中国散裂中子源

Development of Spherical Neutron Polarimetry devices at CSNS

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Report Outline

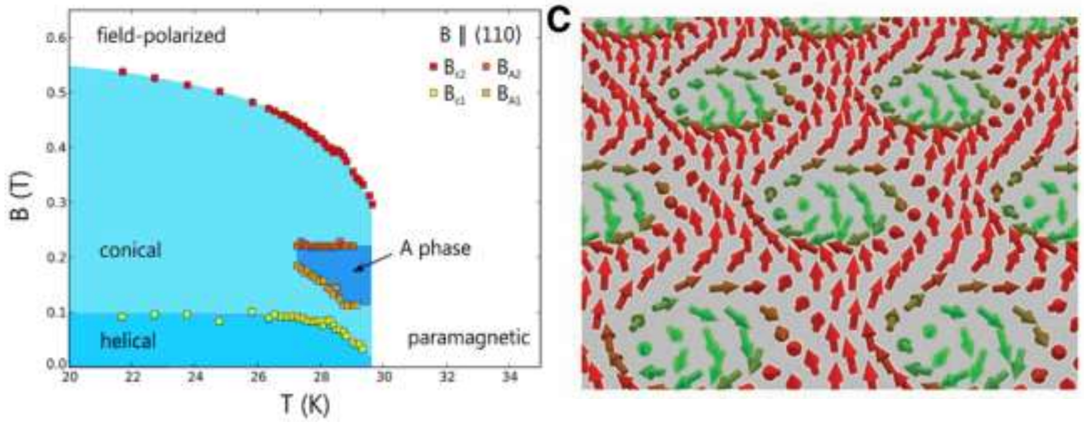
- Motivation
- Neutron polarization analysis
- Spherical neutron polarimetry (SNP) devices development
- Summary & Outlook

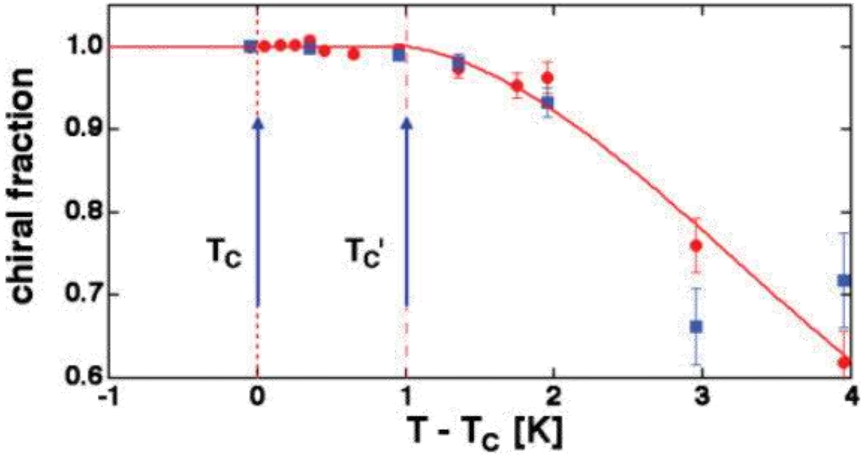
Motivation

Motivation

- Measuring complex magnetic structure

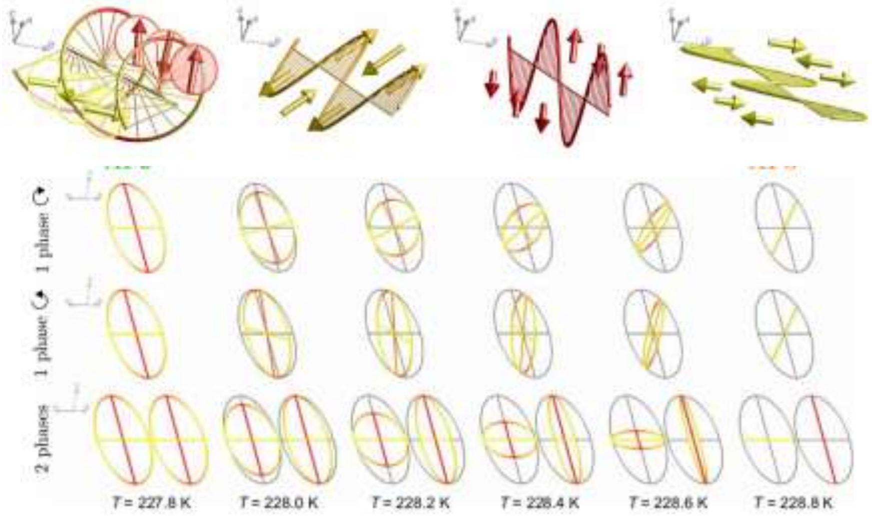
Chiral skyrmion spin liquid phase in MnSi

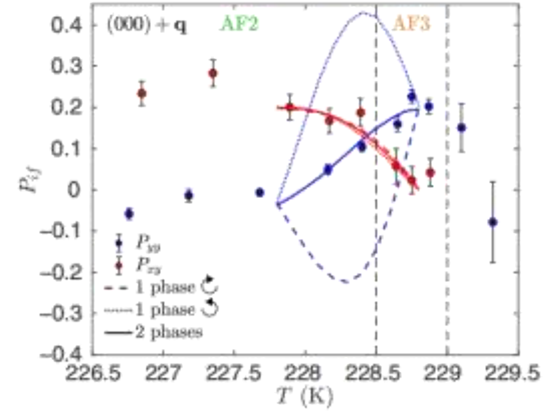




Mühlbauer, S. *et al*. *Science* **323**, 915–919 (2009).
C. PAPPAS *et al.* PHYSICAL REVIEW B **83**, 224405 (2011)

The high-temperature incommensurate phase in CuO





Qureshi, N. *et al.*. *Sci. Adv.* **6**, eaay7661 (2020).

Motivation

- Blume-Maleyev Equation

$$I = N N^* + M_\perp \cdot M_\perp^* + P \cdot M_\perp N^* + P \cdot M_\perp^* N - iP \cdot (M_\perp \times M_\perp^*)$$

$$\boldsymbol{P}^f = \begin{pmatrix} \frac{N^2 - M^2}{I_x} & \frac{J_{nz}}{I_x} & \frac{J_{ny}}{I_x} \\ -\frac{J_{nz}}{I_y} & \frac{N^2 - M^2 + R_{yy}}{I_y} & \frac{R_{yz}}{I_z} \\ -\frac{J_{ny}}{I_z} & \frac{R_{zy}}{I_z} & \frac{N^2 - M^2 + R_{zz}}{I_z} \end{pmatrix} \boldsymbol{P}^i + \begin{pmatrix} -\frac{J_{yz}}{I} \\ \frac{R_{ny}}{I} \\ \frac{R_{nz}}{I} \end{pmatrix}$$

$$= \tilde{P}\boldsymbol{P}^i + \boldsymbol{P}''$$

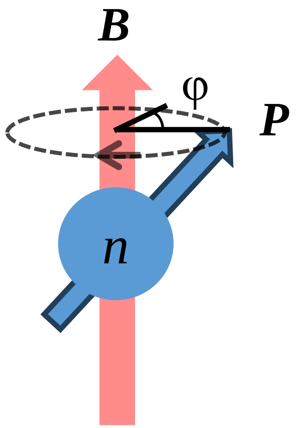
Nuclear-magnetic interference
Chiral magnetic scattering
→ **Polarization rotation**

Brown, P. J. CHAPTER 5 - Spherical Neutron Polarimetry. in *Neutron Scattering from Magnetic Materials* (ed. Chatterji, T.) 215–244 (Elsevier Science, 2006).

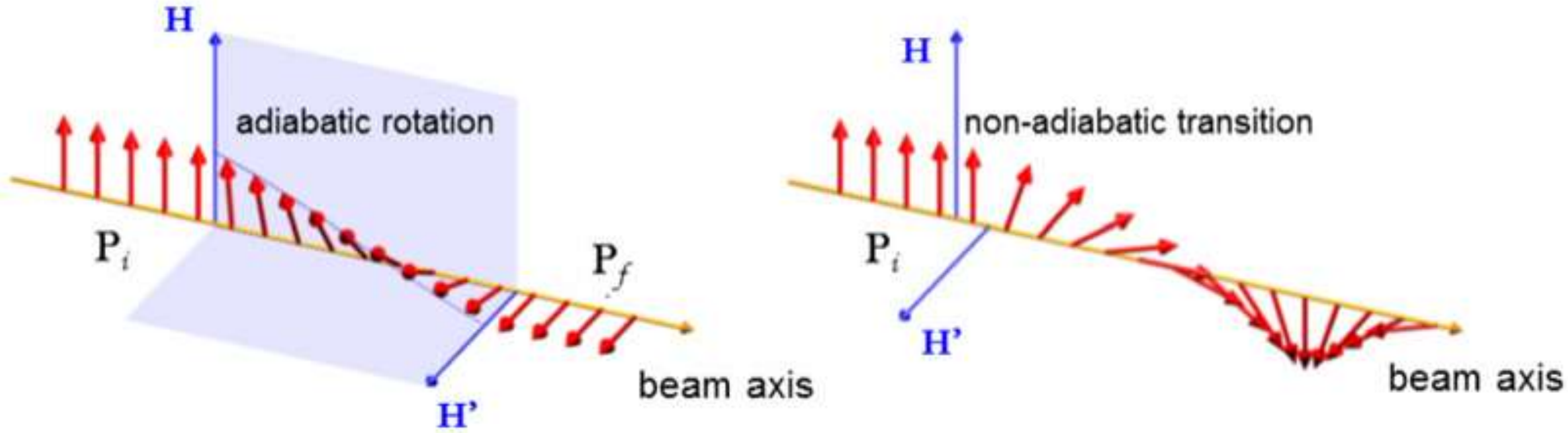
Neutron polarization analysis

Neutron Polarization Analysis

Larmor precession



Polarization transition



For non-adiabatic transition

$$\varphi = \frac{\gamma_n \cdot \mathrm{m}}{h} \cdot \lambda \cdot \int B\,(l)\mathrm{d}l$$

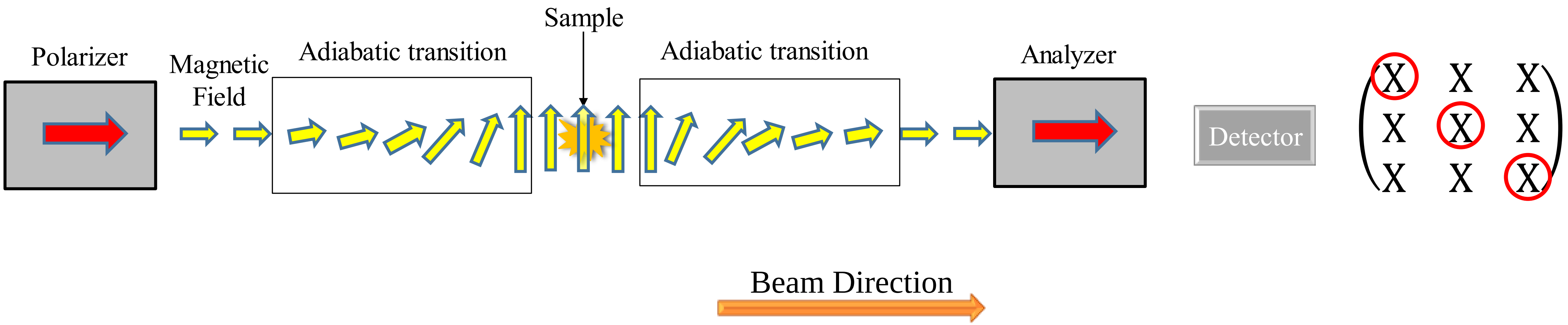
Stray field influence:

4Å neutron under earth field (B=0.5 G) will do 120° precession within 25 cm

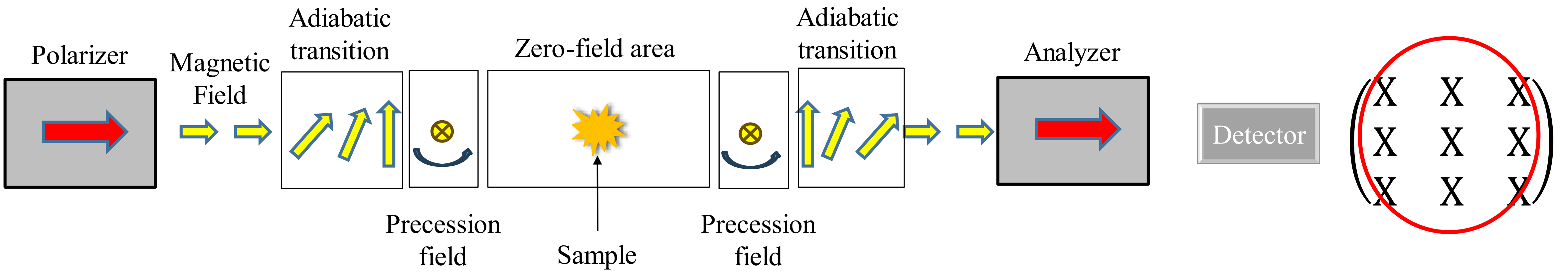
Qureshi, N. *EPJ Web Conf.* **155**, 00002 (2017).

Neutron Polarization Analysis

- **Longitudinal polarization analysis**



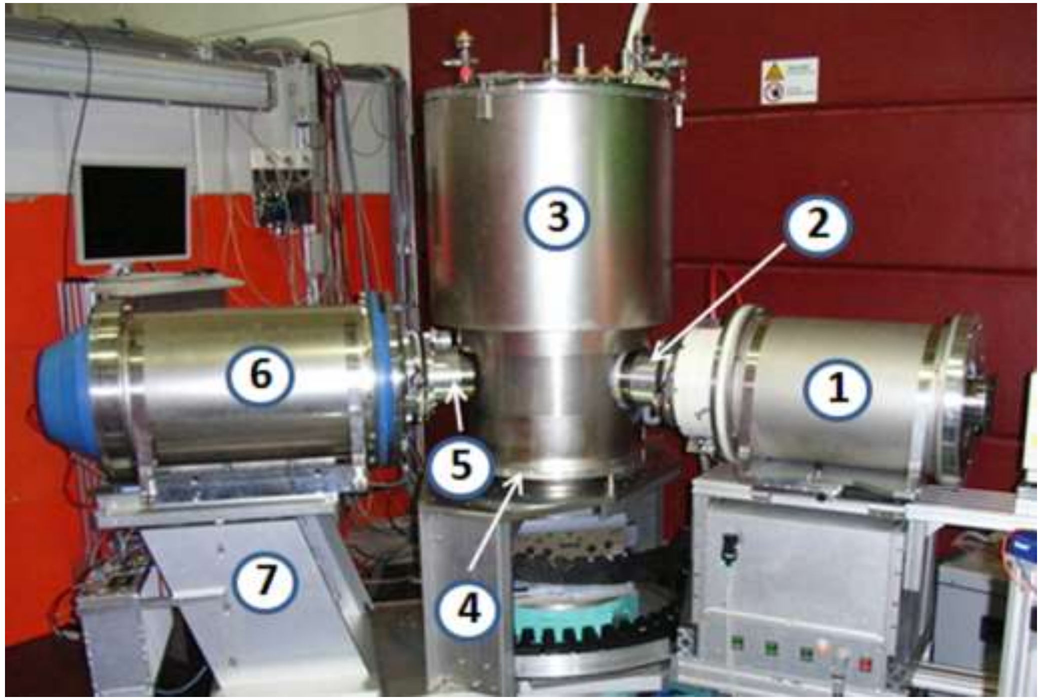
- **Spherical neutron polarimetry**



SNP devices development

SNP devices design

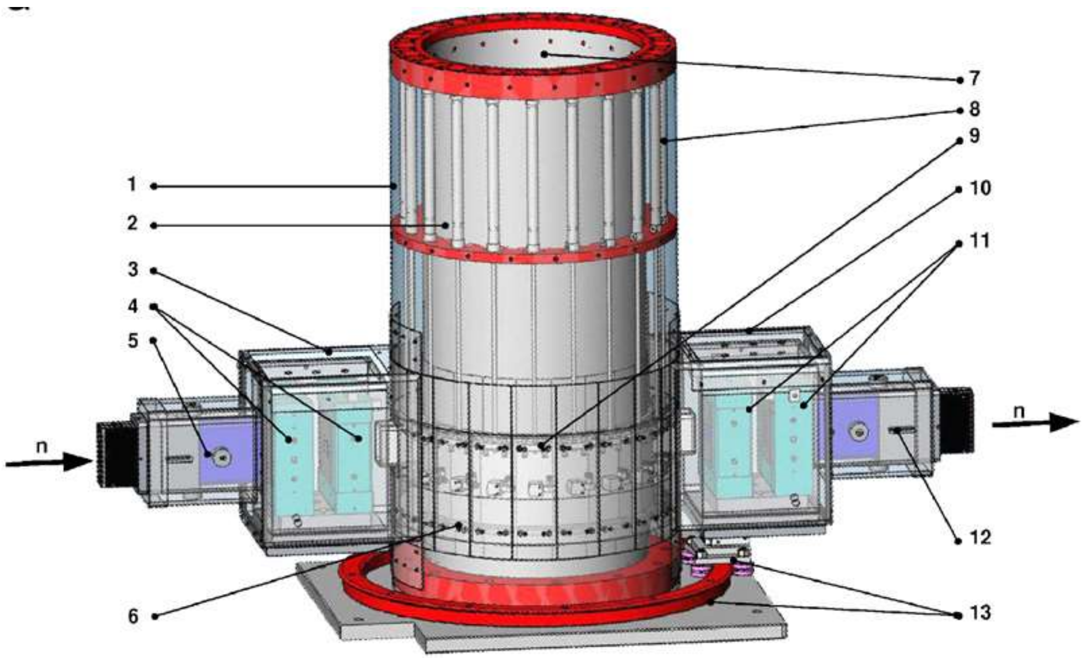
CRYOPAD -ILL



- Niobium Meissner shielding

Tasset, F. *et al. Physica B: Condensed Matter* **267–268**, 69–74 (1999).

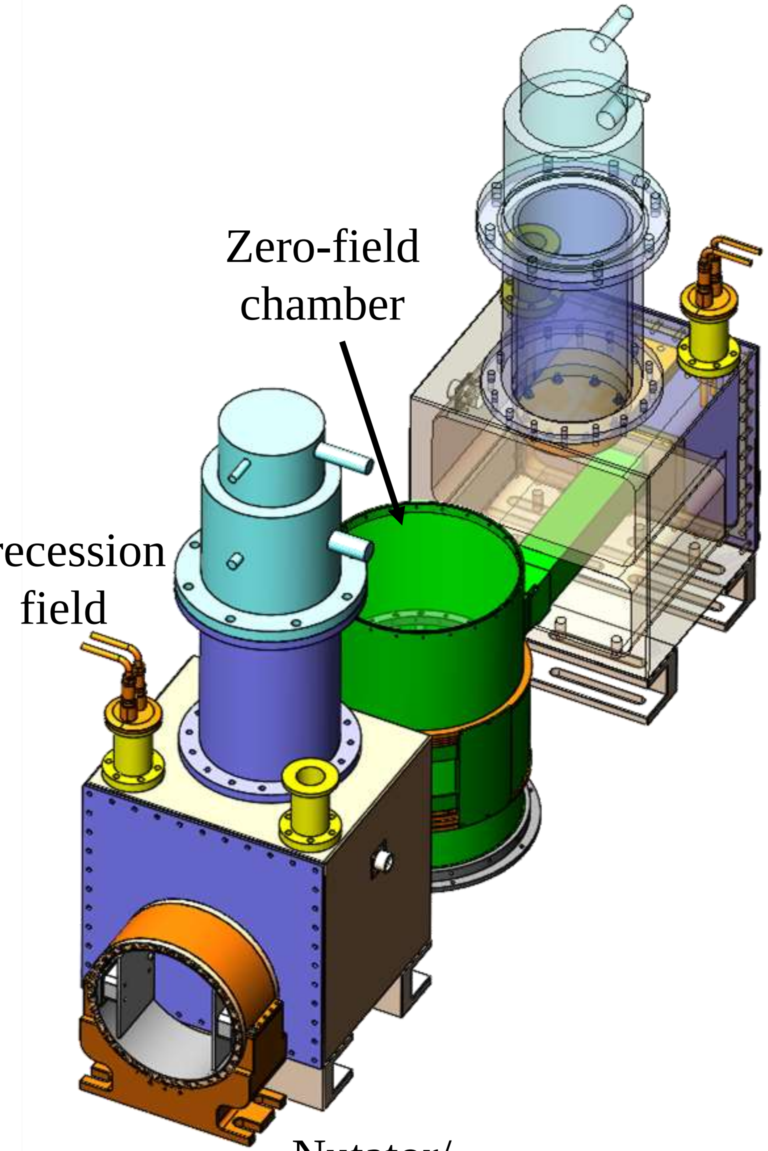
MuPAD -PSI

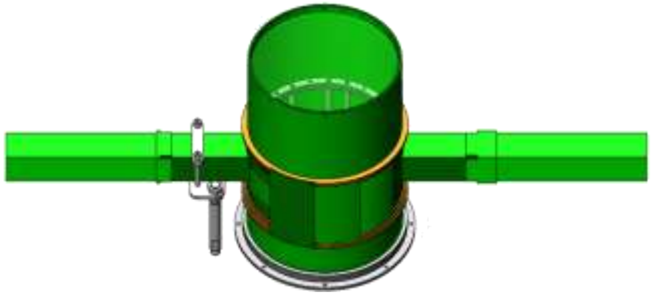


- High permeability Mumetal shielding

Janoschek, M. *et al. Physica B: Condensed Matter* **397**, 125–130 (2007).

SNP devices design





Zero-field chamber
– maintaining incident & scattered neutron polarization

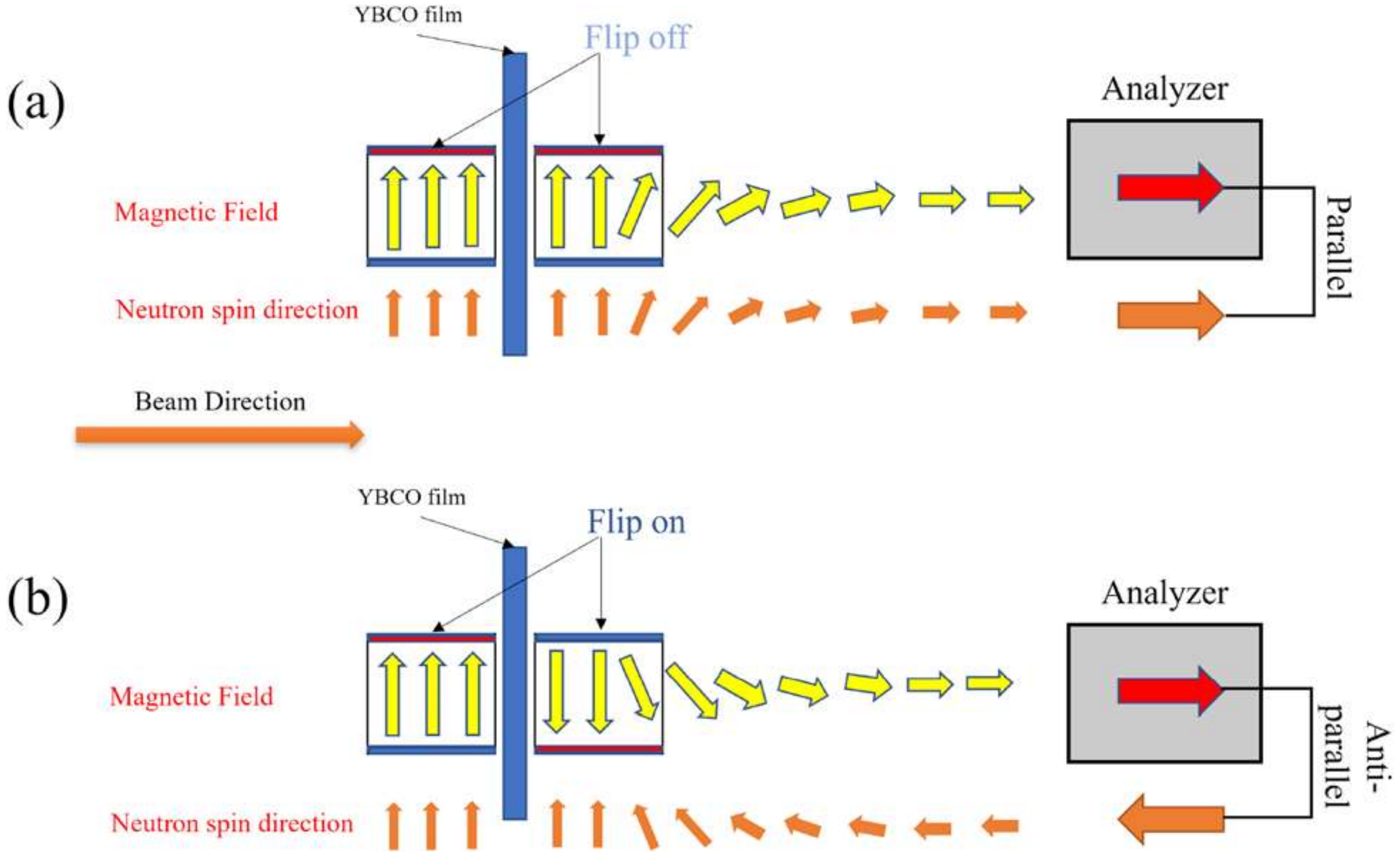
Precession field
– controlled precession

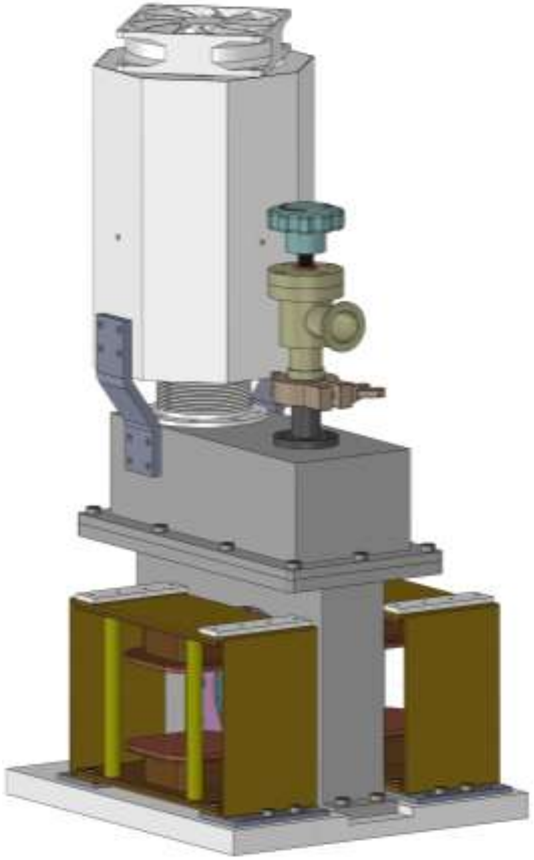
Nutator
– adiabatic transition to the outer guide field

- Permalloy-based zero-field chamber
- Precession field generated by high-T_C superconducting wire
- YBCO films shielding for ZFC & Precession field
- Without liquid helium cooling

Pre-validation work – Superconducting spin flipper

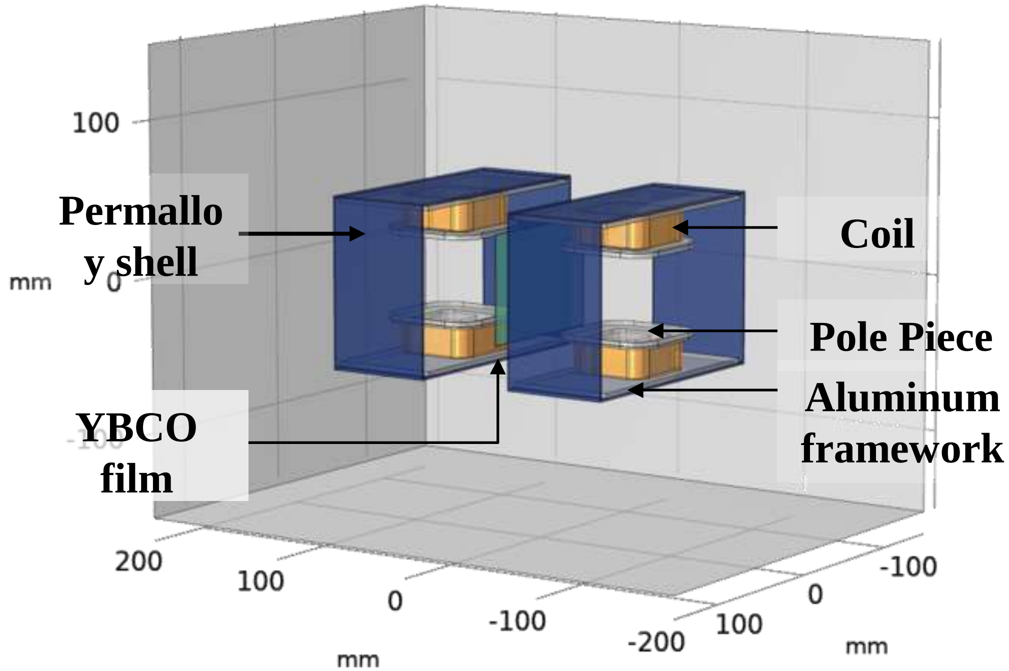
Theory and structure design



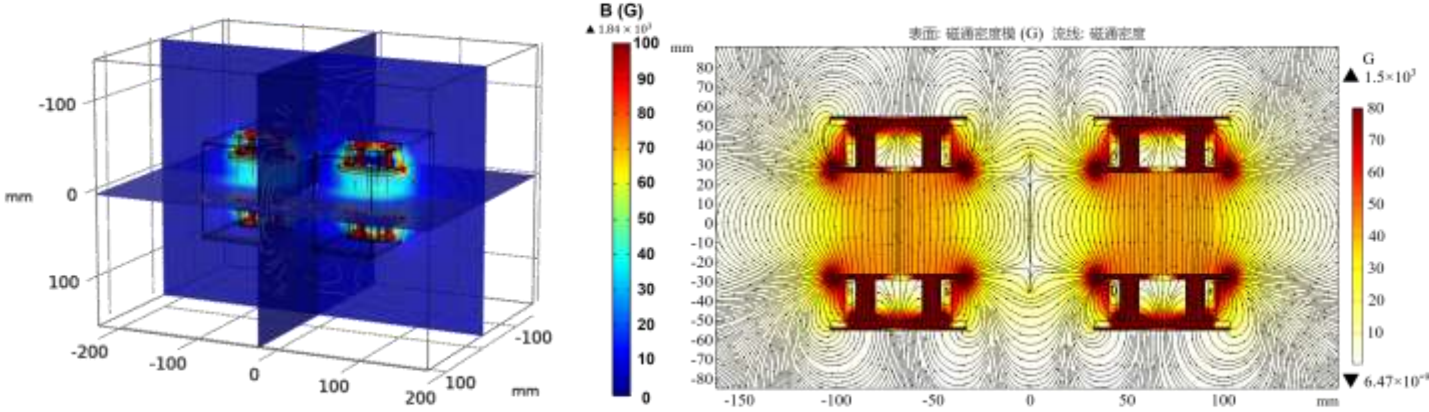


Pre-validation work – Superconducting spin flipper

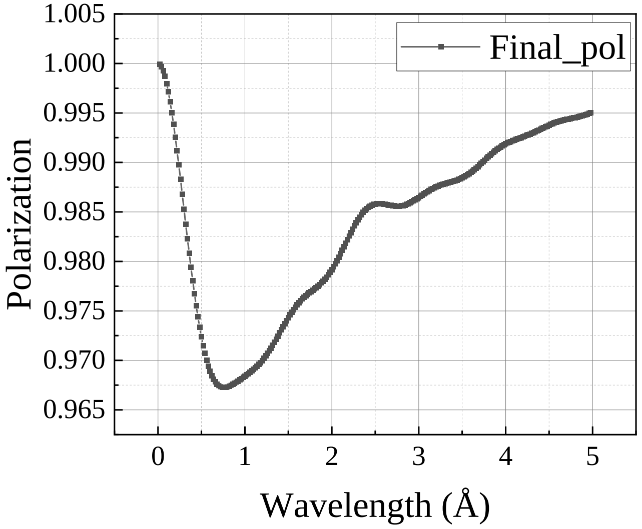
Magnetic field simulation & Bloch equation simulation



Finite element method (FEM) simulation model



Magnetic field simulation result - COMSOL Multiphysics



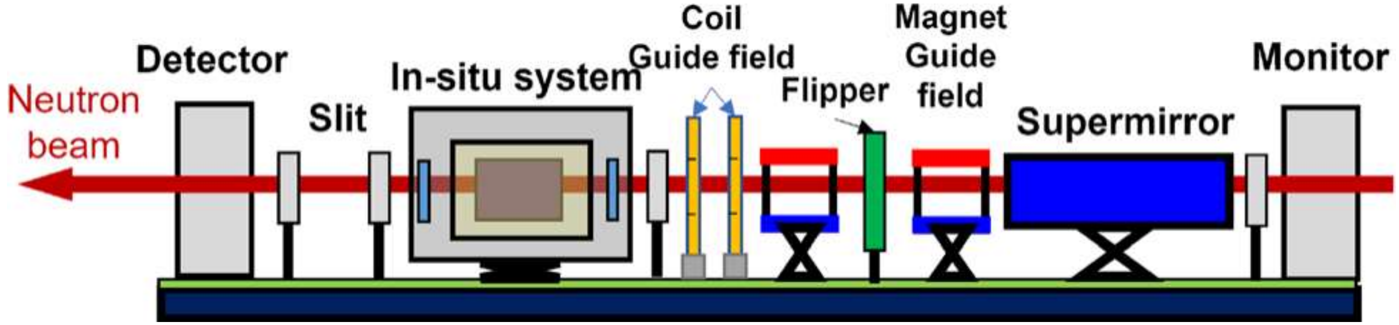
Performance simulation – Bloch equation solver

Dong, Y.-C. *et al.* *NUCL SCI TECH* **33**, 145 (2022).

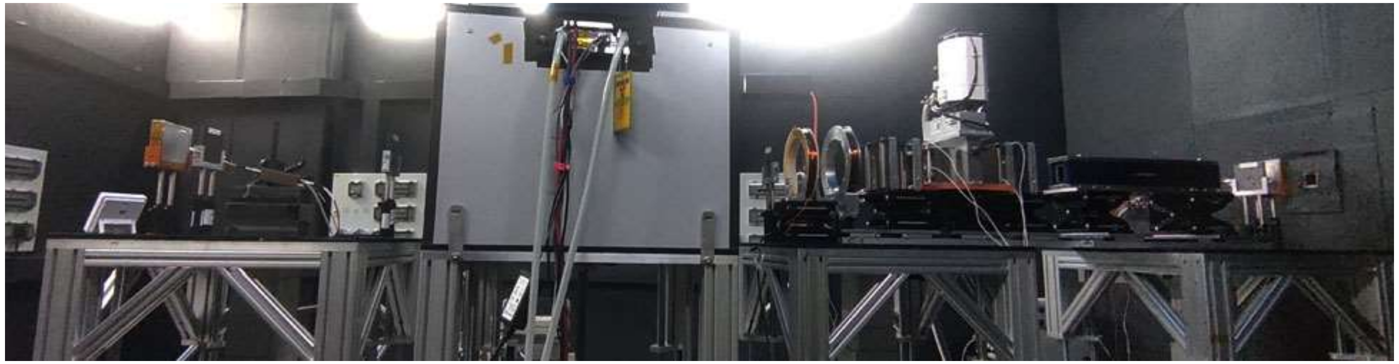
Pre-validation work – Superconducting spin flipper

Performance test

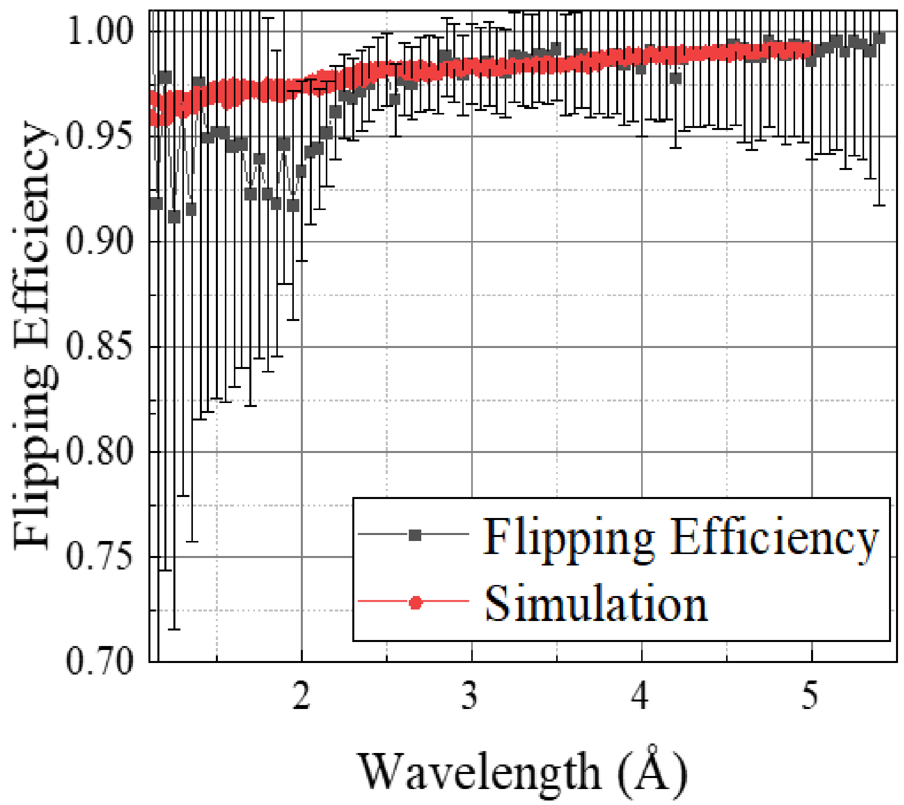
Experiment model



Experiment photo (CSNS BL-20)



Simulation & experiment result

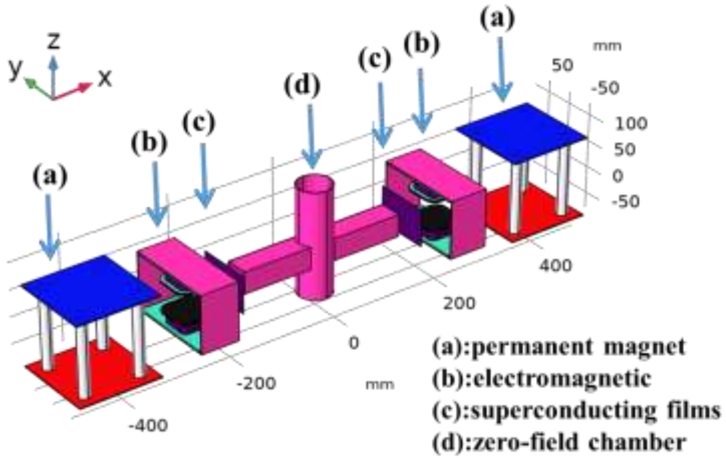


99% flipping efficiency @ 4Å neutron

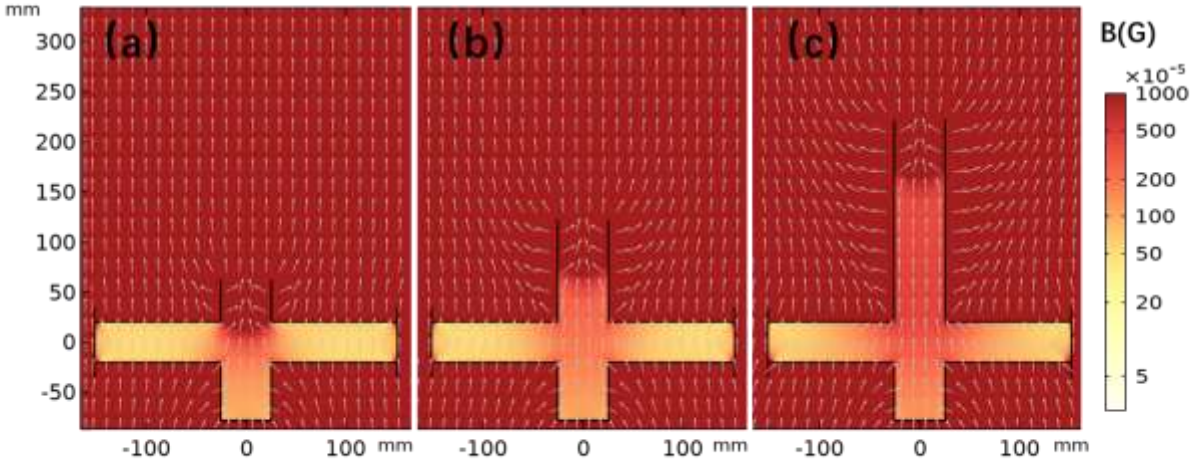
Dong, Y.-C. *et al.* *NUCL SCI TECH* **33**, 145 (2022).

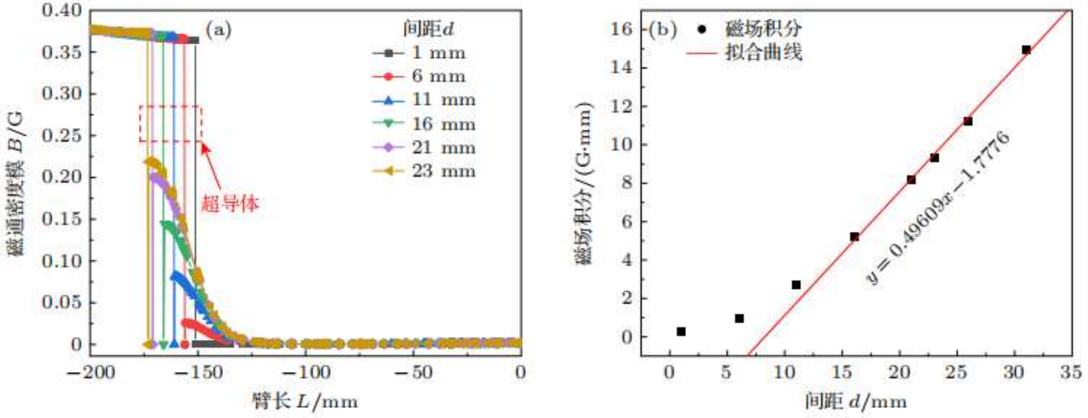
Zero-field chamber development

Prototype simulation

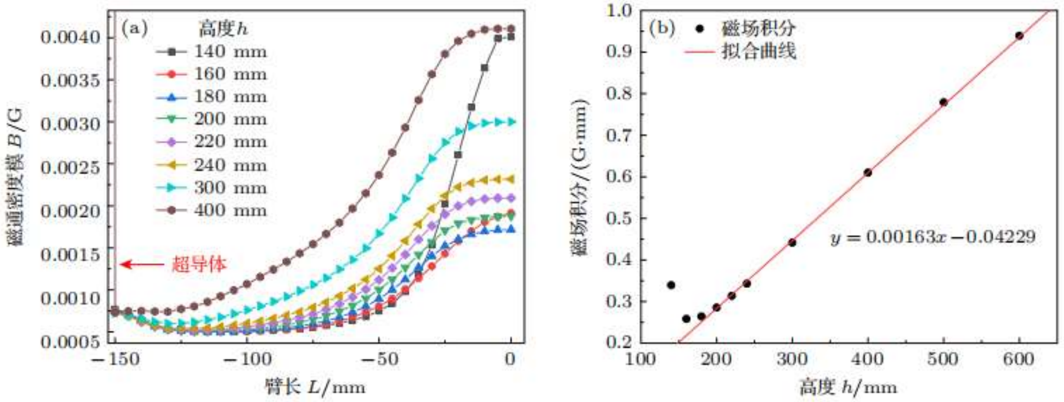


FEM simulation model





Influence of the distance between superconducting thin film and ZFC



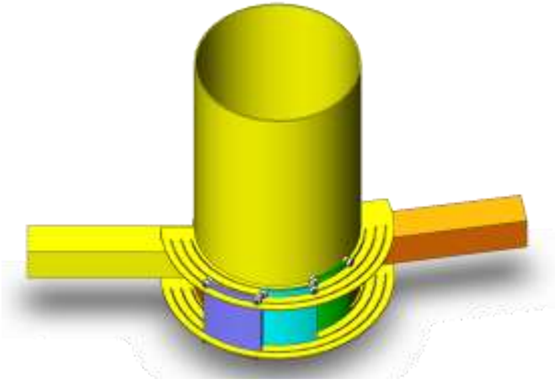
Influence of the height of the center cylinder

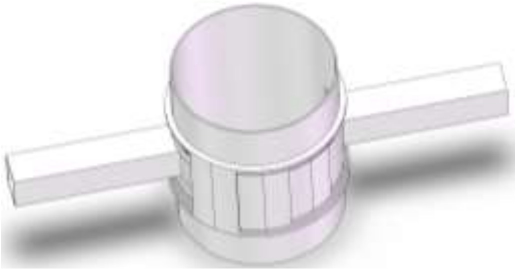
Zeng T. *et al.*. *Acta Phys. Sin.* **72**, 142801 (2023).

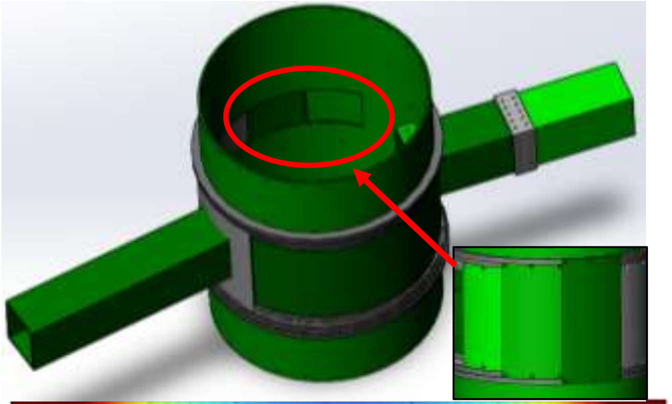
Zero-field chamber development

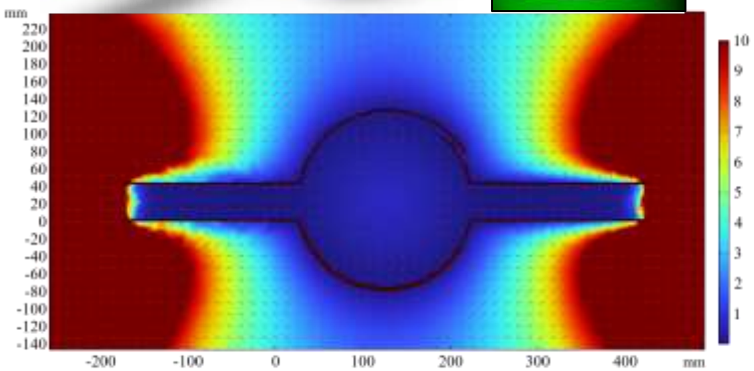
Rotatable ZFC design

Structure modify & simulation







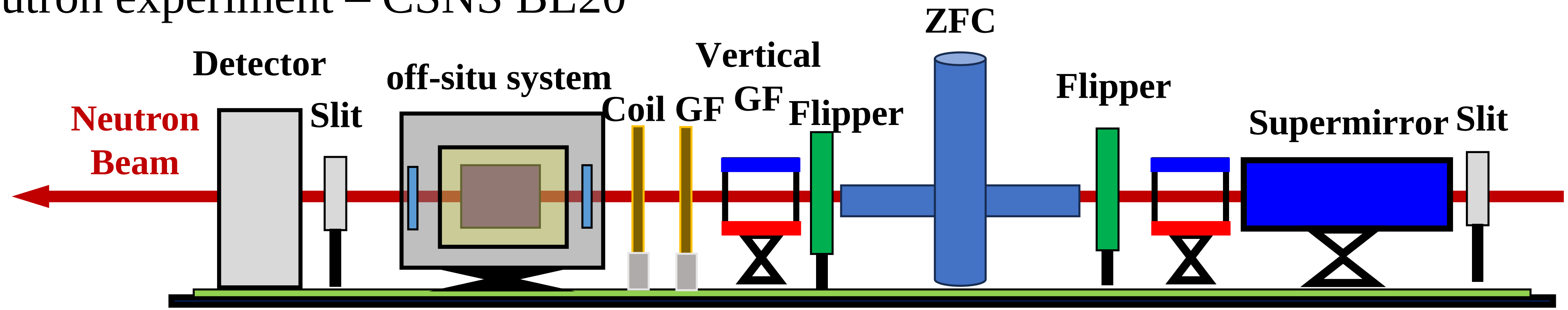


Device photo

- Scattering angle coverage： -10° ~120°
- Stepless adjustable
- Center magnetic field ≤ 0.01 G (Geomagnetic field)

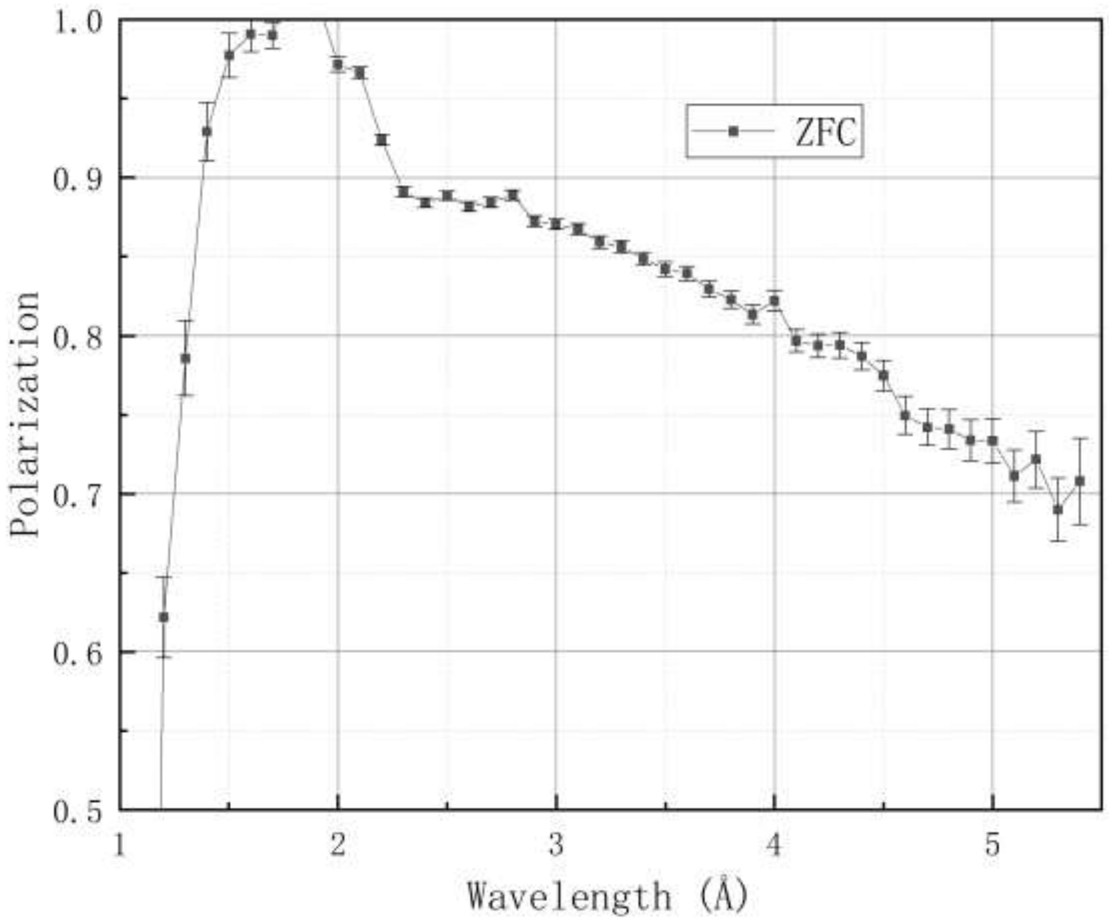
Zero-field chamber development

Neutron experiment – CSNS BL20



Zero-field chamber development

Experiment result

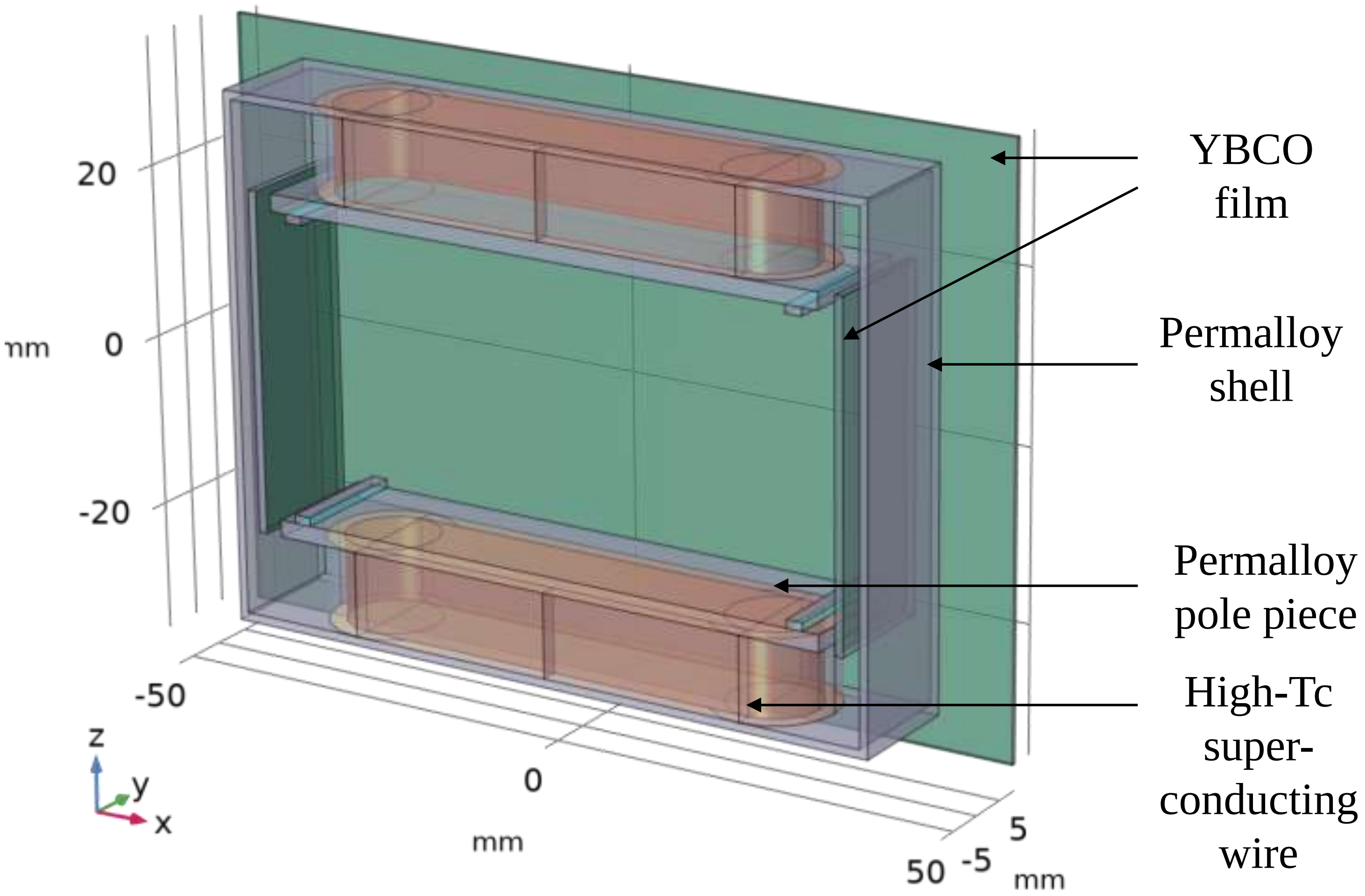


- Shows restrictive shielding effect
- Unexpected polarization loss at longer wavelength
- Depolarization may come from the un-optimized distance between YBCO films and the end of ZFC.

Precession field design

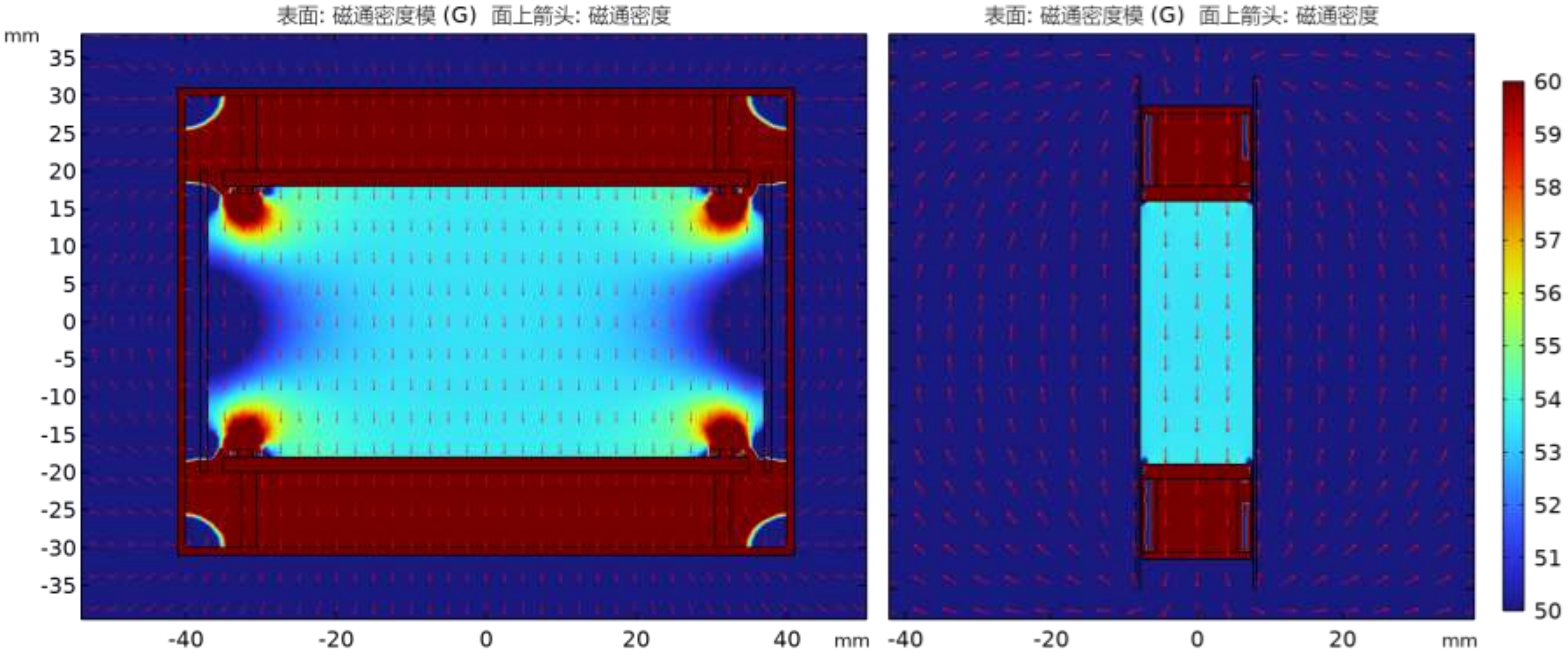
FEM simulation

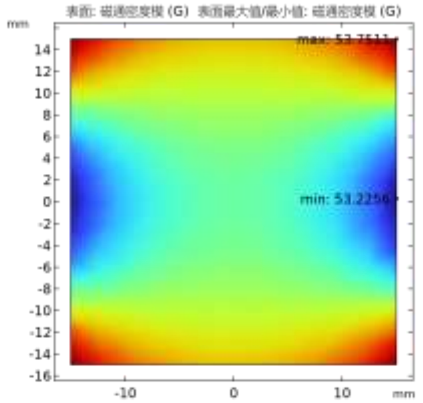
- YBCO films with permalloy shell to restrict the field
- YBCO pieces and permalloy pole pieces for field uniformity
- High-Tc superconducting wire to enough precession field without heat load



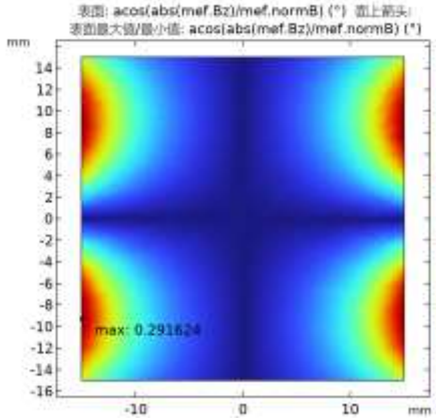
Precession field design

FEM simulation





$\Delta B_{max} = 0.523G$

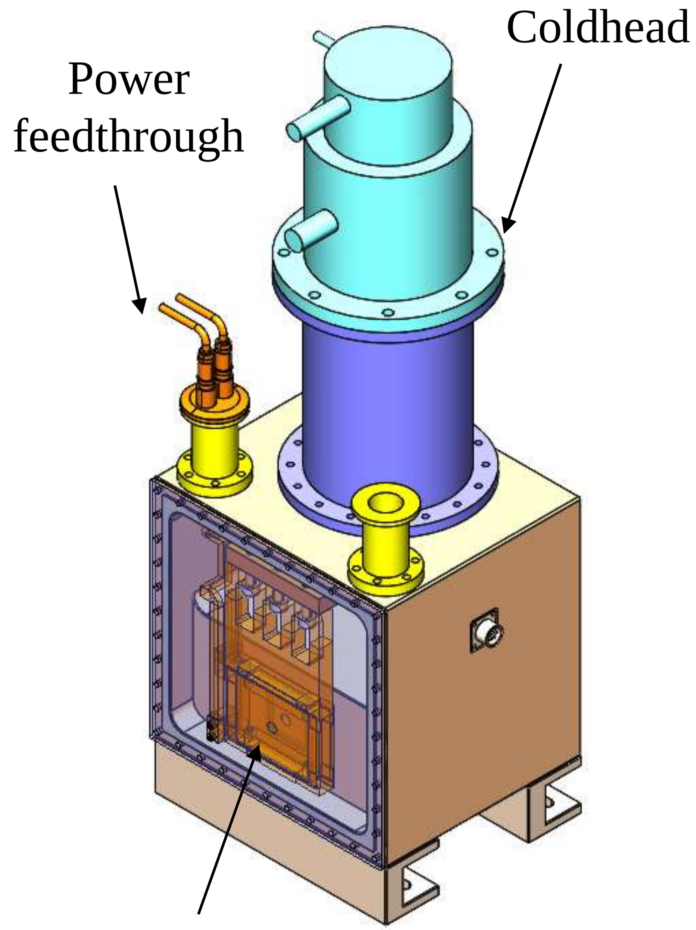


$\theta_{max} = 0.2916°$

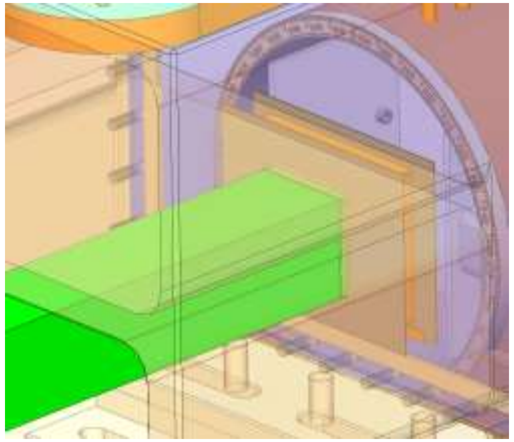
- Center magnetic field 53.5G ×15cm @20A current
- Magnetic field highly homogeneous
- Maximum deviation of precession angle is about 2° (30mm × 30mm)

Precession field design

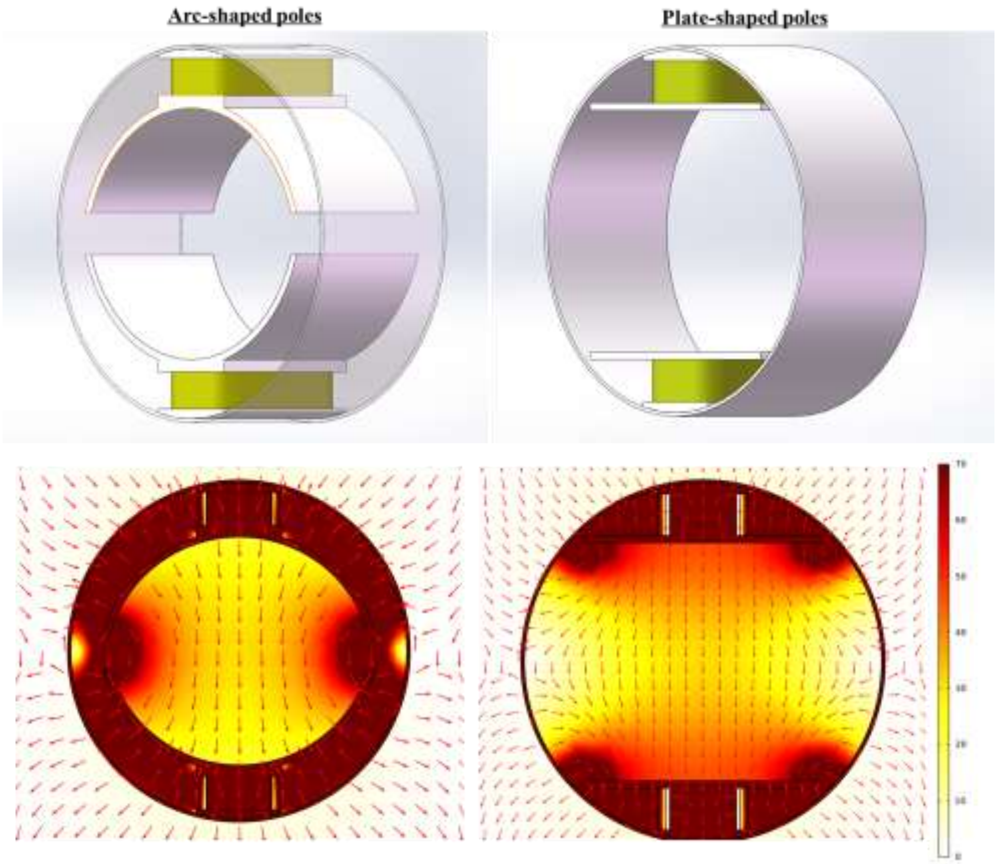
Vacuum chamber design



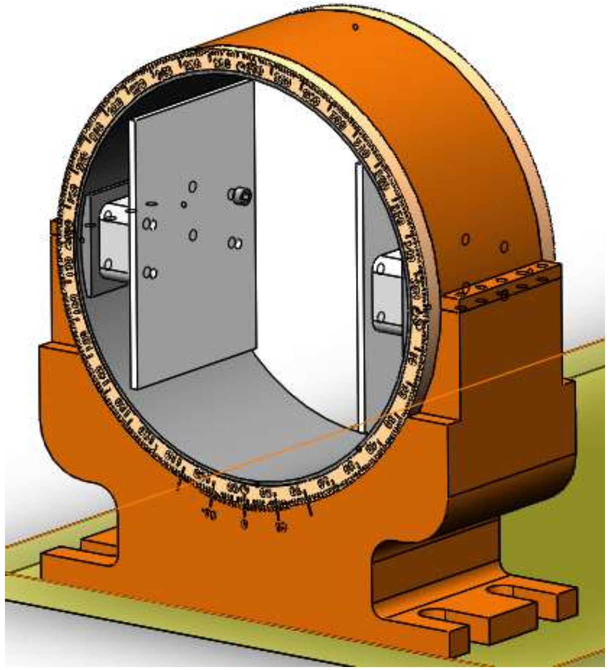
- Prototype machining is finished
- Ongoing vacuum test and cooling test
- Compact structure shortened the distance to the end of ZFC



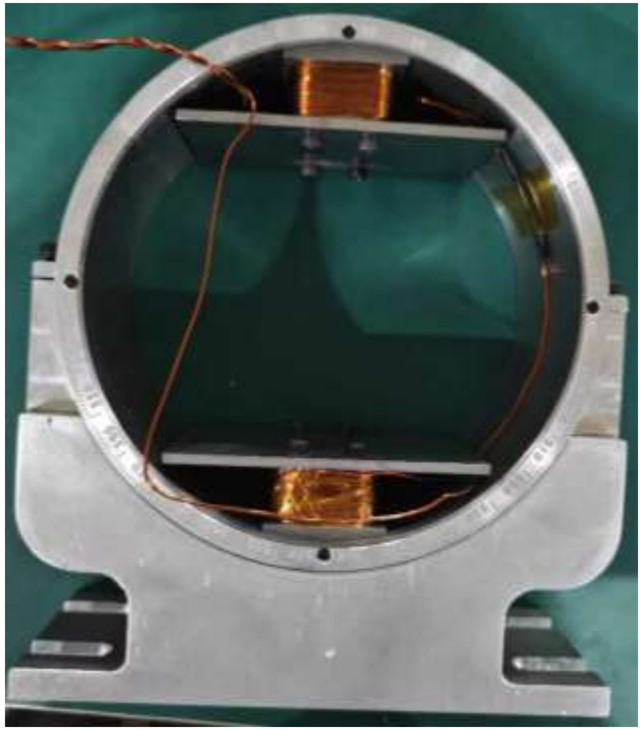
Nutator design



FEM simulation result



Structure design



Device picture

- Plate-shape pole pieces for directional uniformity
- Complete 360° rotatable guide field
- 40 cm × 40 cm directional uniform field area

Summary & Outlook

Summary & Outlook

- Compact design of the superconducting film
- Permalloy based ZFC covered -10° ~120° scattering angle
- YBCO films & permalloy shielding precession field
- Optimized vacuum chamber to shorten the distance to the end of ZFC

- Whole set of devices test in early next year
- Spin flipper optimization for smaller vacuum chamber
- Development on TOF polarization manipulation apply to SNP.

Thank you!