Future Studies of Nucleon Spin Structure with 12 GeV Electron Beams at Jefferson Laboratory

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Workshop on

Gluon Polarization in the Nucleon

U. Illinois Champaign-Urbana

16-17 June 2008

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ΔG at JLab?

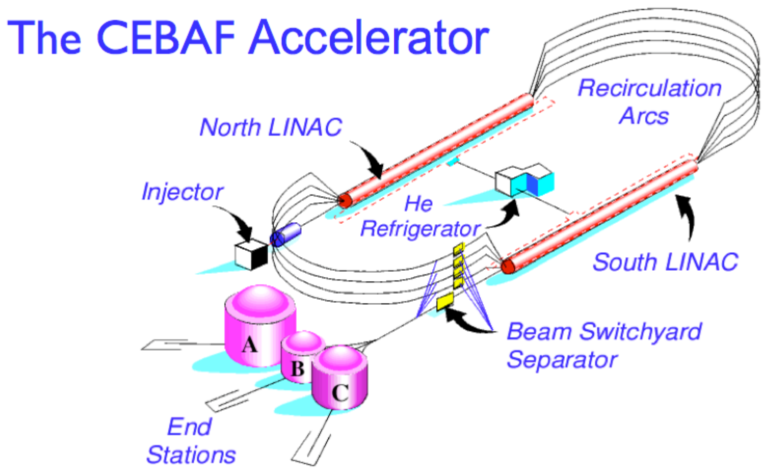
$$\frac{1}{2} = \frac{\Delta\Sigma}{2} + \Delta G + L_z$$

Known

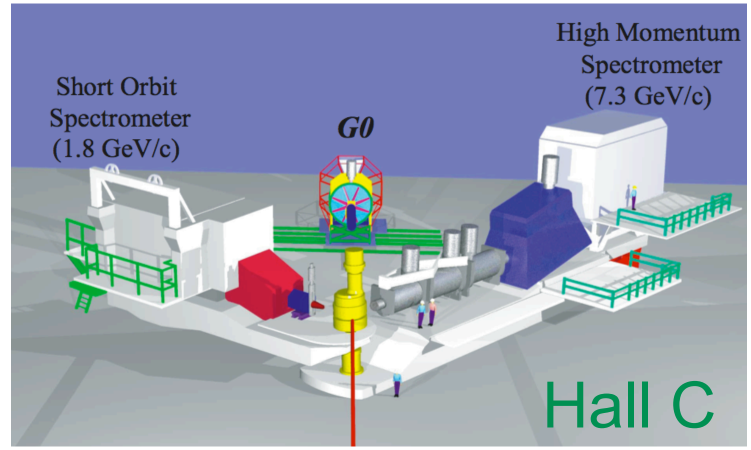
Could be constrained by QCD evolution but this requires an understanding of higher twist at moderate Q^2

Transverse momentum dependent distributions are sensitive to quark orbital angular momentum

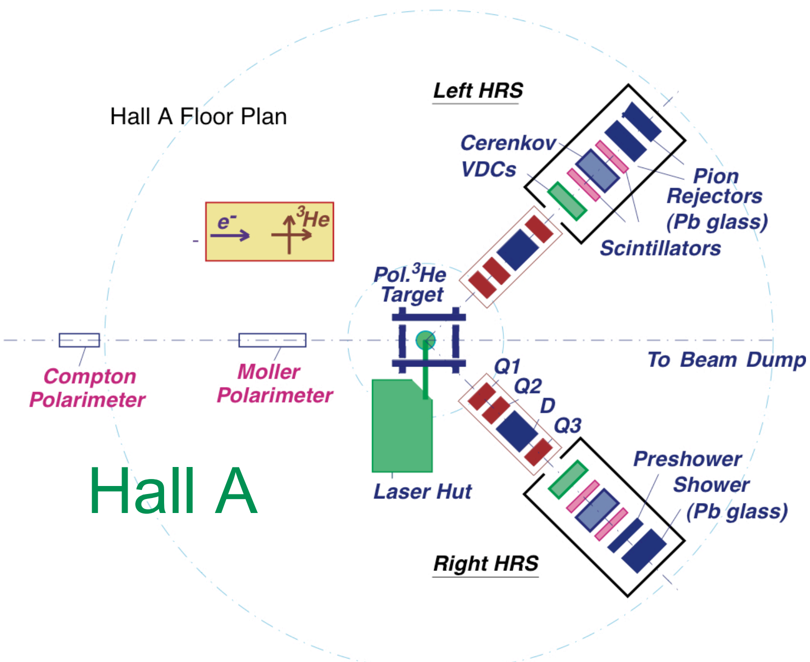
JLab



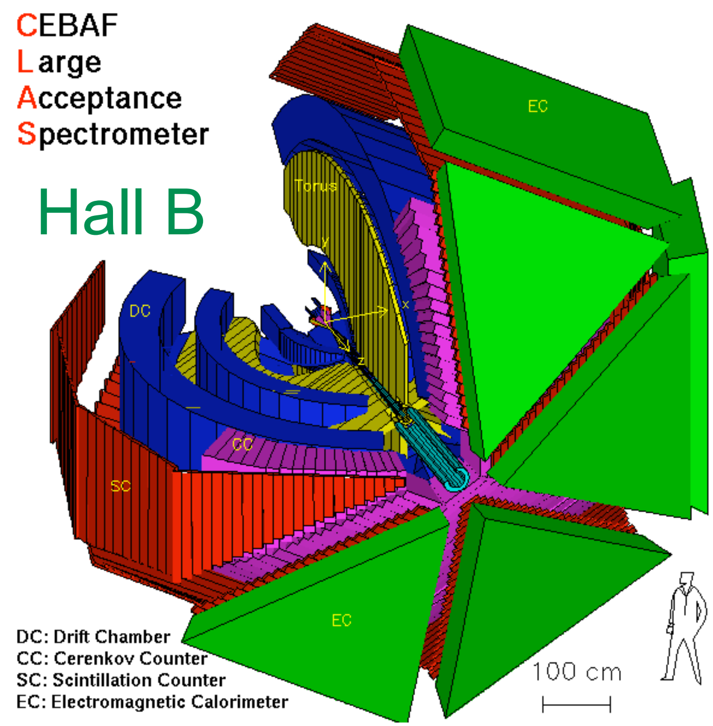
The CEBAF Accelerator
Recirculation Arcs
North LINAC
Injector
He Refrigerator
South LINAC
Beam Switchyard Separator
A
B
C
End Stations



Short Orbit Spectrometer (1.8 GeV/c)
G0
High Momentum Spectrometer (7.3 GeV/c)
Hall C

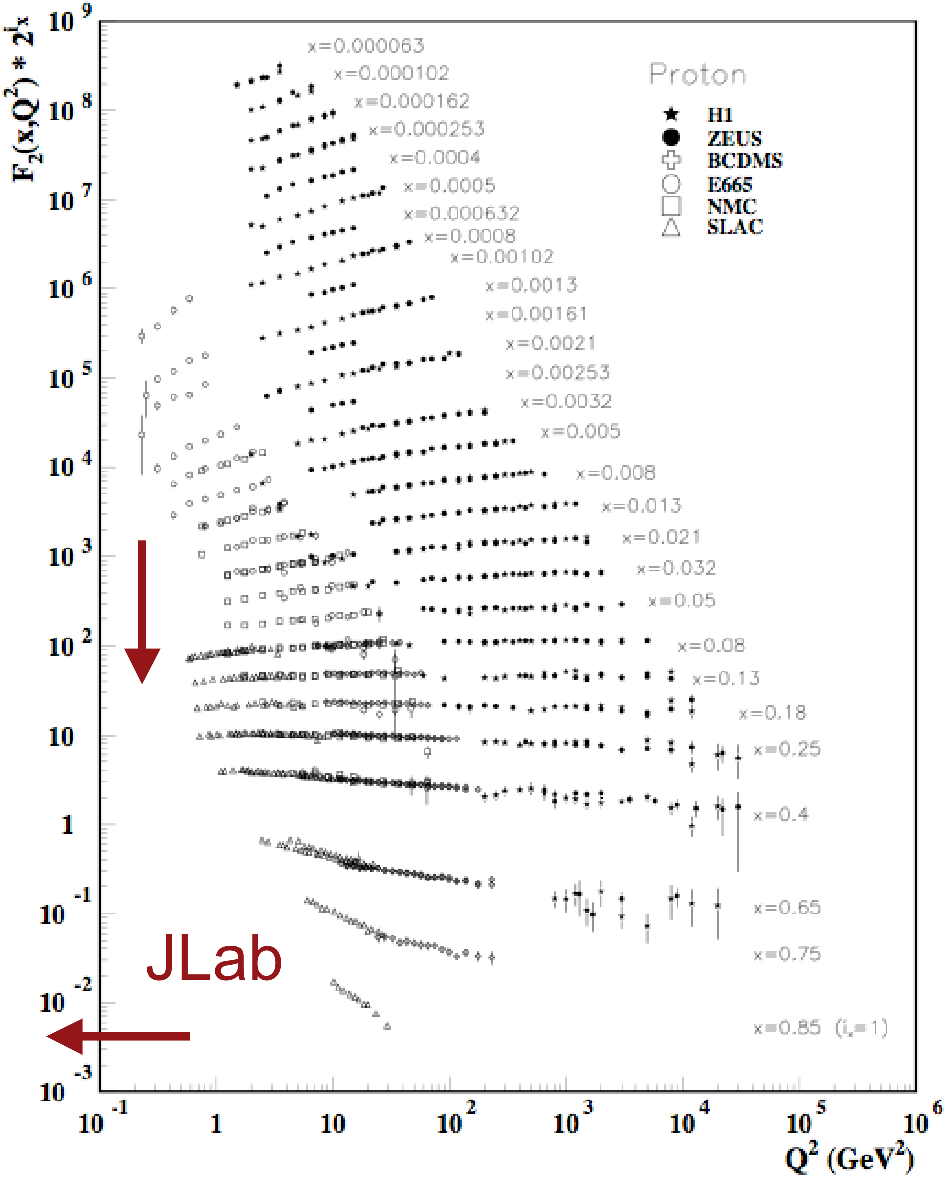


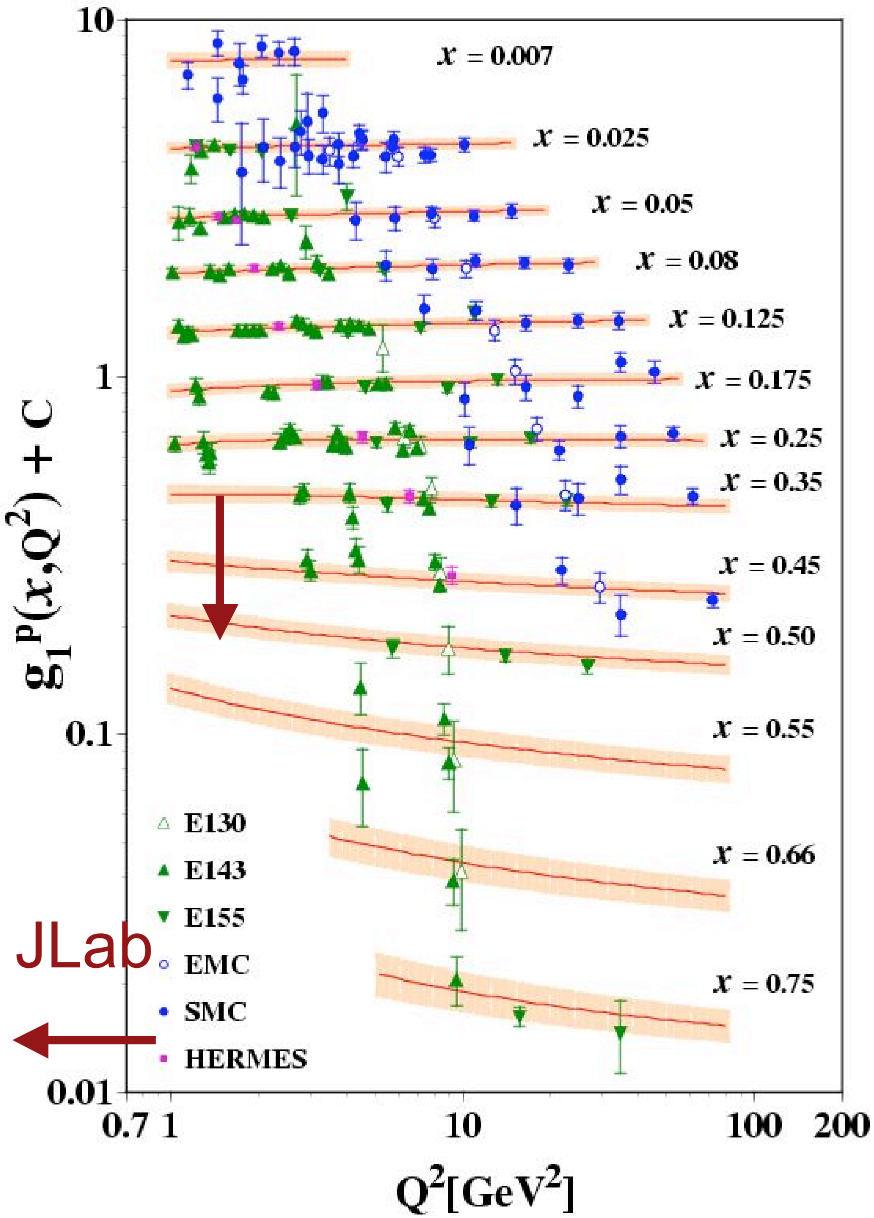
Hall A Floor Plan
Left HRS
Cerenkov
VDCs
Pion Rejectors (Pb glass)
Scintillators
e⁻
³He
Pol.³He Target
Compton Polarimeter
Moller Polarimeter
To Beam Dump
Q1
Q2
D
Q3
Preshower
Shower (Pb glass)
Laser Hut
Right HRS
Hall A



CEBAF
Large
Acceptance
Spectrometer
Hall B
EC
Torus
DC
CC
SC
EC
DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter
100 cm

$F_2(x,Q^2)$ and $g_1(x,Q^2)$





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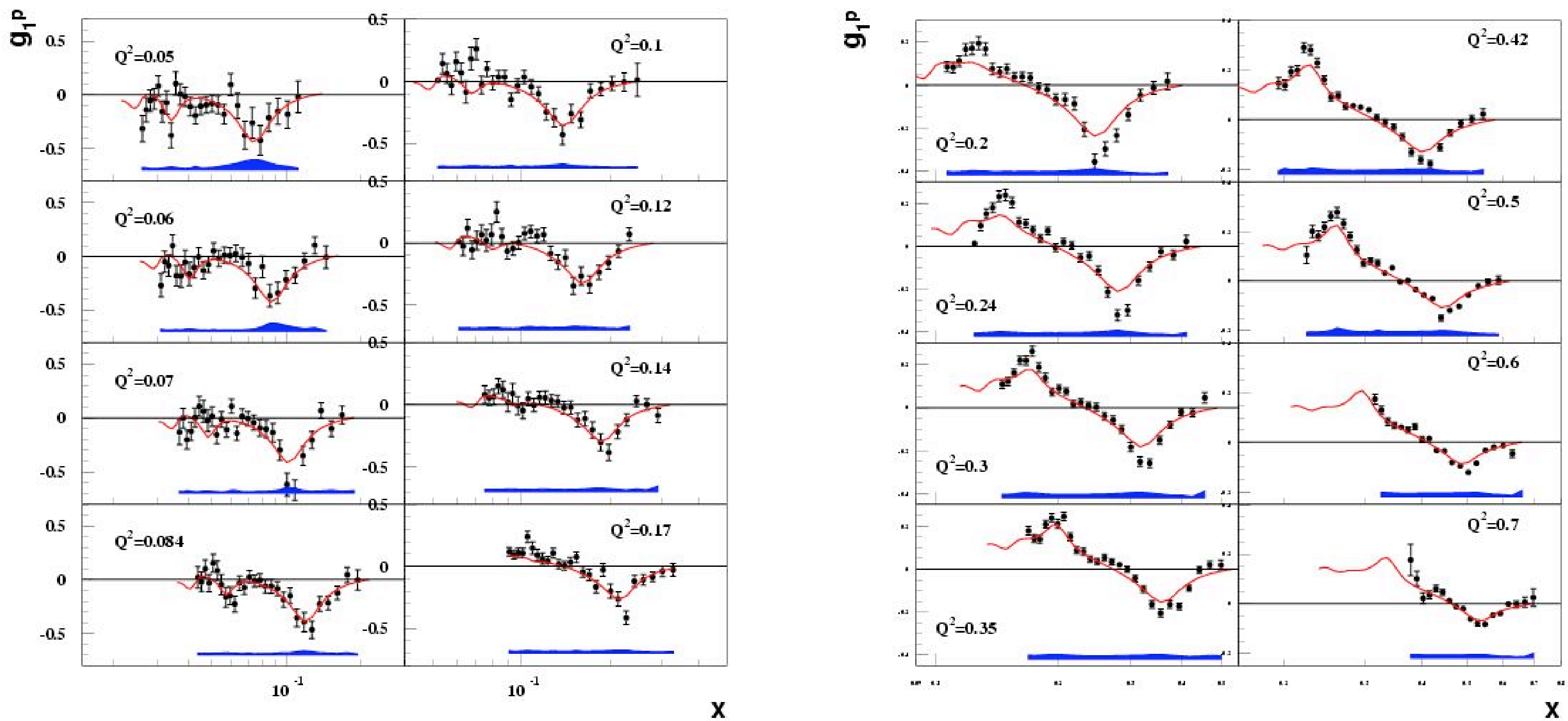
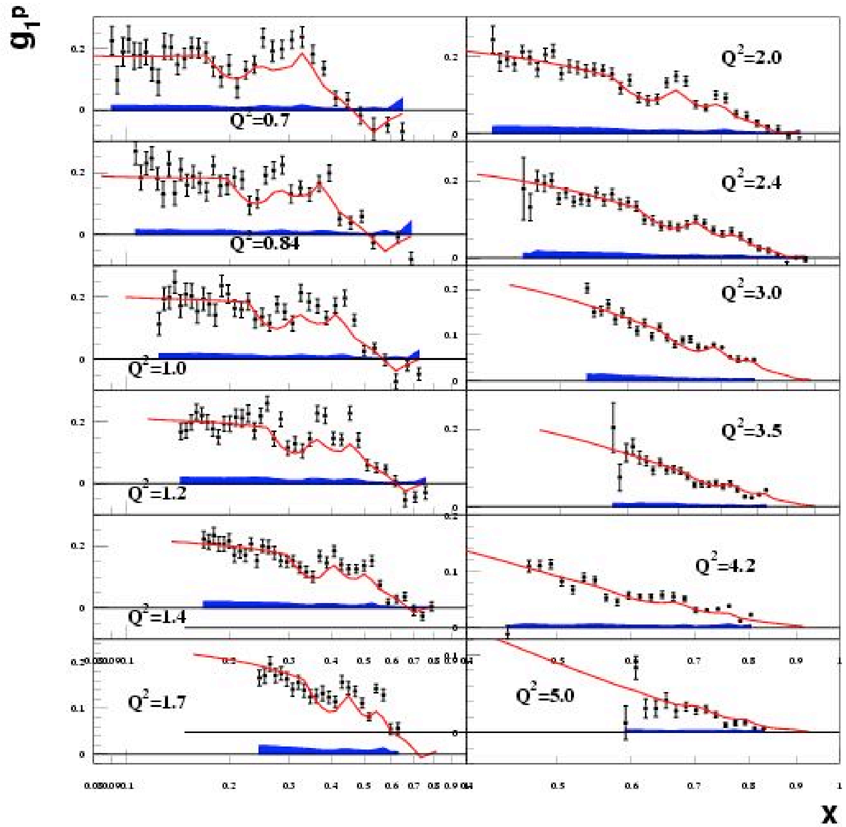
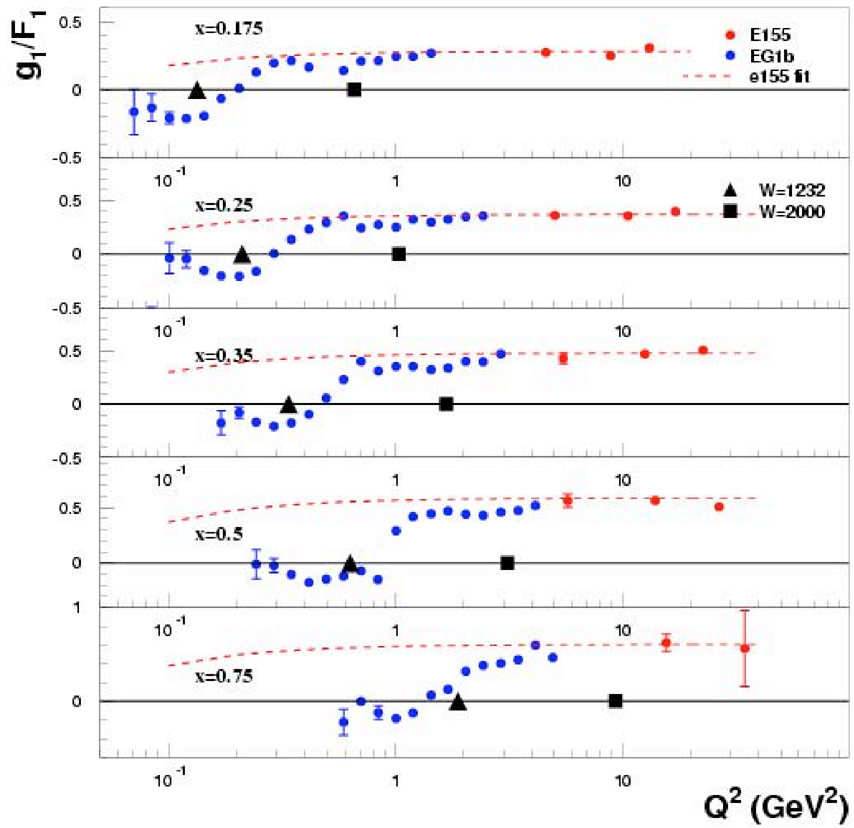
CLAS EG1 g_1^p (Q^2<0.7)



- At low Q^2 the Δ resonance drives g_1 negative
- Extensive x-range at fixed Q^2 allows integration over x
- Red curve is the EG1 model used for radiative corrections

CLAS EG1 g_1^p (Q^2>0.7) & g_1/F_1





- At higher Q^2, g_1 becomes positive everywhere
- g_1/F_1 falls far below the DIS extrapolation at low Q^2
- Red curve is the EG1 model (dashed: DIS extrapolation)

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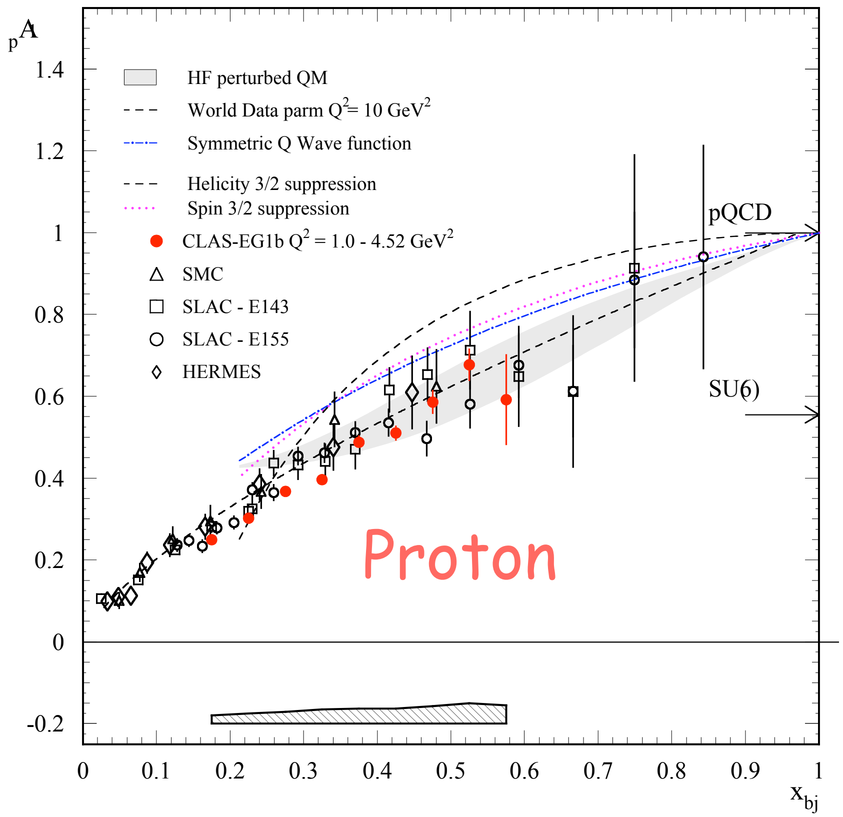
A_1 Data from EG1

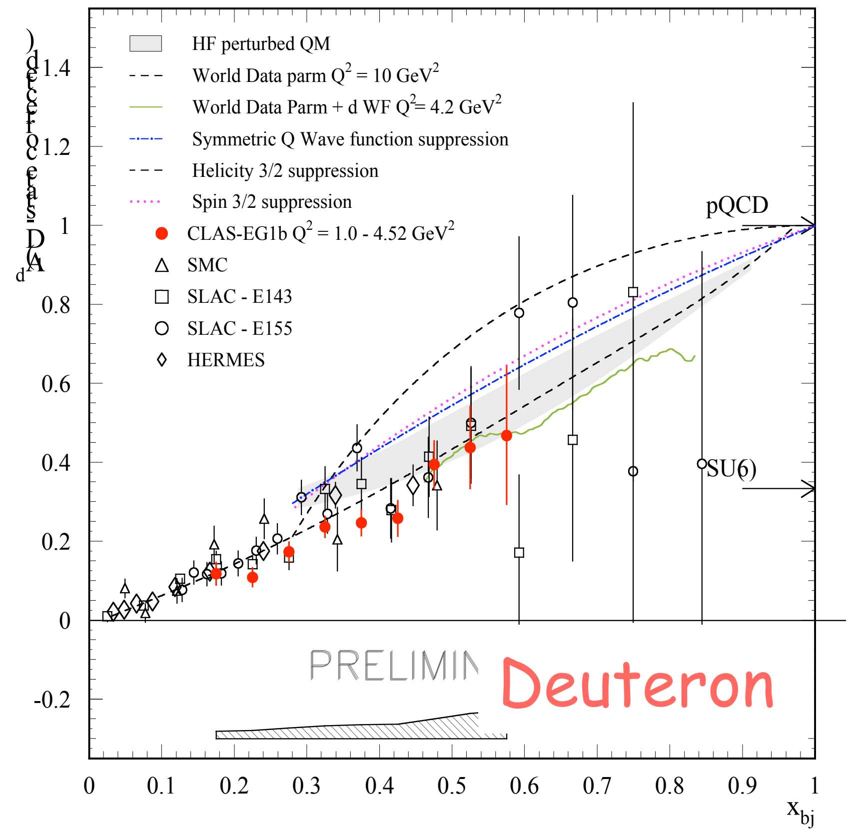
$\sim g_1/F_1$

Close and Melnitchouk, PRC **68**, 035210 (2003)

Isgur, PRD **59**, 034013 (2003)

W > 2; Q^2 > 1





Bjorken Sum & Higher Twist

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

$$\Gamma_2^{(n)} = \int_0^1 x^n g_2(x,Q^2)dx = \frac{1}{2}\frac{n}{n+1}(d_n - a_n), \quad n=2,4,\ldots,$$

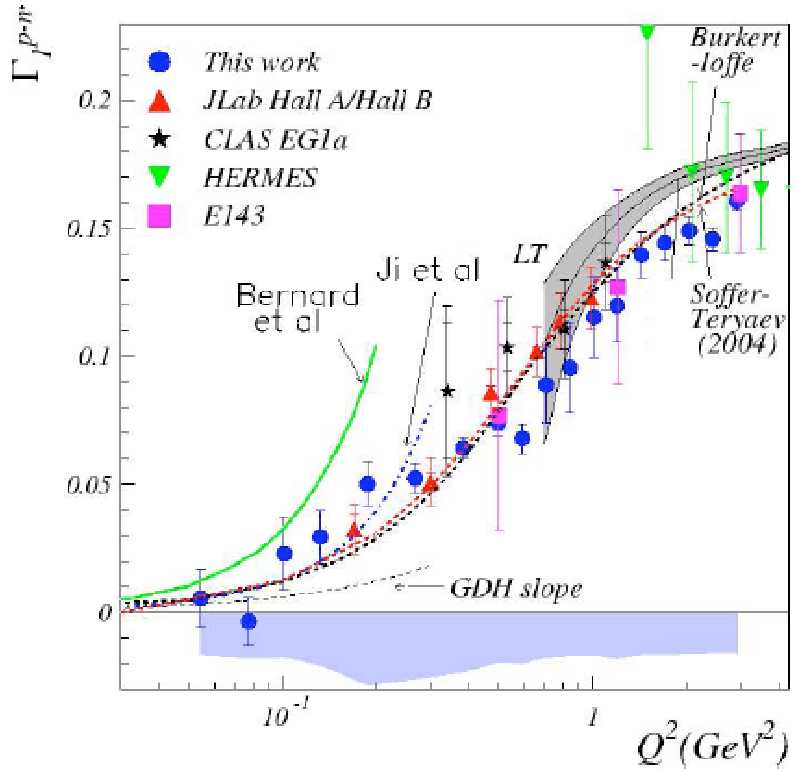
Bjorken Sum Rule:

CLAS: Deur

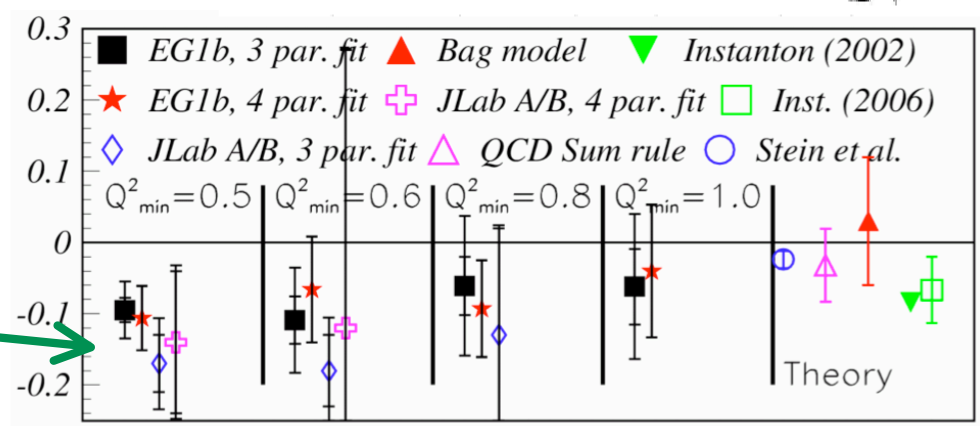
$$\Gamma_1^{p-n} = \frac{g_A}{6}\left[1 - \frac{\alpha_s}{\pi} - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.21\left(\frac{\alpha_s}{\pi}\right)^3\right] + \frac{\mu_4^{p-n}}{Q^2} + \ldots$$

$$\mu_4^{p-n} = \frac{M^2}{9}\left(a_2^{p-n} + 4d_2^{p-n} + 4f_2^{p-n}\right)$$

$$d_2^{p-n} = \int_0^1 dx\, x^2 \left(2g_1^{p-n} + 3g_2^{p-n}\right)$$



Fit Γ_1^{p-n} to powers of $1/Q^2$ and extract f_2^{p-n}



Higher Twist from g_1 in CLAS

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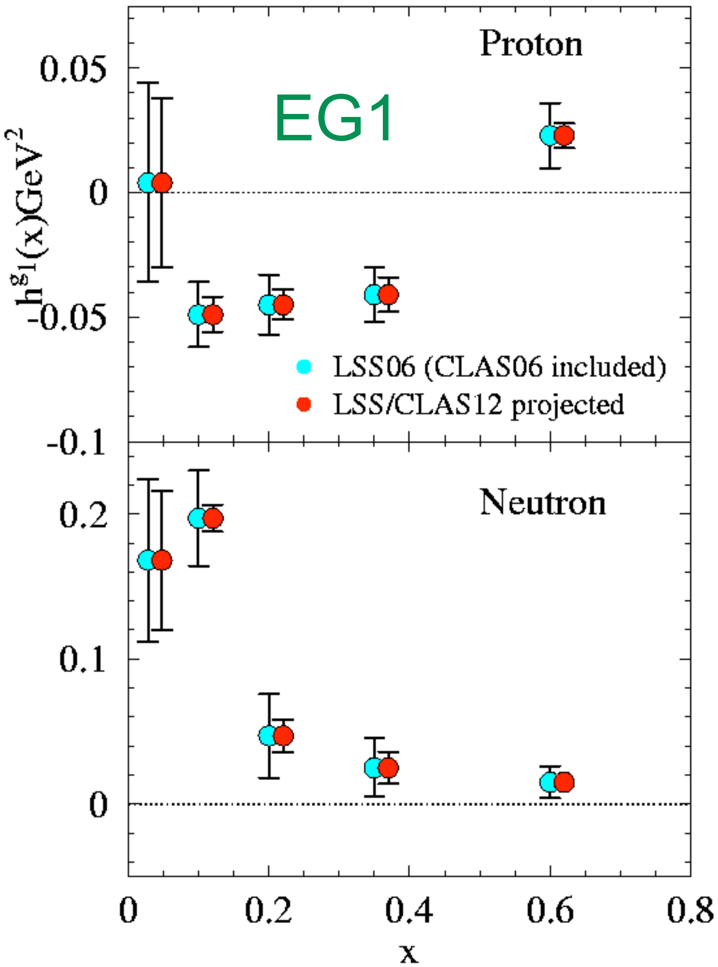
$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\text{exp}} F_1(x,Q^2)_{\text{exp}} = g_1(x,Q^2)_{\text{exp}} = g_1(x,Q^2)_{LT} + h^{g_1}(x)/Q^2$$



$$1 < Q^2 < 5\ \text{GeV}^2, \quad 2 < W < 3.5\ \text{GeV}$$

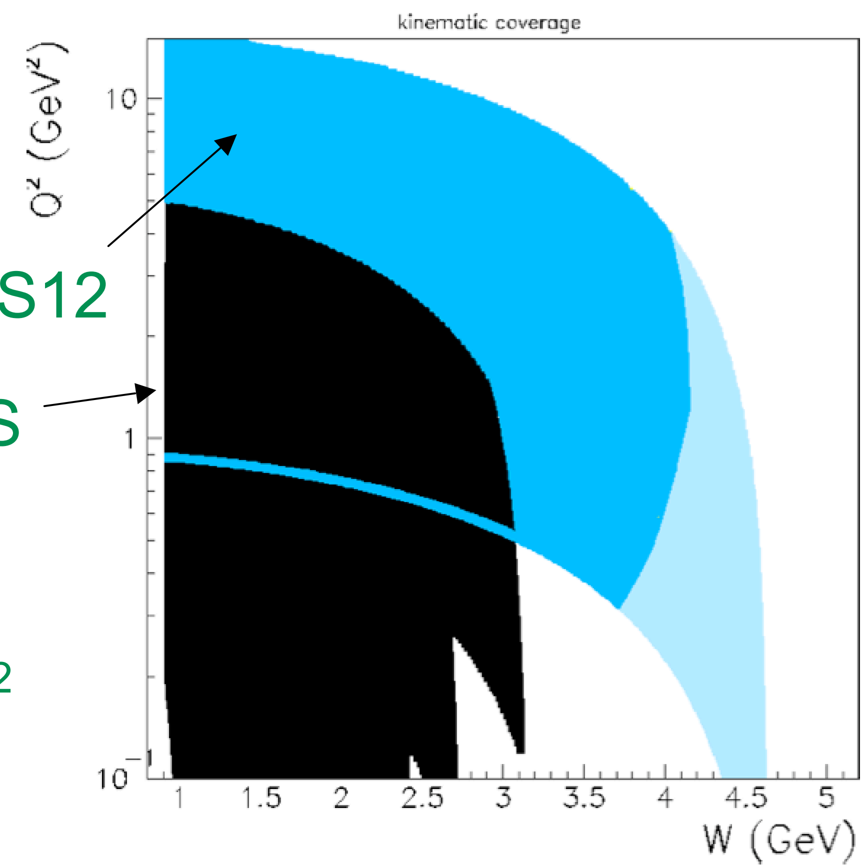
$$\int_0^1 dx h^{g_1}(x) = \frac{4}{9} M^2 (d_2 + f_2)$$

- F_1 from NMC fit to F_2 and 1998 SLAC fit to R
- g_1 (leading twist) from NLO fit at high Q^2
- h from fit to all data, especially CLAS in the pre-asymptotic region
- d_2: twist-3, f_2: twist-4

PR12-06-109

The Longitudinal Spin Structure of the Nucleon

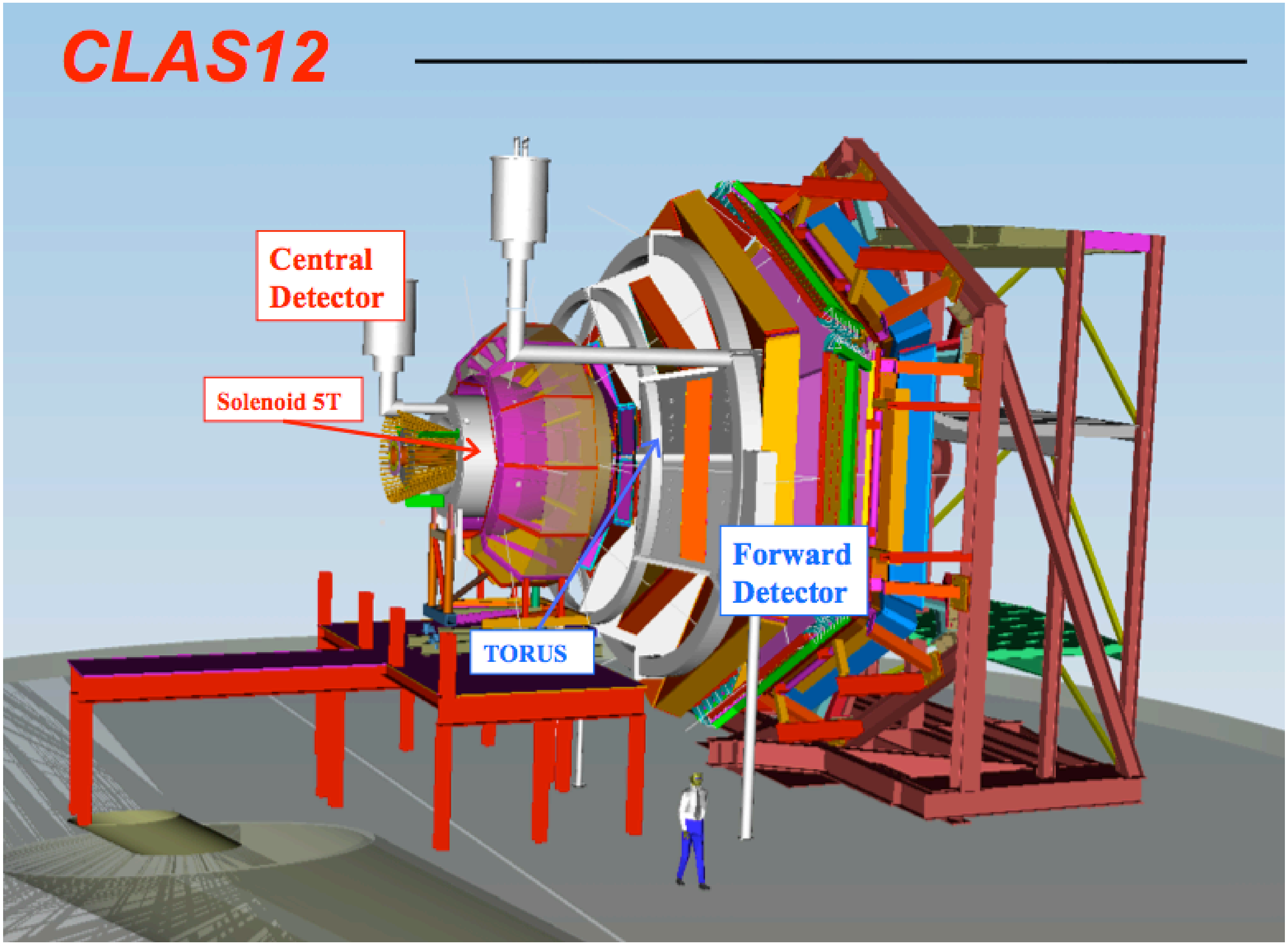
D. Crabb
A. Deur
V. Dharmawardane
T. Forest
K. Griffioen
M. Holtrop
S. Kuhn
Y. Prok
Hall B



80 Days	11 GeV
10 nA	$L=10^{35}/cm^2/s$
$0.1<x<0.8$	$0.4<Q^2<12$ GeV^2

NH_3 and ND_3 polarized long.

JLab CLAS12


CLAS12
Central Detector
Solenoid 5T
TORUS
Forward Detector

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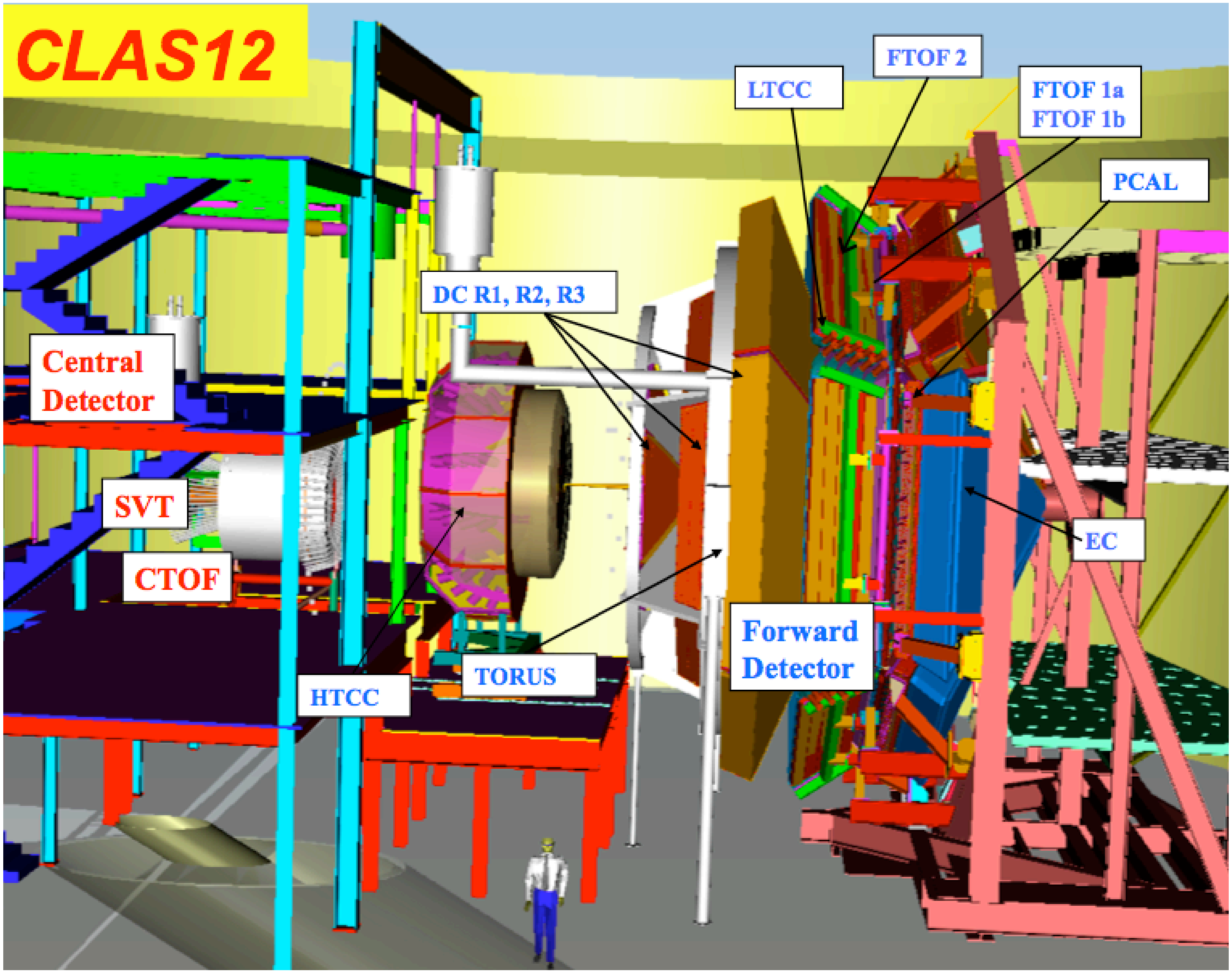
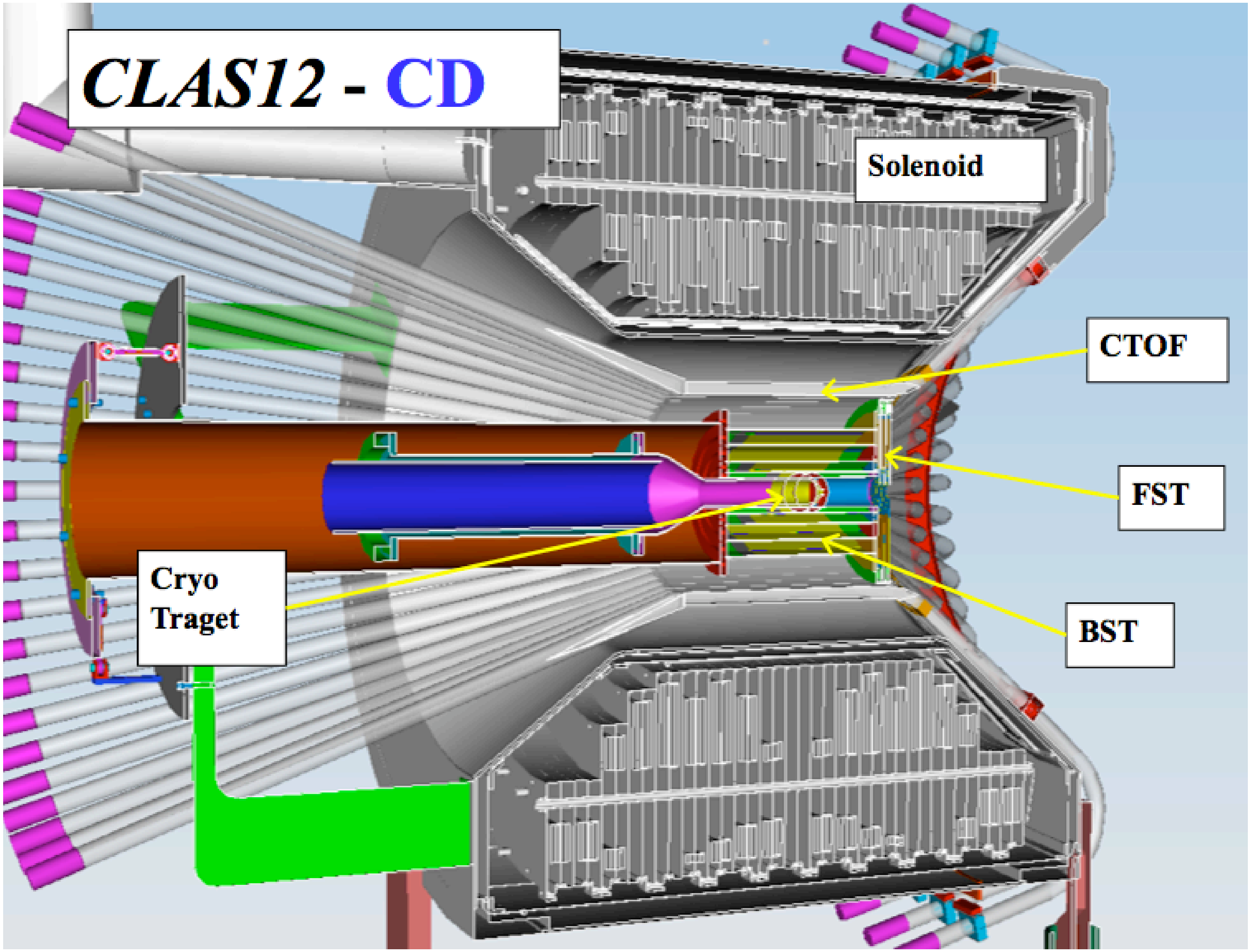
CLAS12 Exploded View

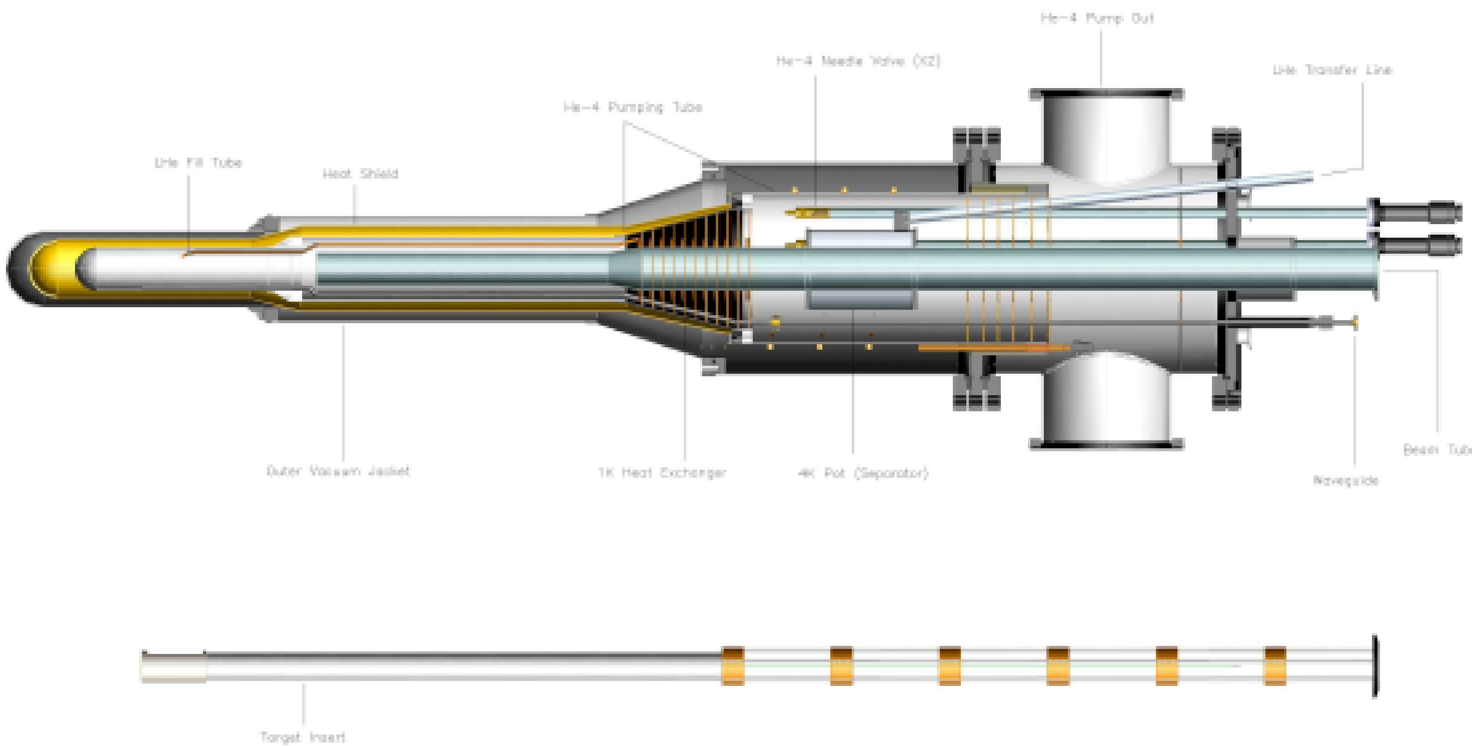


CLAS12 Target Region



Polarized Target

NH_3 (80%), ND_3(40%) or ^{6}LiD(25%) target, dynamically polarized along beam direction in 1K horizontal cryostat. Holding field supplied by Central Detector Solenoid



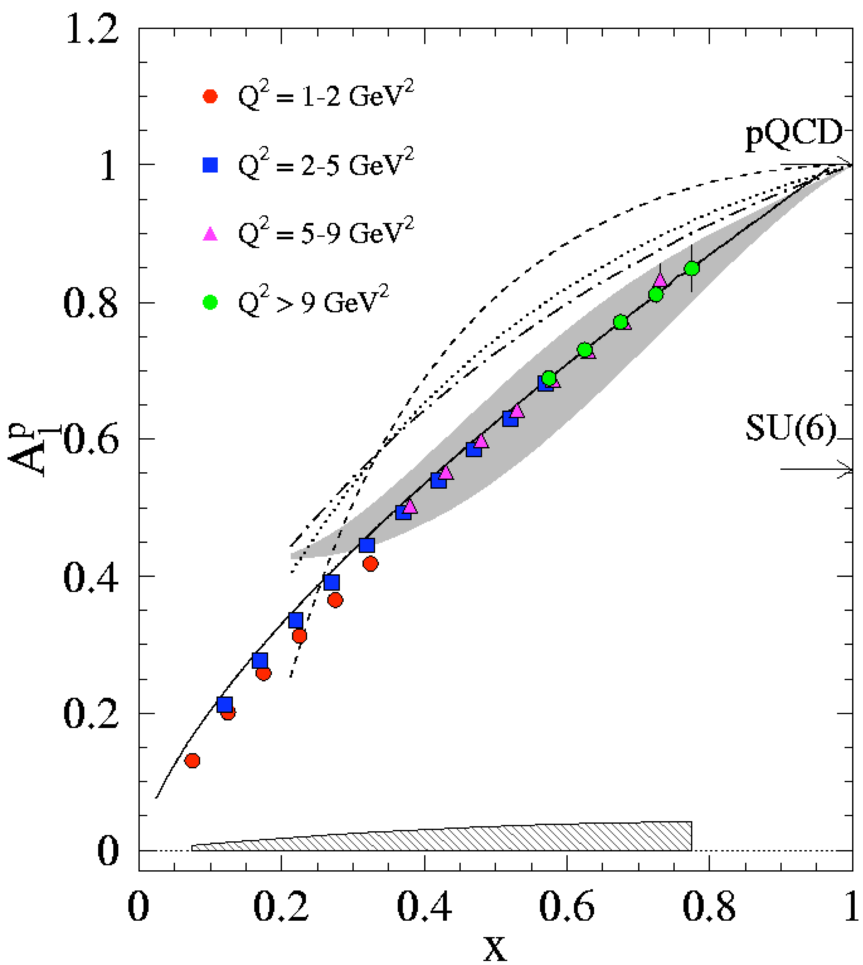
Presently being designed by UVa (Don Crabb), MIT (Yelena Prok) and Jefferson Lab. Part of CLAS12 base equipment.

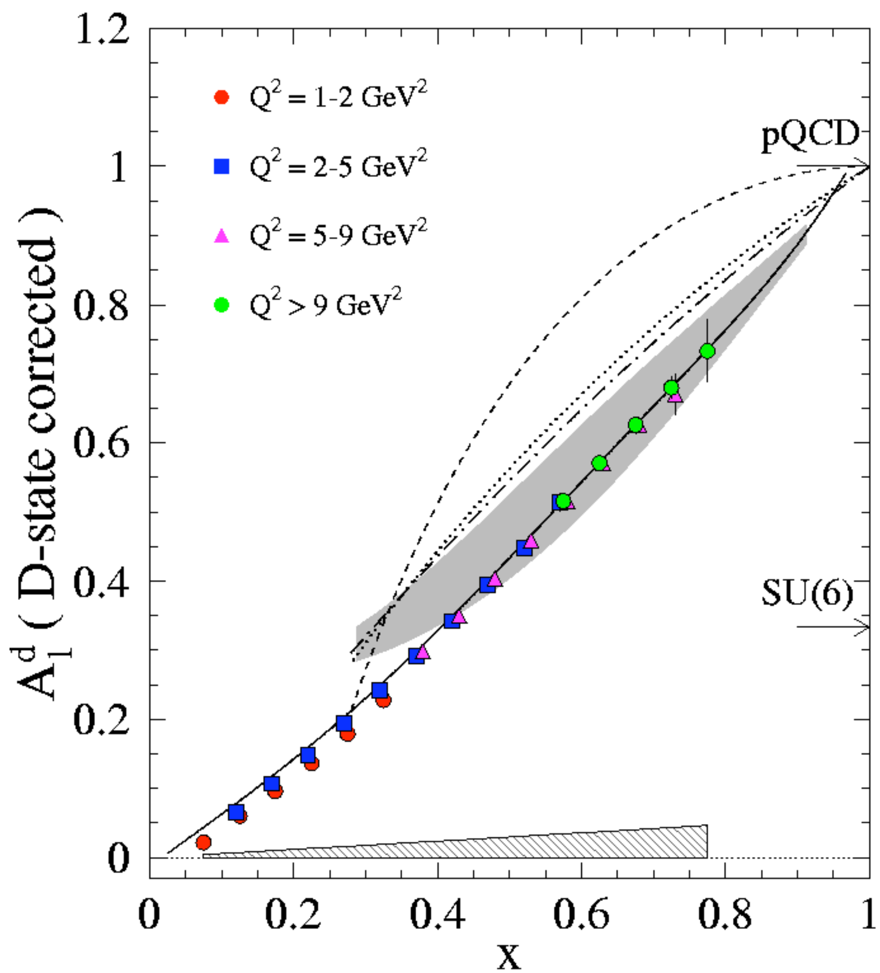
CLAS12 A_1

Proton

W > 2; Q^2 > 1

Deuteron





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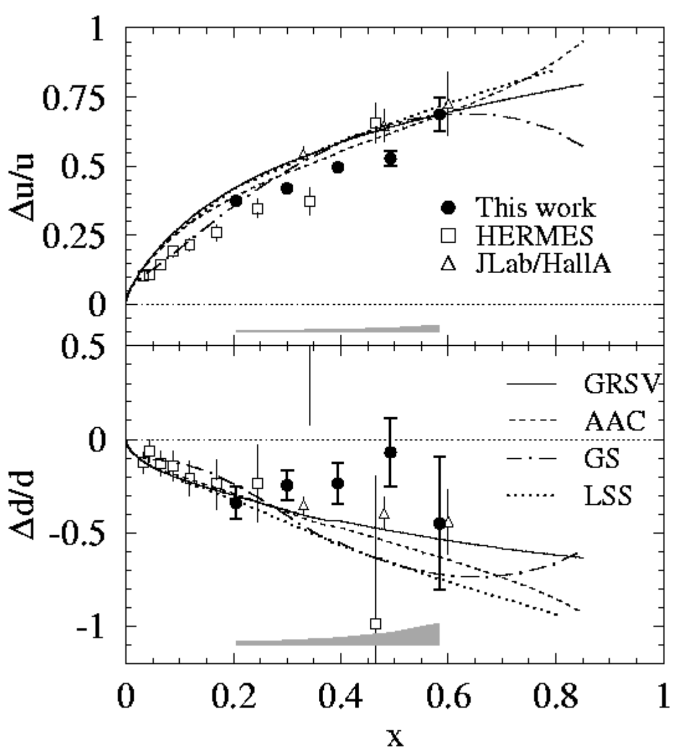
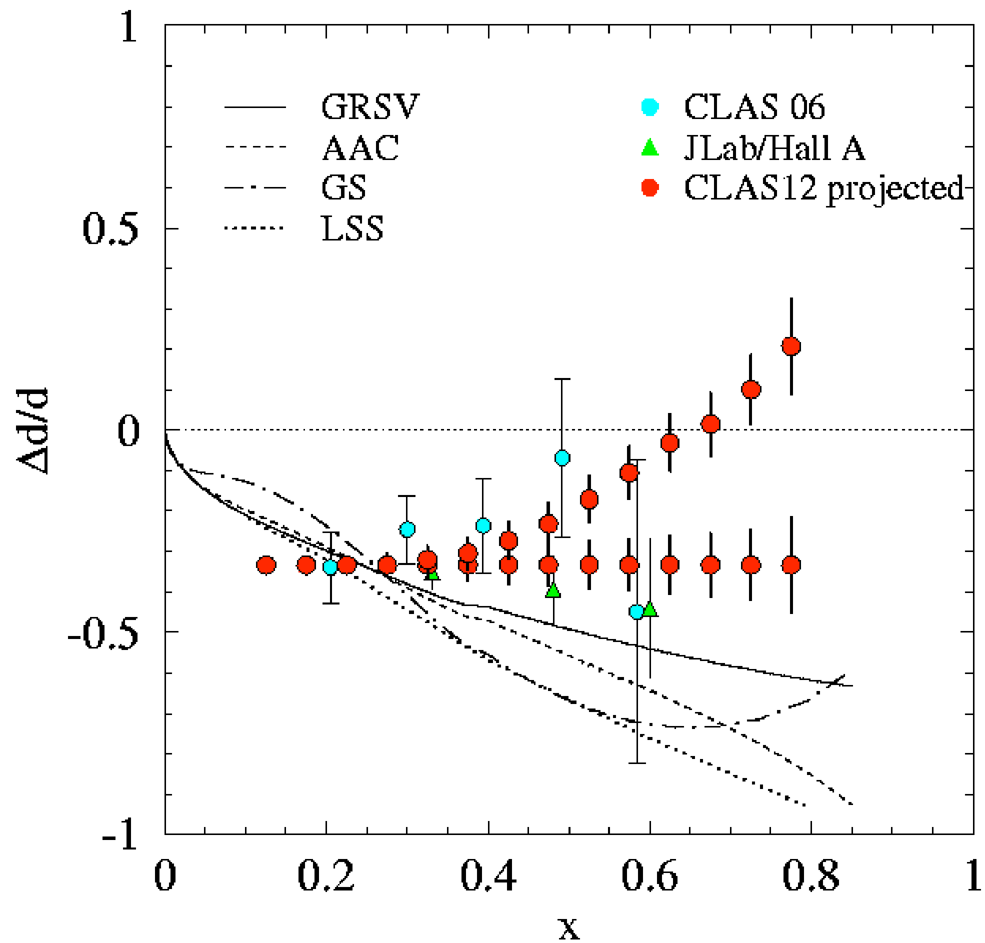
CLAS12 Δu & Δd

$$A_1(x,Q^2) = \frac{\sum e_i^2 \Delta q_i(x,Q^2)}{\sum e_i^2 q_i(x,Q^2)}$$

Existing Data



Simulated Data for EG12
Extracted from A_1^p, A_1^d and d/u



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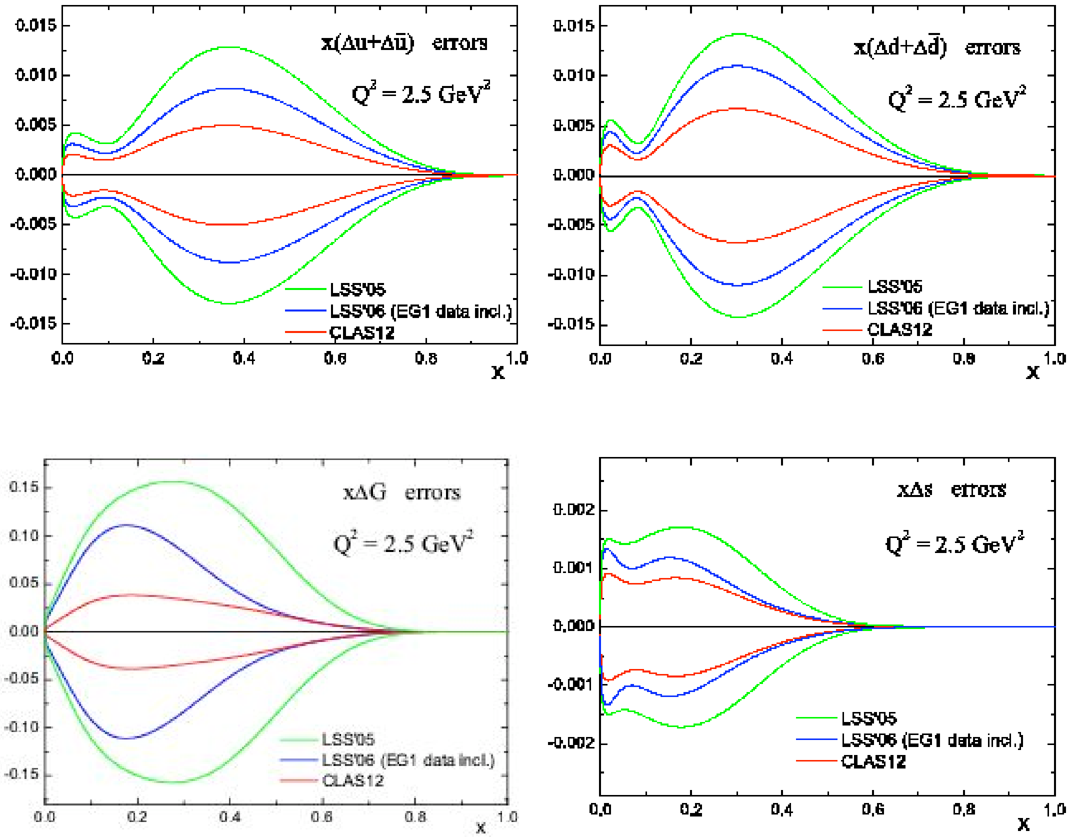
PDFs and CLAS



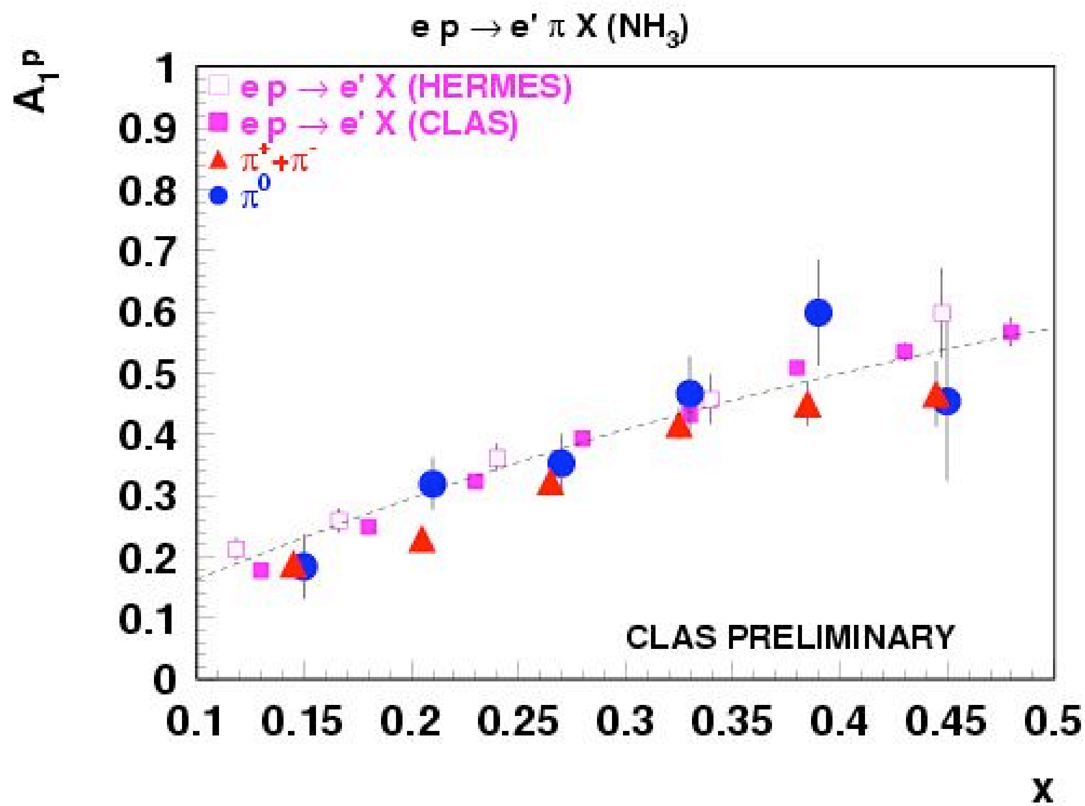
- Error envelopes for PDFs from LSS05 global analysis (green)
- CLAS EG1 data significantly improve errors on Δu, Δd, Δx and ΔG (blue)
- CLAS EG12 (12 GeV upgrade) will especially improve ΔG (red)

CLAS SIDIS

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_{q'} e_{q'}^2 q'(x,Q^2) D_{q'}^h(z,Q^2)}$$

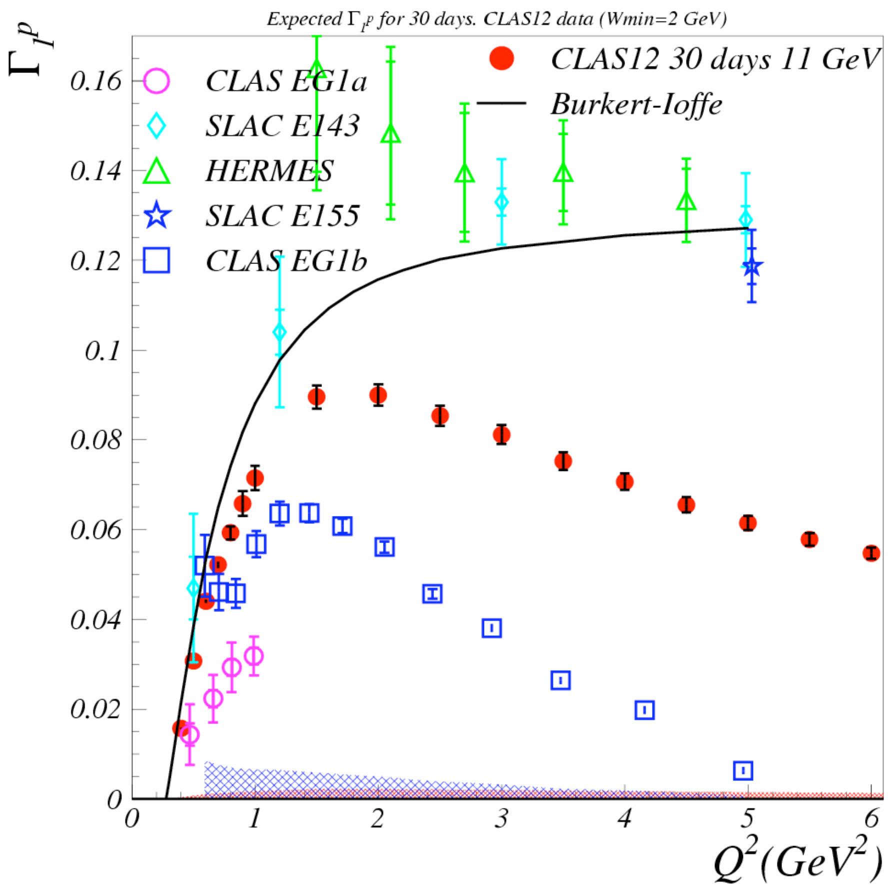
- Existing EG1 data show that factorization works remarkably well

- g_1/F_1 for inclusive, $\pi^+ + \pi^-$, and π^0 are consistent with each other in the range $0.4 < z < 0.7$, as expected in LO with factorization and current fragmentation dominance.
- No significant z-dependence seen for $0.3 < z < 0.7$; only weak p_T dependence.

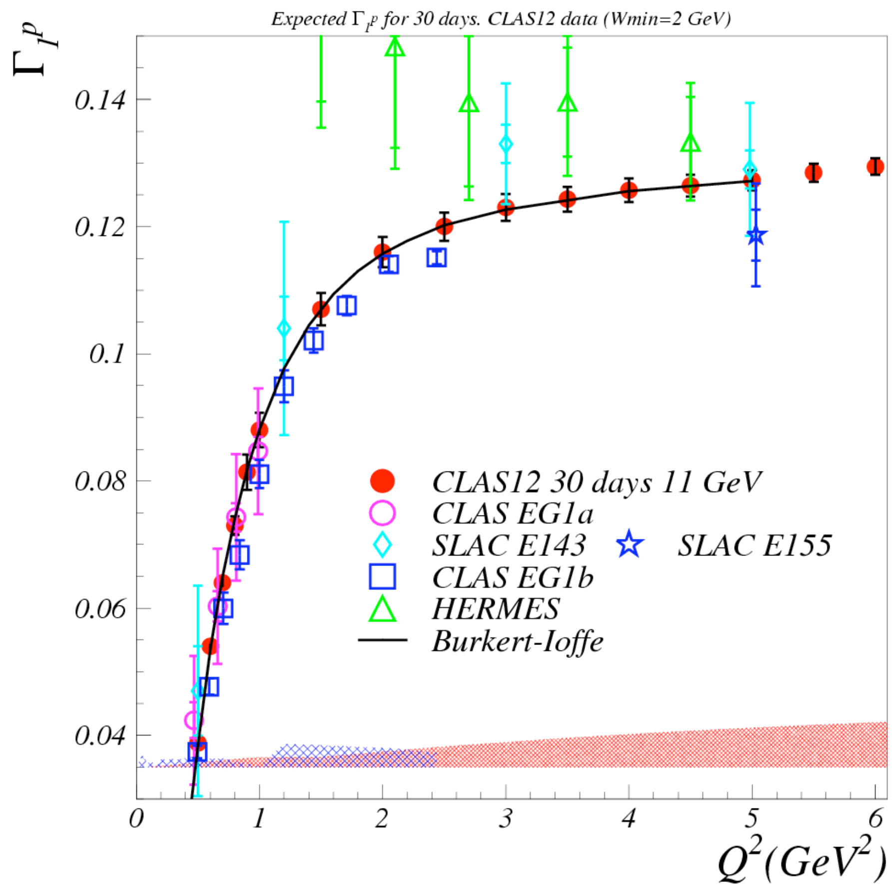


CLAS12 Moments

- Coverage predicted for CLAS12 Γ_1^p

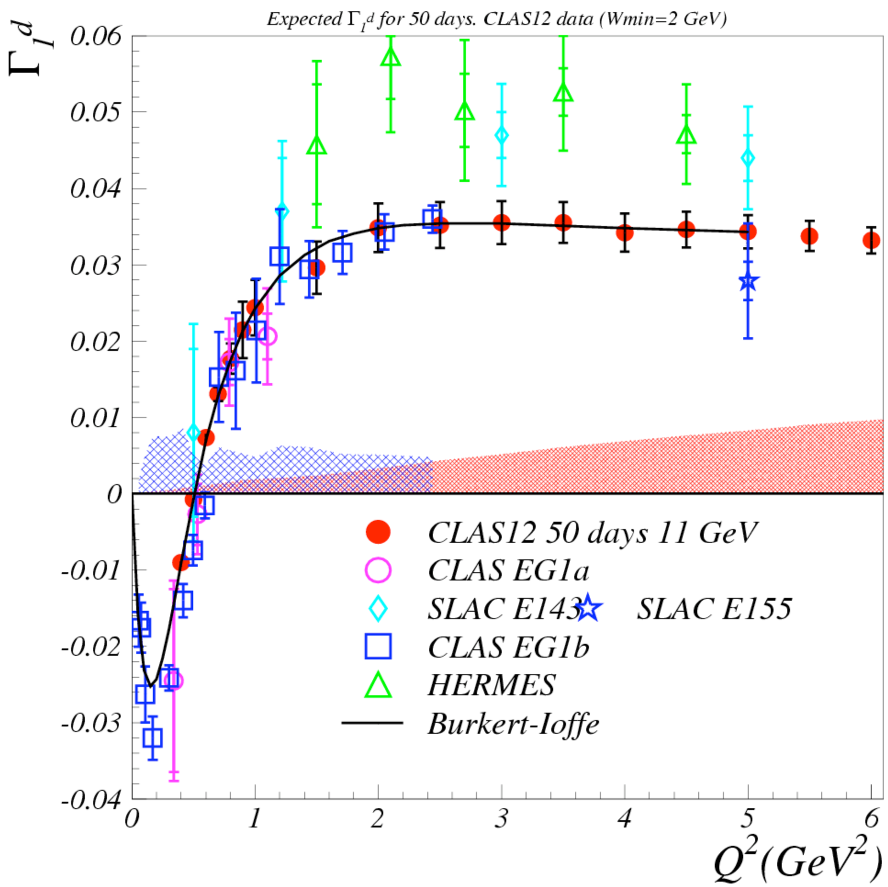


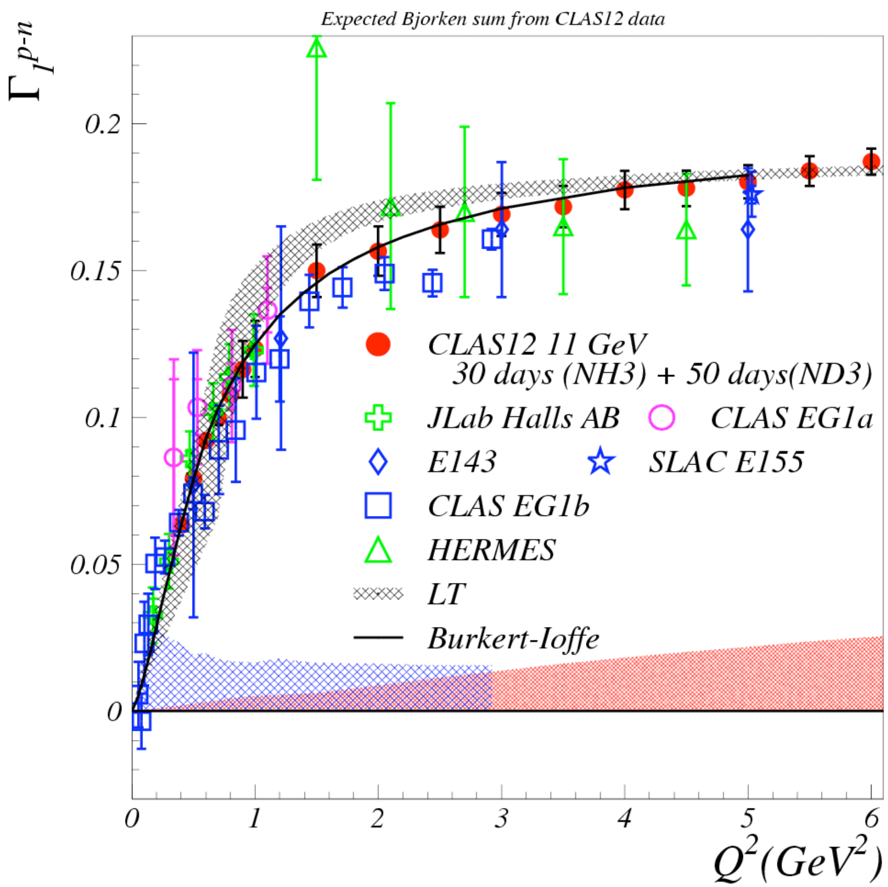
- Expected error bars for CLAS12 Γ_1^p



CLAS12 Moments

- Coverage predicted for CLAS12 Γ_1^d
- Expected error bars for CLAS12 Γ_1^{p-n}





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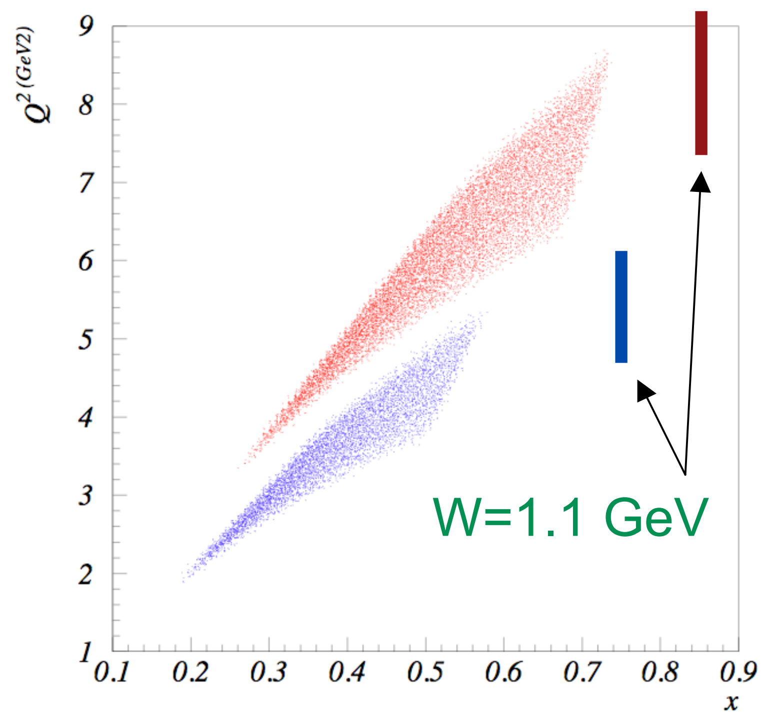
PR12-06-122

G. Cates
N. Liyanage
Z. Meziani
G. Rosner
B. Wojtsekhowski
X. Zheng
Hall A

Measurement of the Neutron Spin Asymmetry A_1^n in the Valence Quark Region Using 8.8 GeV and 6.6 GeV Beam Energies and the BigBite Spectrometer in Hall

23 days	6.6 & 8.8 GeV
10 μA	$L=5\times10^{36}/cm^2/s$
$0.2<x<0.7$	$4<Q^2<9.5\ GeV^2$

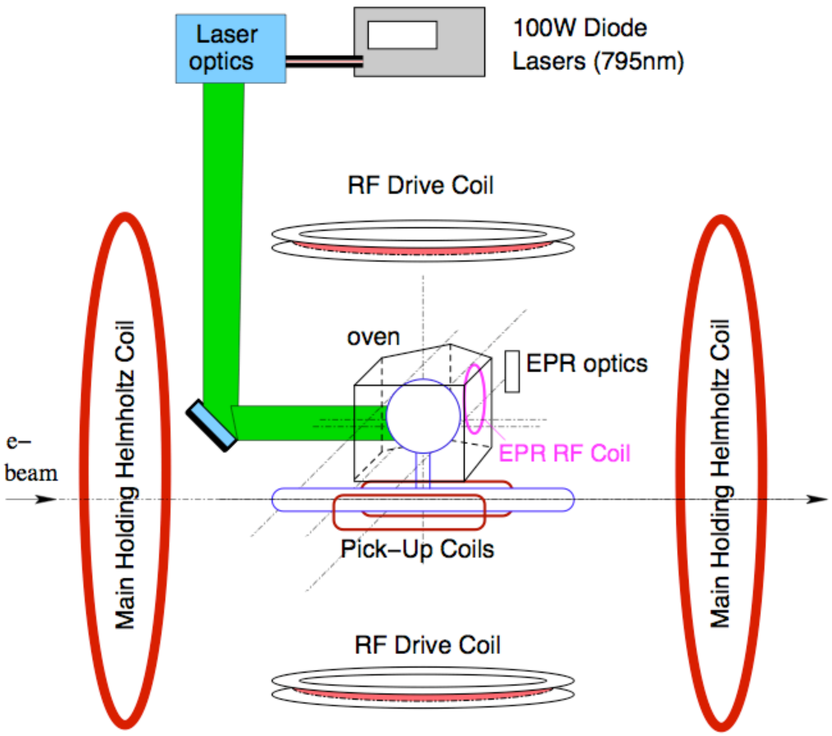
^3He polarized long. and trans.

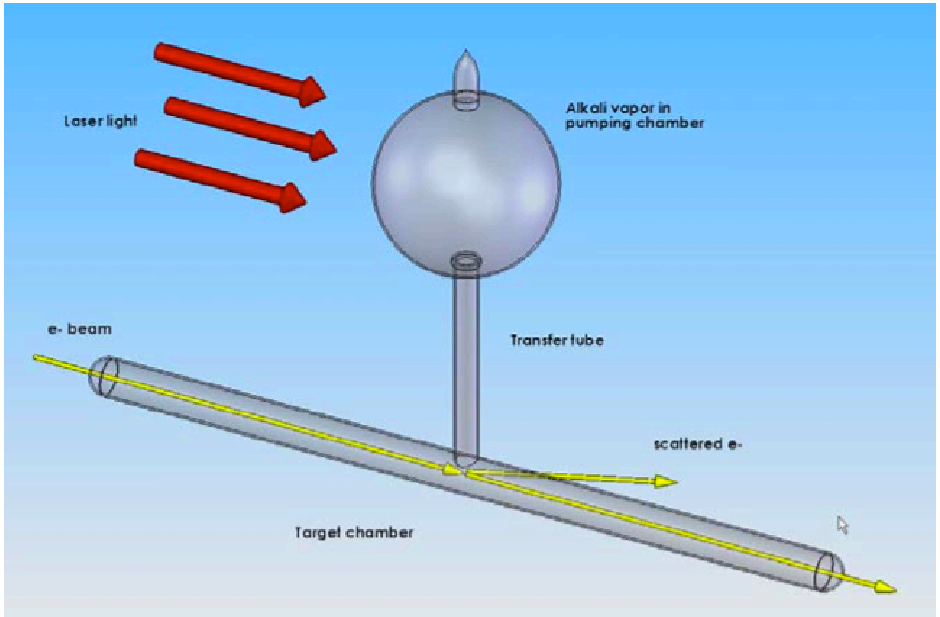


A_1 in Hall A

Polarized ^3He Target

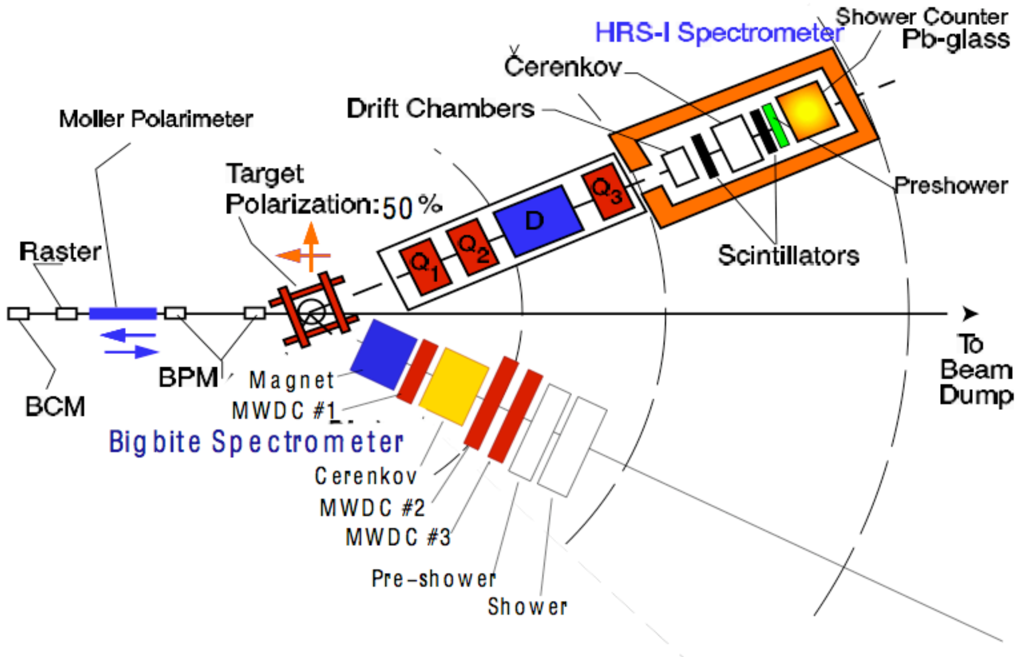
$P_t > 50\%$

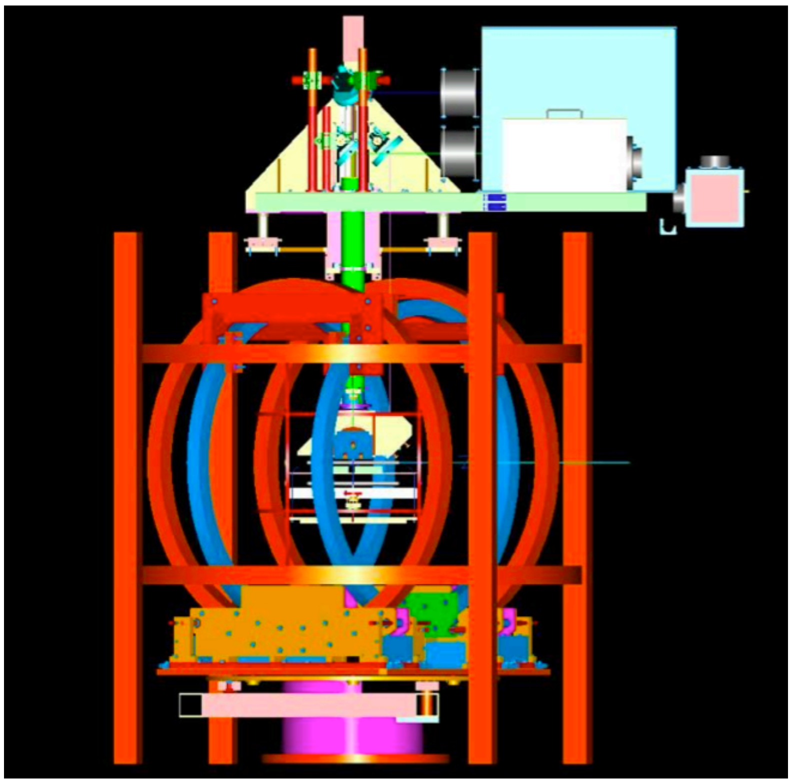




A_1 in Hall A

Hall A Setup

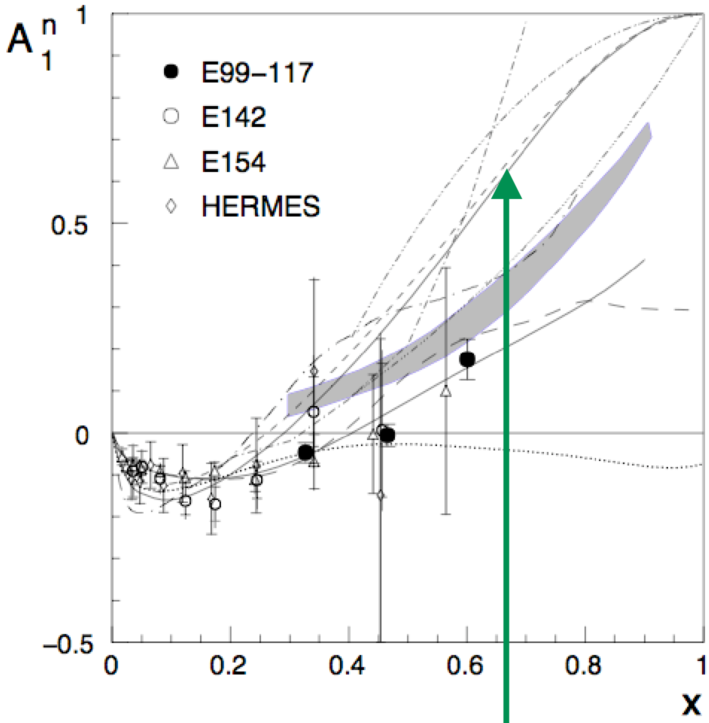


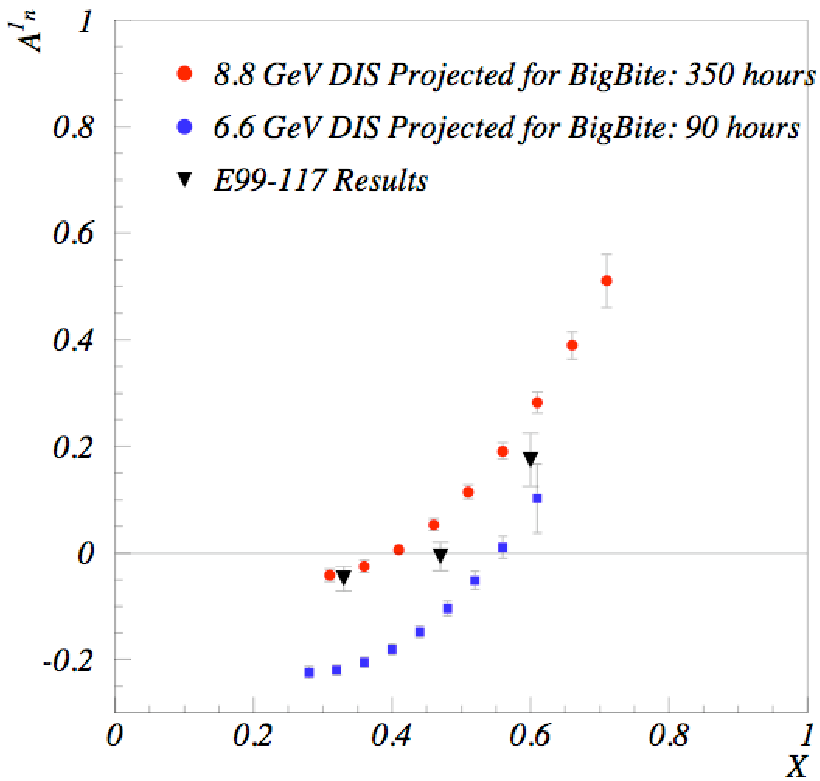


BigBite Spectrometer gives large acceptance

HRS allows precise cross-check and normalization

A_1 in Hall A

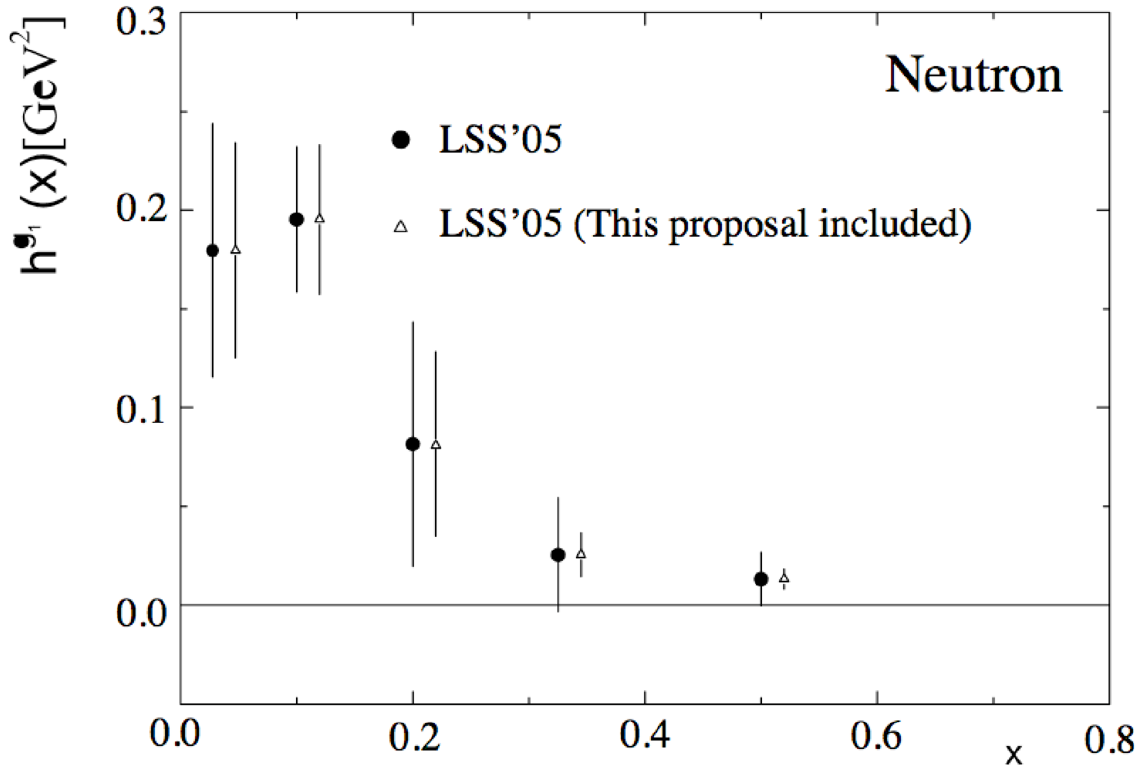




Existing data
The upper solid curve --- pQCD with hadron helicity conservation using BBS parameterization at $Q^2=4$ GeV^2 --- is way off.
Helicity non-conservation suggests orbital angular momentum

Error projections

A_1 in Hall A



From Q^2 evolution

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} = \frac{g_1(x,Q^2)_{LT} + h(x)/Q^2}{F_1(x,Q^2)_{exp}}$$

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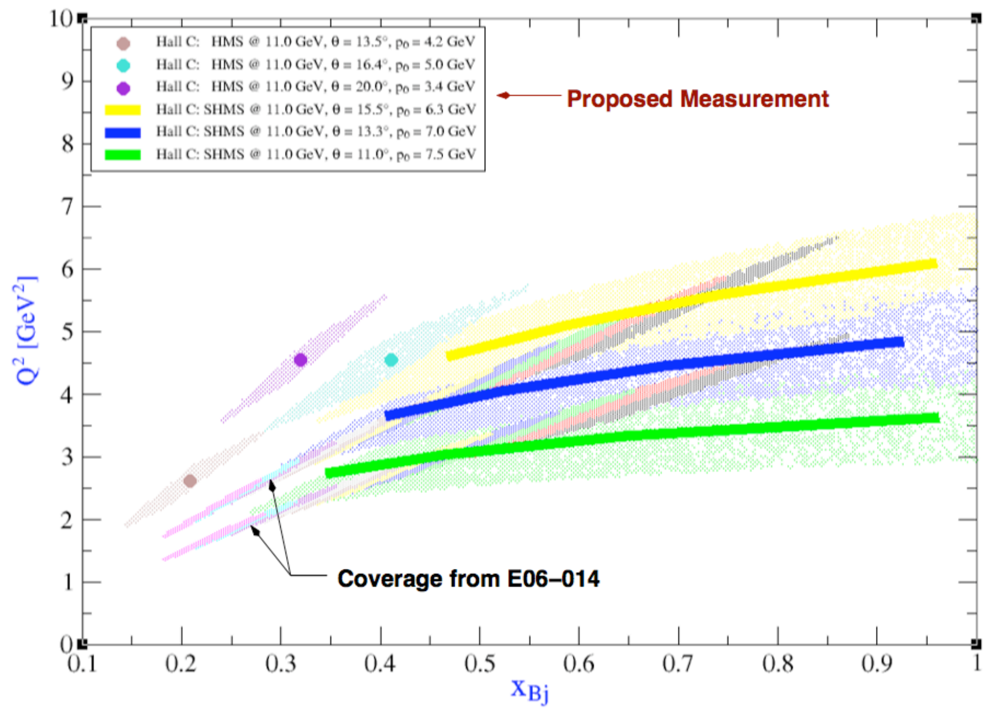
PR12-06-121

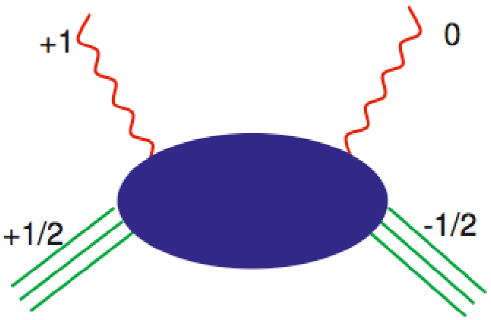
T. Averett
Z. Meziani
B. Sawatzky
Hall C

A Path to Color Polarizabilities in the Neutron: A Precise Measurement of the Neutron g_2 and d_2 at High Q^2 in Hall C

29 Days 11 GeV
10 μA $L=7 \times 10^{35}/cm^2/s$
$0.2<x<0.95$ $2.5<Q^2<6$ GeV^2
^3He polarized long. and trans.



g_2 in Hall C



Compton amplitude of $\gamma^*(+1) + N(+1/2) \rightarrow \gamma^*(0) + N(-1/2)$

g_2 contains information on quark-gluon correlations

Massless quarks cannot produce a helicity flip. Therefore, QCD allows

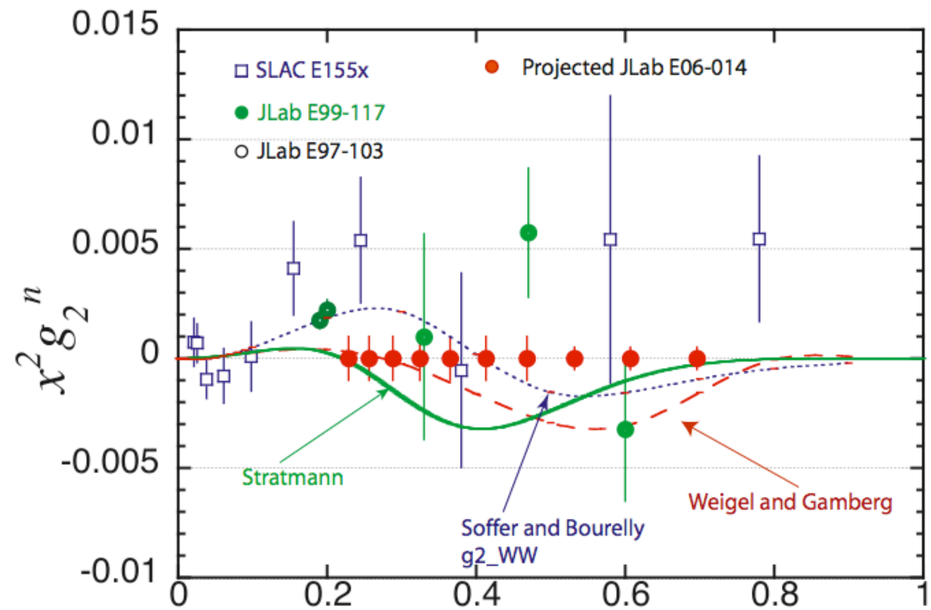
1) single quark scattering with the quark carrying off one unit of angular momentum
2) quark scattering with an additional transversely polarized gluon

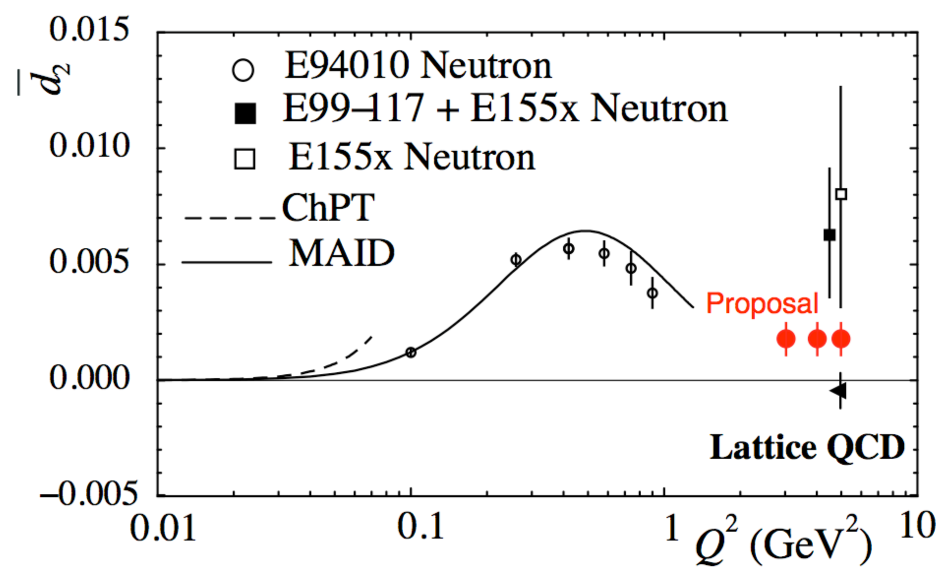
g_2 in Hall C

Estimates for g_2

Data are taken for a number of x values at fixed Q^2, which allows an accurate integration and extraction of d_2 (Q^2) at three points.

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





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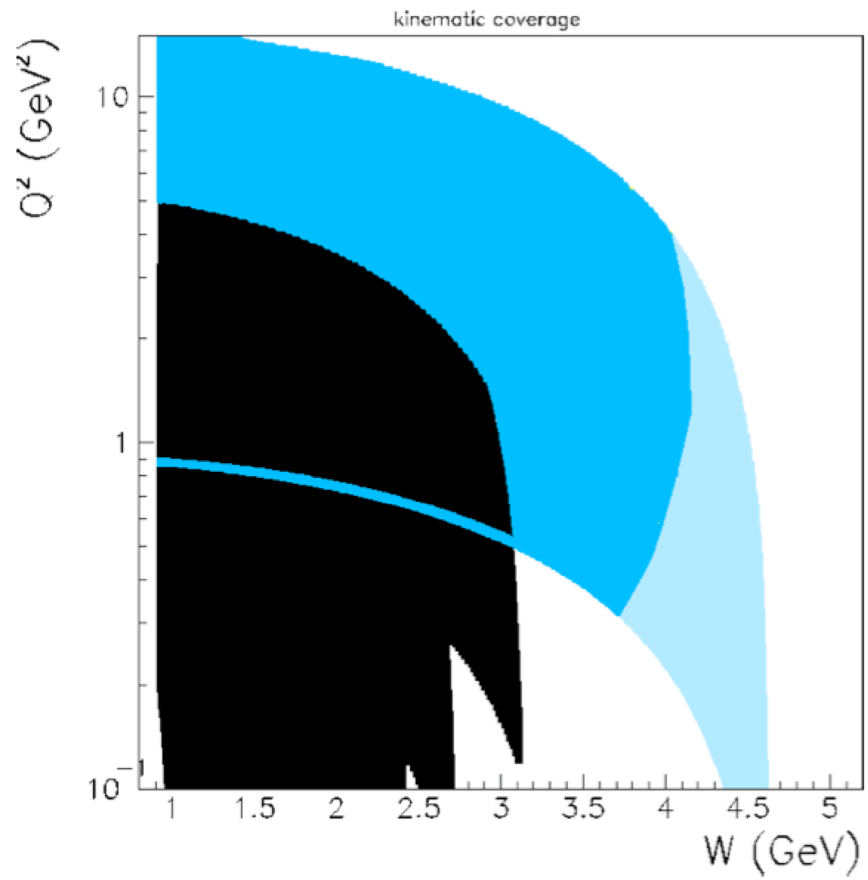
PR12-07-107

P. Bosted
K. Griffioen
K. Hafidi
P. Rossi
Hall B

Studies of Spin-Orbit Correlations with a Longitudinally Polarized Target



80 Days 11 GeV
10 nA $L=10^{35}/cm^2/s$
$0.1<x<0.8$ $0.4<Q^2<12$ GeV^2
NH_3 and ND_3 polarized long.
Simultaneous with g_1 run

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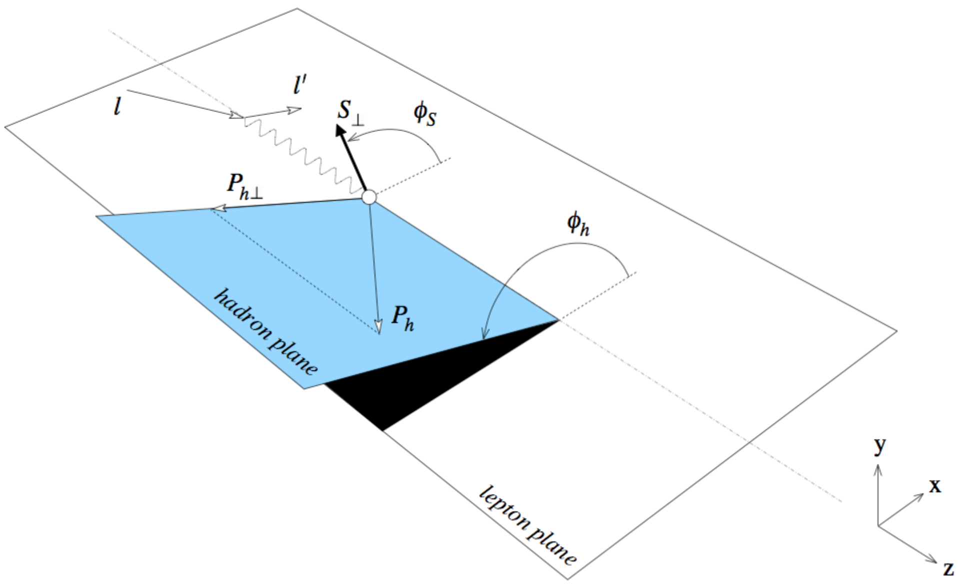
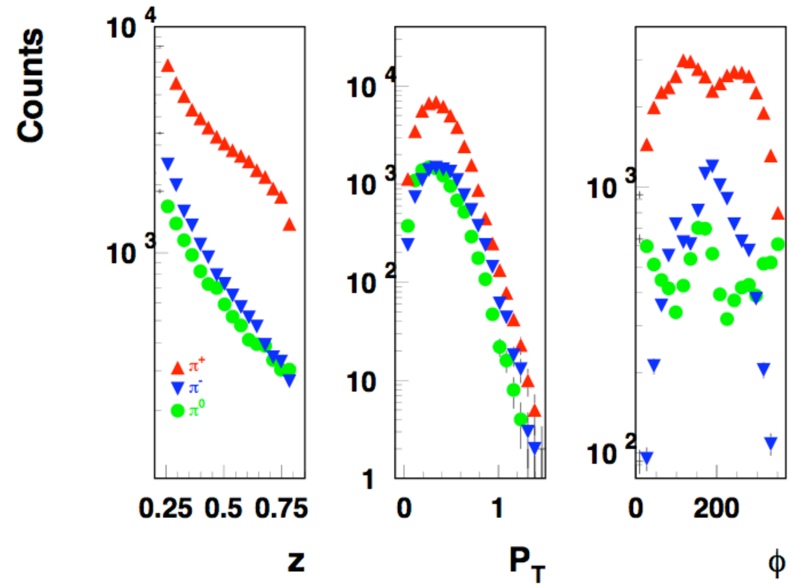
Hall B SIDIS





- Measures SIDIS for π^+, π^0, π^-
- Large acceptance with CLAS12
- Look at A_{LL} (or A_1) and A_{UL}

N/q	U	L	T
U	$\mathbf{f_1}$		$h_1^\perp$
L		$\mathbf{g_1}$	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$\mathbf{h_1}$ $h_{1T}^\perp$

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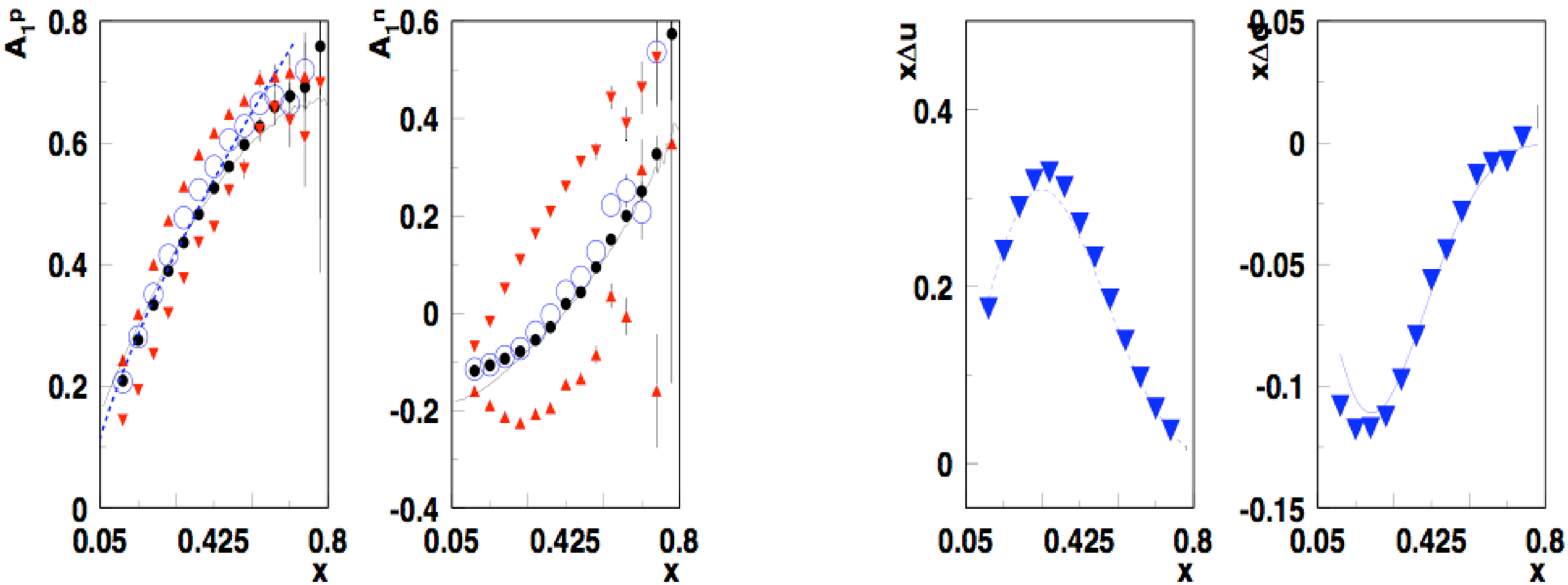
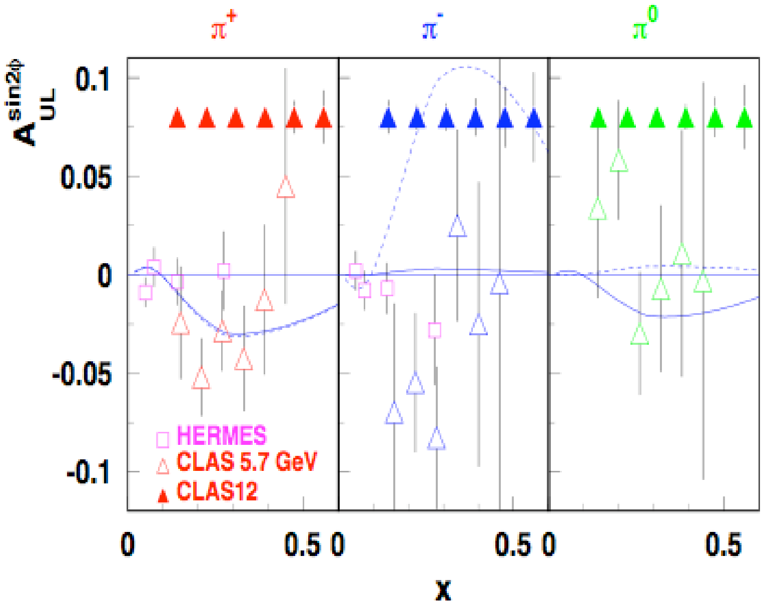
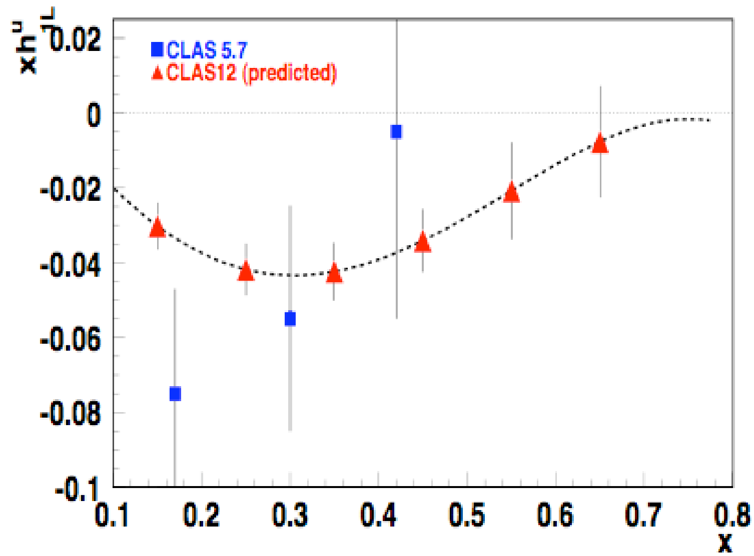
Hall B SIDIS

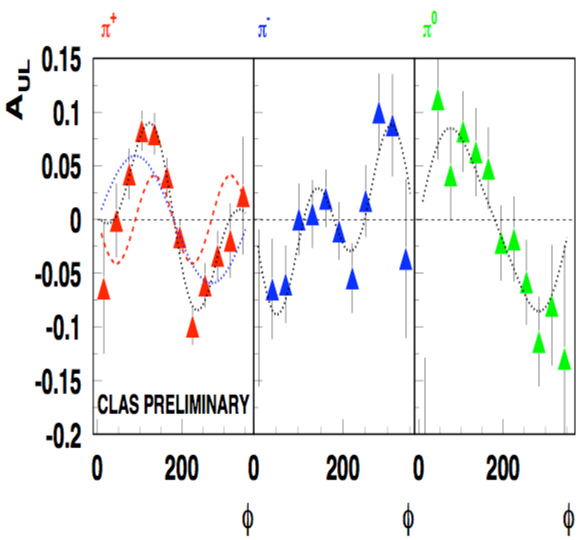


- π^+ (triangles), π^0(open circles), π^- (inverted trianges)
- inclusive (solid circles), $A_1=x^{0.72}$ (dashes)
- GRV98 and GRSV PDFs at $Q^2=2$ GeV^2 (solid line)

Hall B SIDIS



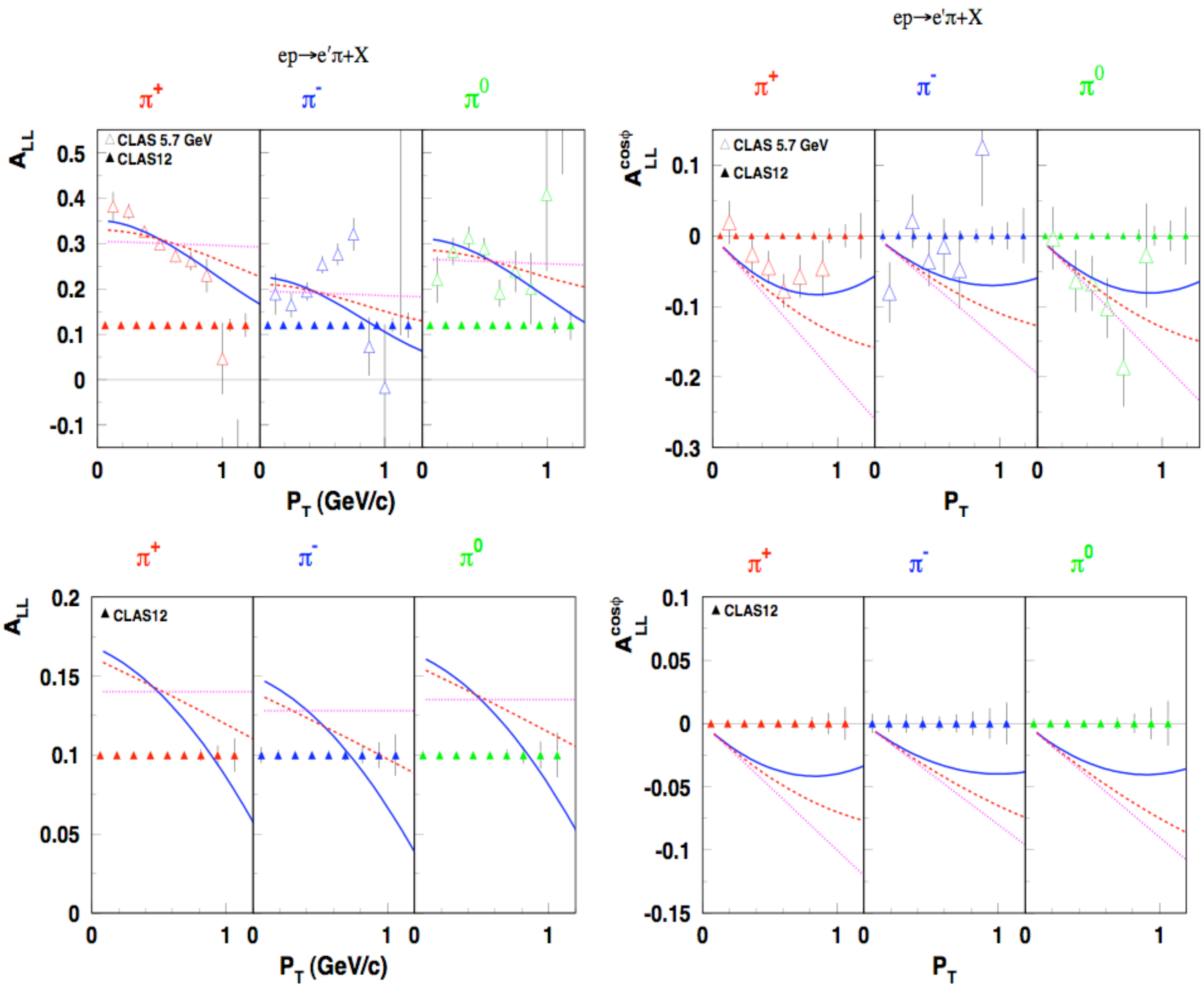




$$\sigma_{UL}^{\sin 2\phi} \propto S_L 2(1-y)\sin 2\phi \sum_{q,\bar{q}} e_q^2 x h_{1L}^{\perp q}(x) H_1^{\perp q}(z)$$

- sin2ϕ moment of A_{UL} gives Mulders distribution function and Collins fragmentation function.
- Mulders: transversely polarized quarks in long. pol. nucleon

Hall B SIDIS



- A_{LL} (left) and cosϕ moment of A_{LL} (right) vs. p_T for proton (upper) and deuteron (lower).

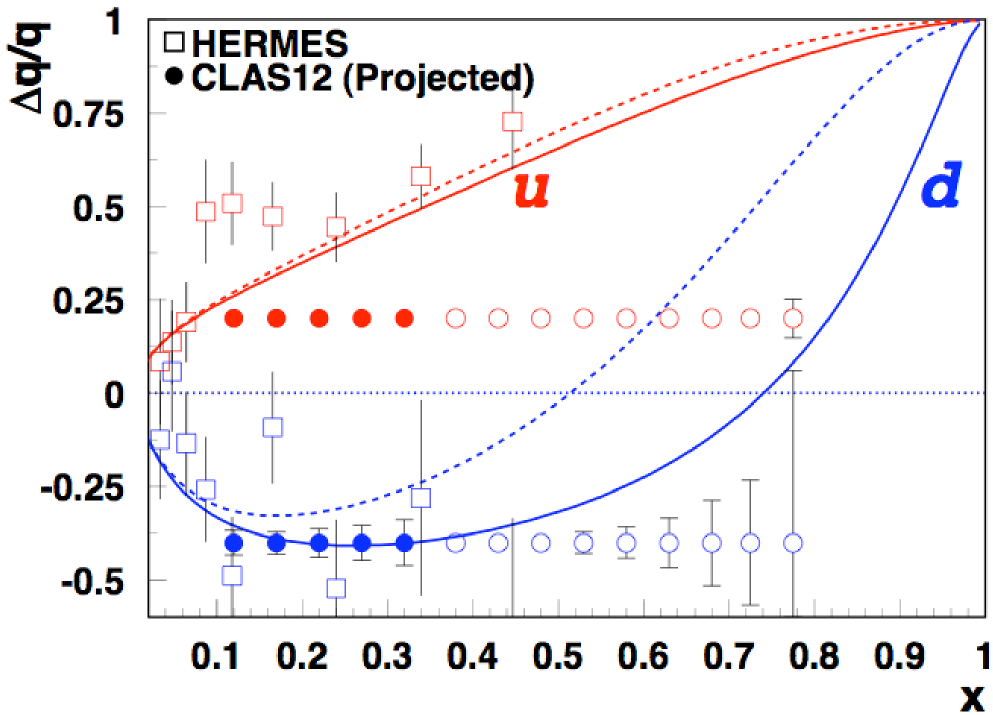
N/q	U	L	T
U	$\mathbf{f_1}$		$h_1^\perp$
L		$\mathbf{g_1}$	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$\mathbf{h_1}$ $h_{1T}^\perp$

$$\sigma_{UU}^{\cos 2\phi} \propto (1-y)\cos 2\phi \sum_{a,\bar{a}} e_a^2 x h_1^{\perp(1)}(x) H_1^{\perp(1)a}(z)$$

$$\sigma_{LL} = \frac{\pi}{xy^2}\left[\, y(2-y) \,\right] \Sigma_q e_q^2 \int d^2\mathbf{k}_\perp \; g_{1L}^q(x,\mathbf{k}_\perp)\; D_q^h(z,\mathbf{P}_{hT}-z\mathbf{k}_\perp) \,,$$

$$\sigma_0 = \frac{\pi}{xy^2}\left[\, 1+(1-y)^2 \,\right] \Sigma_q e_q^2 \int d^2\mathbf{k}_\perp \; f_1^q(x,\mathbf{k}_\perp)\; D_q^h(z,\mathbf{P}_{hT}-z\mathbf{k}_\perp)$$

Hall B SIDIS



Predictions with (solid) and without (dashed) orbital angular momentum

$$A^{\pi^+-\pi^-} = \frac{N^{\pi^+}_{\uparrow\downarrow} - N^{\pi^-}_{\uparrow\downarrow} - N^{\pi^+}_{\uparrow\uparrow} + N^{\pi^-}_{\uparrow\uparrow}}{N^{\pi^+}_{\uparrow\downarrow} - N^{\pi^-}_{\uparrow\downarrow} + N^{\pi^+}_{\uparrow\uparrow} - N^{\pi^-}_{\uparrow\uparrow}}$$

$$A_p^{\pi^+-\pi^-}(x) = \frac{4\Delta u_V(x) - \Delta d_V(x)}{4u_V(x) - d_V(x)} \qquad A_d^{\pi^+-\pi^-}(x) = \frac{\Delta u_V(x) + \Delta d_V(x)}{u_V(x) + d_V(x)}$$

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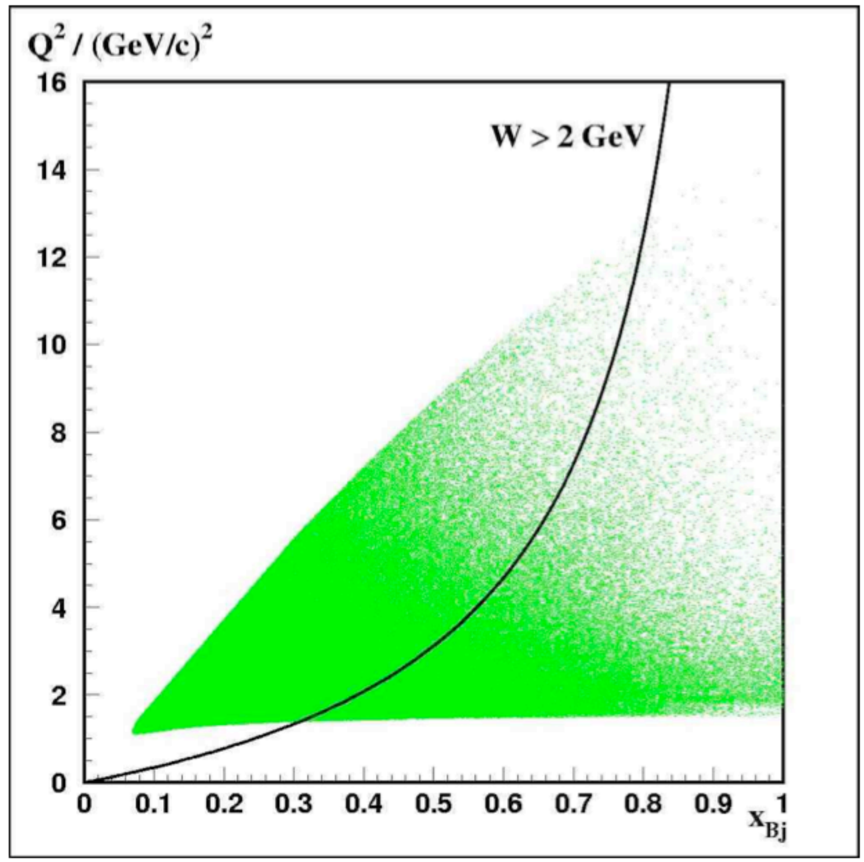
The Structure of the Free Neutron at Large x-Bjorken

40 Days 11 GeV
50 nA $L=5x10^{33}/cm^2/s$
$0.1<x<0.8$ $0.1<Q^2<14$ GeV^2
Deuterium unpolarized (BONUS)



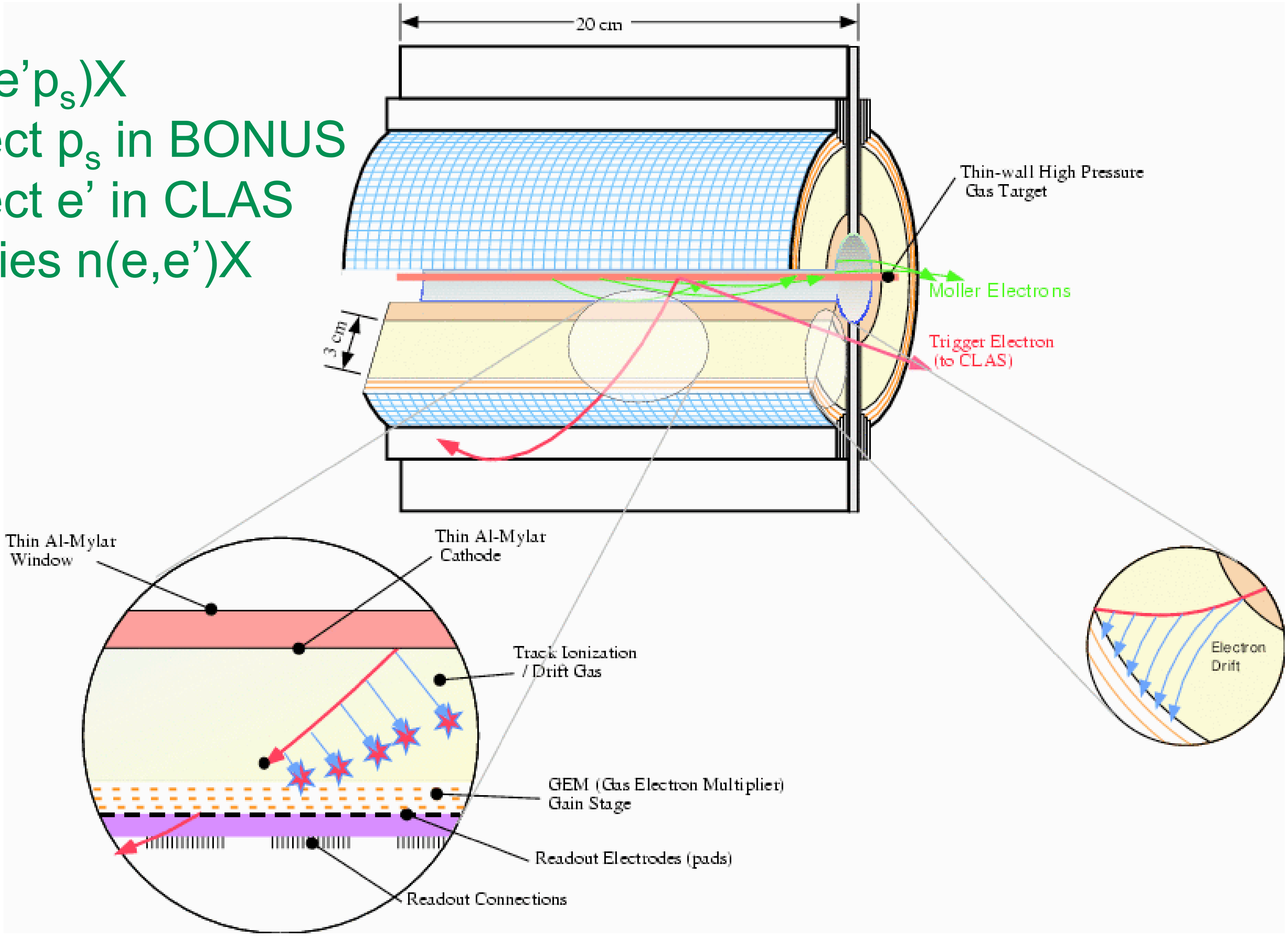
BONUS

$d(e,e'p_s)X$

detect p_s in BONUS

detect e' in CLAS

implies $n(e,e')X$



BONUS

D(e,e′) (black - untagged)

D(e,e′p_s) (red - tagged)

70 < p_s < 150 MeV/c

cross section vs. W (W*)

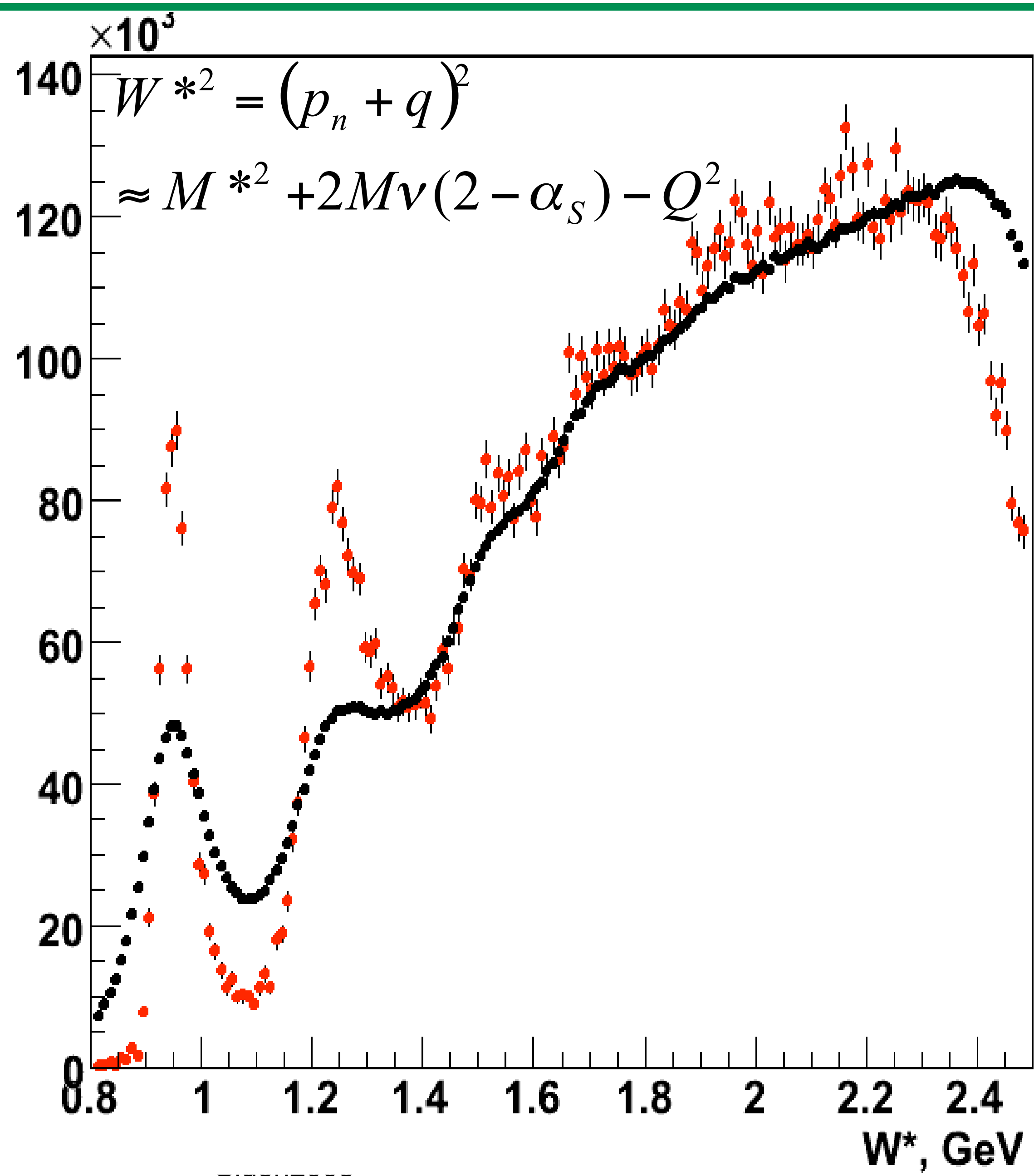
E_{beam} = 4.223 GeV

<Q^2> = 1.19 $(GeV/c)^2$

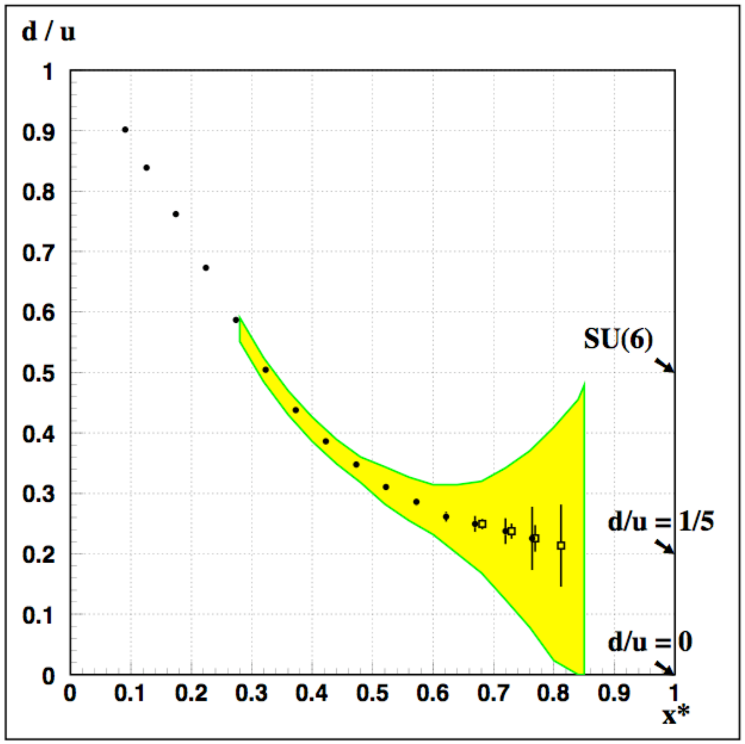
Backwards p_s implies no FSI and initially

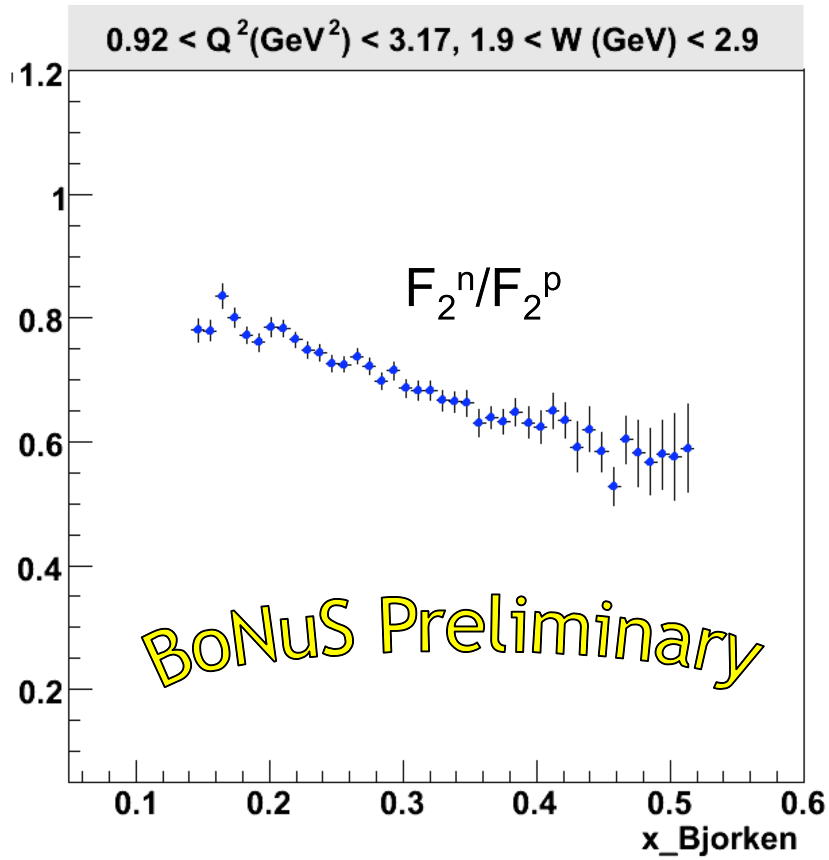
$\mathbf{p}_n = -\mathbf{p}_s$ and $E_n^2 = M^{*2} + p_s^2$

Provides F_2^n for extracting g_1 from g_1/F_1 at high x



BONUS





11 GeV
points: W* > 2 GeV
squares: W* > 1.8 GeV

2.1, 4.2, 5.3 GeV

Conclusions

- JLab at 12 GeV will measure g_1, g_2, F_1 and F_2 on polarized p, d and ^{3}He targets
  - $0.1 < x < 0.95$ $0.4 < Q^2 < 12$ GeV^2
- JLab at 12 GeV will measure SIDIS
  - for π^+, π^-, π^0
  - $0.25 < z < 0.8$ $0.1 < p_T < 1.5$
- JLab at 12 GeV will measure A_{LL}, A_{UL} and their azimuthal moments
- These measurements will help us understand
  - higher twist
  - gluon polarization ΔG
  - quark orbital angular momentum
- Proposals can be found at http://www.jlab.org/div_dept/physics_division/experiments/