The GDH Sum Rule of the neutron using nearly real photons

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Thesis Progress Report

Temple University

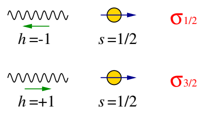
September 16, 2002

1 Theoretical Background

1.1 GDH Sum Rule (real photon)

The GDH sum rule relates the integral from the pion threshold to the infinity over the energy spectrum of the total photo-absorption cross section of the nucleon in the helicity states 1/2 and 3/2 with the anomalous magnetic moment κ:

$$\int_{thr}^{\infty} \frac{d\nu}{\nu}[\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}] = -\frac{2\pi^2\alpha}{M_N^2}\kappa^2$$



The GDH sum rule follows from:

1. The dispersion relation for forward Compton Scattering.

   Forward Compton Scattering:

$$f(\nu) = f_1(\nu)\vec{e'}^{*}.\vec{e} + \nu f_2(\nu) i\vec{\sigma}.\vec{e'}^{*} \times \vec{e}$$

$\vec{e}$ and $\vec{e'}$ are the transverse polarization vectors of the incident and forward scattered photon.

Causality $\Rightarrow$ analyticity of f_2 $\rightarrow$ dispersion relation:

$$Re[f_2(\nu')] = \frac{2\nu}{\pi} P \int_0^\infty d\nu' \frac{Im[f_2(\nu')]}{\nu'^2 - \nu^2}$$

2. The Optical Theorem.

   Unitarity $\Rightarrow$ Optical Theorem:

$$Im[f_2(\nu)] = \frac{\nu}{8\pi}(\sigma_{1/2} - \sigma_{3/2})$$

3. The Low Energy Theorem.

   Gauge invariance and relativity $\Rightarrow$ Low Energy Theorem

$$f_2(0) = -\frac{\alpha\kappa}{2m^2}$$

1.2 Extended GDH Sum Rule (virtual photon)

When moving away from Q^2=0, another sum rule exists in the case of the virtual photon. The extended GDH sum rule relates the spin-dependent structure function G_1 to the virtual-photon Compton amplitude S_1:

$$S_1(0, Q^2) = 4 \int_{Q^2/2M}^\infty \frac{d\nu}{\nu} G_1(\nu, Q^2)$$

Following some proprieties of the extended GDH sum rule:

$\rightarrow$ applicable for any finite Q^2

$\rightarrow$ at the limit Q^2=0, reduces to the GDH sum rule

$\rightarrow$ For $Q^2 < 0.2$ GeV^2: χPT prediction based on QCD symmetry

The GDH sum rule gives the prediction at Q^2=0 (real photon) point which can be related to the spin structure functions in electron (muon) scattering by:

$$\sigma_{TT'} = \frac{\sigma_{3/2} - \sigma_{1/2}}{2} = -\frac{4\pi^2\alpha m}{(1-x)}(G_1(Q^2,\nu) - 2xG_2(Q^2,\nu))$$

with $G_1(Q^2, \nu) = \frac{m^2 g_1}{\nu}$ and $G_2(Q^2, \nu) = \frac{m^4 g_2}{\nu^2}$.

In DIS and real photo-absorption, the second term vanishes:

$$I(Q^2) = -\frac{m^2}{4\pi\alpha}\int_{thr}^{\infty}\frac{d\nu}{\nu}(1-x)\sigma_{TT'}(Q^2,\nu) = \frac{2m^2}{Q^2}\int_0^1 dx[g_1(Q^2,x) - \frac{4x^2m^2}{Q^2}g_2(Q^2,x)]$$

2 The E97-110 experiment

The experiment will cover the kinematic region $0.02 < \mathrm{Q}^2 < 0.5$ $(\mathrm{GeV/c})^2$. In this Q^2 range, we will be able to measure the slope of the GDH sum rule at Q^2 near zero predicted by χPT, to extrapolate to the real photon point.

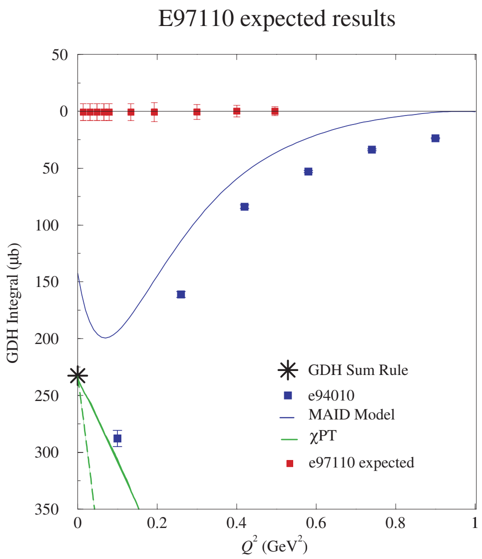


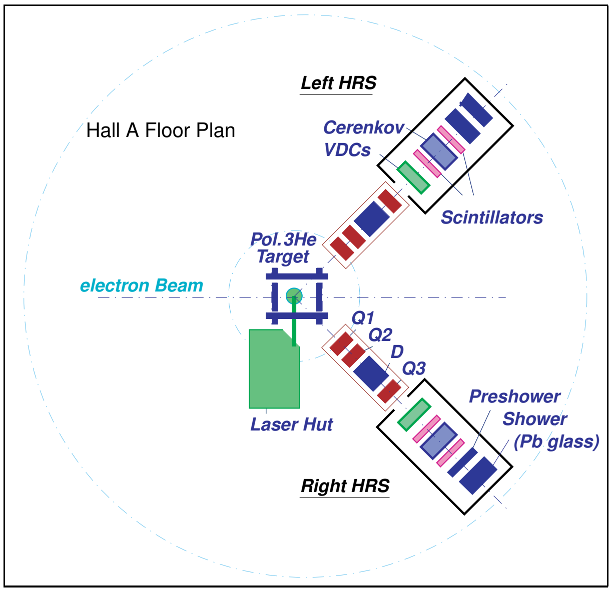
Figure 1: E97-110 expected uncertainties

Morever the highest Q^2 points allow a nice overlap with the previous experiment E94-010.

3 The Experimental setup

The experiment will run in the Hall A at the Jefferson Lab. The polarized electron beam will scattered on the polarized ^{3}He target placed in the center of the Hall. The target can be polarized in longitudinal and in transverse with its two pairs of Helmholtz coils. Then the scattered e− will be detected with the standard detector packages of the two almost identical High Resolution Spectrometer.

To access the low Q^2 region, two septum magnets will be added between the polarized ^{3}He target system and the entrance of the spectrometer, one at each entrance. Thus we will be able to measure at forward scattering angles (6° to 12.5°).



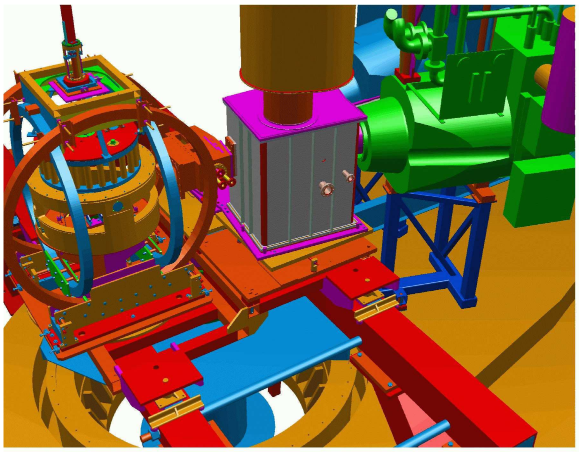


Figure 2: The Hall A standard setup and on the left the septum magnets

4 Polarized ^{3}He

4.1 Optical Pumping of the Rubidium

The Rb vapor is polarized by optical pumping with circularly polarized light. The excitation process follows the selection rule $\Delta m = +1$. The deexcitation is equiprobable in the two ground states. Thus after a certain time, most of the electrons are in the ground state M=+1/2 and the Rb is polarized.

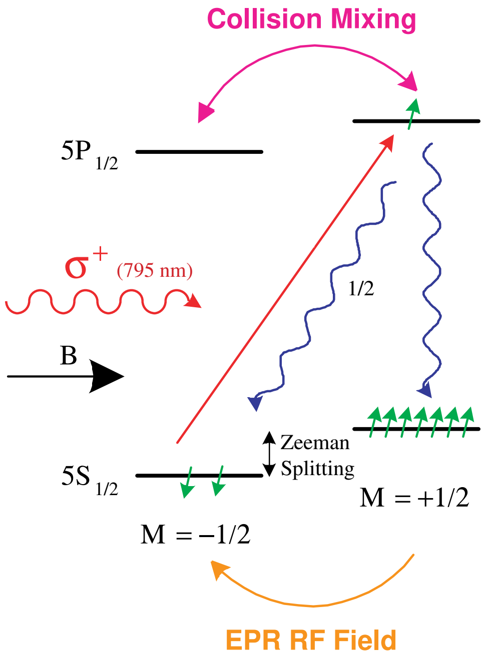


Figure 3: Simplified sketch of Rb energy levels in an external magnetic field B

The Rb e^- polarization is transferred to ^{3}He nucleus by spin-exchange interaction.

4.2 The ^{3}He target cells

The ^{3}He target cells are two-chambers cells. The top part is called the pumping chamber in which the rubidium is pumped and spin-exchange with the ^{3}He nuclei happens. Then the ^{3}He nuclei diffuse into the target chamber where the incident electron beam goes through.

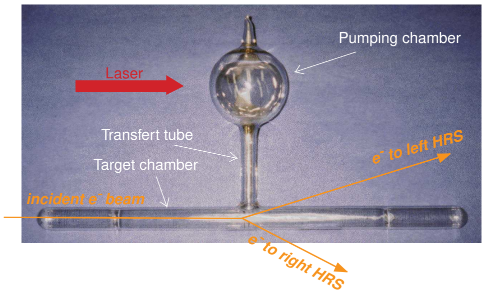


Figure 4: Standard cell (length $\sim$ 40cm, density $\sim$ 10 atm)

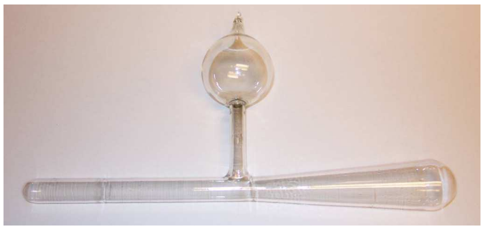


Figure 5: Ice-cone cell (length $\sim$ 34cm, density $\sim$ 7 atm)

4.3 The polarized ^{3}He target system

The cell is placed in the center of the system. An oven heats the pumping chamber to vaporize the rubidium and then the rubidium is polarized with a circularly polarized laser light. A pair of Helmhotz coils holds the polarization.
What is not shown on figure 6 is the second pair of Helmhotz coils perpendiculair to the page. The double Helmhotz coils pair configuration allows us to access the longitudinal and the transverse orientations, and more generally any orientation angle.

The other parts drawn on figure 6 (RF drive coils, pick-up coils, EPR optics and EPR coil) are for two independent polarimetries: NMR and EPR.

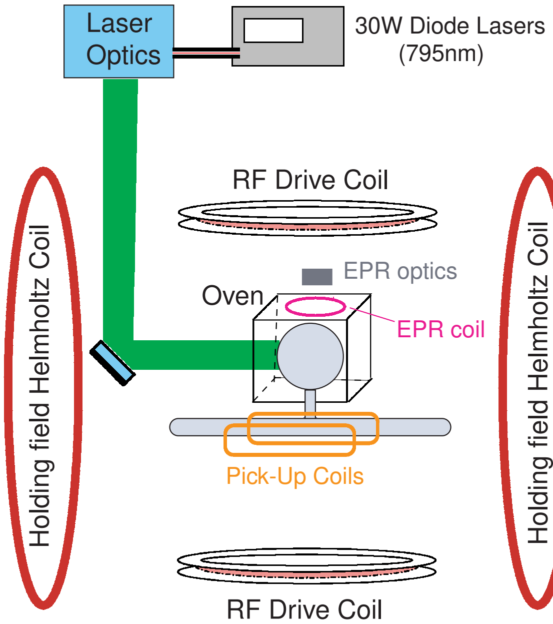


Figure 6: The Hall A polarized ^{3}He target system

4.4 Polarimetries

4.5 NMR

As a spin 1/2 particle, ^{3}He is a two-levels system. When there is no field $|\uparrow>$ and $|\downarrow>$ are degenerate. When an external field H_0 is applied the degeneracy is removed and the two states are separated by $\Delta E = \gamma \hbar H_0$. It is possible to induce the transition between the two states with an RF field $H_1(\omega)$. During an NMR measurement we keep the RF field constant and the holding field is ramped through the resonance: $\omega = \omega_0$ where $\omega_0 = \gamma H_0 = \frac{E(\uparrow)-E(\downarrow)}{\hbar}$.

The ^{3}He polarization is proportional to the height of the signal at the resonance.

$$P_{^3He} = \kappa . S$$

The proportionality constant has to be calibrated by using an identical target cell filled with water since the density of water is well known and the thermal polarization is described by the Boltzman description.

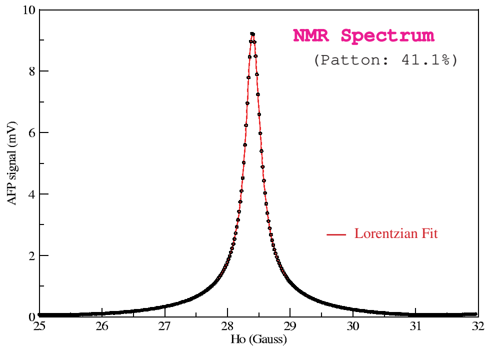


Figure 7: An NMR measurement on Patton

4.6 EPR

During an EPR measurement we are looking at the Zeeman splitting of the Rubidium due to the presence of polarized ^{3}He.

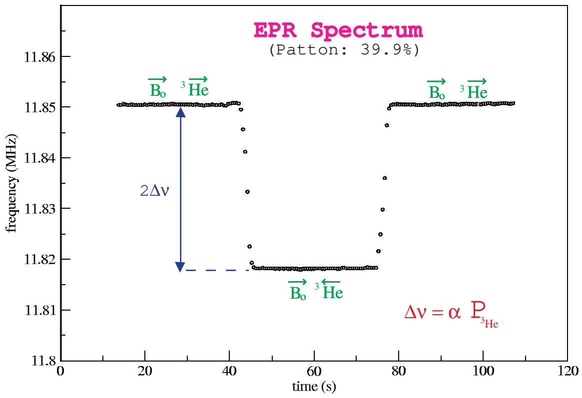


Figure 8: An EPR measurement on Patton

Polarized ^{3}He creates an extra magnetic field: $B_{^3He}$. We measure the Zeeman splitting with B_0 and $B_{^3He}$ aligned and anti-aligned by flipping the spins. The difference between the two Zeeman frequency is proportional to the ^{3}He polarization:

$$\Delta\nu = \kappa_{epr}.P_{^3He}$$

where κ_{epr} depends of the holding field, the temperature and the geometry of the cell.

5 Conclusion

I have principally worked on the polarized target for the past year. The polarized ^{3}He system is ready for the experiment. Now I am focusing on the online data analysis.
The experiment E97-110 will run in January-February 2003.