Neutron Polarization and Transmission Measurement for the SNS Neutron EDM Experiment

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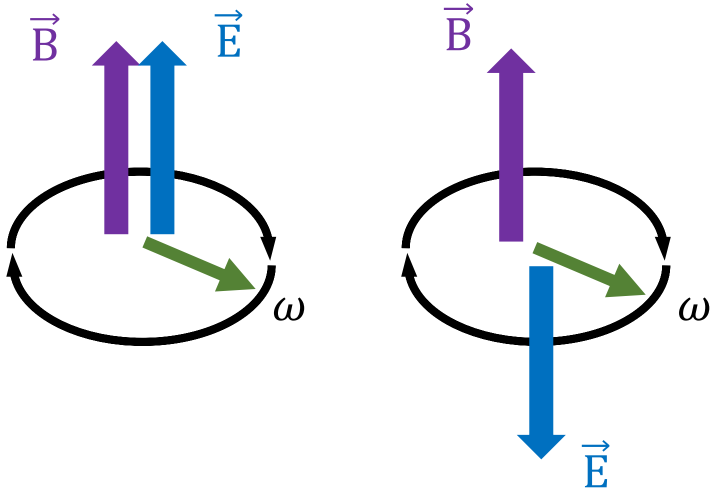
18th International Workshop on Polarized Sources, Targets, and Polarimetry 2019

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Principle of EDM Measurement

Existence of EDM will change the precession frequency of Neutron



$$\omega = \frac{2(\mu_n B_0 \pm d_n E_0)}{\hbar}$$

$$\Delta\omega = \frac{4 d_n E_0}{\hbar}$$

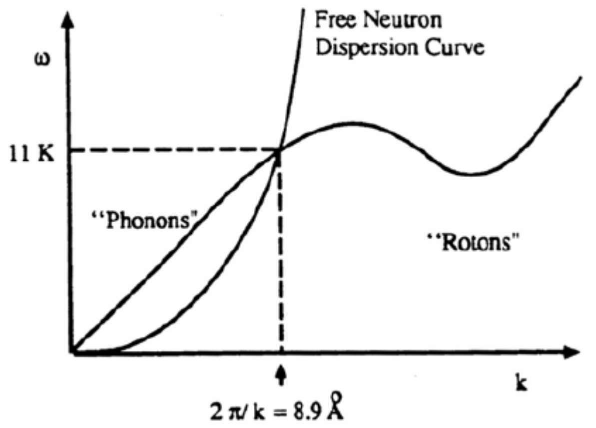
Sensitivity $\sigma_{d_n} \simeq \dfrac{1}{P_n E_0 \tau \sqrt{N_{UCN}}}$

The goal is to reach $\sigma_{d_n} \simeq 10^{-28} e \cdot cm$ (current limit $d_n < 3.0 \times 10^{-26}\ e \cdot cm\ (90\%\ CL)$[PDG])

- Ultracold Neutrons (UCN) production via superthermal scattering in superfluid He.
- B field of 30 mG and field uniformity of 30 ppm/cm and E field of 75 kV/cm.
- Free precession method
  - ^{3}He co-magnetometry to monitor B field via SQUIDS.
  - Scintillation rate via spin dependent n-^{3}He reaction.

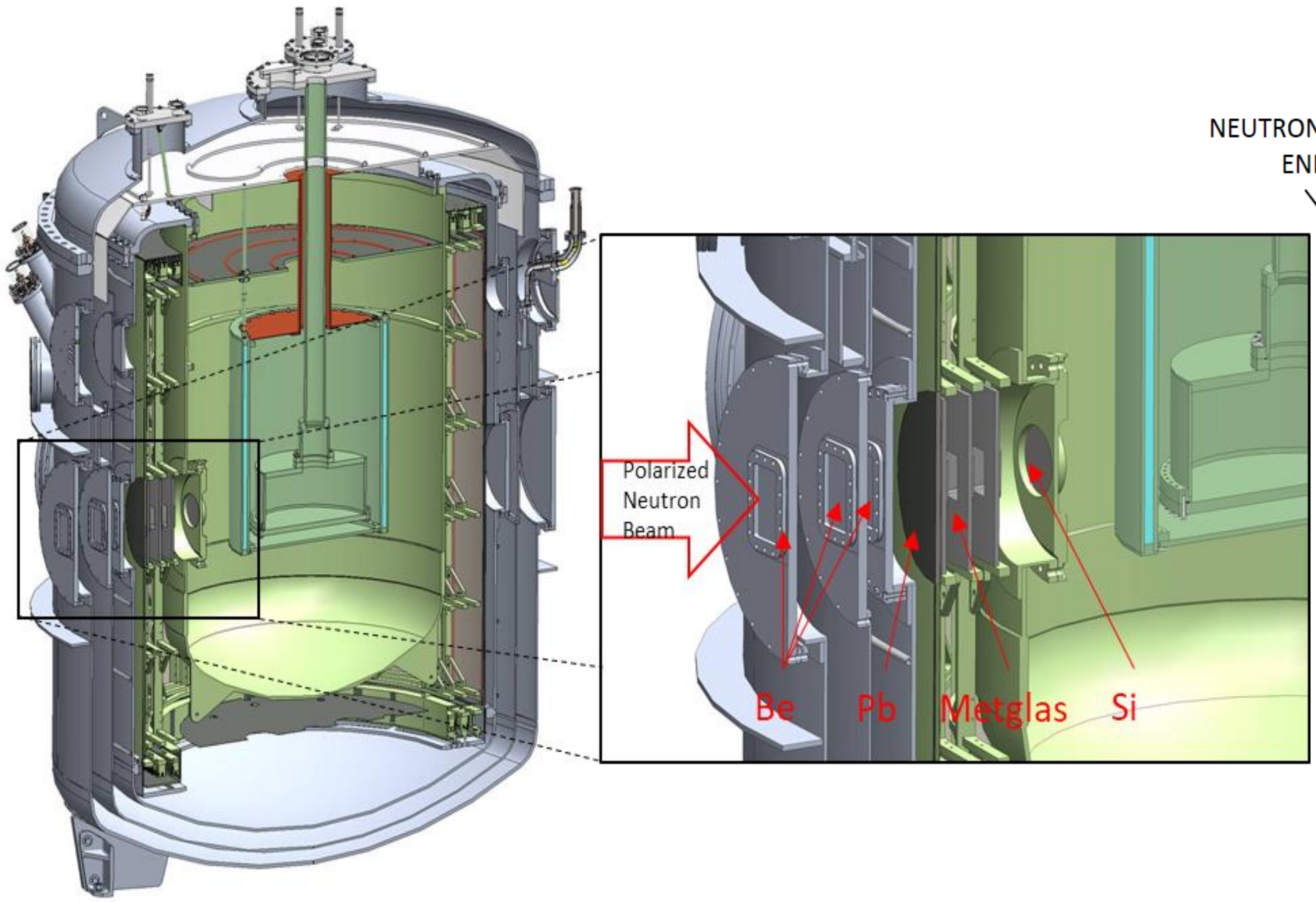
$$n \uparrow + {}^3He \downarrow \rightarrow {}^3H + p + 765\ keV$$

- Critical spin dressing method for better sensitivity and cross check on systematics



R. Golub and S.K. Lamoreaux, Physics Reports 237, 1 (1994).

Cryostat Magnet Package and its associated windows



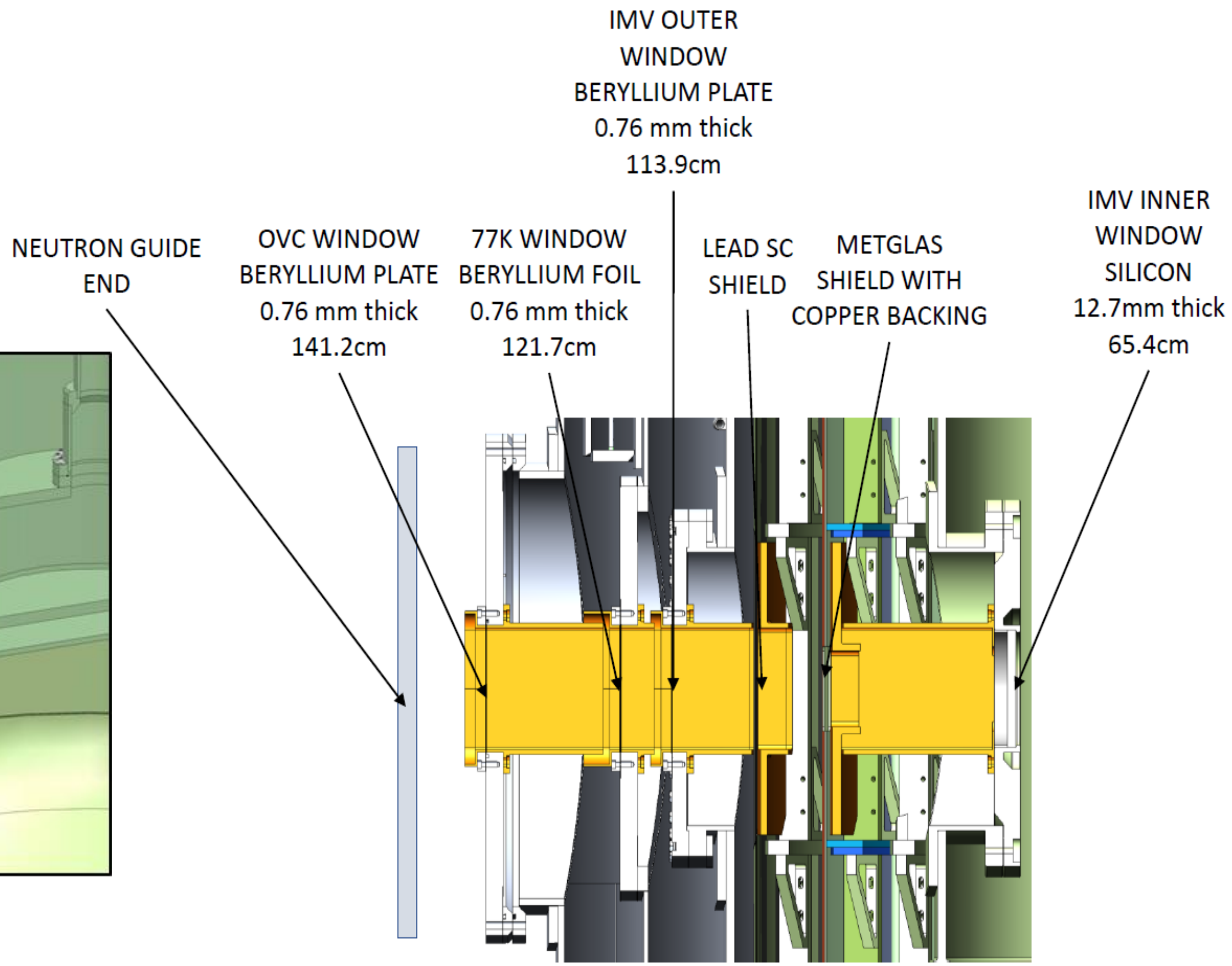
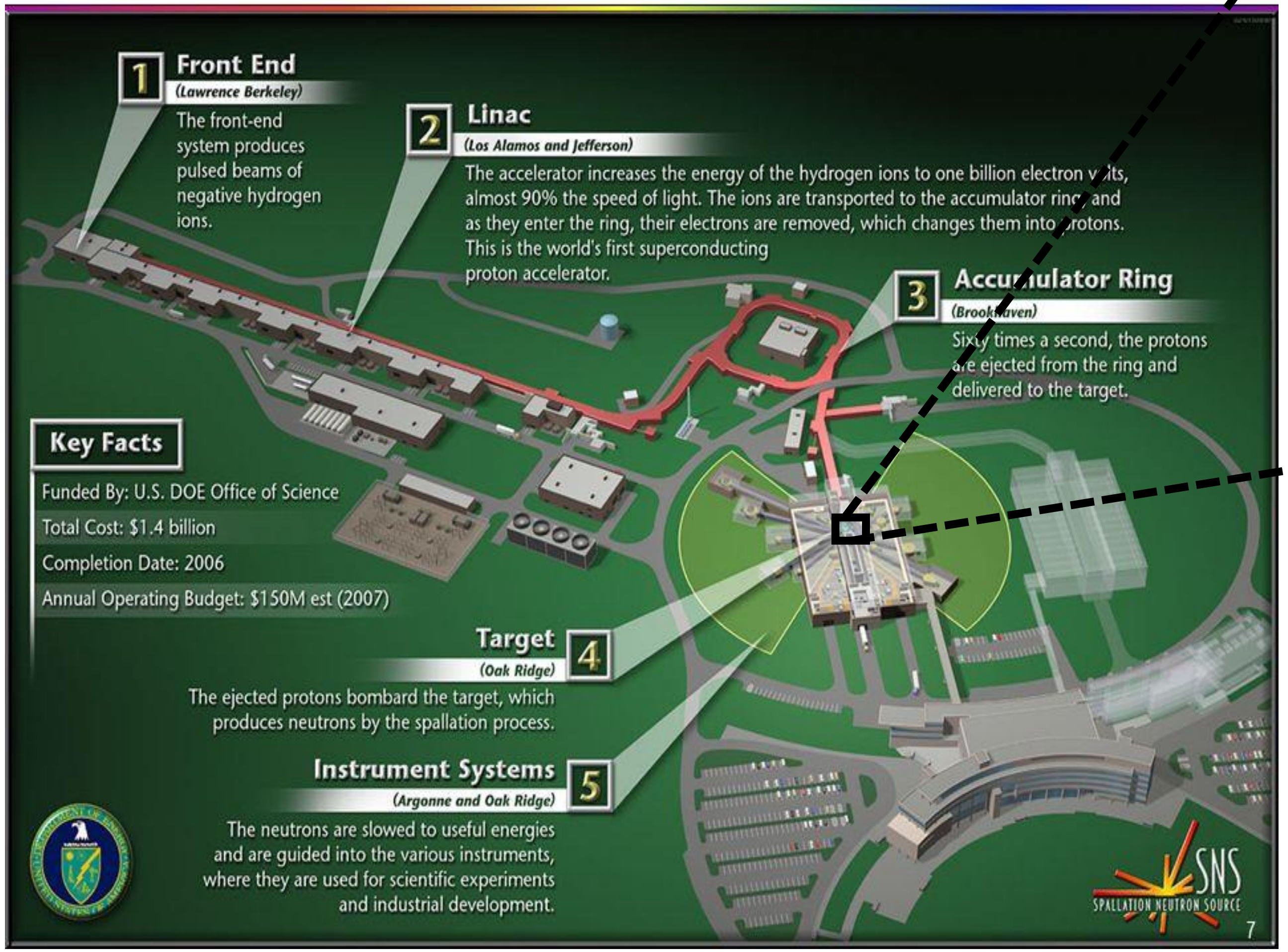


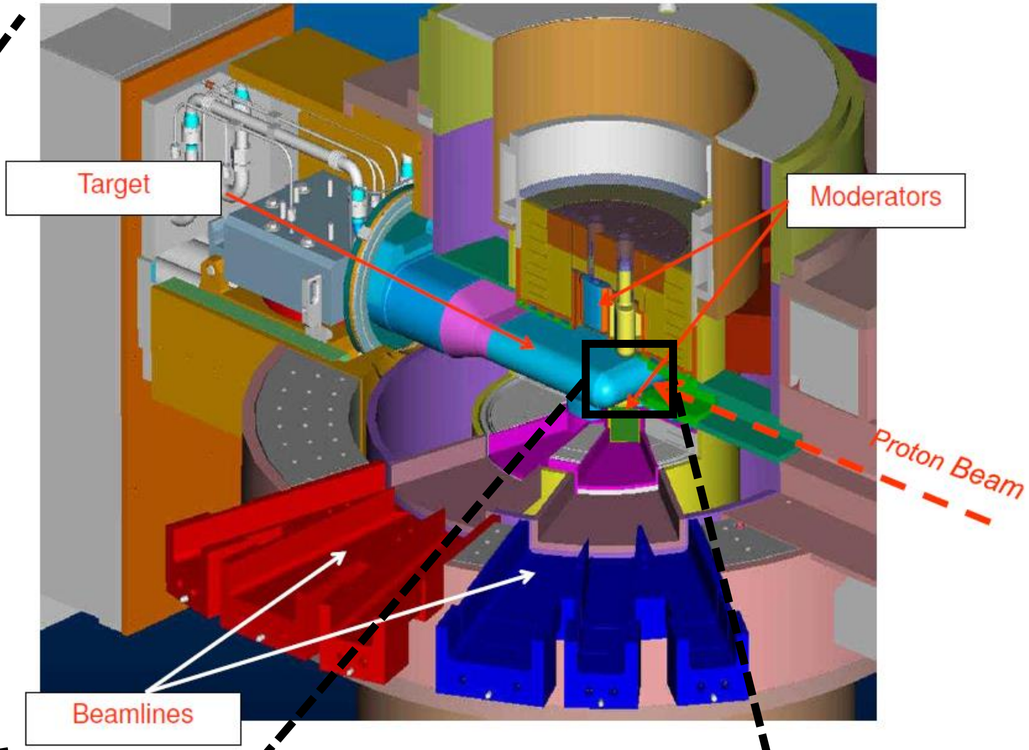
Image courtesy of J. Ramsey

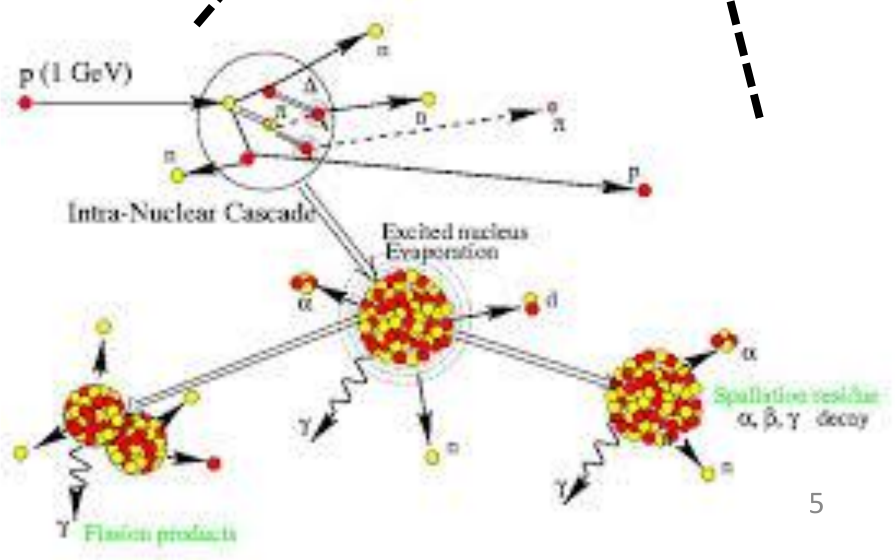
Polarization and Transmission of Neutrons

- Need to measure polarization loss of monochromatic neutrons from nEDM cryostat magnet windows.
  - Especially superconducting Pb shielding and ferromagnetic flux-return Metglas.
  - presence of microscopic magnetic domains and the fact that windows can act as current sheets can cause diabatic transitions to the polarization of neutrons
- Need to measure the transmission efficiency of monochromatic neutrons from nEDM cryostat magnet windows.
- Need to see if any magnetic field non-uniformities can cause neutron depolarization.

Spallation Neutron Source

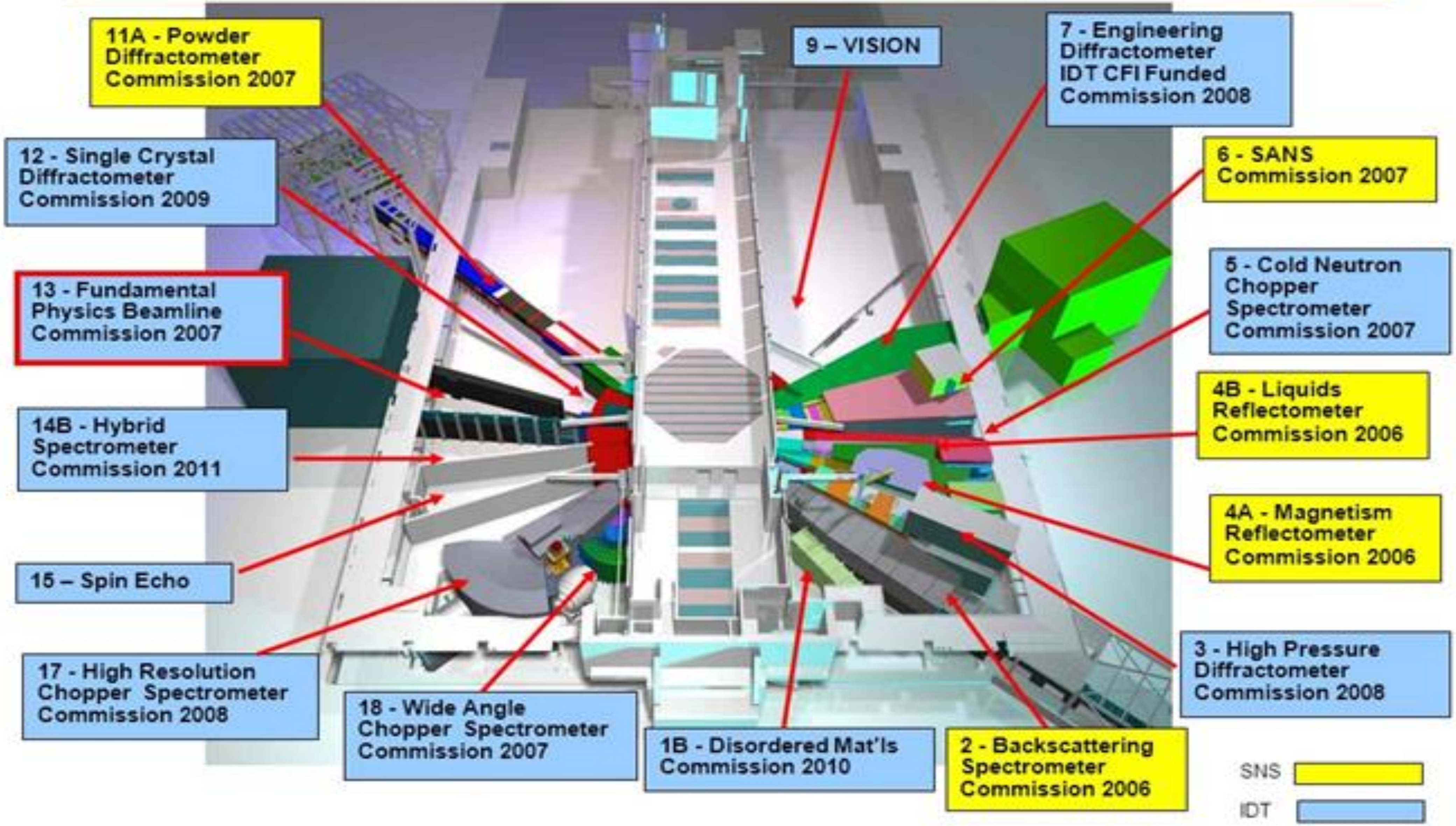




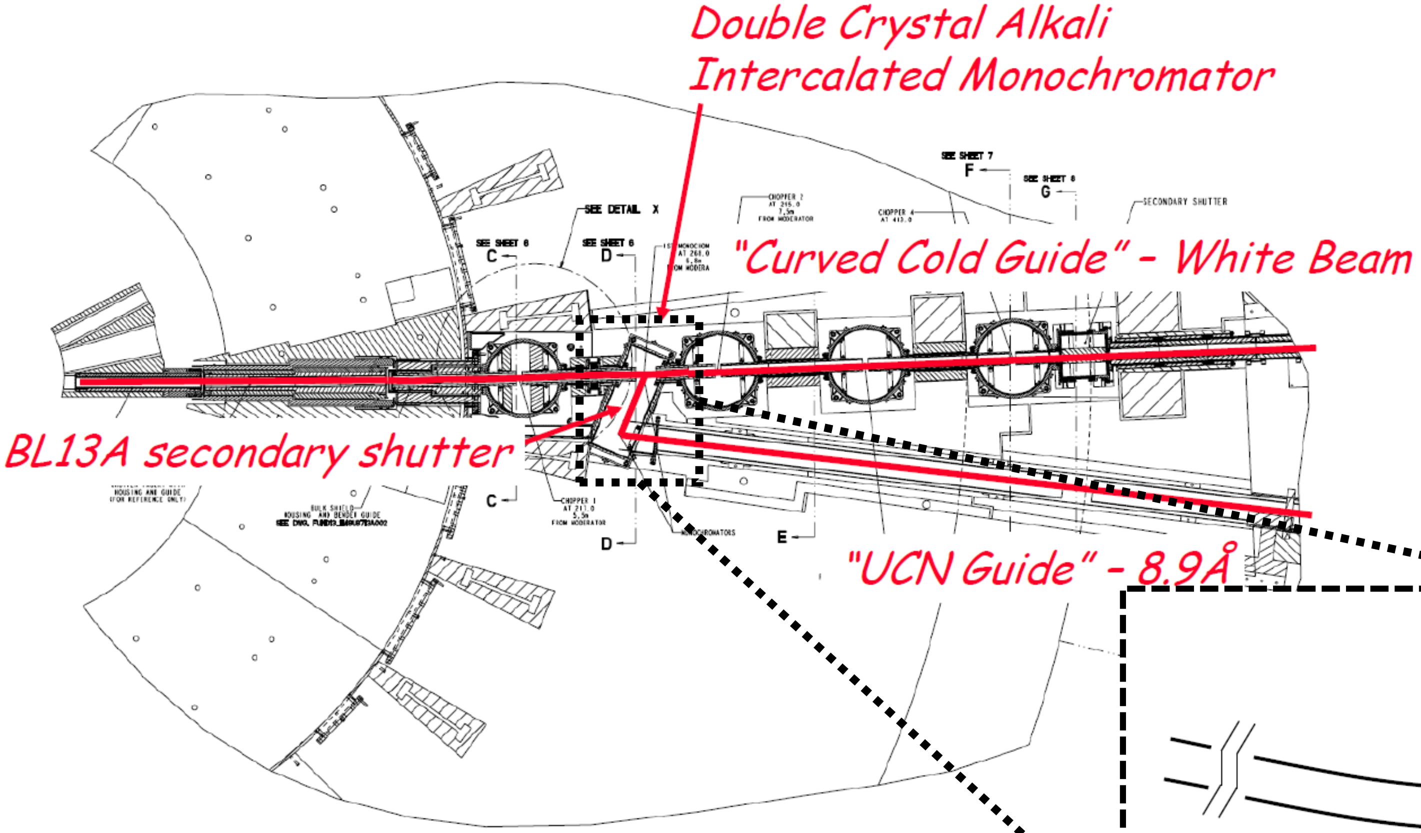


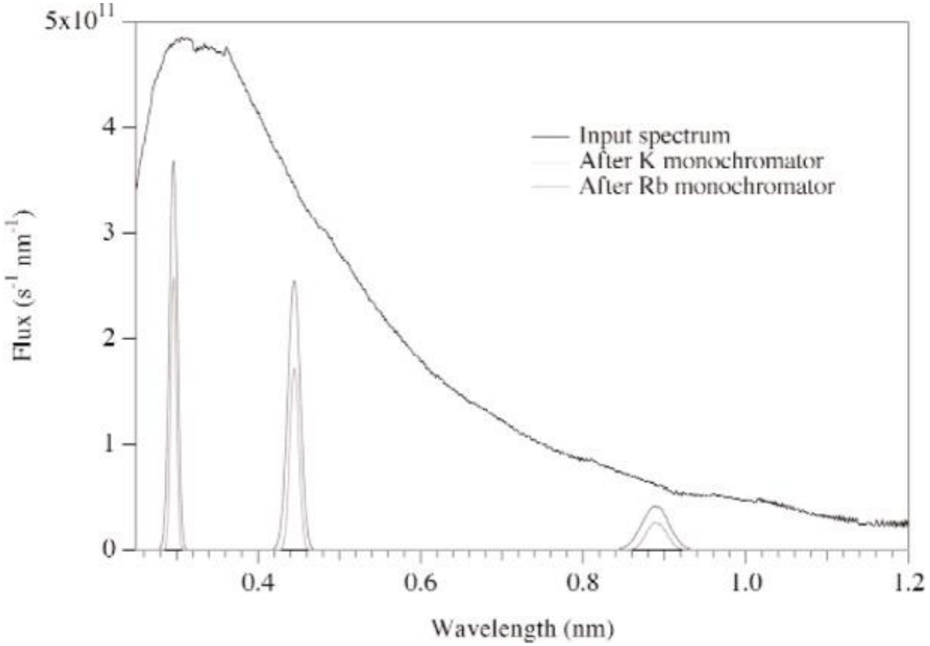
N. Fomin et. al, Nucl. Instrum. Methods A773 (2015) 45

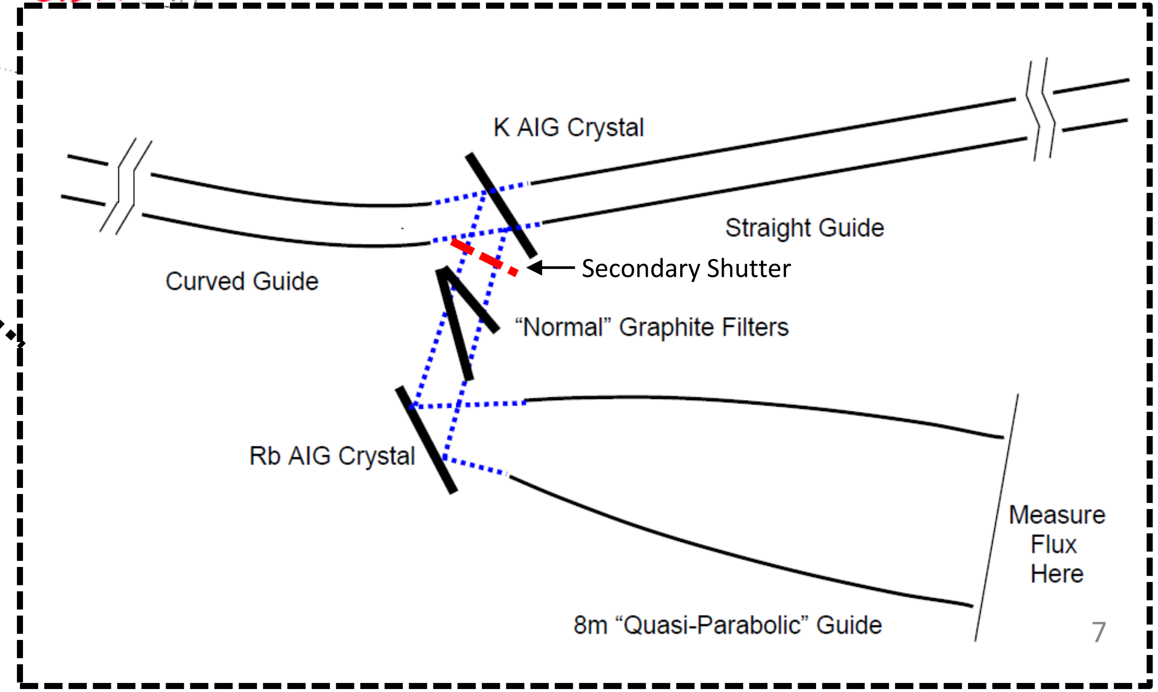
SNS Target Hall



Beamline 13 Schematic Diagram

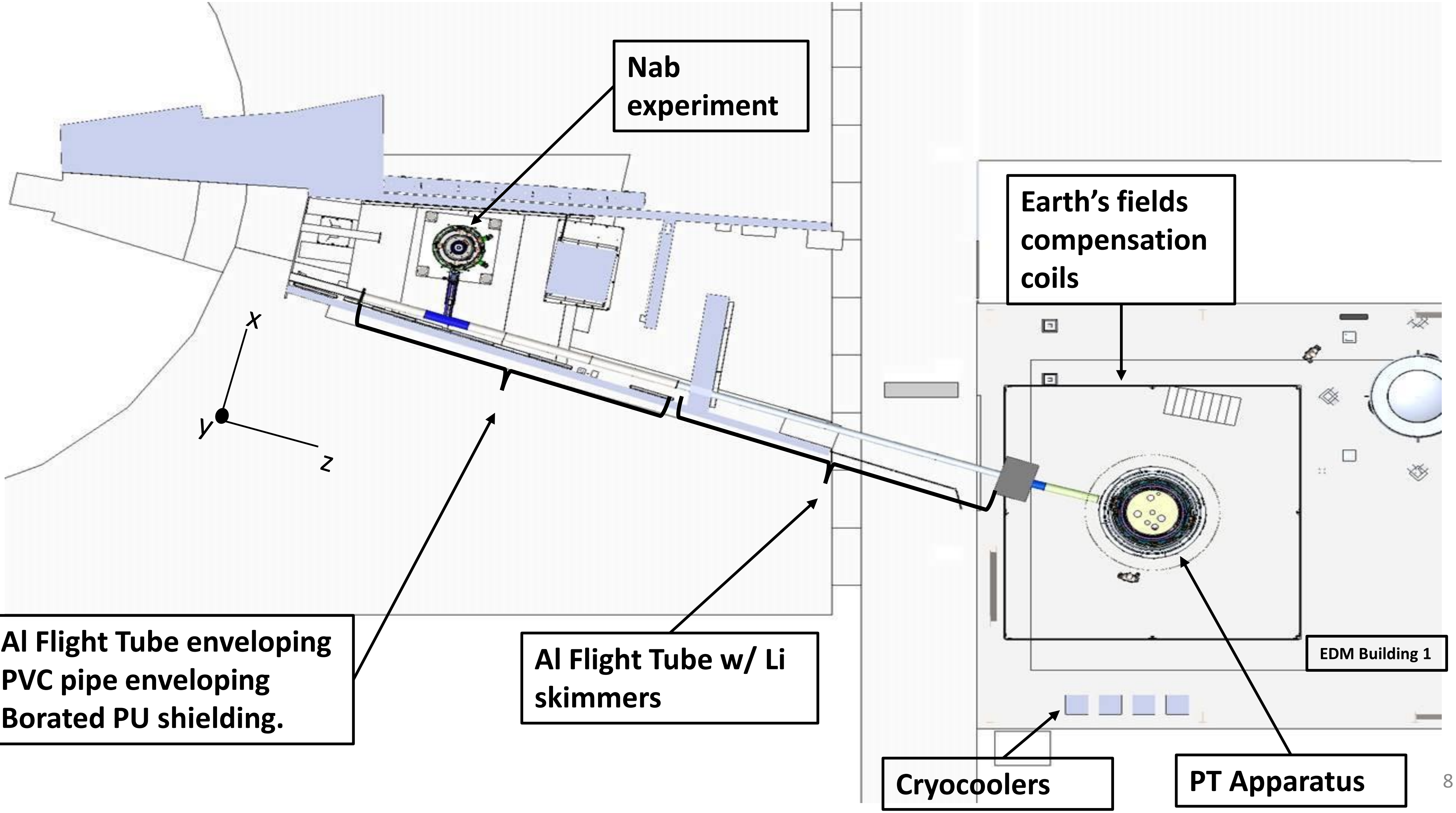






N. Fomin et. al, Nucl. Instrum. Methods A773 (2015) 45

P & T Measurement Setup



Flight Tube Prototype

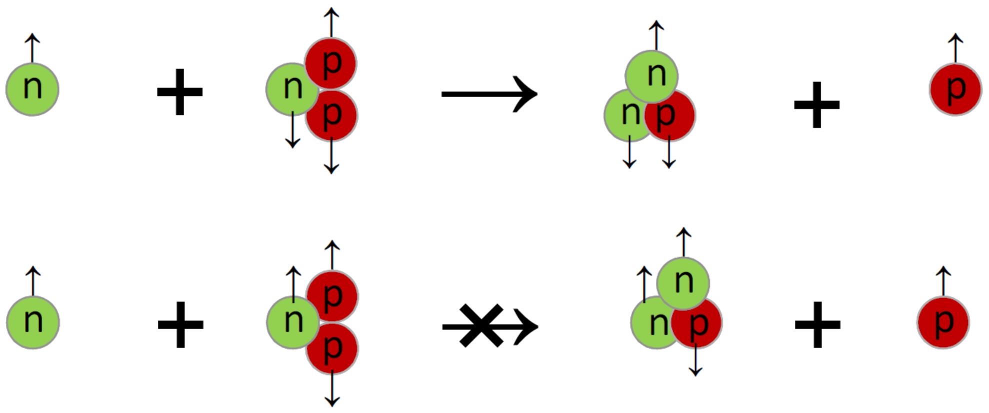
^{3}He Polarimetry

Takes advantage of the spin dependence in the capture cross section of neutrons on polarized ^{3}He.

$$P_n = \tanh[\sigma(\lambda) N_{He} L_{He} P_{He}]$$

$$T_{pol} = T_0 \cosh[\sigma(\lambda) N_{He} L_{He} P_{He}]$$

$$T_0 = N_0 e^{-\sigma(\lambda) n_{He} l}$$



^{3}He analyzer cell parameters are difficult to accurately measure.

G. L. Greene et. al, Nuc. Inst. Methods A 356 (1995).

Determination of Neutron Polarization

$$P_n = \frac{R - R_{sf}}{\sqrt{\left[\left(2\varepsilon_{sf} - 1\right)R + R_{sf}\right]^2 - 4{\varepsilon_{sf}}^2}}$$

$$R = \frac{T}{T_0}, R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$

- Neutron polarization can be determined by R and R_{sf} which simply represent ratios of transmissions through ^{3}He analyzer.
- ^{3}He polarization and the physical properties of the ^{3}He cell do not need to be known to determine the neutron polarization.

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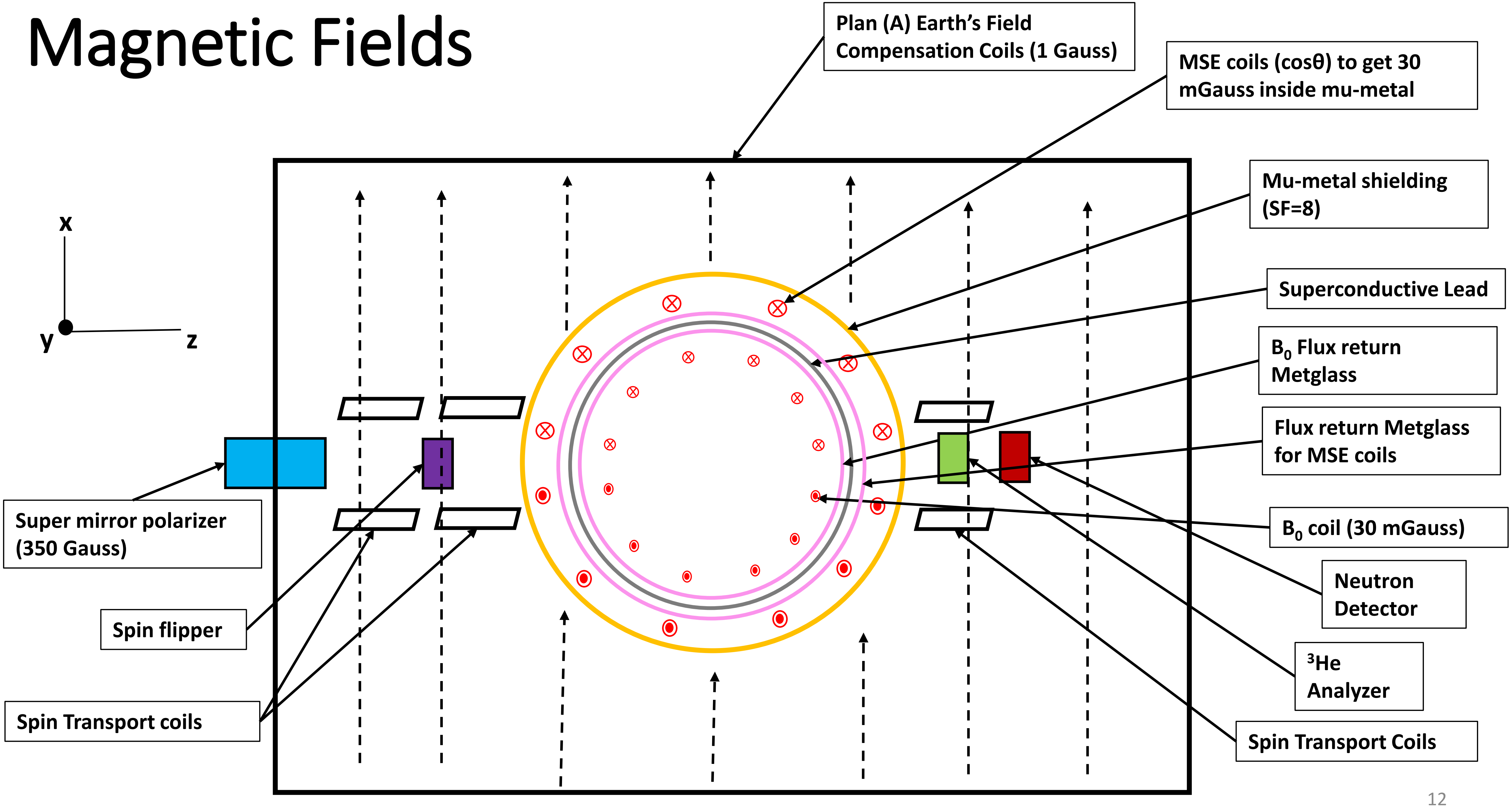
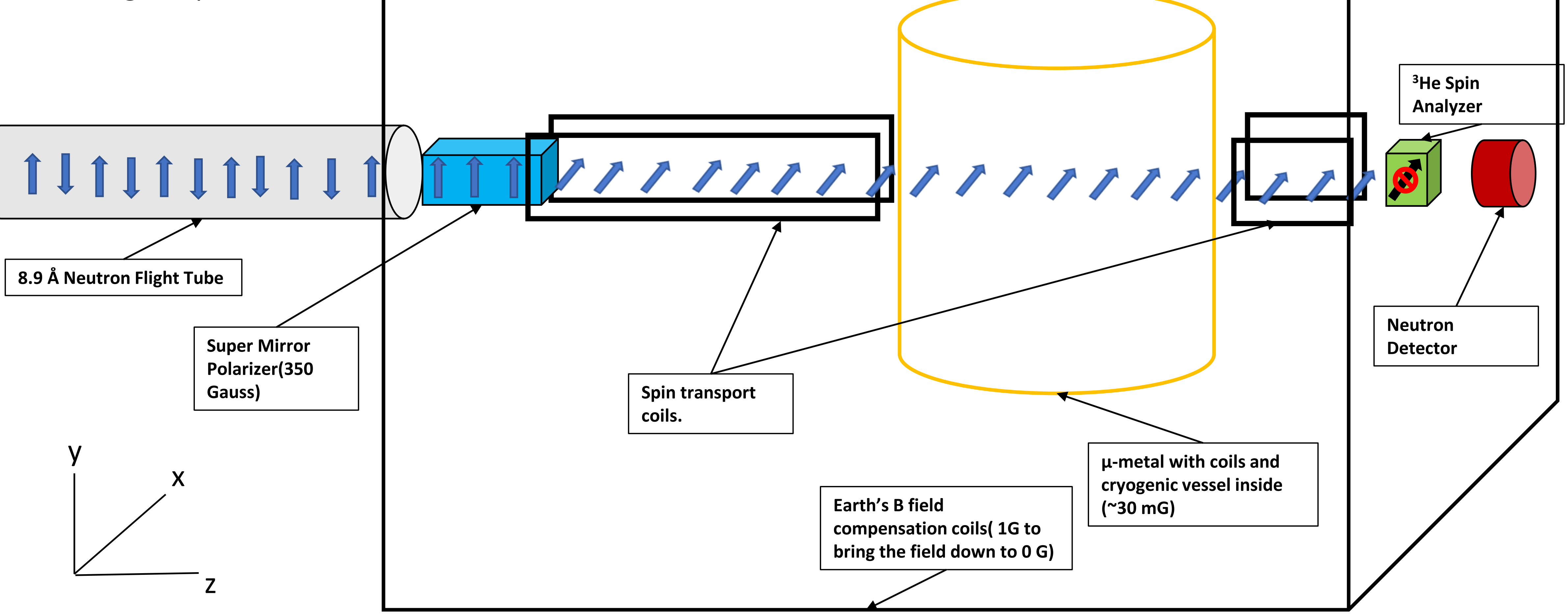
Magnetic Fields



P & T Measurement Setup

1) Transmission of polarized neutrons through unpolarized ^{3}He.

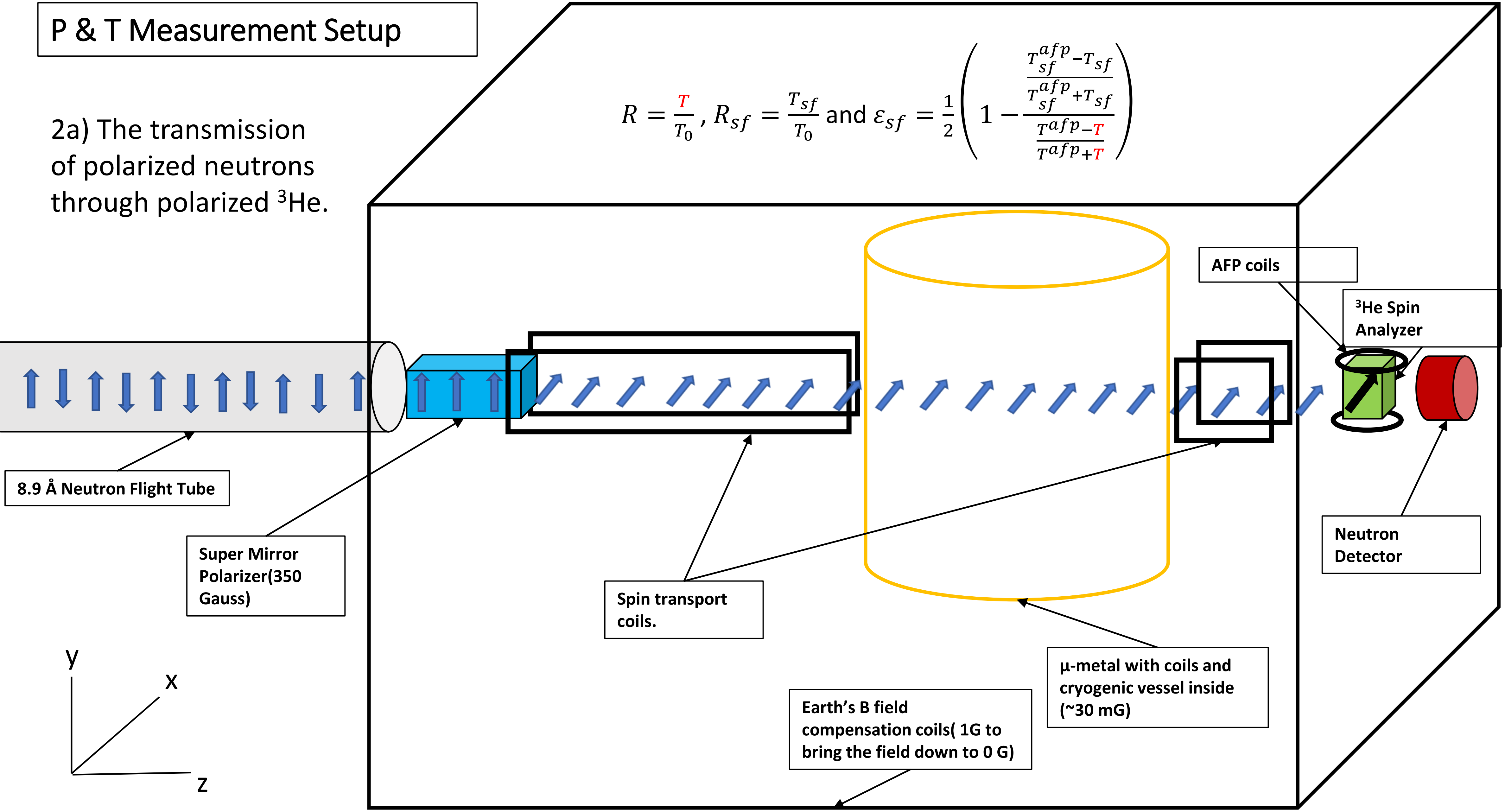
$$R = \frac{T}{T_0}, \; R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$



P & T Measurement Setup

2a) The transmission of polarized neutrons through polarized ^{3}He.

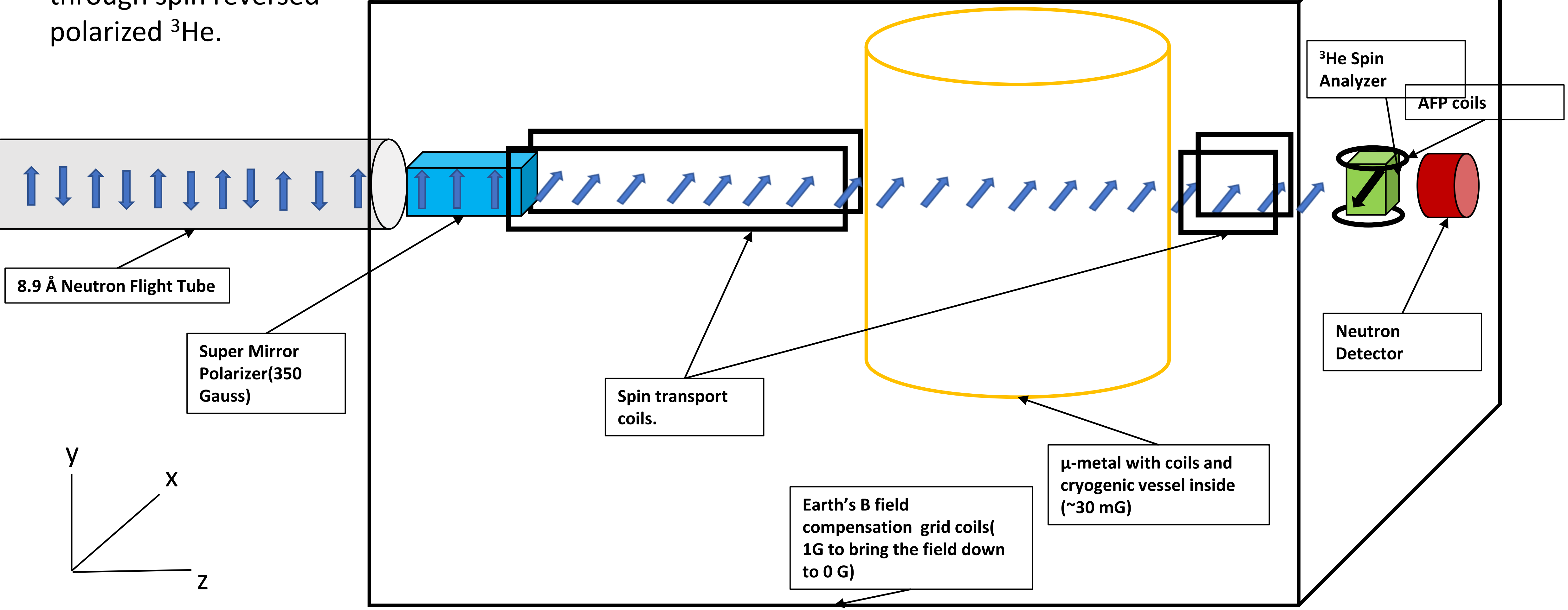
$$R = \frac{T}{T_0},\ R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$



P & T Measurement Setup

2b) The transmission of polarized neutrons through spin reversed polarized ^{3}He.

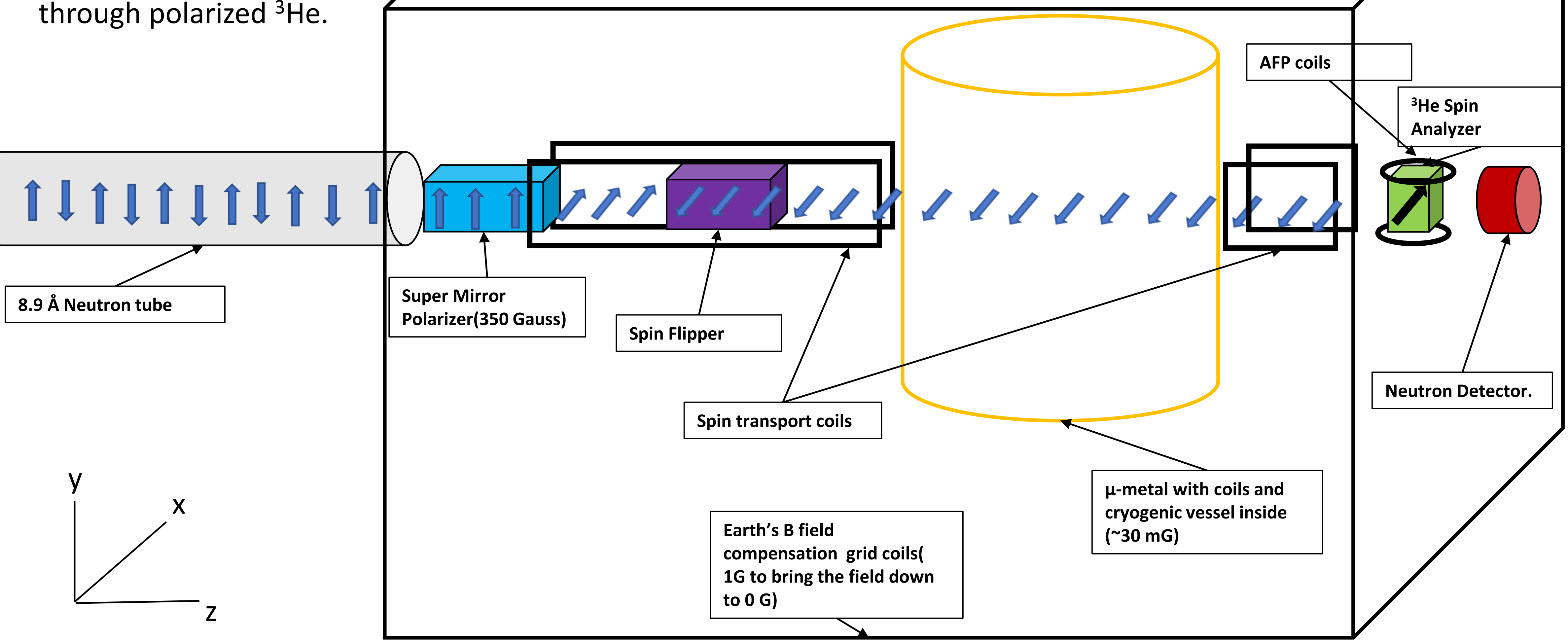
$$R = \frac{T}{T_0},\ R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$



P & T Measurement Setup

3a) The transmission of spin flipped neutrons through polarized ^{3}He.

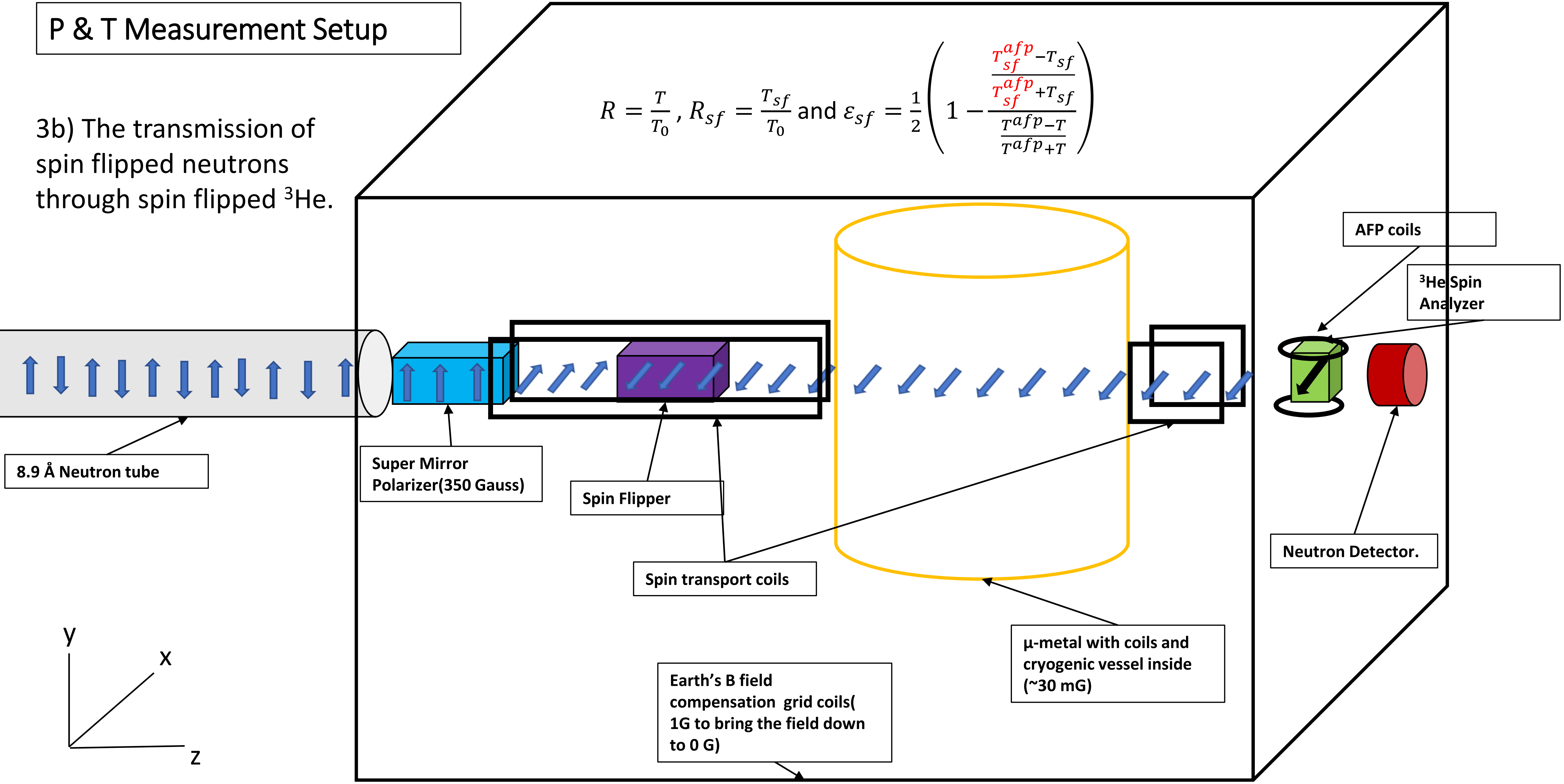
$$R = \frac{T}{T_0}\,,\ R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$



P & T Measurement Setup

3b) The transmission of spin flipped neutrons through spin flipped ^{3}He.

$$R = \frac{T}{T_0},\ R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$



Determination of Neutron Polarization

$$P_n = \frac{R - R_{sf}}{\sqrt{\left[\left(2\varepsilon_{sf} - 1\right)R + R_{sf}\right]^2 - 4\varepsilon_{sf}{}^2}}$$

$$R = \frac{T}{T_0}, R_{sf} = \frac{T_{sf}}{T_0} \text{ and } \varepsilon_{sf} = \frac{1}{2}\left(1 - \frac{\frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}}}{\frac{T^{afp} - T}{T^{afp} + T}}\right)$$

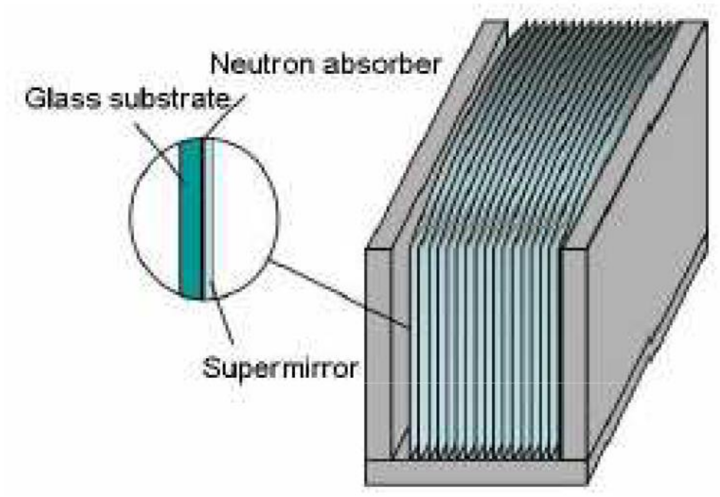
- Neutron polarization can be determined by R and R_{sf} which simply represent ratios of transmissions through ^{3}He analyzer.
- ^{3}He polarization and the physical properties of the ^{3}He cell do not need to be known to determine the neutron polarization.

G. L. Greene et. al, Nuc. Inst. Methods A 356 (1995).

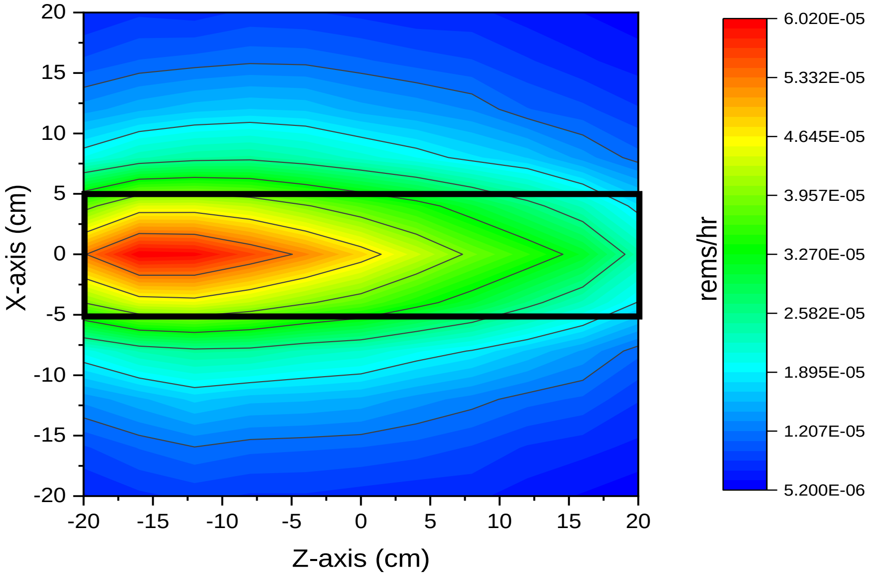
Supermirror Polarizer

$$n = \sqrt{1 - \left(\frac{N b_{coh}}{\pi} \pm \frac{\mu B}{2\pi^2 \hbar^2}\right)\lambda^2}$$

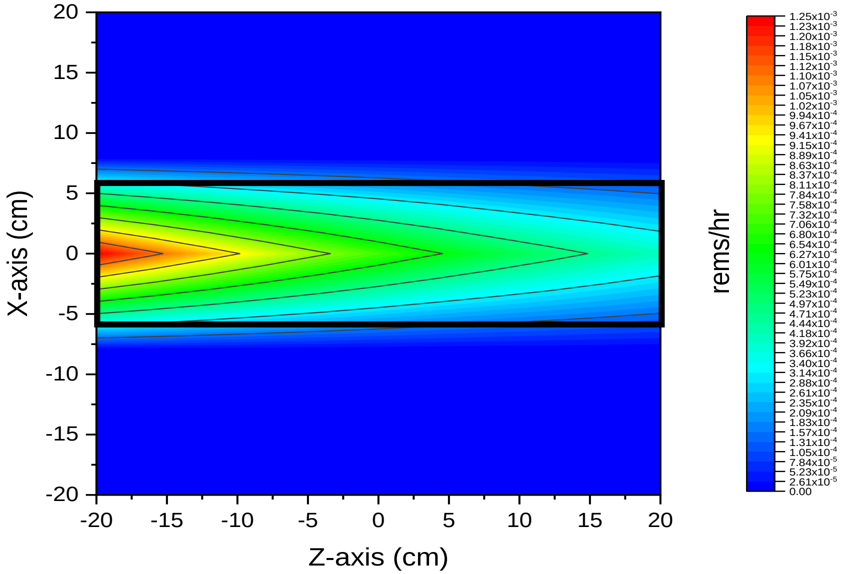
The supermirror polarizer spin filters the neutron beam by preferentially reflecting one neutron spin state. The other spin state is absorbed in the Borofloat glass substrate.



MCNP simulations



γ-rays dose rate

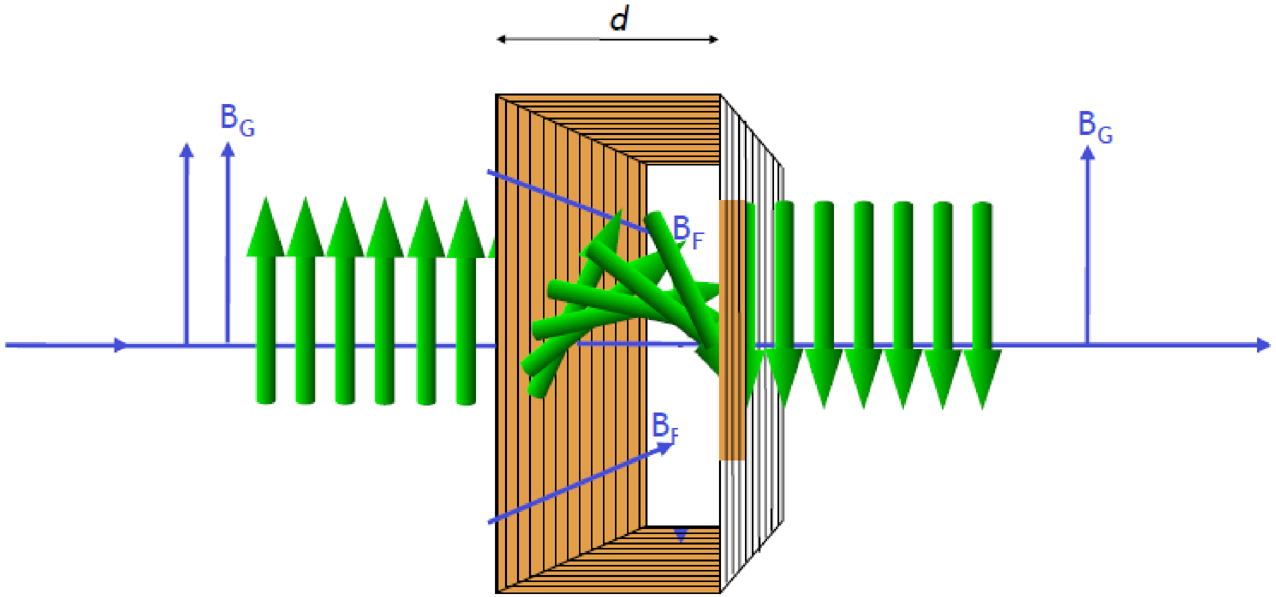


Neutron dose rate

Gamma and Neutron dose rate is less than 250 μrems/hr (SNS unposted area limit)

Mezei coil spin flipper

The Mezei flipper uses a non-adiabatic field perpendicular to the guide field change to project the polarization direction of the beam onto any arbitrary field axis.



Useful for monochromatic beams i.e. fixed velocity

A flip of ϕ radians with respect to the guide field can be achieved if the resultant field within the coil, B_F, is perpendicular to B_G and

$$d = \frac{\phi v}{\gamma_n B_R}$$

e.g. a polarized 8.9Å (444 m/s) neutron will be spin flipped by π radians in a distance of 1cm if B_R=7.749 Gauss

^{3}He Analyzer Cell

- Work with SNS polarimetry group to borrow one.
- Offsite polarization using SEOP.
- Transport to site using transport coils.

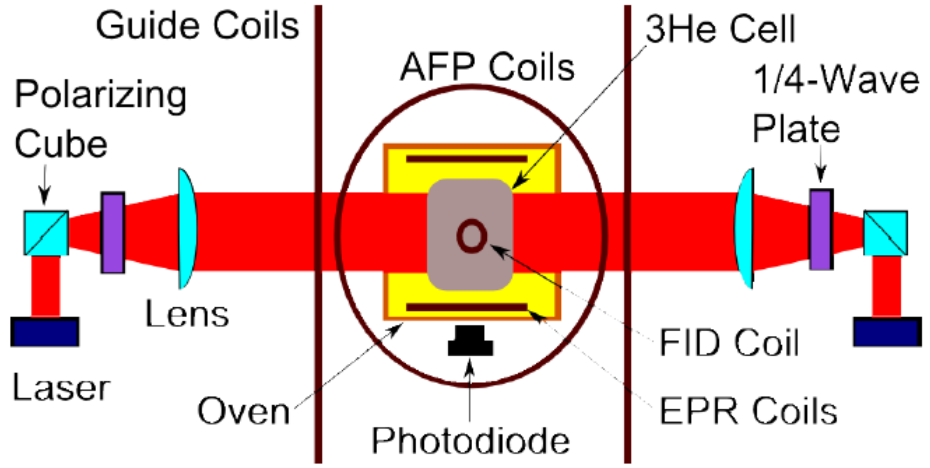
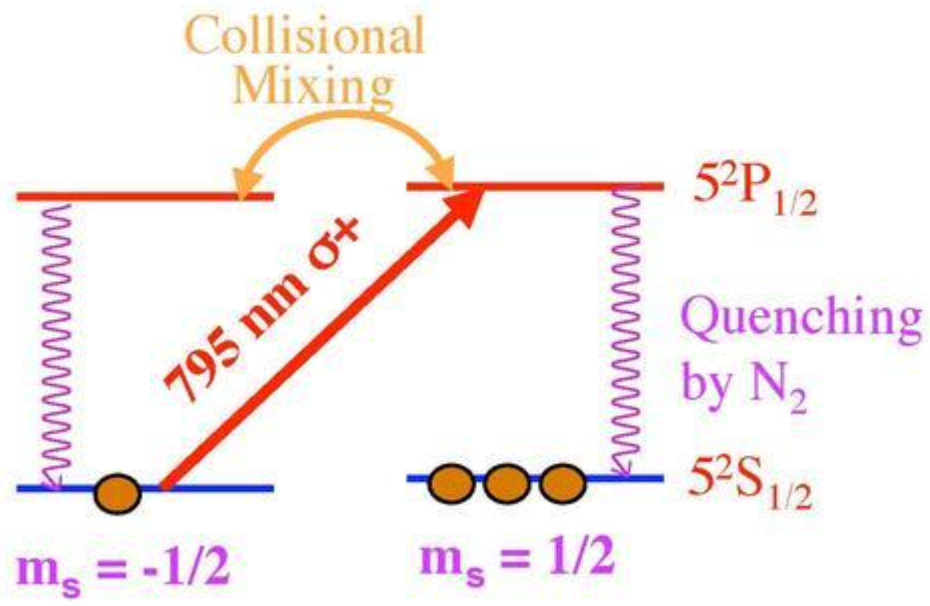
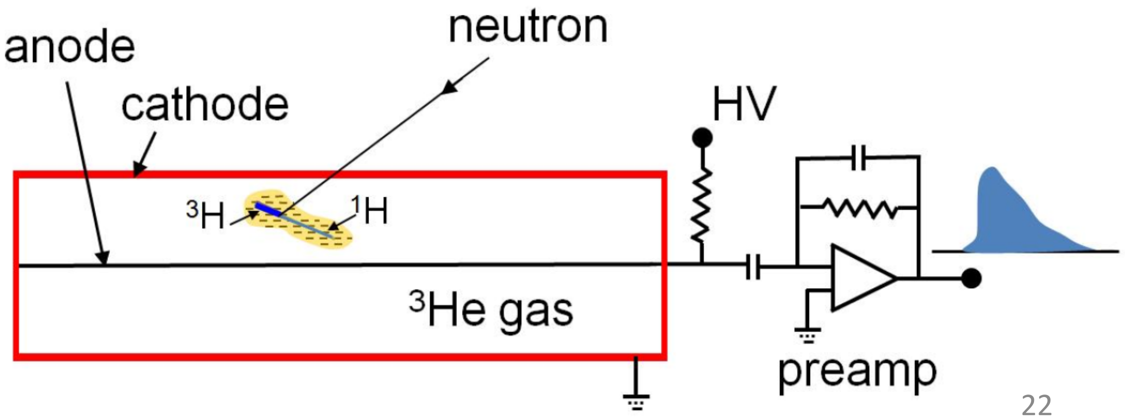


Figure 4.7: Schematic of the optical pumping station used to polarize ^{3}He cells.



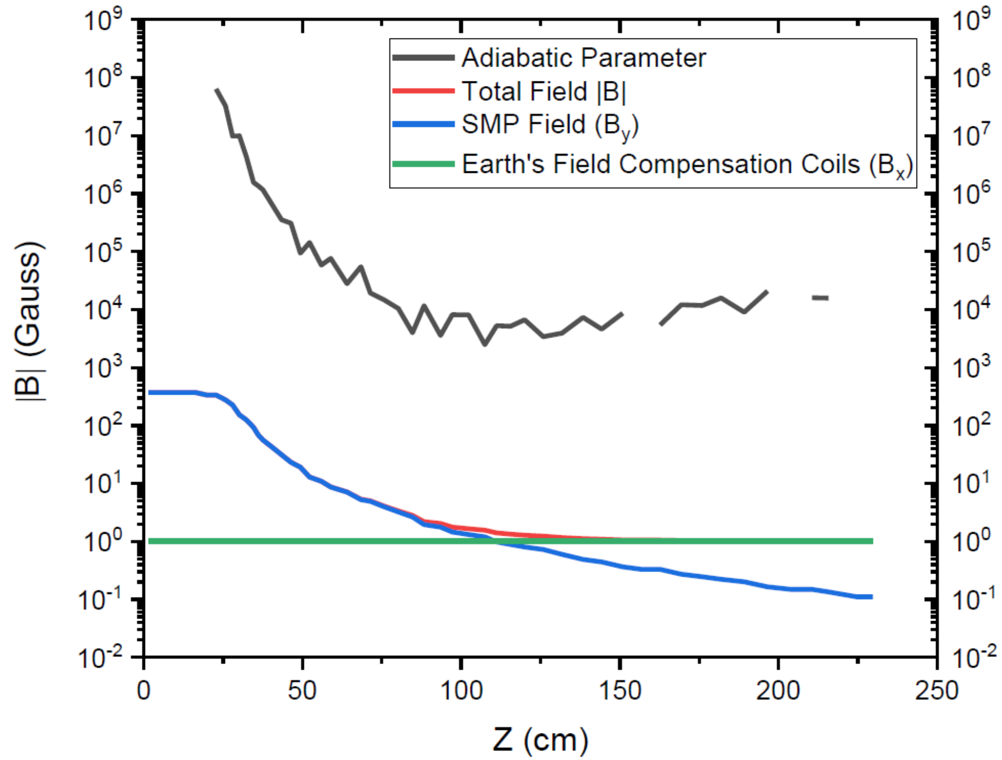
Neutron Detector

- 8 or 6 pack of Reuter Stokes ^3He Gas Filled Proportional Detectors.
- Borrow these from the SNS polarimetry group.
- ^3He counter($n+{}^3He \rightarrow {}^3H+p$)
    - Proton and triton create avalanche multiplication
    - Proportional counters operating in Geiger mode.

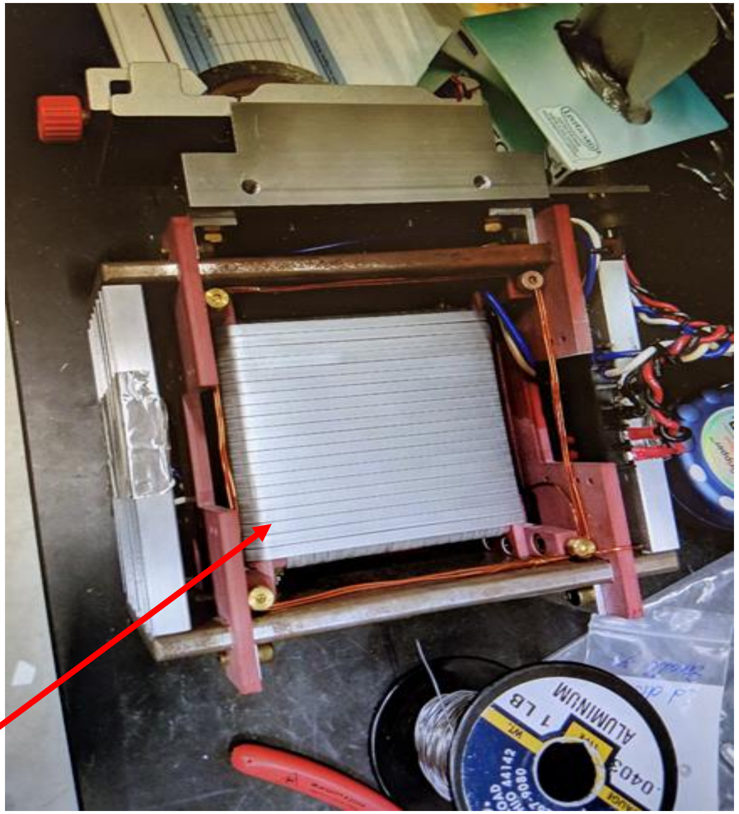


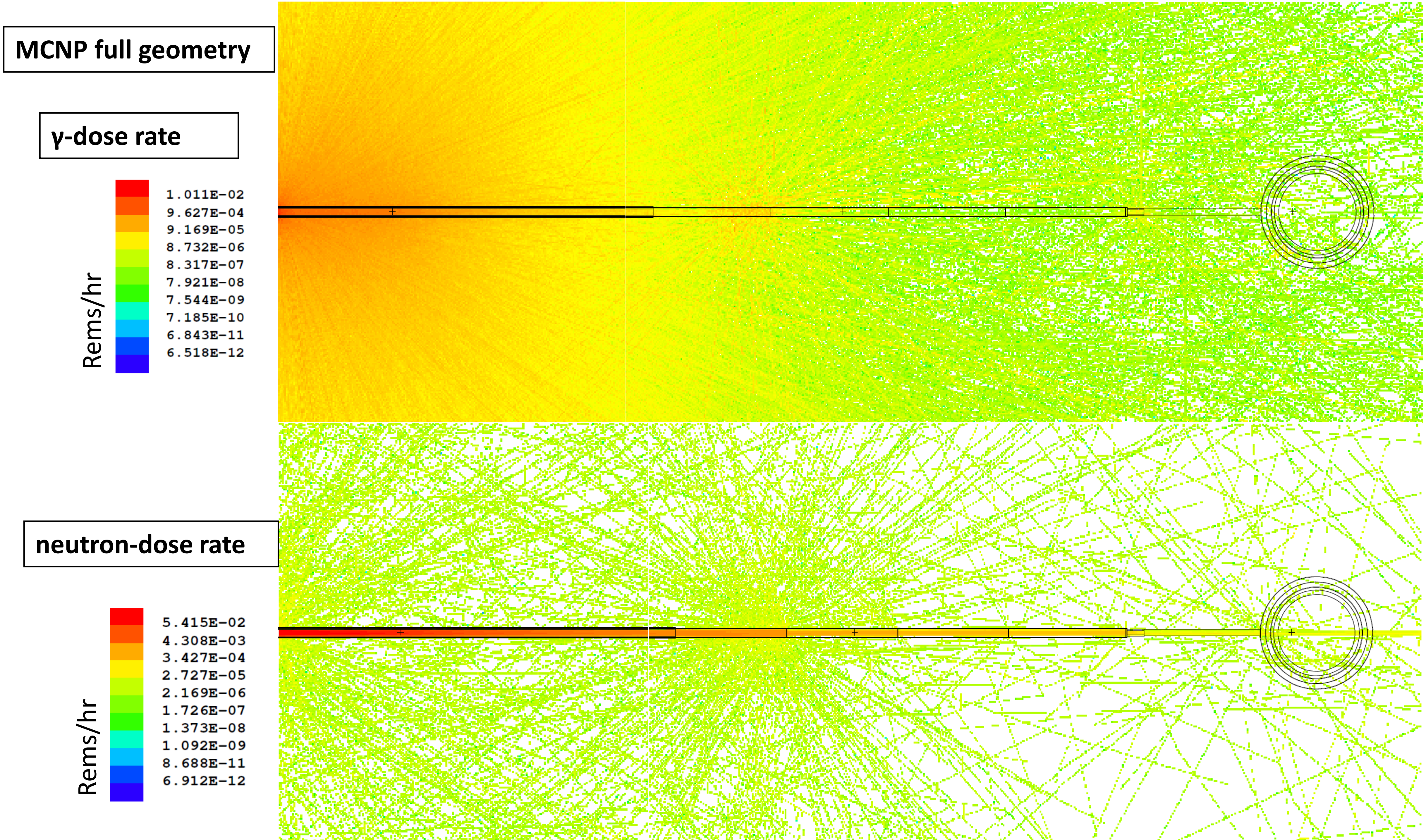
In progress work…

- Building Spin flipper (Mezei coil design in the works)
- Spin precession calculations for adiabaticity.
- MCNP calculations for full experiment in progress.



Windings made from anodized Al




MCNP full geometry
γ-dose rate
Rems/hr
1.011E-02
9.627E-04
9.169E-05
8.732E-06
8.317E-07
7.921E-08
7.544E-09
7.185E-10
6.843E-11
6.518E-12
neutron-dose rate
Rems/hr
5.415E-02
4.308E-03
3.427E-04
2.727E-05
2.169E-06
1.726E-07
1.373E-08
1.092E-09
8.688E-11
6.912E-12

Timeline

- Infrastructure and Beamline installation summer 2020.
- Plan to do neutron scattering and absorption studies when the SNS starts up after summer 2020 shutdown.
- Caltech magnet cryostat arrival late 2020 to early 2021.
- Measurement to start summer 2021.

nEDM@SNS Collaboration

NSF

U.S. DEPARTMENT OF ENERGY

NC Central University

Duke University

TUNL

ASU Arizona State University

University of Kentucky

University of Virginia

Oak Ridge National Laboratory

Universidad Nacional Autónoma de México

Bartoszek Engineering

Illinois — University of Illinois at Urbana-Champaign

Massachusetts Institute of Technology

California Institute of Technology

Los Alamos National Laboratory

Mississippi State University

The University of Tennessee Knoxville

NC State University

SFU Simon Fraser University

Tennessee Tech

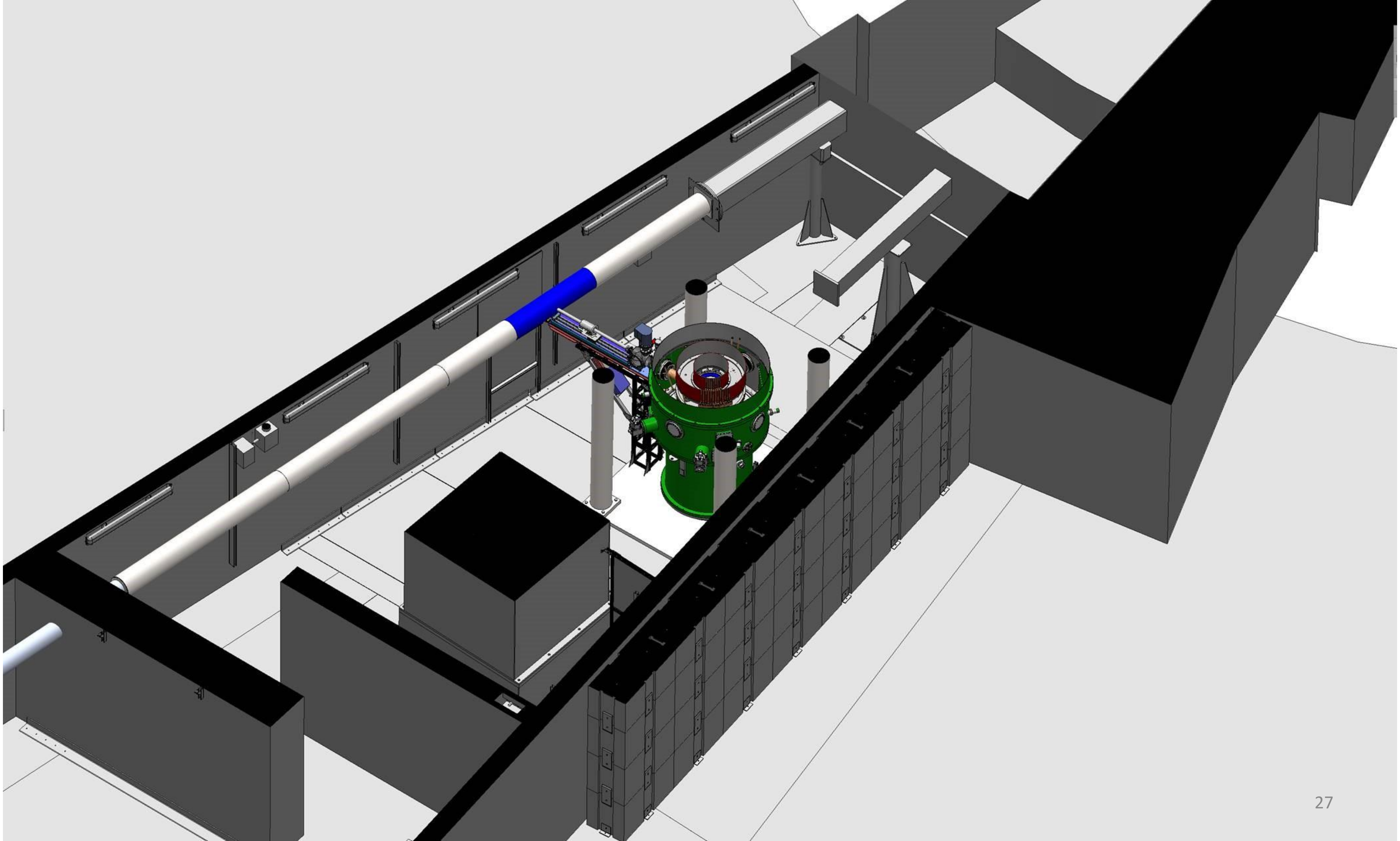
Indiana University

Yale University

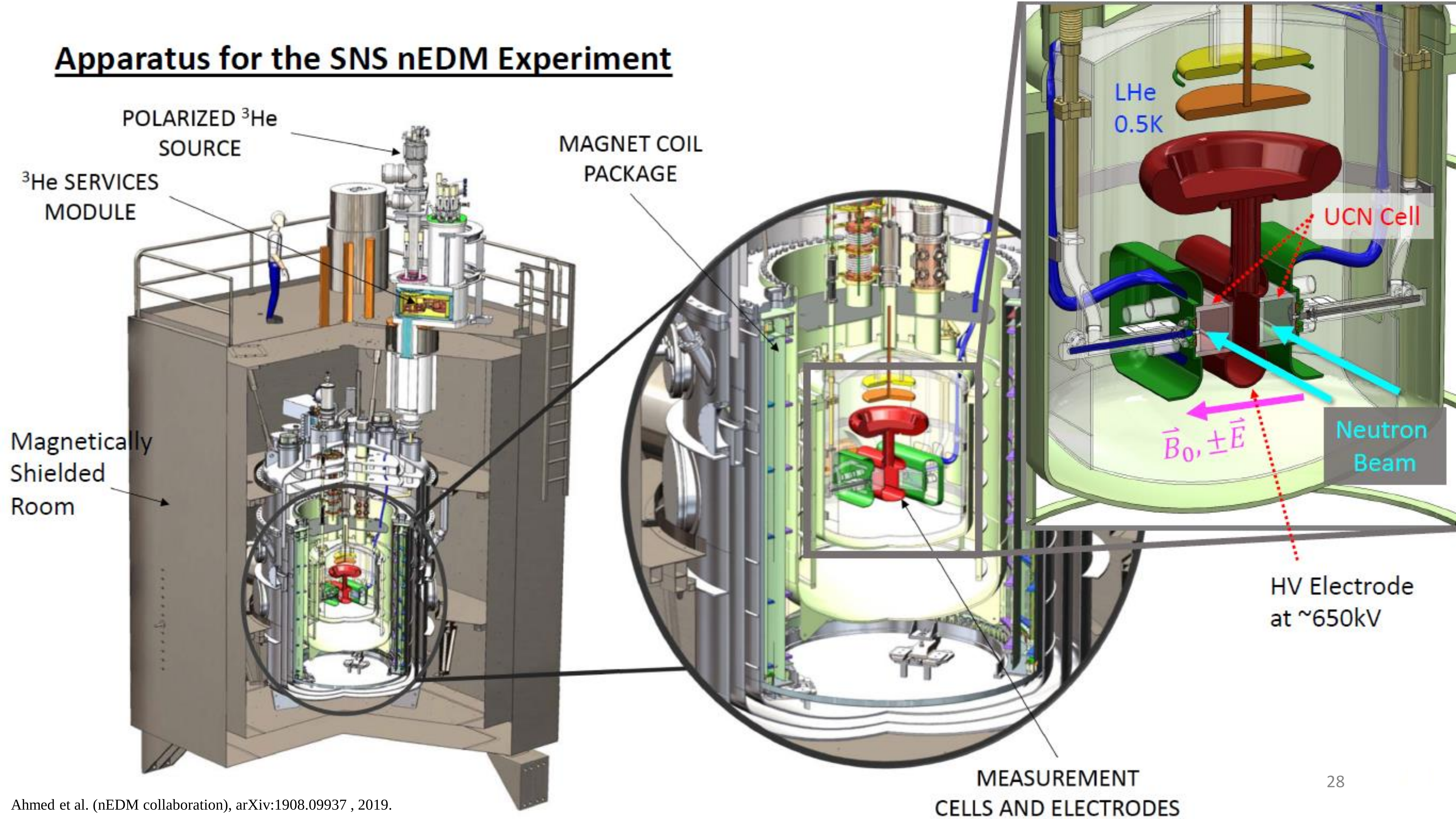
Brown University

Harvard University

Valparaiso University

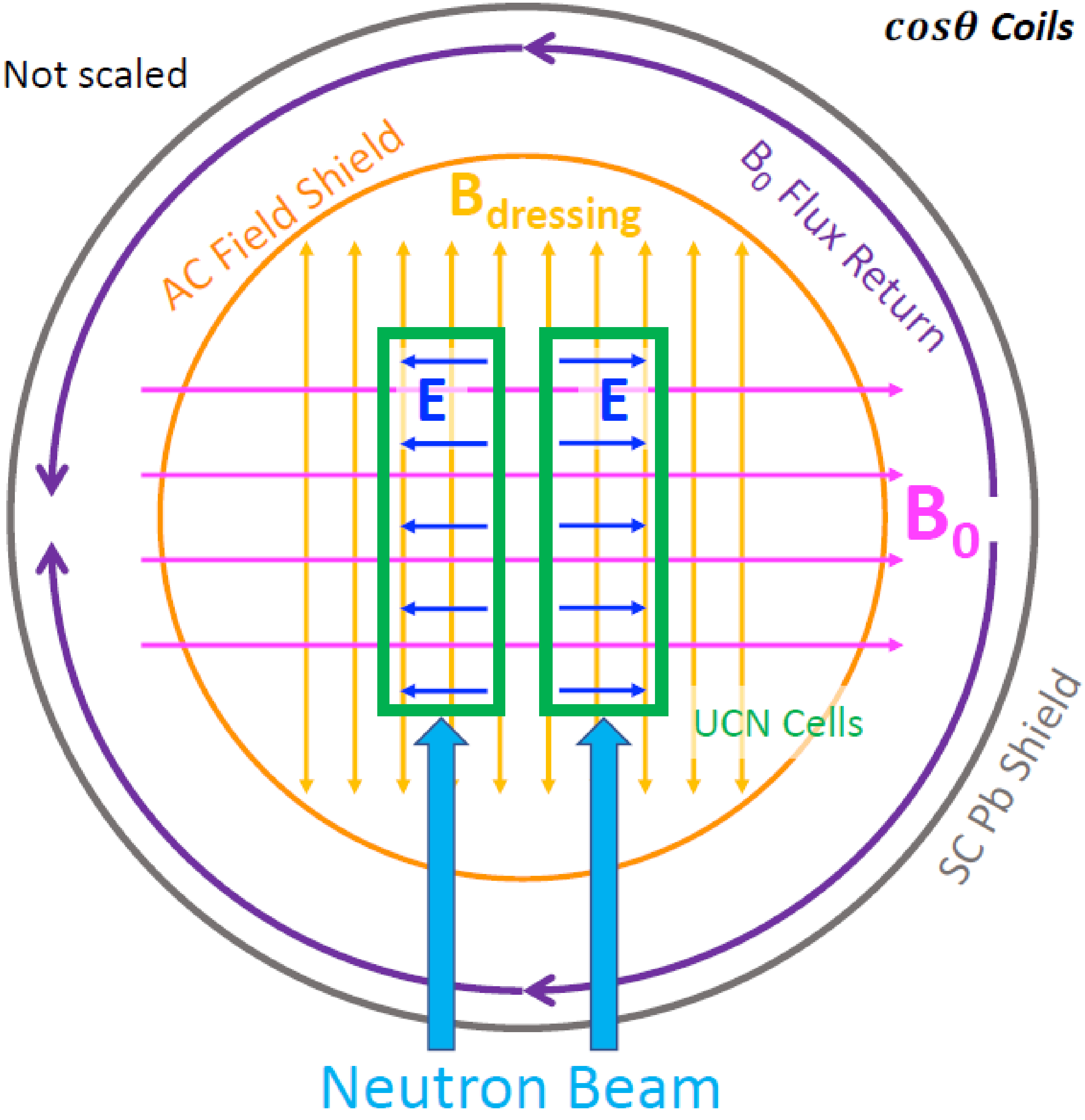


Apparatus for the SNS nEDM Experiment



Ahmed et al. (nEDM collaboration), arXiv:1908.09937 , 2019.

Illustration of the Magnetic Fields



B_0 Coil: (Superconducting Cu-clad NbTi wire)

30 mG and uniformity of 3 ppm/cm

uniformity is crucial for the transverse coherence time T_2 of UCN and helium-3

Dressing Coil: (Superconducting Ti/Pb Solder Wire)

AC field < 0.5 G and uniformity of 45 ppm/cm

also used as $\pi/2$ spin flip

Superconducting Pb Shield:

Further shield the ambient environmental magnetic fields and stabilize the magnetic drifts over the measurement time

B_0 Flux Return:

Metglas 2826M, location accuracy < 1 mm

improve field uniformity, mitigating the effect of errors in wire placement and reducing field distortions due to the cylindrical superconducting shield just outside of this shield

AC Field Shield:

A copper film shields the Metlas from heating of the dressing field