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A SMALL-ANGLE NEUTRON DIFFRACTOMETER AT THE COMPACT PULSED HADRON SOURCE

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ABSTRACT

The time-of-flight (TOF) small-angle neutron scattering (SANS) diffractometer is one of the first instruments to be built at the Compact Pulsed Hadron Source (CPHS) of Tsinghua University, China. This SANS project strives to serve two purposes: its instrumental design, fabrication and optimization will help glean valuable scientific and engineering experiences; and its utilization will help promote fruitful domestic user programs on research of large structures using neutrons.

The design draws experiences from other TOF SANS instruments, particularly that of the long-pulse LENS of Indiana University but also considers the space constraint at CPHS and the user priority in China. The primary flight path is approximately 5m long conforming conventional pin-hole geometry and the secondary flight is 3m. Because of the relatively high source repetition rate (50Hz) and limited space, a bandwidth-selection (1-10 Å) chopper and a 2D-detector (1x1m^2) will be employed. The design calls for a Q-coverage of approximately 0.006~1 Å^{-1} and a $\Delta Q/Q_{min} < 30\%$, and pays attention to possible use of optical devices such as focusing lenses, filters, chopper, etc. and novel detectors.

1. Introduction

CPHS, the Compact Pulsed Hadron Source, is a multi-purpose neutron and proton facility. It is small, a 13-MeV proton-linac-driven neutron source, situated on the Tsinghua University campus. Its instruments are unique experimental tools for students to learn the techniques of proton accelerators and neutron/proton scattering. It complements China's other neutron sources such as the CSNS, CARR and accelerator facilities. At the international scale, CPHS partners with other hadron facilities such as LENS-USA and PEFP-Korea and contributes to the R&D of long-pulse neutron sources and proton applications.

The time-of-flight (TOF) small-angle neutron scattering (SANS) diffractometer is one of the first instruments to be built at CPHS. This SANS project strives to serve two purposes: its instrumental design, fabrication and optimization will help glean valuable scientific and engineering experiences; and its utilization will help promote fruitful domestic user programs on research of large structures in materials, such as macromolecules in solutions, using neutrons.

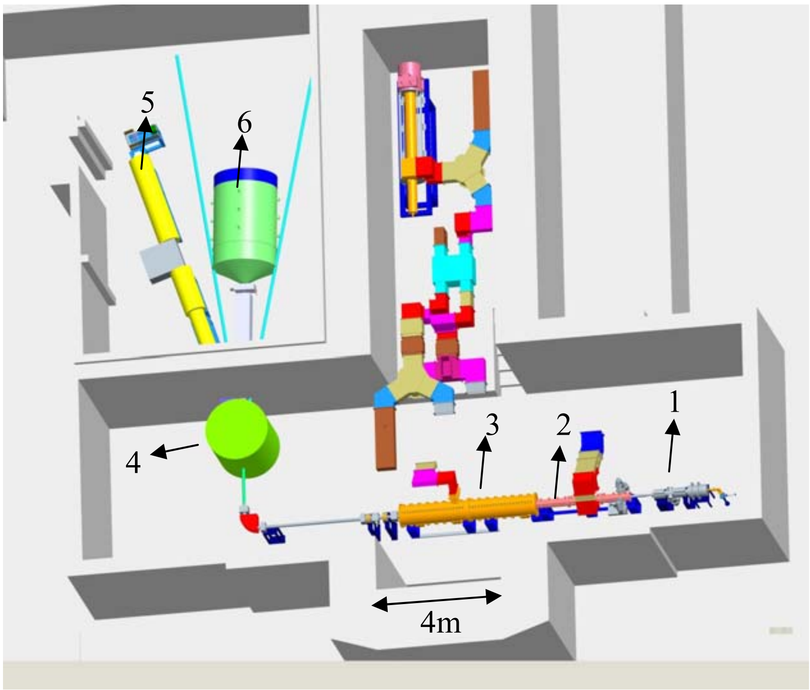

Fig. 1. The schematic illustration of CPHS: (1) ion source, (2) RFQ, (3) DTL, (4) target-moderator-reflector (TMR) system, (5) neutron imaging station, (6) SANS instrument.

2. Design of the SANS

The present design of SANS is shown in Fig.2. It consists of a shutter, a bandwidth chopper, collimator, a sample-stage, a 2D detector and a beam stop. The design is optimized based on two principles: (1) to make full use of a broad bandwidth, particularly the long-wavelength neutrons; (2) high signal-to-noise ratio to provide some useful data. The preliminary design parameters are listed in Table I.

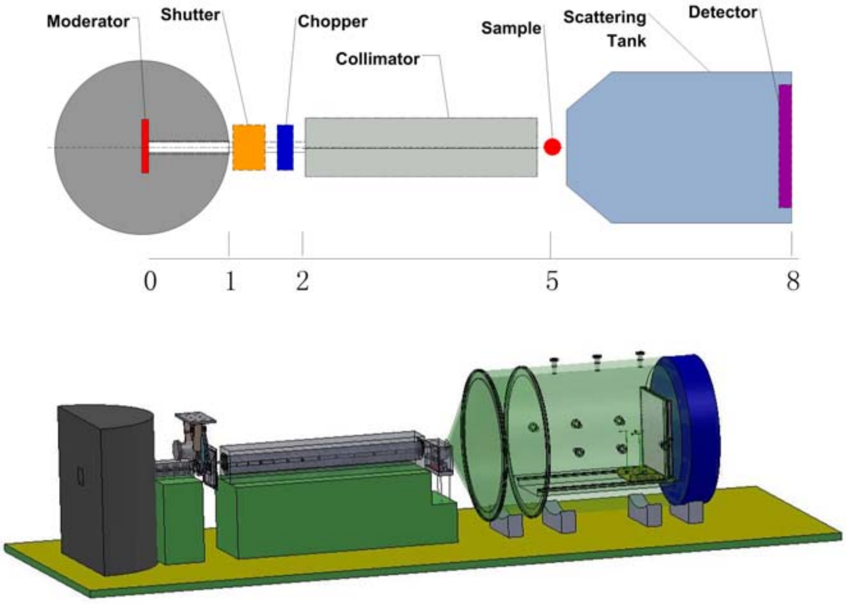

Fig.2. Design of the SANS at CPHS. The upper part shows the schematic illustration and the lower part the 3D layout.

Table I. SANS instrument parameters

Source frequency	50 Hz
Wavelength Range	1 – 10 Å
Source-to-Sample Distance	5 m
Sample-to-Detector Distance	3 m
Collimation	Circular pinhole collimation
Sample size	1-2 cm diameter
Area Detector	^{3}He LPSD Array
Active Area	1 x 1 m^2
Pixel Size	12 mm
Q-Range	0.006 – 1 Å^{-1}
Q-Resolution (δQ/Q)	2% – 27%

2.1. Source Characteristics

The SANS will be viewing a coupled cold methane moderator (10×10cm^2, 20K) on the 50Hz target. Fig.3 shows the neutron flux and the pulse shape from the Monte Carlo simulation results. Due to the ~500μs long proton pulse and coupled moderator, the FWHM of neutron pulse may vary between 0.5 to 1 millisecond. However, this long-pulse character of the source does not seriously affect the Q-resolution of a SANS instrument.

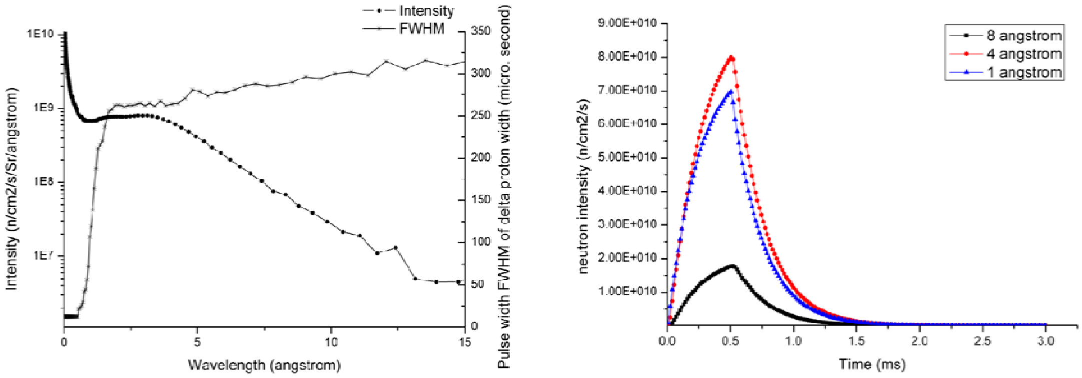

Fig. 3. MCNP simulation results of source spectrum. The left one shows intensity and pulse width (FWHM) as a function of neutron wavelength. The right one shows the pulse shape for different wavelength neutrons.

2.2. Bandwidth Chopper

Only one bandwidth chopper is considered in the preliminary design which will be placed at 2m from the source. The 8m total flight path and 20ms pulse interval allow a bandwidth of ~10 Å without overlap. Due to the long pulse width the penumbra region is ~2 Å which cause a notable part of unusable flux in the frame. When the “umbra” is set to 1-8 Å the first bleed-through wavelength will be ~40Å which takes up a negligible part. Fig. 4 shows the time diagram of the bandwidth chopper.

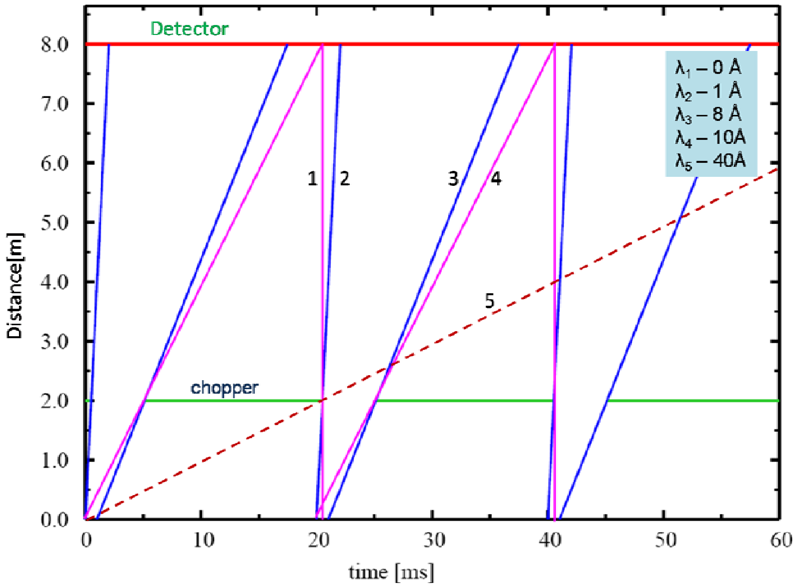

Fig. 4. Time diagram of the bandwidth chopper. The penumbra effect is shown.

2.3. Pinhole Collimator

According to the chopper setting mentioned above and the long pulse width, fast neutrons will just go through which bring forward higher requirements for the collimator system. The ISIS beam collimation design, which is easy to manufacture and assemble, serves as a good reference [1]. The collimator must be configured carefully to ensure that the strayed neutrons will not enter the pinhole. Fig.5 shows the layout of conventional pinhole collimator using B_4C inserts. The expected performance has been considered using the ray-tracing method.

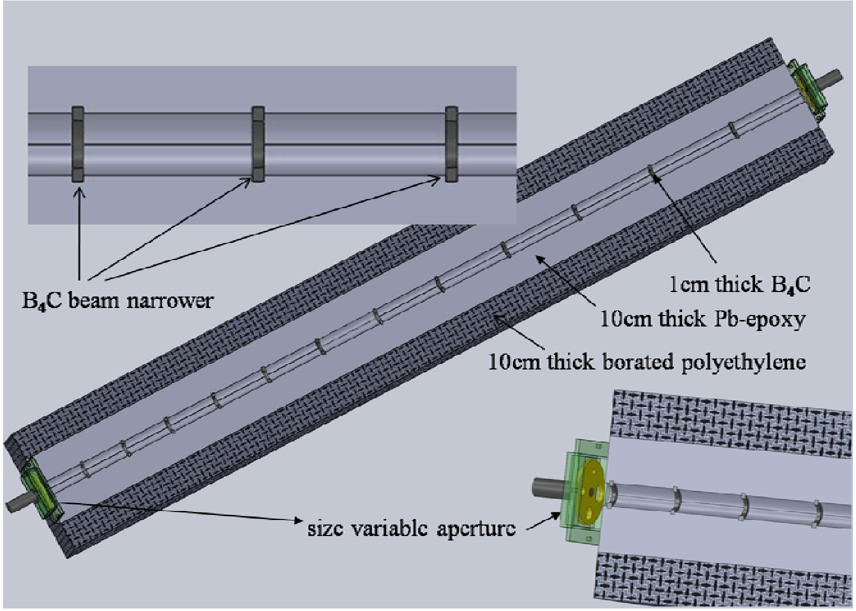

Fig. 5. Conventional pinhole collimation system using B_4C narrower.

2.4. Detector

The SANS has a two-dimensional detector with an 1x1m^2 area, which is located at 3m from the sample position. The detector is composed by an array of 1/2 in.-Φ ^{3}He linear position-sensitive proportional counters. Such detector bank can help cover a Q-range of 0.006-1 Å^{-1} without moving the detector. The readout electronics will be installed in an air-cooled box behind the detector assembly.

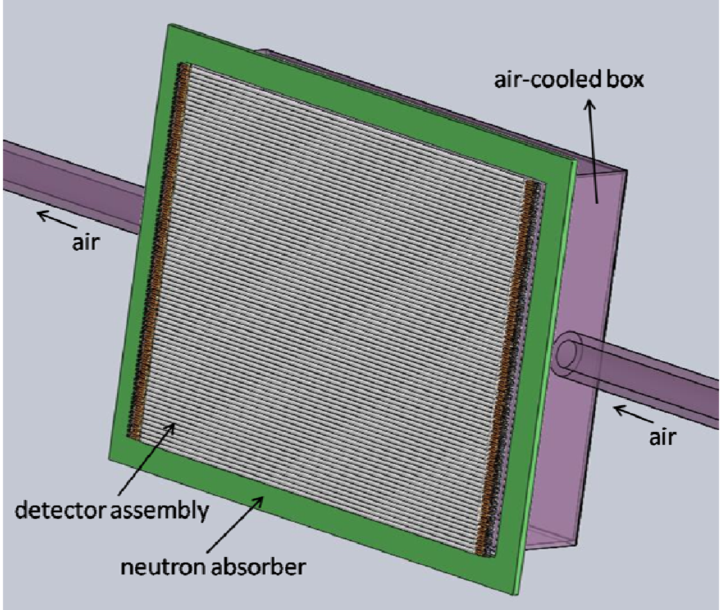

Fig. 6. Schematic diagram of detector assembly with air-cooled box.

The LPSDs have cylindrical geometries with an active length of 1 meter and diameter of 12mm. The cathode is made of nickel-plated stainless steel (Type 304) of 0.5 millimeter thickness while the anode is a nickel-chrome wire of 8.5K ohms resistance. The filling gas consists of ^{3}He at a pressure of 8 atmospheres and argon at a pressure of 2 atmospheres.

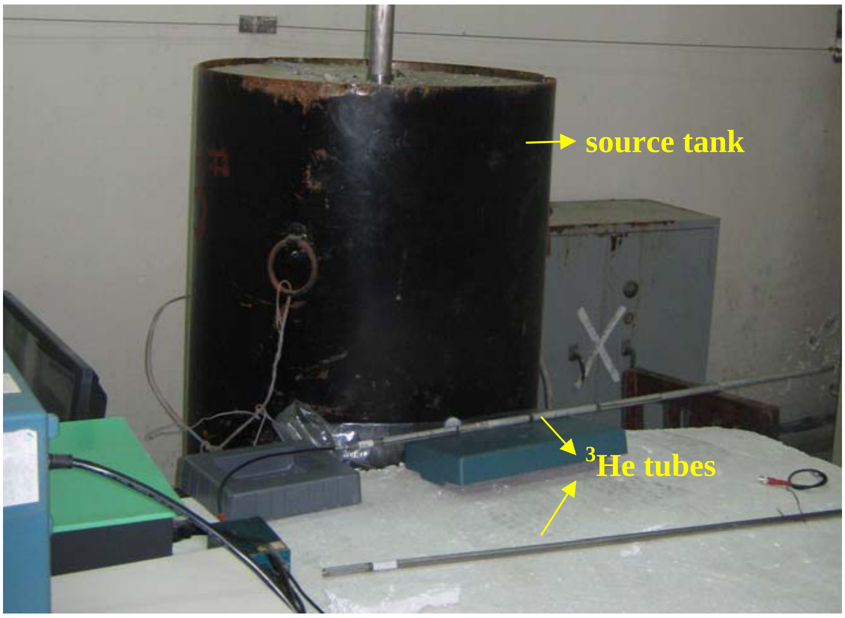

Fig. 7. Detector prototype experiment using isotope neutron source.

3. Performance analysis

Using 1cm as default sample size, it can cover a Q-range of 0.006-1 $Å^{-1}$ with one chopper setting using the maximum bandwidth as shown in Fig. 4. The Q-resolution $\delta Q/Q$ is affected mainly by the contributions from the angular uncertainty $\delta\theta/\theta$ and wavelength uncertainty $\delta\lambda/\lambda$. The worst $\delta\theta/\theta$ is ~23% at θ_{min}, which is determined by the penumbra beam size at the detector, and decrease to ~3% at θ_{max}, i.e. at the edge of the detector bank. Due to the long pulse, $\delta\lambda/\lambda$ can reach 14% for 1Å neutrons, much worse than that in short pulse source. Fig. 8 shows the Q-resolution $\delta Q/Q$ as a function of R (distance of detector pixel to direct beam) for 1 Å and 10 Å neutrons.

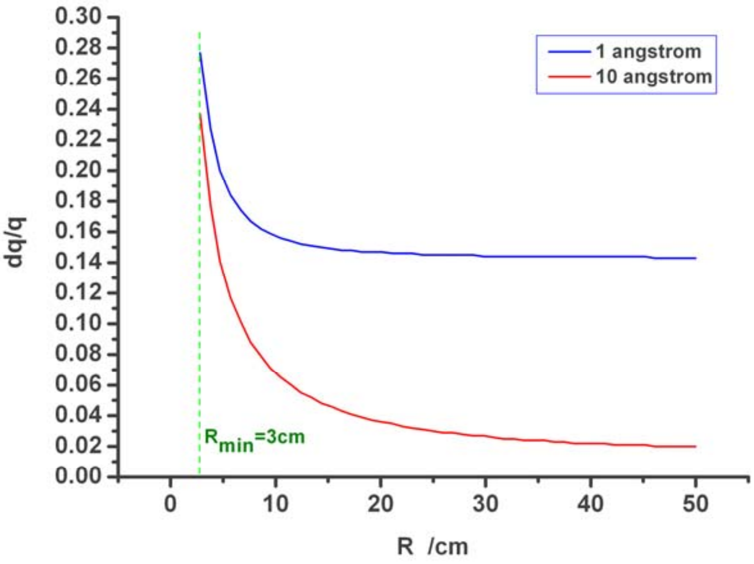

Fig. 8. The Q-resolution $\delta Q/Q$ as a function of R for 1 Å and 10 Å neutrons.

Wider Q-range can be covered if using a two-chopper setting. For example, the minimum Q_{min} can extend to ~0.0037 using 16 Å neutrons. The incident neutron flux on the sample position is estimated to be ~1×10^{5} $n/cm^{2}/s$ using 1cm sample size.

The performance of the SANS was analyzed using VITESS simulation package. All parameters of the simulation are summarized in Table I with 1cm sample size. Count rates at the detector are shown as a function of momentum transfer Q in logarithmic binning [2].

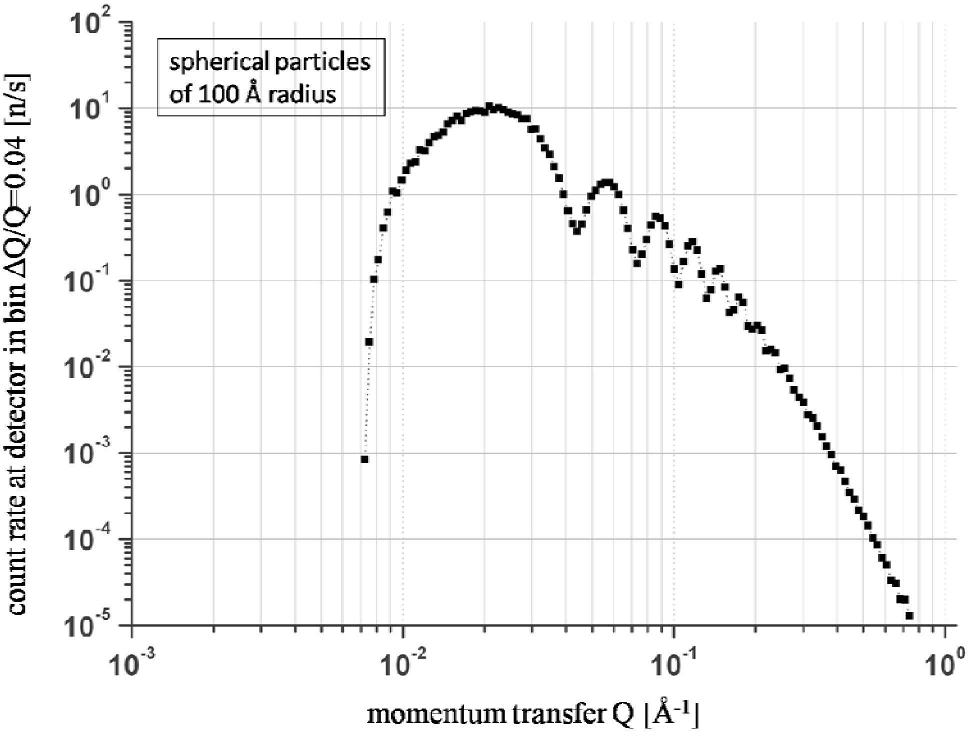

Fig. 9. Neutron count rate at the detector as a function of Q using a sample with spherical particles of 100 Å radius.

4. Conclusion

The design optimization and performance analyses of the new TOF-SANS instrument of CPHS have been performed using both theoretical calculations and MC simulations. With an accessible Q-range from 0.006 to 1 Å^{-1} it is expected to provide some useful data with a satisfactory signal-to-noise ratio.

The SANS at CPHS could well be China's first experience with pulsed SANS technique. Such a compact instrument can provide flexibility and potential for education, research and technical development.

Acknowledgements

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References

1. A D Taylor, T A Broome and D J Picton, *Proceeding of the ICANS IX* (Villingen, September 22-26, 1986), p. 527.
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