1.62×10^{-3}
10^4	0.110	34.5	3.20×10^{-3}
10^5	0.0450	11.4	3.95×10^{-3}
10^6	0.0164	3.78	4.34×10^{-3}
10^7	0.00380	1.20	3.17×10^{-3}

Regardless of the proton pulse, the neutron time resolution is less than 5/1000. The proton pulse structure plays a decisive role in the time resolution of high-energy neutrons.

Simulation results
--high over-all property beamline



Extracted from the longitudinal depth of the thick target about 10 cm along the incident proton direction 30° ,flight length: 100 m

The spectrum shape is close to that of the high-energy beamline. The neutron flux is in the order of 10^6 n/cm²/s, where the proportion of neutrons(>100 MeV) is close to 30%.

En (eV)	FWHM (μs)	Flight time (μs)	$\Delta t/T$(100 m)
1	3.80	9080	4.19×10^{-4}
10	1.00	2580	3.88×10^{-4}
10^2	0.360	843	4.27×10^{-4}
10^3	0.134	273	4.90×10^{-4}
10^4	0.128	86.8	1.47×10^{-3}
10^5	0.0540	28.6	1.89×10^{-3}
10^6	0.0166	8.94	1.86×10^{-3}
10^7	0.00354	2.60	1.36×10^{-3}

The time resolution of low-energy neutrons can be less than 1/1000, while that of high-energy neutrons can be affected by proton pulses.

Summary

- Back-n WNS at the CSNS has been running successfully this year.

- A hybrid target station which is composed of a thin target and an adjacent thick target, is proposed to serve both neutron scattering applications and white neutron applications.

- Four white neutron beamlines at the CSNS TS2 are planned to provide beams with different characteristics: high resolution, high flux, high energy and over-all properties.

- It will provide some guidance for the future design and construction of the TS2, and could also be a reference for other new white neutron sources.

- Next, we will further study on white neutron beamlines at the CSNS TS2, including collimation, shielding, background control, etc.

Thanks for your attention!