SLAC E143 ANALYSIS OF THE Q^2 EVOLUTION OF THE NUCLEON SPIN STRUCTURE FUNCTIONS

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Polarized Deep Inelastic Scattering

- Polarize incident lepton
- Polarize target nucleon

For longitudinal target polarization

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

For transverse target polarization

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

- g_1 and g_2 are polarized (spin dependent) structure functions.

Lepton-Nucleon Asymmetries

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

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

$$f_k = \frac{1-\epsilon}{\nu F_1(1+\epsilon R(x,Q^2))} \qquad \epsilon = \frac{1}{[1+2(1+\frac{\nu^2}{Q^2})\tan^2(\frac{\theta}{2})]}$$

$$R(x,Q^2) = \frac{(1+\gamma^2)F_2}{(2xF_1)} - 1 \qquad \gamma^2 = \frac{Q^2}{\nu^2}$$

Experimentally:

$$A_{\parallel}(or\, A_{\perp}) = (\frac{N_L - N_R}{N_L + N_R})\frac{1}{fP_bP_t} + A_{RC}$$

N_L, N_R = Left and right counts/incident charge.

P_b, P_t = Beam and target polarizations.

f = Dilution factor

A_{RC} = Radiative correction.

Why measure spin structure functions?

- Test sum rules

  Bjorken sum rule

  $\int (g_1^p(x) - g_1^n(x))\, dx = \frac{1}{6}\frac{g_A}{g_V}\left(1 - \frac{\alpha_s(Q^2)}{\pi}\right) = 0.185 \pm 0.004$

  Ellis-Jaffe sum rules

  $\int g_1^p(x) dx = \frac{1}{18}(9F - D)\left(1 - \frac{\alpha_s(Q^2)}{\pi}\right) = 0.173 \pm 0.015,$

  $\int g_1^n(x) dx = \frac{1}{18}(6F - 4D)\left(1 - \frac{\alpha_s(Q^2)}{\pi}\right) = -0.019 \pm 0.011$

- Study quark contributions to the nucleon spin

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

  $\int g_1^p(x) dx = \frac{1}{2}\left[\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right]$

  $\rightarrow$ "SPIN CRISIS"

  $\Sigma = \Delta u + \Delta d + \Delta s < 1$

  $\Delta s \neq 0$

History of Spin Structure Measurements

Year	Group	Exp.	Data	target
1978	Yale-SLAC	E80	$A_{\parallel}^{p}$	Butanol
1983	Yale-SLAC	E130	$A_{\parallel}^{p}$	Butanol
1988	CERN	EMC	$A_{\parallel}^{p}$	NH_3
1991	CERN	SMC	$A_{\parallel}^{d}$	Butanol
1992	SLAC	E142	$A_{\parallel}^{n}$, $A_{\perp}^{n}$	^3He
1993	CERN	SMC	$A_{\parallel}^{p}$, $A_{\perp}^{p}$	Butanol
1994	SLAC	E143	$A_{\parallel}^{p}$, $A_{\perp}^{p}$	$^{15}NH_3$
			$A_{\parallel}^{d}$, $A_{\perp}^{d}$	$^{15}ND_3$

SMC deuterium: Phys. Lett., B302, 533 (1993).

SMC proton: Phys. Lett., B329, 399 (1994).

SMC transverse: CERN-PPE-94-116 (1994).

E142 neutron: Phys. Rev. Lett., 71, 959 (1993).

E143 proton: Phys. Rev. Lett., 74, 346 (1995).

E143 deuteron: SLAC-PUB-95-6734, accepted by PRL.

The E143 Experiment

- Proton, deuteron: 1993-94
- Electron Beam

  Energy: 9.7 - 29.1 GeV

  Electrons from a strained GaAs photocathode illuminated by a flash-lamp pumped Ti-sapphire laser.

  Polarization: $\pm 0.85 \pm 0.03$

  Polarization randomly reversed from pulse-to-pulse
- Polarized target

  Composition: Ammonia granules, $^{15}NH_3$ and $^{15}ND_3$

  Polarized via DNP at 5 T and 1 K

  Longitudinal and transverse polarization

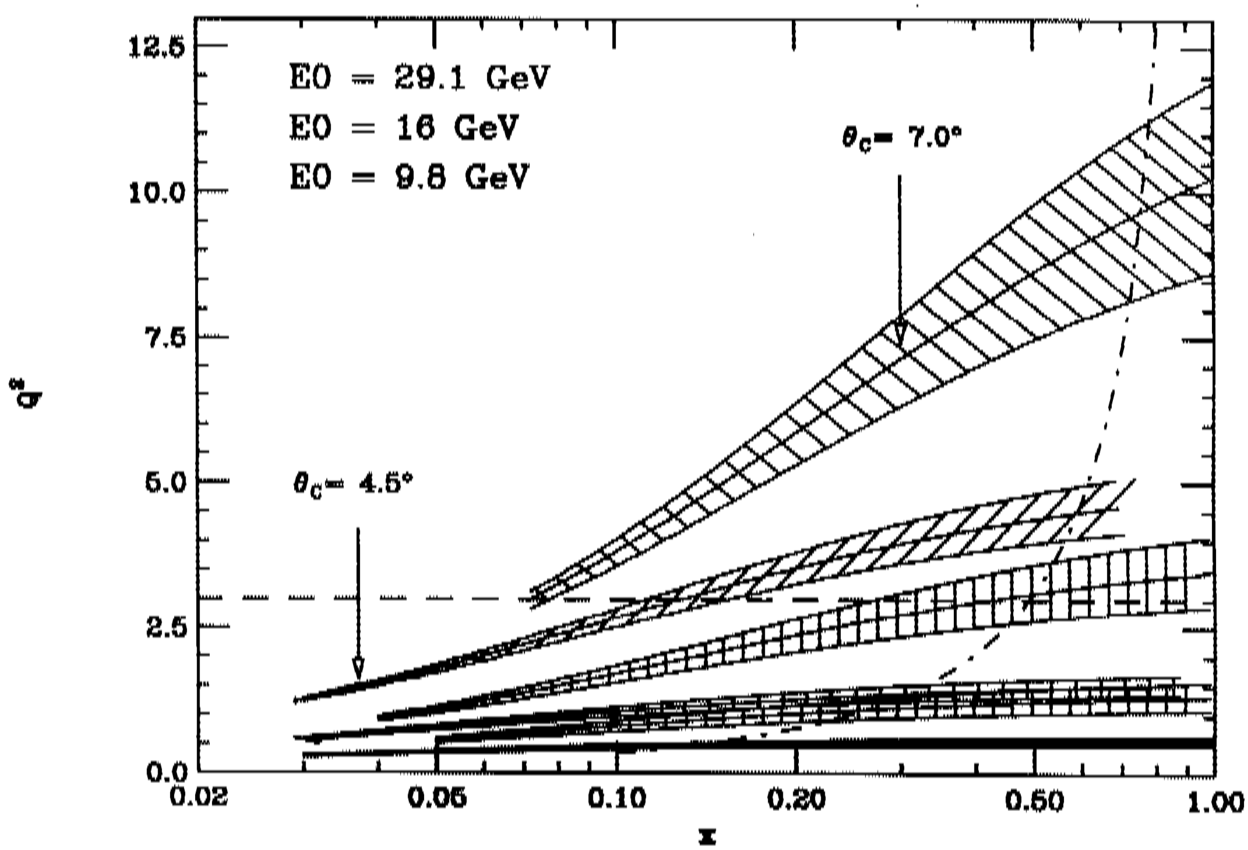
  Polarization: Proton:0.50$-$0.80, Deuteron: 0.20$-$0.40

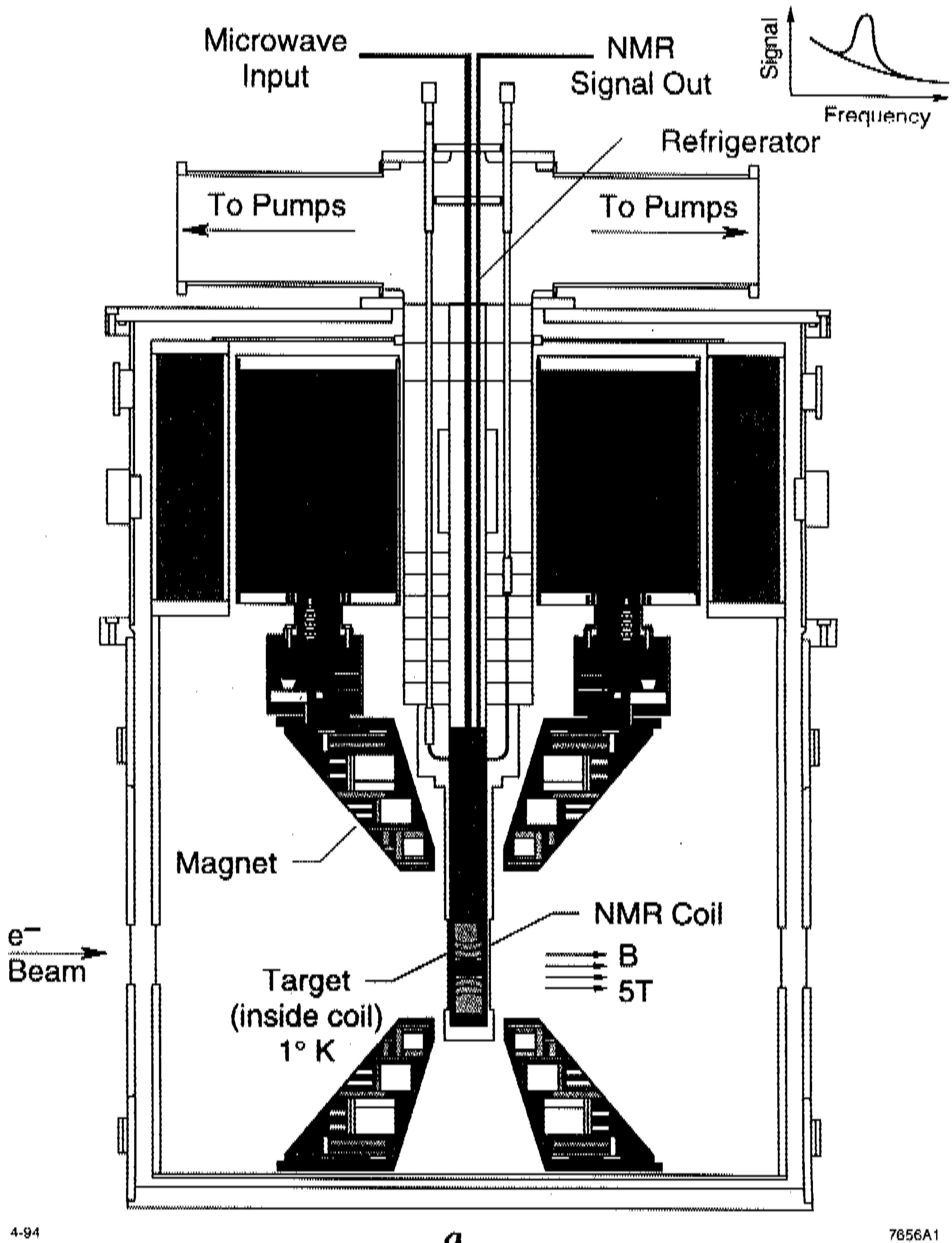
  Polarization reversal every 8-12 hours
- Kinematic coverage (29 GeV data)

  $0.029 < x < 0.8$; $Q^2 > 1.0$ (GeV/c)^2

  $< Q^2 >= 3.0$ (GeV/c)^2

E143 KINEMATICS




Microwave Input
NMR Signal Out
Signal
Frequency
Refrigerator
To Pumps
To Pumps
Magnet
NMR Coil
e⁻ Beam
Target (inside coil) 1° K
B
5T
4-94
7656A1

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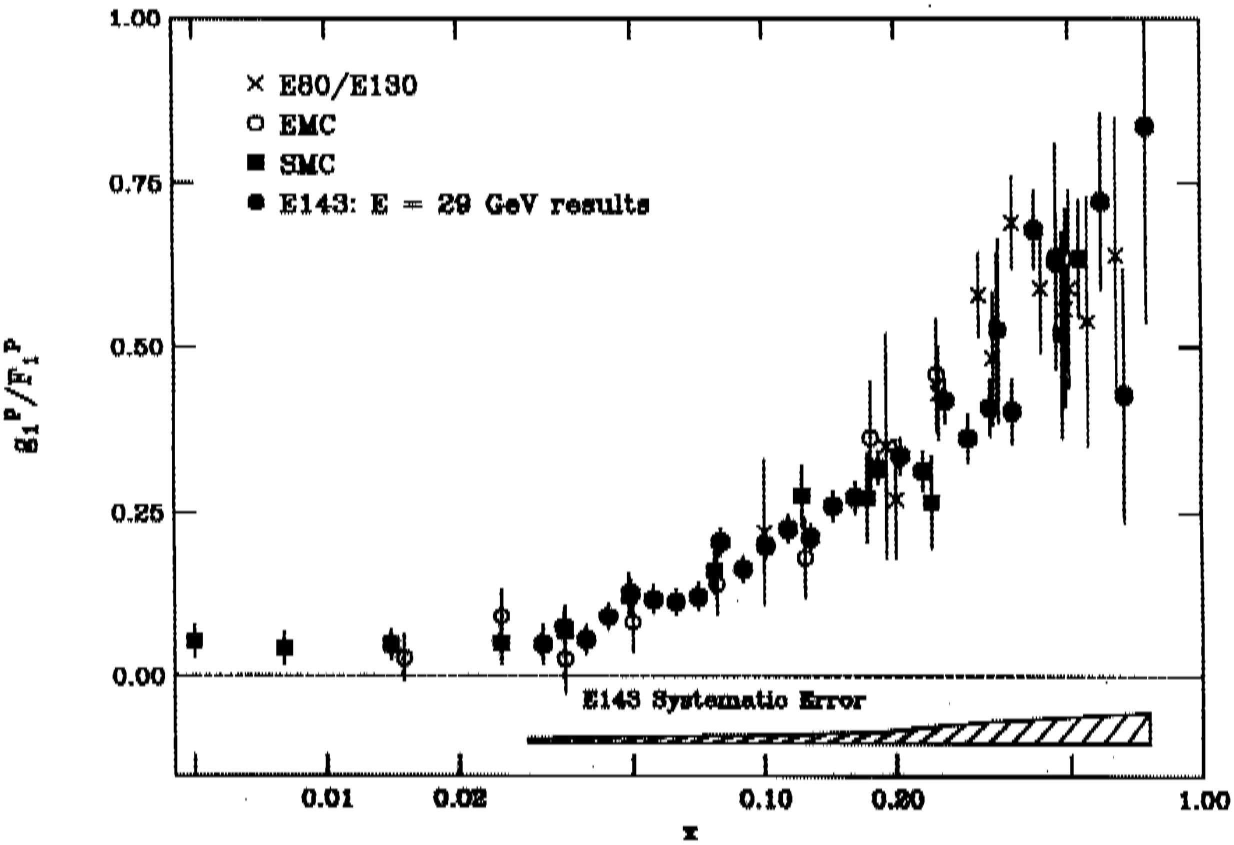
Proton Results



E143 Results at $Q^2 = 3$ (GeV/c)^2 for Integrals over g_1

	Measured	Prediction	Sum Rule
Γ_p	$0.127 \pm 0.004 \pm 0.010$	0.160 ± 0.006	Ellis-Jaffe
Γ_d	$0.042 \pm 0.003 \pm 0.004$	0.069 ± 0.004	Ellis-Jaffe
Γ_n	$-0.037 \pm 0.008 \pm 0.011$	-0.011 ± 0.006	Ellis-Jaffe
$\Gamma_p - \Gamma_n$	$0.163 \pm 0.010 \pm 0.016$	0.171 ± 0.008	Bjorken

For Comparison

$\Gamma_p^{SMC} = 0.126 \pm 0.015$ $\Gamma_d^{SMC} = 0.023 \pm 0.024$

$\Gamma_n^{E142} = -0.022 \pm 0.011$ $\Gamma_p^{E143} - \Gamma_n^{E142} = 0.149 \pm 0.014$

E143 Quark helicity extraction at $Q^2 = 3$ (GeV/c)^2

	Γ_p	Γ_d
Δu	0.81 ± 0.04	0.83 ± 0.02
Δd	-0.44 ± 0.04	-0.43 ± 0.02
Δs	-0.10 ± 0.04	-0.09 ± 0.02
Δq	0.27 ± 0.11	0.30 ± 0.06

Evolving Data to Constant Q^2

- Current Approaches:

(*a*) Assume g_1/F_1 independent of Q^2 and use F_1 evaluated at $Q^2 = 3$ (GeV/c)^2.

(*b*) Assume A_1 *and* A_2 independent of Q^2 and use F_1 evaluated at $Q^2 = 3$ (GeV/c)^2.

- Errors on experimental data cannot are not small enough to distinguish one approach over the other.

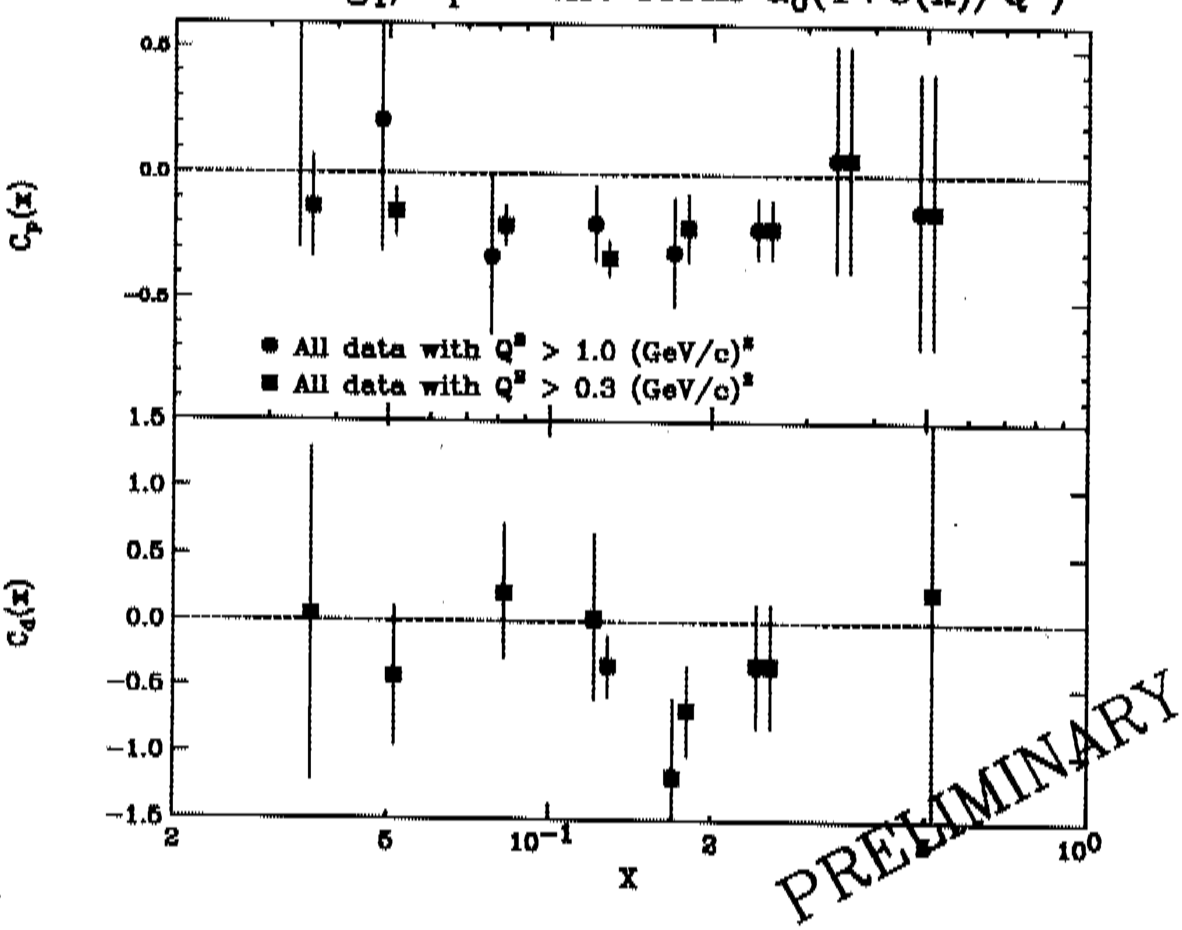
- Choose the first approach

- New approaches being pursued:

(*a*) Altarelli-Parisi evolution.(G. Altarelli, *et al.*, Phys. Lett. B320 152, 1994).

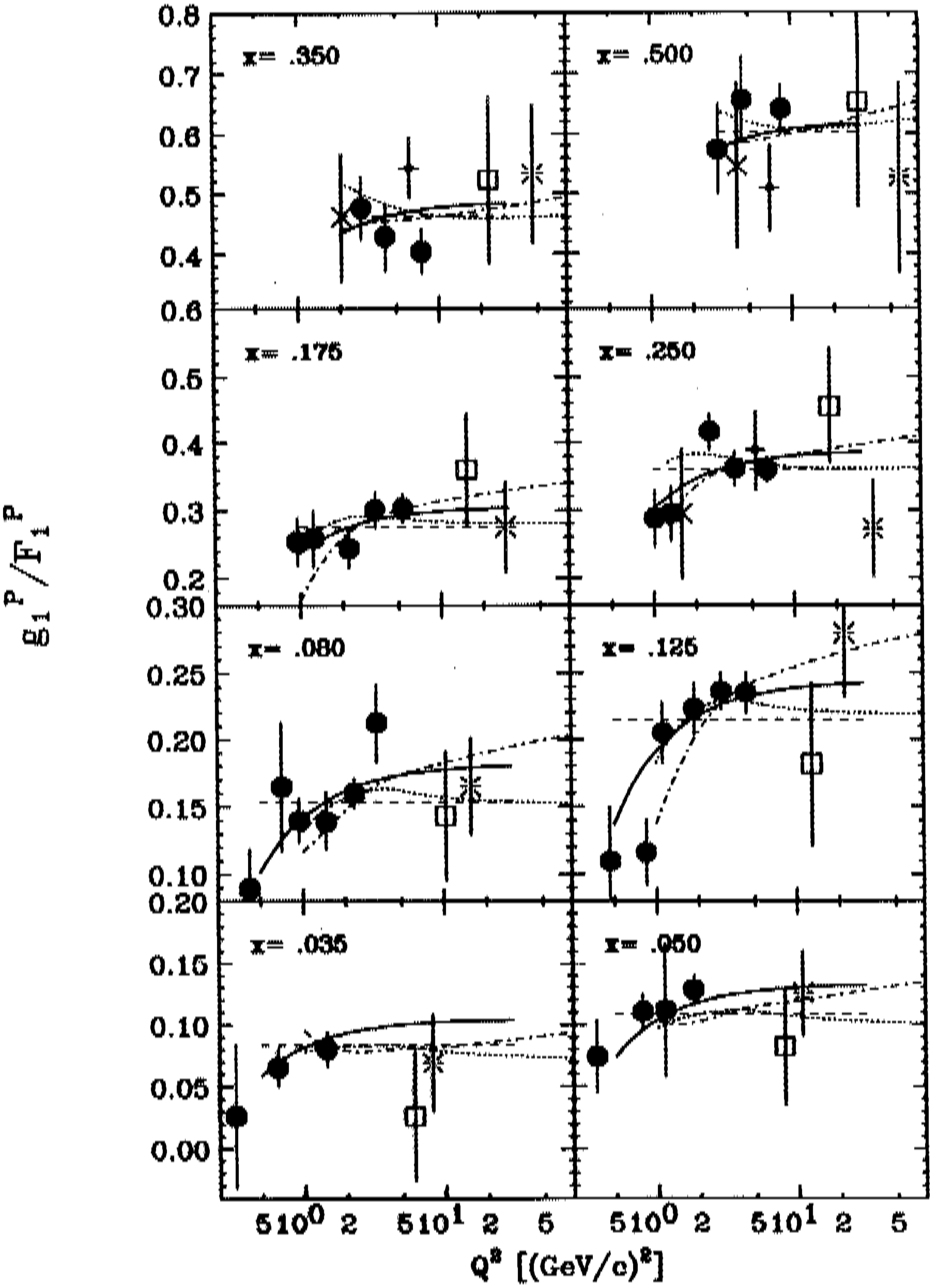
(*b*) A model which uses $A_1(x, Q^2)$ and $g_2(x, Q^2) = g_2^{WW}(x, Q^2) + \overline{g_2}$. All of these have been measured in E143.

Fit to g_1/F_1 of the form $a_0(1+C(x)/Q^2)$



- - - - - - $\frac{g_1}{F_1} = a x^{\alpha} (1 + bx + cx^2 + dx^3)$

——— $\frac{g_1}{F_1} = a x^{\alpha} (1 + bx + cx^2 + dx^3)(1 + c/Q^2)$



.... } BALL, FORTE, RIDOLFI
(CERN-TH-95-31) 1995
(PHYS. LET. B, 378 (1996) 255-266)

LEGEND FOR Q^2 PLOTS

($g_2 = g_2^{WW}$)

- E143
- E80
- E130
- EMC
- SMC

- - - - - - $\frac{g_1}{F_1} = a x^{\alpha} (1 + bx + cx^2 + dx^3)$

——— $\frac{g_1}{F_1} = a x^{\alpha} (1 + bx + cx^2 + dx^3)\left(1 + \frac{c}{Q^2}\right)$

$\chi^2/\mathrm{d.f.} = .85$

. . . . "minimal" polarized gluon strength

$\chi^2/\mathrm{d.f.} = 1.04$

—·—·—·— "maximal" strength

} Fits to all data except 16 + 9 GeV E143

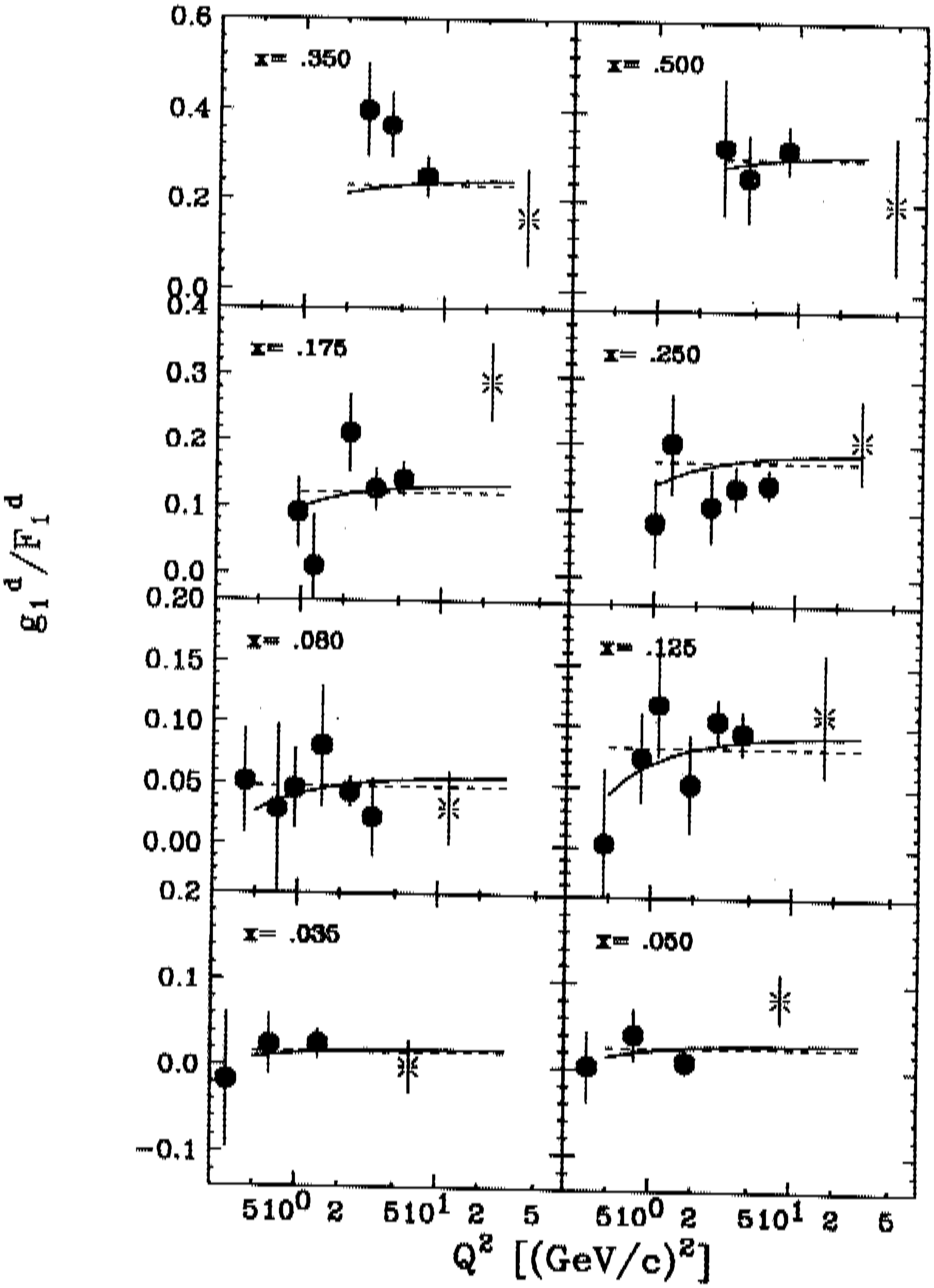
BALL, FORTE, RIDOLFI (CERN-TH-95-31) 1995

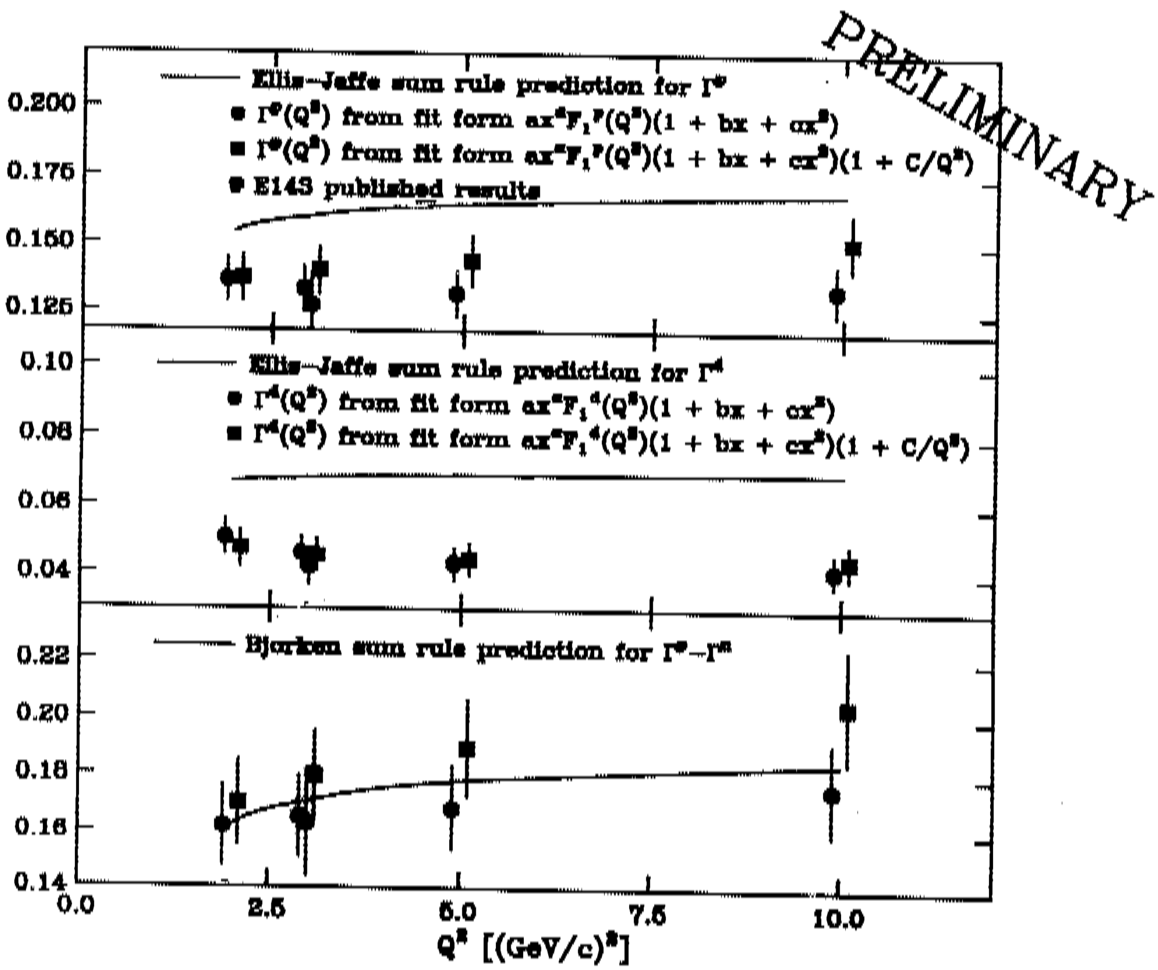
Q^2 Dependence studies: PRELIMINARY

- Fits made to data of the form:

$$g_1/F1 \text{ (or } A_1) = ax^{\alpha}(1+bx+cx^2)(1+Cf(Q^2))$$

case	Low Q^2 cut $(\mathrm{GeV/c})^2$	C	$f(Q^2)$	χ^2	d.f.
I. g_1^p/F_1^p	0.3	0	0	80	56
II. g_1^p/F_1^p	1.0	0	0	43	46
III. g_1^p/F_1^p	0.3	-0.22	$1/Q^2$	46	55
IV. g_1^p/F_1^p	0.3	0.10	$ln(Q^2)$	63	55
V. A_1^d	0.3	-0.24	$1/Q^2$	50	55
I. g_1^d/F_1^d	0.3	0	0	48	41
II. g_1^d/F_1^d	1.0	0	0	45	30
III. g_1^d/F_1^d	0.3	-0.24	$1/Q^2$	46	40
IV. g_1^d/F_1^d	0.3	0.16	$ln(Q^2)$	46	40
V. A_1^d	0.3	-0.26	$1/Q^2$	46	40


x= .350
x= .500
x= .175
x= .250
x= .080
x= .125
x= .035
x= .050
0.6
0.4
0.2
0.0
0.3
0.1
0.20
0.15
0.10
0.05
0.00
−0.1
g_1^d/F_1^d
5 10^0 2 5 10^1 2 5
Q^2 [(GeV/c)^2]


PRELIMINARY
Ellis–Jaffe sum rule prediction for Γ^p
Γ^p(Q²) from fit form ax^a F_1^p(Q²)(1 + bx + cx²)
Γ^p(Q²) from fit form ax^a F_1^p(Q²)(1 + bx + cx²)(1 + C/Q²)
E143 published results
Ellis–Jaffe sum rule prediction for Γ^d
Γ^d(Q²) from fit form ax^a F_1^d(Q²)(1 + bx + cx²)
Γ^d(Q²) from fit form ax^a F_1^d(Q²)(1 + bx + cx²)(1 + C/Q²)
Bjorken sum rule prediction for Γ^p–Γ^n
Q² [(GeV/c)²]

CONCLUSION

- g_1^p/F_1^p shows slight trend to rise with increasing Q^2 if the low Q^2 data is included.

- For $Q^2 > 1$, the assumption that g_1/F_1 is independent of Q^2 is reasonable as far as can be determined with existing data.

- We will learn more about the Q^2 evolution of the structure functions next year with the SLAC 50 GeV data on the proton and deuteron, as well as this year's 50 GeV neutron data.