Measurement of the Spin Structure Function g_1 of the Proton and the Deuteron

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On Behalf of the Hermes Collaboration

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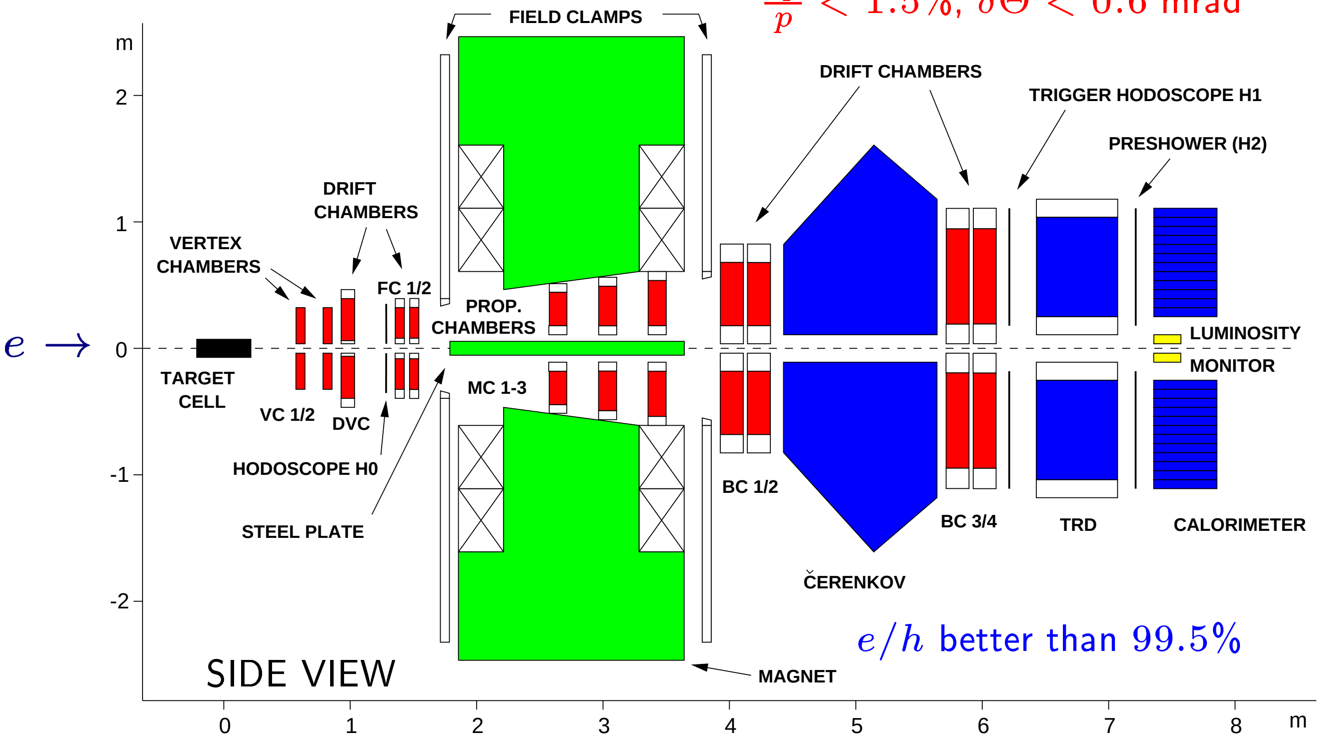
- The HERMES Experiment
- Formalism
- Measurement of g_1 of the
  - ▷ Proton in the extended kinematic range
  - ▷ Deuteron in the standard kinematic range
- Summary

Results are based on the data taking periods 1997 and 1999 of the HERMES experiment at HERA

The HERMES Experiment at DESY

- forward spectrometer $(0.04 < |\Theta| < 0.22 \text{ mrad})$

$\frac{\delta p}{p} < 1.5\%,\ \delta\Theta < 0.6 \text{ mrad}$

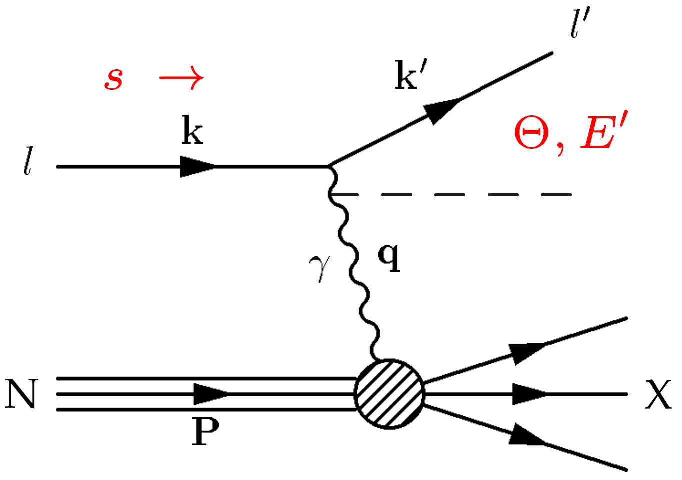


- $\overrightarrow{e^+} / \overrightarrow{e^-}$: $E = 27.57$ GeV , $P_B \approx \pm 0.55$

year	target	P_T	N/cm^2
1995	$^3\overset{\Rightarrow}{\text{He}}$	~ 0.46	$10 \cdot 10^{14}$
1996 - **1997**	$\overset{\Rightarrow}{\mathbf{H}}$	~ 0.86	$0.7 \cdot 10^{14}$
1998 - **1999** - 2000	$\overset{\Rightarrow}{\mathbf{D}}$	~ 0.90	$1 \ldots 2 \cdot 10^{14}$

Deep Inelastic Scattering

- DIS kinematics:



$S \ \Rightarrow \ (\Leftarrow)$

$$Q^2 = -q^2 \overset{\text{lab}}{\approx} 4EE' \sin^2\frac{\Theta}{2}$$

$$y = \frac{Pq}{Pk} \overset{\text{lab}}{=} \frac{E - E'}{E}$$

$$\nu \overset{\text{lab}}{=} E - E'$$

$$x = \frac{Q^2}{2Pq} \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}$$

$$W^2 \overset{\text{lab}}{=} -Q^2 + M^2 + 2M\nu$$

- longitudinal cross section asymmetry :

$$A_{\parallel} = \frac{\sigma^{\overset{\rightarrow}{\Leftarrow}} - \sigma^{\overset{\rightarrow}{\Rightarrow}}}{\sigma^{\overset{\rightarrow}{\Leftarrow}} + \sigma^{\overset{\rightarrow}{\Rightarrow}}}$$

$$= \frac{1}{\langle P_{\mathrm{T}} P_{\mathrm{B}} \rangle} \; \frac{(N/L)^{\overset{\rightarrow}{\Leftarrow}} - (N/L)^{\overset{\rightarrow}{\Rightarrow}}}{(N/L)^{\overset{\rightarrow}{\Leftarrow}} + (N/L)^{\overset{\rightarrow}{\Rightarrow}}}$$

P_{T} , P_{B} :	target and beam polarisation
N :	number of inclusive DIS events
L :	deadtime corrected luminosity

Formalism

- from $A_{\parallel}$ to g_1/F_1

$$A_{\parallel} = \frac{\sigma^{\overset{\rightarrow}{\Leftarrow}} - \sigma^{\overset{\rightarrow}{\Rightarrow}}}{\sigma^{\overset{\rightarrow}{\Leftarrow}} + \sigma^{\overset{\rightarrow}{\Rightarrow}}} = D(A_1 + \eta A_2)$$

- virtual photon asymmetries A_1 , A_2

$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1} \quad ; \quad A_2 = \gamma \frac{g_1 + g_2}{F_1} \approx \gamma \frac{g_1}{F_1} \ll \frac{g_1}{F_1}$$

$$\frac{g_1}{F_1} = \frac{1}{1+\gamma^2}\left[\frac{A_{\parallel}}{D} + (\gamma - \eta) A_2\right] \quad ; \quad \frac{(\gamma-\eta)A_2^{\mathrm{p}}}{g_1^{\mathrm{p}}/F_1^{\mathrm{p}}} < 2\%$$

D : photon depolarization factor ($D \approx y$)

η , γ : kinematic factors ($\eta \approx \gamma \xrightarrow{Q^2 \gg M^2} 0$)

- spin structure function $g_1(x, Q^2)$

$$g_1 = \left(\frac{g_1}{F_1}\right)_{\mathrm{meas}} \cdot F_1^{\mathrm{param}}$$

using normalization $F_1^{\mathrm{param}} = \frac{F_2(x,Q^2)(1+\gamma^2)}{2x(1+R(x,Q^2))}$

$R = \sigma_{\mathrm{L}}/\sigma_{\mathrm{T}}$: PL **B250** (1990) 193

F_2^{p} : hep-ph/9712415

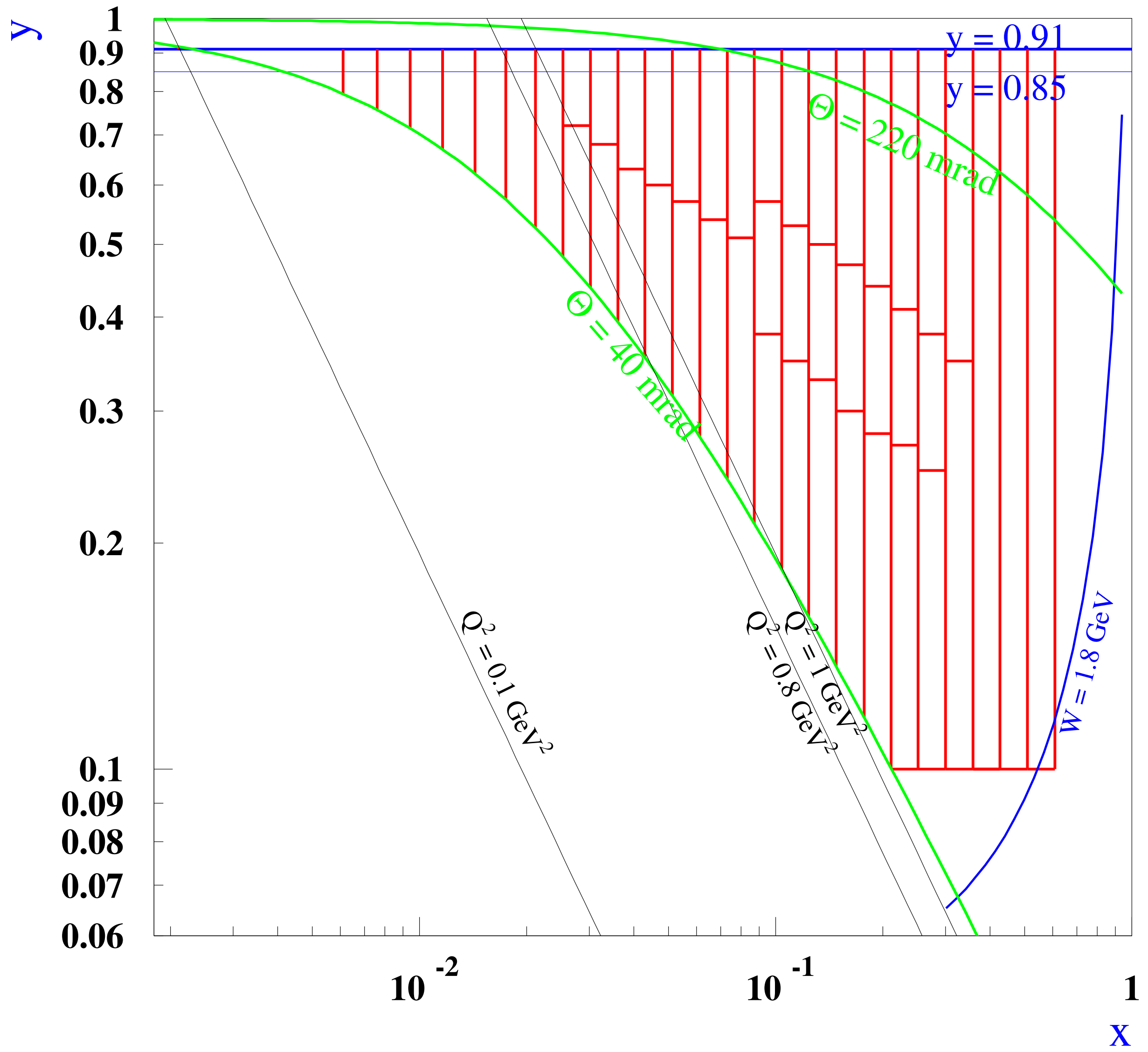
F_2^{d} : NP **B371** (1992) 3

Inclusive DIS Data

- HERMES kinematic range

  ($*$) standard range as used in PL **B 442** (1998) 484

				D 1998 (*)	extension for H 1997
0.85	$>$	x	$>$	0.0212	$\rightarrow$ 0.0021
0.1	$<$	y	$<$	0.85	$\rightarrow$ 0.91
		Q^2	$>$	0.8	$\rightarrow$ 0.1 GeV^2



DIS candidates after data quality cuts:

▷ 1997 H : $2.5 \cdot 10^6$ (about $0.8 \cdot 10^6$ due to extension of the kinematic range)

▷ 1998 D : $1.1 \cdot 10^6$ (about 1/6 of all D data taken)

Why g_1 at Low $x_{\rm Bj}$ and Low Q^2?

Why g_1 at low $x_{\rm Bj}$?

- low–x region is important for determining the quark contribution $\Delta\Sigma$ to the nucleon spin (extrapolation into the unmeasured region)

Why g_1 at low Q^2?

- provide new data for the study of scaling violations $\Longrightarrow$ indirect access of ΔG
- allow further tests of the pQCD concept: down to which Q^2 is the concept valid?

$$
\begin{aligned}
x g_1(x, Q^2) \quad = \quad & x g_1^{tw-2}(x, Q^2) \\
& + \frac{1}{Q^2} h^{tw-4}(x, Q^2) \\
& + \frac{1}{Q^2} \left(h_{TMC}^{tw-2}(x, Q^2) + h_{TMC}^{tw-3}(x, Q^2) \right) \\
& + \mathcal{O}\left(\frac{1}{Q^4}\right)
\end{aligned}
$$

$\Longrightarrow$ field in progress

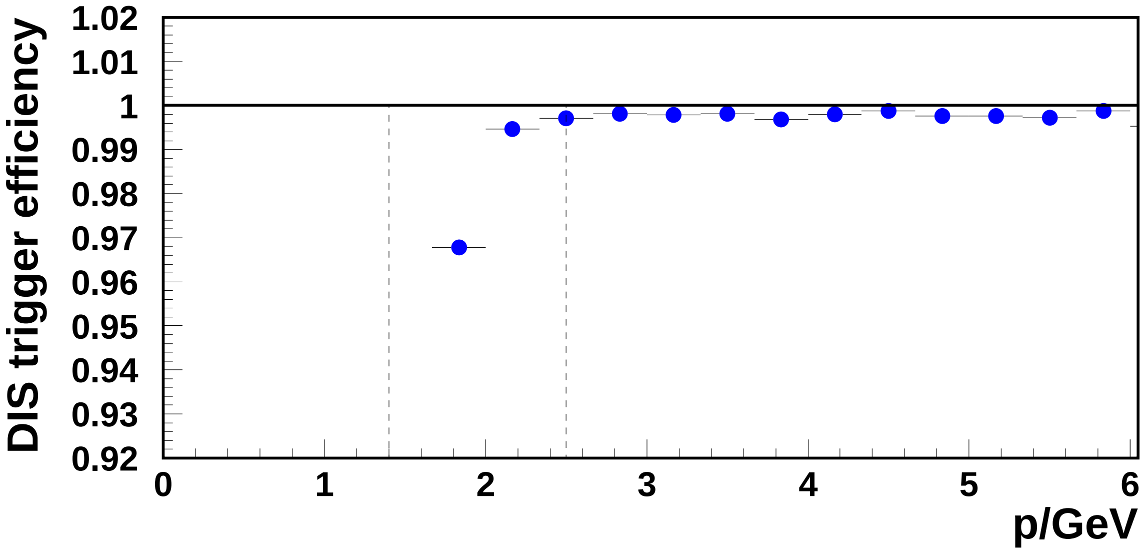
[DIS '99: E.Stein, NP **B79** (1999) 567]
[J.Blümlein, A.Tkabladze, hep-ph/9812478]

- analysis of PROTON target data in the extended kinematic range

Extended Kinematic Range

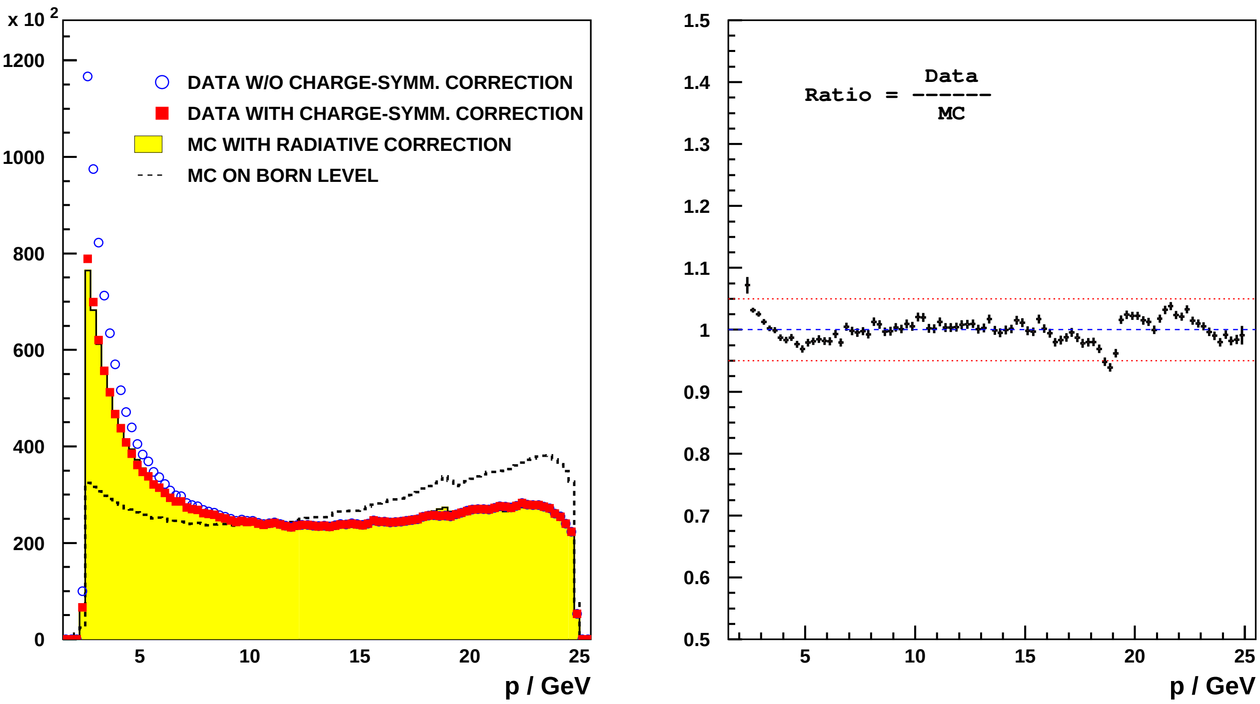
- trigger efficiency for proton data at low momenta

DIS trigger = hodoscopes * calorimeter
$\Longrightarrow$ dominated by the calorimeter energy threshold $E' > 1.4$ GeV



$\Longrightarrow$ plateau for $p > 2.5$ GeV (y-cut$= 0.91$)

- comparison of data with a DIS Monte Carlo simulation



$\Longrightarrow$ shape comparison better than 5%

Syst. Uncertainties at Low x and Q^2

- experimental systematic uncertainties:

→ beam polar.: $\Delta_{P_\mathrm{B}} =$ 3.4 %

→ target polar.: $\Delta_{P_\mathrm{T}} =$ 4.7 %

→ other sources: $\Delta_\mathrm{misc} =$ 5.5 %

(normalization, contamination, cut stability, Θ–systematics)

- systematic uncertainties in the iterative extraction of the Born asymmetry:

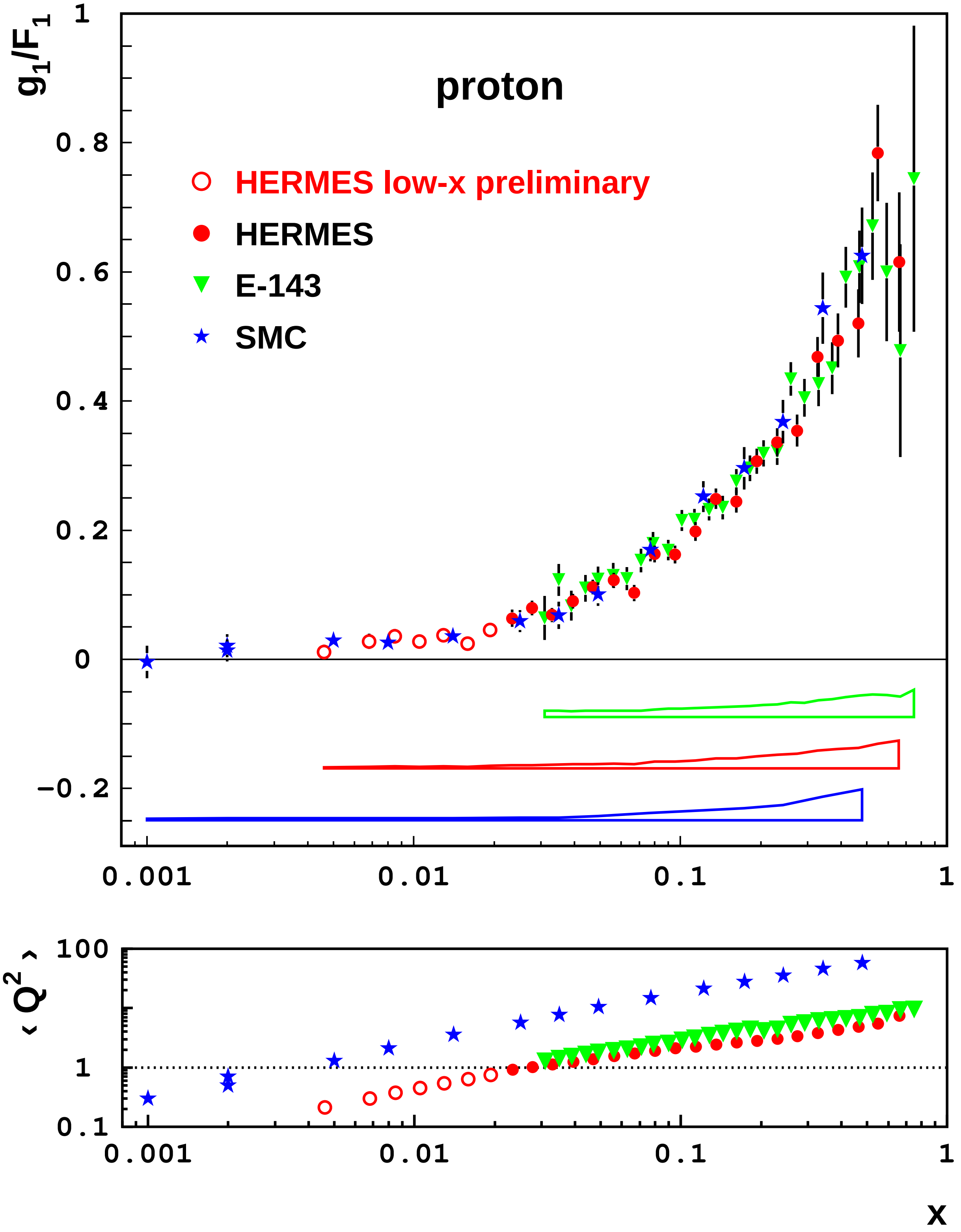
→ radiative [POLRAD: J. Phys. G20(1994)513]
and smearing corrections:
$\Delta_\mathrm{corr} \approx$ 5.0 % (11 % lowest x)

→ A_2–parameterization: $A_2 = 0.5x/\sqrt{Q^2/Q_0^2}$, $Q_0^2 = 1$ GeV^2
[based on E-143 data: Phys. Rev. D58(1998)112003]
$\Delta_{\mathrm{A}_2} \leq$ 0.5 %

Fixed: F2: ALLM97 [hep-ph/9712415] with low-W modification (for $W < 2.2$ GeV and $Q^2 < 0.5$ GeV^2) and R1990 [Phys. Lett. B250(1990)193]

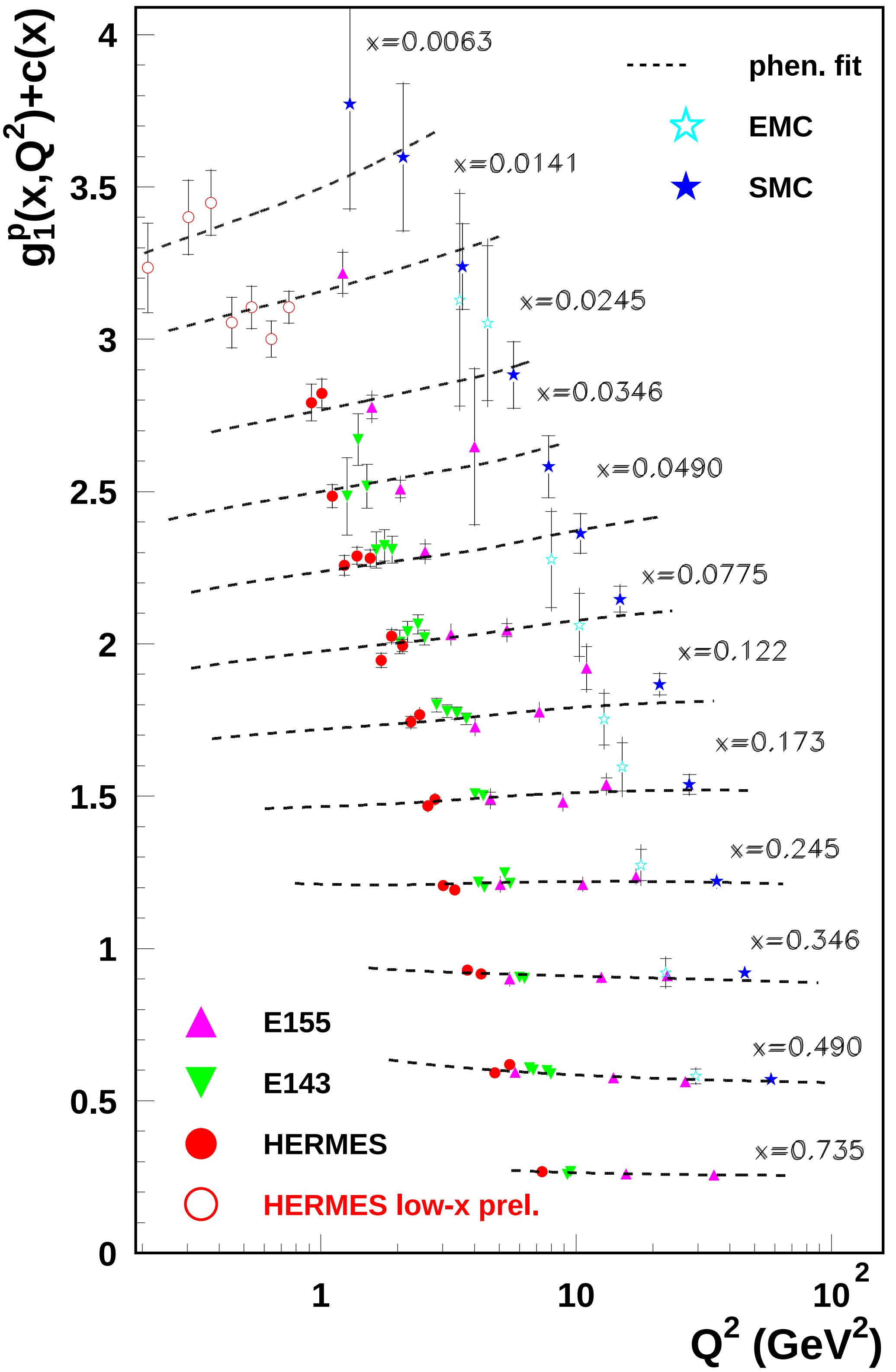
⇒ total for low–x region: 10 %
(14 % lowest x bin)

$g_1^{\mathrm{p}}/F_1^{\mathrm{p}}$: Comparison to E143 & SMC



$\Longrightarrow$ No statistically significant Q^2 dependence

g_1^{p} versus Q^2



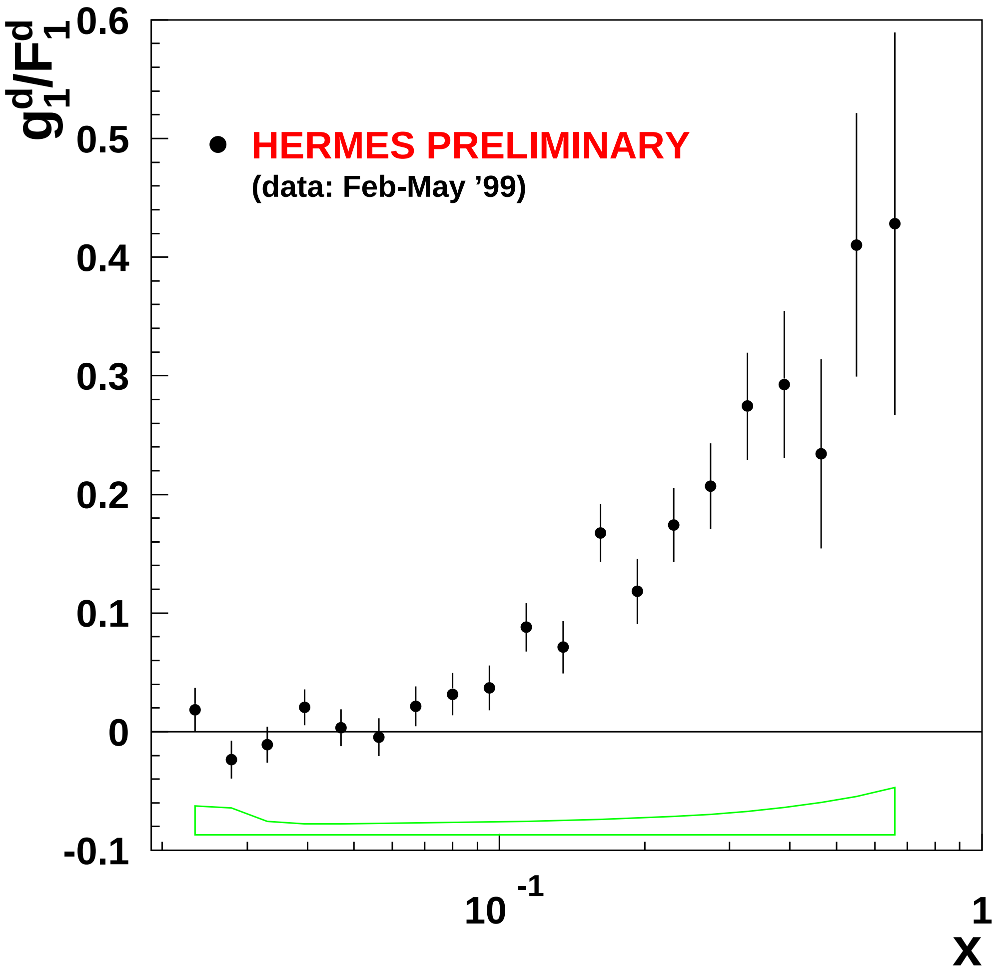
Fit by E155 using $Q^2 > 1$ GeV^2 world data:
$g_1/F_1 = x^{0.7}(0.817 + 1.014x - 1.489x^2)(1 - 0.04/Q^2)$ [hep-ph/0007248].

Measurement of $g_1^{\rm d}/F_1^{\rm d}$

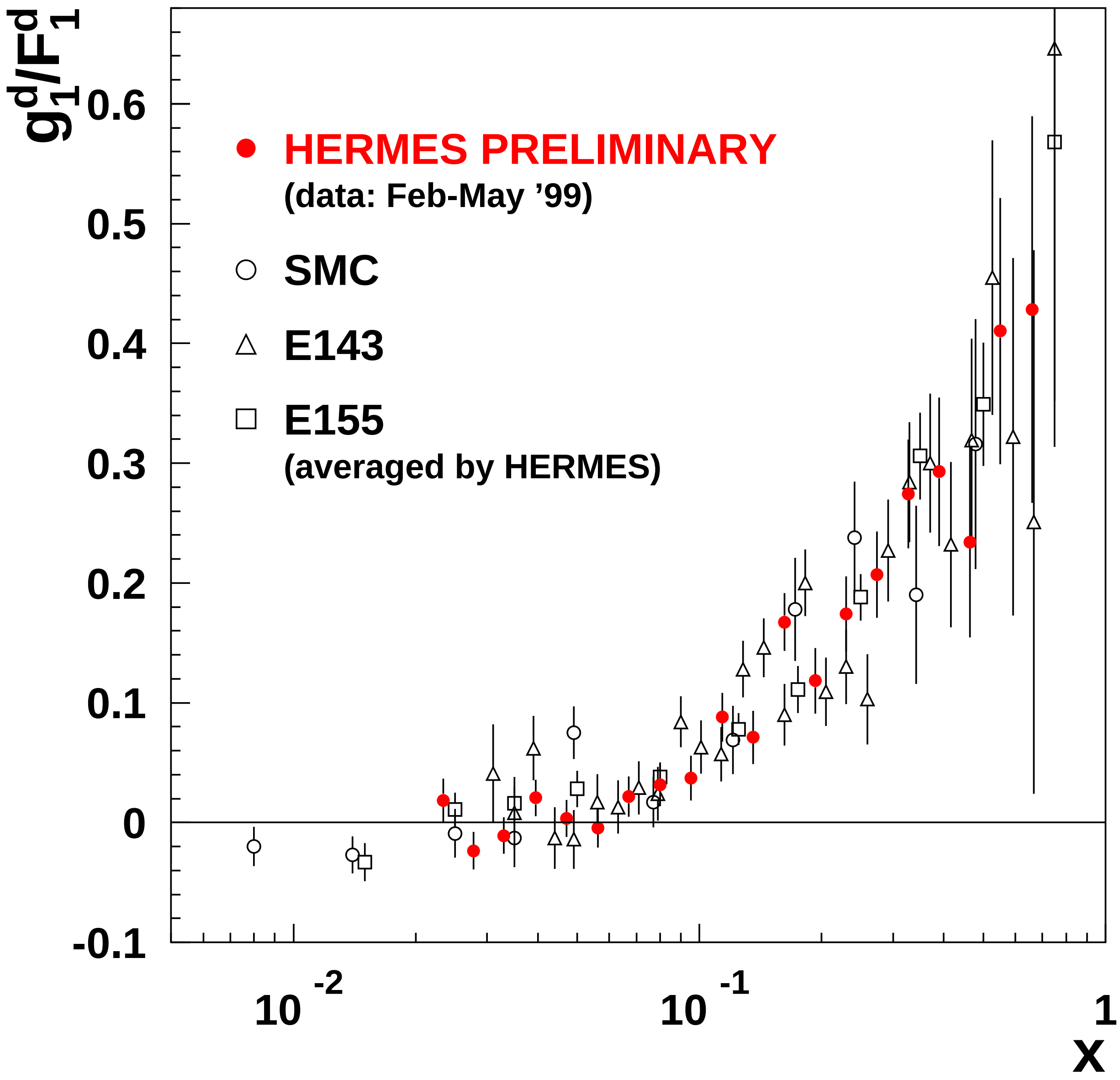
- assume $g_2^{\rm d} = 0 \Longrightarrow A_2^{\rm d} = \gamma A_1^{\rm d}$ using fit to world data $A_1^{\rm d} = -0.022 + 0.86x - 0.2x^2$
- assume $b_1^{\rm d} = 0$ DATA NOT ANALYZED YET!

▷ resulting preliminary $g_1^{\rm d}/F_1^{\rm d}$ in standard kin. range:

- relative statistical uncertainty of about 36%
- absolute systematic uncertainty of about 0.01 (at edges 0.03) dominated by contributions:
  - → beam polarization: $\Delta_{P_{\rm B}} = 3.4\%$
  - → target polarization: $\Delta_{P_{\rm T}} = 8.0\%$ (prel.!)
  - → radiative+smearing corr.: $\Delta_{\rm corr} < 0.024$ (abs.) (no iteration so far!)
  - → $A_2^{\rm d}$ assumption: $\Delta_{A_2} < 3\%$ at highest x



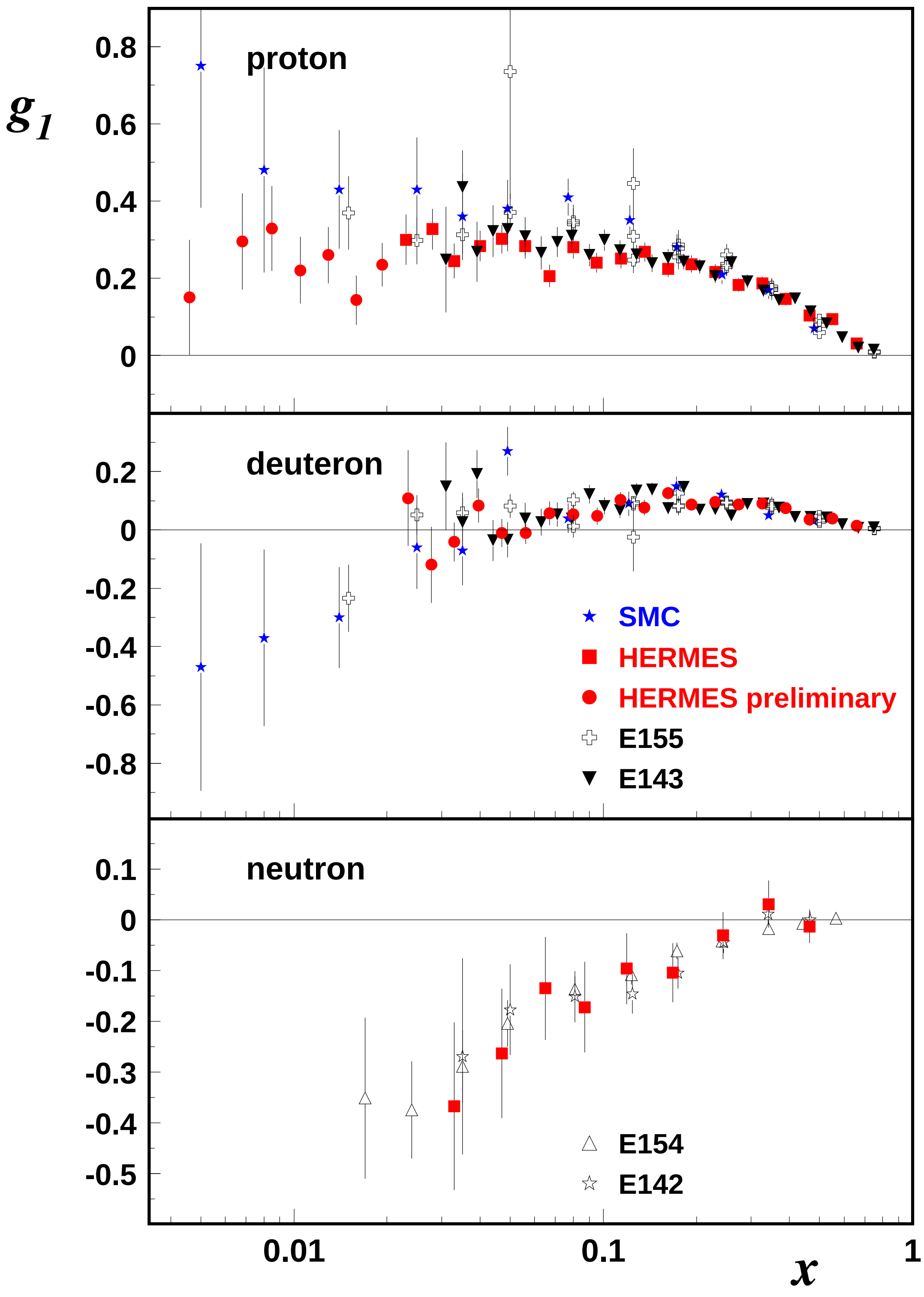
$g_1^{\mathrm{d}}/F_1^{\mathrm{d}}$: Comparison with World Data



$\Longrightarrow$ no statistically significant Q^2 dependence

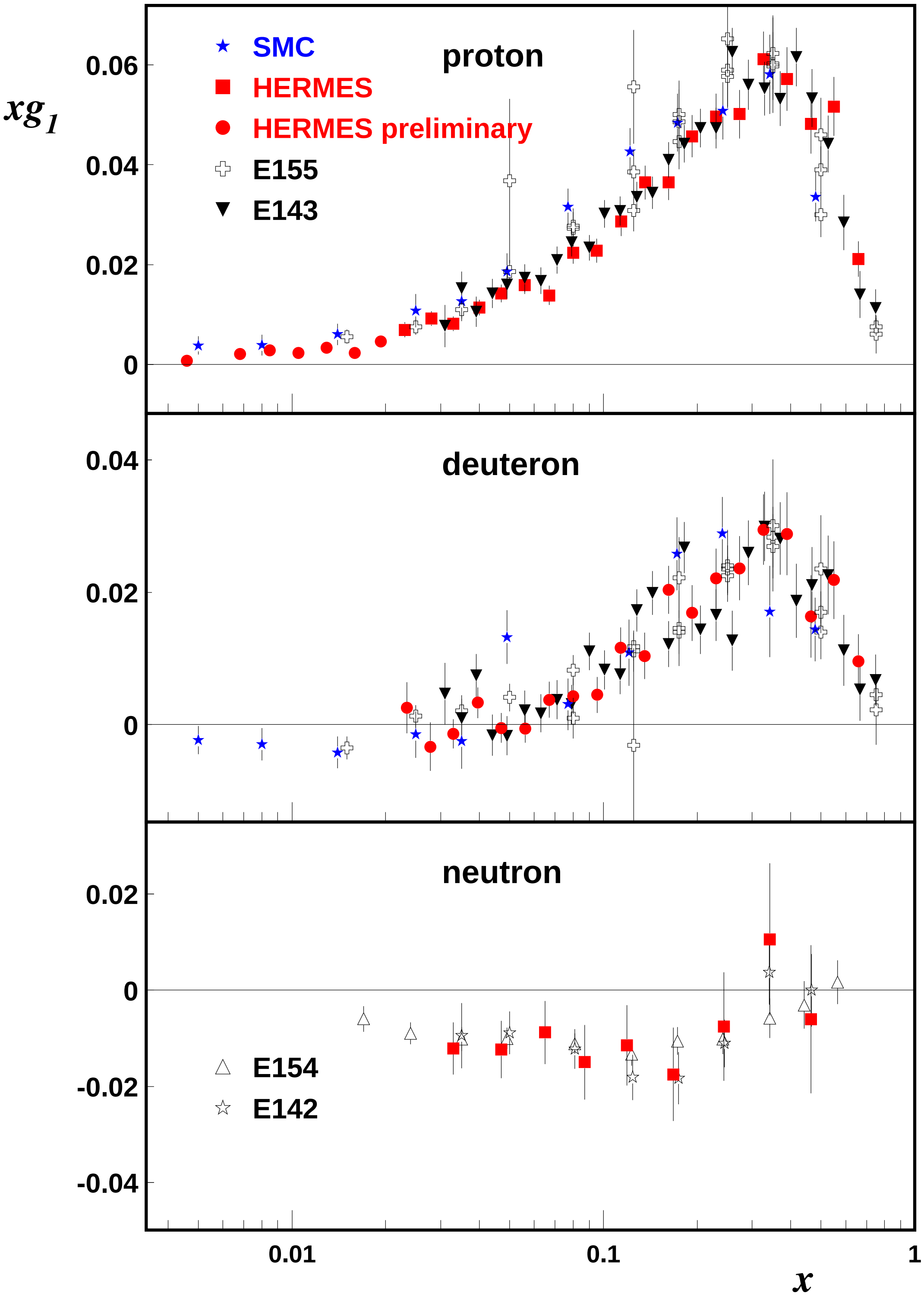
$\Longrightarrow$ more PRECISE data needed:
factor 6 of HERMES statistics 'on tape', analysis of extended kinematic range planned

World Data of g_1 versus x



Data points shown at measured Q^2 values.
SMC data shown for $Q^2 > 1$ GeV^2.

World Data of xg_1 versus x



Data points shown at measured Q^2 values.
SMC data shown for $Q^2 > 1$ GeV^2.

Summary

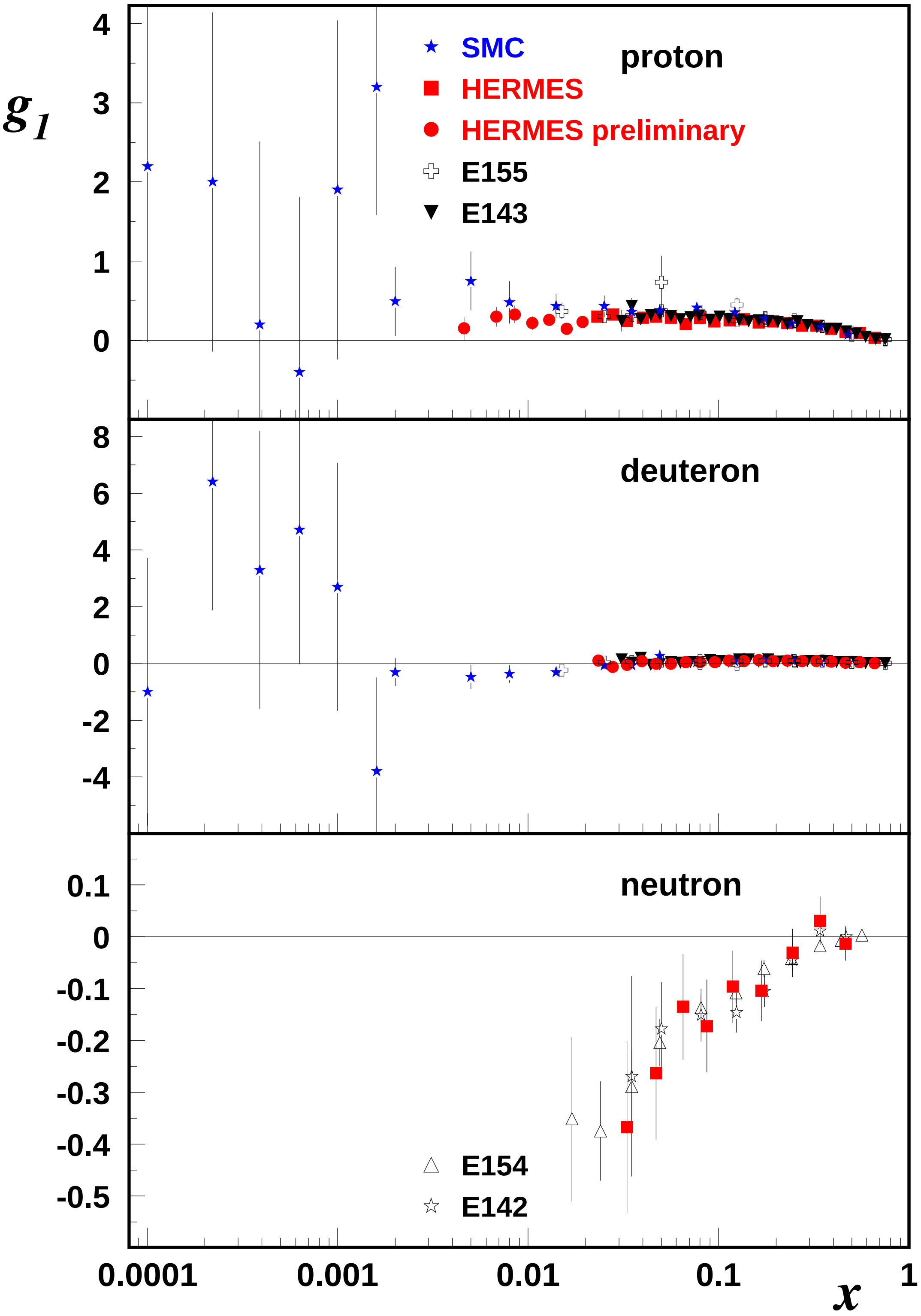
- new preliminary HERMES results for the spin structure function g_1
  - for the proton in the extended kinematic range $0.0021 < x < 0.0212$ and $0.1 < Q^2 < 0.8\ \mathrm{GeV}^2$
  - for the deuteron in the kinematic range $0.0212 < x < 0.85$ and $Q^2 > 0.8$ GeV^2
- very good agreement for resulting g_1/F_1 values with other experimental data

  $\Rightarrow$ no statistically significant Q^2 dependence observed for both proton and deuteron g_1/F_1 values
  - for deuteron analysis 6 times more statistics forthcoming in full HERMES kinematic range

- more precise data needed at low $x < 0.05$ and at higher $Q^2 > 10$ GeV^2

$\Rightarrow$ planning of forthcoming experiments (ELFE, TESLA-N, EPIC, eRHIC...) !

World data of g_1 versus x



Data points shown at measured Q^2 values.