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Status of Polarized PDFs and Higher Twist after the CLAS and COMPASS Data

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OUTLINE

- **Method of analysis – higher twist corrections are taken into account**

- **Two new sets of very precise data are included in the analysis**

  - *low* Q^2 *CLAS* data

  - *COMPASS* data mainly at *large* Q^2

  ⇐ ***Very different kinematic regions***

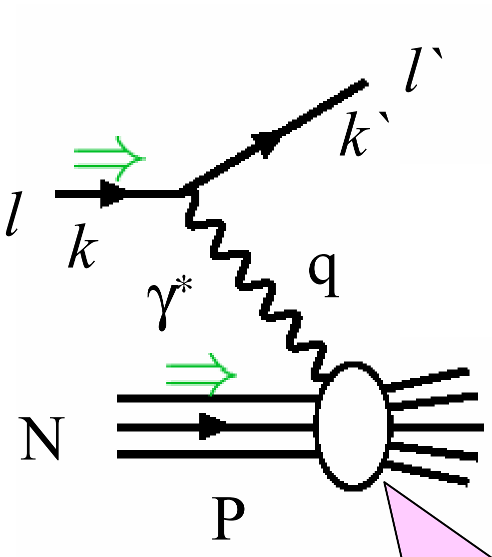
- **Impact of the new data on *LSS'05* polarized PD and HT**

- **The sign of the gluon polarization**

- **Summary**

LSS: PR D75, 074027, 2007

Inclusive DIS ⇒ one of the best tools to study the structure of **nucleon**



$Q^2 = -q^2 = 4EE`\sin^2(\theta/2)$

$x = Q^2/(2M\nu)$ $\quad \nu = E - E`$

DIS regime ==> $Q^2 \gg M^2,\ \nu \gg M$

$\mathbf{F_i(x, Q^2)}$ $\quad \mathbf{g_i(x, Q^2)}$

unpolarized SF

polarized SF

As in the unpolarized case the main goal is:

- to test **QCD**
- to extract from the DIS data the **polarized** PD

$$\Delta q(x,Q^2) = q_+(x,Q^2) - q_-(x,Q^2)$$

$$\Delta \bar{q}(x,Q^2) = \bar{q}_+(x,Q^2) - \bar{q}_-(x,Q^2)$$

$$\Delta G(x,Q^2) = G_+(x,Q^2) - G_-(x,Q^2)$$

where "+" and "-" denote the helicity of the parton, along or opposite to the helicity of the parent nucleon, respectively.

The knowledge of the polarized PD will help us:

- to make predictions for other processes like polarized **hadron-hadron** reactions, etc.
- more generally, to answer the question how the helicity of the nucleon is divided up among its constituents:

$$\mathbf{S_z = 1/2 = 1/2\, \Delta\Sigma(Q^2) + \Delta G\,(Q^2) + L_z\,(Q^2)}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

the parton polarizations Δq_a and ΔG are the first moments

$$\Delta q_a(Q^2) = \int_0^1 dx \Delta q_a(x, Q^2) \qquad \Delta G(Q^2) = \int_0^1 dx \Delta G(x, Q^2)$$

of the helicity densities: $\Delta u(x,Q^2), \Delta\bar{u}(x,Q^2) \ldots, \Delta G(x,Q^2)$

DIS Cross Section Asymmetries

Measured quantities $$A_{\parallel} = \frac{d\sigma^{\downarrow\Uparrow} - d\sigma^{\uparrow\Uparrow}}{d\sigma^{\downarrow\Uparrow} + d\sigma^{\uparrow\Uparrow}}, \quad A_{\perp} = \frac{d\sigma^{\downarrow\Rightarrow} - d\sigma^{\uparrow\Rightarrow}}{d\sigma^{\downarrow\Rightarrow} + d\sigma^{\uparrow\Rightarrow}}$$

$$(A_{\parallel}, A_{\perp}) \Rightarrow (A_1, A_2) \Rightarrow (g_1, g_2)$$

where A_1, A_2 are the virtual photon-nucleon asymmetries.

At present, $A_{\parallel}$ is much better measured than $A_{\perp}$

If $A_{\parallel}$ and $A_{\perp}$ are measured $\Rightarrow \quad g_1 / F_1$

If only $A_{\parallel}$ is measured $$\Rightarrow \frac{A_{\parallel}^N}{D} \approx (1+\gamma^2)\frac{g_1}{F_1}$$

$\gamma^2 = 4M_N^2 x^2 / Q^2$ - kinematic factor

NB. γ cannot be neglected in the SLAC, HERMES and JLab kinematic regions

Theory

In QCD

$$g_1(x,Q^2) = g_1(x,Q^2)_{LT} + g_1(x,Q^2)_{HT}$$

$$g_1(x,Q^2)_{LT} = g_1(x,Q^2)_{pQCD} + \frac{M^2}{Q^2} h^{TMC}(x,Q^2) + O(\frac{M^4}{Q^4})$$

$$g_1(x,Q^2)_{HT} = \mathrm{h}(x,Q^2)/Q^2 + O(\frac{\Lambda^4}{Q^4})$$

dynamical HT power corrections (τ =3,4)
=> non-perturbative effects (model dependent)

target mass corrections which are calculable
A. Piccione, G. Ridolfi

In NLO pQCD

$$g_1(x,Q^2)_{pQCD} = \frac{1}{2}\sum_q^{N_f} e_q^2[(\Delta q + \Delta\bar{q}) \otimes (1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \otimes \frac{\delta C_G}{N_f}]$$

$\delta C_q, \delta C_G - Wilson$ coefficient functions

polarized PD evolve in Q^2 according to **NLO DGLAP** eqs.

N_f (=3) - the number of flavors

- An important difference between the kinematic regions of the unpolarized and *polarized* data sets

- A lot of the present data are at moderate Q^2 and W^2 :

$$Q^2 \approx 1-5\,GeV^2,\ 4 < W^2 < 10\,GeV^2$$

preasymptotic region

While in the determination of the PD in the unpolarized case we can cut the low Q^2 and W^2 data in order to eliminate the less known non-perturbative HT effects, it is impossible to perform such a procedure for the present data on the spin-dependent structure functions without loosing too much information.

$O(\Lambda^2/Q^2)$

⇨ **HT corrections** have to be **accounted for** in **polarized** DIS !

Method of analysis

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\exp} \overset{\chi^2}{\Longleftrightarrow} \frac{g_1(x,Q^2)_{\rm LT} + h^{g_1}(x)/Q^2}{F_1(x,Q^2)_{\exp}}$$

F_2^{NMC}, R_{1998}(SLAC)

in model independent way

Input PD

$$\Delta f_i(x,Q_0^2) = A_i x^{\alpha_i} f_i^{MRST}(x,Q_0^2)$$

$Q_0^2 = 1\,GeV^2,\ A_i, \alpha_i - free\ par.$

$h^p(x_i), h^n(x_i) - 10\ parameters\ \ (i = 1,2,\ldots 5)$ to be determined from a fit to the data

8-2(SR) = 6 par. associated with PD; positivity bounds imposed by **MRST'02** unpol. PD

SUM RULES

$$a_3 = g_A = (\Delta u + \Delta\bar{u})(Q^2) - (\Delta d + \Delta\bar{d})(Q^2) = F - D = 1.2670 \pm 0.0035$$

$$a_8 = (\Delta u + \Delta\bar{u})(Q^2) + (\Delta d + \Delta\bar{d})(Q^2) - 2(\Delta s + \Delta\bar{s})(Q^2) = 3F - D = 0.585 \pm 0.025$$

Flavor symmetric sea convention: $\Delta u_{sea} = \Delta\bar{u} = \Delta d_{sea} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$

Higher twist effects

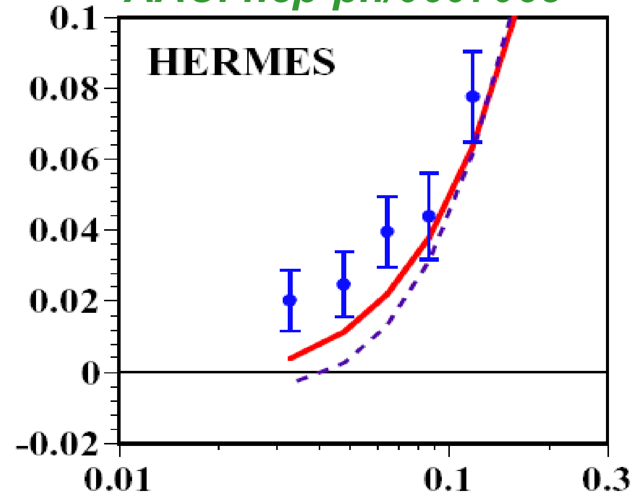
(CLAS'06 and COMPASS'06 not included)

$$g_1 = (g_1)_{LT} + h^{g_1}(x)/Q^2$$

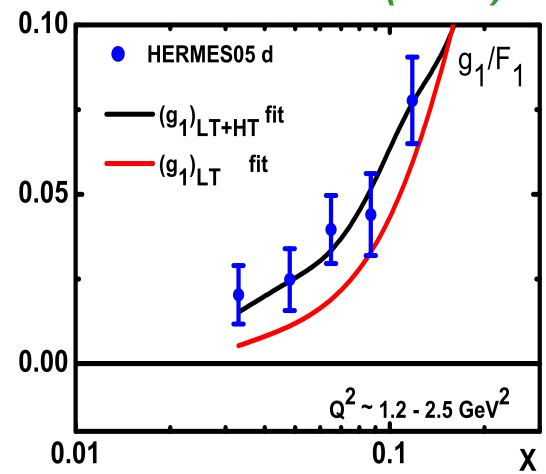
- The low x and low Q^2 (1.2 ~ 2.5 GeV^2) HERMES/d data can **not** be described by the LT (logarithmic in Q^2) term in g_1 => red curves

- Excellent agreement with the data if the HT corrections to g_1 are taken into account in the analysis

AAC: hep-ph/0607063



LSS: PR D73 (2006)



DATA (old set)

CERN EMC - A_1^p SMC - $A_1^p,\ A_1^d$ COMPASS'05 - A_1^d

DESY HERMES - $\frac{g_1^p}{F_1^p},\ \frac{g_1^d}{F_1^d}$

SLAC E142, E154 - A_1^n E143, E155 - $\frac{g_1^p}{F_1^p},\ \frac{g_1^d}{F_1^d}$

JLab Hall A - $\frac{g_1^n}{F_1^n}$

$$A_1^N \approx (1+\gamma^2)\frac{g_1^N}{F_1^N}$$

$\gamma^2 = 4M^2x^2/Q^2$ - kinematic factor

Number of exp. points: 190

DATA

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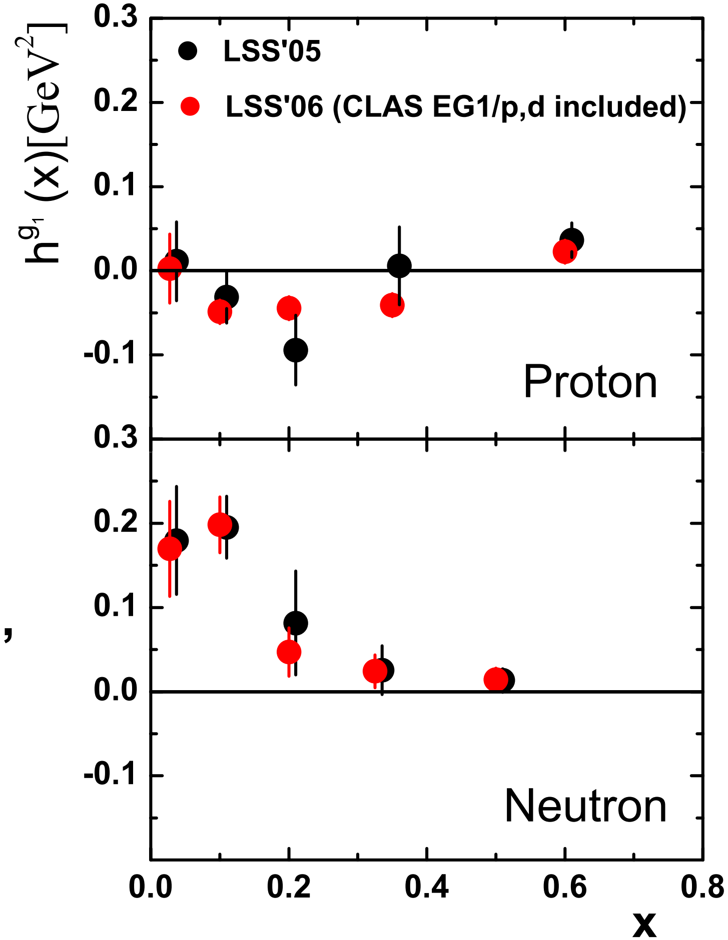
$\gamma^2 = 4M^2x^2/Q^2$ - kinematic factor

Number of exp. points: 190 ⟹ 823

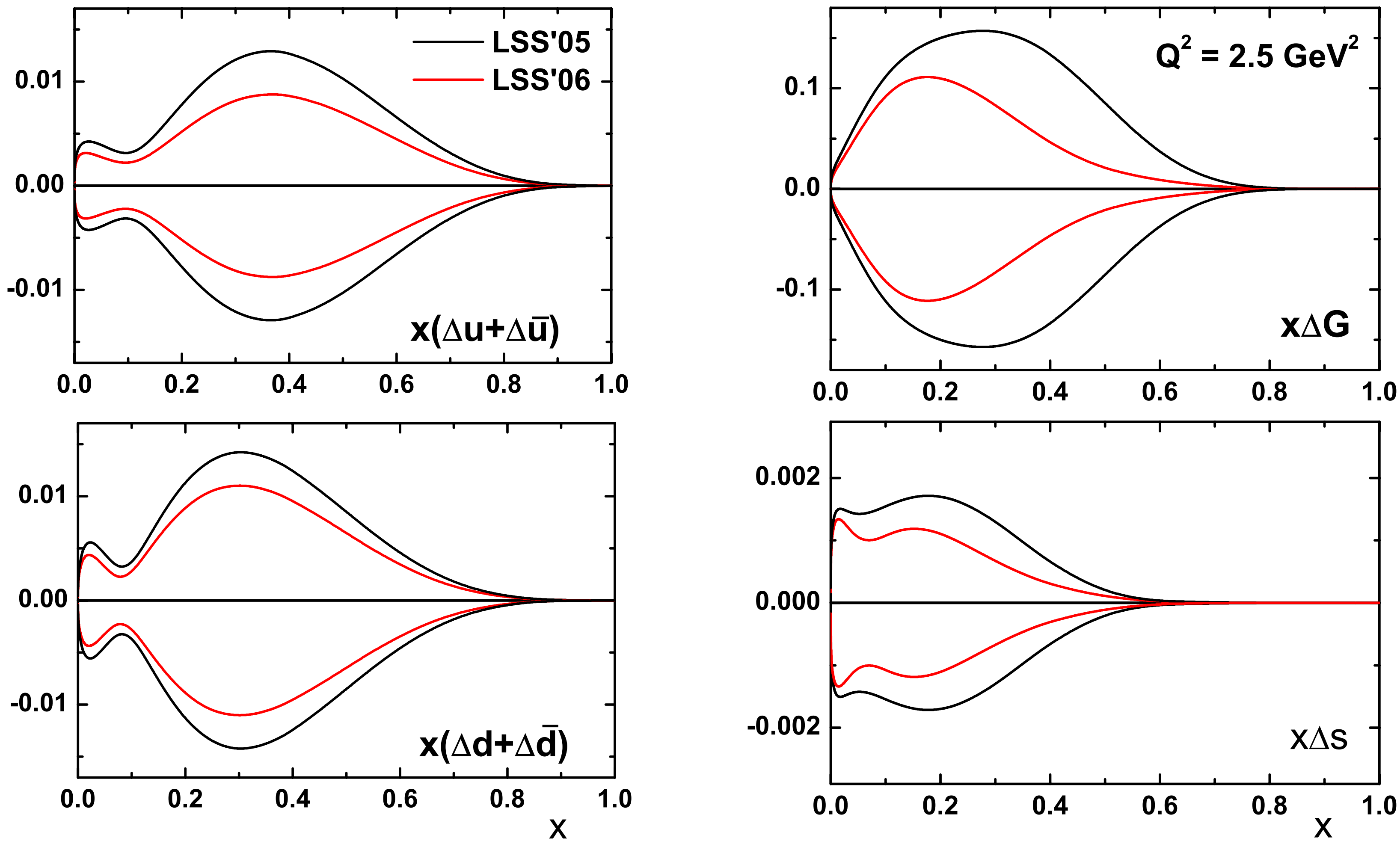
Effect of CLAS'06 p and d data *(PL B641, 11, 2006)* on polarized PD and HT

- Very accurate data on g_1^p and g_1^d at low Q^2: 1~ 4 GeV^2 for x ~ 0.1 - 0.6
- The determination of HT/p and HT/n is significantly improved in the *CLAS* x region compared to HT(LSS'05)
- As expected, the central values of PPD are practically not affected by *CLAS* data, but the accuracy of its determination is essentially improved (a consequence of much better determination of HT corrections to g_1)

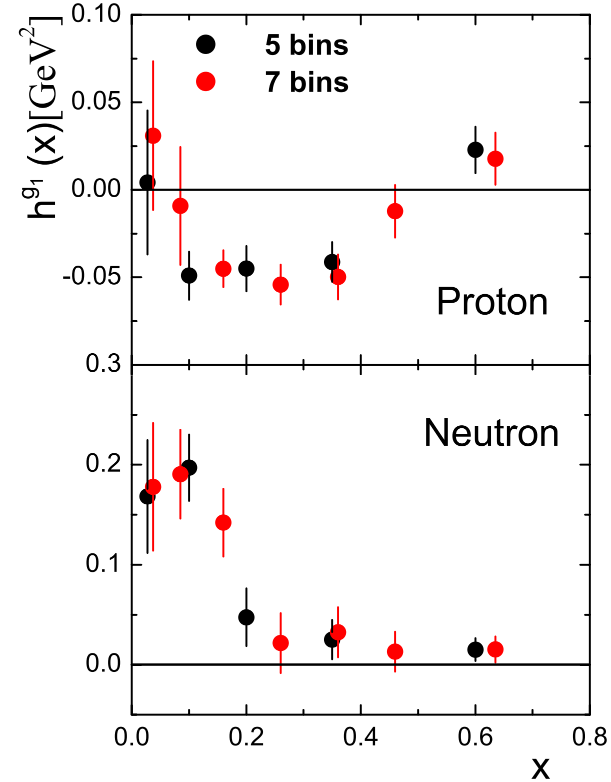
LSS'05: PR D73 (2006)



Impact of CLAS'06 data on the uncertainties for NLO polarized PD

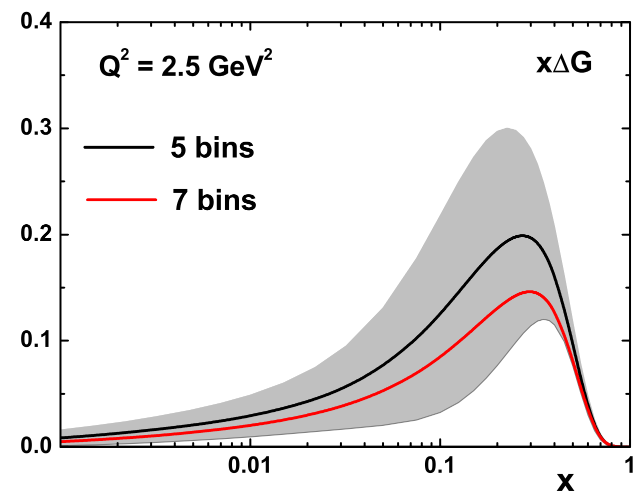


- **Due to the good accuracy of the *CLAS* data, one can split the measured x region of the *world+CLAS* data set into 7 bins instead of 5, and to determine more precisely the x-dependence of HT**



- **The corresponding PPD are practically identical with those of LSS'06 (5 bins)**

- **The only exception is $x\Delta G$, but it lies within the error band of $x\Delta G$ (5 bins) → small correlation between gluons and HT**



The main message from this analysis

→ It is impossible to describe the very precise CLAS data if the HT corrections are NOT taken into account

NOTE: If the low Q^2 data are not too accurate, it would be possible to describe them using only the leading twist term (logarithmic in Q^2) of g_1, *i.e*. to mimic the power in Q^2 dependence of g_1 with a logarithmic one (using different forms for the input PDFs and/or more free parameters associated with them) which was done in the analyses of another groups before the CLAS data have appeared.

DATA

CERN EMC - A_1^p SMC - $A_1^p,\ A_1^d$ COMPASS'06 - A_1^d

DESY HERMES - $\dfrac{g_1^p}{F_1^p},\ \dfrac{g_1^d}{F_1^d}$

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JLab Hall A - $\dfrac{g_1^n}{F_1^n}$ CLAS'06 - $\dfrac{g_1^p}{F_1^p},\ \dfrac{g_1^d}{F_1^d}$

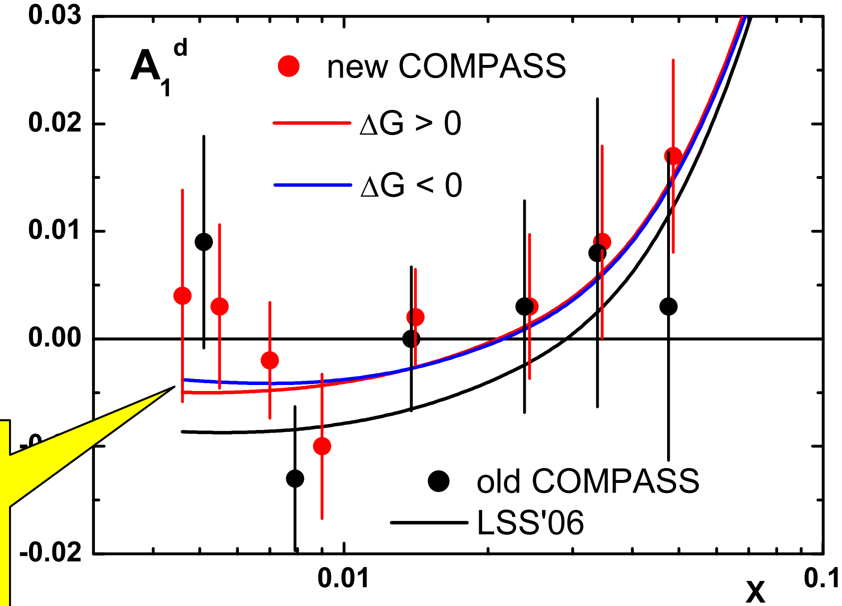
$$A_1^N \approx (1+\gamma^2)\frac{g_1^N}{F_1^N}$$

$\gamma^2 = 4M^2x^2/Q^2$ - kinematic factor

Number of exp. points: 823 ⟹ 826

Effect of COMPASS'06 A_1^d data (*hep-ex/0609038*) on polarized PD and HT

In contrast to the *CLAS* data, the *COMPASS* data are mainly at large Q^2 and the only precise data at small x: $0.004 < x < 0.02$. The new data are based on 2.5 times larger statistics than those of *COMPASS'05*



The new QCD curves corresponding to the best fits lie above the old one at $x < 0.1$

- $(\Delta u + \Delta\bar{u}), \ (\Delta d + \Delta\bar{d})$ do NOT change
- $x|\Delta s(x)|$ and $x\,\Delta G(x)$ and their first moments Δs and ΔG slightly decrease

$Q^2 = 1\ GeV^2$

COMPASS	Δs	ΔG	$a_0 = \Delta\Sigma_{MS}$
old	-0.070 ± 0.006	0.173 ± 0.184	0.165 ± 0.044
new ($\Delta G > 0$)	-0.063 ± 0.005	0.129 ± 0.166	0.207 ± 0.040
new ($\Delta G < 0$)	-0.057 ± 0.010	-0.200 ± 0.414	0.243 ± 0.065

Spin of the proton

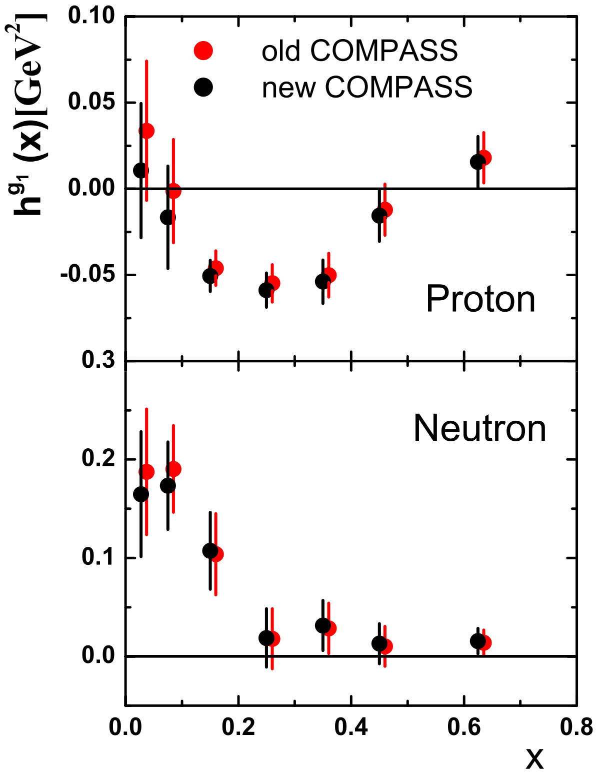
$$S_z = 1/2 = 1/2\ \Delta\Sigma(Q^2) + \Delta G\,(Q^2) + L_q\,(Q^2) + L_g(Q^2)$$

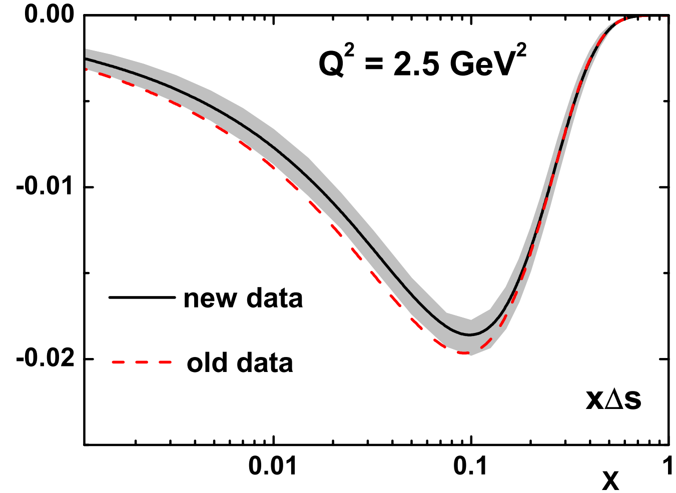
$$= 0.23(-0.08) +/- 0.17(0.41) + L_q\,(Q^2) + L_g(Q^2)$$

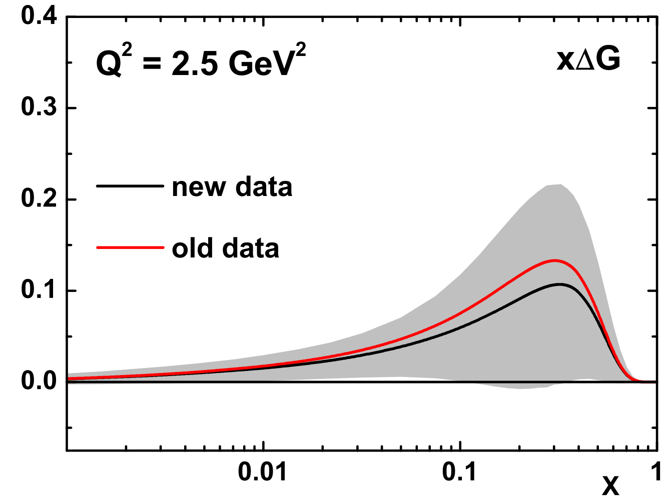
The big uncertainty is coming from gluons

To be determined from forward extrapolations of generalized PD

$L_g \approx 0$, *Brodsky, Gardner: PL B643 (2006) 22*







The values of HT are practically NOT affected by *COMPASS* data excepting the small x where Q^2 are also small

The first moments of higher twist

- Thanks to the **very precise** CLAS data the **first** moments of HT corrections are now **much better** determined.

$$\bar{h}^N = \int_{0.0045}^{0.75} dx\, h^N(x), \quad \mathrm{N} = \mathrm{p,n}$$

$$\bar{h}^p = (-0.014 \pm 0.005)\, GeV^2 \qquad \bar{h}^n = (0.037 \pm 0.008)\, GeV^2$$

$$\bar{h}^p - \bar{h}^n = (-0.051 \pm 0.009)\, GeV^2 \qquad \bar{h}^p + \bar{h}^n = (0.023 \pm 0.009)\, GeV^2$$

- $\bar{h}^p - \bar{h}^n < 0$ ← In **agreement** with the **instanton model** predictions and **sum rules** in QCD

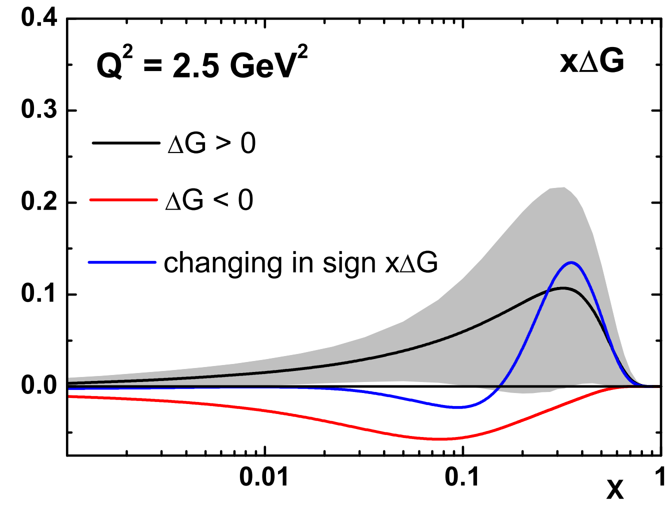
- $\bar{h}^p + \bar{h}^n < |\bar{h}^p - \bar{h}^n|$ ← In **agreement** with **$1/N_C$** expansion in QCD (*Balla et al., NP B510, 327, 1998*)

The sign of gluon polarization

- The present **inclusive** DIS data **cannot rule out** the solutions with negative and changing in sign gluon polarizations

$$\chi^2_{DF}(\Delta G > 0) = 0.895$$

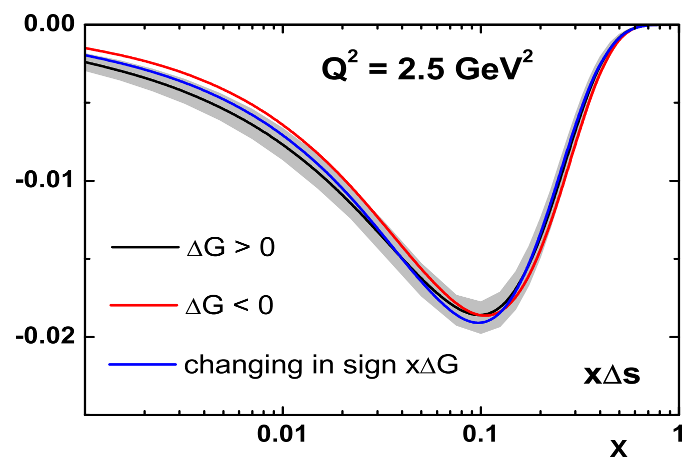
$$\chi^2_{DF}(\Delta G < 0) = 0.897, \chi^2_{DF}(x\Delta G / chsign) = 0.895$$



- The shape of the negative gluon density **differs** from that of positive one

- In all the cases the magnitude of ΔG is small: **|ΔG | ≤ 0.2**

- The corresponding polarized quark densities are **very close** to each other



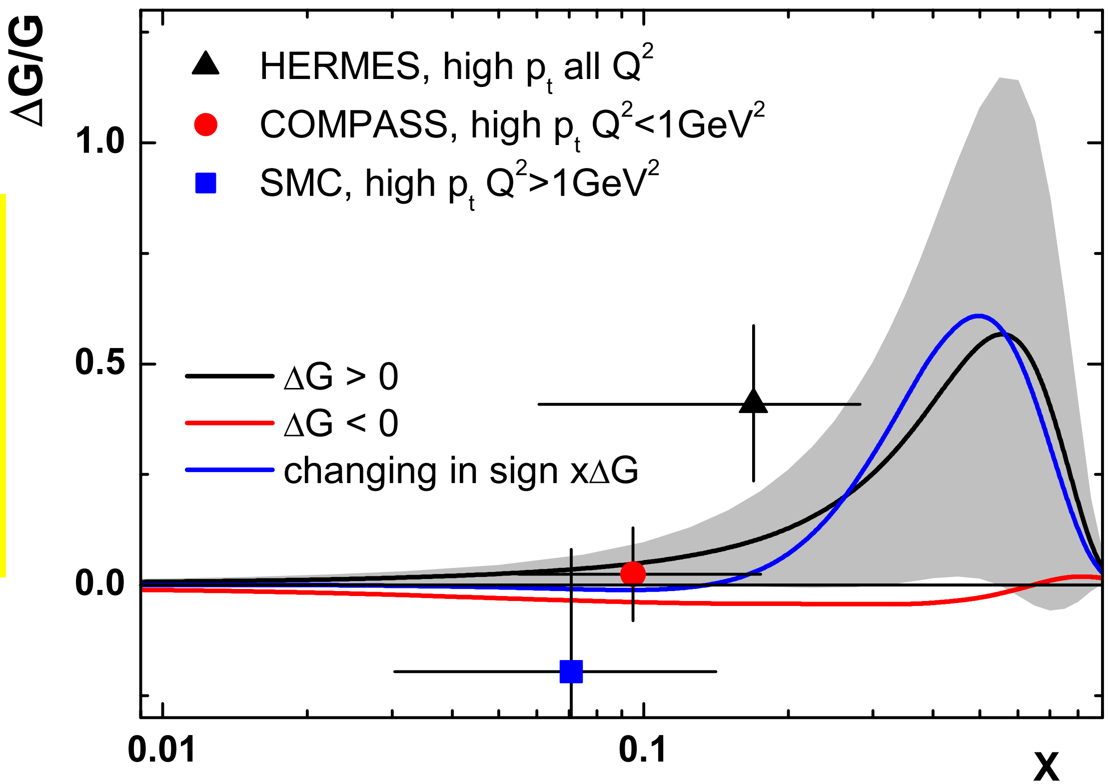
Comparison with directly measured ΔG/G at $Q^2 = 3$ GeV^2

MRST'02 unpolarized gluon density is used for G(x)

The error band corresponds to statistic and systematic errors of ΔG

The error bars of the experimental points represent the **total errors**

The most precise value of ΔG/G, the *COMPASS* one, is well consistent with any of the polarized gluon densities determined in our analysis



Comparison with directly measured $\Delta G/G$ at $Q^2 = 3$ GeV^2

MRST'02 unpolarized gluon density is used for G(x)

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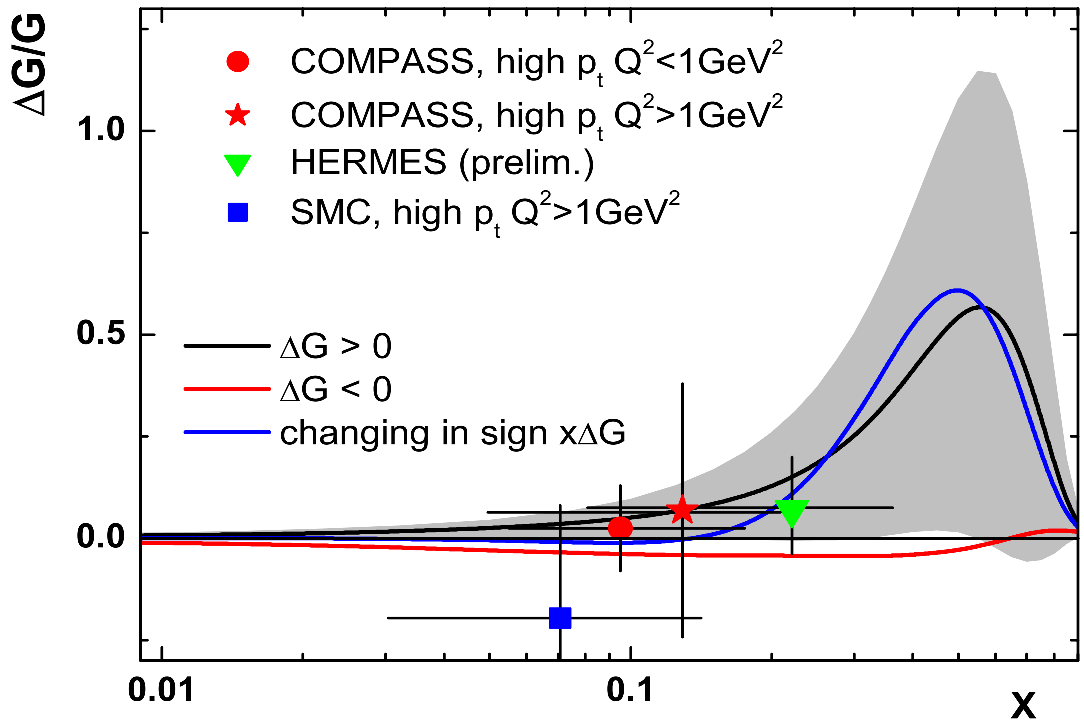


LSS'06 *vs* C0MPASS'06

- At small x: 0.004 – 0.02 (Q^2 ~ 1-3 GeV^2) our results differ from those of *COMPASS*

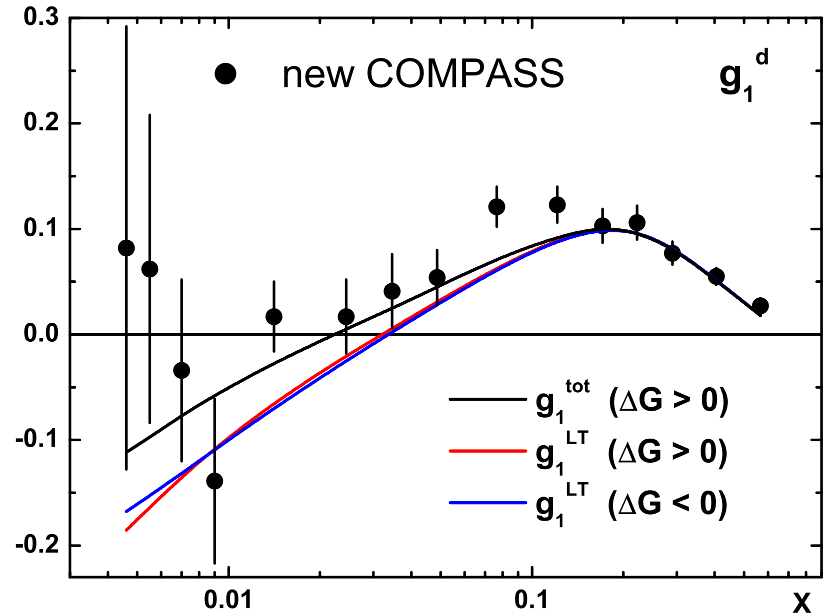
$$(g_1)_{exp} \leftrightarrow (g_1)_{LT}(COMPASS) \approx$$

$$(g_1)_{LT}(LSS) + h^d(x)/Q^2$$

- *COMPASS* → significant difference between $(g_1)_{th}$ corresponding to the best fits for ΔG > 0 and ΔG < 0

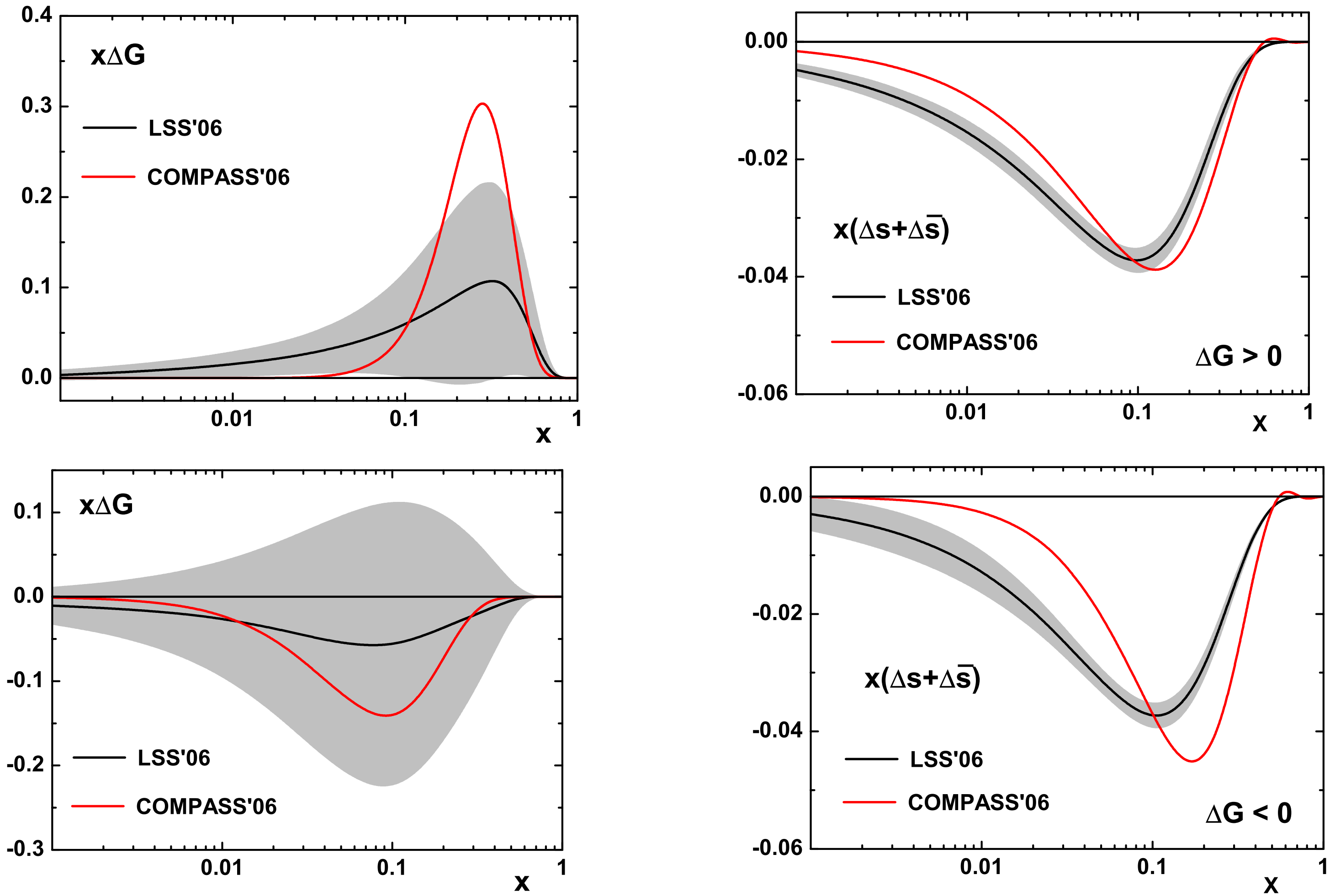
- *LSS'06* → the theoretical curves for both cases are very close to each other

- The reason → HT effects (40% at small x) which are NOT taken into account by *COMPASS*



- **$x\Delta s$ are different, especially in the case of $\Delta G < 0$**
- **$x\Delta G$ obtaned by COMPASS in both fits are more peaked than ours**

$Q^2 = 3$ GeV^2



SUMMARY

- The low Q^2 *CLAS* data improve essentially our knowledge of higher twist corrections to g_1 structure function
- The central values of polarized PD are NOT affected, but the accuracy of its determination is essentially improved
- The *COMPASS* data (mainly at large Q^2) influence $|\Delta s|$ and ΔG which slightly decrease, but practically do NOT change HT

→ **Strong support of the QCD framework**

- Large (40%) contribution of HT to $(g_1)^d$ at small x (low Q^2)
- The present inclusive DIS data cannot rule out the negative and changing in sign gluon densities
- Good agreement with the directly measured $\Delta G/G$

HEPDATA
The Durham HEP Databases

from the **Durham Database Group**, at Durham University(UK).

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Address http://durpdg.dur.ac.uk/hepdata/pdf.html

Parton Distribution Functions

Polarized Parton Distributions

Currently available parametrizations:

E.Leader, A.V.Sidorov and D.B.Stamenov, Eur.Phys.J.C23 (2002) 479: LSS2001
E.Leader, A.V.Sidorov and D.B.Stamenov, Phys.Rev.D73 (2006) 034023: LSS2005
M. Glueck, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D53 (1996) 4775: GRSV
M. Glueck, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D63 (2001) 094005: GRSV2000
T. Gehrmann and W.J. Stirling, Phys. Rev. D53 (1996) 6100: GS
J. Bluemlein and H. Boettcher - Nucl.Phys.B636(2002)225: BB
Asymmetry Analysis Collaboration - M. Hirai et al- Phys. Rev. D69 (2004) 054021: AAC
D. de Florian and R. Sassot, Phys. Rev. D62 (2000) 094025: DS2000
D. de Florian, G.A. Navarro and R. Sassot, Phys. Rev. D71 (2005) 094018: DNS2005

Additional slides

Constraint on ΔG from π^0 production at RHIC *(AAC, hep-ph/0612037)*

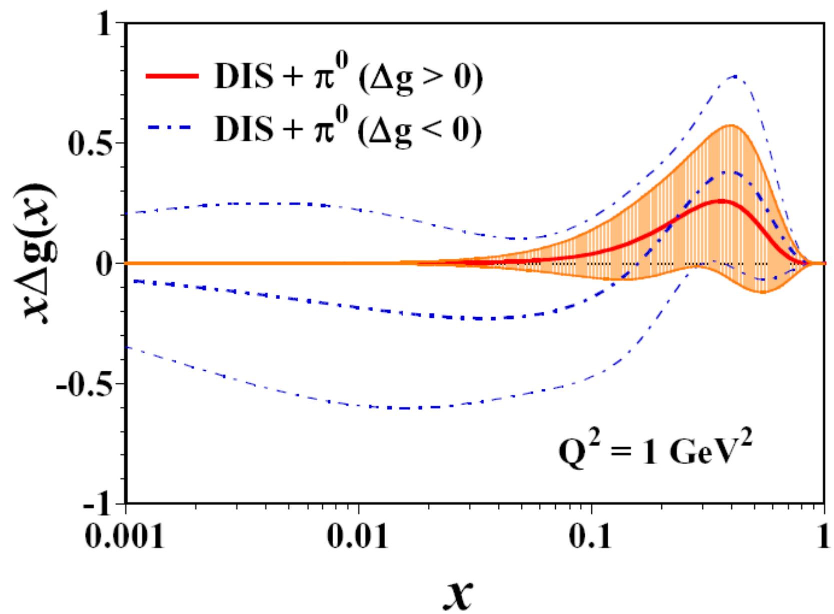
$\vec{p} + \vec{p} \rightarrow \pi^0 + X$

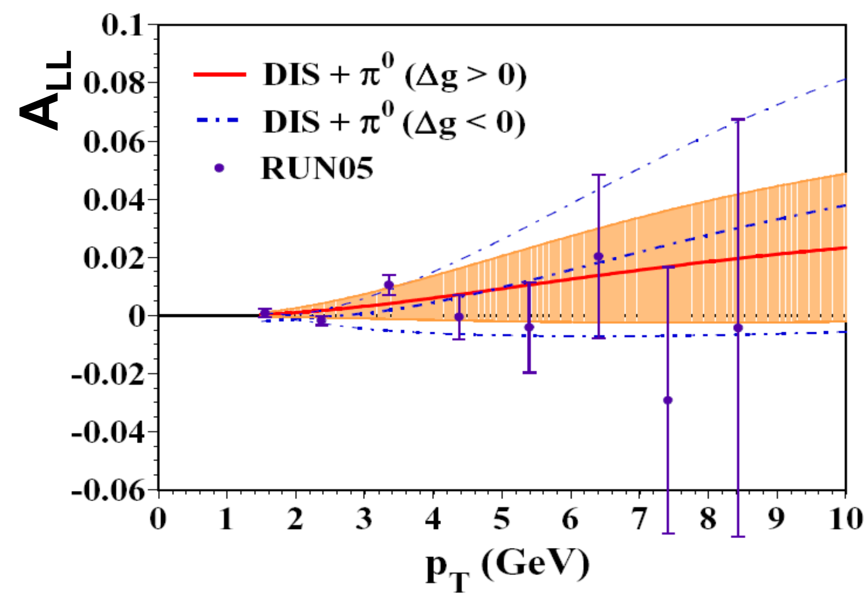
From DIS + π^0 analysis:

$\Delta G = 0.31 \pm 0.32$

$\Delta G = -0.56 \pm 2.16$

($Q^2 = 1$ GeV^2)





Note: In contrast to LSS changing in sign $x\Delta G$, which for $Q^2 > 6$ GeV^2 is positive for any x, $x\Delta G_{AAC}$ becomes negative for large x too with increasing of Q^2.