Looking Inside the Neutron

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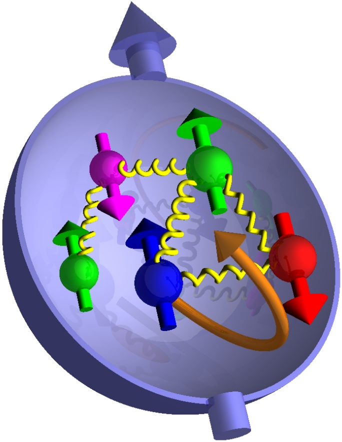
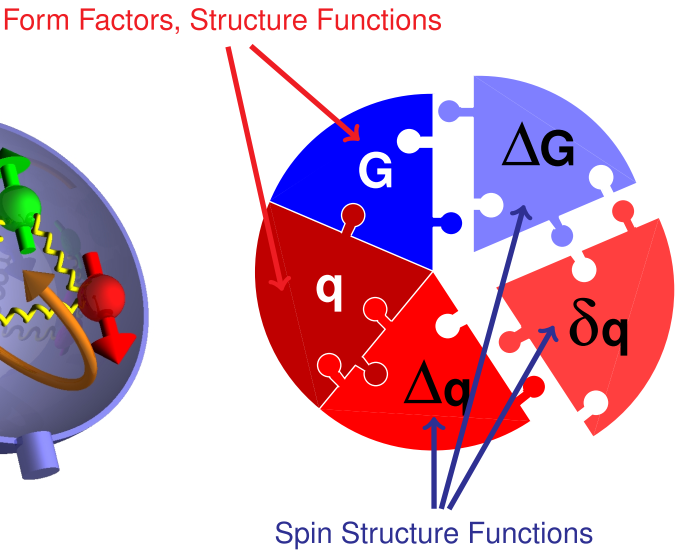
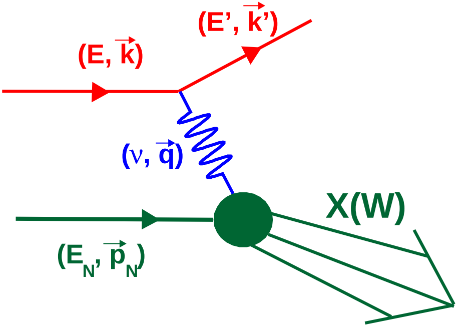
Inside the Nucleon





Unpolarized DIS:



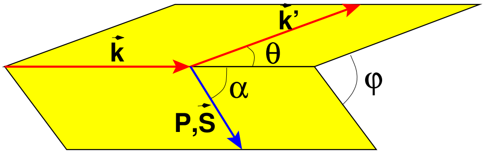
Kinematic variables:

$$W = \text{ invariant mass}$$
$$Q^2 = -q^2 = 4EE' sin^2(\theta/2)$$
$$\nu = E - E' = \frac{P \cdot q}{M}$$
$$x = \frac{Q^2}{2M\nu} \text{ (Bjorken Scaling Variable)}$$
$$y = \frac{P \cdot q}{P \cdot K} = \frac{\nu}{E}$$
$$\gamma = \frac{2Mx}{\sqrt{Q^2}}$$

Spin-averaged cross section:

$$\frac{d\overline{\sigma}}{dx\, dy} = \frac{e^4}{4\pi^2 Q^2}\left(\frac{y}{2}F_1(x,Q^2) + \frac{1}{2xy}\left(1 - y - \frac{y^2}{4}\gamma^2\right)F_2(x,Q^2)\right)$$

Polarized DIS:



Spin-dependent cross section:

$$\frac{d\Delta\sigma(\alpha,\varphi)}{dx\,dy} = \frac{e^4}{4\pi^2 Q^2}\left(cos\alpha\left(\left(1-\frac{y}{2}-\frac{y^2}{4}\gamma^2\right)g_1(x,Q^2) - \frac{y}{2}\gamma^2 g_2(x,Q^2)\right)\right.$$

$$\left. - sin\alpha\ cos\varphi\sqrt{\gamma^2\left(1-y-\frac{y^2}{4}\gamma^2\right)}\left(\frac{y}{2}g_1(x,Q^2)+g_2(x,Q^2)\right)\right)$$

$\alpha,\ \varphi$ refer to target spin orientation

- two new (spin) Structure Functions: $g_1(x,Q^2),\ g_2(x,Q^2)$
- $\alpha = 0^\circ,\ 180^\circ \Rightarrow$ longitudinally polarized target
- $\alpha = 90^\circ, \varphi = 0^\circ(180^\circ) \Rightarrow$ transversely polarized target (*note: $d\Delta\sigma$* changes sign for $\varphi:\ 0^\circ \leftrightarrow 180^\circ$)

Experiment ⇒ measure scattering asymmetries:

Beam: longitudinally polarized
Target: longitudinally or transversely polarized

Measure scattering asymmetries ⇒ virtual photon asymmetries:

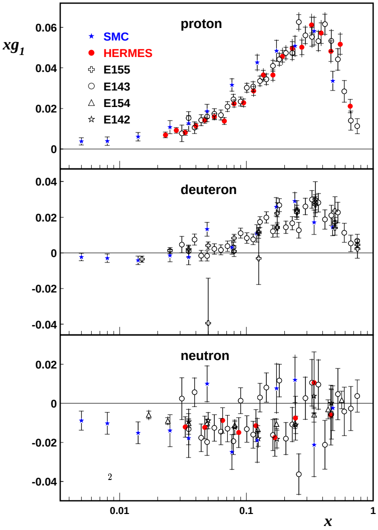
$$A_1(x, Q^2) = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}} = \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{F_1(x, Q^2)}$$

$$A_2(x, Q^2) = \frac{2\sigma_{TL}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}} = \frac{\gamma[g_1(x, Q^2) + g_2(x, Q^2)]}{F_1(x, Q^2)}$$

$F_1(x, Q^2)$ for neutron:

- “well” known in DIS region (SLAC, CERN, DESY)
- “poorly” known in resonance region
  ⇒ need to *measure* spin dependent cross sections

World Data on $g_{1,2}(x, Q^2)$ (before JLab)



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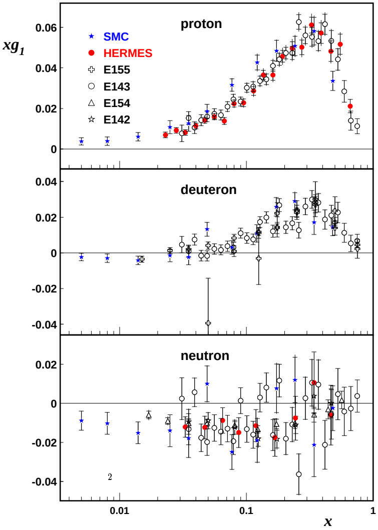
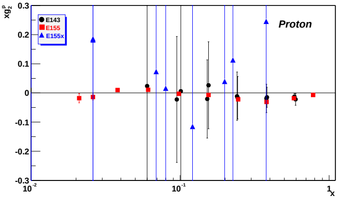
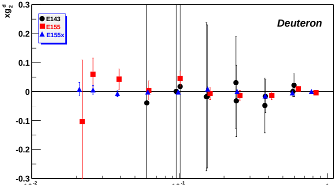
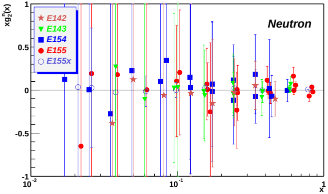
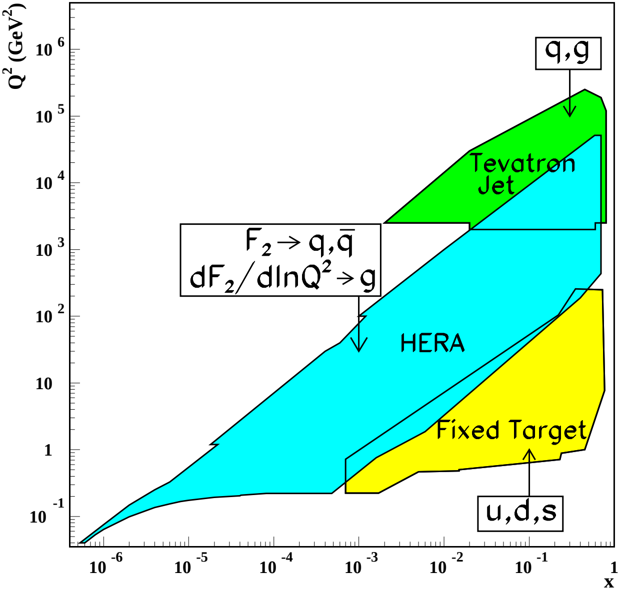






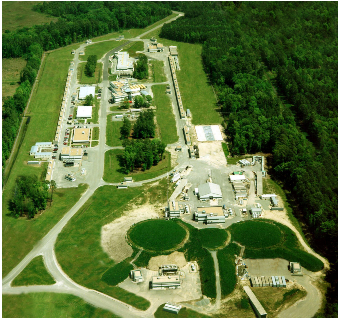


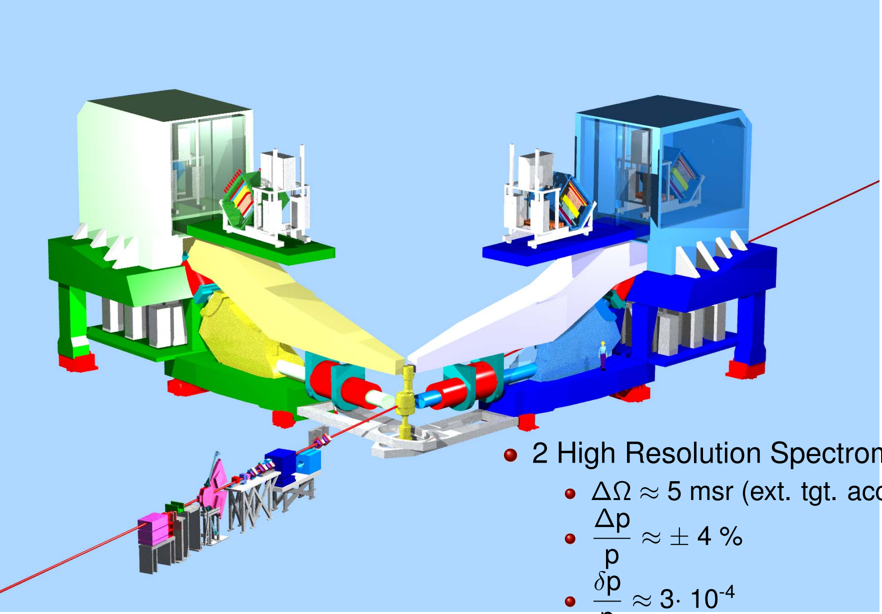
What can Jefferson Lab Contribute?



JLab	Experimental Parameters				
Hall	Target	density [cm^{-2}]	polarization	current	$\Delta\Omega$ [msr]
A	$^3\vec{He}$	10^{22}	0.5	10 μA	2×6
B	$N\vec{H}_3$, $N\vec{D}_3$	$> 10^{23}$	0.7(p), $\sim$0.3(d)	2 nA	1500
C	$N\vec{H}_3$, $N\vec{D}_3$	$> 10^{23}$	0.7(p), $\sim$0.2(d)	100 nA	8

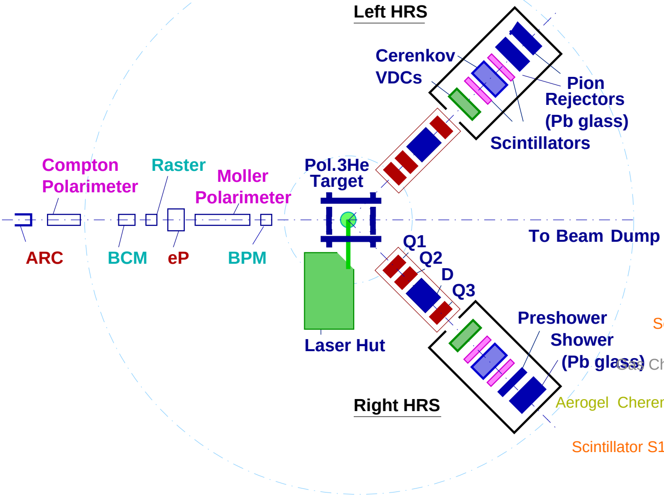
- ✘ beam energy < 6 GeV
- ✘ beam polarization $\sim$ 0.8
- ✘ polarized luminosities: $\mathcal{L} \approx (10^{35} - 10^{36})/\text{cm}^2/\text{s}$
- ✘ ideal for large-x physics and moments

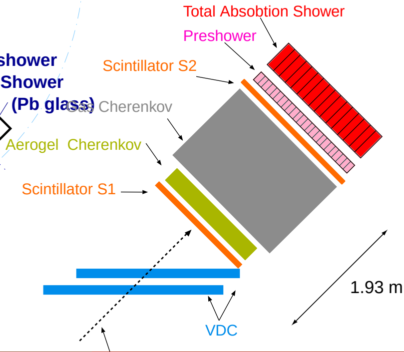




- 2 High Resolution Spectrometers
  - $\Delta\Omega \approx 5$ msr (ext. tgt. accep.)
  - $\frac{\Delta p}{p} \approx \pm 4$ %
  - $\frac{\delta p}{p} \approx 3 \cdot 10^{-4}$
  - $\pi^{-}/e^{-} < 10^{-4}$

Hall A floorplan



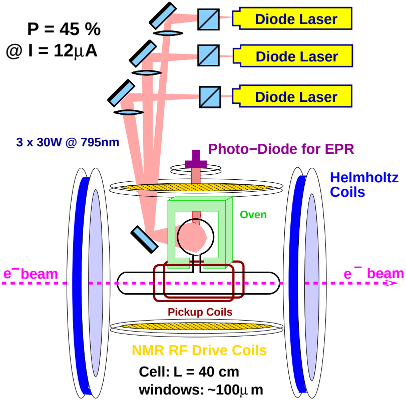


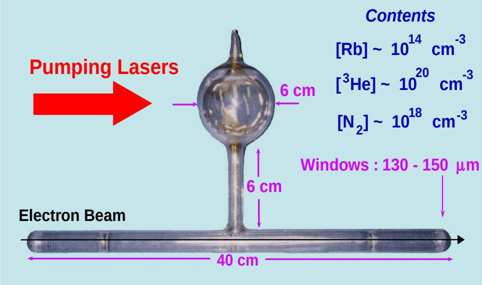
Pion rejection: $> 10^4$

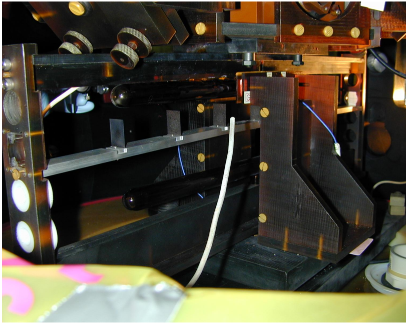
Hall A Polarized ^{3}He Program

$^3\vec{He}$ Target

- $P_t \approx 35\% \to 50\%$
  spin orientation: $\parallel$ or $\perp$
  (any horizontal direction)
- fast polarization reversal
  (few mins.)
- high pressure ($\approx$ 10 atm)
  spin-exchange target.
- high pol. $\mathcal{L} \approx 6\times 10^{35}/cm^2/s$

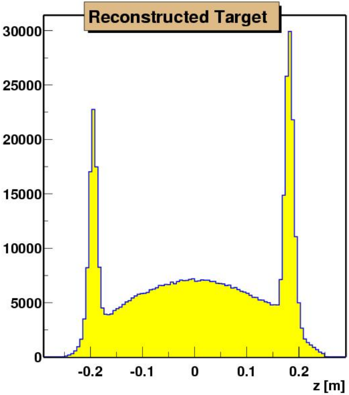


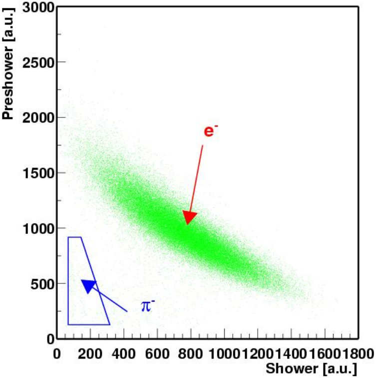




- Q^2 evolution of moments of $g^n_{1,2}$ in resonance region
- "large" x ($\gtrsim$ 0.2), measurements in resonance and DIS regimes
- transverse asymmetries in DIS regime (small)

Reconstruction and PID





From ^{3}He to the Neutron

In general: $g_{1,2}^{^3He}(x,Q^2) = P_n g_{1,2}^n(x,Q^2) + 2P_p g_{1,2}^p(x,Q^2)$

- spin depolarization → S′ -, D - states → $P_n = 0.86^{+0.036}_{-0.020}$, $P_p = -0.028^{+0.094}_{-0.004}$
- nuclear binding, Fermi motion ⟶ Δ isobar, pions, vector mesons, off-shell effects
- small-x-effects (nuclear shadowing, nuclear anti-shadowing: $0.05 \lesssim x \lesssim 0.2$)

In resonance region: nuclear binding and Fermi motion significant:
$g_{1,2}^n$ ⇒ (20-30)% uncertainty, but effects on integrals smaller ($\lesssim$10%)

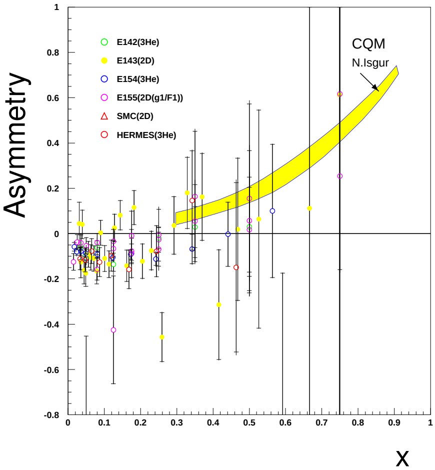
$$\Gamma^n(Q^2) = \frac{1}{P_n}\Gamma^{^3He}(Q^2) - 2\frac{P_p}{P_n}\Gamma^p(Q^2)$$

Proton: MAID or CLAS (Hall B)

J.L. Friar et al., PRC42, 2310 (1990)
C. Ciofi degli Atti et al., PRC48, R968 (1993)
F. Bissey et al., PRC65, 064317 (2002)

Measurement of A_1^n at Large x

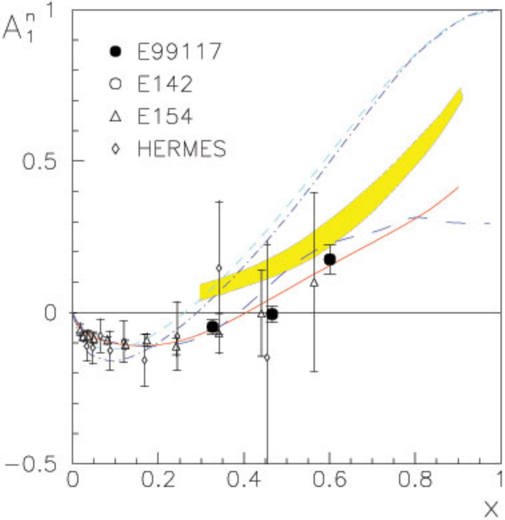
World data on A_1^n: (at measured Q^2)



☞ Large x data even consistent with SU(6) prediction: $A_1^n = 0$

Experiment E99-117 at JLab:

x	Q^2 [GeV^2/c^2]	W^2 [GeV^2]
0.33	2.72	6.38
0.48	3.55	4.80
0.61	4.86	4.00



Dominating Experimental Systematic Uncertainties:

- $\frac{\Delta E_b}{E_b} < 5 \cdot 10^{-4}$
- $\frac{\Delta p}{p} < 5 \cdot 10^{-4}$
- $\Delta\theta_e < 0.1^\circ$
- $\frac{\Delta P_b}{P_b} < 3\%$
- $\frac{\Delta P_t}{P_t} < 4\%$
- $\Delta\theta_t < 0.5^\circ$

dashed-dotted: S. Brodsky, M. Burkardt, I. Schmidt; Nucl. Phys. B441 (1995)
short dashed: E. Leader, A. Sidorov, D. Stamenov, Int. J. Mod. Phys. A13 (1998)
red solid: E. Leader, A. Sidorov, D. Stamenov; Eur.Phys. J C23 (2003)
long dashed: C. Bourrely, J. Soffer, F. Bucella; Eur.Phys. J C23 (2002)

Neglecting the sea quarks and combining neutron and proton data:

$$\frac{g_1^p}{F_1^p} = \frac{4\Delta u+\Delta d+4\Delta\bar{u}+\Delta\bar{d}}{4u+d+4\bar{u}+\bar{d}}$$

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

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

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

with $R^{du} = \frac{d+\bar{d}}{u+\bar{u}}$.

Spin-Flavor Decomposition at Large x

Neglecting the sea quarks and combining neutron and proton data:

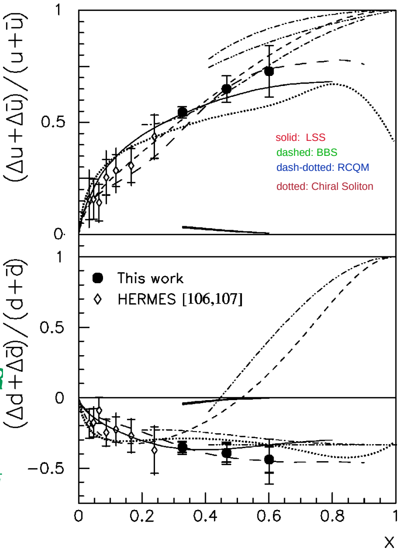
$$\frac{g_1^p}{F_1^p} = \frac{4\Delta u+\Delta d+4\Delta\bar{u}+\Delta\bar{d}}{4u+d+4\bar{u}+\bar{d}}$$

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

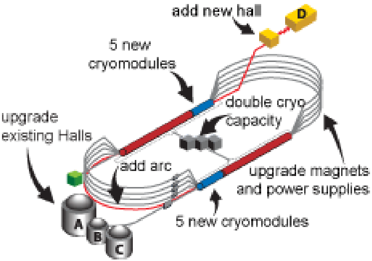
$$\frac{\Delta u+\Delta\bar{u}}{u+\bar{u}} = \frac{4}{15}\frac{g_1^p}{F_1^p}(4+R^{du}) - \frac{1}{15}\frac{g_1^n}{F_1^n}(1+4R$$

$$\frac{\Delta d+\Delta\bar{d}}{d+\bar{d}} = \frac{4}{15}\frac{g_1^n}{F_1^n}\left(4+\frac{1}{R^{du}}\right) - \frac{1}{15}\frac{g_1^p}{F_1^p}\left(1+\frac{4}{R^{du}}\right.$$

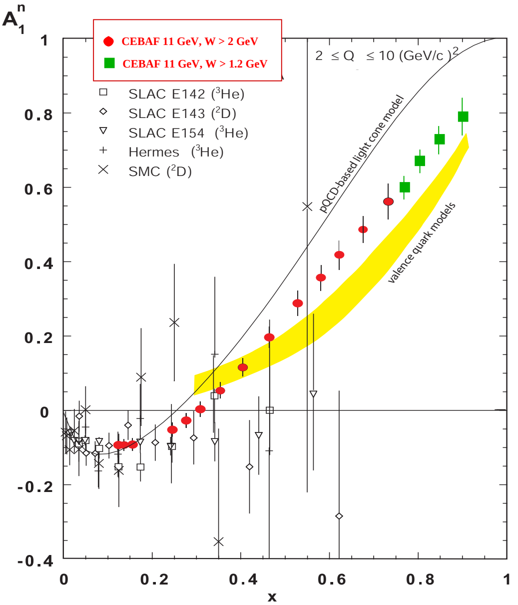
with $R^{du} = \frac{d+\bar{d}}{u+\bar{u}}$.



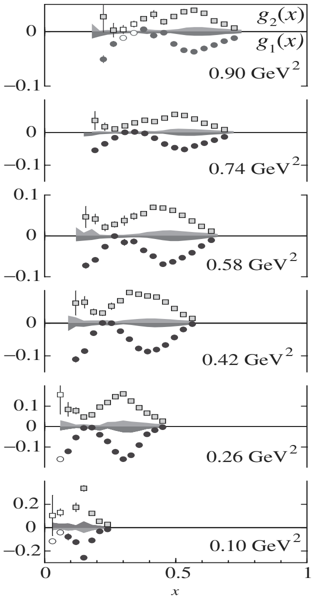
Quark Orbital Angular Momentum?



add new hall
D
5 new cryomodules
double cryo capacity
upgrade existing Halls
add arc
upgrade magnets and power supplies
5 new cryomodules
A
B
C



A_1^n
CEBAF 11 GeV, W > 2 GeV
CEBAF 11 GeV, W > 1.2 GeV
SLAC E142 (^{3}He)
SLAC E143 (^{2}D)
SLAC E154 (^{3}He)
Hermes (^{3}He)
SMC (^{2}D)
2 ≤ Q ≤ 10 (GeV/c)^2
pQCD-based light cone model
valence quark models
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



Extraction of $g_{1,2}^{3He}$ at low Q^2 and low W

Hall A: g_1^{3He} and g_2^{3He}

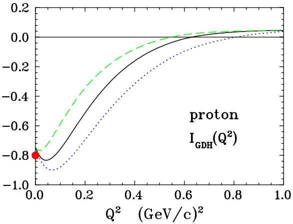
- pronounced Δ resonance
- $g_2 \approx -g_1 \Rightarrow g_2$ is not small !!
  note: $\sigma_{LT} \propto (g_1 + g_2)$, Δ is M1 transition

The GDH Integral for the Neutron

$$I(Q^2=0) = \int_{\nu_{thresh}}^{\infty} \frac{d\nu}{\nu}(\sigma_{\uparrow\downarrow}(\nu) - \sigma_{\uparrow\uparrow}(\nu)) = -\frac{2\pi^2\alpha}{M_N}\kappa_N^2$$ ⇐GDH Sum rule

S.B. Gerasimov, Sov. J. Nucl. Phys. 2, 430, 1966
S.D. Drell and A.C. Hearn, Phys. Rev. Lett. 16, 908, 1966

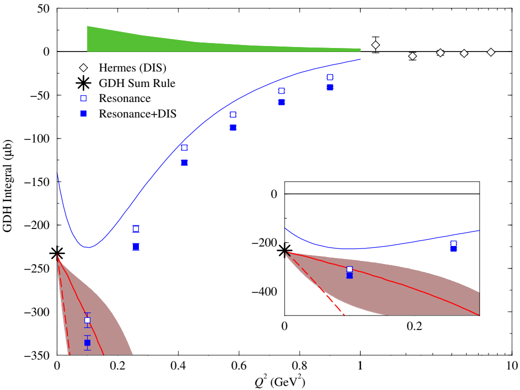
For finite Q^2: $I(Q^2) = \frac{16\pi^2\alpha}{Q^2}\int_0^1 dx g_1(x,Q^2) = \frac{16\pi^2\alpha}{Q^2}\Gamma_1(Q^2)$



D. Drechsel *et al.*, *Phys. Rev.***D63**,114010, 2001

→ data from Hall B

C. Ciofi degli Atti, S. Scopetta; PLB 404, 223 (1997)



Extension of pQCD to Resonance Regime

Relation between 1st Cornwall-Norton moment of (spin-dependent) scaling function (N =p,n) and the OPE:

$$\Gamma_1^N(Q^2) \equiv \int_0^1 dx\, g_1^N(x, Q^2) = \sum_{\tau=2,4,\ldots} \frac{\mu_\tau^N(Q^2)}{Q^{\tau-2}} = \mu_2^N(Q^2) + \frac{\mu_4^N(Q^2)}{Q^2} + \frac{\mu_6^N(Q^2)}{Q^4} +$$

- μ_τ contain nucleon matrix elements
  - μ_2 ➛ incoherent scattering of partons (+ perturbative QCD corrections) ➛ large Q^2
  - $\mu_{\tau>2}$ ➛ coherent scattering of several (few) partons (+ pertubative QCD corrections), measure of quark-gluon and quark-quark correlations
  - measure of “Initial(Final) State Interactions” ➛ should become more important at lower Q^2
- related to quark-hadron duality

Look at μ_2:

$$\mu_2(Q^2 \to \infty) = \int_0^1 dx\, g_1(x) = \pm a_3 + a_8 + a_0$$

- Axial charges:
  $a_3 \to g_A|_{np} = 1.2670(35)$ ✔
  $a_8 \to$ hyperon weak decay (0.579(25))✔
  $a_0 \to \Delta\Sigma = \sum_{u,d,s}(\Delta q + \Delta\bar{q})$, from fit to high Q^2 data ✔

  ($SU(3)_f$ symmetry assumed)
- finite Q^2: use Q^2 dependence of coefficient functions
- Accessing higher twist terms:

$$\Rightarrow \Delta\Gamma_1(Q^2) \equiv \Gamma_1(Q^2) - \mu_2(Q^2)$$

twist-2 (target mass correction): $a_2 = 2\int_0^1 dx\, x^2 g_1(x)$ ✔

$$\mu_4 = \frac{M^2}{9}(a_2 + 4d_2 + 4f_2)$$

twist-4: f_2 **→extract from fit**

twist-3: $d_2 = \int_0^1 dx\, x^2(2g_1(x) + 3g_2(x)) = 3\int_0^1 dx\, x^2 g_2^{\tau=3}(x)$

X. Ji and P. Unrau, Phys. Lett. B333 (1994)
E. Stein et al., Phys. Lett. B353 (1995)
X. Ji and W. Melnitchouk, Phys. Rev. D56 (1997)

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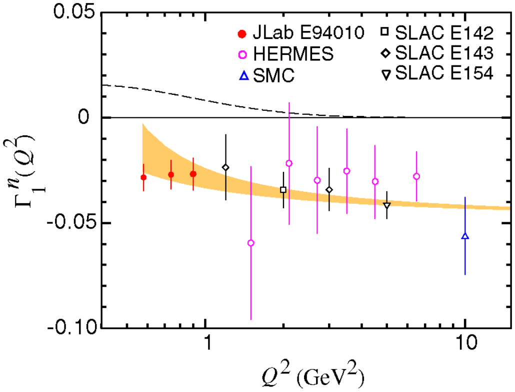
Higher Twist Contributions to $\Gamma_1^n(Q^2)$

pol. ^{3}He from Hall A:



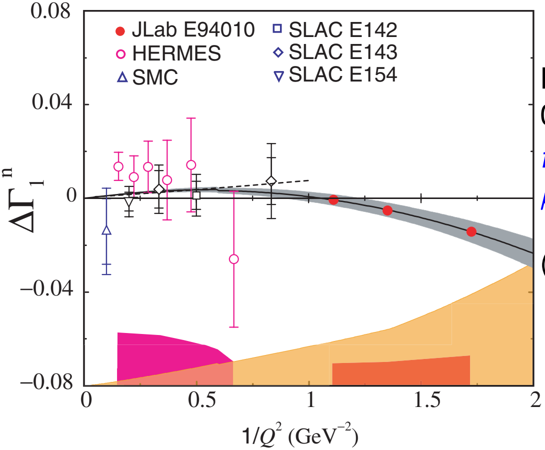
Elast. contribution included

$$\Gamma_1(Q^2) = \int_0^1 dx g_1(x, Q^2)$$

twist-2: $\Delta\Sigma_n = 0.35 \pm 0.08$

note: $\Delta\Sigma_p = 0.330 \pm 0.039$ $\quad Q^2 > 5$ GeV^2

Z.-E. Meziani et al., Phys. Lett. B 613 (2005)
M. Osipenko et al., Phys.Lett. B 609 (2005)



Fitted range:

0.5 GeV^2 < Q^2 < 10 GeV^2

$f_2^n = 0.034 \pm 0.043$ (*tot. uncert.*)

$\mu_6^n/M^4 = -0.019 \pm 0.017$

(Values for Q^2 = 1 GeV^2)

$a_2^n = -0.0031(20)$

$d_2^n = 0.0079(48)$ (E155x)

Z.-E. Meziani et al., Phys. Lett. B 613 (2005)

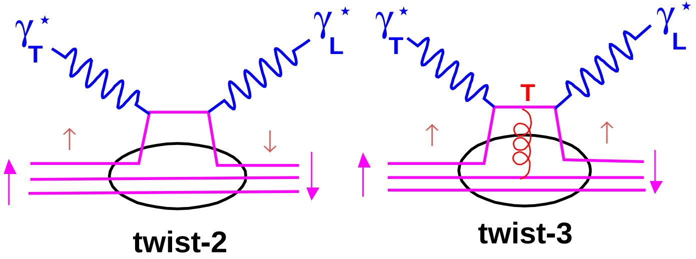
The Spin Structure Function g_2^n

- s.s.f. $g_2(x, Q^2)$ has no interpretation in the parton model !
- related to the "transverse" spin structure function
  $g_T(x,Q^2) = g_1(x, Q^2) + g_2(x, Q^2)$
- higher-twist structure function ⇒ *coherent* lepton-parton scattering with more than one parton involved in scattering process.
- twist-2 part of $g_2(x, Q^2)$ is completely determined by twist-2 part of $g_1(x, Q^2)$:

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_{x'}^{1} dx' \, \frac{g_1(x', Q^2)}{x'}$$

S. Wandzura and F. Wilczek, Phys. Lett. B72 (1977)

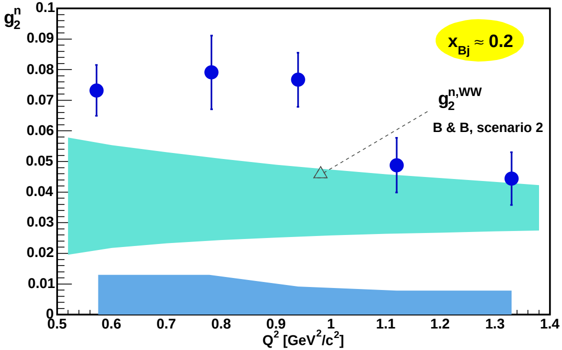
- ✘ twist-2 *and* twist-3 contributions are leading twist
- ✘ higher twist (twist-3 and higher) contributions can be directly separated. → $g_2(x, Q^2)$ is a unique structure function!!!



⇒ sensitive to quark-gluon correlations.

Q^2 Dependence of g_2^n at $x \approx 0.2$

E97-103: 1.92 GeV $<$ W $<$ 2.48 GeV

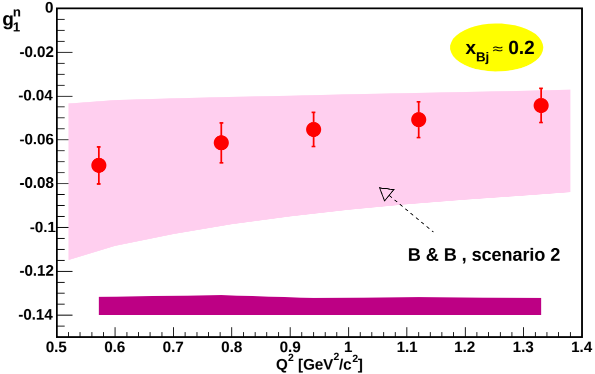


➩ higher twist (twist-3?) increase for $Q^2 \lesssim 1$ GeV^2, but not huge (h.t. > 0)

K. Kramer et al., Phys. Rev. Lett. 95 (2005)

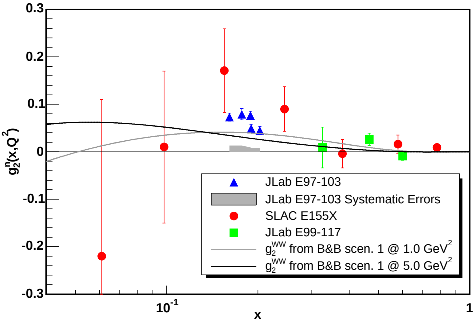
Higher Twist Contributions to g_1^n at $x \approx 0.2$

Evolve Blümlein and Böttcher pol. parton distribution functions down to low Q^2: twist-2 evolution



➩ higher twist contributions appear to be small (or cancel) down to $Q^2 \approx 0.54$ GeV^2

K. Kramer et al., Phys. Rev. Lett. 95 (2005)

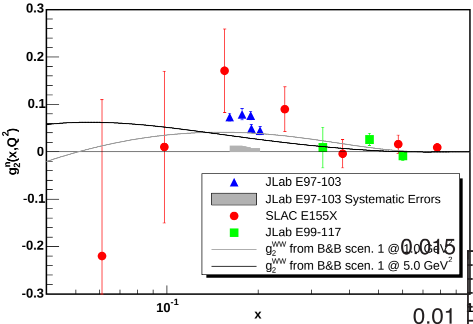


$$d_2 = \int_0^1 dx\ x^2(2g_1(x) + 3g_2(x))$$

$$d_n^2 = 0.0062 \pm 0.0028$$

$\overline{Q^2} \approx 5$ GeV^2
(w/o E97-103)

X. Zheng et al., Phys.Rev.C 70 (2004)
P.L. Anthony et al., Phys. Lett. B553 (2003)



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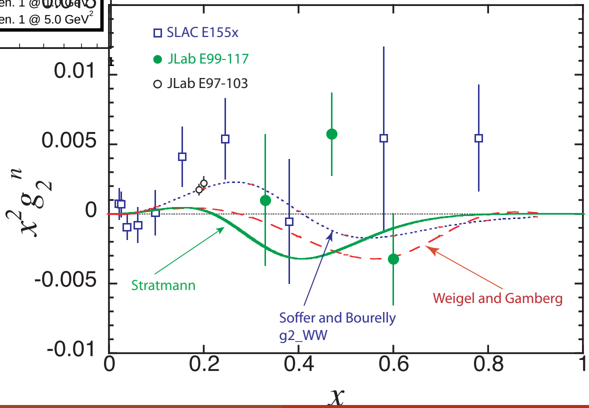
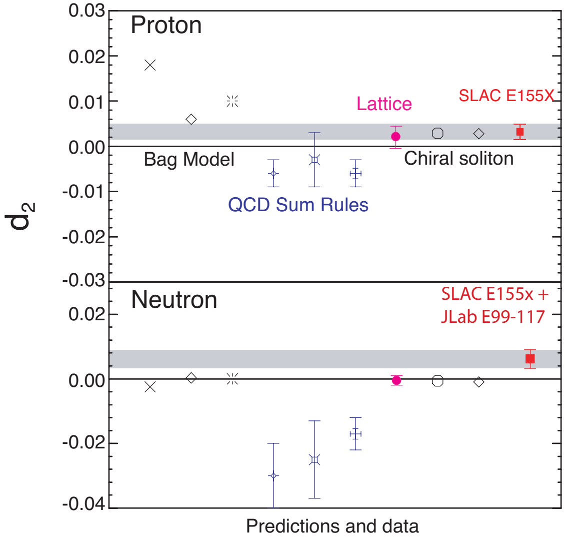
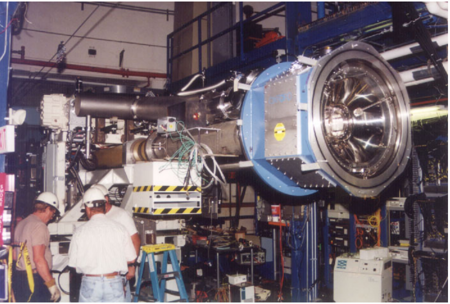


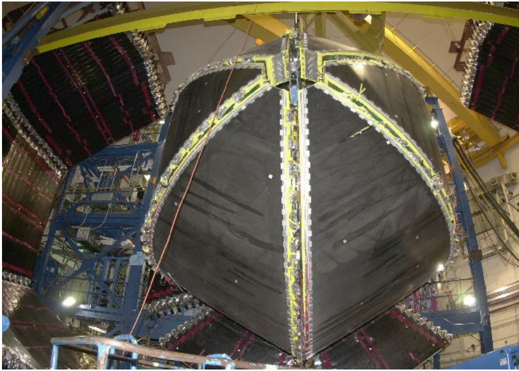
Theoretical Predictions for d_2



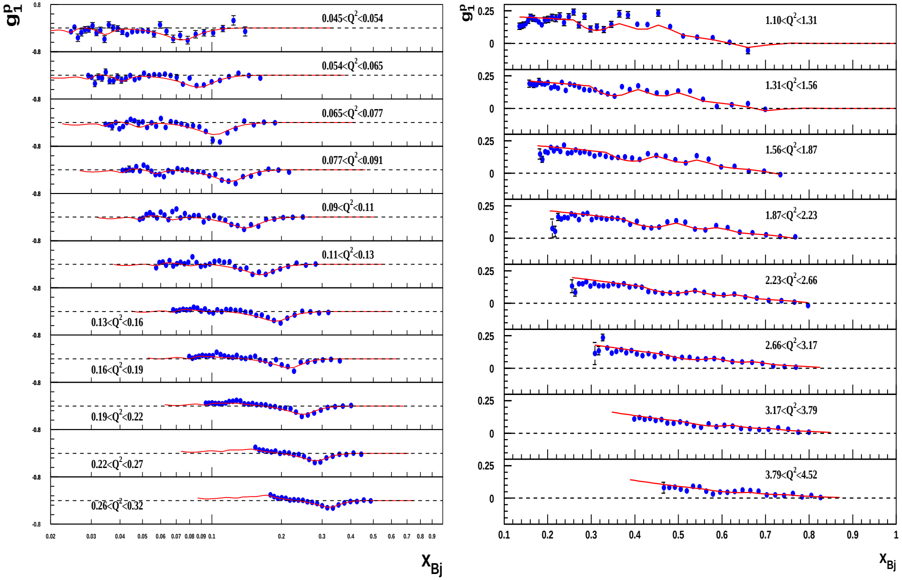
Hall B Polarized p, d Program

- $^{15}N\vec{H}_3$, $P_t \lesssim 70\%$ ($\|$), solid
- $^{15}N\vec{D}_3$, $P_t \lesssim 45\%$ ($\|$), solid
- Spectrometer: CLAS, $\Delta\Omega \approx 1.5$ sr

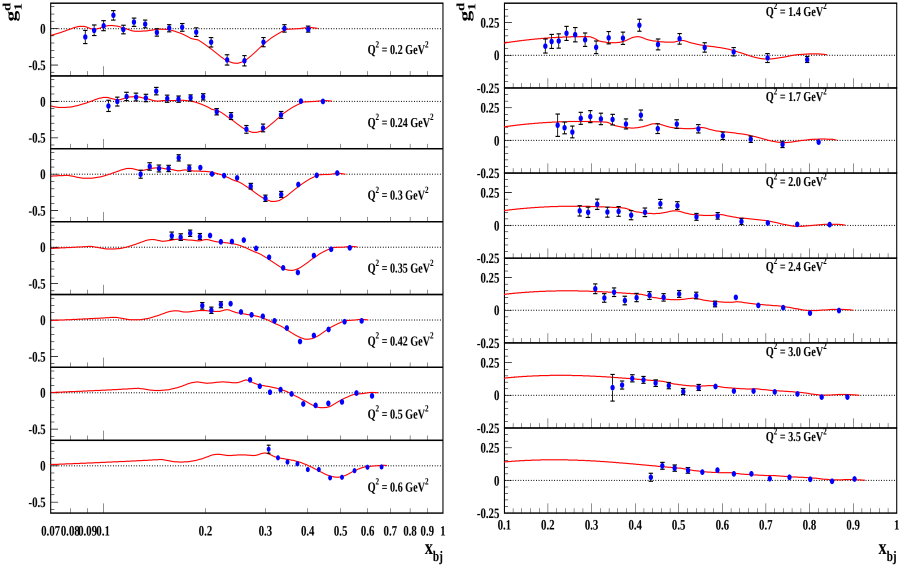




New Results on g_1^p from Hall B

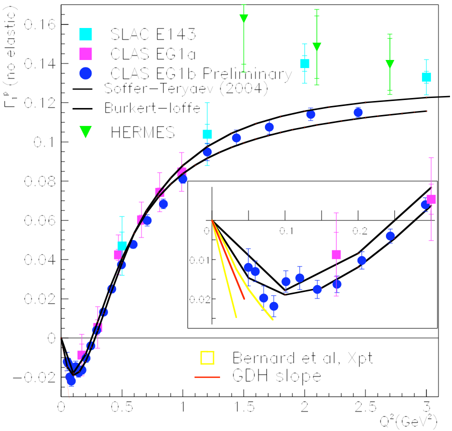


New Results on g_1^d from Hall B

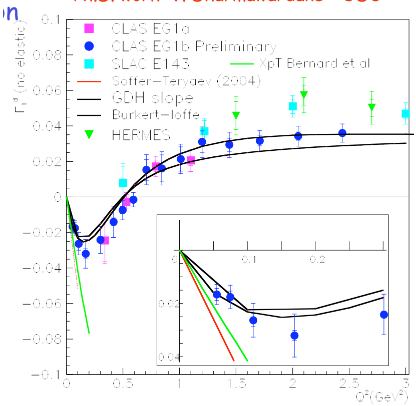


$\Gamma_1^p(Q^2)$ and $\Gamma_1^d(Q^2)$ from Hall B

Ph.D. work: Y. Prok - UVa

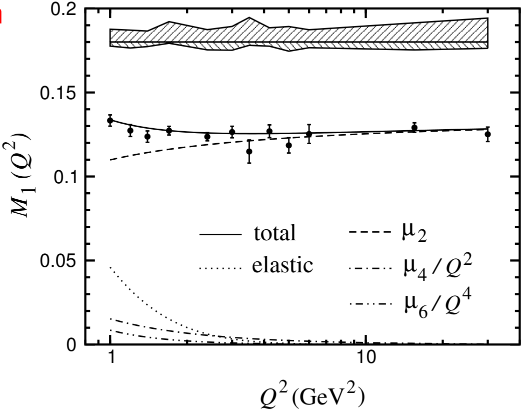


Ph.D. work: V. Dharmawardane - ODU



G.E. Dodge, Jour. Phys., Conf. Ser. 9 (2005)
G.E. Dodge, First Meeting of the APS Topical Group on Hadronic Physics

EG1a Collaboration

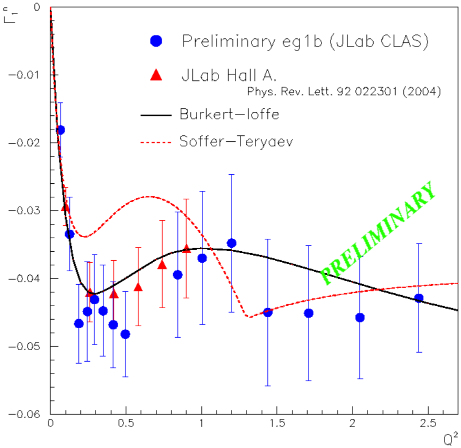


$f_2^p = 0.039 \pm 0.022(stat.) \pm {}^{0.000}_{0.018}(sys.) \pm 0.030(low\ x) \pm {}^{0.007}_{0.011}(\alpha_s)$

$\mu_6^p = 0.011 \pm 0.013(stat.) \pm {}^{0.010}_{0.000}(sys.) \pm 0.011(low\ x) \pm 0.000(\alpha_s)$

Values at Q^2 = 1 GeV^2

M. Osipenko et al., Phys.Lett. B 609 (2005)



$$\Gamma_1(Q^2) = \int_0^1 dx\, g_1(x, Q^2)$$

Low x extrapolation:

Hall A: 2 GeV $<$ W $<$ 32 GeV
➛ Bianchi & Thomas

Hall B: own model

Determination of Γ_1^n very consistent $\Rightarrow$ nuclear effects are understood

G. Dodge, talk at GDH2004
M. Amarian et al., Phys. Rev. Lett. 92 (2004)
N. Bianchi and E. Thomas, Phys. Lett. B450 (1999)

Color polarizabilites: Response of color electric and magnetic fields to spin orientation.

$$\chi_E = \frac{2}{3}(2d_2 + f_2)$$

$$\chi_B = \frac{1}{3}(4d_2 - f_2)$$

E. Stein et al., Phys. Lett. B 353 (1995)
X. Ji, hep-ph/9510362 (1995)

Proton (Q^2 = 1 GeV^2)

$$\chi_E^p = 0.026 \pm 0.015(stat.) \pm^{0.021}_{0.024} (sys.)$$

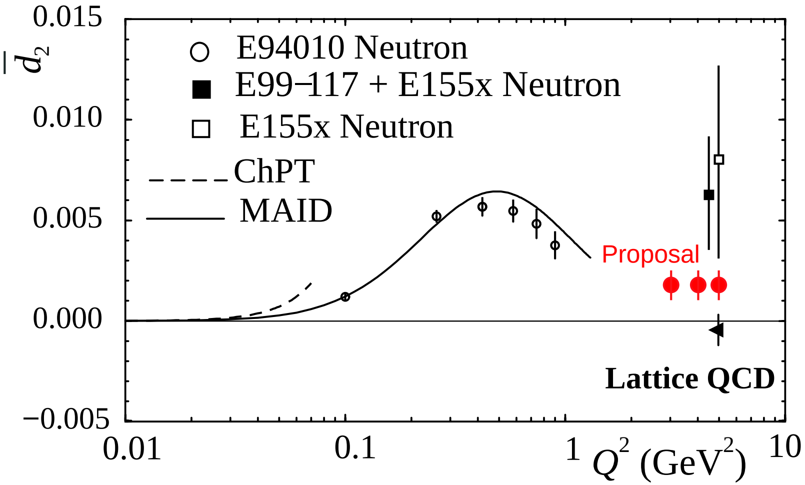
$$\chi_B^p = -0.013 \mp 0.007(stat.) \mp^{0.010}_{0.012} (sys.)$$

Neutron (Q^2 = 1 GeV^2)

$$\chi_E^n = 0.033 \pm 0.029$$

$$\chi_B^n = -0.001 \pm 0.016$$

Future Higher Twist Studies in Hall A



2008: $d_2(\langle Q^2 \rangle = 3 GeV^2)$
JLab at 12 GeV: $d_2(\langle Q^2 \rangle = 3, 4, 5 GeV^2)$

Higher Twist Contributions to the Bj Integral

- at infinite Q^2:
  Bjorken integral: Hall A and Hall B data combined

$$\Gamma_1^{p-n} \equiv \Gamma_1^p - \Gamma_1^n \equiv \int_0^1 dx\, (g_1^p(x) - g_1^n(x)) = \frac{g_A}{6}$$

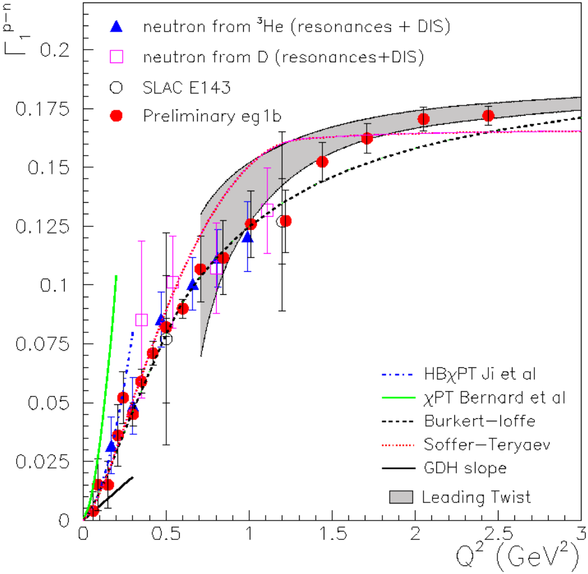
- at finite (large) values of Q^2 and leading twist (= twist-2), $\overline{\text{MS}}$ scheme:

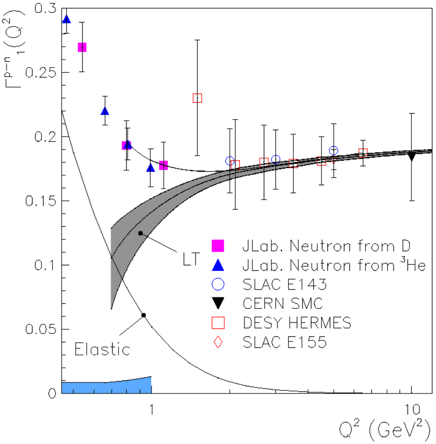
$$\Gamma_1^{p-n}(Q^2) = \frac{g_A}{6}\left[1 - \frac{\alpha_s}{\pi} - 3.58\left(\frac{\alpha_s}{\pi}\right)^2 - 20.21\left(\frac{\alpha_s}{\pi}\right)^3 + \ldots\right] = \mu_2^{p-n}(Q^2)$$

- at finite (small) values of Q^2 and power corrections (OPE):

$$\Gamma_1^{p-n}(Q^2) = \sum_{i=1}^{\infty} \frac{\mu_{2i}^{p-n}(Q^2)}{Q^{2i-2}} = \mu_2^{p-n}(Q^2) + \frac{\mu_4^{p-n}(Q^2)}{Q^2} + \frac{\mu_6^{p-n}(Q^2)}{Q^4} + \ldots$$

The Bjorken Integral in the Transition Regime





Fitted range:
0.8 GeV$^2 < Q^2 <$ 10 GeV^2

$$f_2^{p-n} = -0.11 \pm 0.15(uncor)^{+0.04}_{-0.03}(cor)$$
$$\mu_6^{p-n}/M^4 = 0.08 \pm 0.06(uncor) \pm 0.01 (cor)$$

Fitted range:
0.66 GeV$^2 < Q^2 <$ 10 GeV^2

$$f_2^{p-n} = -0.17 \pm 0.05(uncor)^{+0.04}_{-0.05}(cor)$$
$$\mu_6^{p-n}/M^4 = 0.12 \pm 0.02(uncor) \pm 0.01 (cor)$$

(Values for Q^2 = 1 GeV^2)

Low x extrapolation consistently done $\rightarrow$ Bianchi & Thomas (2 GeV $< W <$ 32 GeV) + Regge parameterization for $W >$ 32 GeV (Note: Bj integral is flavor non-singlet)

A. Deur et al., Phys. Rev. Lett. 93 (2004)

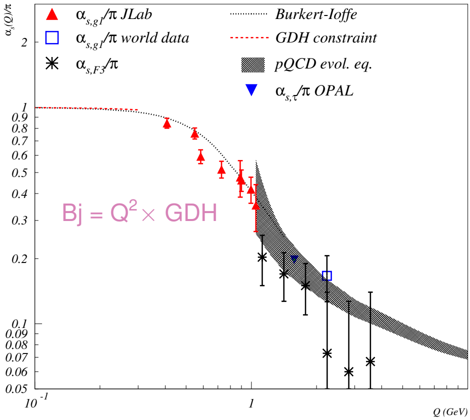
Extraction of α_s^{eff} at Low Q^2

Define $\alpha_s^{\rm eff}$ using the Bjorken integral

$$\Gamma_1^{p-n}(Q^2) = \frac{g_A}{6}\left(1 - \frac{\alpha_s^{eff}(Q^2)}{\pi}\right)$$

➡ absorb power and pQCD corrections in $\alpha_s^{\rm eff}$

S. Brodsky, hep-ph/0310289
G. Grunberg, Phys. Rev. D29 (1984)
G. Grunberg, Phys. Lett. B95 (1980)



$\alpha_s^{\rm eff}$ stays finite as Q → 0 !!

EG1b data consistent
with Burkert-Ioffe curve !

Summary

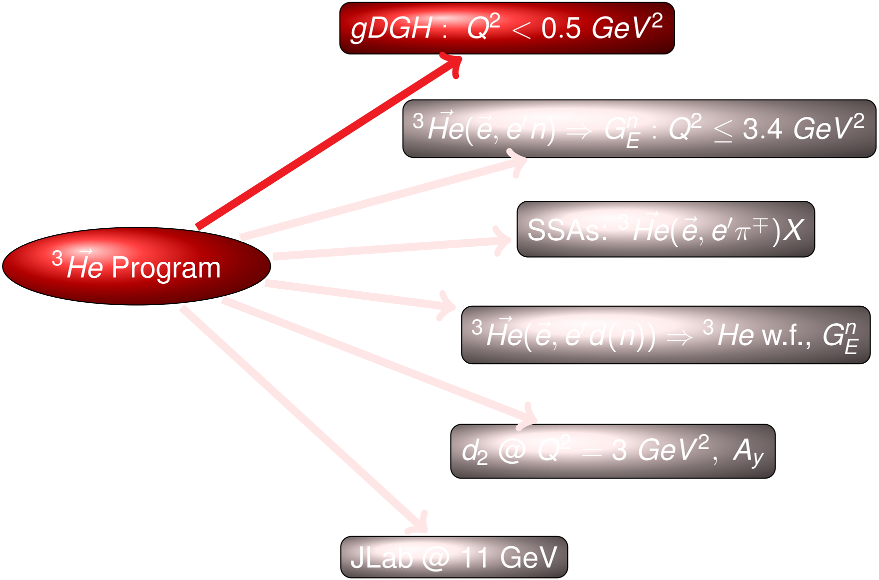
- ✗ Polarized ^{3}He program in Hall A has been successfully taking data for ≈8 years.
- ✗ Precision measurements of the nucleon spin structure functions at low Q^2.
- ✗ High luminosity ⇒ Q^2 evolution of moments can be measured.
- ✗ Higher twist effects in spin structure g_1 and g_2 functions appear to be small for the proton and the neutron down to $Q^2 < 1$ GeV^2.
- ✗ Q^2 dependence of the Bjorken Integral allows for the extraction of an effective α_s^{eff}

Outlook

$^3\vec{He}$ Program

- $gDGH: \ Q^2 < 0.5 \ GeV^2$
- $^3\vec{He}(\vec{e}, e'n) \Rightarrow G_E^n : Q^2 \leq 3.4 \ GeV^2$
- SSAs: $^3\vec{He}(\vec{e}, e'\pi^{\mp})X$
- $^3\vec{He}(\vec{e}, e'd(n)) \Rightarrow {}^3He$ w.f., G_E^n
- $d_2 \ @ \ Q^2 = 3 \ GeV^2, \ A_y$
- JLab @ 11 GeV

Outlook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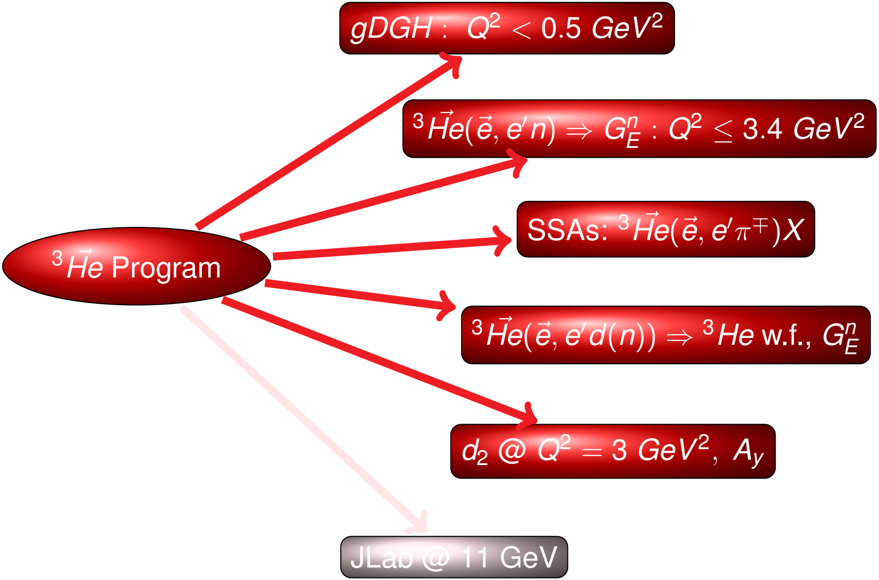
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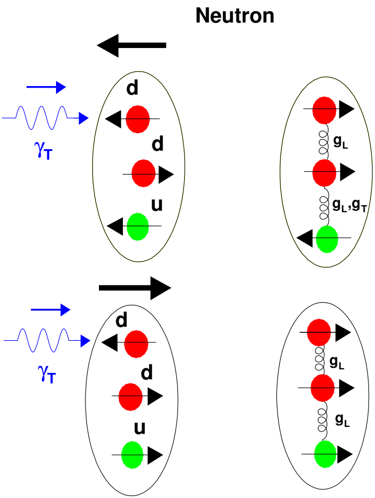
Additional Slides



Coupling of a large-k^2 $[\approx m^2/(1-x)]$ longitudinal gluon to small-p^2 quarks is suppressed by $(p^2/k^2)^{1/2} \sim (1-x)^{1/2}$ relative to the transverse coupling.

G.R. Farrar and D.R. Jackson, *Phys. Rev. Lett.* **35**, 1416 (1975)