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Quark-hadron duality in neutron spin structure and g_2 moments at intermediate Q^2

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Spin Structure at long distance

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U.S. Department of Energy

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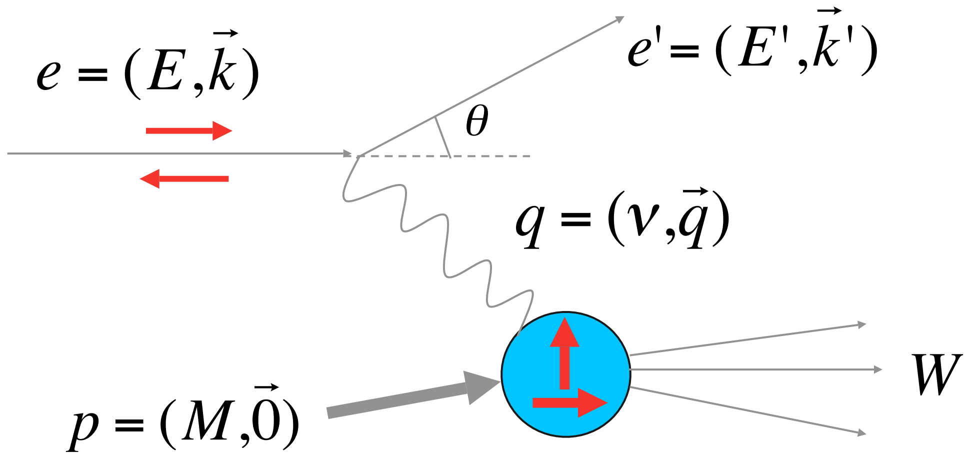
Inclusive electron scattering



Unpolarized case

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\tfrac{\theta}{2}\right]$$

Polarized case

$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{\nu E Q^2}\left[(E + E'\cos\theta)g_1(x,Q^2) - 2Mxg_2(x,Q^2)\right]$$

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

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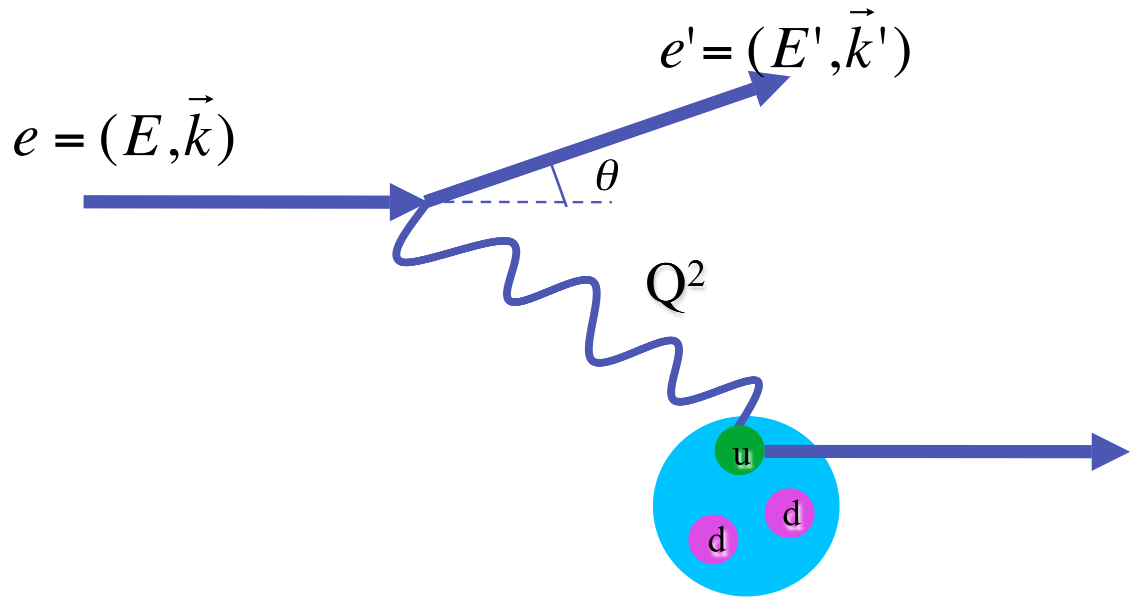
Deep inelastic scattering



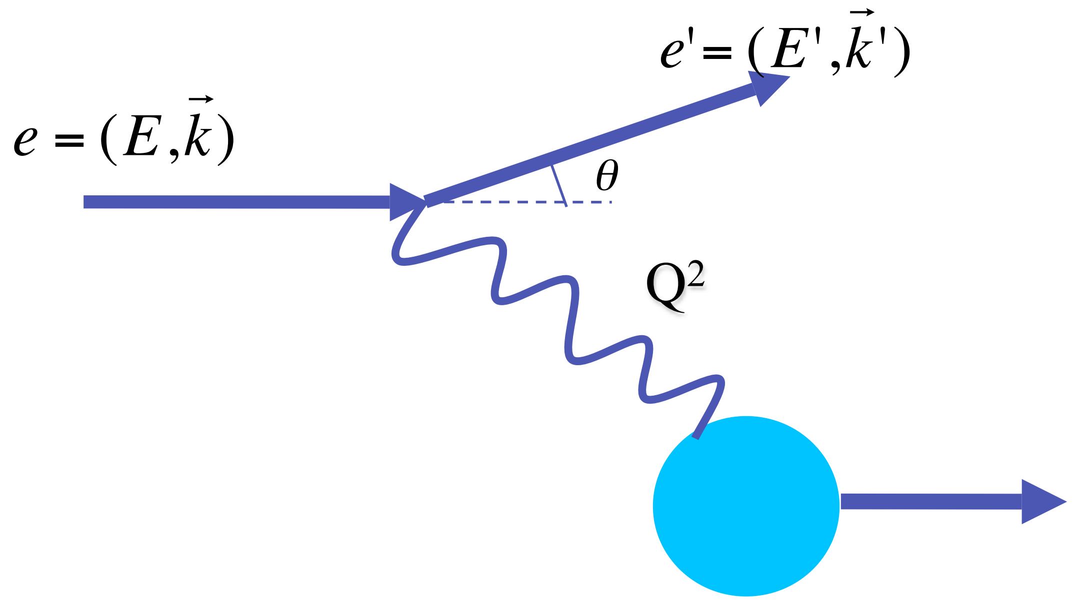
High Q^2 and W>2GeV: fine resolution → we see partons

→ scaling → asymptotic freedom of the strong interaction

→ 2004 Nobel Prize

D. J. Gross, H. D. Politzer and F. Wilczek

The resonance region



Low Q^2 and W<2 GeV : coarse resolution → we don't see individual partons.

→ The nucleon goes through different excited states: the resonances

VOLUME 25, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1970

SCALING, DUALITY, AND THE BEHAVIOR OF RESONANCES IN INELASTIC ELECTRON-PROTON SCATTERING*

E. D. Bloom and F. J. Gilman
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 25 June 1970)

We propose that a substantial part of the observed behavior of inelastic electron-proton scattering is due to a nondiffractive component of virtual photon-proton scattering. The behavior of resonance electroproduction is shown to be related in a striking way to that of deep inelastic electron-proton scattering. We derive relations between the elastic and inelastic form factors and the threshold behavior of the inelastic structure functions in the scaling limit.

VOLUME 25, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1970

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Stanford Linear Accelera ... 4305

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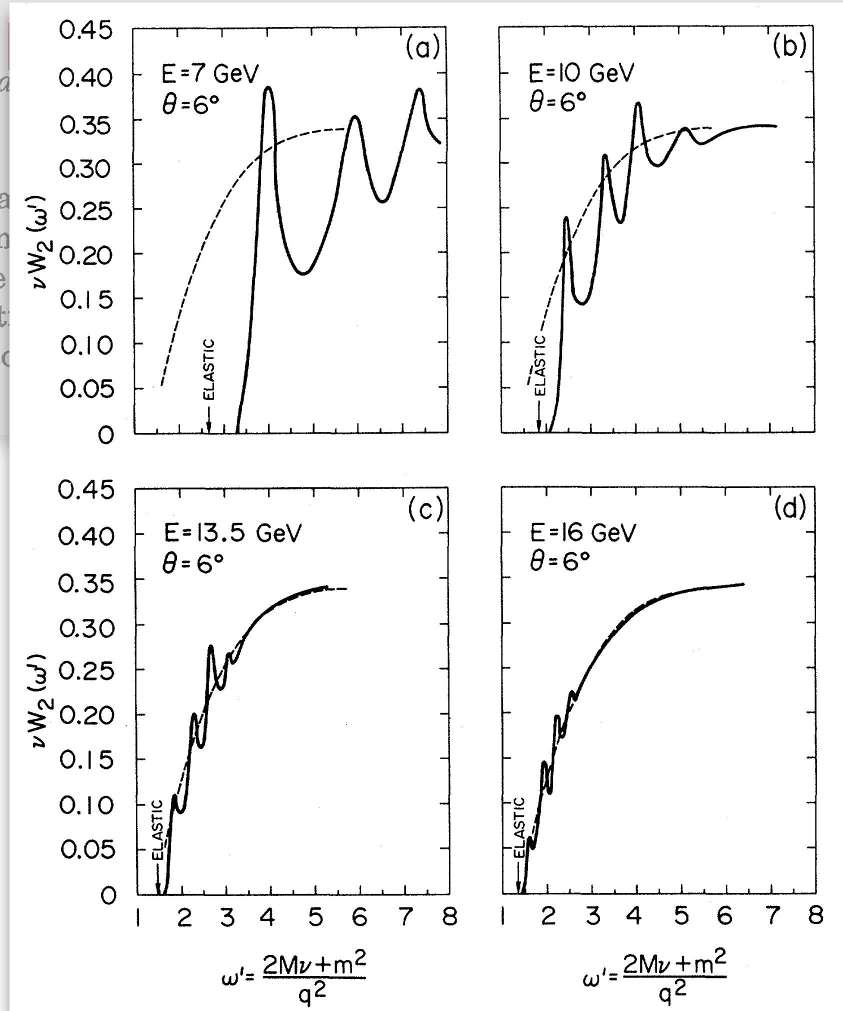
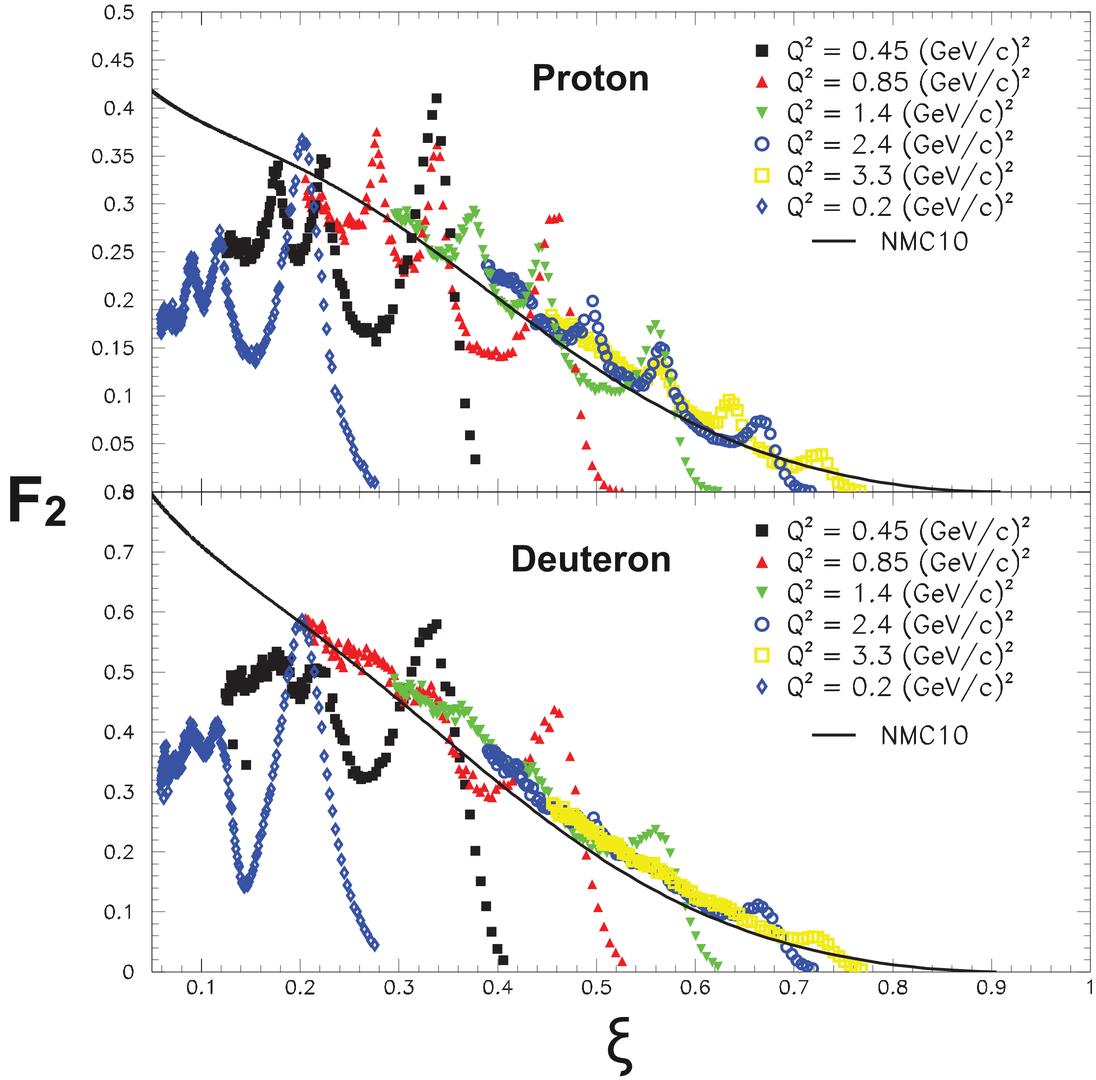


Scaling curve seen at high Q^2 is an accurate average over the resonance region at lower Q^2

Quark-hadron duality

I. Niculescu et al., PRL 85 (2000) 1182

High precision Hall C data allowed the confirmation global duality and the observation of local duality for F_2



What about spin-dependent structure functions ?

Theoretical interpretations

Lattice QCD

χPT   Quark models   OPE   pQCD

$Q^2 = 0$ ⟷ $Q^2 = \infty$

pQCD (Carlson, Mukhopadhyay):

➡ Q^2 dependence of transition form factors vs. x dependence of parton distribution functions

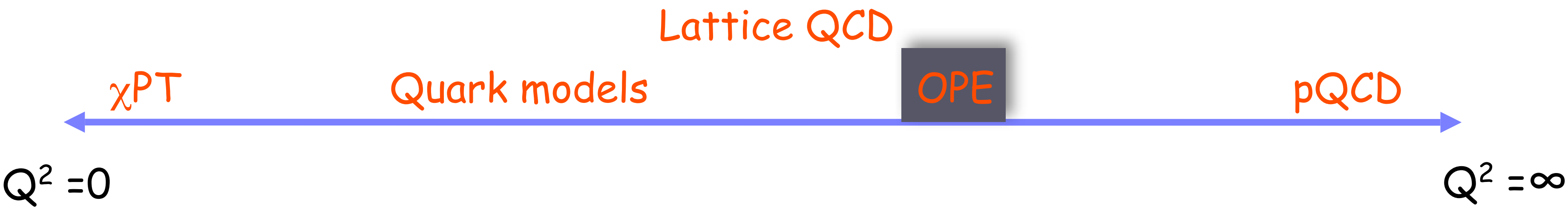
In resonance

$$g_1 = \frac{M_N^2}{\pi M_R \Gamma_R}\frac{g_+^2}{Q^6} \approx \frac{M_N^2}{\pi M_R \Gamma_R}\frac{g_+^2}{\left(M_R^2 - M_N^2\right)^3}(1-x)^3$$

In DIS

$$\lim_{x\to 1} g_1(x) \propto (1-x)^3$$

Theoretical interpretations



Operator Product Expansion (Rujula, Georgi, Politzer):

➡ Higher twist corrections are small or cancel.

$$\Gamma_1(Q^2) = \mu_2(Q^2) + \frac{\mu_4(Q^2)}{Q^2} + \frac{\mu_6(Q^2)}{Q^4} + O\left(\frac{1}{Q^6}\right)$$

Leading twist

Higher twists

Theoretical interpretations

SU(6) symmetry breaking in the quark model (Close, Isgur and Melnitchouk):

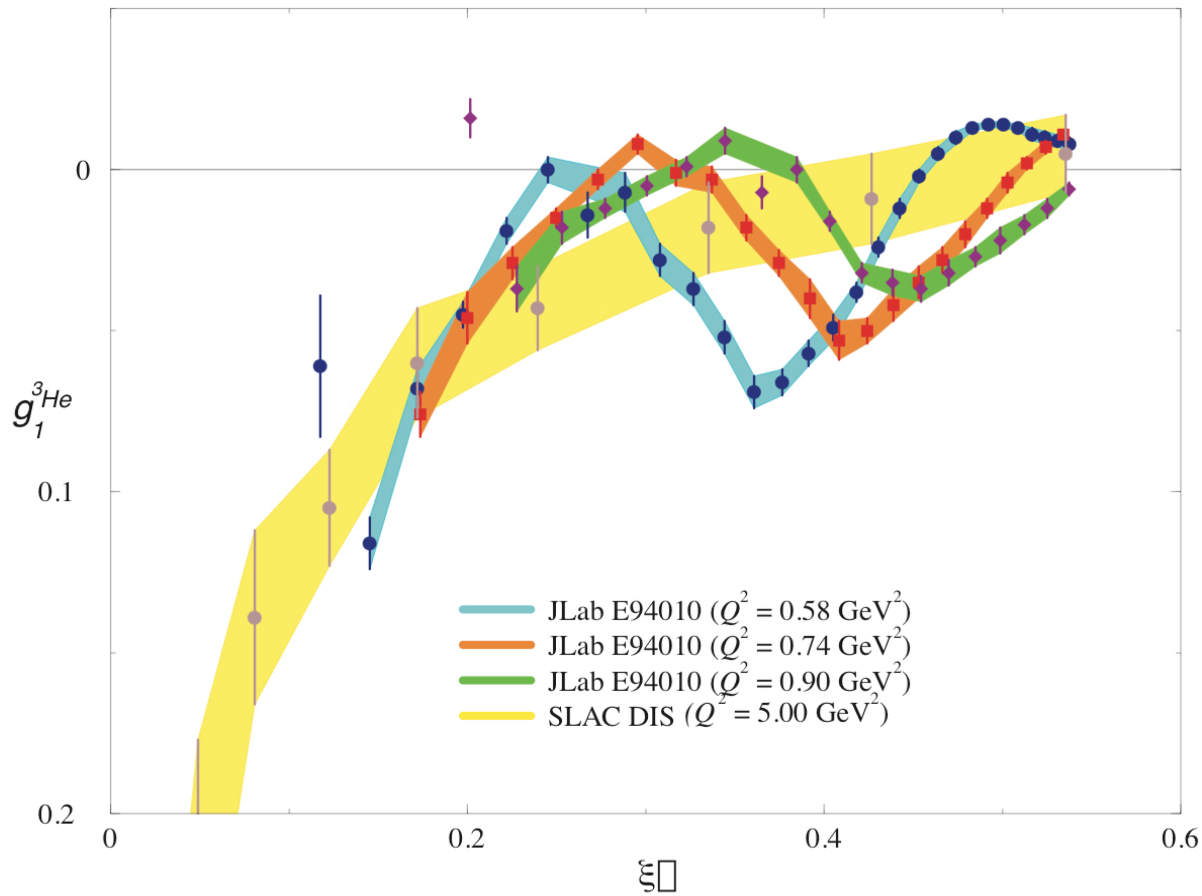
➥ investigate several scenarios with suppression of spin-3/2, helicity-3/2 or symmetric wave function

$$|N\rangle = \cos\theta_w |\psi_\rho\rangle + \sin\theta_w |\psi_\lambda\rangle$$

Model	SU(6)	no $^4\mathbf{10}$	no $^2\mathbf{10}$, $^4\mathbf{10}$	no $S_{3/2}$	no $\sigma_{3/2}$	no ψ_λ
R^{np}	2/3	10/19	1/2	6/19	3/7	1/4
A_1^p	5/9	1	1	1	1	1
A_1^n	0	2/5	1/3	1	1	1

Existing data on "spin duality"

Indication of duality for g_1^{3He} from Hall A (E94-010)

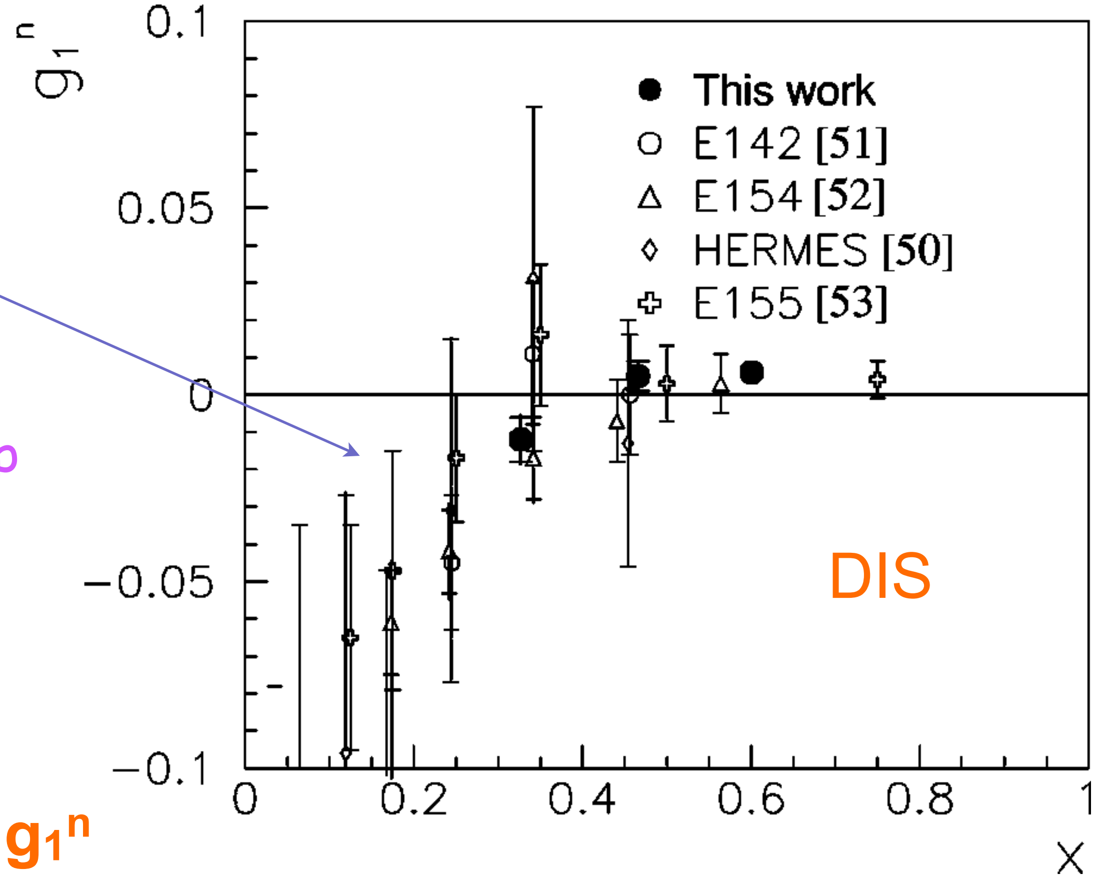


Neutron spin duality ?

X. Zheng et al, Phys. Rev. C 70 (2004) 065207

$g_1^n(\mathrm{DIS}) < 0$

and $g_1^n(\Delta)$ is negative up to the its FF fall off



Onset of duality for g_1^n is expected "sooner"

Quark-hadron duality: accidental or universal phenomenom ?

In order to improve our understanding of duality, we need to explore duality in:

polarized SF vs. unpolarized SF

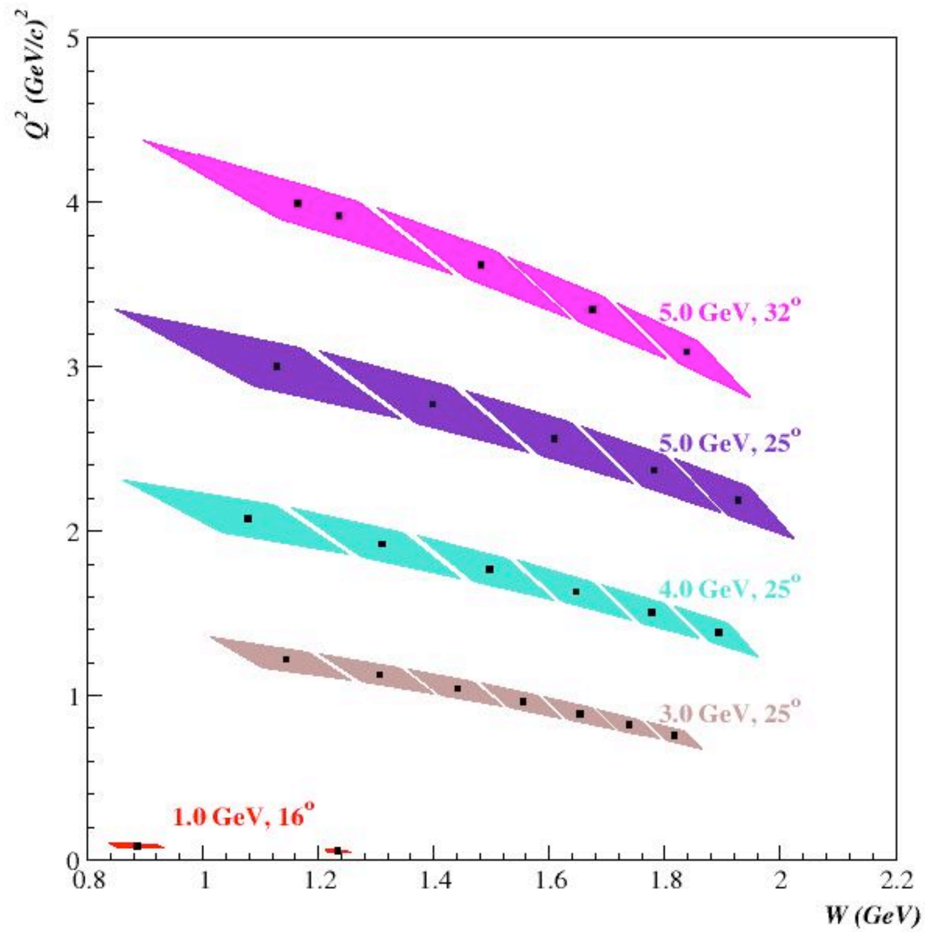
and

proton vs. neutron

a dedicated experiment to study spin duality on the neutron was necessary

The experiment 01-012

- Ran in Jan.-Feb. 2003
- Inclusive experiment: $^{3}\vec{H}e(\vec{e},e')X$
  - ➢ Polarized electron beam:
    $70 < P_{beam} < 85\%$
  - ➢ Hall A in standard equipment
  - ➢ Pol. ^{3}He target (para and perp):
    $\langle P_{targ} \rangle = 37\%$
- Measured polarized cross section differences and form g_1 and g_2 for ^{3}He

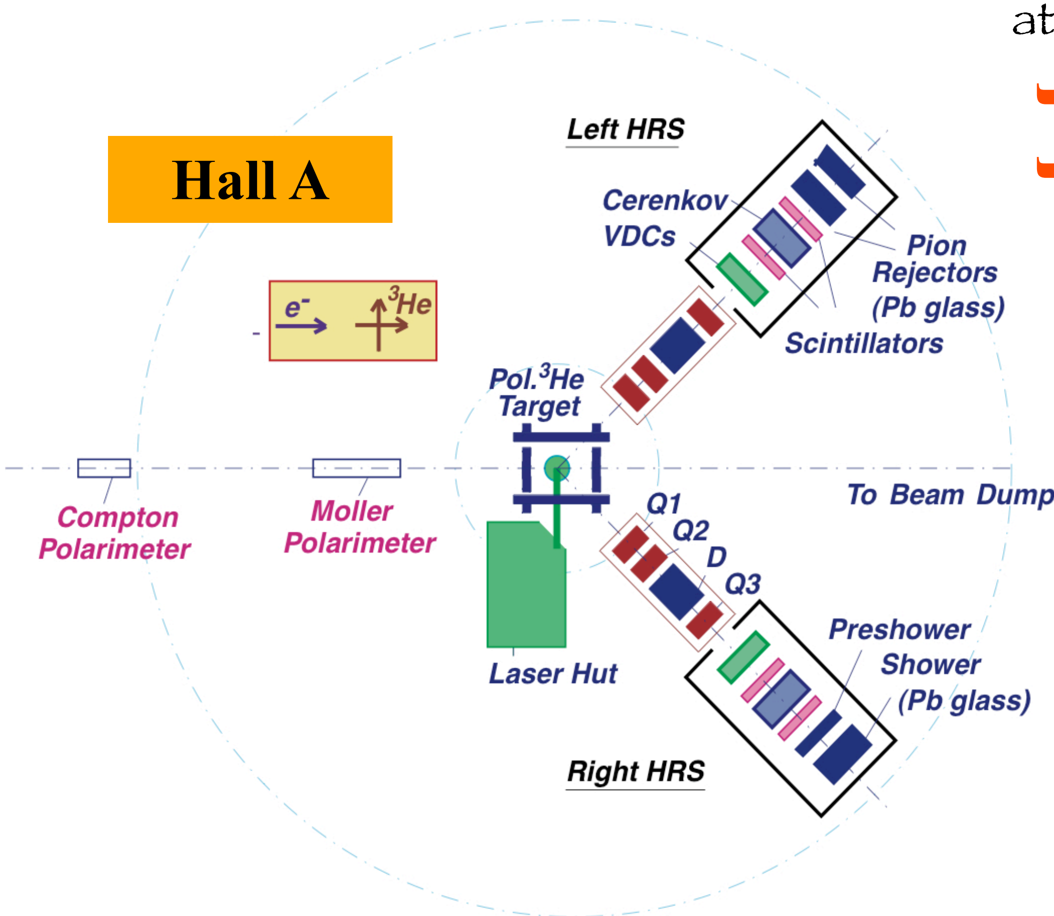


➥ **Test of spin duality on the neutron (^{3}He)**

The E01-012 Collaboration

K. Aniol, T. Averett, W. Boeglin, A. Camsonne, G.D. Cates,
G. Chang, J.-P. Chen, Seonho Choi, E. Chudakov, B. Craver,
F. Cusanno, A. Deur, D. Dutta, R. Ent, R. Feuerbach,
S. Frullani, H. Gao, F. Garibaldi, R. Gilman, C. Glashausser,
O. Hansen, D. Higinbotham, H. Ibrahim, X. Jiang, M. Jones,
A. Kelleher, J. Kelly, C. Keppel, W. Kim, W. Korsch,K. Kramer,
G. Kumbartzki, J. LeRose, R. Lindgren, N. Liyanage, B. Ma,
D. Margaziotis, P. Markowitz, K. McCormick, Z.-E. Meziani,
R. Michaels, B. Moffit, P. Monaghan, C. Munoz Camacho,
K. Paschke, B. Reitz, A. Saha, R. Sheyor, J. Singh, K. Slifer,
P. Solvignon, V. Sulkosky, A. Tobias, G. Urciuoli, K. Wang,
K. Wijesooriya, B. Wojtsekhowski, S. Woo, J.-C. Yang,
X. Zheng, L. Zhu

Experimental setup



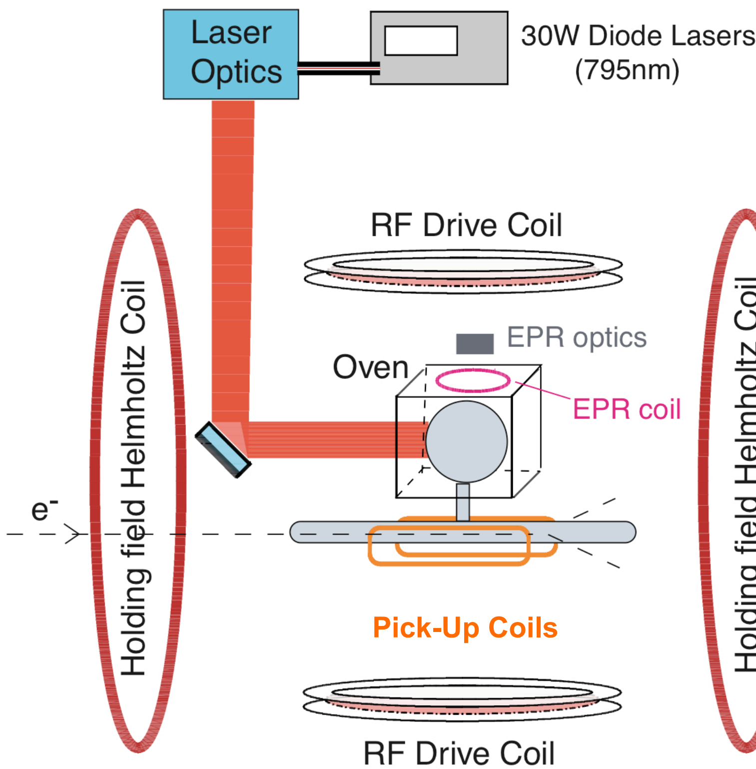
Both HRS in symmetric configuration at 25° and 32°

- ➡ Double the statistics
- ➡ Control the systematics

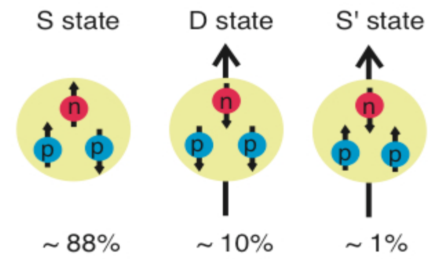
Particle ID = Cerenkov + EM calorimeter

- ➡ π/e reduced by 10^4

The polarized ^3He target

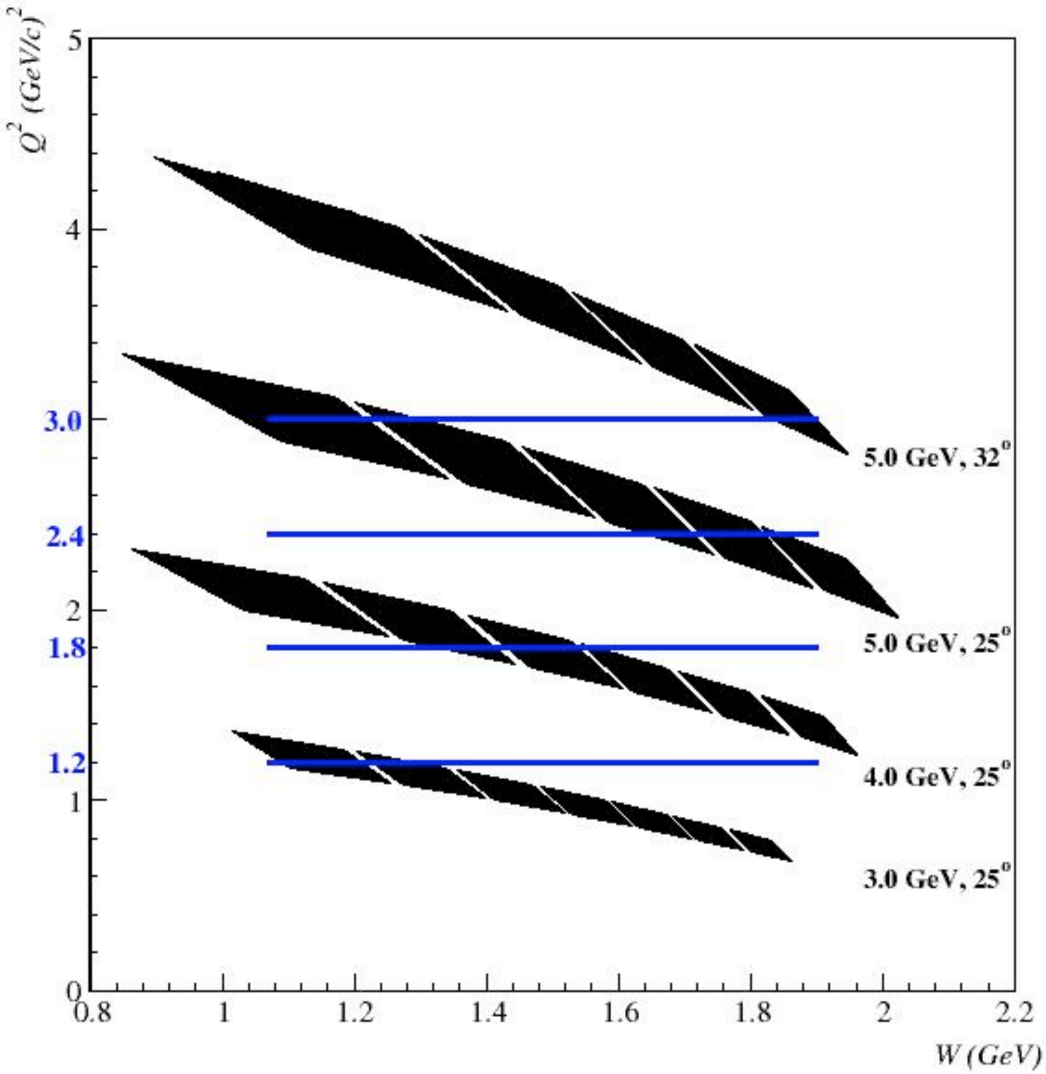


^3He as neutron target



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

From constant (E, θ) to constant Q^2



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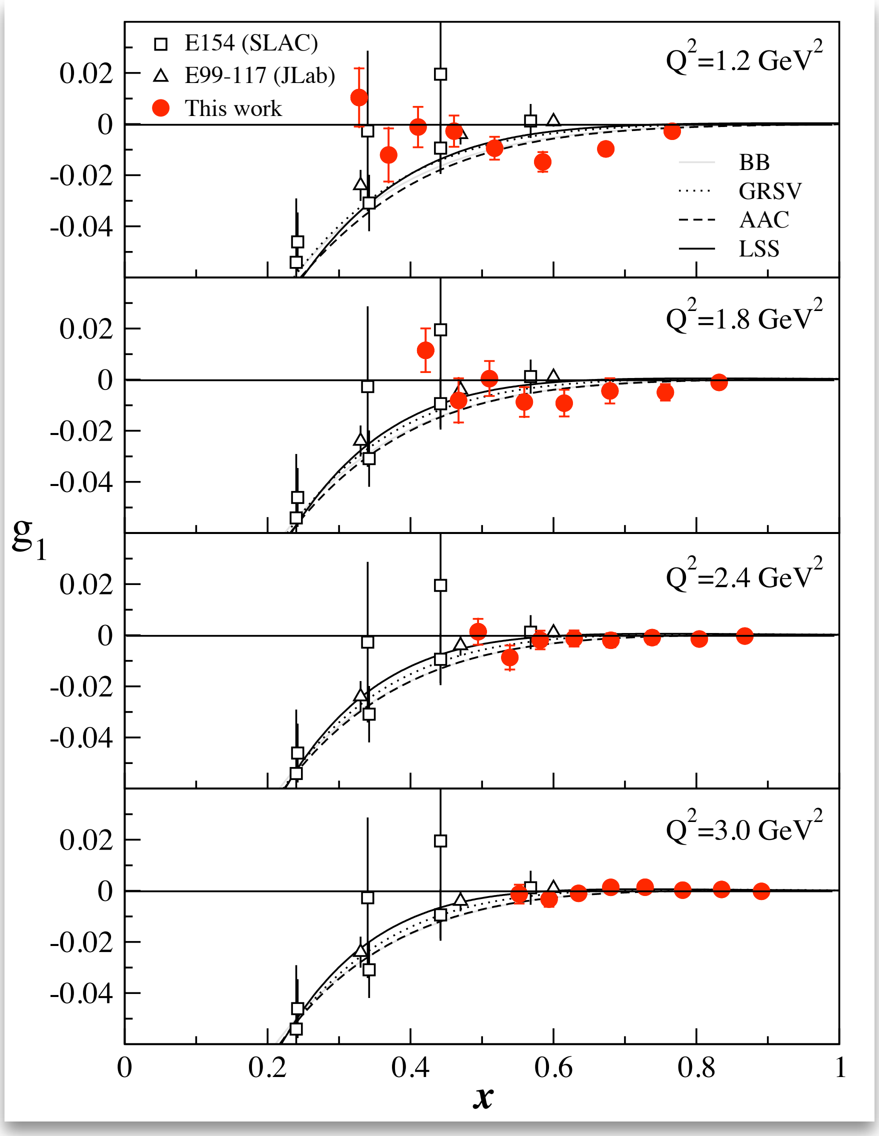
The structure function g_1 in ^{3}He

P. Solvignon et al., PRL 101, 182502 (2008)

Target mass corrections were applied on PDFs



Spin duality on ^{3}He and neutron

Use partial moments:

Integrate g_1^{res} and g_1^{dis} over the same x-range and at the same Q^2:

$$\tilde{\Gamma}_1^{res} = \int_{x_{\min}}^{x_{\max}} g_1^{res}(x,Q^2)dx$$

$$\tilde{\Gamma}_1^{dis} = \int_{x_{\min}}^{x_{\max}} g_1^{dis}(x,Q^2)dx$$

If $\tilde{\Gamma}_1^{res} = \tilde{\Gamma}_1^{dis}$ duality is verified

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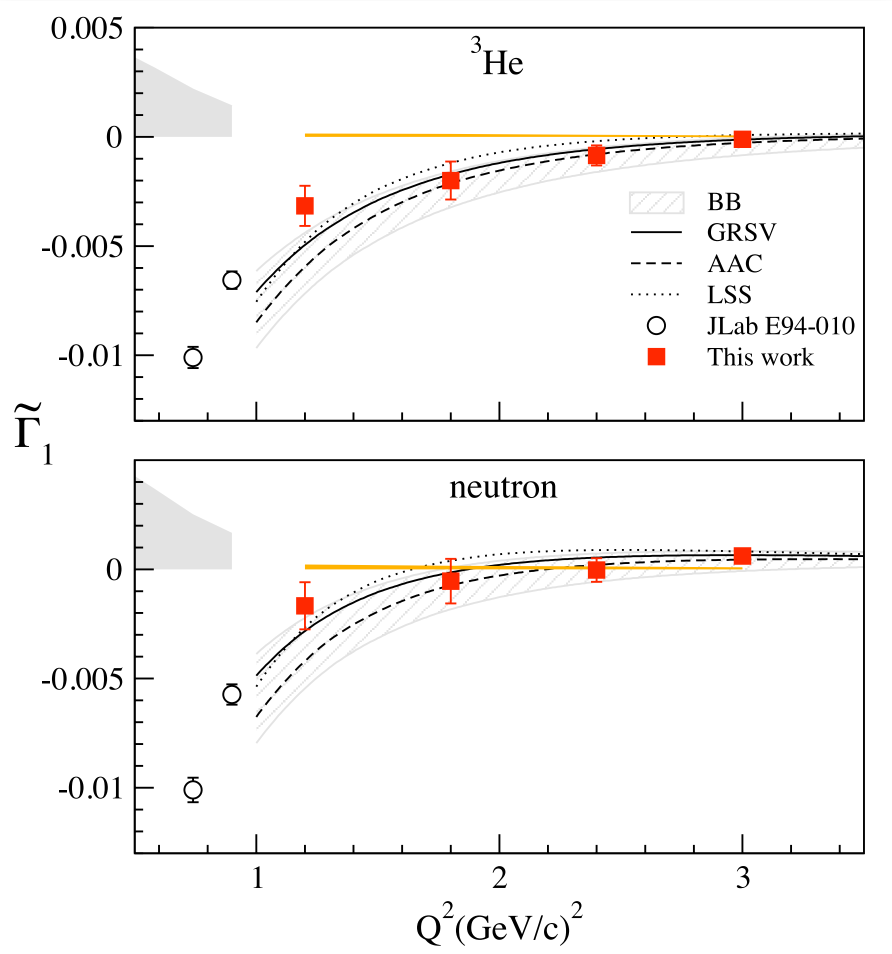

Target mass corrections were applied on PDFs

Neutron extraction using the effective polarization equation:

$$\tilde{\Gamma}_1^{\,^3He} = P_n \tilde{\Gamma}_1^{\,n} + 2P_p \tilde{\Gamma}_1^{\,n}$$

P_n=86%

P_p=-2.8%

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:

$$A_1(x,Q^2) \approx \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{\sum_i e_i^2 \; \Delta q_i(x,Q^2)}{\sum_i e_i^2 \; q_i(x,Q^2)}$$

If Q^2 dependence similar for g_1 and for F_1

⇒ weak Q^2 dependence of A_1

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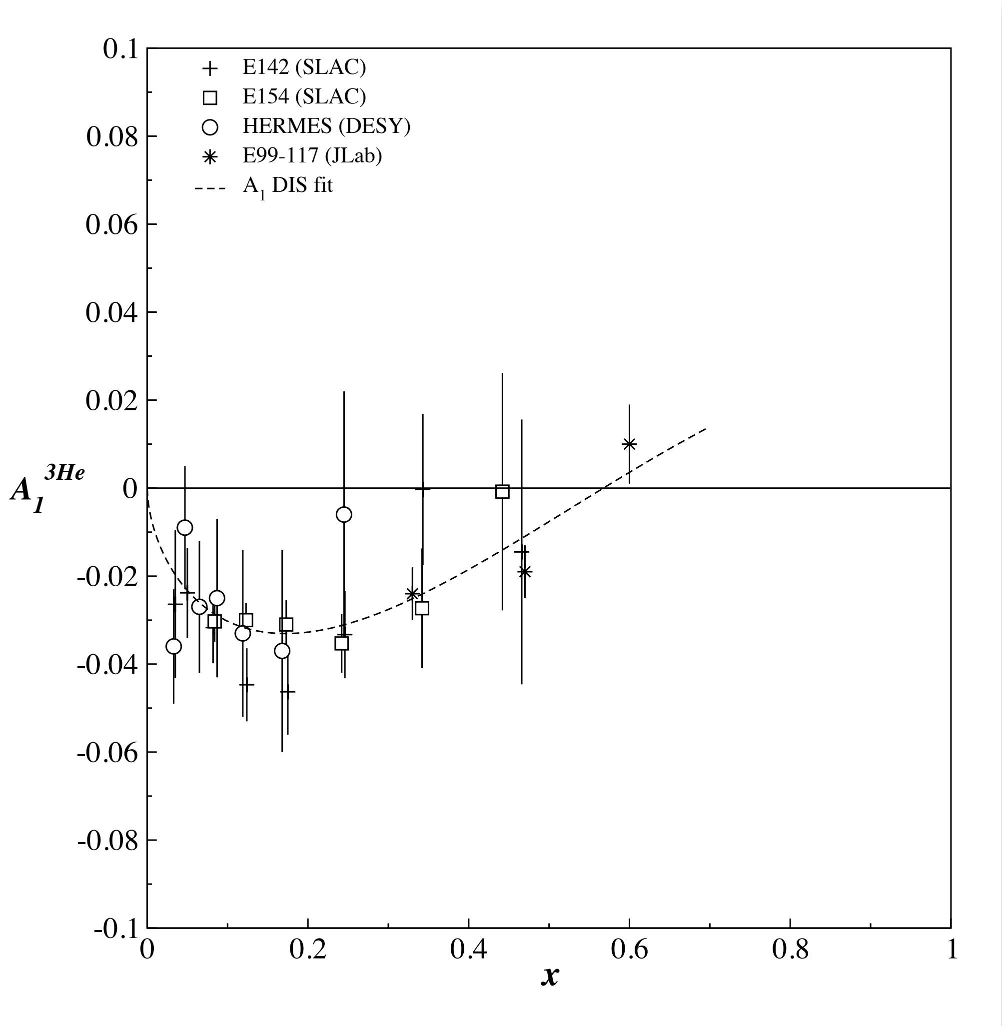
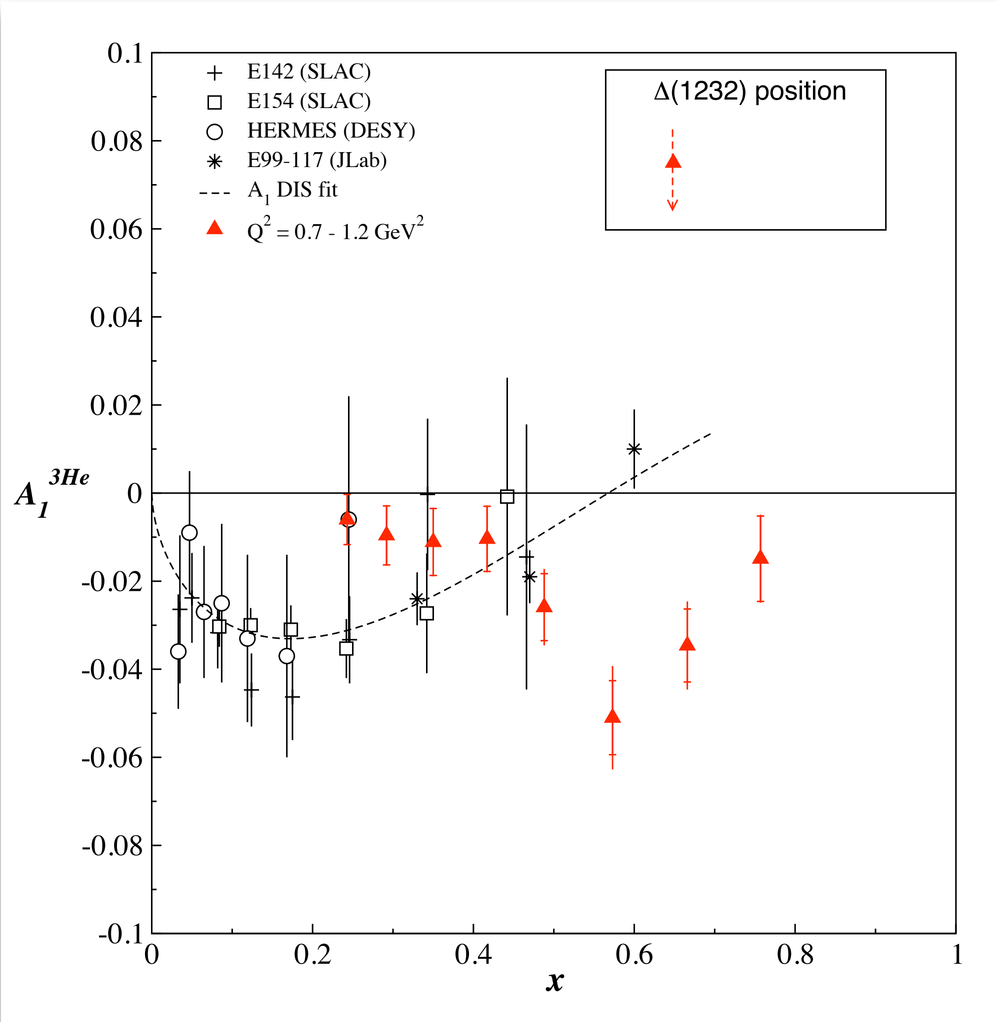
A_1 for ^3He



E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99-117 (JLab)
A1 DIS fit
A1 3He
x
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
0.2
0.4
0.6
0.8
1

A_1 for ^{3}He

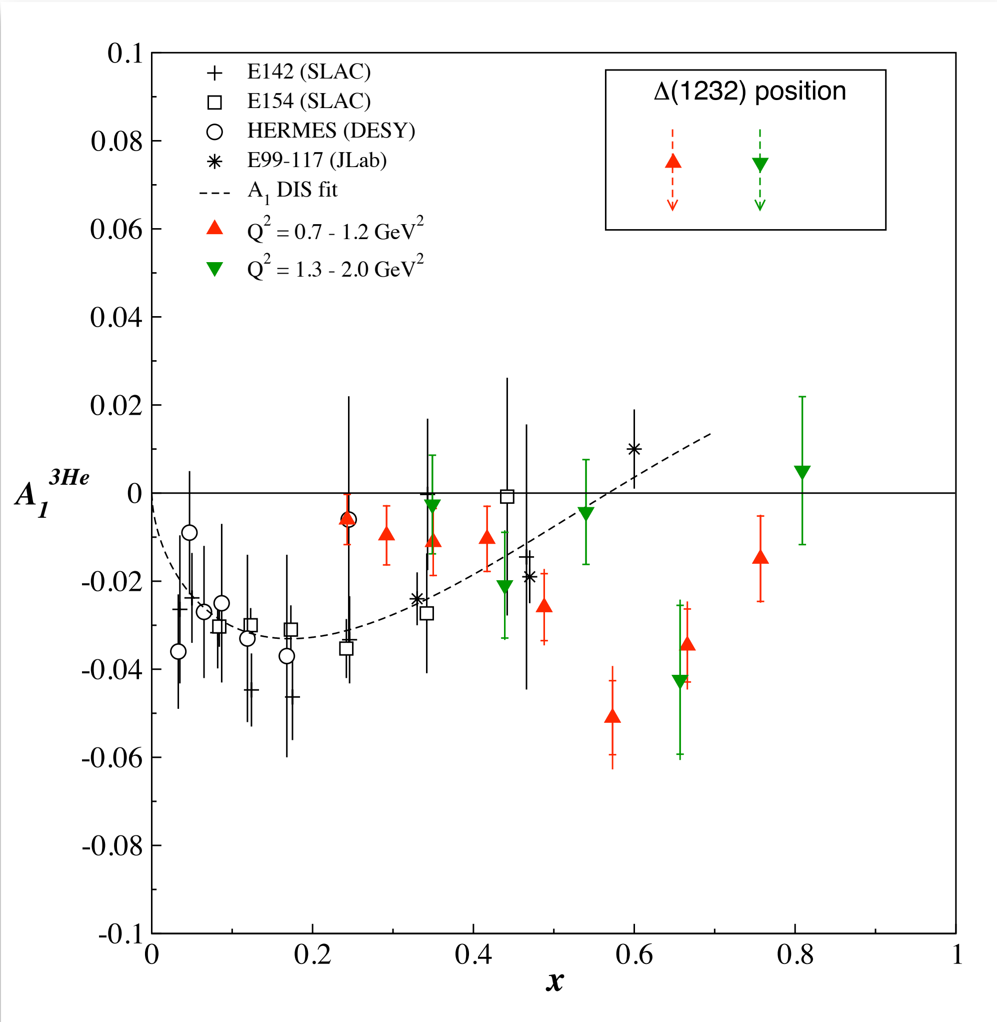
P. Solvignon et al., PRL 101, 182502 (2008)



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

A_1 for ^{3}He

P. Solvignon et al., PRL 101, 182502 (2008)

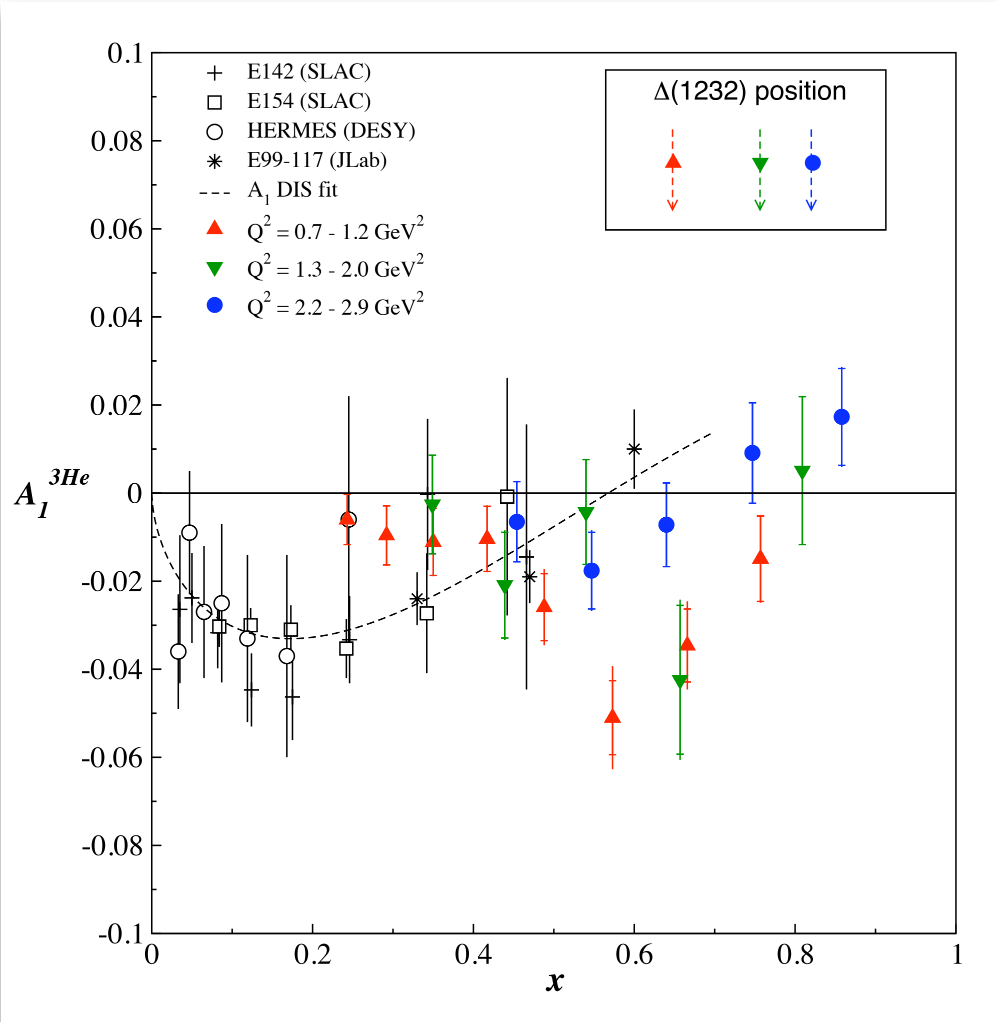


Large negative value in the Δ(1232) region

Still large negative value in the Δ(1232) region

A_1 for ^{3}He

P. Solvignon et al., PRL 101, 182502 (2008)



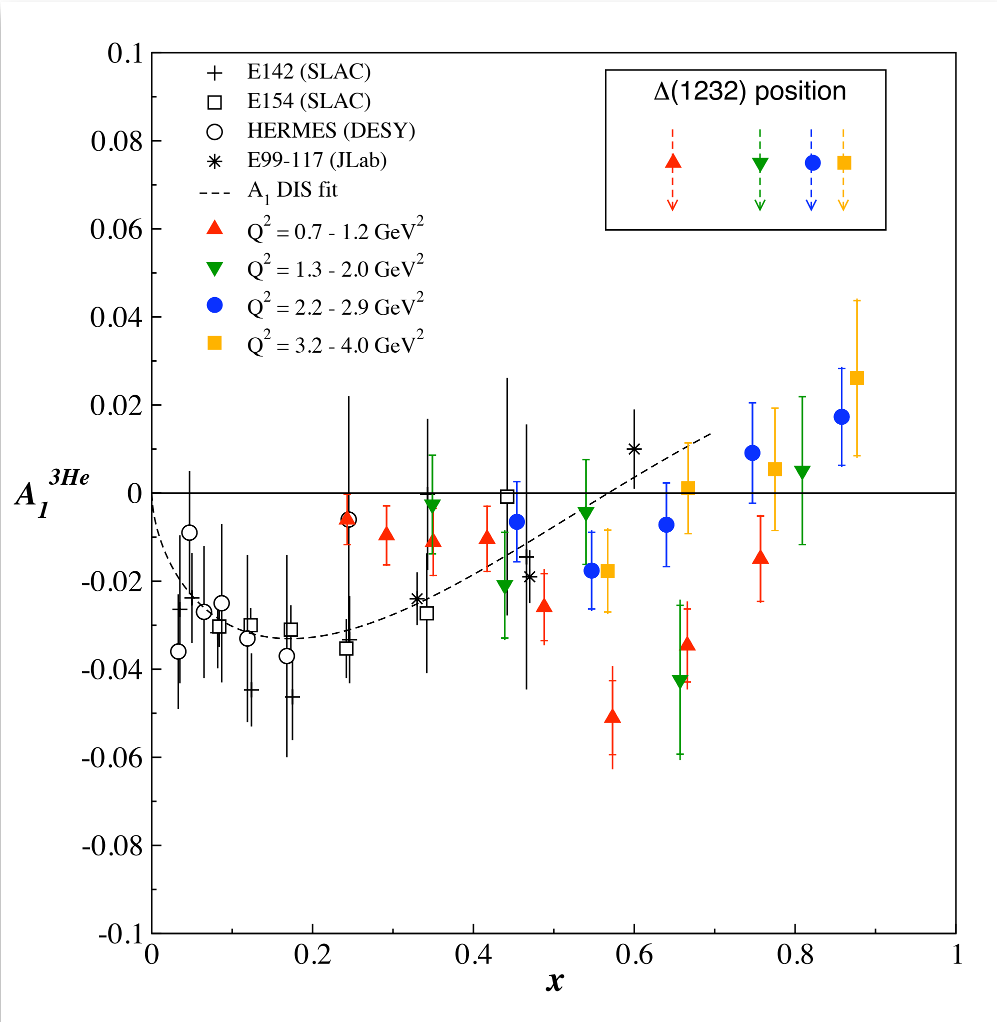
Large negative value in the Δ(1232) region

Still large negative value in the Δ(1232) region

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

A_1 for ^{3}He

P. Solvignon et al., PRL 101, 182502 (2008)



Large negative value in the Δ(1232) region

Still large negative value in the Δ(1232) region

A_1 becomes positive in the Δ(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^n in the resonance region

$$A_1^n = \frac{g_1^n - \gamma^2 g_2^n}{F_1^n}$$

- Effective equation polarization cannot be used for a pt-to-pt neutron extraction in the resonance region

- Y. Kahn, W. Melnitchouk and S. Kulagin are including a Q^2-dependence in their convolution model (arXiv:0809.4308)

- Goal: test of quark-hadron duality on A_1^n and possible access to high x region

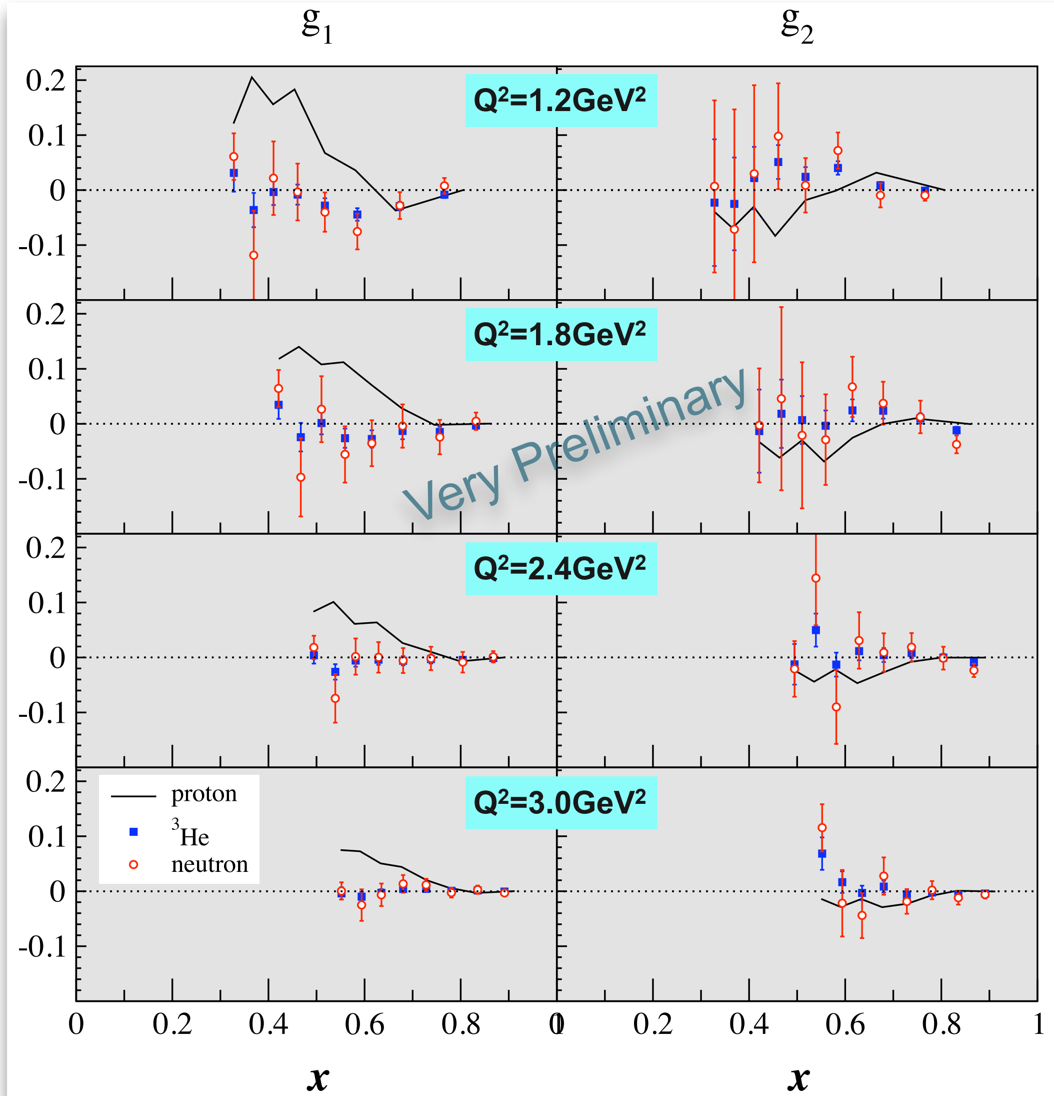
g_1^n and g_2^n in the resonance region

g_1^p from Hall B

g_2^p from MAID: its use is questionable for $Q^2 > 1 GeV^2$

Convolution code: courtesy of Yonatan Kahn

neutron uncertainties will be improved by using fit of our data in the convolution



The g_2 structure function

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

Leading twist contribution determined entirely from g_1 through the Wandzura-Wilczek relation:

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_0^x dy \, \frac{g_1(y, Q^2)}{y}$$

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The g_2 structure function

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

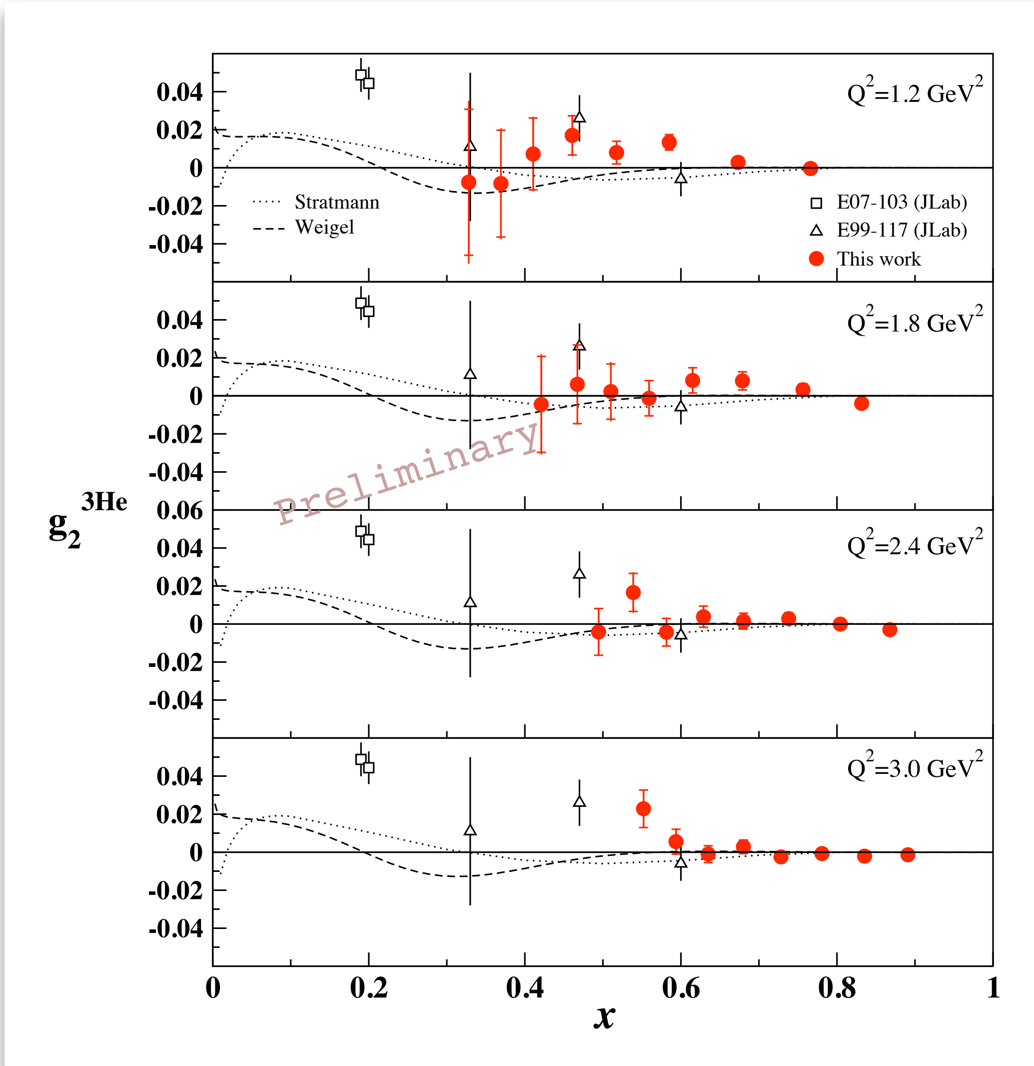
higher twist contribution

Leading twist contribution determined entirely from g_1 through the Wandzura-Wilczek relation:

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_0^x dy \, \frac{g_1(y, Q^2)}{y}$$

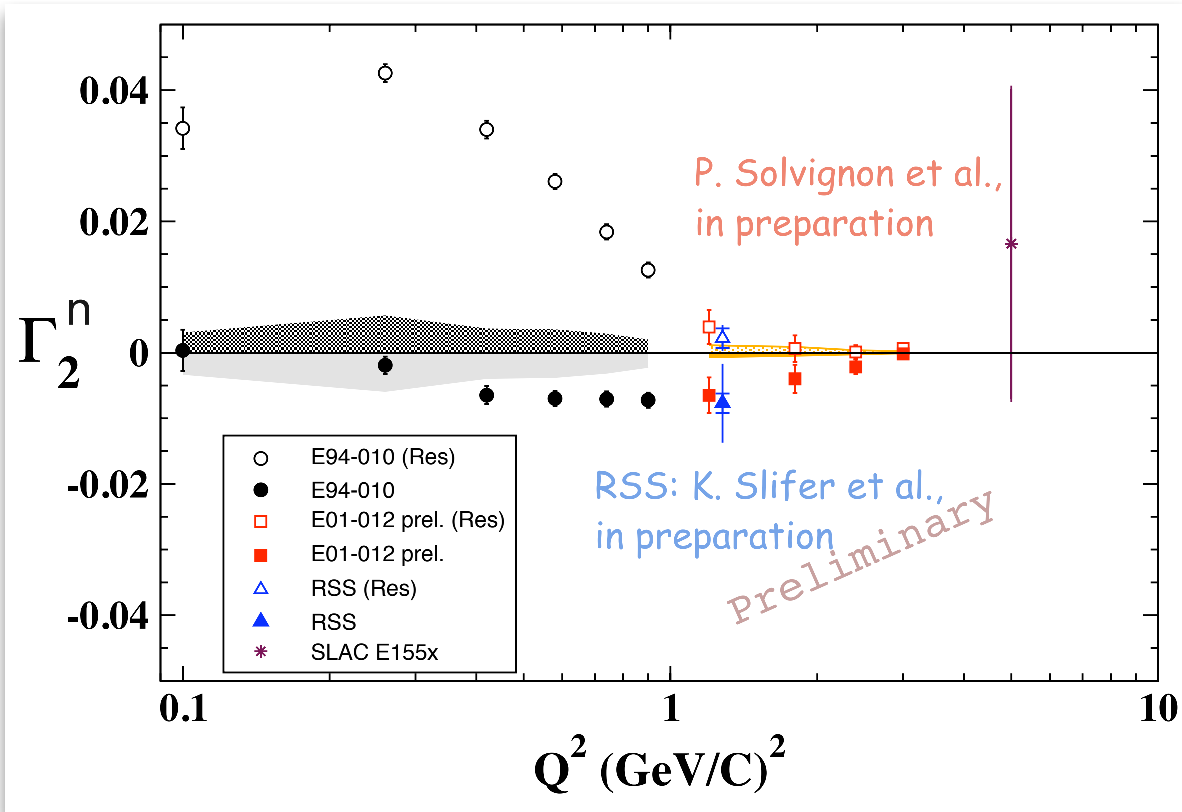
The structure function g_2 in ^{3}He

P. Solvignon et al., in preparation



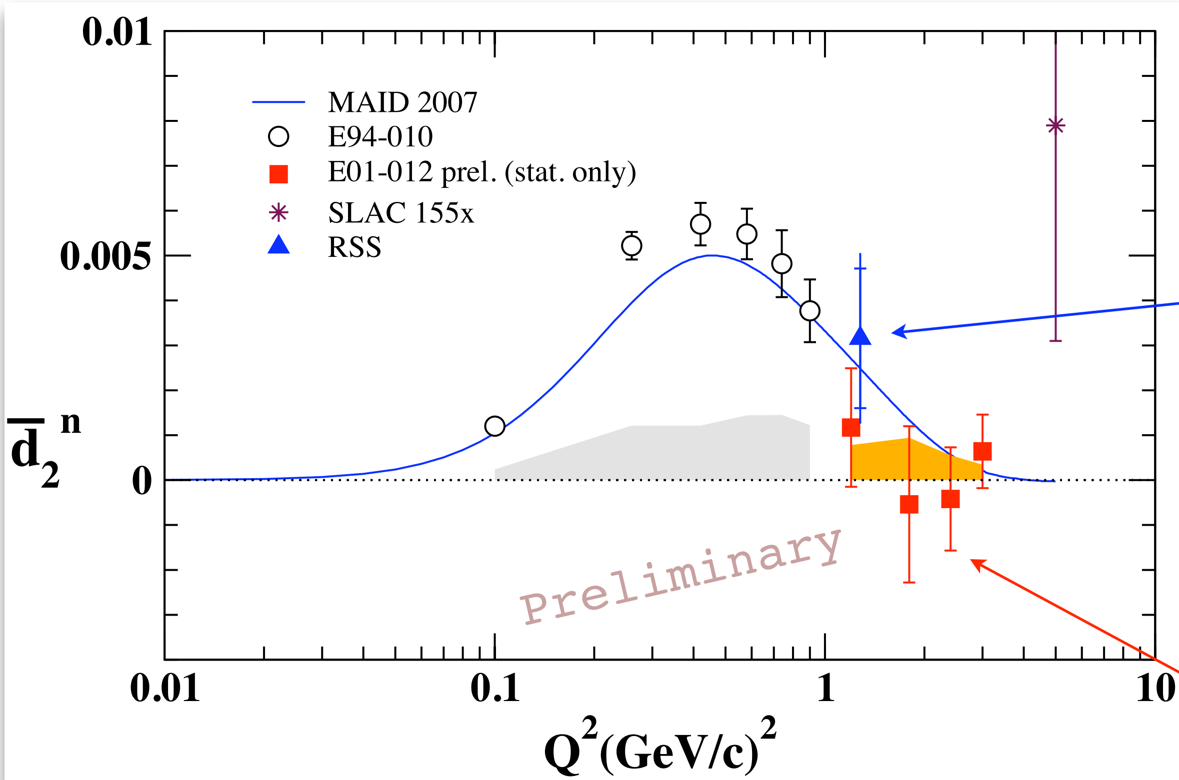
Burkhard-Cottingham sum rule on the neutron

$$\Gamma_2(Q^2) = \int_0^1 dx\; g_2(x, Q^2) = 0$$



Higher moment d_2

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

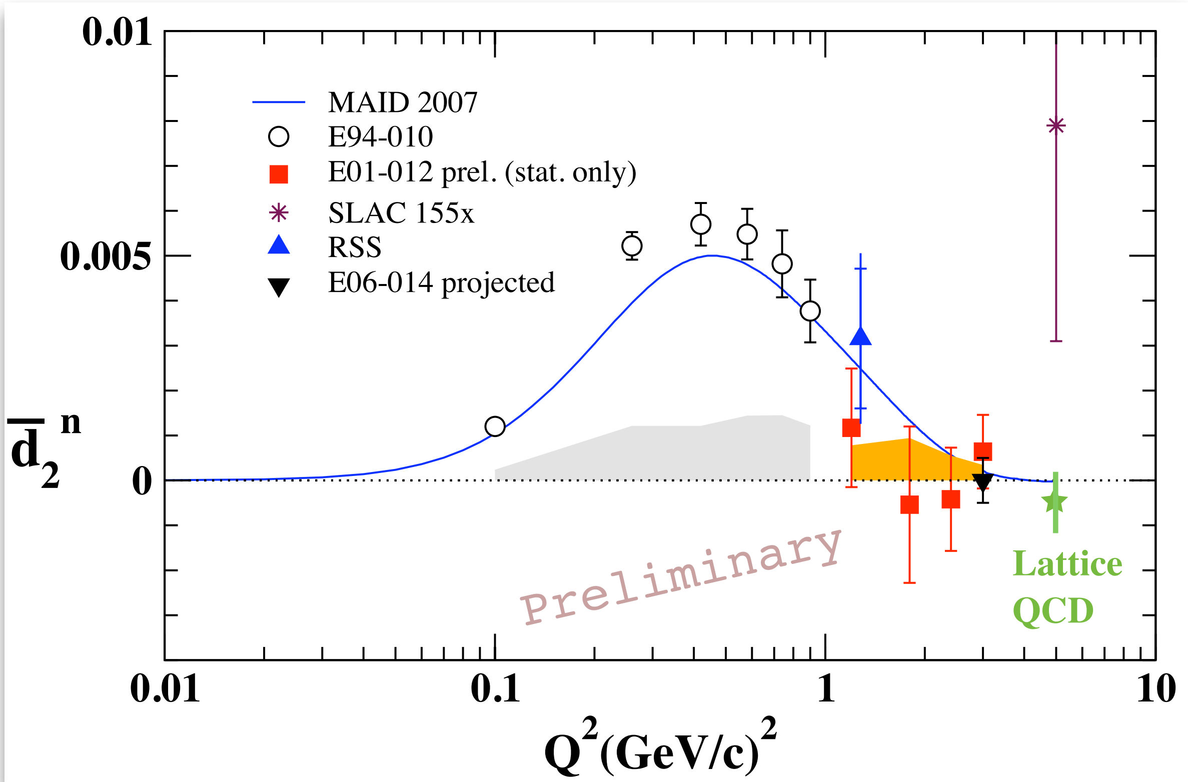


RSS: K. Slifer et al., in preparation

P. Solvignon et al., in preparation

Higher moment d_2

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



M. Gockeler et al. PRD 63, 074506(2001). hep-lat/0011091.

Summary

E01-012 provides first precise data of Spin Structure Functions on neutron (^{3}He) in the resonance region for $1.0 < Q^2 < 4.0 GeV^2$

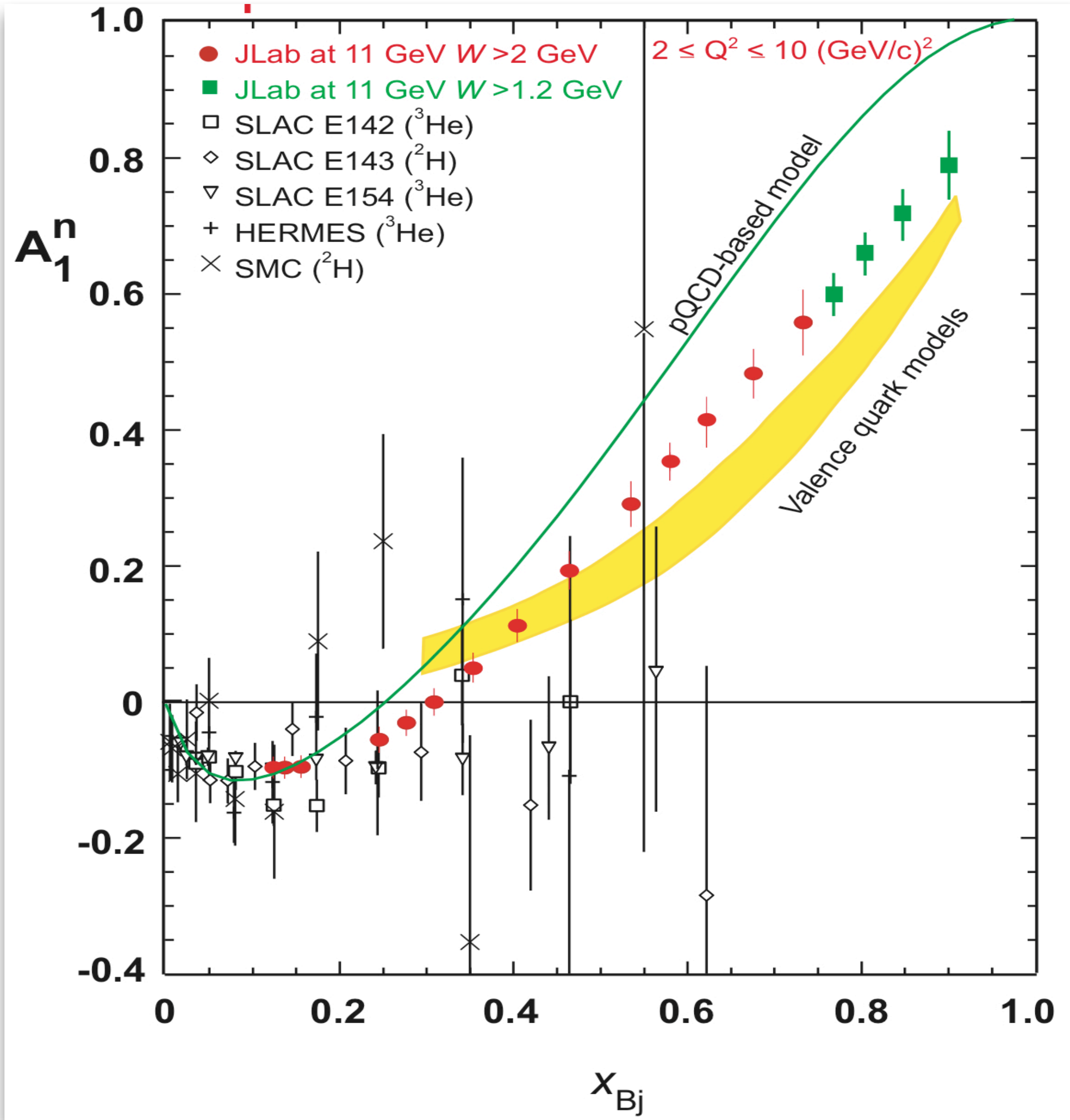
- ✓ Overlap between E01-012 resonance data and DIS data:
  first dedicated test of Quark-Hadron Duality for neutron and ^{3}He SSF
- ✓ No strong Q^2-dependence in resonance A_1^{3He} for Q^2>2.0 GeV^2
  ➥ DIS-like behavior

Preliminary extraction of g_1^n and g_2^n in the resonance region $\Rightarrow$ A_1^n will come soon

Preliminary results on the Burkhard-Cottingham sum rule and d_2^n at moderate Q^2

and more to come ...

At JLab 12GeV



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