Jefferson Laboratory, August 18, 2003

The Role of Higher Twists in Determining Polarized Parton Densities

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OUTLINE

Peculiarity of the **polarized** DIS

- There are NO charged current (neutrino) DIS data

⇨ $(\Delta q + \Delta \bar{q})$ and ΔG from inclusive DIS data

- A lot of the present data are at low Q^2

⇨ the role of HT effects ?!

Connection between theory and experiment

$\Rightarrow$ different approaches to the data fit

Method of analysis $\Rightarrow$ $g_1^{pQCD} + HT$

Results - HT effects, NLO polarized parton densities

Conclusions

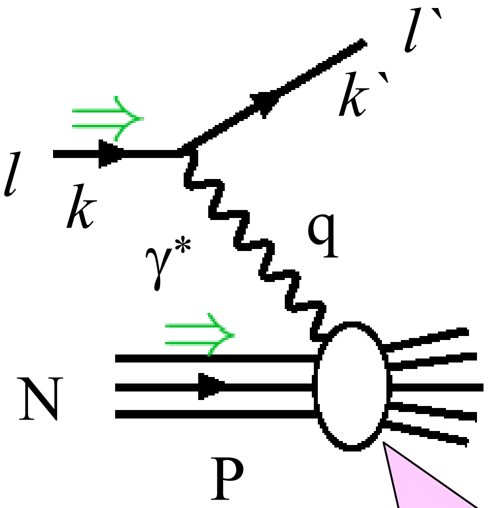
Phys. Rev. D67 (2003) 074017 [hep-ph/0212085]

Inclusive DIS ⇒

one of the best tools to study the structure of **nucleon**

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

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



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

$F_i(x, Q^2)$ **$g_i(x, Q^2)$**

unpolarized SF

polarized SF

DIS Cross Section Asymmetries

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

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

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

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

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

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

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

A lot of the present data are at low Q^2 and W^2

$$Q^2 \approx 1-5\, GeV^2, \quad W^2 > 4 GeV^2$$

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 !**

DATA

185 exp. p.

CERN **EMC -** A_1^p **SMC -** $A_1^p,\ A_1^d$

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

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

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 $(1+\gamma^2)\dfrac{g_1^N}{F_1^N}$
even when $\gamma(\eta)$ ***can not been neglected***

Theory

In QCD

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

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

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

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

dynamical HT power corrections
=> non-perturbative effects (model dependent)

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.

Factorization scheme dependence

Beyond the LO approximation the PD are scheme depended !

In the *unpolarized* case $M_n(PD)_{scheme1} = M_n(PD)_{scheme2} + O(\alpha_s)$

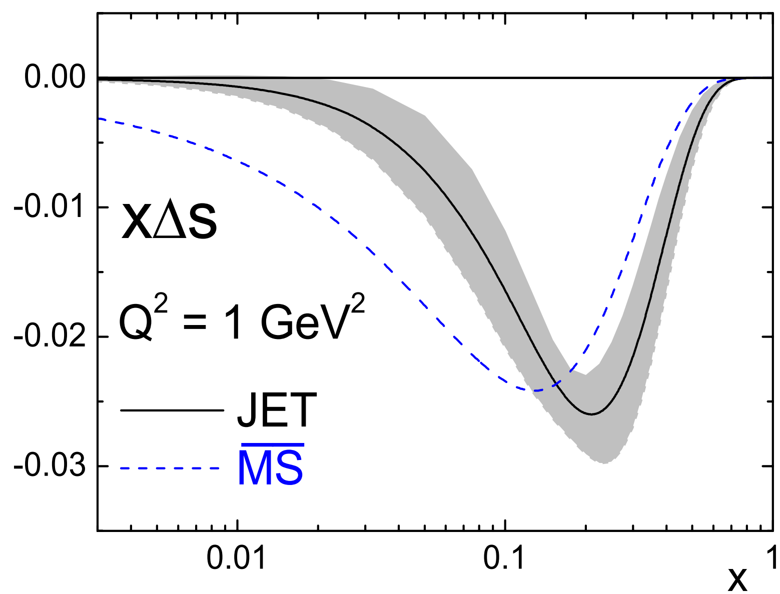
In the *polarized* case because of the *gluon anomaly* $\Delta G(Q^2) = \int_0^1 dx \Delta G(x, Q^2) \sim \frac{1}{\alpha_s(Q^2)}$

$\Delta s = \Delta \bar{s},\ \Delta G = 0.80$

n=1

$$(\Delta s + \Delta \bar{s})_{JET} = (\Delta s + \Delta \bar{s})_{\overline{MS}}(Q^2) + \frac{\alpha_s(Q^2)}{2\pi} \Delta G$$
$$= (\Delta s + \Delta \bar{s})_{\overline{MS}}(Q^2) + O(1)$$

$$\Delta\Sigma_{JET} = \Delta\Sigma_{\overline{MS}}(Q^2) + N_f \frac{\alpha_s(Q^2)}{2\pi} \Delta G(Q^2)$$
$$= \Delta\Sigma_{\overline{MS}}(Q^2) + O(1)$$



LO is a bad approximation, at least for $\Delta \bar{q}$

The larger ΔG → **the bigger the difference**

On theoretical grounds we prefer to use the *JET* scheme (all hard effects are absorbed in the Wilson coefficient functions).

Carlitz, Collins, Mueller (1988)
Efremov, Teryaev (1989); Muller, Teryaev (1997)
Anselmino, Efremov, Leader (1995)

In the JET scheme (as well as in AB scheme)

$$\Delta\Sigma(Q^2),\ \text{as well as}\ (\Delta s + \Delta\bar{s}),\ \text{are inpedendent of}\ Q^2$$

⇨ it is meaningful to directly interpret $\Delta\Sigma$ as the contribution of the quark spins to the nucleon spin and to compare its value obtained from **DIS region** with the predictions of the different (constituent, chiral, etc.) quark models at **low** Q^2 **.**

Connection between Theory and Experiment

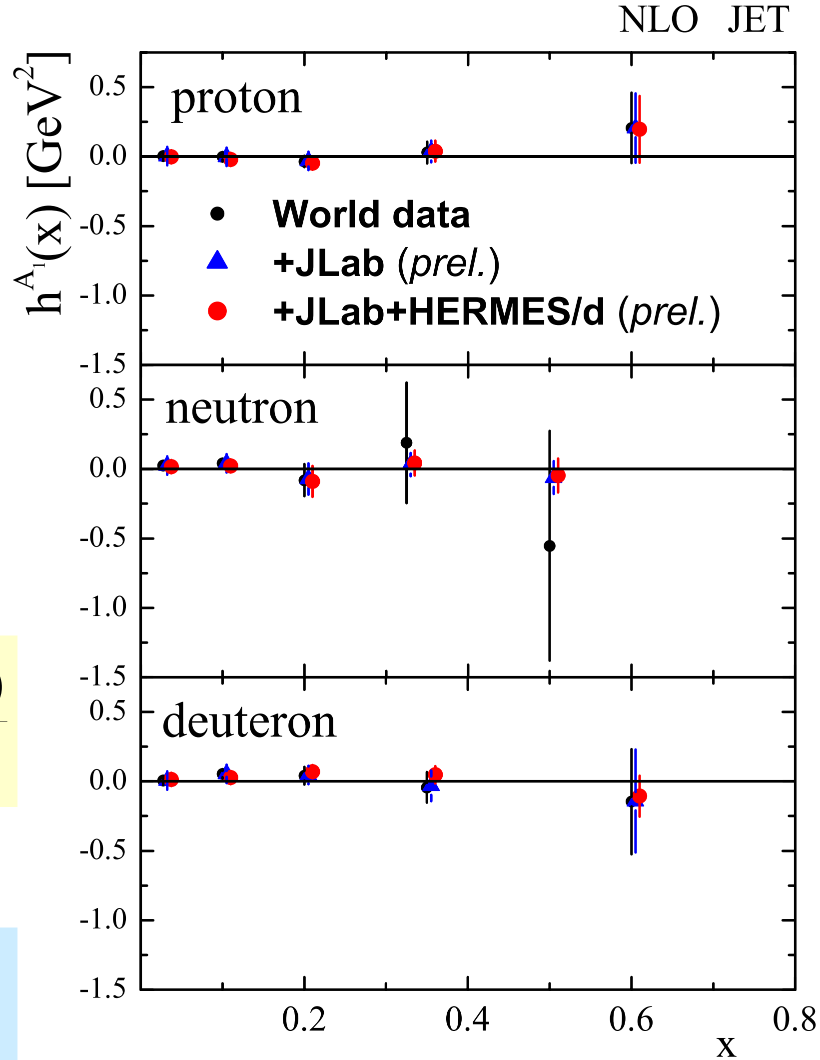
E.Leader, A.Sidorov, D.Stamenov
[hep-ph/0212085] Eur. Phys. J. C23, 479 (2002)

GRSV, LSS

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\exp} \Leftrightarrow \frac{g_1(x,Q^2)_{LT}}{F_1(x,Q^2)_{LT}}$$

$$A_1(x,Q^2)_{\exp} \Leftrightarrow (1+\gamma^2)\frac{g_1(x,Q^2)_{LT}}{F_1(x,Q^2)_{LT}}$$

$$A_1(x,Q^2)_{\exp} \Leftrightarrow (1+\gamma^2)\frac{g_1(x,Q^2)_{LT}}{F_1(x,Q^2)_{LT}} + \frac{h^{A_1}(x)}{Q^2}$$



The HT corrections to g_1 and F_1 compensate each other in the ratio $\frac{g_1}{F_1}$ and the PPD extracted by this way are less sensitive to HT effects.

$$h^{A_1}(x) \approx 0$$

SMC; Blumlein, Bottcher

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\exp} \Leftrightarrow \frac{g_1(x,Q^2)_{LT}}{F_2(x,Q^2)_{\exp}} 2x \frac{[1+R(x,Q^2)_{\exp}]}{(1+\gamma^2)}$$

$$A_1(x,Q^2)_{\exp} \Leftrightarrow \frac{g_1(x,Q^2)_{LT}}{F_2(x,Q^2)_{\exp}} 2x[1+R(x,Q^2)_{\exp}]$$

In this case the ``effective higher twist'' contribution $h^{A_1}(x)$ is found to be sizeable and important in the fit **(GRSV)**

To extract correctly PPD from g_1 data, the HT corrections to g_1, $h^{g_1}(x)/Q^2$, have to be included into data fits

AAC; de Florian, Sassot
have used a procedure in which $F_{2\,\exp} \Rightarrow (F_2)_{LT}$.

We have found that $h^{A_1}(x)$ is also NOT negligible in this case

METHOD of ANALYSIS

HT to g_1 included in model independent way

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{\exp} \Leftrightarrow \frac{g_1(x,Q^2)_{LT} + h^N(x)/Q^2}{F_2(x,Q^2)_{\exp}} 2x\frac{[1+R(x,Q^2)_{\exp}]}{(1+\gamma^2)}$$

NMC

R_{1998} (SLAC)

$$A_1(x,Q^2)_{\exp} \Leftrightarrow \frac{g_1(x,Q^2)_{LT} + h^N(x)/Q^2}{F_2(x,Q^2)_{\exp}} 2x[1+R(x,Q^2)_{\exp}]$$

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

Input parton densities

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

$Q_0^2 = 1\, GeV^2$, $A_i, \alpha_i - free\ par.$ $(\mathrm{i}=1,2,\ldots 4)$

⇨ **8-2(SR) = 6 par. associated with PD**

The inverse Mellin - transformation method has been used to calculate $\mathrm{g}_1^{\mathrm{N}}(\mathrm{x},\mathrm{Q}^2)_{\mathrm{LT}}$ from its moments

SR for n=1 moments of PD

$$g_A = (\Delta u + \Delta\bar{u})(Q^2) - (\Delta d + \Delta\bar{d})(Q^2) \quad = 1.2670 \pm .0035 \qquad (1)$$

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

The sum rule (1) reflects the isospin SU(2) symmetry, whereas the relation (2) is a consequence of the SU(3) flavour symmetry treatment of the hyperon β-decays.

While isospin symmetry is not in doubt, there is some question about the accuracy of assuming SU(3)$_f$ symmetry in analyzing hyperon β-decays. The results of the recent KTeV experiment at Fermilab on the β-decay of Ξ^0, $\Xi^0 \to \Sigma^+ e\bar{\nu}$, however, are all *consistent* with *exact* SU(3)$_f$ symmetry. Taking into account the experimental uncertainties one finds that SU(3)$_f$ breaking is at most of order 20%.

KTeV experiment
Fermilab

$$\Xi^0 \to \Sigma^+ e \bar{\nu}$$

β-decay

SU(3)$_f$ prediction for the form factor ratio g_1/f_1

$$\frac{g_1}{f_1} = g_A = 1.2670 \pm .0035$$

Experimental result

$$\frac{g_1}{f_1} = 1.32^{+0.21}_{-0.17} \pm 0.05$$

A good agreement with the ***exact*** SU(3)$_f$ symmetry !

From exp. uncertainties ⇒ SU(3) breaking is at most of order **20%**

RESULTS OF ANALYSIS

Kinematic region - 185 exp. p.

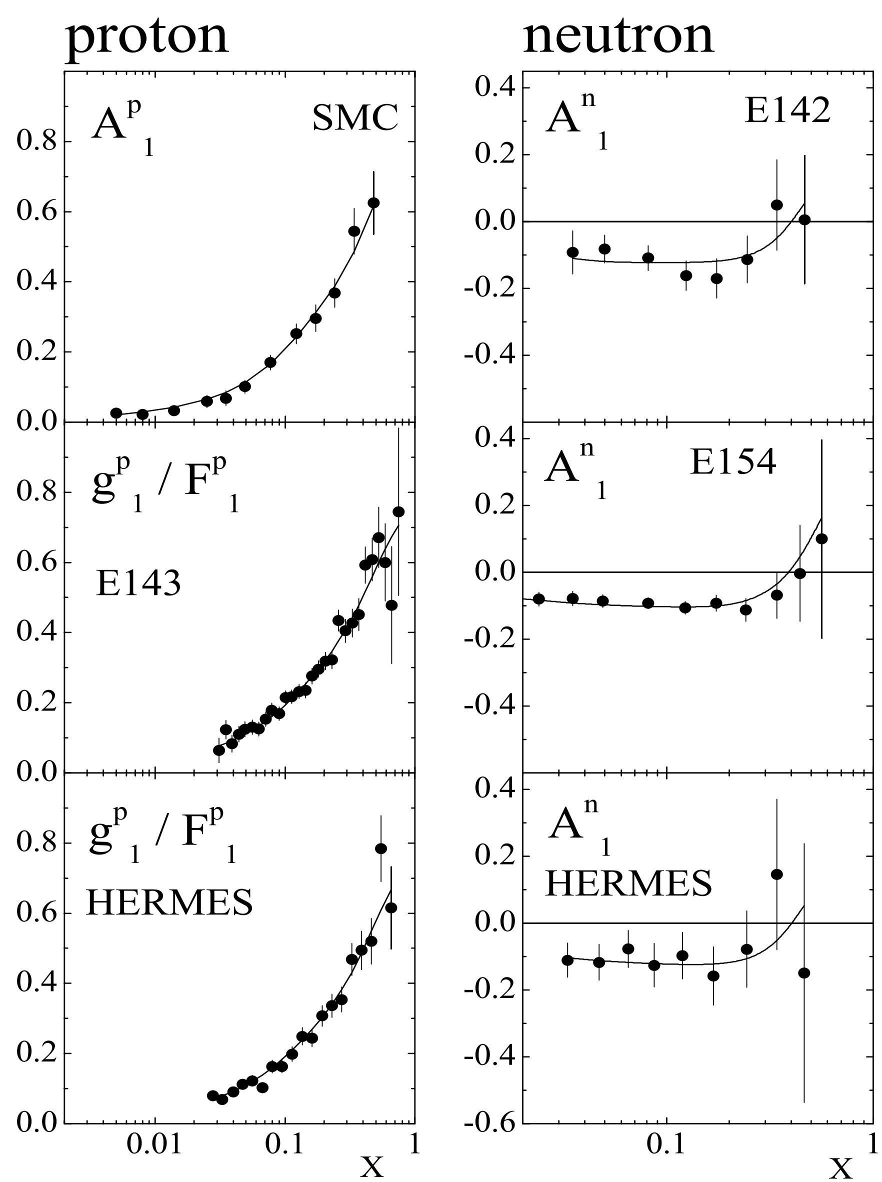
$0.005 \le x \le 0.75 \quad 1 < Q^2 \le 58 \ \mathrm{GeV}^2$

Quality of the fits

A very good description of the world A_1 and g_1 data is achieved.

$$\text{LO} \Rightarrow \chi^2_{DF,LO} = 0.892$$

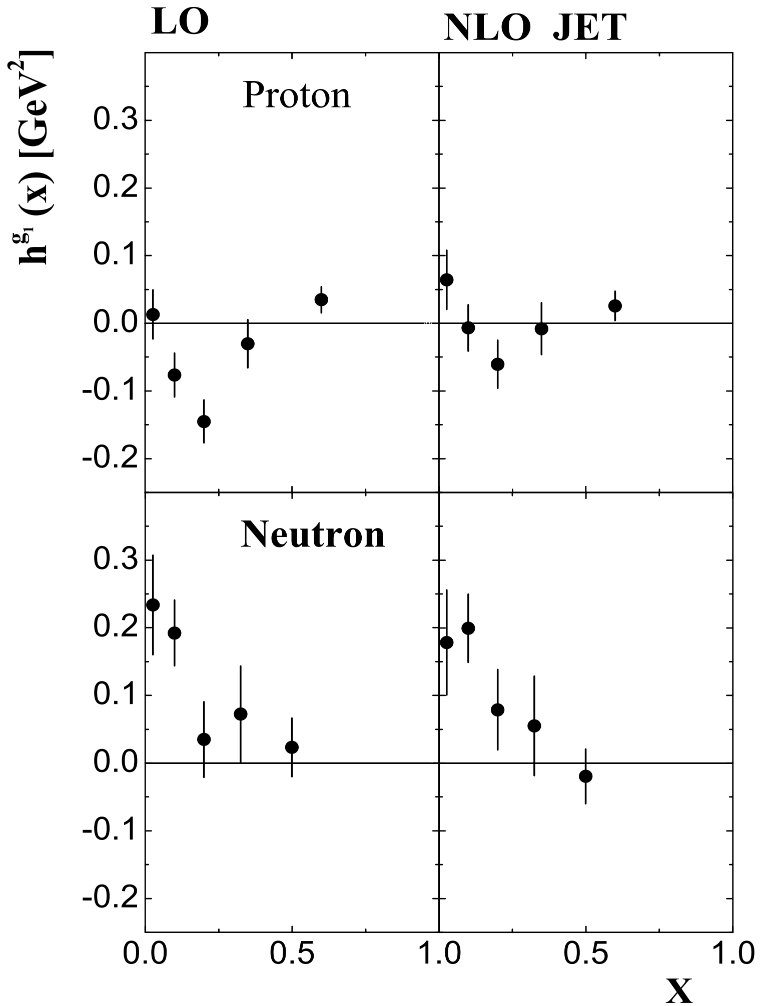
$$\text{NLO(JET)} \Rightarrow \chi^2_{DF,NLO} = 0.885$$



Higher twist effects

Dependence of χ^2 on HT corrections

Fit	LO HT=0	NLO HT=0	LO+HT	NLO+HT
χ^2	244.5	218.8	150.7	145.0
DF	185-6	185-6	185-16	185-16
χ^2 / DF	1.36	1.22	0.892	0.858

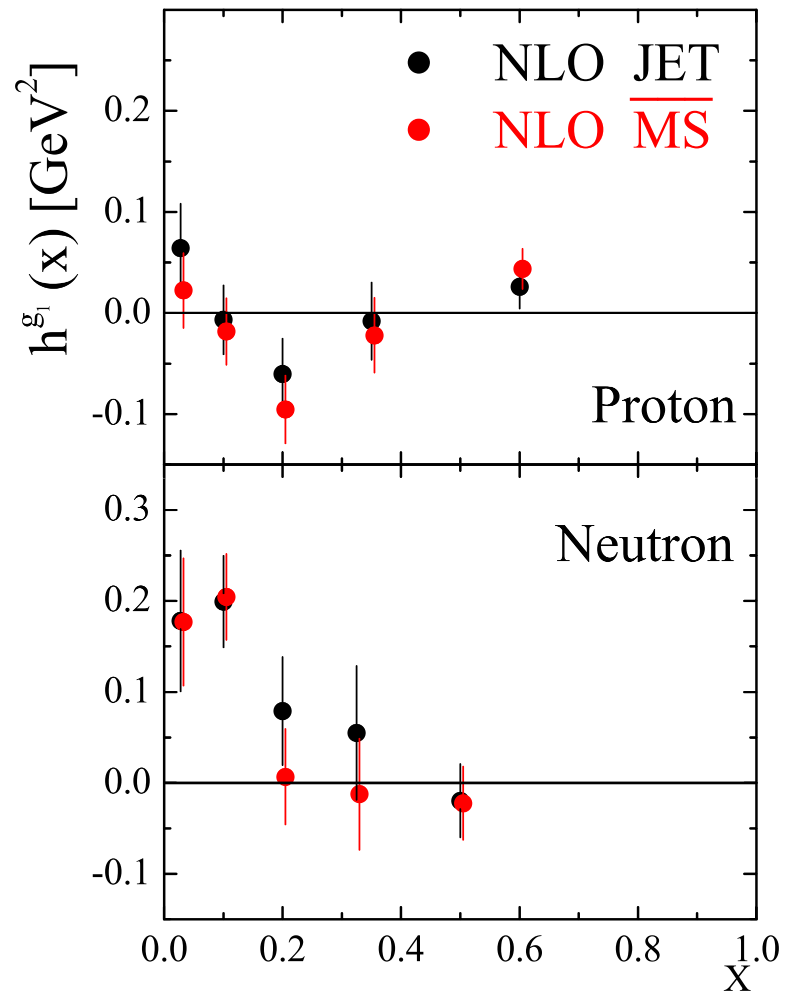


The size of HT corrections to g_1 is NOT negligible

The shape of HT depends on the target

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

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



an estimation of the NNLO effects in $(g_1)_{LT}$

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

NLO polarized PD

From inclusive DIS data $\Rightarrow (\Delta q + \Delta\bar{q})$ and ΔG

$(\Delta u + \Delta\bar{u}), (\Delta d + \Delta\bar{d})$ well determined

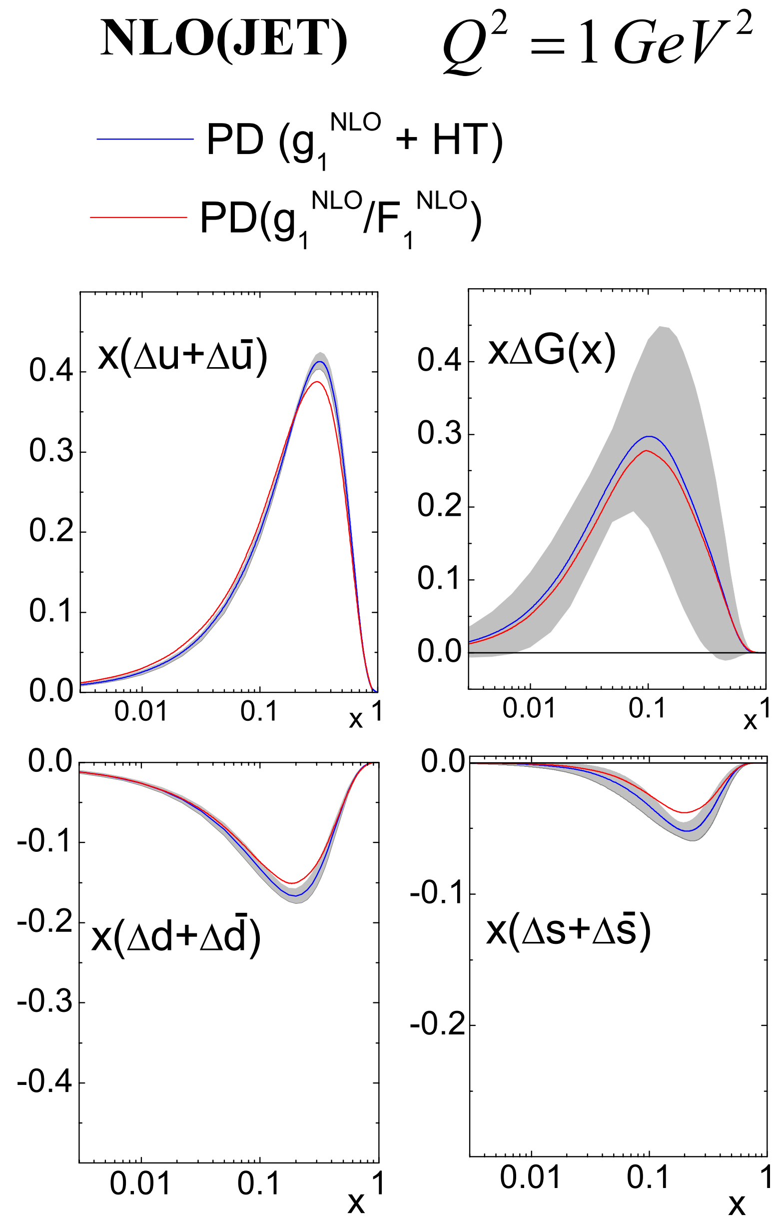
$(\Delta s + \Delta\bar{s})$ reasonably well determined
if accept for a_8 its SU(3) symmetric value
$a_8 = 3F - D = 0.58$

ΔG not well constrained,
but it seems to be large

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

$$\chi^2_{DF,NLO} = 0.858 \Leftrightarrow \chi^2_{DF,NLO} = 0.859$$

If F_1 is expressed via $(F_2)_{exp}$ and R_{exp}
then the HT corrections to g_1
have to be taken into account!



n=1 moments of PD, JET scheme, $Q^2=1$ GeV^2

- the correlations between the parameters are taken into account

$$(\Delta u + \Delta\bar{u})(Q^2) = 0.84 \pm 0.03$$

$$(\Delta d + \Delta\bar{d})(Q^2) = -0.43 \pm 0.04$$

$$(\Delta s + \Delta\bar{s}) = -0.09 \pm 0.03$$

$$\Delta G(Q^2) = 0.80 \pm 0.48$$

$$\Delta\Sigma_{JET} = 0.32 \pm 0.06$$

$$a_0(Q^2) = \Delta\Sigma(Q^2)_{\overline{MS}} = 0.14 \pm 0.08$$

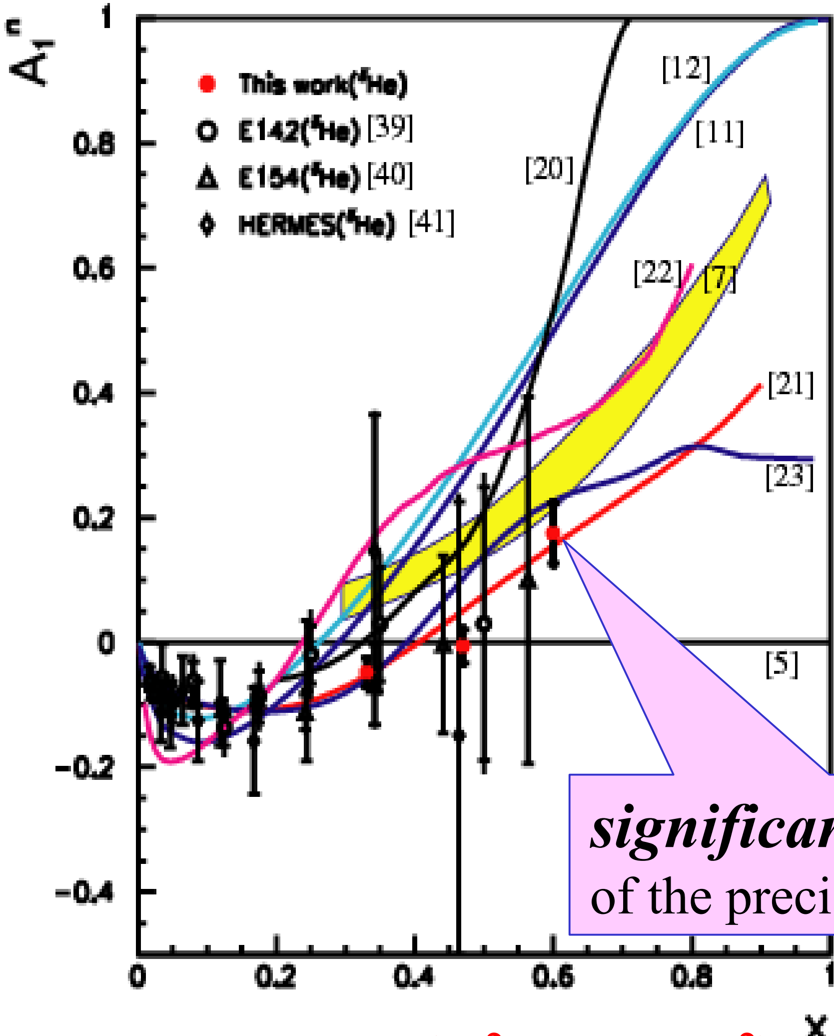
N.B. In JET scheme $\Delta\Sigma$, as well as $(\Delta s + \Delta\bar{s})$, do NOT depend on Q^2.

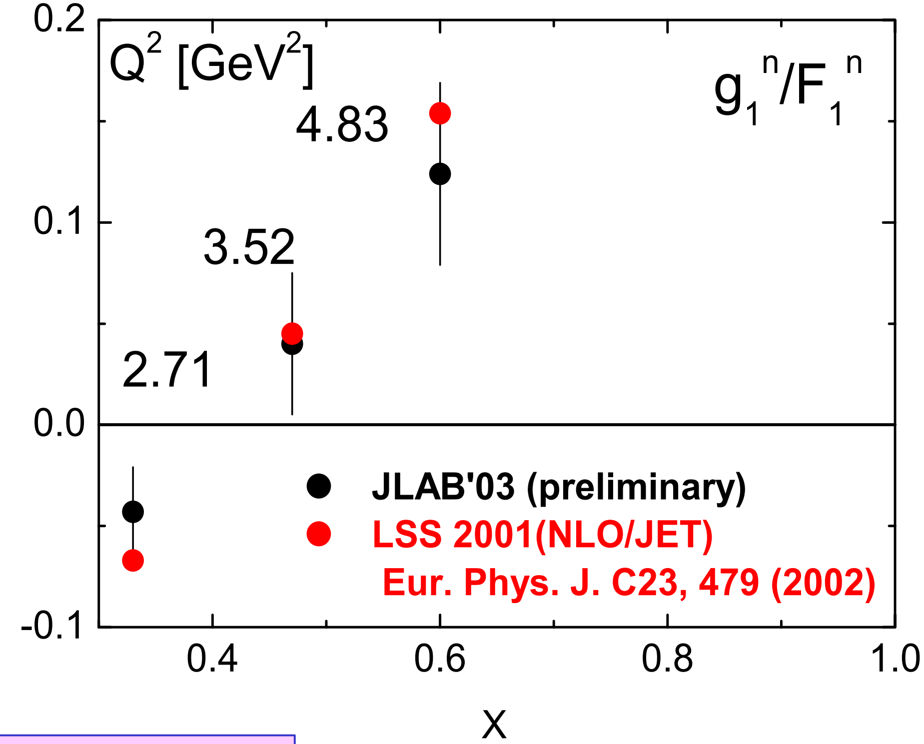
- Spin sum rule: $\mathbf{1/2} = \frac{1}{2}\, 0.32 + 0.80 + \mathbf{L_z} = \mathbf{0.96} + \mathbf{L_z}$

$\mathbf{L_z}$ is ***negative***

JLAB preliminary
hep-ex/0302020

Our predictions for the JLAB experimental values of g_1^n/F_1^n using the LSS'2001 NLO(JET) polarized PD





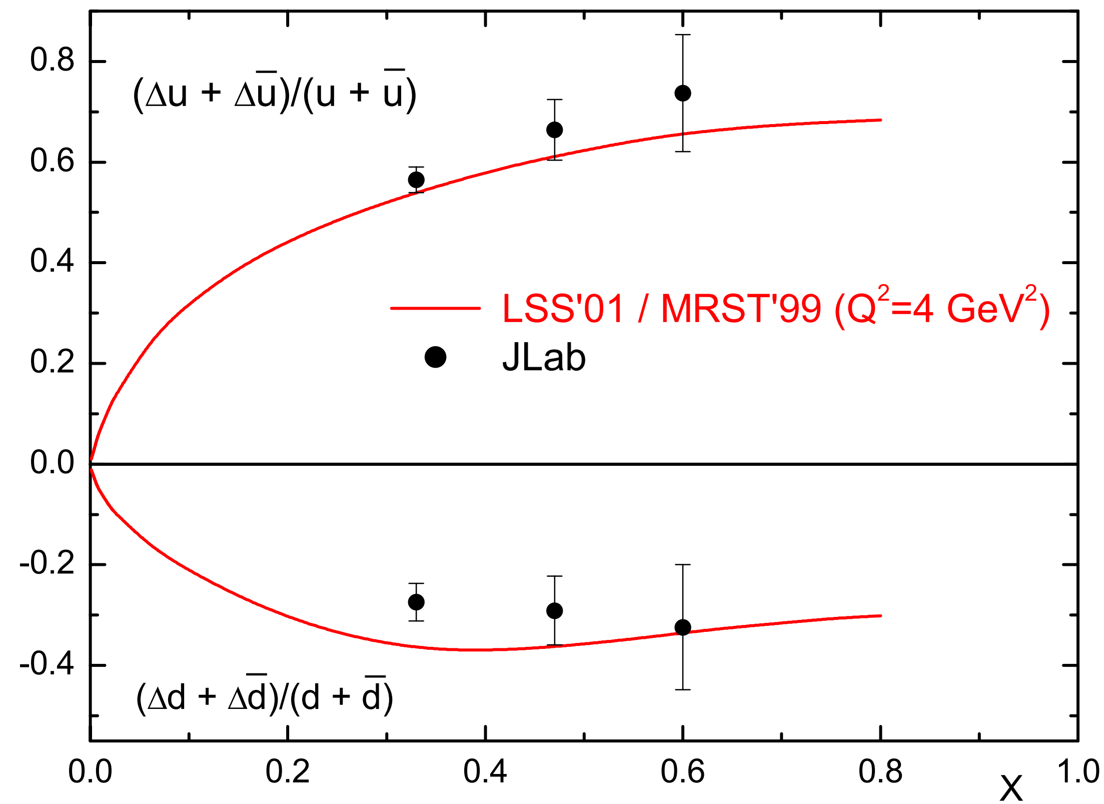
significant improvement of the precision of the data

-LSS 2001 ($Q^2 = 5$ GeV^2)

[21] *Leader, Sidorov, Stamenov, Euro Phys. J. C23, 479 (2002)*

$(\Delta q/q)_{Jlab}$ have been extracted from the data:

- **in the naive quark-parton model**
- **assuming the strange quark densities $s(x)$, $\bar{s}(x)$, $\Delta s(x)$ and $\Delta\bar{s}(x)$ to be negligible in the region $x > 0.3$**



BBS model for the input PD

- $\Delta q_V / q_V \to 1 \;\; (x \to 1)$ $\Delta \bar{q} / \bar{q} \to 1 \;\; (x \to 1)$
- At which Q² ? May be at Q² $\approx \Lambda^2_{QCD}$?

In our analysis the BBS model was accepted as a parametrization for the input PD

LSS, Int. J. Mod. Phys. A13 (1998) 5573

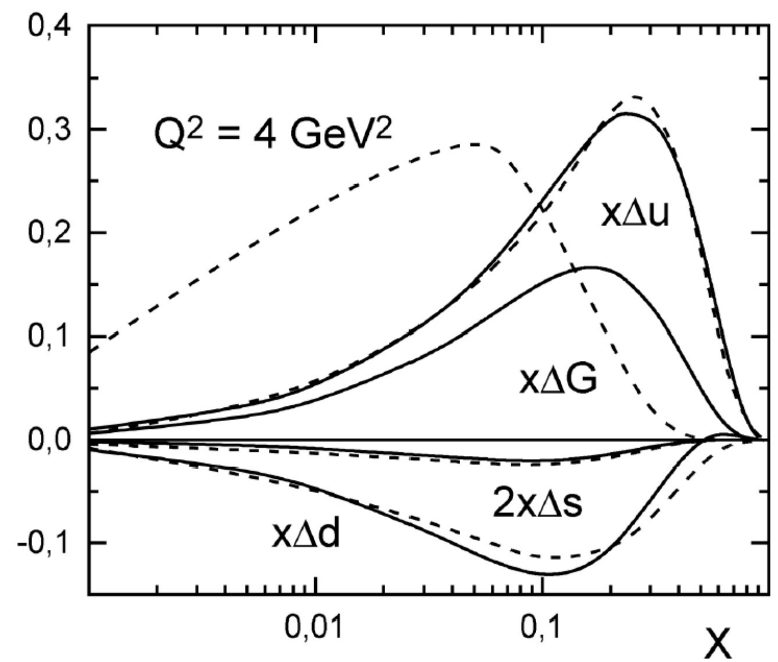
—— BBS

- - - $x\Delta f(x) = A_f x^{\alpha_f} x f^{MRS(A')}(x)$

$$\Delta q \equiv \Delta q + \Delta \bar{q}$$

NB. $(\Delta \mathbf{d} + \Delta \bar{\mathbf{d}})_{\mathbf{BBS}} > 0$

for x > 0.35 !



BBS model for the input PD

- $\Delta q_V / q_V \to 1 \ (x \to 1)$ $\qquad$ $\Delta \bar{q} / \bar{q} \to 1 \ (x \to 1)$
- At which Q^2 ? $\qquad$ May be at Q^2 $\approx \Lambda^2_{QCD}$?

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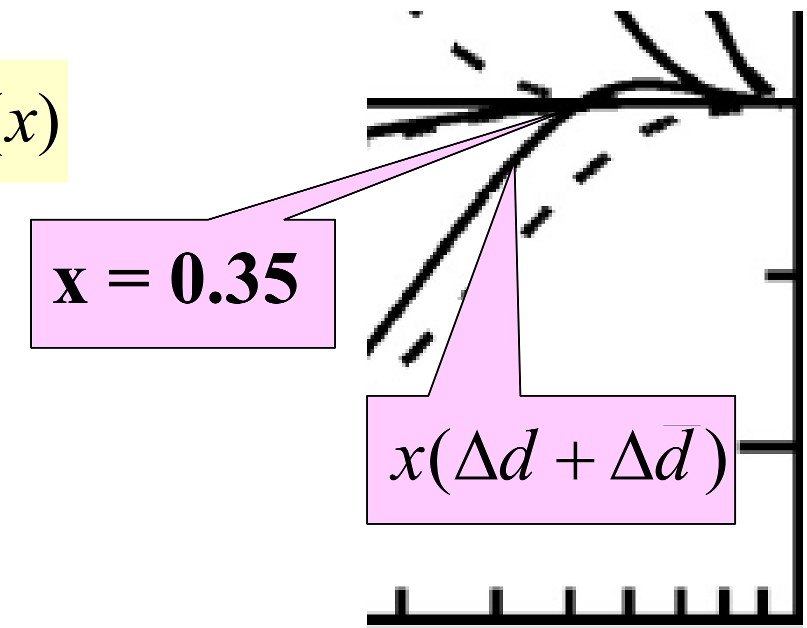


NB. $(\Delta \mathrm{d} + \Delta \bar{\mathrm{d}})_{\mathrm{BBS}} > 0$

for x > 0.35 !

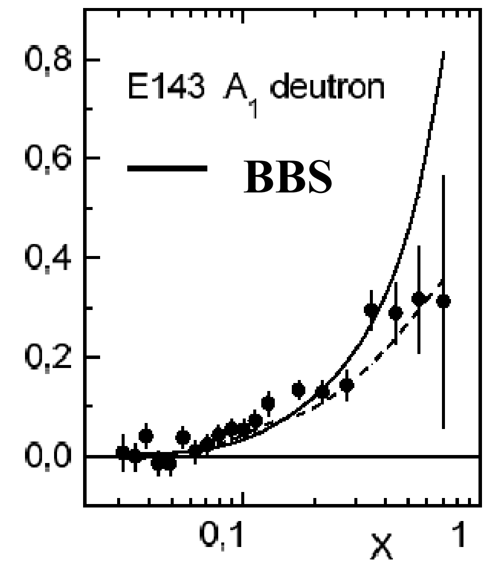
Fit to the world **(1997)** data on A_1 and g_1/F_1

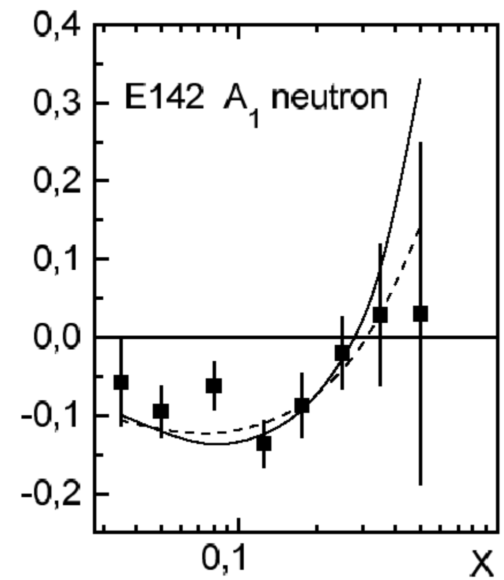
LSS, Int. J. Mod. Phys. A13 (1998) 5573

N.B. A lot of more accurate data have been reported after that period: final SMC, final SLAC/E143, SLAC/E154, SLAC/E155, HERMES/p and JLab data

"… the difference between $x(\Delta d + \Delta \bar{d})(x, Q_0^2)$ leads to a considerably different behaviour of $A_1^d(x,Q^2)$ in the kinematic region: x>0.35, $Q^2 \sim$ 5-10 GeV^2, and allows a better fit to the SLAC E143 data on $A_1^d(x,Q^2)$ in this region in the case of the para-metrization $\Delta f(x) = A_f x^{\alpha_f} f^{MRS}(x)$ for the input polarized parton densities. The difference

for $x(\Delta d + \Delta \bar{d})$ at large x is a consequence of the fact that the BBS distributions are forced to satisfy $\Delta d / d \rightarrow 1$ as $x \rightarrow 1$."





HEPDATA
The Durham HEP Databases

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

Parton Distribution Generator - Microsoft Internet Explorer

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

Parton Distribution Functions

Polarized Parton Distributions

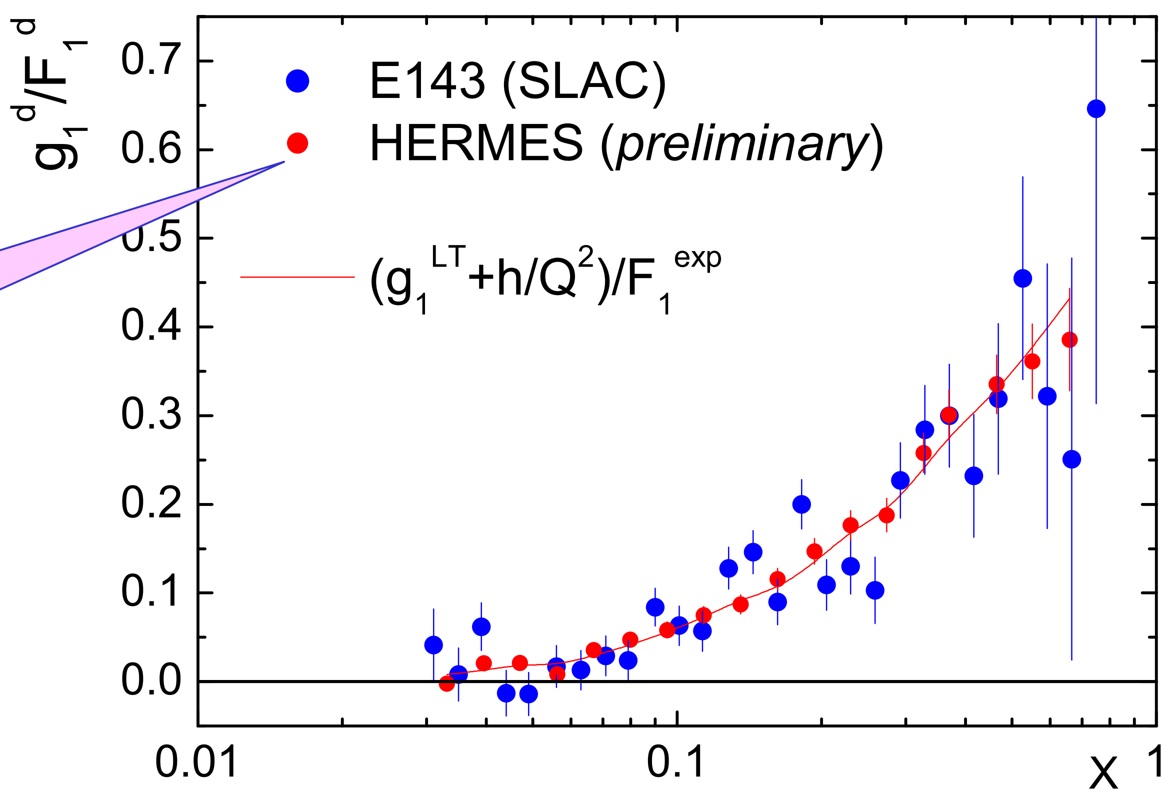
Currently available parametrizations:

E.Leader, A.V.Sidorov and D.B.Stamenov, hep-ph/0111267: LSS2001
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 - hep-ph/0203155 BB
Asymmetry Analysis Collaboration - Y. Goto et al- Phys. Rev. D62 (2000) 034017 AAC
D. de Florian and R. Sassot, Phys. Rev. D62 (2000) 094025: DS2000

Very recent (unpublished) results from the fit to the world data including the **JLAB** and **HERMES/d** data

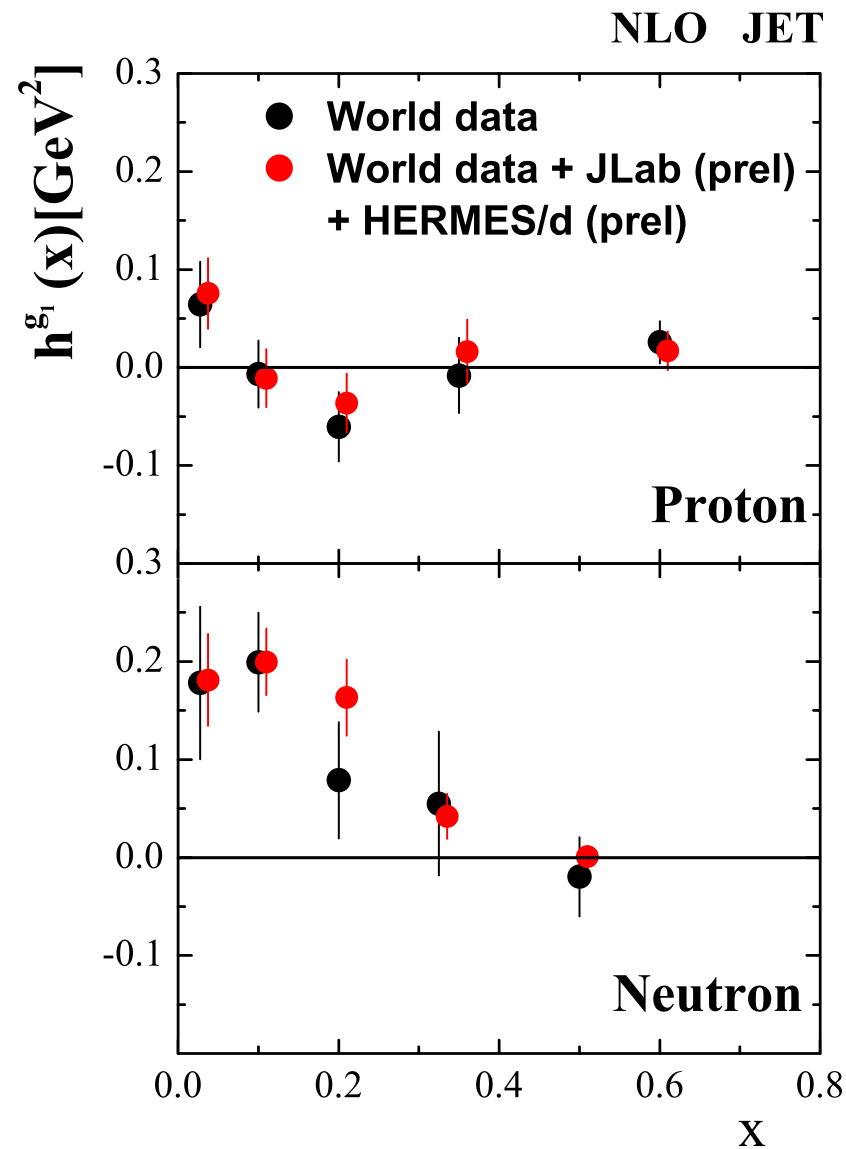
- a very good description of the HERMES/d data
  χ^2=11.0 for 18 points
- PD(g_1^{NLO}+ HT) practically do **NOT** change !!

Ch. Weiskopf
02-043 Thesis (2002)



- HT corrections to g_1 are better determined now, especially for the neutron target

- HT/n changes essentially at $x \approx 0.2$ region



CONCLUSIONS

- The fit to the ***present*** data on g1 is **essentially improved**, especially in the LO case, when the higher twist terms are included in the analysis.

- The size of **HT** corrections have been extracted from the data in ***model independent*** way

- $PD(g_1^{LT} + HT)$ **well consistent with** $PD(g_1^{LT} / F_1^{LT})$

To extract *correctly* the polarized PD from the g_1 data,

the HT corrections to g_1 *have* to be taken into account in the analysis.

MORE GENERALLY

- Given the limited range and precision of present $g_1(x,Q^2)$ measurements, one would like

  ⇒ **a direct measurement of ΔG (COMPASS, RHIC)**

- Inclusive DIS measurements are sensitive only to $(\Delta q + \Delta\bar{q})$

  ⇒ thus a new probe is needed to **separate quark and anti-quark polarized PD from SIDIS, W production**

  (HERMES, COMPASS, RHIC)

- Data at ***larger*** **Q^2** and ***smaller*** **x** would be very important for our understanding of the spin properties of the nucleon.