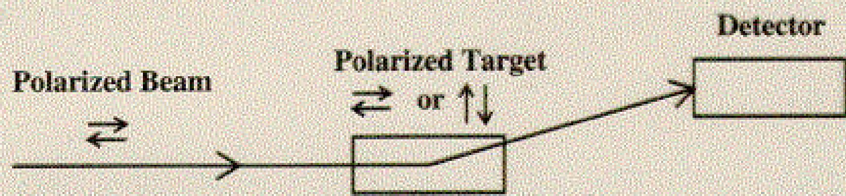
SPIN STRUCTURE OF THE NUCLEON AT SLAC

Sum Rules, Gluon Spin and Nuclear Corrections

P. Bosted, April 2002

- **Final Results on** g_1, NLO Fit
- **Nearly Final Results for** g_2, Sum Rules
- *Future:* **Open Charm Photoproduction and** $\Delta G(x)$.
- *Future:* **GDH Sum Rule**

POLARIZED DEEP INELASTIC SCATTERING



$$A_{\parallel} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = f_k\left[g_1(x,Q^2)[E + E'\cos(\theta)] - \frac{Q^2}{\nu} g_2(x,Q^2)\right]$$

$$A_{\perp} = \frac{\sigma^{\downarrow\leftarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\downarrow\leftarrow} + \sigma^{\uparrow\leftarrow}} = f_k E' \sin(\theta)\left[g_1(x,Q^2) + \frac{2E}{\nu} g_2(x,Q^2)\right]$$

g_1 and g_2 are the polarized structure functions.

- → $A_{\parallel}$ is primarily sensitive to g_1
- → $A_{\perp}$ is more sensitive to g_2
- → f_k includes contribution from kinematics and unpolarized structure functions

E155 MEASUREMENTS OF g_1^p and g_1^n

- Measured in 1997: published 2000.
- Electron beam 48 GeV, polarization $P_b = 0.83$
- NH_3 target for protons, polarization $P_t = 0.8$, dilution factor $f = 0.16$
- LiD target for deuterons, $P_t = 0.25$, $f = 0.22$. ^{6}Li treated like unpolarized α plus polarized d.
- Neutron results from proton and deuteron.
- Spectrometers at 2.75, 5.5 and 10.5 degrees.
- Kinematics: $0.014 < x < 0.9$, $1 < Q^2 < 40$ GeV^2.

Nuclear Target Corrections

$$A_\parallel = \frac{R^{\uparrow\downarrow} - R^{\uparrow\uparrow}}{R^{\uparrow\downarrow} + R^{\uparrow\uparrow}} \frac{1}{C_1 P_B P_T f} \left(1 + \frac{C_2 A_p}{A_d}\right)$$

→ $P_B P_T f$ accounts for beam polarization, target polarization, and dilution factor. [Radiative corrections are also made].

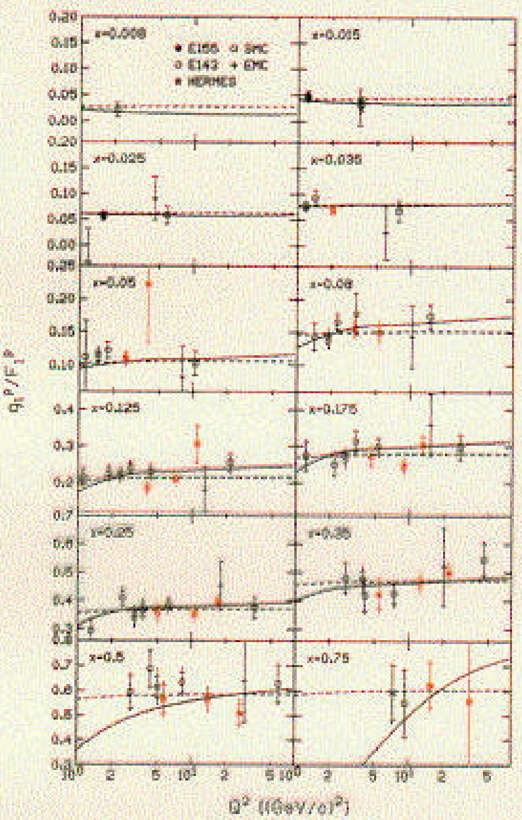
→ for NH3 $C_2 = 0$ and C_1 accounts for polarized ^{15}N, polarized opposite to free protons because acts like single proton "hole".

→ for NH3 $C_1 \approx 1 - 0.11 * P_N/P_p$ ranges from 1.01 to 1.04.

→ for LiD $C_1 \approx 1.86$ because ^6Li very much like 0.86 of a free deuteron, plus spectator α particle.

→ LiD also has 6% ^7Li, which has an unpaired proton, and gives a non-negligible C_2 correction.

RESULTS FOR g_1 PROTON VRS Q^2



g1 for Proton

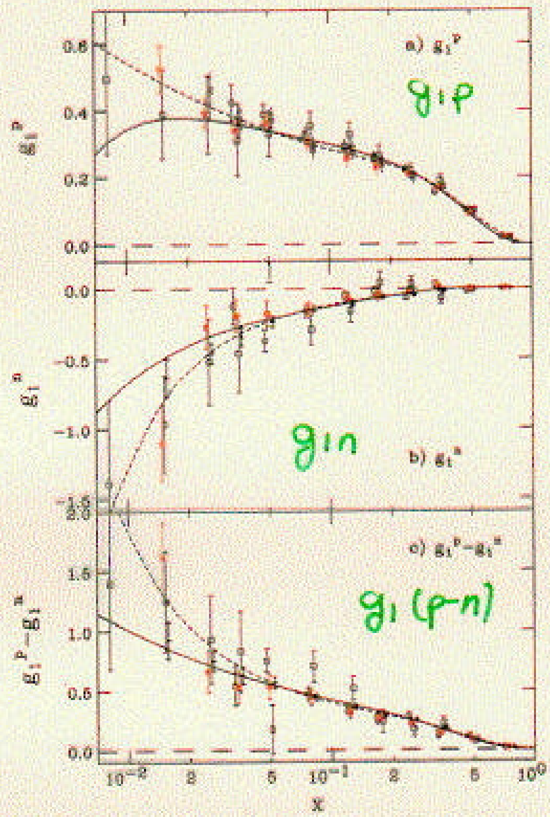
Dashed curve: Empirical Fit

Solid curve: pQCD fit

g1/F1 consistent with slight Q^2 dependance

- LARGE Q^2-RANGE IN SINGLE EXP.
- LiD (E155) USED FOR D AGREES WITH ND_3 (E143) (NOT SHOWN)
- SMALL STATISTICAL ERRORS

RESULTS FOR g_1 VRS x

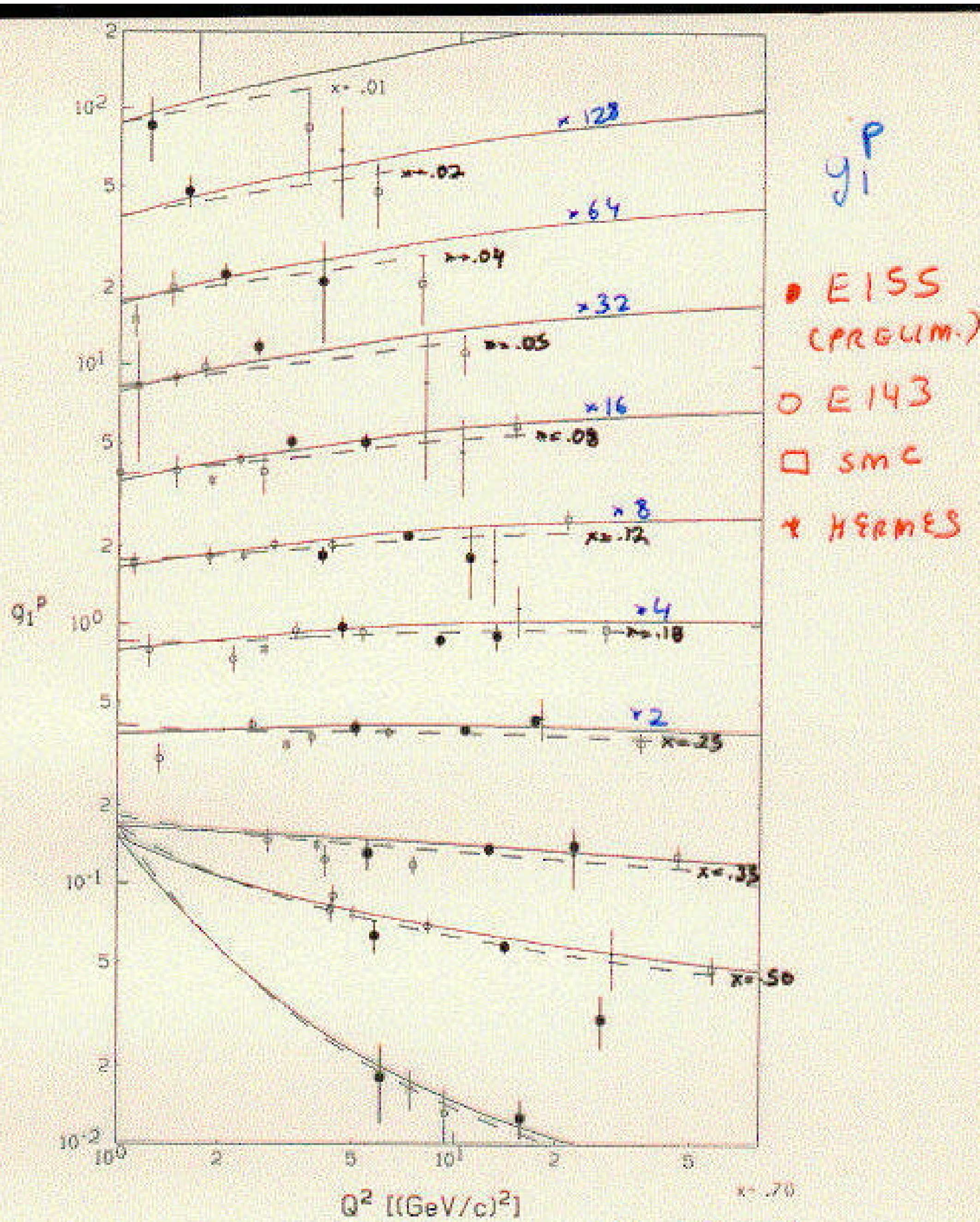


g1 at Q^2=5 GeV^2

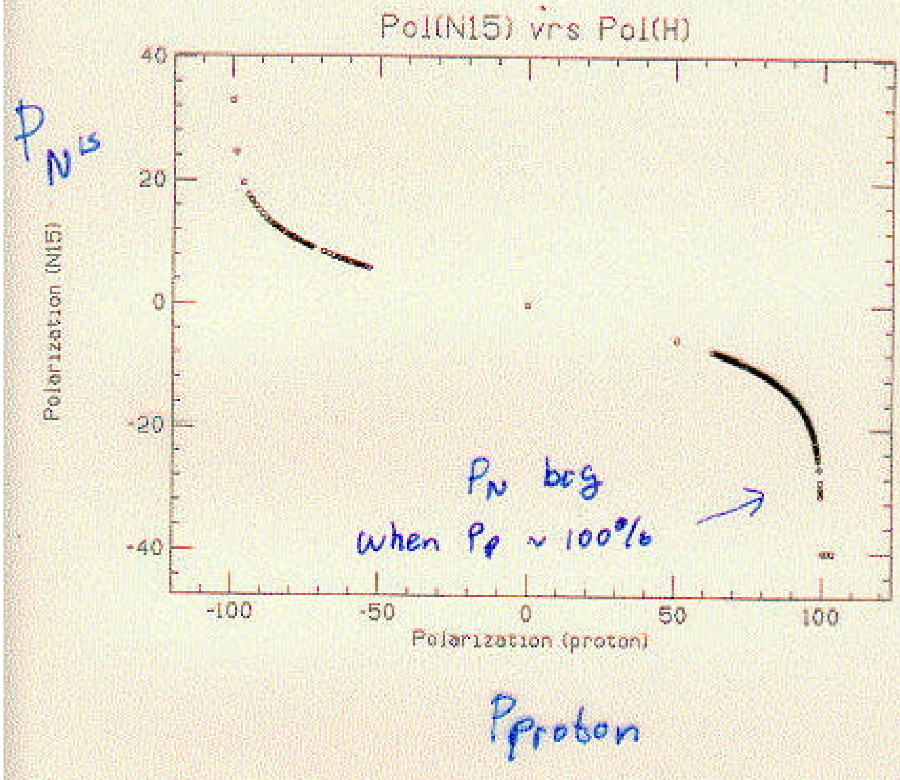
Proton well-determined for x>0.02

Neutron has larger errors

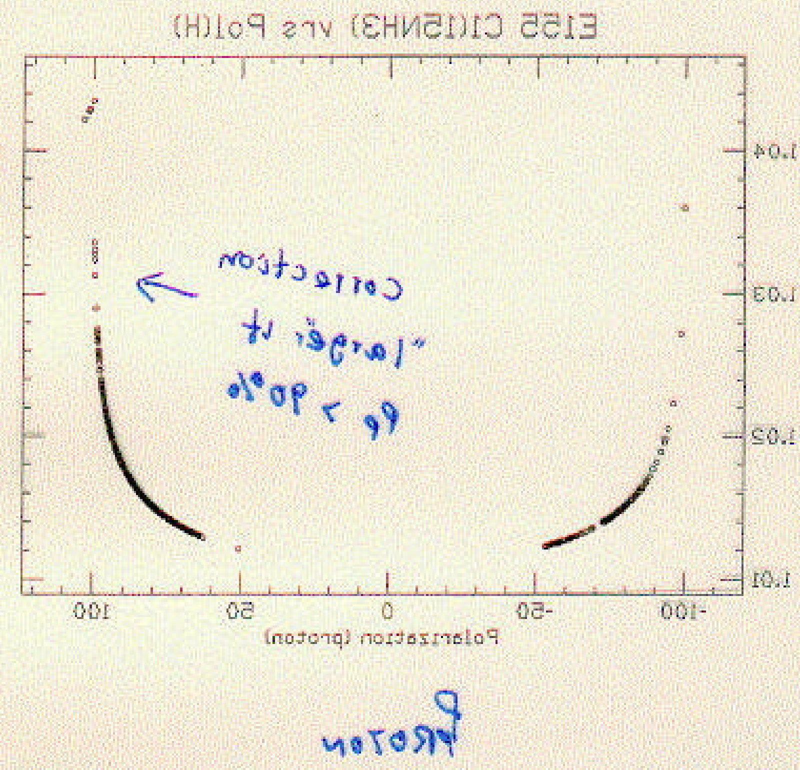
Low-x extrapolation uncertain (less so for p-n)

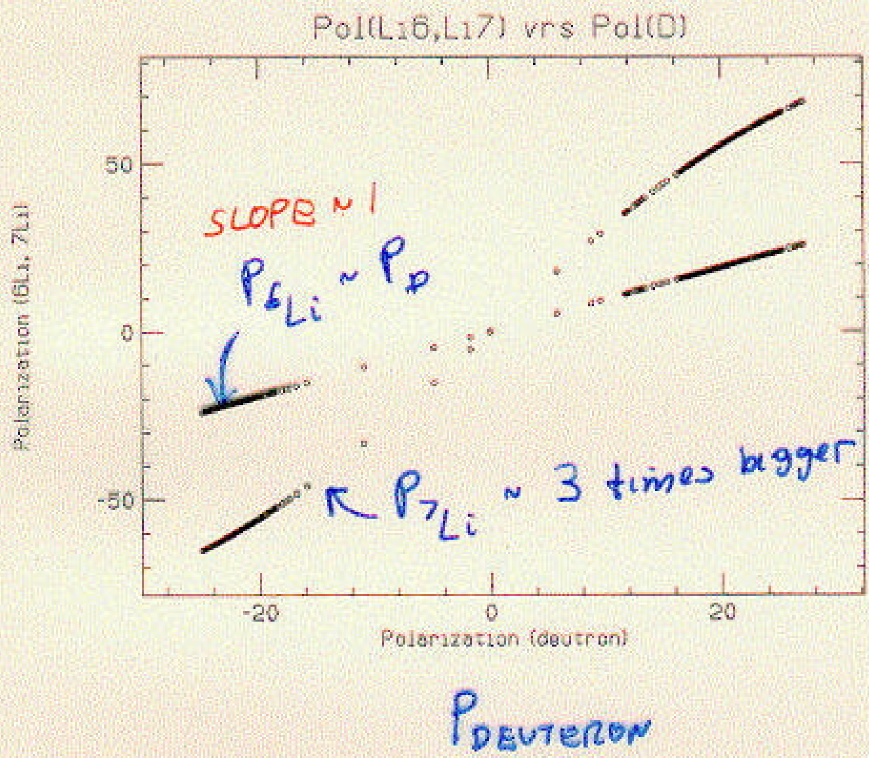


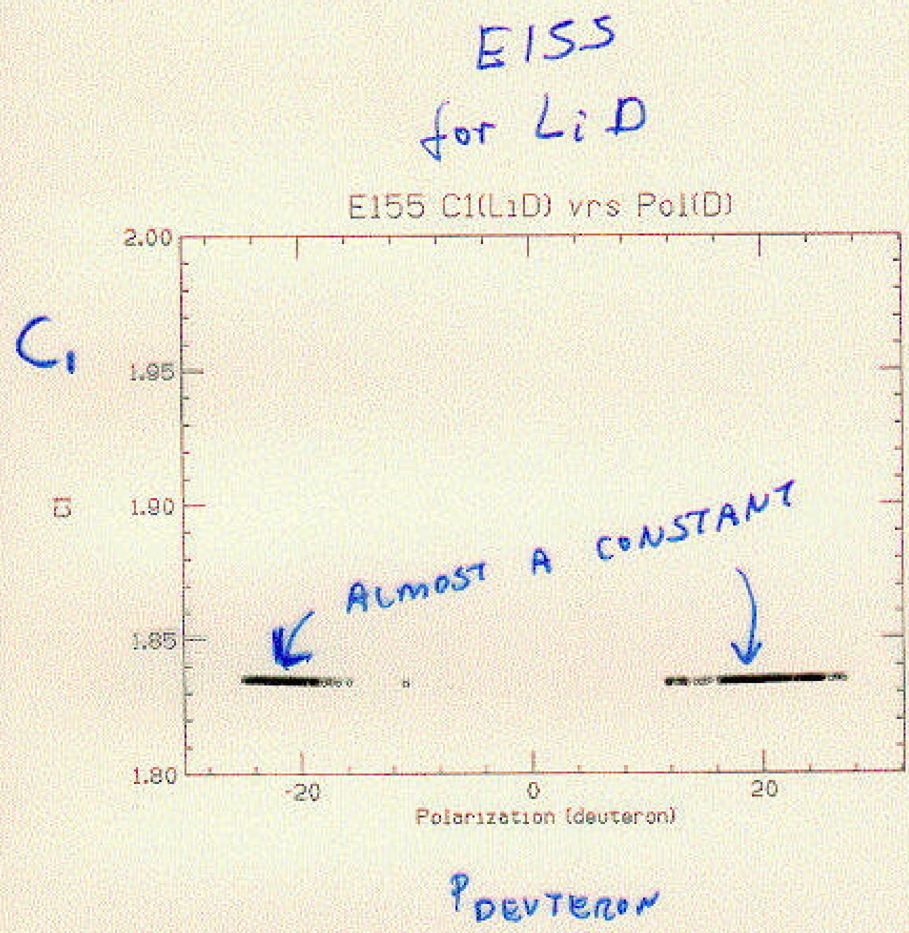
g_1 covers more limited Q^2 range, but Q^2-dep. gives some information on $\Delta G(x)$



Pol(N15) vrs Pol(H)
Polarization (N15)
Polarization (proton)
40
20
0
-20
-40
-100
-50
0
50
100
$P_{N^{15}}$
P_N big
when $P_p \sim 100\%$
P_{proton}


E155 C1(15NH3) vrs Pol(H)
1.01
1.02
1.03
1.04
-100
-50
0
50
100
Polarization (proton)
correction
"larger" if
Pe > 90%
proton


Pol(Li6,Li7) vrs Pol(D)
50
0
-50
-20
0
20
Polarization (6Li, 7Li)
Polarization (deutron)
SLOPE ~ 1
P6Li ~ PD
P7Li ~ 3 times bigger
PDEUTERON


E155
for LiD
E155 C1(LiD) vrs Pol(D)
C1
2.00
1.95
1.90
1.85
1.80
C1
ALMOST A CONSTANT
-20
0
20
Polarization (deuteron)
P DEUTERON

Structure Functions

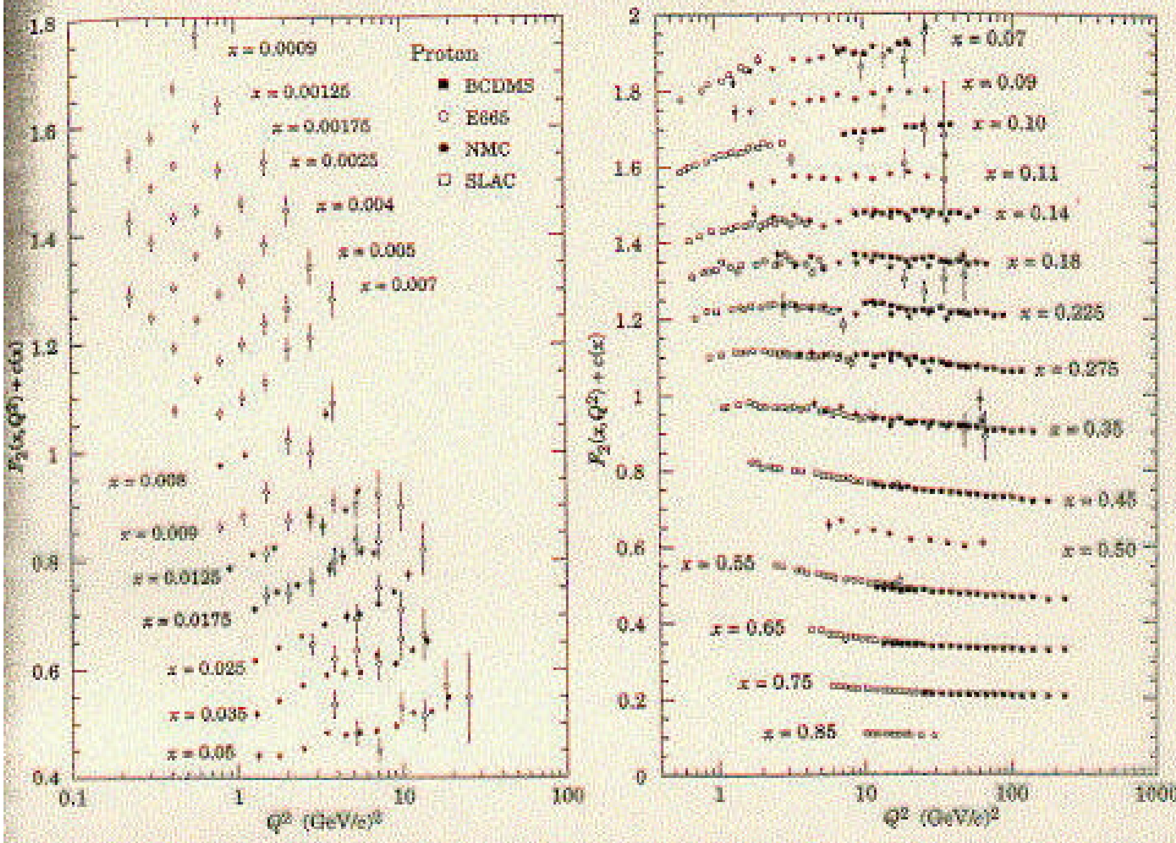


Figure 38.3: The proton structure function F_2^p measured in electromagnetic scattering of electrons (SLAC) and muons (BCDMS, E665, NMC), shown as a function of Q^2 for bins of fixed x. Only statistical errors are shown. For the purpose of plotting, a constant $c(x) = 0.1 i_x$ is added to F_2^p where i_x is the number of the x bin, ranging from 1 ($x = 0.05$) to 14 ($x = 0.0009$) on the left-hand figure, and from 1 ($x = 0.85$) to 15 ($x = 0.07$) on the right-hand figure. For HERA data in the kinematic range of this figure, see Fig. 38.1. References: **BCDMS**—A.C. Benvenuti *et al.*, Phys. Lett. **B223**, 485 (1989); **E665**—M.R. Adams *et al.*, Phys. Rev. **D54**, 3006 (1996); **NMC**—M. Arneodo *et al.*, Phys. Lett. **B364**, 107 (1995). **SLAC**—L.W. Whitlow *et al.*, Phys. Lett. **B282**, 475 (1992). (Courtesy of R. Voss, 1996.)

FROM F_2 data v/s (x, Q^2),

extract good information on $G(x)$, α_s, ...

GLOBAL PQCD FIT TO g_1

- At $Q^2 = 5$ GeV^2 find quark singlet contribution:

  $\Delta\Sigma = 0.23 \pm 0.04(stat) \pm 0.06(syst)$

  (low compared to Ellis-Jaffe prediction of 0.58).

- Proton first moment:

  $$\Gamma_1^p = 0.118 \pm 0.004 \pm 0.007$$

- Neutron first moment:

  $$\Gamma_1^n = -0.058 \pm 0.005 \pm 0.008$$

- Bjorken Sum Rule:

  $$\Gamma_1^p - \Gamma_1^n = 0.176 \pm 0.003 \pm 0.007$$

  (in agreement prediction 0.182 ± 0.005).

published: Phys. Rev. Lett. B463 (1999) 339; B493 (2000) 19.

Gluon Contribution $\Delta G(5\ \mathrm{GeV}^2)$

NLO fit ($\overline{MS}$): $1.8\ ^{+0.6}_{-0.4}\ ^{+1.4}_{-1.2}$

→ Scheme dependence is expected (different treatment of axial anomaly)

→ Indication of positive contribution

→ Errors smaller with inclusion of E155 data

IMPROVEMENT WOULD REQUIRE LARGER (Q^2, x) RANGE WITH SMALL ERRORS

E155x MEASUREMENTS OF g_2^p and g_2^d

- Measured in 1999: to be published soon.
- Electron beam 29 GeV and 32 GeV, polarization $P_b = 0.83$
- NH_3 and LiD targets as in E155.
- Spectrometers at 2.75, 5.5 and 10.5 degrees.
- Kinematics: $0.02 < x < 0.8$, $1 < Q^2 < 30 \text{ GeV}^2$.
- Compare to Twist-2 Wandzura-Wilczek:

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

E161

MEASUREMENT OF

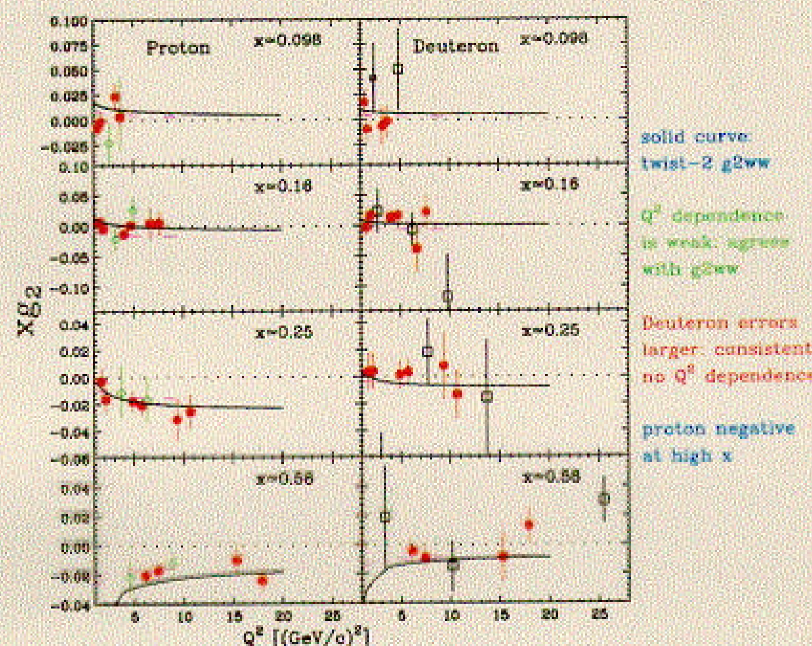
GLUON SPIN DISTRIBUTION IN NUCLEONS USING POLARIZED OPEN CHARM PHOTOPRODUCTION

S. Rock, D. Crabb, P. Bosted co-spokespersons

Planned to run in 2004

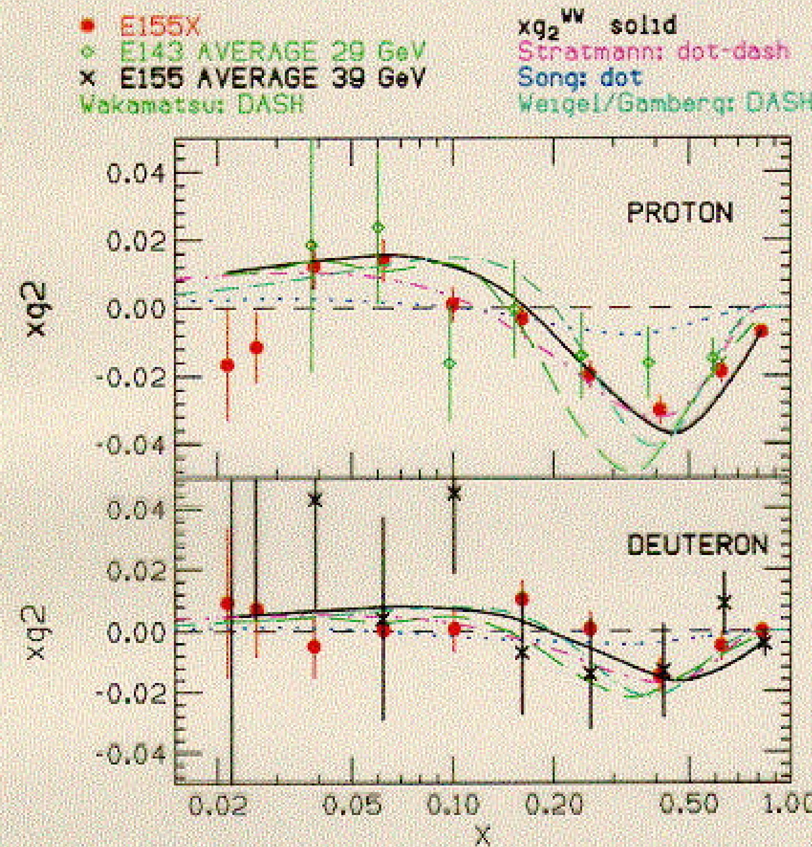
http:www.slac.stanford.edu/exp/e161/

RESULTS FOR g_2 VRS Q^2



- ERRORS 3-4x SMALLER THAN PREVIOUS DATA
- Q^2 DEPENDANCE CONSISTENT WITH g_2^{ww} - USED TO EVOLVE DATA TO CONSTANT Q^2 FOR SUM RULES

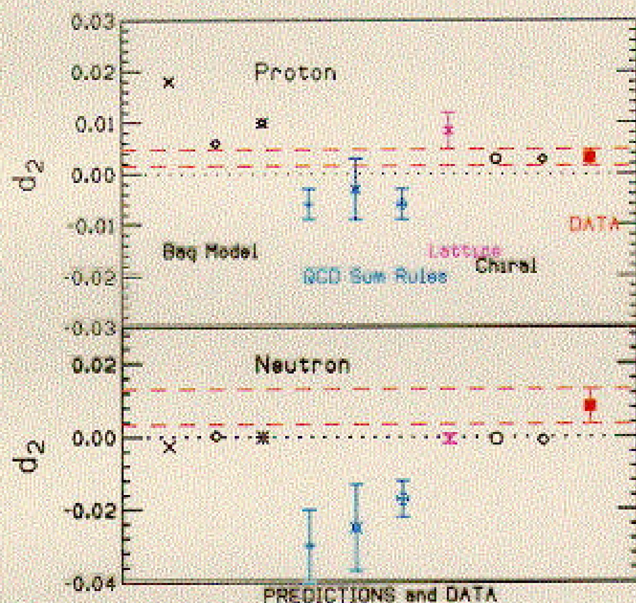
RESULTS FOR g_2 VRS x



THE TWIST-3 d_2 MATRIX ELEMENT

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

is a measure of twist-3 quark-gluon correlations (if $m_q h_T/M_n$ neglected).



E155x MEASUREMENTS OF A_2^p and A_2^d

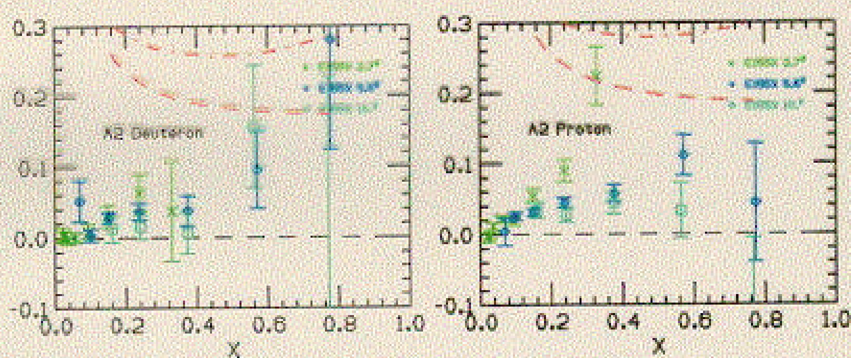
$$A_2(x,Q^2) = \frac{2\sigma_{TL}}{\sigma_T^{1/2} + \sigma_T^{3/2}} = \gamma \frac{g_1(x,Q^2) + g_2(x,Q^2)}{F_1(x,Q^2)}$$

Compare to positivity limit

$$A_2 < \sqrt{R(x,Q^2)}$$

and Soffer limit

$$A_2 < \sqrt{R(x,Q^2)(1 + A_1(x,Q^2))/2}$$



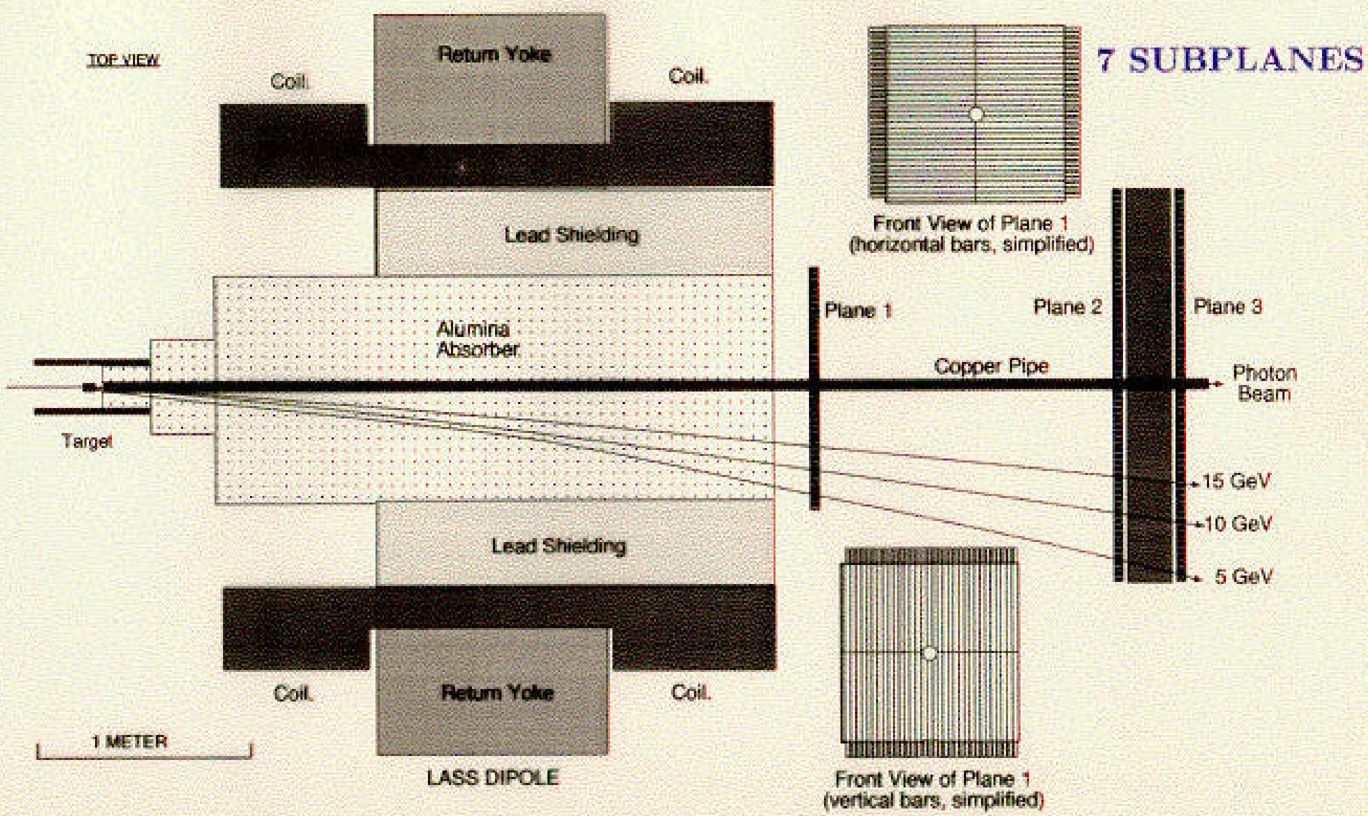
$\boxed{A_2 > 0}$

→ STRONG Q^2- DEPENDANCE

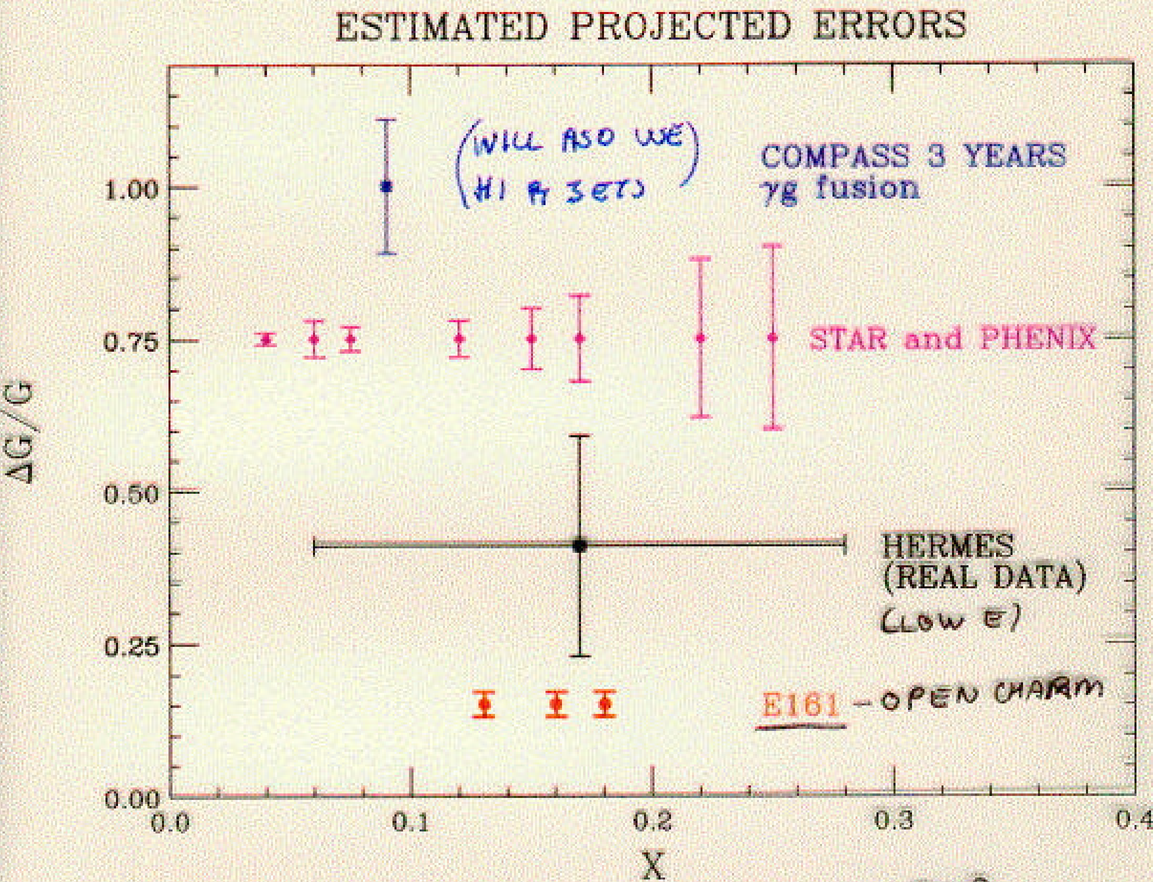
→ << SOFFER BOUND EXCEPT AT HIGH X

μ SPECTROMETER

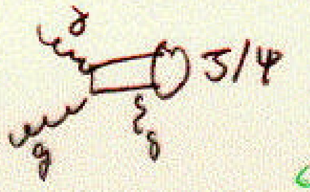
NORMAL MODE



COMPARISON OF EXPERIMENTS



ALSO: CAN HOPE TO OBTAIN ERROR
~0.05 OR LESS FROM



INELASTIC $z < 0.9$
$p_T > 0.5$

COLOR SINGLET MODEL

WHAT WE KNOW

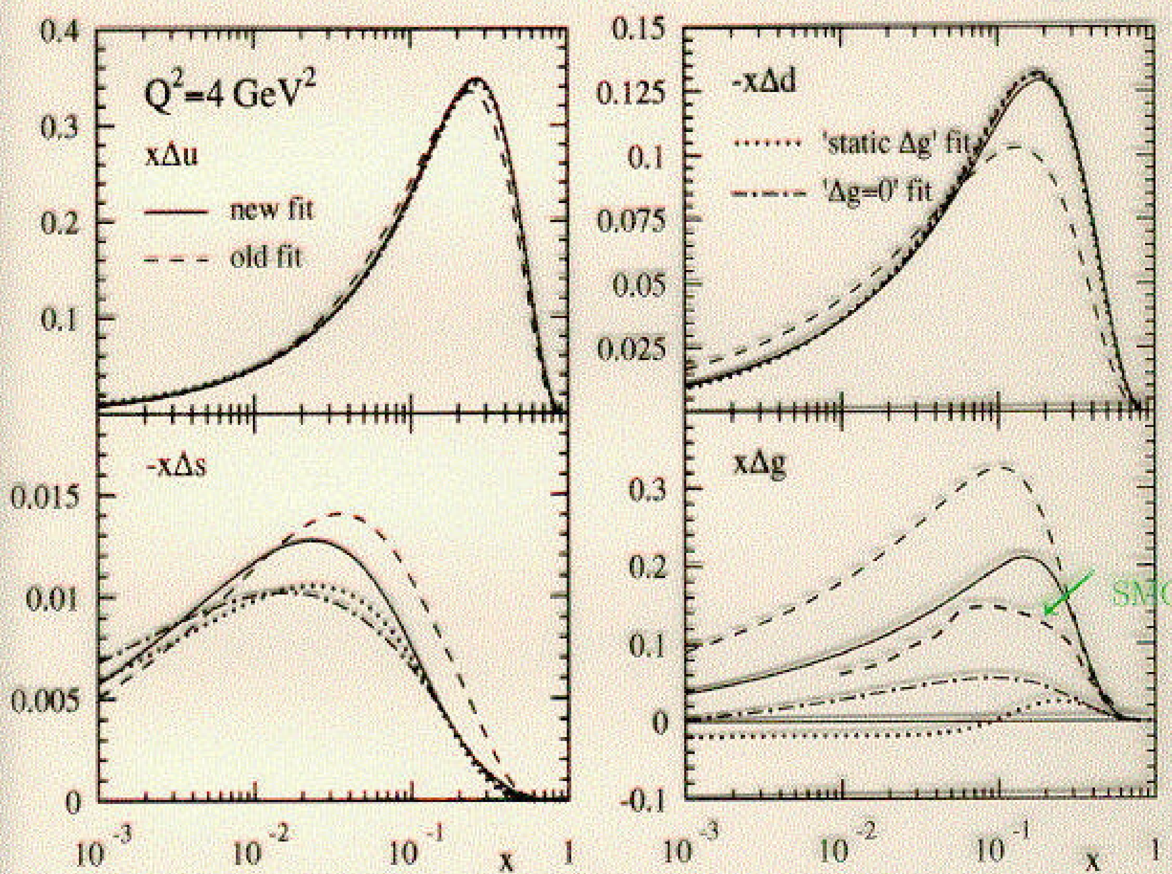
POLARIZED PARTON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

THE FIT OF

Gluck, Reya, Stratmann and Vogelsang (1999)

$$\Delta q(x, Q^2) = q_i^{\uparrow}(x, Q^2) - q_i^{\downarrow}(x, Q^2)$$

Δg ONLY APPEARS in NLO

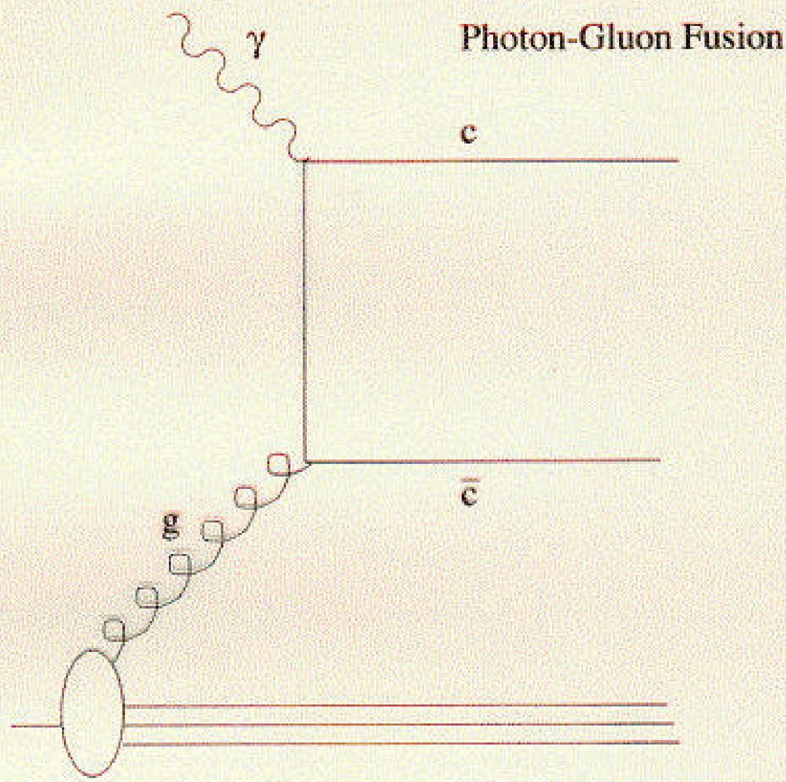


HOW TO MEASURE $\Delta g(x, Q^2)$ DIRECTLY

POLARIZED PHOTON BEAM

POLARIZED LiD TARGET

PHOTON-GLUON FUSION

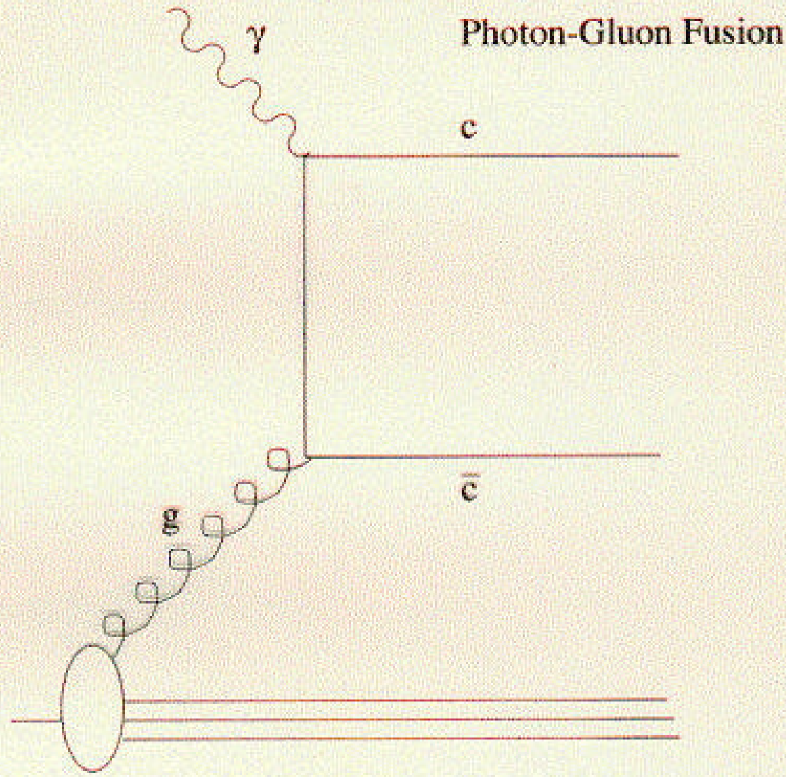


HOW TO MEASURE $\Delta g(x, Q^2)$ DIRECTLY

POLARIZED PHOTON BEAM

POLARIZED LiD TARGET

PHOTON-GLUON FUSION



EXPERIMENTAL STRATEGY

- HIGH POLARIZATION TARGET
- HIGH POLARIZATION BEAM
- MEASURE MOMENTUM of μ
  - High Field Magnet
  - Fine Grain Hodoscopes
  - Good Time Resolution
- ABSORB K and π BEFORE DECAY
  - $\sim$ 10 Interaction Lengths (38 R.L.)
  - Monte Carlo Predicts Rates
  - Asymmetry Very Small (E155)
  - Two Absorber Setups
    75% and 25% of Time
  - Multiple Scattering of μ Almost the Same
- VETO $\mu^+\mu^-$ PAIRS
  (B-H, J/ψ, VECTOR MESONS)
  - Some Singles Remain (Acceptance)
  - Calculate Based on Pairs and Known σ

EXPERIMENTAL STRATEGY

Tag Charm With Single Decay μ

	D^+	D^0	D_s^+	Λ_c^+
produced(%)	19	63	8	8
Branching Ratio(%)	17	7	8	4
fraction of μ^+(%)	37	47	8	4
	D^-	$\bar{D}^0$	D_s^-	Λ_c^-
produced(%)	21	71	6	2
fraction of μ^-(%)	40	53	5	1

BACKGROUNDS

- μ FROM K and π DECAY (Long Lifetime)
- Bethe-Heitler μ PAIRS
- J/ψ DECAY (Small)
- VECTOR MESON DECAYS (Small)
- ASSOCIATED PRODUCTION (Small)
- FINAL STATE INTERACTIONS (Small)
- DIFFRACTIVE PRODUCTION (Small)

ALTERNATE METHOD

- DETECT TWO MUONS (ONE FROM EACH CHARM QUARK (UNDER STUDY)

TWO MORE g_2 SUM RULES

- The Burkhardt-Cottingham sum rule predicts:

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

- For $0.02 \leq x \leq 0.8$ at $Q^2 = 5$ (GeV/c)^2. we find -0.034 ± 0.008 for proton and -0.002 ± 0.011 for deuteron.
- Disagreement for proton could be due to low-x.
- Efremov-Leader-Teryaev Sum Rule (assuming isospin symmetry):

$$\int_0^1 x[g_1^p(x)+2g_2^p(x)-g_1^n(x)-2g_2^n(x)]dx = 0.$$

- We find -0.009 ± 0.008 at $Q^2 - 2.5$ GeV^2, consistent with prediction.
- Low-x region suppressed by x-weighing in integral, test more conclusive than for B.C. Sum Rule.