Spin Physics in JLab Hall A

Kathy McCormick
Rutgers, The State University of New Jersey
April 23, 2003

OUTLINE

Introduction - Polarized DIS and Spin Structure Functions

Theories - A_1^n, g_2^n

Experiments E99-117, E97-103

Overview Experimental Setup Polarized ^{3}He Target Data Analysis

Results

Discussion, Summary and Outlook

The Hall A Polarized ^{3}He Collaboration

J. Gao

California Institute of Technology

K. Aniol, D. Margaziotis

California State University, LA

P. Markowitz

Florida International University

R. Roche

Florida State University

M. Roedelbronn

University of Illinois

F. Cusanno, R. De Leo, F. Garibaldi, S. Frullani, G. Urciuoli

INFN

J.-P. Chen, E. Chudakov, J. Gomez, K. de Jager, R. Michaels, O. Hansen, J. LeRose, N. Liyanage, B. Reitz, A. Saha, B. Wojtsekhowski

Jefferson Lab

K. McCormick

Kent State University

W. Korsch, P. Zolnierczuk

University of Kentucky

J. Kelly, T. Horn, N. Savvinov

University of Maryland

L. Kaufman, A. Vacheret

University of Massachussetts

W. Bertozzi, Z. Chai, D. Dutta, H. Gao, D. Higinbotham, M. Rvachev, S. Sirca, H. Xiang, Y. Xiao, F. Xiong, B. Zhang, X. Zheng, L. Zhu

Massachussetts Institute of Technology

J. Calarco

University of New Hampshire

W. Hinton

Old Dominion University

E. Busato, S. Dieterich, R. Gilman, X. Jiang, S. Strauch

Rutgers University

P. Souder

Syracuse University

G. Ron

Tel Aviv

Z.-E. Meziani, S. Choi, K. Slifer, P. Solvignon

Temple University

A. Camsonne, G. Cates, A. Deur, J. Singh

University of Virginia

D. Armstrong, T. Averett, K. Kramer, S. Binet, C. Butuceanu, M. Finn, B. Moffit, S. Phillips, A. Powell, J. Roche, D. Steiner, V. Sulkosky, X. Zhu

College of William and Mary

Experimental Program

NEUTRON SPIN STRUCTURE PROGRAM IN JLAB HALL A

(USING POLARIZED ^{3}He)

Sum Rules

E94010 A Connection between Bjorken and GDH Sum Rules, (Nov, Dec '98)

E97110 The Generalized GDH Sum Rule for Nearly Real Photons (April '03)

Spin Structure Functions

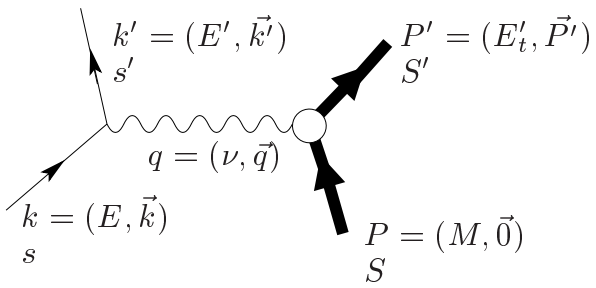
E99117 Neutron Asymmetry A_1^n at large xB_j (June, July 2001)

E97103 Search for Higher Twist Effect in g_2^n (Aug, Sept 2001)

E01012 Neutron Spin Structure in the Resonance Region (Jan 2003)

Polarized Deep Inelastic Scattering

POLARIZED DIS



STRUCTURE FUNCTIONS

- Unpolarized Target:

$$\frac{d^2\sigma_{\uparrow\Uparrow}}{d\Omega dE'} + \frac{d^2\sigma_{\uparrow\Downarrow}}{d\Omega dE'} = \frac{8\alpha^2 E'^2}{mQ^4}\left[2\sin^2\frac{\theta}{2}F_1(x,Q^2) + \frac{m^2}{\nu}\cos^2\frac{\theta}{2}F_2(x,Q^2)\right]$$

$$F_1(x,Q^2) = \frac{F_2(x,Q^2)(1+\gamma^2)}{2x\left(1+R(x,Q^2)\right)}$$

- Longitudinally Polarized Target:

$$\frac{d^2\sigma_{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma_{\uparrow\Downarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{E\nu Q^2}\left[(E + E'\cos\theta)g_1(x,Q^2) - 2xmg_2(x,Q^2)\right]$$

- Transversely Polarized Target:

$$\frac{d^2\sigma_{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma_{\uparrow\Leftarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{E\nu Q^2}\sin\theta\left[g_1(x,Q^2) + \frac{2Em}{\nu}g_2(x,Q^2)\right]$$

STRUCTURE FUNCTIONS IN QPM

Within the Quark-Parton Model,

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 \left[q_i^{\uparrow}(x) + q_i^{\downarrow}(x)\right]$$

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

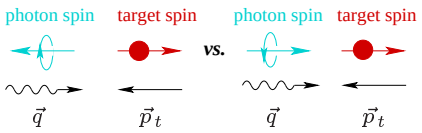
Ignoring quark mass effects,

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

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

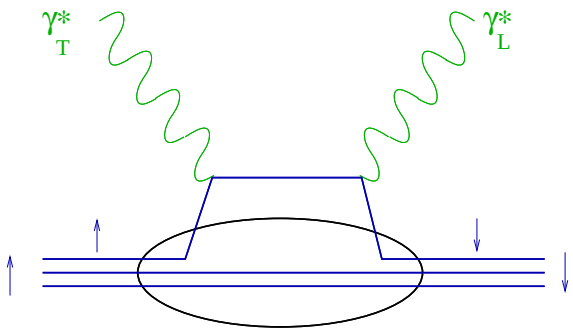
VIRTUAL PHOTON ASYMMETRIES

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



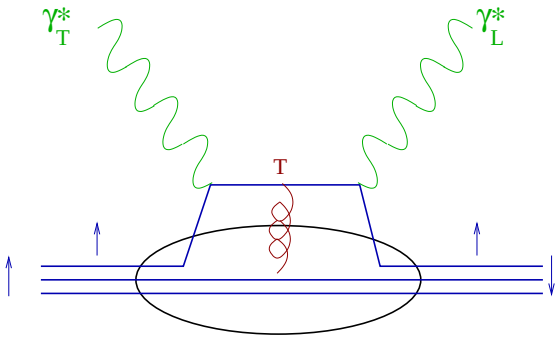
$$A_1(x,Q^2) = \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)}$$

What are higher twist terms?



Twist − 2

Leading order term, Dominant in DIS, in g_1 and g_2



Twist − 3

Next to leading order term, only present in g_2

Higher order terms are suppressed by increasing orders of $1/Q^2$

Theoretical Predictions of A_1^n

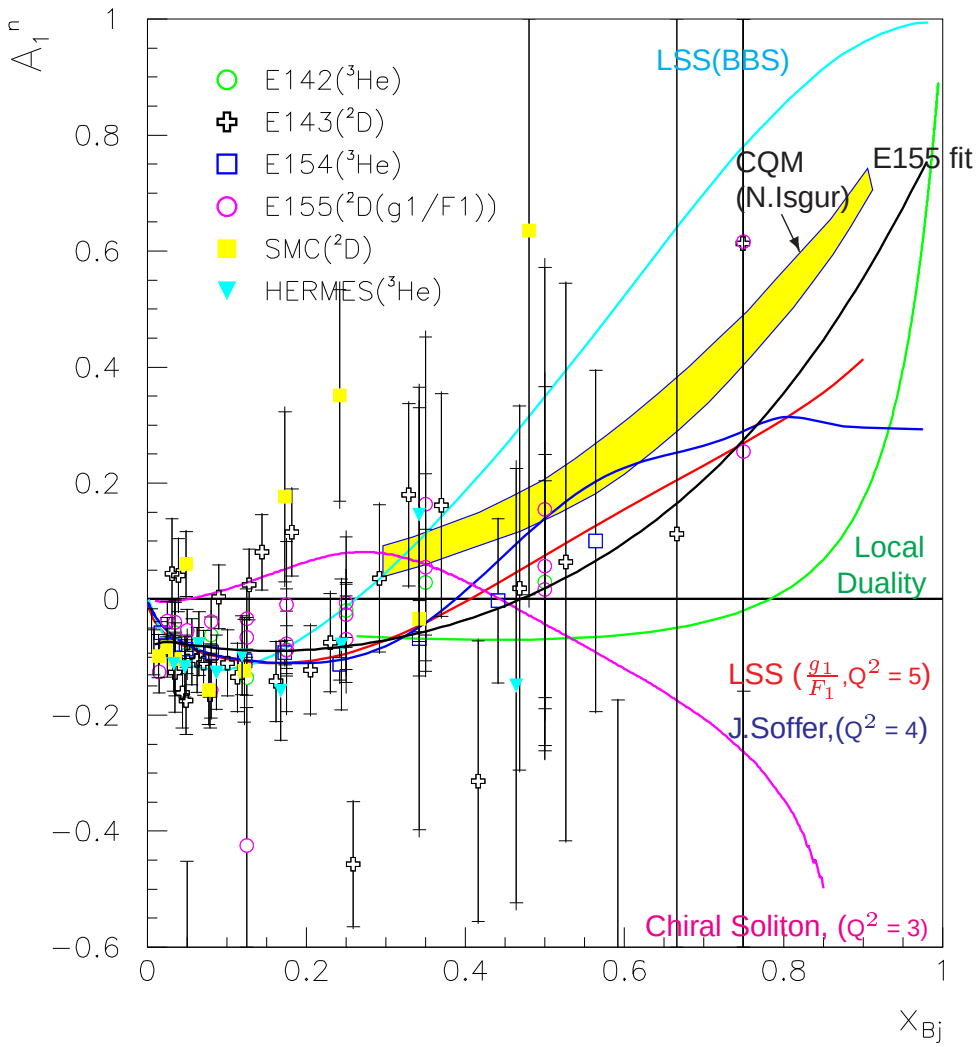
- SU(6)

- Constituent quark models (CQM): N.Isgur
- pQCD - E. Leader, A.V.Sidorov, D.B.Stamenov (LSS 2001) (BBS);

- Statistical model, C.Bourrely, J. Soffer ;
- Local Duality: W. Melnitchouk;

- Chiral Quark-Soliton Model, H. Weigel;
- Instanton Model, N.I.Kochelev, $A_1^n \sim 0$ or $A_1^n < 0$;

Theoretical Predictions of A_1^n (cont.)



Experiment E99-117

Measure A_1^n at

x_{Bj}	0.331	0.474	0.609
Q^2 (GeV/c)^2	2.738	3.567	4.887
W^2 (GeV/c)^2	6.426	4.846	4.023

Measure asymmetries $A_{||}$ and $A_{\perp}$ in inclusive $\vec{e}$-$^3\vec{H}_e$ DIS

$$A_1 = \frac{A_{||}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$

Experimental Setup

CEBAF polarized electron beam:

5.734 GeV, $P_{beam} = 80\%$

Hall A polarized ^{3}He target

~10 atm, $P_{targ} = 40\%$

Two Hall A High Resolution Spectrometers (HRS) at symmetric positions.

Experiment E97-103

Measure g_2^n at

x_{Bj}	0.17	0.20	0.18	0.20	0.21
Q^2 (GeV/c)^2	0.579	0.956	0.796	1.138	1.358
W^2 (GeV/c)^2	3.82	4.43	4.83	5.57	6.03

Measure asymmetries $A_{||}$ and $A_{\perp}$ in inclusive $\vec{e}$-$^3\vec{H}_e$ DIS:

$$g_2(x,Q^2) = \frac{F_1(x,Q^2)}{2D'y\sin\theta}\left[\frac{E+E'\cos\theta}{E'}A_{\perp} - \sin\theta\, A_{||}\right]$$

Experimental Setup

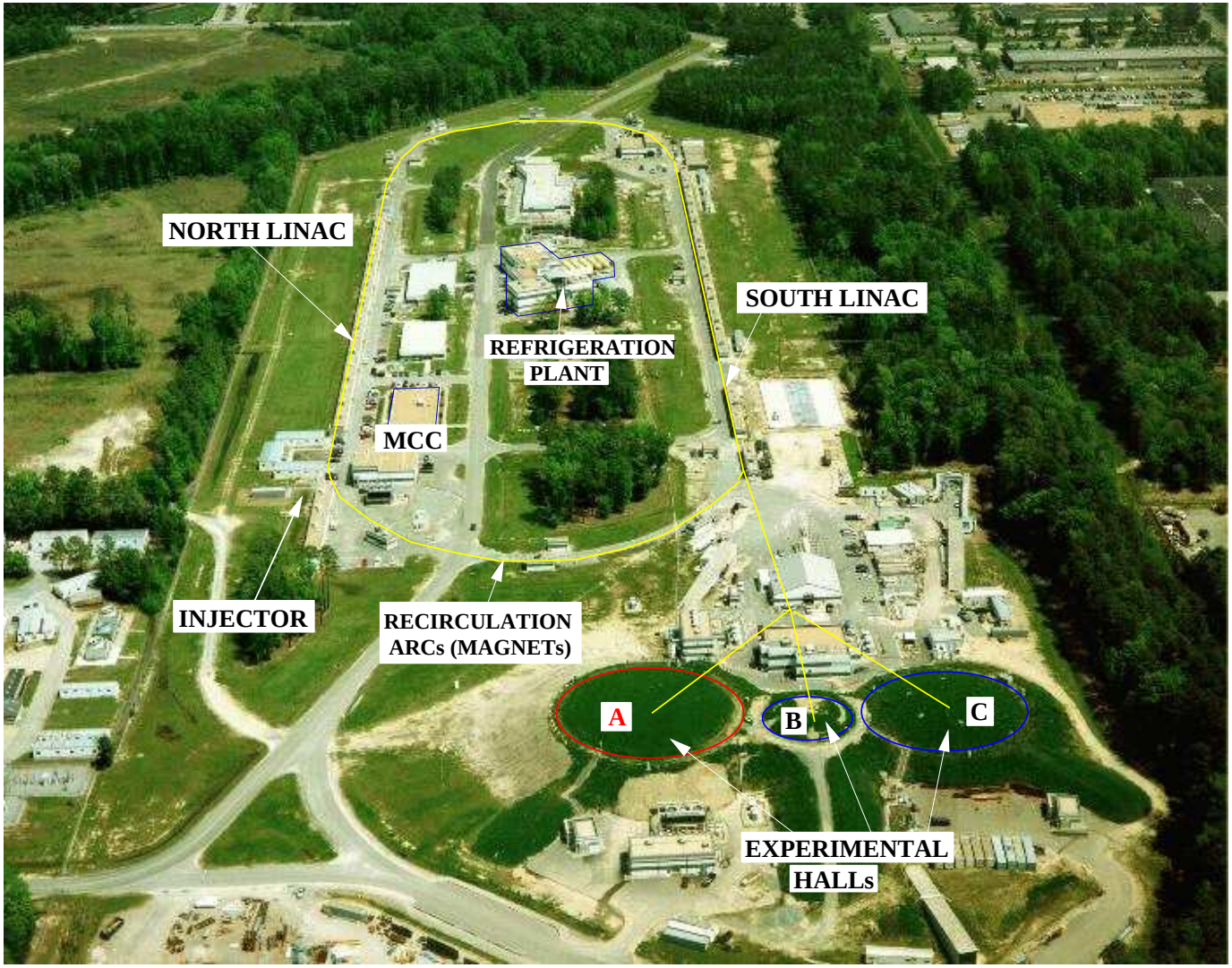
CEBAF polarized electron beam:

5 energies from 3.464 to 5.726 GeV, $P_{beam} = 80\%$

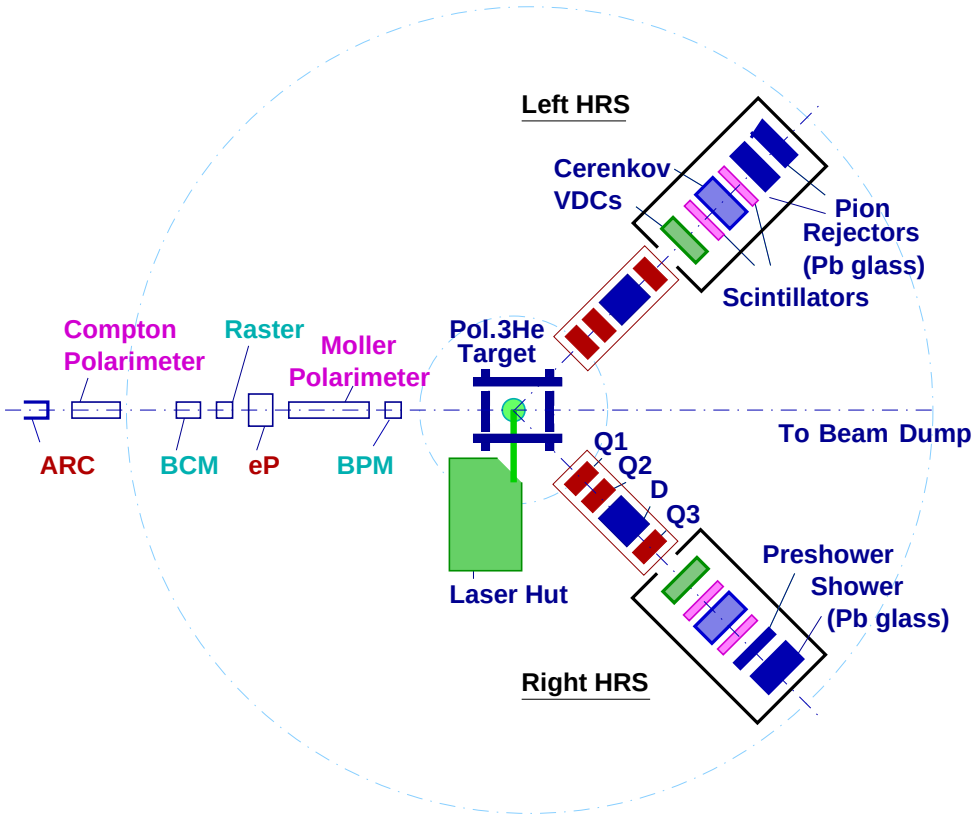
Hall A polarized ^{3}He target

~10 atm, $P_{targ} = 40\%$

Two Hall A High Resolution Spectrometers (HRS) at symmetric positions.

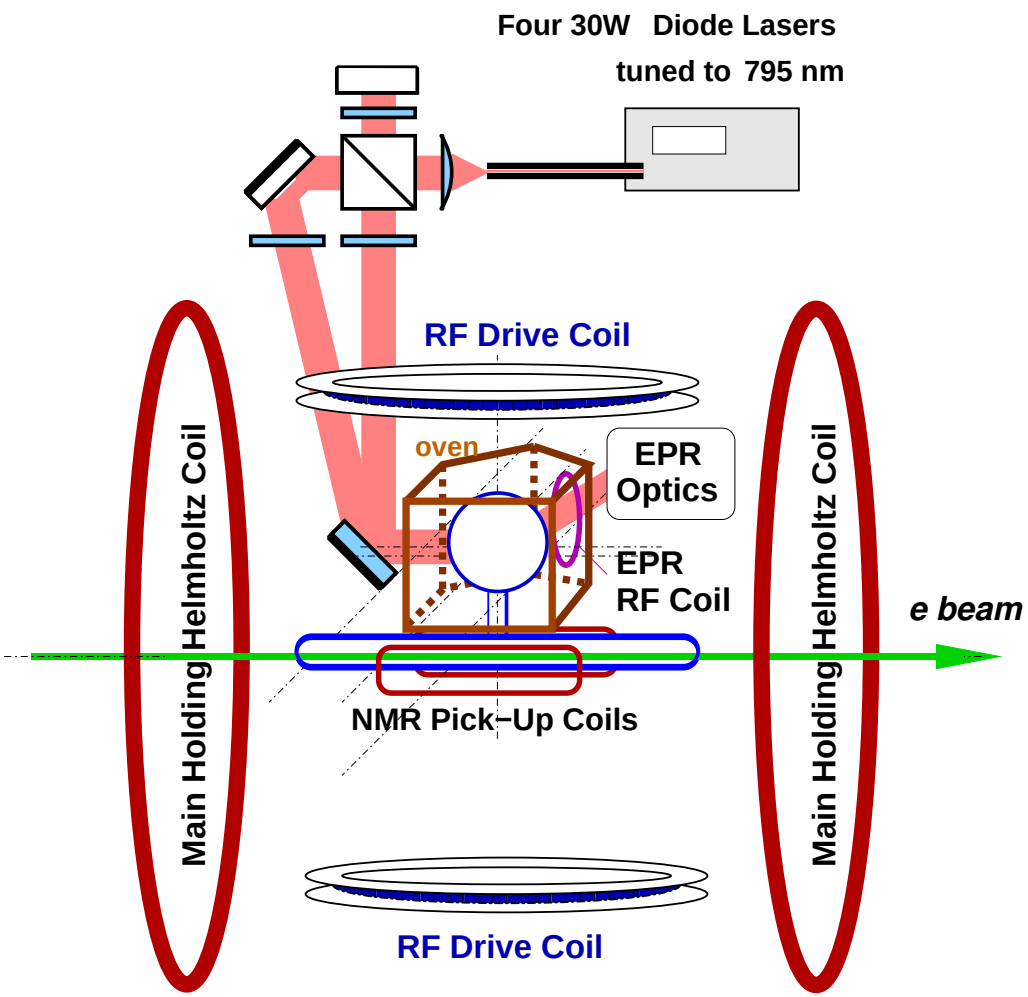

NORTH LINAC
SOUTH LINAC
REFRIGERATION PLANT
MCC
INJECTOR
RECIRCULATION ARCs (MAGNETs)
A
B
C
EXPERIMENTAL HALLs

EXPERIMENTAL HALL A



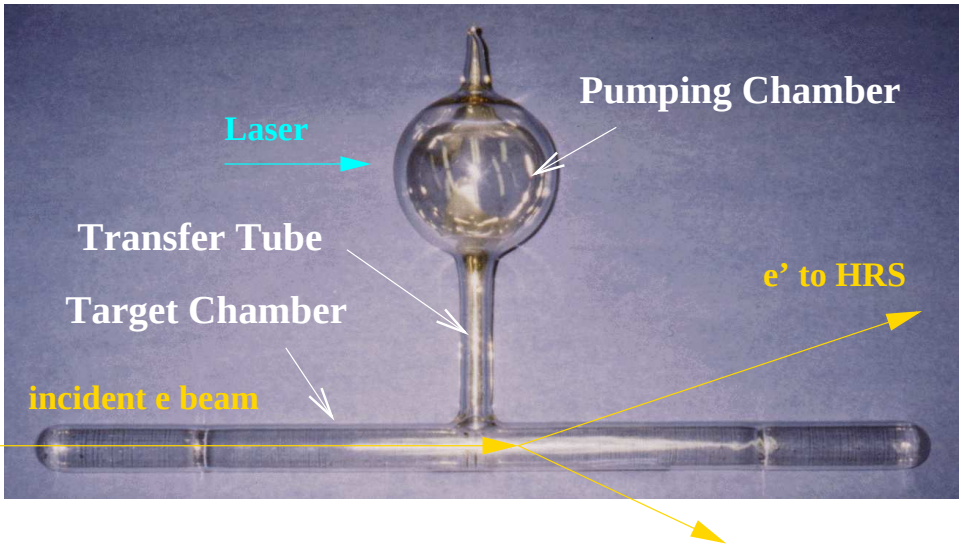
- *Two VDCs* for tracking;
- *Sets of scintillators* for triggering on charged particles;
- *Gas cherenkov detector* for pion rejection;
- *Two layers of lead glass counters* for additional PID;
- *Pion rejection efficiency:* better than 10^{-4} with electron efficiency 99%.

TARGET SETUP

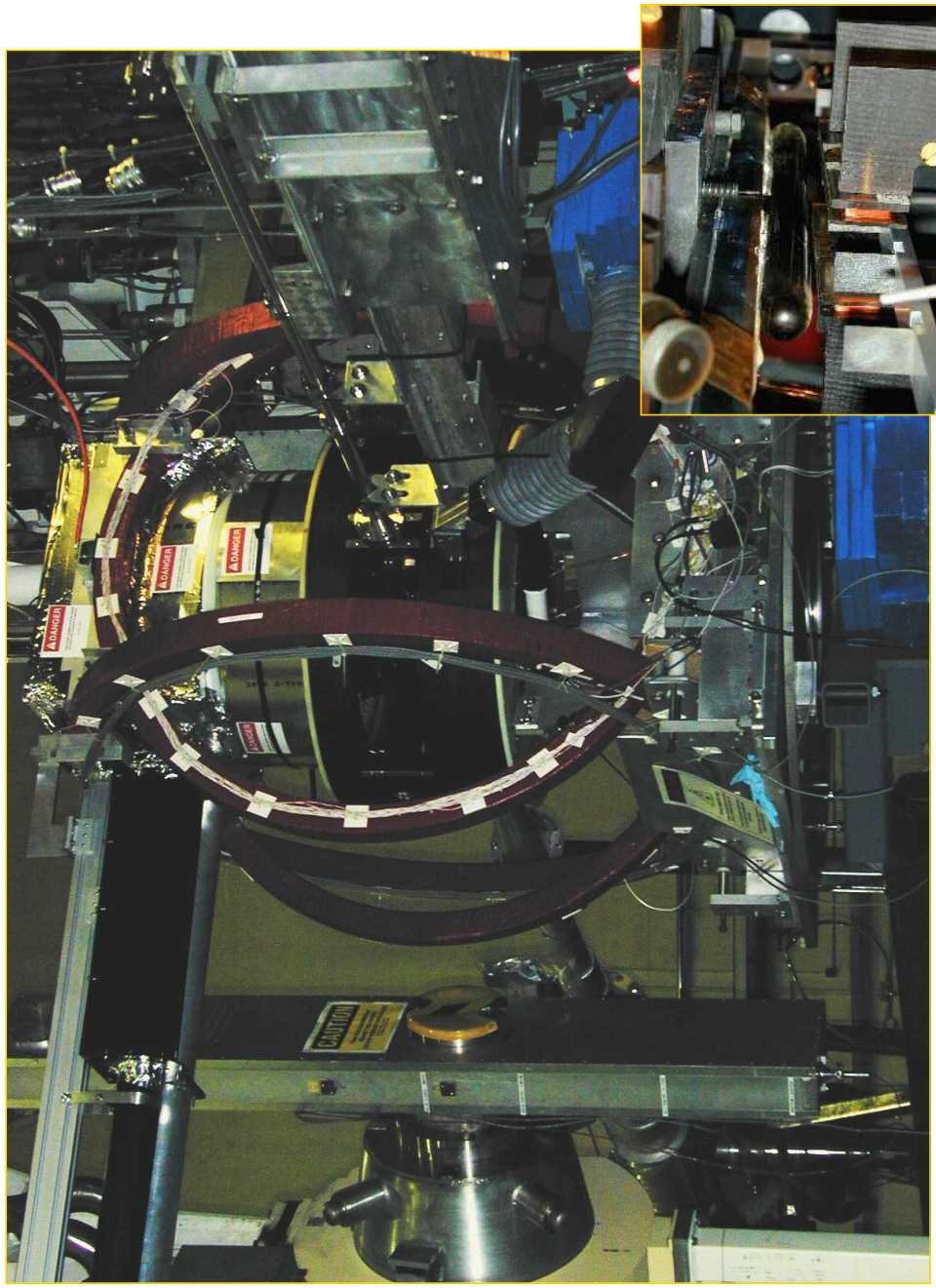


THE CELL

- Cell density: 7.5$\sim$10 amg (20 $^{\circ}$C).
- Maximum polarization: $\sim$40% (in beam)
- Cell lifetime: $\Gamma = \Gamma_{He} + \Gamma_{wall} + \Gamma_{beam} + \Gamma_{\Delta B}$
  $\sim (40)^{-1} = (744/[He])^{-1} \ (90)^{-1} \ (655/I)^{-1} \ (1700)^{-1}$ (hours)$^{-1}$
- Cell end windows 100μm, wall thickness $\sim$ 130 mm
- Polarization diffusion: $P_p - P_t \sim 1\%$



TARGET IN SITU



Asymmetry Analysis

Electron asymmetries

$$A_{raw} = \frac{N^+/Q^+ - N^-/Q^-}{N^+/Q^+ + N^-/Q^-}$$

$$A_{\parallel,\perp} = \frac{A_{raw}}{f P_b P_t}$$

^{3}He asymmetries

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

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

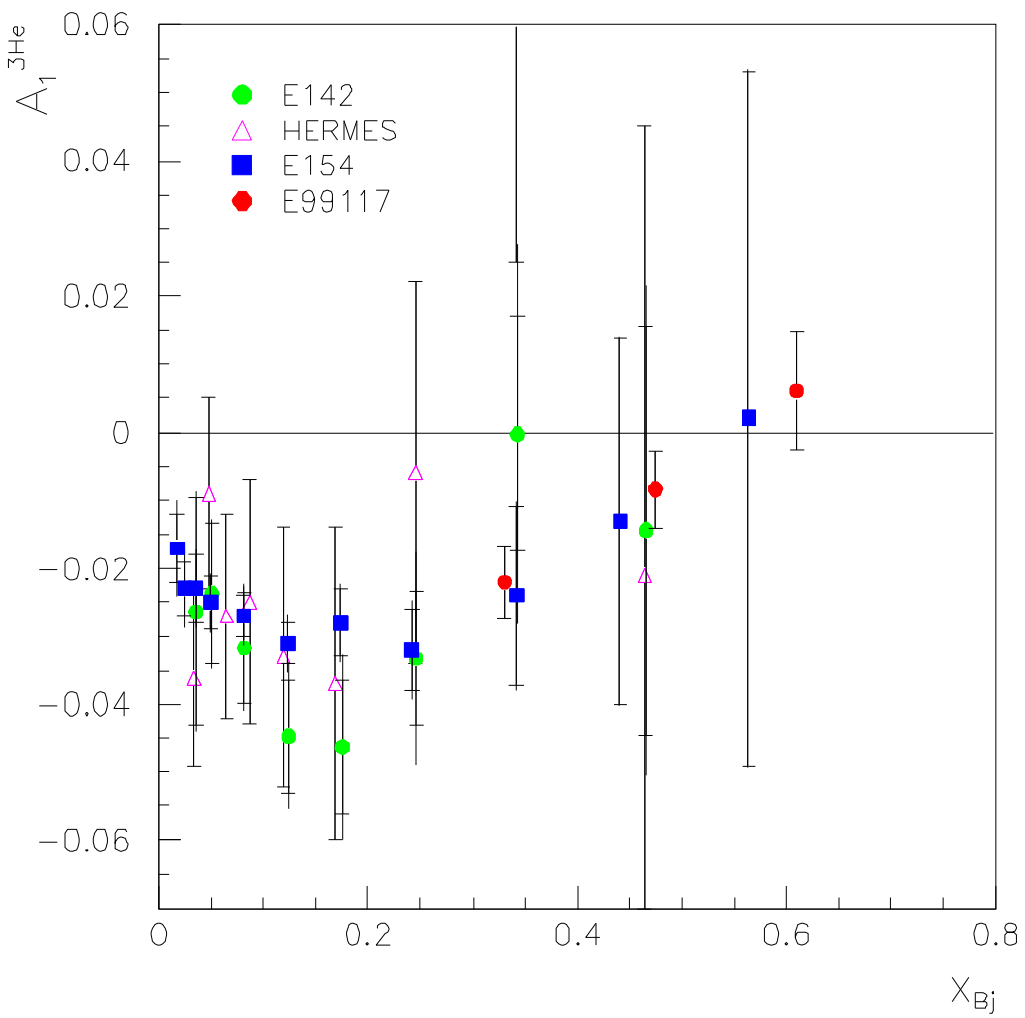
$$g_1(x,Q^2) = \frac{F_1(x,Q^2)}{D'}\left[A_\parallel + \tan(\theta/2)\cdot A_\perp\right]$$

$$g_2(x,Q^2) = \frac{F_1(x,Q^2)}{2D'y\sin\theta}\left[\frac{E+E'\cos\theta}{E'} A_\perp - \sin\theta\cdot A_\parallel\right]$$

Radiative Correction

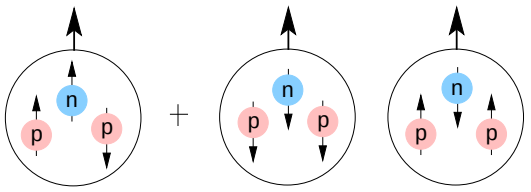
From ^{3}He to Neutron

$A_1^{^3He}$ *Results*



From ^{3}He to Neutron

POLARIZED ^{3}HE AS AN EFFECTIVE NEUTRON TARGET



S state ($\sim$88.2%) + D state ($\sim$9.8%) + S' state ($\sim$1.4%)

Effective nucleon polarizations:

$$P_n = 86\%,\ P_p = -2.8\%$$

$$\vec{^3He} \approx \vec{n}$$

Effective Neutron Target

From ^{3}He to Neutron

CONVOLUTION APPROACH

Ciofi degli Atti et.al., Phys.Rev.**C48**, 968(1993); Phys. Lett., **B404**, 223(1997)

- ^3He consists S, S', D
- Three body calculation using Fadeev wavefunction

$$\tilde{g_1^n} = \frac{1}{\rho_n}(g_1^{^3\mathrm{He}} - 2\rho_p g_1^p)$$

$$\tilde{A_1^n} = \frac{W_1^{^3\mathrm{He}}}{W_1^n}\frac{1}{\rho_n}(A_1^{^3\mathrm{He}} - 2\frac{W_1^p}{W_1^{^3\mathrm{He}}}\rho_p A_1^p)$$

COMPLETE ANALYSIS

F. Bissey et. al., hep-ph/0109069

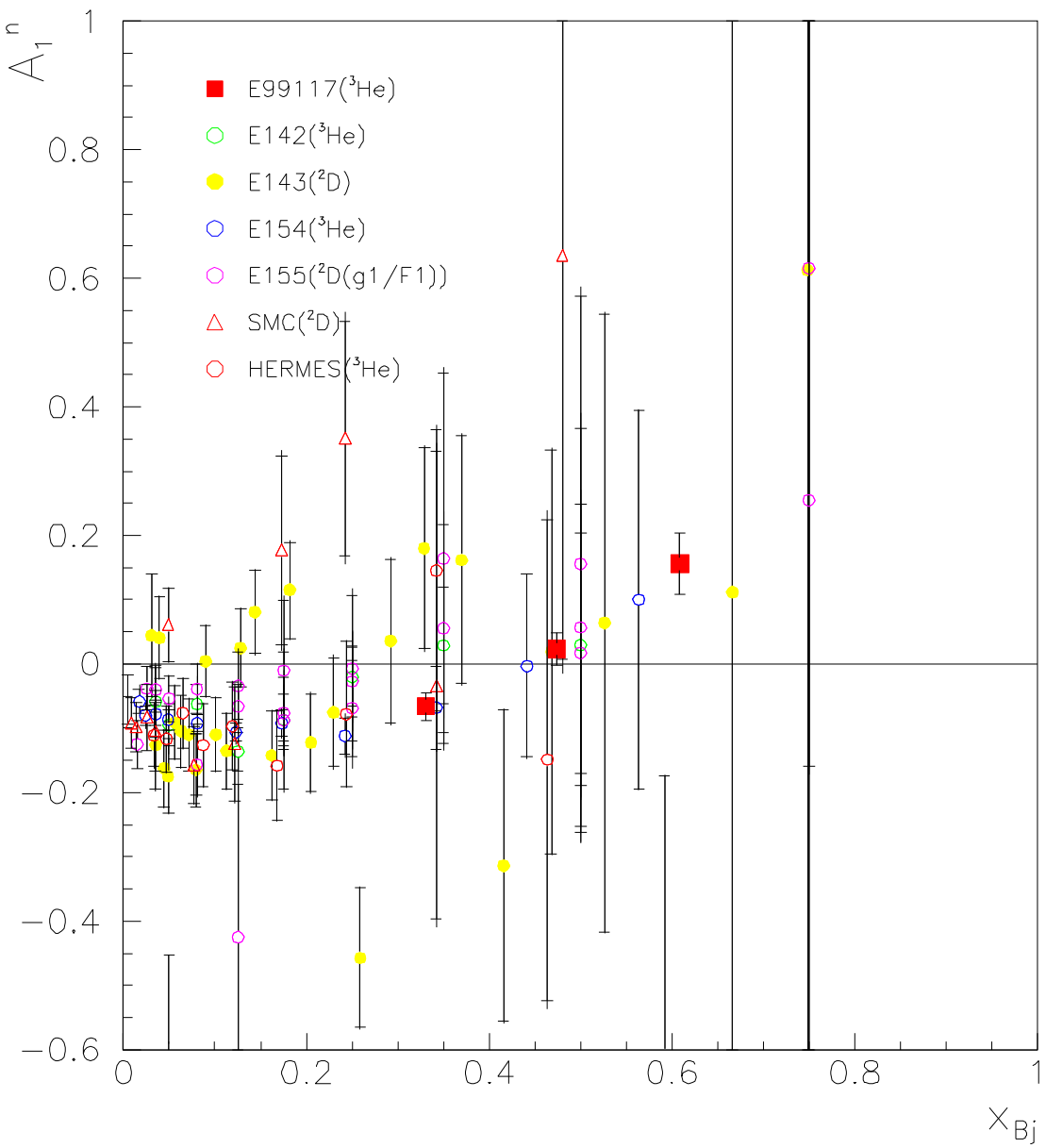
- S, S', D, Δ isobar in ^3He wavefuntion

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

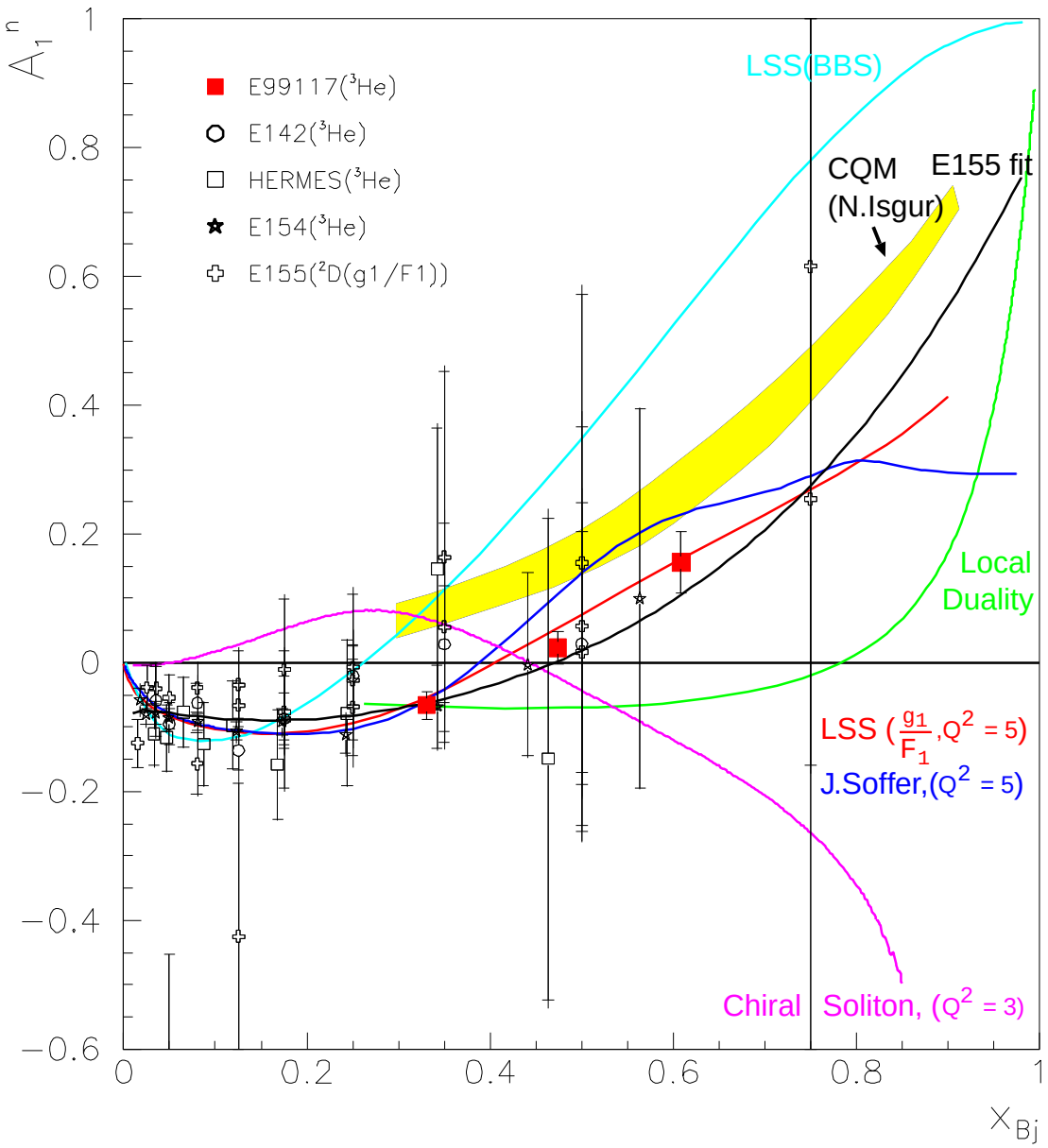
OTHER INPUTS

- $R(x, Q^2)$ - E143, K. Abe et. al., hep-ex/9808028
- F_2^p, F_2^D - NMC95, M. Arneodo et. al., hep-ph/9509406,
- EMC $F_2^{^3He} = \mathcal{R}^{^3He}(2F_2^p + F_2^n)$, $F_2^n = \frac{F_2^D}{\mathcal{R}^D} - F_2^p$, W. Melnitchouk, pri.comm.
- Effective nucleon polarization P_p, P_n
  - $P_p = -0.028 \pm 0.004$,$P_n = 0.86 \pm 0.02$
    C. Ciofi degli Atti et.al.,*Phys.Rev.***C48**, R968(1993)
  - $P_p = -0.021$,$P_n = 0.879$
    PEST5, F. Bissey et. al., *Phys. Rev.* **C64**, 024004(2001)
  - $P_p = -0.018$,$P_n = 0.897$
    CD-Bonn2000 + TM (Tucson-Melbourne) 3NF, A. Nogga, Ph.D. thesis, (2001)
- A_1^p - E155 fit, P. L. Anthony et. al., *Phys.Lett.***B493**:19-28,(2000) (hep-ph/0007248)
- g_2, using g_2^{ww} (E155x)

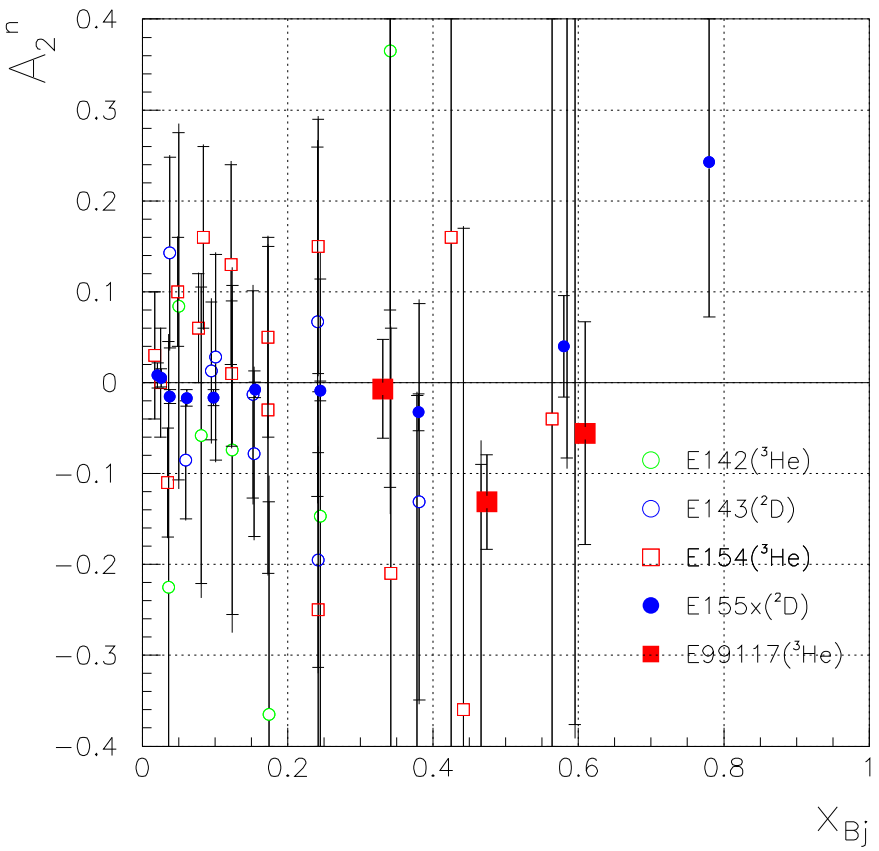
A_1^n *Results*


A_1^n
E99117(^{3}He)
E142(^{3}He)
E143(^{2}D)
E154(^{3}He)
E155(^{2}D(g1/F1))
SMC(^{2}D)
HERMES(^{3}He)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
0.2
0.4
0.6
0.8
1
X_{Bj}

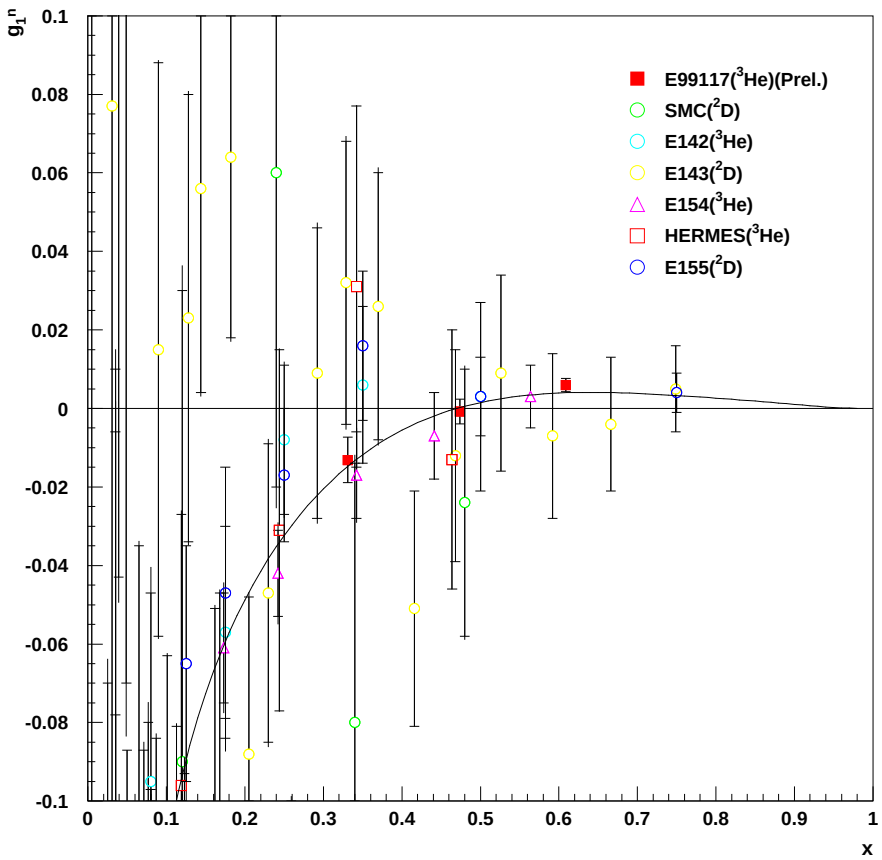
A_1^n Compared to theory



Preliminary Result (cont.)

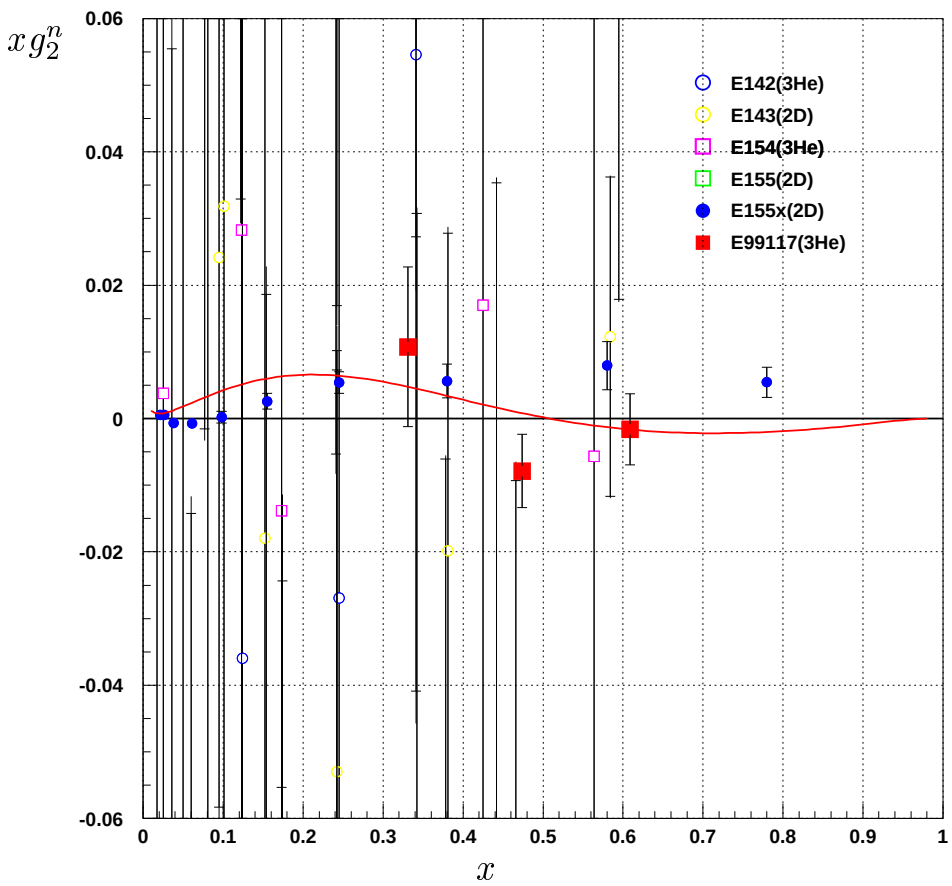


Preliminary Result (cont.)

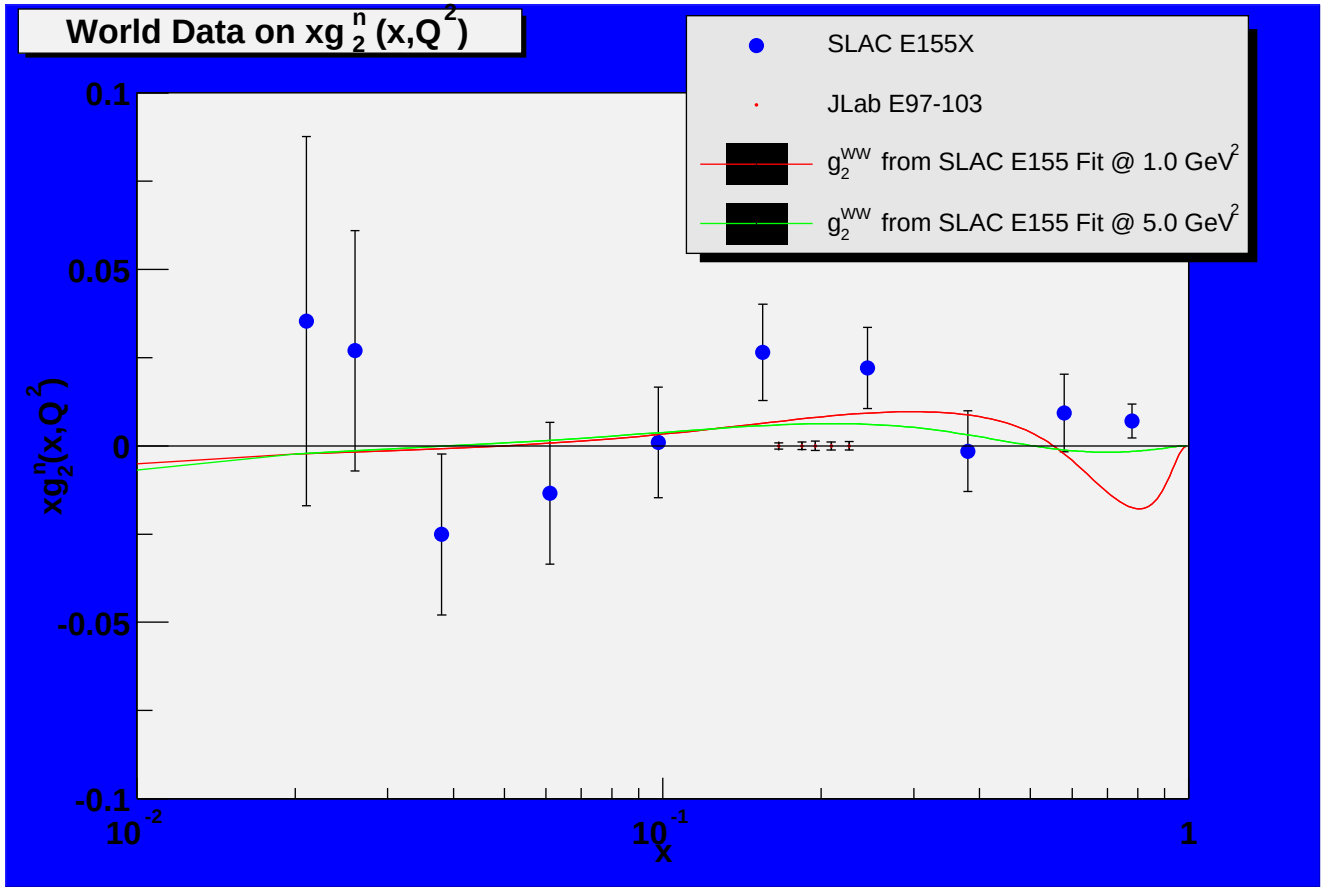


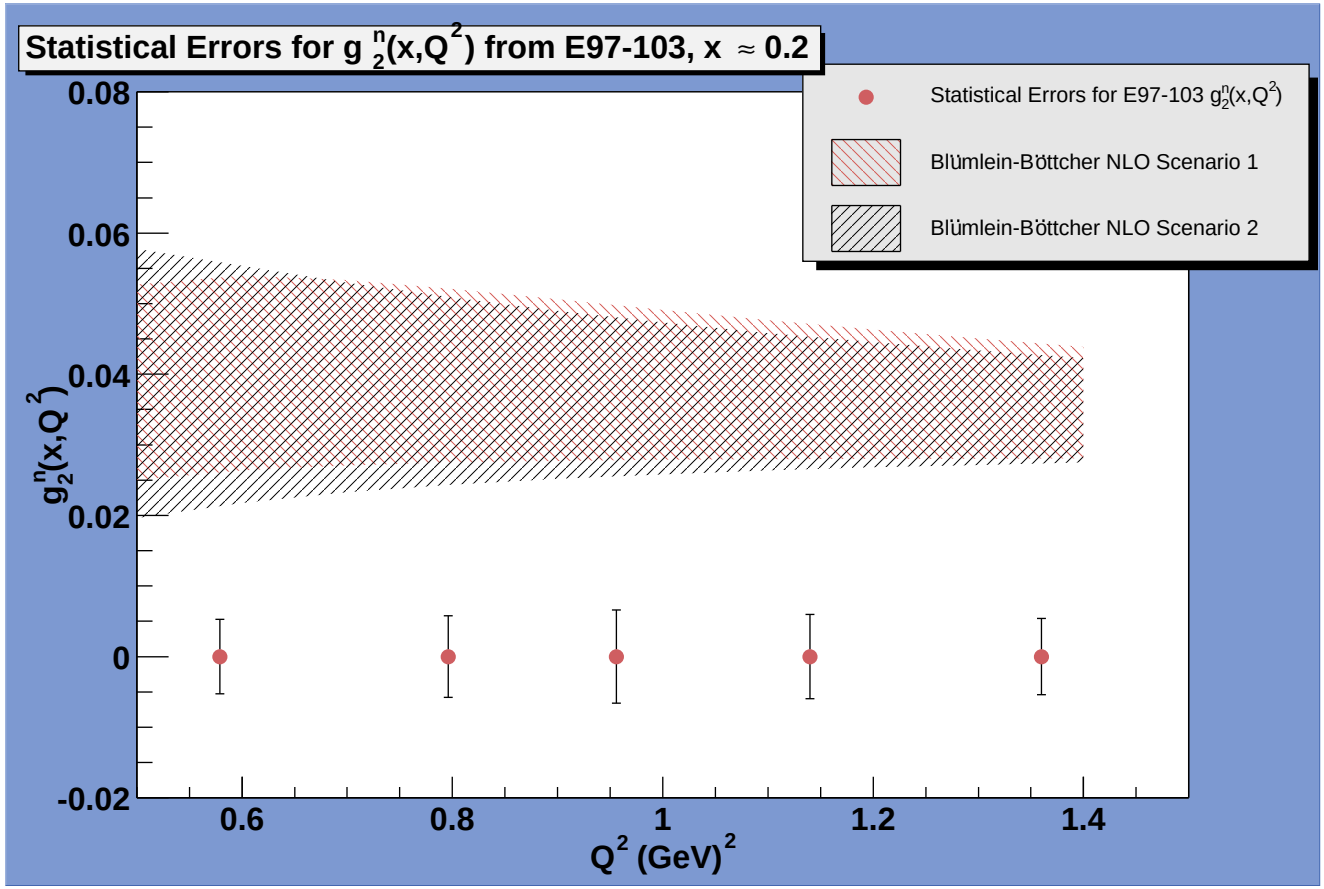
black solid curve: $g_1^n = \frac{g1}{F1}$(E155)$\times F_1$(NMC95) at $Q^2 = 4.0$ (GeV/c)^2

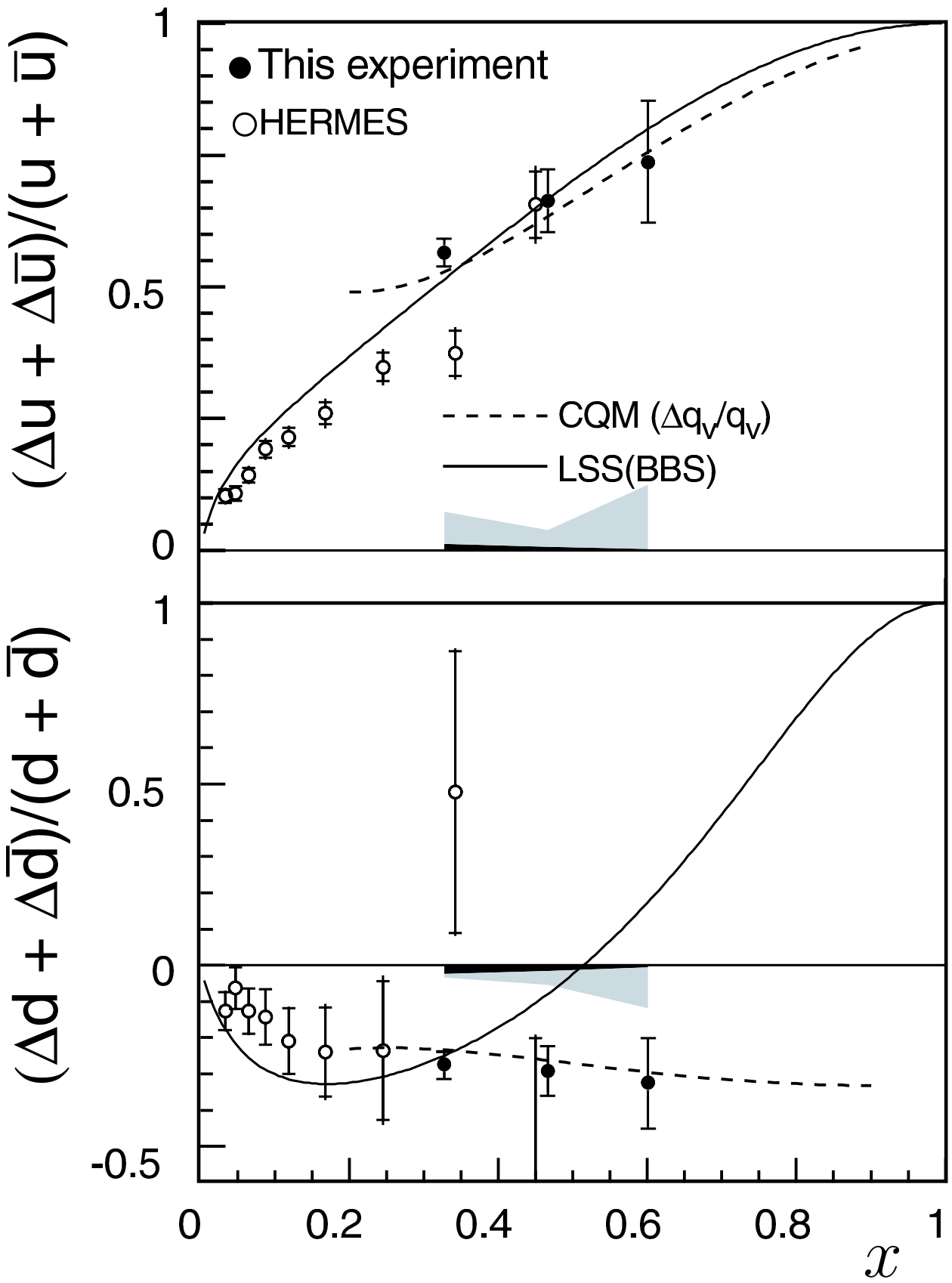
Preliminary Result (cont.)



red solid curve: xg_2^{WW} from E155 fit, at $Q^2 = 4.0$ (GeV/c)^2


World Data on $xg_2^n(x,Q^2)$
SLAC E155X
JLab E97-103
g_2^{WW} from SLAC E155 Fit @ 1.0 GeV^2
g_2^{WW} from SLAC E155 Fit @ 5.0 GeV^2
0.1
0.05
0
-0.05
-0.1
$xg_2^n(x,Q^2)$
10^{-2}
10^{-1}
1
x


Statistical Errors for g 2n(x,Q2) from E97-103, x ≈ 0.2
Statistical Errors for E97-103 g2n(x,Q2)
Blümlein-Böttcher NLO Scenario 1
Blümlein-Böttcher NLO Scenario 2
0.08
0.06
0.04
0.02
0
-0.02
g2n(x,Q2)
0.6
0.8
1
1.2
1.4
Q2 (GeV)2


This experiment
HERMES
CQM ($\Delta q_v/q_v$)
LSS(BBS)
$(\Delta u + \Delta\bar{u})/(u + \bar{u})$
$(\Delta d + \Delta\bar{d})/(d + \bar{d})$
1
0.5
0
-0.5
0.2
0.4
0.6
0.8
x

Summary

EXPERIMENT E99-117

- Provides the first precise data of A_1^n and g_1^n at $x > 0.4$;
- Data on A_2^n, g_2^n also available;
- Check current understanding of nucleon spin;
- Help to understand constituent quark models;
- Provide valuable input to other models, PDFs.

E97-103

- Most Precise DIS measurement of $g_2^n(x,Q^2)$
- Sign, magnitude and Q^2 evolution of higher twist terms of theoretical interest
- Radiative Correction analysis still ongoing