Introduction to Spallation Neutron Source

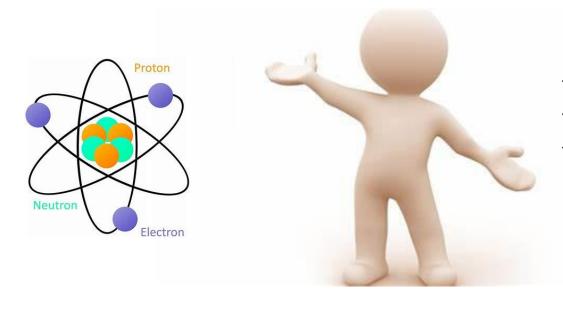**CSNS, Institute of High Energy Physics**

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Sep. 9, 2025

Outline

1. Neutron and neutron scattering

2. Introduction to Spallation Neutron Source

3. China Spallation Neutron Source

4. CSNS accelerators

5. Upgrade project CSNS-II

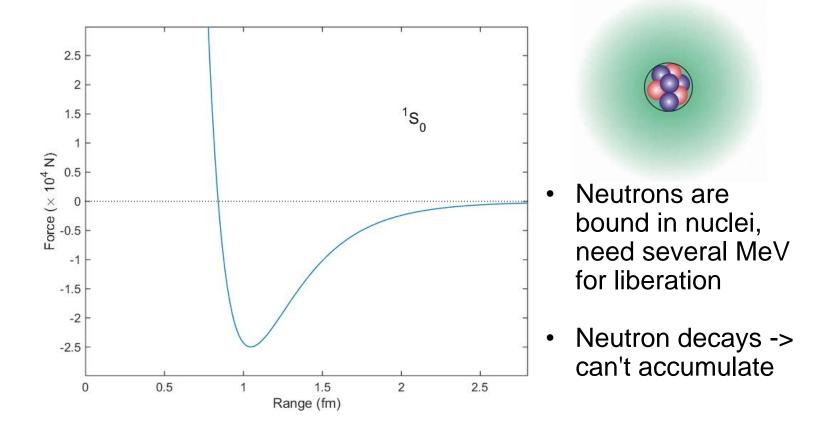# Neutron and neutron scattering

Neutrons are everywhere

- ❖ **Protons: 40kg**
- ❖ **Neutrons: 32kg**
- ❖ **Electrons: 22g**

Free neutrons

$^1S_0$

- Neutrons are bound in nuclei, need several MeV for liberation

- Neutron decays -> can't accumulate

Reid, R.V. (1968). Annals of Physics. 50: 411–448

The discovery of neutron

1920   *Noting that atomic number (Z) does not correspond to atomic weight (A), Rutherford suggests that, in addition to "bare" protons, the nucleus contains a heavy neutral particle.*
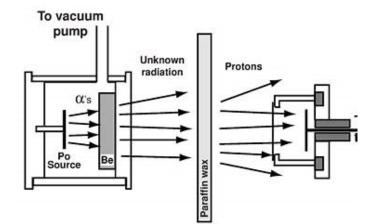
Walter Bothe

1930   *Bothe and Becker discover a penetrating, neutral radiation when alpha particles hit a Be target.*

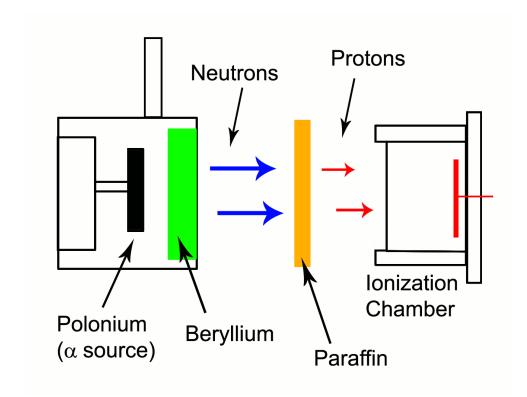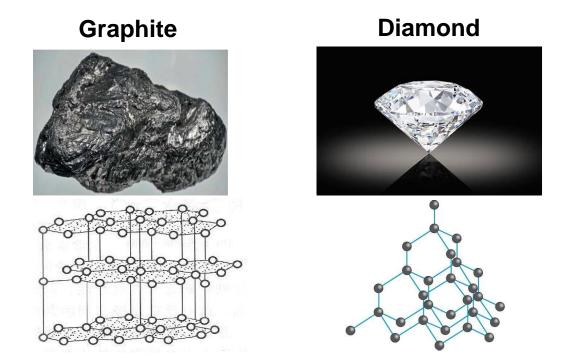$$\alpha + {}^{9}Be \rightarrow {}^{12}C + n$$

1931

The discovery of neutron

James Chadwick 1932

Neutrons

Protons

Polonium (α source)

Beryllium

Paraffin

Ionization Chamber

J. Chadwick, Proc. Roy. Soc., A 136 692 (1932)

Neutron: the perfect tool for atomic studies

Graphite   **Diamond**
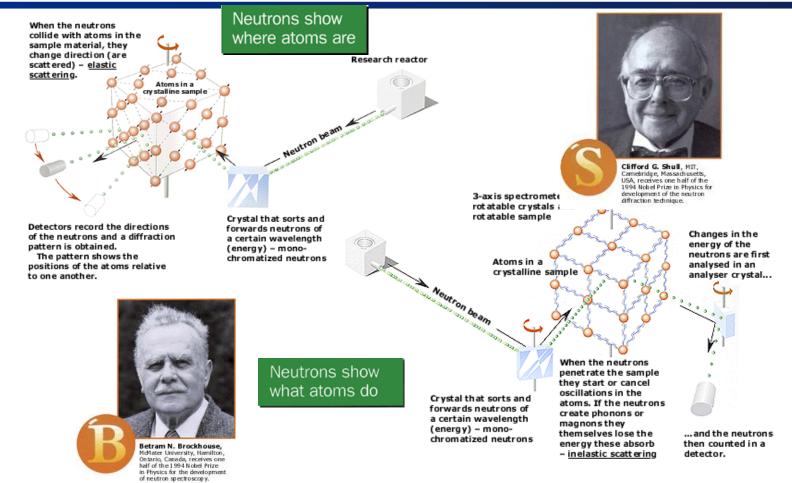
Atomic Structure and Dynamics Determine the Macroscopic Properties of Matter

When the neutrons collide with atoms in the sample material, they change direction (are scattered) – elastic scattering.

Neutrons show where atoms are

Atoms in a crystalline sample

Research reactor

Neutron beam

Detectors record the directions of the neutrons and a diffraction pattern is obtained.
  The pattern shows the positions of the atoms relative to one another.

Crystal that sorts and forwards neutrons of a certain wavelength (energy) – mono-chromatized neutrons

Clifford G. Shull, MIT, Camebridge, Massachusetts, USA, receives one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.

3-axis spectrometer rotatable crystals and rotatable sample

Atoms in a crystalline sample

Changes in the energy of the neutrons are first analysed in an analyser crystal...

Neutron beam

Neutrons show what atoms do

Betram N. Brockhouse, McMater University, Hamilton, Ontario, Canada, receives one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.

Crystal that sorts and forwards neutrons of a certain wavelength (energy) – mono-chromatized neutrons

When the neutrons penetrate the sample they start or cancel oscillations in the atoms. If the neutrons create phonons or magnons they themselves lose the energy these absorb – inelastic scattering

...and the neutrons then counted in a detector.

http://www.nobelprize.org/nobel_prizes/physics/laureates/1994/illpres/neutrons.html

Applications of Neutrons

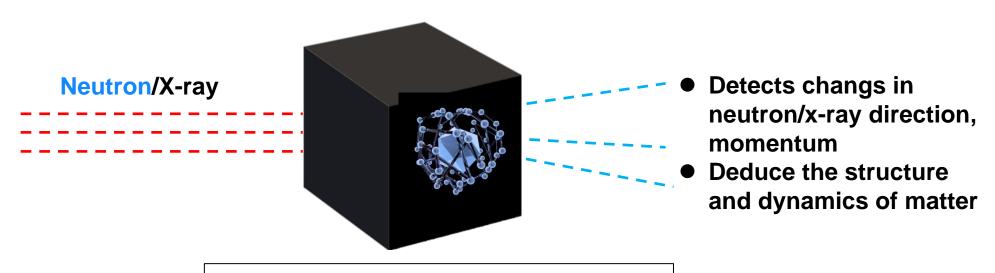Neutron is an indispensable tool for material science study

"If the neutron had not been discovered by Chadwick in 1932, it would have been invented."
--Brockhouse
'94 Physics Nobel Prize

Neutron and X-ray

Neutron Scattering and X-rays: powerful complementary tools for studying material structure and dynamics
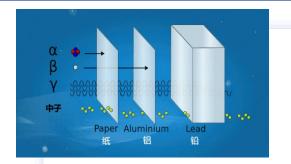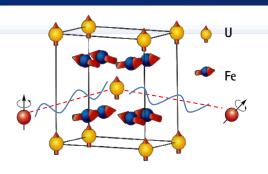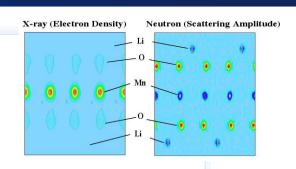
Neutron/X-ray

- Detects changs in neutron/x-ray direction, momentum
- Deduce the structure and dynamics of matter

Neutron interacts with nucleus
X-ray interacts with e-cloud

A dispensable Research Platform

high penetration

magnetic moment

Sensitivity to Light Elements:

Deep stress detection	Atmospheric Neutron	Nuclear Data	New Energy Materials	Supercond-ucting Materials
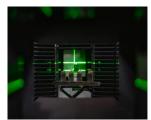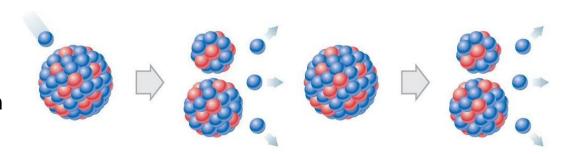
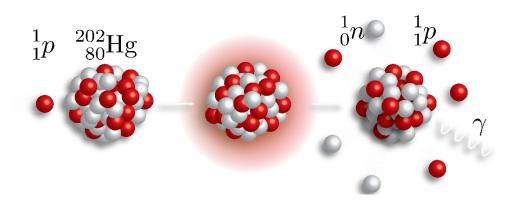# Spallation Neutron Source

Production of neutrons

SNS

Fission Reactors

- Chain reaction
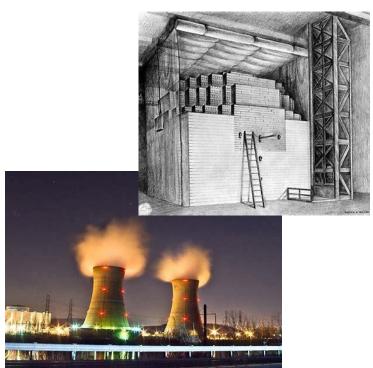- Continuous
- 2-3 neutrons/fission
- ~180MeV/neutron

Spallation

- No chain reaction
- Pulsed
- 30-40 neutrons/proton
- ~30MeV/neutron

$$^{1}_{1}p \quad ^{202}_{80}\text{Hg}$$
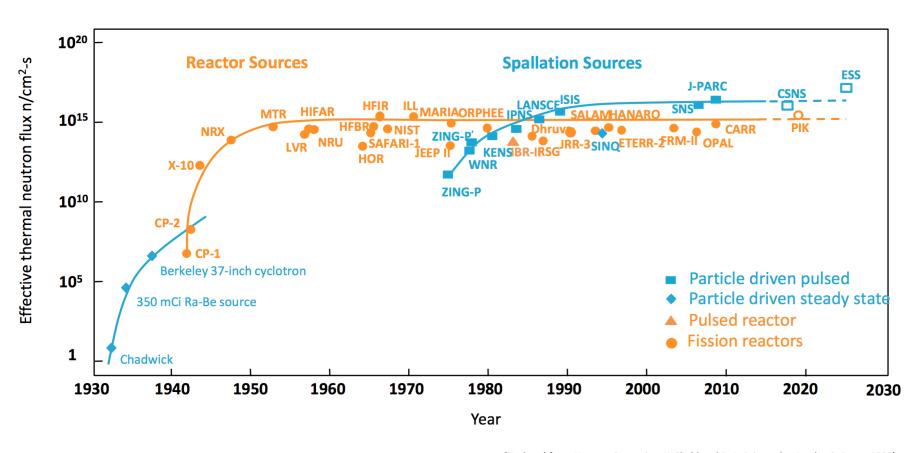
$$^{1}_{0}n \quad ^{1}_{1}p$$

γ

Chicago Pile 1, CP1, 1942

History neutron source

(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)
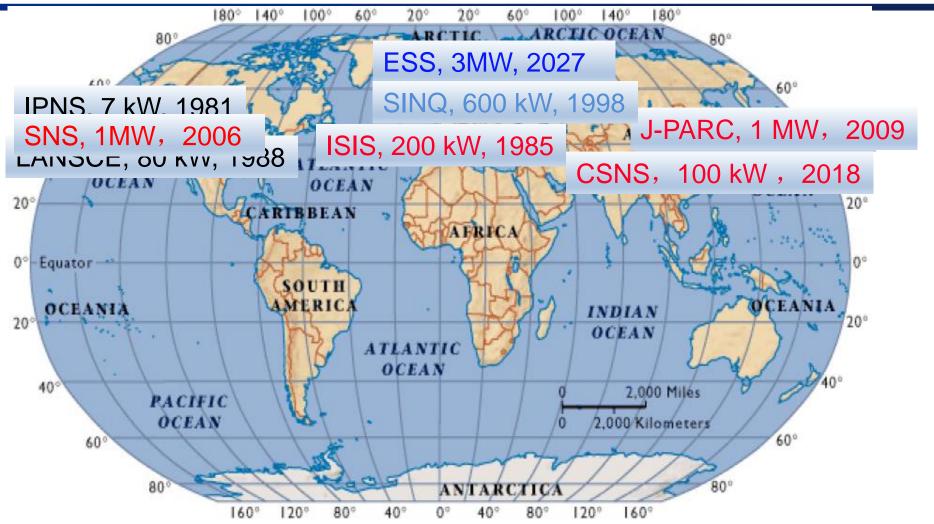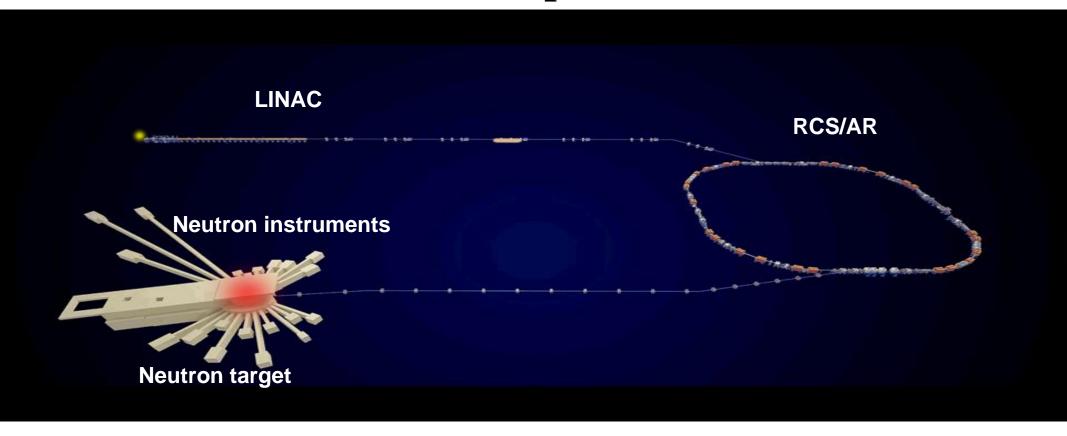
Spallation neutron source in the world

IPNS, 7 kW, 1981

SNS, 1MW, 2006

LANSCE, 80 kW, 1988

ESS, 3MW, 2027

SINQ, 600 kW, 1998

ISIS, 200 kW, 1985

J-PARC, 1 MW, 2009

CSNS, 100 kW, 2018

Basic Components and Principles of a Spallation Neutron Source （Short pulse）
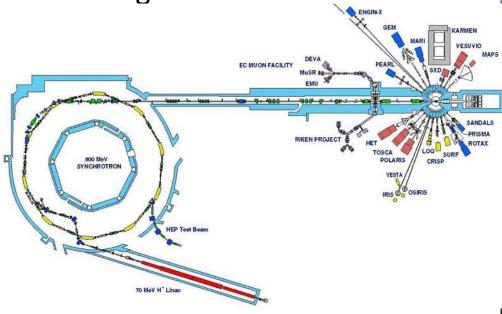
UK: ISIS

- Started from 1980
- 160+32kW
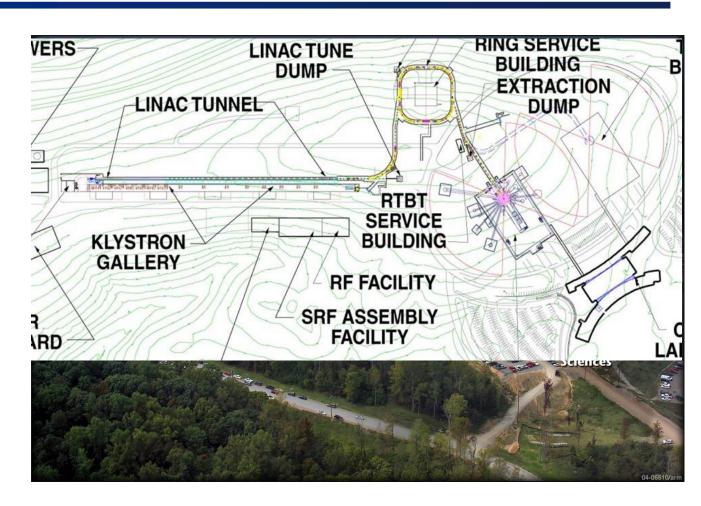- Two target stations

Diamond

2nd target

ISIS

US: SNS

- Started from 1998, 6 institues, 8 years, $1.4B

- Now operating with 1.7MW
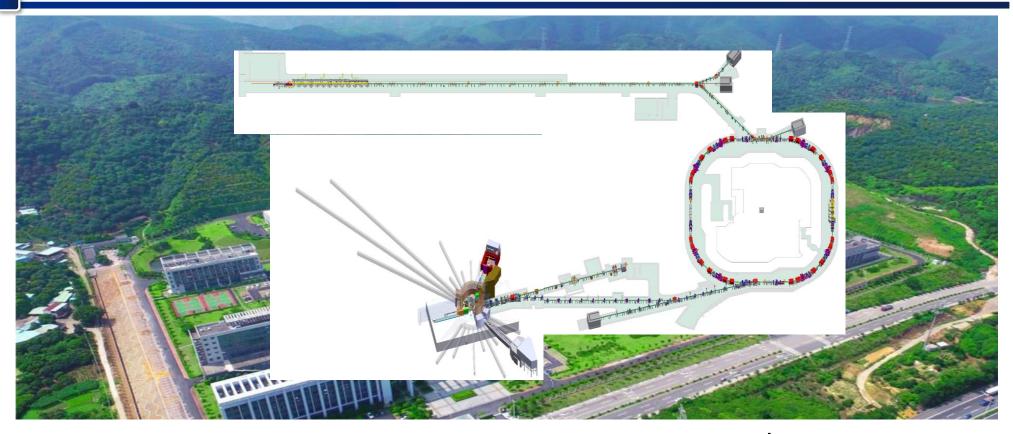
Japan: J-PARC

- Started from 2001,design beam power 1MW，$2B，finished at 2009

- Including a 30GeV synchrotron for high energy physics

China: CSNS

- Start from 2011,design beam power 100kW, $0.3B，
  finished at 2018

Spallation neutron source

Machine	Energy [GeV]	Intensity [ppp]	Tune-shift	Rep-rate [Hz]	Power [MW]	Type
ISIS	0.07-0.8	2.5×10^{13}	~0.4	50	0.2	RCS
J-PARC	0.4 - 3.0	0.8×10^{14}	0.15	25	1.0	RCS
SNS	1.0	1.6×10^{14}	0.1	60	1.0	AR
CSNS	0.08-1.6	1.56×10^{13}	0.28	25	0.1~0.5	RCS
ESS	1.0	2.3×10^{14}		14	1	LINAC

China Spallation Neutron Source

Location of CSNS
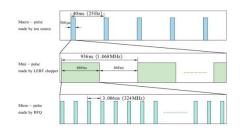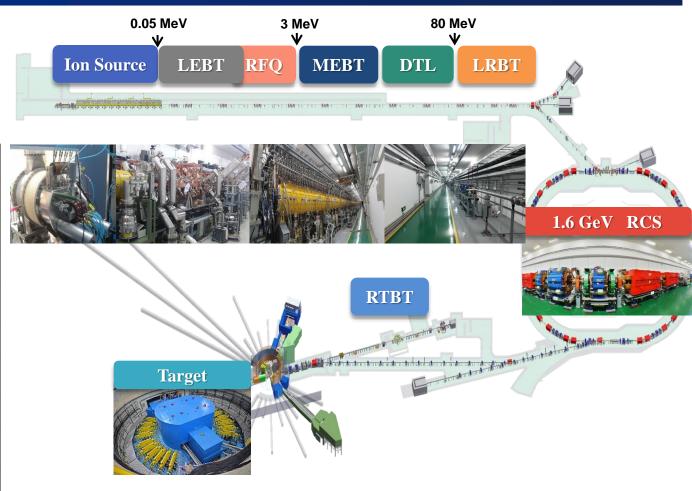
CSNS campus

Aug. 2024

- ◆ **Proposed at year of 2000**
- ◆ **Budget: about 2.2 B CNY**
- ◆ **Construction started at Sep. 2011, and finished at Mar. 2018**
- ◆ **User program started in Oct. 2018**
- ◆ **Beam power increased from 20kW to 170kW**
- ◆ **Operation with long user hours and high availability**
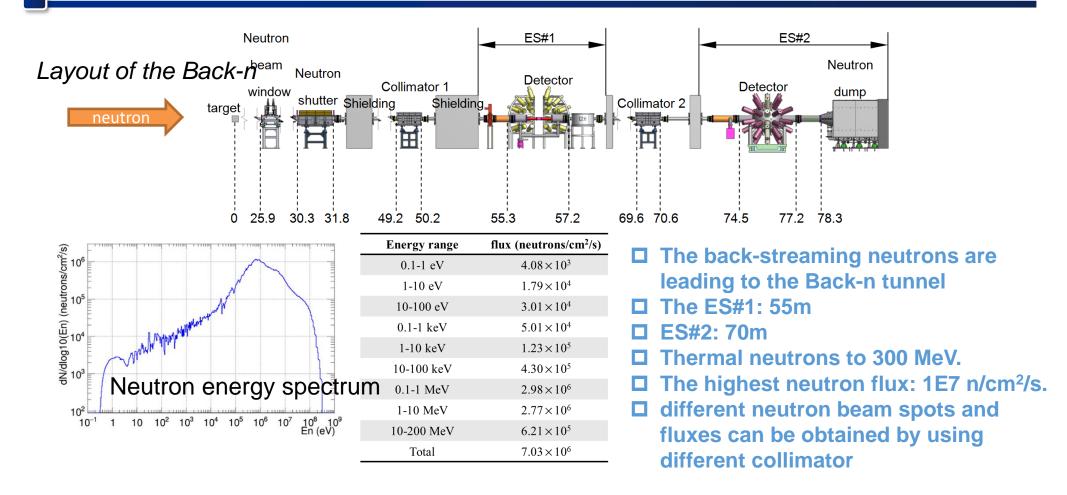- ◆ **11 neutron instruments and in user program**

CSNS Facility

Beam Power on target [kW]	100
Proton energy [GeV]	1.6
Average beam current [uA]	62.5
Pulse repetition rate [Hz]	25
Linac energy [MeV]	80
Linac type	NC
Linac RF frequency [MHz]	324
Macropulse duty factor	1.05
RCS circumference [m]	228
RCS harmonic number	2

0.05 MeV   3 MeV   80 MeV

Ion Source | LEBT | RFQ | MEBT | DTL | LRBT

1.6 GeV RCS

RTBT

Target
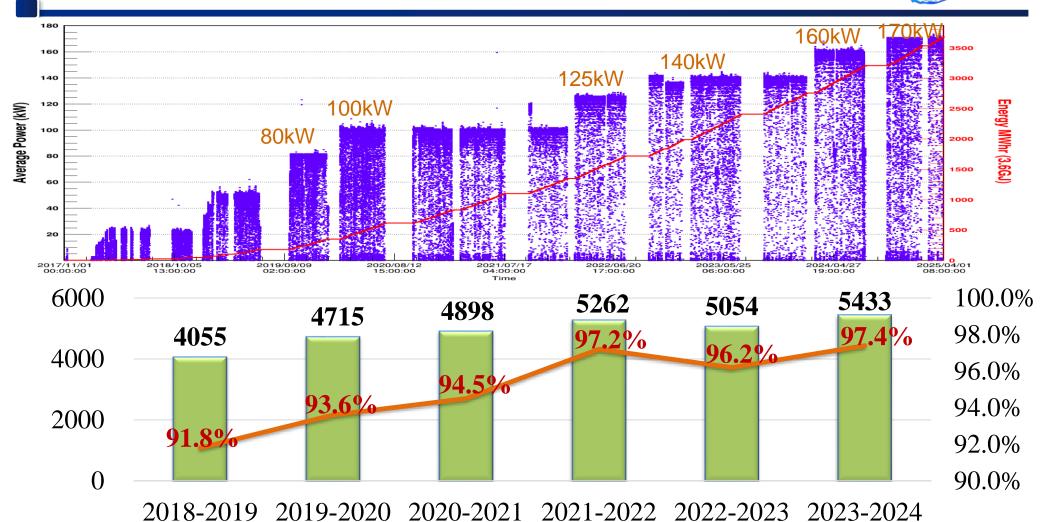
Back-n White neutron source

Layout of the Back-n

Neutron beam window

Neutron shutter

target

Shielding

Collimator 1

Shielding

ES#1

Detector

Collimator 2

ES#2

Detector

Neutron dump

neutron

0 25.9 30.3 31.8   49.2 50.2   55.3   57.2   69.6 70.6   74.5   77.2 78.3

Neutron energy spectrum

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

- ☐ The back-streaming neutrons are leading to the Back-n tunnel
- ☐ The ES#1: 55m
- ☐ ES#2: 70m
- ☐ Thermal neutrons to 300 MeV.
- ☐ The highest neutron flux: 1E7 n/cm^2/s.
- ☐ different neutron beam spots and fluxes can be obtained by using different collimator

CSNS Beam Power History

Neutron Instruments

BL16: Multiple Physics Instrument

BL05: High energy inelastic spectrometer

BL15: High Pressure Diffractometer

BL14: Very small angle neutron scattering

BL13: Energy resolved neutron imaging

BL11: Atmosphere Neutron Irradiation

BL08: Engineering Material Diffractometer

BL09: High resolution Diffractometer

➢ **3 phase-I instruments**
➢ **8 cooperative neutron instruments**
  ● **5 in user program**
  ● **3 in trail user operation**
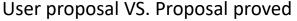
User Program
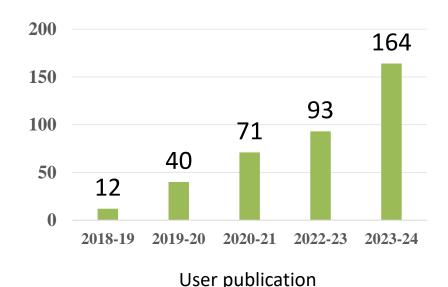
https://user.csns.ihep.ac.cn (in both Chinese and English）

- Registration user: 8000+ (130+ abroad)

- A total of over 2,000 projects from ~240 units were completed, with industry users comprising approximately 10% of the total.
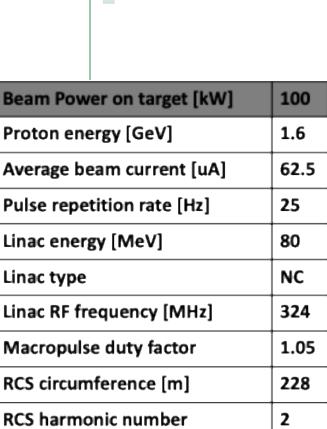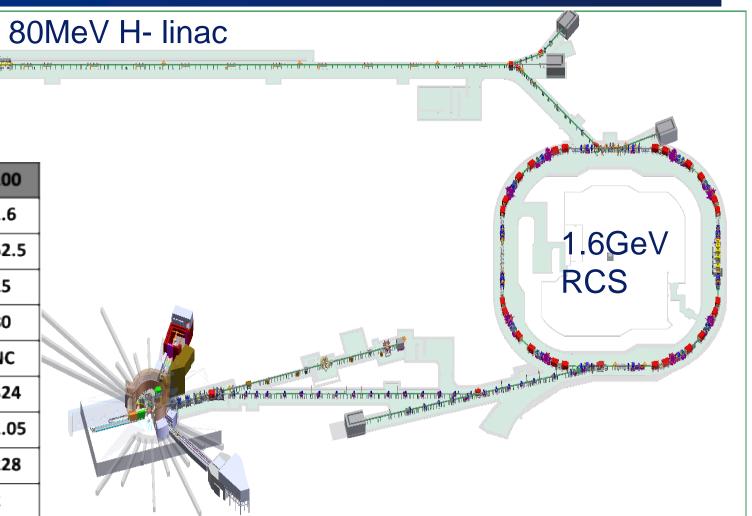
- Two rounds of proposal calls each year

User proposal VS. Proposal proved

User publication

Research Areas

University: ~45%
Research institution: ~49%
Enterprise: ~6%

Pie chart labels:
- Energy & Battery 30%
- Magnetism&Multiferroic 13%
- Metal&Alloy 15%
- Oxides Film 7%
- Spintronics 5%
- Polymer 8%
- Nano Composite 7%
- Superconductivity 3%
- Biology 1%
- Engineering 6%
- others 5%
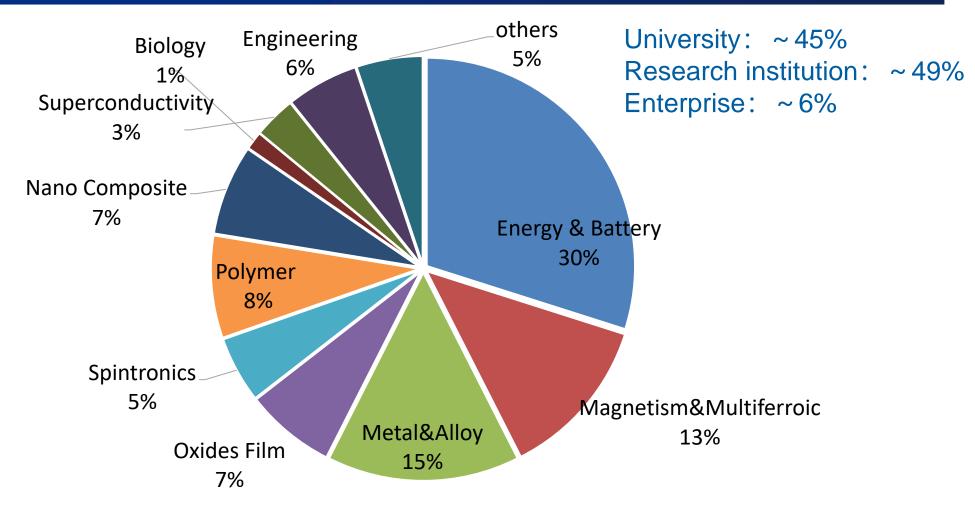
CSNS Accelerators:

Design and Commissioning

CSNS accelerators

80MeV H- linac

1.6GeV RCS

Beam Power on target [kW]	100
Proton energy [GeV]	1.6
Average beam current [uA]	62.5
Pulse repetition rate [Hz]	25
Linac energy [MeV]	80
Linac type	NC
Linac RF frequency [MHz]	324
Macropulse duty factor	1.05
RCS circumference [m]	228
RCS harmonic number	2

The Evolution of Beam

	Beam	Kinetic Energy (GeV)	Emittance/ Acceptance (πmmmrad)	Peak Current	Bunch Length	Beam Power (kW)
LRBT	H⁻	0.08	4/25	15mA	~ 500μs	5
Injection	H⁻→p	0.08	300/540			5
RCS	p	0.08 →1.6	300 →80/540			5 →100
Extraction	p	1.6	~ 80/350	~ 3.5A	80ns+80ns	100
RTBT	p	1.6	~ 80/350	~ 3.5A	80ns+80ns	100

Average current 62.5μA

Beam at the exit of Linac   Beam at the target

Space charge effects

Let two charged particles move parallel with same velocity, then electric field and magnetic field experienced by particles are

$$E = \frac{q}{4\pi\varepsilon_0 d^2}$$

$$B = \frac{\mu_0 q v}{4\pi d^2}$$

Where q is charge, ε_0 the dielectric constant, μ_0 the permeability, v the velocity.

The ratio of magnetic and electric forces is

$$\frac{F_m}{F_e} = \frac{v^2}{c^2} = \beta^2$$

For non-relativistic beam, *Fm<<Fe.* Due to the signs of *Fm and Fe* are inverse, the space charge effects are decreased with the increase of the velocity.

Space charge tune-shfit

Space charge is a fundamental limit to beam power in high intensity AR and synchrotron. The incoherent space-charge tune shift is

$$\Delta\nu_{x,y} = -\frac{f_{sc}Nr_0R}{2\pi B_f\nu_{0x,y}\beta^2\gamma}\left[\frac{1}{\sigma_{x,y}(\sigma_x+\sigma_y)}(\frac{1}{\gamma^2}-\eta_e)+A_{im}^e(\frac{1}{\gamma^2}-\eta_e)+A_{im}^m\right]$$
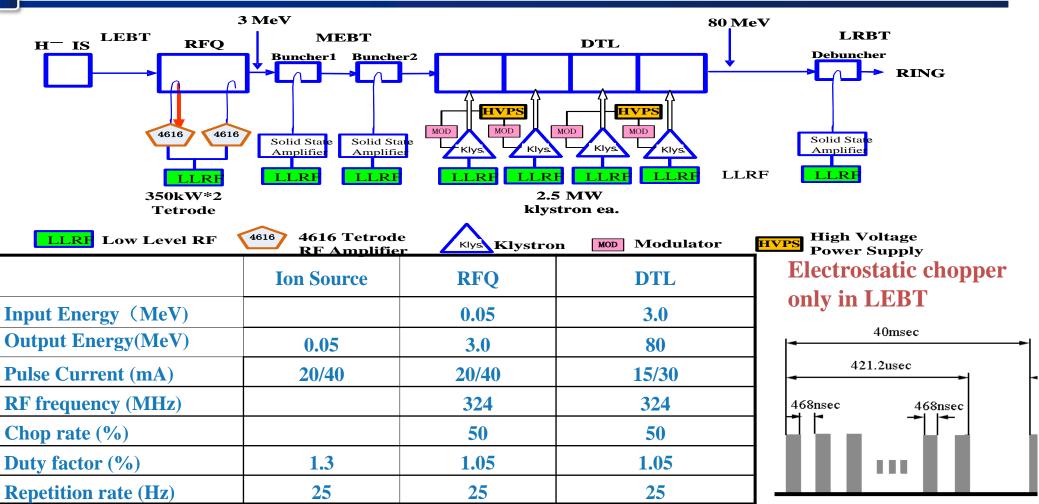
The contribution from the electric and magnetic images of the beam are represented by the Laslett tune shifts $A_{im}{}^e$ and $A_{im}{}^m$, respectively. For a round beam with no neutralization, the direct space-charge tune shift becomes

$$\Delta\nu_{x,y} \approx \frac{f_{sc}Nr_0}{4\pi B_f\varepsilon_{rms}\beta^2\gamma^3}$$

Where N is the proton number, r_0 is the classical radius of a proton, The bunch form factor $f$sc is equal to 1/2 for a uniform distribution, and to 1 for a Gaussian distribution. The B_f is bunching factor. ε rms=$\sigma_\perp^2/\beta_\perp^2$, $\beta_\perp$=R$_0$/ν_0

Front end and Linac

	Ion Source	RFQ	DTL
Input Energy（MeV)		0.05	3.0
Output Energy(MeV)	0.05	3.0	80
Pulse Current (mA)	20/40	20/40	15/30
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

Electrostatic chopper only in LEBT
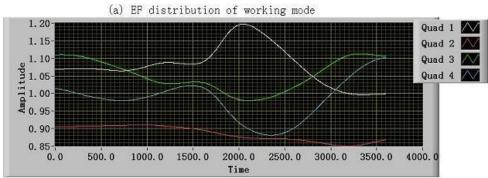
CSNS-RFQ
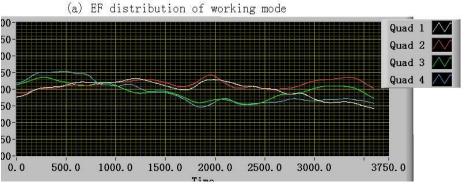
Output energy	3.0 MeV
Repetition rate	25 Hz
Pulse H⁻ beam width	500 μs
Pulse H⁻ beam current	40 mA
RF Freq.	324MHz
Length	3.5

(a) EF distribution of working mode

Field tuning (before)

(a) EF distribution of working mode
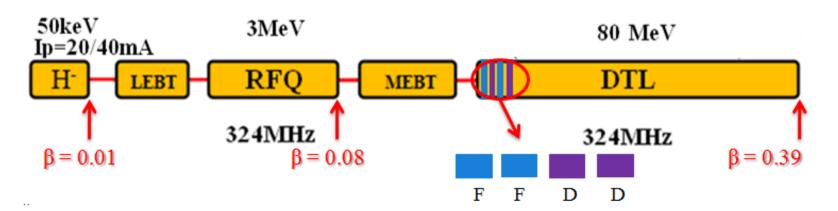
Field tuning (after)

Drift Tube Linac (DTL)
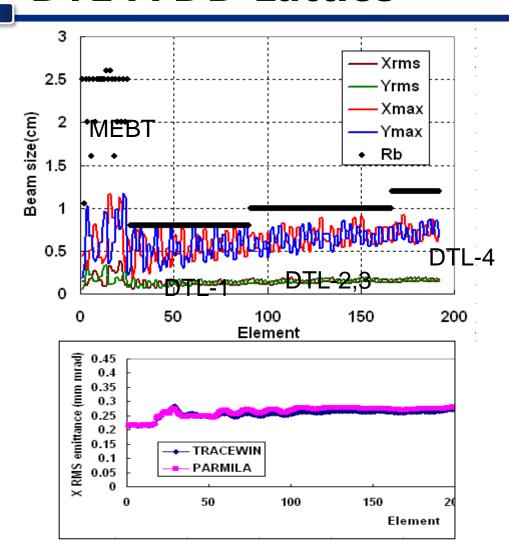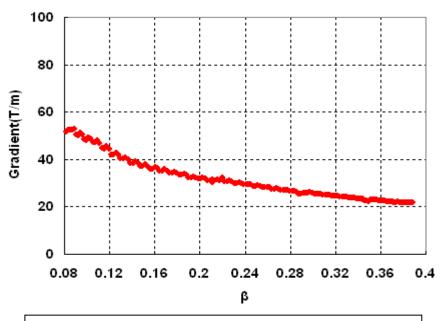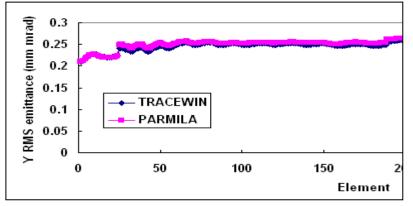
	DTL	
Length	35.44	m
Frequency	324	MHz
Beam energy	3-80.1	MeV
Number of Tanks	4	
Copper RF power	5.3	MW
Peak current	15	mA
Aperture radius	8-12	mm
Number of Cells	161	

FFDD
Rb=0.8cm

FFDD
Rb=1.0cm

FFDD
Rb=1.0cm

FFDD
Rb=1.2cm

DTL FFDD Lattice
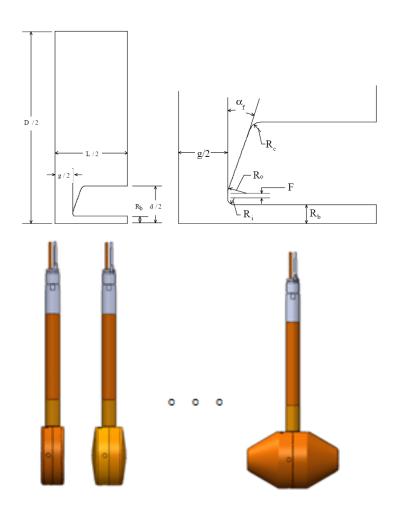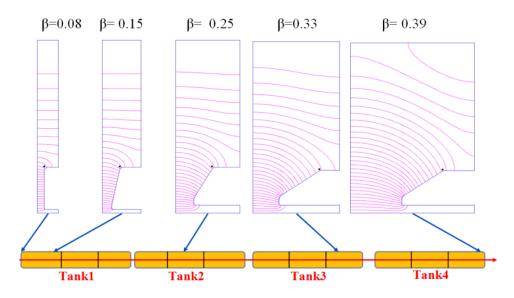
Design of drift tube

Cell geometry

β=0.08   β= 0.15   β= 0.25   β=0.33   β= 0.39

Tank1   Tank2   Tank3   Tank4
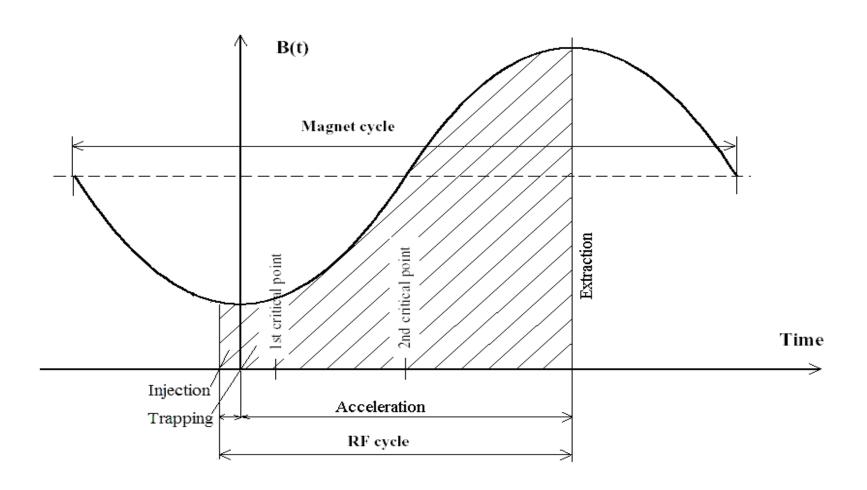
- 9 different profiles of drift tube were adopted based on the optimization on ZTT and kilpatrick.
- The DT Face angle varies from 0⁰ to 60⁰ to reach a relatively high ZTT and a tolerable kilpatrick,

Characteristics of RCS
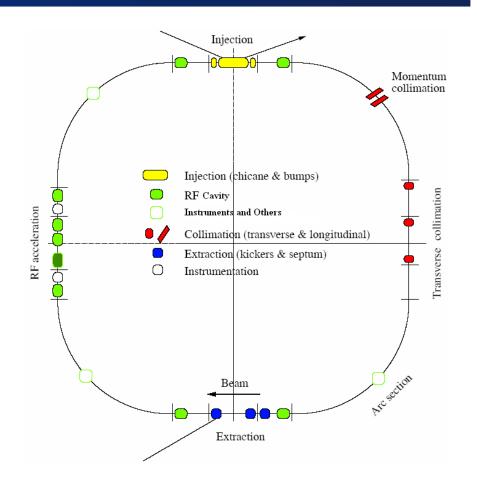
RCS design

- **RCS may be divided into various systems according to their beam-handling functions**
  - Injection
  - Capture and acceleration
  - Extraction
  - Collimation, and transport
  - Beam instruments and correctors
- **These systems are integrated by the 'lattice' magnets, usually symmetrically arranged to alleviate the lower-order resonances**

CSNS/RCS Lattice Design - 4-fold Structure
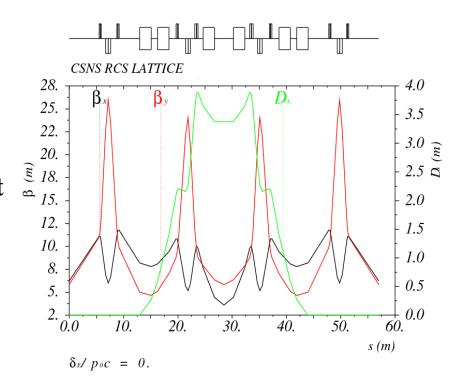
- Separated-function design

- The collimation be performed in a separate straight section.

- The superperiodicity of 4 is better for reducing the impact of low-order structure resonance than the superperiodicity of 3.

A Lattice with Triplet Cells
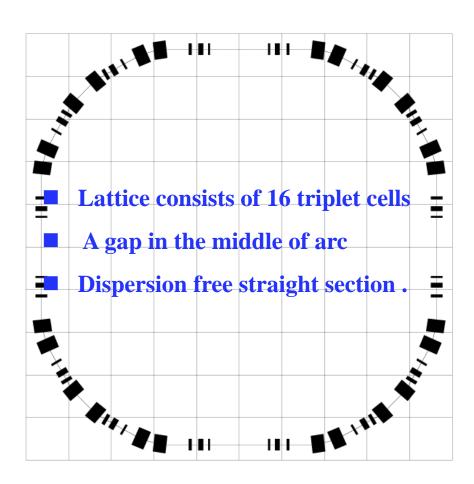
- **Four-fold symmetry**
  - **Separated functions**
- **Triplet structure**
  - **Small magnet aperture**
- **Dispersion-free long uninterrupted straight**
  - **For collimation & injection/extraction**
- **Straight at arc with large dispersion**
  - **High efficiency momentum collimation**
- The all-triplet structure is not good for chromaticity correction and dynamic aperture

CSNS RCS LATTICE

$\delta_E / p_0 c = 0.$

A Lattice with Triplet Cells
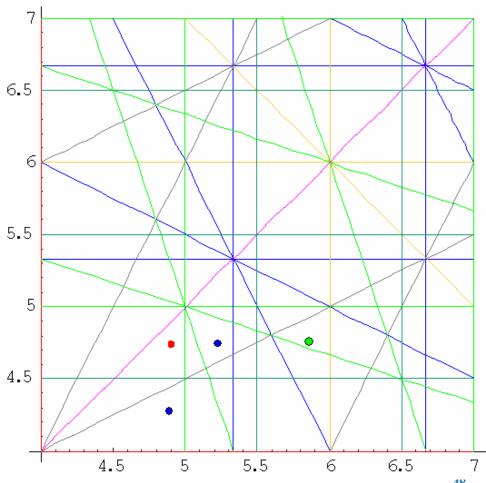
Circumference (m)	**227.92**
Superperiod	4
Number of dipoles	24
Number of quadrupoles	48
Lattice structure	Triplet
Total Length of long drift (m)	**3.85*8+11*4**
Nominal Betatron tunes (h/v)	4.82/4.80
Chromaticity (h/v)	**-4.3/-9.2**
RF Freq. (MHz)	1.02~2.44
RF Voltage (kV)	**165**
Trans. acceptance (μπm.rad)	540
Momentum acceptance	1%
Effective length of dipoles(m)	2.1
Dipole gap (mm)	**160**
Max. quadrupole aperture (mm)	**265**
Number of quadrupole power supplies	5

- Lattice consists of 16 triplet cells
- A gap in the middle of arc
- Dispersion free straight section .

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Tune Diagram for 4-fold Structure

red: 1st order structure resonance

golden: 2nd order structure resonance

blue: 3rd order structure resonance

green: 4th order structure resonance

gray: 3rd deference structure resonance
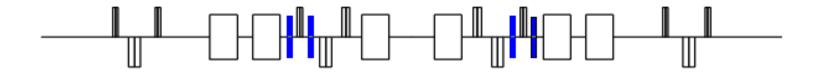
pink: coupling resonance

$$mQ_x + nQ_y = 4l$$

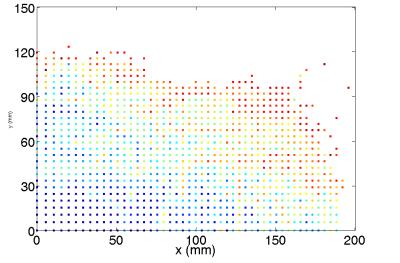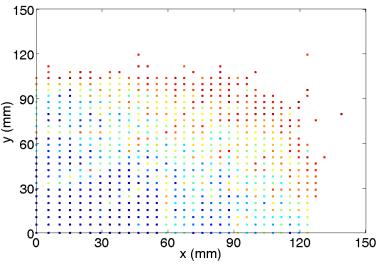m, n = 0, ± 1, ± 2, ± 3, …

Chromaticity Correction

- ➤ Powered with DC power supply

- ➤ 2 families power supplies

- ➤ Designed for low beam density

  - for commissioning

Dynamic aperture

4.5σx×2.5σy, ∆p/p=±1% with sextupoles

2.5σx×2σy,　∆p/p=±1% with sextupoles and high order field of dipoles and quadrupoles

  σx and σy are h and v beam size (320πmm.mrad)
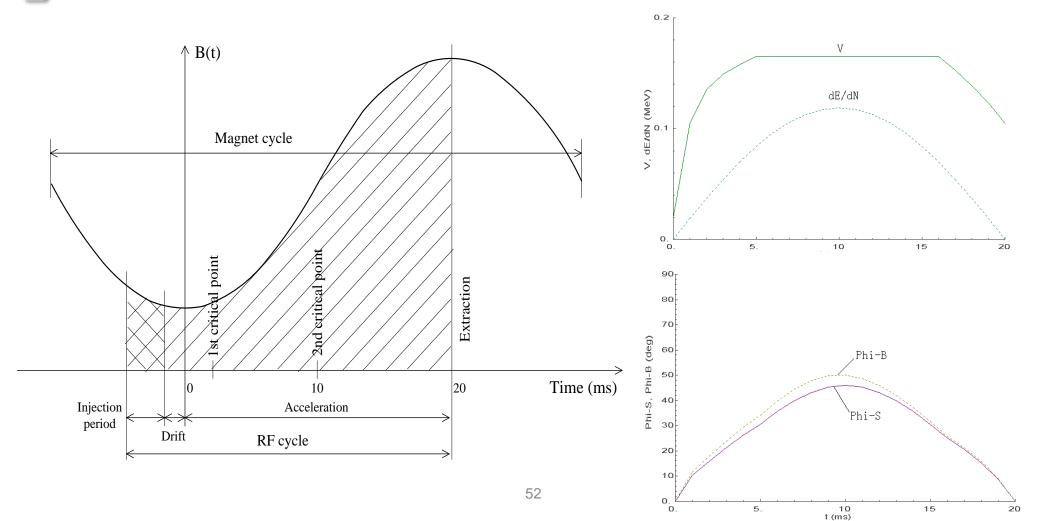
Longitudinal dynamics

- The RF cavities with harmonic number of 2 are adopted;

- Dual harmonic cavities will be added in the future upgrade for higher beam power;

- 8 RF cavities provide total RF voltage of 165 kV, with one additional cavity for redundancy.

- The design of RF voltage and phase curves is an important issue to decrease the beam loss due to the space charge and phase changes
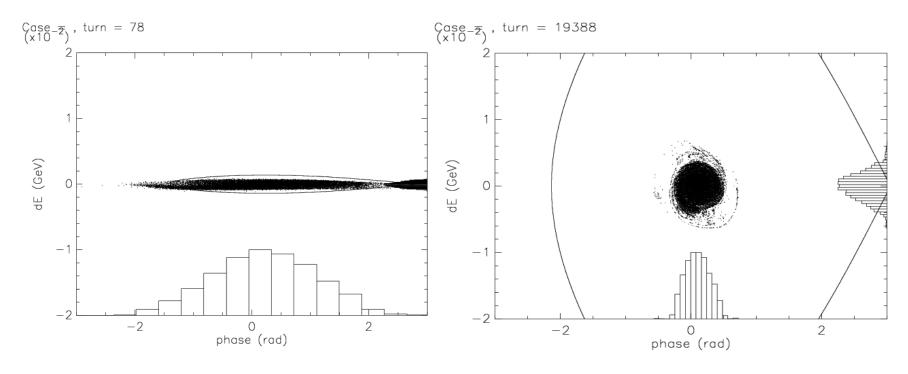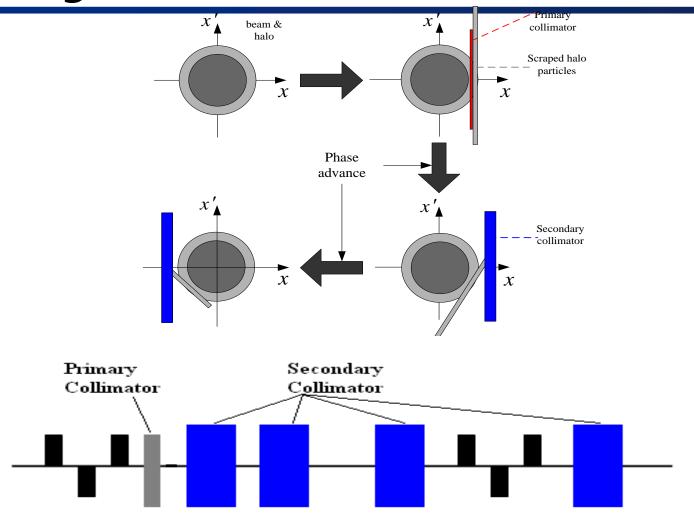
RF voltage and phase

The Longitudinal Phase Space
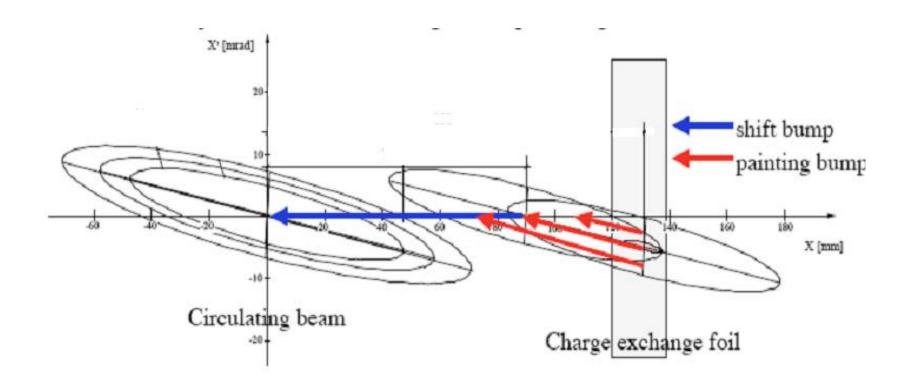

Beginning of acceleration
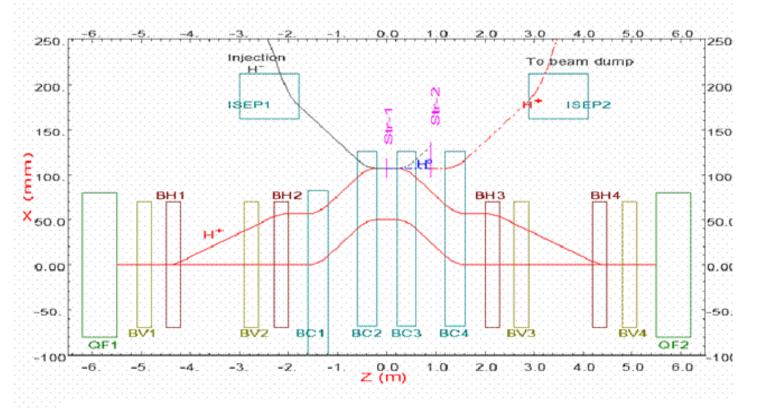
End of acceleration

Two-stage beam collimation

H⁻ stripping Painting injection

RCS injection design

Injection component layout. BC1~BC4：Fixed orbit bump magnets，BH1~BH4：horizontal painting bumpers，BV1~BV4：vertical painting bumpers，ISEP1&2: septum
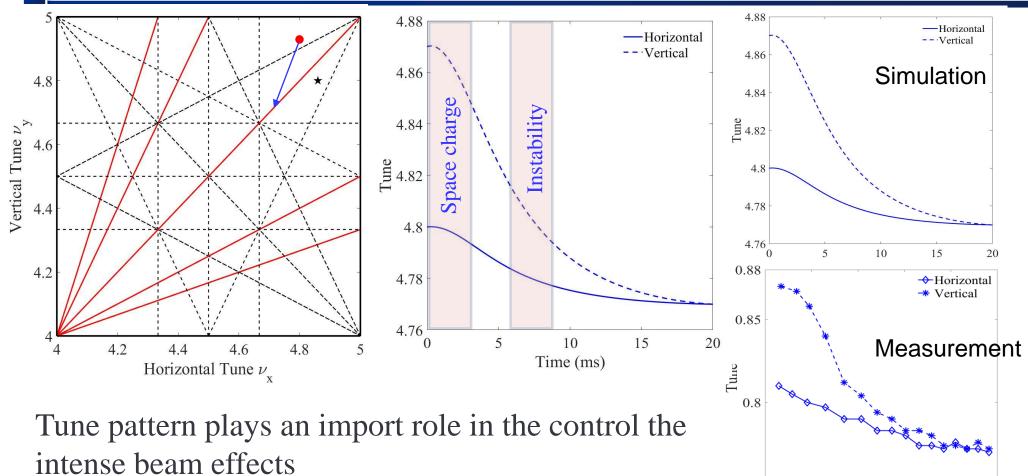
Intense beam effects in RCS commissioning

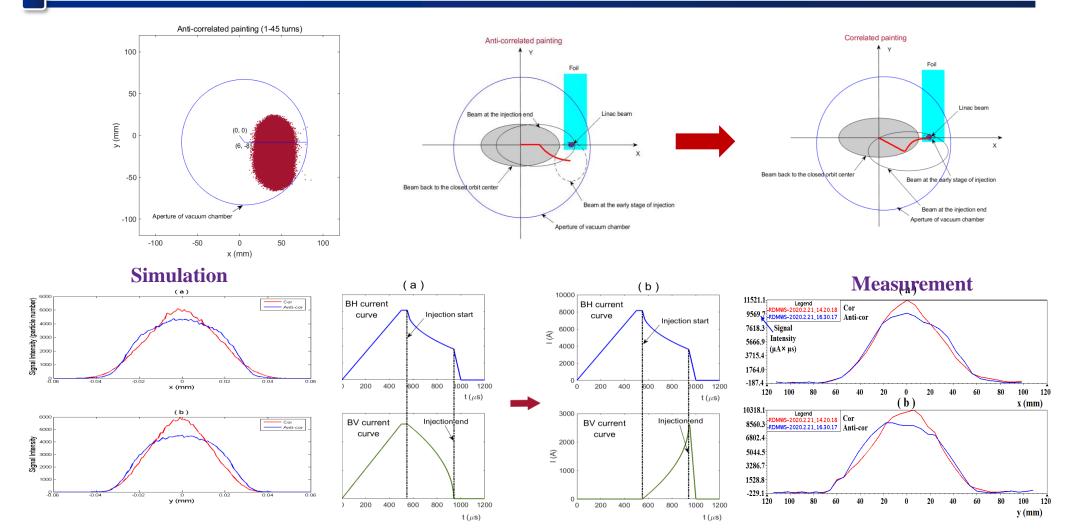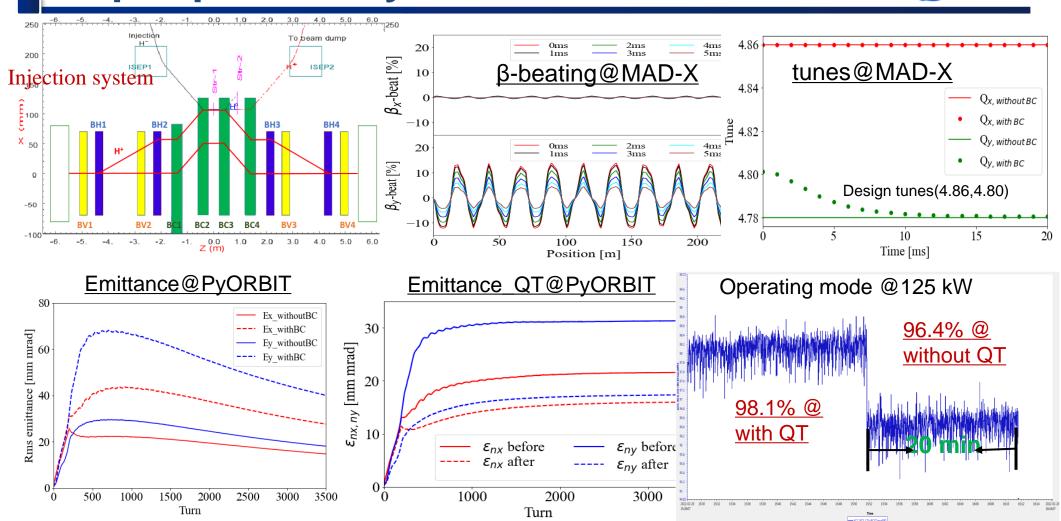| Beam power on target	Challenges	Solutions
50kW→80kW	Too large beam size after painting, non-uniform beam distribution, large transverse coupling	By using the correlated painting instead of the anti-correlated painting
80kW→100kW	Serious beam instability	Optimization of the tune and chromaticity
100kW→125kW	Emittance increase caused by broken four-fold symmetry of the RCS; Stranger beam instability	Slight modification of injection system; installation of AC trim quadrupoles and AC sextupoles
125kW→170kW	Strong space charge effects	Installation of a dual harmonic RF cavity

Tune Pattern Optimization

Tune pattern plays an import role in the control the intense beam effects

Painting scheme optimization

Anti-correlated painting (1-45 turns)

Anti-correlated painting

Correlated painting

Simulation

Measurement

Super-periodicity restoration

Injection system

β-beating@MAD-X

tunes@MAD-X

Design tunes(4.86,4.80)

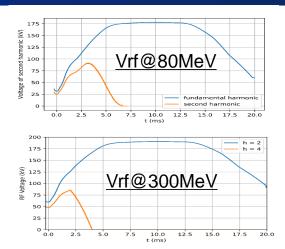Emittance@PyORBIT

Emittance_QT@PyORBIT

Operating mode @125 kW
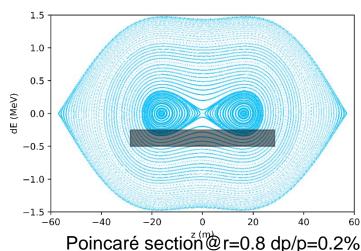
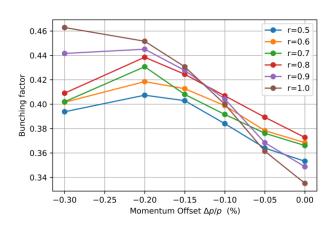98.1% @ with QT

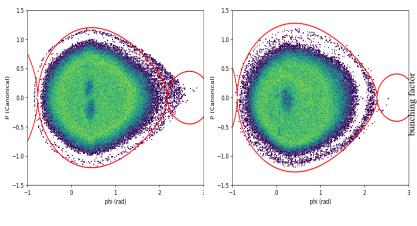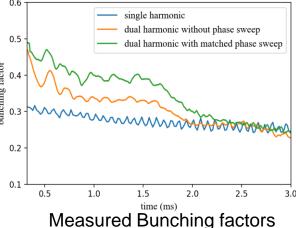96.4% @ without QT

20 min

The duel harmonic RF system

- **The dual harmonic system is designed for ease the space charge effect in the upgrade of CSNS**
- **The prototype MA cavity was installed and operated online**
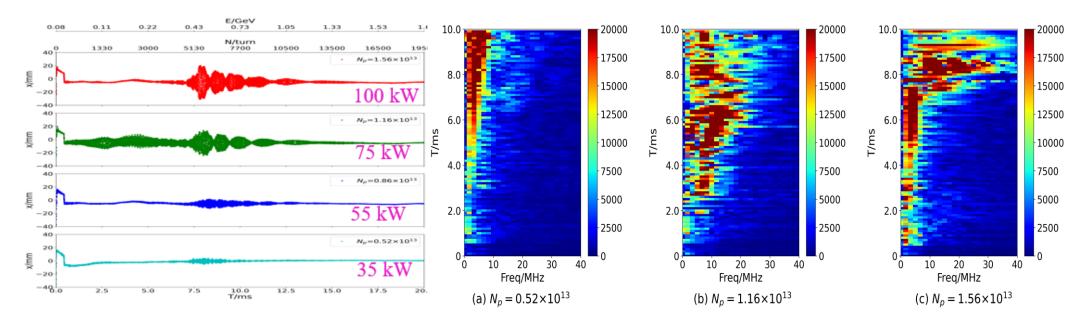- **The initial use of dual harmonic system effectively reduces beam loss and increases beam power.**

Poincaré section@r=0.8 dp/p=0.2%

Bunching factor with *r* and *dp/p*

Optimization of Dual RF pattern

Measured Bunching factors

Collective instability in RCS

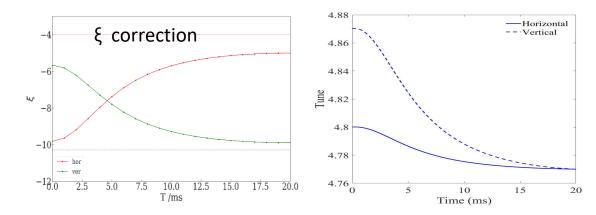- With nominal tune (4.86/4.78) and nature chromaticity, coherent oscillations were observed when beam power >50 kW, with amplitude increasing as the intensity increases.
- The growth time is less than 1 ms for 100 kW
- The impedance is several handred kΩ/m
- It is a "broadband" impedance

(a) $N_p = 0.52 \times 10^{13}$ (b) $N_p = 1.16 \times 10^{13}$ (c) $N_p = 1.56 \times 10^{13}$

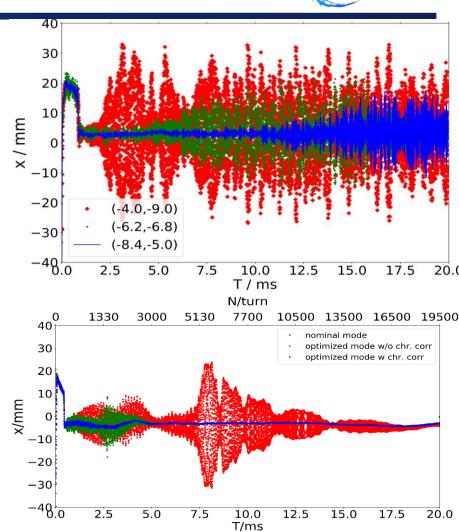# Mitigation of instability

- The coherent oscillation was damped by increasing chromaticity (DC sextupoles)
- Optimizing tune pattern to mitigate the coherent oscillation

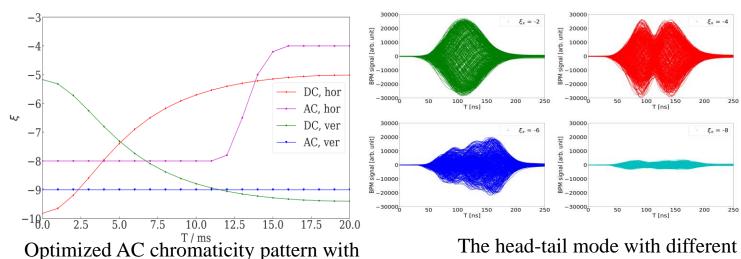✓ With two mitigation methods, the beam power reached 100 kW successfully.

Upgrading sextupoles for high beam power
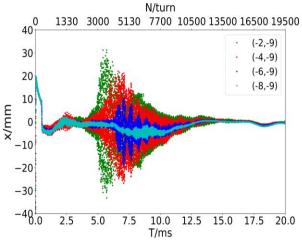
- ➢ **DC sextupoles were replaced by AC after beam power reached 100kW (in 2021)**

- ➢ **With AC sextupoles, the chromaticity can be well controlled in an RCS cycle**

- ➢ **AC sextupole plays a crucial role in beam power of 100 kW+**

- ➢ **AC sextupoles made significant contribution from 100KW to 170 kW**

- ➢ **The instability can be completely suppressed with beam power of 170 kW**

Optimized AC chromaticity pattern with DC and AC sextupole field.

The head-tail mode with different chromaticities

Coherent oscillation well controlled in the commissioning

Possible source of impedance

- **Many studies have been done on the collective instability in design stage, but this instability is unexpected.**
- **Measurements revealed that the ceramic vacuum chamber exhibits low-frequency resonance.**
- **The further study confirmed that the impedance originates from the shielding layer of the ceramic vacuum chamber.**

5.5 mm wide Cu strip

15 nm thick TiN coating

7.5 mm thick ceramic

10mm
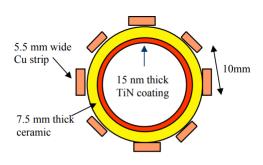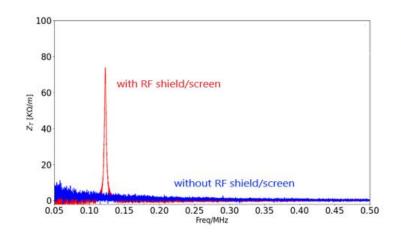
Figure 2: Illustration of the cross-sectional view of the ceramic chamber.

with RF shield/screen

without RF shield/screen

Z_T [KΩ/m]

Freq/MHz

With RF shield/screen
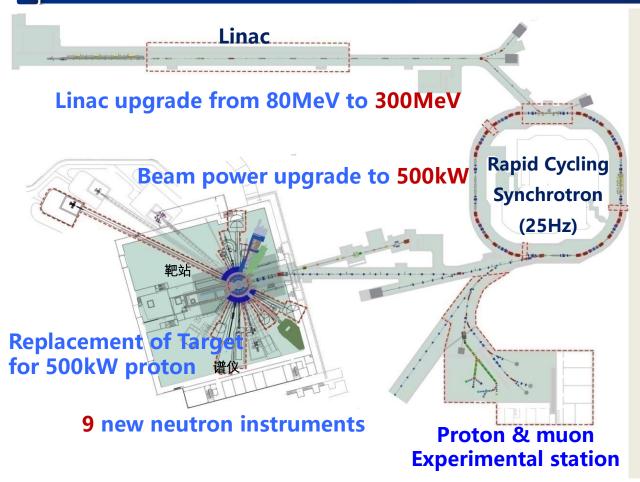
Without RF shield/screen

China Spallation Neutron Source-II

China Spallation Neutron Source-II

Linac

Linac upgrade from 80MeV to 300MeV

Beam power upgrade to 500kW

Rapid Cycling Synchrotron (25Hz)

靶站

Replacement of Target for 500kW proton

谱仪

9 new neutron instruments

Proton & muon Experimental station

➢ Project Budget: 2.9 B CNY

➢ Funded by central and Guangdong local government

➢ Design and R&D completed

➢ Construction: 2024.1~2029.10 (5 years and 9 months）

Beam Power Upgrade （two-step）

1. **Linac (80MeV) + RCS upgrade** **150~200kW** **(the first step)**

   - ✓ New dual harmonic RF system

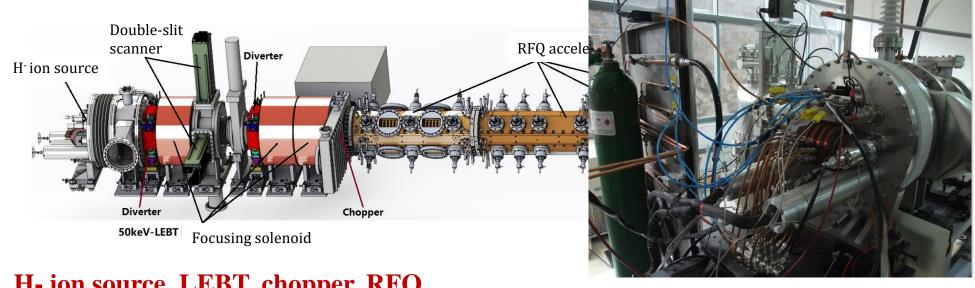   - ✓ Adding AC trim quadrupoles, sextupoles and octupoles

   - ✓ New injection region

2. **Linac (300MeV+) + upgraded RCS** **500kW (the second step)**

   - ✓ SC linac to 300MeV

   - ✓ Upgrade the power supplies for main magnets

The Front End of CSNS Accelerator

H- ion source, LEBT, chopper, RFQ

- The LEBT has 3 solenoids, initially designed for the former penning ion source.
- The penning source has been replaced by RF-driven H^- ion source in Sep. of 2021.
- The ion source current is up to 60mA, and throttled to the required value.
- New LEBT and new RFQ for CSNS-II is under construction and test in the lab.
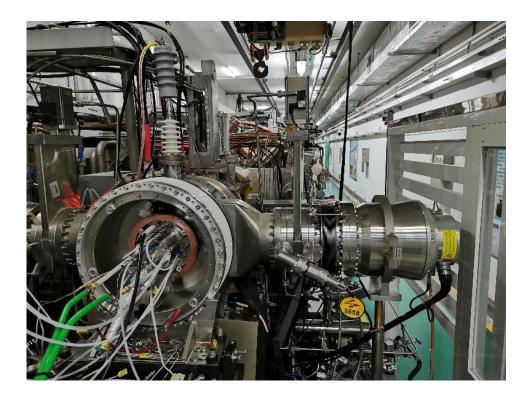
RF Driven H- Ion Source

Typical operation parameter
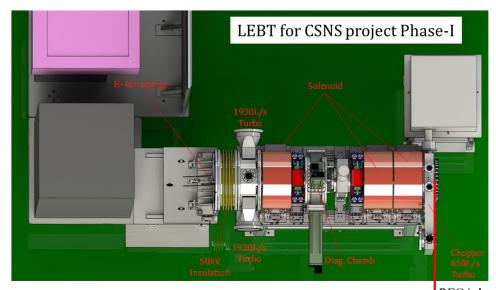
	CSNS service	Test bench study
Peak RF-power	31 kW	25~40kW
H2 flow rate	21 SCCM	18~24 SCCM
Repetition rate	25 Hz	25 Hz
Plasma pulse width	680 μs	500~1000μs
Beam pulse width	498 μs	100~600 μs
H- peak current	37 mA	50~60mA
Cs reservoir temp	80~87C	77~120°C
Service cycle	>330days	
Beam energy	50 keV	50 keV
Norm. RMS emitt.	Not measured	0.31π@60mA

The RF ion source installed in the tunnel
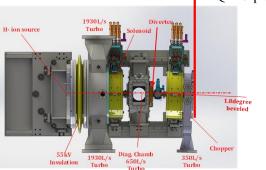
New LEBT for CSNS-II

LEBT for CSNS project Phase-I
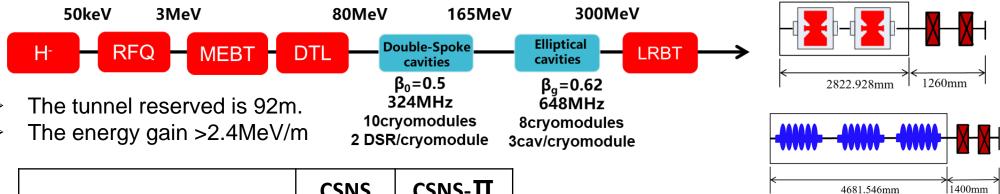
LEBT for CSNS-II

Parameters	CSNS LEBT	CSNS-II LEBT
Length	1668mm	738mm
Inner diameter	138mm	64mm
RFQ inlet current	~40mA	60mA
RMS Emitt. @RFQ inlet	0.307@37mA	0.24@52mA
Num. of solenoids	3	2
Length of solenoids	240mm	127mm
Stripped proton removal	No deflection	1.8 degree （3.6 to H-）
Chopper length	50mm	27mm
Chopper voltage	3.8~5kV	6~8kV

Linac Upgrade

- The tunnel reserved is 92m.
- The energy gain >2.4MeV/m

Double-Spoke cavities: $\beta_0=0.5$, 324MHz, 10cryomodules, 2 DSR/cryomodule

Elliptical cavities: $\beta_g=0.62$, 648MHz, 8cryomodules, 3cav/cryomodule

50keV · 3MeV · 80MeV · 165MeV · 300MeV

H⁻ — RFQ — MEBT — DTL — Double-Spoke cavities — Elliptical cavities — LRBT

2822.928mm / 1260mm

4681.546mm / 1400mm
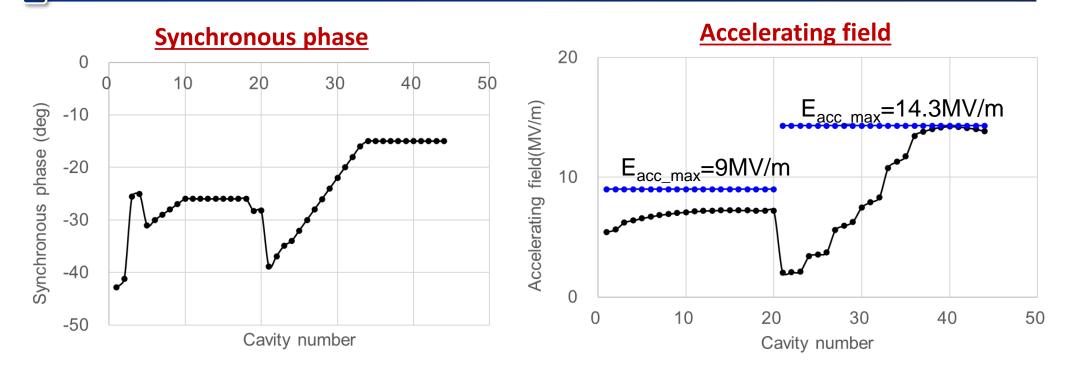
	CSNS	CSNS-II
Particle species	H^-	H^-
Pulse repitition frequency(Hz)	25	25+25
Linac beam energy (MeV)	80	300
Average current(μA)	62.5	625
Peak current (mA)	15	50
Pulse width(μs)	500	500

Special requirements;

- Energy jitter <0.04%
- Energy spread: <0.03%
- High availability (>97%)

Beam dynamics-ϕ_s and E_{acc}

Synchronous phase

Accelerating field

$E_{acc\_max}=14.3\text{MV/m}$

$E_{acc\_max}=9\text{MV/m}$

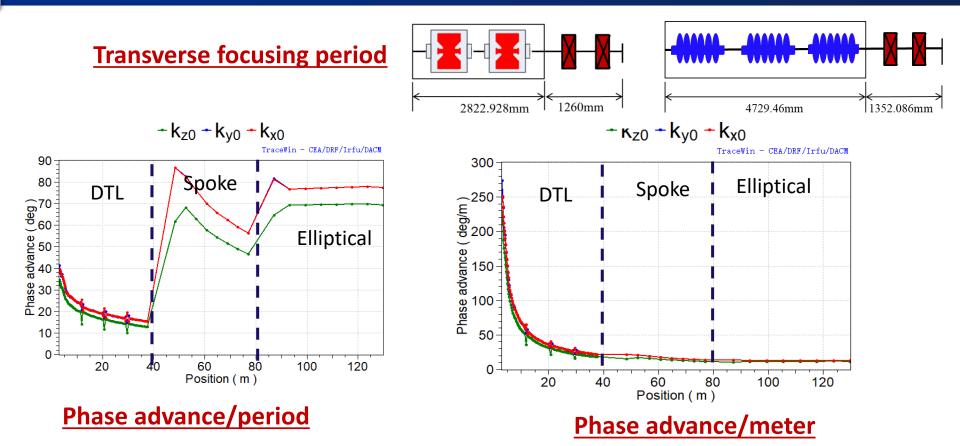$$(\phi_s)_{648MHz} = 2 \times (\phi_s)_{324MHz}$$

$$k_{l0}^2 = \frac{2\pi q E_0 T \sin(-\phi_s)}{mc^2 \beta_s^3 \gamma_s^3 \lambda},$$

maximum variation per period $< 2deg/m$

Beam dynamics-*lattice*

Transverse focusing period

Phase advance/period
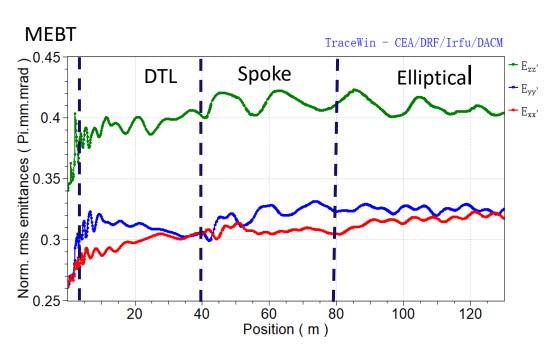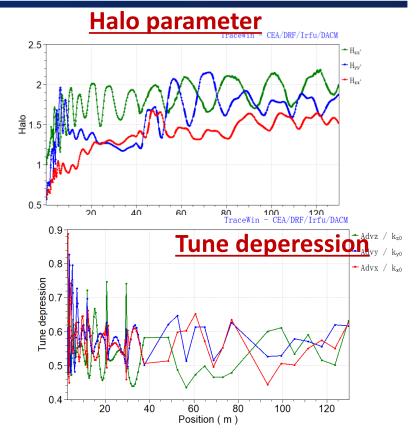
Phase advance/meter

- Zero-current phase advance per period should be less than 90 degrees to avoid parametric resonances.
- Average phase advance per meter should be continuous to avoid mismatch.

Multi-particle tracking results
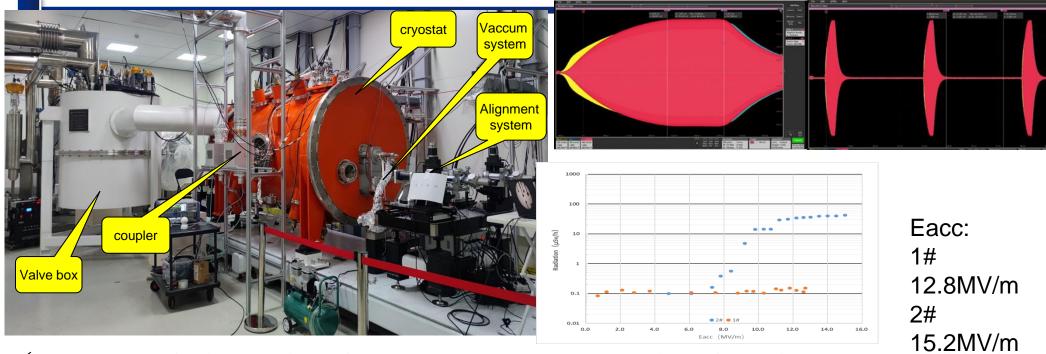

Halo parameter

Tune deperession

Emittance evolution along the MEBT+DTL+SC

➢ The RMS emittance growth through MEBT+DTL+SC is 26%(horizontal), 32%(Vertical) and 32%(longitudinal).

➢ Halo parameter is less than 2.2, and the tune depression is bigger than 0.4

Horizontal testing

cryostat
Vaccum system
Alignment system
coupler
Valve box

Eacc:
1#
12.8MV/m
2#
15.2MV/m

✓ The successful integration of the cryostat and the completion of the high-power conditioning process for the couplers mark significant milestones.

✓ Horizontal testing yielded promising results with a maximum gradient of 15.2 MV/m and a static heat load of 16.3 W.

✓ Further measurements are required to accurately determine the dynamic heat load.
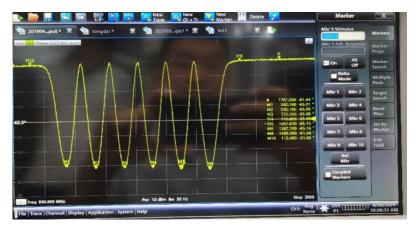
6-cell Elliptical cavity

- 648 MHz 6-cell Elliptical Cavity

parameter	design
Frequency(MHz)	648
TTF@β_g	0.7
β_g	0.62
E_p/E_{acc}	2.53
B_p/E_{acc}(mT/(MV/m)2	5.45
R/Q (Ω)	309
G (Ω)	177
Beam tube diameter (mm)	105/120
Cell-cell coupling (%)	1.35
E_{acc}(MV/m)	14

mechanical structure of prototype ellipsoidal cavity

BCP and HPR
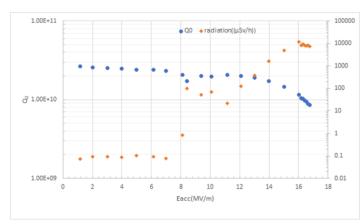

The flatness of the electric field is 97.9%.

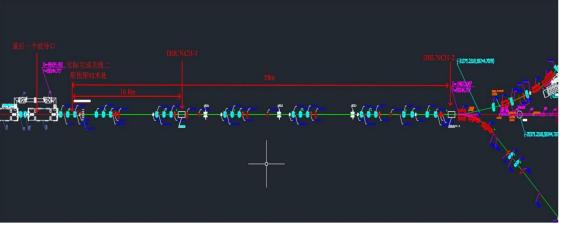During testing, the highest gradient reaches 21.7 MV/m

Debuncher System

Two Debuncher cavities:

- **DBUNCH-1 reduces beam energy jitter**
- **DBUNCH-2 controls energy spread**
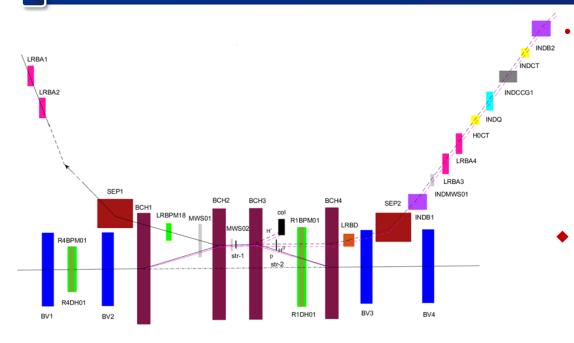
Parameters	Value
Beam Energy at the End of SC Linac	300 MeV
Repetition Frequency	50Hz
Debuncher Cavity-1 Frequency	648 MHz
Debuncher Cavity-1 Aperture	70 mm
Debuncher Cavity-1 ETL	3.3 MV
Debuncher Cavity-2 Frequency	648 MHz
Debuncher Cavity-2 Aperture	70 mm
Debuncher-Cavity-2 ETL	1.0 MV
Reducing Ratio of Momentum Jitter	77.3%
Minimum $\Delta P/P$ at the end of Linac (99.5%)	0.35‰

New injection scheme for CSNS-II

- **New idea:** chicane bump and horizontal painting bump are combined into one bump which make the chicane bump "move". The horizontal painting is performed by using the position and angle scanning at the same time.

◆ **Advantages:**

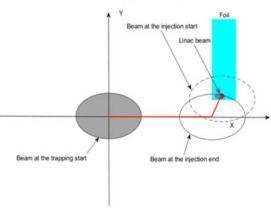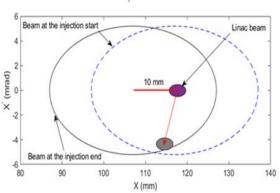◆ Peak temperature of the stripping foil can be greatly reduced.

◆ Both correlated and anti-correlated painting can be performed.

◆ The edge focusing effect of bump magnets is greatly reduced

◆ The difficulty of large aperture of the injection port and transport line required by angular scanning is solved.

◆ It saves a set of bump magnets and is easier to optimize the layout of the injection system.

Description for the new painting scheme
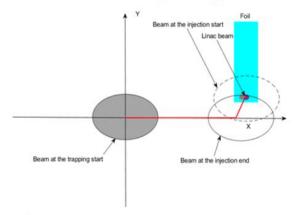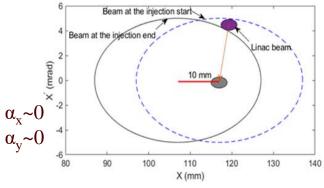
Correlated painting

Anti-correlated painting

$$\alpha_x \sim 0$$
$$\alpha_y \sim 0$$
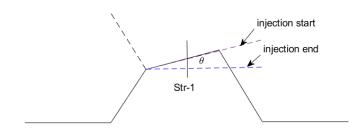
- ◆ **Injection beam**: BCH is used for horizontal angular scanning, while the horizontal position is also scanned in a small range.

- ◆ **Circulating beam**: horizontal and vertical position scanning can be performed with BCH and BV magnets.

- ◆ **Residual H^0 beam**: H^0 beam at the waste beam outlet has an angle distribution with time. A small pulse magnet is installed for angular scanning compensation.

- ◆ **Compatibility mode for correlated and anti-correlated painting:** match the angle of SEP and BCH magnets.

- ◆ **Spatial optimization**: BCH bump is irregularly shaped to allow the waste beam line to move a short distance along outside the RCS.

BCH bump and key magnets
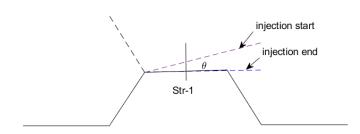
Correlated painting

Scanning angle : 4.5 mrad

Anti-correlated painting

Scanning angle : 5.0 mrad

Painting	Time	SEP1 (mrad)	BCH2 (mrad)	BCH3 (mrad)	BCH4 (mrad)	LRBD (mrad)	SEP2 (mrad)	INDB1 (mrad)	INDB2 (mrad)	BCH1 (mrad)
Correlated	Begin	226.713	53.549	64.681	60.181	-4.5	349.82	-13.419	-34.356	58.049
	End	226.713	49.049	60.181	55.681	+4.5	349.82	-13.419	-34.356	53.549
Anti-correlated	Begin	222.32	58. 442	58. 442	58. 442	-5	351.558	-13.066	-34.708	58.442
	End	222.32	53. 442	53. 442	53. 442	+5	351.558	-13.066	-34.708	53.442

81

Upgrade of RCS Injection System

CSNS Injection

dismantling

CSNS-II Injection Installing…

Jun. 20- Aug.31

MA Cavity

- 1.8m 3 gaps water-cooling cavity with external diameter 850mm MA rings
- 2 cavity were put into operation in 2022 and 2023
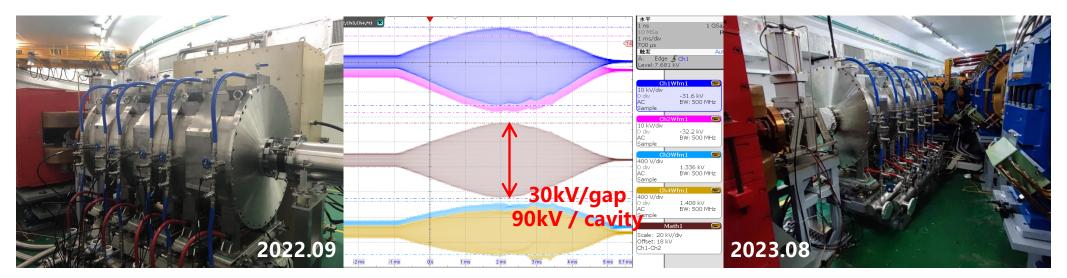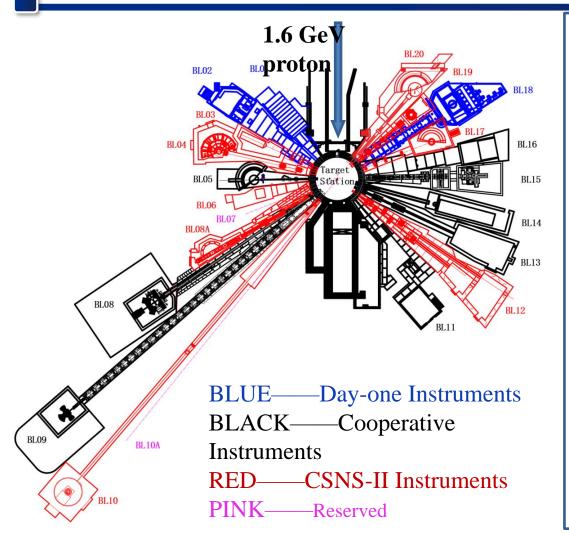- Gradient >50kV/m on second hormonic mode (15% duty factor)
- Gradient >25kV/m on fundamental hormonic mode (50% duty factor)
- Cavity impedance is stable after long-term operation (variation < 3%)

30kV/gap
90kV / cavity

2022.09

2023.08

Neutron Instruments for CSNS-II

1.6 GeV proton

BLUE——Day-one Instruments

BLACK——Cooperative Instruments

RED——CSNS-II Instruments

PINK——Reserved

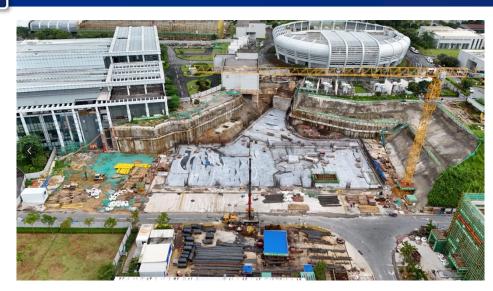| Location	Instrument
BL01	Small Angle Neutron Scattering
BL02	Multiple Purpose Reflectometer
BL03	Liquids Neutron Reflectometer
BL04	Cold Neutron Inelastic Spectrometer
BL05	High Energy Direct Geometery Inelastic Spectrometer
BL06	Molecular Vibrational Spectrometer
BL07	Reserved
BL08	Engineering Material Diffracmeter
BL08A	Neutron Technology Testing Station
BL09	High-resolution Neutron Powder Diffractometer
BL10	Neutron Backscattering Spectrometer
BL10A	Reserved
BL11	Atmosphere Neutron lrradiation Spectrometer
BL12	Neutron Physics and Application Instrument
BL13	Energy-resolved Neutron lmaging Instrument
BL14	Very Small Angle Neutron Scattering Instrument
BL15	High Pressure Neutron Diffractometer
BL16	Multi-Physics Instrument
BL17	Elastic Diffuse Scatting Spectrometer
BL18	General Purpose Powder Diffractometer
BL19	Single Crystal Neutron Diffractometer
BL20	PolArized Chopper Spectrometer

CSNS-II New Buildings

Linac and Cryogenic Building （CSNS-II）

Neutron Backscattering Spectrometer Hall

Muon and High-energy Proton Beam Experimental Hall

Temporary Storage Hall for Solid Radioactive Waste
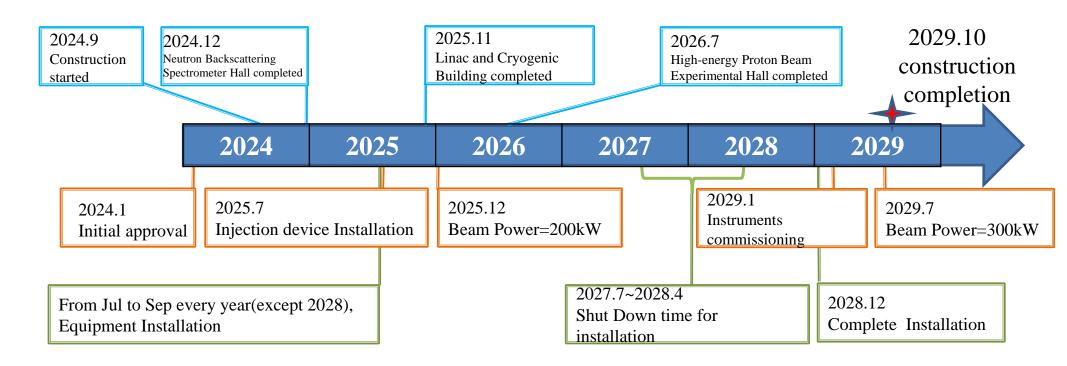
User Laboratories Hall

CSNS-II CPM

During the construction period, the open operation is minimally impacted due to the implementation of a well-planned installation and commissioning plan.

2024.9
Construction started

2024.12
Neutron Backscattering Spectrometer Hall completed

2025.11
Linac and Cryogenic Building completed

2026.7
High-energy Proton Beam Experimental Hall completed

2029.10
construction completion

2024 2025 2026 2027 2028 2029

2024.1
Initial approval

2025.7
Injection device Installation

2025.12
Beam Power=200kW

2029.1
Instruments commissioning

2029.7
Beam Power=300kW

From Jul to Sep every year(except 2028), Equipment Installation

2027.7~2028.4
Shut Down time for installation

2028.12
Complete Installation

Plans to maintain user operation almost unaffected during CSNS II construction

谢 谢！