Review of results on polarized glue from fixed-target DIS experiments

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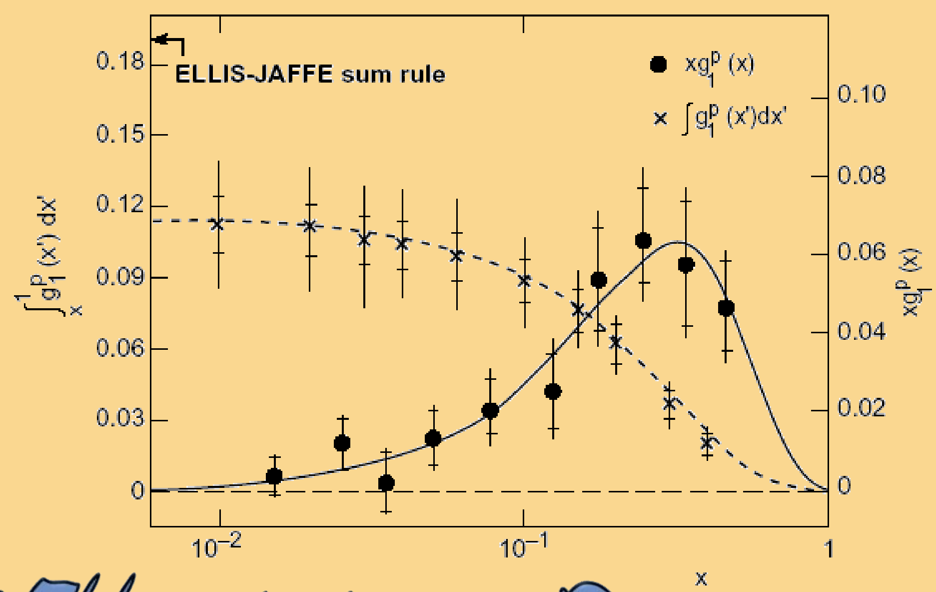
APS Meeting, St. Louis, MO, 12-15 April , 2008

EMC 1987/88



20TH ANNIVERSARY

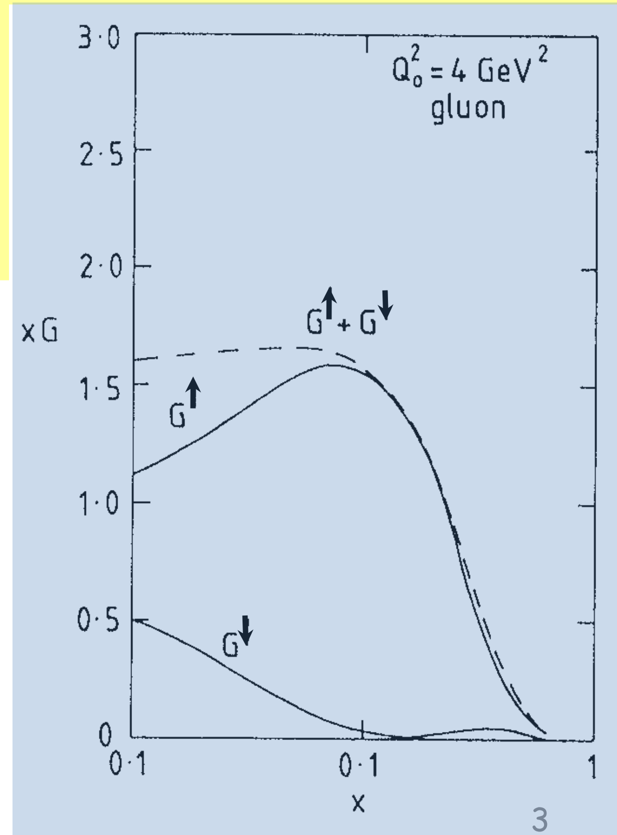
Lepton-Photon 1989

To summarise, let us return to the fit of Fig. 7 and 8. At Q^2=10GeV^2 this corresponds to Δg=6.3 and so the proton helicity is given by

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

$$= 0.35 + 6.3 - 6.15$$

G. Ross 1989



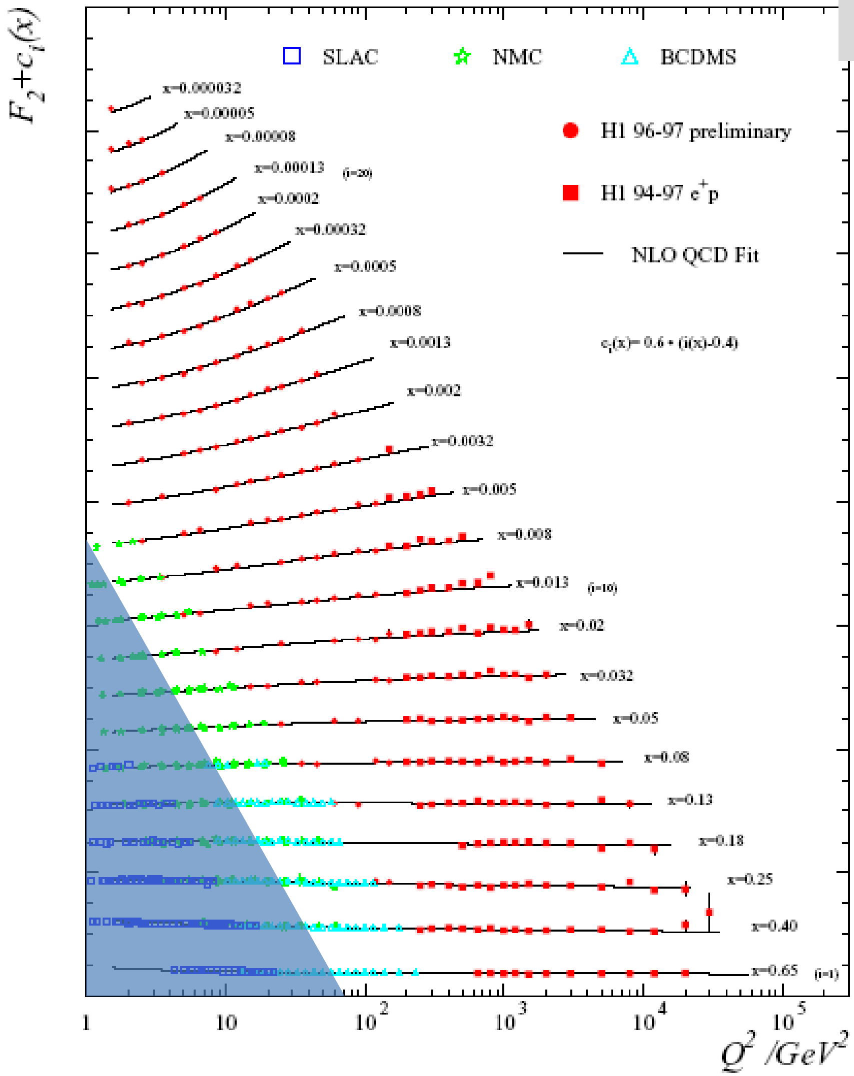
possible scenario:
$\Delta G \approx 6$ (Q^2=10 GeV^2)
$\Delta g/g(x) = 1$ for $x_g > 0.1$
Let's measure it!

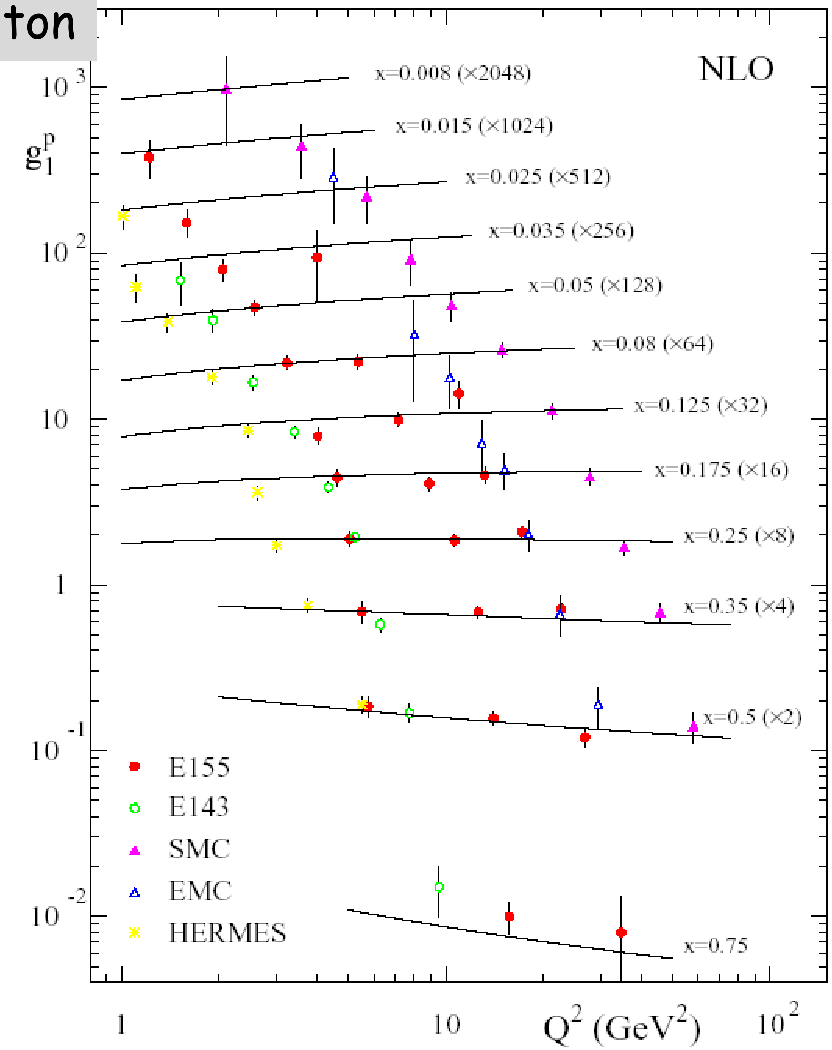
Δg in fixed-target DIS exp.

- scaling violations of g_1
  - inclusive DIS — EMC, SMC, SLAC, HERMES, COMPASS, JLab
- hadron production via PGF
  - hadron pairs — SMC, HERMES, COMPASS
  - single hadrons — HERMES, (COMPASS)
  - charmed hadrons — COMPASS

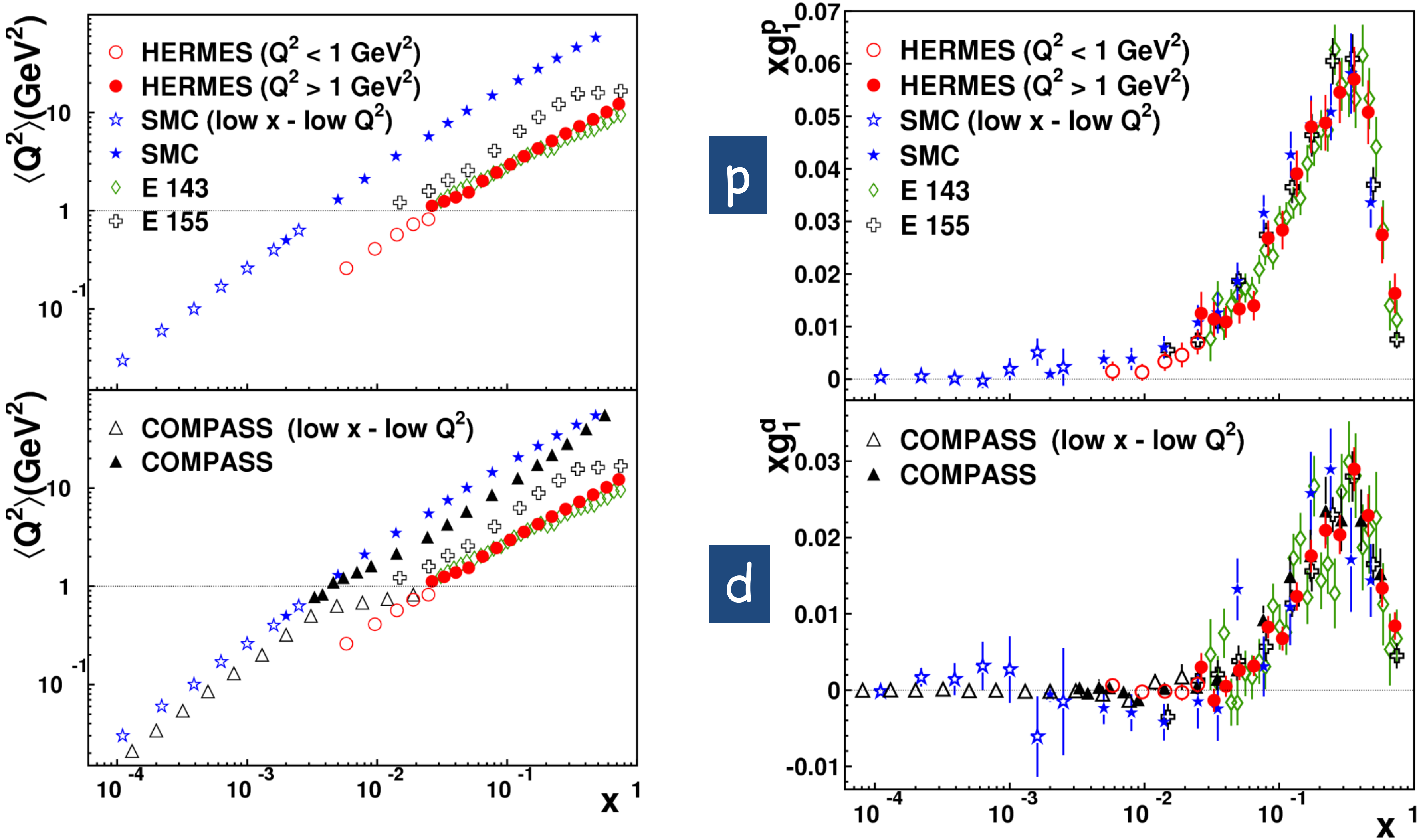
$F_2(x,Q^2)$ $g_1(x,Q^2)$

proton

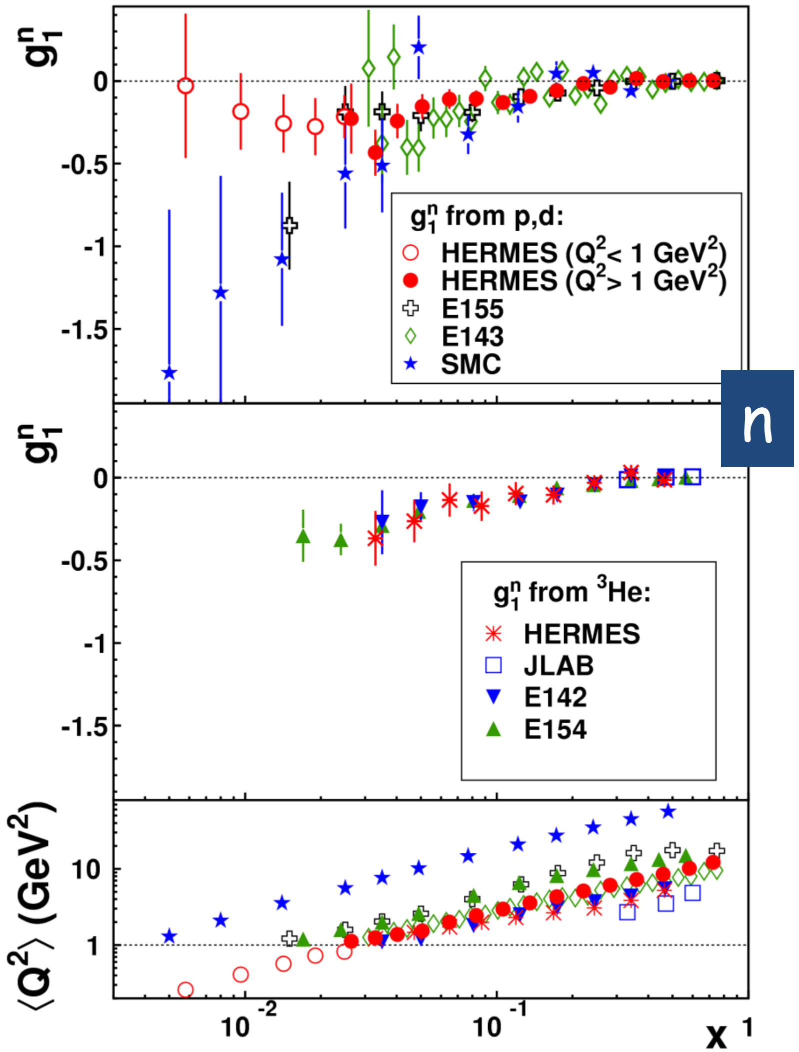




World data on $xg_1(x,Q^2)$



World data on neutron g_1



from p and d

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

from ^{3}He

Scaling violations: QCD fits

NLO DGLAP:

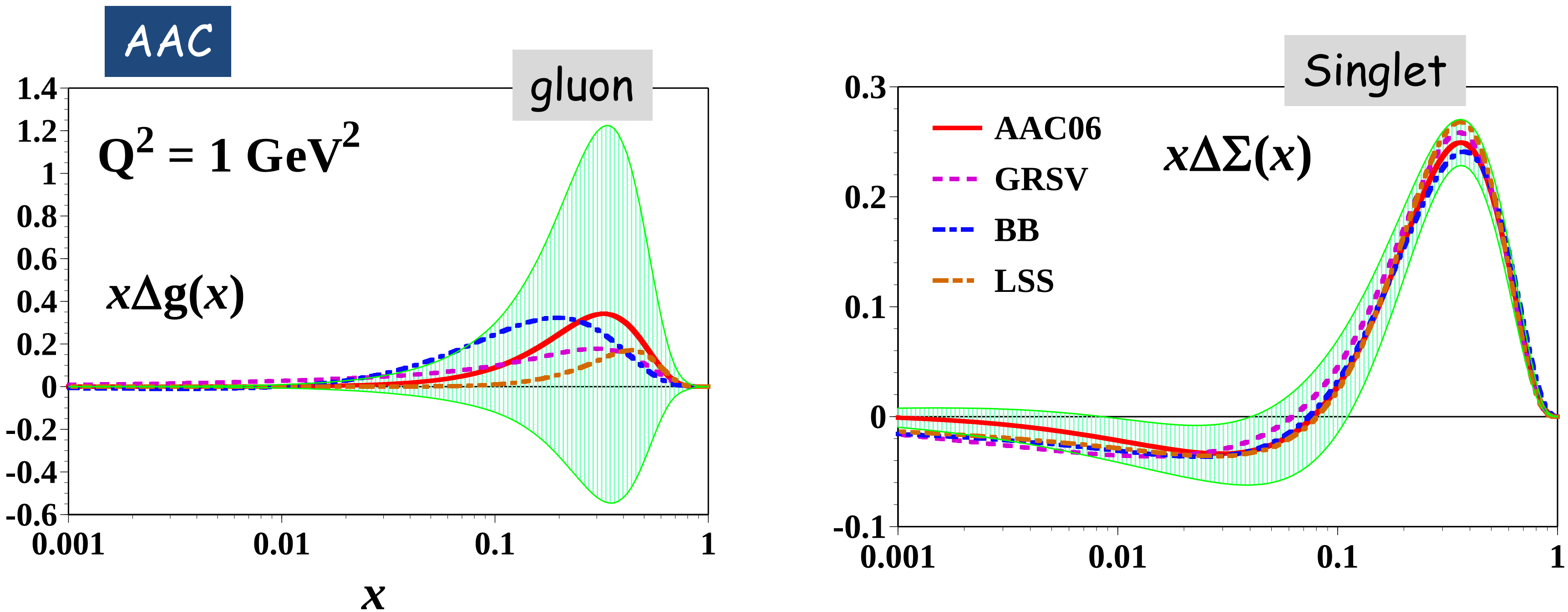
$$\frac{d}{d\ln Q^2}\Delta q^{ns} = \Delta\mathcal{P}^{ns}_{qq} \otimes \Delta q^{ns}$$

$$\frac{d}{d\ln Q^2}\begin{pmatrix}\Delta q^{s}\\ \Delta g\end{pmatrix} = \begin{pmatrix}\Delta\mathcal{P}^{s}_{qq} & \Delta\mathcal{P}^{s}_{qg}\\ \Delta\mathcal{P}^{s}_{gq} & \Delta\mathcal{P}^{s}_{gg}\end{pmatrix} \otimes \begin{pmatrix}\Delta q^{s}\\ \Delta g\end{pmatrix}$$

- choose scheme $\overline{MS}$, AB, jet and Q_0^2
- optionally fix ns moments from hyperon decays (a_3, a_8)
- fit PDFs for quark non-singlet and singlet and gluon to g_1 data
- functional form of PDFs biases error band
- extra problems in polarized case:
  - no positivity condition, no momentum sum rule
- higher twist, …

QCD fits

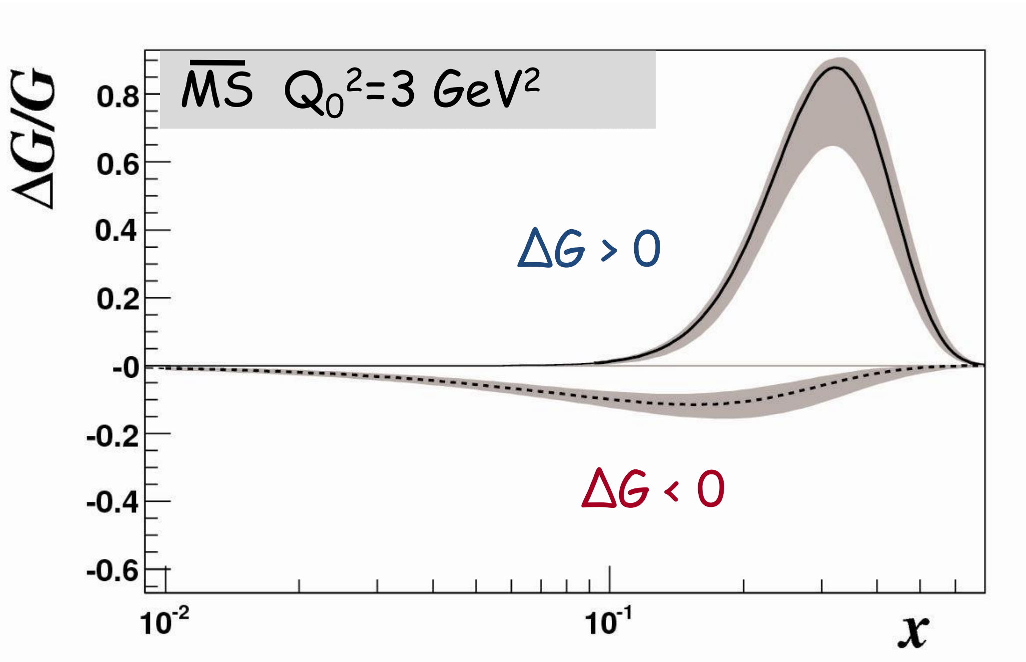
- many groups performing World Data fits
- most recent and complete DSSV → De Florian
- here: *AAC*, LSS06, COMPASS

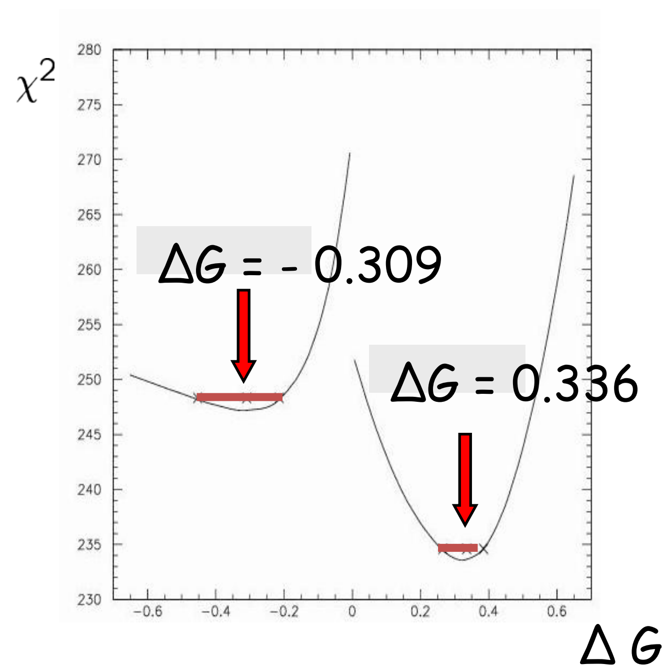


note: errors of *AAC* account for simultaneous deviation of all parameters

Fit with new deuteron g_1

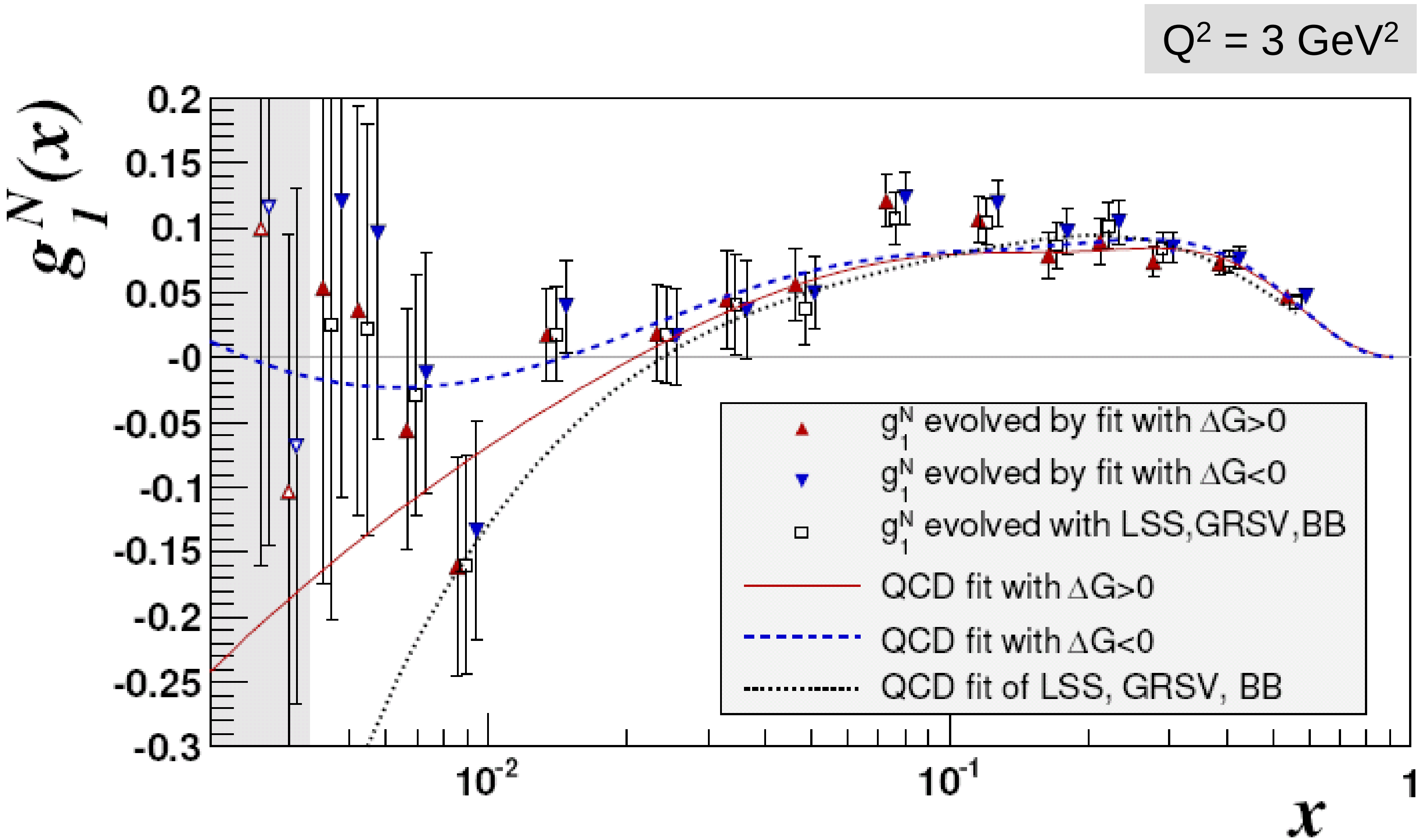
- two solutions with $\Delta G > 0$ and $\Delta G < 0$
- uncertainty due to parametrization not included





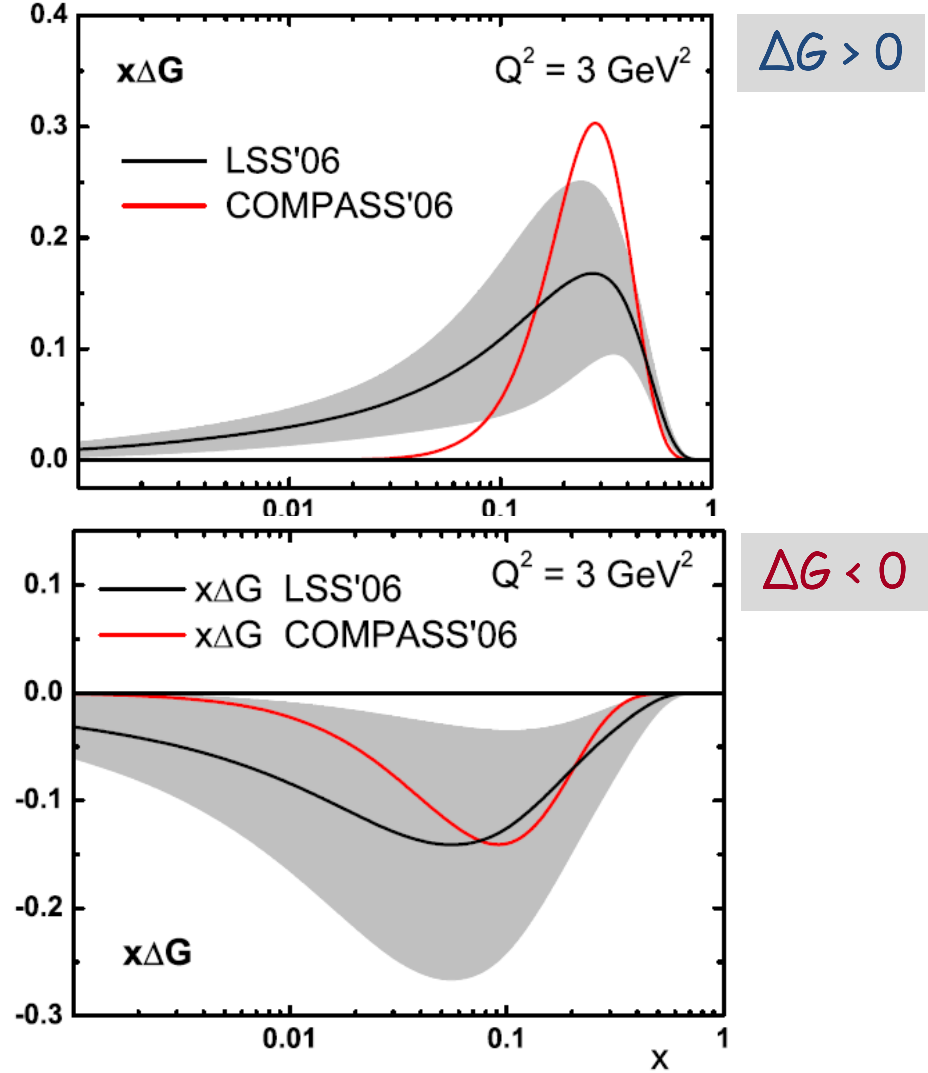
PLB 647 (2007) 8-17

COMPASS deuteron g_1



LSS06 / COMPASS06

- LSS06 also finds two solutions with small $\Delta G > 0$ and $\Delta G < 0$
- includes HT and Clas data
- How to tell sign of ΔG?

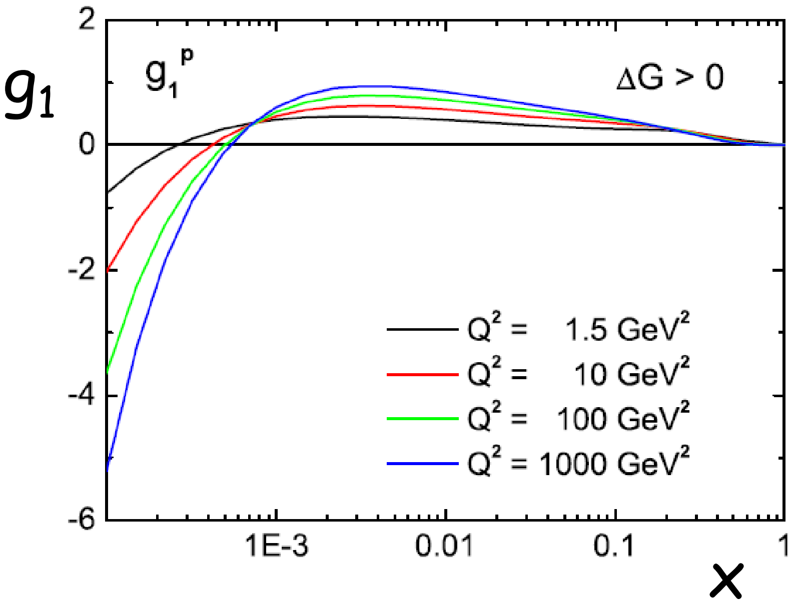


Sign of ΔG and low g_1 at small x

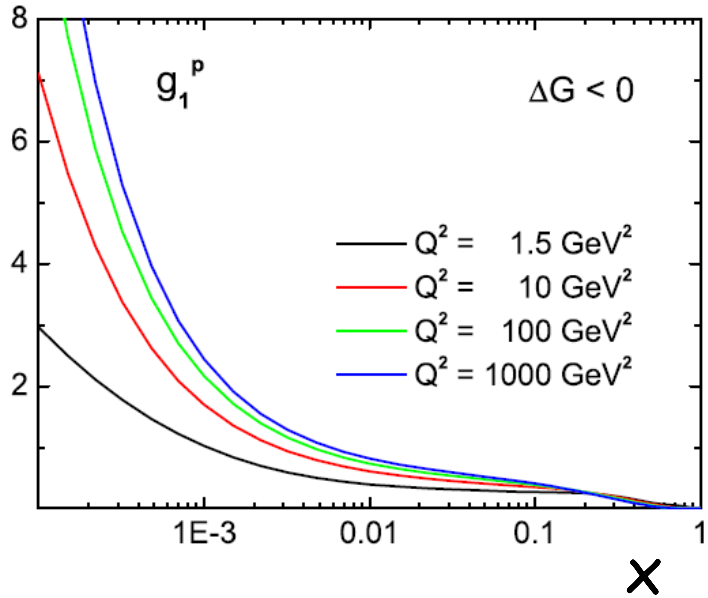
ΔG > 0

ΔG < 0

LSS06



p

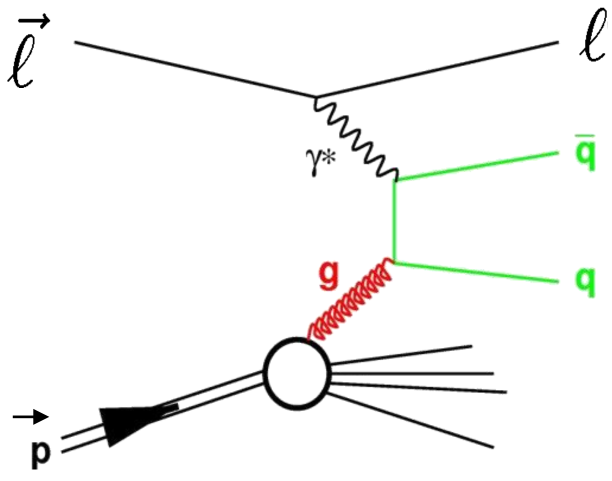


Leader, DIS2008

measurable at a polarized ep collider (EIC)

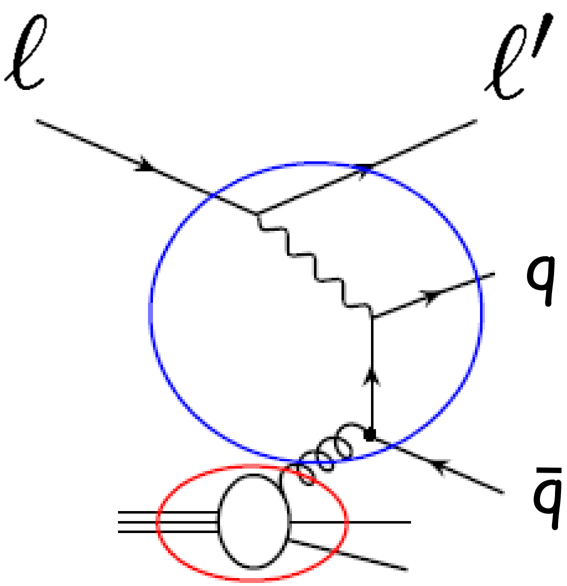
$\Delta g/g$

from hadron production in DIS



Hadron production in DIS via PGF

Principle: Gluon polarization enters via photon-gluon fusion (PGF)



$$A_{\parallel} = R_{pgf} \langle \hat{a}_{pdf} \rangle \left\langle \frac{\Delta g}{g} \right\rangle$$

- measure $A_{\parallel}$
- calculate R_{pgf} ,$\langle \hat{a}_{pgf} \rangle$ and background by Monte Carlo

Analysed channels

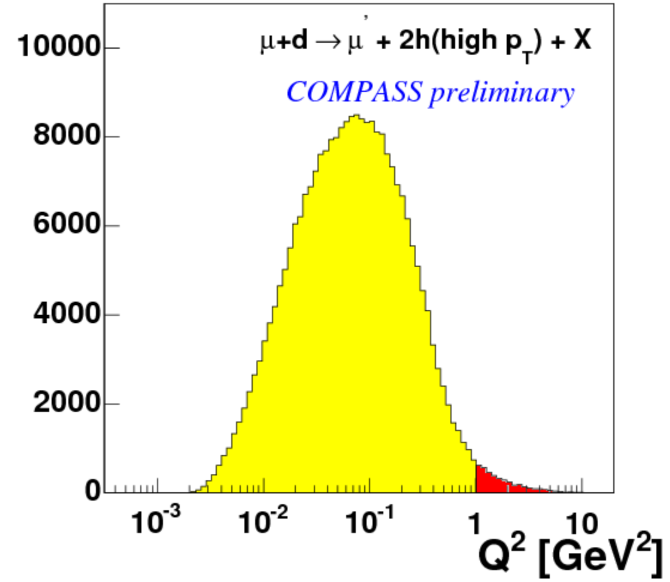
analysed data sets:

- high-p_T hadron pairs (no ID, pions/kaons)
  - $Q^2 > 1$ GeV^2 — LEPTO
  - $Q^2 < 1$ GeV^2 or unmeasured — PYTHIA
- high-p_T single hadron
  - small Q^2 or unmeasured — PYTHIA
- single charmed meson
  - quasi-real photons — AROMA, RAPGAP

All analyses in LO till now (plus parton showers)

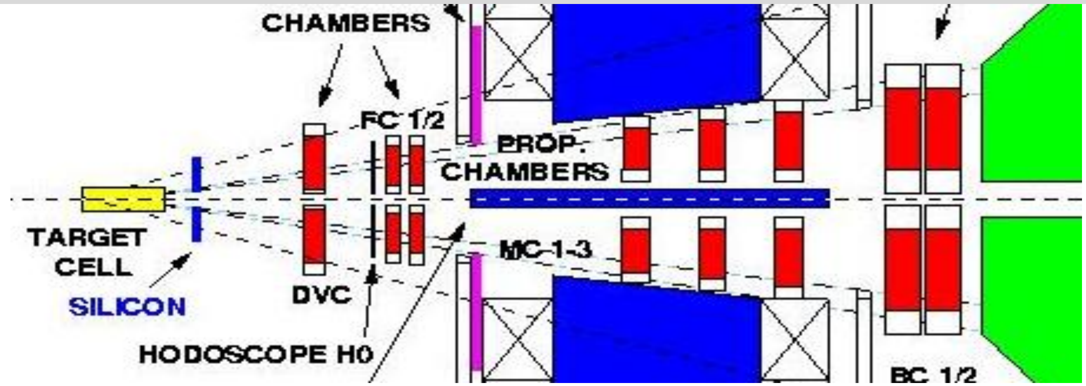
Why is small Q^2 interesting

- much larger cross section
- Hermes cannot measure Q^2 for most events
  - scattered e out of acceptance
  - dominated by small Q^2
- hard scale given by
  - high-p_T hadrons: $\sum p_T^2$
  - charmed hadron: $4m_c^2$



Hermes high-p_T hadrons

e^+ 27.5 GeV



scattered electron:

- "tagged"
  - inside acceptance
  - Q^2 measured
  - p_T wrt γ^*
- "anti-tagged"
  - outside acceptance
  - Q^2 small, unmeasured
  - p_T wrt beam

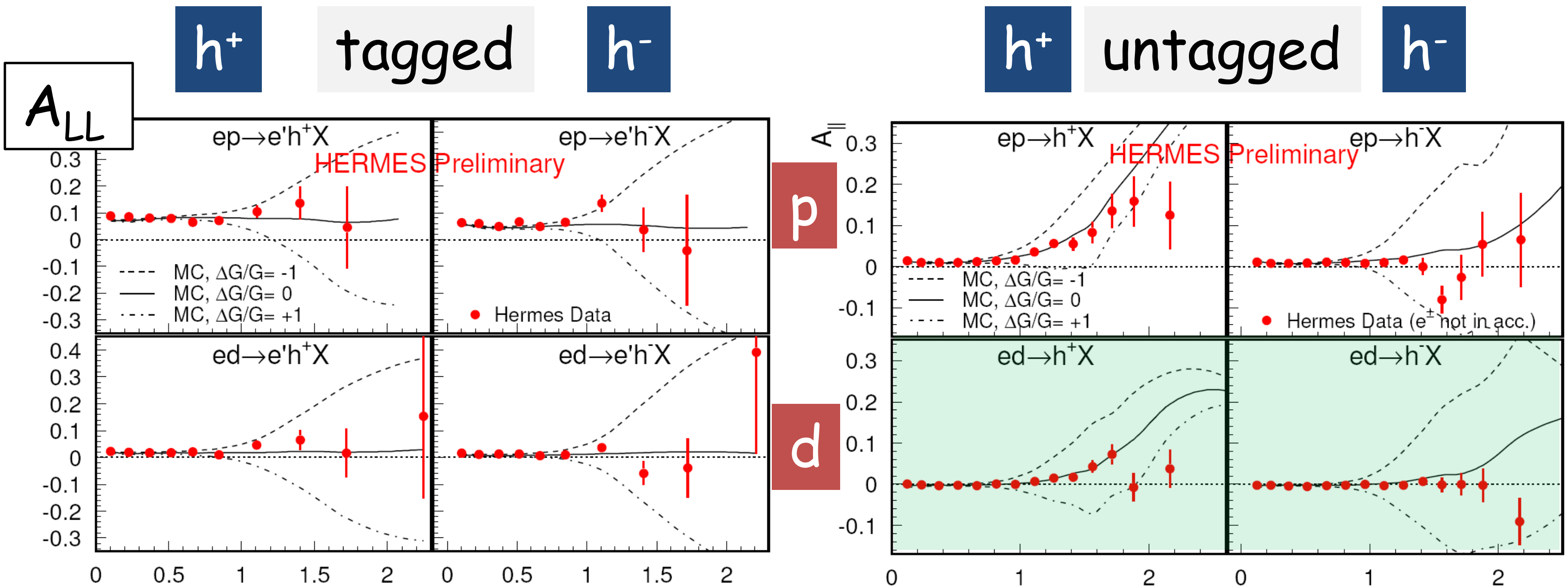
3 samples for p/d, h^+/h^-:

- single hadrons
  - tagged ~ 4%
  - anti-tagged ~92%
- hadron pairs
  - combined ~ 4%

rough percentages for events after respective cuts: p_T>1 GeV/c

see: N.Bianchi, Pacific SPIN07, Vancouver BC

A_{LL} for single hadrons

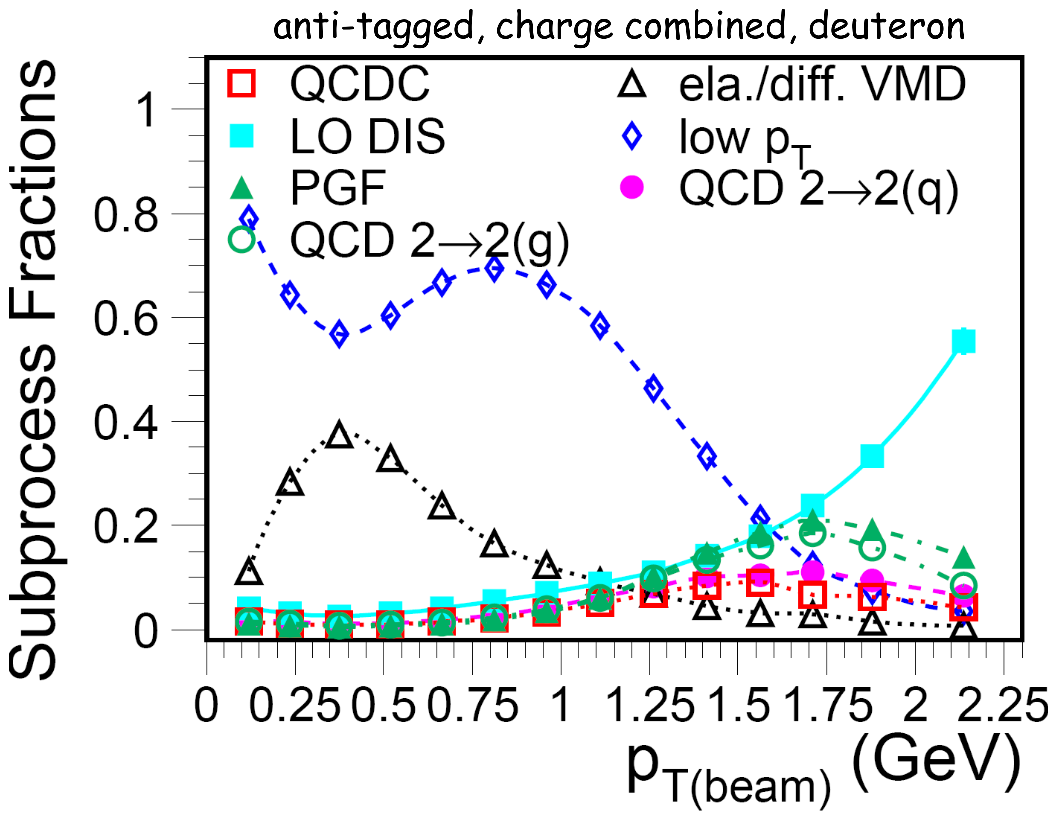


$Q^2>0.1$ GeV^2, $W^2>4$ GeV^2 p_T p_T (beam)

MC plus asymmetry model with $\Delta g/g(x) = -1, 0, 1$ for upper, middle and lower curve

Subprocesses in MC

PYTHIA 6.2



VMD (elast.+diffr., soft low-pT): decreasing with p_T

DIS: increasing (dominating) with p_T

QCDC/QCD2->2(q): increasing with p_T

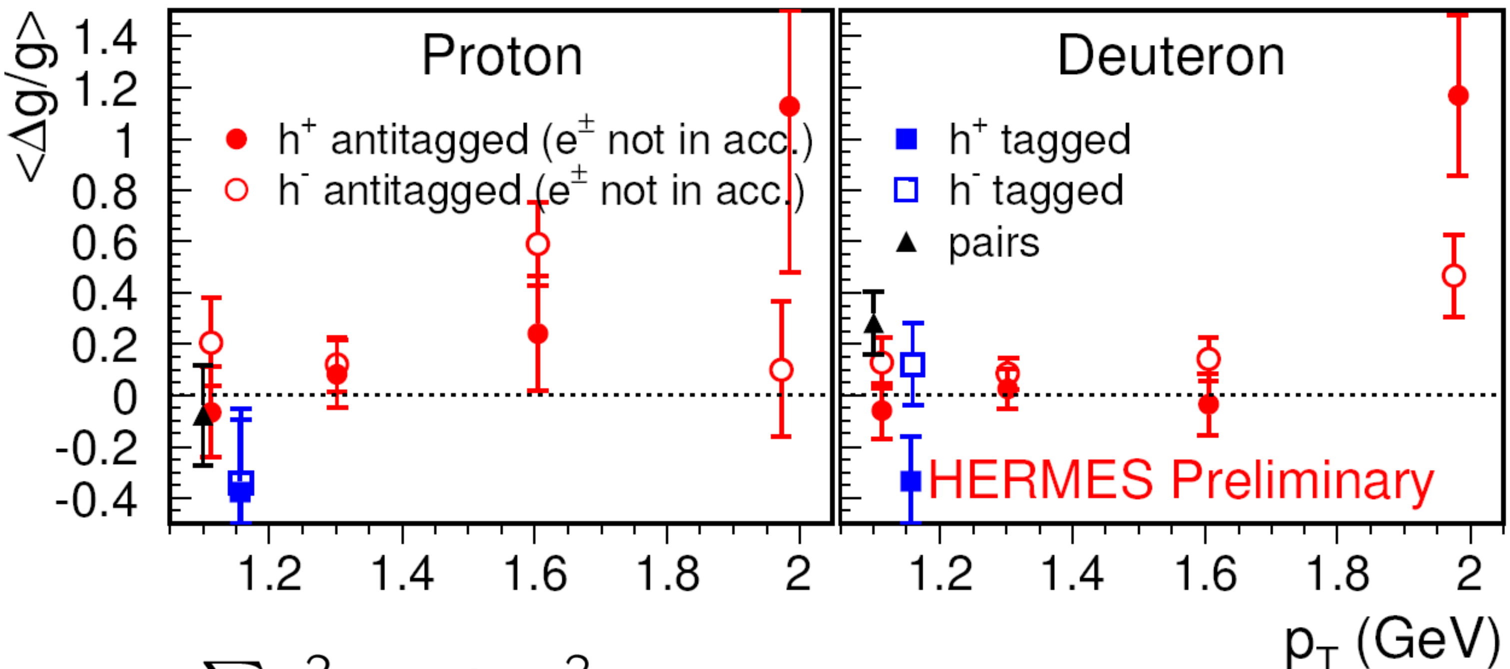
Signal processes are PGF and QCD2>2(g) (resolved photon)

Direct Method (I)

$$\left\langle \frac{\Delta g}{g} \right\rangle = \frac{1}{R_{sig}\langle \hat{a} \rangle} \left\{ A_{\parallel}^{meas} - R_{bg} A_{bg} \right\}$$

from Monte Carlo

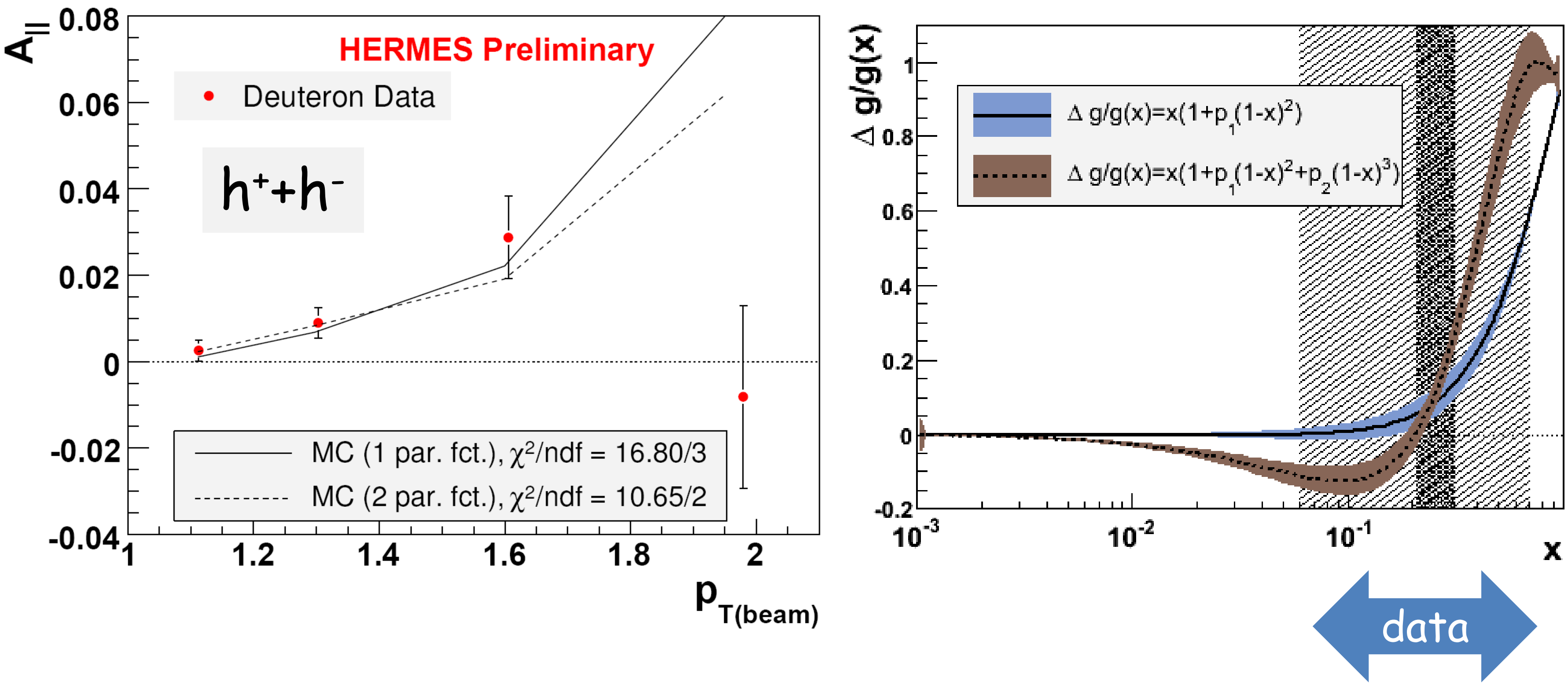
statistical errors only



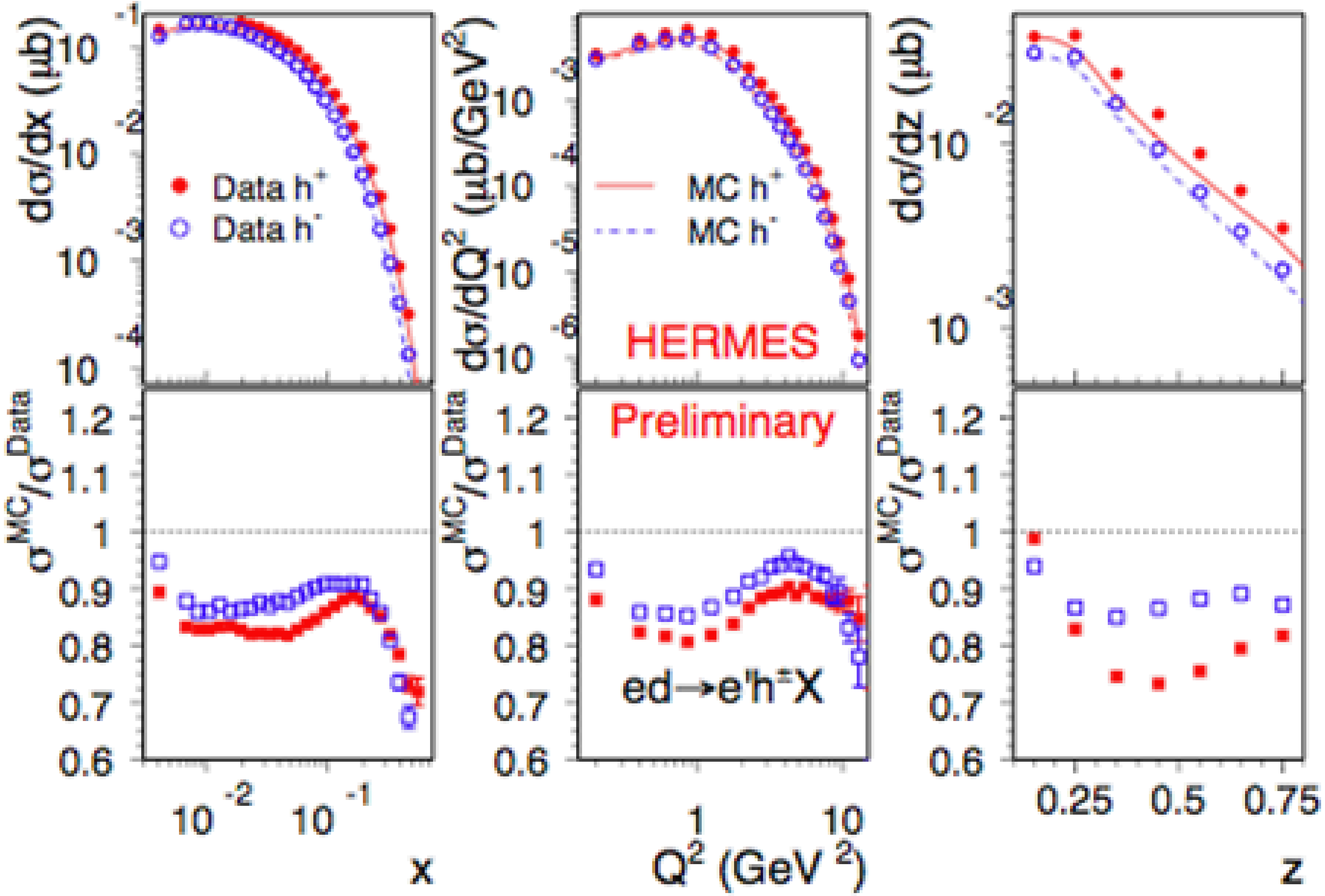
pairs: $\sum p_T^2 > 2\text{GeV}^2$

Indirect Method (II)

Fit parameters of polynomial function to $A_{\parallel}$ using MC



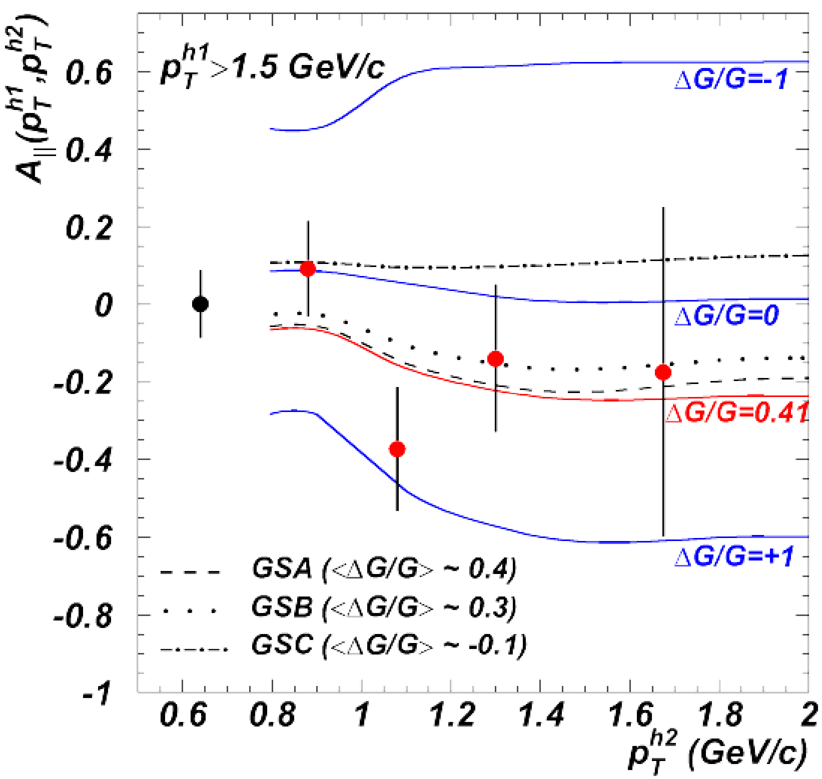
MC tuning/systematics

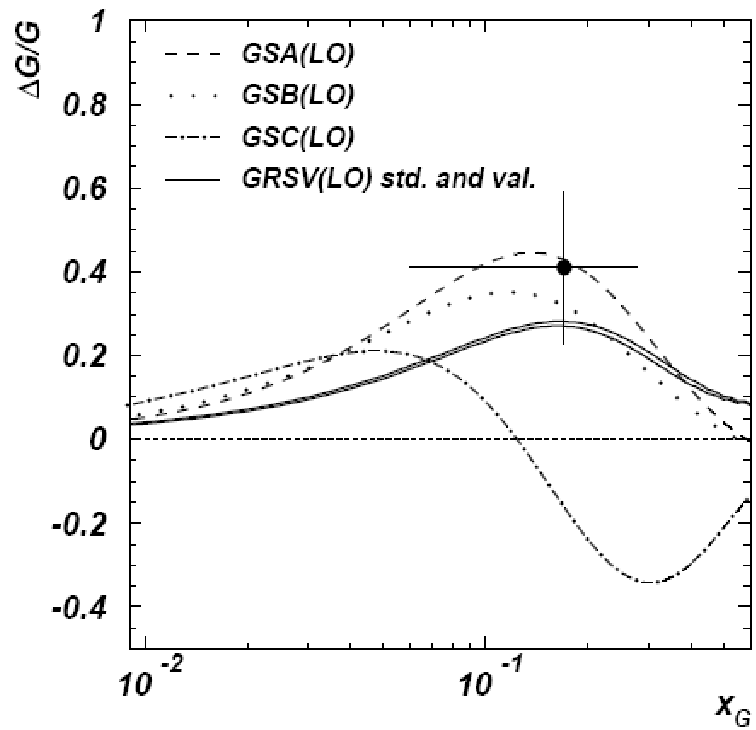


varied: MC parameters, PDFs, low p_T asymmetry

Original HERMES measurement

- proton data only, high-p_T pairs
- missing generator processes (Pythia 5.7 vs 6.3)





Phys. Rev. Lett. 84 (2000) 2584

N.Bianchi, Pacific SPIN07, Vancouver BC

Results for $\Delta g/g$

Method I

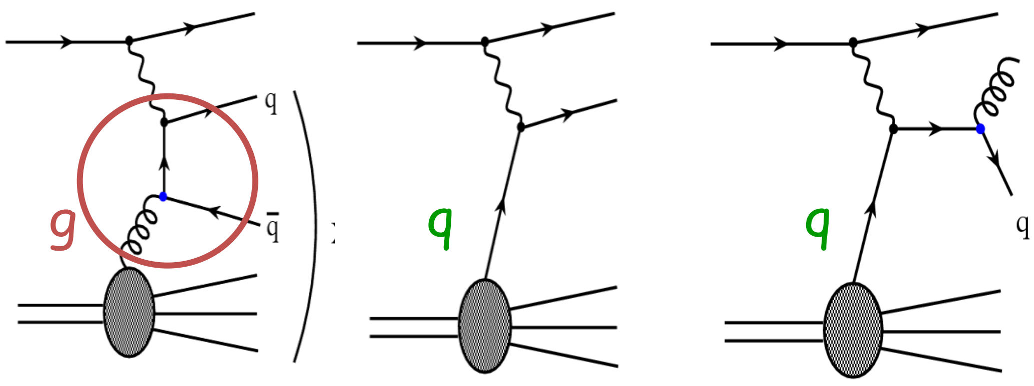
$$\Delta g/g(x,\mu^2) = 0.078 \pm 0.034(\text{stat}) \pm 0.011(\text{syst-exp})\,{}^{+0.125}_{-0.082}\,(\text{syst-model})$$

Method II

$$\Delta g/g(x,\mu^2) = 0.071 \pm 0.034(\text{stat}) \pm 0.010(\text{syst-exp})\,{}^{-0.127}_{-0.105}\,(\text{syst-model})$$

$\Delta G/G$ from high-p_T pairs

all Q^2



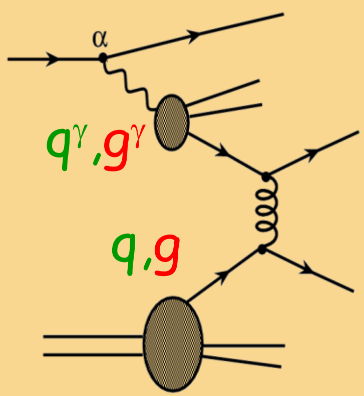
Photon Gluon Fusion ~ 30%

Leading Order

QCD Compton

+

$Q^2 < 1$ GeV^2



Resolved γ ~50%

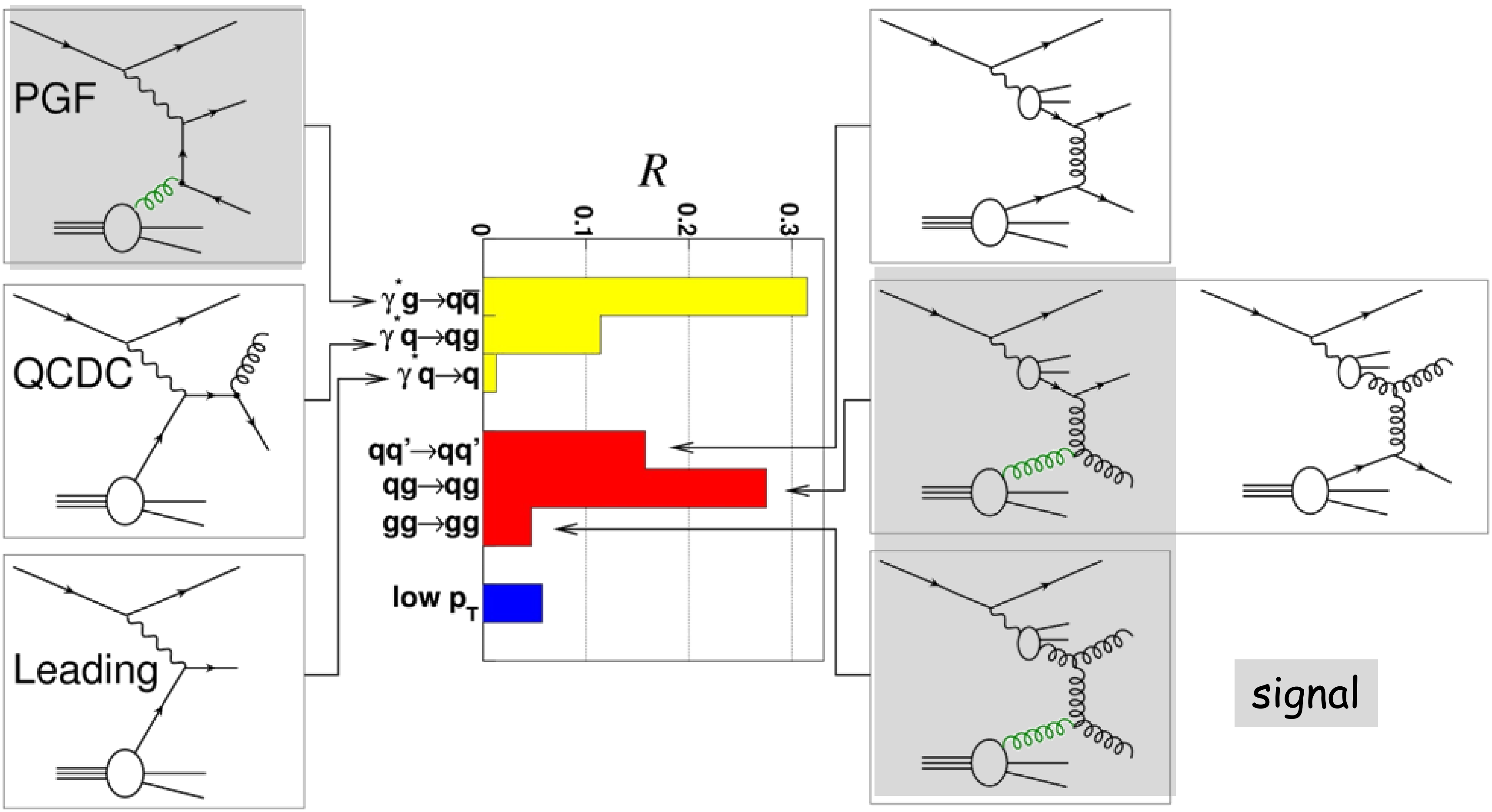
$$A_{LL}^{2h} = R_{pgf}\, a_{LL}^{pgf} \frac{\Delta g}{g}(x_g) + R_{LO}\, D A_1^{LO}(x_{Bj}) + R_C\, a_{LL}^{C} A_1^{LO}(x_C)$$

use also inclusive A_{LL}

High-p_T pairs, low Q^2

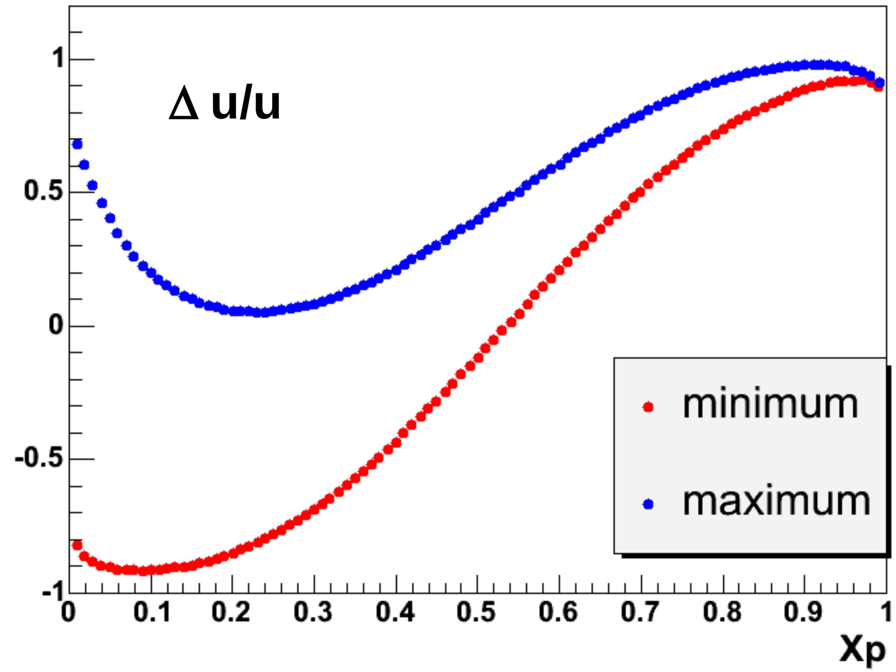
Ratios for hadron pairs with for $Q^2 < 1$

Resolved photons



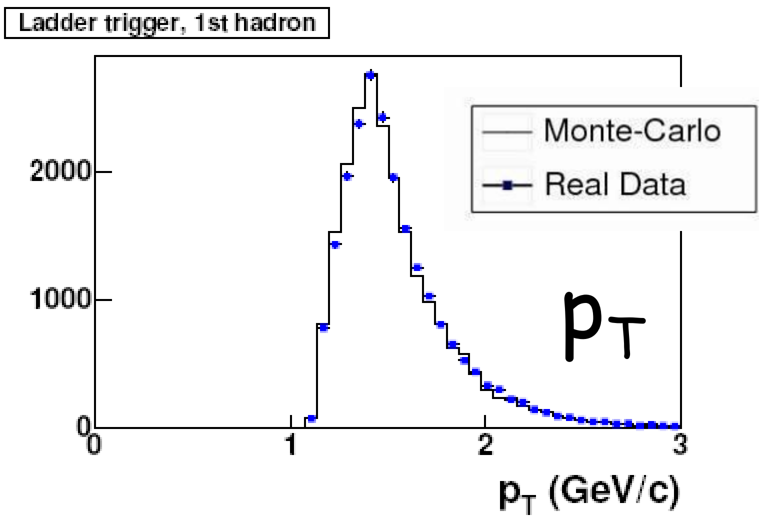
Resolved photons

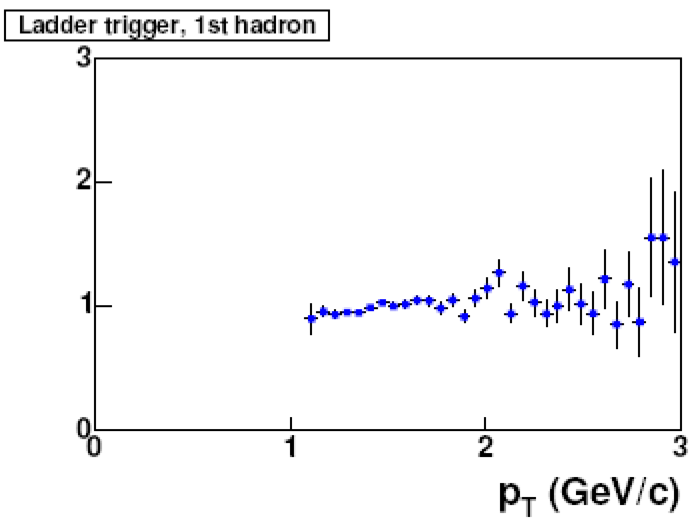
- More than 50%, however assuming a min and max scenario, shows little difference.
- Probing photon at large *x*, where photon PDF rather well determined



Glück, Reya, Sieg

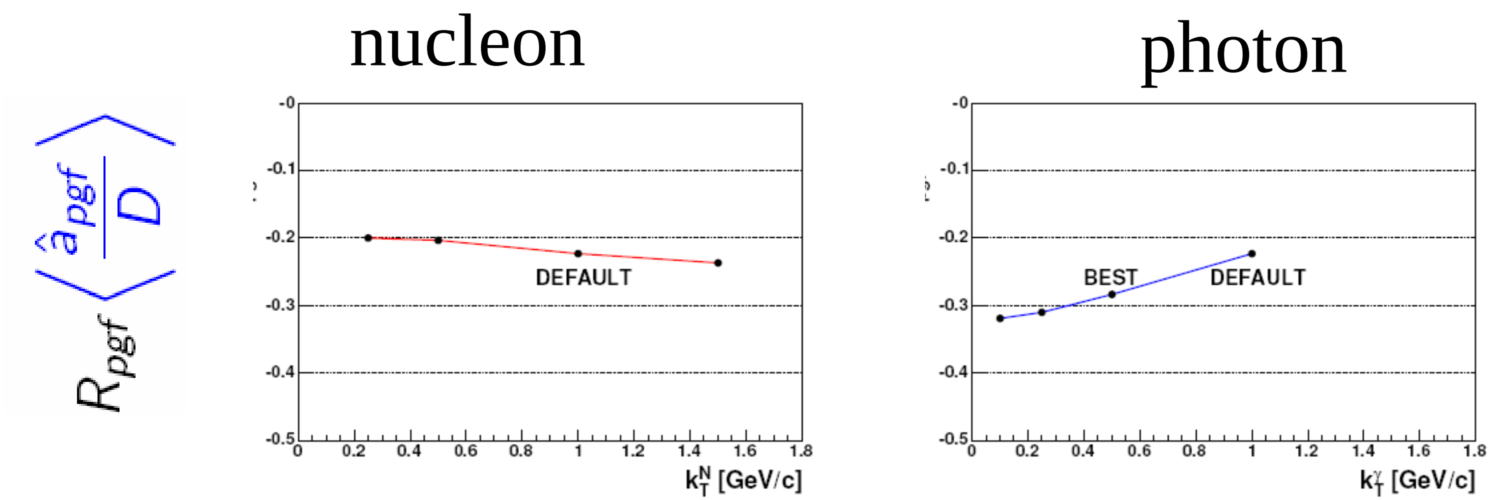
Data versus MC, low Q^2





- excellent to good agreement for all kinematics variables

Systematics: e.g. k_T-tuning, low Q^2



- systematic error:
  - determined using 15 independent MC simulations
  - exploring the parameter space
    - in k_T of nucleon and photon
    - fragmentation functions
    - parton shower on/off,
    - renormalization scale

$\Delta g/g$ from high-p_T hadron pairs, low Q^2

- 2002 - 2004 data: high-p_T, $Q^2 < 1$ GeV^2

$\Delta G/G$ = 0.016 ± 0.058 (stat) ± 0.055 (syst)

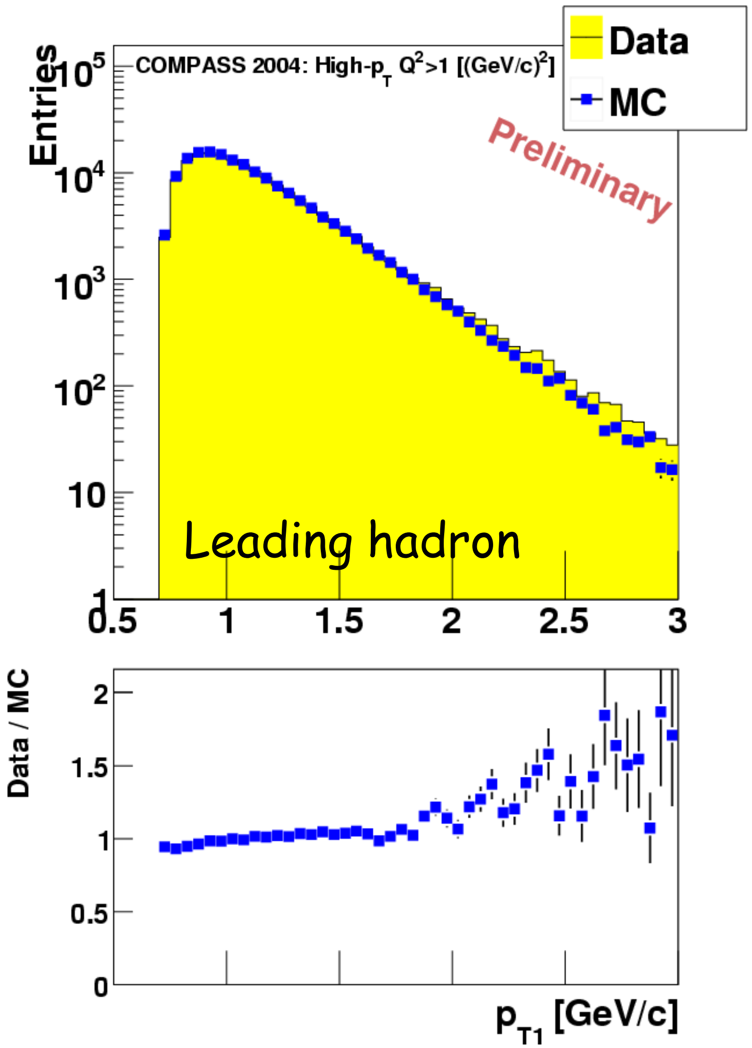
@ $\langle x_g \rangle = 0.085$, $\mu^2 = 3$ GeV^2

High-p_T pairs, Q^2 >1 GeV ^{2}

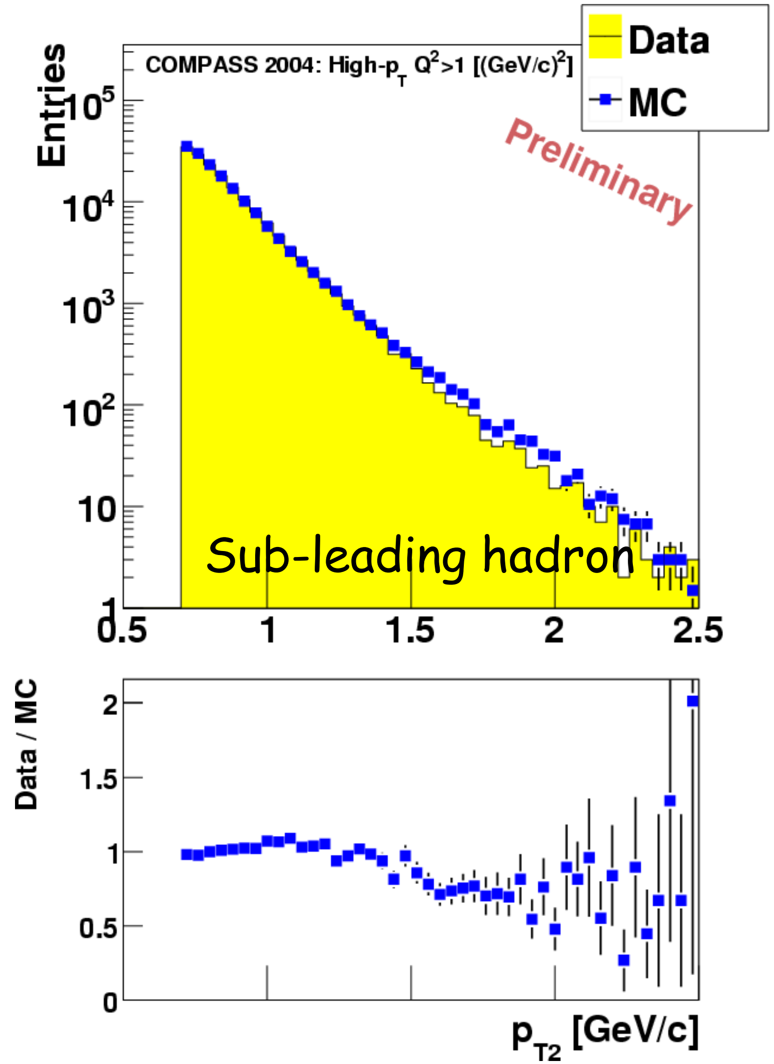
$$A_{LL}^{2h} = R_{pgf} a_{LL}^{pgf} \frac{\Delta g}{g}(x_g) + R_{LO} D A_1^{LO}(x_{Bj}) + R_C a_{LL}^C A_1^{LO}(x_C)$$

- tune MC (Lepto) to reproduce data
- estimate relative fractions *R* on event-by-event basis using NN trained with MC events (kin. variables)
- use in NN output as event weight
- looser cuts possible
  - $Q^2 > 1$ GeV^2
  - $p_{T1,2} > 0.7$ GeV
  - $x_F > 0$, inv. mass 2h > 1.5 GeV^2
- for details see M. Stolarski DIS2008

Monte Carlo

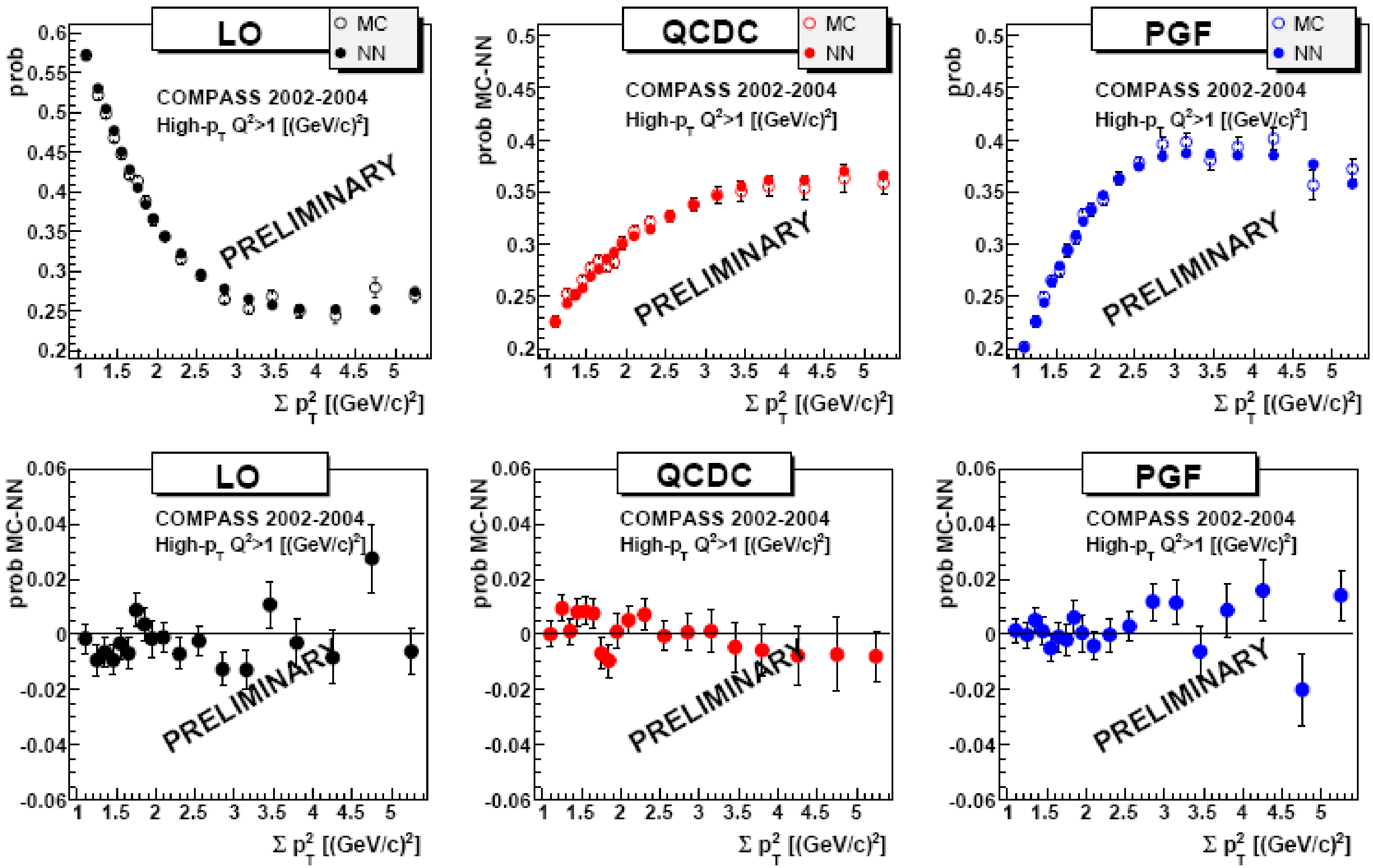


COMPASS 2004: High-p_T Q^2>1 [(GeV/c)^2]
Data
MC
Preliminary
Entries
Leading hadron
Data / MC
p_{T1} [GeV/c]



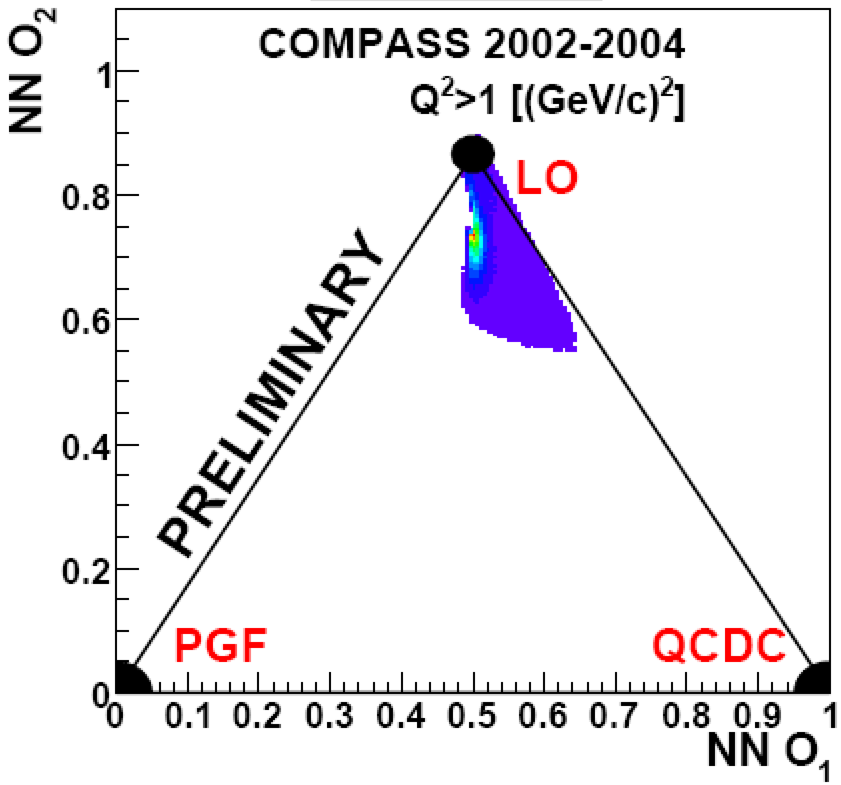
COMPASS 2004: High-p_T Q^2>1 [(GeV/c)^2]
Data
MC
Preliminary
Entries
Sub-leading hadron
Data / MC
p_{T2} [GeV/c]

NN description

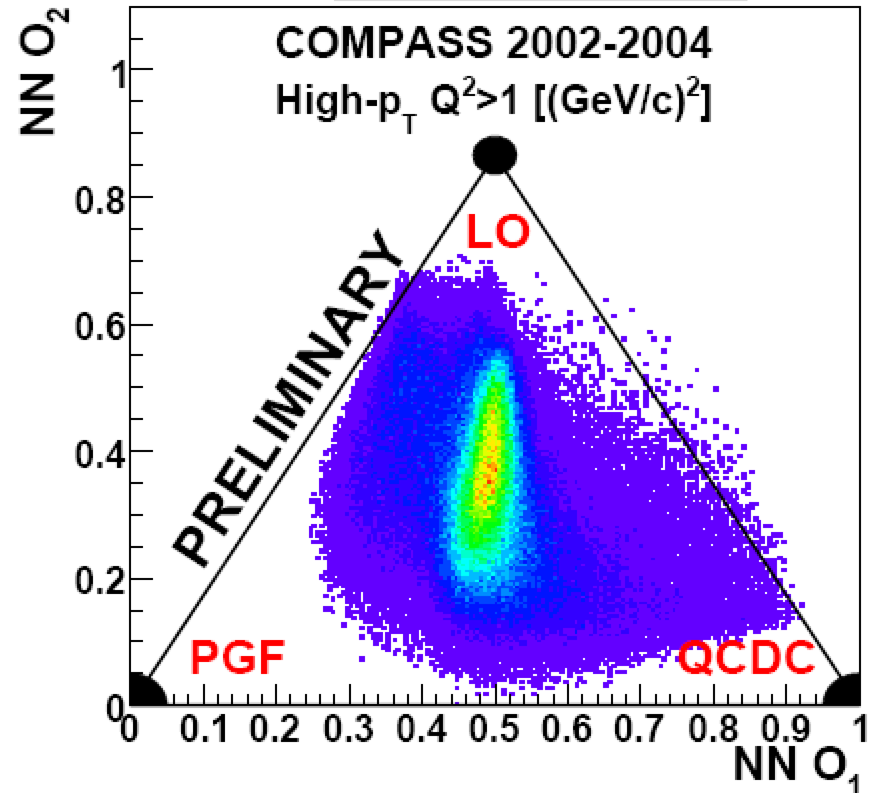


NN output

inclusive



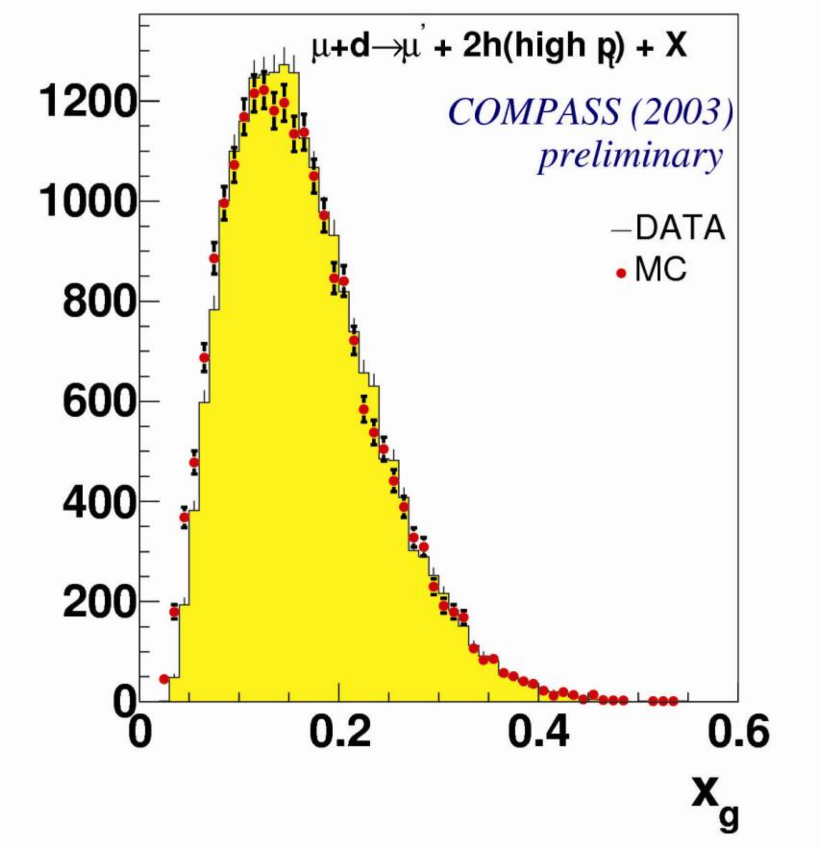
hadron pairs

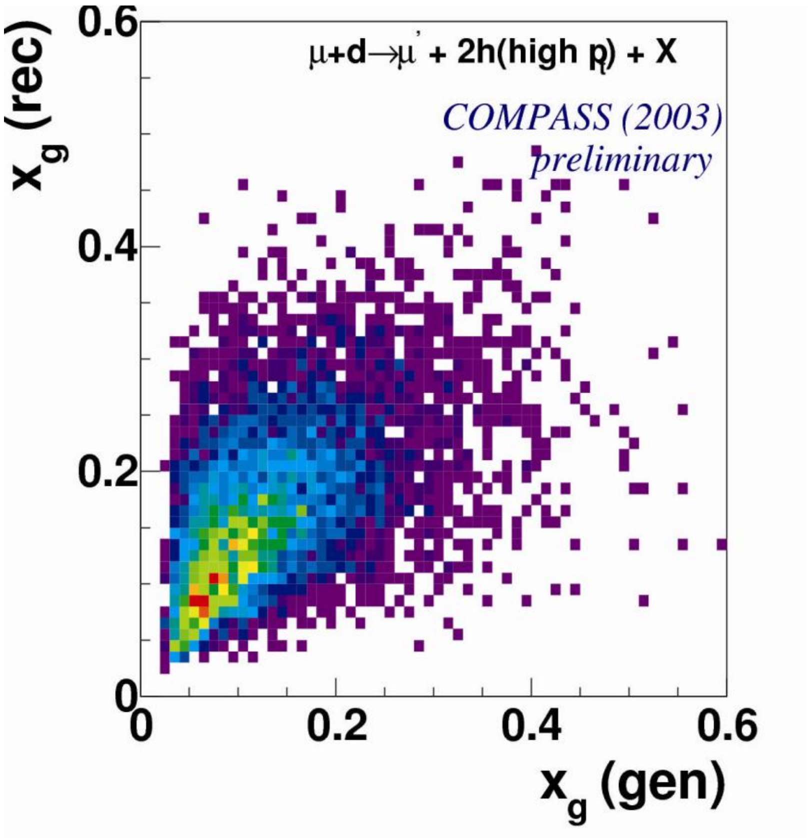


$$R_{PGF} = 1 - o_1 - \frac{1}{\sqrt{3}} o_2 \qquad R_C = o_1 - \frac{1}{\sqrt{3}} o_2 \qquad R_L = \frac{2}{\sqrt{3}} o_2$$

Can we learn about x_g?

here Lepto and Q2>1





All processes

PGF events (MC)

$\Delta g/g$ from high-p_T hadron pairs

- 2002 - 2004 data: High p_T, $Q^2 > 1$ GeV/c^2

$\Delta G/G$ = 0.08 ± 0.10 (stat) ± 0.05(syst)

@ $\langle x_g \rangle$ = 0.082, (range: 0.055 – 0.123) $\mu^2 \sim 3$ (GeV/c)2

$\Delta g/g$ from open charm

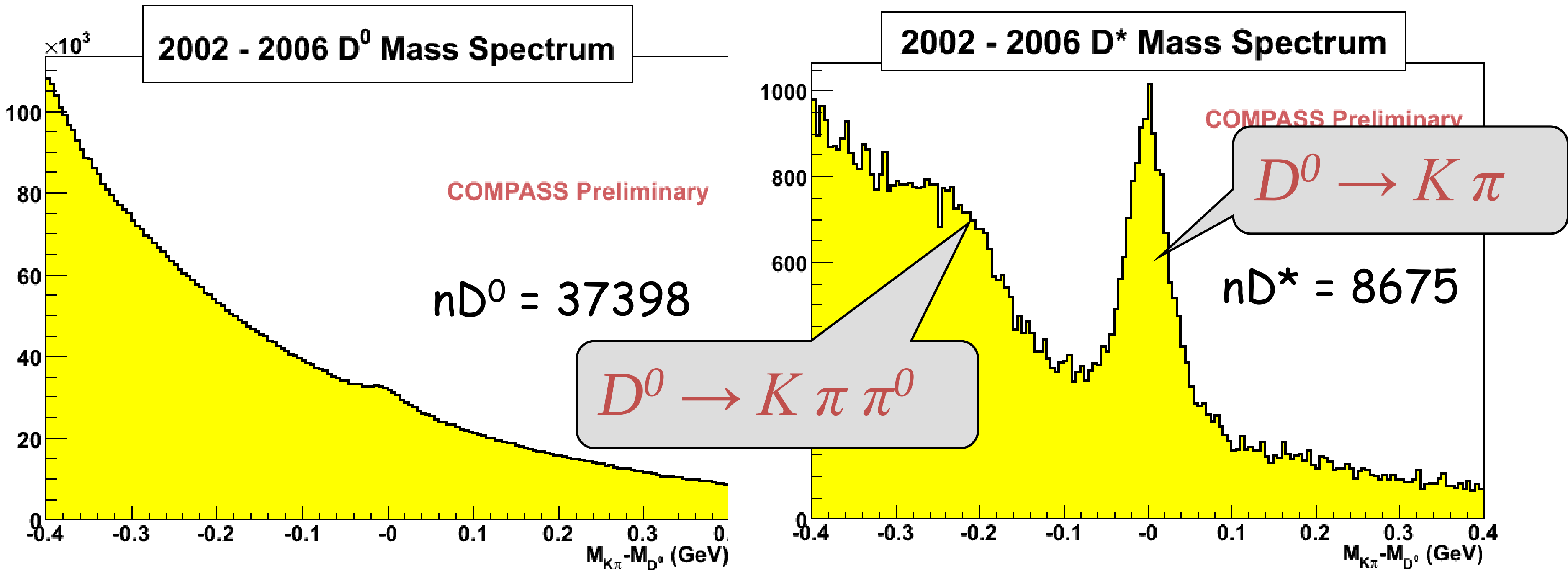
- cleanest process ("golden channel")
  - no or little physics background (LO, QCDC)
- observe asymmetry in D meson production
  - strongly statistics limited
  - only one D meson via $D \rightarrow \pi K$ (BR ~ 4%)
  - combinatorial background large
  - drastically reduced when looking to D* decay in coincidence with slow pion

$$D^* \rightarrow D^0 + \pi_s \rightarrow K + \pi + \pi_s$$

- for details see F. Robinet DIS2008

D mass spectra

$$D^0 \rightarrow K + \pi \qquad D^* \rightarrow D^0 + \pi_s \rightarrow K + \pi + \pi_s$$

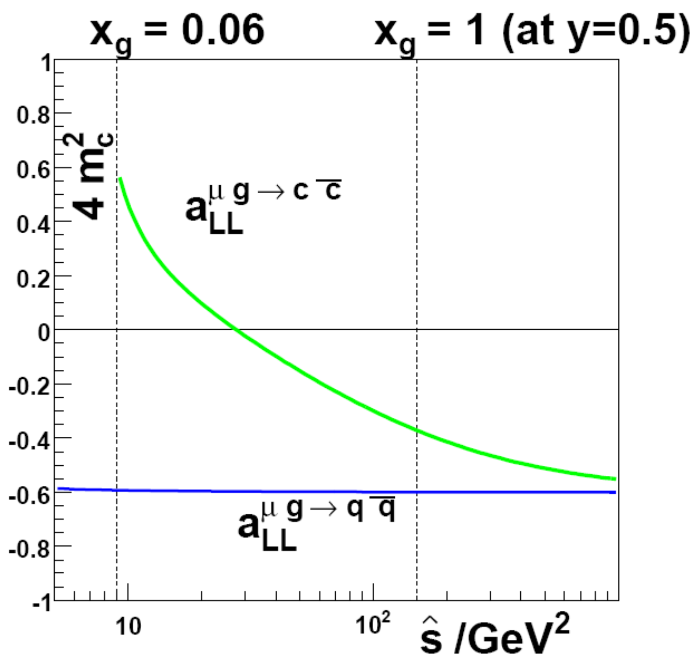


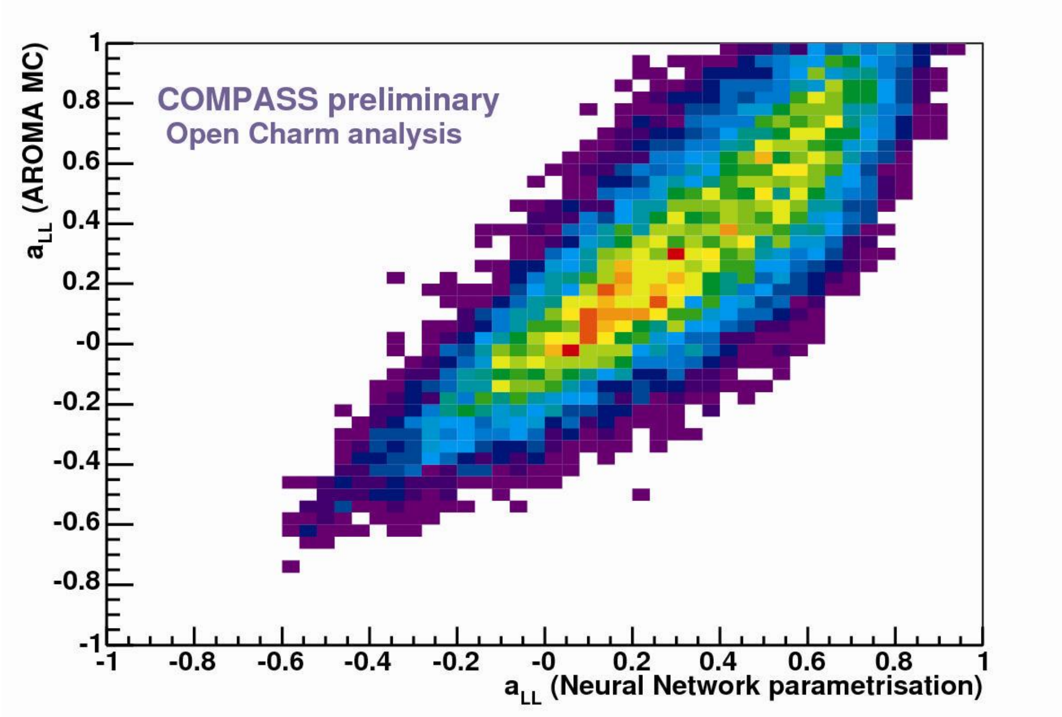
$\Delta G/G$ from open charm

$$A_{LL}/D \simeq \frac{S}{S+B} a_{LL} \frac{\Delta g}{g}(x_g)$$

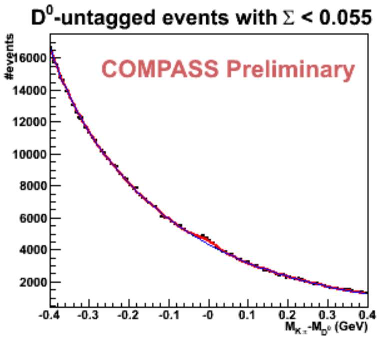
- Analysis uses both a_{LL} and S/(S+B) weighting
- a_{LL} obtained from Neural Network trained on MC (AROMA) using: Q^2, x_{bj}, y, p_T, z_D
- S/(S+B) given by a parameterization in $fP_\mu a_{LL}$, p_K, θ_K, z_D, $\cos\theta^*$, p_T, RICH likelihoods
- weighting brings significant improvement in statistics due to large variations of a_{LL} and S/(S+B) in phase-space

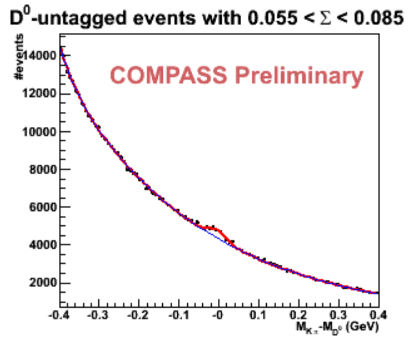
a_{LL} variation

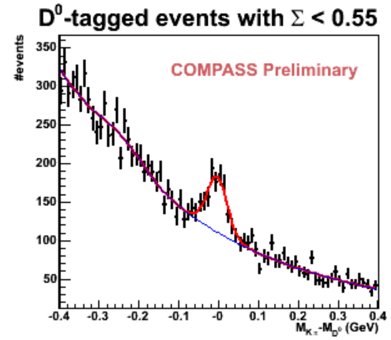


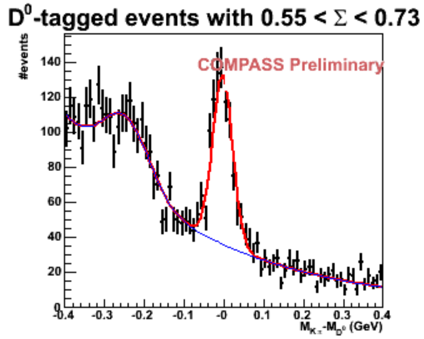


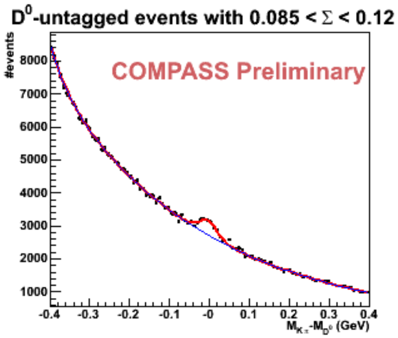
S/S+B weighting

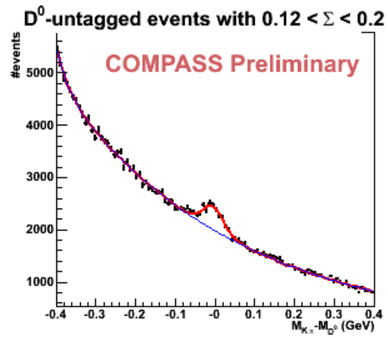


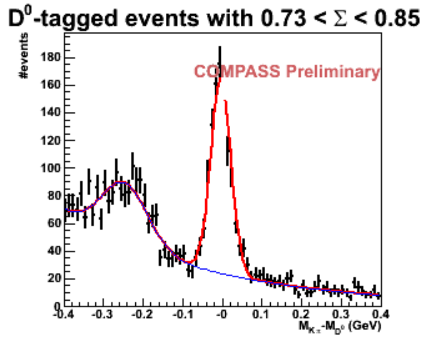


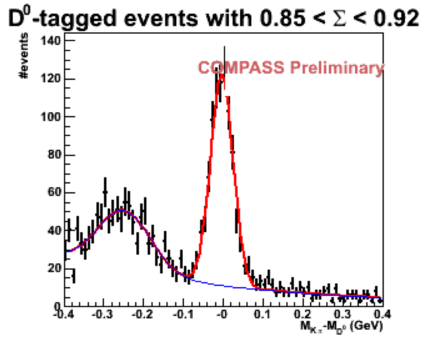


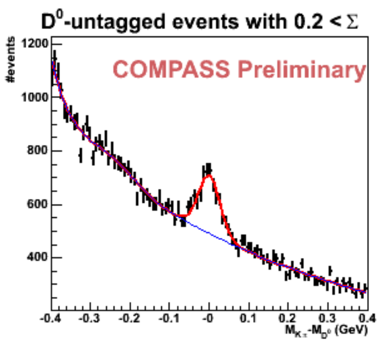




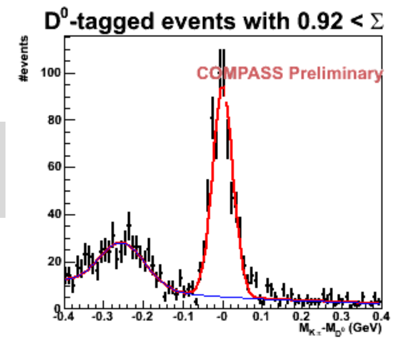








D^0 -untagged



D^* -tagged

5 bins in $\Sigma = S/(S+B)$

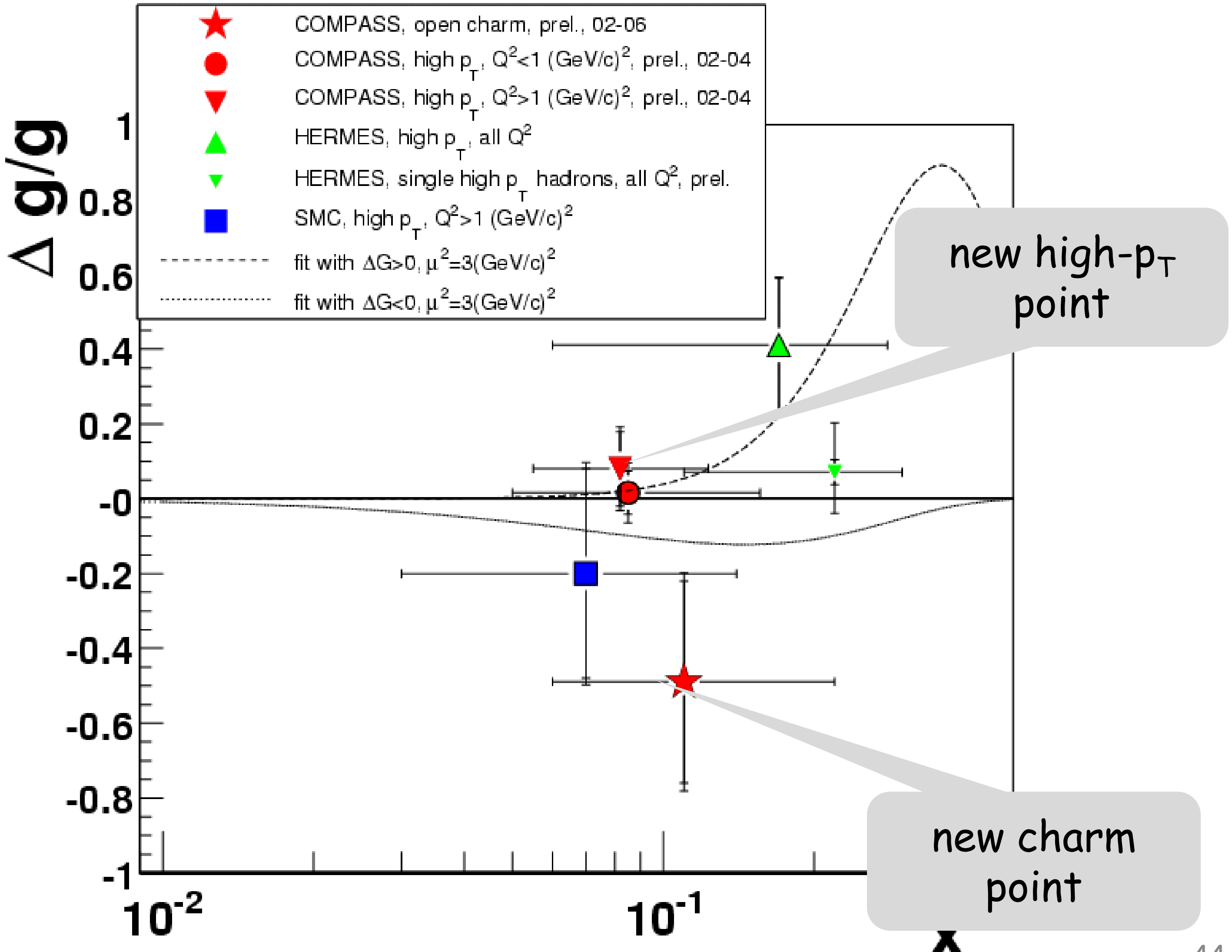
$\Delta G/G$ from open charm

- 2002 - 2006 data $D^0 + D^*$

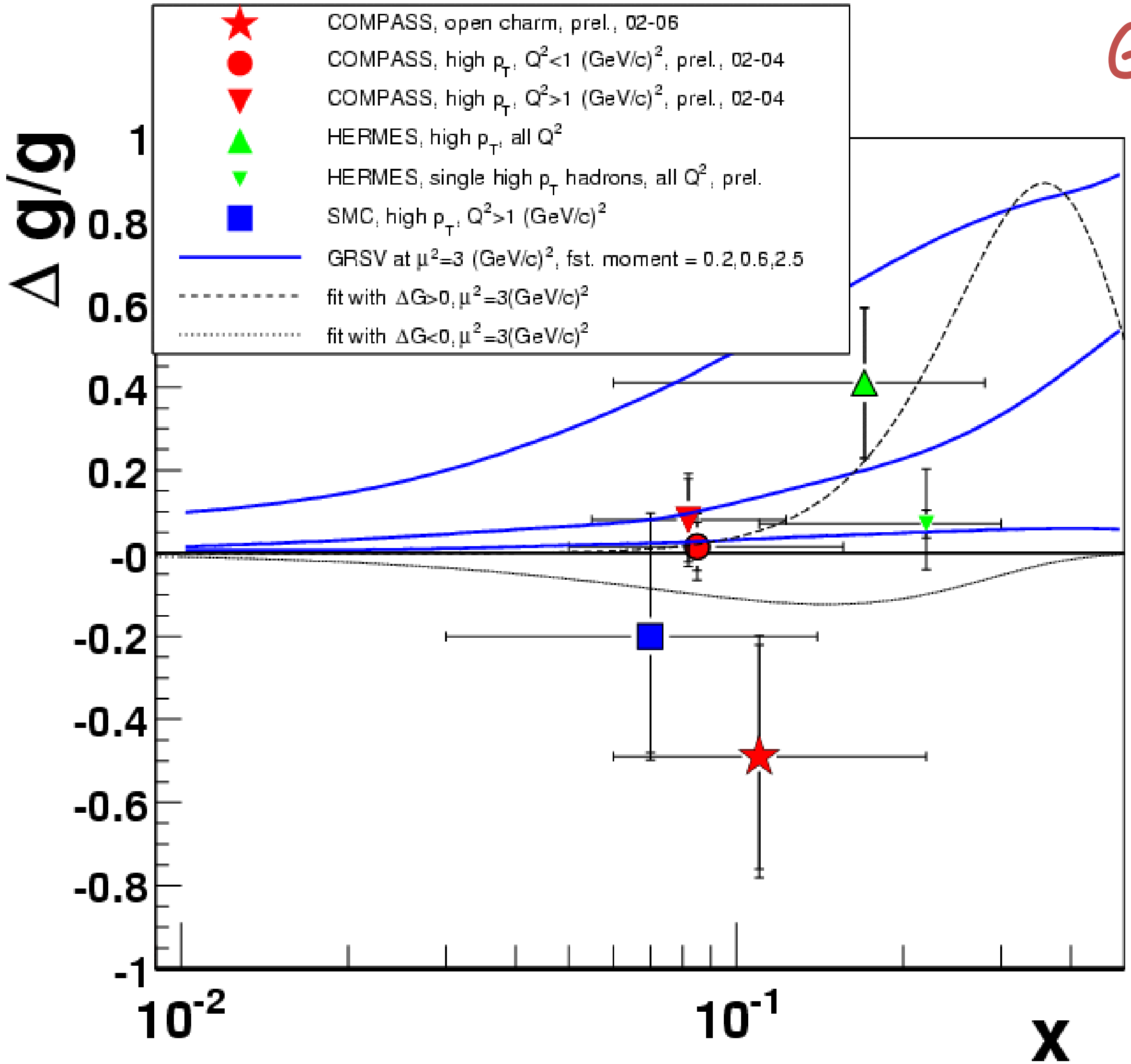
$\Delta G/G$ = -0.49 ± 0.27 (stat) ± 0.11 (syst)

@ $\langle x_g \rangle \sim 0.11$, $\langle \mu^2 \rangle \sim 13\ (\mathrm{GeV}/c)^2$

Summary of results



DIS-FT ΔG/G measurements



GRSV, ΔG

max, 2.5

std, 0.6

min, 0.2

QCD Fits

|ΔG| ~ 0.3

Summary

- all results point to small $\Delta g/g$
- DIS results are very precise
- NLO analysis urgently needed

- use results in global fits