China Spallation Neutron Source

Design and R&D

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Outline

- Project overview
- Accelerator design and prototyping
- Target system R&D
- Instrument system R&D
- Summary
Types of SNS accelerators

- Continuous-wave facilities
  - Driven by a high intensity proton cyclotron
  - 1.2 MW SINQ (PSI) driven by 590 MeV cyclotron

- Long (ms) pulse facilities
  - Driven by a high intensity proton linac
  - 1 MW LANSCE (LANL) driven by 800 MeV linac

- Short (μs) pulse facilities
  - Partial energy linac and rapid-cycling synchrotron(s):
    - ISIS (RAL) driven by 70 MeV linac/800 MeV RCS
    - J-PARC driven by 400 MeV linac/3 GeV RCS/50 GeV MR
  - Full-energy linac and an accumulator ring:
    - SNS (ORNL) driven by 1 GeV linac/accumulator
Accelerators at power frontier

CHINA SPALLATION NEUTRON SOURCE

Diagram showing the relationship between kinetic energy (GeV) and average beam current (mA) for various accelerators. The diagram includes markers for existing (SP), under construction (SP), proposed (SP), existing (CW, LP), under construction (CW, LP), and proposed (CW, LP) accelerators. Key sites and their corresponding power levels are indicated, including LEDA, 1 MW, 0.1 MW, SNS, ISIS-II, J-PARC RGS, CSNS-II, CSNS-I, J-PARC MR, AGS, NuMI, and CNGS.
High power accelerator applications

**CW and long pulse applications**

High average power, high current proton source, high duty factor (~10% or higher) to minimize mechanical shock, ~1 GeV to reduce power deposition in window & cost

- Irradiation, Rare isotope, ...
- Transmutation of nuclear waste
- Accelerator driven subcritical power generation

**Short pulse applications**

High peak power, H- ion source for accumulation, pulsed high intensity secondary beam generation (duty factor < 10^-4)

- Neutrons, Kaons, neutrinos, muons for neutrinos, muons for muon collider, radioactive isotope (ISOL)
Projects proposed in China

China Spallation Neutron Source (CSNS) - Chinese Academy of Sciences and Guangdong
- Huge domestic demand from the user community
- Compliments light sources (4 in China) and reactors
- Bridges the technology towards ADS

Accelerator Driven Sub-critical programs
- Compliments fast-breeder reactor (FBR) and pressured water reactors (PWR)
- Transmutation of waste from nuclear power plants
  - No long-lifetime waste, more abundant fuel ($^{238}$U), higher safety/possibly lower cost, less proliferation problem

Proton/ion cancer therapy (synchrotron based)
CSNS layout

- Linac: H- beam, 81 MeV (DTL) to 250 MeV (SCL)
- Rapid-cycling synchrotron: 1.6 GeV at 25 Hz
CSNS accelerator schematics

50keV 3 MeV H: I.S. RFQ

H: I.S. RFQ MEBT DTL Linac

80/130MeV (I_{ave}=63/125 \mu A)

Ip=20mA 324MHz 324MHz

LEBT LRBT

upgrade

RCS
1.6 GeV, 25Hz
63/125 \mu A

P_B= 100/200kW

RTBT

Chinese Academy of Sciences
Challenges

Physics:
- Space charge & halo, electron cloud, fringe field, impedance & instability, diagnostics (same as those for SNS and J-PARC)

Engineering:
- High-efficiency, high-yield target & moderator, rapid-cycling technology (power supply, ceramic vacuum chamber, RF shielding, RF system, magnet/coil ...), high-intensity source, RFQ, Linac and transport, collimation, remote handling, coating, diagnostics

Management (budget):
- SNS: US$1.4B + upgrade funds
- J-PARC: ~US$1.5B + people
- CSNS: ~ US$0.2B; (accel.: budgeted < $100M extremely tight)

Primary challenges:
- Complete project scope at high quality with limited budget
- Reserve potential for future development in phases
Design philosophy

- Fit in China’s present economical situation
  - Total phase-I cost ~1.46B CNY (~US$188M)
- An advanced facility with upgrade potential
  - Phase I beam power goal: 120 kW; phase II: 240 kW
  - Expandable to higher power/2nd target
- Adopt mature technology as much as possible
  - First high-intensity proton machine in China
  - High reliability for our users
- Closely collaborate with world leaders & develop domestic technology to control cost
  - Keep final fabrication in China as much as possible
## CSNS proposed budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost [10k CNY]</th>
<th>Percentage [%]</th>
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<tr>
<td>Total</td>
<td>146.505</td>
<td>100.0</td>
</tr>
</tbody>
</table>

1. Conventional engineering: 44,566 (30.4%)
2. Civil construction: 19,629 (13.4%)
3. Conventional facility: 20,223 (13.8%)
4. Installation: 4,714 (3.2%)
5. Linac: 15,950 (10.9%)
6. Synchrotron & transports: 42,578 (29.1%)
7. Target station: 16,126 (11.0%)
8. Instrumentations: 13,810 (9.4%)
9. Controls: 3,809 (2.6%)
10. Project management: 2,666 (1.8%)
11. Contingency: 7,000 (4.8%)

**Note:** The total cost is 146.505 (100.0%).
## CSNS project schedule

### CSNS—Schedule

<table>
<thead>
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<th>任务名称</th>
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<td>Preliminary Design Report</td>
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<tr>
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<tr>
<td>Starting Installation</td>
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<td>First Beam to Target</td>
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### Timeline

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WEZMA02 Wei 2007-1-31
Limited R&D fund for prototyping

- Funds are very limited (US$3.8 M)
- Limited prototyping efforts
  - Five accelerator systems:
    - DTL (half tank), Ring magnet (2), RF cavity (1), vacuum duct (2), magnet power supply (1)
  - Target body material tests, moderator & cooling system, decouple & poison
  - Neutron super-mirror guide, background chopper, neutron detector
- Much more R&D funding is needed; schedule is extremely tight
Ion source & LEBT

Ion source

- Collaborating with & assisted by ISIS: Penning H⁻ source
- Backup: SNS type RF source with external antenna

LEBT & pre-chopper

- J-PARC type magnetic LEBT

Ion species: H⁻
Repetition rate: 25 Hz
Output energy: 50 keV
Transverse emittance (rms normalized): 0.2 π mm m⁻¹
Lifetime: 30 days

<table>
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<tr>
<th>Current [mA]</th>
<th>Pulse length [us]</th>
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<td>Phase I</td>
<td>20</td>
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<tr>
<td>Phase II</td>
<td>40</td>
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RFQ

Following the ADS/RFQ design (352MHz)
324 MHz, 4-vane, 3 MeV output energy
Domestic vendor experience
- World class quality at a fraction of “world standard” cost
RFQ 出入口ACCT信号:

入口 $I_{in} = 44\text{mA}$

出口 $I_{out} = 41\text{mA}$.

92% transmission; 6% duty

First digital LLRF developed in China

S. Fu, H.F. Ouyang, Z.H. Zhang et al

黄色：RFQ腔内射频场信号，凹部：束流负载。

蓝色：输入耦合器反射信号，凹部：束流负载使反射下降。
Drift tube linac prototyping

- Phase I to 81 MeV with four DTL tanks
- 324 MHz with duty factor < 3% (frequency chosen by several projects/programs)
- Tank: Electro vs. explosive forming explored - seeking collaboration with PEFP
- EM quad, J-PARC type coil
Linac RF system

- R&D on HV power supply
  - No step-up high voltage transformers and high voltage multi-phase rectifiers
  - IGBT frequency converter (50 Hz 3-phase mains to 25 Hz single phase)
  - Synchronous phase-lock control between AC charging and DC pulse discharging

Diagram:
- Collector → Modulating anode → Cathode
Ring lattice

- Four-fold symmetry
  - Separated functions
- FODO arc
  - Easy correction
- Dispersion-free doublet straight
  - Long, uninterrupted straight for collimation & injection
- Missing-gap momentum collimation
  - High efficiency

Relation amplitude functions [m] versus distance [m]

Dispersion functions [m] versus distance [m]
Ring magnet

- Large aperture, laminated magnets with eddy-current cuts near the ends and plates
  - Dipole: stranded Al wire coil; successfully developed by 3 domestic vendors
  - Quad: considering split hollow-Cu wire
  - Can be used for rapid cycling medical machines
Ring vacuum

- Ceramic vacuum chamber of large aperture/length
  - Metallic brazing (J-PARC) and glass joint (ISIS)
- Possible external wrap-on RF shielding (used at KEK)
- Quadrupole duct developed by domestic vendor
- Dipole duct: parallel development in progress (assistance from ISIS and J-PARC)
Ring radio-frequency system

- Ferrite-loaded RF cavity 1 - 2.5 MHz
- Test of ferrite rings supplied by BNL etc.
- Controls: feed-forward, dynamic tuning, feedback, radial & phase loops
Target material R&D

- Corrosion test of Tungsten
- Ta cladding by Hot Isostatic Pressing
- Plasma coating (air or vacuum) coating
  - Uniformity, strength, porosity
- Supersonic plasma spray (Ta-Ni-W)
- W-Re alloy

(X.J. Jia et al)
Target station

Top shielding
Concrete external shielding
Air cooling vessel Ø10m
Shutter
Middle iron shielding
Helium cooling vessel Ø2m
T-M-R vessel
Trolley

Proton
Level +1.2m
Level +0m
Level –2m

Level +8m

Level +0m
Instrument layout

Target Cooling System

Low energy RG spectrometer
Long wavelength PND
Neutron physics

High Intensity PND
EV Spectrometer
Single crystal diffractometer
Engineering PND

High resolution PND
Backscattering spectrometer

High pressure PND
Single crystal RG spectrometer
Low energy DG spectrometer
Disorder materials PND
High energy RG spectrometer
High energy DG spectrometer

Magnetism reflectometer
Liquid reflectometer
Small angle diffractometer

Moderator:

- LCH4 (100K)
- LH2 (20K)
- Water (300K)
CSNS in perspective

- Towards higher energy
- Towards higher power

Medical facility

(0.5 MW pulsed / 5 MW cw)

H^+ (20 mA +) → ADTF

H^- (0.32 mA) → 0.25 GeV

0.25 – 1.6 GeV

(0.5 MW pulsed)

SNS
Summary

CSNS is progressing with limited funds under tight schedule

Priority: quality/user reliability, cost, future potential

To accomplish the project with an extremely tight budget, we must
- Develop domestic technology
- Seek world-wide collaboration
C1 Accelerator system development (front end & linac)
- D. Faircloth (ISIS), (D.C.Faircloth@rl.ac.uk) ok
- K. Hasegawa (J-PARC), (hasegawa.kazuo@jaea.go.jp) ok
- H.F. Ouyang (ouyanghf@mail.ihep.ac.cn) ok

D1 Accelerator system development (ring)
- S. Henderson (SNS), (shenderson@ornl.gov) ok
- A. Chao (SLAC), (achao@slac.stanford.edu) ok (may not attend)
- S. Wang (wangs@ihep.ac.cn) ok

F1 Accelerator and target/experiment interface
- G. Murdoch (SNS), (murdochgr@ornl.gov)
- J.Y. Tang (tangyv@ihep.ac.cn) ok

G1 Accelerator commissioning and operations
- D. Findlay (ISIS), (D.J.S.Findlay@rl.ac.uk) ok
- J. Galambos (SNS), (jdq@ornl.org) ok
- S.N. Fu (fusn@ihep.ac.cn) ok

H1 Accelerator projects in China
- J. Xia (IMP), (xiajw@impcas.ac.cn)
- Z.T. Zhao (SSRF), (Zhaozt@ssrc.ac.cn) ok

J1 Medical applications
- S. Peggs (BNL), (peggs@bnl.gov) ok (f)
- L. Teng (ANL), (teng@aps.anl.gov) ok (f)
- Q. Qin (qinq@ihep.ac.cn) ok

K1 ADS, RIA, Drivers
- J. Lagnie (CEA), (jean-michel.lagnie@cea.fr) ok
- W.T. Weng (BNL), (weng@bnl.gov) ok
- X.L. Guan (CIAE), (gxl@iris.ciae.ac.cn) ok
Thank you!
# Main accelerator parameters

## Table 1: CSNS accelerator primary parameters.

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<th>Project Phase</th>
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<td>Beam power on target [kW]</td>
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<td>500</td>
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<tr>
<td>Proton energy on target [GeV]</td>
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<td>Average beam current [$\mu$A]</td>
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<td>315</td>
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<tr>
<td>Pulse repetition rate [Hz]</td>
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<td>25</td>
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<tr>
<td>Proton per pulse on target [$10^{13}$]</td>
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<td>Pulse length on target [ns]</td>
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<td>&lt;400</td>
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<td>Linac output energy [MeV]</td>
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<td>Ion source/linac length [m]</td>
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<td>Linac RF frequency [MHz]</td>
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<td>Macropulse ave. current [mA]</td>
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<td>Macropulse duty factor [%]</td>
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<td>Ring RF frequency [MHz]</td>
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<td>Target material</td>
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<tr>
<td>Moderators</td>
<td>$\text{H}_2\text{O}$, $\text{CH}_4$, $\text{H}_2$</td>
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<tr>
<td>Number of spectrometers</td>
<td>5</td>
<td>18</td>
<td>$&gt;$18</td>
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CSNS target design

CSNS Tungsten Target

- cladding with Tantalum
- 40 high x 100 wide x 400 long (mm)---pieces stacking
- Heavy water cooling, 1.5mm gaps between both disks for cooling
CSNS moderator configuration

CSNS Be/Fe Reflector
Be Ø800 x 1000mm
Iron Ø_in800/ Ø_out2000mm x 1000mm

Moderators
Top upstream    H₂O, Decoupled
                 300 K
Top downstream  CH₄, Decoupled+Poisoned
                 100 K
                 with premoderator
Bottom          H₂, Coupled
                 20 K
                 with premoderator
Monte Carlo simulation for instruments

**Example:** Monte Carlo Simulation to optimize the neutron optics for the high intensity powder diffractometer

Wavelength range: 0.3~5 Å
Resolution: ~0.2%

The neutron transmission of different neutron guides
Target materials

Tungsten becomes brittle by radioactive damage and easily corrodiible under heavy water coolant.

• Ta cladding on W by hot isostatic press.

• Fabrication of W-Re (Re 25%) alloy.
Sputtering system for neutron guide

Neutron guide is an important neutron optical components to transfer neutrons efficiently to sample studied.

• Small neutron supermirror film with m = 2 deposited successfully.

• New sputtering system to fabricate large area supermirror film.