THE SPIN STRUCTURE FUNCTION g_2 and ASYMMETRY A_2 FROM SLAC E155X

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REPRESENTING THE E155X COLLABORATION

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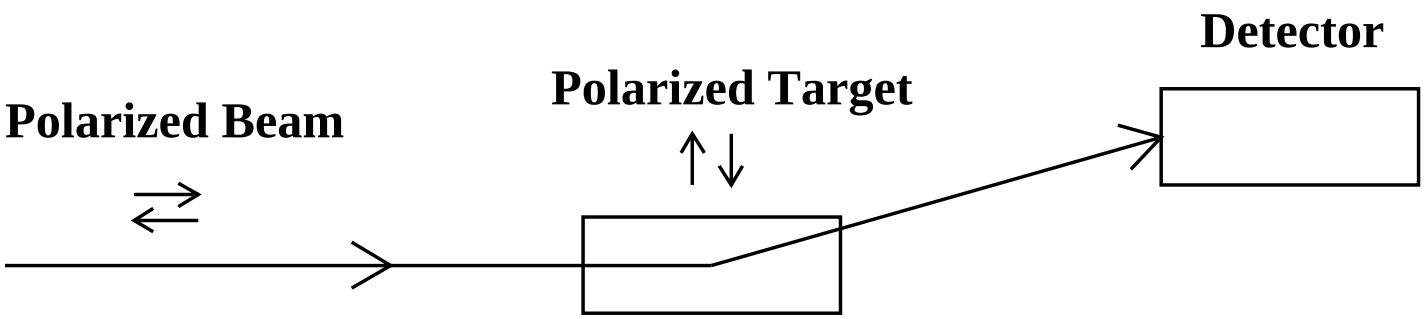
- EXPERIMENT
- SOME THEORY
- g_2 AND A_2 FOR PROTON/DEUTERON
- Q^2 DEPENDENCE OF g_2 AND A_2
- TWIST-3 MATRIX ELEMENT d_2
- SUM RULES

Polarized Deep Inelastic Scattering



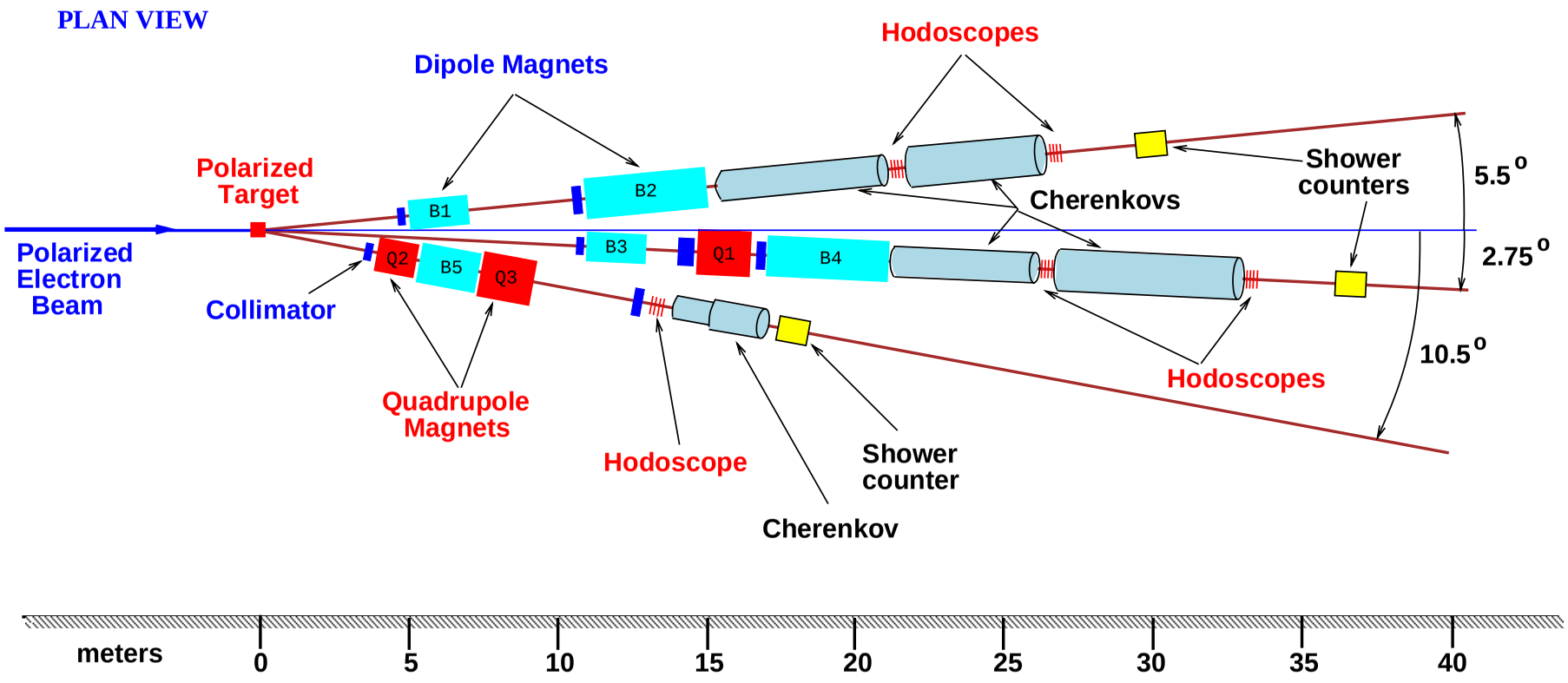
$$A_{\perp} = \frac{\sigma^{\downarrow\leftarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\downarrow\leftarrow} + \sigma^{\uparrow\leftarrow}} = f_k E' \sin(\theta)\left[\mathbf{g_1}(x, Q^2) + \frac{2E}{\nu}\mathbf{g_2}(x, Q^2)\right]$$

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

$\mathbf{g_1}$ 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

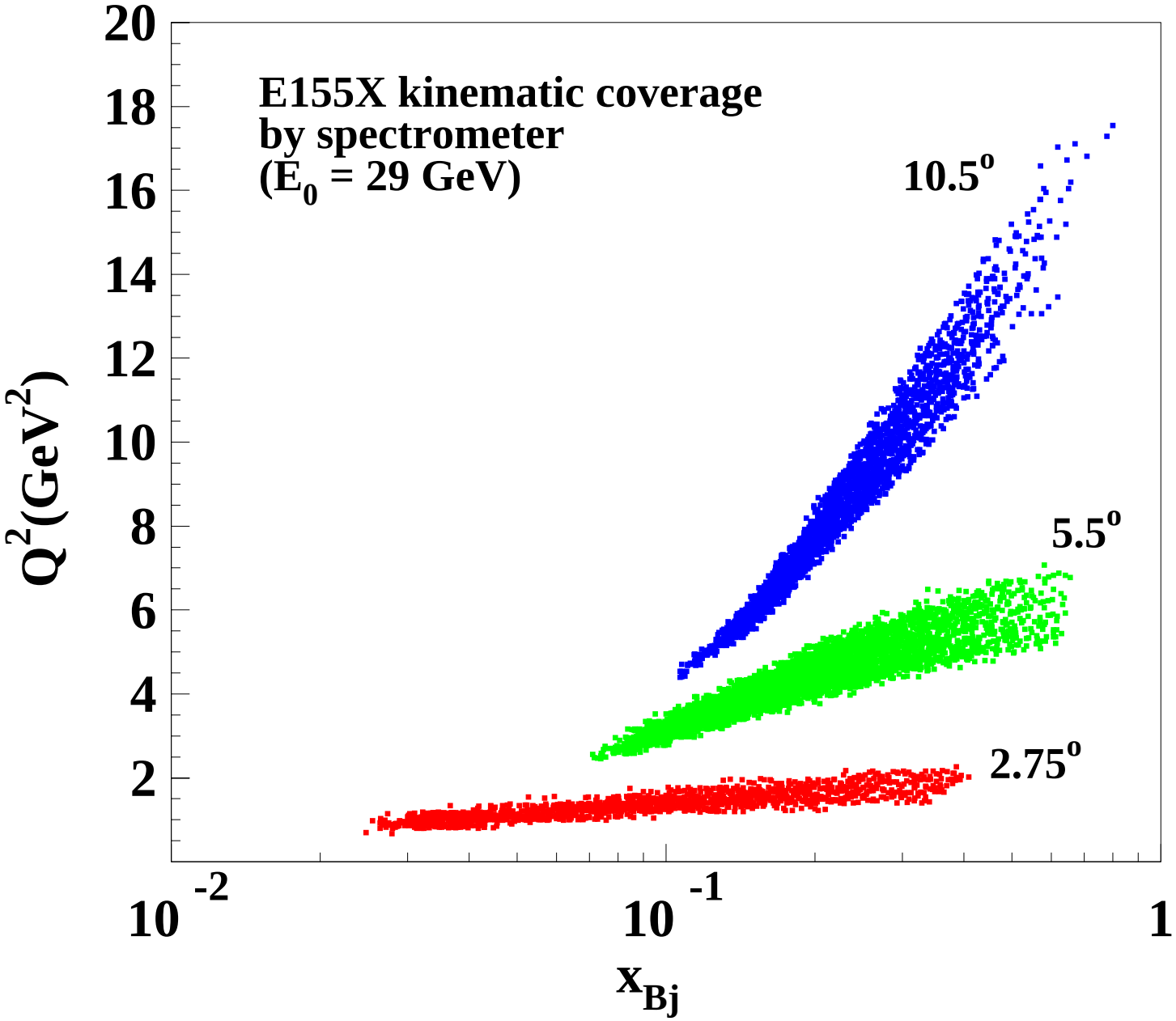
E155 Spectrometers



EXPERIMENTAL OVERVIEW

- **SLAC ELECTRON BEAM:**
  - **POLARIZATION $P_b = 0.83$**
  - **ENERGY $E = 29.1$ or $E = 32.3$**
- **TRANSVERSELY POLARIZED TARGETS:**
  - **1 K, 5 T, D.N.P**
  - **NH_3 (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**
  - **CERENKOV AND LEAD GLASS FOR PARTICLE I.D.**
  - **HODOSCOPES FOR TRACKS ($dP/P \approx 0.03$)**

KINEMATICS


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

THE $A_\perp$ ASYMMETRY

$$\tilde{A}_\perp = \frac{1}{f_{RC}}\left[\frac{C_1}{fP_t}\left(\left(\frac{N_L - N_R}{N_L + N_R}\right)\frac{1}{P_b} + A_{EW}\right) + C_2\right] + A_{RC}$$

- 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 PLANE OF ELECTRON SCATTERING.
- f IS DILUTION FACTOR ($\approx$ 0.16 PROTON)
- A_{EW}: ELECTROWEAK ASYMMETRY ($\approx 8 \times 10^{-5} Q^2$)
- f_{RC} AND A_{RC}: RADIATIVE CORRECTIONS
  - f_{RC} Mostly from Elastic and Quasi-elastic tail: Increases Statistical Error
  - A_{RC} Mostly From Resonance and DIS

DETERMINATION OF g_2 and A_2

- **WE USE MEASURED $\tilde{A}_\perp$ and E155 g_1 FIT TO OBTAIN g_2 USING:**

$$g_2 = \frac{yF_1}{2E'(\cos\Theta - \cos\alpha)}\left[\tilde{A}_\perp \nu \frac{(1+\epsilon R)}{1-\epsilon} - \frac{g_1}{F_1}[E\cos\alpha + E'\cos\Theta]\right]$$

- **WE CAN ALSO EXTRACT VIRTUAL PHOTON-NUCLEON ASYMMETRY**

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

- **COMPARE TO POSITIVITY LIMIT**
  $A_2 < \sqrt{R(x,Q^2)}$

- **COMPARE TO SOFFER LIMIT**
  $A_2 < \sqrt{R(1+A_1)/2}$

SYSTEMATIC ERRORS

$A_\perp$ ERRORS

- RADIATIVE CORRECTIONS
  - Used Many Different Models of $A_\perp$
  - Resonance, twist-3, Quasi-elastic ..
- MULTIPLICATIVE ERR: 5.1% (p); 6.2% (d)
  - TARGET POL: 1.7% (p); 4.5% (d)
  - DILUTION FACTOR: 3.0% (p); 2.1% (d)
  - BEAM POLARIZATION: 3.7%

g_2 ERRORS

- g_1: 5% INCLUDES MODEL ERRORS
- POLARIZATION ANGLE
- F_2: 2%
- R

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

OTHER FITS USED: INCLUDED IN SYSTEMATIC ERROR ON g_1

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

- **In general**

twist-2 $\Downarrow$ twist-2 $\Downarrow$ twist-3 $\Downarrow$

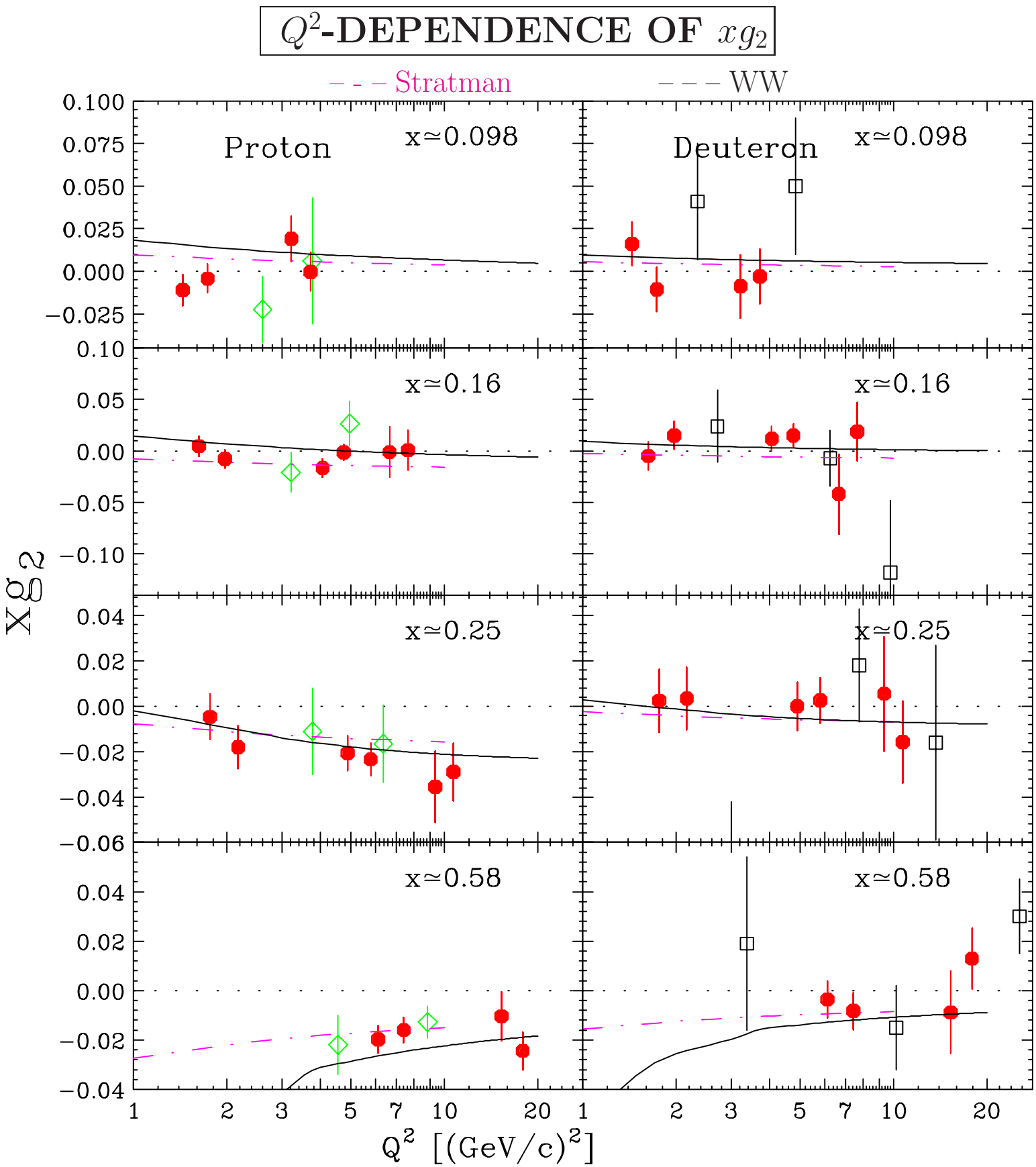
$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) - \int_x^1 \frac{\partial}{\partial y}\left(\frac{m}{M} h_T(y, Q^2) + \xi(y, Q^2)\right)\frac{dy}{y}$$

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

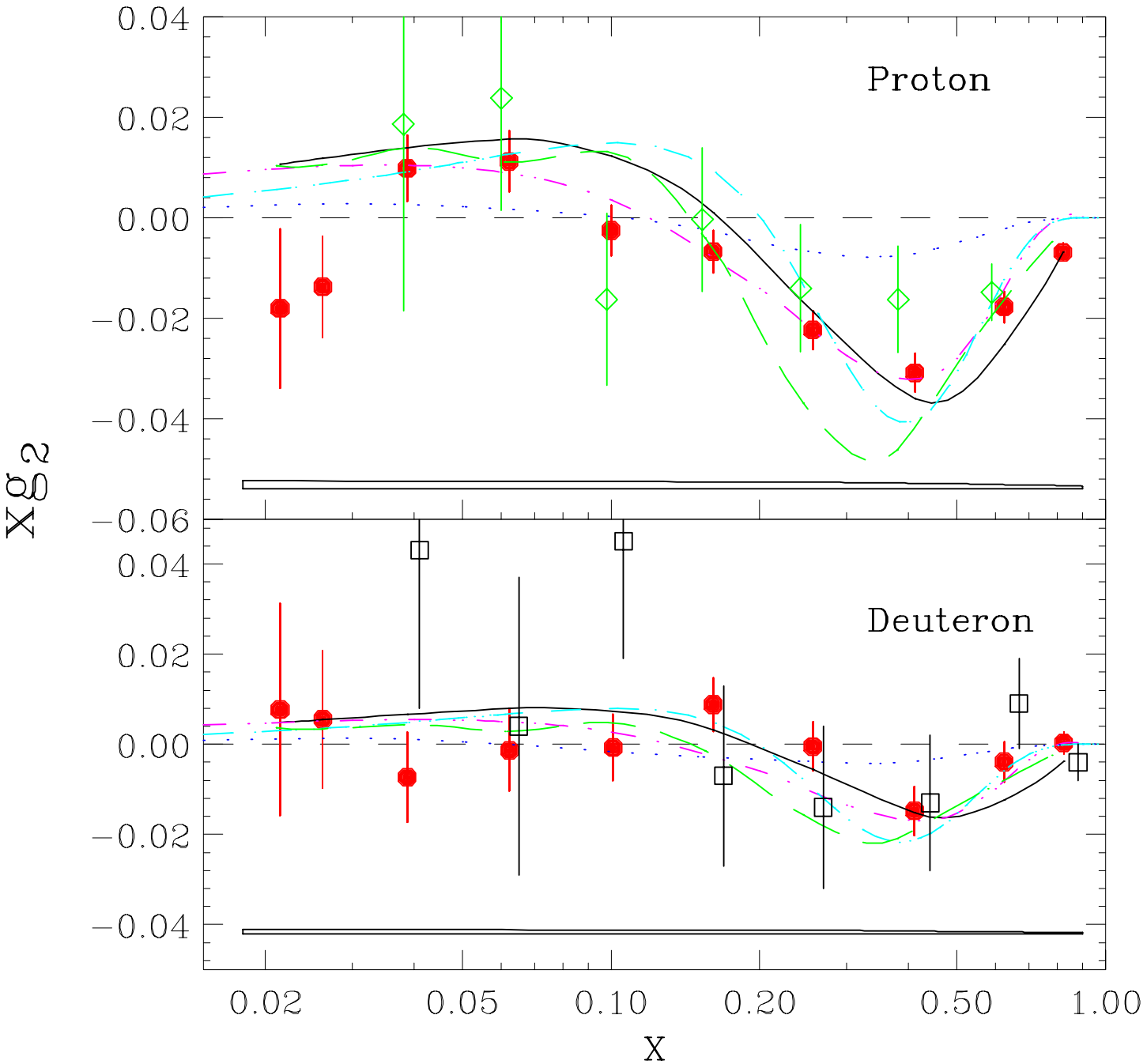
- **Wandzura-Wilczek g_2 expression (twist-2 only)**

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

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


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]

RESULTS FOR Q^2-AVERAGED xg_2



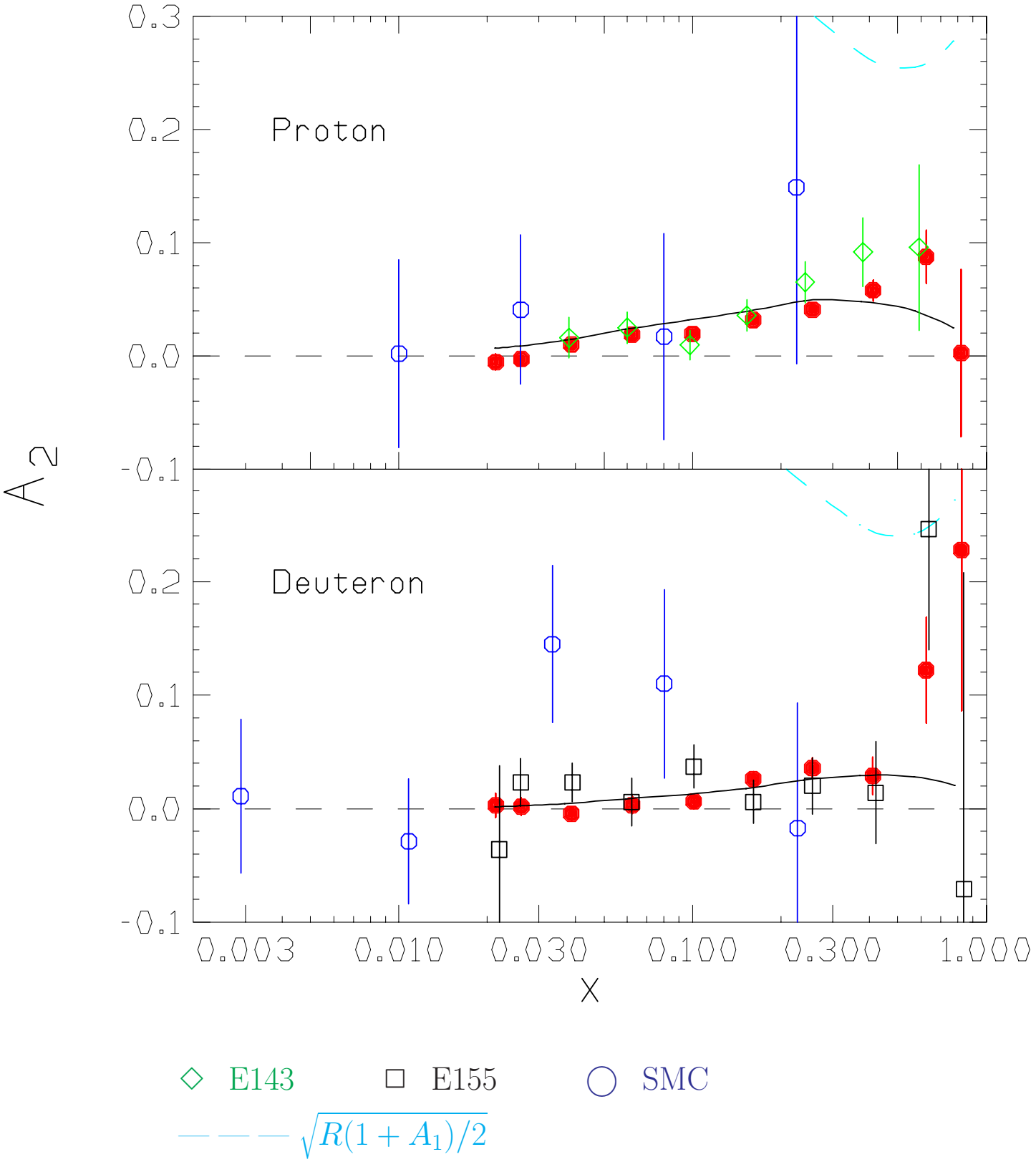
____ WW __ . __ Stratmann .... Song

__ __ __ Weigel ___ ___ Wakamatsu

◇ E143 □ E155

χ^2/df agreement with g_2^{WW} = 3.1(p) 1.2(d)

RESULTS FOR Q^2-AVERAGED A_2



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 NON-PERTURBATIVE PIECE (unknown matrix elements).

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

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

$$n=2,4,...$$

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

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

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

Q^2 DEPENDENCE

- All the Integrals are at <u>FIXED</u> Q_o^2 while 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.
  - g_1/F_1 has errors.
  - Statistical Errors on g_2 Dominate
- Low x Extrapolation: Suppressed By x^2
- High x Extrapolation: g_2 Very Small

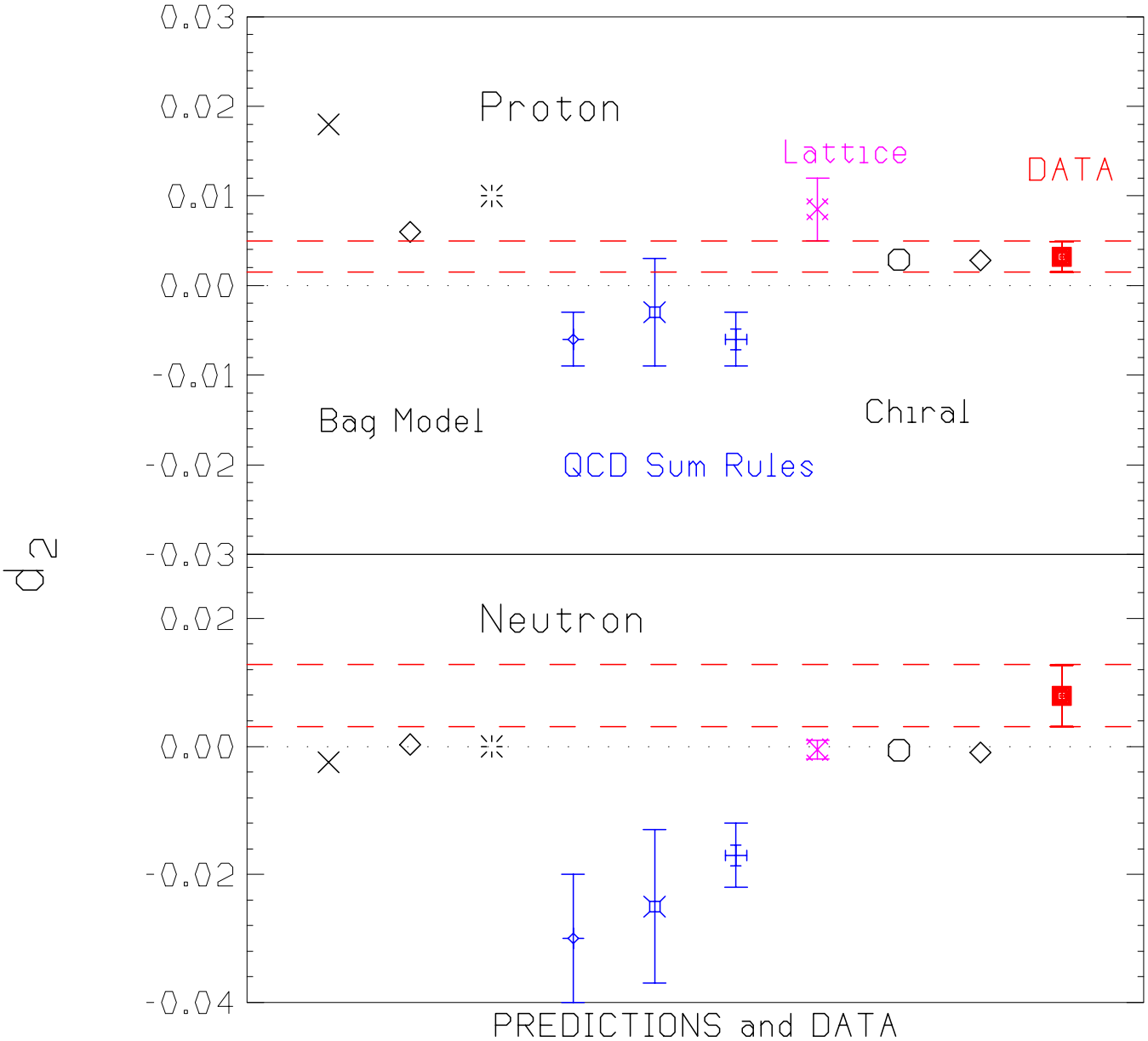
THE TWIST-3 d_2 MATRIX ELEMENT

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

E155X: $0.0025 \pm .0016 \pm .0010$(proton)

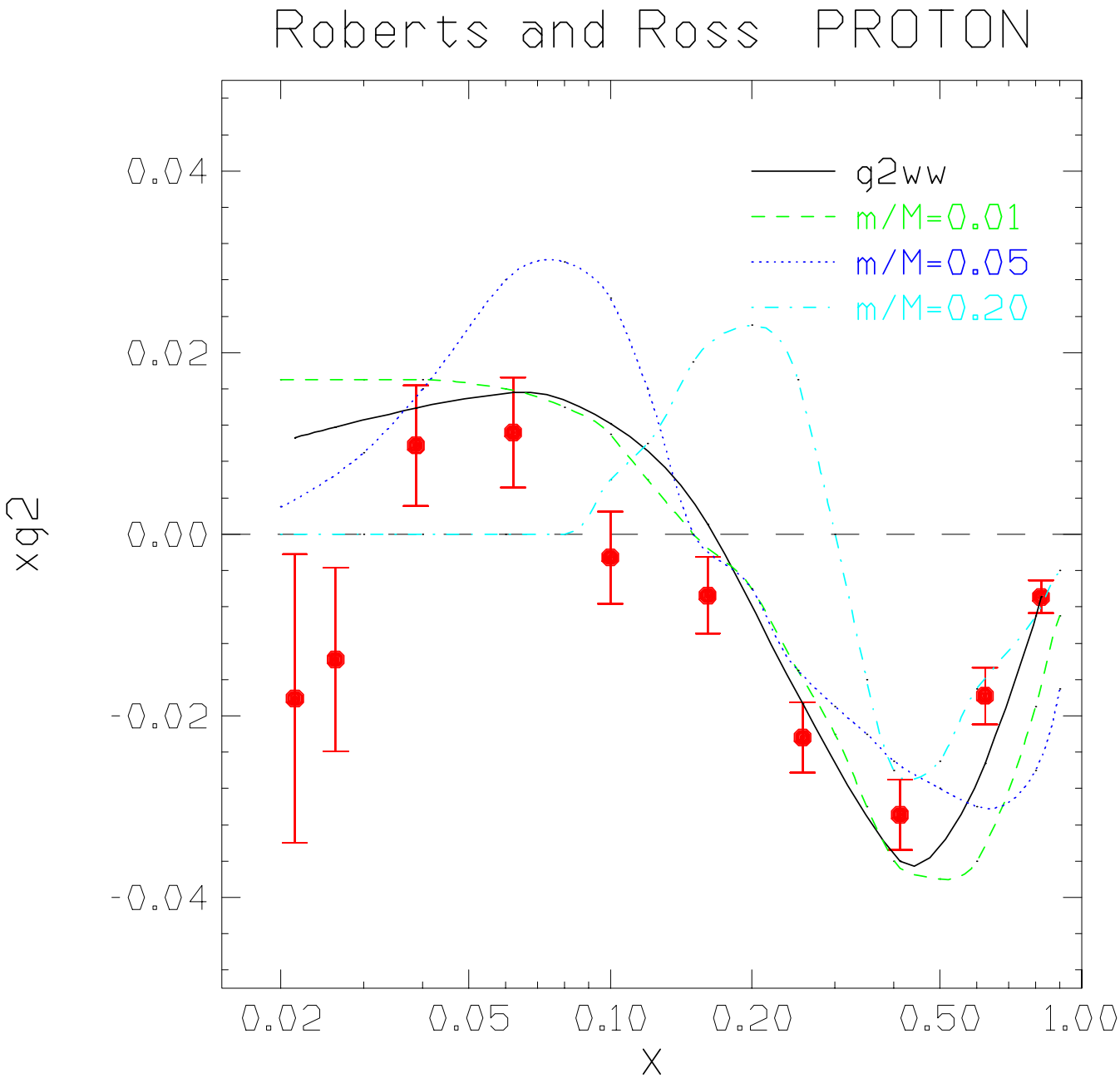
$0.0054 \pm .0023 \pm .0005$(deuteron)

AVERAGE: $0.0032 \pm .0017$(p) $0.0079 \pm .0048$(n)



QUARK MODEL WITH TRANSVERSE MOMENTUM

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



BURKHARDT-COTTINGHAM SUM RULE

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

- **Derived from Virtual Compton Scattering Dispersion Relations.**
- **Does not follow from the OPE since $n = 0$.**
- **Validity depends on the lack of singularities for g_2 at $x = 0$.**
  - **Dramatic rise of g_2 at low x could invalidate the sum rule**

$$\int_{.02}^{.9} g_2(x)dx \text{ at } Q^2 = 5$$

	E155X	AVERAGE
P:	$-0.044 \pm 0.008 \pm .003$	$-0.042 \pm .008$ (5 σ)
D:	$-0.008 \pm 0.012 \pm .002$	$-0.006 \pm .011$

LOW x EXTRAPOLATION

IF $g_2 = g_2^{WW}$ AT LOW x

$$\int_0^x g_2^{WW}(y)dy = x\left[g_2^{WW}(x) + g_1(x)\right]$$

$$\int_0^{.9} = -0.022 \pm 0.008(p) \quad -0.002 \pm .011(d)$$

EFREMOV-TERYAEV-LEADER SUM RULE

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

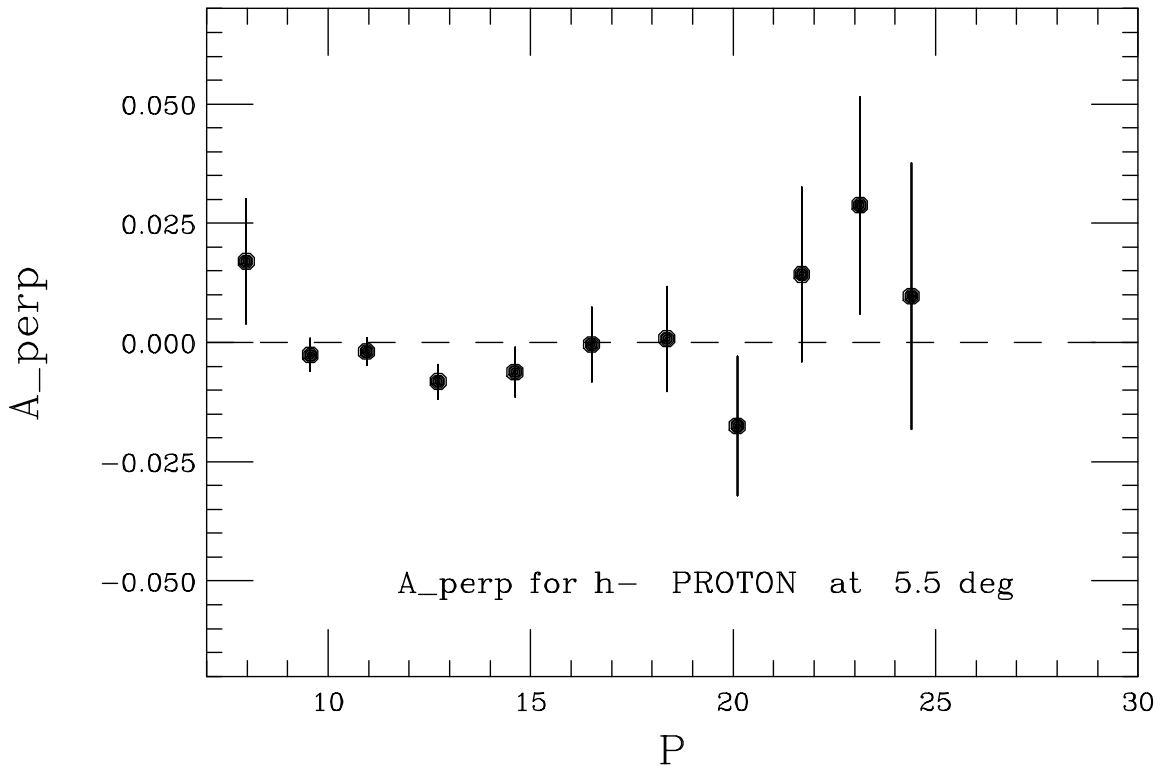
IF $\Delta u_{sea} = \Delta d_{sea} \Rightarrow$

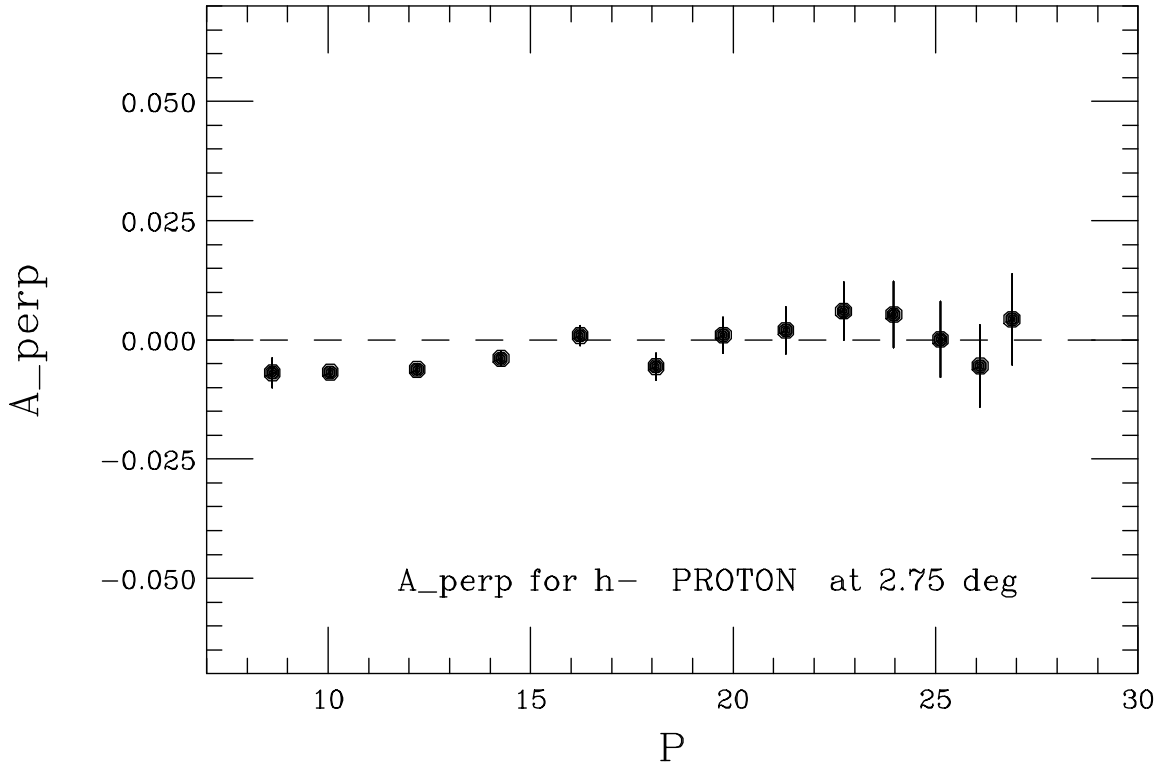
$$\int_0^1 x[g_1^p(x)+2g_2^p(x)-g_1^n(x)-2g_2^n(x)]dx = 0$$

E155X	AVERAGE
$-0.013 \pm .008 \pm .002$	$-0.011 \pm .008$

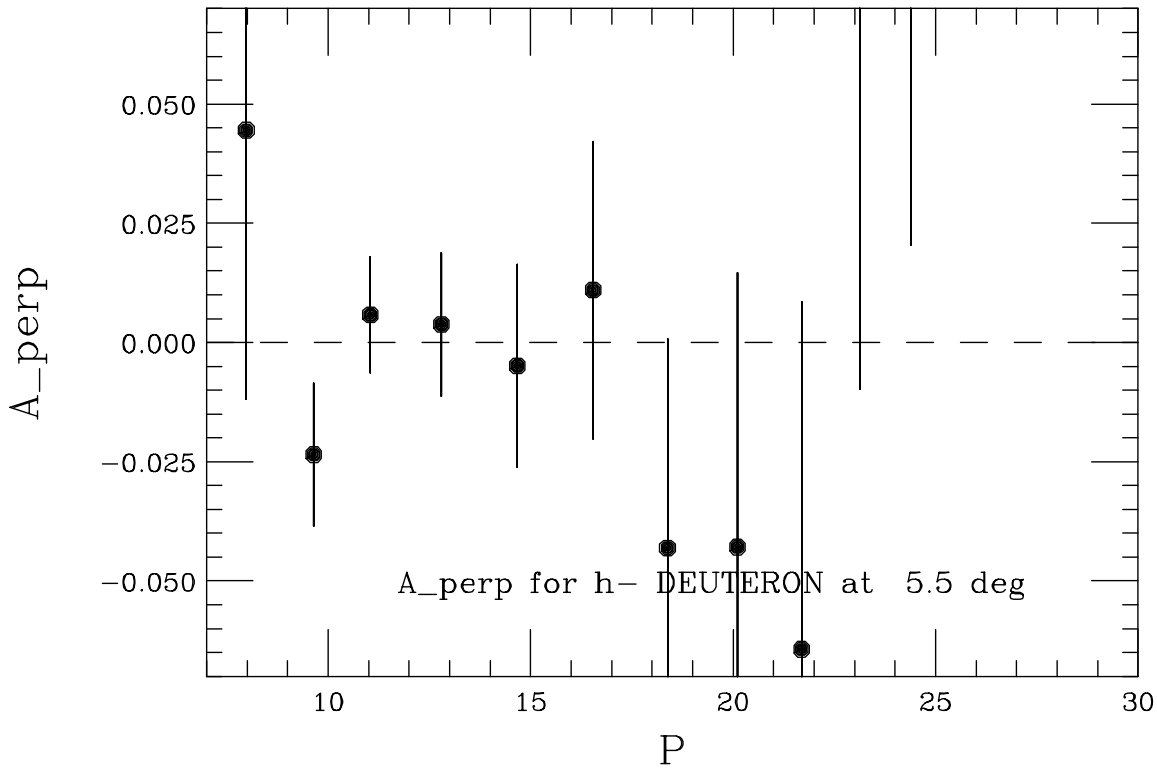
LOW x EXTRAPOLATION SUPPRESSED BY x FACTOR

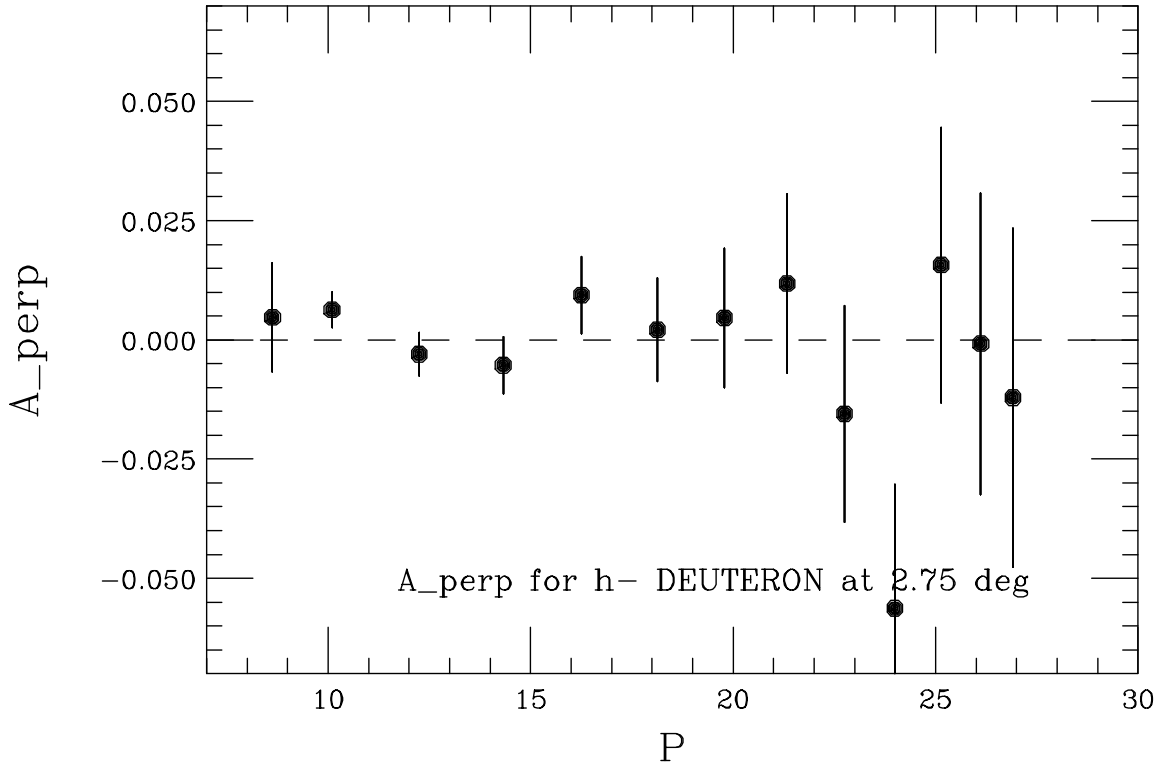
TRANSVERSE PION ASYMMETRIES from P





TRANSVERSE PION ASYMMETRIES from D





g_2 SUMMARY

- PROTON g_2 IS POSITIVE FOR $x < 0.1$, NEGATIVE FOR $x > 0.2$.
- ROUGH AGREEMENT SEEN WITH SHAPE OF g_2^{WW} and BAG MODEL OF STRATMANN
- DISAGREES IN DETAIL WITH g_2^{WW}: $\chi^2/\mathrm{dof} = 3.1$
- $A_2 < \sqrt{R(1 + A_1)/2}$
- PROTON A_2 IS POSITIVE FOR ALL x, $A_2 \to 0$ FOR $x \to 0$.
- d_2 SMALL
- ELT SUM RULE OK
- BURKHARDT-COTTINGHAM SUM RULE NOT OK FOR PROTON
- JLAB EXPERIMENTS ON g_2

E155/E155x Collaboration

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