Measurement of the proton spin structure functions at very low Q^2 region

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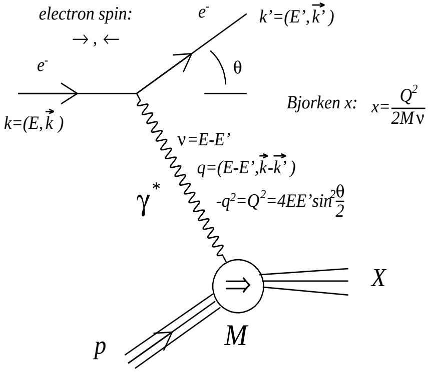
Outline

Deep Inelastic Scattering



$$W_X^2 = (p+q)^2 = \mathrm{M}^2 + 2\mathrm{M}\nu - \mathrm{Q}^2$$

Beyond the elastic scattering,

- Internal structure of the nucleon is excited coherently,(e.g. $\Delta(1232)$).
  $\rightarrow$ Inelastic scattering.
- As Q^2 increases, the nucleon reacts more and more incoherently.
  $\rightarrow$ Deep Inelastic Scattering.
- Q^2 larger than 1 - 2 GeV^2 is referred to as the DIS region.

Structure Functions and Sum Rules

$$\frac{d^2\sigma}{dE'd\Omega}^{\rightarrow\Leftarrow(\leftarrow\Leftarrow)} = \frac{4\alpha^2 E'^2}{Q^4}\left[\frac{2}{M}F_1(\nu,Q^2)sin^2\frac{\theta}{2} + \frac{1}{\nu}F_2(\nu,Q^2)cos^2\frac{\theta}{2}\right]$$
$$\pm \frac{2\alpha^2}{Q^2}\frac{E'}{ME\nu}\left[(E+E'cos\theta)\,\mathbf{g_1}(\nu,\mathbf{Q^2}) - \frac{Q^2}{M\nu}\,\mathbf{g_2}(\nu,\mathbf{Q^2})\right]$$

Cross section in terms of Structure Functions:

- F_1 and F_2 are spin-independent structure functions.
- g_1 and g_2 are spin-dependent structure functions and obtained via difference of helicity-dependent cross sections.

Sum Rule:

- It relates a sum over microscopic properties to a quantity characterizing the target.
- Fundamental theories like QCD can be tested.
- Gerasimov-Drell-Hearn sum rule is one of the examples.

Gerasimov-Drell-Hearn Sum Rule

Gerasimov-Drell-Hearn Sum Rule

- Relation between photo-absorption cross sections and magnetic moment:

$$\int_{thr}^{\infty}(\sigma_{3/2}-\sigma_{1/2})\frac{d\nu}{\nu}=2\pi^2\alpha\frac{\kappa^2}{M^2}$$

where κ is nuclear magnetic moment, M nucleon mass.

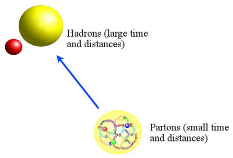
GDH integral:

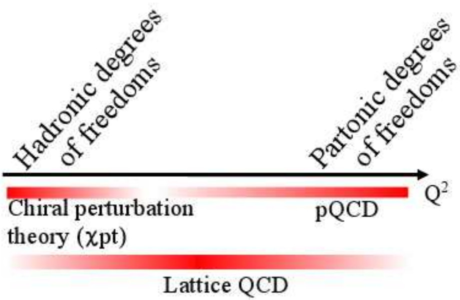
- The extended sum rule for $Q^2>0$ becomes the integration of spin structure function over Bjorken x:
  $I_{GDH}\left(Q^2\right)=\frac{16\pi^2\alpha}{Q^2}\int_0^{x_{th}}g_1\left(x,Q^2\right)dx=\frac{16\pi^2\alpha}{Q^2}\Gamma_1(Q^2)$
- The first moment of g_1,

$$\Gamma_1(Q^2)=\int_0^{x_{th}}g_1(x,Q^2)dx.$$

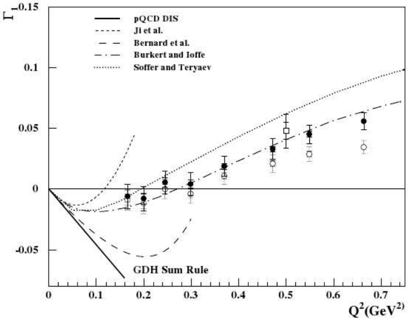
Importance of GDH sum rule

- Chiral Perturbation Theory(χPT) allows us to understand the Q^2 dependence below 0.2 GeV^2.
- Perturbative QCD(pQCD) does for Q^2 greater than 1.
- EG4 can test the χPT calculations for very low Q^2 region.





Previous Measurements

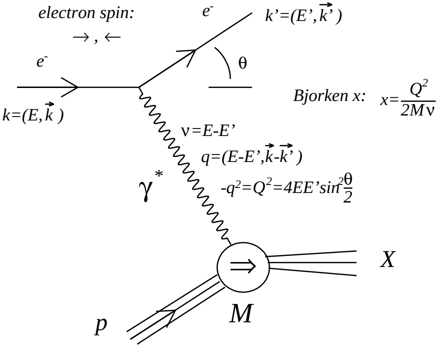


- CERN, SLAC and DESY measured at high Q^2.
- JLab also did at intermediate regions.(EG1)
- EG4 at JLab measured the Q^2 region below 0.5.

Experimental Objectives

Using $ep \to eX$ reactions,

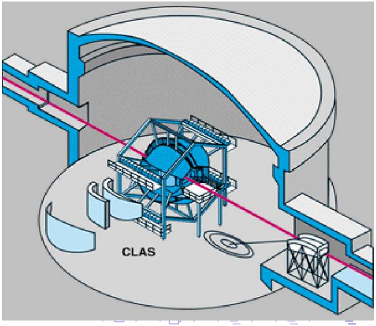
- Measuring cross sections for the two different electron beam helicities(+/-),
- acquire the g_1 and Γ_1 of the proton at low momentum transfer(Q^2).
- The range is tentatively 0.01 - 0.2 GeV^2



- EG4 focused on the very low Q^2 region.
- Its new results can test the theoretical predictions at the low energies.

Experimental Equipments

- Data were taken from February to May 2006
- Polarization: 85% for electrons, 80% for protons and 37% for deuterons
- Beam energies(GeV): 1.0, 1.3, 2.0, 2.3, 3.0 (proton) 1.3 and 2.0 (deuteron)



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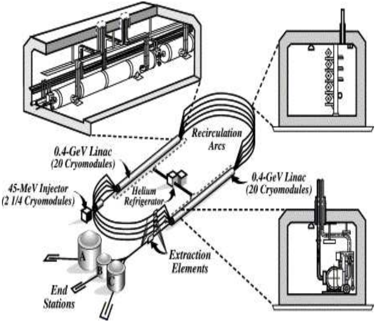

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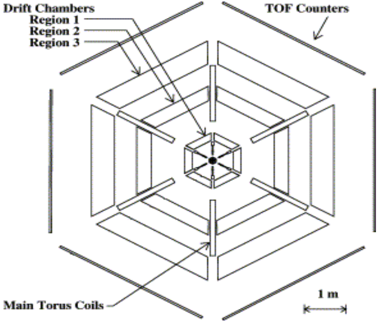
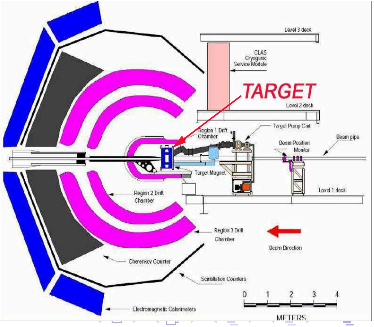
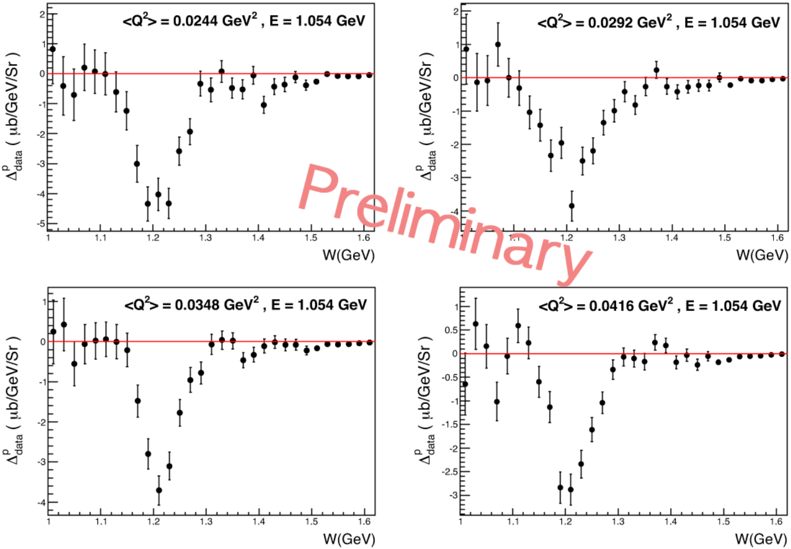




Cross section difference, $\Delta\sigma^p_{data}(W, Q^2)$.



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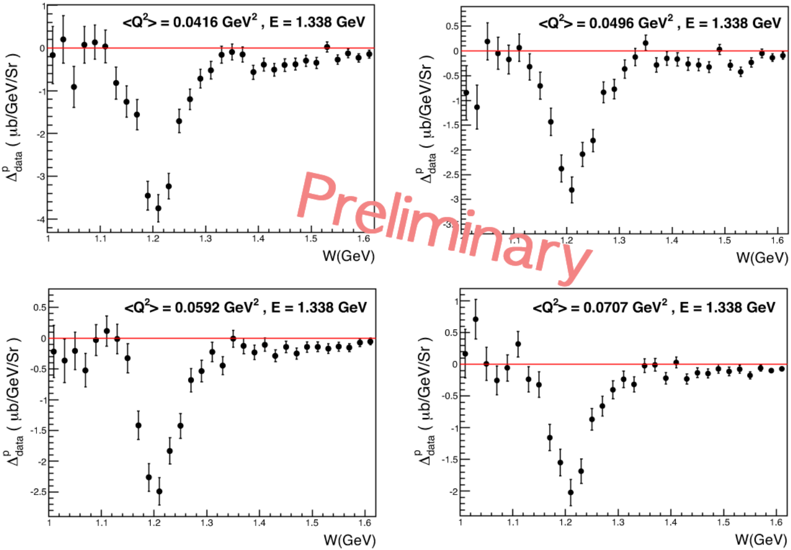
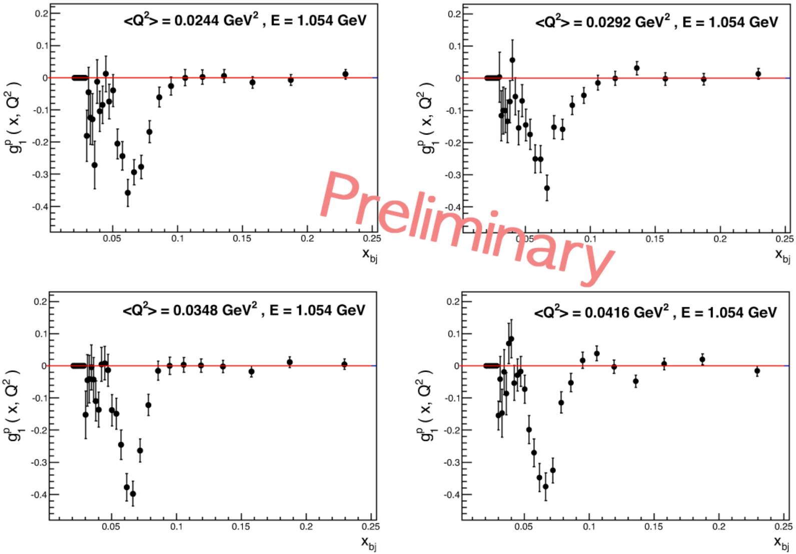


Extraction of $g_1^p(x, Q^2)$ function



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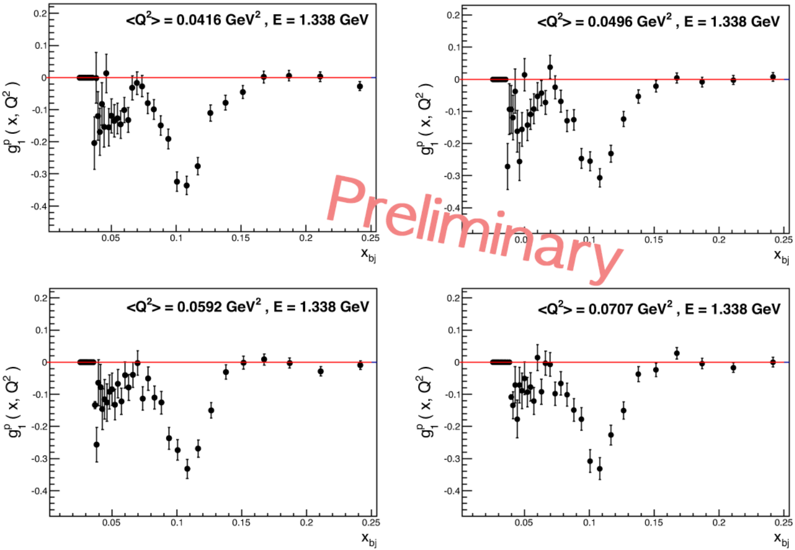
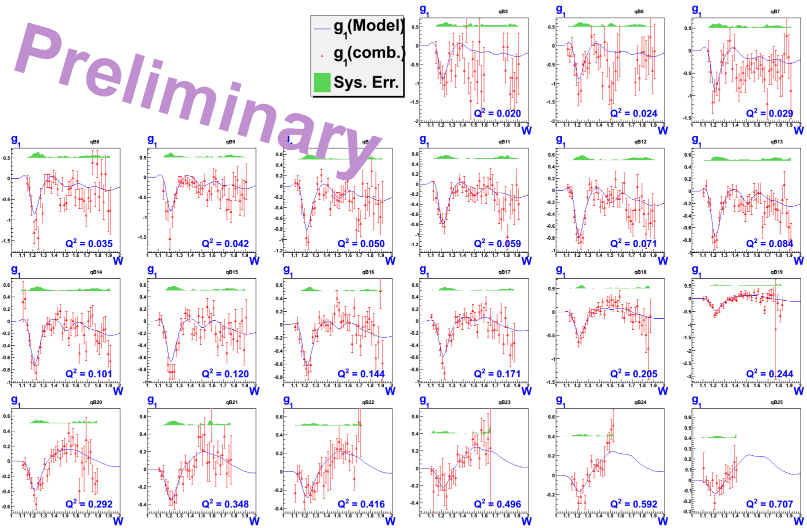
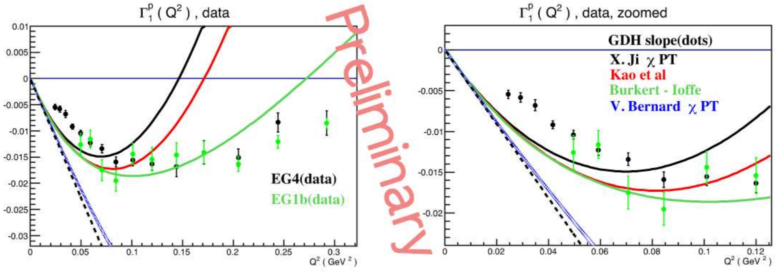


$g_1(W, Q^2)$ from deuteron data (Courtesy of Krishna Adhikari)

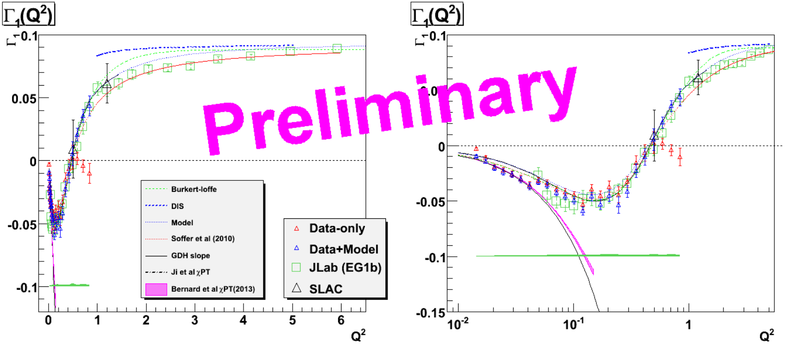


The first moment of g_1^p: Γ_1



- Integrated from π-threshold to the smallest x accessbile at our kinematics.
- Preliminary comparison to the previous measurement(Green dots).

Γ_1 from deuteron data (Courtesy of Krishna Adhikari)



Summary

- Integral of g_1 is very useful observable to study the transitional behaviour of strong interaction between its perturbative and non-perturbative regimes.
- The EG4 experiment was performed at J-Lab. It measured g_1 at very low Q^2.
- Preliminary results are available now for both proton and deuteron.
- Integration of g_1 is compared to some theoretical predictions.

- (Proton) The integration uses the g_1 from data only. Small x region is not included.
- (Proton) Inclusion of g_1 at small x can change the $\Gamma_1^p(Q^2)$.

Thank you!

Sum Rules

Gottfried sum rule:

$$\int_0^1 \frac{dx}{x}\left(F_{2p}\left(x,Q^2\right) - F_{2n}\left(x,Q^2\right)\right) = \frac{1}{3}$$

- New Muon Collaboration at CERN provided the evidence of a violations. Measured value is about 0.23.

Bjorken sum rule:

$$\int_0^1 \left[g_1^p(x) - g_1^n(x)\right] dx = \frac{g_A}{6}\left[1 - \frac{\alpha_s}{\pi} - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.22\left(\frac{\alpha_s}{\pi}\right)^3 \cdots\right]$$

g_A: isovector, axial charge of nucleon, measured via β-decay.

- This sum rule had been confirmed at the level of 10%.

Ellis-Jaffe sum rule:

- $\Delta u - \Delta d = g_A$ measured via neutron β-decay , $\Delta u + \Delta d = \Delta q_8$ via hyperon β-decay.
- Expectation is about 0.167 and EMC measured 0.114.

GDH sum rule beyond $Q^2 = 0$

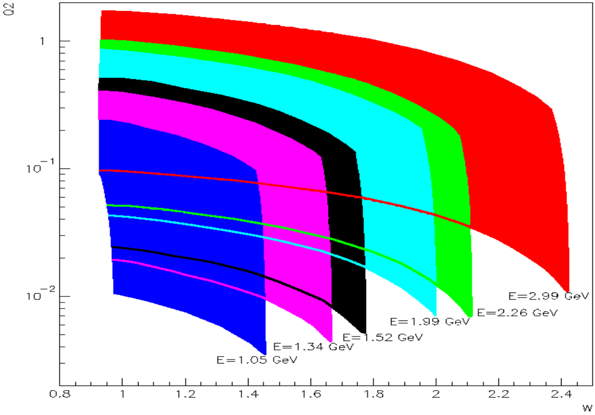
Generalization of GDH sum rule

- GDH sum rule has its origin at the Compton amplitude and it is calculable by chiral perturbation theory when Q^2 is small compared with the nucleon mass.
- When Q^2 gets greater than zero, elastic contribution comes in.
- But GDH sum rule has no elastic contributions, so this should be subtracted.

Theoretical methods

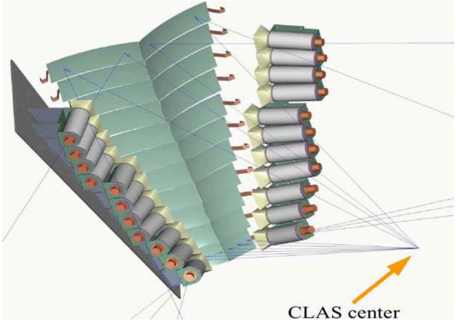
- Chiral perturbation theory allows to understand the Q^2 dependence from 0 to 0.2 GeV^2.
- Perturbative QCD does for the Q^2 greater than 0.5.
- There is no firm theoretical tool between 0.2 and 0.5.

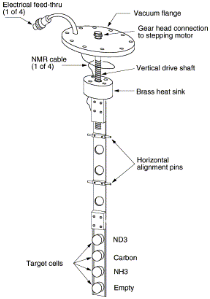
Kinematic Coverage



CEBAF Large Acceptance Spectrometer(CLAS)

- CLAS covers nearly 4π of solid angle.
- Cherenkov Counter at sector 6 is newly installed only for EG4(Left).

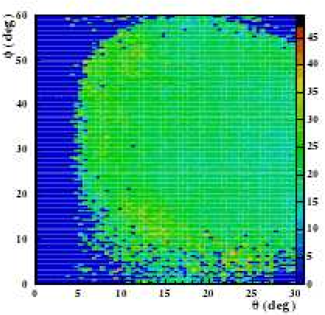


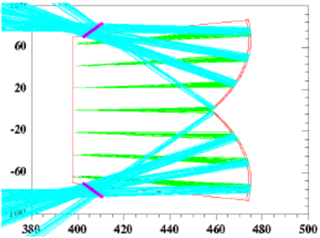


Target Insert for EG4 experiment

Cherenkov Counter for EG4

- CC for CLAS has low efficiency for electron detection at forward angle
- It leads to require more corrections when one measures the absolute cross section.
- Improving the detection efficiency at forward angle is done at the new CC for EG4.

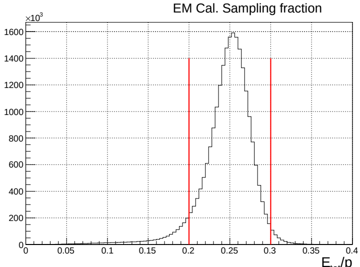


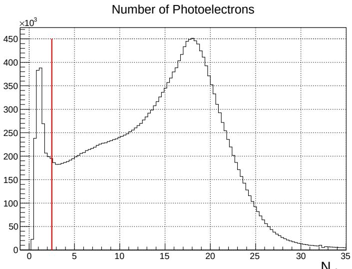


Particle Selection Cuts:

At first, Selection of good events:

- At least one particle recorded and the first one has negative charge.
- Successfully reconstructed, hitting all 4 detectors, DC, CC, SC, EC.
- recorded momentum is greater than minimum(0.3GeV) and hitting sector 6.





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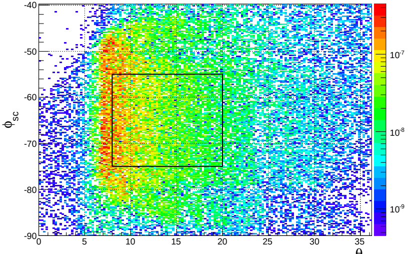

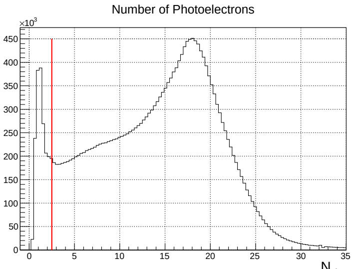

Details on Radiative Correction.

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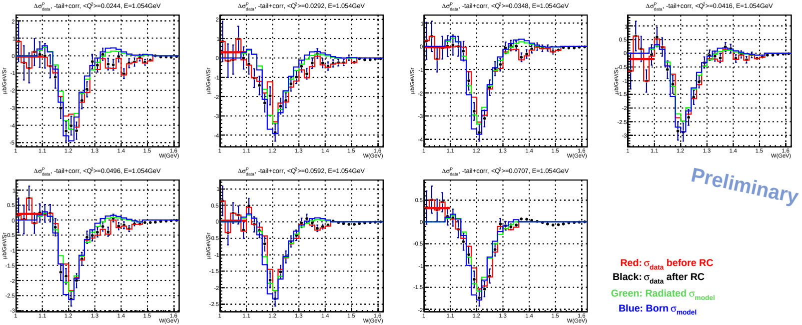
- External correction is Based on Mo and Tsai's approach.
- Updated with the most recent models.



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