New Results on the Resonance Spin Structure of ^{3}He and Deuteron

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Argonne National Laboratory

ECT 2008 Workshop

Nuclear Medium Effects on the Quark and Gluon Structure of Hadrons

June 3-7, 2008

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Outline

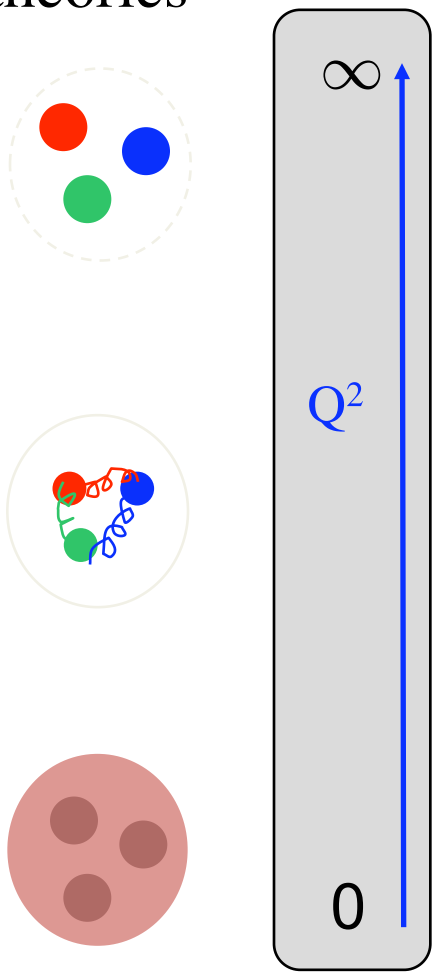
- Brief introduction and motivations
- Experimental setups
- Results
  - *Sum rules*
  - *Spin Duality*
  - *Structure function g_2*
  - *Virtual photon asymmetry A_1*

Motivations

- ✦ Access to neutron spin structure functions
- ✦ Sum rules work for nuclei even when extra disintegration channels and nuclear excitation are added
- ✦ Test of sum rules without worrying of nuclear corrections
- ✦ Light nuclei measurements important to test EFT
- ✦ True understanding of QCD means being able to describe nucleon and nuclei in terms of fundamental degrees of freedom

Implementations of QCD

Due to complexity of QCD we often employ approximations or effective theories



Perturbative QCD

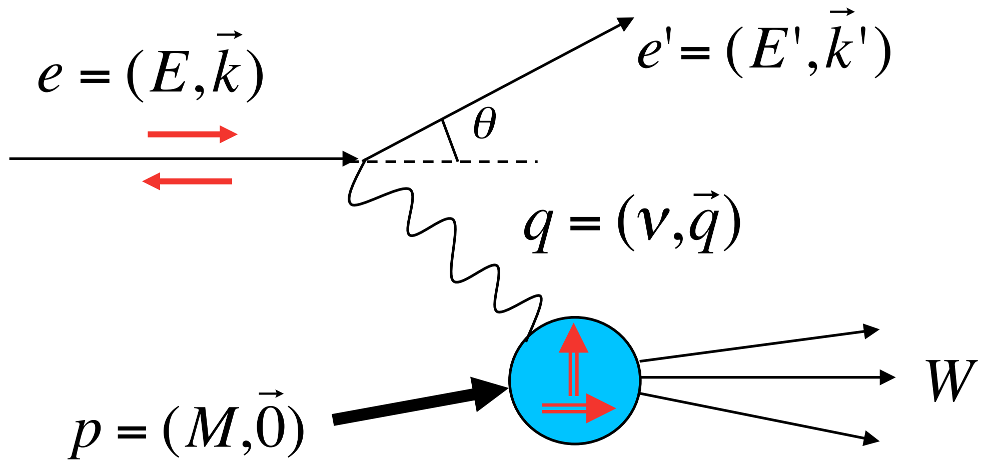
Operator Product Expansion (OPE)

Quark models

Chiral Perturbation Theory (χPT).

Lattice QCD

Inclusive electron scattering



4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

Invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

Bjorken variable

$$x = \frac{Q^2}{2M\nu}$$

Polarized case

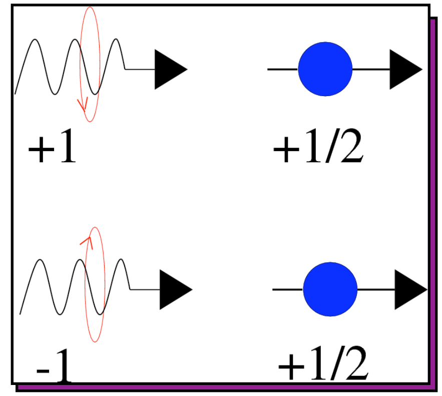
$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{\nu E Q^2}\left[(E + E'\cos\theta)\, g_1(x,Q^2) - 2Mx\, g_2(x,Q^2)\right]$$

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

GDH Sum Rule and extention to finite Q^2

Real Photon Scattering

$$\int_{\nu_0}^{\infty} \left(\sigma_{1/2} - \sigma_{3/2}\right) \frac{d\nu}{\nu} = -\frac{2\alpha\pi^2}{M^2}\kappa^2$$

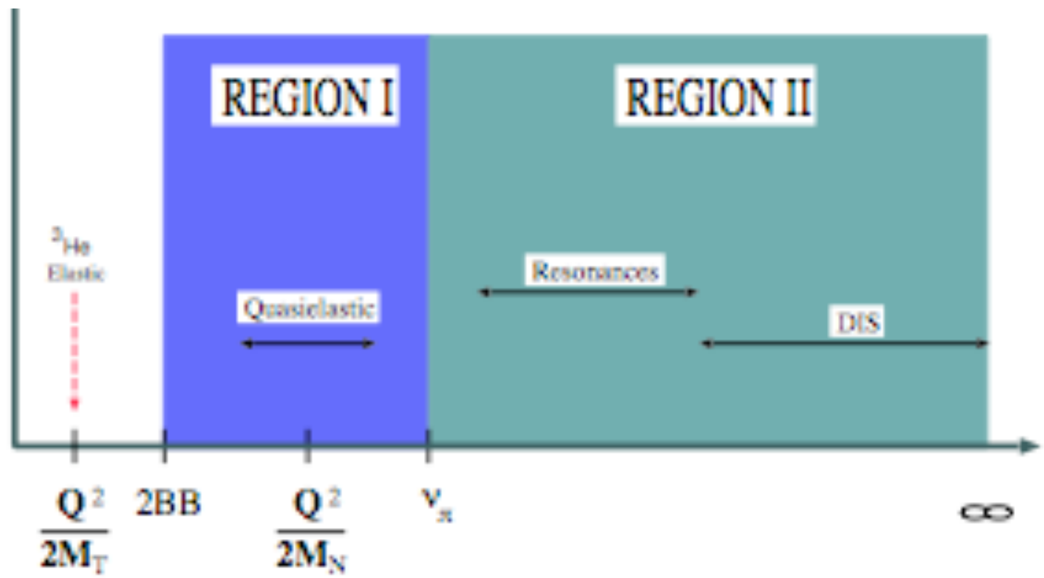


$I_p^{GHD} = -204\mu b$

$I_n^{GDH} = -234\mu b$

$I_d^{GDH} = -0.65\mu b$

$I_{3He}^{GDH} = -496\mu b$



GDH Sum Rule and extention to finite Q^2

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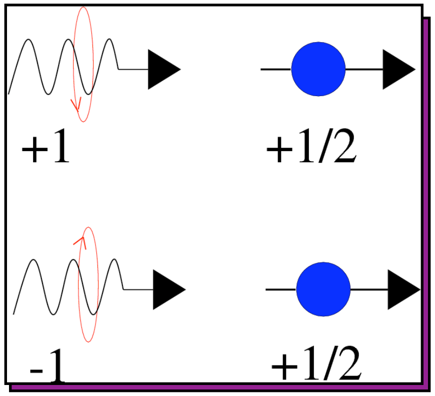
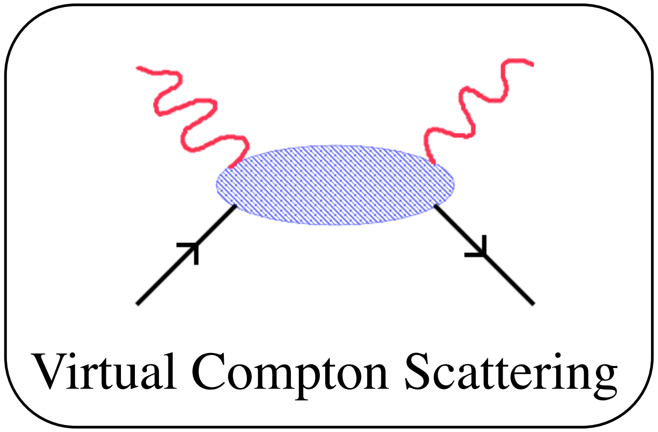


Extension to finite Q^2

$$S_1(0, Q^2) = \frac{8}{Q^2} \int_0^1 g_1(x, Q^2) dx$$

Ji and Osborne, J. Phys. G27 (2001) 127



S_1 calculable (in principal)

Reduces to GDH sum rule as $Q^2 \rightarrow 0$

The g_2 structure function

<u>Wandzura-Wilczek relation</u> PLB **<u>72</u>** (1977) 195

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

Leading twist determined entirely by g_1

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

Higher twist

Burkhardt-Cottingham Sum rule

$$\int_0^1 g_2(x, Q^2)dx = 0$$

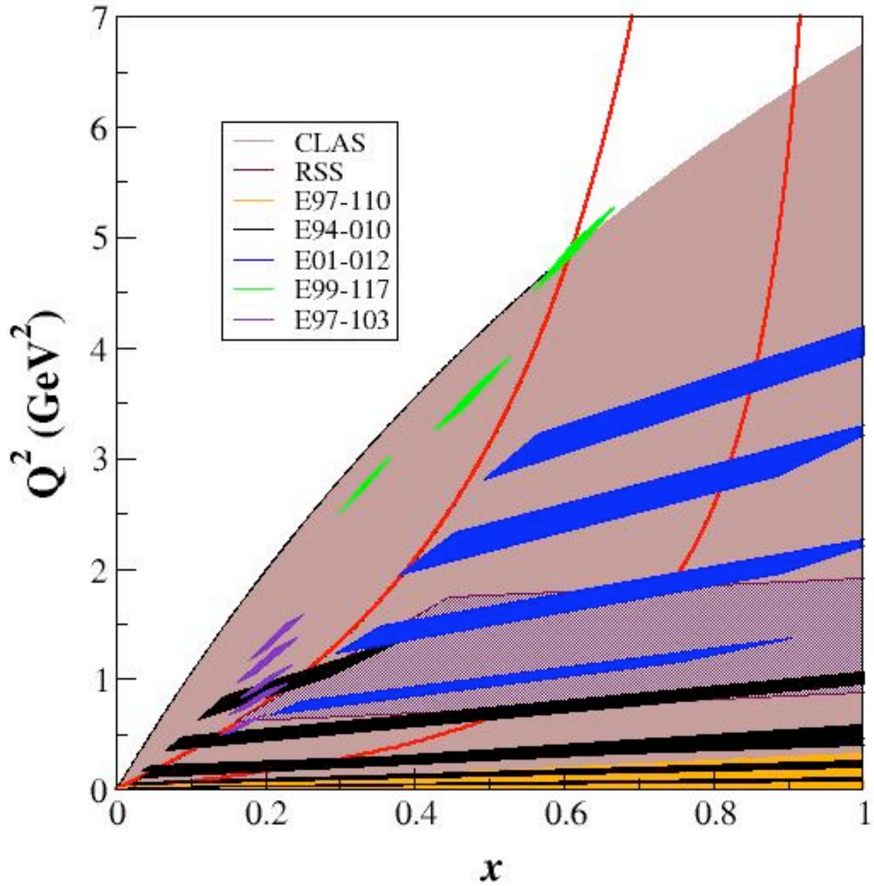
H.Burkhardt, and W.N. Cottingham
Annals Phys. 56 (1970) 453.

Relies on the virtual Compton scattering amplitude S_2 falling to zero faster than $1/\nu$ as $\nu \rightarrow \infty$

Overview of available kinematic range at Jlab

- ***Deuteron:***
  - Hall B Eg1b
  - Hall C RSS
  - Hall B Eg4

- ***^3He***
  - Hall A E94-010
  - Hall A E01-012
  - Hall A E97-110

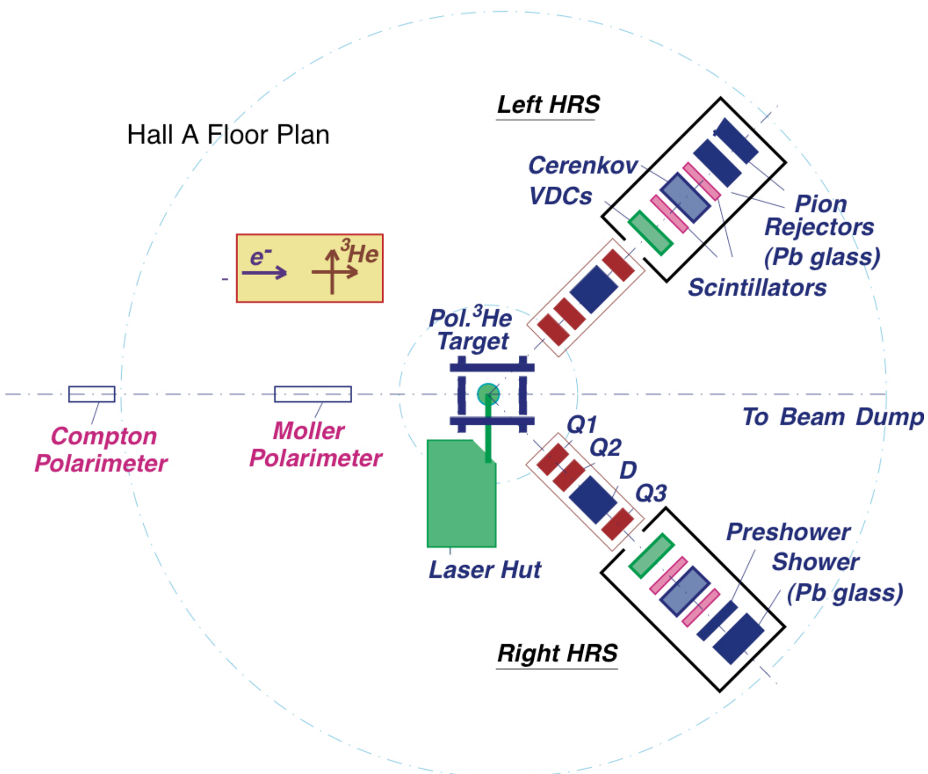


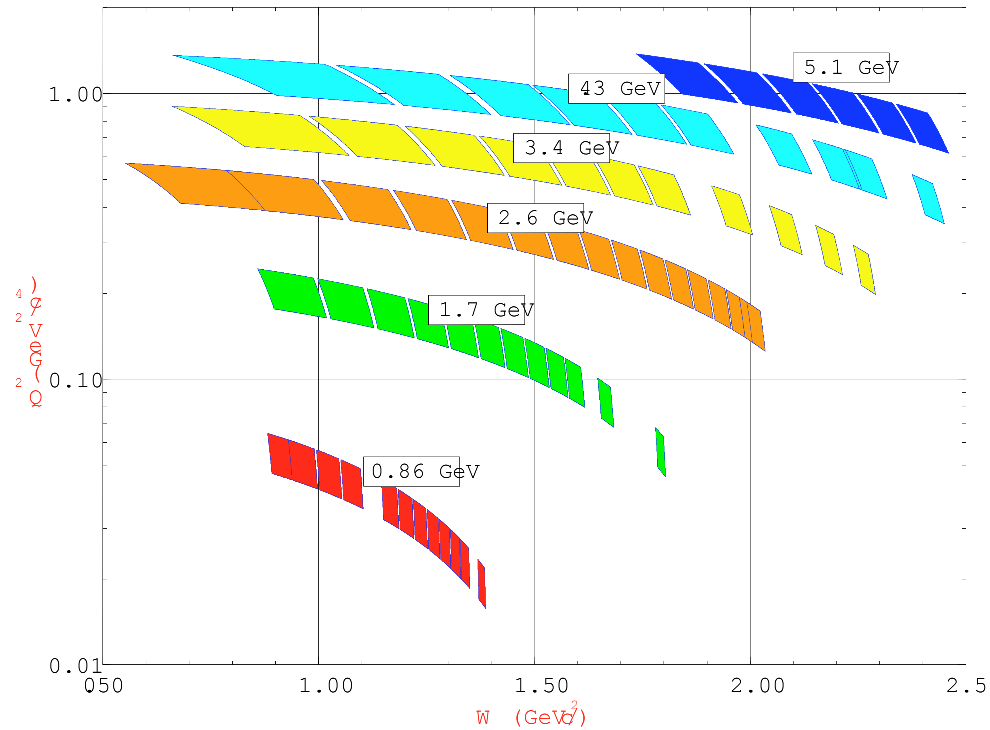
Uniquely positioned to provide data in transition region of QCD

Jlab Hall A: E94-010

Spokespersons
G. Cates, J-P Chen, Z-E Meziani

PhD. Students
A. Deur, P. Djawotho, S. Jensen, I. Kominis, K. Slifer





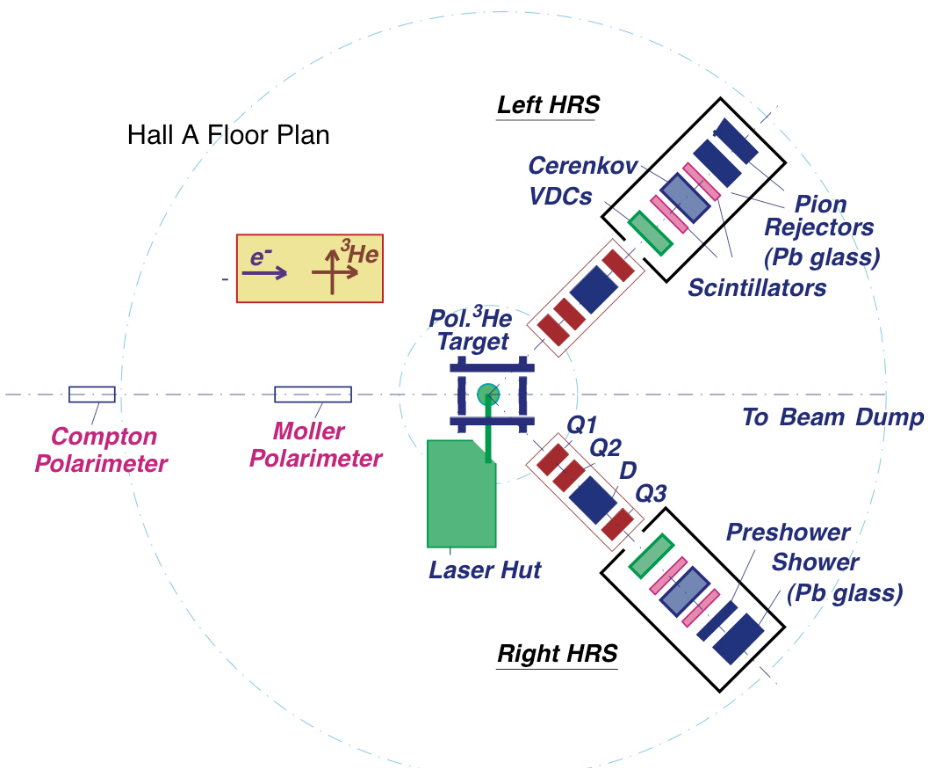
g_1 and g_2

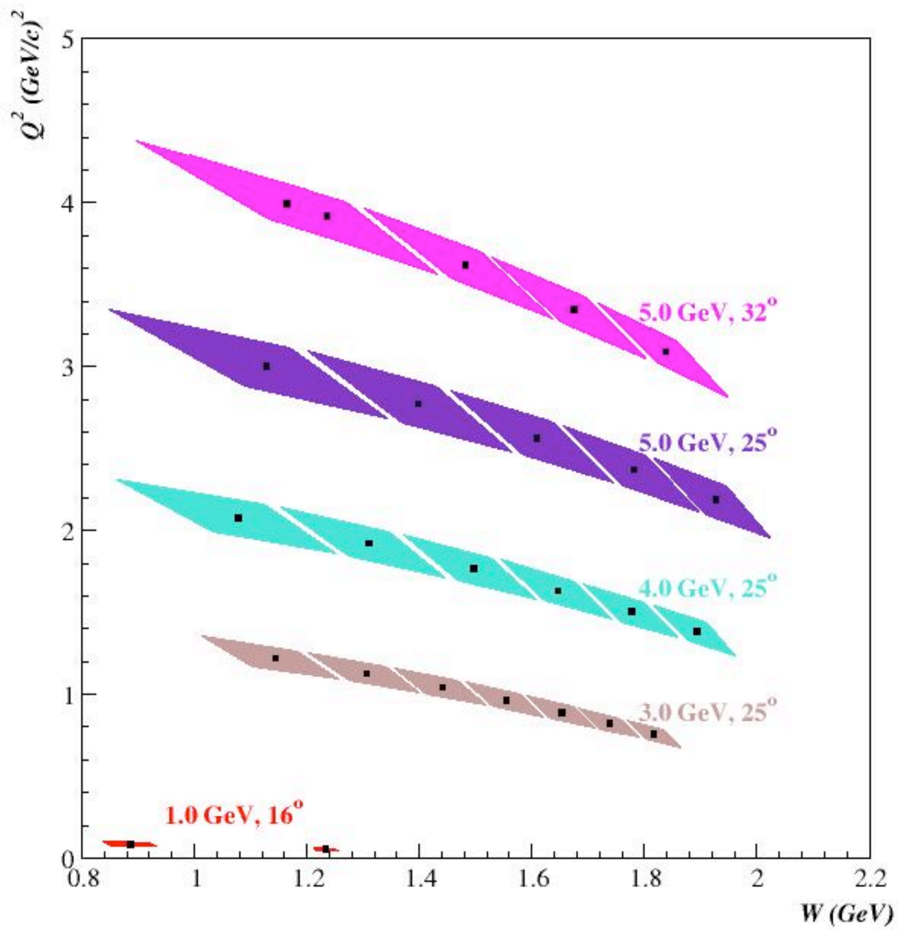
Primary goal: extended GDH

Jlab Hall A: E01-012

Spokespersons
J-P Chen. Seonho Choi, N. Liyanage

PhD. Student
P. Solvignon





g_1 and g_2

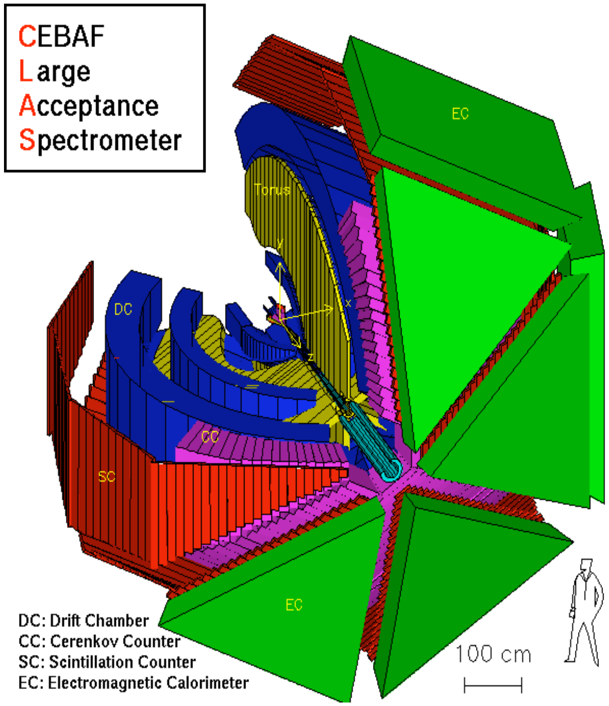
<u>Primary goal:</u> spin duality

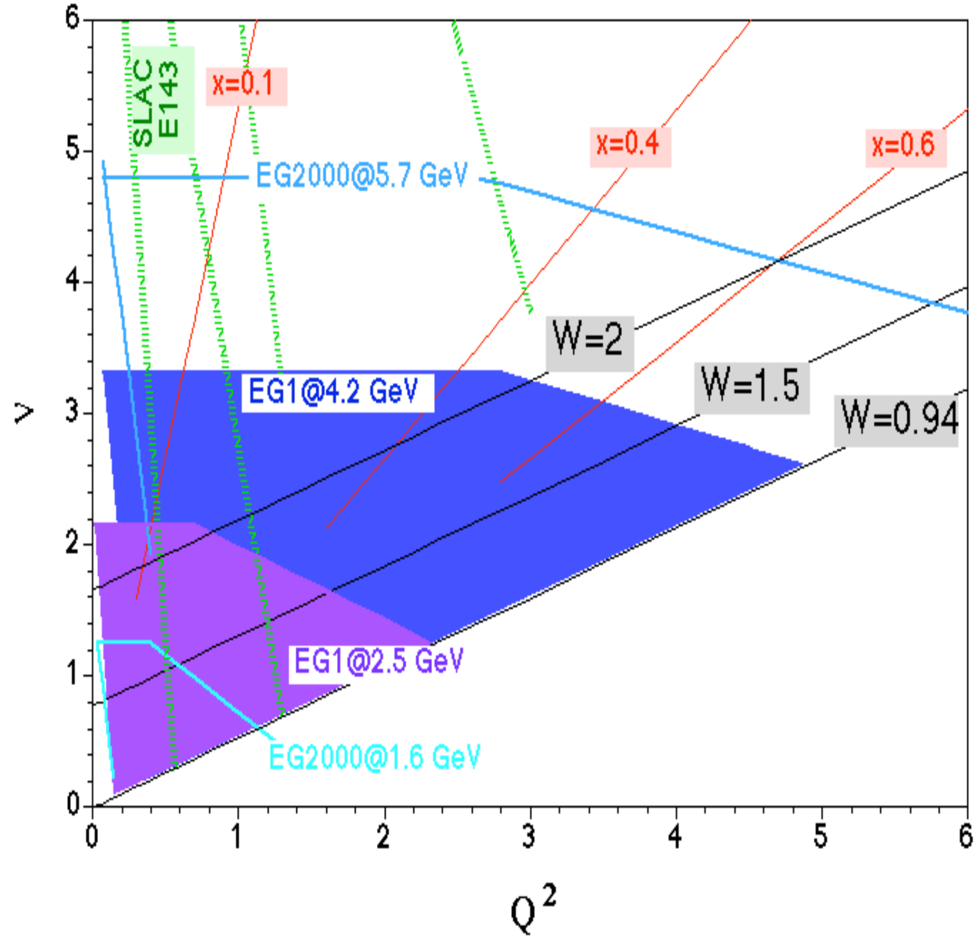
JLab Hall B: EG1b

Spokespersons
V. Burkert, D. Crabb, G. Dodge,
S. Kuhn, R. Minehart, M. Taiuti

PhD. Students
V. Dharmawardane, Y. Prok
S. Chen, S. Careccia, R. Fersch, N.Guler, J. Pierce

CEBAF
Large
Acceptance
Spectrometer



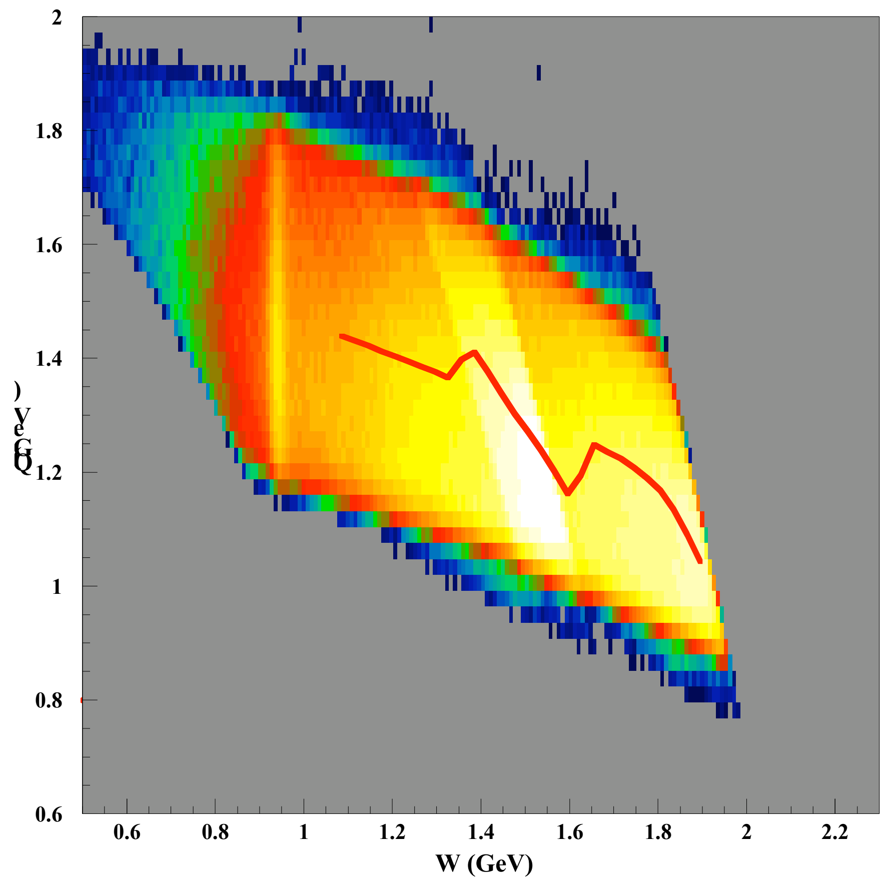


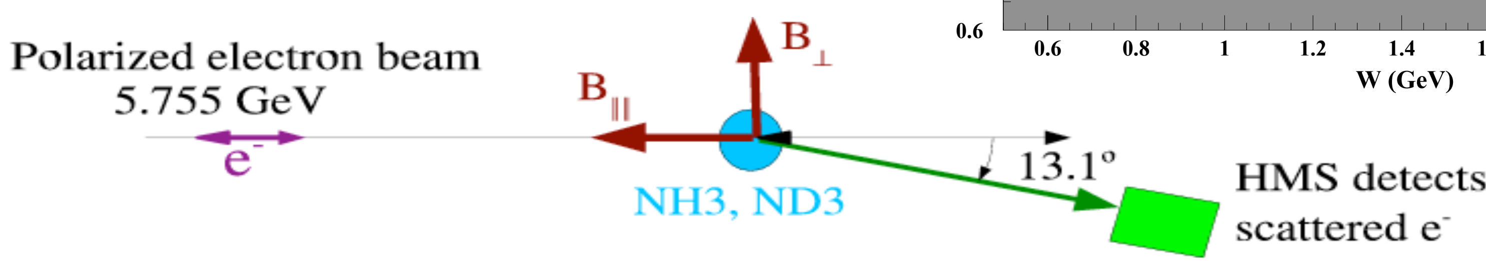
g_1

Primary goal: **extended GDH**

JLab Hall C

Spokespersons
M. Jones, O. Rondon





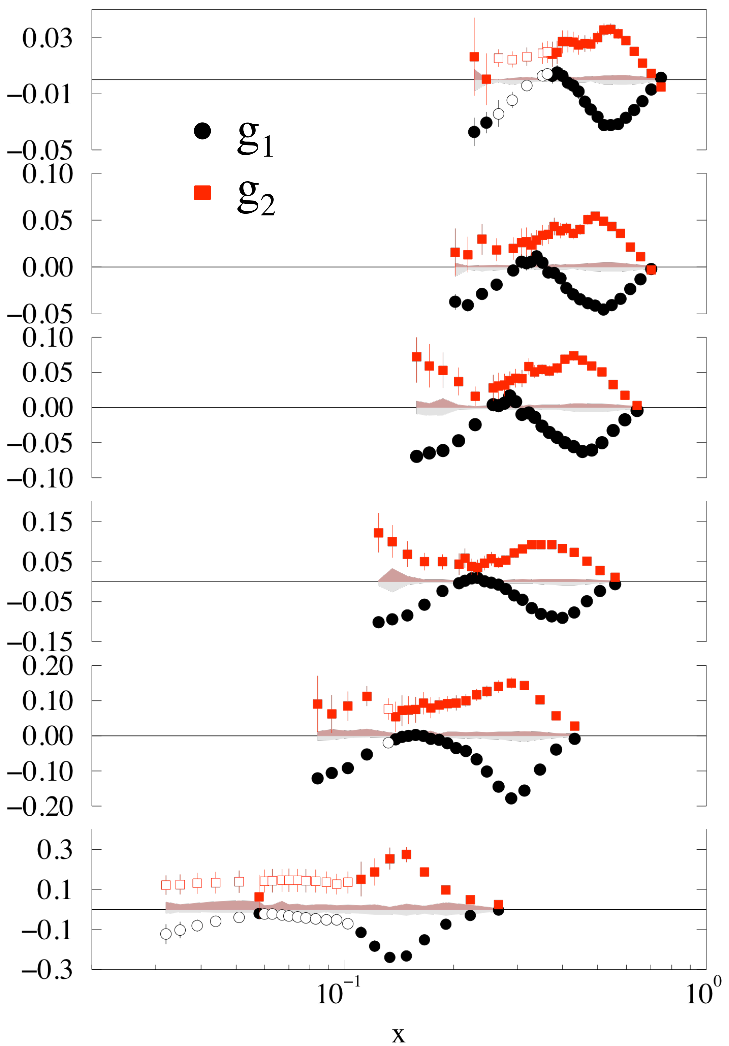
g_1 and g_2

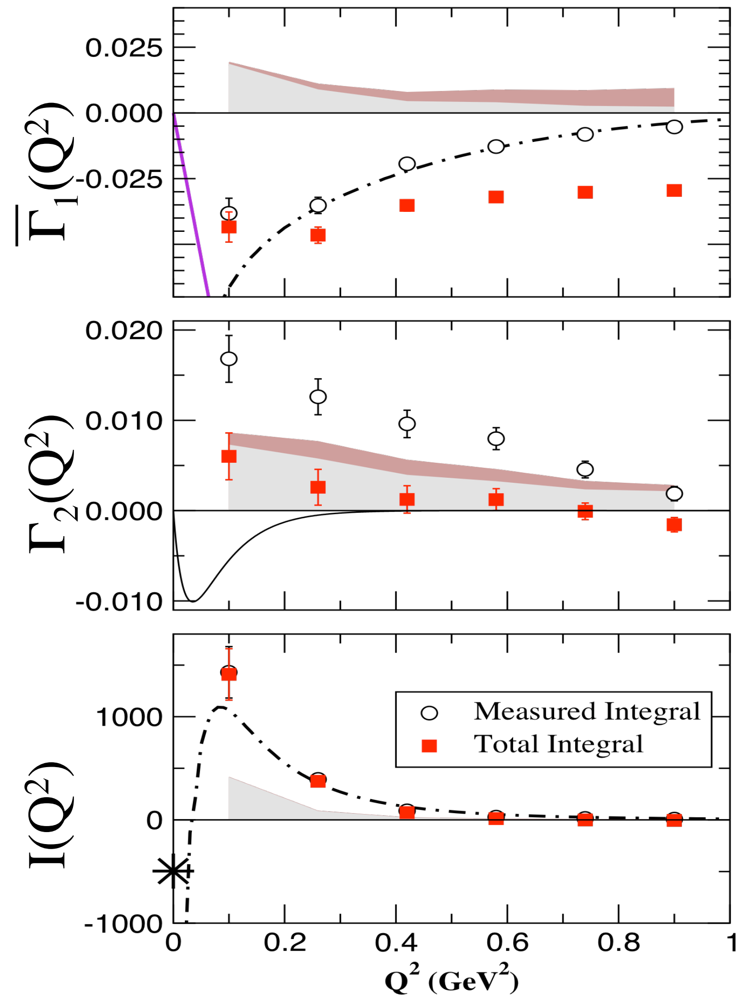
<u>Primary goal:</u> spin duality

^{3}He: low Q^2 Structure functions and sum rules

Hall A

K. Slifer et al., arXiv:0803.2267 (submitted to PRL)





^3He: low Q^2 Structure functions and sum rules

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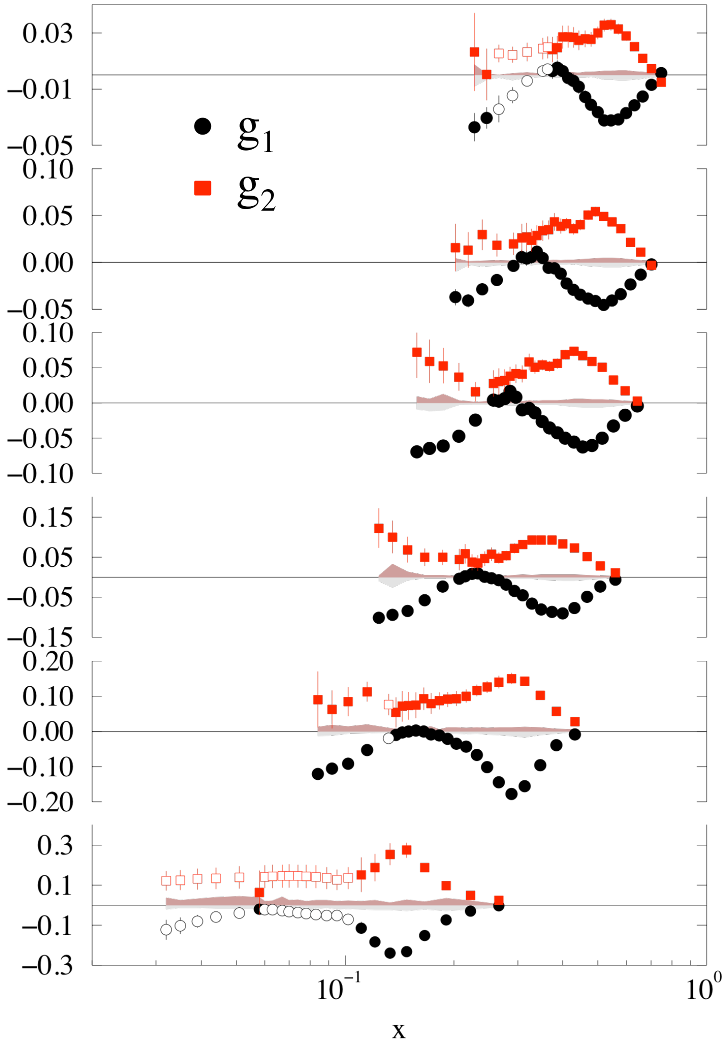

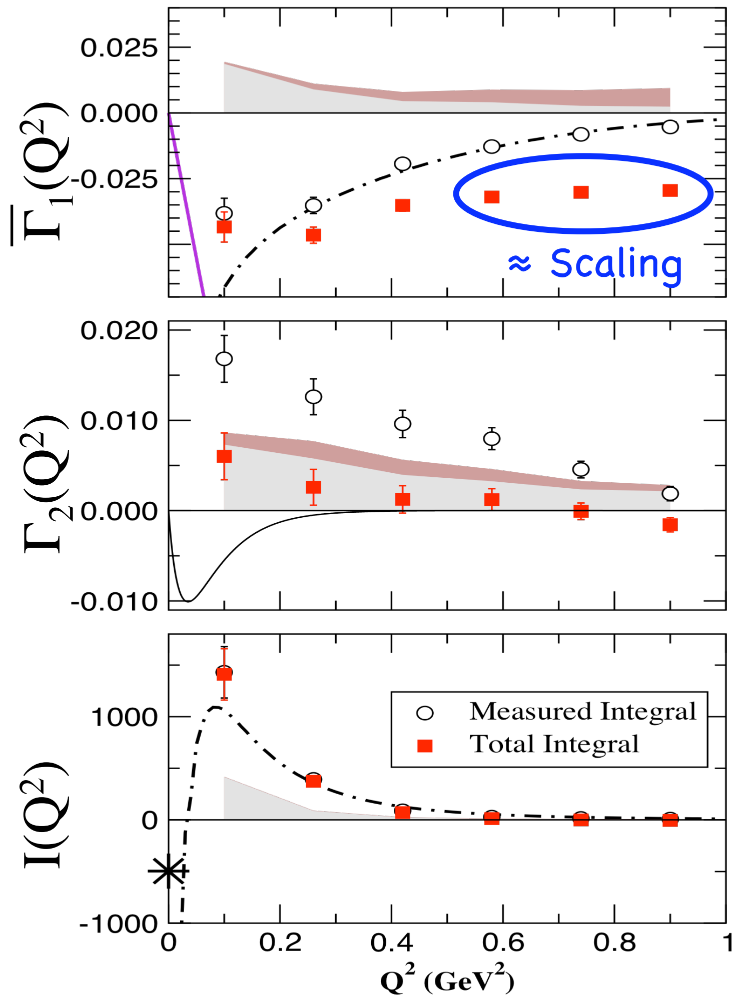

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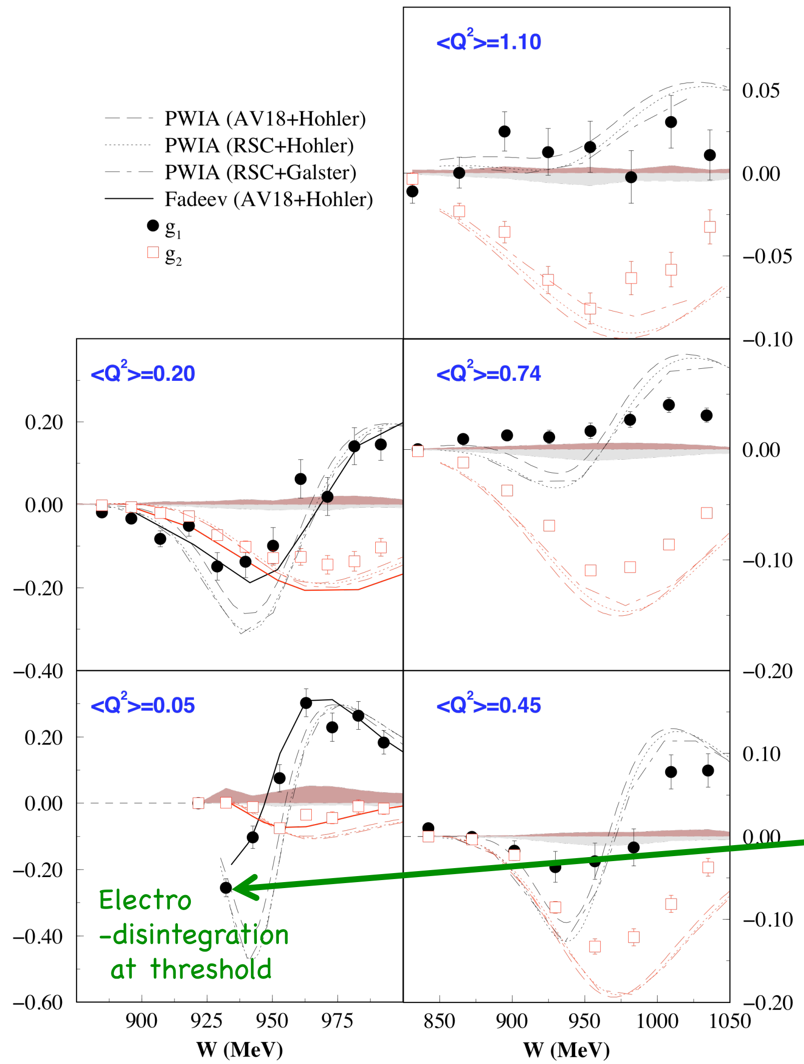
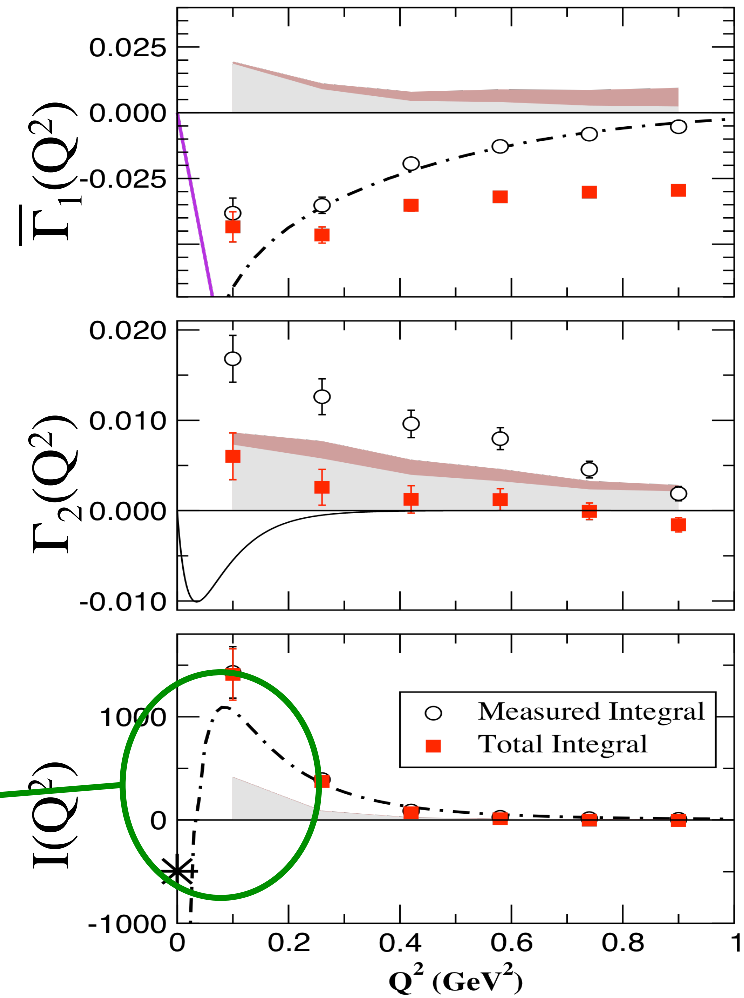
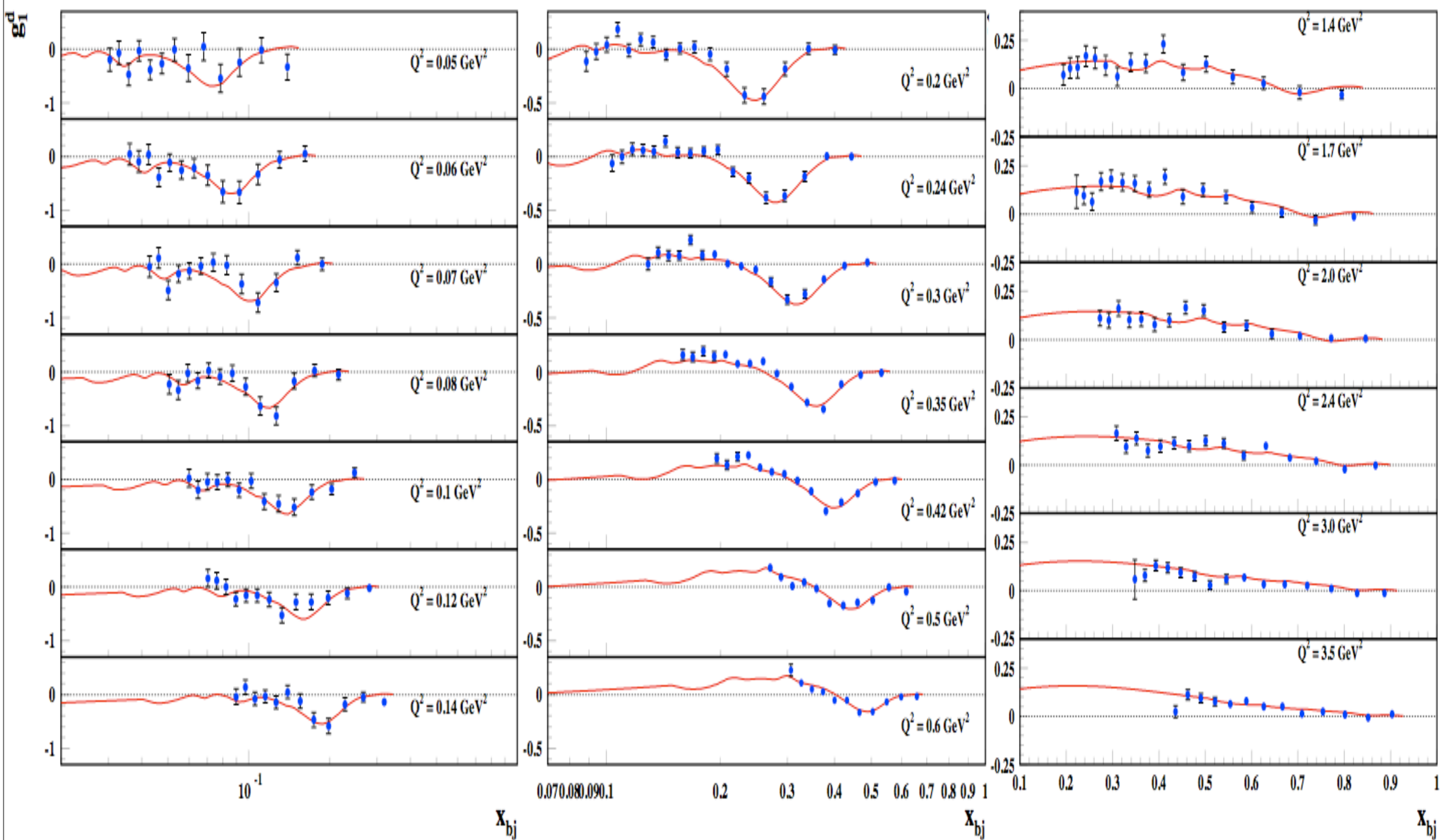




Deuterium: Structure function g_1^d (per nucleon)

Hall B



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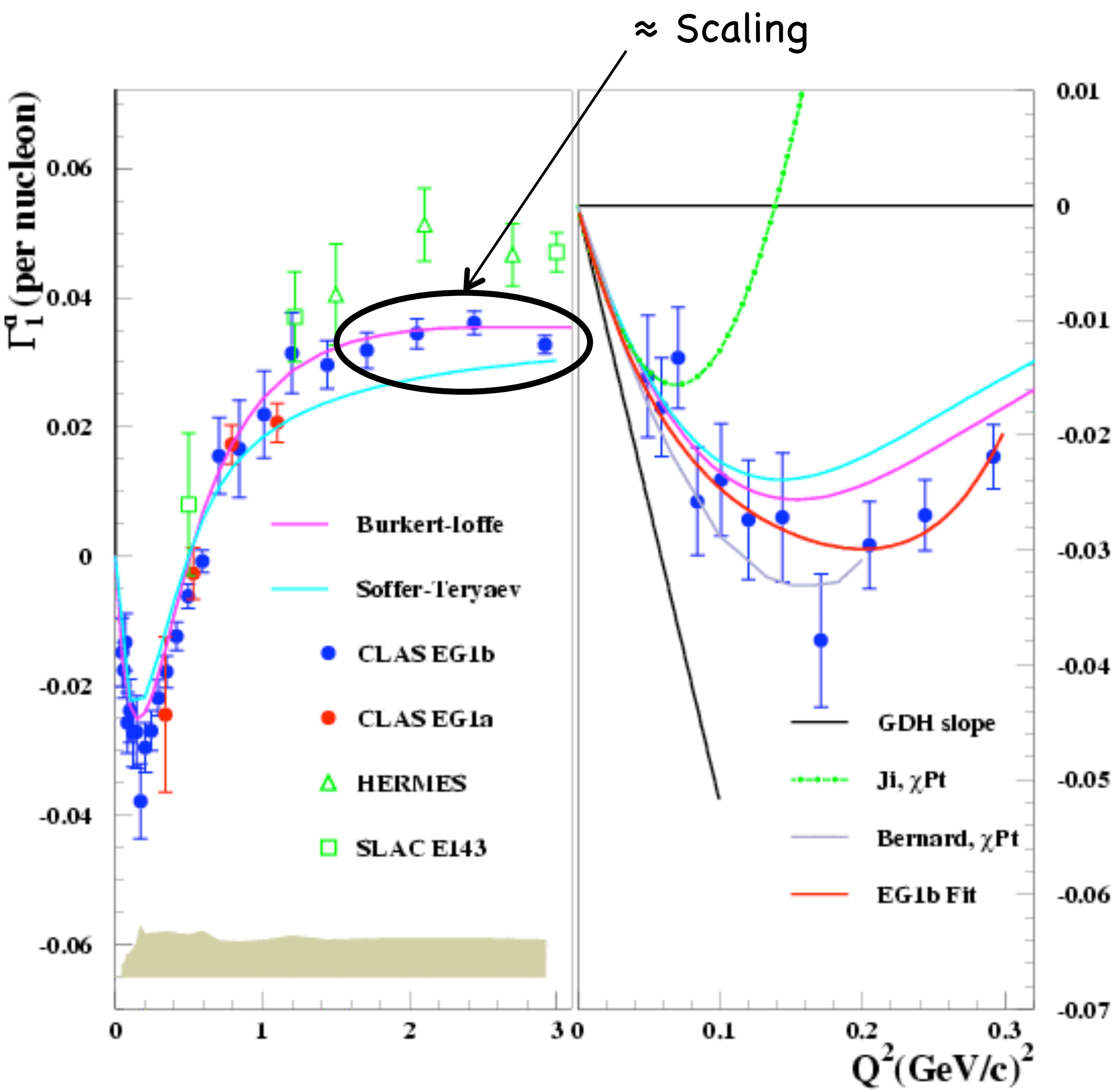
Deuterium: first moment

Hall B

Y. Prok et al., arXiv:0802.2232
(submitted to PRL)



Observation of turn over at low Q^2 as expected from GDH slope

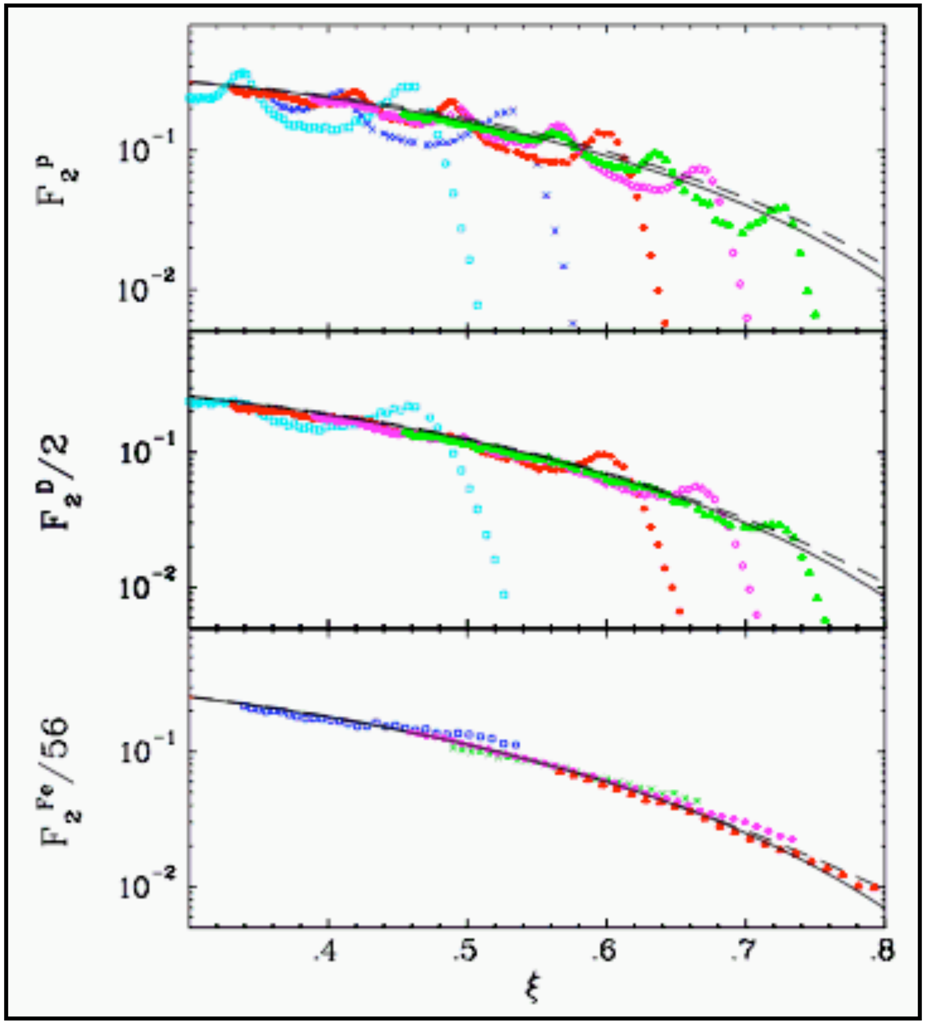
Quark-hadron duality

First observed by Bloom and Gilman in the 1970's on F_2:

Scaling curve seen at high Q^2 is an accurate average over the resonance region at lower Q^2

In nuclei, the averaging is in part done by the Fermi motion.

J. Arrington, et al., PRC73:035205 (2006)



Spin Duality

Bianchi, Fantoni and Liuti, PRD 69 014505 (2004)

1) Determine g_1^{res} at constant Q^2
2) Integrate over region of interest (local or global)
3) Compare to DIS result evolved to same Q^2

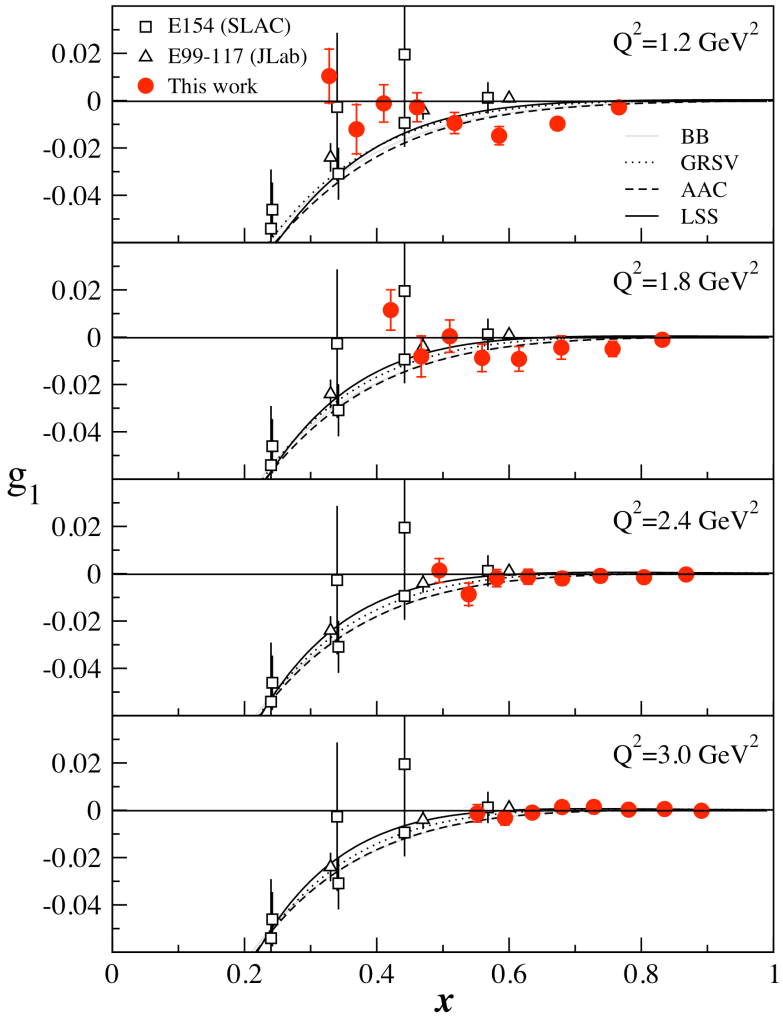
$$\Gamma_1^{res}(Q^2) \equiv \int_{x\,min}^{x\,max} g_1^{res}\, dx \qquad \Gamma_1^{dis}(Q^2) \equiv \int_{x\,min}^{x\,max} g_1^{dis}\, dx$$

$$\Gamma_1^{res}(Q^2) = \Gamma_1^{dis}(Q^2) \Rightarrow Duality$$

Spin duality on ^3He

Hall A

P. Solvignon et al., arXiv:0803.3845 (submitted to PRL)



Target mass corrections were applied on PDFs

Spin duality on ^3He

Hall A

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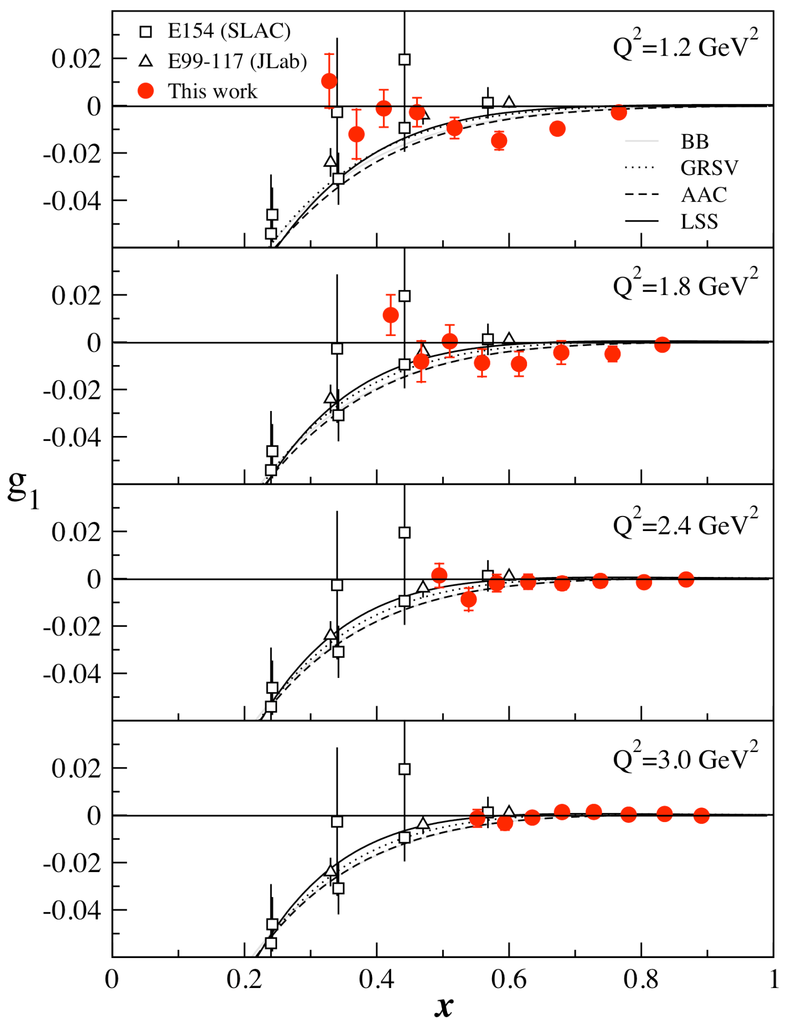

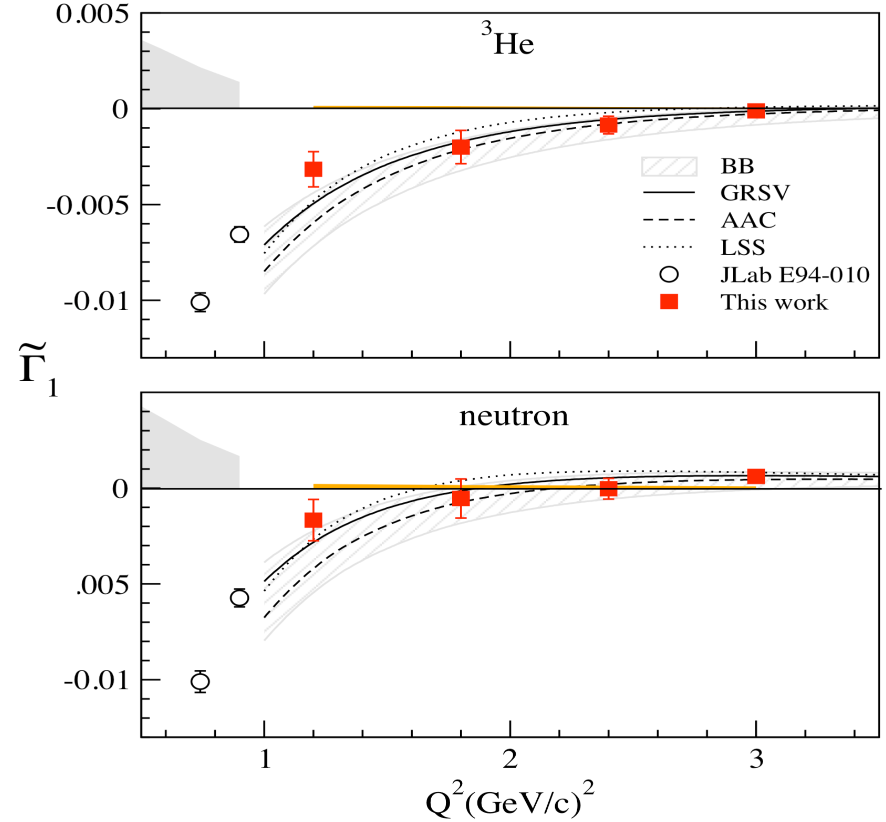

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P. Solvignon et al., arXiv:0803.3845
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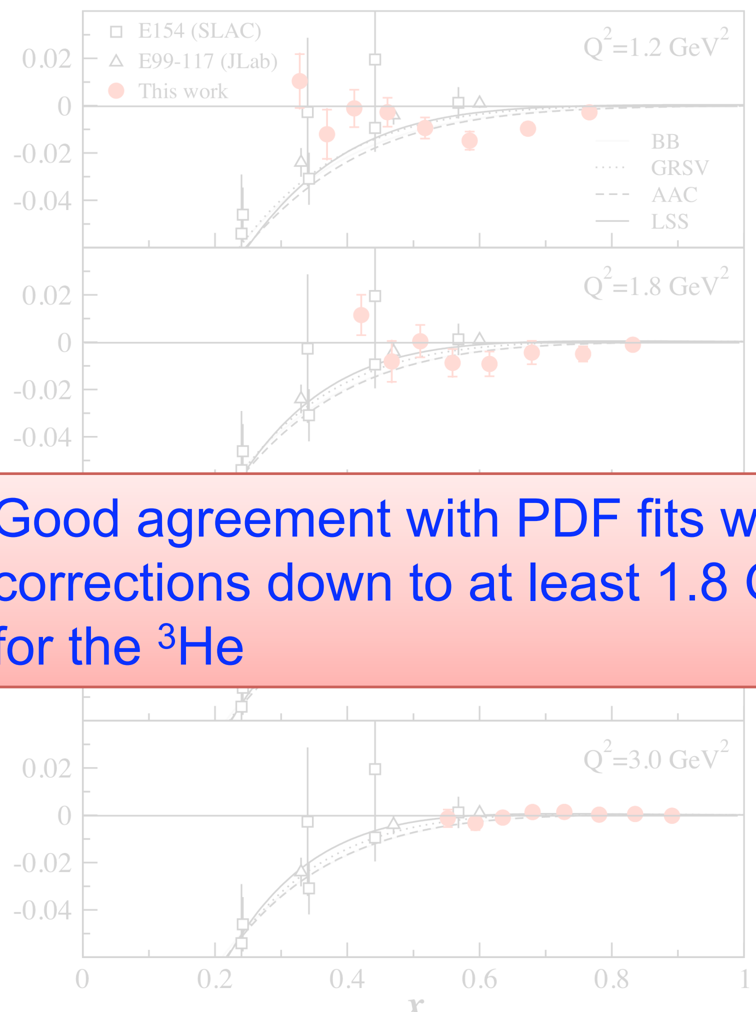
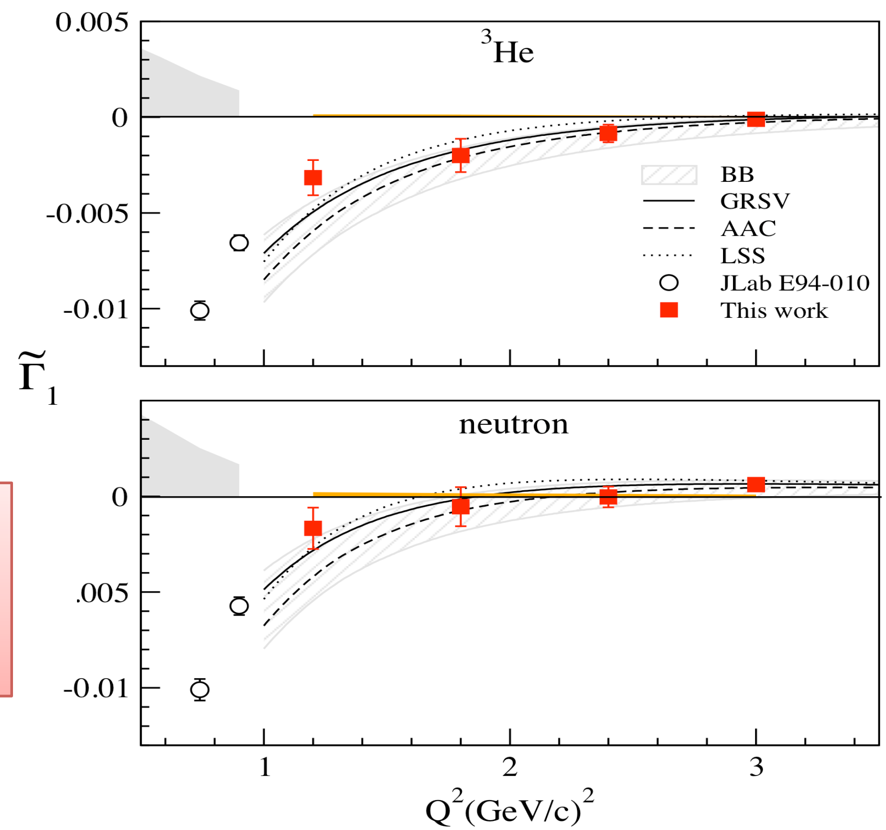


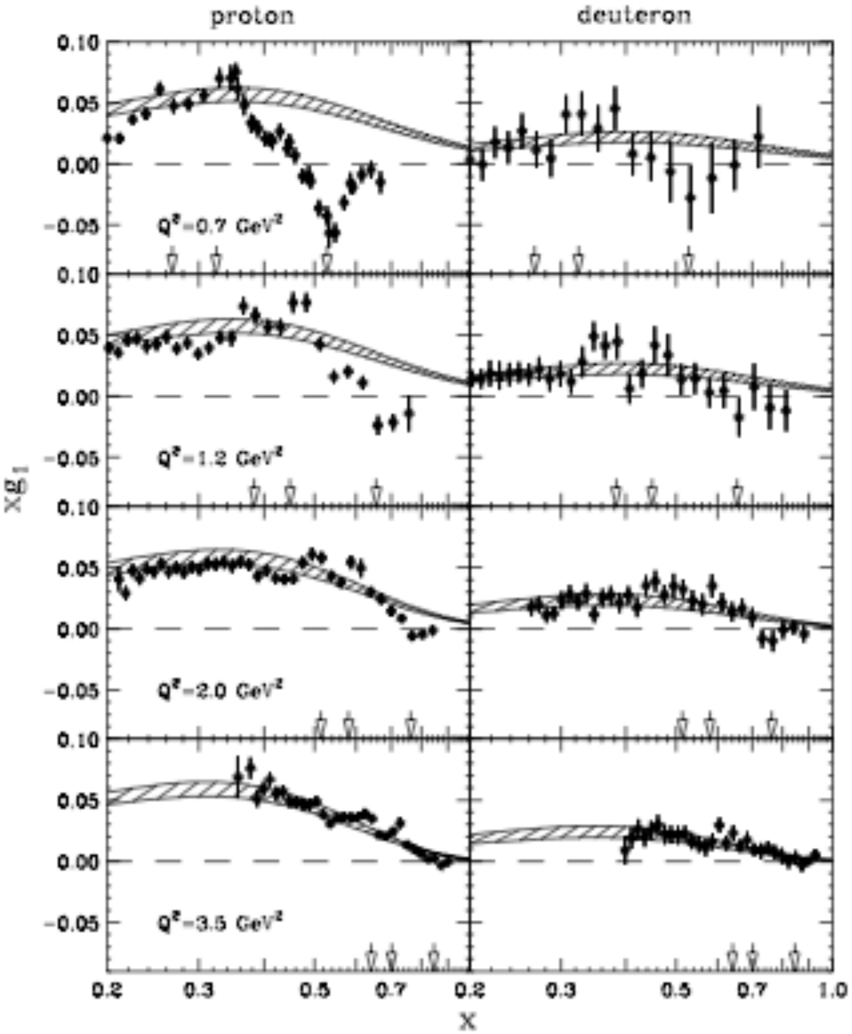
Good agreement with PDF fits with TM corrections down to at least 1.8 GeV^2 for the ^3He

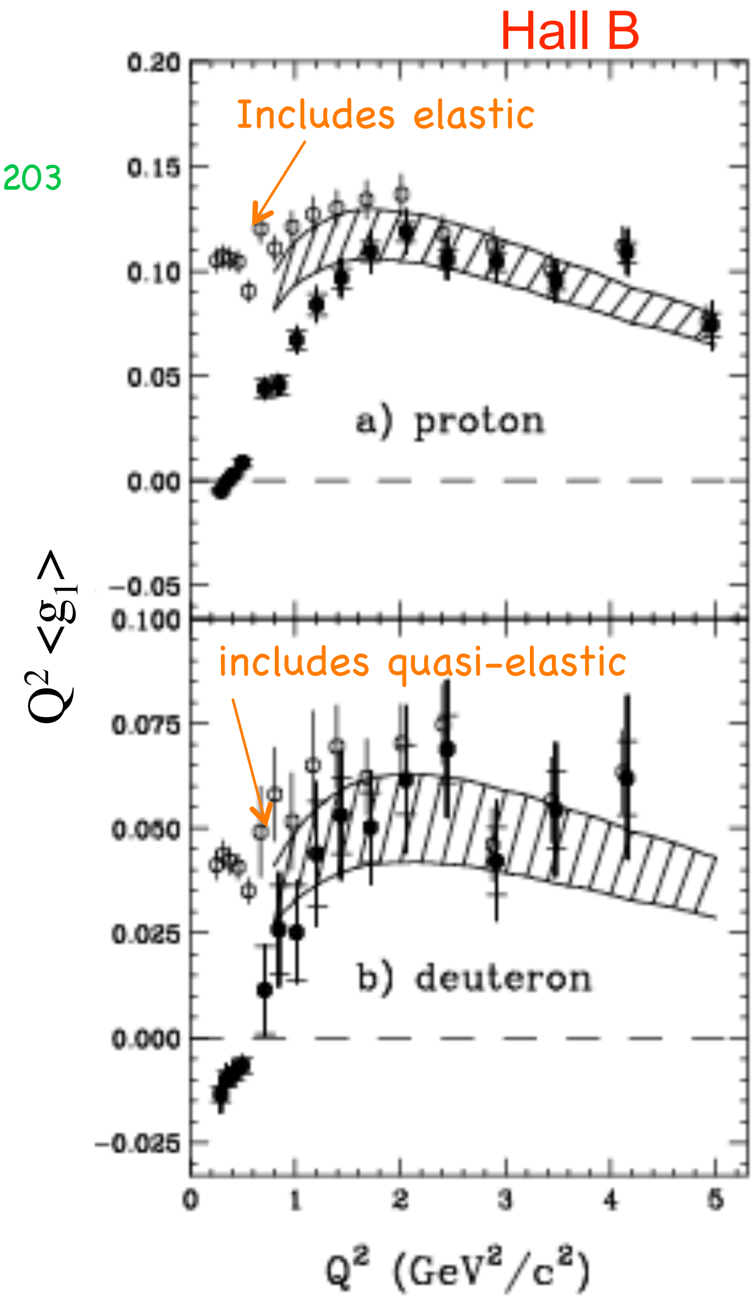


Target mass corrections
were applied on PDFs

Spin Duality on deuterium

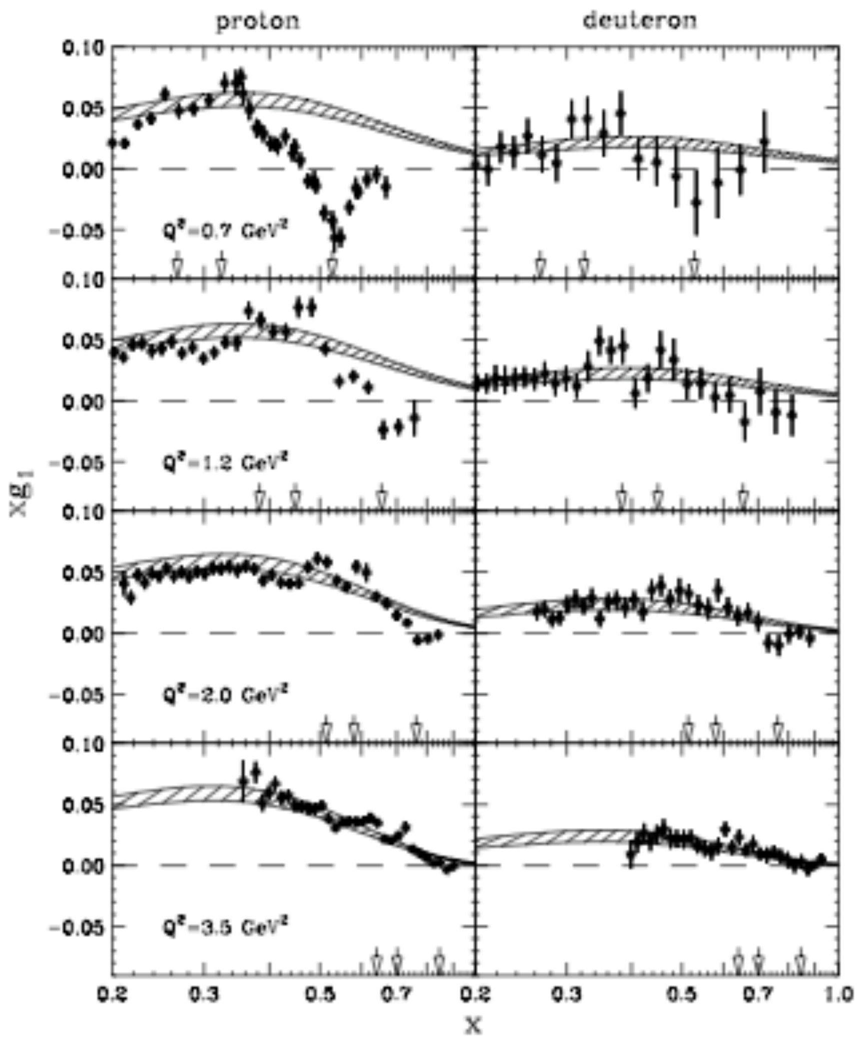
P. Bosted et al., PRC75 (2007) 035203





Spin Duality on deuterium

P. Bosted et al., PRC75 (2007) 035203

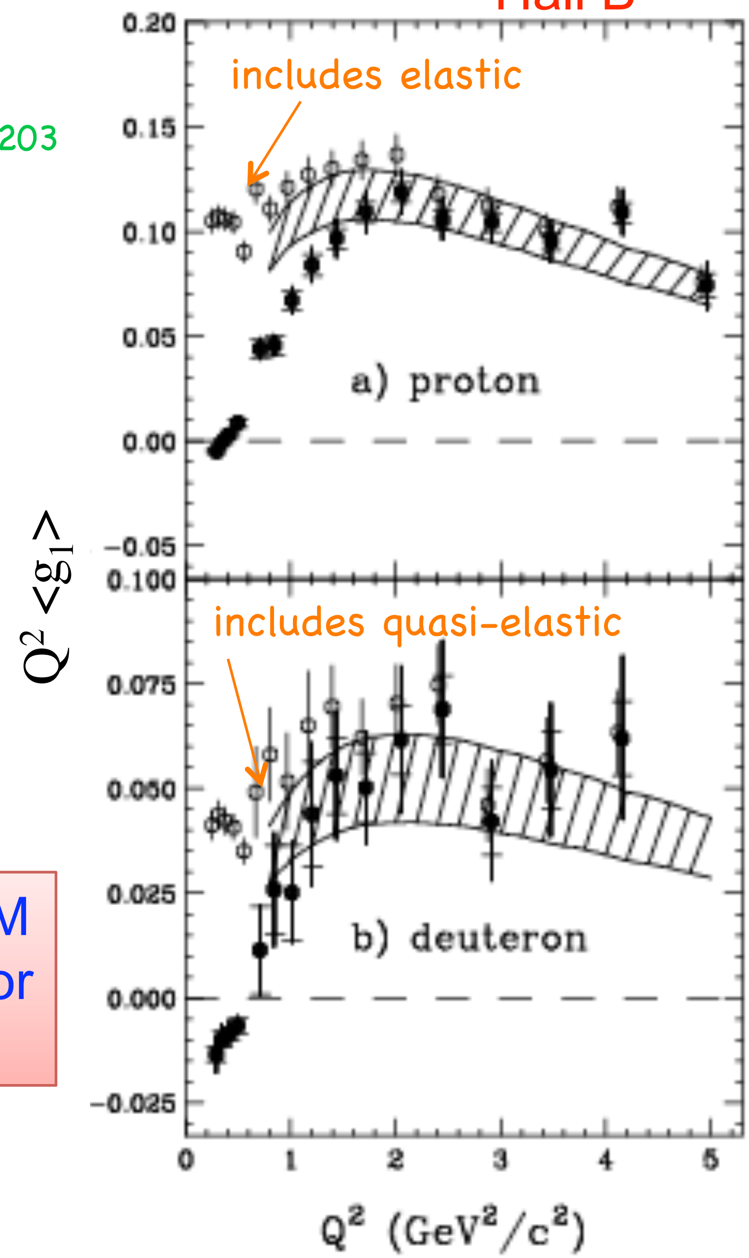


Spin Duality on deuterium

P. Bosted et al., PRC75 (2007) 035203

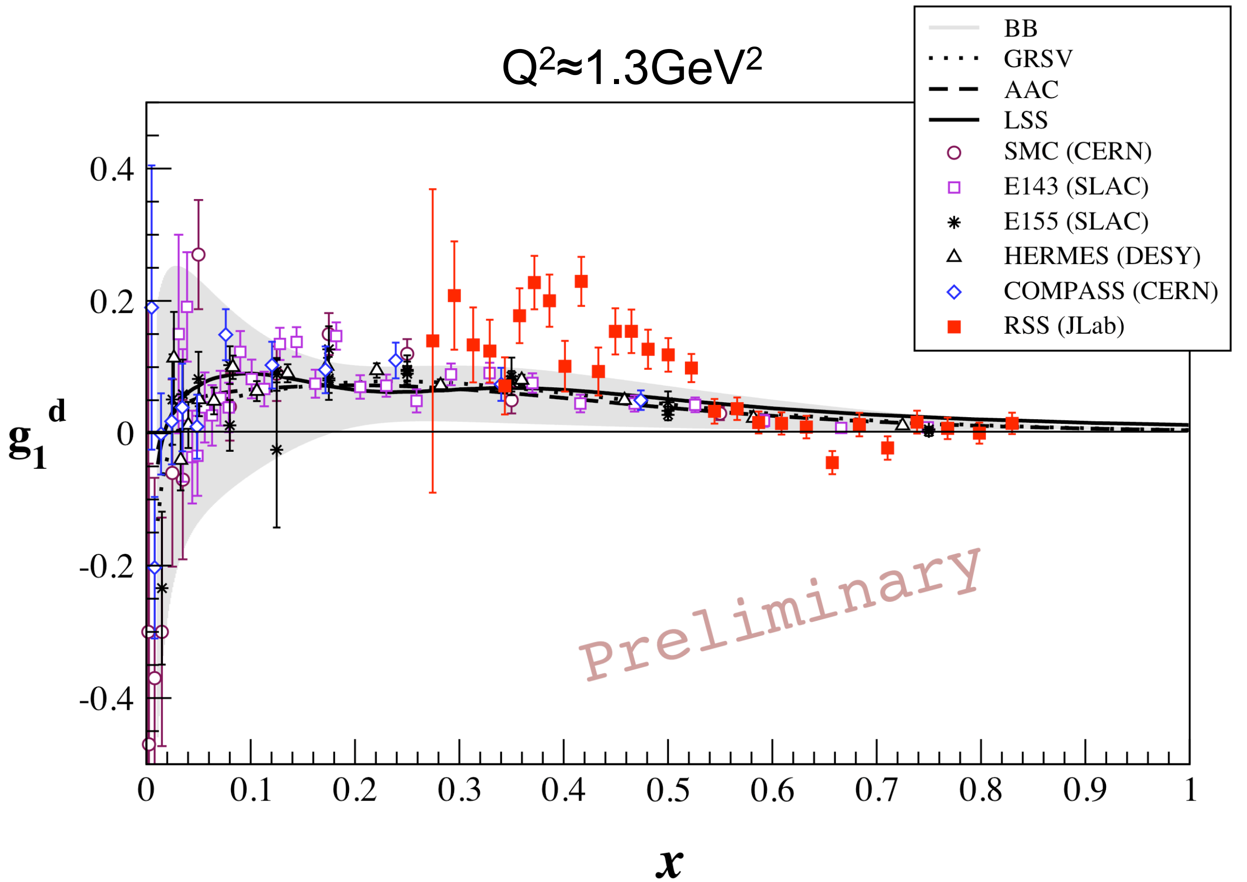
Good agreement with PDF fits with TM corrections down to about 1.2 GeV^2 for the deuteron

Hall B



Spin Duality on deuterium

Hall C

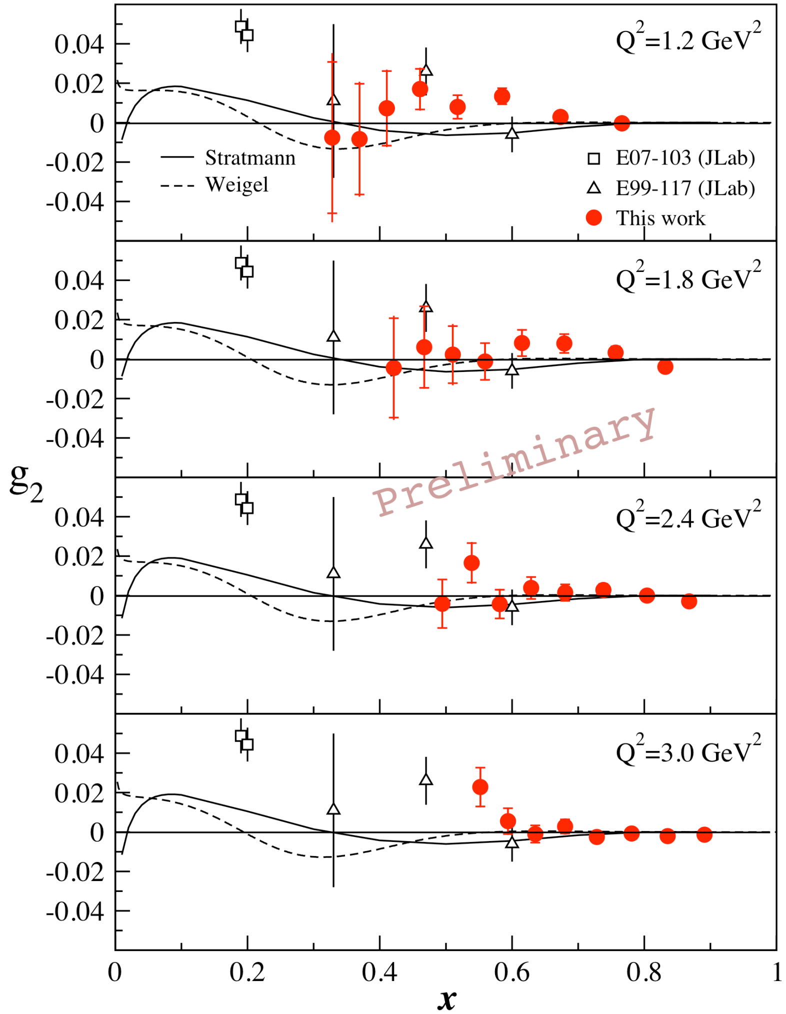


From qualitatively, spin duality doesn't seem to hold at 1.3GeV^2 for the deuteron ≠ Hall B

→ but low statistics

Structure function g_2^{3He} at moderate Q^2

Hall A

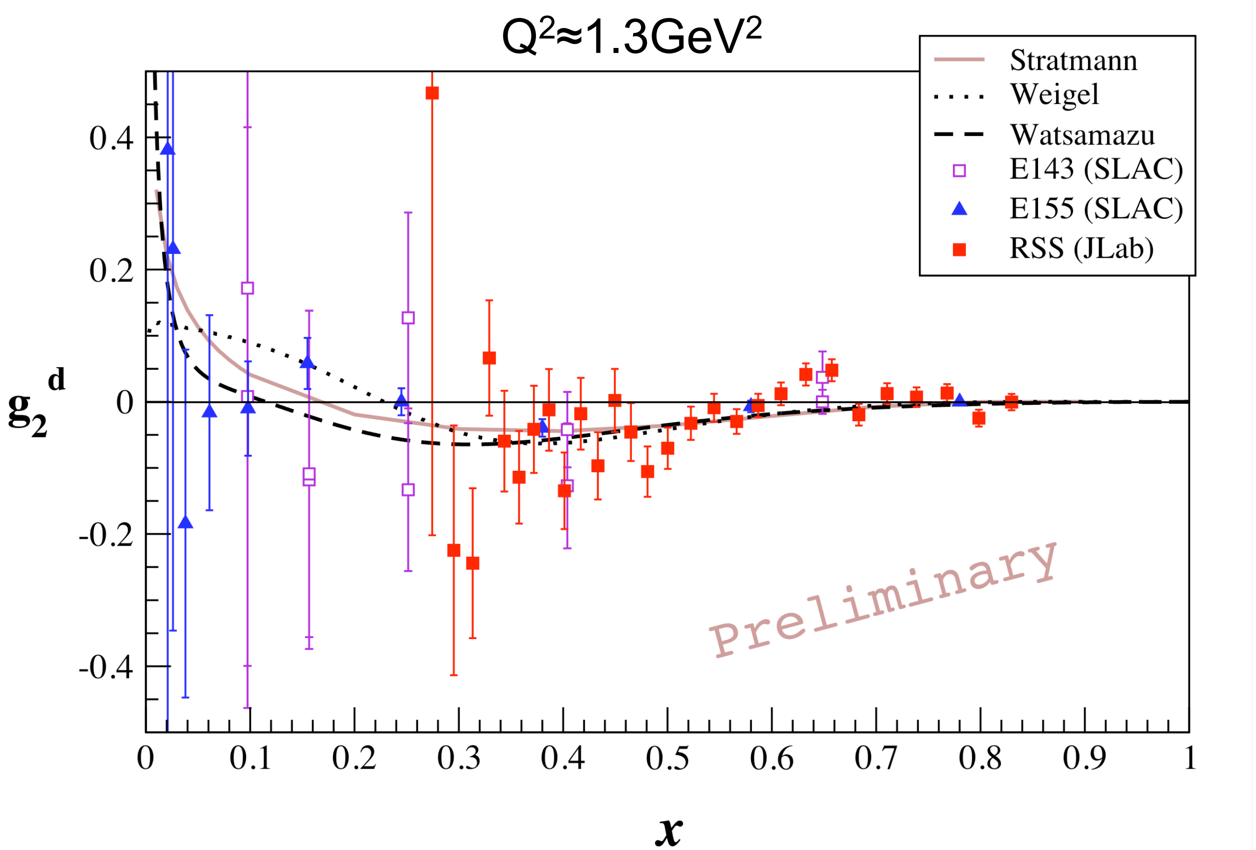


<u>Early observation</u>: above Q^2≈ 1.8 GeV^2, qualitative good agreement in average with models

Comparison with g_2^{WW} will give an estimate of the size of the HT effects

Structure function g_2^d at moderate Q^2

Hall C



Early observation: qualitative good agreement in average with models

Virtual photon-nucleon asymmetry

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

with $\gamma^2 = \frac{4M^2x^2}{Q^2}$

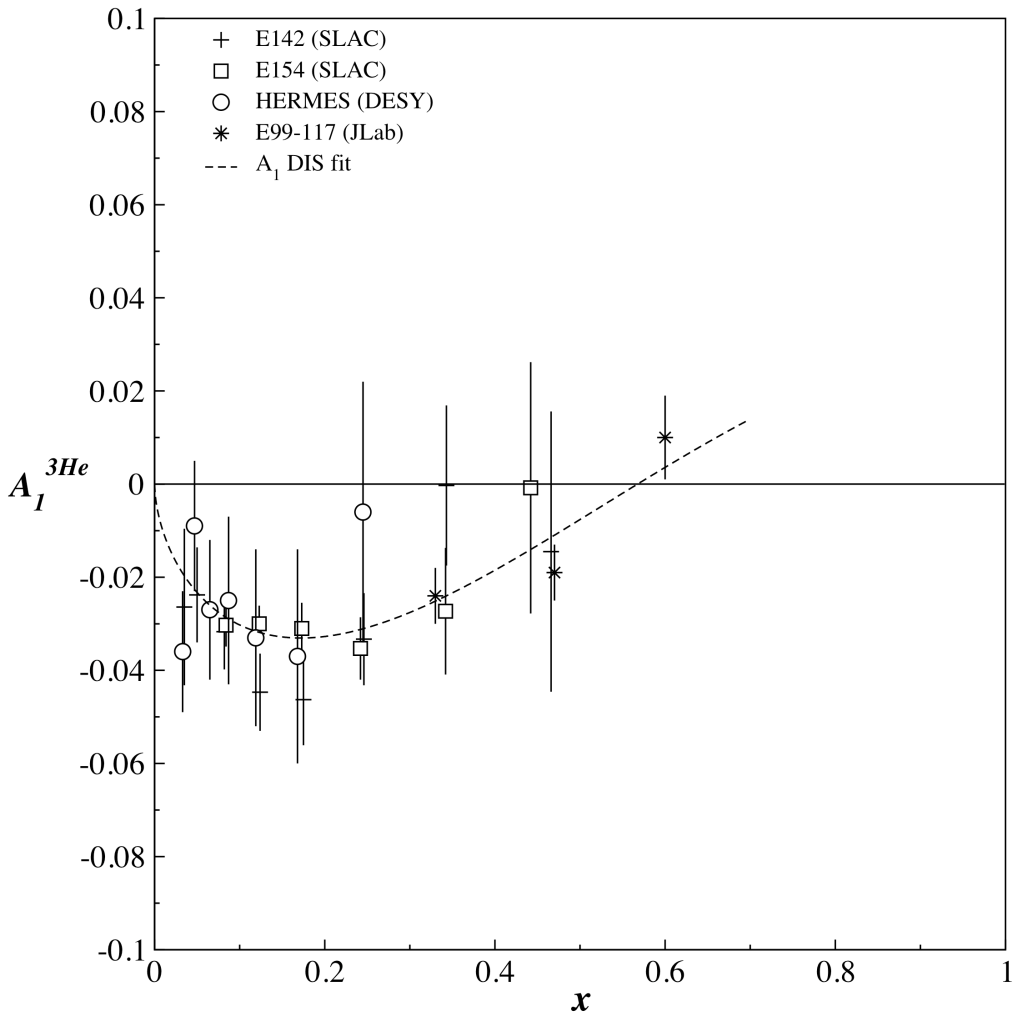
In the parton model:

$$A_1 = \frac{g_1}{F_1}$$

If Q^2 dependence similar for g_1 and for F_1 $\Rightarrow$ weak Q^2 dependence of A_1

A_1 for ^3He

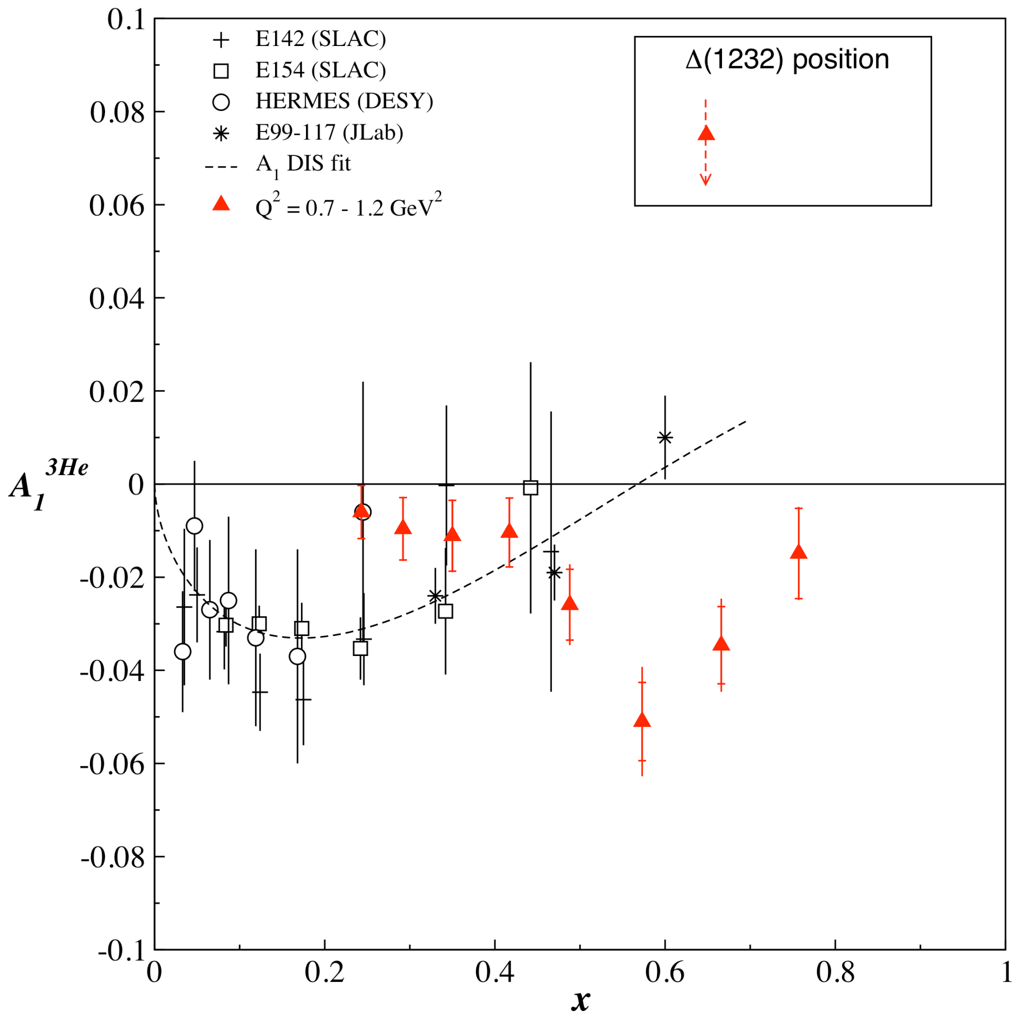
Hall A



A_1 for ^3He

Hall A

P. Solvignon et al., arXiv:0803.3845
(submitted to PRL)

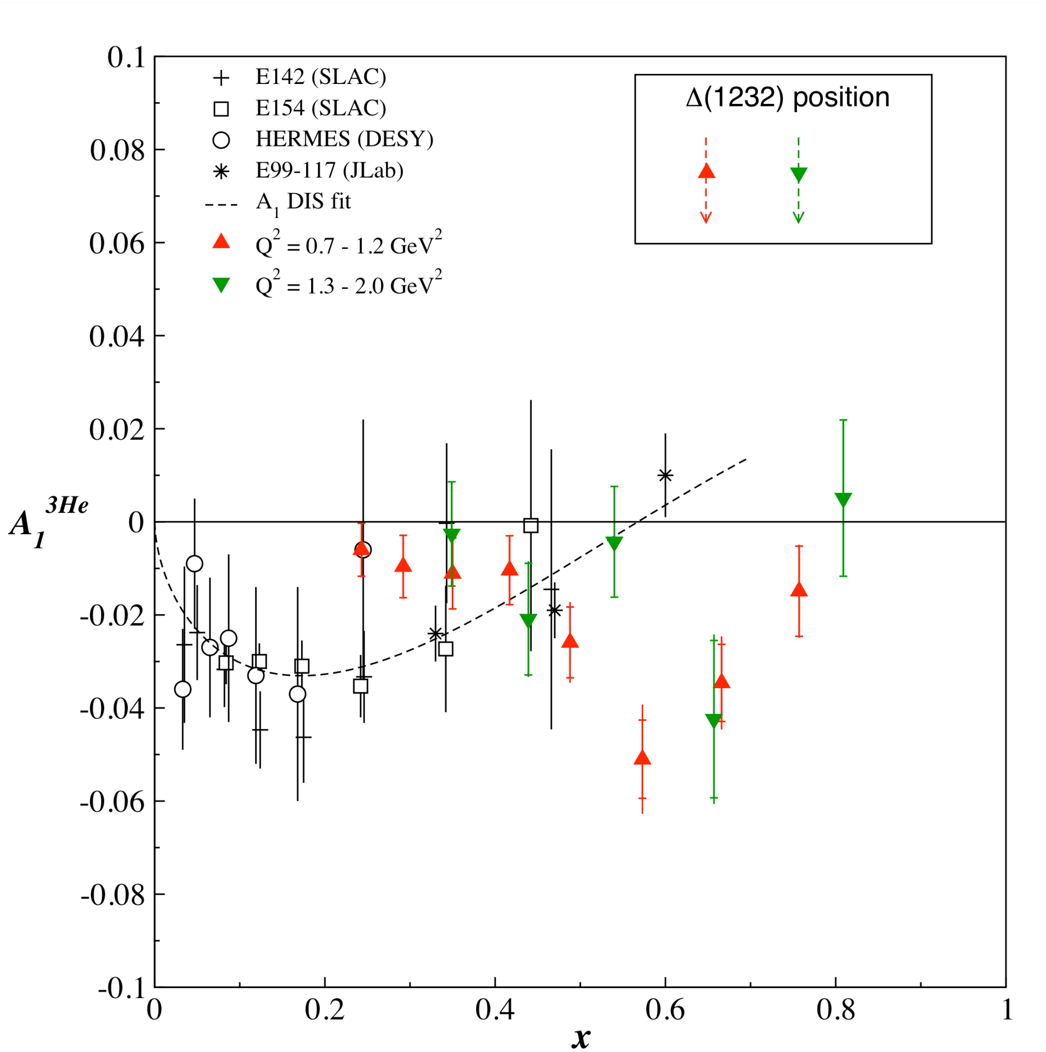


Large negative value in the Δ(1232) region

A_1 for ^3He

Hall A

P. Solvignon et al., arXiv:0803.3845 (submitted to PRL)



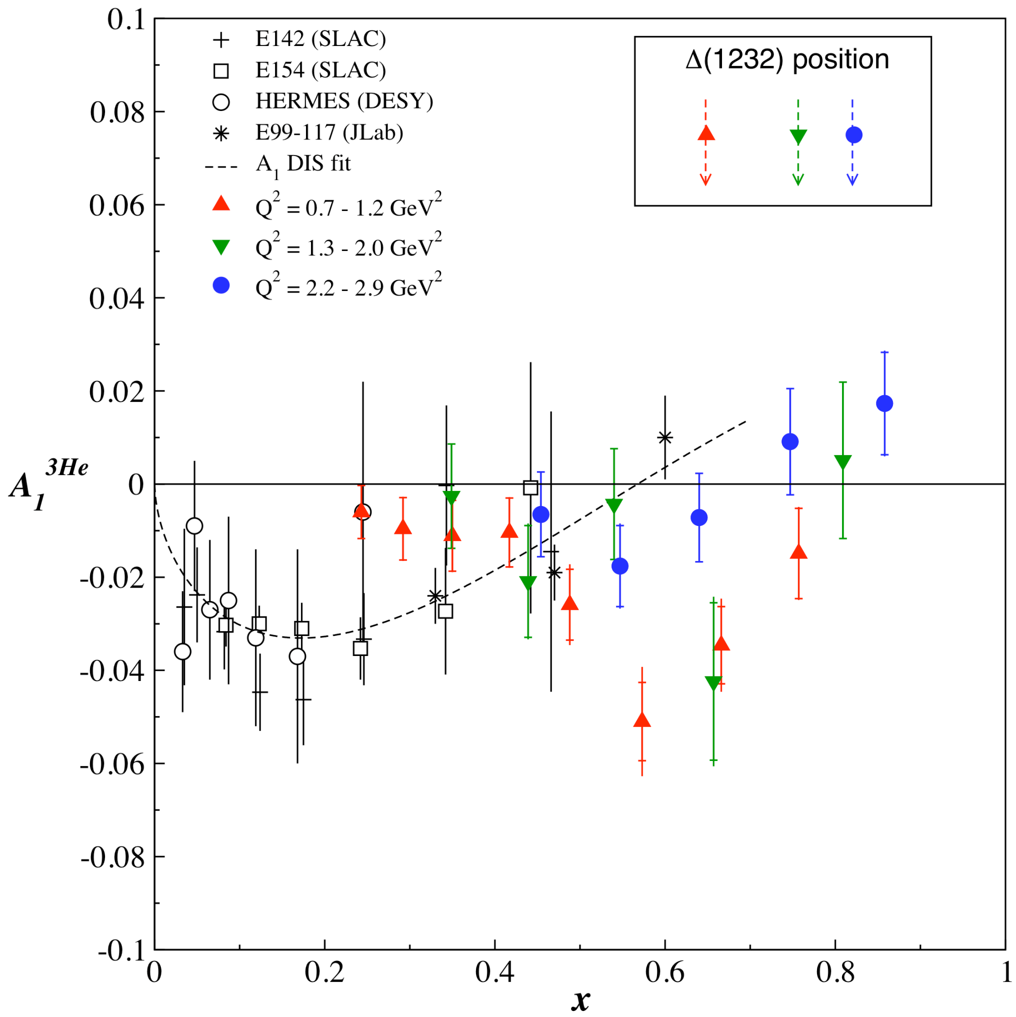
Large negative value in the Δ(1232) region

Still large negative value in the Δ(1232) region

A_1 for ^3He

Hall A

P. Solvignon et al., arXiv:0803.3845 (submitted to PRL)



Large negative value in the $\Delta(1232)$ region

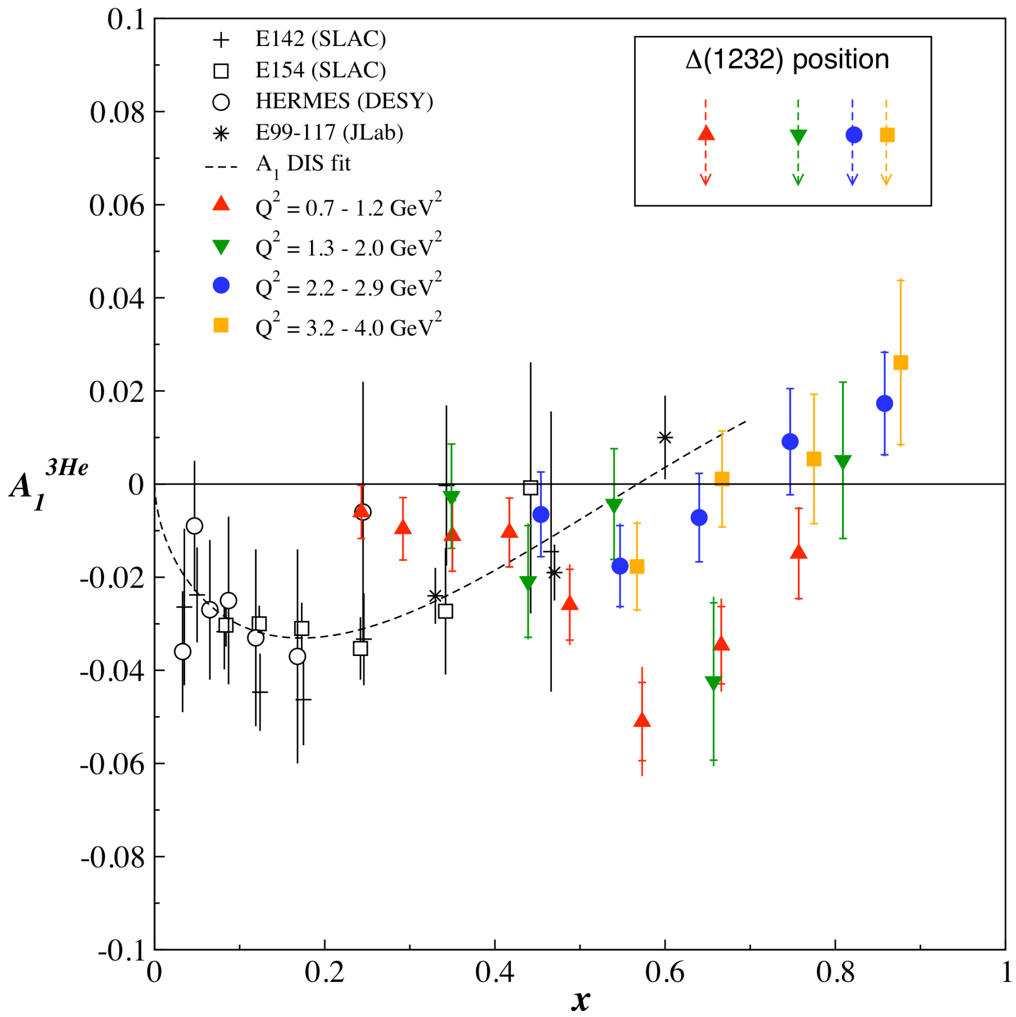
Still large negative value in the $\Delta(1232)$ region

A_1 becomes positive in the $\Delta(1232)$ region due to the drop in the Δ FF and the rising of the DIS background

A_1 for ^3He

Hall A

P. Solvignon et al., arXiv:0803.3845 (submitted to PRL)



Large negative value in the $\Delta(1232)$ region

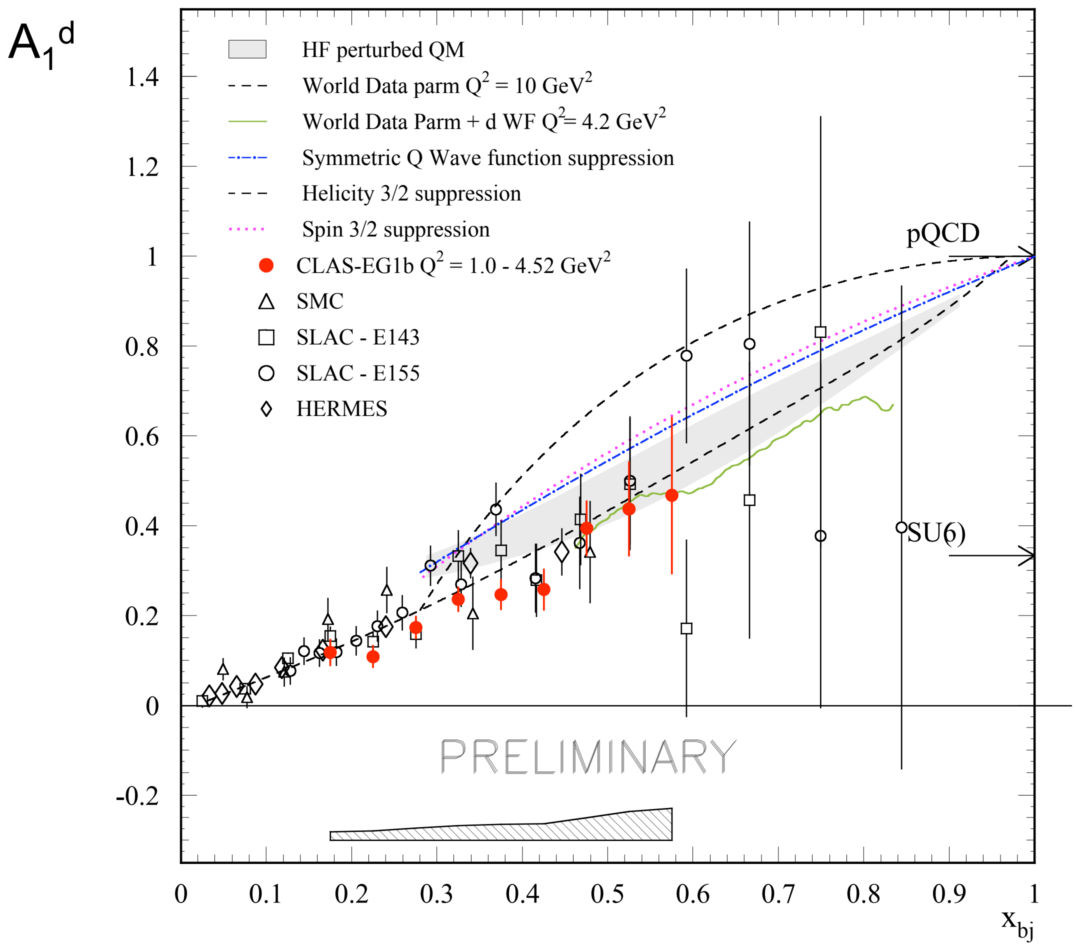
Still large negative value in the $\Delta(1232)$ region

A_1 becomes positive in the $\Delta(1232)$ region due to the drop in the Δ FF and the rising of the DIS background

No strong Q^2-dependence is now observed

A_1 for deuteron

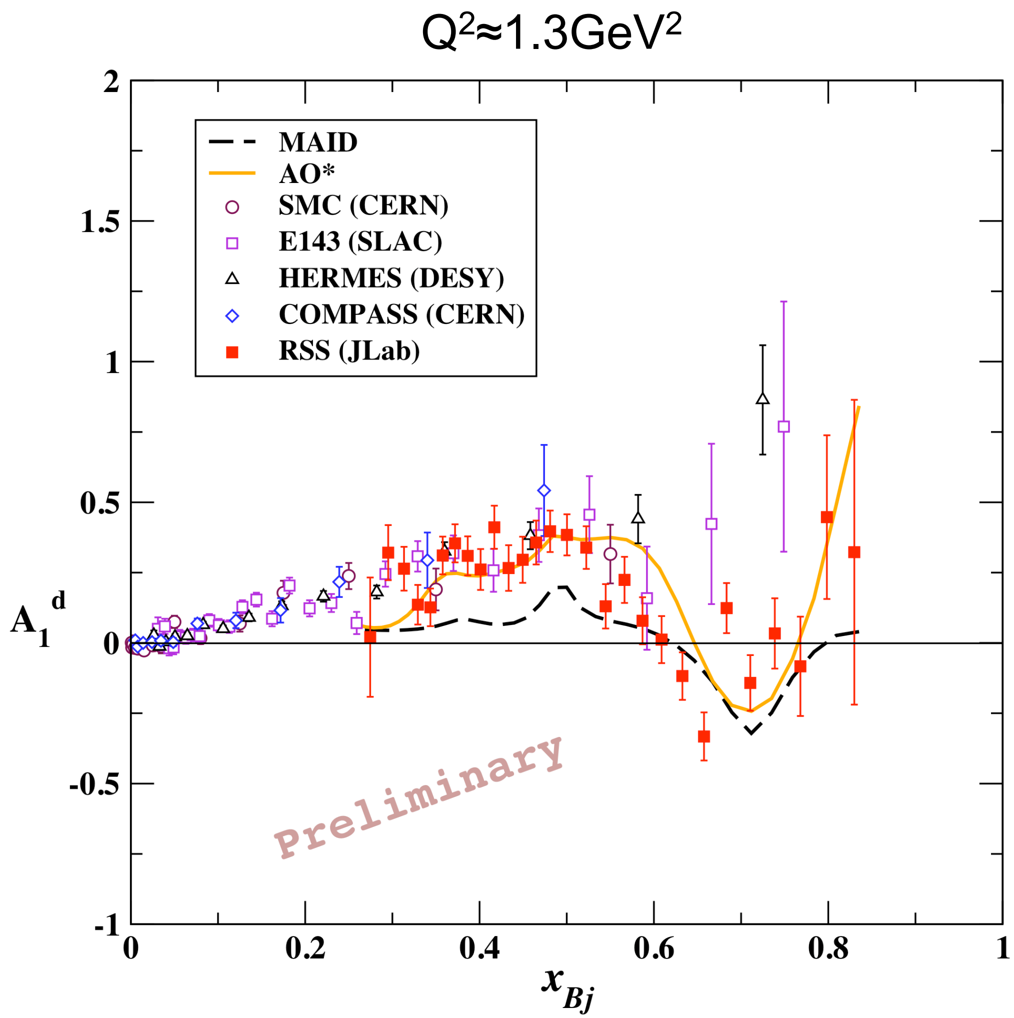
Hall B



High W resonance data are in good agreement with the DIS data

A_1 for deuteron

Hall C

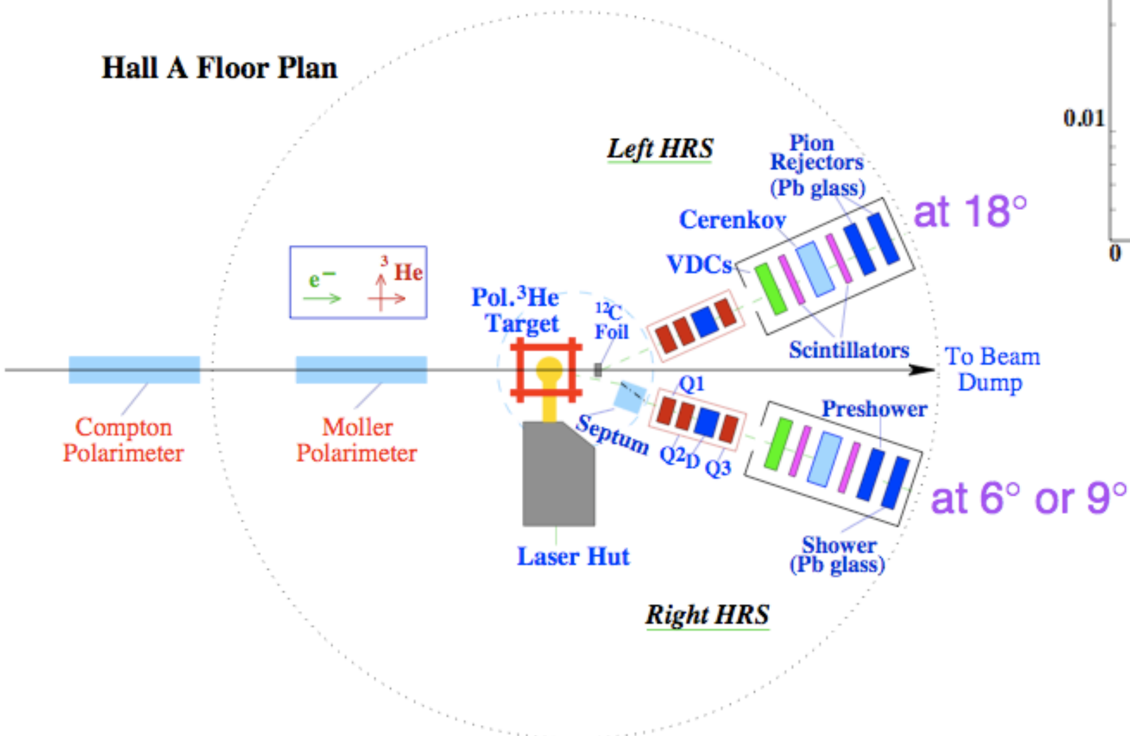


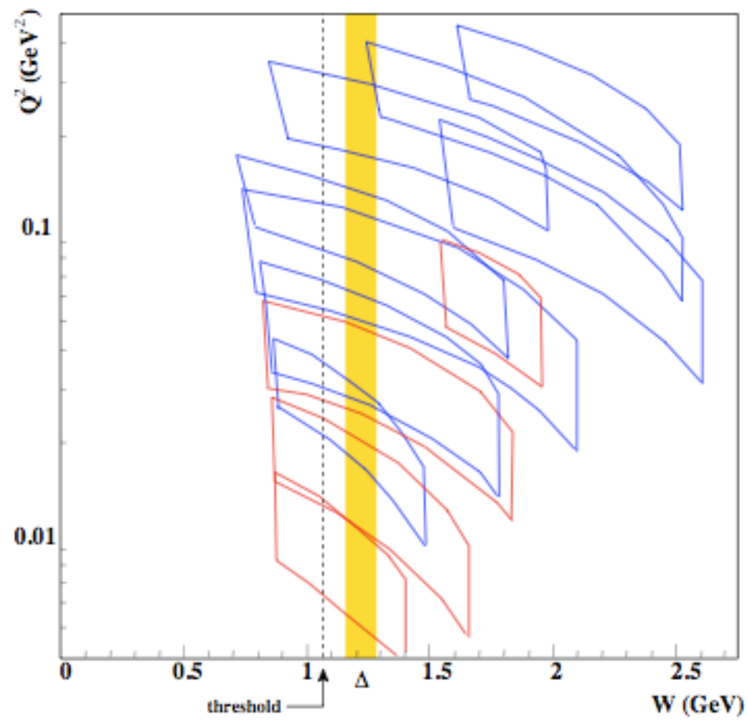
Good agreement between resonance and DIS data for W above the $\Delta(1232)$ region

Jlab Hall A: E97-110

Spokespersons
J-P Chen, A. Deur, F. Garibaldi

PhD. Students
J. Singh, V. Sulkosky, J. Yuan





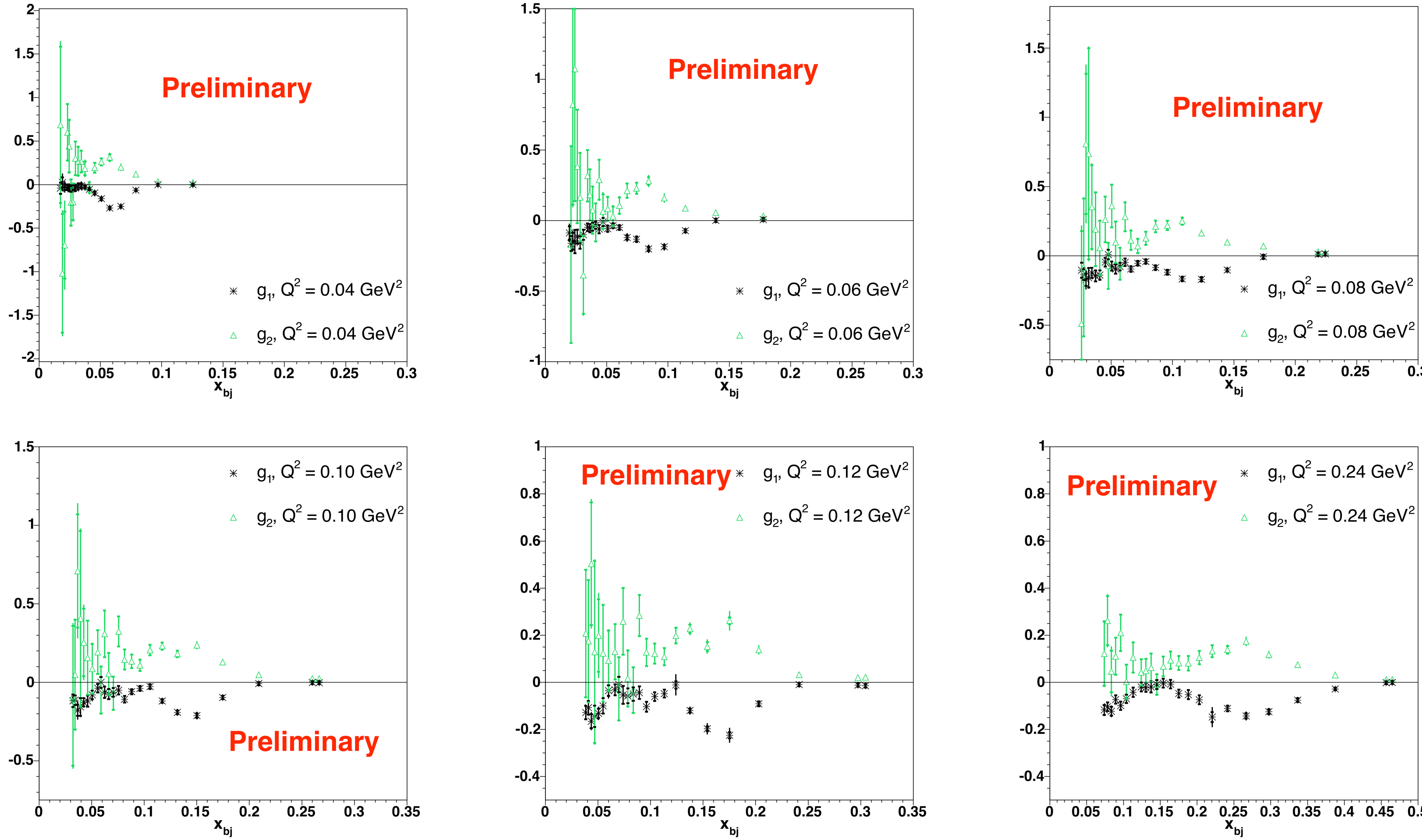
g_1 and g_2

Primary goal: χpt

Low Q^2 Structure functions: g_1 and g_2

Hall A

Figures from V. Sulkosky

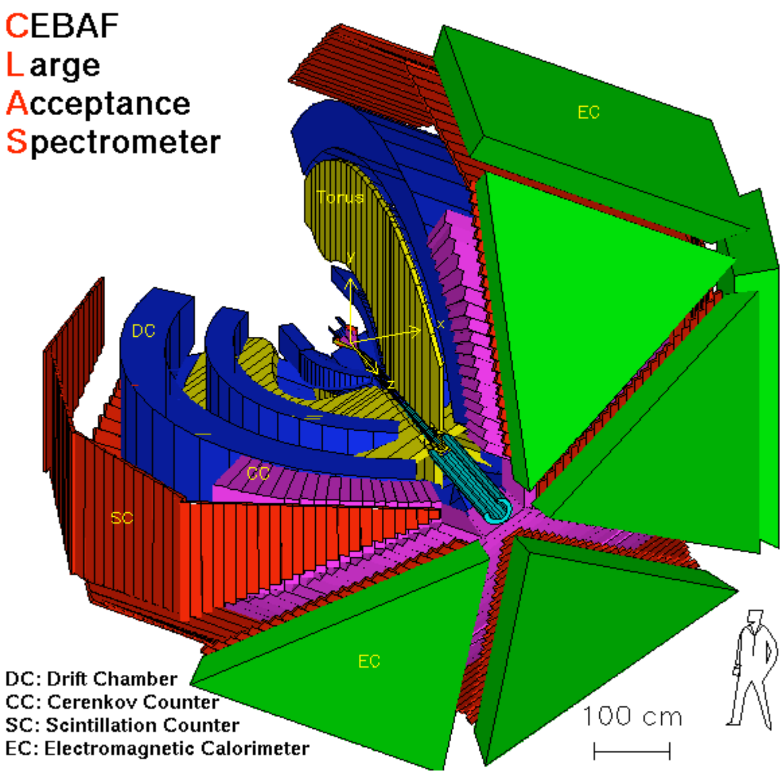


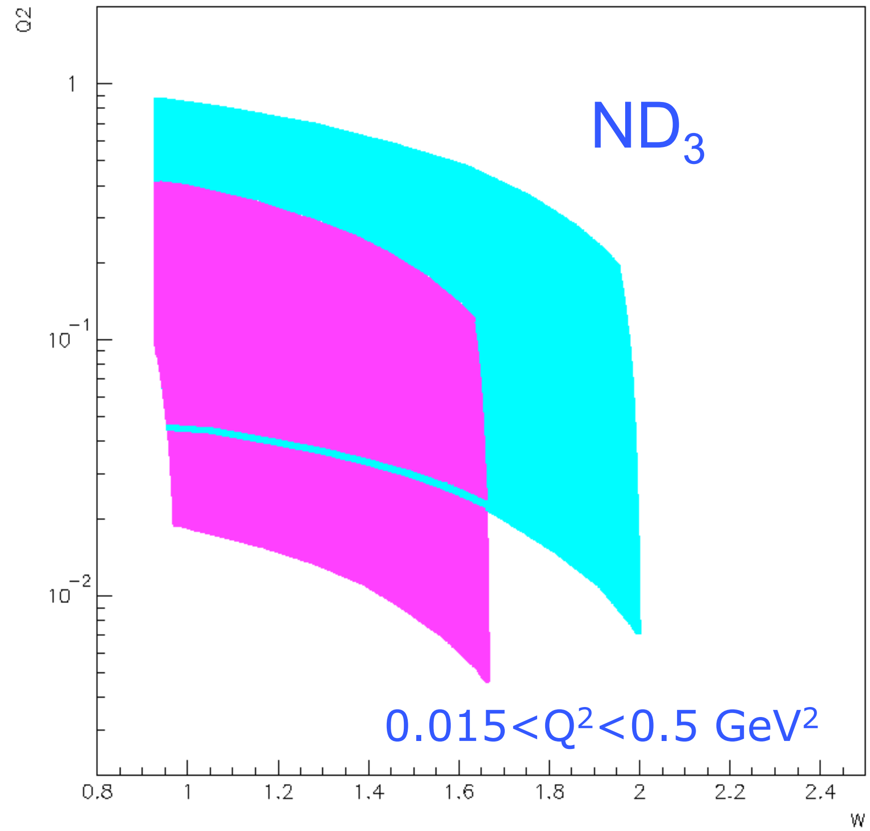
JLab Hall B: EG4

E_0 = 1.3, 2.0 GeV

Spokespersons
NH_3: M. Battaglieri, A. Deur, R. De Vita, M. Ripani (Contact)
ND_3: A. Deur(Contact), G. Dodge, K. Slifer

PhD. Students
K. Adhikari, H. Kang, K. Kovacs





g_1

Primary goal: χpt

JLab Hall B: EG4

Spokespersons

NH_3: M. Battaglieri, A. Deur, R. De Vita, M. Ripani (Contact)

ND_3: A. Deur(Contact), G. Dodge, K. Slifer

PhD. Students

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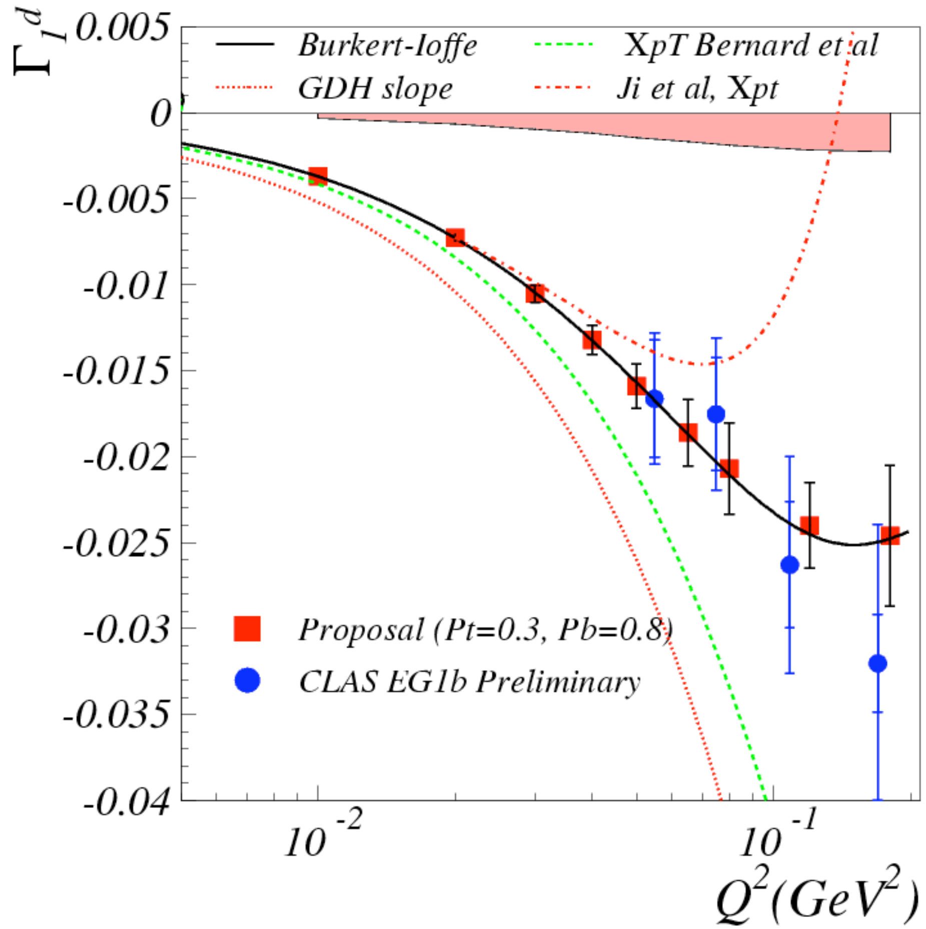

Summary

- Rich study of ^3He spin structure in the resonance region for $0.04<Q^2<4.0$ GeV^2
  - ✓ Precision test of the extended GDH and BC sum rules
  - ✓ Observation of spin duality for Q^2 down to at least 1.8GeV^2
  - ✓ A_1 shows no strong Q^2-dependence above $Q^2 \approx 2.0$GeV^2

- Same coverage for the study of deuterium spin structure in the resonance region, except for the lack of coverage for the perpendicular data:
  - ✓ First moment of g_1 shows the turn over required by the GDH slope
  - ✓ Observation of spin duality for Q^2 down to at least 1.5GeV^2
  - ✓ A_1 shows same trend as DIS data for W above the $\Delta(1232)$ region

All these results have the advantage to be free from nuclear corrections