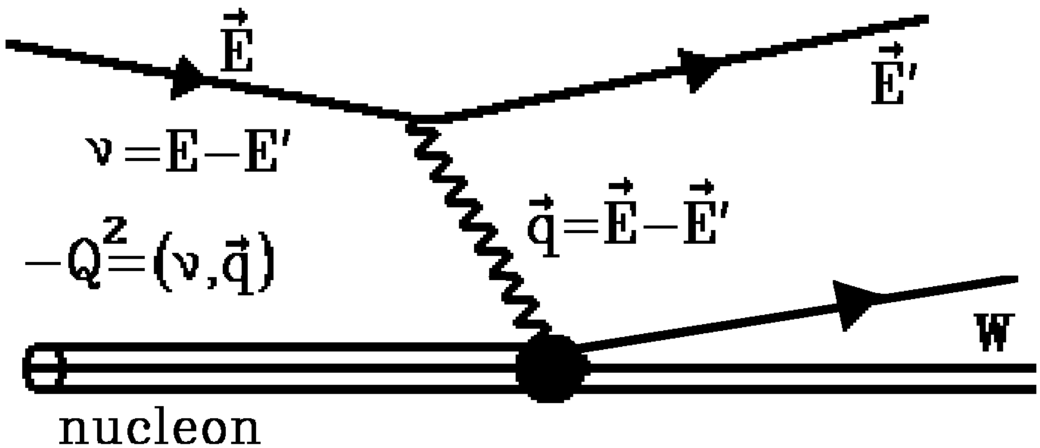
THE SPIN STRUCTURE FUNCTION g_2 FROM SLAC E155X

STEPHEN ROCK
UNIVERSITY OF MASSACHUSETTS
REPRESENTING THE E155X COLLABORATION

March, 2000

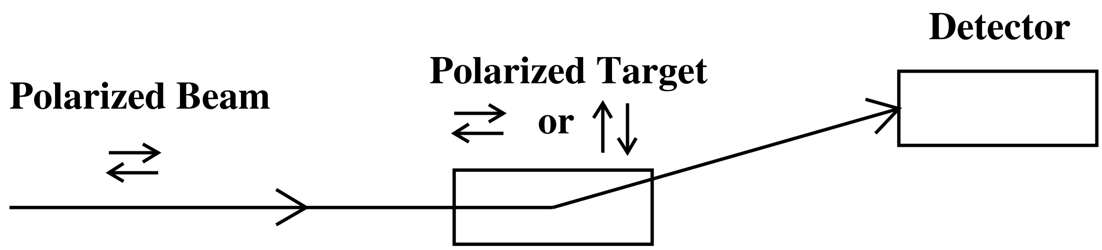
- EXPERIMENT
- SOME THEORY
- g_2 AND A_2 FOR PROTON/DEUTERON
- Q^2 DEPENDENDENCE OF g_2 AND A_2
- TWIST-3 MATRIX ELEMENT d_2
- SUM RULES

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



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

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

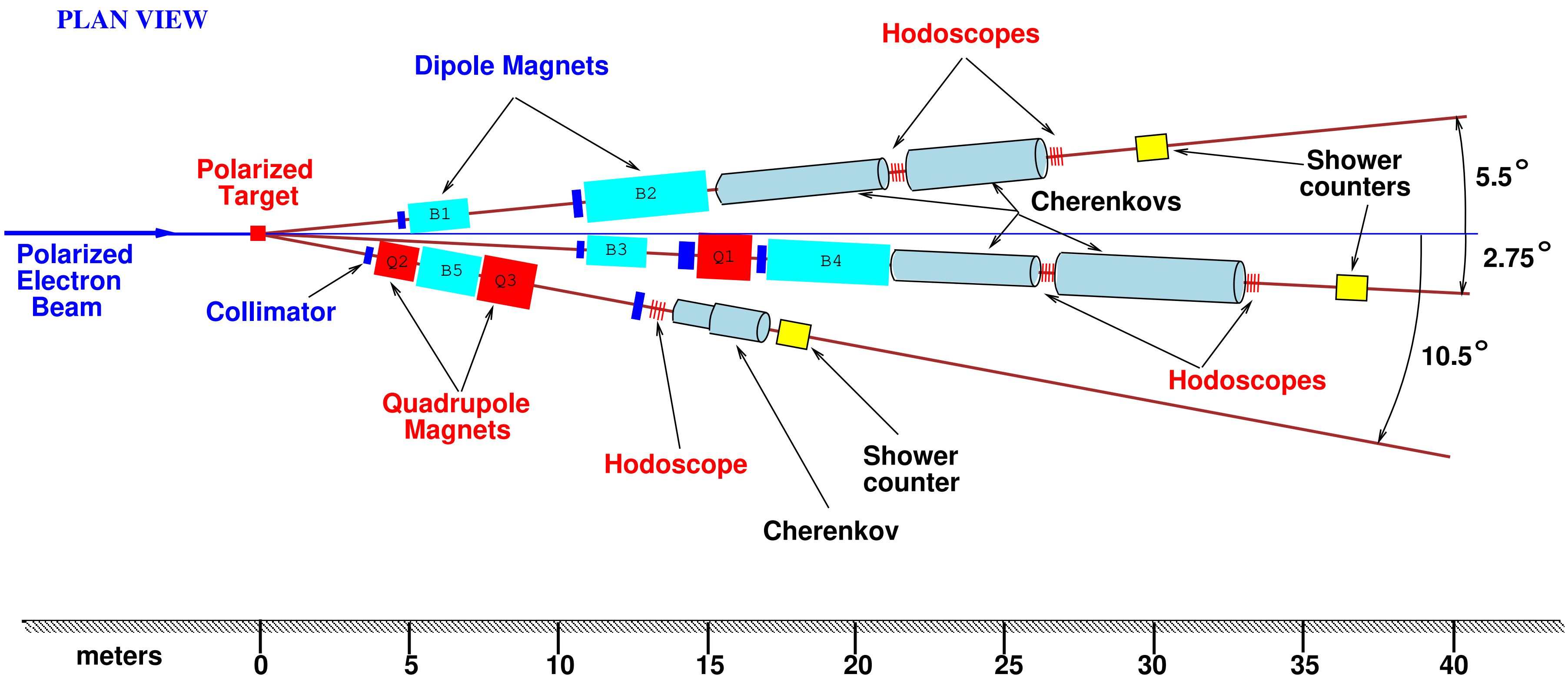
g_1 and g_2 are the polarized structure functions.

$\rightarrow$ $A_{\parallel}$ is primarily sensitive to g_1

$\rightarrow$ $A_{\perp}$ is more sensitive to g_2

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

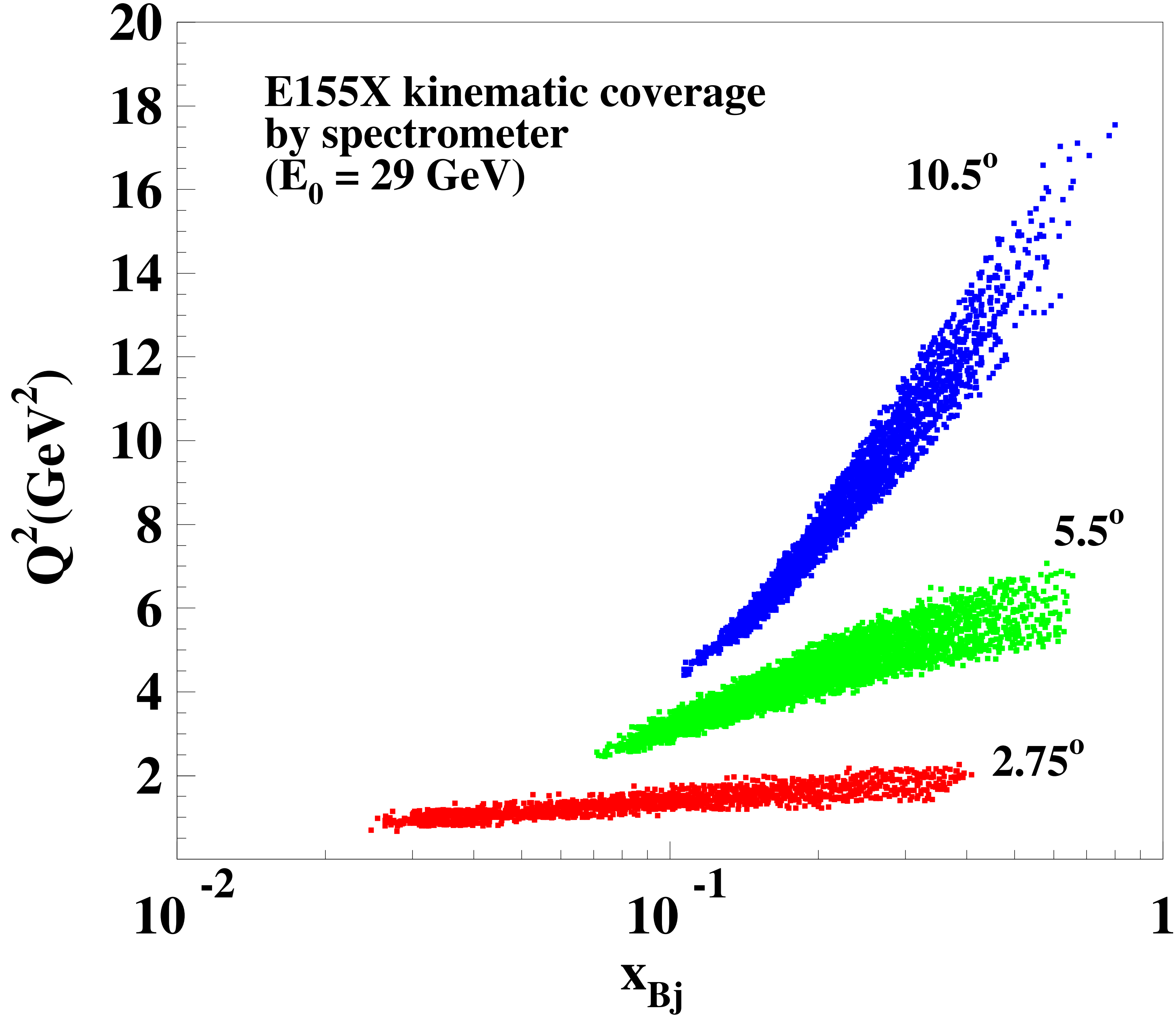
E155 Spectrometers



EXPERIMENTAL OVERVIEW

- SLAC ELECTRON BEAM:
  - LONGITUDINAL POLARIZATION $P_b = 0.83$
  - ENERGY $E = 29.1$ or $E = 32.3$
  - 120 HZ, 400 nsec SPILLS, 25 nA CURRENT.
- TRANSVERSELY POLARIZED TARGETS:
  - 1 K, 5 T, D.N.P
  - NH3 FOR PROTONS (AVERAGE $P_t = 0.75$).
  - LiD FOR DEUTERONS ($< P_t >= 0.22$).
- SCATTERED ELECTRONS DETECTED:
  - AT 2.75, 5.5, AND 10.5 DEGREES
  - CHERENKOV AND LEAD GLASS FOR I.D.
  - HODOSCOPES FOR TRACKS ($dP/P \approx 0.03$)
- PHOTOPRODUCED INCLUSIVE PIONS ALSO DETECTED (ANALYSIS IN PROGRESS)

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

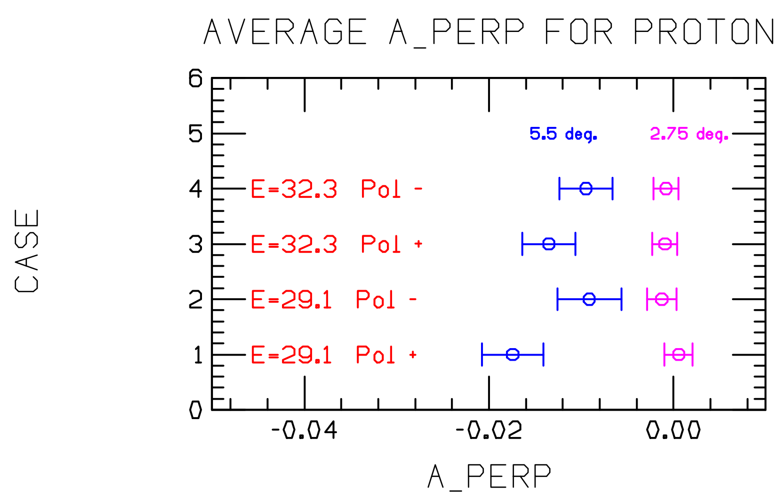
THE $A_\perp$ ASYMMETRY

$$A_\perp = \frac{C_1}{f P_t f_{RC} \cos(\phi)} \Big(\big(\frac{N_L - N_R}{N_L + N_R} \big) \frac{1}{P_b} + A_{EW} \Big) + A_{RC}$$

- N_L AND N_R ARE RATES FOR L AND R BEAM HELICITY, CORRECTED FOR PAIR-SYMMETRIC CONTRIBUTIONS (FEW PERCENT) AND PIONS 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 g_2 and A_2

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

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

- WE CAN COMPARE g_2 TO THE SIMPLE TWIST-2 MODEL OF WANDZURA-WILCZEK

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

- WE CAN ALSO EXTRACT VIRTUAL PHOTON-NUCLEON ASYMMETRY

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

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

$g_2(x,Q^2)$ **Structure Function**

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

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

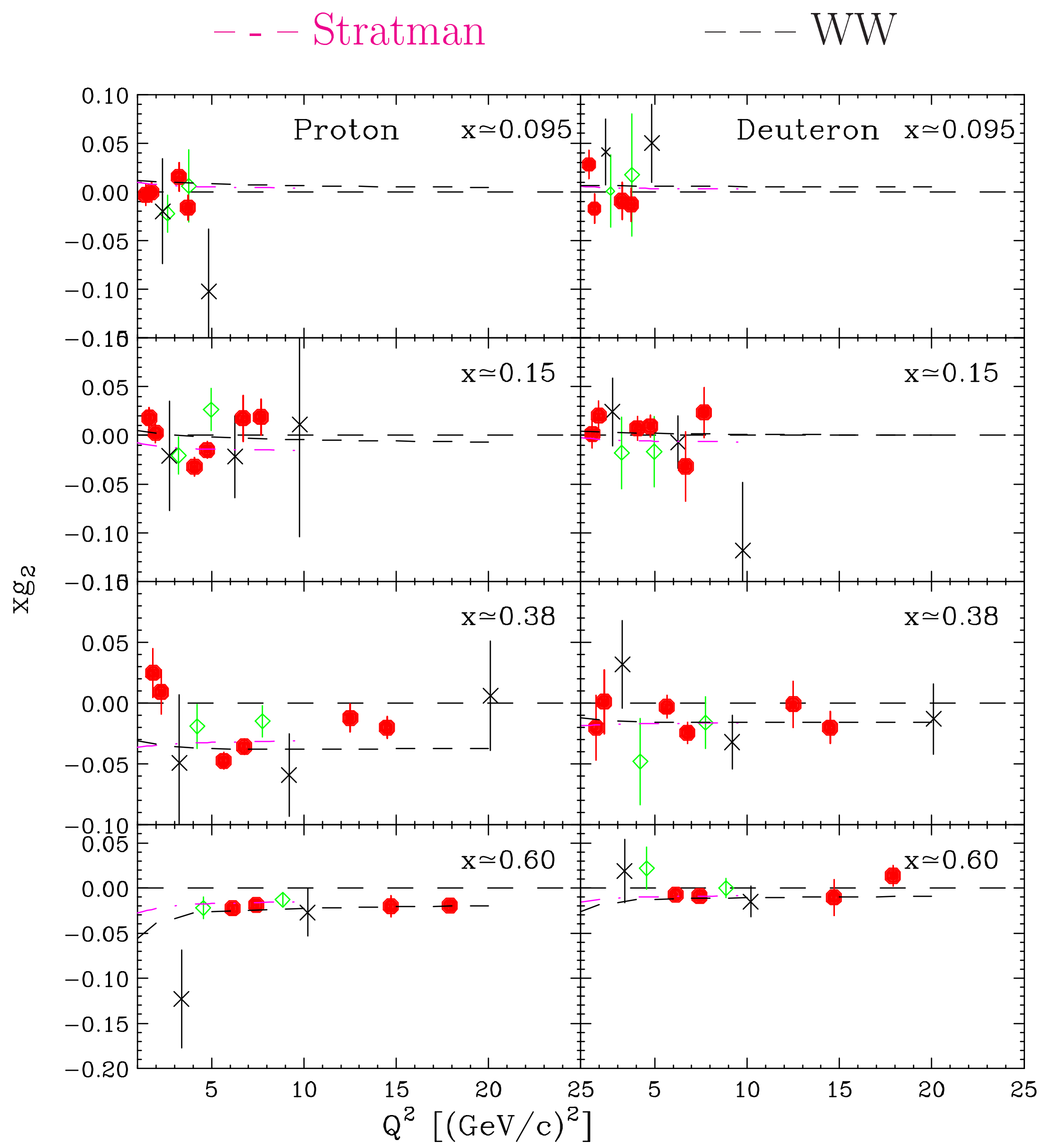
- In general there are additional contributions.

$$g_2(x,Q^2) = \underbrace{g_2^{WW}(x,Q^2)}_{\text{twist-2}} - \int_x^1 \frac{\partial}{\partial y}\Big(\underbrace{\frac{m}{M}h_T(y,Q^2)}_{\text{twist-2}} + \underbrace{\xi(y,Q^2)}_{\text{twist-3}}\Big)\frac{dy}{y}$$

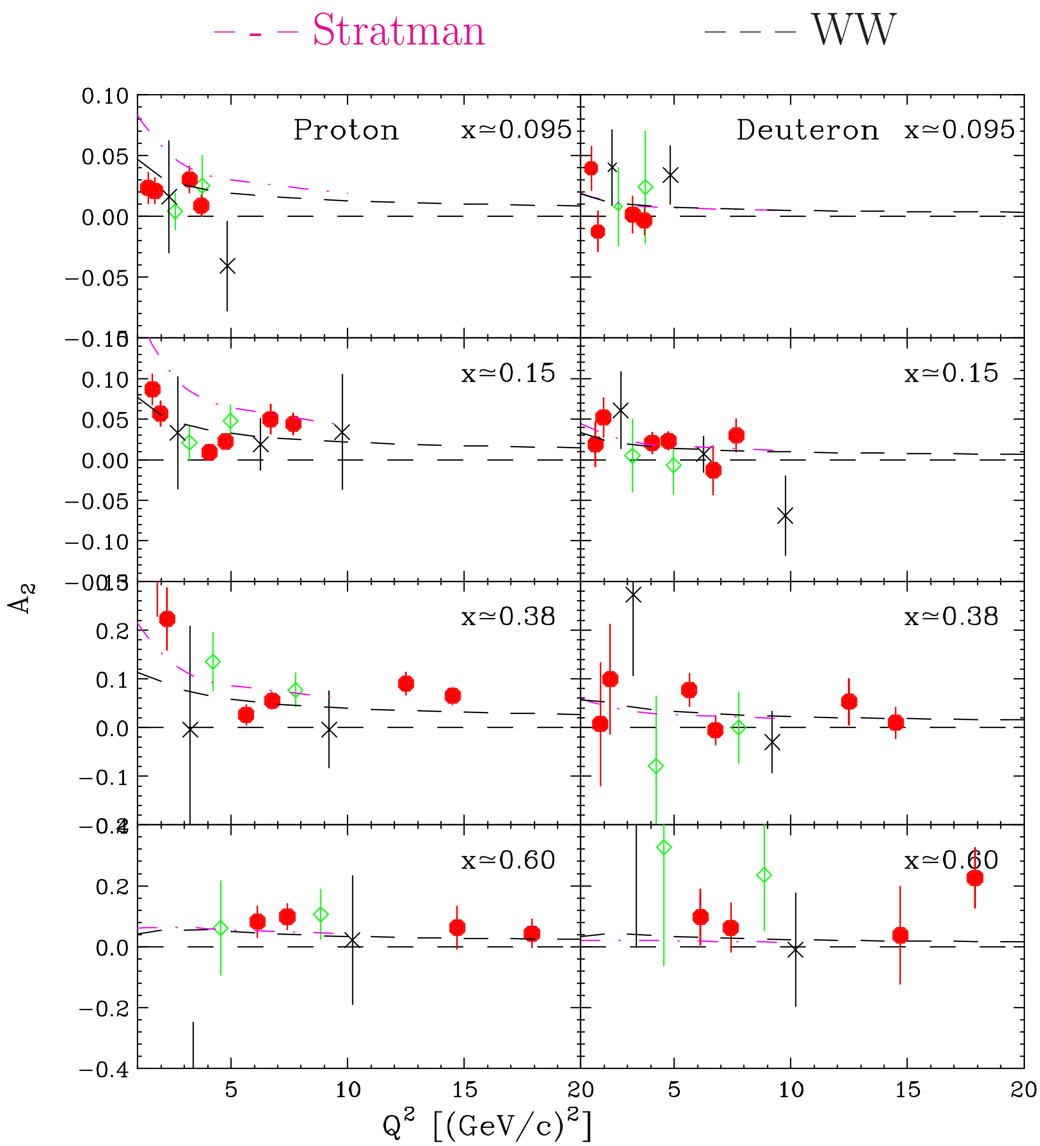
$$= g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

- $\overline{g_2}$ 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: $\int_0^1 g_2(x,Q^2)dx = 0$

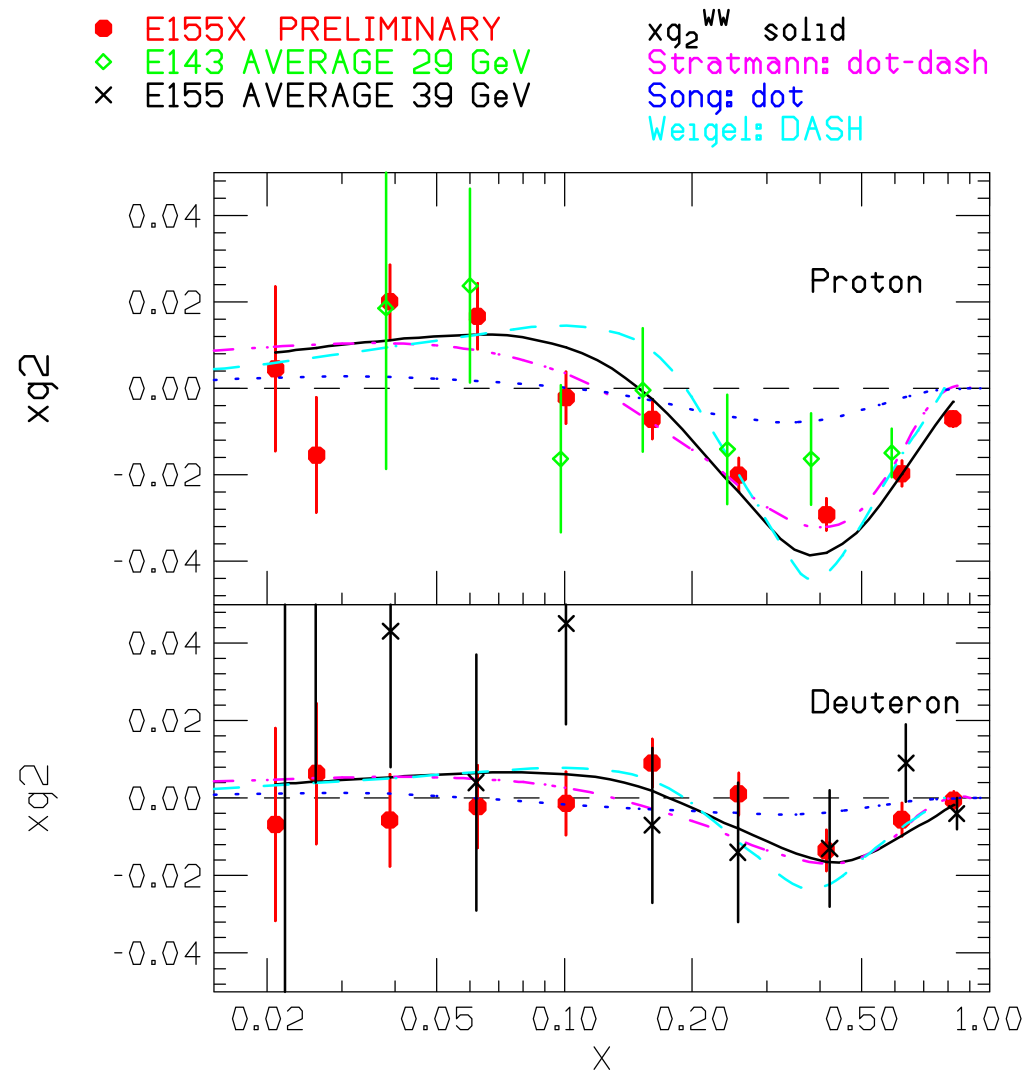
Q^2-DEPENDENCE OF xg_2



Q^2-DEPENDENCE OF A_2

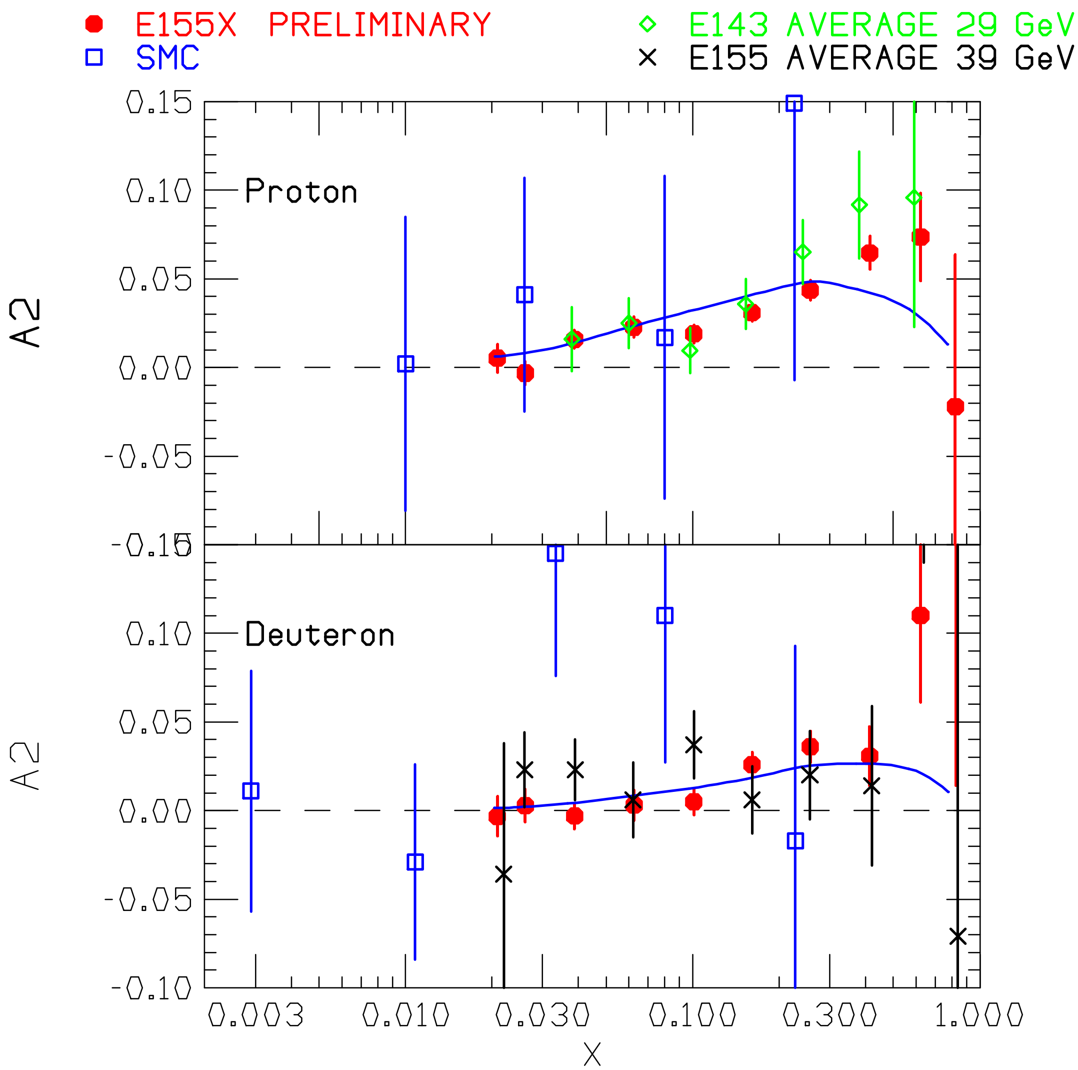


RESULTS FOR Q^2-AVERAGED xg_2



χ^2/df agreement with $g_2^{WW} = 1.6$(p) 0.7(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).

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

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

n=2,4,...

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

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

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

d_2^n

$$
\begin{aligned}
\Gamma_1^{(2)} &= \int_0^1 x^2 g_1(x, Q^2) dx \\
\Gamma_2^{(2)} &= \int_0^1 x^2 g_2(x, Q^2) dx \\
\overline{\Gamma_2^{(2)}} &= \int_0^1 x^2 \overline{g_2}(x, Q^2) dx
\end{aligned}
$$

$$d_2 = 2\Gamma_1^{(2)} + 3\Gamma_2^{(2)} = 3\overline{\Gamma_2^{(2)}}$$

FOR TWIST-2 ONLY: $d_2 = 0$

OTHER TWIST-2 RELATIONS

$$n\Gamma_1^{(n)} + (n+1)\Gamma_2^{(n)} = 0$$

Q^2 DEPENDENCE

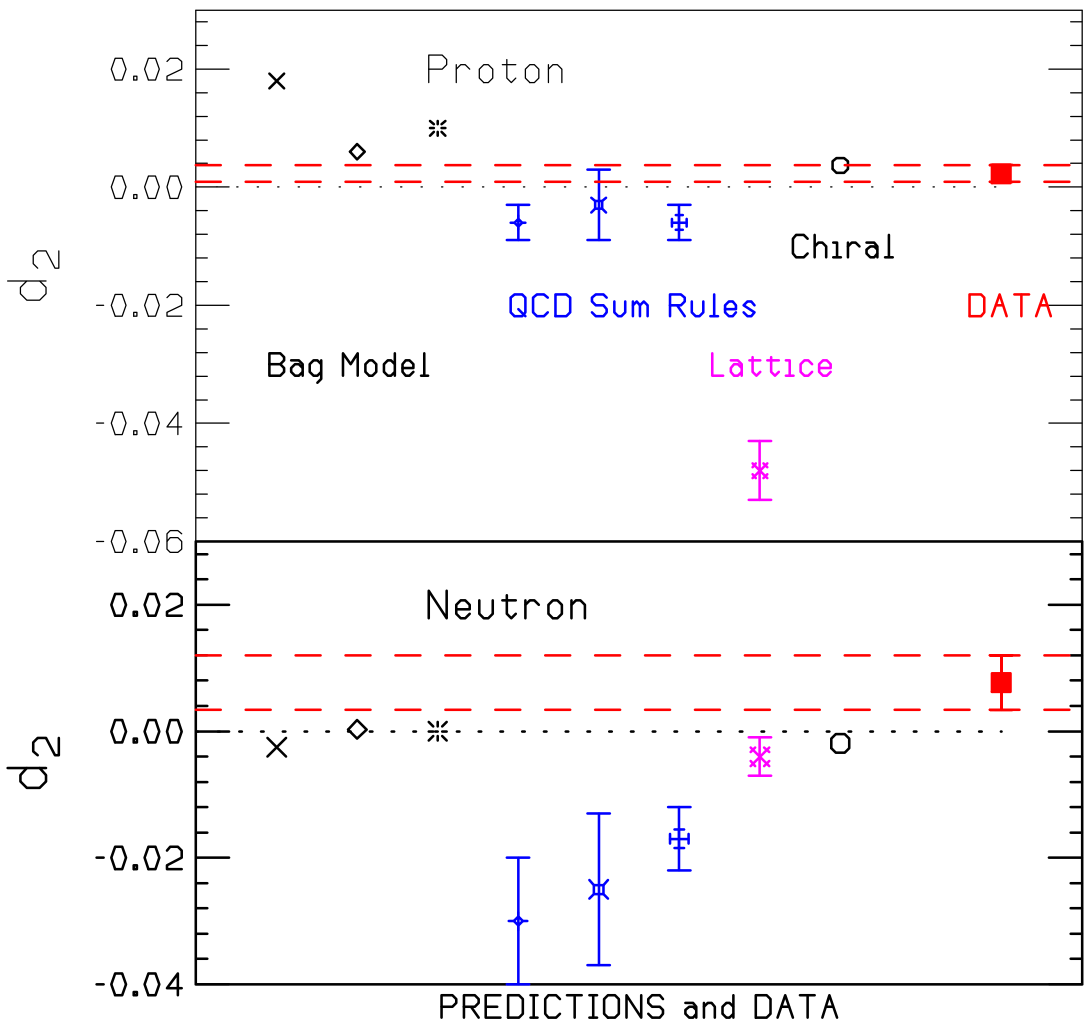
- d_2 depends logarithmically on Q^2.
- All the Integrals are at FIXED Q^2 whilst the Measurements have Q^2 and x correlated.
- For g_1 integrals, we have 'evolved' to fixed Q^2 using Q^2 dependent fits to g_1/F_1
- For g_2 we use:

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

  and ASSUME that the Q^2 dependence of $\overline{g_2}(x,Q^2)$ is negligible.
- To calculate g_2^{WW} we utilize a global Q^2 dependent fit to A_1.

THE TWIST-3 d_2 MATRIX ELEMENT

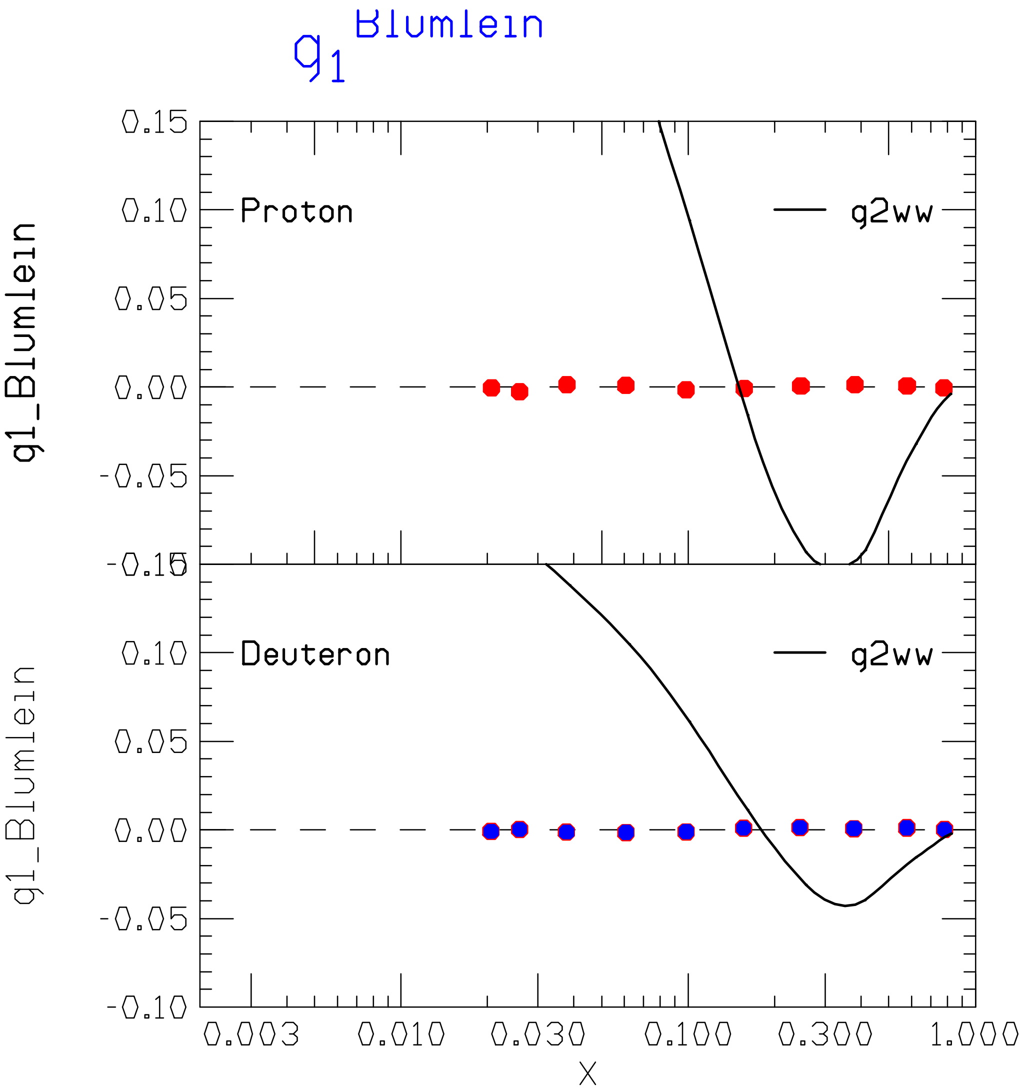
$$d_2 = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$



THE TWIST-3 SUM RULE

Blumlein and Tkabadze

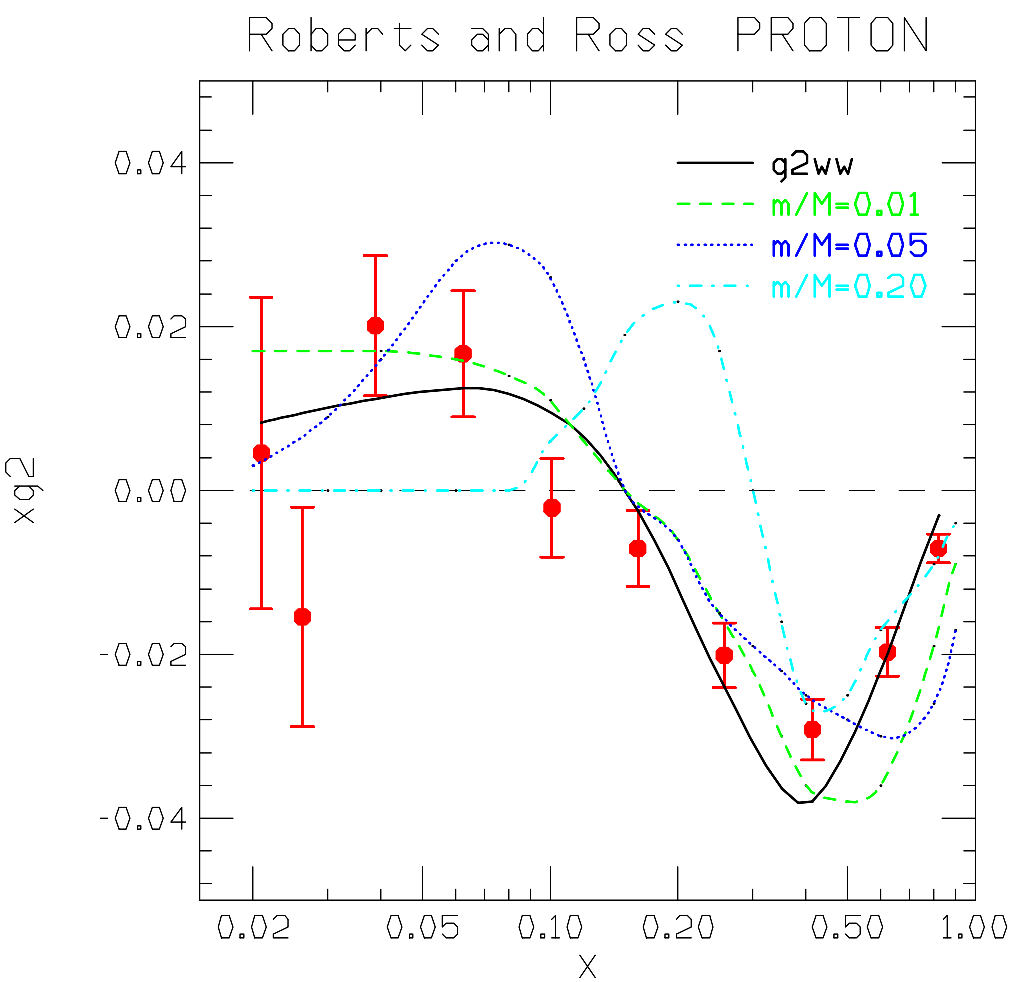
$$g_1(x,Q^2) = \frac{4M^2x^2}{Q^2}\left[\bar{g_2}(x,Q^2) - 2\int_x^1 \frac{dy}{y}\bar{g_2}(y,Q^2)\right]$$



QUARK MODEL WITH TRANSVERSE MOMENTUM

Roberts and Ross

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



SUM RULES

Burkhardt-Cottingham

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

	p	d
EXPERIMENT:	-0.010 ± 0.020	-0.005 ± 0.015

Efremov-Teryaev-Leader

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

IF SEA QUARKS EQUAL IN PROTON AND NEUTRON $\Rightarrow$

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

EXPERIMENT (at $Q^2 = 3$) : -0.0040 ± 0.0082

SUMMARY

- E155x ERRORS $\approx$ 3x SMALLER THAN PREVIOUS RESULTS.
- NORMALIZATION SYSTEMATIC ERROR SMALL COMPARED TO STATISTICAL ERRORS.
- RADIATIVE CORRECTIONS AND RESOLUTION SMEARING CORRECTIONS STILL NEED STUDY.
- 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, APPROACHING 0 FOR $x \rightarrow 0$.
- d_2 SMALL
- SUM RULES VALID