Optimization of ^{3}He Neutron Spin Filters for the Neutron Spin Echo Spectrometer

Hannah Burrall

NIST

CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NIST

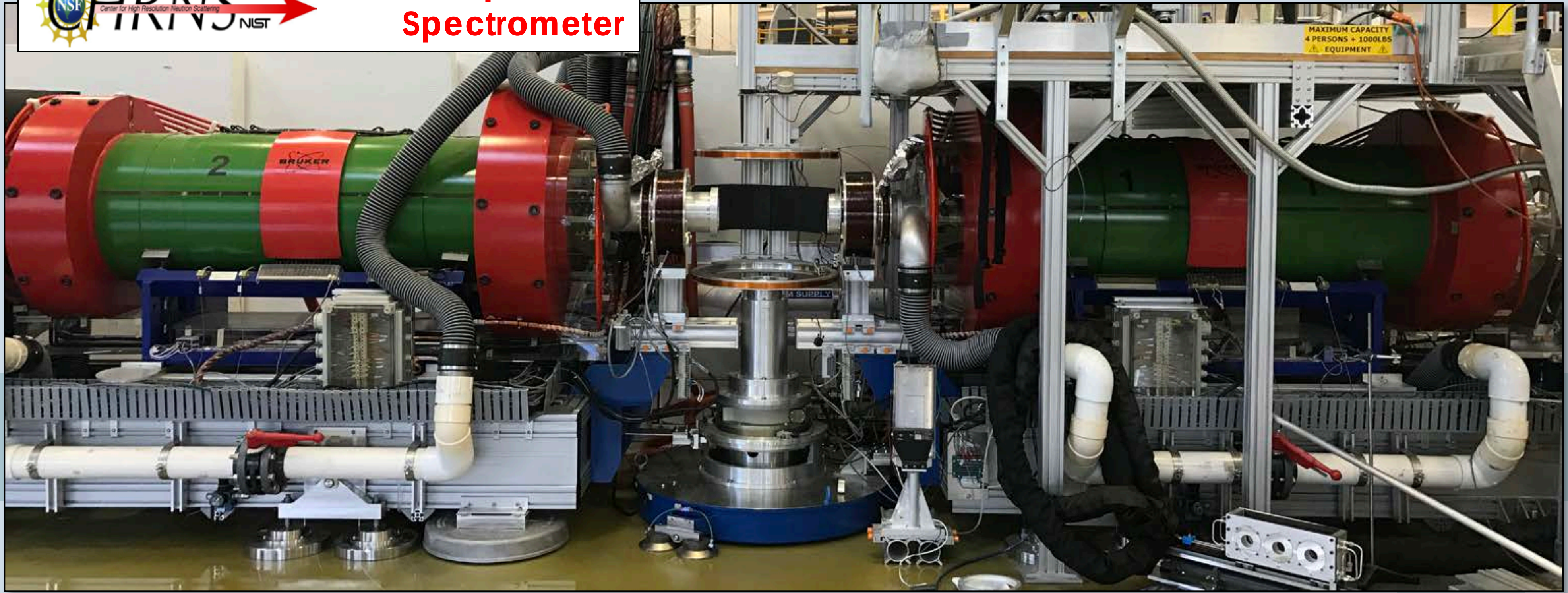
Hamilton

Presentation Overview

- Motivation
- Background
  - What is a neutron spin filter (NSF)?
  - Why use NSF?
- Developing ^{3}He polarizer and analyzer
- Optimization techniques
- Applications on *CHRNS* Neutron Spin Echo (NSE) Spectrometer
- Closing Remarks

Project Motivation

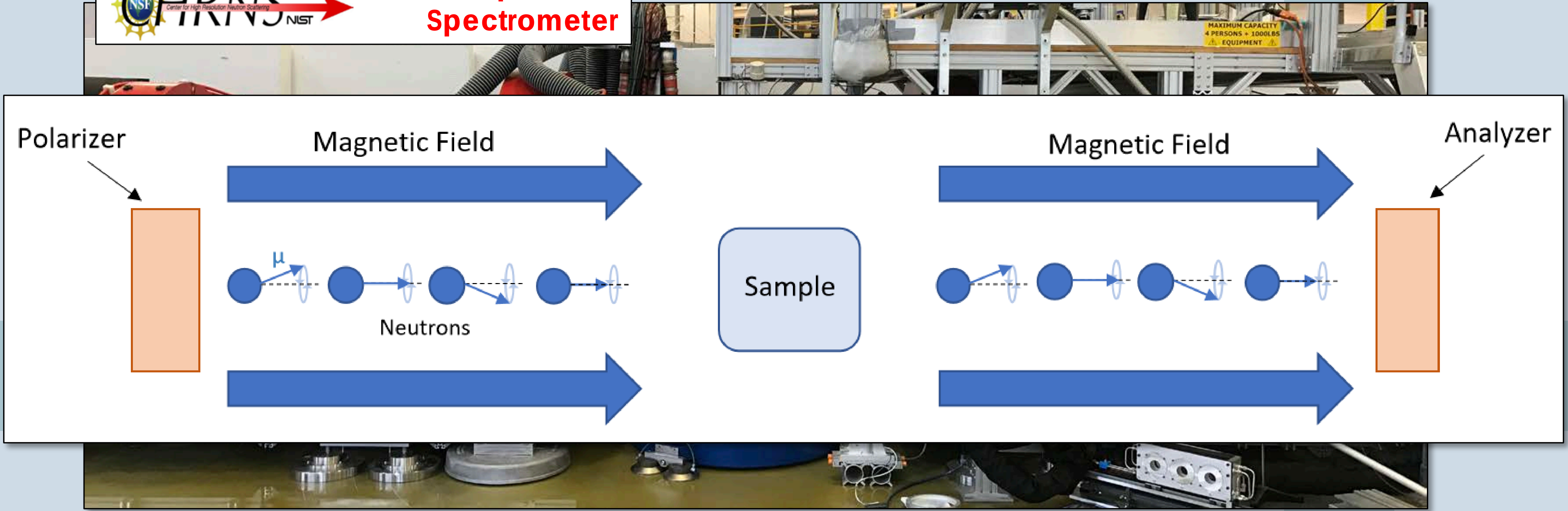
Neutron Spin Echo Spectrometer



Project Motivation

NIST Center for Neutron Research

CHRNS Neutron Spin Echo Spectrometer



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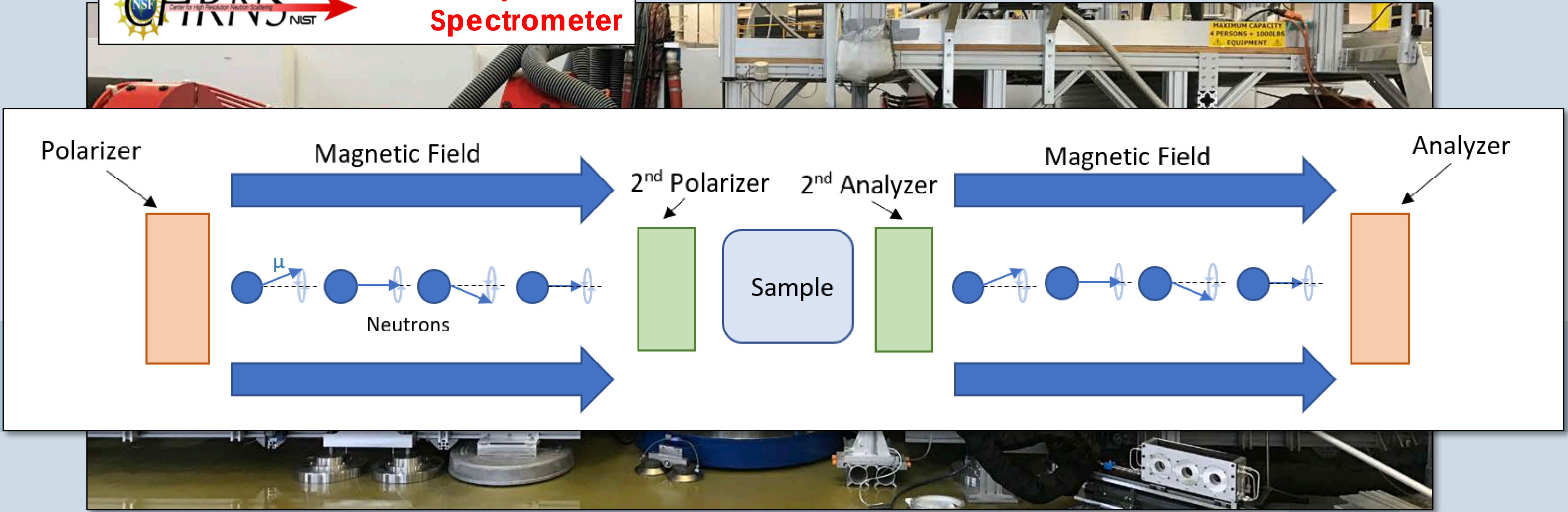
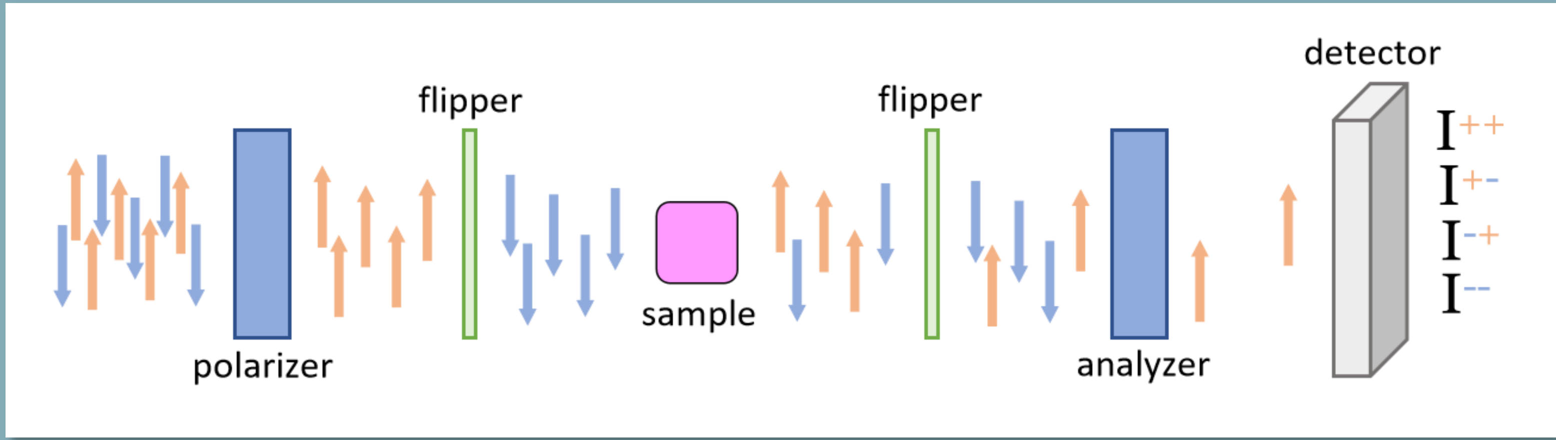
Project Motivation

Neutron Spin Echo Spectrometer



Polarized Neutron Scattering

Cross Sections: ↑↑ ↑↓ ↓↑ ↓↓



Moon et al, Phy. Rev.181, 920 (1969)

- Study magnetic systems
- Measure four cross sections
  - Example: ↑↓
    - Polarize spin-up
    - Collect spin-down
- Separate magnetic scattering from nuclear scattering

(Polarization analysis)

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Slide courtesy of Joelle Baer

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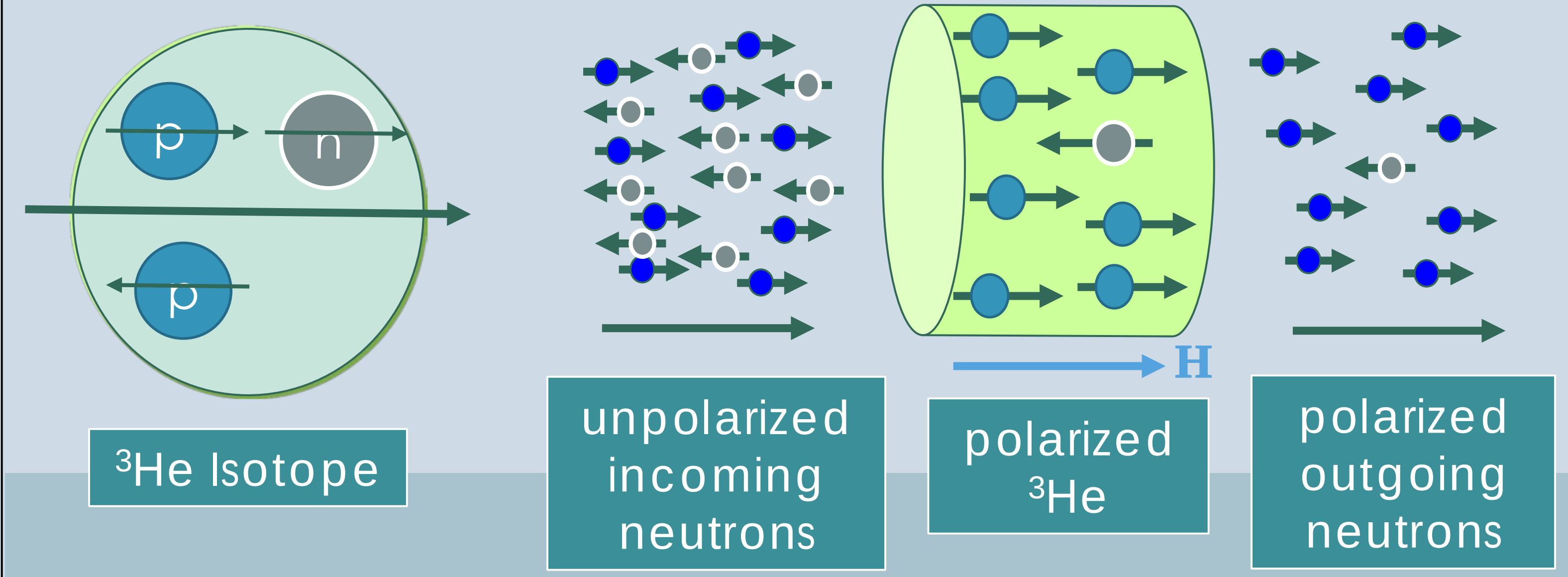
Neutron Spin Filter (NSF)



K.P. Coulter et al, NIM A 288, 463 (1990)

- Neutron Spin Filters:
  1. Polarize broad wavelength band of neutrons
  2. Polarize larger & widely divergent neutron beams
  3. Integrate polarizer and flipper capabilities
- Strong spin-dependent neutron absorption cross section

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What is a ^{3}He Cell?

- Boron-free aluminosilicate GE180 glass container
- Filled with pressurized ^{3}He
- Combination of Rb/K distilled metals
- Variety of shapes & sizes

Blush

Reliance

Mozart

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Polarizing the Cell

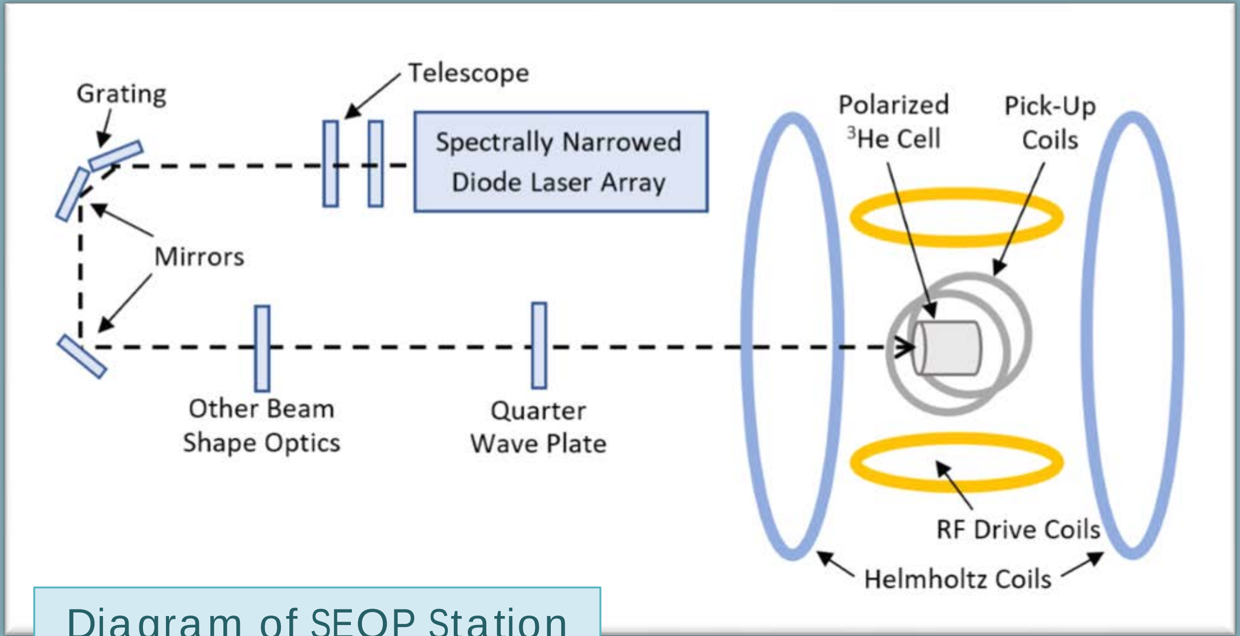

Diagram of SEOP Station

Schematic from Wangchun Chen

Spin-Exchange Optical Pumping (SEOP)

1. Polarize rubidium (Rb)/potassium (K) electrons
2. Spin exchange between Rb/K and ^{3}He nuclei

- Heat ^{3}He cell to vaporize Rb/K
- Fully illuminate near infrared laser light on cell
- Photons excite electrons in the metal

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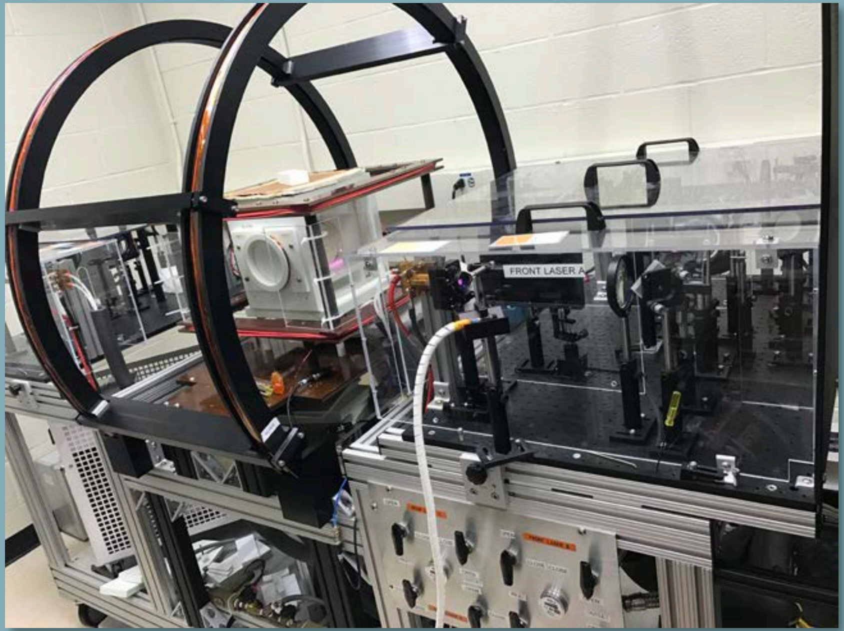
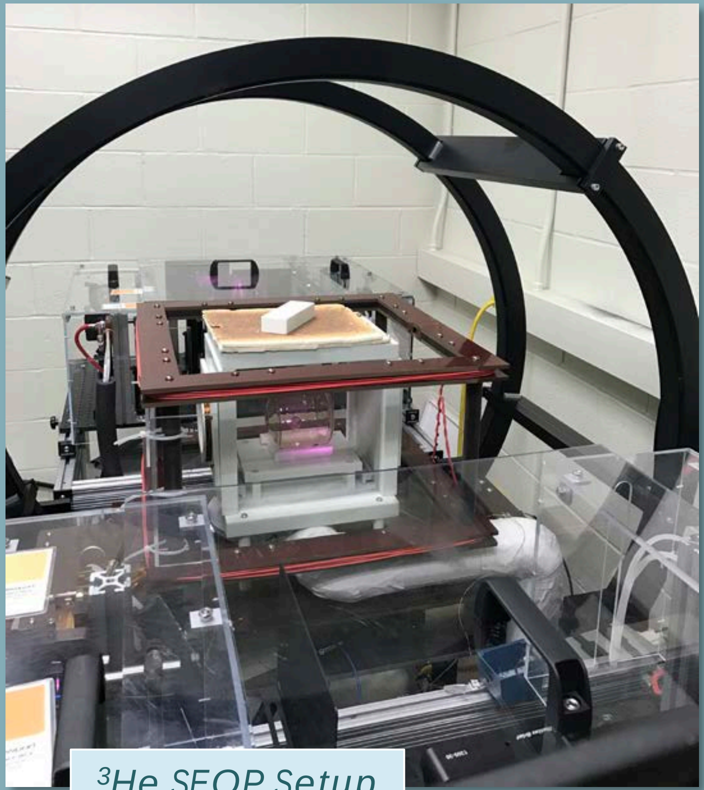
Polarizing the Cell

- Hyperfine interaction between Rb/K and ^{3}He
- Cool cell before moving to beamline
- 1-2 days to prep for experiment





^{3}He SEOP Setup

Magnetically Shielded Solenoid

- Optimize ^{3}He cell lifetime
  - $T_1^{d\text{-}d}$ - Dipole-dipole
  - T_1^{wall} - Cell wall
  - T_1^{fg} - Field gradient

$$\frac{1}{T_1} = \frac{1}{T_1{}^{d-d}} + \frac{1}{T_1{}^{wall}} + \frac{1}{T_1{}^{fg}}$$

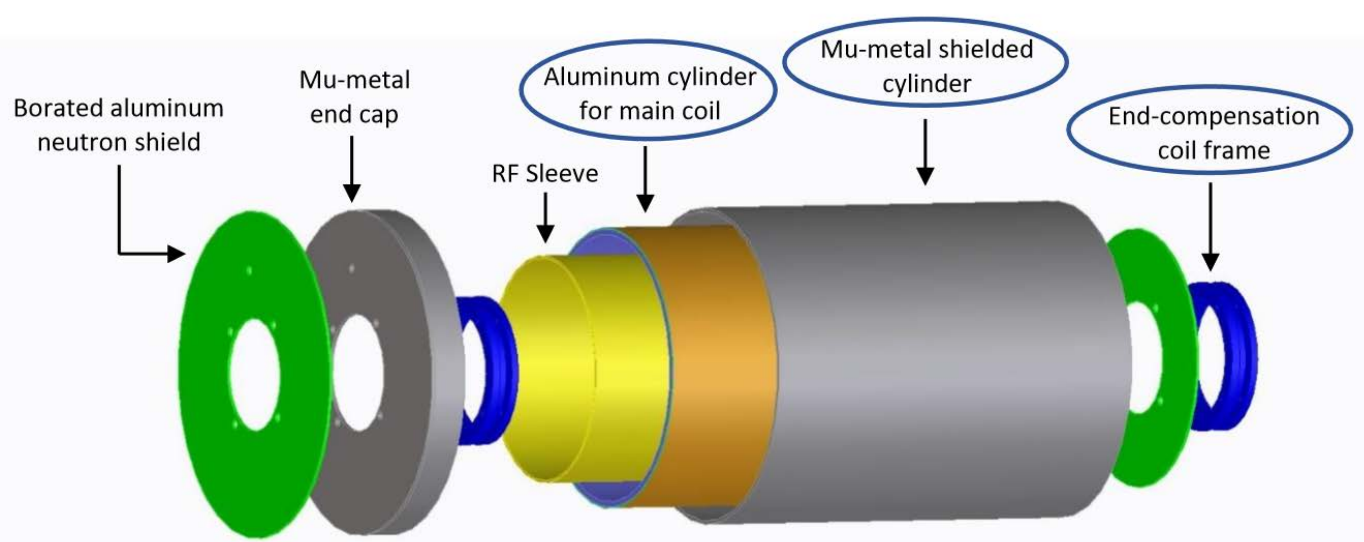


Diagram of Magnetically Shielded Solenoid

Diagram from M. T. Hassan

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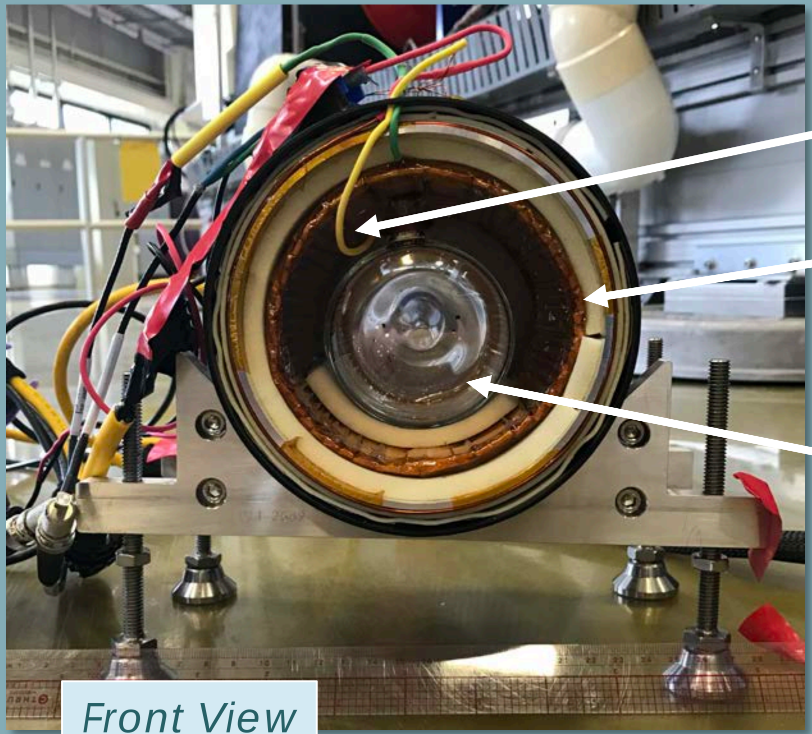
Magnetically Shielded Solenoid

Side View



Front View

NMR Coil

RF Sleeve

^{3}He Cell

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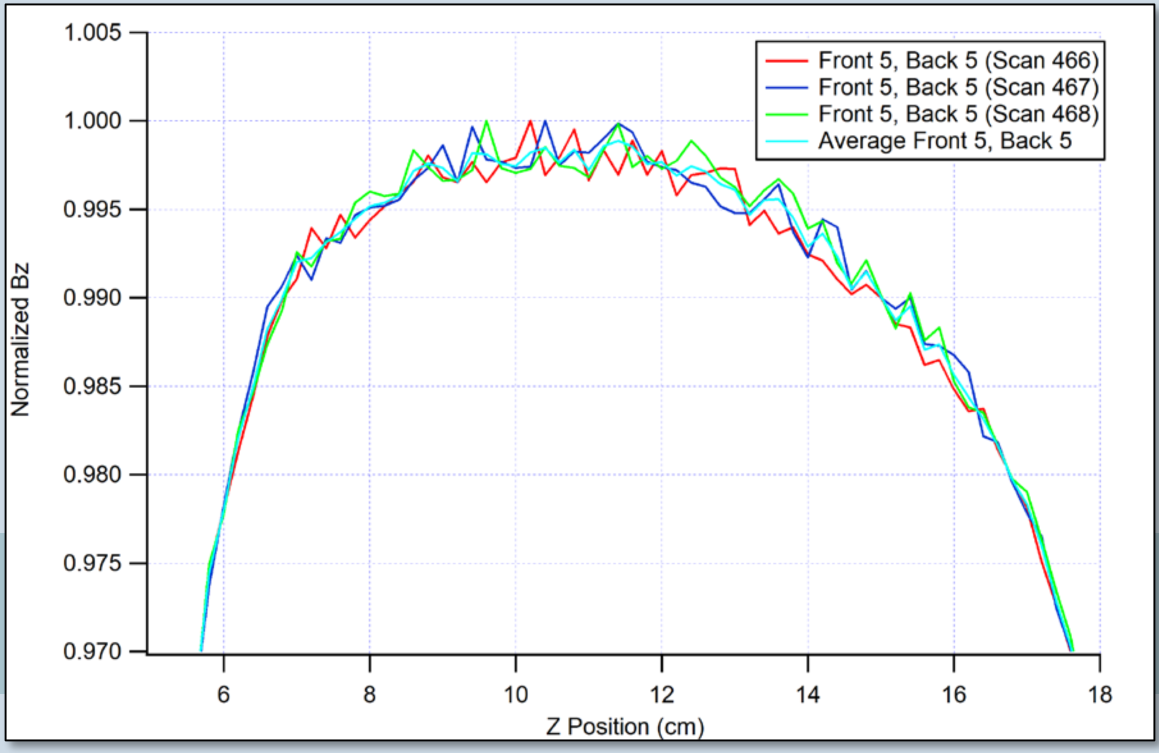
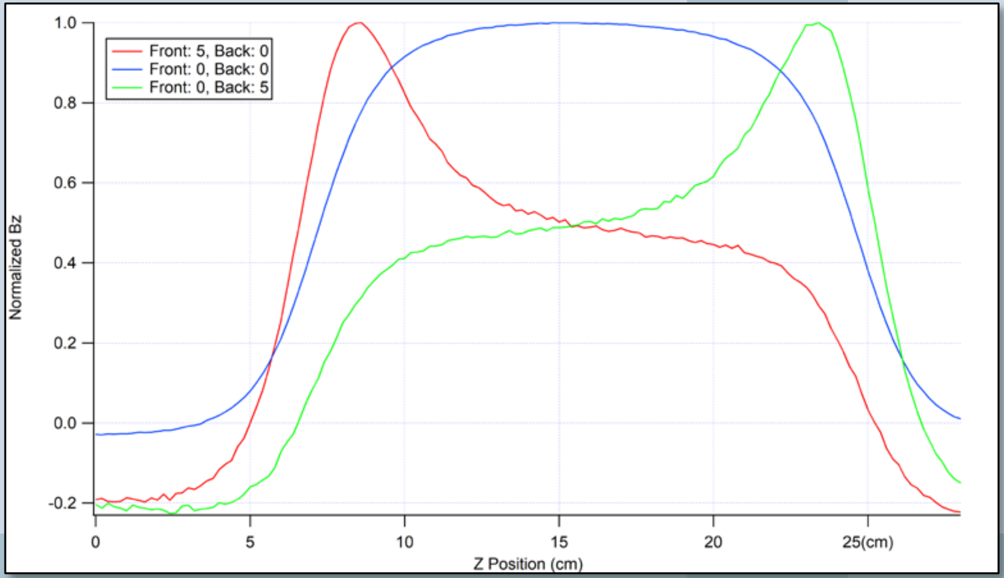
Optimization of End Compensation

- Computer controlled mapping system
- 3-axis Hall probe & Fluxgate magnetometer
- Axial & vertical translation

Field Mapping Setup

Optimization of End Compensation





- Scan length of device plus 3 cm on either side (0-24 cm)
- Take B-Field measurement every 0.2 cm

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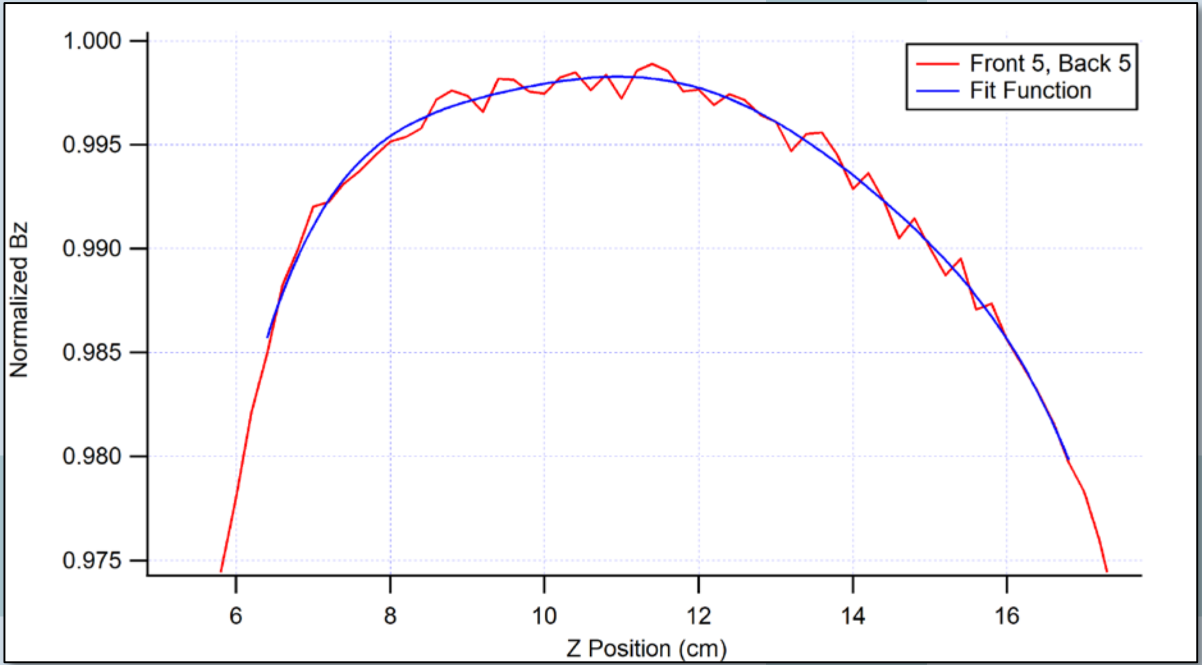
Optimization of End Compensation

- Fit scan with a superposition of three Gaussian functions

$$y_0 + A_1 e^{-\frac{(x-x_1)^2}{{w_1}^2}} + A_2 e^{-\frac{(x-x_2)^2}{{w_2}^2}} + A_3 e^{-\frac{(x-x_3)^2}{{w_3}^2}}$$



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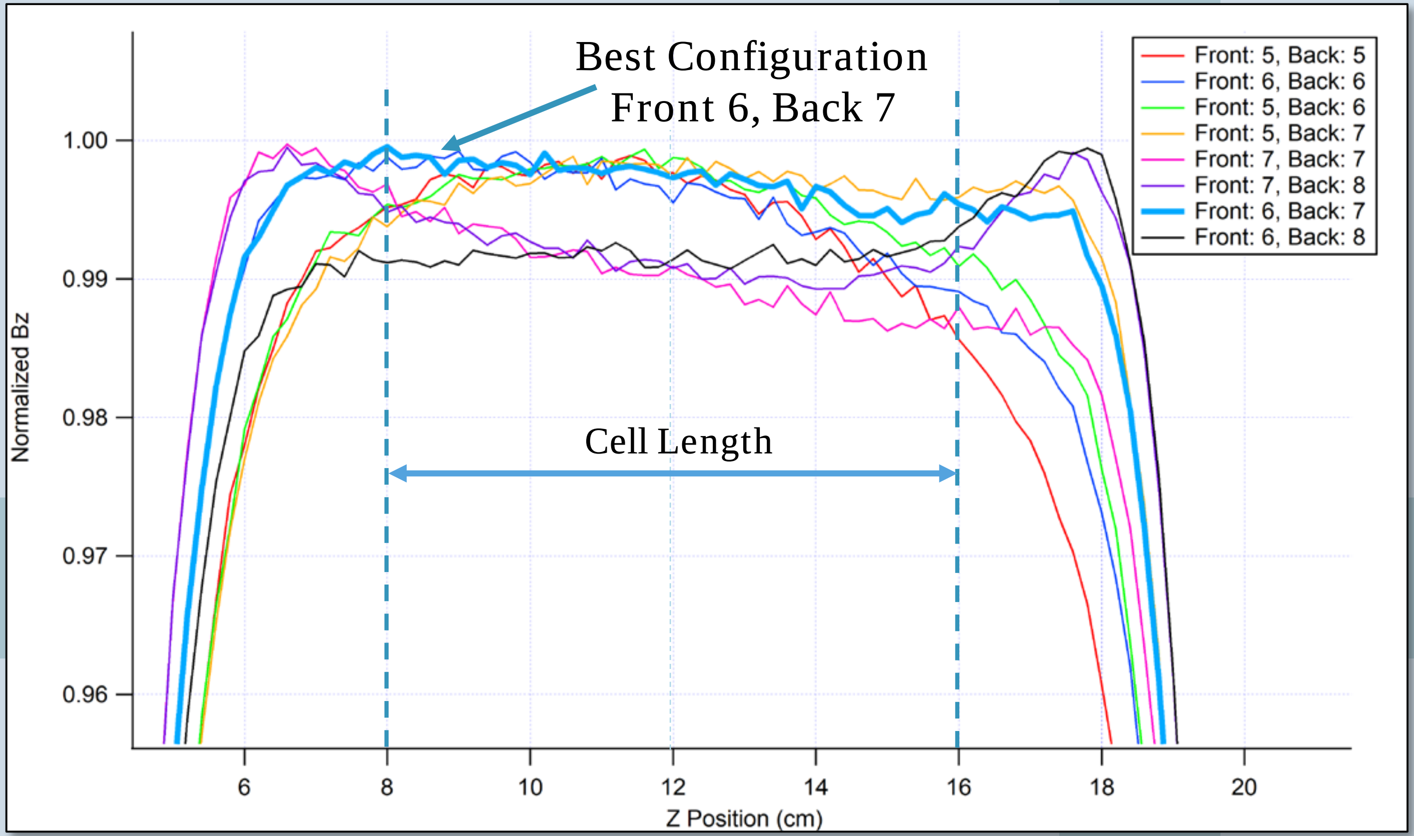
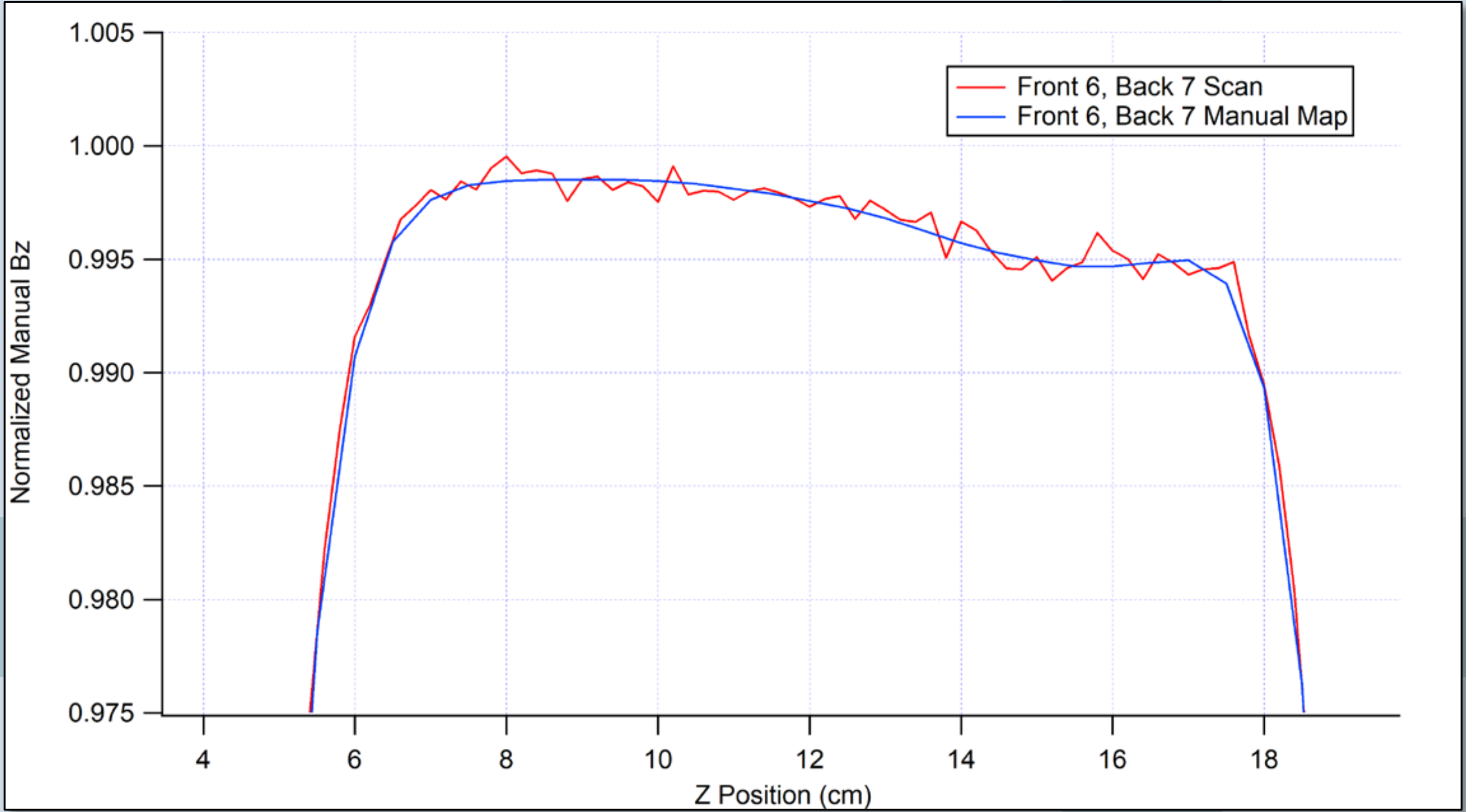
Optimization of End Compensation

- Scan multiple end compensation winding configurations
  - Vary number of turns
- Calculate field gradient (8 – 16 cm)



Optimization of End Compensation

- Manual maps limit noise from DAQ
- Gradient: $\left|\frac{\partial Bz/\partial x}{B}\right|$
  - Scan: 5.6 x 10^{-4} cm^{-1}
  - Manual: 4.8 x 10^{-4} cm^{-1}



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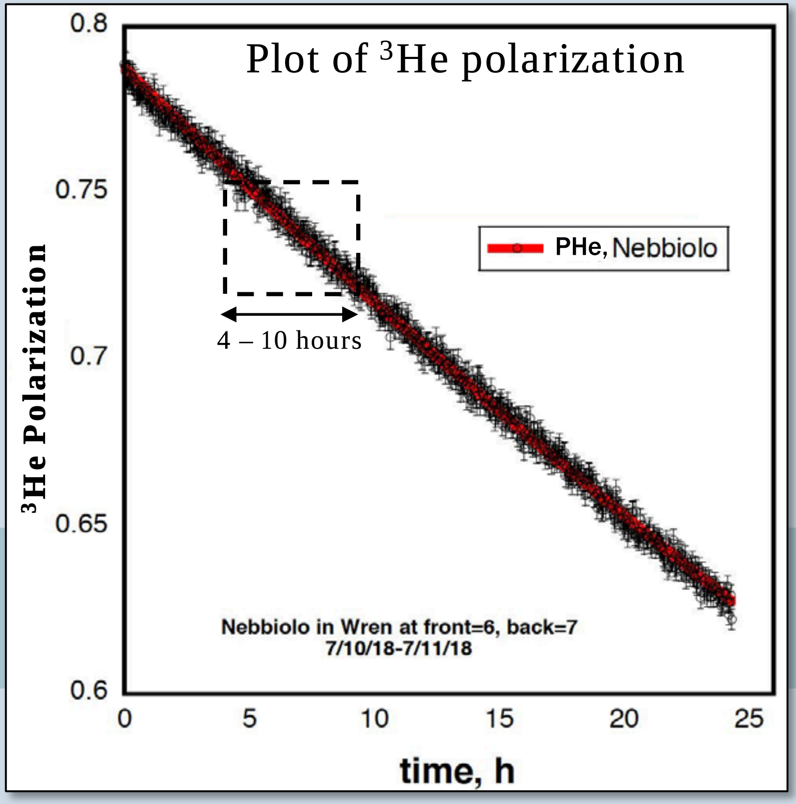
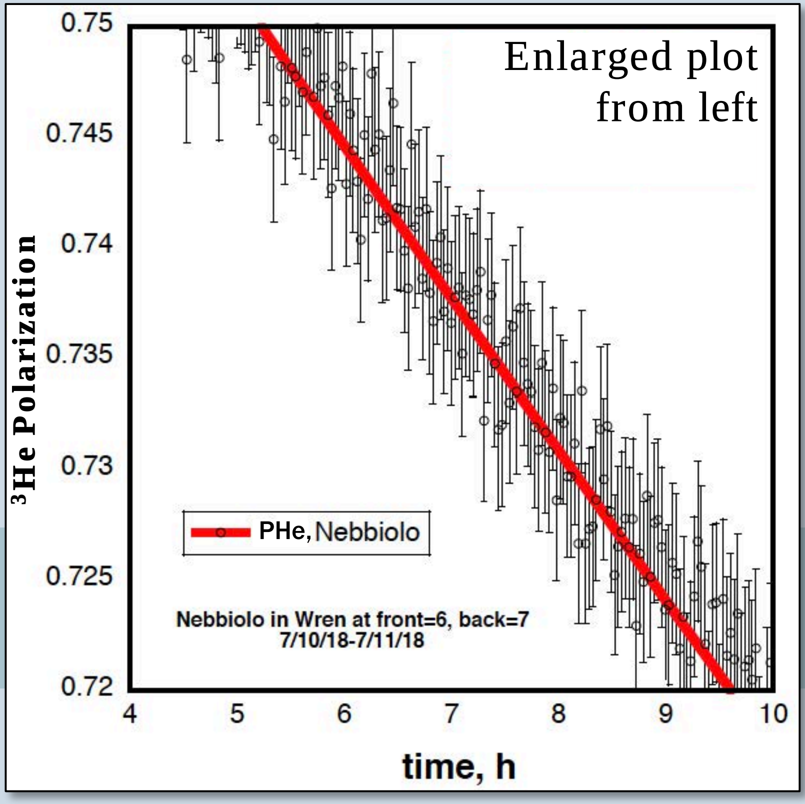
Testing the Cell Lifetime





- Characterize field gradients on PHADES neutron beamline
- Cell lifetime: 107.4 ± 0.2 hours
- Confirms previous optimization results
  - Front 6, Back 7

$$\frac{1}{T_1} = \frac{1}{{T_1}^{d-d}} + \frac{1}{{T_1}^{wall}} + \frac{1}{{T_1}^{fg}}$$

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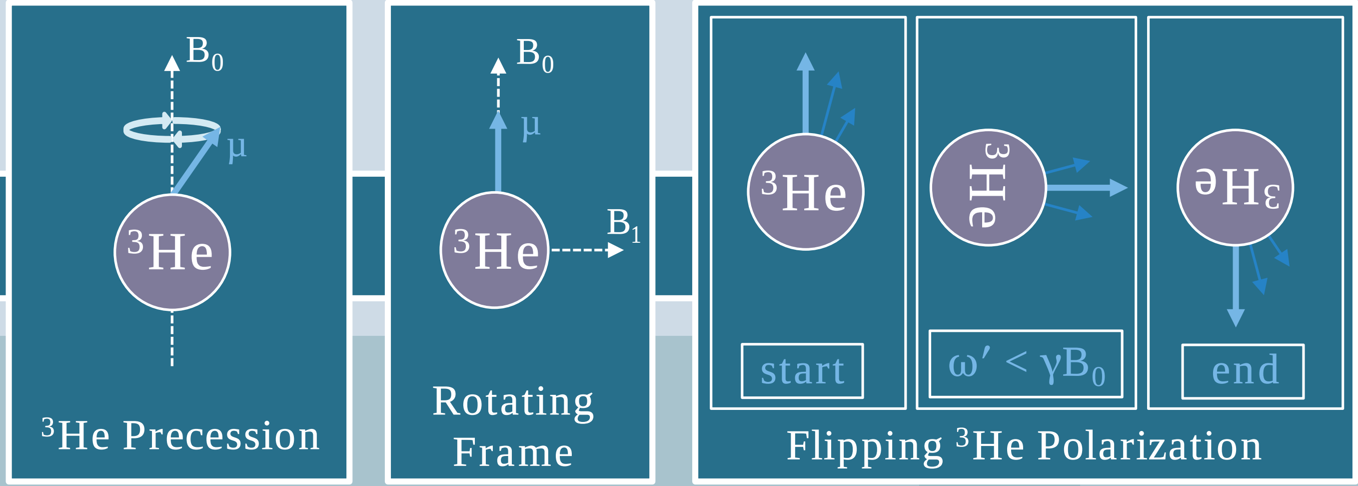
Flipping the ^{3}He Cell Polarization

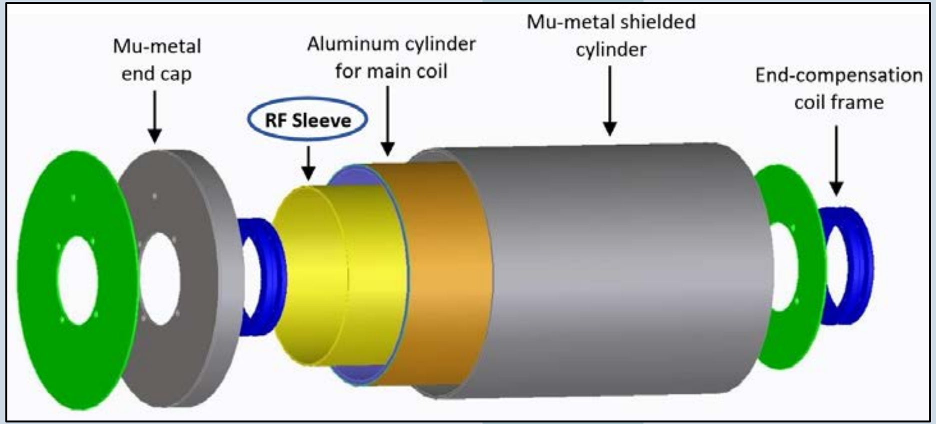
- ^{3}He magnetic moment (μ) precess about B_0
  - Larmor Frequency: $\omega = \gamma B_0$
- Oscillating B_1 orthogonal to B_0 causes μ to precess about B_1
- Adiabatic Fast Passage (AFP) Condition
  - Rotation rate (ω') << Larmor Frequency (ω)

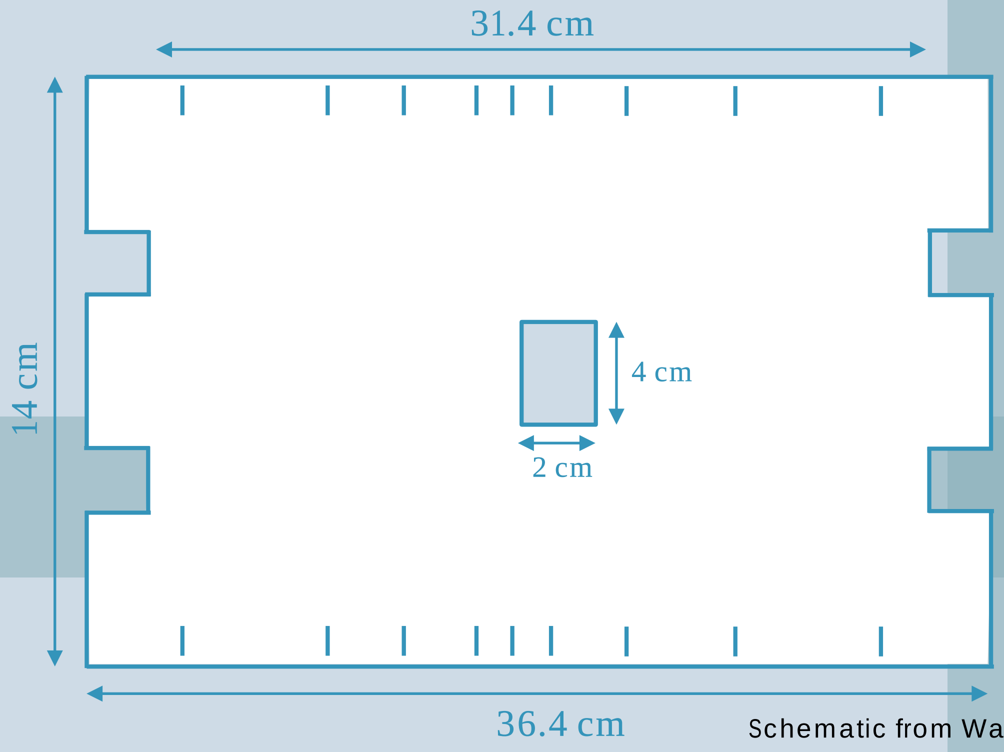


Schematic from Joelle Baer

Building the RF Sleeve

- Sheet of Teflon rolled into a cylinder
- 8 cm^2 hole for cell tip-off
- 2.5 cm on either end for interlocking tabs
- ~0.5 cm slits in sinusoidal distribution





Schematic from Wangchun Chen

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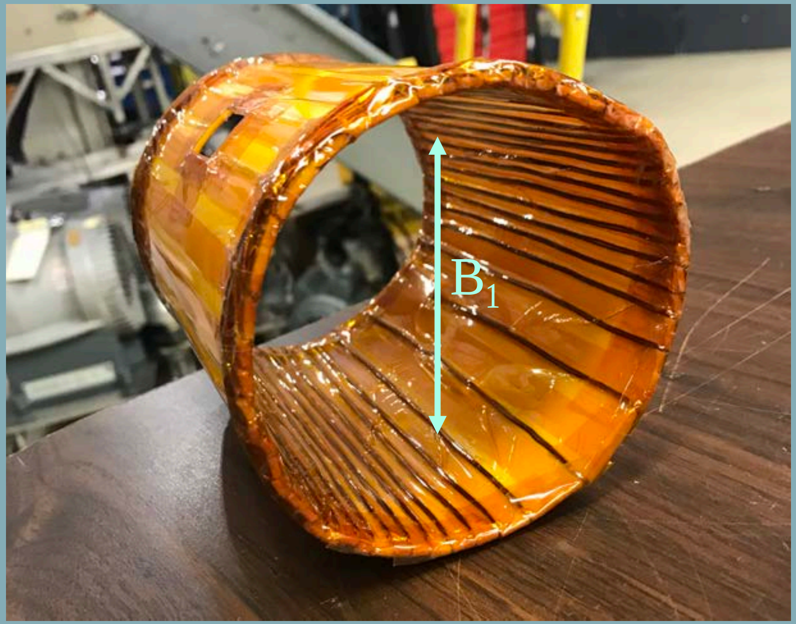
Building the RF Sleeve



- 48 slits wound with 22 AWG Cu wire
- Unique sinusoidal winding pattern
- Right Hand Rule
- Creates B Field (B_1) orthogonal to main field (B_0)

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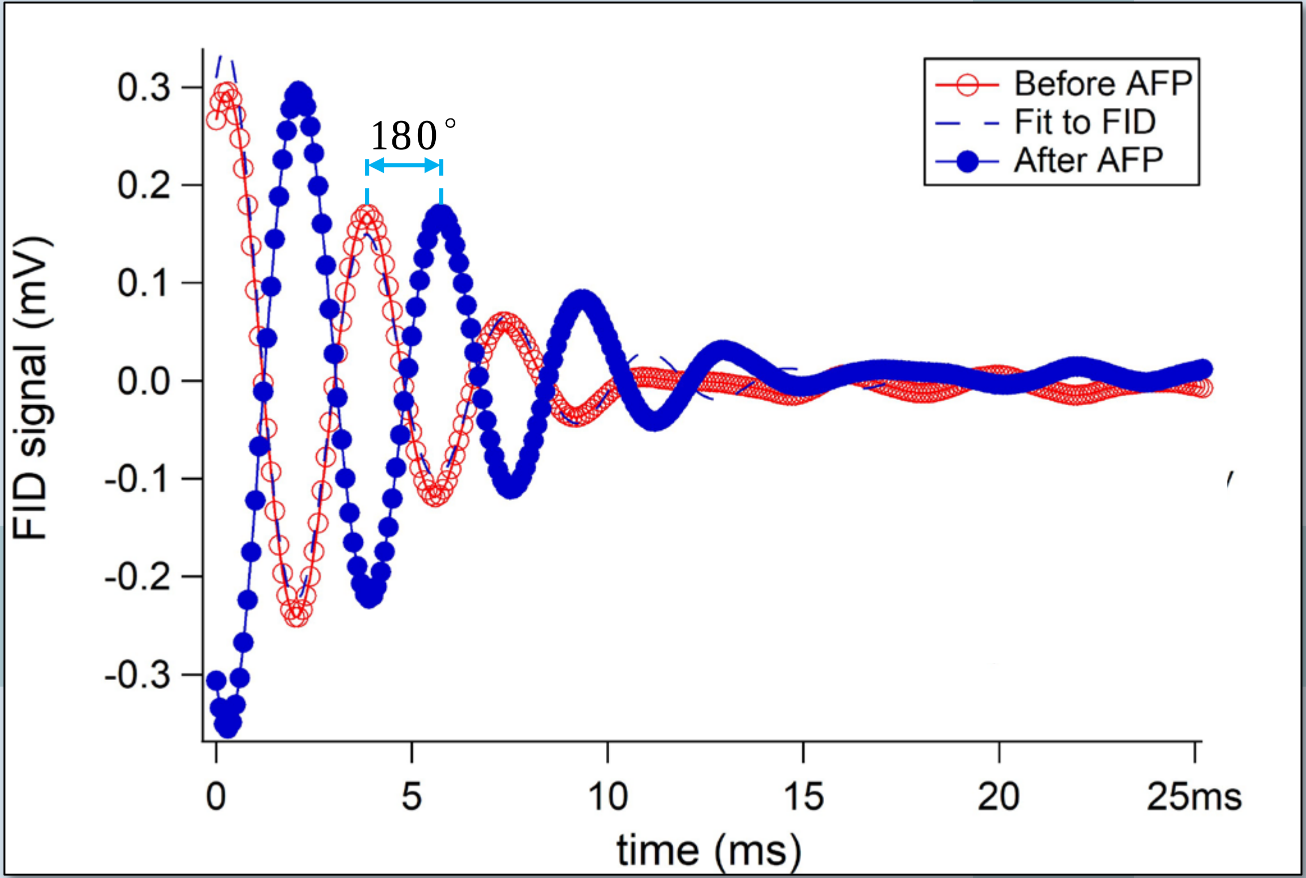
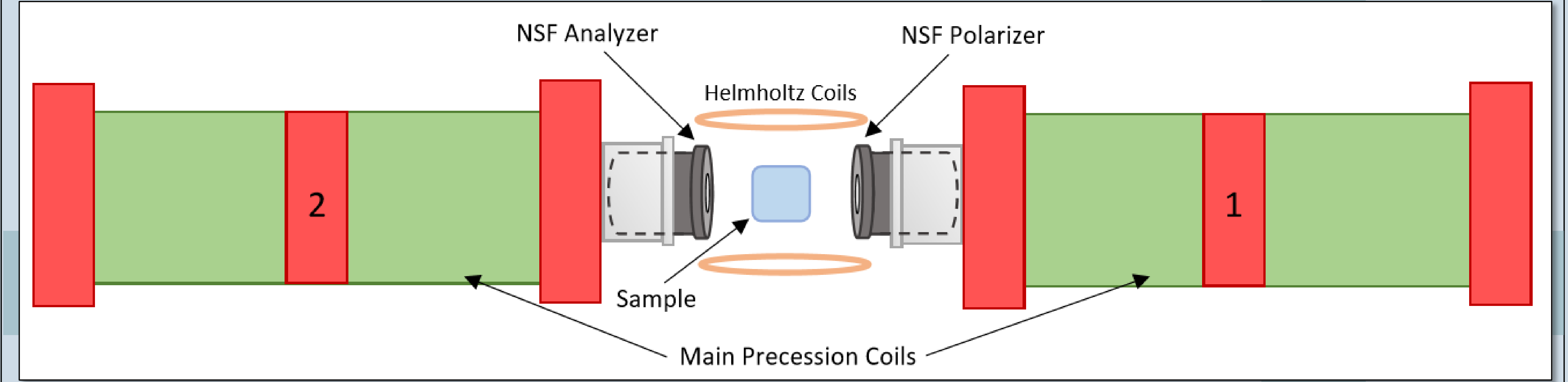
Testing the RF Sleeve

- Free Induction Decay (FID) Signal from NMR pick-up coil
- 180° phase shift after AFP inversion
- 4 x 10^{-4} loss in polarization



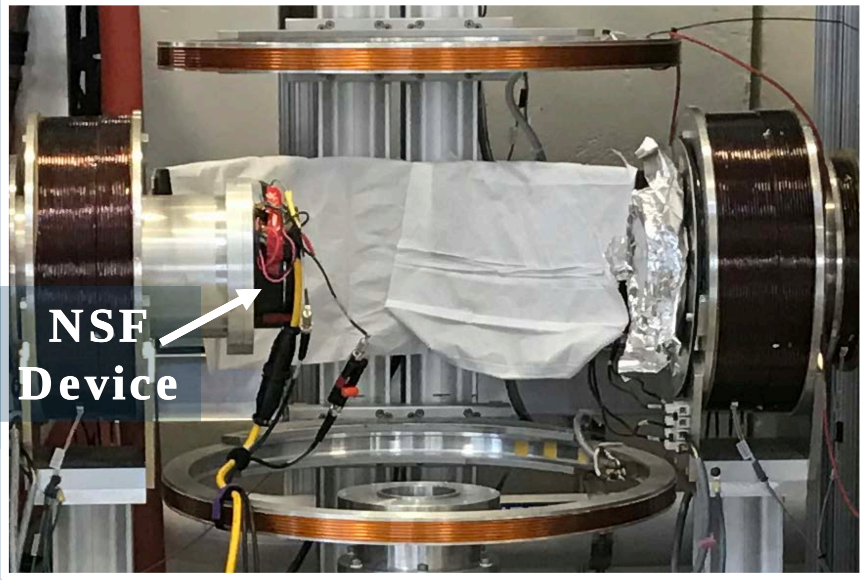
Application on NSE Spectrometer

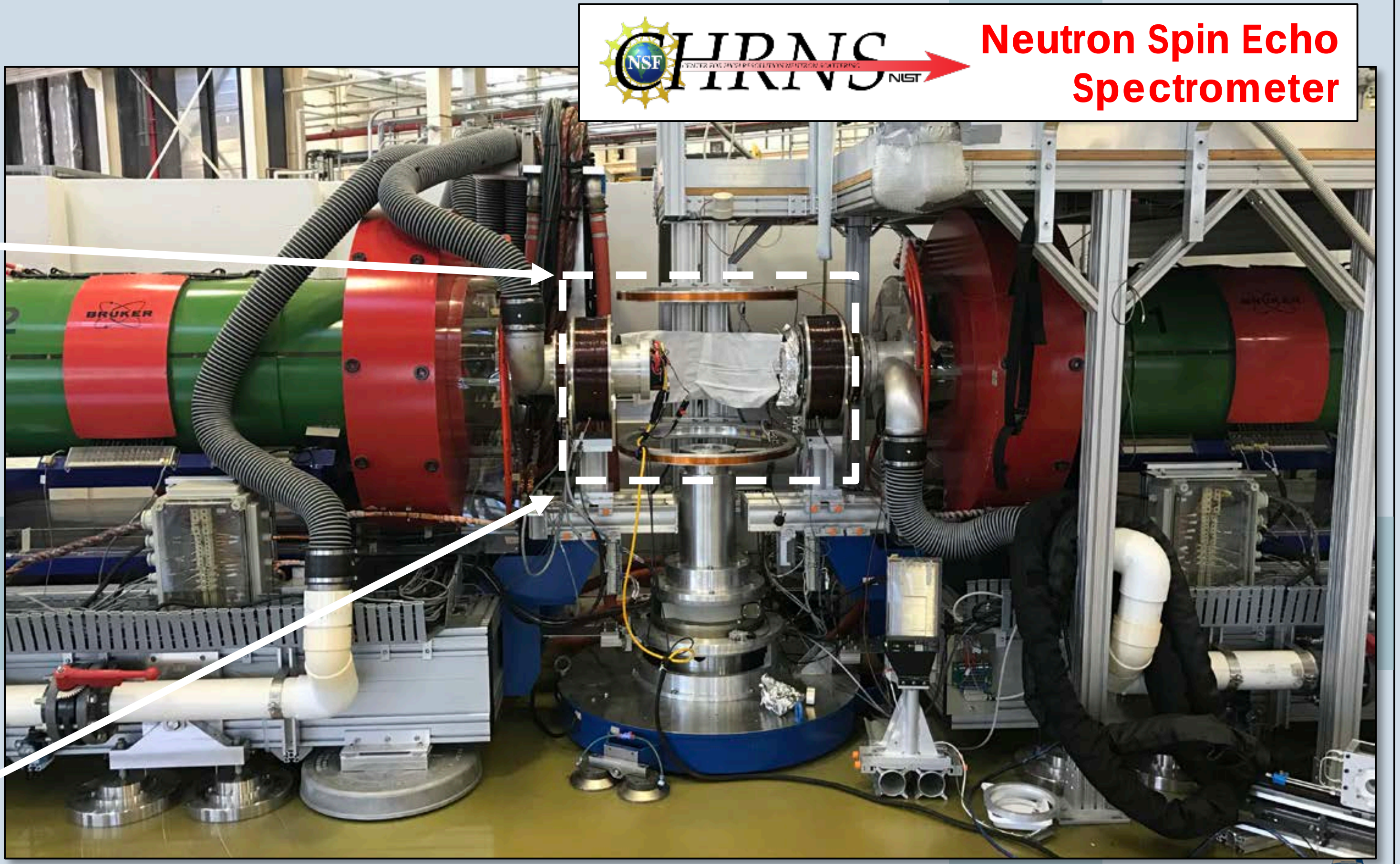
Neutron Spin Echo Spectrometer



Application on NSE Spectrometer

- New measurement capability
  - Intensity Modulated Neutron Spin Echo Spectroscopy





Acknowledgements

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NIST SURF Program

Fellow SURFers!!

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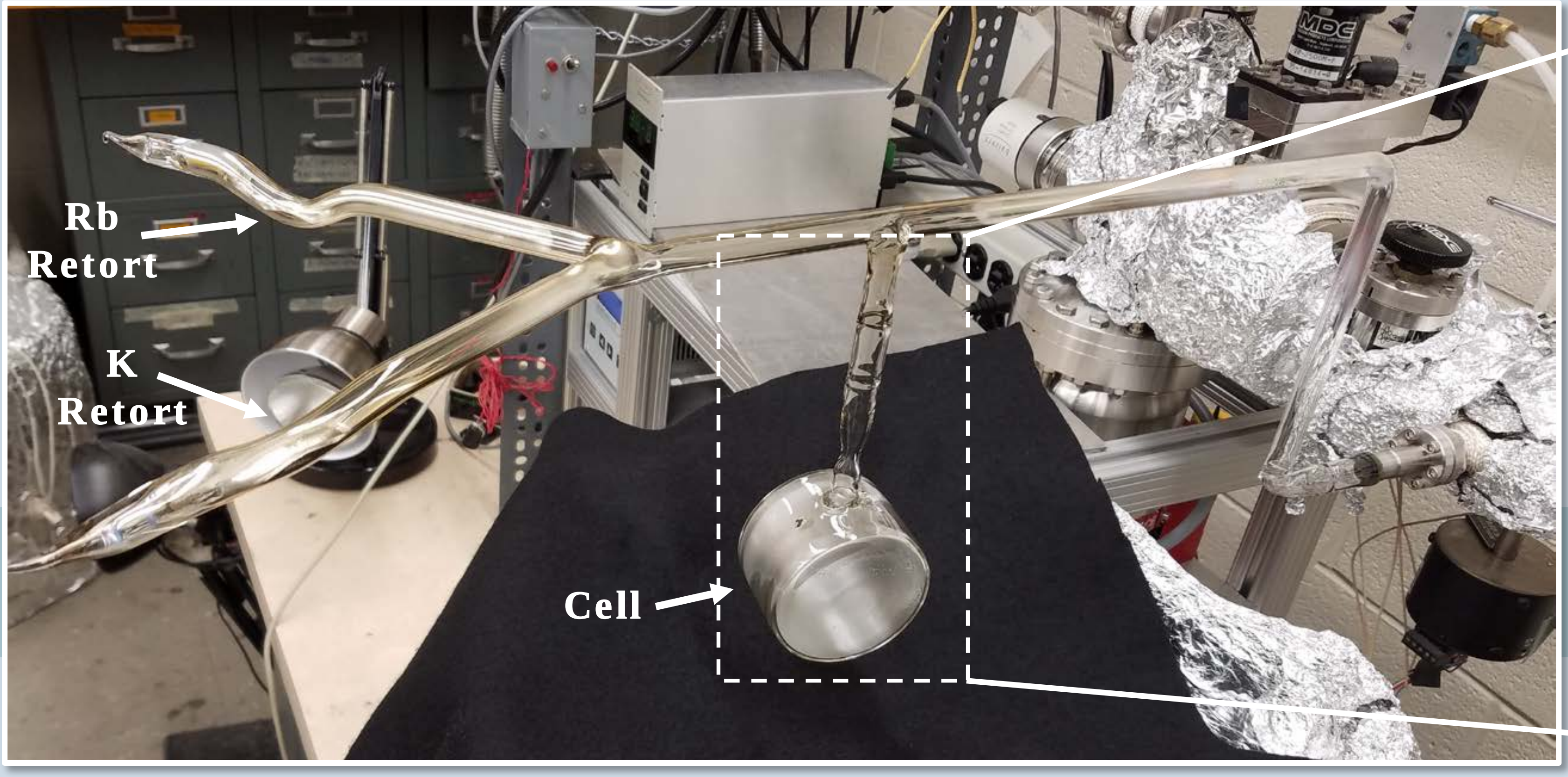
Making a ^{3}He Cell



Photos from M. T. Hassan