

The introduction of Back-n beamline

Ruirui Fan on behalf of Back-n collaboration



白光中子实验装置 Back-n





Back-n





Shutter	Coll#1	Coll#2	ES#1 spot	ES#1 flux	ES#2 spot	ES#2 flux
(mm)	(mm)	(mm)	(mm)	$(n/cm^2/s)$	(mm)	$(n/cm^2/s)$
Ф3	Φ15	Φ40	Ф15	1.27E5	Ф20	4.58E4
Φ12	Φ15	Φ40	Ф20	2.20E6	Ф30	7.81E5
Φ50	Φ50	Φ58	Ф50	4.33E7	Ф60	1.36E7
78×62	76×76	90×90	75×50	5.98E7	90×90	2.18E7

The back-streaming neutrons are leading to the Back-n tunnel, which has a long flight distance for the neutron time-of-flight method. Two end stations ES#1 and ES#2 are constructed for different nuclear data measurements. The ES#1 has a distance of about 55 m, and ES#2 is about 70 m from the target. Different sets of beam spots, collimator apertures and neutron fluxes at Back-n at 100 kW in proton beam power can be found in table.

1. 2017 JINST 12 P07022

Oct 30, 2023

2. Eur. Phys. J. A (2019) 55: 115

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The white neutron energy range



The Back-n has a wide neutron energy range from cold neutron (0.4 meV) to 300 MeV. To avoid the frame overlap, a Cadmium filter is employed at the upstream end of the beamline (window). Some important parameters such as neutron polarization need to be calibrated using thermal neutrons. Changing the beam filter 1 mm Cadmium \rightarrow 1.7 mm boron nitride (BN), can get a lower cutoff energy.



Back-n beam monitor



Two monitors are employed:

- Proton beam monitor (Fast Current Transformer)
- Li-Si monitor (⁶LiF foil and silicon detectors)



Nuclear Inst. and Methods in Physics Research, A 946 (2019) 162497





Comparison of Li-Si monitor measurements with proton current intensity monitor measurements

Back-n shielding & background measurement





Neutron and γ background measurements of the experimental halls at the CSNS back-streaming white neutron source, NIMA Volume 980, 11 November 2020, 164506

Oct 30, 2023

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核数据测量探测器 Detectors @ Back-n

The beam diagnostics and several detector systems, for example the Fission chamber, the light charged particle detector array, the C6D6 scintillation detectors and the camera system were developed before the beamline Li-Si beam established and serviced most of the experiments at flux monitor Back-n.

Several ambitious developments, for example, the multipurpose time projection chamber (MTPC), the radiation resistant semiconductor detectors, the Gamma-ray total absorption facility (GTAF-II) and the neutron-sensitive microchannelplate detector (B-MCP) are in progress for future experiments.

Proton beam

ES#1

The detectors are not fixed with any experiment station:

Light charged Particle

Detector Array

 $C_{6}D_{6}$

Dump

Gamma-ray total

absorption facility

ES#2

Collimator#1

- Fission ionization chamber
- Micromegas

Collimator#

shutter Neutron beam

15°

- Multi-layer fission ionization chamber
- Multi-purpose Time Projection Chamber
- Radiation-resistant semiconductor detector
- Gated CMOS camera
- Neutron sensitive Micro-Channel-Plate

Ruirui, F., Qiang, L., Jie, B. et al. Radiat Detect Technol *Methods* **7**, 171–191 (2023).

target

GTAF (40 BaF₂ detector array)



Belongs to CIAE, Designed to measure (n, γ) nuclear data

- 42 segments (40segments with crystals)
 - 2 different crystal shapes
 - Inner radius = 10cm
 - Crystal depth = 15cm





The fission chamber





The fission ionization chamber detector measures the fission fragments generated through the reaction between the fission material (²³⁵U, ²³⁸U) and neutrons, and records the energy of the neutrons by measuring their flight time.

Nuclear Inst. and Methods in Physics Research, A 940 (2019) 486–491

Δ E- E detector array (LPDA)





The photo of LPDA



The LPMWPC (ΔE) vs Si-PIN (E) spectrum and Si-PIN (ΔE) vs CsI(Tl) (E) spectrum

The LPDA is divided into two modules, each covering an angle of 23.5-90 degrees. It includes 8 sets of LPMWPC+Si+CsI detector telescopes, with a total of 48 channels. It was completed in June 2020 and has undergone preliminary testing.

Kang Sun et al 2023 JINST 18 P04004

Back-n multipurpose TPC

Time Projection Chamber, which is a type of detector that records the three-dimensional trajectory of charged particles. The design of the TPC detector for the white neutron beam line started in 2019 and took 4 years to complete. The measurement of the neutron reaction cross section of ⁶Li has been completed at beginning of this year, and the data is being analyzed while a new round of measurements has been proposed.

- 1. Z. Chen *et al* 2022 *JINST* **17** P05032
- 2. NIMA 1039 (2022) 16715





DAQ



Common electronics system overall architecture

Common electronics: it consists of an analog conditioning module (SCM), a trigger clock module (TCM), and a waveform digitization module (FDM). resolution:12 Bit Sample rate: 1 GHz PXIe based, more than 60 channels.



electronics photos



Review of Scientific Instruments **89**, 013511 (2018); doi: 10.1063/1.5006346 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 66, NO. 7, JULY 2019



核数据测量实验 Nuclear data measurement

Nuclear data measurement experiments



Since 2018, we have measured the neutron reaction cross sections of more than 50 nuclides and will continue to measure at a rate of over 10 nuclides per year.

- Neutron capture
 - C₆D₆: ¹⁶⁹Tm, ¹⁹⁷Au, ⁵⁷Fe, ^{nat}Se, ⁸⁹Y, ^{nat}Er/¹⁶²Er, ²³²Th, ²³⁸U, ⁹³Nb, ^{nat}Cu, ^{nat}Lu, ^{113&115}In, ^{185&187}Re, ¹⁸¹Ta, ^{107&109}Ag, ¹⁶⁵Ho, ^{nat}Yb, ¹²⁷I, ¹³³Cs, ^{nat}Dy, ¹⁰³Rh
 - GTAF-II: ¹⁶⁹Tm, ⁹³Nb , ^{nat}Re, ^{nat}Xe, ^{nat}Sn, ¹²⁷I, ^{nat}La
- Total cross-section
 - ¹²C, ²⁷Al, ⁹Be, ⁷Li, ^{nat}Fe, ²⁰⁹Bi, ^{nat}Pb, ^{nat}Cr, ⁹Be, ¹⁶⁹Tm
- Fission cross-section
 - ²³⁵U, ²³⁸U, ²³⁶U, ²³⁹Pu, ²³²Th, ²³⁹Pu, ²³⁶U
- Light charged particle emission
 - LPDA: ⁶Li(n, x), ¹⁰B(n, x), ⁶³Ni, (n-d), ¹⁷O, (n-p), 12C(n,d), 12C(n,α) (13C cluster)
 - TPC: ¹²C, ¹⁴N, ⁶Li
- Inelastic cross-section (in-beam gamma)
 - ⁵⁶Fe (n, n'), ^{nat}Mo, ¹⁶O, ^{nat}Ru, ^{nat}Lu, ^{nat}Mo, ^{nat}Ti, ²⁰⁹Bi, ⁹⁰Zr, ⁵⁵Cr, ¹⁵⁵Eu, ¹⁷⁸Hf, ²³²Th

⁶Li(n, t) α , ¹⁰B(n, α)⁷Li cross section measurements

- $6Li(n, t)\alpha$, $10B(n, \alpha)7Li$ reaction cross-sections are widely used as standard cross-sections and require higher precision results, and $10B(n, \alpha)7Li$ reaction cross-sections are also important parameters required in BNCT (Boron Neutron Capture Therapy) research.
- $6Li(n, t)\alpha$, $10B(n, \alpha)7Li$ reaction differential cross-sectional measurement, data analysis to obtain high-precision results, which is the most systematic measurement results of this energy region in the world.





(59能点)

(59能点)

E_a (MeV)

En (Me)

102

 10^{-1}

n-p scattering measurement

- The 1H(n, n)1H reaction is one of the important reactions to study nuclear forces, and there are no measurement results in some energy regions covered by Back-n.
- Overcoming the interference of γ-flash to the detection system, the telescope system worked stably during the 400-hour beam experiment.
- Relative differential cross-sections were obtained at 23 energy points in the 6.14 MeV--52.48 MeV energy region, and experimental results were obtained for the first time in the 6.52 ≤ En ≤ 9.09 MeV, 10.57 ≤ En ≤ 12.43 MeV and 18.05 ≤ En ≤ 20.05 MeV energy regions.





²³²Th fission cross section measurement



- Back-n ES#1 ~φ18 mm beam size
- Double bunches mode ~100 kW
- FIXM(Fission chamber) measures the FFs (fission fragments)
- PRT(Proton recoil telescope) measures the recoiled proton as reference



A cross-sectional measurement of 232Th (n, f) was measured using two methods (two reference standards):

- Reference 1: ²³⁵U(n, f) [neutron energy range: 1-300 MeV]
- **Reference 2**: n-p scattering [neutron energy range : 10-70 MeV]



²³²Th (n,f) cross-section measurement results



Comparison of this work with evaluation data

Comparison of this work with other measurements

Reviewer #2: - The article describes the procedure to measure 232Th(n,f) x.s. in the CSNS-Back-n facility, presenting some results and comparing it with previous results from other authors.

 It is a novel and very interesting work with high impact on the improvement of ND evaluated libraries, and nuclear fission applications.

- The neutron energy in this work ranges up to 300 MeV, when previous experiments retrieved from EXFOR don't reach above 200 MeV. This is relevant for a better understanding of fission at intermediate energies.

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since the agreement is mostly good elsewhere. The extension of the analysis to higher energies clarified the structure

Summary/Conclusions

4.

of interfering 3/2 levels in the 4-6 MeV range, and removed a prominent bump in the previous "Li(n.f) evaluated cross section at ~ 6 MeV.

 A new 'Li R-matrix analysis, extended to 8 MeV incident neutron energy, forms the basis for a new evaluation of the n+*U reactions.

. The data for most reactions are fit well, including the extensive new CSNS data set of Bai et al., which may be overall the most complete,

and best-cowiny, set of relative differential cross sections for the "Li(n,t)/He reaction that presently exists at energies below 3 MeV.

· Fractuations in the scale of this measurement were observed at energies below 4 eV, and a large difference in the integrated cross section (3.54 vs. 3.18 b) near the peak of the resonance is puzzling.



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IAEA committee invitation

Fit to ⁶Li(n,t)⁴He Data from Bai et al., cont.

- The results of standard cross-sectional measurements are highly • valued by the International Atomic Energy Agency (IAEA):
 - 1. ⁶Li(n, t) measurement
 - 2. 235 U(n, f)/ 238 U(n, f)
 - 3. ²³²Th (n, f) measurement



Fission relative cross-section measurement results were invited to participate in the 2022 IAFA Neutron Standard Data Conference and give an invited presentation

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2023-06-19

(A) IAEA

I have the honour to inform you that the International Atomic Energy Agency (IAEA) will hold the Technical Meeting on Neutron Data Standards (hereinafter referred to as "event") at its Headquarters in Vienna, Austria, from 9 to 13 October 2023.

Invitation of the Oct2023 IAFA Technical Meeting on Neutron Data Standards









What can we do at Back-n?





the beam flux comparison between Back-n and n_TOF

Back-n has the most insensitive neutron flux, and is an ideal environment for astrophysical experiments.

- Small reaction cross-section (mb-μb)
- Important targets, which are difficult to prepare or radioactive
- <u>Neutron energy requirements 1-300 keV</u>

Oct 30, 2023

1 Astrophysics experiments

- S-process neutron capture reaction
 - Almost all cross-sections are measurable
- Rare nuclides reactions
 - Determines the key (n, p), (n, α) and other reactions produced by a nuclide
 - Solve the problem of anomalies in the abundance of interstellar matter and AGB stars: reaction section of 17O(n, α)14C key energy region;
 - The 25Mg(n, α)22Ne reaction measurement (its inverse reaction is the main neutron source reaction in AGB stars, also one of the important physical targets of Jinping II).





¹⁷O(n, alpha) experiment

 $^{17}O(n, \alpha)^{14}O$ reaction cross-section measurement: Professor Li Yunju of the China Institute of Atomic Energy proposed experiments and planned to obtain the results of the 1 ~ 400 keV neutron energy region.

¹⁷O(n, α) experiment, June 2020:

Targets include ¹⁷O targets (W¹⁷O₃), ¹⁶O targets for background, and ⁶LiF reference targets. A silicon carbide detector array (8 pieces) is installed in the front corner area and a silicon detector array (8 pieces) is installed in the rear corner area.

SiC and silicon detectors are used to measure the α particles ejected in the reaction. The reaction cross-section of $^{17}O(n, \alpha)^{14}C$ was obtained in the energy region of interest.







2 Neutrinos: Spectral Shape

All reactor-based neutrino experiments have the problem of measurement and calculation of neutrino energy spectrum discrepancy.





- O13 experiments show disagreement with spectrum models
- Could be a contribution from a single isotope or multiple isotopes

LEU Reactors: ²³⁵U ~ 45-65% ²³⁹Pu ~ 25-35% ²³⁸U,²⁴¹Pu < 10% each

- 1. J.K.Ahn et al. (RENO Collaboration), Phys. Rev. Lett. 108:191802, (2012)
- 2. JUNO collaboration, Neutrino Physics with JUNO, JOURNAL OF PHYSICS Inconsistent with neutrino oscillation scenarios G-NUCLEAR AND PARTICLE PHYSICS, 2016, 43 (3).
- PatrickHuber. Reactor antineutrino fluxes Status and challenges. Nuclear PhysicsB, 908 (2016) 268–278
- Reactor models wrong? Recent beta conversion calculations reduce somewhat, 1908.08302
- But, need data

From P. Mumm for the PROSPECT Collaboration

The neutron energy spectrum?



Pressurized water reactor core neutron spectroscopy and ILL experimental reactor thermal neutron



- In the 80s of last century, the French Institute Laue-Langevin (ILL) used the reactor to measure the fission β spectrum of reactor nuclides, which is currently widely used experimental data in calculating the expected neutrino energy spectrum of reactor nuclides;
- Some theories suggest that the difference between the reactor neutron energy and the core neutron energy is the main source of error.¹

^{1.} Asner, D.M., et al., Method of fission product beta spectra measurements for predicting reactor anti-neutrino emission. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2015. 776: p. 75-82.

235 U fission fragments β spectrum measurement





Results





Preliminary results indicate that electron energy spectra measured using higher energy neutrons are higher than ILL's result. But a lot of PID and background subtract work is still undertaking.....

3 Nuclide identification radiography (NIR)



sample:

Au、 Ag、 W、 Ta、 In



Transmission image



For the inspected sample containing nuclides that exhibit sharp cross-section resonances, the nuclides' distributions can be identified by analyzing the time-resolved transmission images of the neutrons through the sample. *



Pub In

Transa and

Indium

Tungsten

*NIMA 1048, 2023, 167892



BMCP detector system







¹⁰Boron loaded Neutron-sensitive microchannel plates (BMCPs) have good spatial and temporal resolution for neutron energy-resolved imaging.

More efficiency, and More sensitive than camera !

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Back-n collaboration

There are a total of more than 90 people from 13 institutions, including:

- the Institute of High Energy Physics of the Chinese Academy of Sciences
- the China Institute of Atomic Energy
- the China Academy of Engineering Physics
- the Northwest Institute of Nuclear Technology
- the University of Science and Technology of China
- Peking University
- Xi'an Jiaotong University and others, in the author list in the Back-n collaboration.





礼 Thanks