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CHINESE ACADEMY OF SCIENCES

Progress of Atmospheric Neutron Irradiation Research at ANIS

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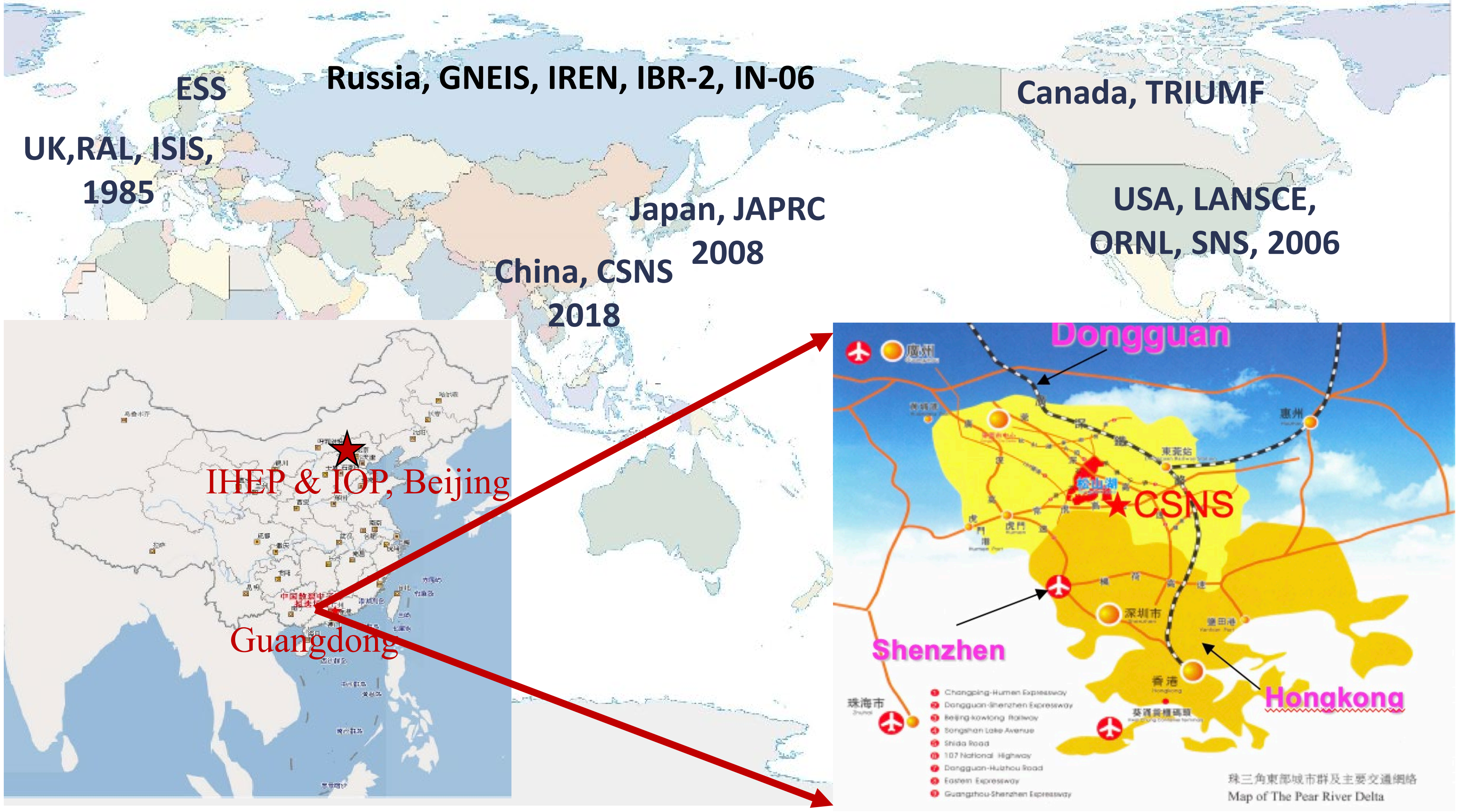
GB-RADNEXT, June 12-13, 2024, RAL, UK

This talk

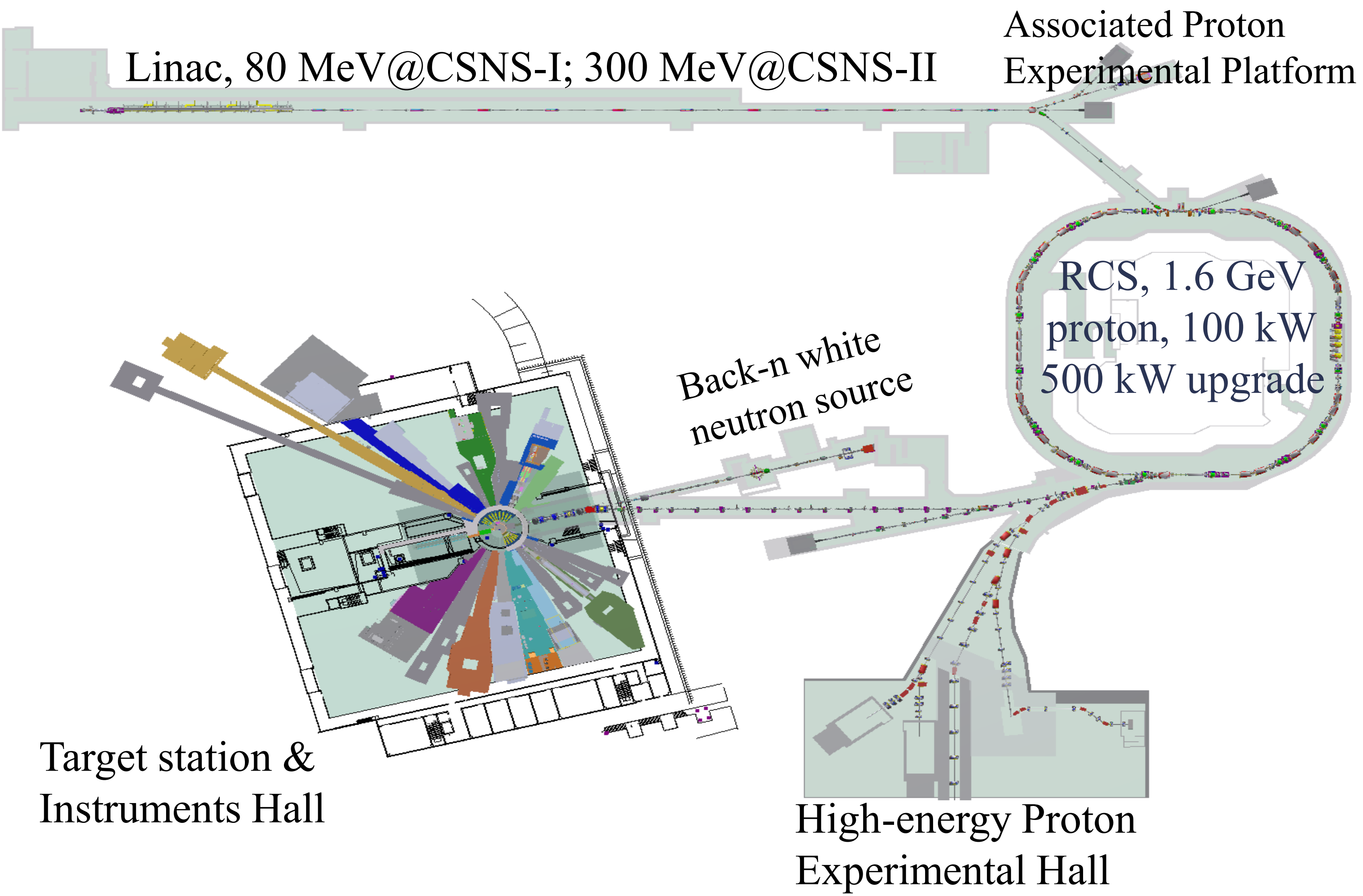
- ☞ China Spallation Neutron Source (CSNS);
- ☞ Atmospheric Neutron Irradiation Spectrometer (ANIS) ;
- ☞ Progress of atmospheric neutron irradiation research at ANIS;

Where we are

Pulse Spallation Neutron Source

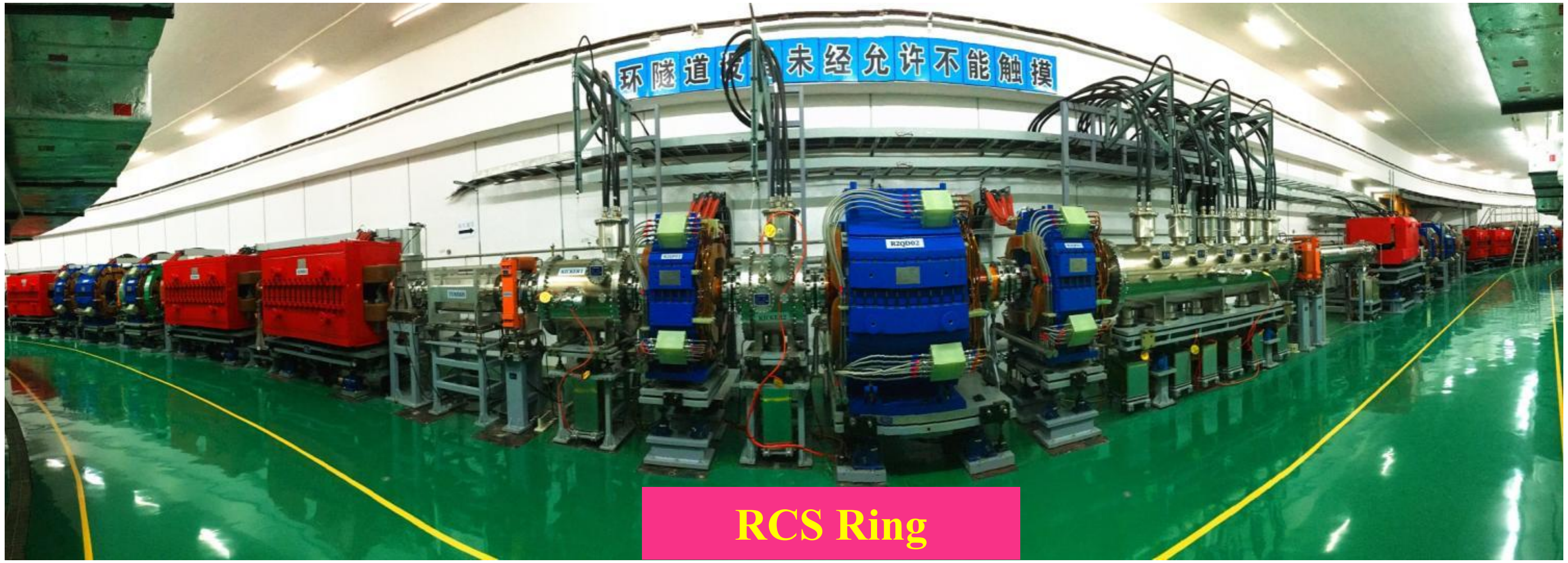


CSNS ---I(100kW)&II(500kW)

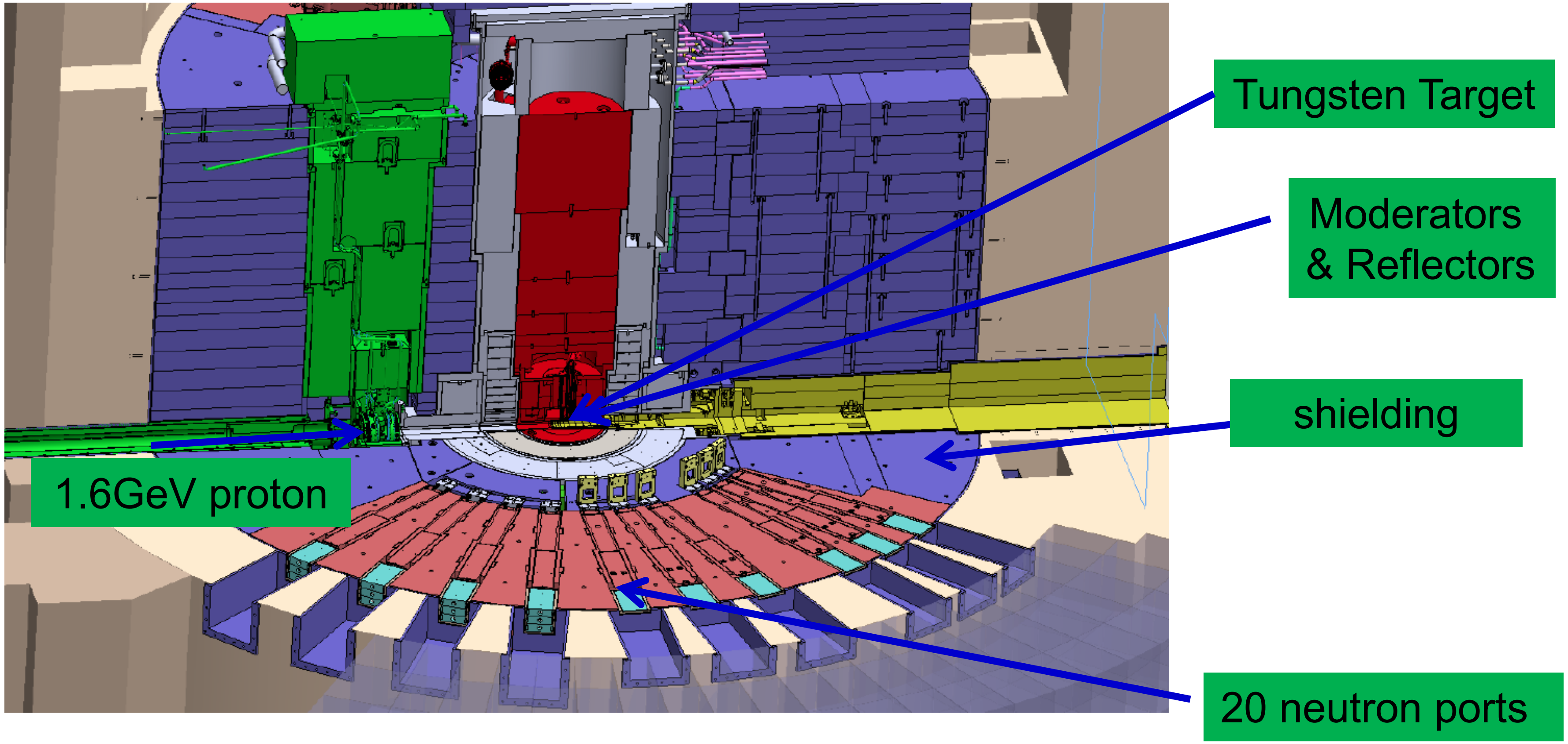


Para.	I (2018)		II (2030)
Power (kW)	100		500
Proton (GeV)	1.6		
Current (mA)	62.5		312.5
Frequency (Hz)	25		
Spallation target	Tungsten/tantalum		
Moderator	CHM DWM DPHM		
Reflector	Be/Fe		
Beam port	20		
Instrument	3	8	20+
Dose (mSv/h)	< 2.5		
Operation (h/y)	~5000		

Accelerator



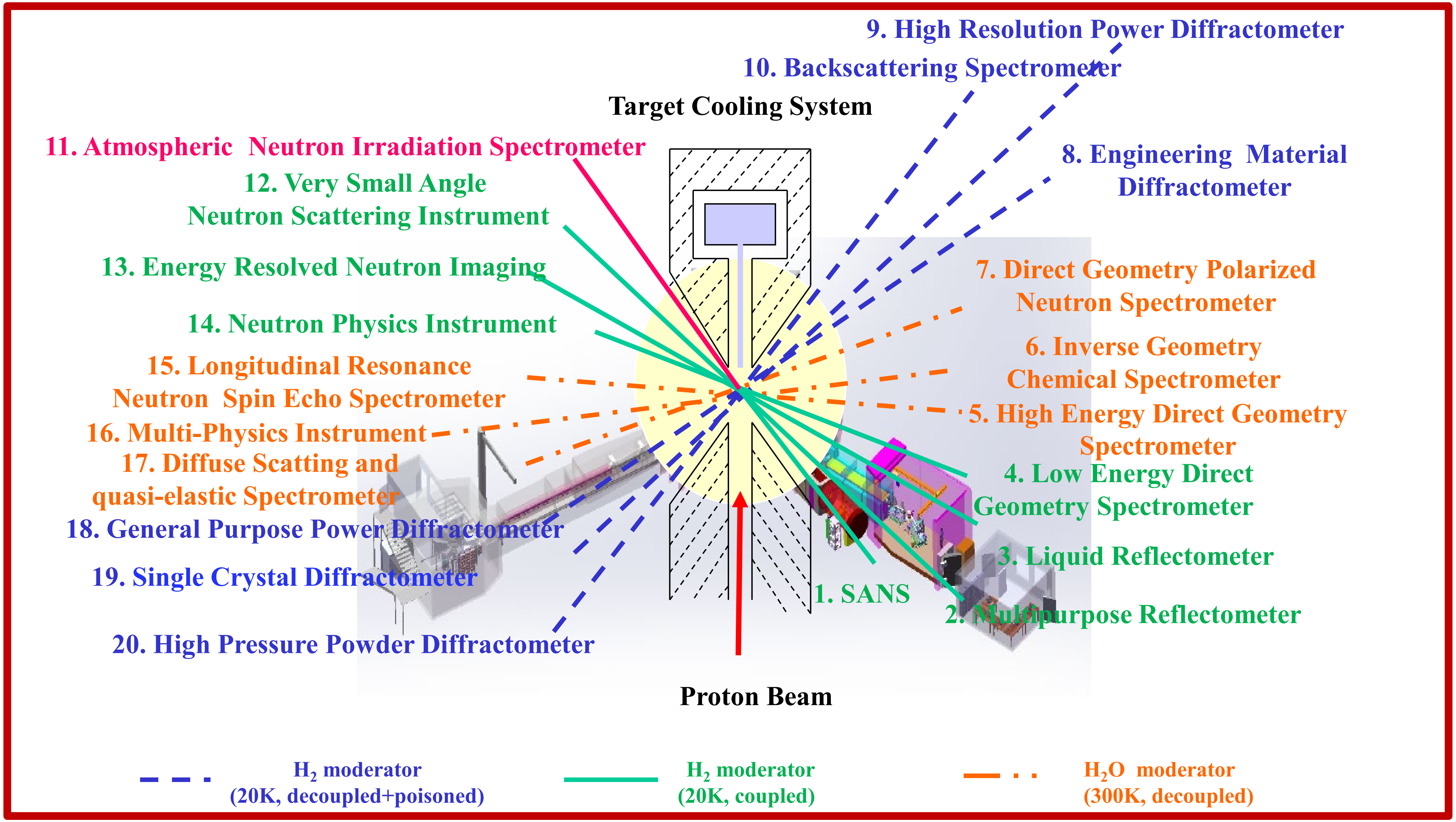
Target station



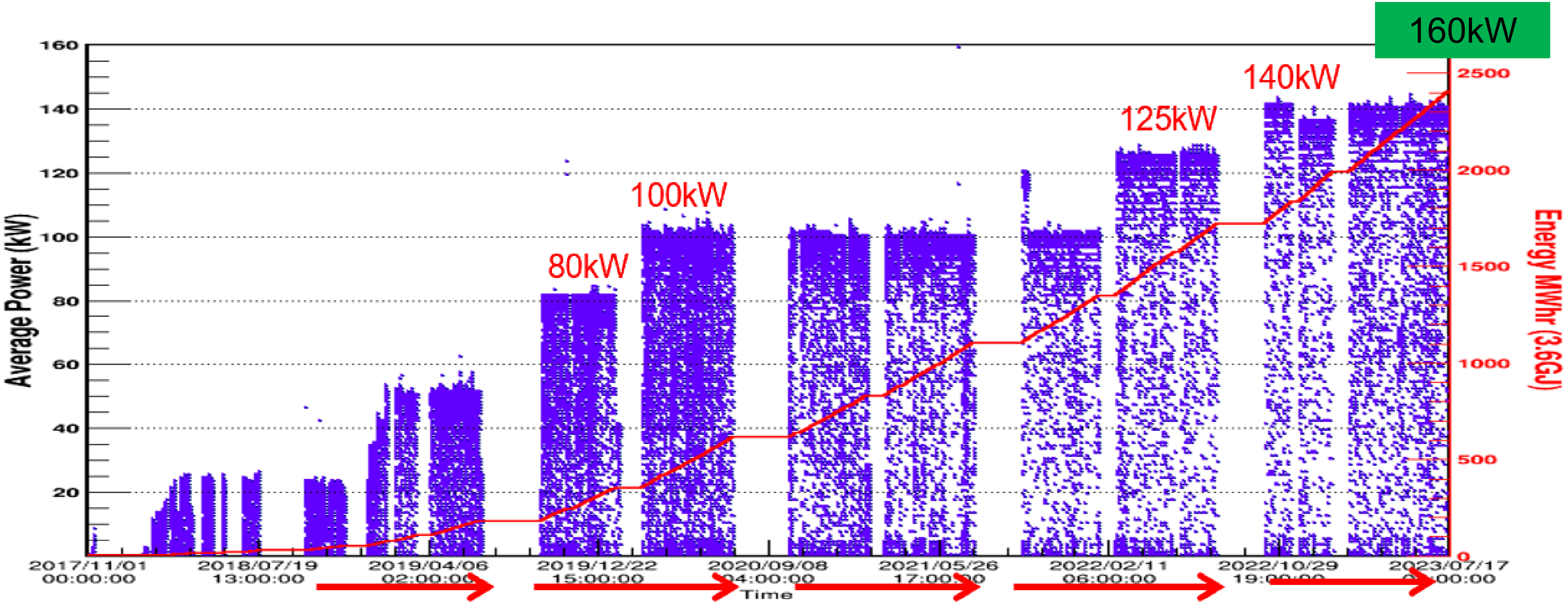
- Provide cold and thermal neutron for 19+ instruments
- Provide meV~GeV neutrons for 1 instrument

Wang F W, Liang T J., Yin W, et al., "Physical design of target station and neutron instruments for China Spallation Neutron Source", Sci. Chin. Phys. Mech. Astron. ***56*** *(2013) 2410.*

Instruments



CSNS operation



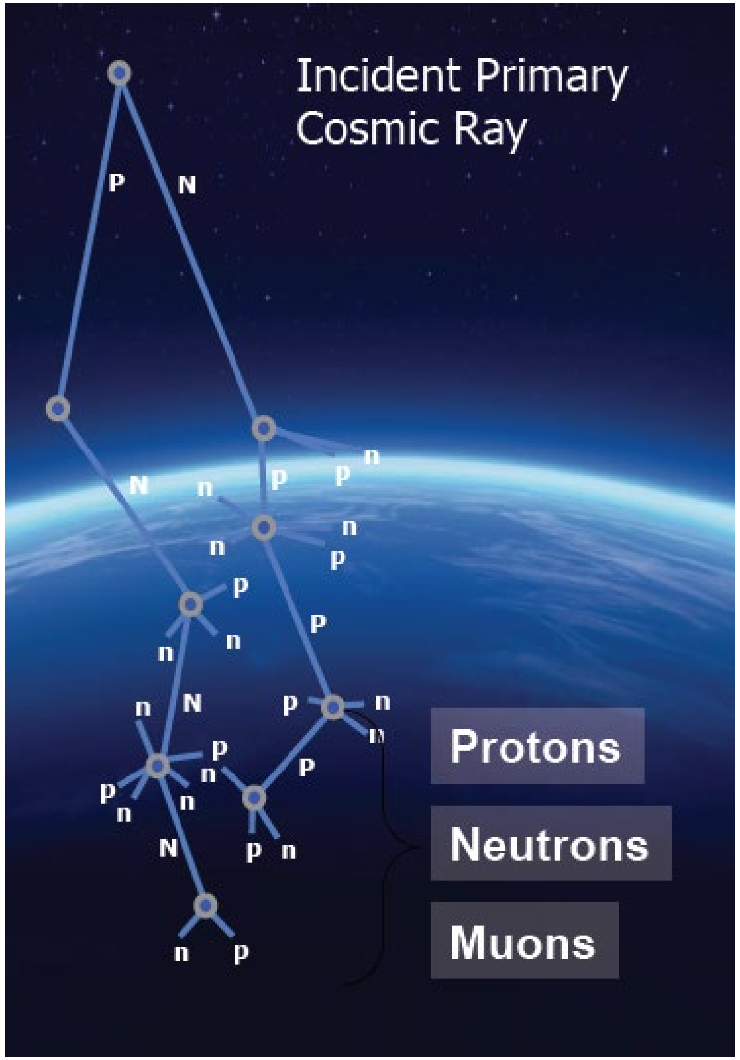
Two round per year

4054h 4687h 4884h 5262h 4995h

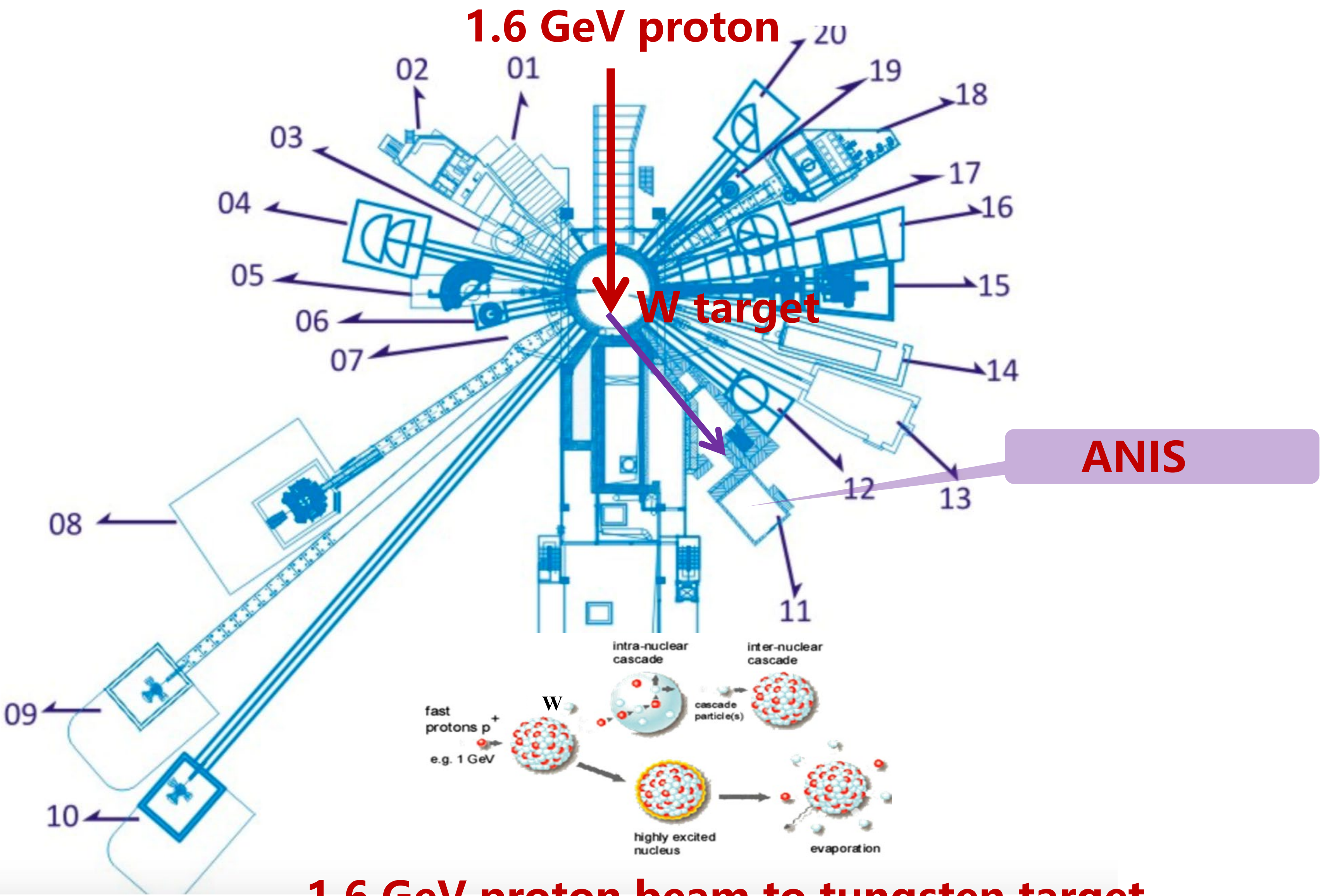
This talk

- ☞ China Spallation Neutron Source (CSNS);
- ☞ **Atmospheric Neutron Irradiation Spectrometer (ANIS) ;**
- ☞ Progress of atmospheric neutron irradiation research at ANIS;

Why ANIS was built at CSNS

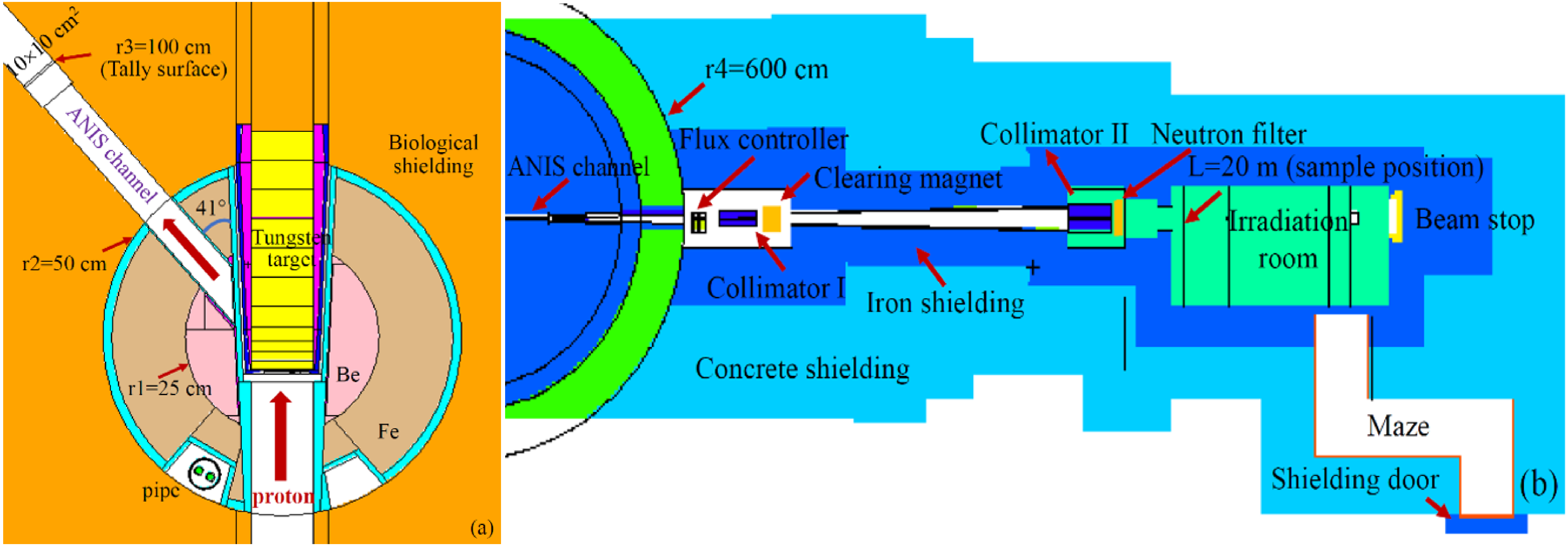


Cosmic ray to N_2 and O_2



1.6 GeV proton beam to tungsten target

Physical design for ANIS

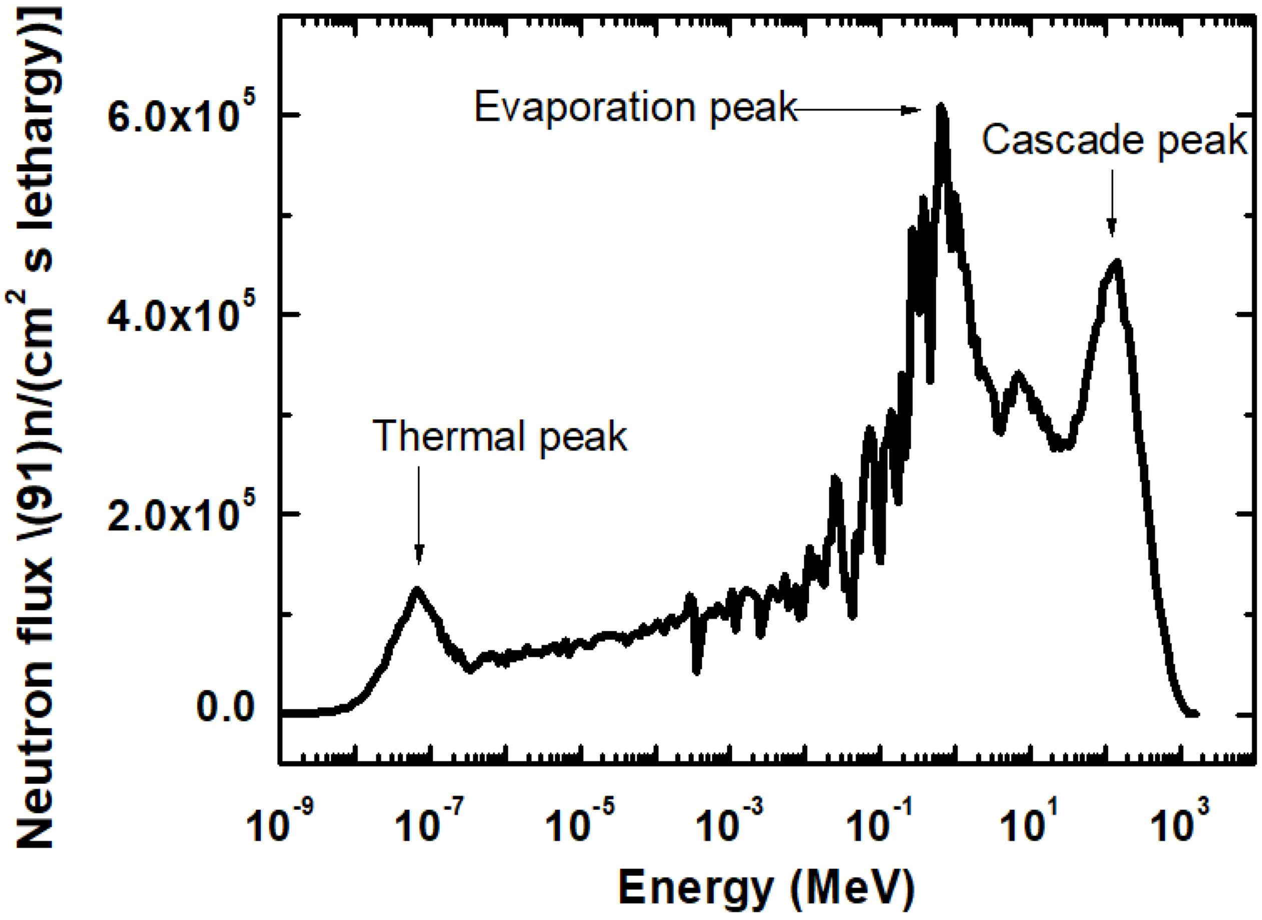


Simulation: MCNP, PHITS, FLUKA, ORIHET, CINDER and their cross check,

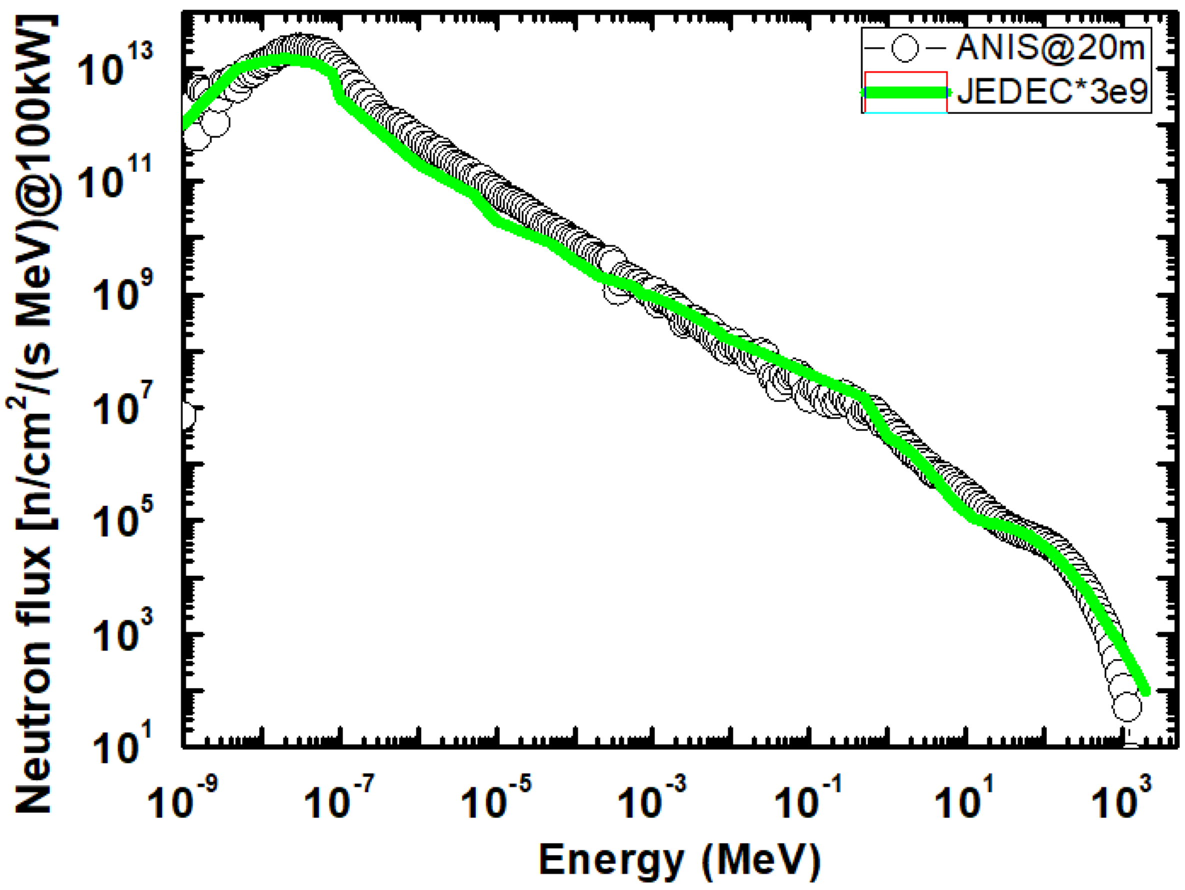
Design: cross design of physics and engineering,

Characters: meV~GeV, flood and collimated beam spots, adjustable neutron flux.

Neutron spectrum

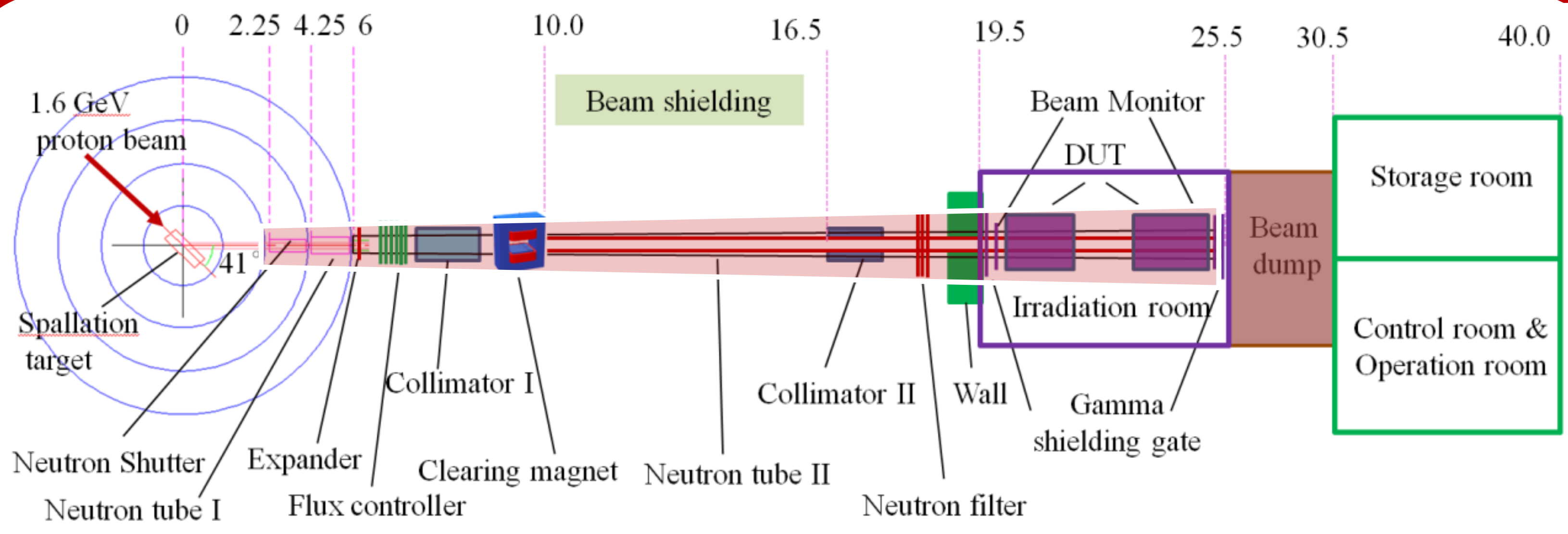


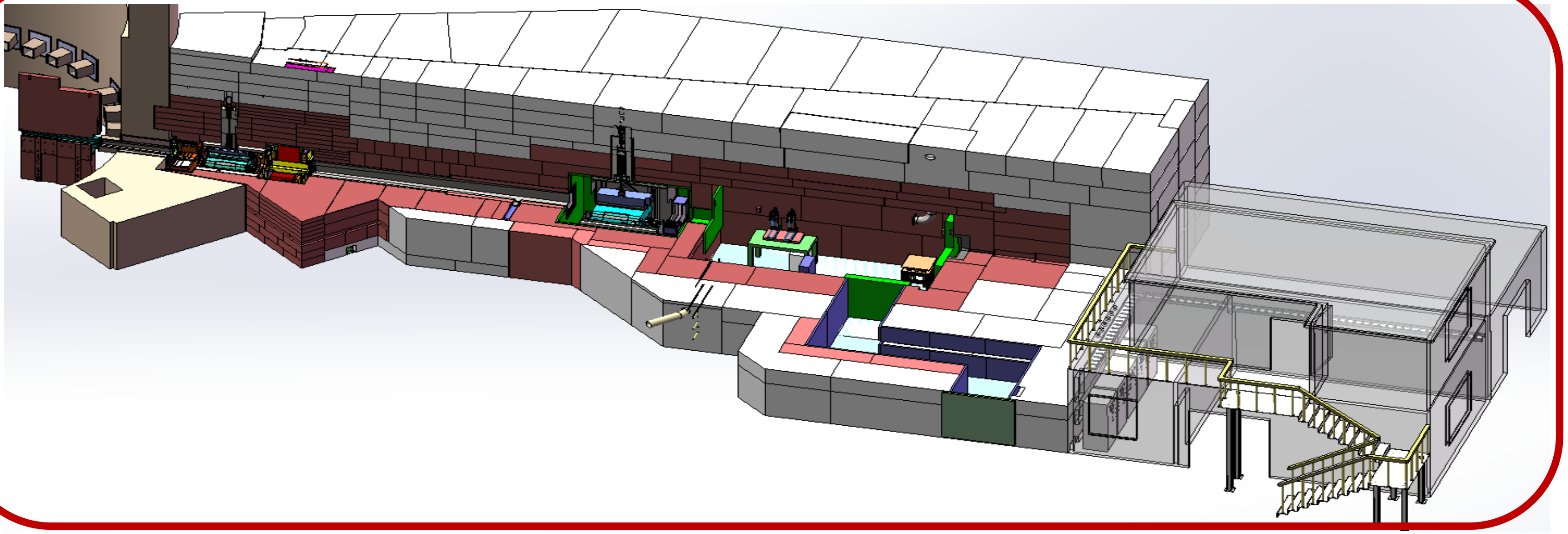
Atmospheric neutron spectrum at ANIS



Neutron spectrum compared with JEDEC

Physical & engineering design





1. Neutron beam control system: beam spots, flux, spectrum.
2. Beamline shielding: safety requirements.
3. Neutron measurement system.
4. Radiation effect test system: tables, lasers, PDU, electrical, cables, temperature.
5. System: vacuum, control, DAQ, PPS, utility.

ANIS at CSNS

ANIS outside target station, Feb. 2020.

ANIS under construction, Mar. 2021.

Construction completed, Dec. 2021.

Main characters of ANIS

Target view	ANIS views the front part of the W-Ta spallation target directly, at an angle of 41° from the incident proton beam.
Charged particles	Charged particles can be switched by a clearing magnet with a strength of 0.5 T, to allow the passage of or to deflect protons, pions, muons, and electrons.
Beam spectrum	The profile of the differential neutron spectrum matches well with the JEDEC standard spectrum. It has the white energy spectrum from meV to GeV, covering 12 decades of neutron energy.
Thermal neutrons	Selectable neutron filters allow tailoring of the neutron spectrum to satisfy the user's demands.
Collimated spots	Four collimated beam spots: 10 cm×10 cm, 5 cm×5 cm, 2.5 cm×2.5 cm and 1.0 cm×1.0 cm.
Flood spots	From 65 cm×65 cm continuously up to 80 cm×80 cm, and an individual 25 cm×25 cm beam spot.
Intensity	Can be increased by approximate 0.5 order of magnitude via flux controller, 10^3-10^7 n/(cm^2 s) for the collimated and flood beam spots.
Sample area	Irradiation room with 6 m (length) ×3 m (width) ×2.8 m (height). First sample position at ~20 m, with one XYZ translation table plus one-dimensional rotation for device testing and nuclear experiments. Second sample position at ~24.5 m, with one XYZ translation table for large system testing.
Beamline shielding	The dose rate is <2.5 μSv/h outside ANIS, satisfying the safety requirement according to the international standards of GB5172-1985 and GB18871-2002.

Yu Q, Shen F, Yuan L, et al. Physical design of an atmospheric neutron irradiation spectrometer at China spallation neutron source, Nuclear Engineering and Design, 2022, 386: 111579.

This talk

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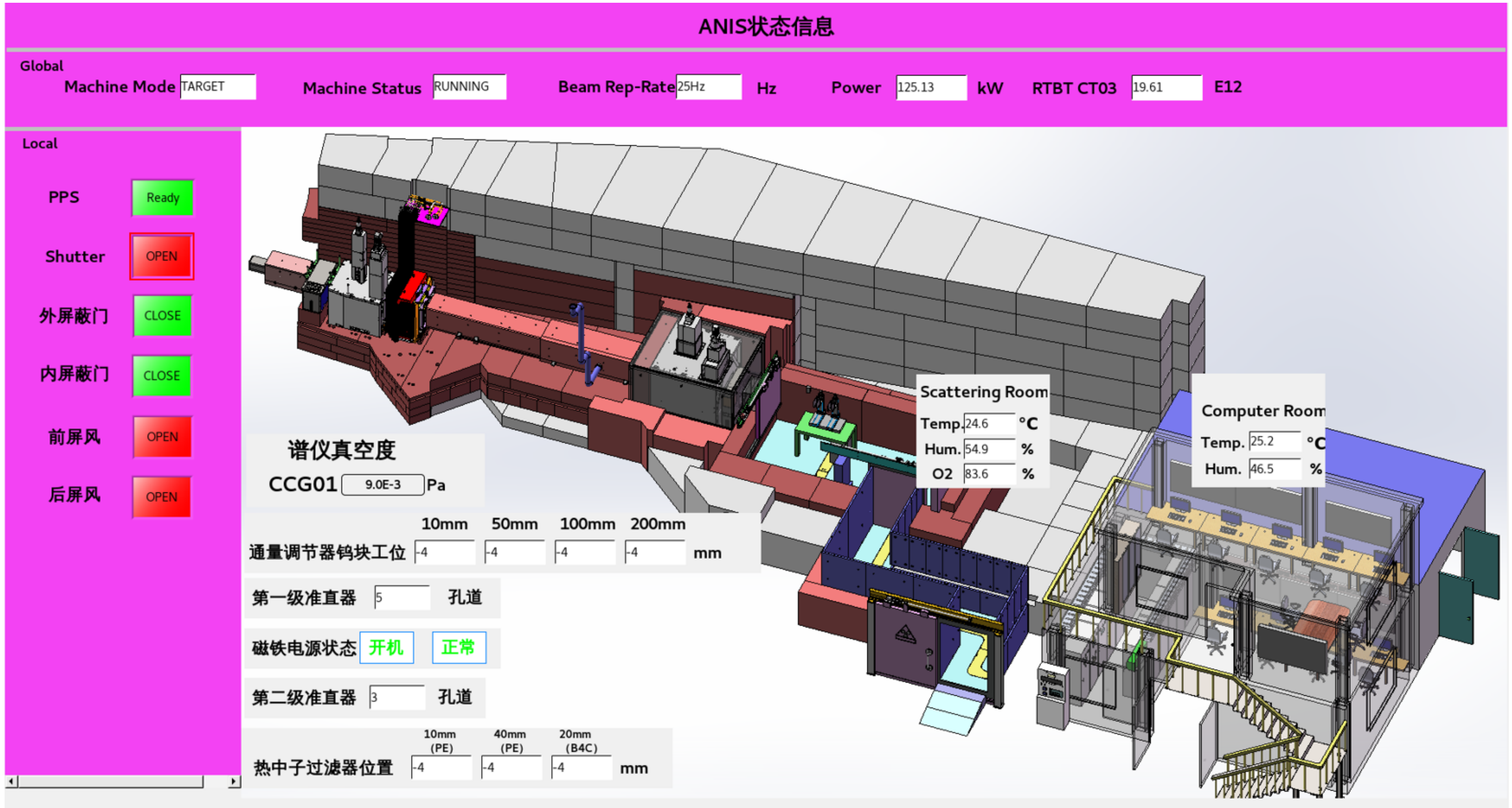
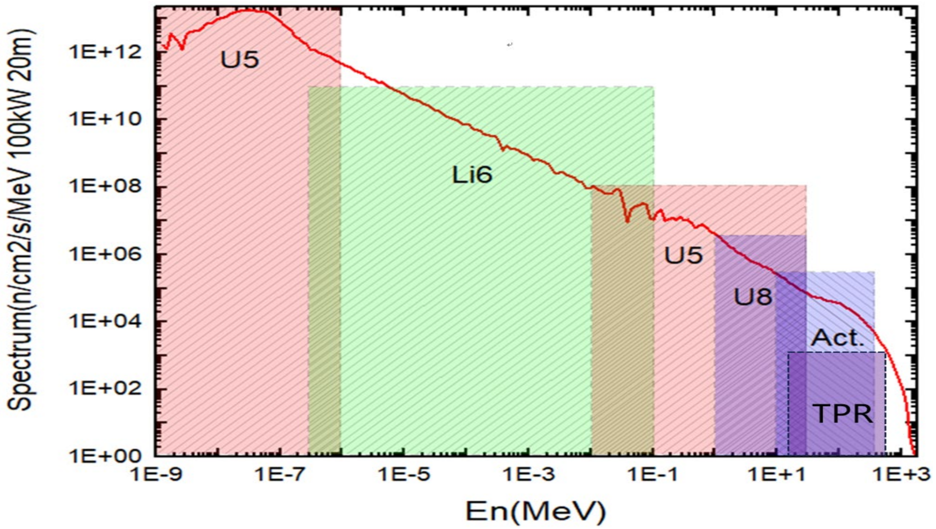
- ☞ **Progress of atmospheric neutron irradiation research at ANIS;**

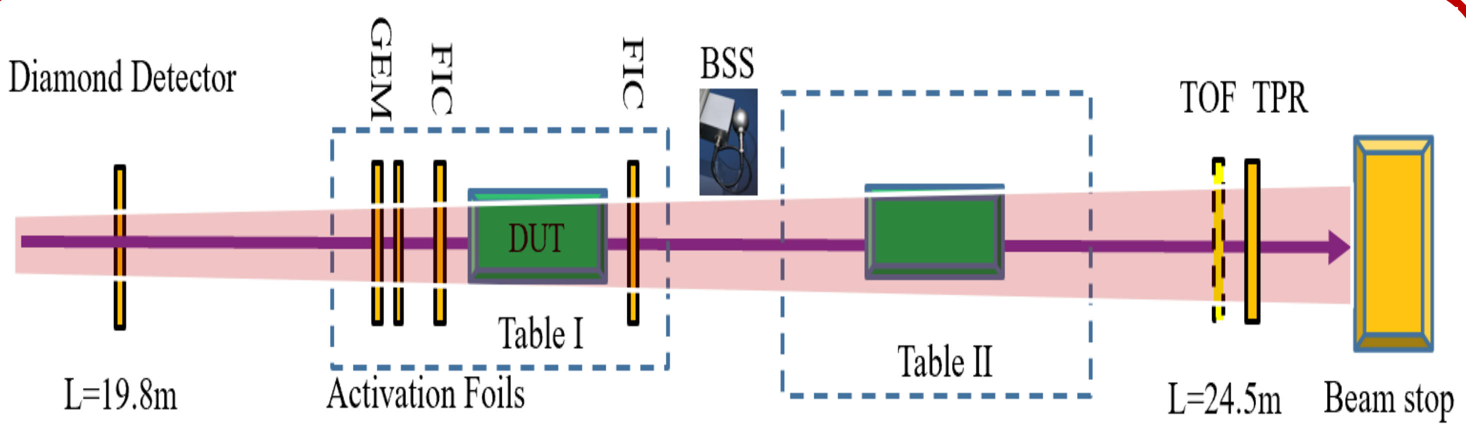
Commissioning

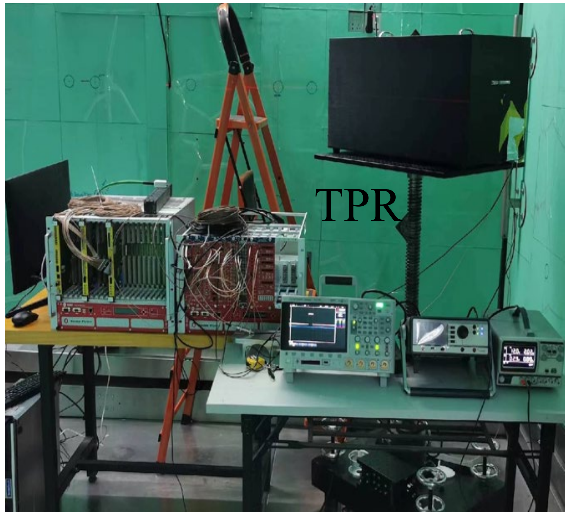


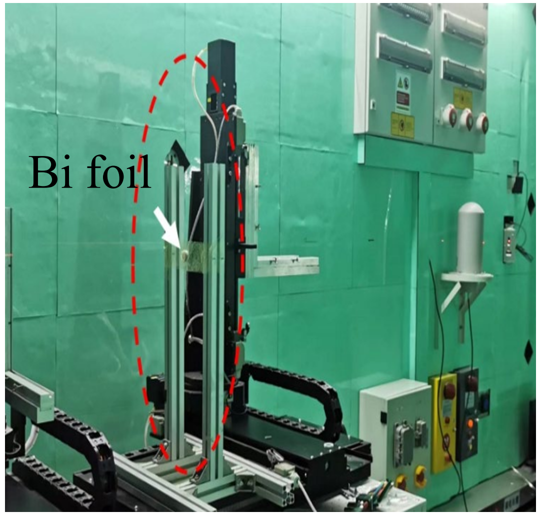
- Components: Shutter, Flux controller, Collimator, Magnet, Filter, Doors, Tables, shielding…
- Systems: Vacuum, Safety, Control, Cooling, Electrical, Cables, DAQ, SEE test systems…
- Neutron measurements: spectrum, flux, beam spot, dose rate, background…
- Verification: Charged particles, Photons, Thermal neutrons, Temperature, Multilayer IC boards…

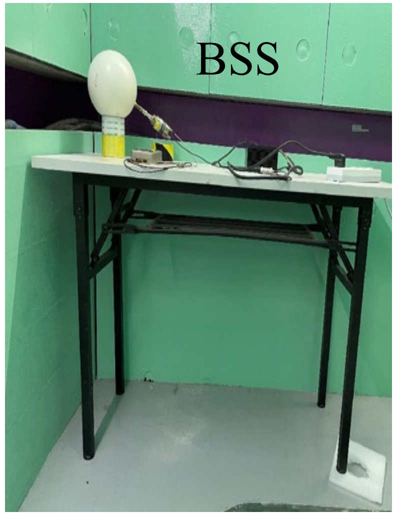
Neutron measurement system





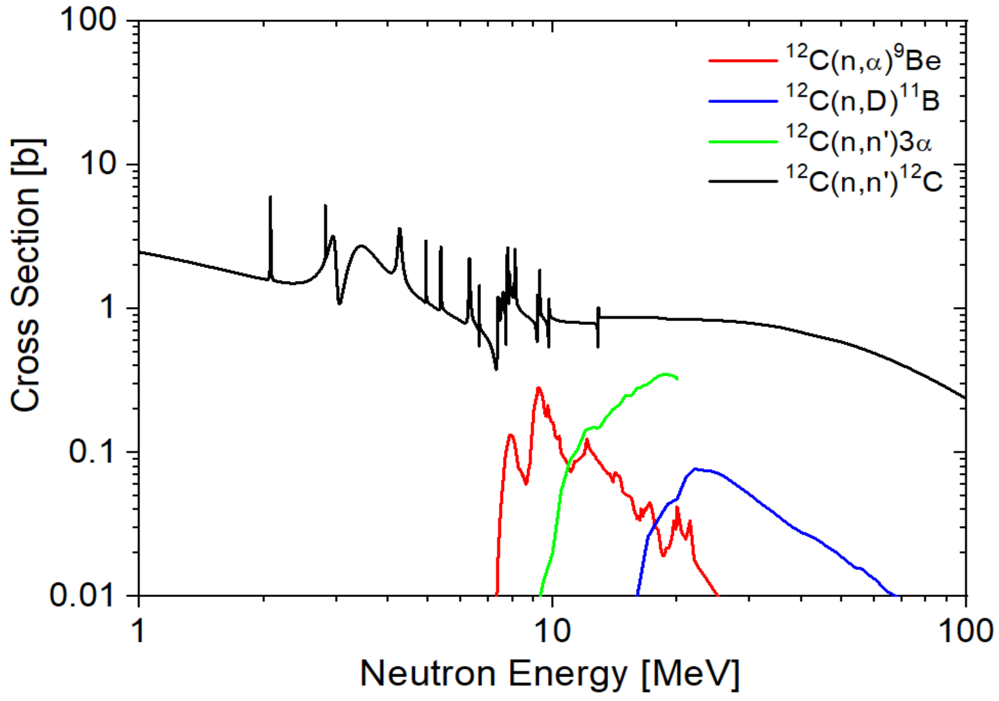


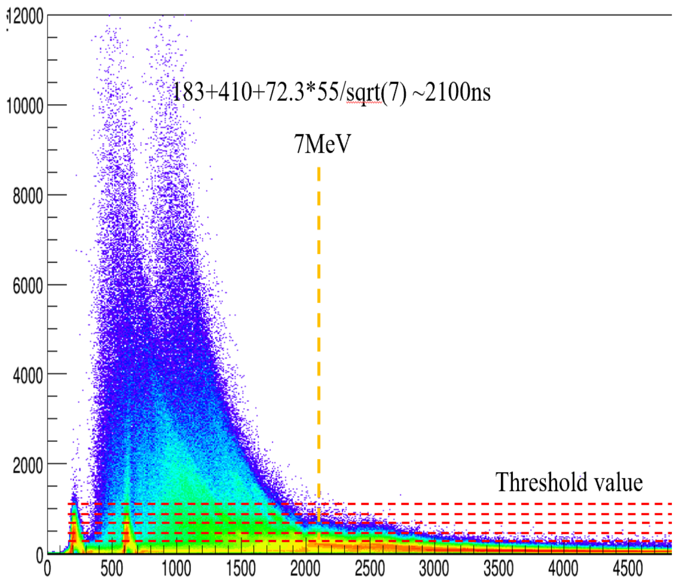


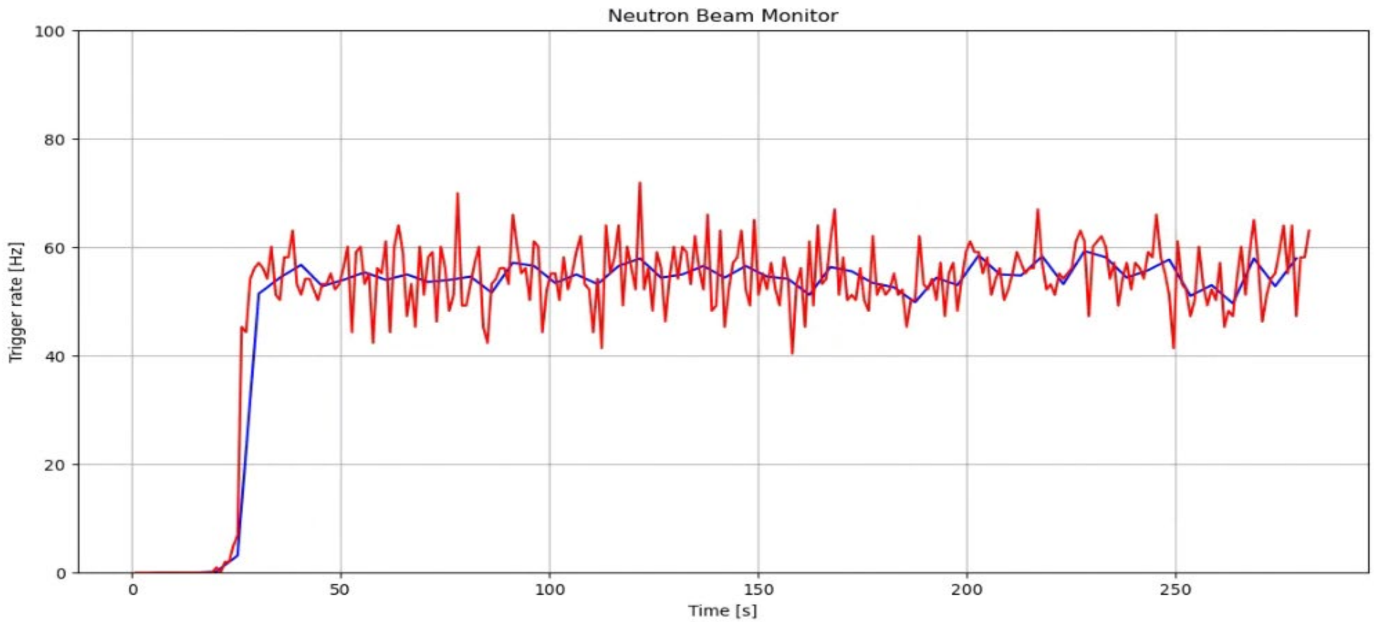


- □ **Neutron spectrum, neutron flux, beam spot, uniformity, background**

Beam flux-FIC+Diamond detector



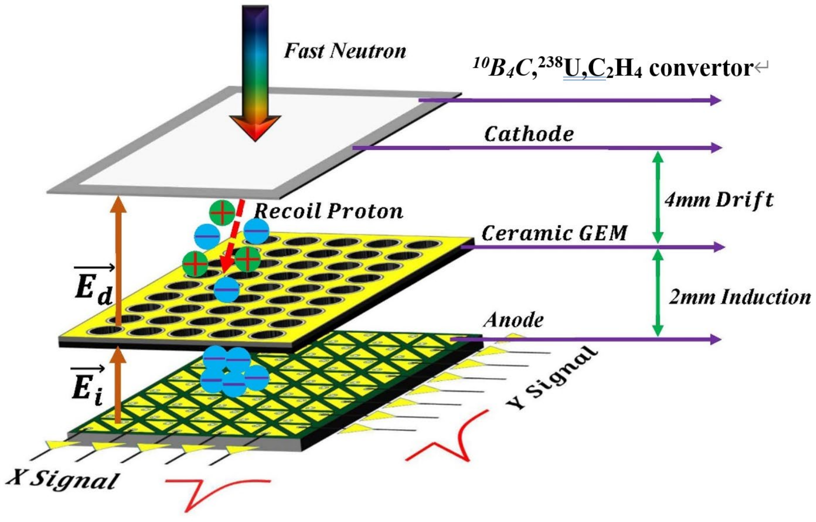


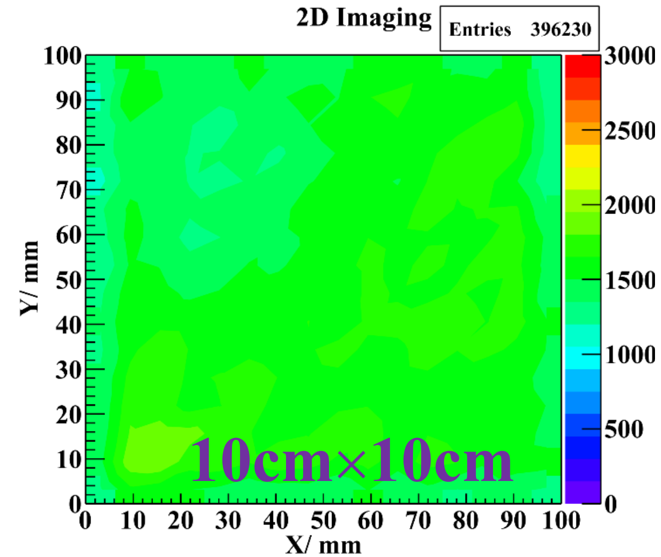


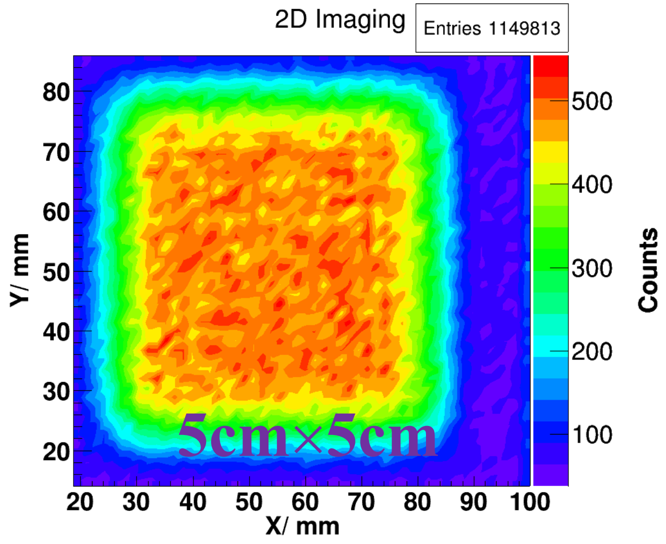
Fast neutron detection is achieved by detecting charge particles produced via the reactions:

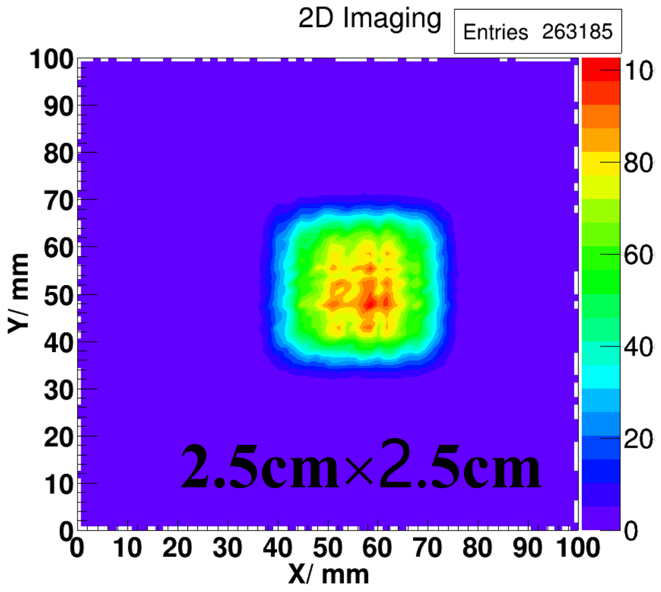
- $^{12}C(n,\alpha)^{9}Be$ (Q_{value}=5.7 MeV, E_{thr}=6.17 MeV)
- $^{12}C(n,n')3\alpha$ (Q_{value}= 7.23 MeV, E_{thr}=7 MeV)
- $^{12}C(n, D)^{11}B$ (Q_{value}= 13.7 MeV, E_{thr}=13.8 MeV)
- $^{12}C(n,n')^{12}C^{*}$ only for 2.5 MeV neutrons.

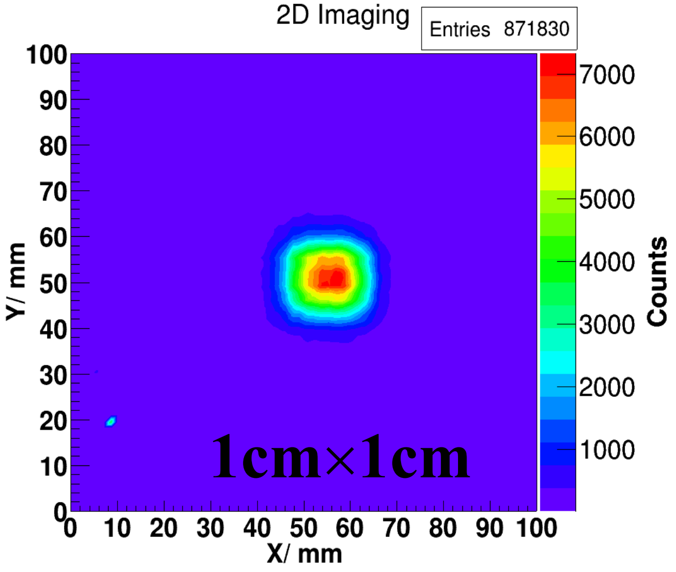
Collimated beam spot-GEM+DD



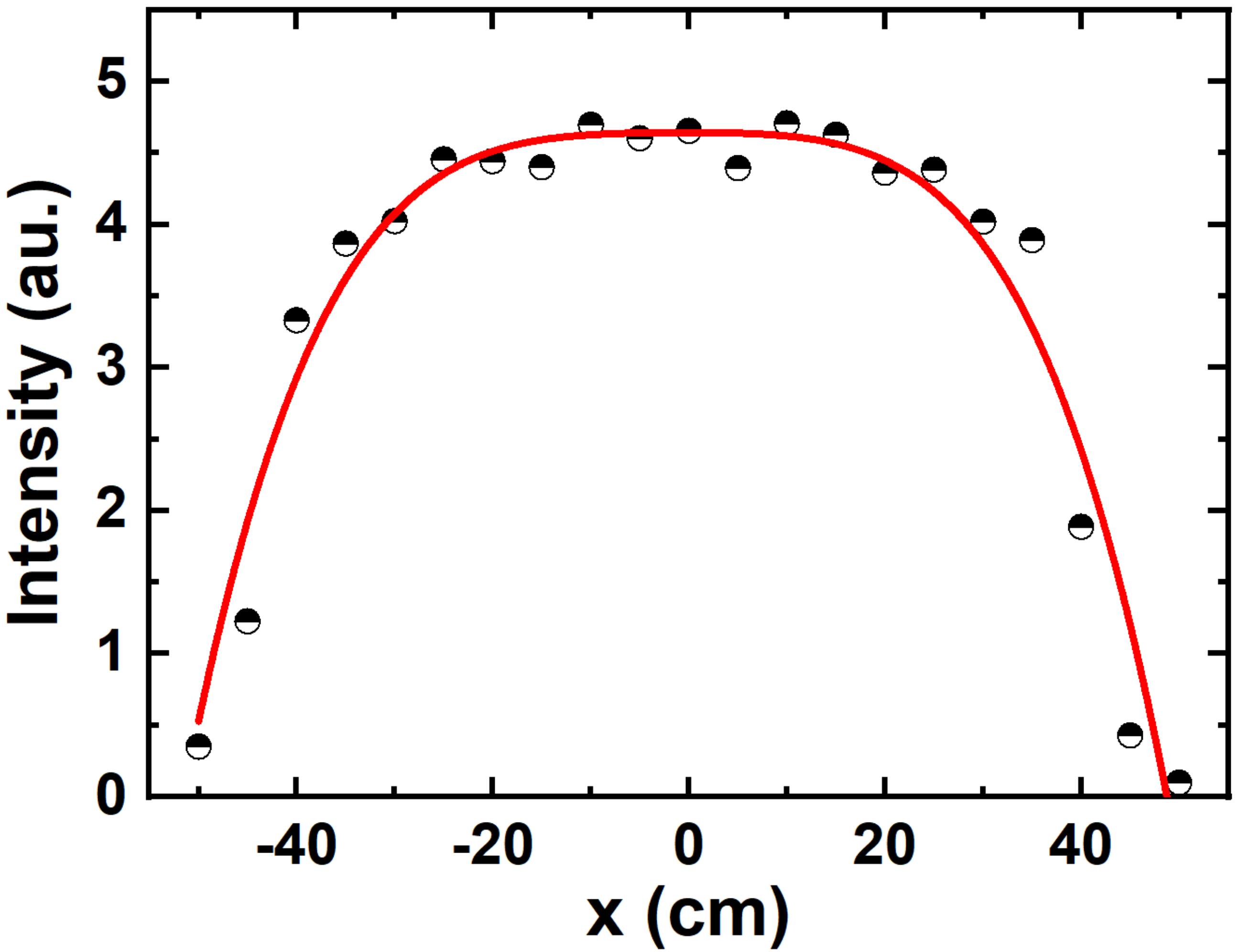




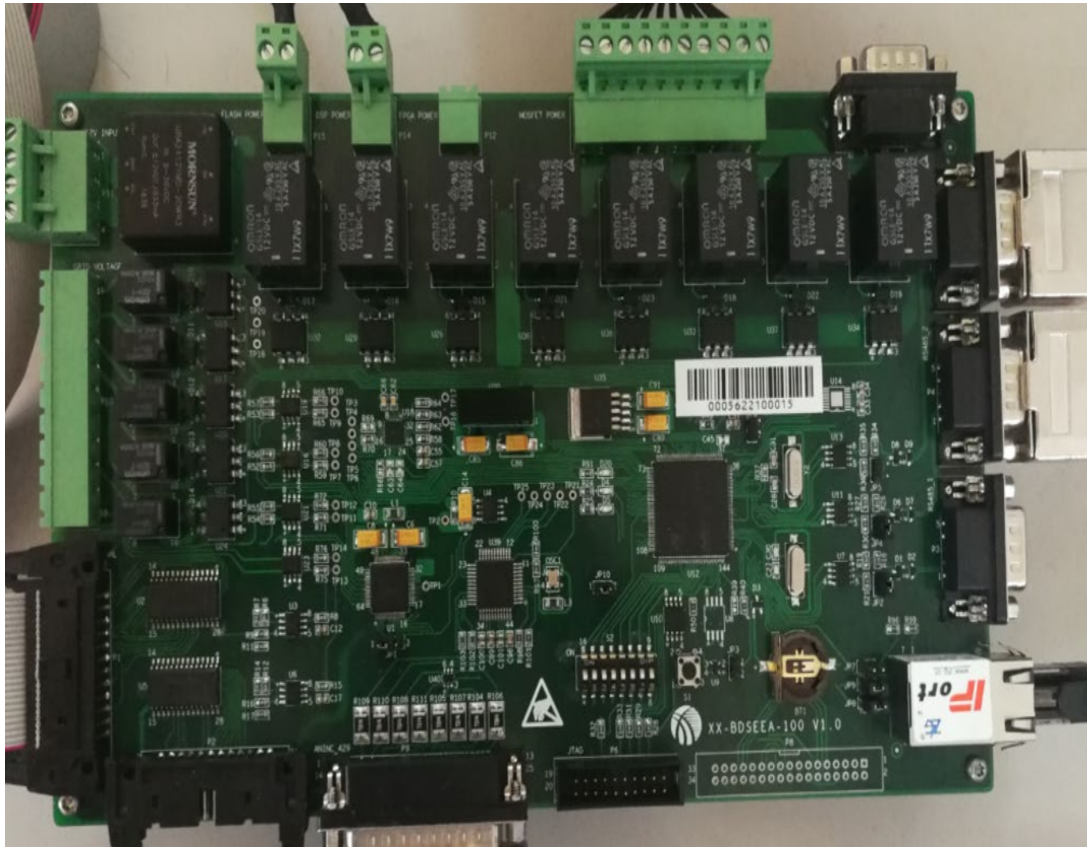


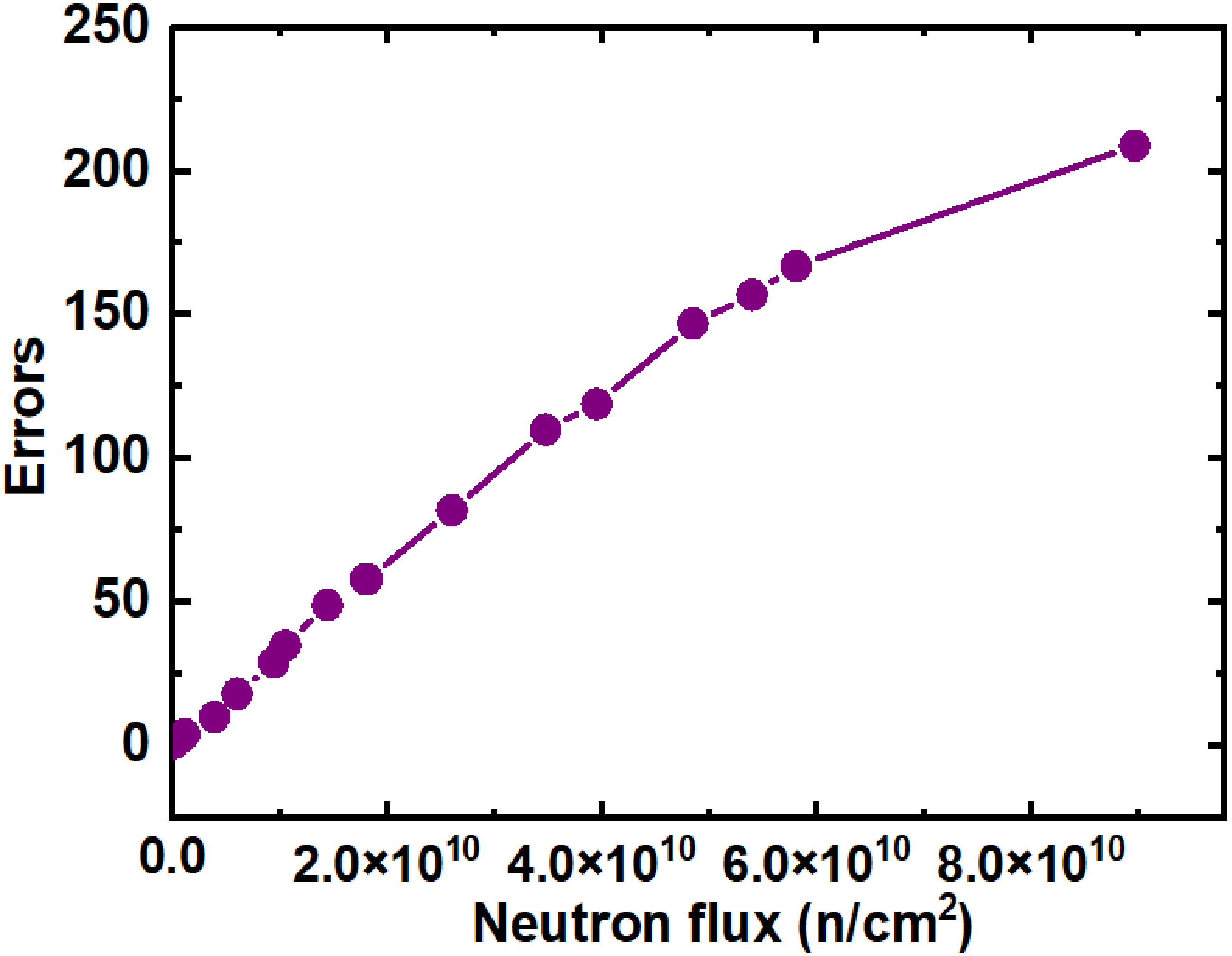


Flood beam spots-DD



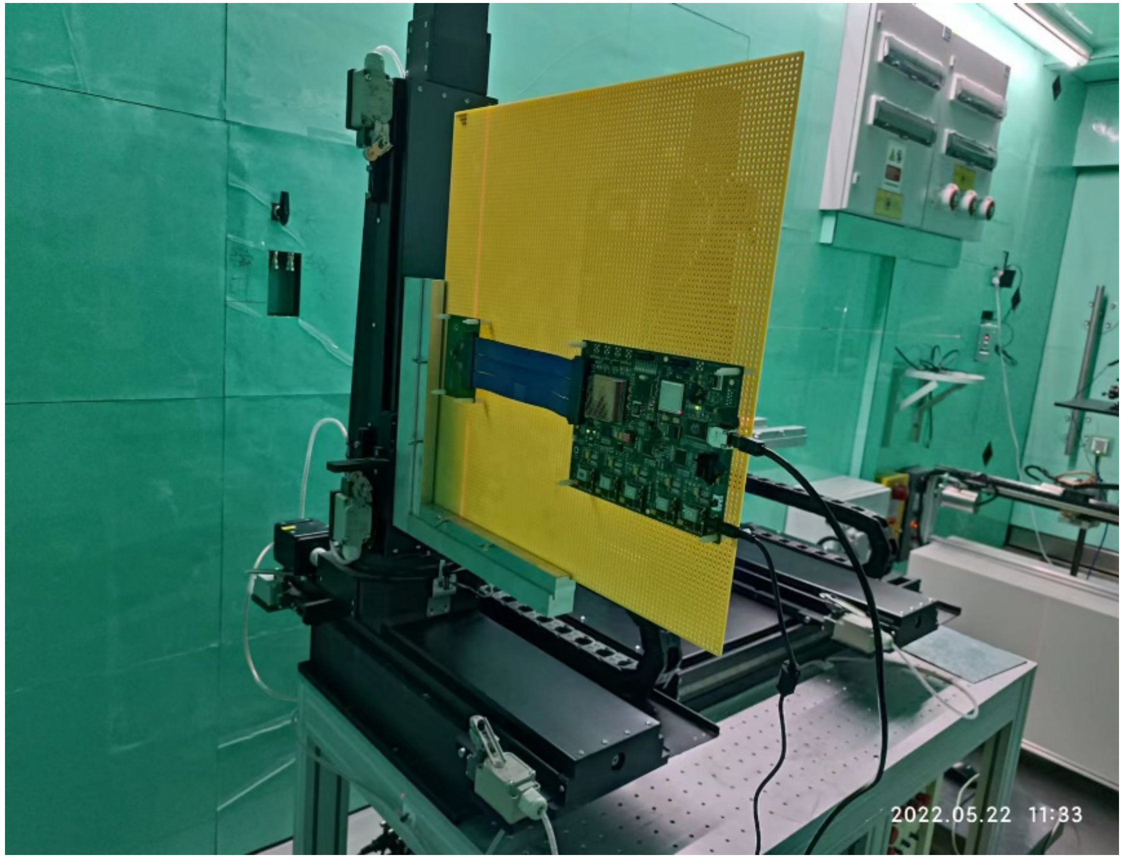
Verifications-neutron flux-FPGA

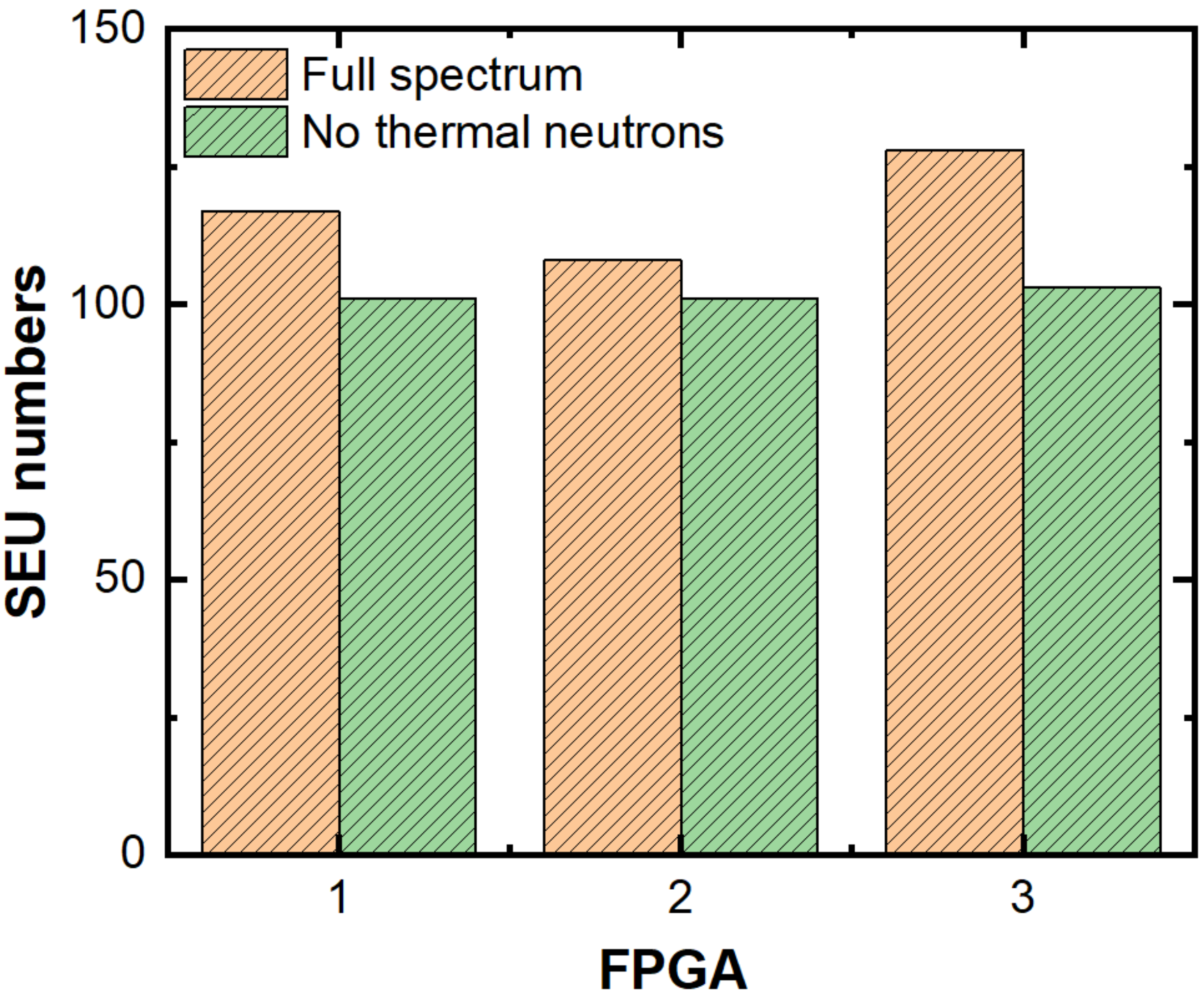




Flux verification was performed by counting the soft errors with different neutron flux. The errors are linear with neutron flux as a whole.

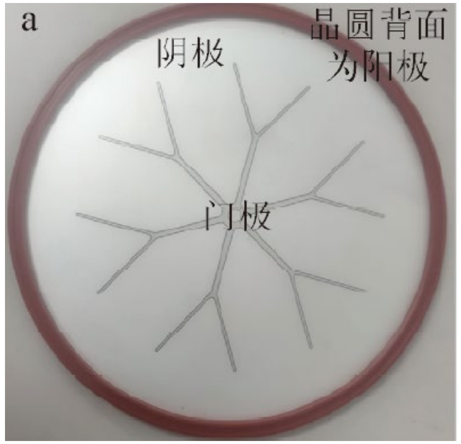
Verifications-Thermal neutrons-FPGA

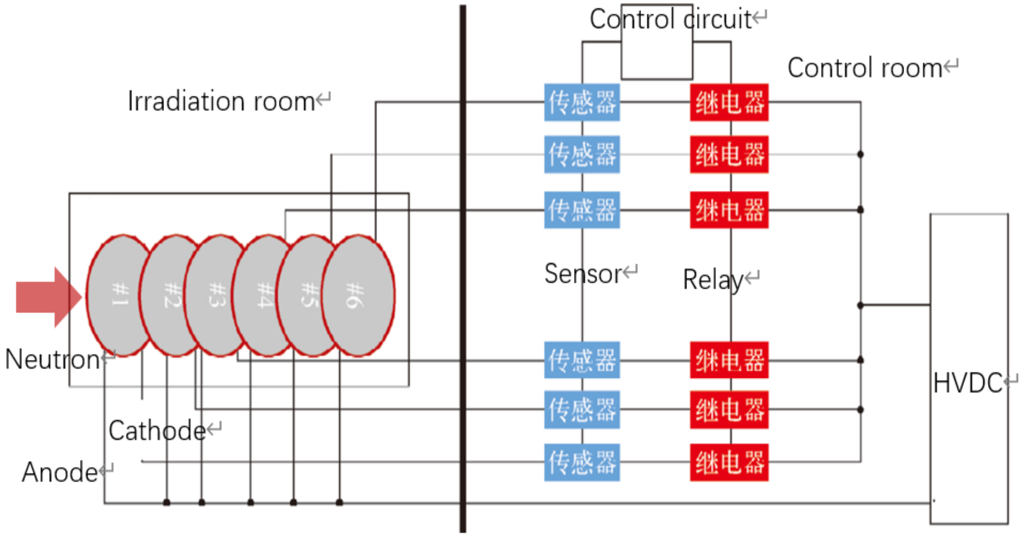


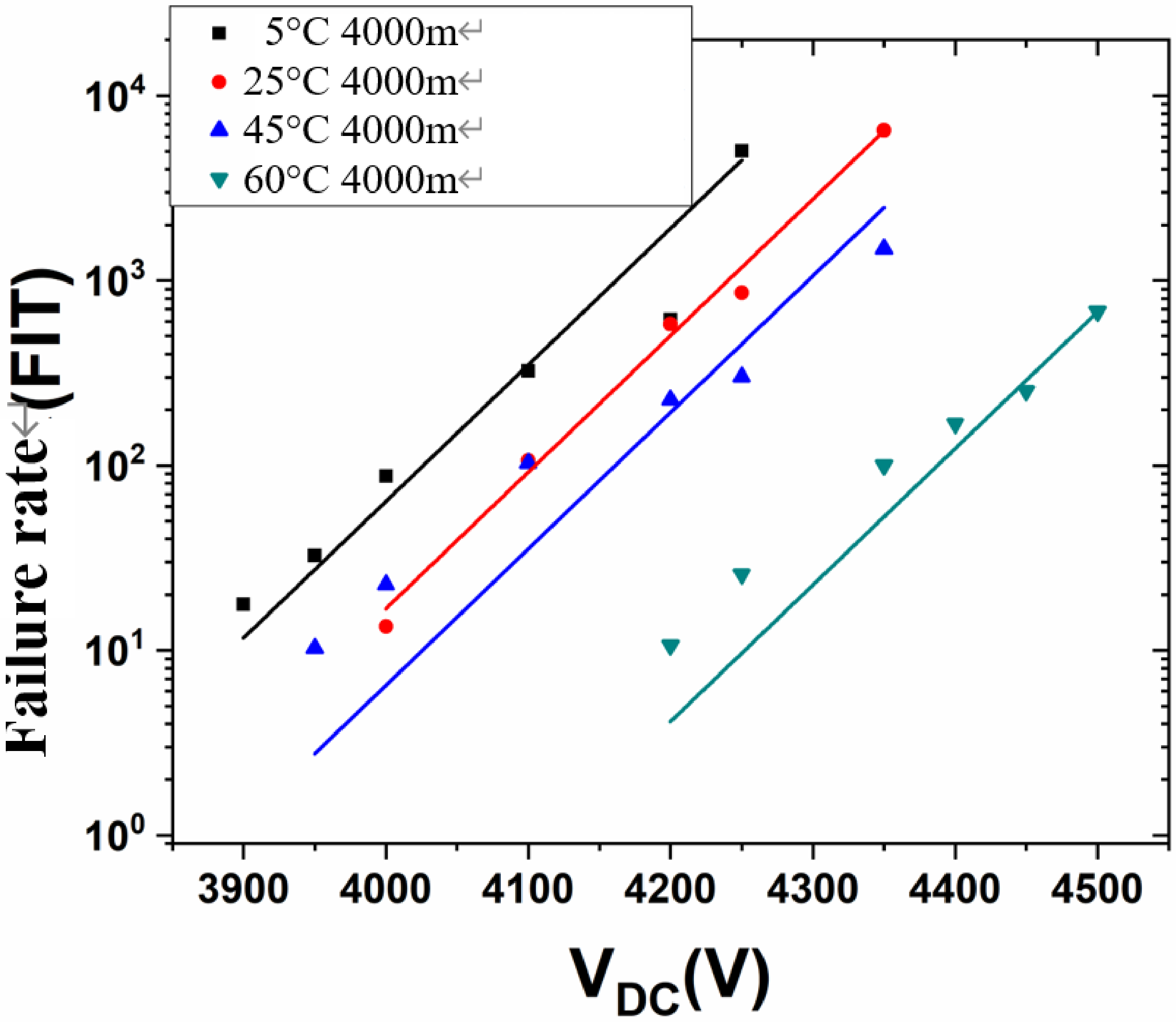


There are about 14 % SEU caused by thermal neutrons. Zhangang Zhang (CEPREI)

Verifications-Temperature-IGBT



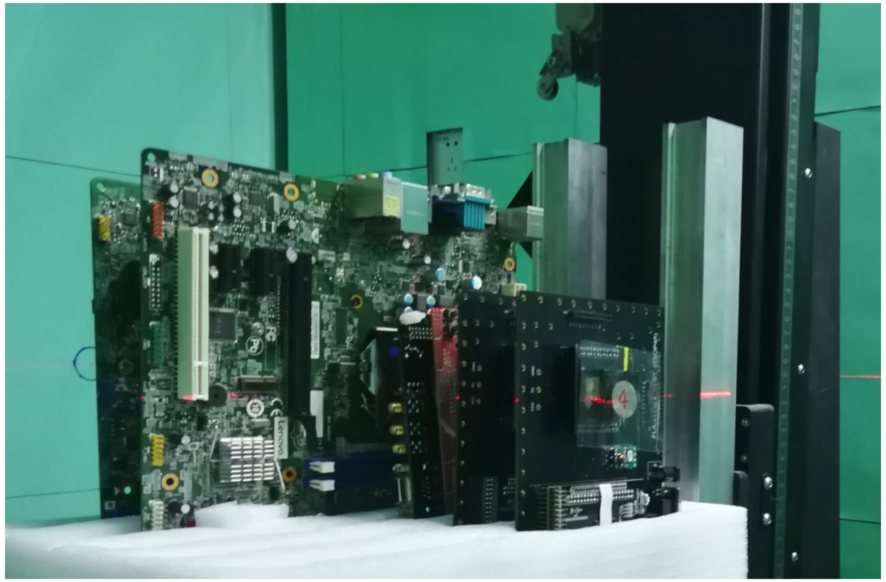


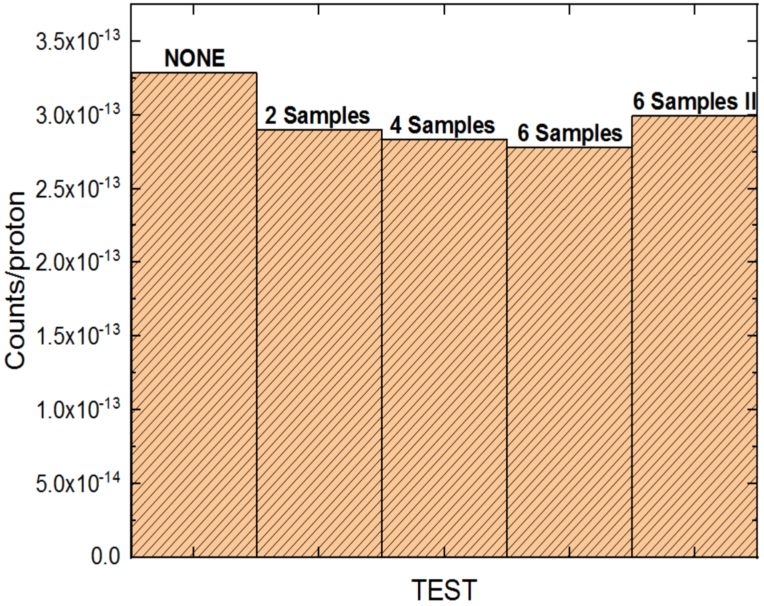


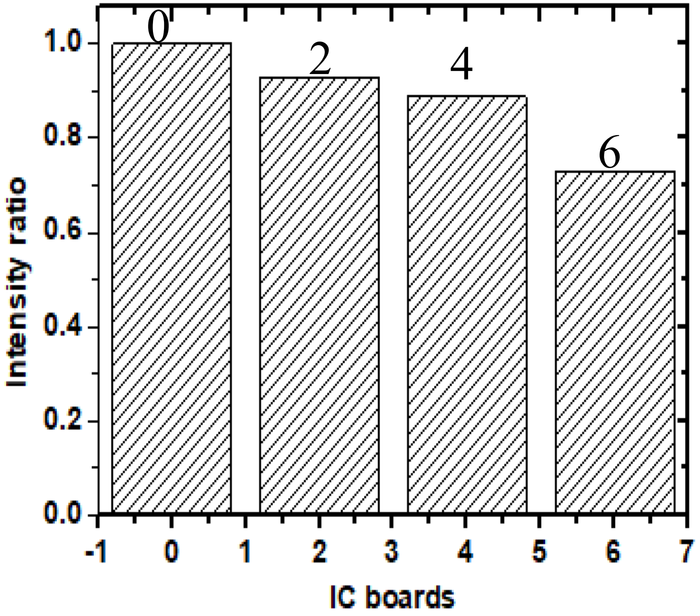
https://link.cnki.net/urlid/11.2044.TL.20230822.1735.012

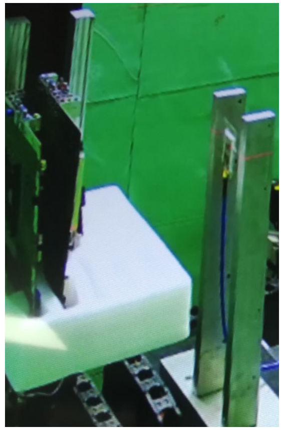
Zhifeng Lei, Chao Peng (CEPREI)

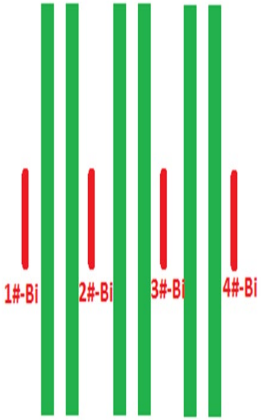
Verifications-multilayer IC boards

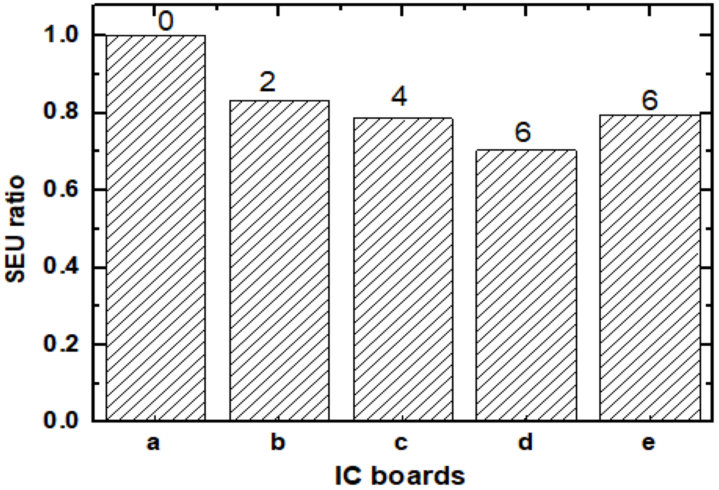


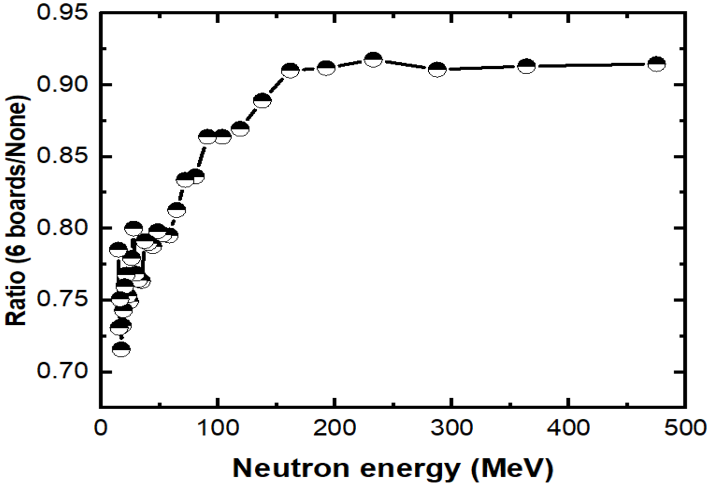






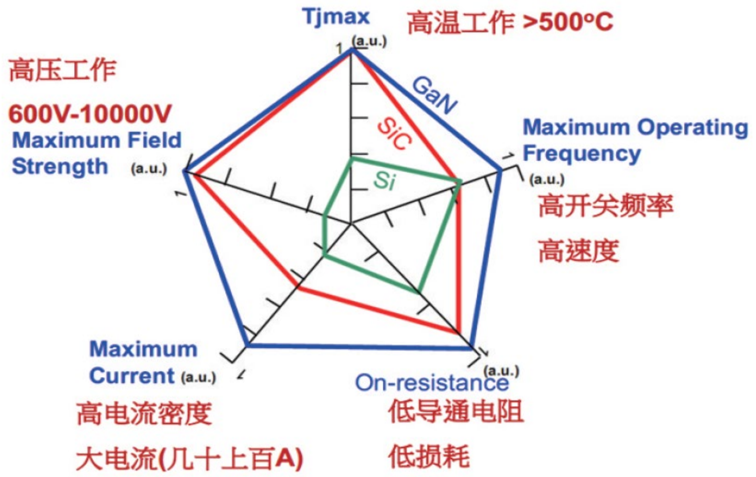


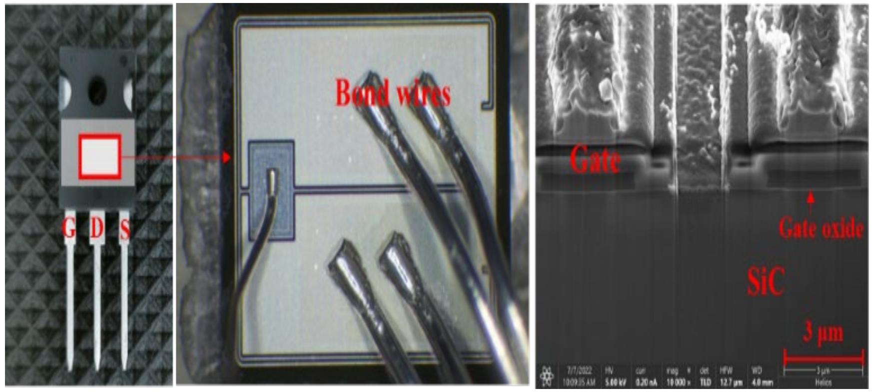


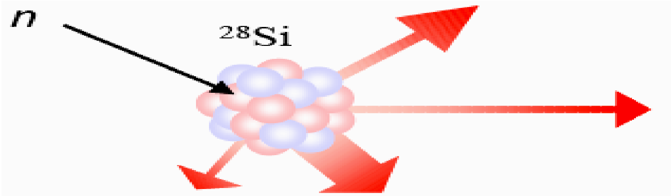


There are ~20% intensity decrease for 6 IC boards, mainly in the range from thermal to ~150 MeV.

Radiation effect-SiC MOSFET

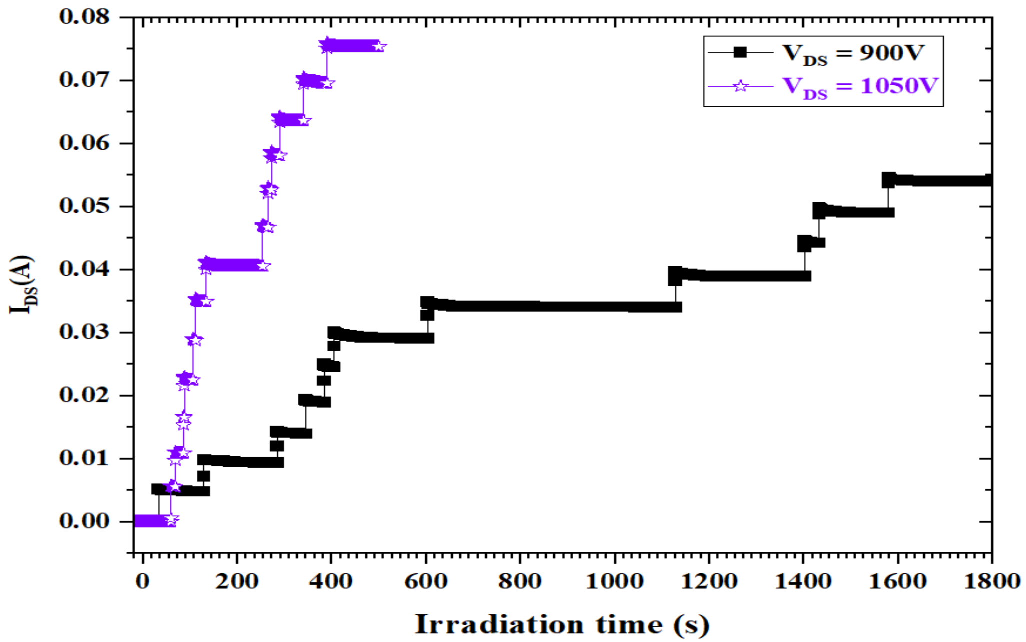






$^{25}Mg + \alpha$	2.75 MeV
$^{28}Al + p$	4.00 MeV
$^{27}Al + d$	9.70 MeV
$^{24}Mg + n + \alpha$	10.34 MeV
$^{27}Al + n + p$	12.00 MeV
$^{26}Mg + {}^{3}He$	12.58 MeV
$^{21}Ne + 2\alpha$	12.99 MeV

From F. Wrobel et al., IEEE Trans. Nucl. Phys., Vol. 47, No. 6, december 2000



Mo L, Yu Q, Hu Z, et al. Single event burnout of SiC MOSFET induced by atmospheric neutrons. Microelectronics Reliability, 2023, 146: 114997.

Summary

- An accelerator based neutron irradiation facility named as ANIS was built at CSNS, 2018-2022.
- ANIS is under scientific commissioning. Neutron measurements, verification experiments, neutron irradiation effects are in progress for universities, institutes and industries. Open operation is coming soon.
- Cooperations are much expected.


Thank you for your attention