Recent Spin Structure Function Measurements from CLAS at Jefferson Laboratory

Robert Fersch
Christopher Newport University
for the CLAS Collaboration

- Overview of the CLAS EG1 experiment at Jefferson Laboratory

- Analysis: from inclusive asymmetries to structure functions

- Recently published EG1 results

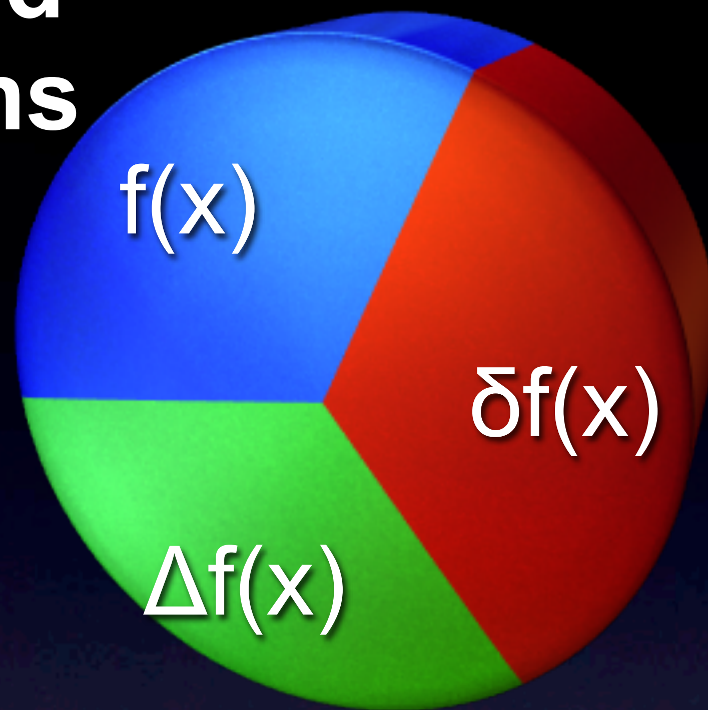
- Related polarized inclusive scattering data from CLAS; impact of data and future experiments in CLAS12

• **Overview of the CLAS EG1 experiment at Jefferson Laboratory**

Structure of the Nucleon

Unpolarized distributions q, g

Helicity Δq, Δg

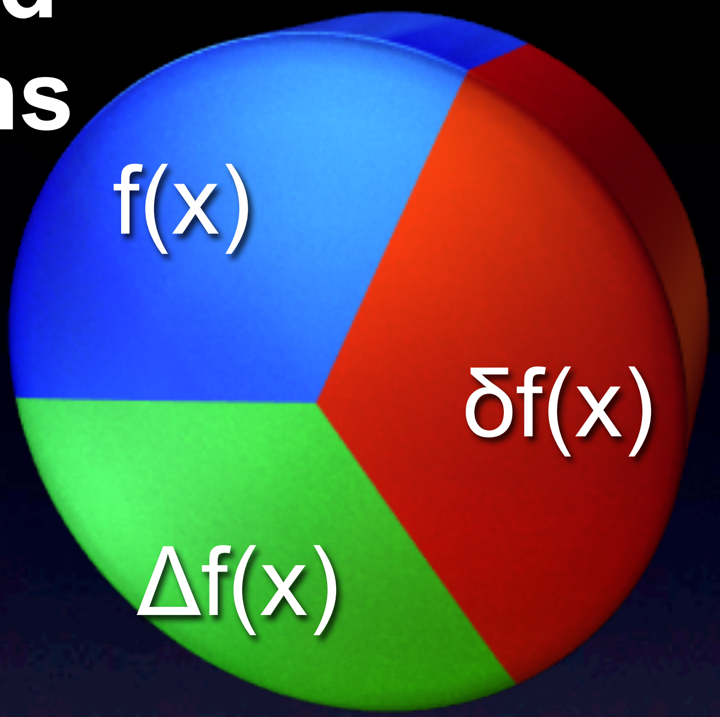


Transversity δq

3 d.o.f. completely describe the nucleon at leading twist when $k_T = 0$

Structure of the Nucleon

Unpolarized distributions
q, g



Transversity δq

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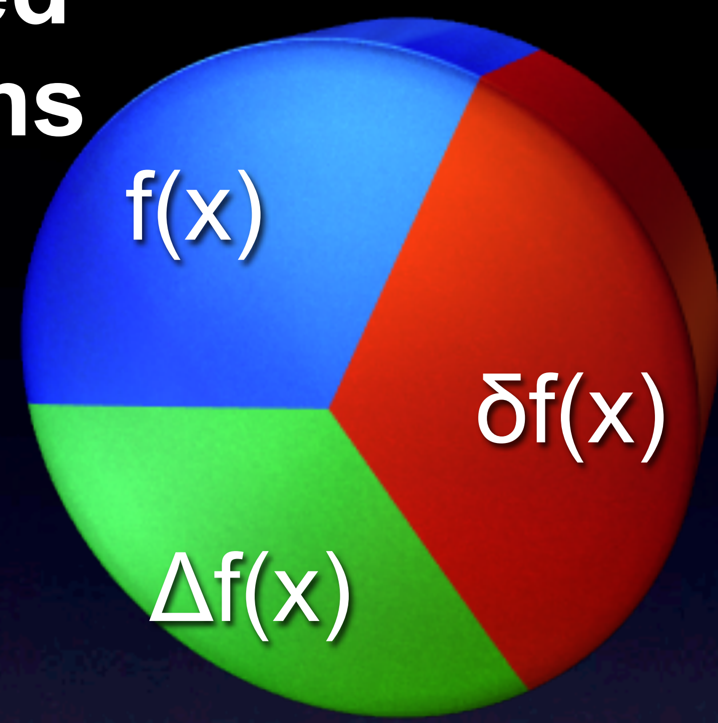
Structure of the Nucleon

Unpolarized distributions
q, g



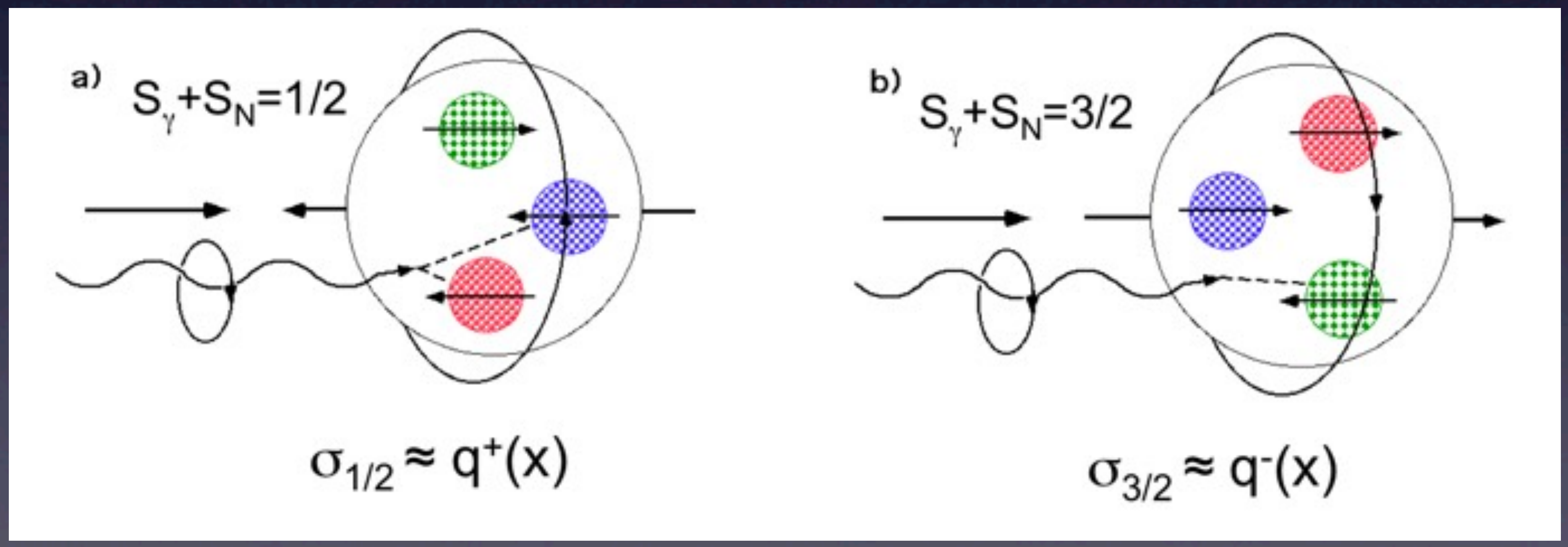
Transversity δq

3 d.o.f. completely describe the nucleon at leading twist when $k_T = 0$

Helicity
$\boxed{\Delta q,}\ \Delta g$

Helicity:
$\Delta q = q^+ - q^-$

Incident electron couples to quarks of opposite longitudinal spin



Structure function $g_1(x,Q^2) \sim \sigma_{1/2} - \sigma_{3/2}$

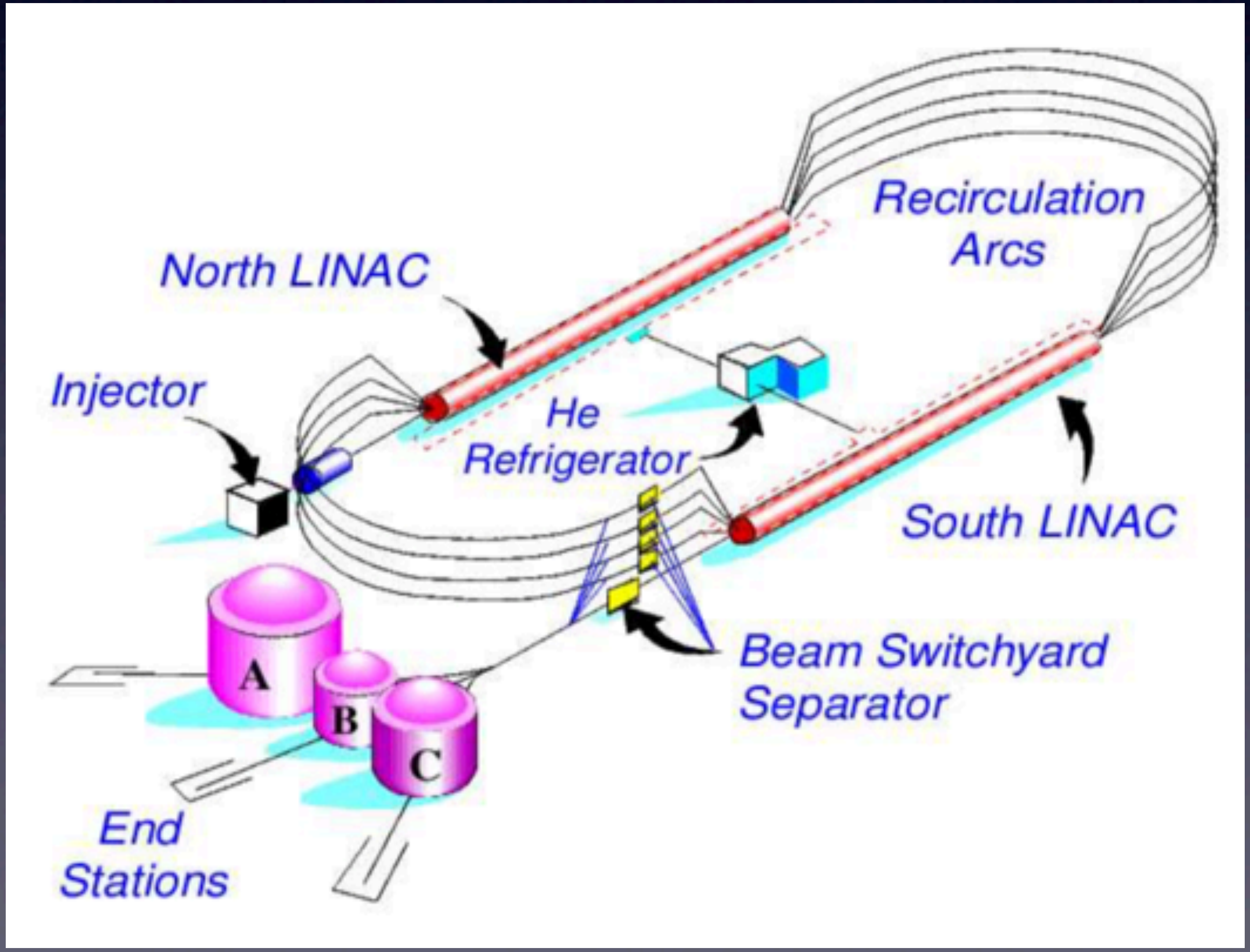
Requires longitudinally polarized beam *and* target

The EG1 experiment

ran in CLAS for 7 months 2000-2001

4 beam energies used (1.6, 2.5, 4.2, 5.7 GeV)

Jefferson Laboratory
(Newport News, VA, USA)



Polarized (~70%) electron beam at energies up to 6 GeV

Beam delivered to fixed targets in detector halls

Beam current of 20 nA typical for EG1 experiment

The EG1 experiment

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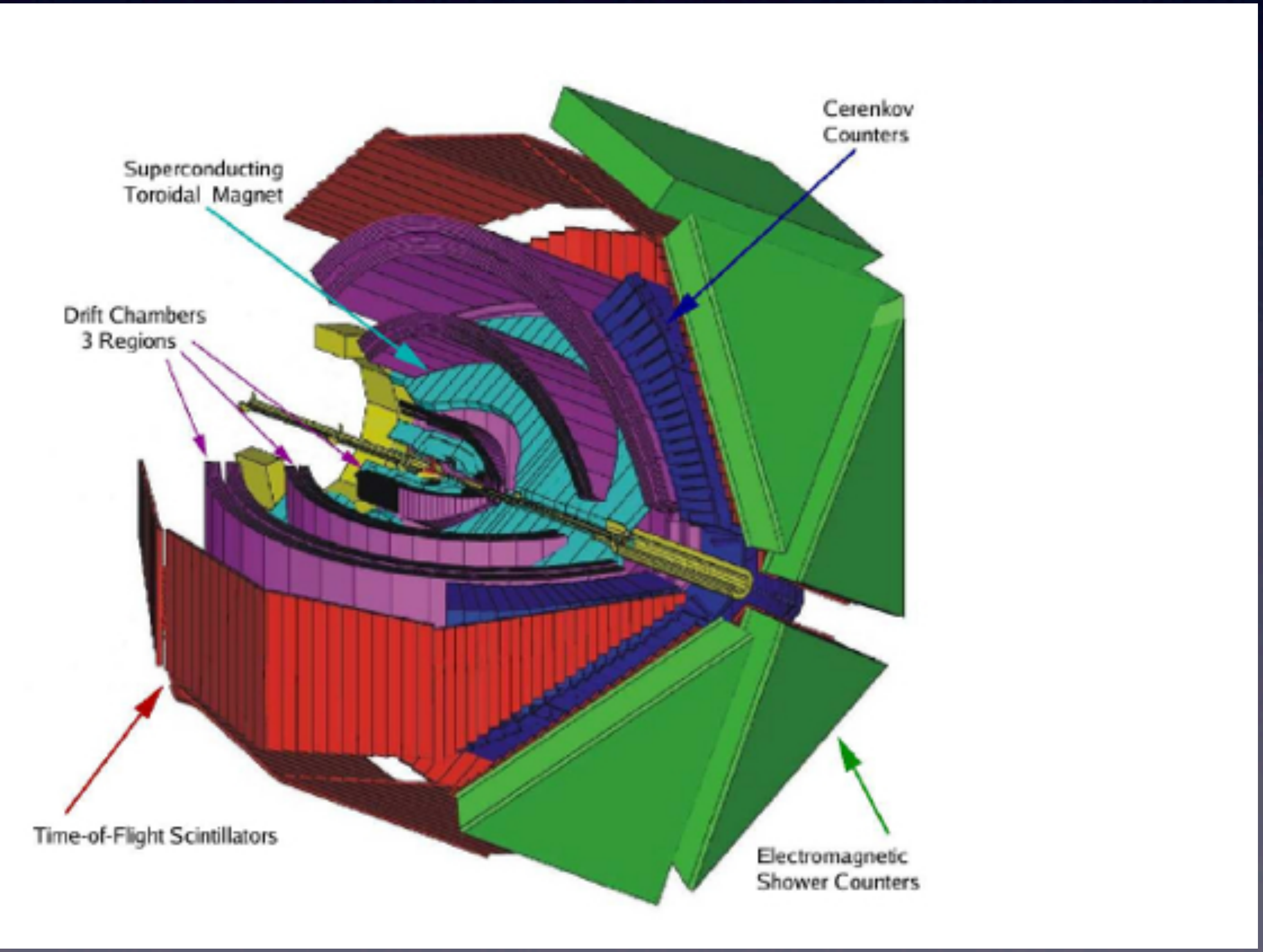
4 beam energies used (1.6, 2.5, 4.2, 5.7 GeV)

CEBAF Large Acceptance Spectrometer (Hall-B) at Jefferson Lab



Drift Chambers (momentum reconstruction)

Scintillation Counters (time-of-flight, PID)

Cherenkov Counters and Electromagnetic Calorimeters (separation of electrons from light hadrons)

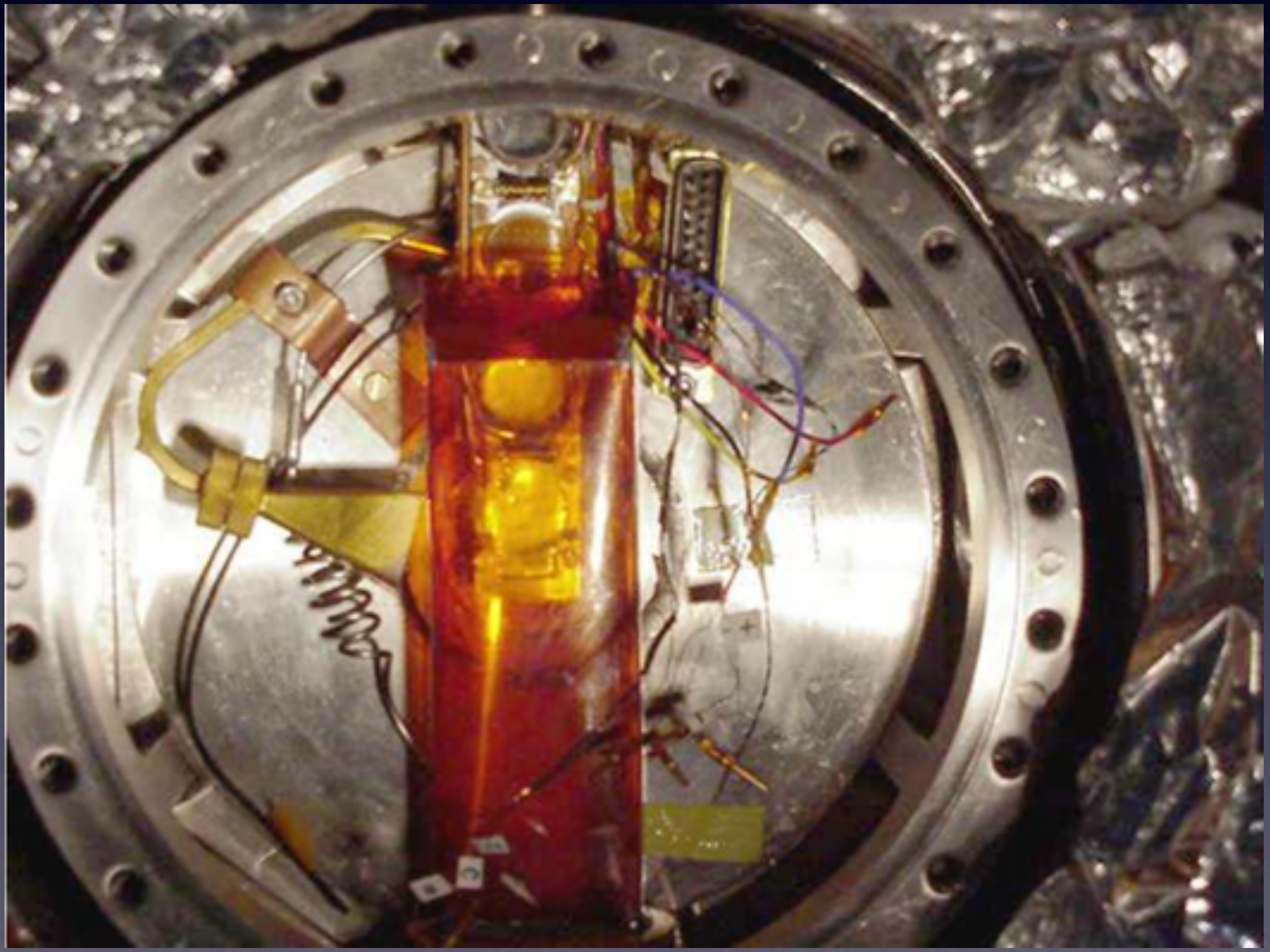
The EG1 experiment

ran in CLAS for 7 months 2000-2001

4 beam energies used (1.6, 2.5, 4.2, 5.7 GeV)

CLAS Longitudinally Polarized Target

- $^{15}NH_3$ and $^{15}ND_3$ target cells
- Typical polarizations of 75% (H) and 30% (D)
- ^{12}C and LHe target cells for unpolarized background subtraction



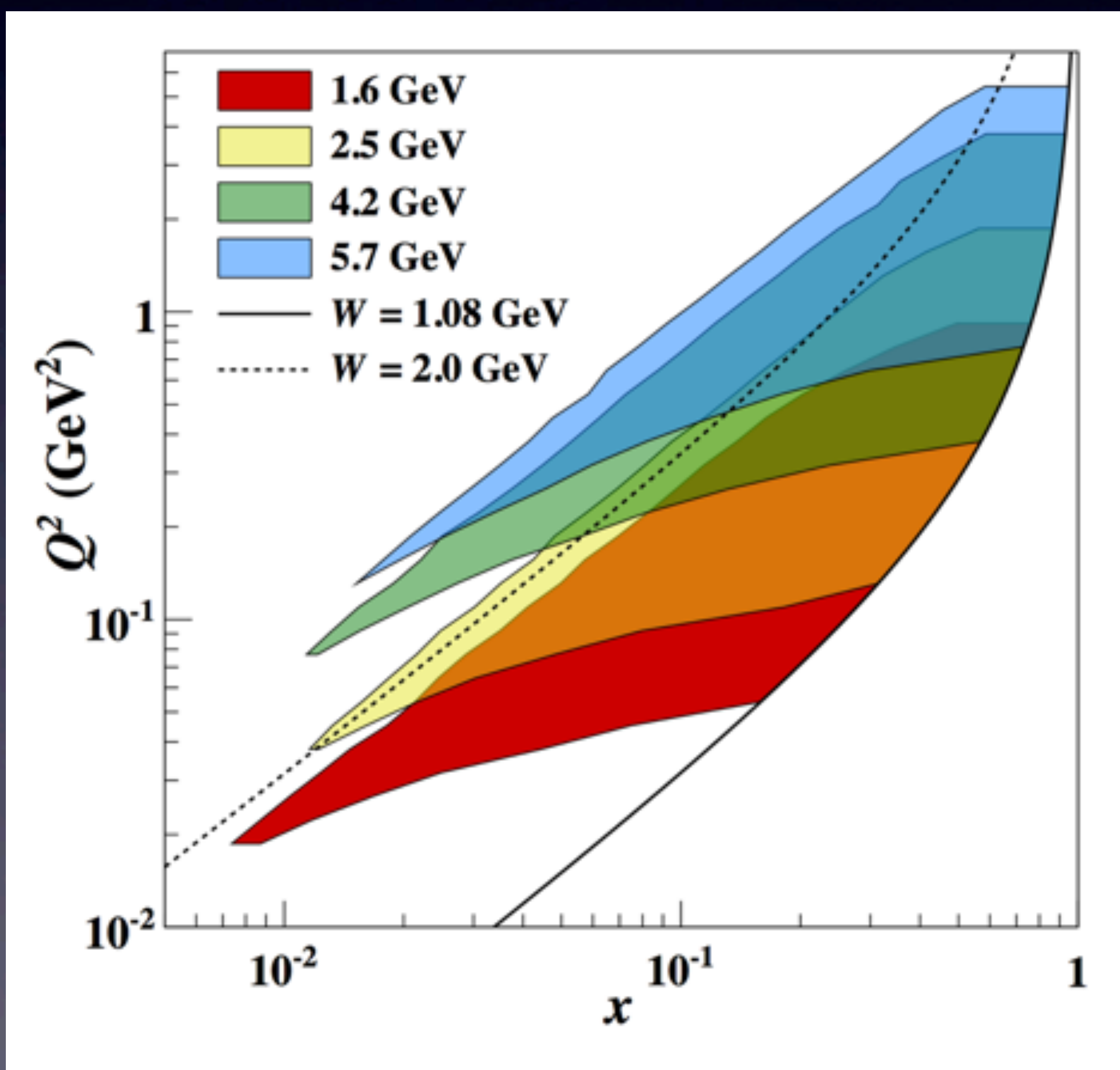
ammonia target cell

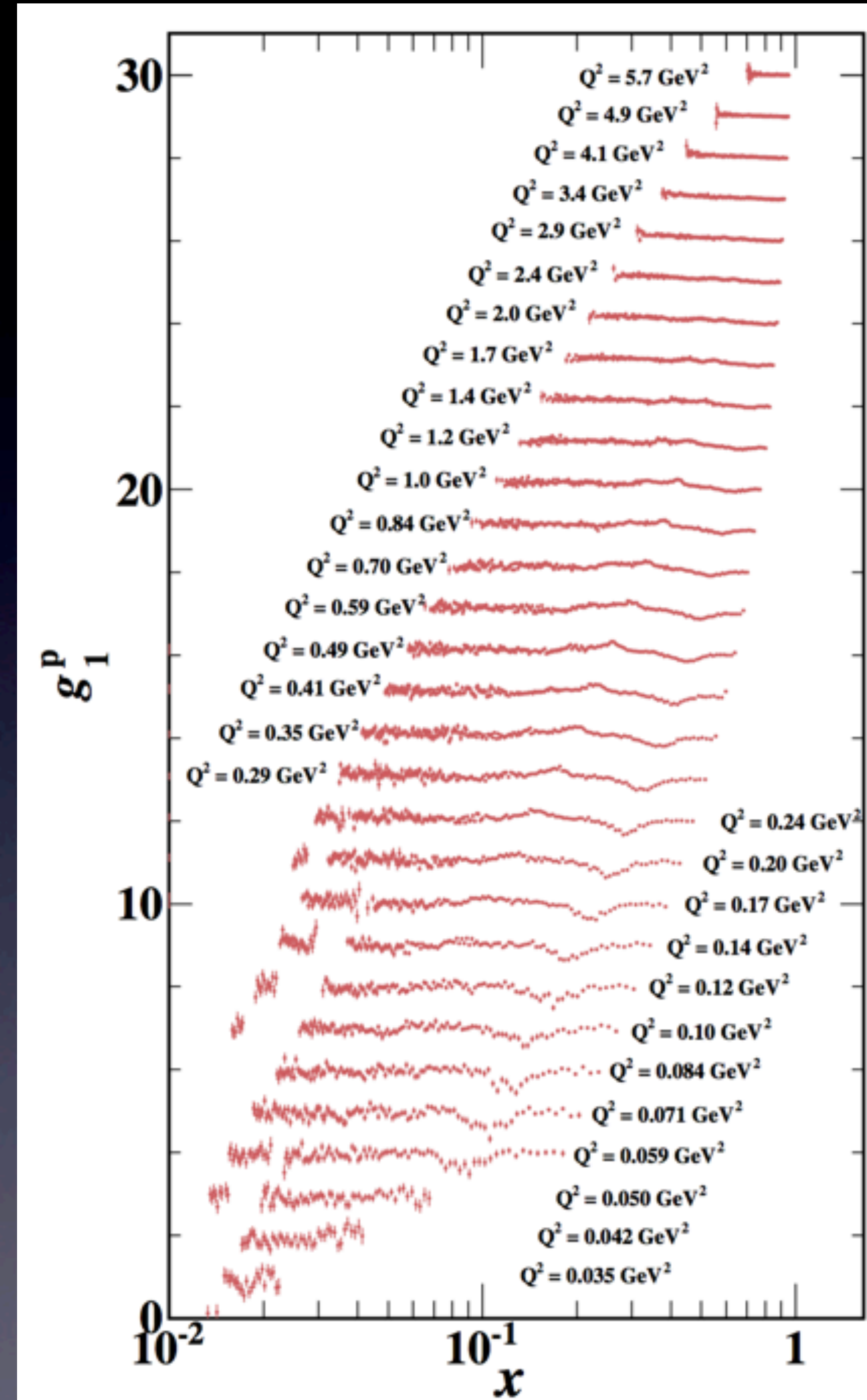
The EG1 experiment

ran in CLAS for 7 months 2000-2001

4 beam energies used
(1.6, 2.5, 4.2, 5.7 GeV)

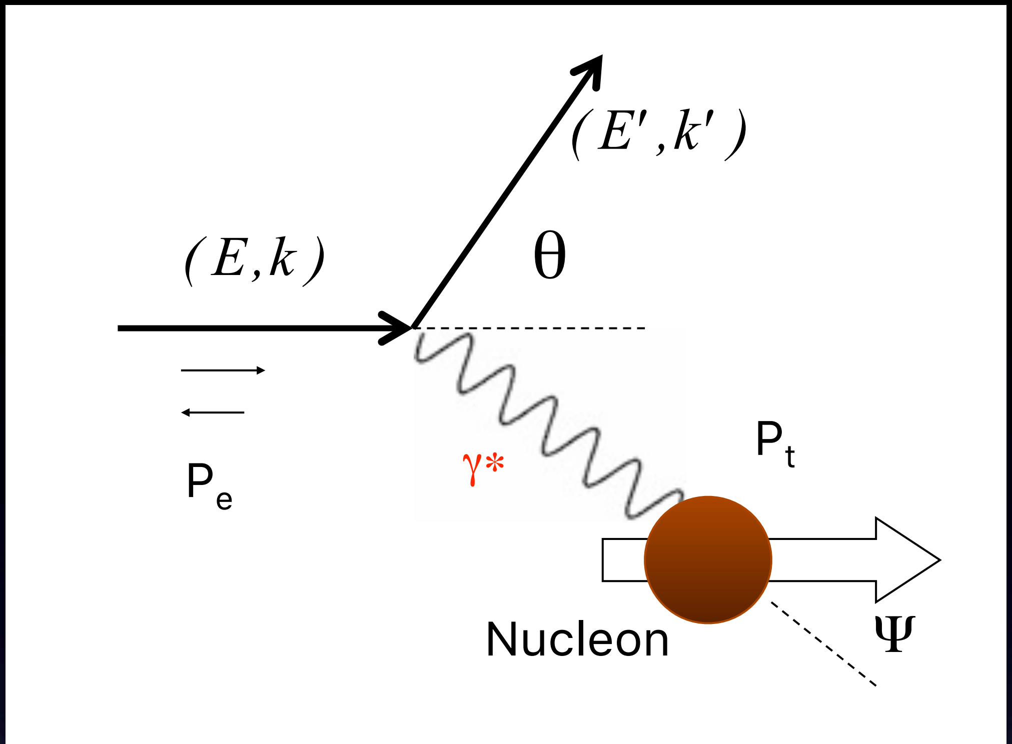
Kinematic coverage & statistics





- Analysis: from inclusive asymmetries to structure functions

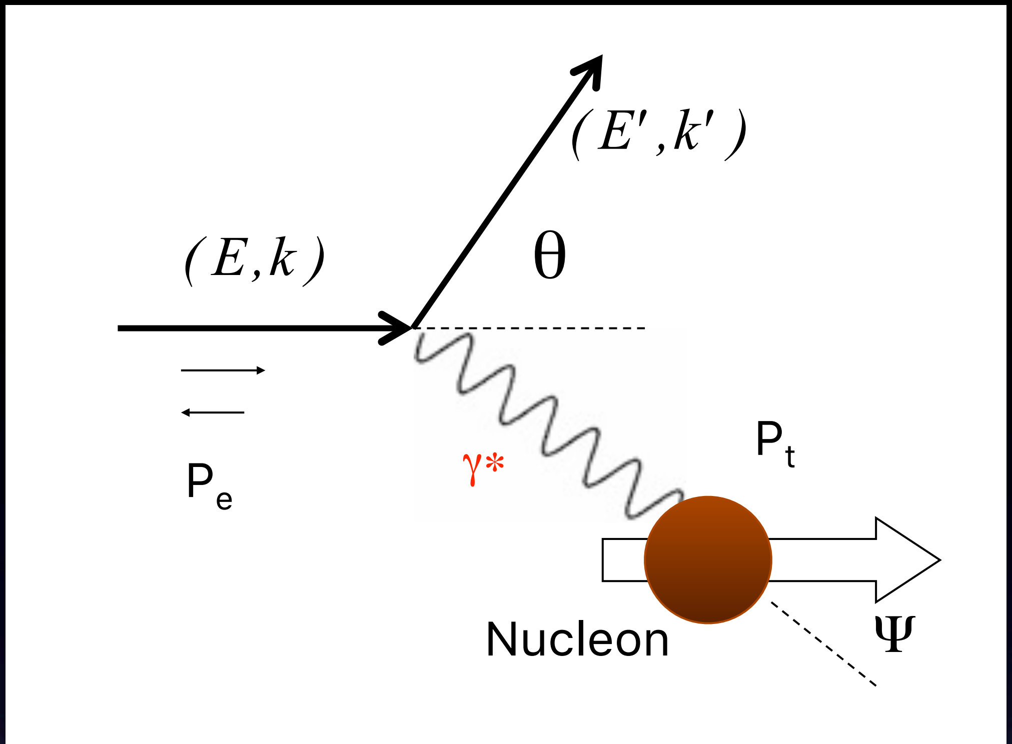
Analysis of Polarized Inclusive *eN* scattering



Double spin asymmetry between + (↑↑,↓↓) and – (↑↓,↓↑) beam and target polarizations

$$A_{\parallel} = \frac{1}{P_b P_t F_{DF}} \frac{n^+ - n^-}{n^+ + n^-}$$

Analysis of Polarized Inclusive *eN* scattering



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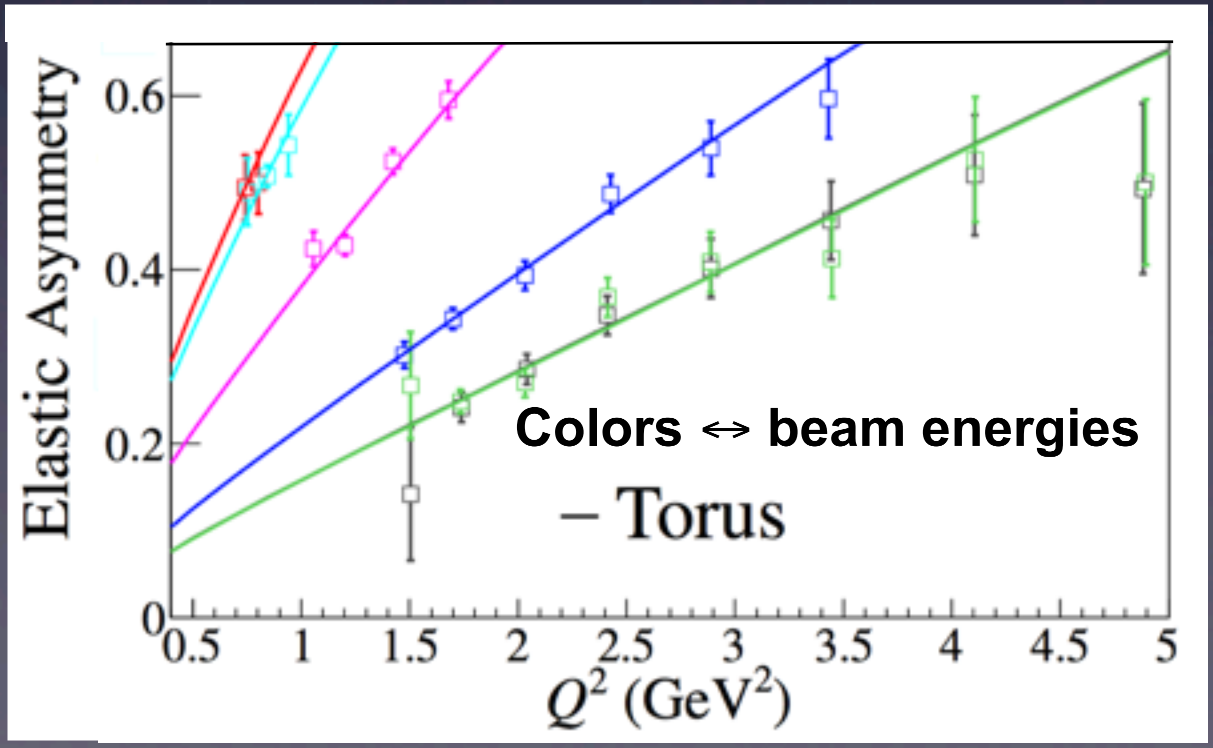
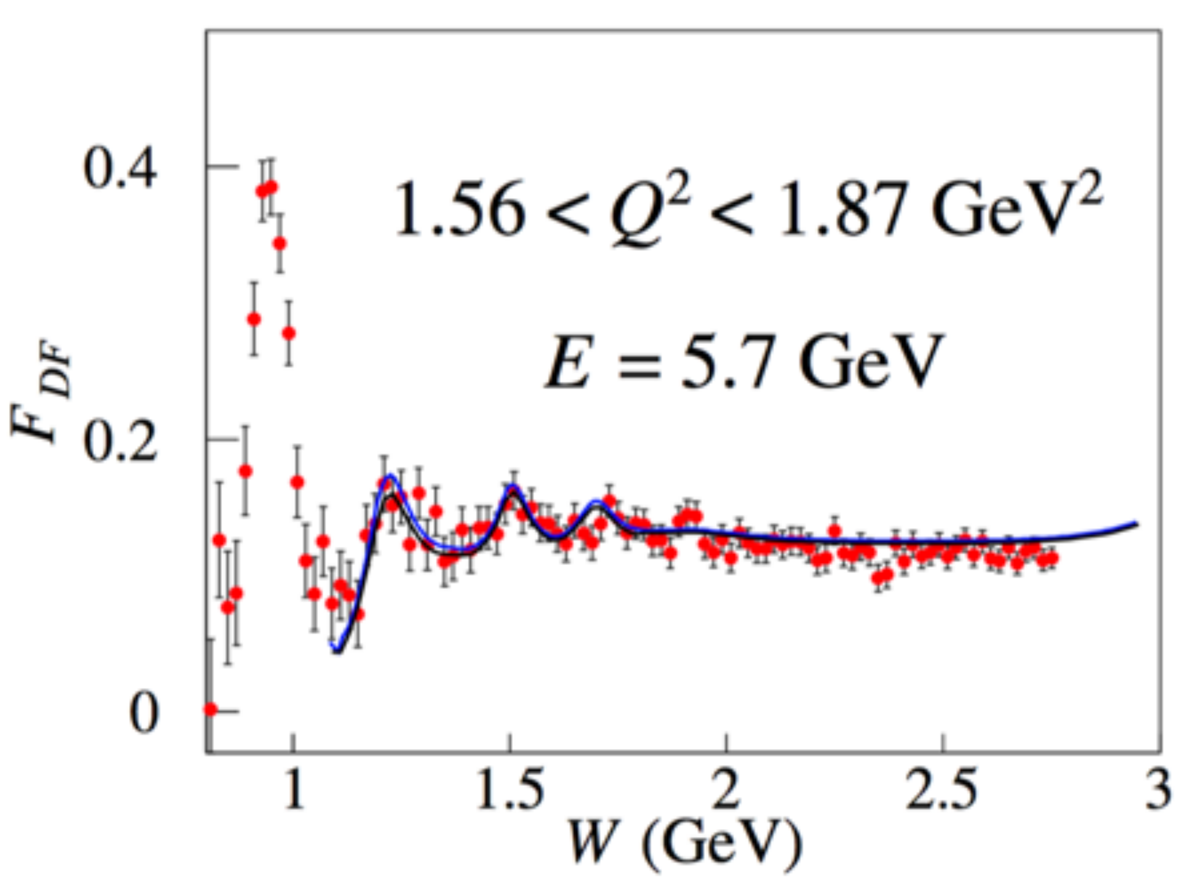
Dilution factor from 12C, LHe runs and radiated cross section model

Polarization product from elastic asymmetry normalization to global data





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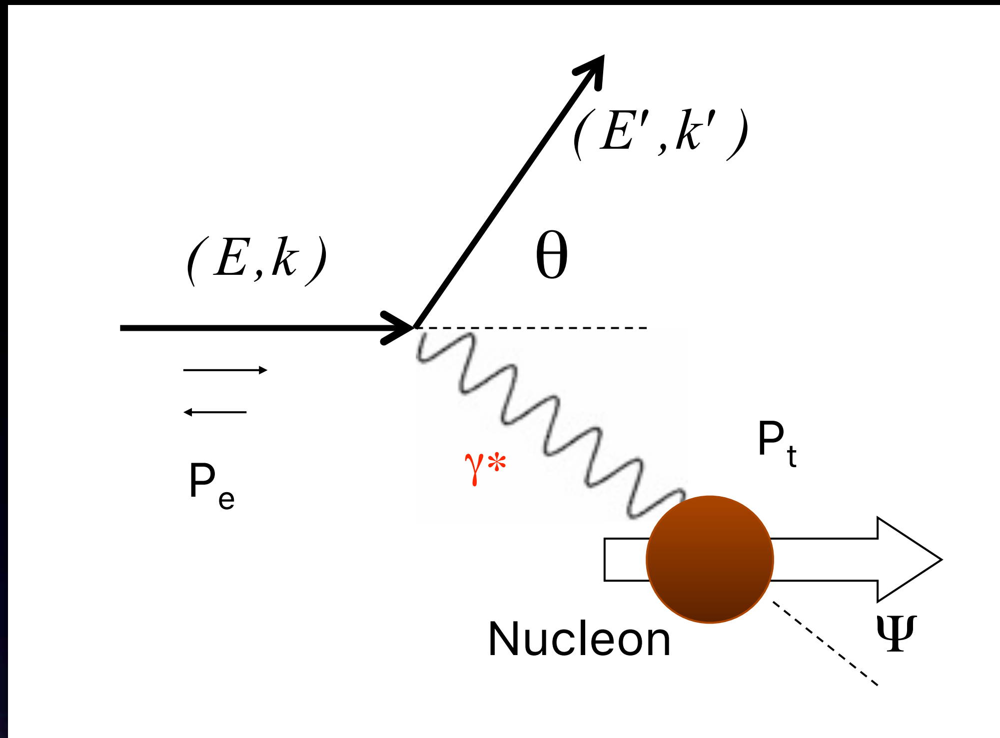


Double spin asymmetry between + (↑↑,↓↓) and – (↑↓,↓↑) beam and target polarizations

$$A_{\|} = \frac{1}{P_b P_t F_{DF}} \frac{n^+ - n^-}{n^+ + n^-}$$

Physics quantities

virtual photon asymmetries A_1 and A_2

$$A_{||}(\nu, Q^2) = D[A_1^p(\nu, Q^2) + \eta A_2^p(\nu, Q^2)]$$

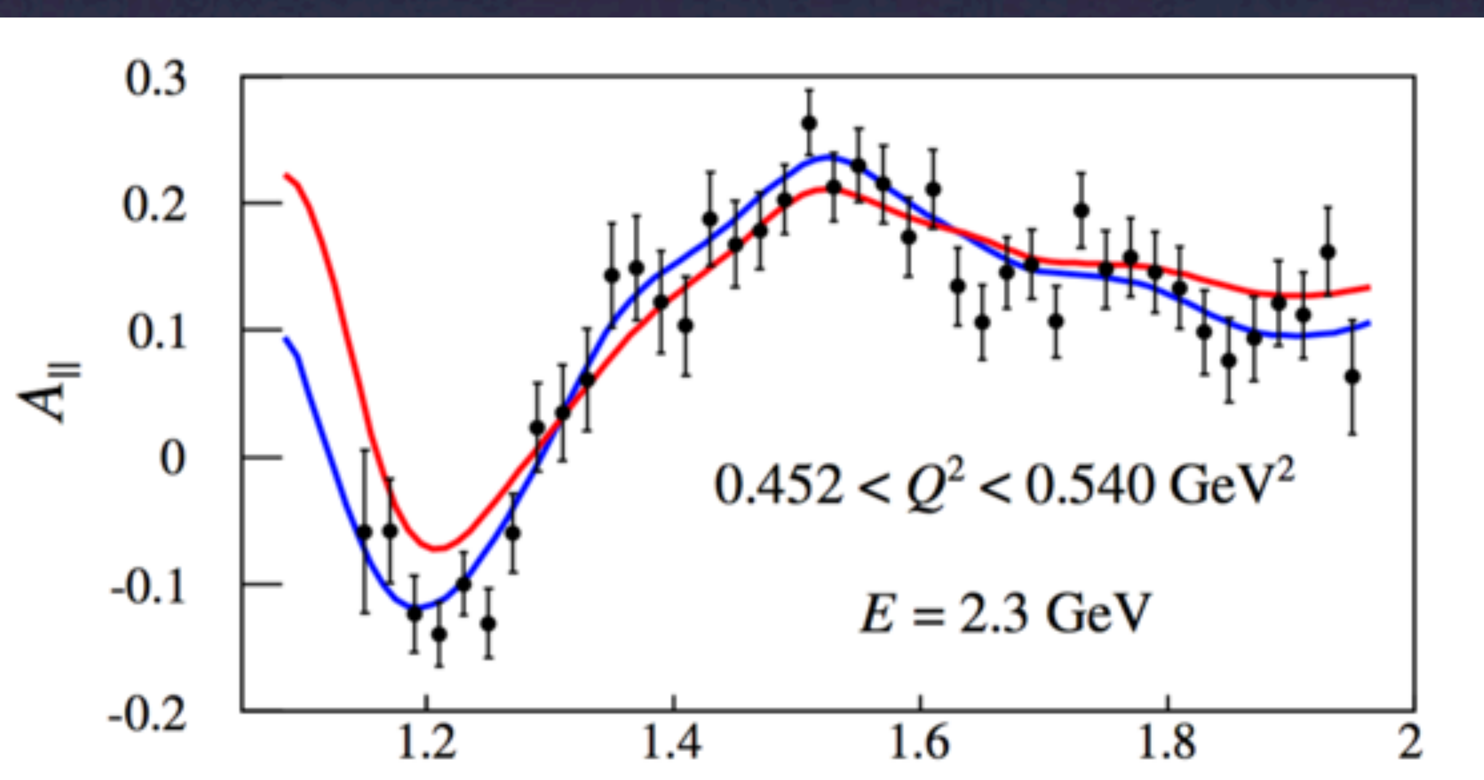
spin structure functions g_1 and g_2

$$\frac{A_{||}}{D} = (1+\eta\gamma)\frac{g_1^p}{F_1^p} + \gamma(\eta-\gamma)\frac{g_2^p}{F_1^p}$$

Radiative corrections

(difference between red, blue lines)

(also nuclear polarization and e^+e^- corrections)

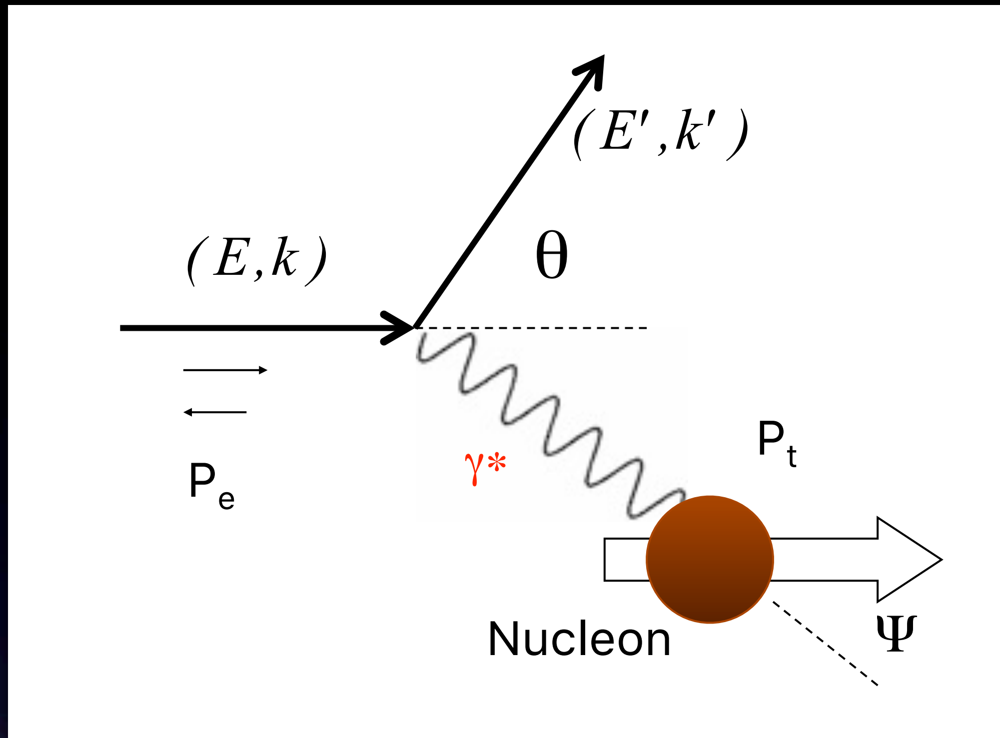


(kinematics/models)

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

$$\gamma = \frac{2Mx}{\sqrt{Q^2}}$$

Analysis of Polarized Inclusive *eN* scattering



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$$\frac{A_{\|}}{D} = (1 + \eta\gamma)\frac{g_1^p}{F_1^p} + \gamma(\eta - \gamma)\frac{g_2^p}{F_1^p}$$

Modeled from world data (kinematics/models)

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

$$\gamma = \frac{2Mx}{\sqrt{Q^2}}$$

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(difference between red, blue lines)

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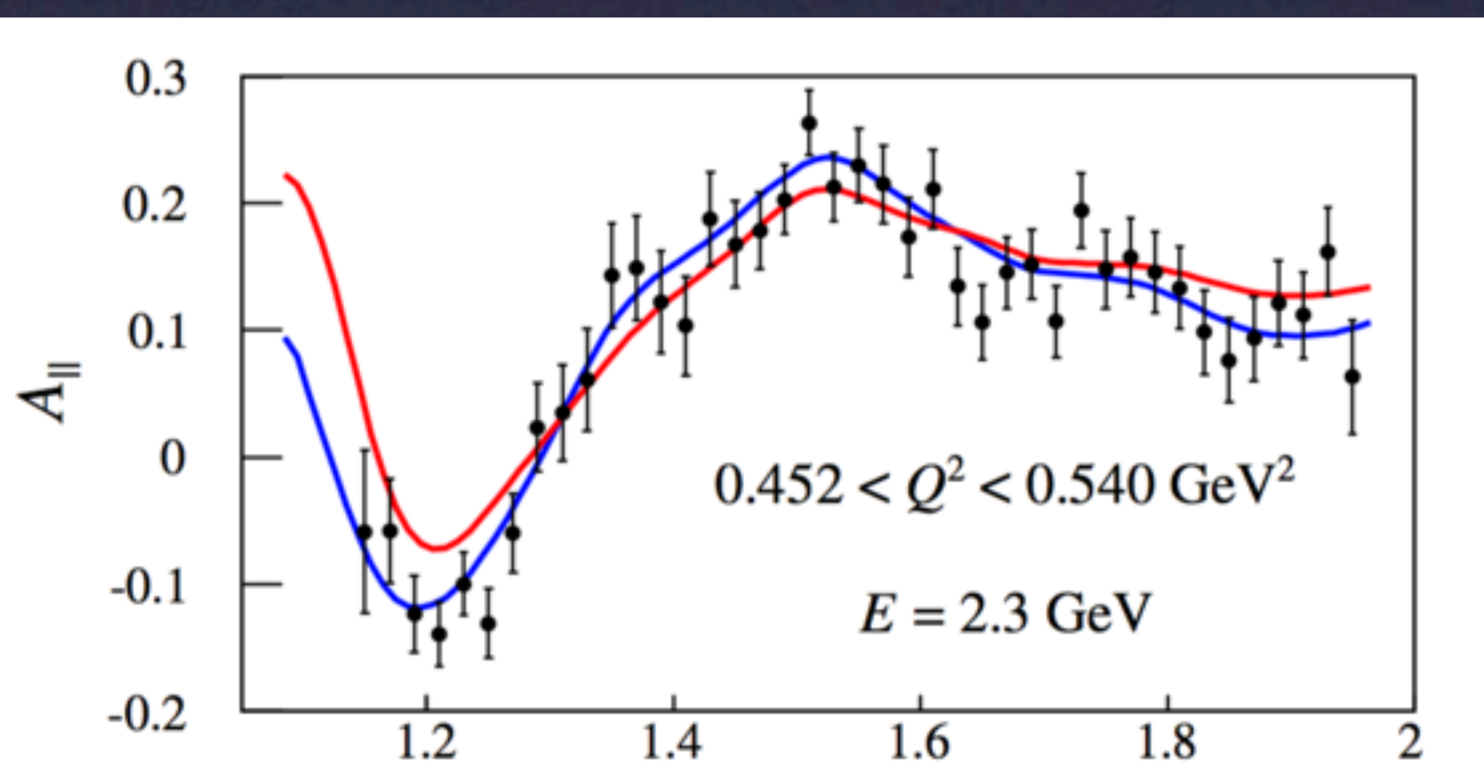
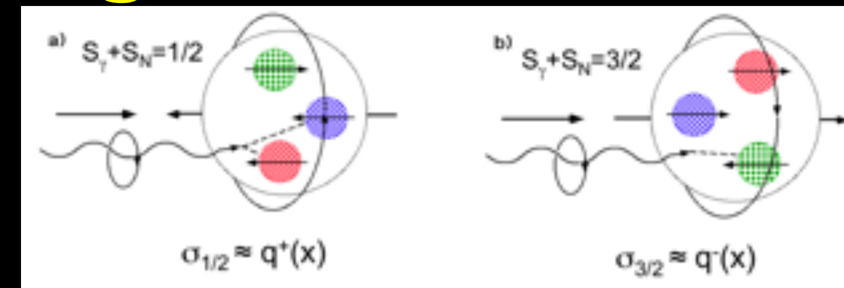
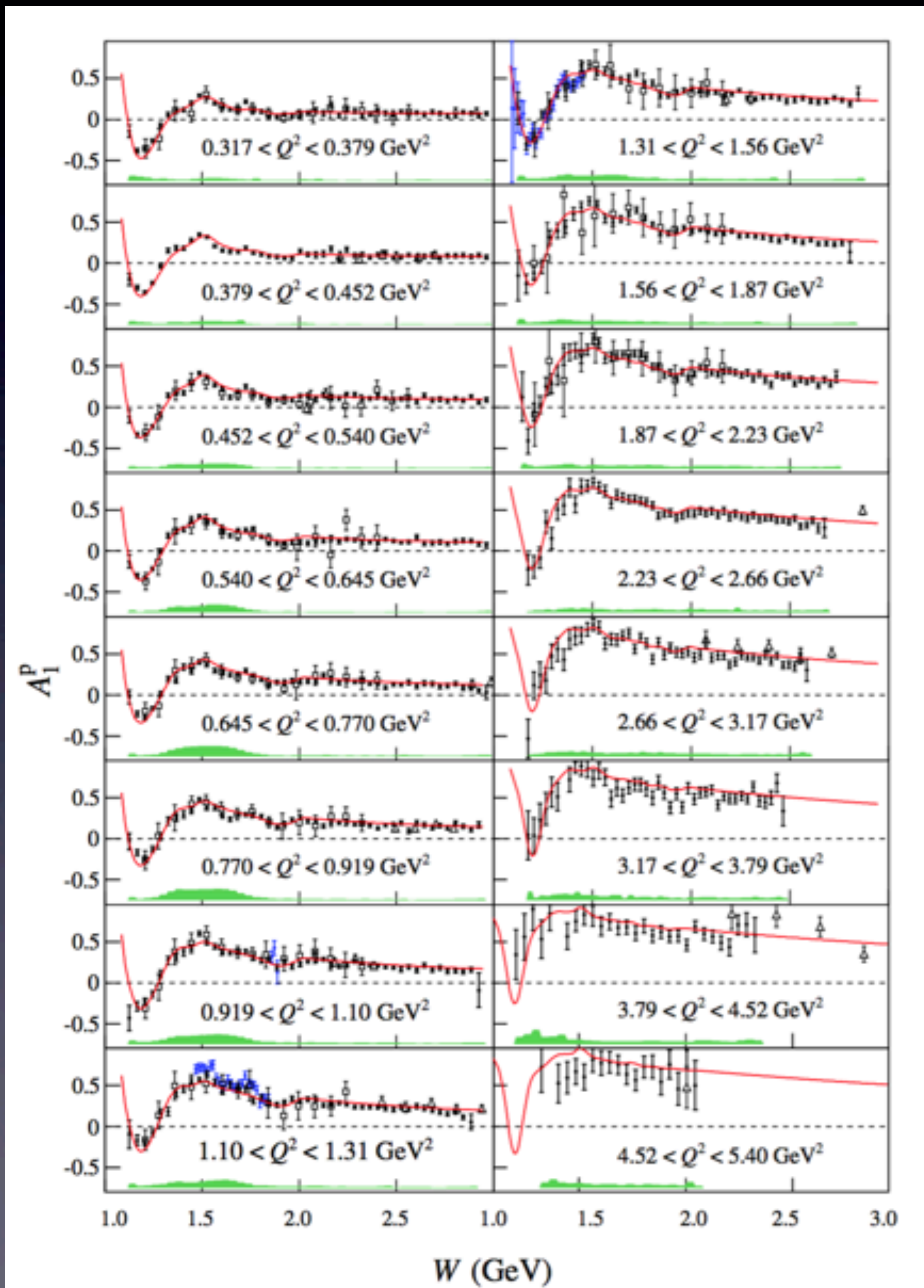


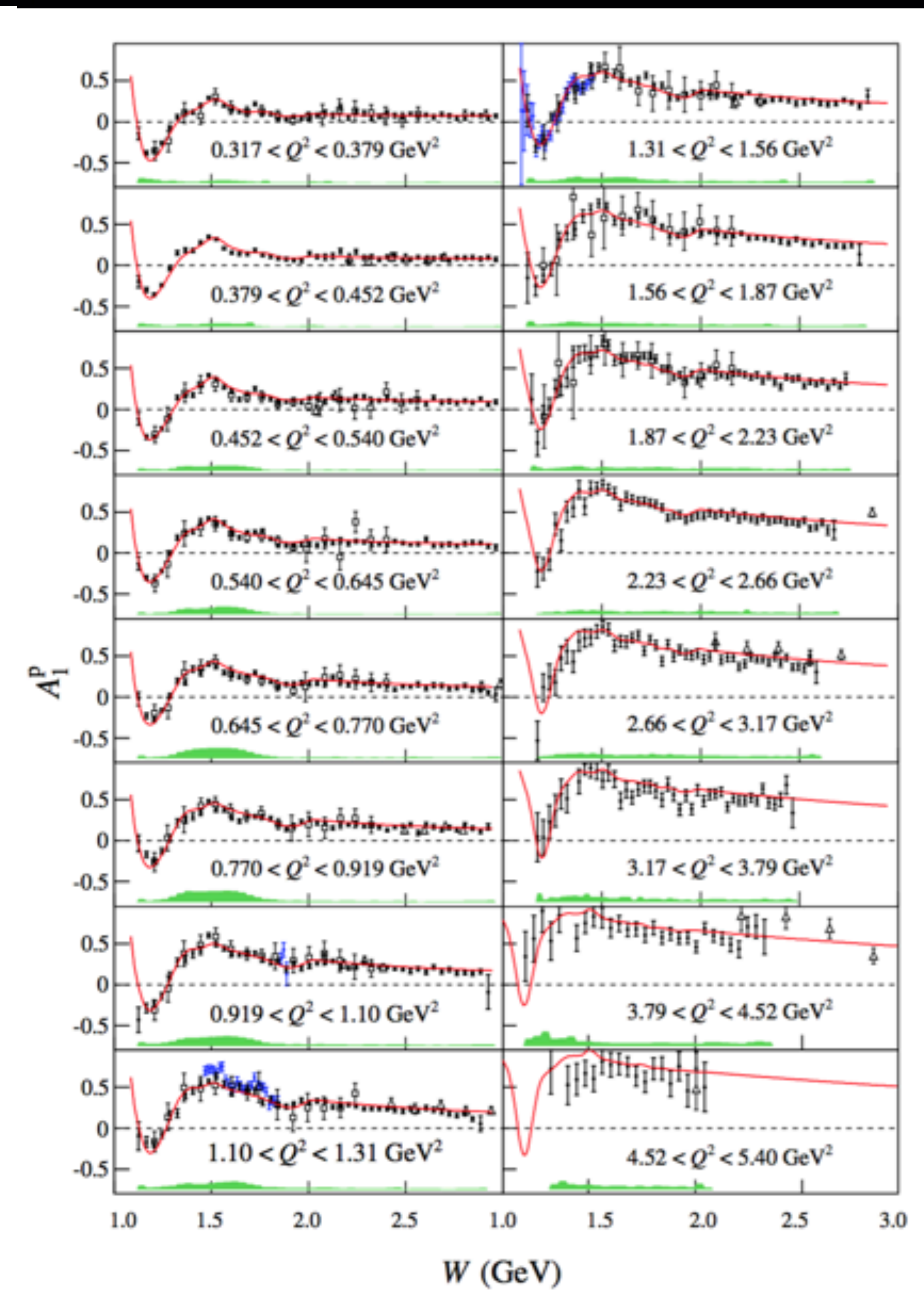
- Recently published EG1 results

A_1 for the proton shown against world data

$$A_1^p(\gamma^*) \equiv \frac{\sigma_T^{\frac{1}{2}}(\gamma^*) - \sigma_T^{\frac{3}{2}}(\gamma^*)}{\sigma_T^{\frac{1}{2}}(\gamma^*) + \sigma_T^{\frac{3}{2}}(\gamma^*)}$$



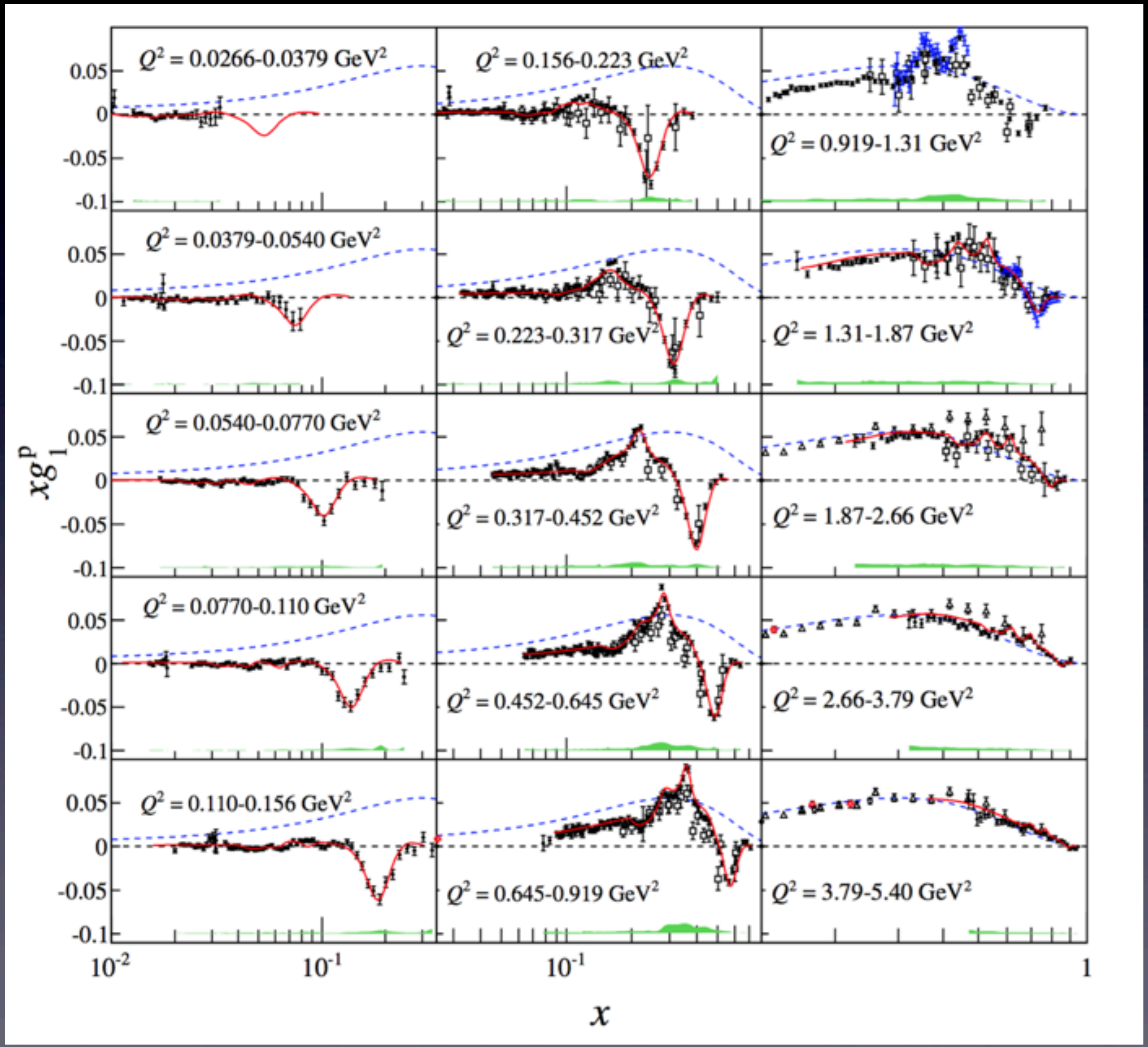




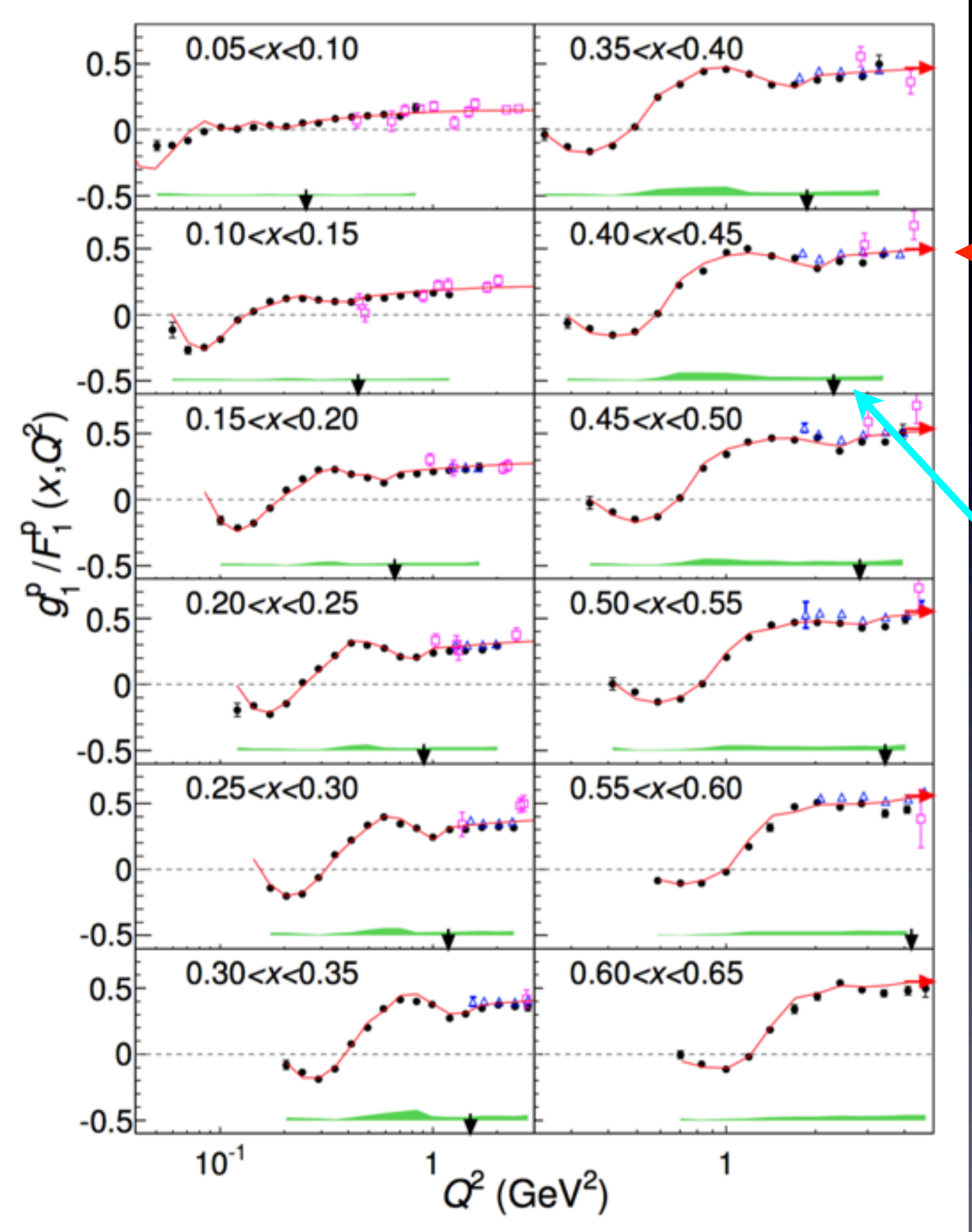
g_1 for the proton shown against world data

$$g_1(x,Q^2) = \frac{1}{2}\sum q_f^2 \Delta f(x,Q^2) = \frac{4}{18}\Delta u(x,Q^2) + \frac{1}{18}\Delta d(x,Q^2) + \frac{1}{18}\Delta s(x,Q^2)$$

(interpretation in DIS scaling limit)



g_1/F_1 vs. Q^2 results for the proton



$$\frac{A_{||}}{D} = (1+\eta\gamma)\frac{g_1^p}{F_1^p} + \gamma(\eta-\gamma)\frac{g_2^p}{F_1^p}$$

NLO PDF fit at $Q^2 = 5$ GeV^2

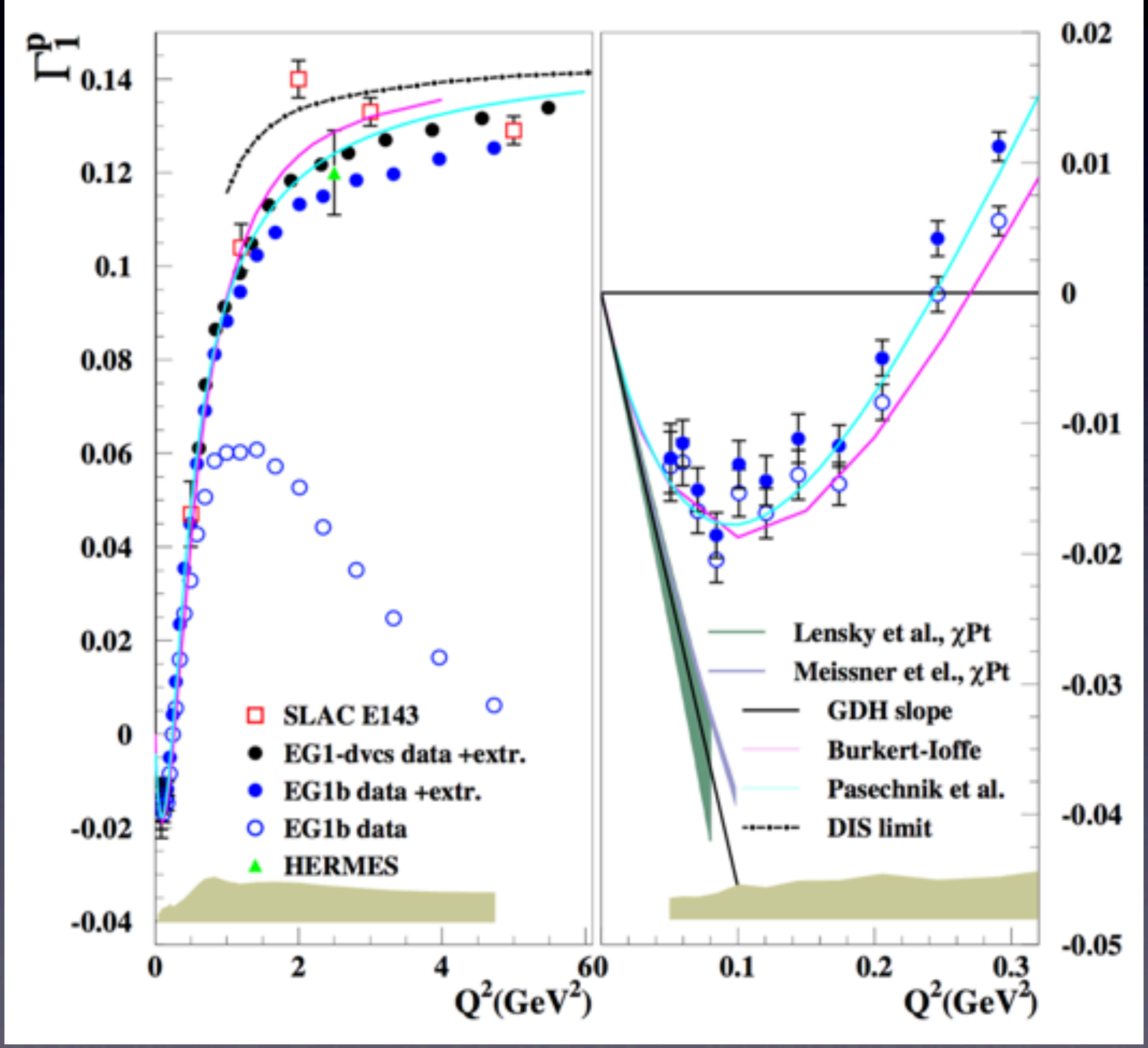
DIS limit ($W = 2$ GeV)

Moments of g_1

Needed to test *sum rules* and determine matrix elements in the OPE (Operator Product Expansion)

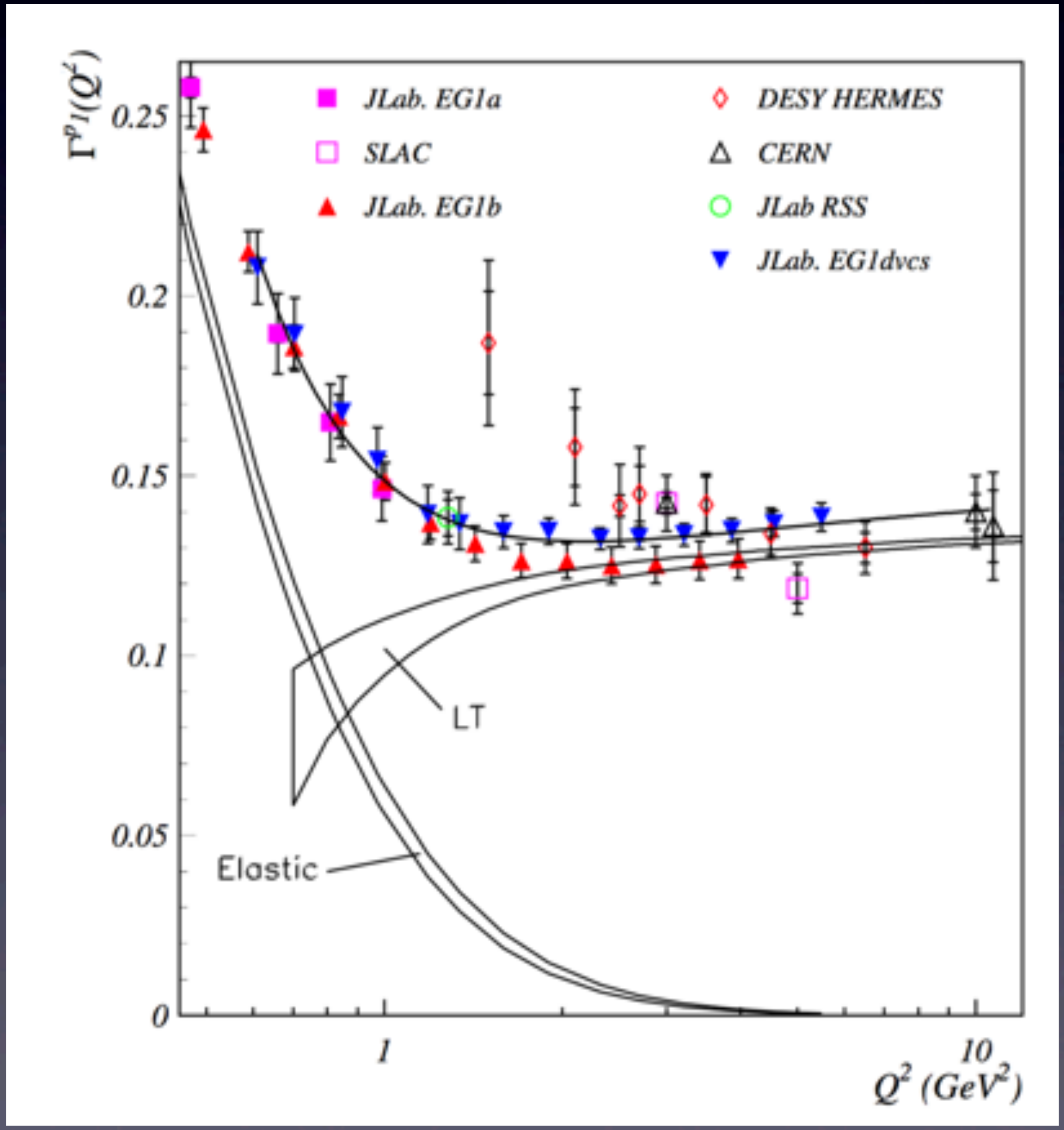
$\Gamma_1 = \int g_1 \, dx$ (integrated over x from x=0.001 to elastic threshold)

("first moment" of g_1)



Higher Twist analysis of Γ_1

(includes elastic contribution)



see also Prok, *et al.* Phys. Rev. B 672, 12 (2009)

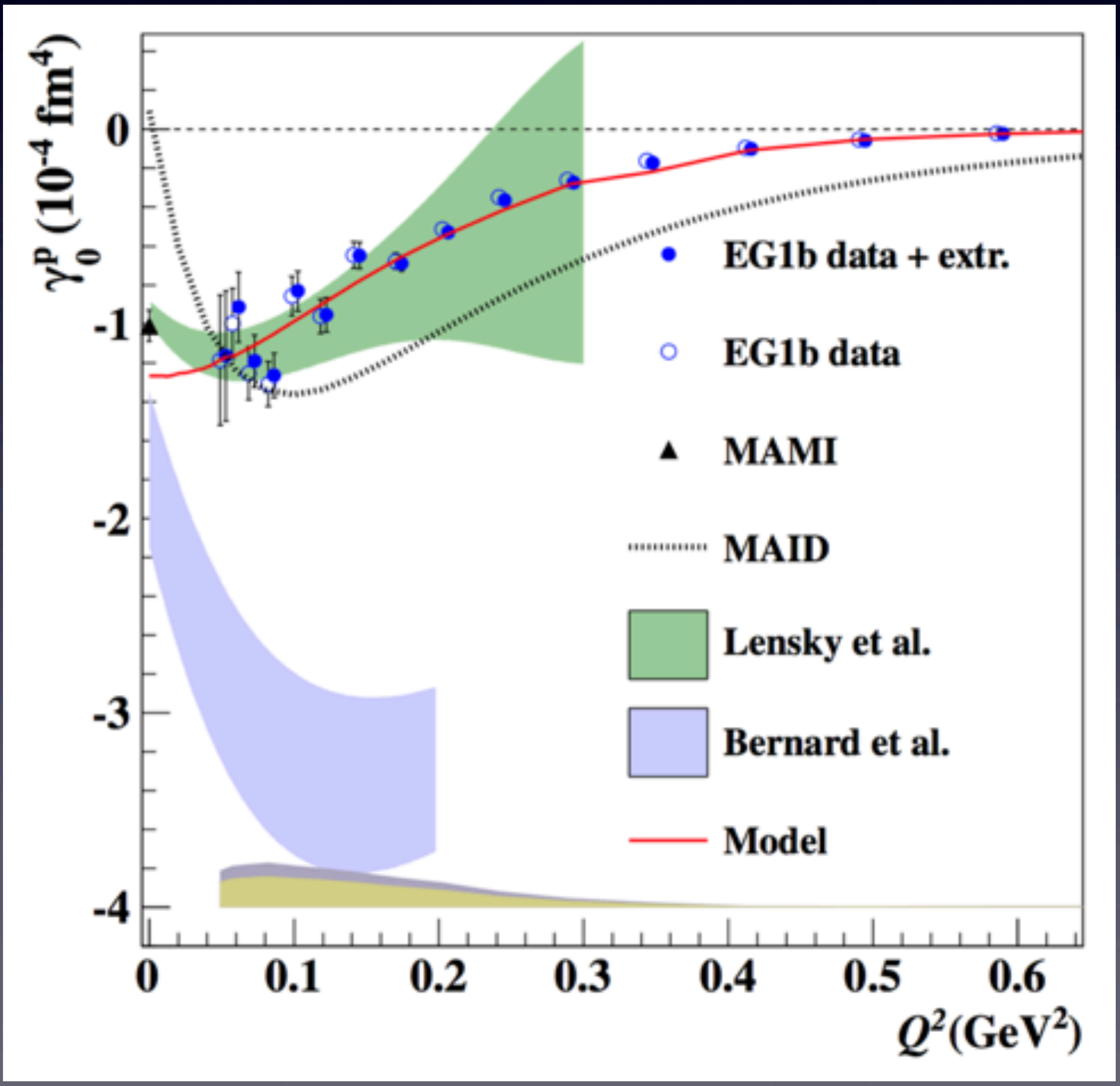
Extraction of higher twist elements through a fit by A. Deur

Forward Spin Polarizability

see also Prok, *et al.* Phys. Rev. B 672, 12 (2009)

For scattering cross-sections in terms of Compton amplitudes

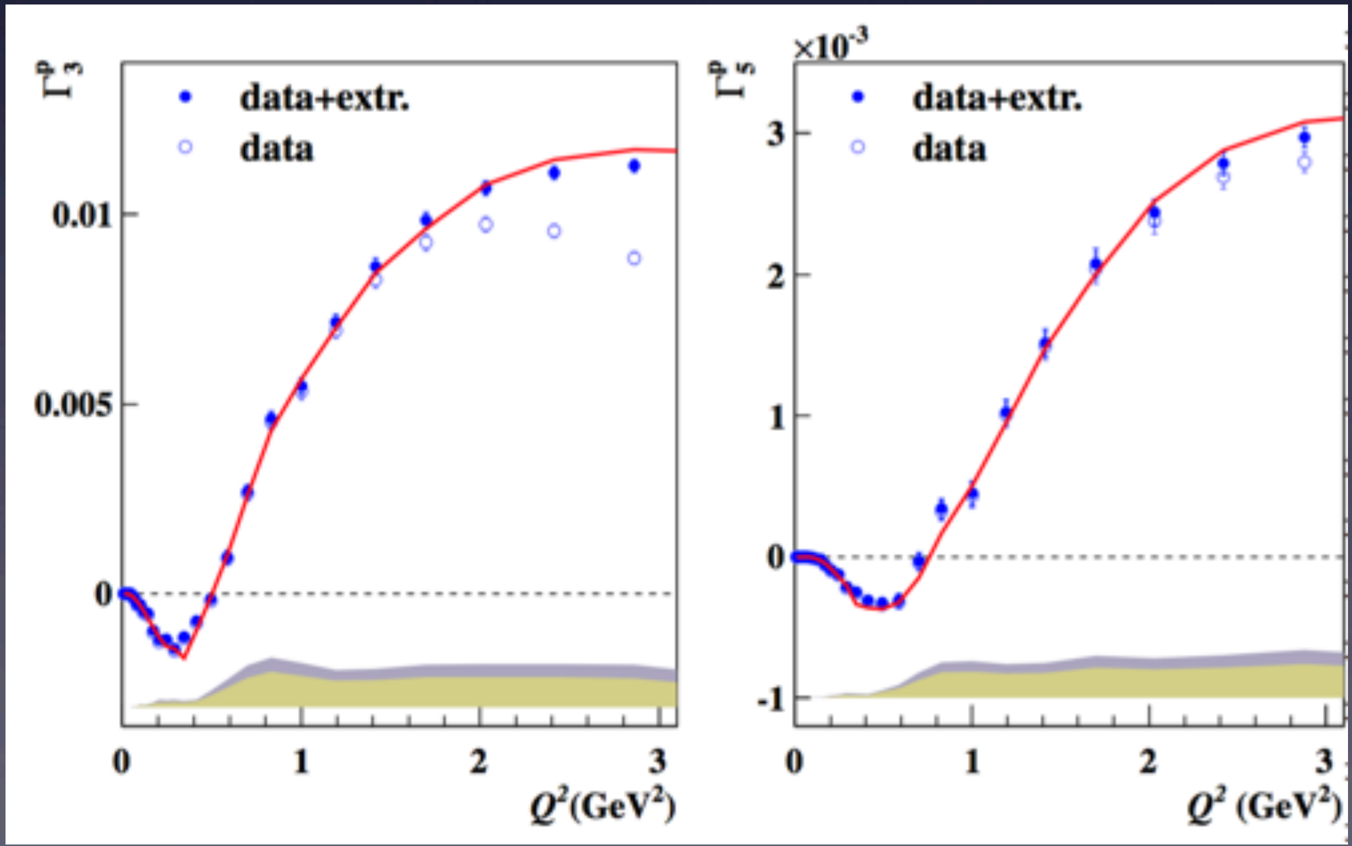
$$\gamma_0 = \frac{1}{4\pi}\int_{\nu_{th}}^{\infty} \frac{\sigma_{3/2}-\sigma_{1/2}}{\nu'^3}\,d\nu'$$
$$= \frac{16M^2\alpha}{Q^6}\int_0^{x_{th}} x^2 A_1(x,Q^2)F_1(x,Q^2)dx$$



Higher Moments

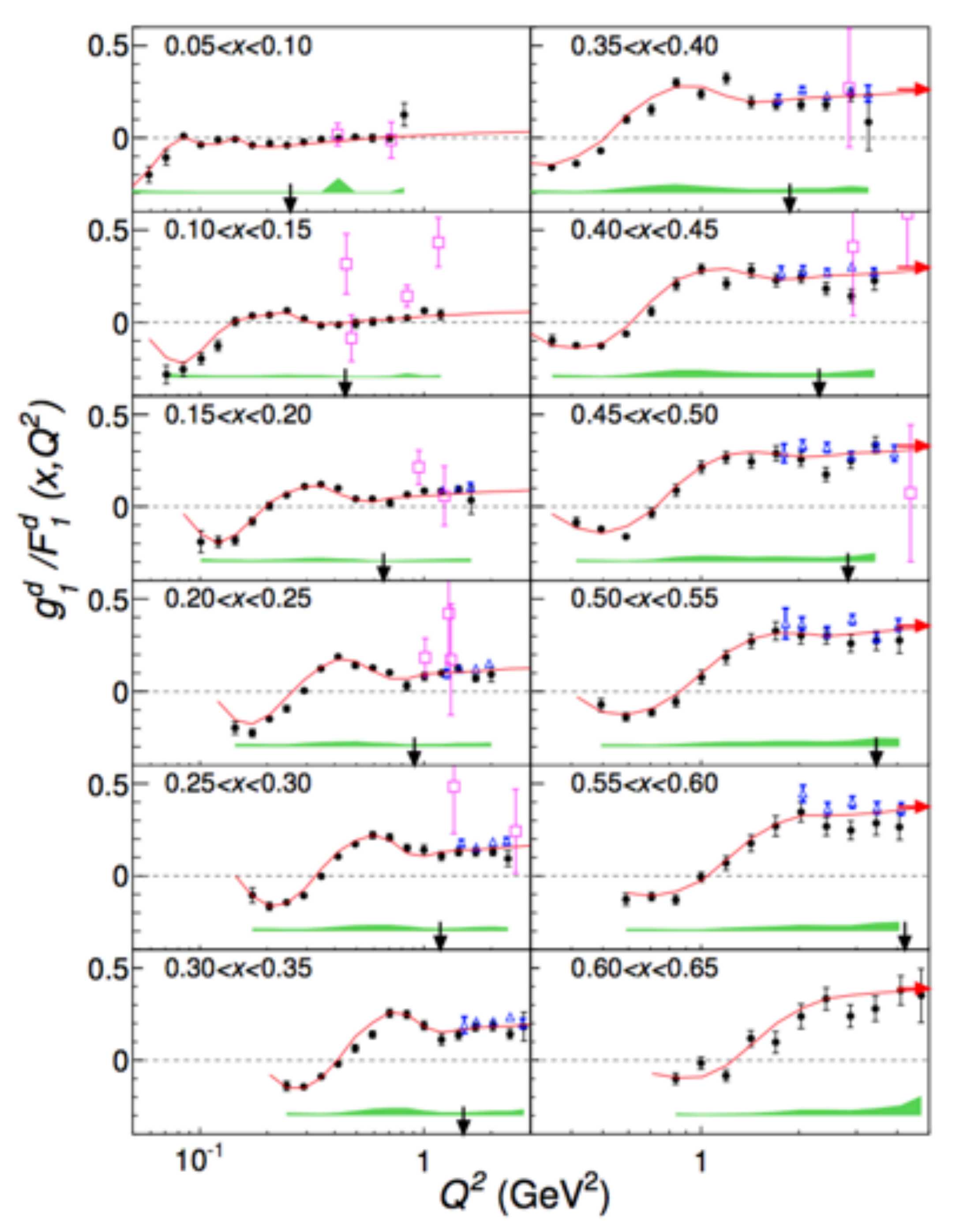
Large *x*-range provided opportunity to measure these

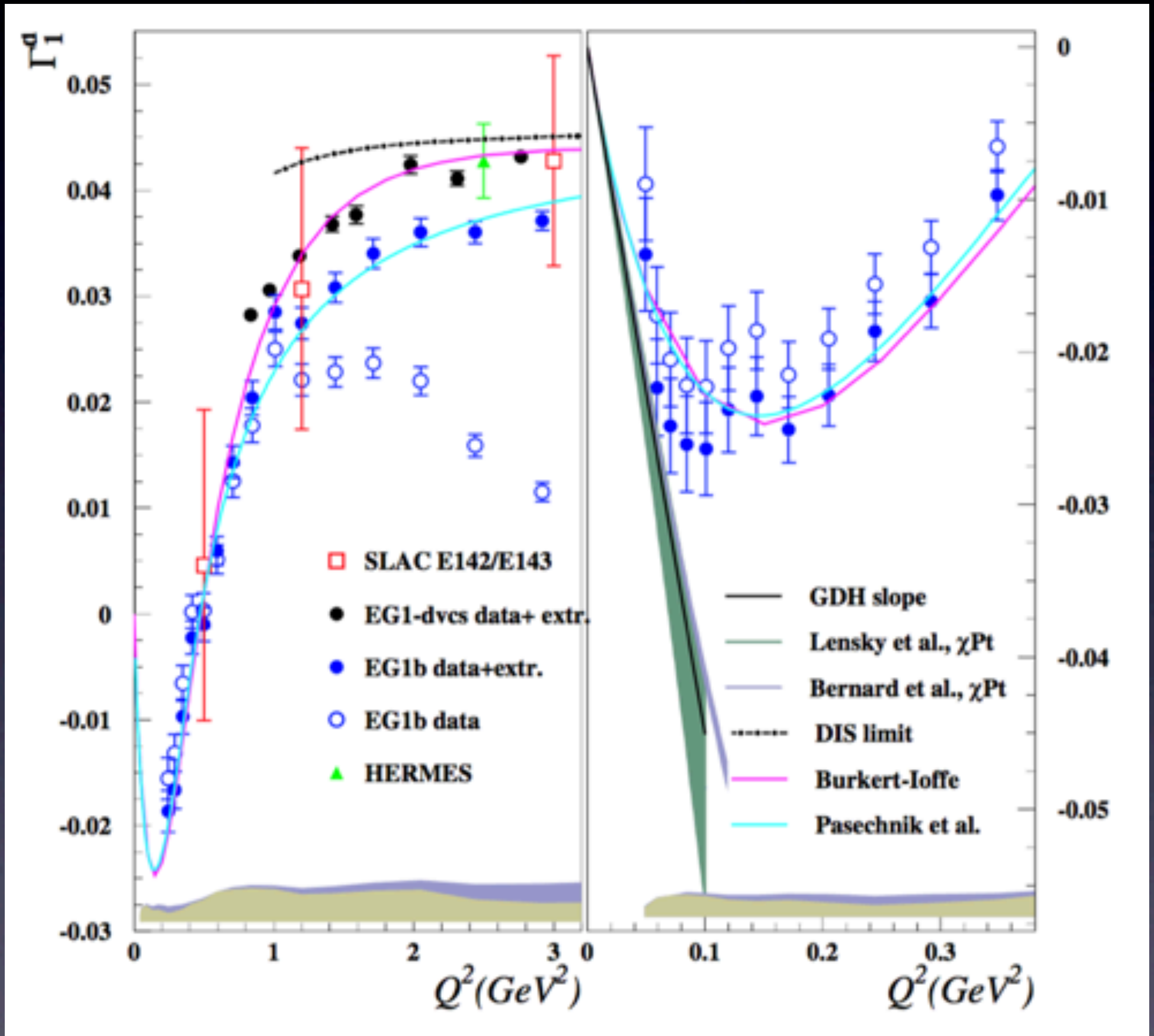
$$\Gamma_1^{\,n} = \int x^{n-1} g_1(x,Q^2)dx$$



All of this is available for the deuteron, too!

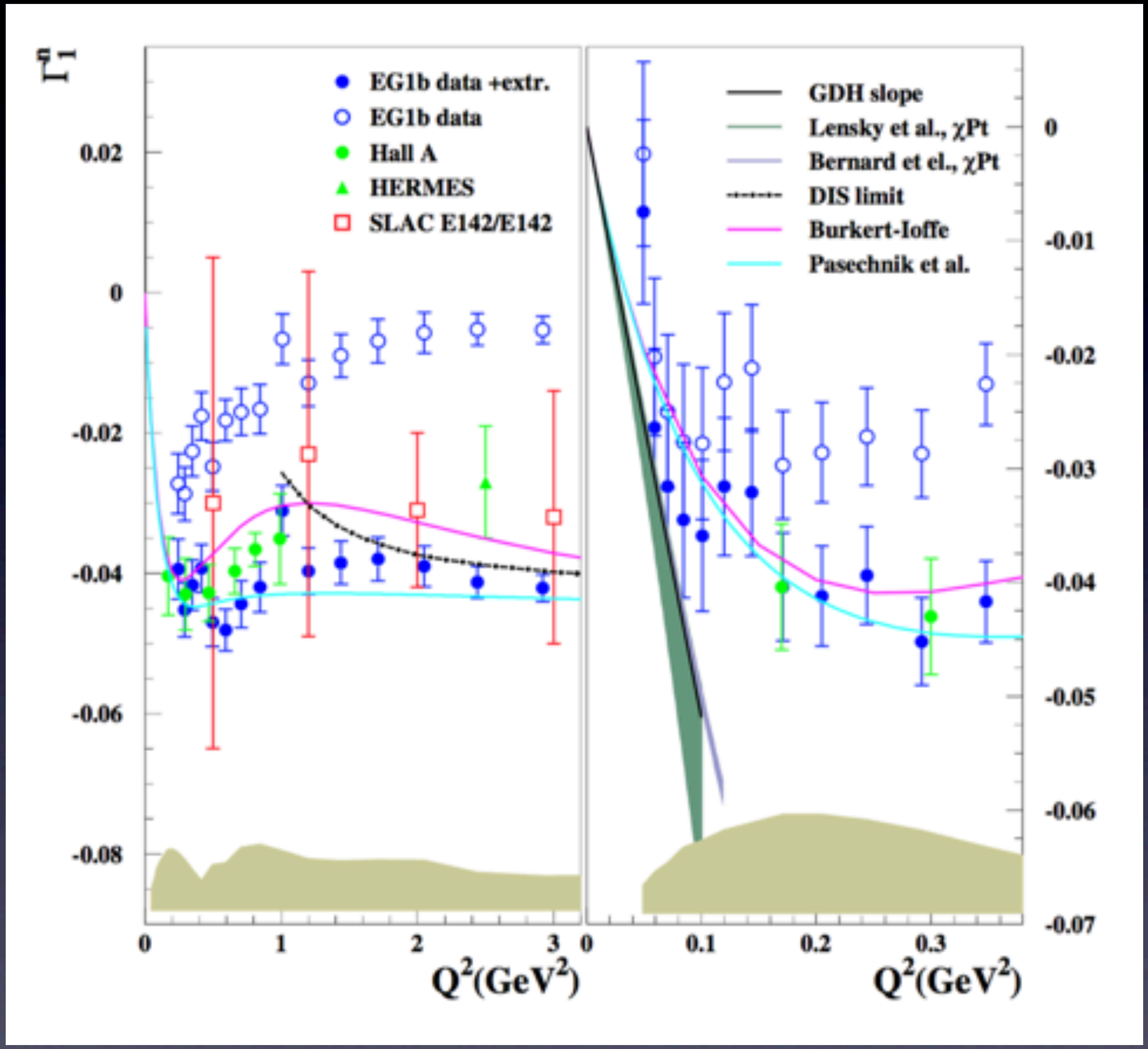
N. Guler *et al. (CLAS Collaboration)*, "Precise Determination of the Deuteron Spin Structure at Low to Moderate Q^2 with CLAS and Extraction of the Neutron Contribution", Phys. Rev. C 92, 055201(2015).

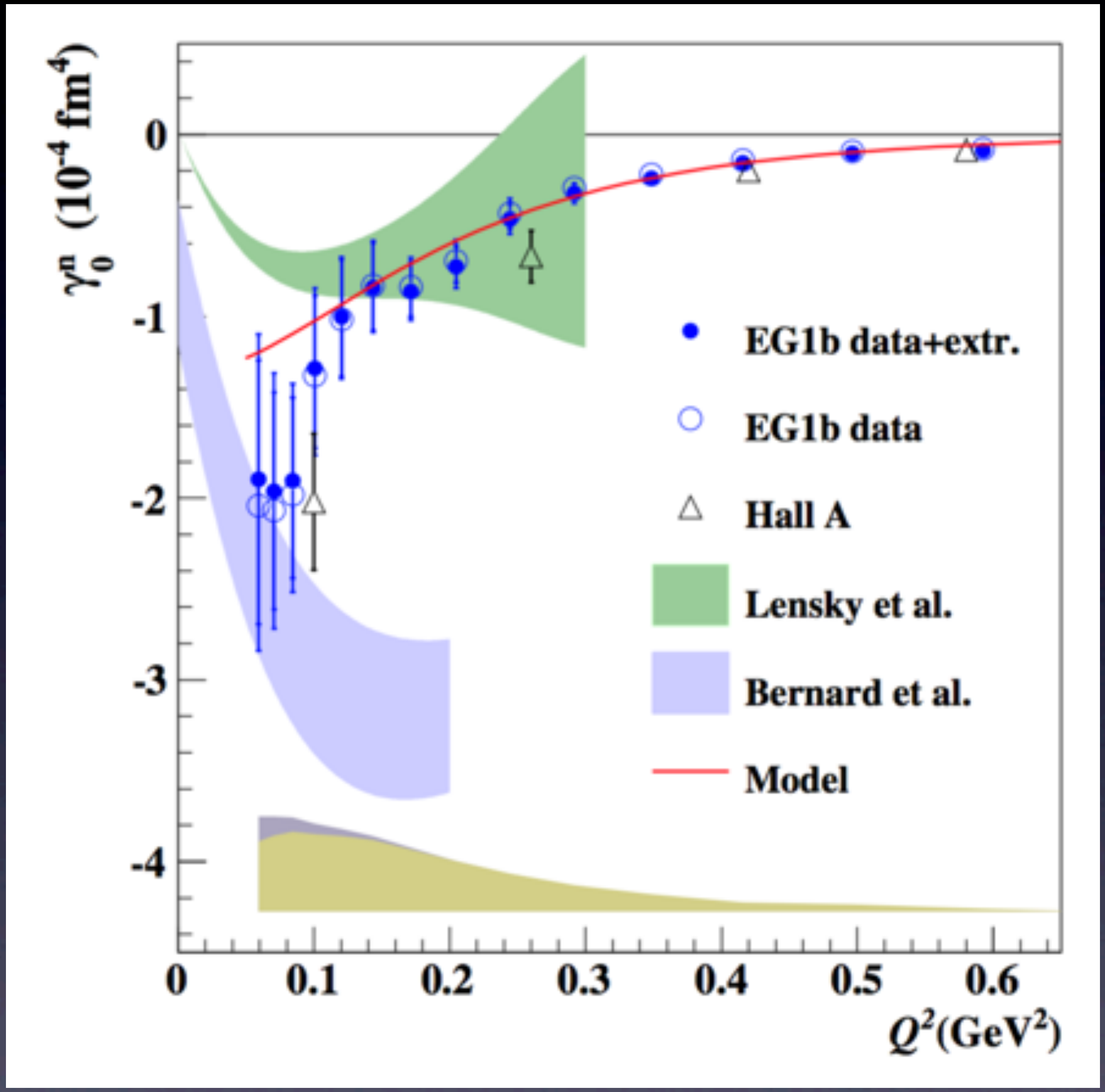




Previous publication also includes extractions for the bound neutron

N. Guler *et al. (CLAS Collaboration)*, “Precise Determination of the Deuteron Spin Structure at Low to Moderate Q^2 with CLAS and Extraction of the Neutron Contribution”, Phys. Rev. C 92, 055201(2015).



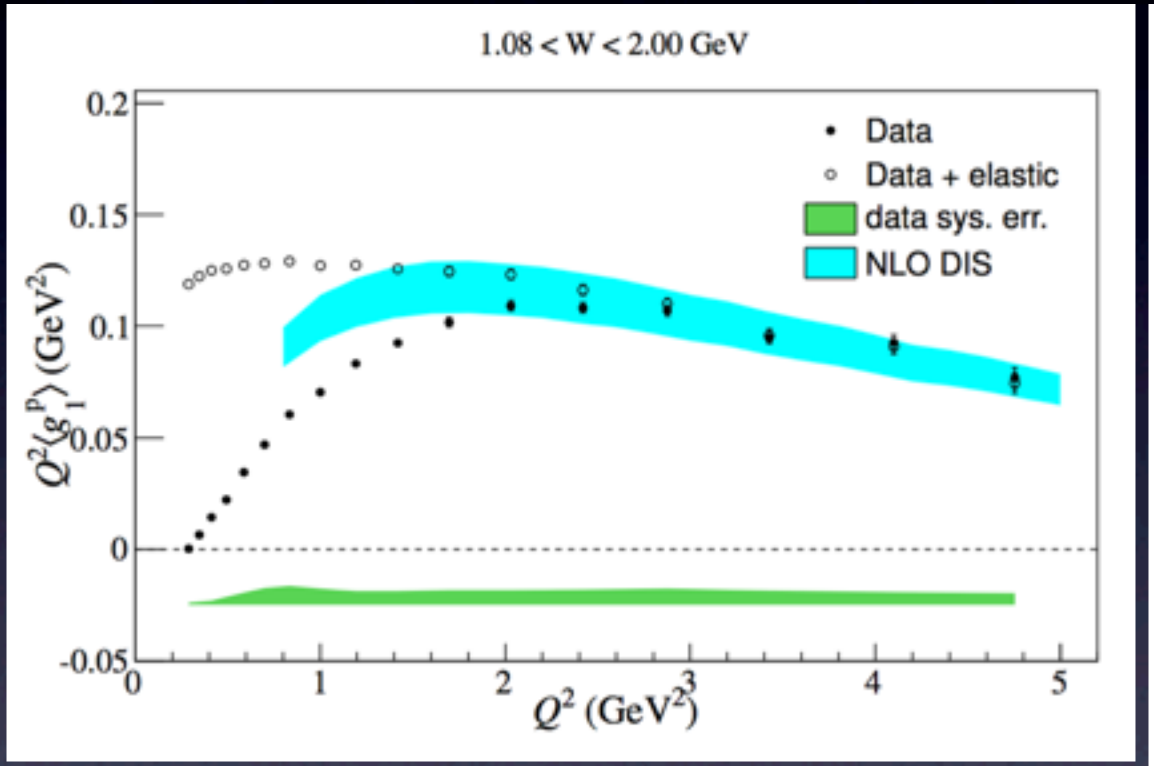


Tests of Bloom-Gillman Duality

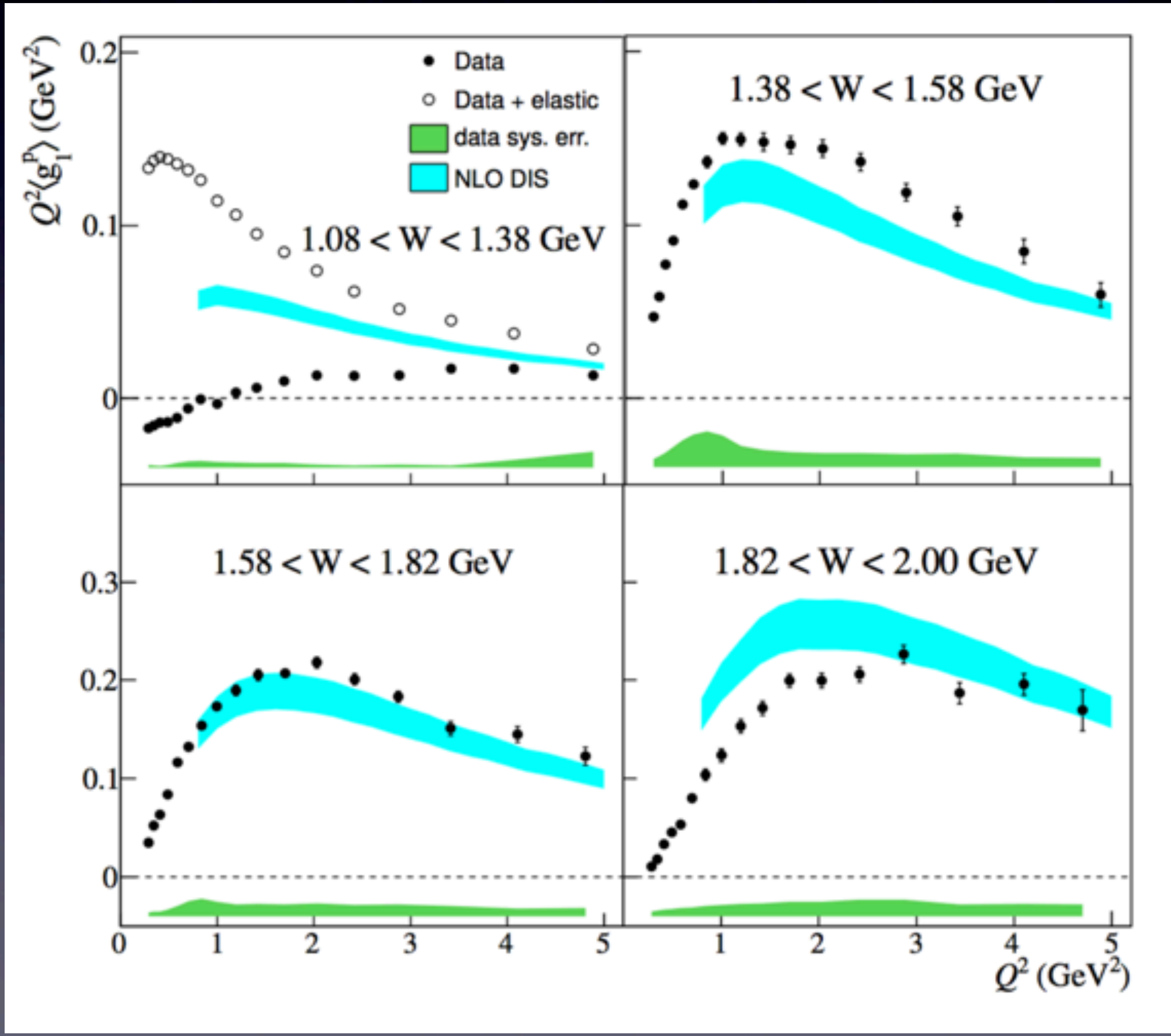
Averaging over resonances - comparing to extrapolated NLO PDFs

(see also Bosted, *et al.* Phys. Rev. C 75, 035203 (2007))

“global” duality



“local” duality

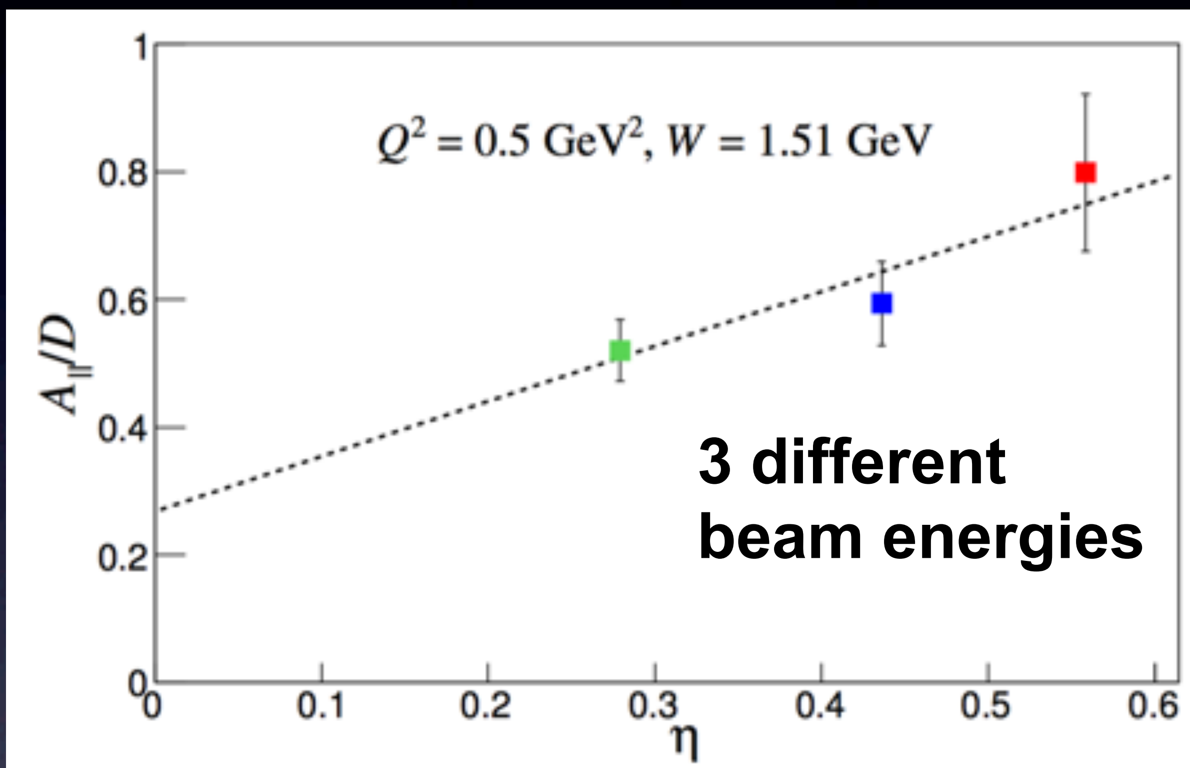


EG1 provides the best existing set of g_1 data in the resonance region

First extraction of A_2 and g_2 from EG1 data

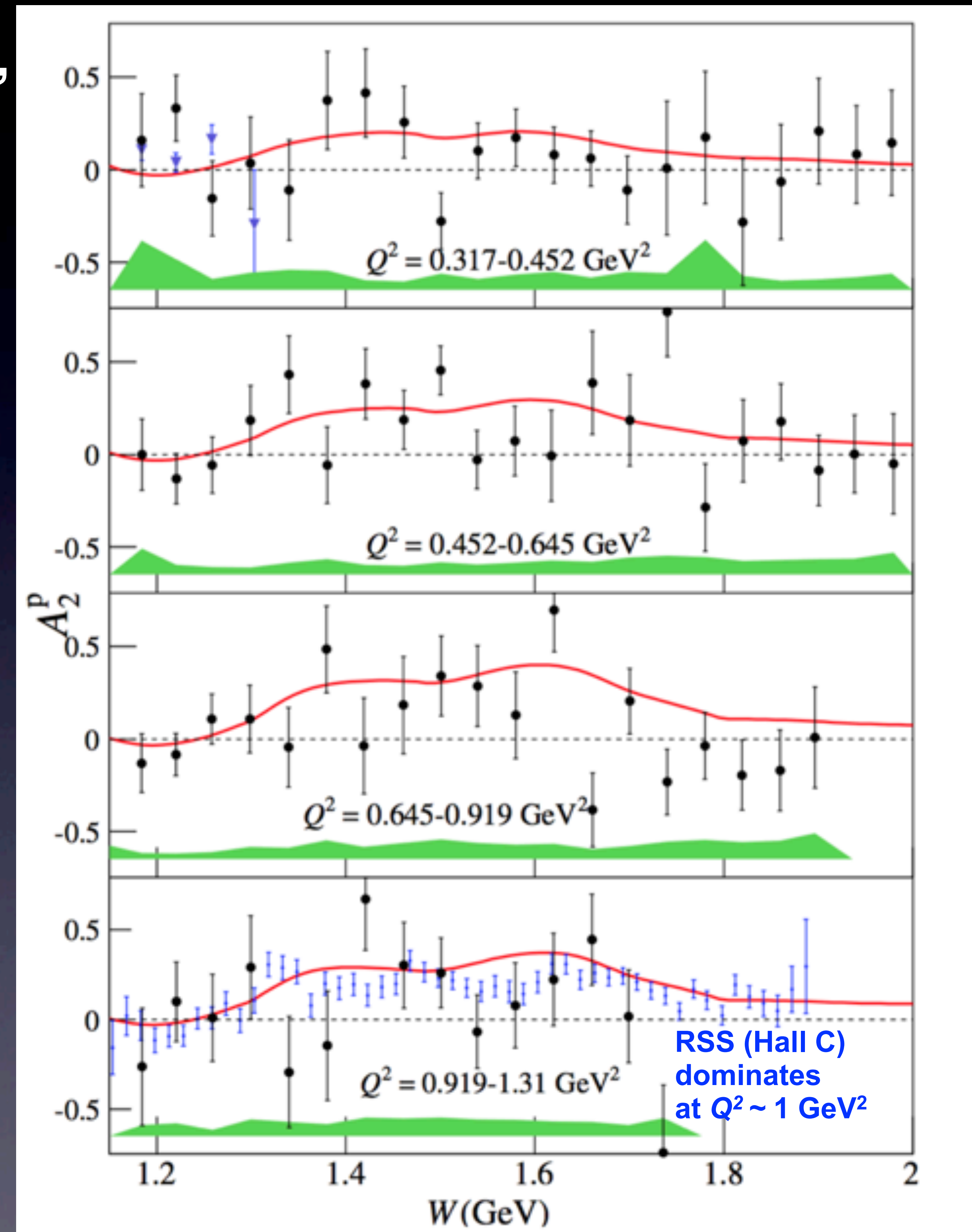
$$A_1 + \eta A_2 = \frac{A_{//}}{D}$$

A_1 = y-intercept,
A_2 = slope



$$A_2^p(\gamma^*) \equiv \frac{\sigma_{LT}}{\sigma_T} = \frac{2\sigma_{LT}(\gamma^*)}{\sigma_T^{\frac{1}{2}}(\gamma^*) + \sigma_T^{\frac{3}{2}}(\gamma^*)}$$

little world data available!



First extraction of A_2 and g_2 from EG1 data

little world data available!

g_2 extracted similarly

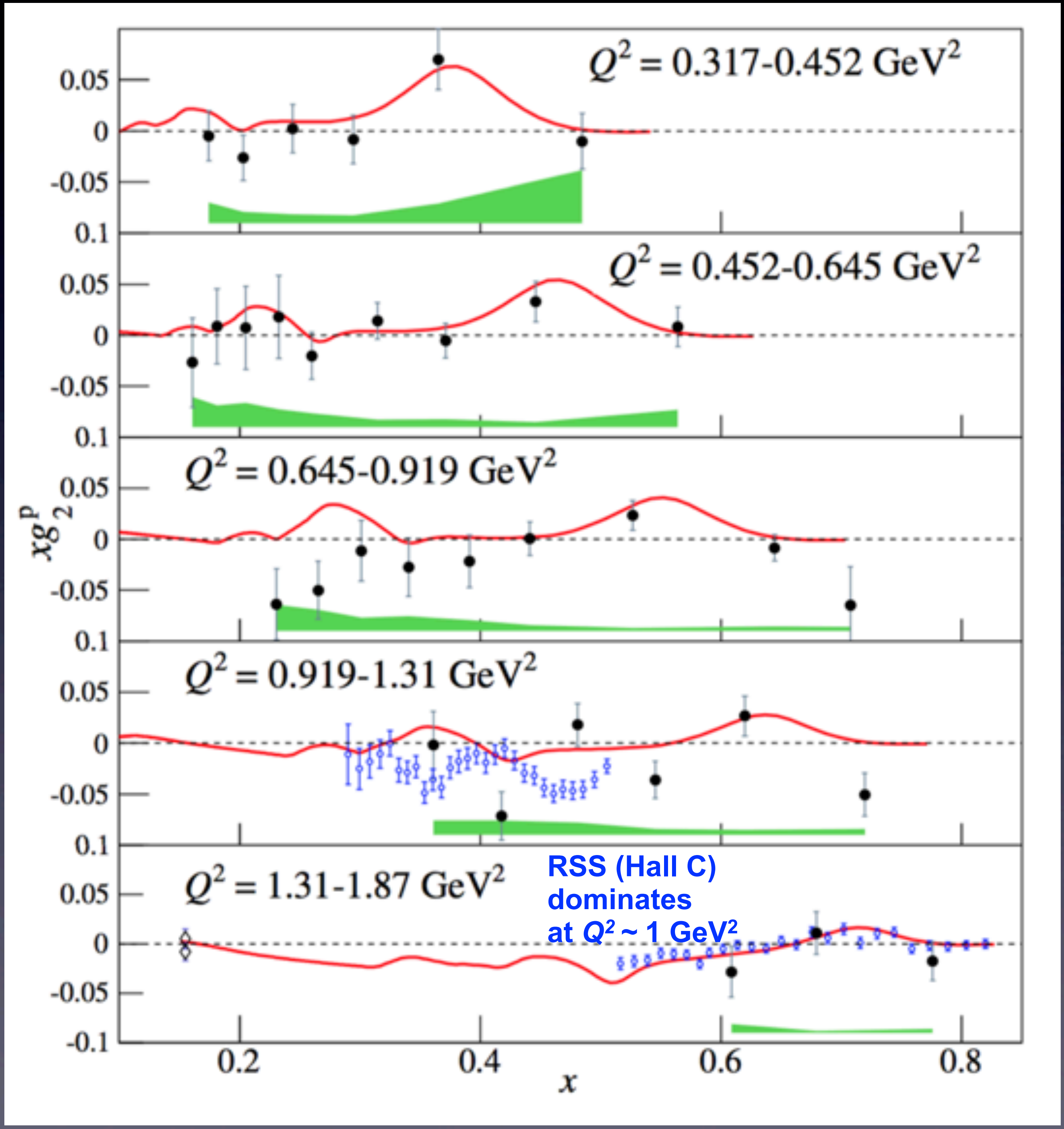
$$\frac{A_{||}}{D} = (1+\eta\gamma)\frac{g_1^p}{F_1^p} + \gamma(\eta-\gamma)\frac{g_2^p}{F_1^p}$$

$$g_1^p + g_2^p = g_T$$

$$\bar{g}_T(x,Q^2) = \int_x^1 \frac{\bar{g}_1(y,Q^2)}{y}dy$$

Wandzura-Wilzek relation (leading twist)

useful for extracting higher twist matrix elements; quark-gluon correlations



Details regarding these results can be found in the paper:

"Determination of the proton spin structure functions for $0.05 < Q^2 < 5$ GeV^2 using CLAS"

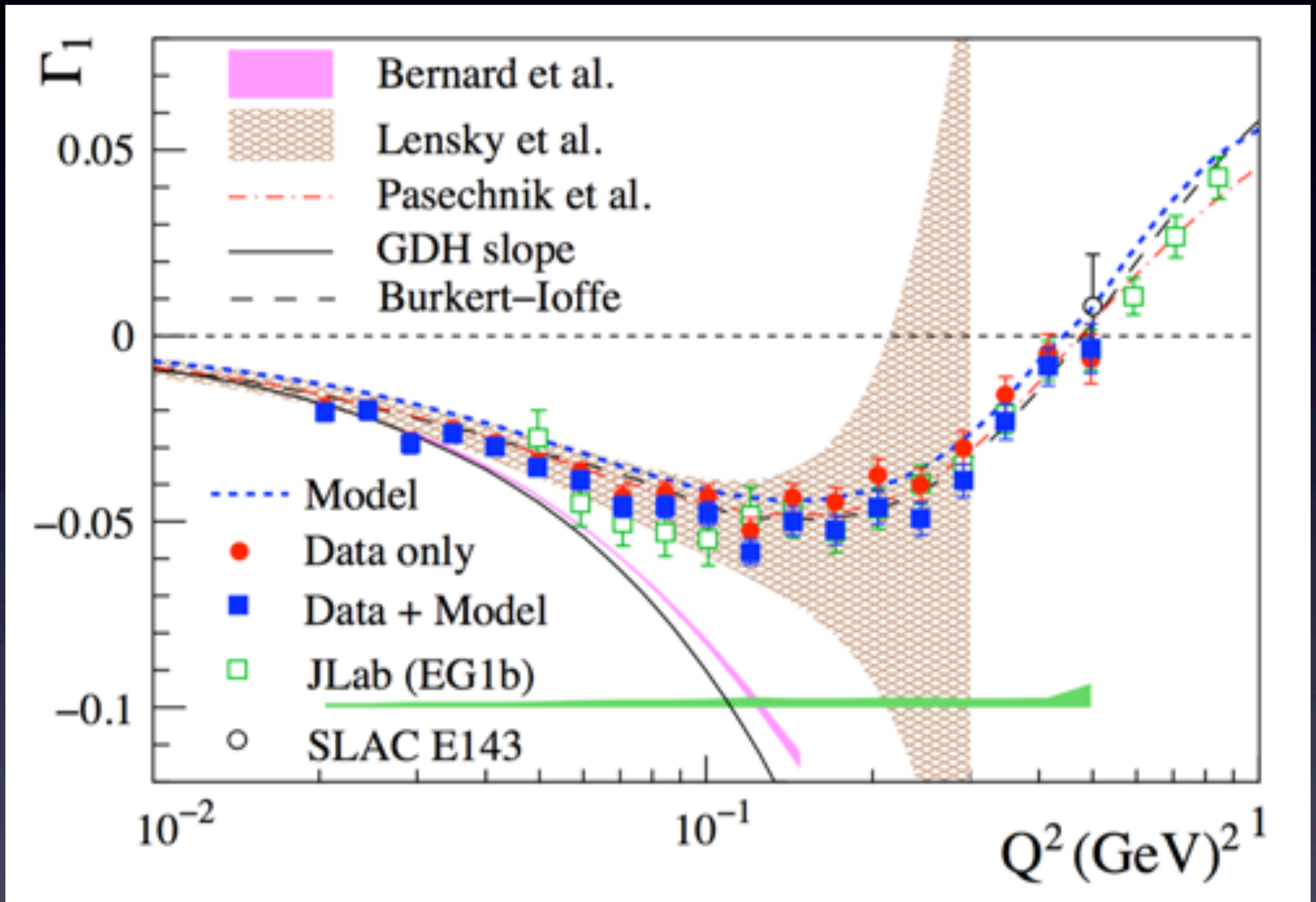
Phys.Rev. C96 (2017) no.6, 065208

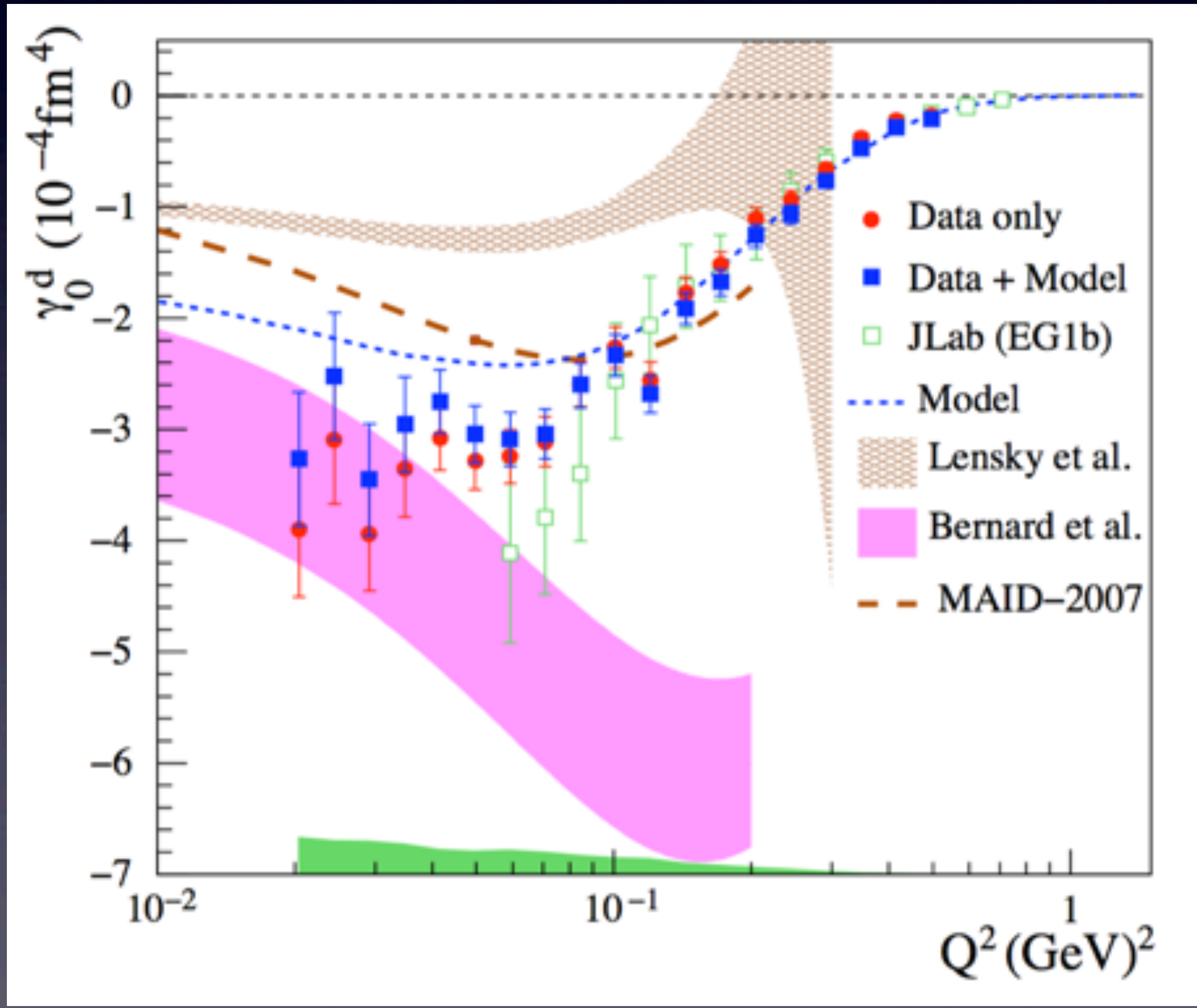
• Related polarized inclusive scattering data from CLAS; impact of data and future experiments in CLAS12

Two other related experiments in CLAS:

EG4: extra small-angle Cherenkov Counter in 1 Sector (Lower Q^2 than EG1; down to $Q^2 = 0.02$ GeV^2)

(inclusive results for deuteron published)





Lower Q^2 limit enables tests of GDH sum rule and chiral perturbation theory

K. Adhikari, et. al. Phys.Rev.Lett. 120 (2018) no.6, 062501

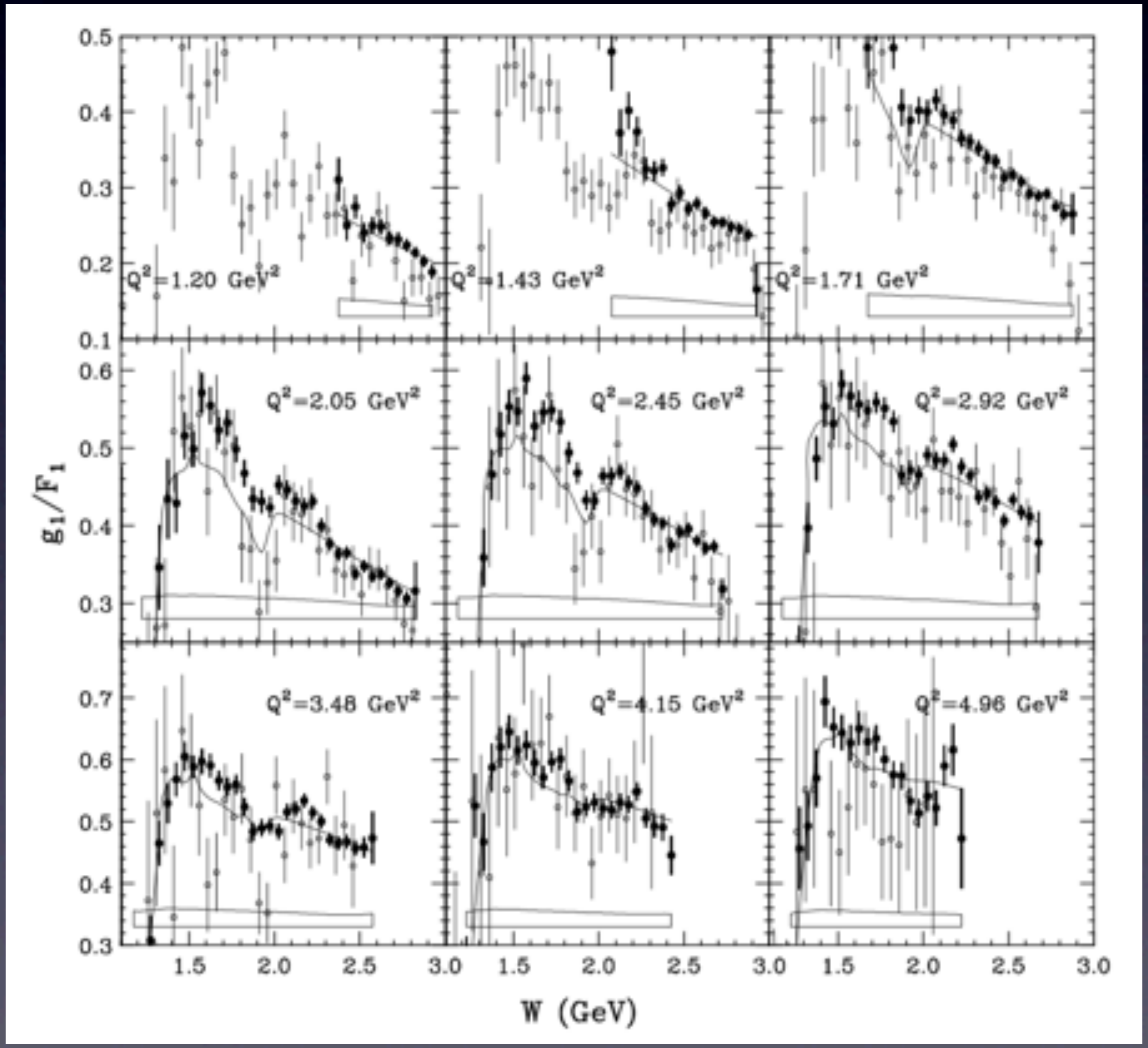
Two other related experiments in CLAS:

EG1-DVCS: focus on higher scattering angles

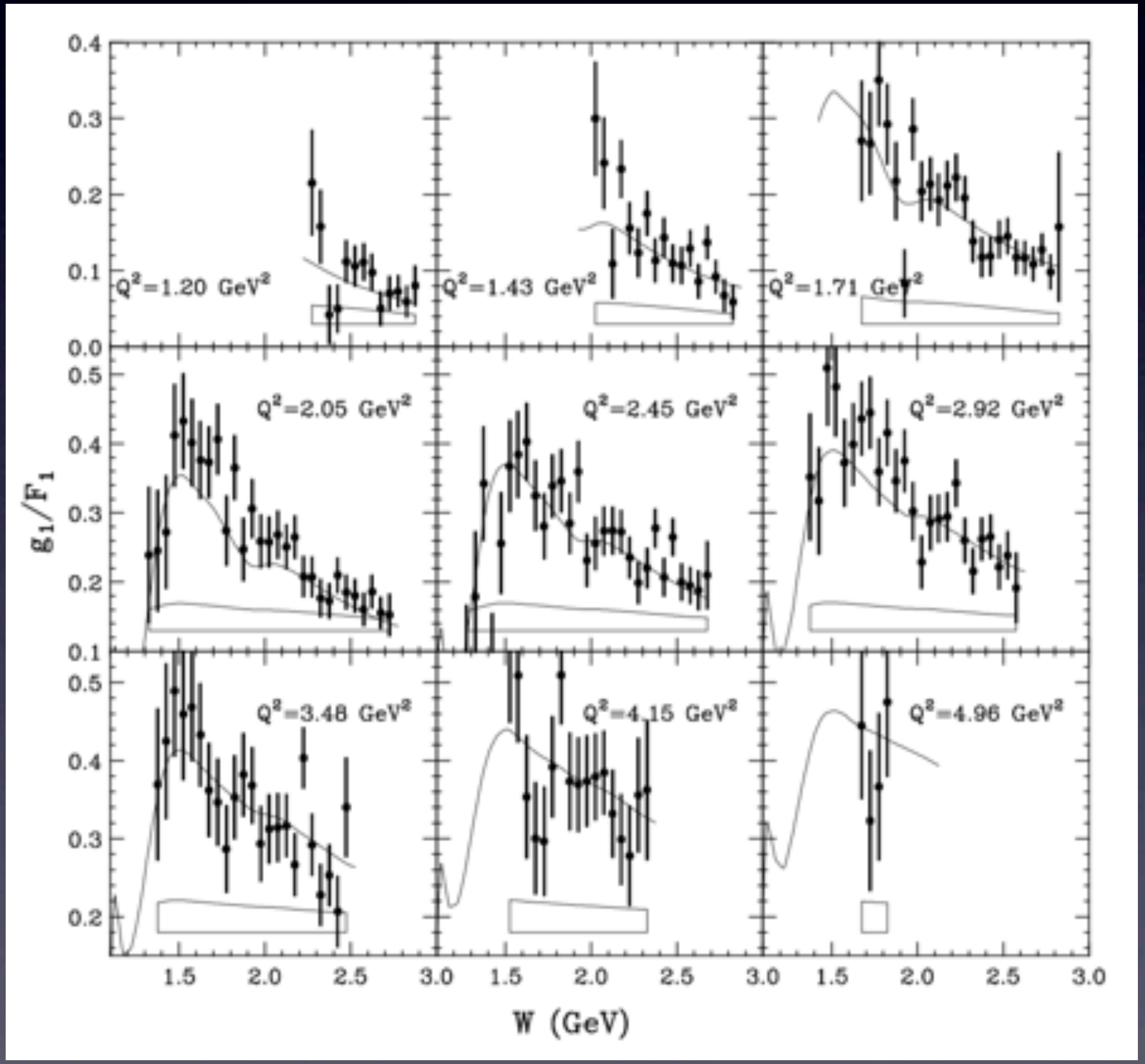
(Higher Q^2 than EG1; better results at Q^2 > 1 GeV^2)

(inclusive results for proton and deuteron published)

proton



deuteron

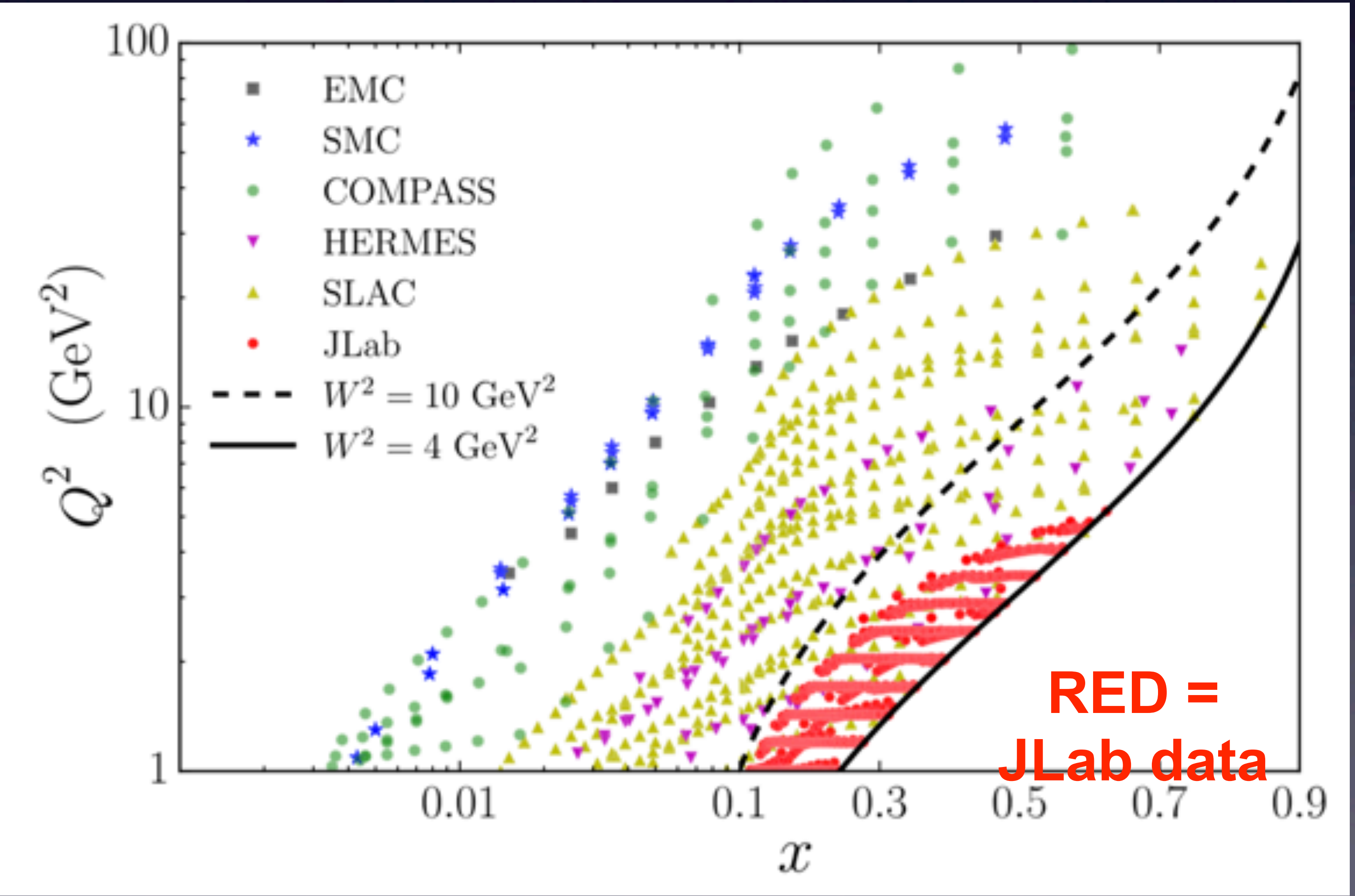


Y. Prok, et. al. Phys.Rev. C90 (2014) no.2, 025212

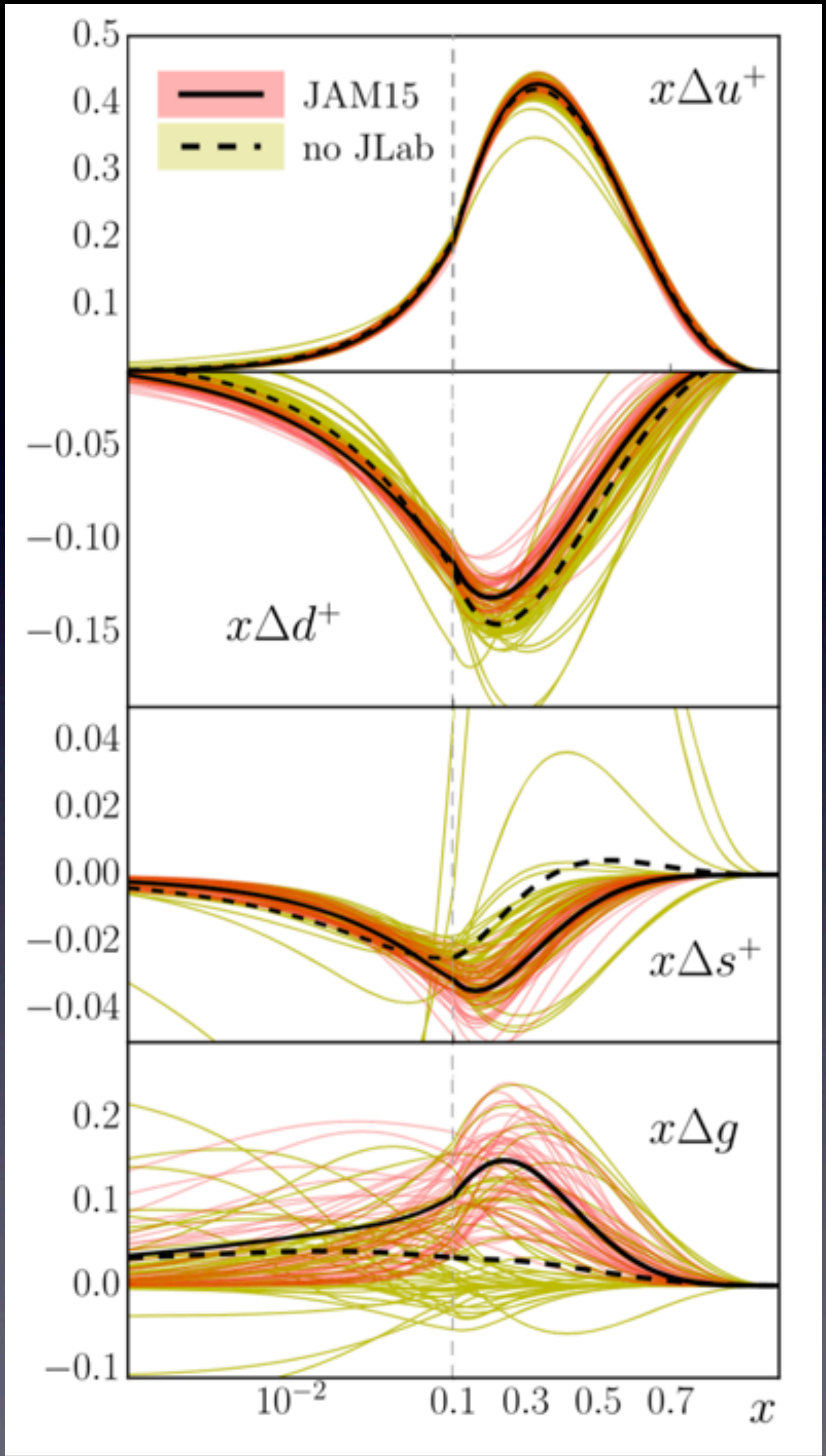
Impact of JLab data on polarized PDFs

Global analysis by JAM (JLab Angular Momentum) Theory group (W. Meltinchouk *et al.*)

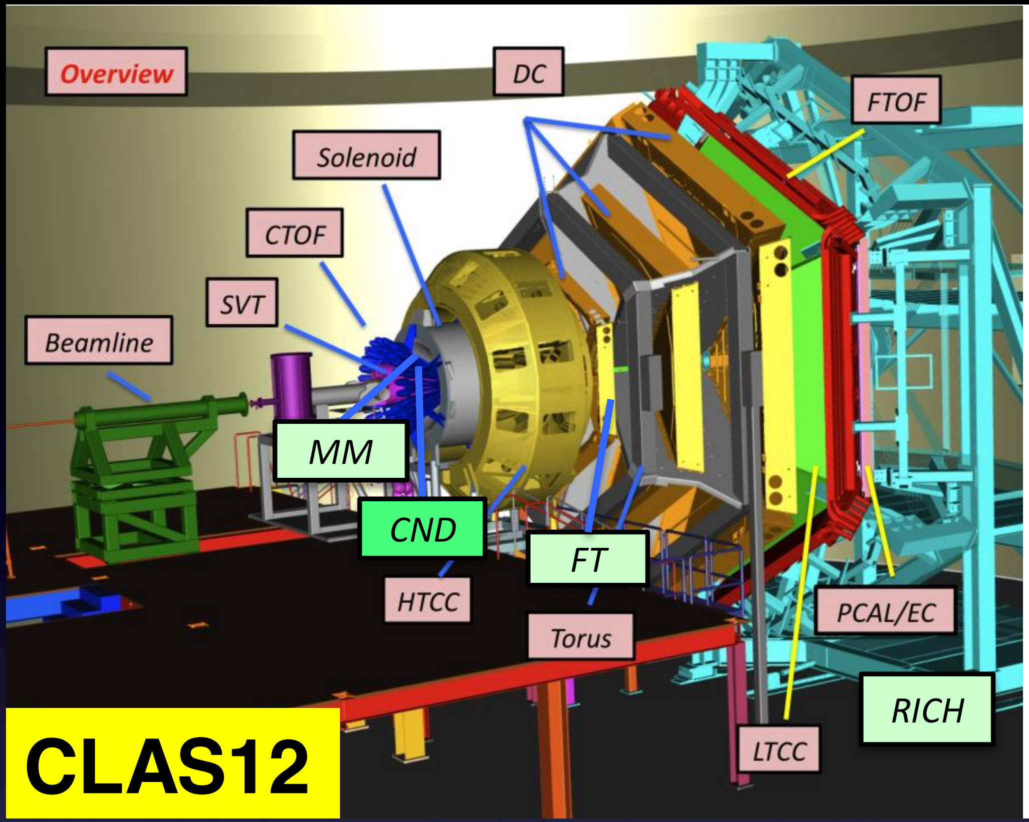
Phys Rev D 93, 074005 (2016)

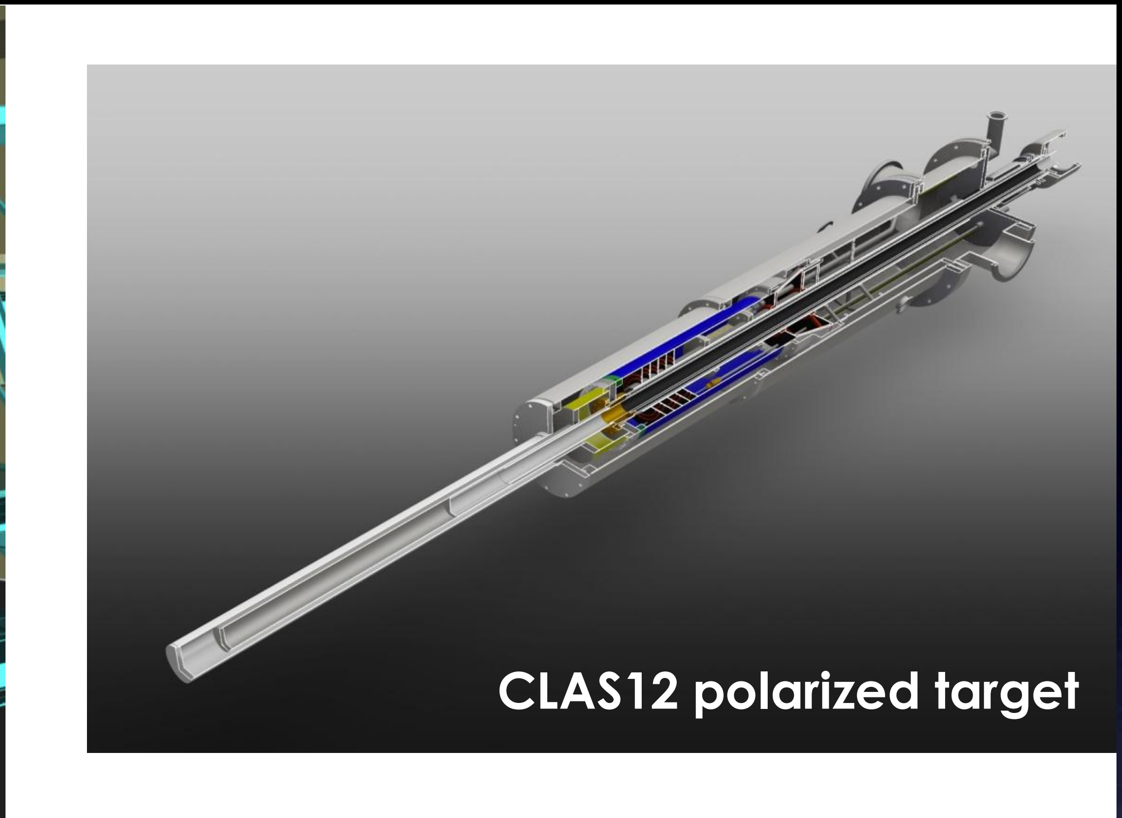


spin distributions within the nucleon

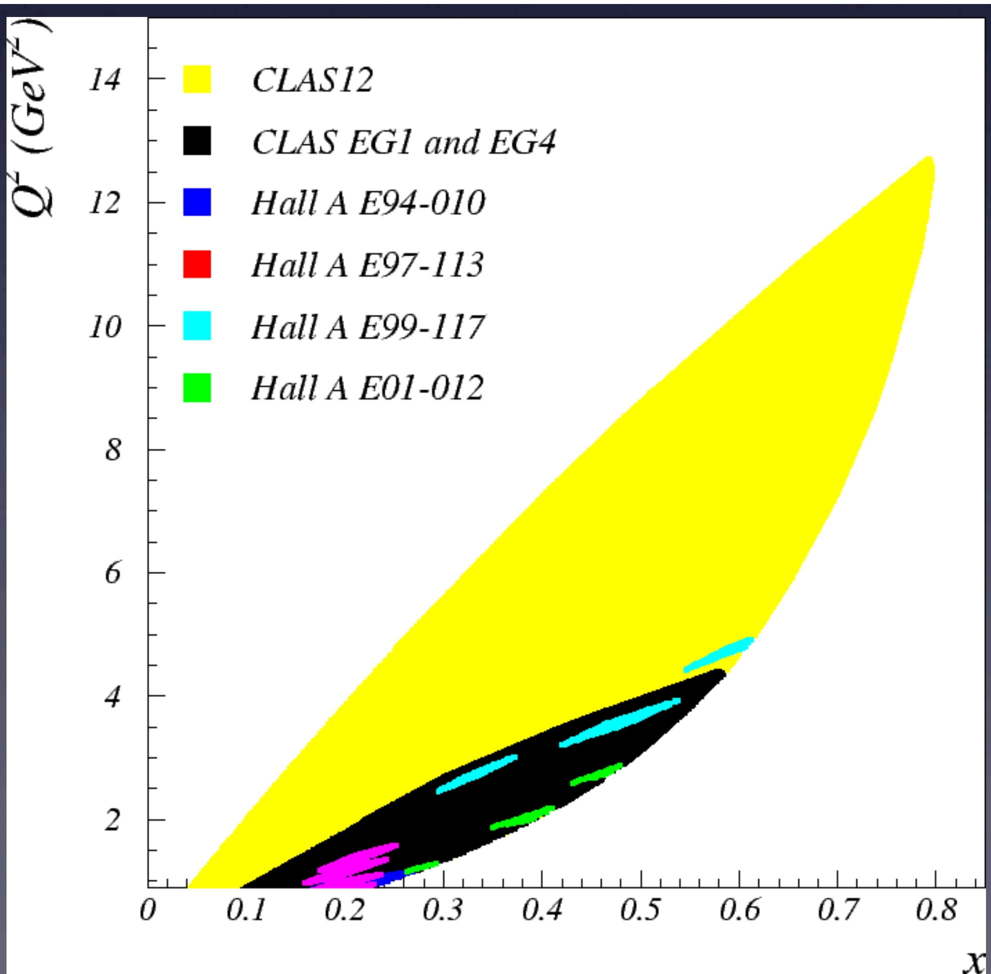


Future polarized experiments in new CLAS12 detector (Beam energies up to 12 GeV)





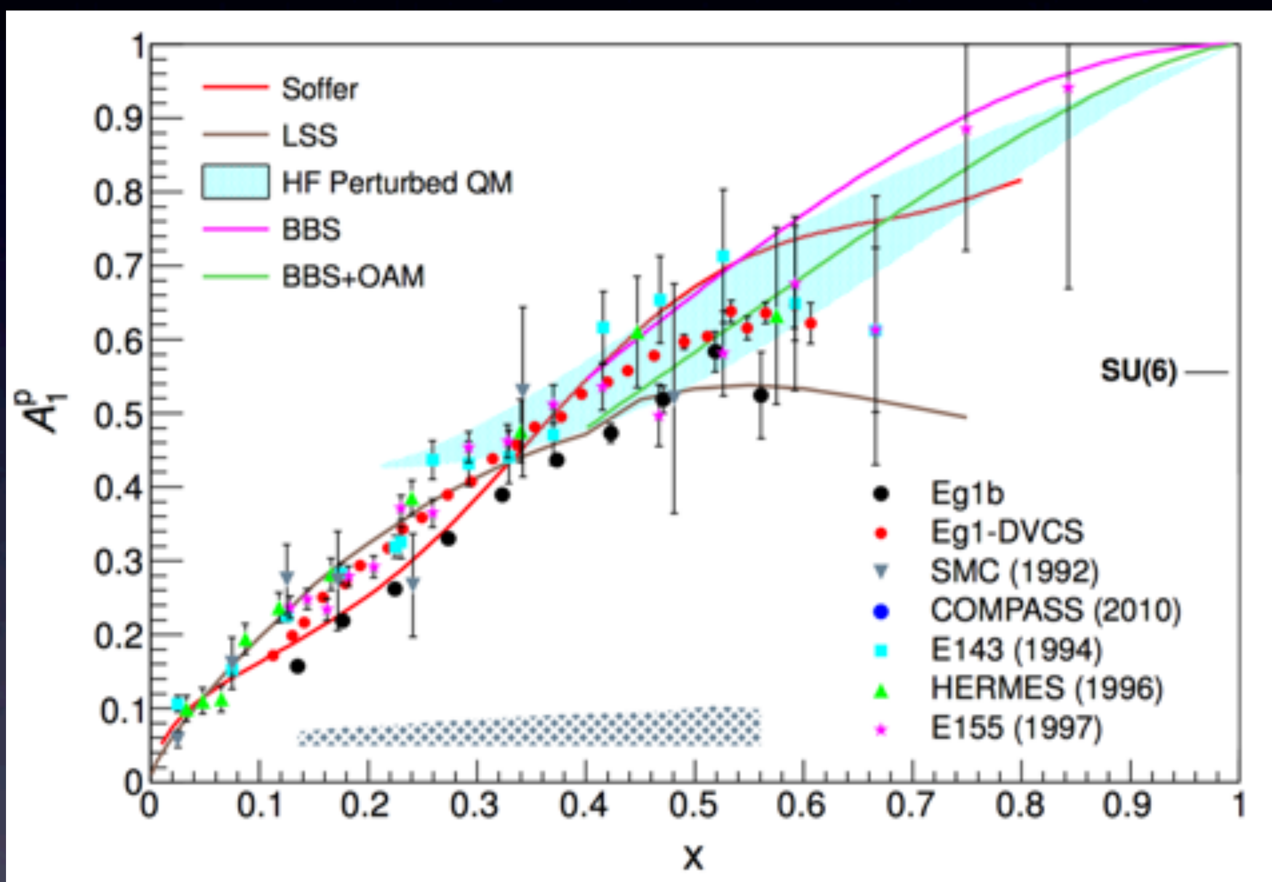
Kinematic coverage will be extended to higher *x* and Q^2



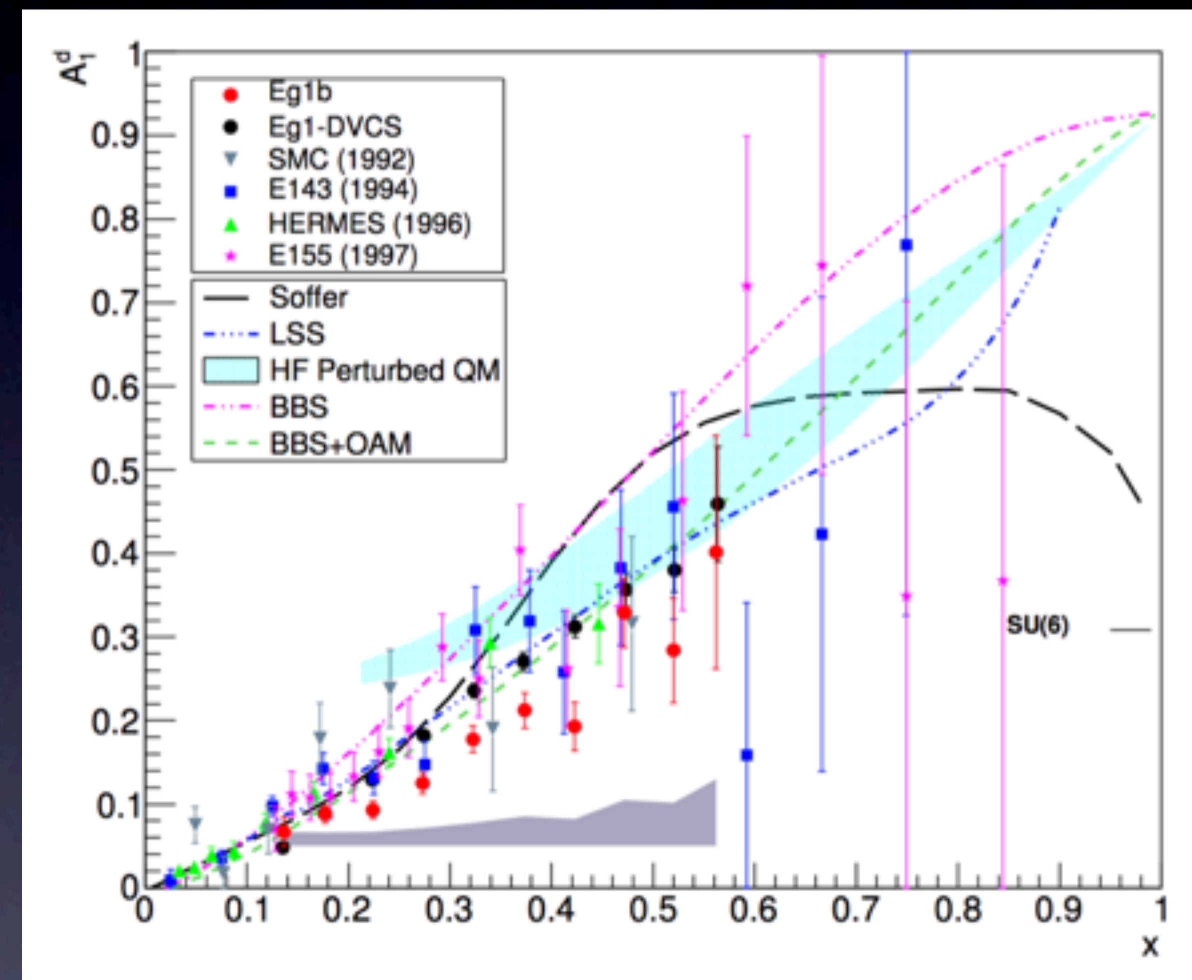
A_1 Deep Inelastic Scattering ($Q^2 > 1$ GeV^2, $W > 2$ GeV)

EG1 and EG1-DVCS results

Proton



Deuteron

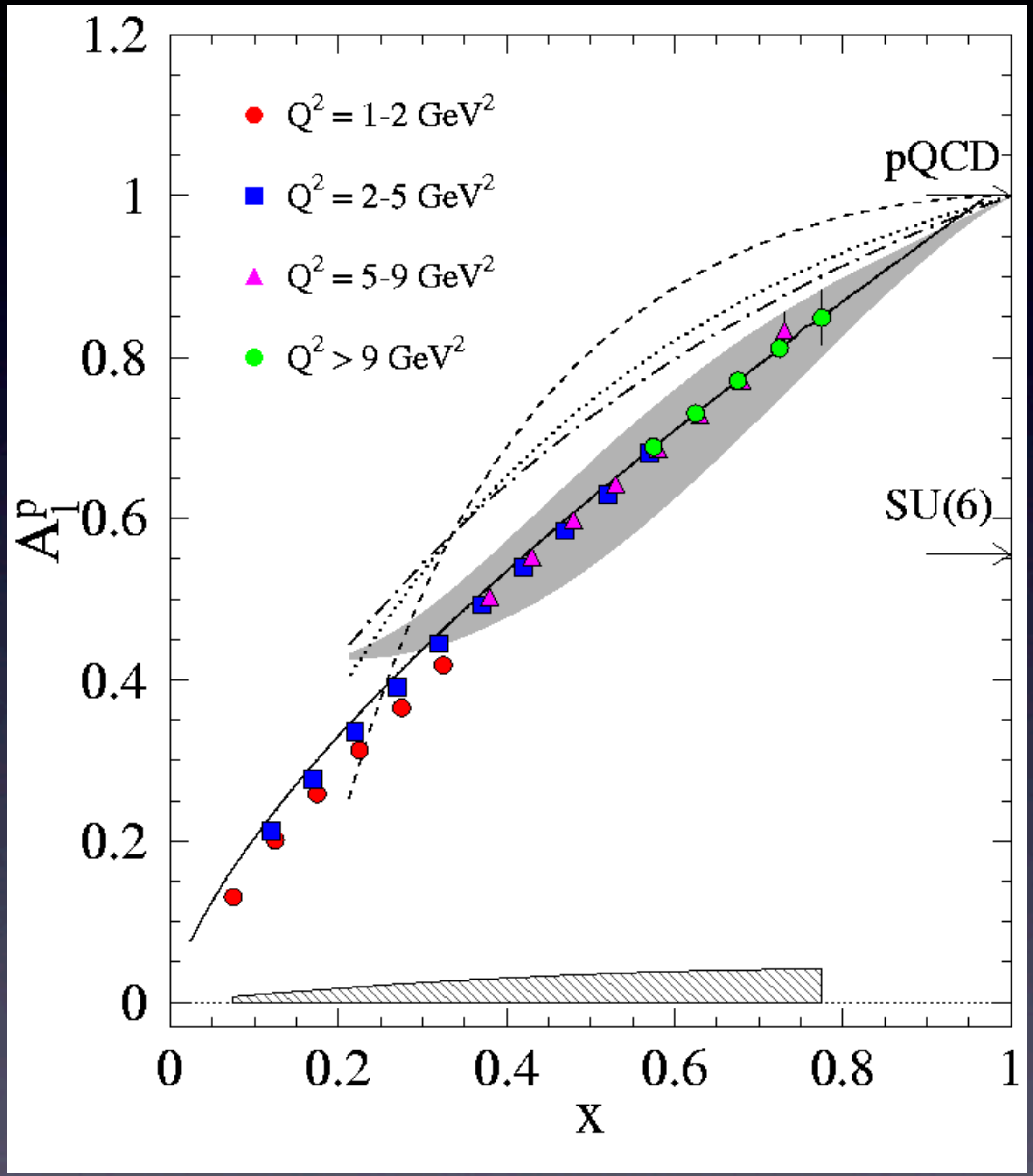


DIS results at high *x* provide insights into QCD models of the nucleon

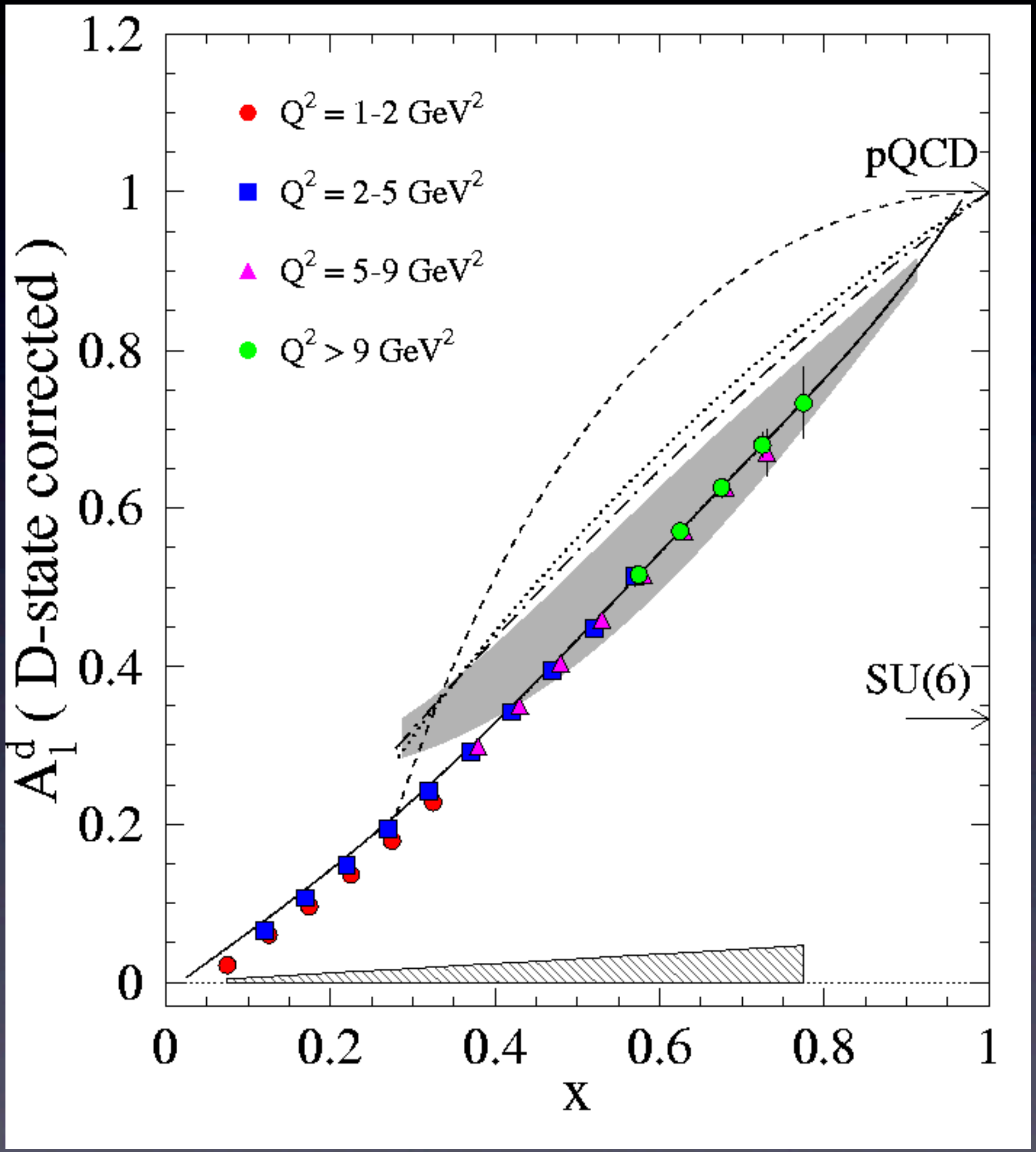
A_1 Deep Inelastic Scattering (Q^2 > 1 GeV^2, W > 2 GeV)

Projected CLAS12 Data

Proton



Deuteron



DIS results at higher *x* will provide better tests of QCD models near the pQCD limit