THE SPIN STRUCTURE FUNCTION g_2 FROM SLAC E155X

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REPRESENTING THE E155X COLLABORATION

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- EXPERIMENT
- SOME THEORY
- g_2 AND A_2 FOR PROTON/DEUTERON
- Q^2 DEPENDENDENCE OF g_2 AND A_2
- TWIST-3 MATRIX ELEMENT d_2
- SUM RULES
- π^- ASYMMETRIES
- FUTURE

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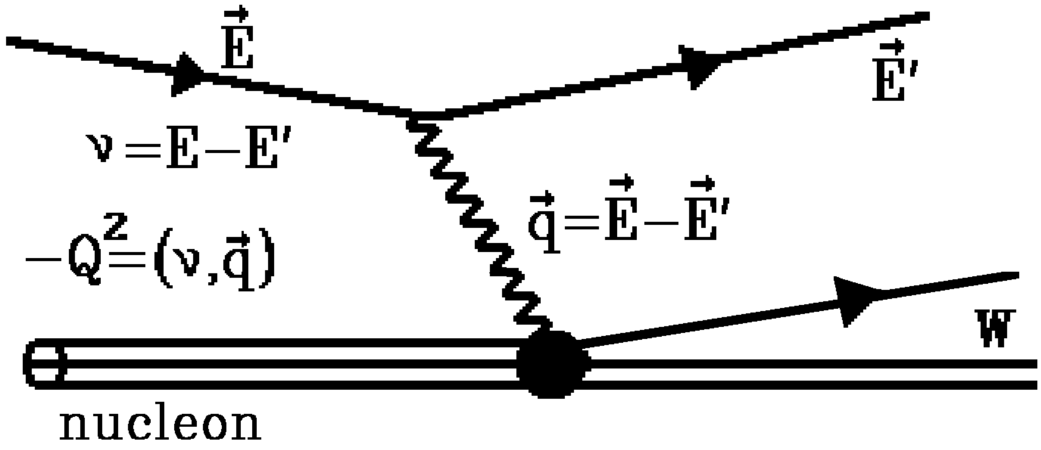
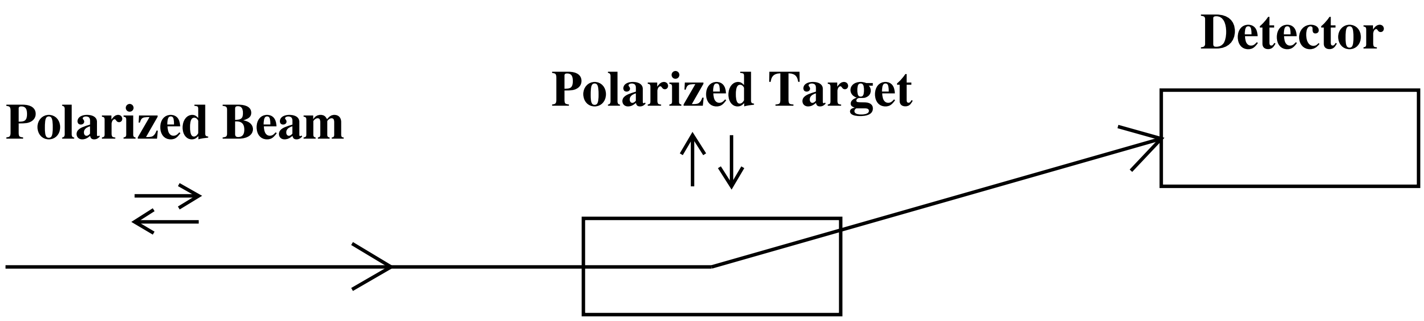
Inclusive Deep Inelastic Scattering



- θ : scattering angle
- Q^2: 4-momentum transfer squared
- ν : energy transfer
- $x = \frac{Q^2}{2M\nu}$: Bjorken scaling variable

Polarized Deep Inelastic Scattering



$$A_{\perp} = \frac{\sigma^{\downarrow\leftarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\downarrow\leftarrow} + \sigma^{\uparrow\leftarrow}} = f_k E' \sin(\theta)[g_1(x,Q^2) + \frac{2E}{\nu} g_2(x,Q^2)]$$

$$A_{\parallel} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = f_k[g_1(x,Q^2)[E + E' \cos(\theta)] - \frac{Q^2}{\nu} g_2(x,Q^2)]$$

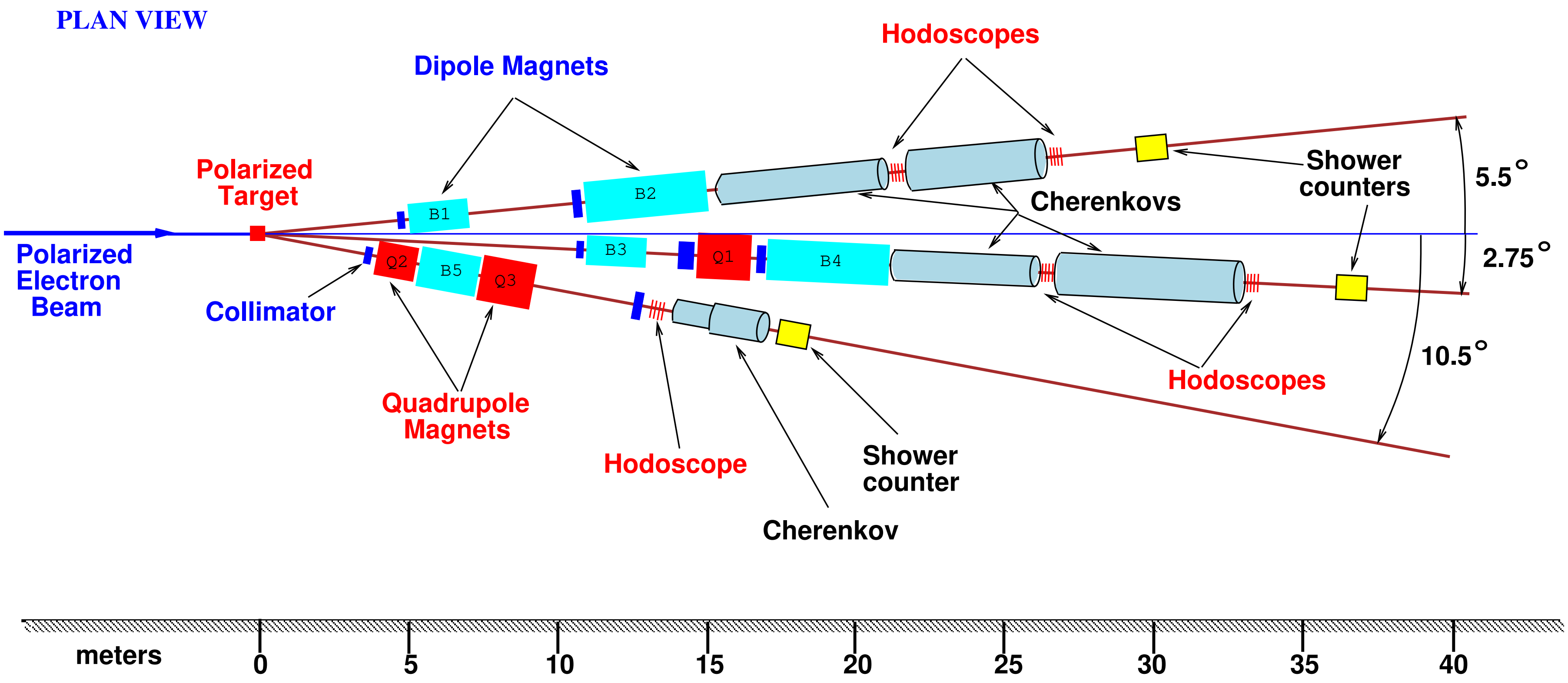
$\mathbf{g_1}$ and $\mathbf{g_2}$ are the polarized structure functions.

$\rightarrow$ $\mathbf{A}_{\parallel}$ is primarily sensitive to g_1

$\rightarrow$ $\mathbf{A}_{\perp}$ is more sensitive to g_2

$\rightarrow$ f_k includes contribution from kinematics and unpolarized structure functions

E155 Spectrometers



EXPERIMENTAL OVERVIEW

- **SLAC ELECTRON BEAM:**
  - POLARIZATION $P_b = 0.83$
  - ENERGY $E = 29.1$ or $E = 32.3$
  - 120 HZ, 400 nsec SPILLS, 25 nA
- **TRANSVERSELY POLARIZED TARGETS:**
  - 1 K, 5 T, D.N.P
  - NH3 (PROTONS) $< P_t >= 0.70$
  - LiD (DEUTERONS) $< P_t >= 0.22$
  - RADIATION DAMAGE
- **SCATTERED ELECTRONS**
  - $2.75^o, 5.5^o,$ AND 10.5^o
  - CHERENKOV AND LEAD GLASS FOR PARTICLE I.D.
  - HODOSCOPES FOR TRACKS $(dP/P \approx 0.03)$
- **PHOTOPRODUCED INCLUSIVE PIONS**

$\boxed{\text{POLARIZED ELECTRON BEAM}}$

- **Intense 29/32 GeV Beam**
- **Highly polarized : $P_b = 0.832 \pm 0.030$**
- **Helicity varied randomly from pulse to pulse (120 Hz)**
- **Beam polarization measured with Møller detector systems**

$$A = \frac{N_{e^-}(\uparrow\uparrow) - N_{e^-}(\uparrow\downarrow)}{N_{e^-}(\uparrow\uparrow) + N_{e^-}(\uparrow\downarrow)}$$

$$= -P_{beam}P_{foil}\frac{(7+\cos^2\theta_{cm})\sin^2\theta_{cm}}{(3+\cos^2\theta_{cm})^2}$$

$\rightarrow$ **20-50 μm thick target foils**

POLARIZED TARGETS

- **Solid cryogenic targets**
  - **Magnet at 5 T**
  - **Temperature 1K**
- **Dynamic nuclear polarization using microwaves**
- **Radiation Damage Limits** $< P_t >$
  - **Raster the Beam**
  - **Anneal**

- $^{15}NH_3$ **used for proton target**

$\rightarrow$ **Improved** μ**wave power delivery** $\rightarrow$ $< \mathbf{P_t} > \approx$ **70%**

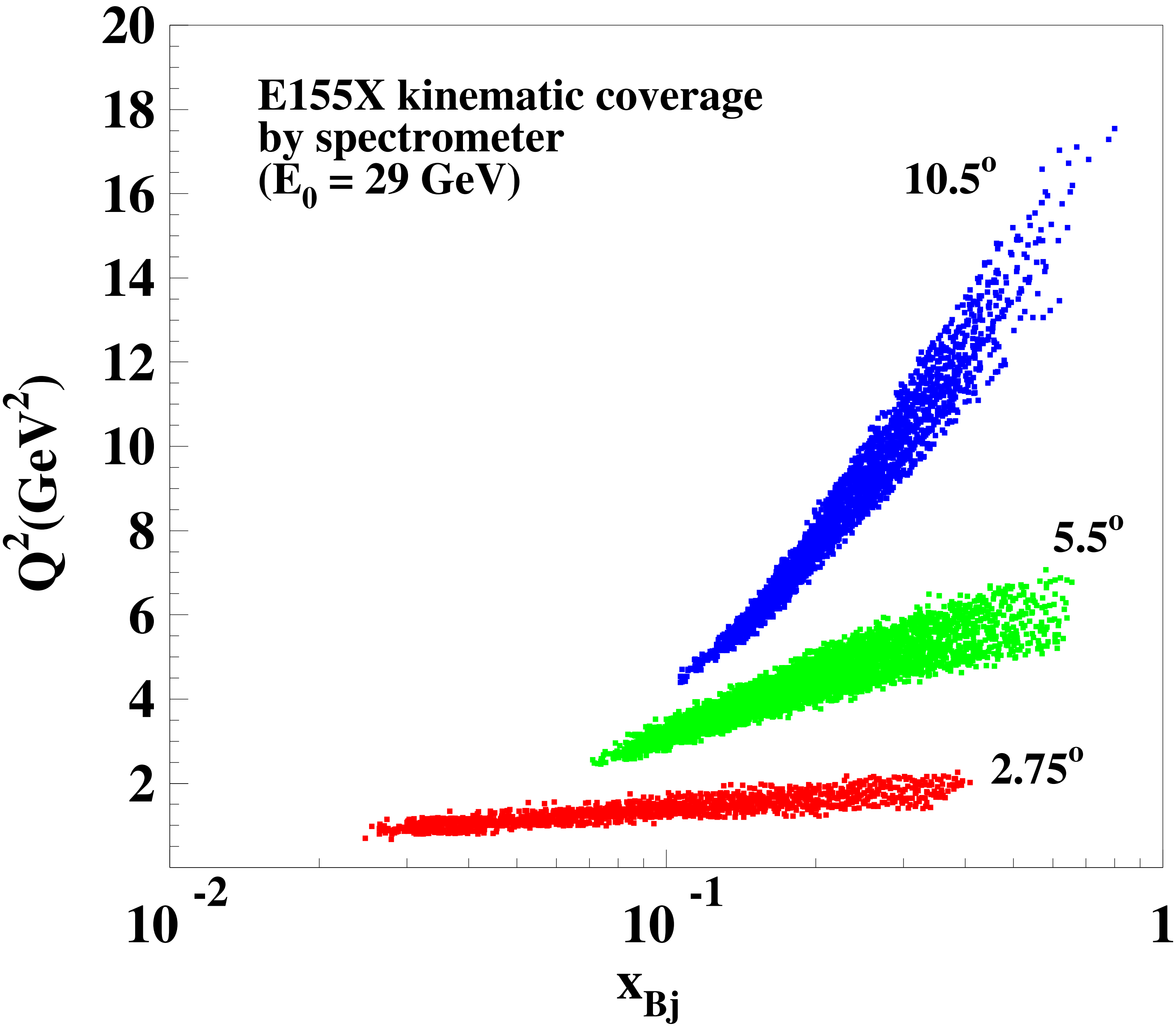
- ^{6}**LiD used for deuteron target**

$\rightarrow$ **LiD** $\approx$ **50% improvement in dilution over** $^{15}ND_3$

$\rightarrow$ **LiD 6 times as radiation resistant**

$\rightarrow$ $< \mathbf{P_t} > \approx$ **22%**

KINEMATICS


E155X kinematic coverage
by spectrometer
(E_0 = 29 GeV)
10.5°
5.5°
2.75°
$Q^2(GeV^2)$
x_{Bj}
20
18
16
14
12
10
8
6
4
2
10^{-2}
10^{-1}
1

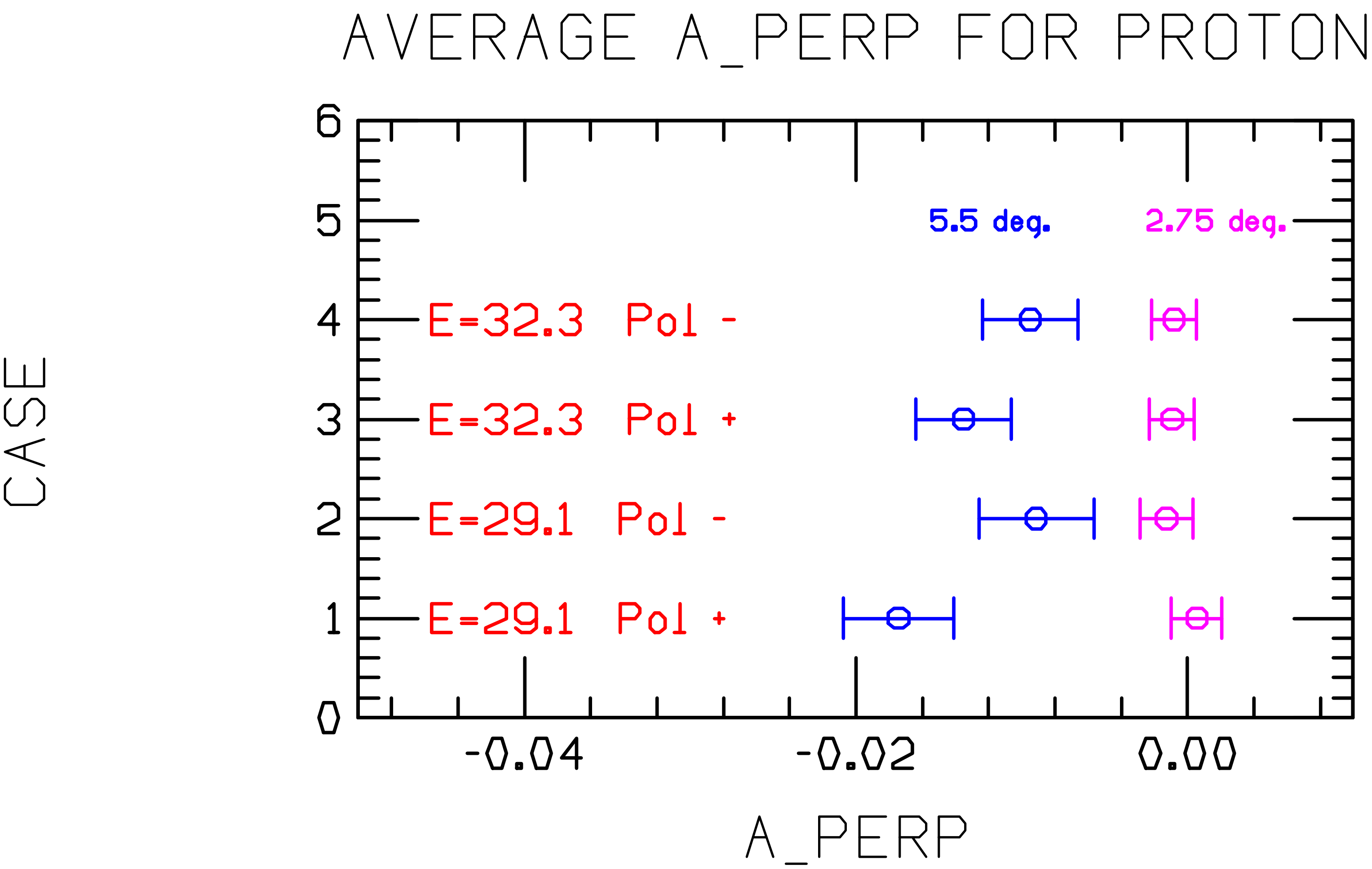
THE $A_\perp$ ASYMMETRY

$$A_\perp = \frac{C_1}{fP_t f_{RC}\cos(\phi)}\left(\left(\frac{N_L - N_R}{N_L + N_R}\right)\frac{1}{P_b} + A_{EW}\right) + A_{RC}$$

- N_L AND N_R ARE RATES FOR L AND R BEAM HELICITY, CORRECTED FOR PAIR-SYMMETRIC CONTRIBUTIONS (FEW PERCENT) AND π MIS-IDENTIFIED AS ELECTRONS (FEW PERCENT)
- $C_1 \approx 1$ CORRECTS FOR POLARIZED ^{15}N or Li
- ADDITIONAL CORRECTION FOR ^{7}Li and LiH CONTAMINATION
- $\cos(\phi)$ IS THE ANGLE BETWEEN PLANE OF ELECTRON/PROTON SPINS AND PLANE OF ELECTRON SCATTERING.
- f IS DILUTION FACTOR (≈ 0.16 PROTON)
- A_{EW}: ELECTROWEAK ASYMMETRY ($\approx 8 \times 10^{-5} Q^2$)
- f_{RC} AND A_{RC} ARE FOR RADIATIVE CORRECTIONS, PRESENTLY MADE USING g_2^{ww} MODEL AND E155 FIT TO g_1. THIS WILL BE REFINED IN FUTURE, LIKELY RESULTING IN REDUCTION OF STATISTICAL ERRORS AT LOWEST x OF EACH SPECTROMETER.

SYSTEMATIC CHECKS

- **TARGET POLARIZATION ALIGNED (+) OR ANTI-ALIGNED (-) WITH B FIELD**
- **BEAM ENERGY CHANGED BY 3.2 GeV TO PRECESS SPIN BY π IN TRANSPORT LINE.**
- **CORRECT FOR EW ASYMMETRY (DEPENDS ONLY ON BEAM HELICITY)**
- **ANY REMAINING FALSE ASYMMETRIES (I.E. HELICITY-DEPENDENT BEAM POSITION) WOULD SHOW UP AS A DIFFERENCE IN AVERAGE $A_\perp$. NONE SEEN.**



DETERMINATION OF $\mathbf{g_2}$ and $\mathbf{A_2}$

- **WE USE MEASURED $A_\perp$ and E155 g_1 FIT TO OBTAIN g_2 USING:**

$$\mathbf{A_\perp(x, Q^2, E)} = \frac{\sigma^{\downarrow\leftarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\downarrow\leftarrow} + \sigma^{\uparrow\leftarrow}} = \mathbf{f_k E' \sin(\theta)[g_1(x, Q^2) + \frac{2E}{\nu} g_2(x, Q^2)]}$$

- WE CAN COMPARE $\mathbf{g_2}$ TO THE SIMPLE TWIST-2 MODEL OF WANDZURA-WILCZEK

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

- WE CAN ALSO EXTRACT VIRTUAL PHOTON-NUCLEON ASYMMETRY

$$\mathbf{A_2(x, Q^2)} = \frac{\mathbf{2}\sigma_{\mathbf{TL}}}{\sigma_{\mathbf{T}}^{\mathbf{1/2}} + \sigma_{\mathbf{T}}^{\mathbf{3/2}}} = \gamma \frac{\mathbf{g_1(x, Q^2) + g_2(x, Q^2)}}{\mathbf{F_1(x, Q^2)}}$$

- COMPARE TO POSITIVITY LIMIT $\mathbf{A_2 < \sqrt{R(x, Q^2)}}$
- COMPARE TO SOFFER LIMIT $\mathbf{A_2 < \sqrt{R(1 + A_1)/2}}$

SIMPLE FIT USED TO CALCULATE g_2^{WW}

$Q^2 > 1$

$$g_1^p/F_1^p = x^{.700}(.817+1.014x-1.489x^2)(1-.04/Q^2)$$

$$g_1^n/F_1^n = x^{-.335}(-.013-.330x+.761x^2)(1+.13/Q^2)$$

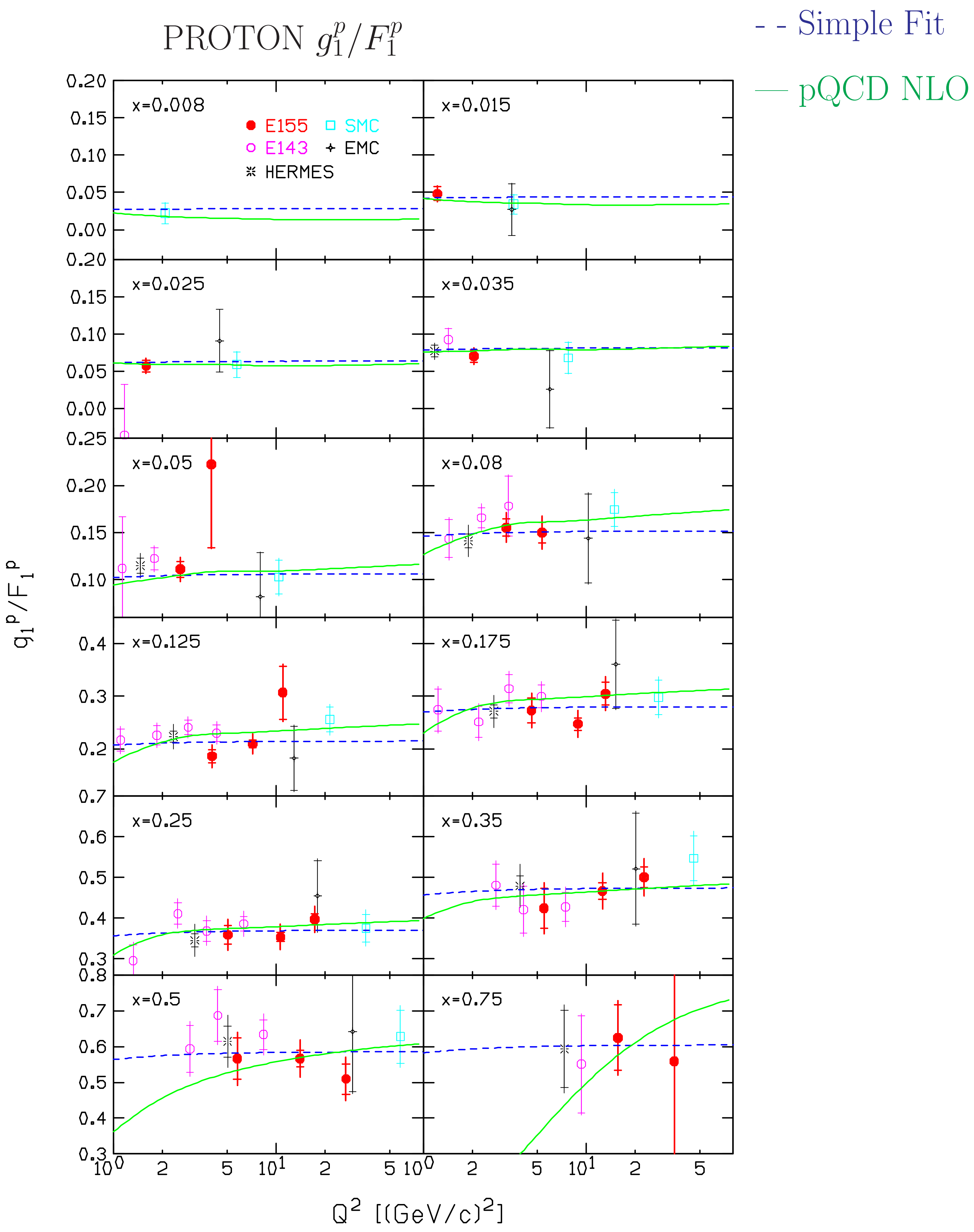
Q^2 DEPENDENCE

Proton -0.04 ± 0.06

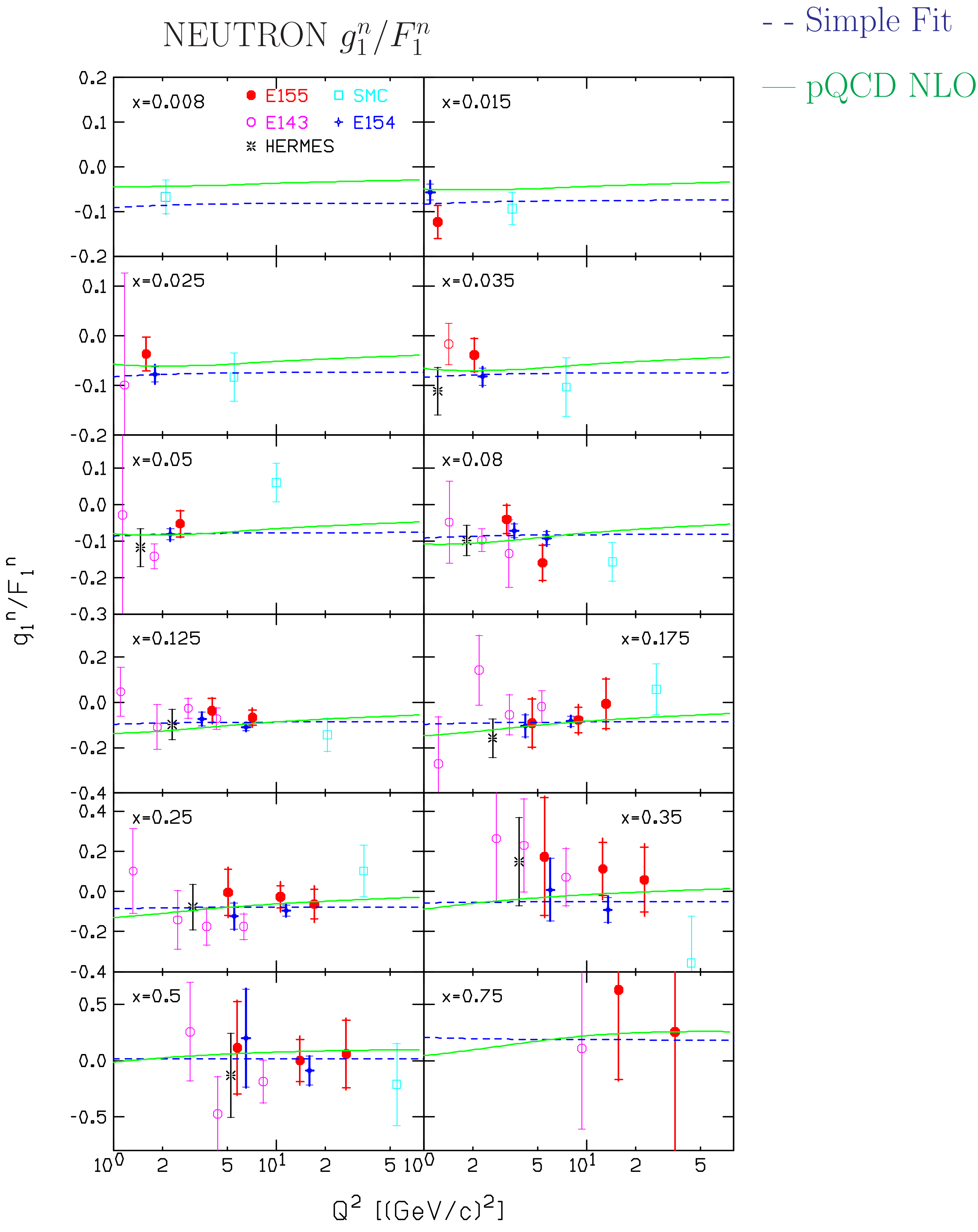
Neutron 0.13 ± 0.45

NLO pQCD $\overline{MS}$ FIT

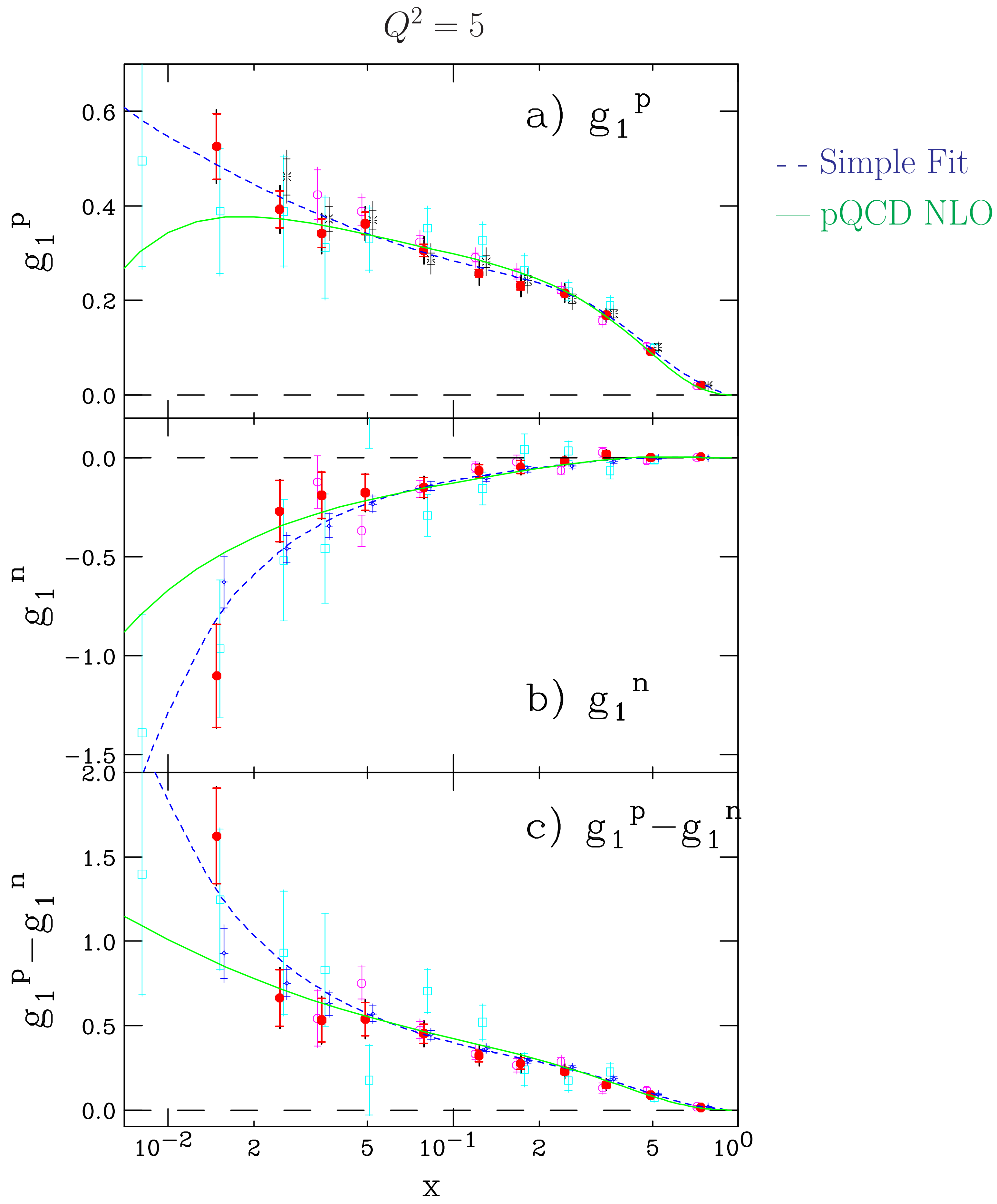
- **Values at** $Q^2 = 5$
- $\Delta\Sigma = 0.23 \pm 0.04 \pm 0.06$
- $\Gamma^{p-n} = 0.176 \pm 0.003 \pm 0.007$
- **(Calculated** 0.182 ± 0.005
- $\Delta G = 1.6 \pm 0.8 \pm 1.1$



PROTON g_1^p/F_1^p
- - Simple Fit
— pQCD NLO
x=0.008
x=0.015
x=0.025
x=0.035
x=0.05
x=0.08
x=0.125
x=0.175
x=0.25
x=0.35
x=0.5
x=0.75
E155
SMC
E143
EMC
HERMES
g_1^p/F_1^p
Q^2 [(GeV/c)^2]



NEUTRON g_1^n/F_1^n
- - Simple Fit
— pQCD NLO
E155
SMC
E143
E154
HERMES
x=0.008
x=0.015
x=0.025
x=0.035
x=0.05
x=0.08
x=0.125
x=0.175
x=0.25
x=0.35
x=0.5
x=0.75
g_1^n/F_1^n
Q^2 [(GeV/c)^2]



$Q^2 = 5$
a) g_1^p
b) g_1^n
c) $g_1^p - g_1^n$
g_1^p
g_1^n
$g_1^p - g_1^n$
x
Simple Fit
pQCD NLO

$g_2(x, Q^2)$ STRUCTURE FUNCTION

- Wandzura-Wilczek g_2 expression (twist-2 only)

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

- In general there are additional contributions.

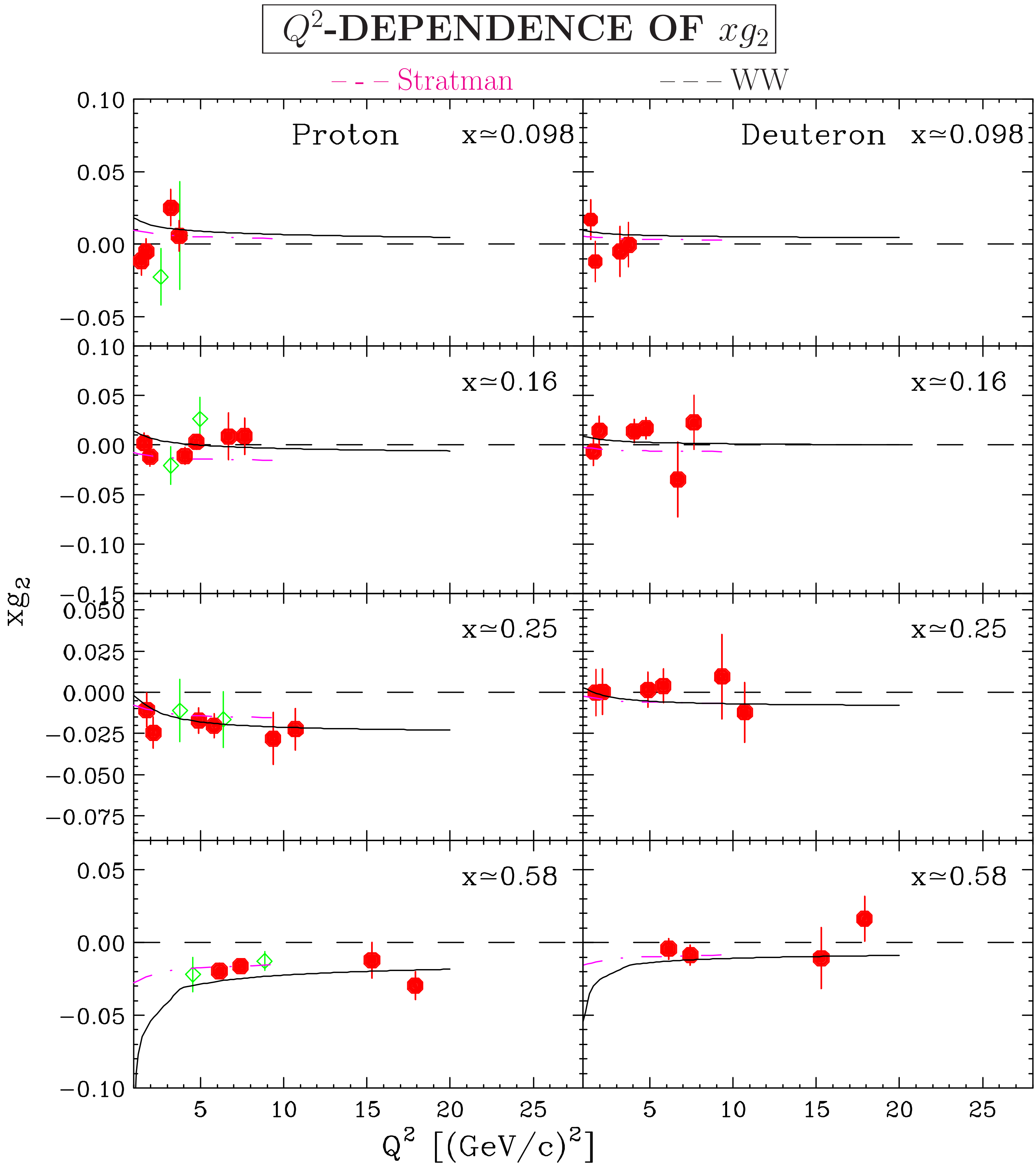
$$\begin{array}{ccc} \text{twist-2} & \text{twist-2} & \text{twist-3} \\ \Downarrow & \Downarrow & \Downarrow \end{array}$$

$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) - \int_x^1 \frac{\partial}{\partial y}\left(\frac{m}{M} h_T(y, Q^2) + \xi(y, Q^2)\right)\frac{dy}{y}$$

$$= g_2^{WW}(x, Q^2) + \overline{g_2}(x, Q^2)$$

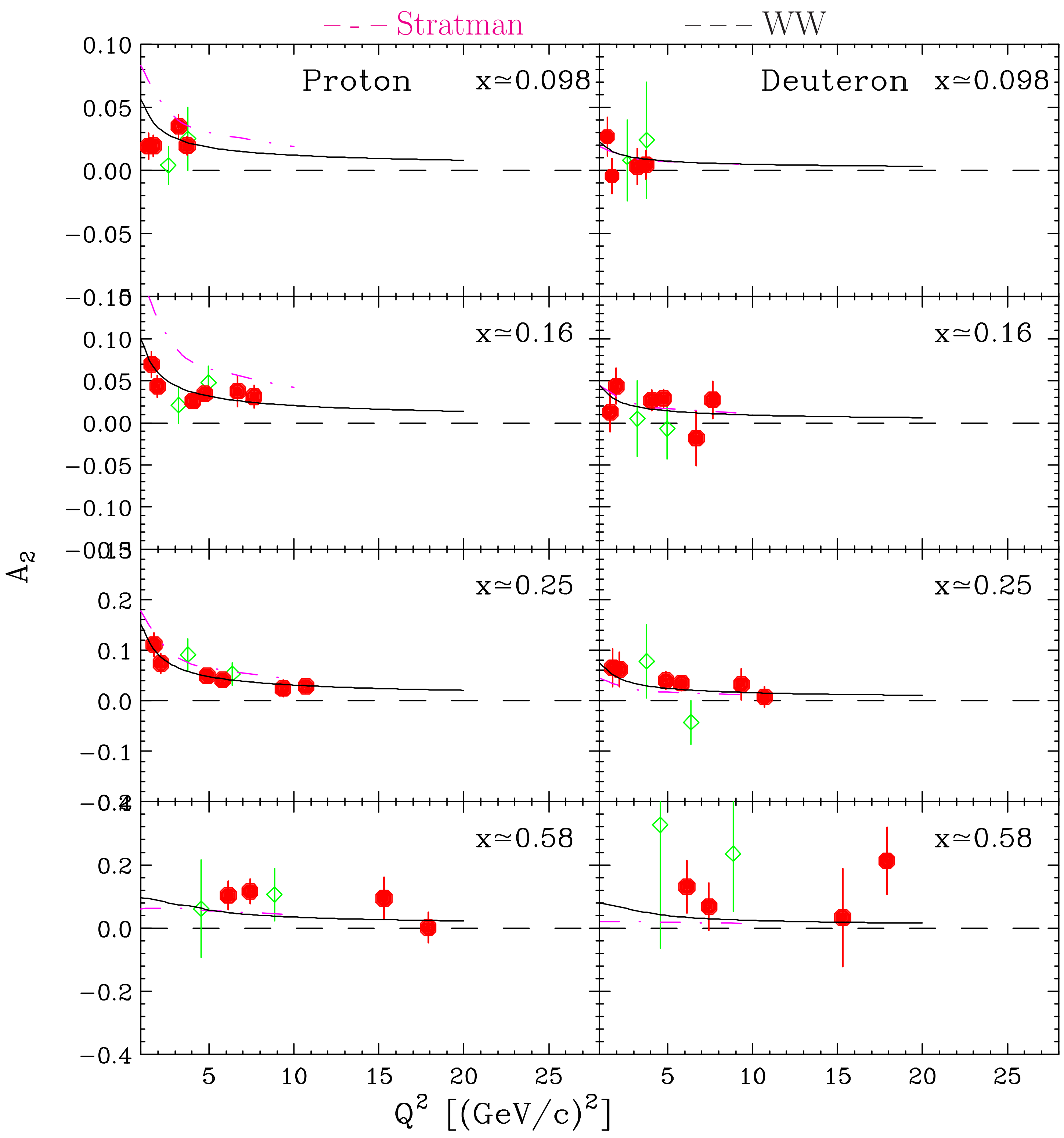
- $\overline{g_2}$ includes quark-gluon correlations (ξ) inside the nucleon
- Twist-2 term (quark transverse spin distribution h_T) in $\overline{g_2}$ suppressed by $\frac{m}{M} << 1$

- Burkhardt-Cottingham (BC) sum rule from virtual Compton scattering dispersion relations in $Q^2 \to \infty$ limit:
$\int_0^1 g_2(x, Q^2)dx = 0$

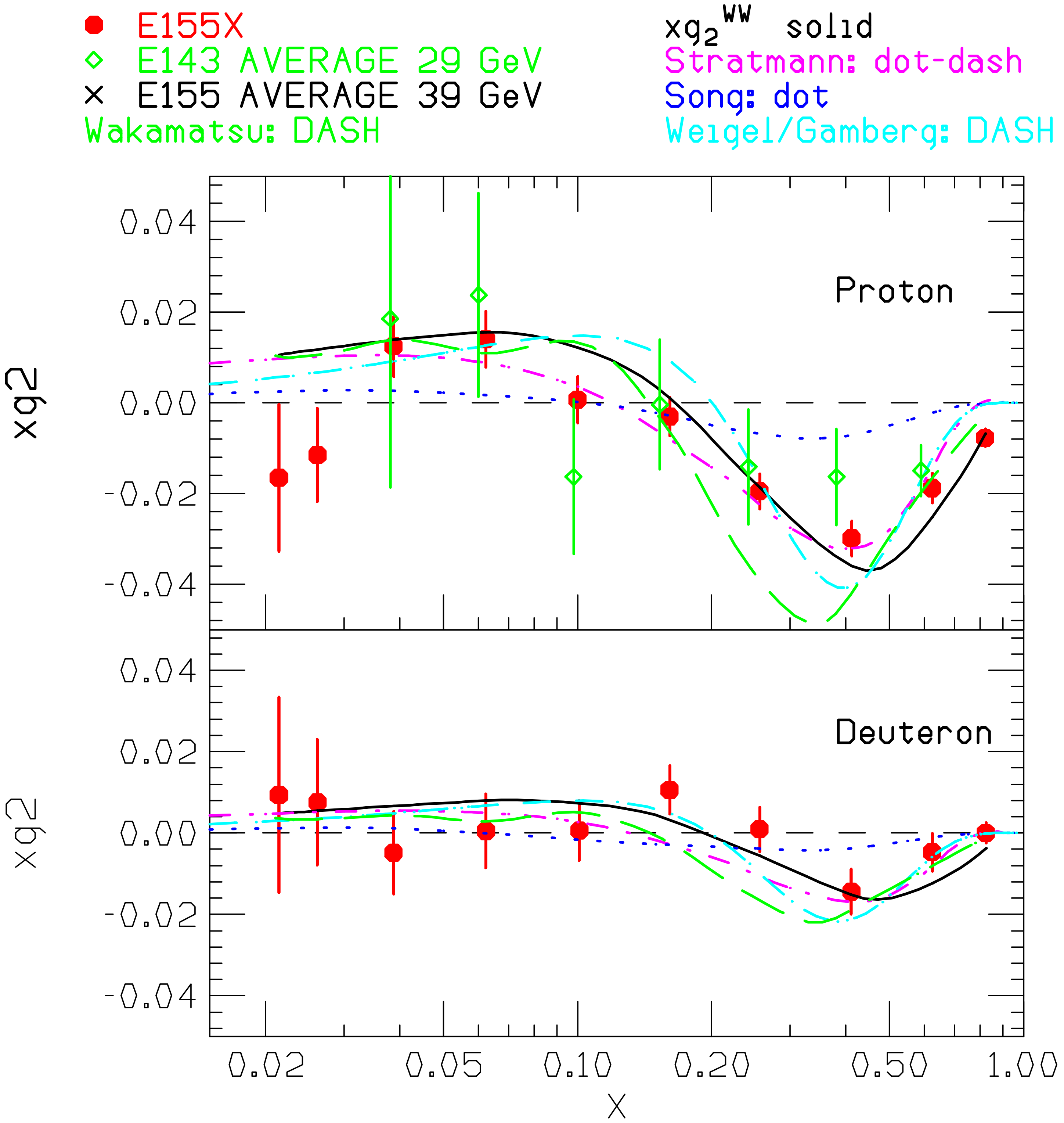


Q^2-DEPENDENCE OF xg_2
- - - Stratman
- - - WW
Proton
Deuteron
x≃0.098
x≃0.16
x≃0.25
x≃0.58
xg_2
Q^2 [(GeV/c)^2]

Q^2-DEPENDENCE OF A_2

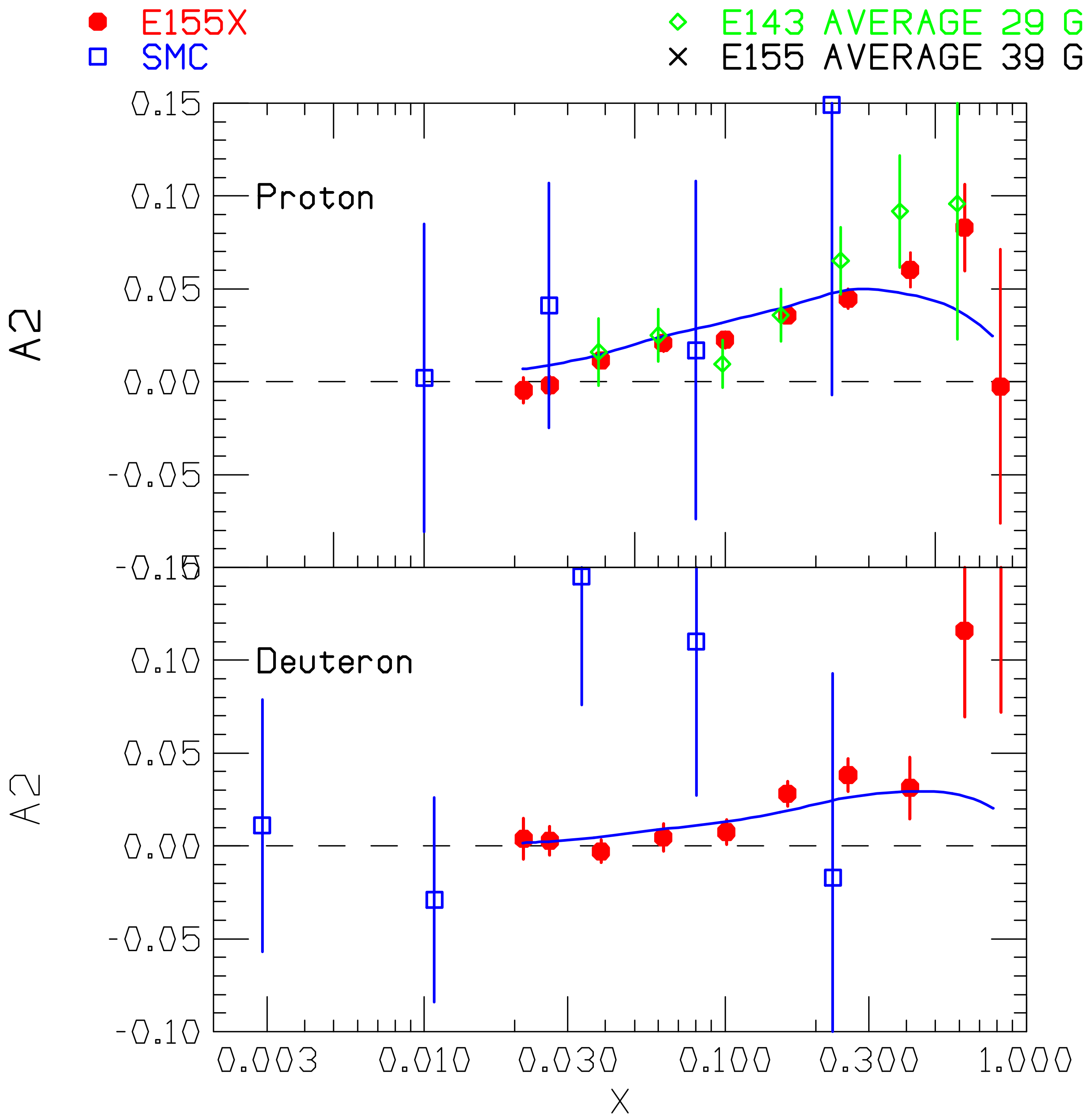


RESULTS FOR Q^2-AVERAGED xg_2



χ^2/df agreement with $g_2^{WW} = 2.1$(p) 1.1(d)

RESULTS FOR Q^2-AVERAGED A_2



$\boxed{\text{Operator Product Expansion}}$
(OPE) For g_1 and g_2

OPE USED IN QCD TO SEPARATE THE PHYSICS INTO A PERTURBATIVE PIECE (easily treated) AND A NONPERTURBATIVE PIECE(unknown matrix elements).

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

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

n=2,4,...

a_n are the twist-2 and d_n are the twist-3 matrix elements.

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

$$= 3\int_0^1 x^2 \overline{g_2}(x, Q^2)dx$$

Q^2 DEPENDENCE

- All the Integrals are at <u>FIXED</u> Q_o^2 whilst the Measurements have Q^2 and x correlated.
- For g_1 integrals, we have 'evolved' to fixed Q^2 using Q^2 dependent fits to g_1/F_1
- For g_2 we use:

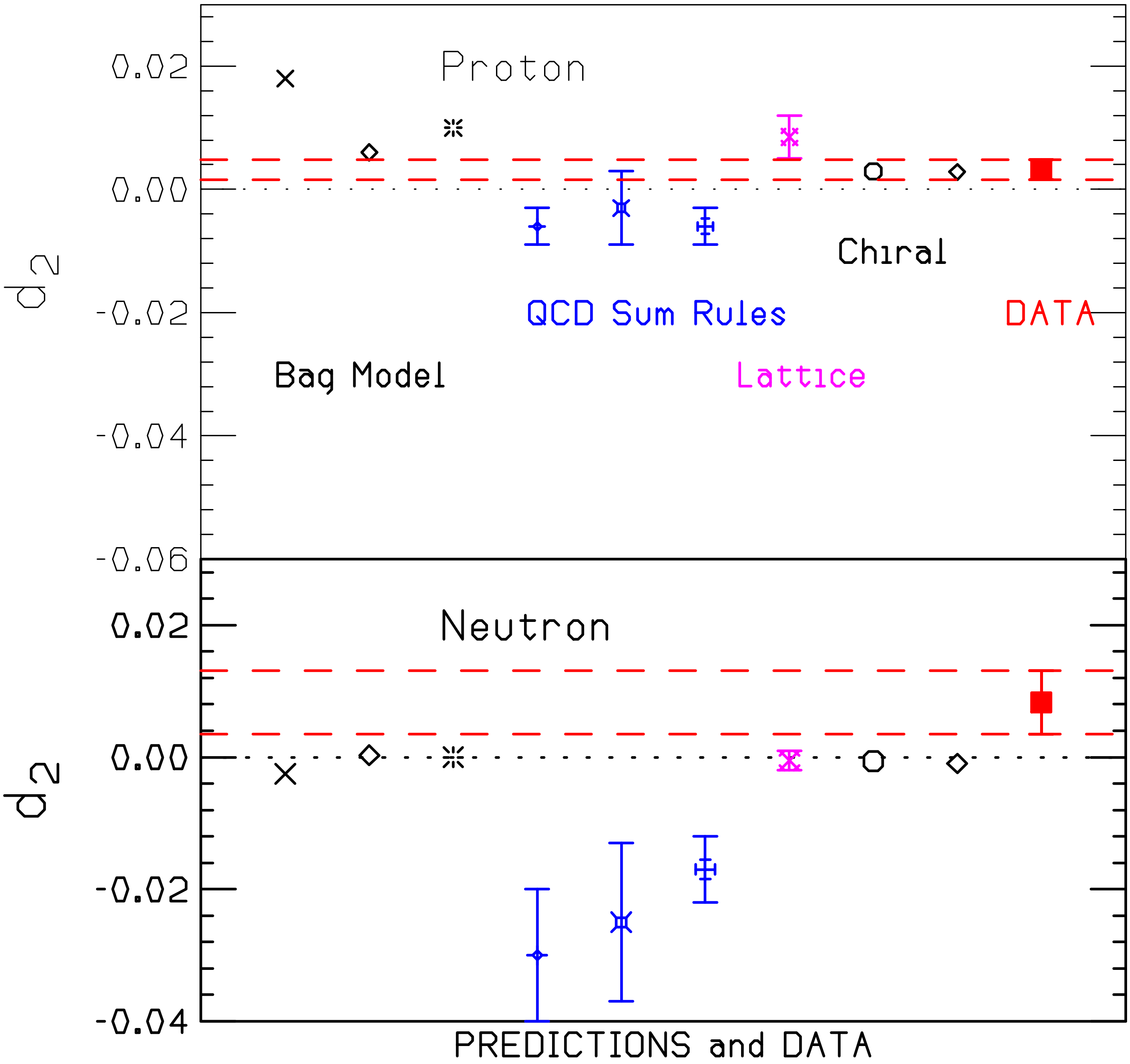
  $$g_2(x, Q_o^2) = \overline{g_2}(x, Q_m^2) + g_2^{WW}(x, Q_o^2)$$

  and <u>ASSUME</u> that the Q^2 dependence of $\overline{g_2}(x, Q^2)$ is negligible.
- d_2 <u>depends logarithmically</u> on Q^2.
- To calculate g_2^{WW} we utilize a global Q^2 dependent fit to g_1/F_1.

THE TWIST-3 d_2 MATRIX ELEMENT

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

$$0.0032 \pm .0016(p) \qquad 0.0083 \pm .0048(n)$$

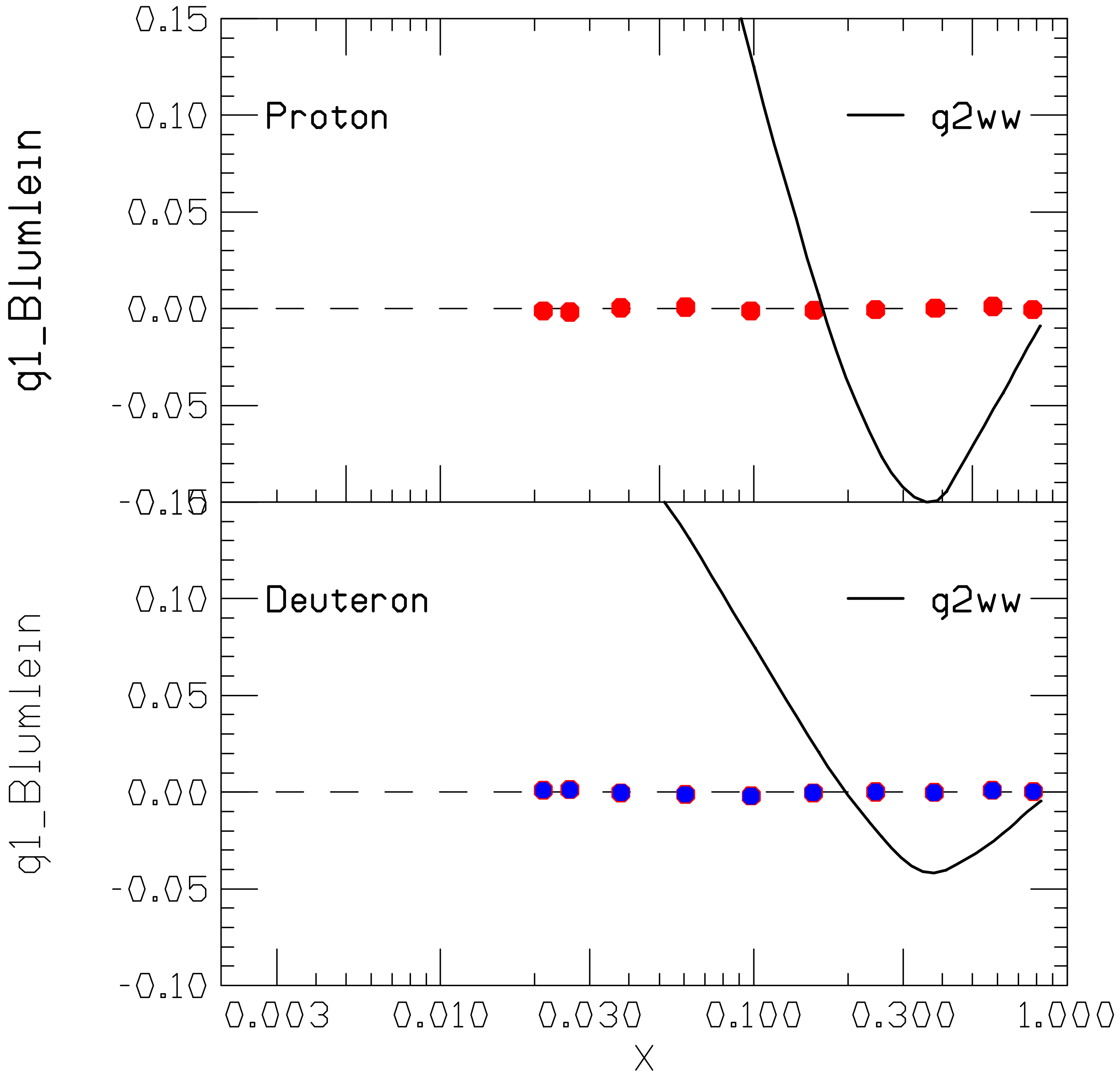


THE TWIST-3 SUM RULE

Blumlein and Tkabadze

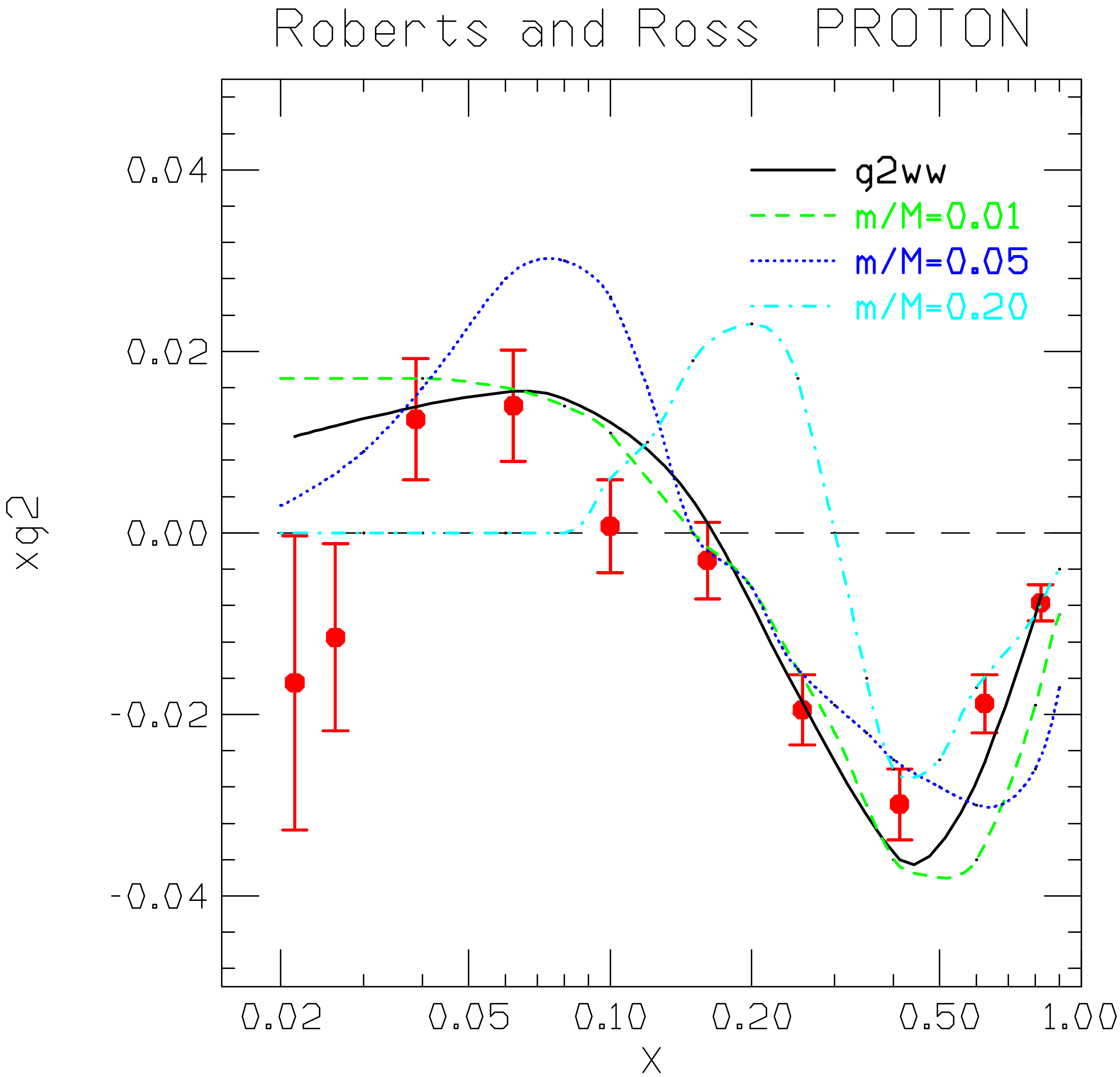
$$\mathbf{g_1(x,Q^2) = \frac{4M^2x^2}{Q^2}\left[\bar{g_2}(x,Q^2) - 2\int_x^1 \frac{dy}{y}\bar{g_2}(y,Q^2)\right]}$$

$g_1^{Blumlein}$



QUARK MODEL WITH TRANSVERSE MOMENTUM

$$\mathbf{A_2F_1 \propto \; g_1+g_2 \; = \int_x^{k_T^2 max} dk_T^2 \tilde{h}(x+\frac{k_T^2}{xM^2})}$$



SUM RULES

Burkhardt-Cottingham

$$\int_0^1 g_2(x)dx = 0$$

	p	d
EXPERIMENT:	-0.028 ± 0.008	0.000 ± 0.011

Efremov-Teryaev-Leader

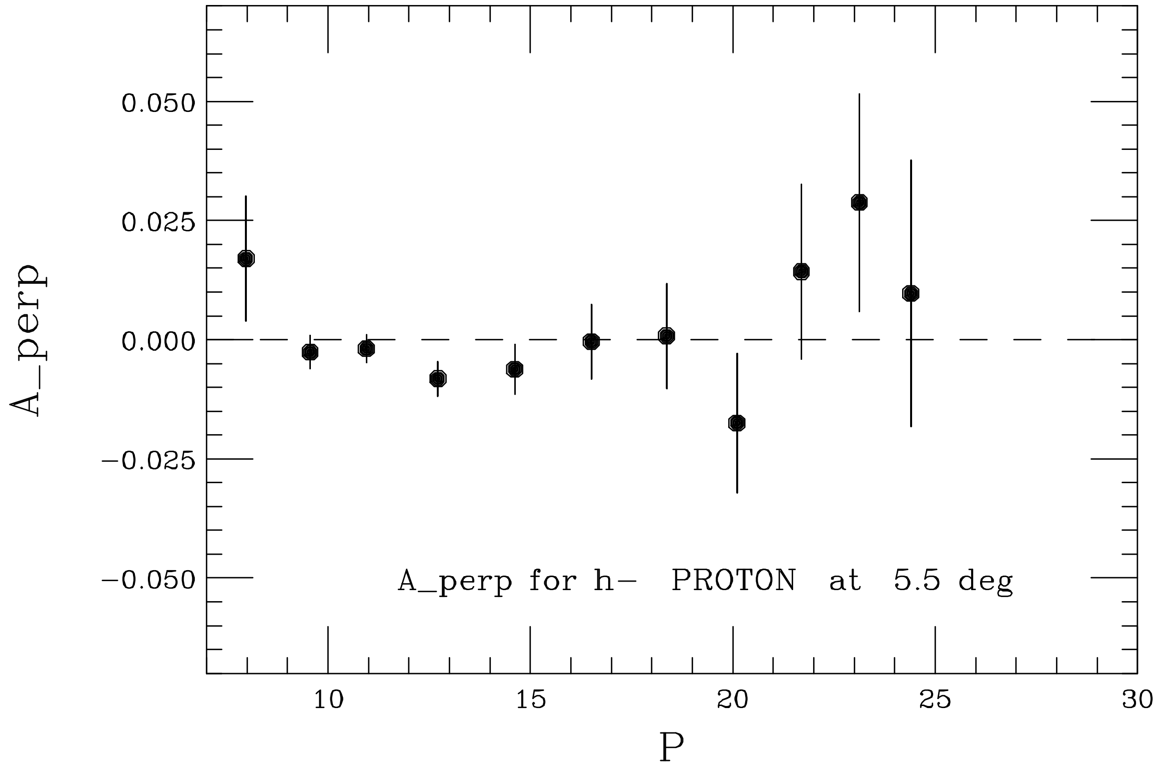
$$\int_0^1 x[g_1^V(x) + 2g_2^V(x)]dx = 0$$

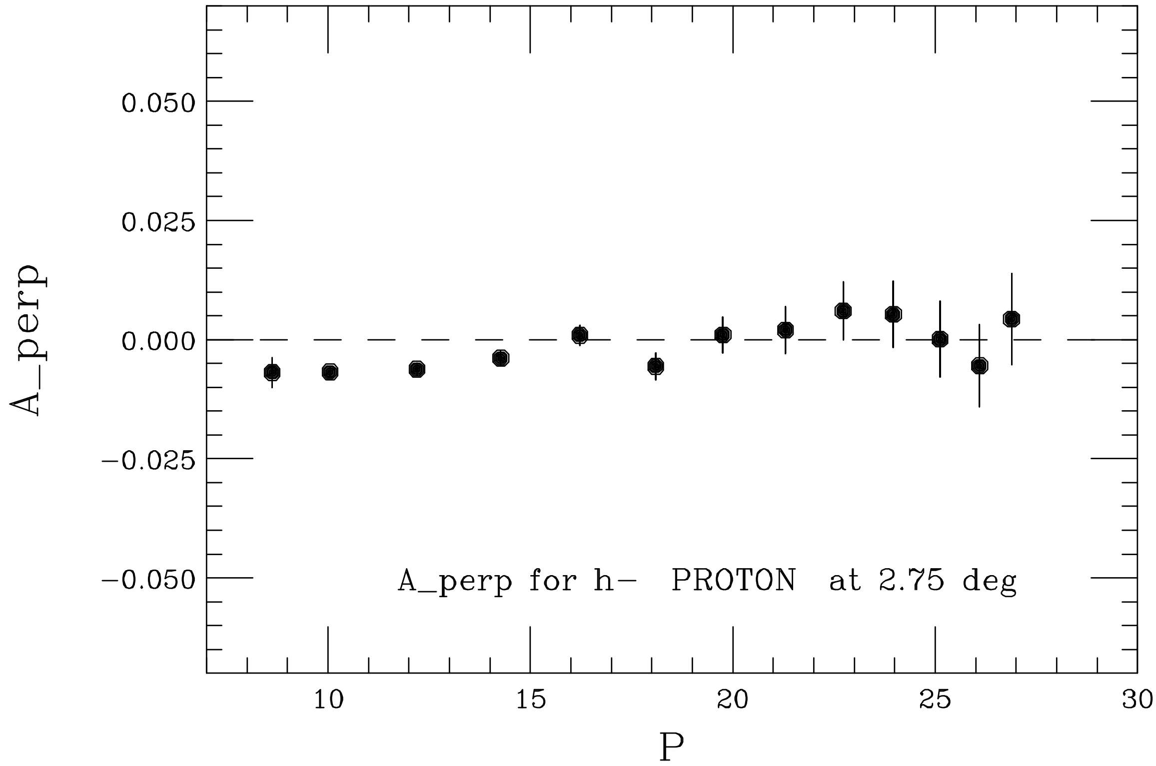
IF $\Delta u_{sea} = \Delta d_{sea} \Rightarrow$

$$\int_0^1 x[g_1^p(x)+2g_2^p(x)-g_1^n(x)-2g_2^n(x)]dx = 0$$

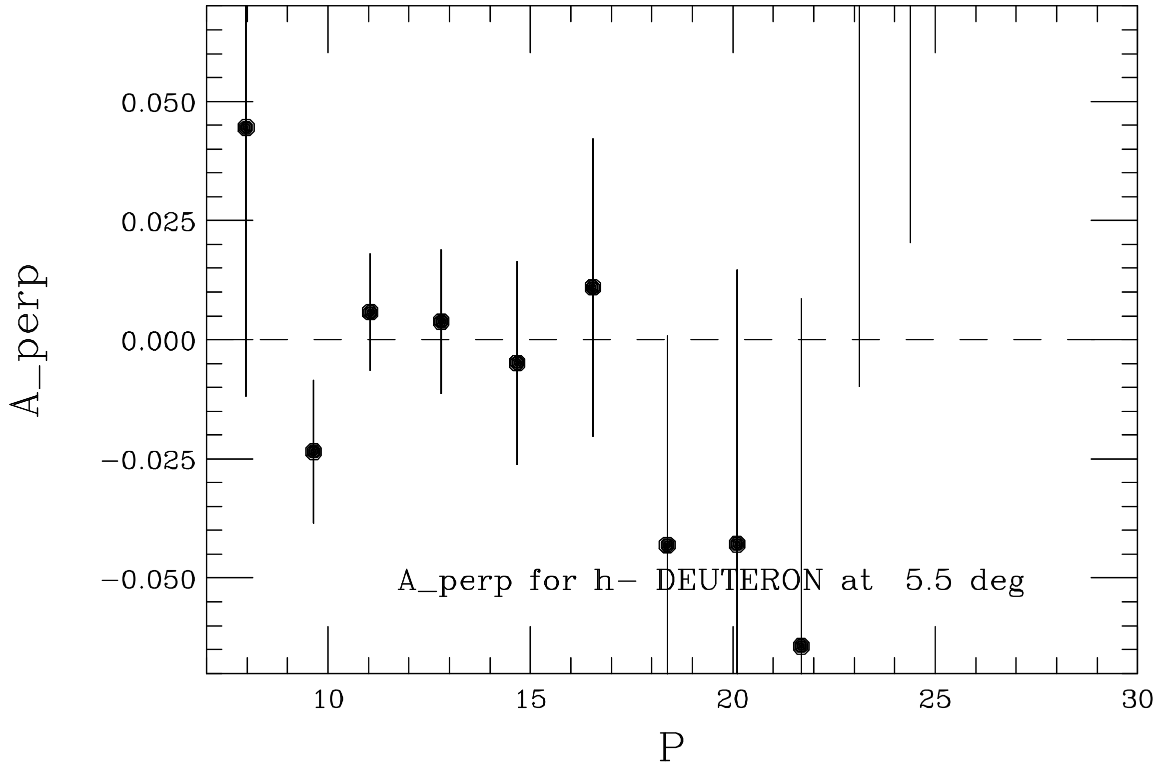
EXPERIMENT (at $Q^2 = 3$) : -0.009 ± 0.008

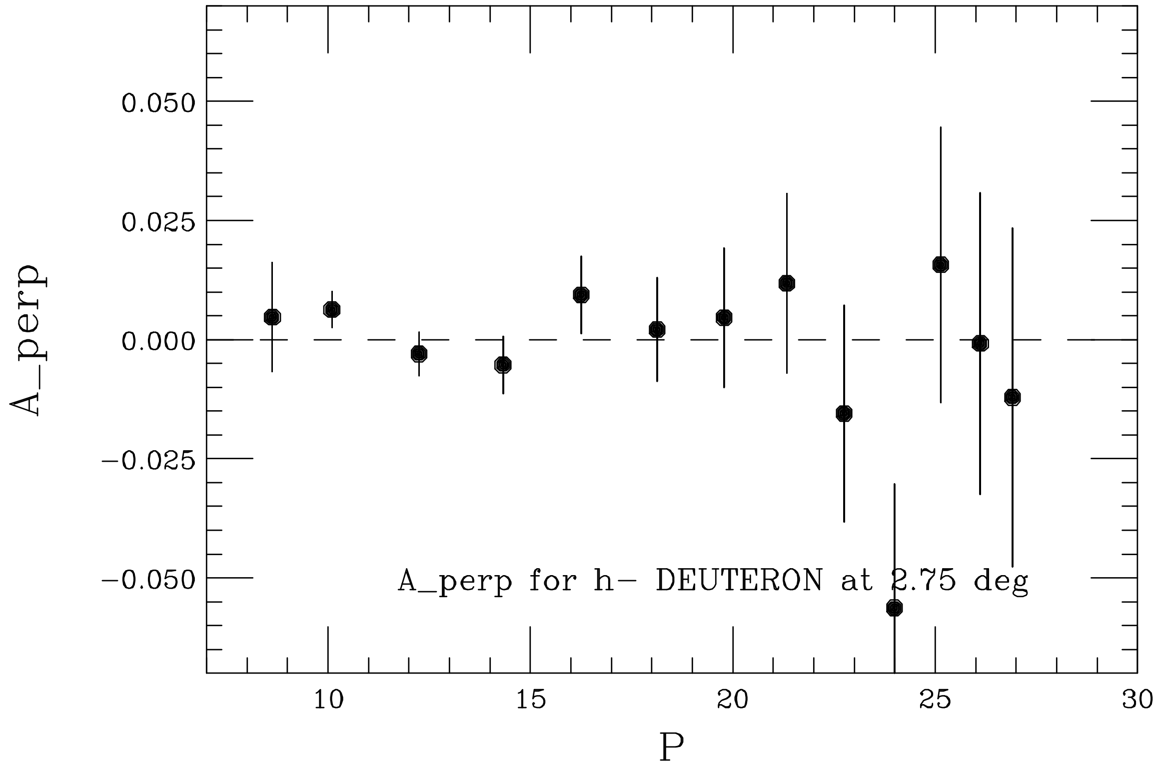
TRANSVERSE PION ASYMMETRIES from P





TRANSVERSE PION ASYMMETRIES from D





SUMMARY

- E155x ERRORS $\approx$ 3x SMALLER THAN PREVIOUS RESULTS.
- NORMALIZATION SYSTEMATIC ERROR SMALL COMPARED TO STATISTICAL ERRORS.
- PROTON g_2 IS POSITIVE FOR $x < 0.1$, NEGATIVE FOR $x > 0.2$.
- ROUGH AGREEMENT SEEN WITH g_2^{WW} MODEL, BAG MODEL OF STRATMANN ET AL., AND CHIRAL MODEL OF WEIGEL ET. AL.
- PROTON A_2 IS POSITIVE FOR ALL x, $A_2 \rightarrow 0$ FOR $x \rightarrow 0$.
- d_2 SMALL
- SUM RULES VALID

FUTURE

3 PHOTOPRODUCTION EXPERIMENTS

POLARIZED QUASI-MONOENERGIC PHOTON BEAM

- **GLUON POLARIZATION FROM OPEN CHARM**
  - **30-45 GeV**
  - **Polarized LiD Target 60%**
  - **Single Muon Spectrometer**
- **GDH SUM RULE**
  - **Total Hadronic Cross Section Asymmetry**

$$\int_{\mathbf{k}_\pi}^{\infty} \frac{\mathbf{dk}}{\mathbf{k}} \Delta\sigma^{\gamma \mathrm{N}}(\mathbf{k}) = \frac{2\pi^2 \alpha \kappa^2}{\mathrm{M}^2} \qquad (1)$$

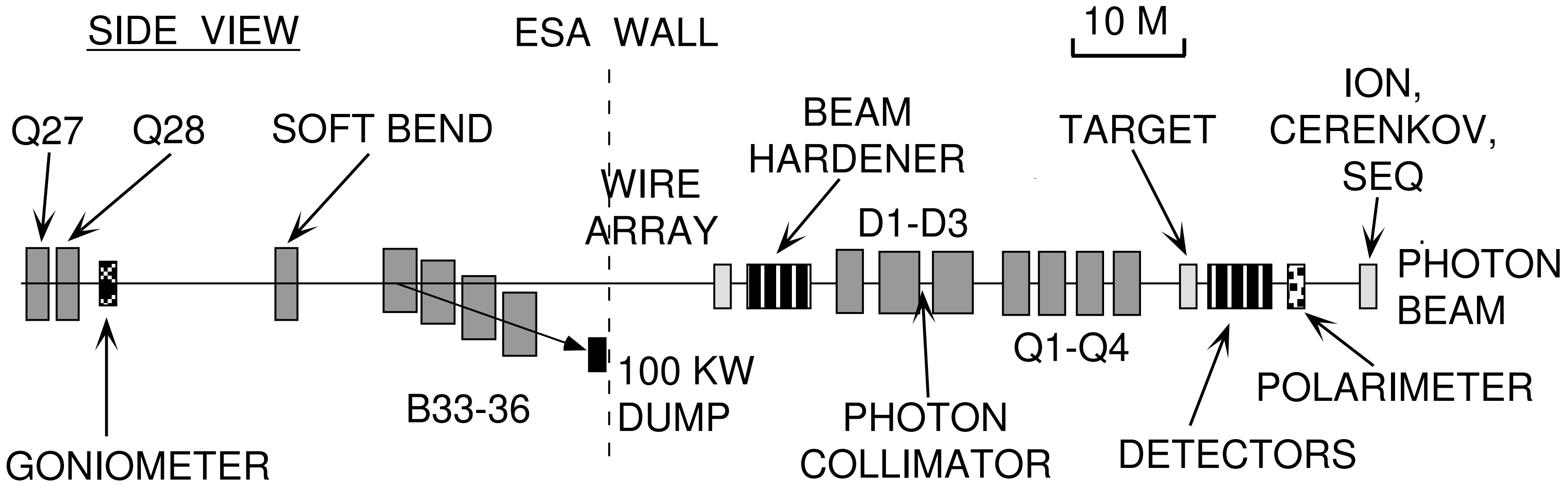
  - **10-45 GeV**
  - **LOWER ENERGIES AT JLAB, MAMI, LEGS, GRAAL, ELSA**
  - **NH_3 and ND_3 Targets**
- **A DEPENDENCE OF J/ψ and ψ'**
  - **J/ψ-NUCLEON CROSS SECTION FOR QUARK-GLUON PLASMA**
  - **COLOR TRANSPARENCY**

$\boxed{\text{FUTURE}}$

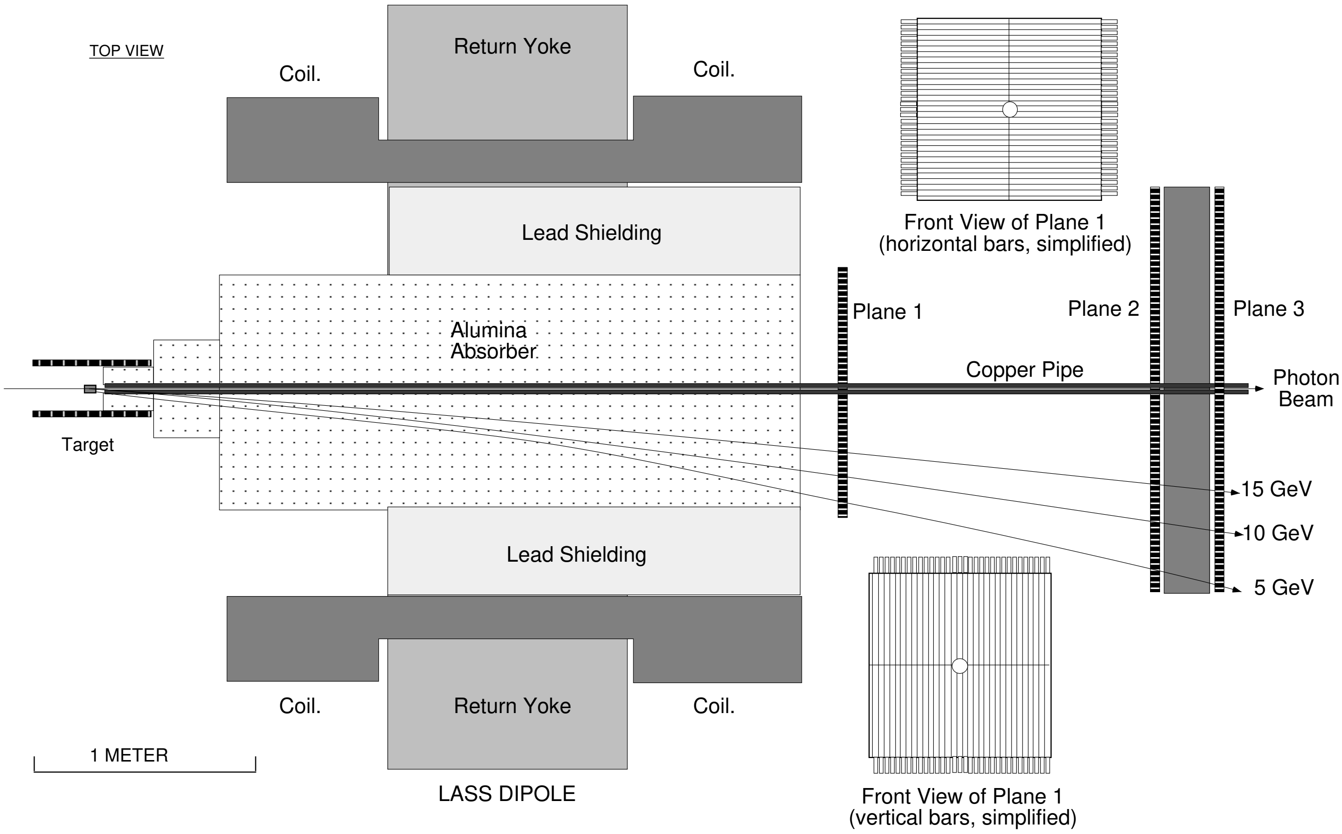
CAN WE LEARN ANTHING WITH

- TRANSVERSE POLARIZED BEAM
- TRANSVERSE POLARIZED TARGET

POLARIZED QUASI-MONOENERGIC PHOTON BEAM

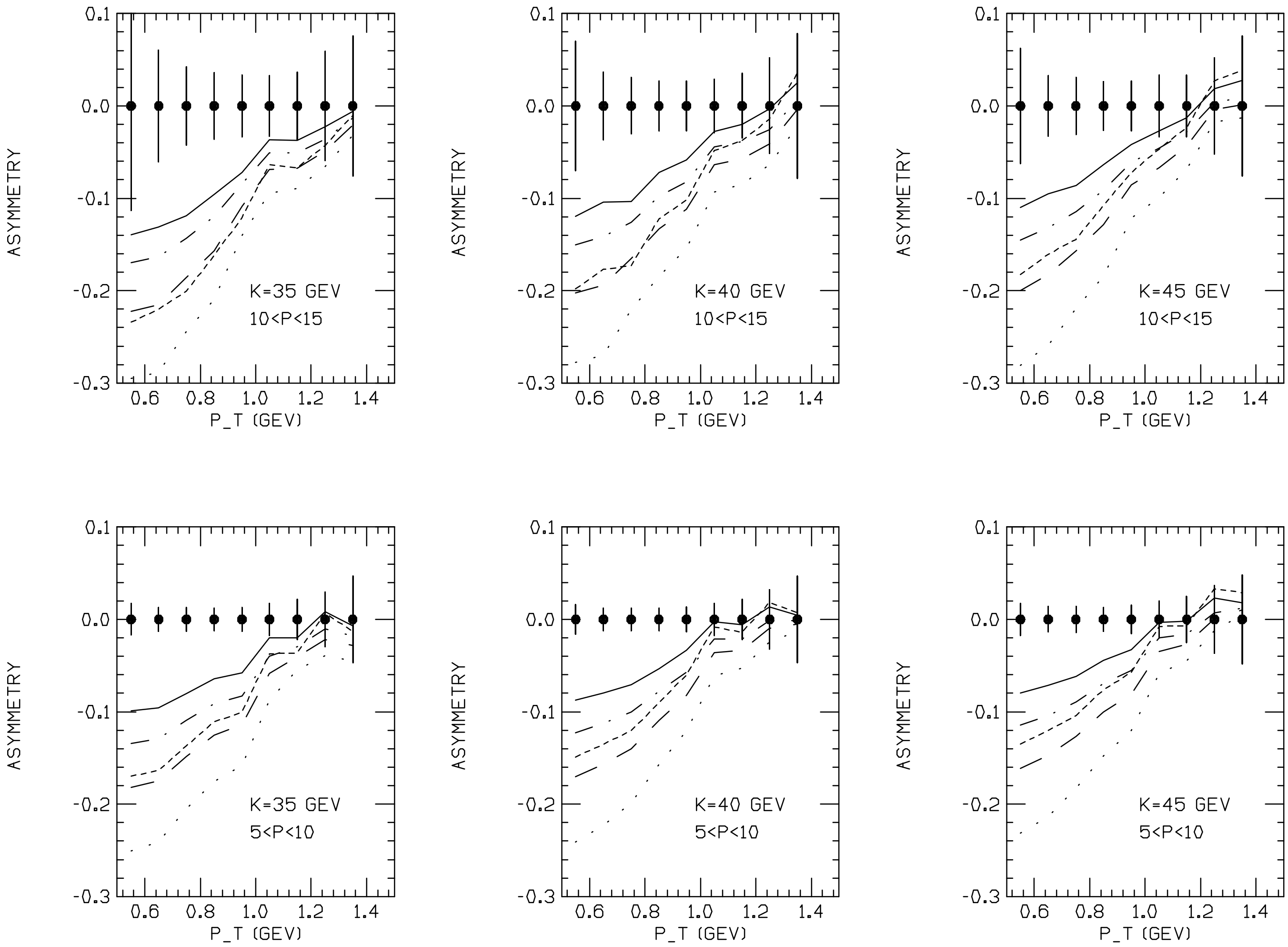


DETECTOR FOR OPEN CHARM



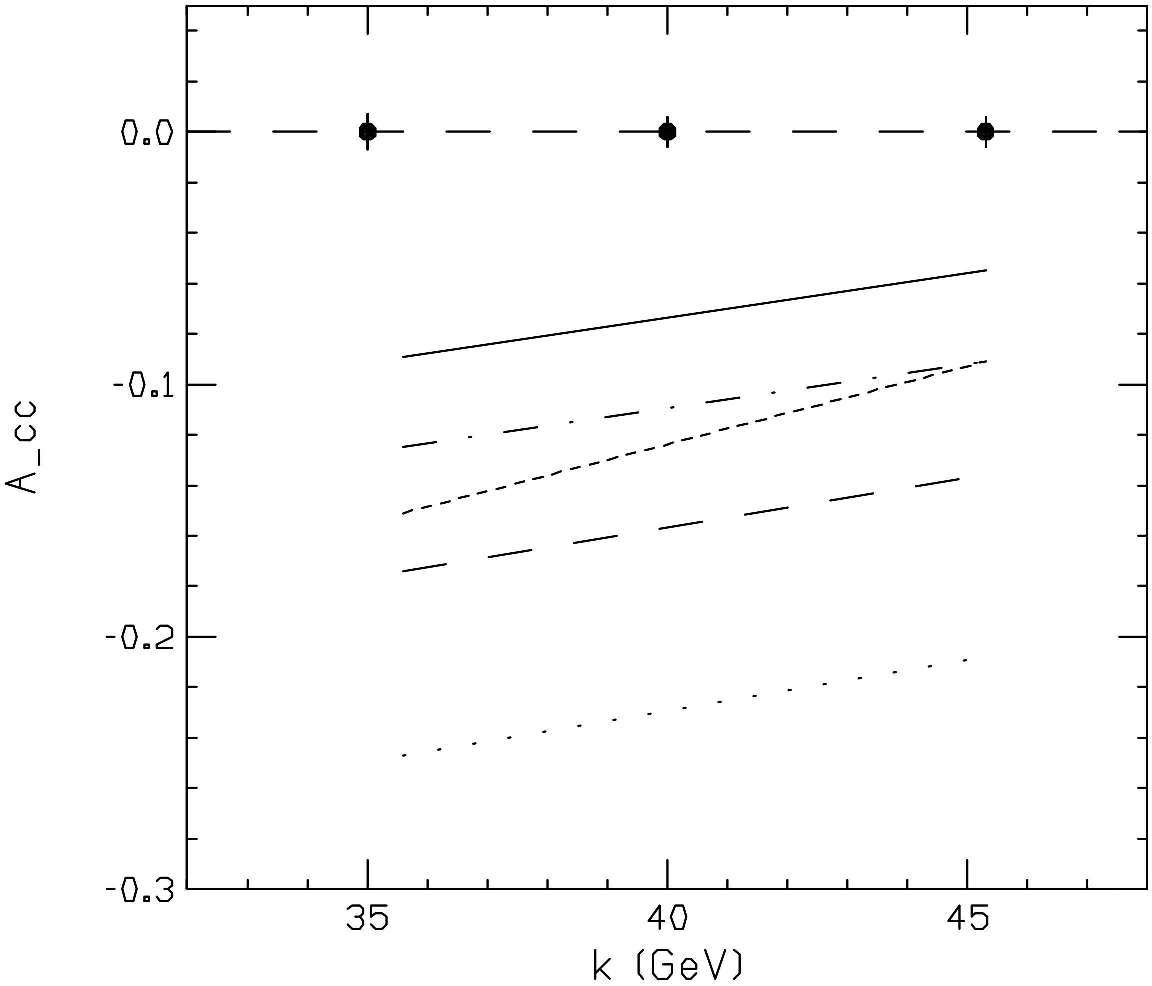
Overall plan view of the main components of the spectrometer. The absorber fills most of the gap of the LASS dipole, and also extends into the warm bore of the target magnet. A thick evacuated copper beam pipe contains the photon beam. The three detector planes are made from scintillator hodoscopes. Two simplified front views of the front plane are shown. The dashed curves are typical trajectories for muons with $p_t = 0.7$ and $P = 5$, 10, and 15 GeV.

EXPECTED ERRORS



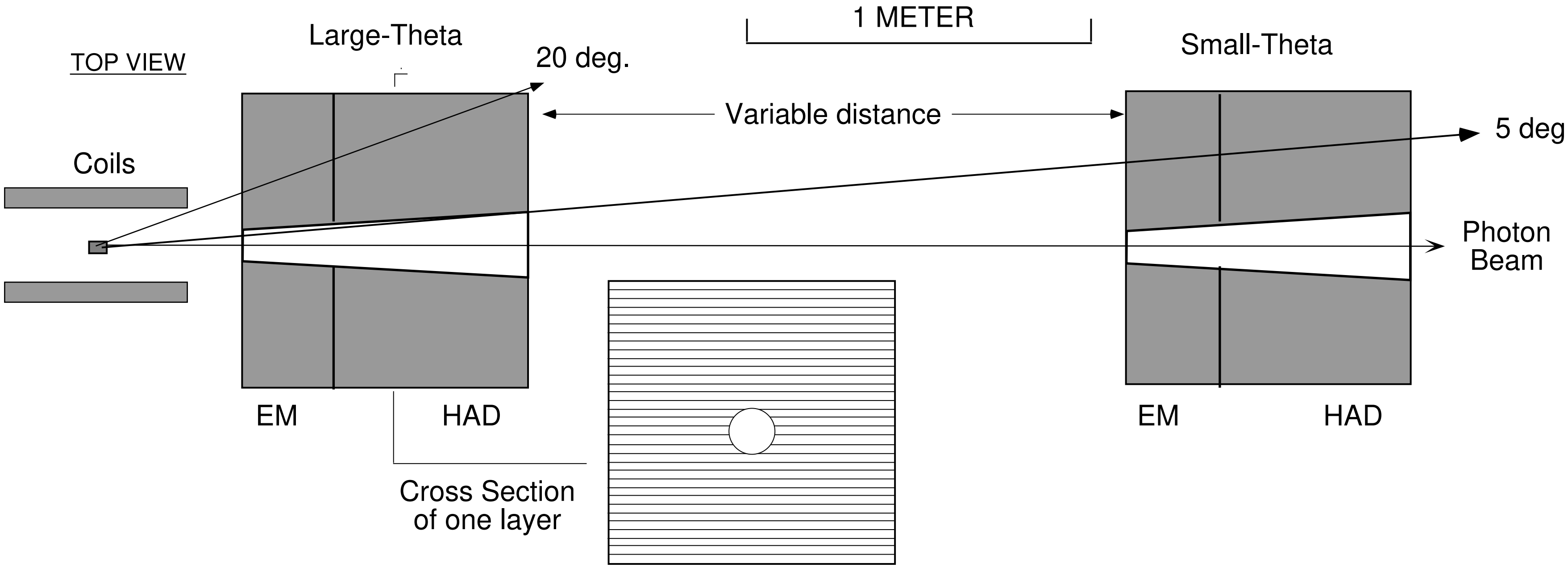
Asymmetries for the five fits to the gluon polarization as a function of p_T^{μ} of the detected muon. The top row is for $10 < P_{\mu} < 15$ GeV and the bottom row for $5 < P_{\mu} < 10$. The three columns correspond to peak beam energies of 35, 40 and 45 Gev. The points indicate the projected statistical errors. Experimental systematic errors will be highly correlated from point-to-point, and will be approximately 0.10 of the measured asymmetries.

AVERAGE EXPECTED ERRORS

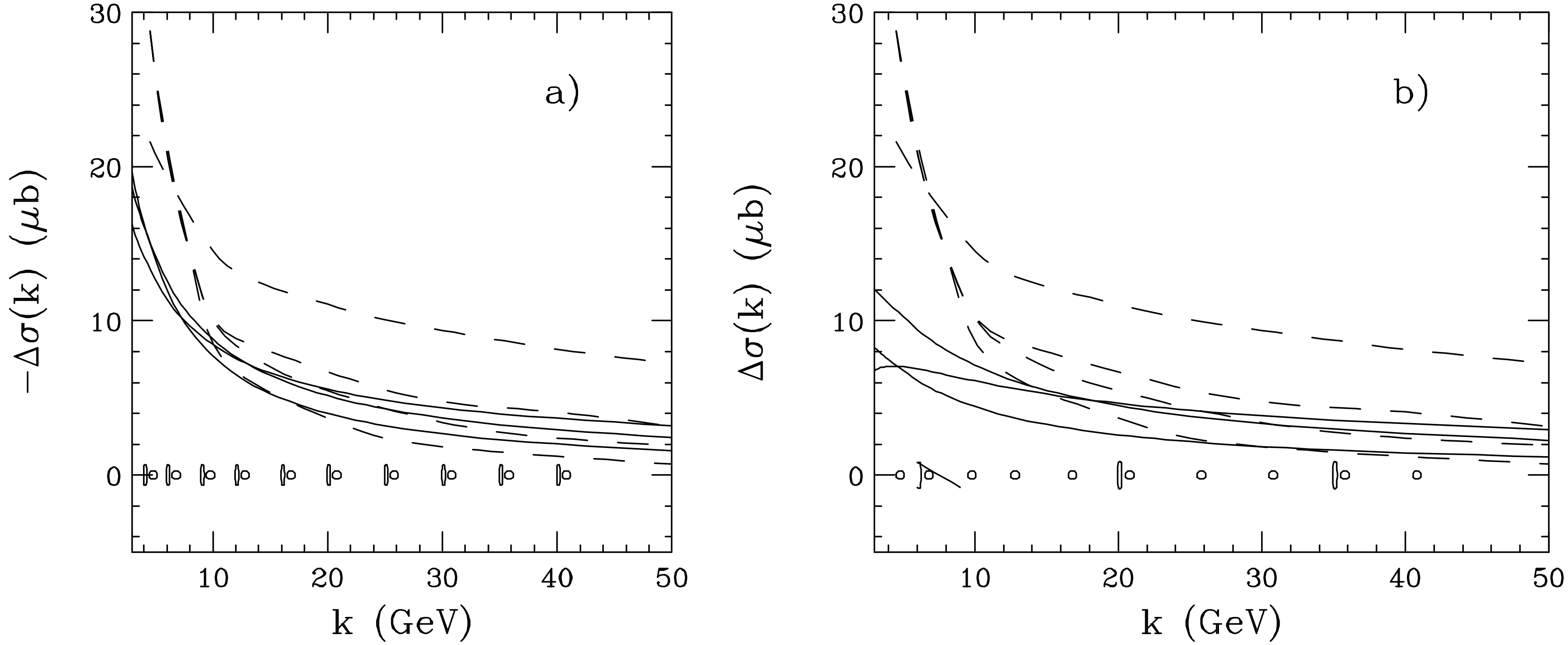


Asymmetries for the five fits to the gluon polarization as a function of beam energy. The points, arbitrarily placed at zero asymmetry, indicate the projected statistical errors for the running conditions given in the text, averaged over p_T.

GDH SUM RULE DETECTOR



GDH: ASYMMETRY ERRORS



Estimated a)proton b) neutron errors for $\Delta\sigma^{\gamma p}(k)$ for this proposal as a function of photon energy for the counting mode (rectangles) and flux integration mode (circles). The symbol heights represent the expected statistical errors in the more conservative analysis. Systematic errors are not shown, but are expected to be 6% to 8% of the measured values of $\Delta\sigma^{\gamma N}(k)$. The dashed curves are representative models.