National Nuclear Physics Summer School 2012

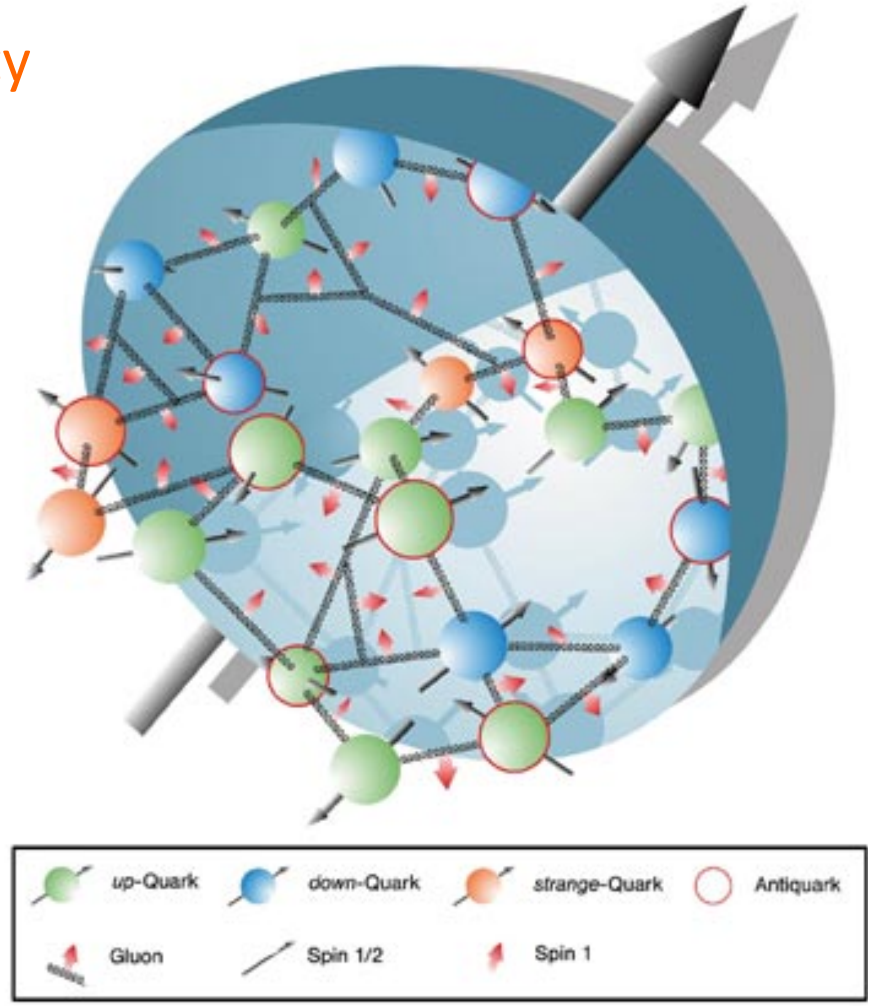
Spin Structure of the Nucleon

Zein-Eddine Meziani

Temple University
Philadelphia

Lecture # 2

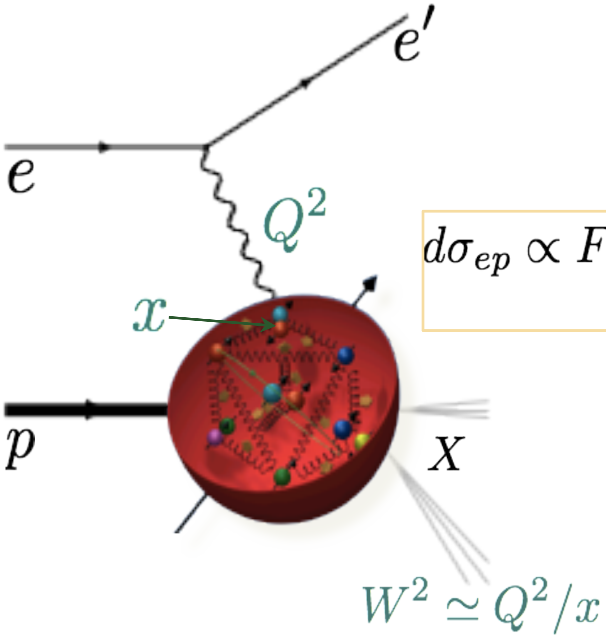
Questions: meziani@temple.edu



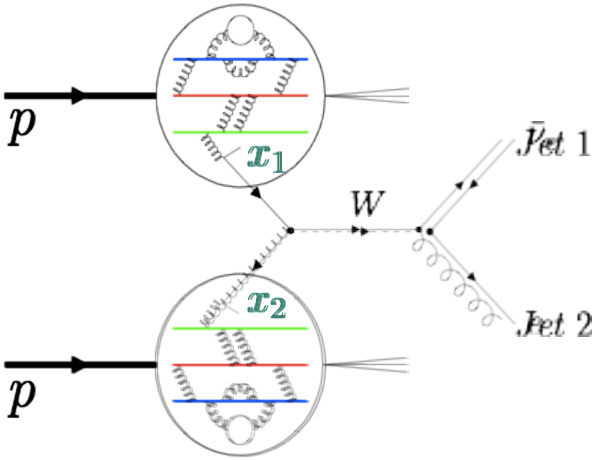
Coutesy of CERN Courier

Probing the constituents

- How do we probe the structure and dynamics of matter in ep / pp scattering?



$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$



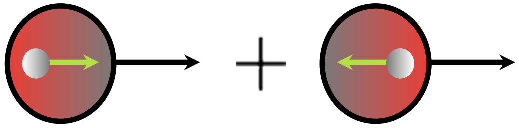
Universality

$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$

Factorization

Momentum contribution

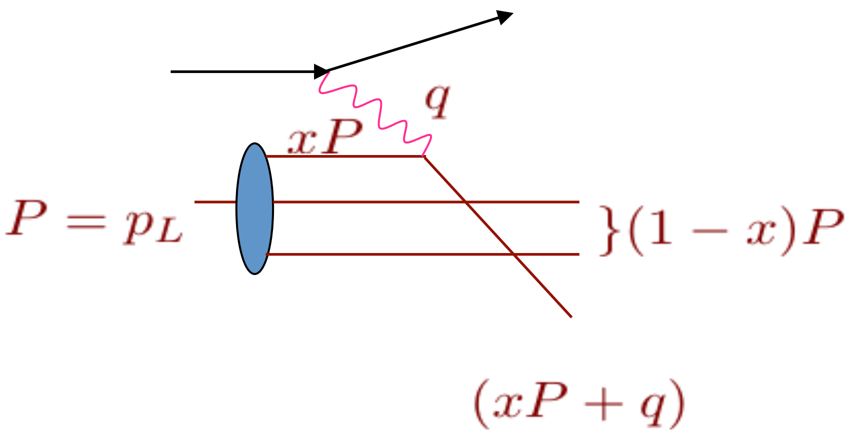
$$f(x) =$$



$$f^+(x) + f^-(x)$$

Quark-Parton Model

Bjorken, Feynman and Paschos



The nucleon is made out of non-interacting point like particles called partons

The photon quark scattering is elastic scattering

	Proton ↓	Parton ↓
Energy	E	xE
Momentum	p_L	xp_L
	$p_T = 0$	$p_T = 0$
Mass	M	$m = (x^2E^2 - x^2p_L^2)^{1/2} = xM$

Where x is the fraction of nucleon momentum carried by the struck quark

Quark Parton Model

$$(xP+q)^2 = m^2 \Rightarrow x^2P^2 + 2xP\cdot q + q^2 = m^2$$

At large q^2 assume $q^2 \gg x^2P^2$ and $q^2 \gg m^2$

thus $2xP\cdot q + q^2 \simeq 0$

solving for x in the Lab frame we obtain

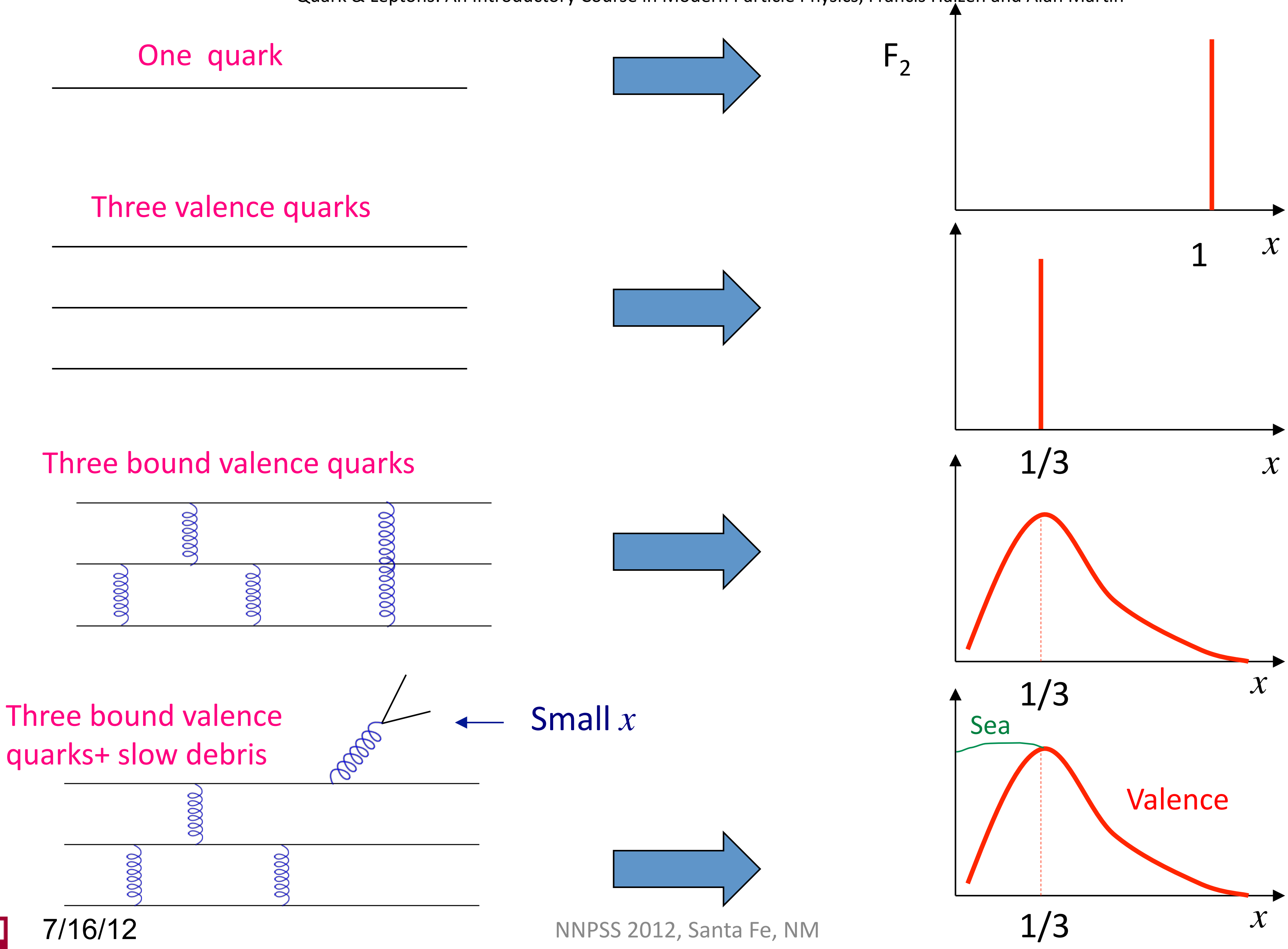
$$2xM\cdot\nu + q^2 = 0 \Rightarrow \boxed{x = \frac{Q^2}{2M\nu}}$$

Elastic scattering off a quark lead to $q^2 = 2m\nu$

Then $\boxed{x = \frac{m}{M}}$ Fraction of nucleon mass carried by struck quark !?

A scattering picture of the proton

Quark & Leptons: An Introductory Course in Modern Particle Physics, Francis Halzen and Alan Martin



One quark

Three valence quarks

Three bound valence quarks

Three bound valence quarks+ slow debris

Small x

Structure functions in the parton model

In the infinite-momentum frame:

- no time for interactions between partons
- Partons are point-like non-interacting particles: $\sigma_{\text{Nucleon}} = \sum_i \sigma_i$

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

$$F_2(x) = \sum_i e_i^2 x [q_i^{\uparrow}(x) + q_i^{\downarrow}(x)]$$

$$2xF_1(x) = F_2(x) = \sum_i e_i^2 x q_i(x)$$

Callan-Gross relation $\quad \frac{\sigma_L}{\sigma_T} \to 0$

It is a consequence of quarks having a spin 1/2

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

$g_2(x)$ has no simple partonic interpretation.

It involves quark-gluon interactions

Virtual photon-nucleon asymmetries

Longitudinal

$$\frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} = A_{\parallel} = D(A_1 + \eta A_2)$$

Transverse

$$\frac{\sigma^{\downarrow\Leftarrow} - \sigma^{\uparrow\Leftarrow}}{\sigma^{\downarrow\Leftarrow} + \sigma^{\uparrow\Leftarrow}} = A_{\perp} = d(A_1 - \xi A_2)$$

D, d, η and ξ are kinematic factors

D depends on $R(x, Q^2) = \sigma_L / \sigma_T$

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

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

where $\gamma = \sqrt{Q^2}/\nu$

- Positivity constraints

$|A_1| \leq 1$ and $|A_2| \leq \sqrt{R(1+A_1)/2}$

In the quark-parton model:

$$F_1(x, Q^2) = \tfrac{1}{2}\sum_f e^2 q_f(x, Q^2) \qquad g_1(x, Q^2) = \tfrac{1}{2}\sum_f e^2 \Delta q_f(x, Q^2)$$

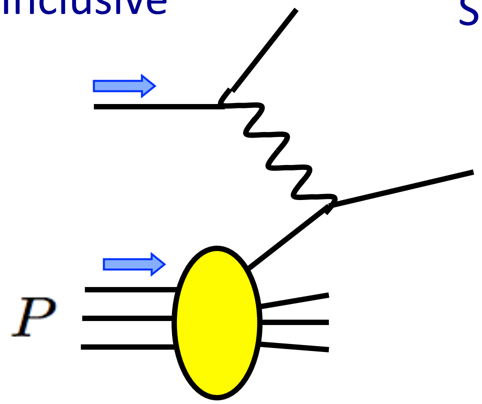
$$q_f(x) = q_f^{\uparrow}(x) + q_f^{\downarrow}(x) \qquad \Delta q_f(x) = q_f^{\uparrow}(x) - q_f^{\downarrow}(x)$$

$q_f(x)$ quark momentum distributions of flavor f

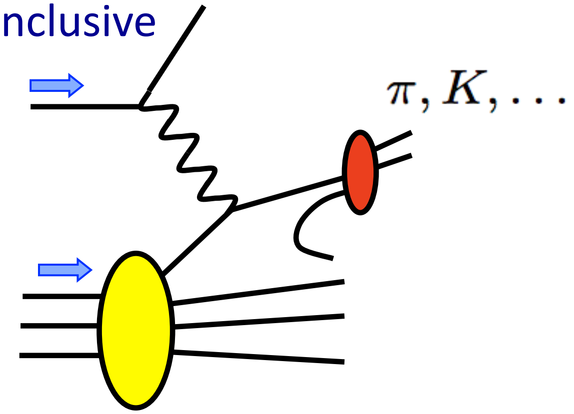
$\uparrow(\downarrow)$ parallel (antiparallel) to the nucleon spin

Probes of nucleon helicity structure:

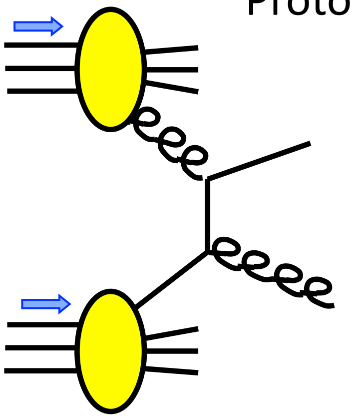
Inclusive



Semi-Inclusive



Proton-proton



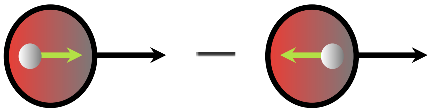
$$\Delta\sigma = \sum_{f=q,\bar{q},g} \int dx \, \Delta f(x, Q^2) \, \Delta\hat{\sigma}^f(xP, \alpha_s(Q^2)) + \ldots$$

$$\Delta\sigma = \sum_{a,b=q,\bar{q},g} \int dx_a \, \Delta f_a(x_a, p_\perp^2) \int dx_b \, \Delta f_b(x_b, p_\perp^2) \Delta\hat{\sigma}^{ab}(x_a P, x_b P', \alpha_s(p_\perp^2)) + \ldots$$

- NLO ($\overline{\mathrm{MS}}$) "global analysis"

de Florian, Sassot, Stratmann, Vogelsang

$\Delta f(x) =$



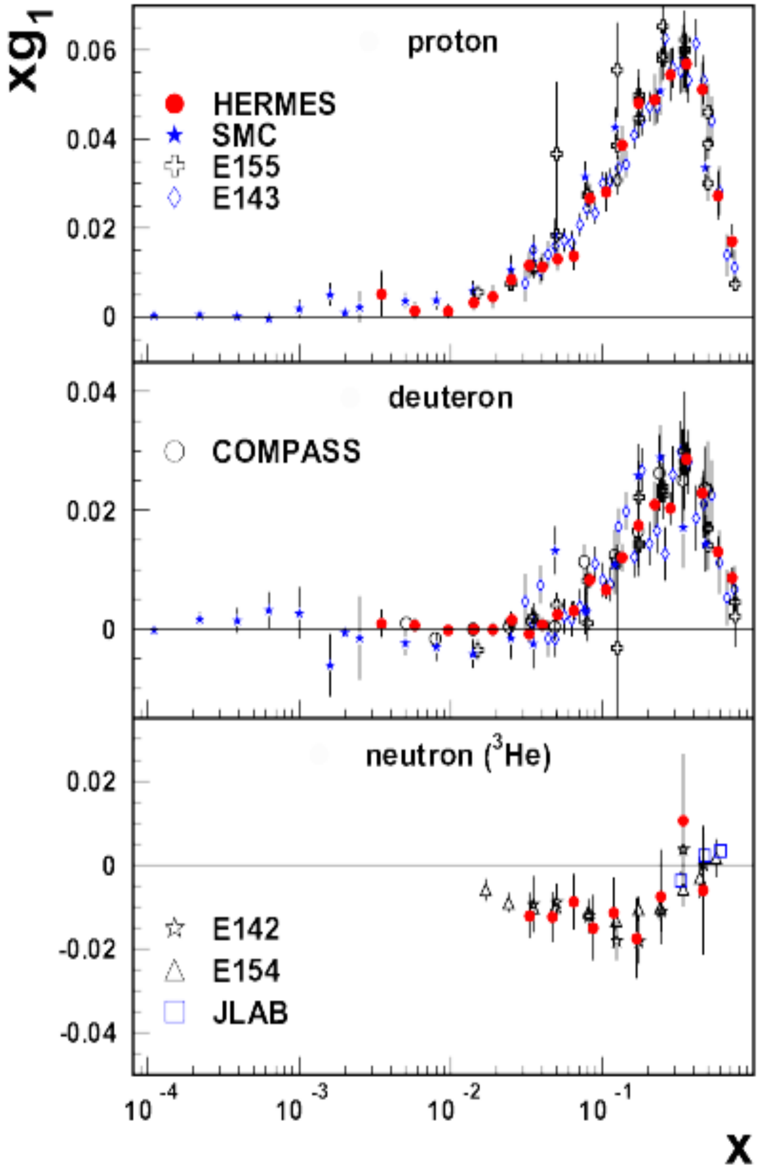
$f^+(x) - f^-(x)$

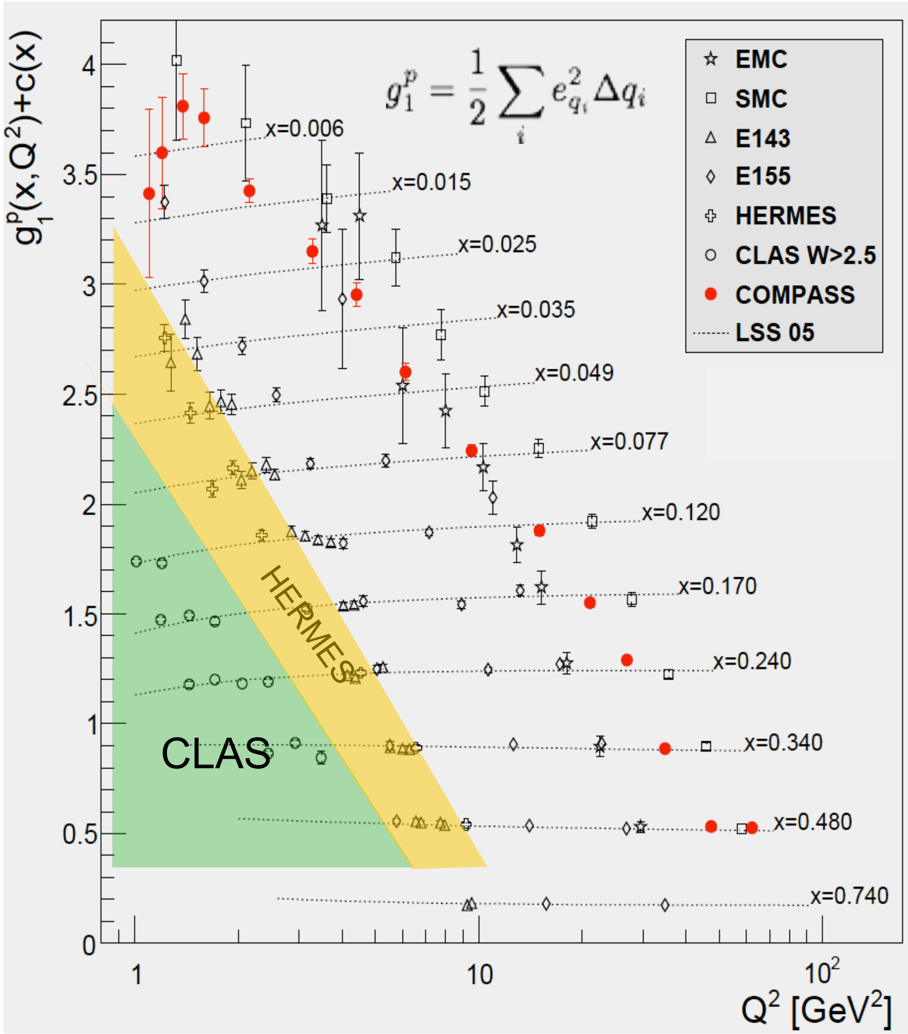
Spin contribution

Impressive experimental progress in QCD spin physics in the last 25 years

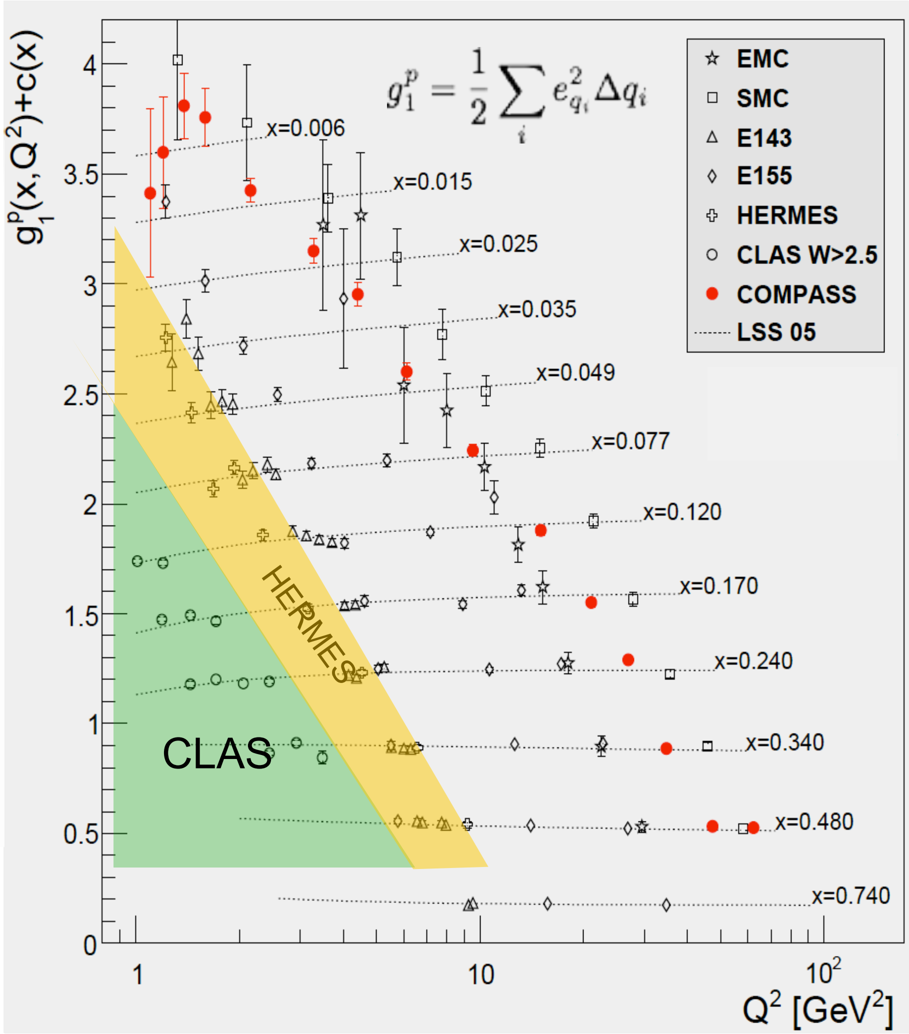
- Inclusive spin-dependent DIS
  - CERN: EMC, SMC, COMPASS
  - SLAC: E80, E142, E143, E154, E155
  - DESY: HERMES
  - JLab: Hall A, B and C
- Semi-inclusive DIS
  - SMC, COMPASS
  - HERMES, JLab
- Polarized pp collisions
  - BNL: PHENIX & STAR
- Polarized e+e- collisions
  - KEK: Belle

Polarized Structure functions





Picture of a proton from polarized ep



- Spin sum rule:

$$\boxed{\frac{1}{2} = \overbrace{\langle S_q \rangle}^{\frac{1}{2}\Delta\Sigma} + \underbrace{\langle S_g \rangle}_{\Delta G} + \langle L_q \rangle + \langle L_g \rangle}$$

(R.L. Jaffe and A. Manohar, Nucl. Phys. B337, 509 (1990))

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x,Q^2)dx \qquad \Delta G(Q^2) = \int_0^1 \Delta g(x,Q^2)dx$$

- Data only from fixed-target experiments (Limited reach in x and Q^2) mostly at lower energy

- Quark spin contribution is small (~25%):

$$\Delta\Sigma = 0.242 \; (Q^2 = 10\,\mathrm{GeV}^2)$$

(D. deFlorian et al., Phys. Rev. D80, 034030 (2009))

Gluon spin contribution unconstrained so far!

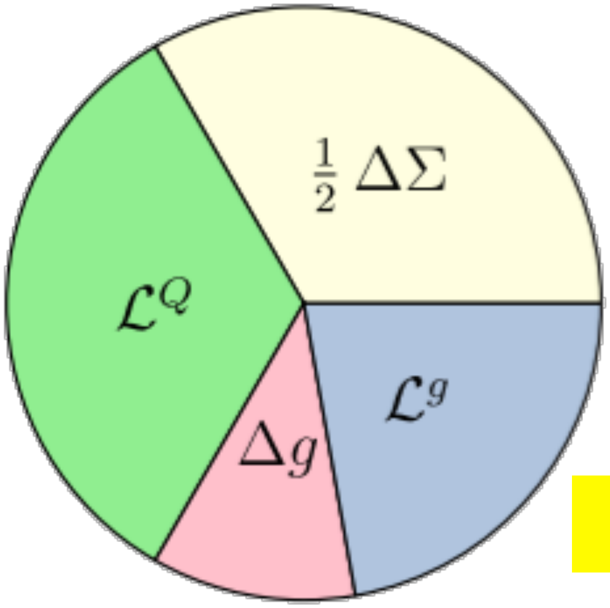
Spin of the Proton: Two views

Ji
1997

Jaffe-
Manohar
1990

Jaffe-Manohar proton spin decomposition

Jaffe-Manohar 1990



Canonical

$$\vec{J}_{QCD} = \frac{1}{2}\int d^3r\ \psi^\dagger\vec{\Sigma}\psi$$
$$+ \int d^3r\ \psi^\dagger\vec{r}\times\left(-i\vec{\nabla}\right)\psi$$
$$+ \int d^3r\ \vec{E}^a \times \vec{A}^a$$
$$+ \int d^3r\ \vec{E}^{ai}\vec{r}\times\vec{\nabla}\vec{A}^{ai}$$

Pros:

- **Satisfies Canonical relations**
- **Complete decomposition**

Cons:

- **Gauge variant decomposition**
- **Missing observables for OAM**

News:

- **Gauge-invariant extension**

[Chen *et al.* (2008)]

- **OAM accessible *via* Wigner distributions**

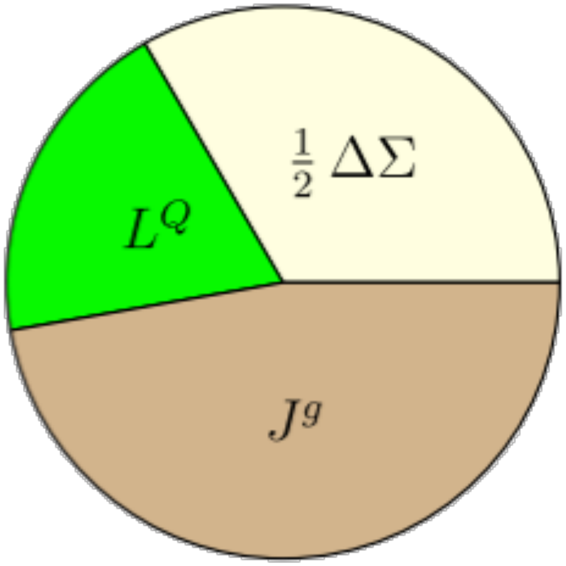
Lorce, Pasquini (2011)
Lorce, Pasquini, Xiong, Yuan(2011)
Hatta (2011)

7/16/12

Coutesy of C. Lorce

Ji's proton spin decomposition

Ji 1997



$$\vec{J}_{QCD} = \frac{1}{2}\int d^3r\psi^\dagger\vec{\Sigma}\psi + \int d^3r\psi^\dagger\vec{r}\times(-i\vec{D})\psi + \int d^3r\vec{r}\times(\vec{E}^a\times\vec{B}^a)$$

Kinetic

Pros:
- **Gauge-invariant decomposition**
- **Accessible in DIS and DVCS**

Cons:
- **Does not satisfy canonical relations**
- **Incomplete decomposition**

News:
- **Complete decomposition**

[Wakamatsu (2009,2010)]

Courtesy of C. Lorce

Proton Spin Decomposition

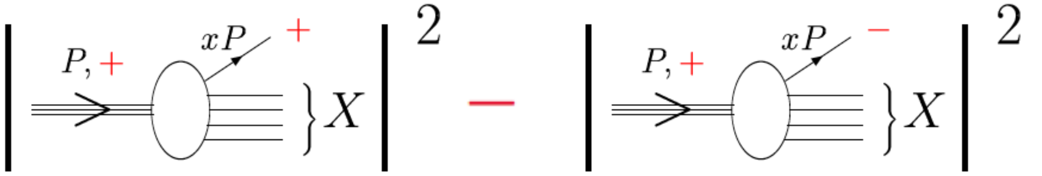
Jaffe and Manohar
1990

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G(Q^2) + L_q(Q^2) + L_g(Q^2)}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

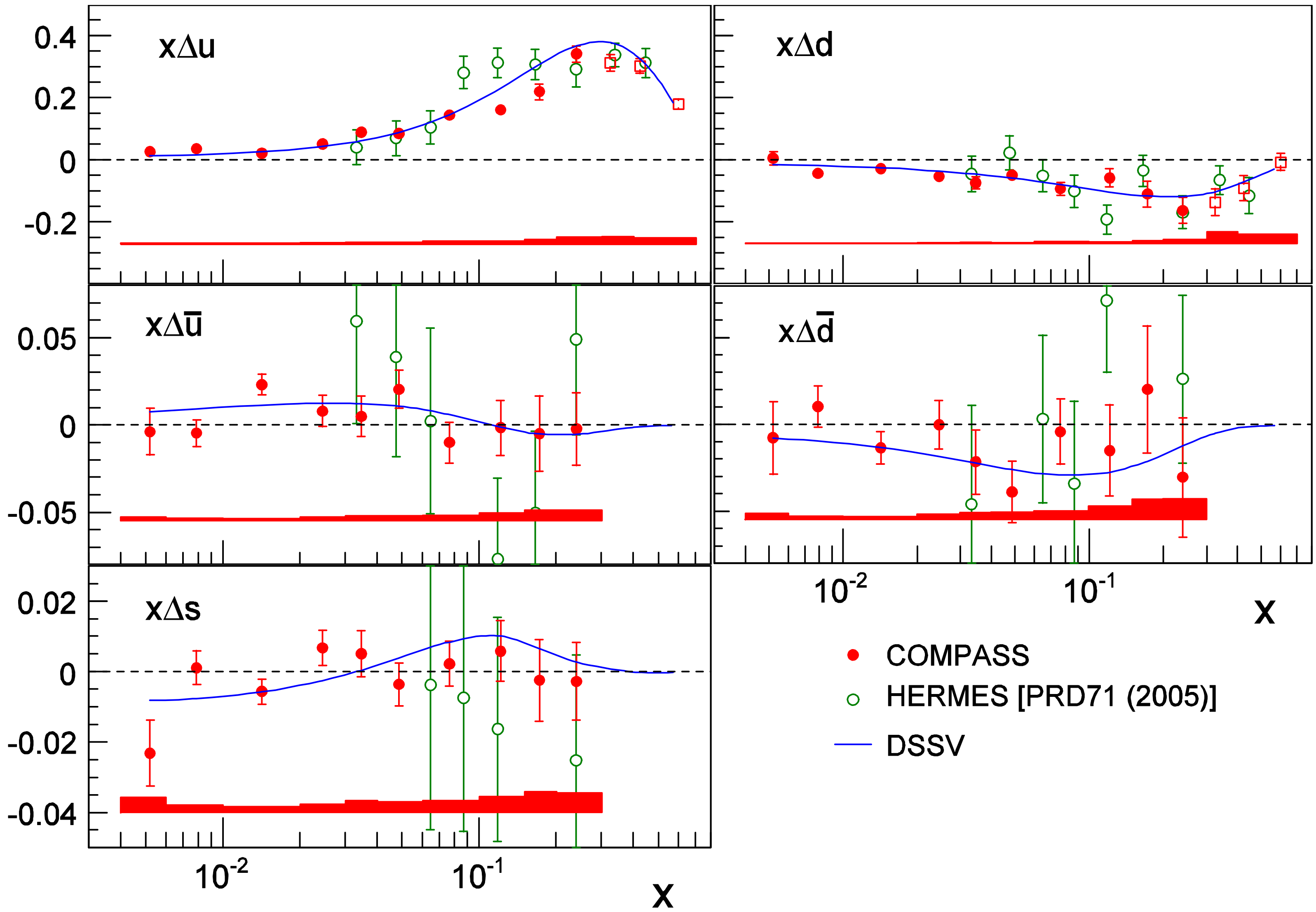
$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx \qquad \Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

$$\Delta q(x) \;=$$



$$\Delta g(x) \;=$$

Quark Helicity Distributions from SIDIS



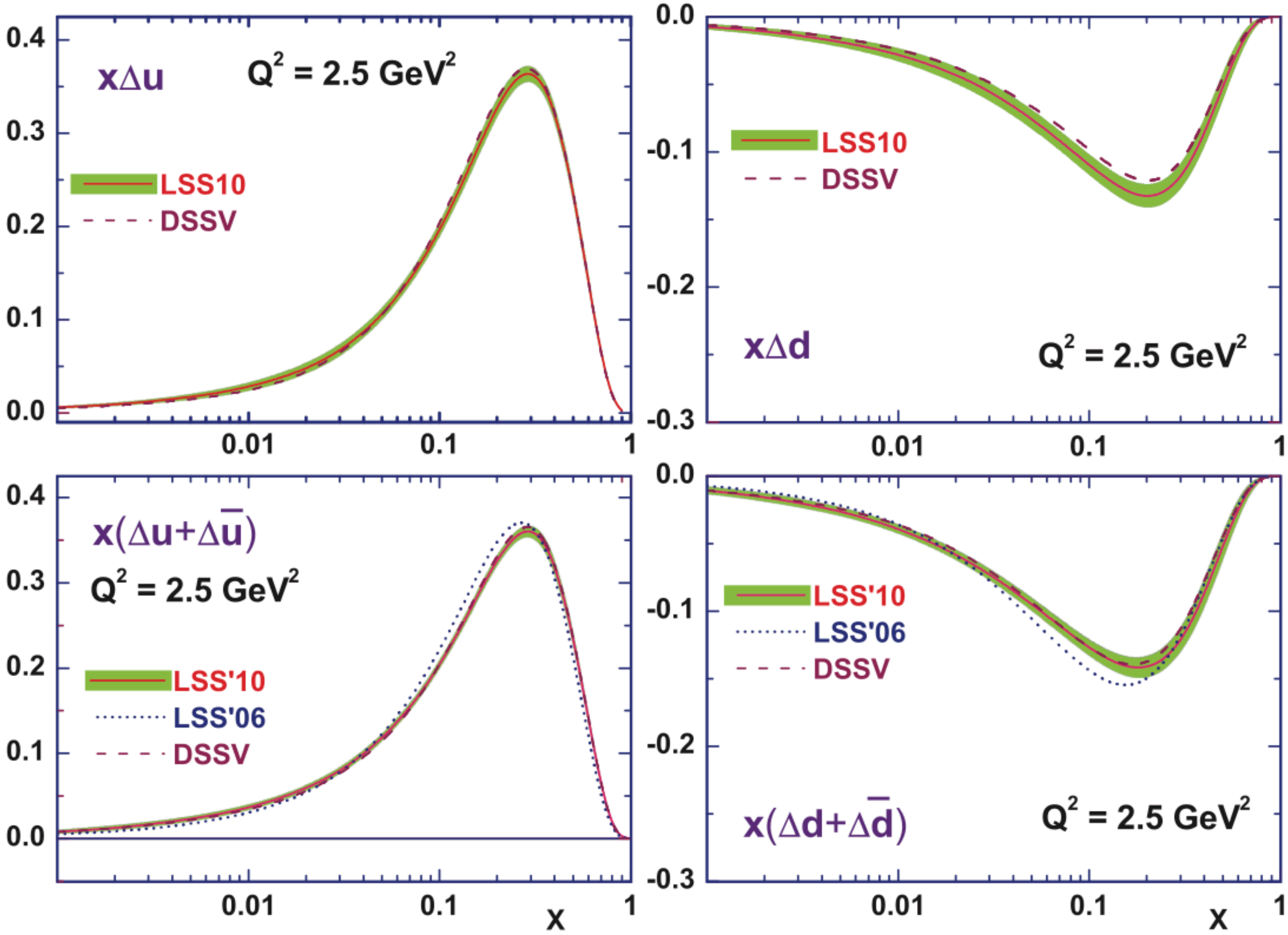
- Results from inclusive and semi- inclusive experiments from different experiments (COMPASS, HERMES, JLab) are consistent

Quark Helicity distributions (continued)

- Recent data analyses
  - ➥De Florian, Sassot, Stratmann, Vogelsang, 2008/2009
  - ➥ Blumlein, Bottcher, 2010
  - ➥ Leader, Sidorov, Stamenov, 2010

  - ➥RHIC results on W-production may provide further information) – so far: proof of principle measurements (PHENIX, 2010 / STAR, 2010)

LSS parametrization



Extracting the quark spin content of the Nucleon

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)\, dx = \mu_2 + \frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \cdots$$

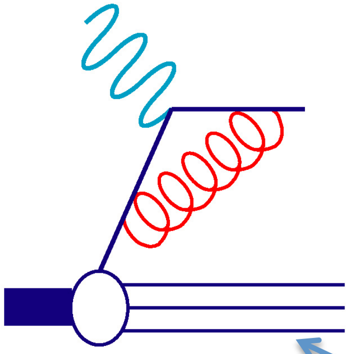
leading twist

higher twist

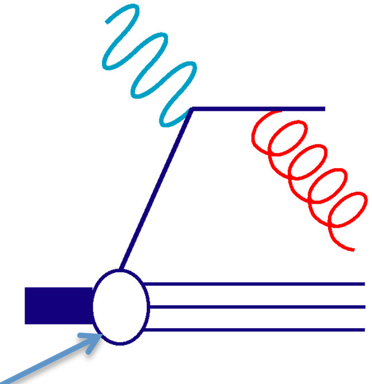
$$\mu_2^{p,n}(Q^2) = (\pm \frac{1}{12} g_A + \frac{1}{36} a_8) + \frac{1}{9} \Delta\Sigma$$ + pQCD corrections

$g_A = 1.257$ and $a_8 = 0.579$ are the triplet and octet axial charge, respectively

$\Delta\Sigma$ = singlet axial charge



$$\begin{aligned} g_A &= \Delta u - \Delta d \\ a_8 &= \Delta u + \Delta d - 2\Delta s \\ \Delta\Sigma &= \Delta u + \Delta d + \Delta s \end{aligned}$$



pQCD radiative corrections

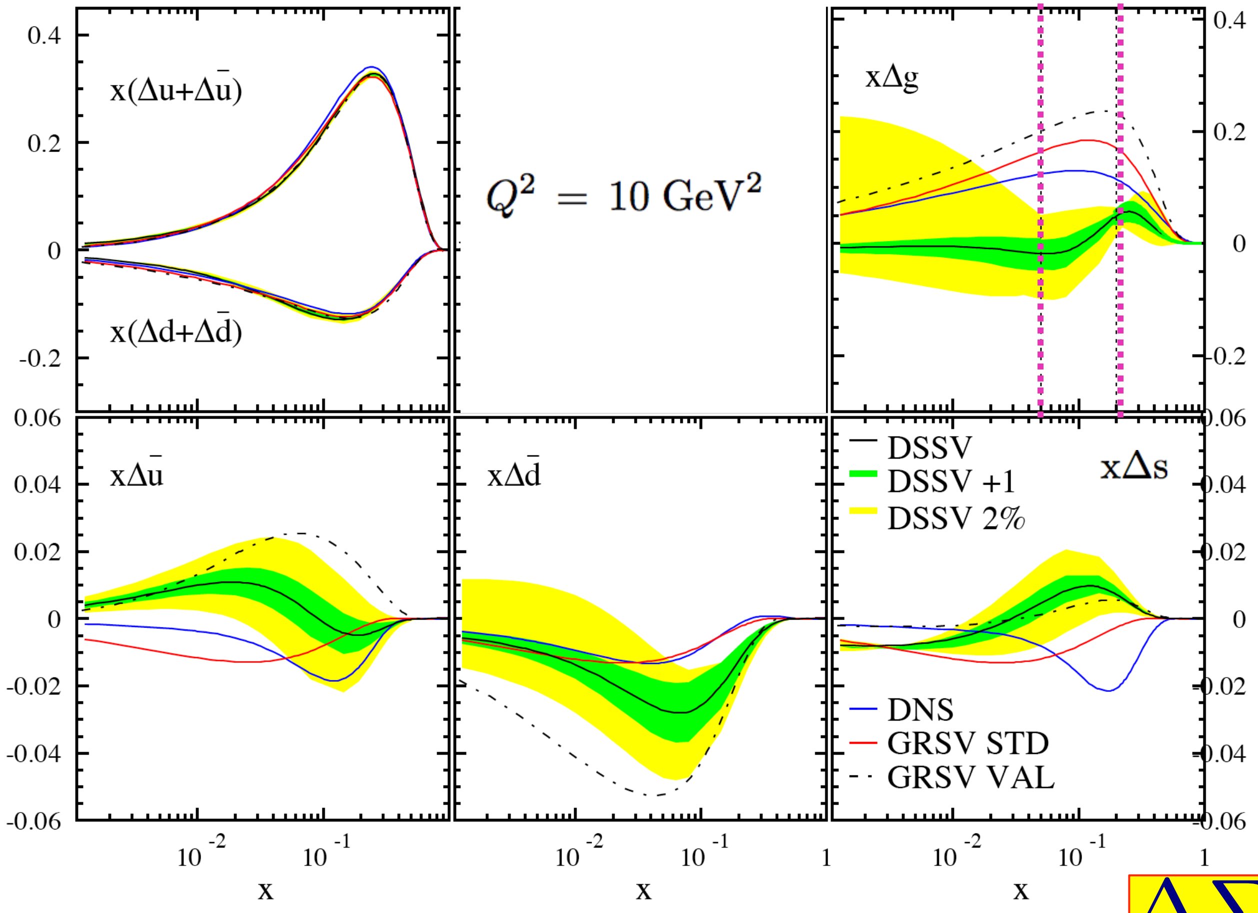
$$\Delta\Sigma \sim 0.3$$

NLO FIT to World Data

D. De Florian et al. arXiv:0804.0422

NLO @ Q^2=10 GeV^2

	χ^2_{DIS}	χ^2_{SIDIS}	Δu_v	Δd_v	$\Delta\bar{u}$	$\Delta\bar{d}$	Δs	Δg	$\Delta\Sigma$
Kretzer	206	225	0.94	−0.34	−0.049	−0.055	−0.051		0.28
KKP	206	231	0.70	−0.26	0.087	−0.11	−0.045		0.31
DSSV			0.813	−0.458	0.036	−0.115	−0.057		0.242



small in measured regime !

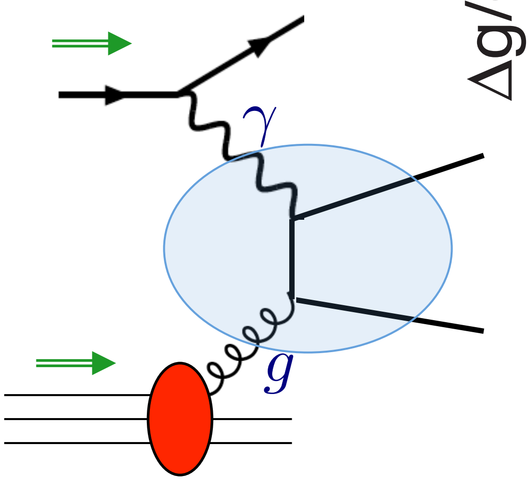
$$\int_{0.05}^{0.2} dx\,\Delta g \approx 0$$

$$\Delta\Sigma \sim 0.25$$

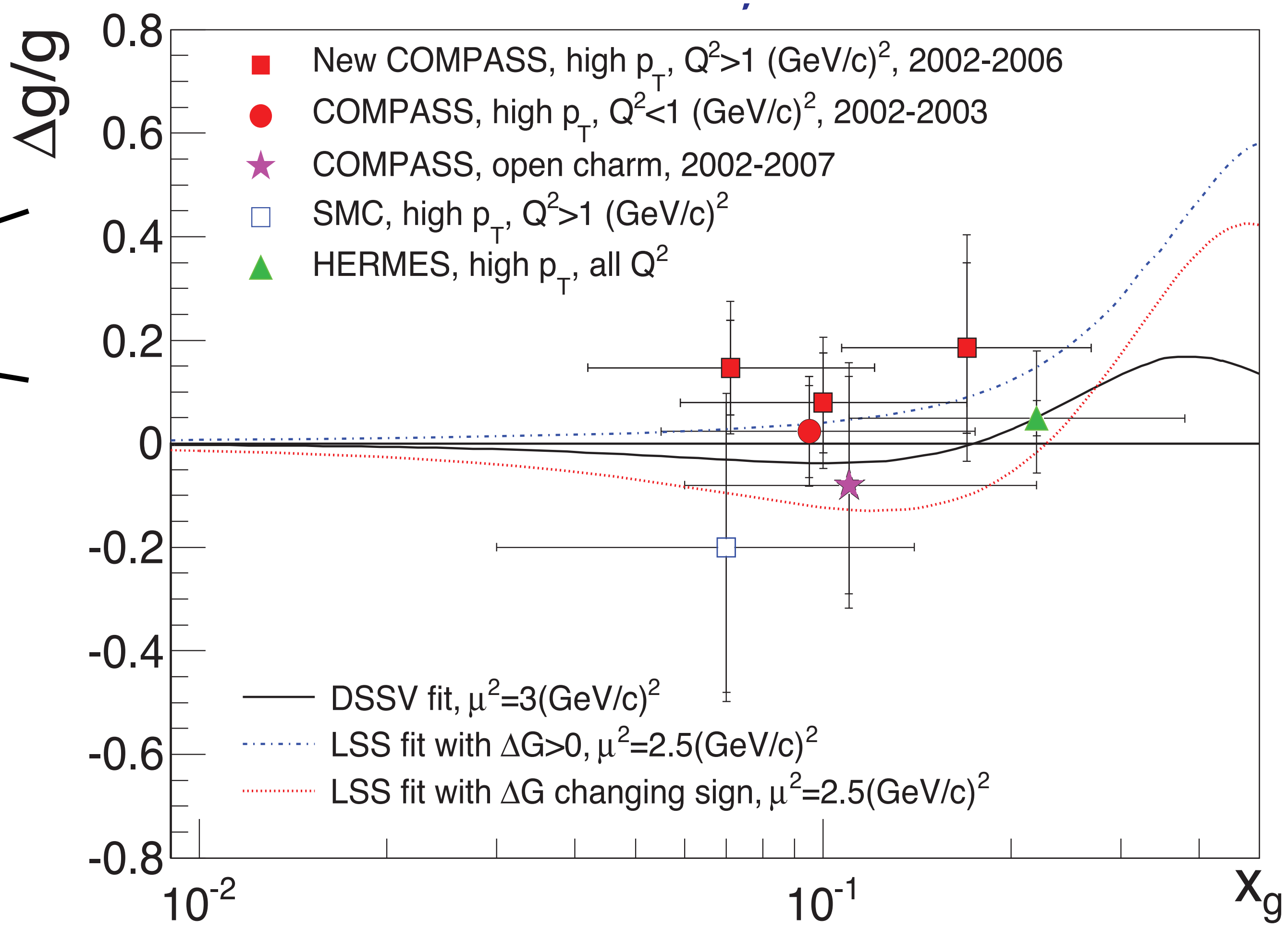
- includes all world data from DIS, SIDIS and pp

Gluon Helicity

Lepton Scattering



Photon-gluon fusion

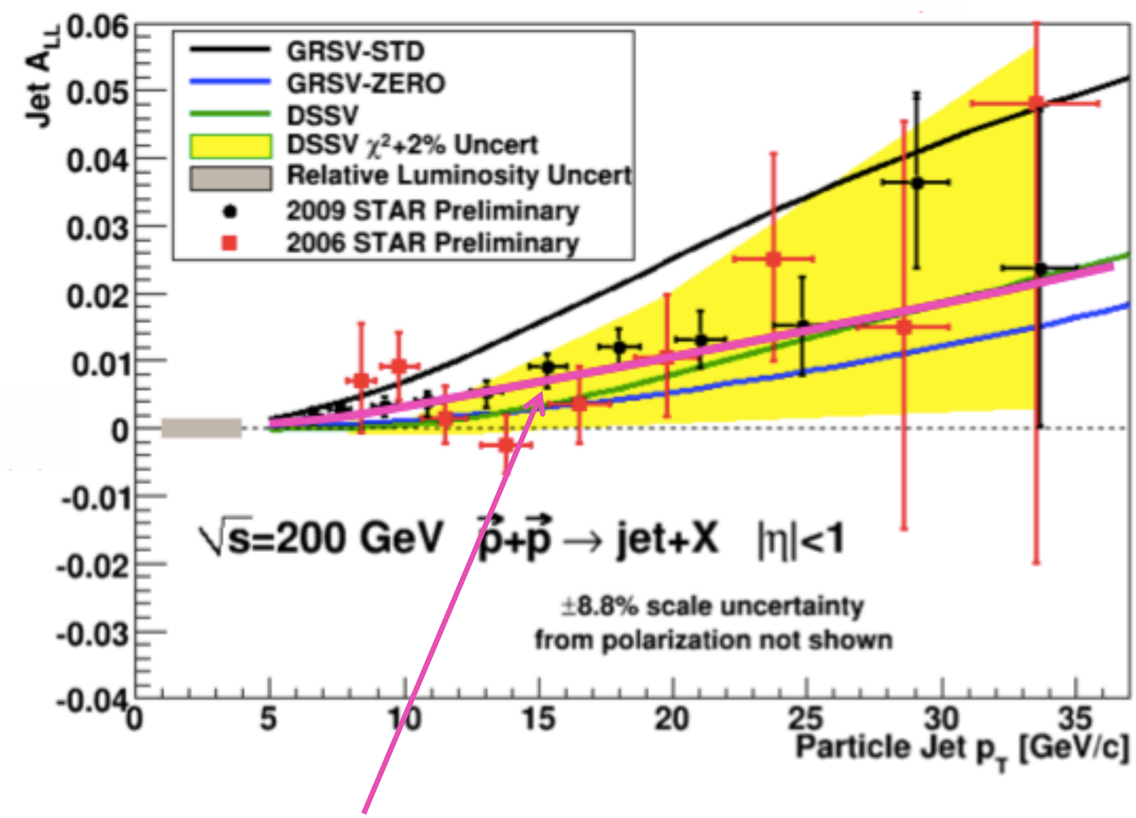


$$\Delta G(Q^2) = \int_0^1 dx\, \Delta g(x, Q^2)$$

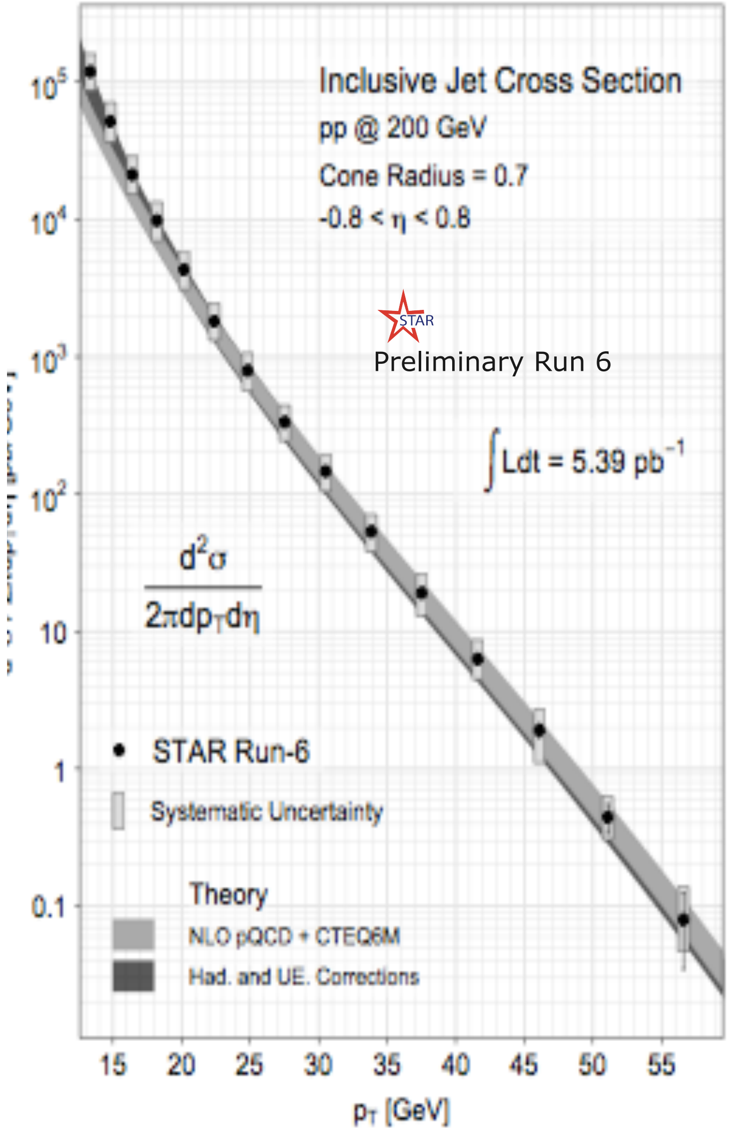
$$\Delta G \sim 0$$

Recent results - Gluon polarization program

- STAR: Mid-rapidity Inclusive Jet A_{LL} measurement



$$\int_{0.05}^{0.2} dx\,\Delta g \approx 0.1$$



Courtesy of B. Surrow

W. Vogelsang, DIS 2012

Jaffe-Manohar $$\frac{1}{2} = \frac{1}{2}\boxed{\Delta\Sigma} + \mathcal{L}^Q + \boxed{\Delta g} + \mathcal{L}^g$$

The Other View: Beyond 1-D description

$$\mathcal{L}^Q - L^Q = \Delta L^Q_{FSI}$$

(Change in OAM as quark leaves nucleon) M. Burkardt arXiv:1205.2916

$$L^Q \neq \mathcal{L}^Q \quad J^Q \neq \mathcal{J}^Q \quad J^g \neq \mathcal{J}^g$$

Ji $$\frac{1}{2} = J^Q + J^g = \frac{1}{2}\boxed{\Delta\Sigma} + L^Q + J^g$$

$$J^Q = \int dx x[H^Q + E^Q] \qquad J^g = \int dx\,[H^g + E^g]$$

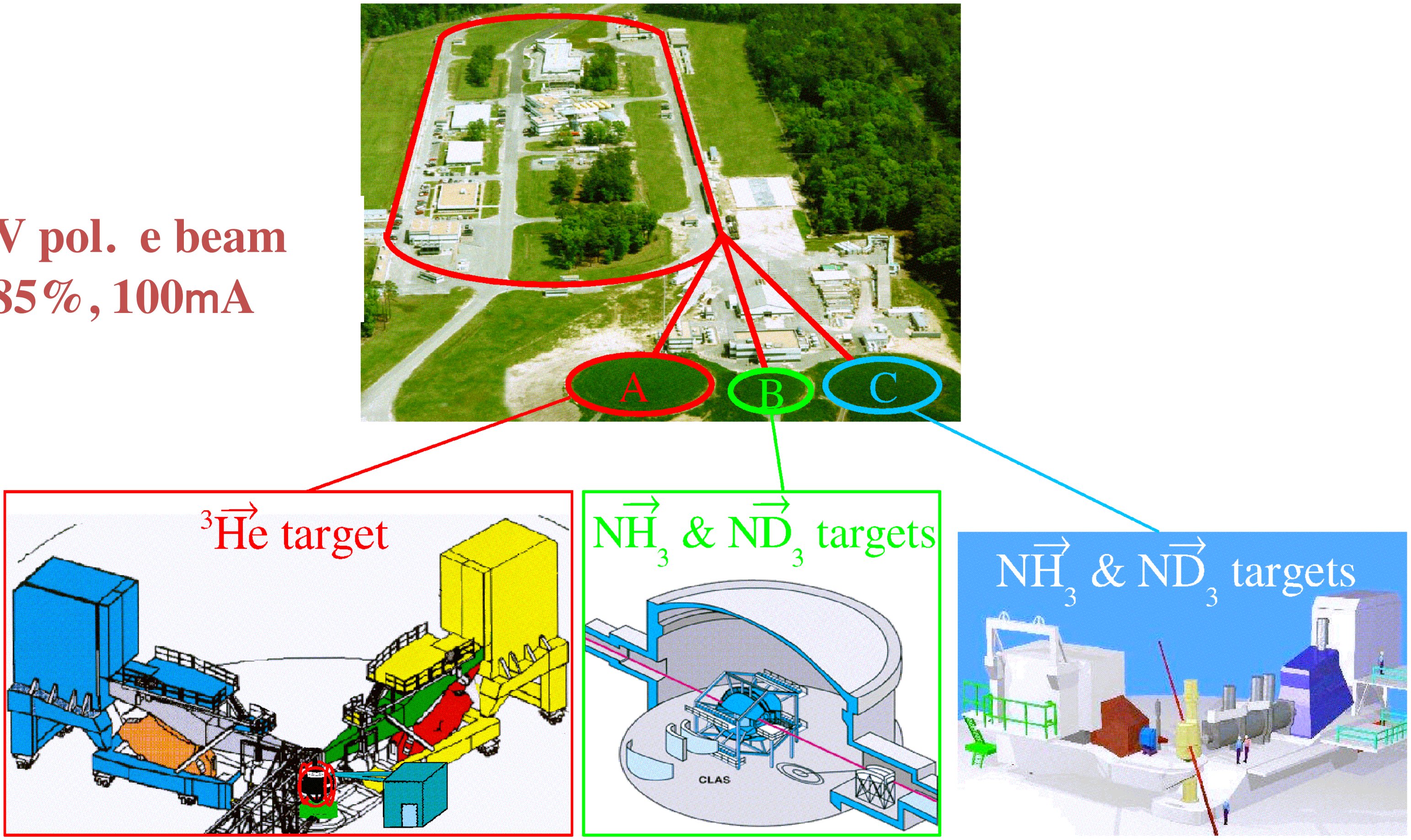
DVCS, DVMP

Deeply Virtual Compton Scattering

Deeply Virtual meson production

Jefferson Lab Experimental Halls

6 GeV pol. e beam
Pol=85%, 100mA



HallA: two HRS'

Luminosity~10^{36} (cm^{-2} s^{-1})

Hall B:CLAS

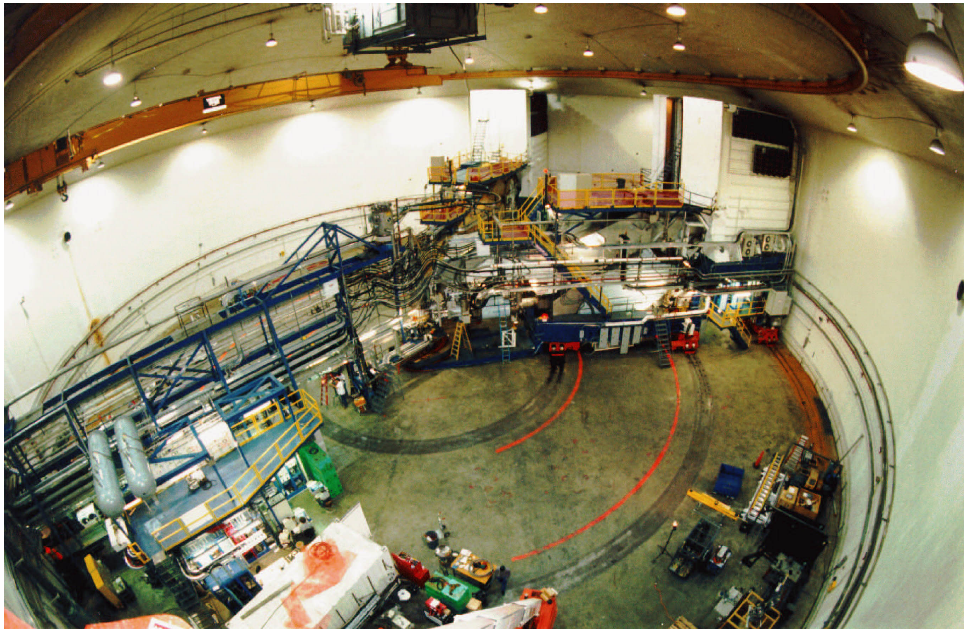
Hall C: HMS+SOS

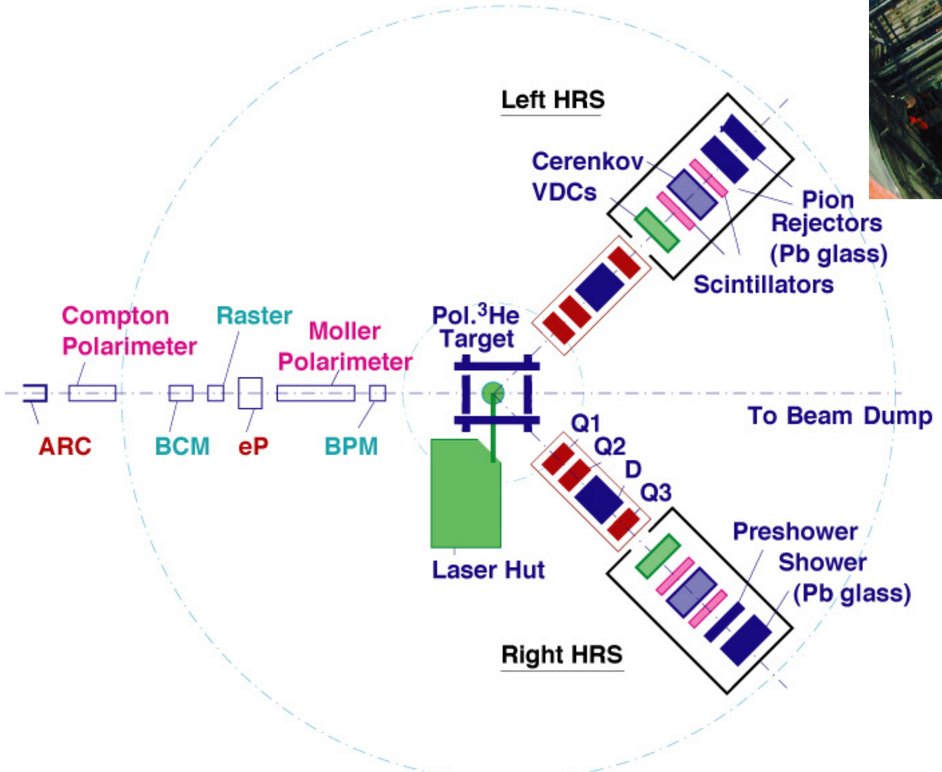
Luminosity up to 10^{35} (cm^{-2} s^{-1})

Jlab Hall A Experimental Setup

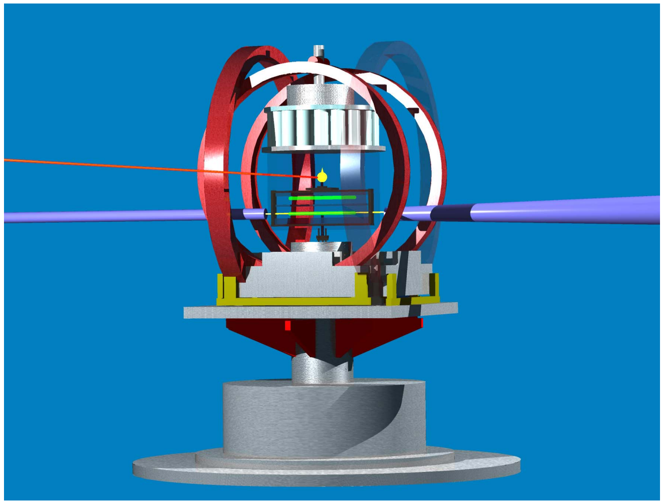
75-80% polarized beam at 15μA

35-60% polarized target in beam

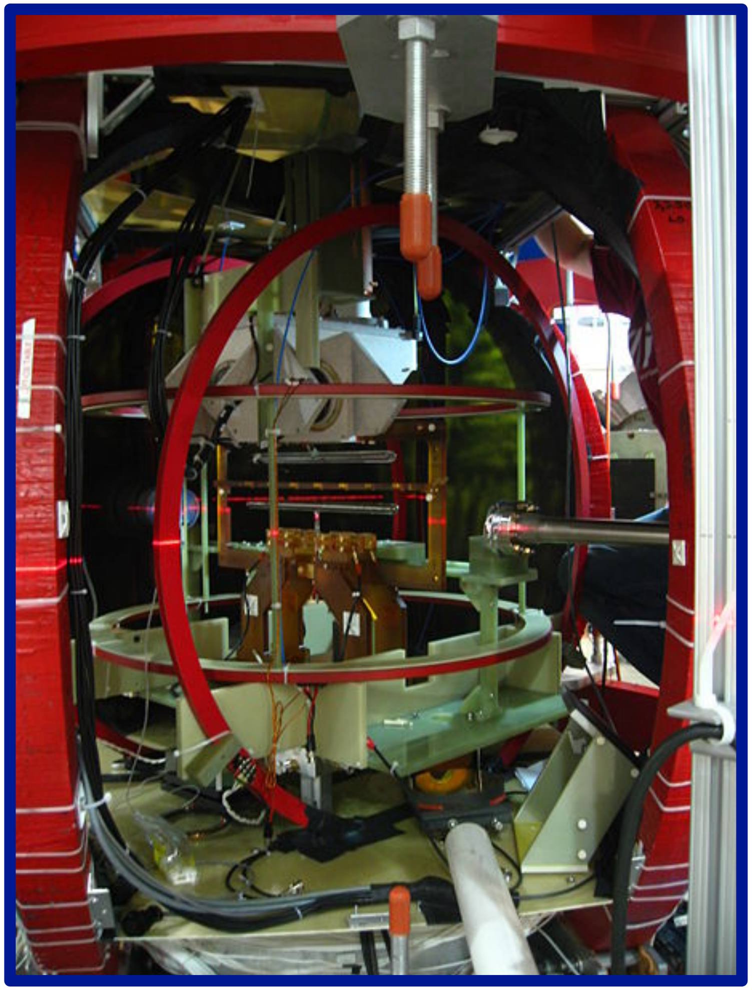


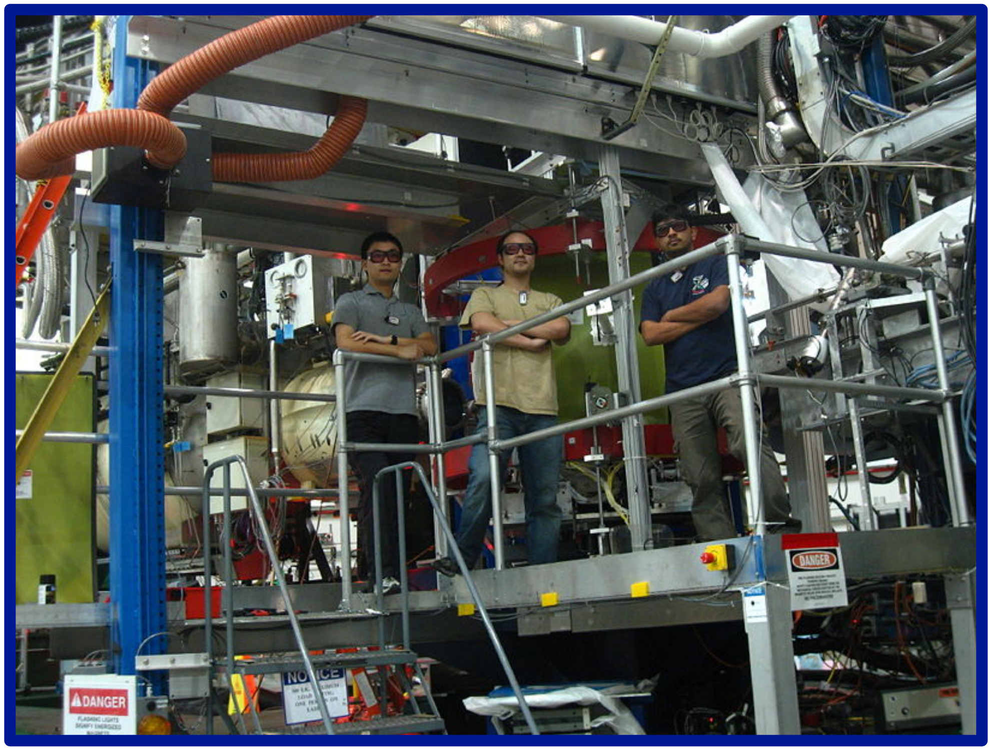


Polarized target

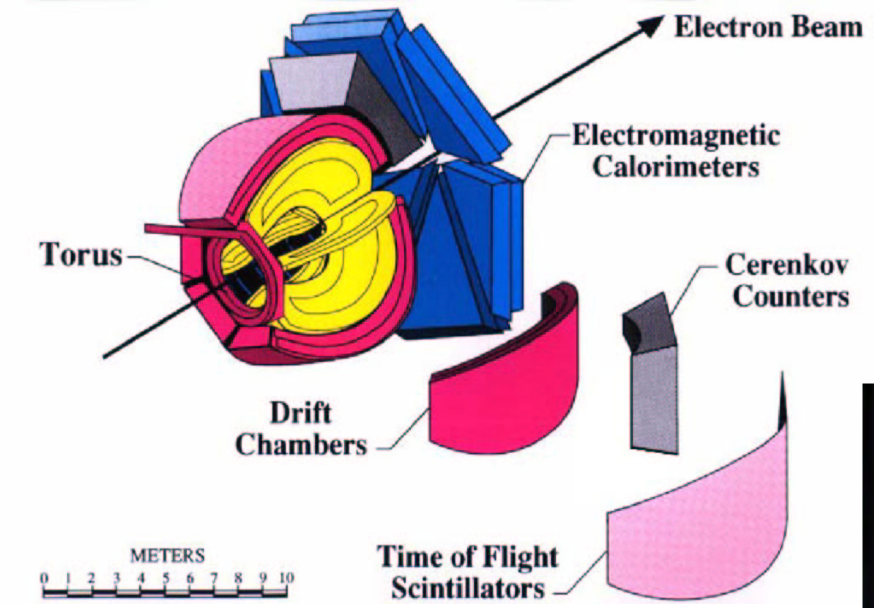


Pol ^{3}He Target Commissioning





Hall B setup



Polarized NH_3 &ND_3

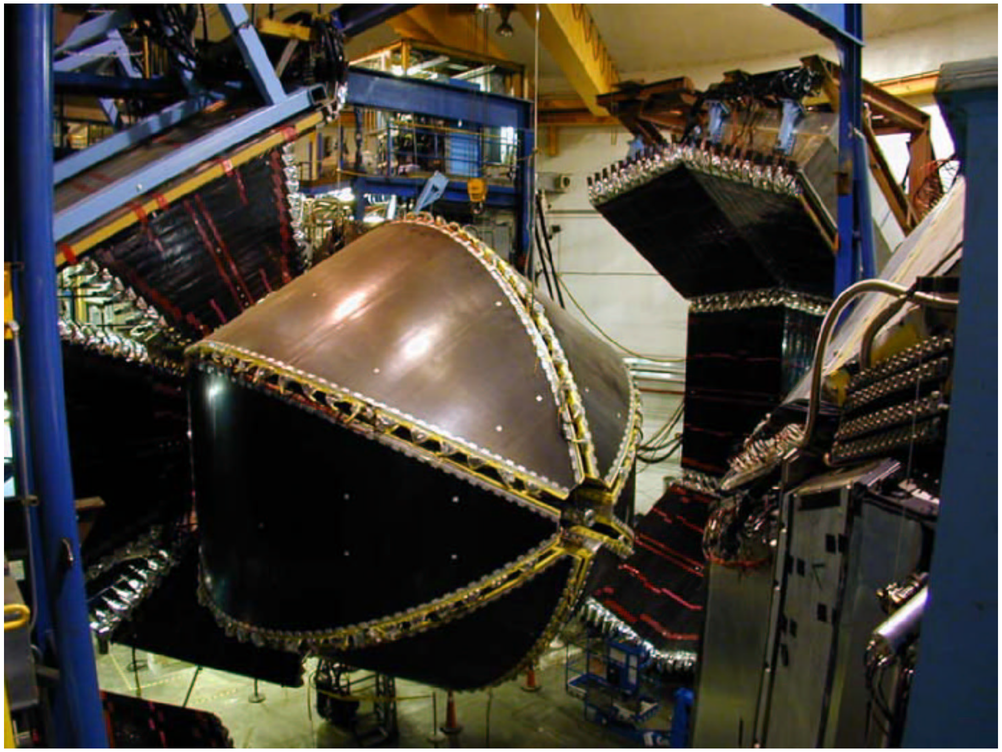
75% (NH_3) or 30% (ND_3)

Longitudial polarization only

Acceptance ~2.5π

Luminosity: 10^{34} cm^{-2} s^{-1}

CEBAF
Large
Acceptance
Spectrometer



- Large kinematical coverage
- detection of charged and neutral particles
- Multiparticle final state

Sum rules and Moments of Structure functions

First moments

$$\int_{thr}^{\infty}\left[\frac{\sigma_{3/2}-\sigma_{1/2}}{\nu}\right]d\nu = \frac{2\pi^2\alpha}{M^2}\kappa^2$$

GDH
Sum Rule
$I_{GDH}(0)$

← Generalized
GDH Integral
$I_{GDH}(Q^2)$ →

$$\int_0^1 [g_1^p(x,Q^2)-g_1^n(x,Q^2)]\,dx = \frac{1}{6}g_A$$

Bjorken
Sum Rule
$\Gamma_1^{\text{p-n}}$

Chiral Perturbation Theory

$$-\frac{\kappa^2}{8M^2}Q^2 + cQ^4 + O(Q^6)$$

Operator product Expansion
Bjorken result for (p-n) at finite Q²

$$\sum_{\tau=2,4\ldots}\frac{\mu_\tau(Q^2)}{Q^{\tau-2}}$$

← Burkhardt-Cottingham
sum rule
$\Gamma_2(Q^2)=0$ →

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

Higher moments

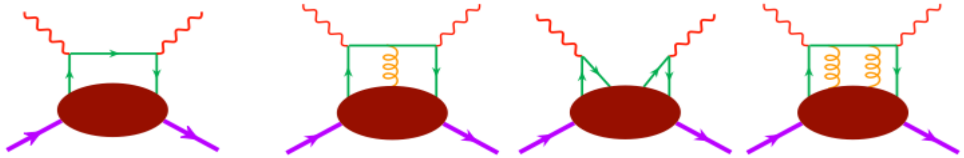
Spin
Polarizabilities
$\gamma_0(Q^2), \delta_{LT}(Q^2)$

Higher twists & color
Polarizabilities
$d_2(Q^2), f_2(Q^2)$

0 ← 1 Q^2 10 ∞

Chiral Perturbation Lattice QCD pQCD

Moments of Structure Functions



$\tau = 2$

single quark scattering

$\tau > 2$

qq and qg correlations

$$\Gamma_1(Q^2) \equiv \int_0^1 \mathrm{d}x\, g_1(x,Q^2)$$

$$= \Gamma_1^{\mathrm{twist-2}}(Q^2) + \frac{M_N^2}{9\,Q^2}\left[a_2(Q^2) + 4\,d_2(Q^2) + 4\,f_2(Q^2)\right] + \mathcal{O}\left(\frac{M_N^4}{Q^4}\right)$$

- $a_2(Q^2) \equiv 2\int_0^1 \mathrm{d}x\; x^2\; g_1^{\mathrm{twist-2}}(x,Q^2) \longrightarrow$ target mass correction term

- $d_2(Q^2) \longrightarrow$ dynamical twist-3 matrix element

$$d_2(Q^2) \equiv \int_0^1 \mathrm{d}x\; x^2\; \{3\,g_2(x,Q^2) + 2\,g_1(x,Q^2)\}$$

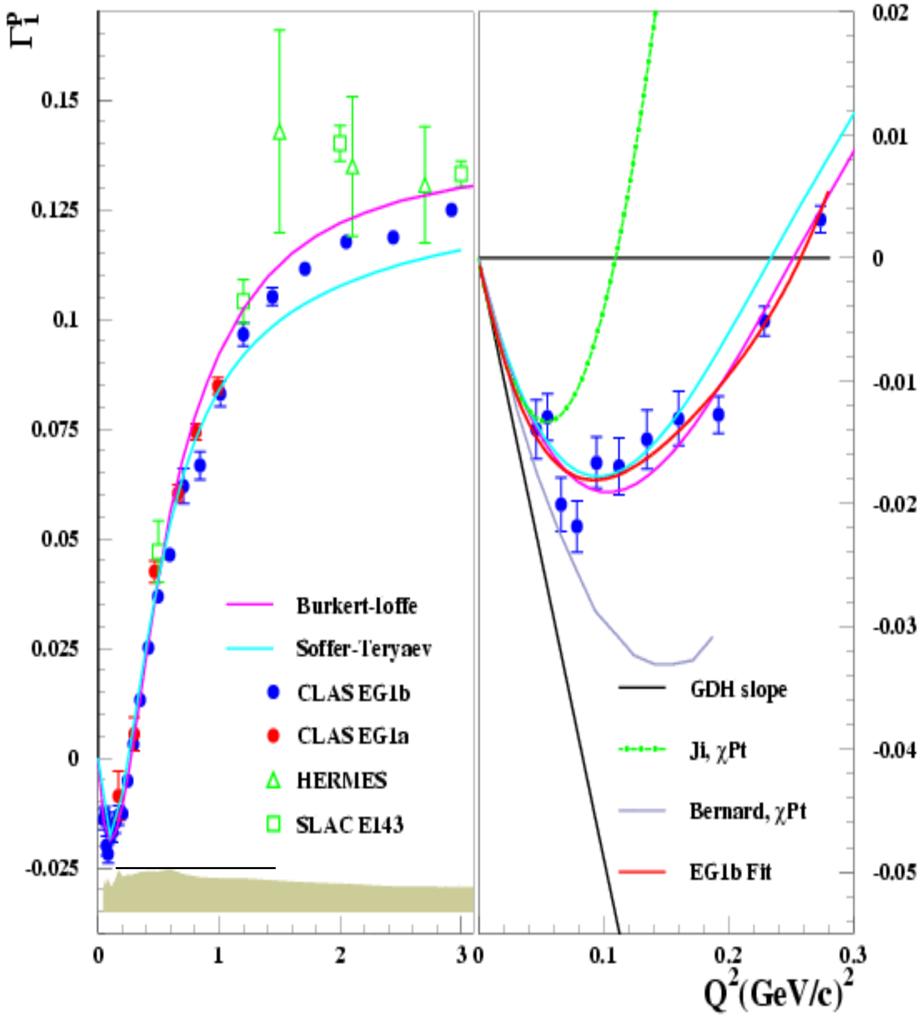
$$d_2 S^{[\mu} P^{\{\nu]} P^{\lambda\}} = \frac{1}{8}\sum_q \langle P,S|\bar{\psi}_q\; g\bar{F}^{\{\mu\nu}\gamma^{\lambda\}}\psi_q|P,S\rangle$$

- $f_2(Q^2) \longrightarrow$ dynamical twist-4 matrix element

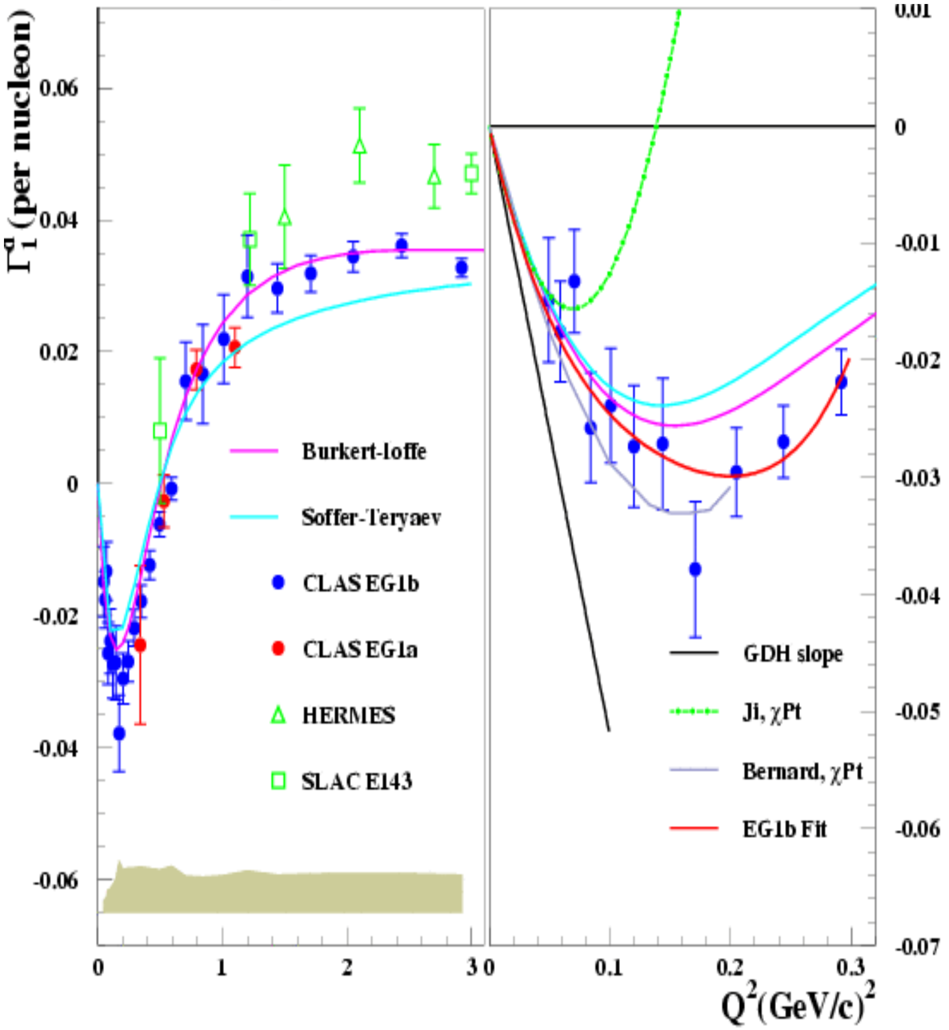
$$f_2 M^2 S^\mu = \frac{1}{2}\sum_q e_q^2 < N|\bar{\psi}_q g\widetilde{F}^{\mu\nu}\gamma_\nu\psi_q|N >$$

Evolution of first moments of g_{1p} and g_{1d}

Γ_{1p}: First moment of g_{1p}



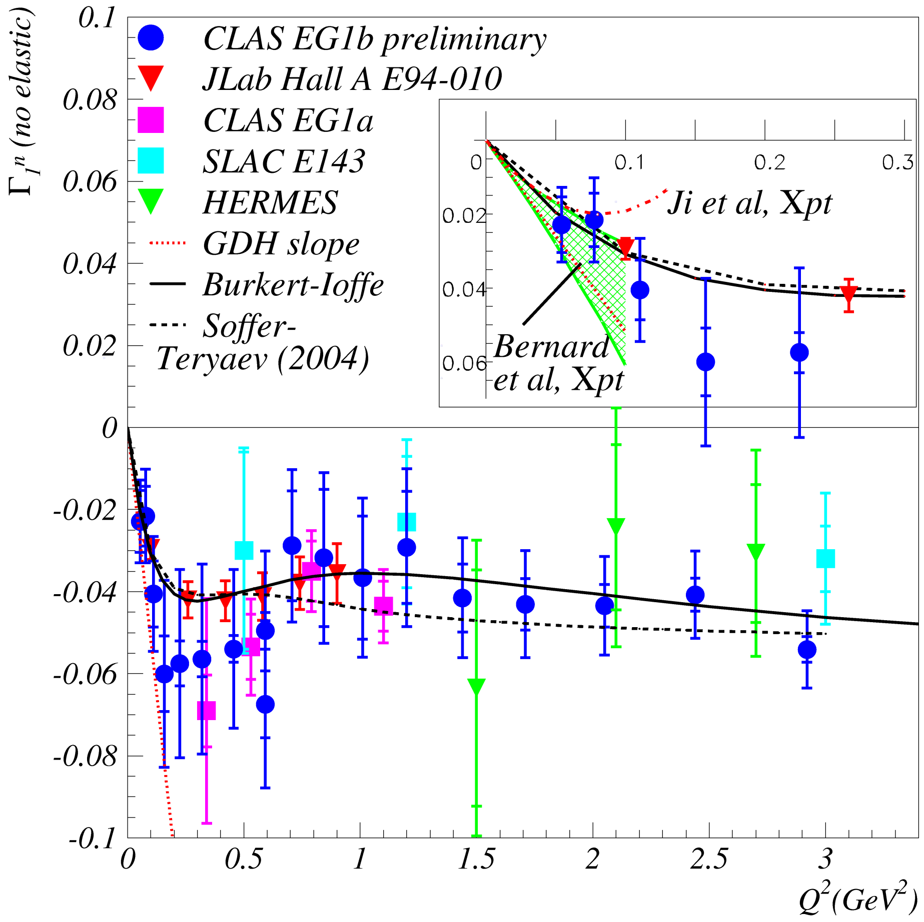
Γ_1 for the deuteron

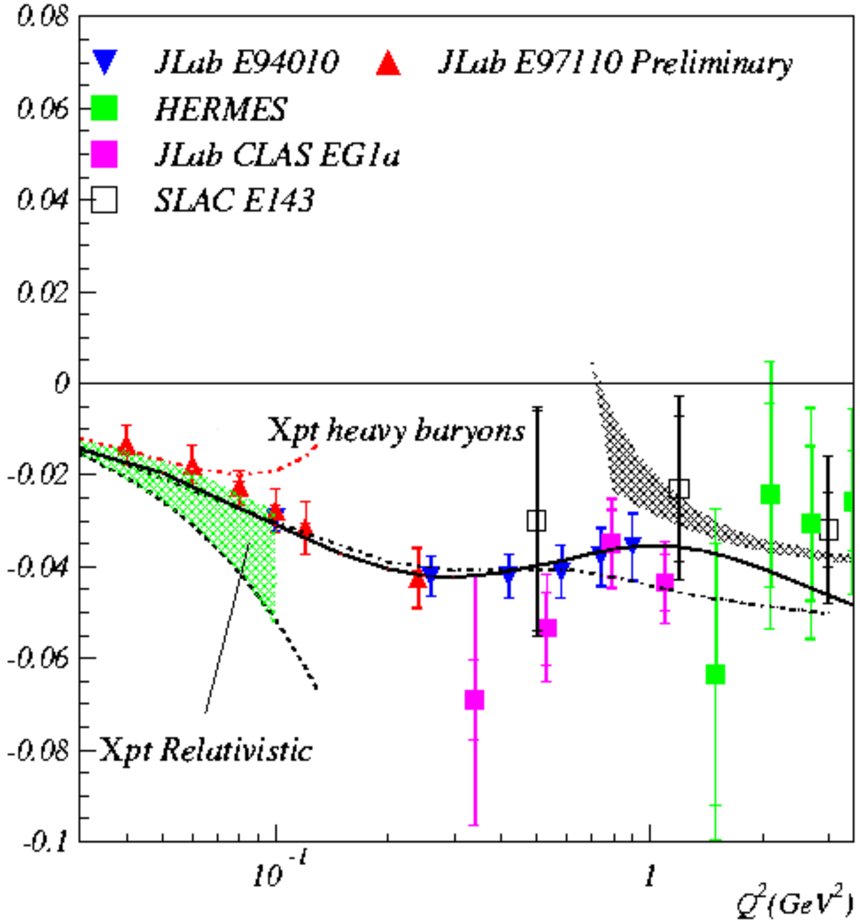


EG1b nucl-ex/802.2232 and EG1a, PRL 91: 222002 (2003)

First moment of g_1^n; Γ_1^n

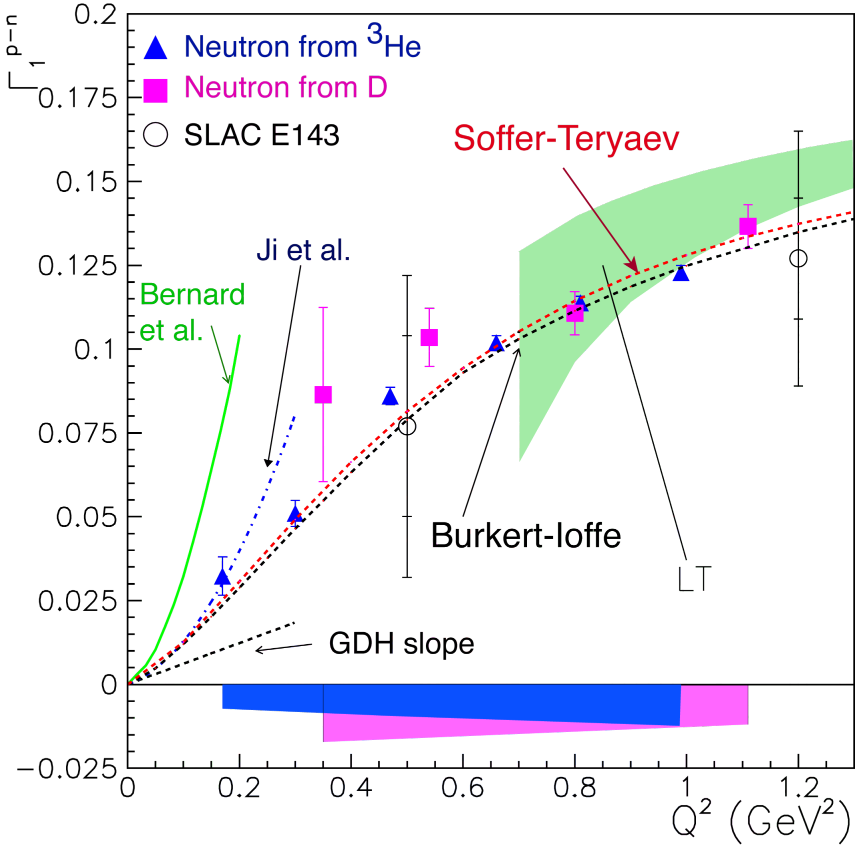
E94-010, PRL 92 (2004) 022301



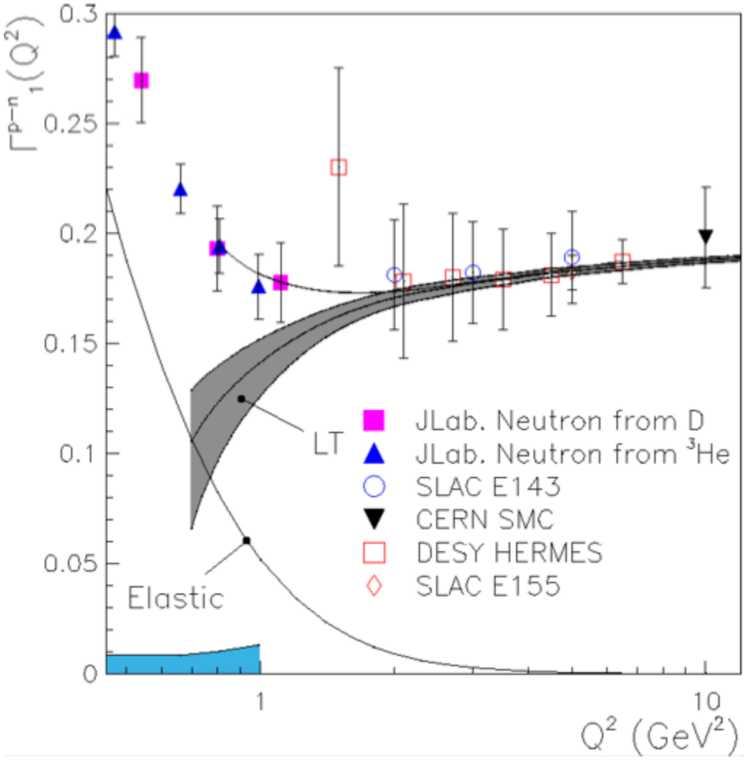


E97-110

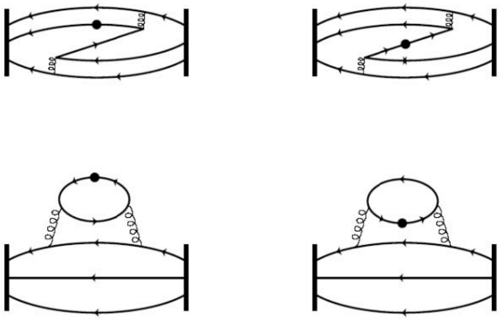
Bjorken Sum Q^2 evolution and higher twists



eg1a + E94-010, A. Deur *et al*. PRL 93, 212001 (2004)



- At low Q^2 good quantity to test Chiral P. T.
  - Little or no contribution from the Delta
- At large Q^2 does not contain non disconnected diagrams. Good to compare to Lattice calculations

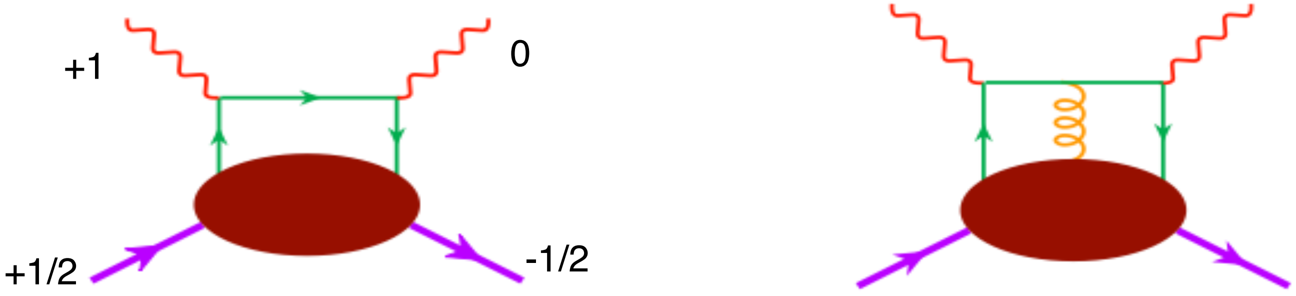


f_2^{p-n}=-0.18±0.10

μ_4/M^2=-0.06±0.02

μ_6/M^4=0.09±0.03

g_2 and Quark-Gluon Correlations



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

- a twist-2 term (Wandzura & Wilczek, 1977):

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

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 1992):

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}\boxed{h_T(y,Q^2)} + \boxed{\xi(y,Q^2)}\right]\frac{dy}{y}$$

Transversity

qg correlations

Moments of Structure Functions

$$d_2(Q^2) = 3\int_0^1 x^2\left(g_2(x,Q^2) - g_2^{WW}(x,Q^2)\right)dx$$

$$\boxed{d_2 S^{[\mu}P^{\{\nu]}P^{\lambda\}} = \frac{1}{8}\sum_q \langle P,S|\bar{\psi}_q\; g\tilde{F}^{\{\mu\nu}\gamma^{\lambda\}}\psi_q|P,S\rangle}$$

$d_2(Q^2) \longrightarrow$ dynamical twist-3 matrix element

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

Color "Polarizabilities"

X.Ji 95, E. Stein et al. 95

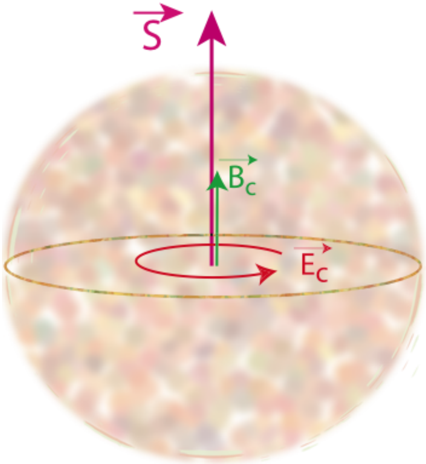
How does the gluon field respond when a nucleon is polarized ?

Define color magnetic and electric polarizabilities (in nucleon rest frame):

$$\chi_{B,E} 2M^2 \vec{S} = \langle PS|\vec{O}_{B,E}|PS\rangle$$

where $\vec{O}_B = \psi^\dagger g\vec{\boldsymbol{B}}\psi$

$$\vec{O}_E = \psi^\dagger \vec{\alpha} \times g\vec{\boldsymbol{E}}\psi$$



$$\boxed{\begin{aligned} d_2 &= (\chi_E + 2\chi_B)/8 \\ f_2 &= (\chi_E - \chi_B)/2 \end{aligned}}$$

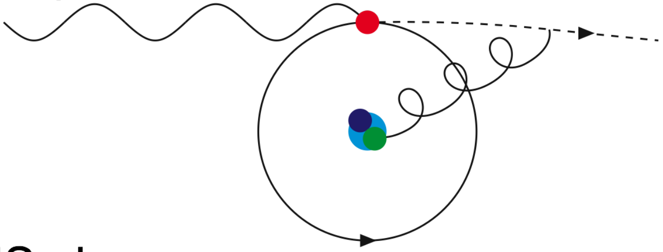
d_2 and f_2 represent the response of the color $\vec{B}$ & $\vec{E}$ fields to the nucleon polarization

Average Color Lorentz Force (M. Burkardt)

$$\int dx x^2 \bar{g}_2(x) = \frac{1}{3} d_2 = \frac{1}{6MP^{+2}S^x} \langle P,S \left| \bar{q}(0) g G^{+y}(0) \gamma^+ q(0) \right| P,S \rangle$$

↪ d_2 a measure for the **color Lorentz force** acting on the struck quark in SIDIS in the instant **after being hit by the virtual photon**

$$\langle F^y(0) \rangle = -M^2 d_2 \qquad \text{(rest frame; } S^x = 1\text{)}$$

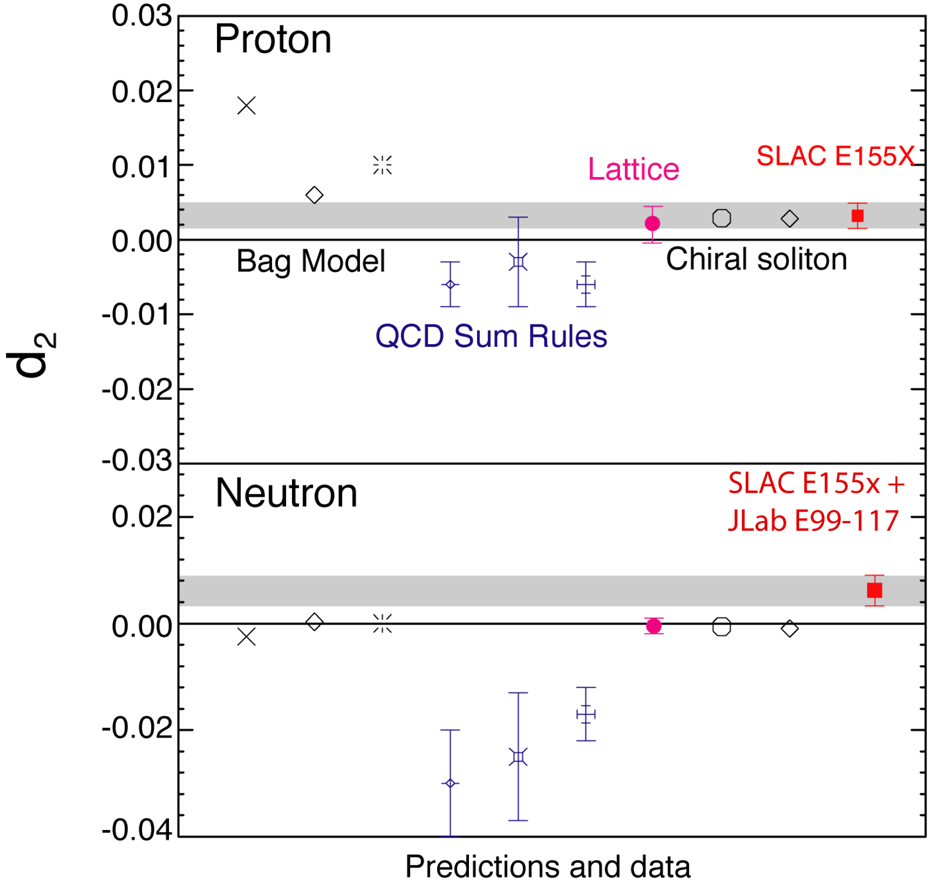


- Interpretation of d_2 with the transverse FSI force in DIS also consistent with $\langle k_\perp^y \rangle \equiv \int_0^1 dx \int d^2 k_\perp \, k_\perp^2 f_{1T}^\perp(x, k_\perp^2)$ in SIDIS (Qiu, Sterman)

$$\langle k_\perp^y \rangle = -\frac{1}{2p^+} \left\langle P,S \left| \bar{q}(0) \int_0^\infty dx^- g G^{+y}(x^-) \gamma^+ q(0) \right| P,S \right\rangle$$

semi-classical interpretation: average $k_\perp$ in SIDIS obtained by correlating the quark density with the transverse impulse acquired from (color) Lorentz force acting on struck quark along its trajectory to (light-cone) infinity

Models and Lattice evaluations of d_2



Quark Bag Models

M.Stratmann, Z.Phys.C60,763(1993).
X.Song,Phys.Rev.D54,1955(1996).
X.Ji and P.Unrau, Phys.Lett.B333,228(1994).

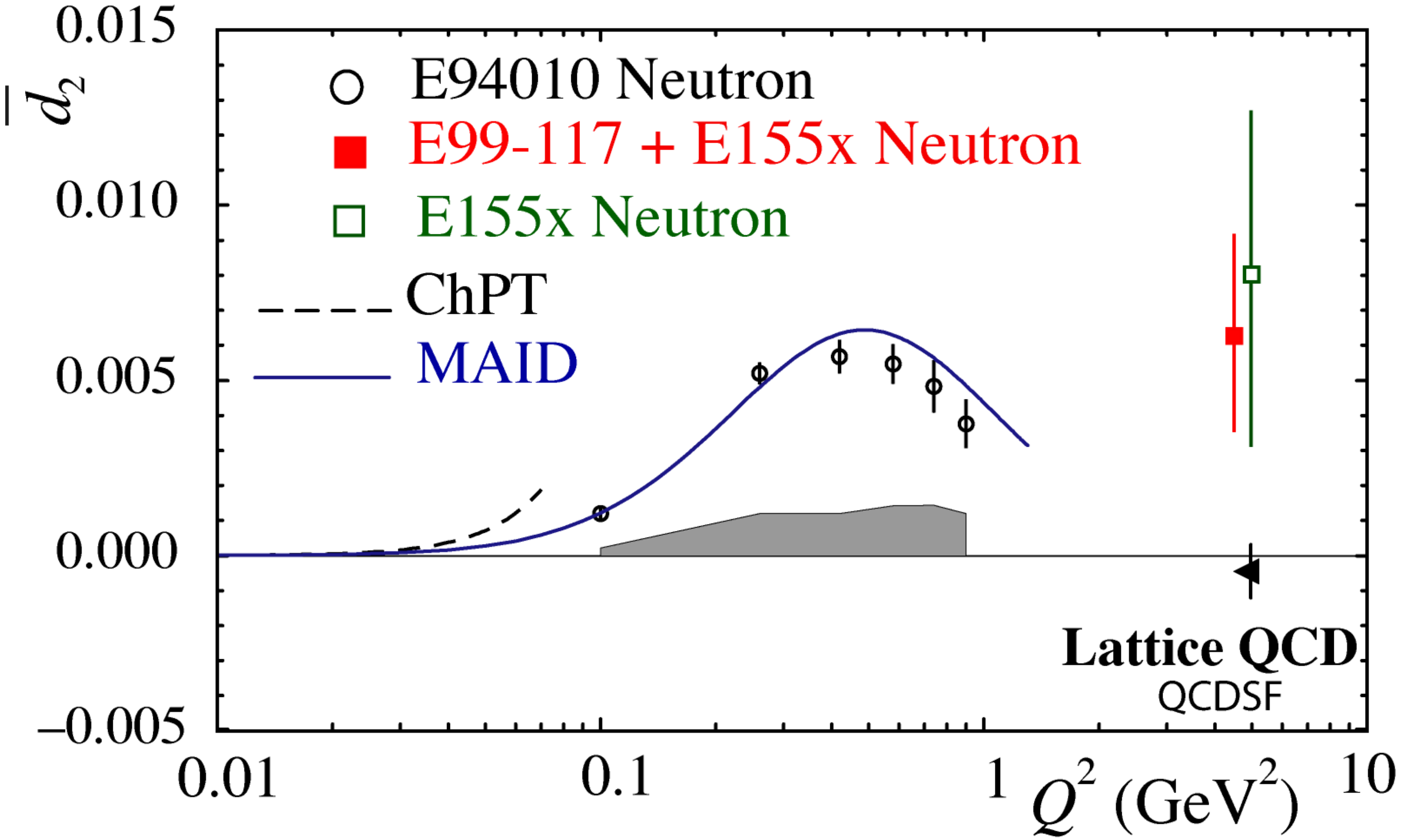
Chiral Soliton Model

H.Weigel and L.Gamberg,
Nucl. Phys. A680, 48 (2000).
M.Wakamatsu, Phys. Lett. B487,118(2000).

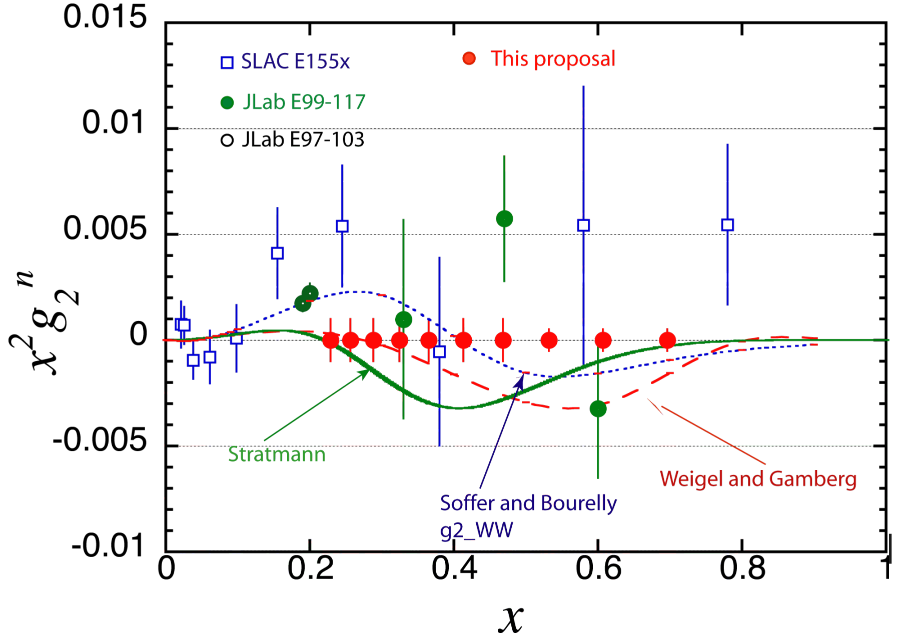
Lattice QCD

M.Gockeler et al., Phys.Rev.D72:054507,
(2005)

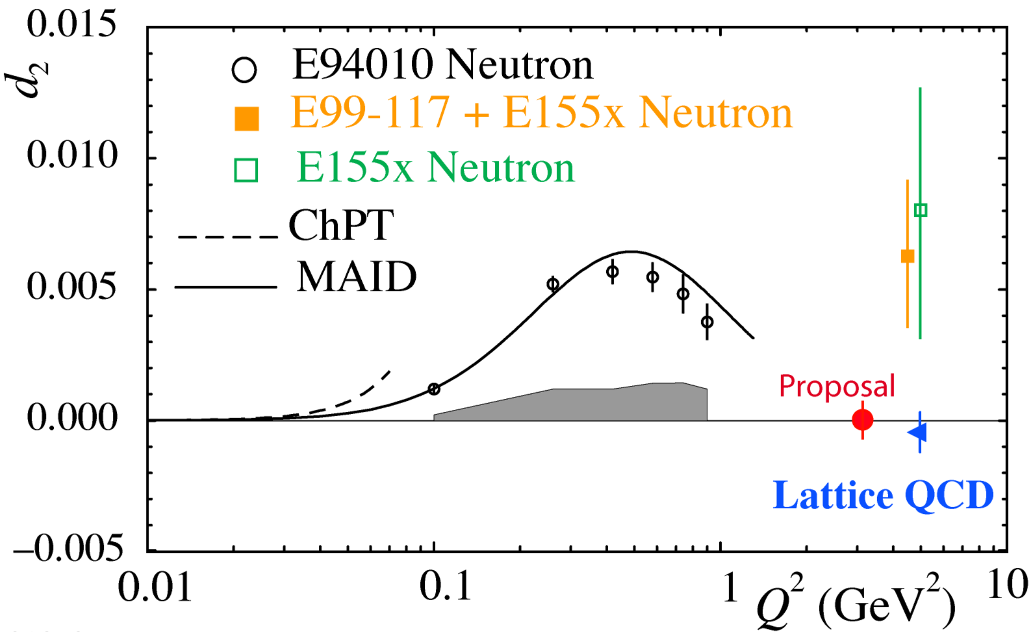
Q^2 evolution of the neutron "d_2"



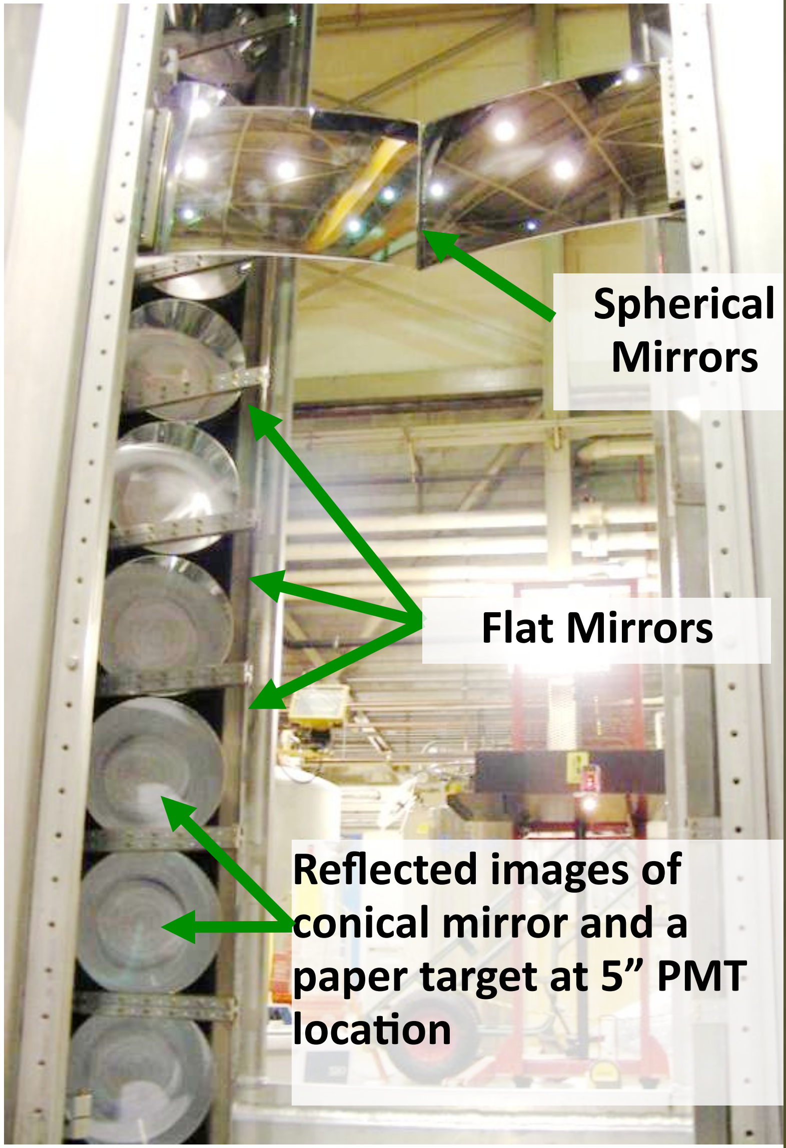
Expected precision in Experiment E06-114



- At large Q^2, d_2 coincides with the reduced twist-3 matrix element of gluon and quark operators
- At low Q^2, d_2 is related to the spin polarizabilities



BB Cherenkov During

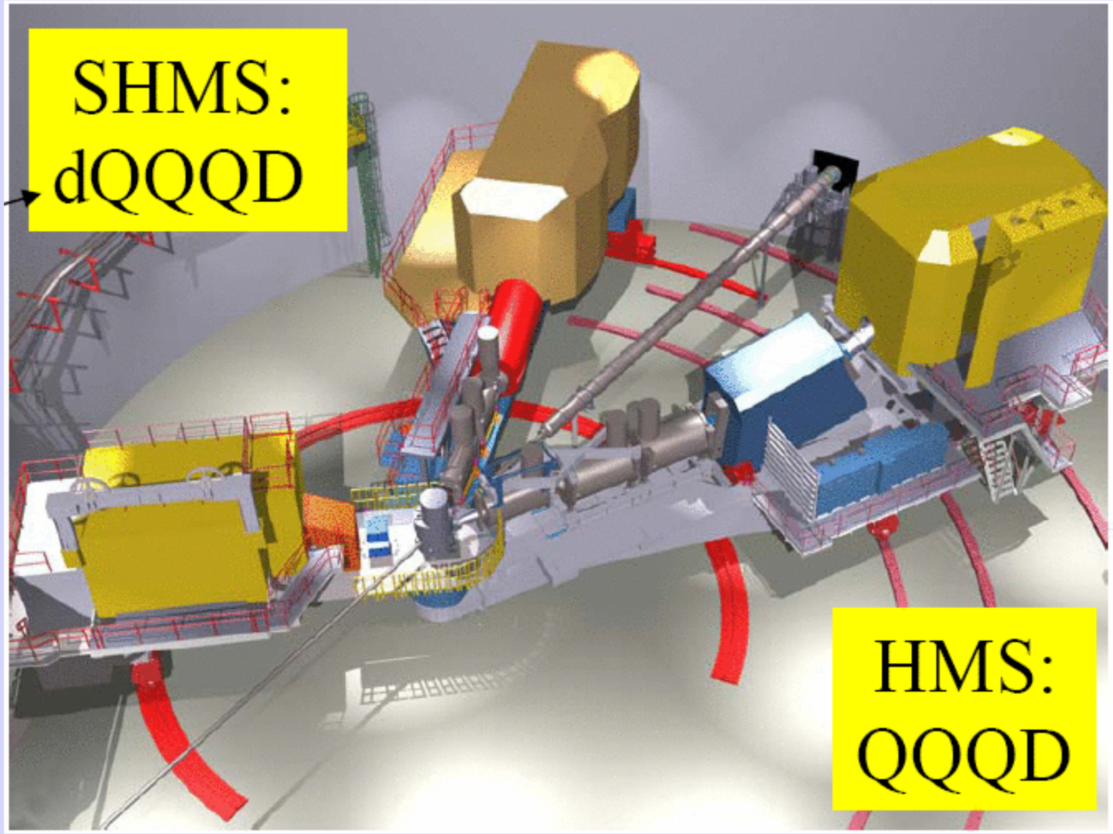


Spherical Mirrors

Flat Mirrors

Reflected images of conical mirror and a paper target at 5” PMT location

Floor layout for Hall C



Hall C

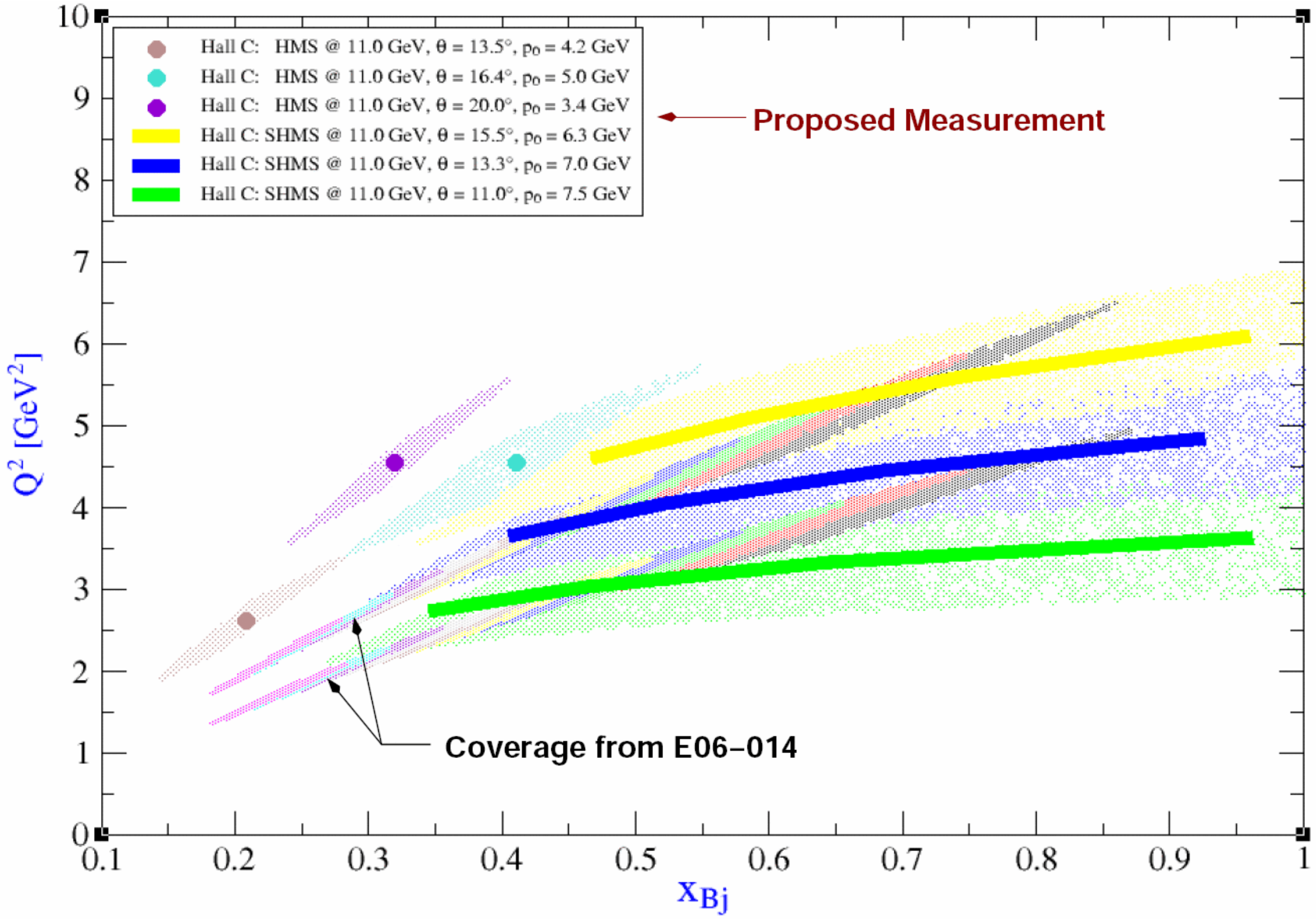
- One beam energy

  11 GeV
- Each arm measures a total cross section independent of the other arm.
- Experiment split into three pairs of 200 hour runs with spectrometer motion in between.

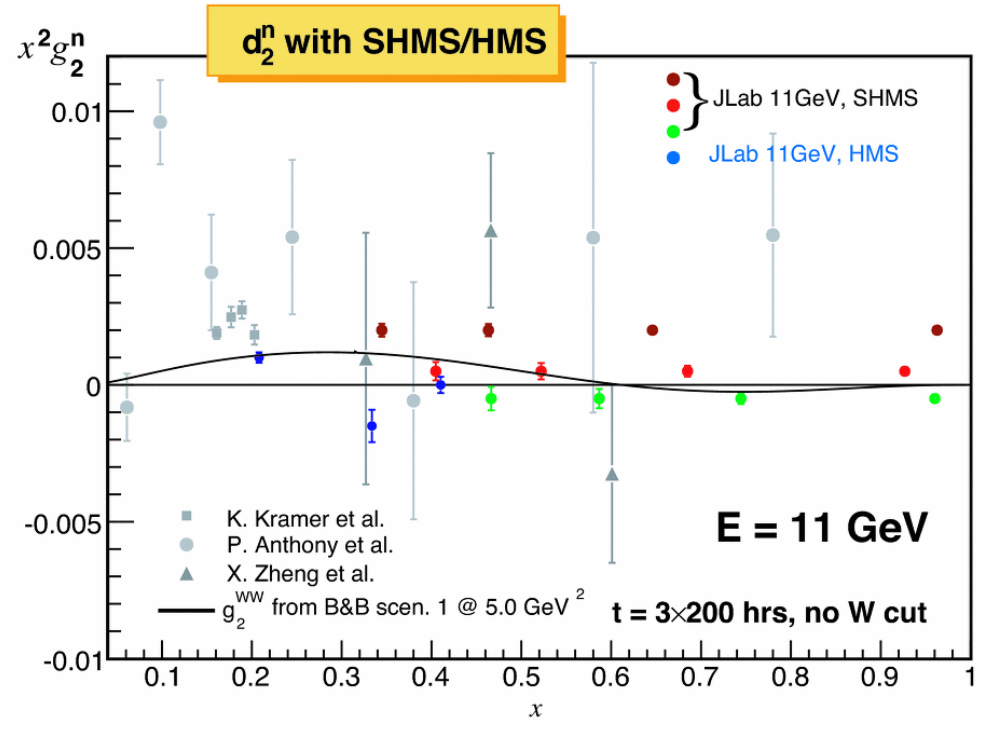
- SHMS collects data at Θ = 11°, 13.3° and 15.5° for 200 hrs each

  data from each setting divided into 4 bins
- HMS collects data at Θ = 13.5°, 16.4° and 20.0° for 200 hrs each

Kinematics for Hall C



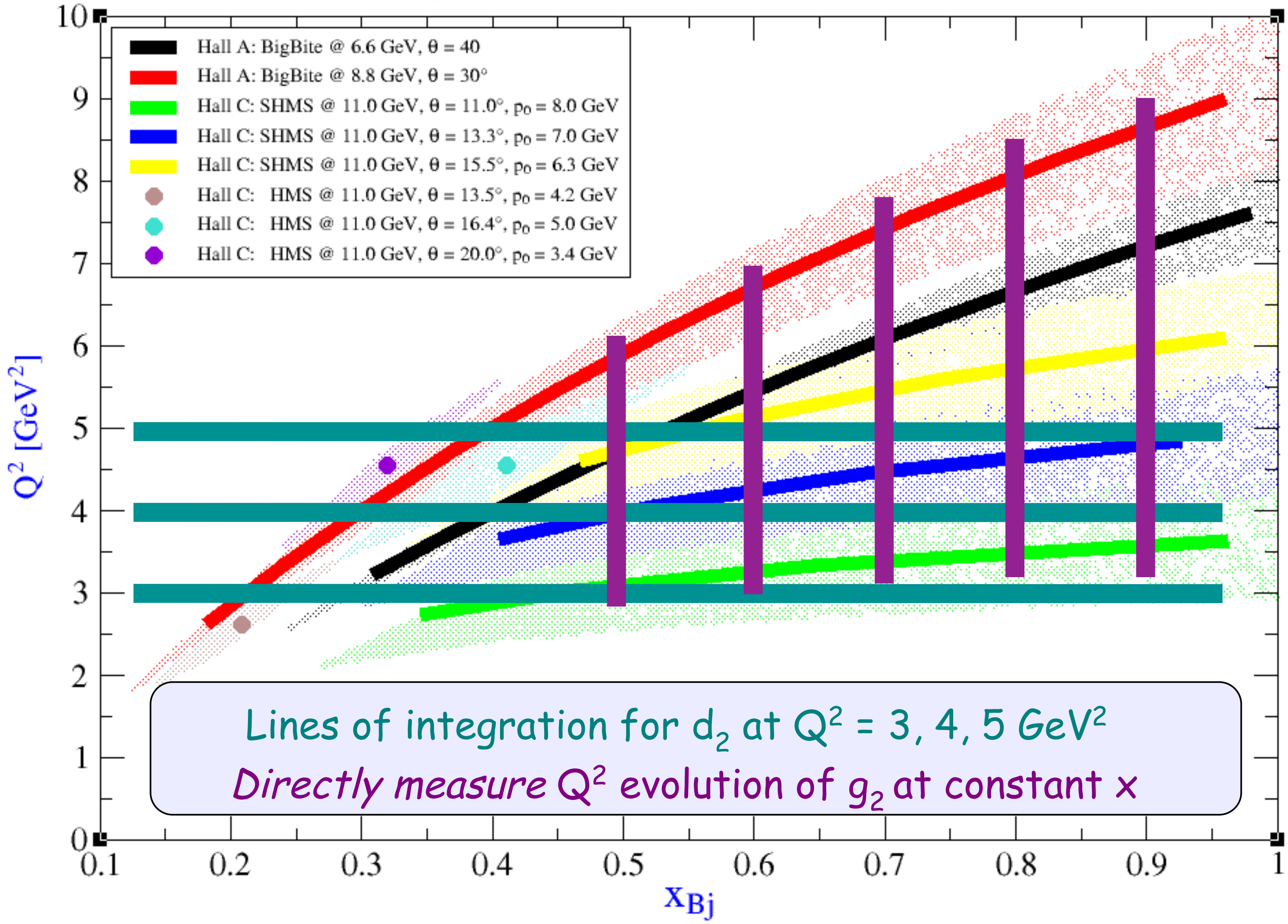
Projected $x^2g_2(x,Q^2)$ results for Hall C



Projected points are vertically offset from zero along lines that reflect different (roughly) constant Q^2 values from 2.5—6 GeV^2.

- g_2 for ^{3}He is extracted directly from L and T spin-dependent cross sections measured within the same experiment.
- Strength of SHMS/HMS:
  nearly constant Q^2 (but less coverage for $x < 0.3$)

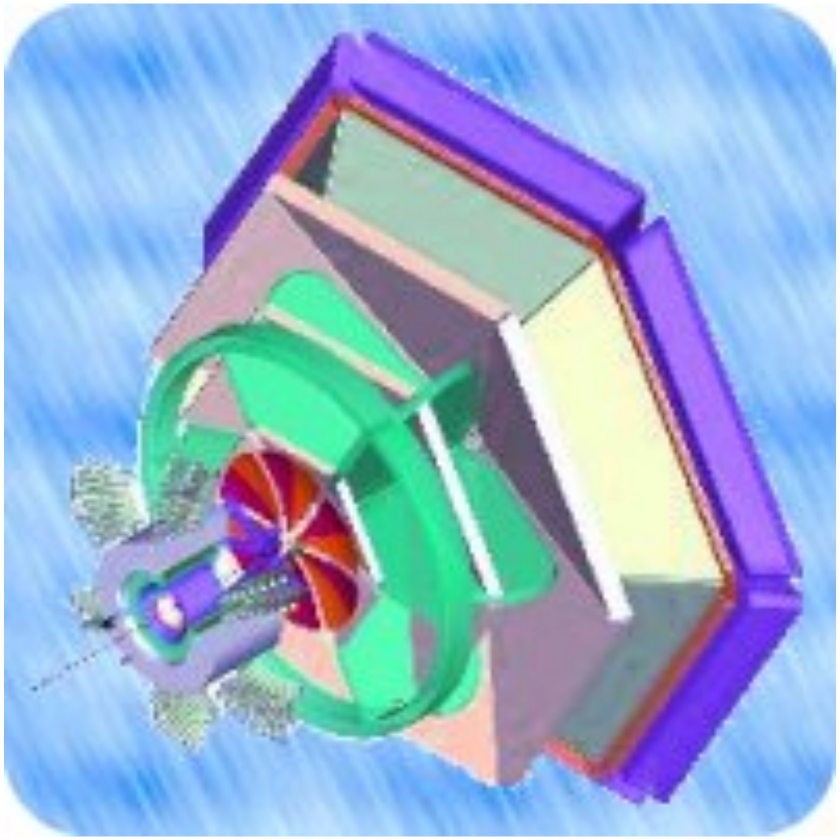
d_2 and g_2 evolution (both Halls)

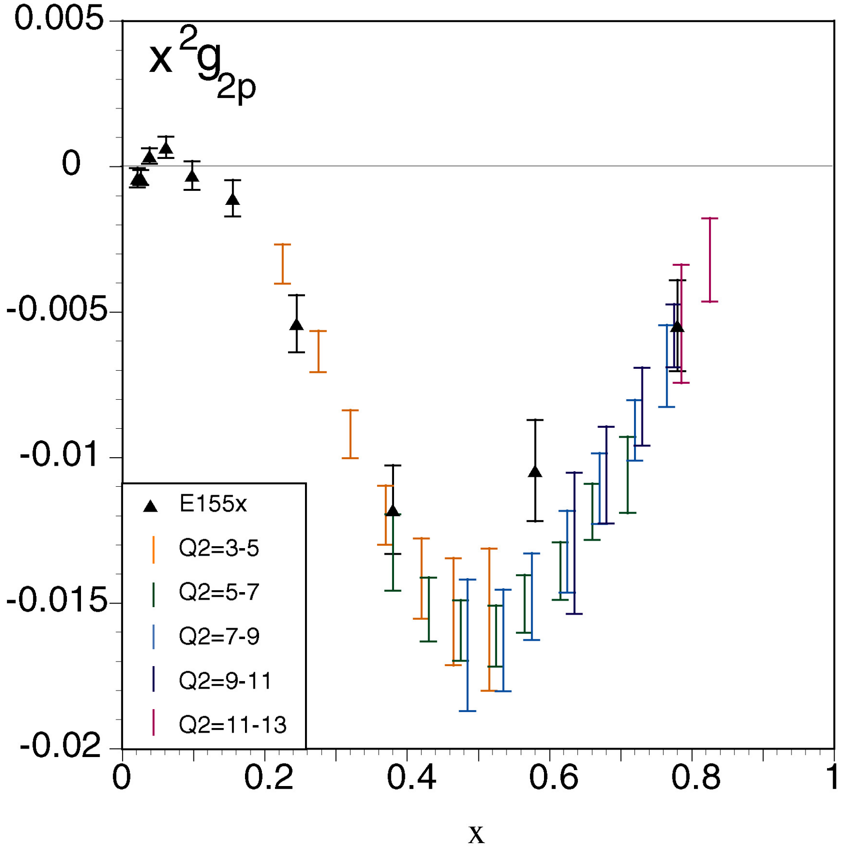


Lines of integration for d_2 at Q^2 = 3, 4, 5 GeV^2

Directly measure Q^2 evolution of g_2 at constant x

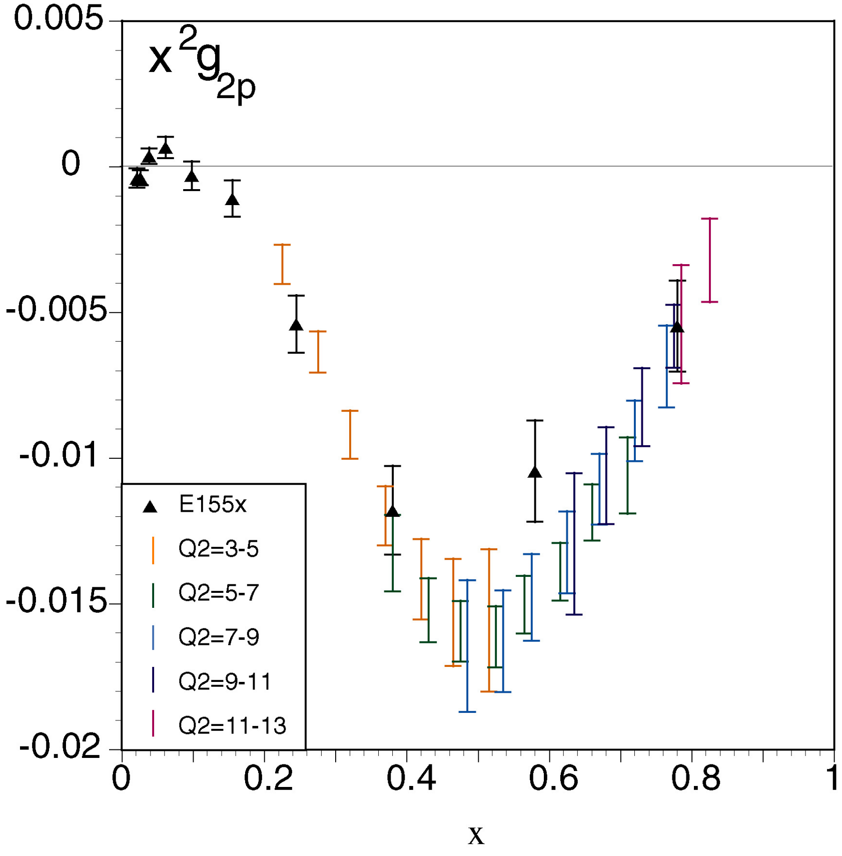
g_2 in CLAS 12 Hall B



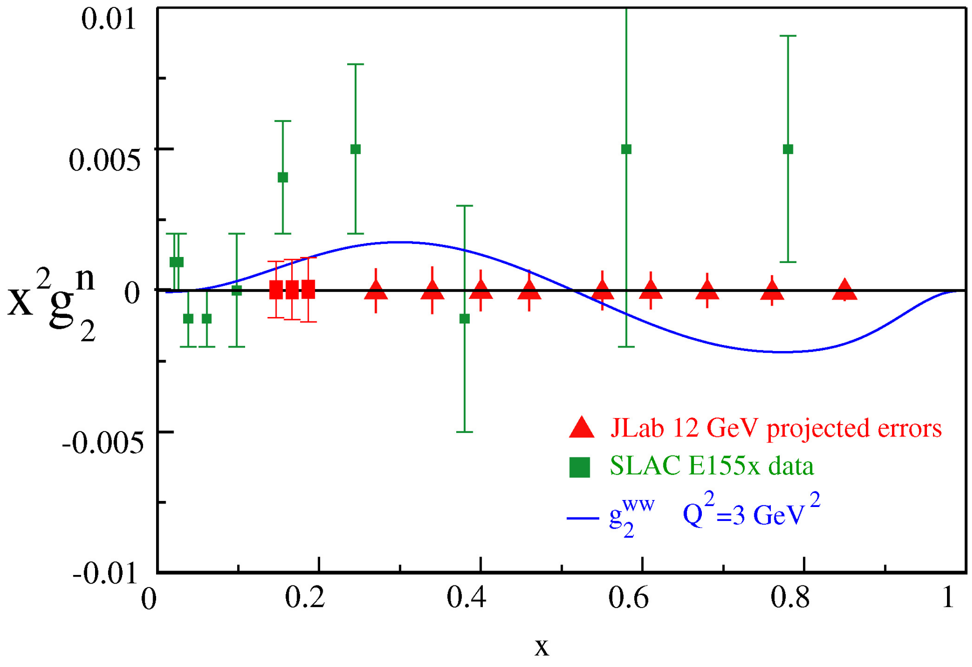


g_2 at JLab with 11 GeV

CLAS 12

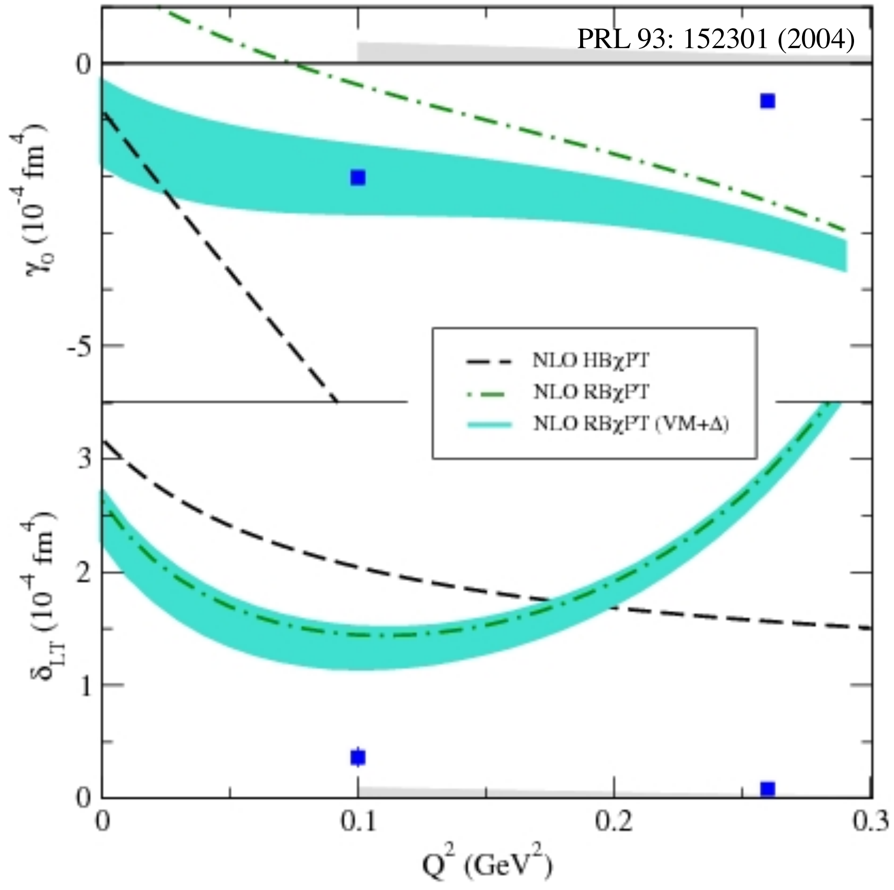


Hall C HMS/SHMS



Forward Spin Polarizabilities

Neutron



$$\gamma_0 = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\left[g_1 - \frac{4M^2}{Q^2}x^2 g_2\right]$$

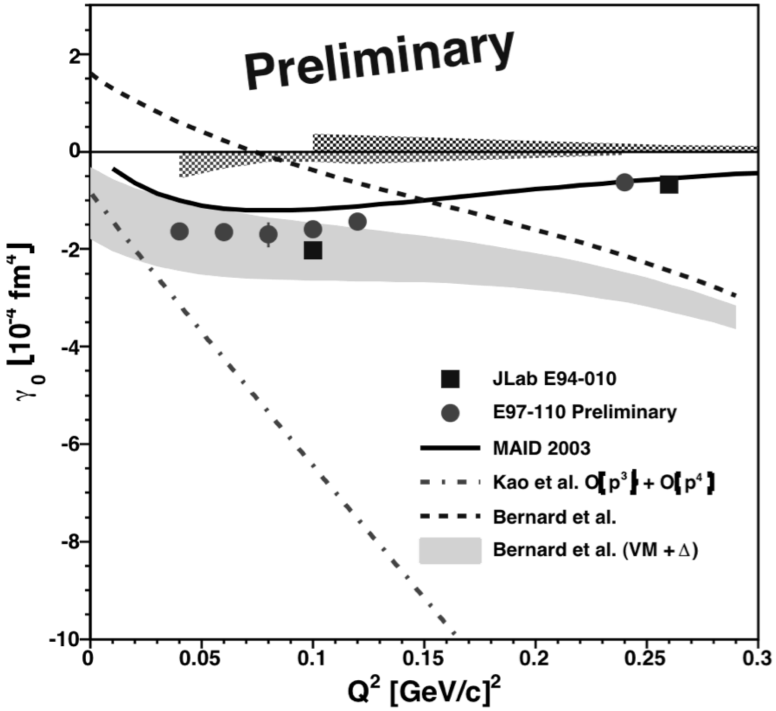
$$\delta_{LT} = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\left[g_1 + g_2\right]$$

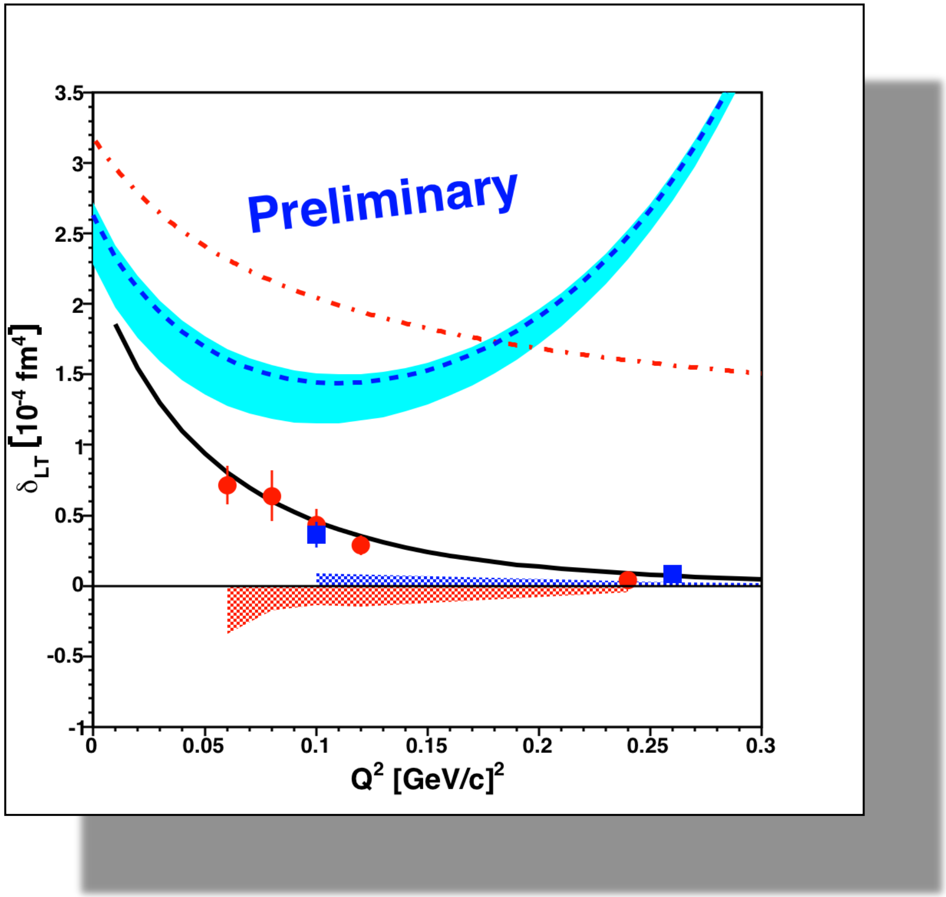
Dramatic Failure of ChiPT

Heavy Baryon χPT Calculation
Kao, Spitzenberg, Vanderhaeghen
PRD 67:016001(2003)

Relativistic Baryon χPT
Bernard, Hemmert, Meissner
PRD 67:076008(2003)

New Data on the Neutron Polarizabilities





Large discrepency with δ_{LT} remains

Plots courtesy of V. Sulkosky

- The spin contribution of quarks to the spin of the proton is about **30 %**
- The gluons spin contribution seem small leaving room for a large orbital contribution of both quarks and gluons
- The quark orbital angular momentum should be accessible through DVCS experiments at 12 GeV. The gluon angular momentum will require an Electron-Ion Collider.
- Precision measurements of g_1 and g_2 in the range $1 < Q^2 < 4$ GeV^2 are crucial for an improved extraction of the
  - ➥ Average color Lorentz force
  - ➥ "Color polarizabilities"
- Results from two recently performed experiments at Jefferson Lab, SANE in Hall C (proton) and JLab-E06-14 in Hall A (neutron).
- The non-singlet combination (d_2^p - d_2^n) should provide a benchmark test for present lattice QCD calculations since no disconnected diagrams are needed.
- This program will be pursued at JLab 11 GeV for higher precision and greater Q^2 and x coverage.