Neutron Polarization Measurements with a 3He Spin Filter for the NPDGamma Experiment

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

\[ A_{\gamma}^{\text{observed}} \propto P_n A_{\gamma}^{\text{physical}} \]
Polarimetry Setup

- Beam guide
- SM polarizer
- Guide field
- RFSF
- Detector array
- Guide coils
- Beam monitors
- Collimators
- $^3\text{He}$ cell
- $^3\text{He}$ 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}

Performs well as the neutron polarizer for the NPDGamma experiment but the beam polarization will have to be measured with a $^3$He analyzer.
Analyzing Neutrons – $^3$He Spin Filter

**Advantages**

- Polarizes a broad range of neutron energies
- $^3$He polarization can be reversed
- Physical mechanism is well understood

**Disadvantages**

- Smaller figure of merit compared to SMP
- Lower transmission
- Lower neutron polarization
A $^3$He spin filter is used as a neutron analyzer to measure the neutron polarization and the RFSF efficiency.
Neutron Capture on Polarized $^3\text{He}$

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

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

\[
T_{\text{unpol}}(\lambda) = e^{-\frac{n\sigma_0 l}{\lambda_0} \lambda}
\]

\[
T_{\text{pol}}(\lambda) = e^{-\frac{n\sigma_0 l}{\lambda_0} \lambda} \cosh\left(\frac{n\sigma_0 l}{\lambda_0} \lambda P_{\text{He}}\right)
\]

\[
P_n^{\text{He}}(\lambda) = \tanh\left(\frac{n\sigma_0 l}{\lambda_0} \lambda P_{\text{He}}\right)
\]

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

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

The RFSF creates an oscillating magnetic field tuned to the Larmor frequency of the neutrons. During passage through the RFSF, neutrons are rotated by 180°.

- $T_0$: RFSF off
- $T_{0}^{afp}$: RFSF off, $^3$He spin flipped
- $T_{sf}$: RFSF on
- $T_{sf}^{afp}$: RFSF on, $^3$He spin flipped

\[
R_0 \equiv \frac{T_{0}^{afp} - T_0}{T_{0}^{afp} + T_0} = P_n \tanh(\kappa \lambda P_{He})
\]

\[
R_{sf} \equiv \frac{T_{sf}^{afp} - T_{sf}}{T_{sf}^{afp} + T_{sf}} = \varepsilon_{sf} P_n \tanh(\kappa \lambda P_{He})
\]

\[
\varepsilon_{sf} = \frac{R_{sf}}{R_0}
\]
RF Spin Flipper Efficiency

The RFSF flips the neutron spin with nearly 99% efficiency and is in close agreement with our model of the RFSF’s performance.
How the Neutron Polarization is Calculated

\[ R_{on} = \frac{T_{on}}{T_0} \quad R_{off} = \frac{T_{off}}{T_0} \quad P_n(\lambda) = \frac{R_{off} - R_{on}}{\sqrt{(\varepsilon R_{off} - R_{on})^2 - (1 - \varepsilon)^2}} \]

\( \xi \) = RFSF Efficiency
Determining the Neutron Polarization at Multiple $^3$He Polarizations

Ideally the neutron polarization can be determined independently of the $^3$He polarization. A scattered neutron background initially distorted the results and introduced a $^3$He polarization dependence.
Background Subtraction

Since the neutron polarization is independent of the $^3$He polarization, the background can be determined from multiple neutron polarization measurements at different $^3$He polarizations by minimizing the variance between the measurements.
Comparing the Two Methods of Determining the Polarization in the Center of the Beam

Flipping the $^3\text{He}$ spins with the RFSF always off.
Simulation of Neutron Polarization

The neutron polarization was modeled with the Monte Carlo neutron ray-tracing package McStas.

Model correctly predicts the lower polarization at higher neutron wavelengths. The 2% difference can be attributed to variations in super mirror fabrication which produces super mirrors with properties different then how McStas models them.
Conclusion

The RFSF efficiency and the neutron polarization were successfully measured with a $^3$He spin filter.

The average RFSF efficiency in the center of the beam was measured to be $\sim$99% with an error less than 1%.

The neutron polarization can be measured to less than a 1% error which meets the requirements of the NPDGamma experiment.

The neutron polarization will be monitored periodically during data production with the H$_2$ Target.