The g_2^p Dynamic Nuclear Polarized Proton Target

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On behalf of the E08-027 collaboration

Abstract

The recently completed g_2^p experiment used a dynamic nuclear polarized (DNP) NH_3 target to investigate the spin structure of the proton at Jefferson Lab. The goal was to extract the proton's inclusive spin structure function at the lowest practical momentum transfer, $0.02 < Q^2 < 0.2\text{GeV}^2$. The incident electron beam energy ranged from 1.1 to 3.3 GeV. Inclusive scattering from a transversely polarized target was detected at 5.6^o in a pair of magnetic spectrometers outfitted with a room temperature septum magnet. The deflection of the electron beam was minimized for a portion of the experiment by limiting the target magnetic field to 2.5 Tesla.
Also of interest during the experiment was the measurement of the proton form factor ratio G_E/G_M, which required a longitudinal target field so a rotatable target chamber was needed to transition between settings

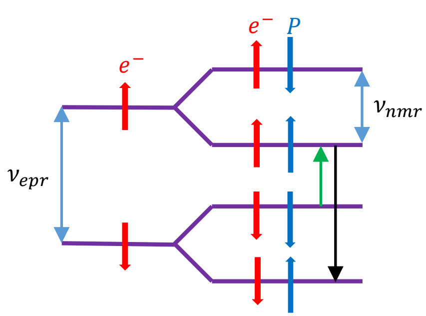
Dynamic Nuclear Polarization

At thermal equilibrium in a liquid Helium bath at 1 Kelvin the polarization of a material can be expressed using Boltzmann statistics as

$$P_{TE} = \frac{e^{\mu B/kT} - e^{\mu B/kT}}{e^{\mu B/kT} + e^{\mu B/kT}} = \tanh\left(\frac{\mu B}{kT}\right)$$

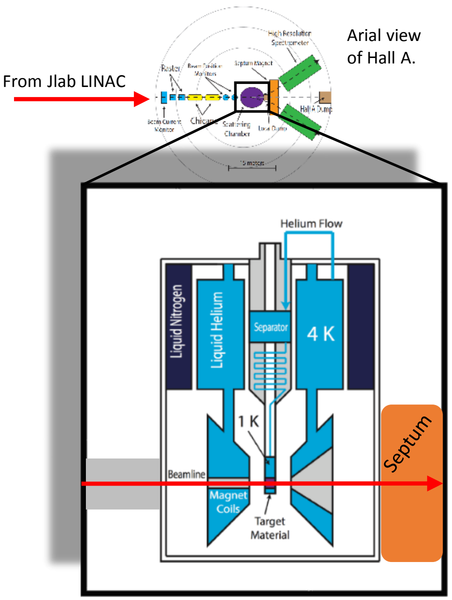
$$P_{TE} = 0.25$$

for a proton at 1 Kelvin in a 2.5T field. This level of polarization is clearly not large enough for experimental data taking, so we must utilize Dynamic Nuclear Polarization to drive the polarization to a more reasonable level.



- Electron-Proton spin coupling is exploited using an RF generator set to the $\nu_{nmr} - \nu_{epr}$ frequency (**green arrow**) that forces the transition of a proton into the desired polarization state.
- The electron then relaxes (**black arrow**) back to the unpolarized state in a matter of micro seconds, while the proton remains polarized for several minutes.
- The relaxed electron is then used to spin-flip another proton, driving polarization.
- Using this method proton polarizations around 90% in a 5 Tesla field or 15% in a 2.5 Tesla field can be achieved on the order of minutes.

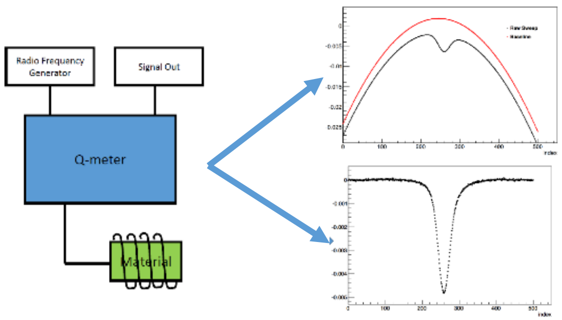
The Solid Polarized Target



Target Insert

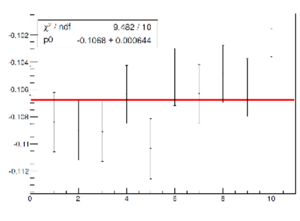
- Aluminum ladder attached to a carbon fiber tube for thermal dissipation.
- Four cups attached to the ladder
  - 2 NH_3 cups
  - 1 empty cup (helium)
  - 1 carbon foil cup
- Microwave horn (gold) used for DNP.

Nuclear Magnetic Resonance



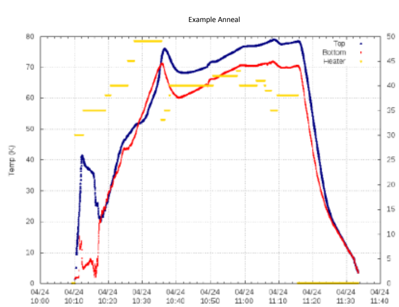
By sweeping a frequency around ν_{nmr} and measuring the Q-meter impedance we are able to find the proton polarization.

Analysis and Results

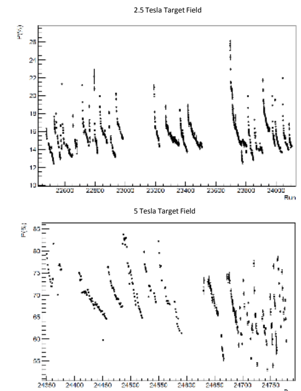


An example Thermal Equilibrium measurement:

- Shut off microwaves (used for DNP)
- Allow spins to relax in magnetic field.
- Measure area of impedance curve in relaxed state.
- $CC = {}^{P_{TE}}/_{A_{TE}}$ where $P_{TE} = \tanh\left(\frac{\mu B}{kT}\right)$
- CC can then be used to find the proton polarization at any time.



As polarization naturally decays over time, the target is heated (annealed) to recombine un-polarizable radicals. The effects of annealing are seen as jumps in polarization on the final polarization plots.



Final polarizations of 15% for a 2.5 Tesla field and 75% for a 5 Tesla field were achieved.