The Longitudinal Spin Structure of the Nucleon

CLAS12 Proposal PR12-06-109 to PAC30

A Third Decade of Spin Structure Functions

Keith Griffioen
College of William & Mary
for the CLAS Collaboration

Author List
PR12-06-109
CLAS12

Decades of Experience

Theoretical Support

The Longitudinal Spin Structure of the Nucleon

A 12 GeV Research Proposal to Jefferson Lab (PAC 30)

Moskov Amarian, Stephen Bültmann, Gail Dodge, Nevzat Guler, Henry Juengst, Sebastian Kuhn†*, Lawrence Weinstein
Old Dominion University

Harut Avakian, Peter Bosted, Volker Burkert, Alexandre Deur†, Vipuli Dharmawardane†
Jefferson Lab

Keith Griffioen†
The College of William and Mary

Hovanes Egiyan, Maurik Holtrop†
University of New Hampshire

Stanley Kowalski, Yelena Prok†
Massachusetts Institute of Technology

Don Crabb†, Karl Slifer
University of Virginia

Tony Forest†
Louisiana Tech

Angela Biselli
Fairfield University

Kyungseon Joo
University of Connecticut

Mahbub Khandaker
Norfolk State University

Elliot Leader
Imperial College, London, England

Aleksander V. Sidorov
Bogoliubov Theoretical Laboratory, JINR Dubna, Russia

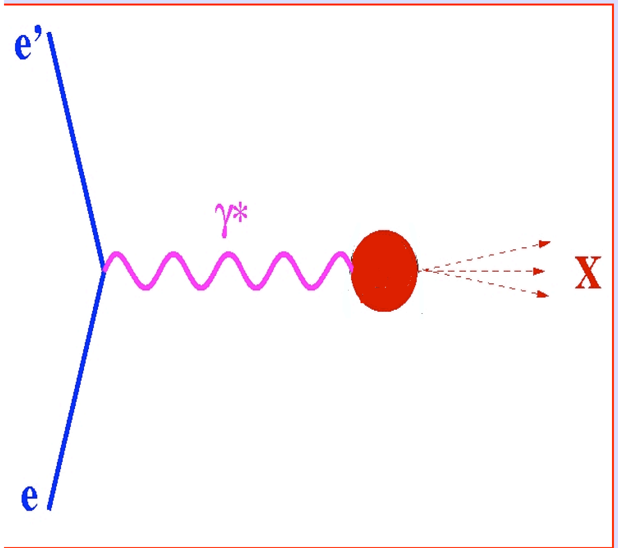
Dimiter B. Stamenov
Inst. for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria

A CLAS collaboration proposal

† Co-spokesperson * Contact: Sebastian Kuhn, Department of Physics, Old Dominion University, Norfolk VA 23529. Email: skuhn@odu.edu

Spin Structure Observed

$$A_{||} = (N^+ - N^-)/(N^+ + N^-)$$

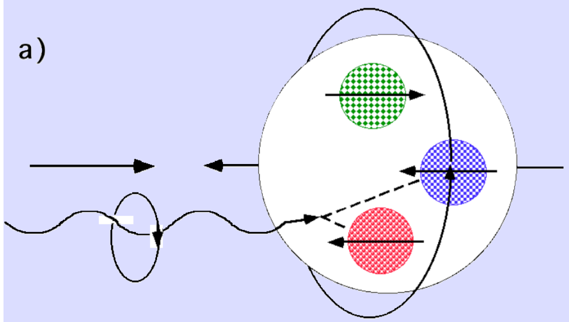


$$\frac{A_{||}^N}{D} = (1+\gamma^2)\frac{g_1^N}{F_1^N} + (\eta - \gamma)A_2^N$$

$$= A_1^N + \eta A_2^N$$

$\gamma \approx \eta$ and A_2 small

very well approximated with $(1+\gamma^2)\frac{g_1^N}{F_1^N}$ even when $\gamma(\eta)$ can not been neglected

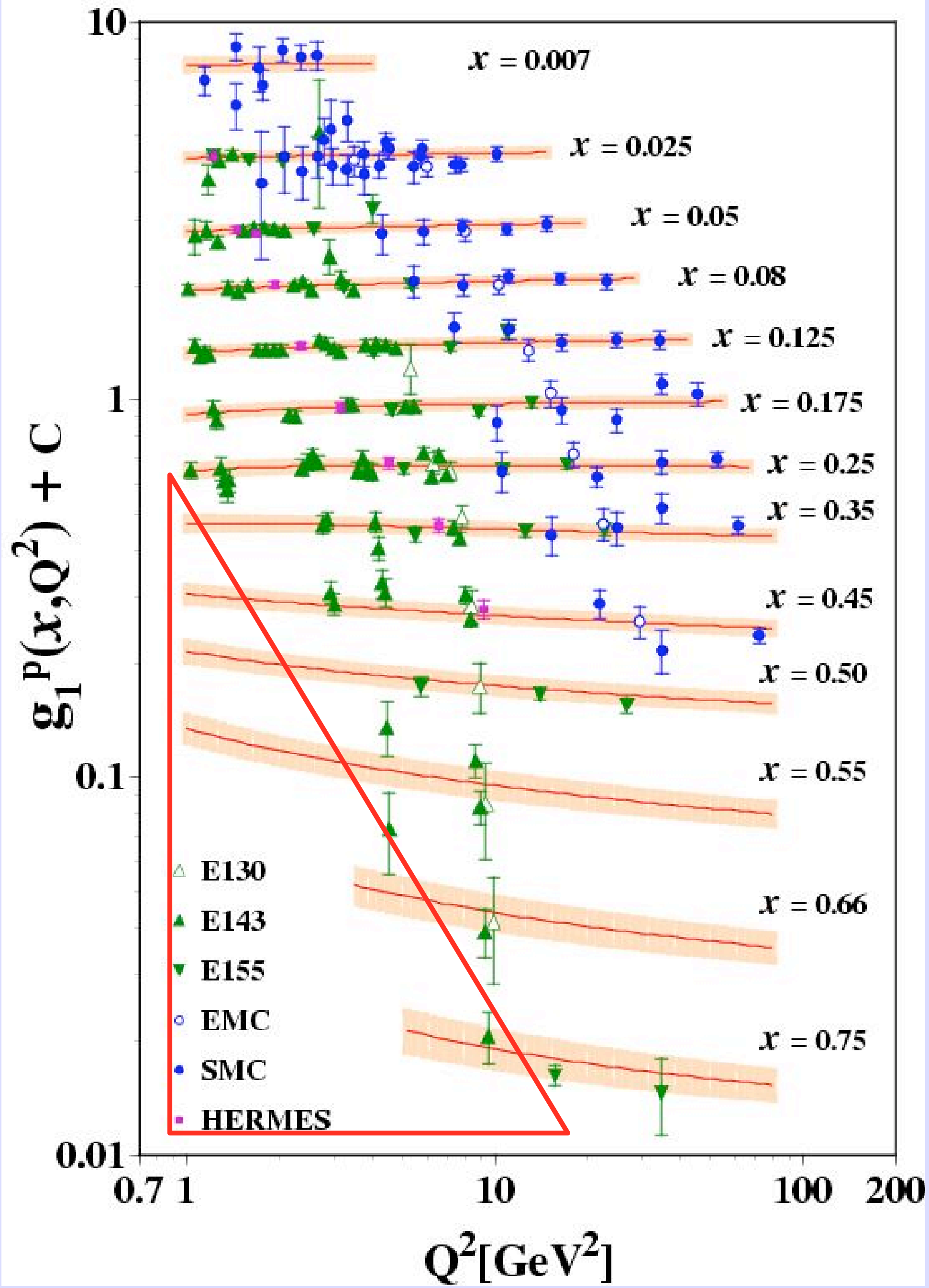


$$F_1(x) = \frac{1}{2}\sum_i e_i^2[q_i^{\uparrow}(x) + q_i^{\downarrow}(x)],$$

$$g_1(x) = \frac{1}{2}\sum_i e_i^2[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)] = \sum_i e_i^2 \Delta q_i(x).$$

The First Decade 1993 ± 5

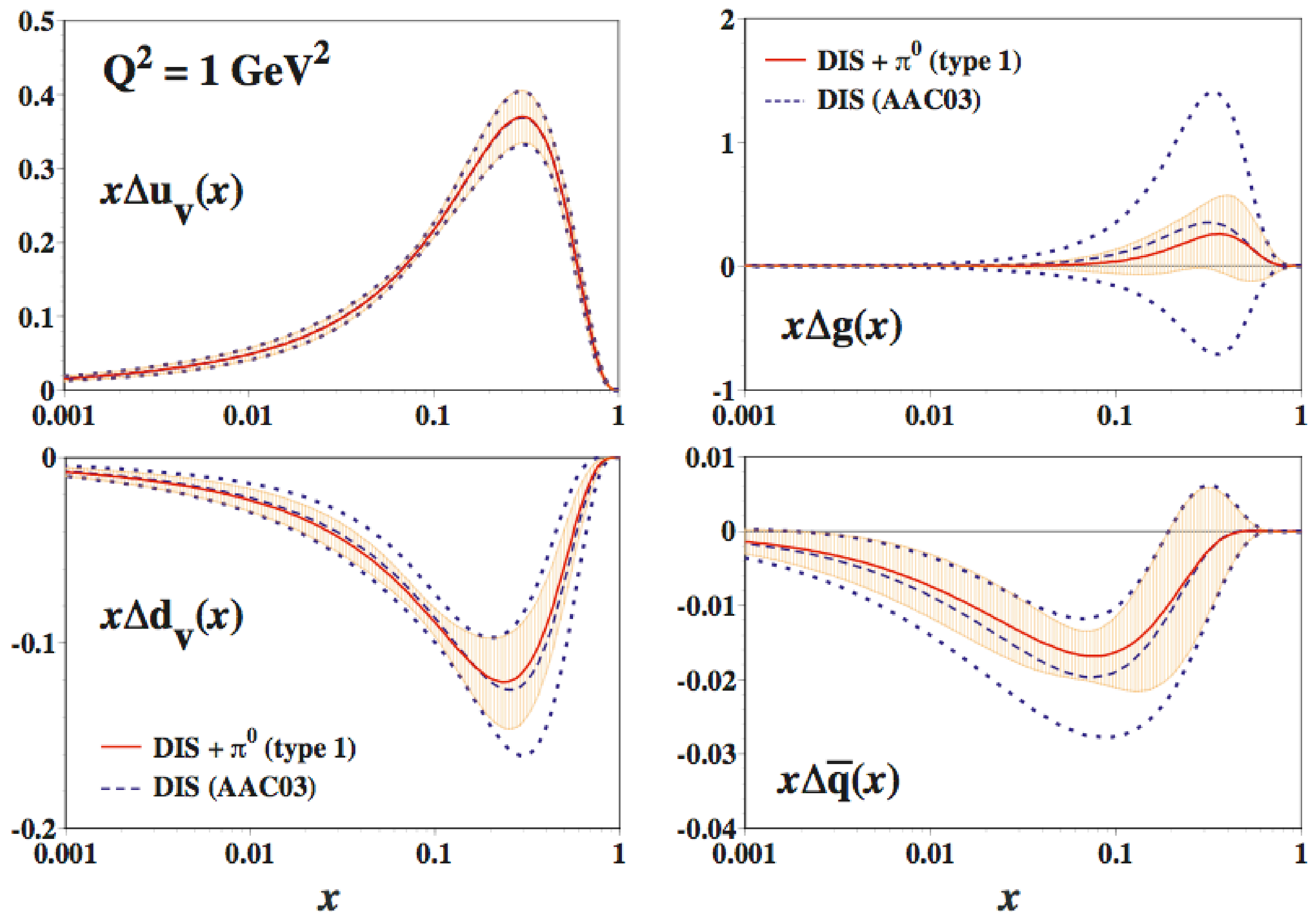
- g_1 DIS measured for p, d and ^{3}He
- CERN/HERA/SLAC
- (AAC: hepph0603213) NLO fits to extract quark and gluon distributions
- Notice the hole at high x and Q^2<10 GeV^2
- CLAS12 coverage (red)



The First Decade

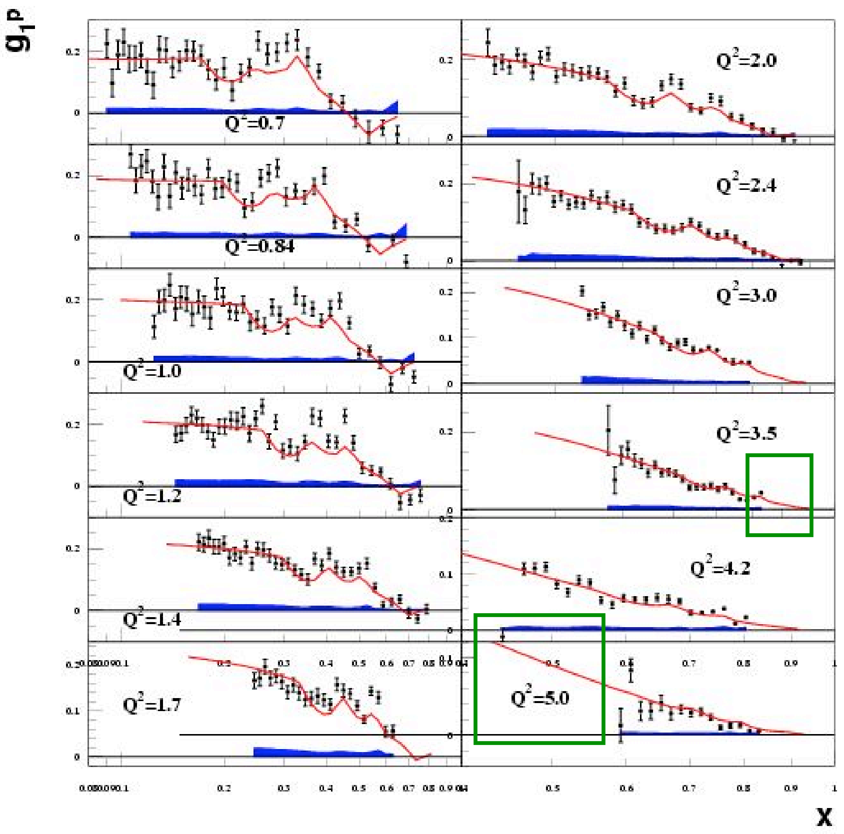
	$\Delta\bar{q}$	Δg	$\Delta\Sigma$
Type 1	-0.05 ± 0.01	0.31 ± 0.32	0.27 ± 0.07
Type 2	-0.06 ± 0.02	0.47 ± 1.08	0.25 ± 0.10
AAC03	-0.06 ± 0.02	0.50 ± 1.27	0.21 ± 0.14

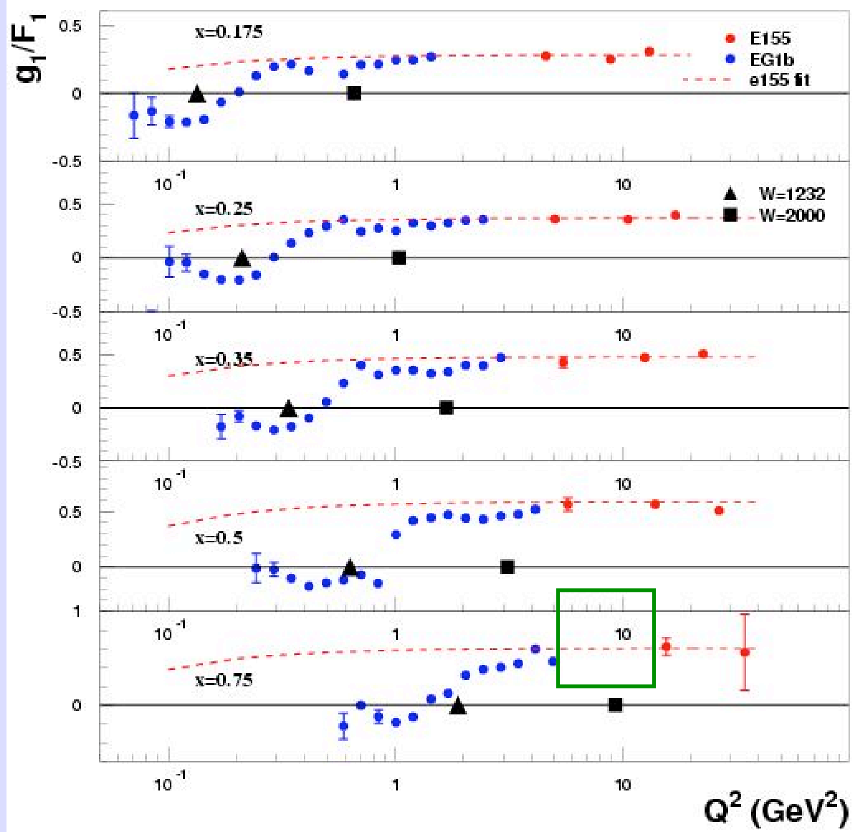
$$\frac{1}{2} = \frac{\Delta\Sigma}{2} + \Delta G + L_z$$



The Second Decade 2004$\pm$6

- Notice the missing data at high and low *x* for Q^2>2 GeV^2.
- Notice the missing A_1 data at high *x* not dominated by the Δ resonance.



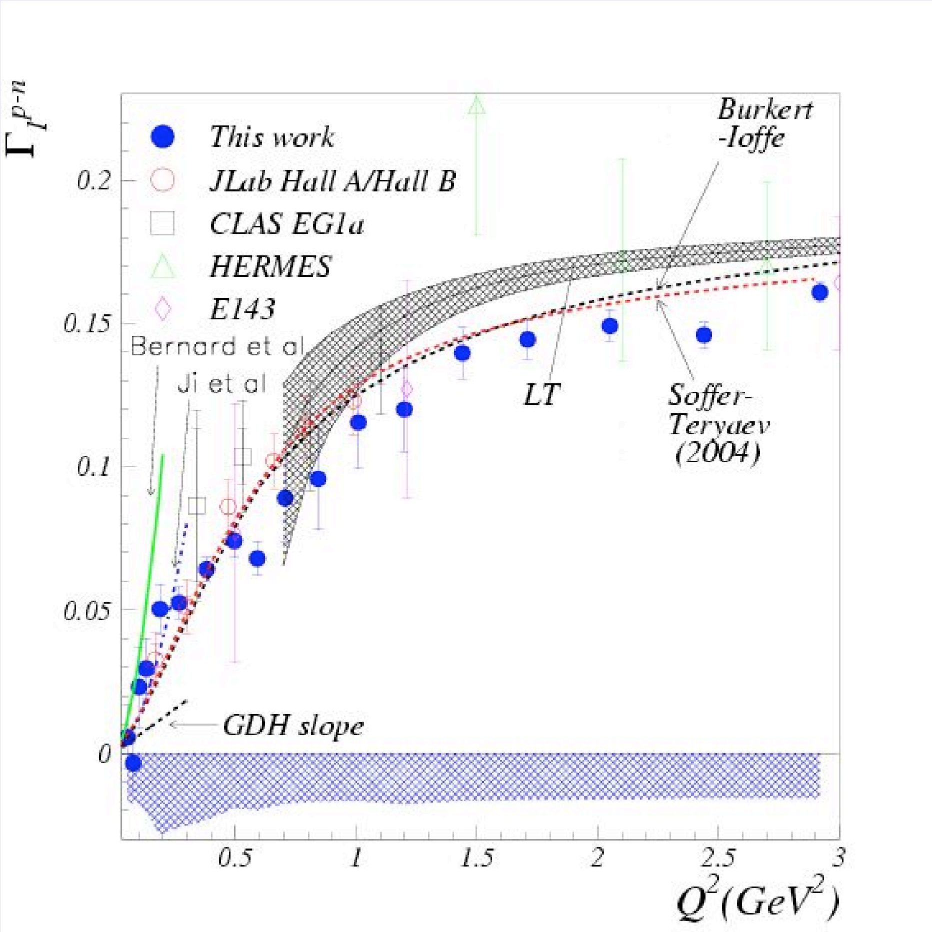


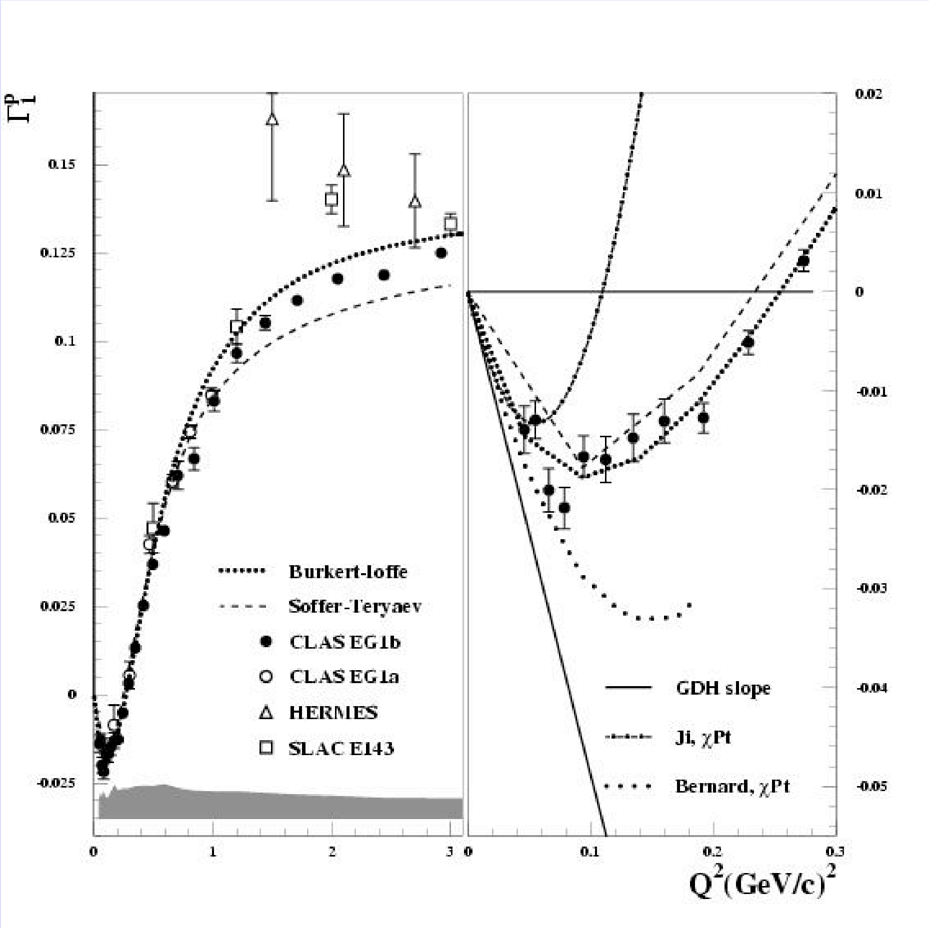
The Second Decade

- Q^2 evolution of moments
- GDH sum rule

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

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



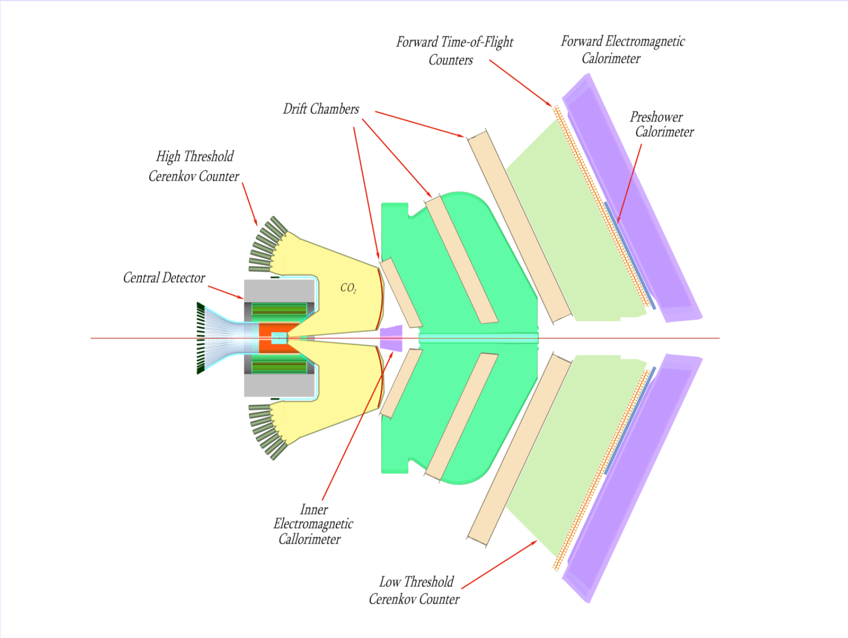


What Still Needs to Be Explored?

- High *x*
- Flavor decomposition
- Higher twist
- Moments

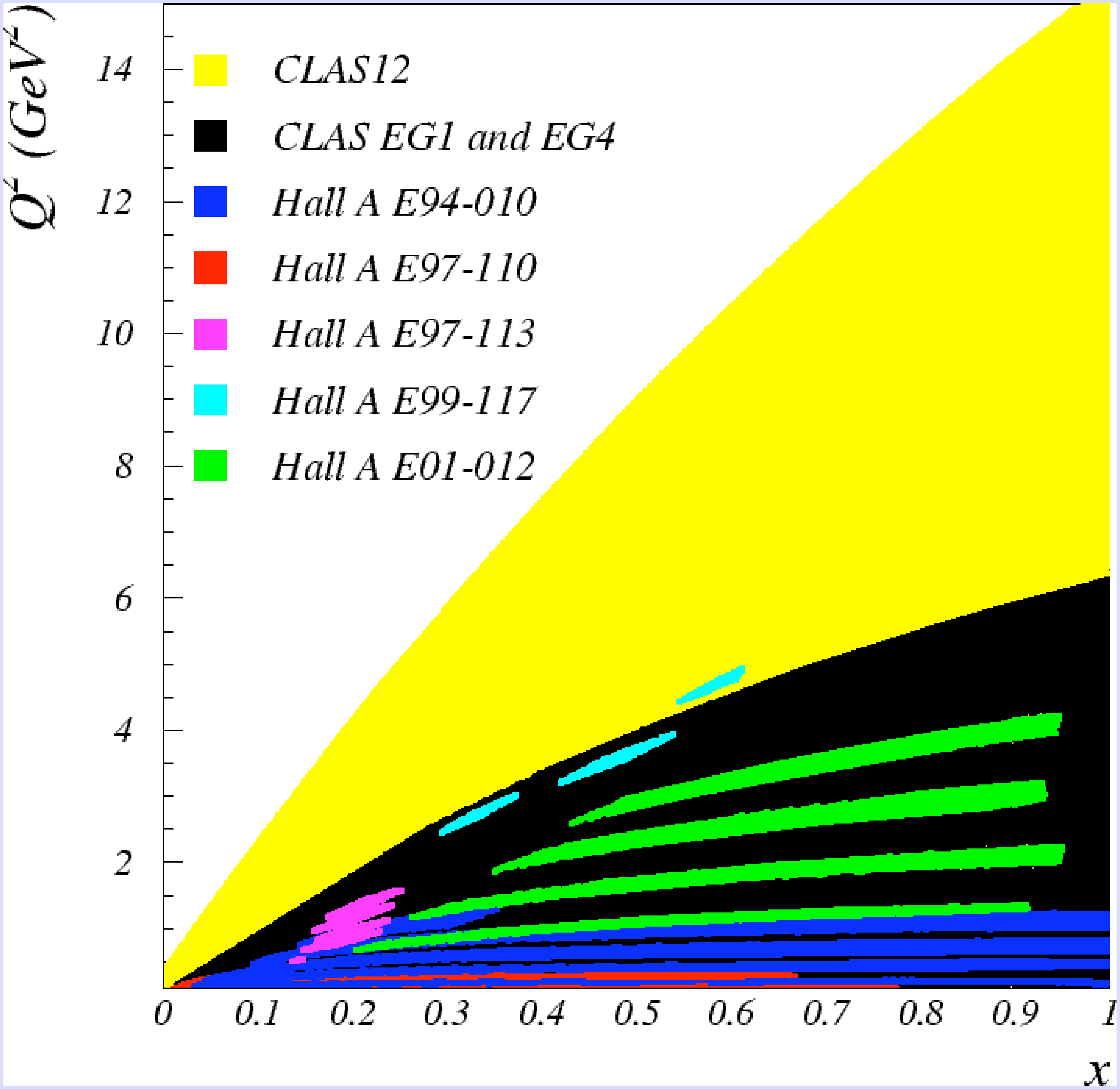
The Third Decade
2015 ± 7

How Do We Do So?

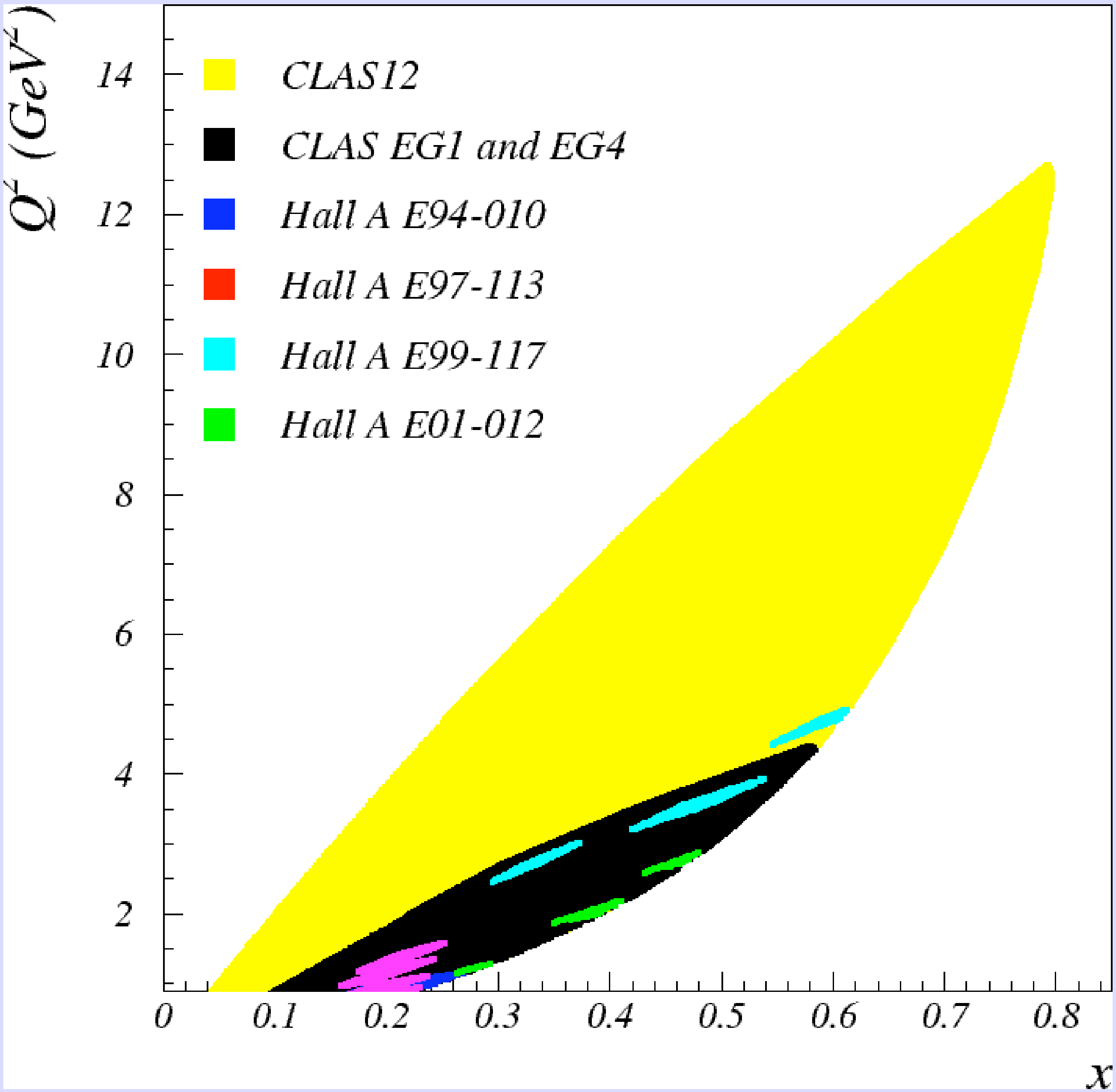


- E_{beam} = 11 GeV
- L = 2 x 10^{35} /cm^2/s
- CLAS12 acceptance
- p and d targets
- P_b=85% P_t=80(40)% p(d)
- 80 days of beam time
- Stat ~ syst errors at high *x*

Kinematic Coverage (full)



Kinematic Coverage (DIS)

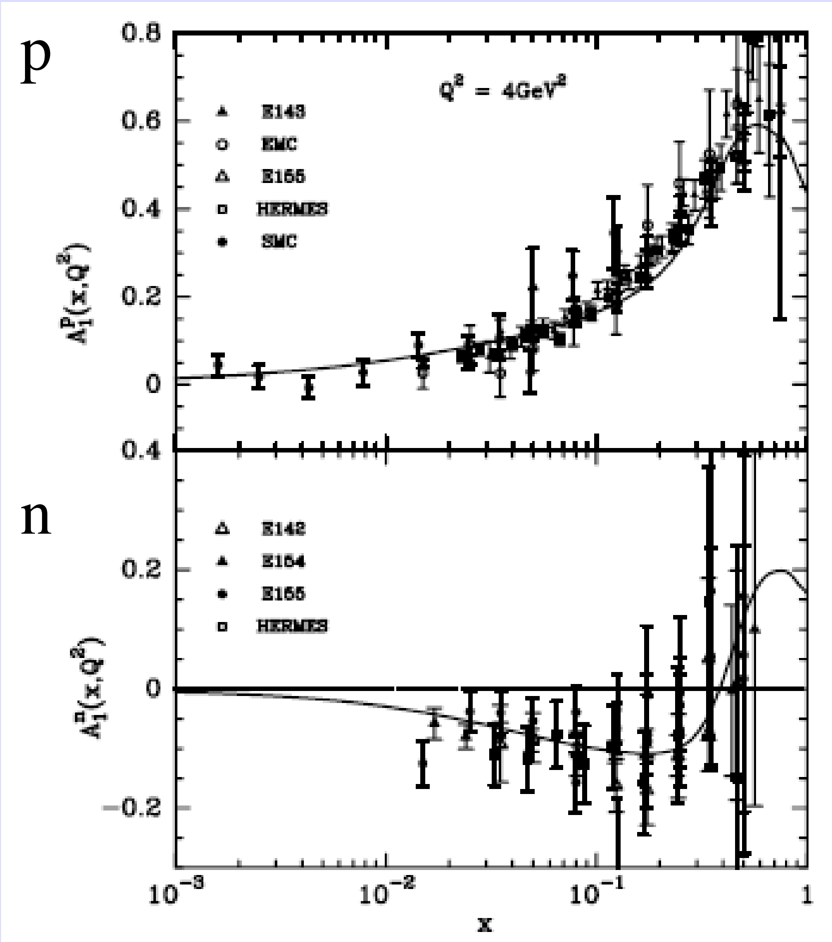


Models at High x

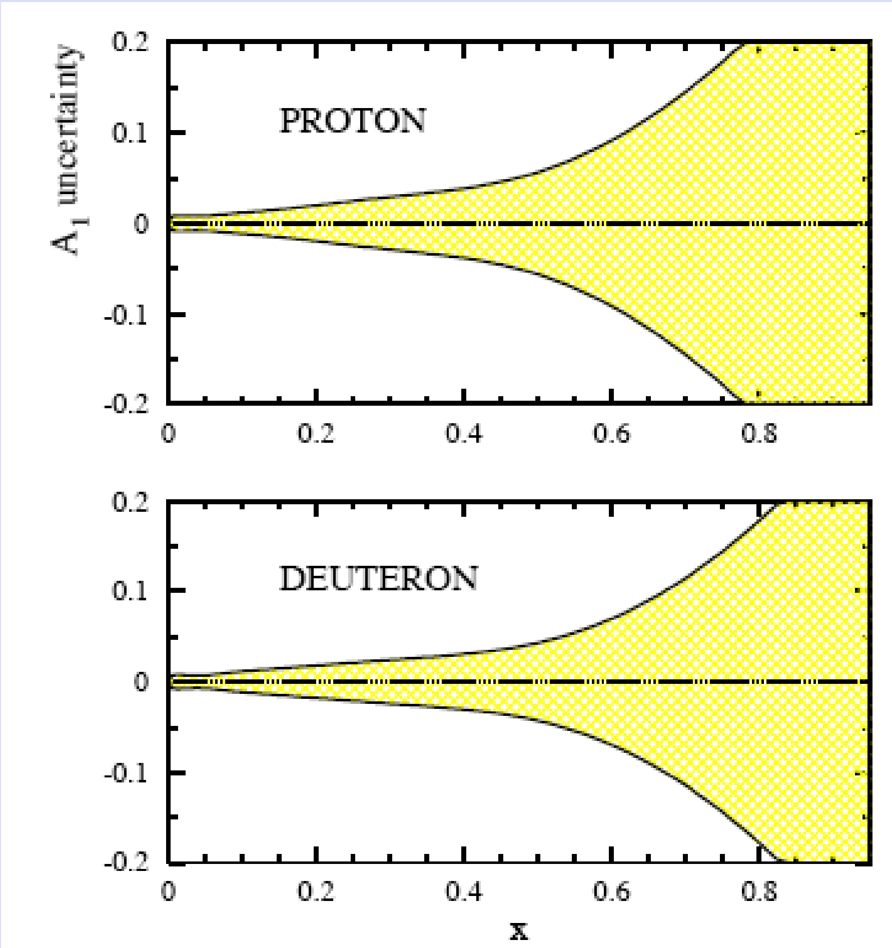
SU(6): $$p\uparrow = \frac{1}{\sqrt{2}} u\uparrow (ud)_{S=0} + \frac{1}{\sqrt{18}} u\uparrow (ud)_{S=1} - \frac{1}{3} u\downarrow (ud)_{S=1} - \frac{1}{3} d\uparrow (uu)_{S=1} - \frac{\sqrt{2}}{3} d\downarrow (uu)_{S=1},$$

Model for x --> 1	A_1^p	A_1^n	d/u	Δu/u	Δd/d
SU(6)	5/9	0	1/2	2/3	-1/3
w/ hyperfine ($E_{S=0} < E_{S=1}$)	1	1	0	1	-1/3
One gluon exchange	1	1	0	1	-1/3
Suppressed symmetric WF	1	1	0	1	-1/3
S=1/2 dominance	1	1	1/14	1	1
$\sigma_{1/2}$ dominance	1	1	1/5	1	1
pQCD (conserved helicity)	1	1	1/5	1	1

World Data on A_1



Measurements (outside of JLab)

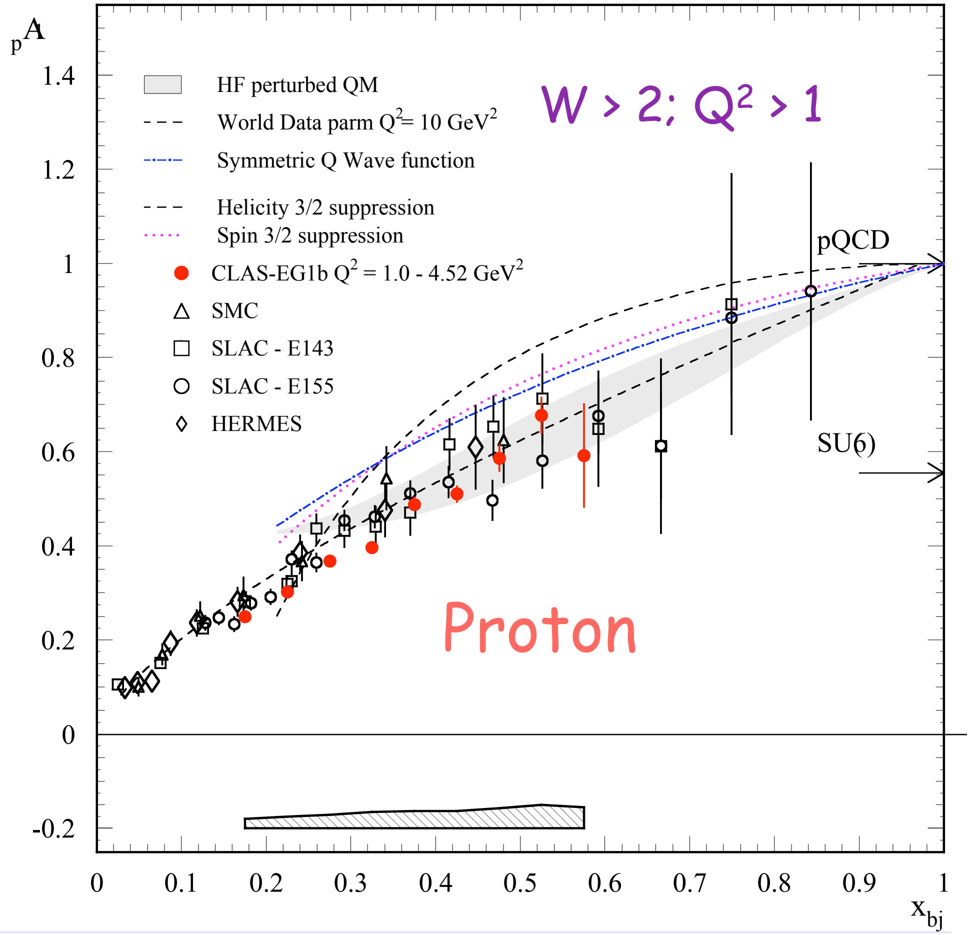


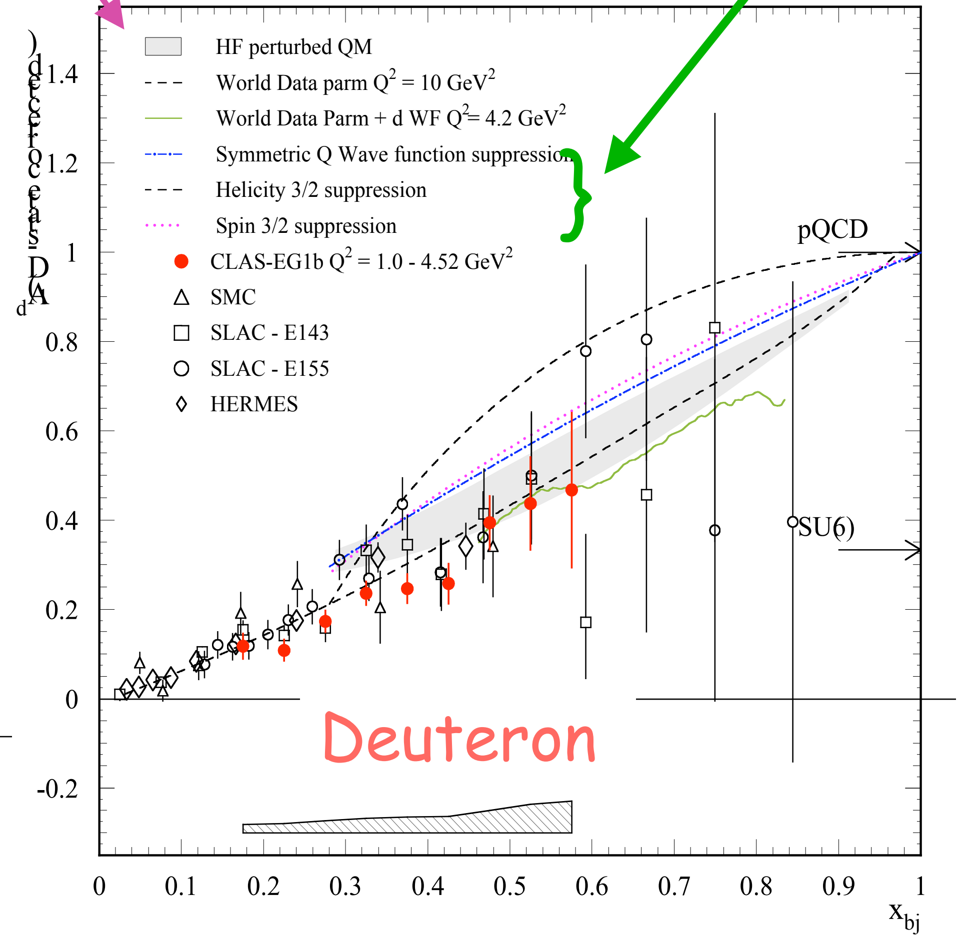
From NLO analysis on PDFs

Existing Data from CLAS

Isgur, PRD **59**, 034013 (2003)

Close and Melnitchouk, PRC **68**, 035210 (2003)



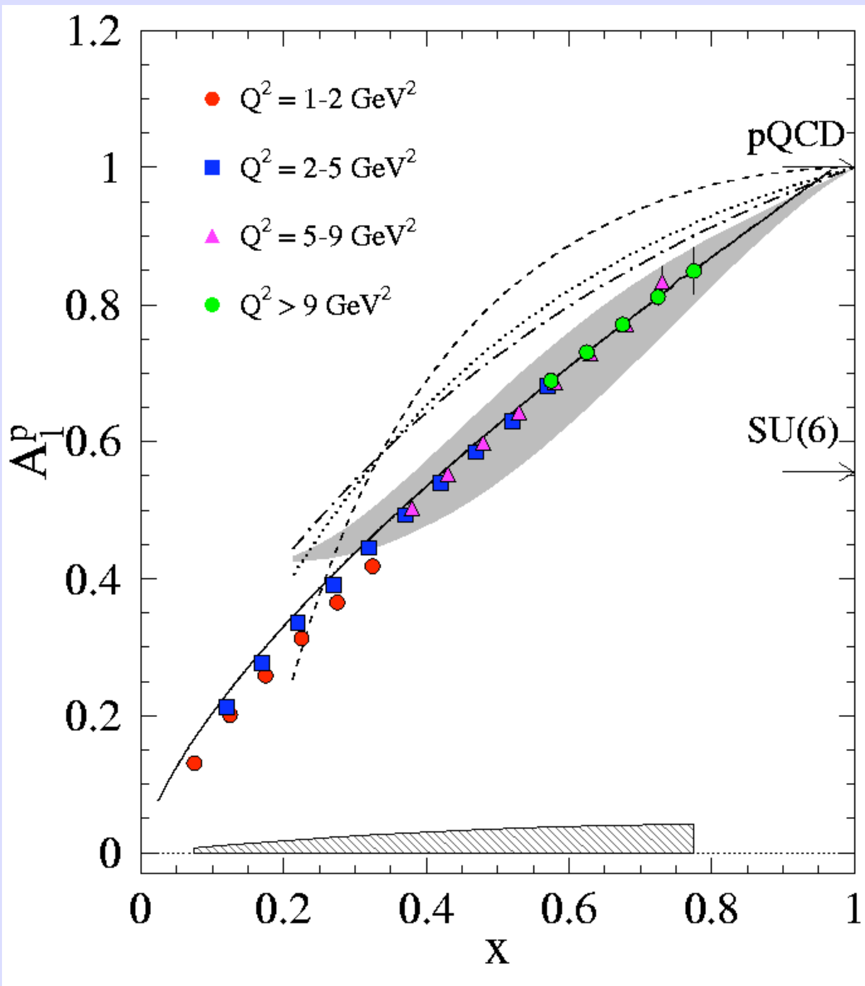


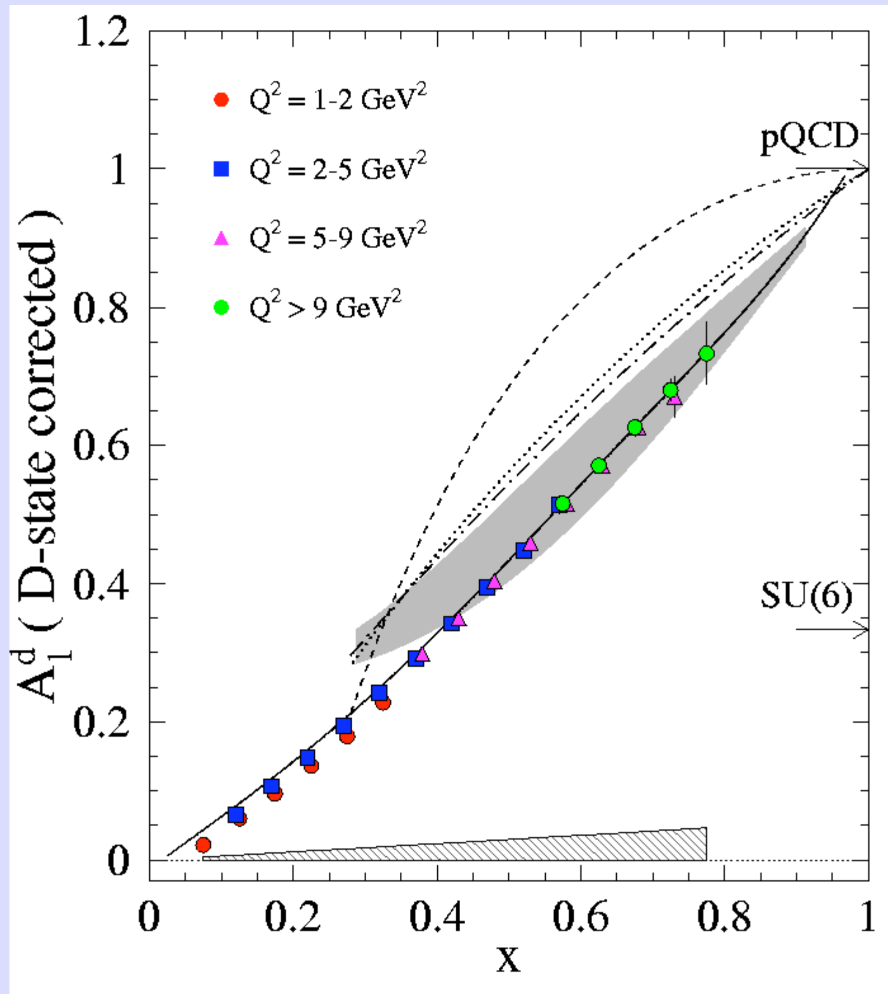
Predicted Data from CLAS12

Proton

W > 2; Q^2 > 1

Deuteron





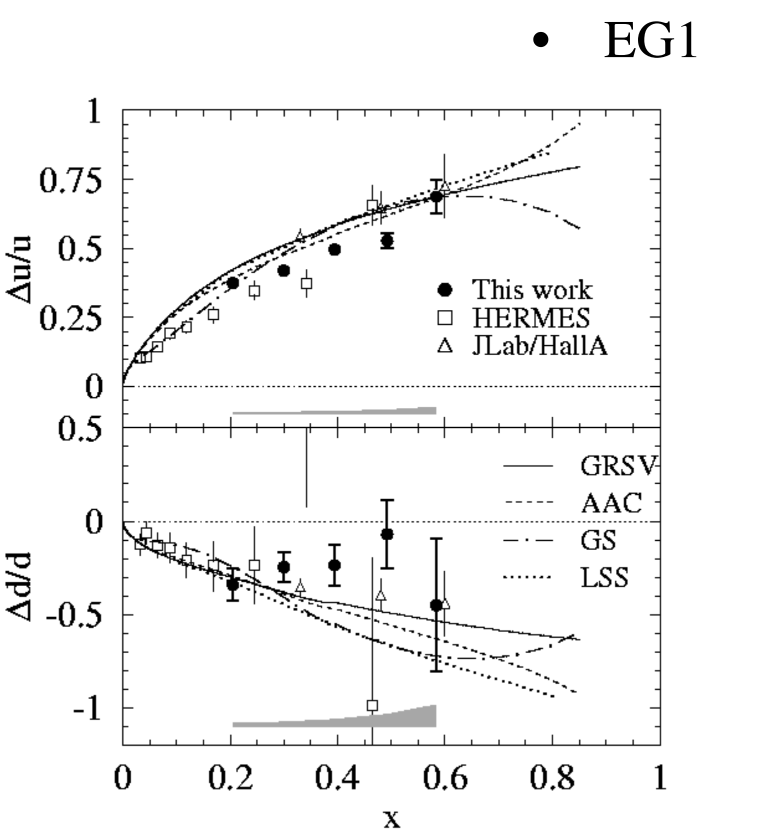
Quark polarization in the valence limit

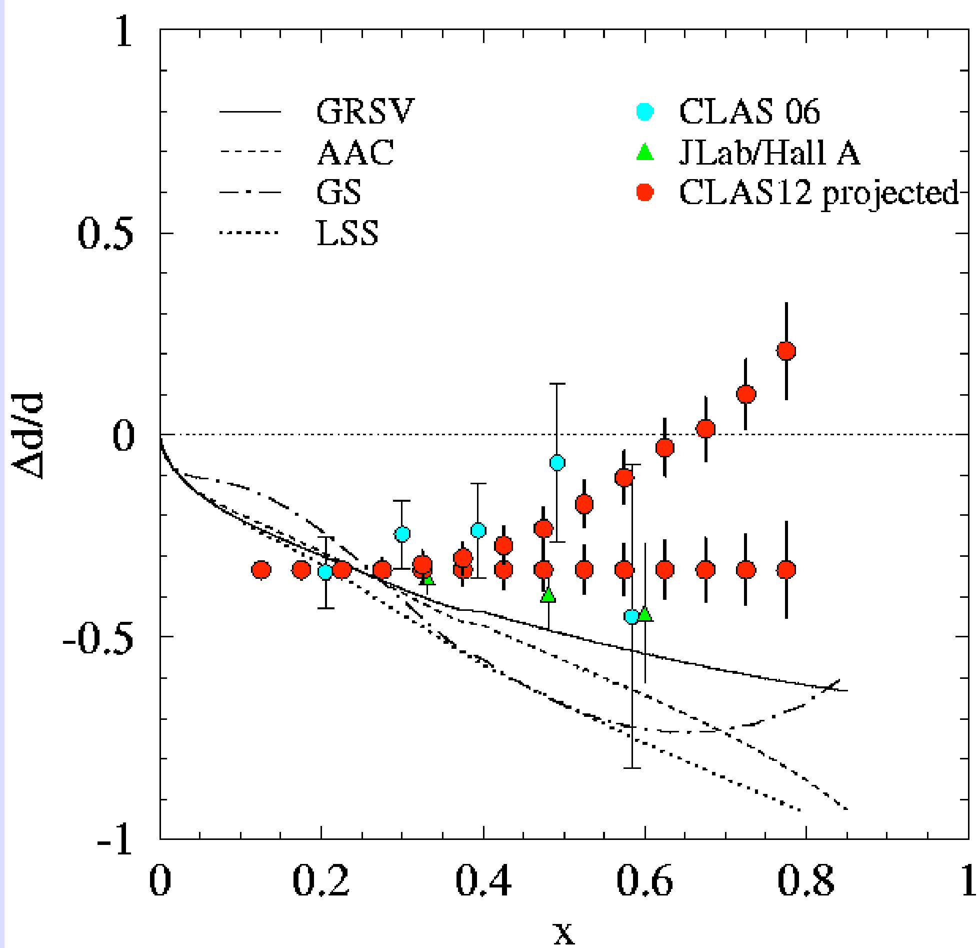
$$A_1(x, Q^2) = \frac{\sum e_i^2 \Delta q_i(x, Q^2)}{\sum e_i^2 q_i(x, Q^2)}$$

Simulated Data for EG12

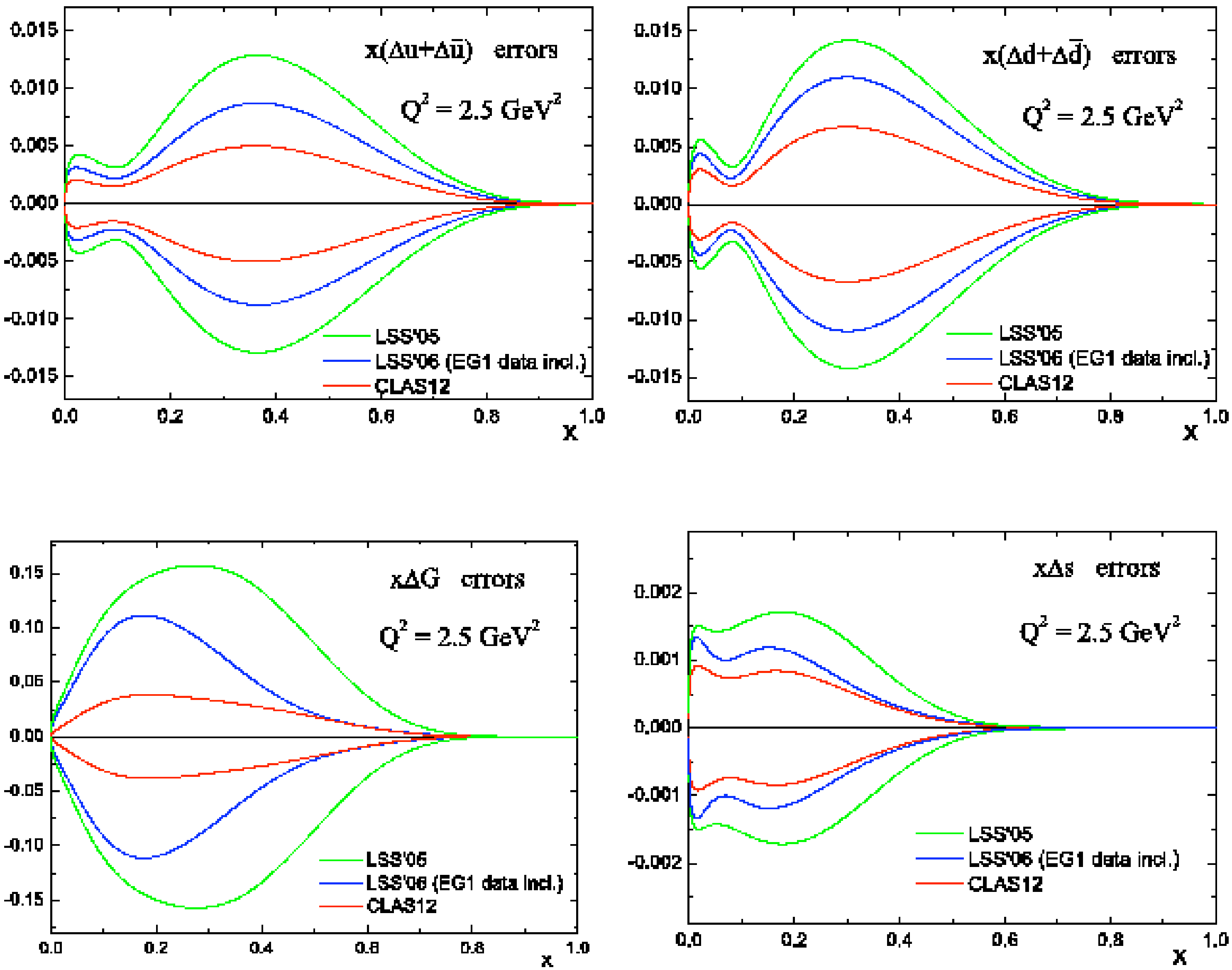
Extracted from A_1^p, A_1^d and d/u

Existing Data





Improvements in Δu, Δd, ΔG, Δs

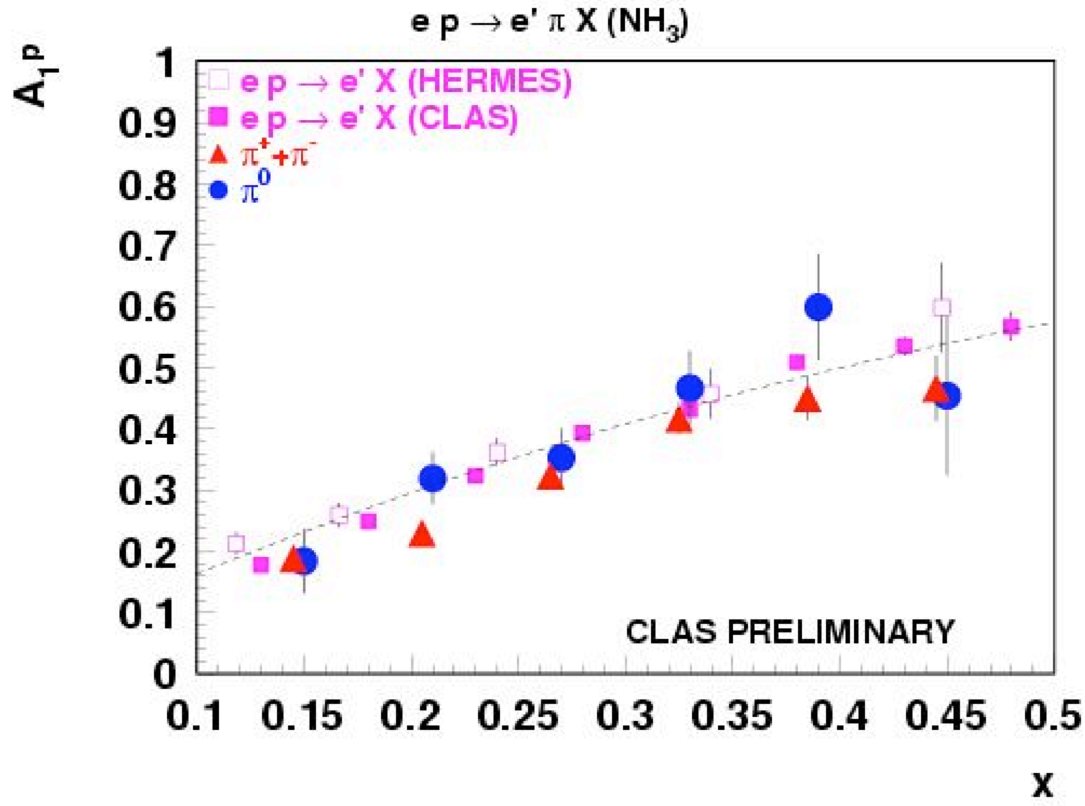


Flavor decomposition from SIDIS

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_{q'} e_{q'}^2 q'(x,Q^2) D_{q'}^h(z,Q^2)}$$

- Existing EG1 data show that factorization works remarkably well

- g_1/F_1 for inclusive, $\pi^+ + \pi^-$, and π^0 are consistent with each other in the range $0.4 < z < 0.7$, as expected in LO with factorization and current fragmentation dominance.
- No significant z-dependence seen for $0.3 < z < 0.7$; only weak p_T dependence.



Flavor decomposition from SIDIS

- Combined DIS and SIDIS analysis at NLO (e.g., Sassot et al.)
- "Model independent" approach (Frankfurt & Strikman): Solve 2 independent equations for Δu_V and Δd_V:

(Requires that fragmentation functions are spin-independent)

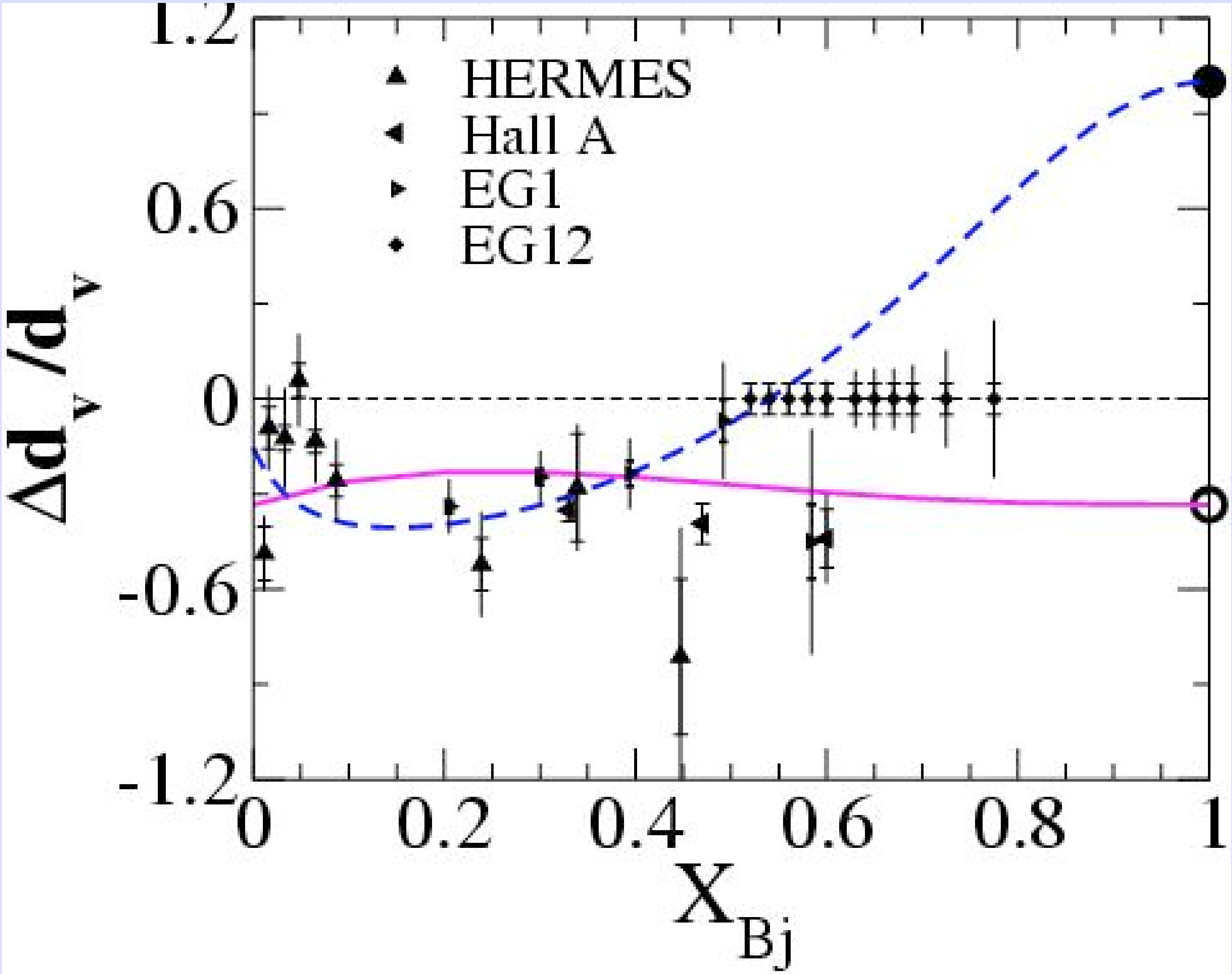
$$A^{\pi^+-\pi^-} \equiv \frac{N^{\pi^+}_{\uparrow\downarrow} - N^{\pi^-}_{\uparrow\downarrow} - N^{\pi^+}_{\uparrow\uparrow} + N^{\pi^-}_{\uparrow\uparrow}}{N^{\pi^+}_{\uparrow\downarrow} - N^{\pi^-}_{\uparrow\downarrow} + N^{\pi^+}_{\uparrow\uparrow} - N^{\pi^-}_{\uparrow\uparrow}}$$

$$A^{\pi^+-\pi^-}_{1,p} = \frac{4\Delta u_v(x) - \Delta d_v(x)}{4u_v(x) - d_v(x)}$$

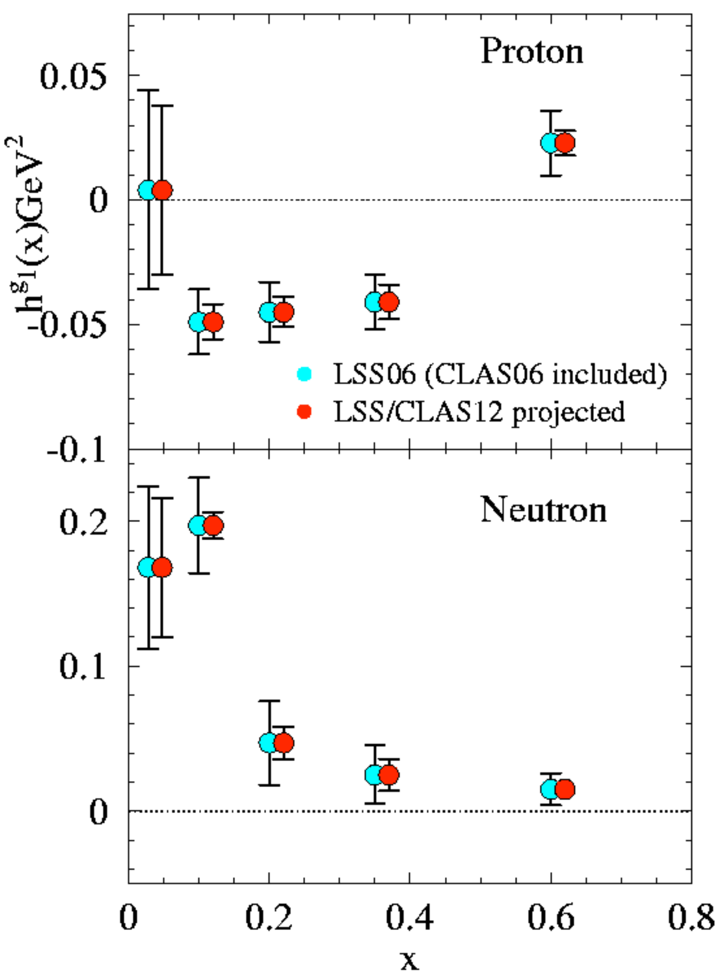
$$A^{\pi^+-\pi^-}_{1,{}^2H} = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

$$\frac{\Delta d_v(x)}{d_v(x)} = \frac{4}{5}A^{\pi^+-\pi^-}_{1,{}^2H}\left(\frac{u}{d}+1\right) - \frac{1}{5}A^{\pi^+-\pi^-}_{1,p}\left(\frac{4u}{d}-1\right)$$

Flavor Decomposition from SIDIS



Higher Twist from g_1



$Q^2 \approx 1-5\,GeV^2,\ 4 < W^2 < 10\,GeV^2$ — *preasymptotic region*

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} F_1(x,Q^2)_{exp} = g_1(x,Q^2)_{exp} \overset{\chi^2}{\Longleftrightarrow} g_1(x,Q^2)_{LT} + h^{g_1}(x)/Q^2$$

F_2^{NMC}, R_{1998}(SLAC)

in model independent way

$$\int_0^1 dx\, h^{g_1}(x) = \frac{4}{9} M^2 (d_2 + f_2)$$

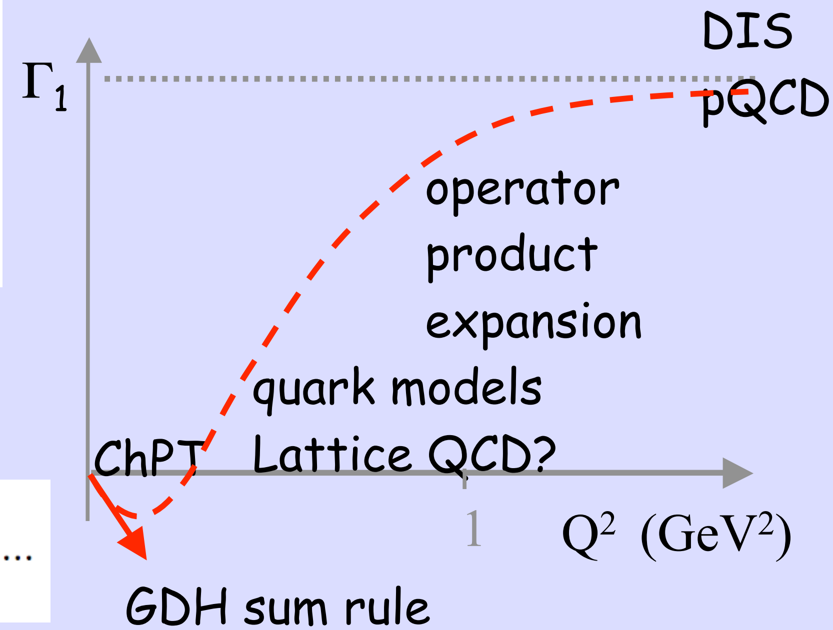
HT (τ=3)

HT (τ=4)

Higher Twist from Moments

$$\Gamma_1^{(n)} = \int_0^1 x^n g_1(x,Q^2)\,dx = \frac{a_n}{2}, \quad n = 0,2,4,\ldots,$$

$$\Gamma_2^{(n)} = \int_0^1 x^n g_2(x,Q^2)\,dx = \frac{1}{2}\frac{n}{n+1}(d_n - a_n), \quad n = 2,4,\ldots,$$



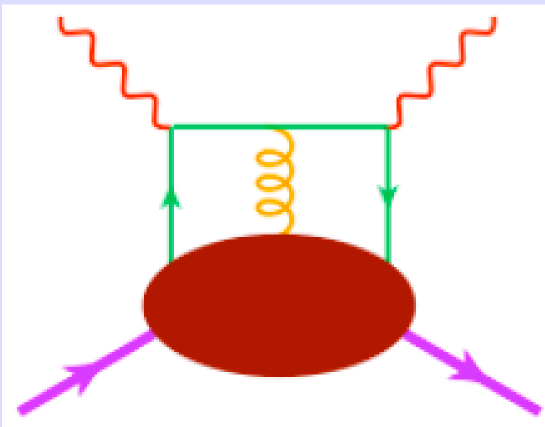
Bjorken Sum Rule:

$$\Gamma_1^{p-n} = \frac{g_A}{6}\left[1 - \frac{\alpha_s}{\pi} - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.21\left(\frac{\alpha_s}{\pi}\right)^3\right] + \frac{\mu_4^{p-n}}{Q^2} + \ldots$$

$$\mu_4^{p-n} = \frac{M^2}{9}\left(a_2^{p-n} + 4d_2^{p-n} + 4f_2^{p-n}\right)$$

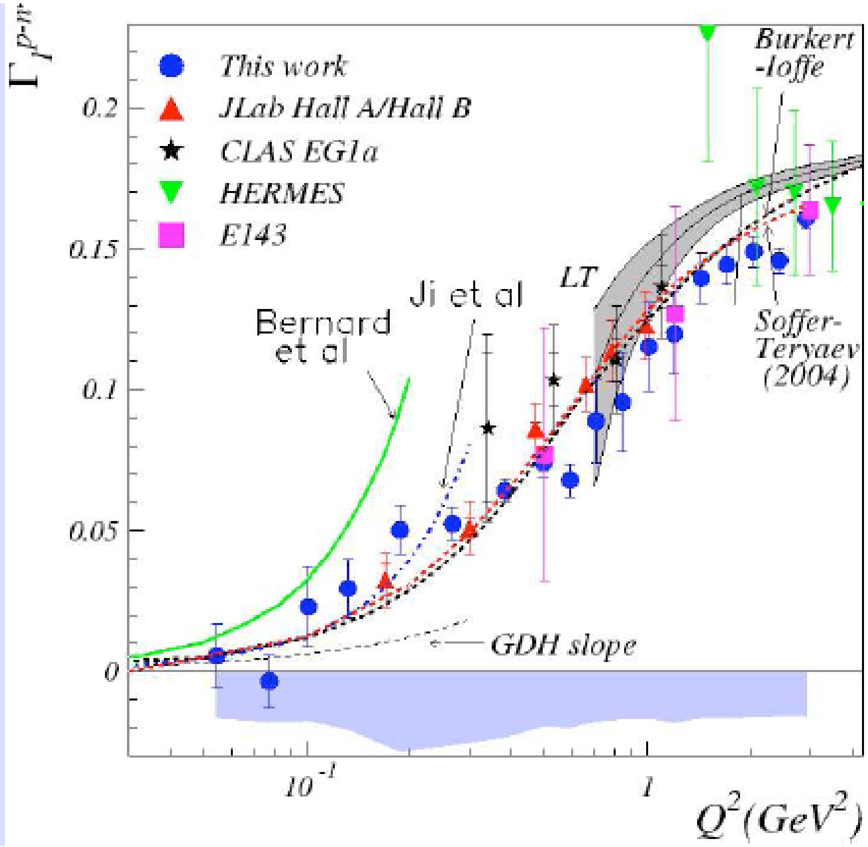
$$d_2^{p-n} = \int_0^1 dx\, x^2 \left(2g_1^{p-n} + 3g_2^{p-n}\right)$$

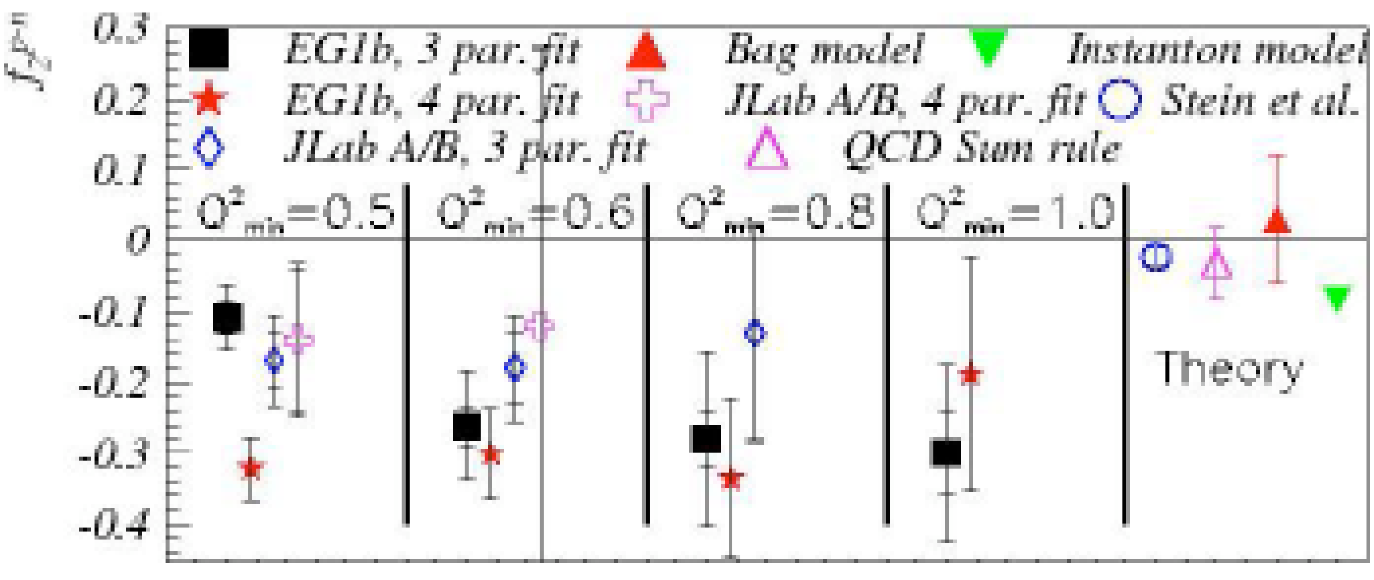
Twist 3:



Higher Twist from Moments

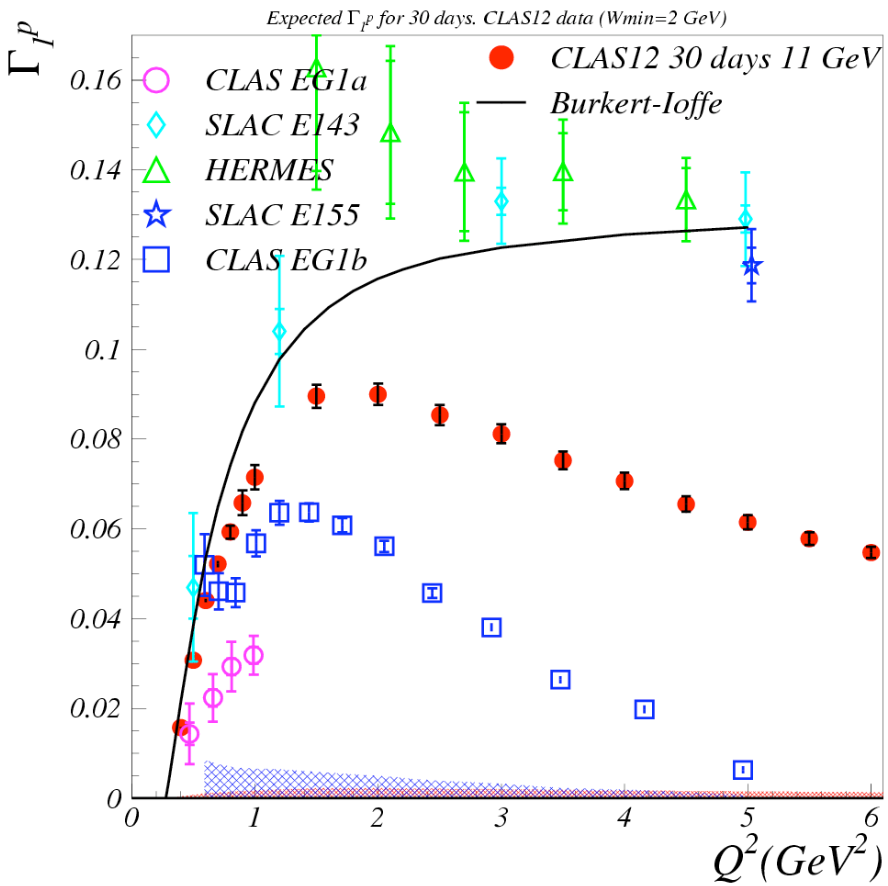
- Example from existing EG1b data
- Fit Γ_1^{p-n} to powers of $1/Q^2$ and extract f_2^{p-n}
- CLAS12 data needed to improve accuracy

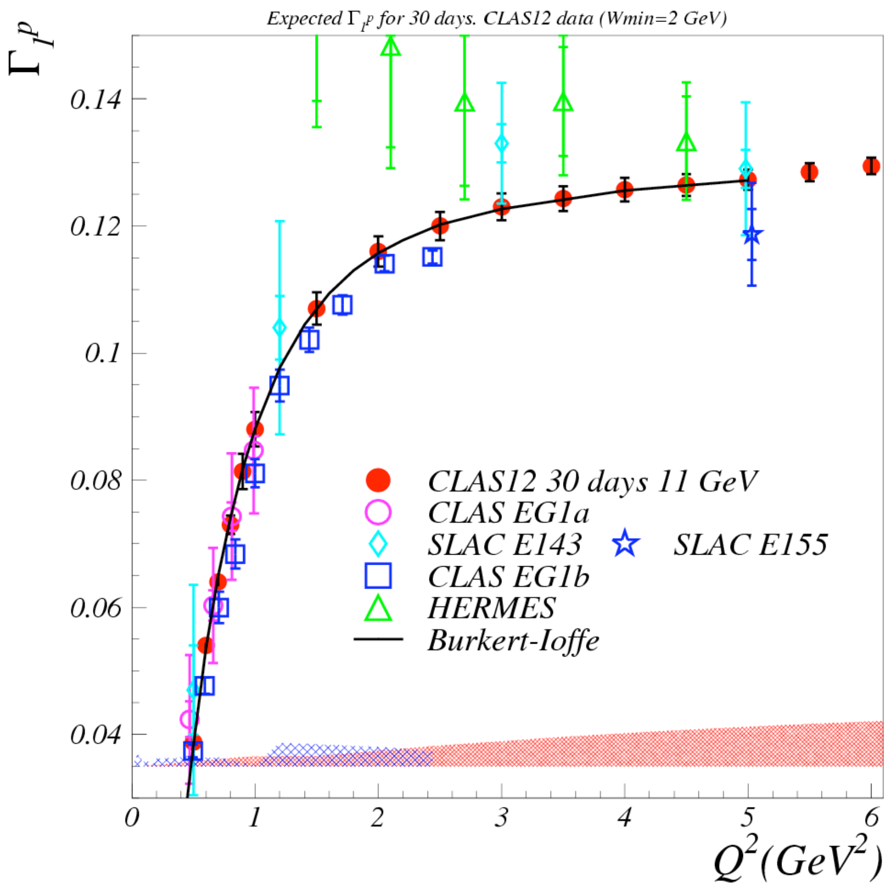




Sum Rules

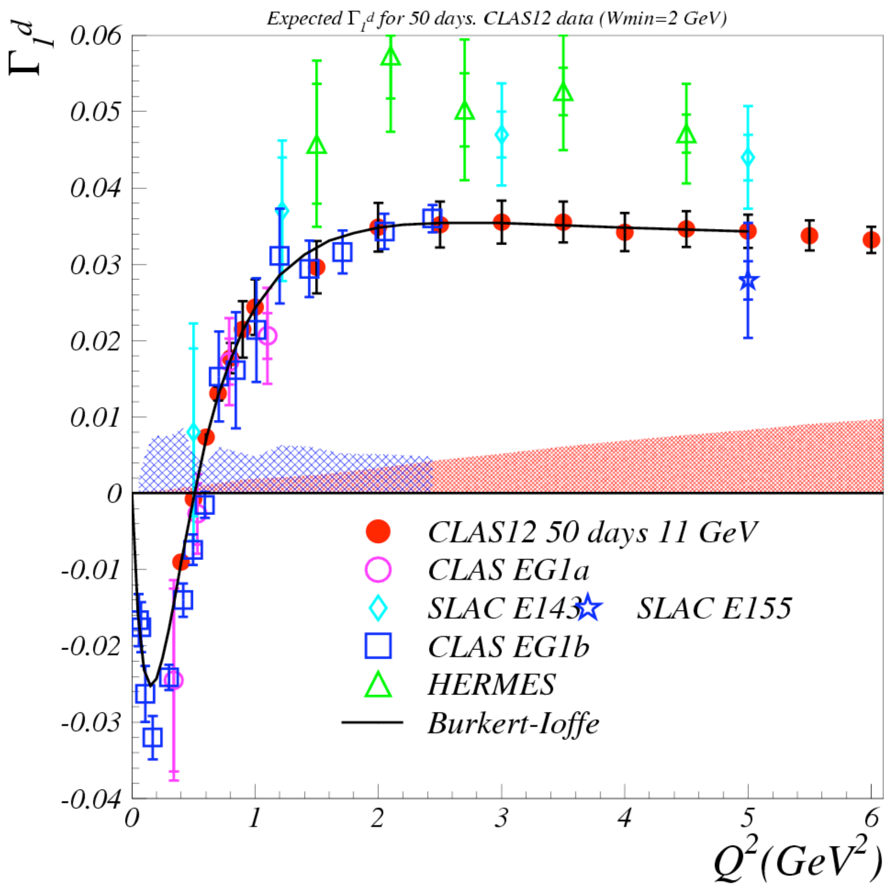
- Coverage predicted for CLAS12 Γ_1^p
- Expected error bars for CLAS12 Γ_1^p

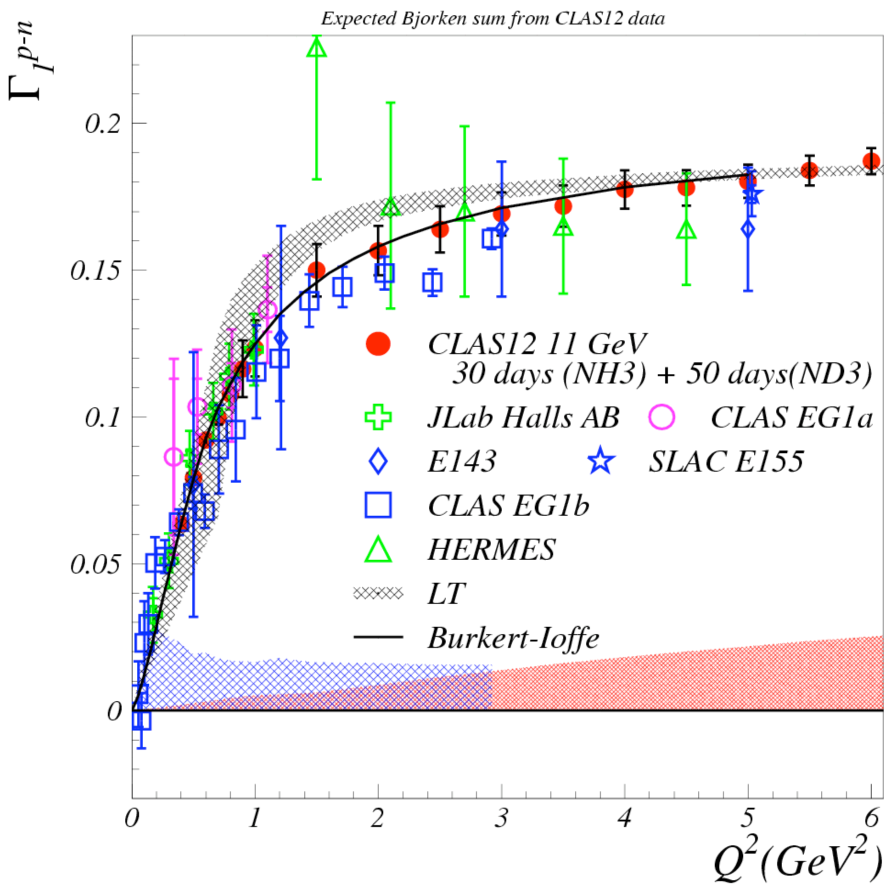




Sum Rules

- Expected errors for CLAS12 Γ_1^d
- Expected errors for CLAS12 Γ_1^{p-n}





Summary

- There is much to learn in a third decade of spin structure function measurements
- JLab and CLAS12 will play a key role in this
- Spin structure measurements are flagship experiments for the 12 GeV program
- Given past experience, this experiment is technically feasible and of great theoretical interest