# Probing the Spin Structure of the Neutron:

# New Experimental Results on $d_2$ and $g_2$ for the Neutron from JLab

**Brad Sawatzky**
**Jefferson Lab**

**E06-014, E12-06-121, and Hall A Collaborations**

**HiX 2014 Conference**
**November 17—21, 2013**

# SSF Measurements at JLab

- $g_1$ measured in all halls
  - $NH_3$, $ND_3$ in all Halls
  - $^3$He in Hall A
- $g_2$ in C and A
- **Duality in $g_1$**
- **Transverse structures $A_2$ and $g_T$**
- **Moments and twist-3**
- Sum Rules: GDH, B-C, Bjorken
- *n* SSF's from $^3$He and from *d* - *p*

| Inclusive Program at 6 GeV | | | | |
|---|---|---|---|---|
| Experiment | Hall | Target | Measured quantity | Kinematics $Q^2$ GeV$^2$ |
| 94-010 | A | $^3$He | A∥, A⊥ | Resonances 0.1 – 0.9 |
| CLAS eg1a-b | B | *p, d* | A∥ | DIS, Resonances 0.2 – 3.5 |
| 97-103 | A | $^3$He | A⊥ | DIS 0.6 – 1.4 |
| 97-110 | A | $^3$He | A∥, A⊥ | Elastic, Resonances 0.02 – 0.5 |
| 99-117 | A | $^3$He | A∥, A⊥ | DIS 2.7, 3.5, 4.8 |
| 01-006 (RSS) | C | *p, d* | A∥, A⊥ | Resonances 1.3 |
| 01-012 | A | $^3$He | A∥, A⊥ | Resonances 1 – 4 |
| CLAS eg4 | B | *p* | A∥ | Elastic, Resonances 0.01 – 0.5 |
| 07-003 (SANE) | C | *p* | A∥, A⊥ | DIS, Resonances 1.6 – 6 |
| 06-014 | A | $^3$He | A∥, A⊥ | DIS <3> |
| 08-027 (g2p) | A | *p* | A∥, A⊥ | Resonances 0.03 – 0.3 |

Slide from O. Rondon

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Slide from O. Rondon

# Polarized DIS cross sections

$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2}{MQ^2}\frac{E'}{\nu E}\left[(E+E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)\right] = \Delta\sigma_\parallel$$

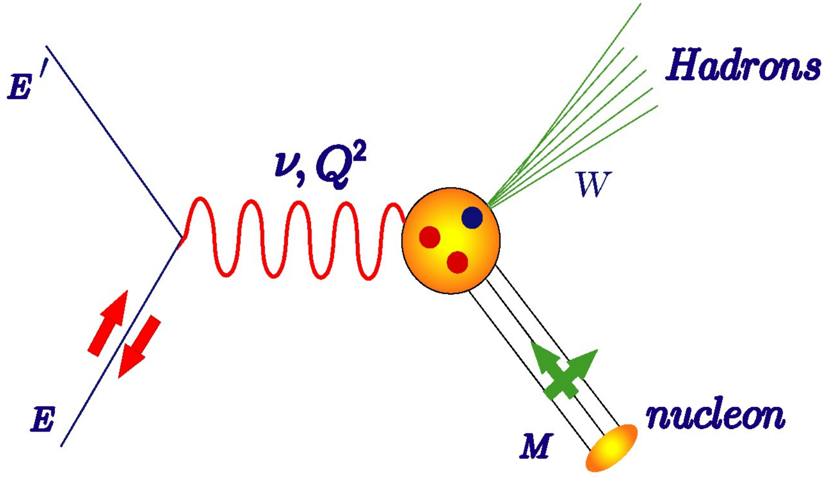
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right] = \Delta\sigma_\perp$$

$Q^2$ = 4-momentum transfer squared of the virtual photon.

$\nu$ = energy transfer.

$\theta$ = scattering angle.

$x = \frac{Q^2}{2M\nu}$ fraction of nucleon momentum carried by the struck quark.

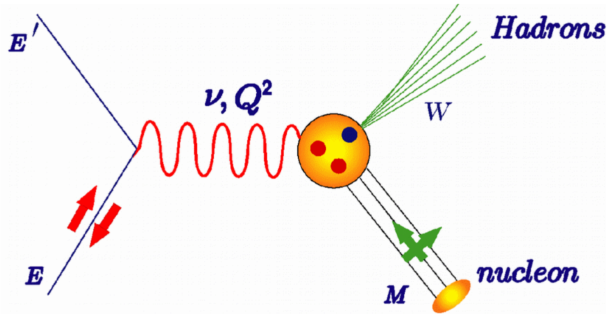


# What are $g_1$ and $g_2$?

- The "g's" play a role analogous to the "F's" in the unpolarized cross section

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2\sin^4\frac{\theta}{2}}\left(\frac{2}{M}F_1(x,Q^2)\sin^2\frac{\theta}{2} + \frac{1}{\nu}F_2(x,Q^2)\cos^2\frac{\theta}{2}\right)$$

- F encodes information about the momentum structure of the nucleon

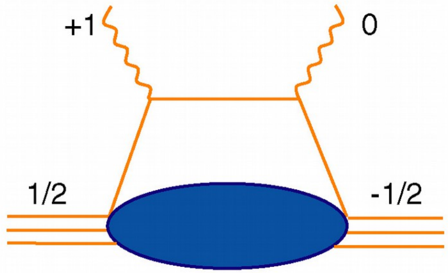



- $g_1$ and $g_2$ encode information about the spin structure of the target nucleon

- The Parton Model
  - → $g_1$ is a measure of the spin distribution among the individual constituent quarks (ie. aligned parallel and anti-parallel to the nucleon spin)
  - → $g_2$ ???

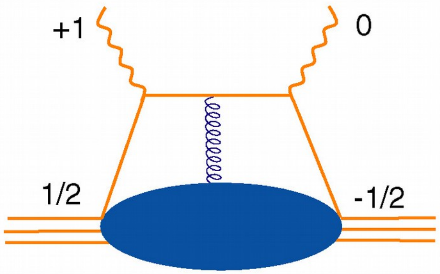
# $g_2$ and Quark-Gluon Correlations

twist-2




QCD allows the helicity exchange to occur in two principle ways

twist-3




Carry one unit of orbital angular momentum

Couple to a gluon

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

- a twist-2 term (Wandzura & Wilczek, 1977):

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 92):

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left(\frac{m_q}{M}h_T(y,Q^2) + \xi(y,Q^2)\right)\frac{dy}{y}$$

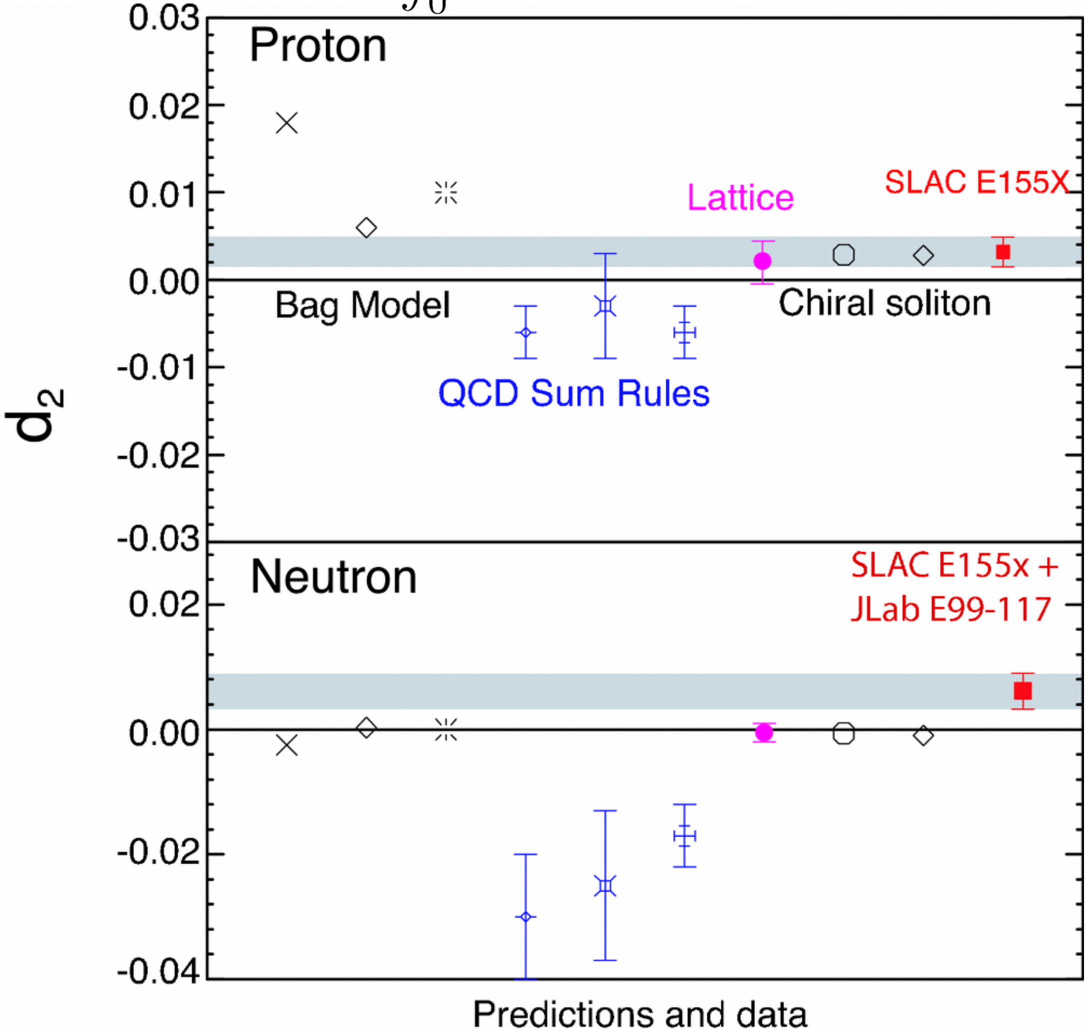
transversity

quark-gluon correlation

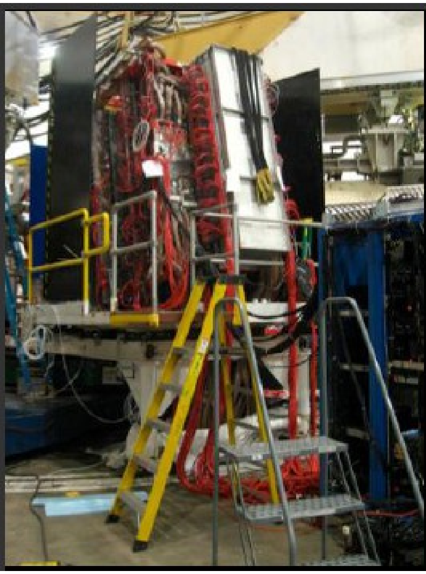
# $d_2$: A clean probe of quark-gluon correlations

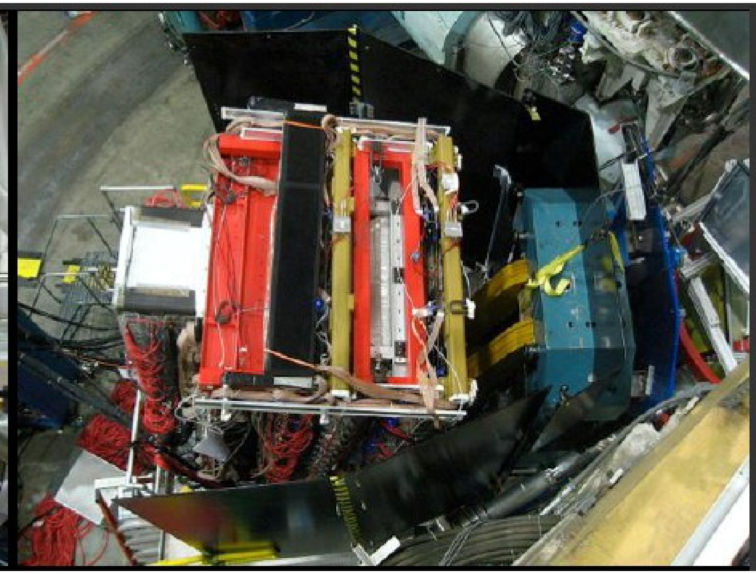
$$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx = 3\int_0^1 x^2\bar{g}_2(x,Q^2)dx$$

- $d_2$ is a clean probe of quark-gluon correlations / higher twist effects
  - → $d_2$ is the 2nd moment of a sum of the spin structure functions
  - → matrix element in the Operator Product Expansion
    - » *it is cleanly computable using Lattice QCD*
- Connected to the *color Lorentz (transverse) force* acting on the struck quark (Burkardt)
  - → same underlying physics as in SIDIS $k_\perp$ studies



# E06-014: The Neutron $d_2$ (Hall A)



- A measurement of the neutron $d_2$
  - → Polarized $^3$He target
  - → Large acceptance detector to measure asyms (BigBite)
  - → High-precision device to measure unpol. x-sec (HRS)
  - → Focus: $d_2$, $g_2$ on the neutron
    - » extracted $A_1$, $g_1$ as well

# The Experiment

- A 4.75 and 5.9 GeV polarized electron beam scattering off a polarized $^3$He target
- Measure unpolarized cross section for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction $\sigma_0^{^3\mathrm{He}}$ in conjunction with the transverse asymmetry $A_\perp^{^3\mathrm{He}}$ and the parallel asymmetry $A_\parallel^{^3\mathrm{He}}$ for 0.23 < x < 0.65 with 2 < $Q^2$ < 5 GeV$^2$.
  - → Asymmetries measured by BigBite
  - → Absolute cross sections measured by L-HRS
- Determine $d_2^n$ using the relation

$$\begin{aligned}\tilde{d}_2(x,Q^2) &= x^2[2g_1(x,Q^2)+3g_2(x,Q^2)] \\ &= \frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0\left[\left(3\frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}+\frac{4}{y}\tan\frac{\theta}{2}\right)A_\perp+\left(\frac{4}{y}-3\right)A_\parallel\right]\end{aligned}$$

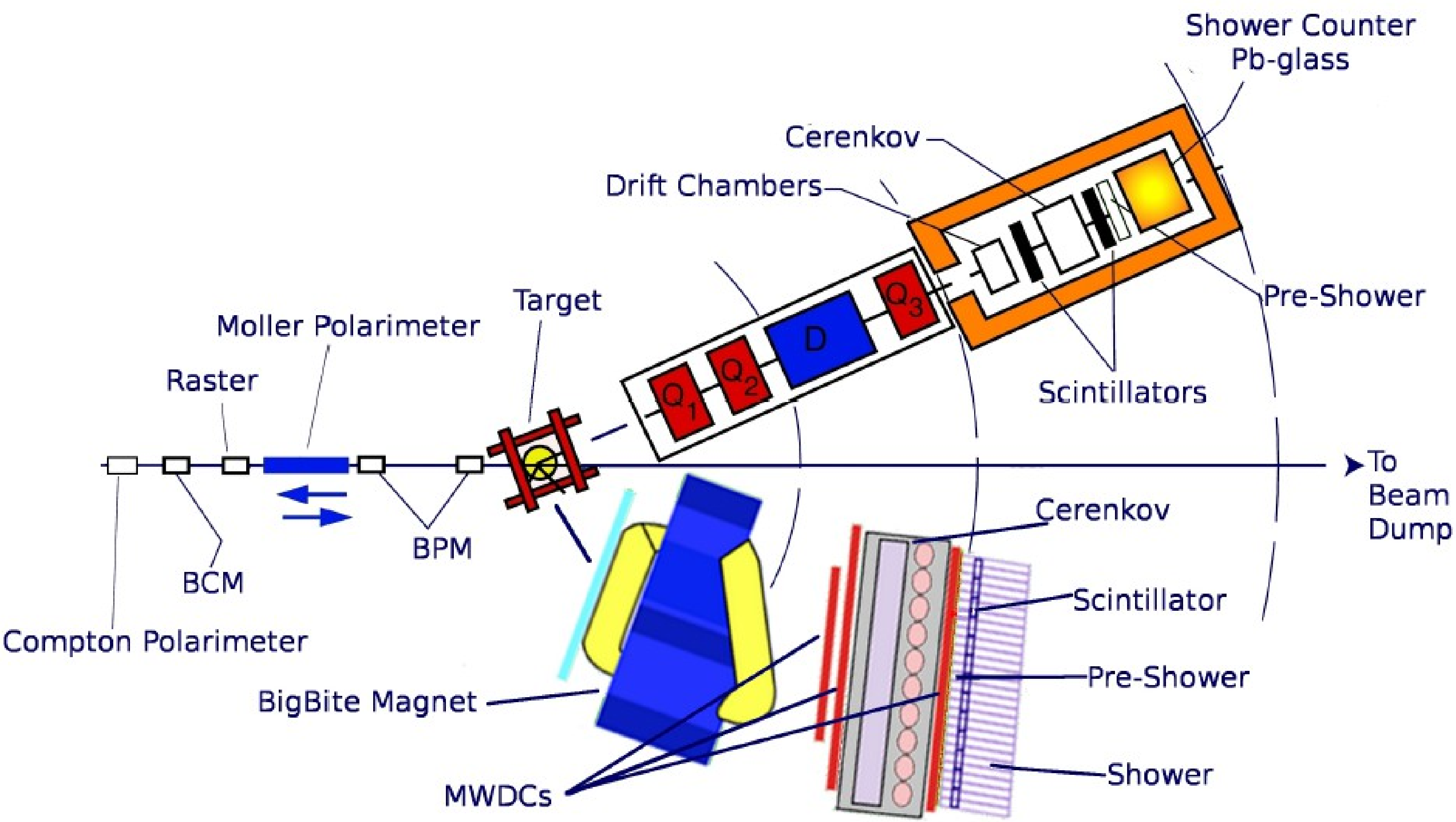
where,

$$A_\perp = \frac{\sigma^{\downarrow\Rightarrow}-\sigma^{\uparrow\Rightarrow}}{2\sigma_0} \qquad A_\parallel = \frac{\sigma^{\downarrow\Uparrow}-\sigma^{\uparrow\Uparrow}}{2\sigma_0}$$

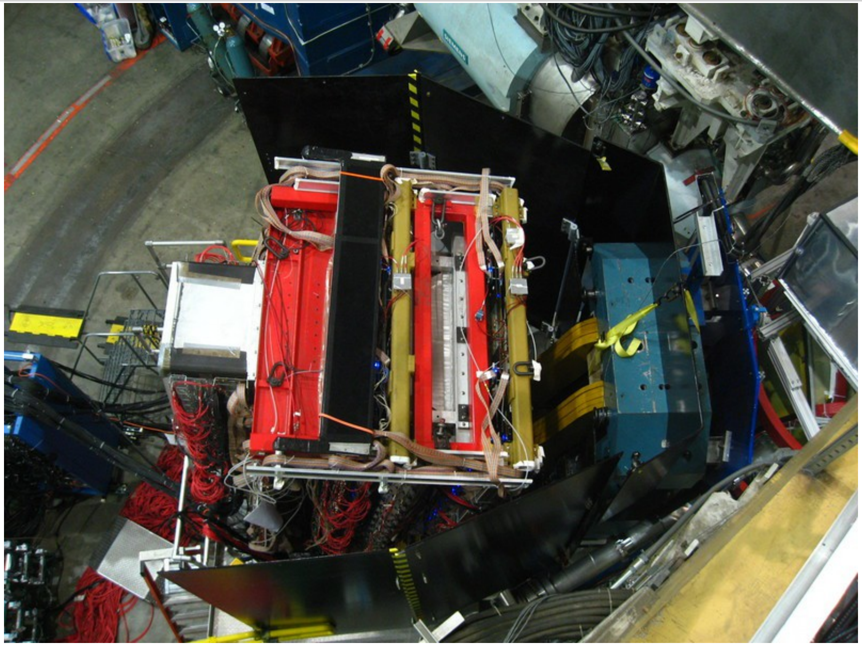
$$A_\perp^{^3He} = \frac{\Delta_\perp}{P_bP_t\cos\phi} \qquad A_\parallel^{^3He} = \frac{\Delta_\parallel}{P_bP_t}$$

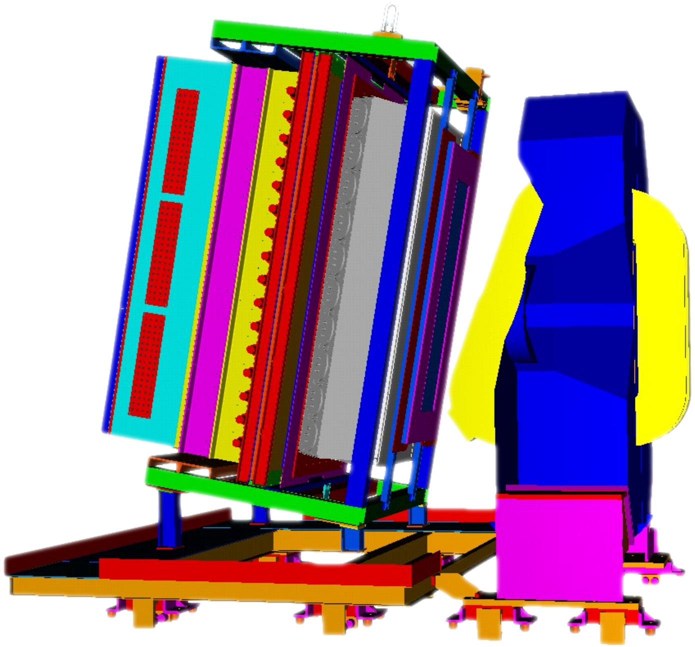
$$\Delta_\perp = \frac{(N^{\uparrow\Rightarrow}-N^{\uparrow\Rightarrow})}{(N^{\uparrow\Rightarrow}+N^{\uparrow\Rightarrow})} \qquad \Delta_\parallel = \frac{(N^{\downarrow\Uparrow}-N^{\uparrow\Uparrow})}{(N^{\downarrow\Uparrow}+N^{\uparrow\Uparrow})}$$

# Floor configuration for $d_2^n$



# BigBite Electron Stack

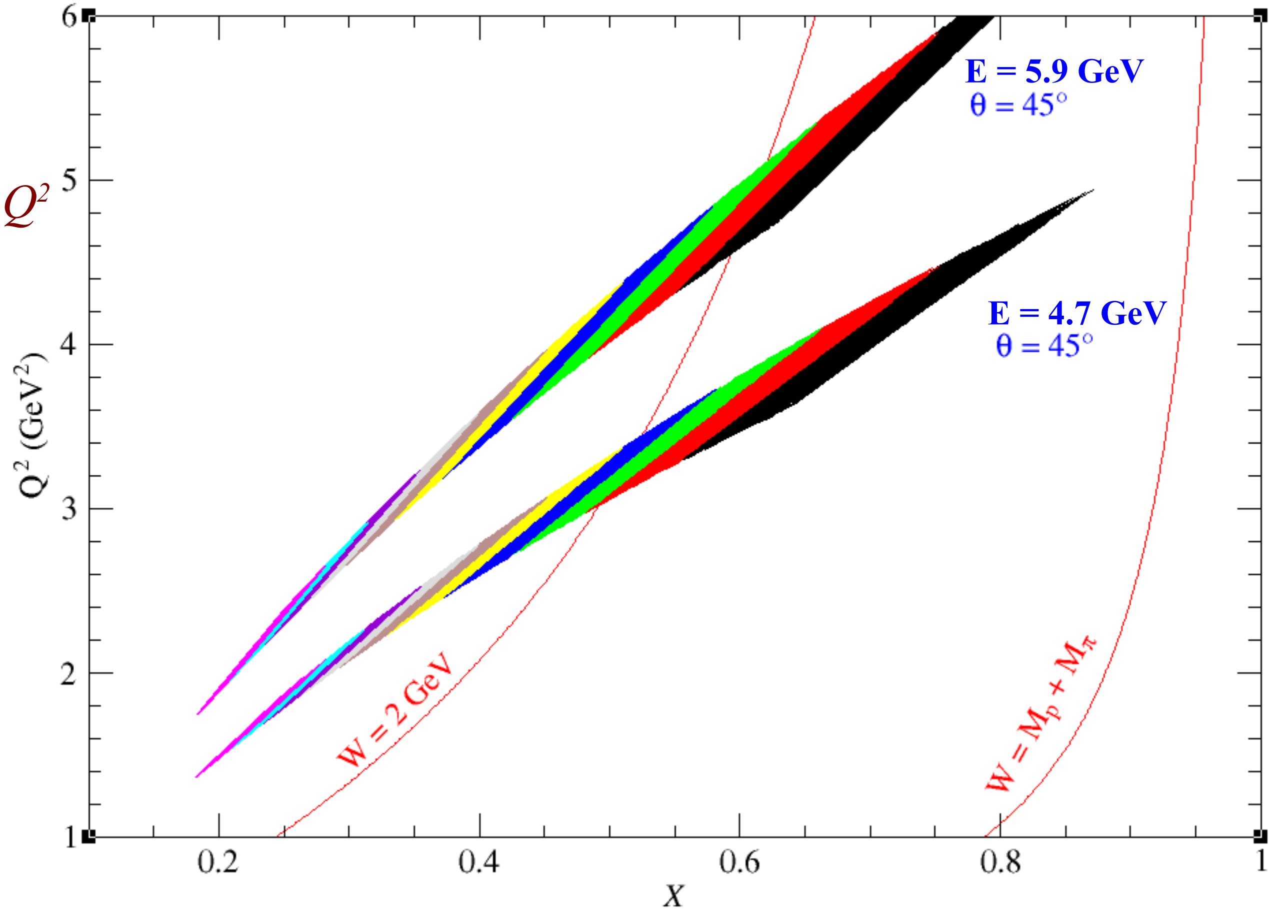




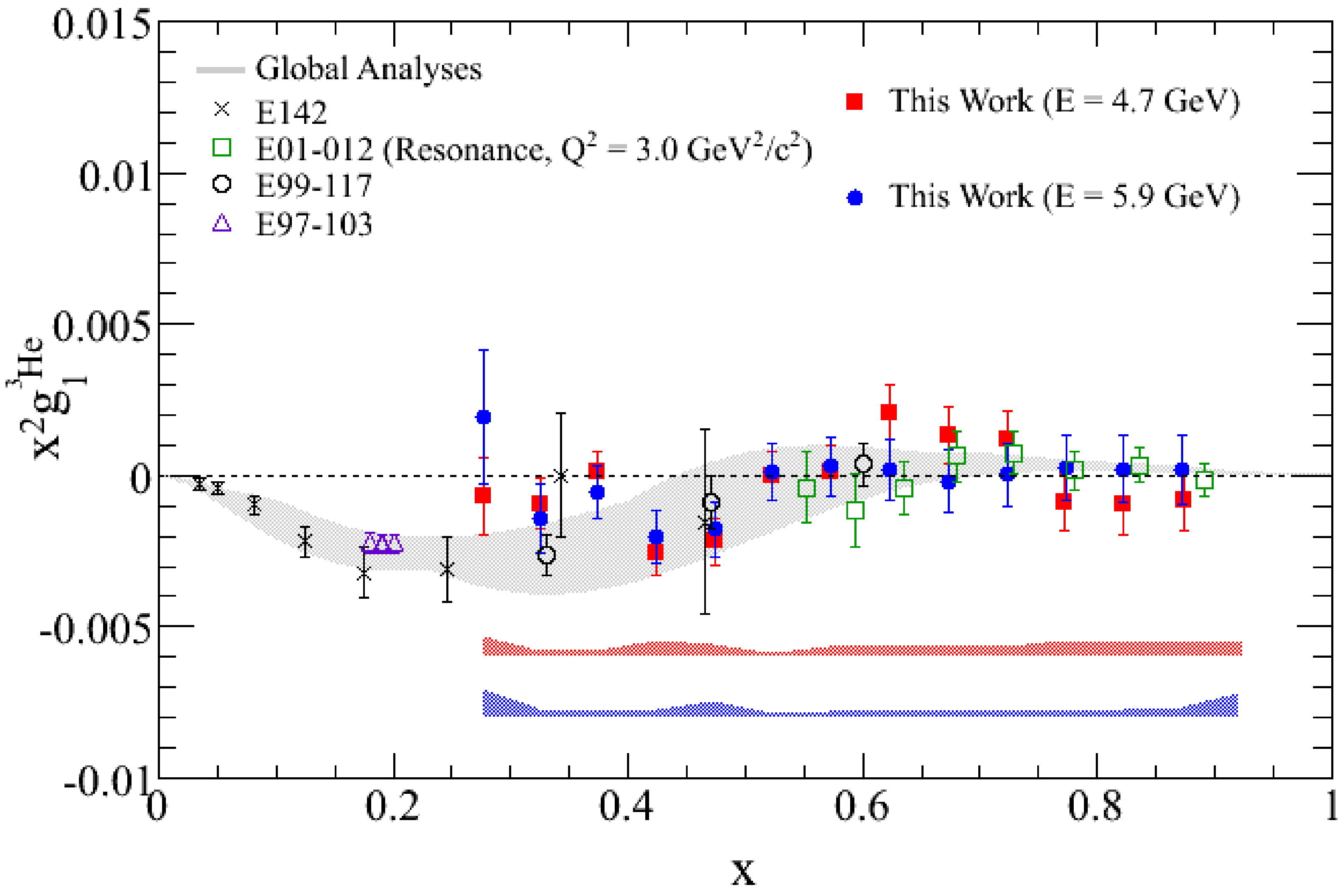
- **BigBite detector package:**
  - →3 Multi-wire drift chambers (MWDC) — Tracking
  - →Scintillator plane — Timing
  - →Pb-glass Calorimeter (Pre-shower + Shower) — Energy/PID
  - →Gas Cherenkov — PID

# Kinematics of the measurement

- Two beam energies 4.75 and 5.9 GeV (4 pass, 5 pass)
  - → provides a handle on the $Q^2$ dependence of $g_2$
  - → supports rad. correction calculations
- BigBite fixed at single scattering angle (θ=45°) (data divided into bins during analysis)
- Avoid resonance region as much as possible.

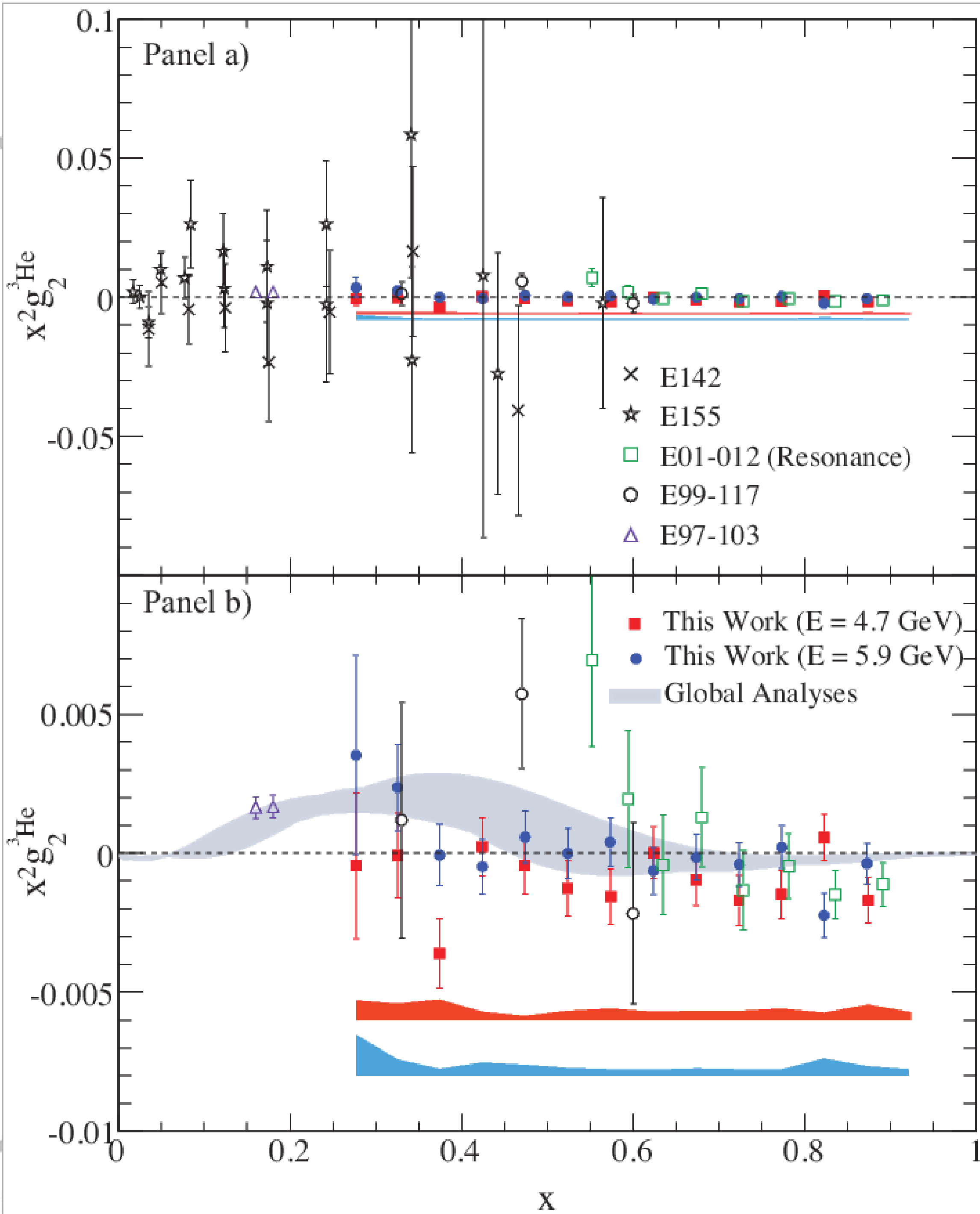


# $x^2 g_1$ for $^3$He



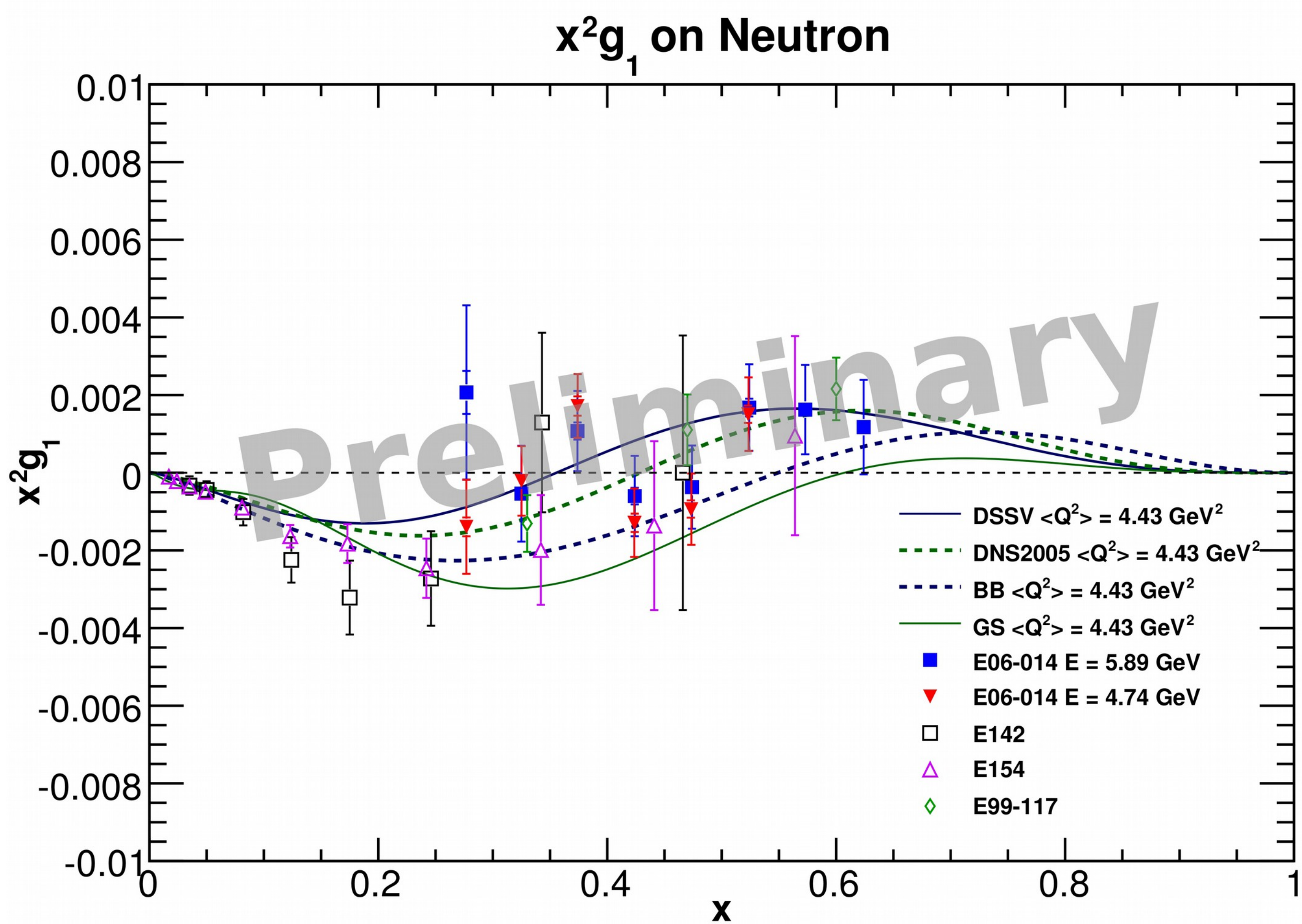
Global Analyses
E142
E01-012 (Resonance, Q² = 3.0 GeV²/c²)
E99-117
E97-103
This Work (E = 4.7 GeV)
This Work (E = 5.9 GeV)
x²g₁³He
x
0.015
0.01
0.005
0
-0.005
-0.01
0
0.2
0.4
0.6
0.8
1

# $x^2 g_2$ for $^3$He




- Panel (a) shows comparison to world data
- Panel (b) is zoomed by 10x on y-axis to show error bars
- Global analyses envelope includes $g_2^{ww}$ by
  → Bourelly, Soffer, Buccella; Stratmann, Thomas, Bissey, de Florian, Navarro, Sassot; Song

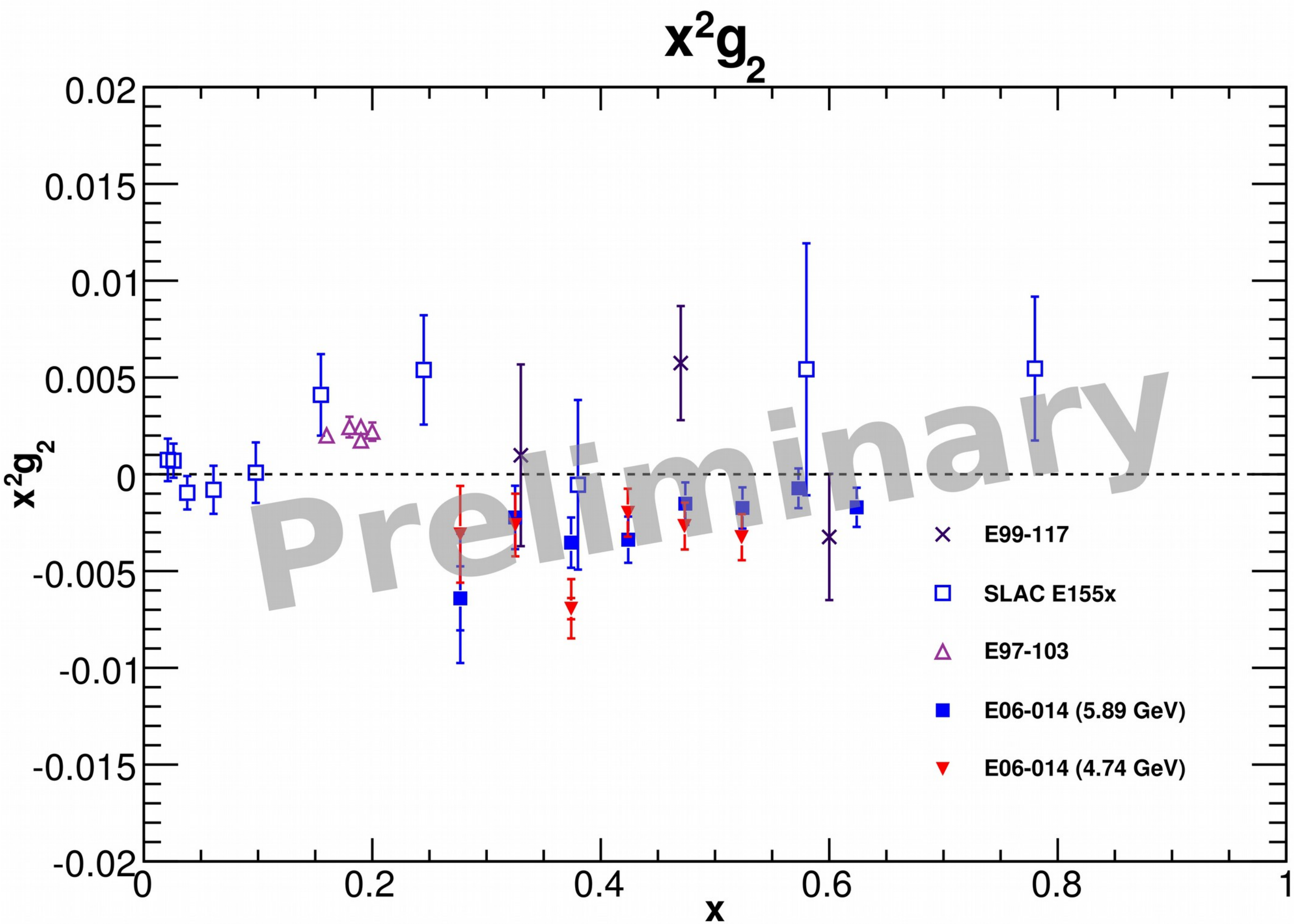
# $x^2g_1$ for the Neutron




- 3He → neutron extraction done using effective polarization model (*very preliminary*)

  → more sophisticated deconvolution method in progress (Melnitchouk, *et al*)

# $x^2g_2$ for the Neutron

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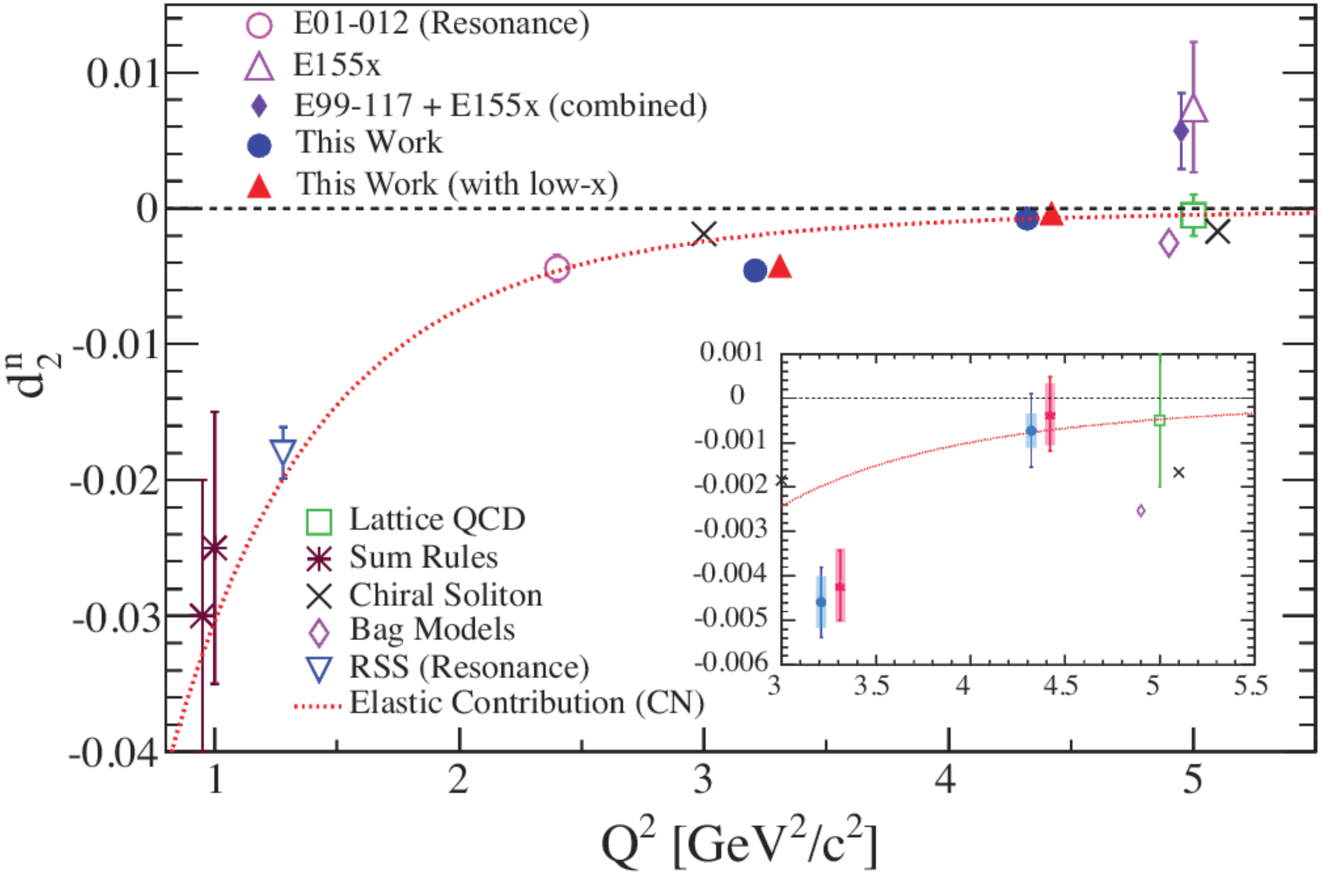
# $d_2$ for the Neutron

$$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx = 3\int_0^1 x^2 \bar{g}_2(x,Q^2)dx$$

*Posik et al., PRL* ***113*** *022002 (2014)*




Archival paper in progress (David Flay ~ Temple U.)

- Our results are consistent with Lattice QCD prediction
- d2n extracted at
  - → $\langle Q^2 \rangle \sim 3.3$ GeV$^2$ (E=4.7 GeV data)
  - → $\langle Q^2 \rangle \sim 4.3$ GeV$^2$ (E=5.9 GeV data)
- Shaded boxes in inset are systematic uncertainties
- Low-x contribution ($0.02 < x < 0.25$) is provided by fits to world data (small impact)
- $^3$He → neutron correction using eff. polarization method applied to $d_2$
  - → (Bissey et al. Phys Rev C, 65:064137, 2002)

# Moments of Structure Functions

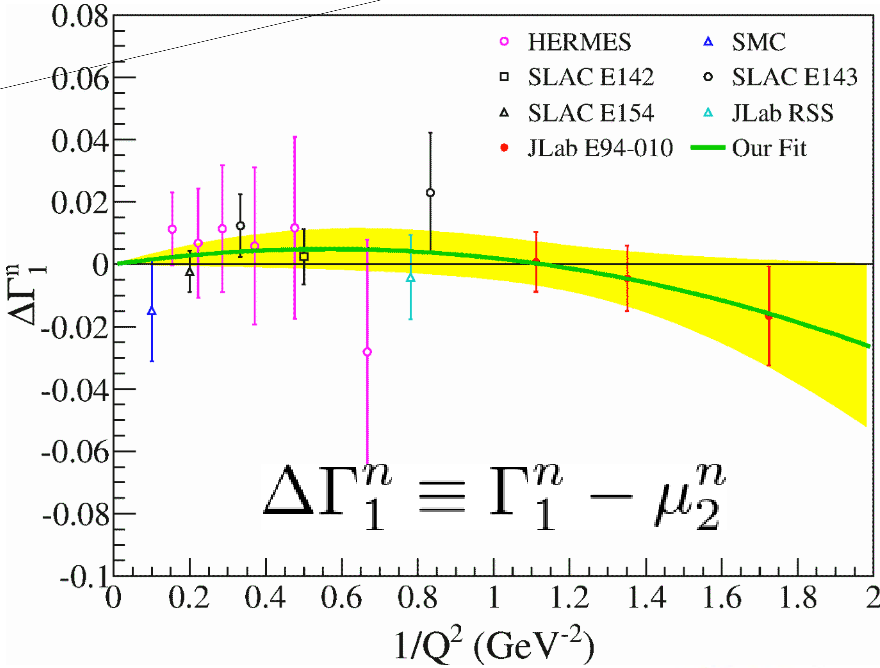
$$\Gamma_1(Q^2) \equiv \int_0^1 g_1(x, Q^2)\mathrm{d}x$$

$$= \mu_2 + \frac{M^2}{9Q^2}(a_2 + 4d_2 + 4f_2) + \frac{\mu_6}{Q^4} + \ldots$$

$$\mu_2(Q^2) = C_{ns}(Q^2)\left(-\frac{1}{12}g_A + \frac{1}{36}a_8\right) + C_s(Q^2)\frac{1}{9}\Delta\Sigma$$

Wilson coefficients
Triplet axial charge
Octet axial charge
Singlet axial charge

(Extracted from neutron B decay and weak hyperon decay measurements.)



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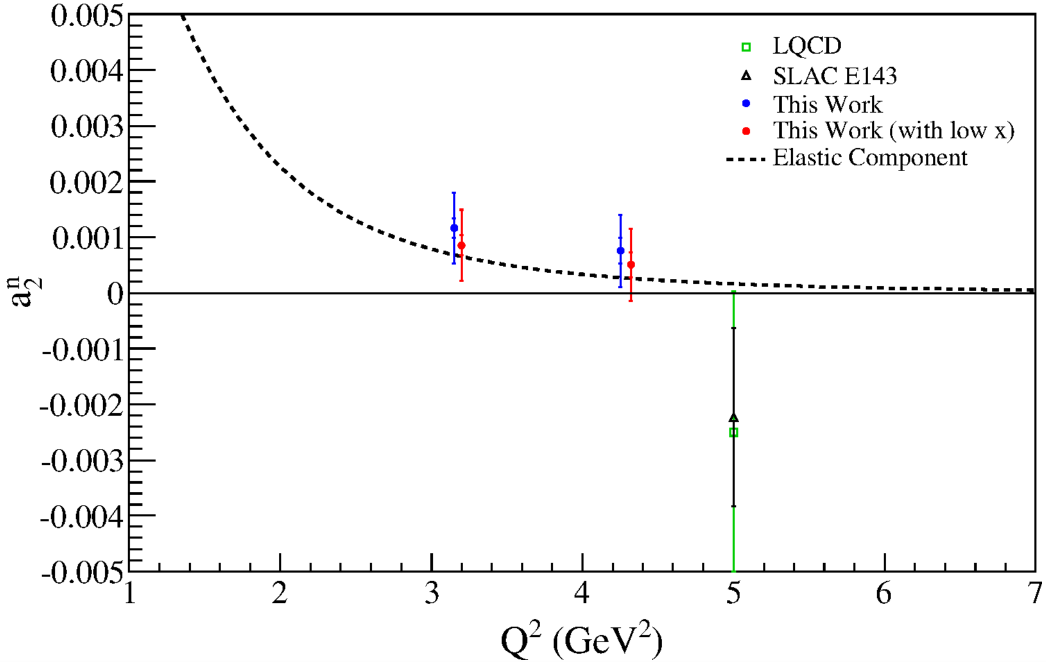
Moments of $g_1$ and $g_2$!

$$a_2 = \int_0^1 x^2 g_1 \mathrm{d}x$$

Twist-2 matrix element connected to target mass corrections.



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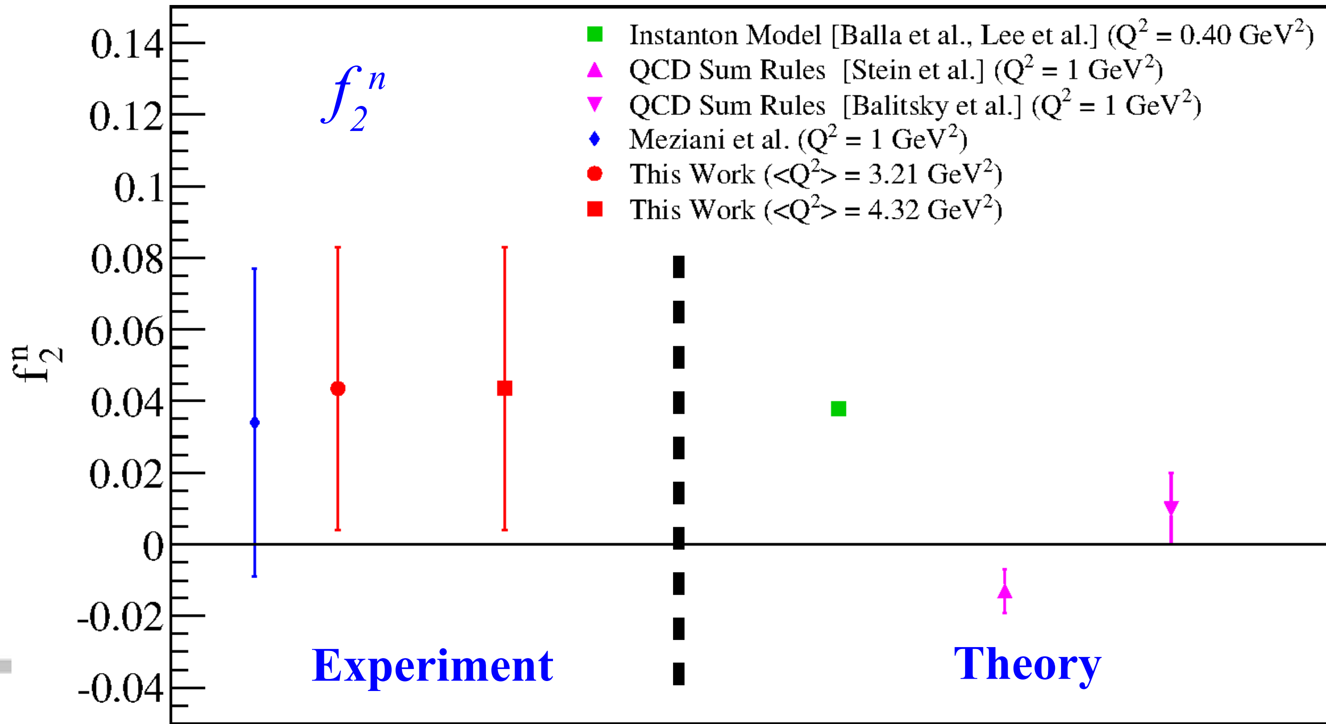
$$= \mu_2 + \frac{M^2}{9Q^2}(a_2 + 4d_2 + 4f_2) + \frac{\mu_6}{Q^4} + \ldots$$

- Rearrange OPE expansion and solve for $f_2$



# Color Electric and Magnetic Forces

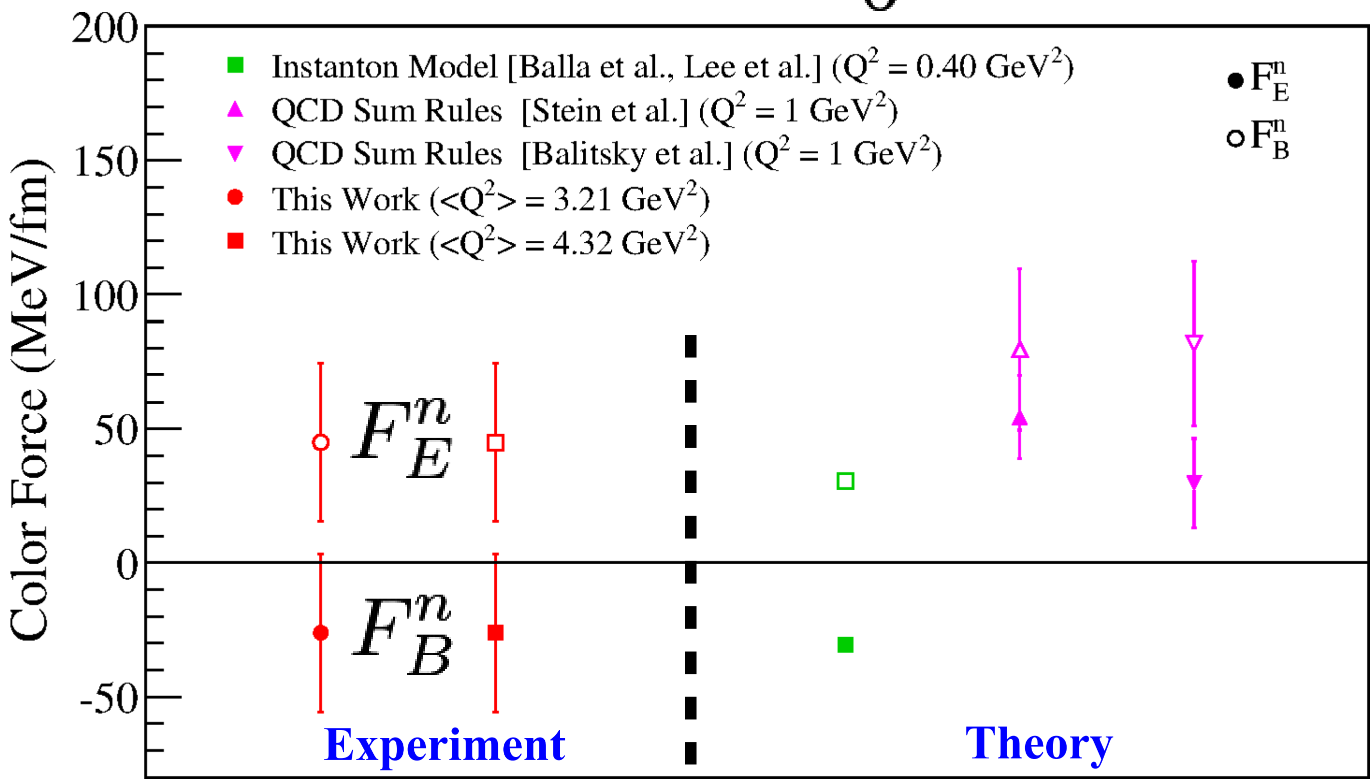
- $d_2$ and $f_2$ are twist-3 and twist-4 matrix elements; both connected to quark-gluon correlations

$$F_E^n = -\frac{M_n^2}{6}(2d_2^n + f_2^n)$$

$$F_B^n = -\frac{M_n^2}{6}(4d_2^n - f_2^n)$$

- Together, they give information on the *Color Lorentz* Electric and Magnetic forces

Burkardt, PRD 88 114502 (2013)



# Summary for E06-014

- **"d2n" (E06-014) Neutron, $^3$He at 6 GeV**
  - → $A_1$($^3$He and neutron) in good agreement with world data
  - → $d^n_2$ is small, negative, and consistent with LQCD prediction at $Q_2$ = 5 (GeV/c)$^2$
  - → $g_1$ and $g_2$ in agreement with world data for both $^3$He
  - → *Color* Electric and Magnetic Forces on struck quark extracted
    - » roughly equal and opposite

- The "Future"
  - → Major JLab upgrades
    - » 12 GeV beam, major new detector apparatus in Hall C (SHMS)
  - → 12 GeV dedicated $d_2^n$, $g_2^n$ (and A1n) measurements are approved in both Halls A and C (tentatively scheduled to be in first "non-commissioning" run group)
    - » focus on high-x and $Q_2$ evolution

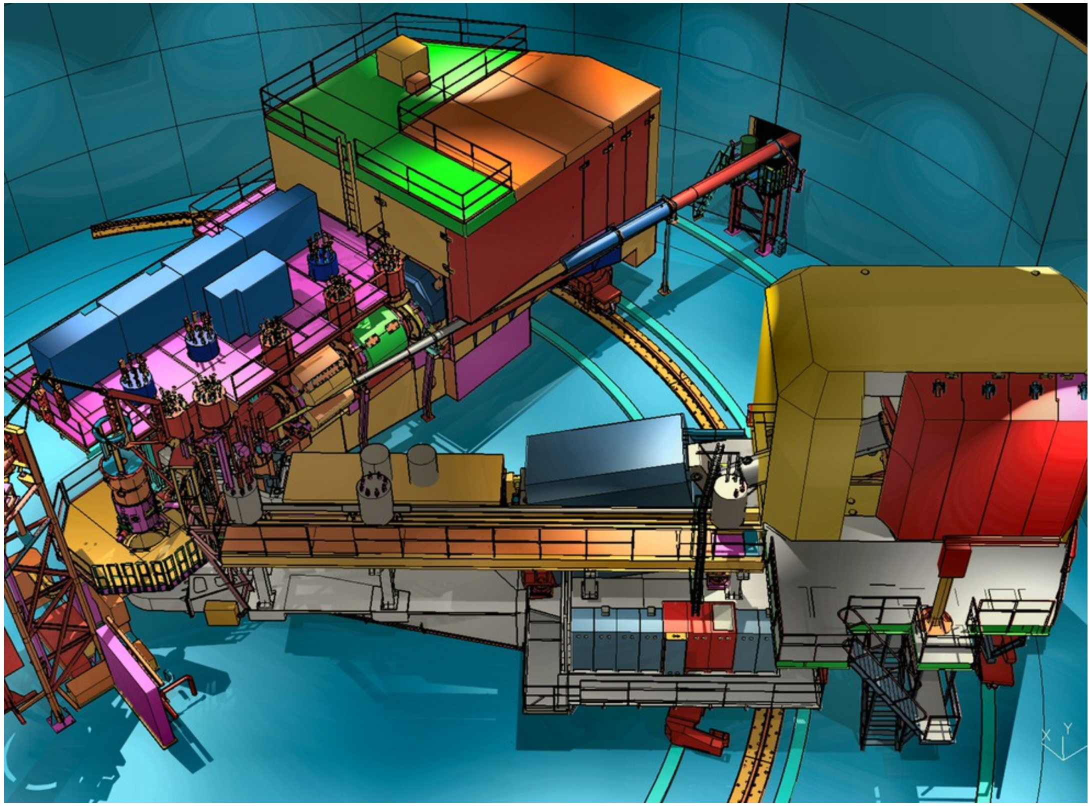

- E06-014 Special thanks to:
  - → D. Flay, M. Posik, D. Parno, ZE Meziani, G. Franklin

[This work is supported in part by
DOE Award from Temple University #DE-FG02-94ER40844.]

# Hall C after 12 GeV Upgrade

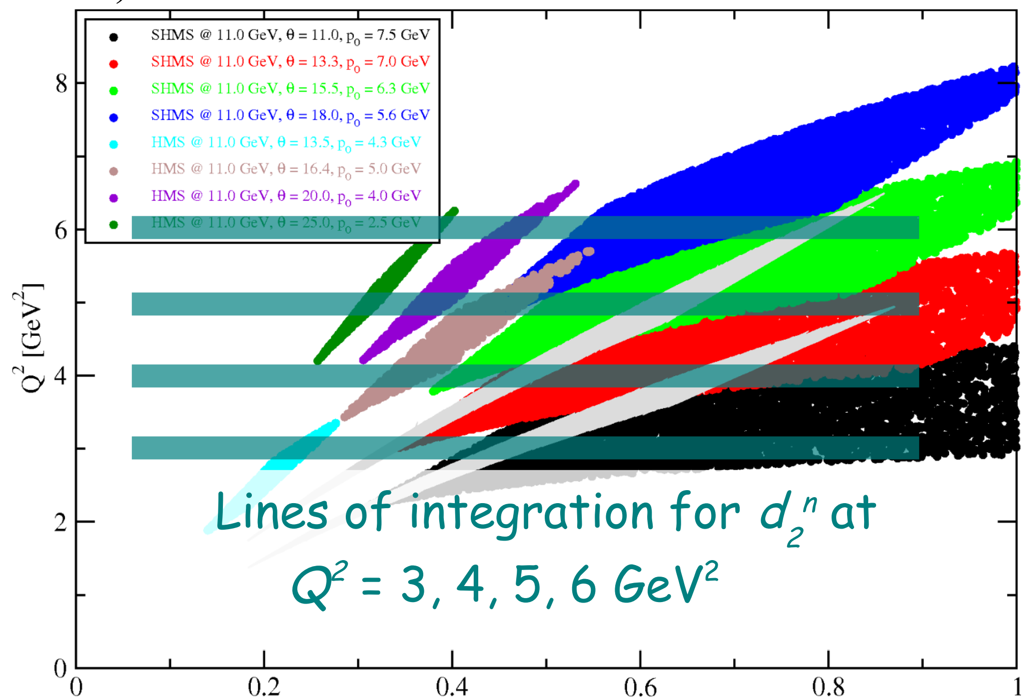
- Beam Energy: 2 – 11 GeV/c
- Super High Momentum Spectrometer (SHMS)
  - Horizontal Bender, 3 Quads, Dipole
  - P → 11 GeV/c
  - dP/P 0.5–1.0 x$10^{-3}$
  - Acceptance: 5msr, 30%
  - 5.5º < θ < 40º
- High Momentum Spectrometer (HMS)
  - P → 7.5 GeV/c
  - dP/P 0.5 - 1.0x$10^{-3}$
  - Acceptance: 6.5msr, 18%
  - 10.5º < θ < 90º
- Minimum opening angle: 17º
- Well shielded detector huts

- Ideal facility for:
  - Rosenbluth (L/T) separations
  - Exclusive reactions
  - Low cross sections (neutrino level)



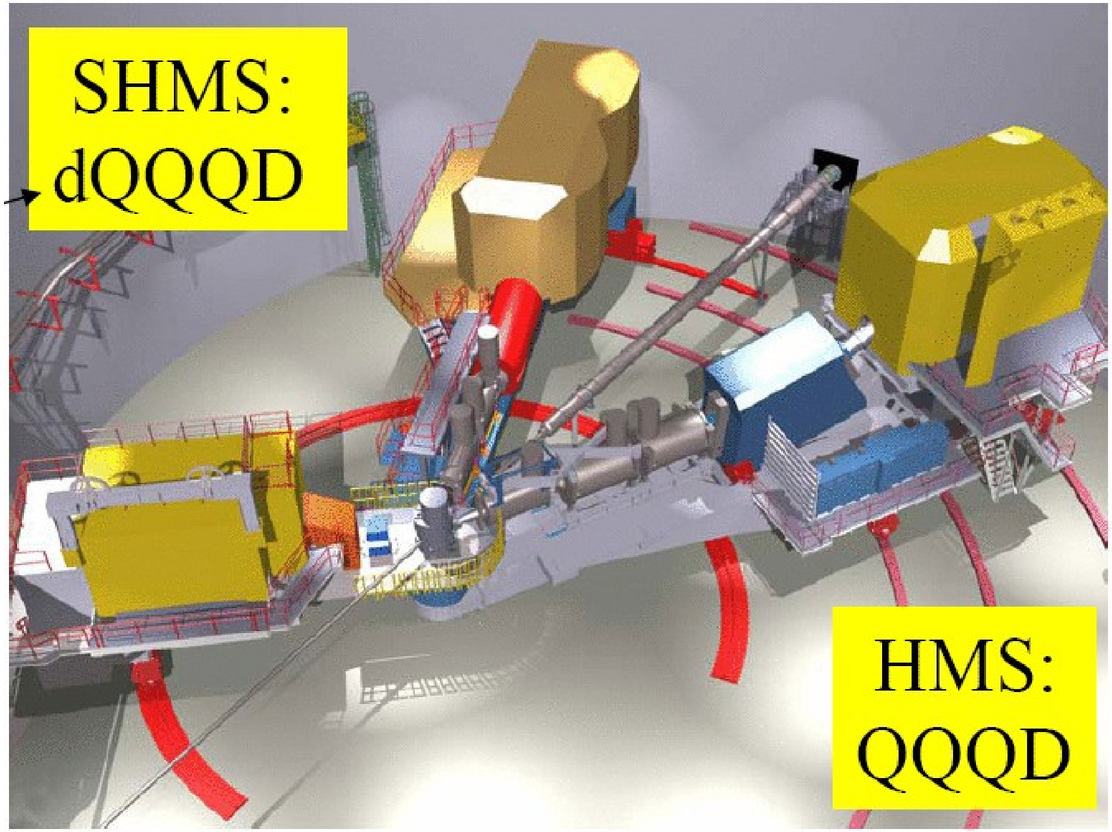
# E12-06-121: $d_2^n$, $g_2^n$

- Directly measure the $Q^2$ dependence of the neutron $d_2^n(Q^2)$ at $Q^2 \approx 3, 4, 5, 6$ GeV$^2$ with the new polarized $^3$He target.
  - → The new Hall C SHMS is ideally suited to this task!
- Doubles number of precision data points for $g_2^n(x, Q^2)$ in DIS region.
  - → $Q^2$ evolution of $g_2^n$ over $(0.23 < x < 0.85)$
- $d_2$ is a clean probe of quark-gluon correlations / higher twist effects
- Connected to the *color Lorentz force* acting on the struck quark (Burkardt)
  - → same underlying physics as in SIDIS $k_\perp$ studies
- Investigate the present discrepancy between data and theories.
  - → Theory calcs consistent but have wrong sign, wrong value.

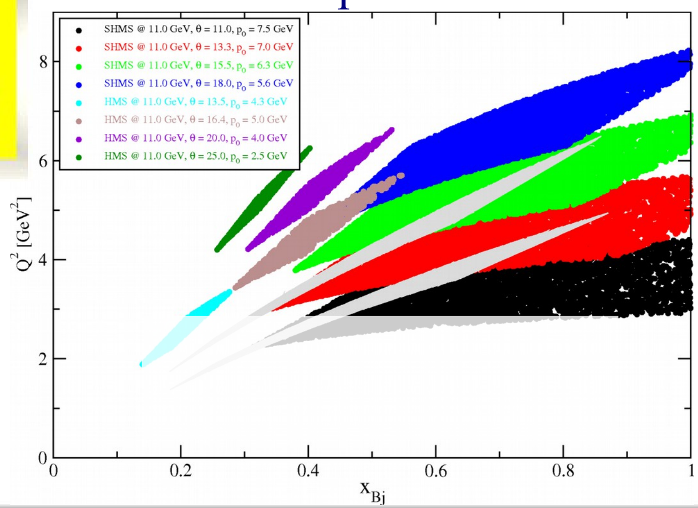



- Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky

# E12-06-121: $d_2^n$, $g_2^n$

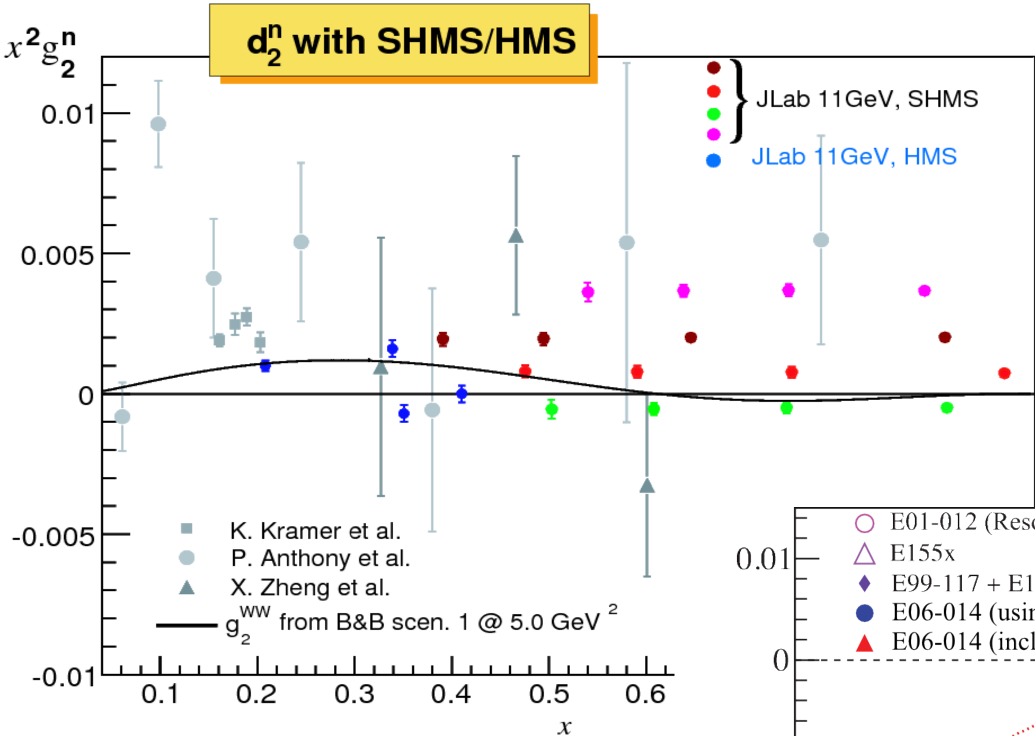



- <u>Hall C: SHMS + HMS</u>
- One beam energy
  → 11 GeV
- Each arm measures a total cross section independent of the other arm.
- Experiment split into four pairs of 125 hour runs with spectrometer



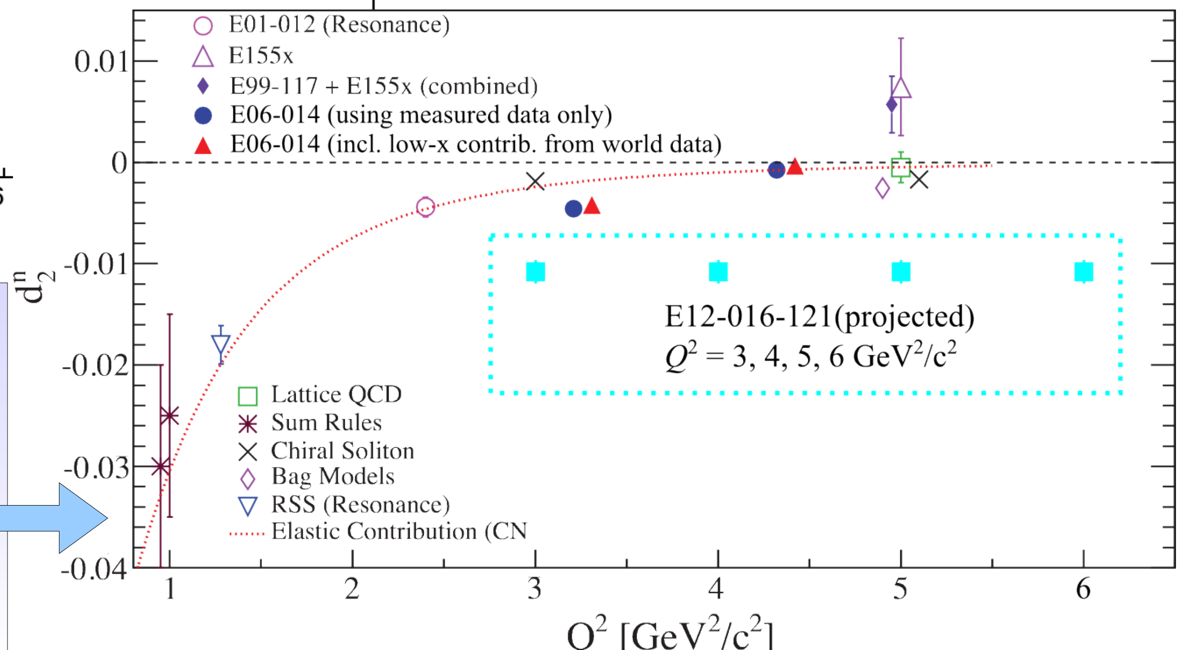

- SHMS collects data at Θ = 11°, 13.3°, 15.5° and 18.0° for 125 hrs each
  → data from each setting divided into 4 bins
- HMS collects data at Θ = 13.5°, 16.4°, 20.0° and 25.0° for 125 hrs each

# Projected results for E12-06-121




Projected $g_2^n$ points are vertically offset from zero along lines that reflect different (roughly) constant $Q^2$ values from 2.5—7 $GeV^2$.

- Q2 evolution of $d_2^n$ in a region where models are thought to be accurate.
- Direct overlap with 6 GeV Hall A measurements.



# The E06-014 Collaboration (Hall A)

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W. Armstrong
T. Averett
F. Benmokhtar
W. Bertozzi
A. Camsonne
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N. Liyanage
E. Long
A. Lukhanin
V. Mamyan
D. McNulty
**Z.-E. Meziani**
R. Michaels
M. Mihovilovič
B. Moffit
N. Muangma
S. Nanda
A. Narayan
V. Nelyubin
B. Norum
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P. Solvignon
R. Subedi
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W. Troth
D. Wang
Y. Wang
B. Wojtsekhowski
X. Yan

H. Yao
Y. Ye
Z. Ye
L. Yuan
X. Zhan
Y. Zhang
Y.-W. Zhang
B. Zhao
X. Zheng

**Co-spokesperson** **PhD (complete)**

BACKUP

# Other Interesting Observables

- Often experimentally simpler to measure Asymmetries
  - → target polarized parallel to beam polarization
  - → target polarized transverse to beam polarization
- Asymmetry is formed by measuring the difference in yields when you flip polarization of the beam
- Virtual photon asymmetries $A_1$ and $A_2$ can be expressed in terms of these experimental asymmetries
  - → these are also connected to $g_1$, $g_2$, of course

$$A_{\parallel} = \frac{N^{\uparrow\Downarrow} - N^{\downarrow\Downarrow}}{N^{\uparrow\Downarrow} + N^{\downarrow\Downarrow}}$$

$$A_{\perp} = \frac{N^{\uparrow\Rightarrow} - N^{\downarrow\Rightarrow}}{N^{\uparrow\Rightarrow} + N^{\downarrow\Rightarrow}}$$

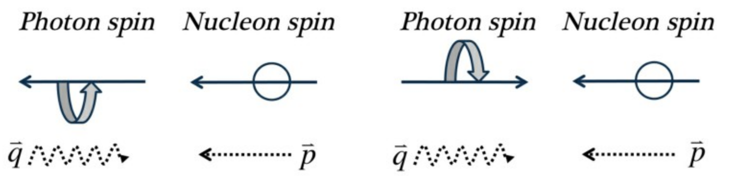
# Virtual Photon Asymmetries

$$A_1 = \frac{1}{(E+E')D'}\left((E-E'\cos\theta)A_{\parallel} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right)$$

$$A_2 = \frac{\sqrt{Q^2}}{2ED'}\left(A_{\parallel} + \frac{E-E'\cos\theta}{E'\sin\theta\cos\phi}A_{\perp}\right)$$

$$A_1 = \frac{1}{F_1}\left(g_1 - \frac{(2Mx)^2}{Q^2}g_2\right)$$

$$= \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}}$$



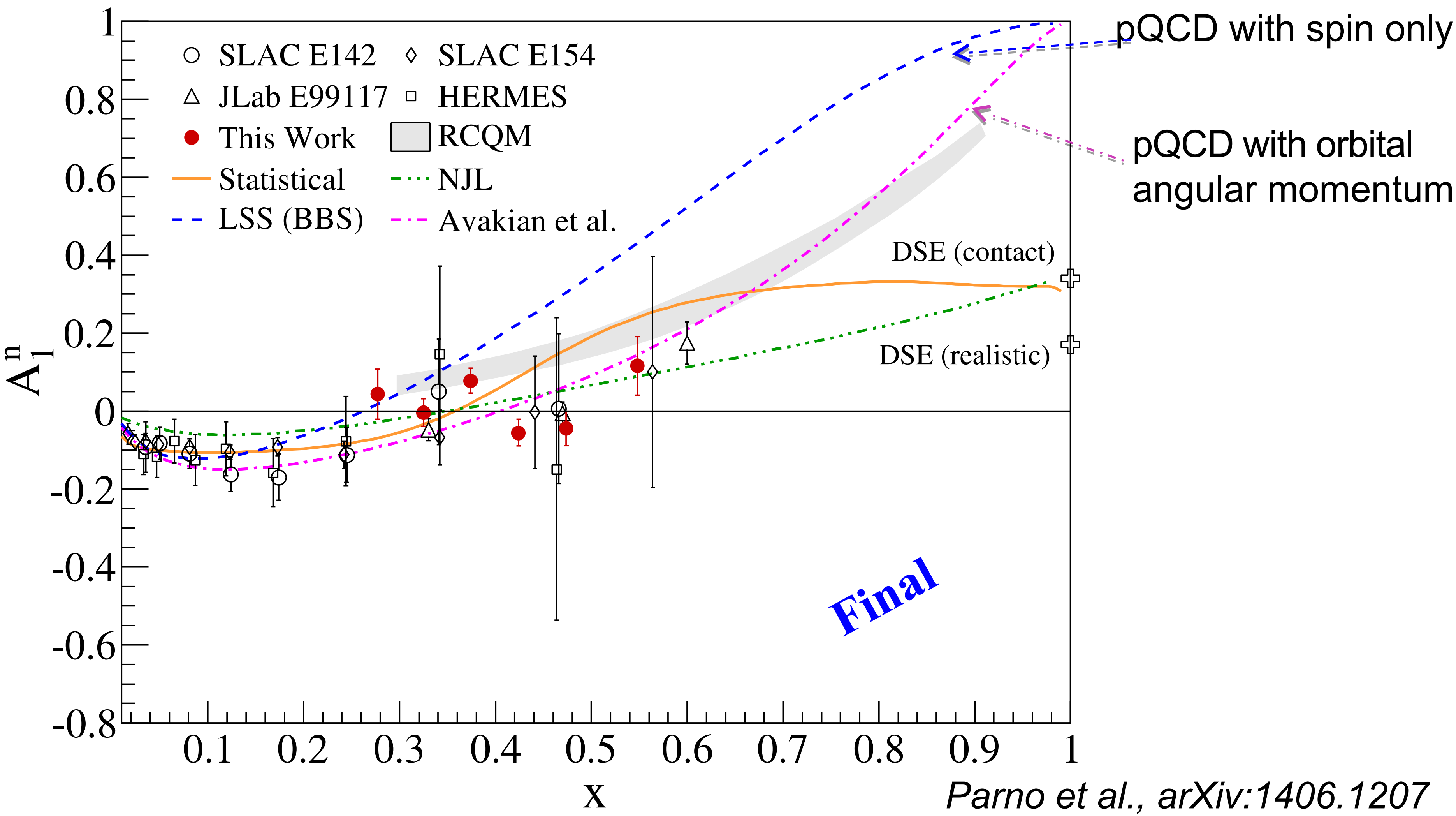

Parallel spins: $\sigma_{3/2}$ Anti-parallel spins: $\sigma_{1/2}$

$$A_2 = \frac{\sqrt{Q^2}}{\nu}\frac{g_T}{F_1}$$

$$g_T = g_1 + g_2$$

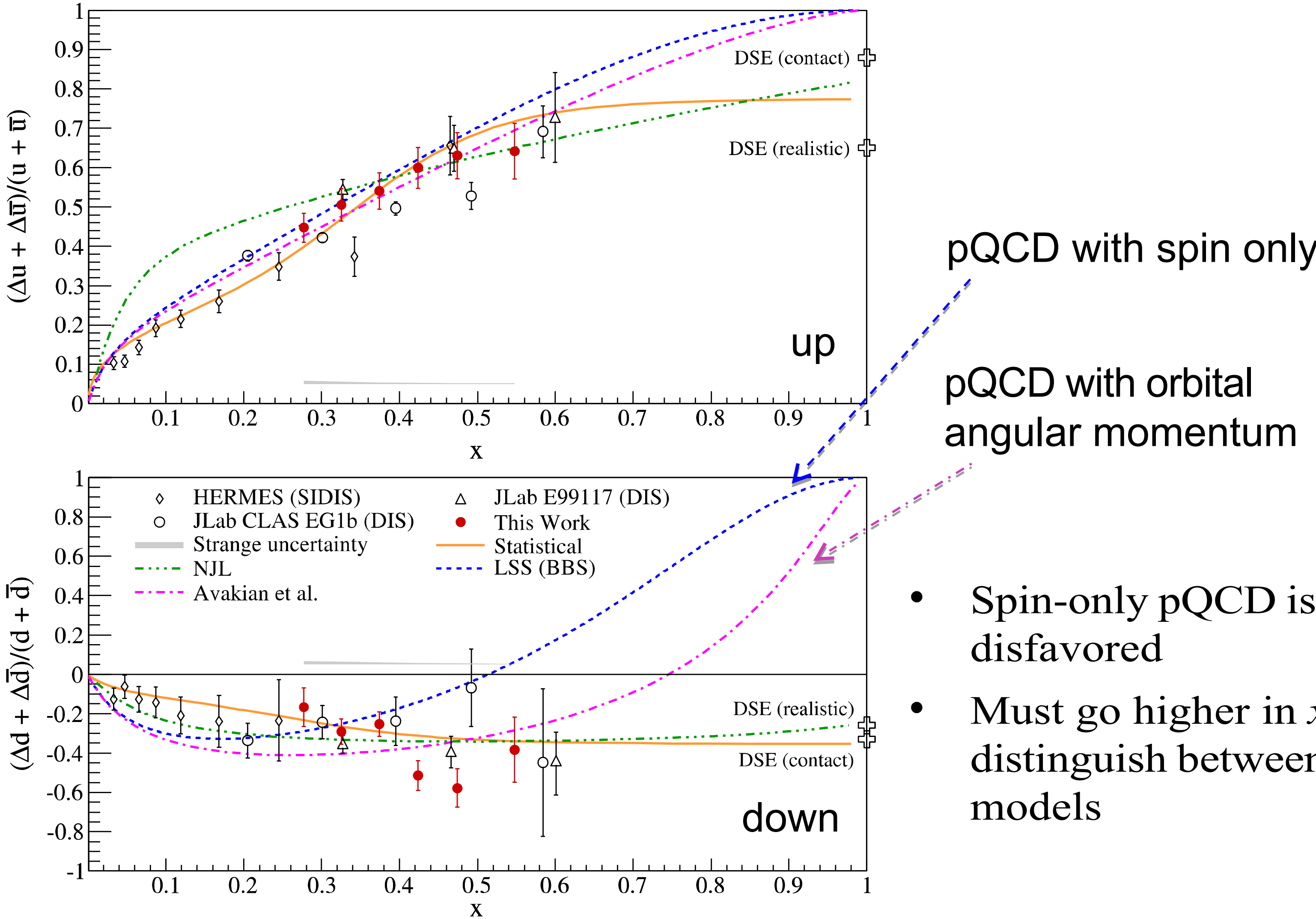
- $g_T$ measures spin distribution normal to the virtual photon

# $A_1$ for Neutron




*Parno et al., arXiv:1406.1207*

# $(\Delta u+\Delta\bar{u})/(u+\bar{u})$ and $(\Delta d+\Delta\bar{d})/(d+\bar{d})$




- Spin-only pQCD is strongly disfavored
- Must go higher in $x$ to distinguish between other models

*Parno et al., arXiv:1406.1207*

# $A_1^n$ vs. CQM Theory

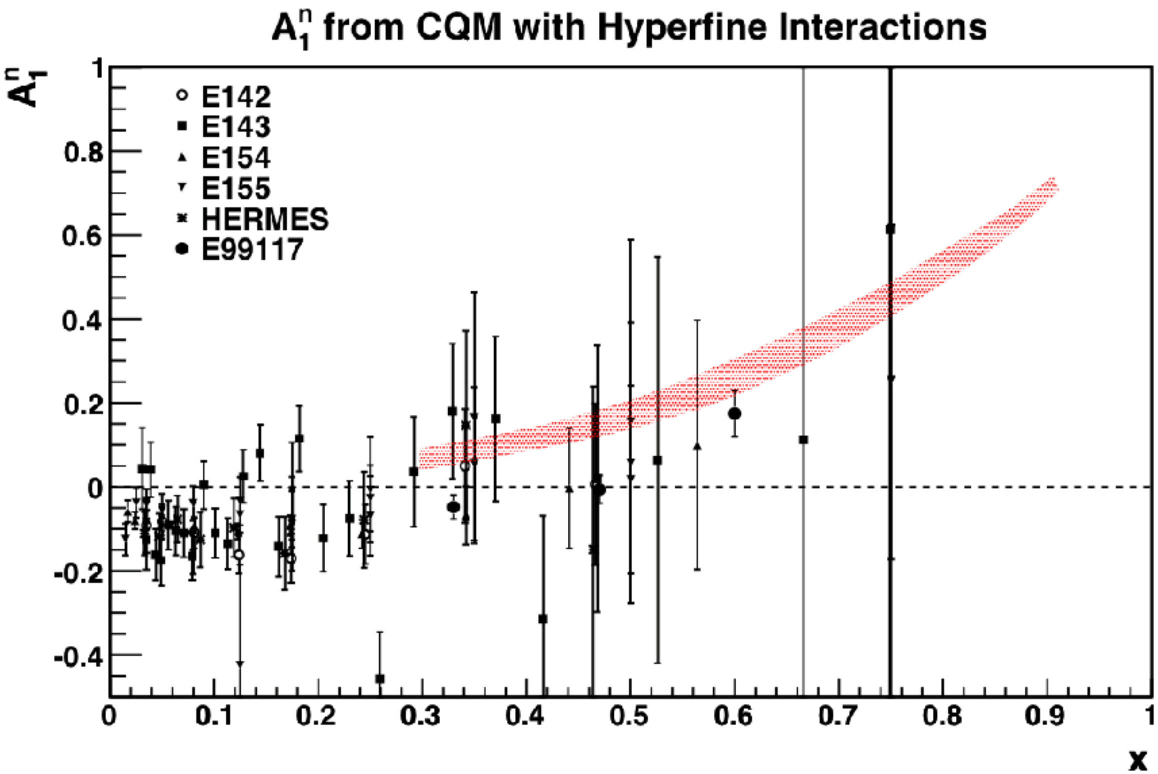



Figure 2.9: Predictions of $A_1^n$ from constituent quark model, compared to world data. The dashed line on the x-axis marks $A_1^n = 0$, the prediction from unbroken SU(6) symmetry. The shaded red band shows the range of $A_1^n$ values allowed in a model where SU(6) symmetry is broken by hyperfine interactions between quarks [70]. We have made use of parameterizations compiled by X. Zheng [71].

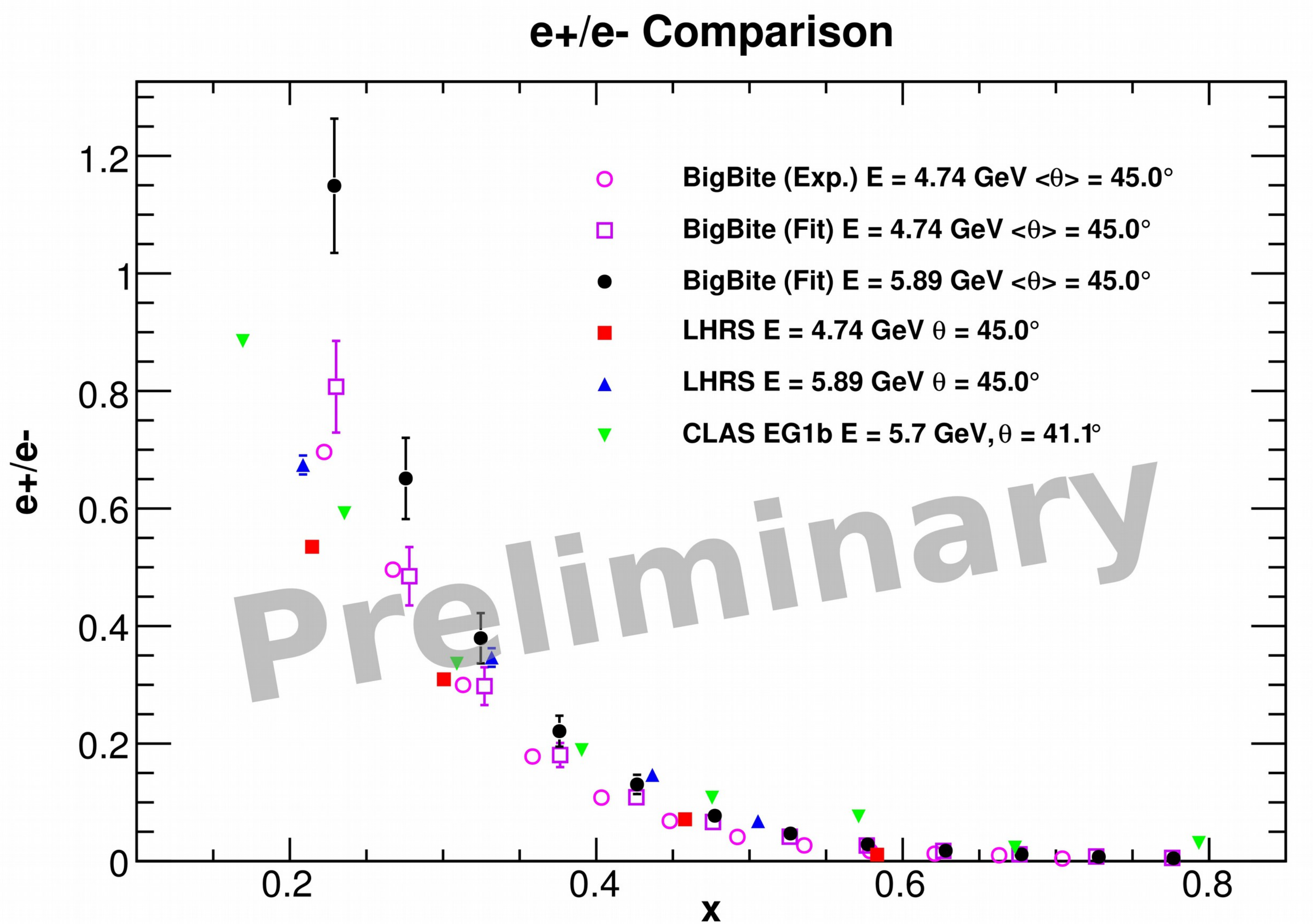
# Systematic Error Contributions to $g_2^n$ and $d_2^n$

| Item description | Subitem description | Relative uncertainty |
|---|---|---|
| **Target polarization** | | 3 % |
| **Beam polarization** | | 1.5% |
| **Asymmetry (raw)** | | |
| | • Target spin direction ($0.1^\circ$) | $< 5 \times 10^{-4}$ |
| | • Beam charge asymmetry | $<$ 50 ppm |
| **Cross section (raw)** | | |
| | • PID efficiency | $<$ 1 % |
| | • Background Rejection efficiency | $\approx$ 1 % |
| | • Beam charge | $<$ 1 % |
| | • Beam position | $<$ 1 % |
| | • Acceptance cut | 2-3 % |
| | • Target density | $<$ 2% |
| | • Nitrogen dilution | $<$ 1% |
| | • Dead time | $<$1% |
| | • Finite Acceptance cut | $<$1% |
| **Radiative corrections** | | $\leq$ 5 % |
| **From $^3$He to Neutron correction** | | 5 % |
| **Total systematic uncertainty (for both $g_2^n(x, Q^2)$ and $d_2(Q^2)$)** | | $\leq$ 10 % |
| **Estimate of contributions to $d_2$ from unmeasured region** | $\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$ | $4.8 \times 10^{-4}$ |
| **Projected absolute statistical uncertainty on $d_2$** | | $\Delta d_2 \approx 5 \times 10^{-4}$ |
| **Projected absolute systematic uncertainty on $d_2$ (*assuming* $d_2 = 5 \times 10^{-3}$)** | | $\Delta d_2 \approx 5 \times 10^{-4}$ |

- Radiative correction uncertainty cross-checked with E01-012 (Spin Duality) experiment
  worst case: 4.4%

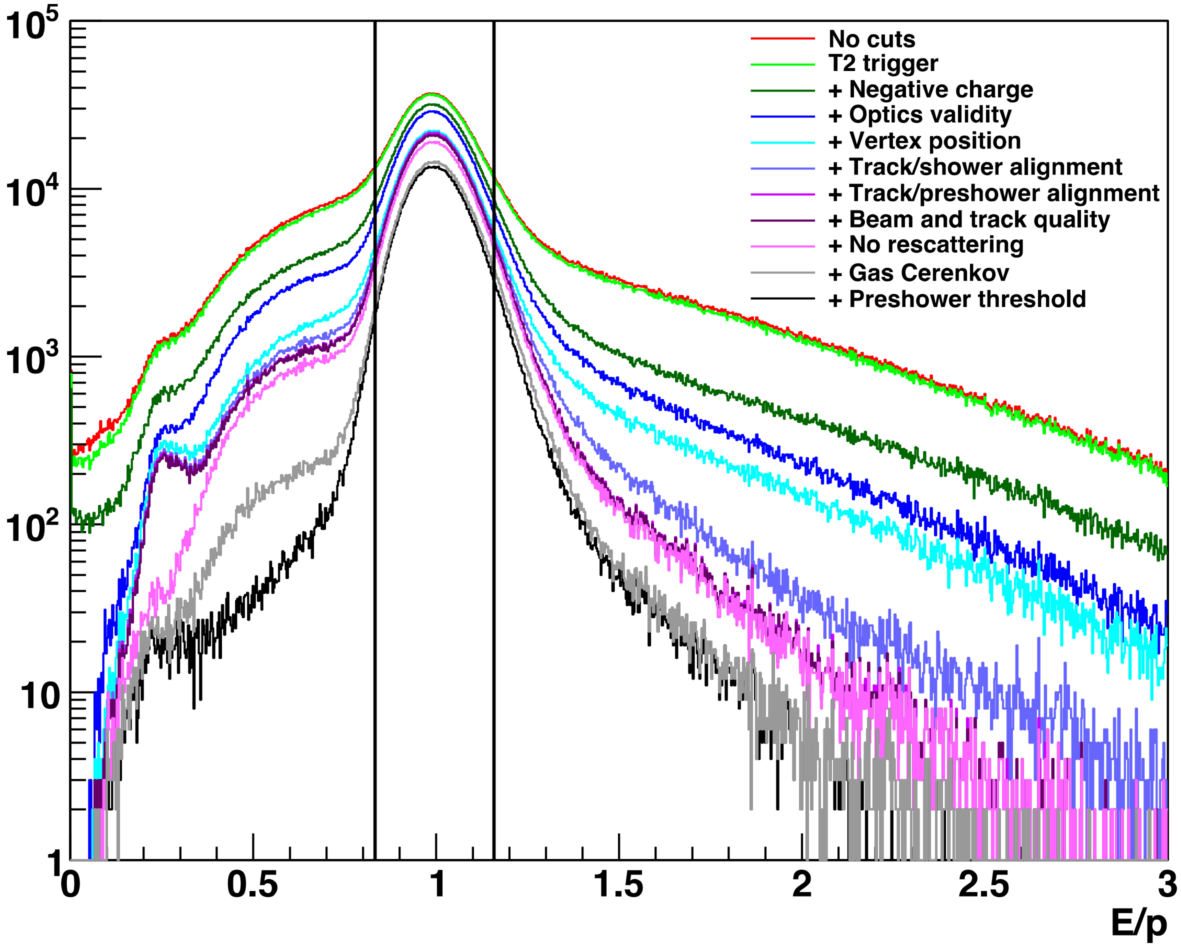
- Pion rejection ratio of ~$10^4$:1 should be achievable with standard SHMS/HMS detectors (~$10^3$:1 would be adequate)

# e+/e- Ratios extracted from data (E06-014)




Courtesy of D.Flay, M. Posik

# Data reduction (E06-014)




- BigBite data shown
- Negligible pion contamination
- Errors associated with momentum reconstruction (tracking) form highest backgrounds

Courtesy of D. Parno

# E12-06-121 Updated Kinematics

Table 3: Kinematic bins and expected rates for the SHMS. The uncertainties for $A_{\parallel}$ and $A_{\perp}$ are *statistical* only.

| SHMS Setting | $E'_{bin}$ [GeV] | $Q^2$ [GeV$^2$] | x | W [GeV] | $e^-$ rate [Hz] | $\pi^-$ rate [Hz] | $t_{\parallel}$ [hrs] | $t_{\perp}$ [hrs] | $\Delta A_{\parallel}$ [$\cdot 10^{-4}$] | $\Delta A_{\perp}$ [$\cdot 10^{-4}$] |
|---|---|---|---|---|---|---|---|---|---|---|
| $\theta_0 = 11°$ | 7.112 | 2.875 | 0.394 | 2.305 | 1058 | 11 | 12 | 113 | 2.0 | 0.5 |
| | 7.709 | 3.116 | 0.504 | 1.988 | 708 | 3.1 | 12 | 113 | 2.3 | 0.7 |
| $E'_{cent} = 7.5$ | 8.304 | 3.357 | 0.663 | 1.610 | 259 | 0.83 | 12 | 113 | 3.7 | 0.1 |
| GeV | 8.900 | 3.597 | 0.912 | 1.109 | 2.7 | 0.21 | 12 | 113 | 36 | 10 |
| $\theta_0 = 13.3°$ | 6.647 | 3.922 | 0.480 | 2.267 | 268 | 3.1 | 12 | 113 | 3.5 | 1.0 |
| | 7.203 | 4.250 | 0.596 | 1.941 | 139 | 0.8 | 12 | 113 | 4.8 | 1.5 |
| $E'_{cent} = 7.0$ | 7.758 | 4.578 | 0.752 | 1.548 | 31.6 | 0.16 | 12 | 113 | 10 | 3.1 |
| GeV | 8.314 | 4.906 | 0.972 | 1.012 | 0.10 | 0.033 | 12 | 113 | 173 | 55 |
| $\theta_0 = 15.5°$ | 5.997 | 4.798 | 0.511 | 2.342 | 96 | 1.9 | 12 | 113 | 5.7 | 1.8 |
| | 6.496 | 5.197 | 0.614 | 2.037 | 49 | 0.47 | 12 | 113 | 7.8 | 2.5 |
| $E'_{cent} = 6.3$ | 6.995 | 5.597 | 0.744 | 1.677 | 13.5 | 0.11 | 12 | 113 | 15 | 4.7 |
| GeV | 7.494 | 5.996 | 0.911 | 1.215 | 0.29 | 0.025 | 12 | 113 | 98 | 33 |
| $\theta_0 = 18.0°$ | 5.348 | 5.756 | 0.542 | 2.397 | 35 | 1.1 | 12 | 113 | 9.5 | 3.1 |
| | 5.790 | 6.235 | 0.637 | 2.106 | 17 | 0.25 | 12 | 113 | 13 | 4.4 |
| $E'_{cent} = 5.6$ | 6.233 | 6.711 | 0.749 | 1.769 | 5.1 | 0.05 | 12 | 113 | 24 | 8.1 |
| GeV | 6.675 | 7.187 | 0.885 | 1.350 | 0.38 | 0.01 | 12 | 113 | 87 | 30 |

Table 4: Expected rates for the three HMS settings. The uncertainties for $A_{\parallel}$ and $A_{\perp}$ are *statistical* only.

| $\theta_0$ [$\circ$] | $E'_{cent}$ [GeV] | $Q^2$ [GeV$^2$] | x | W [GeV] | $e^-$ rate [Hz] | $\pi^-$ rate [Hz] | $t_{\parallel}$ [hrs] | $t_{\perp}$ [hrs] | $\Delta A_{\parallel}$ [$\cdot 10^{-4}$] | $\Delta A_{\perp}$ [$\cdot 10^{-4}$] |
|---|---|---|---|---|---|---|---|---|---|---|
| 13.5 | 4.305 | 2.617 | 0.208 | 3.293 | 954 | 765 | 8 | 117 | 2.0 | 0.6 |
| 16.4 | 5.088 | 4.555 | 0.410 | 2.727 | 218 | 15 | 12 | 113 | 3.9 | 1.2 |
| 20.0 | 4.000 | 5.31 | 0.404 | 2.951 | 76 | 66 | 10 | 115 | 6.0 | 1.8 |
| 25.0 | 2.500 | 5.15 | 0.323 | 3.417 | 20 | 84 | 13 | 112 | 10.7 | 3.1 |

# Updated Kinematics