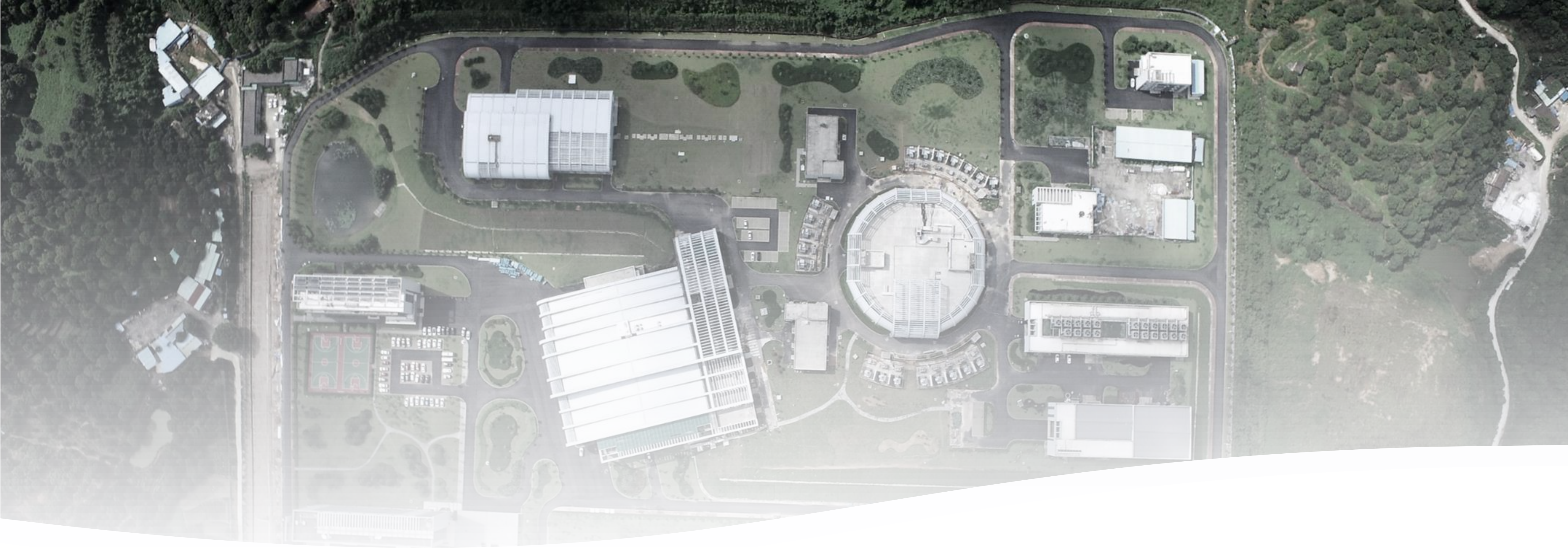


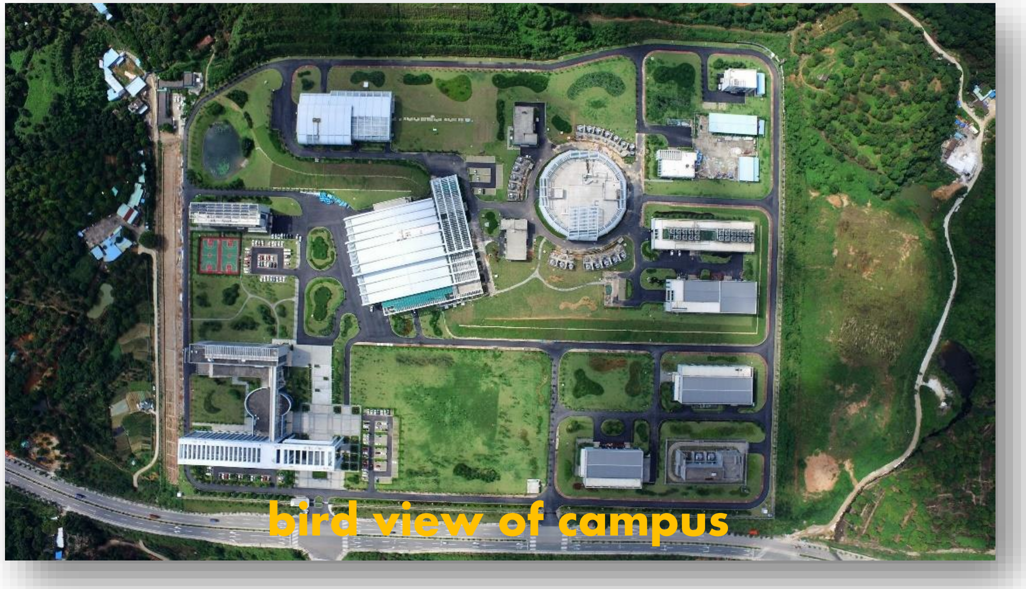
The introduction of Back-n beamline

Ruirui Fan on behalf of Back-n collaboration

白光中子实验装置

Back-n

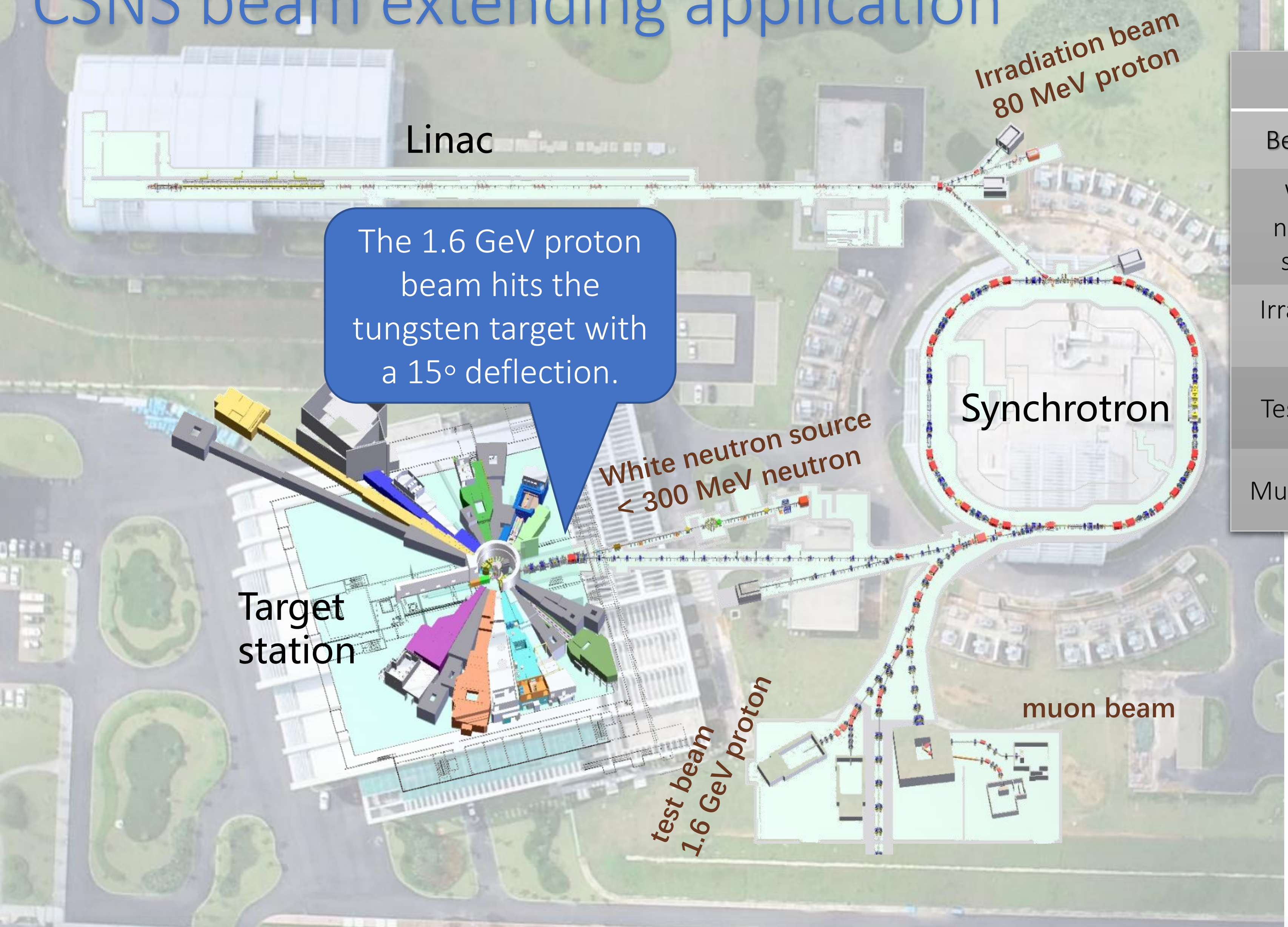
China Spallation Neutron Source



The China Spallation Neutron Source, located in Dongguan city, near Hong Kong, was established on August 28, 2017, with a budget of 2.3 billion yuan.

It consists of a 1.6 GeV proton accelerator with a repetition rate of 25 Hz and a beam power of 100 kW, will be 500 kW in next six years.

CSNS beam extending application

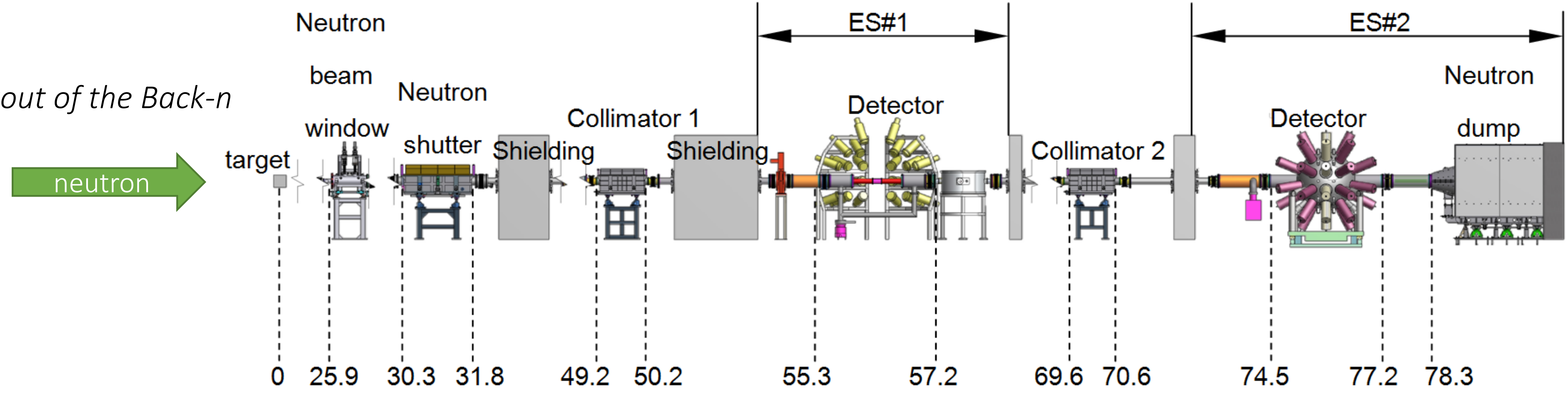


Beam parameters			
Beamline	Particle	Energy	flux
White neutron source	Neutron	thermal-300 MeV	1E7 n/cm^{-2}/s
Irradiation beam	Proton	80 MeV	1E9 p/s
Test beam	Proton	1.6 GeV	1E3 – 1E8 p/s
Muon beam	Muon	4 MeV	1E5 muon/pulse

The Back-n is a white neutron beam line that is opposite to the target station direction. It started running in 2018 for nuclear data measurements.

Back-n

Layout of the Back-n



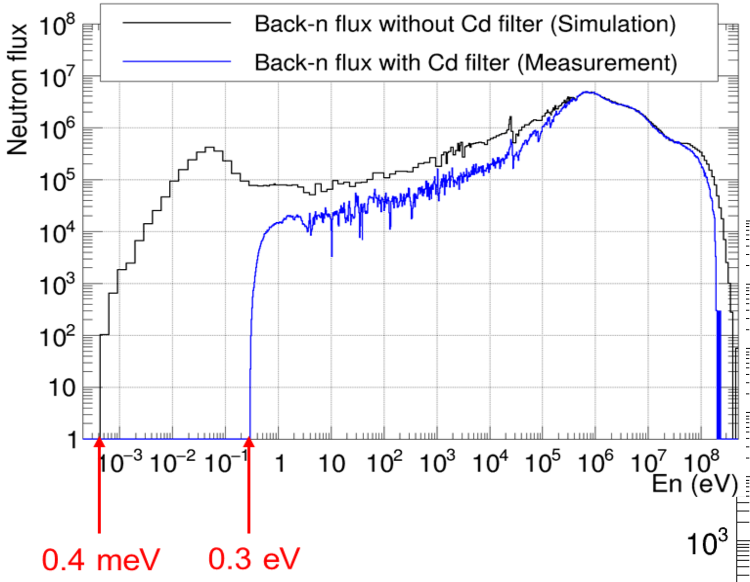
Shutter (mm)	Coll#1 (mm)	Coll#2 (mm)	ES#1 spot (mm)	ES#1 flux ($n/cm^2/s$)	ES#2 spot (mm)	ES#2 flux ($n/cm^2/s$)
Φ3	Φ15	Φ40	Φ15	1.27E5	Φ20	4.58E4
Φ12	Φ15	Φ40	Φ20	2.20E6	Φ30	7.81E5
Φ50	Φ50	Φ58	Φ50	4.33E7	Φ60	1.36E7
78×62	76×76	90×90	75×50	5.98E7	90×90	2.18E7

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.

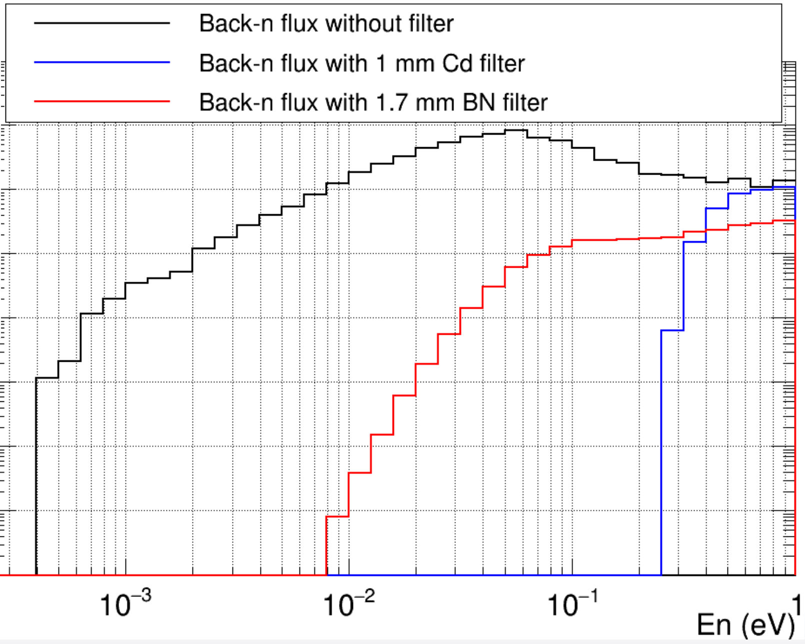
1. 2017 JINST 12 P07022
2. Eur. Phys. J. A (2019) 55: 115

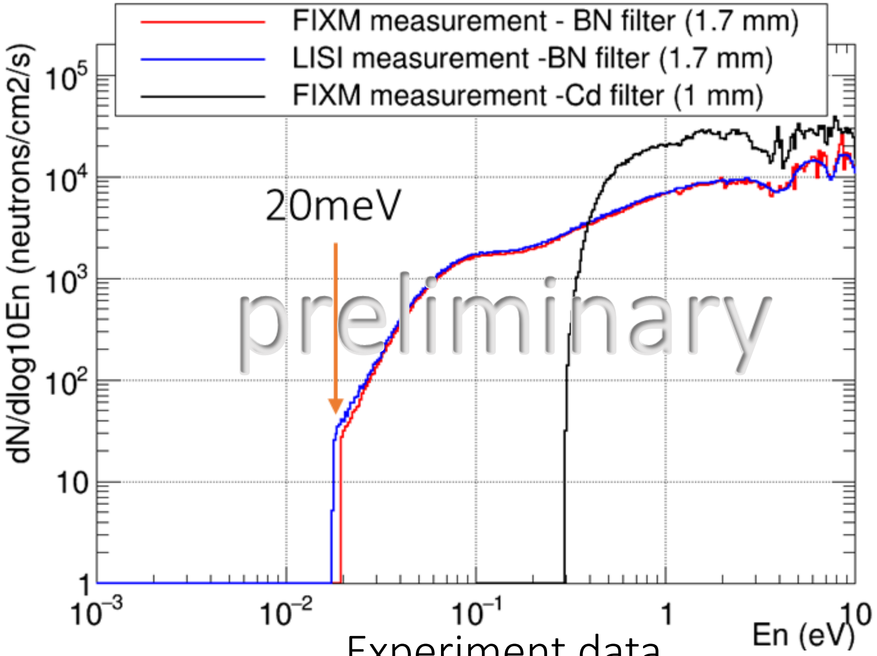
The white neutron energy range

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).
Thermal neutrons or epithermal neutrons are the reference for the NOPTREX experiment, and some important parameters such as neutron polarization need to be calibrated using thermal neutrons.
Changing the beam filter 1 mm Cadmium ⟶ 1.7 mm boron nitride (BN), can get a lower cutoff energy.



simulation

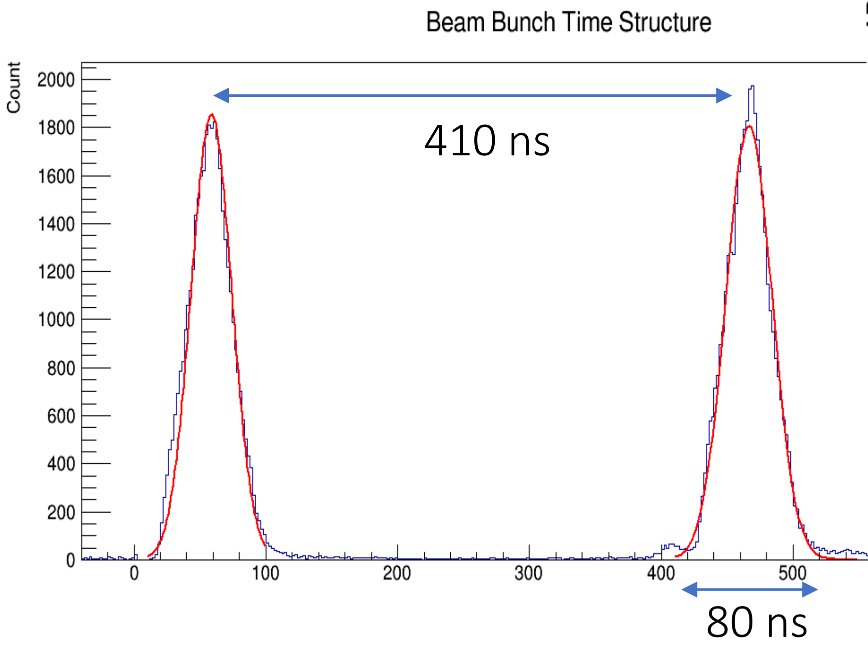




Experiment data

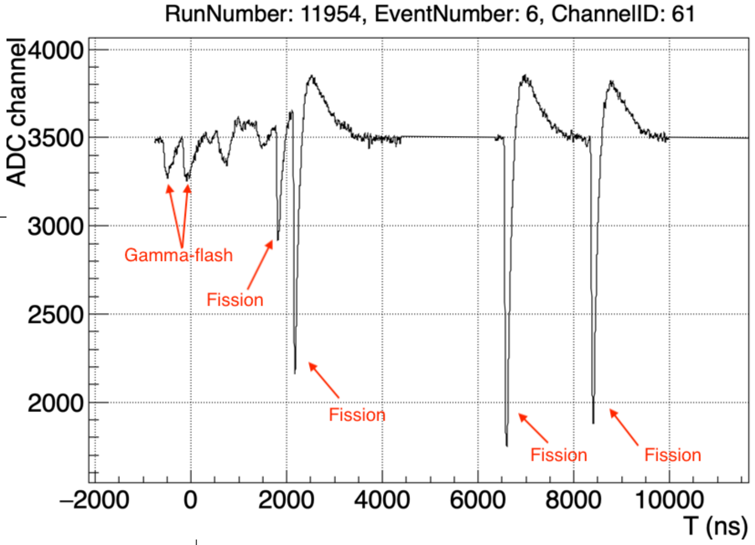
The BN filter have been used in polarized ^{3}He experiment since last month, in Junpei's report.

The neutron beam time structure of Back-n



Double bunches time structure

A typical detector response in one pulse



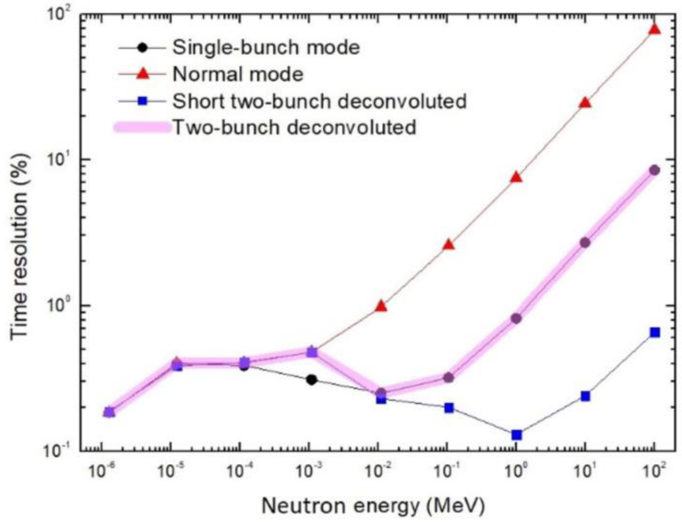
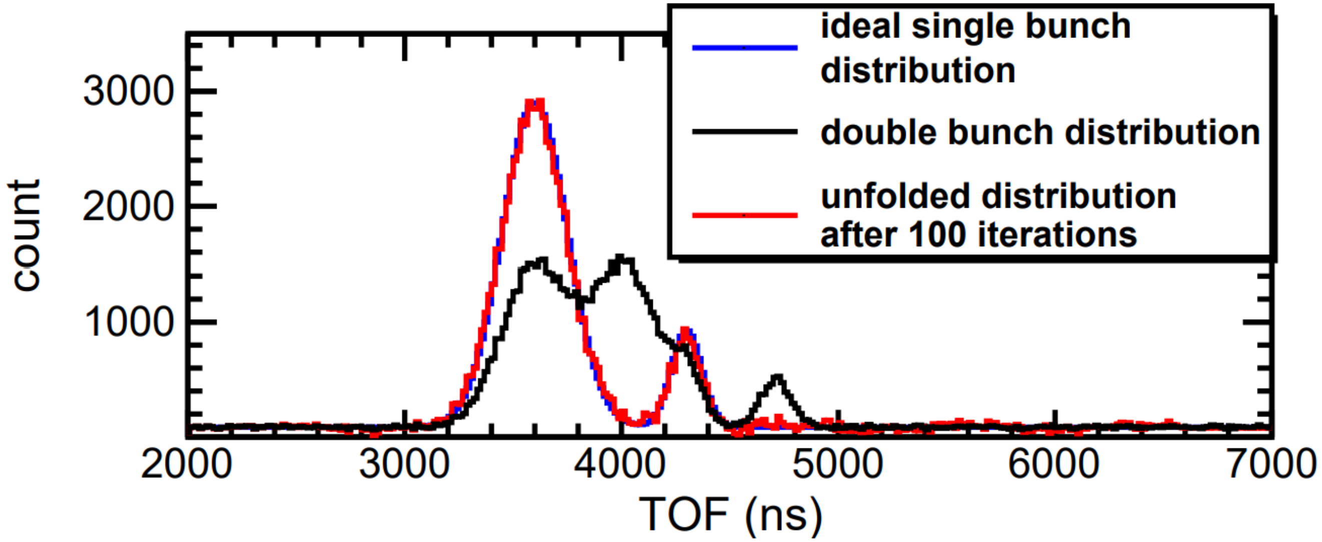


Fig. 3 (Color online) Time resolutions with respect to neutron energy for different acceleration operation modes (flight path: 77 m)

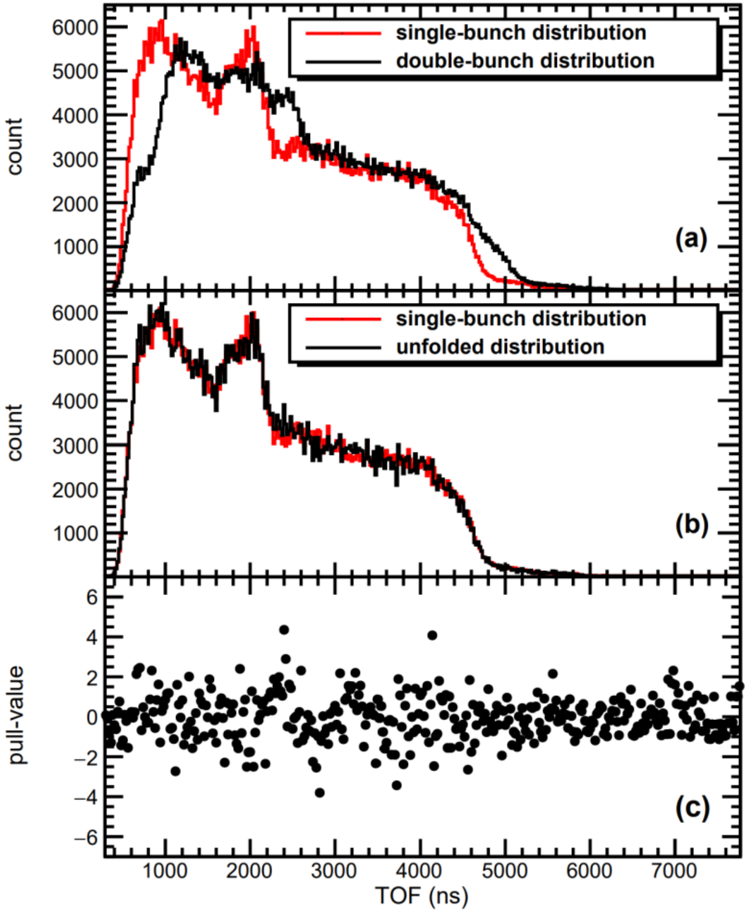
The accelerator normally works in double bunch mode, with a time interval of 410 ns between two bunch of protons. The double bunch structure leads to a large time-of-flight measurement error.

Acta Phys. Sin. Vol. 68, No. 8 (2019) 080101

Double-bunch unfolding methods



A simulated example of the spectrum unfolding

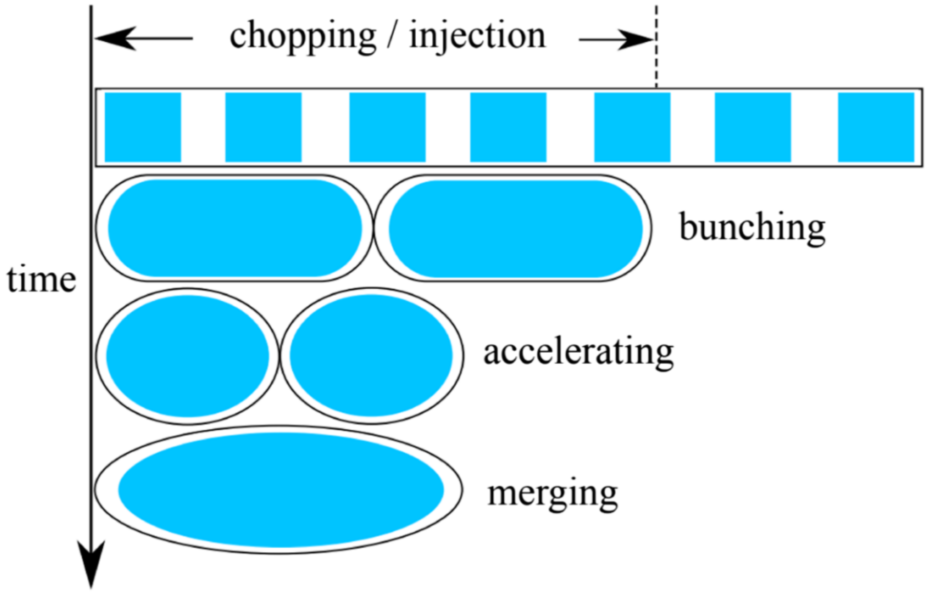


Unfolding result of the ^{238}U data

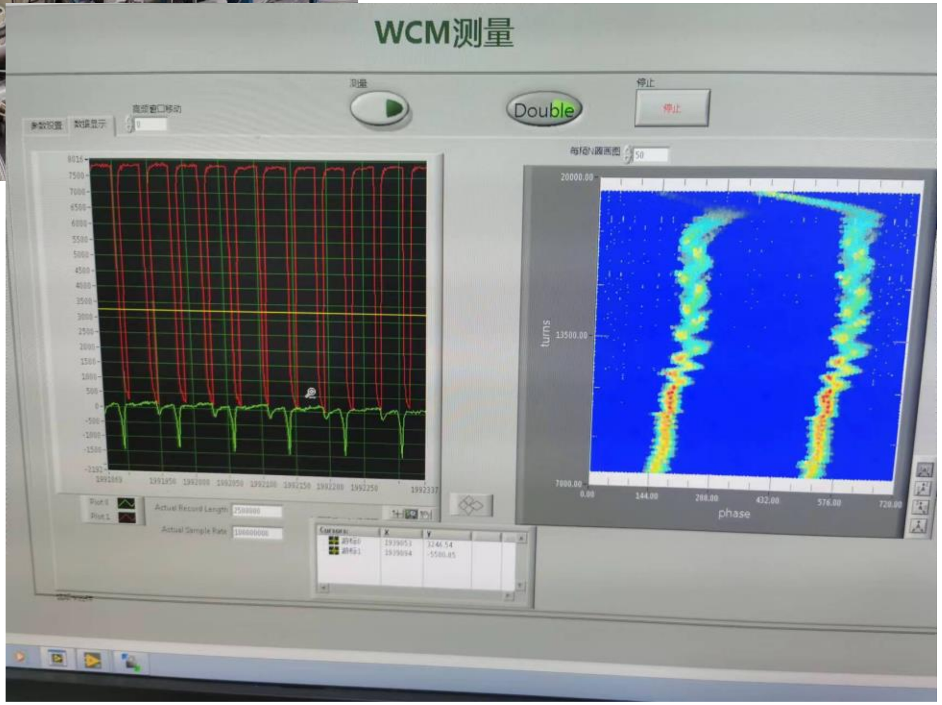
A Bayesian unfolding method is developed for diverse types of experiments performed in the double-bunch mode at Back-n. The experiment data from single bunch mode and the unfolded result from the double bunch mode experiment match well. The unfolding method has been used in most Back-n experiments.

H. Yi et al 2020 JINST 15 P03026

Bunch merge research



The RF cavity loaded with Magnetic Alloy (MA) for CSNSII



The utilization of the combined system of the fundamental and second RF cavities makes it possible to perform a bunch merging process before beam extraction to improve (double) the proton intensity in the single bunch mode for the Back-n white neutron experiments.*

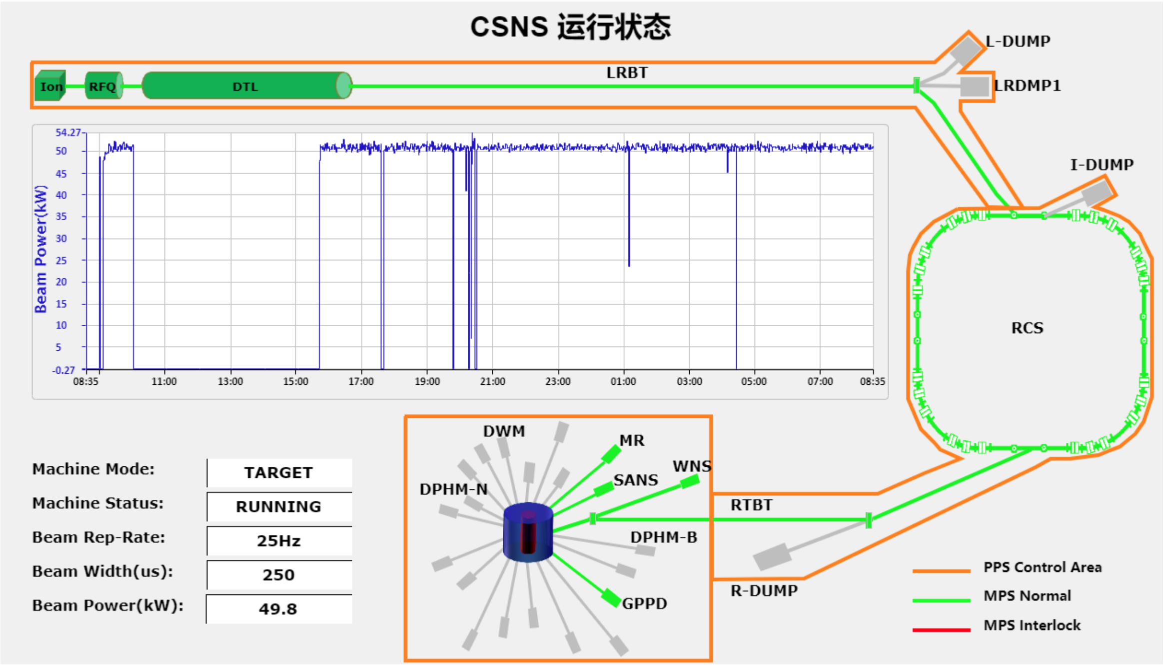
*PHYSICAL REVIEW ACCELERATORS AND BEAMS 26, 024201 (2023)

First bunch merge experiment attempt in May 30th 2023

Back-n beam monitor

Two monitors are employed:

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



CSNS 运行状态

Machine Mode: TARGET

Machine Status: RUNNING

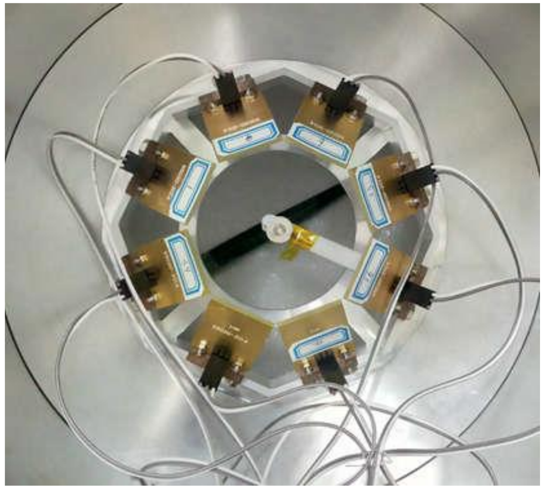
Beam Rep-Rate: 25Hz

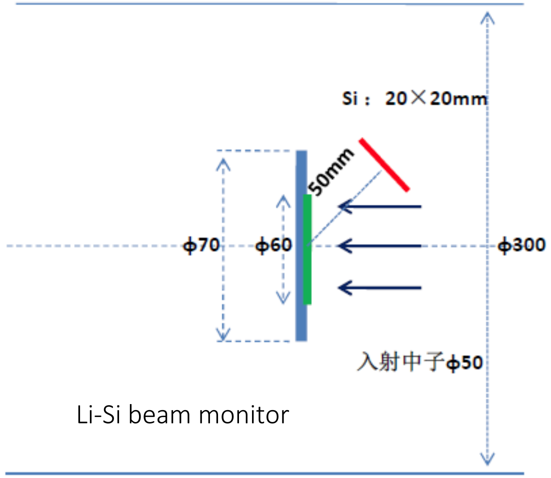
Beam Width(us): 250

Beam Power(kW): 49.8

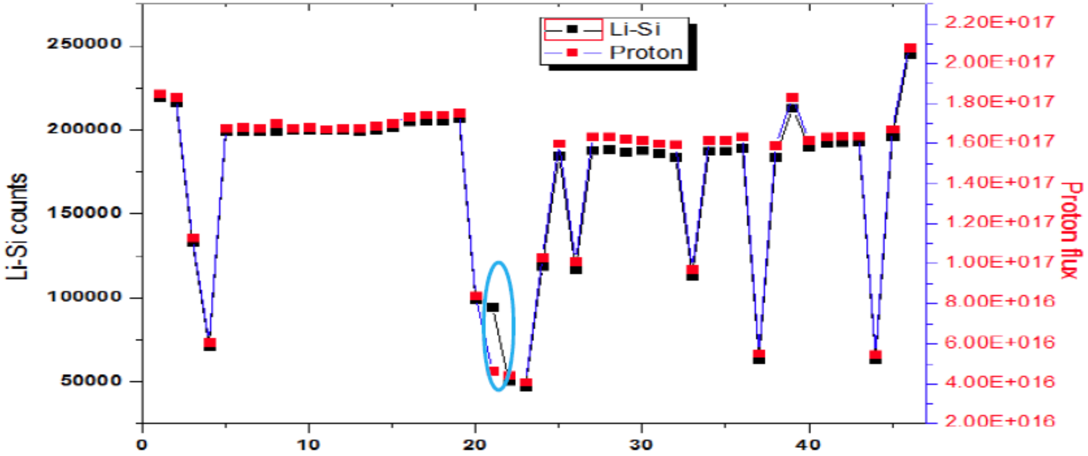
Nuclear Inst. and Methods in Physics Research, A 946 (2019) 162497

Photo of Li-Si



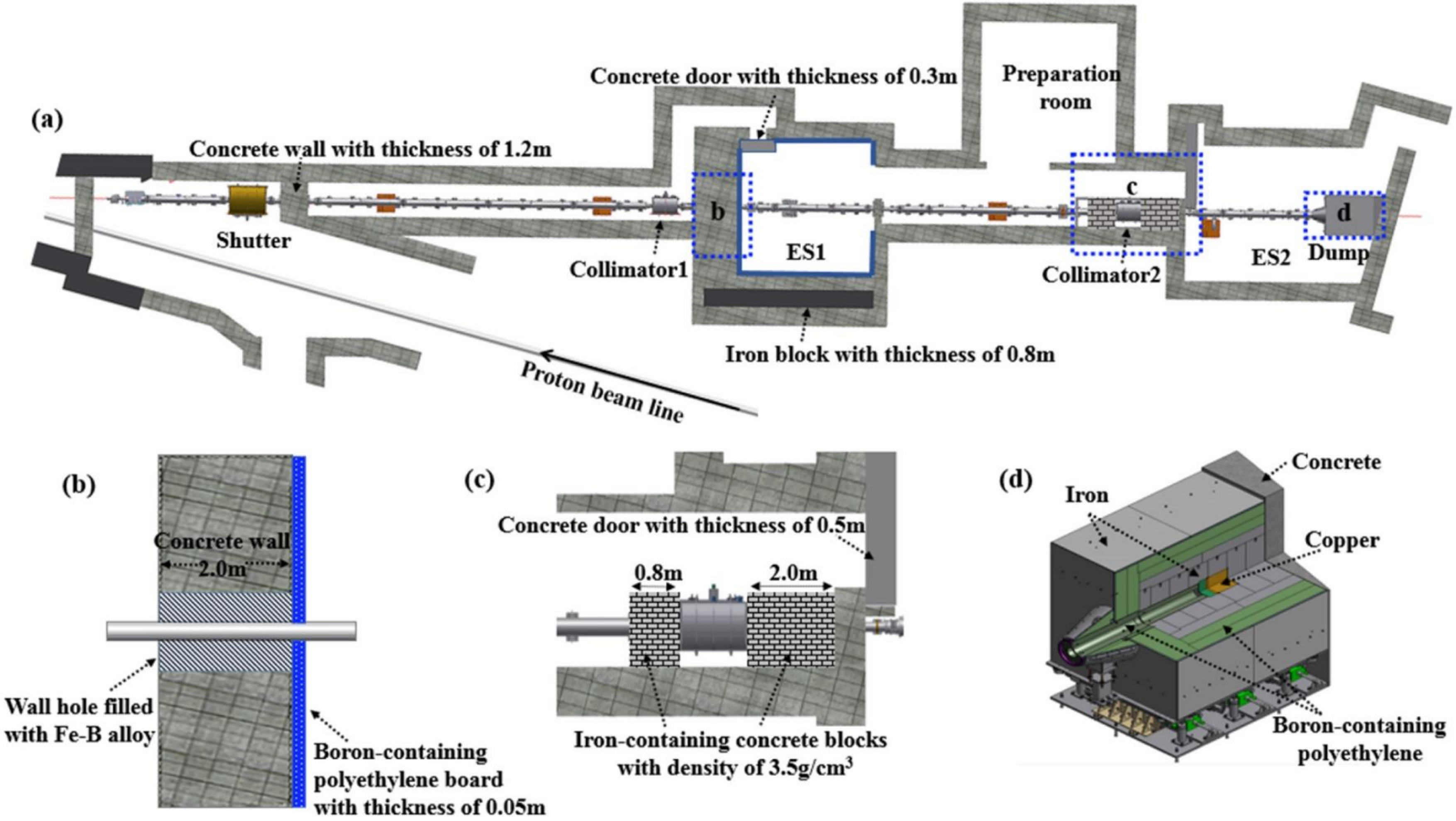


Li-Si beam monitor



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

Back-n shielding & background measurement

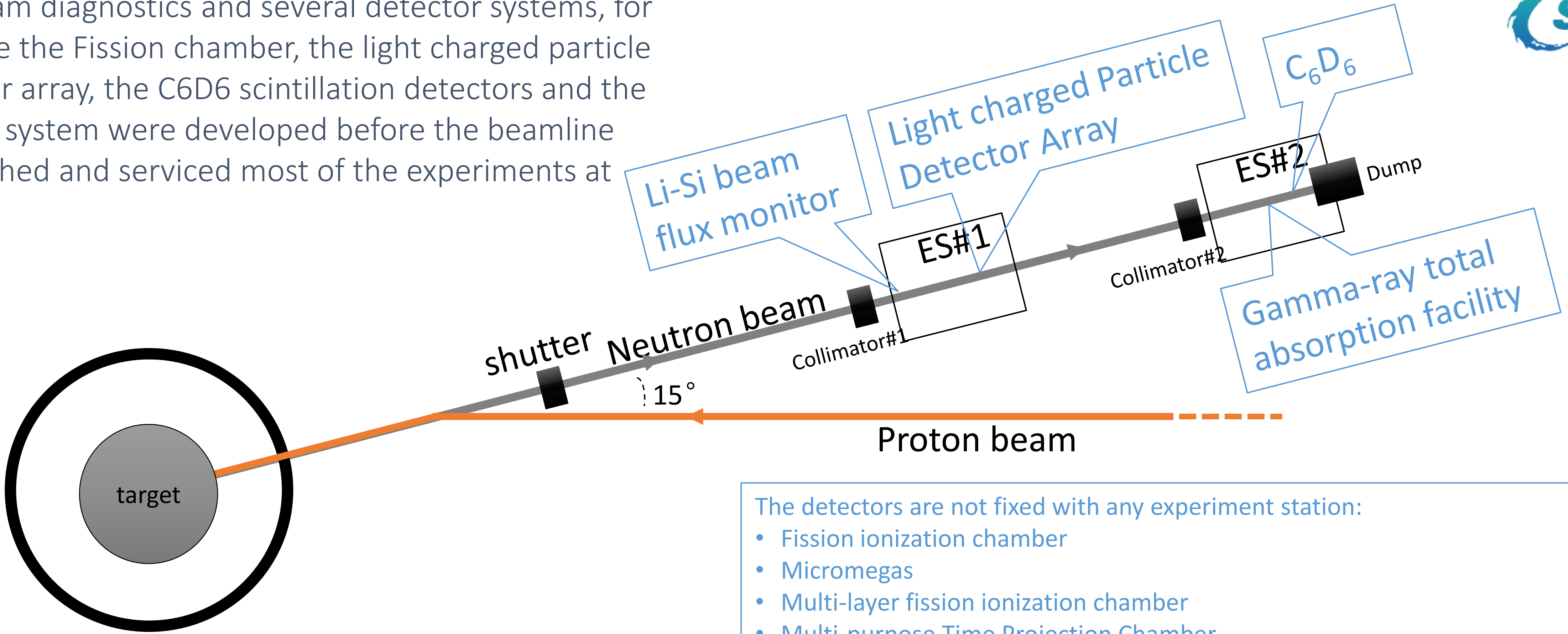


Neutron and γ background measurements of the experimental halls at the CSNS back-streaming white neutron source,
NIMA Volume 980, 11 November 2020, 164506

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 established and serviced most of the experiments at Back-n.



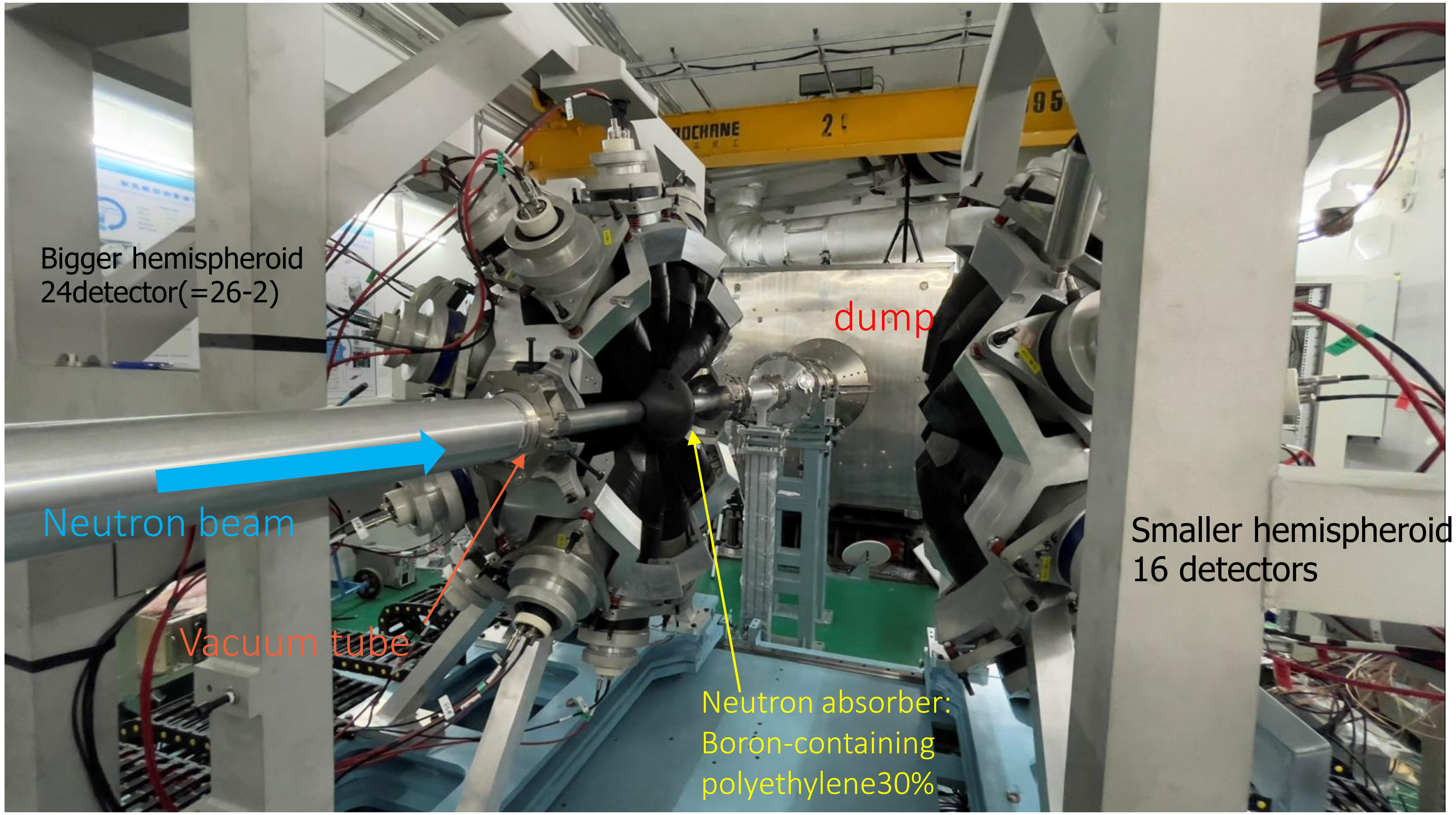
The detectors are not fixed with any experiment station:

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

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

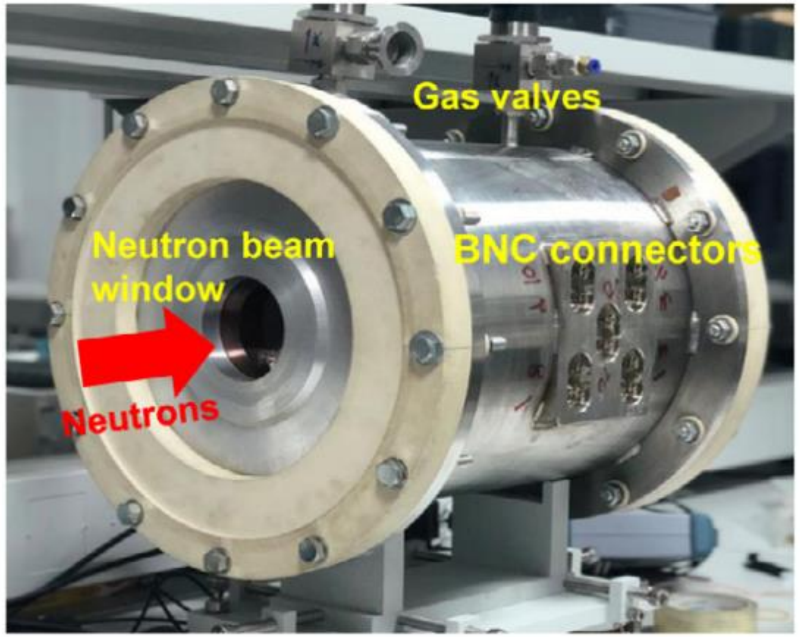
Ruirui, F., Qiang, L., Jie, B. *et al.* *Radiat Detect Technol Methods* **7**, 171–191 (2023).

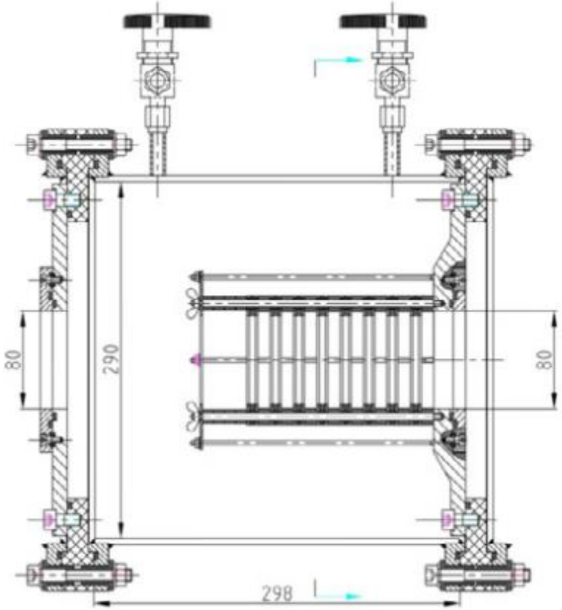
GTAF (40 BaF_2 detector array)

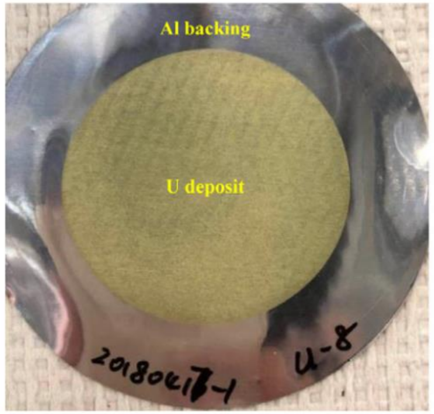


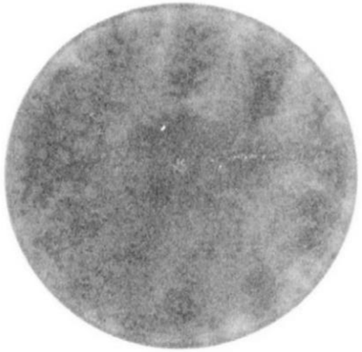
More details can be found in Guangyuan' presentation.

The fission chamber





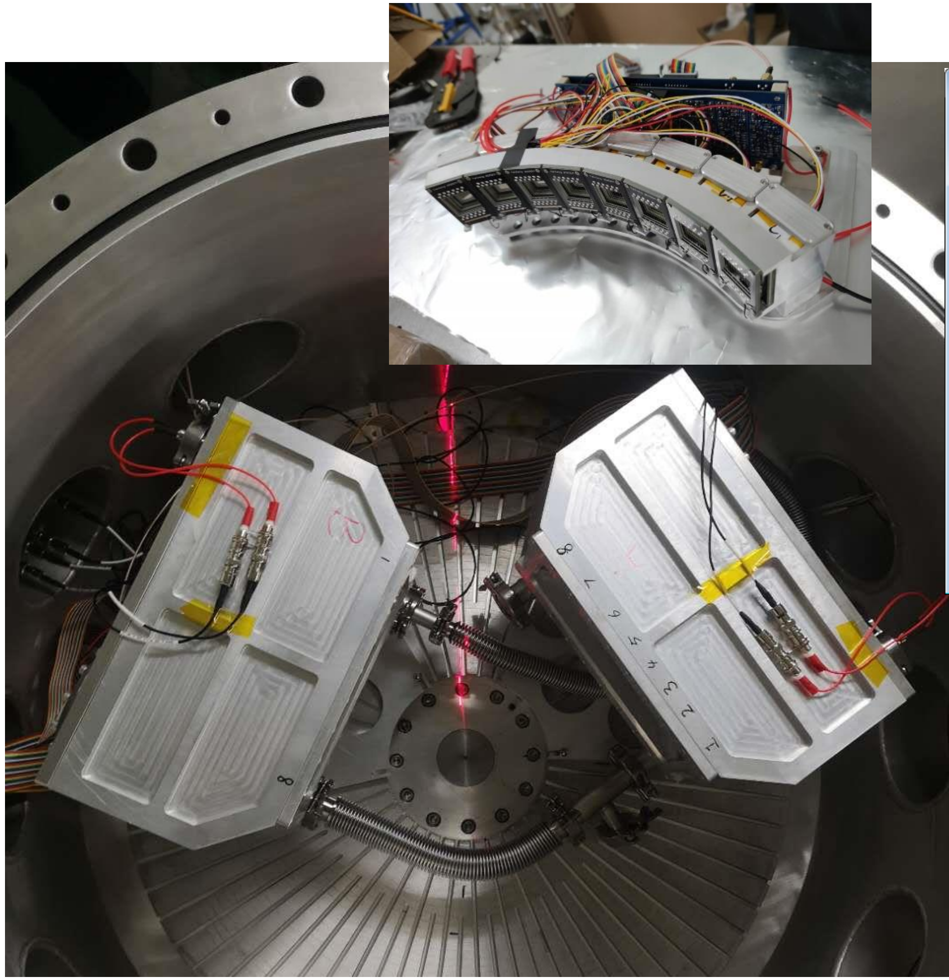




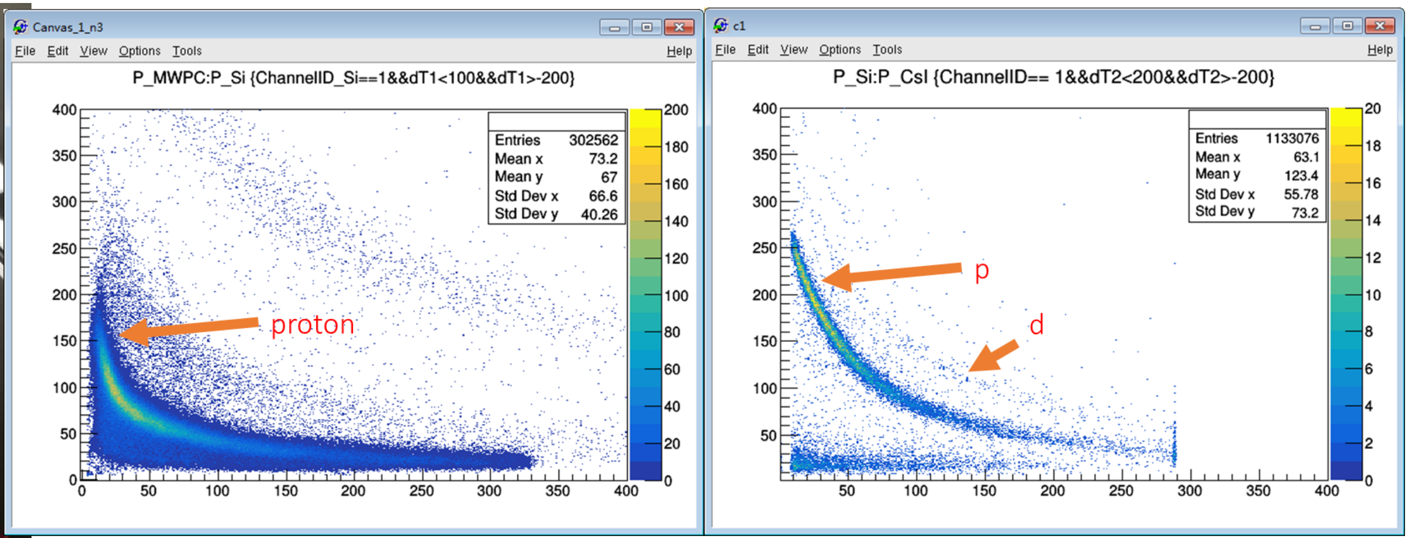
The fission ionization chamber detector measures the fission fragments generated through the reaction between the fission material (^{235}U, ^{238}U) and neutrons, and records the energy of the neutrons by measuring their flight time.

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

∆E- E detector array (LPDA)



The photo of LPDA



```
Entries     302562
Mean x        73.2
Mean y          67
Std Dev x     66.6
Std Dev y    40.26
```

```
Entries    1133076
Mean x        63.1
Mean y       123.4
Std Dev x    55.78
Std Dev y     73.2
```

The LPMWPC (∆*E*) vs Si-PIN (*E*) spectrum and Si-PIN (∆*E*) 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 ^{6}Li has been completed at beginning of this year, and the data is being analyzed while a new round of measurements has been proposed.

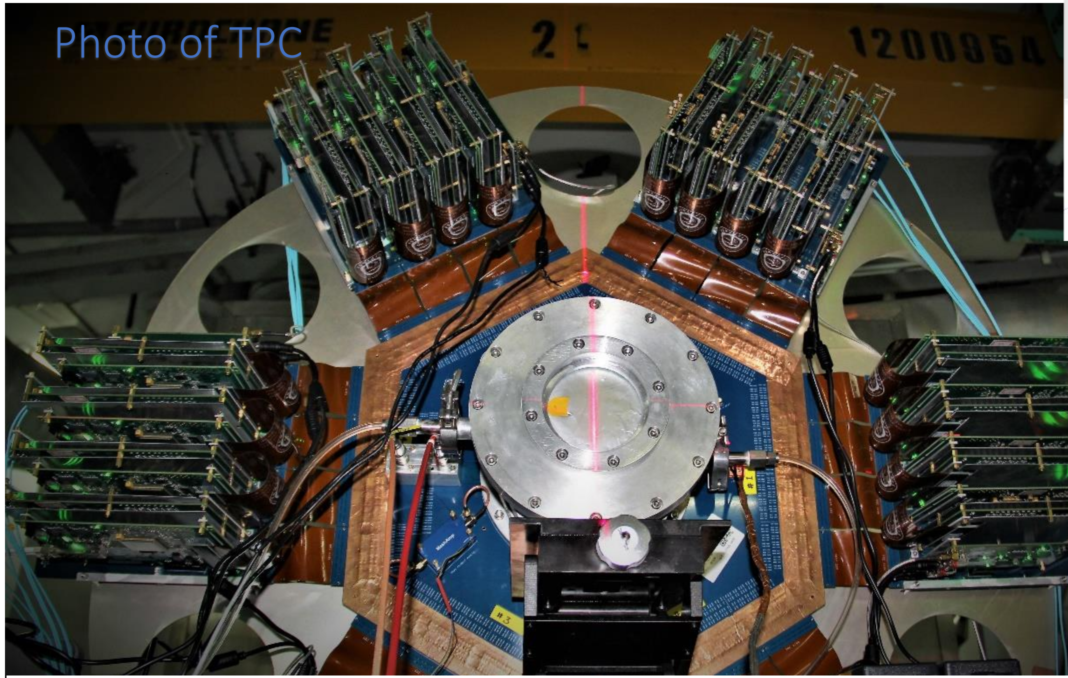
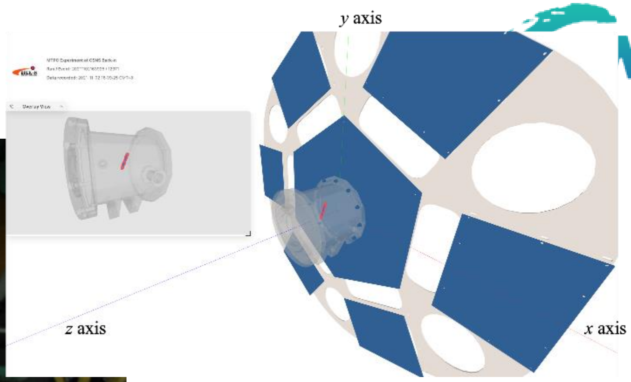
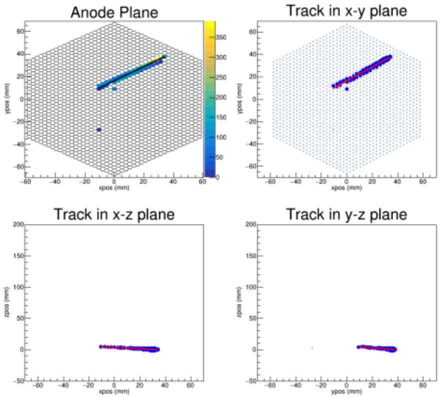
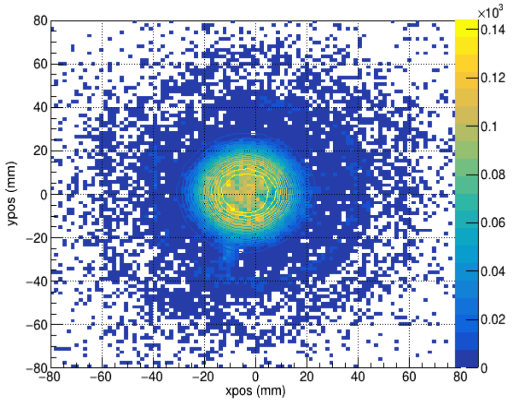
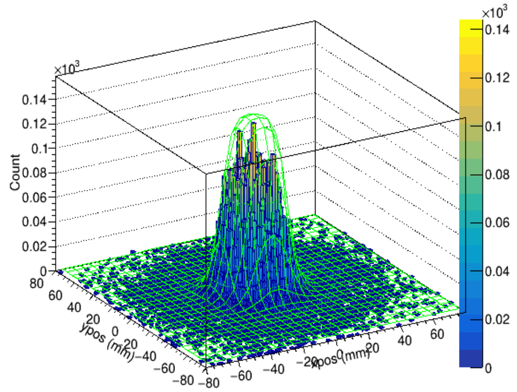


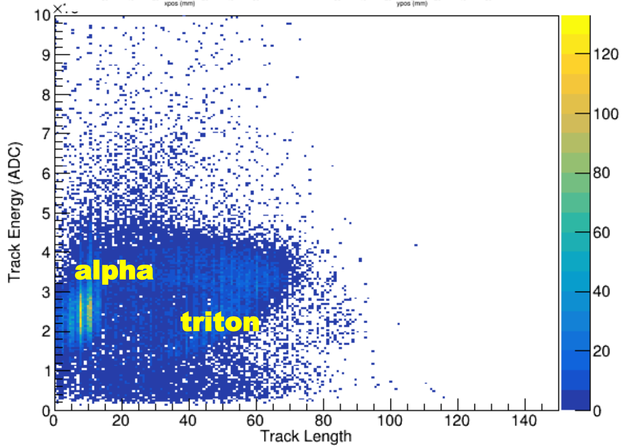
Photo of TPC





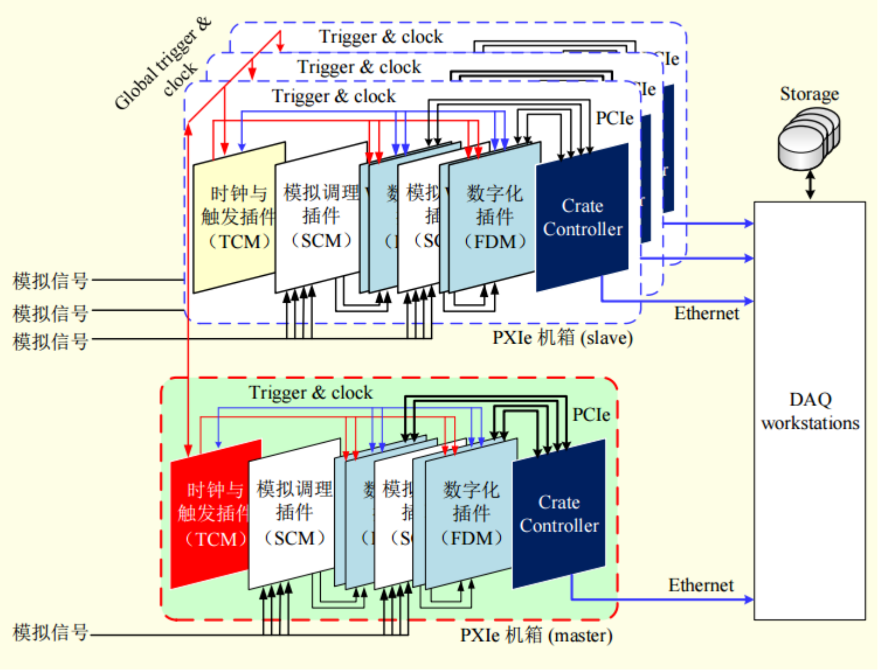






1. Z. Chen *et al* 2022 *JINST* **17** P05032
2. NIMA 1039 (2022) 16715

DAQ



Common electronics system overall architecture

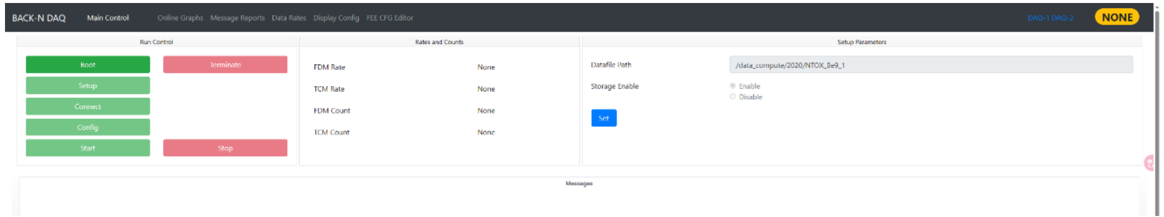
Common electronics： it consists of an analog conditioning module (SCM), a trigger clock module (TCM), and a waveform digitization module (FDM).

resolution:12 Bit

Sample rate: 1 GHz

PXIe based, more than 60 channels.

electronics photos



FDM Rate None
TCM Rate None
FDM Count None
TCM Count None

Datafile Path /data_compute/2020/NTOX_8e9_1
Storage Enable ● Enable ○ Disable

Web based GUI

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

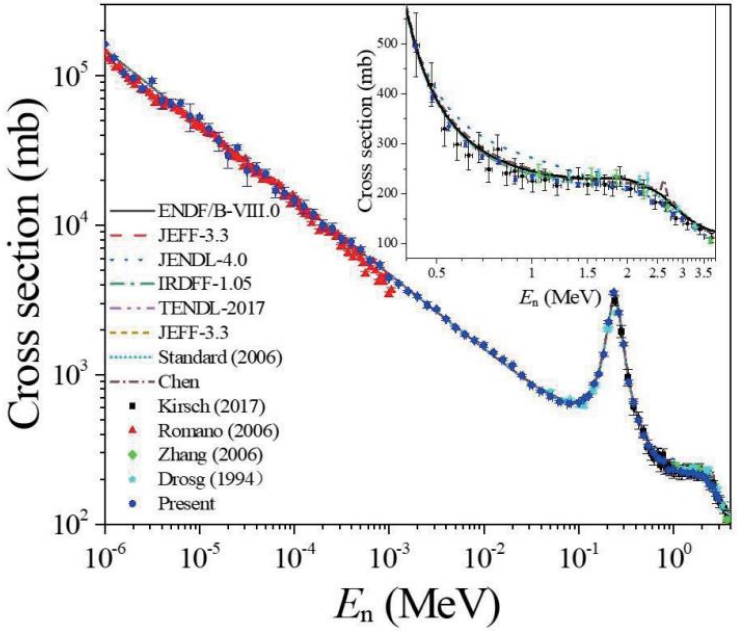
Since 2018, we have measured the neutron reaction cross sections of more than 50 nuclides and will continue to measure at a rate of over 10 nuclides per year.

- Neutron capture
  - C_6D_6: ^{169}Tm, ^{197}Au, ^{57}Fe, ^{nat}Se, ^{89}Y, ^{nat}Er/^{162}Er, ^{232}Th, ^{238}U, ^{93}Nb， ^{nat}Cu， ^{nat}Lu, $^{113\&115}$In, $^{185\&187}$Re , ^{181}Ta, $^{107\&109}$Ag, ^{165}Ho
  - GTAF-II: ^{169}Tm, ^{93}Nb
- Total cross-section
  - ^{12}C, ^{27}Al， ^{9}Be， ^{7}Li， ^{nat}Fe
- Fission cross-section
  - ^{235}U, ^{238}U, ^{236}U, ^{239}Pu, ^{232}Th， ^{239}Pu
- Light charged particle emission
  - LPDA: ^{6}Li(n, x), ^{10}B(n, x), ^{63}Ni， (n-d)， ^{17}O, (n-p) Elastic scattering
  - TPC: ^{12}C， ^{14}N， ^{12}C (^{13}C Nuclear clusters)
- Inelastic cross-section (in-beam gamma)
  - ^{56}Fe (n, n’), ^{nat}Mo， ^{16}O， ^{nat}Ru， ^{nat}Lu， ^{nat}Mo， ^{nat}Ti, ^{209}Bi, ^{90}Zr, ^{55}Cr, ^{155}Eu, ^{178}Hf, ^{232}Th

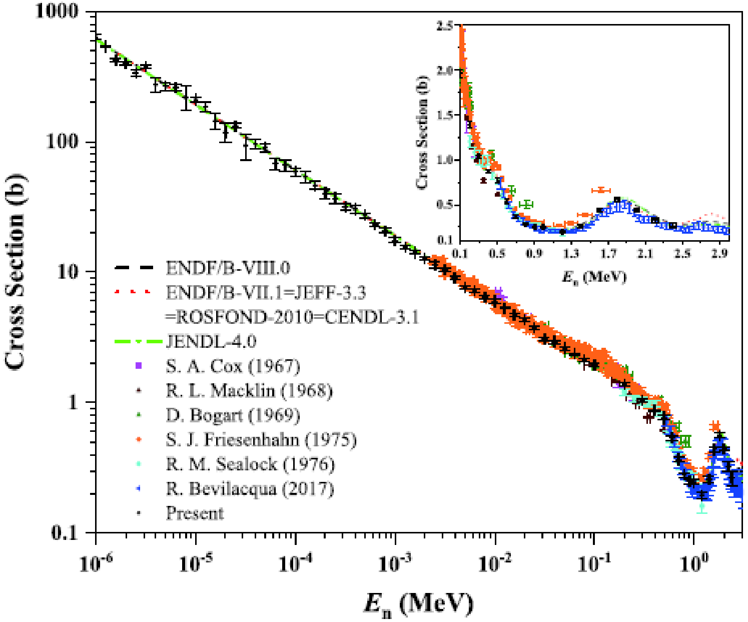
^{6}Li(n, t)α、 ^{10}B(n, α)^{7}Li cross section measurements

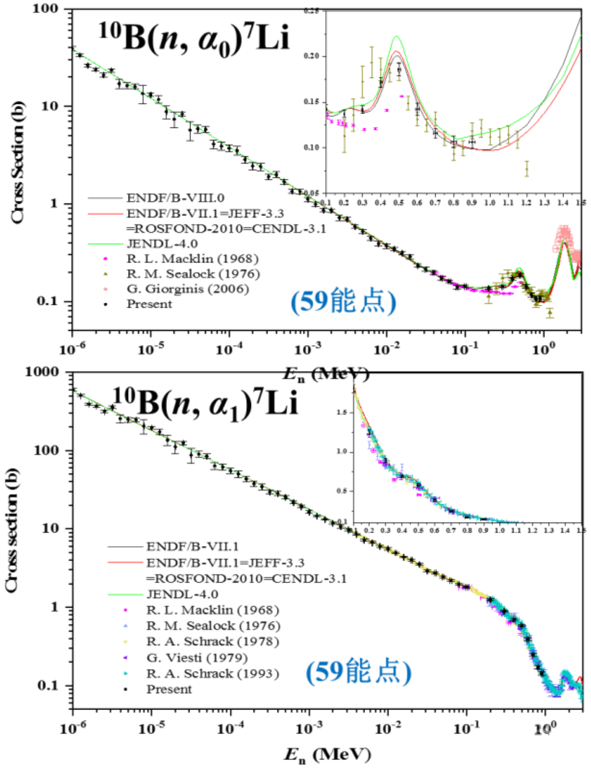
- 6Li(n, t)α, 10B(n, α)7Li reaction cross-sections are widely used as standard cross-sections and require higher precision results, and 10B(n, α)7Li reaction cross-sections are also important parameters required in BNCT（Boron Neutron Capture Therapy） research.

- 6Li(n, t)α, 10B(n, α)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.



^{6}Li(n, t) α measurement result



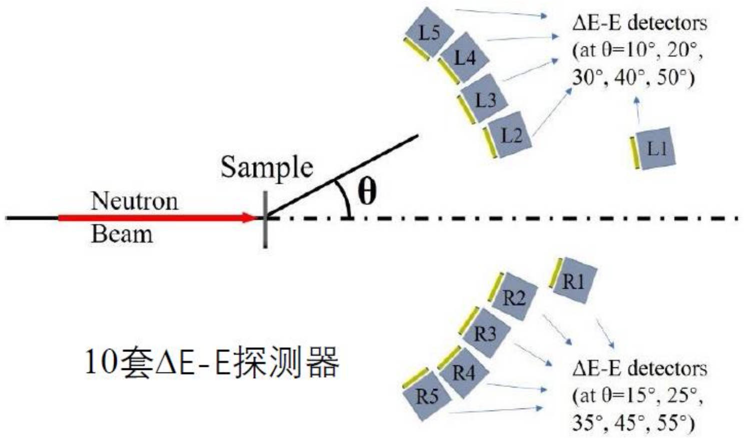


^{10}B(n, α)^{7}Li measurement result

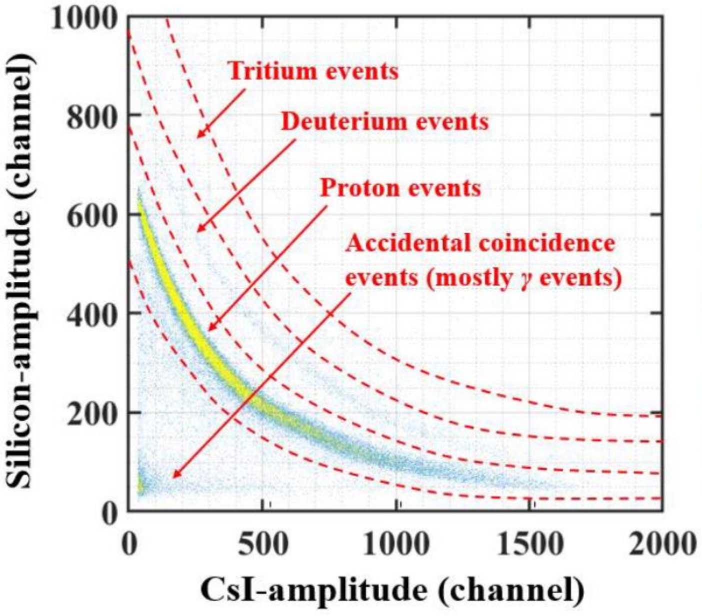
Huaiyong Bai et al 2020 Chinese Phys. C 44 014003
H. Jiang, et al., Chin. Phys. C 43 (12) (2019) 124002

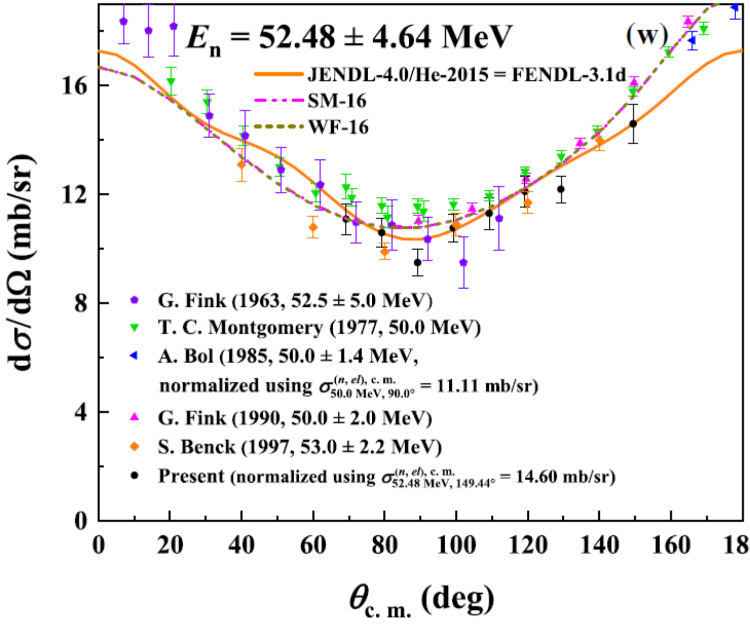
n-p scattering measurement

- 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.



Jiang H Y, et al. Eur. Phys. J. A (2021) 57 6

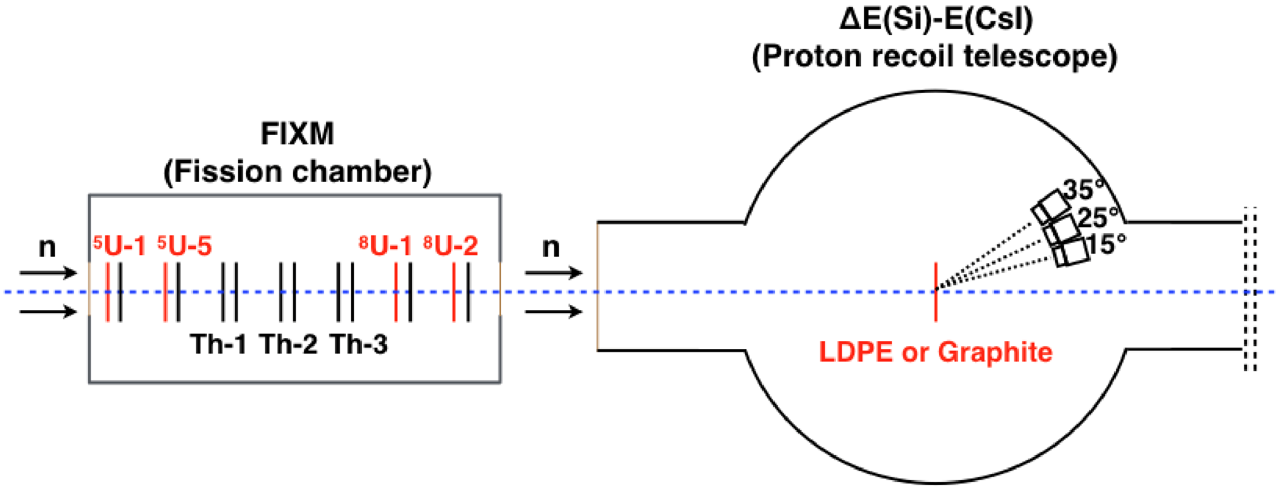




^{1}H(n,n)^{1}H angle distribution at En=52.48MeV

^{232}Th 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



$$\sigma_x = \frac{R_x \varepsilon_s N_s}{R_s \varepsilon_x N_x} \sigma_s$$

(x: targer， s: standard)

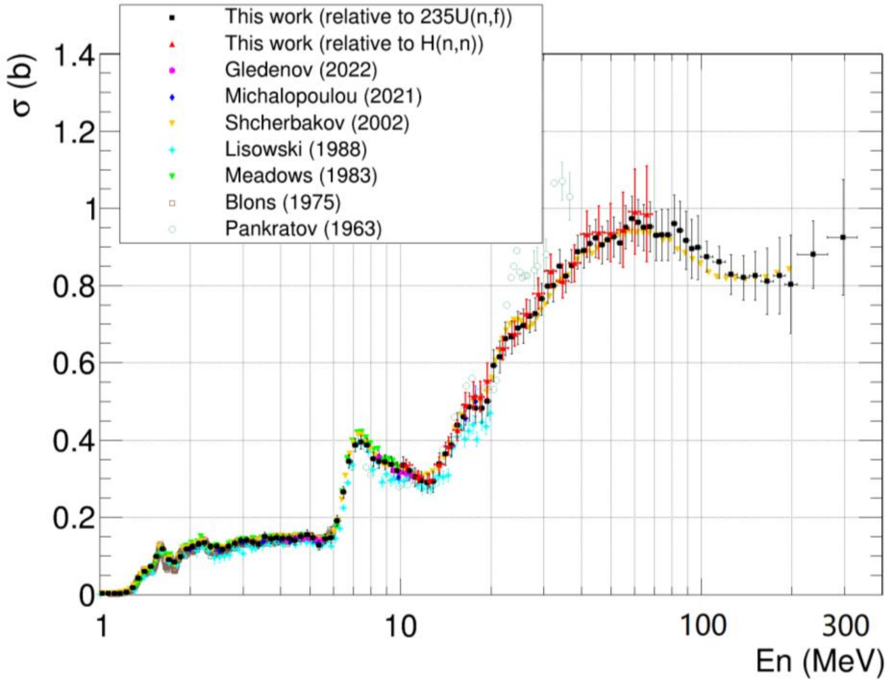
A cross-sectional measurement of 232Th (n, f) was measured using two methods (two reference standards):

- **Reference 1**： ^{235}U(n, f) 【neutron energy range： 1-300 MeV】
- **Reference 2**： n-p scattering 【 neutron energy range ： 10-70 MeV】

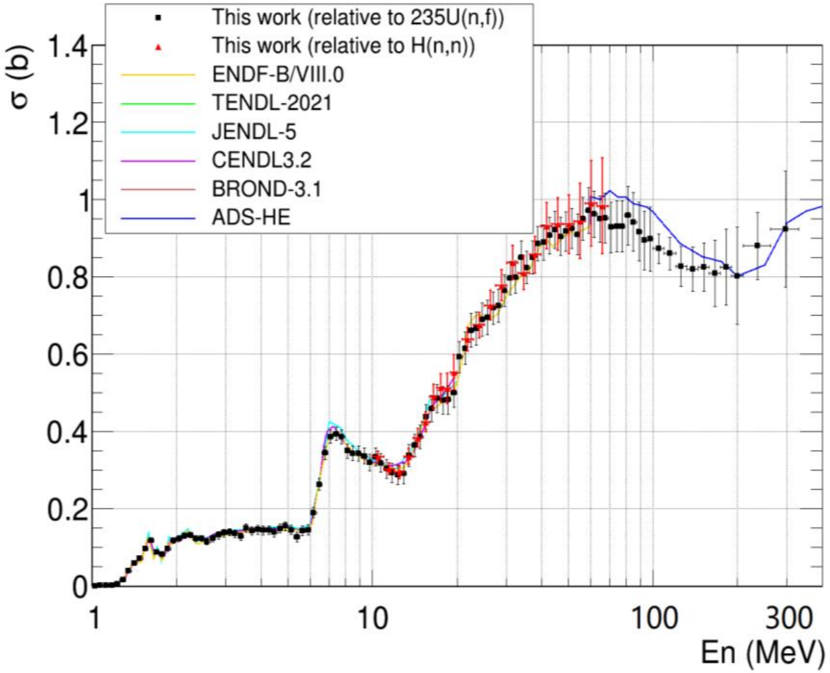
Physics Letters B (2023) **839**: 137832

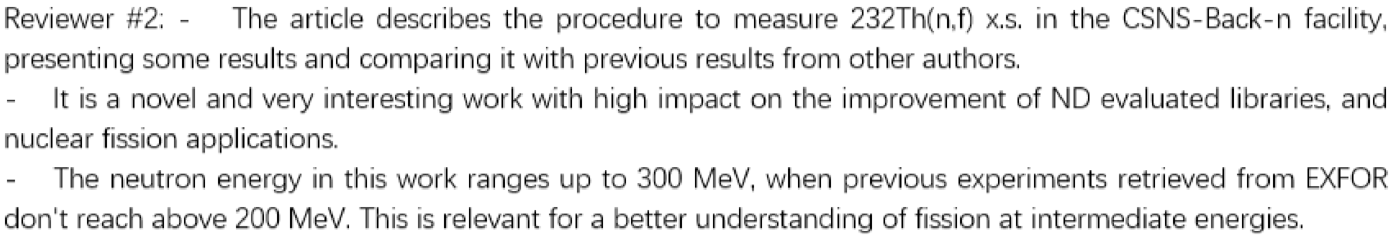
^{232}Th (n,f) cross-section measurement results

Comparison of this work with other measurements



Comparison of this work with evaluation data



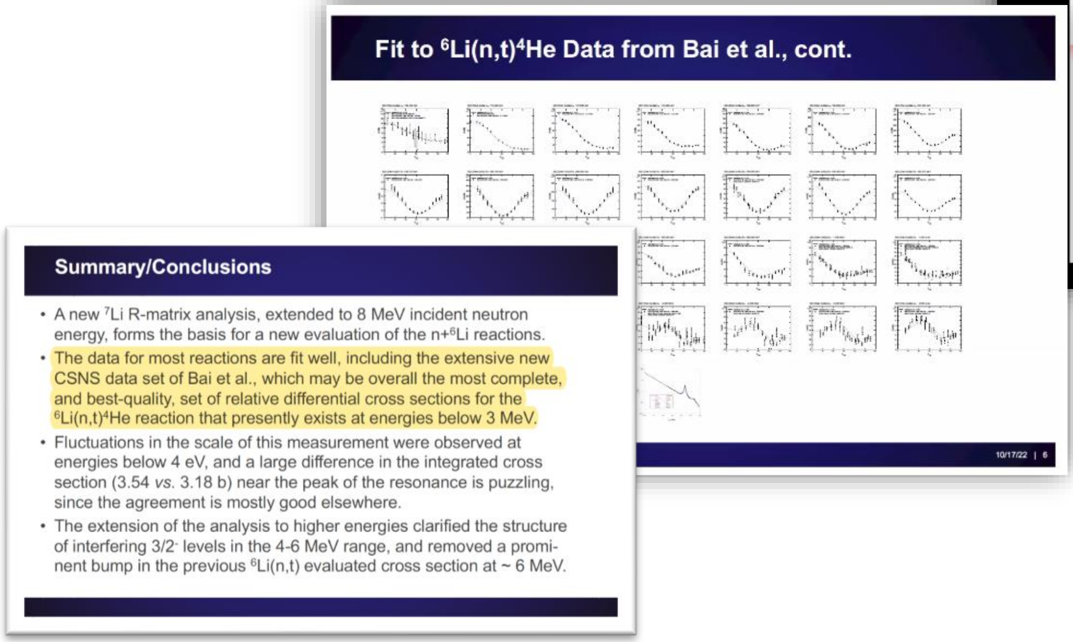


Reviewer #2: - The article describes the procedure to measure 232Th(n,f) x.s. in the CSNS-Back-n facility, presenting some results and comparing it with previous results from other authors.

- 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.

IAEA committee invitation

- The results of standard cross-sectional measurements are highly valued by the International Atomic Energy Agency (IAEA):
  1. ^{6}Li(n, t) measurement
  2. ^{235}U(n, f)/^{238}U(n, f)
  3. ^{232}Th (n, f) measurement
  4. ……

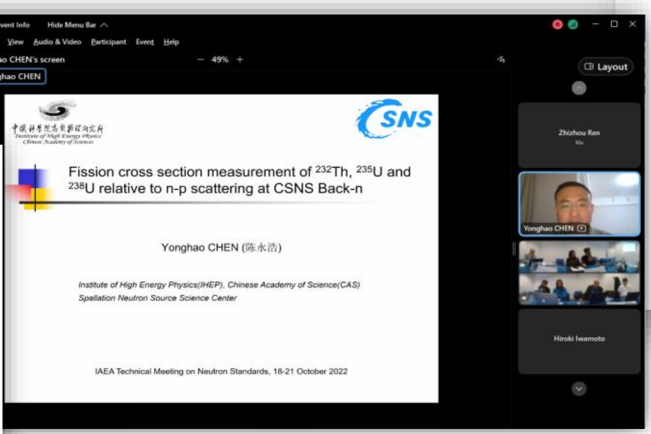


Fit to ^{6}Li(n,t)^{4}He Data from Bai et al., cont.

10/17/22 | 6

Summary/Conclusions

- A new ^{7}Li R-matrix analysis, extended to 8 MeV incident neutron energy, forms the basis for a new evaluation of the n+^{6}Li 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-quality, set of relative differential cross sections for the ^{6}Li(n,t)^{4}He reaction that presently exists at energies below 3 MeV.
- Fluctuations 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, since the agreement is mostly good elsewhere.
- The extension of the analysis to higher energies clarified the structure of interfering 3/2^{-} levels in the 4-6 MeV range, and removed a prominent bump in the previous ^{6}Li(n,t) evaluated cross section at ~ 6 MeV.



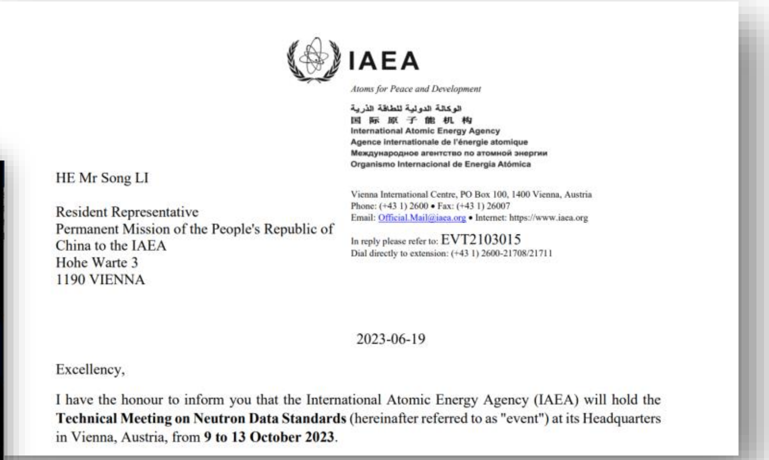
Fission cross section measurement of ^{232}Th, ^{235}U and ^{238}U relative to n-p scattering at CSNS Back-n

Yonghao CHEN (陈永浩)

Institute of High Energy Physics(IHEP), Chinese Academy of Science(CAS)
Spallation Neutron Source Science Center

IAEA Technical Meeting on Neutron Standards, 18-21 October 2022

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



IAEA
Atoms for Peace and Development
الوكالة الدولية للطاقة الذرية
国 际 原 子 能 机 构
International Atomic Energy Agency
Agence internationale de l'énergie atomique
Международное агентство по атомной энергии
Organismo Internacional de Energía Atómica

Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Phone: (+43 1) 2600 • Fax: (+43 1) 26007
Email: Official.Mail@iaea.org • Internet: https://www.iaea.org

In reply please refer to: EVT2103015
Dial directly to extension: (+43 1) 2600-21708/21711

HE Mr Song LI

Resident Representative
Permanent Mission of the People's Republic of
China to the IAEA
Hohe Warte 3
1190 VIENNA

2023-06-19

Excellency,

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**.

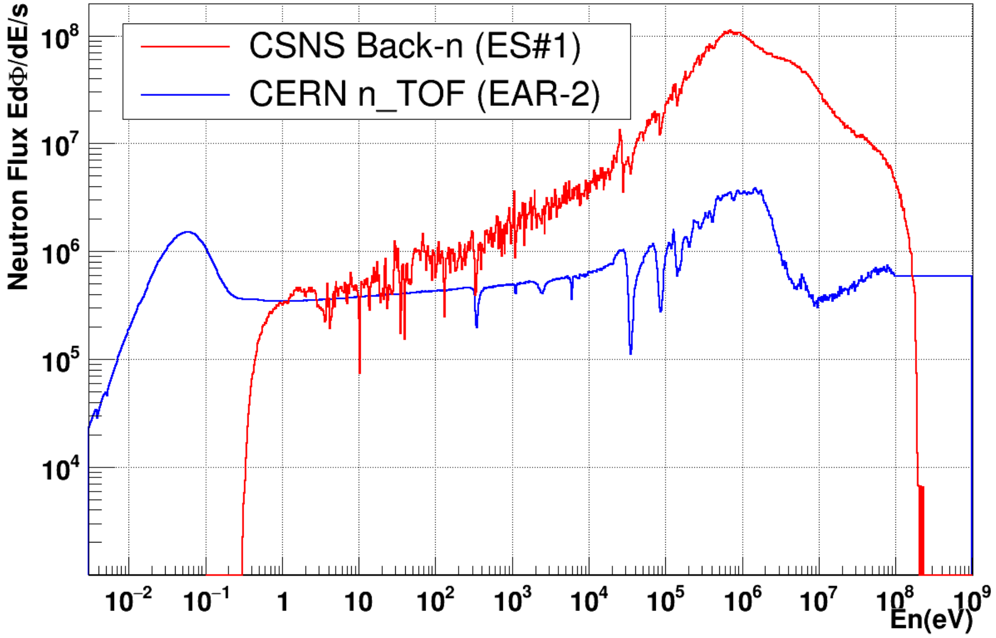
Invitation of the Oct2023 IAEA Technical Meeting on Neutron Data Standards

展望

prospect

What can we do at Back-n?

	n_TOF	Back-n
Energy range	2 meV – 1 GeV	0.3 eV- 300 MeV
flux(n/s)	1.89×10^7	3.66×10^8



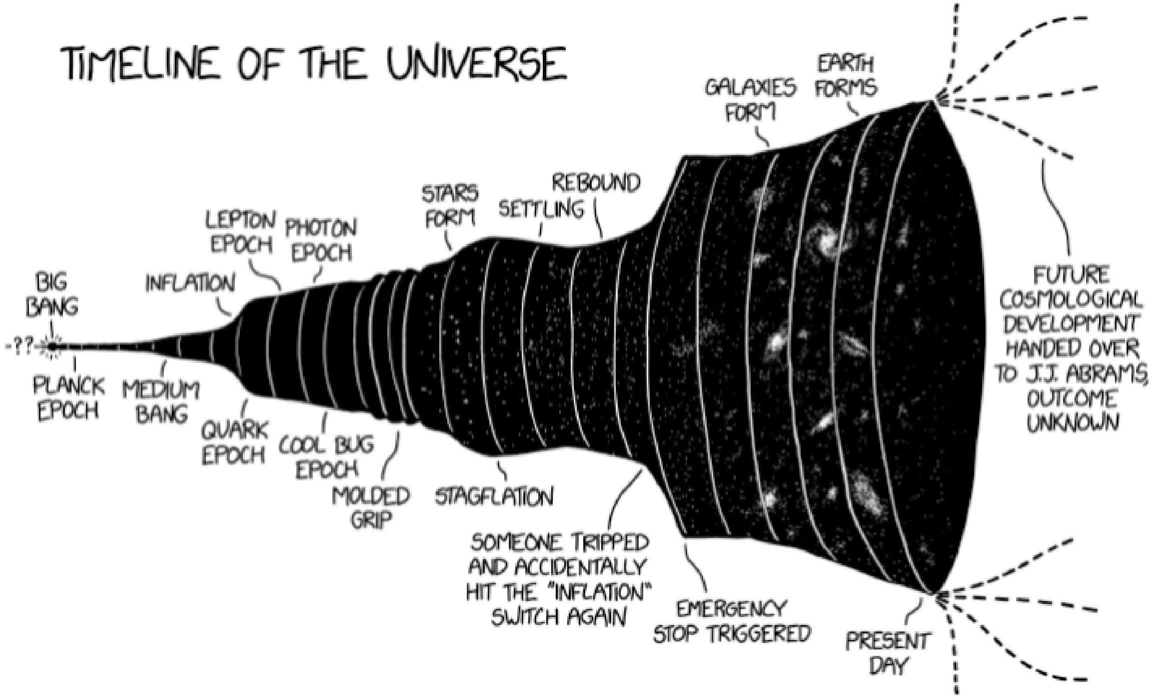
the beam flux comparison between Back-n and n_TOF

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
- Neutron energy requirements 1-300 keV

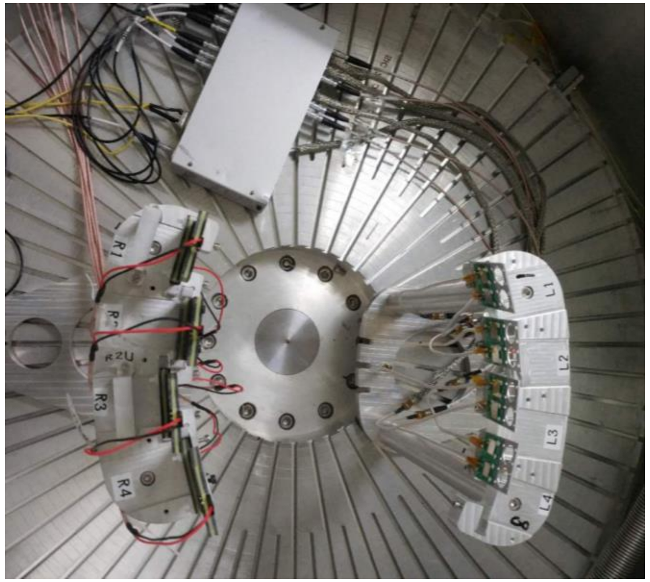
Astrophysics experiments

- 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).



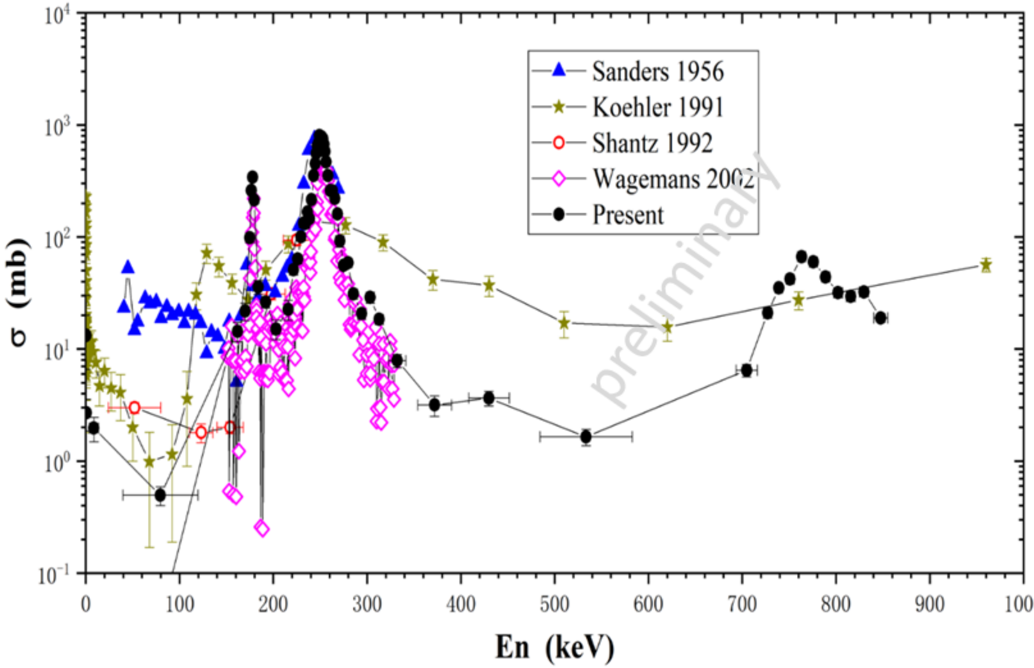
^{17}O(n, alpha) experiment

$^{17}O(n, \alpha)^{14}O$ 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.



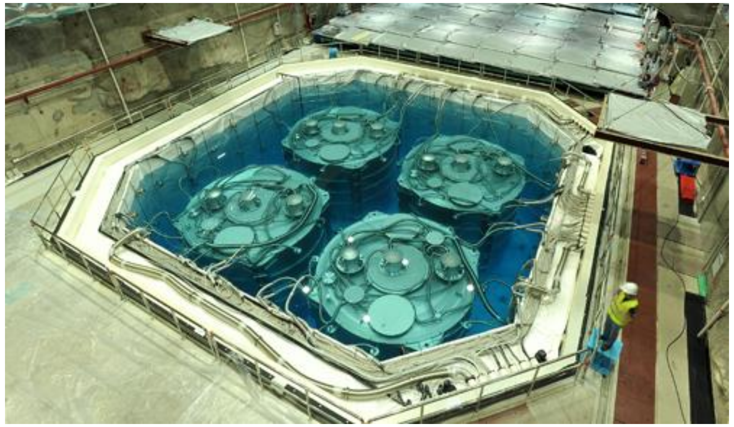
$^{17}O(n, \alpha)$ experiment, June 2020:
Targets include ^{17}O targets ($W^{17}O_3$), ^{16}O targets for background, and ^{6}LiF reference targets. A silicon carbide detector array (8 pieces) is installed in the front corner area and a silicon detector array (8 pieces) is installed in the rear corner 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.



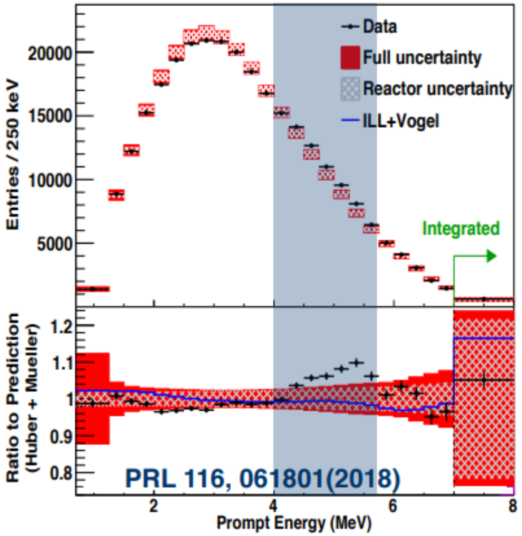
Neutrinos: Spectral Shape

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



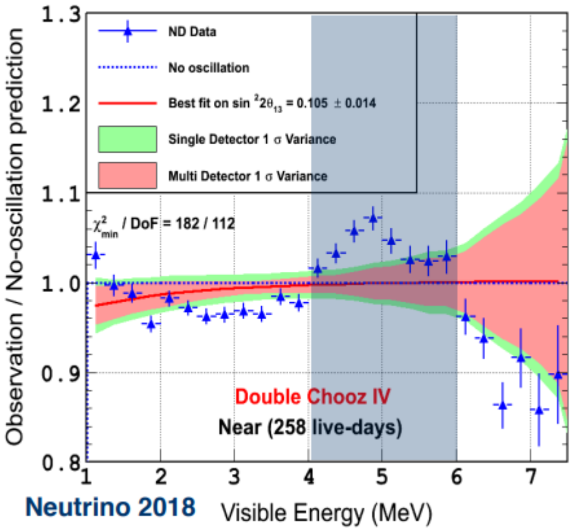
1. J.K.Ahn et al. (RENO Collaboration), Phys. Rev. Lett. 108:191802, (2012)
2. JUNO collaboration, Neutrino Physics with JUNO, JOURNAL OF PHYSICS G-NUCLEAR AND PARTICLE PHYSICS , 2016 , 43 (3).
3. PatrickHuber. Reactor antineutrino fluxes – Status and challenges. Nuclear PhysicsB, 908 (2016) 268–278

Daya Bay



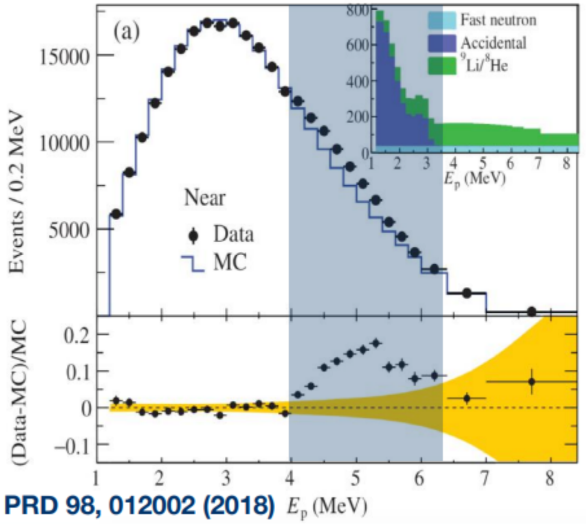
PRL 116, 061801(2018)

Double Chooz



Neutrino 2018

RENO



PRD 98, 012002 (2018)

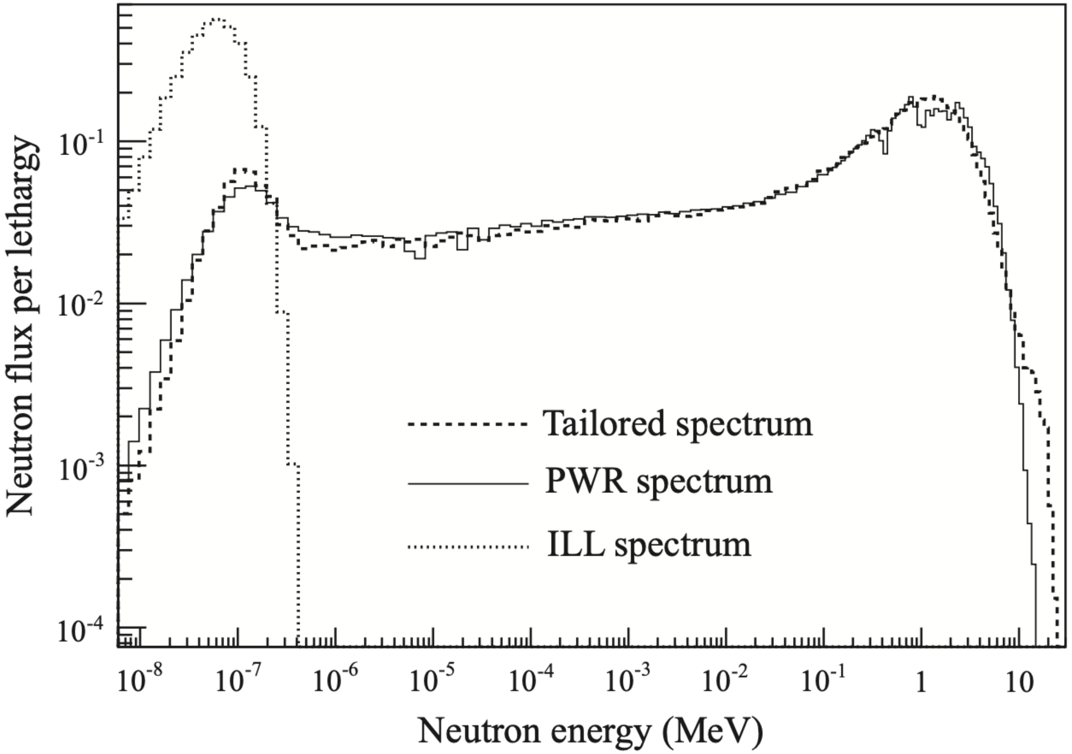
- θ_{13} experiments show disagreement with spectrum models
- Could be a contribution from a single isotope or multiple isotopes
- Inconsistent with neutrino oscillation scenarios
- Reactor models wrong? Recent beta conversion calculations reduce somewhat. 1908.08302
- But, need data

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

From P. Mumm for the PROSPECT Collaboration

The neutron energy spectrum?

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

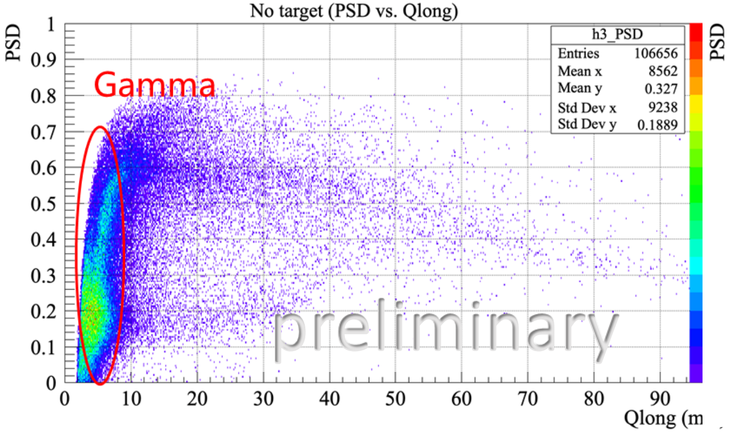


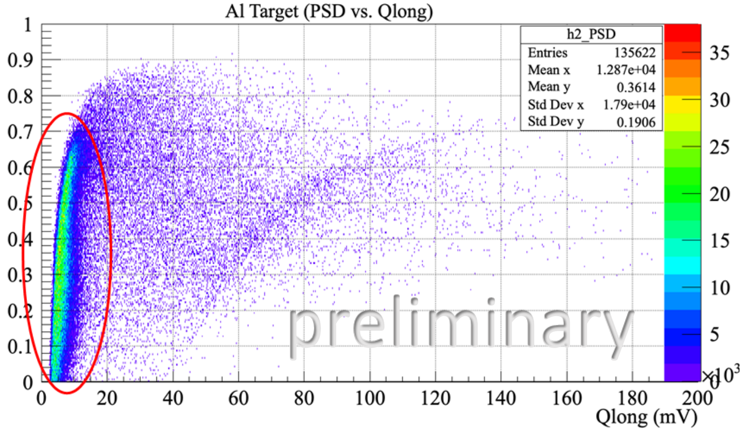
- In the 80s of last century, the French Institute Laue-Langevin (ILL) used the reactor to measure the fission β spectrum of reactor nuclides, which is currently widely used experimental data in calculating the expected neutrino energy spectrum of reactor nuclides;
- Some theories suggest that the difference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

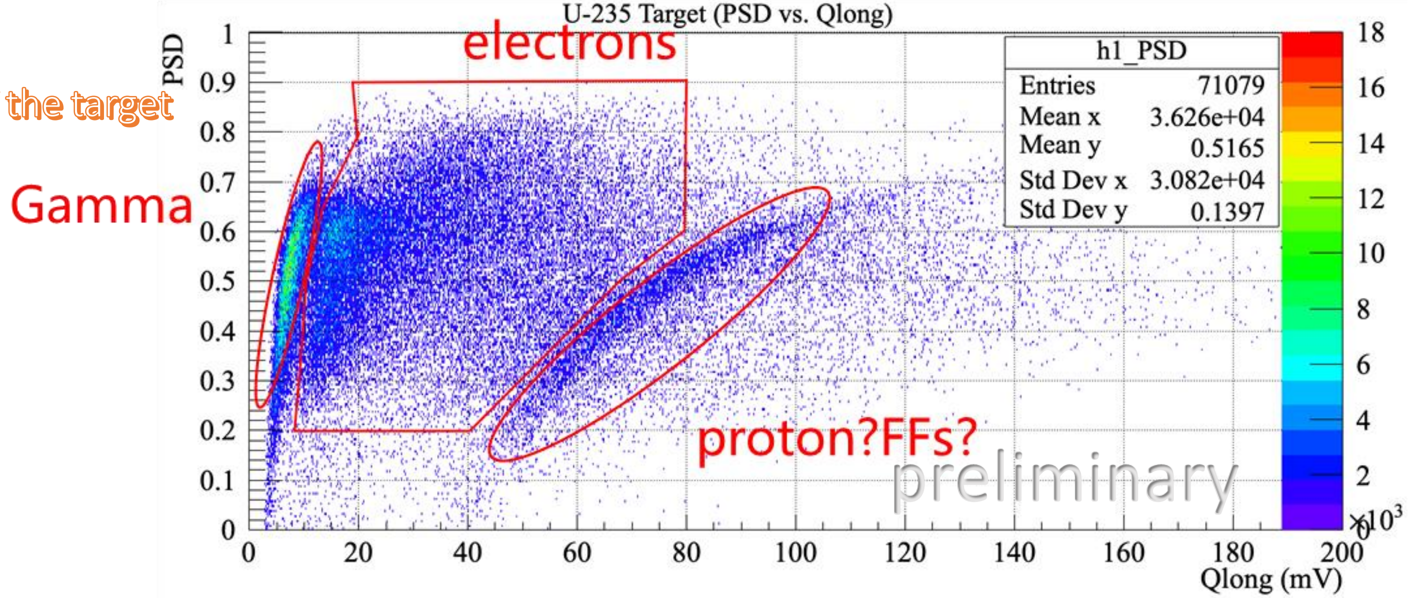
---

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.

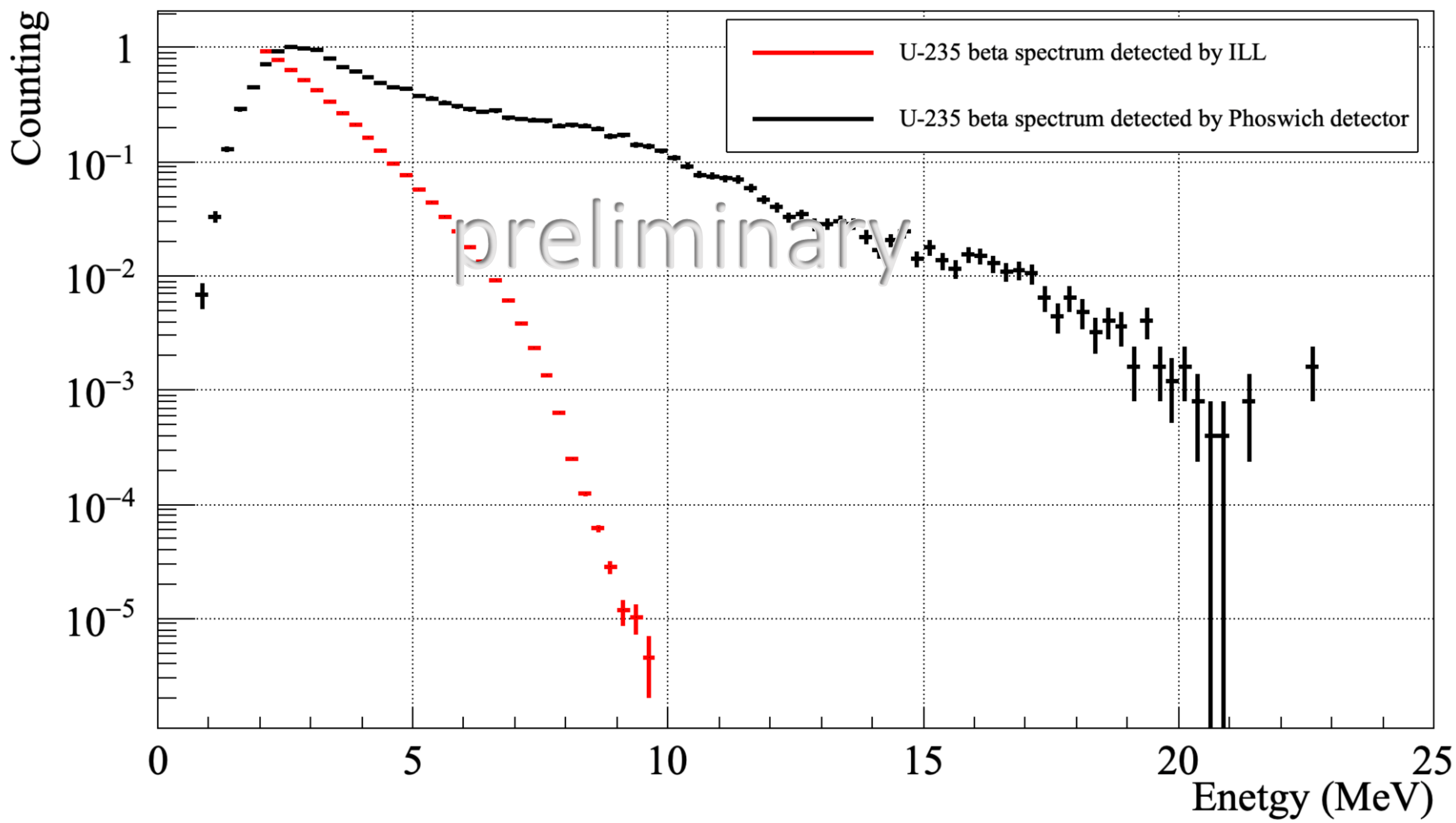
^{235}U fission fragments β spectrum measurement







Results



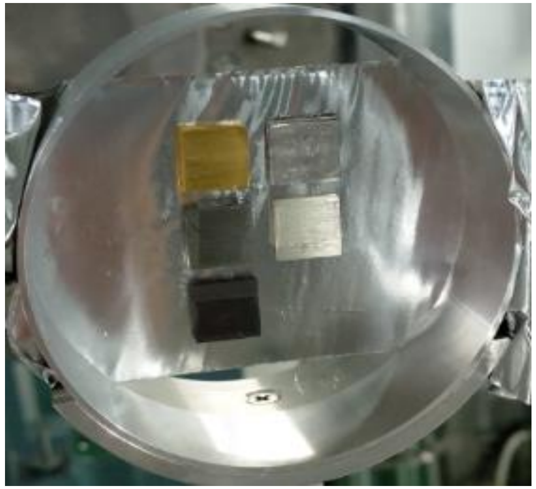
Preliminary results indicate that electron energy spectra measured using higher energy neutrons are higher than ILL's result.

But a lot of PID and background subtract work is still undertaking……

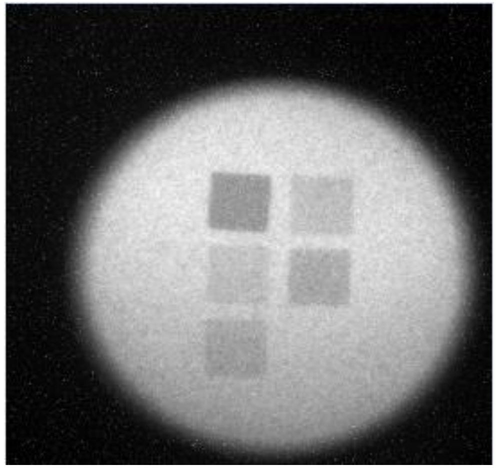
Nuclide identification radiography (NIR)

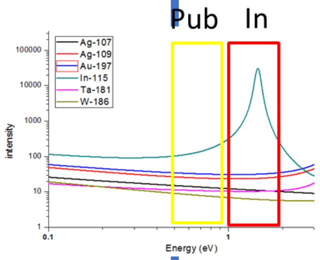
sample：

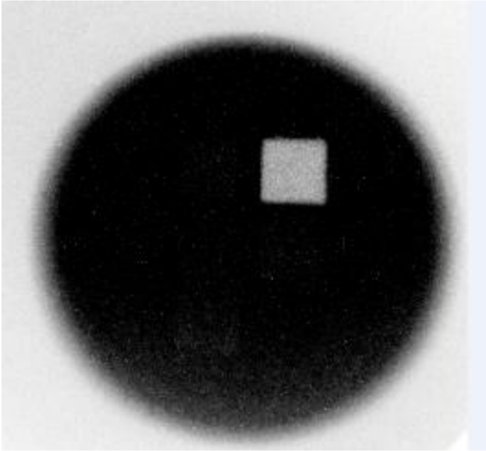
Au、Ag、W、Ta、In



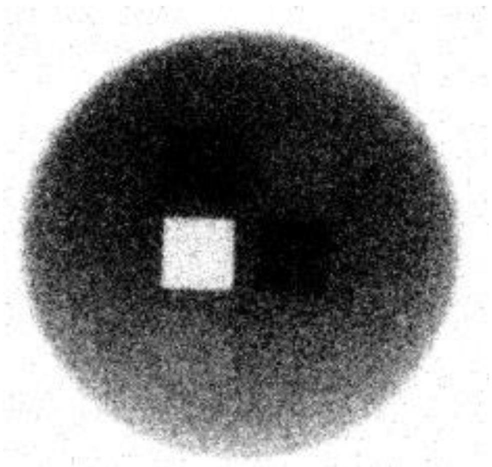
Transmission image







Indium

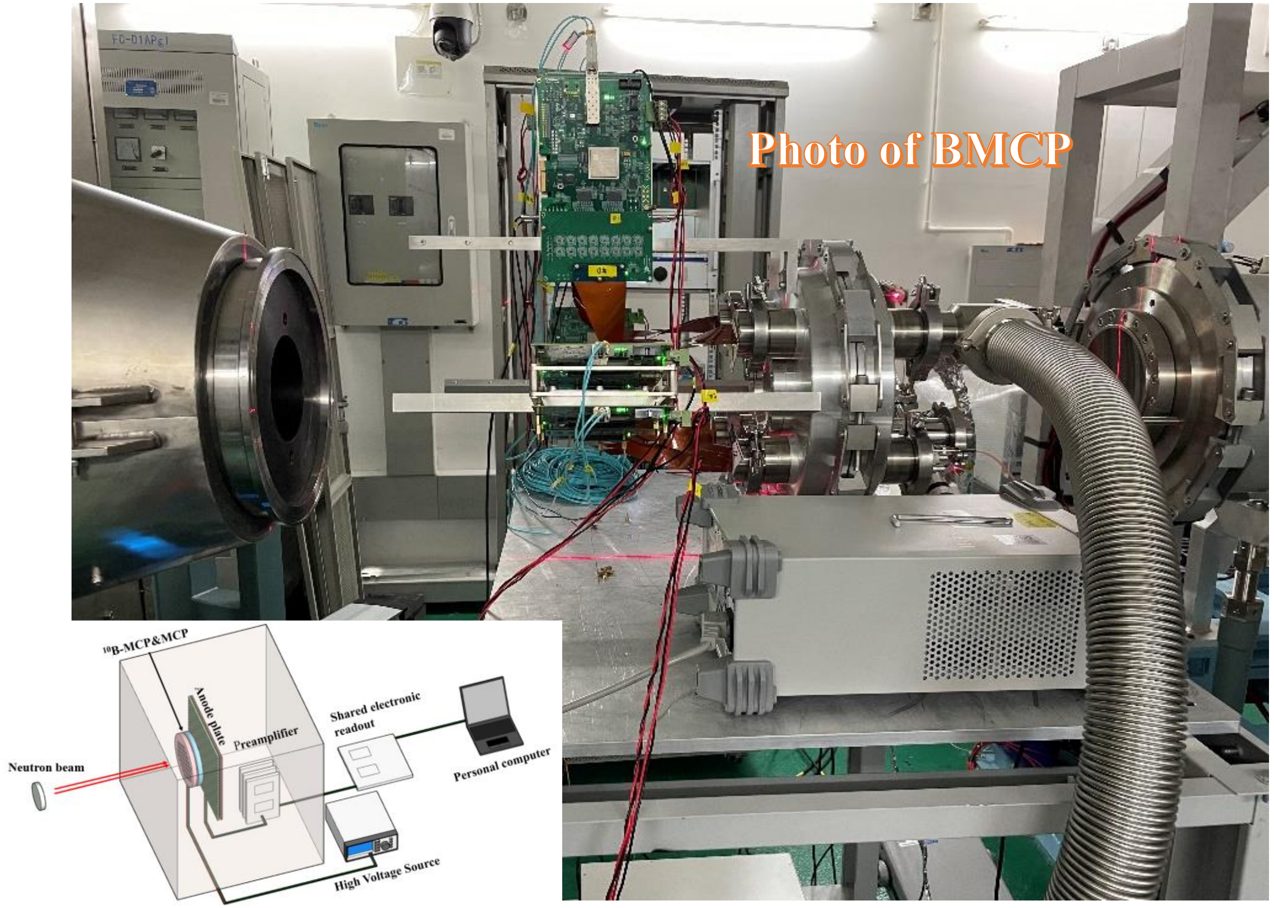


Tungsten

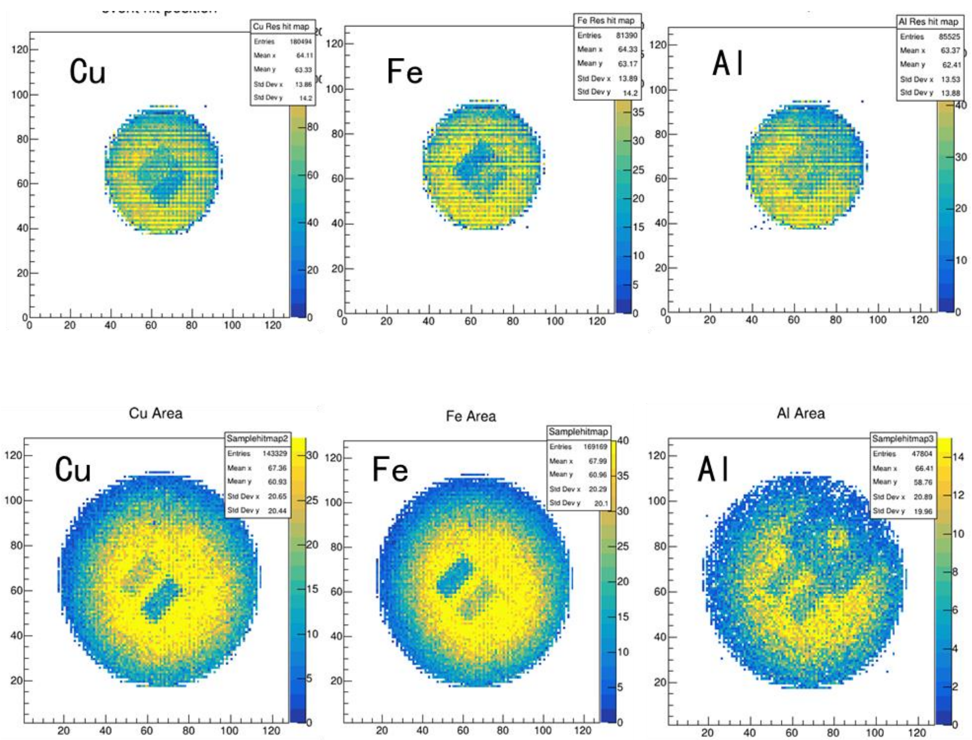
For the inspected sample containing nuclides that exhibit sharp cross-section resonances, the nuclides’ distributions can be identified by analyzing the time-resolved transmission images of the neutrons through the sample. *

*NIMA 1048, 2023, 167892

BMCP detector system



Experimental layout of BMCP



Φ 30mm

Φ 60mm

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

More efficiency, and More sensitive than camera！

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