Nuclear data experiments and beam applications at the CSNS Back-n

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CSNS CHINESE ACADEMY OF SCIENCES

Outline

- Introduction to CSNS
- Back-n white neutron facility at CSNS
- First year experiments on nuclear data measurements and applications
- User community and future prospects
- Summary

I. Introduction to CSNS

- CSNS is the first spallation neutron source, also the largest proton accelerator ever built in China.
- 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

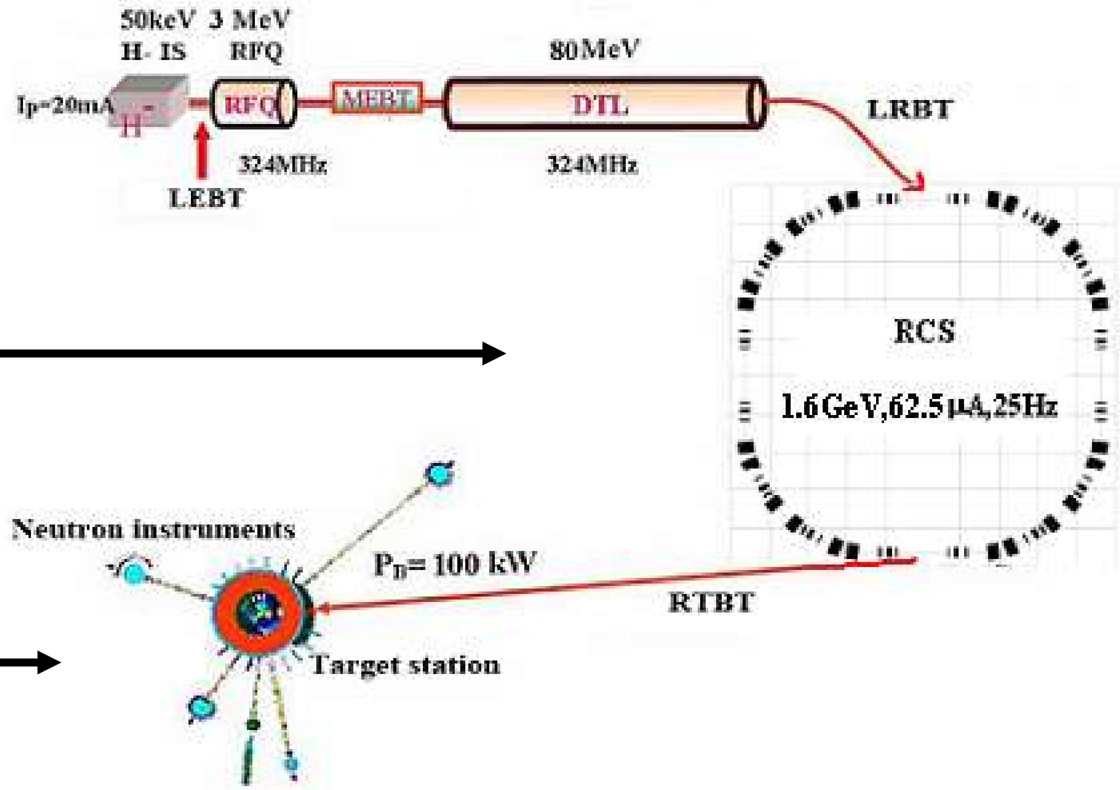
	CSNS-I	CSNS-II
Beam Power (kW)	100	500
Repetition rate (Hz)	25	25
Target stations	1	1 or 2
Average beam current (μA)	63	313
Linac output energy (MeV)	80	250
RCS output energy (GeV)	1.6	1.6

Layout of CSNS Core Facility

Linac

Rapid Cycling Synchrotron

Target and Instruments



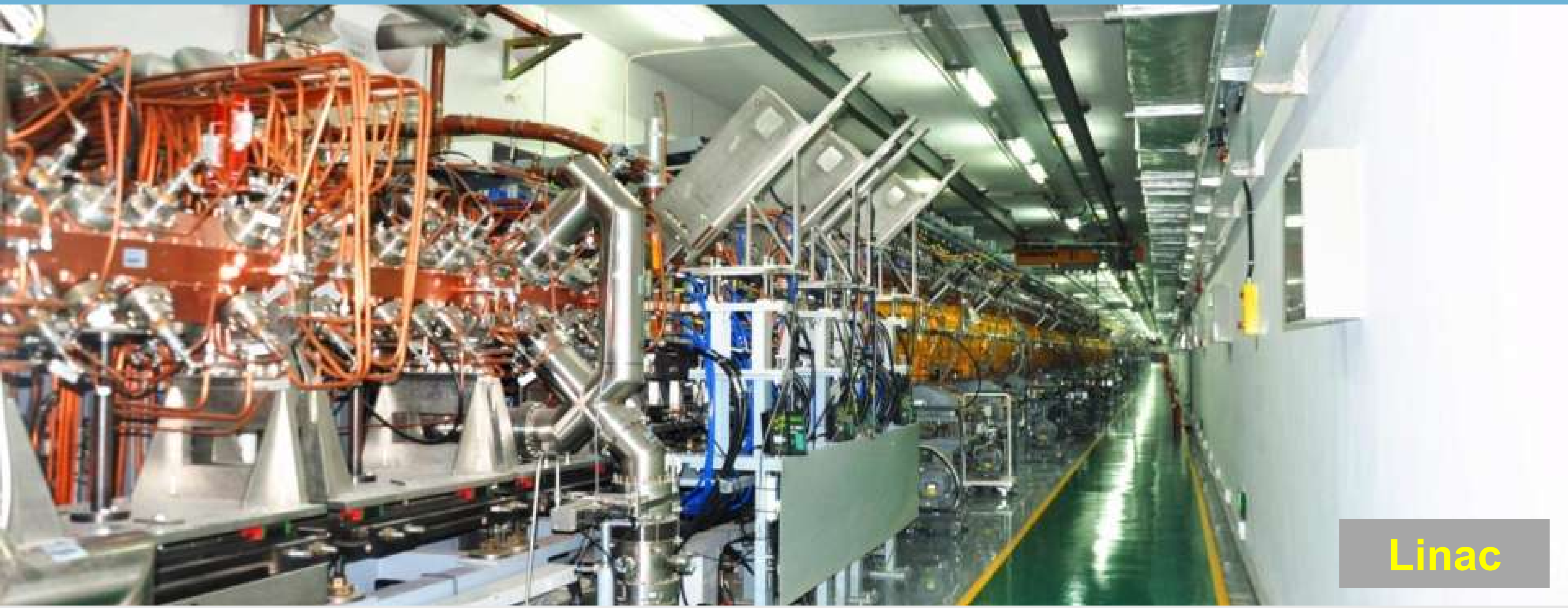
The phase-I CSNS facility consists of an 80-MeV H^- linac, a 1.6-GeV RCS, beam transport lines, a target station, and 3 instruments.

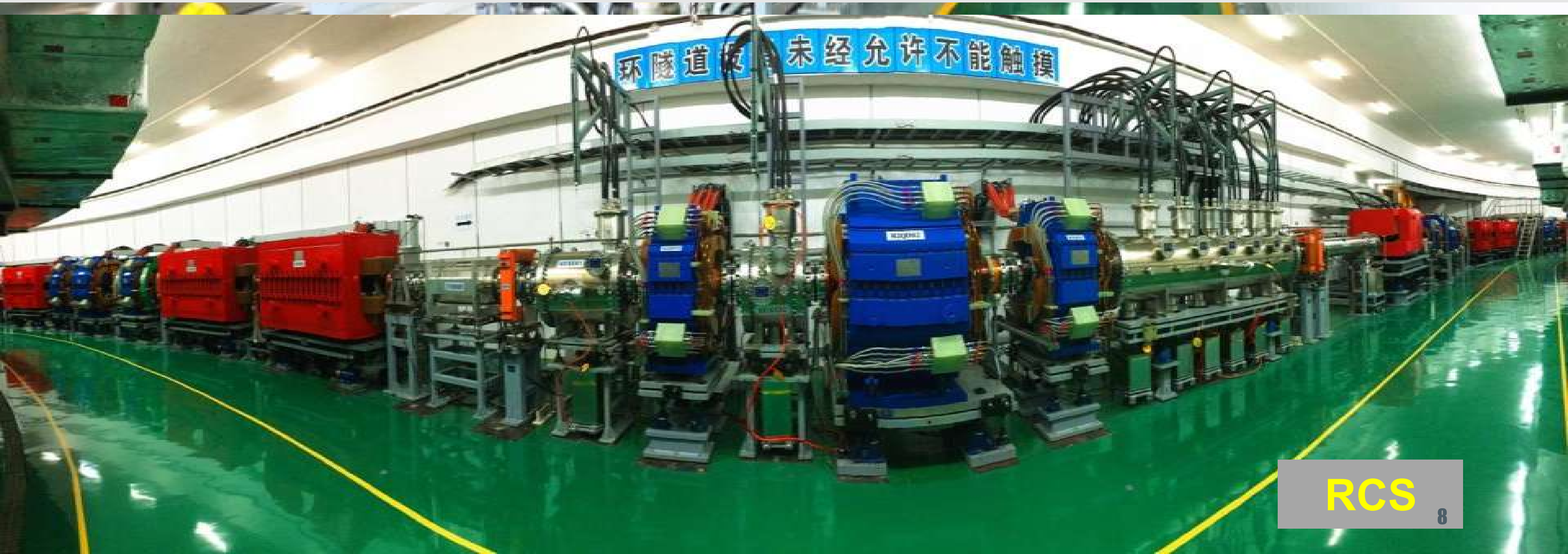
Key Milestones

February 2001	CSNS initiative
June 2005	Proposal approved in principle by the central government
January 2006	CAS funded 30M CNY for R&D
July 2007	Guangdong province funded 40M CNY for R&D
December 2007	Review of the CSNS proposal
September 2008	Proposal approved by the central government
October 2009	Review of the feasibility study
September 2011	Ground breaking
August 2017	First beam on target
March 2018	Completion of CSNS-I construction

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)


Linac


环隧道
未经允许不能触摸
RCS


Target Station


Target


South Exp. Hall


North Exp. Hall

3 first neutron scattering spectrometers

GPPD

Detector banks

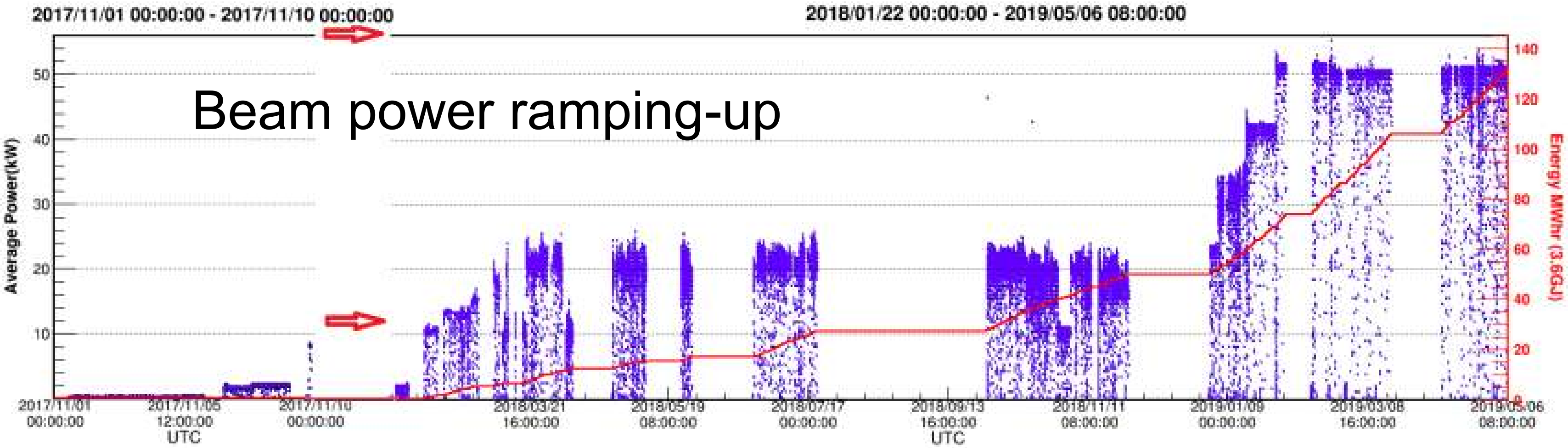
Reflectometer

SANS

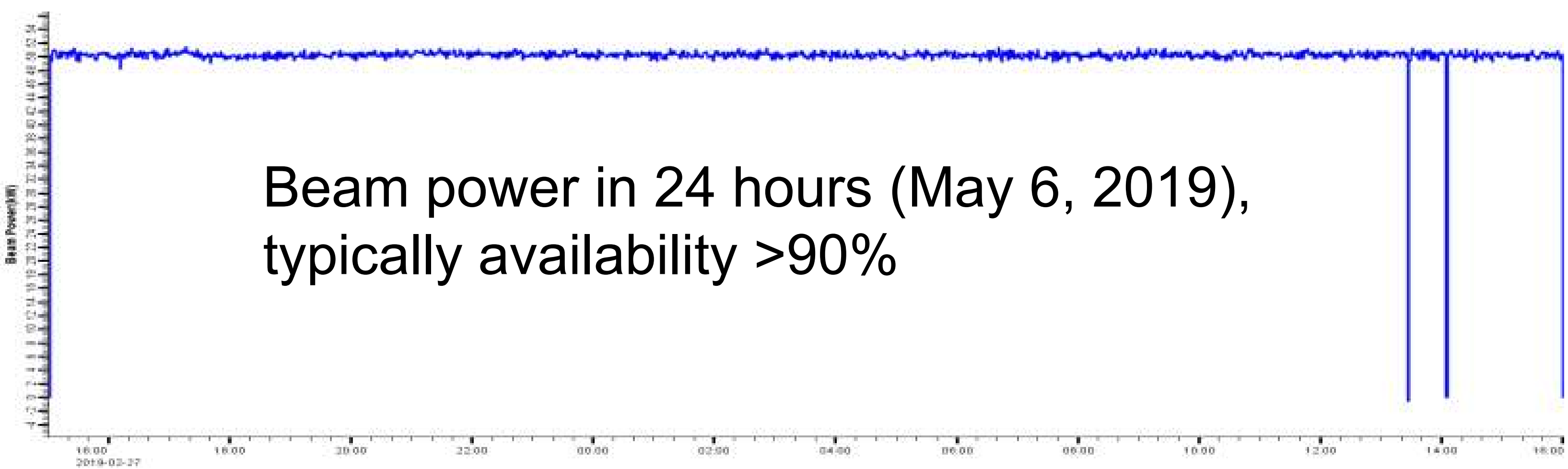
CSNS Beam Power Ramping-up

- 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
- Before end 2019 (expected): >80 kW

Beam power ramping-up



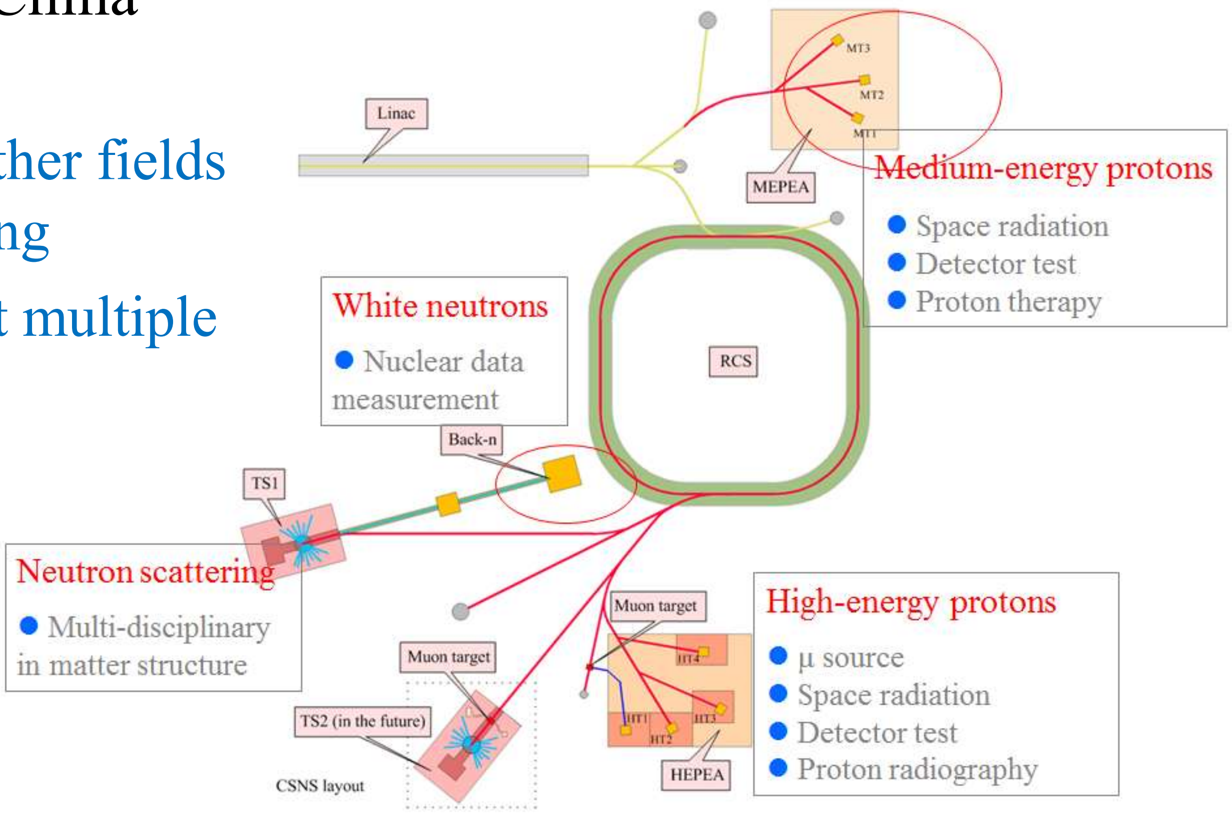
Beam power in 24 hours (May 6, 2019), typically availability >90%



CSNS as multiple platforms

CSNS is the only large-scale proton accelerator in China until 2018

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



Schematic for CSNS multiple platforms

II. Back-n white neutron facility at CSNS

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)

World trends in white neutron sources

- First generation: from 1960s, using high-intensity medium-energy electron linacs and producing pulsed intense via the production of bremsstrahlung and consecutive photonuclear reactions, and time-of-flight techniques. Typical facilities are: GELINA, ORELA, RPI, IREN
- Second generation: from late 1980, using high-power proton beams to white energy range pulsed neutrons shows advantageous, wider energy range and higher flux. Representative facilities: LANL/LANSCE, CERN/n-TOF，J-PARC/ANNRI (to a much less level)
- China is a new comer in white neutron sources, with the CSNS Back-n facility into operation from 2018

Worldwide white neutron sources

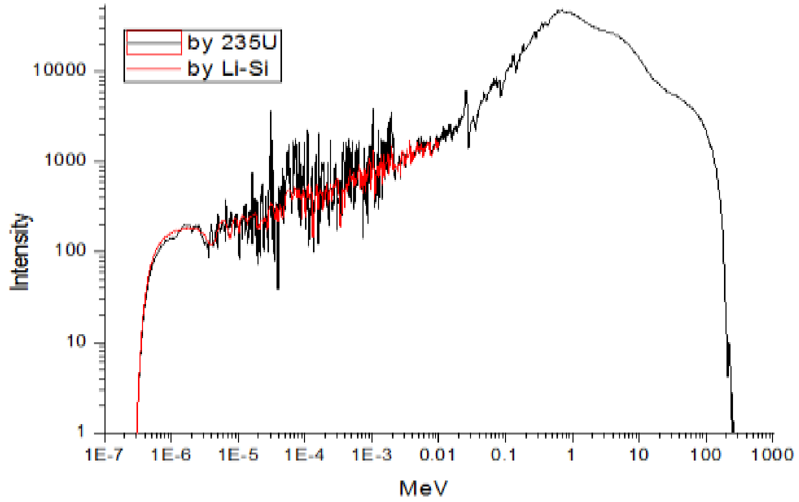
Parameters	United States				Europe		China
	ORELA	LANSCE WNR		RPI	GELINA	CERN n_TOF	CSNS-I Back-n
Accelerator	e- linac	p-Synch	p-linac	e- linac	e- linac	p-Synch	p-Synch
Energy (GeV)	0.14	0.8	0.8	>0.06	0.12	24	1.6
Flight (m)	10-200	7-55	7-90	10-250	8-400	185	55, 76
Pulse (ns)	2-30	125	0.15	15	1	7	14 (1.5)
B. Power (kW)	50	48	1.6	>10	11	45	100
Rep. rate (Hz)	1-1000	20	32k	1-500	Max. 900	0.28-0.42	25
Time res. (ns/m)	0.01	3.9		0.06	0.0025	0.034	0.18 (0.02)
n yield (n/s)	1×10^{14}	6.4×10^{13}	2.1×10^{12}	4×10^{13}	3.2×10^{13}	8.1×10^{14}	2.0×10^{16}

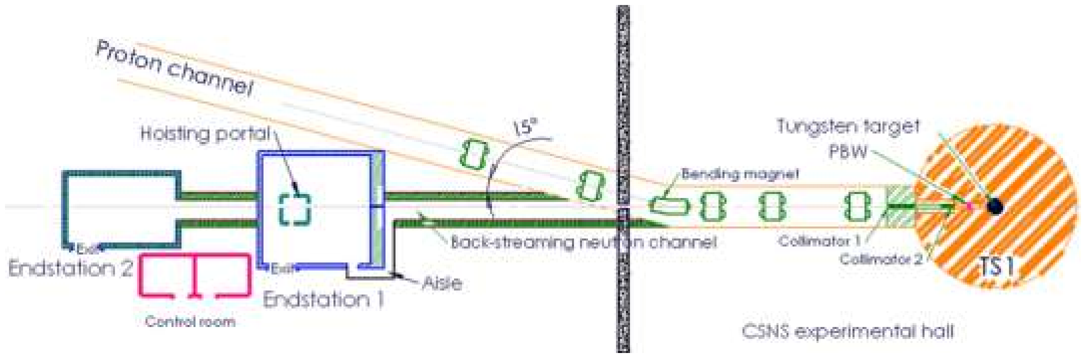
Back-n: most intense neutron flux at the target

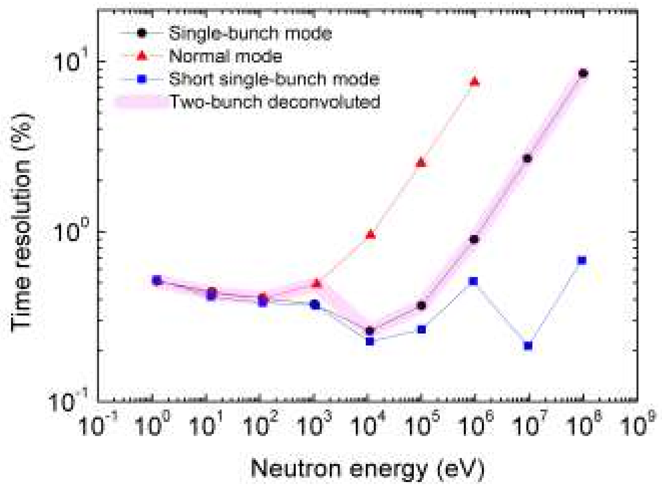
Back-streaming neutrons from the CSNS target

- 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)

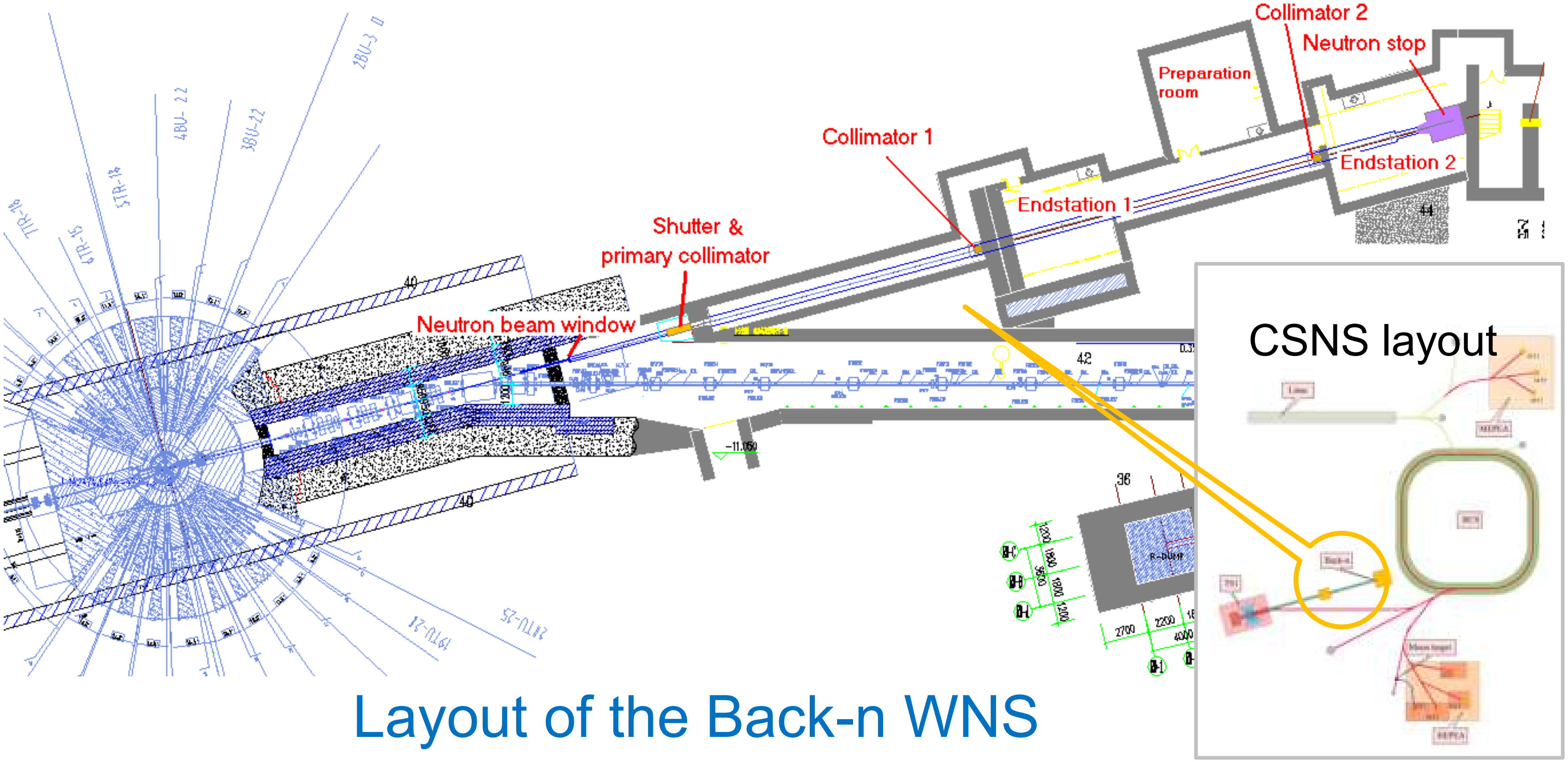
  (10^7 n/cm^2/s at 50 m)







- 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.
- Back-n completed simultaneously with CSNS



Layout of the Back-n WNS

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 (300-500 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

Beam spots and fluxes

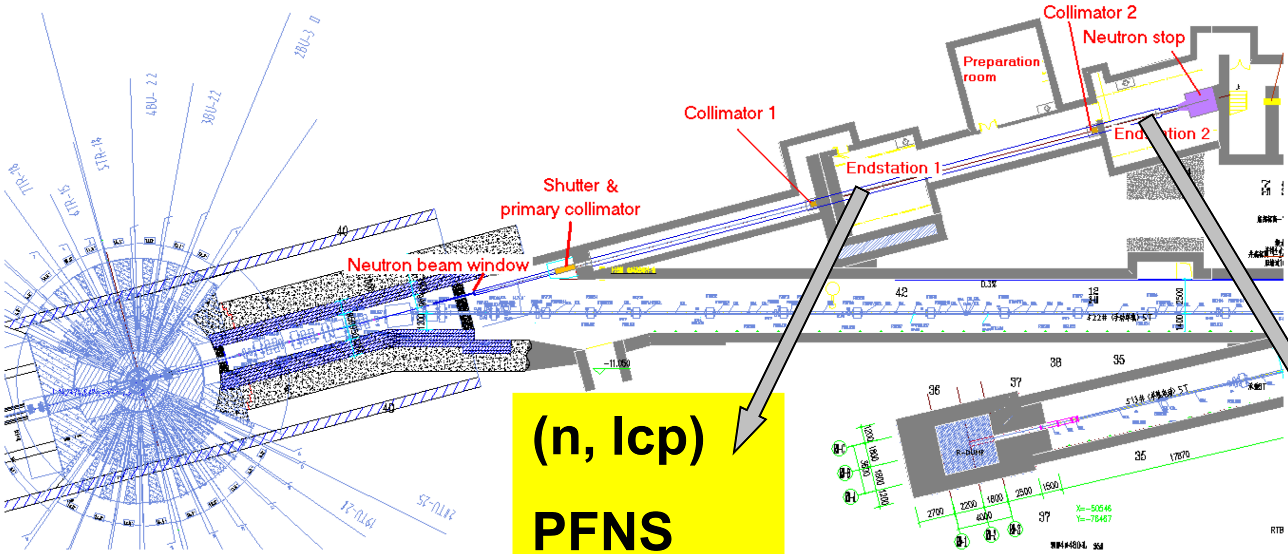
- Four sets of standard beam spots are designed, but more combinations are possible
- Using different apertures of the shutter and two collimators, with help of auxiliary collimators in the shielding wall
- Clean definition of spot (minimizing halo)
- The smallest spot is for largely reducing flux for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

Spectrometers for 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,t), 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

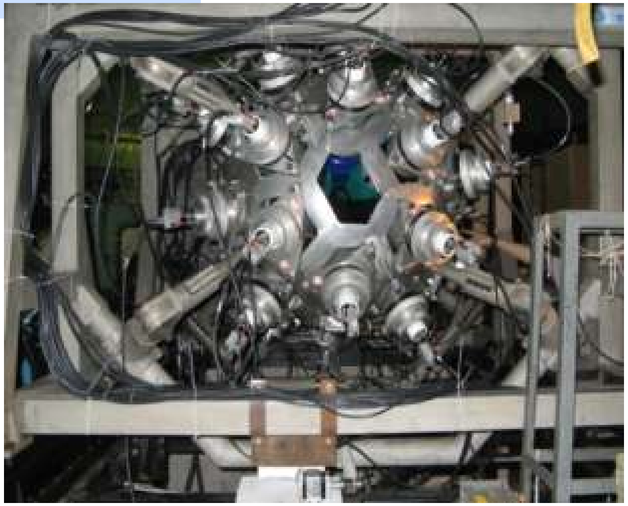


(n, lcp)
PFNS
Others

(n, t)
(n, f)
(n, γ)
(n, n'γ/2nγ)

1 - (n,γ) reaction cross section measurements

GTAF-II

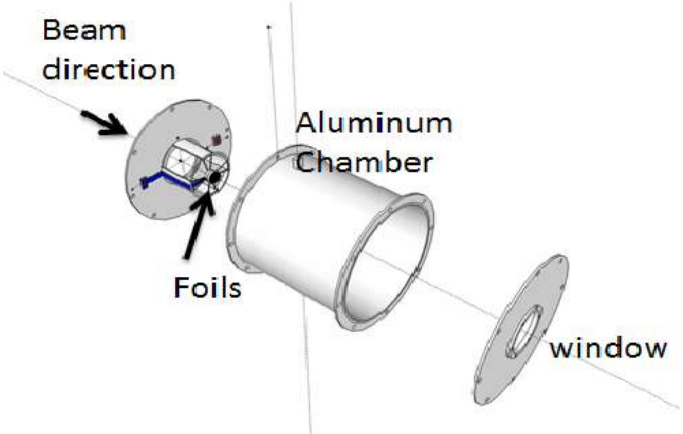


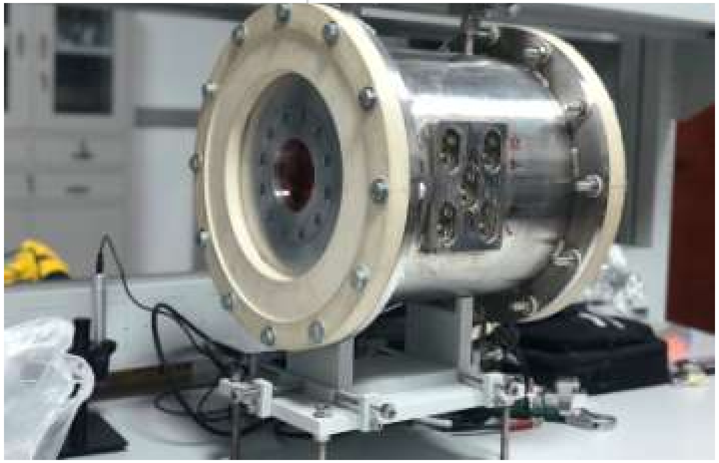
- A 4π total gamma ray absorption detection array based on BaF_2 crystals :
  - GTAF-II (40 units) ready in late 2019,
  - GTF-III (90 units) planned
- Energy: eV – 1 MeV continuous
- Solid angle: ~90%; Eff. : >90%; Time res.: <5 ms
- Measurements: (n, γ) for actinides and minor- actinides

- 4-unit C_6D_6 is in use (Left)

2 – (n, f) cross-section measurements

FIXM Spectrometer



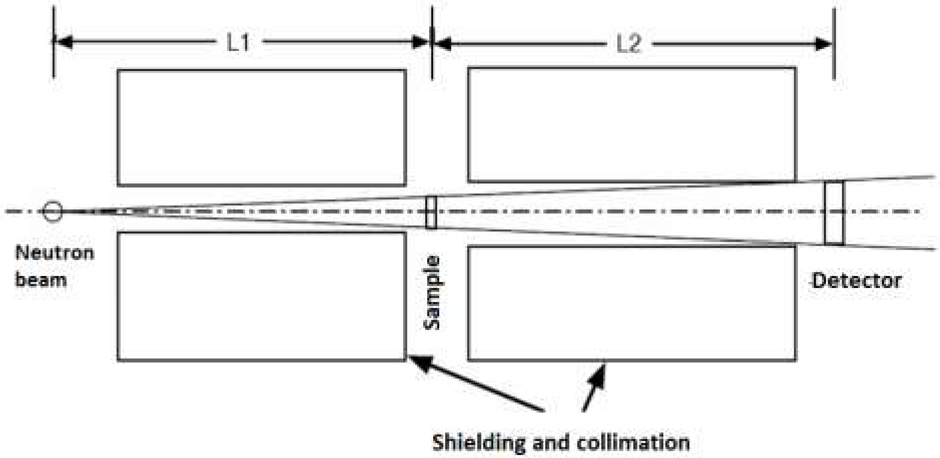


- 8-layer fission chamber, several samples simultaneously
- Fast response (<30 ns), resistant to α pile-up
- Energy: eV – 20 MeV continuous
- Measurements: (n, f) for actinides and minor- actinides
- Sample coating difficult, relevant techniques are under development

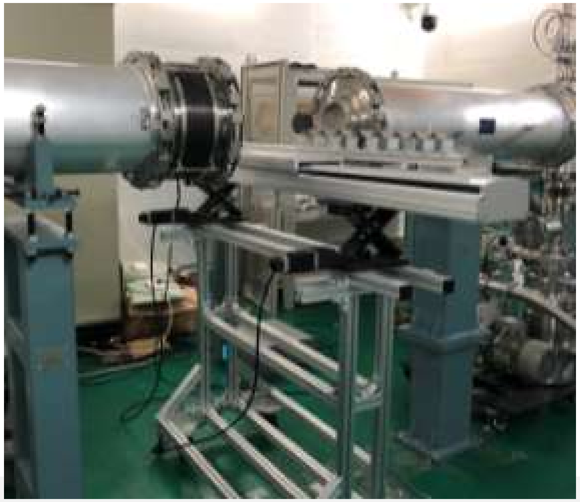
- **TPC planned**

3 – Total cross-section measurement

NTOX spectrometer

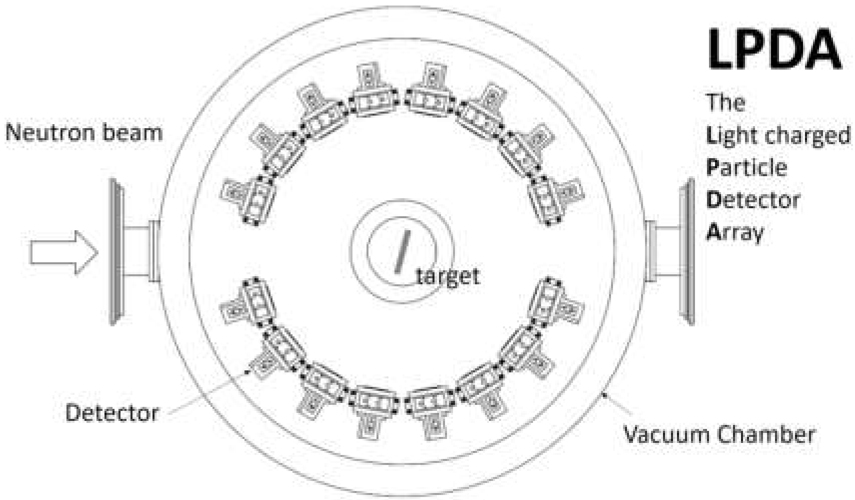


$$\sigma_t = \frac{1}{N}(-\ln T)$$



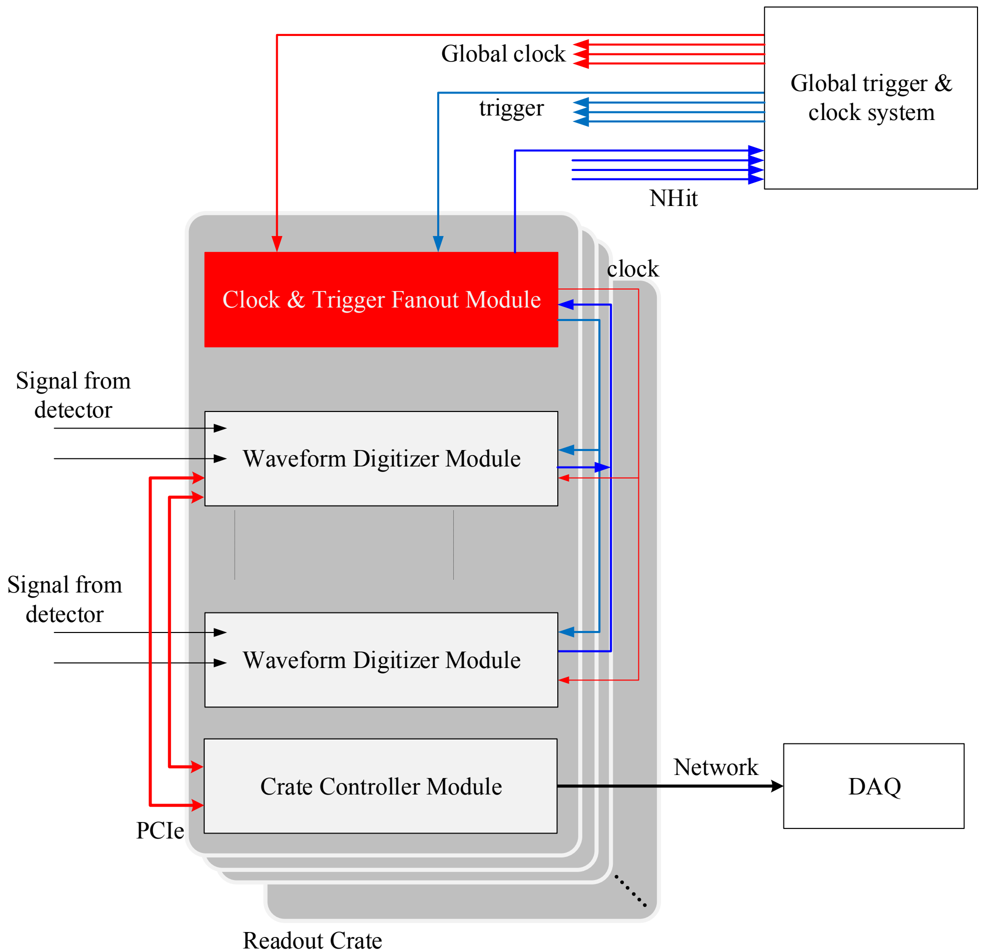
- Measuring transmission thru the sample
- Energy: eV - 20 MeV, continuously
- Different detectors for specific energy ranges (also electronics);
  Phase-I: Use the 8-layer fission chamber, and movable sample
- Also used for monitoring neutron energy spectrum and flux

4 - (n, lcp) reaction measurements



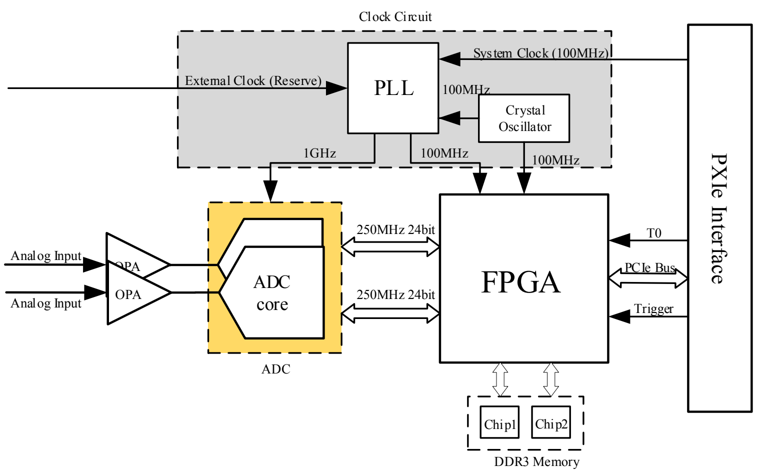
- Meas.: (n, p/α/d/t) cross-section and energy spectrum
- A vacuum chamber (1-1.5 m) and a charged particle detection array
- ΔE-ΔE-E telescope, 16 units (MWPC+Si+CsI(TI)) for particle discrimination
- Energy: 0.5-100 MeV (proton), continuously
- Day one: 4 units + 2 GIC + 8 Si (different combinations)

Readout Electronics



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

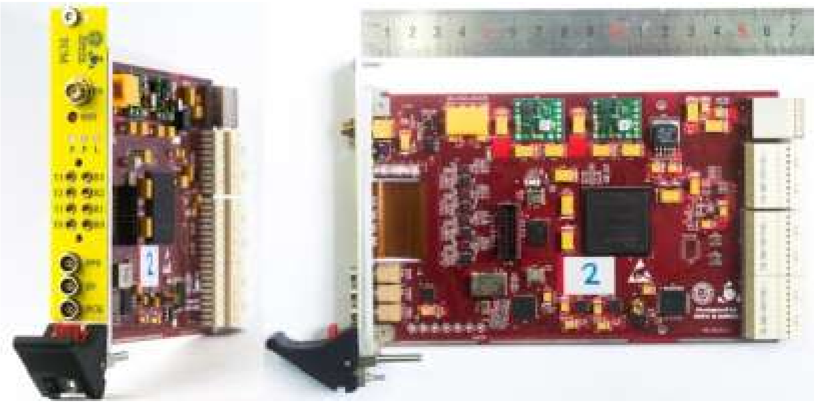
- Features:
- PXIe high speed serial bus
- Data transmission simultaneously
- Clock & trigger distributed through dedicated differential STAR bus on backplane
- Crates are connected with Ethernet to DAQ
- Digitizer based on Folding ADC: 12bit@1GSPS (large dynamic range)



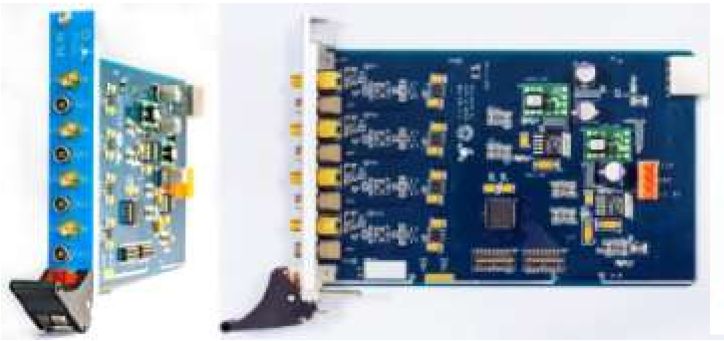
Digitizer based on folding ADC
trade off between power consumption and precision

Cards for Electronics

Field Digitalization Module (FDM): @ 2ch



TCM: trigger & clock



SCM: signal conditioning

TFM: T0 fan-out

At work

30-channel common electronics at work

Beamline and detectors at place

- Neutron beam window & Shutter in RTBT
- Neutron dump
- Beam ducts and collimator

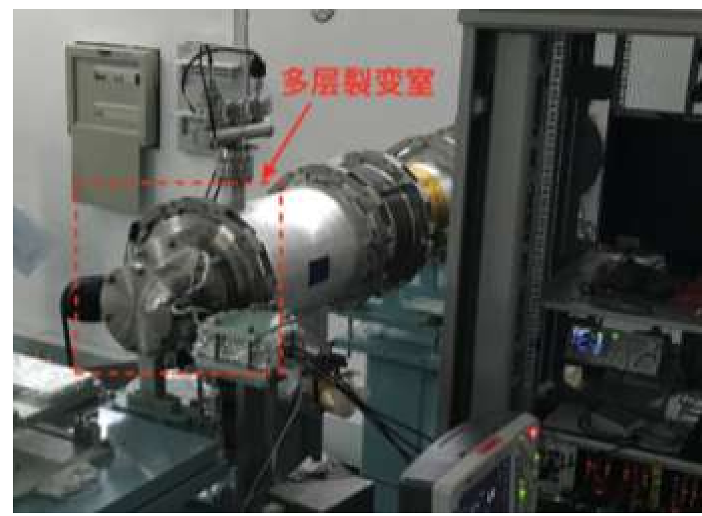
Control Room (Left)

Electronics Room (Right)

Detectors on line

FIXM (Left)

Energy spectrum measurement chamber (Right)



III. First year experiments on nuclear data measurements and applications

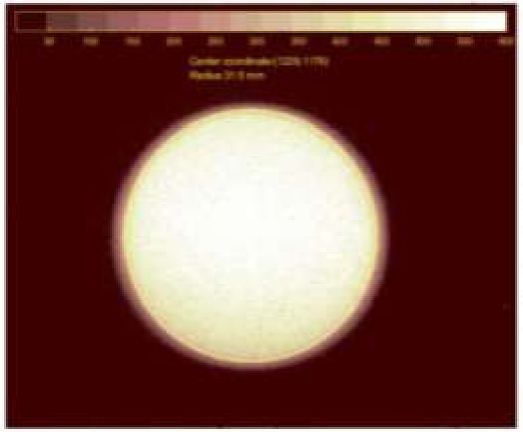
Back-n facility for nuclear data measurements

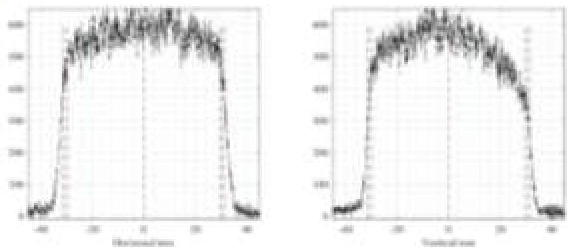
- Neutron source: beamline, conventional facilities, controls, common electronics and DAQ
- Four spectrometers are available for nuclear data measurements:
  - C6D6
  - FIXM
  - NTOX
  - LPDA
- Two spectrometers under upgrading and available by end 2019
  - LPDA with full designed specifications
  - GTAF-II (40-unit BaF_2 array)

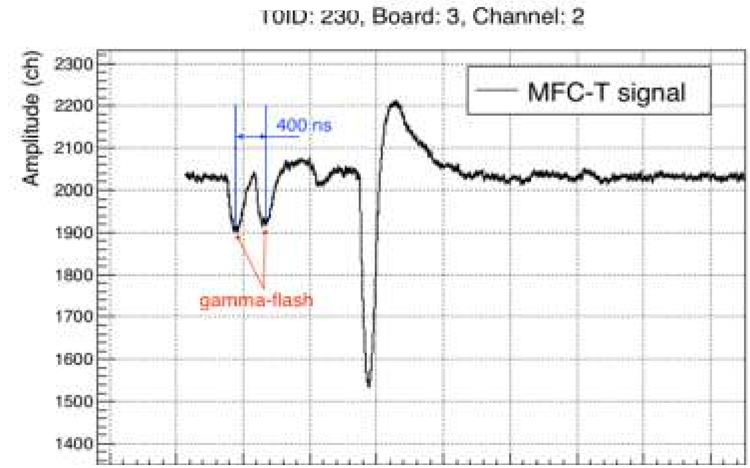
Back-n Commissioning and Day-one experiments

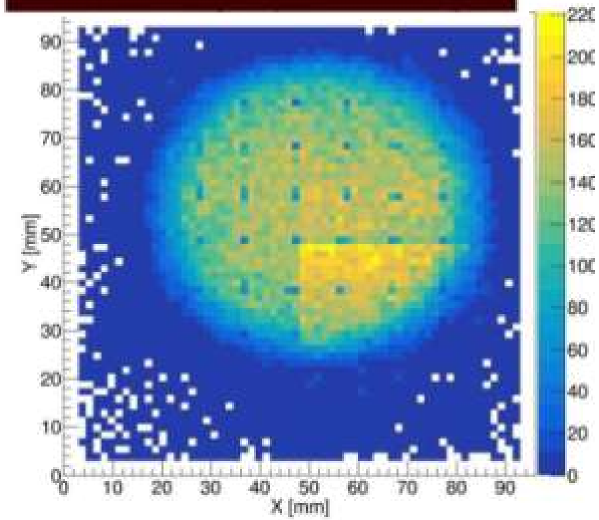
- Period: November 2017 to June 2018
- Background measurements: Bonner balls, liquid scintillators, NaI
- Beam characterization: all monitors (T0, profile, energy spectrum, flux, time structure)
- Day-one experiments
  - Fission cross-section measurements: FIXM, U-235,238,236
  - Total cross-section 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

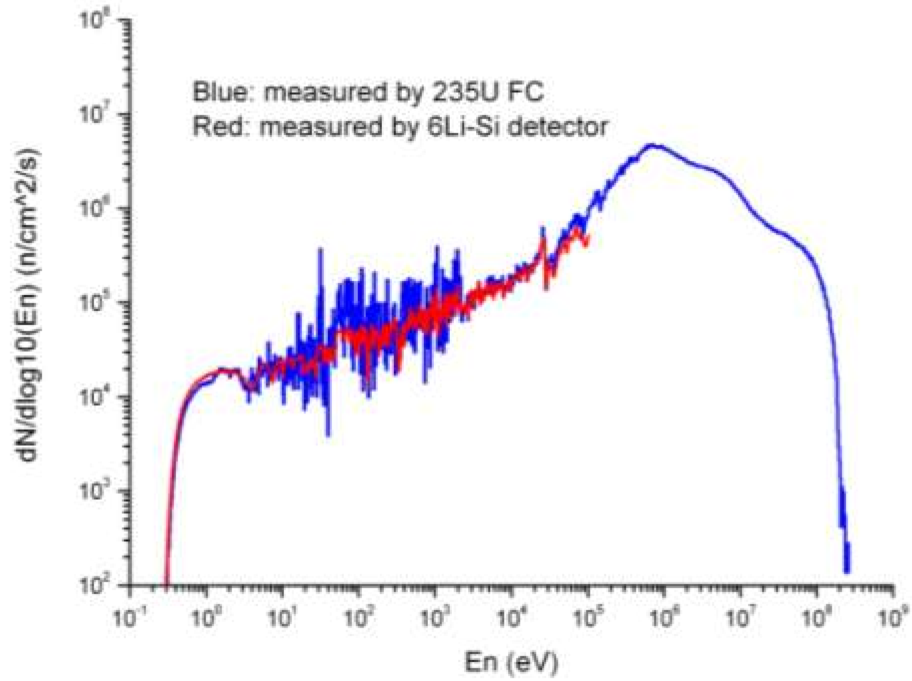
Beam characterization







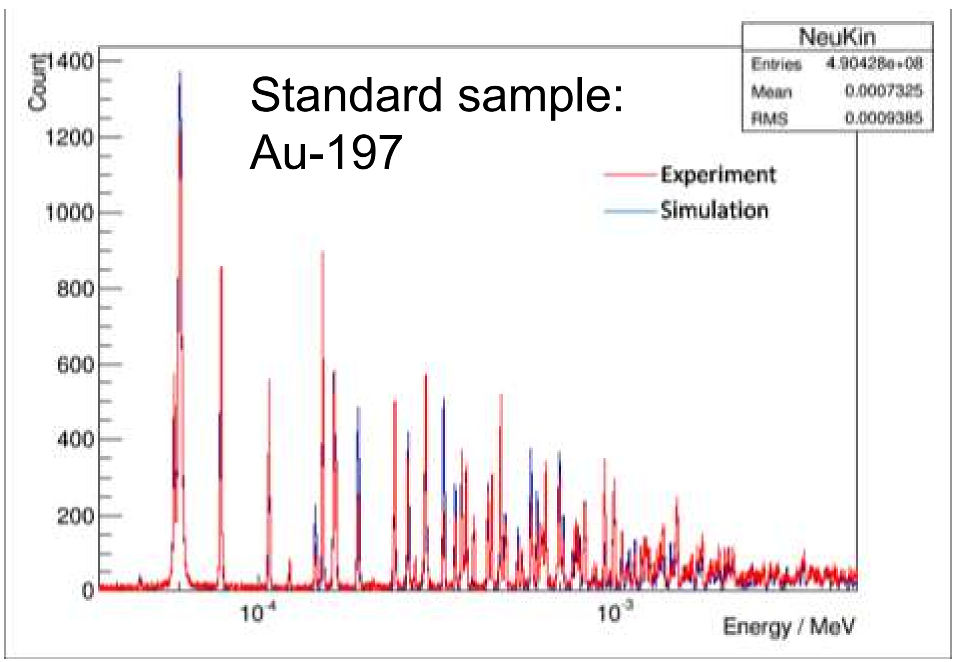


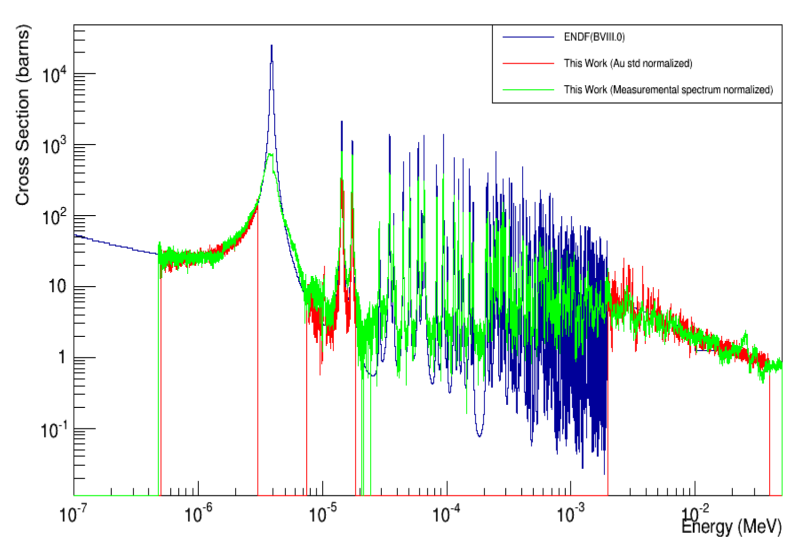


U-L: spot by CMOS camera
U-R: fission signal for energy spectrum
L-L: spot by Micromegas
L-R: energy spectrum

Day-one experiments – preliminary results

--C6D6 (n, γ): first experiment in resonance region in China

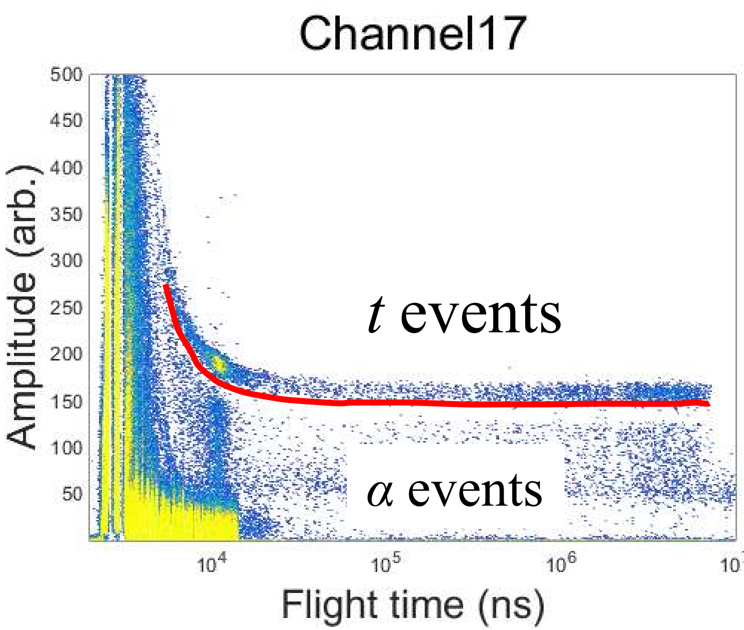




To measure: Tm-169

LPDA- Light charged particle emission

- Detector: 15 units Si, 3 units ΔE-E, 1 unit GIC
- Sample: Li-6
- Science goal: 1-3MeV, (n,t)^{4}He; Angular distribution at lower E



List of cross-section measurements in 1st year

- Neutron capture
  - ^{169}Tm, ^{197}Au, ^{57}Fe, ^{nat}Se, ^{89}Y, $^{nat}Er/^{162}Er$, ^{232}Th, ^{238}U, ^{93}Nb
- Total cross-section
  - ^{12}C, ^{27}Al
- Fission cross-section
  - ^{235}U, ^{238}U, ^{236}U, ^{232}Th
- Light charged particle emission
  - $^{6}Li(n, t)$, $^{10}B(n, \alpha)$, n-p scattering
- Elastic cross-section (in-beam gamma)
  - ^{56}Fe (n, n')

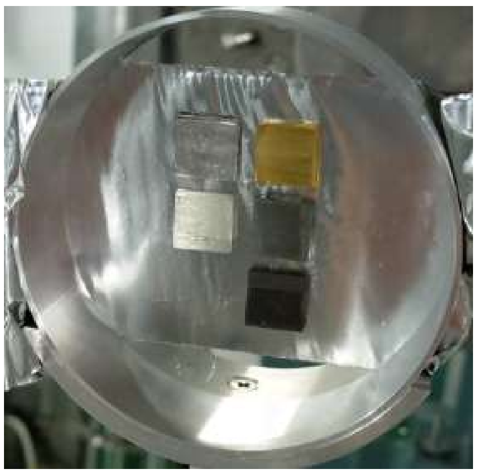
Other applications using the white neutron beam

- Detector calibrations or tests
  - Wide energy range much suitable for detector calibration
  - New advanced detectors, system tests
- Single-event effects by high-energy neutrons (microchips)
  - Important effects in terrestrial space or on the earth
  - Big demands in China, some from enterprises
- Neutron radiography: energy-resolved neutron imaging
  - New technique with characteristic resonances measurement, possible all nuclide identification: unique due to the beam of very intense and wide-energy range, technically challenging
  - More general energy-resolved imaging: easy to implement
- Fundamental neutron physics
  - Advantage on flux in eV range, attracting some physicists

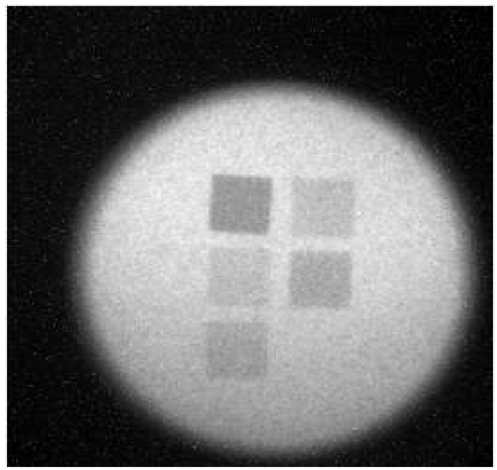
Experiment with a CMOS camera

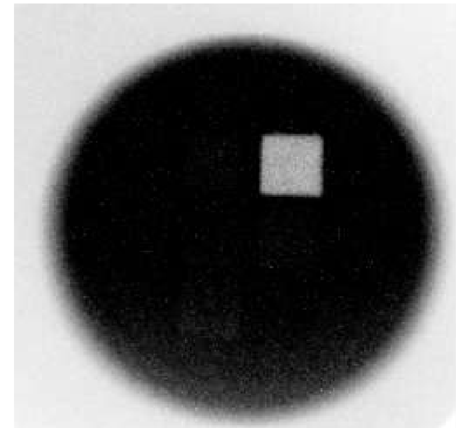
Sample elements:

Au、Ag、W、Ta、In

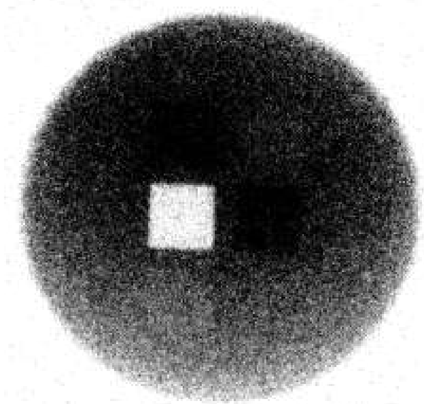


Simple transmission image



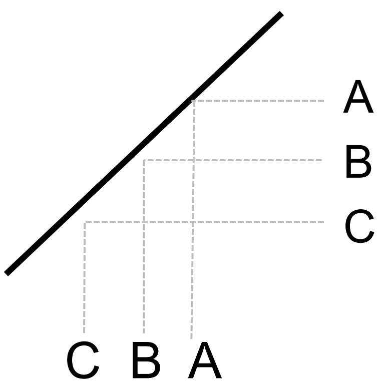


Resonance selection on In



Resonance selection on W

Optics:



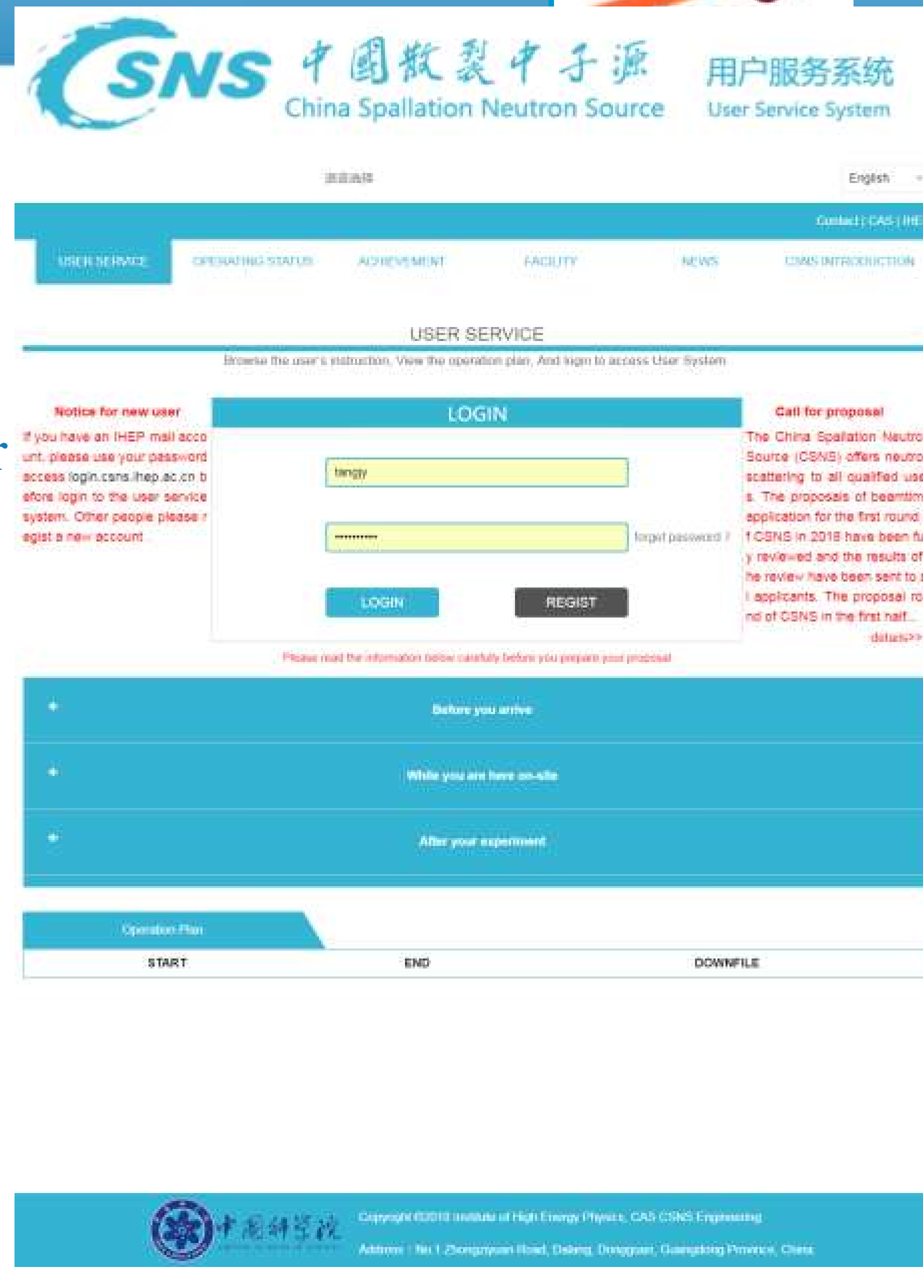
IV. User community and future prospects

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
- ✓ Collaboration groups on topical research areas also established
- ✓ Welcome international users
- ✓ Annual user workshop started from 2017

User program

- Day-one experiments were selected and reviewed a few times by the project
- 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



Future prospects

- New spectrometers, application for funding large detectors in course:
  - 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
- CSNS upgrade
  - CSNS-II Project in application, beam power from 100 kW to 500 kW, hopeful 2022-2028
  - A new white neutron beamline for chips irradiation: partial time for nuclear data measurements (Flux better for >30 MeV)

Summary

- First phase of the Back-n WNS completed, physics experiments started from March 2018.
  - ➔ First WNS in China for nuclear data measurements, also for other applications
  - ➔ Spectrometers improvement in course
- Major spectrometers have been planned, while four are in place; more funding needed for four largest ones.
  - ➔ Towards a world-class WNS facility
- A strong collaboration from domestic institutions has been formed (construction and experiments).
  - ➔User-oriented facility as a part of CSNS
- Welcome international collaboration

Thanks for your attention!