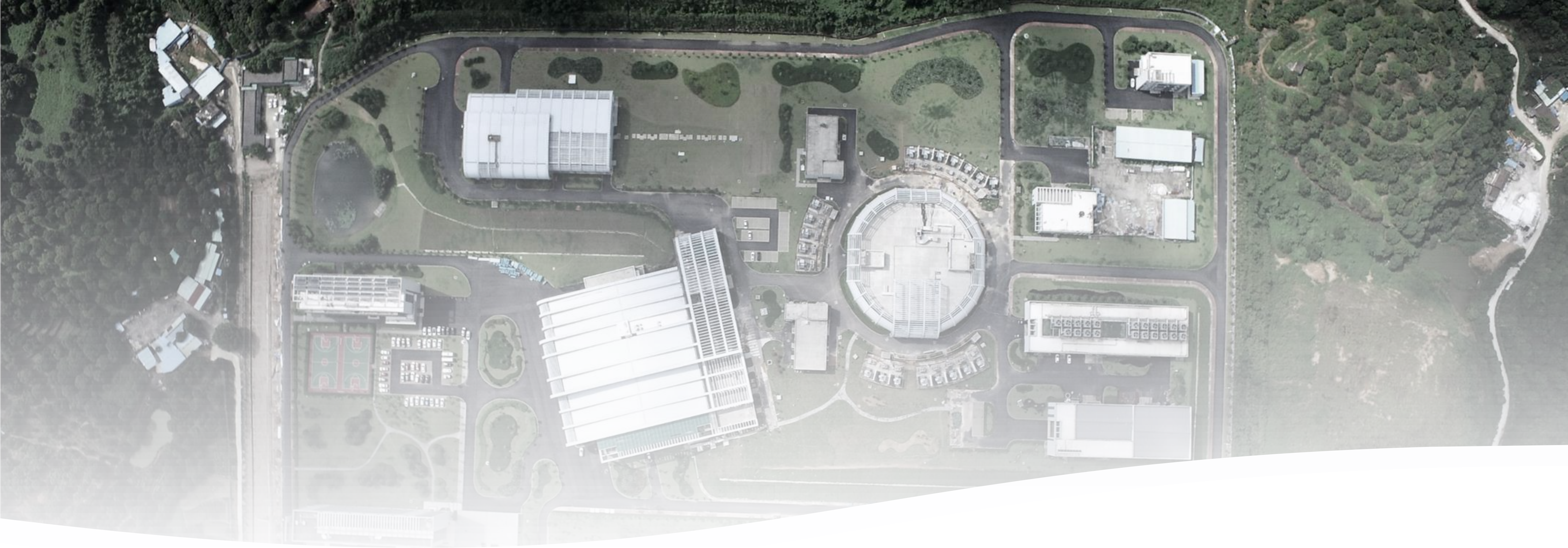


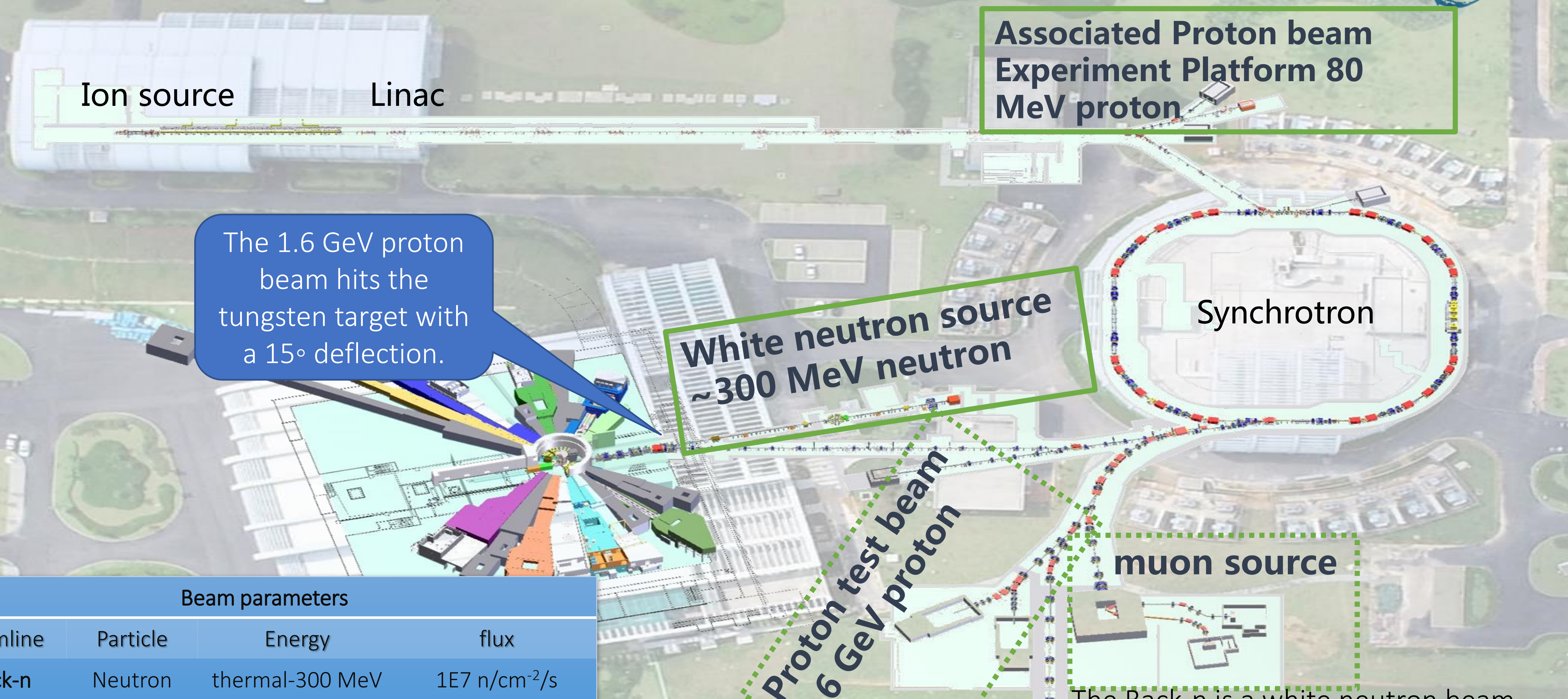
Back-n introduction and Nuclear data measurement

Ruirui Fan on behalf of Back-n team

白光中子实验装置

Back-n

CSNS Beam Expansions Application

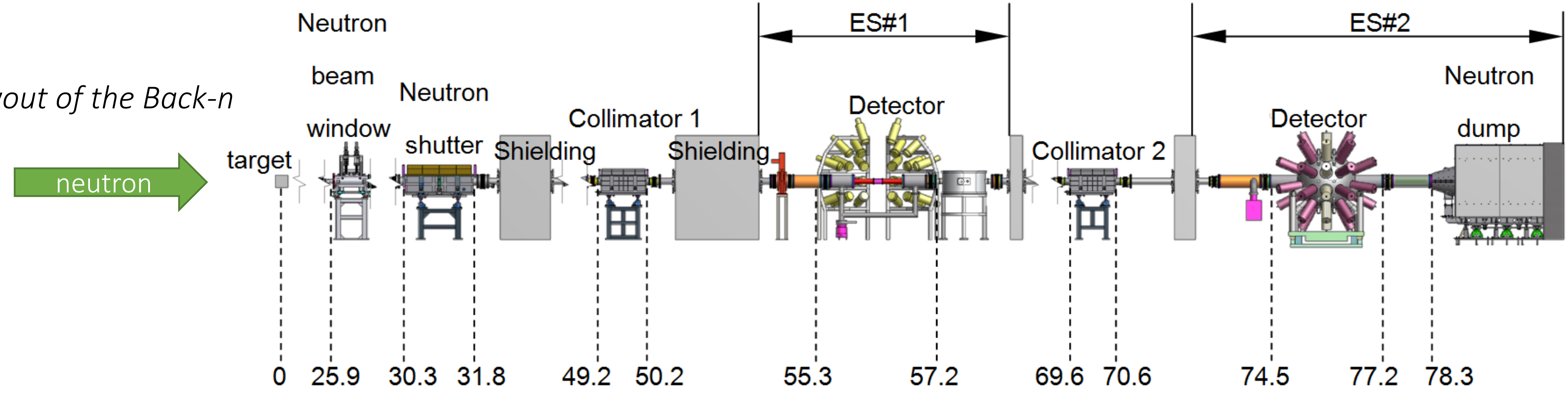


Beam parameters			
Beamline	Particle	Energy	flux
Back-n	Neutron	thermal-300 MeV	1E7 n/cm^{-2}/s
APEP	Proton	80 MeV	1E9 p/s
HPES	Proton	1.6 GeV	1E3 – 1E8 p/s
MELODY	Muon	4 MeV	1E5 muon/pulse

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

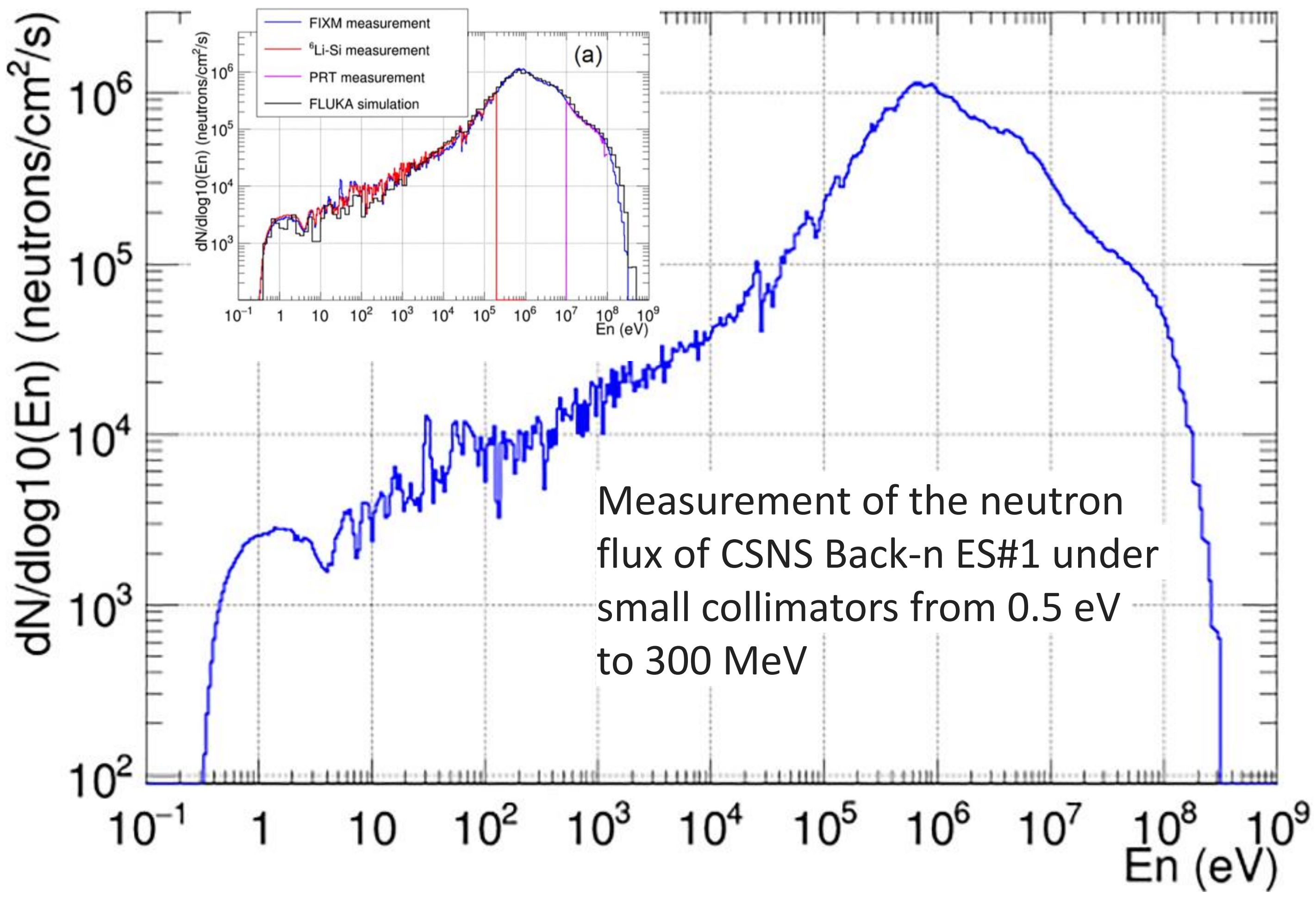


Shutter (mm)	Coll#1 (mm)	Coll#2 (mm)	ES#1 spot (mm)	ES#1 flux (n/cm^2/s)	ES#2 spot (mm)	ES#2 flux (n/cm^2/s)
Φ3	Φ15	Φ40	Φ15	1.27E5	Φ20	4.58E4
Φ12	Φ15	Φ40	Φ20	2.20E6	Φ30	7.81E5
Φ50	Φ50	Φ58	Φ50	4.33E7	Φ60	1.36E7
78×62	76×76	90×90	75×50	5.98E7	90×90	2.18E7

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

Back-n neutron energy spectrum measurement



Energy range	flux (neutrons/cm^2/s)
0.1-1 eV	4.08×10^3
1-10 eV	1.79×10^4
10-100 eV	3.01×10^4
0.1-1 keV	5.01×10^4
1-10 keV	1.23×10^5
10-100 keV	4.30×10^5
0.1-1 MeV	2.98×10^6
1-10 MeV	2.77×10^6
10-200 MeV	6.21×10^5
Total	7.03×10^6

We used different reference cross-sections to measure the energy spectrum, including: (n, p), ^{6}Li(n, t), ^{235}U(n, f), ^{238}U(n, f)

Eur. Phys. J. A (2019) 55: 115
Chen, Y., Qiu, Y., Li, Q. *et al. Eur. Phys. J. A* **60**, 63 (2024).

The white neutron energy range

The Back-n has a wide neutron energy range from **cold neutron (0.4 meV) to 300 MeV (Fig 1)**. 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 lots of experiments, 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(**300->20 meV**).

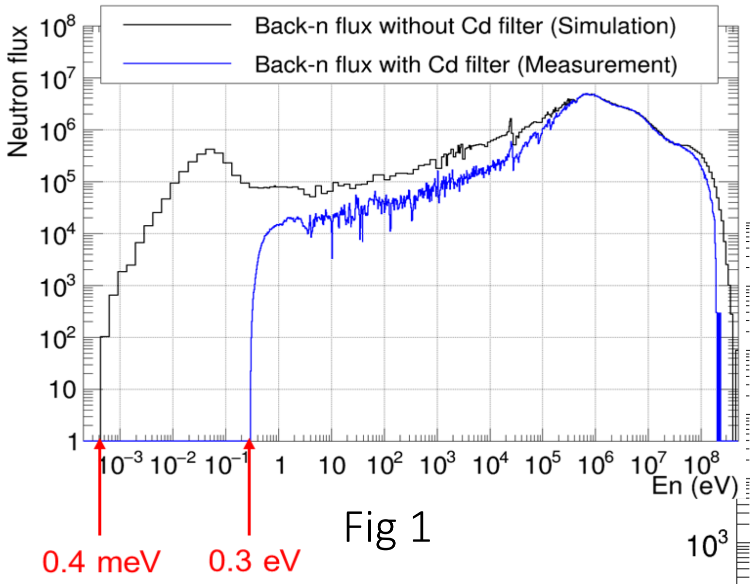
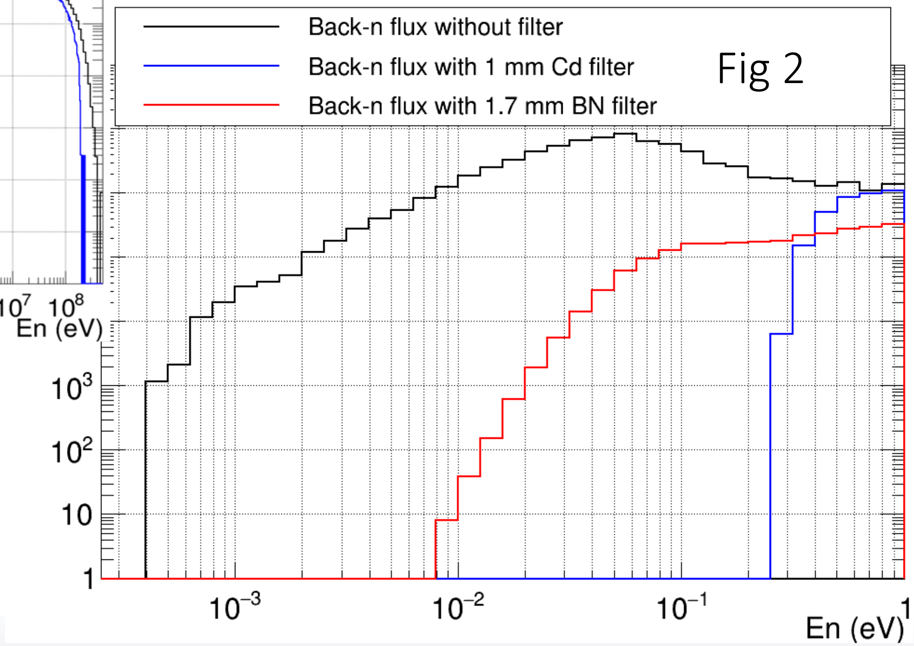
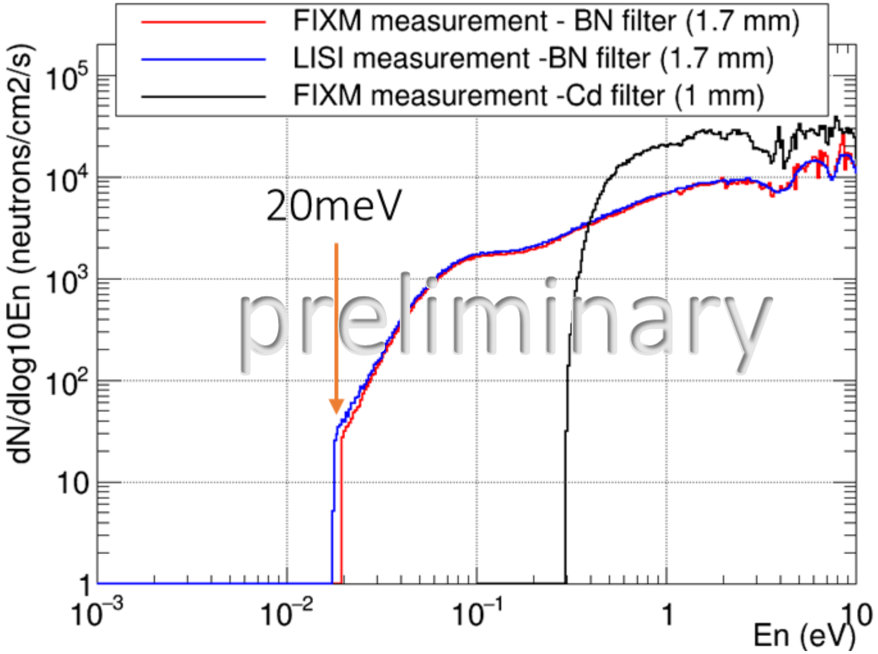


Fig 1

Simulation spectrum of different filter



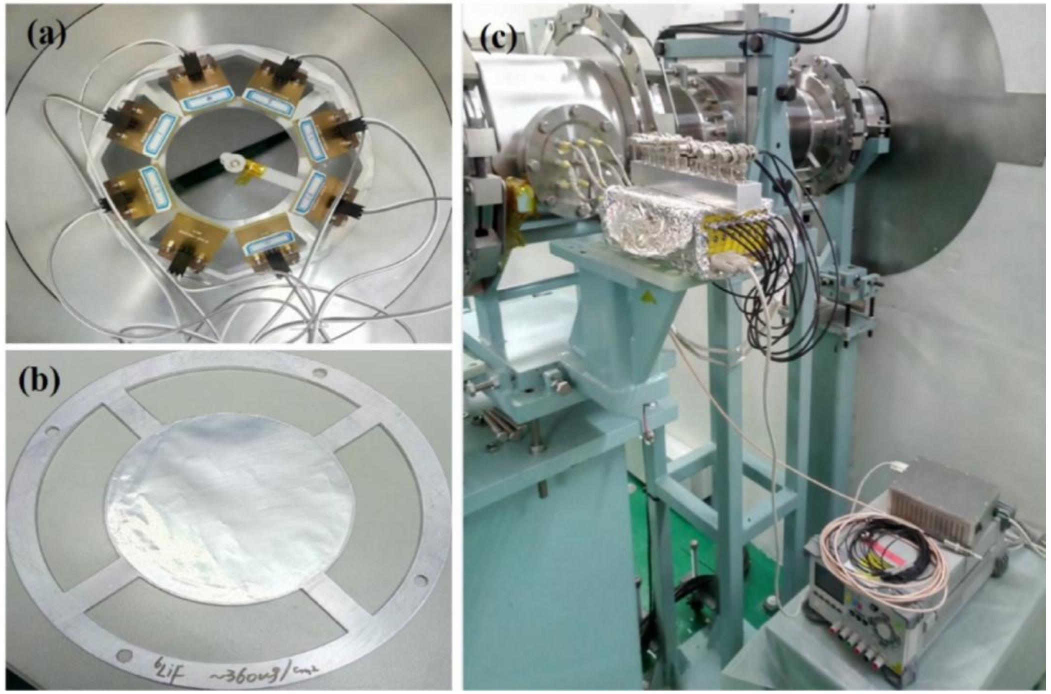


Experimental spectrum Fig 3

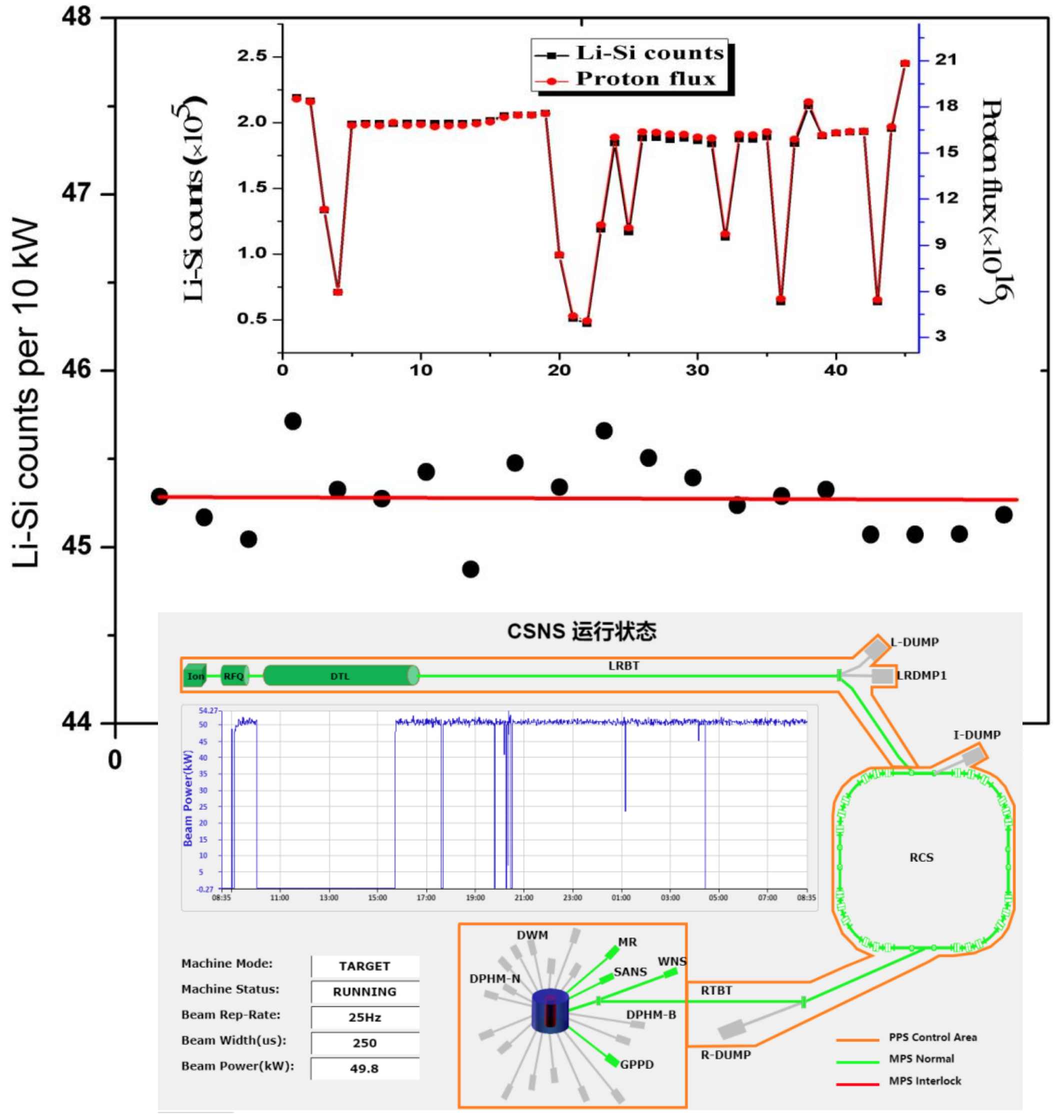
Back-n beam monitor

Two monitors are employed:

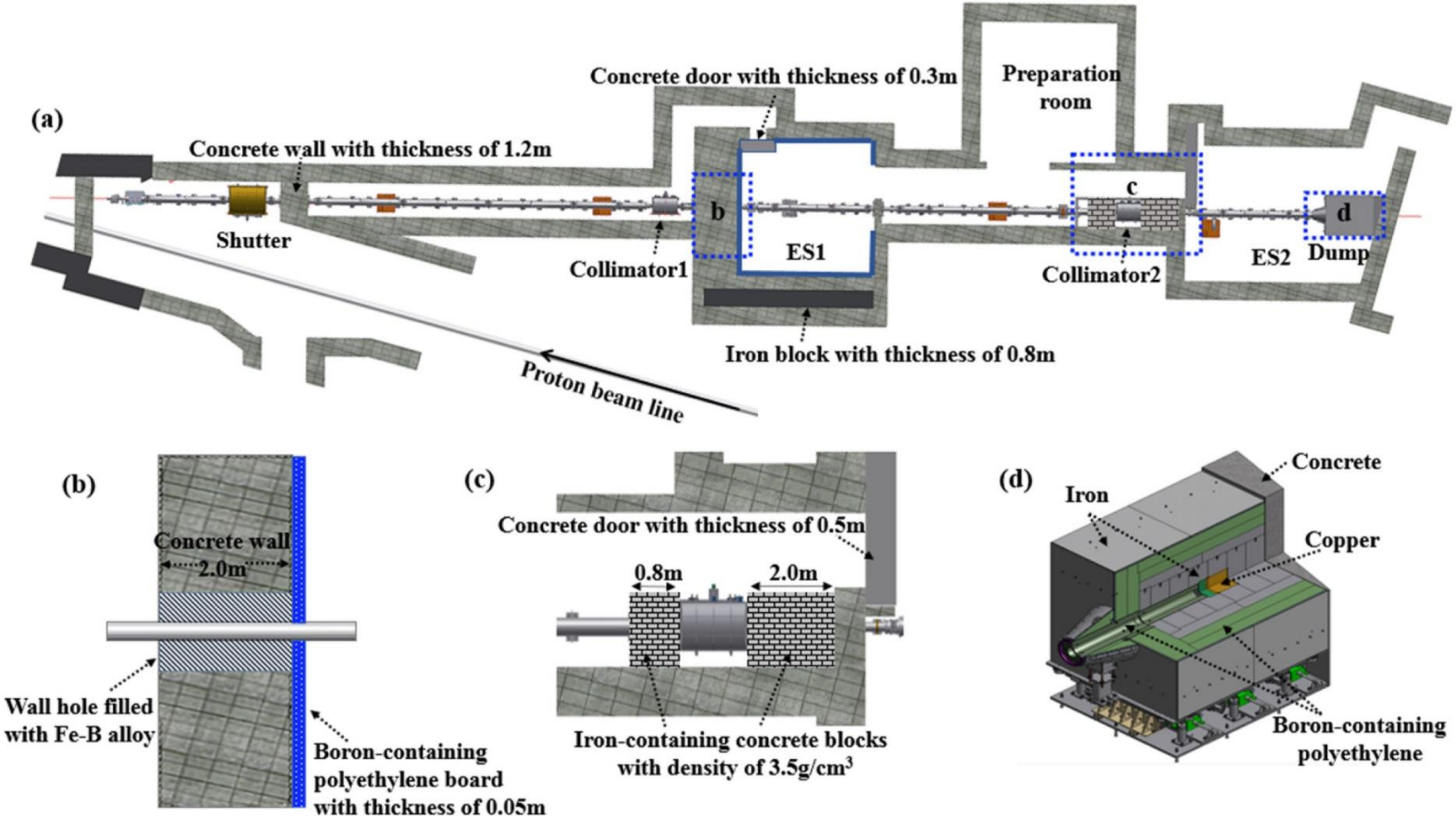
- Proton beam monitor (Fast Current Transformer)
- Li-Si monitor (^{6}LiF foil and silicon detectors)



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

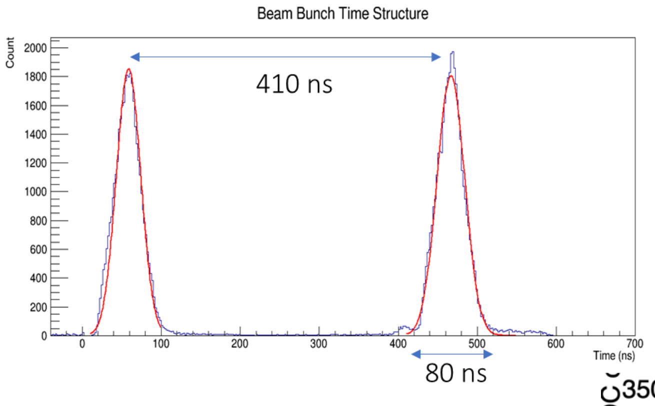


Back-n shielding & background measurement



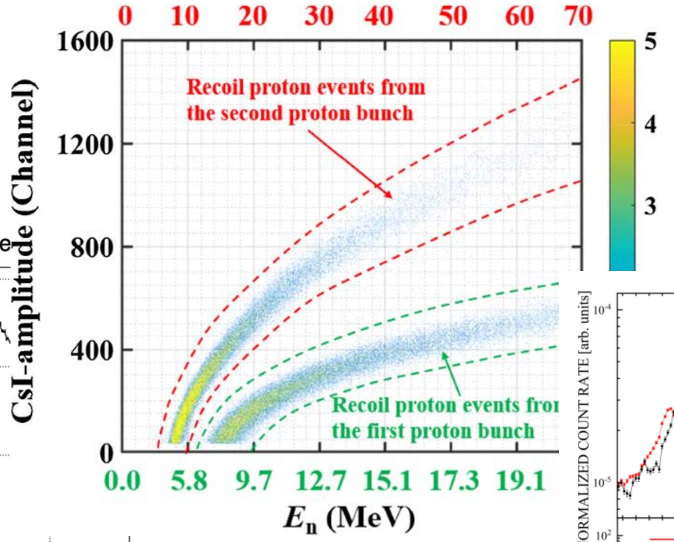
Neutron and γ background measurements of the experimental halls at the CSNS back-streaming white neutron source , NIMA Volume 980, 11 November 2020, 164506

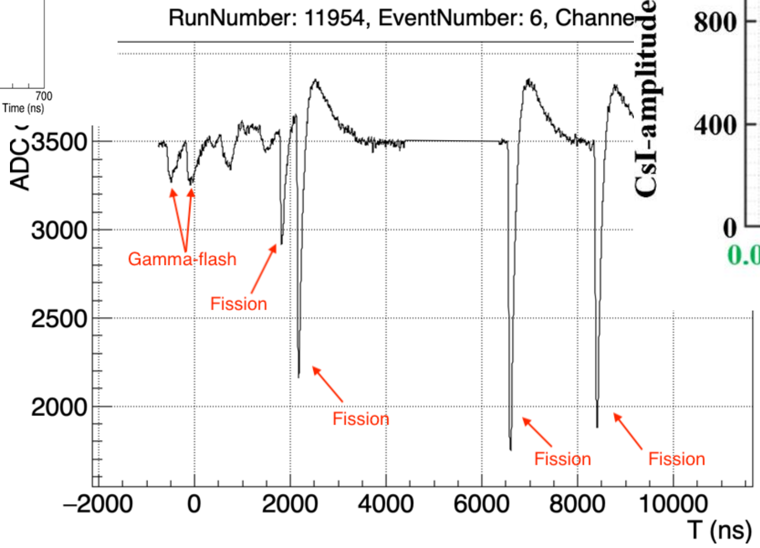
The neutron beam time structure of Back-n



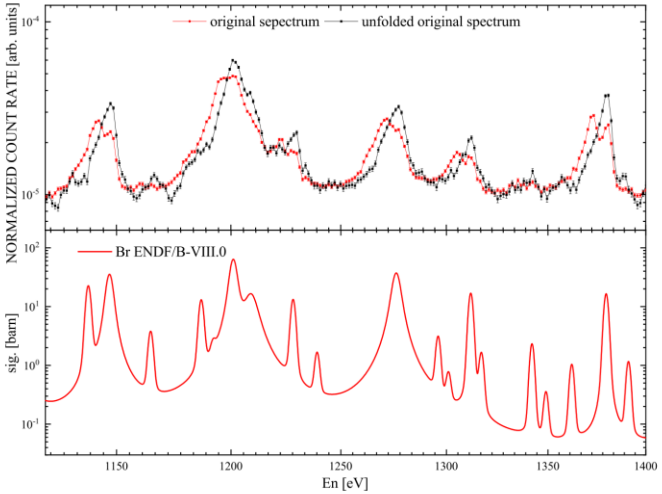
Double bunches time structure

A typical detector response in (n, p) reaction





A typical detector response in one pulse

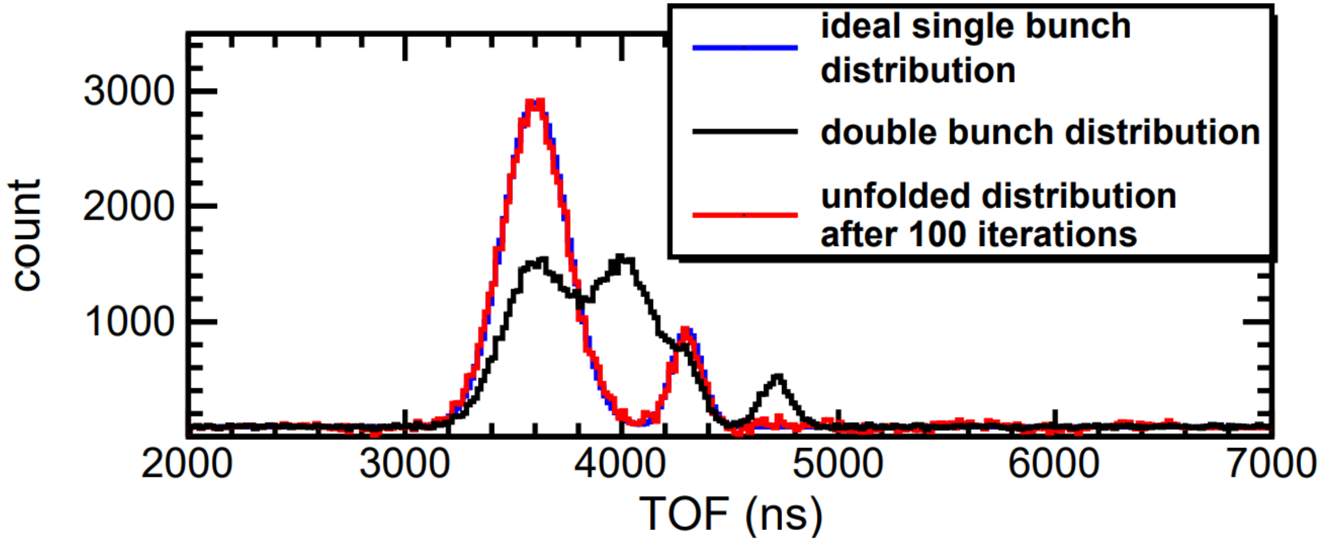


A typical detector response in (n, γ) reaction

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.

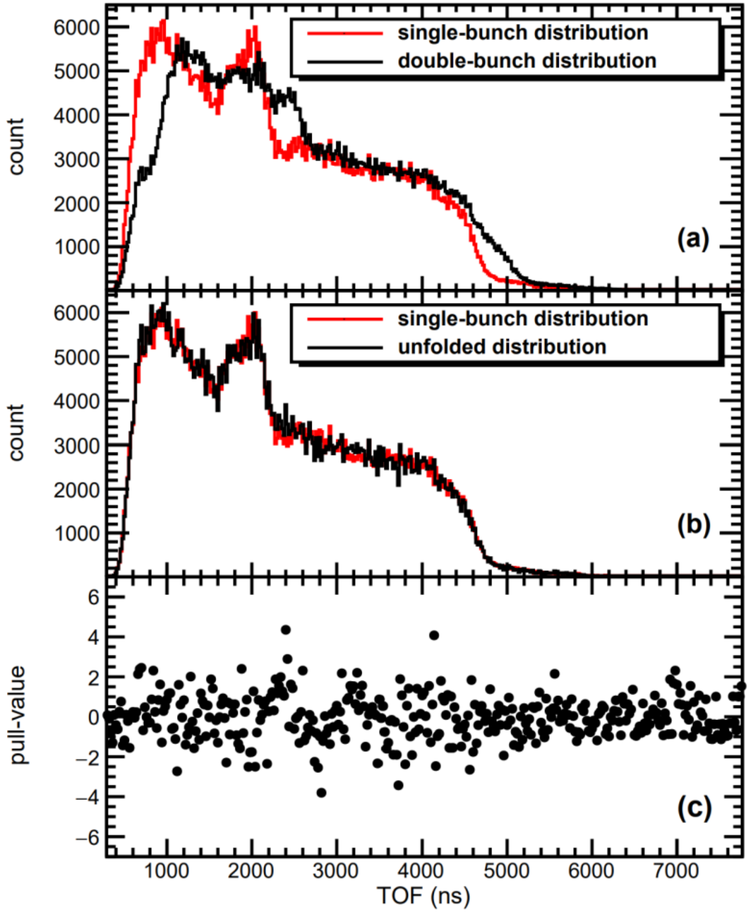
Acta Phys. Sin. Vol. 68, No. 8 (2019) 080101
The European Physical Journal A, 57(1): 6.

Double-bunch unfolding methods



A simulated example of the spectrum unfolding

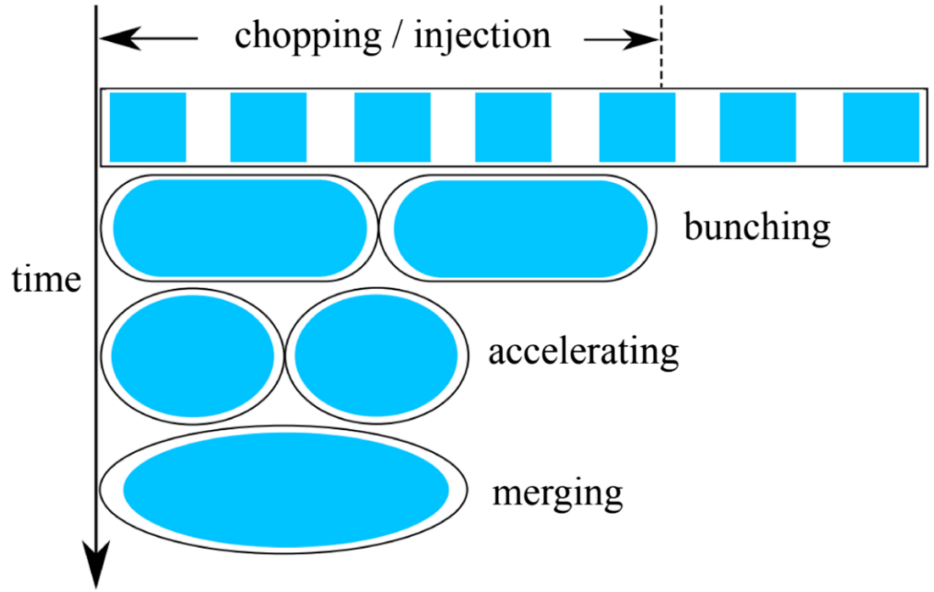
A Bayesian unfolding method is developed for diverse types of experiments performed in the double-bunch mode at Back-n. The experiment data from single bunch mode and the unfolded result from the double bunch mode experiment match well. The unfolding method has been used in most Back-n experiments.



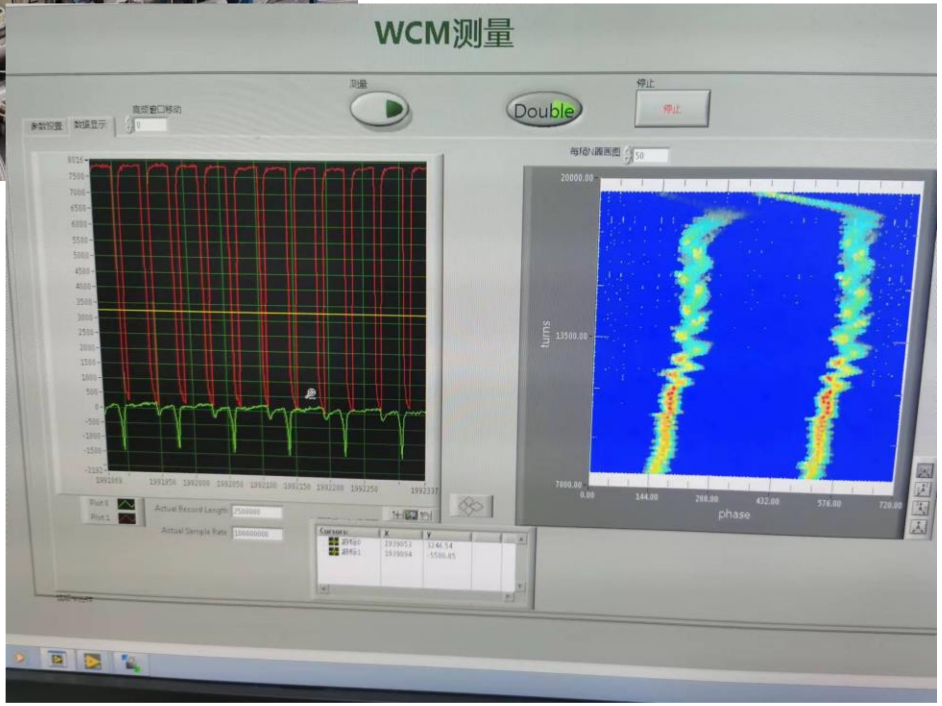
Unfolding result of the ^{238}U data

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)

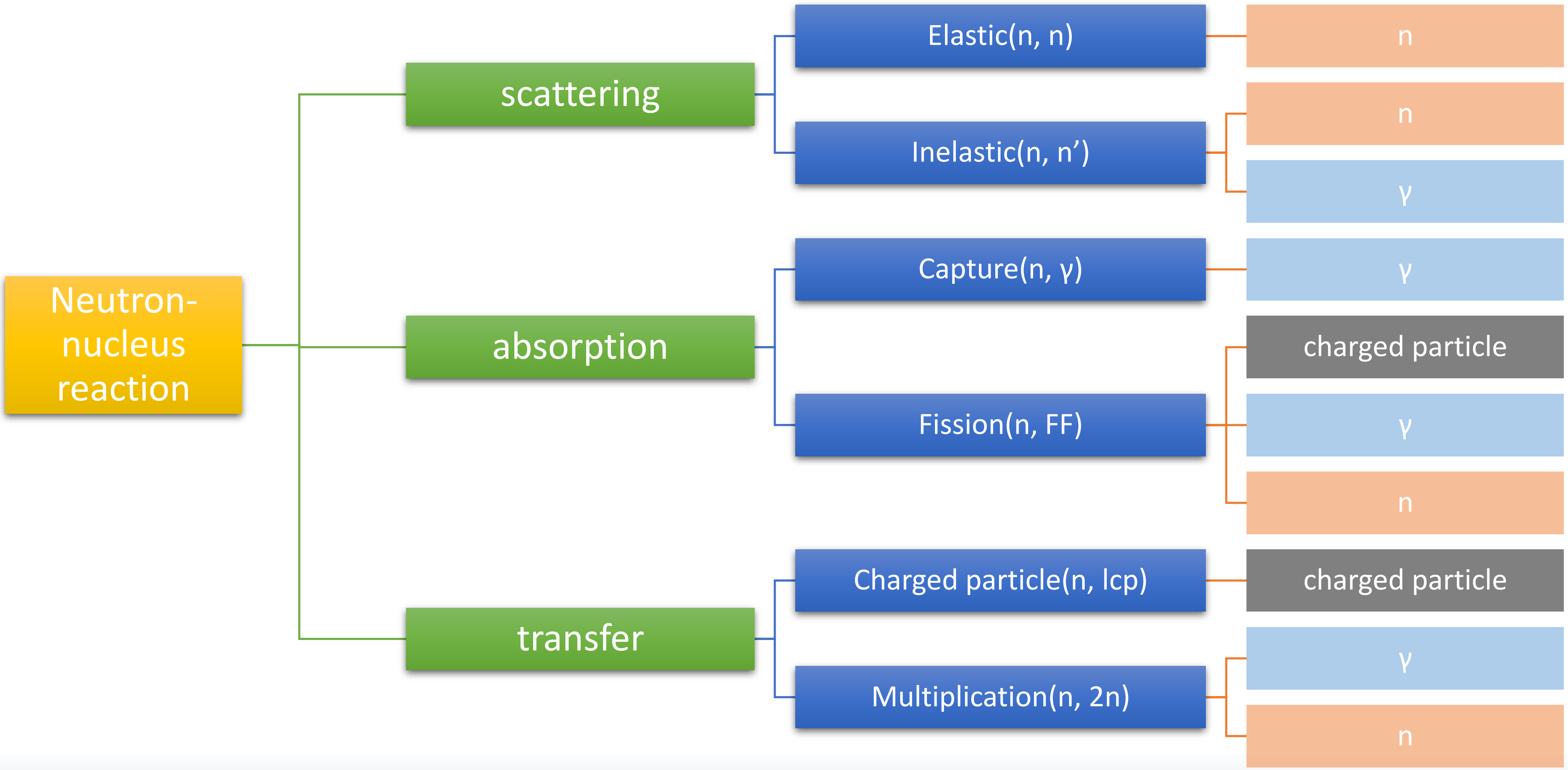
First bunch merge experiment attempt in May 30th 2023

核数据测量实验

Nuclear data measurement

Classification of Neutron and Nucleus Reactions

Neutron and nucleus reactions can be divided into three main categories based on the nuclear reaction process: scattering reactions, absorption reactions, and transfer reactions.



C_6D_6(Benzene-d6) scintillator detector

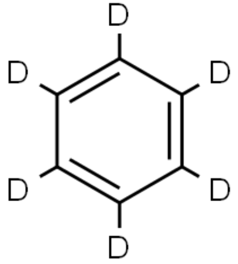


Photo of the C6D6 detector system

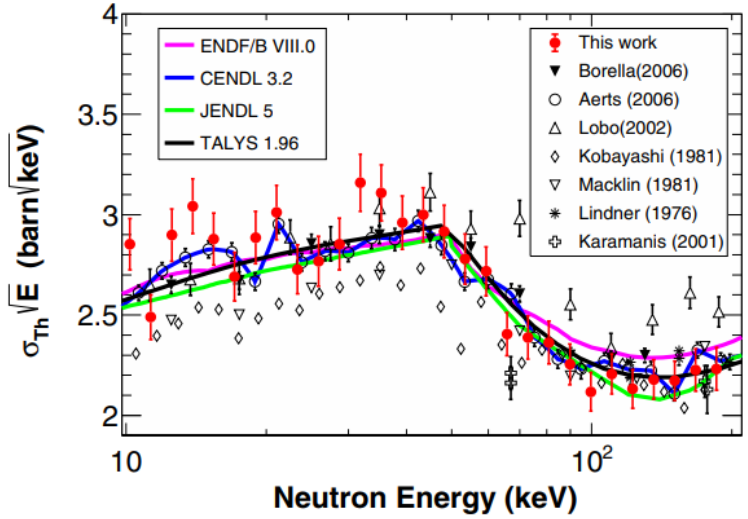


Fig. 10 The capture cross sections of ^{232}Th multiplied by the square root of the neutron energy. The uncertainty of some data sets is omitted to maintain the readability of the figure

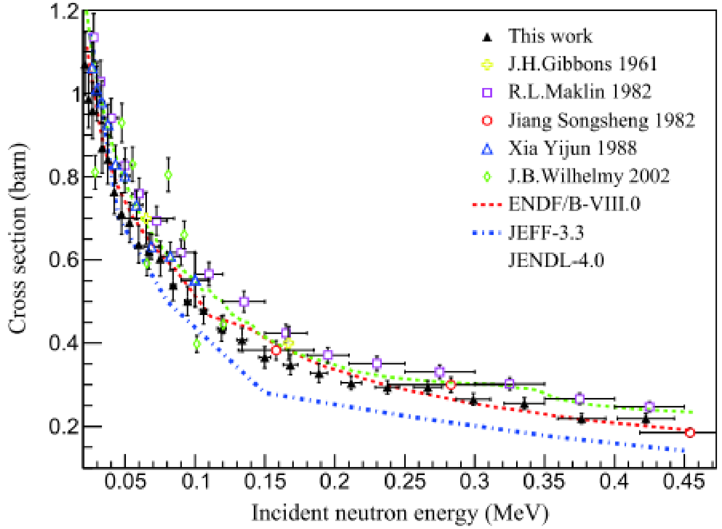
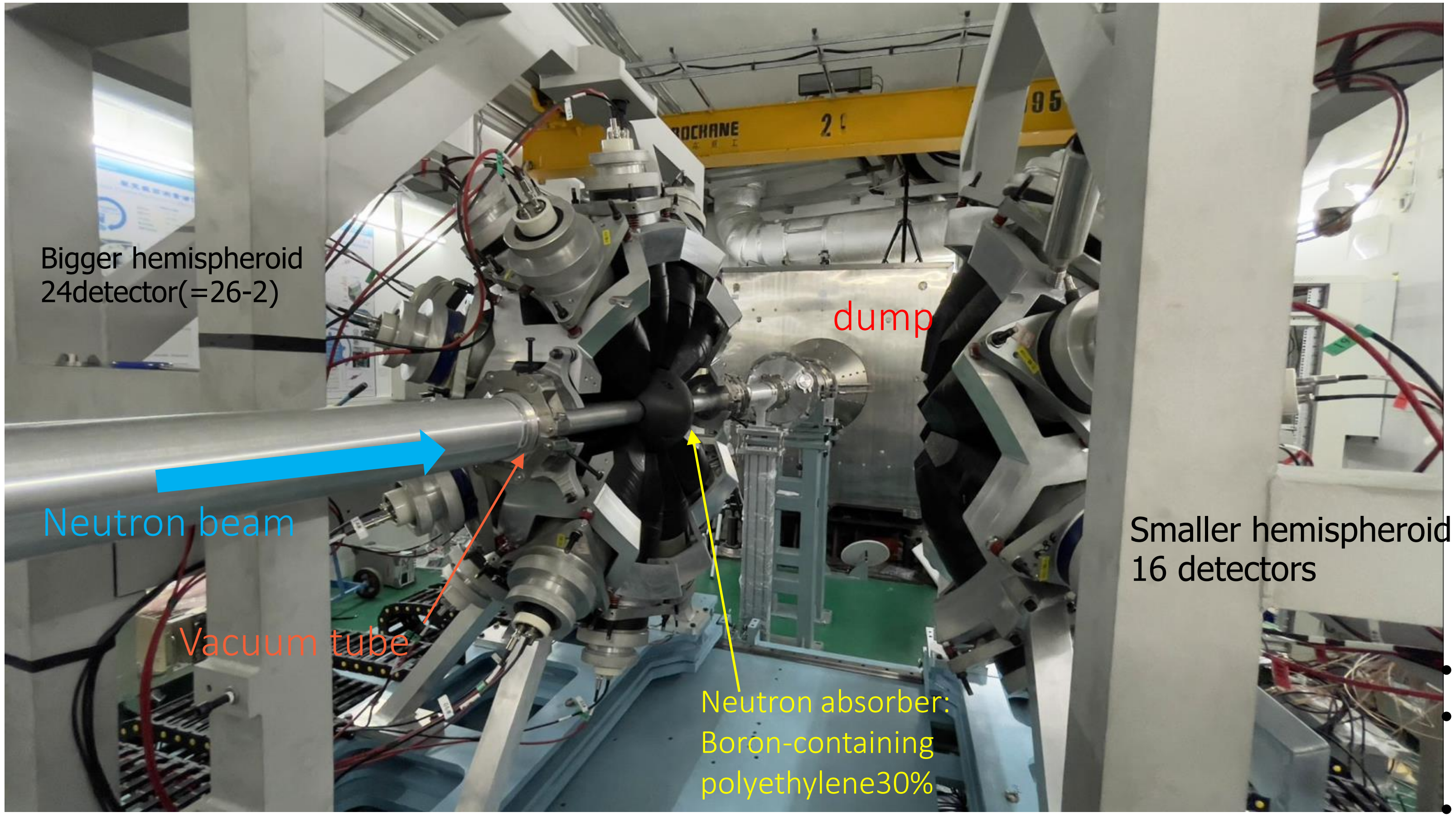


Fig. 15. (color online) The capture cross sections of ^{169}Tm obtained by the relative measurement of ^{197}Au(n,γ).

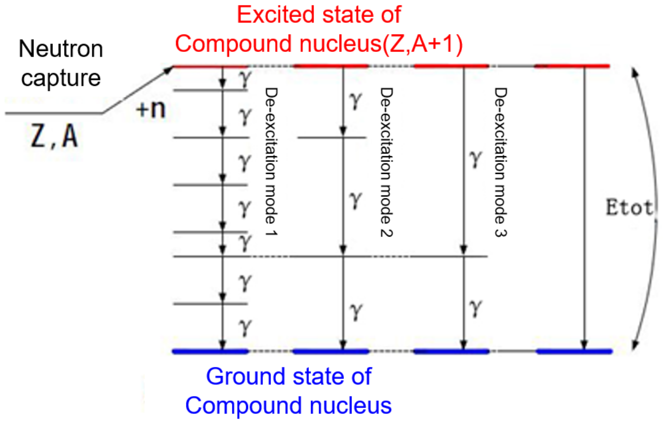
The C_6D_6 liquid scintillator is EJ315, which is produced by ELJEN Technology Corporation. The shell of the scintillator is made of aluminum and the size is 130mm in diameter and 76.2mm in length. The C_6D_6 detectors are placed upstream of the sample relative to the neutron beam, and the detector axis is at an angle of 125 degrees from the neutron beam.

Radiation Detection Technology and Methods, 3(3): 52
Chinese Physics C, 46(4): 044002
Chinese Physics B, 31(6): 060101

GTAF (40 BaF_2 detector array)

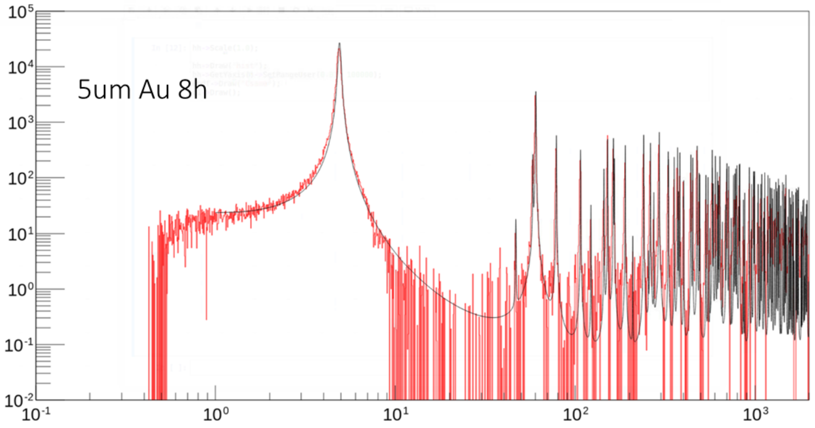


Courtesy: Guangyuan Luan(CIAE)



Recent experiment result of Au by GTAF

ENDF/B-8



- **GTAF(Gamma Total Absorption Facility)**
- **Prompt gamma measurement, neutron time of flight method(neutron energy)**
- **Cascade gamma matches measurements——Multiplicity and Total Energy of Cascade gamma can be measured**

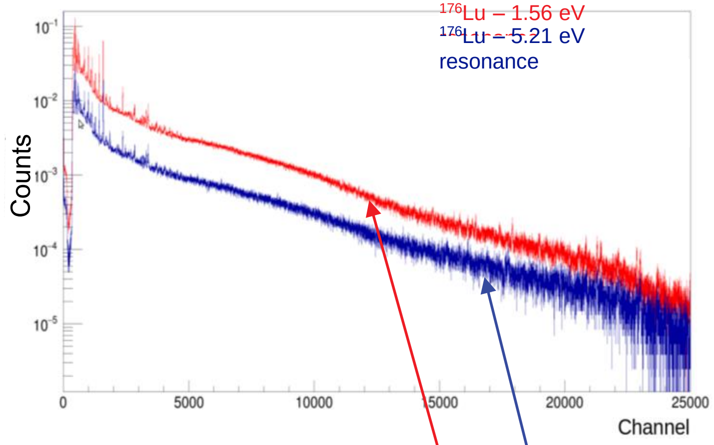
Journal of Instrumentation, 16(10): P10029

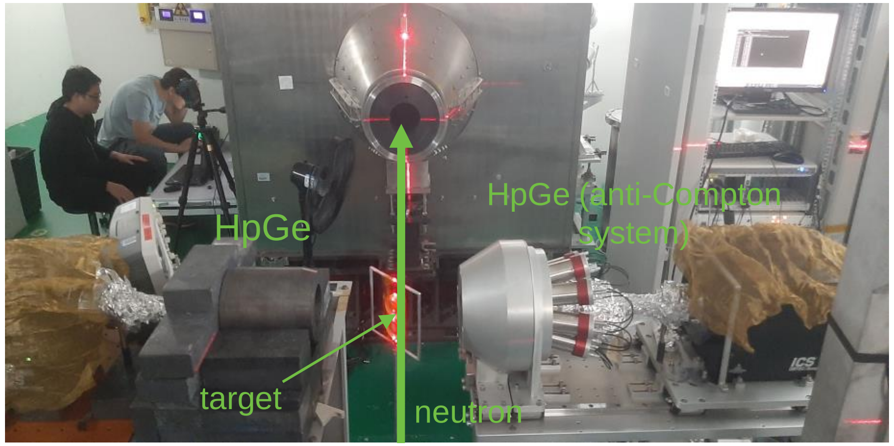
Measurement of gamma decay properties of compound states of 176Lu and 177Lu

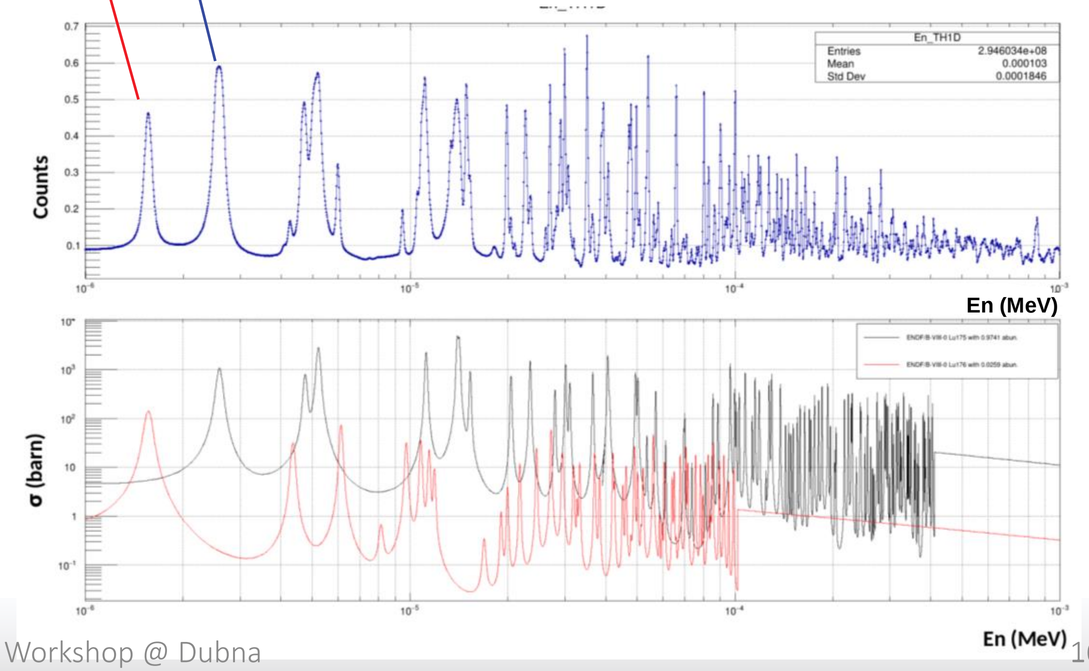
- The aims of the experiment are

1) to clarify influence of a collective rotation of the deformed nuclei on conservation of quantum number K (the projection of the spin J onto a symmetry axis).
2) to extract the dipole electric and magnetic photon strength function with better accuracy.
3)

- The target nuclei ^{175}Lu and ^{176}Lu are very suitable due to large spin J of neutron resonances (J=3-4, J=13/2, 15/2, respectively).
- It is necessary to increase number of neutron resonances under investigation in comparison with previous experiments. So far, E_γ and I_γ (^{176}Lu) for γ quanta have been measured from 15 neutron resonances in the range from 2.6 to 50.2 eV. We are planning to measure in the energy range of 1-100 eV.
- The preliminary measurements were carried out in 2023 at the IREN resonance neutron source and at the CSNS neutron source (China). It is necessary to significantly increase the integral counting statistics in the energy range (5-7 MeV) of γ quanta. Therefore, the experiment is planned to continue in 2024.

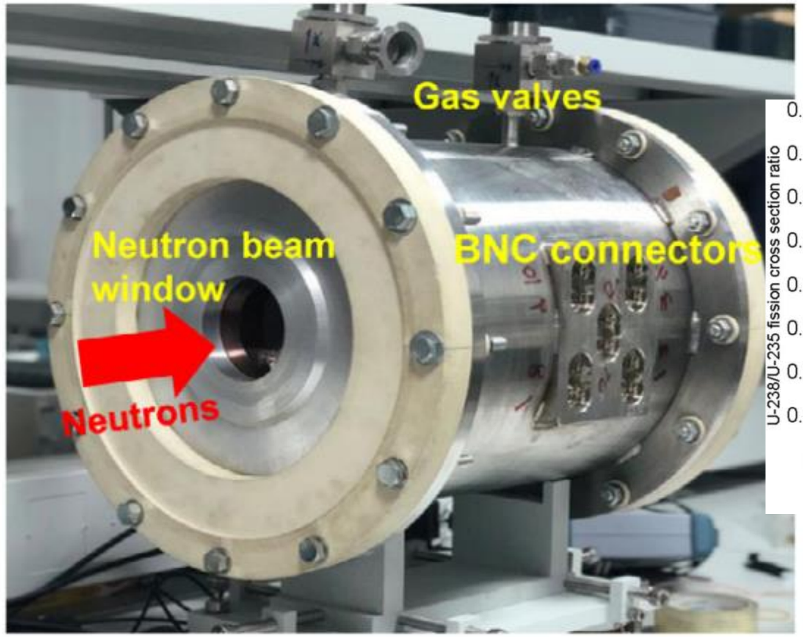


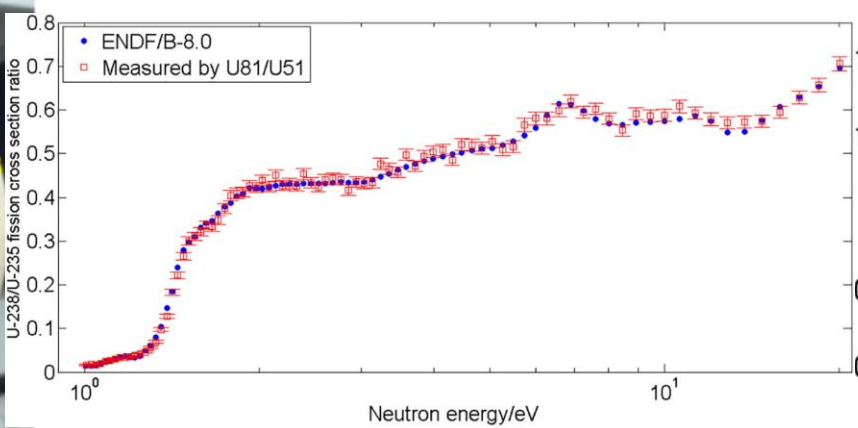




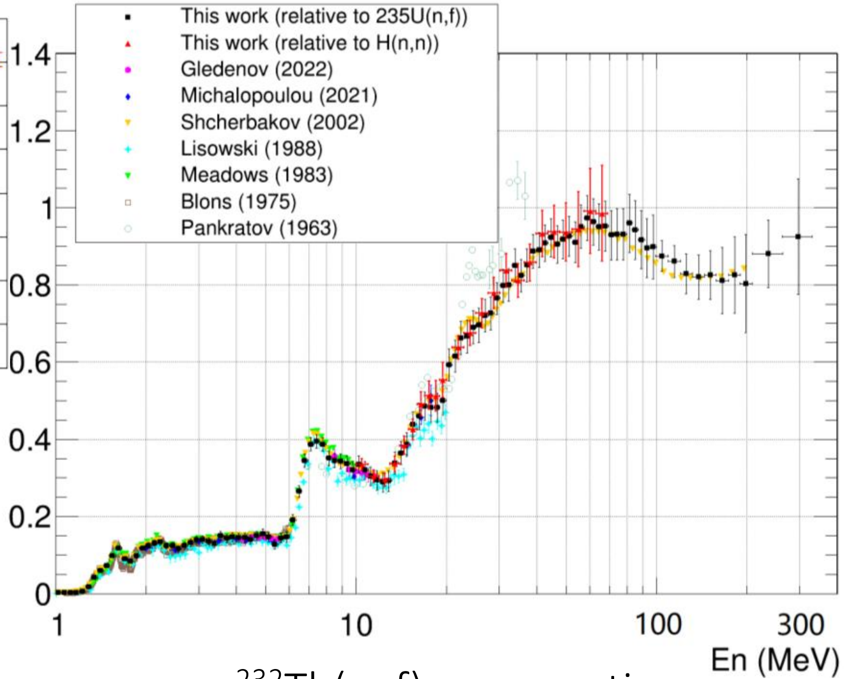
Courtesy: Gadir Ahmadov (JINR)

The fission chamber





$^{235}U/^{238}U$ ratio measurement

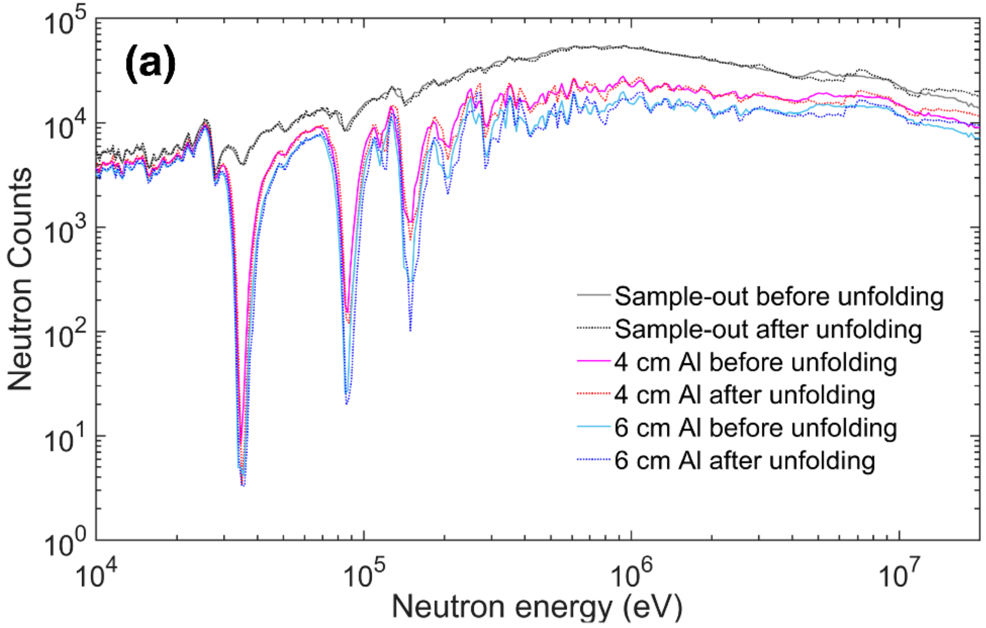


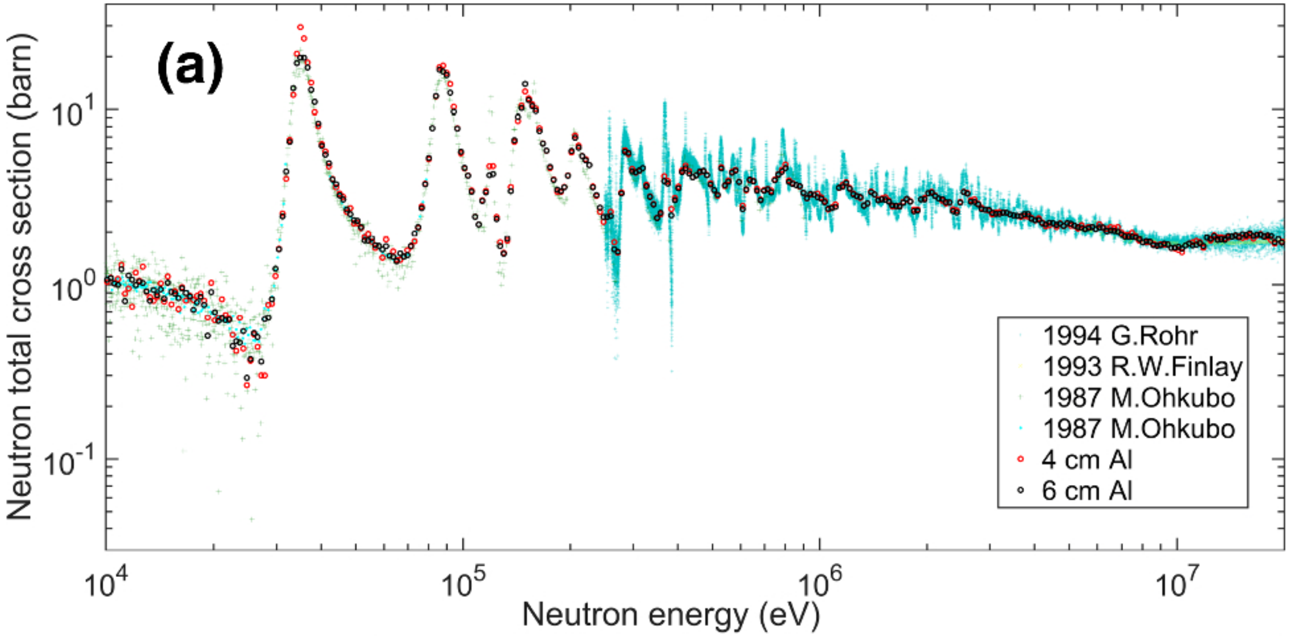
$^{232}Th(n, f)$ cross section

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
Physics Letters B, 839: 137832
EPJ Web of Conferences, 284: 01013
Annals of Nuclear Energy, 140: 107301

Total cross section

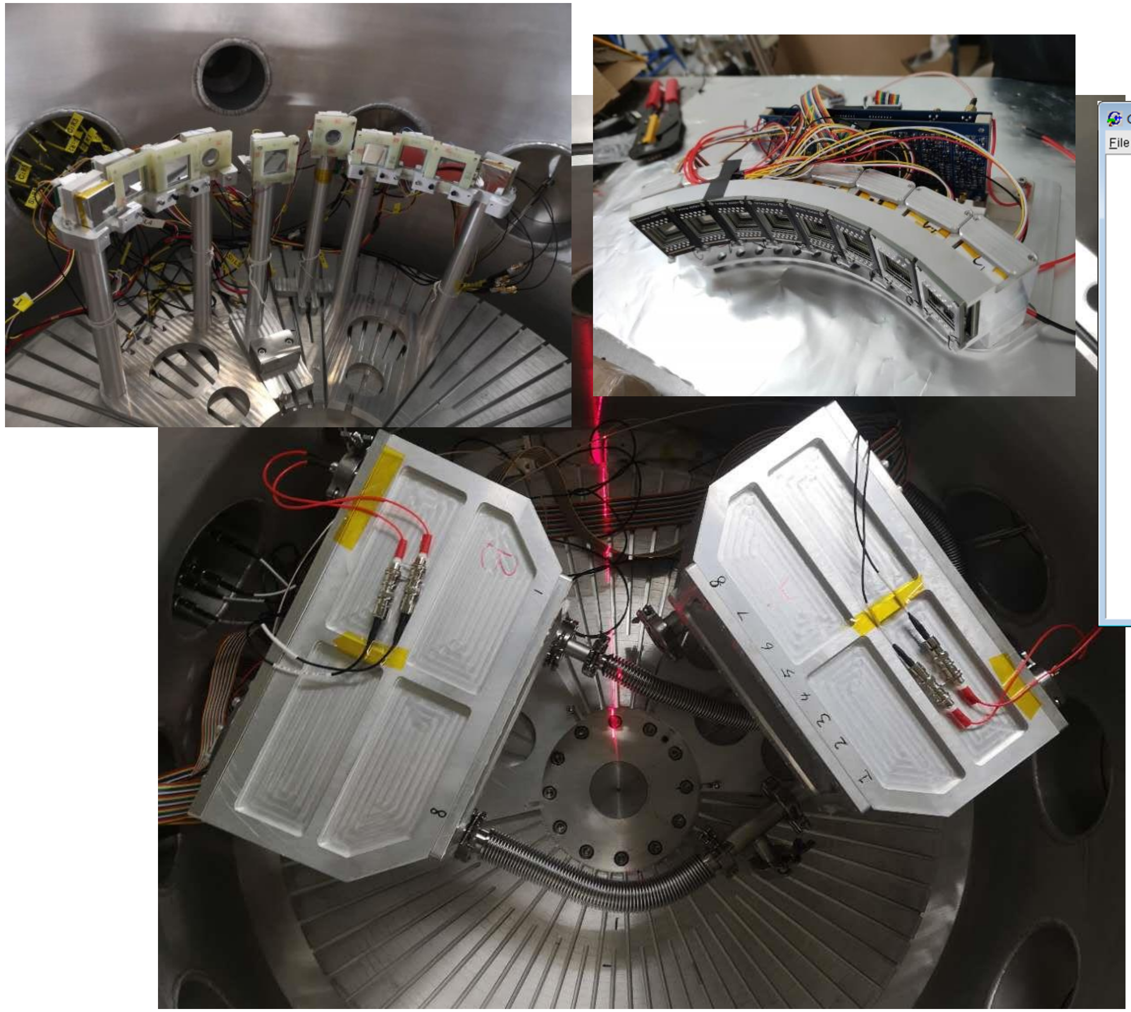




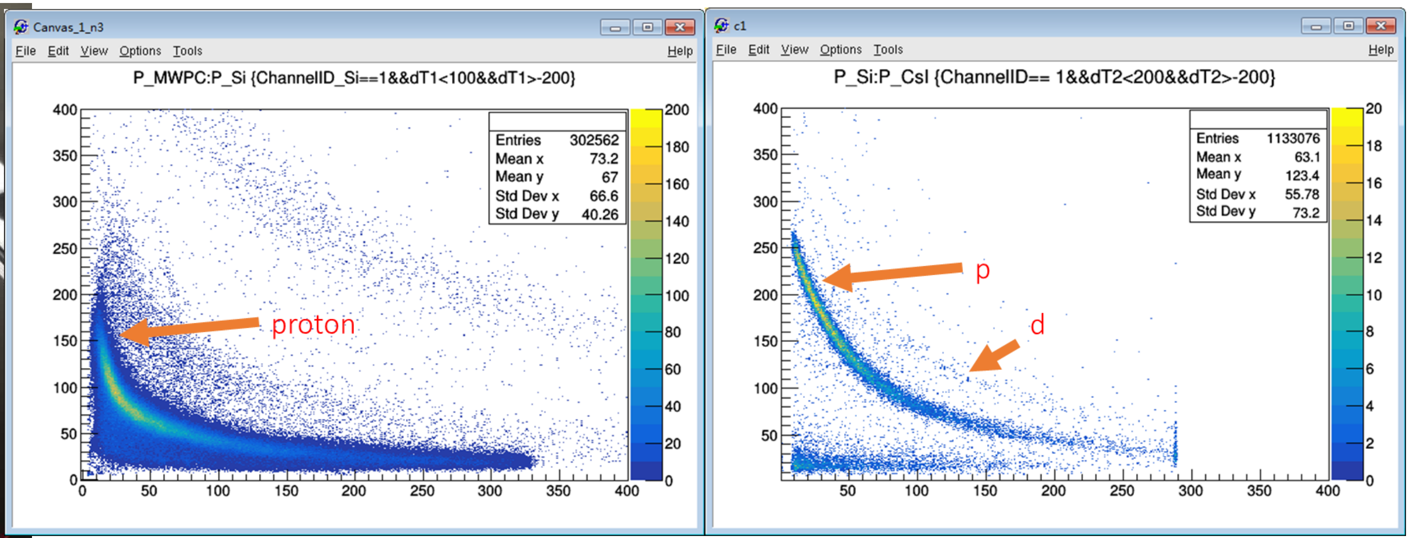
Measurement of the neutron total cross sections of aluminum at the back-n white neutron source of CSNS

The European Physical Journal A, 57(7): 232.

ΔE- E detector array (LPDA)



The photo of LPDA

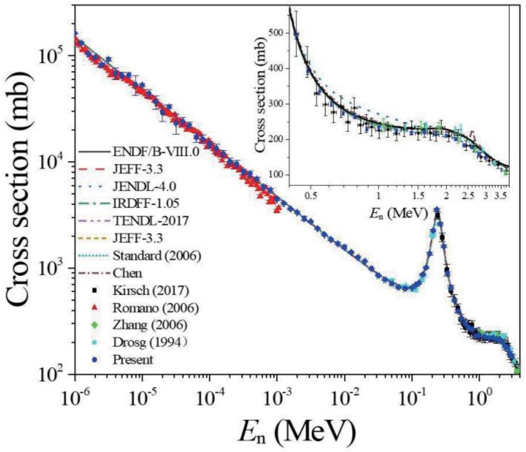


The LPMWPC (Δ*E*) vs Si-PIN (*E*) spectrum and Si-PIN (Δ*E*) vs CsI(Tl) (*E*) spectrum

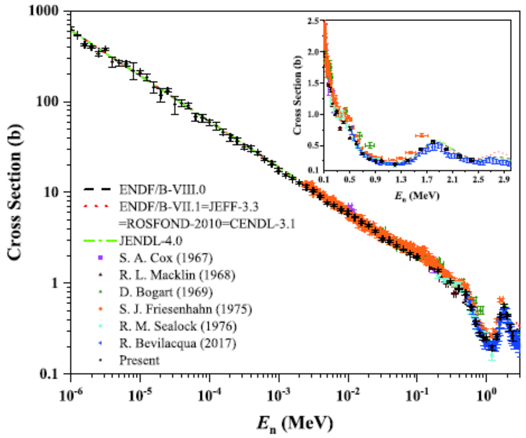
The LPDA is divided into two modules, each covering an angle of 23.5-90 degrees. It includes 8 sets of LPMWPC+Si+CsI detector telescopes, with a total of 48 channels. It was completed in June 2020.

NIMA, 973: 164126
NIMA, 981: 164343
JINST 18 P04004

LCP cross section measurements



$^{6}Li(n, t)\ \alpha$



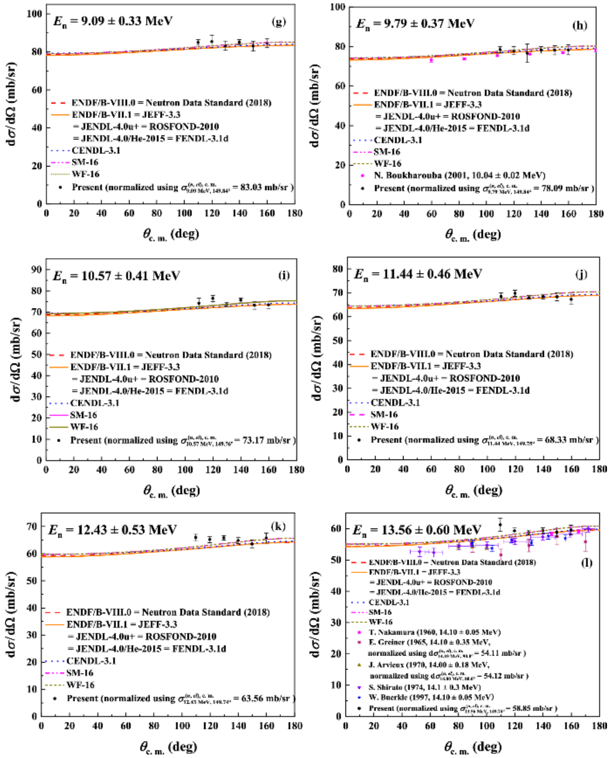
$^{10}B(n, \alpha)^{7}Li$

Huaiyong Bai et al 2020 Chinese Phys. C 44 014003

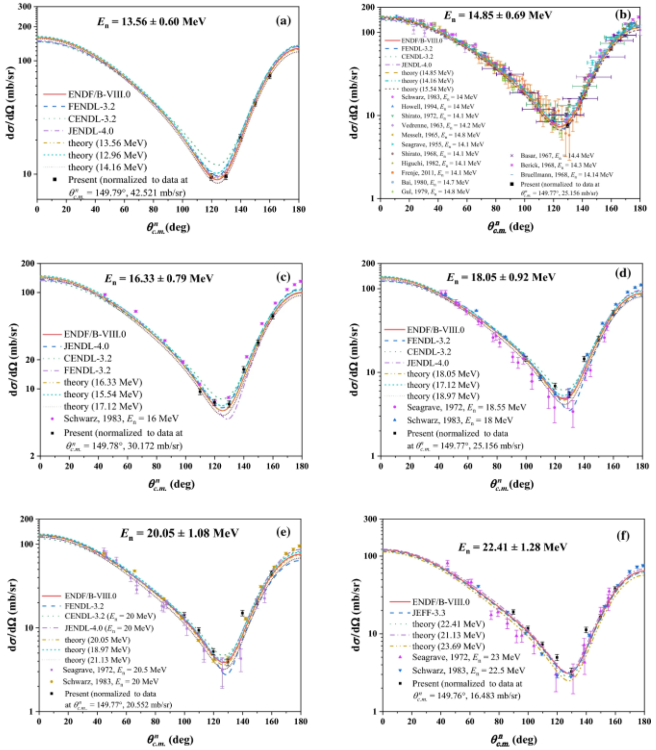
H. Jiang, et al., Chin. Phys. C 43 (12) (2019) 124002

The European Physical Journal A, 57(11): 310

The European Physical Journal A, 57(1): 6

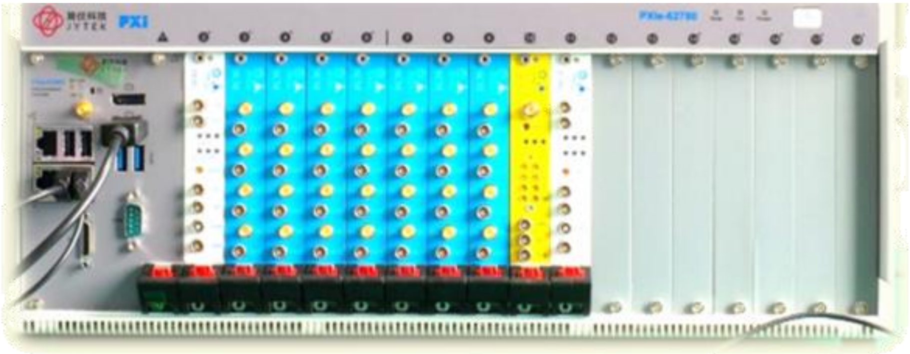


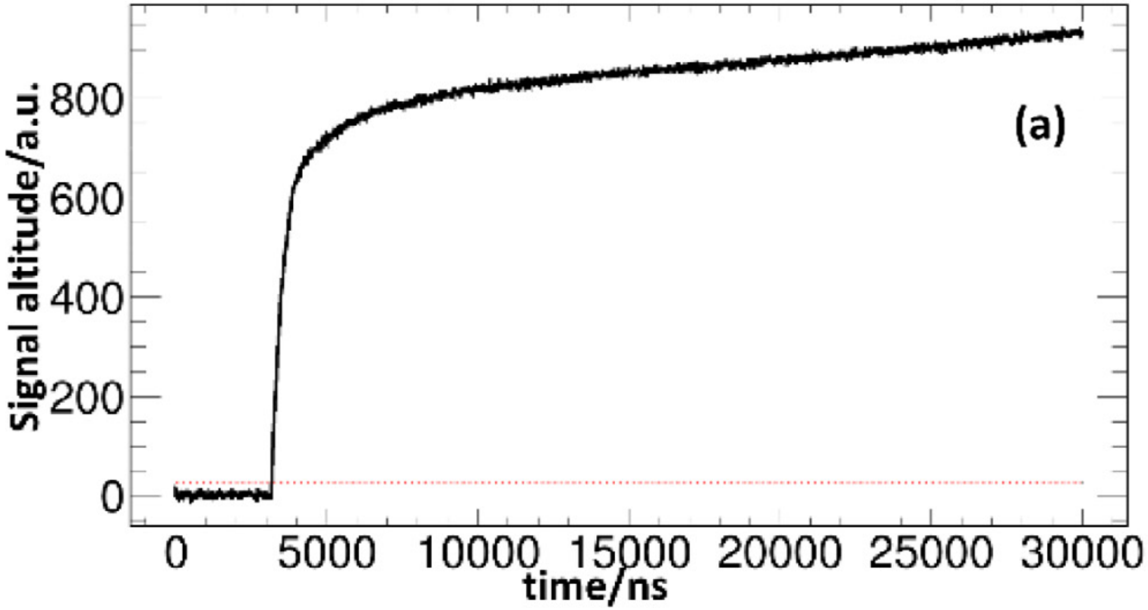
(n, p)



(n, d)

DAQ



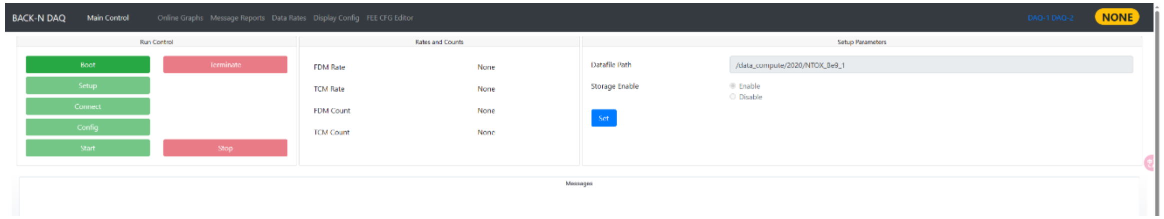


Common electronics： it consists of an analog conditioning module (SCM), a trigger clock module (TCM), and a waveform digitization module (FDM).

resolution:12 Bit

Sample rate: 1 GHz

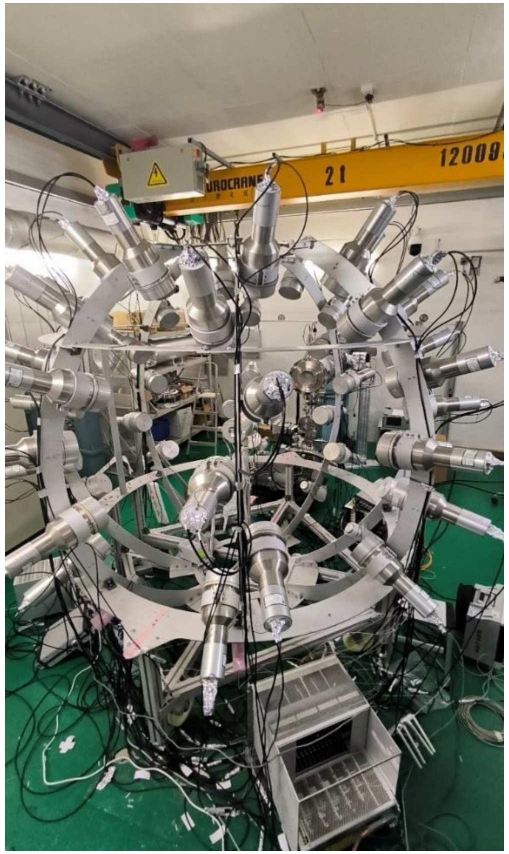
PXIe based, more than 60 channels.



Web based GUI

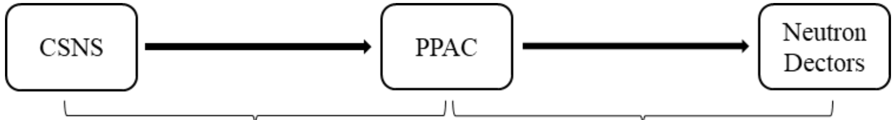
Review of Scientific Instruments **89**, 013511 (2018); doi: 10.1063/1.5006346
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 66, NO. 7, JULY 2019

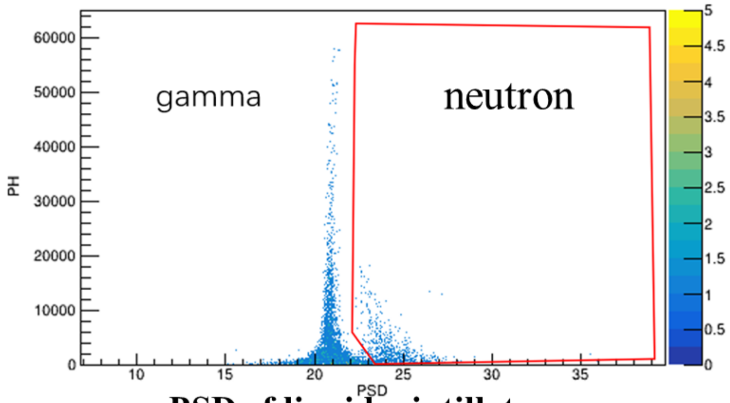
PFNS-Prompt Fission Neutron Spectra



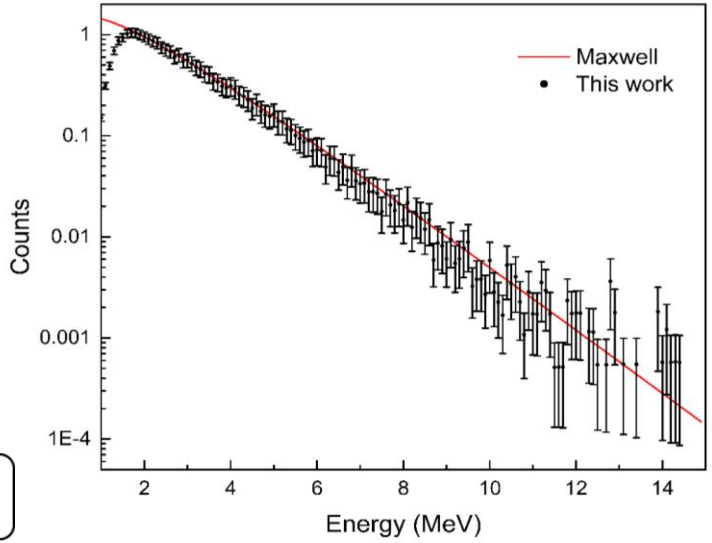
FIssion Neutron spectrum Detector Array-FINDA

Parameter	content
Detector number	48
Detector type	Liquid scintillator (LS)
Sample	^{235}U
Sample mass	~40 mg
Time resolution between PPAC and LS	1 ns
DAQ time	~300 hours
Distance for source neutron	55 m
Distance for fission neutron	1 m
LS type	EJ301





PSD of liquid scintillator

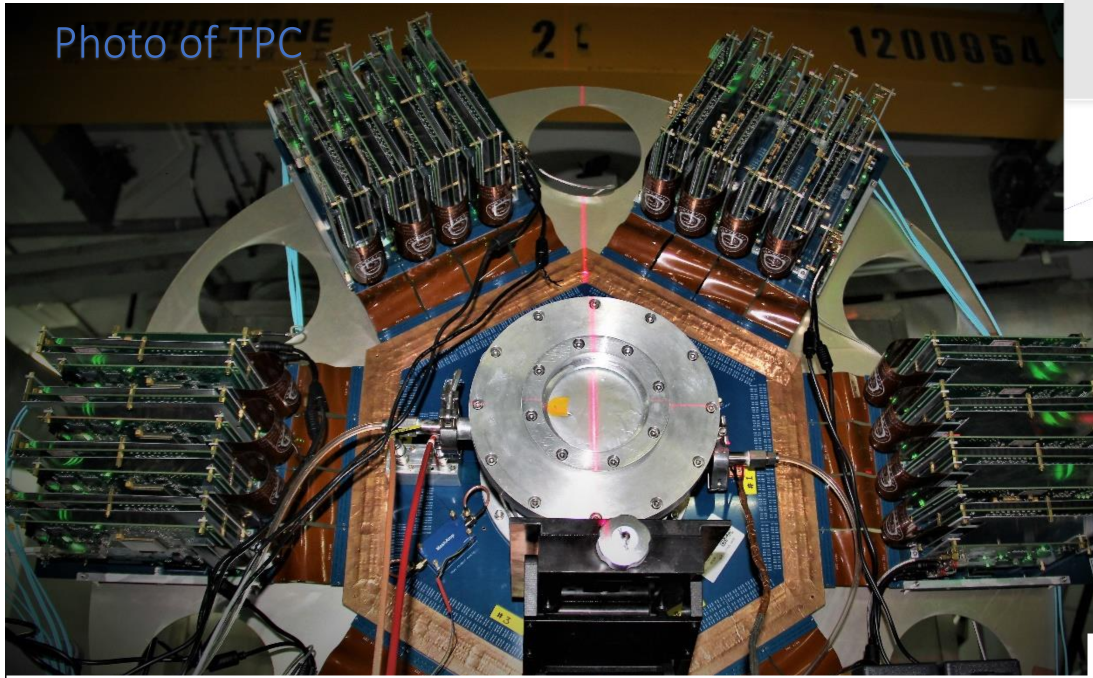


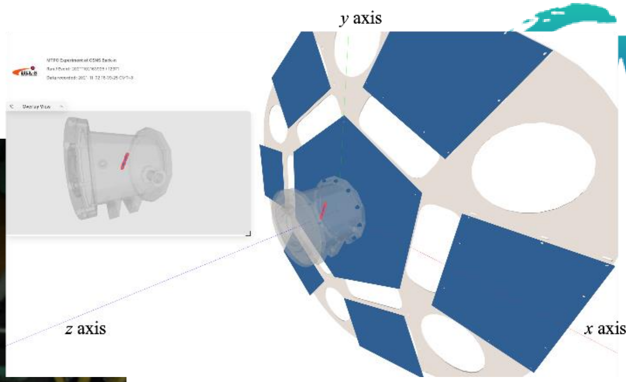
It uses the dual time-of-flight method and employs the PSD (Pulse Shape Discrimination) method inherent in liquid scintillation detectors to distinguish between neutrons and gamma rays. It can measure the energy spectrum of prompt fission neutrons as well as prompt gamma rays.

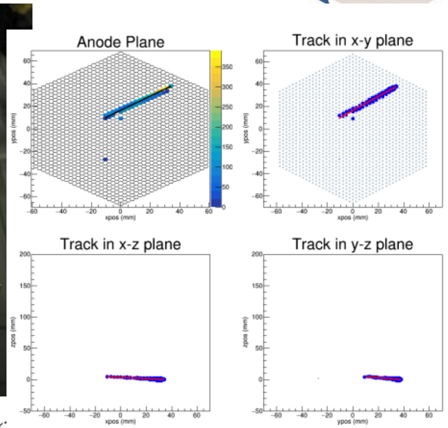
Courtesy: Hanxiong Huang(CIAE)

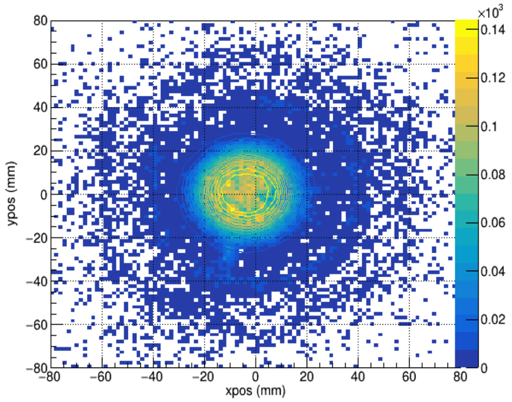
Back-n multipurpose TPC

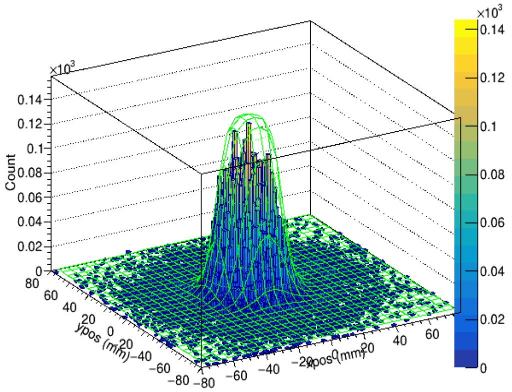
Time Projection Chamber, which is a type of detector that records the three-dimensional trajectory of charged particles. The design of the TPC detector for the white neutron beam line started in 2019 and took 4 years to complete. The measurement of the neutron reaction cross section of ^{6}Li has been completed at beginning of last year. (n, p) and (n, f) measurement will be taken in this year.

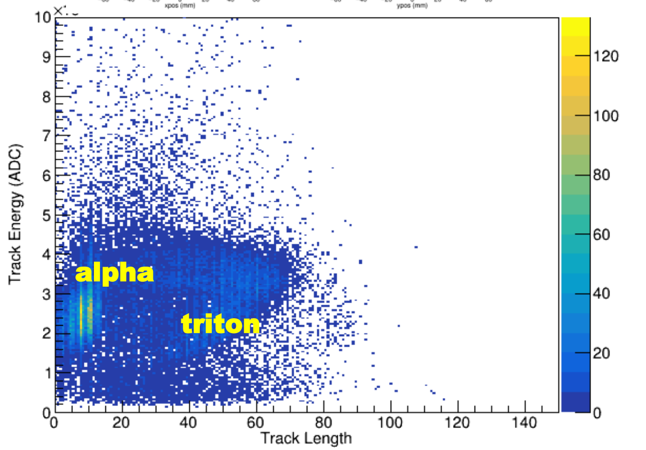












1. NIMA 1039 (2022) 167157
2. Z. Chen et al 2022 JINST 17 P05032
3. NIMA1058(2024)168912
4. NIMA 1060 (2024) 169045

Nuclear data measurement experiments

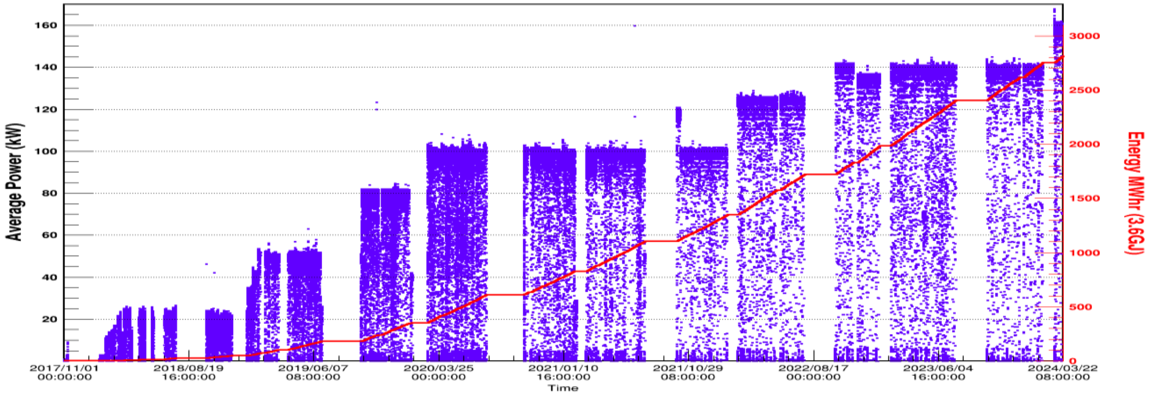
Since 2018, we have measured the neutron reaction cross sections of more than 50 nuclides and will continue to measure at a rate of over 10 nuclides per year.

- 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, ^{nat}Yb, ^{127}I, ^{133}Cs, ^{nat}Dy, ^{103}Rh
  - GTAF-II: ^{169}Tm, ^{93}Nb, ^{nat}Re, ^{nat}Xe, ^{nat}Sn, ^{127}I, ^{nat}La
- Total cross-section
  - ^{12}C, ^{27}Al, ^{9}Be, ^{7}Li, ^{nat}Fe, **^{209}Bi, ^{nat}Pb, ^{nat}Cr, ^{9}Be, ^{169}Tm**
- Fission cross-section
  - ^{235}U, ^{238}U, ^{236}U, ^{239}Pu, ^{232}Th, ^{239}Pu, **^{236}U**
- Light charged particle emission
  - LPDA: ^{6}Li(n, x), ^{10}B(n, x), ^{63}Ni, (n-d), ^{17}O, (n-p), 12C(n,d), 12C(n,α) (13C cluster)
  - TPC: ^{12}C, ^{14}N, ^{6}Li
- 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

展望

prospect

What can we do at Back-n?



We have almost **5000** hrs beamtime per year opening to every scientist in the world.

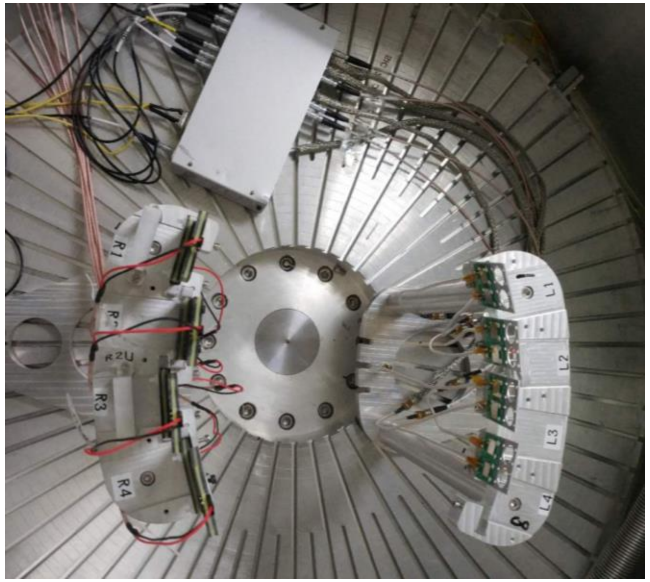
Back-n has the most insensitive resonance neutron flux.

In the next six years (CSNS II), the CSNS accelerator power will increase from 100 to 500 kW. The beam intensity of Back-n will increase with a factor of 5.

- ***Small reaction cross-section (mb-μb)***
- ***Important targets, which are difficult to prepare or radioactive***

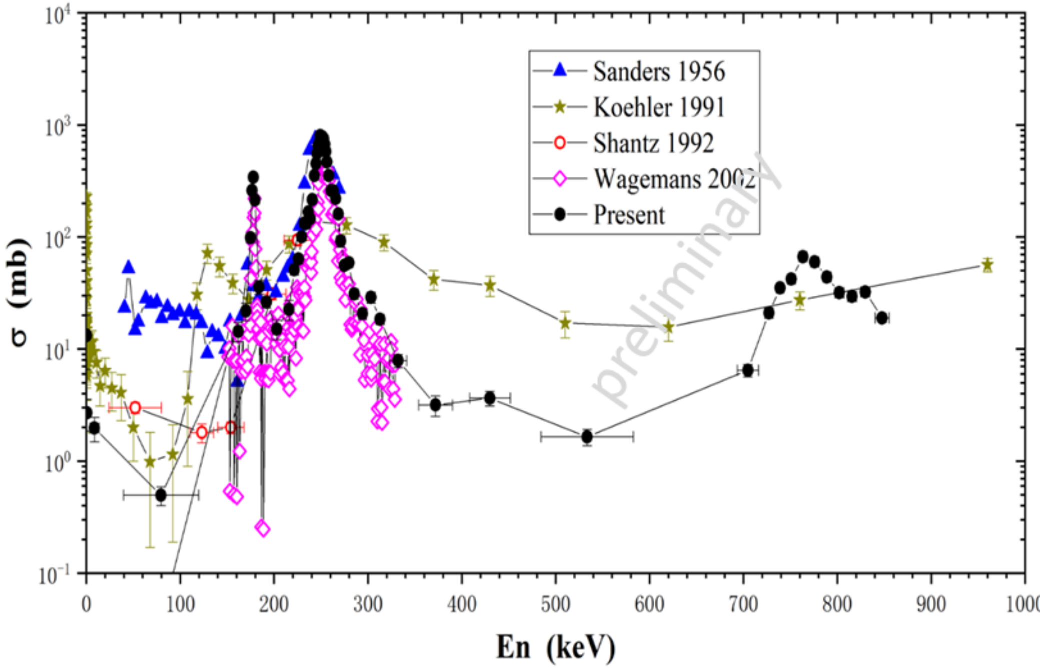
^{17}O(n, alpha) experiment

$^{17}O(n, \alpha)^{14}O$ reaction cross-section It is an important experiment in astrophysics, but due to the small cross-section and the difficulty in target fabrication, there is not much measurement data available. Back-n 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.

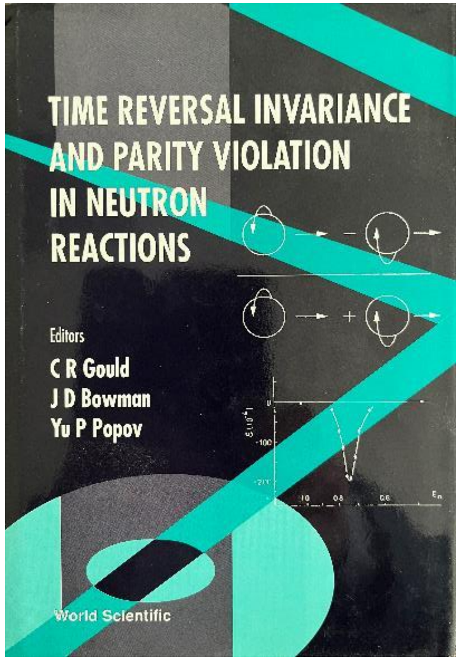
SiC and silicon detectors are used to measure the α particles ejected in the reaction. The reaction cross-section of $^{17}O(n, \alpha)^{14}C$ was obtained in the energy region of interest.

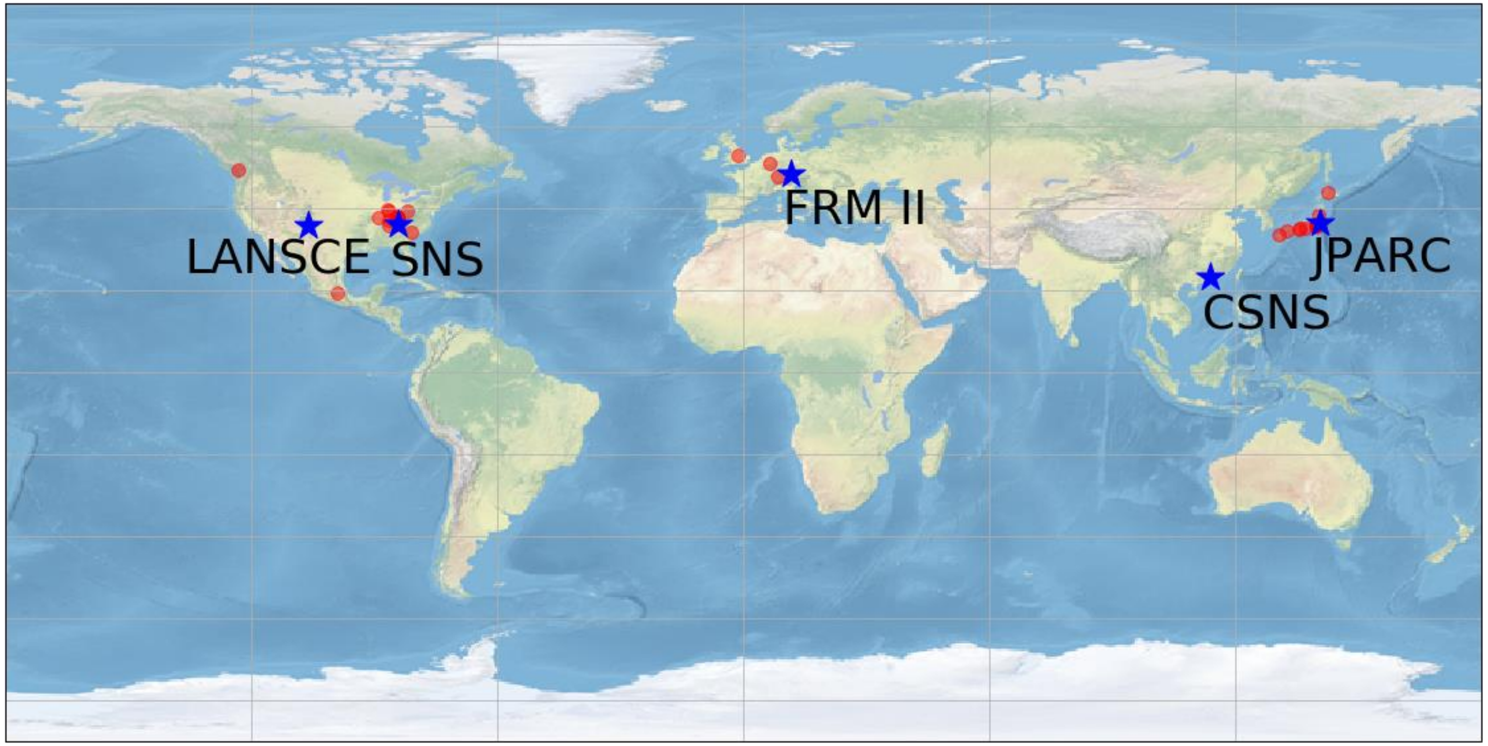


Courtesy: Professor Li Yunju (CIEA)

NOPTREX

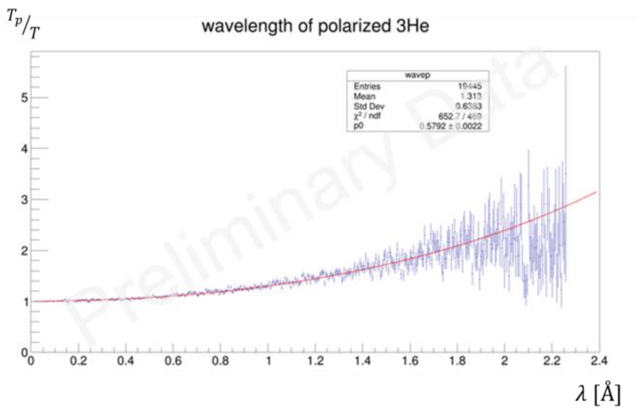
Neutron Optical Parity and Time-Reversal EXperiment





Back-n is currently a member of the NOPTREX international collaboration, which is dedicated to experiments on parity and time reversal violation in neutron-nuclear reactions. This experiment originated at JINR. Professors Snow and Shimizu, the spokespersons of the collaboration, to extend their regards to the scientists at JINR and express their hope that JINR would be interested in joining us.

First attempt setup (2023/4)



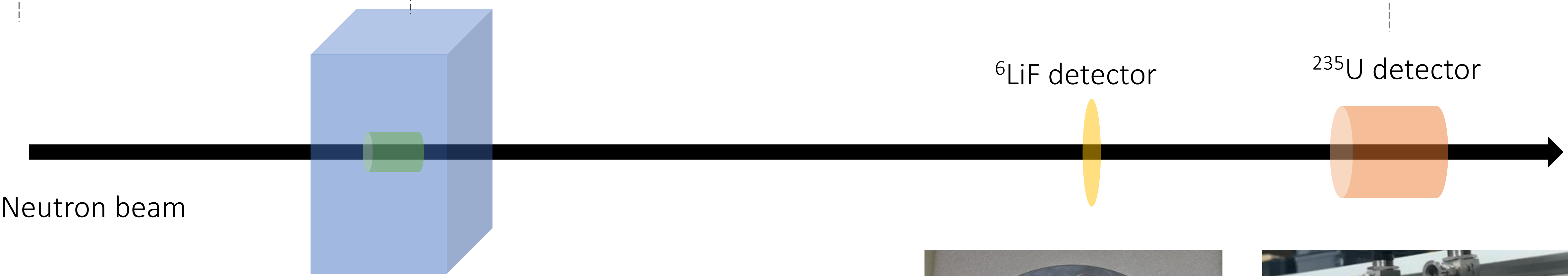
Spallation Target

Room #1

Room #2

55m

76m

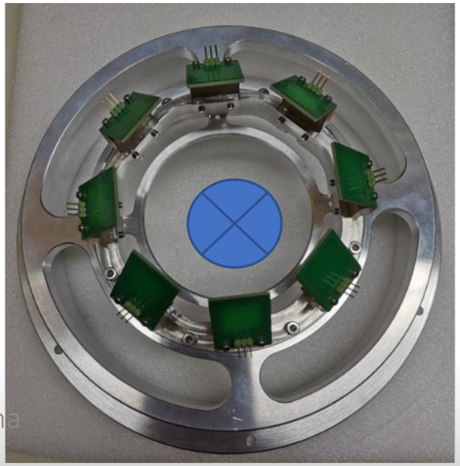


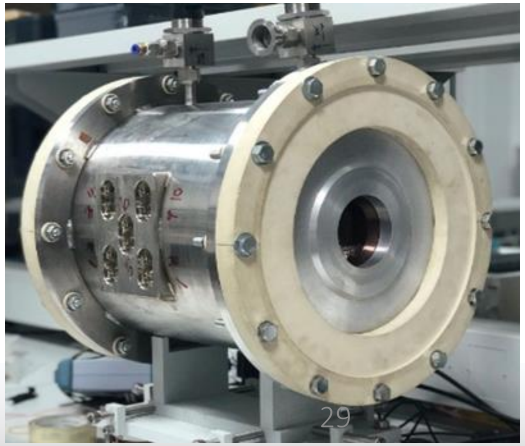
^{6}LiF detector

^{235}U detector

Neutron beam

In-situ 3He Spin filter





Back-n user and community

There are a total of more than 200 people from different 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
- Indiana University
- JINR
- ……

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Thanks

You are welcome mailto:*fanrr@ihep.ac.cn*