The Spin Structure of the Nucleon

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DIS97

- polarized DIS formalism
- current status of inclusive data
- NLO analysis
- semi-inclusive DIS
- future

WORKING GROUP IV

In particular see :

Tues.

Meziani	E154 g_1^n, g_2^n
Zyla	NLO analysis of SLAC data
Radyushkin	Deeply virtual Compton scatt.
Guichon	"
Magnon	SMC inclusive
Kabuss	SMC semi-inclusive
Ridolfi	NLO fits to polarized s.f.

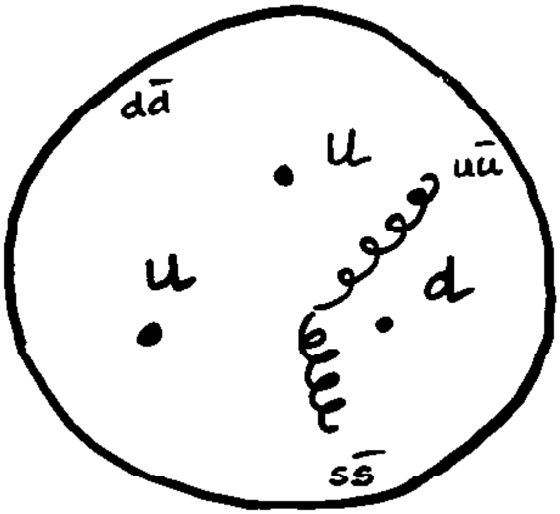
Wed.

Stoesslein	HERMES g_1^n
Schüler	HERMES semi-inclusive

Thurs.

Martin	COMPASS
De Roeck	Polarized HERA

$J = \frac{1}{2}$



- valence quarks } $\frac{1}{2}\Delta\Sigma$
- sea quarks }
- gluons Δg
- quark orbital A.M. L_q
- gluon orbital A.M. L_g

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q + L_g$$

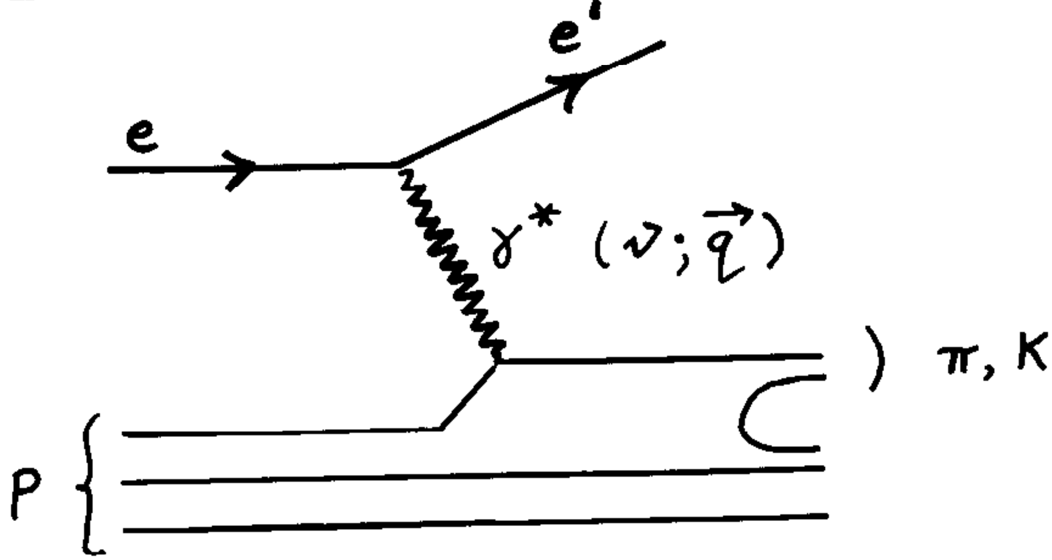
Ji, hep-ph/960324

$$\frac{1}{2}\Delta\Sigma + L_q \xrightarrow{Q^2 \to \infty} \sim \frac{1}{4}$$

$$\Delta g + L_g \longrightarrow \sim \frac{1}{4}$$

spin-dependent DIS is a tool to probe nucleon spin

deep inelastic scattering



- inclusive : detect e' only

- semi-inclusive : detect e' and hadrons

specific final-states $\rho, \phi, K_s, \Lambda, \pi^0, \eta, \ldots$

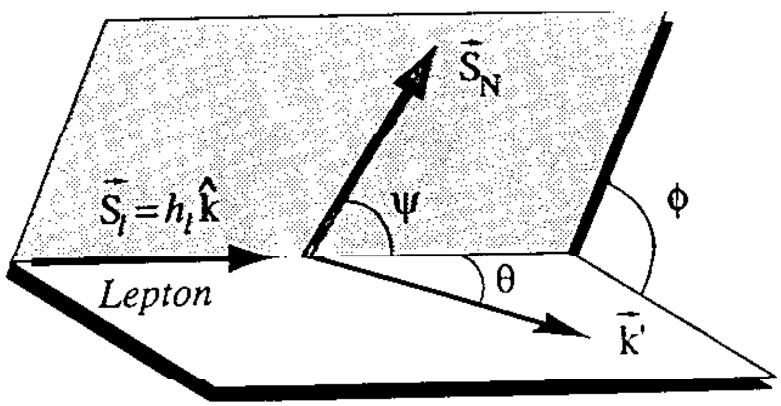
- to probe spin require beam and nucleon to be polarized

inclusive spin-dependent DIS

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{2MQ^4} \cdot \frac{E}{E'} \quad L_{\mu\nu} W^{\mu\nu}$$

$$\nu = E - E' \qquad Q^2 = -(k-k')^2 \qquad y = \nu/E \qquad x = \frac{Q^2}{2M\nu}$$

$$W_{\mu\nu} = -g_{\mu\nu} F_1 + \frac{p_\mu p_\nu}{\nu} F_2$$
$$+ \frac{i}{\nu} \varepsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma \; g_1$$
$$+ \frac{i}{\nu^2} \varepsilon_{\mu\nu\lambda\sigma} q^\lambda [p\cdot q\, s^\sigma - s\cdot q\, p^\sigma] \; g_2$$



$$\sigma = \sigma_u - \tfrac{1}{2} h_e \Delta\sigma$$

$$\frac{d^2\bar{\sigma}}{dx\, dQ^2} = \frac{4\pi\alpha^2}{Q^4 x} \left[x y^2 \left(1 - 2\frac{m_e^2}{Q^2}\right) F_1(x,Q^2) + \left(1 - y - \gamma^2 \, y^2/4\right) F_2(x,Q^2) \right]$$

$$\Delta\sigma = \cos\psi\ \Delta\sigma_{\parallel} + \sin\psi\ \cos\phi\ \Delta\sigma_{\perp}$$

$$\frac{d^2\Delta\sigma_{\parallel}}{dx\,dQ^2} = \frac{16\pi\alpha^2 y}{Q^4}\left[\left(1-\frac{y}{2}-\gamma^2\frac{y^2}{4}\right)g_1 - \gamma^2\frac{y}{2}\,g_2\right]$$

$$\frac{d^3\Delta\sigma_T}{dx\,dQ^2\,d\phi} = -\cos\phi\ \frac{8\alpha^2 y}{Q^4}\gamma\sqrt{1-y-\frac{\gamma^2 y^2}{4}}\left[\frac{y}{2}g_1 + g_2\right.$$

cross-section asymmetries

$$A_{\parallel} = \frac{\Delta\sigma_{\parallel}}{2\bar{\sigma}} \qquad\qquad A_{\perp} = \frac{\Delta\sigma_{\perp}}{2\bar{\sigma}}$$

$$= D\,(A_1 + \eta A_2) \qquad\qquad = d\,(A_2 - \xi A_1)$$

D – virtual photon depoln. factor

d, η, ξ kinematic factors

$$A_1 \approx \frac{A_{\parallel}}{D} \qquad\qquad \frac{g_1}{F_1} \approx \frac{1}{1+\gamma^2}\,\frac{A_{\parallel}}{D}$$

$$F_1 = \frac{1+\gamma^2}{2x(1+R)}\,F_2$$

spin-dependent structure function g_1

Quark parton model:

$$g_1(x) = \frac{1}{2} \sum_{i=1}^{n_f} e_i^2 \, \Delta q_i(x)$$

where

$$\Delta q_i(x) = q_i^+(x) + \bar{q}_i^+(x) - q_i^-(x) - \bar{q}_i^-(x)$$

QCD:

gluon exchange $\Rightarrow$ Q^2 dependence of g_1

$$g_1(x, Q^2) = \frac{1}{2} \sum_{k=1}^{n_f} \frac{e_k^2}{n_f} \int_x^1 \frac{dy}{y}$$

$$\Big[C_q^S\left(\frac{x}{y}, \alpha_s(Q^2)\right) \Delta\Sigma(y, Q^2)$$

$$+ 2 n_f \, C_g\left(\frac{x}{y}, \alpha_s(Q^2)\right) \Delta g(y, Q^2)$$

$$+ C_q^{NS}\left(\frac{x}{y}, \alpha_s(Q^2)\right) \Delta q^{NS}(y, Q^2) \Big]$$

C - coefficient functions

$\Delta g\,(x,Q^2)$ – polarized gluon distribution

$\Delta\Sigma\,(x,Q^2)$ – singlet polarized quark distributic

$\Delta q^{NS}(x,Q^2)$ – non-singlet " " "

$$\Delta\Sigma\,(x,Q^2) = \sum_{i=1}^{n_f} \Delta q_i\,(x,Q^2)$$

$$\Delta q^{NS}(x,Q^2) = \frac{\sum_{i=1}^{n_f}\left(e_i^2 - \frac{1}{n_f}\sum_{k=1}^{n_f} e_k^2\right)\Delta q_i(x,Q^2}{\frac{1}{n_f}\sum_{k=1}^{n_f} e_k^2}$$

Q^2 dependence : GLAP eqns.

$$\frac{d}{dQ^2}\Delta\Sigma(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{qq}^S\left(\frac{x}{y},\alpha_s(Q^2)\right)\Delta\Sigma(y,Q\right.$$

$$+ 2n_f\, P_{qg}\left(\frac{x}{y},\alpha_s(Q^2)\right)\Delta g(y,Q^2$$

$$\frac{d}{dQ^2}\Delta g(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{gq}\left(\frac{x}{y},\alpha_s(Q^2)\right)\Delta\Sigma(y,Q\right.$$

$$\left. + P_{gg}\left(\frac{x}{y},\alpha_s(Q^2)\right)\Delta g(y,Q^2)\right]$$

$$\frac{d}{d\ln Q^2}\Delta q^{NS}(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\, P_{qq}^{NS}\left(\frac{x}{y},\alpha_s(Q^2)\right)\Delta q^{NS}(y,Q^2)$$

P_{ij} – splitting functions

co-efficient + splitting functions

- C_{ij}, P_{ij} depend on mass factorization and renormalization scales
- setting both scales to Q^2 in leading order

$$C_q^{0,S} = C_q^{0,NS} = \delta\left(1-\frac{x}{y}\right)$$

$$C_g^0 = 0$$

=> g_1 decouples from Δg

- beyond leading order C_{ij}, P_{ij} depend on renormalization scheme

C_{ij} up to $O(\alpha_s^2)$ $\overline{MS}$ scheme Zijlstra, van Neerve

P_{qq}, P_{qg} " " $O(\alpha_s^2)$ "

P_{gq}, P_{gg} Mertig, van Neerve. Vogelsang

allows Next-to-Leading Order (NLO) QCD analysis of the scaling violations of spin-dependen structure functions

sum Rule predictions

- use operator product expansion
- restrict to u, d, s quarks

At leading twist only gauge invariant contributions are due to the non-singlet and singlet axial currents

$$A_\mu^k = \bar{\psi} \; \frac{\lambda_k}{2} \gamma_5 \gamma_\mu \psi \qquad k = 1, \cdots, 8$$

first moment of g_1:

$$\Gamma_1^{p(n)}(Q^2) = \frac{C_1^S(Q^2)}{9} a_0 + \frac{C_1^{NS}(Q^2)}{12} \left[+(-) \, a_3 + \frac{1}{2} a_8 \right]$$

$$S_\mu \, a_i(Q^2) = \langle ps | \bar{q}_i \gamma_5 \gamma_\mu q_i | ps \rangle$$

assuming isospin symmetry:

$$a_3 = a_u - a_d = \frac{1}{2} \left| g_A / g_V \right|$$

$$a_8 = a_u + a_d - 2 a_s$$

$$a_0 = (a_u + a_d + a_s)$$

Bjorken sum Rule

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{6} \left| \frac{g_A}{g_V} \right| C_1^{NS}$$

$$C_1^{NS} = 1 - c_1^{NS} \left[\frac{\alpha_s(Q^2)}{\pi}\right] - c_2^{NS} \left[\frac{\alpha_s(Q^2)}{\pi}\right]^2 - c_3^{NS} \left[\frac{\alpha_s(Q^2)}{\pi}\right.$$

$$- O(c_4^{NS}) \left[\frac{\alpha_s(Q^2)}{\pi}\right]^4$$

$\overline{MS}$ scheme

c_1, c_2, c_3 computed Larin et al.

$O(\alpha_s^4)$ esimated Kataev + Starshenko

Ellis- Jaffe sum Rule

$$\Gamma_1^{p(n)} = C_1^{NS} \left[+(-) \frac{1}{12} \left| \frac{g_A}{g_V} \right| + \frac{1}{36} (3F - D) \right]$$

$$+ \frac{1}{9} C_1^S (3F - D)$$

by assuming $a_s = 0$ (in QPM $\Delta S = 0$)

$SU(3)_f$ symmetry F, D from hyperon decay

$$C_1^S = 1 - c_1^S \left[\frac{\alpha_s(Q^2)}{\pi}\right] - c_2^S \left[\frac{\alpha_s(Q^2)}{\pi}\right]^2 -$$

$$O(c_3^S) \left[\frac{\alpha_s(Q^2)}{\pi}\right]^3$$

c_1^S, c_2^S computed Larin

$O(\alpha_s^3)$ estimated Kataev

physical interpretation of $a_0(Q^2)$

Quark parton model:

$$a_0 = a_u + a_d + a_s = \Delta\Sigma$$

the contribution of the quarks to the nucleon spin

QCD:

U(1) anomaly causes a gluon contribution to $a_0(Q^2)$

=> $\Delta\Sigma$ dependent on the factorization scheme

a_0 not " " " "

note $\Delta\Sigma + L_q$ not " " " " "

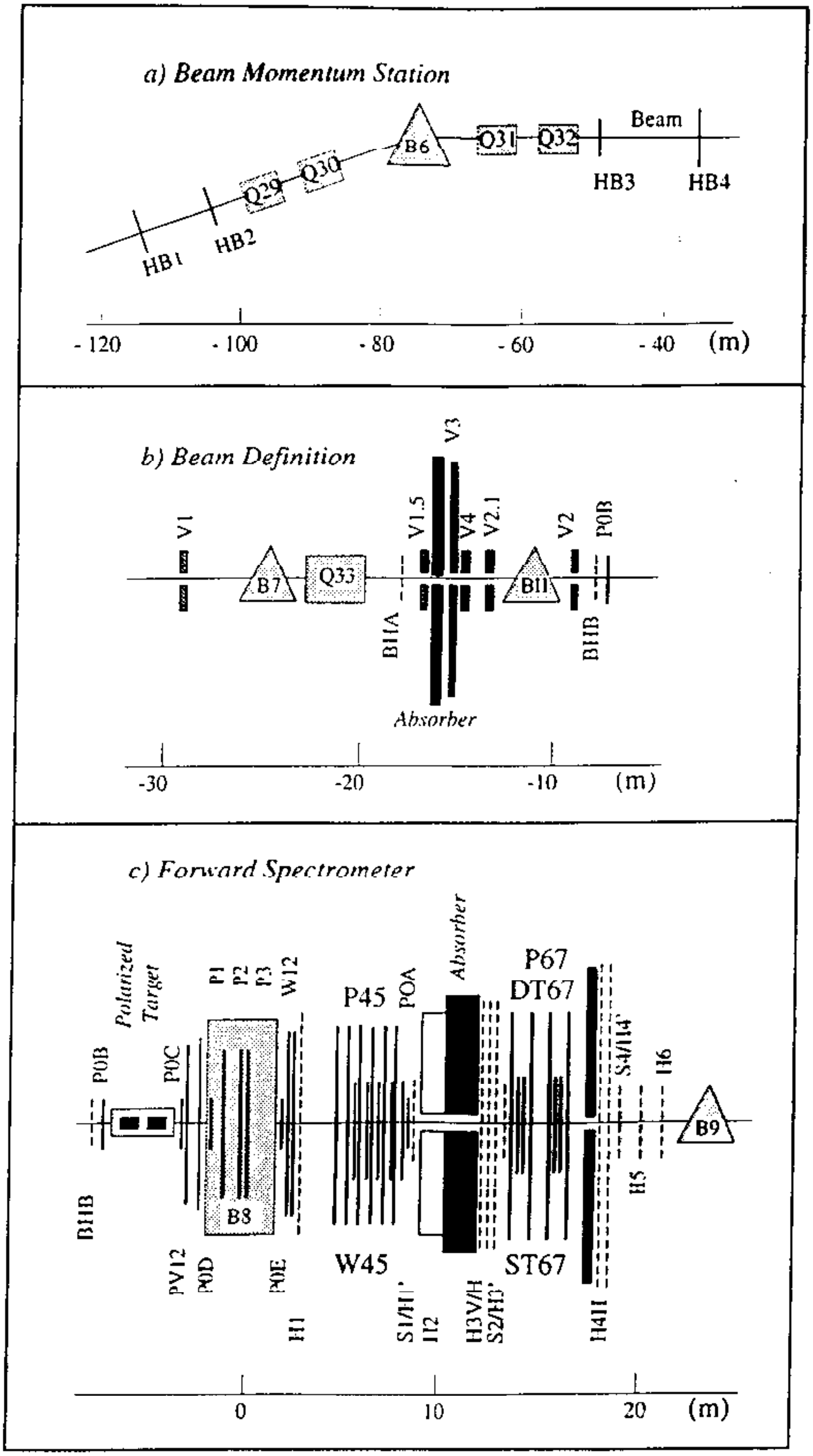
Adler-Bardeen factorization scheme

$$\boxed{a_0(Q^2) = \Delta\Sigma - n_f \frac{\alpha_s(Q^2)}{2\pi} \Delta g(Q^2)}$$

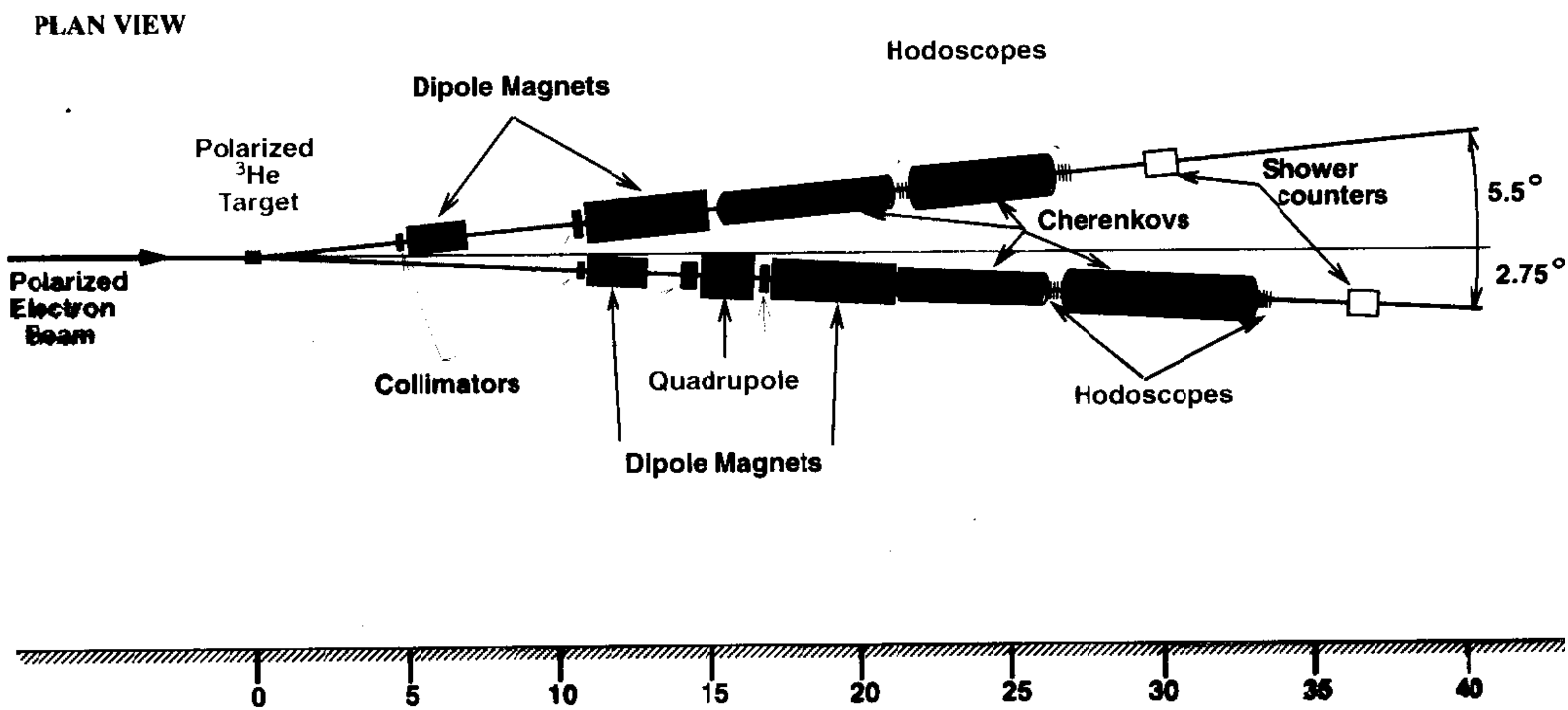
$\Delta\Sigma$ independent of Q^2

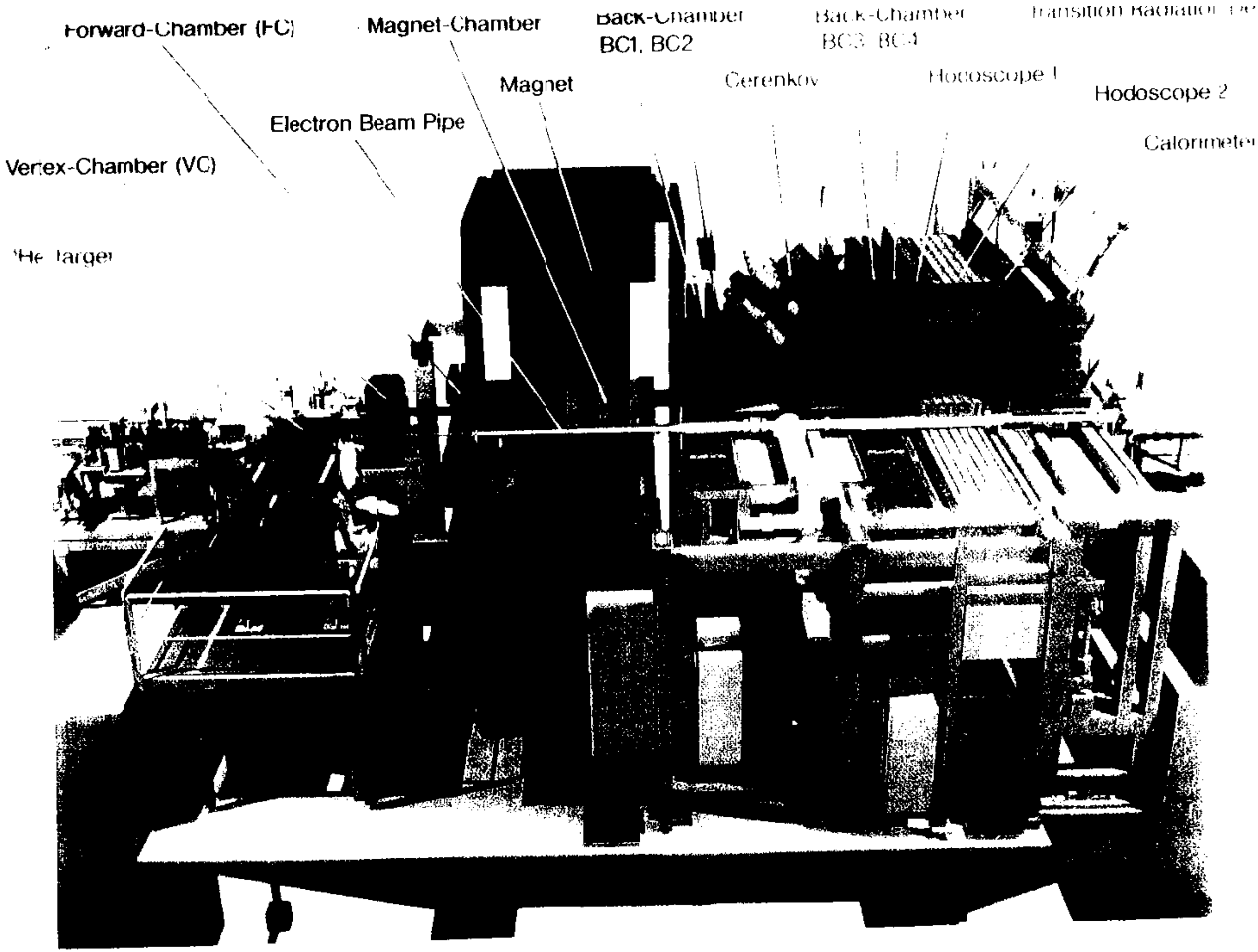
SUMMARY OF Experiments

Lab	Exp.	Year	Beam	Target
LAC	E80	~75	23 GeV e^-	H-butanol
	E130	~80	23 GeV e^-	H-butanol
	E142	92	25 GeV e^-	^3He
	E143	93	29 GeV e^-	NH_3, ND_3
	E154	95	49 GeV e^-	^3He
	E155	97	49 GeV e^-	NH_3, LiD
ERN	EMC	~85	100-200 GeV μ^-	NH_3
	SMC	92	100 GeV μ^-	D-butanol
	"	93	190 GeV μ^-	H-butanol
	"	94	190 GeV μ^-	D-butanol
	"	95	190 GeV μ^-	D-butanol
	"	96	190 GeV μ^-	NH_3
ESY	HERMES	95	28 GeV e^+	^3He
		96	28 GeV e^+	H
		97	28 GeV e^+	H


a) Beam Momentum Station
Beam
HB1
HB2
Q29
Q30
B6
Q31
Q32
HB3
HB4
- 120
- 100
- 80
- 60
- 40
(m)
b) Beam Definition
V1
B7
Q33
B11A
V1.5
V3
V4
V2.1
Absorber
B11
V2
P0B
B11B
-30
-20
-10
(m)
c) Forward Spectrometer
Polarized Target
P0B
B11B
P0C
PV12
P0D
B8
P1
P2
P3
W12
P0E
H1
P45
W45
POA
S1/H1'
H2
Absorber
H3V/H
S2/H3'
P67
DT67
ST67
S4/H4'
H4H
H5
H6
B9
0
10
20
(m)

E154 Setup


PLAN VIEW
Hodoscopes
Dipole Magnets
Polarized
^{3}He
Target
Shower
counters
5.5°
Cherenkovs
2.75°
Polarized
Electron
Beam
Collimators
Quadrupole
Hodoscopes
Dipole Magnets
0
5
10
15
20
25
30
35
40


Forward-Chamber (FC)
Magnet-Chamber
Back-Chamber BC1, BC2
Back-Chamber BC3, BC4
Transition Radiation Det
Magnet
Cerenkov
Hodoscope 1
Hodoscope 2
Electron Beam Pipe
Calorimeter
Vertex-Chamber (VC)
He Target

Extraction of g_1

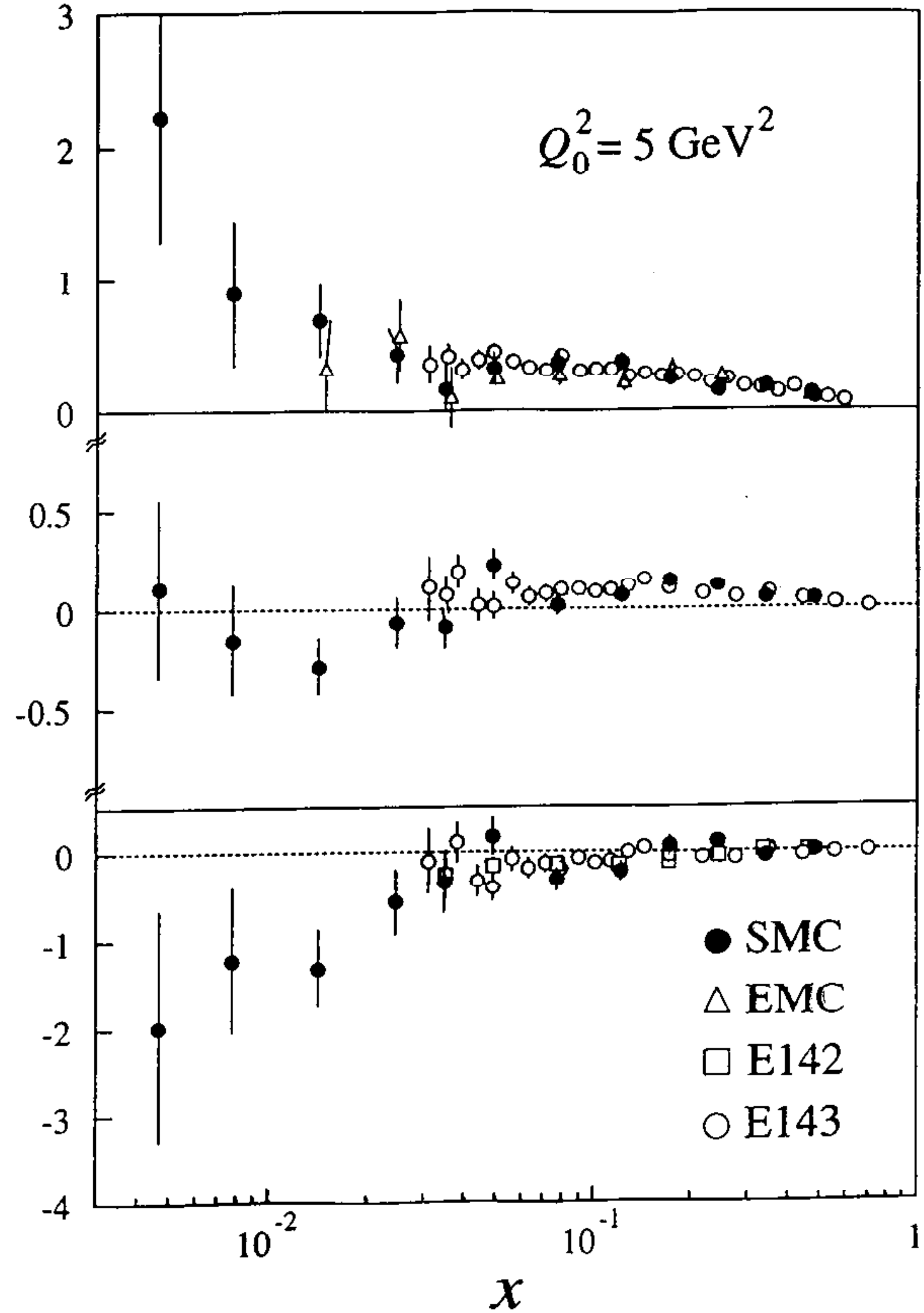
- data quality cuts P_B, P_T, spectrometer
- kinematic cuts
- particle identification
- extraction of $A_{\parallel}$
- extraction of A_1 dilution corrections
  radiative "
  nuclear "
- extraction of g_1 input R, F_2^d, F_2^p
- evolve to a fixed Q_0^2

  assume $A_1 \approx g_1/F_1$ independent of Q^2

  NLO pQCD evolution

SMC D. Adams et al. hep-ex/9702005 - 1

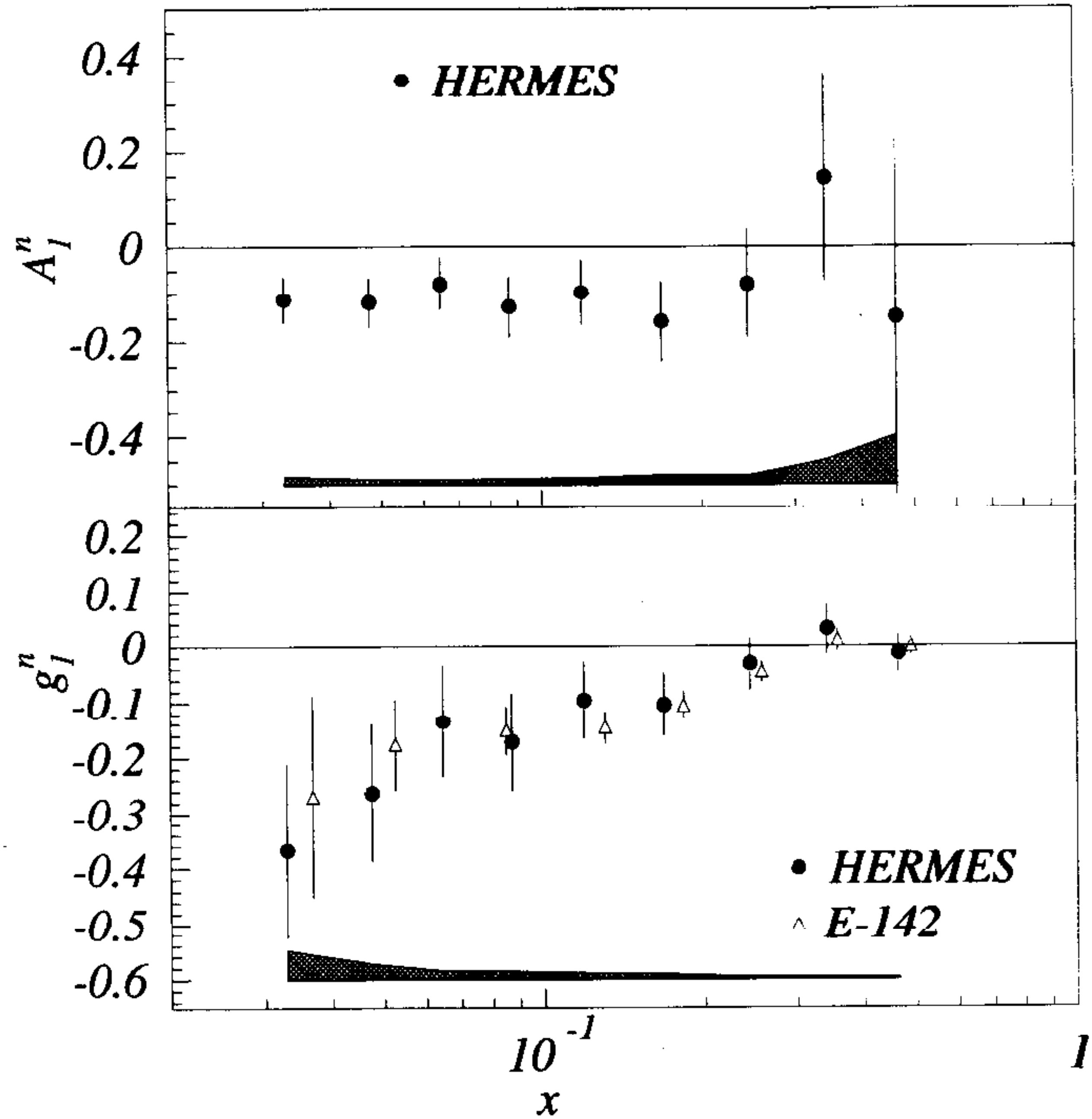
reanalysis of 93 proton data



Measurements of g_1^p, g_1^d and g_1^n evolved to $Q_0^2 = 5\ \mathrm{GeV}^2$. The SMC and E143 g_1^n data are obtained from g_1^p and g_1^d.

First HERMES Results

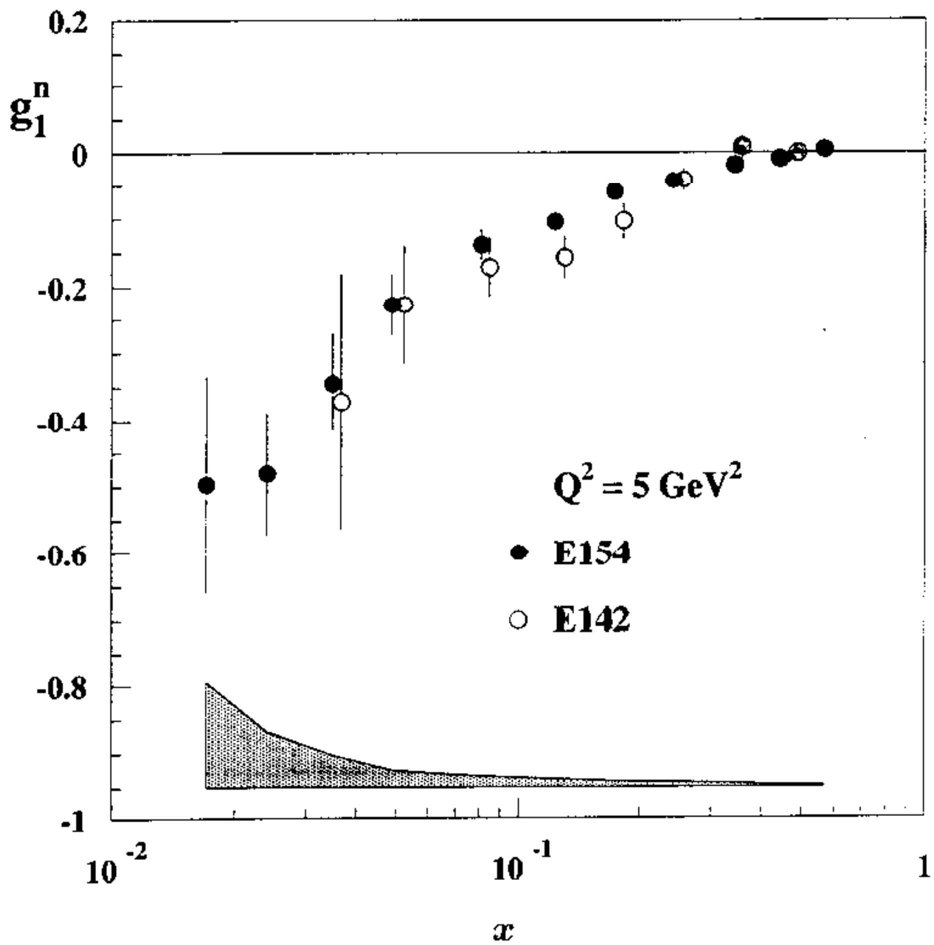
Spin Asymmetry $A_1^n(x)$ and Spin Structure Function $g_1^n(x)$ of the Neutron:



Ellis-Jaffe Sum (HERMES at $Q^2 = 2.5$ (GeV/c)^2):

$$\int_0^1 g_1^n(x)\,dx = -0.037 \pm 0.013_{stat.} \pm 0.005_{syst.} \pm 0.006_{extrapol.}$$

E154 final results (April 97)



E154 preliminary (July 96):

$$\int_{0.014}^{0.7} g_1^n(x)\,dx = -0.037 \pm 0.004 \pm 0.010$$

QCD analysis of polarized structure fns. in NLO

- Ellis + Karliner Phys. Lett. B341, 397 (1995)
- Ball, Forte, Ridolfi Phys. Lett. B378, 255 (1996)
- Glück, Reya, Stratmann, Vogelsang Phys. Rev. D53, 4775 (1996)
- Gehrmann + Sterling Phys. Rev. D53, 6100 (1996)
- Altarelli, Ball, Forte, Ridolfi hep-ph/9701289

  EMC, SMC, E142, E143, E154 prelim.

- SMC hep-ph/9702005

  EMC, SMC, E142, E143

  SMC p reanalysis

Focus on two most recent analyses

polarized parton densities from g_1 data

- parametrize initial parton distributions at $Q_0^2 = 1\ (\mathrm{GeV}/c)^2$

$$\Delta f(x, Q_0^2) = N_f\, \eta_f\, x^{\alpha_f} (1-x)^{\beta_f} (1 + \gamma_f x^{\delta_f})$$

$$\Delta f \sim \Delta q_{NS}\,,\ \Delta\Sigma\,,\ \Delta g$$

N_f chosen so that $\int_0^1 \Delta f(x)\, dx = \eta_f$

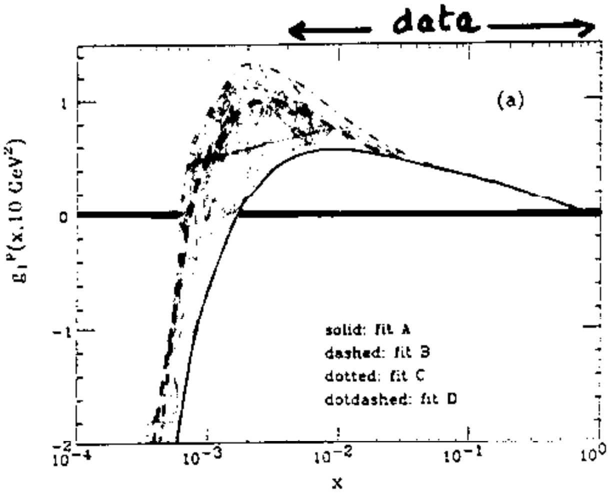
- evolve Δf up to values of x and Q^2 where data are taken

- determine free parameters by a best fit to all the data on $g_1(x, Q^2)$

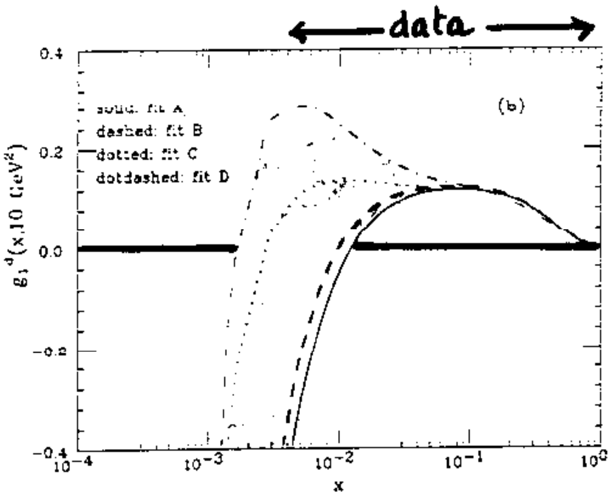
- assume

$$\alpha_s(M_Z) = 0.118 \pm 0.005$$

$SU(3)_f$ symmetry $\quad a_8 = 0.579 \pm 0.025$



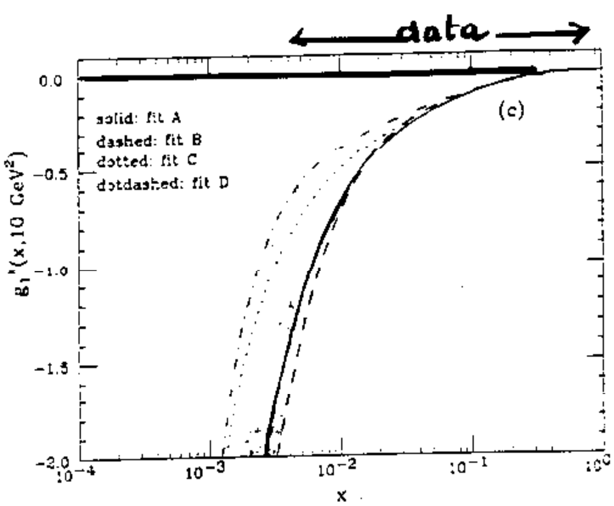
proton



deuteron

N.B.

$Q^2 = 10\ (GeV/c)^2$

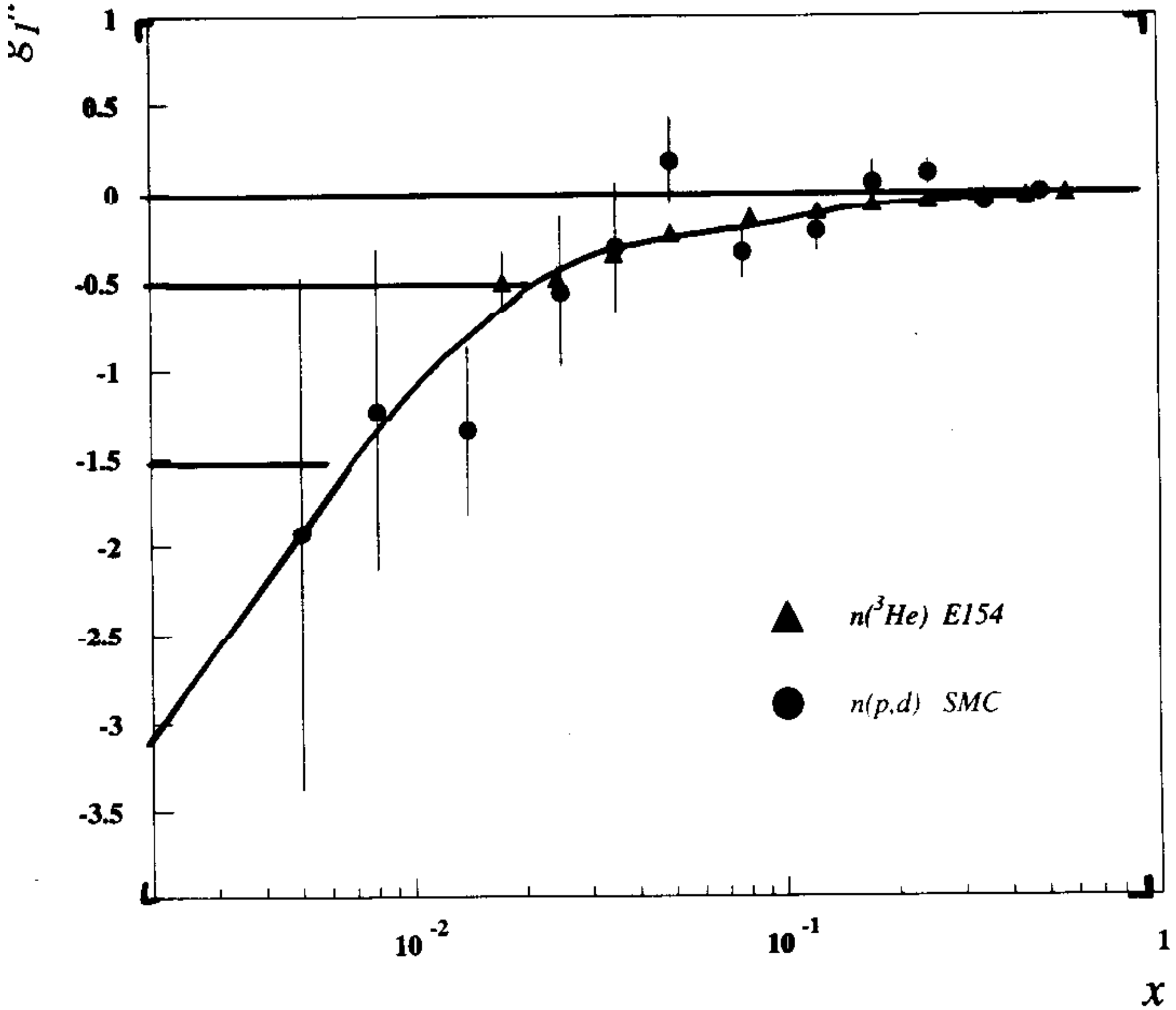


neutron

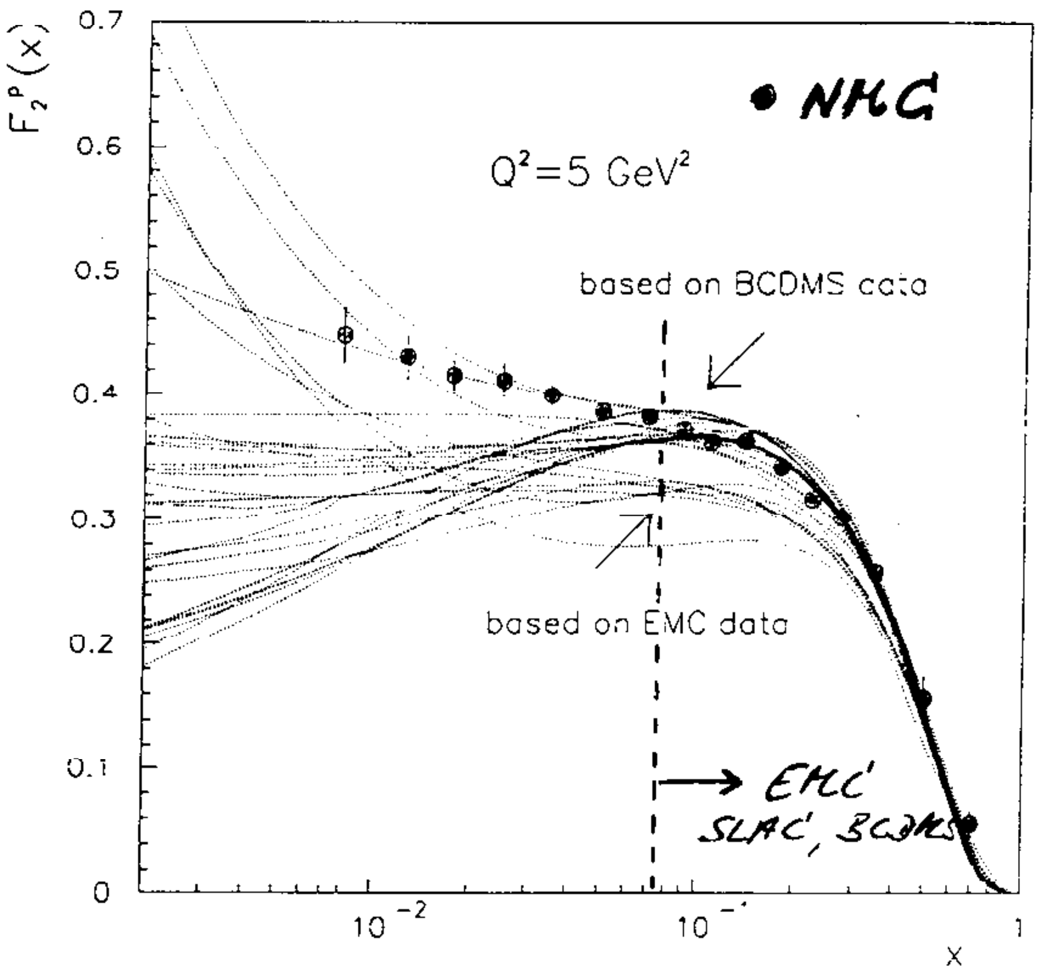
Parameters	A	B	C	D
d.o.f.	$114-11$	$114-11$	$114-8$	$114-8$
Q_0^2/GeV^2	1	1	0.3	0.3
η_Σ	0.408 ± 0.041	0.410 ± 0.039	0.422 ± 0.026	0.492 ± 0.036
α_Σ	0.741 ± 0.353	1.710 ± 0.416	2.600 ± 0.964	0.5 (fixed)
β_Σ	3.105 ± 1.049	2.735 ± 0.466	3.359 ± 1.210	1.039 ± 0.241
γ_Σ	0.185 ± 2.496	0 (fixed)	0 (fixed)	0 (fixed)
η_g	1.068 ± 0.403	1.032 ± 0.330	0.479 ± 0.095	0.650 ± 0.104
α_g	-0.597 ± 0.286	2.970 ± 0.611	0.217 ± 0.319	0.5 (fixed)
β_g	0.831 ± 2.322	1.286 ± 0.895	15 (fixed)	13.19 ± 9.57
γ_g	0.185 ± 2.496	21.2 ± 22.5	0 (fixed)	-0.548 ± 9.139
g_A	1.168 ± 0.052	1.234 ± 0.066	1.146 ± 0.038	1.141 ± 0.036
a_8	0.579 (fixed)	0.579 (fixed)	0.579 (fixed)	0.579 (fixed)
α_{NS}	-0.537 ± 0.057	1.656 ± 0.166	0.765 ± 0.228	0.5 (fixed)
β_{NS}	2.503 ± 0.274	5.320 ± 0.251	2.087 ± 0.448	2.622 ± 0.410
γ_{NS}	17.46 ± 8.43	-0.229 ± 0.105	0 (fixed)	5.024 ± 4.647
χ^2	83.7	83.0	83.8	90.9
χ^2/d.o.f.	0.813	0.806	0.790	0.858
$\Delta g(1,1\mathrm{GeV}^2)$	1.07 ± 0.40	1.03 ± 0.33	1.61 ± 0.32	2.08 ± 0.34
$a_0(10\mathrm{GeV}^2)$	0.15 ± 0.07	0.16 ± 0.05	0.05 ± 0.04	0.02 ± 0.04

	g_A	$\Delta\Sigma$	Δg	a_0	α_s
[redacted]	± 0.05	± 0.04	± 0.4	± 0.05	$^{+0.004}_{-0.005}$
fitting	± 0.05	± 0.05	± 0.5	± 0.07	± 0.001
α_s & a_8	± 0.03	± 0.01	± 0.2	± 0.02	± 0.000
thresholds	± 0.02	± 0.05	± 0.1	± 0.01	± 0.003
higher orders	± 0.03	± 0.04	± 0.6	$^{+0.15}_{-0.07}$	$^{+0.007}_{-0.004}$
higher twists	± 0.03	-	-	-	± 0.004
[redacted]	± 0.07	± 0.08	± 0.8	$^{+0.17}_{-0.010}$	$^{+0.009}_{-0.006}$

which low x extrapolation to use?



unpolarized low-x



measurements have been essential at low x

Conclusions :-

Altarelli et al. hep-ph/9701289

- Bjorken Sum Rule

$$g_A = 1.18 \pm 0.05\ (\text{exp.}) \pm 0.07\ (\text{th.})$$
$$= 1.18 \pm 0.09$$

cf. 1.257 ± 0.003 from β-decay

- Singlet First Moments

$$a_0(\infty) = 0.10 \pm 0.05\ (\text{exp.})\ {}^{+0.17}_{-0.10}\ (\text{th.})$$
$$= 0.10\ {}^{+0.17}_{-0.10}$$

$$\Delta\Sigma = 0.45 \pm 0.04\ (\text{exp.}) \pm 0.08\ (\text{th.})$$
$$= 0.45 \pm 0.09$$

$$\Delta g(Q^2=1) = 1.6 \pm 0.4\ (\text{exp.}) \pm 0.8\ (\text{th.})$$
$$= 1.6 \pm 0.9$$

SMC analysis

hep-ex / 9702005

$Q_0^2 = 5 \ (\mathrm{GeV}/c)^2$

$a_0 = 0.37 \pm 0.11$ all proton data

$a_u = 0.85 \pm 0.04$

$a_d = -0.41 \pm 0.04$

$a_s = -0.07 \pm 0.04$

Bjorken sum Rule

$\Gamma_1^p - \Gamma_1^n = 0.202 \pm 0.022$ $(Q_0^2 = 5)$

all data (p, d, n)

prediction 0.181 ± 0.003

$\Gamma_1^p = 0.142 \pm 0.011$ $(Q_0^2 = 5)$

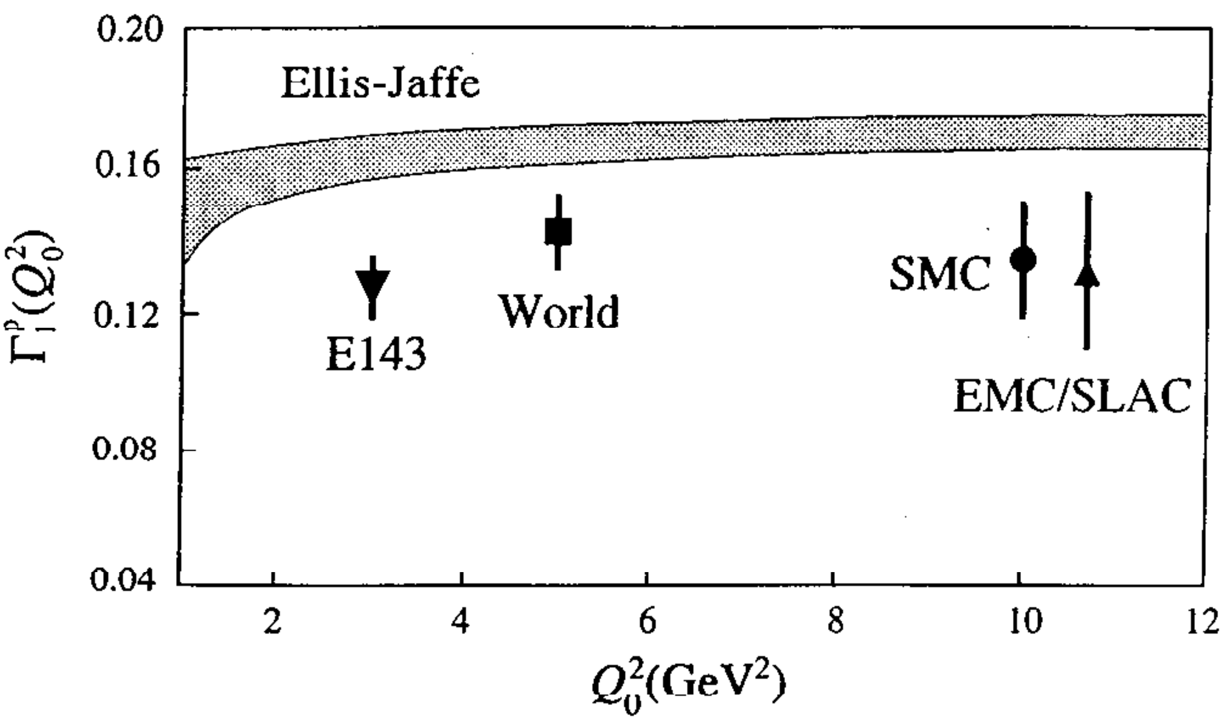
all data

prediction 0.167 ± 0.05

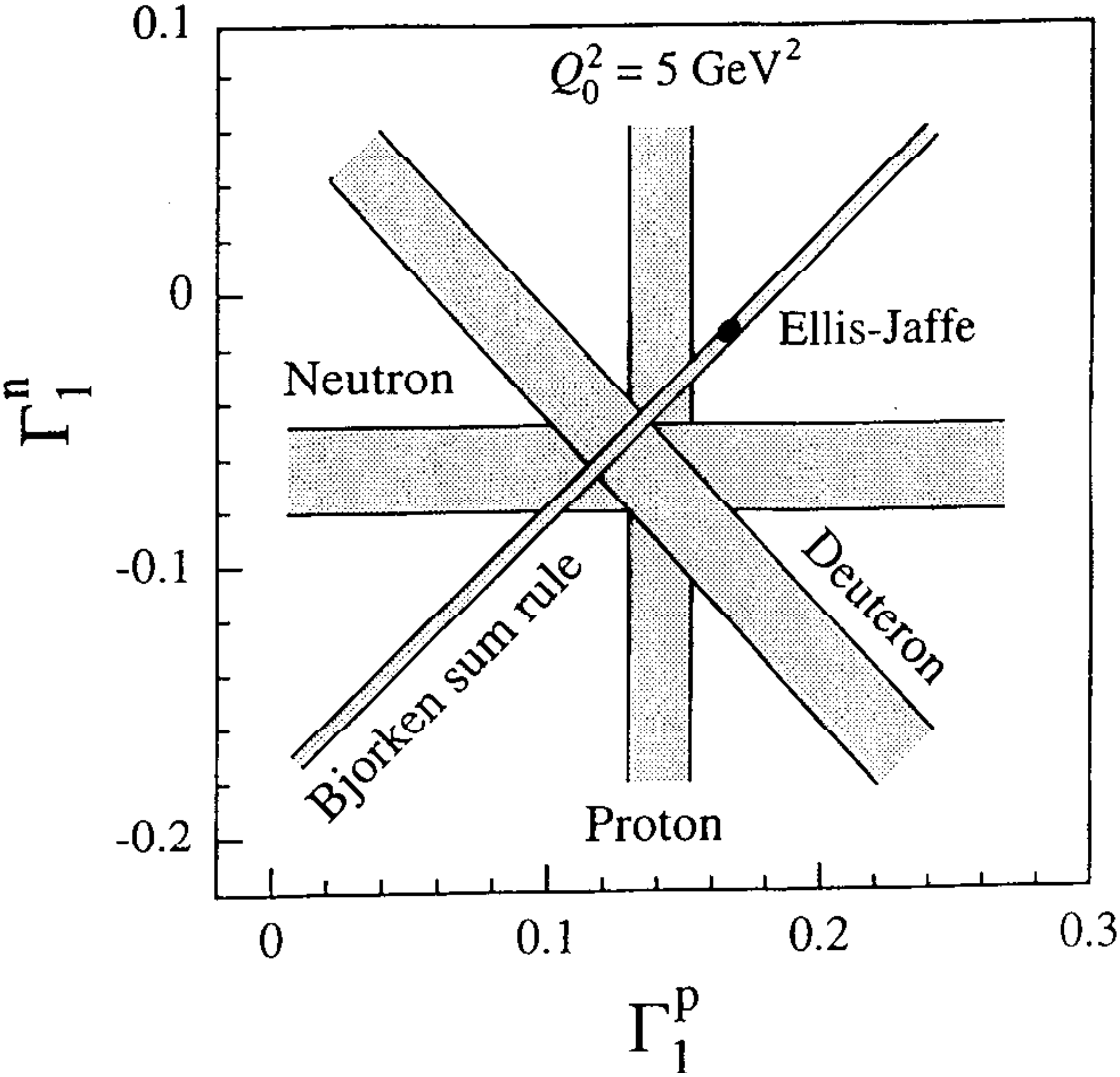
$\Gamma_1^n = -0.061 \pm 0.016$ $(Q_0^2 = 5)$

all data (p, d, n)

prediction -0.015 ± 0.004



Comparison of the experimental results for Γ_1^p to the prediction of the Ellis–Jaffe sum rule.



Comparison of the combined experimental results for Γ_1^p, Γ_1^n and Γ_1^d with the predictions for the Bjorken and the Ellis–Jaffe sum rules. The Ellis–Jaffe prediction is shown by the black ellipse inside the Bjorken sum rule band.

summary of long. poln. inclusive data

- NLO analysis provides another successful test of QCD

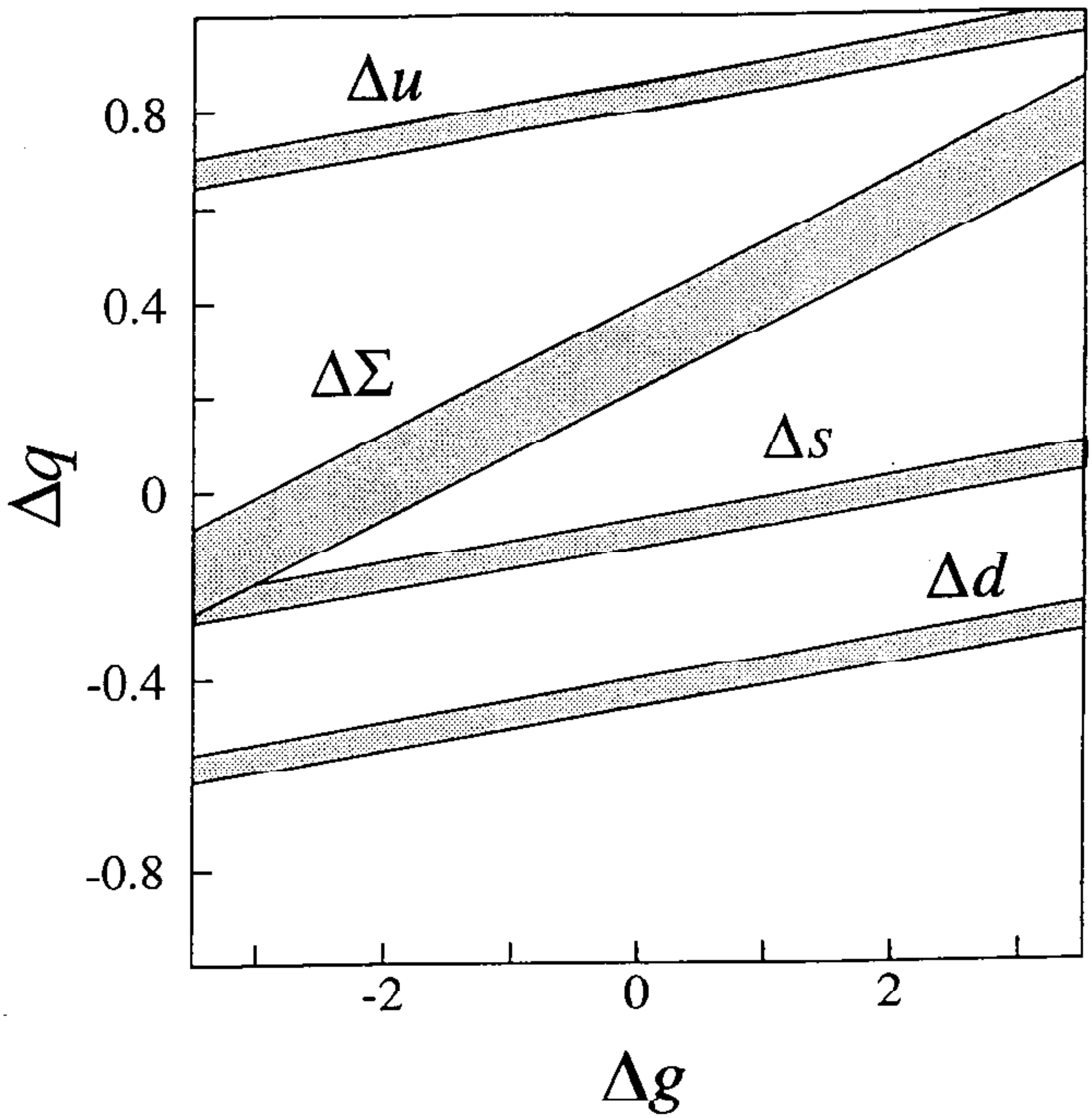
$$\alpha_s(M_Z) = 0.120 \begin{array}{l} +0.010 \\ -0.008 \end{array}$$

- Bjorken sum rule confirmed within 1σ
  $\pm 8\%$

- singlet axial charge of nucleon small
  EMC result

- evidence for $(\sim 2\sigma)$ +ive gluon poln.

- amount of gluon poln. allows $\Delta\Sigma$ to be consistent $(\sim 1\sigma)$ with the constituent spin fraction from QPM



Quark spin contributions to the proton spin as a function of the gluon contribution at $Q^2 = 5$ GeV^2 in the Adler–Bardeen scheme.

semi-inclusive spin-dependent DIS

Quark parton model:

fragmentation function $D_i^h(z, Q^2)$ = probability for a quark of flavor i to fragment into hadron h

$$z = \frac{E_h}{\nu}$$

Assuming factorization + scaling of D_i^h

$$\frac{1}{\sigma_{TOT}} \cdot \frac{d\sigma_N^h(x,z)}{dz} = \frac{\sum_{k=1}^{n_f} e_k^2\, q_k(x) D_k^h(z)}{\sum_{k=1}^{n_f} e_k^2\, q_k(x)}$$

Spin asymmetry:

$$A_N^h(x) = \frac{\sum_{k=1}^{n_f} e_k^2\, \delta q_k(x)\, D_k^h(z)}{\sum_{k=1}^{n_f} e_k^2\, q_k(x) D_k^h(z)}$$

HERMES

$E_0 = 27.5$ GeV

look at π, K

$\rho, \phi, K_s, \Lambda, \pi^0, \eta, J/\psi, \ldots$

B. Adeva et al., Phys. Lett. B 369, 93 (96) - 1

SMC

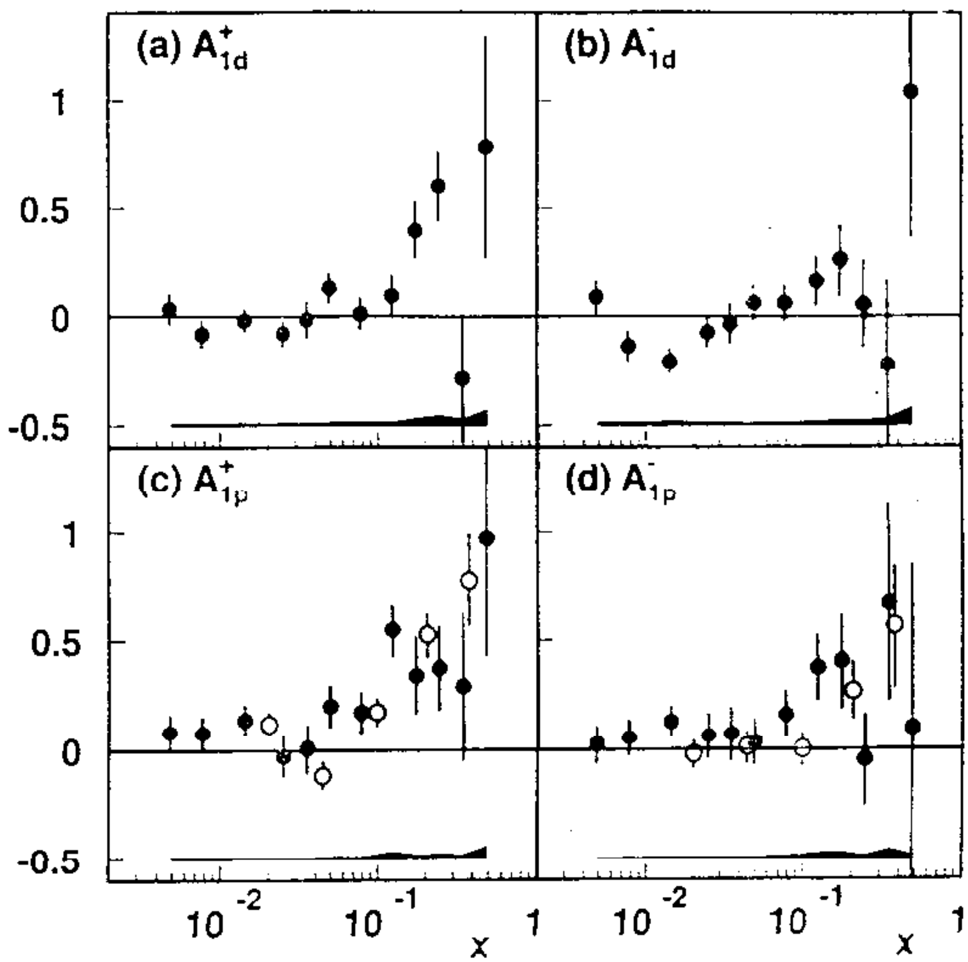


Fig. 1. Semi-inclusive asymmetries of spin-dependent cross sections for muoproduction of (a) positive hadrons on deuteron, (b) negative hadrons on deuteron, (c) positive hadrons on proton and (d) negative hadrons on proton. The error bars are statistical and the shaded areas represent the systematic uncertainty. The open circles represent the asymmetries measured by EMC [7].

- relatively low statistics
- no hadron particle i.d.

Ratio of Valence Quark Distributions

hermes

$$\underbrace{\frac{1}{\sigma_{tot}}}_{\propto N^{e^+}} \frac{d\sigma_N^h(x,z)}{dz} = e\frac{\sum_i e_i^2 f_{i/N}(x)\cdot D_i^h(z)}{\underbrace{\sum_i e_i^2 f_{i/N}(x)}_{F_2^N}}$$

⟹Comparing Proton and Neutron:

$$\frac{1}{N_{e^+}^{p}}\left(\frac{dN_p^{\pi^+}}{dz} - \frac{dN_p^{\pi^-}}{dz}\right) = \frac{x}{F_2^p}\left(\frac{4}{9}u_v - \frac{1}{9}d_v\right)\left(D^+ - D^-\right),$$

$$\frac{1}{N_{e^+}^{n}}\left(\frac{dN_n^{\pi^+}}{dz} - \frac{dN_n^{\pi^-}}{dz}\right) = \frac{x}{F_2^n}\left(\frac{4}{9}d_v - \frac{1}{9}u_v\right)\left(D^+ - D^-\right)$$

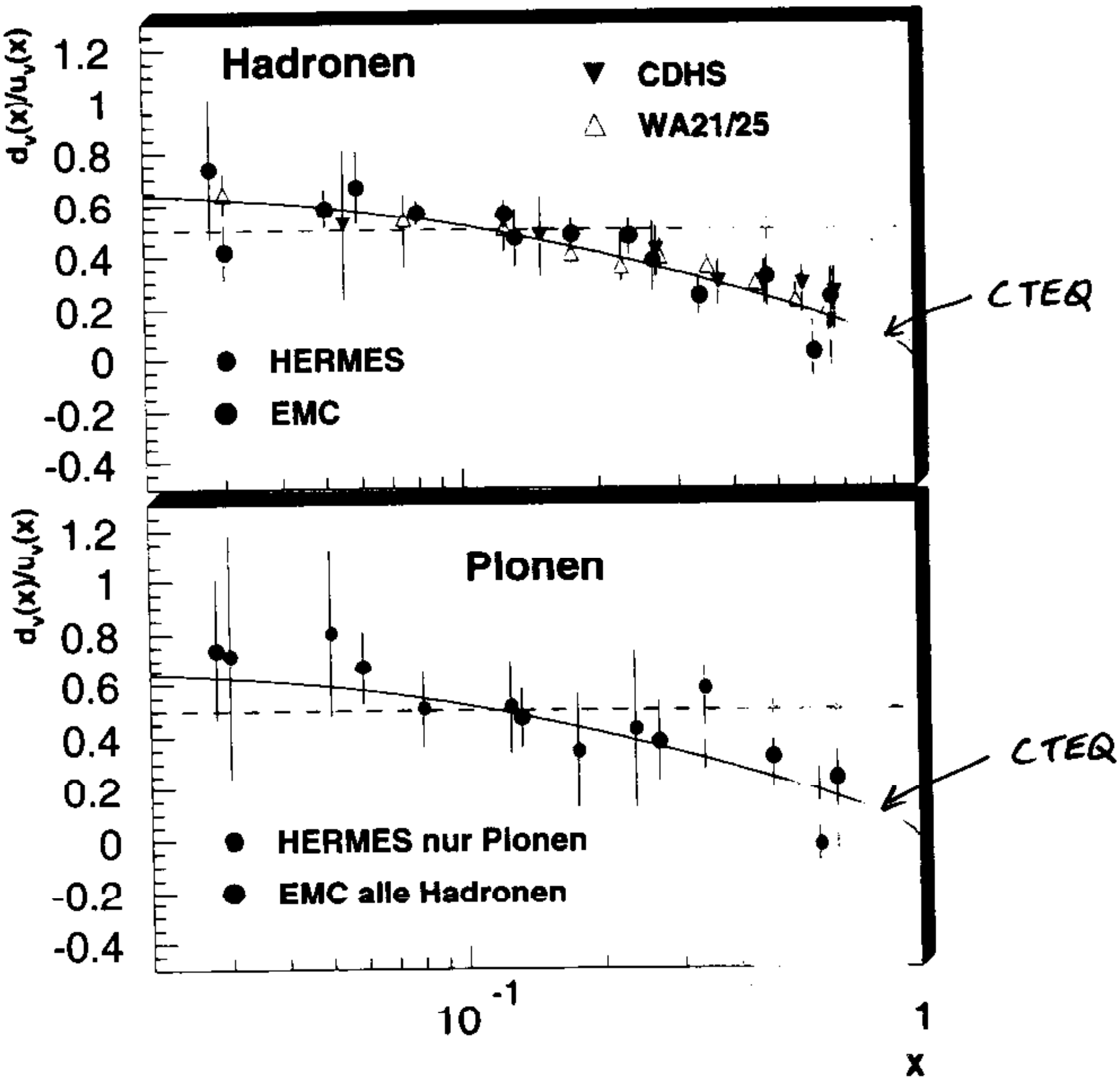
- Sea contributions cancel
- Ratio (p/n) independent of Fragmentation functions

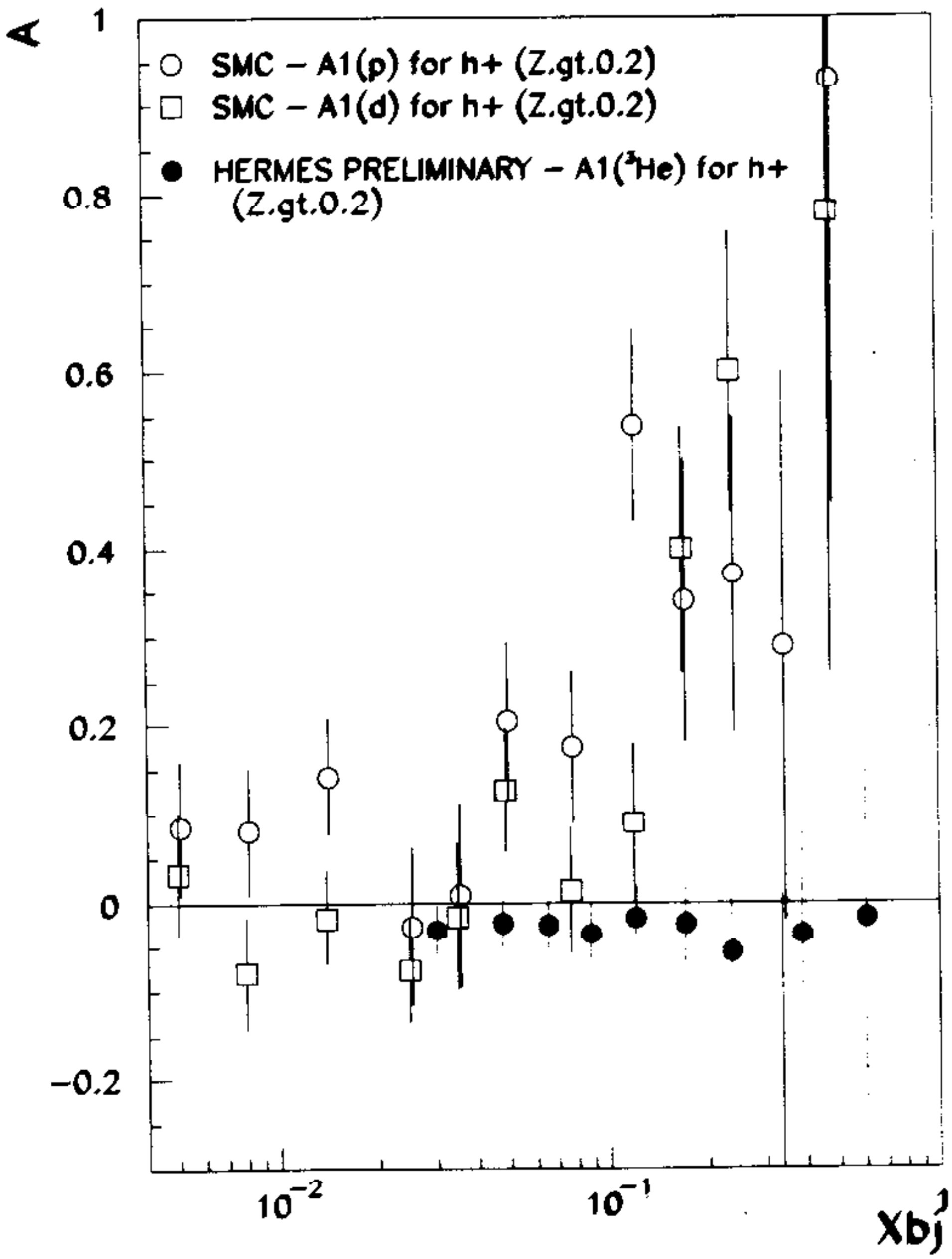
⟹Gives measure of $\dfrac{d_v(x)}{u_v(x)}$

$$\boxed{\frac{d_v(x)}{u_v(x)}}$$

hermes

unpolarized H + D data




A
SMC – A1(p) for h+ (Z.gt.0.2)
SMC – A1(d) for h+ (Z.gt.0.2)
HERMES PRELIMINARY – A1(^{3}He) for h+ (Z.gt.0.2)
1
0.8
0.6
0.4
0.2
0
-0.2
10^{-2}
10^{-1}
Xbj

Λ spin-dependent electroproduction

Is there a significant $u \rightarrow \Lambda$ spin transfer?

proton $\qquad\qquad\qquad\qquad$ Λ $\qquad\qquad$ R. Joffe

$$\left.\begin{array}{l} \Delta u_p \approx \ \ 0.88 \\ \Delta d_p \approx -0.37 \\ \Delta s_p \approx -0.07 \end{array}\right\} \Rightarrow \begin{array}{l} \Delta u_\Lambda = -0.16 \\ \Delta d_\Lambda \approx -0.16 \\ \Delta s_\Lambda \approx +0.58 \end{array}$$

$$P_\Lambda = -P_e \frac{y(2-y)}{1+(1-y)^2} \frac{\Delta u_\Lambda}{u_\Lambda}$$

$$\approx 0.4 \, P_e \frac{\Delta u_\Lambda}{u_\Lambda}$$

- unpolarized target
- look at Λ polarization $\quad \sim 2000 \ \Lambda$ from 95 data
- reverse beam polarization

N.B.

Also interest in target fragmentation Λ

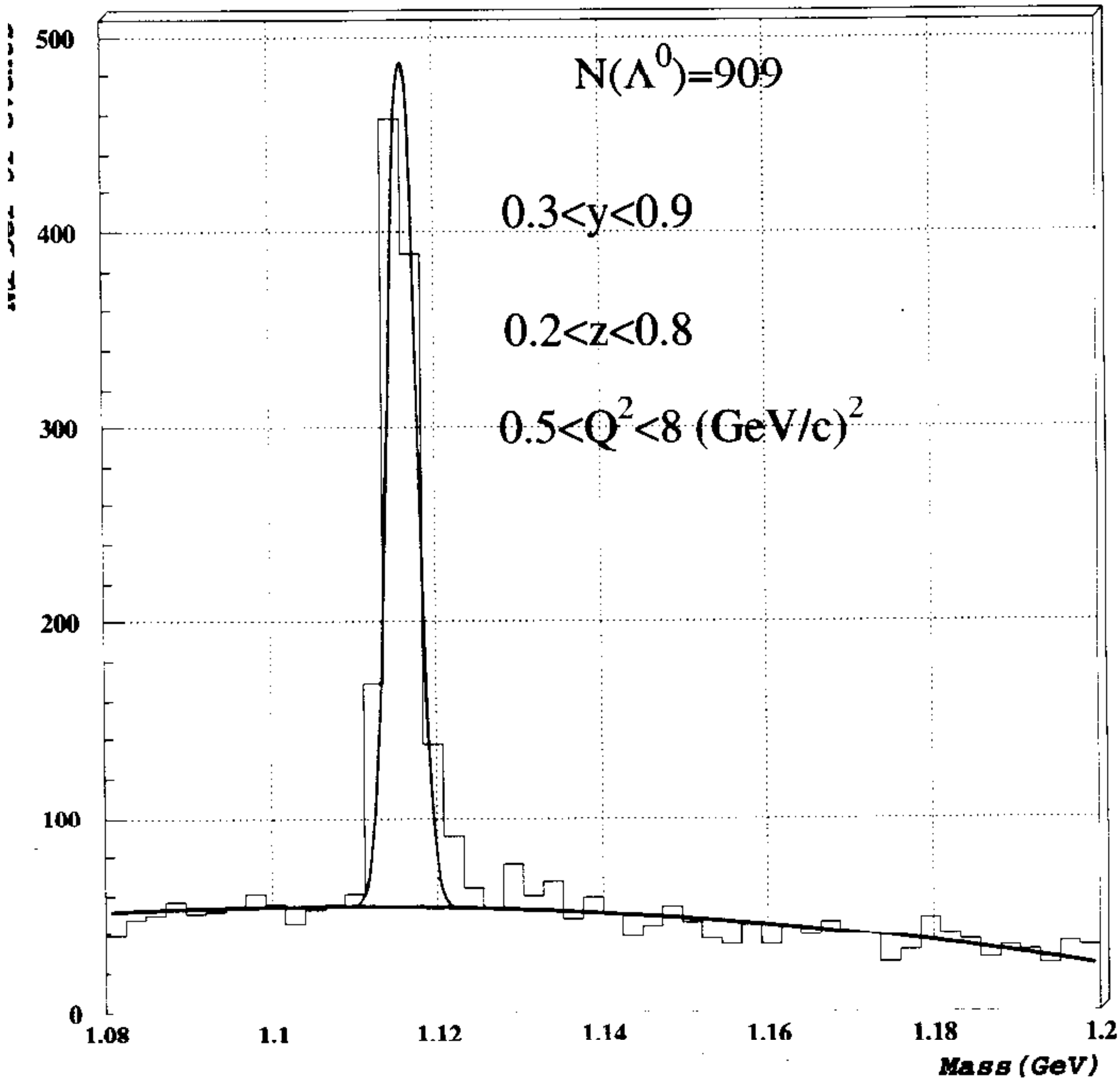
Ellis, Kharzeev, Kotzinian

- proceed to measure with target polarized

- 1

HERMES preliminary

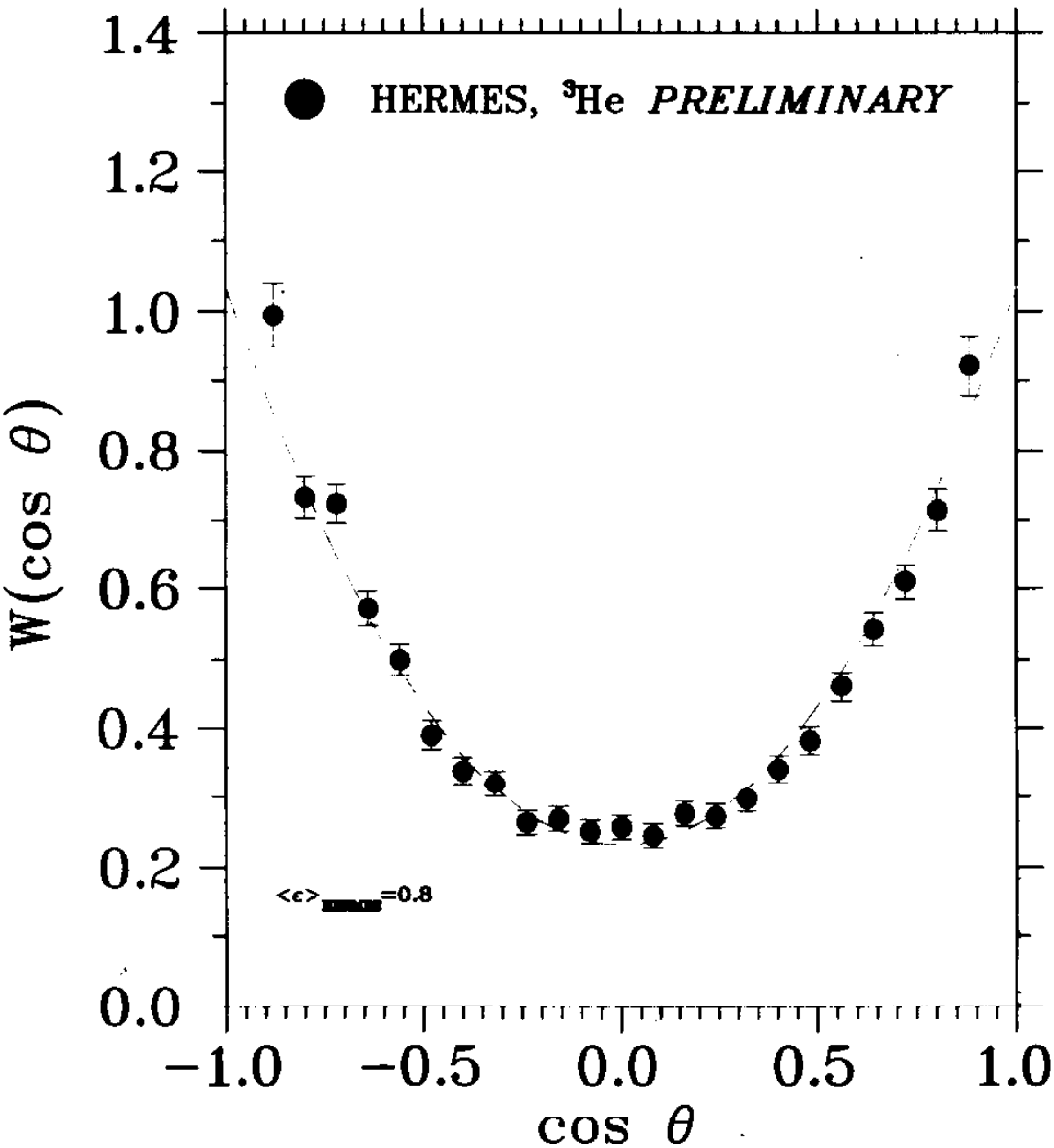
97/02/10 13.18

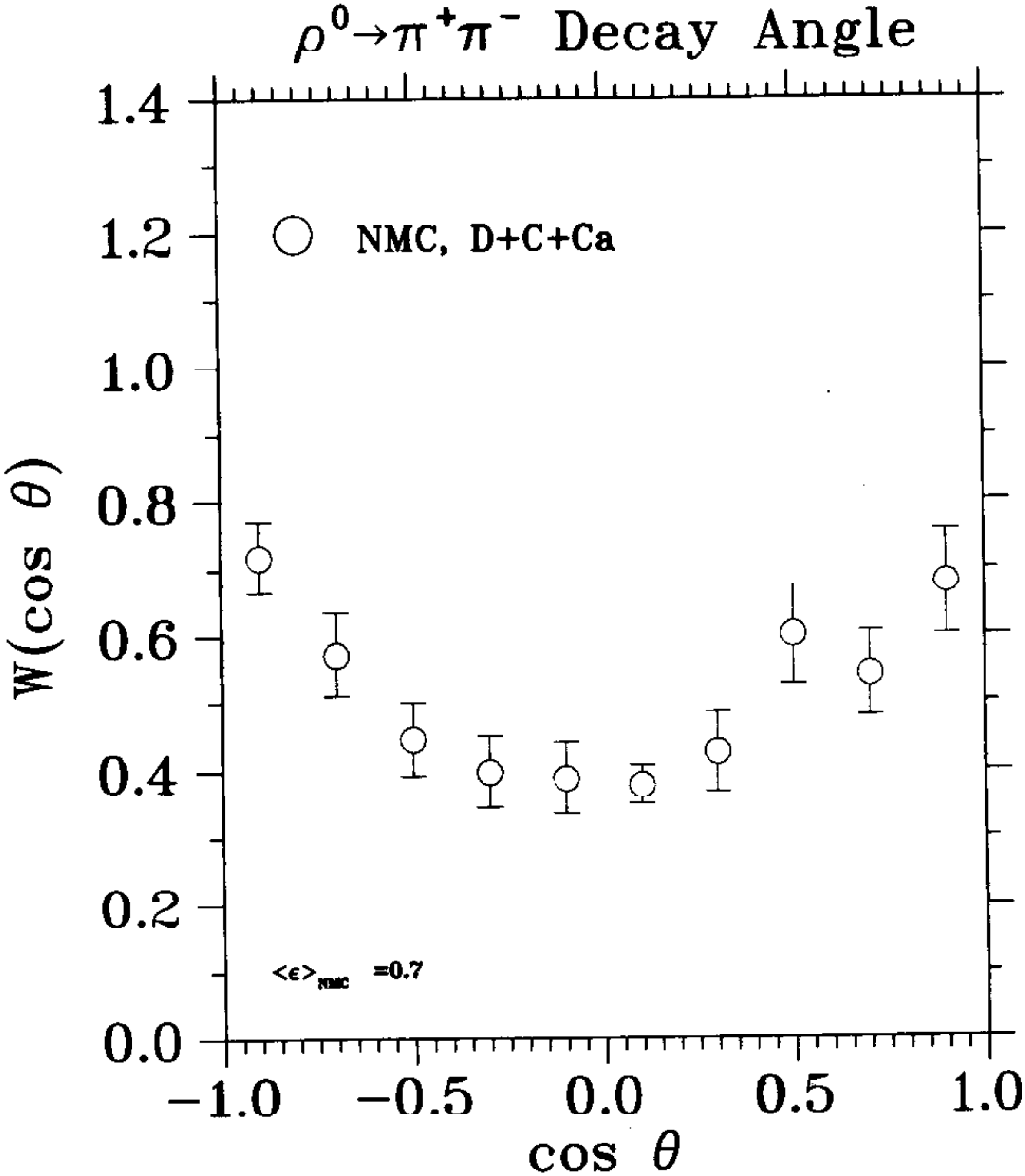


$$W(\cos\theta) = \frac{3}{4}\left[1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos\theta\right]$$

r^{04}_{00} = long. poln. of ρ

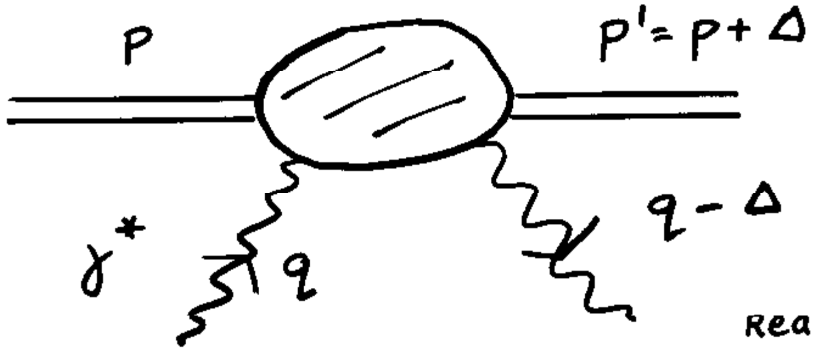
$\rho^0 \to \pi^+\pi^-$ Decay Angle





$\rho^0 \rightarrow \pi^+\pi^-$ Decay Angle
NMC, D+C+Ca
$<\epsilon>_{NMC}$ =0.7
W(cos θ)
cos θ
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−1.0
−0.5
0.0
0.5
1.0

deeply virtual compton scattering



Ji hep-ph /9603249

experimentally $(e, e'\gamma)$

coherent with Bethe-Heitler

amplitude $T^{\mu\nu}(p, q, \Delta)$ contains

$H, \tilde{H}, E, \tilde{E}$ new off-forward twist-2 parton distributions

$$H(x, \Delta^2 = 0, \Delta\cdot n = 0) = F_1(x)$$

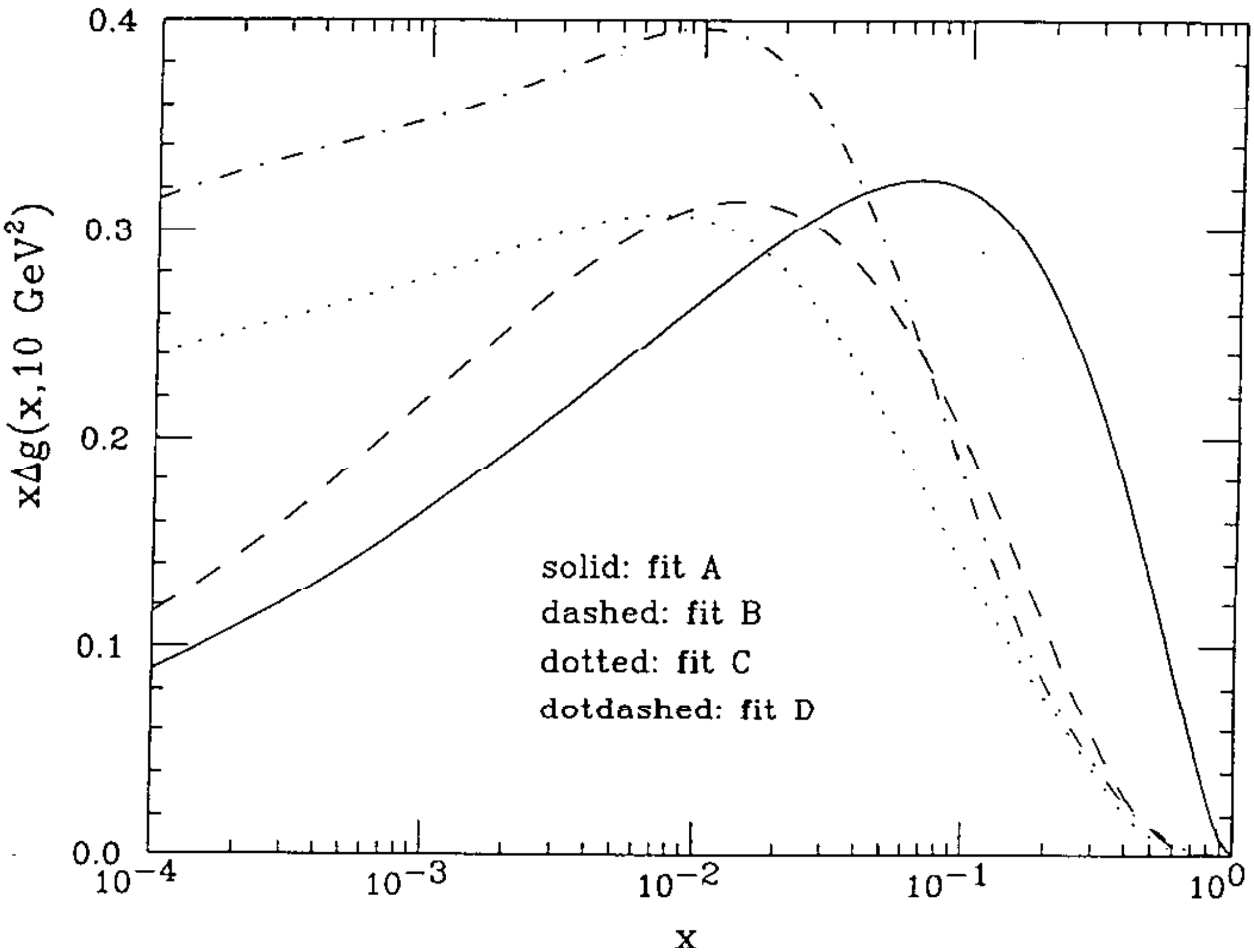
$$\tilde{H}(x, \Delta^2 = 0, \Delta\cdot n = 0) = g_1(x)$$

$$\int x\,dx \left[H(x, \Delta^2, \Delta\cdot n) + E(x, \Delta^2, \Delta\cdot n)\right] = A_q(\Delta^2) + B_q(\Delta^2)$$

$$\frac{1}{2}\left[A_q(0) + B_q(0)\right] = J_q = \text{TOTAL QUARK A.M.}$$

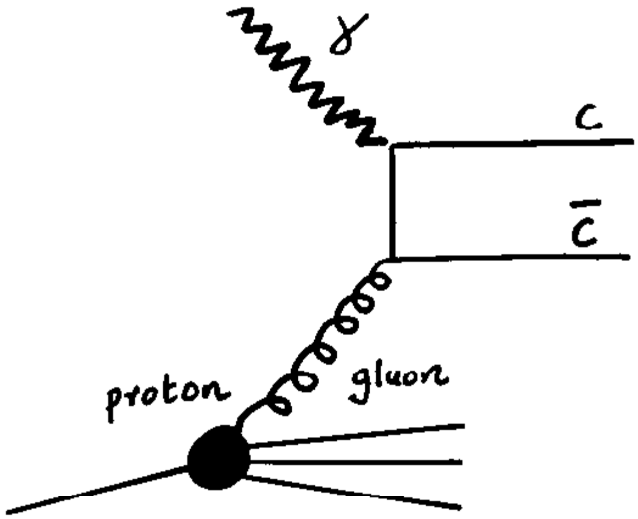
$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

Altarelli et al. hep-ph/9701289



possibility to measure gluon spin directly

photon gluon fusion :



J/ψ
open charm

HERMES
COMPASS
E-156

dijet production
polarized HERA

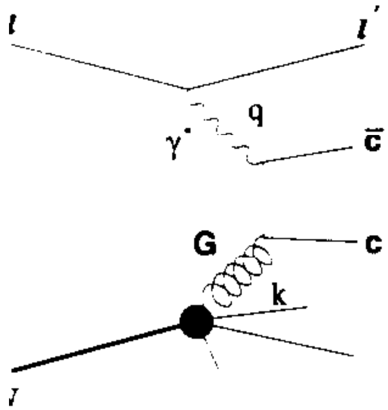
direct photon production :

$$g + q \rightarrow \gamma + q$$

RHIC

hoton-Gluon Fusion

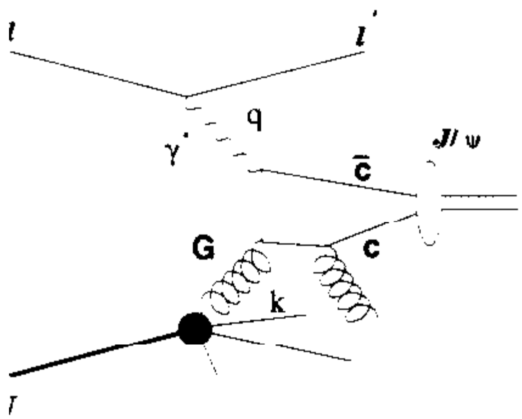
Open Charm



Clear Interpretation for $\Delta(G)/G$

$$A_{\gamma N}^{c\bar{c}} \sim \frac{1}{1.2}\frac{\Delta(G)}{G}$$

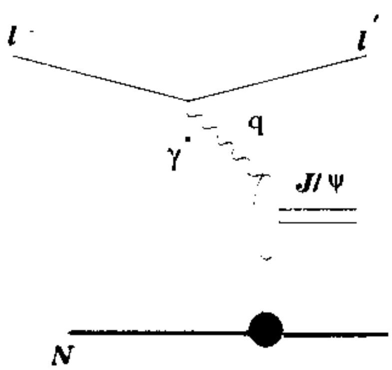
Inelastic J/ψ



Interpretation for $\Delta(G)/G$ in Colour Singlet Model

$$A_{\gamma N}^{J/\psi} \sim \frac{1}{1.8}\frac{\Delta(G)}{G}$$

Diffractive Elastic J/ψ

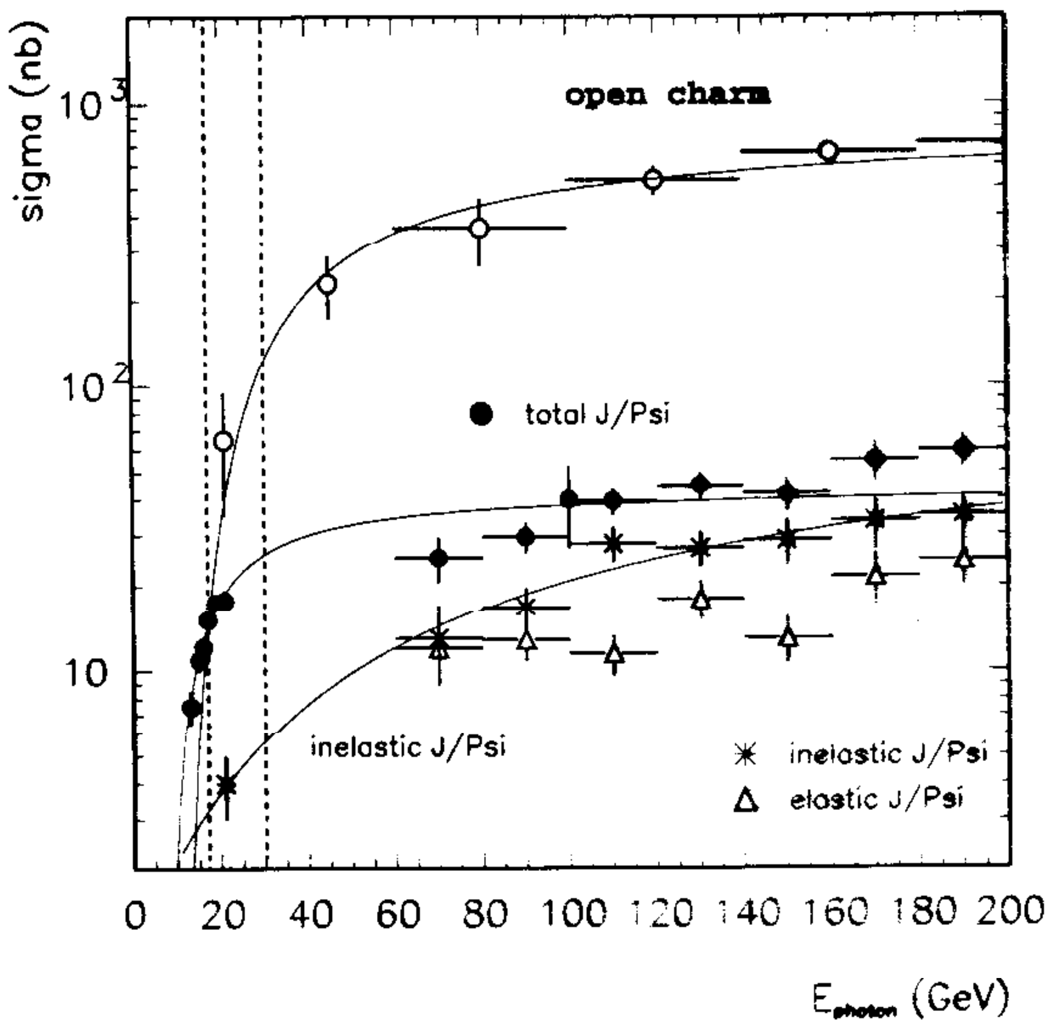


Relationship to $\Delta(G)/G$ is under theoretical investigation

$$A_{\gamma N}^{J/\psi} \sim 2\,\frac{\Delta(G)}{G}\ ?$$

$$A_{\gamma N} = \frac{1}{D}\,A_{eN} = \frac{1}{D f P_b P_t}\,A^{exp}$$

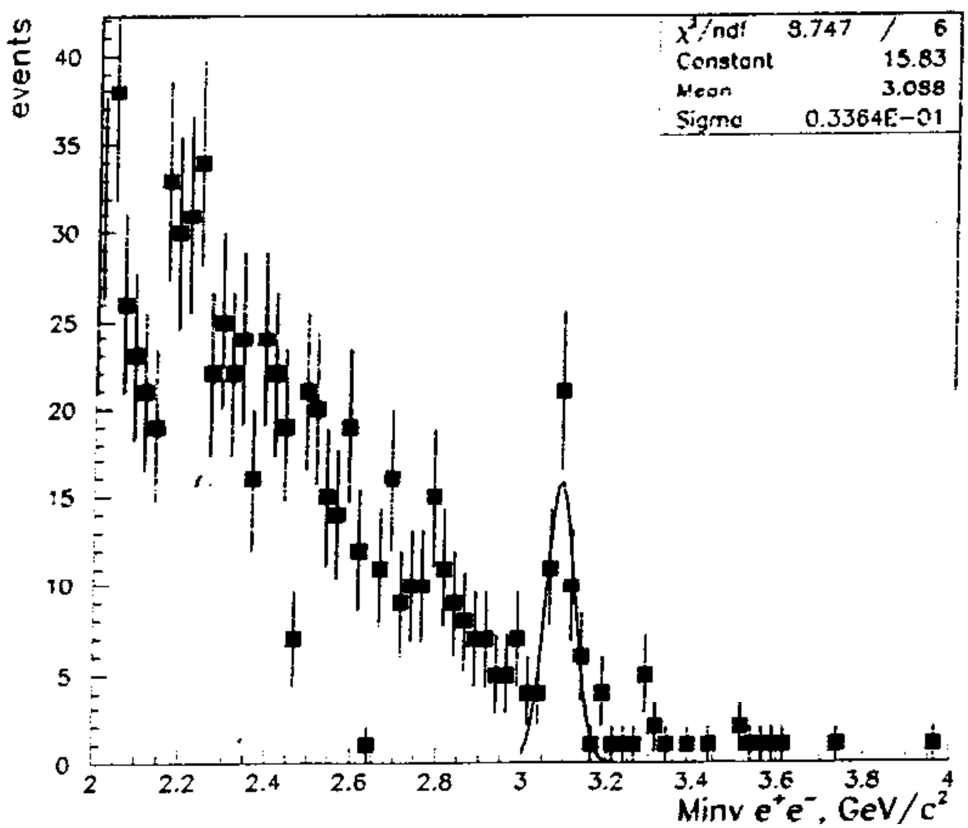
Charm Physics



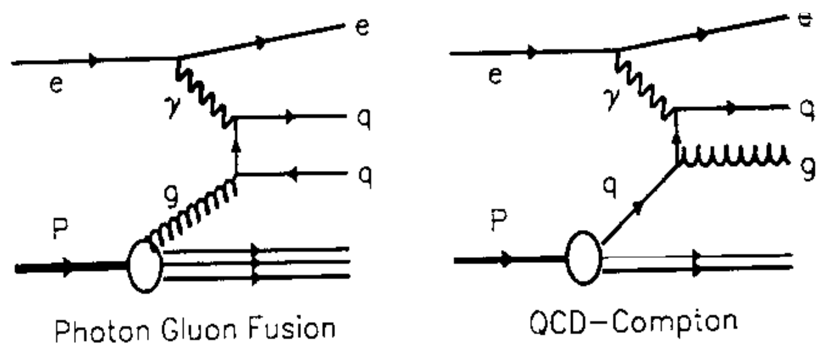
- cross sections for open charm and J/ψ production near threshold ?
- s channel helicity conservation in J/ψ production ?
- spin dependent charm production $\longrightarrow \Delta G/G$

PRELIMINARY

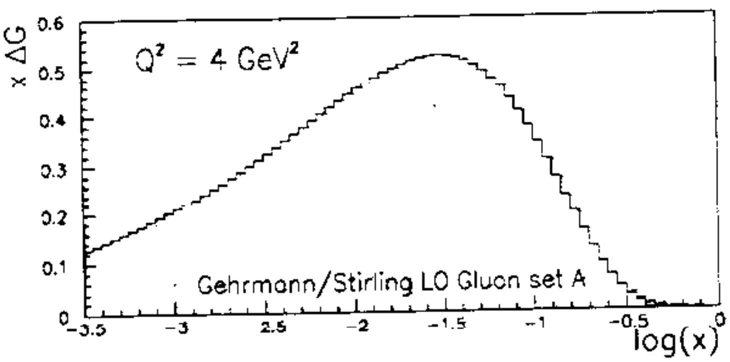
$J/\psi \rightarrow e^+e^-$ search, HERMES '95 data, He^3 target

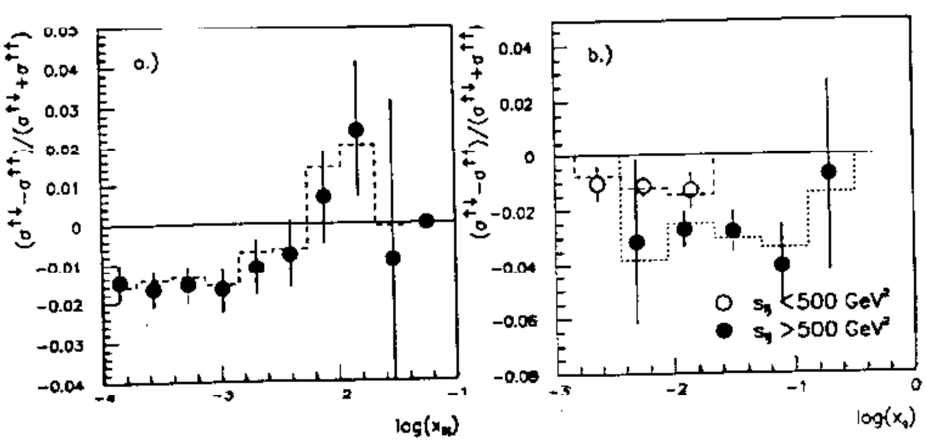


$(\Delta G/G)$ from boson-gluon-fusion in polarized e-p scattering at HERA



- Measure crosssection for (2+1)-jet events
- In LO: $\sigma \sim \alpha_s \times G \;\Rightarrow\; \frac{\Delta G}{G} \sim \frac{1}{P_e P_p D} \times \frac{\sigma^{\uparrow\downarrow}-\sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow}+\sigma^{\uparrow\uparrow}}$



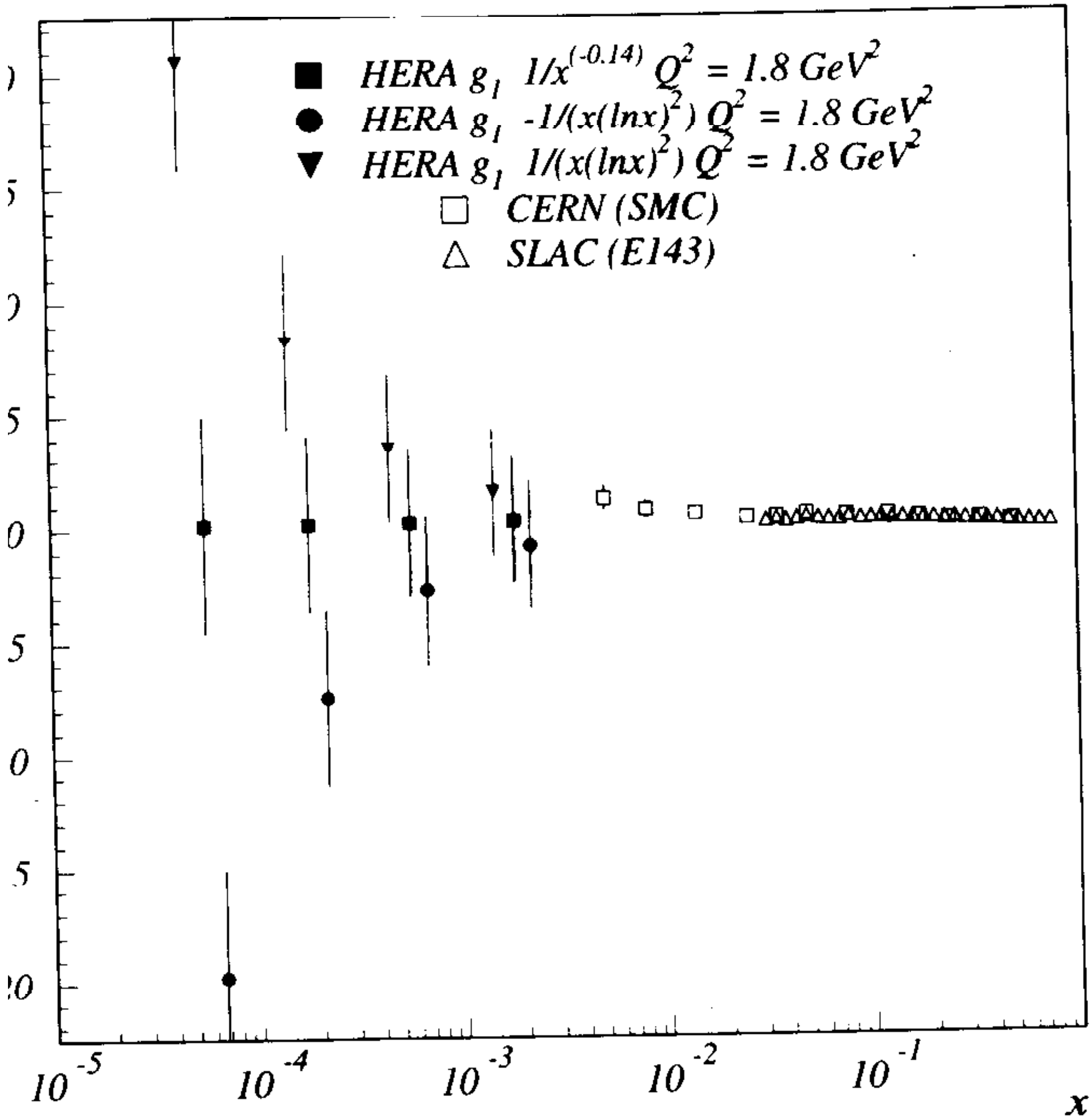


- **Asymmetries vs. a) $\log(x_{Bj})$ and b) $\log(x_g)$ at the parton level(histogram), and at the detector level($\bullet$, $\circ$ with error bars) assuming HERA $\mathcal{L} = 200\ \mathrm{pb}^{-1}$.**

$P_e = P_b = 70\%$

Summary of experiments to probe gluon spin

expt.	when?	kinematic Range	$\delta\left(\frac{\Delta G}{G}\right)$
HERMES	Running	$x_g \sim 0.3$	~ 0.4 /year after 98
RHIC	~ 2000	$x_g \sim 0.05 - 0.3$	$\sim .01 - .3$
COMPASS	~ 2000	$x_g \sim 0.15$	~ 0.1
E-156	not approved ~ 2000	$x_g \sim 0.1$ to 0.5	~ 0.02
HERA	not approved $\gtrsim 2005$	$x_g \sim 10^{-2}$ to 10^{-1}	~ 0.1


HERA g1 1/x(-0.14) Q2 = 1.8 GeV2
HERA g1 -1/(x(lnx)2) Q2 = 1.8 GeV2
HERA g1 1/(x(lnx)2) Q2 = 1.8 GeV2
CERN (SMC)
SLAC (E143)
10 -5
10 -4
10 -3
10 -2
10 -1
x

SUMMARY

- inclusive

high quality data on $p+n$ $\quad 10^{-2} \lesssim x \lesssim 0.6$

NLO QCD analysis provides

$$a_0 = 0.10 \,{}^{+0.17}_{-0.11}$$

$$\Delta\Sigma = 0.45 \pm 0.09$$

$$\Delta g = 1.6 \pm 0.9$$

successful test of QCD

- low x data
- A_1^n at large x
- transverse asymms.

- semi-inclusive

$$\text{HERMES}\begin{cases} \Delta u_v(x),\ \Delta d_v(x) \\ \Delta s(x) \\ \text{spin transfer to } \Lambda \\ \rho \text{ production} \end{cases}$$

DVCS

- glue