Measurement of the spin structure functions $g_1^{p,d,n}$ and the gluon helicity $\Delta g/g$ at HERMES

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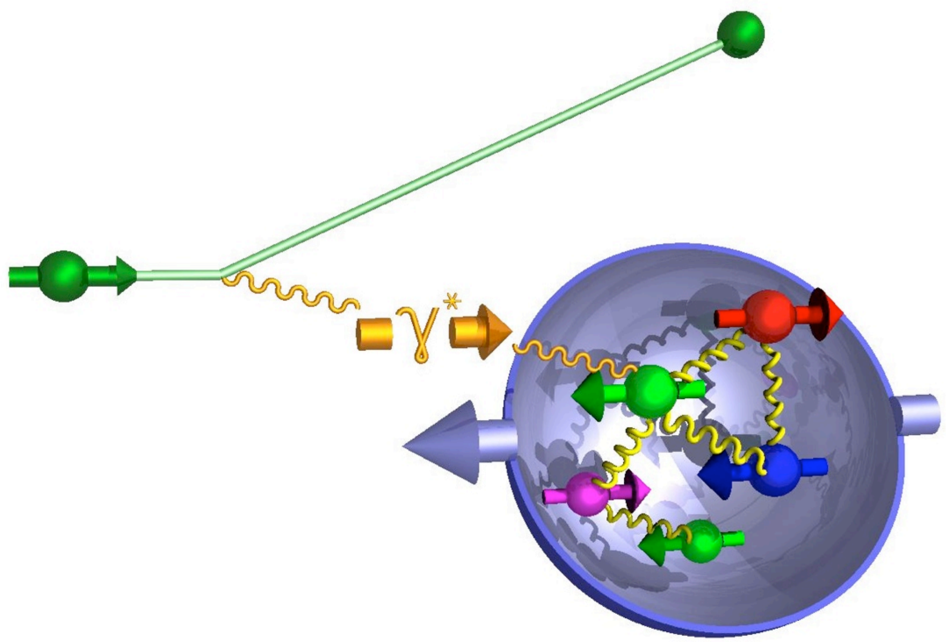
(DESY)

for the hermes collaboration

- g_1 from inclusive longitudinal double-spin asymmetries
- $\Delta g/g$ from high-p_t hadrons

g_1: Inclusive DIS

HERA:
e^+ @ 27.6 GeV
$P_B \sim 53\%$



long. pol. undiluted gas target:
H (P_z~ 76%, 85%)
D (P_z~ 84%)

Cross section ➡ structure functions

	F_1, F_2	unpol
	g_1, g_2	pol
	b_1 … b_4	pol (spin-1)

$$g_1(x, Q^2) = \frac{1}{2} \sum_q e_q^2 \left[\Delta q(x, Q^2) + \Delta \bar{q}(x.Q^2)\right]$$

in LO QCD

$$\Delta q = q_{\overset{\rightarrow}{\Rightarrow}} - q_{\overset{\rightarrow}{\Leftarrow}}$$

Measured Inclusive Asymmetries

$\boxed{P_{zz} = 0.83 \pm 0.03}$ $\boxed{A_{zz} \sim 0.01}$ $\Rightarrow \frac{b_1^d}{F_1^d} = -\frac{3}{2} A_{zz}$

(measured by HERMES)

$$\sigma = \sigma_{\text{unpol}} \left[1 + P_B P_z A_{\parallel} + \underbrace{\frac{1}{2} P_{zz} A_{zz}}_{\text{Deuterium}} \right]$$

measured DIS cross section

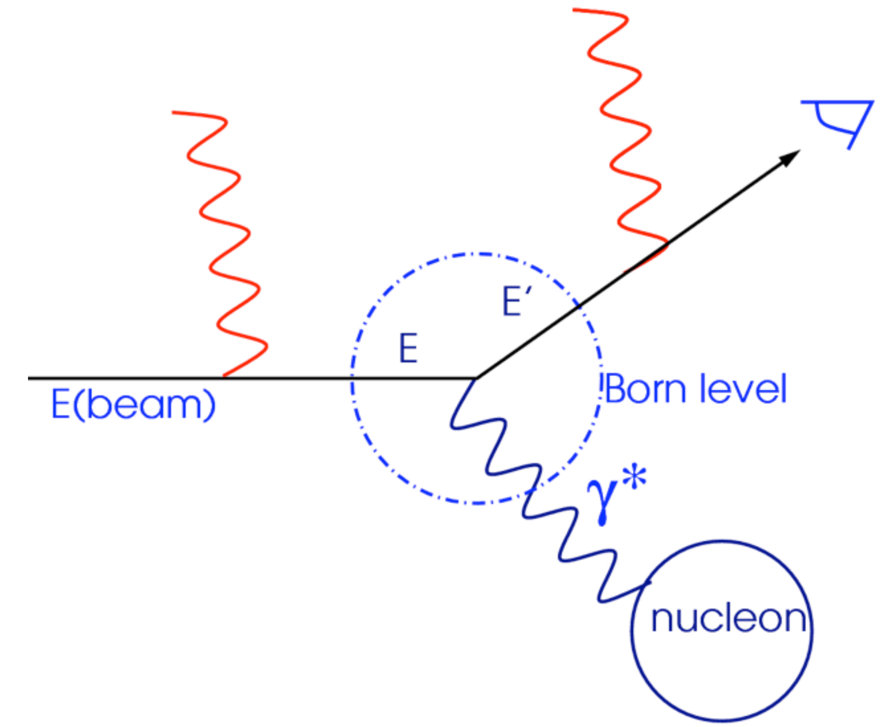
inclusive asymmetry:

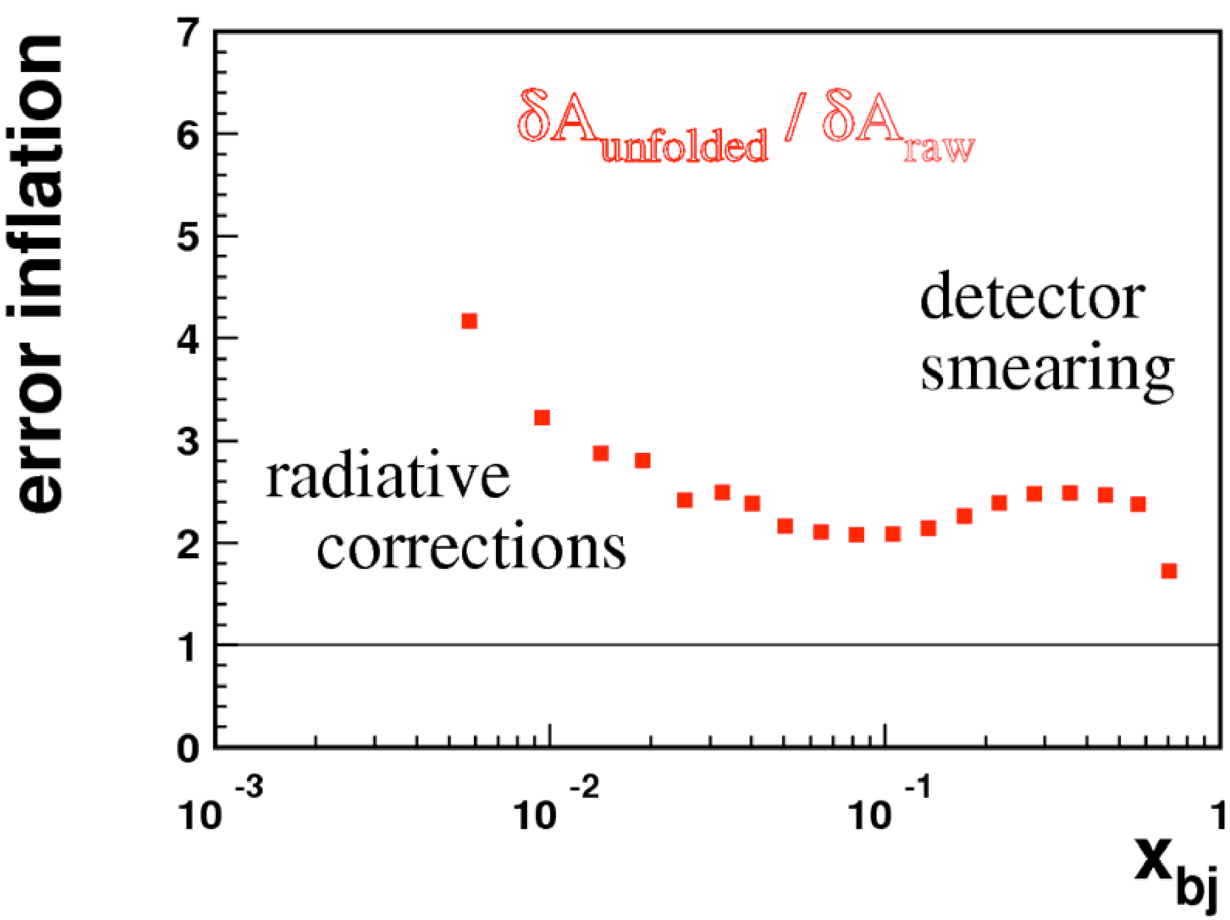
$$A_{\parallel} = \frac{\sigma^{\overleftarrow{\Leftarrow}} - \sigma^{\overrightarrow{\Rightarrow}}}{\sigma^{\overleftarrow{\Leftarrow}} + \sigma^{\overrightarrow{\Rightarrow}}} = \frac{1}{P_B P_z} \cdot \frac{\frac{N^{\overleftarrow{\Leftarrow}}}{L^{\overleftarrow{\Leftarrow}}} - \frac{N^{\overrightarrow{\Rightarrow}}}{L^{\overrightarrow{\Rightarrow}}}}{\frac{N^{\overleftarrow{\Leftarrow}}}{L^{\overleftarrow{\Leftarrow}}} + \frac{N^{\overrightarrow{\Rightarrow}}}{L^{\overrightarrow{\Rightarrow}}}}$$

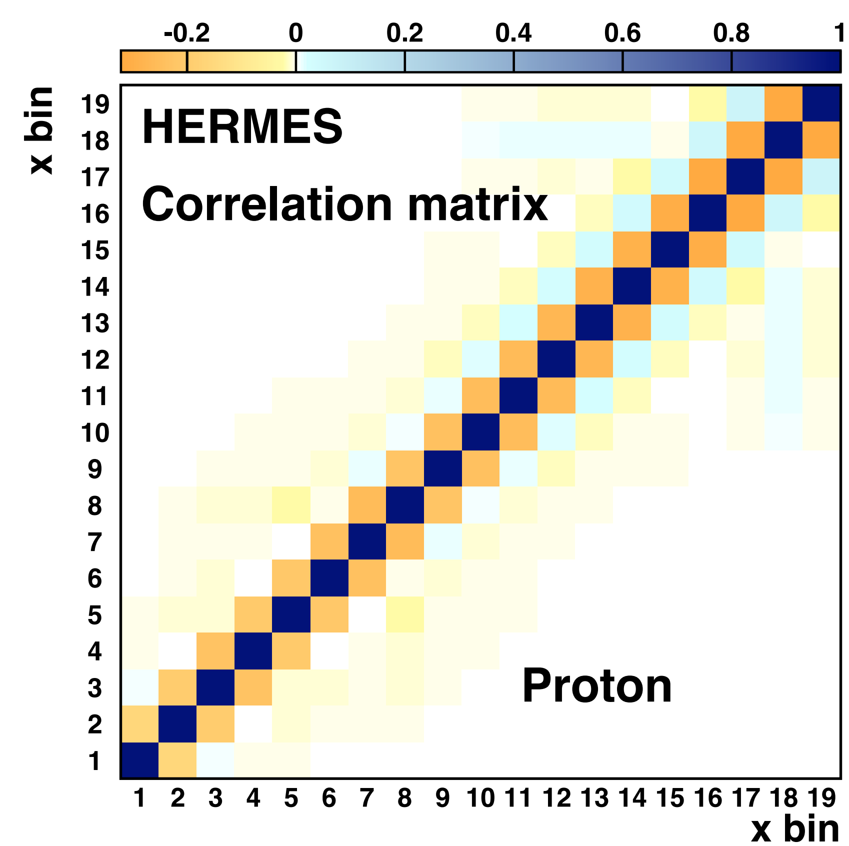
$$g_1(x, Q^2) = \underbrace{\frac{1}{1 - \frac{y}{2} - \frac{1}{4} y^2 \gamma} \left[\frac{Q^4}{8\pi\alpha^2 y} \right.}_{\text{kinematic factors}} \underbrace{\frac{\partial^2 \sigma_{\text{unpol}}}{\partial x \partial Q^2}}_{\text{param.}} \underbrace{A_{\parallel}(x, Q^2)}_{\text{meas.}} + \underbrace{\frac{y}{2} \gamma^2}_{\text{kin. fac.}} \left. \underbrace{g_2(x, Q^2)}_{\text{param.}} \right]$$

Unfolding of radiative effects

- Measured events have to be corrected for:
  - Background tail (radiation from (quasi)-elastic)
  - Radiation from DIS and detector smearing
- Event migration is simulated by Monte Carlo which includes a full detector description and a model for the cross section
- The approach is independent on the model for the asymmetry in the measured region

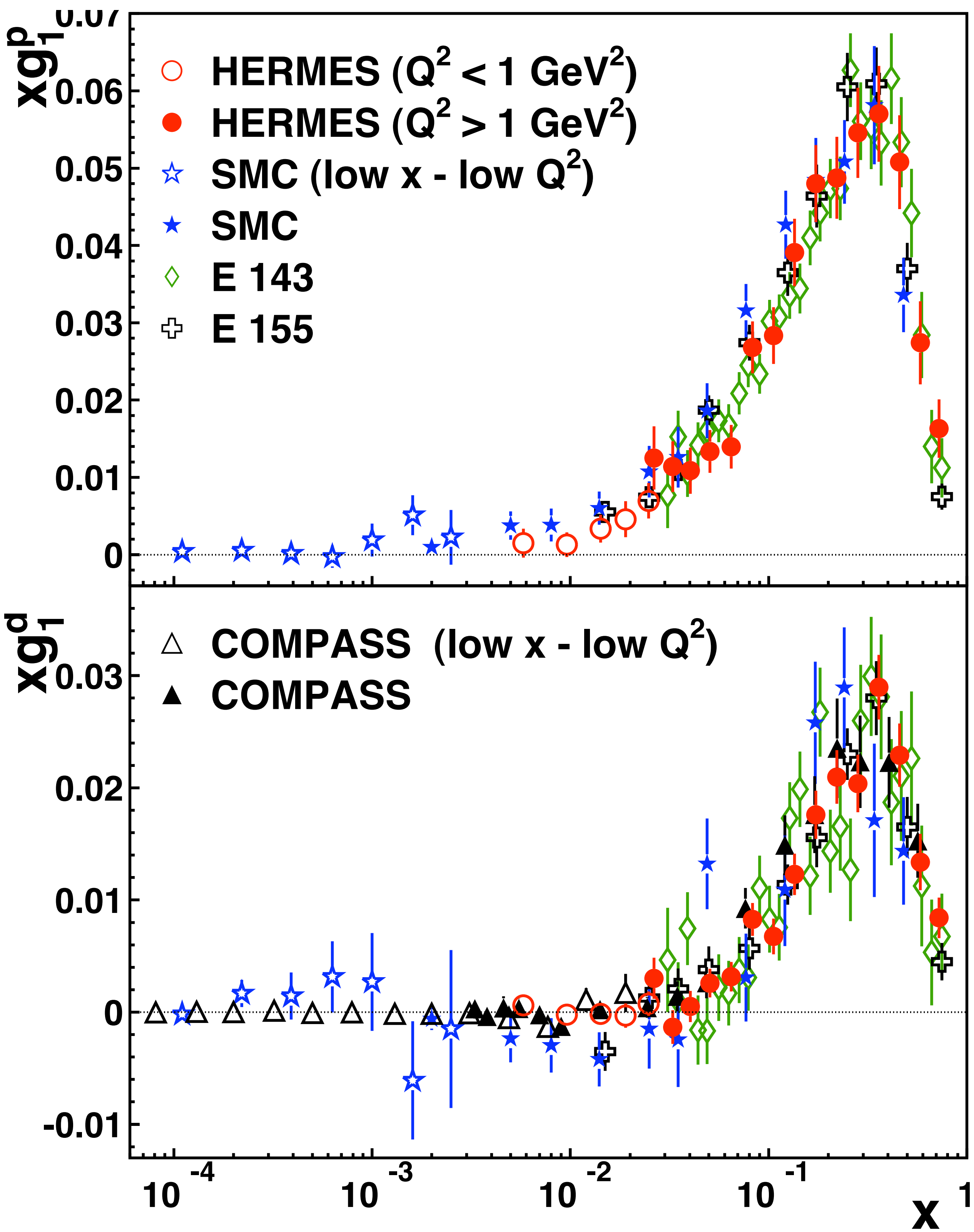






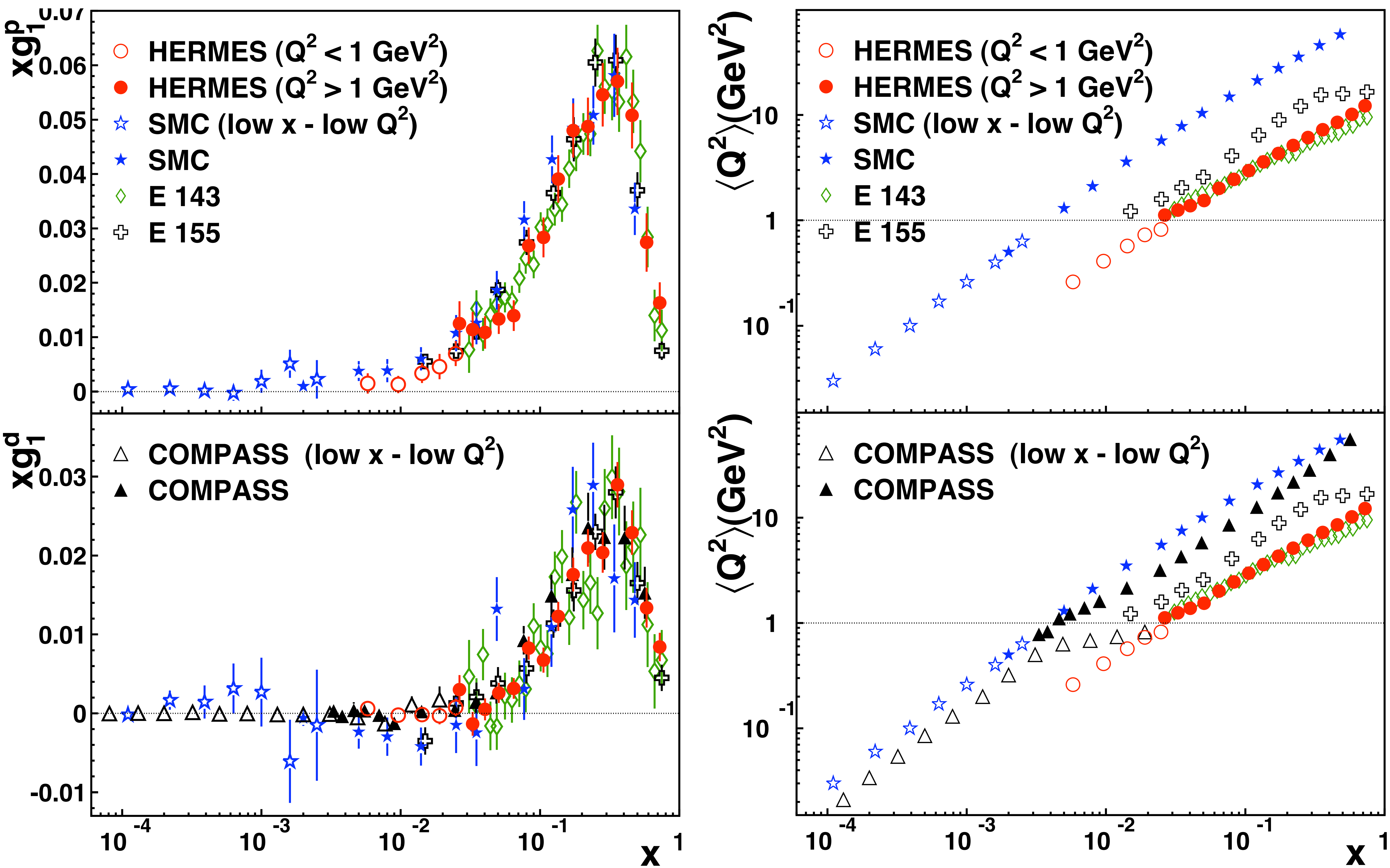
Correction introduces statistical correlation

g_1 : Results for p and d

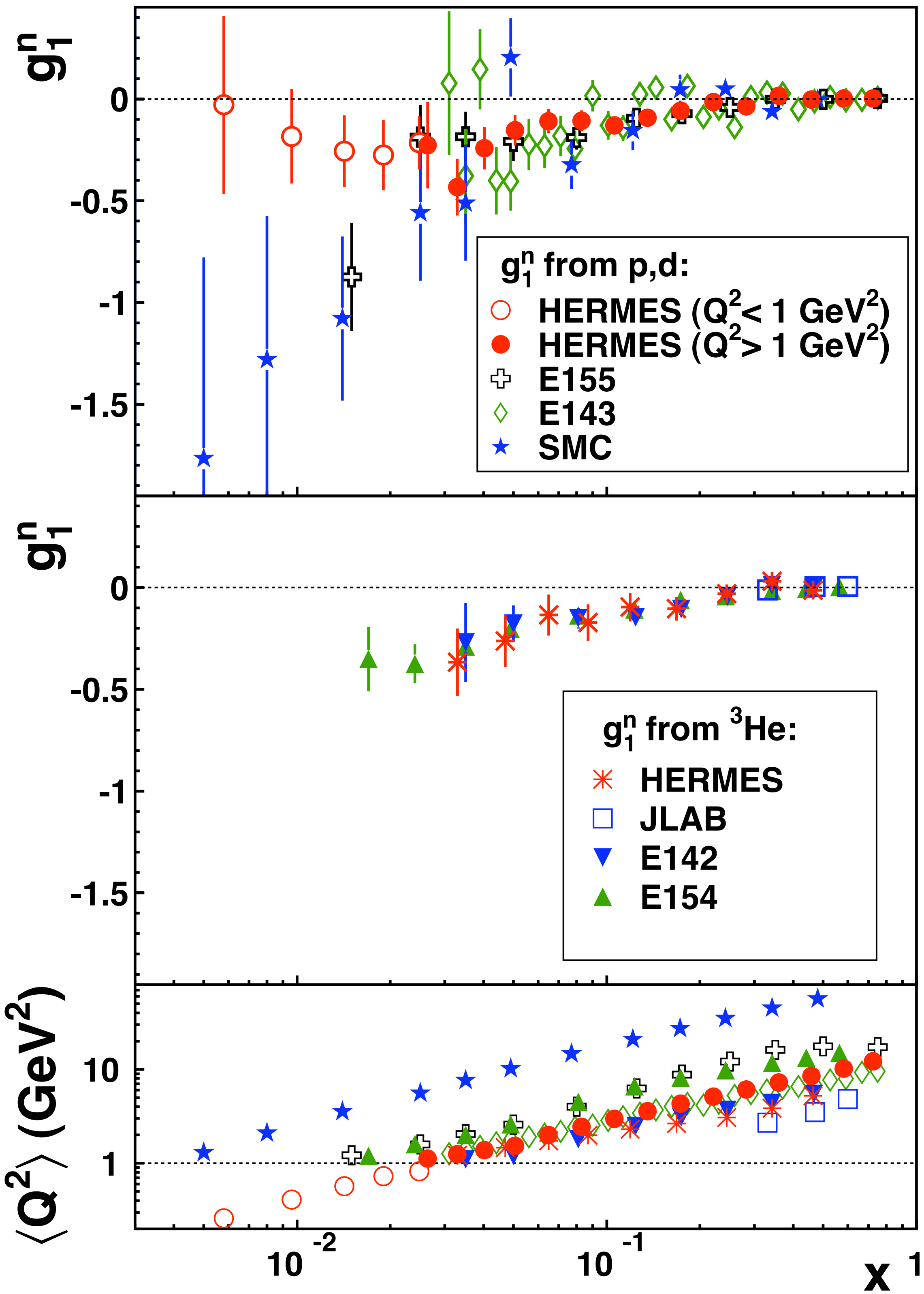


- HERMES points: stat. and syst. errors added in quadrature
  - Stat. uncertainties are diagonal elements of covariance matrix
  - Syst. uncertainties dominated by target and beam polarisation
- Deuteron data:
  - Most precise published data in valence x region
- Proton data:
  - Stat. precision comparable to previous data
- Q^2 different from SMC/COMPASS

g_1 : Results for p and d



g_1 : Neutron results

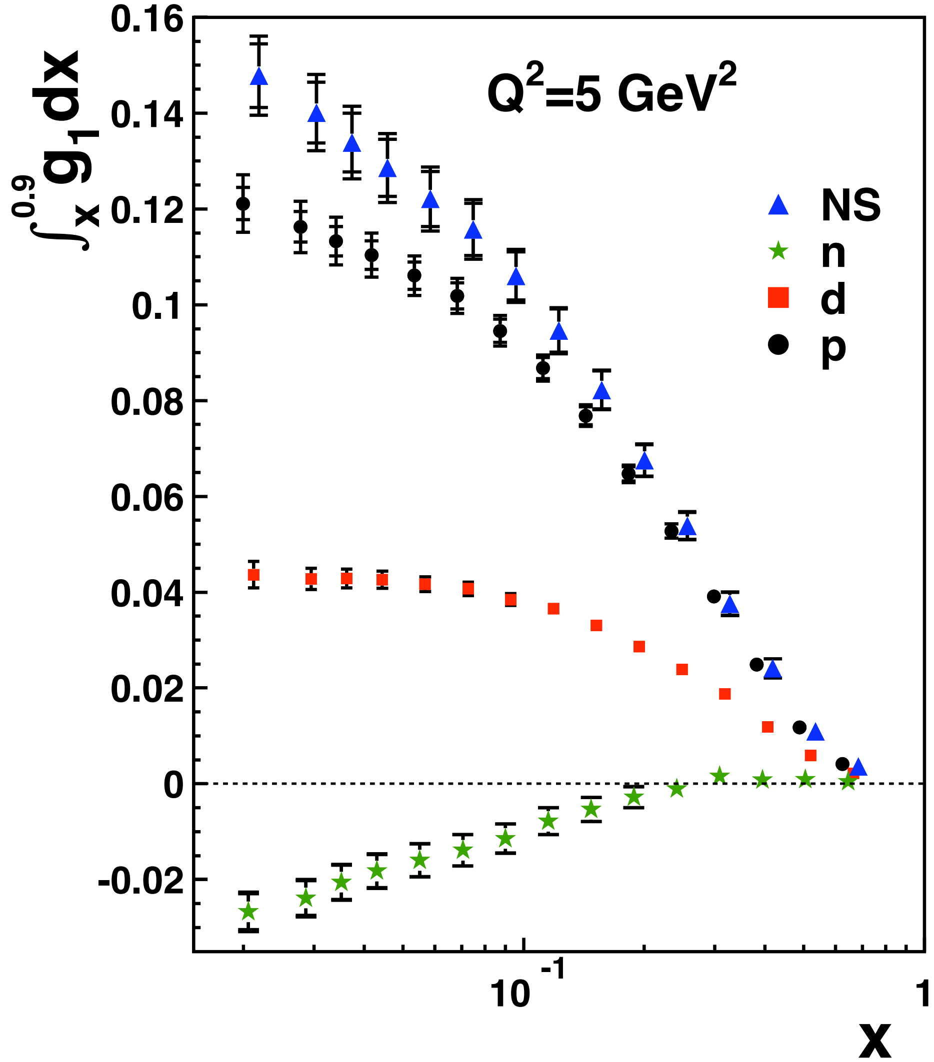


$$g_1^n = \frac{2}{1 - \frac{3}{2}\omega_D} \cdot g_1^d - g_1^p$$

$$\boxed{\omega_D = 0.05 \pm 0.01}$$

- $g_1{}^n$ negative everywhere except at very high x
- Low-Q^2 data tends to zero at low x
  - Contrary to SMC data at higher Q^2

g_1 : Integrals



$$\Gamma_1^d = \int dx\, g_1^d$$

Assuming saturation in the deuteron integral:

➠ Use only deuteron data!

$$\Gamma_1^d = \left(1 - \frac{3}{2}\omega_D\right)\frac{1}{36}\left[4a_0\Delta C_S^{\overline{MS}} + a_8\Delta C_{NS}^{\overline{MS}}\right]$$

$$a_0 \overset{\overline{MS}}{=} \Delta\Sigma$$

in NNLO	central value	uncertainties theor.	exp.	evol.
a_0	0.330	0.011	0.025	0.028
$\Delta u + \Delta\bar{u}$	0.842	0.004	0.008	0.009
$\Delta d + \Delta\bar{d}$	-0.427	0.004	0.008	0.009
$\Delta s + \Delta\bar{s}$	-0.085	0.013	0.008	0.009

$Q^2 = 5\text{GeV}^2$, NNLO in $\overline{\text{MS}}$ scheme

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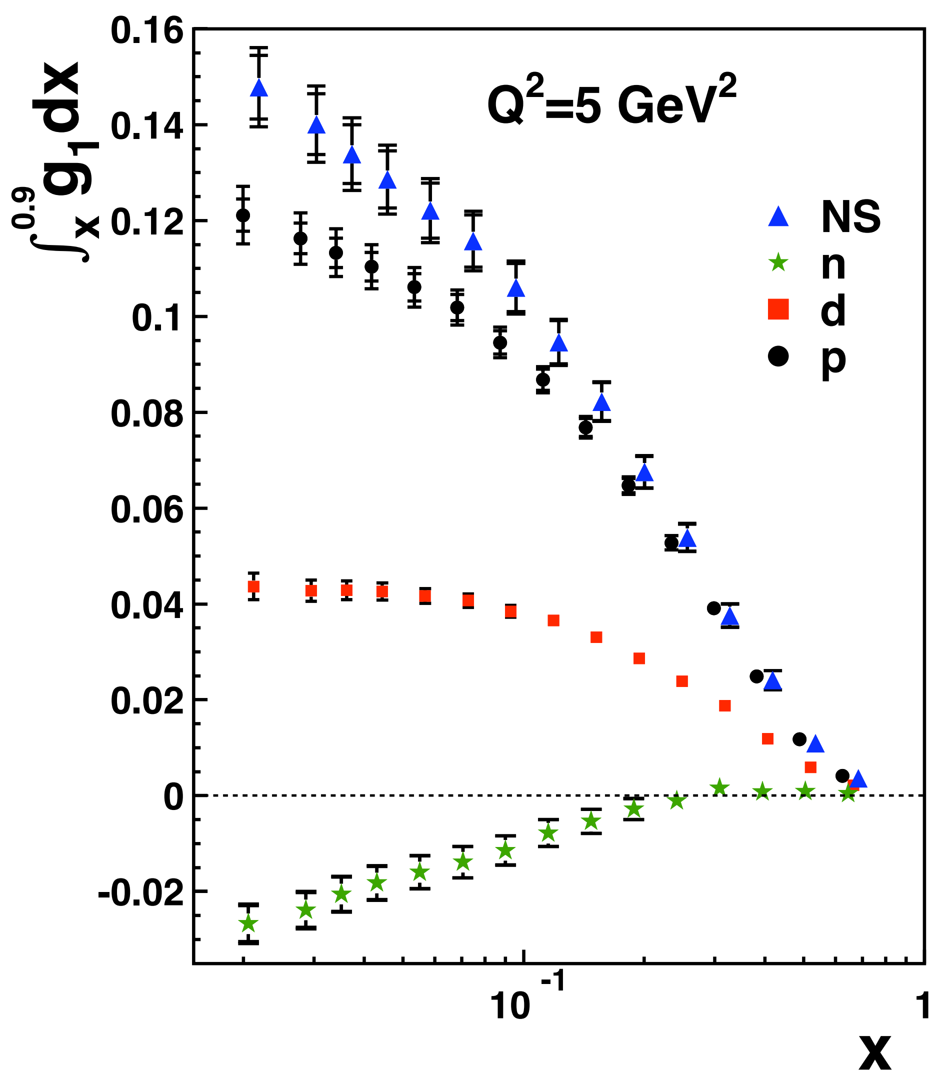

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from hyperon beta decay (a_8=0.586±0.031)

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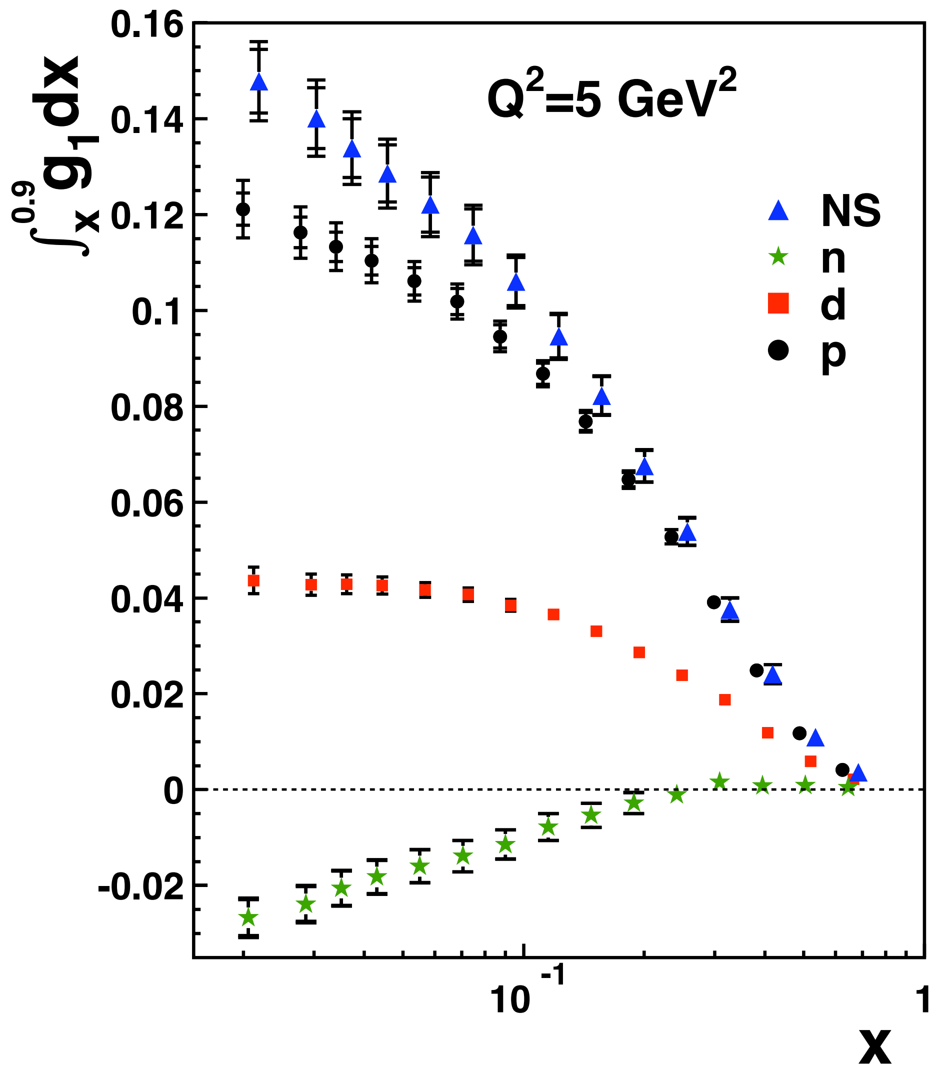

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from hyperon beta decay (a_8=0.586±0.031)

$$a_0 \overset{\overline{MS}}{=} \Delta\Sigma$$

$$\Delta u + \Delta\bar{u} = \frac{1}{6}\left[2a_0 + a_8 + 3a_3\right]$$

$$\Delta d + \Delta\bar{d} = \frac{1}{6}\left[2a_0 + a_8 - 3a_3\right]$$

$$\Delta s + \Delta\bar{s} = \frac{1}{3}\left[\ a_0 - a_8\right]$$

from neutron beta decay (a_3=1.269±0.003)

in NNLO	central value	uncertainties theor.	exp.	evol.
a_0	0.330	0.011	0.025	0.028
$\Delta u + \Delta\bar{u}$	0.842	0.004	0.008	0.009
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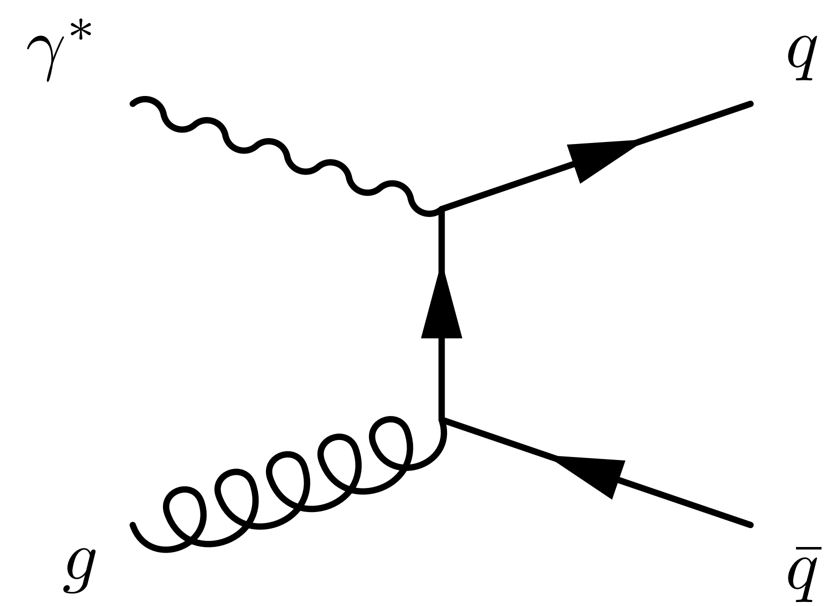
How to measure Δg?

- Indirect from scaling violation of g_1
  - for fixed target experiment small x-Q^2 lever arm
- Direct measurement:
  via processed with the gluon of the nucleon in the initial state
  Photon-Gluon-Fusion (PGF)



- Measure longitudinal double-spin asymmetries of high-p_t hadrons vs p_t for:
  - "anti-tagged" data: scattered lepton not in acceptance (p_t with respect to the beam axis)
  - "tagged" data: scattered lepton detected
  - inclusive pairs of charged hadrons

  low statistics

Extraction Method

- Measured asymmetry is an incoherent superposition of different sub-process asymmetries:

$$A_{\parallel}^{\text{meas}}(p_t) = \sum_i f_i A_{\parallel}^i = f_{\text{Sig}} A_{\parallel}^{\text{Sig}} + f_{\text{Bg}} A_{\parallel}^{\text{Bg}} \qquad f_i = \frac{\sigma_i}{\sigma_{\text{tot}}}$$

Signal: Gluon of the nucleon in the initial state

$$A_{\parallel}^{\text{Sig}}(p_t) \propto \int_{x(p_t)} dx\, \sigma(x, p_t)\hat{a}(x, p_t)\frac{\Delta g(x)}{g(x)}$$

Background: all other sub-processes ➟ MC

- Two methods to extract $\Delta g/g$
  - Method I: $\Delta g(x)/g(x)=\text{const}$
  - Method II: $\Delta g(x)/g(x)=x(1+p_1(1-x)^2+p_2(1-x)^3)$

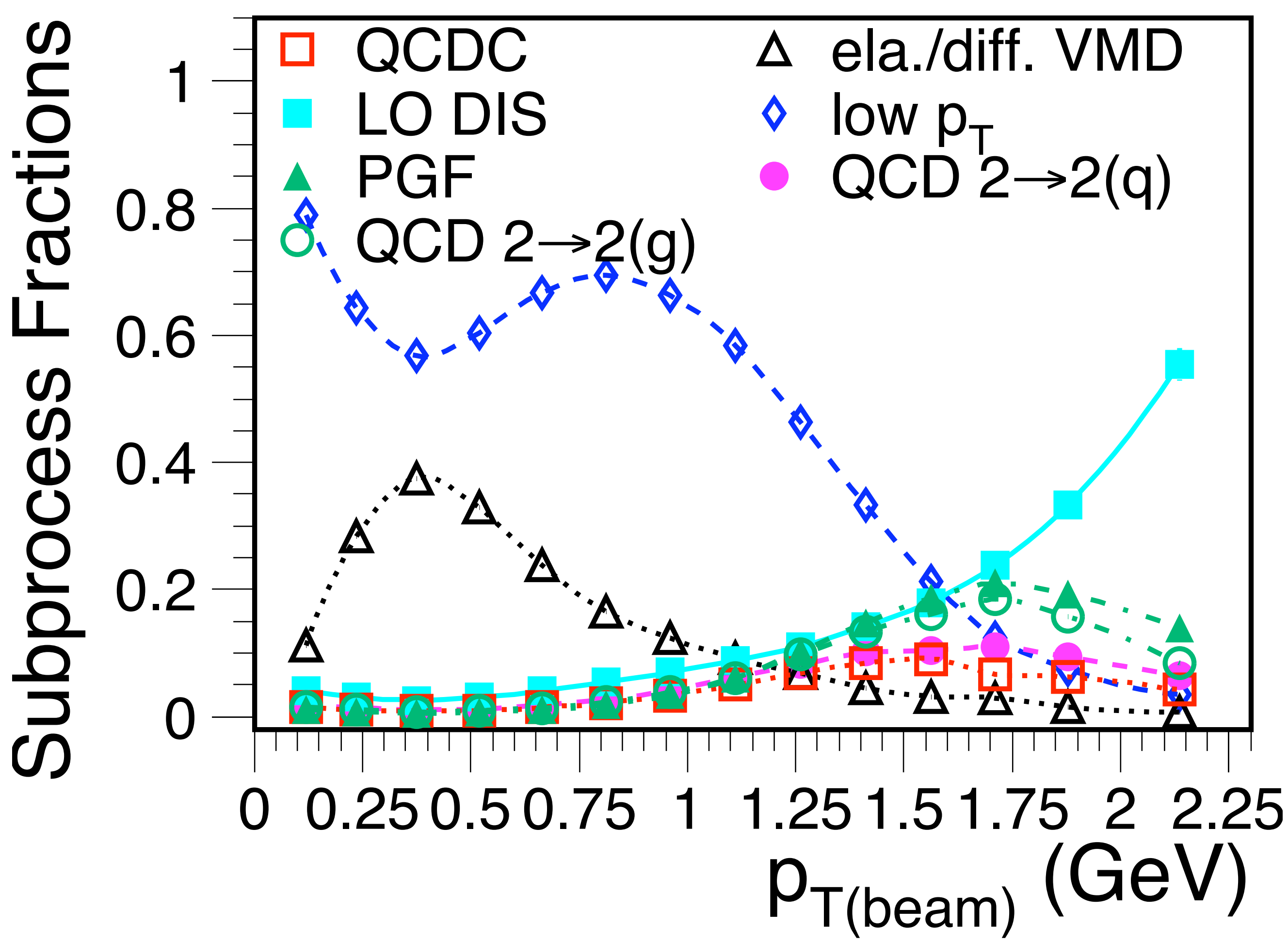
Models and Assumptions

- MC model
  - PYTHIA 6.2 ,tuned and adapted for HERMES data
    fragmentation process, exclusive ρ^0 cross section (VMD)
- provides
  - relative contributions f_i of the background and signal subprocesses in the relevant p_t range
  - background asymmetries and the hard subprocess asymmetries of the signal processes
    - weight calculated for every MC event
    - PDFs (unpol/pol): CTEQ5L/GRSV2000 (nucleon), SaS2/GRS (photon)
    - Asymmetry assumptions for soft processes (soft VMD)
- Vary PDFs/assumptions for syst. error

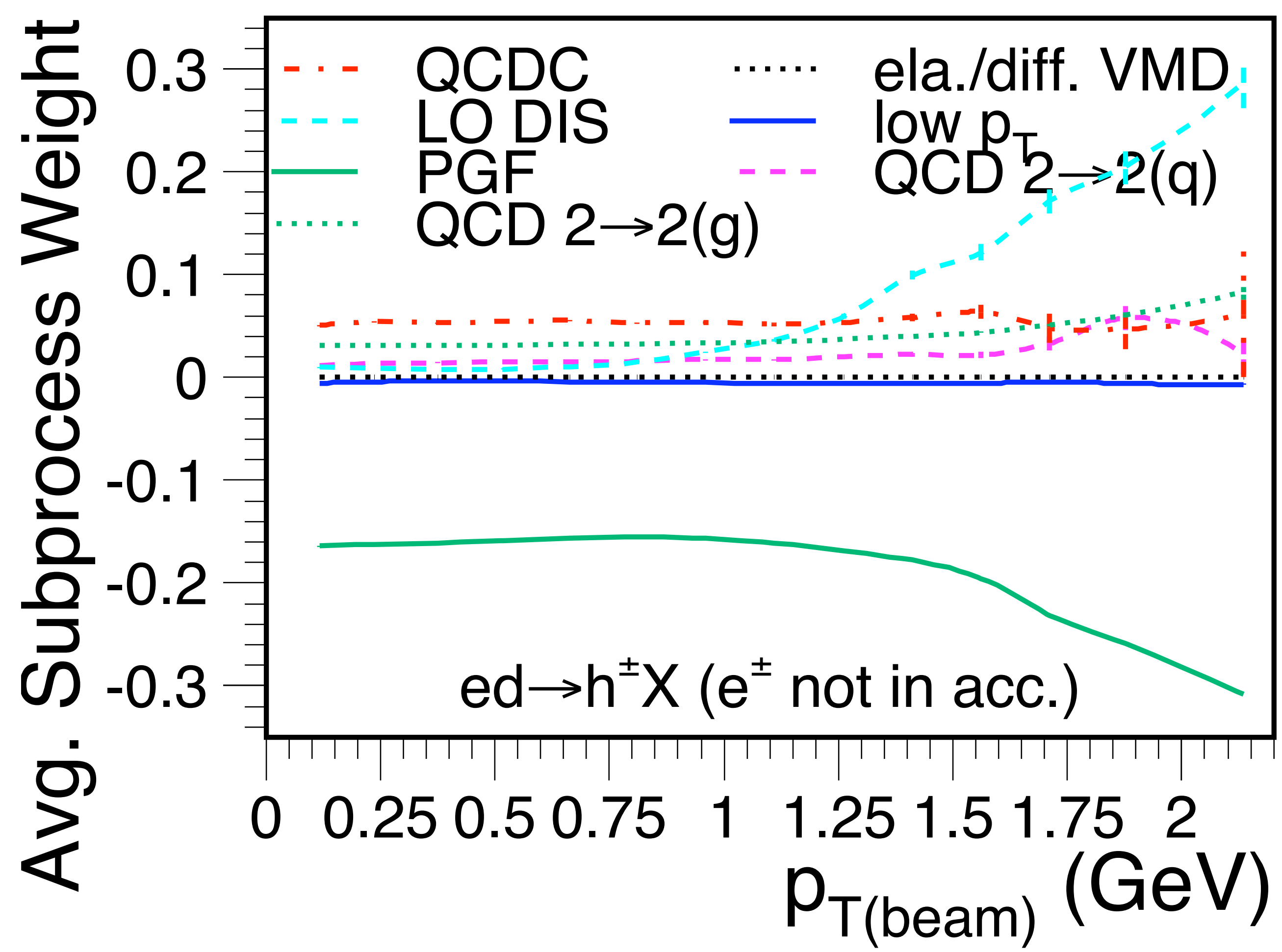
Fractions and Asymmetries

(anti-tagged data)

Sub-process fraction



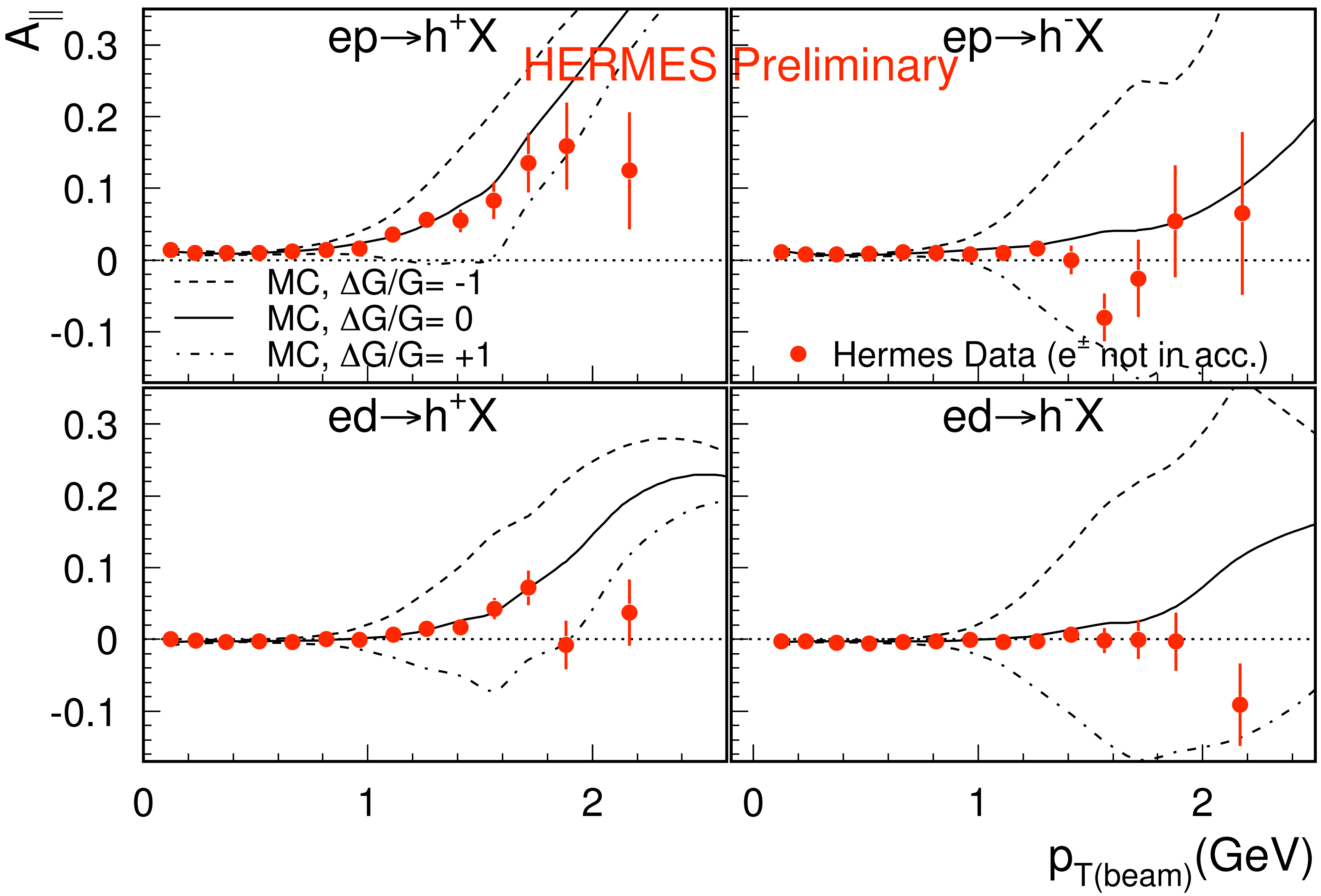
Sub-process asymmetries (using GRSV std.)



- DIS dominating at high p_t
- Signal processes are PGF and QCD2→2(g) (resolved photon)

- Background processes have (mostly) small and positive asymmetries
- |PGF| increasing with p_t, negative (for positive dg/g from GRSV)

Asymmetries



- Anti-tagged data:
  - Scattered lepton not in acceptance
  - p_t measured with respect to beam axis
- Curves from MC +asymmetry model using:
  - $\Delta g/g(x)=0$: central
  - $\Delta g/g(x)=-1$: upper
  - $\Delta g/g(x)=+1$: lower

$\Delta g/g(x)=0$ asymmetry is due to quarks only!
Gluons become important for the cross section (asymmetry) above $p_t \approx 1$ GeV

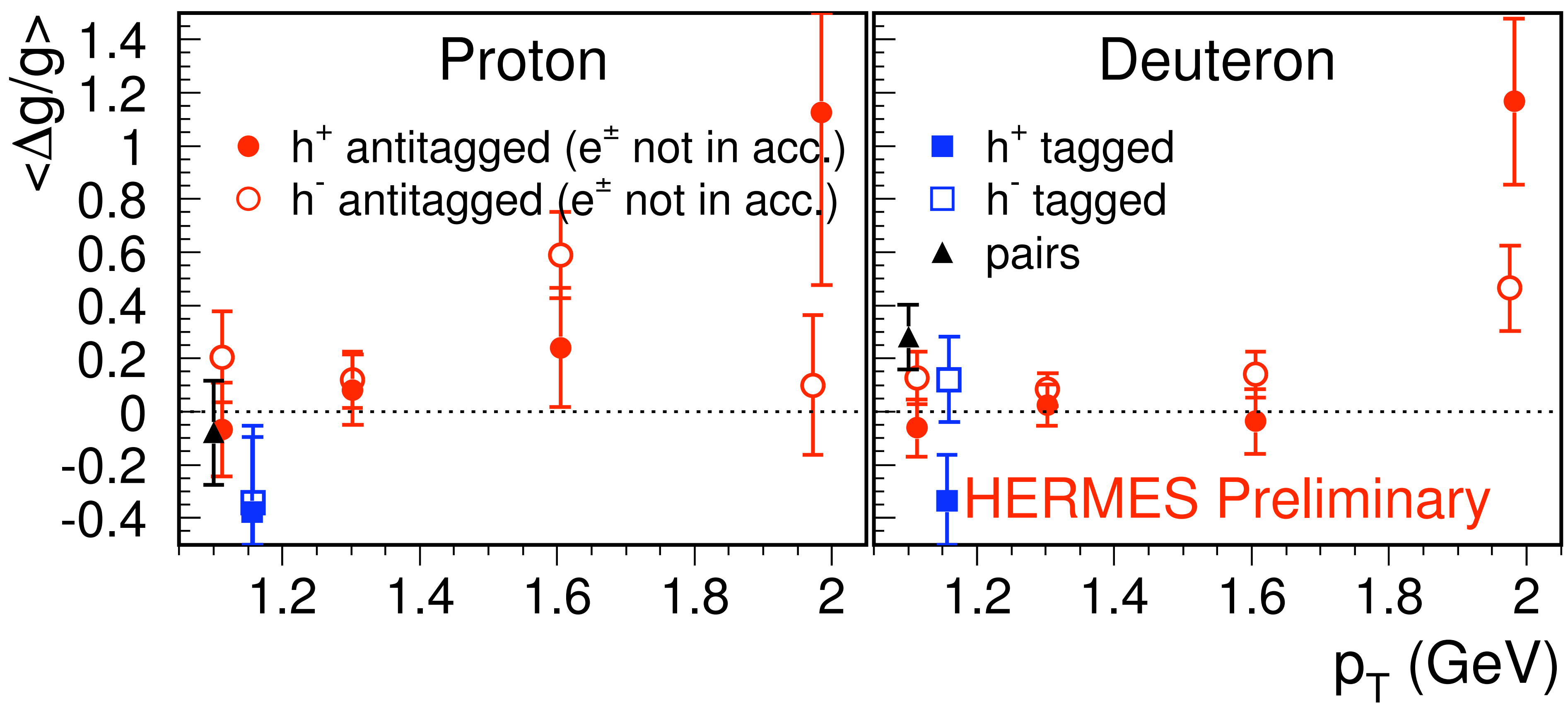
Δg/g: Method I

assume Δg(x)/g(x) const. over x: $\langle \frac{\Delta g}{g} \rangle = \frac{1}{f_{\mathrm{Sig}} \langle \hat{a} \rangle} \left[A_{\parallel}^{\mathrm{meas}} - f_{\mathrm{Bg}} A_{\parallel}^{\mathrm{Bkg}} \right]$

h^+, h^- anti-tagged
4 points between
$1.05 < p_t < 2.5$ GeV

h^+, h^- tagged
1 point for
$p_t > 1$ GeV

h pairs
1 point for
$\sum p_t^2 > 2\mathrm{GeV}$



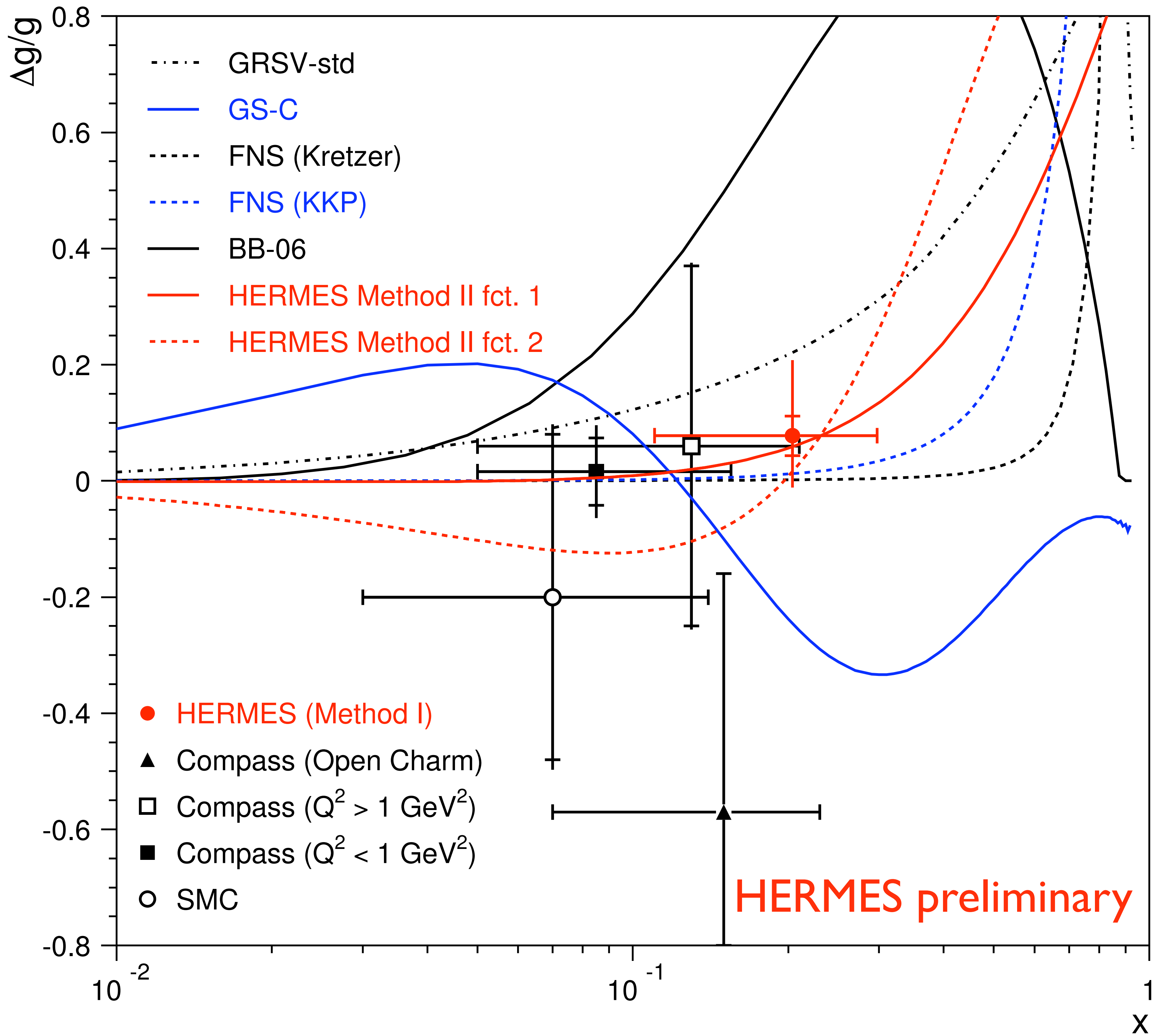
- Results for different data samples agree within statistics
- Dominating sample: Deuteron antitagged
  ➡Used for Method II

Δg/g: World data

- Black and blue curves: pQCD fits to g_1
- Red curves (Method II): fit $\Delta g(x)/g(x)$ such that

$$A_{\parallel}^{\mathrm{MC}} = A_{\parallel}^{\mathrm{meas}}$$

- Sys. model uncert. dominating:
  - PDFs
  - PYHTIA model



Conclusions

- HERMES has measured g_1 for proton and deuteron for $0.0041<x<0.9$ and $0.18<Q^2<20$ GeV^2
- Proton data precision is comparable with CERN and SLAC
- Deuteron data is the most precise so far
- The deuteron integral is observed to saturate

$$\Rightarrow \quad a_0 = 0.330 \pm 0.011(\text{theor}) \pm 0.025(\text{exp.}) \pm 0.028(\text{evol})$$

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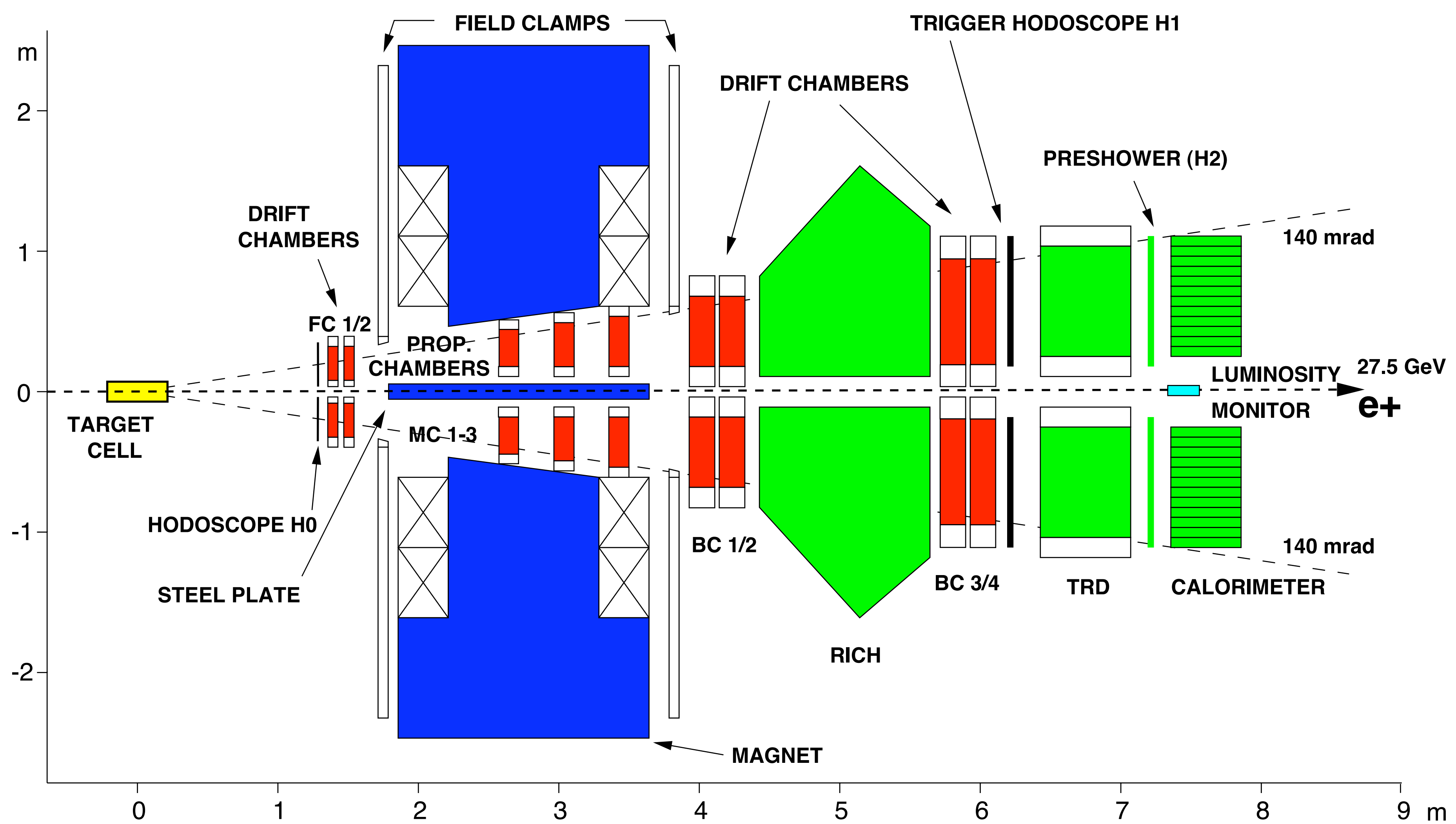
- $\Delta g/g$ has been extracted using two different methods
- $\Delta g/g$ is likely small
- Method I: $\frac{\Delta g}{g}(x,\mu^2) = 0.078 \pm 0.034(\text{stat}) \pm 0.011(\text{sys}-\text{exp})\,^{+0.125}_{-0.082}(\text{sys}-\text{Models})$
- Method II: $\frac{\Delta g}{g}(x,\mu^2) = 0.071 \pm 0.034(\text{stat}) \pm 0.010(\text{sys}-\text{exp})\,^{+0.127}_{-0.105}(\text{sys}-\text{Models})$

Additional slides

HERMES



Internal gas target: pol. : He, H, D

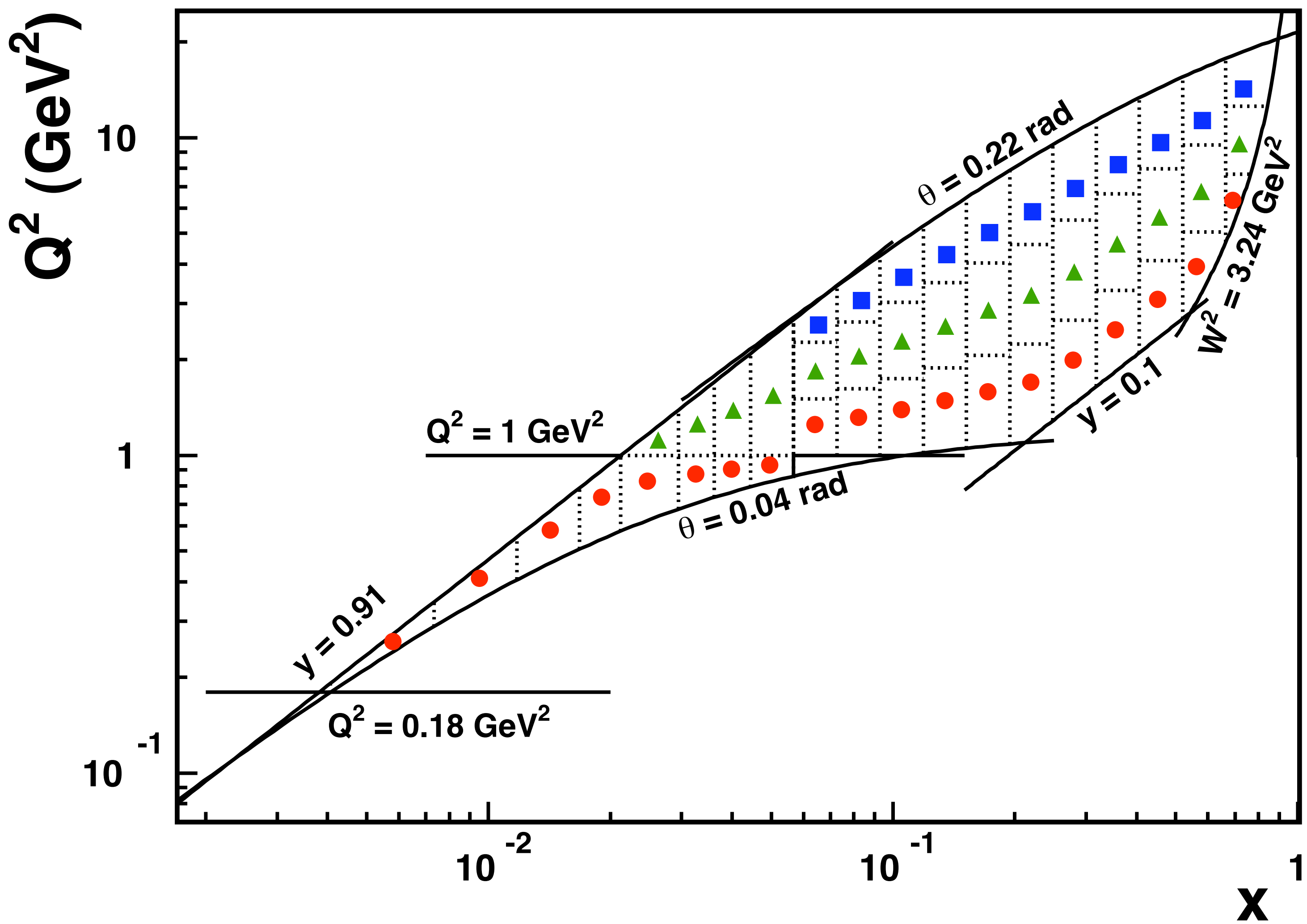
unpol: H_2, D_2, He, N_2, Ne, Kr, Xe

Particle ID: TRD, Preshower, Calorimeter, Cerenkov (until 1997), RICH (since 1998)

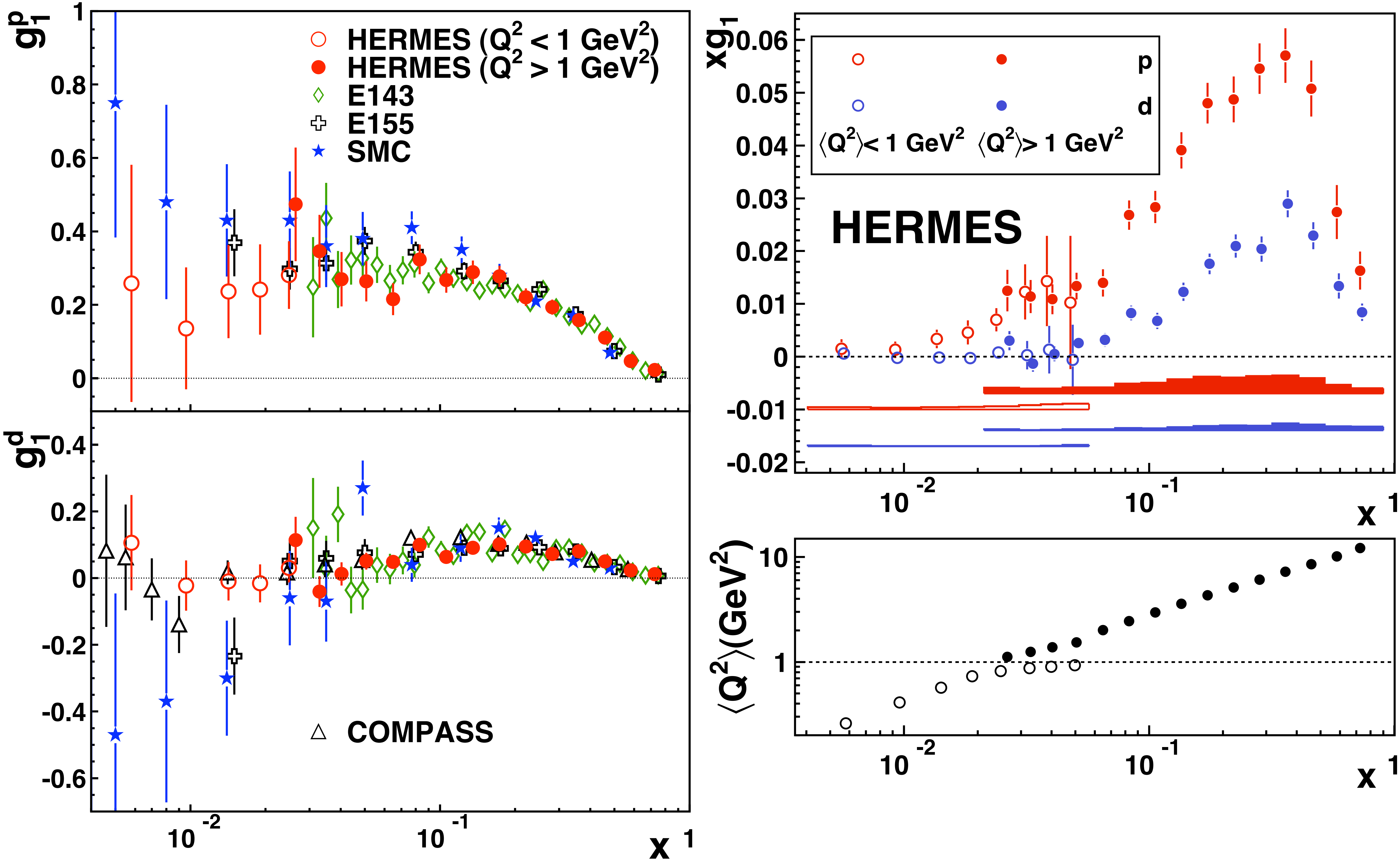
Reconstruction: $\Delta p/p < 2\%$, $\Delta\Theta < 1$ mrad

g_1: Data Set and Binning

Target	Year	Luminosity (pb^{-1})	#	P_{Target}(%)	P_{Beam}(%)
H	1996	12.6	670,000	75.9±3.2	~53±1.8
H	1997	37.3	2,800,000	85.1±3.2	
D	2000	138.7	10,900,000	85.1±3.2(+) 84.0±3.1(-)	~53±1.0

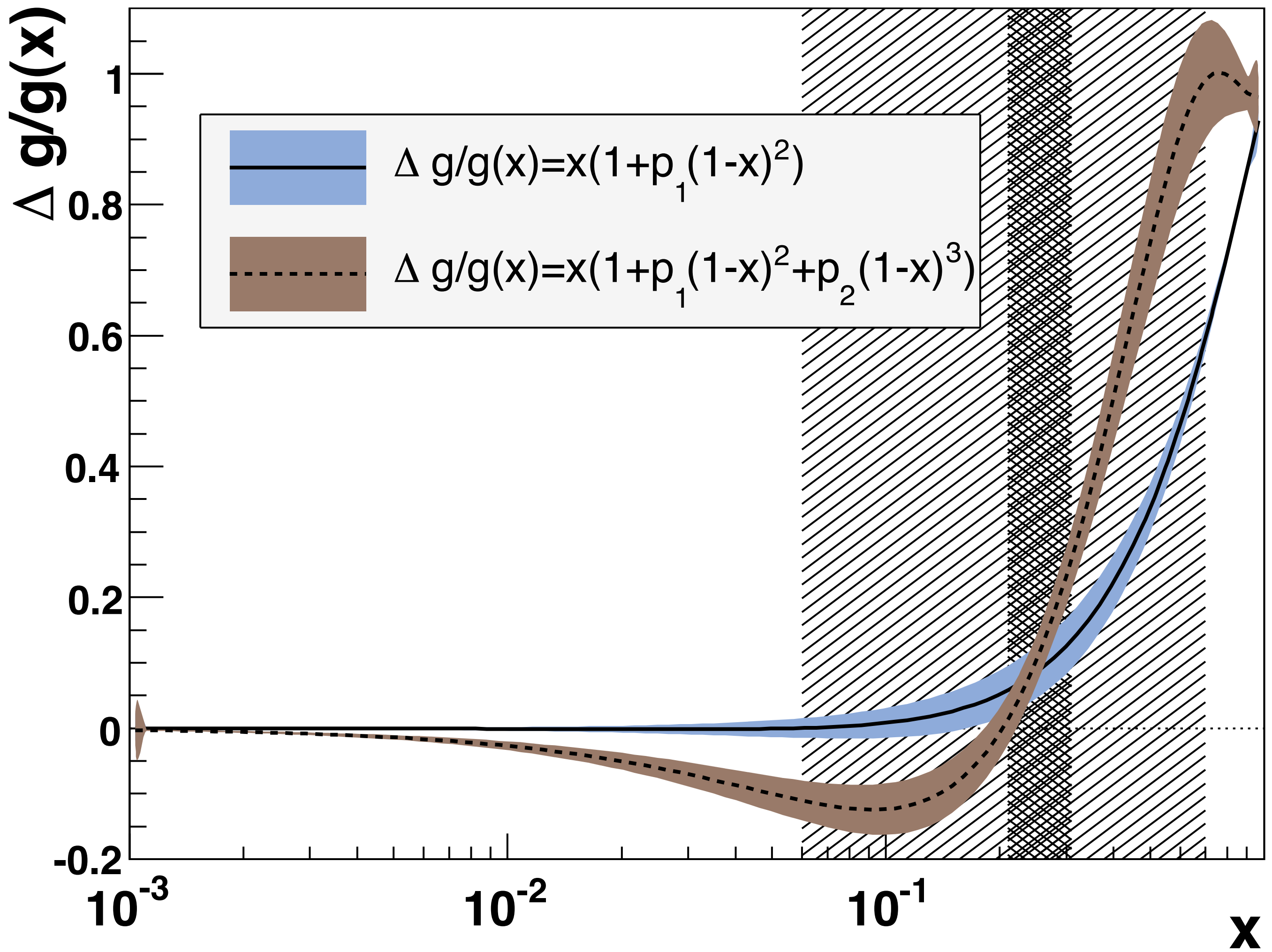


$g_1^{p,d}$



g_1^p
HERMES (Q^2 < 1 GeV^2)
HERMES (Q^2 > 1 GeV^2)
E143
E155
SMC
g_1^d
COMPASS
x
xg_1
p
d
$\langle Q^2\rangle$< 1 GeV^2 $\langle Q^2\rangle$> 1 GeV^2
HERMES
$\langle Q^2\rangle$(GeV^2)

Fit results (Method II)



- Light shaded area: range of data
- Dark shaded area: center of gravity for fit

- Functions are polynomials with 1 or 2 free parameters
- Fix $\Delta g/g \rightarrow x$ for $x \rightarrow 0$ and $\Delta g/g \rightarrow 1$ for $x \rightarrow 1$ (Brodsky et al.)
- $|\Delta g(x)/g(x)|<1$ for all x
- Difference between functions is systematic uncertainty