Neutron Polarization Measurements with a $^3\text{He}$ Spin Filter for the NPDGamma Experiment

Matthew Musgrave
University of Tennessee
for the NPDGamma Collaboration

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The observed $\gamma$-ray asymmetry measured by the NPDGamma experiment is proportional to the product of the neutron polarization and the physical asymmetry.

$$A_{\gamma}^{\text{observed}} \propto P_n A_{\gamma}^{\text{physical}}$$

The accuracy requirement for the hydrogen asymmetry and the Cl asymmetry set the required accuracy of the polarization measurement at 2%.
Polarimetry Setup

Beam guide  SM polarizer  Beam monitors

Guide field  RFSF  Detector array

Guide coils  

Collimators  \(^3\)He cell  \(^3\)He ion chamber
Polarizing Neutrons – Super Mirror Polarizer

Advantages

● High neutron polarization (>90%)
● High transmission of desired spin state
● Stable polarization

Disadvantages

● Physical mechanism is complicated
● Polarization is not known \textit{a priori}

A Super Mirror Polarizer performs well as the neutron polarizer for the NPDGamma experiment but the beam polarization will have to be measured with a $^3$He spin filter.
Analyzing Neutrons – $^3\text{He}$ Spin Filter

- The capture cross section for low energy neutrons on $^3\text{He}$ is large for antiparallel spins and nearly zero for parallel spins.

- Both capture rates scale with the inverse of the neutron velocity (1/v).
Polarimetry Components

- 6Li Shielding
- Collimators
- $^3$He Spin Filter
- $^3$He Ion Chamber
- Coils to reverse the $^3$He polarization by AFP
Neutron Capture on Polarized $^3$He

Transmission and polarization of an unpolarized neutron beam through a polarized $^3$He cell:

\[ T_{unpol}(\lambda) = e^{-\frac{n\sigma \rho l}{\lambda_0} \lambda} \]

\[ T_{pol}(\lambda) = e^{-\frac{n\sigma \rho l}{\lambda_0} \lambda} \cosh\left(\frac{n\sigma \rho l}{\lambda_0} \lambda P_{He}\right) \]

\[ P_{n}^{He}(\lambda) = \tanh\left(\frac{n\sigma \rho l}{\lambda_0} \lambda P_{He}\right) \]

These equations are derived from the spin dependent exponential attenuation of neutron polarization states through polarized $^3$He.

For the NPDGamma experiment, the neutron beam is polarized, so the RFSF is used to approximate an unpolarized neutron beam.
The RF Spin Flipper

Following an eight step spin sequence, the RFSF creates an oscillating magnetic field tuned to the Larmor frequency of the neutrons. The amplitude of the RF signal varies with the velocity of the neutrons transmitted through it.

During passage through the RFSF, neutrons are rotated by 180° with a position dependent efficiency.
Model of the RFSF Efficiency

The efficiency of the RFSF was modeled as a function of position in the beam and found to have near unity efficiency at the center.

Two measurements of the RFSF efficiency were taken with a $^3$He spin filter to benchmark the model.

When compared to the measurement, the modeled RFSF efficiency is weighted by a McStas model of the neutron density across the beam profile.

A 2 inch diameter collimator was used in front of the $^3$He cell.
The RFSF Efficiency

The RFSF efficiency is determined from a series of 4 transmission measurements and compared to a Monte Carlo simulation of the neutron beam.

\[ R_0 = \frac{T_{0 \, \text{afp}} - T_0}{T_{0 \, \text{afp}} + T_0} = P_n \tanh\left(\frac{n \sigma_{ol}}{\kappa_0} \lambda P_{He}\right) \]

\[ R_{sf} = \frac{T_{sf \, \text{afp}} - T_{sf}}{T_{sf \, \text{afp}} + T_{sf}} = (1 - 2 \varepsilon_{sf})P_n \tanh\left(\frac{n \sigma_{ol}}{\kappa_0} \lambda P_{He}\right) \]

\[ \varepsilon_{sf} = \frac{1}{2} \left(1 - \frac{R_{sf}}{R_0}\right) \]

Beam Center

4 cm Off-Center
How the Neutron Polarization is Calculated

![Graph showing the relationship between voltage signal and wavelength for RFSF off and RFSF on conditions.]

\[ R_{on} = \frac{T_{on}}{T_0} \quad R_{off} = \frac{T_{off}}{T_0} \]

\[ P_n(\lambda) = \frac{R_{off} - R_{on}}{\sqrt{(\epsilon R_{off} - R_{on})^2 - (1 - \epsilon)^2}} \]

\[ \epsilon = \text{RFSF Efficiency} \]
A 2 inch diameter collimator was used in front of the 3He cell.
The neutron polarization is independent of the $^3$He polarization, so the scattered neutron background was determined by measuring the neutron polarization at multiple $^3$He polarizations and minimizing the variance between the measurements.
Neutron Polarization

The McStas model is consistently higher than the measured polarization, but it does accurately predict the wavelength dependence on the polarization.
Beam Averaging

- Red data points are a weighted average polarization determined by McStas at the 9 collimator positions.
- Green data points are the total beam polarization determined by McStas.

The average deviation between the total polarization and the average of the 9 collimator positions is 0.3%. This error will be used to determine the systematic error associated with averaging the polarization data to determine the beam average polarization.
The RFSF efficiency and neutron polarization were both measured to an accuracy better than 1% with a $^3$He spin filter, and McStas simulations show that the beam average polarization can be determined with a systematic error less than 1%. This will meet the accuracy required by the NPDGamma experiment.

The neutron polarization will be extrapolated out to higher neutron wavelengths that are now permitted by a new chopper window.

The neutron polarization continues to be monitored on a regular basis to verify that the efficiency of the RFSF and the neutron polarization have not changed.