Spin physics with CLAS and CLAS12

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Overview

- Experiments EG1, EG4 with CLAS
- Nucleon Structure Functions results
- EG1-DVCS experiment with CLAS
- DVCS results
- Future experiments with CLAS12
- Summary
Jefferson Laboratory and CLAS

CEBAF is a superconductive electron accelerator

- continuous beam
- high longitudinal polarization
- energy range \(0.75 - 5.9\) GeV
- current range \(0.1\) nA – 200 mA
- Beam polarization 80-90%

CEBAF

Large Acceptance Spectrometer

- Six individually instrumented sectors
- Toroidal magnetic field
- Multi-particle final state
- Large acceptance
The polarized target

EG1/EG4 target (CLAS):
Polarization up to 0.9 (p) or 0.4 (d)

Irradiated ammonia beads

$\text{NH}_3$/$\text{ND}_3$

$^{15}\text{N}$
Experiments EG1 and EG4 with CLAS

EG1: $Q^2 = 0.05...5$ GeV$^2$

Largest possible kinematic coverage
→ inbending and outbending configuration, $E = 1.6...5.8$ GeV

EG4: $Q^2_{\text{min}} = 0.015$ GeV$^2$

note: $m_{\pi}^2 = 0.02$ GeV$^2$

Focus on low $Q^2$ (GDH, $\chi$PT) => lower beam energies (up to 3 GeV), new Cherenkov for optimal acceptance in outbending configuration, $\theta_e$ as small as 6 degrees
JLab experiments

“Everything”

Sum Rules at low $Q^2$
very low $Q^2 - \chi$PT
$Q^2$-dep. of $g_2$
$A_{1n}$ at high $x$
Duality

Res. Region, Duality

✓ 8 completed experiments
3 (+3) approved with 6 GeV JLab
3 (+1) approved with 12 GeV (A/B/C)
DIS of lepton off nucleon

Virtual photon probes the structure

Important variables:

\[ Q^2 = -q^2 = 4 E E' \sin^2 \frac{\theta}{2} \]

\[ W^2 = M^2 + 2 M \nu - Q^2 \]

\[ x = \frac{Q^2}{2 M \nu} \]

\[
\frac{d^2 \sigma}{d\Omega dE'} = \sigma_{\text{Mott}} \left[ \frac{1}{n} F_2(x, Q^2) + \frac{2}{M} F_1(x, Q^2) \tan^2 \frac{\theta}{2} \right]
\]

\[
\frac{d^2 \sigma^{\uparrow\uparrow}}{d\Omega dE'} - \frac{d^2 \sigma^{\downarrow\downarrow}}{d\Omega dE'} = \frac{4 \alpha^2 E'}{n E Q^2} \left[ (E + E' \cos \theta) g_1(x, Q^2) - 2 M \nu g_2(x, Q^2) \right]
\]
Virtual photon asymmetries

Experimentally:

\[ A_{\parallel} = \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\downarrow\downarrow}}{2d\sigma_{\text{unpol}}} = D(A_1 + \eta A_2) \]

\[ A_{\perp} = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\downarrow\uparrow}}{2d\sigma_{\text{unpol}}} = d(A_1 + \xi A_2) \]

\[ \gamma^2 = \frac{4M^2x^2}{Q^2} \]

The virtual photon asymmetries \( A_1 \) and \( A_2 \) can be extracted by varying the direction of the nucleon polarization or by varying the beam energy at fixed \( Q^2, \nu \).

Large-x behavior of the \( A_1 \) asymmetry

- **SU(6) \( \rightarrow \)** \( A_1^p = \frac{5}{9}, \quad A_1^n = 0 \)
- Hyperfine perturbed QM
  - Makes \( S=1 \) pairs more energetic than \( S=0 \) pairs \( \rightarrow A_1 \rightarrow 1 \)
- In DIS, and in pQCD
  - Minimal gluon exchanges
  - Spectator pair: quarks have opposite helicities
  - At large \( x \) struck quark carries the helicity of the nucleon
  - \( A_1 \rightarrow 1 \)

Isgur, PRD 59, 034013 (1999)

Farrar and Jackson, PRL 35, 1416 (1975)
$A_1$ deuteron for different $Q^2$ bins

$A_1(D)$ for $Q^2 [0.06, 0.08] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.08, 0.09] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.08, 0.11] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.11, 0.13] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.13, 0.16] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.16, 0.19] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.19, 0.22] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.22, 0.27] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.27, 0.32] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.32, 0.38] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.38, 0.45] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.45, 0.54] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.54, 0.64] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.64, 0.77] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.77, 0.92] \text{GeV}^2$

$A_1(D)$ for $Q^2 [0.92, 1.10] \text{GeV}^2$

$A_1(D)$ for $Q^2 [1.10, 1.31] \text{GeV}^2$

$A_1(D)$ for $Q^2 [1.31, 1.56] \text{GeV}^2$

$A_1(D)$ for $Q^2 [1.56, 1.87] \text{GeV}^2$

$A_1(D)$ for $Q^2 [1.87, 2.23] \text{GeV}^2$

$A_1(D)$ for $Q^2 [2.23, 2.66] \text{GeV}^2$

$A_1(D)$ for $Q^2 [2.66, 3.17] \text{GeV}^2$

$A_1(D)$ for $Q^2 [3.17, 3.79] \text{GeV}^2$

$A_1(D)$ for $Q^2 [3.79, 4.52] \text{GeV}^2$

$W(\text{GeV})$
Virtual Photon Asymmetry $A_1$

- $p$ and $d$ results fall below parameterization of world data at $10 \text{ GeV}^2$ \(\Rightarrow\) include in DGLAP fits
- To be used to extract $\Delta q/q$ in this momentum transfer region
- $p$ and $d$ results are in better agreement with the HFP quark model

*HP perturbed QM* N. Isgur, *Phys. Rev. D* 59, 34013

*E. Close and W. Melnitchouk*, *Phys. Rev. C* 68, 035210

Virtual Photon Asymmetry $A_1$

- New results from CLAS eg1b
- Better statistical precision
- Better systematic errors
Spin Structure Function $g_1$

$$g_1(x) = \frac{l}{2} \sum_q e_q^2 \Delta q + \Delta \bar{q} = \frac{l}{2} \sum_q e_q^2 \left( q^+(x) - q^-(x) + \bar{q}^+(x) - \bar{q}^-(x) \right)$$

- Virtual photon couples to quarks of opposite helicity
- $q^+(x)$ or $q^-(x)$ are chosen by changing the configuration of the incident lepton and target nucleon spin
- $g_1(x) \sim \sigma_{1/2} - \sigma_{3/2}$
$g_1^p$ @ Jefferson Lab

World data on the proton before JLab (without COMPASS)
$g_1^p$ @ Jefferson Lab

World data on the proton before JLab (without COMPASS)

World data on the proton including EG1
World data on the proton before JLab (without COMPASS)

World data on the proton including EG1

...including resonance region data!
$g_1(x, Q^2)$ proton for different $Q^2$ bins – eg1
First moment $\Gamma_1$ and GDH

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2) dx$$

At high $Q^2$ - QPM

$$g_1(x) = \frac{1}{2} \sum_i e_i^2 \Delta q_i(x)$$

$$\Gamma_1^p = \frac{1}{9} \left( \frac{3}{4} a_3 + \frac{1}{4} a_8 + a_0 \right)$$

$$a_0 = \Delta \Sigma$$

Net Quark Spin

Q$^2 \rightarrow 0$ - GDH

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

$$I_{GDH} = \frac{M^2}{8\alpha\pi^2} \int_{thr}^{\infty} \left( \sigma_{1/2} - \sigma_{3/2} \right) dv = -\frac{1}{4} \kappa^2$$

A connection between dynamic and static properties.
First moment $\Gamma_1$ and GDH - CLAS

$\Gamma_1(P)$

$\Gamma_1^1(D)/2$

PRELIMINARY

Graphs showing data and models for $\Gamma_1(P)$ and $\Gamma_1^1(D)/2$ as a function of $Q^2(GeV)$. Different data sets and models are compared, including EG1b, HERMES, and SLAC E143. Various theoretical models are also plotted for comparison.
First moment $\Gamma_1$ and GDH - CLAS

$\Gamma_1(P)$

$\Gamma_1(D)/2$

PRELIMINARY
First moment $\Gamma_1$ and GDH - CLAS

EG4 expected results
Duality

Structure functions averaged over resonances behave like DIS

$$\langle g_1(Q^2) \rangle = \int_{x_i}^{x_h} g_1(x,Q^2) dx / (x_h - x_i)$$

- Local duality
- Global duality

Excludes elastic
Includes quasi-elastic
Includes elastic
Excludes quasi-elastic

1 < W < 2 GeV
Extracting $A_2 / g_2$

Black points: EG1b data
Blue points: RSS data
Line: EG1b model for $A_2$
Assuming the naïve parton model with no sea contribution, quark polarizations in the valence region can be estimated directly from the data:

\[
\begin{align*}
    \frac{\Delta u}{u} &\approx \frac{5g_1^p - 2g_1^d}{5F_1^p - 2F_1^d} / (1 - 1.5\omega_D) \\
    \frac{\Delta d}{d} &\approx \frac{8g_1^d}{8F_1^d - 5F_1^p} - \frac{5g_1^p}{5F_1^p}
\end{align*}
\]

• Also NLO analysis on this data
• New results for recent data coming soon!

Orbital angular momentum may change this picture
Effect of CLAS data on NLO fits of PDFs

$g_1(x, Q^2)_{\text{exp}} = g_1(x, Q^2)_{LT} + h^{g_1}(x)/Q^2$

NLO fit by Leader, Stamenov and Siderov, including both CLAS data and new COMPASS data on the deuteron
Generalized Parton Distributions (GPD)

3-dimensional quark structure of nucleon

**Elastic Scattering**
transverse quark
distribution in
coordinate space

**Deep inelastic scattering**
Longitudinal quark
Distribution in momentum space

**Deep exclusive scattering**
Fully-correlated
quark distribution in
both coordinate and
momentum space - GPDs
Deeply Virtual Compton Scattering and GPDs

- DVCS is the cleanest process to access GPDs

Handbag mechanism: the exclusive process can be factorized into a hard scattering part and a nucleon structure part parameterized via GPDs

\[
Q^2 = - (e-e')^2 \\
x_B = Q^2/2Mv \\
v = E_e - E_e' \\
t = (p-p')^2 \\
\xi = x_B/(2-x_B)
\]

DIS at \( t=\xi=0 \): parton distributions

\[
H^q(x,\xi=0,t=0) = q(x) \\
\tilde{H}^q(x,\xi=0,t=0) = \Delta q(x) \\
E^q, \tilde{E}^q
\]

ew information

First moments: form factors

\[
\int dx H^q(x,\xi,t) = F_1^q(t) \\
\int dx E^q(x,\xi,t) = F_2^q(t)
\]
The eg1-dvcs experiment

- eg1 configuration + IC calorimeter
- 6 GeV beam energy
- NH3 and ND3 targets
- DVCS Target and double spin asymmetry
- Semi-inclusive
- Uses $2\pi$ inner calorimeter for $\gamma/\pi^0$ coverage

IC calorimeter to

- increase $\gamma$ acceptance
  - EC: $17^\circ<\theta<43^\circ$
  - IC: $4^\circ<\theta<15^\circ$
- Better resolution

- 424 PbWO$_4$ crystals
- 16 cm x 1.3 cm x 1.3 cm
- Pointing geometry
- $\sim1.2$ degree/crystal
- 18 radiation lengths
- APD readout
DVCS preliminary results

Target asymmetry

\[ \Delta \sigma_{UL} \sim \sin \phi \text{Im}\left\{ F_1 \tilde{H} + \bar{\xi}(F_1 + F_2)(H + ..) \right\} d\phi \]

Double spin asymmetry

\[ \Delta \sigma_{LL} \sim \cos \phi \text{Re}\left\{ F_1 \tilde{H} + \bar{\xi}(F_1 + F_2)(H + ..) \right\} d\phi \]

- No \( \pi^0 \) corrections
- Estimated dilution factor of 0.8
Semi-inclusive pion production

TMDs and Collins fragmentation function

Data: eg1 run Avakian et al arXiv:1003.4549

Expected Precision for $\sin \phi$ and $\sin 2\phi$ moments of target SSA

See talks by Harut Avakian and Patrizia Rossi on Friday!
Study of spin orbit correlations in semi inclusive DIS and Sivers distribution function (E08-015 – running in 2011)

HD target

\[ E_{\text{beam}} = 6 \text{ GeV} \]

25 days (\( P_H = 75\% \), \( P_D = 25\% \))

Potential to add to world data on \( g_2 \) and \( A_2 \)
12 GeV program: CLAS12

- Superconducting coils for toroidal magnetic field
- Drift Chambers are for tracking of the forward going charged particles
- Cherenkov Counters and Time-of-Flight system are for Particle Identification
- Central detector for large angle particle detection and identification
- Electromagnetic Calorimeter and Preshower Calorimeter for neutral particle detection, triggering and electron identification
12 GeV program: CLAS12

Superconducting coils for toroidal magnetic field

Drift Chambers are for tracking of the forward going charged particles

Cherenkov Counters and Time-of-Flight system are for Particle Identification

Central detector for large angle particle detection and identification

Electromagnetic Calorimeter and Preshower Calorimeter for neutral particle detection, triggering and electron identification
Superconducting coils for toroidal magnetic field

Drift Chambers are for tracking of the forward going charged particles

Cherenkov Counters and Time-of-Flight system are for Particle Identification

Central detector for large angle particle detection and identification

Electromagnetic Calorimeter and Preshower Calorimeter for neutral particle detection, triggering and electron identification
The polarized target

Chemical Structure: \( \text{NH}_3 \)
Length: 3.3 cm
Diameter: 3.0 cm
Polarization: 85%
Dilution Factor: 0.15
Luminosity: \( 2 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1} \)
12 GeV program

DVCS

Proton \( W > 2; Q^2 > 1 \)

Deuteron

Also Semi-inclusive
Conclusions

- Broad spin program at Jefferson Lab.
- Complex look at the structure of the nucleon.
- Many observables asymmetries, structure functions, sum rules, moments, GPDs, TMDs
- New information to understand the transition between hadron and partonic degrees of freedom
- Plenty results from Jefferson Lab, large acceptance and access to resonance region
- Much more to come JLab @ 12 GeV: DIS, SIDIS, DVCS
- Also COMPASS+RHIC, Spring8, J-PARC, FAIR, … EIC?

Thanks to Sebastian Kuhn, Nevztat Guler, Yelena Prok, Keith Griffioen, Peter Bosted, Erin Seder, Silvia Pisano, Sucheta Jawalkar
Additional results

- NLO PDF fit
- $A_2/g_2$
- Duality
- Two particle channel
\[ \sigma(W, Q^2, \vartheta^*, \phi^*) \propto \sigma_o + P_e \sigma_e + P_t \sigma_t + P_e P_t \sigma_{et} \]

- Different sensitivities to resonant and non-resonant contributions for the double \( \sigma_{et} \) and target \( \sigma_t \) polarization terms.
- Polarized measurements to provide new constraints to phenomenological models which are based on previous unpolarized photo- and electro-production data.

**Semi-inclusive**

- Semi-inclusive process: \( e p \rightarrow e' p X \)
- Struck quark of different flavors produce the hadron with different probabilities.
- SIDIS can help to separate contributions from quark flavors.
- Access to orbital angular momentum of quarks.
- Transverse momentum distributions.
Semi-inclusive $p(e,e'p)\pi^0$
Outlook: The Future at JLab

- Remaining experiments at 6 GeV
  - Hall A
    - E-06-010: Transverse target single spin asymmetry in $n\uparrow(e,e'^\pi^-)$
    - E-06-011: Transverse target single spin asymmetry in $n\uparrow(e,e'^\pi^+)$
    - E-06-014: Precision measurement of $d_2$ on the neutron
    - E-08-027: $g_{2p}$ and $\delta_{LT}$
  - Hall B
    - E-05-113: Semi-inclusive pion production (and DVCS) on $p\rightarrow$
    - E-08-015: Semi-inclusive pion production (and DVCS) on $p\uparrow$
  - Hall C
    - E-07-011: High precision $g_{1d}$ in DIS region
    - E-07-003: SANE (SSFs on p, with emphasis on $g_2$)

- Approved experiments for 12 GeV
  - Hall A/C
    - E12-06-122: $A_{1n}$ at high $x$ with 8.8 GeV and 6.6 GeV beam in Hall A
    - E12-06-121: Precision measurement of $g_2$ and $d_2$ on the neutron
  - Hall B
    - E12-06-10: SSFs on longitudinal target with CLAS12
    - E12-07-107: Semi-inclusive pion production on $p\rightarrow$
$g_1/F_1$ falls below the DIS extrapolation at low $Q^2$ (dashed curve)
Large-x behavior of the $A_1$ asymmetry

Large x region dominated by valence quarks $\rightarrow$ can test quark models

- SU(6) QM: Exact SU(6) symmetry
  Equal probability for $S=0$ and $S=1$ di-quark configuration

- Hyperfine perturbed QM
  makes $S=1$ pairs more energetic than $S=0$ pairs

- Duality
  Close and Melnitchouk, PRC 68, 035210 (2003)
  Suppress transitions to specific resonances ($56^+$ and $70^-$)

- In DIS, pQCD: Minimal gluon exchanges
  Close and Melnitchouk, PRC 68, 035210 (2003)

Spectator pair: quarks have opposite helicities

Farrar and Jackson, PRL 35, 1416 (1975)

<table>
<thead>
<tr>
<th>Model for $x \rightarrow 1$</th>
<th>$A_1^p$</th>
<th>$A_1^n$</th>
<th>$d/u$</th>
<th>$\Delta u/u$</th>
<th>$\Delta d/d$</th>
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</thead>
<tbody>
<tr>
<td>SU(6)</td>
<td>5/9</td>
<td>0</td>
<td>1/2</td>
<td>2/3</td>
<td>-1/3</td>
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<td>w/ hyperfine ($E_{S=0} &lt; E_{S=1}$)</td>
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<td>1</td>
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<td>One gluon exchange</td>
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<td>0</td>
<td>1</td>
<td>-1/3</td>
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<td>$S=1/2$ dominance</td>
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<td>1/14</td>
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<td>1/5</td>
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<tr>
<td>pQCD (conserved helicity)</td>
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<td>1</td>
<td>1/5</td>
<td>1</td>
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</table>
Parton Distributions Functions and NLO pQCD

- Two effects modify simple parton picture:
  - pQCD evolution makes PDFs $Q^2$-dependent (NLO DGLAP equations) – mild logarithmic dependence
  - (Gluon) radiative corrections change elementary cross section generating a contribution to $g_1$ due to the gluon polarization

$$g_1^{NLO}(x, Q^2) = g_1^{LO} + \frac{1}{2} \left< e^2 \right> \sum_q e_q^2 [\Delta q(x, Q^2) \otimes C_q + \Delta g(x, Q^2) \otimes C_g]$$

we can extract information on the gluon from DIS
Virtual photon asymmetries

\[
\frac{d\sigma}{dE'\,d\Omega} = \Gamma_v \left[ \sigma_T + \varepsilon\sigma_L + P_eP_t \left( \sqrt{1 - \varepsilon^2} A_1\sigma_T \cos\psi + \sqrt{2\varepsilon(1 - \varepsilon)} A_2\sigma_T \sin\psi \right) \right]
\]

\[
A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_T} \quad A_2 = \frac{\sigma_{LT'}}{\sigma_T}
\]

the asymmetries \( A_1 \) and \( A_2 \) can be extracted by varying the direction of the nucleon polarization or by varying the beam energy at fixed \( Q^2, \nu \)

\[
A_{||} = D(A_1 + \eta A_2) \\
A_{\perp} = d(A_1 + \zeta A_2)
\]

[where \( D, \eta, d, \zeta \) are functions of \( Q^2, E', E, R, \) e.g.:

\[
D = \frac{1 - \varepsilon E'/E}{1 + \varepsilon R} \\
\eta = \varepsilon \sqrt{\frac{Q^2}{E - \varepsilon E'}} \\
R = \frac{\sigma_L}{\sigma_T}
\]

EG1 used parameterization of world data on \( A_2 \) to extract \( A_1 \) (\( \eta \) is usually small)
The asymmetry analysis

\[ A_{\text{raw}} = \frac{N^-/Q^- - N^+/Q^+}{N^-/Q^- + N^+/Q^+} \]

- N\(^+/-\)Yield for electron/target spins
- antiparallel (-) or parallel (+)
- Q\(^+/-\)gated FC

Physics asymmetry \(A_{||}\)

\[ A_{||} = \frac{C_{\text{back}} A_{\text{raw}}}{P_e P_t \times DF} \]

- \(P_e\) Beam polarization
- \(P_t\) Target polarization
- DF Dilution factor
- \(C_{\text{back}}\) Background processes
(pion contamination & pair symmetric)

\[ A_1 + \eta A_2 = \frac{A_{||}}{D} \]

\(A_1, g_1\) can be extracted

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

\[ g_1(x, Q^2) = \frac{\tau}{1 + \tau} \left( A_1 + \frac{1}{\sqrt{\tau}} A_2 \right) F_1 = \frac{\tau}{1 + \tau} \left( \frac{A_{||}}{D} + \left( \frac{1}{\sqrt{\tau}} - \eta \right) A_2 \right) F_1 \]

\[ g_2(x, Q^2) = \frac{\tau}{1 + \tau} (\sqrt{\tau} A_2 - A_1) F_1 \]

\(\tau = \frac{v^2}{Q^2}\)

\(D = \frac{1 - E'\epsilon/E}{1 + \epsilon R} ; \quad \eta = \frac{\epsilon \sqrt{Q^2}}{E - E'\epsilon} \quad R = \frac{\sigma_L}{\sigma_T} \)
$A_1$ proton for different $Q^2$ bins

Similar for proton...
Virtual Photon Asymmetry $A_1$

- P and d results fall below parameterization of world data at $10 \text{ GeV}^2$ → include in DGLAP fits
- To be used to extract $\Delta q/q$ in this momentum transfer region
- P and d results are in better agreement with the HFP quark model

*HP perturbed QM N. Isgur, Phys. Rev. D 59, 34013*  
*E. Close and W. Melnitchouk, Phys. Rev. C 68, 035210*
$g_1(x,Q^2)$ proton for different $Q^2$ bins

\[ g_1(x,Q^2) \]
Moments and Sum Rules

\[ \Gamma_1(P) \]

**Diagram Description:**
- The graph shows the variation of \( \Gamma_1(P) \) with \( Q^2 \) (GeV) for different data sets and models.
- Key data sources include CLAS EG1B, Soffer-Taryaev, Burkert-Ioffe, JiPT, and HERMES.
- The preliminary nature of the data is indicated.

**Note:** Similar for deuteron...
Link between GPDs, DIS and form factors

- DIS at \( \xi = 0 \): ordinary parton distributions

\[
H^q(x, \xi = 0, t = 0) = q(x) \quad \text{unpolarized quark distributions}
\]

\[
\tilde{H}^q(x, \xi = 0, t = 0) = \Delta q(x) \quad \text{polarized quark distributions}
\]

\[
E^q, \tilde{E}^q \quad \text{new information}
\]

- First moments: form factors

\[
\int_{-1}^{1} dx H^q(x, \xi, t) = F_1^q(t)
\]

\[
\int_{-1}^{1} dx \tilde{H}^q(x, \xi, t) = G_A^q(t)
\]

\[
\int_{-1}^{1} dx E^q(x, \xi, t) = F_2^q(t)
\]

\[
\int_{-1}^{1} dx \tilde{E}^q(x, \xi, t) = G_P^q(t)
\]

- Dirac
- Pauli
- axial
- pseudo-scalar