Precision Measurement of Neutron Spin Asymmetry A_1^n and Spin-Flavor Decomposition in the Valence Quark Region

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OUTLINE

- Overview
- JLab E99-117 and Neutron Results
- $\Delta q/q$ from g_1^n/F_1^n Results and Proton World Data
- $\Delta q/q$ from g_1^n/F_1^n Results and Deuteron World Data
- Summary and Conclusion

Structure of the Nucleon

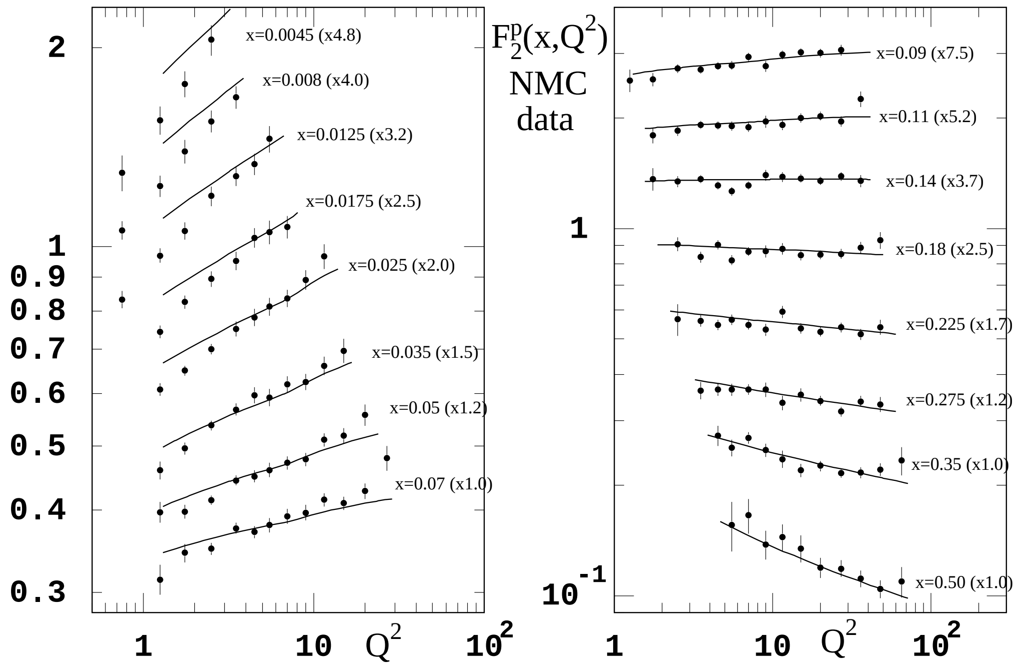
Nucleon are made of Partons

- How do partons - quarks and gluons - form the nucleon?
- How does the strong interaction bind them together?
- How do they contribute to the nucleon spin?

DIS as a tool to study the Nucleon Structure

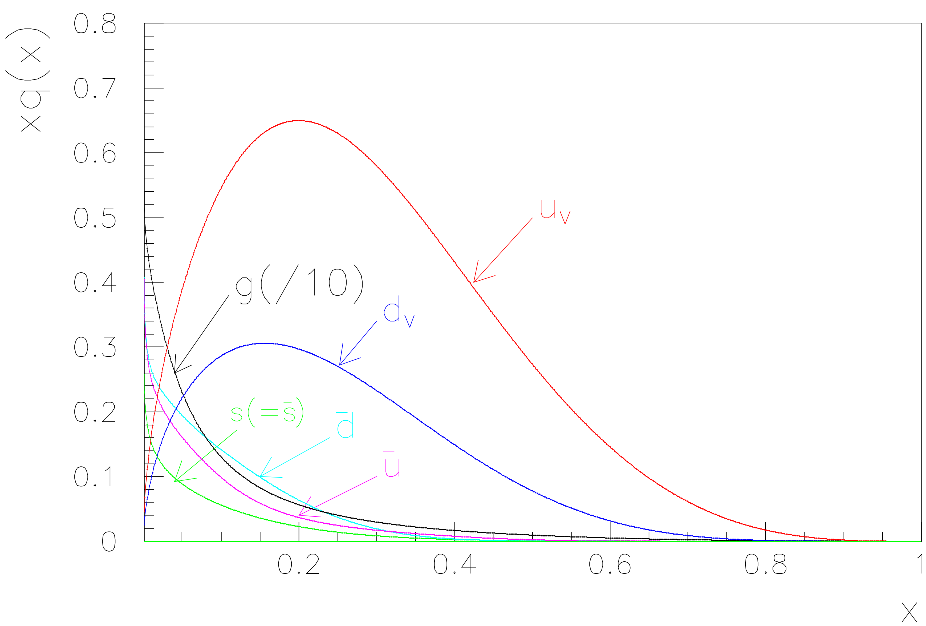
- Unpolarized
- Polarized

From Unpolarized DIS



Structure Functions in QPM

$$F_1(x) = \frac{1}{2}\sum_i e_i^2\,[q_i(x)]$$



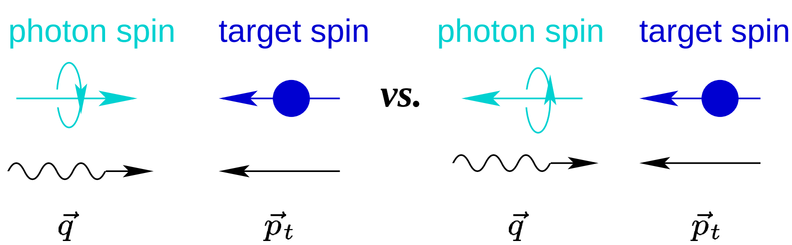
After 35 years of DIS experiments, the unpolarized structure of the nucleon is reasonably well understood (for moderate x region).

Polarized Structure Functions in QPM

$$g_1(x) = \frac{1}{2}\sum_i e_i^2\left[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)\right] = \frac{1}{2}\sum_i e_i^2\left[\Delta q_i(x)\right]$$

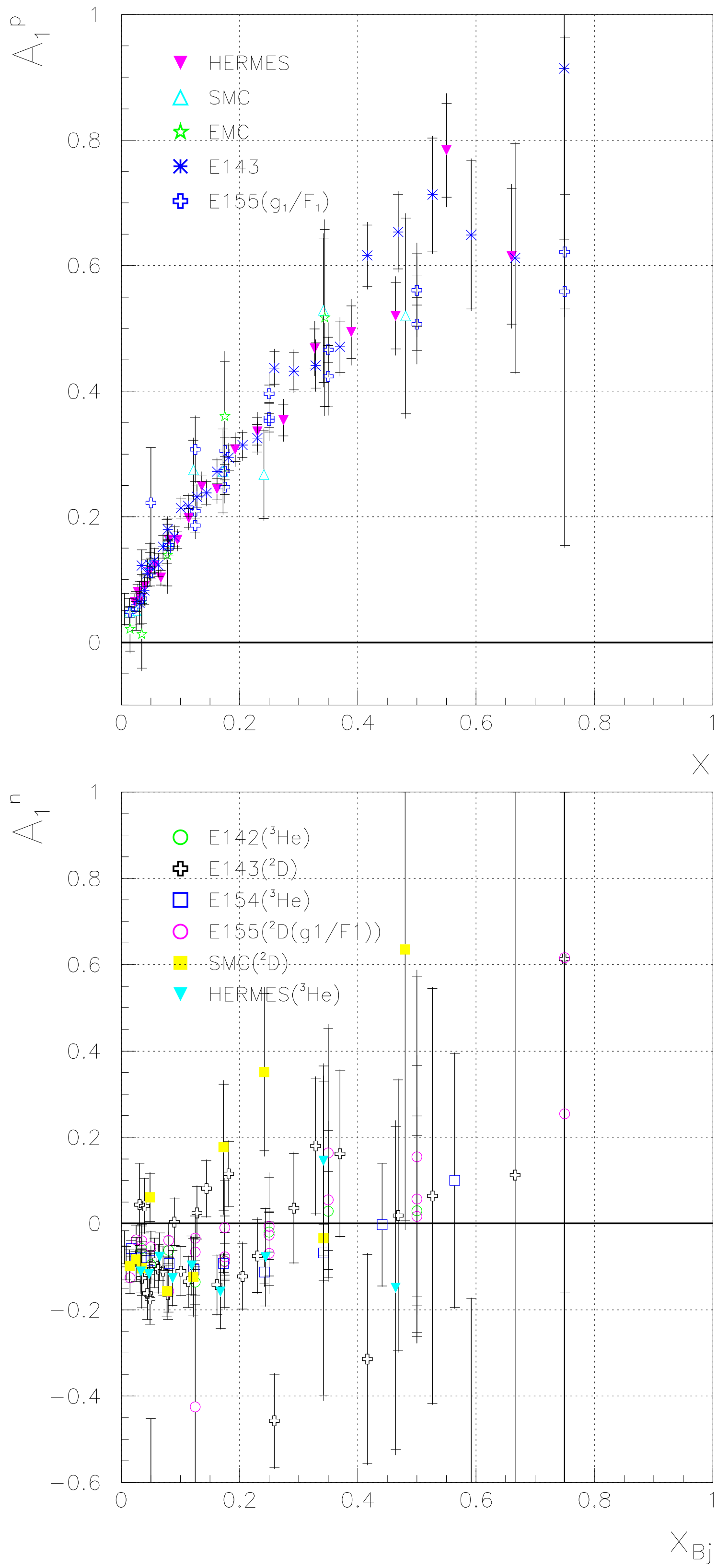
Virtual photon asymmetries

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



$$\begin{aligned} A_1 &= \frac{g_1 - \gamma^2 g_2}{F_1} \quad \text{with } \gamma^2 = \frac{Q^2}{\nu^2} = \frac{4M^2x^2}{Q^2} \\ &\approx \frac{g_1}{F_1} \quad \text{at large } Q^2 \end{aligned}$$

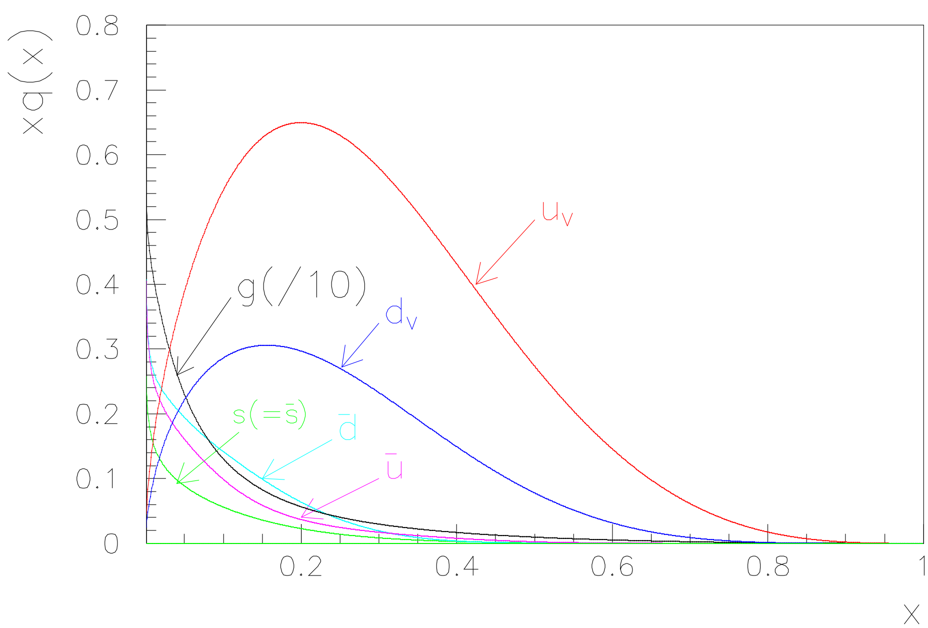
$$A_2 = \frac{\sigma_{LT}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\gamma\left[g_1 + g_2\right]}{F_1}$$

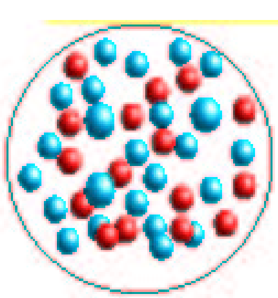


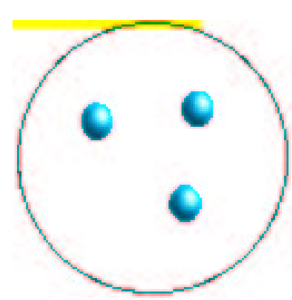
After 20 years of Polarized DIS study, the large x region stays poorly explored.

What Makes the Large x Region Interesting?

- At large x, valence quark dominate;
- Less contribution from $q - \bar{q}$ sea and gluons;
- A relatively clean region to study the nucleon structure.







Theoretical Predictions of A_1 and $\Delta q/q$

SU(6)

$$|n\uparrow\rangle = \frac{1}{\sqrt{2}}\left|d^{\uparrow}(du)_{0,0,0}\right\rangle + \frac{1}{\sqrt{18}}\left|d^{\uparrow}(du)_{1,1,0}\right\rangle - \frac{1}{3}\left|d^{\downarrow}(du)_{1,1,1}\right\rangle - \frac{1}{3}\left|u^{\uparrow}(dd)_{1,1,0}\right\rangle + \frac{\sqrt{2}}{3}\left|u^{\downarrow}(dd)_{1,1,1}\right\rangle$$

$$A_1^p = \frac{5}{9},\, A_1^n = 0, \qquad \frac{\Delta u}{u} = \frac{2}{3},\, \frac{\Delta d}{d} = -\frac{1}{3}$$

CQM + hyperfine interaction

$$|n\uparrow\rangle = \frac{1}{\sqrt{2}}\left|d^{\uparrow}(du)_{0,0,0}\right\rangle$$

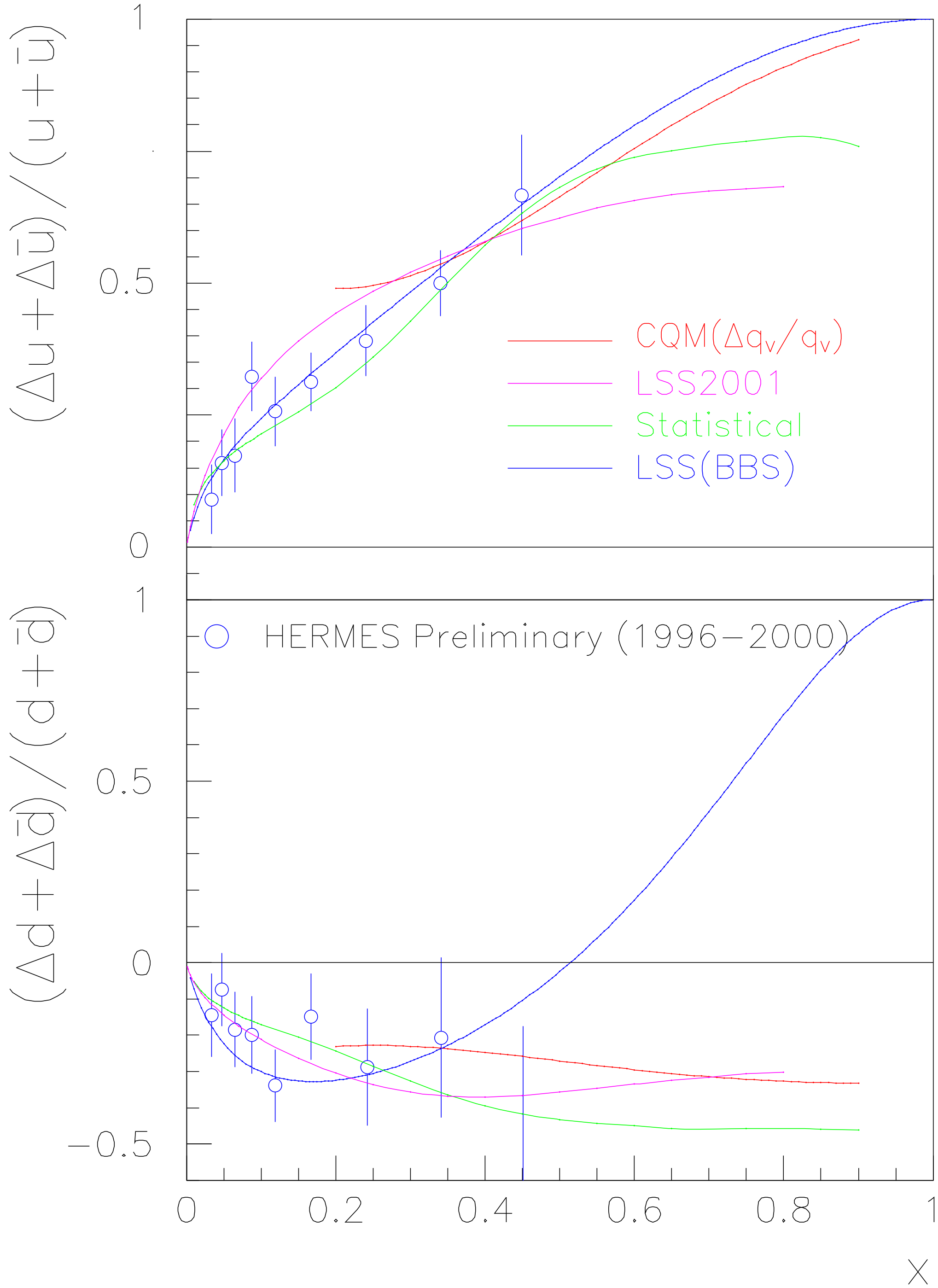
$$A_1^p \to 1,\, A_1^n \to 1, \qquad \frac{\Delta u}{u} \to 1,\, \frac{\Delta d}{d} \to -\frac{1}{3} \quad \text{as } x \to 1$$

HHC

$$|n\uparrow\rangle = \frac{1}{\sqrt{2}}\left|d^{\uparrow}(du)_{0,0,0}\right\rangle + \frac{1}{\sqrt{18}}\left|d^{\uparrow}(du)_{1,1,0}\right\rangle - \frac{1}{3}\left|u^{\uparrow}(dd)_{1,1,0}\right\rangle$$

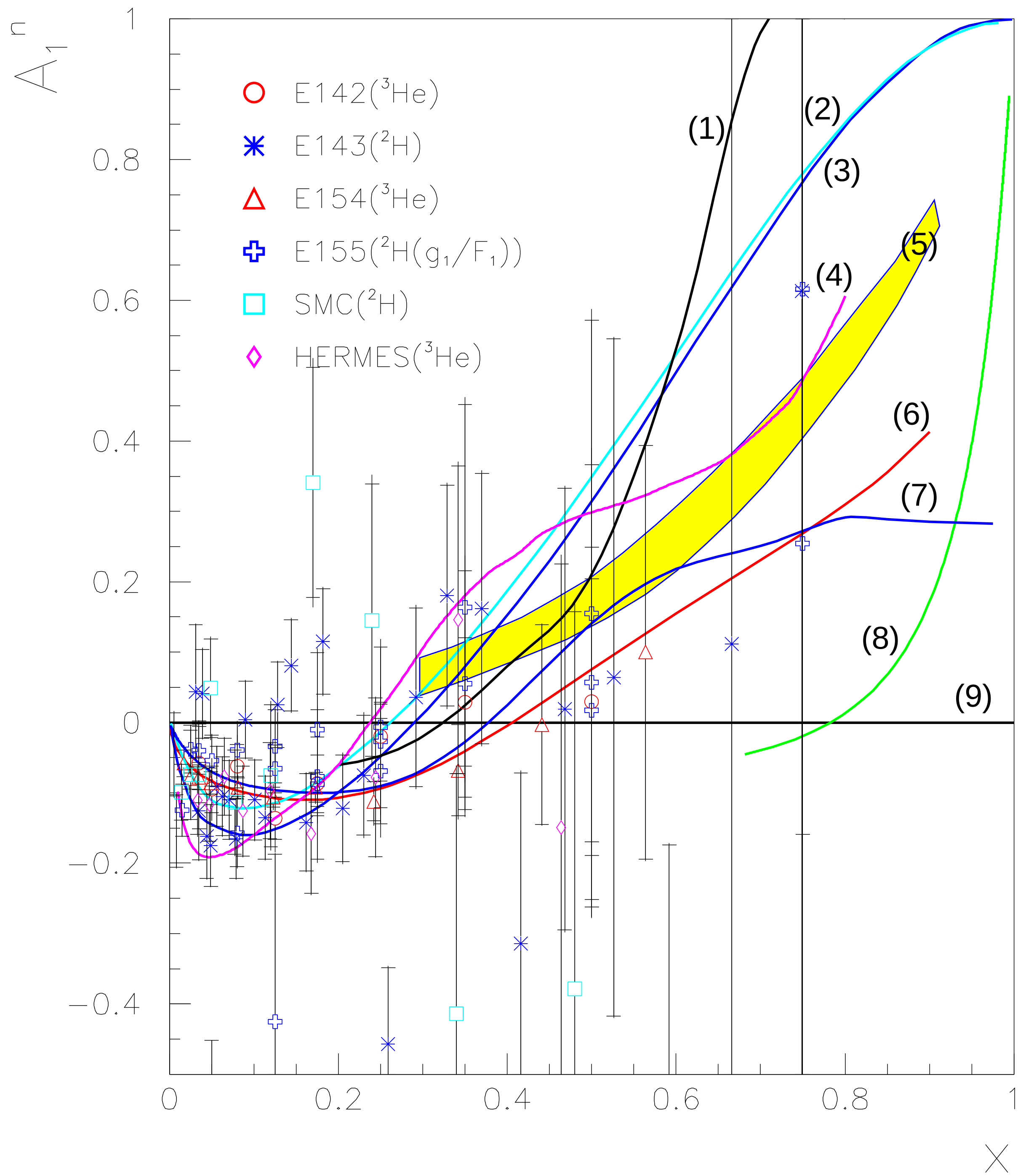
$$A_1^p \to 1,\, A_1^n \to 1, \qquad \frac{\Delta u}{u} \to 1,\, \frac{\Delta d}{d} \to 1 \quad \text{as } x \to 1$$

Theoretical Predictions of $\Delta q/q$



(1) CQM; (2) LSS(BBS); (3) Stat Model; (4) LSS 2001 ;

Theoretical Predictions of A_1^n



Curves: (1) Bag; (2) LSS(BBS); (3) BBS; (4) Chiral Soliton (g_1^n/F_1^n); (5) CQM; (6) LSS 2001 (g_1^n/F_1^n); (7) Stat Model; (8) Local Duality; (9) SU(6);

Experiment E99-117

Measured A_1^n at

x_{Bj}	0.327	0.466	0.601
Q^2 $(GeV/c)^2$	2.709	3.516	4.833
W^2 $(GeV/c)^2$	6.462	4.908	4.090

Experimental Setup

$^3\vec{\mathrm{He}}(\vec{e}, e')$

- $\vec{e}$: Jefferson Lab(JLab) polarized e^- beam 5.734 GeV, $P_{beam} = 80\%$
- $^3\vec{\mathrm{He}}$: Hall A polarized ^{3}He target $\sim$ 14 atm @ 50°C, $P_{targ} = 40\%$
- e': Two Hall A High Resolution Spectrometers (HRS).

Measured $A_\parallel$ and $A_\perp$ in inclusive $\vec{e}^- - {}^3\vec{\mathrm{He}}$ DIS

$$A_1 = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{\eta A_\perp}{d(1+\eta\xi)}, \qquad A_2 = \frac{\xi}{D(1+\eta\xi)} A_\parallel + \frac{1}{d(1+\eta\xi)} A_\perp$$

$$\frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{1}{D'}\left[A_\parallel + \tan(\theta/2)\cdot A_\perp\right], \qquad \frac{g_2(x,Q^2)}{F_1(x,Q^2)} = \ldots$$

From ^{3}He to Neutron

$$A_1^n = \frac{F_2^{^3\mathrm{He}}}{P_n F_2^n (1 + \frac{0.056}{P_n})} [A_1^{^3\mathrm{He}} - 2\frac{F_2^p}{F_2^{^3\mathrm{He}}} P_p A_1^p (1 - \frac{0.014}{2P_p})]$$

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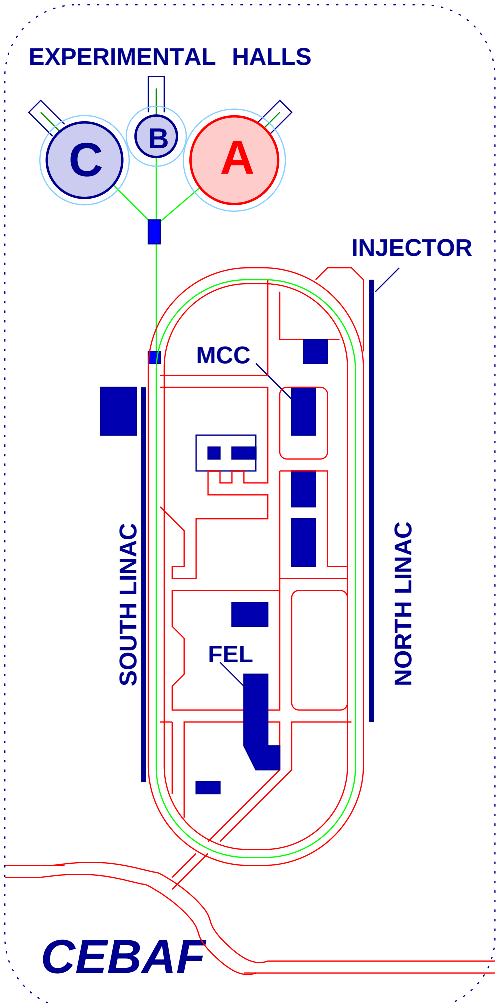
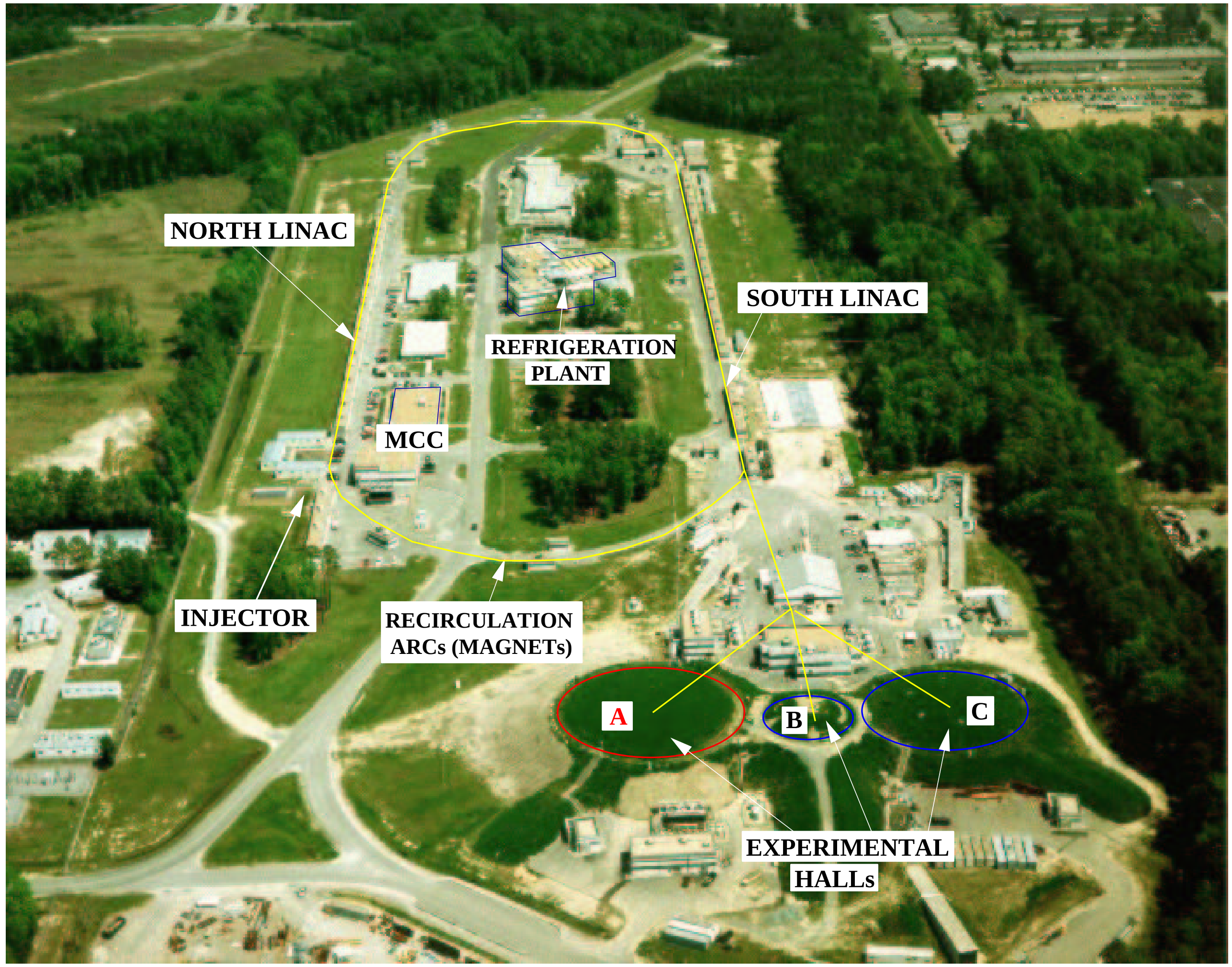
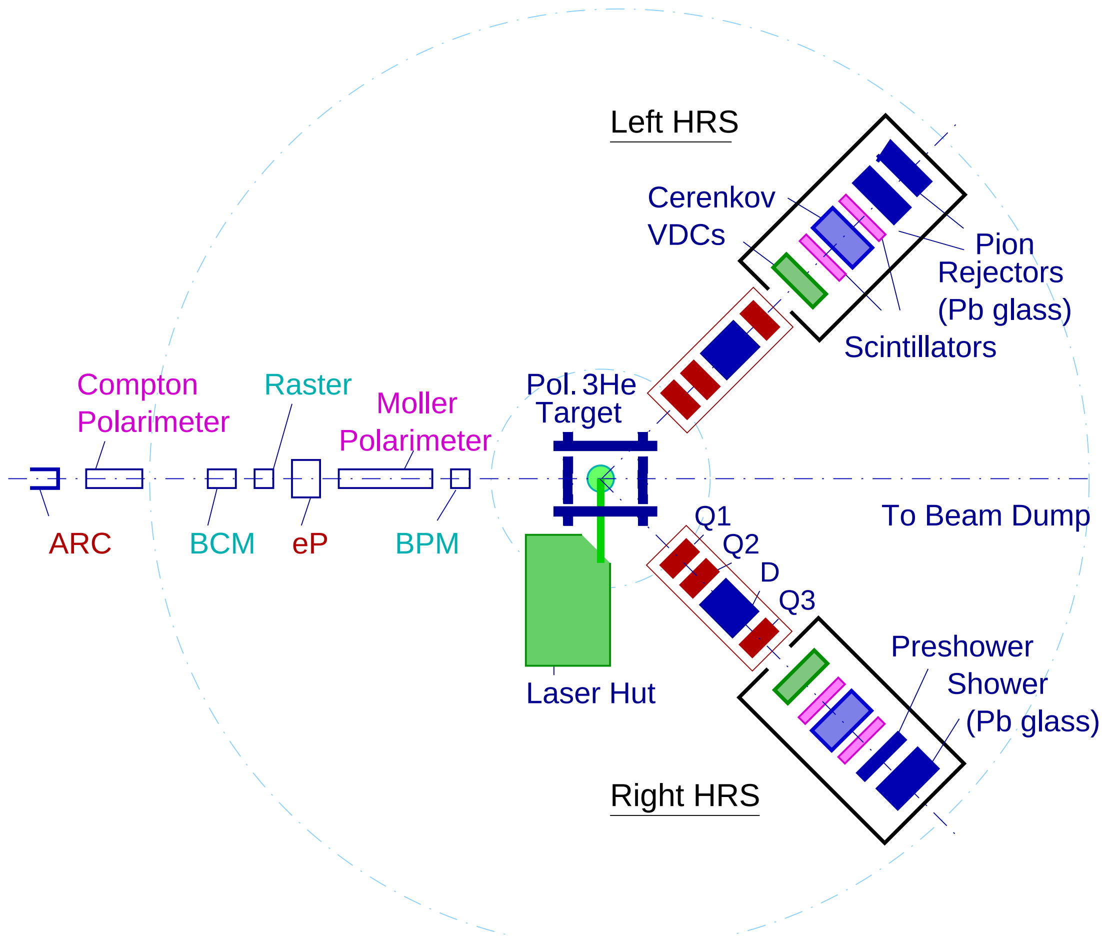
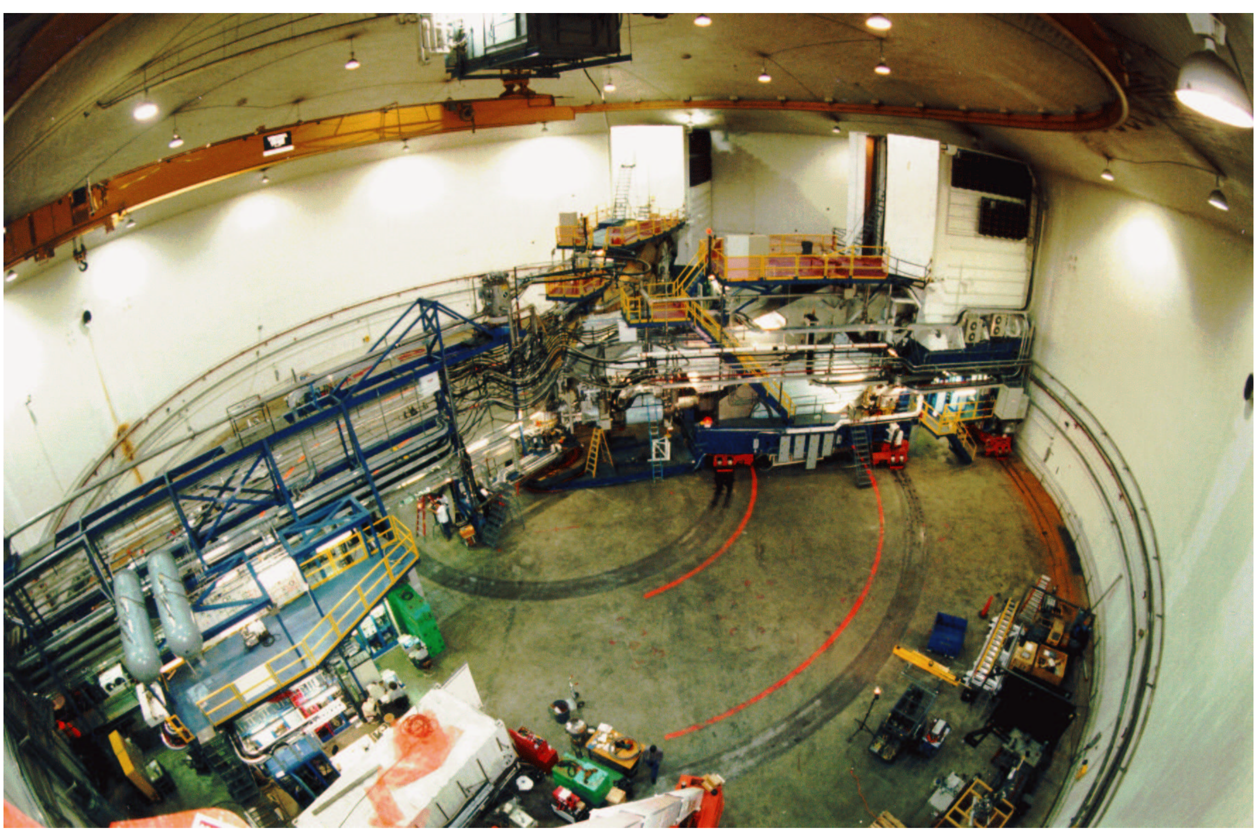
The Jefferson Lab Accelerator





EXPERIMENTAL HALL A



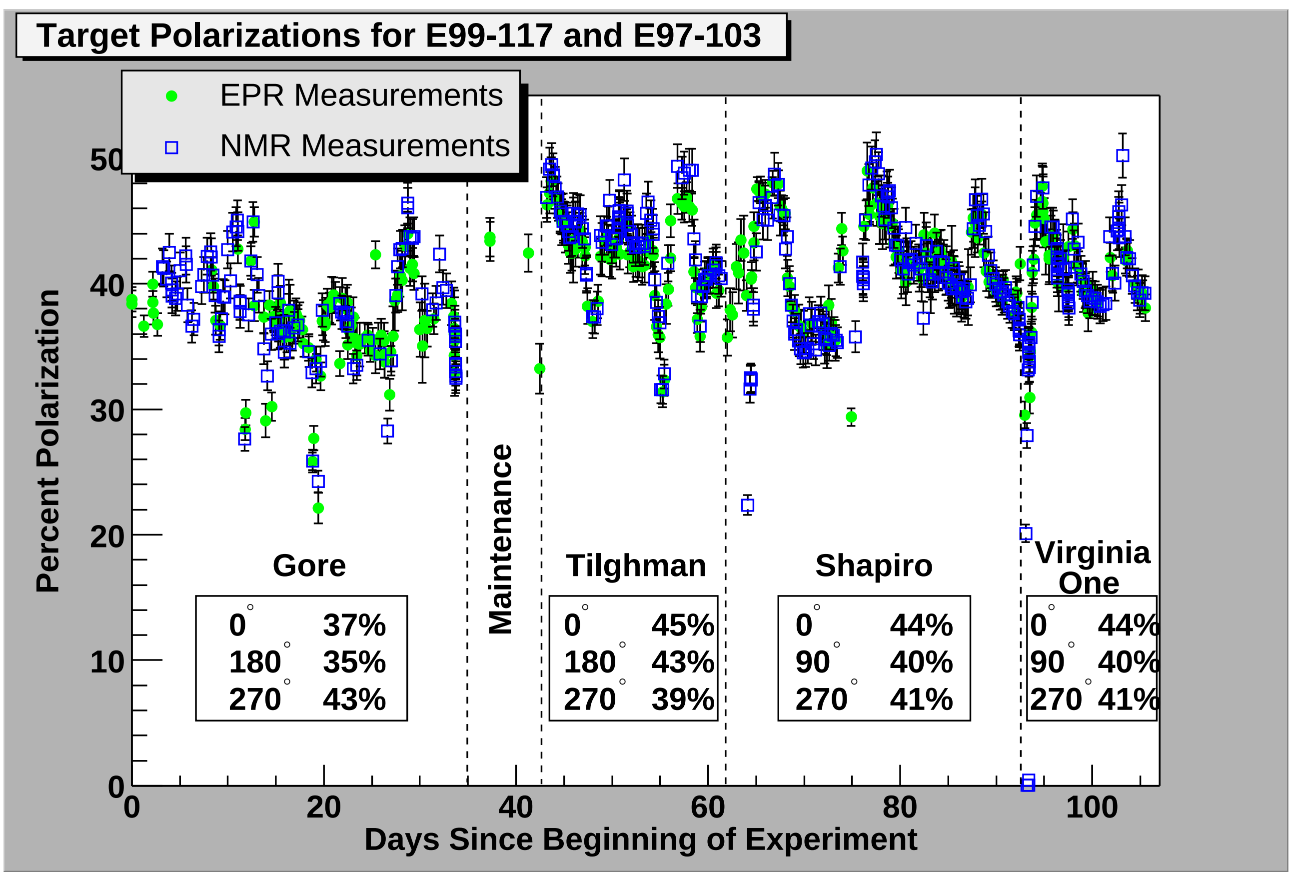


Polarized ^{3}He Target

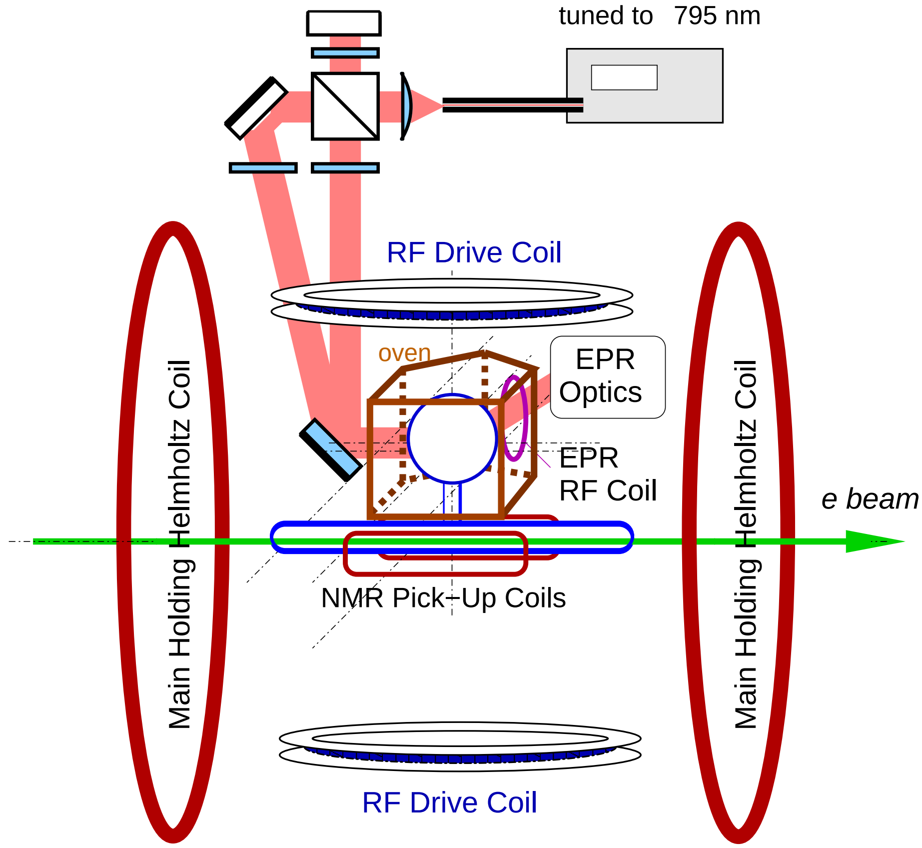
Basics

- Optical Pumping of Rb and Spin exchange during Rb-^{3}He collisions
- Cell density: 7.5 $\sim$ 10 amg (0°C).
- Polarization: $\approx$ 40% (in beam)
- Polarimetries: NMR, EPR

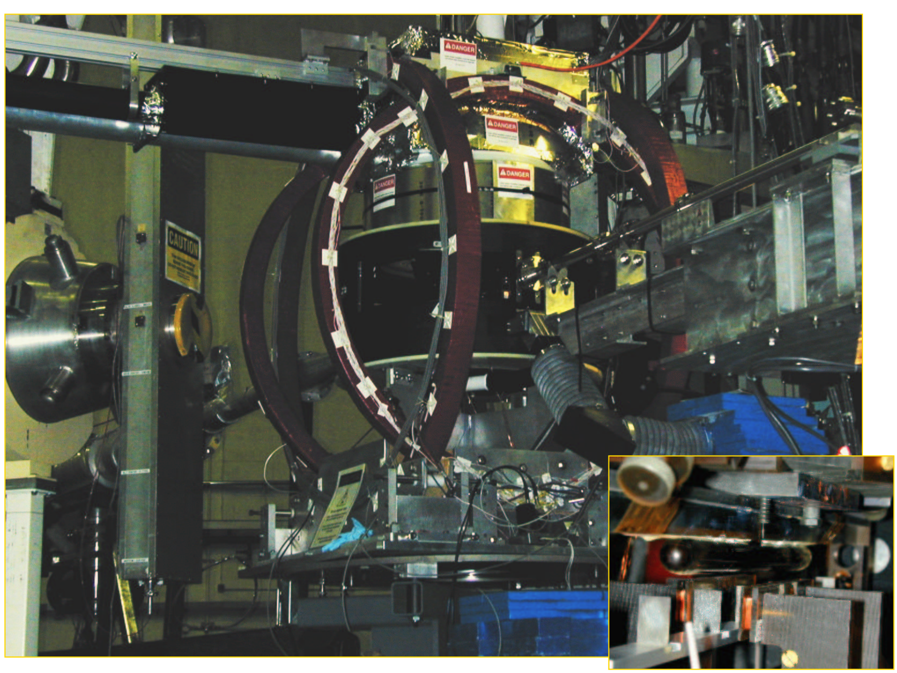
Target Performance



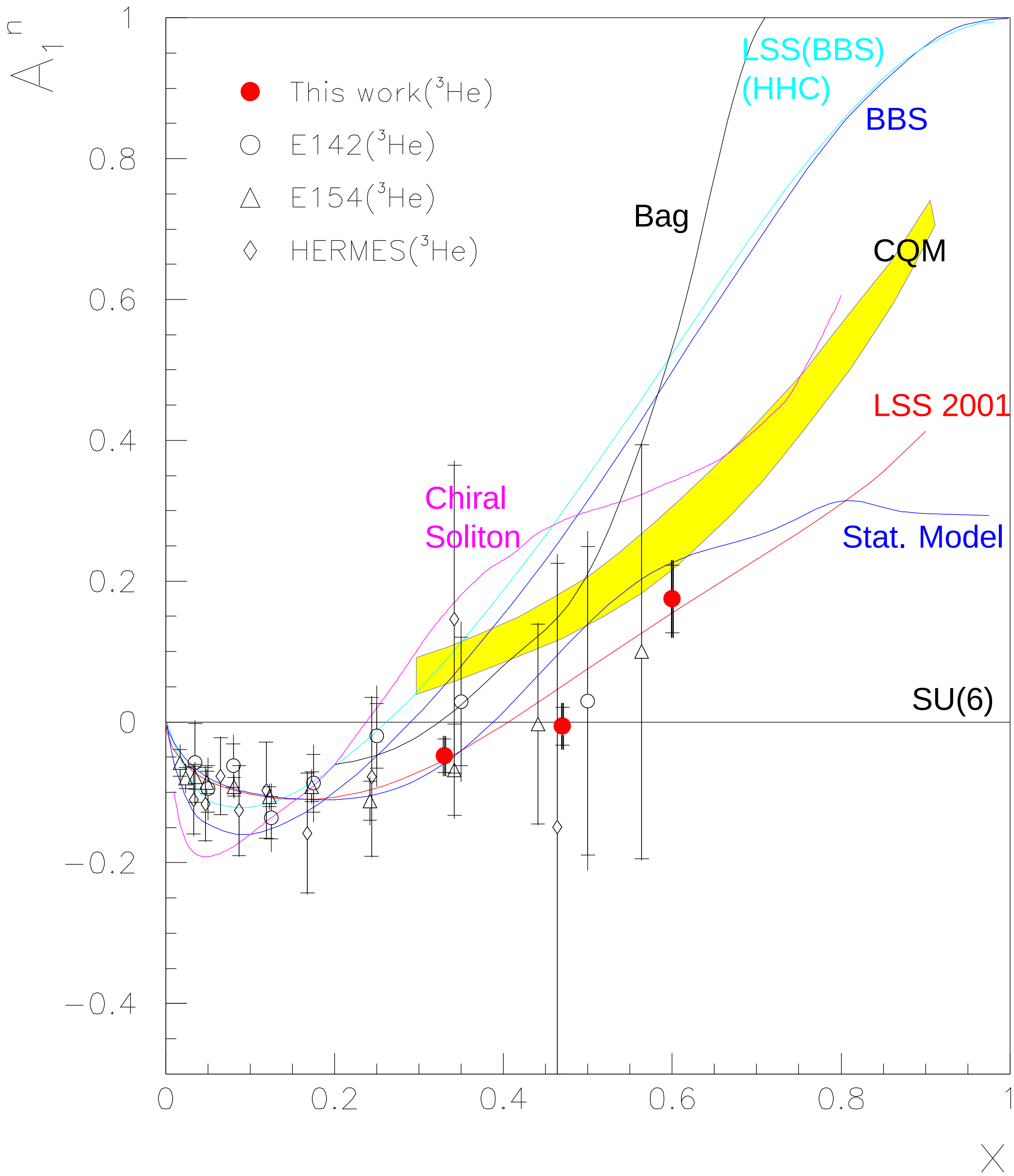
Target Setup



Target In Situ

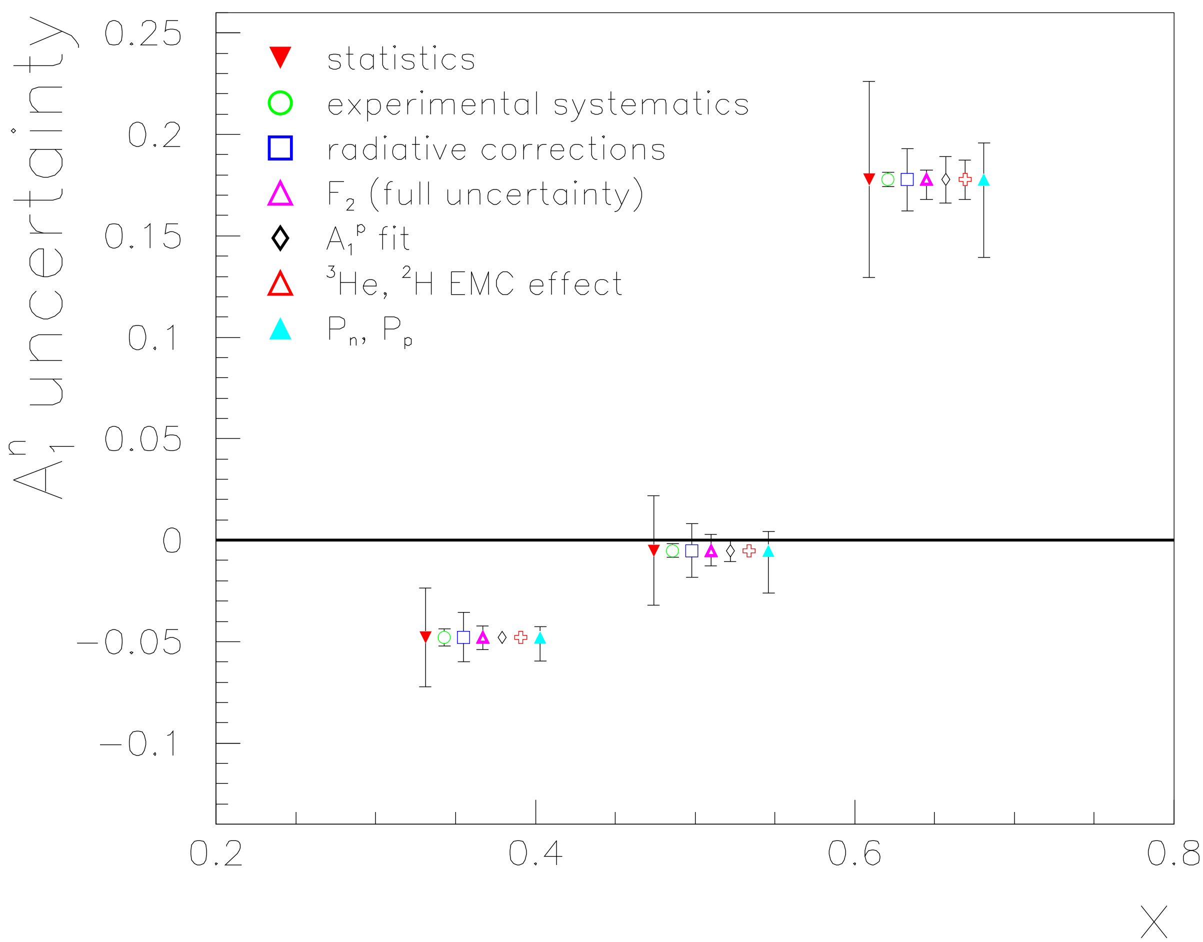


A_1^n *Results*

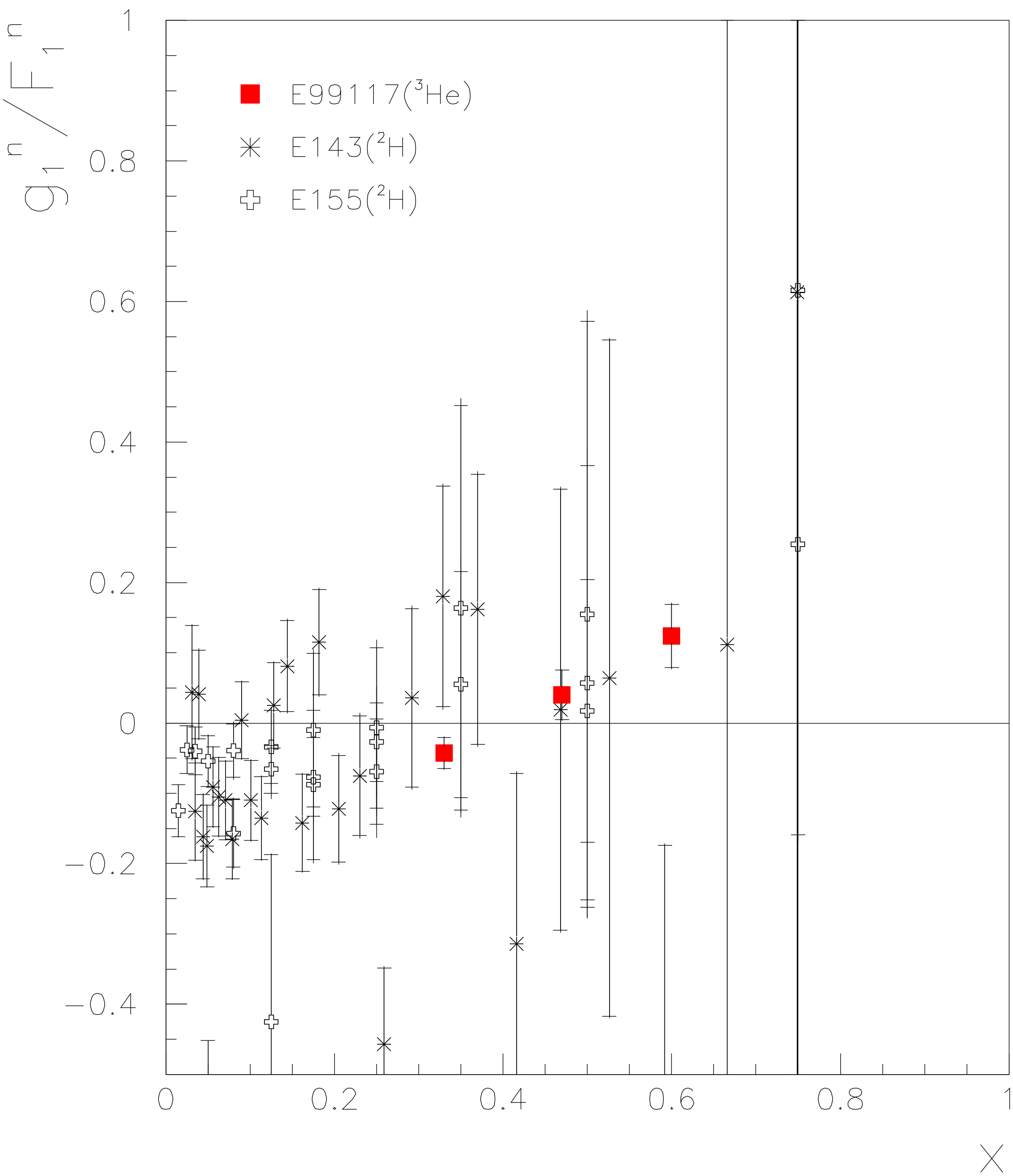


A_1^n
This work(^{3}He)
E142(^{3}He)
E154(^{3}He)
HERMES(^{3}He)
LSS(BBS)
(HHC)
BBS
Bag
CQM
LSS 2001
Chiral
Soliton
Stat. Model
SU(6)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
0.2
0.4
0.6
0.8
1
X

A_1^n Error Analysis



g_1^n / F_1^n Results



$\Delta q/q$ *from Neutron Results*

- Recall that

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 \left[q_i(x)\right] \text{ and } g_1(x) = \frac{1}{2}\sum_i e_i^2 \left[\Delta q_i(x)\right]$$

- At large x, assuming s, $\bar{s}(x)$ are negligible

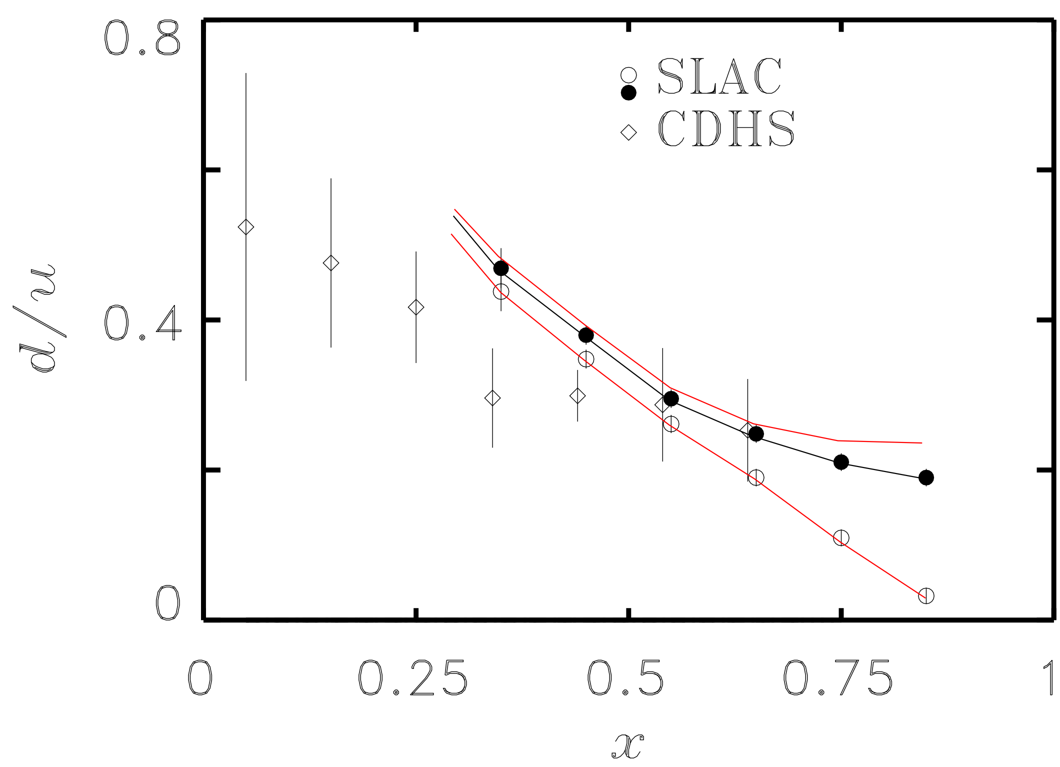
$$\frac{g_1^n}{F_1^n} = \frac{\Delta u + 4\Delta d}{u + 4d}, \qquad \frac{g_1^p}{F_1^p} = \frac{4\Delta u + \Delta d}{4u + d}$$

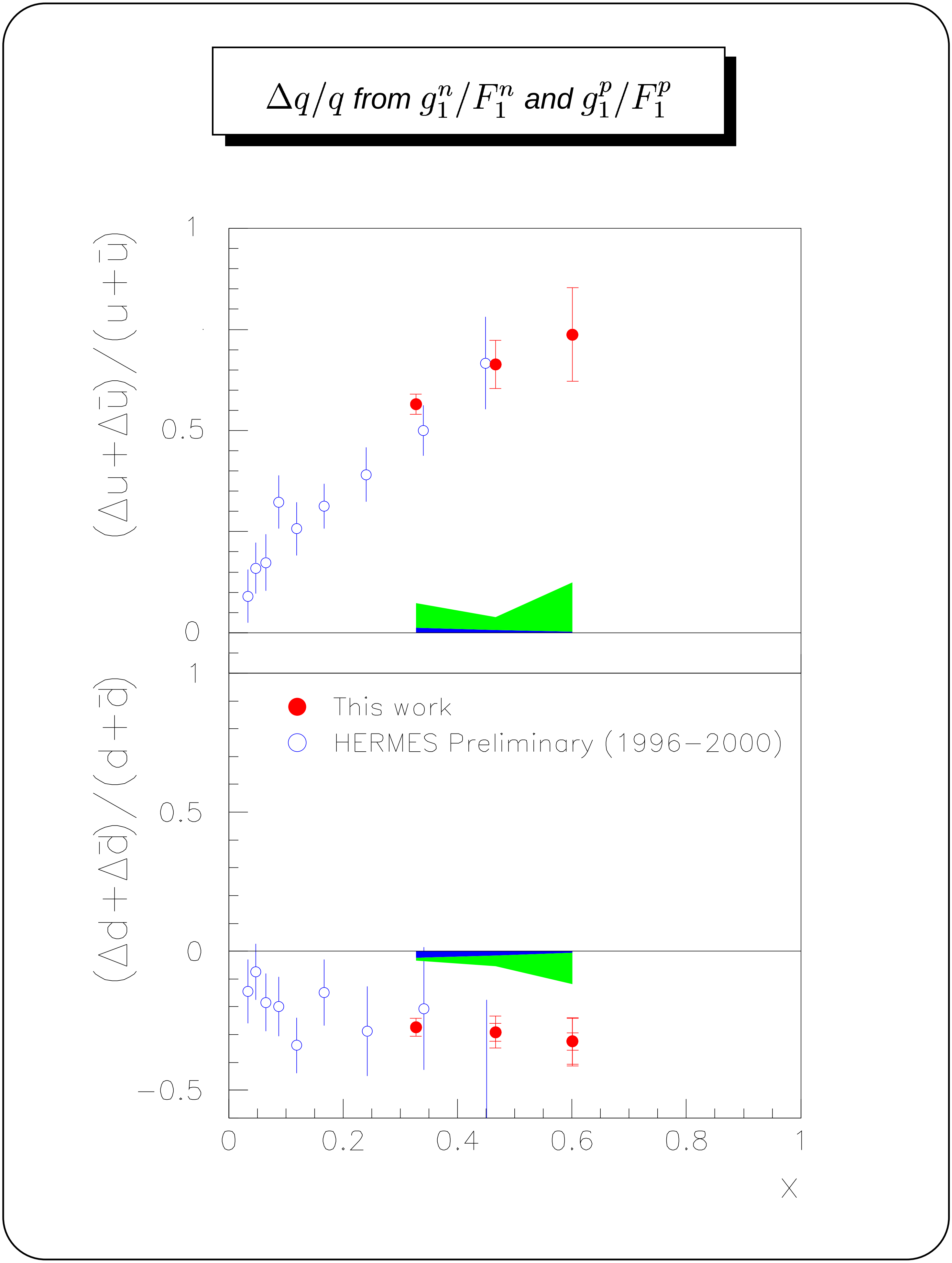
- Can extract $\frac{\Delta q}{q}$ as

$$\frac{\Delta u}{u} = \frac{4}{15}\frac{g_1^p}{F_1^p}(4 + \frac{d}{u}) - \frac{1}{15}\frac{g_1^n}{F_1^n}(1 + 4\frac{d}{u})$$

$$\frac{\Delta d}{d} = \frac{4}{15}\frac{g_1^n}{F_1^n}(4 + 1/\frac{d}{u}) - \frac{1}{15}\frac{g_1^p}{F_1^p}(1 + 4/\frac{d}{u})$$

• d/u Ratio from *Phys.Lett.* **B377**, 11-17 (1996)





Δq/q from g₁ⁿ/F₁ⁿ and g₁ᵖ/F₁ᵖ
(Δu+Δū)/(u+ū)
(Δd+Δd̄)/(d+d̄)
This work
HERMES Preliminary (1996−2000)
1
0.5
0
−0.5
0.2
0.4
0.6
0.8
x

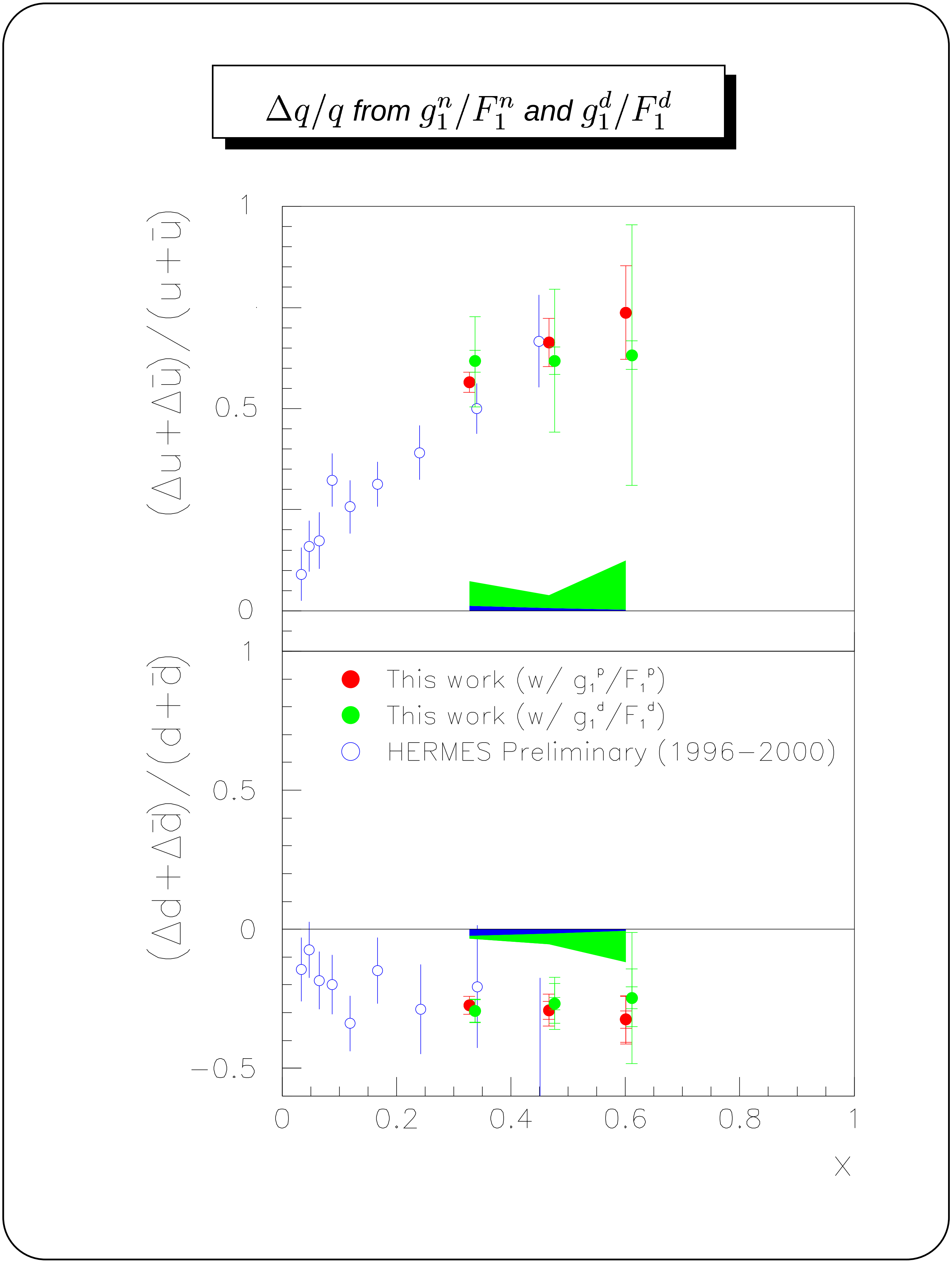
$\Delta q/q$ *from* g_1^n/F_1^n *and* g_1^d/F_1^d

- Simularly, using deuteron data set

$$\frac{g_1^n}{F_1^n} = \frac{\Delta u + 4\Delta d}{u + 4d}, \qquad \frac{g_1^d}{F_1^d} = \frac{\Delta u + \Delta d}{u + d}$$

- Can extract $\frac{\Delta q}{q}$ as

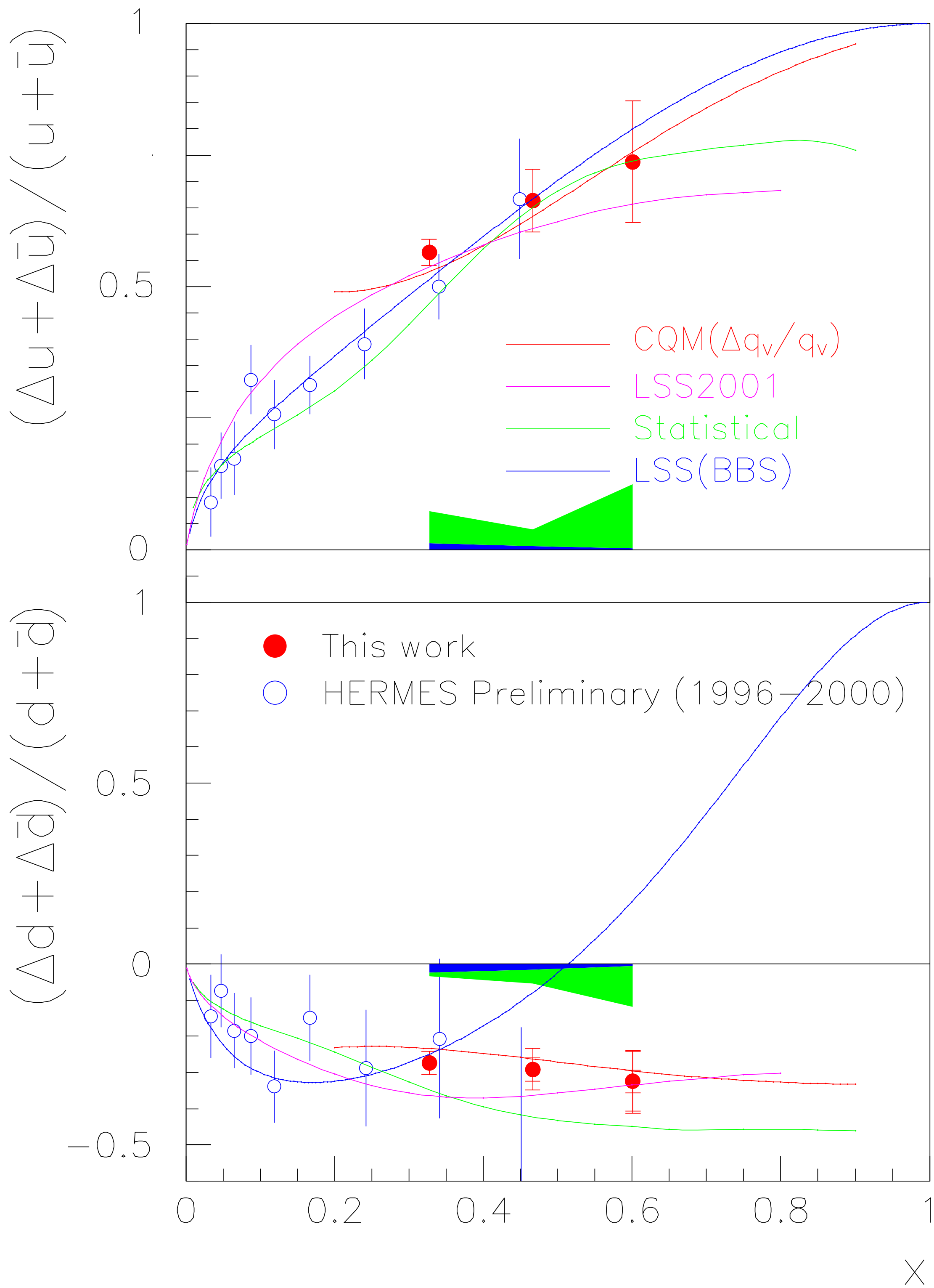
$$\begin{aligned}
\frac{\Delta u}{u} &= -\frac{1}{3}\frac{g_1^n}{F_1^n}\left(\frac{4d}{u} + 1\right) + \frac{4}{3}\frac{g_1^d}{F_1^d}\left(\frac{d}{u} + 1\right) \\
\frac{\Delta d}{d} &= \frac{1}{3}\frac{g_1^n}{F_1^n}\left(4 + 1/\frac{d}{u}\right) - \frac{1}{3}\frac{g_1^d}{F_1^d}\left(1 + 1/\frac{d}{u}\right)
\end{aligned}$$



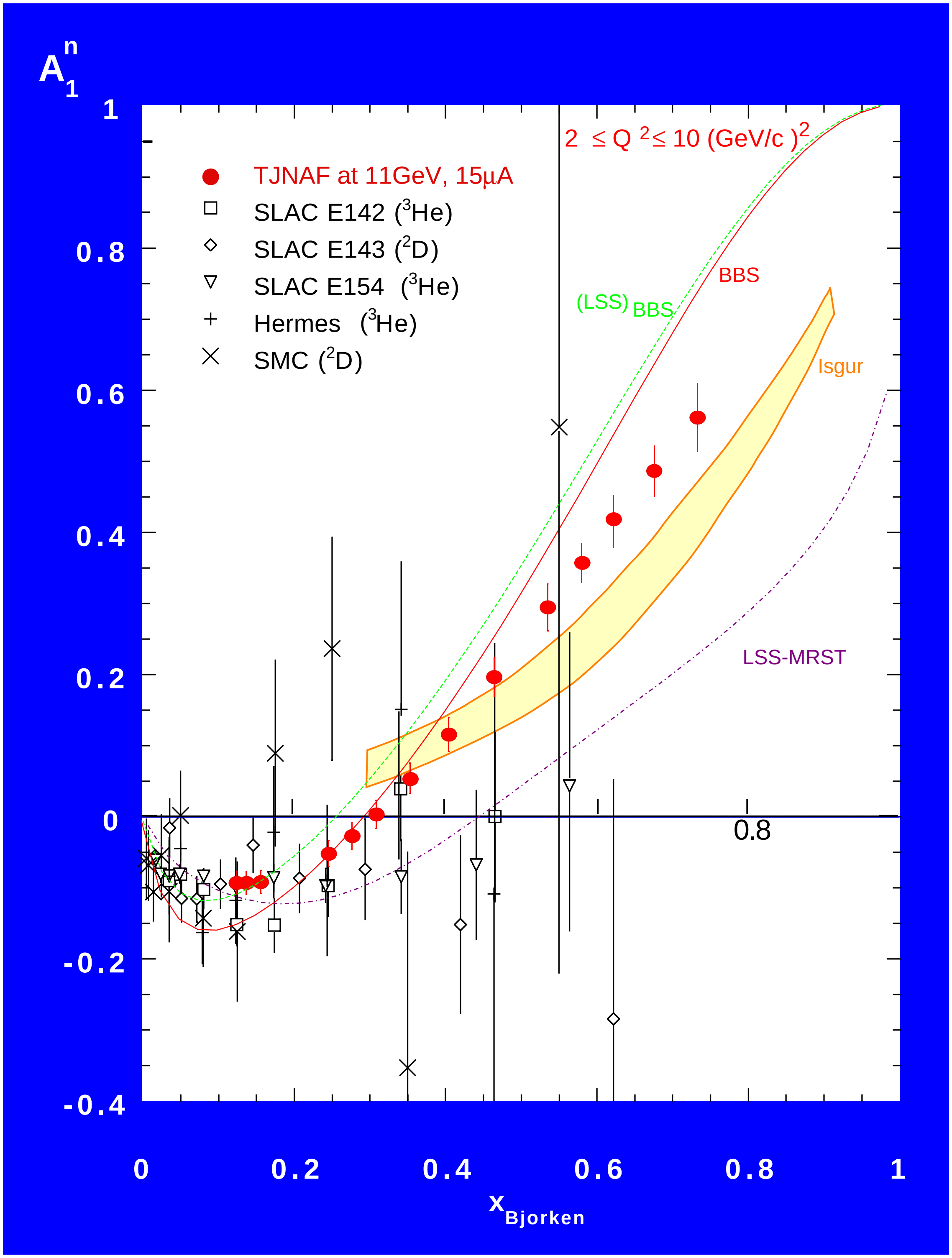
Δq/q from g_1^n/F_1^n and g_1^d/F_1^d
(Δu+Δū)/(u+ū)
(Δd+Δd̄)/(d+d̄)
This work (w/ g_1^p/F_1^p)
This work (w/ g_1^d/F_1^d)
HERMES Preliminary (1996−2000)
1
0.5
0
−0.5
0.2
0.4
0.6
0.8
X

$\Delta q/q$ *from* g_1^n/F_1^n *and* g_1^p/F_1^p

(w. models)



A_1^n @ JLab 12 GeV Upgrade



Summary

Experiment E99-117

- Provide the first precise data of A_1^n and g_1^n at $x > 0.4$;
- Based on QPM, $\Delta u/u$ and $\Delta d/d$ extracted from g_1^n/F_1^n results;

Impact

- Check current understanding of nucleon spin in the valence quark region;
- Check HHC – effect beyond LO pQCD (e.g. quark OAM);
- Provide constraints to other models;

More data are expected at 12 GeV