# E155x Measurements

## of the

# $g_2^p$ and $g_2^n$ Structure Functions

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# E155x Collaboration

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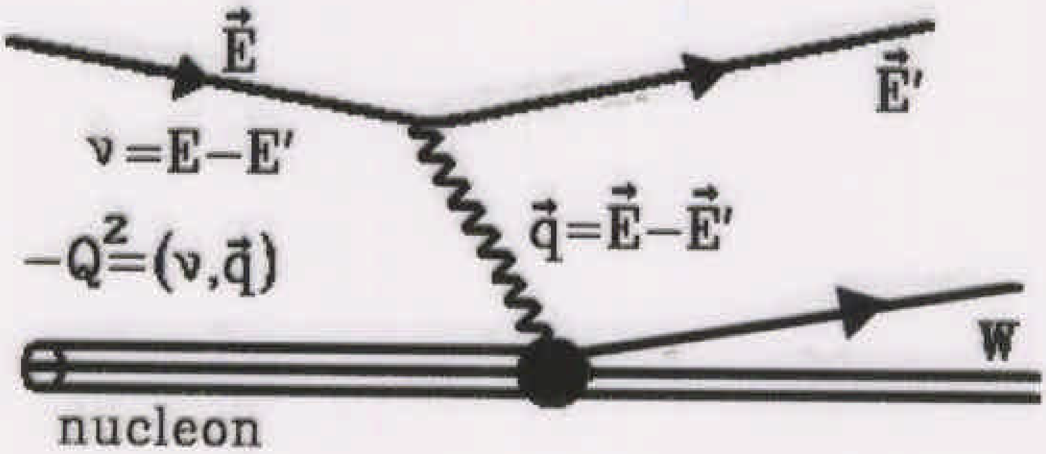
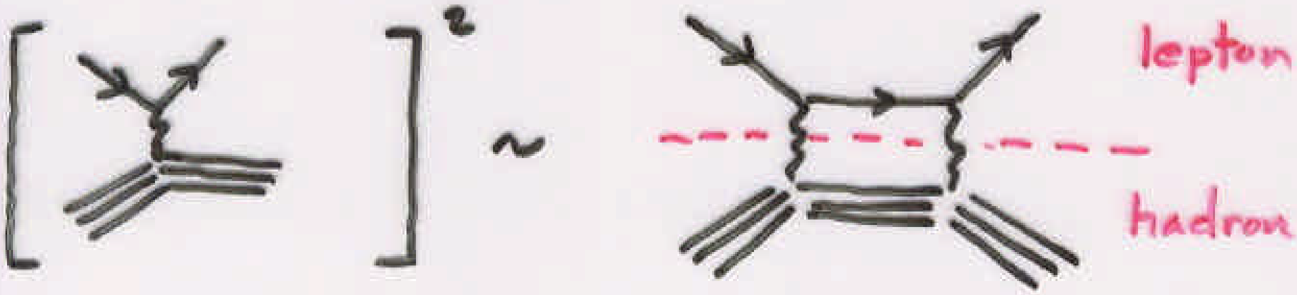
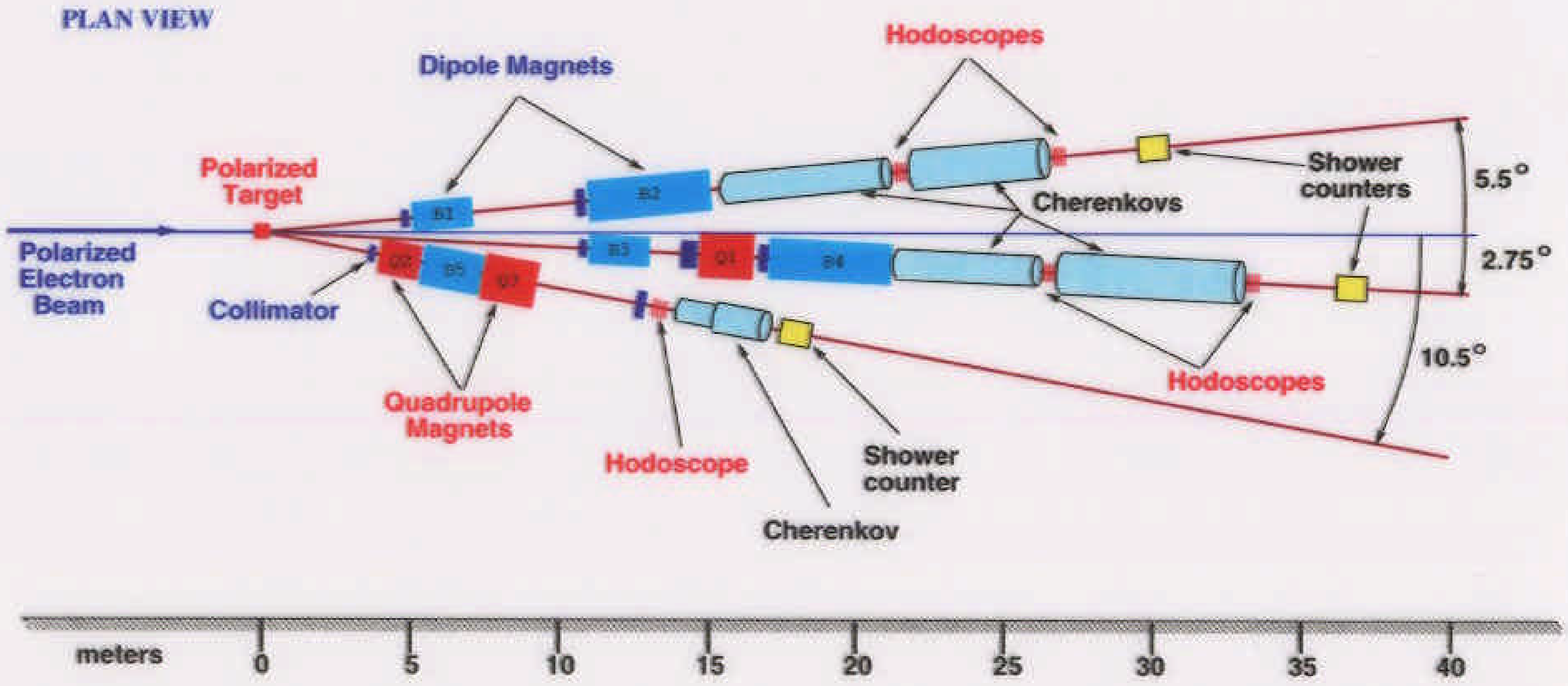
# Inclusive Deep Inelastic Scattering



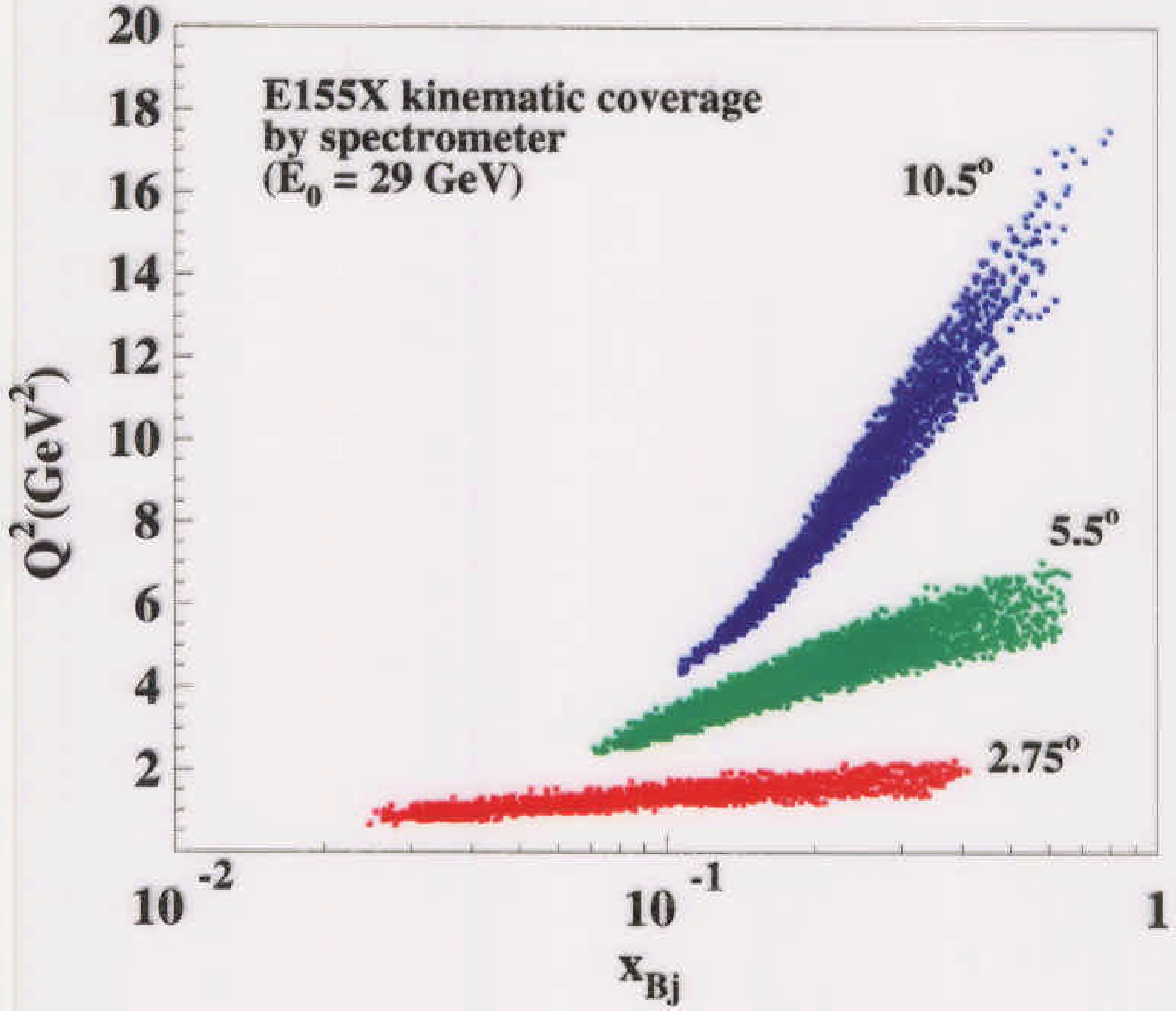

- $\theta$ : scattering angle
- $Q^2$: 4-momentum transfer squared
- $\nu$ : energy transfer
- $x = \frac{Q^2}{2M\nu}$ : Bjorken scaling variable
- Use optical theorem



# E155 Spectrometers



# 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
$x_{Bj}$

# Structure Functions

**Parton Distributions in QCD defined by Light-Cone Fourier Transform of Field Operator Products**
**Simplest Bilinear Products require 9 functions:**

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle PS \mid \overline{\psi}(0)\psi(\lambda n) \mid PS \rangle = 2\, M\, e(x)$$

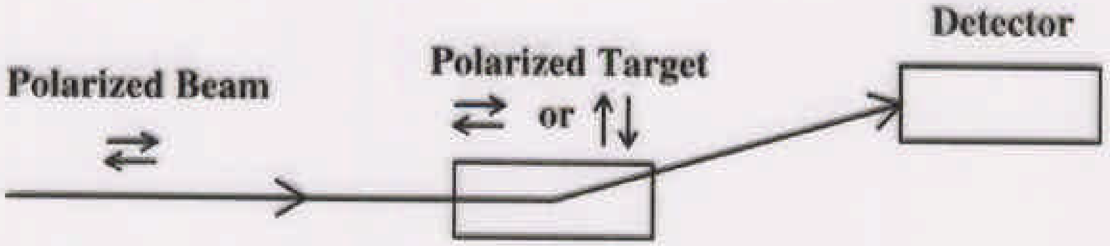
$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle PS \mid \overline{\psi}(0)\gamma_\mu \psi(\lambda n) \mid PS \rangle = 2\, [\, f_1(x)\, p_\mu + M^2\, f_4(x)\, n_\mu ]$$

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle PS \mid \overline{\psi}(0)\gamma_\mu \gamma_5 \psi(\lambda n) \mid PS \rangle = 2\, \{\, g_1(x)\, p_\mu (S\cdot n) + [\, g_1(x) + g_2(x)\, ] S_{\perp\mu} + M^2\, g_3(x)\, (n\cdot S)\, n_\mu ] \}$$

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle PS \mid \overline{\psi}(0)\sigma_{\mu\nu} i\gamma_5 \psi(\lambda n) \mid PS \rangle = 2\, [\, h_1(x)\, (S_{\perp\mu} p_\nu - S_{\perp\nu} p_\mu)/M + [\, h_2(x) + h_1(x)/2\, ] M (p_\mu n_\nu - p_\nu n_\mu)(S\cdot n) + h_3(x)\, M (S_{\perp\mu} n_\nu - S_{\perp\nu} n_\mu) ]$$

| Leading Order | Spin Average | Chiral Even | Chiral Odd |
|---|---|---|---|
| Twist-2 | $f_1$ | $g_1$ | $h_1$ |
| Twist-3 | $e$ | $g_T$ | $h_L$ |
| Twist-4 | $f_4$ | $g_3$ | $h_3$ |

# Polarized Deep Inelastic Scattering




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

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

- $g_1$ and $g_2$ are the polarized structure functions
- $f_k$ includes contribution from kinematics and unpolarized structure functions

→ $A_{\|}$ is primarily sensitive to $g_1$

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

- Measure $A_{\perp}$ in E155x [29.1 & 32.3 GeV]
- Use E155 $g_1(x,Q^2)$ fit to determine $g_2$

# Structure Functions and Sum Rules

## Exact Sum Rules:

**Burkhardt-Cottingham**

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

**Efremov-Leader-Teryaev**

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

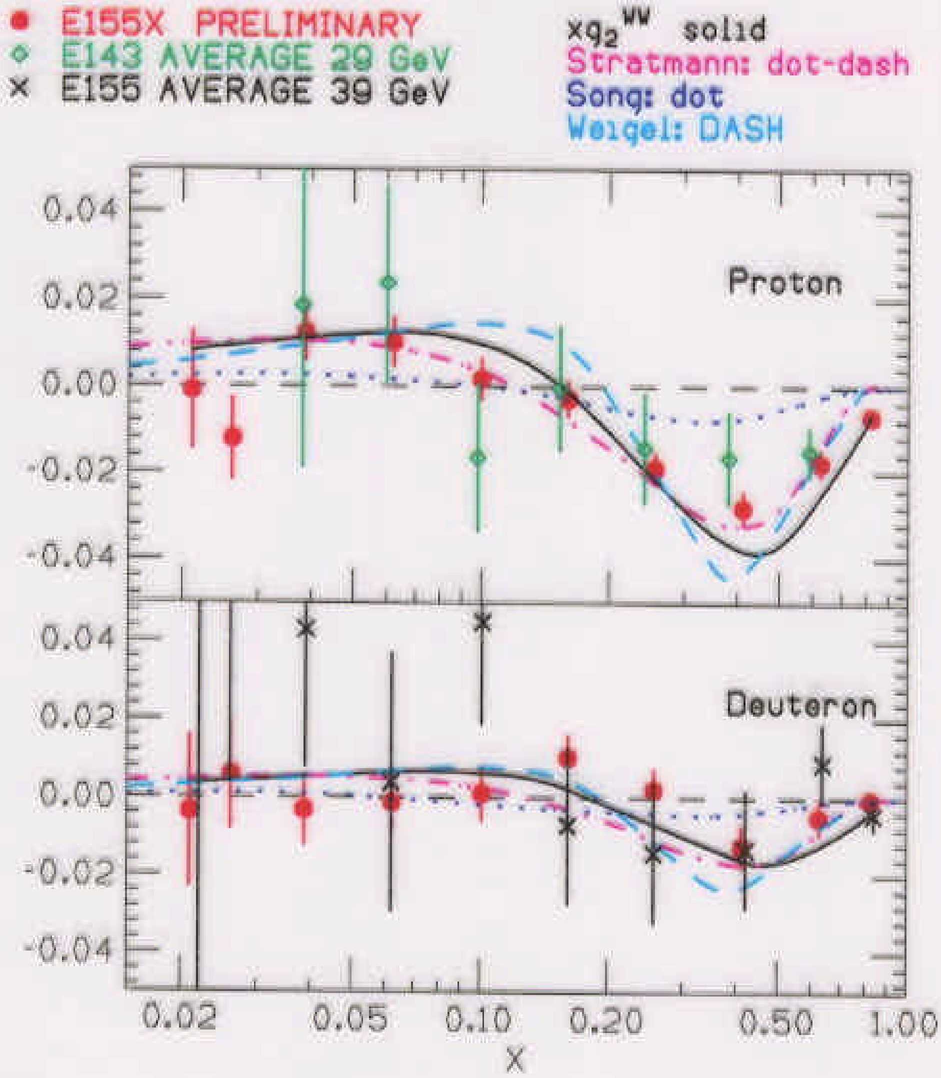
## Twist-2 Sum Rules:

**Wandzura and Wilczek**

$$\int_0^1 dx\, x^{J-1}\, [\frac{J-1}{J}\, g_1(x) + g_2(x)] \;=\; 0$$

**invert to get:**

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




Stratmann / Song - Bag Models

Weigel - Chiral Soliton

# SUM RULES

## Burkardt-Cottingham

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

| | Proton | Deuteron |
|---|---|---|
| E155x | -0.004 ±0.014 | -0.006 ± 0.019 |
| E143 | -0.010 ±0.025 | 0.023 ± 0.050 |
| E155 | -0.018 ±0.071 | 0.024 ± 0.044 |
| Average | -0.009 ±0.012 | -0.005 ± 0.017 |

# Efremov-Teryaev-Leader

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

If sea quarks are equal in the proton and neutron, then use generalization of Bjorken sum rule:

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

| $Q^2\,(GeV/c)^2$ | E155x | Ave with E143(Todd) |
|---|---|---|
| 1 | -0.0076 ±0.0084 | |
| 2 | -0.0077 ±0.0084 | |
| 3 | -0.0081 ±0.0084 | -0.0059 ± 0.0081 |
| 5 | -0.0073 ±0.0084 | |
| 10 | -0.0075 ±0.0084 | |
| 25 | -0.0075 ±0.0084 | |

# Twist-3 Contribution to $g_2$

**Cortes, Pire and Ralston**

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

$h_T(x)$ **(Twist-2) is suppressed by** $m_q/M$
$\xi(x)$ **(Twist-3) contains multiparton correlations**

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

**Take WW Sum Rule (J=3 Case)**

$$\int_0^1 dx\, x^{J-1} \left[ \frac{J-1}{J} g_1(x) + g_2(x) \right] = 0$$

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

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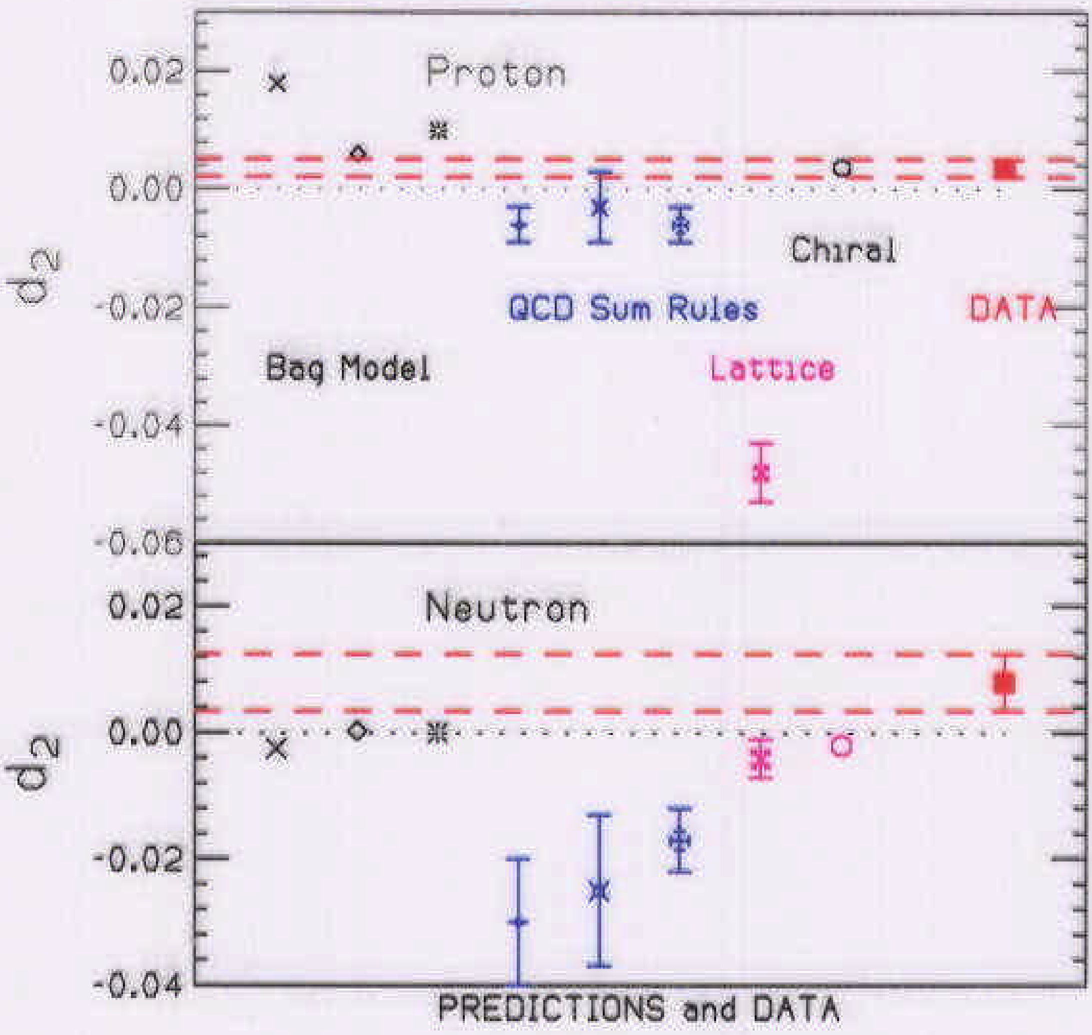
$$d_2 = 3 \int_0^1 x^2 \bar{g}_2\, dx$$

- $d_2$ is a correction to Bjorken, Ellis-Jaffe Sum Rules
- $d_2 \sim \langle \bar{q}\gamma_0 \tilde{G}_{01} q \rangle = \langle \bar{q} B_1 q \rangle$ Measure of mean color magnetic field in direction of transverse spin.


Proton
Chiral
QCD Sum Rules
DATA
Bag Model
Lattice
Neutron
d2
0.02
0.00
-0.02
-0.04
-0.06
PREDICTIONS and DATA

## E155x Experimental Results (Preliminary)

$$d_2 = 0.0036 \pm 0.0015 \quad \text{(proton)}$$
$$d_2 = 0.0080 \pm 0.0045 \quad \text{(neutron)}$$

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X. Song
M. Stratmann
X. Ji and P. Unrau
E. Stein *et al*
I. Balitsky, V. Braun and A. Kolesnichenko
B. Ehrnsperger and A. Schafer
M. Göckeler *et al*
H. Weigel, L. Gamberg and H. Reinart

# Summary

- E155x has measured $g_2(x, Q^2)$ over the kinematic range $0.02 < x < 0.8$ and $0.6 < Q^2 < 20$ $(\mathrm{GeV/c})^2$ for the proton and deuteron

- Errors are ~3x smaller than previous data; Systematic errors are small compared to statistical errors

- Agreement with $g^{WW}$ Twist-2 model, Bag Model of Stratmann et al., Chiral Model of Weigel et al.

- Twist-3 Matrix Element $d_2$ is small.

- BC and ELT Sum Rules are valid.