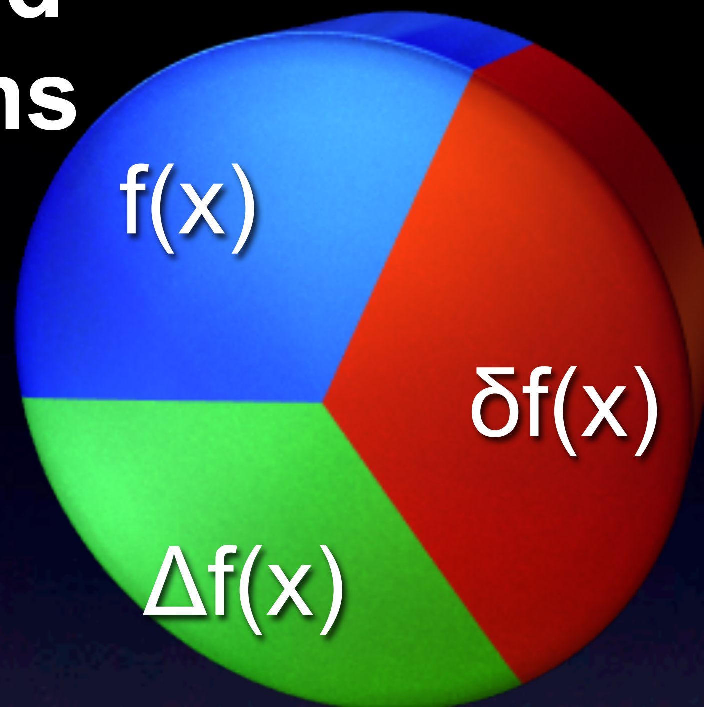
Determination of the Proton Spin Structure Functions for $0.05 < Q^2 < 5$ GeV^2 using CLAS

Robert Fersch
Christopher Newport University
for the EG1 collaboration

Structure of the Nucleon

Unpolarized distributions
q, g



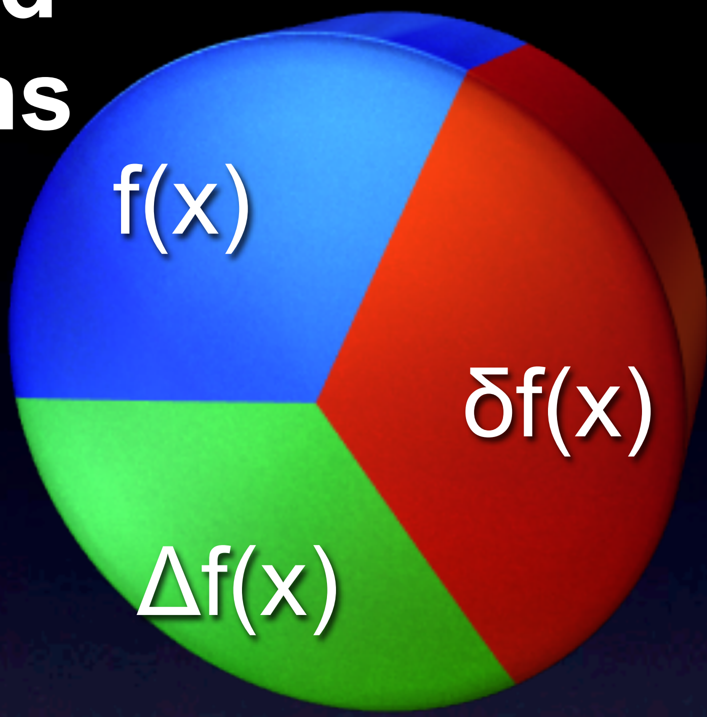
Transversity δq

Helicity
Δq, Δg

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

Structure of the Nucleon

Unpolarized distributions
q, g



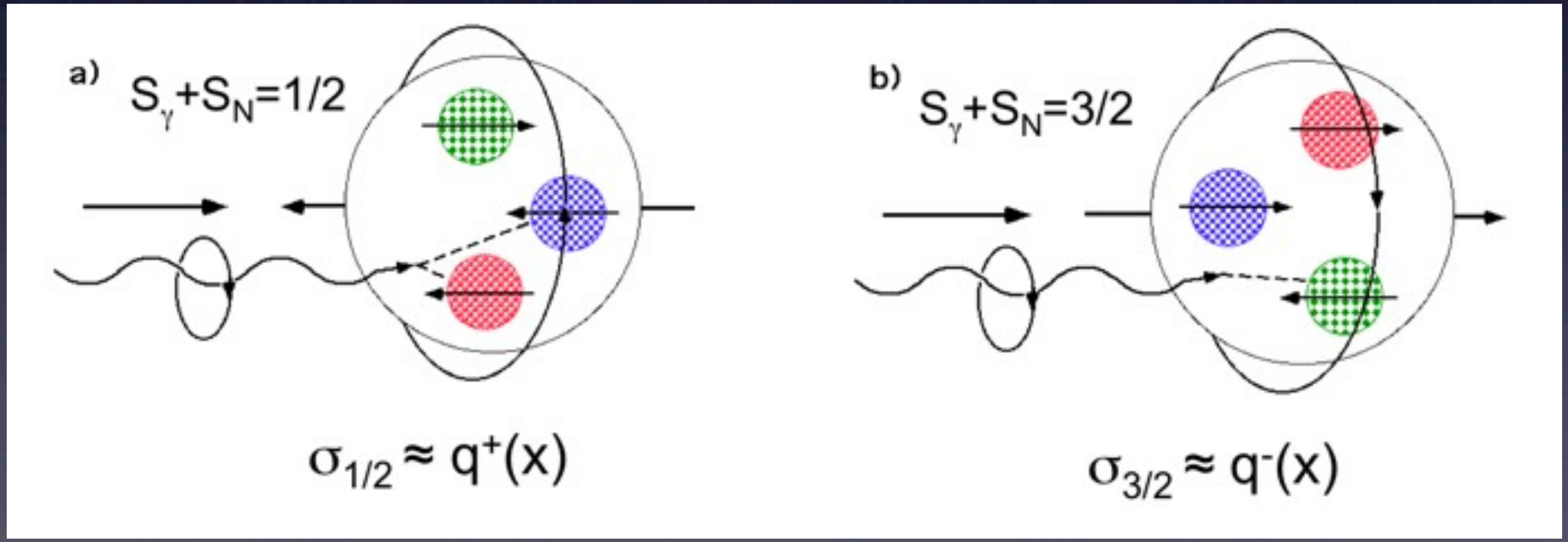
Transversity δq

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

Helicity
$\boxed{\Delta q,}$ **Δg**

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

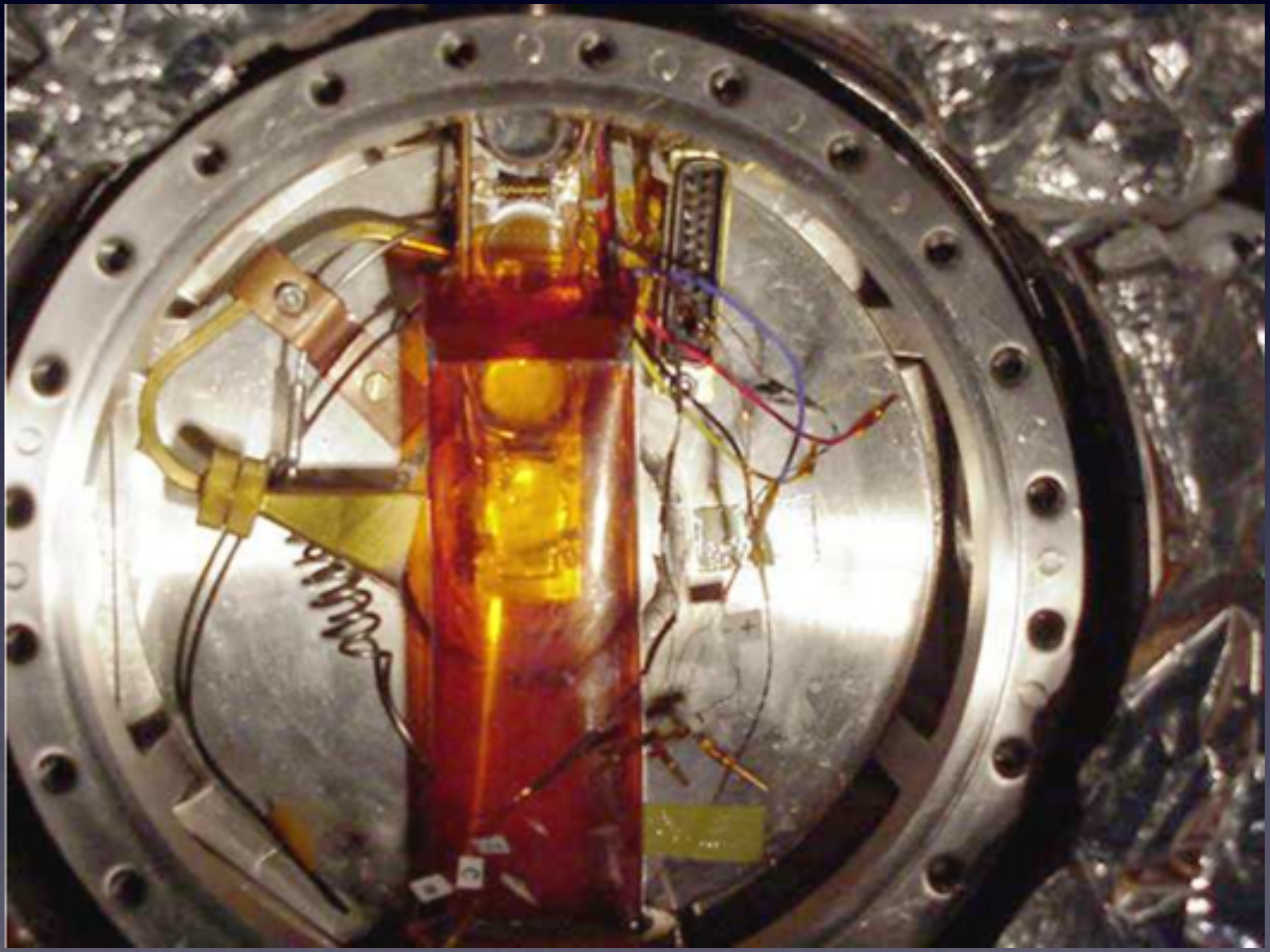
The EG1 experiment

ran in CLAS for 7 months 2000-2001

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

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

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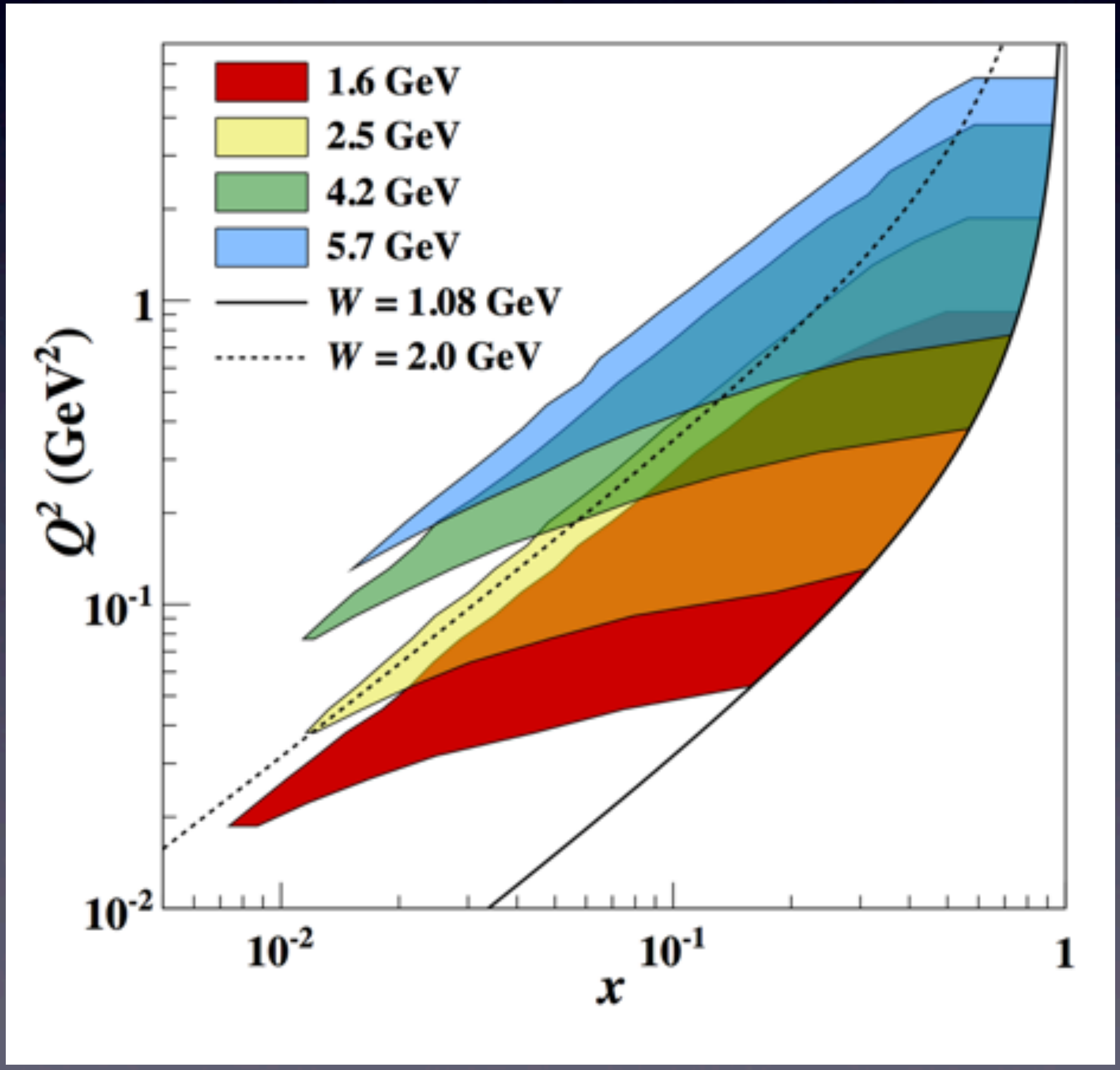
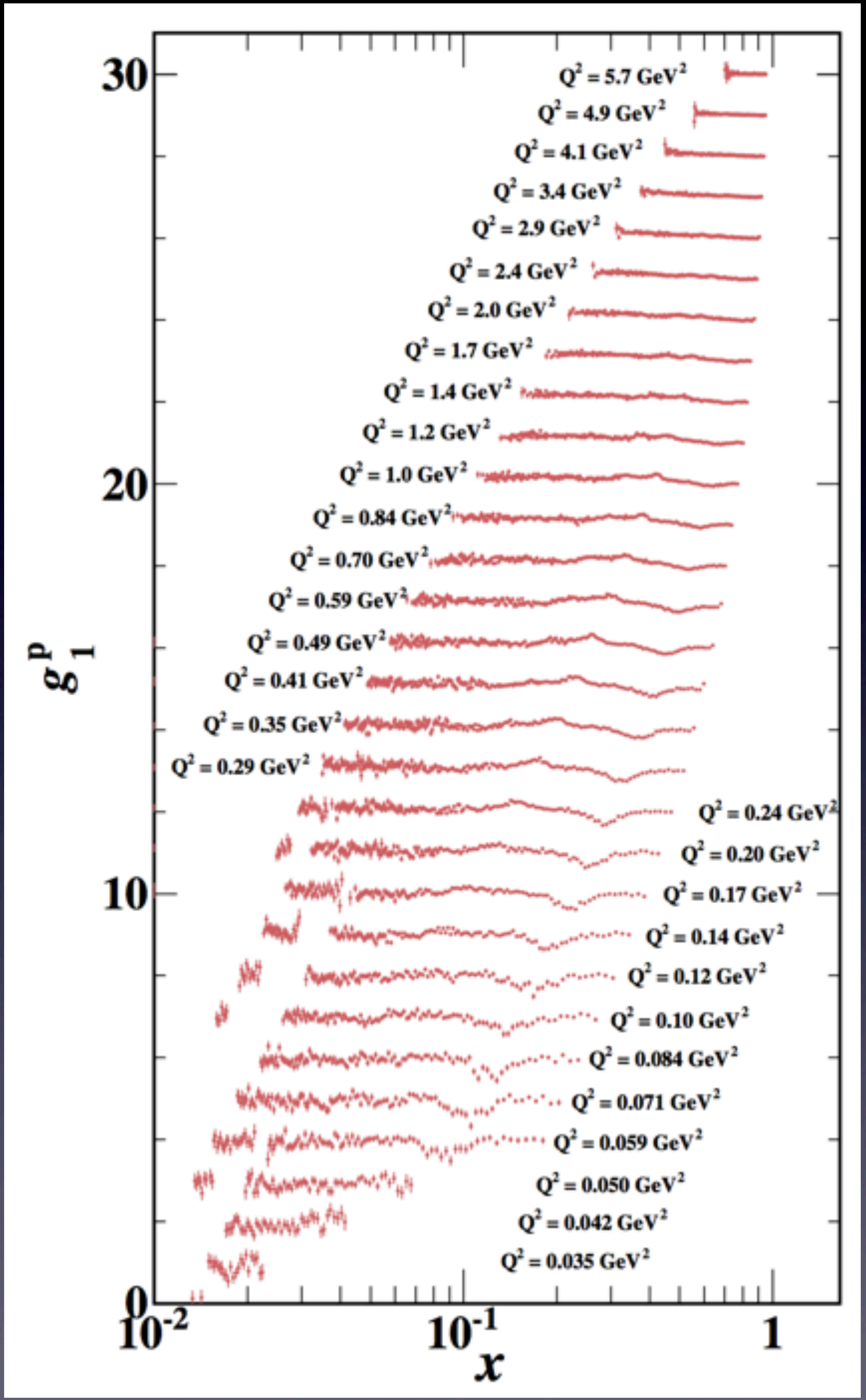
4 beam energies used
(1.6, 2.5, 4.2, 5.7 GeV)

Kinematic coverage & statistics





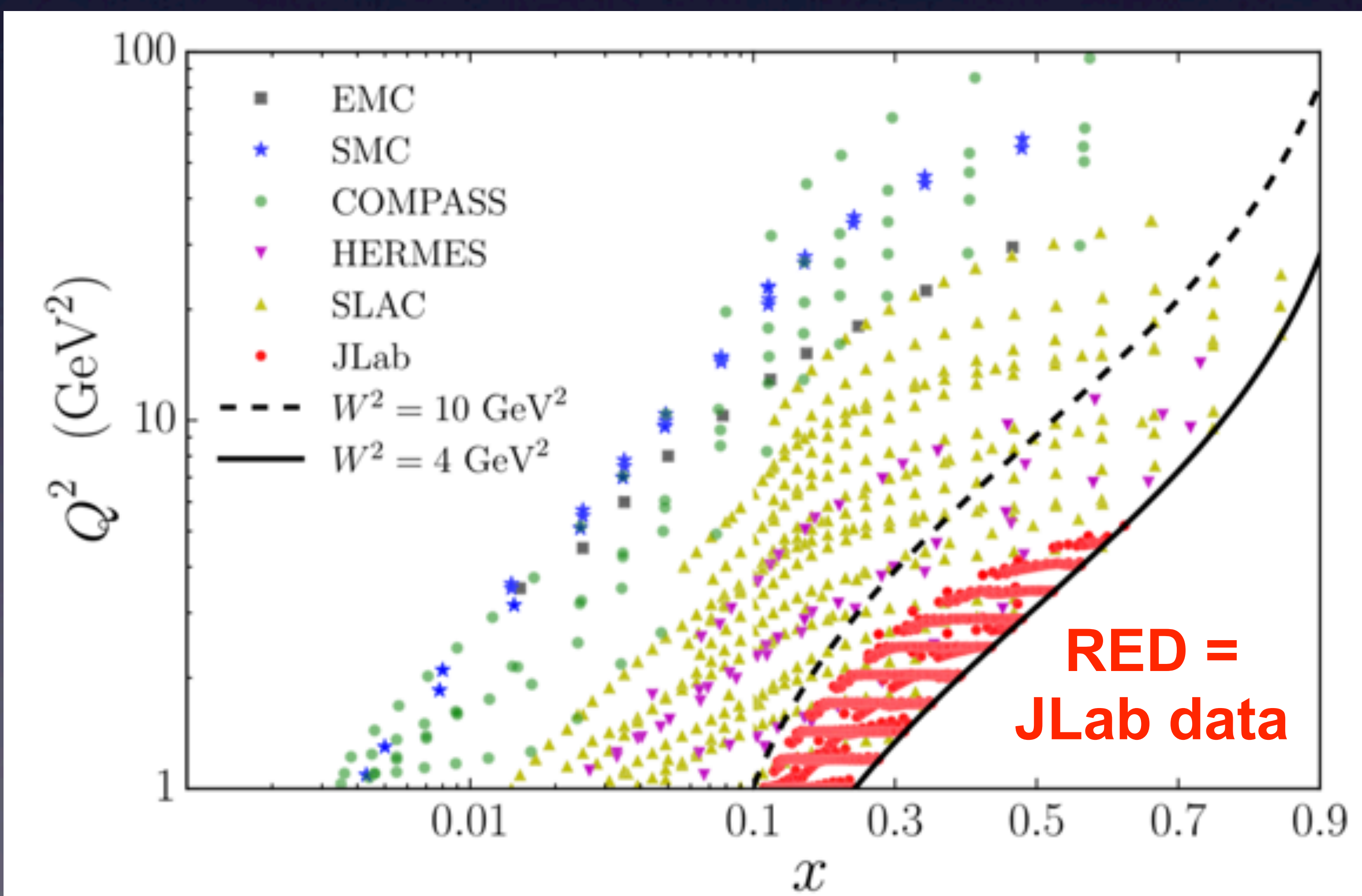
Many papers already published using EG1 data:

- 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).
- P. Bosted *et al. (CLAS Collaboration)*. "Target and Beam-Target Spin Asymmetries in Exclusive π^+ and π^- electroproduction with 1.6- to 5.7-GeV electrons", Phys. Rev. C 94, 055201(2016)
- H. Avakian *et al. (CLAS Collaboration)*, "Measurement of Single and Double Spin Asymmetries in Deep Inelastic Pion Electroproduction with a Longitudinally Polarized Target", Phys. Rev. Lett. 105, 262002 (2010).
- Y. Prok *et al. (CLAS Collaboration)*, "Moments of the Spin Structure Functions g^p_1 and g^d_1 for $0.05 < Q^2 < 3.0$ GeV^2", Phys. Lett. B 672, 12 (2009).
- A. Biselli *et al. (CLAS Collaboration)*, "First Measurement of Target and Double Spin Asymmetries for $ep \rightarrow e'p\pi^0$ in the Nucleon Resonance Region Above the $\Delta(1232)$", Phys. Rev. C 78, 045204 (2008).
- P.E. Bosted *et al. (CLAS Collaboration)*, "Ratios of $^{15}N/^{12}C$ and $^4He/^{12}C$ Inclusive Electroproduction Cross Sections in the Nucleon Resonance Region", Phys. Rev. C 78, 015202 (2008).
- P.E. Bosted *et al. (CLAS Collaboration)*, "Quark-Hadron Duality in Spin Structure Functions g_1^p and g_1^d", Phys. Rev. C 75, 035203 (2007).
- K.V. Dharmawardane *et al. (CLAS Collaboration)*, "Measurement of the x and Q^2 Dependence of the Spin Asymmetry A_1 of the Nucleon", Phys. Lett. B. 641, 28 (2006).
- S. Chen *et al. (CLAS Collaboration)*, "Measurement of Deeply Virtual Compton Scattering with a Polarized Proton Target", Phys. Rev. Lett. 97, 072002 (2006).
- A. Biselli *et al. (CLAS Collaboration)*, "Study of $ep \rightarrow ep\pi^0$ in the $\Delta(1232)$ Mass Region Using Polarization Asymmetries", Phys. Rev. C 68, 035202 (2003).
- R. Fatemi *et al. (CLAS Collaboration)*, "Measurement of the Spin Structure Functions in the Resonance Region for Q^2 from 0.15 to 1.6 GeV^2", Phys. Rev. Lett. 91, 222002 (2003).
- J. Yun *et al. (CLAS Collaboration)*, "Measurement of Inclusive Spin Structure Functions of the Deuteron with CLAS", Phys. Rev. C 67, 055204 (2003).
- R. DeVita *et al. (CLAS Collaboration)*, "First Measurement of the Double Spin Asymmetry in $ep \rightarrow e'\pi^+n$ in the Resonance Region", Phys. Rev. Lett. 88, 082001 (2002).

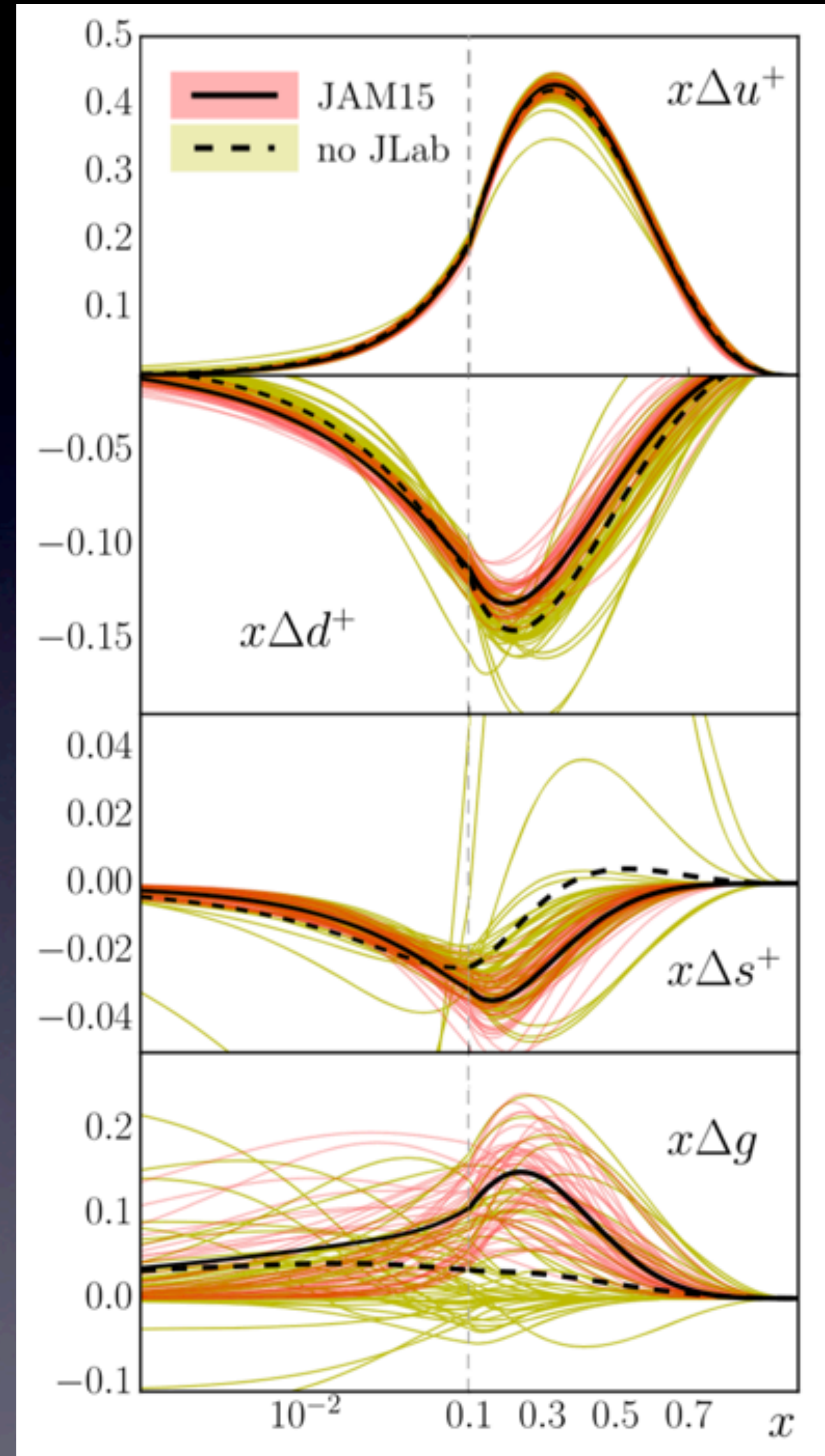
Impact of JLab / EG1 data on polarized PDFs

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

Phys Rev D 93, 074005 (2016)



spin distributions within the nucleon



Final proton "long paper" has completed collaboration review and resulting corrections are done; author check then submission to Phys. Rev. C next

Determination of the Proton Spin Structure Functions for $0.05 < Q^2 < 5$ GeV^2 using CLAS

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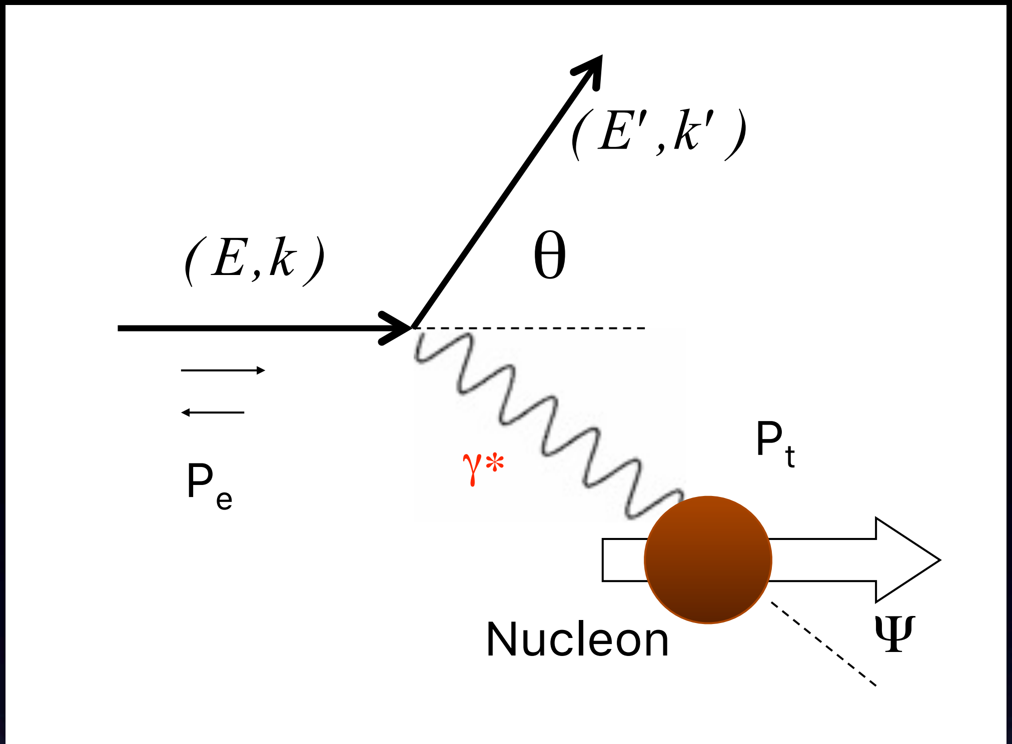
(The CLAS Collaboration)

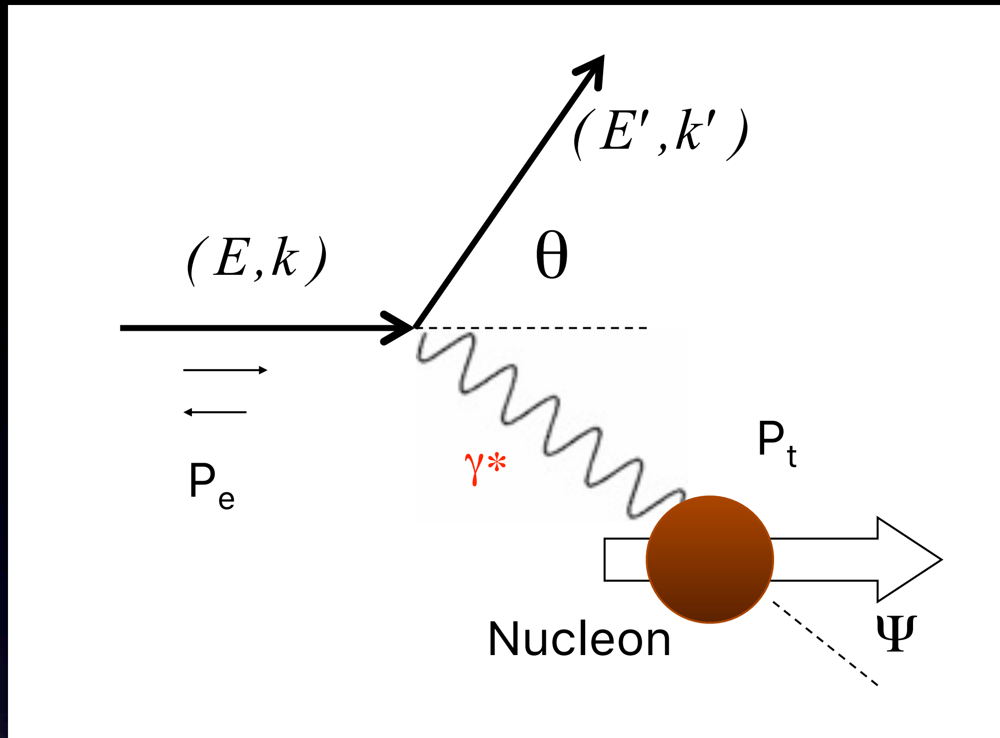
Analysis of Polarized Inclusive *ep* scattering



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 *ep* scattering

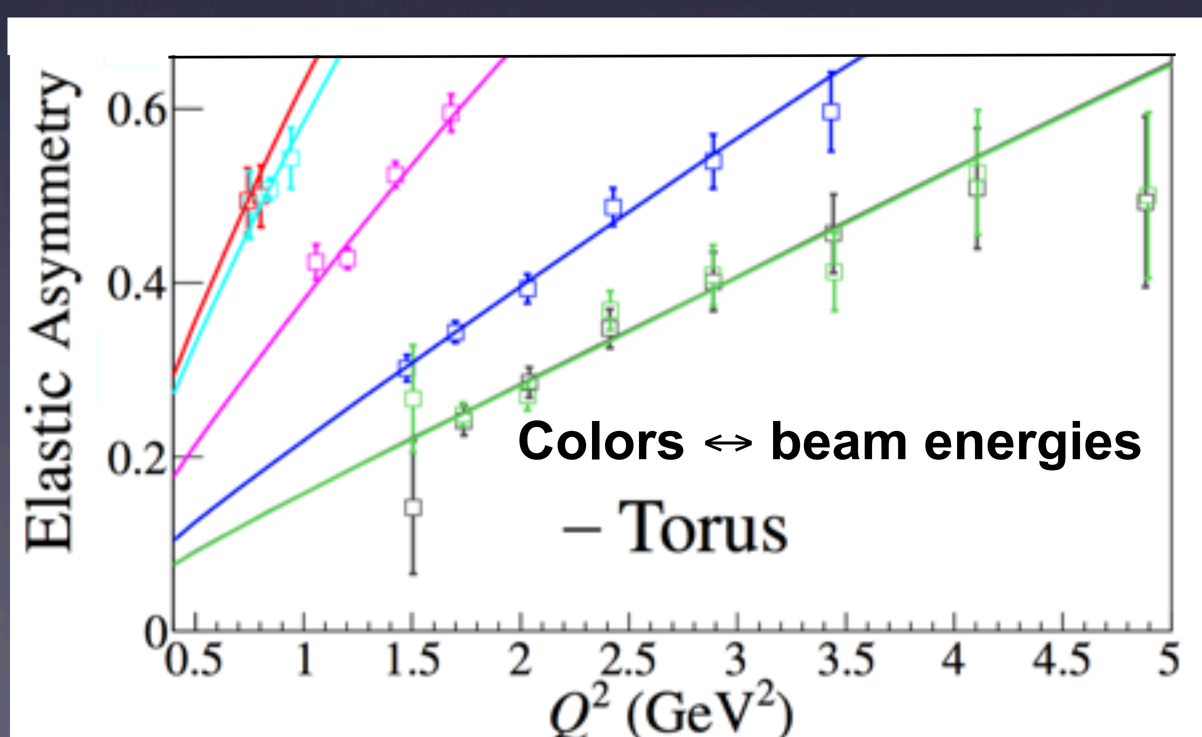


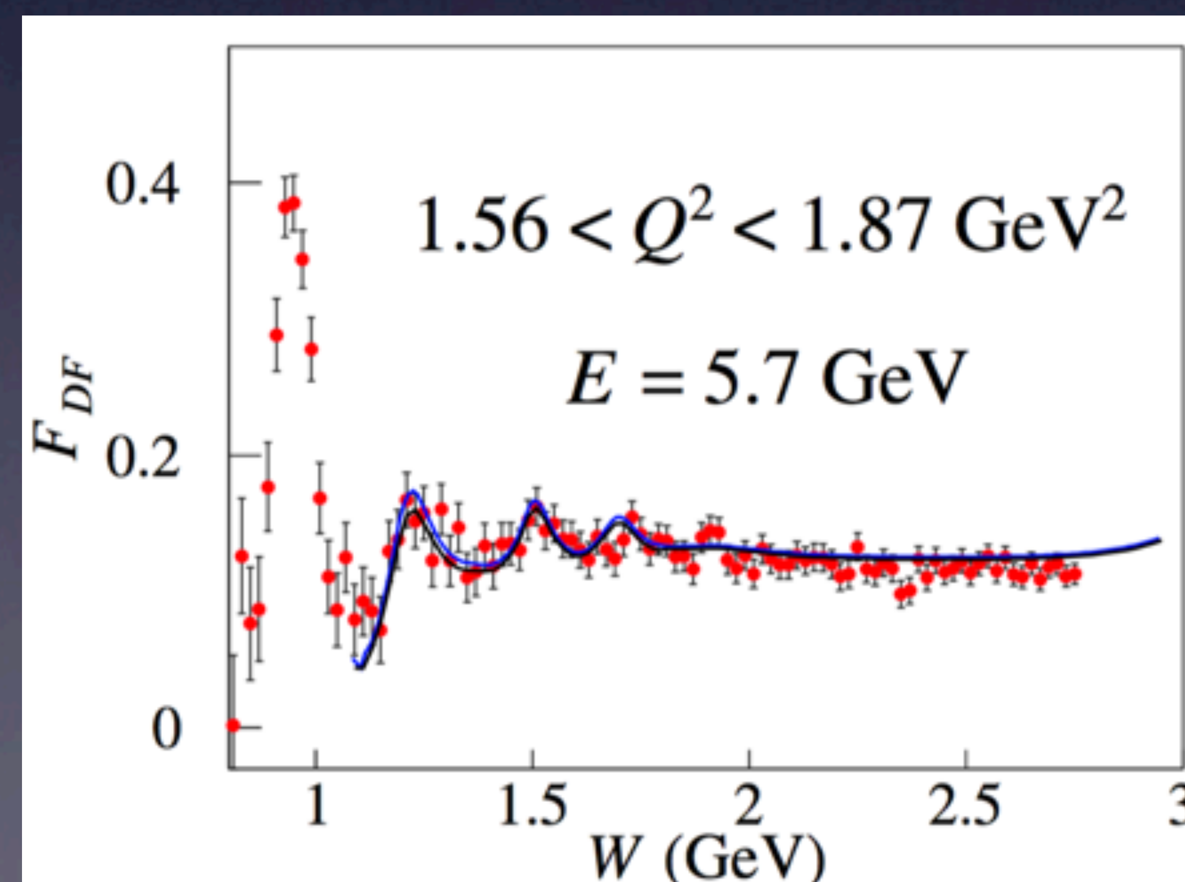
Double spin asymmetry between + (↑↑,↓↓) and – (↑↓,↓↑) beam and target polarizations

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

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

Polarization product from elastic asymmetry normalization to global data





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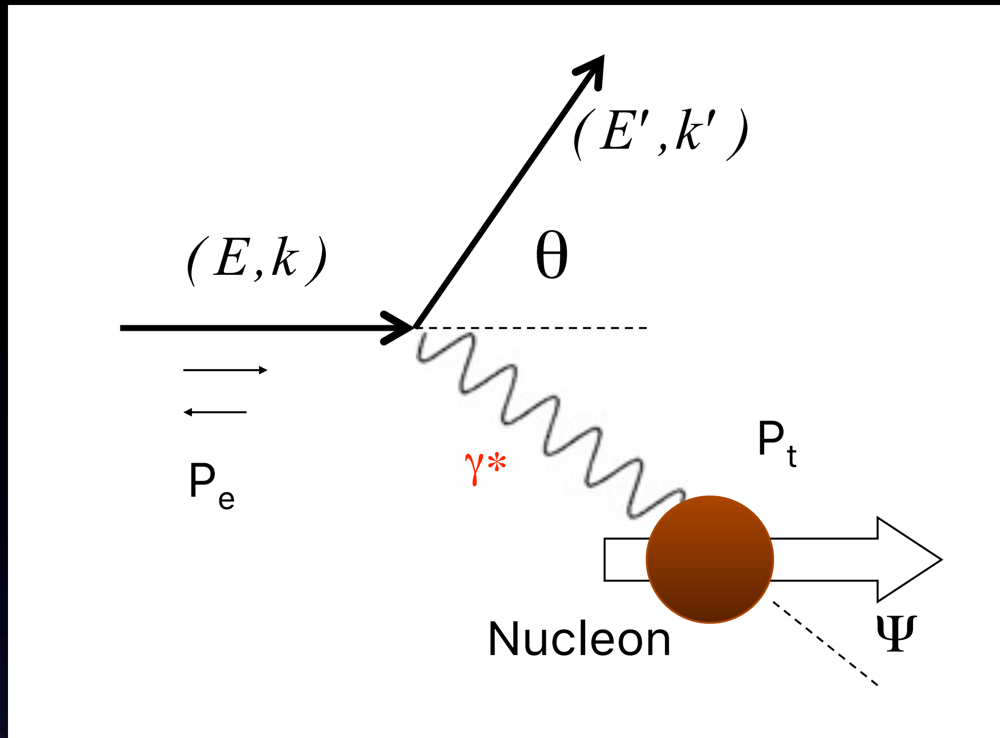


Double spin asymmetry between + (↑↑,↓↓) and – (↑↓,↓↑) beam and target polarizations

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

Physics quantities

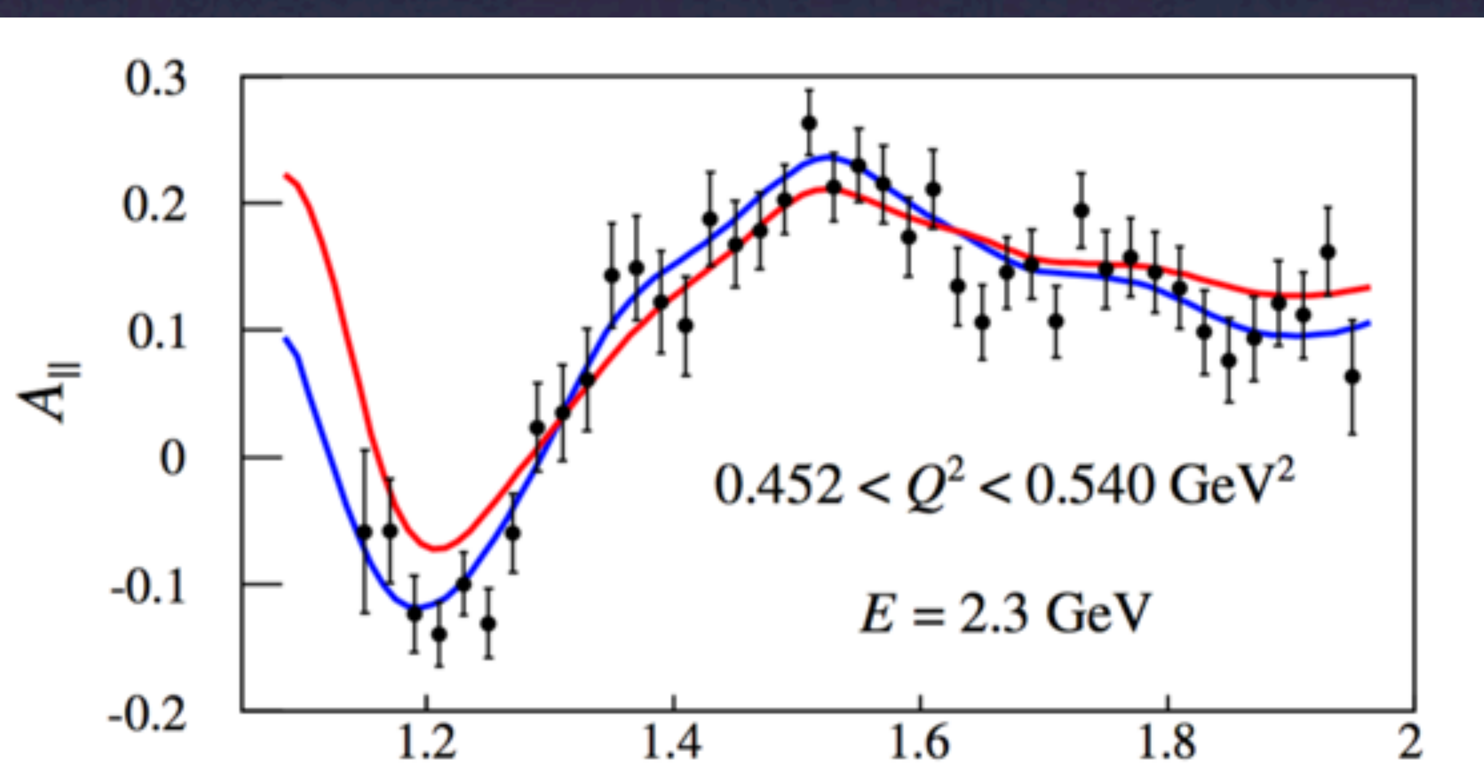
virtual photon asymmetries A_1 and A_2

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

Radiative corrections **(difference between red, blue lines)** (also nuclear polarization and e^+e^- corrections)

spin structure functions g_1 and g_2

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



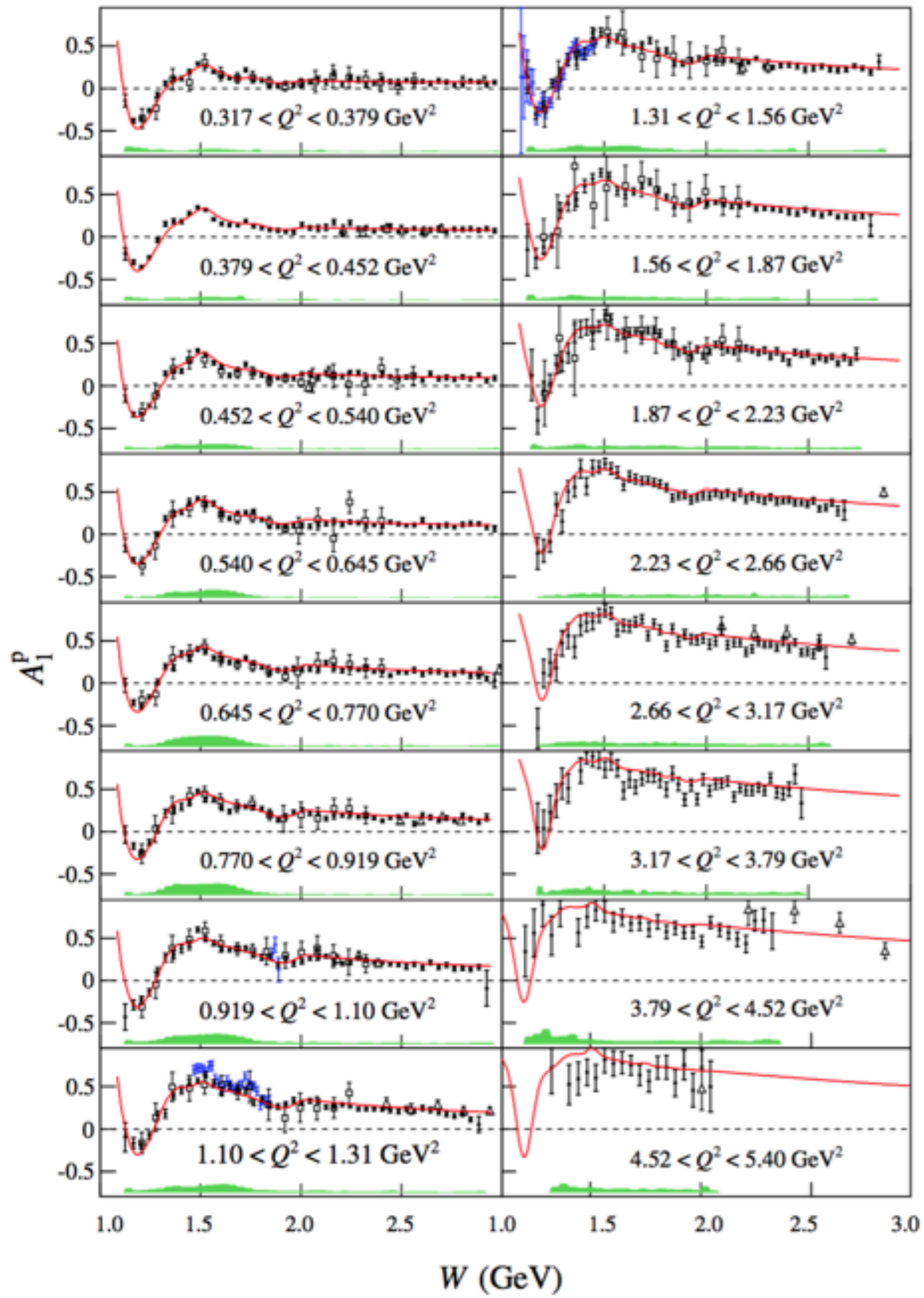
(kinematics/models)

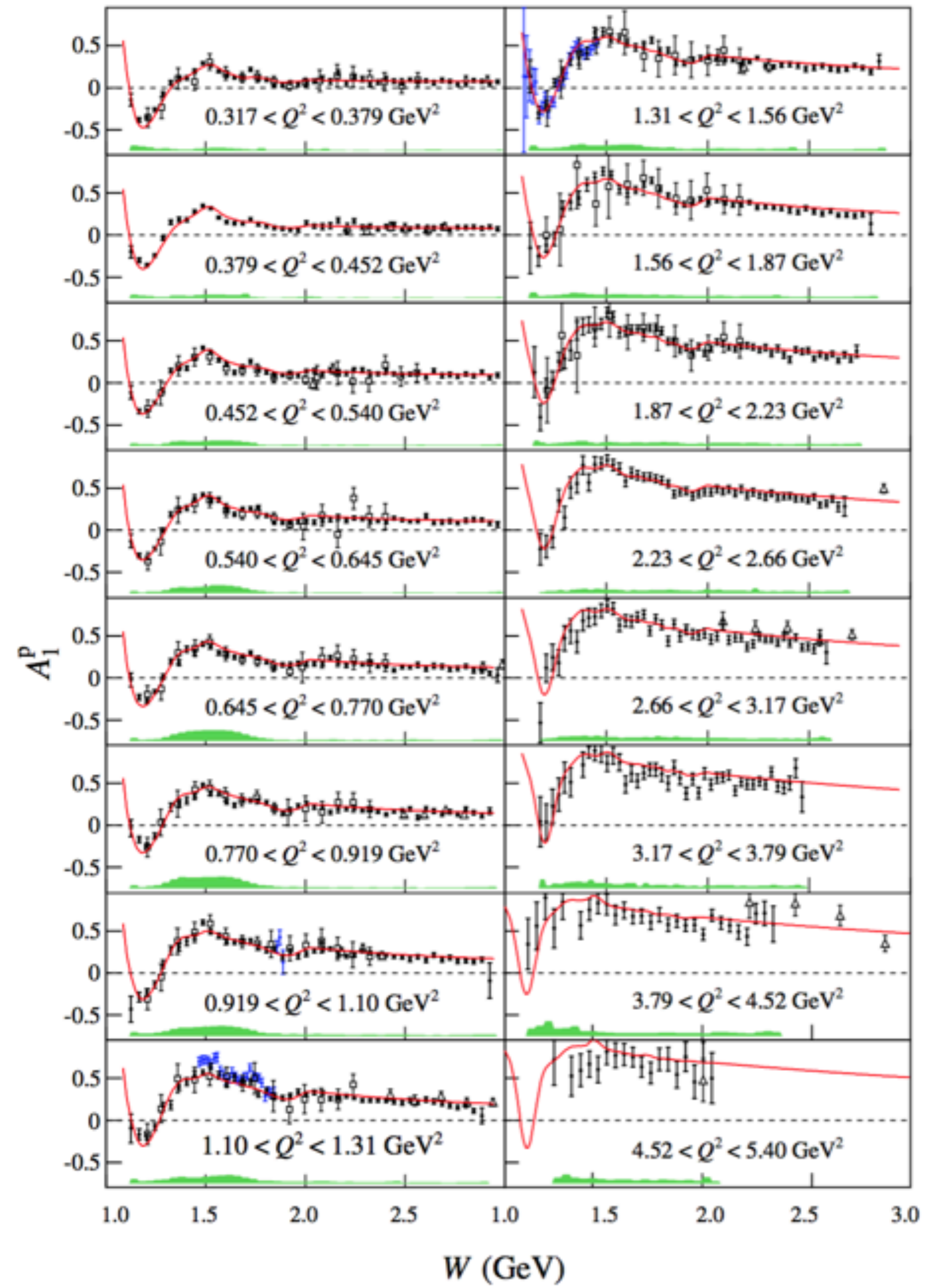
$$D = \frac{1 - E'\varepsilon / E}{1 + \varepsilon R}; \quad \eta = \frac{\varepsilon\sqrt{Q^2}}{E - E'\varepsilon} \qquad R = \frac{\sigma_L}{\sigma_T}$$

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

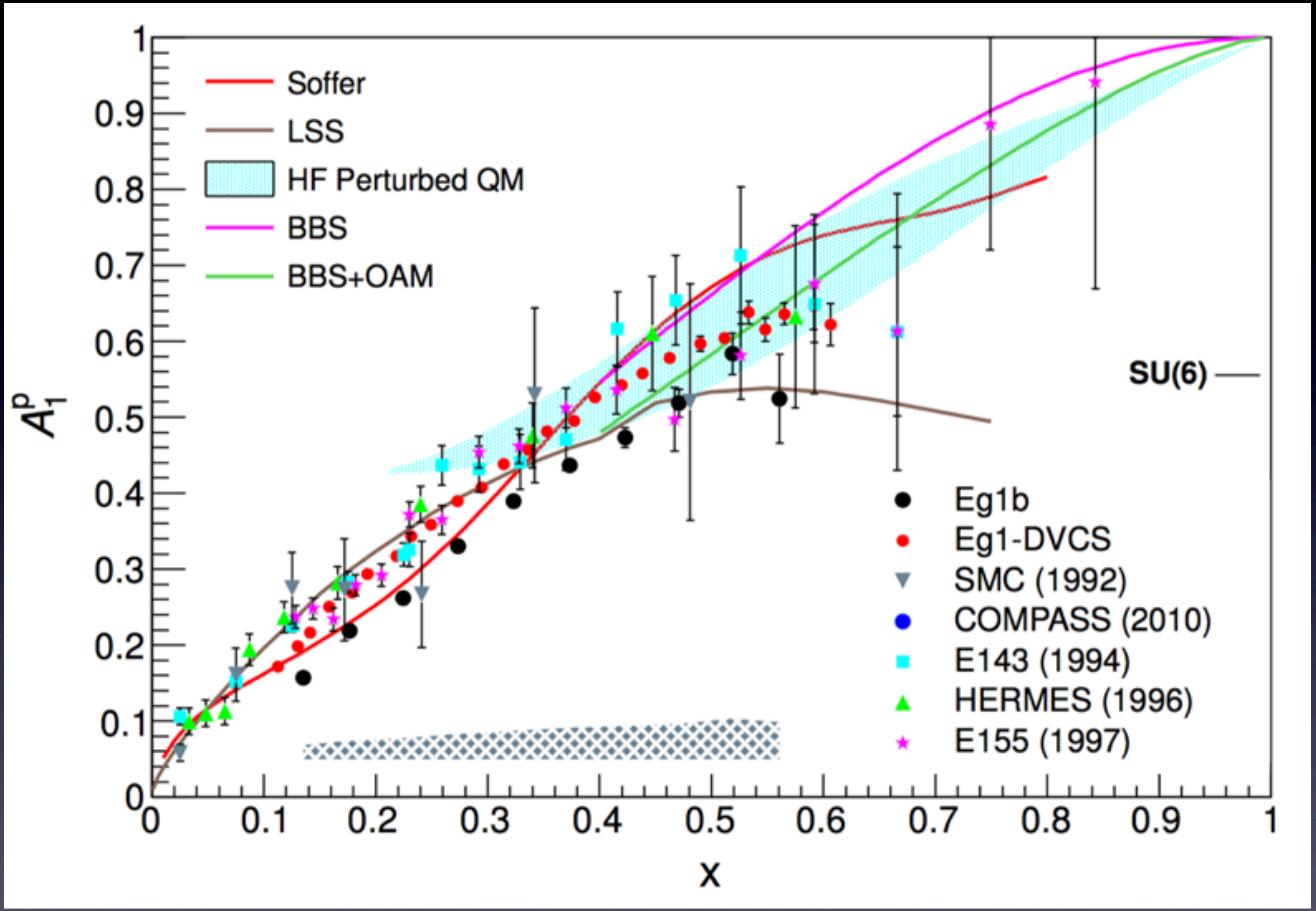
A_1 for the proton shown against world data

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





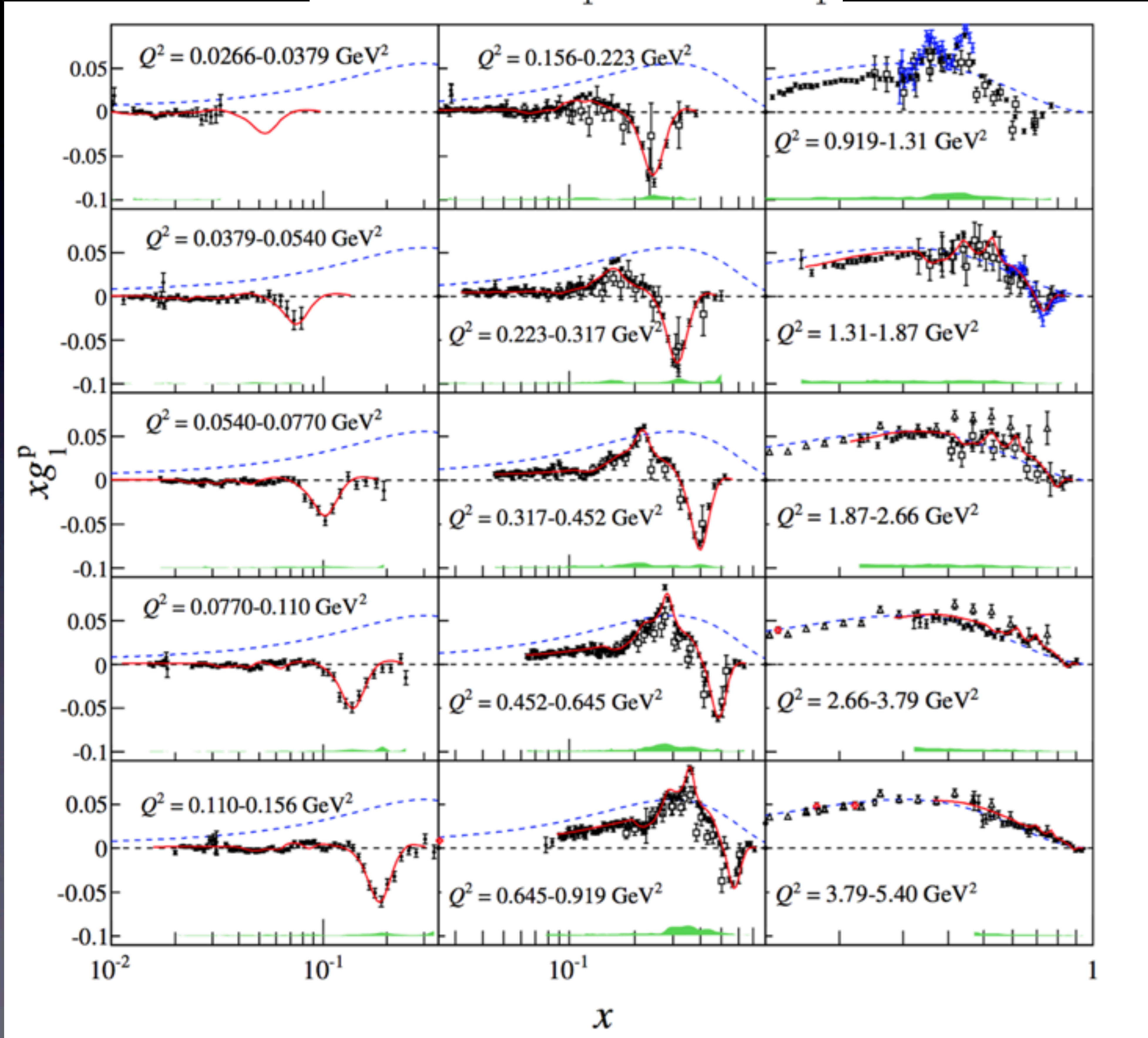
A_1 Deep Inelastic Scattering (Q^2 > 1 GeV^2, W > 2 GeV)



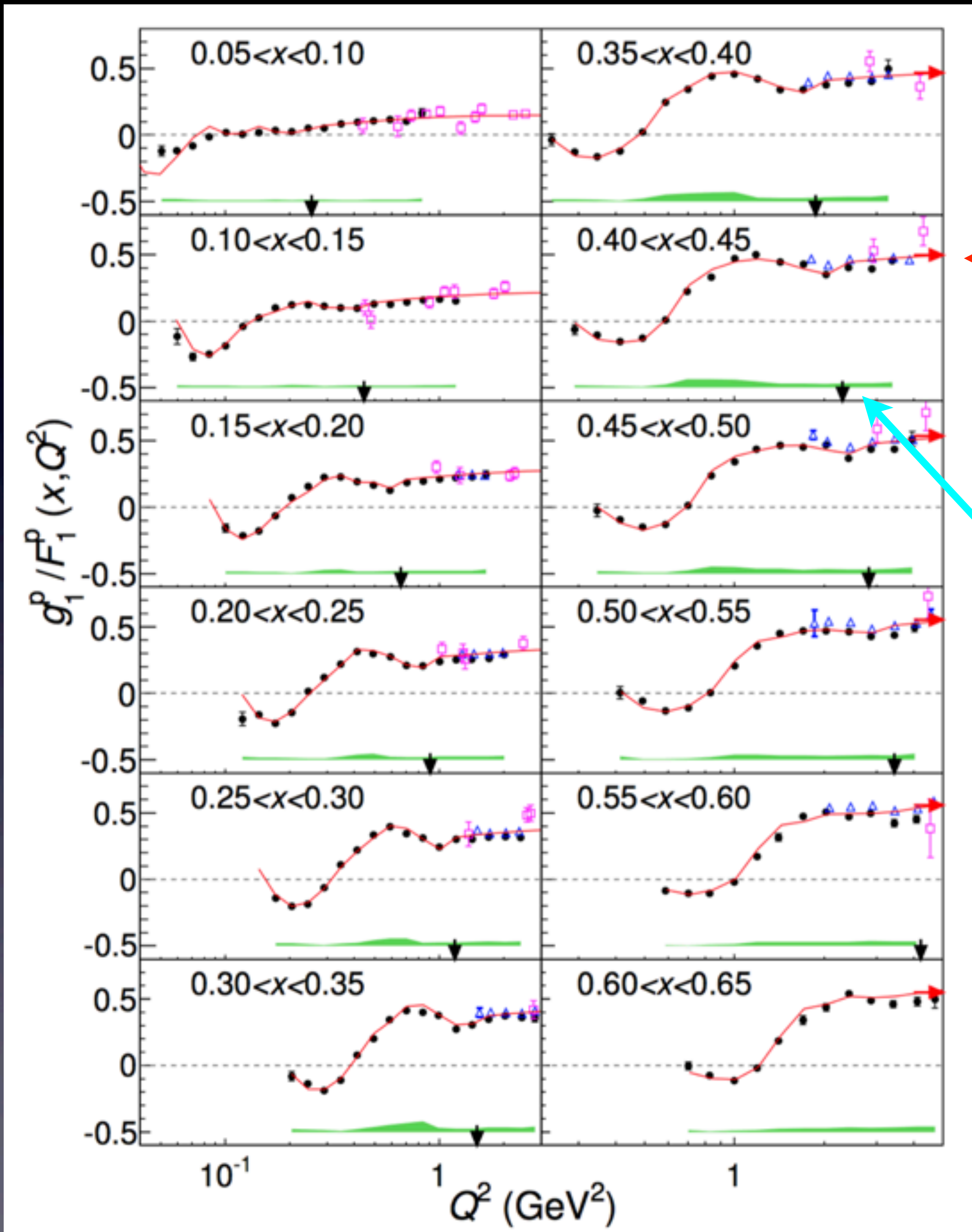
DIS results at high *x* provide insights into QCD models of the nucleon

g_1 for the proton shown against world data

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



g_1/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

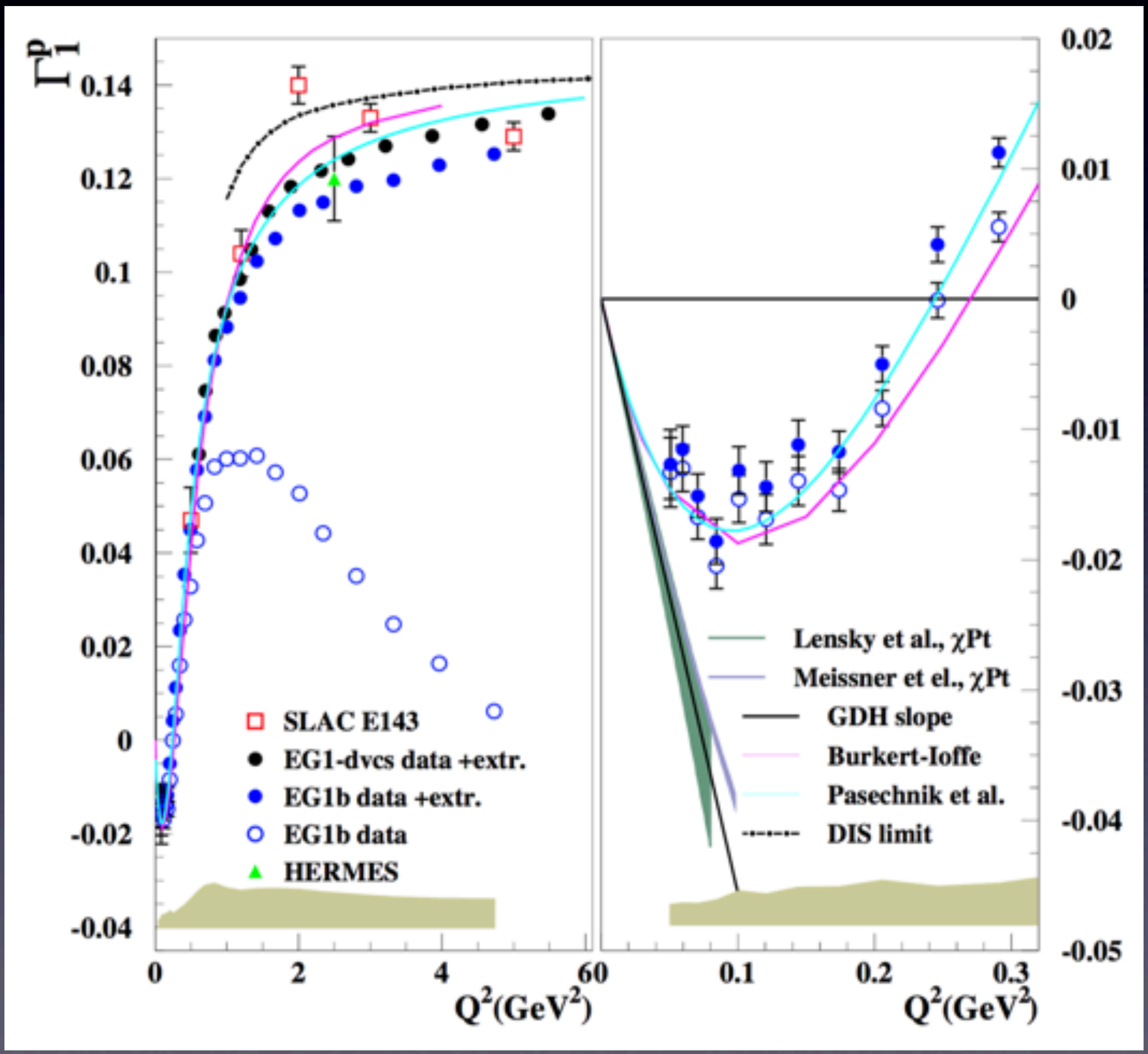
DIS limit ($W = 2$ GeV)

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)

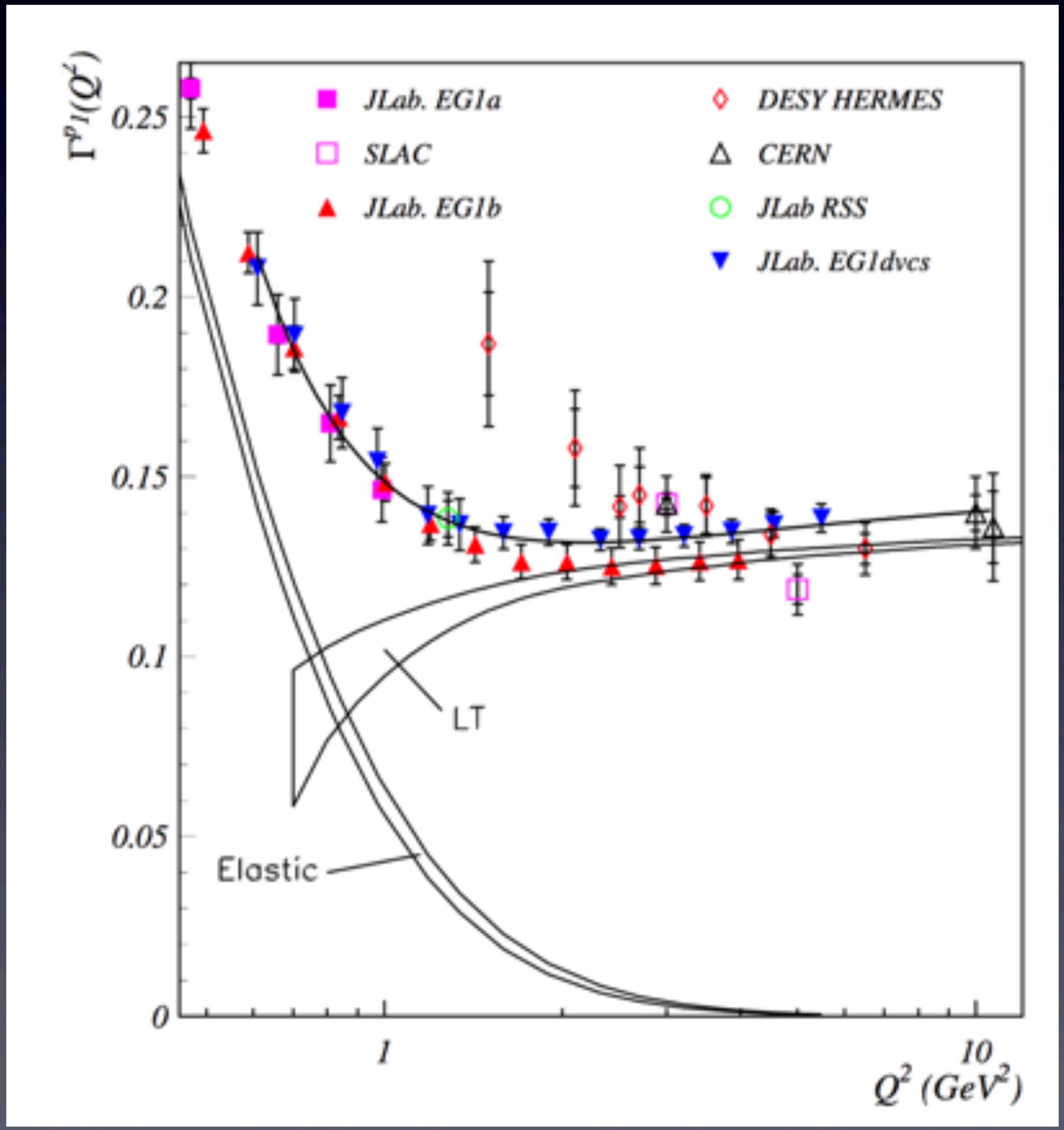
("first moment" of g_1)



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

Higher Twist analysis of Γ_1

(includes elastic contribution)



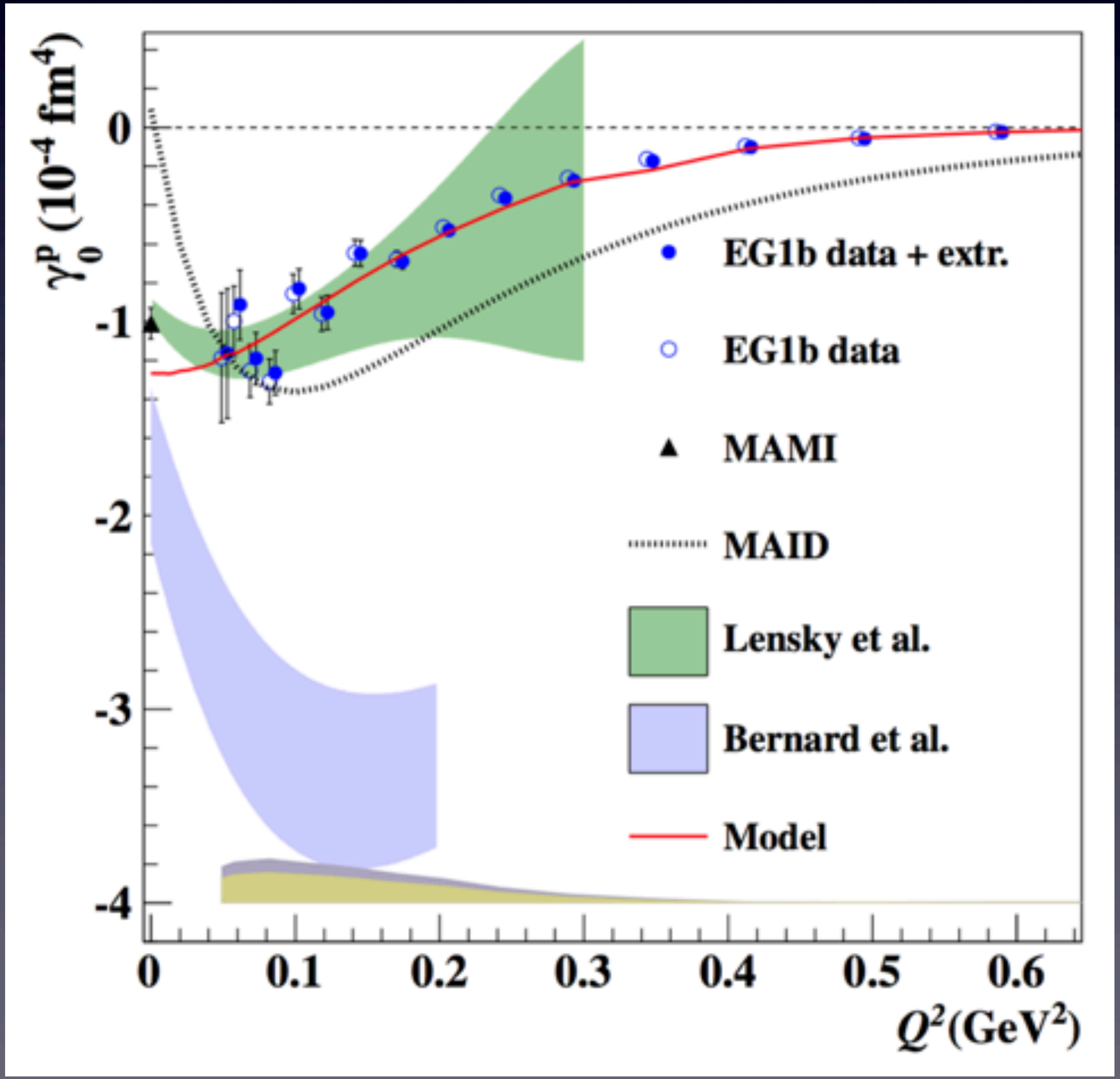
Extraction of higher twist elements through a fit by A. Deur

Forward Spin Polarizability

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

For scattering cross-sections in terms of Compton amplitudes

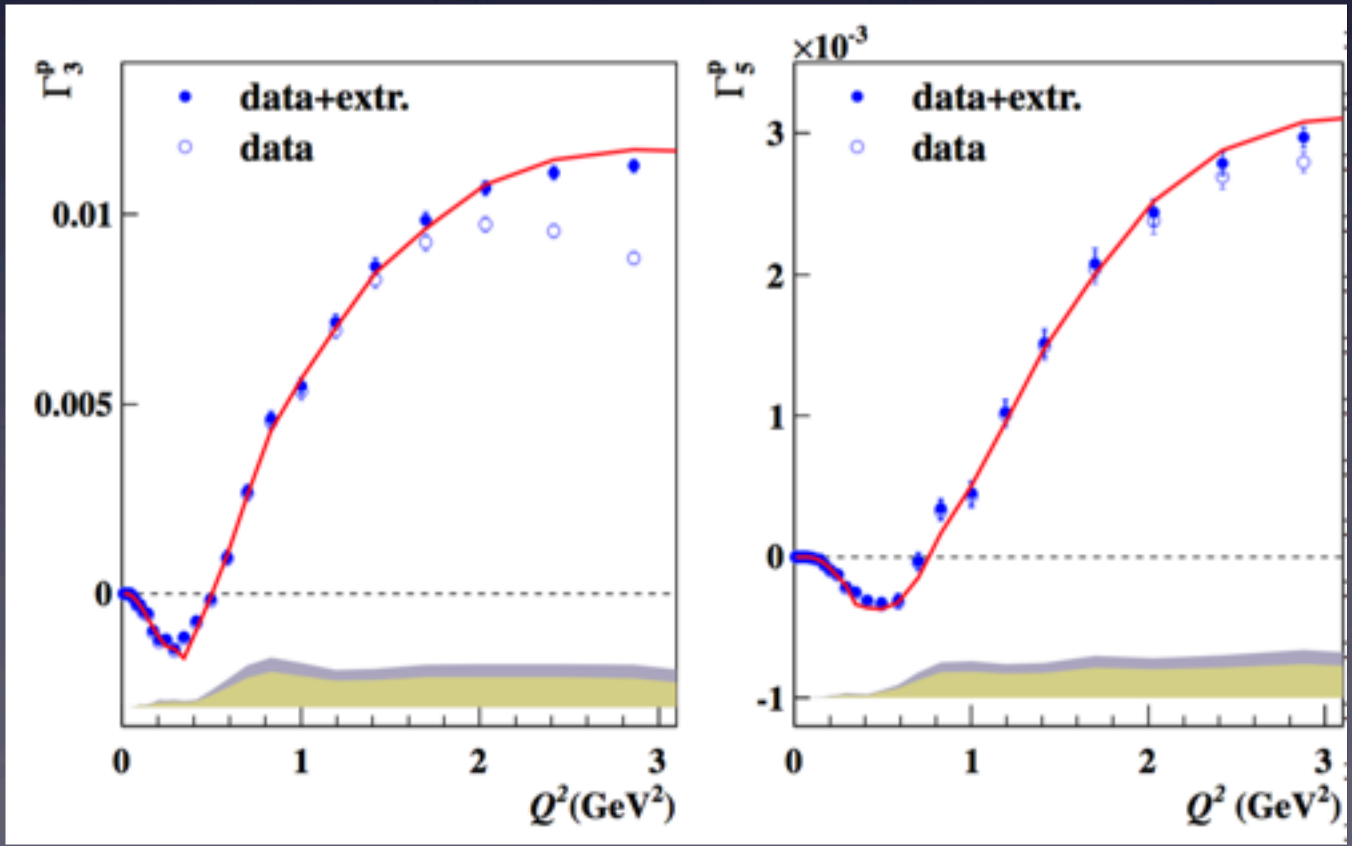
$$\gamma_0 = \frac{1}{4\pi}\int_{\nu_{th}}^{\infty}\frac{\sigma_{3/2}-\sigma_{1/2}}{\nu'^3}\,d\nu'$$
$$= \frac{16M^2\alpha}{Q^6}\int_0^{x_{th}} x^2 A_1(x,Q^2)F_1(x,Q^2)dx$$



Higher Moments

Large *x*-range provided opportunity to measure these

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

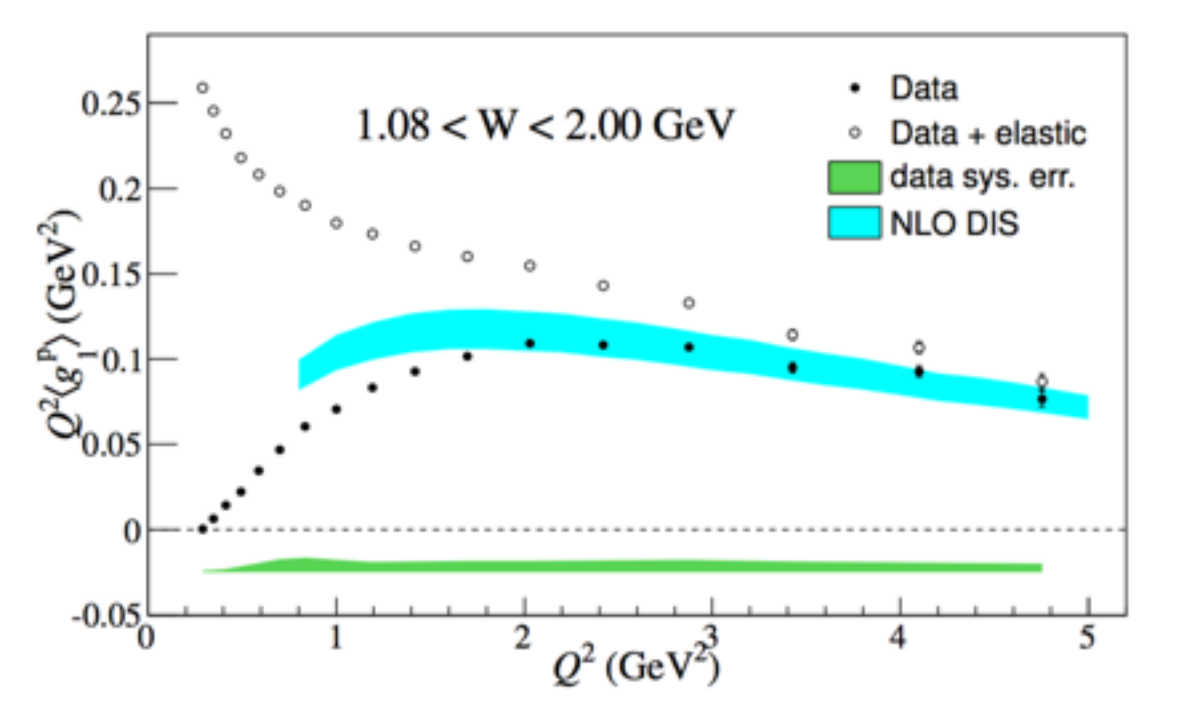


Tests of Bloom-Gillman Duality

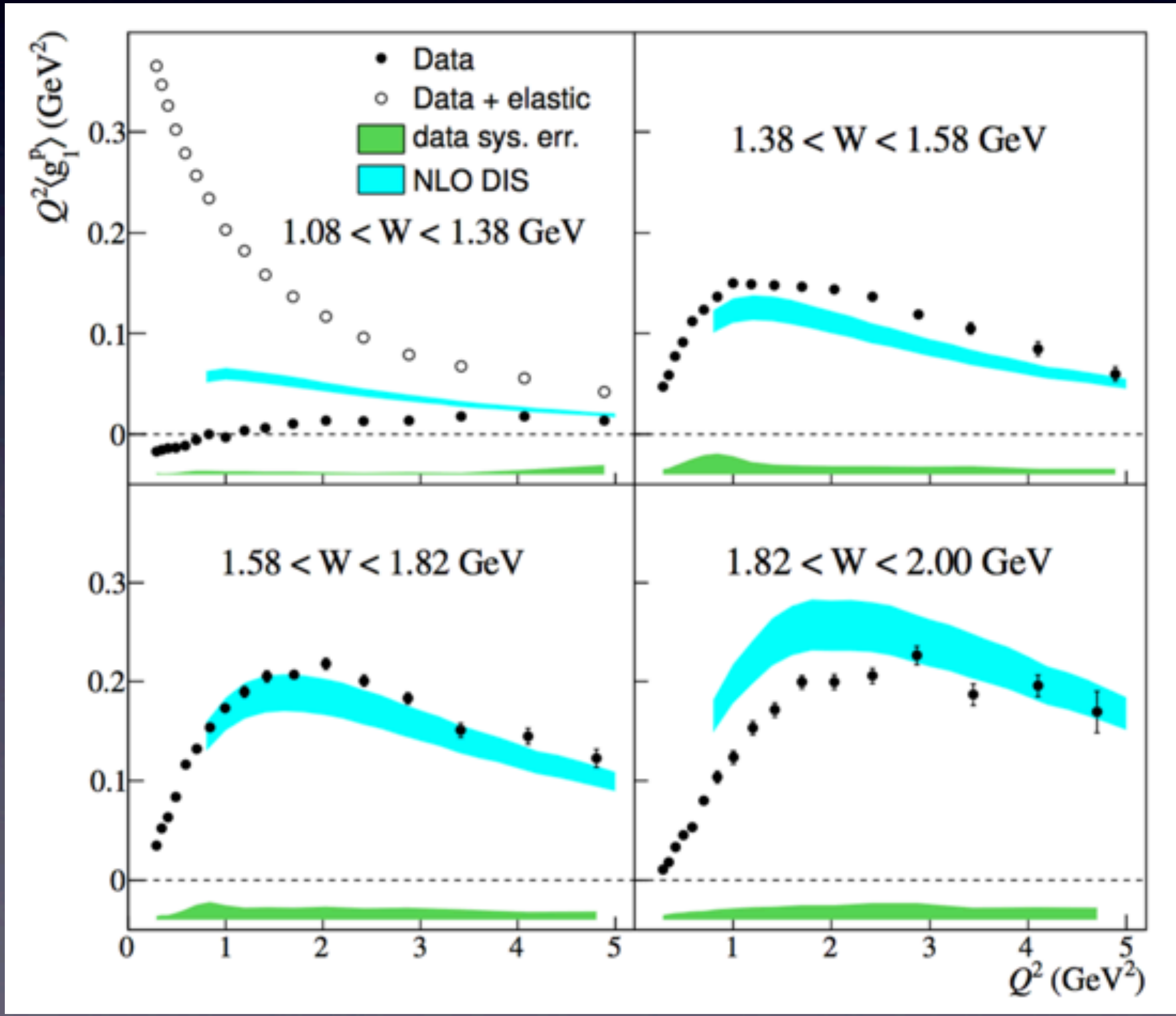
Averaging over resonances - comparing to extrapolated NLO PDFs

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

"global" duality



"local" duality

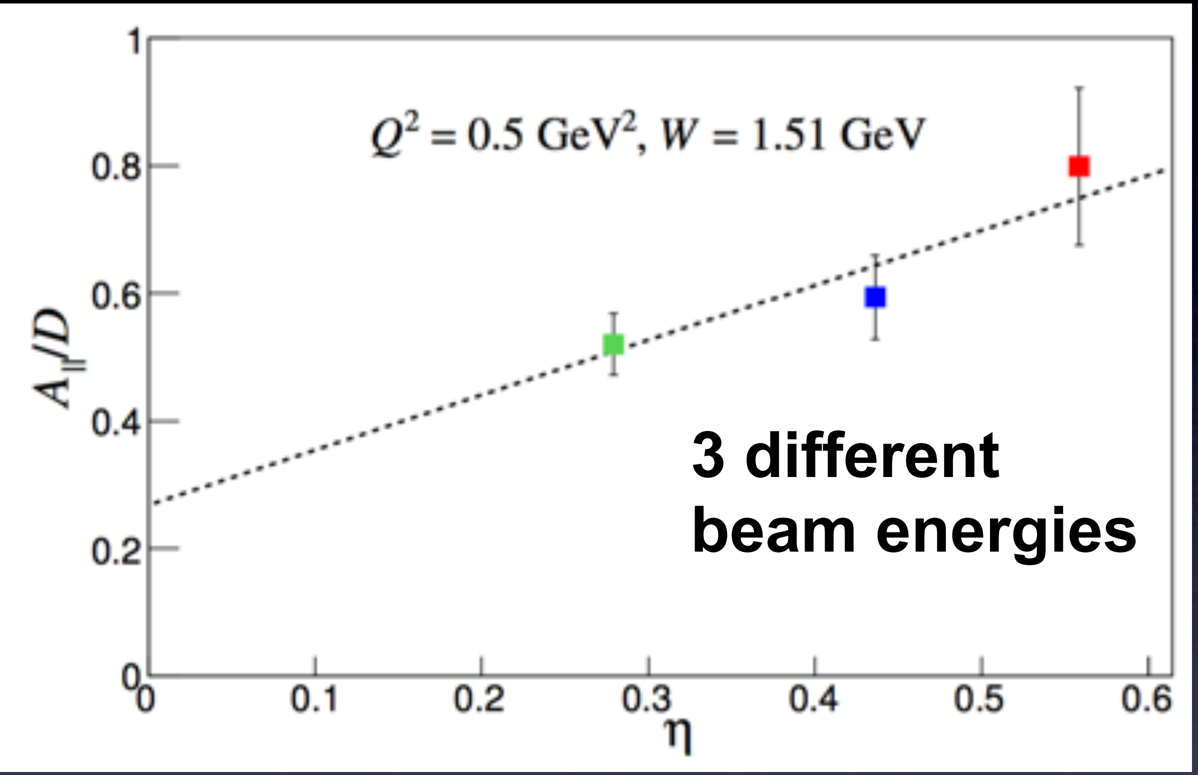


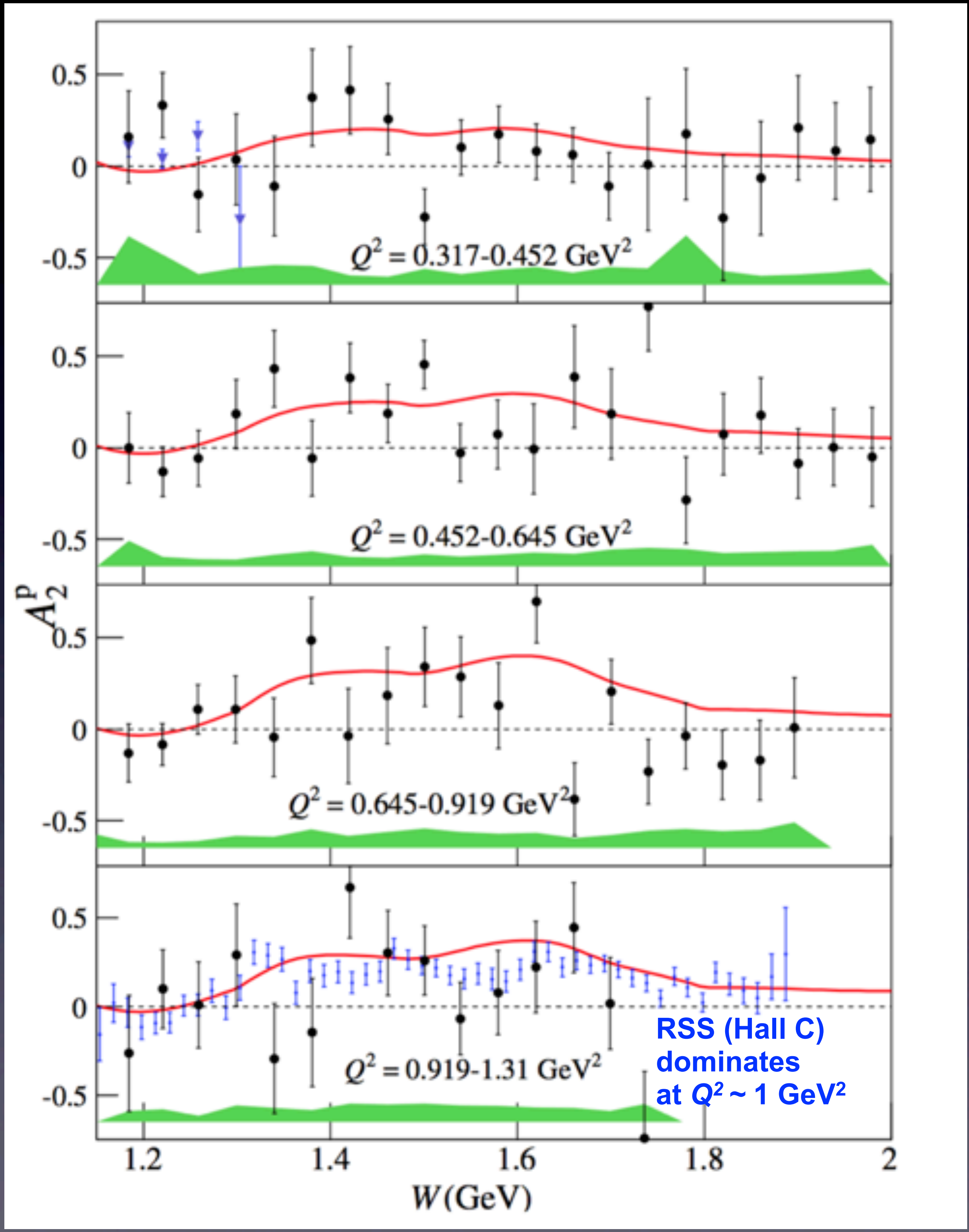
First extraction of A_2 and g_2 from EG1 data

little world data available!

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

A_1 = y-intercept,
A_2 = slope





First extraction of A_2 and g_2 from EG1 data

little world data available!

g_2 extracted similarly

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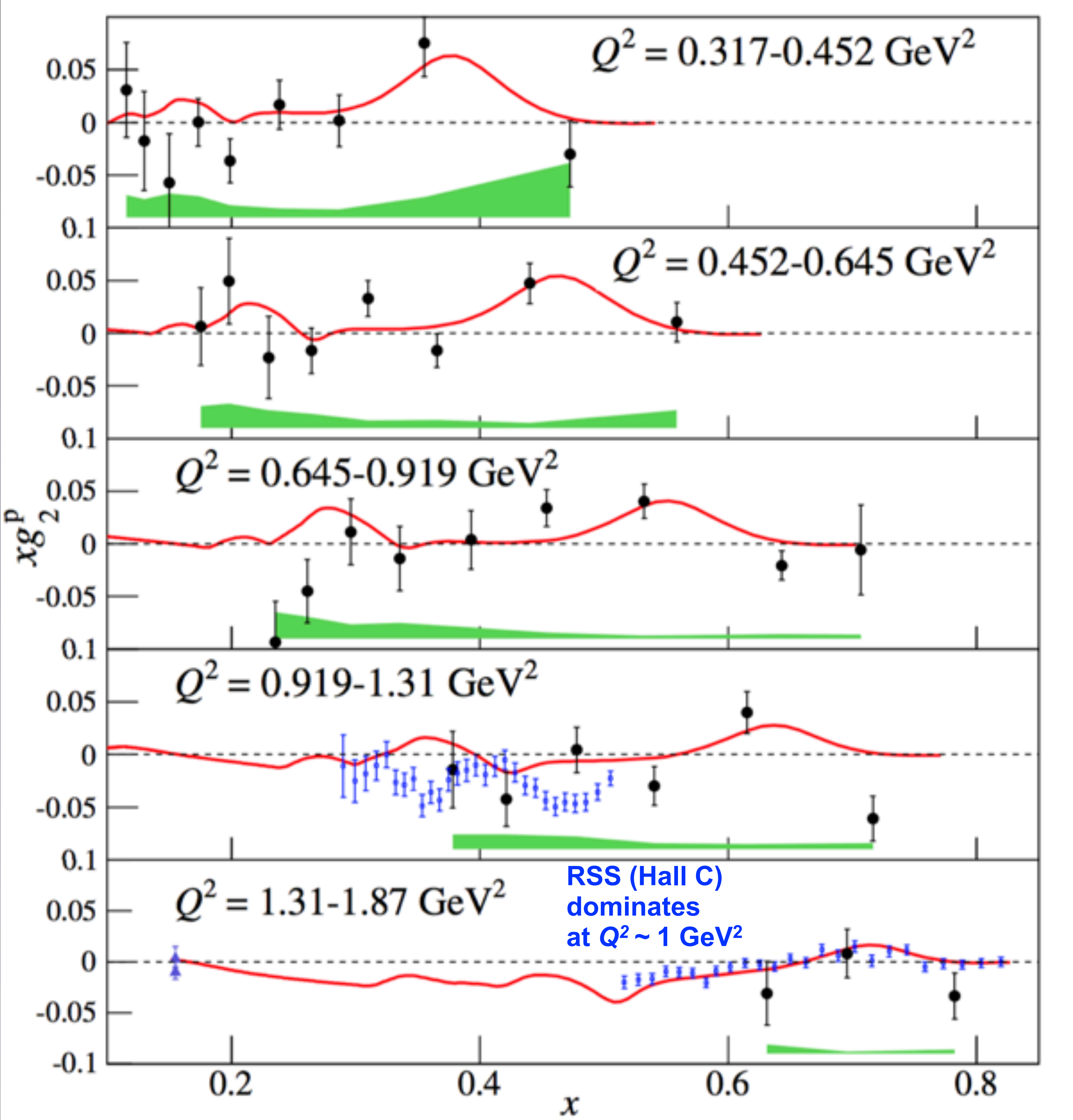

-Many EG1 publications helped build global models of nucleon spin structure!

-The 12 GeV longitudinally polarized target: higher *x* means better testing of QCD models

CLAS12 longitudinally polarized target design