A Precise Measurement of the g_2 Structure Function of the Proton and Deuteron

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- Theoretical Overview
- E155x Experiment
- A_2 and g_2 Results

E155/E155x Collaboration

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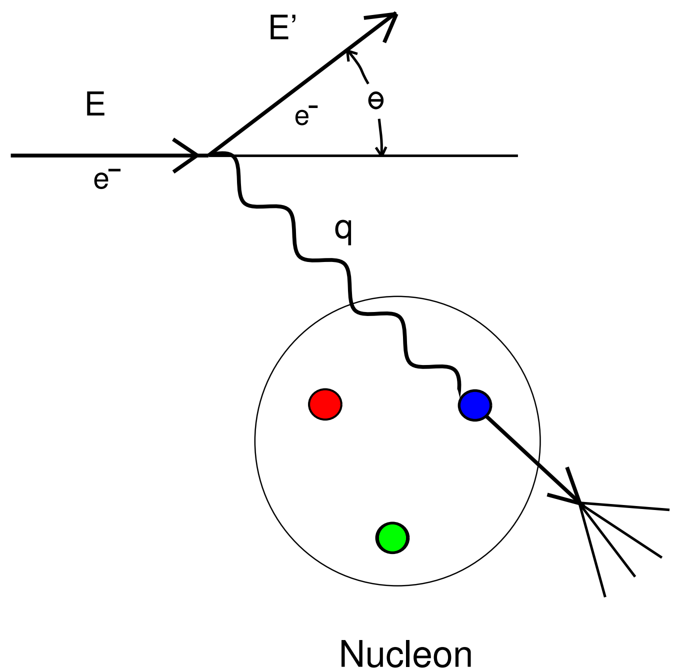
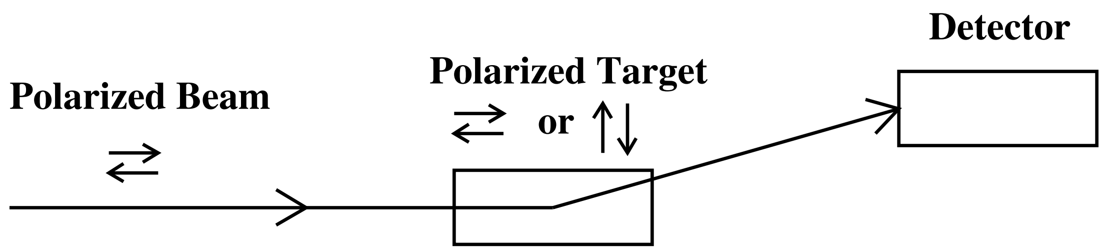
Inclusive Deep Inelastic Scattering



- 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



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

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

g_1 and g_2 are the polarized structure functions.

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

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

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

Virtual Photon-Nucleon
A_2 Asymmetry

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

σ_{TL} is the transverse-longitudinal interference term.

$\sigma_T^{1/2}$ and $\sigma_T^{3/2}$ are transverse virtual photoabsorption cross sections for final helicity states of 1/2 and 3/2

$\rightarrow \sigma_T^{1/2} \sim \frac{1}{2} \sum_i e_i^2 q_i^{\uparrow}$ and $\sigma_T^{3/2} \sim \frac{1}{2} \sum_i e_i^2 q_i^{\downarrow}$

Positivity limit on A_2: $A_2 \leq \sqrt{R(x, Q^2)}$

$R(x, Q^2)$ is the ratio of longitudinal to transverse photoabsorption cross sections (σ_L/σ_T)

$g_2(x, Q^2)$ **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.

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

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

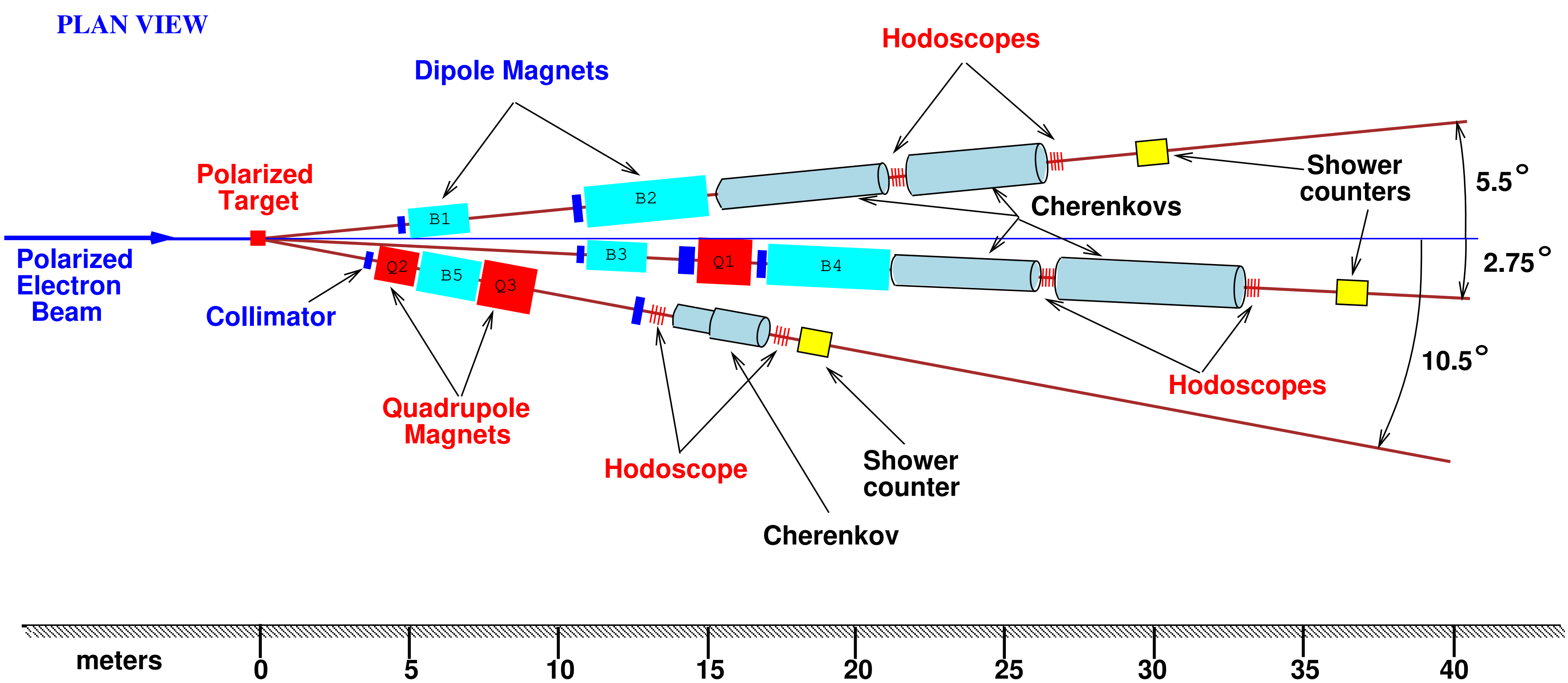
- Twist-3 term ξ related to quark-gluon correlations inside the nucleon
- Twist-2 term h_T due to quarks' spin distribution transverse to nucleon momentum
- $\overline{g_2}$ represents deviation of g_2 from g_2^{WW} and includes above terms

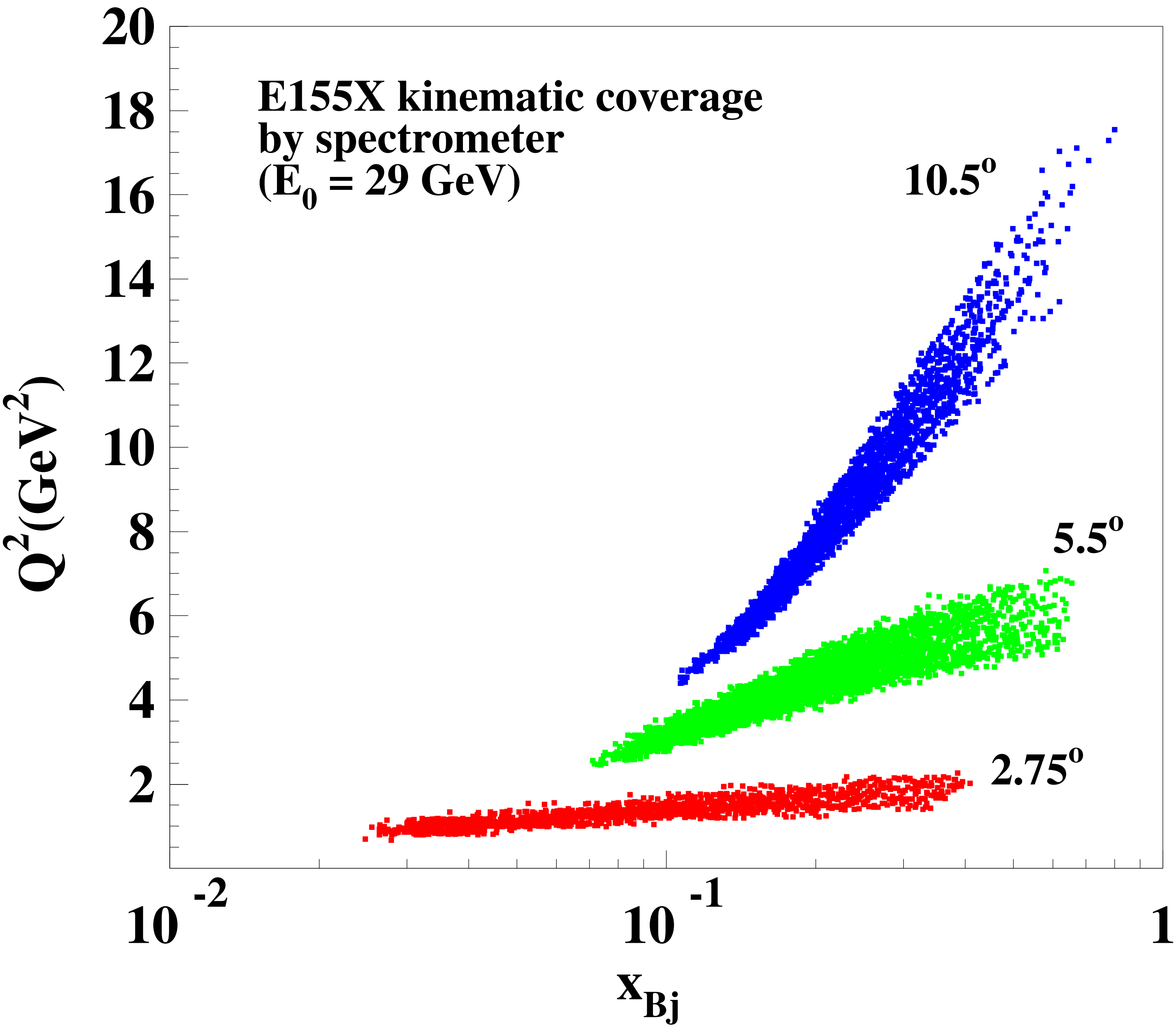
Experimental $A_\perp$ Asymmetry

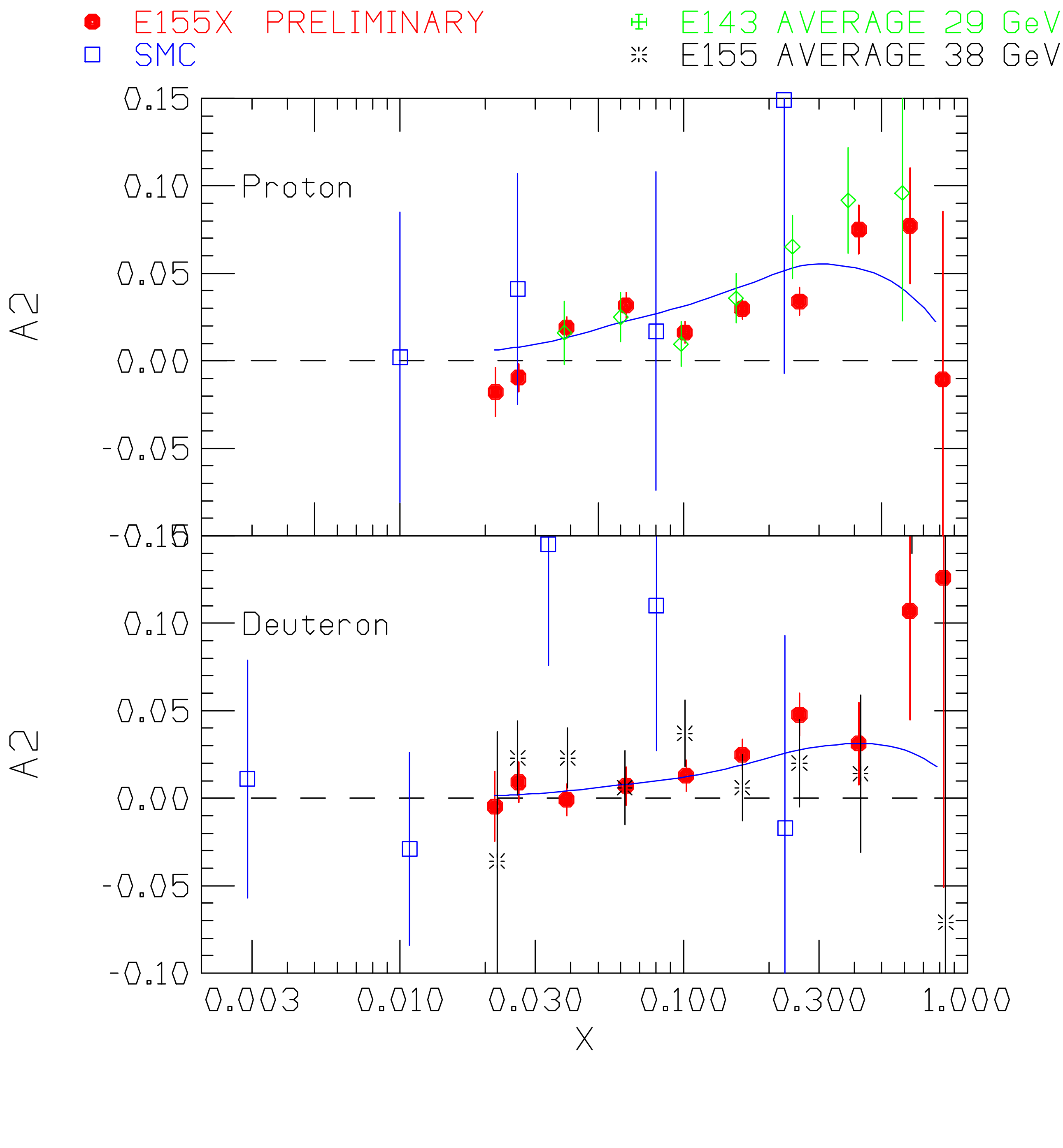
$$A_\perp = \frac{C_1}{f P_t f_{RC}}\Big(\Big(\frac{N_L - N_R}{N_L + N_R}\Big)\frac{1}{P_b} + C_2 + A_{EW}\Big) + A_{RC}$$

- N_L and N_R are rates for L and R beam helicity, corrected for pair-symmetric contributions, pions misidentified as electrons, and electronics dead time.
- P_b is beam polarization (≈ 0.83)
- P_t is the target polarization (≈ 0.75 for NH_3, ≈ 0.22 for LiD)
- C_1 and C_2 are for nuclear corrections and/or target contamination corrections.
- f is the dilution factor (≈ 0.15 for NH_3, $\approx 0.35 - 0.40$ for LiD)
- A_{EW} is electroweak asymmetry ($\approx 8 \times 10^{-5} Q^2$)
- f_{RC} and A_{RC} are for radiative corrections.

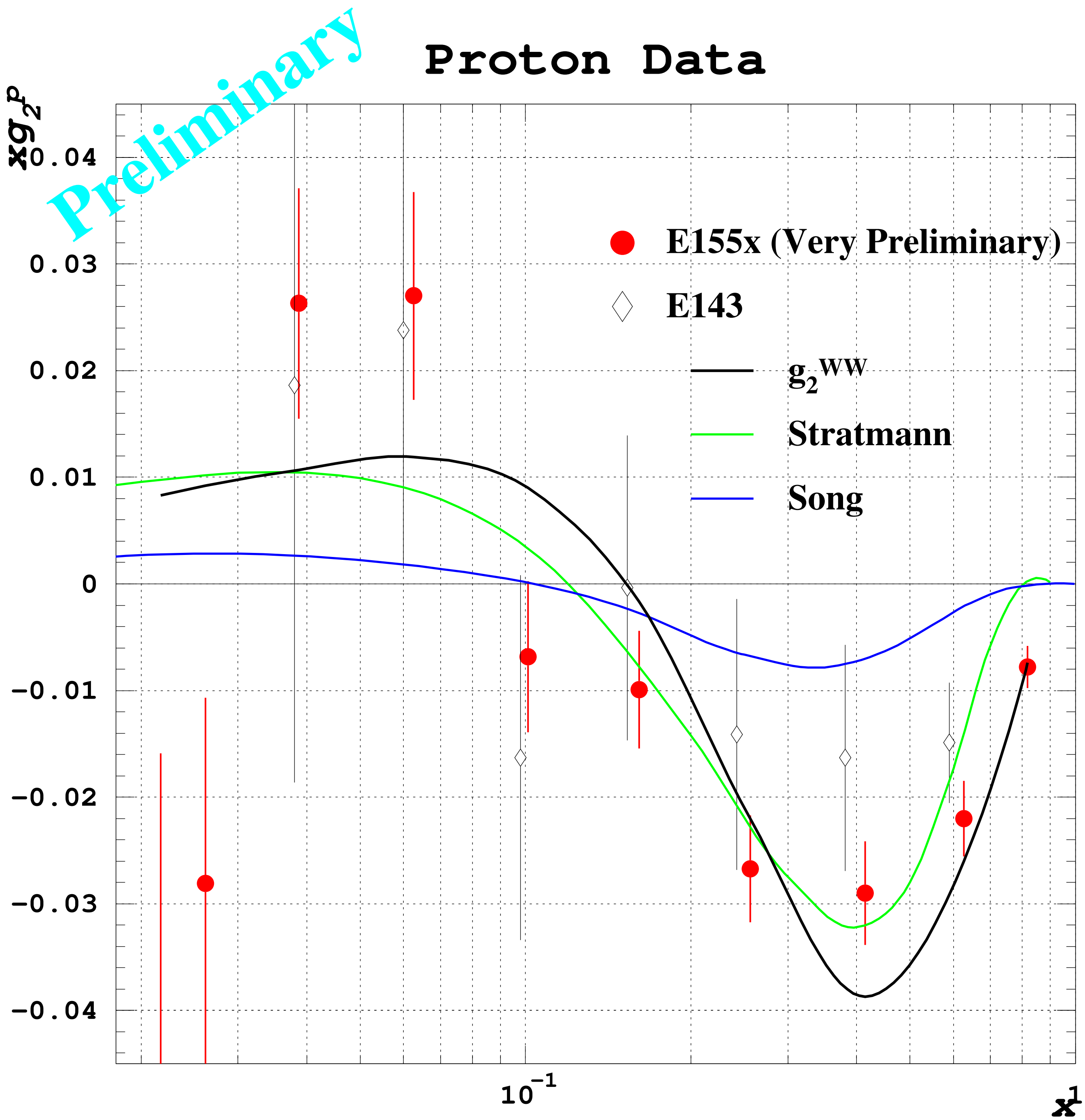
E155x Spectrometers



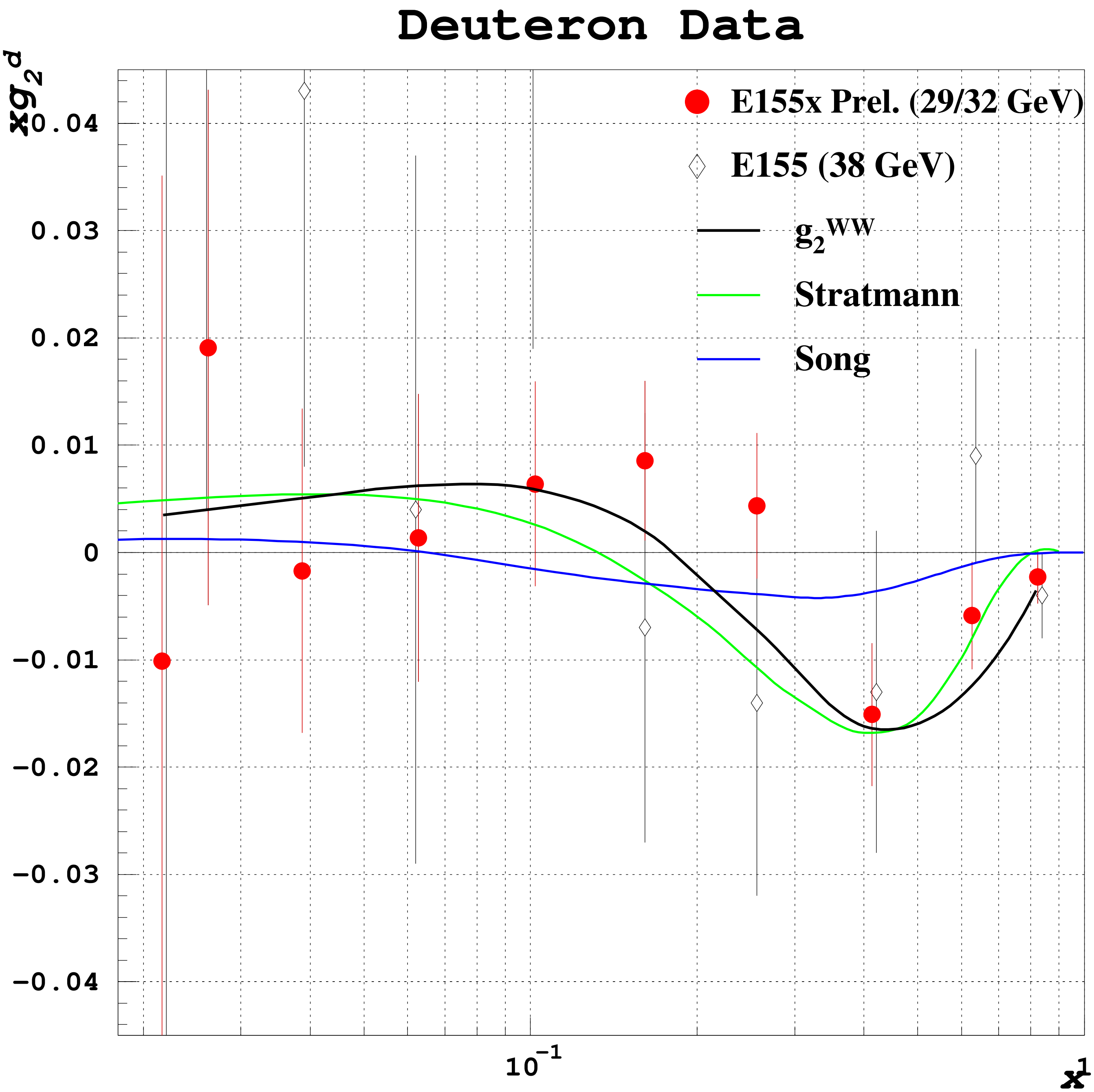

E155X kinematic coverage
by spectrometer
(E_0 = 29 GeV)
10.5°
5.5°
2.75°
Q^2(GeV^2)
20
18
16
14
12
10
8
6
4
2
10^{-2}
10^{-1}
1
x_{Bj}



E155X PRELIMINARY
SMC
E143 AVERAGE 29 GeV
E155 AVERAGE 38 GeV
Proton
Deuteron
A2
A2
0.15
0.10
0.05
0.00
-0.05
-0.15
0.10
0.05
0.00
-0.05
-0.10
0.003
0.010
0.030
0.100
0.300
1.000
X



Preliminary
Proton Data
xg_2^p
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
10^{-1}
x
1
E155x (Very Preliminary)
E143
g_2^{WW}
Stratmann
Song



Deuteron Data
$xg_2{}^d$
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
10^{-1}
x
1
E155x Prel. (29/32 GeV)
E155 (38 GeV)
$g_2{}^{WW}$
Stratmann
Song

Summary

- Analysis continuing

- Proton A_2 is positive for all x

- Statistical power of g_2 data resolves clearly between g_2^{ww} and zero and excludes one of the bag models

- Inclusion of 10.5° data will allow study of Q^2 dependence of g_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).

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

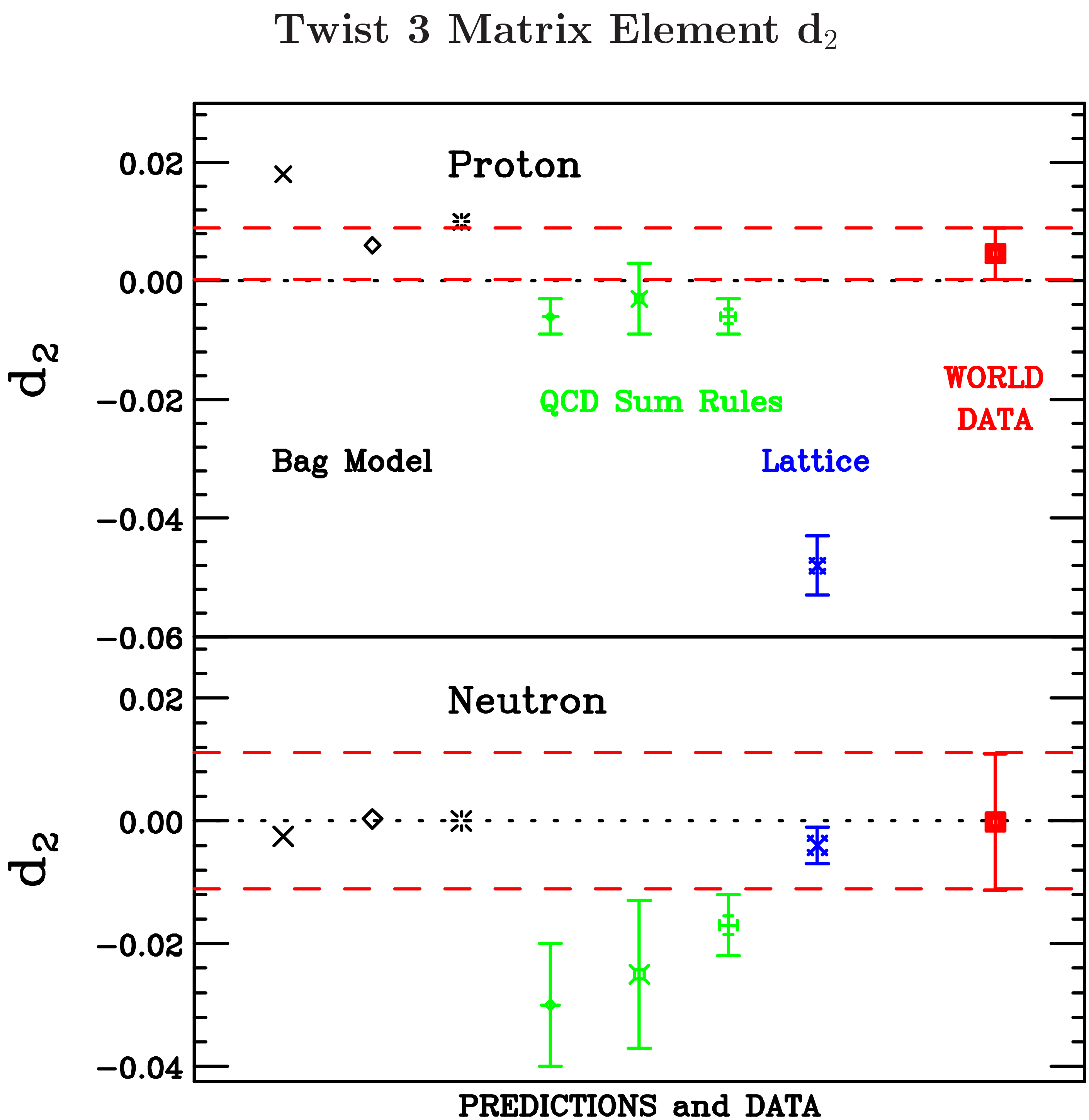
$$\Gamma_2^{(n)} = \int_0^1 x^n g_2(x, Q^2) dx = \frac{1}{2} \frac{n}{n+1} (d_n - a_n)$$

n=2,4,...

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

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

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



Twist 3 Matrix Element d_2
Proton
Neutron
d_2
d_2
0.02
0.00
−0.02
−0.04
−0.06
0.02
0.00
−0.02
−0.04
Bag Model
QCD Sum Rules
Lattice
WORLD DATA
PREDICTIONS and DATA

E155X sensitivity for d_2