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First use of a polarized ^3He neutron spin filter on the Back-n White Neutron Source of CSNS

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ABSTRACT

Polarized eV neutrons can address interesting scientific questions in nuclear physics, particle physics, and astrophysics/cosmology. We present the first experiment to polarize the neutrons on the Back-n beamline at the Chinese Spallation Neutron Source (CSNS) using an *in-situ* NSF using spin-exchange optical pumping (SEOP) of ^3He . A ^3He polarization of $68\% \pm 0.7\%$ for this *in-situ* NSF was measured through neutron transmission method at Back-n. This is high enough to enable new experiments on the Back-n beamline.

1. Introduction

The discovery of parity violation in the decay of polarized ^{60}Co in the late 1950s shocked physicists and motivated a reexamination of the validity of discrete symmetries in physics which remains a vital research frontier. Soon after the discovery of parity violation, in 1964, indirect time reversal symmetry violation was discovered in the 2π decay of the K^0 meson [1] which was later accommodated into the CKM matrix. As shown by A. Sakharov [2] in 1967, CP-violation was demonstrated to be an essential criterion required to produce the matter–antimatter asymmetry in the early stage of the universe in Big Bang theory. However the CP violation seen in K^0 decay was several orders of magnitude smaller than the size needed to explain the lack of anti-matter we see in today's universe. Thus, new sources of CP/T violation are required to explain the currently observed baryon asymmetry of the universe within the Big Bang theory.

Starting in the 80s, scientists started the construction of the theory and the experimental search for parity violation in p-wave resonances in heavy nuclei. Very large P-odd effects were discovered in ^{81}Br , ^{111}Cd , ^{117}Sn , ^{139}La and ^{238}U at Dubna [3] and at KEK. In the 90s, the TRIPLE collaboration performed a very broad survey of parity violation in heavy nuclei at LANSCE. They scanned through many nuclei with a neutron beam with energies of 1 eV to several keV, polarized

using a polarized proton spin filter at their p-wave resonances. They discovered more than 75 P-odd asymmetries in p-wave resonances and were able to perform a statistical analysis of the distribution of results to show that the observed effects were consistent with the expected size of the nucleon–nucleon weak interaction [4]. The ongoing work of the Neutron Optics Party and Time Reversal EXperiment (NOPTREX) collaboration builds upon the previous work at Dubna, KEK, and LANSCE to continue the search for Parity Violation (PV) in p-wave resonances and to perform Time Reversal Invariance Violation (TRIV) searches. The Chinese NOPTREX collaboration at China Spallation Neutron Source (CSNS) aims to utilize the special properties of the Back-n white neutron source [5] and ^3He neutron polarizer [6] to perform PV and TRIV experiments in China.

PV and TRIV can be probed using polarized neutrons in the p-wave resonances of nuclei. More detailed discussions on such new physics search exists [7,8]. Both PV and TRIV can be amplified in p-wave resonances by very large factors of $10^4 - 10^6$ compared to their size in NN interactions [3,9,10]. The amplification occurs through the mixing of p-wave resonances (neutron orbital angular momentum: $l=1$) and s-wave resonances ($l=0$) through a parity-odd matrix element. This resonance amplification mechanism makes the compound nucleus a very sensitive system to probe fundamental interactions and is complementary to

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neutron or nuclear EDM searches [11–14] which also search for TRIV.

Neutron Nucleus Forward Scattering Amplitude

For a neutron of spin $\vec{\sigma}_n$, momentum \vec{k}_n incident on a target nucleus of spin \vec{I} , we can construct an expression for the forward scattering amplitude f as the following [7]:

$$f = f_0 + f_1(\vec{\sigma}_n \cdot \vec{I}) + f_2(\vec{\sigma}_n \cdot \vec{k}_n) + f_3(\vec{\sigma}_n \cdot [\vec{k}_n \times \vec{I}]) + f_4(\vec{\sigma}_n \cdot (\vec{I} \times \vec{k}_n)(\vec{I} \cdot \vec{k}_n)) \quad (1)$$

Notice each term reacts differently under parity and/or time-reversal. f_0 is P-even/T-even and spin-independent, f_1 is P-even/T-even but spin-dependent (leading to the so-called “pseudomagnetic precession”), f_2 is P-odd/T-even the parity violating time-reversal conserving term, f_3 is P-odd/T-odd parity and time-reversal violating term and f_4 is P-even/T-odd parity conserving time-violating term. A more detailed discussion of the formalism shown above exists [15,16].

The different symmetries of each term access different physics and require different experimental setups to observe. As we can see from Eq. (1), all the terms excluding the most trivial one f_0 have a neutron helicity ($\vec{\sigma}_n$) dependence which makes a neutron polarizer a critical and essential tool to probe such terms especially f_3 and f_4 that may lead to a beyond standard model discovery. From thermal to epithermal neutron energies, the SEOP *in-situ* ^3He polarizer is an effective choice for neutron polarization due to its high neutron polarization efficiency, low cost and convenience in installation relative to a proton polarizer that usually requires a high-power liquid helium cryostat to operate. Recently, a solid-state super-mirror neutron polarizer was developed at ILL and was put in use at PF1B to polarize neutrons from 0.3–2.0 nm in wavelength with a record neutron polarization of 99.7% [17]. This is a major advance in the extension of supermirror polarizer technology effectiveness for higher energy neutrons.

From Optical Theorem to connecting PV and TRIV terms

The optical theorem of quantum scattering theory relates the imaginary part of the forward scattering amplitude to the total cross-section.

$$\sigma_{\text{tot}} = \frac{4\pi}{k} \text{Im}[f(0)] \quad (2)$$

The forward scattering amplitude f describes how initial state $|i\rangle$ and final state $|f\rangle$ are connected by the parity violating V_p and parity and time reversal violating V_{pT} weak interaction potentials:

$$f = \langle f | V_p + V_{pT} | i \rangle \quad (3)$$

Weak mixing matrix elements v and w are obtained by acting s- and p-wave resonance wave functions $|\phi_s\rangle$ and $|\phi_p\rangle$ on V_p and V_{pT} :

$$v + iw = \langle \phi_p | V_p + V_{pT} | \phi_s \rangle \quad (4)$$

The connection between terms f_2 and f_3 in the approximation where the mixing with the p-wave amplitude is dominated by one nearby s-wave amplitude is then illustrated by the following [15]:

$$\frac{\Delta\sigma_{pT}}{\Delta\sigma_p} = \kappa(J) \frac{w}{v} \quad (5)$$

for which $\kappa(J)$ is an amplification term and w , v are the weak mixing matrix elements. $\Delta\sigma_{pT}$ and $\Delta\sigma_p$ are the difference of f_2 and f_3 total cross-section by varying neutron helicity going into target nuclei which is directly proportional to the size of observed asymmetries. Term f_2 and f_3 are both amplified at p-wave resonances by the mixing of s- and p-wave resonances for 10^4 to 10^6 times. Although through different channel, the same mixing mechanism lets us connect the size of effect of these two types of asymmetries. By measuring $\Delta\sigma_p$ and $\kappa(J)$, we can estimate the size of $\Delta\sigma_{pT}$ for a particular p-wave resonance of a nuclei. Due to the statistical model of atomic nuclei, these quantities of interest along with resonance parameters are unique for each individual resonance. Hence, each p-wave resonance of interest should have their size of PV asymmetry $\Delta\sigma_p$ and amplification term $\kappa(J)$ measured in order to come up with a list of hierarchy for the future $\Delta\sigma_{pT}$ TRIV measurement.

General definition of asymmetry

A helicity dependent resonance cross-section is defined as the following:

$$\sigma^\pm = \sigma_p [1 \pm P_n f_n] \quad (6)$$

σ^\pm is the helicity dependent resonance cross-section for which + is defined as neutron polarization along its direction of travel and – as the opposite, σ_p is the p-wave resonance cross-section of a nuclear target, P_n is the polarization of the neutron beam and f_n is the parity-odd longitudinal analyzing power which is an intrinsic property of a p-wave resonance.

Longitudinal asymmetry A_L can be measured by transmission of neutrons with opposite helicities through a target defined in the following equation:

$$A_L = \frac{N_+ - N_-}{N_+ + N_-} \quad (7)$$

where N_\pm is the helicity dependent neutron transmission yield for which + and – are defined as neutron polarization aligned and anti-aligned with its momentum vector. $N_\pm = N_0 \exp(-n\sigma^\pm l)$ for N_0 is the detector yield when the p-wave cross-section $\sigma_p = 0$, n the number density of the nuclear target in nuclei/cm². A_L can be rewritten as [4]:

$$A_L = \tanh(-P_n f_n n \sigma_p) \quad (8)$$

$$\approx -P_n f_n n \sigma_p \quad (9)$$

Any non-p-wave resonances or p-waves without an asymmetry will exhibit a near zero behavior on the A_L calculations while the actual effect of interest should reveal itself with an A_L value that stands out from the $A_L = 0$ in nearby neutron energies.

In this paper we describe the first operation of a polarized ^3He NSF on the Back-n beamline at the CSNS. The polarized neutron beam created by this device on the Back-n beamline can enable many new types of experimental investigations on the different spectrometers and detector systems installed at this facility. We begin by reviewing the operation principles of polarized ^3He NSF and present the transmission measurements that demonstrate the effective operation of the polarized ^3He NSF on the Back-n beamline. We then describe the spectrometer systems on the Back-n beamline which we expect to be most well-suited to take advantage of this new polarized beam capability. Finally we describe one example of such a scientific application in the conclusion and discussion section: the search for parity violation in polarized neutron interactions in p-wave neutron-nucleus resonance reactions.

2. Polarized ^3He as Neutron Spin Filter

Polarized ^3He NSF is a widely used instrument for neutron polarization. ^3He NSF is very useful for material science and neutron scattering research due to its high efficiency in polarizing Angstrom-wavelength neutrons. The less well known application of ^3He NSF is to polarize neutrons to probe fundamental nucleon nucleon (NN) interactions in the compound nucleus [18–21]. An off-situ ^3He NSF may achieve a high ^3He polarization (>80%) [22–24] and requires lesser space when applied to neutron beamlines due to its compactness since neither a laser system or a heating system is required, the advantage of an *in-situ* system lies in its ability to constantly pump a ^3He cell that is in the beam, maintaining a stable polarization for an experiment and is free from cell change. Optically pumped ^3He is a well developed and widely used tool in facilities like NIST in the U.S. [25–27], ORNL in the U.S. [28–31], CSNS in China [6,32,33], CAEP in China [23,34], J-PARC in Japan [24,35–37], JCNS in Germany [31,38–40], ILL in France [31,41–44], ISIS in the U.K [31,45,46], and LENS at Indiana University in the U.S. [47].

³He neutron transmission formalism

For unpolarized ³He gas, the neutron transmission T_0 is given by the following equation [48]:

$$T_0 = T_e \exp(-n_{\text{He}} \sigma_0 l) = T_e \exp(-0.0732 p l \lambda) \quad (10)$$

$$= T_e \exp(-O) \quad (11)$$

T_e is neutron transmission through an empty glass cell with no ³He gas. $O = n_{\text{He}} \sigma_0 l$ is the neutron opacity factor. O is linearly proportional to n_{He} the number density of ³He gas, $\sigma_0 \approx 3000 \lambda$ [41,48] is the total cross-section of unpolarized ³He in barn, and l the length of ³He gas neutrons have to travel through. For ³He gas, O can be expressed into a more convenient form: $O = 0.0732 p l \lambda$ for which p is the pressure of ³He at 20 °C in bar, l in cm, and λ is the neutron wavelength in Å. Polarized ³He neutron transmission T_n is given by:

$$T_n = T_e \exp(-O) \cosh(O P_{\text{He}}) \quad (12)$$

$$= T_0 \cosh(O P_{\text{He}}) \quad (13)$$

for which P_{He} is the ³He polarization and let us define the neutron transmission yield $T'_n = T_n/T_e = \exp(-O)\cosh(O P_{\text{He}})$.

The ratio between polarized ³He neutron transmission and unpolarized ³He neutron transmission is then:

$$\frac{T_n}{T_0} = \cosh(O P_{\text{He}}) \quad (14)$$

Polarization of neutrons P_n through a spin filter is,

$$P_n = \tanh(O P_{\text{He}}) = \sqrt{1 - \frac{T_0^2}{T_n^2}} \quad (15)$$

We can use the figure of merit Q ,

$$Q = T_n P_n^2 \quad (16)$$

to evaluate the analyzing power of certain spin filter system. Using Eq. (14), through the ratio of T_n and T_0 , we can obtain the absolute ³He polarization of our *in-situ* NSF system and the resulting neutron transmission T_n and polarization P_n .

³He polarizer developed at CSNS

CSNS neutron polarization device development started in 2019. Since then, a spin-exchange optical pumping (SEOP)-platform [6], a ³He glass cell workshop [49] and further development in ³He polarization instrument techniques [33] were conducted at CSNS. The group manages to produce a ~8 cm long by $\phi 5$ cm standard cylindrical ³He GE180 glass cell capable of holding 3.1 bar gas pressure at room temperature which can withstand 200 °C temperature in May of 2023. The previous *in-situ* system achieves a 74% ³He polarization as measured on BL-20 of CSNS [32]. The typical fluctuation in the *in-situ* ³He polarization arises from two main sources: variations in ³He polarization due to changes in laser power, and slight losses in flipping, as the ³He flipping process is not perfectly efficient. At the very most, such fluctuation was $\sigma_{P_{\text{He}}} = \pm 2\%$ seen on FID measurements.

Neutron total cross-sectional spectrometer (NTOX)

NTOX [50] shown in Fig. 1 is a multilayer fast fission chamber spectrometer utilizing ²³⁵U and ²³⁸U for fission cross-section or neutron total cross-section measurement at Back-n CSNS. The neutron counts are determined by counting and analyzing the fission events from the ²³⁵U(n, f) and ²³⁸U(n, f) reactions. Data was acquired through the Back-n public DAQ system and stored at the Back-n data cluster.

³He transmission experimental results

We applied a new-designed *in-situ* ³He NSF system developed at the CSNS on the Back-n White Neutron Source (WNS) in April of 2024. This is the first time that an *in-situ* ³He SEOP NSF system has been applied to the only WNS in China. From Fig. 3 we can see where the ³He NSF and NTOX detector were placed. The ³He system was placed at a flight path of 55 m from the spallation target at ES#1. NTOX installed at ES#2 down stream of ES#1 at 77.1 m flight path to measure neutron transmission through the ³He NSF. A cell with 2.53 bar pressure, 7.2 cm gas length was used in the *in-situ* ³He SEOP

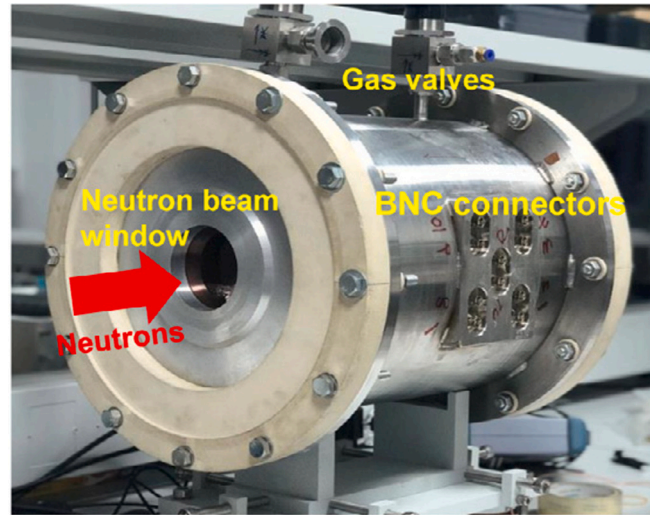


Fig. 1. NTOX neutron total cross-section spectrometer.

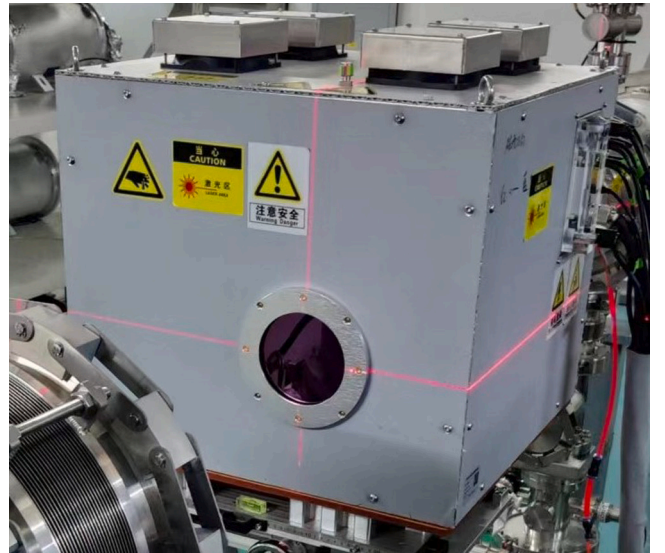


Fig. 2. *in-situ* ³He SEOP NSF.

system shown in Fig. 2 [32]. The *in-situ* ³He NSF system was deployed on the Back-n beam at location ES#1 and the NTOX detector for the neutron flux measurement was located at ES#2. The flight path distance of 77.1 m from the spallation target was calibrated using a pre-established method [50].

Our neutron transmission experiment of the ³He *in-situ* NSF system performed on Back-n beamline took 75 h of data, consisting of a polarized run of 57 h and an unpolarized run of 18 h. The ³He cell was pre-pumped before the experiment for in order to reach maximum polarization. The polarized ³He neutron transmission was measured first, with continuous pumping during the measurement to maintain the high ³He polarization. Second, depolarizing procedure was performed through period off-resonance Adiabatic Fast Passage (AFP) operation. Finally, the neutron transmission for the fully unpolarized *in-situ* ³He NSF was measured. A 1.7 mm thick BN (boron nitride) filter was applied in the beamline right before the shutter (Fig. 6) to extend the neutron energy cutoff to below 19 meV, much lower than the 0.3 eV cutoff energy than is normal on the Back-n beam, which usually employs a Cd+Ag+Co filter configuration. Frame overlap was observed for neutron energies lower than 19.4 meV, so data lower than this

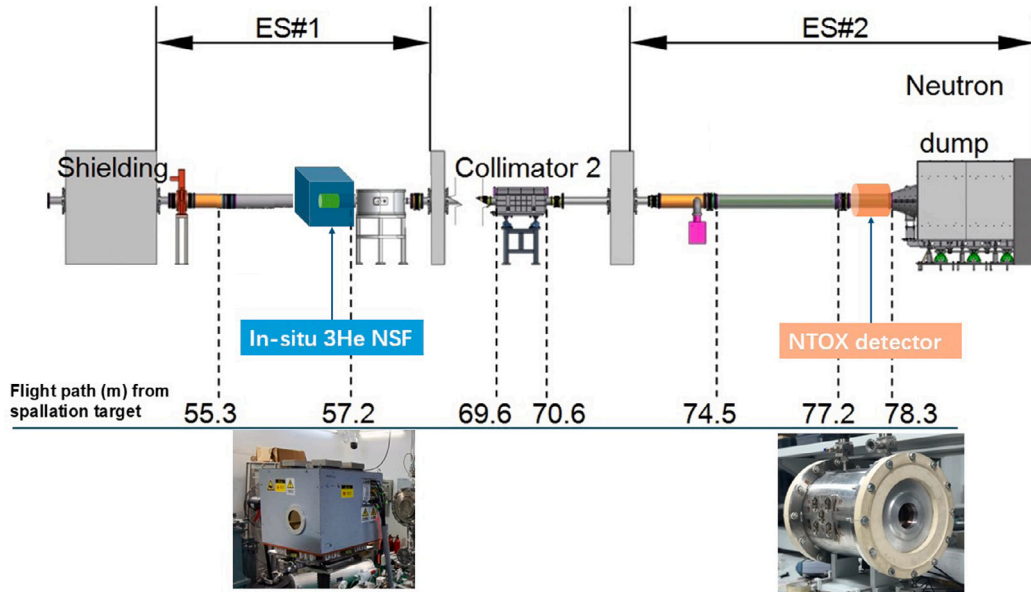


Fig. 3. This is the layout of this experiment. *In-situ* ^3He NSF was placed at ES#1. NTOX detector was placed at ES#2 right in front of beam dump.

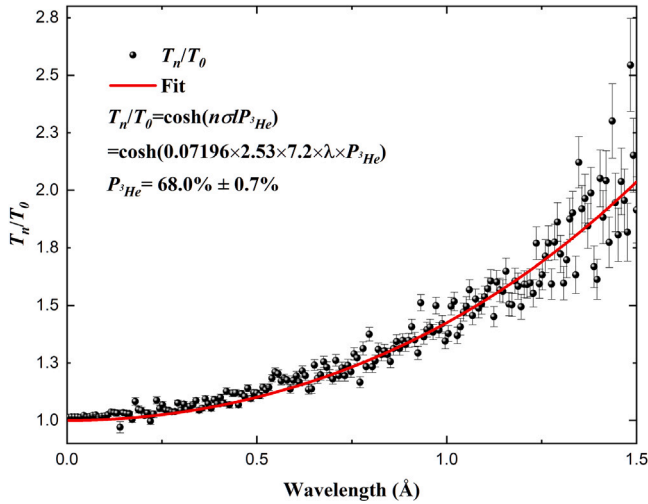


Fig. 4. Fitting result for the ^3He polarization measured on Back-n with the NTOX detector. The y -axis is the ratio of polarized(T_n) vs unpolarized(T_0) ^3He transmission data. T_n refers to the polarized ^3He transmission. The x -axis is neutron energy in wavelength (\AA).

energy was ignored in our analysis. This was the first experiment of Back-n with such a filter configuration. Normalization of the neutron transmission data was performed using the number of protons injected to the spallation target.

The result shown in Fig. 4 is the plot of ratio of polarized ^3He transmission data and unpolarized ^3He transmission data fitted using Eq. (14). All the data are normalized with the number of protons injected to the spallation target as discussed in the previous section. The uncertainty on $P_{^3\text{He}}$ is purely from fitting and does not include any systematic error. The larger uncertainty in T_n/T_0 at longer wavelengths in Fig. 4 comes from the significant decrease in neutron flux near the cutoff. The neutron flux of Back-n beamline from 0.3 to 0.9 \AA (10^{-1} - 10^0 eV) is about 10 to 10^2 lower than higher neutron energy regions [51].

Fig. 5 shows the theoretical performance of a polarized ^3He cell of $p = 2.53$ bar, $l = 7.2$ cm and $P_{^3\text{He}} = 68\%$ in the measured *in-situ* NSF

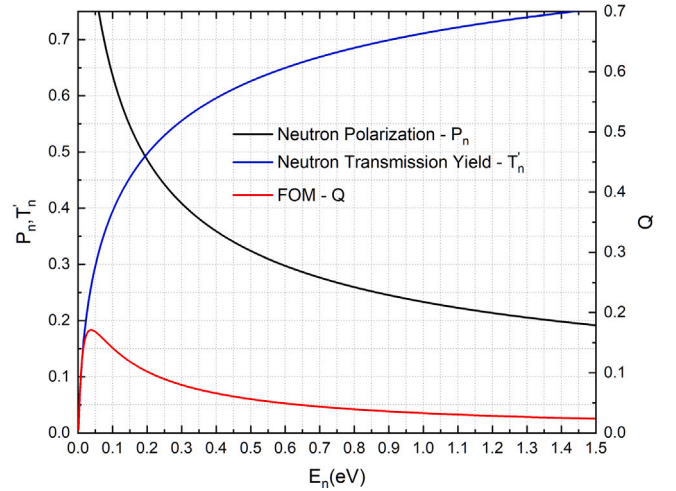


Fig. 5. Theoretical performance of the measured ^3He NSF system with: Neutron Transmission Yield T_n , Neutron Polarization P_n and Figure Of Merit (FOM) Q as a function of Neutron Energy E_n .

system. Figure of merit Q peaks at 0.038 eV indicates this NSF balances polarization and transmission near this energy.

^3He system on Parity Violation measurement

If we assume A_L is only a function of the neutron polarization P_n and use the approximated form of A_L from Eq. (8) we get the effect of neutron polarization fluctuation σ_{P_n} on the relative error of A_L to be:

$$\left(\frac{\sigma_{A_L}}{A_L}\right)^2 = \left(\frac{\partial A_L}{\partial P_n} \frac{\sigma_{P_n}}{P_n}\right)^2 \quad (17)$$

$$= (n\sigma_p f_n \frac{\sigma_{P_n}}{P_n})^2 \quad (18)$$

If we also assume P_n is only a function of ^3He polarization $P_{^3\text{He}}$, using a first order approximation on Eq. (15) just like what we did to A_L . Notice the λ dependence in $O = -0.0732pl\lambda$. Such approximation will deviate from the actual value if we consider large λ neutrons which has very small neutron energy. For epithermal energy where $\lambda \ll 1$, this divergence is negligible. For epithermal energy or lower, the contribution of neutron energy uncertainty is significantly suppressed

so O is treated as a constant here. We then get the relative error of P_n to be:

$$\left(\frac{\sigma_{P_n}}{P_n}\right)^2 = \left(\frac{\partial P_n}{\partial P_{\text{He}}} \frac{\sigma_{P_{\text{He}}}}{P_{\text{He}}}\right)^2 \quad (19)$$

$$= \left(O \frac{\sigma_{P_{\text{He}}}}{P_{\text{He}}}\right)^2 \quad (20)$$

Combining equations above, we get the estimate of the effect of ^3He polarization fluctuation on A_L :

$$\left(\frac{\sigma_{A_L}}{A_L}\right)^2 = (n_{\text{target}} \sigma_p f_n O \frac{\sigma_{P_{\text{He}}}}{P_{\text{He}}})^2 \quad (21)$$

$$= (0.0732 * pl \lambda n_{\text{target}} \sigma_p f_n \frac{\sigma_{P_{\text{He}}}}{P_{\text{He}}})^2 \quad (22)$$

Eventually, we can estimate the rough size of relative error from ^3He polarization fluctuation contributing to the relative error of A_L . Using the *in-situ* NSF system we discussed before for which: $p = 2.53$ bar, $l = 7.2$ cm, $\sigma_{p_{\text{He}}} = \pm 2\%$ and $P_{\text{He}} = 68\%$, for a ^{nat}La of 2 cm thickness $n = 5.34 \times 10^{22}$ nuclei/cm², $\sigma_p(0.734\text{eV}) = 13.6$ barns, $f_n = 0.084$ [18], and $\lambda = 0.334$ Å for a 0.734 eV neutron energy, we get the contribution to be 0.0059%. Hence, such fluctuation in ^3He polarization will not be the major source of error in asymmetry measurements.

A commonly used resonance in the measurement of PV as a check to a PV experimental setup is the 0.734 eV p-wave resonance of ^{139}La . This resonance has the largest measured parity violation asymmetry ($A_L \approx 10\%$) at epithermal neutron region [4]. From Fig. 5 we can see at 0.734 eV there 29% of neutron polarization P. Previous NOPTREX experiments at J-PARC on BL-04 [24] used an off-situ ^3He cell that provides 27% neutron polarization at 0.734 eV when at maximum polarization. This current *in-situ* polarizer developed at CSNS is capable to carrying out PV measurements for near 1eV p-wave resonances. At 10 eV, only 8% neutron polarization remains. We can still measure A_L to a desired statistical accuracy but with the expense of greatly increase the required beam time. We can see from Eq. (15) we can improve neutron polarization P_n as either the neutron polarization P_{He} or the opacity factor O increases. The simplest solution is to increase O by increasing neutron travel l through polarized ^3He gas which can be achieved through stacking two or more *in-situ* systems in the beamline.

3. Back-n beamline properties and instrumentation

The CSNS Back-n WNS is a unique beamline due to its wide energy range of incident neutrons, from thermal to 300 MeV, and its long flight path: approximately 54 meters to ES #1 and 77 meters to ES #2. It also features a high neutron flux of $10^4 - 10^7$ n/cm² when operating at 125 kW power with a 25 Hz double bunch pulse [5]. The NOPTREX collaboration consider the Back-n beamline most suitable for Parity and Time violating asymmetry measurements due to its high flux, long flight path, low beam divergence and spacious ES#1 and ES#2 which opens up many possible experimental setups. The NTOX neutron detector was introduced in Section 2, so there will not be further detailed in this section.

GTAF-II (n, γ) spectrometer

The Gamma Total Absorption Facility - II (GTAF-II) shown in Fig. 7 is a 4 π BaF₂ (n, γ) spectrometer located at location ES#2 of Back-n. It consists of 42 detector elements of which 40 are BaF₂ scintillation detectors capable of covering near 90% of 4 π solid angle [52]. The near unity detection efficiency combined with the high intensity of WNS can perform efficient searches for neutron parity violation in p-wave resonances. Its high precision in neutron energy measurement and the capability of measuring the gamma angular distribution is invaluable in probing T-violating terms in spin-angular correlations between incoming neutrons and outgoing gamma-rays. The combination of a polarized eV neutron beam and a 4 π BaF₂ gamma calorimeter on an intense spallation neutron source like the CSNS is unique in the world and will enable new physics measurements.

4. Conclusions and discussions

An *in-situ* SEOP ^3He neutron polarizer was successfully operated on the Back-n beamline and ^3He neutron transmission under different conditions was measured. The ^3He NSF achieved a $68\% \pm 0.7\%$ maximum polarization. This successful demonstration opens up various different types of future possible experiments probing fundamental symmetries at the Back-n WNS.

4.1. Possible experiments on Back-n WNS with polarized neutrons

In this section, we consider PV and TRIV experimental setups which only need the addition of a ^3He NSF of the type that we have just described. A description of the extensive range of possibilities for combining a WNS with a neutron polarizer warrants a separate article. **P-odd/T-even**(f_2)

In Fig. 8 is the setup which can probe the $f_2(\vec{\sigma}_n \cdot \vec{k}_n)$ P-odd/T-even parity violating time reversal conserving term. By changing the direction of polarization of the ^3He NSF, $T_{+/-}$ or $R_{+/-}$ can be measured and an asymmetry acquired as specified in Eq. (7). The two methods differ mainly in the means of detection from an instrumental point of view. At Back-n, the existing spectrometers that are most adequate for the requirements of both PV experiment methods are NTOX and GTAF shown in Fig. 1 and Fig. 7 respectively.

CRedit authorship contribution statement

Mofan Zhang: Writing – review & editing, Writing – original draft, Formal analysis. **Zhou Yang:** Data curation. **Junpei Zhang:** Writing – review & editing, Resources, Methodology. **Chuyi Huang:** Conceptualization. **Tianhao Wang:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Yonghao Chen:** Resources, Methodology, Data curation. **Ruirui Fan:** Supervision, Resources, Project administration, Investigation, Funding acquisition. **W. Michael Snow:** Writing – review & editing. **Xin Tong:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

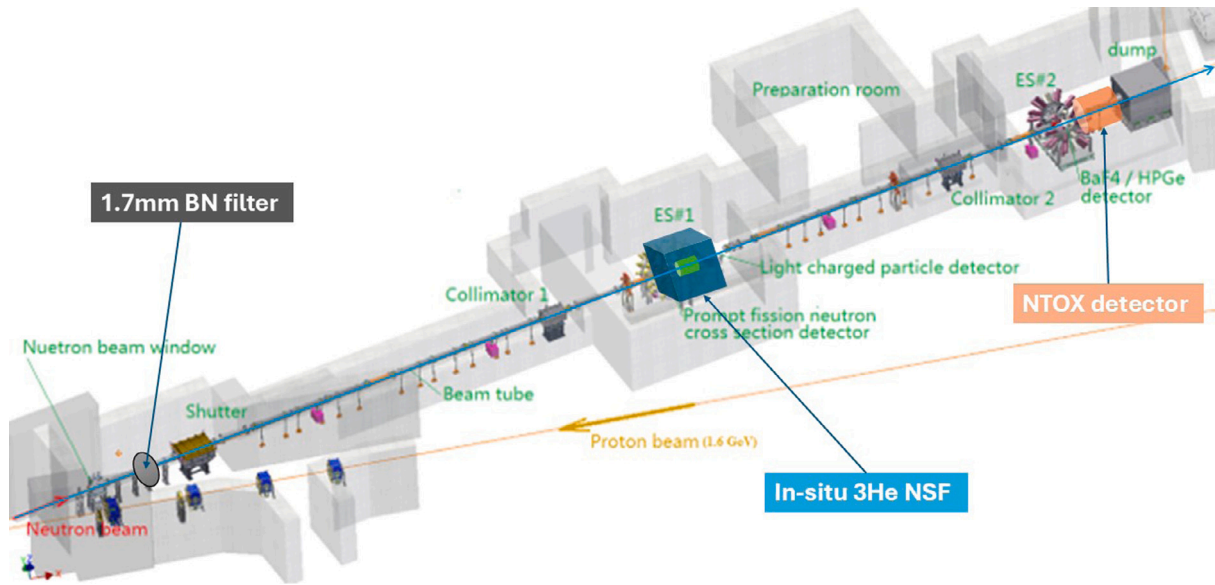


Fig. 6. Back-n beamline layout with indication of the location of ^3He NSF and NTOX detector.

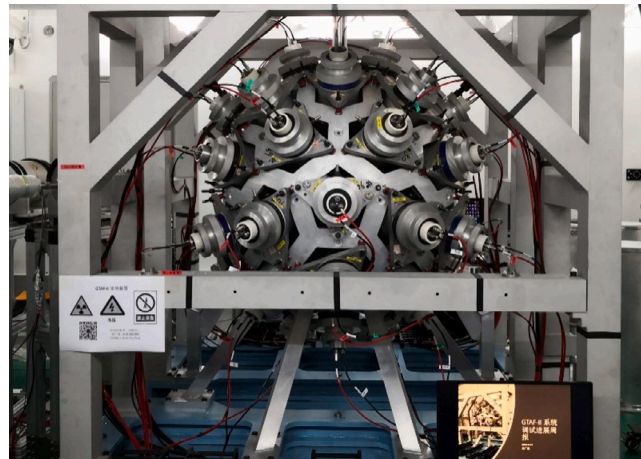


Fig. 7. GTA-II 4π BaF_2 (n, γ) spectrometer.

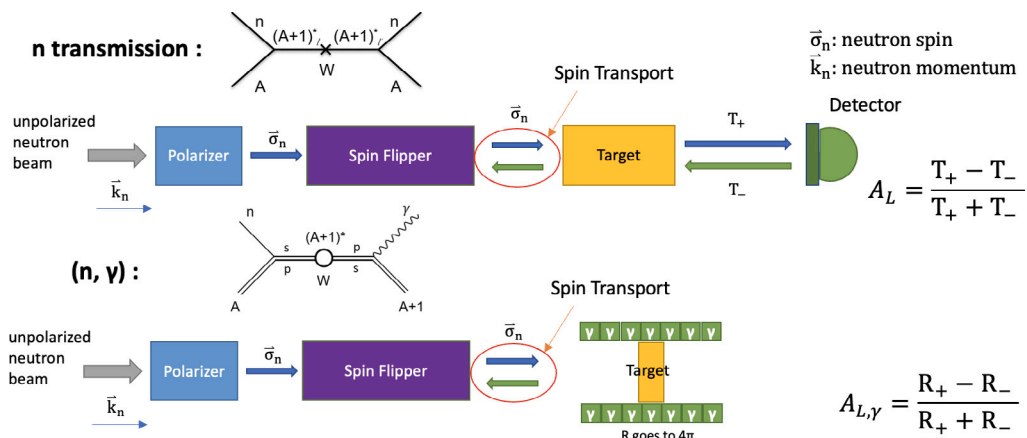


Fig. 8. PV experiment setups. There exists two methods shown in this figure to probe Parity Violation: the neutron transmission method [4] and the (n, γ) method [53].

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