SETTING UP (HIGH-ENERGY) POLARIZED NEUTRON AT THE CHINA SPALLATION NEUTRON SOURCE

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Outline

I. CSNS polarized neutron overview

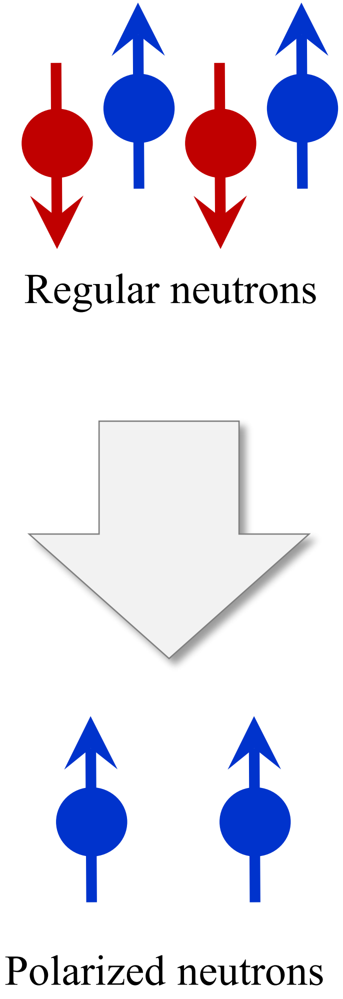
II. Current polarized instrument capability

III. Polarized neutron on Back-n beamline

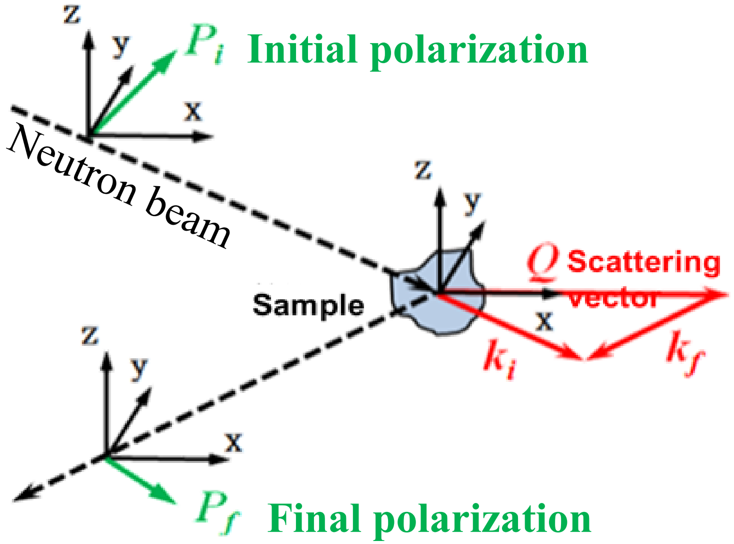
IV. Summary

CSNS Polarized Neutron Overview

❑ Polarized neutron have applications in material and nuclear research

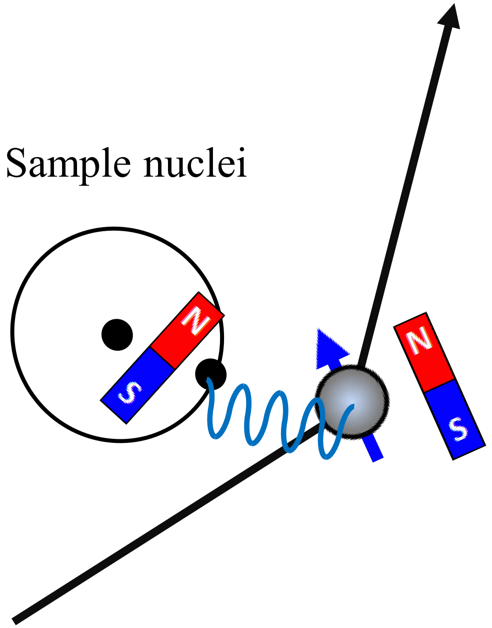


Polarized neutron scattering



Momentum shift	Energy shift	**Polarization Shift**
$Q = k_f - k_i$	$\Delta E = E_f - E_i$	$P_i \rightarrow P_f$
$k_f = (k_{fx}, k_{fy}, k_{fz})$		$P_f = (P_{fx}, P_{fy}, P_{fz})$
$k_i = (k_{ix}, k_{iy}, k_{iz})$		$P_i = (P_{ix}, P_{iy}, P_{iz})$

- ❖ **Study of magnetic materials**
- ❖ **Separation of incoherent scattering**
- ❖ **Neutron Spin manipulation**
- ❖ **Nuclear physics**



CSNS Polarized Neutron Overview

- **Support polarized neutron demand at CSNS through in-house development**

❑ Initial development (2019 – 2020)

- Glass cell manufacturing shop
- Off-situ and In-situ SEOP ^{3}He neutron spin filter systems
- Neutron beamline for testing and calibration

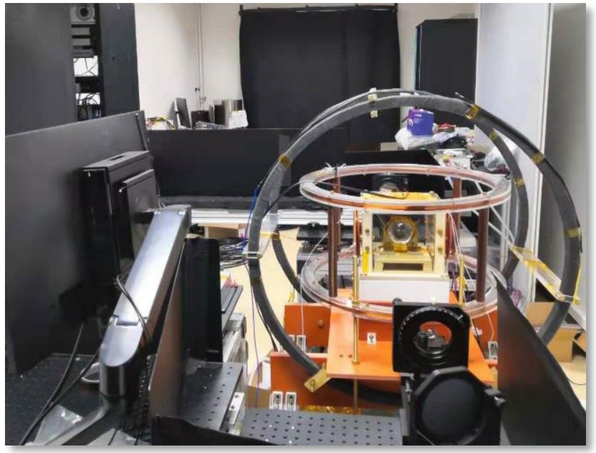
❑ Current development (2021 – 2024)

- Beamline implementation and commission
- Scientific application of polarized neutron and ^{3}He

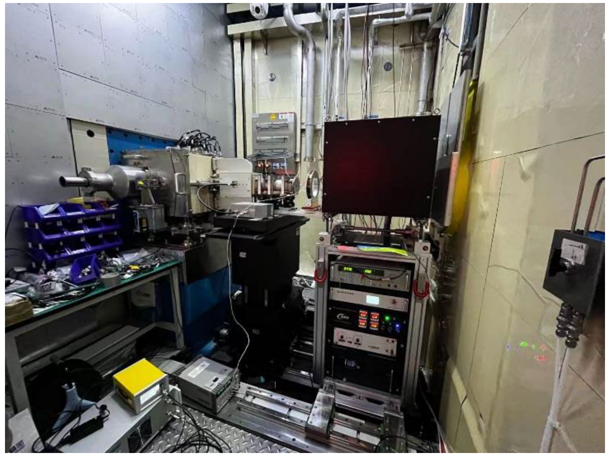
❑ Future development (2025 - 2029)

- CSNS phase-II development
- Novel polarized gas and polarized neutron techniques

CSNS SEOP laser lab



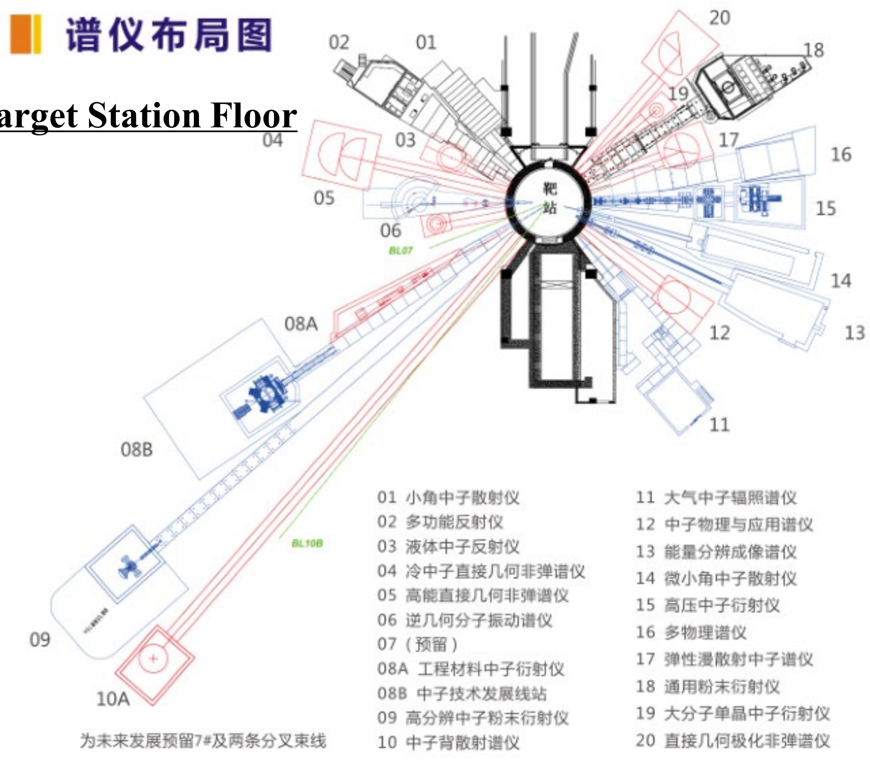
Pol-SANS experiment at BL-14



CSNS Polarized Neutron Overview

- **Polarized Neutron at CSNS – condensed matter physics**

Target Station Floor



Commissioning

BL-01	Small Angle Neutron Scattering instrument
BL-02	Multi-Purpose Reflectometer
BL-18	General-Purpose Powder Diffractometer

CSNS Phase - I

BL-05	High-Energy Direct-Geometry Inelastic Spectrometer
BL-08	Engineering Material Neutron Diffractometer
BL-09	High-Resolution Neutron Diffractometer
BL-11	Atmospheric Neutron irradiation Spectrometer
BL-13	Energy-Resolved Neutron Imaging Instrument
BL-14	Very Small-Angle Neutron Scattering instrument
BL-15	High-Pressure Neutron Diffractometer
BL-16	Multi-Physics Instrument
BL-20	Neutron Technology Development beamline

CSNS Phase - II

BL-03	Liquid Reflectometer
BL-04	Cold Neutron Inelastic Spectrometer
BL-06	Indirect-Geometry Molecular Vibrational Spectrometer
BL-8A	Neutron Technology Development beamline
BL-10	Neutron Backscattering Spectrometer
BL-12	Neutron Physics and Application Spectrometer
BL-17	Elastic Diffuse Scattering neutron Diffractometer
BL-19	Macromolecular Single-Crystal Neutron Diffractometer
BL-20	Direct-Geometry Polarized Inelastic Spectrometer

CSNS Polarized Neutron Overview

- **Polarized Neutron at CSNS back-n beamline**

First Use of a Polarized ^{3}He Neutron Spin Filter on the Back-n White Neutron Source of CSNS

Mofan Zhang (张墨凡)[2,3], Zhou Yang (杨洲)[2], Junpei Zhang (张俊佩)[1,2,4], Chuyi Huang (黄楚怡)[1,2,4], Tianhao Wang (王天昊)*[1,2,4], Yonghao Chen (陈永浩)[1,2], Ruirui Fan (樊瑞睿)†[1,2,5], W. Michael Snow[3] and Xin Tong (童欣)‡[1,2,4]

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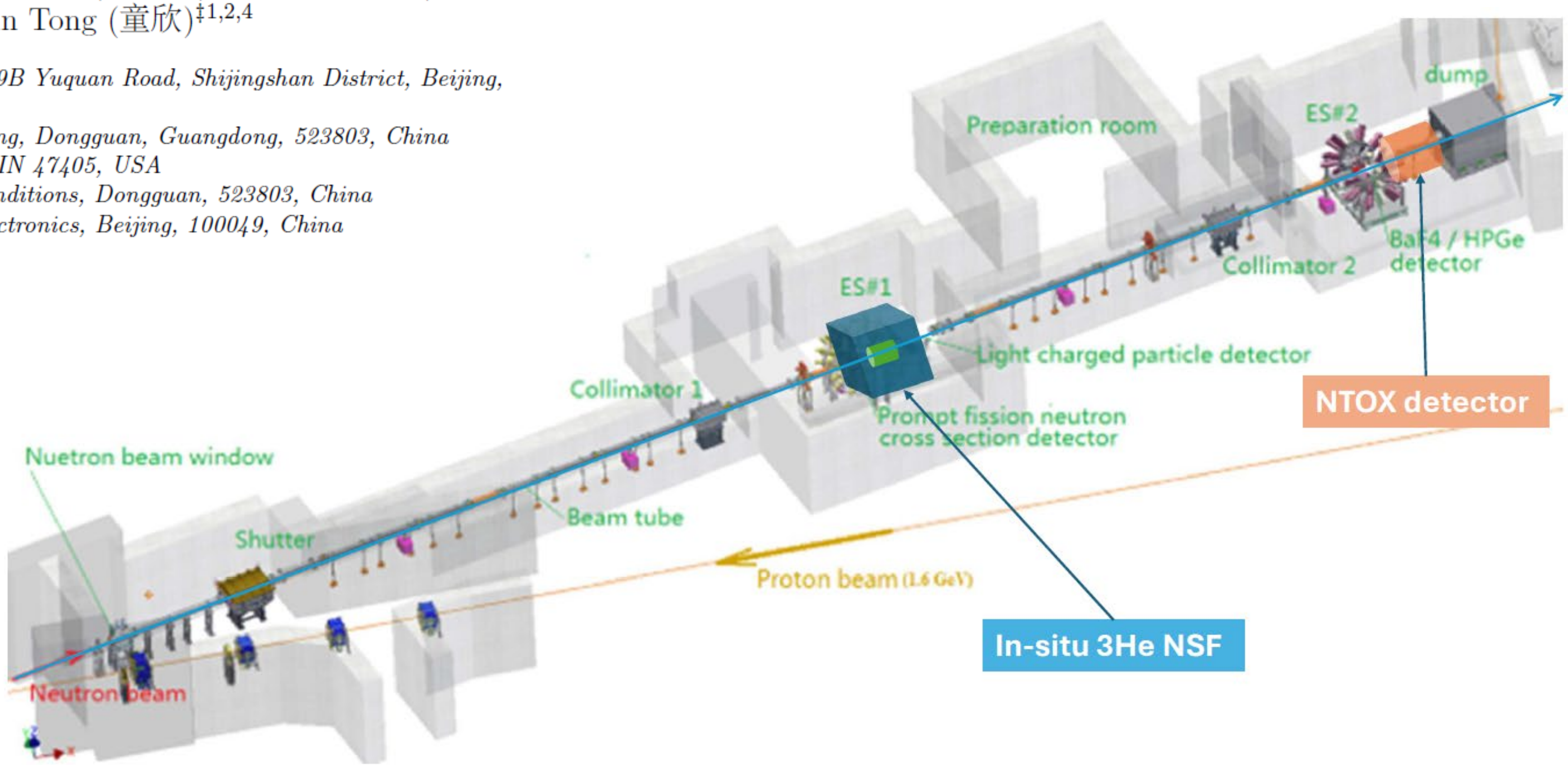
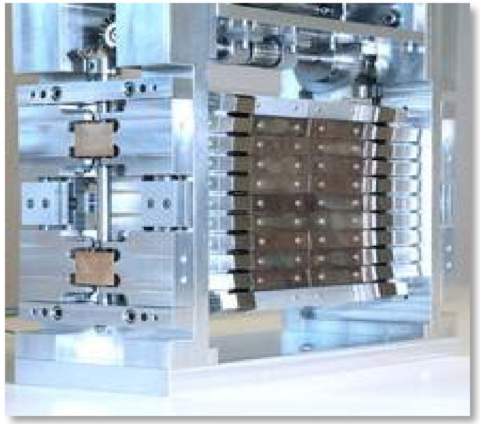
[2] *China Spallation Neutron Source, 1 Zhongziyuan Road, Dalang, Dongguan, Guangdong, 523803, China*
[3] *Indiana University, Bloomington, IN 47405, USA*
[4] *Guangdong Provincial Key Laboratory of Extreme Conditions, Dongguan, 523803, China*
[5] *State Key Laboratory of Particle Detection and Electronics, Beijing, 100049, China*



Current polarized instrument capability

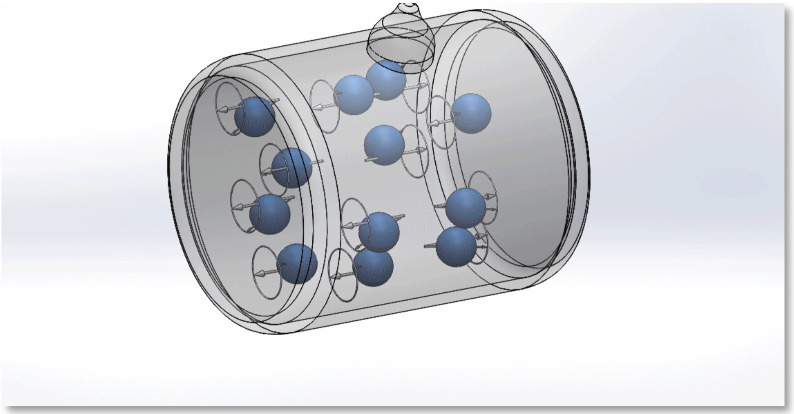
- **SEOP polarized 3He is the primary neutron polarizing method for CSNS**

Single Crystal Monochromators

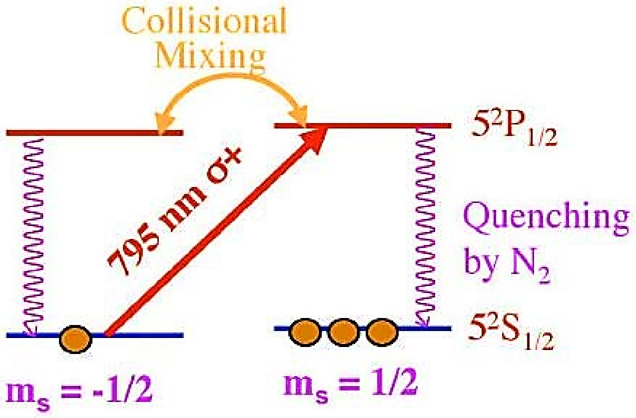


Polarizing Supermirrors

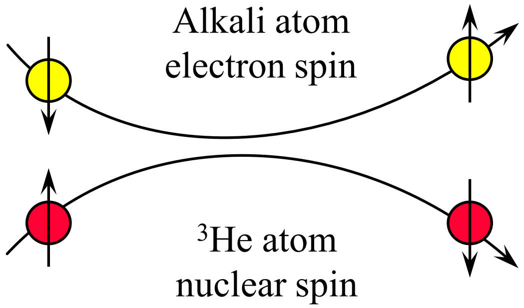
Polarized ^{3}He Target



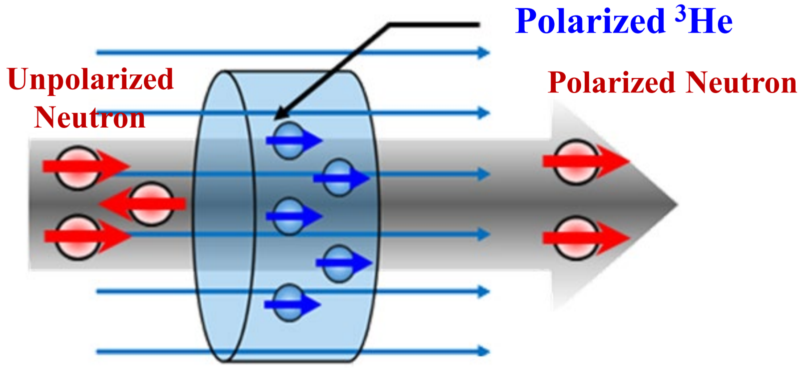
1. Laser pumping Alkali atom electron



2. Exchange polarization to ^{3}He atom



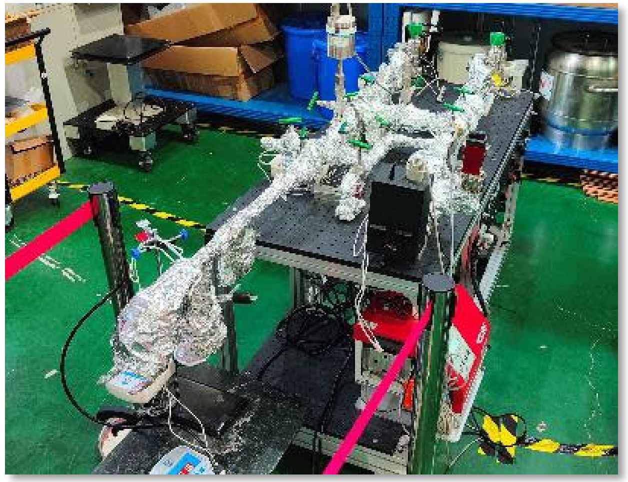
3. Neutron spin filtering by polarized ^{3}He



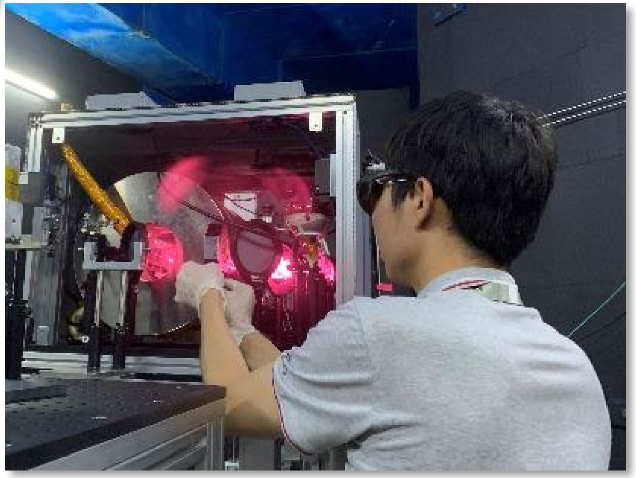
Current polarized instrument capability

- **CSNS established in-house development capability for SEOP ^{3}He system**

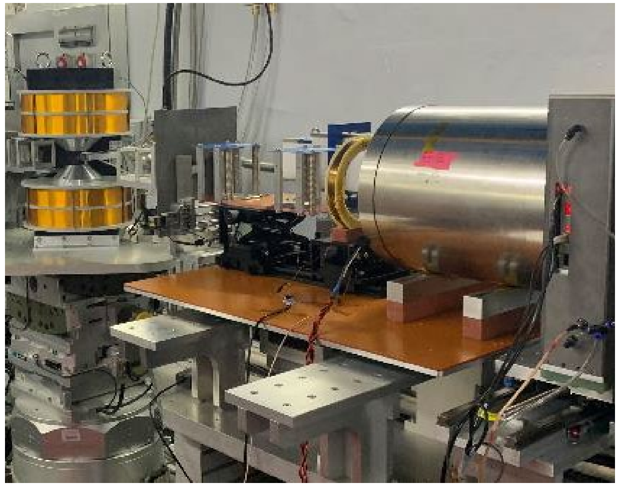
1. In-house ^{3}He cell fabrication and filling

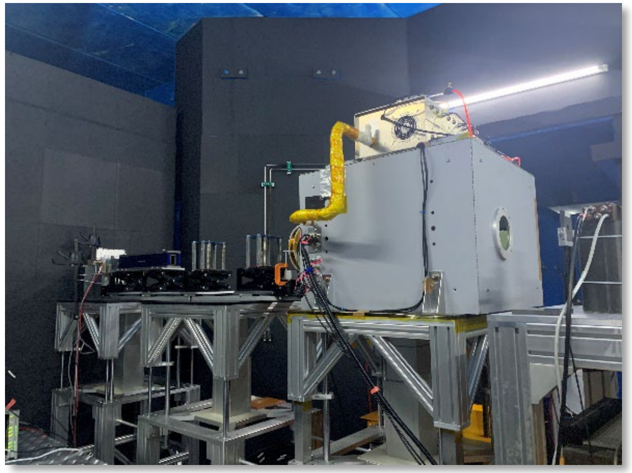


2. Off-situ and in-situ SEOP ^{3}He spin filter



3. Beamline commission and scientific application

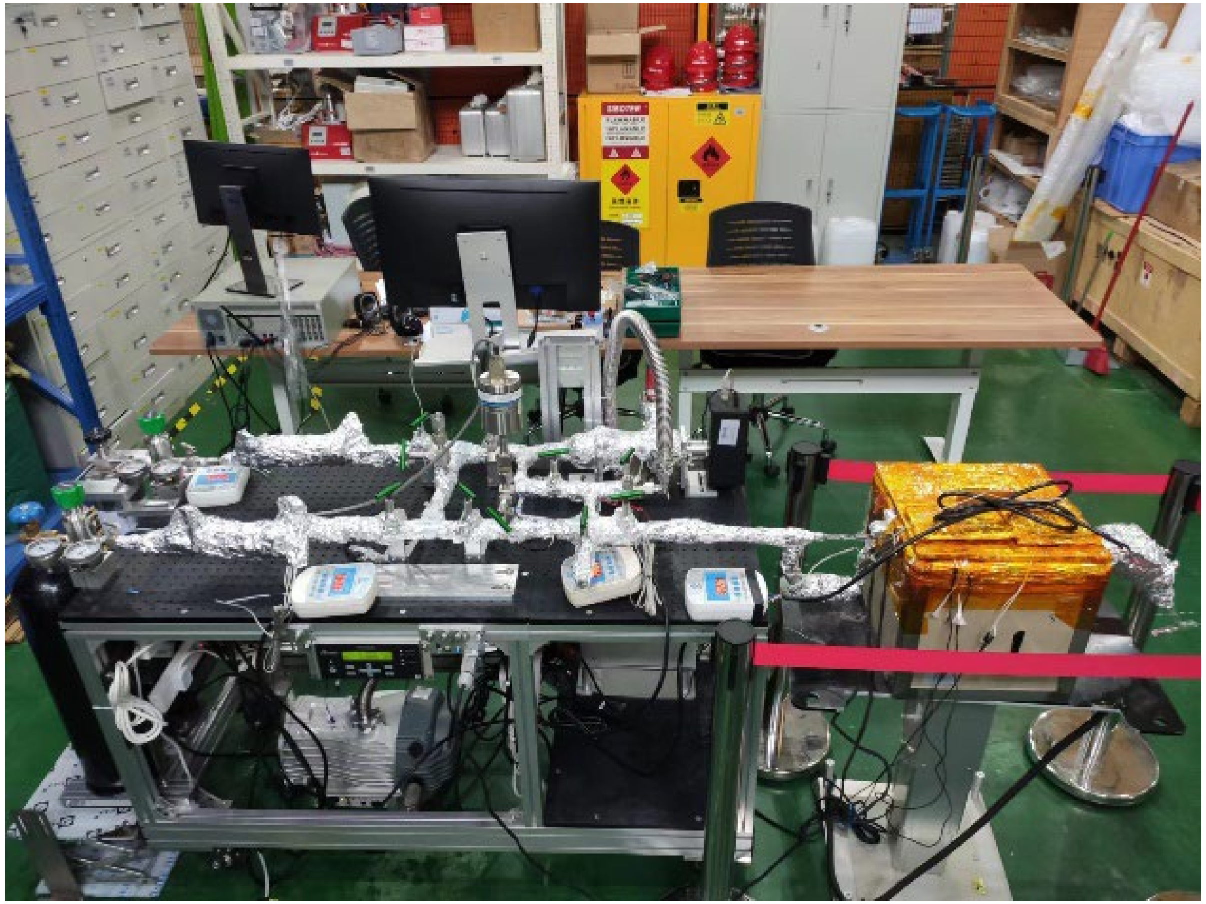




Current polarized instrument capability

- **CSNS is currently producing and benchmarking SEOP 3He cells**

SEOP ^{3}He cell filling station (2022)



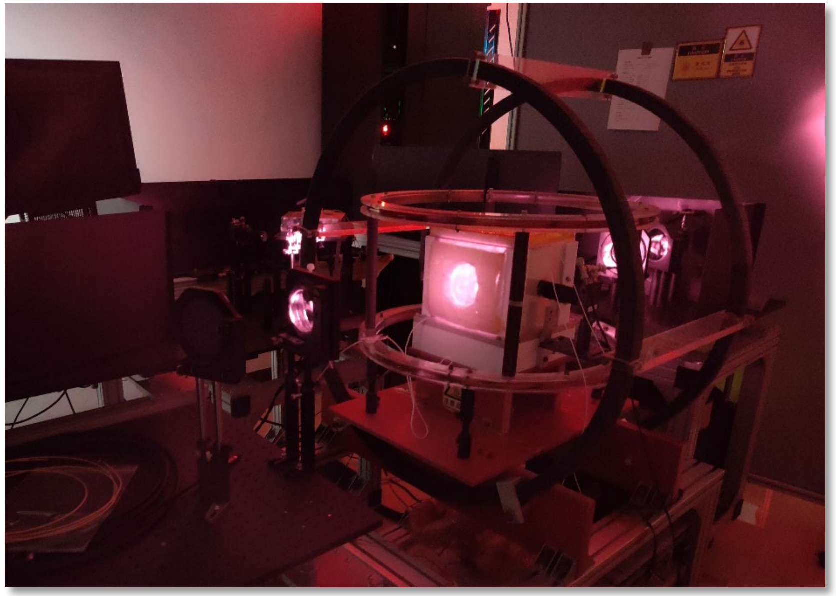
Glass cell blowing and tipping off

- ❑ **More than 40 cells produced every year**
- ❑ **Customized glass manifolds, gaskets and socket components**

Current polarized instrument capability

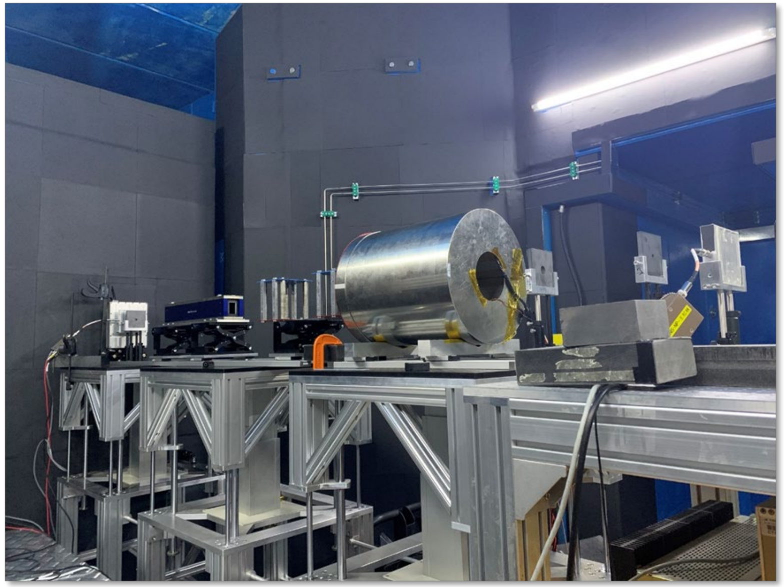
- **Routinely operating Off-situ 3He pumping station in the target building**

1. SEOP ^{3}He pumping



2. Polarized cell transfer

3. Deliver to Beamline



Key performance of the current off-situ system

^{3}He life time	^{3}He polarization	Transfer time	Cell exchange rate
100 - 200 hrs.	60% - 77%	<30 min	24 – 48 hrs.

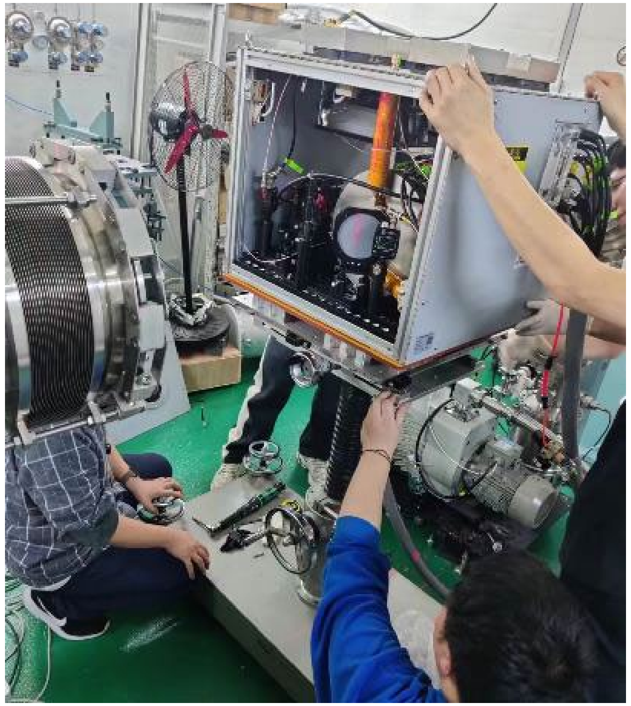
Chin Phys Lett, 38 (2021), DOI: 10.1088/0256-307x/38/9/092801

Current polarized instrument capability

- **In-situ SEOP 3He spin filter as part of neutron beamline instrument**

1. Transfer the in-situ ^{3}He system

2. Install ^{3}He system on beamline



3. Powering and control system

Key performance of the current In-situ system

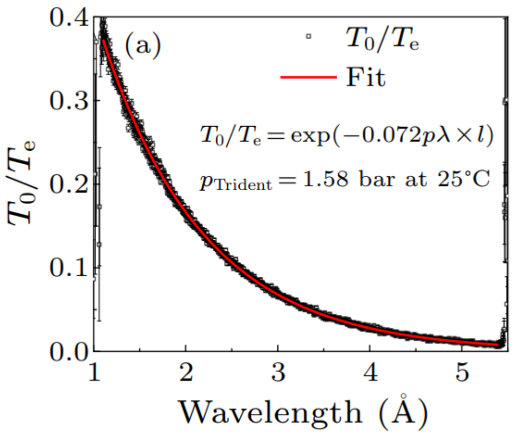
^{3}He polarization	Operation time	Neutron polarization	^{3}He spin flip loss
65%-75%	> 240h (10days)	>99% (4 Å)	<0.1%

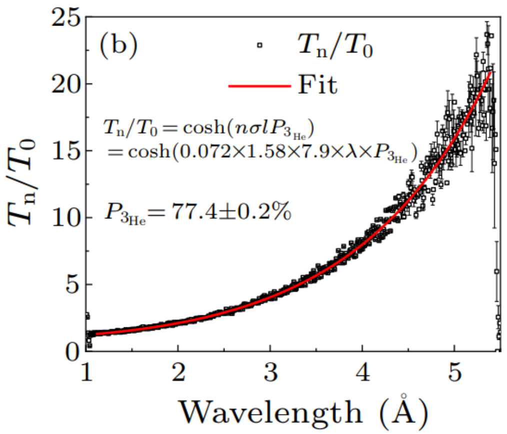
Sci. China Phys. Mech. Astron. 65, 241011 (2022). DOI: 10.1007/s11433-021-1876-0

Current polarized instrument capability

- **Cell quality assessment using TOF neutron and NMR method**

Online benchmarking: Neutron transmission measurement at CSNS





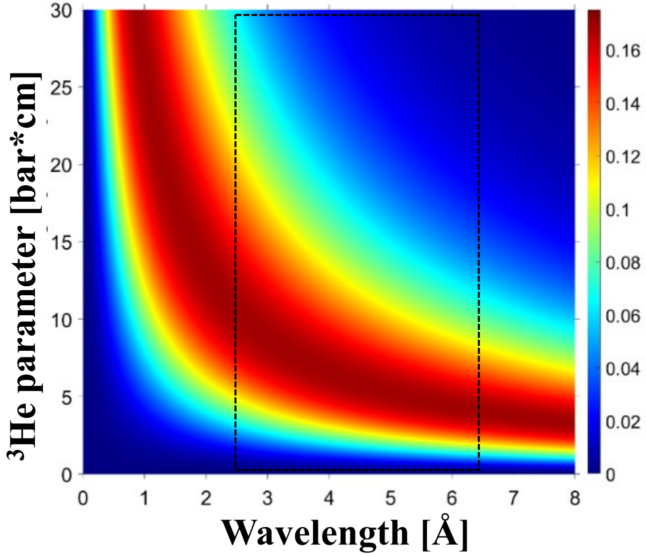
^{3}He gas pressure calibration

$$T_{depol}(\lambda)/T_0 = exp(-0.072\, P_{3He} \cdot l \cdot \lambda)$$

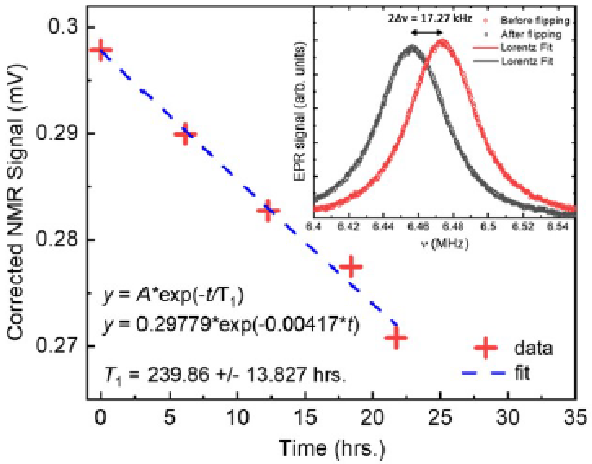
^{3}He polarization calibration

$$T_{pol}(\lambda)/T_{depol}(\lambda) = cosh(0.072\, P_{3He} \cdot l \cdot \lambda \cdot P_{3He})$$

^{3}He filter parameter

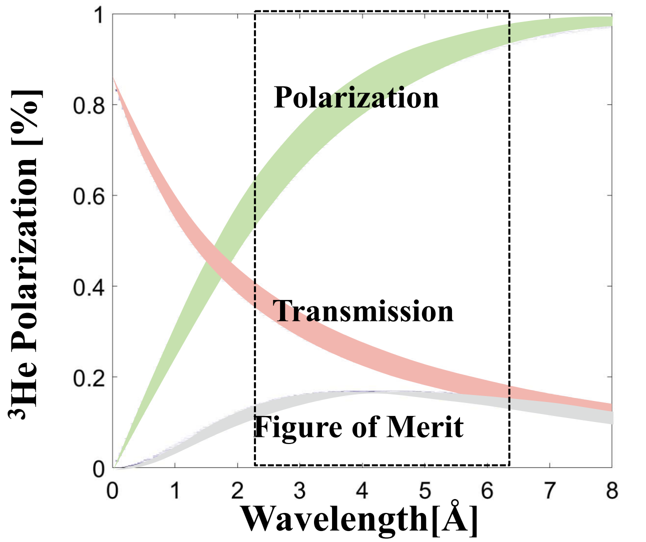


Offline benchmarking: FID and EPR measurement



$$P_{3_{He}} = \frac{\Delta\nu}{kHz} \cdot \frac{Amagat}{1.13 \times \kappa_{eff}[He]}$$

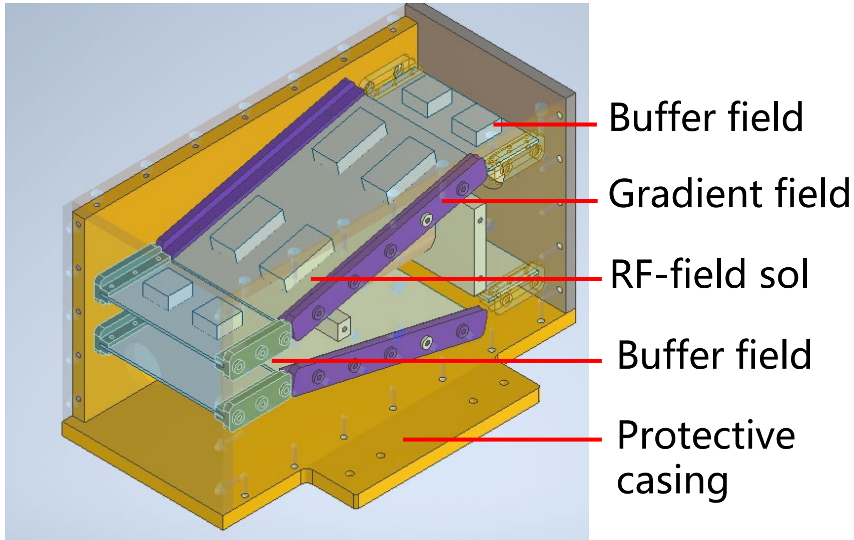
Amagat: gas density unit（2.686 $\times 10^{25}$m^{-3}）
κ_{eff}: frequency shift coefficient（6.2）
[He]: ^{3}He gas density

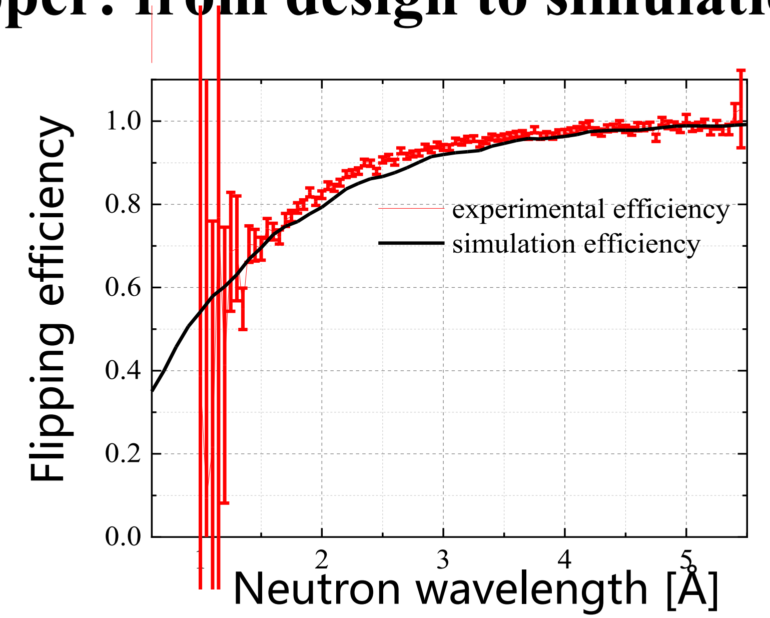


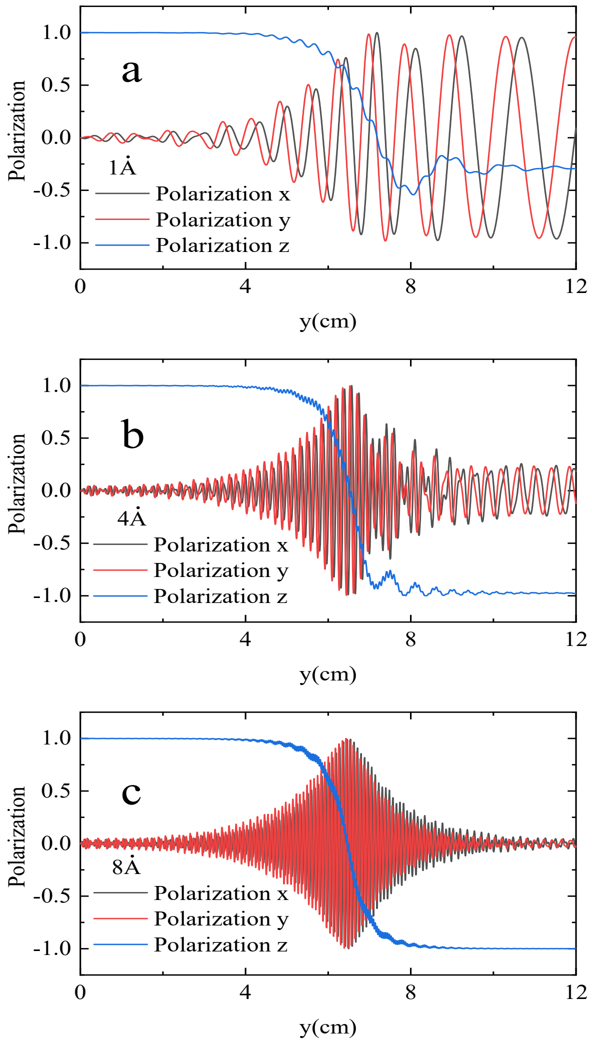
❖ Chuyi Huang *et al; Chinese Phys. Lett.* 38 092801 (2021)
❖ J.P. Zhang, et. al.; *Sci China Phys Mech*, 65 (2022).

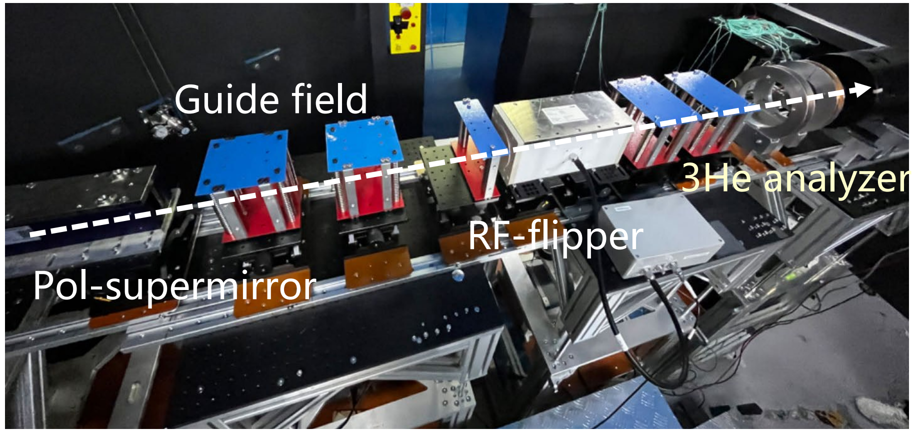
Current polarized instrument capability

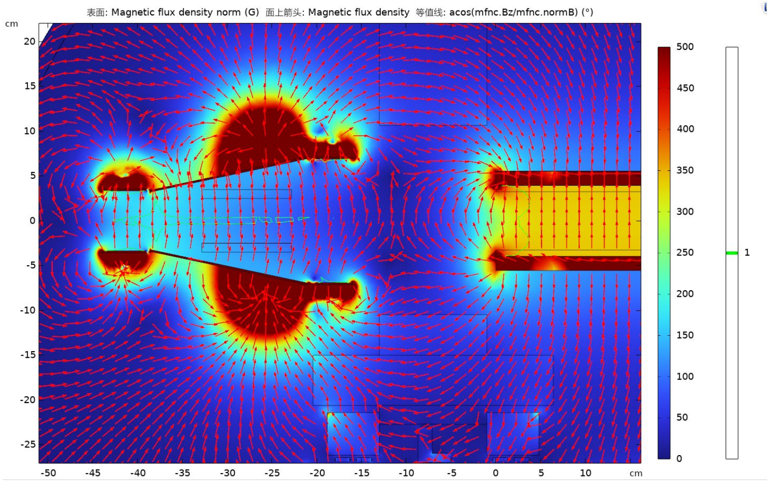
- **Building in-house build RF-flipper: from design to simulation**





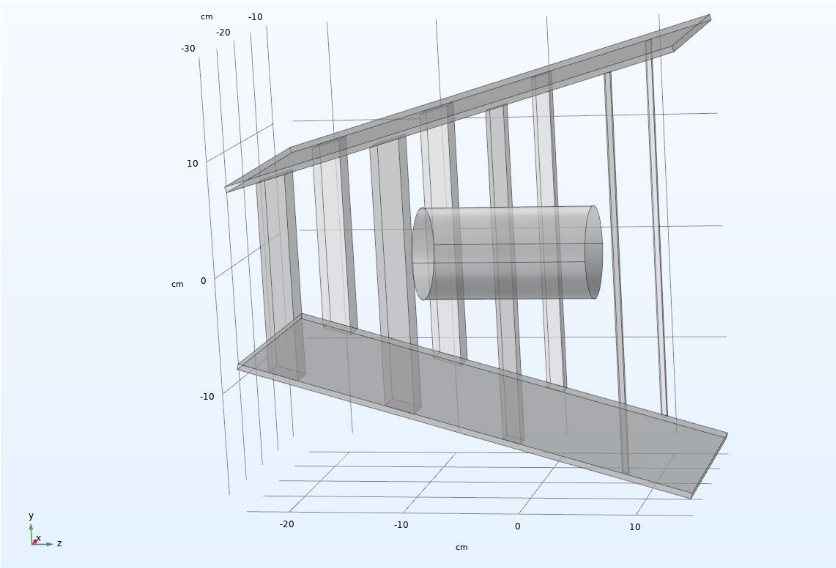


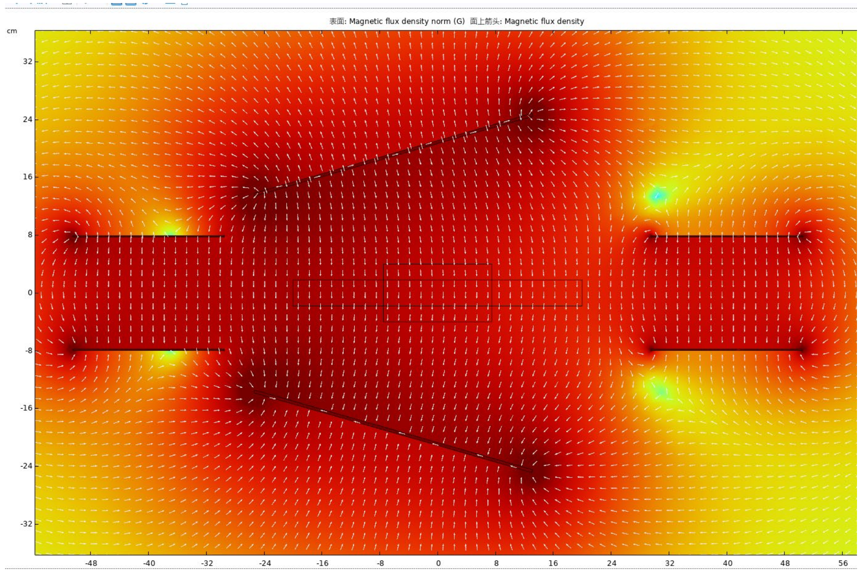


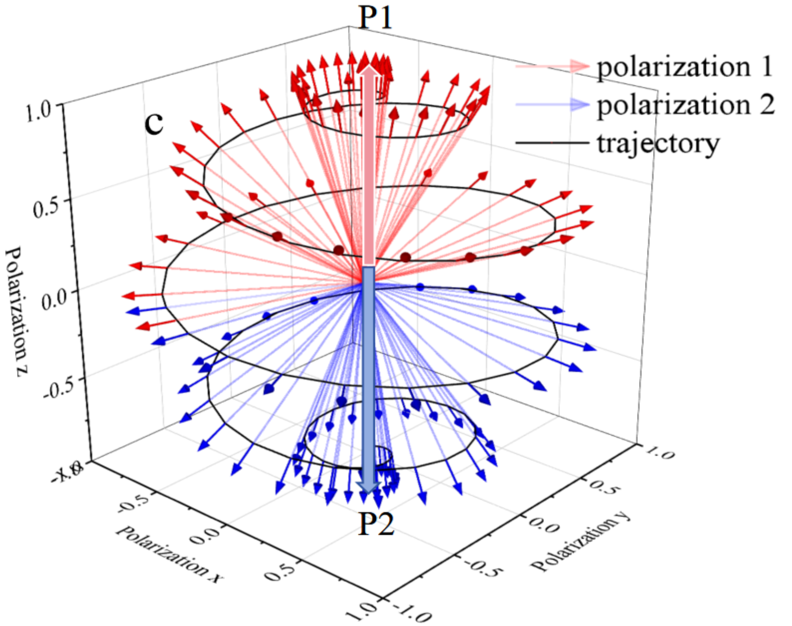


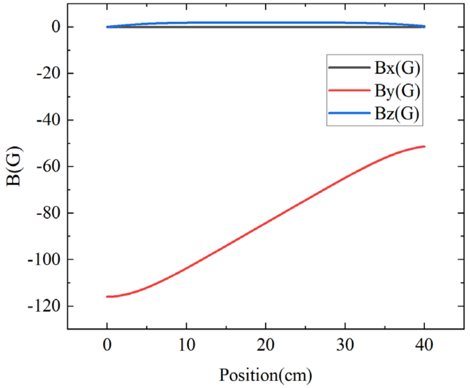
Current polarized instrument capability

- **Pushing the boundary for RF-flipper to eV neutron**

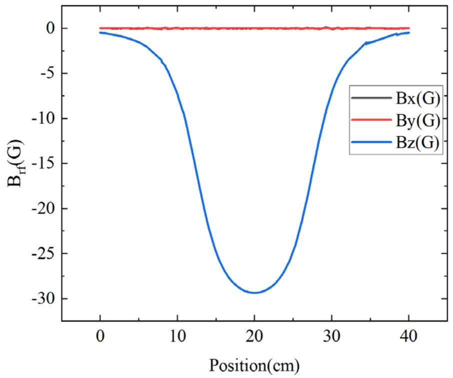




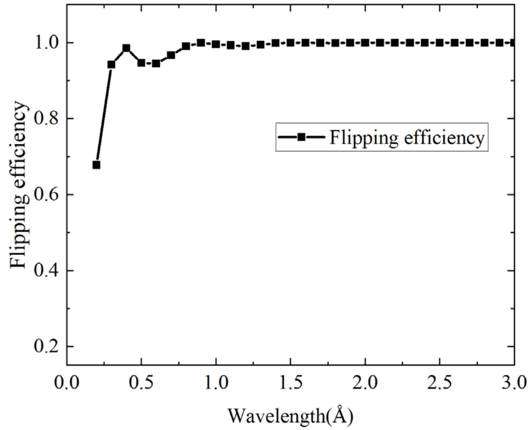




One-dimensional gradient magnetic field distribution



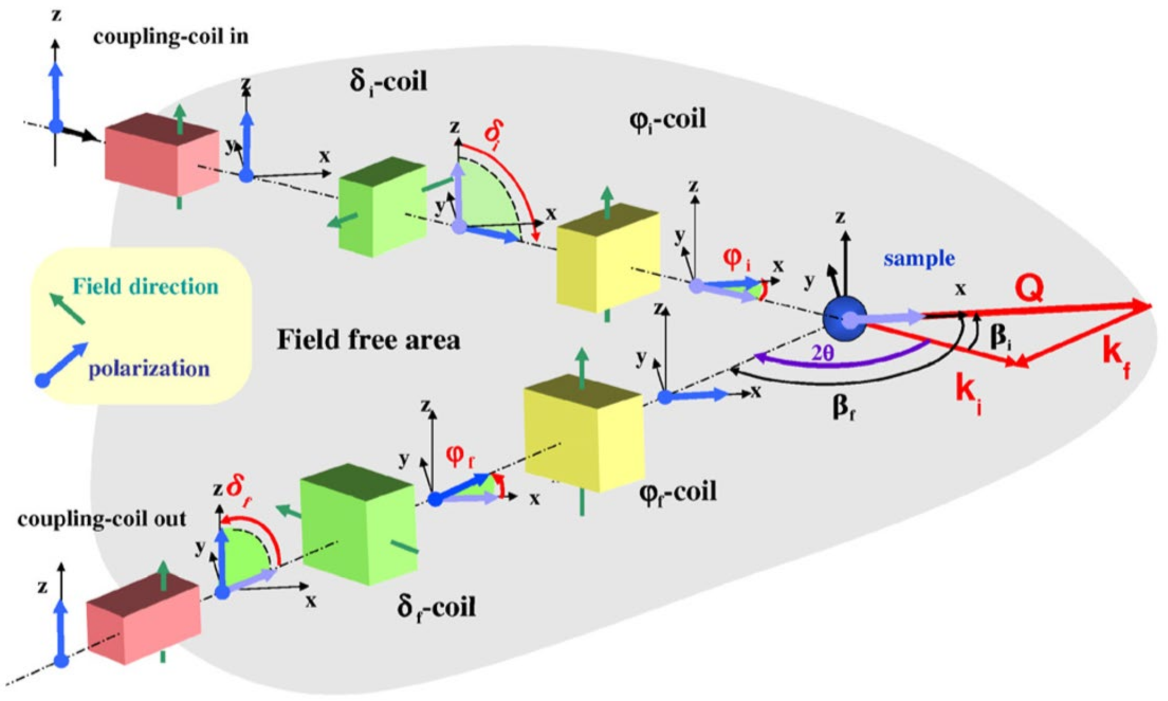
One-dimensional RF magnetic field distribution



Simulation results of flipping efficiency at different wavelengths

Current polarized instrument capability

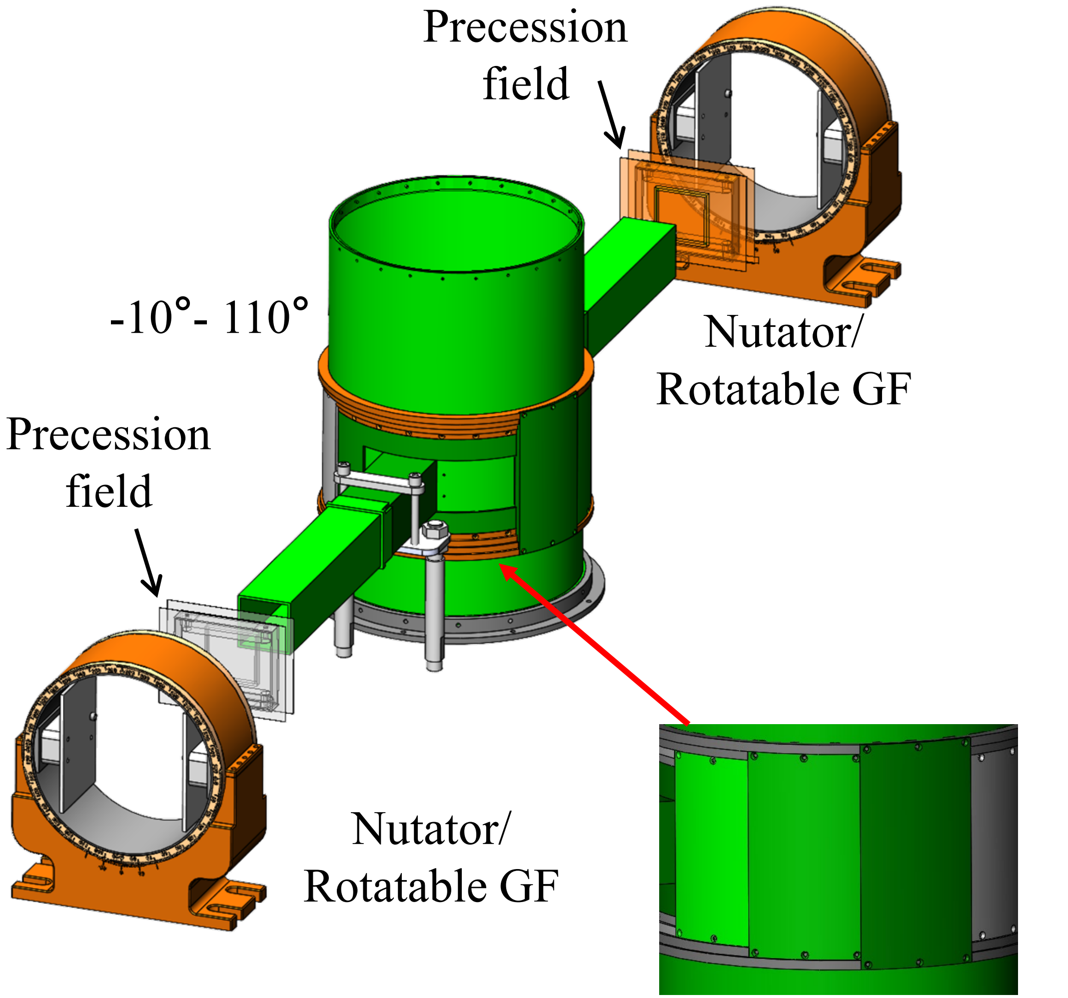
- **Developing Spherical Neutron Polarimetry for future adaptation**



$$\sigma = N^*N + \vec{M}_\perp^* \cdot \vec{M}_\perp + \vec{P}_i \cdot (N\vec{M}_\perp^* + N^*\vec{M}_\perp) + i\vec{P}_i(\vec{M}_\perp^* \times \vec{M}_\perp) \qquad \vec{P}_f\,\sigma = \overline{\overline{T}}_s \cdot \vec{P}_i + \vec{P}_g$$

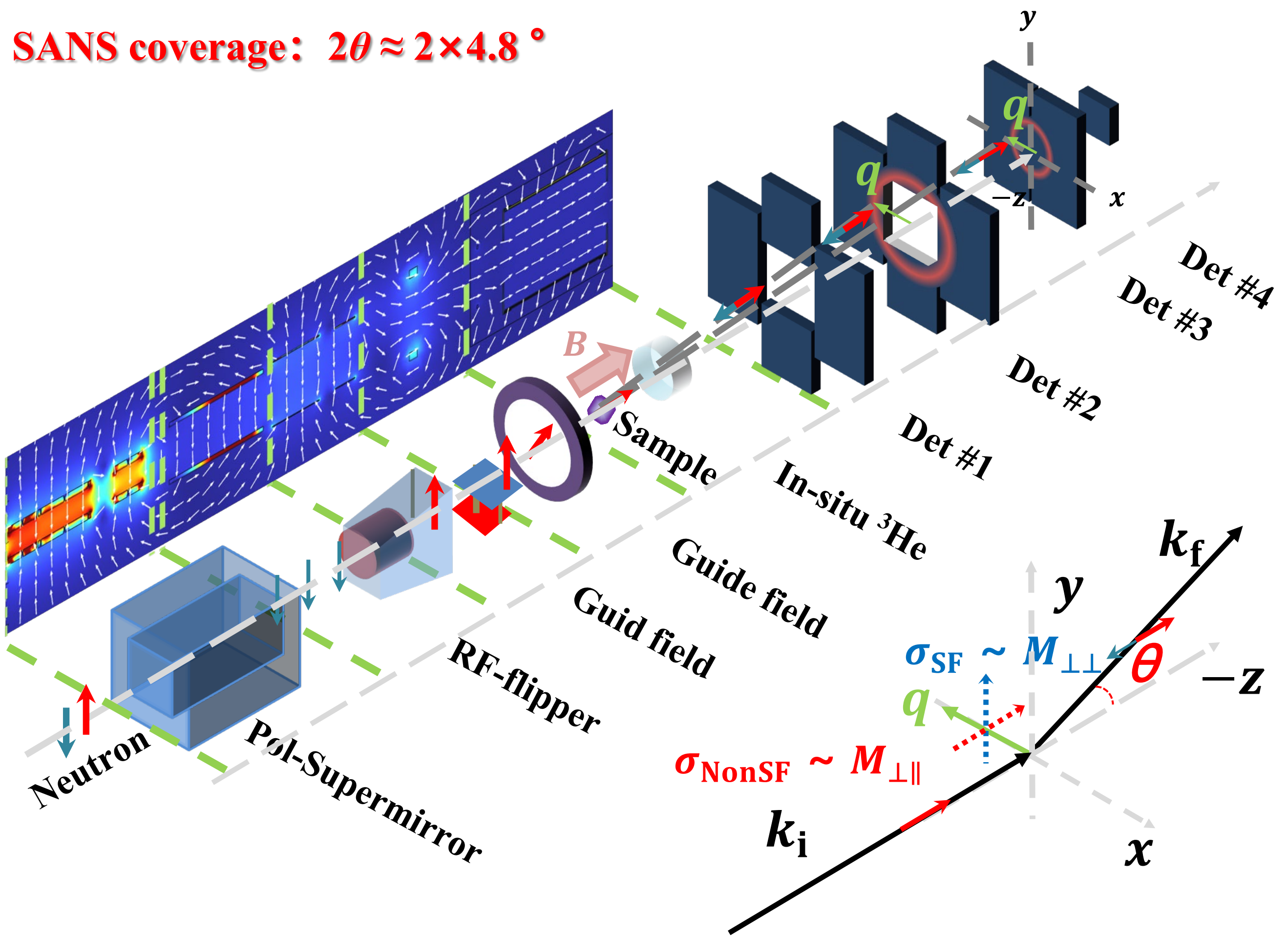
核散射　磁散射　核磁相干散射　手性磁散射

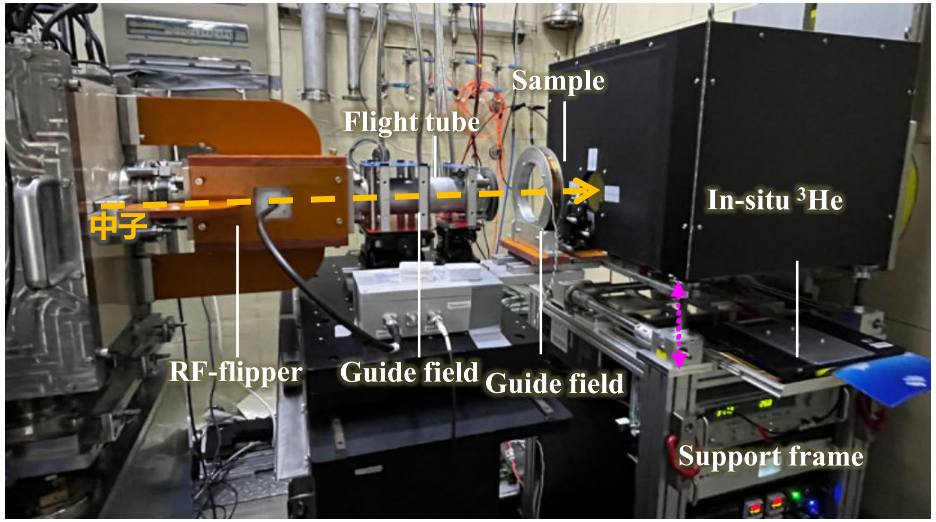
$$\overline{\overline{T}}_s = \begin{bmatrix} (N^*N - \vec{M}_\perp^* \cdot \vec{M}_\perp) & 2\,Im[NM_{\perp z}^*] & 2\,Im[NM_{\perp y}^*] \\ -2\,Im[NM_{\perp z}^*] & (N^*N - \vec{M}_\perp^* \cdot \vec{M}_\perp + 2\,Re[M_{\perp y}M_{\perp y}^*]) & 2\,Re[M_{\perp y}M_{\perp z}^*] \\ -2\,Im[NM_{\perp y}^*] & 2\,Re[M_{\perp z}M_{\perp y}^*] & (N^*N - \vec{M}_\perp^* \cdot \vec{M}_\perp + 2\,Re[M_{\perp z}M_{\perp z}^*]) \end{bmatrix} \qquad \vec{P}_g = \begin{bmatrix} -2\,Im[M_{\perp y}M_{\perp z}^*] \\ 2Re[NM_{\perp y}^*] \\ 2Re[NM_{\perp z}^*] \end{bmatrix}$$



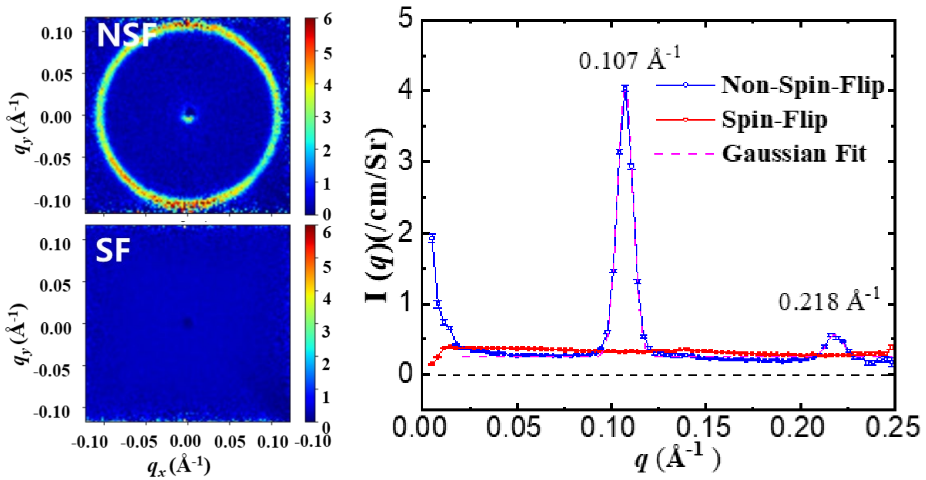
Polarized Neutron Applications

- **Polarized Small Angle Neutron Scattering on VSANS beamline**



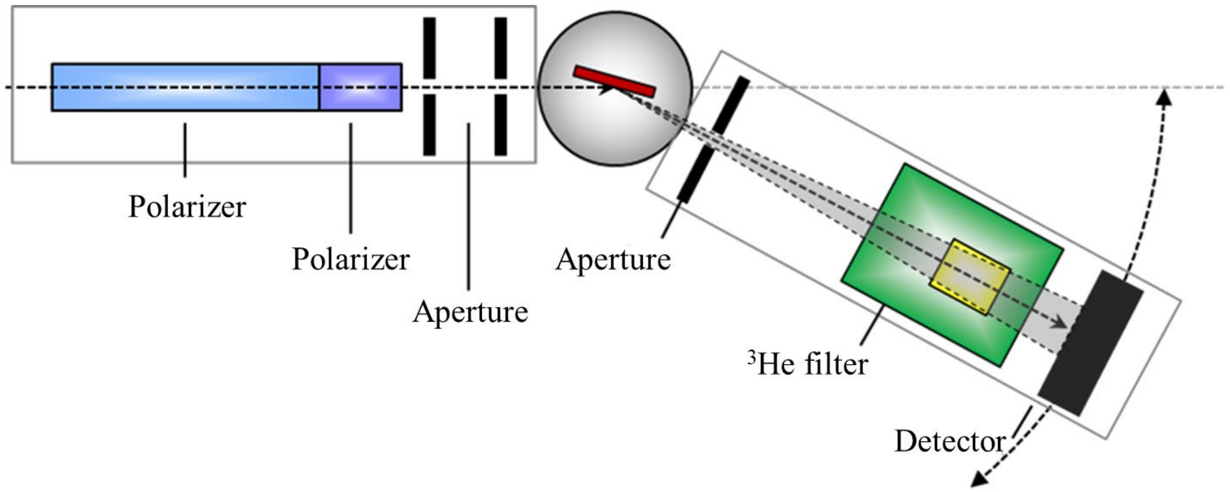


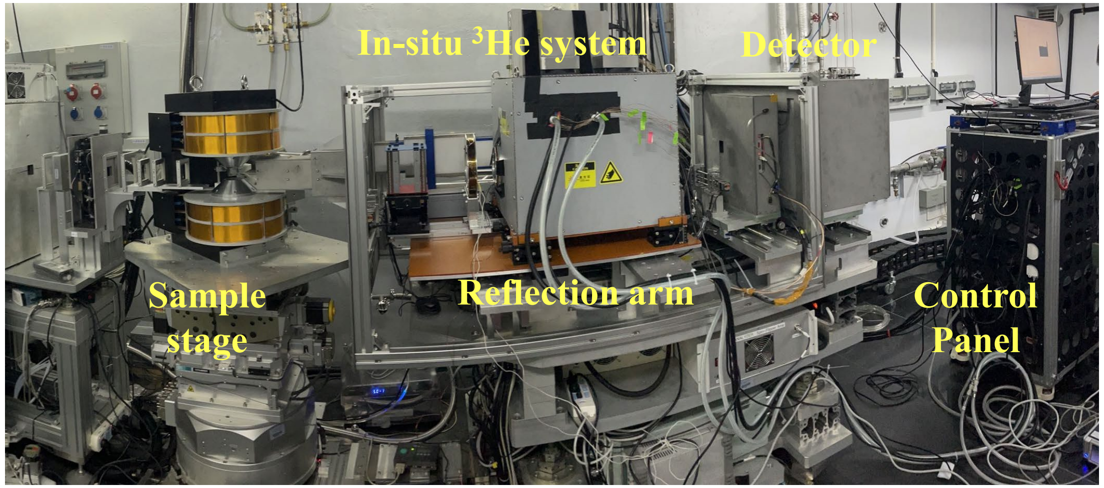
Separate coh/in-coh scattering

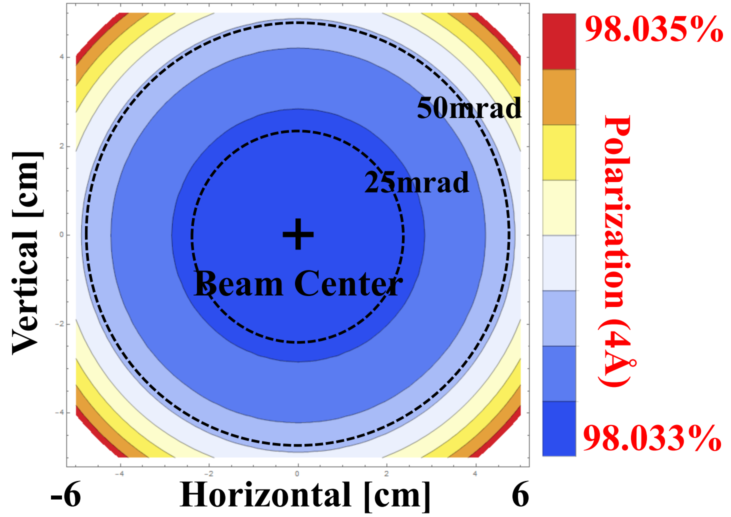


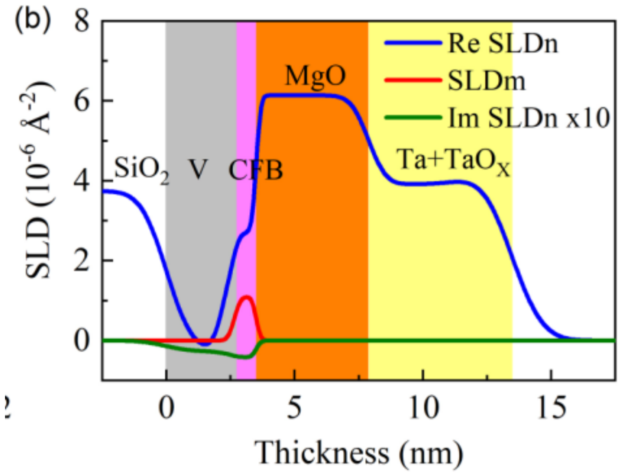
Polarized Neutron Applications

- **Polarized 3He as spin analyzer on reflectometer enables off-specular measurement**



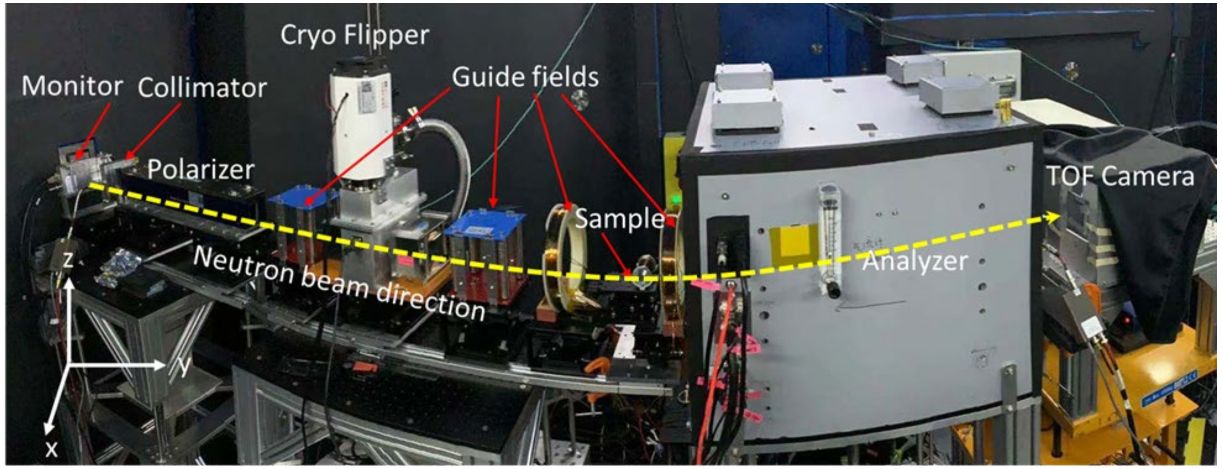


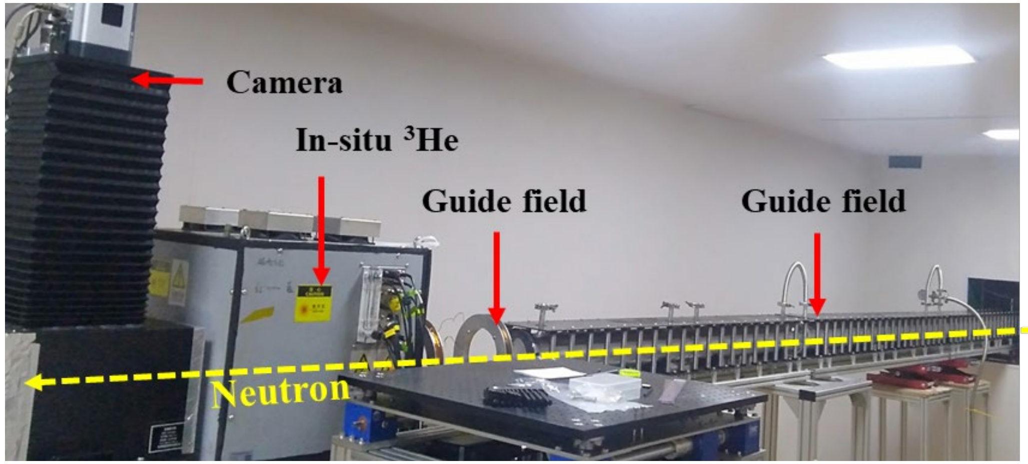


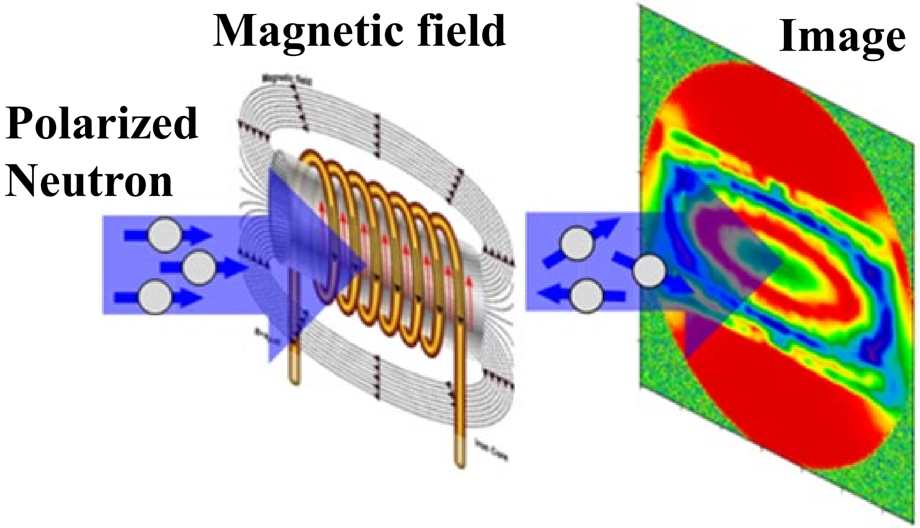


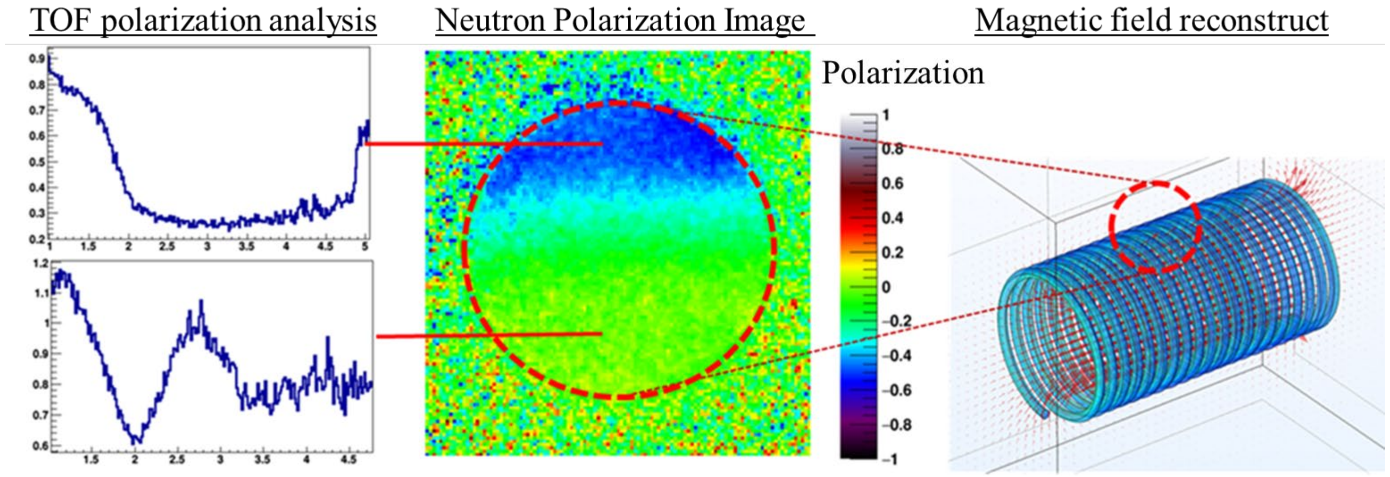
Polarized Neutron Applications

- **Time-of-flight polarized neutron analysis - imaging**





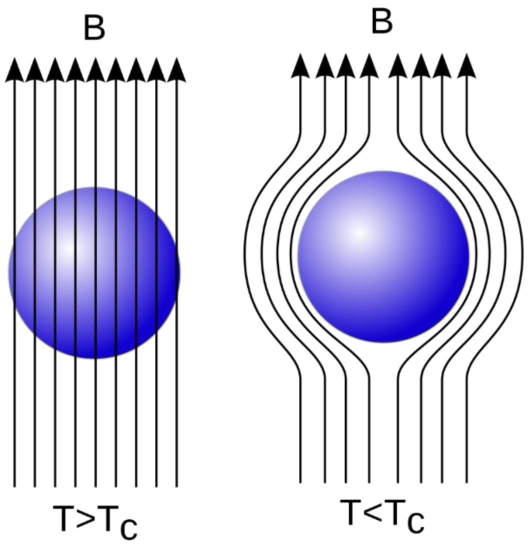


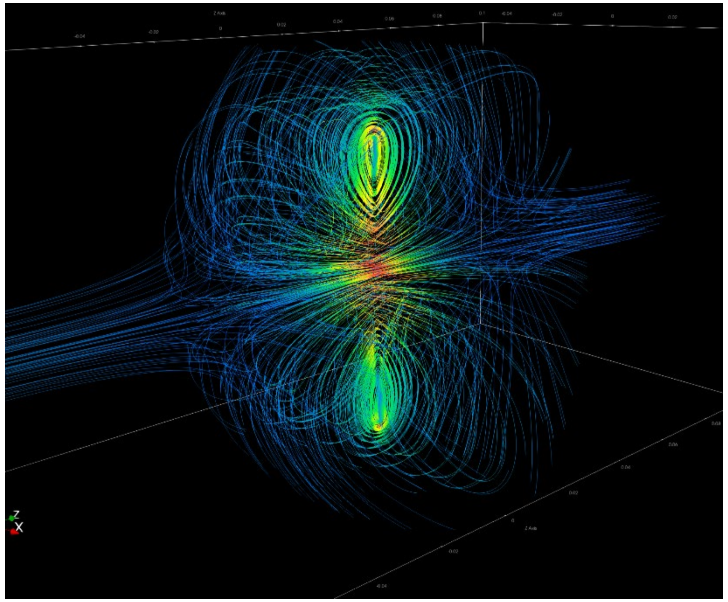


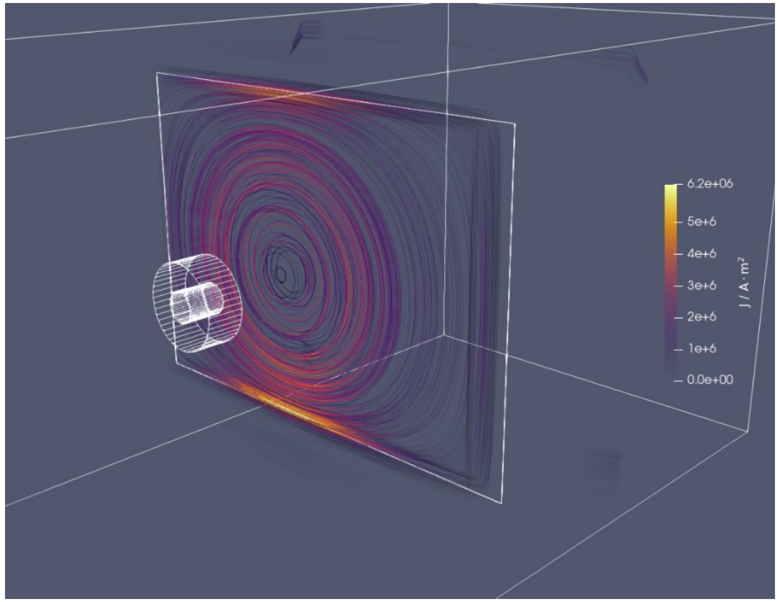
Chin. Phys. Lett. 2022, Vol. 39 (6): 062901; DOI:10.1088/0256-307X/39/6/062901

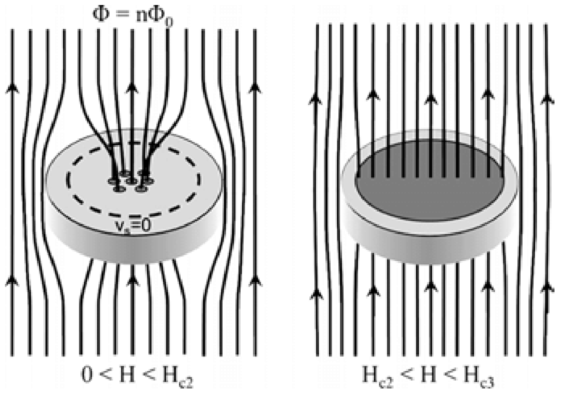
Polarized Neutron Applications

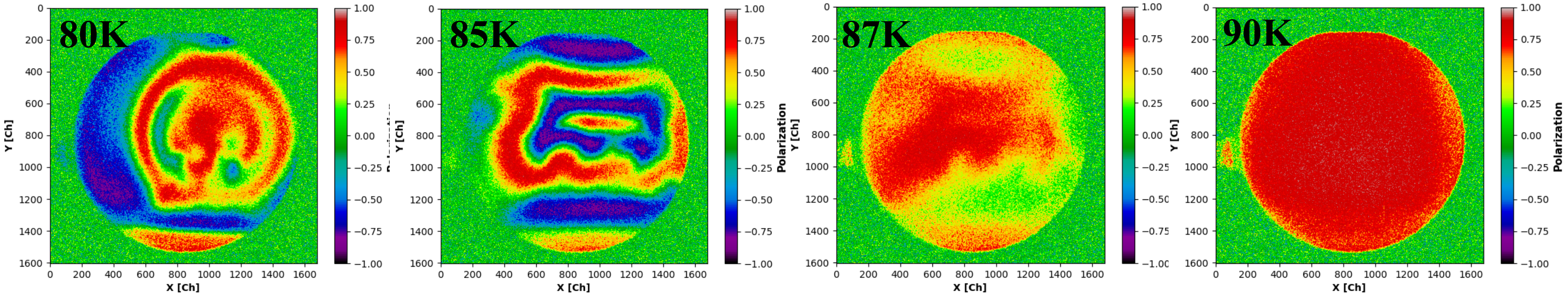
- **Visualizing magnetic field distortion from superconductor Meissner effect**











Polarized neutron for nuclear research

- **Polarized neutron can be applied to parity no conservation measurement**

PARITY NONCONSERVATION IN NEUTRON RESONANCES

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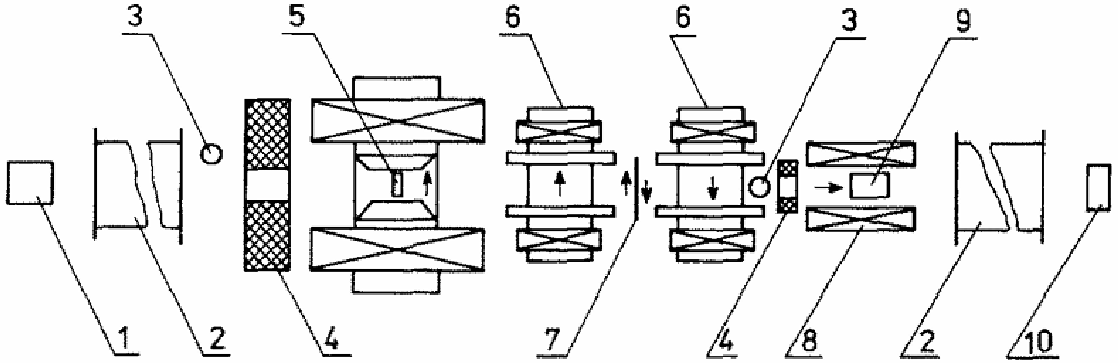


Fig. 1. Experimental arrangement: 1 – reactor, 2 – evacuated neutron guide tube, 3 – monitors, 4 – collimators, 5 – polarized proton target, 6 – electromagnets of the guide field, 7 – current sheet, 8 – solenoid, 9 – sample, 10 – neutron detector. Arrows along the neutron beam path show the direction of magnetic field.

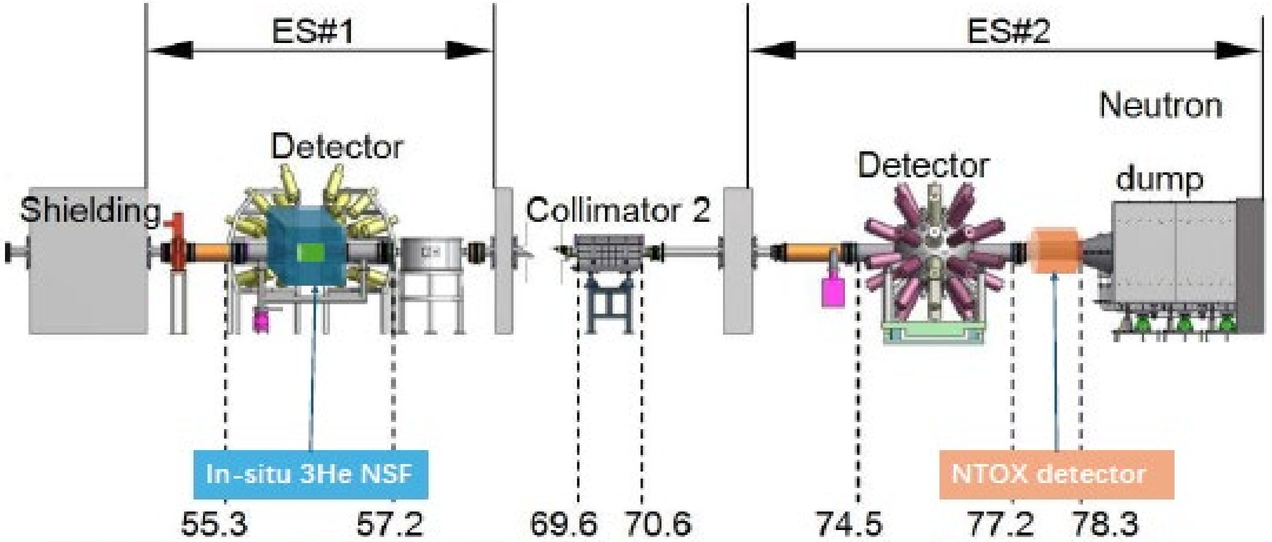
NUCLEAR REACTIONS ^{81}Br, ^{111}Cd, ^{117}Sn, ^{139}La(polarized n, X), $E = 0.5$–5 eV, measured transmission. ^{82}Br, ^{112}Cd, ^{118}Sn, ^{140}La resonances deduced σ(total) neutron helicity dependence, p-wave parity nonconservation effect.

In 1964 an experiment was proposed [1]) to observe rotation of the neutron spin due to parity nonconserving (*P*-odd) effects for a beam of transverse polarized neutrons passing through an unpolarized target. Further papers [2–6]) considered, in addition to the spin rotation, the difference between the total cross sections for the two helicity states of longitudinally polarized neutrons. All the above-mentioned papers discussed the *P*-odd effects connected with single-particle processes, i.e. the nuclei were considered to have no internal degrees of freedom. The estimates of the effects were on the verge of experimental possibilities of their observation.

Transmission measurements were performed by the time-of-flight method on the beam of polarized neutrons from the IBR-30 reactor of the Laboratory of Neutron Physics of the Joint Institute for Nuclear Research. The flight path was 58 m long. Measurements in the energy range up to 1.5 eV were carried out with a neutron pulse duration of 70 μs and a reactor mean power of 20 kW. In order to improve resolution at higher neutron energies we used the booster mode of the IBR-30 reactor with the electron accelerator. In this case the pulse duration was 4 μs and the mean power about 5 kW.

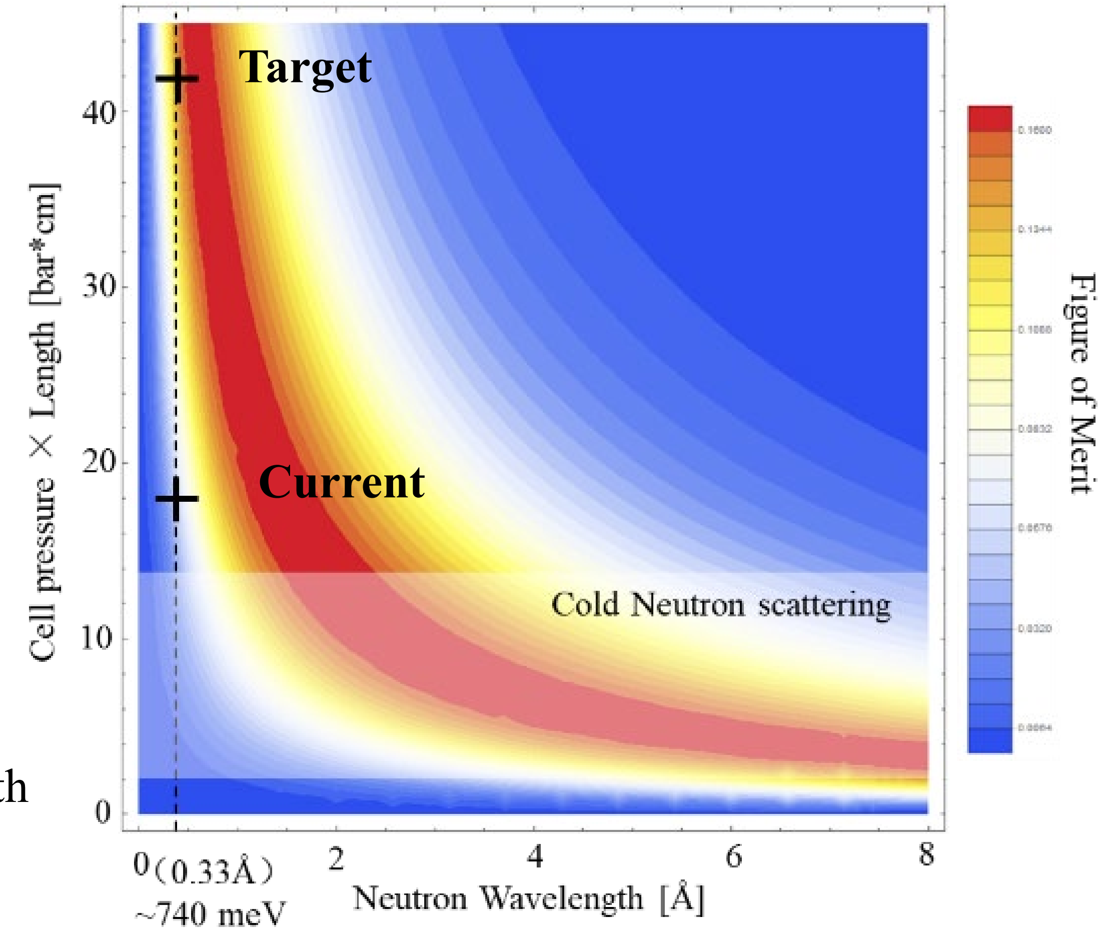
Polarized neutron for nuclear research

- **Setting up SEOP Polarized ^{3}He for epithermal neutron (La139 - 740meV) spin filtering**



- ❑ High pressure and effective length
- ❑ Stable polarization
- ❑ Fast flipping

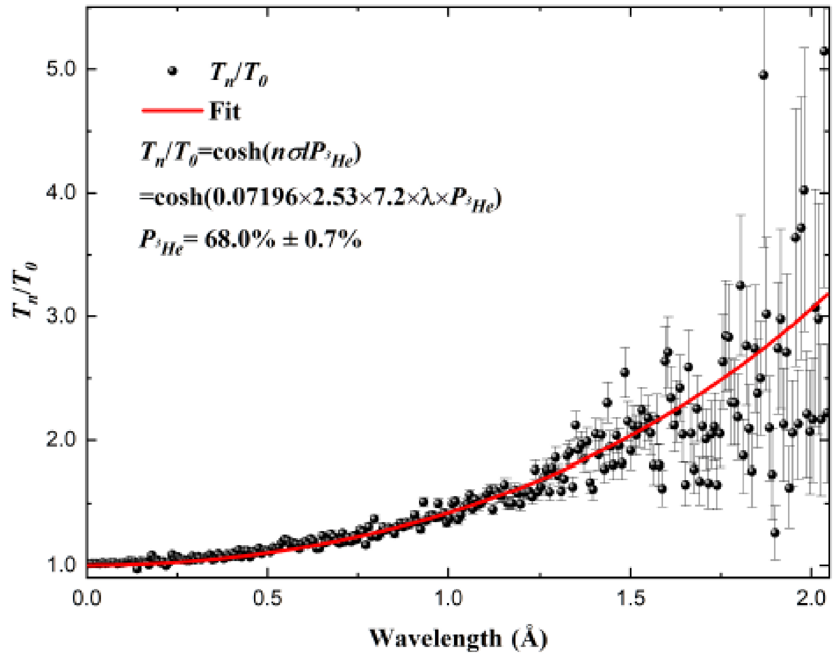
Required ^{3}He spin filter parameter

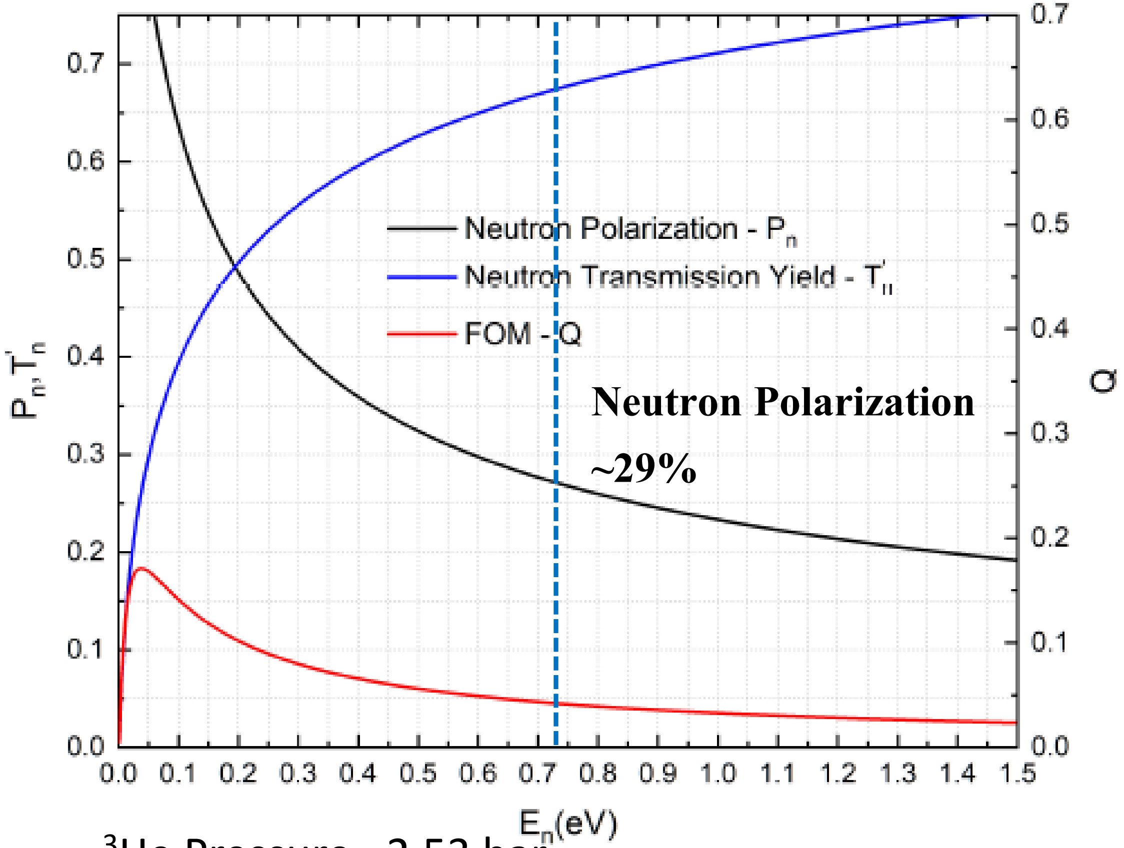


Polarized neutron for nuclear research

- **Polarizing high-energy neutron remains challenging**
  - **High background and require frequent flipping**

$$T_0 = T_e\ exp(-O) = T_e\ exp(-n_{\mathrm{He}}\ \sigma_0\ l)$$
$$= T_e\ exp(-0.0732\ p\ l\ \lambda)$$

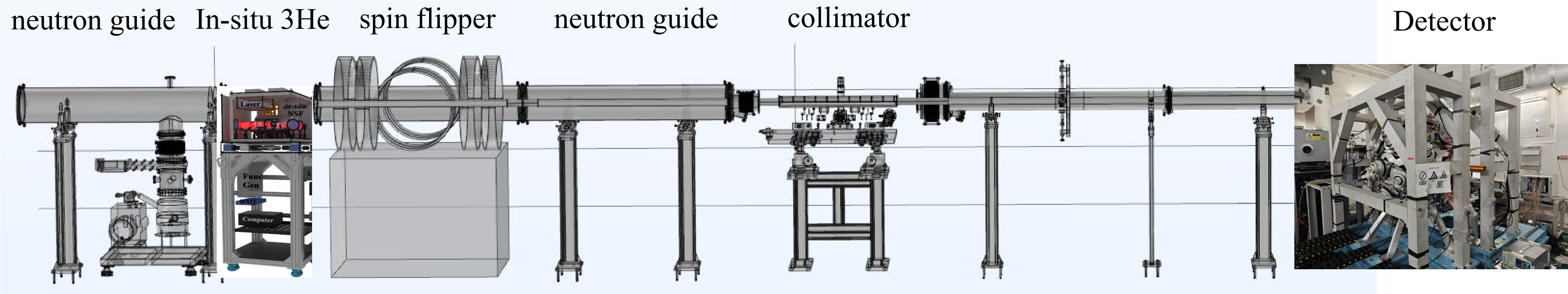




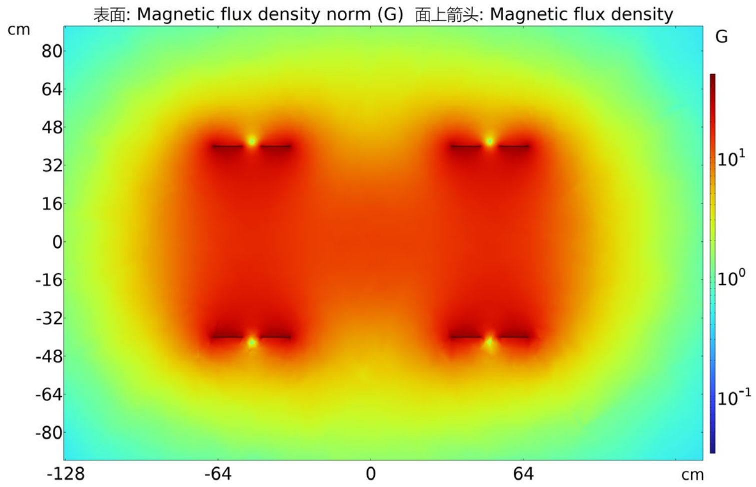
^{3}He Pressure= 2.53 bar,
l = 7.2 cm, σ_{PHe} = ±2% and P_{He} = 68%,

Polarized neutron for nuclear research

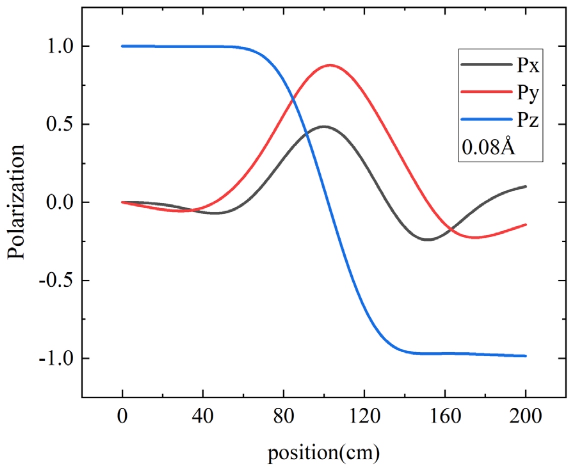
- **Moving forward: better spin filter and flipper setup**



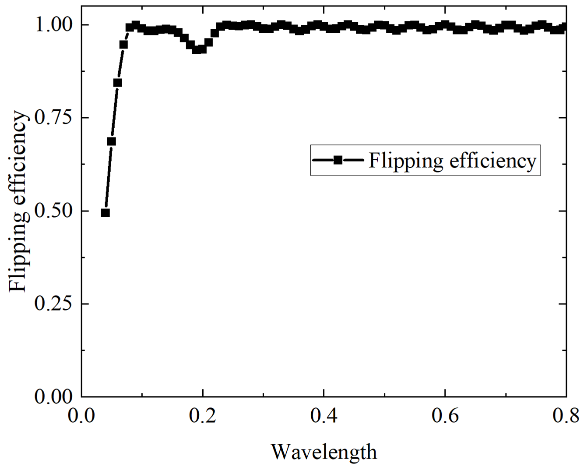
FEM magnetic field mapping



Polarization tracing – 0.08Å

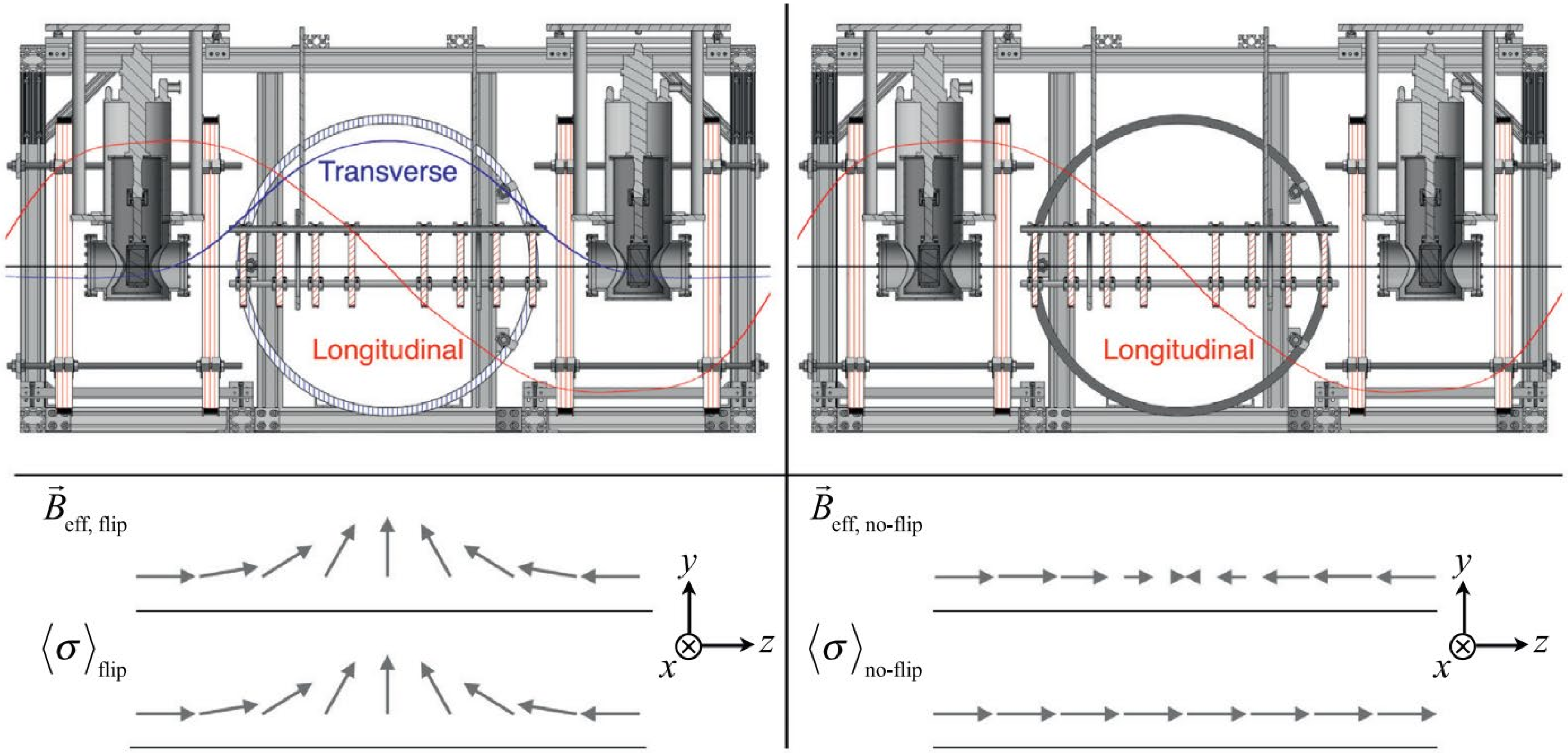


Polarization flipping efficiency



Polarized neutron for nuclear research

- **Moving forward: better spin filter and flipper setup**



Summary

- Support all CSNS beamline polarized neutron demand through in-house instrument capability.
- Conducting novel polarized neutron technique (spin manipulation and PNI) in parallel to CSNS construction project
- Developing polarized neutron for nuclear research becomes one of the major applications focus.

Looking forward to application and collaboration

Thank you for your attention!