Operation and Experiments of the CSNS Back-n Facility

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CSNS
CHINESE ACADEMY OF SCIENCES

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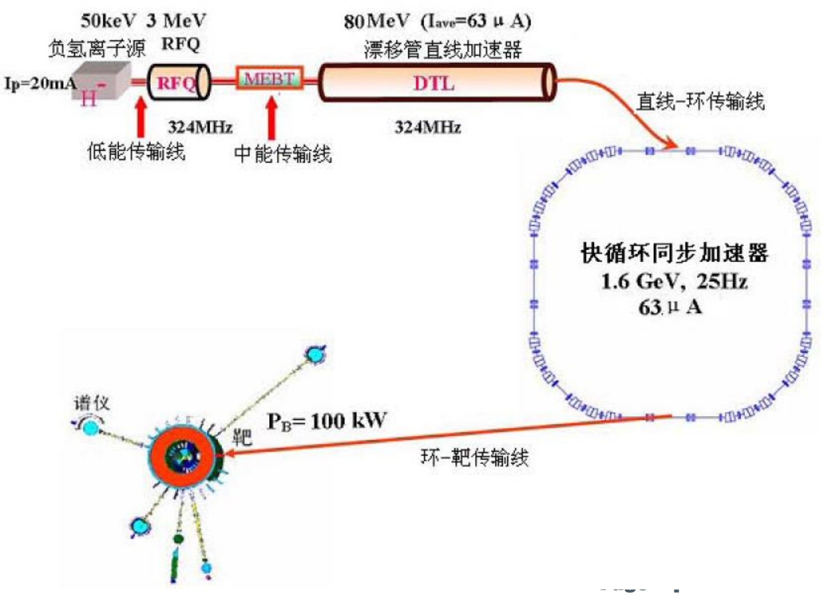
Outline

- Back-n white neutron facility at CSNS
- Initial years' operation
- Experiments at Back-n
- User community and future prospects
- Summary

I. Back-n Facility at CSNS

- CSNS is the first spallation neutron source, also the largest proton accelerator ever built in China, completed in 2018.
- It mainly supports multidisciplinary research based on neutron scattering, but also other research based on proton beams, muon beams and white neutron beams.
- It is based on a high-power proton accelerator complex, with 100 kw at Phase-I, and 500 kW at Phase-II

	CSNS-I	CSNS-II
Beam Power (kW)	100	500
Repetition rate (Hz)	25	25
Target stations	1	1
Average beam current (μA)	63	313
Linac output energy (MeV)	80	300
RCS output energy (GeV)	1.6	1.6



Site for CSNS facility

- The site for CSNS is in Dongguan, Guangdong Province.
- CSNS is the first large scientific facility in southeastern China, jointly invested by the central government and local government. It will promote advanced researches in the economic developed zone of Guangdong-Hong Kong. Total budget: ~2.3B CNY (or 350M USD)

CSNS Beam Power Ramping-up

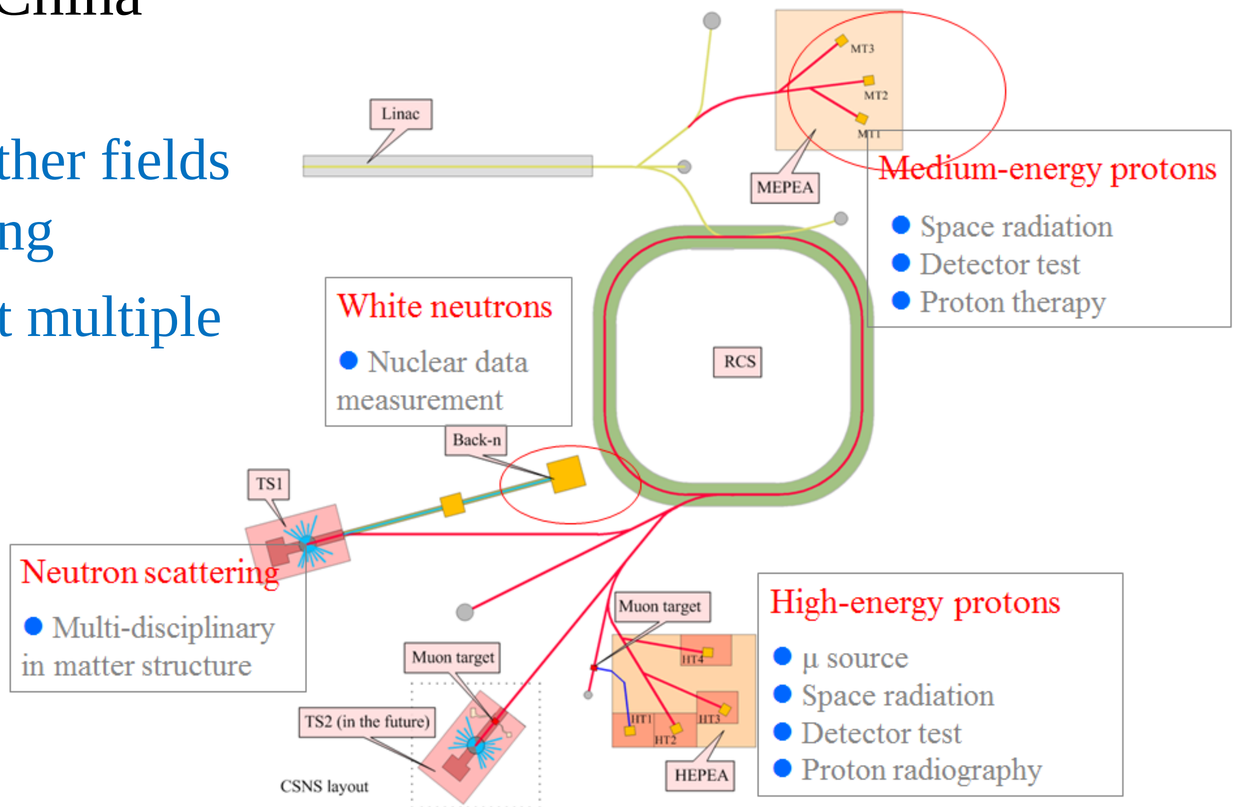
- First beam on target: Aug.28, 2017
- Accelerator-target-instruments joint commissioning: November 1-9, 2017
- Accelerator reached the acceptance beam power of 10 kW: Nov. 9, 2017
- Instrument tuning and Day-one experiments: from January to June, 2018
- From March to December, 2018: 20-25 kW
- Since January 2019: ~ 50 kW
- Since February 2020: ~100 kW, efficiency>90%

CSNS-II upgrading project has been approved in principle by the central government

CSNS as multiple platforms

CSNS is the only large-scale proton accelerator in China until now

- Strong needs from other fields than neutron scattering
- Capability to support multiple platforms
- Phased development



Schematic for CSNS multiple platforms

White neutron sources for nuclear data measurements

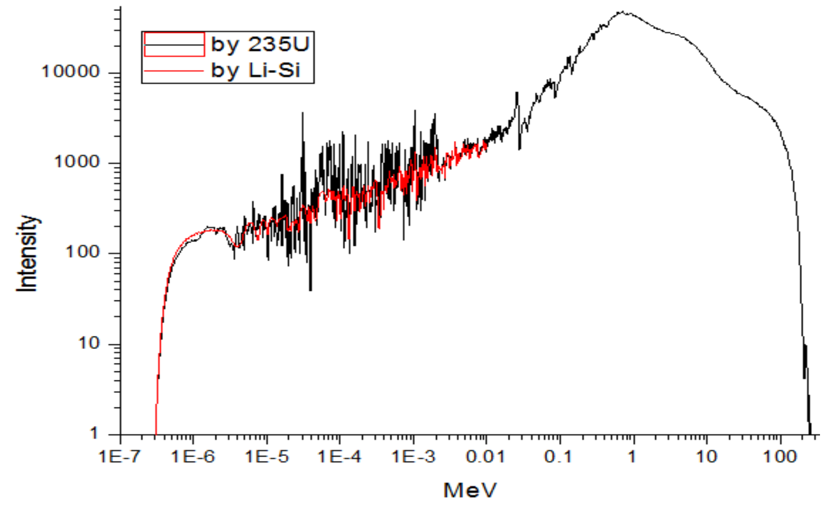
- New advanced nuclear energy
  - –Accelerator-Driven System (ADS)
  - –Thorium-based Molten Reactor
  - –Other IVth-generation reactors
  - –Strong development programs in China
- Nuclear astrophysics and basic nuclear physics
  - –How were the heavy elements from iron to uranium made?
- Others: nuclear medicine, …
- Strong and imminent demand in China
  - –CSNS Back-n: the first WNS in China (before: only reactors, small accelerator-based neutron sources)

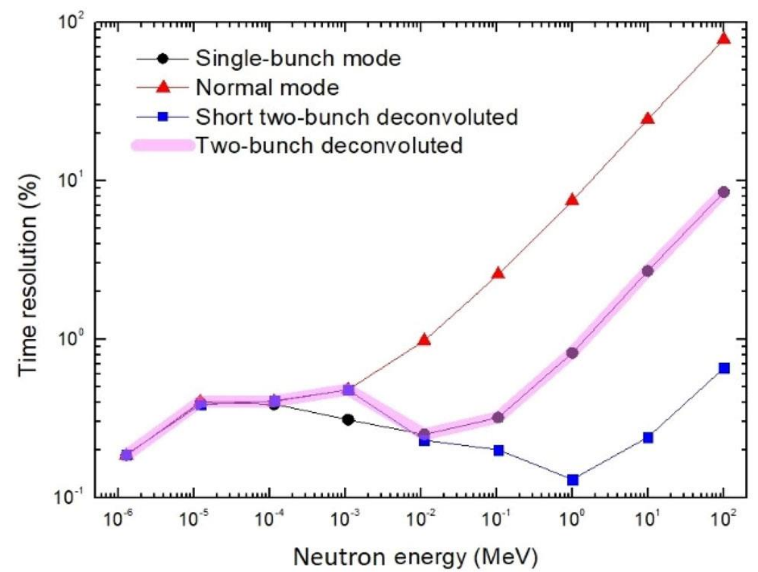
Back-streaming neutrons from the CSNS target

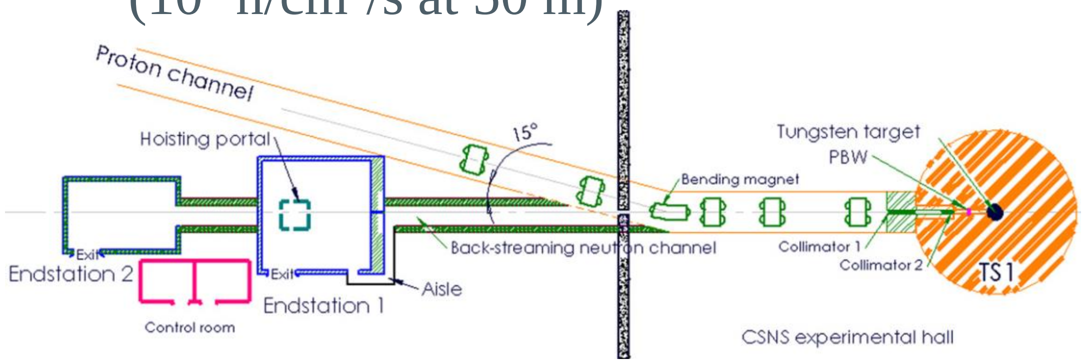
- Beam power on target:

  1.6 GeV, 100 kW
- Back-streaming neutrons from the CSNS target into the RTBT channel
  - Very intense, harmful to the devices in RTBT, should be carefully treated (collimation and bending/neutron stopper)
  - Good energy spectrum and time structure, exploited as white neutron source (first its kind in the world)

  (10^7 n/cm^2/s at 50 m)







- As an expanded facility to CSNS, the Back-n WNS was added late in the CSNS construction, and supported by a consortium of five institutions, completed simultaneously with CSNS (2018.3)
- Back-n as a multi-purpose neutron facility
- Back-n passed performance inspection and assessment in Nov. 2020

Back-n operation modes

- Parasitic modes (normal mode, >4000 hrs per year)
  - No influence to neutron scattering programs
  - **Basic mode**: RCS as its nominal setting (proton rms bunch length: 13 ns in rms; 2 bunches)
  - **Short-bunch mode**: RCS set to have shorter bunches (3.9 ns)
- Dedicated WNS modes (100-300 hrs per year)
  - With reduced beam power: 50% or 30% of the nominal one (Phase-I: 50 kW or 30 kW) (proton bunch down to 3.3/1.5 ns)
  - Single bunch extraction: 50% power, 13 ns in rms
  - Accelerator: change chopping factor in LEBT and RF pattern in RCS
- Machine studies
  - Achieved (in rms): 6.9 ns @30 kW, 14 ns @50 kW (normal: 26.4 ns @ 100 kW)

Beam spots and fluxes

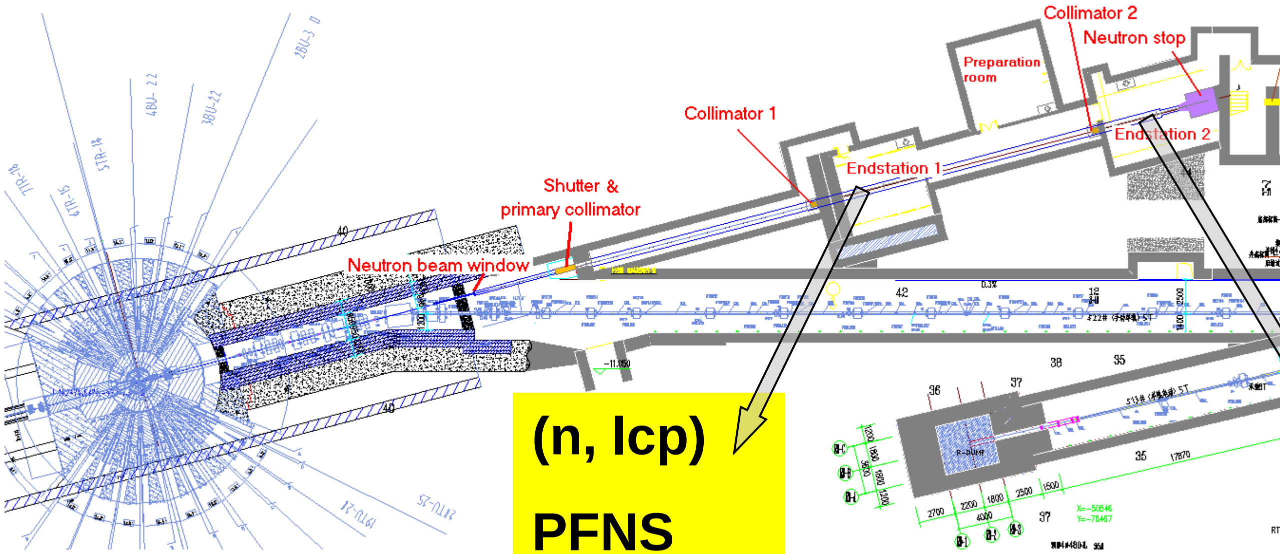
- Four sets of standard beam spots are designed, but more combinations are possible
- Using different apertures of the shutter and two collimators, with help of auxiliary collimators in the shielding wall
- Clean definition of spot (minimizing halo)
- The smallest spot is for largely reducing flux for special experiments.

ES2 spot (mm)	Shutter (mm)	Coll#1 (mm)	Coll#2 (mm)	ES1 spot (mm)	ES1 flux (/cm^2/s)	ES2 flux (/cm^2/s)
Φ20	Φ3	Φ15	Φ40	Φ15	1.3E5	4.6E4
Φ30	Φ12	Φ15	Φ40	Φ20	1.6E6	6.1E5
Φ60	Φ50	Φ50	Φ58	Φ50	1.6E7	6.9E6
90×90	78×62	76×76	90×90	75×50	1.8E7	8.6E6

(Simulation/exp. at 100 kW)

Field I: Nuclear data measurements

- All major data measurements suitable for TOF method are planned at the Back-n
- Planned spectrometers: Multi-layer ionization chamber for (n,f) and (n,tot), 4π BaF_2 and 4-unit C_6D_6 for (n,γ), ΔE-ΔE-E array for light charged particles emission, 4π HPGe for (n, n'γ/2nγ), PPAC+scintillators for PFNS, and TPC for fission and LCP



(n, lcp)

PFNS

Others

(n, tot)

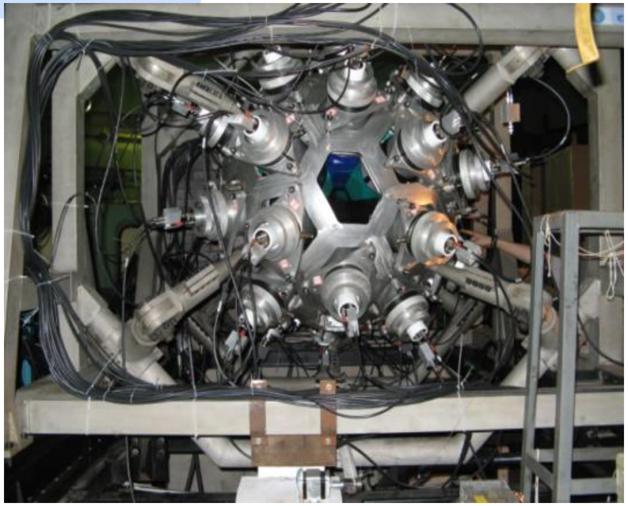
(n, f)

(n, γ)

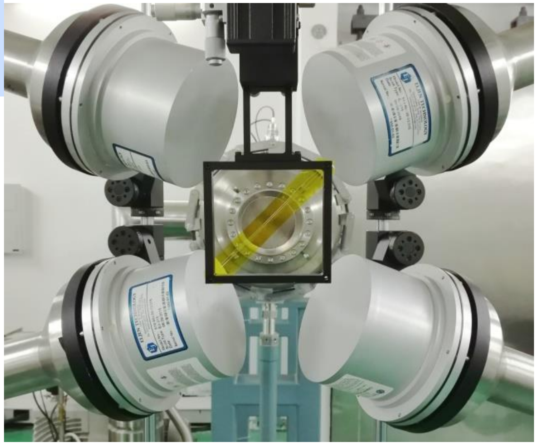
(n, n'γ/2nγ)

1 - (n,γ) reaction cross section measurements

GTAF-II



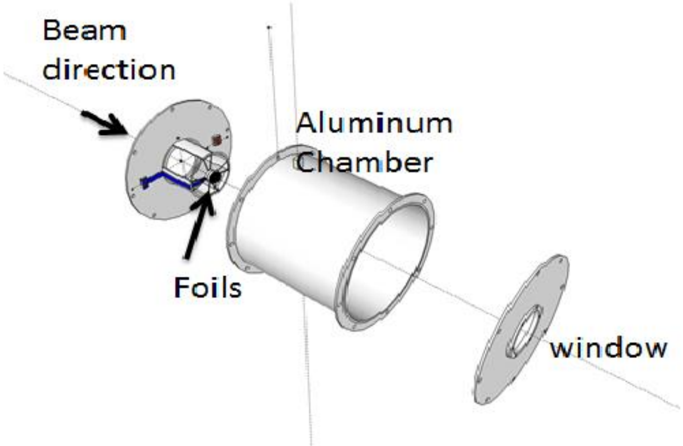
C_6D_6



- A 4π total γ absorption detection array based on BaF_2 crystals :
  - GTAF-II (40 units) since in late 2019, GTF-III (90 units) planned
  - Energy: eV – 1 MeV continuous
  - Solid angle: ~90%; Eff. : >90%; Time res.: <5 ms
  - Measurements: (n, γ) for actinides and minor- actinides
- 4-unit C_6D_6 is in use (Left)
  - High detection efficiency for single γ, less sensitive to neutrons

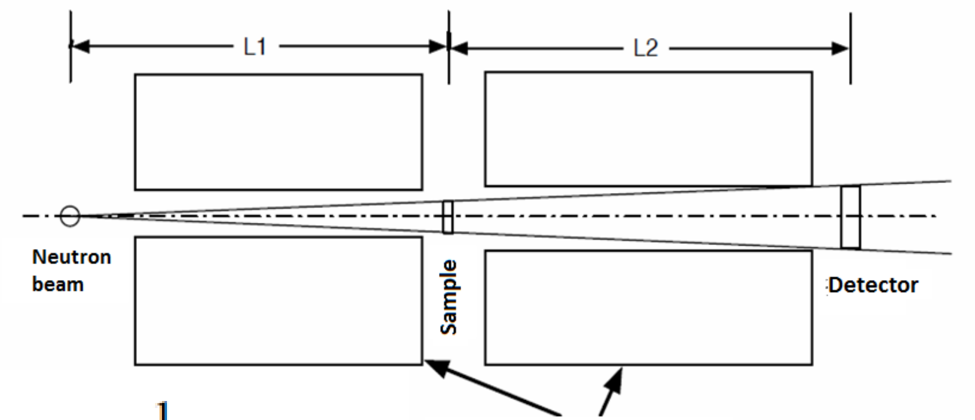
2 – (n, f) cross-section measurements

FIXM Spectrometer



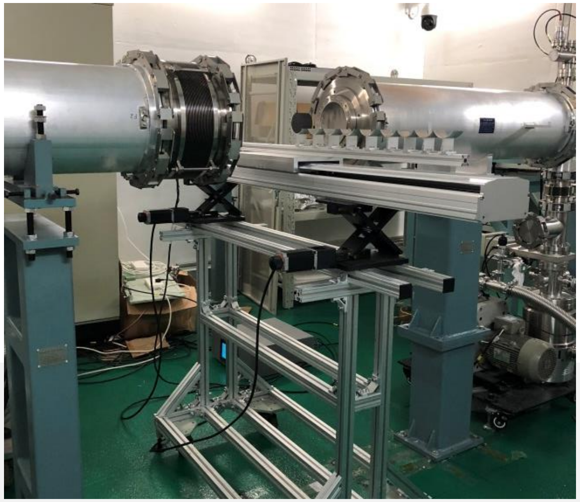
- 8-layer fission chamber, several samples simultaneously
- Fast response (<30 ns), resistant to α pile-up
- Energy: eV – 20 MeV continuous
- Measurements: (n, f) for actinides and minor- actinides
- Sample coating difficult, relevant techniques are under development
- **TPC under development**

3 – Total cross-section measurement



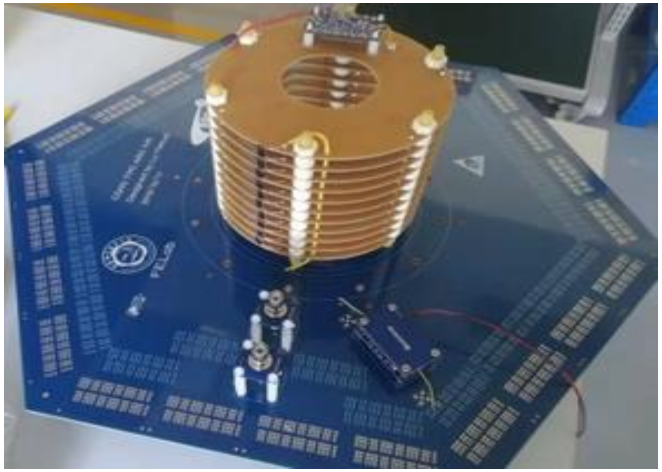
$$\sigma_t = \frac{1}{N}(-\ln T)$$

NTOX spectrometer



- Measuring transmission thru the sample
- Energy: eV - 20 MeV, continuously
- Sample changing system in ES#1
- Different detectors for specific energy ranges in ES#2
  - Current: 8-layer fission chamber
  - In development: scintillators and other types
- Also used for monitoring neutron energy spectrum and flux

4 - (n, lcp) reaction measurements

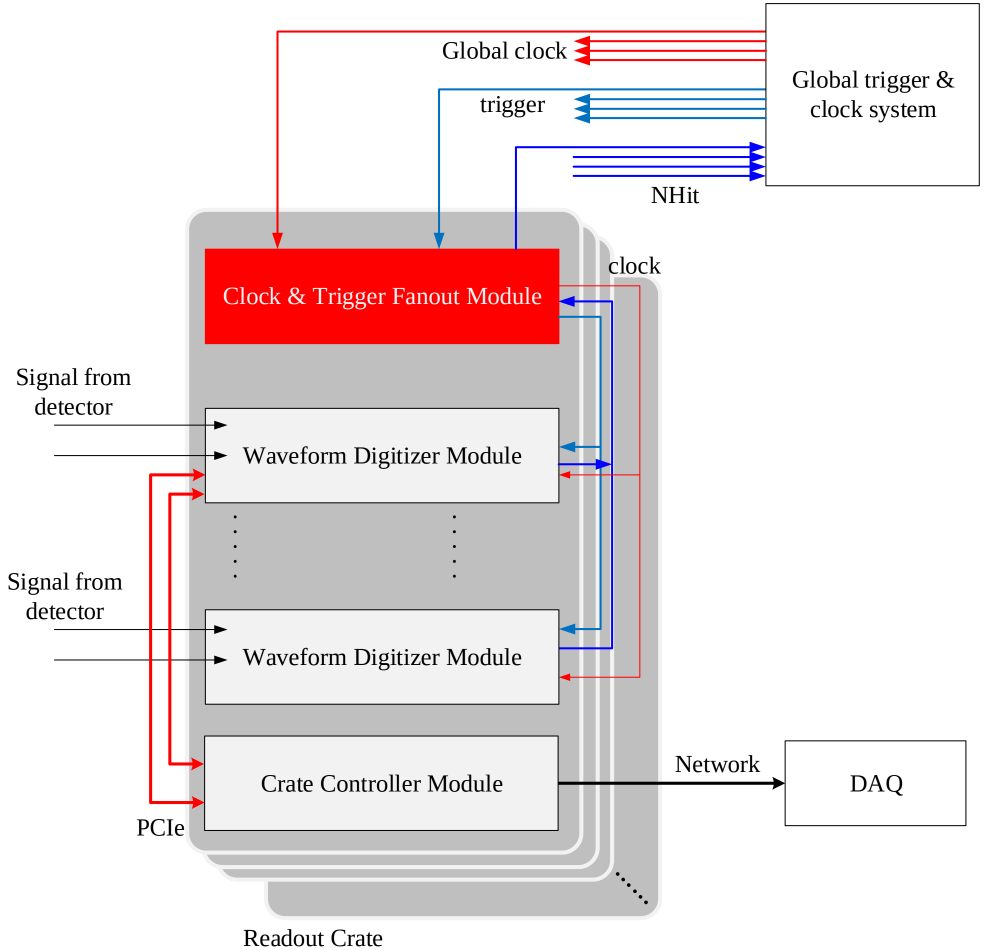


- Meas.: (n, p/α/d/t) cross-section and energy spectrum
- A vacuum chamber (D~1.1 m) and a charged particle detection array
- ΔE-ΔE-E telescope, 16 units (in 2 groups) (MWPC+Si+CsI(TI)) for particle discrimination
- Energy: 0.5-100 MeV (proton), continuously
- Different combinations used
- A TPC prototype is under development/testing

5 - Gamma spectroscopy and inelastic cross-section measurements

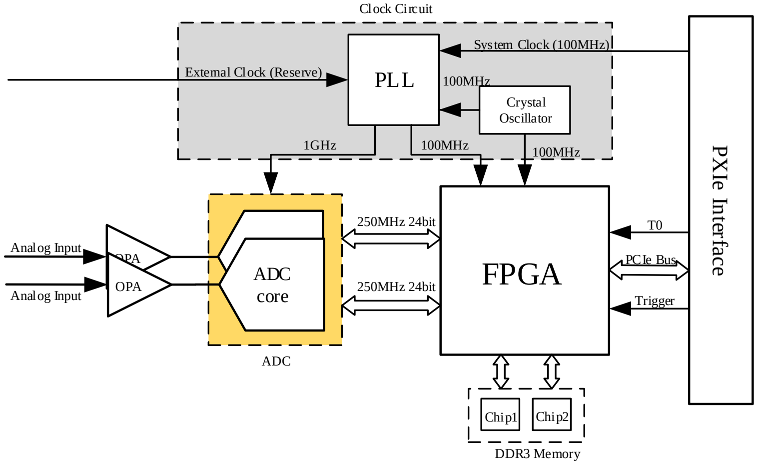
- Currently using users-owned detectors, different setups of HPGe and $LaBr_3$ detector units

Readout Electronics



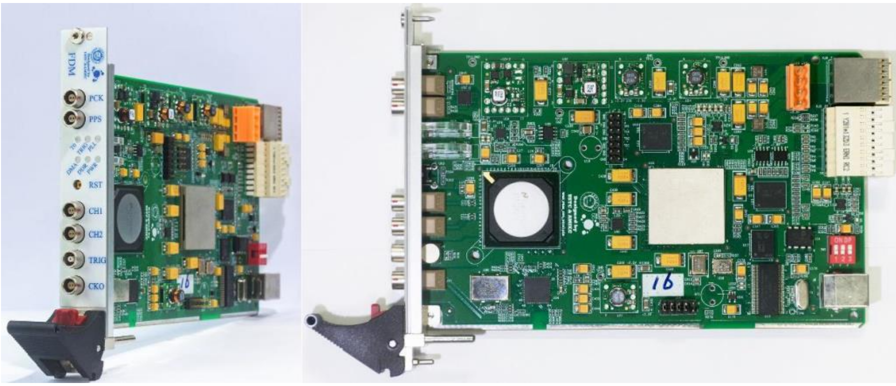
Readout architecture based on PXIe platform
(Common electronics for all the detectors)

- Features:
- PXIe high speed serial bus
- Data transmission simultaneously
- Clock & trigger distributed through dedicated differential STAR bus on backplane
- Crates are connected with Ethernet to DAQ
- Digitizer based on Folding ADC: 12bit@1GSPS (large dynamic range)

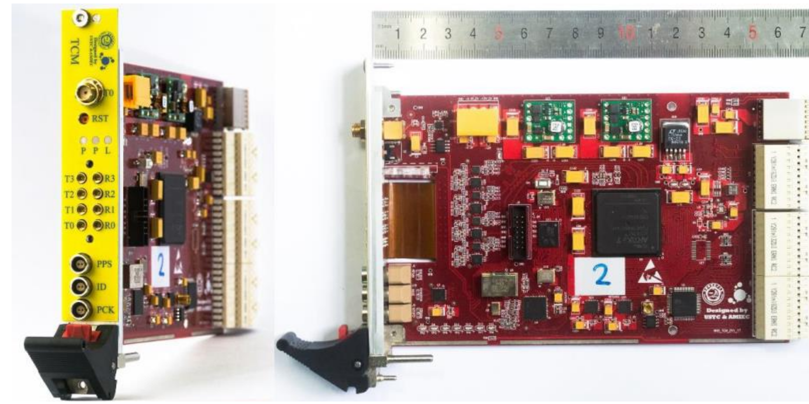


Digitizer based on folding ADC
trade off between power consumption and precision

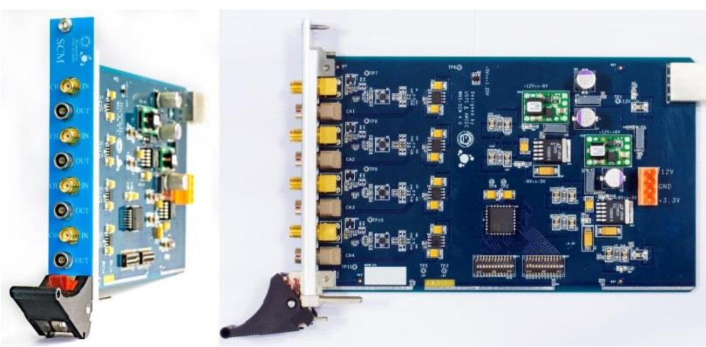
Cards for Electronics



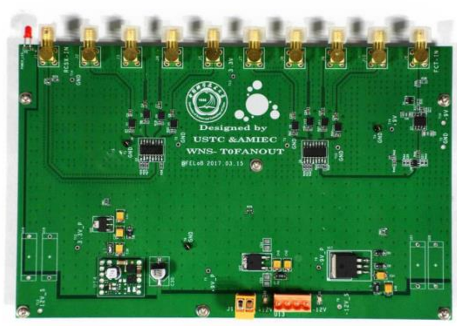
Field Digitalization Module (FDM): @2ch



TCM: trigger & clock



SCM: signal conditioning @4ch



TFM: T0 fan-out

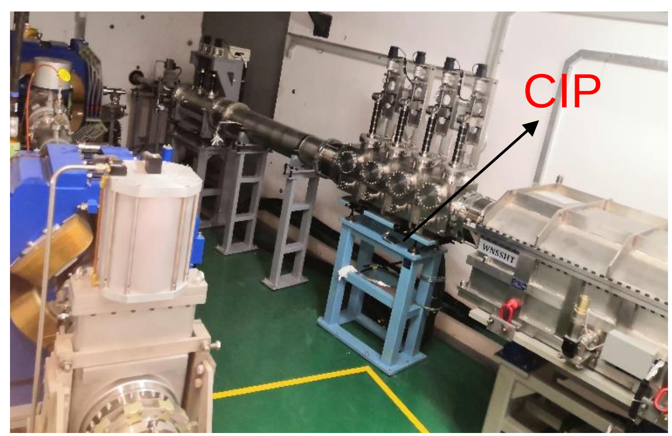
At work

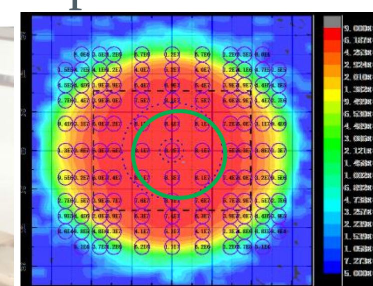
100-channel electronics (in 2 cabinets, ES#1/2) at work

Field II: Irradiation tests

- High-flux, good energy spectrum (eps. high energy) neutron beam very suitable for semiconductor SEE tests
  - High demand in China, both from industry and research
  - In ES#1 or ES#2, some as secondary parallel experiments in ES#2
- High-dose irradiation
  - Neutron induced damage in diverse types of samples (long-term experiments in parasitic mode)
  - Locations: Common Irradiation Platform (CIP), neutron damp

NTOX sample changer

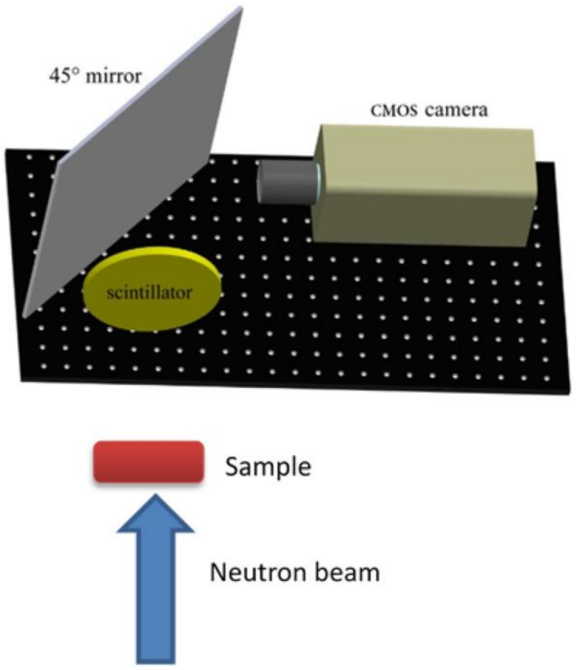




~10^8 n/cm^2/s

Field III: Imaging and element identification

- Neutron imaging using a white neutron beam
  - Possible to identify element composition when taking transmission images
  - Current: use gated-CMOS camera
  - In development: B-doped MCP
- Element identification
  - Using characteristic resonances by either total cross-section or neutron capture measurements
  - Current: successively with total cross-section (NTOX)

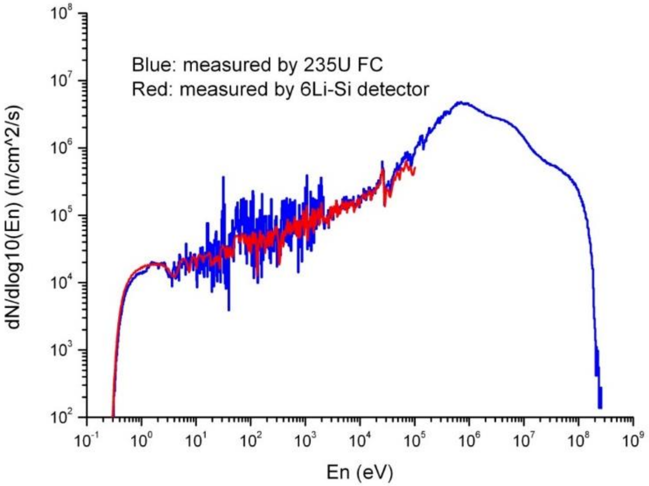


Field IV: Detector Calibration

- Wide-spectrum neutron beam with TOF, very suitable for detector calibrations
  - Different types of detectors for different purposes
  - Sometime, single-bunch dedicated CSNS mode is used (beam power halved) (2-dimensional two-bunch unfolding method in testing)
- The project to make the Back-n a standard neutron source in dosimetry has started.

II. Initial years' operation

Commissioning and Day-one experiments



- Period: November 2017 to June 2018
- Background measurements:
  - Bonner balls, liquid scintillators, NaI
- Beam characterization:
  - all monitors (T0, profile, energy spectrum, flux, time structure)
- Day-one experiments
  - Fission cross-section measurements: FIXM, U-235,238,236
  - Total cross-section measurements: NTOX (FIXM), C-12
  - Capture cross-section measurement: C_6D_6, Au-197, Tm-169
  - Light charged particles emission: LPDA (15 Si), Li-6

Initial years' operation

- As a part of the CSNS facility, Back-n has been operating very efficiently
  - Beam time: 4500 hrs/year
  - Number of experiments: ~50/year (including parallel experiments in ES#1 and ES#2)
  - Types of experiments: nuclear data measurements, detector calibrations, irradiation effects, imaging and element identifications
  - Further development on detectors/spectrometers: new FIXM, new fission chamber for NTOX, add-in GTAF-II, LPDA in final configuration, new common irradiation platform, TPC under development, nMCP under development
  - Machine studies: experimental methods

2018.3-2021.5 Back-n Experiments

Year	2018	2019	2020	2021/1-5
No. experiments	46	60	52	25
Beam time	4045	5742	4702	~2000

Including experiments for machine studies

III. Experiments at Back-n

List of cross-section measurements

- Neutron capture

C6D6: ^{169}Tm, ^{197}Au, ^{57}Fe, Se, ^{89}Y, ^{nat}Er/^{162}Er, ^{232}Th, ^{238}U, ^{93}Nb, ^{nat}Cu, ^{nat}Lu, $^{151/153}$Eu, ^{nat}Ir, ^{nat}Re, ^{nat}Ta, ^{nat}Ag, ^{165}Ho

GTAF-II: ^{169}Tm, ^{197}Au, ^{93}Nb

- Total cross-section

^{12}C, ^{27}Al, ^{9}Be, ^{7}Li, ^{nat}Fe,

- Fission cross-section

^{235}U, ^{238}U, ^{236}U, ^{232}Th, ^{239}Pu, ^{232}Th+(n-p)

- Light charged particle emission

LPDA: ^{6}Li(n, x), ^{10}B(n, x), (n-p), ^{63}Ni, (n-d), ^{17}O

TPC proto: ^{12}C, ^{14}N

- In-beam gamma (inelastic cross-section, nucl. structure)

^{56}Fe (n, n'), Mo, ^{16}O, ^{nat}Ru, ^{nat}Lu, ^{nat}Mo, ^{nat}Ti, ^{178}Hf

Highlights

- Measurements on the standard cross-sections highly appraised by the international community at the IAEA Consultancy (Virtual) Meeting on Neutron Data Standards, Oct.12-16, 2020
  - ^{6}Li(n, t), ^{10}B(n, α), H(n, n) and ^{238}U(n, f)/^{235}U(n, f)
  - Expanding the energy range
  - Providing more reference data
  - Providing complete angular distributions for light elements
- This gives us confidence that Back-n can perform high-level experiments

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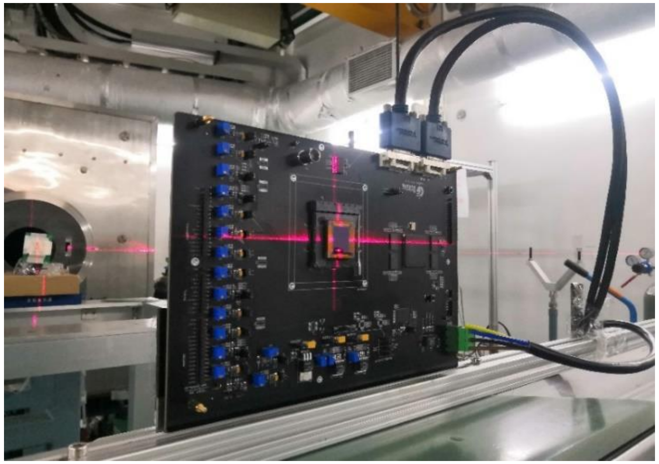
BACK-N CSNS-WHITE NEUTRON SOURCE

Irradiation and Detector Calibration Tests

- Single event effects (high-energy neutrons) in semiconductors
  - Until 2020.12: about 41 experiments, about 900 samples
  - Users are from industry, research institutions, and universities
- Radiation damage, intended activation and modification in material properties by radiation
  - Samples: semiconductors, optical crystals, detectors, minerals, accelerator materials in radiation-hard environment, etc.
- About 5 detector calibration tests per year

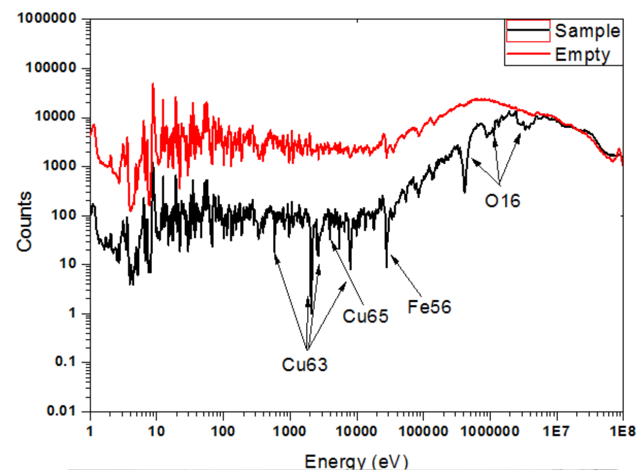


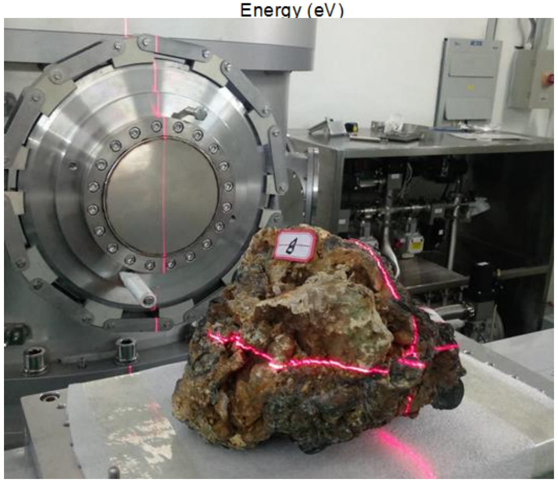
Neutron imaging and element identification

- Currently methodology study
  - Exploiting characteristic resonances (NTRA) to identify element/isotope composition using NTOX
  - Exploiting neutron resonance transmission imaging (NRTI) using gated CMOS camera (with NTOX)
  - Focus on archaeological items, characteristic samples
  - Some success: NRTA effective for most elements, NRTI effective for heavy elements
  - More studies needed

Supported by an NSFC key fund

Sample from sunk ship South China Sea

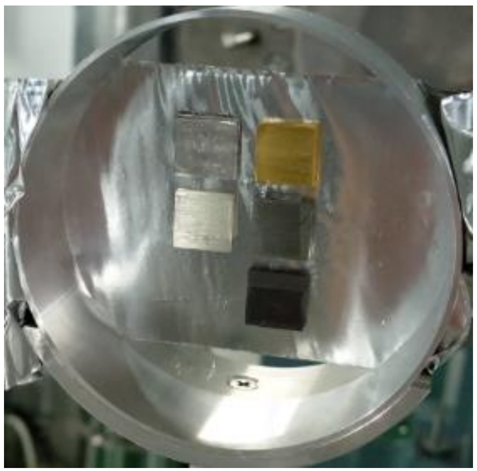




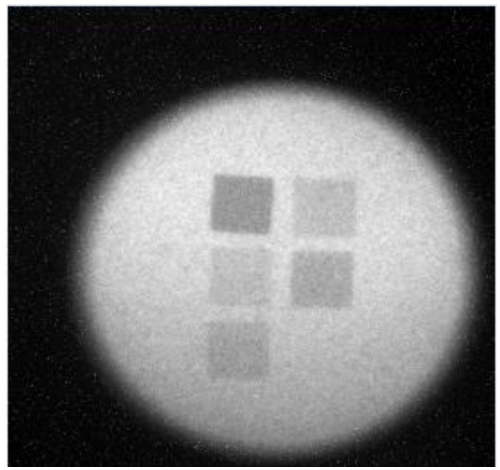
Experiment with a gated CMOS camera

Sample elements:

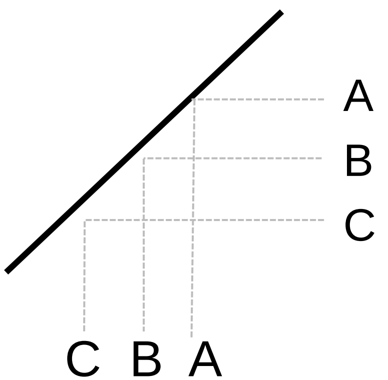
Au、Ag、W、Ta、In

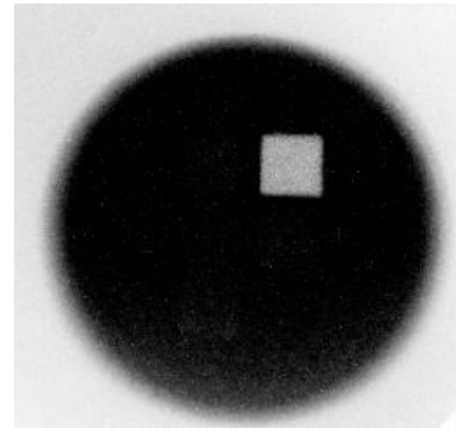


Simple transmission image

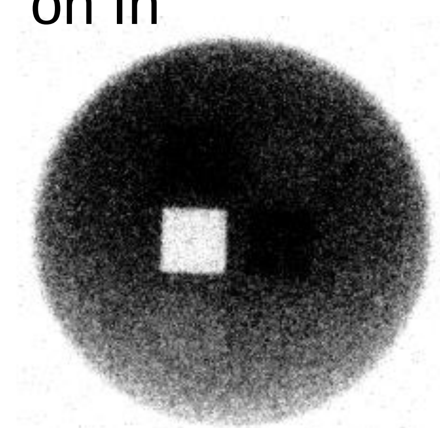


Optics:





Resonance selection on In



Resonance selection on W

IV. User community and future prospects

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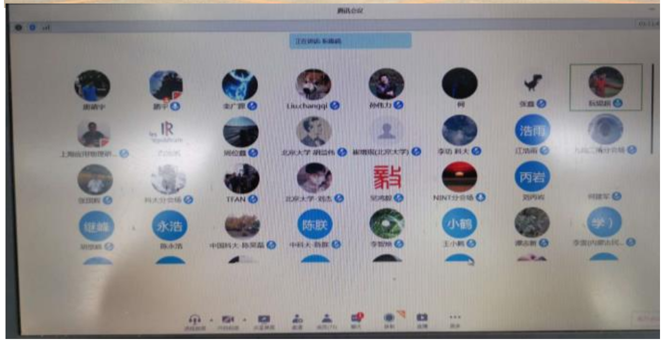
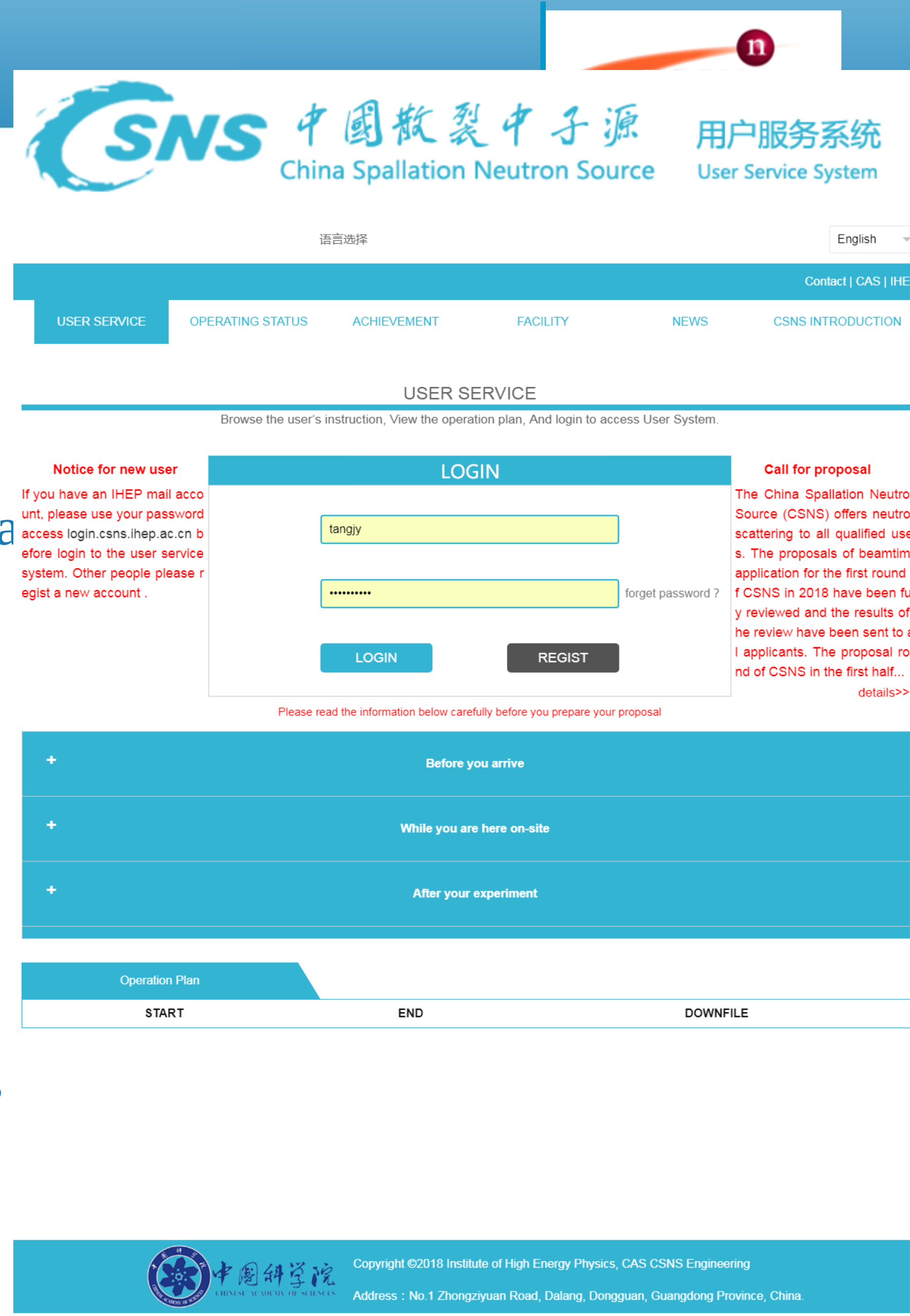
User community

- ✓ Formed in May 2017, with good representation from the Chinese nuclear physics and technology institutions
- ✓ It is an integrated part of the general CSNS user community, independent operation
- ✓ The Back-n Collaboration: facility staff and core users; collaborative groups on topical research areas also established
- ✓ Welcome international users
- ✓ Annual user workshop started from 2017



User program

- Since September 2018, selective user program has been implemented
- User Committee is responsible for evaluating and proving proposals, twice a year in the moment. Short and urgent beam applications are being evaluated and arranged by the managing team.
- On-line applications and reviews are being started from May 2019
- Applications from outside China is welcome by emails (tangjy@ihep.ac.cn), and will be treated case by case



Future prospects

- CSNS-II Upgrade Project
  - Approved in principle, expected to start the construction in 2022
  - Beam power from 100 kW to 500 kW, enhancing the Back-n capability
- Efforts to find financial resources to support new large spectrometers continue:
  - GTAF-III for neutron capture: 90 units BaF_2 array
  - GAEA for gamma spectrum: 90 units (50 HPGe, 10 Clover, 10 Planar, 20 $LaBr_3$) detector array, 120-channel
  - FINDA for PFNS measurements: multi-layer fission PPAC, 48 Liquid Scint., 16 Li-glass
  - MTPC for fission products and LCP: in design

Summary

- Back-n WNS has been operating efficiently in the initial years
- Experiments in all four research fields in deployment
  - Nuclear data measurements
  - Detector calibration
  - Chips SEE and irradiation applications
  - Neutron resonance transmission imaging and element analysis
- Highlight
  - Some experiments (standard cross-sections) gain international recognition
- Big efforts still needed to master the methods with the intense white neutron beam
- Welcome international collaboration and users

Thanks for your attention!