XI WORKSHOP ON HIGH ENERGY SPIN PHYSICS (SPIN - 05)

Dubna, September 27- October 1 , 2005

Impact of Higher Twist and Positivity Constraints on Polarized Parton Densities

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OUTLINE

- **New** QCD fits to the inclusive **polarized** DIS data
  - ⇒ two sets of **polarized** PD (in both the $\overline{\text{MS}}$ and the JET schemes)
  - JLab Hall A neutron data
    very recent COMPASS data on A_1^d ⇐ included in the analysis
- Role of **higher twist** in determining polarized PD
- Factorization scheme dependence of the results
- Impact of **positivity constraints** on polarized PD
- Summary

LSS: JHEP, 06 (2005) 033

Theory

In QCD

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

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

$$g_1(x,Q^2)_{HT} = h(x,Q^2)/Q^2 + O(\frac{1}{Q^4})$$

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

target mass corrections which are calculable *J. Blumlein, A.Tkabladze*

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) - a number of flavours

- 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.

$O(1/Q^2)$

⇨ **HT corrections** should be **important in polarized DIS !**

DATA

188 exp. p.

200 exp. p.

CERN **EMC -** A_1^p **SMC -** A_1^p, A_1^d **COMPASS -** A_1^d

DESY **HERMES -** $\frac{g_1^p}{F_1^p}, A_1^n$

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 -** $\frac{g_1^n}{F_1^n}$

The data on A_1 ***are really the experimental values of the quantity***

$$\frac{A_{||}^N}{D} = (1+\gamma^2)\frac{g_1^N}{F_1^N} + (\eta - \gamma)A_2^N$$

$$= A_1^N + \eta A_2^N$$

$\gamma \approx \eta$ and A_2 small

very well approximated with $(1+\gamma^2)\frac{g_1^N}{F_1^N}$ ***even when*** $\gamma(\eta)$ ***can not been neglected***

Methods of analysis

- Fit to g_1/F_1 data - `$g_1/F_1$` fit => PD(g_1/F_1) or Set 1

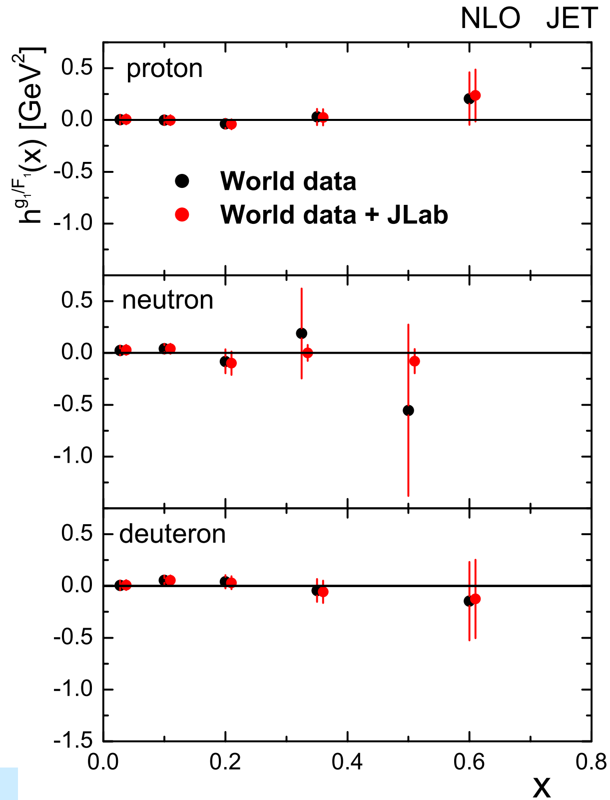
$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} \overset{\chi^2}{\Longleftrightarrow} \frac{g_1(x,Q^2)_{LT}}{F_1(x,Q^2)_{LT}} + \frac{h^{g_1/F_1}(x)}{Q^2}$$

$$(g_1)_{QCD} = (g_1)_{LT} + (g_1)_{HT}$$

$$(F_1)_{QCD} = (F_1)_{LT} + (F_1)_{HT}$$

$$\Rightarrow h^{g_1/F_1} \approx 0 \Rightarrow \frac{(g_1)_{HT}}{(g_1)_{LT}} \approx \frac{(F_1)_{HT}}{(F_1)_{LT}}$$

The HT corrections to g_1 and F_1 approximately compensate each other in the ratio g_1/F_1 and the PPD extracted this way are less sensitive to HT effects



LSS: EPJ C23 (2002) 479
hep-ph/0309048

- Fit to g_1 data - `$g_1$+HT` fit => PD(g_1+HT) or Set 2

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

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

in model independent way

HT corrections to g_1 cannot be compensated because the HT corrections to F_1(F_2 and R) are absorbed in the phenomenological parametrizations of the data on F_2 and R.

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

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

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

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

RESULTS OF ANALYSIS

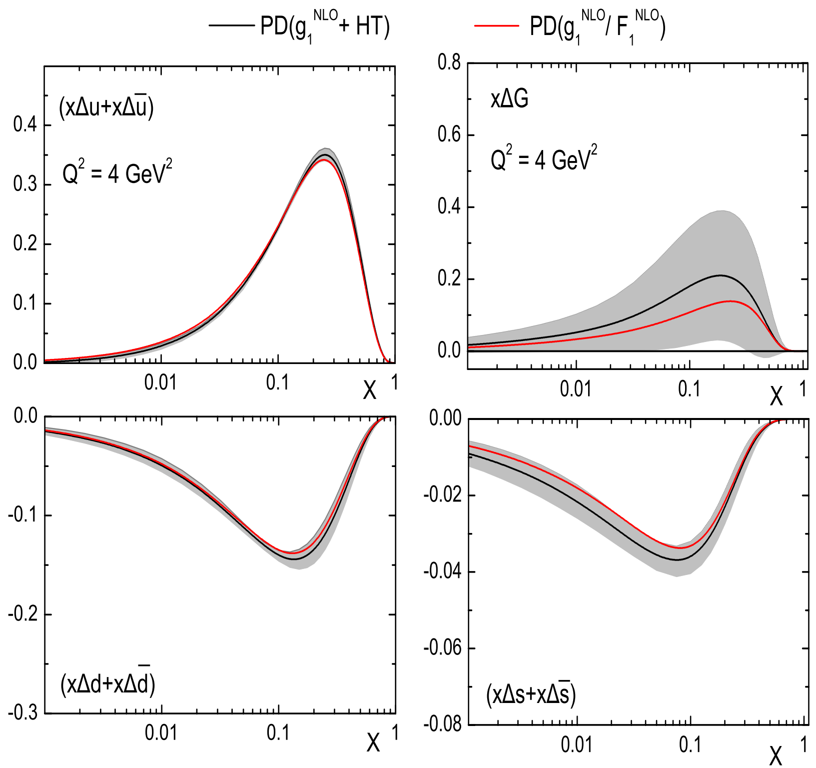
- $(\Delta u + \Delta\bar{u}), (\Delta d + \Delta\bar{d})$ well determined
- $(\Delta s + \Delta\bar{s})$ reasonably well determined and negative if accept for a_8 its SU(3) symmetric value $a_8 = 3F\text{-}D = 0.58$
- ΔG not well constrained

$$PD(g_1^{NLO} + HT) \Leftrightarrow PD(g_1^{NLO} / F_1^{NLO})$$

$$\chi^2_{DF,NLO} = 0.872 \Leftrightarrow \chi^2_{DF,NLO} = 0.874$$

In g_1 data fit HT corrections are important !

NLO($\overline{MS}$)



The two sets of polarized PD are very close to each other, especially for u and d quarks.

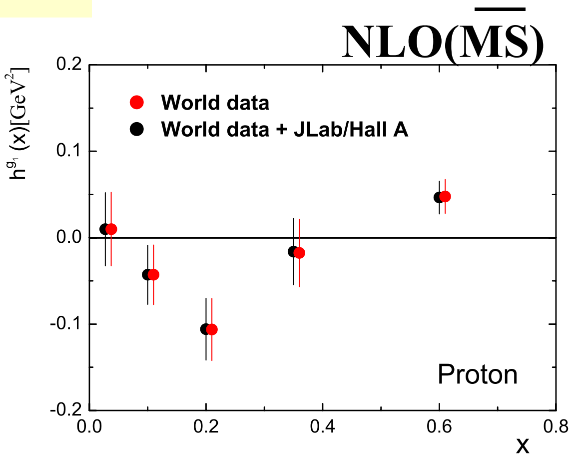
Higher twist effects

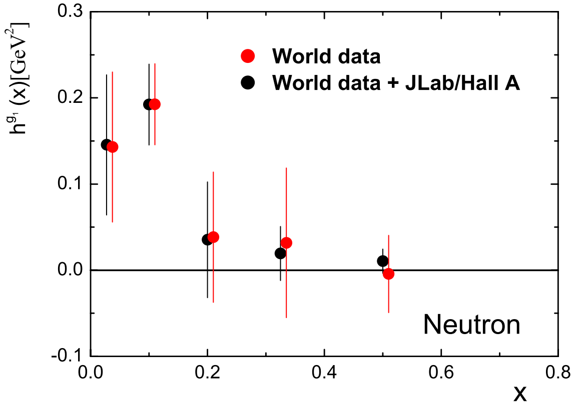
- **The size of HT coorections to g_1 is NOT negligible**
- **The shape of HT depends on the target**
- **Thanks to the very precise JLab Hall A data the higher twist corrections for the neutron target are now much better determined at large x.**

$$\int_0^1 dx\, h^{g_1}(x) = \frac{4}{9} M^2 (d_2 + f_2)$$

HT (τ=3) HT (τ=4)

- **Our result is in agreement with the instanton model predictions (*Balla et al., NP B510, 327, 1998*) but disagrees with the renormalon calculations (*Stein, NP 79, 567, 1999*).**





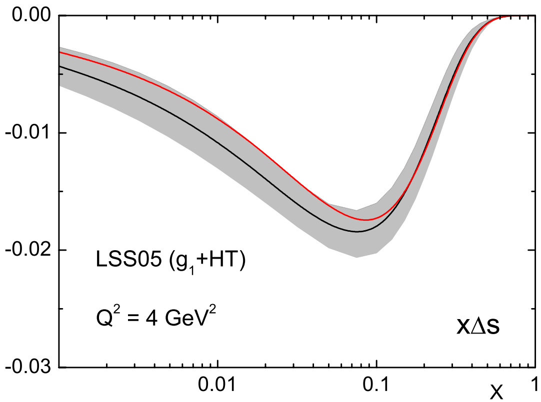
Effect of COMPASS A_1^d data (*PL B612, 154, 2005*) on polarized PD and HT

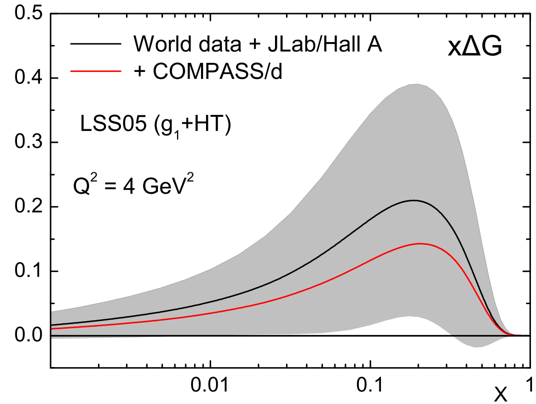
NLO($\overline{MS}$)

- The statistical accuracy at small x:
  $0.004 < x < 0.03$
  is **considerably** improved

- $\Delta u_v(x)$ and $\Delta d_v(x)$ do **NOT** change in the exp. region

- $x|\Delta s(x)|$ and $x\ \Delta G(x)$ **decrease**, but the corresponding curves lie within the error bands





LSS'05: *JHEP, 06 (2005) 033*

COMPASS (high p_t hadron pairs)

- $Q^2 > 1$ GeV^2 – *hep-ex/0501056*

$\Delta G/G = 0.06 \pm 0.31(\text{stat}) \pm 0.06(\text{syst})$ at $\langle x_G \rangle = 0.13 \pm 0.08$

- $Q^2 < 1$ GeV^2 – *hep-ex/0507045*

$\Delta G/G\ (x=0.095,\ \mu^2=3\ \text{GeV}^2) = 0.024 \pm 0.089(\text{stat}) \pm 0.057(\text{syst})$

LSS'05 result

$$\Delta G/G = \begin{cases} 0.070 & \text{Set 1/NLO}(\overline{\text{MS}}) \\ 0.108 & \text{Set 2/NLO}(\overline{\text{MS}}) \end{cases}$$

for $x=0.13$, $\mu^2=3$ GeV^2

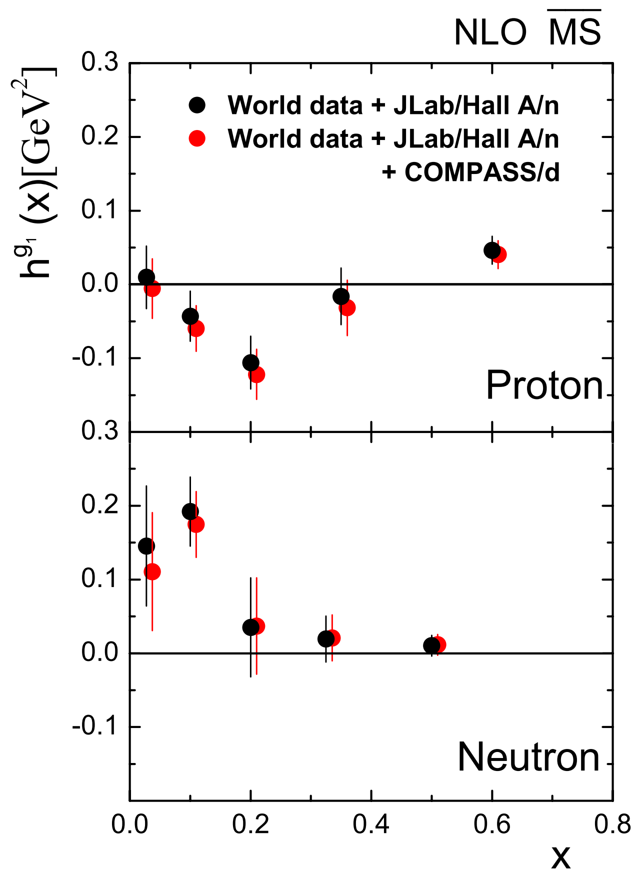
$$\Delta G/G = \begin{cases} 0.048 & \text{Set 1/NLO}(\overline{\text{MS}}) \\ 0.074 & \text{Set 2/NLO}(\overline{\text{MS}}) \end{cases}$$

for $x=0.095$, $\mu^2=3$ GeV^2

$G(x,Q^2)$ is the NLO MRST'02 unpolarized gluon density

Effect of the COMPASS data on the HT values

- The new values are in **good agreement** with the old ones
- The COMPASS data are in the DIS region
  ➡ their effect on HT is **negligible**



Factorization scheme dependence

NLO polarized PD in $\overline{MS}$ and JET schemes

- In NLO QCD the **valence quarks** and **gluons** should be the **same** in both schemes, while

$$\Delta s(x,Q^2)_{JET} = \Delta s(x,Q^2)_{\overline{MS}} + \frac{\alpha_S}{2\pi}(1-x)\otimes\Delta G(x,Q^2)_{\overline{MS}}$$

n=1:

$$\Delta\Sigma_{JET} = \Delta\Sigma(Q^2)_{\overline{MS}} + 3\frac{\alpha_S(Q^2)}{2\pi}\Delta G(Q^2)_{\overline{MS}}$$

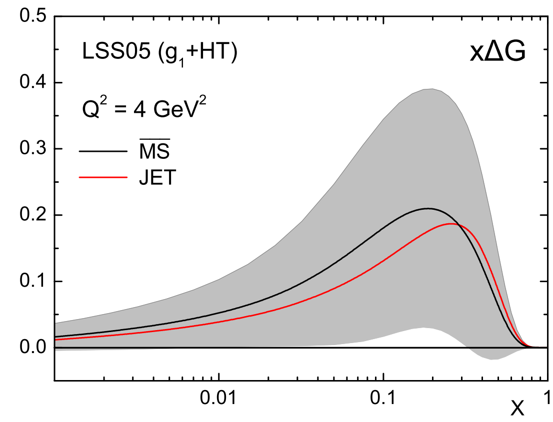
$\Delta\Sigma_{JET}$ is a **Q^2 independent** quantity

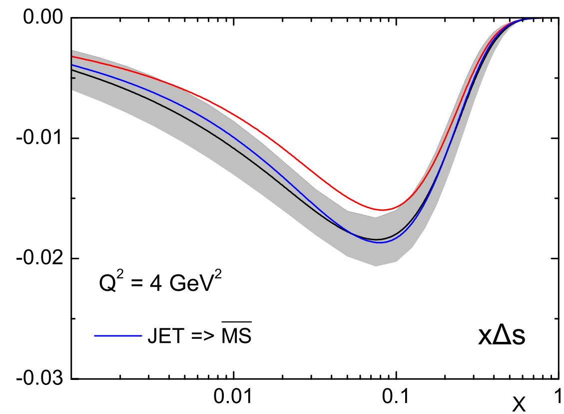
→ $\Delta\Sigma_{JET}(\mathrm{DIS}) \Longleftrightarrow \Delta\Sigma(Q2\sim\Lambda^2_{QCD})$

CQM, chiral models

Q^2 = 1 GeV^2

Fit	$\Delta\Sigma(Q^2)_{\overline{MS}}$	$\Delta G(Q^2)_{JET}$	$\Delta\Sigma_{JET}$
LSS01	0.21 ± 0.10	0.68 ± 0.32	0.37 ± 0.07
LSS05	0.19 ± 0.06	0.29 ± 0.32	0.29 ± 0.08





Our numerical results for PPD are in a good agreement with pQCD

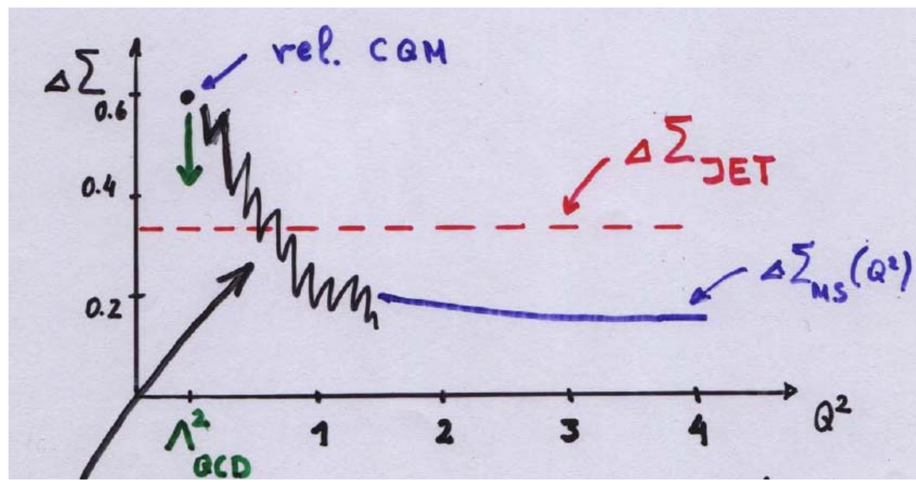
$$\Delta\Sigma(Q^2 \sim \Lambda^2_{QCD}) = \begin{cases} 0.6 \quad \text{-- relativistic CQM} \\ \downarrow \\ \text{Nonpert. vacuum spin effects} \end{cases}$$

0.6 -- relativistic CQM

Nonpert. vacuum spin effects
(instanton models) - *Shore, Veneziano; Forte, Shuryak; Dorokhov, Kochelev*

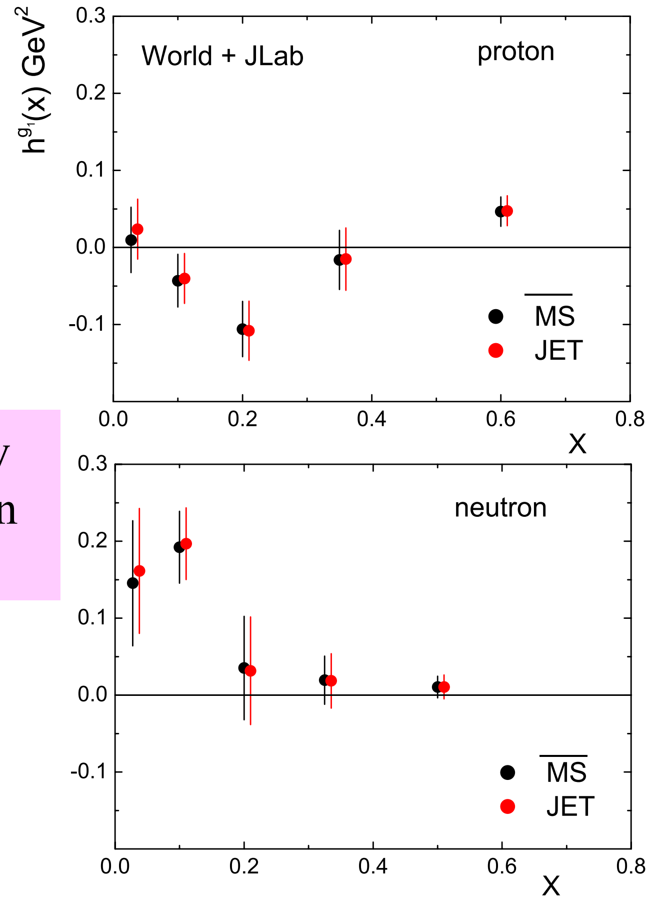
$\Delta\Sigma(Q^2)$ in QCD is a scheme dependent quantity!

$$\Delta\Sigma_{JET}(DIS) \Leftrightarrow \Delta\Sigma(Q^2 \sim \Lambda^2_{QCD})$$



Nonperturbative effects!

How the choice of the factorization scheme for $(g_1)_{LT}$ influence the higher twist results ?



The HT corrections are **well consistent** – they practically do NOT depend on the factorization scheme used for $(g_1)_{LT}$

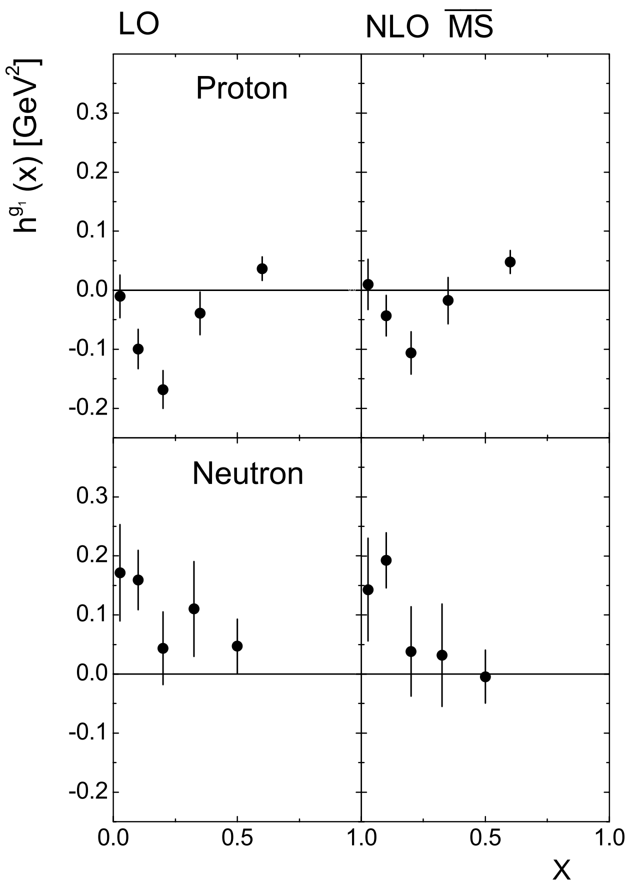
$$g_1(x,Q^2) = g_1(x,Q^2)_{LT} + h^N(x)/Q^2$$

LO QCD approximation - NOT reasonable in the preasymptotic region

- $\alpha_s(Q^2)$ is large
- HT effects are large

Dependence of χ^2 on HT corrections

Fit	LO HT=0	NLO HT=0	LO+HT	NLO+HT
χ^2	249.8	212.5	153.8	149.8
DF	185-8	185-6	185-16	185-16
χ^2 /DF	1.41	1.19	0.910	0.886



Impact of positivity constraints on polarized PD

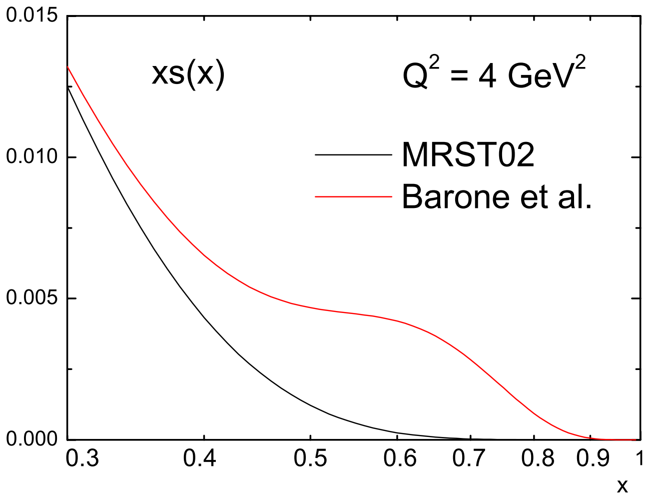
LSS'01 ⟷ LSS'05 (Set 1)

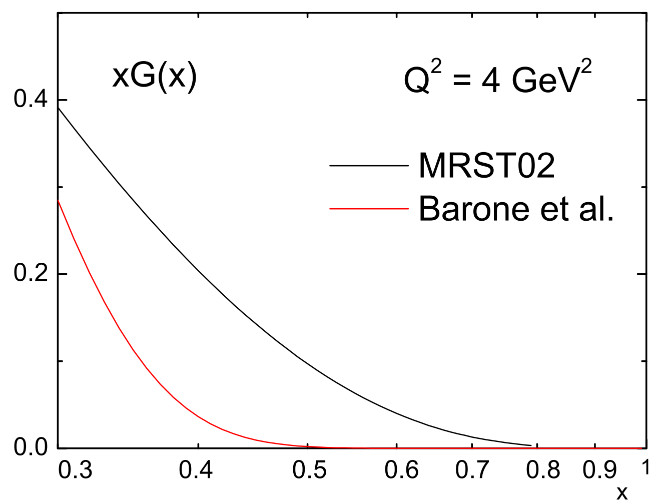
$|\Delta f(x)| \leq f(x)_{\text{Bar.}}$

$|\Delta f(x)| \leq f(x)_{\text{MRST02}}$

Bar.: ***Barone et al., EPJ C12 (2000) 243***

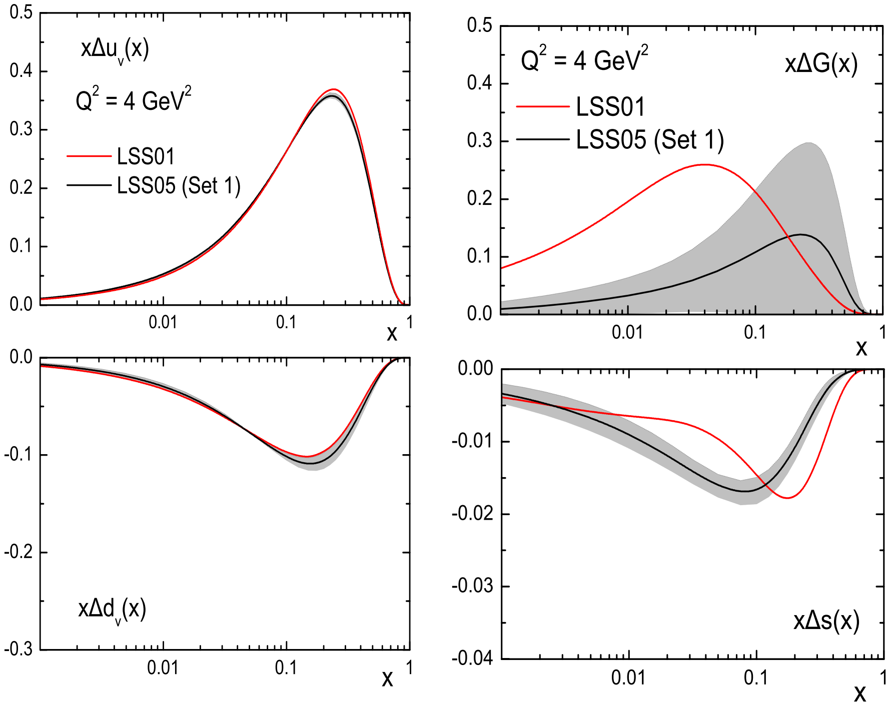
MRST02: ***EPJ C28 (2003) 455***





At large x: $s(x)_{Bar} > s(x)_{MRST02}$ $G(x)_{Bar} < G(x)_{MRST02}$

NLO($\overline{\text{MS}}$)



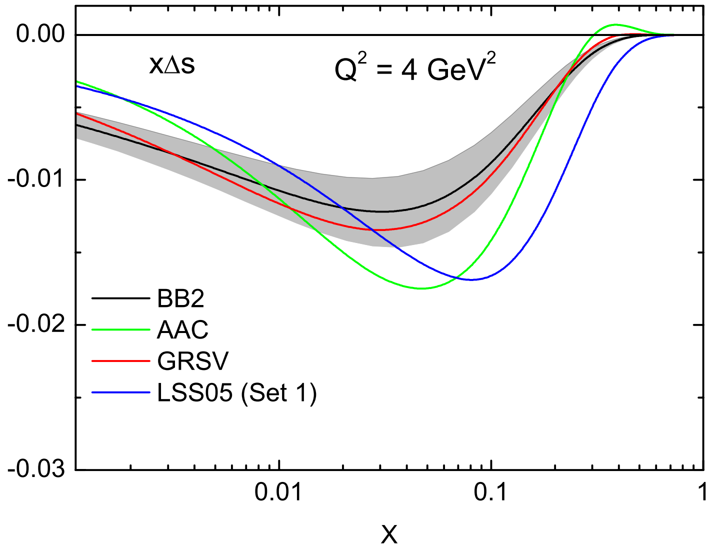
Flavour symmetric sea convention:

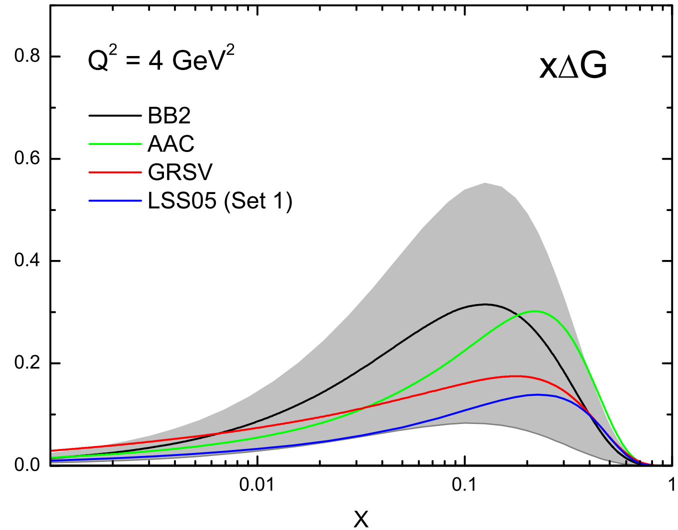
$$\Delta u_{sea} = \Delta\bar{u} = \Delta d_{sea} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$$

- Δu_v and Δd_v of the two sets are closed to each other
- Δs and ΔG are **significantly** different
- Δs and ΔG are **weakly** constrained from the data, especially for high x. That is why the role of positivity constraints is very **important** for their determination in this region.

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

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





GRSV: Glück et al., hep-ph/0011215

BB: Blümlein, Böttcher, hep-ph/0203155

AAC: Goto et. al., hep-ph/0312112

LSS'05: Leader et al., hep-ph/0503140

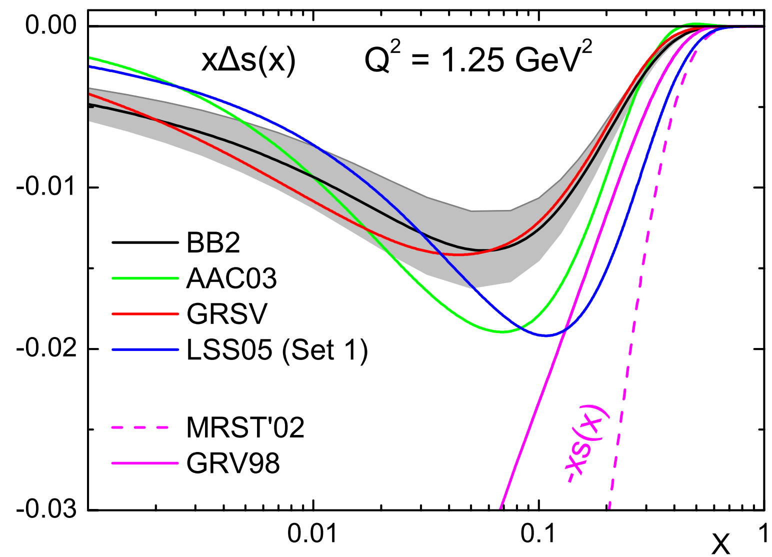
$x\Delta u_v$ and $x\Delta d_v$ well consistent

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

GRSV: Glück et al., hep-ph/0011215
BB: Blümlein, Böttcher, hep-ph/0203155
AAC: Goto et. al., hep-ph/0312112
LSS'05: Leader et al., hep-ph/0503140

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

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

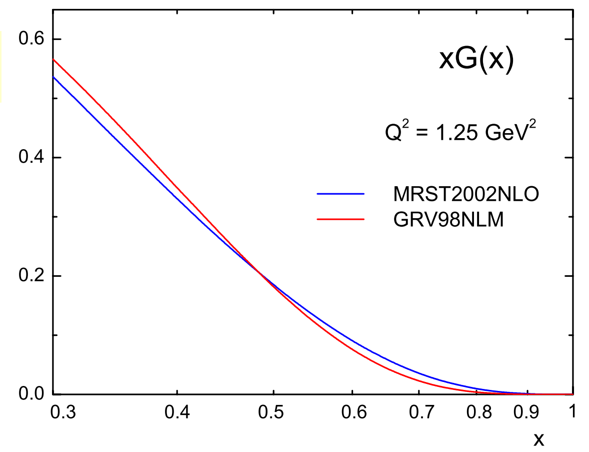


GRSV, BB and AAC have used the **GRV** **unpolarized** PD for constraining their PPD, while LSS have used those of **MRST'02**.

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.

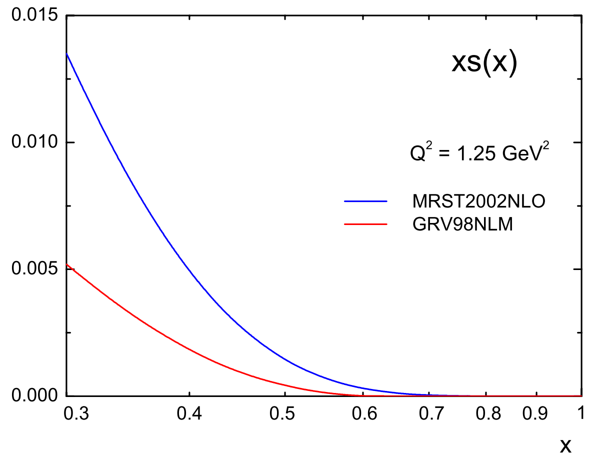
Role of unpolarized PD in detreminig PPD at large x

- At large x the unpolarized GRV and MRST'02 **gluons** are practically **the same**, while $xs(x)_{GRV}$ is much smaller than that of MRST'02.



- For the adequate determination of $x\Delta s$ and $x\Delta G$ at large x, the role of the corresponding **unpolarized** PD is very important.

- Usually the sets of unpolarized PD are extracted from the data **in the DIS region** using cuts in Q^2 and W^2 chosen in order to minimize the higher twist effects.



- The latter have to be determined with good accuracy at large x in the **preasymptotic** (Q^2, W^2) region too.

SUMMARY

- Two sets of **polarized** PD in both the $\overline{MS}$ and the JET schemes are extracted from the world DIS data including the new **JLab** and **COMPASS** data

- The NLO PPD determined in the two schemes are in a **good agreement** with the pQCD predictions

- While the HT corrections to g_1 and F_1 **compensate** each other in $\mathbf{g_1/F_1}$, $\mathbf{HT(g_1)}$ are **important** for the ***correct*** determination of PPD from the $\mathbf{g_1}$ data analysis

- Impact of COMPASS data on PPD ⟹ Δu_v and Δd_v unchanged, $|\Delta s|$ and ΔG **decrease**

- Δs and ΔG are **not** well determined from the data ⟹ the effect of the positivity conditions used to constrain them is **essential**, especially at high x

- A more precise determination of **unpolarized** PD in the **preasymptotic** region is very important