Jefferson Lab-Overview

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Temple University

XV International Workshop on Deep Inelastic Scattering and Related Subjects

Munich, Germany
April 16-20, 2007

Outline

Recent Results and near future experiments

on

- Inclusive measurements
  - Upolarized Structure functions,
  - Polarized Structure functions

K. Griffioen: Spin physics 1, Hall B
K. Slifer: Spin physics 3, Hall C

- Semi-Inclusive DIS
  - Transversity
  - Transverse Momentum distributions (TMDs)

- Exclusive (Deeply Virtual Compton Scattering,DVMP)
  - Generalized Parton Distributions (GPDs)

E. Voutier, Spin physics 7

A window into future high luminosity and high energies studies

Will not talk about

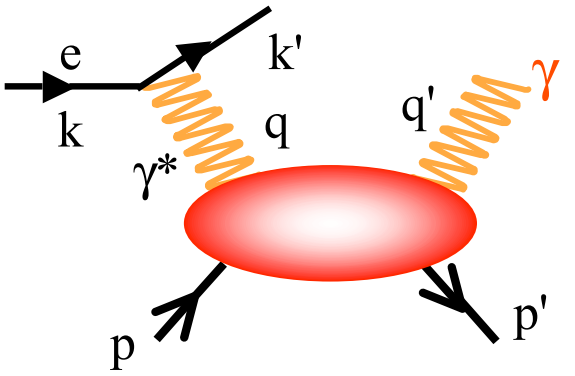
- DIS JLab at 12 GeV, Z.-E. M, session: Future of DIS 1.
- Parity DIS at Jlab, K.Kumar, session: Future of DIS 2.

New Framework for Nucleon Structure Studies

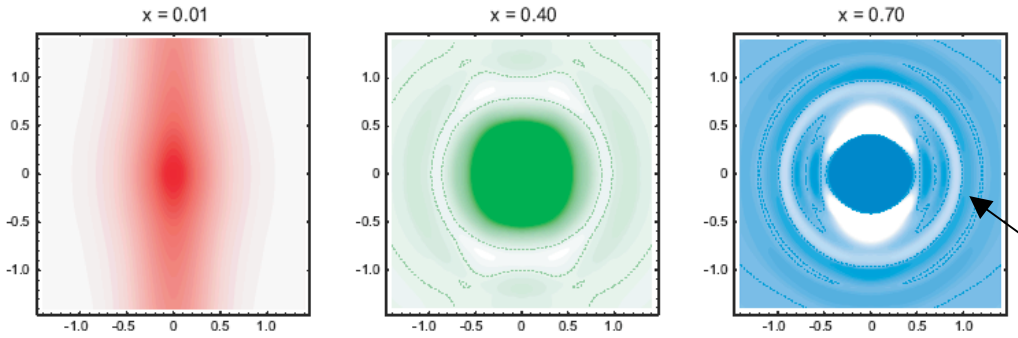
Goal: 3D mapping of the nucleon structure

- Theoretical tools:
  - ➥ Generalized parton Distributions
  - ➥ Transverse momentum distributions
- Experimental tools:
  - ➥ Deep exclusive reactions
  - ➥ Semi-Inclusive reactions

An example



Deep Virtual Compton scattering

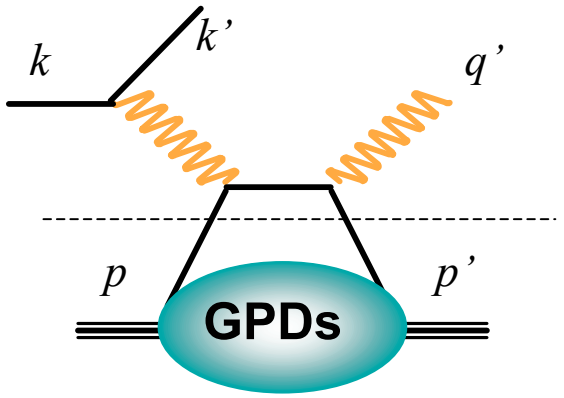


Model calculation of u-quark distributions in protons at different momentum fractions.

pQCD

Interference pattern

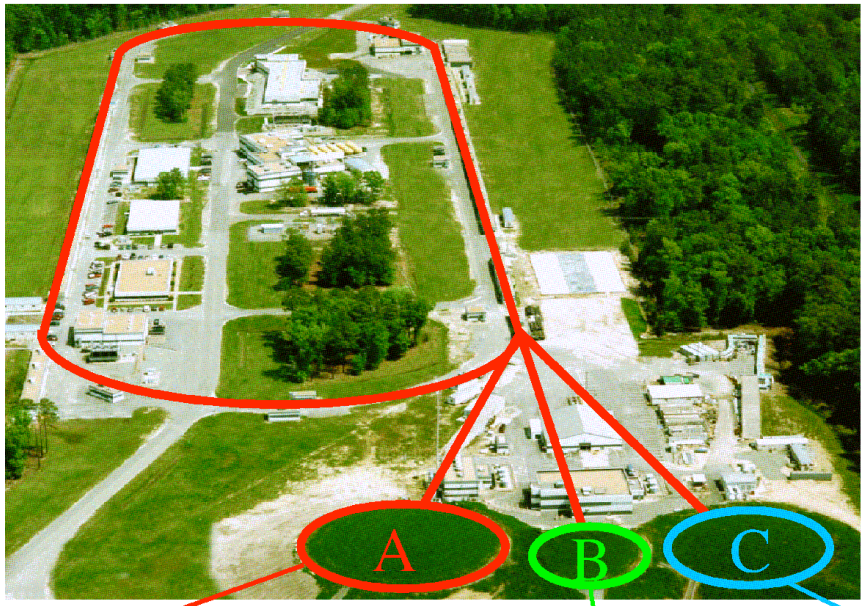
sQCD

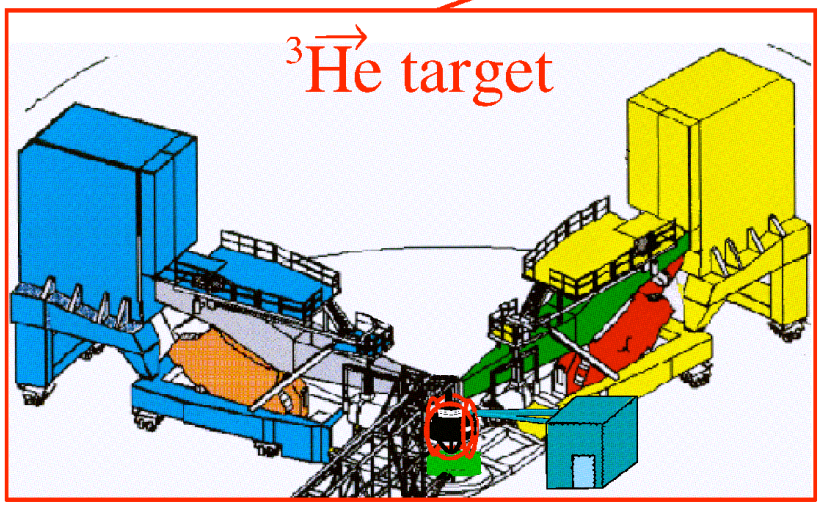


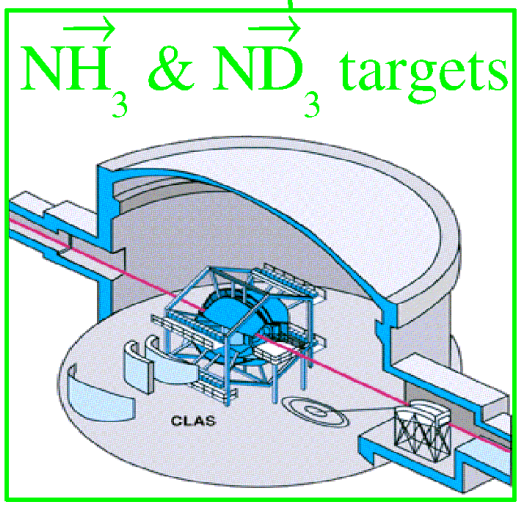
Handbag diagram

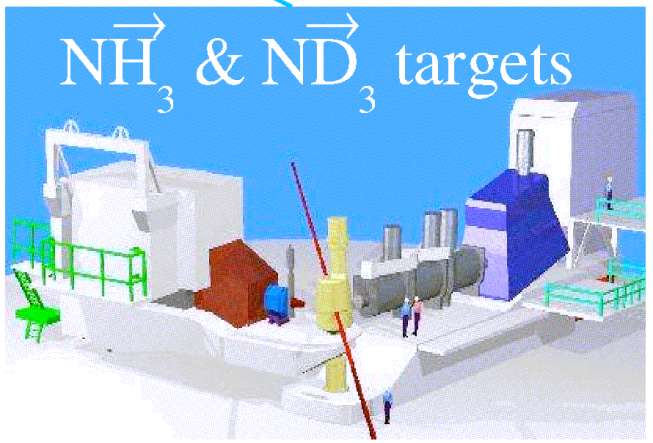
Jefferson Lab Experimental Halls

6 GeV pol. e beam
Pol = 85%, 100μA







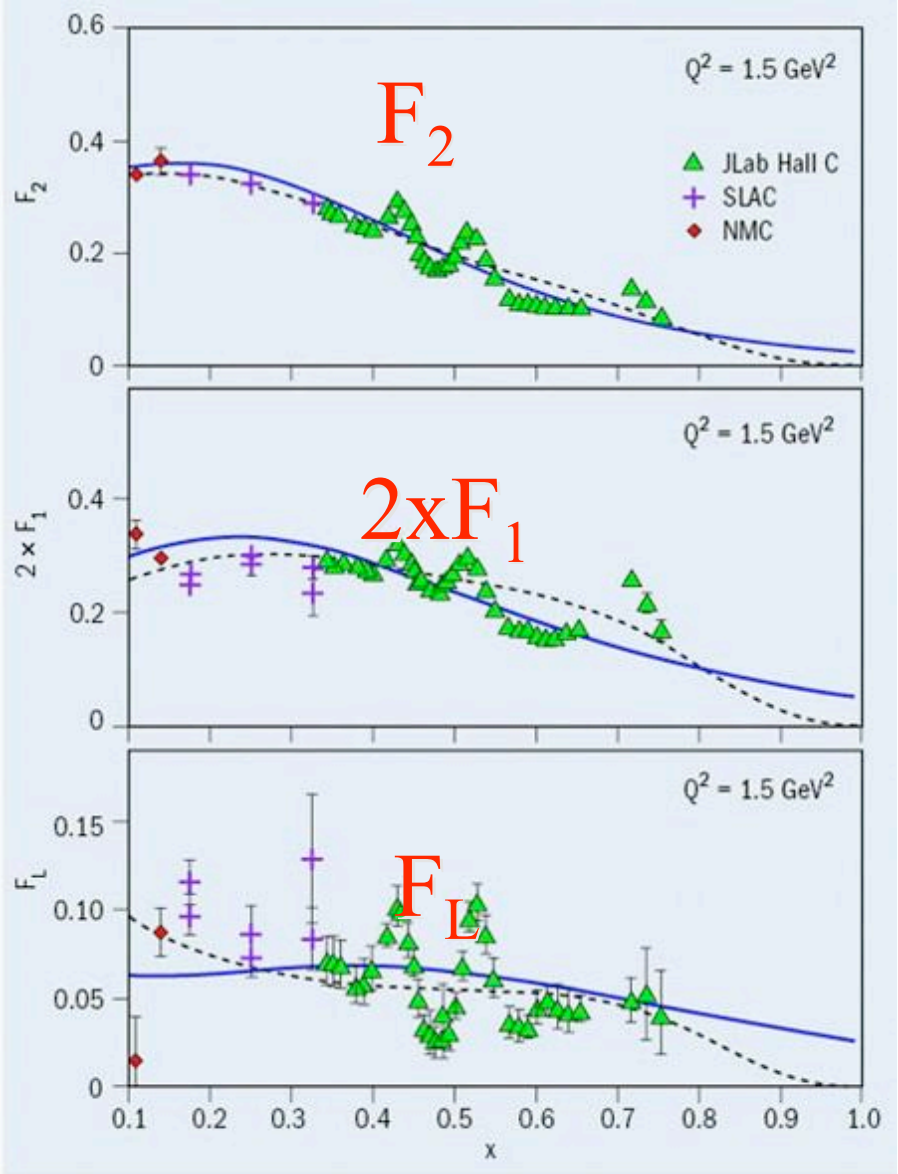


Inclusive Inelastic Scattering

Resonance +DIS

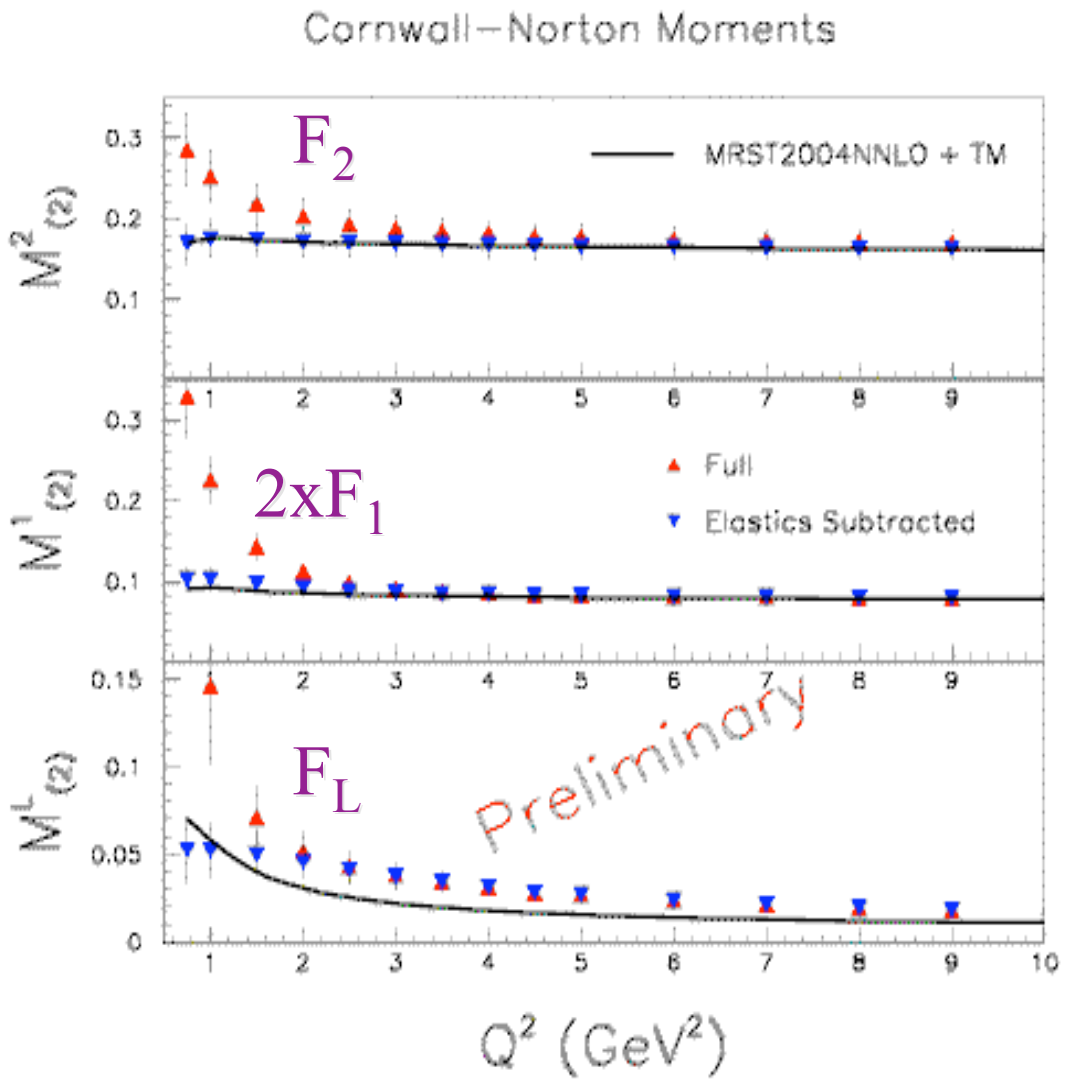
Unpolarized Structure Functions

Separated Structure Functions at Large x and Duality



- Data from JLab Hall C E94-110
- The resonance region is, on average, well described by NNLO QCD fits.
- The result is a smooth transition from Quark Model Excitations to a Parton Model description, or a smooth quark-hadron transition.

n = 2 Cornwall-Norton Moments



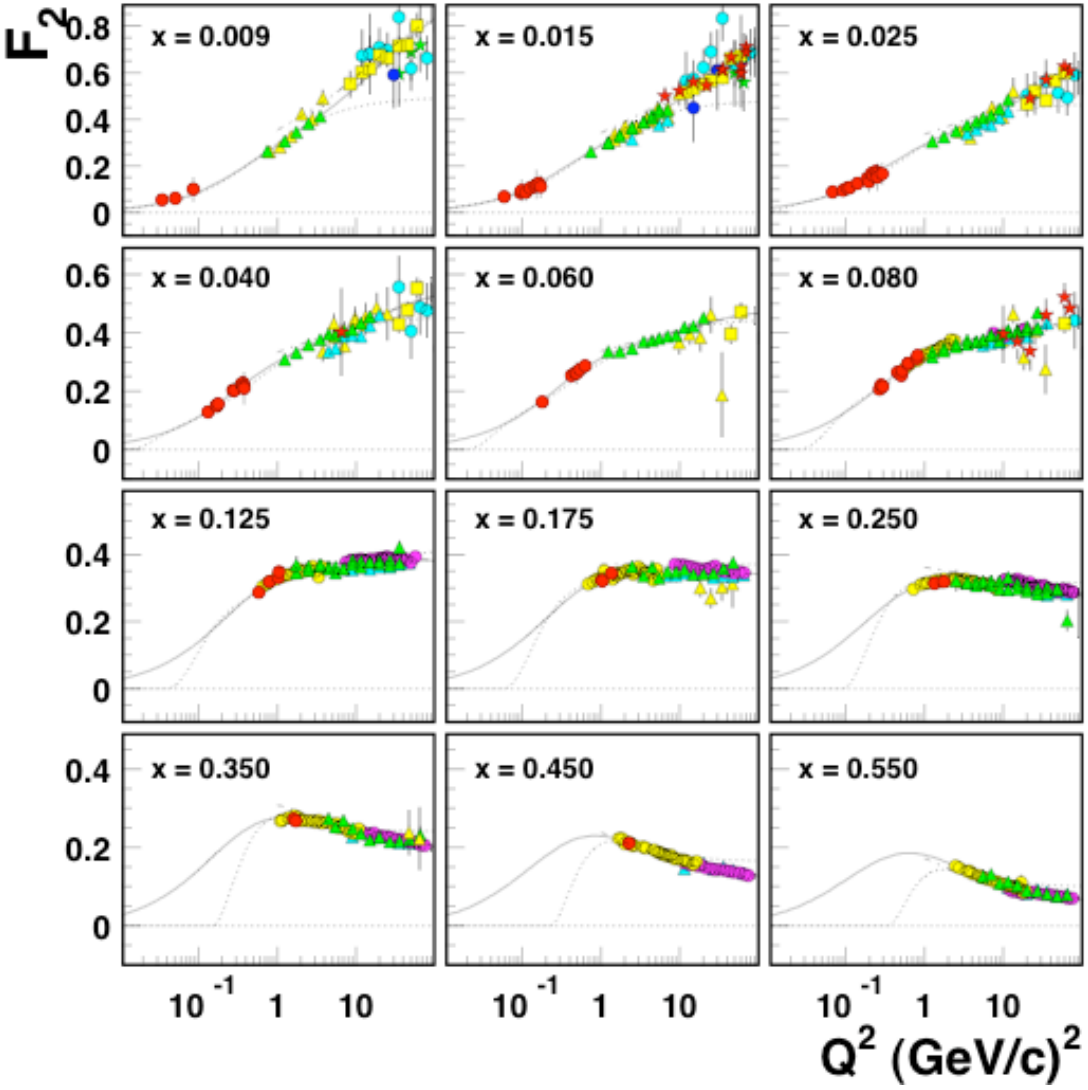
F_2, F_1 in excellent agreement with NNLO + TM above Q^2 = 2 GeV^2

Implies no (or canceling) higher twists yet, dominated by large x and resonance region

Remove known HT (a bit novel), the elastic, and there is no more down to Q^2 = 0.5 GeV^2

The case looks different for F_L (data or curve?)

Jlab Hall C E99-118 DIS data



Red: Jlab data *preliminary*

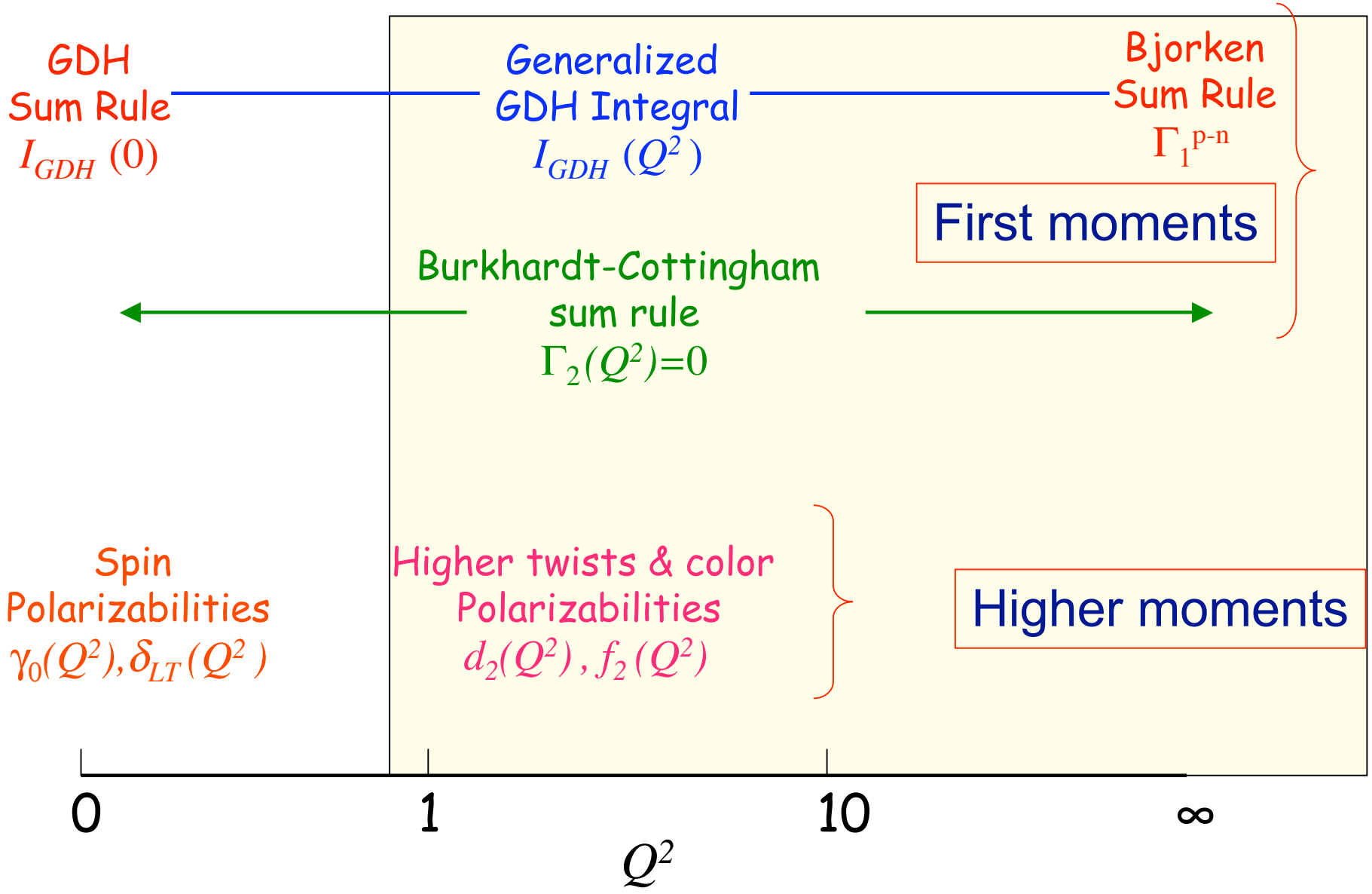
HERA, NMC,SLAC

Q^2 Evolution of Moments of Structure Functions

and

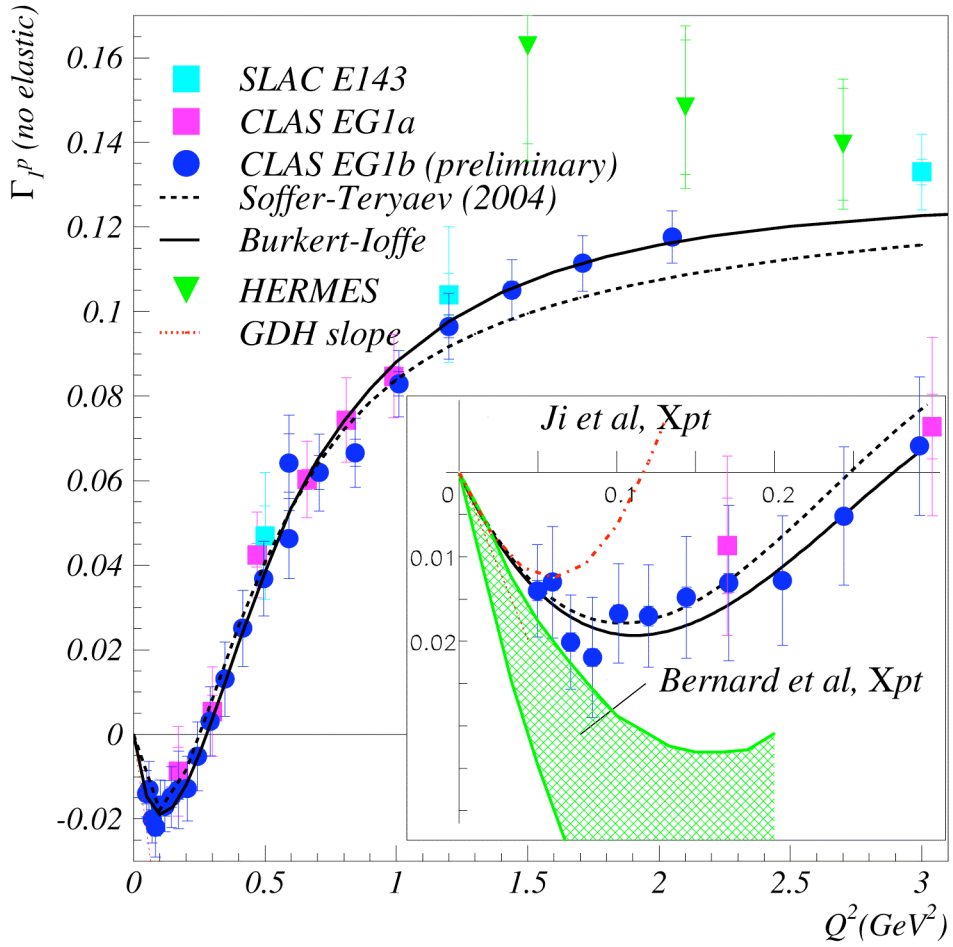
Colors Polarizabilities

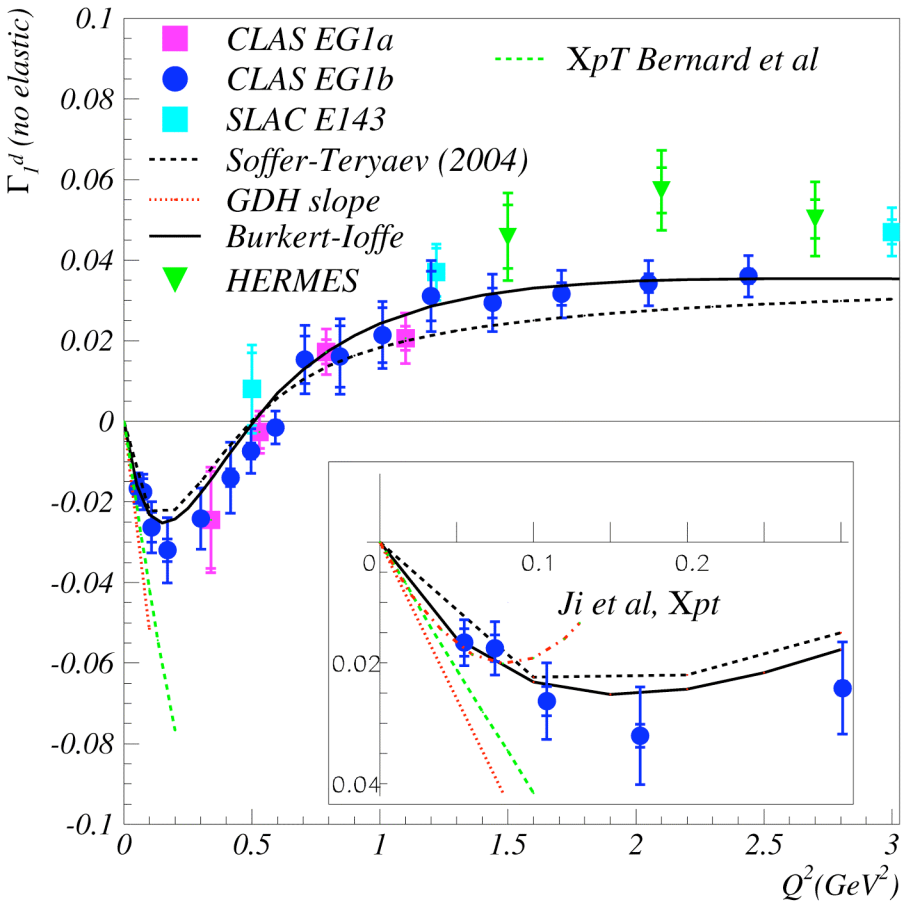
Moments of spin structure functions



Hall B EG1b Preliminary Results: Γ_1^p and "Γ_1^d"

Spokespersons: V. Burkert, D. Crabb, G. Dodge, S. Kuhn, R. Minehart, M. Taiuti

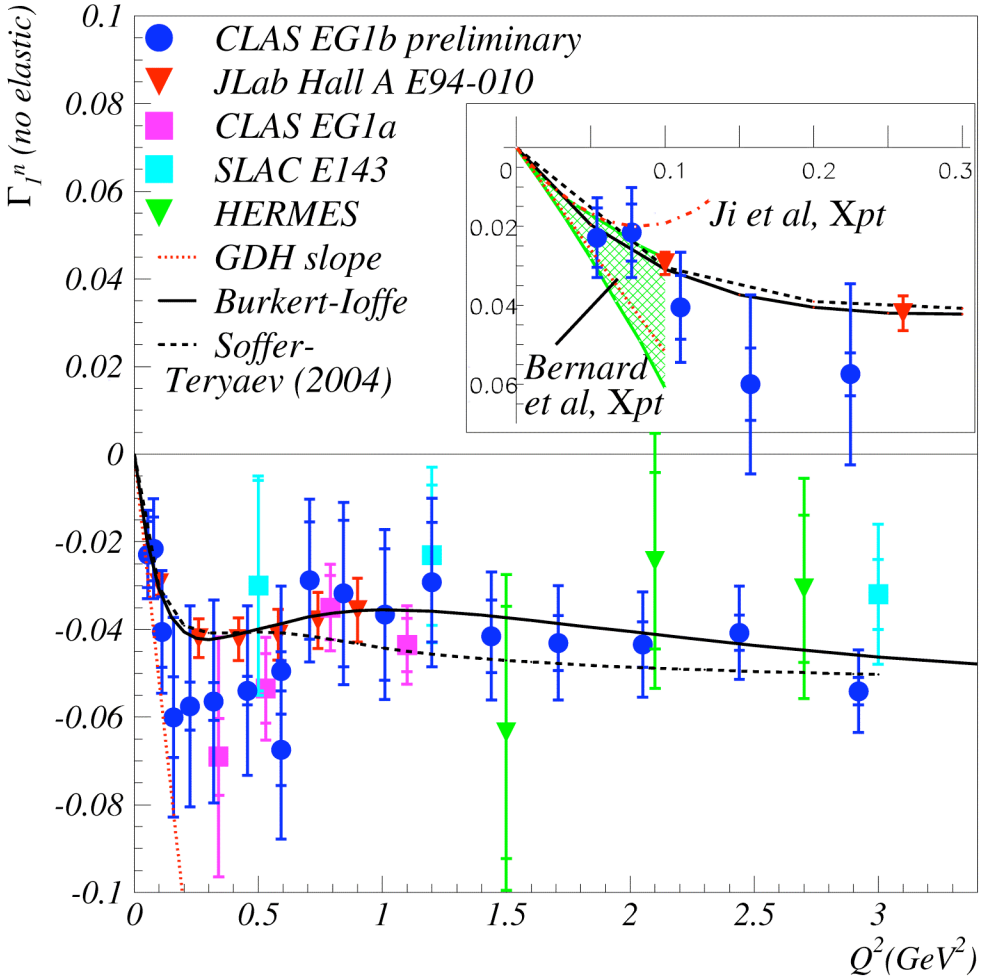




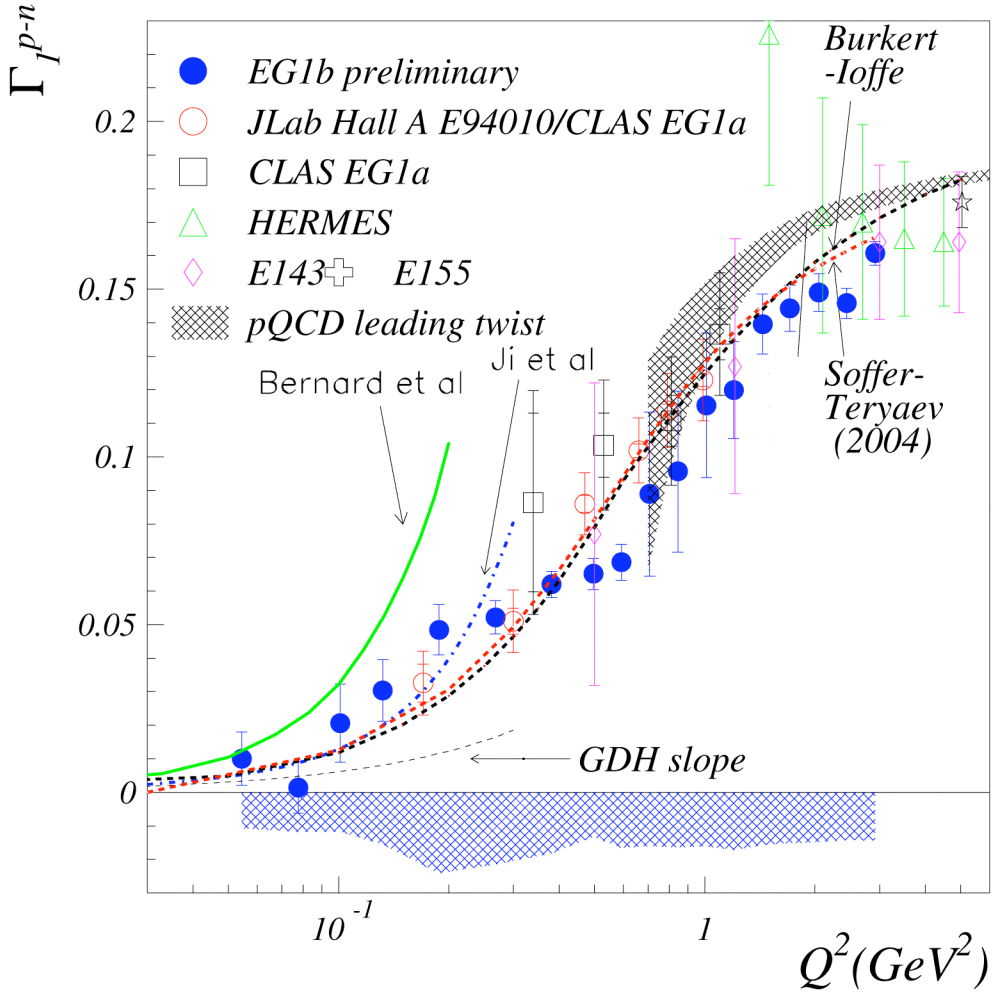
EG1b preliminary and
EG1a, PRL 91: 222002 (2003)

EG1b preliminary and
EG1a, PRC 67, 055204 (2003)

Moments of neutron and proton-neutron

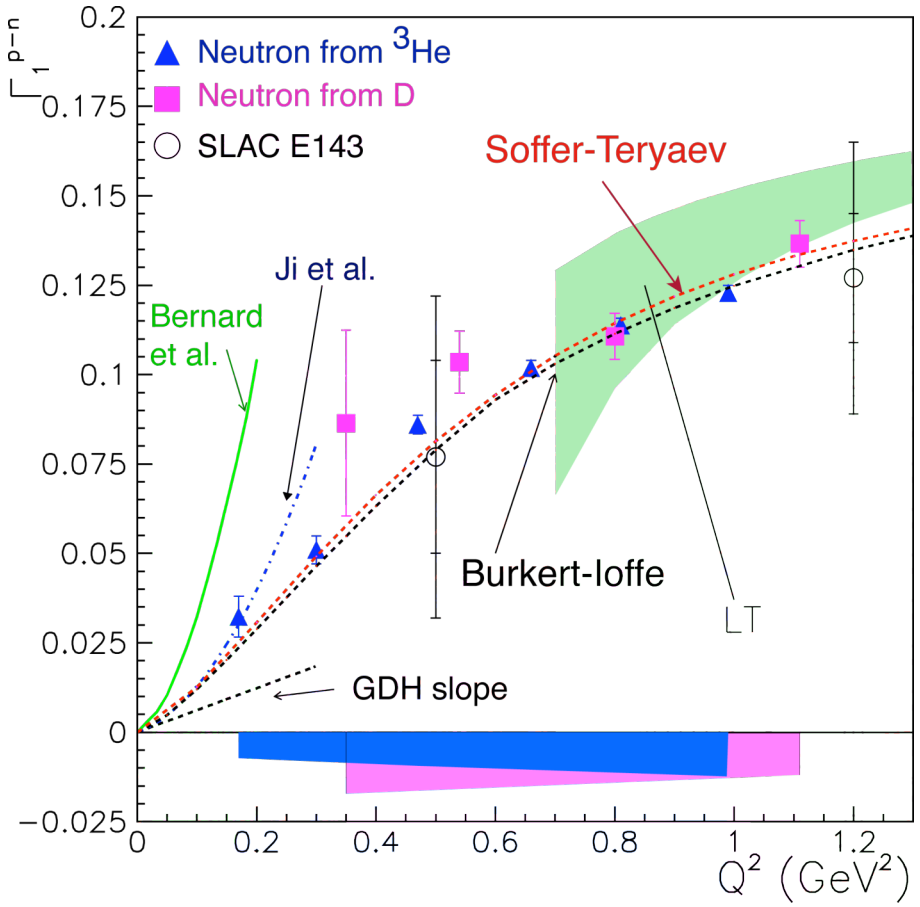


Hall B EG1b preliminary and Hall A

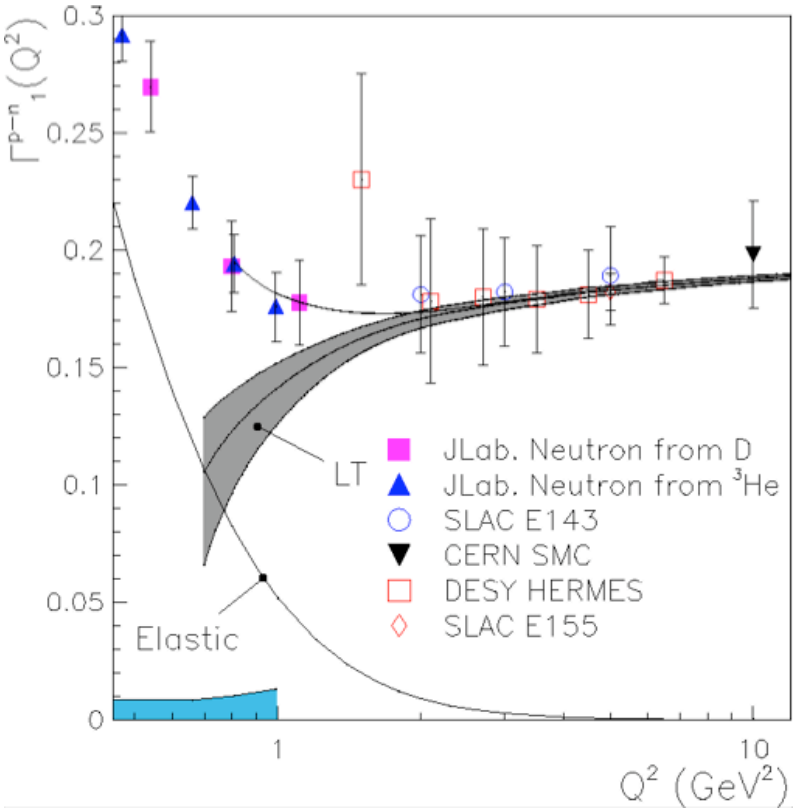


EG1b preliminary and Hall A + Hall B EG1a: PRL 93 (2004) 212001

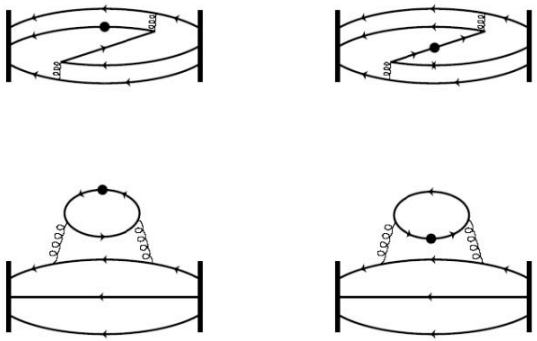
Bjorken Sum Q^2 evolution and higher twists



eg1a + E94-010, A. Deur *et al.* PRL 93, 212001 (2004)



- At low Q^2 good quantity to test Chiral P. T.
  - ➥ Little or no contribution from the Delta
- At large Q^2 does not contain non disconnected diagrams. Good to compare to Lattice calculations



f_2^{p-n}=-0.18±0.10

μ_4/M^2=-0.06±0.02

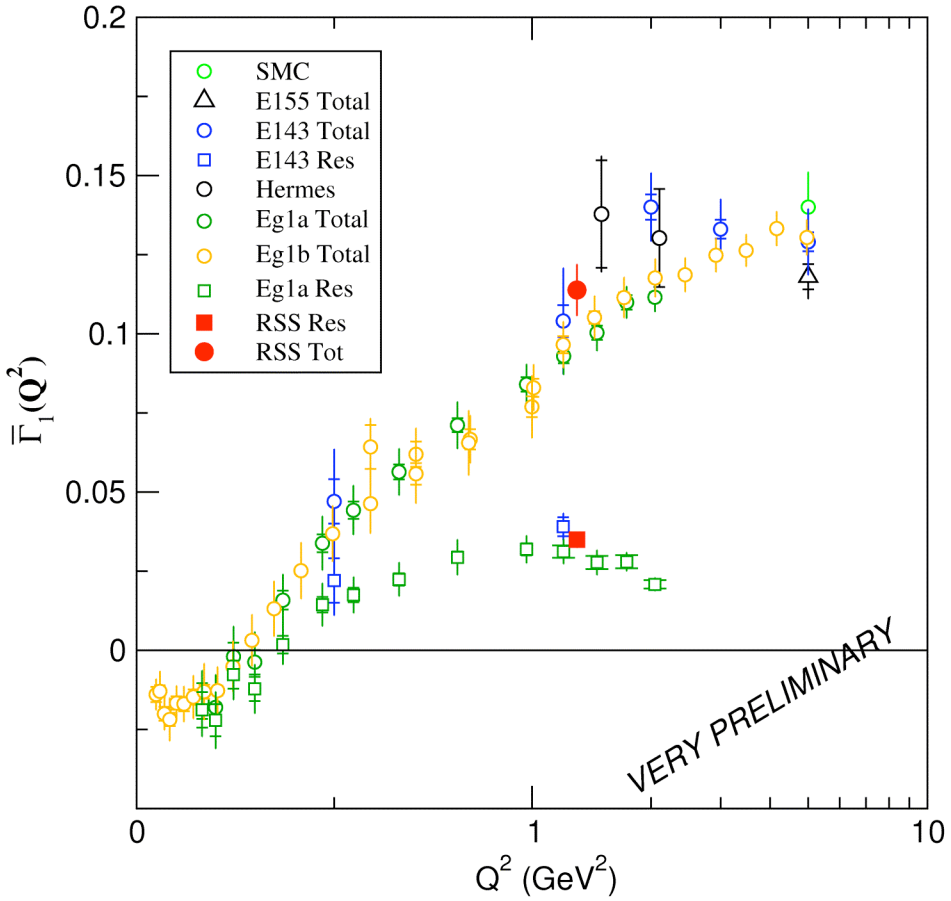
μ_6/M^4=0.09±0.03

Hall C, RSS Preliminary Results on Γ_1^p and Γ_2^p

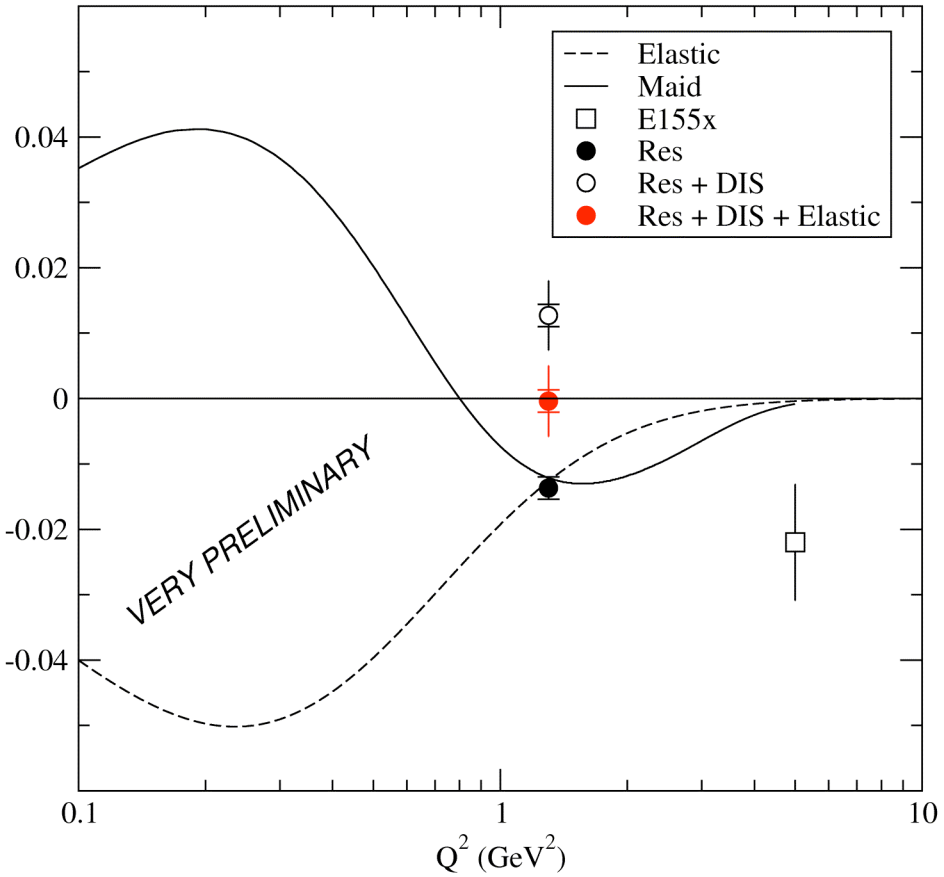
See K. Slifer's talk (Spokesperons: M. Jones, O. Rondon)

- Q^2=1.3 GeV^2, Γ_1^p consistent with Hall B results
  Γ_2^p satisfies B-C sum rule

Γ_1^p



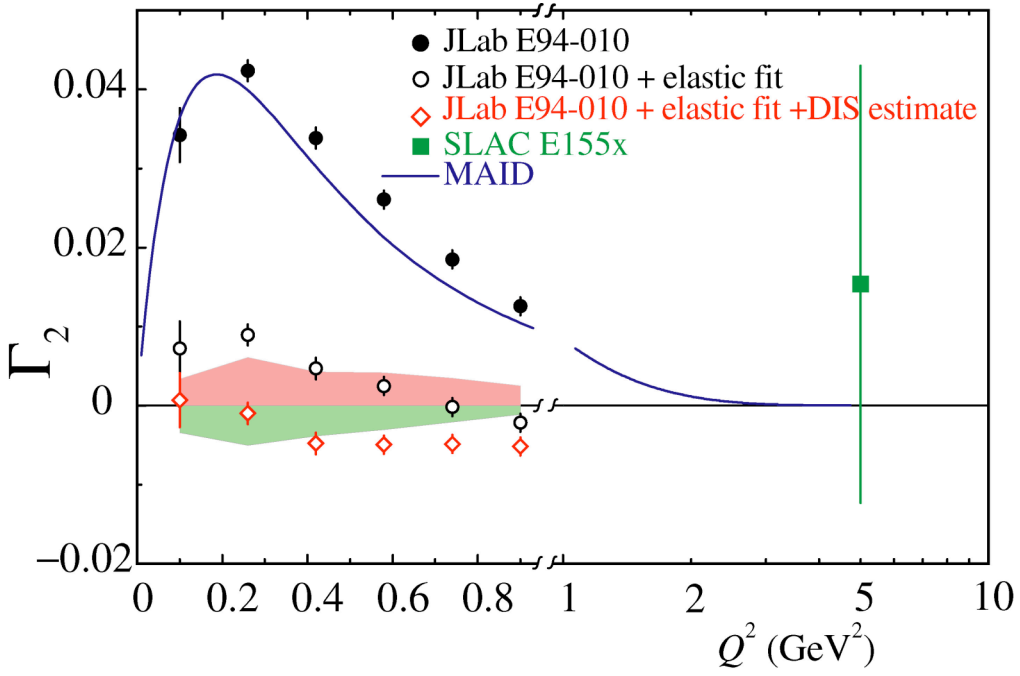
Γ_2^p



Γ_2 :First Moment of g_2 for neutron and proton

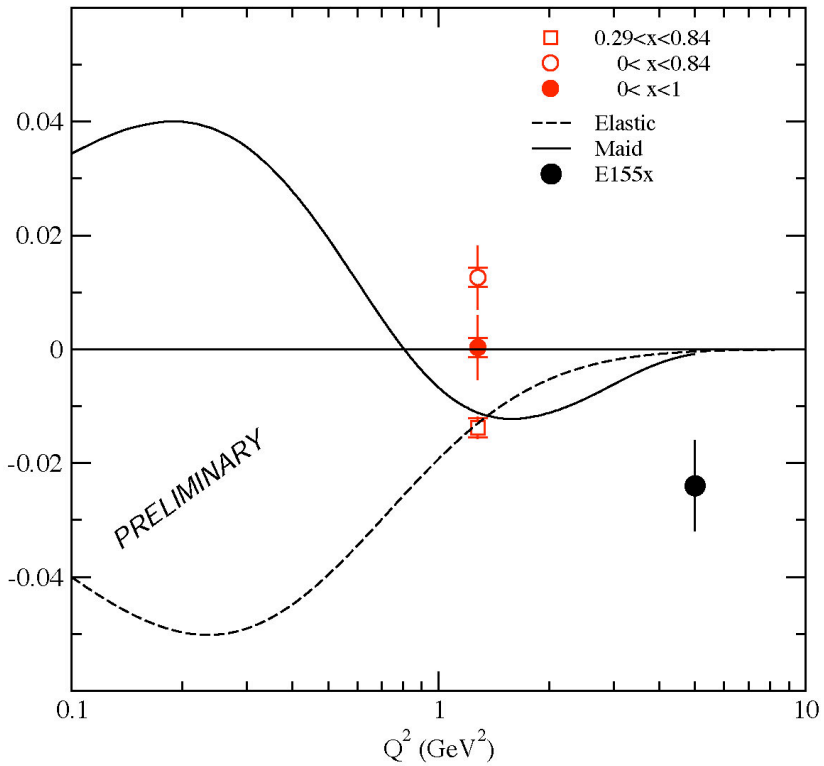
- Q^2 evolution of Γ_2^p and Γ_2^n
- B-C sum rule satisfied within uncertainties

Γ_2^n



Hall A, E94-010, PRL 92 (2004) 022301

Γ_2^p *RSS in Hall C*



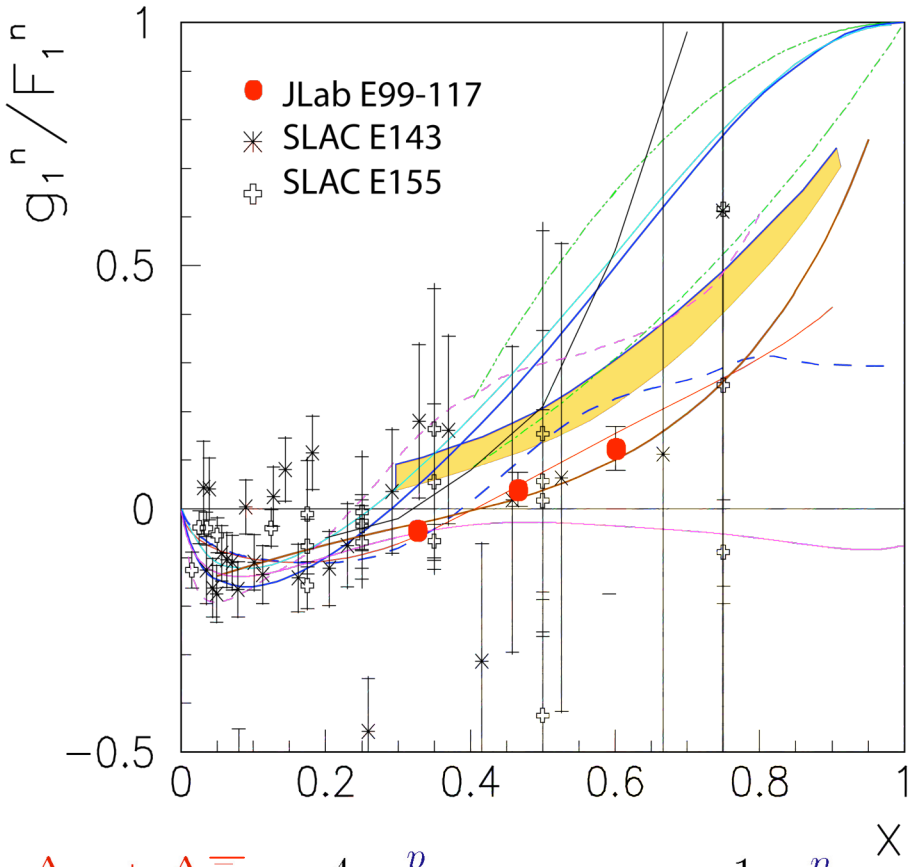
K. Slifer's talk

Spin Structure in the Valence Region |Duality and Helicity Dependent Parton Distributions

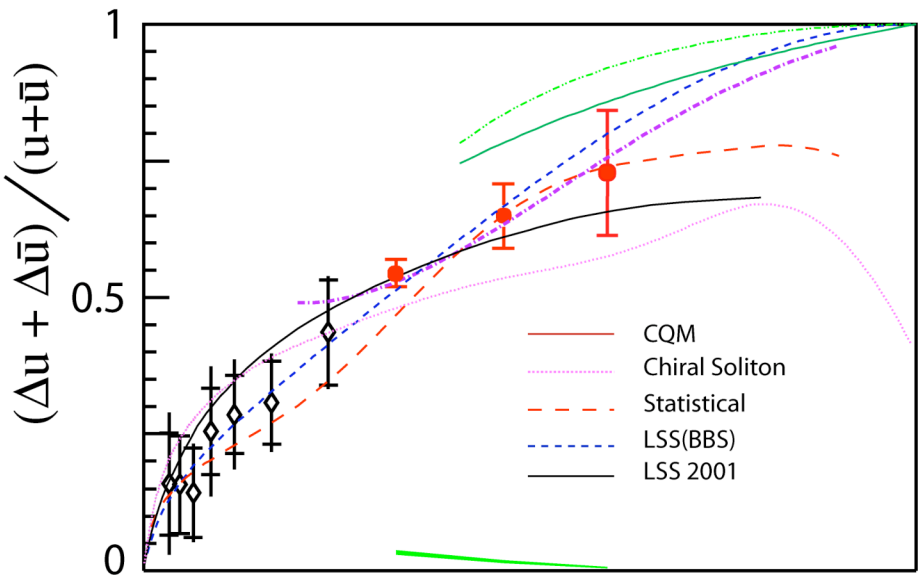
April 16, 2007

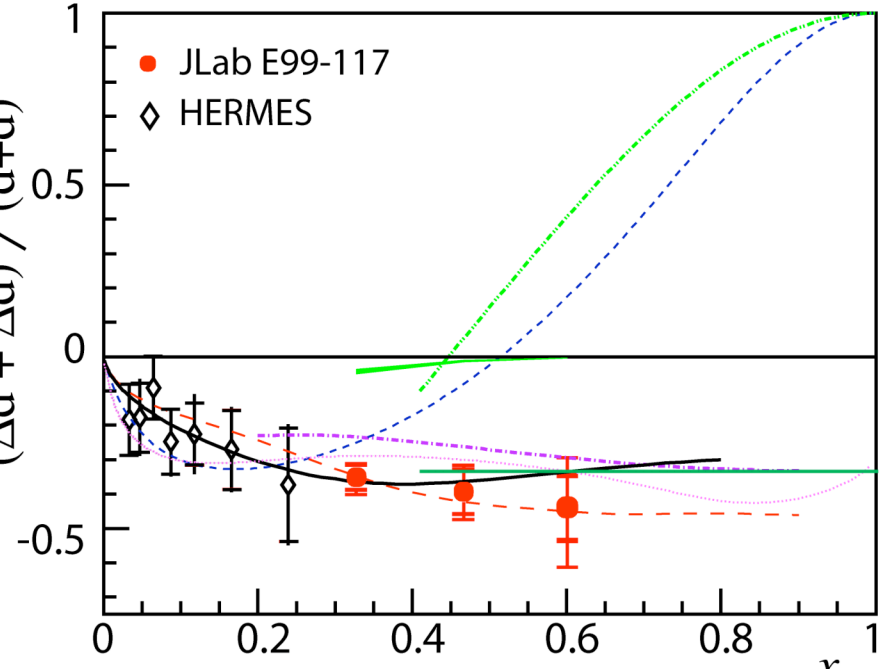
DIS 2007, Munich, Germany

Flavor Decomposition of PDFs at large x, E99-117



X. Zheng et al. PRL 92, 012004 (2004) and PRC70, 065270 (2004)





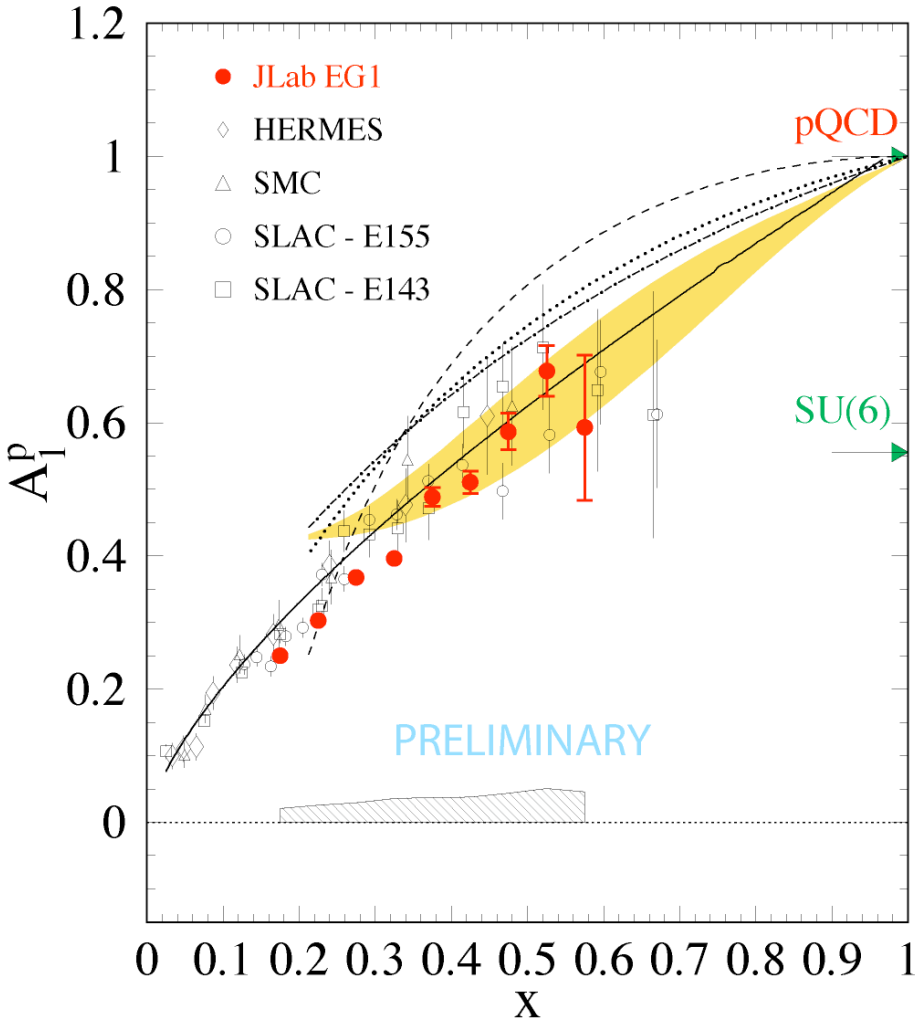
$$\frac{\Delta u + \Delta\overline{u}}{u} = \frac{4}{15}\frac{g_1^p}{F_1^p}(4 + R^{du}) - \frac{1}{15}\frac{g_1^n}{F_1^n}(1 + 4R^{du})$$

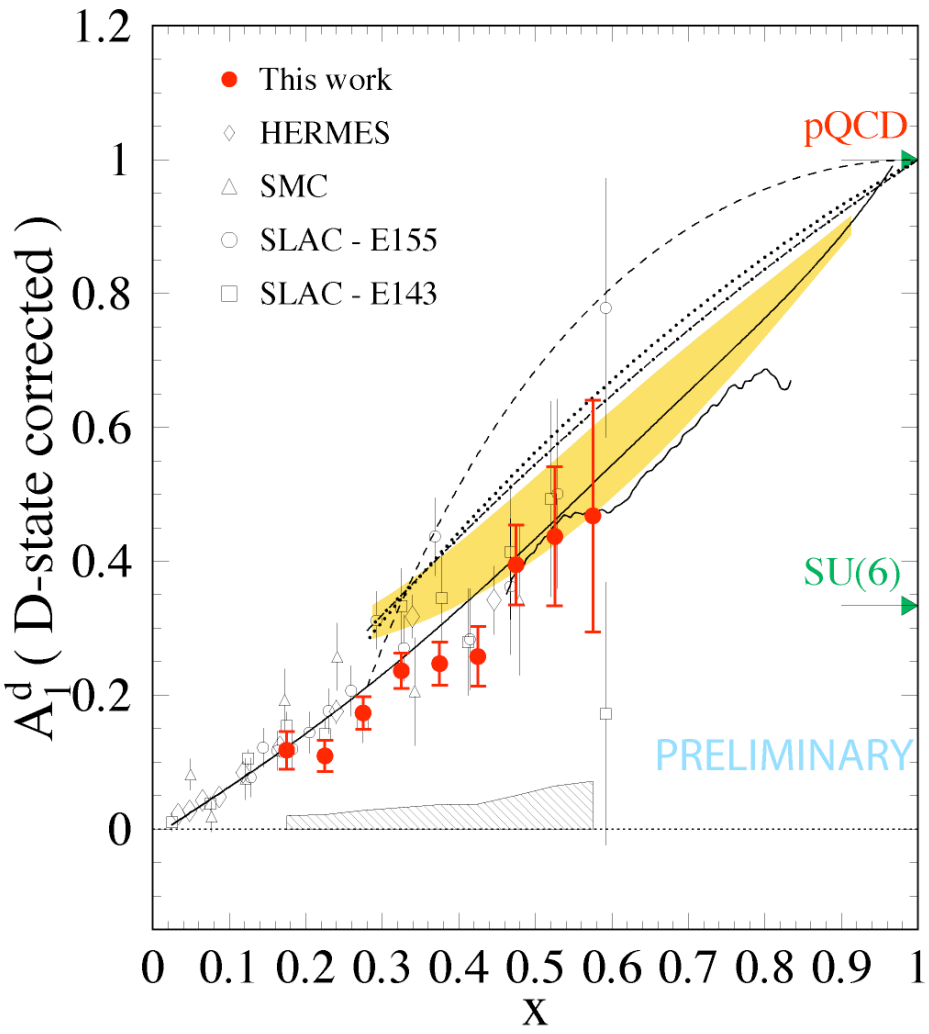
$$\frac{\Delta d + \Delta\overline{d}}{d} = \frac{4}{15}\frac{g_1^n}{F_1^n}(4 + \frac{1}{R^{du}}) - \frac{1}{15}\frac{g_1^p}{F_1^p}(1 + 4\frac{1}{R^{du}})$$

$$R^{du} = \frac{d + \overline{d}}{u + \overline{u}}$$

$A_1^{p,d}$ From NH_3 and ND_3 in Hall B

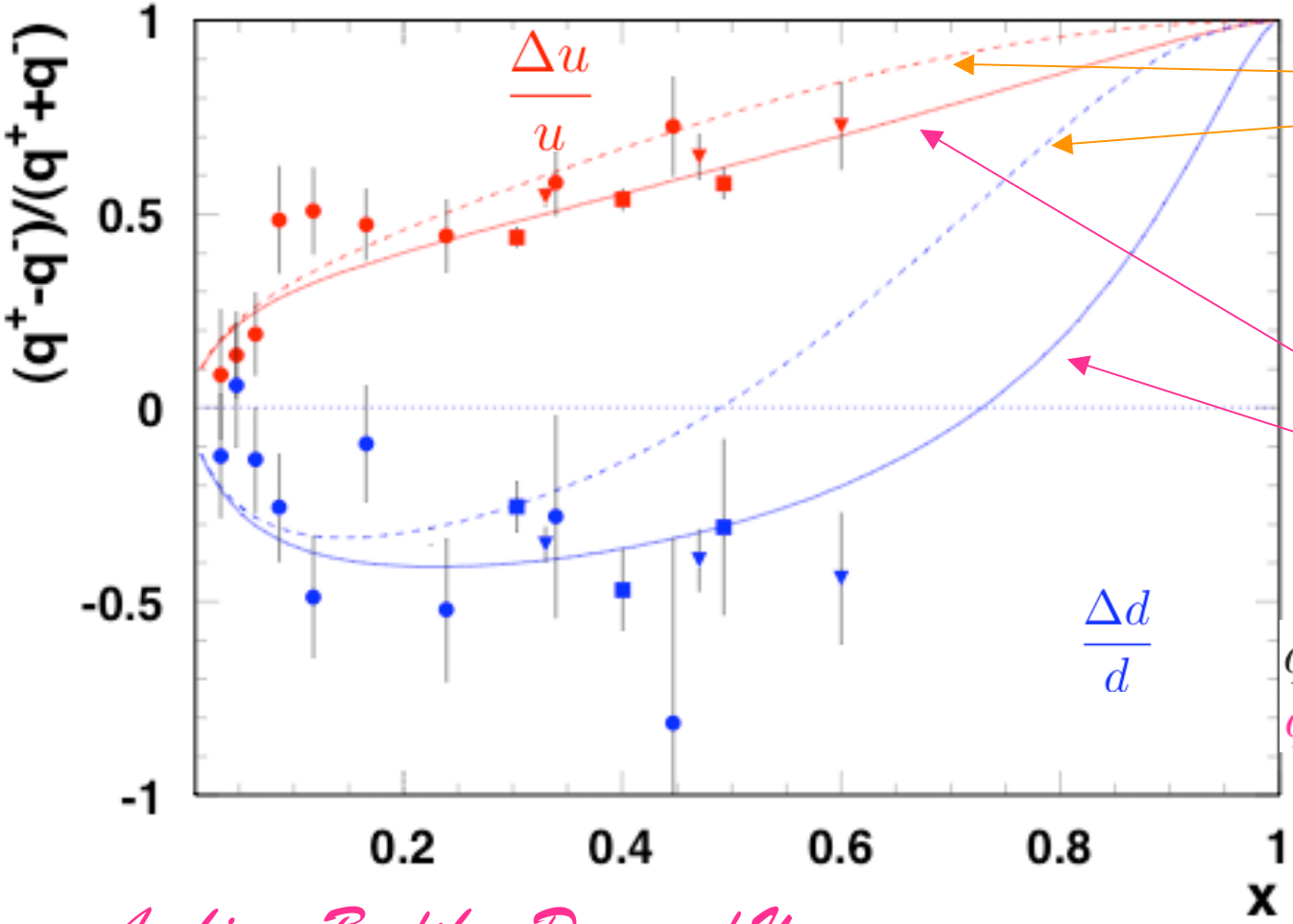
V. Burkert, S. Kuhn R. Mineheart, G. Dodge et al. EG1 collaboration





Effect of quark orbital angular momentum

Inclusive Hall A and B and Semi-Inclusive Hermes



BBS

$q^+(x) \propto (1-x)^3$
$q^-(x) \propto (1-x)^5$
$x \longrightarrow 1$

BBS+OAM

$q^+(x) \propto (1-x)^3$
$q^-(x) \propto (1-x)^5 \ln^2(1-x)$
$x \longrightarrow 1$

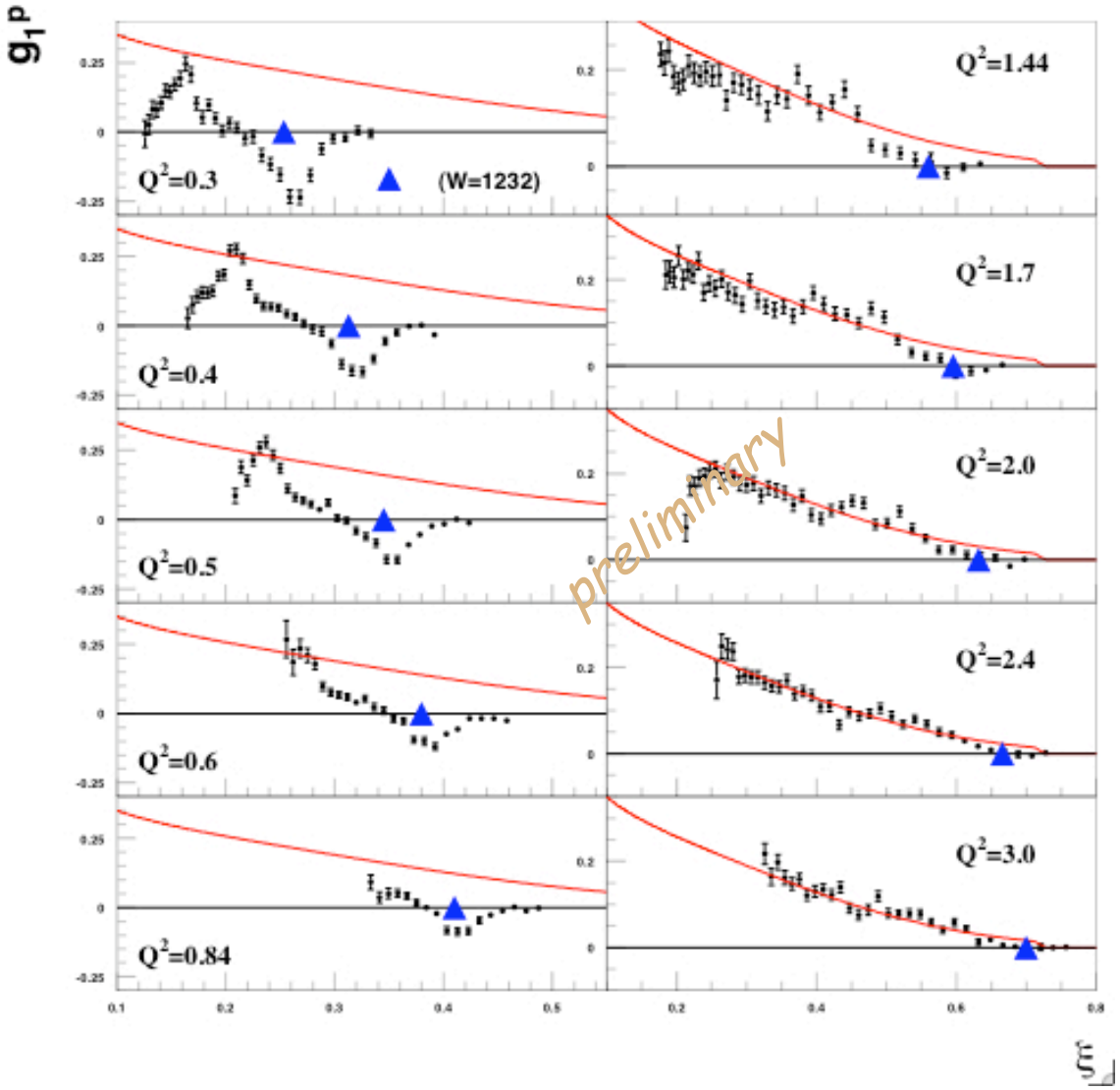
Avakian, Brodsky, Deur and Yuan

To be submitted to PRL

CLAS data on g1p

JLab Hall B for g_1^p

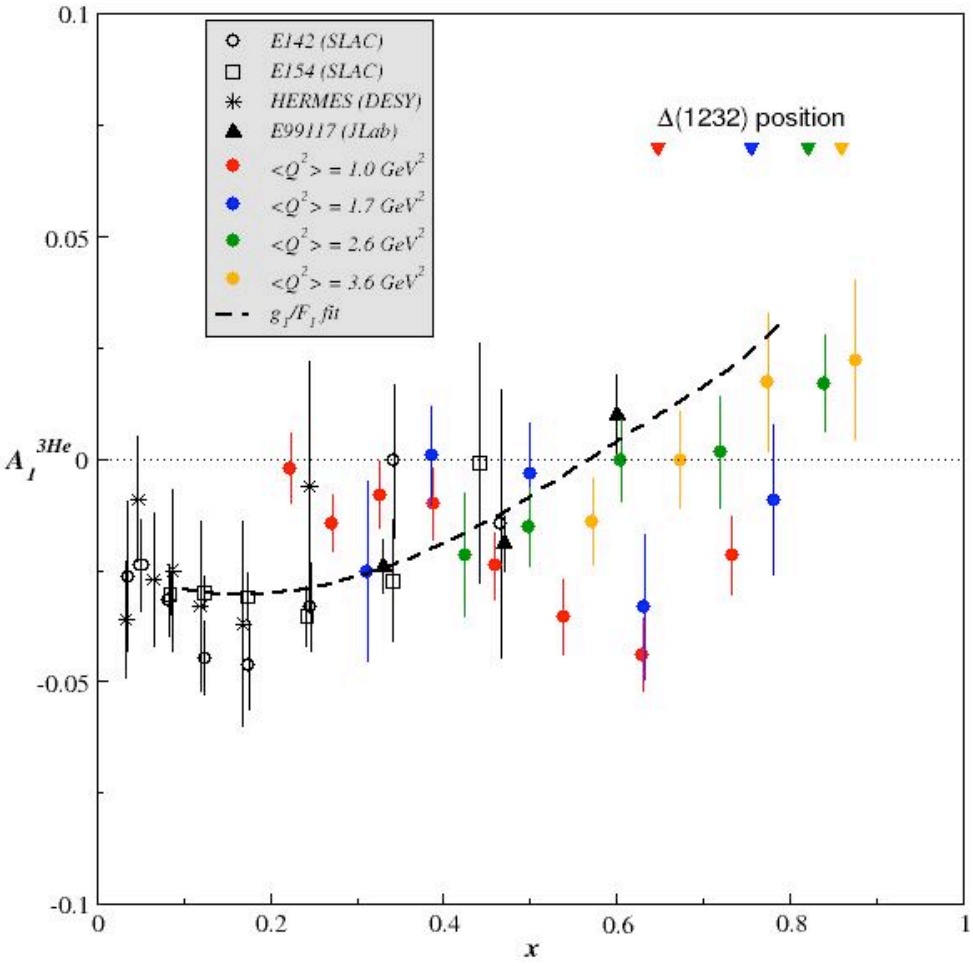
See K. Griffioen's talk

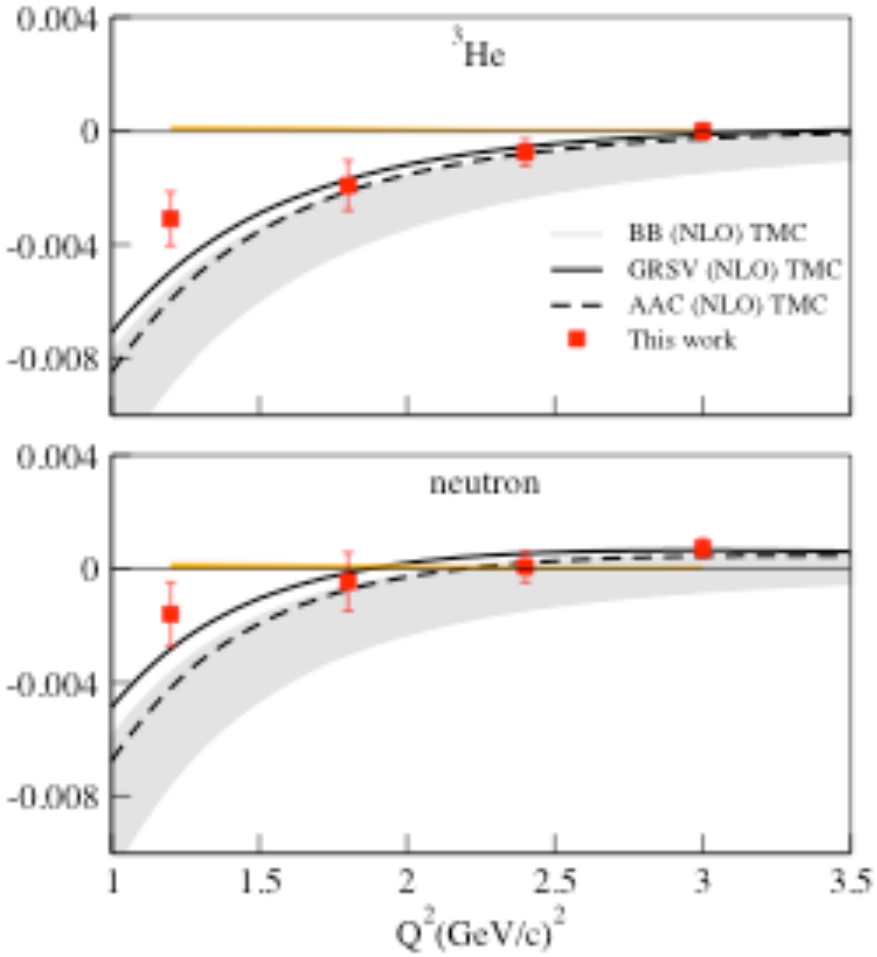


Hall A E01-012 Preliminary Results: Γ_1^n and A_1^{3He}

Spokespersons: N. Liyanage, J. P. Chen, S. Choi, **PhD Student:** P. Solvignon

- g_1/g_2 and A_1/A_2 (^{3}He/n) in resonance region, $1 < Q^2 < 4$ GeV^2
- Study quark-hadron duality in spin structure





Higher Moments
Twist-3 and Twist 4
"Color Polarizabilities"

d_2: twist-3 matrix element

- 2nd moment of g_2-g_2^{WW}

  d_2: twist-3 matrix element

$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

$$= \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$

Color polarizabilities

Provide a benchmark test of Lattice QCD at high Q^2

Avoid issue of low-x extrapolation

Color "Polarizabilities"

X.Ji 95, E. Stein et al. 95

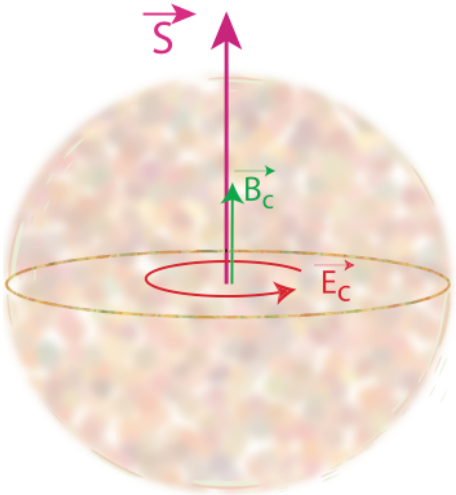
How does the gluon field respond when a nucleon is polarized ?

Define color magnetic and electric polarizabilities (in nucleon rest frame):

$$\chi_{B,E}\, 2M^2 \vec{S} = \langle PS|\vec{O}_{B,E}|PS\rangle$$

where $\vec{O}_B = \psi^\dagger g\vec{\boldsymbol{B}}\psi$

$\vec{O}_E = \psi^\dagger \vec{\alpha} \times g\vec{\boldsymbol{E}}\psi$

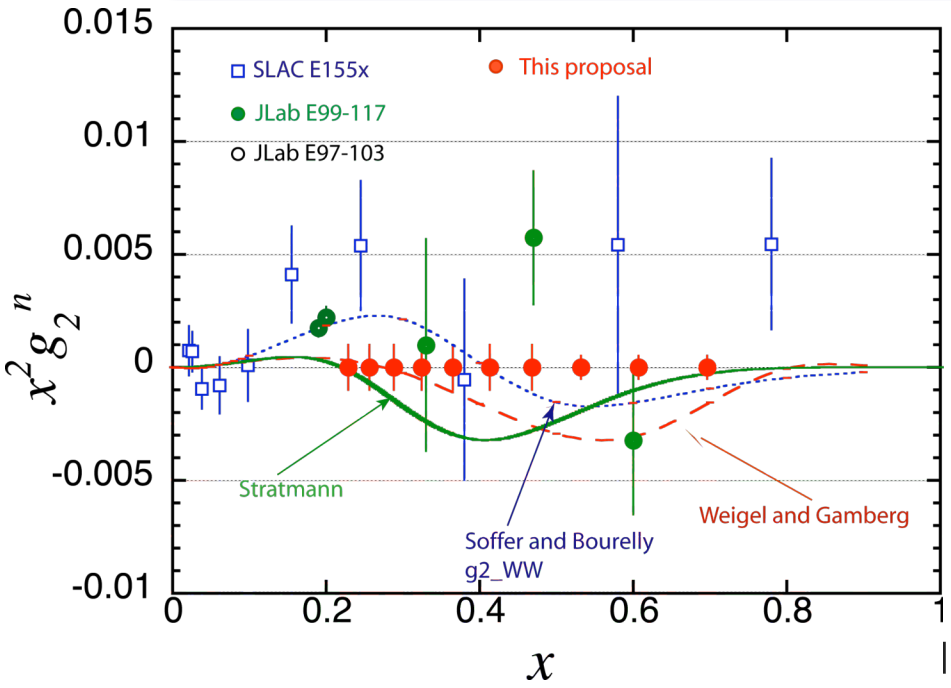


$$d_2 = (\chi_E + 2\chi_B)/8$$

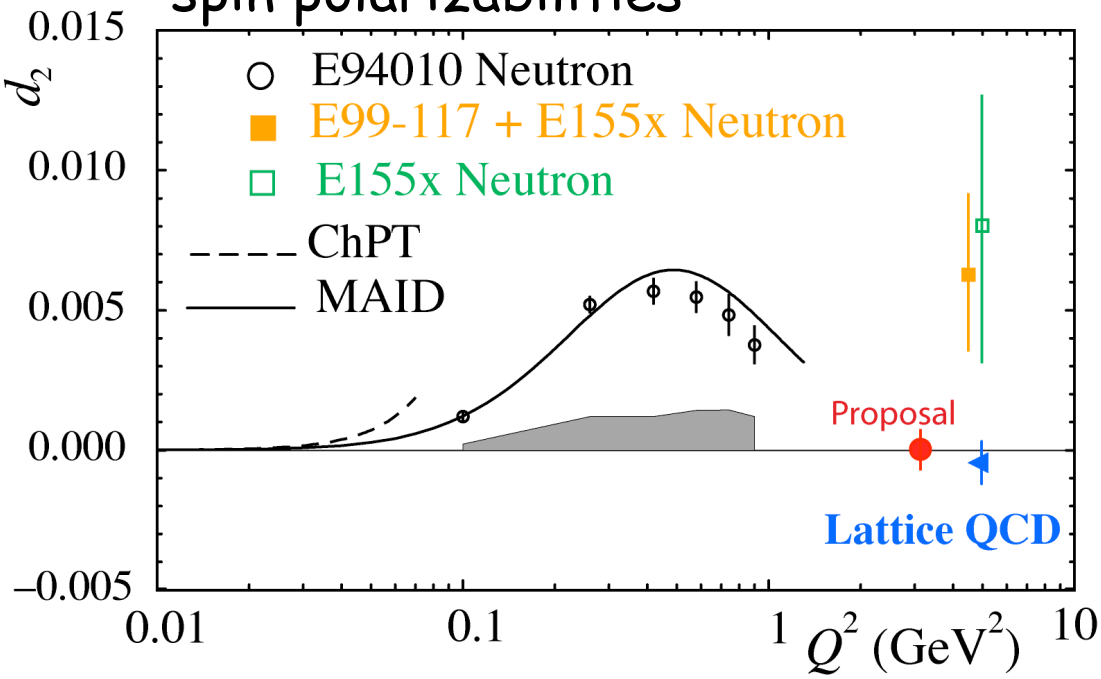
$$f_2 = (\chi_E - \chi_B)/2$$

d_2 and f_2 represent the response of the color $\vec{B}$ & $\vec{E}$ fields to the nucleon polarization

Color "Polarizability": d_2^n (Hall A)



- At large Q^2, d_2 coincides with the reduced twist-3 matrix element of gluon and quark operators
- At low Q^2, d_2 is related to the spin polarizabilities

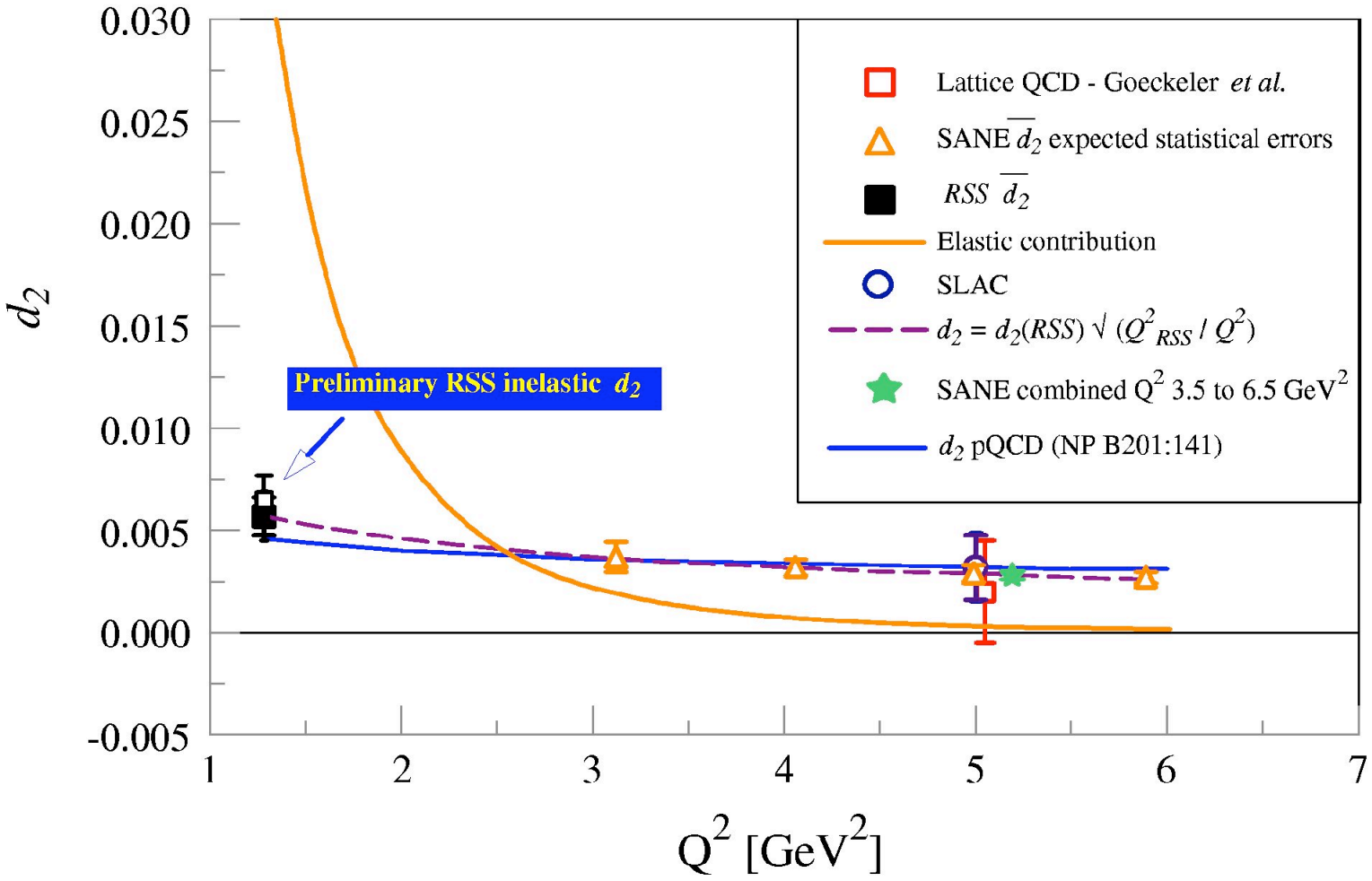


Approved experiment E06-114
Running in Fall 2007

Spokespersons: S. Choi, X. Jiang, Z. M, B. Sawatzky

d_2^p RSS and SANE d_2^p projection in Hall C

RSS spokesperons: M. Jones, O Rondon
SANE spokespersons: S. Choi, O. Rondon, Z.-E. M

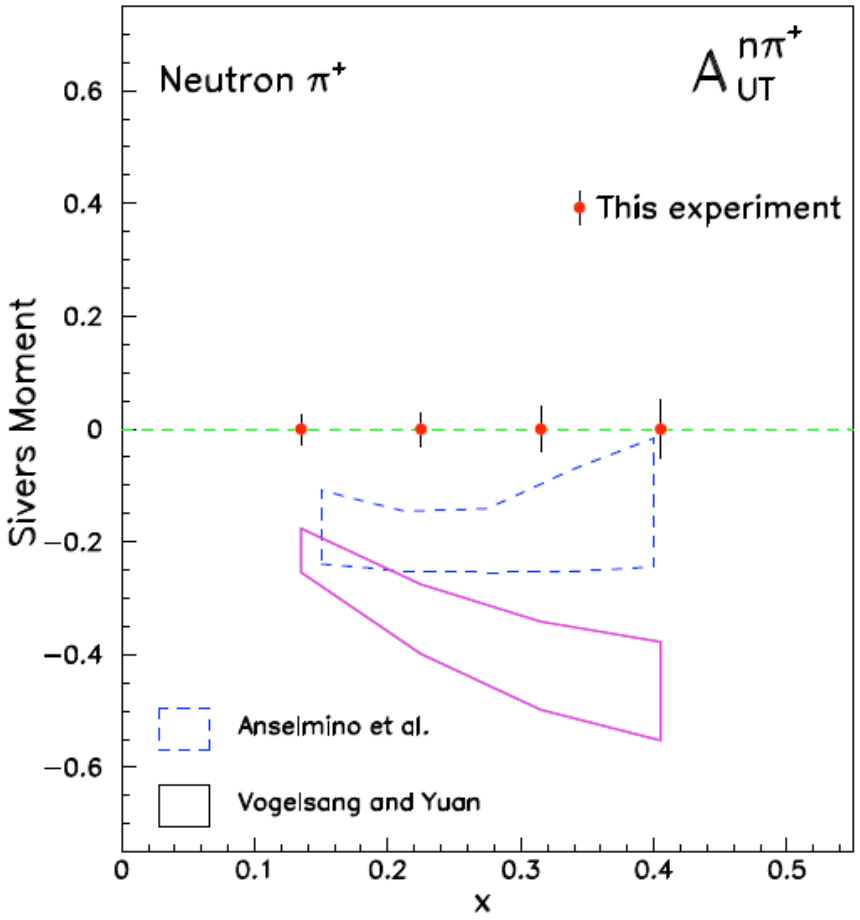


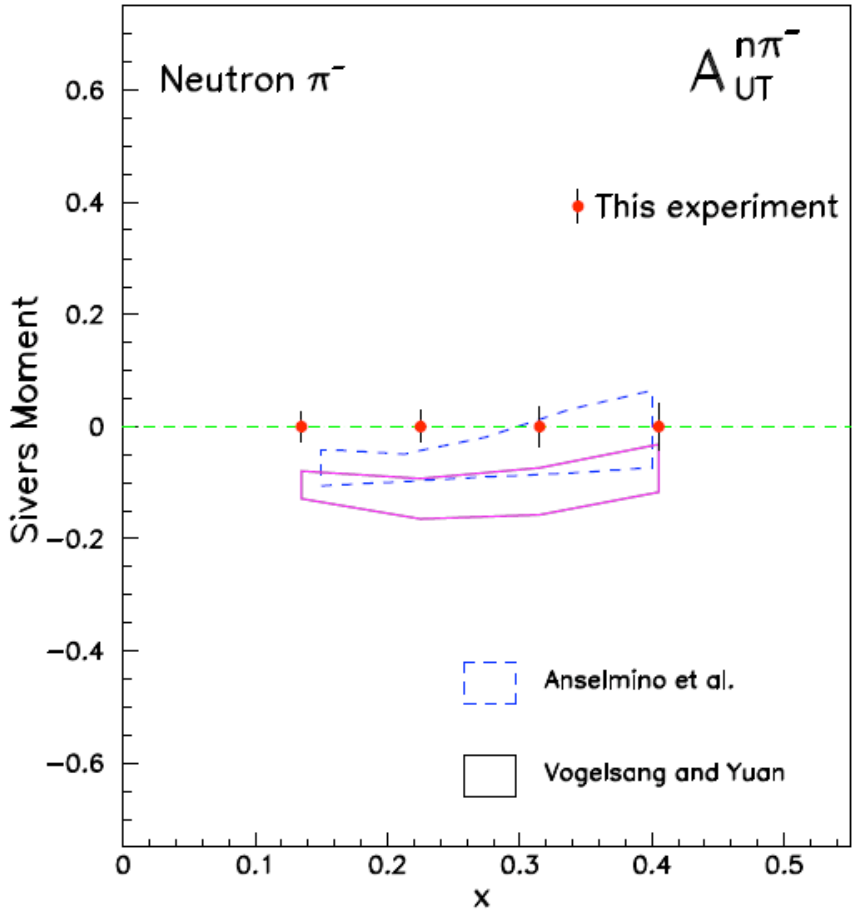
JLab E06-010/E06-011

Neutron Transversity: Collins and Sivers Asymmetries

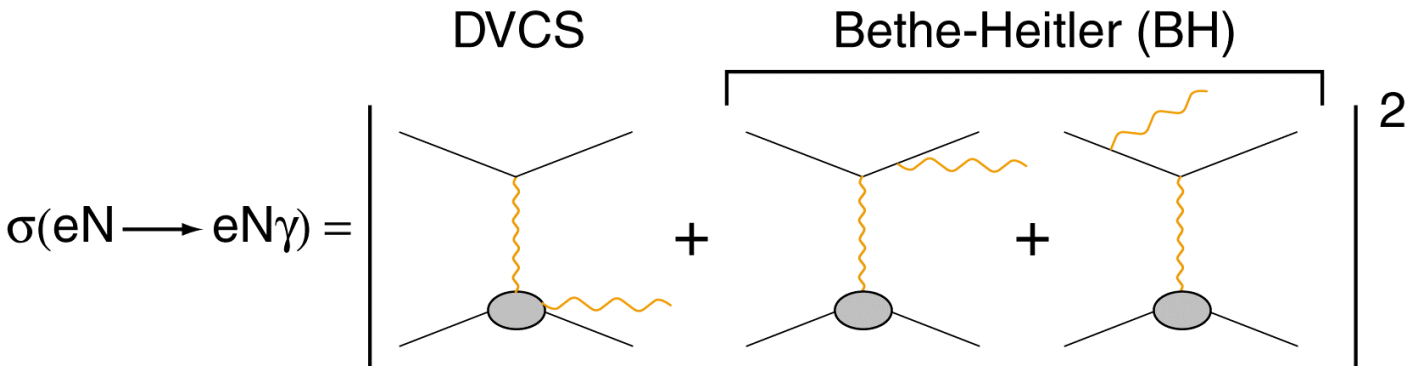
Spokespersons: X. Jiang, J. P. Chen, E. Cisbani, H. Gao, J.C. Peng

- 6 GeV longitudinally polarized electron beam
- Vertically and transversely polarized 3He target
- Hall A HRS and BigBite spectrometers
- Separate Collins and Sivers moments





DVCS and Bethe-Heitler



$$d^5\vec{\sigma} - d^5\overleftarrow{\sigma} \approx 2\Im\mathrm{m}(T^{BH}.T^{DVCS}) + \left[\left|\vec{T}^{DVCS}\right|^2 - \left|\overleftarrow{T}^{DVCS}\right|^2\right]$$

Purely real and **fully calculable**

Small at JLab enegies (twist-3 term)

The **cross-section difference** accesses the Imaginary part of DVCS and therefore **GPDs at x=±ξ**

$$d^5\sigma \approx \left|T^{BH}\right|^2 + 2\vec{T}^{BH}.\Re\mathrm{e}(T^{DVCS}) + \left|T^{DVCS}\right|^2$$

The **total cross-section** accesses the real part of DVCS and therefore an **integral of GPDs over x**

GPDs properties, link to DIS and elastic form factors

Generalized Parton distributions

$$H^q, E^q, \widetilde{H}^q, \widetilde{E}^q (x,\xi,t)$$

Link to DIS at $\xi=t=0$

$$H^q(x,0,0) = q(x) = -\bar{q}(-x)$$

$$\tilde{H}^q(x,0,0) = \Delta q(x) = -\Delta\bar{q}(-x)$$

No similar relations for E^q and $\tilde{E}^q$

Link to form factors (sum rules)

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t) \quad , \quad \int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$

$$\int_{-1}^{1} dx\ \tilde{H}^q(x,\xi,t) = g_A^q(t) \ , \quad \int_{-1}^{1} dx \tilde{E}^q(x,\xi,t) = h_A^q(t)$$

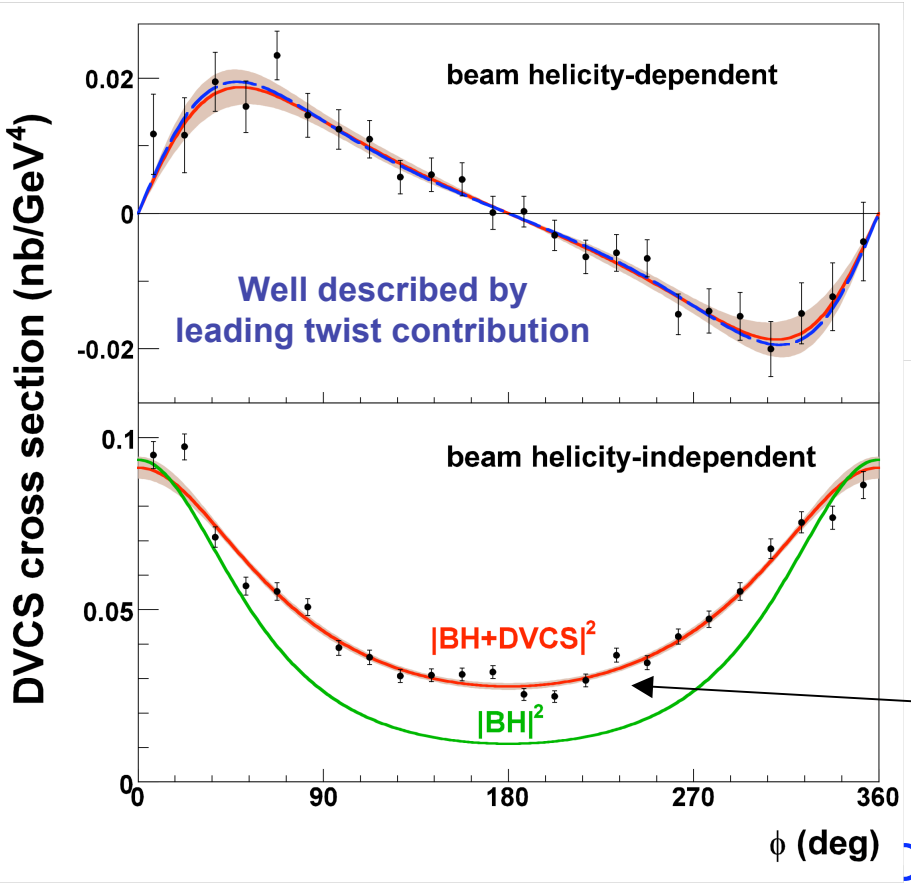
Access to **quark angular momentum** (Ji's sum rule)

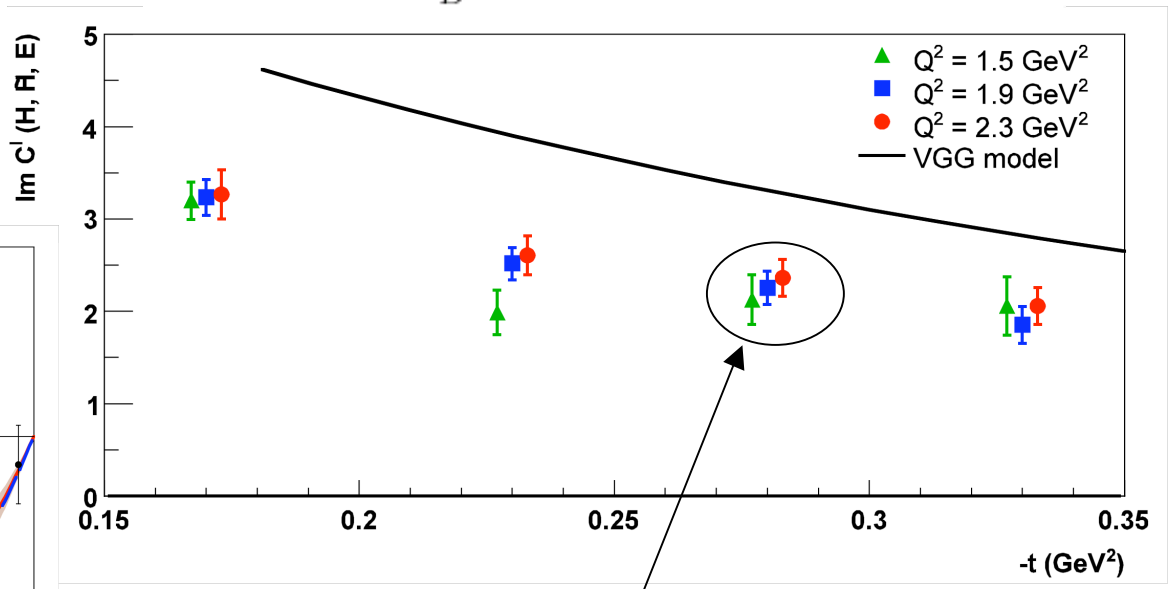
$$J_q = \frac{1}{2}\Delta\Sigma_q + L_q = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

E00-110: first dedicated DVCS experiment (Hall A)

- Absolute cross-section measurements
- Test of scaling
- First linear combination of GPDs extracted from data

$$F_1(t)\mathcal{H} + \frac{x_B}{2-x_B}[F_1(t)+F_2(t)]\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2(t)\mathcal{E}$$





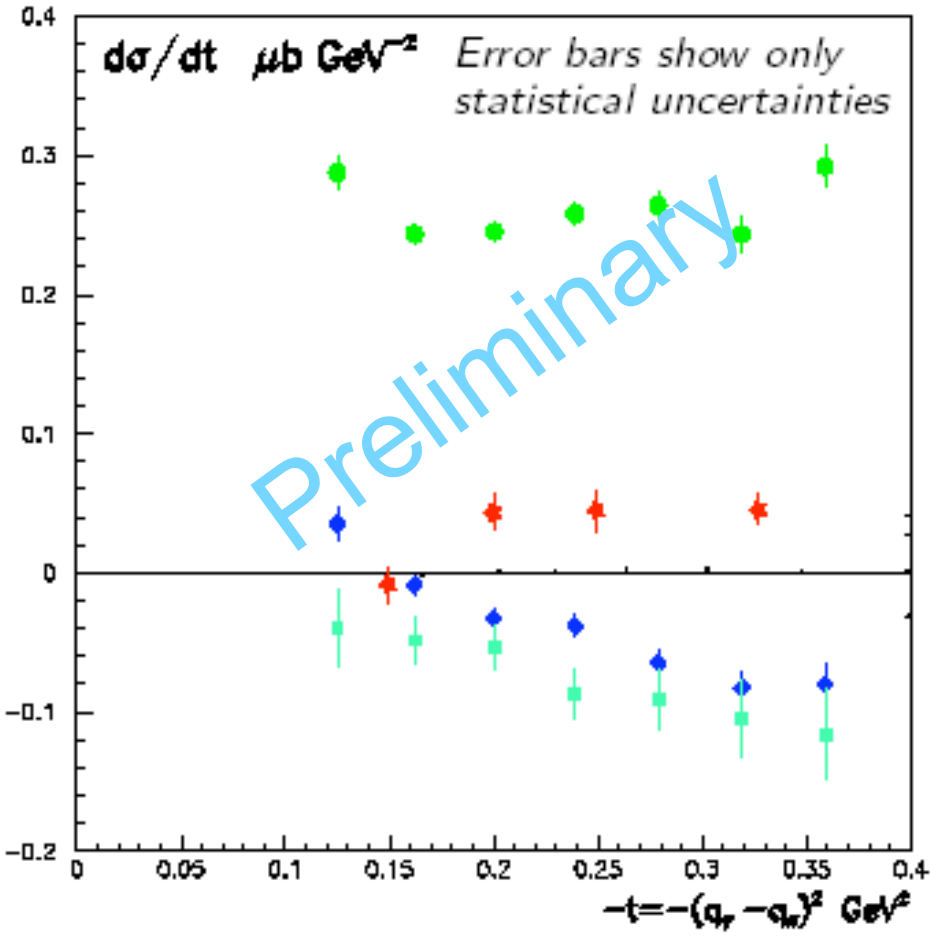
Q^2 - independent: strong evidence of factorization

Significant deviation from Bethe-Heitler

C. Muñoz Camacho *et al.*, PRL**97**, 262002 (2006)

E00-110: preliminary ep → epπ^0 results

$$\frac{d\sigma}{dt} = \frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + \lambda\sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{dt}\sin\phi$$



➢ *If factorization applies*, σ_L is proportional to GPD integrals with **different flavor weights** than in DVCS:

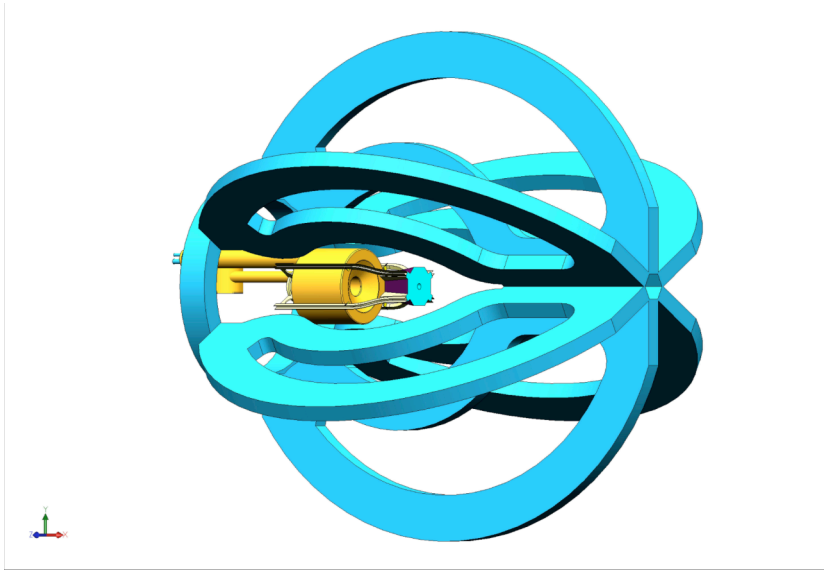
$$\widetilde{H}_{\pi^0} = \frac{1}{\sqrt{2}}\left\{\frac{2}{3}\widetilde{H}^u + \frac{1}{3}\widetilde{H}^d\right\}$$

$$H_{DVCS} = \frac{4}{9}H^u + \frac{1}{9}H^d$$

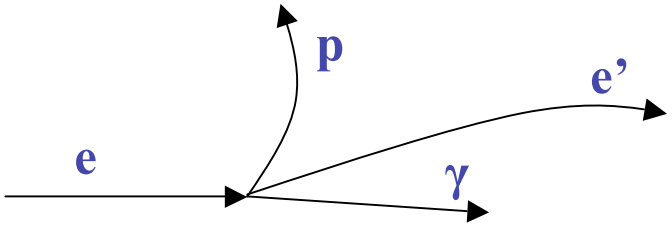
E07-007: new approved experiment to isolate σ_L as a function of Q^2

CLAS dedicated DVCS experiment in 2005

Calorimeter and superconducting magnet within CLAS



- *Full exclusivity, three particles detected.*



→ Virtual Compton scattering at the quark level

→ If scaling laws are observed (up to $Q^2 \sim 5$ GeV^2), or deviations thereof understood, first significant exploration of GPDs.

→ Large kinematical coverage in x_B and t leads to 3D-picture of the nucleon

Binning and examples of results for A_{LU} (Φ)

Please request this DVCS from the CLAS collaboration

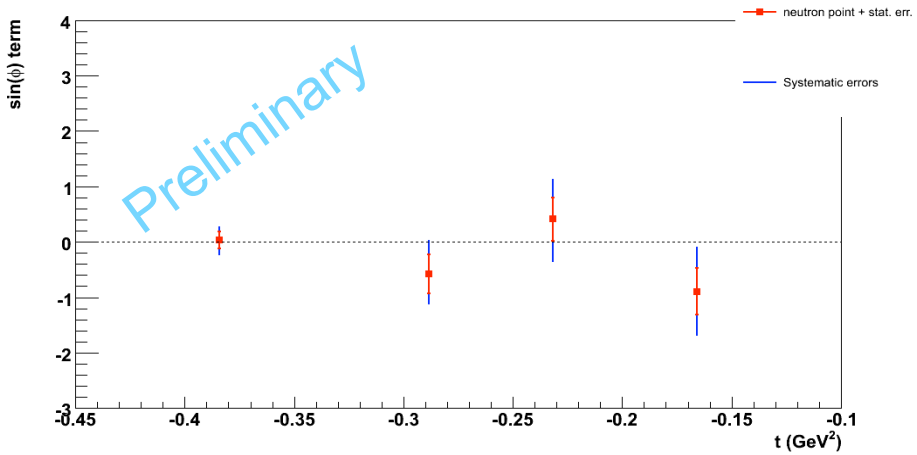
A_{LU} (Φ): results for one (out of 5) bin in t, for the 13 bins in (x_B,Q^2)

Please request this graph from the CLAS collaboration

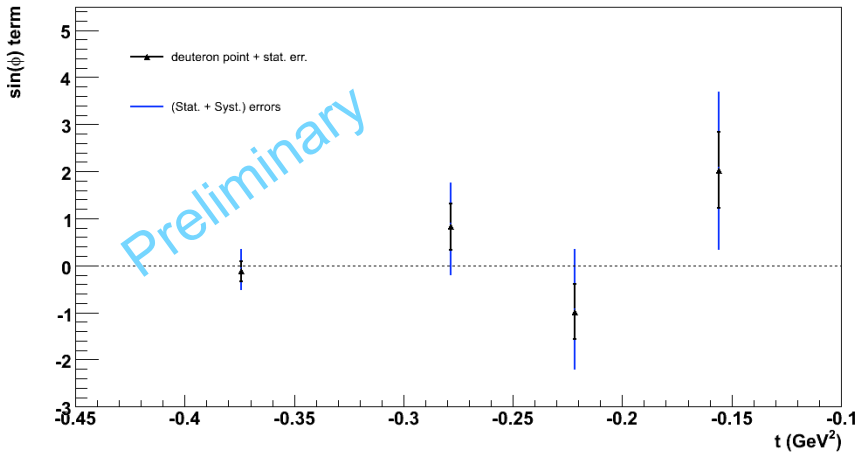
E03-106: DVCS on the neutron (Hall A)

- **Particularly sensitive to GPD E**
- **Access GPDs with different flavor weights than DVCS on the proton**

Helicity-dependent cross section on the neutron:

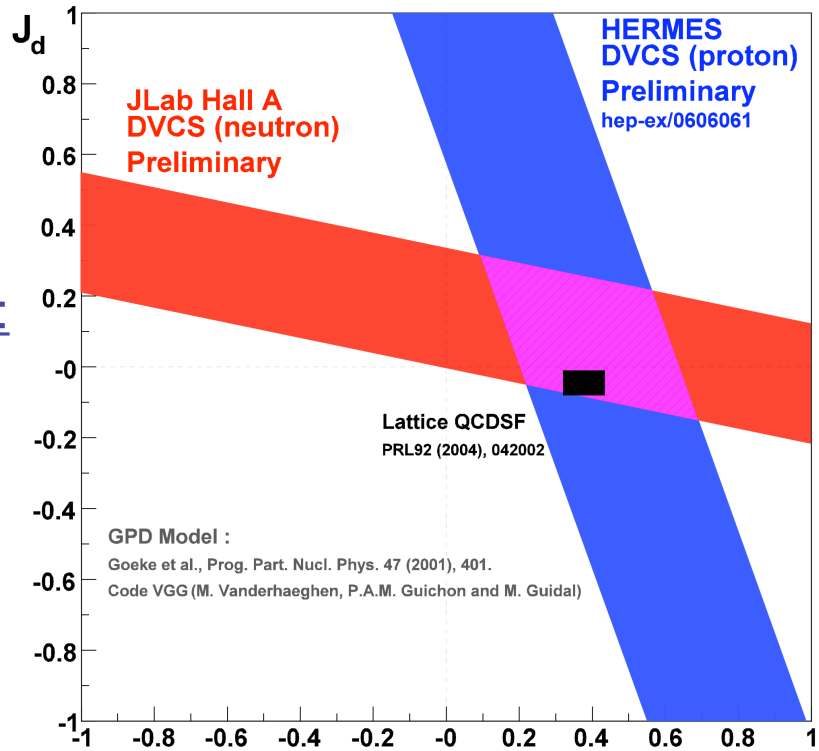


Helicity-dependent cross section on the deuteron:



Ji's sum rule:

$$\int_{-1}^{1} dx\, x[H^i(x,\xi,0) + E^i(x,\xi,0)] = J^i$$



M. Mazouz, Doctorat Thesis, Grenoble (2006)

Conclusion

A very rich program that will extend into the Future
with
the 12 GeV Jefferson Lab Upgrade

(see Future of DIS session)