Jefferson Lab's results on the Q^2-evolution of spin structure functions

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On behalf of the CLAS and E94010 collaborations

Moments of spin structure functions

N^{th}-moments: $\begin{cases} \int g_1 x^{n-1} dx \\ \int g_2 x^{n-1} dx \end{cases}$

First moments: Γ_1, Γ_2

Why are moments interesting ?

Related to particle static properties via sum rules:

- Γ_1^N: $\begin{cases} \text{Ellis-Jaffe sum rule (large } Q^2) \\ \text{Gerasimov-Drell-Hearn (GDH) sum rule } (Q^2=0) \end{cases}$
- Γ_1^{p-n}: Bjorken sum rule (large Q^2)
- Γ_2^N: Burkhardt–Cottingham (BC) sum rule (any Q^2)

Higher moments:

- d_2 ”sum rule”
- Spin polarizability sum rules

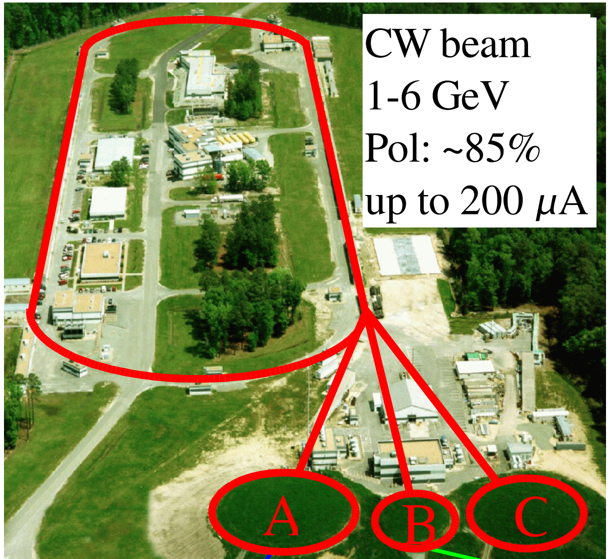
- Some moments are calculable in OPE (large Q^2, n odd).
- Low Q^2 moments can be calculated using χpT.
- Any Q^2 : Lattice QCD.
- Other (BC sum rule)

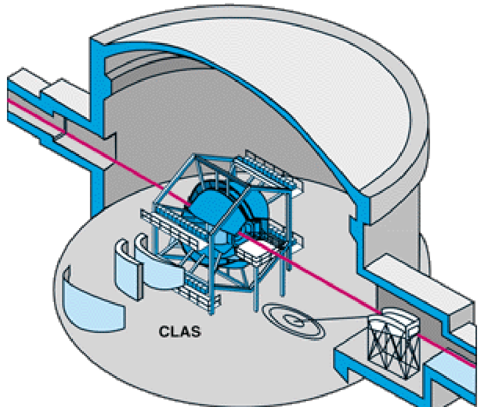
⇒Moments, (via sum rules) can:

- Check theories (e.g. QCD and Bjorken sum rule)
- Check hypothesis (e.g. EJ Sum Rule)
- Check calculations (e.g. OPE, χpT, Lattice and generalized GDH sum rule)
- Extract quantities (e.g. d_2, WW, spin pol. sum rules)

In addition, Q^2-evolution of moments are instrumental to study strong coupling constant, hadron-parton duality...

→ See N. Liyanage talk, Friday

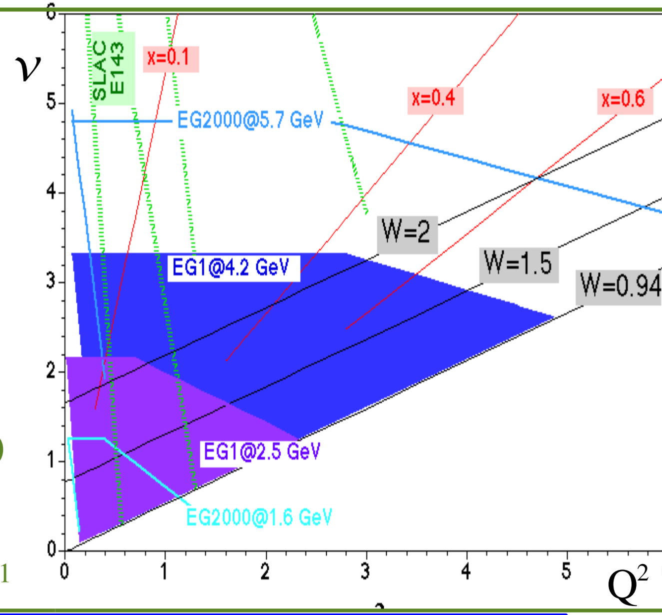


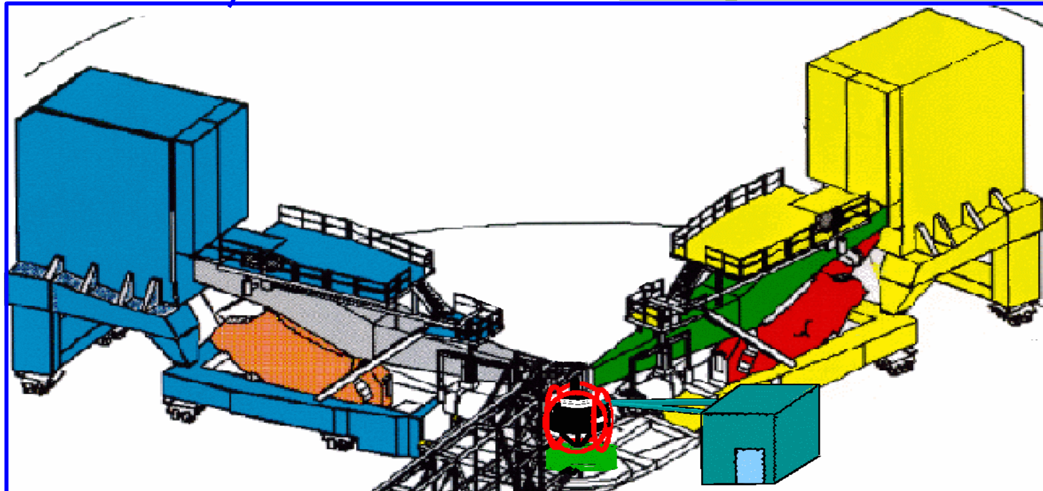


Pol. NH_3 & ND_3 (spin // to beam)

Pol : 75% (NH_3) or 30% (ND_3)

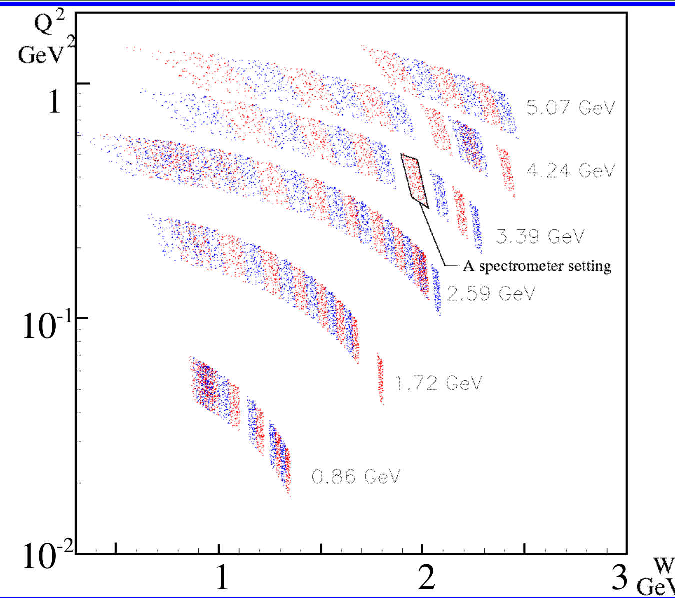
Accept ~ 2.5π $\mathscr{L}$:10^{34} cm^{-2} s^{-1}





Pol. ^{3}He target (// and ⊥ directions) Pol: ~40%

Accept: 6 mSr, $\mathscr{L}$:10^{36} cm^{-2} s^{-1}



Extraction of SSF

- CLAS/EG1

  Only longitudinal asymmetry:

  ⇒Model for F_1 : well measured at low Q^2(Hall C)

  ⇒Model for g_2 : MAID (resonance) & g_2^{ww}(DIS)

  ⇒Model for R : SLAC+Hall C measurements

  ⇒Model dependence is minimal.

  (±5% typical uncertainty, dominated by polarization measurement (6%) and dilution factor. Uncertainty at the Δ_{1232} larger (dominates for moments).

  For deuteron, models not as constraint but statistical is not as good

- Hall A/ E94-010

  Measure polarized cross-sections (both // and ⊥)

  ⇒Model indep. extraction and no dilution factor

  Errors:

  polarization measurements:~5%

  cross section: ~5%

  Interpolation uncertainty: small (high $\mathscr{L}$uminosity)

Γ_1^p from CLAS

$$\text{OPE: } \int g_1^N dx = \left(\pm 12 g_A + \frac{a_8}{36}\right) C_{NS} + \frac{a_0}{9} C_S + \frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \ldots$$

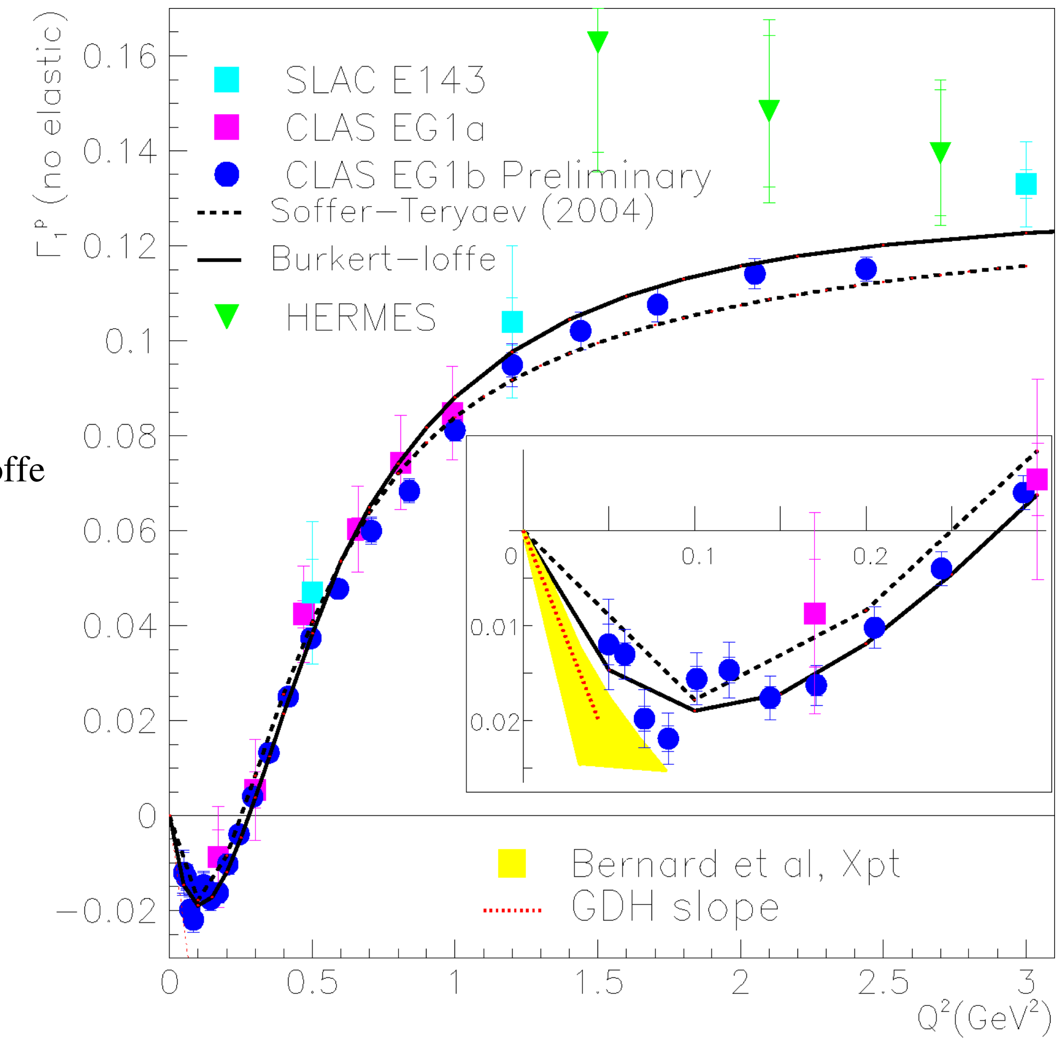
Elastic not included

Low-x extrapolation :

EG1a: Bianchi-Thomas

EG1b: EG1 “Model”

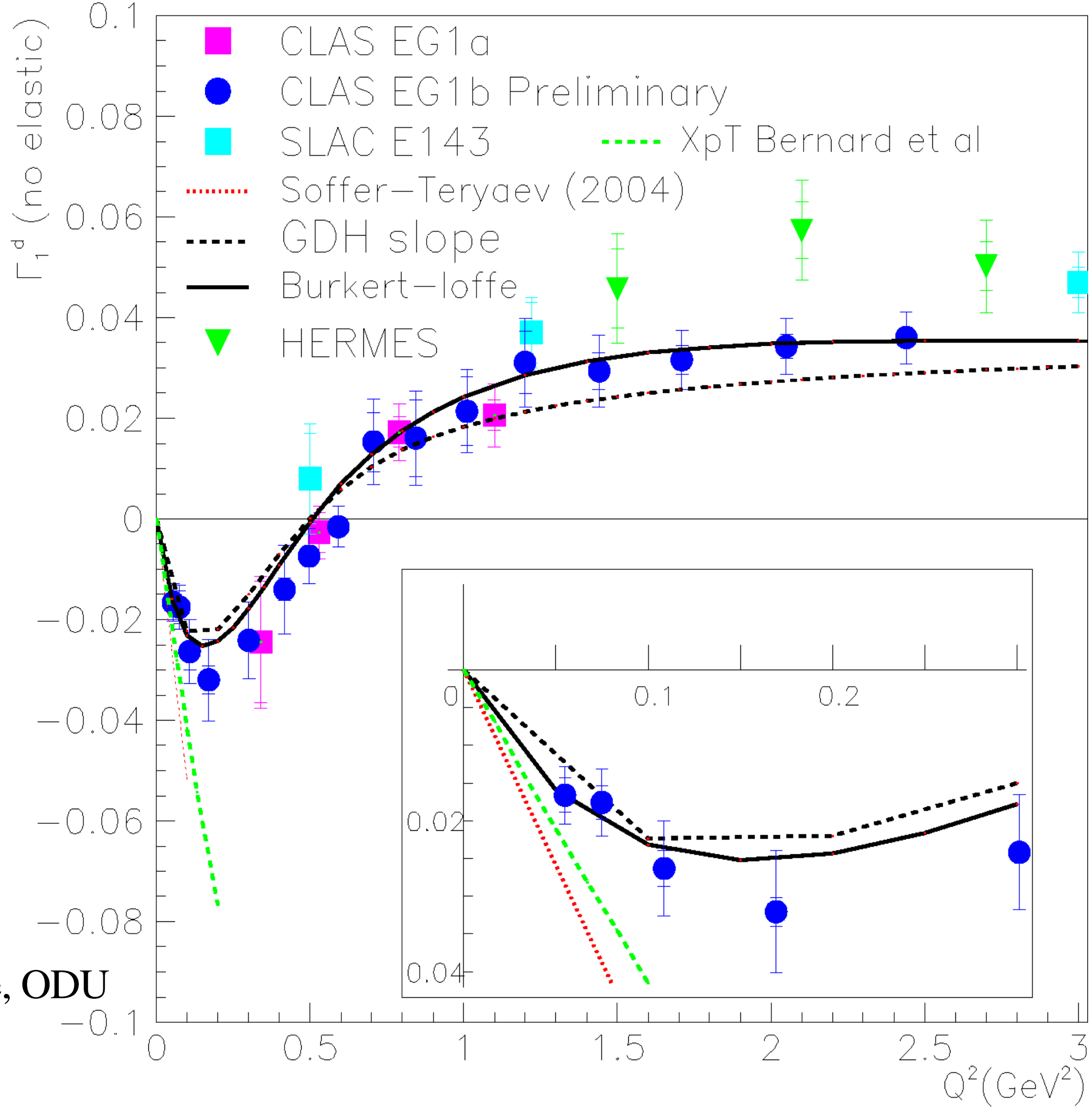
Non-res.: DIS fit , res.: Burkert-Ioffe



EG1b data analysis: Y. Prok, U.Va

EG1a data: R. Fatemi et al., PRL.91: 222002, 2003

Γ_1^d from CLAS



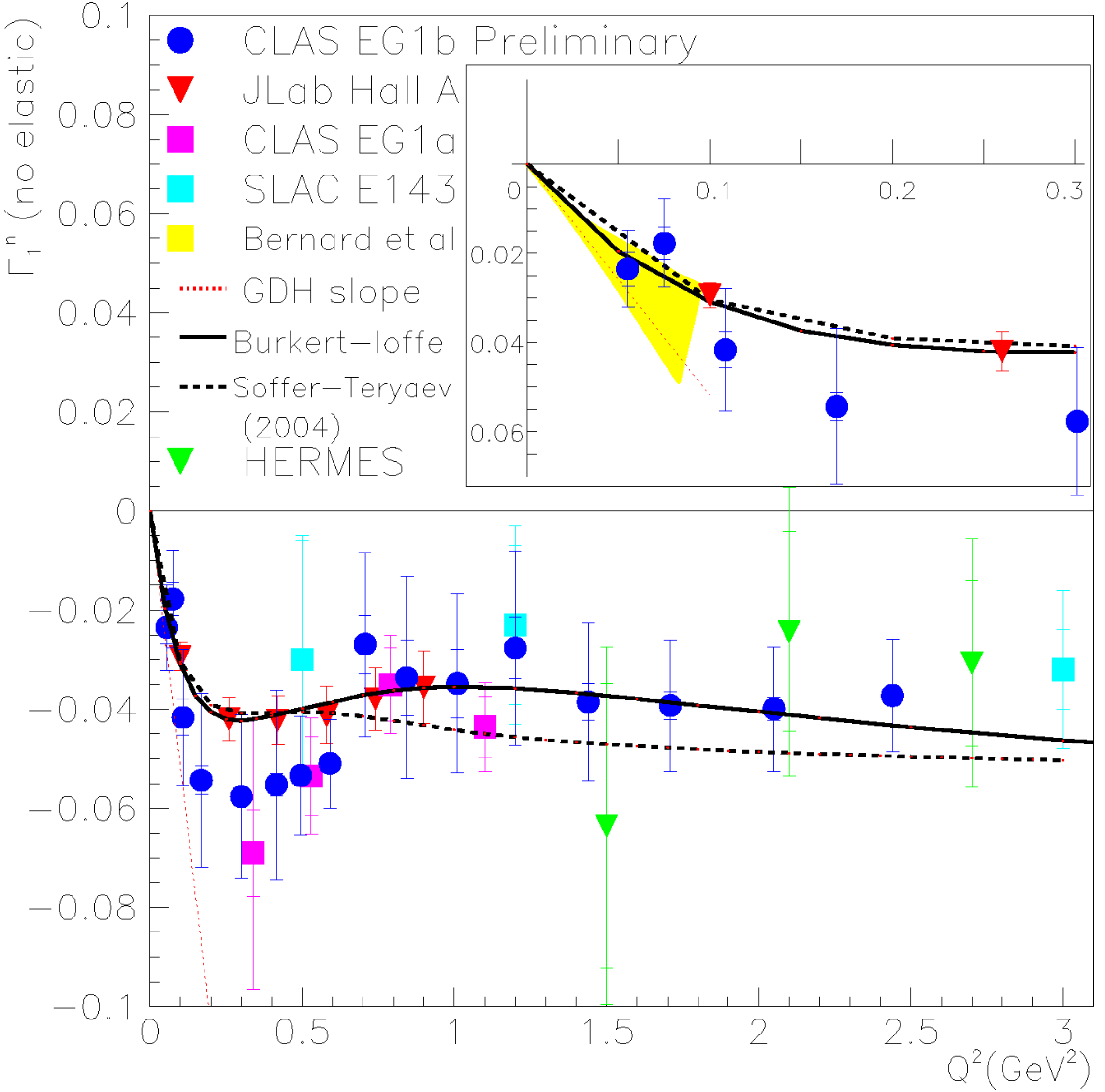
EG1b data analysis: V. Dharmawardane, ODU
EG1a data: J. Yun et al.,
Phys.Rev.C67:055204,2003

Γ_1^n from Hall A & CLAS

Low-x extrapolation :

Hall A/EG1a: Bianchi-Thomas

EG1b: “Model”



Hall A exp E94-010 data:

M. Amarian et al., PRL 92, 022301, 2003

Bjorken sum from Hall A & CLAS

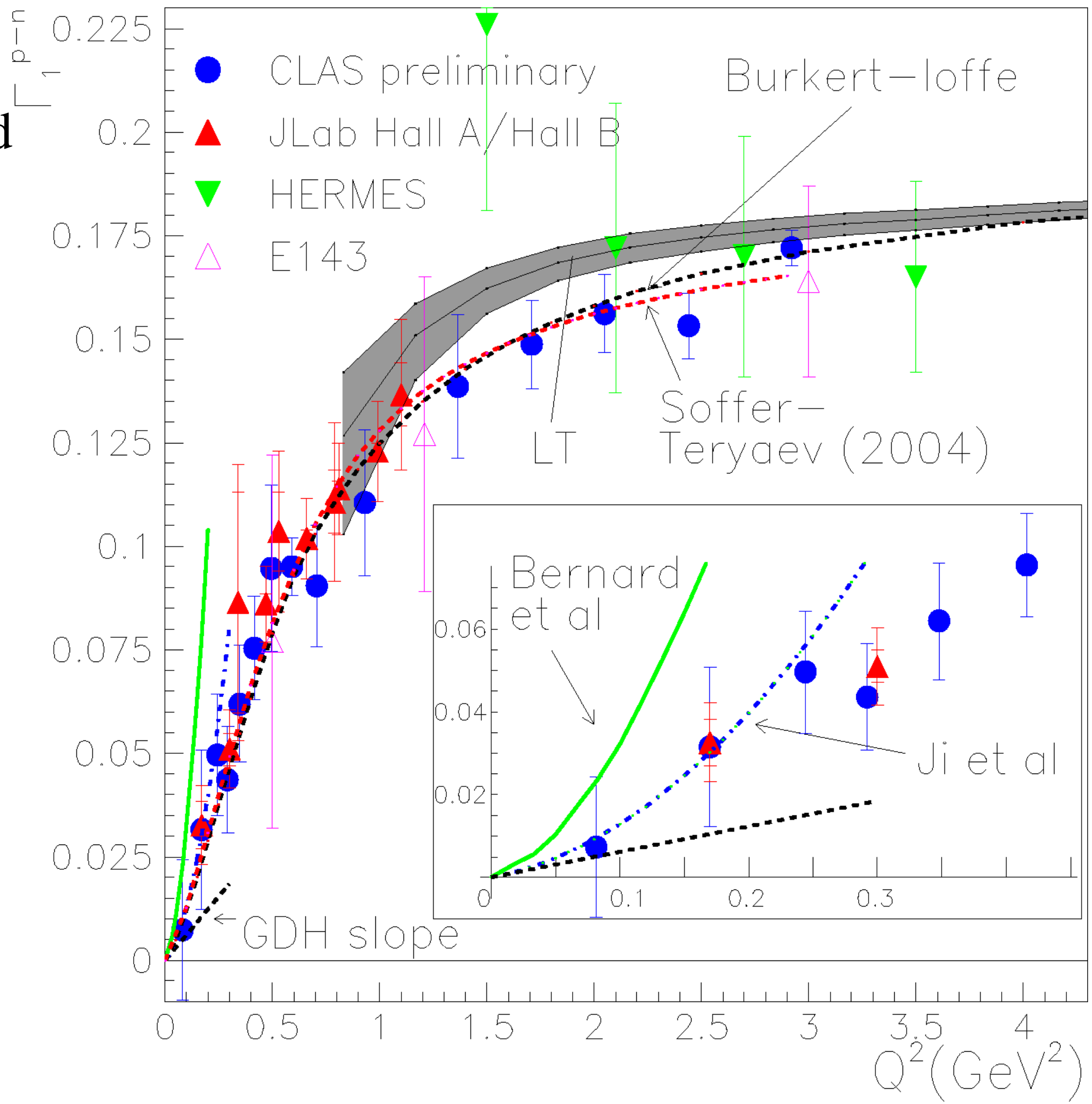
Δ_{1232} contribution suppressed

$\Rightarrow$better check of χpT.

Low-x extrapolation :

Hall A/EG1a: Bianchi-Thomas

EG1b: “Model”



Hall A/CLAS data: A. Deur et al.

PRL 93 212001 (2004)

Generalized GDH sum from Hall A

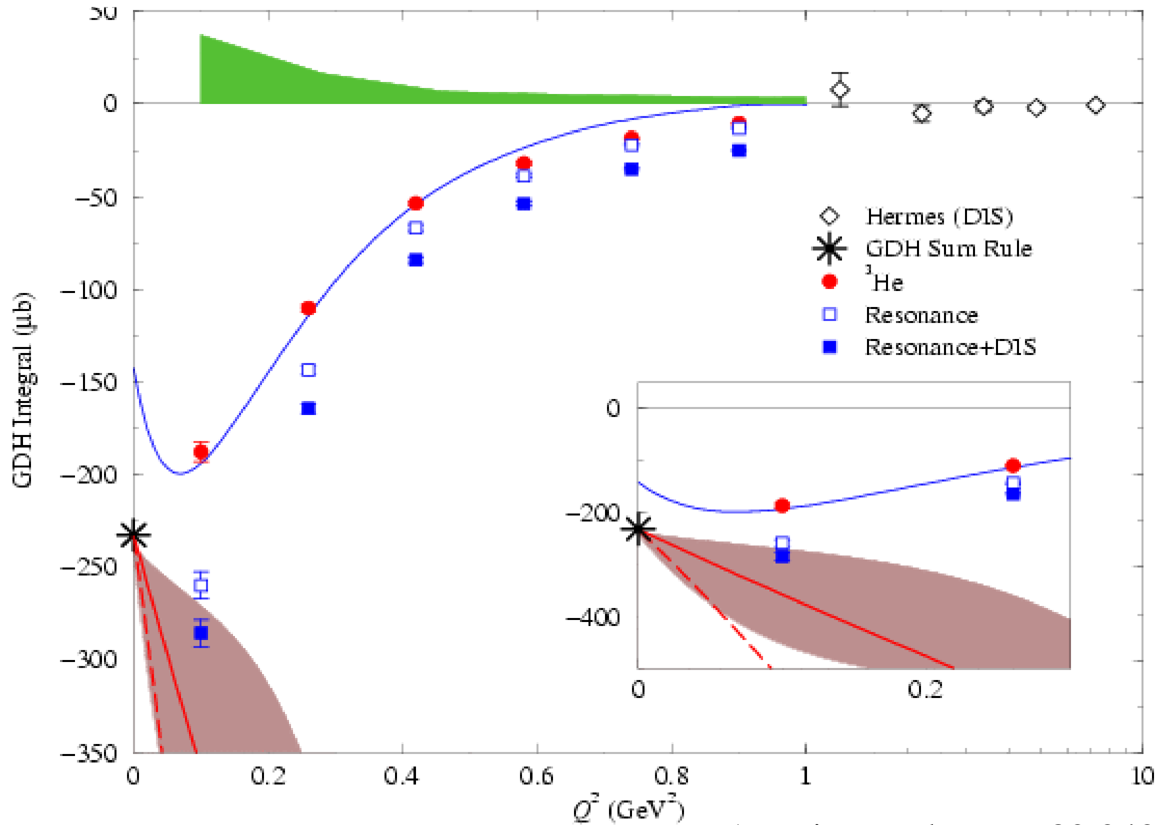
GDH sum ($Q^2=0$): $\int_{\nu_{thr}}^{\infty} \sigma^{1/2} - \sigma^{3/2} \frac{d\nu}{\nu} = \frac{-2\alpha\pi^2\kappa^2}{M^2}$ κ: anomalous magnetic moment

Generalized: Photoproduction → electroproduction

- Bernard et al, χpT (red solid line)
- Bernard et al, χpT (Δ_{1232} included) (shaded band)
- Ji et al, χpT (red dashed line)
- Maid model (blue line)

(Multipole analysis
of world inclusive and exclusive
data in the resonance region
D. Drechsel, S.S. Kamalov, L.Tiator,
Nucl. Phys. A645 145, 1999)

Low-x extrapolation :
Bianchi-Thomas



M. Amarian et al. PRL 89 242301 (2002)

⇨

- Accurate (p and n) mapping at intermediate Q^2.
- Connection with DIS data.
- χpT not valid beyond Q^2 =0.2 GeV^2 .
- Phenomenological models work well.
- Good leading twist description even at low Q^2 (Bjorken sum).

Higher Twists

OPE:

$$\int g_1^N dx = \left(\pm \frac{1}{12} g_A + \frac{a_8}{36}\right) C_{NS} + \frac{a_0}{9} C_S + \frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \ldots$$

Wilson coef. C_{NS} and C_s known (pQCD)

a_8 $(=\Delta\Sigma)$, g_A, and a_0 measured.

$$\frac{\mu_4}{Q^2} = \frac{M^2}{9}(a_2 + 4d_2 + 2f_2)$$

Twist 2 (from DIS) → a_2; Twist 3 (DIS+JLab@large x) → d_2; Twist 4 → f_2

Bjorken sum:

$$\int g_1^{p-n} dx = \frac{1}{6} g_A C_{NS} + \frac{\mu_4^{p-n}}{Q^2} + \frac{\mu_6^{p-n}}{Q^4}$$

Simpler: Low Q^2: ~no Δ_{1232} contribution

Large Q^2: easier DGLAP evolution, Easier low-x extrapolation, sum rule

Extraction:

- include elastic.
- Consistent low-x extrapolation for world data.
- Fit DIS world data + JLab data for Q^2 > X using above functional forms.

Results (values at $Q^2=1$):

Proton:

$4\mu_4'/9M^2=f_2=0.039^{+0.037}_{-0.043}$

$\mu_6'/M^4=0.011^{+0.017}_{-0.013}$

World data+EG1a (no EG1b)
M. Osipenko et al.
Phys. Lett B609: 258 (2005)

Nachtmann moment used

Neutron:

$f_2=0.034\pm0.043$

$\mu_4/M^2=0.019\pm0.024$

$\mu_6/M^4=-0.019\pm0.017$

Hall A E94-010 data
Z-E Meziani et al.
Phys. Lett. B613 148 (2005)

P-N:

$f_2=-0.18\pm0.10$

$\mu_4/M^2=-0.06\pm0.02$

$\mu_6/M^4=0.09\pm0.03$

EG1a+E94-010 data
A. Deur et al.
PRL 93 212001 (2004)

⇨ Overall, higher twist contribution small at $Q^2=1$.

From these analysis, we can extract color polarizabilities for the nucleons:

$\chi_E=(4d_2+2f_2)/3$

$\chi_B=(4d_2-f_2)/3$

Proton:

$\chi_E=0.026\pm0.015(\text{stat})\,^{+0.021}_{-0.024}(\text{sys})$

$\chi_B=-0.013\pm0.007(\text{stat})\,^{-0.010}_{-0.012}(\text{sys})$

Neutron:

$\chi_E=0.033\pm0.029$

$\chi_B=-0.001\pm0.016$

Extraction of generalized spin polarizabilities (electromagnetic) using sum rules

Same derivation as GDH sum rule but one higher order in the low energy theorem.

Better convergence (low-x less of an issue).

Generalized forward spin polarizability:

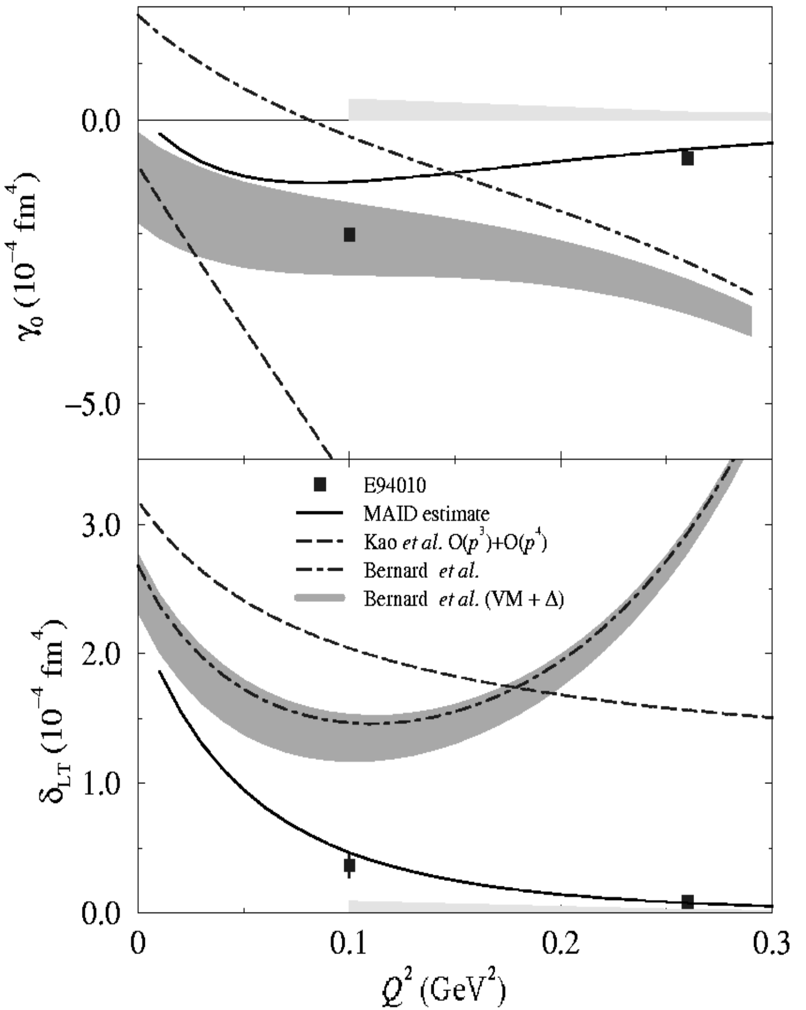
$$\gamma_0 = \frac{4e^2M^2}{\pi Q^6}\int_{\nu_{thr}}^{\infty} x^2\left(g_1 - \frac{4M^2}{Q^2}x^2 g_2\right)dx$$

Longitudinal-Transverse polarizability:

$$\delta_{LT} = \frac{4e^2M^2}{\pi Q^6}\int_{\nu_{thr}}^{\infty} x^2(g_1+g_2)dx$$

δ_{LT} has its Δ_{1232} contribution suppressed.

$\Rightarrow$better check of χpT.



Data from Hall A E94-010. First measurement of Generalized spin polarizabilities.

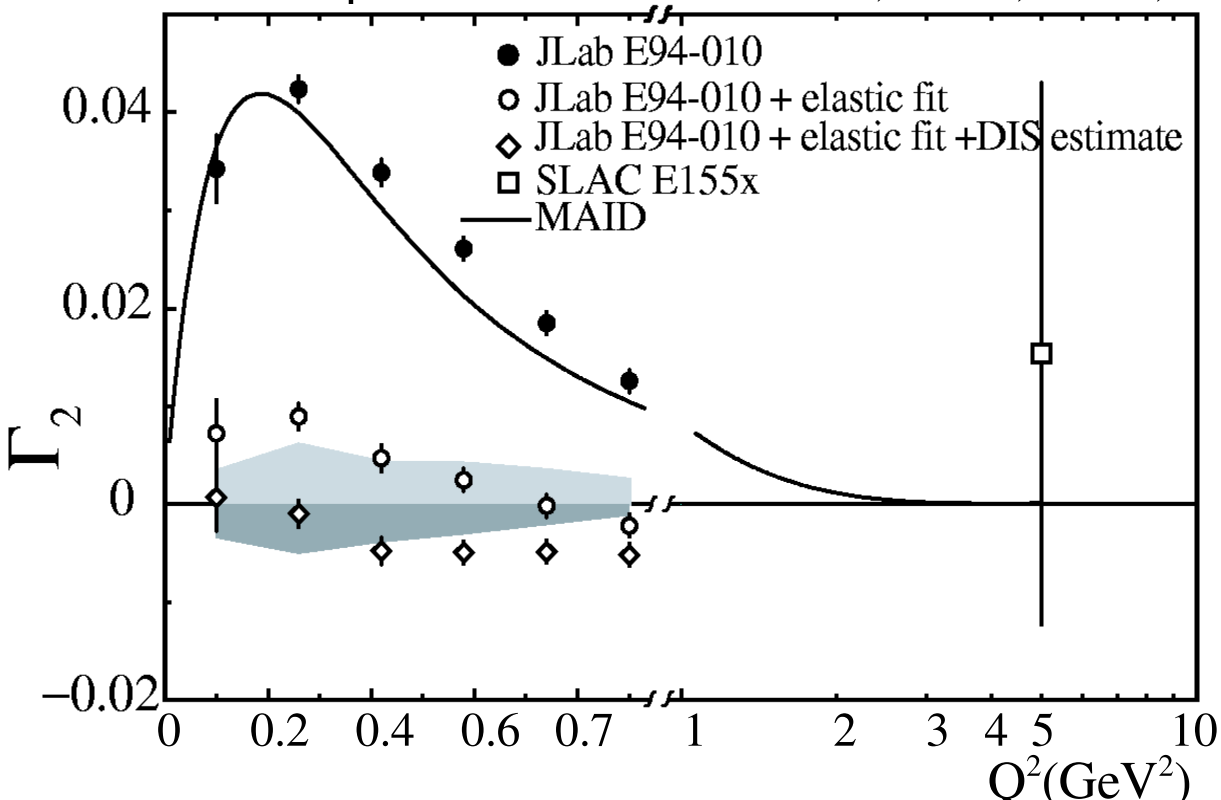
M. Amarian et al., PRL 9 152301 2004

The Burkhardt–Cottingham sum rule on neutron

BC sum rule: $\Gamma_2 = \int_0^1 g_2 dx = 0$

Based on dispersion relation+nice low-x behavior of g_2 (no OPE ⇒ stands at all Q^2).

Not well measured in DIS, but SLAC E155x found a 3σ deviation for proton.
Data from Hall A exp E94-010: M. Amarian et al., PRL 92, 022301, 2003



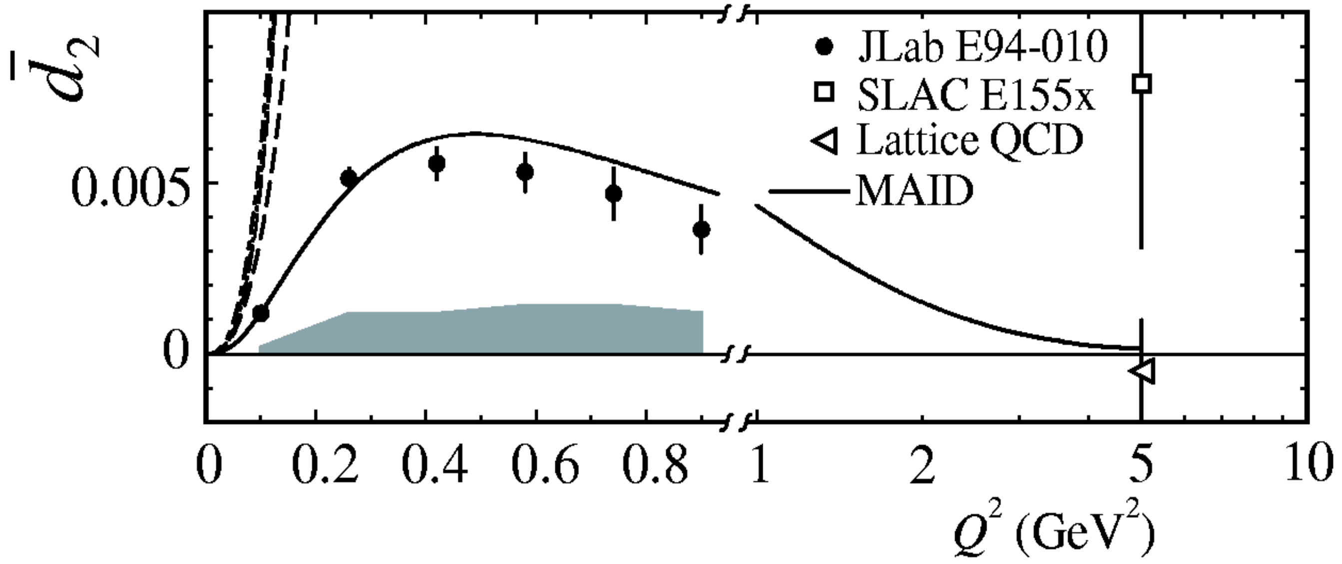
Sum rule seems to hold due to a cancellation between elastic and inelastic contribution.

The d_2 sum on neutron

$d_2 = \int x^2(2g_1+3g_2)dx = 3\int x^2(g_2-g_2^{ww})dx$

Sensitive to Twist-3 and higher (parton interpretation). No low-x issue

Data from Hall A exp E94-010: M. Amarian et al., PRL 92, 022301, 2003



Precise mapping in the hadron-parton transition. Trend toward the Lattice result.
Good description from resonance model.

Summary & perspectives

- JLab data provided an accurate mapping of the hadron-parton transition region.
- Moments that can be calculated at any Q^2 were presented.
- OPE analysis reveals that Higher Twist effects are small even at $Q^2=1$.
- Upcoming results at higher Q^2: CLAS EG1b, Hall A E01-012, Hall C RSS
- New results at very low Q^2 will complete mapping: Hall A E97-110, *CLAS E03-006*

- 12 GeV JLab Upgrade will allow us to:
  - Improve large-x coverage, minimize low-x issue.
  - Study convergence of sum rules.
  - Increase Q^2 range.