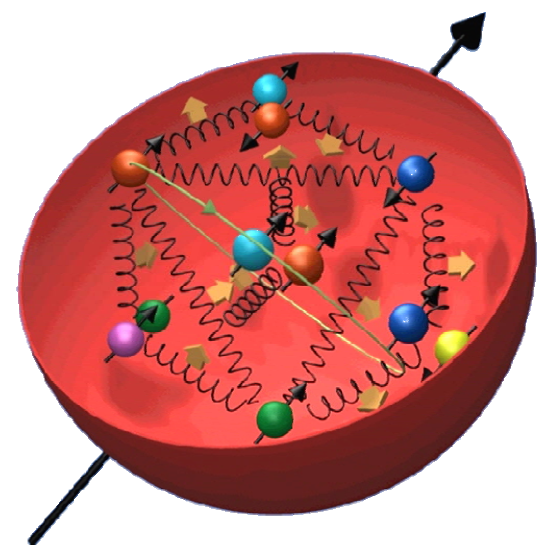
Polarised DIS Experiment

Lecture II

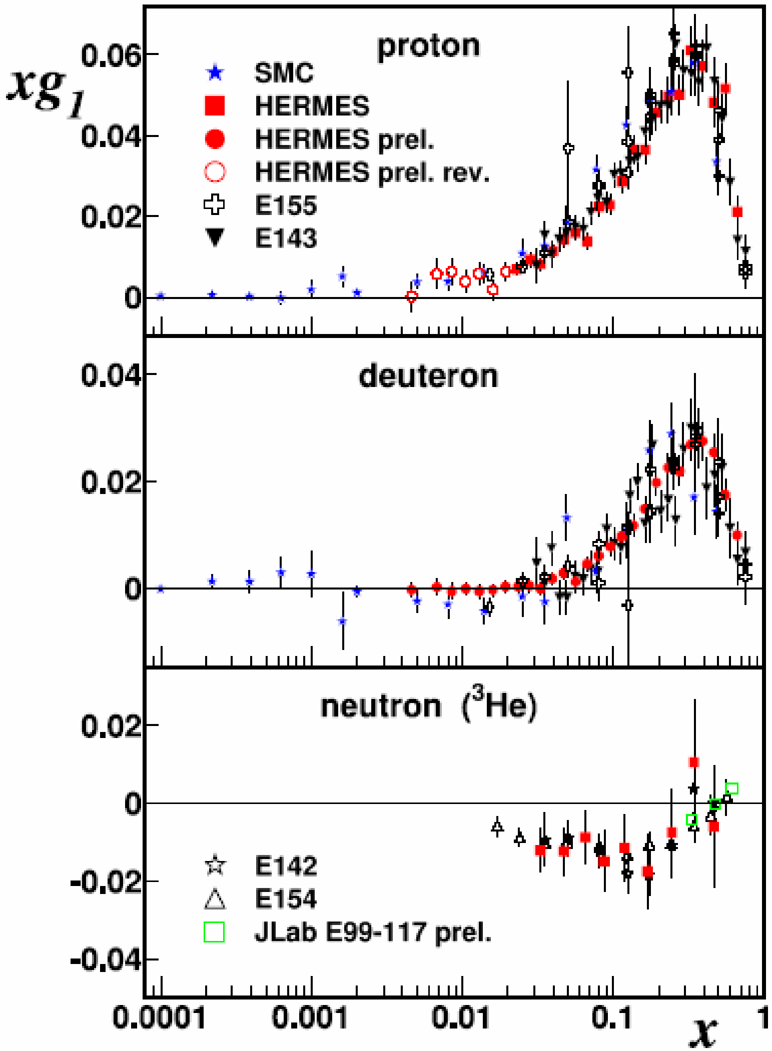
Gerhard Mallot



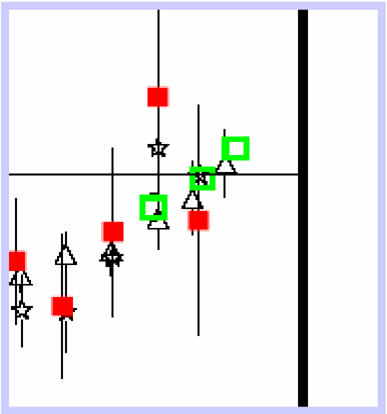
Plan

- QCD analysis of $g_1(x,Q^2)$ and PDFs
- status of g_2
- semi-inclusive scattering and flavour decomposition
- transversity h_1 and Collins asymmetry
- the hunt for ΔG
  - *high-p_T* hadron pairs
  - *open charm* production
- summary

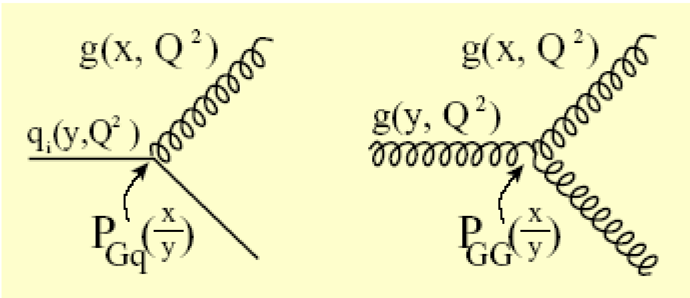
Status of g_1

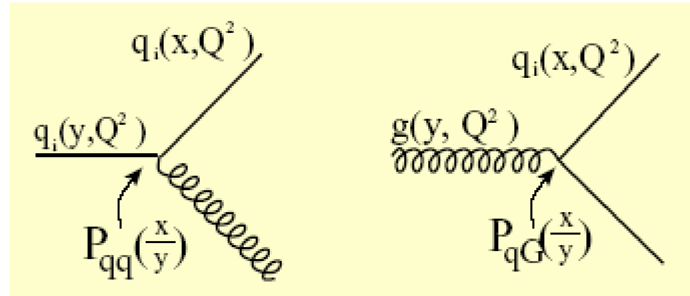


- Wealth of data g_1 data for p, n and d
- Data taken at different Q^2
- Only weak Q^2-dependence in overlap region
- Interesting data from JLAB at large x for neutron: $g_1^n > 0$



Q^2 Evolution





splitting functions

non-singlet quark distribution

$$\Delta q^{\mathrm{ns}}(x,Q^2) = \sum_{i=1}^{n_f} \left(\frac{e_i^2}{\langle e^2 \rangle} - 1 \right) \Delta q_i(x,Q^2)$$

singlet quark distribution

$$\Delta\Sigma(x,Q^2) = \sum^{n_f} \Delta q(x,Q^2)$$

$$\frac{\mathrm{d}}{\mathrm{d}\ln Q^2}\Delta q^{\mathrm{ns}} = \frac{\alpha_s}{2\pi}\Delta P_{qq}^{\mathrm{ns}} \otimes \Delta q^{\mathrm{ns}}$$

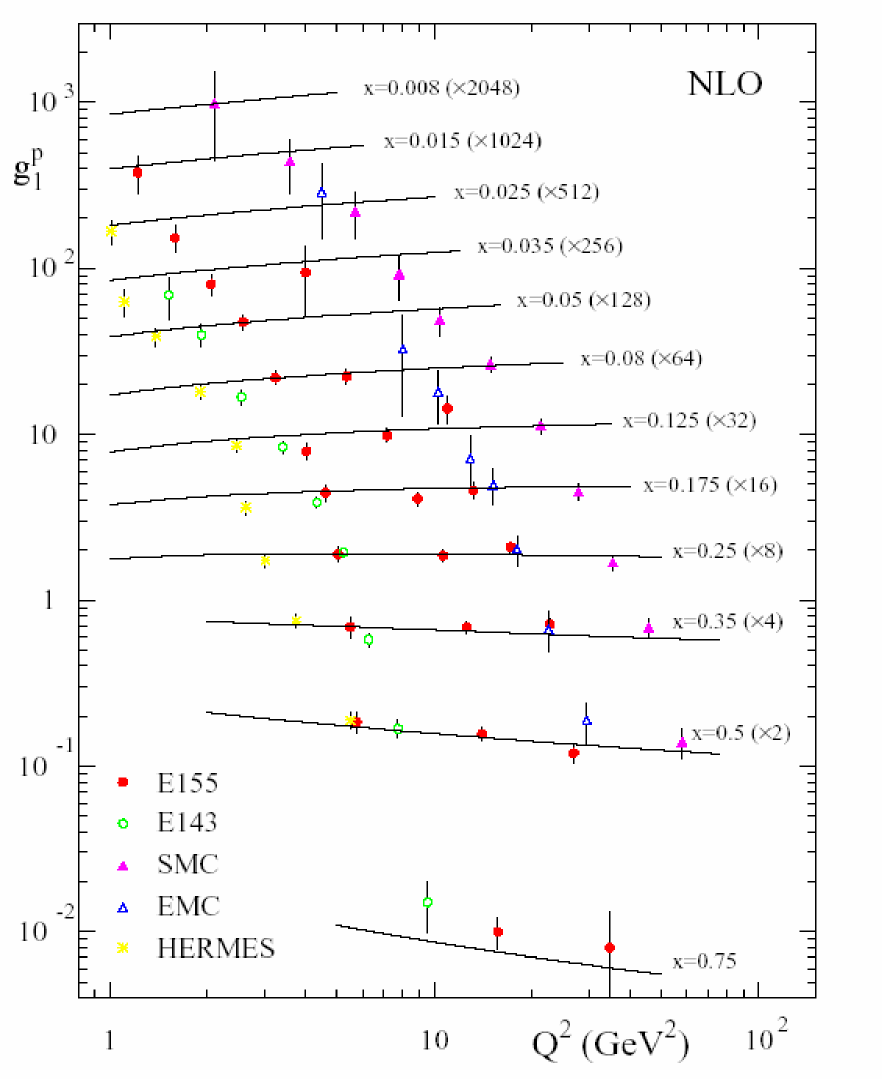
$$\frac{\mathrm{d}}{\mathrm{d}\ln Q^2}\begin{pmatrix} \Delta\Sigma \\ \Delta g \end{pmatrix} = \frac{\alpha_s}{2\pi}\begin{pmatrix} \Delta P_{qq}^{\mathrm{s}} & 2n_f \Delta P_{qg}^{\mathrm{s}} \\ \Delta P_{gq}^{\mathrm{s}} & \Delta P_{gg}^{\mathrm{s}} \end{pmatrix} \otimes \begin{pmatrix} \Delta\Sigma \\ \Delta g \end{pmatrix}$$

DGLAP evolution

Q^2 Evolution

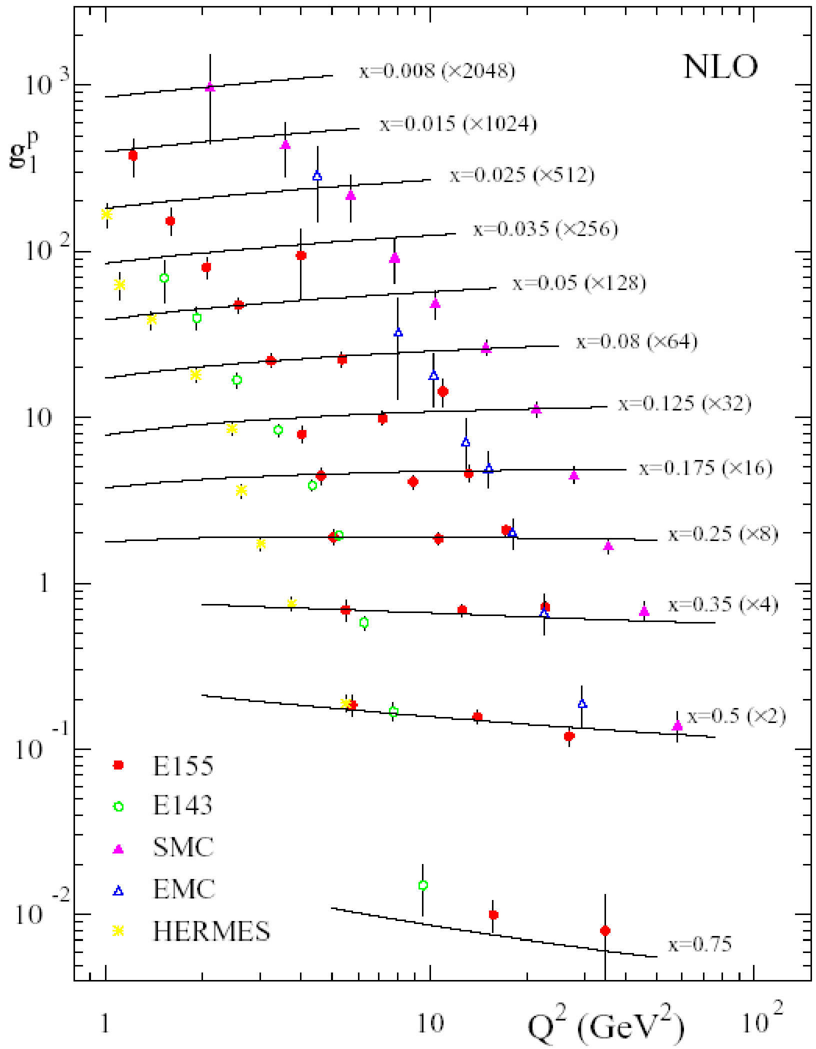
- non-singlet decouples from gluon evolution, moments Q^2-independent, like Δu - $\Delta d = g_a$
- Evolution of singlet and gluon coupled, moments $\Delta\Sigma$ and ΔG evolve with Q^2
- In principle ΔG can be determined from the Q^2 evolution of $g_1(x,Q^2)$
- Need reasonable range Q^2 at fixed x
- We have some Q^2 range, but not much, important large Q^2 at small x

$g_1(x,Q^2)$

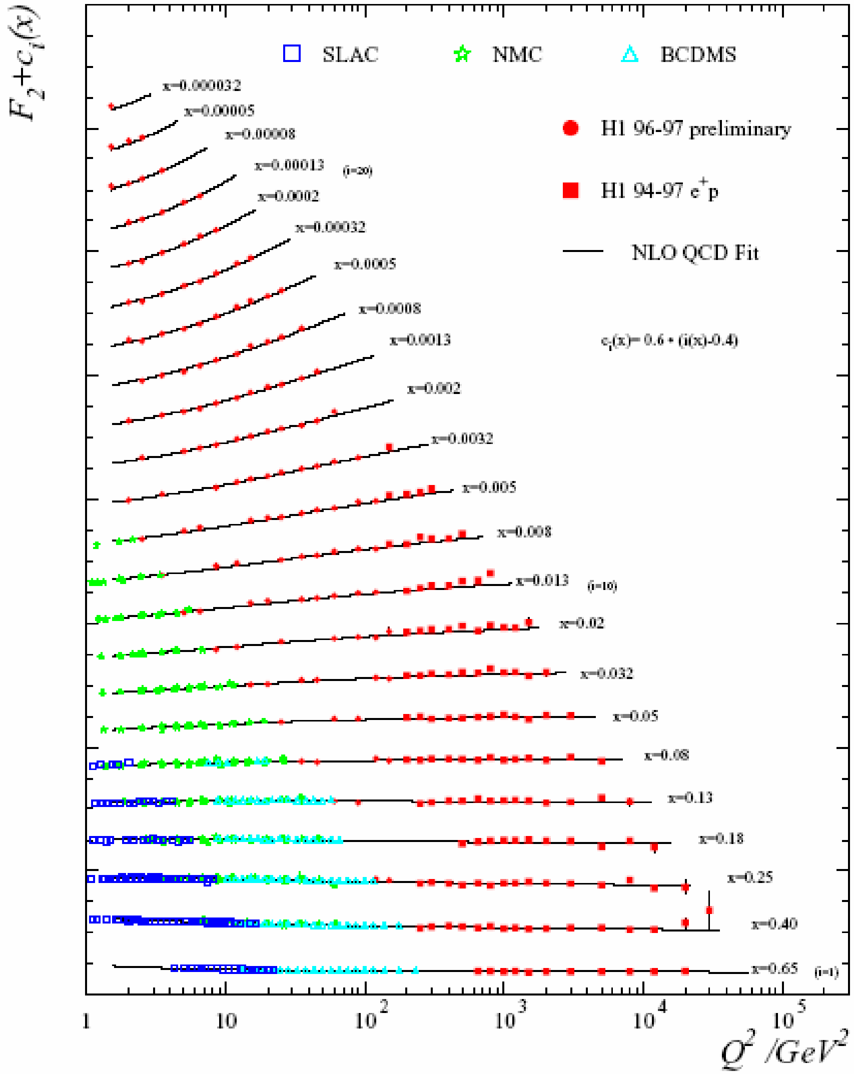


Looks quite nice, but...

$g_1(x,Q^2)$ $F_2(x,Q^2)$



NLO
g_1^p
x=0.008 (×2048)
x=0.015 (×1024)
x=0.025 (×512)
x=0.035 (×256)
x=0.05 (×128)
x=0.08 (×64)
x=0.125 (×32)
x=0.175 (×16)
x=0.25 (×8)
x=0.35 (×4)
x=0.5 (×2)
x=0.75
E155
E143
SMC
EMC
HERMES
Q^2 (GeV^2)



$F_2+c_i(x)$
SLAC
NMC
BCDMS
H1 96-97 preliminary
H1 94-97 e$^+$p
NLO QCD Fit
$c_i(x)= 0.6 \cdot (i(x)-0.4)$
Q^2 /GeV^2

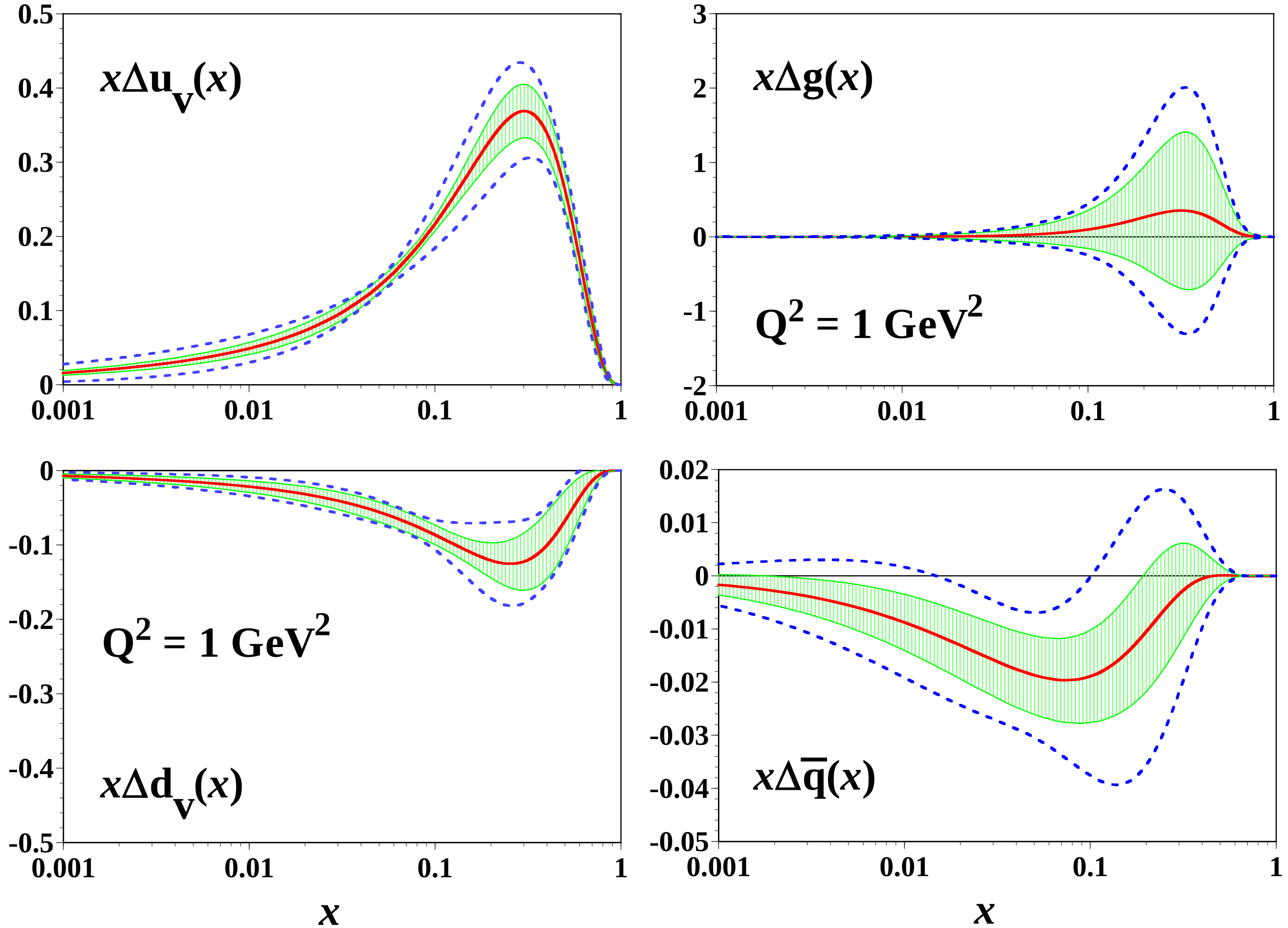
NLO QCD Fits

- choose scheme, usually $\overline{\text{MS}}$
- choose start value for evolution, Q^2_0
- choose parametrisations for

$$\Delta\Sigma,\ \Delta G,\ \Delta\, q^{ns}(x,Q^2_0)$$

- fit parameters of these parametrisations using the DLGAP equations (NLO)
- many groups, an example...
  - AAC03 Kumano DIS2004

AAC03 Fit

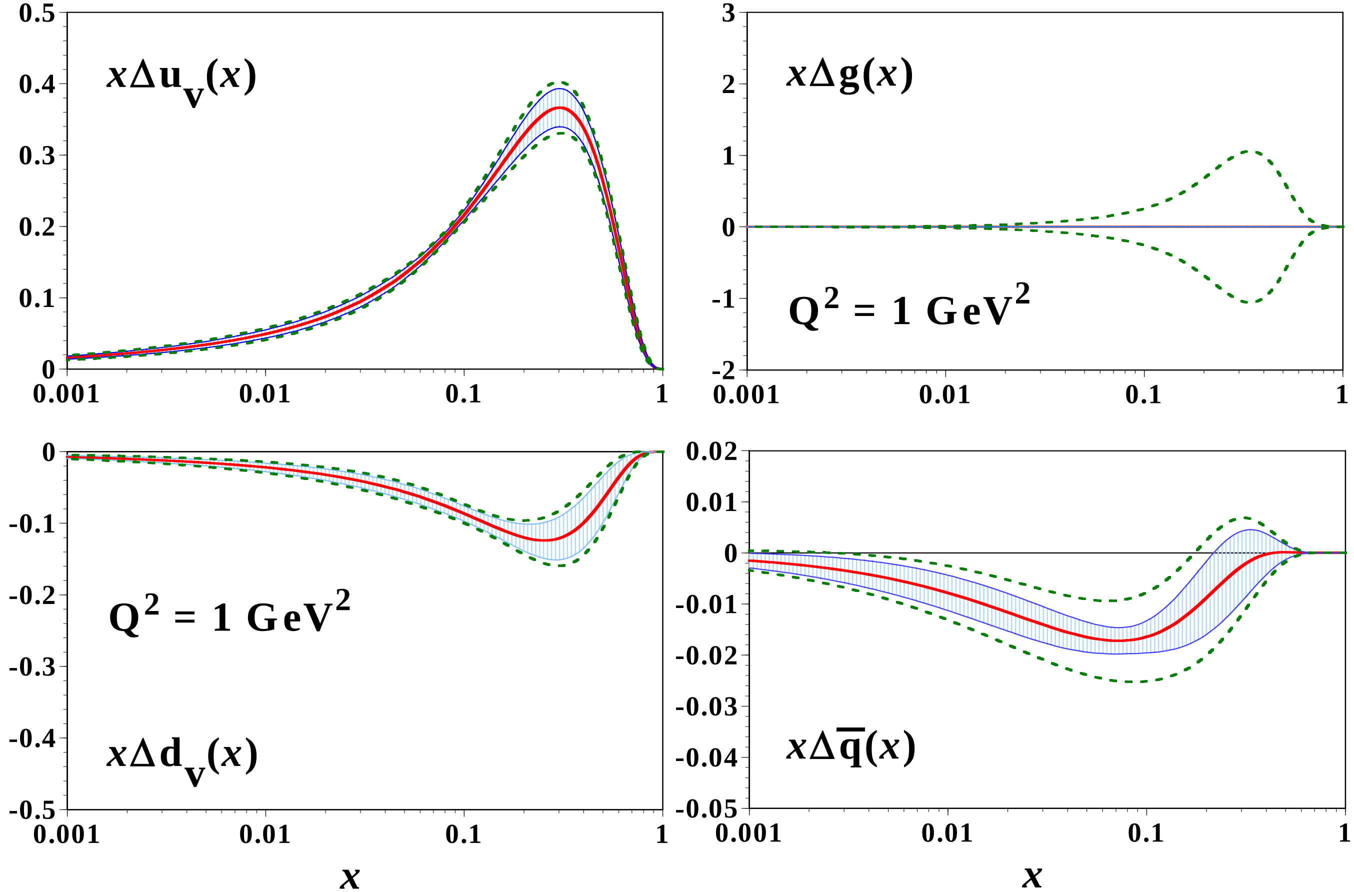


error of AAC00

valence well fixed
gluon undetermined
sea quarks negative

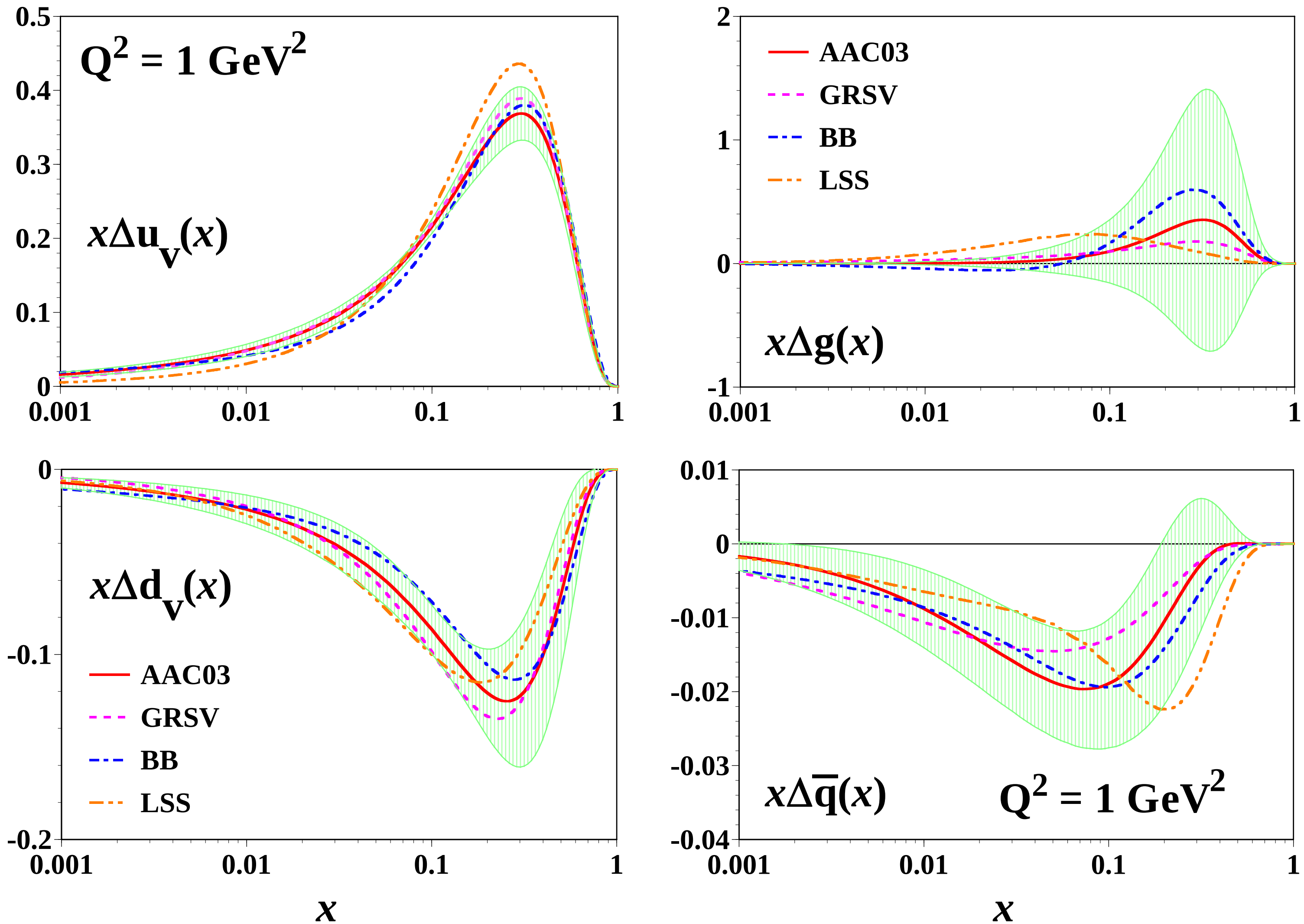
AAC03 with zero gluon at Q^2_0

χ^2/d.o.f. = 0.915

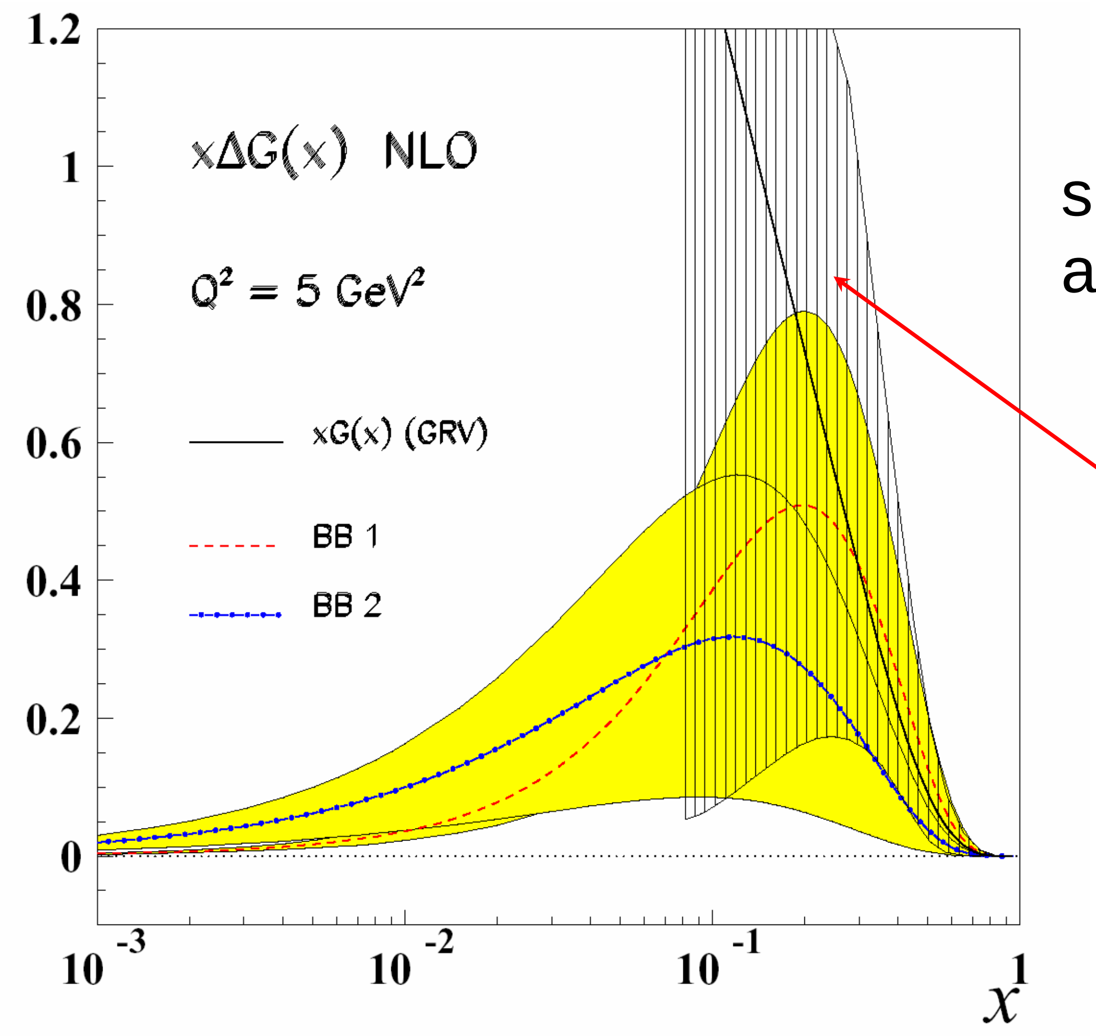


error with free gluon

Comparsion of PDF Fits



BB Fit



slightly positive gluon pol. at Q^2=5 GeV^2

unpolarised gluon

Blümlein & Böttcher

First moments

$Q^2 = 1\ \mathrm{GeV}^2$

	Δg	$\Delta\Sigma$
AAC03	0.499 ± 1.268	0.213 ± 0.138
GRSV01	0.420	0.204
LSS	0.680	0.210
BB	1.026	0.138

Kumano DIS2004

- GRSV01 [Phys. Rev. D63 (2001) 094005]
- LSS01 [Eur.Phys.J. C23 (2002) 479]
- BB02 [Nucl. Phys. B636 (2002) 225]

g_2

$$g_2(x,Q^2) = g_2^{\mathrm{WW}} + \bar{g}_2(x,Q^2)$$

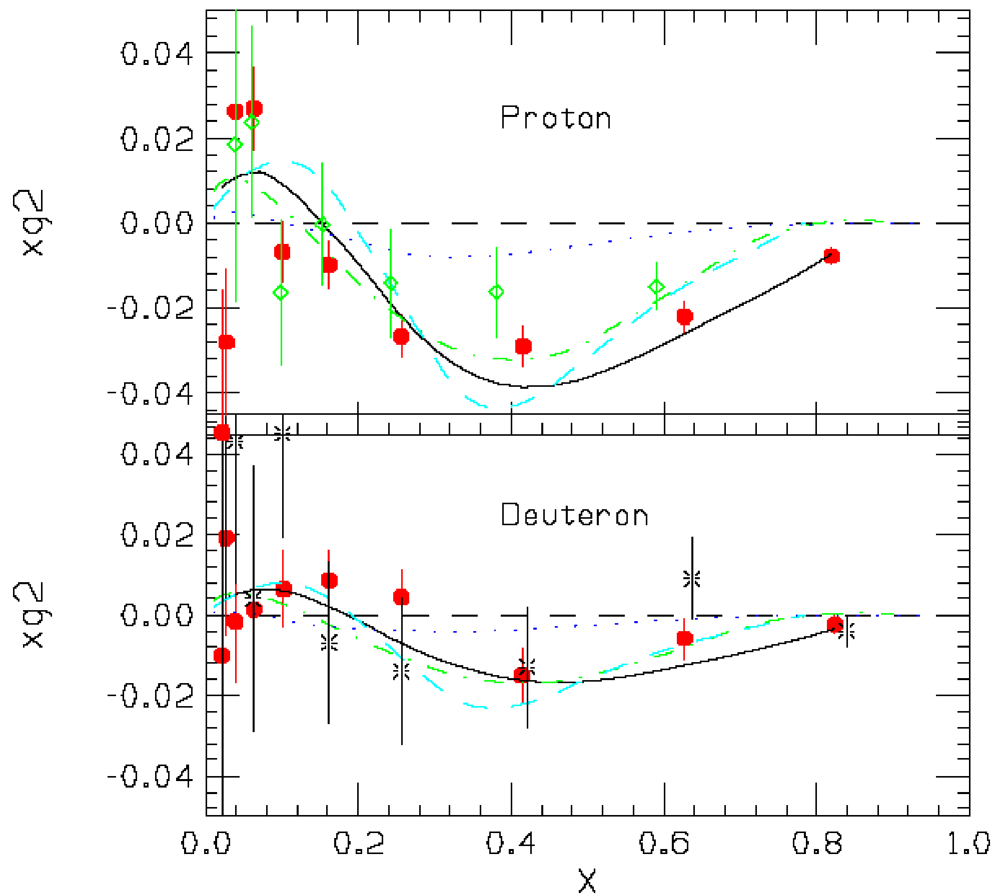
$$g_2^{\mathrm{WW}}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y}\,\mathrm{d}y$$

- twist-3 term $\bar{g}_2$, matrix element d_2

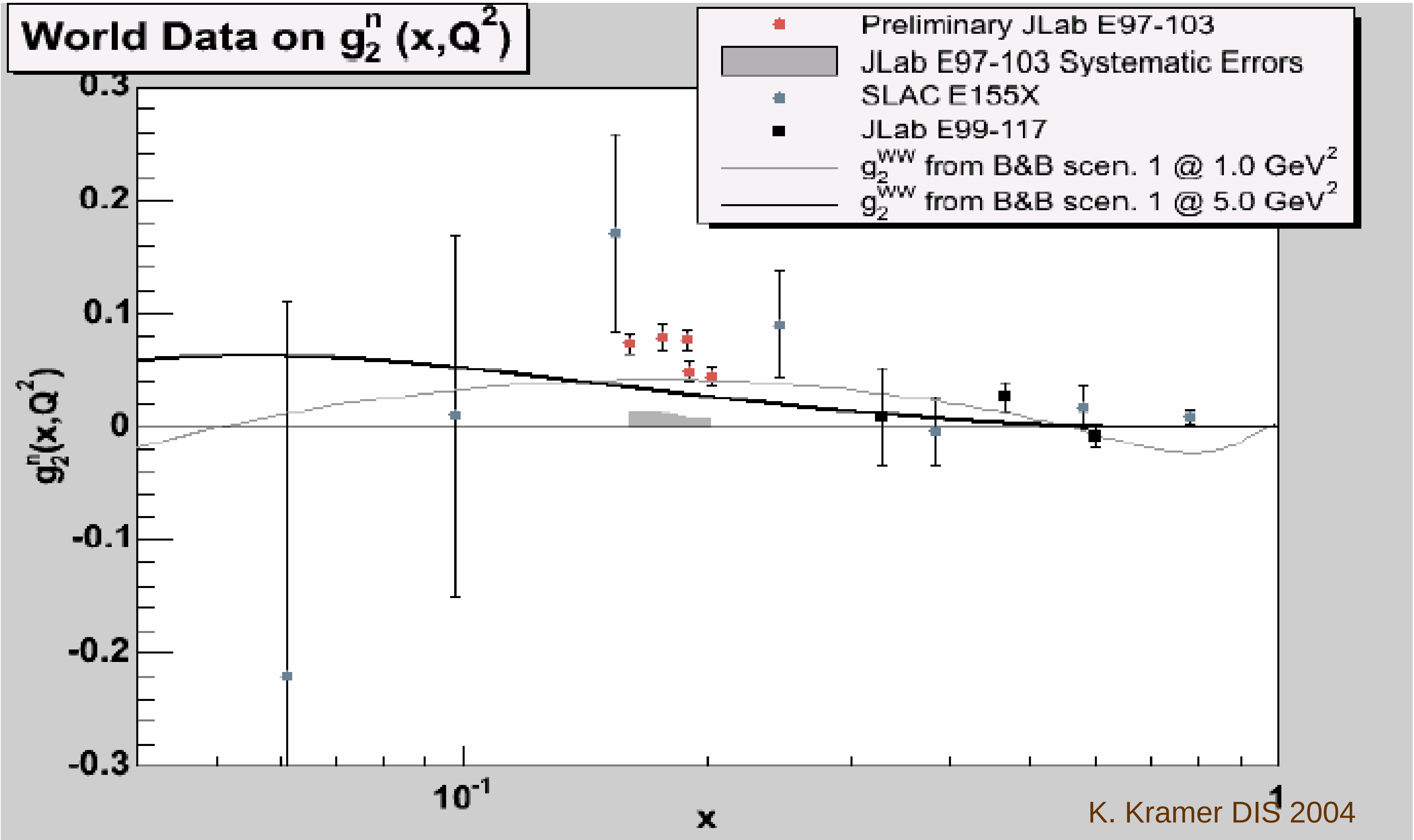
$$d_2 = 3\int_0^1 x^2\,\bar{g}_2(x,Q^2)\,\mathrm{d}x$$

g_2

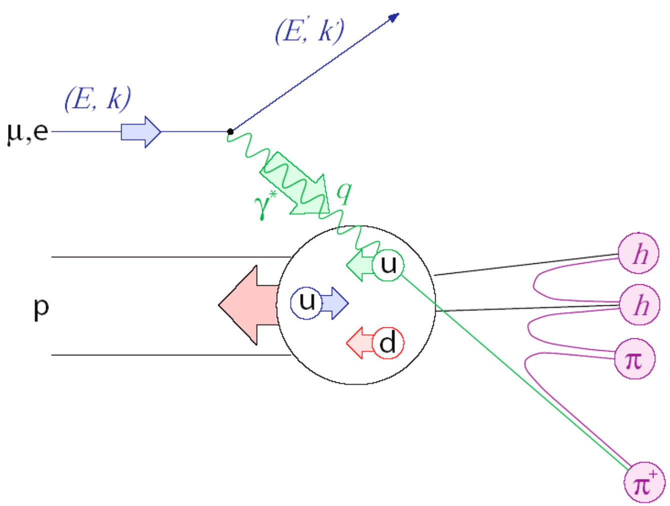
- —— twist-2 term: g_2^{WW}
- -- -- bag model calculations



Neutron g_2 from JLAB

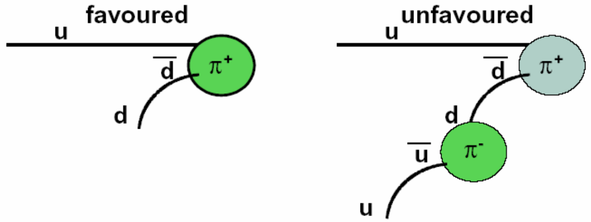


Fragmentation Function $D_f^h(z, Q^2)$



D_q^h from quark q into hadron h

$z = \frac{E_h}{\nu}$ energy fraction carried by h

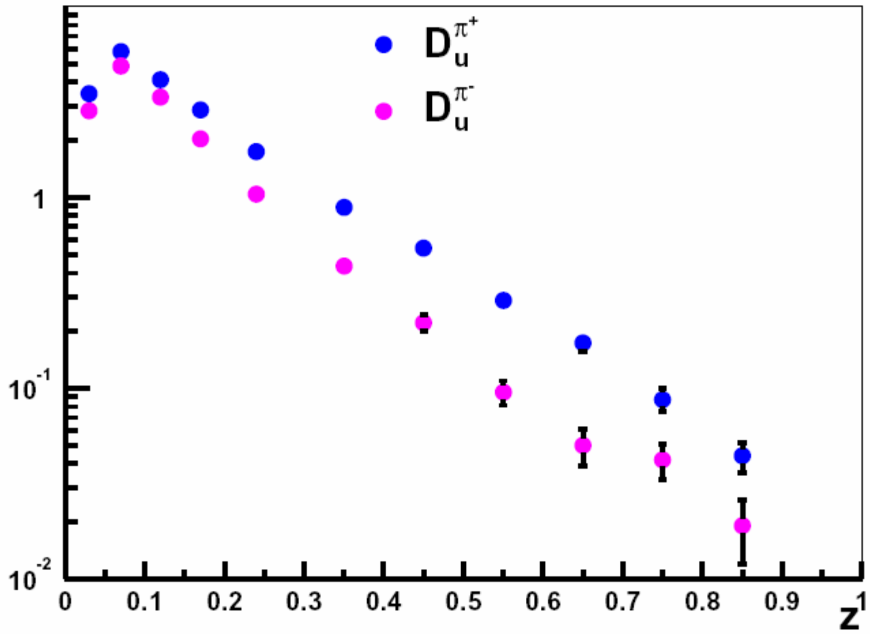


$$D_u^{\pi^+} \underset{CC}{=} D_{\bar{u}}^{\pi^-} \underset{IS}{=} D_{\bar{d}}^{\pi^+} \underset{CC}{=} D_d^{\pi^-}$$

$$D_d^{\pi^+} \overset{CC}{=} D_{\bar{d}}^{\pi^-} \overset{IS}{=} D_{\bar{u}}^{\pi^+} \overset{CC}{=} D_u^{\pi^-}$$

$$\frac{1}{\sigma_0} \frac{d\sigma^h}{dz} = \frac{\sum_f e_f^2 \; q_f(x, Q^2) \cdot D_f^h(z, Q^2)}{\sum_f e_f^2 \; q_f(x, Q^2)}$$

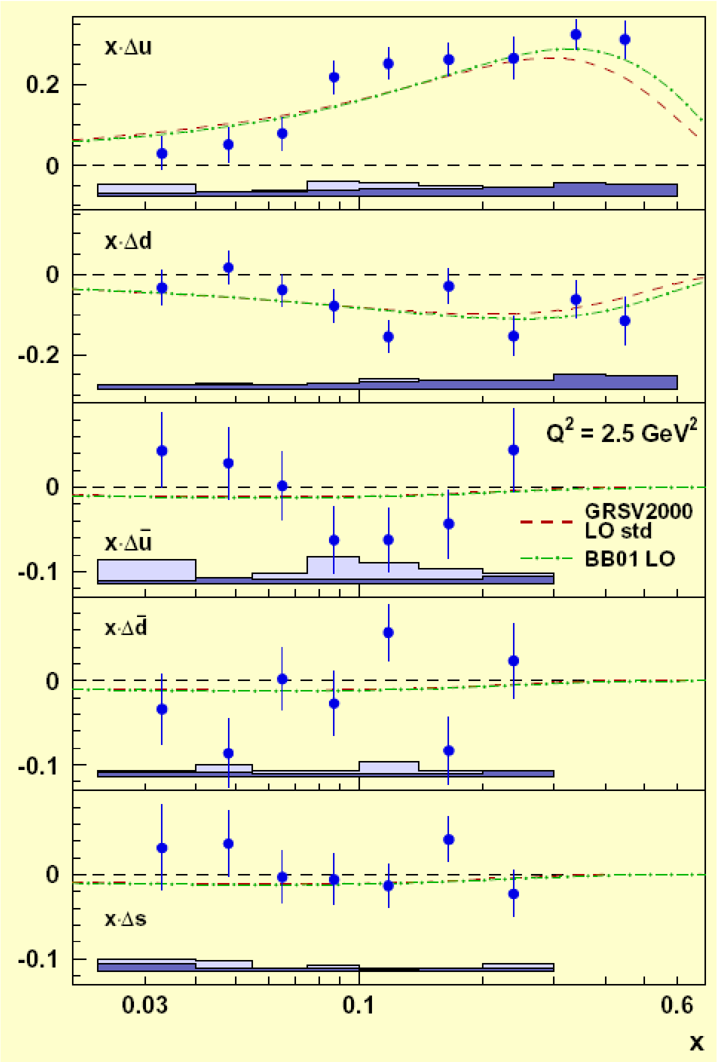
Semi-inclusive DIS



final hadron “remembers” flavour of initially struck!

$$A_1^h(x,Q^2) = \frac{\int \mathrm{d}z \sum_f e_f^2 \Delta q_f(x,Q^2) \cdot D_f^h(z,Q^2)}{\int \mathrm{d}z \sum_f e_f^2 \; q_f(x,Q^2) \cdot D_f^h(z,Q^2)}$$

Flavour separated polarisation



Asymmetries can in LO be related to Δq by

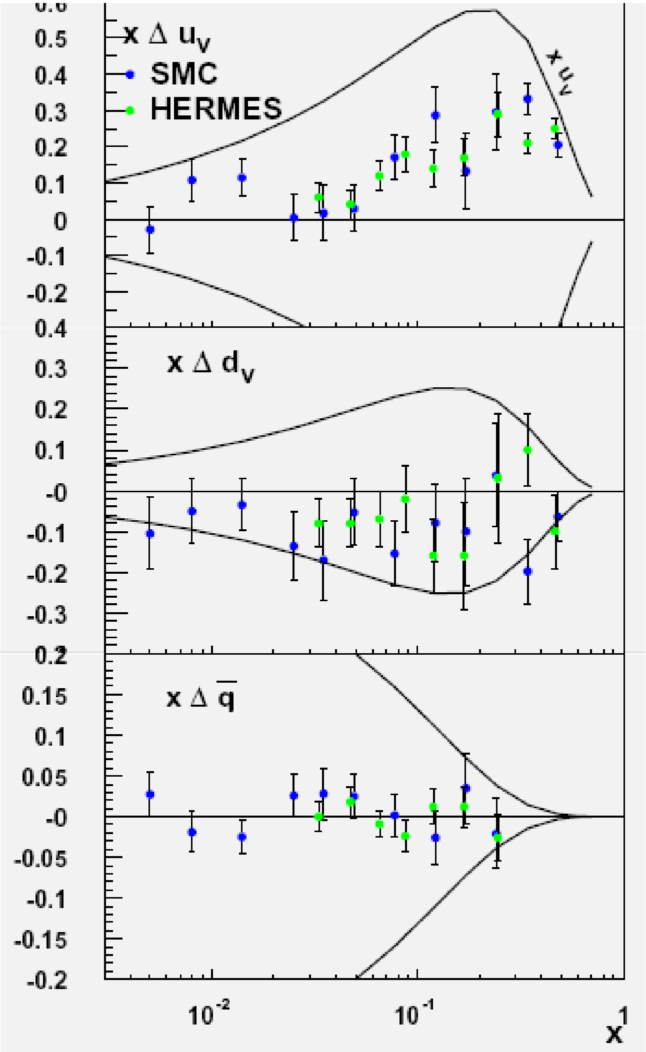
$$\vec{\mathcal{A}} = \mathcal{P}\vec{\mathcal{Q}}$$

where

$$\vec{\mathcal{A}} = (A^h_{1,t}, \ldots)$$
$$\vec{\mathcal{Q}} = (\Delta q_f, \ldots)$$

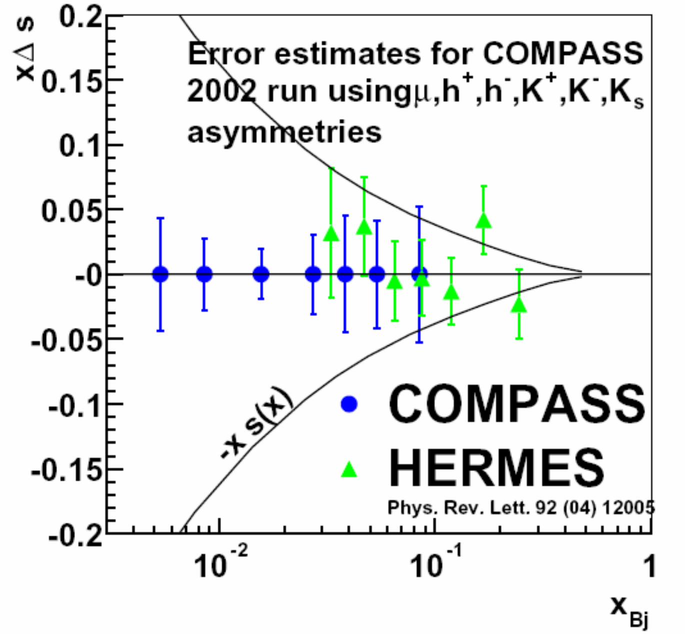
$$\mathcal{P}^h_f = \frac{e^2_f q_f(x) \int dz D^h_f}{\sum_i e^2_i q_i(x) \int dz D^h_i(z)}$$

more data



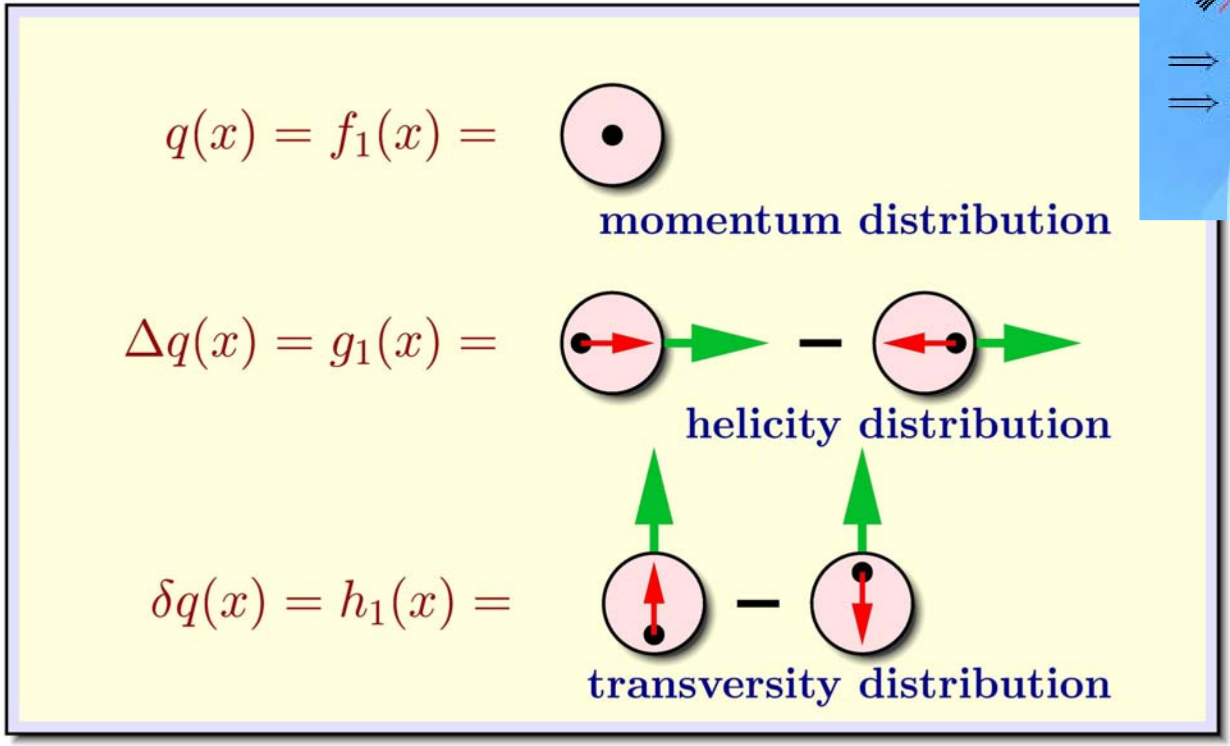
SMC and COMPASS have more small *x* data.
Will help to clarify Δ s

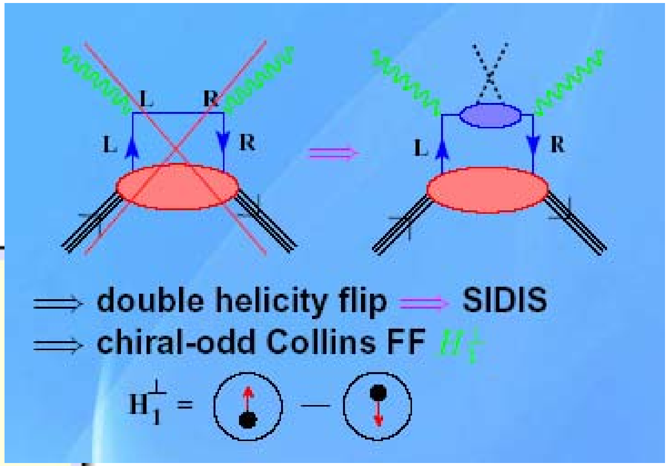
Projection for Δs **(2002 data)**



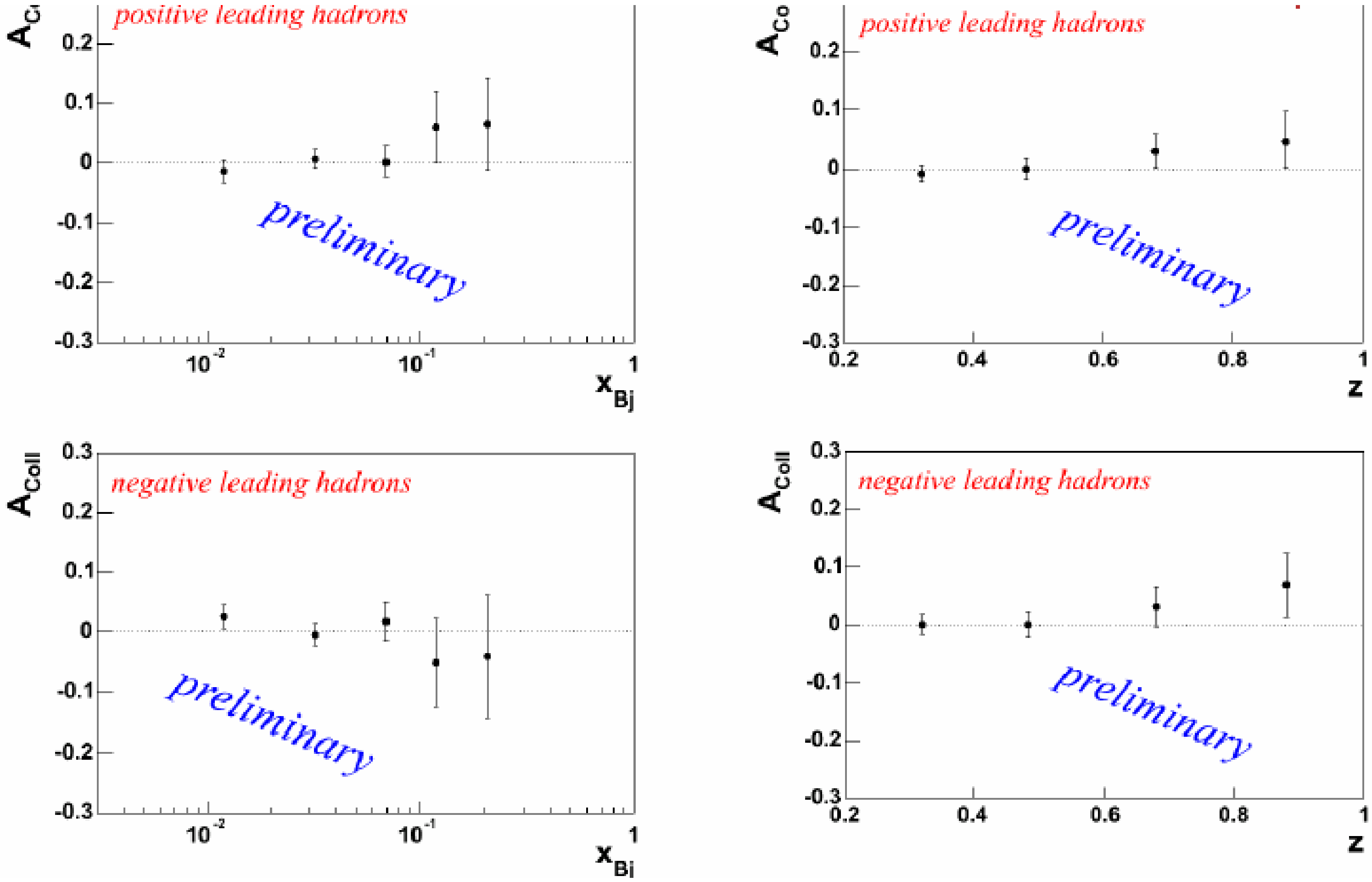
G. Mallot/CERN

Transversity h_1



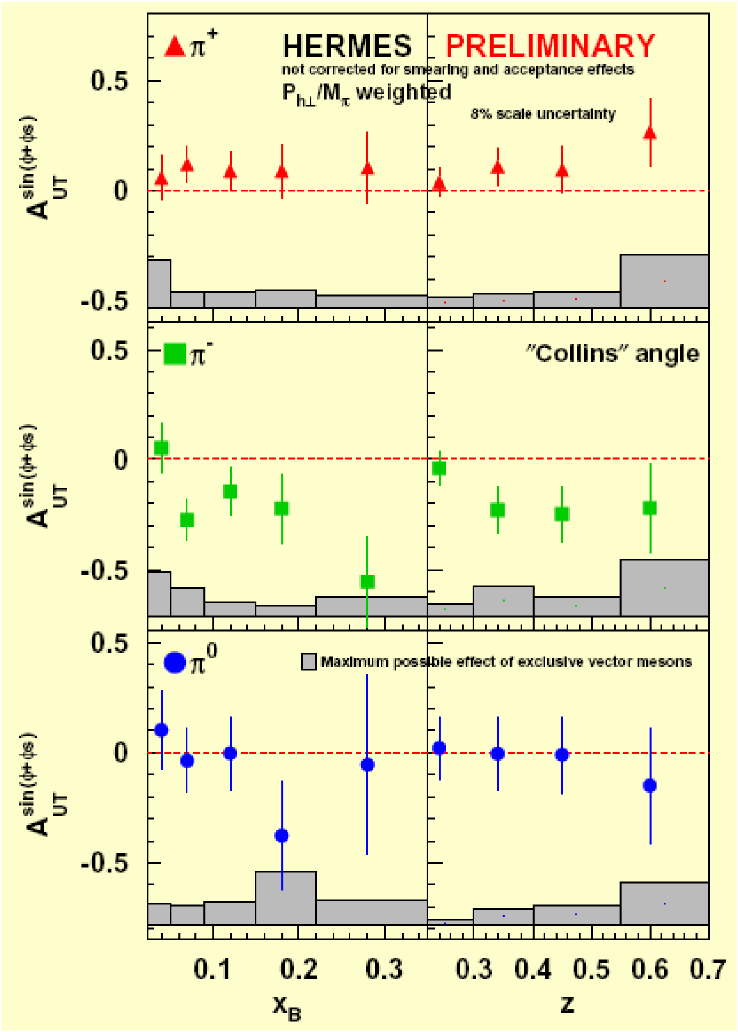


Collins asymmetries 2002



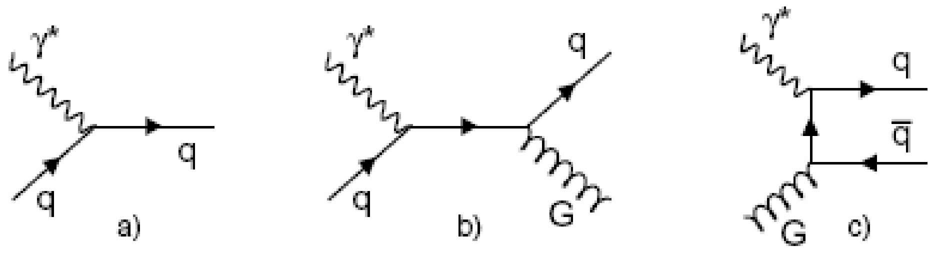
Deuteron

Hermes Collins asymmetry



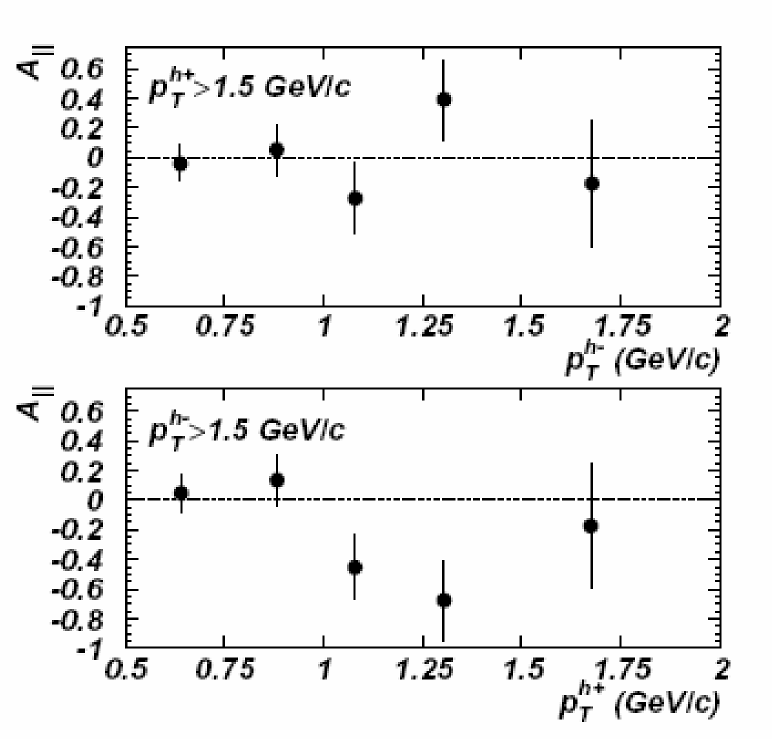
Δ G from high-p_T hadron pairs

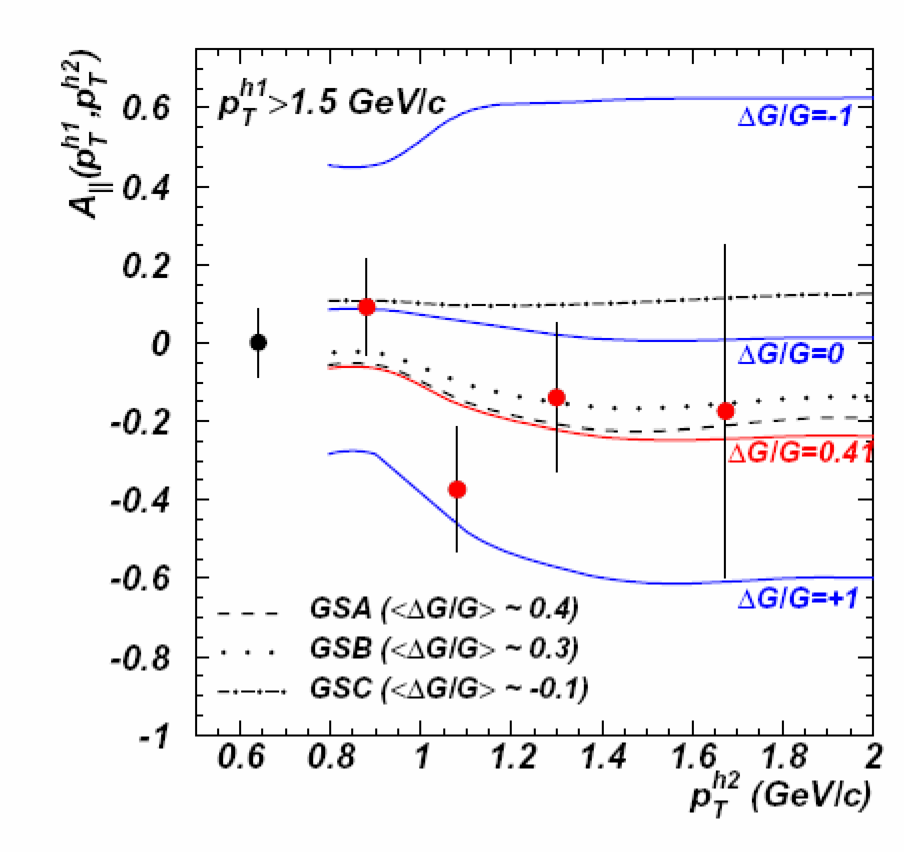
- Contributions: a) LO b) QCD Compton c) PGF



$$A_{\mathrm{LL}}^{\ell N} \simeq \langle \hat{a}_{\mathrm{LL}}^{\gamma g \to qg} \rangle \frac{\Delta q}{q} + \langle \hat{a}_{\mathrm{LL}}^{\gamma g \to q\bar{q}} \rangle \frac{\Delta g}{g}$$

Hermes high-p_T pairs

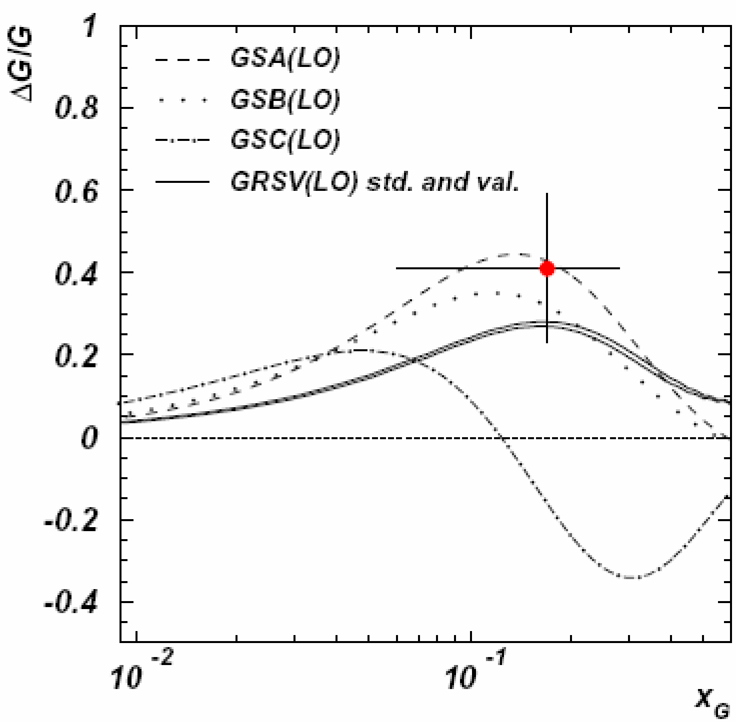


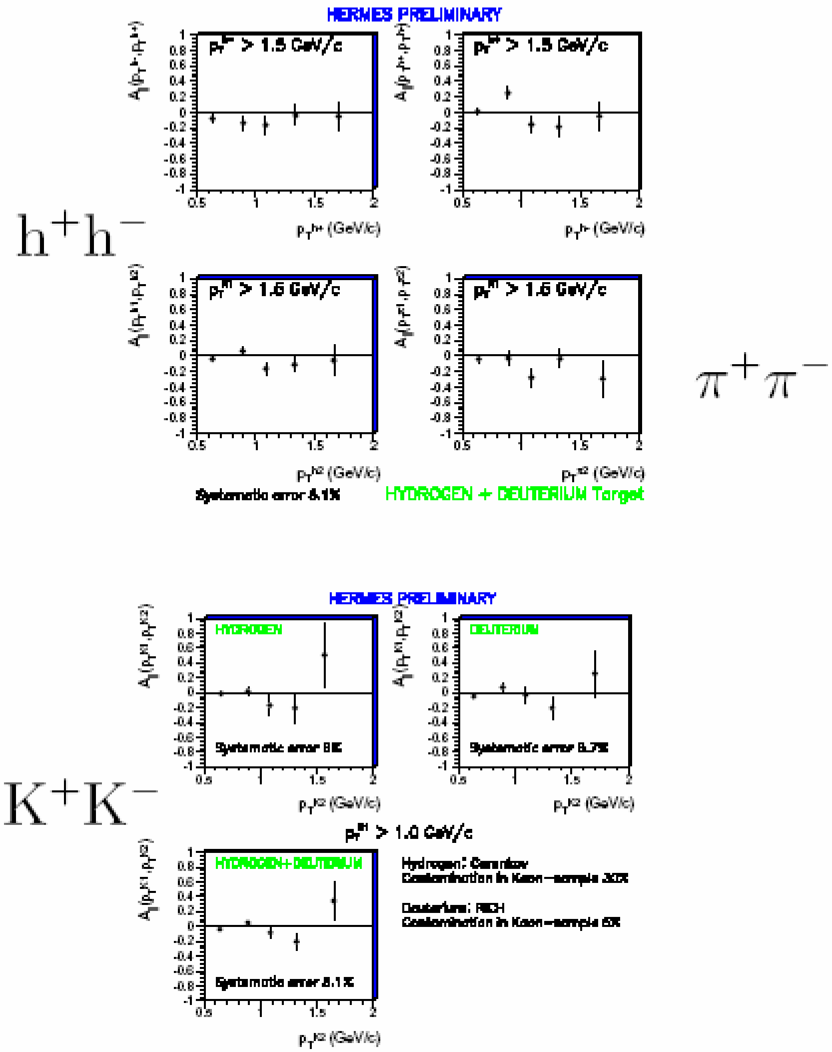


Hermes high-p_T pairs

- Hermes conclusion:
  $\Delta g/g = 0.41 \pm 0.18(\text{stat}) \pm 0.03(\text{syst exp})$
  $\langle x_g \rangle = 0.17$; $\langle p_T^2 \rangle = 2.1\ \text{GeV}^2$

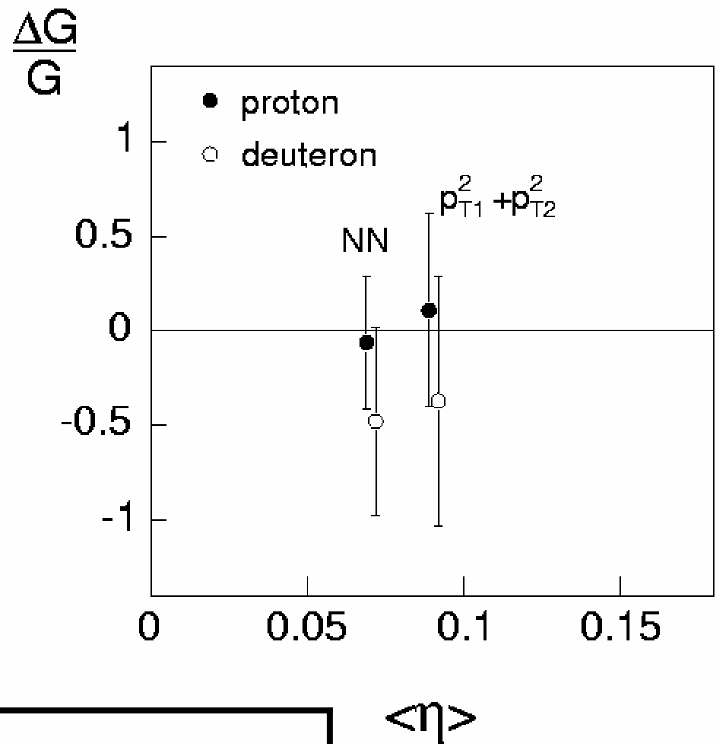
$\int_{0.06}^{0.028} \frac{\Delta g}{g} g(x) \mathrm{d}x \approx 0.6$





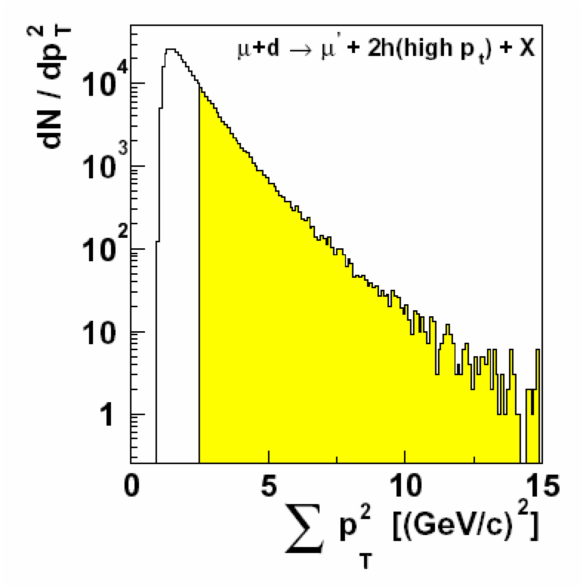
SMC high-p_T anaylysis

- Hermes: Q^2 not reconstructed for high-p_T
- SMC: cut on $Q^2 > 1$ GeV^2, theoretical description more sound, limited statistics



Selection	$\Delta G/G \pm \delta(\Delta G/G)_{stat}$	$\langle x_g \rangle_{genPGF}$
$\sum p_T^2 > 2.5 GeV^2$	-0.07 ± 0.40	0.09
NN >0.26	-0.20 ± 0.28	0.07

COMPASS high-p_T hadron pairs



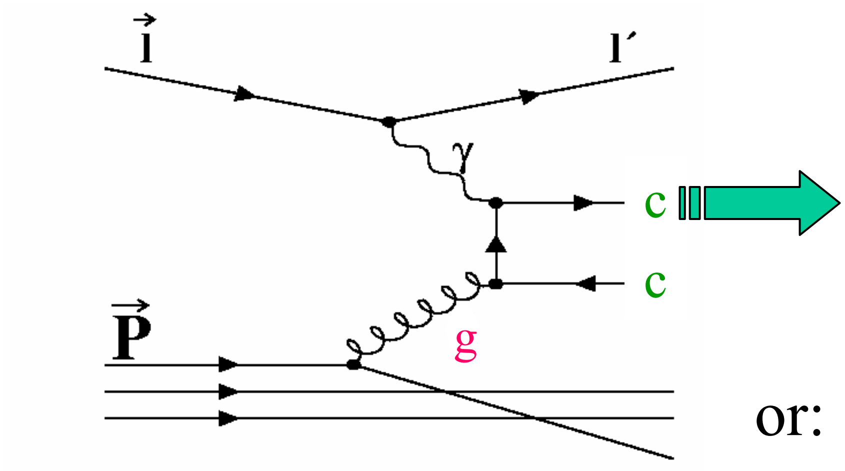
2002 data only, all Q^2, *75000 events*

- High p_T cut
  - $p_{T1}, p_{T2} > 0.7$ GeV/c
  - $p_{T1}^2 + p_{T2}^2 > 2.5$ GeV^2/c^2
- Vector mesons are removed
  - $m(h_1 h_2) > 1.5$ GeV/c^2
- Products of the target fragmentation are removed
  - $x_F > 0.1$
  - $z > 0.1$

$$\left(\frac{A_{\parallel}}{D}\right)^{\mu d \rightarrow hh} = -0.065 \pm 0.036(stat.) \pm 0.01(syst.)$$

Open charm at COMPASS

- Photon-gluon fusion: 1.2 D^0 per PGF $c\bar{c}$ event



$$D^0 \Rightarrow K^- \pi^+$$ BR 4 %

or: $$D^{*+} \Rightarrow D^0 \pi_s^+$$

$$\Rightarrow K^- \pi^+ \pi_s$$

D^0 from D^* about 20 %

Open charm, cuts

- most of 2002 data, prel. RICH and tracking
- $z_D > 0.2$ (background reduction)
- $|\cos(\theta^*)| < 0.85$ (background reduction)
- $10 < p_K < 35$ GeV/c (Rich πK sep.)
- define:

$$\Delta M_{K\pi\pi} = M_{K\pi\pi_s} - (M_{K\pi} + M_{\pi_s})$$

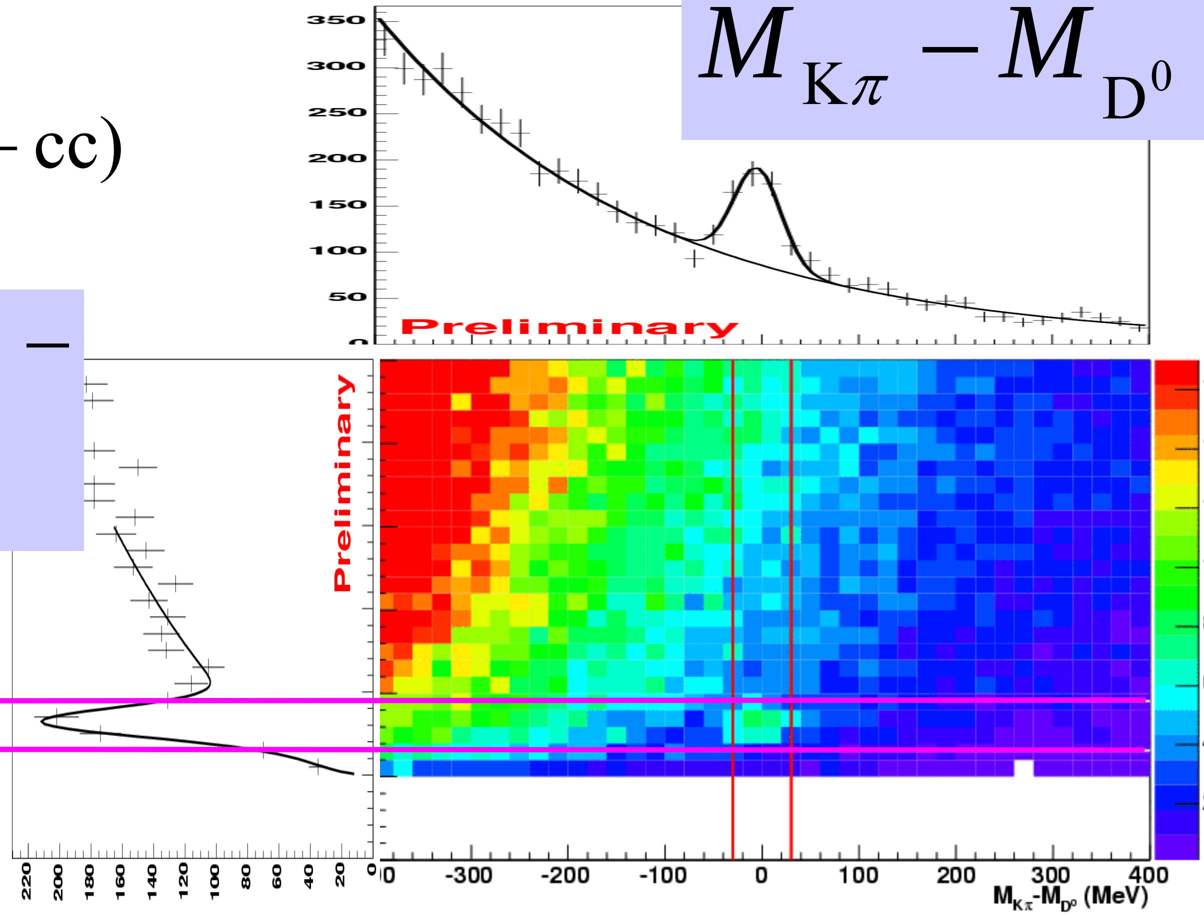
$$M(D^*) - [M(D^0)+M(\pi)]$$

$D^{*+} \to D^0 \pi_s^+$ tagging

$$D^* \to D^0 \pi_s$$
$$\to K\pi\pi_s \quad (+\,cc)$$

$$\Delta M_{K\pi\pi} = M_{K\pi\pi_s} - (M_{K\pi} + M_{\pi_s})$$

$$M_{K\pi} - M_{D^0}$$

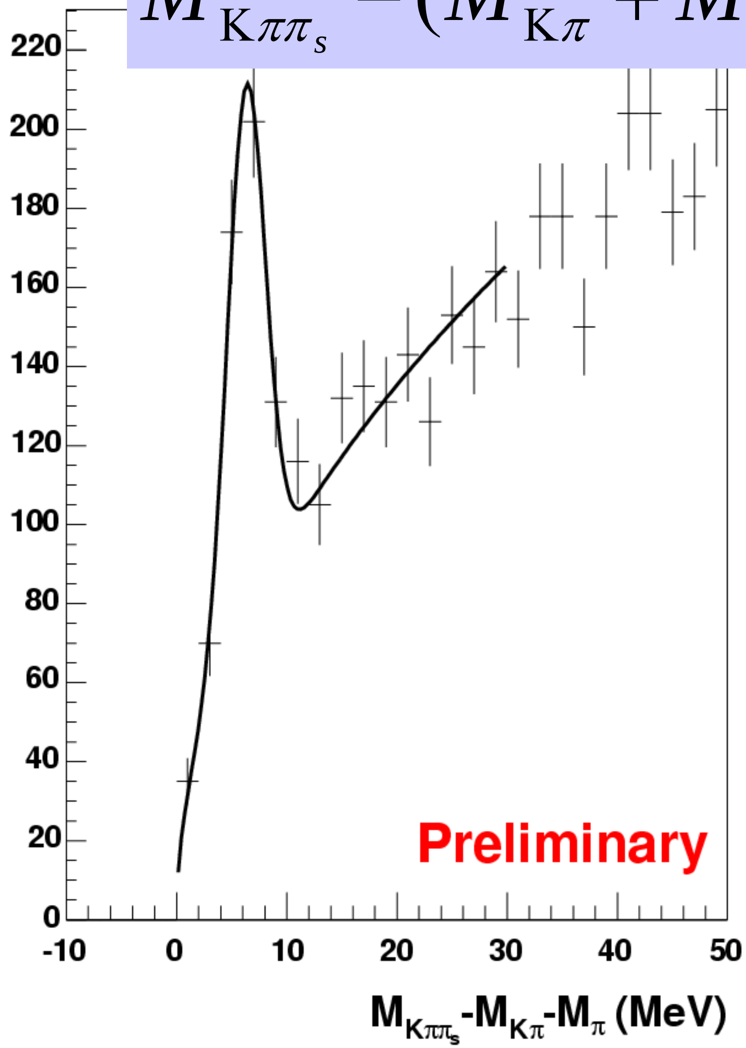


Choose:

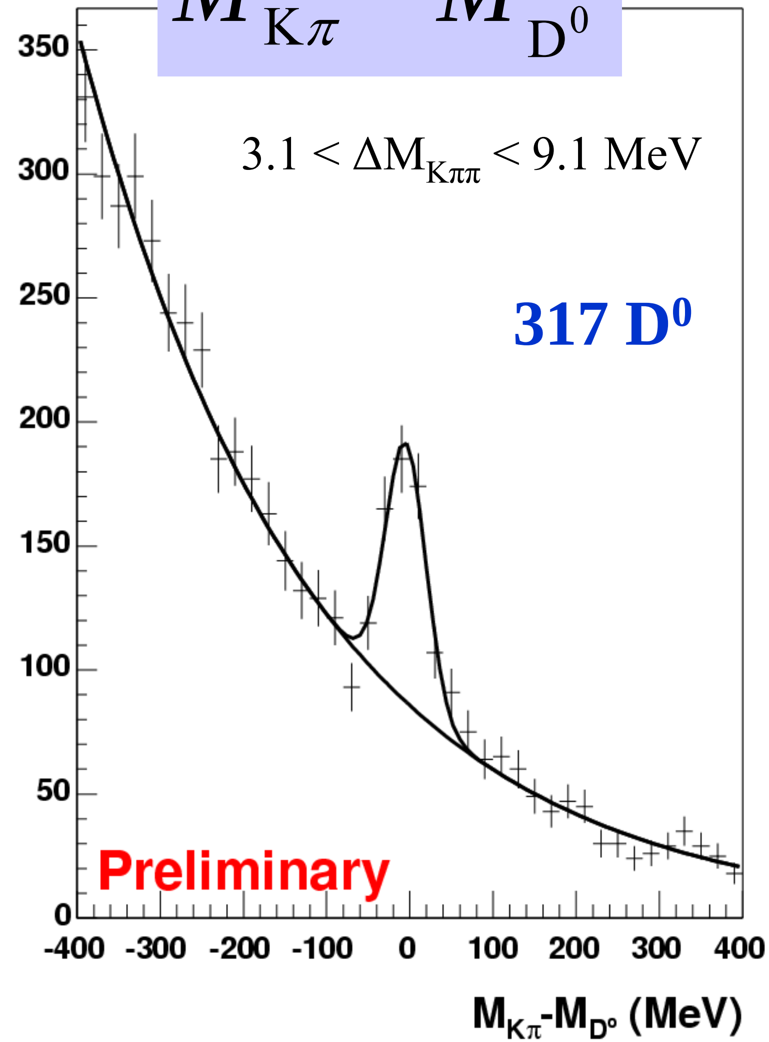
$3.1 < \Delta M_{K\pi\pi} < 9.1$ MeV

$D^{*+} \rightarrow D^0 \pi_s^+$ tagging

$M_{K\pi\pi_s} - (M_{K\pi} + M_{\pi_s})$



$M_{K\pi} - M_{D^0}$



Projected precision for Δ G/G

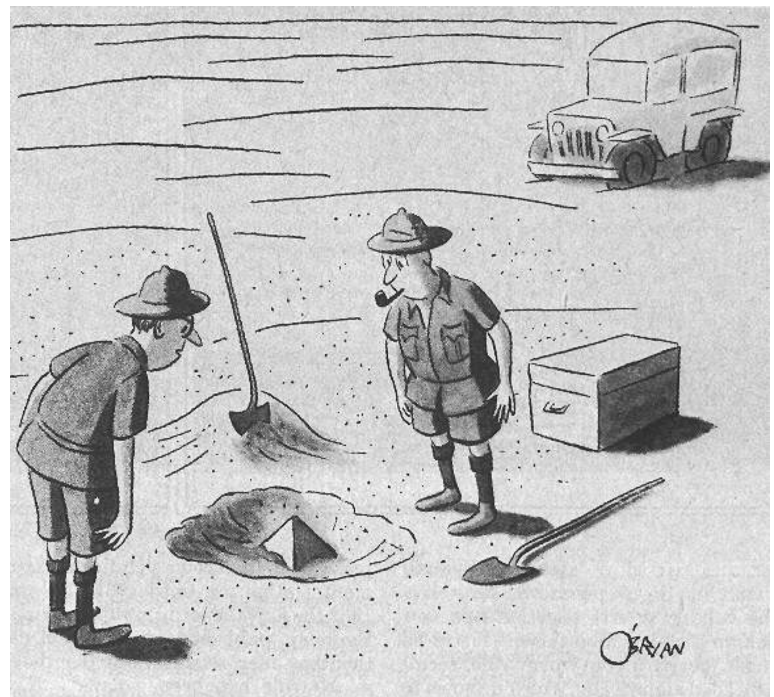
- 2002 – 2004 data:
- from high-p_T: *(all Q^2)* $$\delta(\Delta G/G) = 0.05$$
- from high-p_T: *($Q^2 > 1$)* $$\delta(\Delta G/G) = 0.16$$
- from open charm: $$\delta(\Delta G/G) = 0.24$$

No systematic error included yet
(not too big, apart from possible theoretical uncertainties)

Summary

- Lots to come from:
  - Hermes
  - COMPASS
  - RHIC

- It seems SPIN goes down very far ...



"This could be the discovery of the century. Depending, of course, on how far down it goes."