Status of China Spallation Neutron Source

Tianjiao Liang

On behalf of CSNS Team

liangtj@ihep.ac.cn
Outline

- CSNS project overview
- Status of civil constructions
- Progress of accelerator system
- CSNS target station and instruments
- Closing Remarks
Institute of High Energy Physics

- Institute of Modern Physics (predecessor of IHEP): established at 1950
- Institute of High Energy Physics: independent Institute for Particle physics at 1973
  → Comprehensive and largest fundamental research center in China
    - 1500 employees
    - 500 PhD Students and 60 postdoctors
- Goal of IHEP:
  - International center of particle physics
  - Multiple discipline research center based on large scientific facilities (neutron/synchrotron).
Wang Ganchang 1907-1998

- One of the founders of JINR
- Deputy director of JINR (1958-1960)
- Academician of CAS
- Worked at the Veksler & Baldin Lab.
  Of high energies of JINR from Sep. 1956 to Dec. 1960
- Discovery of anti-sigma minus hyperon at JINR
Tang Xiaowei 1931-

- Academician of CAS
- Development of total absorption Cerenkov Counter & sampling electro-magnetic calorimeter at JINR

Ю.Д. Прокошкн, Тан Сяо-вэй: Измерение энергии электронов и гамма-квантов счетчиком с малой эффективностью, Приб. и тех. Экспер., 3(1959)32.
Ю.Д. Прокошкн,Тан Сяо-вэй: Ливни, образованные позитронами с энергией от 100 до 400MeV. ЖЭТФ,36(1959),10.
В.Вишияков, А. Тяпкин,Тан Сяо-вэй: Низковольтные галогенные счетчики, Усп. Физ. Наук, 72(1960)133.
Wang Naiyan 1935-
- Academician of CAS
- Worked at the Frank Lab. of Neutron Physics of JINR from 1959 to 1965
- Chairman of China Nuclear Society 2001-2009

Wang Shiji 1932-
- Academician of CAS
- Worked at the Frank Lab. Of Neutron Physics of JINR from 1959 to 1964
CSNS Project Overview
Chinese Spallation Neutron Source (CSNS)

Site: Dongguan, Guangdong
IHEP in charge the project, in cooperation with Inst. of Physics

<table>
<thead>
<tr>
<th></th>
<th>CSNS-I</th>
<th>CSNS-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam power (kW)</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td># of Target</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>current (μA)</td>
<td>62.5</td>
<td>312</td>
</tr>
<tr>
<td>beam energy (GeV)</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Linac energy (MeV)</td>
<td>80</td>
<td>250</td>
</tr>
</tbody>
</table>
Design Philosophy

● **Build facility within the approved budget and time schedule**
  - phase-I budget 1.82B CNY (~US$281M)+marching fund
  - 6.5 year construction duration

● **Build advanced facility with upgrade potential:** 100kW beam power at phase I (with minimum initial cost, lower energy linac + high energy RCS), expandable to 500kW at Phase II (Using SC cavities to increasing energy of Linac to 250MeV, R&D is finished)

● **Adopt proven technology to reduce risk**
  - first high-power proton beam facility in China
  - high operational reliability for user facility

● **Develop domestic technology to control cost**
  - keep final fabrication in China as much as possible
  - closely collaborate with world leaders
Strong supports from the local governments

- 500M RMB match fund
- Land of 0.67km²: 0.27-km² land for phase-I. slope protection
- 3.6-km dedicated road to the site was finished.
- 110kV/10kV transform station: ready
- In charge of the management of civil engineering and will take care the deficit of the budget of the civil engineering if any.
- 50 min. by car from the Shenzhen Airport; 70 min. by train from Hongkong+25min. of car.
Key Milestones

- Feb. 2001: Idea of CSNS discussed
- June 2005: Proposal approved in principle (CD-0)
- Dec. 2007: Proposal reviewed
- Sept. 2008: Proposal approved
- October 2009: Feasibility study reviewed
- February 2011: Feasibility study approved (CD-1)
- May 2011: Preliminary design approved (CD-2)
- May 2012 – June 2016: Construction start (CD-3)
- Sept. 2011–May 2017: Civil construction
- Jan. 2017: Installation & tests
- Sept. 2017: RCS commissioning start
- March 2018: First beam on target
- March 2018: Project complete/operation start (6.5 years)
CSNS: Dongguan Branch of IHEP

- CAS opened 400 positions for CSNS.
- About 270 persons were hired for the Dongguan Branch.
- There about 78 physicists and engineers from IHEP working at Dongguan, most of them are senior, backbone.
- IHEP Beijing provides strong supports to the construction, commissioning and research in CSNS.
Status of Civil Construction
The civil construction near finish

June, 2012

March, 2016
Civil Constructions

Linac surface building

Ring Building

Target building & Experimental halls
Birds View of CSNS

May, 2016
Progress of Accelerator System
## Linac Design

### Input and Output Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ion Source</th>
<th>RFQ</th>
<th>DTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Energy (MeV)</td>
<td></td>
<td>0.05</td>
<td>3.0</td>
</tr>
<tr>
<td>Output Energy (MeV)</td>
<td></td>
<td>0.05</td>
<td>3.0</td>
</tr>
<tr>
<td>RF frequency (MHz)</td>
<td></td>
<td>324</td>
<td>324</td>
</tr>
<tr>
<td>Pulse Current (mA)</td>
<td>20/40</td>
<td>20/40</td>
<td>15/30</td>
</tr>
<tr>
<td>RF frequency (MHz)</td>
<td></td>
<td>324</td>
<td>324</td>
</tr>
<tr>
<td>Chop rate (%)</td>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Duty factor (%)</td>
<td>1.3</td>
<td>1.05</td>
<td>1.05</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

### Diagram

- **Linac Block Diagram**
  - H^- IS → RFQ → MEBT → DTL → RING
  - Key components: RFQ, MEBT, DTL, RING
  - EMQ option in FFDD lattice for DTL
  - Electrostatic chopper in LEBT

### Key Parameters

- **Input Energy**: 0.05 MeV
- **Output Energy**: 3.0 MeV
- **Pulse Current**: 20/40 mA
- **RF Frequency**: 324 MHz
- **Chop Rate**: 50 MHz
- **Duty Factor**: 1.3%
- **Repetition Rate**: 25 Hz
RCS Design

- Lattice of 4-fold symmetry, triplet.
- 227.92m circumference.
- Four long straight sections for injection, acceleration, collimation and extraction.
- 24 main dipoles with one power supply.
- 48 main quadruples with 5 power supplies.
- Ceramic vacuum chambers for the AC&pulsed magnets.
- 8 RF ferrite loaded cavities to provide 165 kV.
Linac Accelerator Installation

Finish commissioning with beam by Dec. 30, 2016
RCS Installation
Complete cold commissioning by Nov. 30, 2016
负氢离子源

注入剥离膜

主准直器

环主四极铁

环高频腔

引出冲击铁

DTL及其速调管

传输线四极铁

RFQ及其功率源

及其功率源

主磁铁电源

加速器设备研制顺利
Linac Front End Commissioning

- Front end installation completed 6 Apr. 2015,
- First H- beam from RFQ 21 Apr. with peak current of 28mA at 3MeV.
- The front end commissioning finished 13 July, and reached the design specification.
Jan.2016 negative hydrogen ion beam was successfully accelerated to the design energy of 21.6MeV with the first Drift Tube Linac. The peak pulsed current reaches 18mA, higher than the design value of 15mA. Almost all the beam go through the linac with 99.7% beam transmission rate.
CSNS target station and instruments
Major design consideration

- **High neutron production**
  - 1.6GeV proton beam; cladding W target; Be reflector; heavy water cooling (light water at beginning due to budget limit)

- **Diverse neutron performance**
  - 3 wings moderators: $\text{H}_2\text{O}$ (300K, decoupled), $\text{H}_2$ (20K, decoupled+poisoned), $\text{H}_2$ (20K, coupled)

- **High neutron utilization**
  - compact configuration between TMR and bulk shielding;
    moderation by para-hydrogen; supermirror neutron guide;
    efficient position sensitive neutron detector with large coverage

- **Optimization for 100 kW, but keeping upgrade capacity to 500 kW**
  - Optimize the TMR for the beam power of 100 kW
  - Design shields with dose control < 2.5 $\mu$Sv/h up to 500 kW
  - Embedded coolant pipes and tanks meet to requirement of 500 kW
Main design parameters
CSNS Target Station

- Proton Beam Window
- Moderator & Reflector
- Target
- Helium Vessel
- Steel Shielding
- PBW plug
- MR plug
- Heavy Concrete Shielding
- Target trolley
Shielding Installation  2015/10/20
Target station

TMR maintenance: the horizontal target plug plus vertical MR plug, similar to the SNS/JPARC type.

– Feasible for 500 kW upgrade
– More compacted configuration between Target and Moderators/Reflector
– Small seal between trolley and helium vessel
– Separated room for liquid hydrogen system at the building roof
– High-bay to define a radiation control area for target station out from scattering hall
Engineering design of CSNS MR
## Baseline parameters of CSNS TMR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton beam energy</td>
<td>1.6 GeV</td>
</tr>
<tr>
<td>Beam footprint VXH</td>
<td>40x120/60x160 mm (100/500kW)</td>
</tr>
<tr>
<td>Beam profile</td>
<td>Gaussian, 2 sigma</td>
</tr>
<tr>
<td>Target material</td>
<td>Tungsten cladded by 0.3 mm tantalum</td>
</tr>
<tr>
<td>Target length</td>
<td>570 mm for W</td>
</tr>
<tr>
<td>Cross section VXH</td>
<td>70x170 mm</td>
</tr>
<tr>
<td>Coolant</td>
<td>D2O/H2O, 1.2 mm channel</td>
</tr>
<tr>
<td>Target container</td>
<td>8 mm SS316 (3 mm for incident window)</td>
</tr>
<tr>
<td>CHM Hydrogen volume</td>
<td>Φ150x106 mm 20K 100% para</td>
</tr>
<tr>
<td>Hydrogen vessel thickness</td>
<td>6 mm except 4 mm for view surface</td>
</tr>
<tr>
<td>Water premoderator thickness</td>
<td>20 mm for target side 10 mm other side</td>
</tr>
<tr>
<td>View surface VxH</td>
<td>100x102.2 mm</td>
</tr>
</tbody>
</table>
## Baseline parameters of CSNS TMR

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DPHM</strong></td>
<td>hydrogen volume</td>
<td>120x120x50 mm 20K 100% para</td>
</tr>
<tr>
<td></td>
<td>hydrogen vessel thickness</td>
<td>5mm</td>
</tr>
<tr>
<td></td>
<td>view surface VxH</td>
<td>100x102.2 mm</td>
</tr>
<tr>
<td></td>
<td>poison position offset from center</td>
<td>5mm</td>
</tr>
<tr>
<td></td>
<td>poisoner</td>
<td>Gd 0.2mm</td>
</tr>
<tr>
<td></td>
<td>decoupler</td>
<td>Cd 0.5mm</td>
</tr>
<tr>
<td><strong>DWM</strong></td>
<td>water volume</td>
<td>120x120x50 mm</td>
</tr>
<tr>
<td></td>
<td>water container thickness</td>
<td>4mm</td>
</tr>
<tr>
<td></td>
<td>decoupler</td>
<td>Cd 0.5mm</td>
</tr>
<tr>
<td></td>
<td>reflector</td>
<td>Be reflector ((S-200-F))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Φ700x800mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fe reflector (SS316)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Φ1000x1000mm</td>
</tr>
<tr>
<td></td>
<td>coolant</td>
<td>D2O/H2O, 10% volume fraction for Be reflector, 5% for Fe reflector</td>
</tr>
</tbody>
</table>
Lethargy Spectra

Beamline 1-4 12-14 CHM

Beamline 5-7 15-17 DWM

Beamline 18-20 DPHM broad

Beamline 8-10 DPHM narrow
Pulse shape @ 4A & pulse width
Neutronics performance

Couple Hydrogen Moderator spectra comparison (normalized to same proton beam power)

Atmospheric neutron spectra comparison
Test of neutronics measurement instruments

Wavelength spectrum (left) and pulse shape of 1.17Å neutron (right) measured at CPHS
Target-moderator-reflector

CSNS target before welding  CSNS target after assembling

Coupled hydrogen moderator  Beryllium reflector  Reflector vessel under fabrication
The first set of shutter had passed acceptance check in January, 2015.
The fixed shielding below the helium vessel and the shutter base plates had been installed and passed the acceptance check in April, 2015.
All other fixed shielding had passed acceptance check in September, 2015.
Helium vessel were manufactured and installed on site.
Target Trolley under fabrication
Pressure vessel of TS cooling system accepted
Neutron Shutter installation
Cryogenic equipment installation
Neutron instruments

- 20 beam lines
- Phase I: BL1: SANS; BL2: MR; BL18: GPPD

Moderator:
- $D+P, LH_2$ (20K)
- $C,LH_2$ (20K)
- $D$, Water (300K)

(PND: Powder Neutron Diffractometer; RG/DG: Reversal/Direct Geometry)
Neutron instruments

- Engineering design of three day-one instruments fixed. Control and data management/analysis are partially tested.
- Detailed time schedule of instrument construction and installation has been determined.
- New state-of-the-art instruments: still looking for other fund
  - the 13th national five-year plan
  - the probability to collaborate with local institutes and universities
- User meeting:
  - Annual national user meeting with training course.
  - Workshops on day one experiments every year
1. General Purpose Powder Diffractometer

Performance:
- For most users to determine crystallographic and magnetic structures in general purposes
- Best resolution $\Delta d/d \sim 0.2\%$
- ~ minutes for a diffraction histogram used by Rietveld refinement on ~ 1-g-weight sample
- Easily loading the ancillary equipment such as cryostat, furnace and pressure cell

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderator</td>
<td>DPHM (20 K)</td>
</tr>
<tr>
<td>Bandwidth ($\Delta \lambda$)</td>
<td>4.5 Å</td>
</tr>
<tr>
<td>Max. Beam Size</td>
<td>40(h) × 20(w) mm</td>
</tr>
<tr>
<td>Flux at sample position</td>
<td>$\sim 10^7$ n/cm$^2$/s</td>
</tr>
<tr>
<td>Best Resolution ($\Delta d/d$)</td>
<td>0.2 % at $2\theta = 150^\circ$</td>
</tr>
<tr>
<td>Guide</td>
<td>Taper focus, $m=3$</td>
</tr>
<tr>
<td>Source to sample distance $L_1$</td>
<td>30 m</td>
</tr>
<tr>
<td>Sample-detector distance $L_2$</td>
<td></td>
</tr>
<tr>
<td>$2\theta = 150^\circ$</td>
<td>1.5 m</td>
</tr>
<tr>
<td>$2\theta = 90^\circ$</td>
<td>2.0 m</td>
</tr>
<tr>
<td>$2\theta = 15^\circ$</td>
<td>3.8 m</td>
</tr>
</tbody>
</table>
2. Multiple Purpose Reflectometer

Performance:
- Vertical sample geometry: solid film
- Reflectivity/diffraction
- Best resolution $\Delta Q/Q < 1\%$
- Polarizing analysis for spinoelectronics.
- In-suit study on growing films
- In-suit MOKE magnetic analysis
- Off-specular scattering
- Grazing-incidence small-angle scattering

<table>
<thead>
<tr>
<th>Moderator</th>
<th>CHM (20 K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth ($\Delta \lambda$)</td>
<td>6 Å</td>
</tr>
<tr>
<td>Guide</td>
<td>Bender+Sraight+Taper</td>
</tr>
<tr>
<td></td>
<td>$40 \times 60 \rightarrow 20 \times 30 \text{ mm}^2$</td>
</tr>
<tr>
<td>SS distance L1</td>
<td>19.5 m</td>
</tr>
<tr>
<td>SD distance L2</td>
<td>2 m</td>
</tr>
<tr>
<td>Sample table</td>
<td>6-axis movements</td>
</tr>
<tr>
<td>Polarizer/analyzer</td>
<td>Supermirror type</td>
</tr>
</tbody>
</table>
| Detector         | 2D position-sensitive detector
|                  | Position resolution: 2 mm |
3. Small Angel Neutron Scattering

**Performance:**

- Reliable SANS data between 0.01~0.5 Å⁻¹
- Instrument resolution better than ~30% around $Q_{min}$
- Good dynamic range, sample space
- Variable sample size

<table>
<thead>
<tr>
<th></th>
<th>Moderator</th>
<th>CHM (20K)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MS distance</strong></td>
<td>14 m</td>
<td></td>
</tr>
<tr>
<td><strong>SD distance</strong></td>
<td>1~5 m</td>
<td></td>
</tr>
<tr>
<td><strong>Detector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Effective area</strong></td>
<td>50 × 50 cm²</td>
<td></td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>1 cm (FWHM)</td>
<td></td>
</tr>
<tr>
<td><strong>$\Delta \lambda$</strong></td>
<td>0.4-8 Å</td>
<td></td>
</tr>
<tr>
<td><strong>q range</strong></td>
<td>0.004-3.4 Å⁻¹</td>
<td></td>
</tr>
</tbody>
</table>
3He-MWPC- 200mm*200mm

- Active area: 200mm*200mm
- Detection efficiency: ~50%@ 2Å
- Pixel size: 2mm*2mm
- Max Counting rates: $10^5$ n/s

3He tube-LPSD for SANS

<table>
<thead>
<tr>
<th>Effective area</th>
<th>1m×1m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>8mm</td>
</tr>
<tr>
<td>Effective length</td>
<td>1000mm</td>
</tr>
<tr>
<td>Detection efficiency</td>
<td>&gt;60%@1.8Å</td>
</tr>
<tr>
<td>Maximum counting rate @ single tube</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Pixel size</td>
<td>&lt;1cm×1cm</td>
</tr>
<tr>
<td>Time resolution</td>
<td>2μs</td>
</tr>
</tbody>
</table>

- Neutron beam test @ CARR
  - Position resolution (FWHM)
    X : 1.23mm, Y: 2mm
- The detector will be ready by the end of October 2016

- 3He tube will arrive in July, 2016
- The design of HV system finished and be tested.
Shifting Scintillator Neutron Detector (SSND)

- Module size 500mm × 250mm
- Pixel size is 5mm × 10mm
- Detection efficiency: over 50%@ 2Å

Neutron beam monitor Based on GEM detector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Area</td>
<td>50mm*50mm</td>
</tr>
<tr>
<td>Neutron Flux</td>
<td>&lt;10⁸n/cm².s</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>&lt;3mm</td>
</tr>
<tr>
<td>Timing Resolution</td>
<td>&lt;1μs</td>
</tr>
<tr>
<td>Efficiency@1.8Å</td>
<td>~4%</td>
</tr>
<tr>
<td>Max Counting Rate</td>
<td>&gt;1MHz</td>
</tr>
<tr>
<td>Working mode</td>
<td>Real-time</td>
</tr>
</tbody>
</table>

Testing with neutron beam @ Mianyang

- Position Reso. 4.1mm*4.1mm(FWHM)
  Efficiency @2.6 Å : 54.3% / layer

- Mass production
  - Lab. In Sun Yat-sen university
  - 6 peoples, one year

- Successful Application
  - Beam monitor @ CMRR
  - Beam monitor @ CARR
Electronics and DAQ System

- Design the data acquisition system of 3 types of detectors in the same structure
- Finished the Prototype of the FEB of GPPD. The key IC is designed by ourselves.
- Finished the prototype of the FEB of MR, under testing.
- The testing board of the FEE of SANS is finished, and the prototype will be done next step.
- Finished the most DAQ software design
The 7th international review meeting of accelerator technology advisory committee (ATAC) and neutron technology advisory committee (NTAC) of CSNS was held 10-12 Oct. 2015 in CSNS, Dongguan.
Other application

White neutron nuclear data measurement

Middle energy proton
Radiation effect test
Proton therapy

High energy proton
- muon source
- detector calibration
- proton radiography
Closing Remark

- CSNS civil construction will be finished. Utility installation goes well.
- The installation of accelerators started Oct. 2014. RFQ and the first DTL reached the design requirements.
- We expect the first neutron beam by Sept. 2017, and open to users by Spring 2018.
- Great efforts to promote the user community and to prepare the day-one experiments.
- Proposal of Phase II (more spectrometers +Power upgrade) are under discussion.
- Look forward for cooperation with JINR in CSNS upgrade and the neutron scattering applications.
Many thanks for your attention