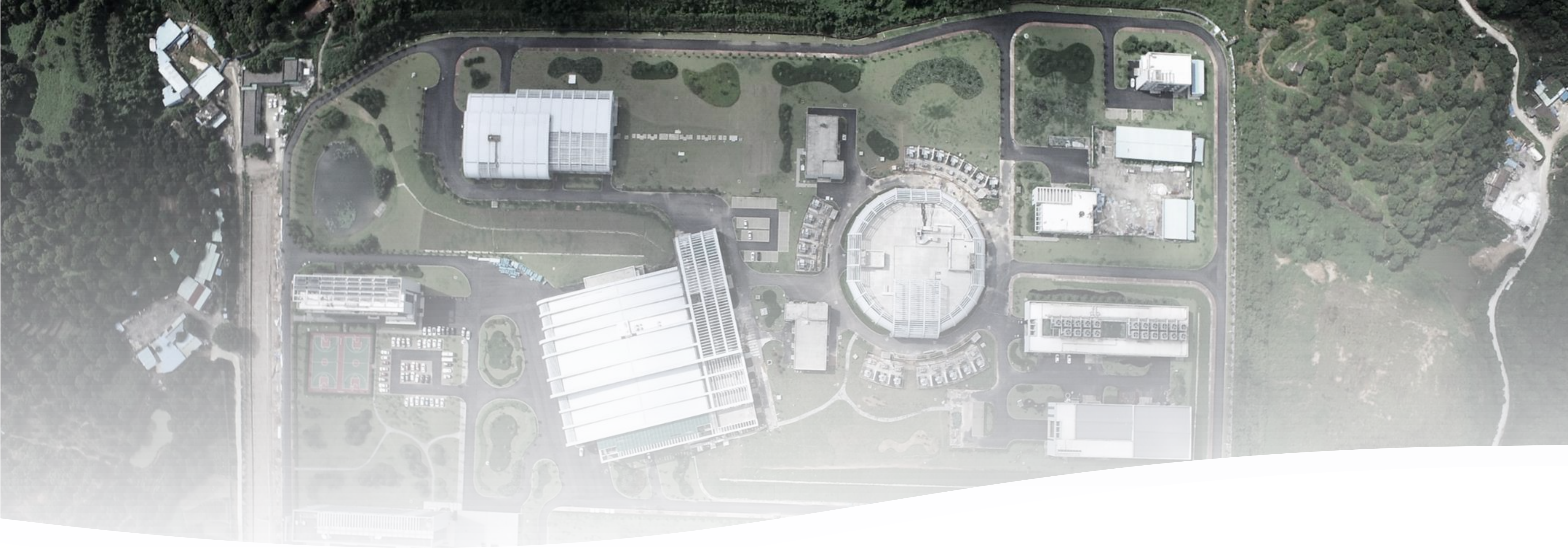


Operation and experimental Introduction of the CSNS Back-n

Ruirui Fan on behalf of Back-n collaboration

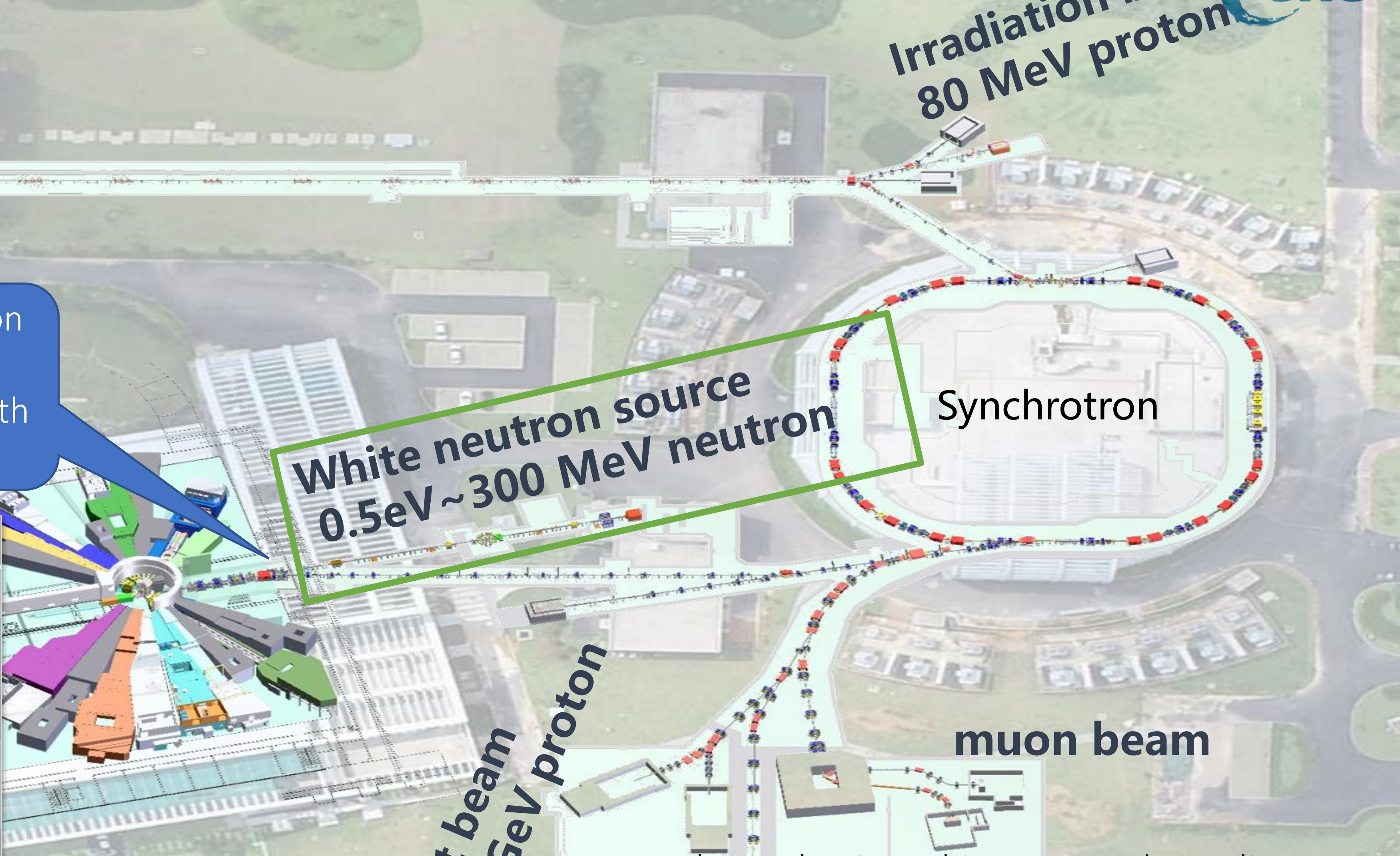
白光中子实验装置

Back-n

China Spallation Neutron Source

The China Spallation Neutron Source, located in Dongguan city, near Hong Kong, was running from 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

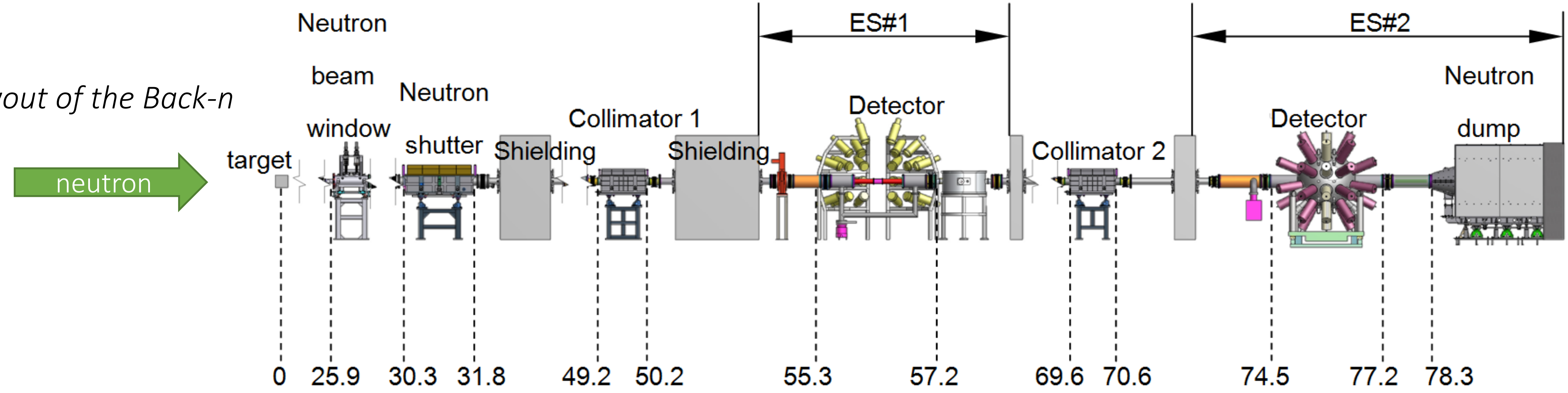


Beam parameters			
Beamline	Particle	Energy	flux
White neutron source	Neutron	thermal-300 MeV	1E7 n/cm-2/s
Irradiation beam	Proton	80 MeV	1E9 p/s
Test beam	Proton	1.6 GeV	1E3 – 1E8 p/s
Muon beam	Muon	4 MeV	1E5 muon/pulse

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



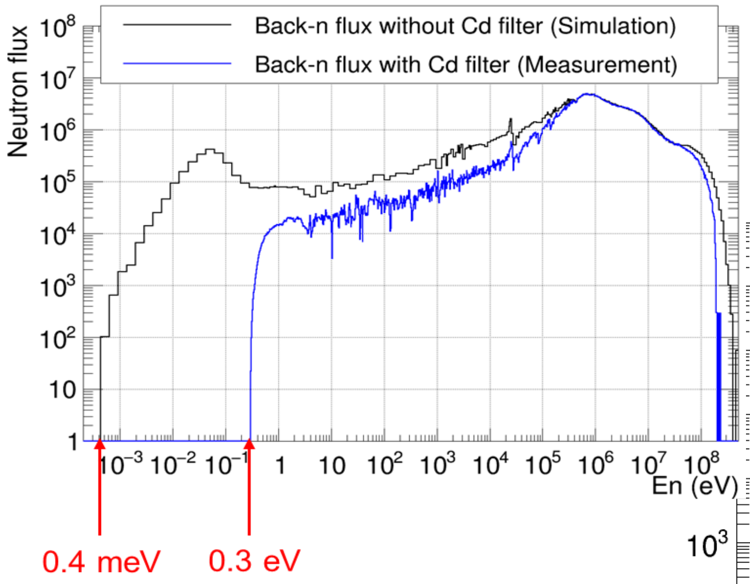
Shutter (mm)	Coll#1 (mm)	Coll#2 (mm)	ES#1 spot (mm)	ES#1 flux ($n/cm^2/s$)	ES#2 spot (mm)	ES#2 flux ($n/cm^2/s$)
Φ3	Φ15	Φ40	Φ15	1.27E5	Φ20	4.58E4
Φ12	Φ15	Φ40	Φ20	2.20E6	Φ30	7.81E5
Φ50	Φ50	Φ58	Φ50	4.33E7	Φ60	1.36E7
78×62	76×76	90×90	75×50	5.98E7	90×90	2.18E7

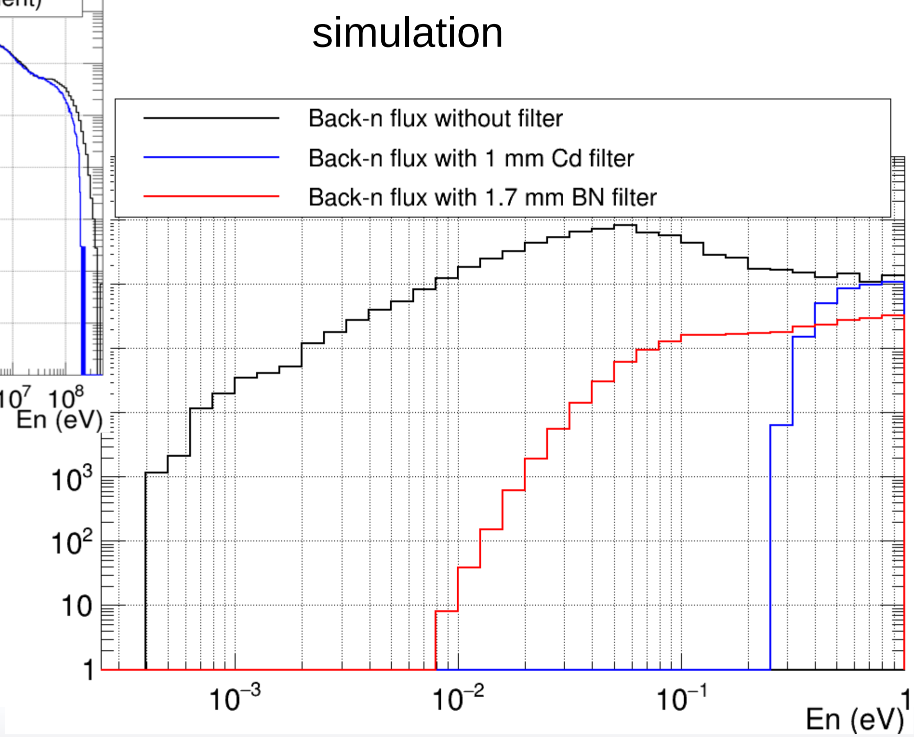
The back-streaming neutrons are leading to the Back-n tunnel, which has a long flight distance for the neutron time-of-flight method. Two end stations ES#1 and ES#2 are constructed for different nuclear data measurements. The ES#1 has a distance of about 55 m, and ES#2 is about 70 m from the target. 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.

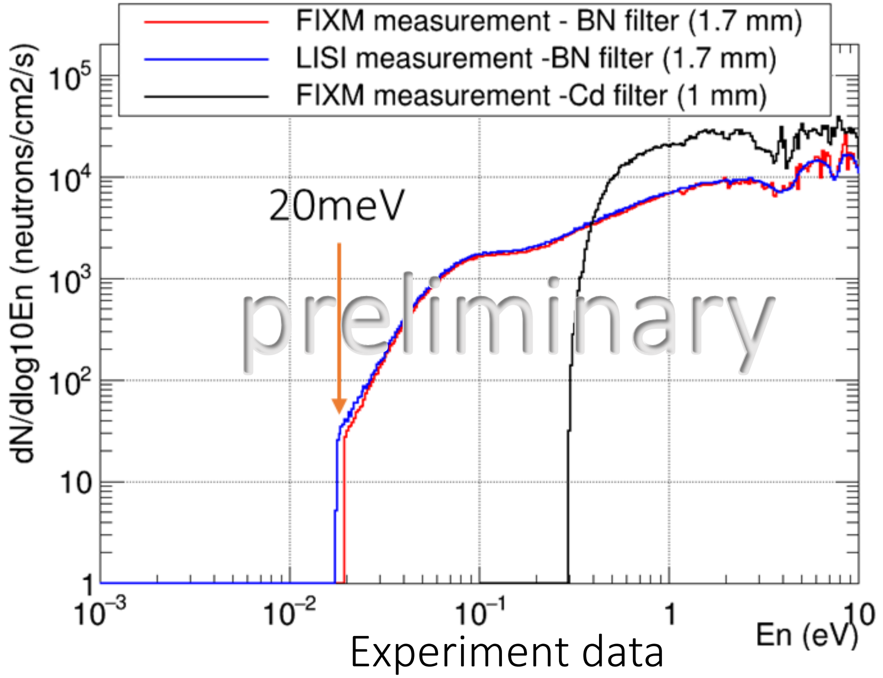
1. 2017 JINST 12 P07022
2. Eur. Phys. J. A (2019) 55: 115

The white neutron energy range

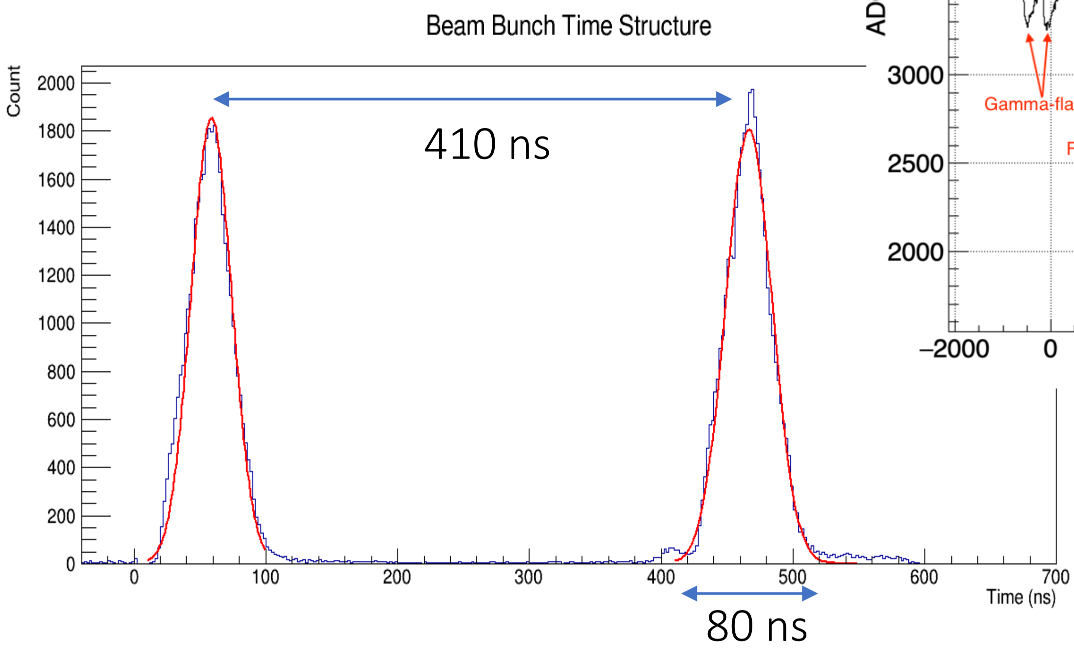
The Back-n has a wide neutron energy range from cold neutron (0.4 meV) to 300 MeV. To avoid the frame overlap, a Cadmium filter is employed at the upstream end of the beamline (window).
Thermal neutrons or epithermal neutrons are the reference for lots of experiments, and some important parameters such 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.





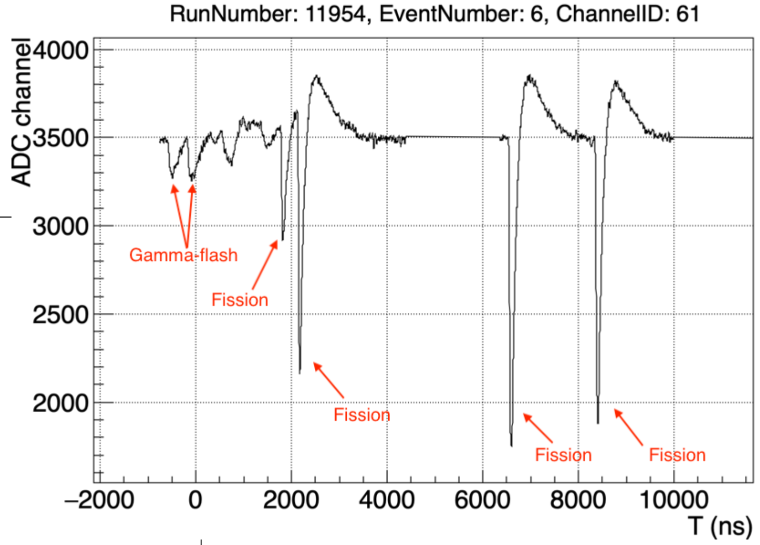


The neutron beam time structure of Back-n



Double bunches time structure

A typical detector response in one pulse



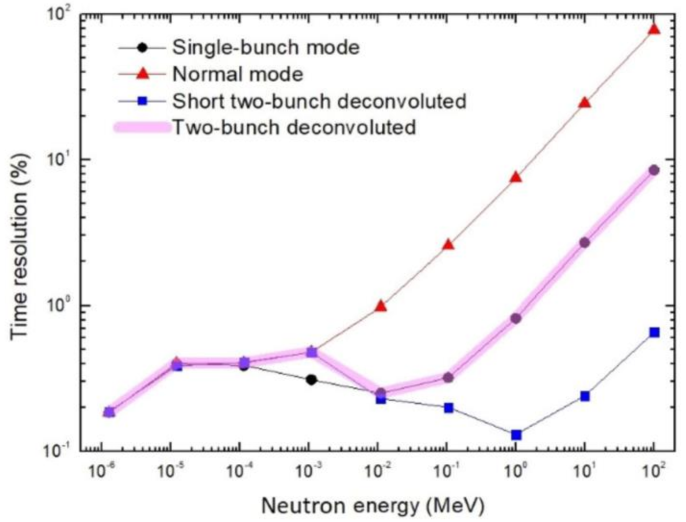
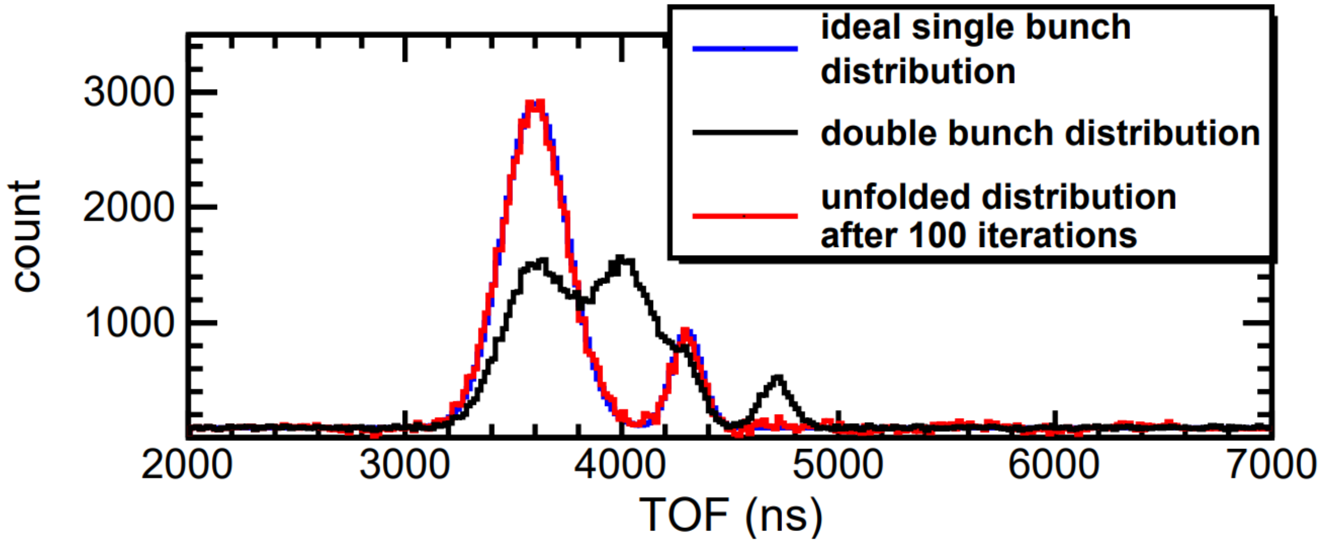


Fig. 3 (Color online) Time resolutions with respect to neutron energy for different acceleration operation modes (flight path: 77 m)

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.

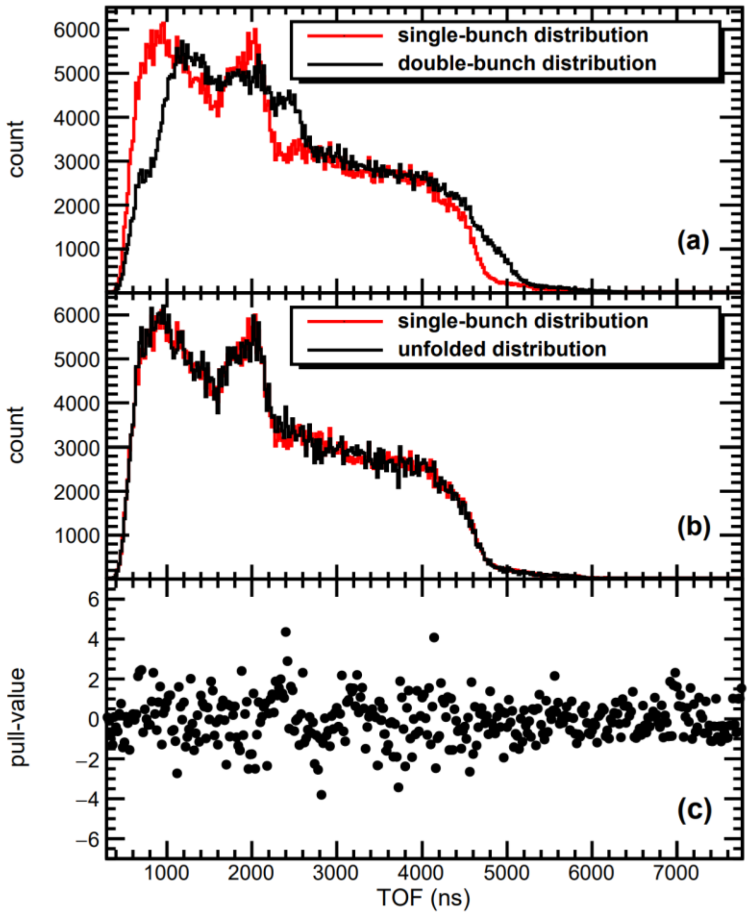
Acta Phys. Sin. Vol. 68, No. 8 (2019) 080101

Double-bunch unfolding methods



A simulated example of the spectrum unfolding

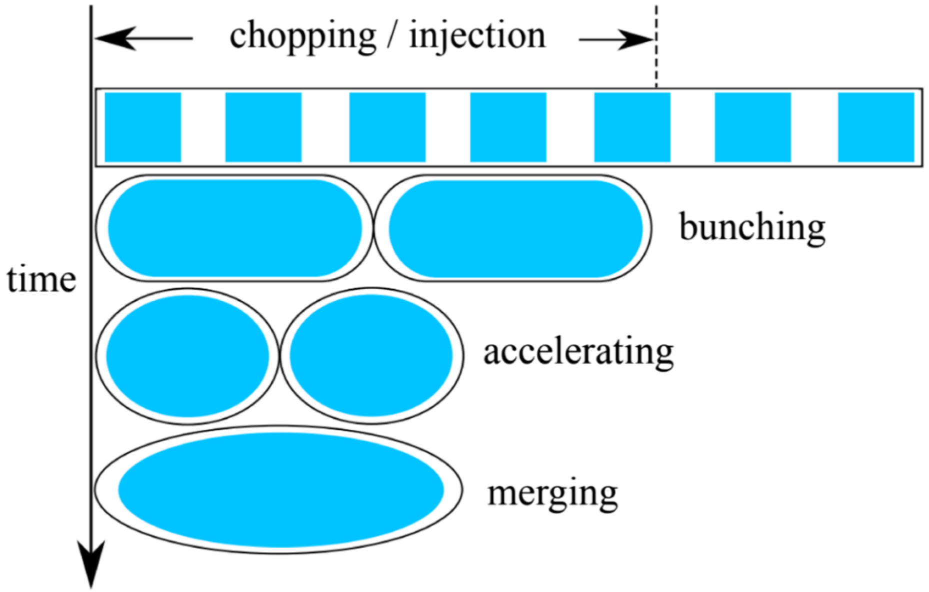
A Bayesian unfolding method is developed for diverse types of experiments performed in the double-bunch mode at Back-n. The experiment data from single bunch mode and the unfolded result from the double bunch mode experiment match well. The unfolding method has been used in most Back-n experiments.



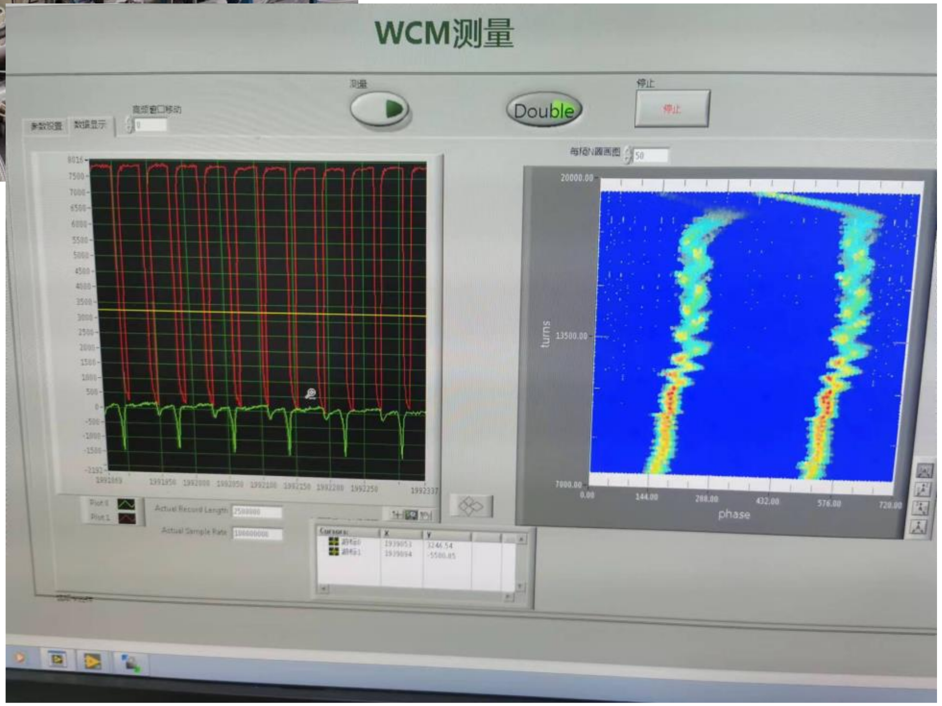
Unfolding result of the ^{238}U data

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.*

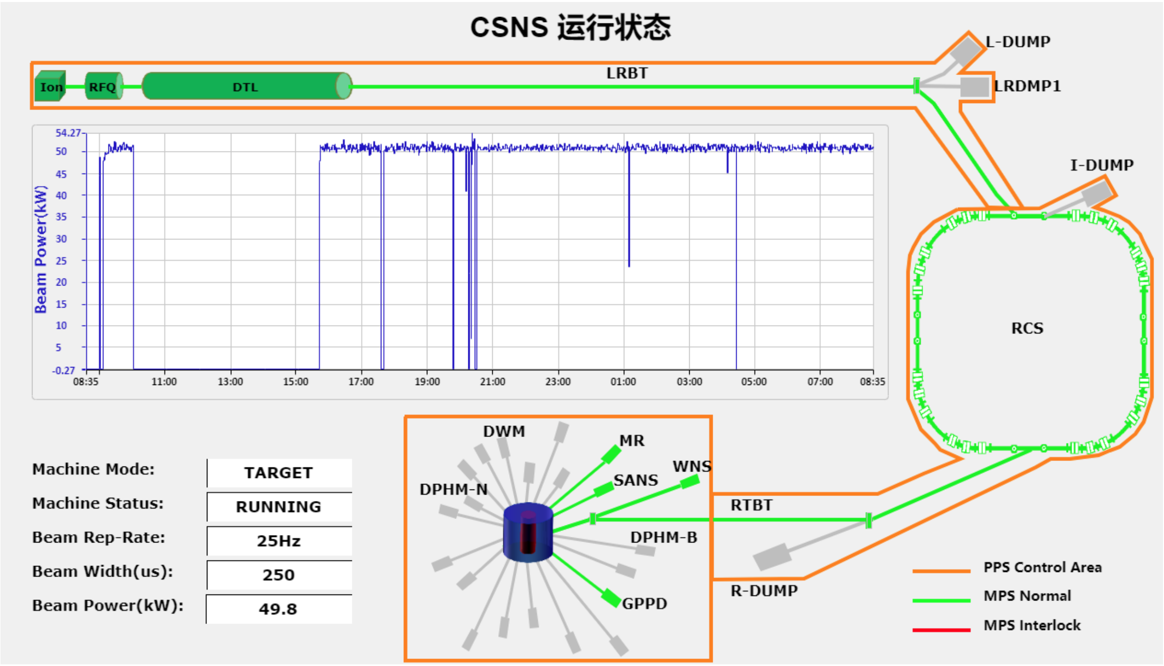
*PHYSICAL REVIEW ACCELERATORS AND BEAMS 26, 024201 (2023)

First bunch merge experiment attempt in May 30th 2023

Back-n beam monitor

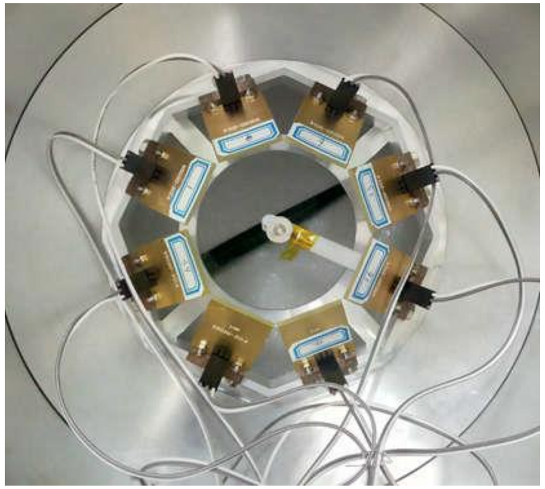
Two monitors are employed:

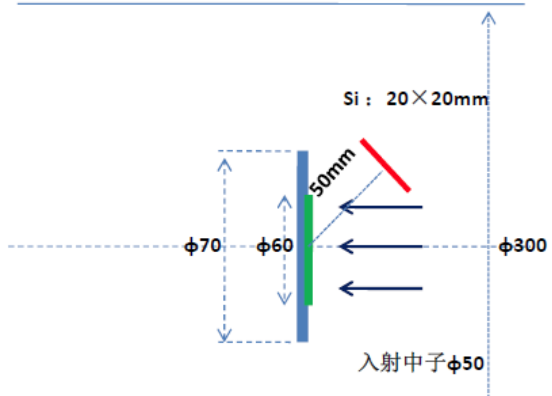
- Proton beam monitor (Fast Current Transformer)
- Li-Si monitor (^{6}LiF foil and silicon detectors)



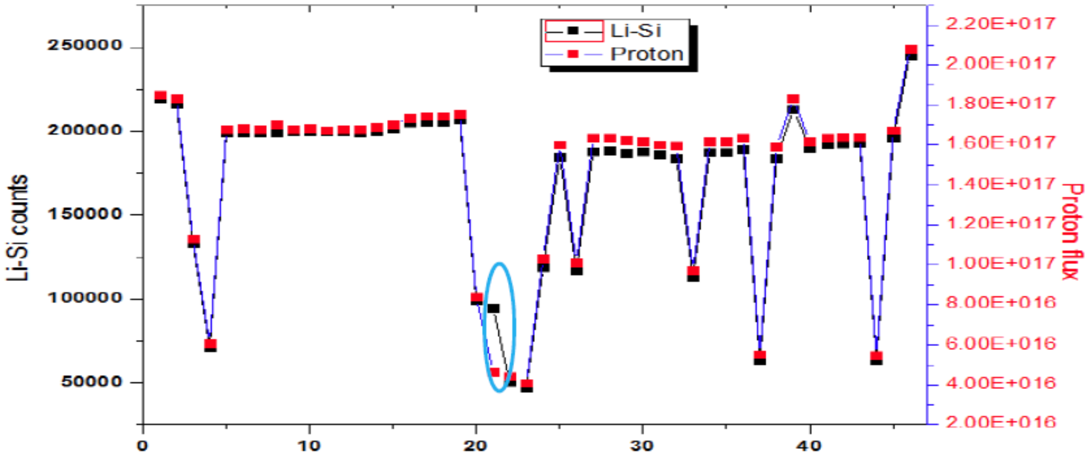
Nuclear Inst. and Methods in Physics Research, A 946 (2019) 162497

Photo of Li-Si



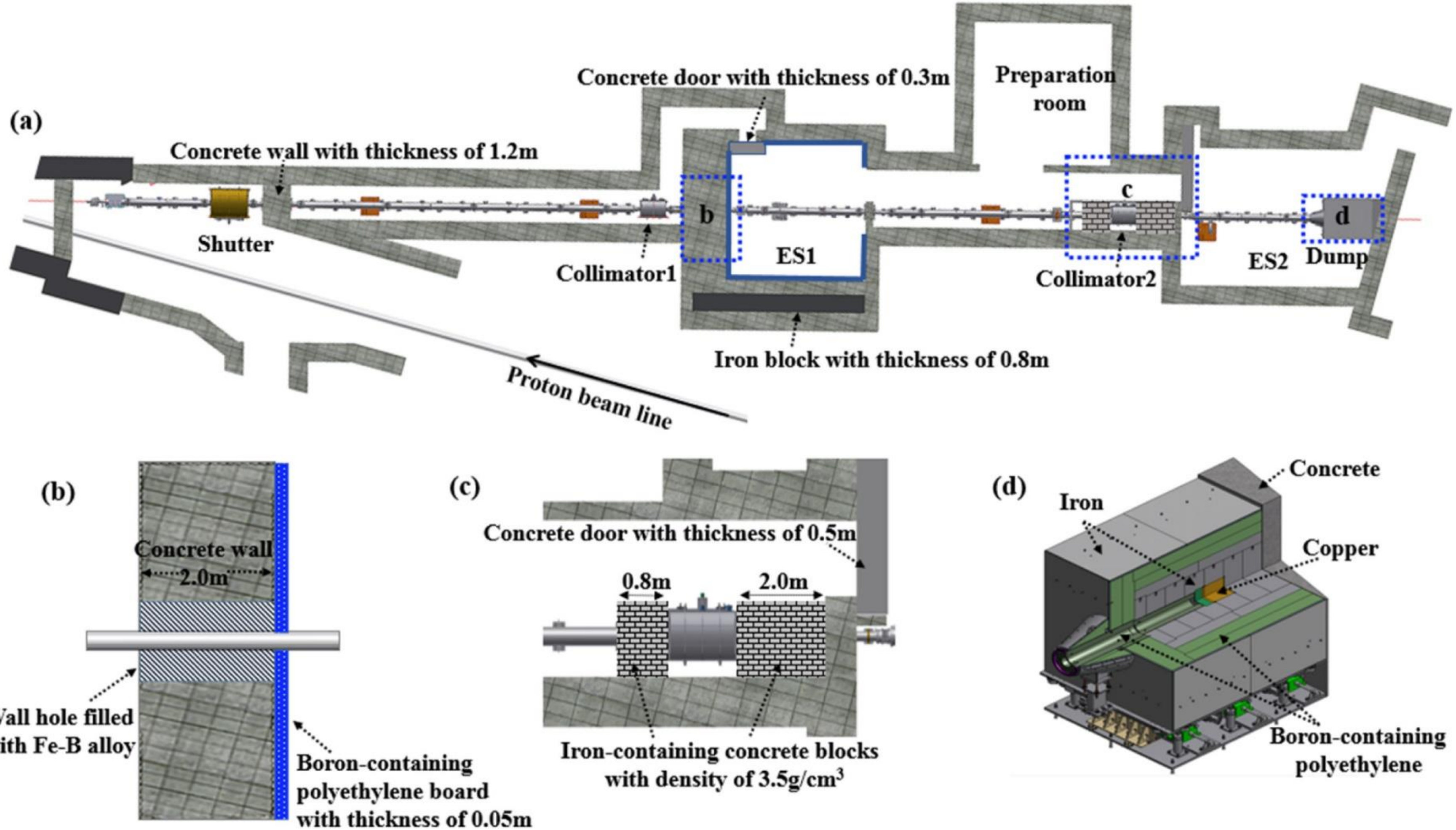


Li-Si beam monitor



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

Back-n shielding & background measurement

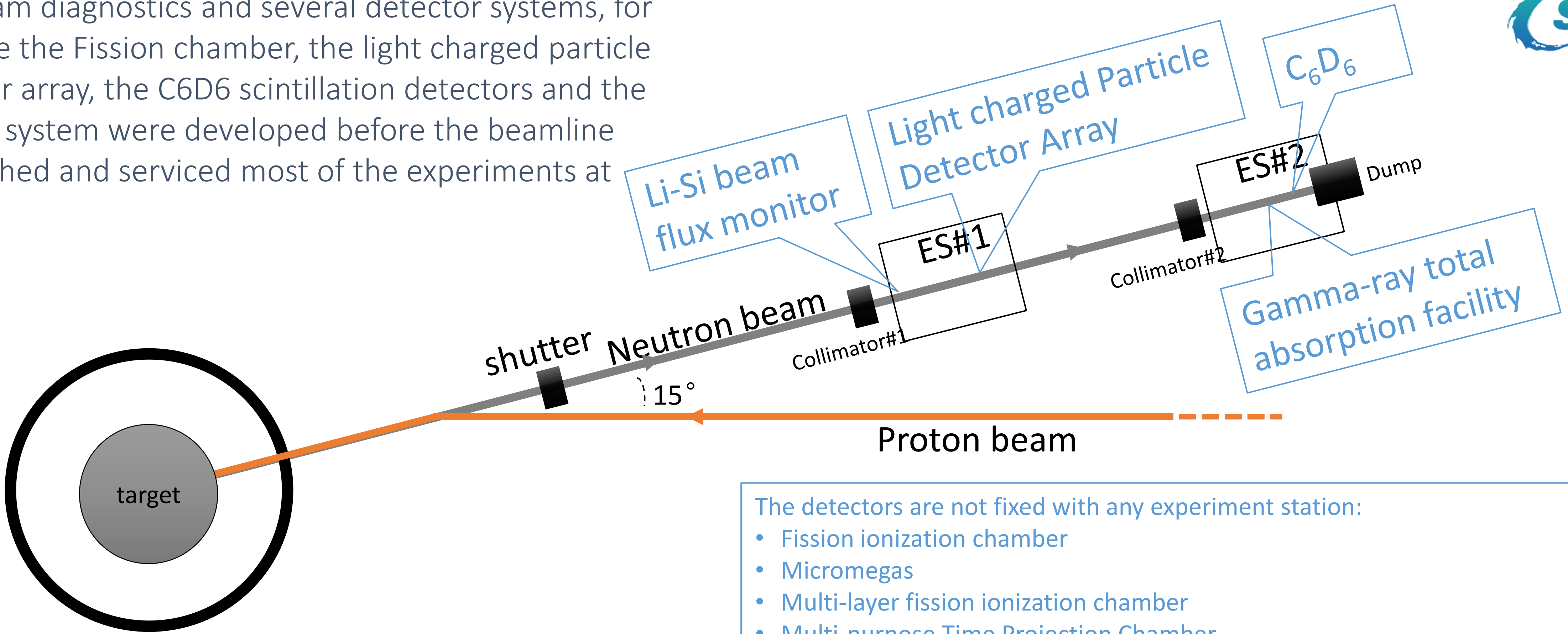


Neutron and γ background measurements of the experimental halls at the CSNS back-streaming white neutron source , NIMA Volume 980, 11 November 2020, 164506

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.



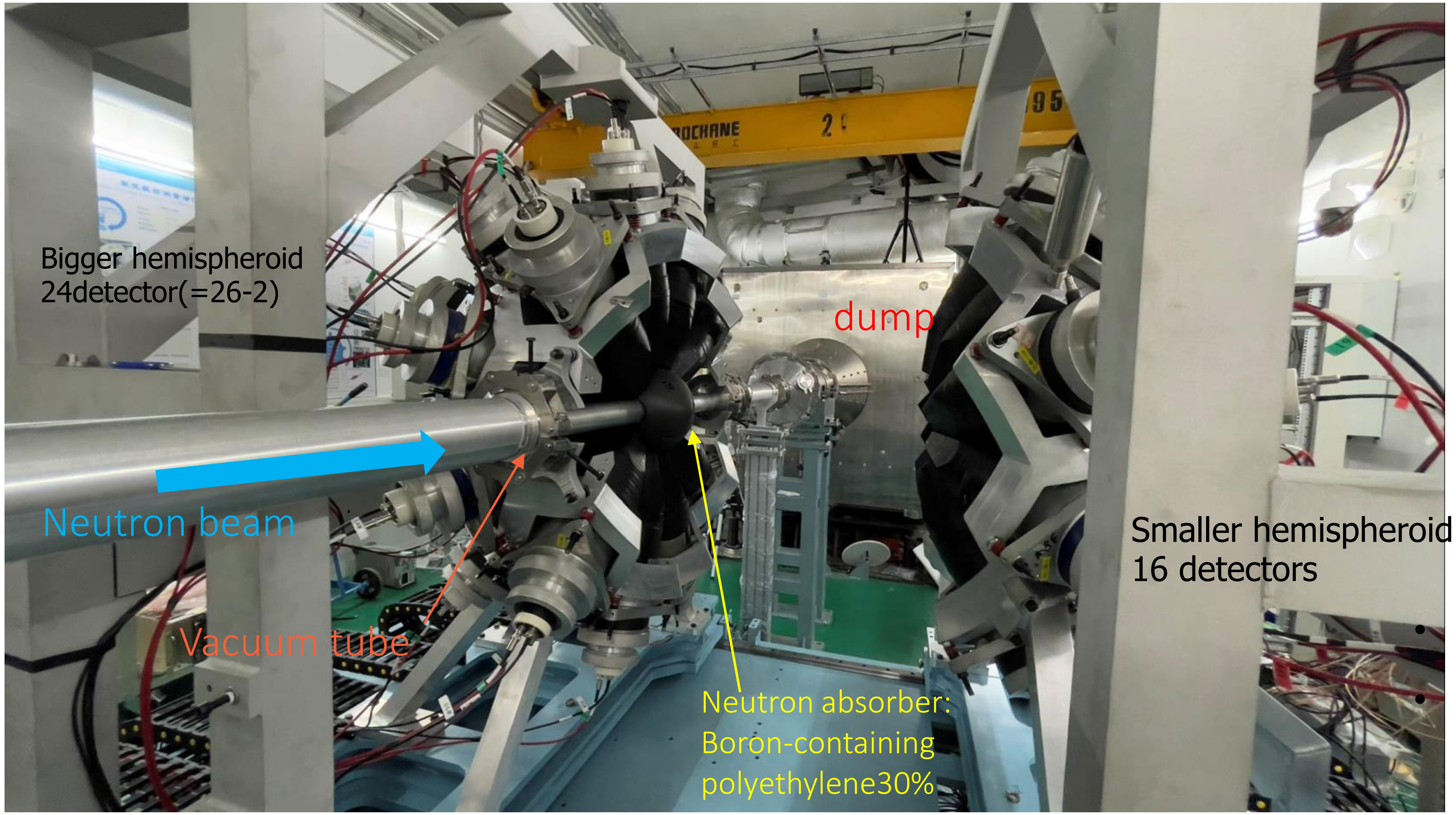
The detectors are not fixed with any experiment station:

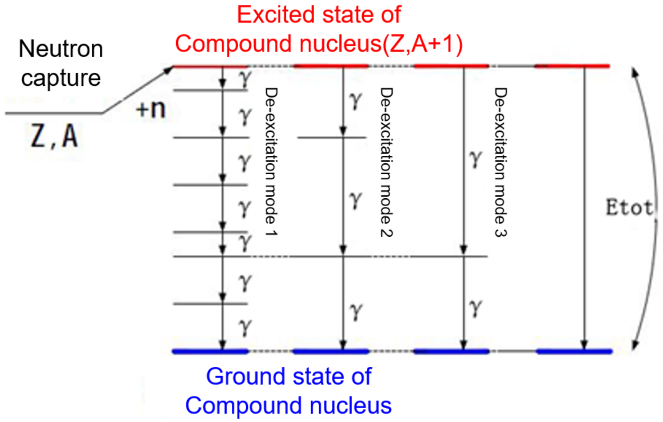
- Fission ionization chamber
- Micromegas
- Multi-layer fission ionization chamber
- Multi-purpose Time Projection Chamber
- Radiation-resistant semiconductor detector
- Gated CMOS camera
- Neutron sensitive Micro-Channel-Plate

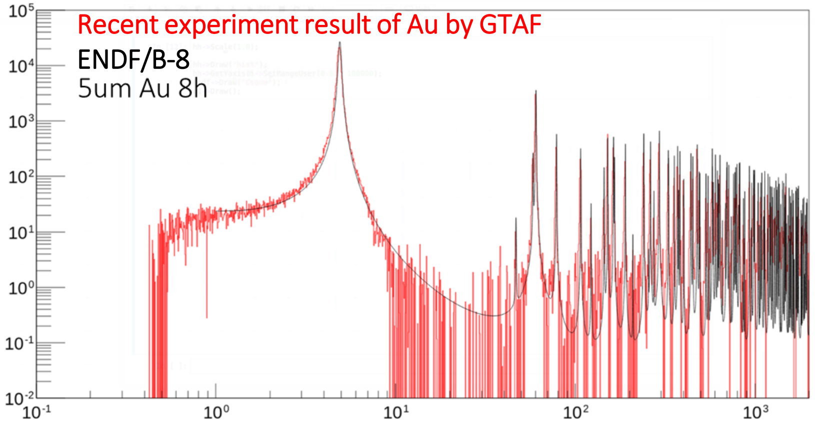
Several ambitious developments, for example, the multi-purpose time projection chamber (MTPC) , the radiation resistant semiconductor detectors, the Gamma-ray total absorption facility (GTAF-II) and the neutron-sensitive micro-channel plate detector (B-MCP) are in progress for future experiments.

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

GTAF (40 BaF_2 detector array)

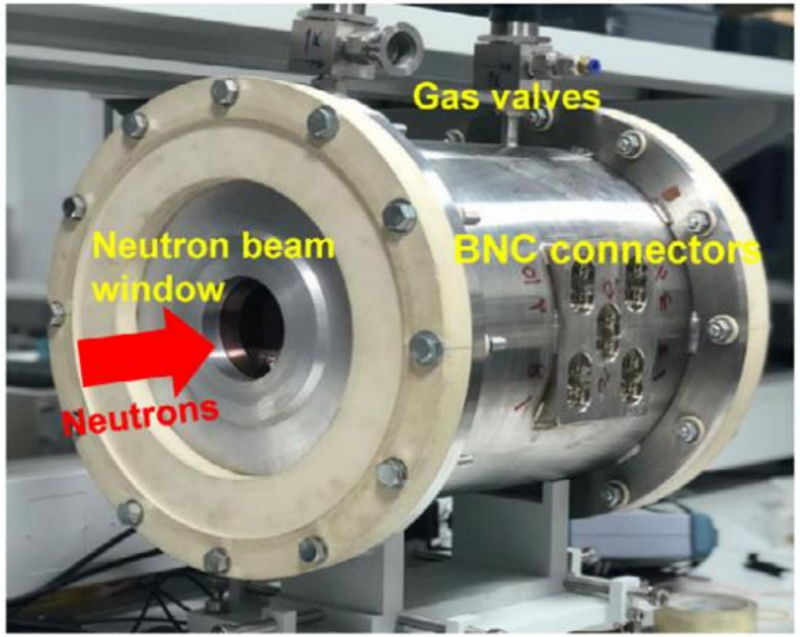


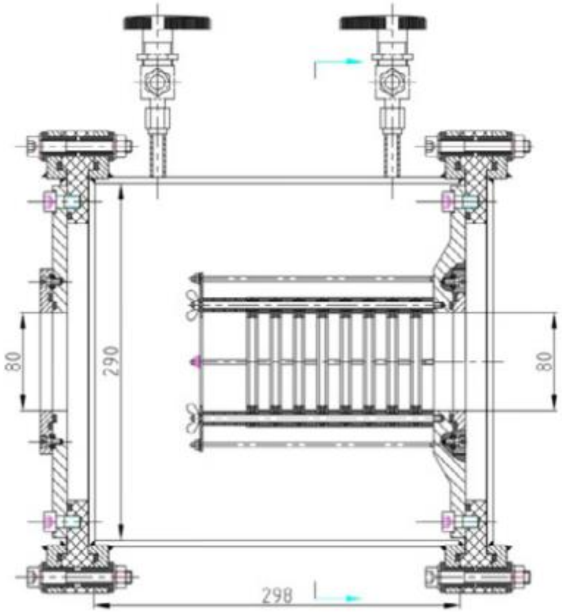


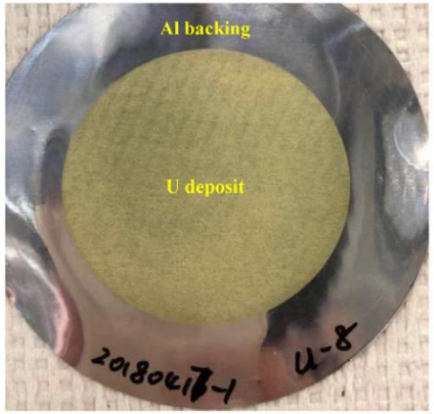


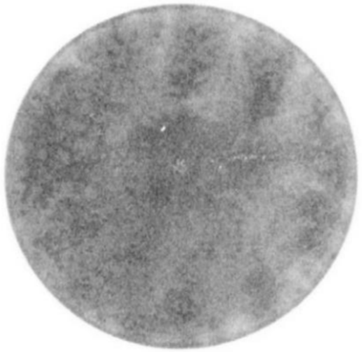
- **GTAF(Gamma Total Absorption Facility)**
- **Prompt gamma measurement, neutron time of flight method(neutron energy)**
- **Cascade gamma matches measurements——Multiplicity and Total Energy of Cascade gamma can be measured**

The fission chamber







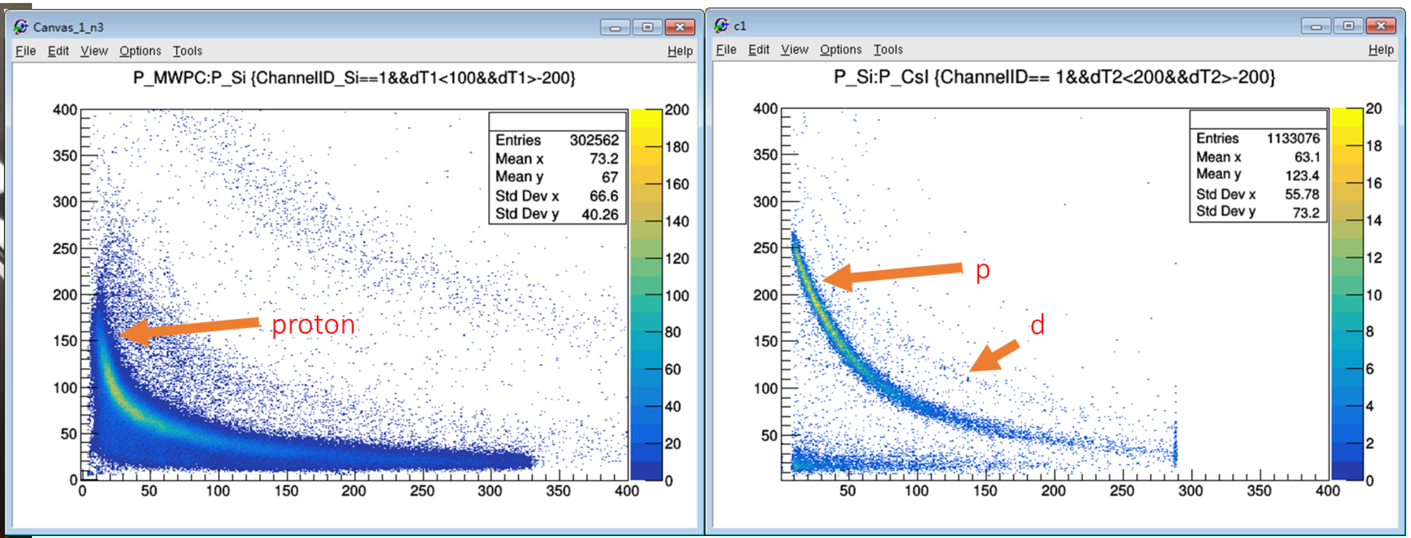


The fission ionization chamber detector measures the fission fragments generated through the reaction between the fission material (^{235}U, ^{238}U) and neutrons, and records the energy of the neutrons by measuring their flight time.

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

ΔE- E detector array (LPDA)

The photo of LPDA

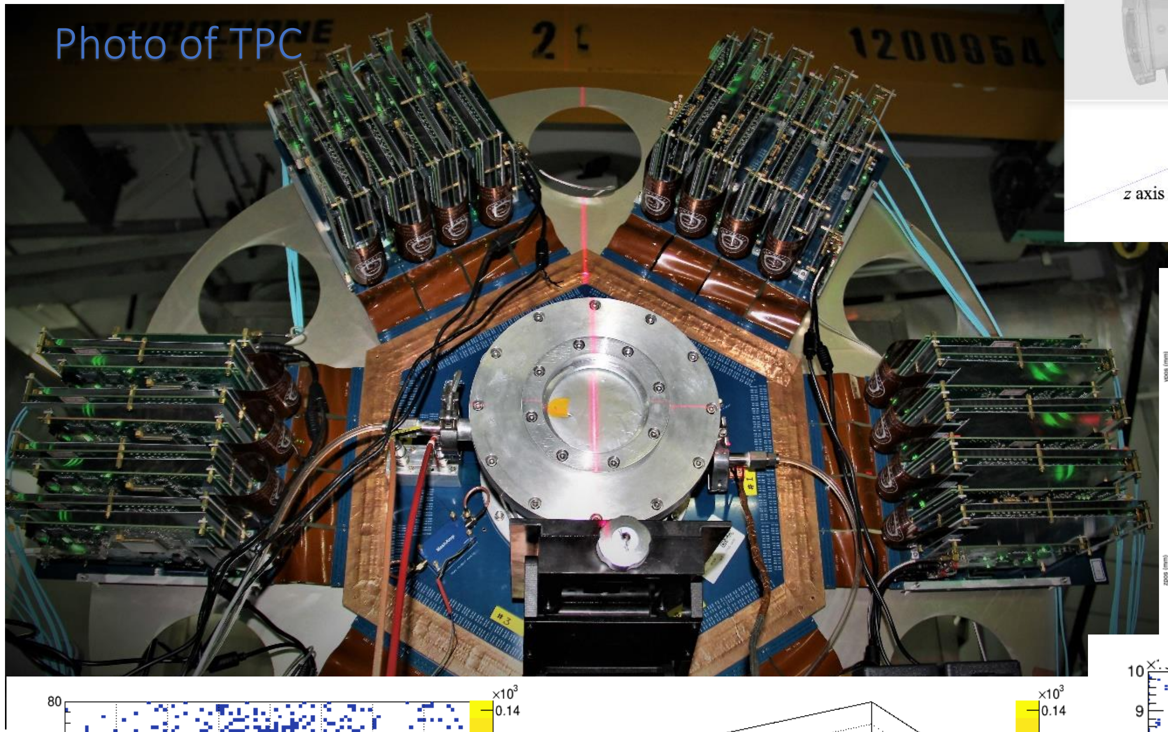


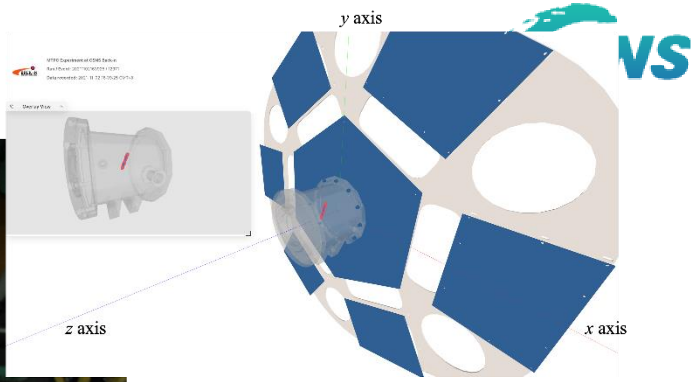
The LPMWPC (Δ*E*) vs Si-PIN (*E*) spectrum and Si-PIN (Δ*E*) vs CsI(Tl) (*E*) spectrum

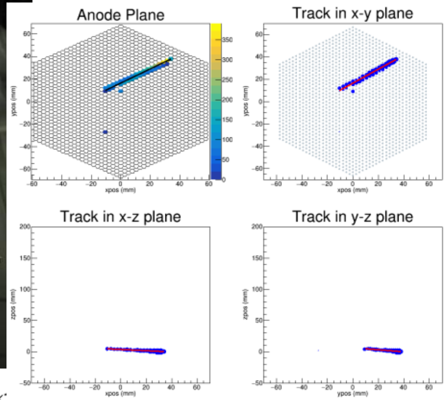
The LPDA is divided into two modules, each covering an angle of 23.5-90 degrees. It includes 8 sets of LPMWPC+Si+CsI detector telescopes, with a total of 48 channels. It was completed in June 2020.

Kang Sun *et al* 2023 *JINST* **18** P04004

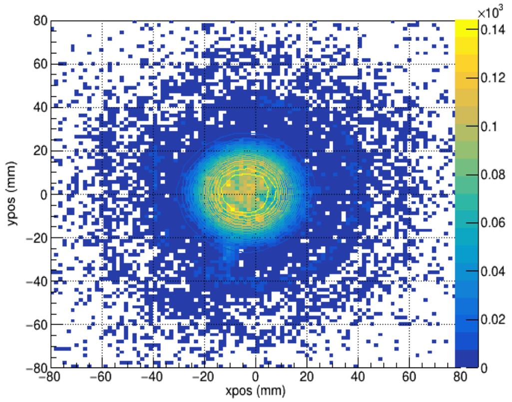
Back-n multipurpose TPC

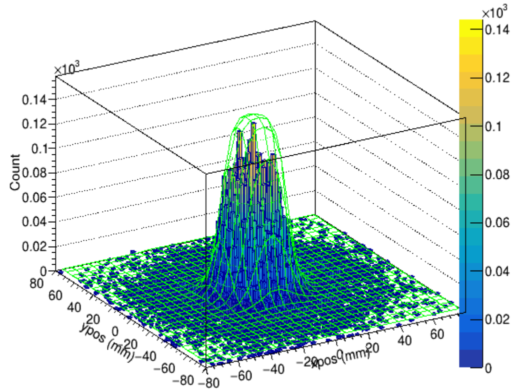


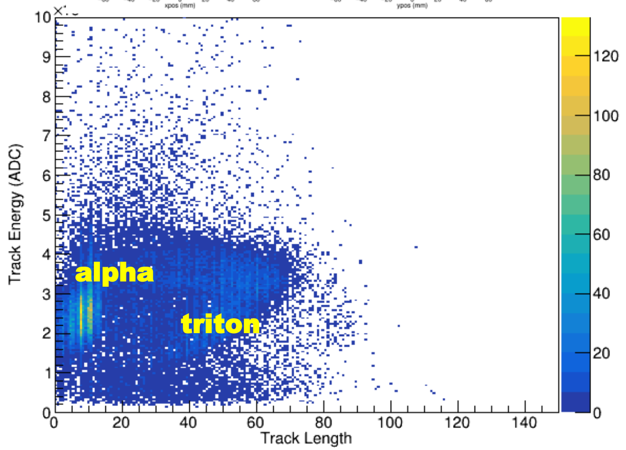




Time Projection Chamber, which is a type of detector that records the three-dimensional trajectory of charged particles. The design of the TPC detector for the white neutron beam line started in 2019 and took 4 years to complete. The measurement of the neutron reaction cross section of ^{6}Li has been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

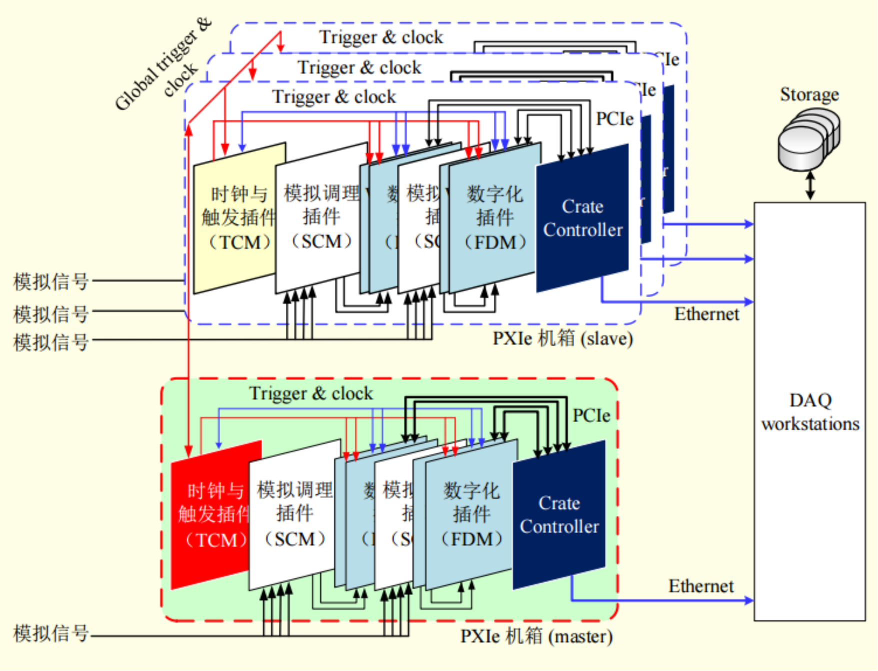






1. Z. Chen *et al* 2022 *JINST* **17** P05032
2. NIMA 1039 (2022) 16715

DAQ



Common electronics system overall architecture

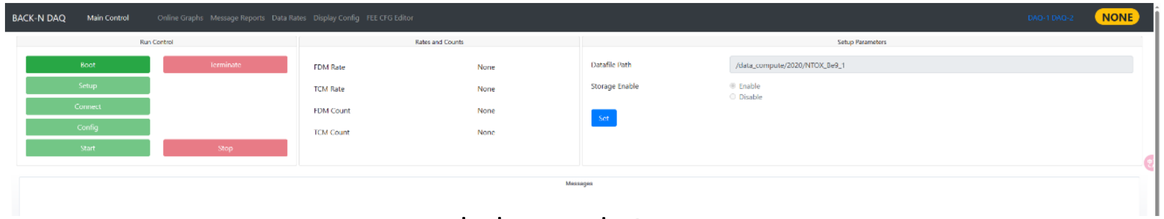
electronics photos

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

核数据测量实验

Nuclear data measurement

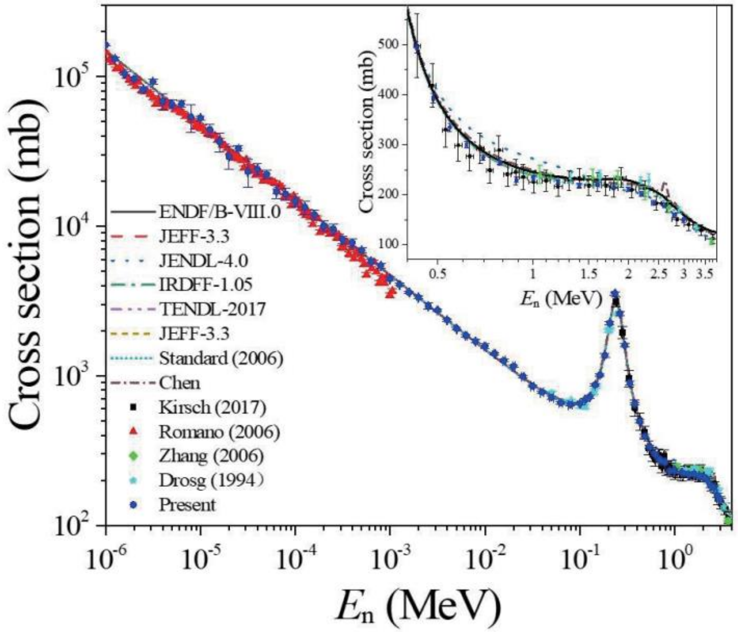
Nuclear data measurement experiments

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.

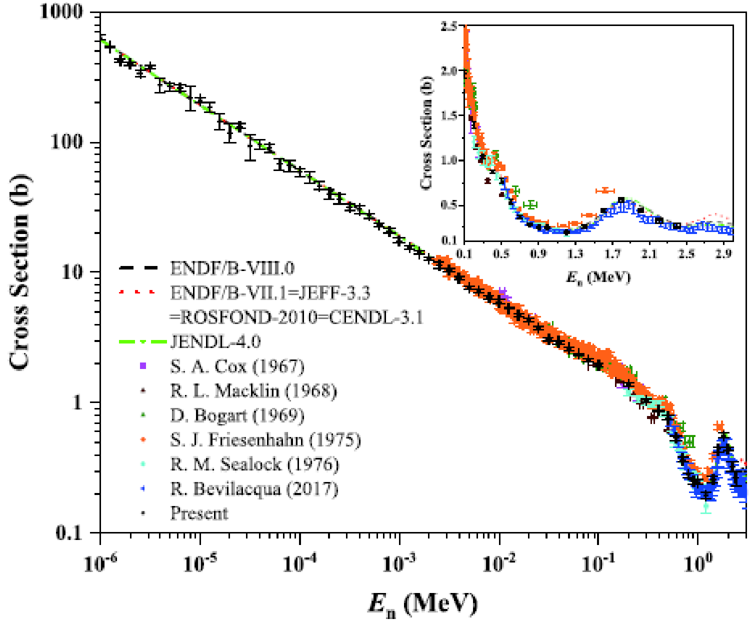
- Neutron capture
  - C_6D_6: ^{169}Tm, ^{197}Au, ^{57}Fe, ^{nat}Se, ^{89}Y, ^{nat}Er/^{162}Er, ^{232}Th, ^{238}U, ^{93}Nb, ^{nat}Cu, ^{nat}Lu, $^{113\&115}$In, $^{185\&187}$Re, ^{181}Ta, $^{107\&109}$Ag, ^{165}Ho, ^{nat}Yb, ^{127}I, ^{133}Cs, ^{nat}Dy, ^{103}Rh
  - GTAF-II: ^{169}Tm, ^{93}Nb, ^{nat}Re, ^{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

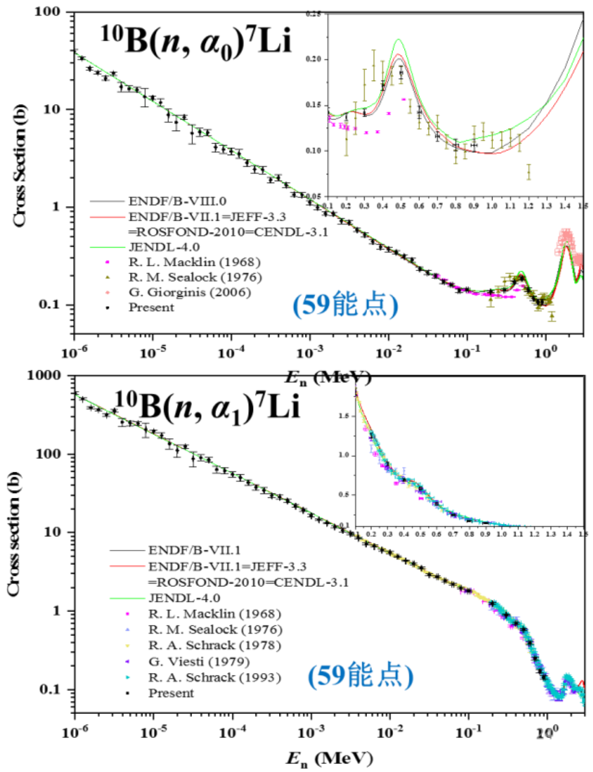
^{6}Li(n, t)α、 ^{10}B(n, α)^{7}Li cross section measurements

- 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



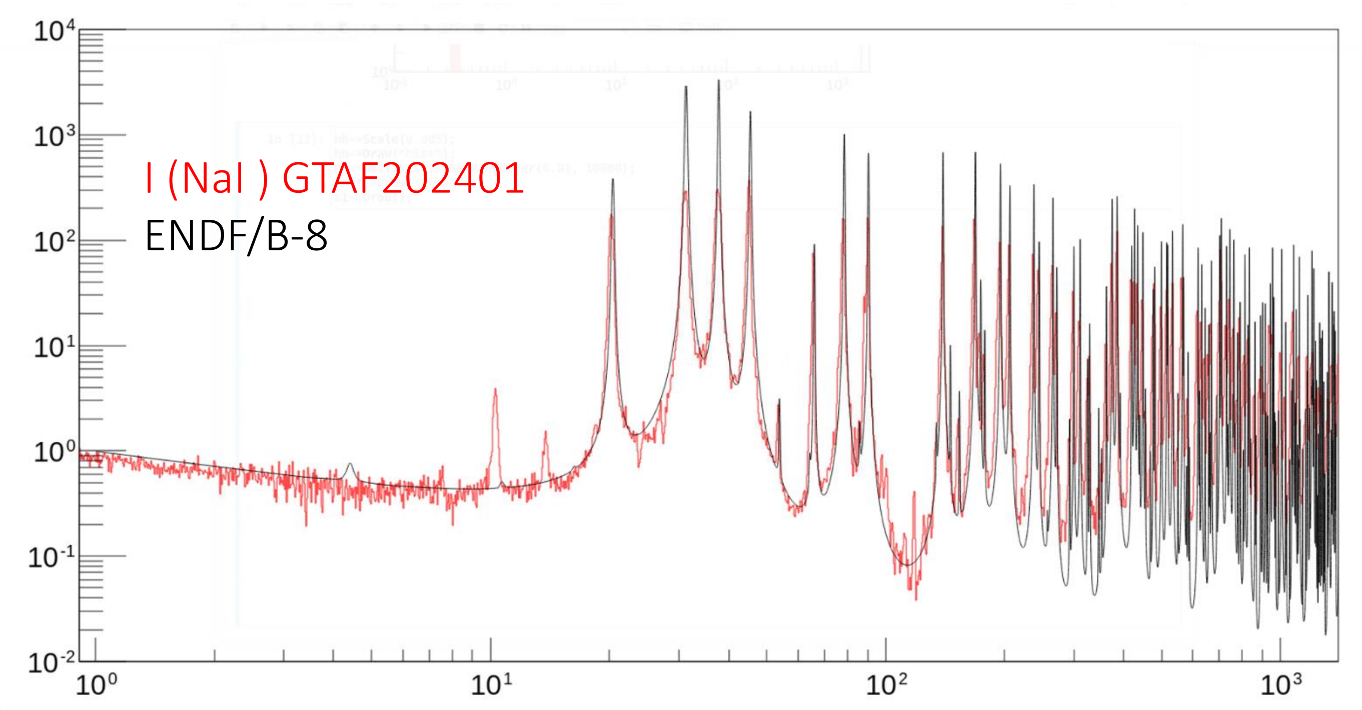


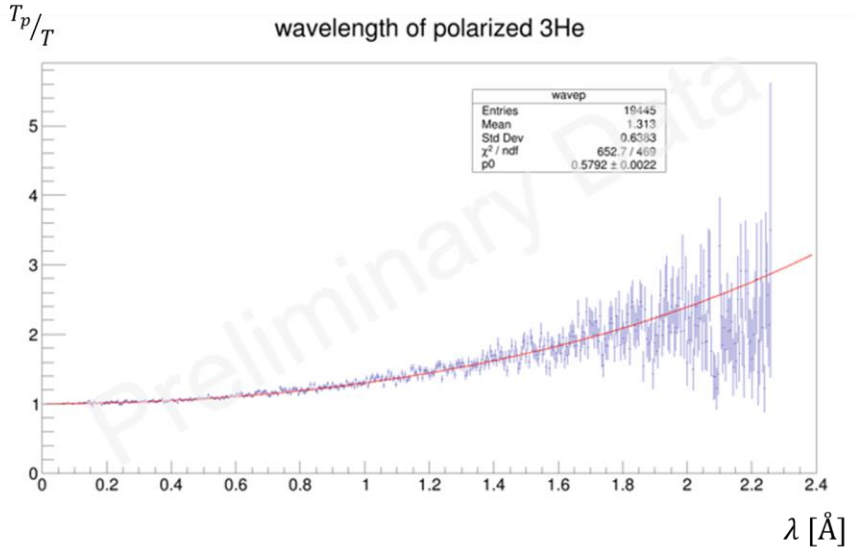
^{10}B(n, α)^{7}Li measurement result

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

Polarized neutron and nucleus reaction

As members of the NOPTREX collaboration, we conducted our first white neutron polarization experiment on Back-n in 2023 using an in-situ neutron polarization device. In the future, we will also utilize polarized white neutrons to carry out experiments that require polarized neutrons, in addition to the NOPTREX experiments.



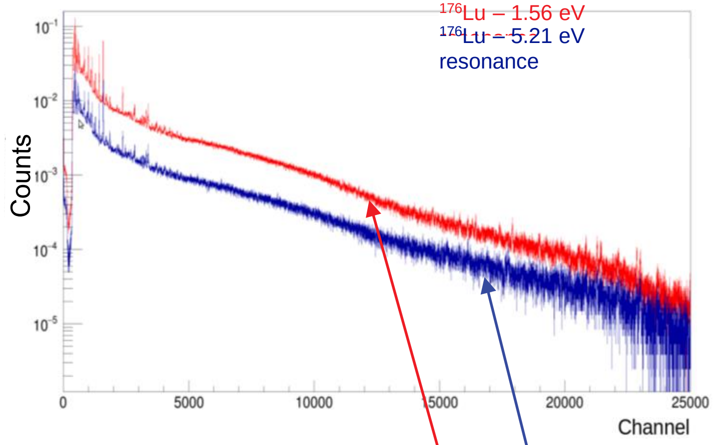


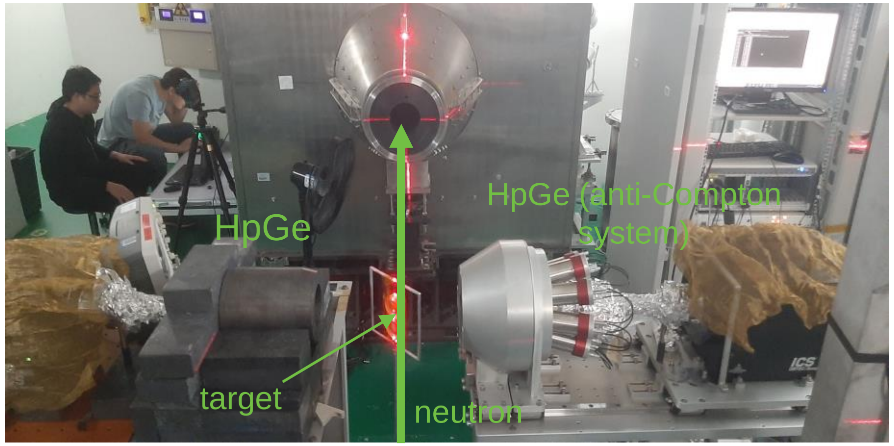
Measurement of gamma decay properties of compound states of 176Lu and 177Lu

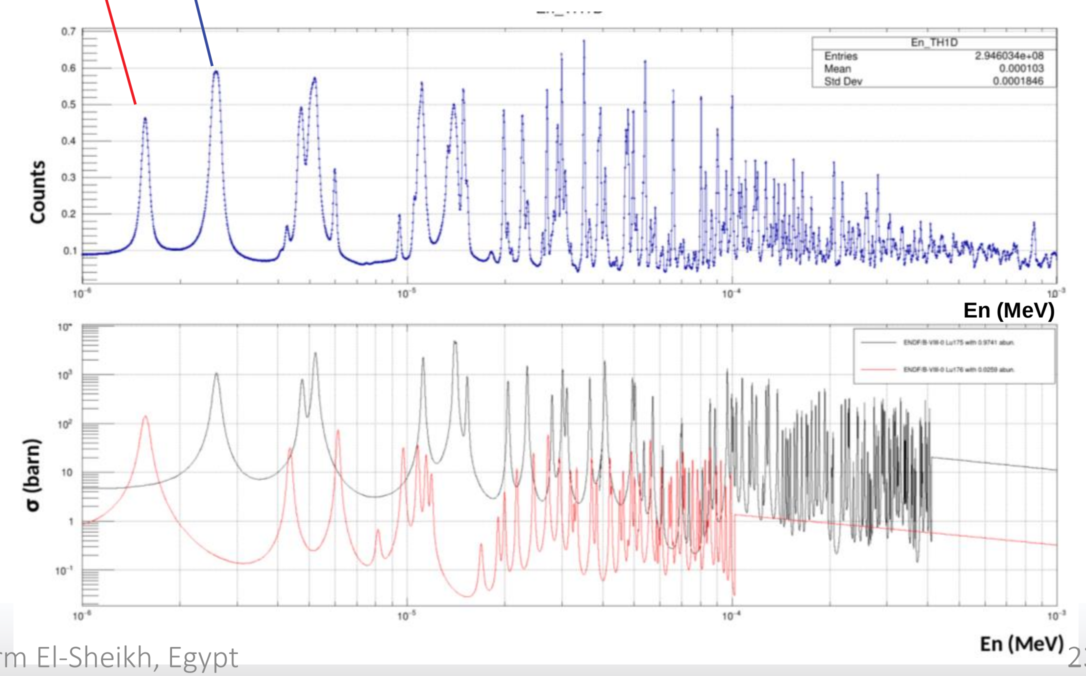
- The aims of the experiment are

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.



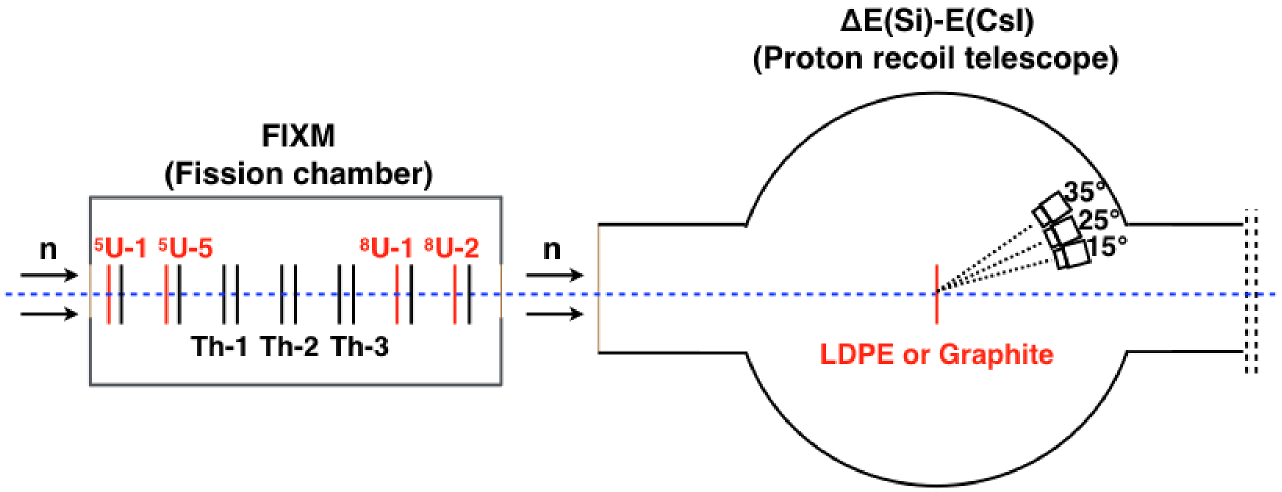




Courtesy: Gadir Ahmadov (JINR)

^{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)

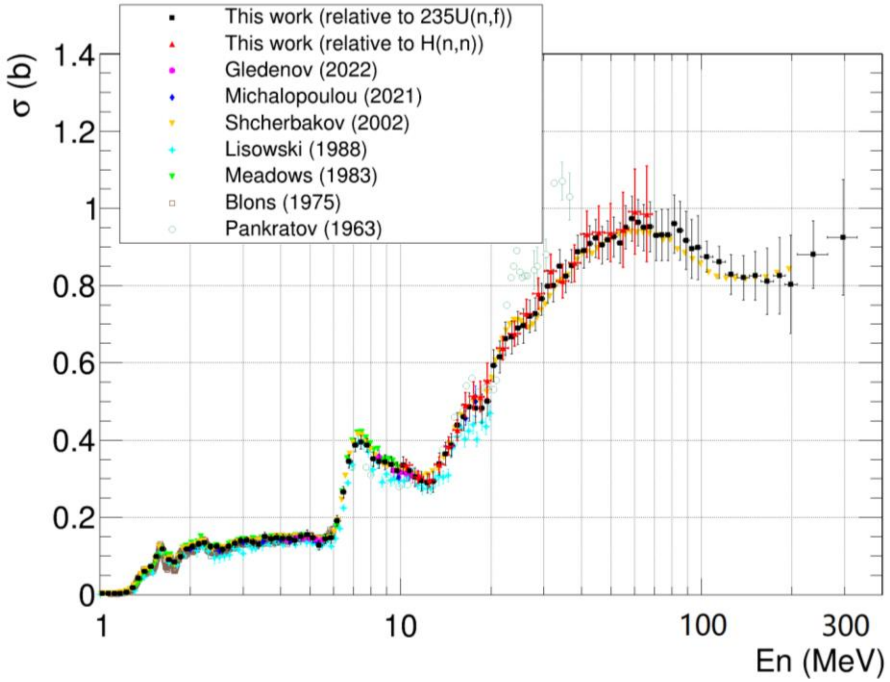
A cross-sectional measurement of 232Th (n, f) was measured using two methods (two reference standards):

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

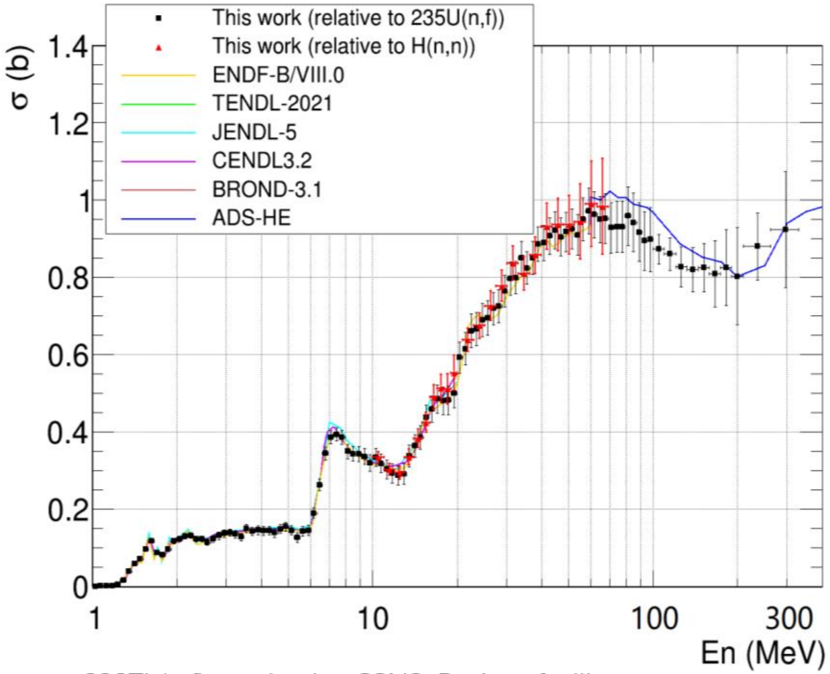
Physics Letters B (2023) **839**: 137832

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

Comparison of this work with other measurements



Comparison of this work with evaluation data

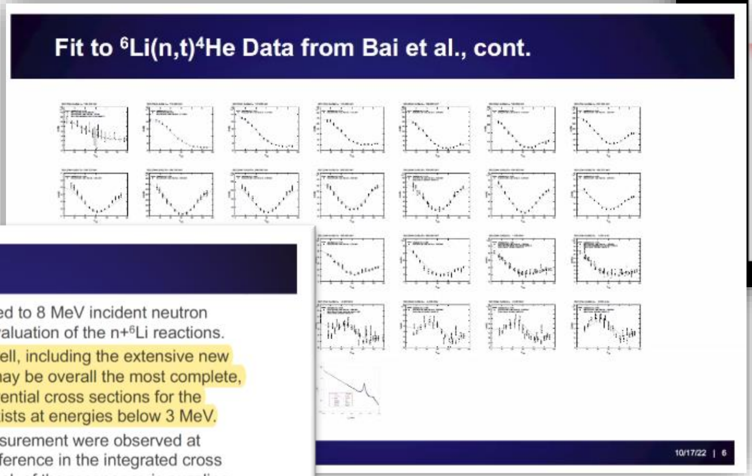


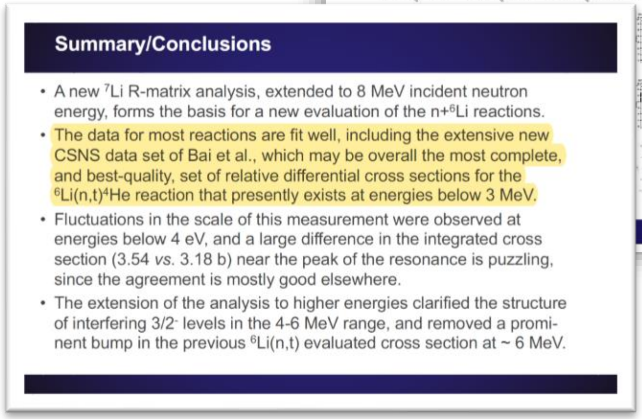
Reviewer #2: - The article describes the procedure to measure 232Th(n,f) x.s. in the CSNS-Back-n facility, presenting some results and comparing it with previous results from other authors.

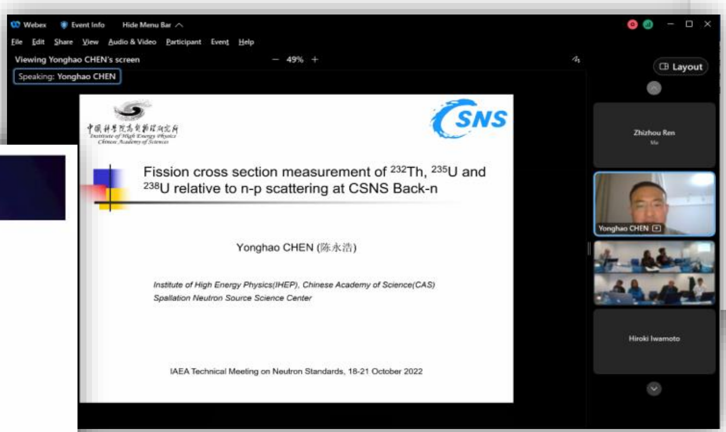
- It is a novel and very interesting work with high impact on the improvement of ND evaluated libraries, and nuclear fission applications.
- The neutron energy in this work ranges up to 300 MeV, when previous experiments retrieved from EXFOR don't reach above 200 MeV. This is relevant for a better understanding of fission at intermediate energies.

IAEA committee invitation

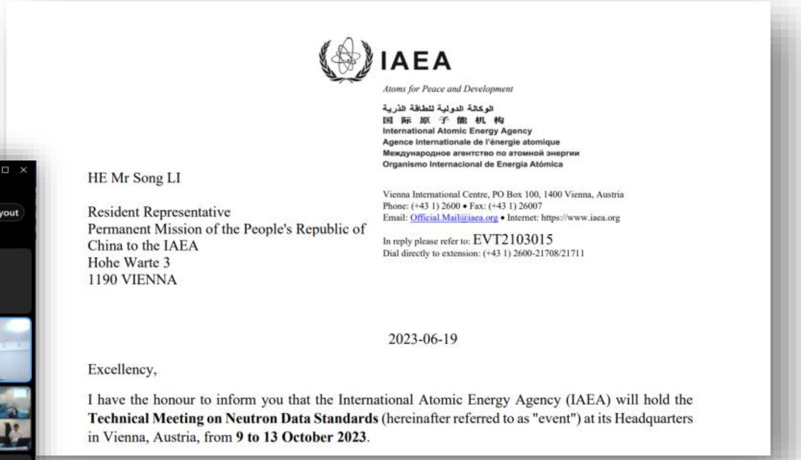
- The results of standard cross-sectional measurements are highly valued by the International Atomic Energy Agency (IAEA):
  1. ^{6}Li(n, t) measurement
  2. ^{235}U(n, f)/^{238}U(n, f)
  3. ^{232}Th (n, f) measurement
  4. ……







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



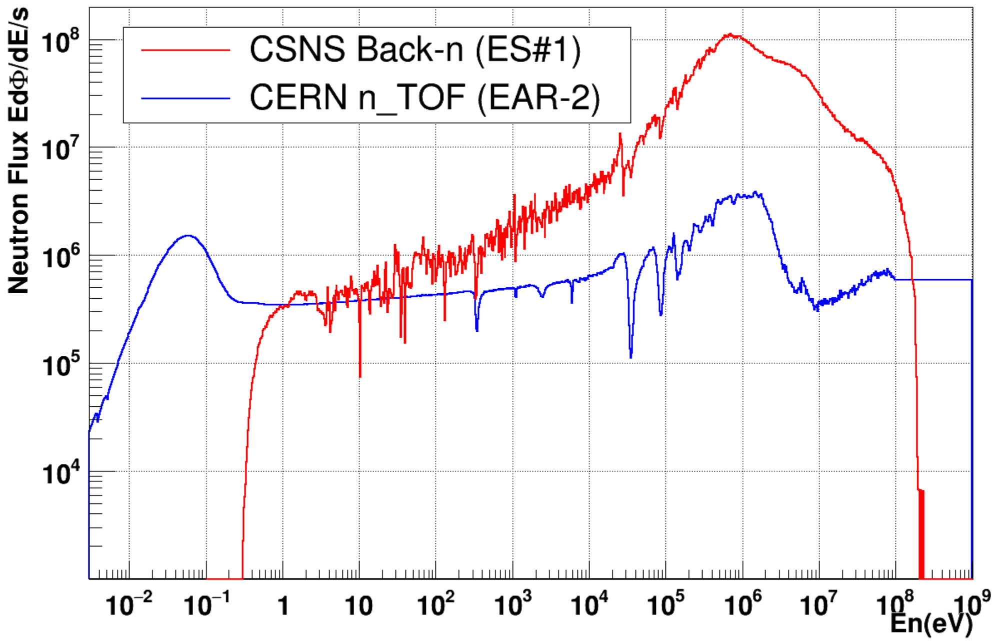
Invitation of the Oct2023 IAEA Technical Meeting on Neutron Data Standards

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

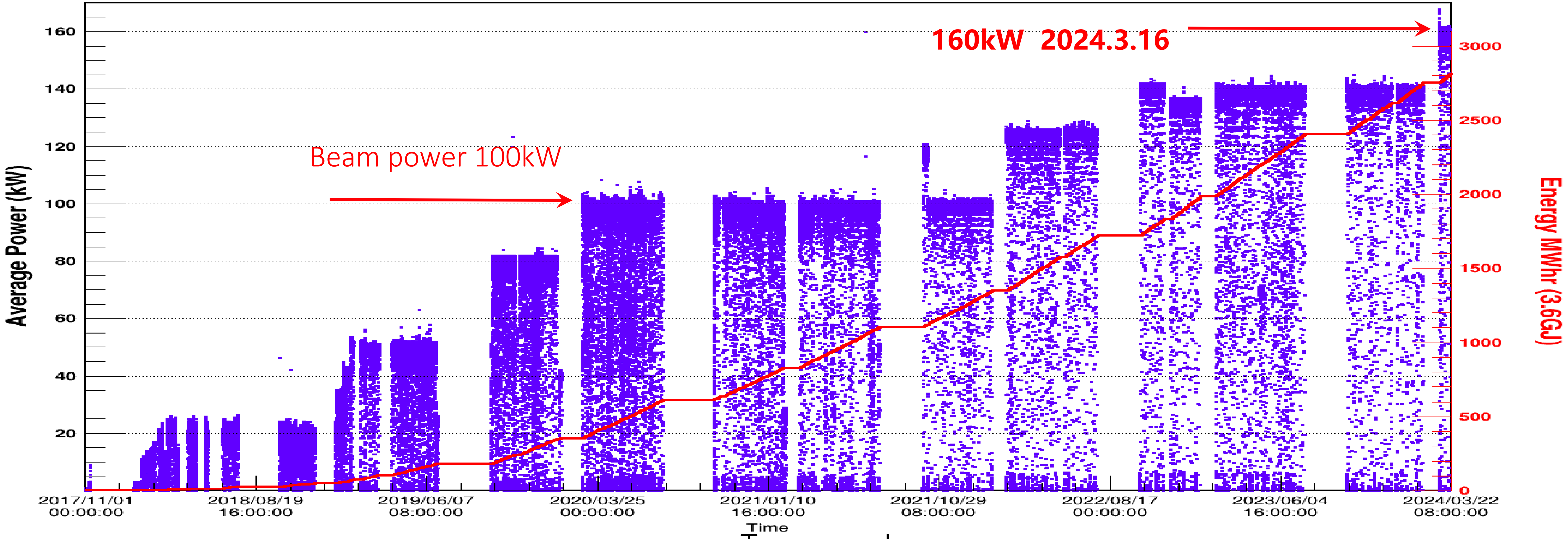
Back-n has the most insensitive resonance neutron flux.

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

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.

Beamtime

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



Two round per year

4054h 4687h 4884h 5262h 4995h

Joint funding projects

- The Chinese government is actively promoting joint funding projects for large scientific facilities with foreign countries.
- RSF-NSFC joint research project(deadline 26 April 2024)

RSF-NSFC Cooperation: 4th Call for Proposals

Source: RSF Press Office

To facilitate the support of collaborative work between Russian and Chinese research groups, the Russian Science Foundation (RSF) and the National Natural Science Foundation of China (NSFC) jointly announce their fourth call for proposals for bilateral Joint Research Projects for the funding period 2025-2027 in Mathematical and Physical Sciences, Earth Sciences, Information Sciences, Materials and Engineering sciences.

- China-Egypt Government Joint Research Projects(deadline June 2024)

  Egyptian Contact: Science, Technology & Innovation Funding Authority (STDF), Dr. Amal Gomaa, Email: amal.gomaa@stdf.eg

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
- ……

礼

Thanks

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