CONTROVERSIAL ISSUES IN THE POLARIZED PARTON DENSITIES:

$\Delta G, \Delta s$, positivity and higher twist

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Two main problems compared with UNPOLARIZED case:

a) Small range of Q^2
$\Rightarrow$ poor determination of $\Delta G(x)$

b) No neutrino and antineutrino data
$\Rrightarrow$ poor flavour separation and
$\Rrightarrow$ can only measure $\Delta q + \Delta \bar{q}$

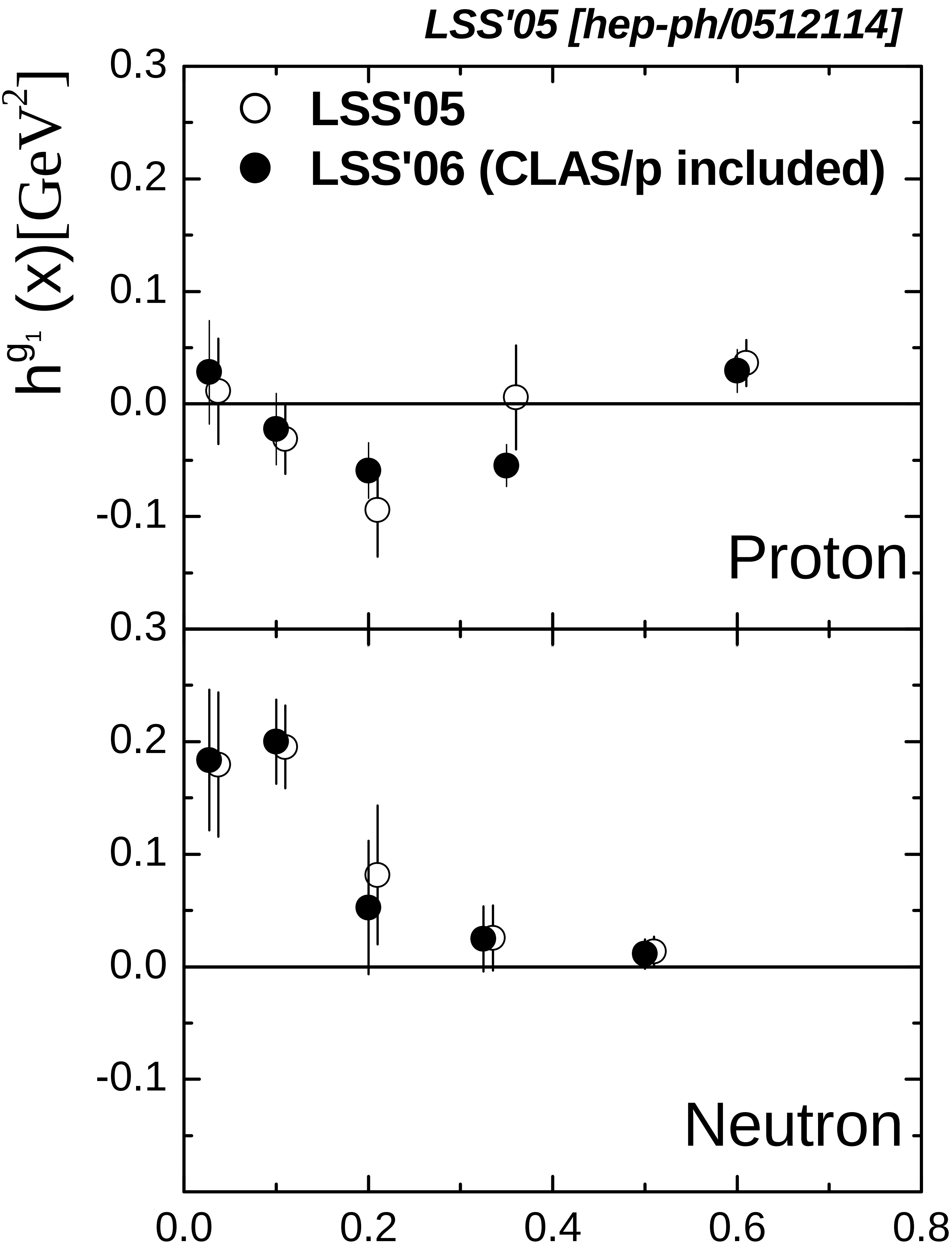
'REMEDIES'

1) Include data at lower Q^2 via HIGHER TWIST terms

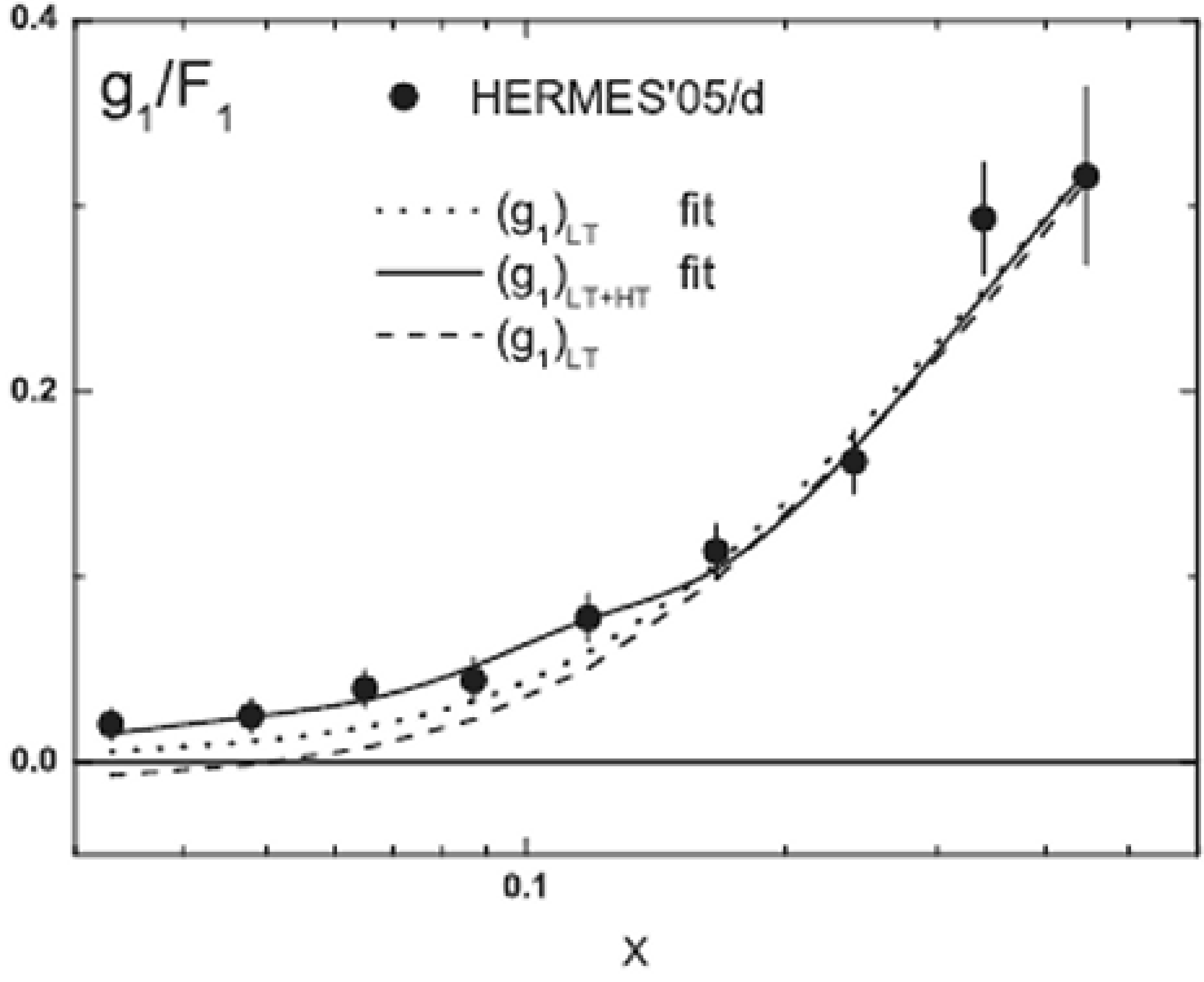
$$\begin{aligned} g_1^{expt} &= F_1^{expt} A_1^{expt} \\ &= \frac{F_2^{expt}}{2x(1+R^{expt})} A_1^{expt} \\ &= g_1^{QCD} + h/Q^2 \end{aligned}$$

HT essential. [Leader, Sidorov, Stamenov (LSS05)include HT]
[Blümlein, Böttcher (BB02) claim HT not necessary; Hirai, Kumano, Saito (AAC06) do not include HT]

An example: HERMES g_1^d data at low $Q^2 = 1GeV^2$ compared with COMPASS data at $6GeV^2$
AAC06 explain difference as possibly due to gluon.
LSS05 claim due to HT.See Fig. 1 and Fig. 2



LSS'05 [hep-ph/0512114]
LSS'05
LSS'06 (CLAS/p included)
Proton
Neutron
h^{g_1}(x)[GeV^2]
x
0.3
0.2
0.1
0.0
-0.1
0.0
0.2
0.4
0.6
0.8



0.4
0.2
0.0
0.1
x
g_1/F_1
HERMES'05/d
$(g_1)_{LT}$ fit
$(g_1)_{LT+HT}$ fit
$(g_1)_{LT}$

2) Impose $SU(3)$ sum rule

Notation:

$$\Delta q \equiv \Delta q(Q^2) = \int_0^1 dx\, \Delta q(x, Q^2)$$

$$\begin{aligned} a_8 &\equiv \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} \\ &- 2(\Delta s + \Delta\bar{s}) \\ &= 3F - D \\ &= 0.585 \pm 0.025 \end{aligned}$$

Leader,Stamenov (2003) showed, depending on which data is used, E155 or E143, that

IF $(\Delta s + \Delta\bar{s}) \geq 0$, then

$$a_8 \leq 0.089 \pm 0.058 \quad (1)$$

or

$$a_8 \leq 0.197 \pm 0.068 \quad (2)$$

But analysis of hyperon decays [Ratcliffe (1999)] implies

$$a_8 = 0.585 \pm 10\%$$

New analysis of SIDIS [de Florian, Navarro, Sassot (2006)(deFNS06)]implies

$$a_8 = 0.585 - 8\% \text{ or } -12\%$$

depending on choice of FRAGMENTATION functions.

These values significantly contradict the bounds in (1) and (2).

Conclusion:A positive value of the first moment $\Delta s + \Delta\bar{s}$ is almost impossible

What are the experimental results on $(\Delta s + \Delta\bar{s})$?

BB02:-0.148 ± 0.034

LLS05: -0.132 ± 0.018

AAC06: -0.12 ± 0.04

deFNS06: -0.116

HERMES05: $+0.056 \pm 0.066 \pm 0.018$

There appears to be incompatibility. Is this real or is it due to underestimating the errors in the analyses ? It will be very interesting to have more accurate data from SIDIS.

What about the $x - dependence$ of $\Delta s(x) + \Delta\bar{s}(x)$?

Surprisingly, it turns out that POSITIVITY plays a crucial role

3) Impose POSITIVITY

$$|\Delta q(x)| \leq |q(x)|$$

NB Impose at LOWEST Q^2 involved in evolution.

The shape of $\Delta s(x) + \Delta\bar{s}(x)$ at medium x is tightly controlled by the unpolarized $s(x)$.

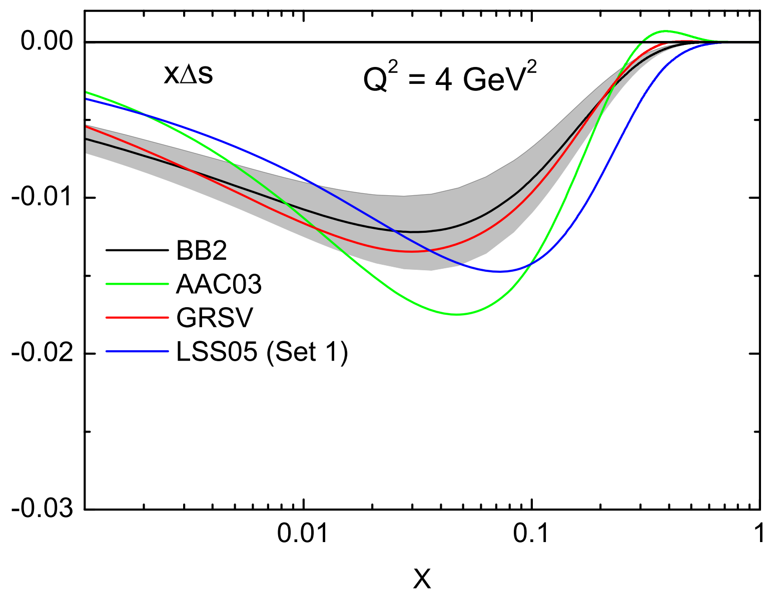
The function $s(x)$ has changed in the many anlayses of the unpolarized data, since the days of Glück, Reya, Vogelsang (GRV 1996).

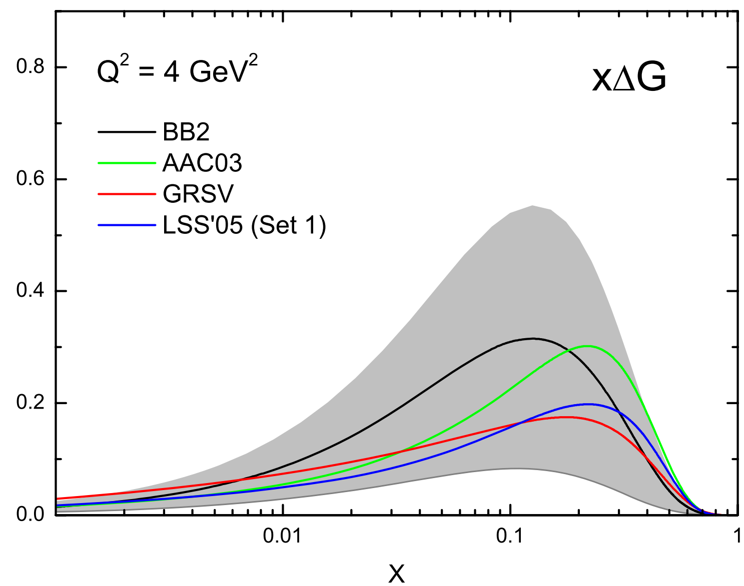
Fig.3 compares the differences between the $\Delta s(x) + \Delta\bar{s}(x)$ from various analyses.
Fig.4 shows the role of positivity in creating these differences.

WHY DO PEOPLE CONTINUE TO USE THE GRV UNPOLARIZED DENSITIES, GIVEN THE MANY, MORE UP TO DATE ONES, AVAILABLE ????????????????

NLO QCD PPD ($\overline{\text{MS}}$) obtained by different groups

$x\Delta s$ and $x\Delta G$ are **weakly** constrained from the present data on inclusive DIS





GRSV: Glück et al., hep-ph/0011215
BB: Blümlein, Böttcher, hep-ph/0203155
AAC03: Goto et. al., hep-ph/0312112
LSS05: Leader et al., hep-ph/0512114

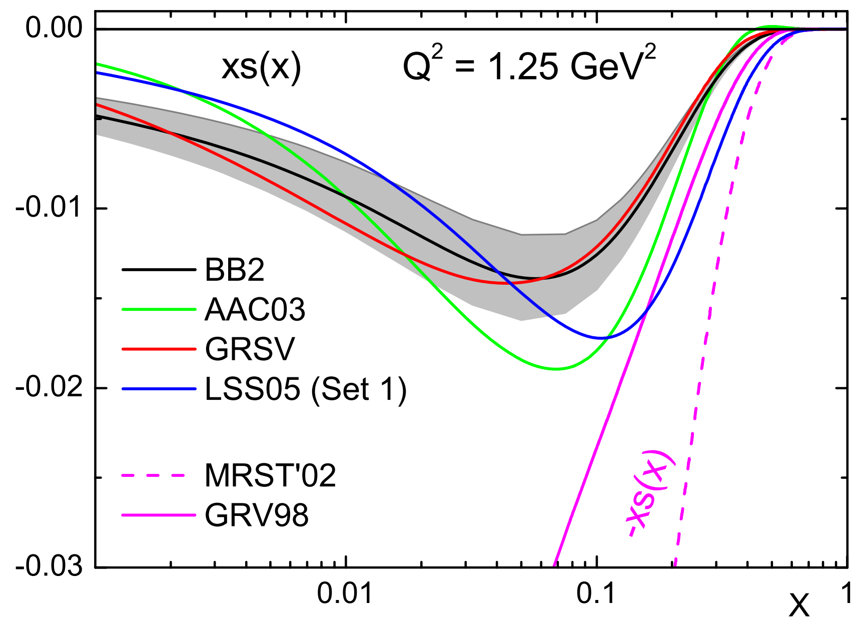
$x\Delta u_v$ and $x\Delta d_v$ well consistent

Impact of positivity constraints on $x\Delta s(x, Q^2)$

GRSV: Glück et al., hep-ph/0011215
BB: Blümlein, Böttcher, hep-ph/0203155
AAC03: Goto et. al., hep-ph/0312112
LSS05: Leader et al., hep-ph/0512114

$$|\, x\Delta f(x, Q_0^2)\,| \leq xf(x, Q_0^2)_{GRV}$$

$$|\, x\Delta f(x, Q_0^2)\,|_{LSS} \leq xf(x, Q_0^2)_{MRST02}$$



GRSV, BB and AAC have used the **GRV** **unpolarized** PD for constraining their PPD, while LSS have used those of **MRST'02**.

As a result, $x|\Delta s(x)|$ (LSS) for $x > 0.1$ is **larger** than the magnitude of the polarized strange sea densities obtained by the other groups.

4) Study ΔG via specific reactions

The range of Q^2 in polarized DIS is too small to give a precise determination of ΔG. Nonetheless essentially all analyses give positive $\Delta G(x)$ with large error bands.

See Fig.3.

For a more precise determination we have to look at other possibilities.

The gold plated reaction is the photon fusion reaction

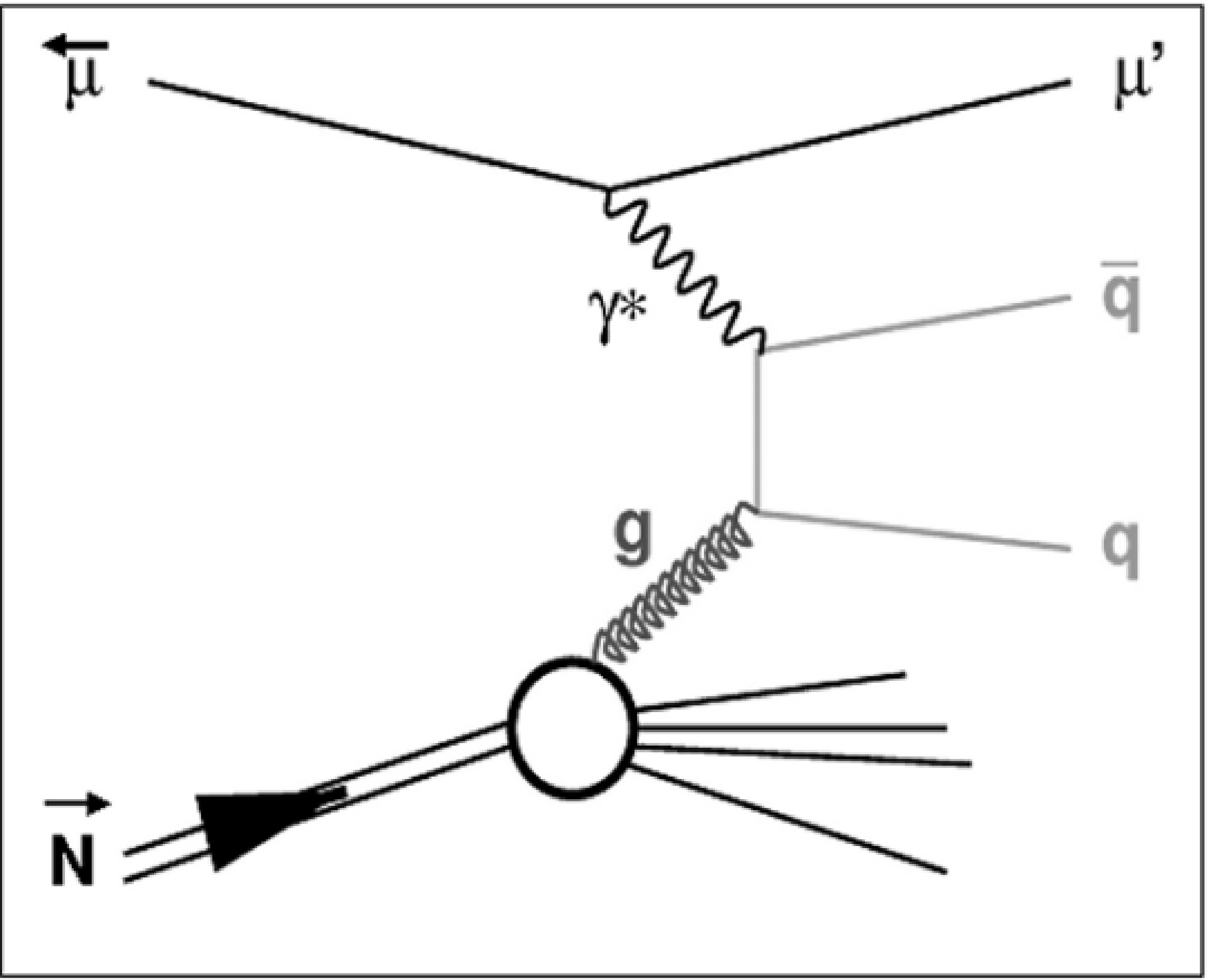
$$`\gamma`p \to c\bar{c}$$

with identification of both charmed particles (open charm).

See Fig.5.

The next best (silver plated) is picking up one of the charmed particles.

Less clean is picking up two high P_T jets.


μ
μ'
γ*
q̄
g
q
N

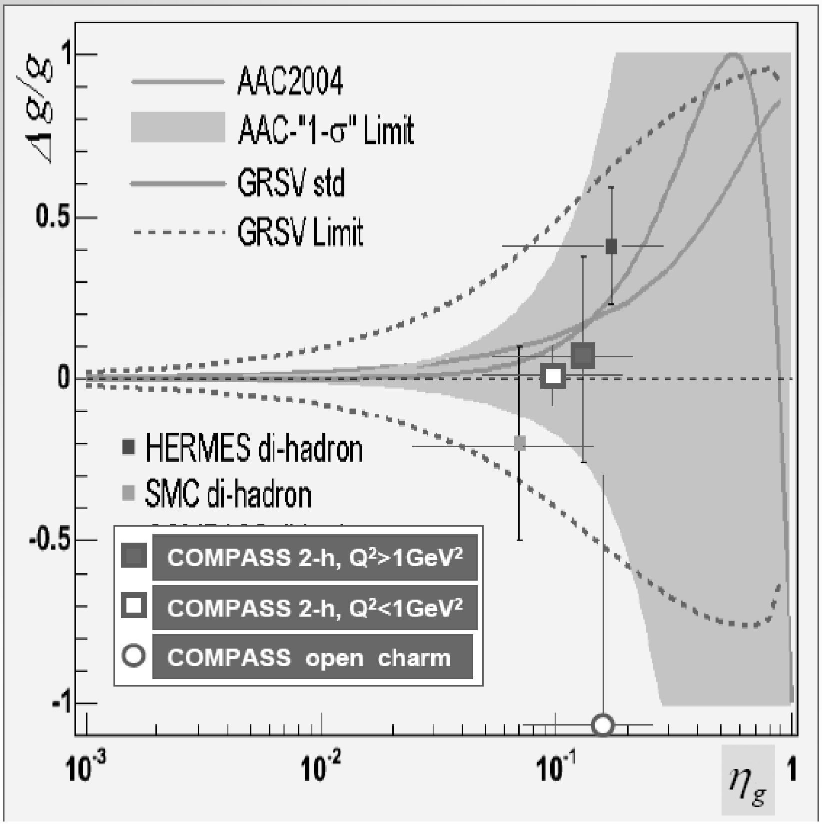
Old and new results are shown in Fig.6
Errors are still large, but the situation looks intriguing.

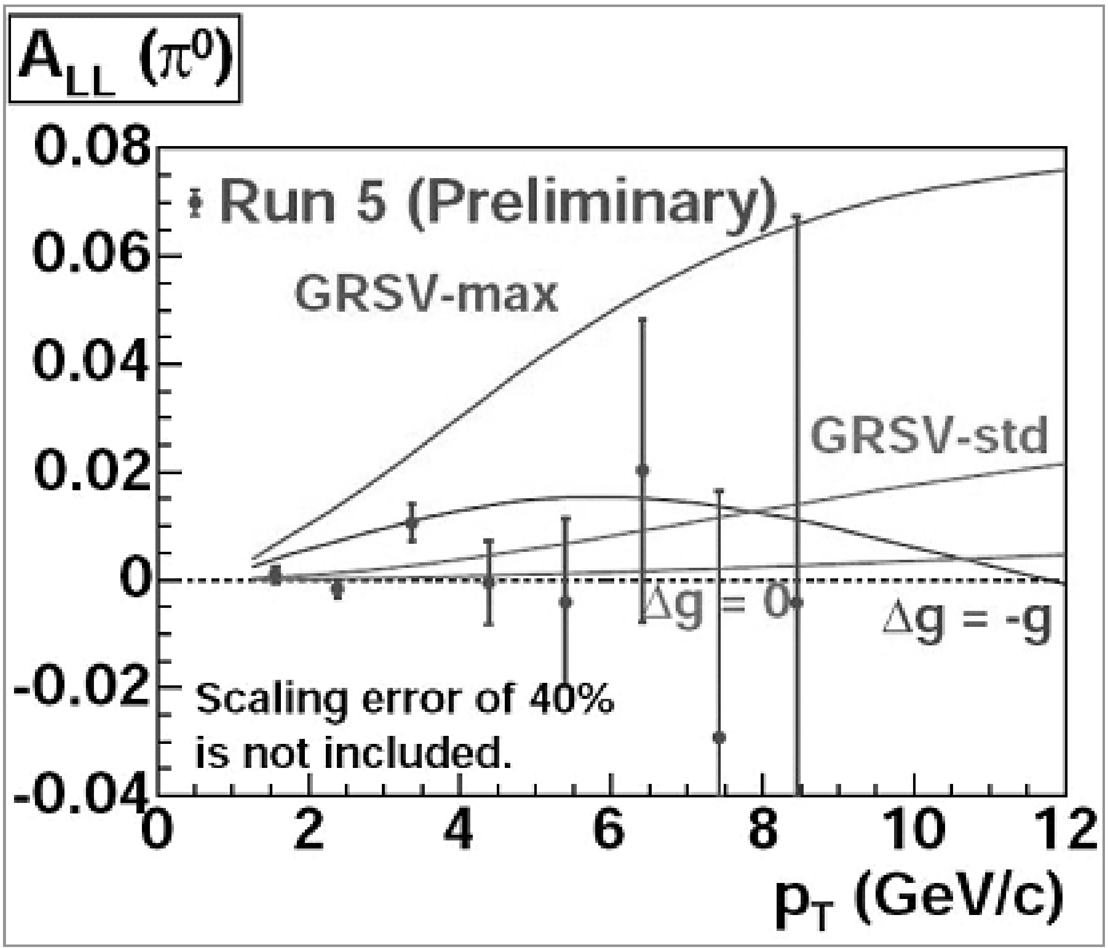
Will there be a contradiction between HERMES and COMPASS?

Is there a hint that $\Delta G(x)$ changes sign?

Another intriguing source of information: A_{LL} in $pp \to \pi X$ which is quadratic in $\Delta G(x)$
Preliminary PHENIX data are shown in Fig.7.
Again errors are still large, but if A_{LL} is almost zero, it will require either that gluons are unpolarized in contradiction with almost all the DIS results, or that $\Delta G(x)$ changes sign as a function of x.

Results on ΔG





A_LL (π⁰)
Run 5 (Preliminary)
GRSV-max
GRSV-std
Δg = 0
Δg = -g
Scaling error of 40%
is not included.
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0
2
4
6
8
10
12
p_T (GeV/c)

An interesting development: AAC06 have fitted the DIS data with a $\Delta G(x)$ which changes sign, and which might fit the PHENIX A_{LL} data.

If $\Delta G(x) \neq 0$, a good way to study its sign is via A_{LL} in $pp \to \gamma X$, which is linear in $\Delta G(x)$.

THE 'GOOD' NEWS: IF $\Delta G(x)$ is very small we will be facing the RESURRECTION of

A CRISIS IN THE PARTON MODEL - WHERE, OH WHERE, IS THE PROTON'S SPIN?

Recall that the small value of the proton's a_0 was explained as a cancellation:-

$$a_0 = \Delta\Sigma - N_f(\alpha_s/2\pi)\,\Delta G$$

thereby allowing $\Delta\Sigma$, the spin carried by the quarks, to be reasonably large (say ≈ 0.6).

Higher Twist: necessity depends on WHAT you fit with QCD

$$
\begin{aligned}
A_1^{expt} &= \frac{g_1^{QCD} + h/Q^2}{F_1^{QCD} + H/Q^2} \\
&\approx (empirically)\,\frac{g_1^{QCD}}{F_1^{QCD}}
\end{aligned}
$$

No HT needed. [Leader, Sidorov, Stamenov (LSS)]

$$
\begin{aligned}
g_1^{expt} &= F_1^{expt}\, A_1^{expt} \\
&= \frac{F_2^{expt}}{2x(1 + R^{expt})}\, A_1^{expt} \\
&= g_1^{QCD} + h/Q^2
\end{aligned}
$$

HT essential. [Leader, Sidorov, Stamenov (LSS05)include HT]

[Blümlein, Böttcher (BB02) do not include HT]

$$
\begin{aligned}
g_1^{hybrid} &= \frac{F_2^{QCD}}{2x(1+R^{expt})} A_1^{expt} \\
&= g_1^{QCD} + h'/Q^2
\end{aligned}
$$

HT necessary. [Hirai, Kumano, Saito (AAC 06) do not include HT]