GDH Sum Rule at JLab Hall B

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For the CLAS and EG4 collaborations

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GDH Sum Rule

\[ I_{GDH} = \frac{M^2}{8a\pi^2} \int_{thr}^{\infty} \left( \sigma_{1/2} - \sigma_{3/2} \right) \frac{dv}{v} = -\frac{1}{4} k^2 \]

- relates the difference of the photo-absorption cross section for helicity 1/2 and 3/2 to the nucleon magnetic moment, i.e. a connection between dynamic and static properties. Recent measurements at Bonn and Mainz, ongoing efforts at other labs

- based on very general principles, as gauge invariance, dispersion relation, low energy theorem

- at non-zero \( Q^2 \) can be related to the integral of the spin structure function \( g_1 \)

\[ \Gamma_1 = \int g_1(x, Q^2) dx \xrightarrow{Q^2 \to 0} \frac{Q^2}{2M^2} I_{GDH} \]

- strong variation of nucleon spin properties as a function of \( Q^2 \)
Asymmetries and Spin Structure Functions

\[ \frac{d\sigma}{dE'd\Omega} = \Gamma_v \left[ \sigma_T + \varepsilon \sigma_L + P_{e't} \left( 1 - \varepsilon^2 A_1 \sigma_T \cos \psi + \sqrt{2\varepsilon (1 - \varepsilon)} A_2 \sigma_T \sin \psi \right) \right] \]

\[ A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_T} \]

\[ A_2 = \frac{\sigma_{L'T'}}{\sigma_T} \]

the structure functions \( A_1 \) and \( A_2 \) can be extracted by varying the direction of the nucleon polarization

\[ A^\parallel = D(\sigma_1 + \eta A_2) \]

\[ A^\perp = d(\sigma_1 + \xi A_2) \]

where \( D, \eta, d, \xi \) are function of \( Q^2, W, E_0, R \)

the structure functions \( g_1 \) and \( g_2 \) are linear combination of \( A_1 \) and \( A_2 \)

\[ g_1(x,Q^2) = \frac{Q^2}{Q^2 + 4M^2x^2} \left( A_i + \frac{2Mx}{\sqrt{Q^2}} A_2 \right) F_1(x,Q^2) \]

\[ g_2(x,Q^2) = \frac{Q^2}{Q^2 + 4M^2x^2} \left( \frac{\sqrt{Q^2}}{2Mx} A_2 - A_i \right) F_1(x,Q^2) \]
Recent Measurements with CLAS

\[ g_1(x, Q^2) = \frac{Q^2}{Q^2 + 4M^2x^2} \left( A_1 + \frac{2Mx}{\sqrt{Q^2}} A_2 \right) F_1(x, Q^2) \]

\[ \Gamma_1 = \int g_1(x, Q^2) \, dx \]

Integral goes down to \( Q^2 \) of 0.05 GeV\(^2\)

Shows strong \( Q^2 \) dependence varying from negative to positive values as \( Q^2 \) increases

Significant systematic uncertainties due to parameterization of \( F_1 \) and \( R \)
The GDH Sum Rule with nearly real photons

- Measurement of spin structure function $g_1(x,Q^2)$ at $Q^2$ down to 0.015 GeV$^2$ ($\theta_{\text{min}} = 6$ degrees)
- Test of $\chi$PT at $Q^2 \to 0$
- Measurement of the absolute cross section difference:

$$\frac{d\sigma^{\leftrightarrow}}{d\Omega dE'} - \frac{d\sigma^{\rightarrow\rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{M E \sqrt{Q^2}} \left[ (E - E' \cos \theta) g_1(x,Q^2) - 2M x g_2(x,Q^2) \right]$$

Cross section measurement requires uniform detection efficiency at low $Q^2$! New Cerenkov detector built by INFN-Genova to detect scattered electrons down to 4.5 degrees.
Experimental Setup

- large kinematical coverage
- simultaneous measurement of exclusive and inclusive reactions
- central field-free region well suited for the insertion of the polarized target
New Cerenkov Counter

“Old” Cerenkov counter was designed to maximize the azimuthal coverage. Complex geometry. Components optimized for high $Q^2$, low-rate experiments using the inbending electron tracks.

New CC counter. Optimized for this experiment. Uniform detection efficiency.

“Old” CC with outbending configuration, $P_{el}=0.6$ GeV.
The new detector fits inside of existing volume (sector 6)

The red track corresponds to an electron emitted at 6 degrees
Polarized Target

Field ~ 5 T
Temperature ~ 1 K

Four target cells:
- NH₃
- ND₃
- Empty (LHe)
- ¹²C

Polarization:
- NH₃ ~ 80-90 %
- ND₃ ~ 30-45 %
E03-006 /E03-111 Status

• Completed data taking in May 2006
• $^{15}$NH$_3$ target:
  E=1.0, 1.3, 1.5, 2.2, 3.0 GeV
  15.8 billion triggers
  Target polarization 80-90%
• $^{15}$ND$_3$ target
  E=1.3, 2.0 GeV
  6.3 billion triggers
  Target Polarization 30-45%
• Improved DAQ rate, ~8.5 kH
Limited azimuthal coverage
Uniform detection efficiency

Reaching down to $Q^2 \sim 0.015$

$E = 1.053$ GeV

$Q^2$ (GeV^2)
Extraction of $P_bP_t$

$$\Lambda_{el}^{th} = \frac{2\tau \tau^{*} \left[ \frac{m_p}{c} + \tau \left( \frac{m_p}{c} + (1 + \tau) \tan^2(\theta/2) \right) \right]}{1 + \tau^2 \epsilon}$$

Normalize to carbon

Elastic asymmetry

$P_bP_t = A_{\text{meas}}/A_{\text{el}}$, in bins of $Q^2$
Achieved high deuterium polarization, up to 45%.

This estimation is based on the method of “peak heights” ratio:

\[ R = \frac{r_1}{r_2} \]

\[ P_t = \frac{1 - R^2}{R^2 + R + 1} \]

(C. Dulya et al., NIM A354 (1995) 249)
Expected Results

\[ \frac{d\sigma^{\rightarrow\leftarrow}}{d\Omega dE} - \frac{d\sigma^{\rightarrow\rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{M E V Q^2} \left[ (E - E' \cos \theta) g_1(x, Q^2) - 2 M x g_2(x, Q^2) \right] \]

\[ \frac{d\sigma^{\rightarrow\leftarrow}}{d\Omega dE} - \frac{d\sigma^{\rightarrow\rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{M E V Q^2} \left[ (E - E' \cos \theta) g_1(x, Q^2) - 2 M x g_2(x, Q^2) \right] \]

Expected Results for statistical errors on top of THEORETICAL cross section difference based on S. Simula's parameterization, [S. Simula et al., PRD 65, 034017 (2002)]

\[ \frac{d\sigma^{\rightarrow\leftarrow}}{d\Omega dE} - \frac{d\sigma^{\rightarrow\rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{M E V Q^2} \left[ (E - E' \cos \theta) g_1(x, Q^2) - 2 M x g_2(x, Q^2) \right] \]
Summary and Outlook

- Accumulated full statistics proposed for the experiment
- Currently in the calibration stage
- Rich physics program:
  - Behavior of the spin structure function $g_1(x,Q^2)$ at very low $Q^2$
  - Test of the Generalized GDH Sum rule
  - Study of the single spin asymmetries
  - $2\pi$ and $\eta$ production
  - ...
- Several dedicated students working on the experiment
- Expect results soon..