Spin Physics with Deuterons at HERA

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Outline

Spin Physics with Polarised Deuterons - The spin problem

- Sum rule; $\frac{1}{2} = L_q + \frac{1}{2}\Delta\Sigma + J_g$

Skewed parton distributions can give L_q via DVCS - we do not know yet what to measure to derive L_q from DVCS.

Measurement of J_g via QCD evolution and Dijets.

Measure spin carried by quarks from CC interactions - spin in a new kinematic region at HERA (higher Q^2 and CC) - the discovery potential ?

Deuterons - Advantages and Disadvantages.

Physics with Unpolarised Deuterons (e.g. at startup).

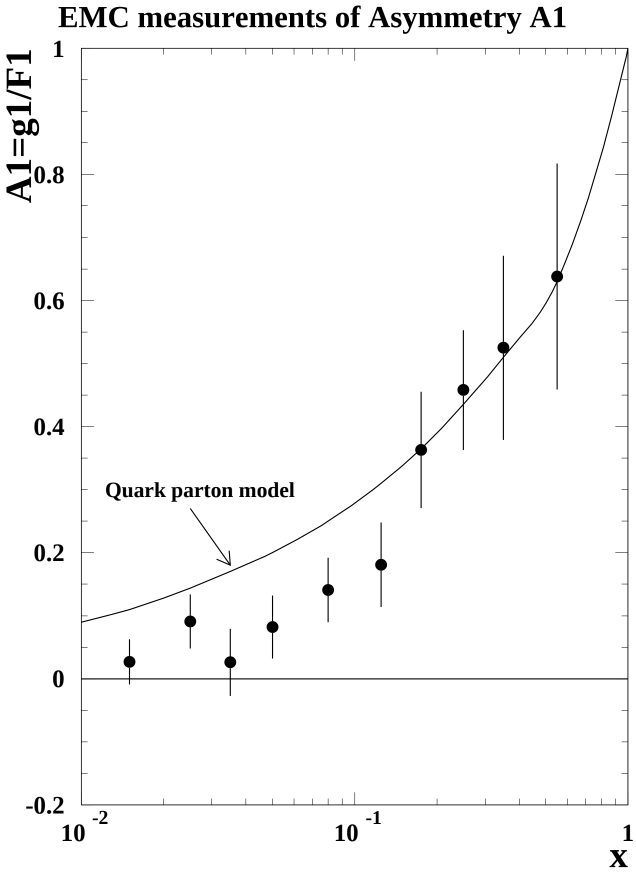
Deuterons - assume spectator detected to allow tagging of interacting nucleon (p or n) . Discuss problems.

DISCOVERY OF THE SPIN DEFICIT - EMC 1987

EMC measured $A_1 = g_1/F_1$ and

$\int_0^1 g_1(x)dx = .126 \pm .010 \pm .015$

Disgrees with Quark Parton Model.



This integral is related to

measurements in β decay.

$$\int_0^1 g_1^{p(n)} dx = +(-)\frac{a_3}{12} + \frac{a_8}{36} + \frac{1}{9}\Delta\Sigma$$

where $a_3 = \Delta u - \Delta d = g_A/g_V$ - from neutron β decay

$a_8 = \Delta u + \Delta d - 2\Delta s$ - from hyperon β decay

$\Delta\Sigma = \Delta u + \Delta d + \Delta s$ = fraction of proton spin carried by spin of quarks.

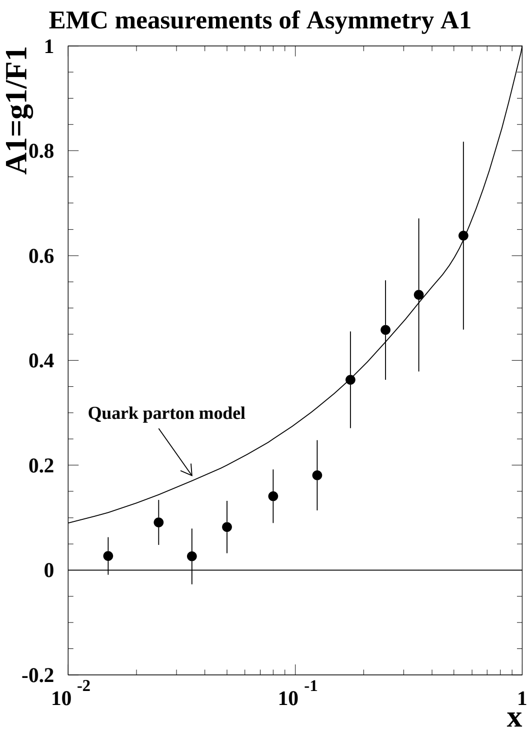
SPIN DEFICIT - from known values $a_3 = 1.25, a_8 = 0.69$ and measured integral - $\Delta\Sigma$ is small i.e.only a small fraction nucleon's spin is carried by the spin of quarks.

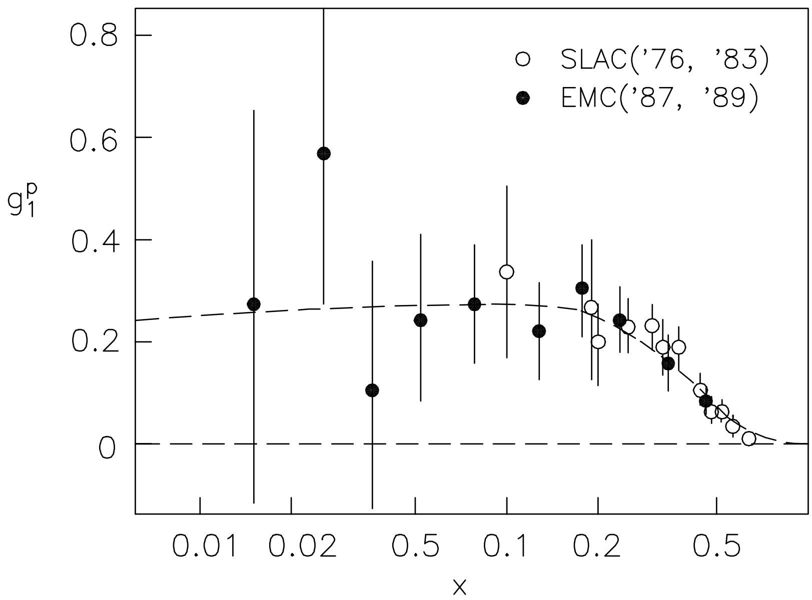
NB Measure virtual photon asymmetry

$$A_1 = \frac{q\uparrow - q\downarrow}{q\uparrow + q\downarrow}$$
$$= \frac{g_1}{F_1}$$

To obtain g_1 use $2xF_1 \approx F_2$, (neglecting $R = \sigma_L/\sigma_T$)

$$g_1 \approx \frac{A_1 F_2}{2x}$$





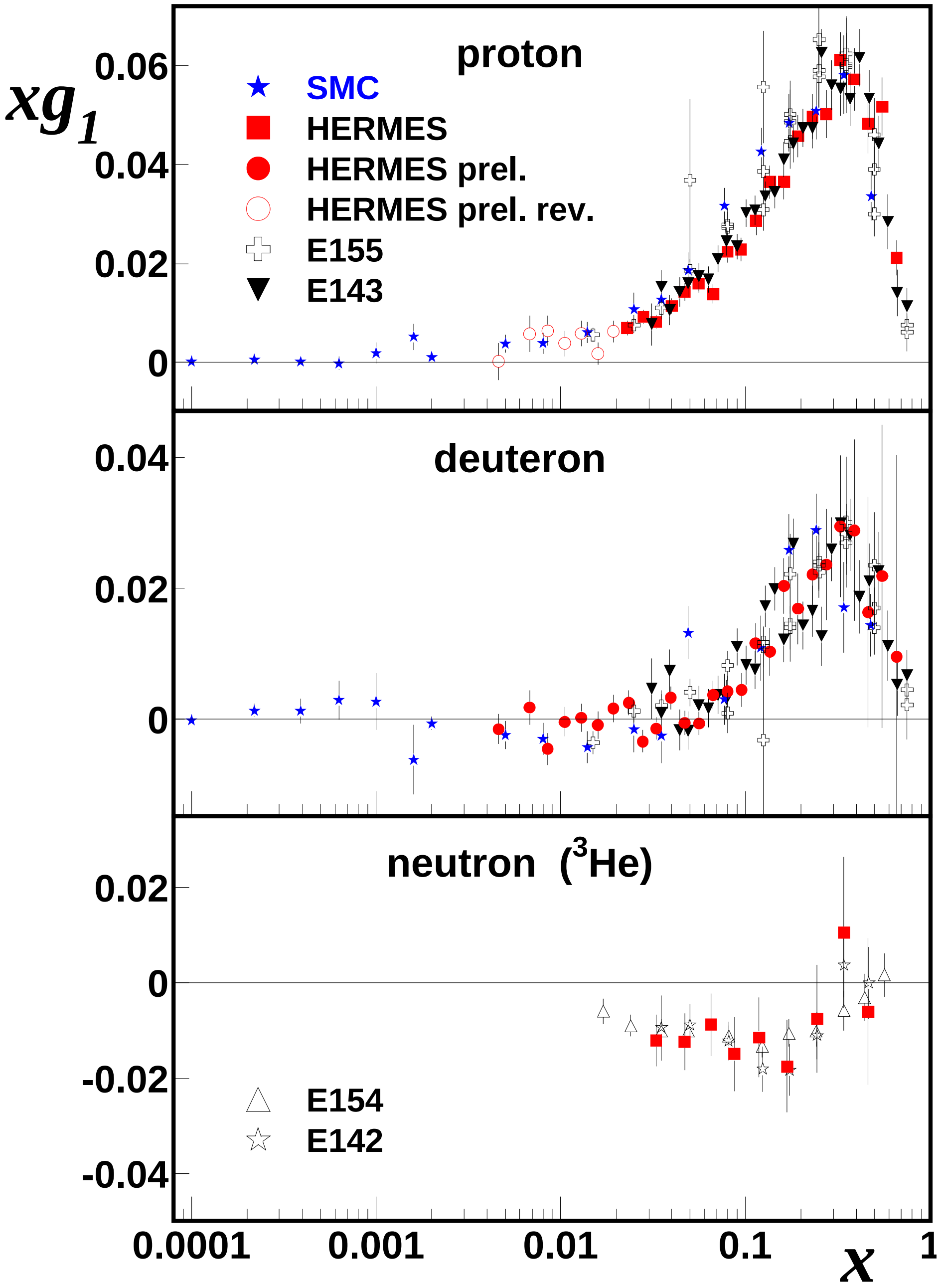
But to arrive here needs a series of measurements.

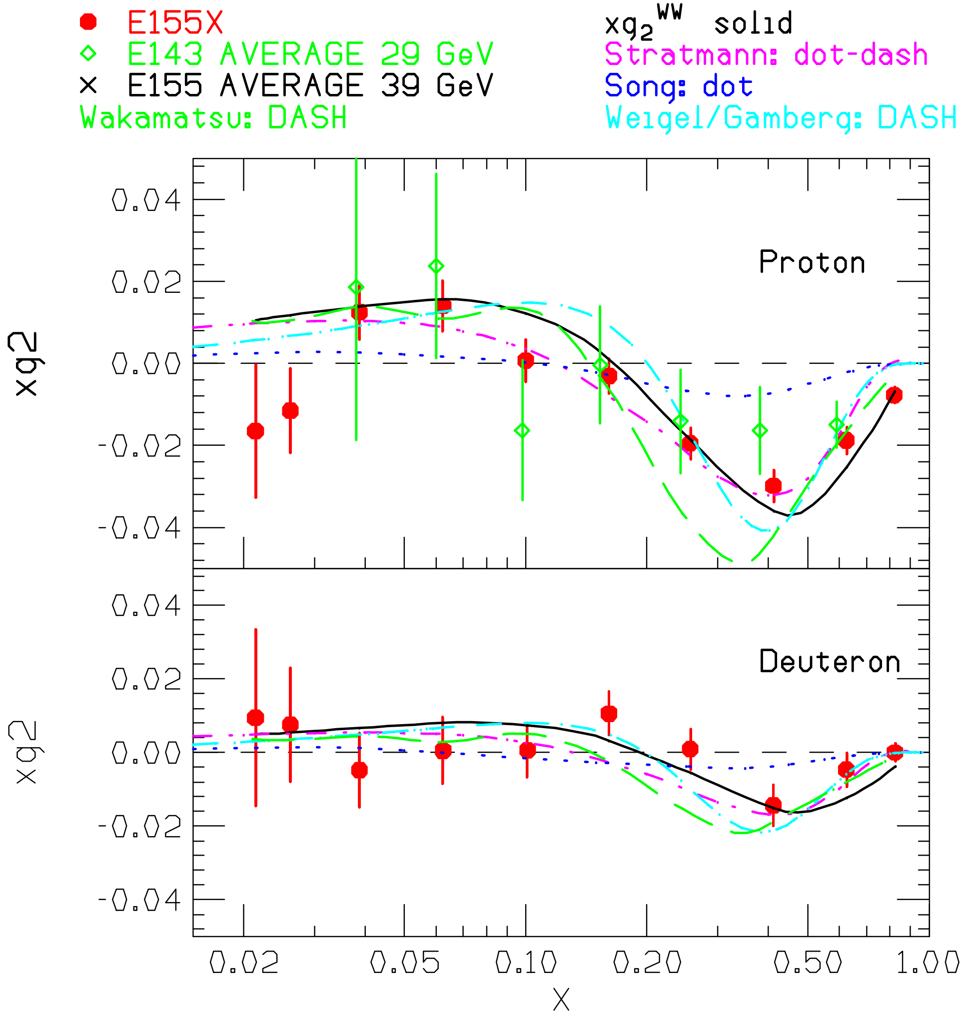
$$A_{meas} = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}} = P_e P_p F D A_1$$

- $P_{e(p)}$ are beam polarisations, F is dilution factor = fraction of target nucleons polarised = 1 for perfect tagged targets and D is a virtual photon depolarisation factor

$$D = \frac{y(2-y)}{y^2 + 2(1-y)(1+R)} \sim y$$

World Data on xg_1 and xg_2





new: HERMES prelim., E155X

data at $\langle Q^2 \rangle$: 0.02-58 GeV^2

WHERE IS THE PROTON'S SPIN ?

Sum rule; Proton Spin = $\frac{1}{2} = L_q + \frac{1}{2}\Delta\Sigma + J_G$

Current value $\Delta\Sigma \sim 0.3$.

So is the remaining spin in orbital ang mom of quarks L_q or in gluons $J_G = \frac{1}{2}\Delta G$?

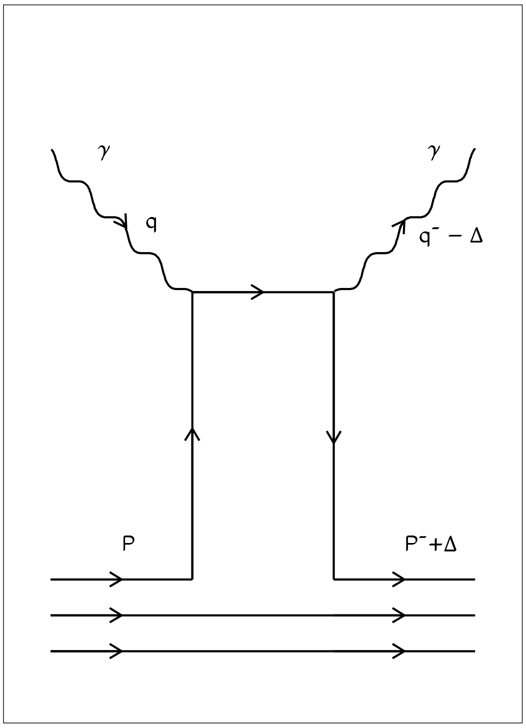
Many theoretical papers written some wanting the spin in L_q,some in ΔG.

What Can Experiment Tell Us ?

Deep Virtual Compton Scattering (DVCS) is sensitive to L_q

ΔG can be measured from the evolution in Q^2 of the structure function g_1 for proton and neutron and directly from dijet production.

DVCS is related to $J_q = L_q + \Delta\Sigma$ via the Ji sum rule.



New functions H, E,$\tilde{H}$,$\tilde{E}$

are related to J_q.

$$\int_{-1}^{1} dx\, xH(x,\xi,\Delta^2)+E(x,\xi,\Delta^2) = A(\Delta^2)+B(\Delta^2)$$

This gives $J_q = \frac{1}{2}(A_q(0) + B_q(0))$ at $\Delta^2 = 0$.(Ji)

Problems

1. Must measure Δ^2 dependence and extrapolate to zero.
2. BUT all measurables are complicated integrals over the $H, E, \tilde{H}$ and $\tilde{E}$.
3. Sum rule may be impossible to measure. Experimental program must be defined - people are trying to do it.

Current measurements of total cross sections (H1) and ϕ asymmetries (HERMES) exist.

Measurements of ΔG - Two Methods

Can be done by studying DGLAP type evolution of g_1 (Ball,Forte,Ridolfi at NLO) or by Measurement of Dijets.

SMC did such a fit and obtained at $Q^2 = 1$ GeV^2

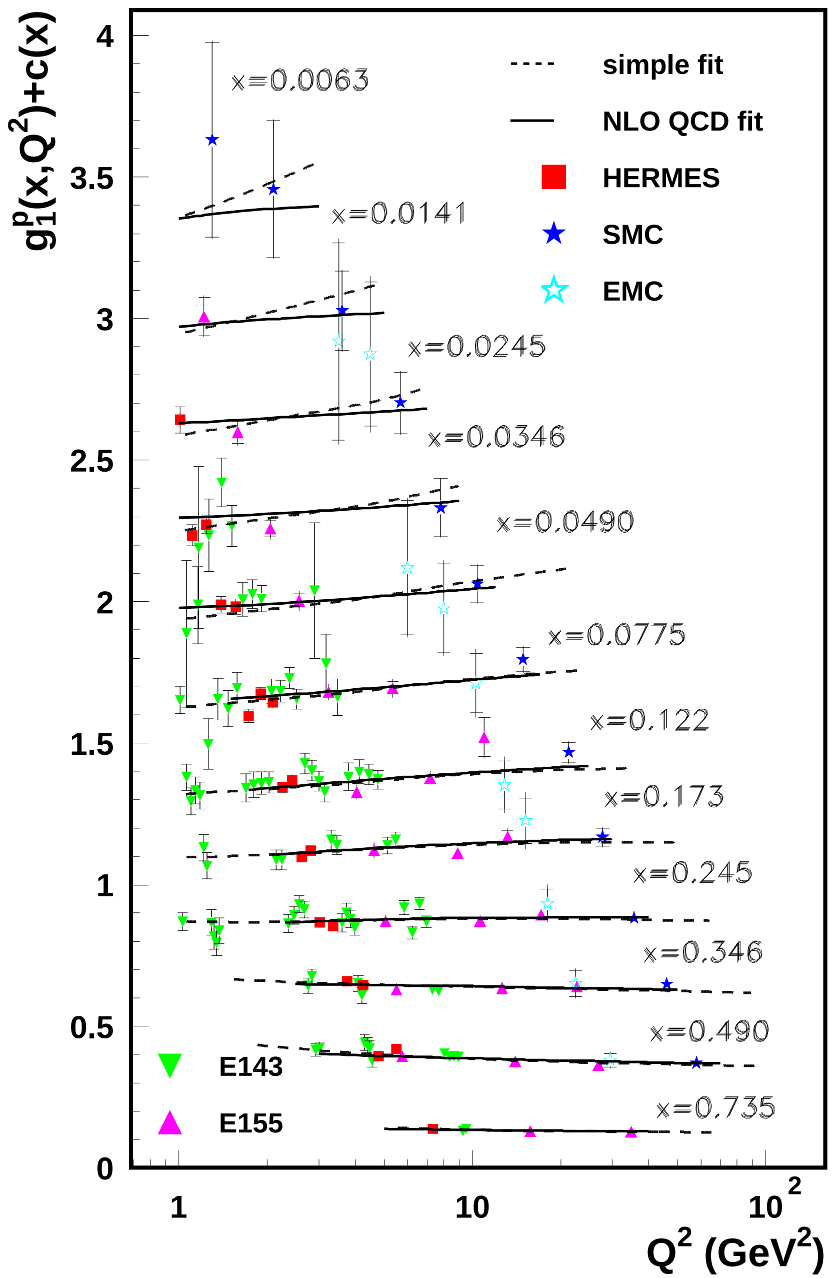
$\Delta G = 0.99^{+1.7}_{-0.31}$ (stat.) $^{+0.42}_{-0.22}$ (sys.) $^{+1.4}_{-0.45}$ (theory)

Largest SMC source of uncertainty is related to low x behaviour of g_1 (factors 2-3 improvement in this by HERA data).

Other sources come from

- Functional form of initial parton distribution functions
- Unknown factorization and renormalization scales

Q^2 Dependence of g_1^p



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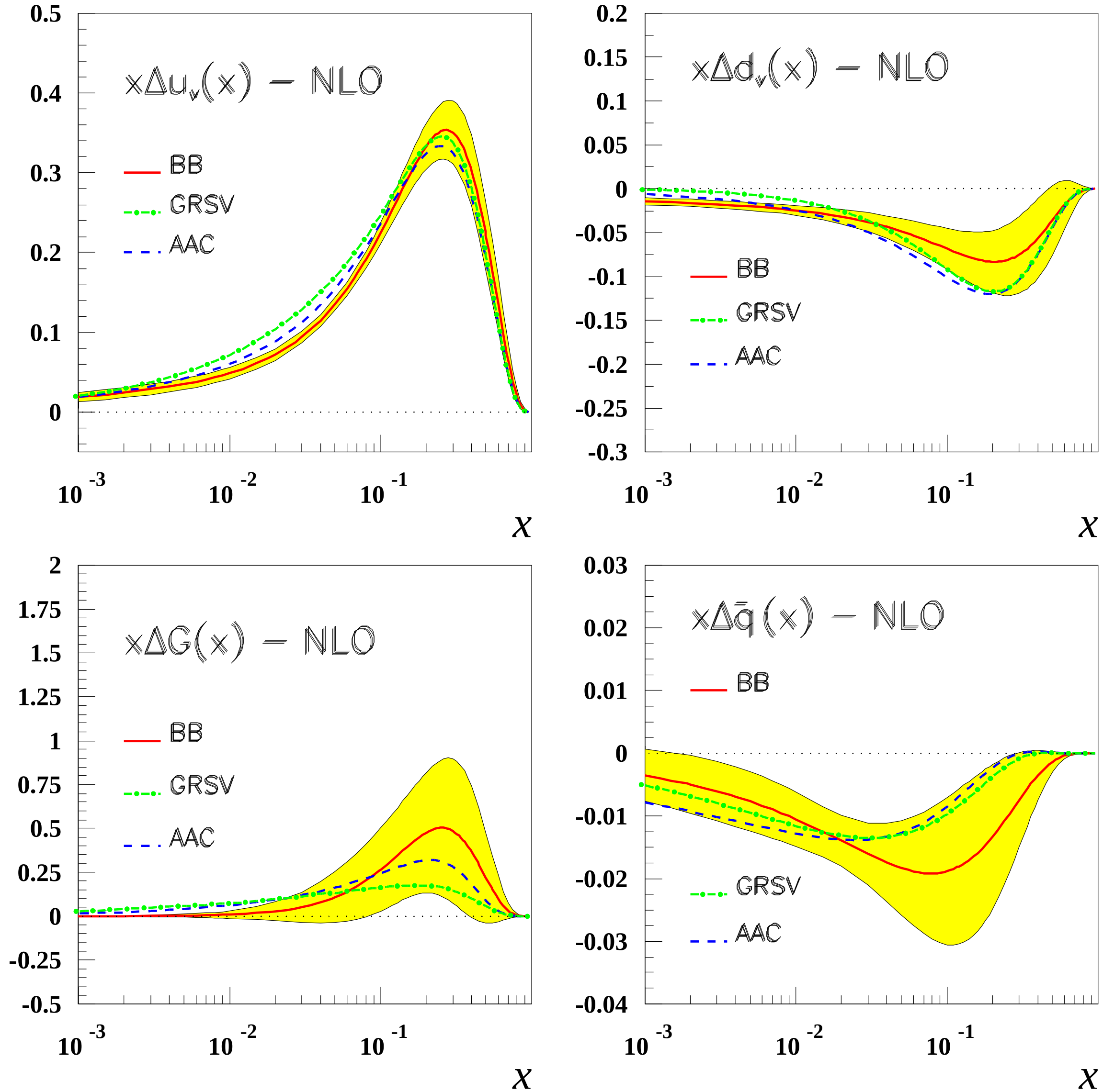
$\rightsquigarrow$ Q^2 dependence of g_1^p similar to the Q^2 dependence of F_1^p

NLO pQCD fit of $g_1^{p,d,n}$ data with $Q^2 > 1$ GeV^2

Fits to $g_1(x, Q^2)$ in NLO pQCD using SU(3)$_f$

updated NLO QCD ($\overline{\mathrm{MS}}$) fits at $Q^2 = 4$ GeV^2

NEW: propagated statistical uncertainties (yellow bands - BB)



BB: Blümlein, Böttcher, DIS2001

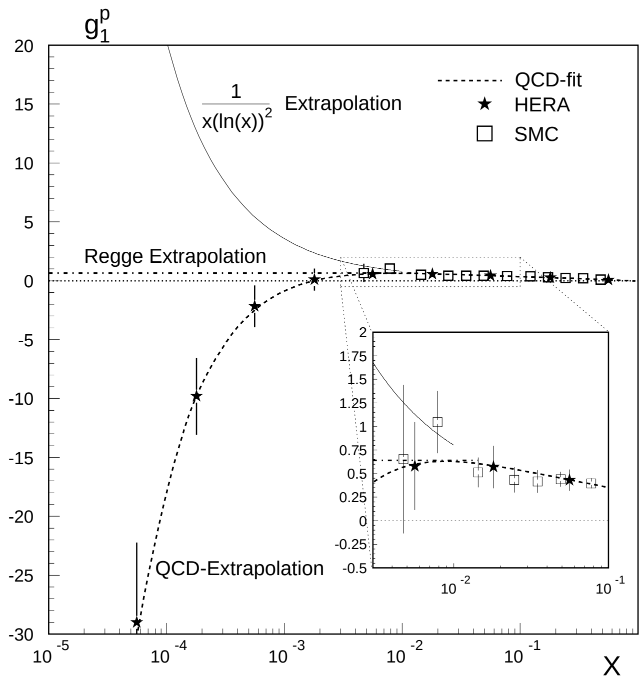
GRSV: Glück et al., hep-ph/0011215

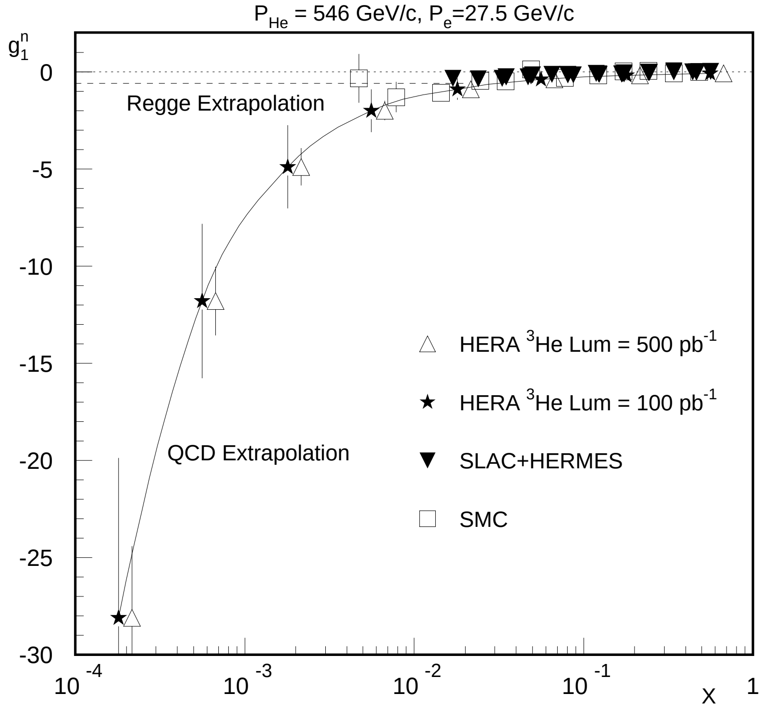
AAC: Goto et al., hep-ph/0001046

$\Rightarrow$ determination of $\alpha_s(\mathrm{M_Z^2}) = 0.114 \pm 0.005(\mathrm{stat})\,^{+0.009}_{-0.006}(\mathrm{scales})$ (BB)

MEASUREMENT OF g_1 AT HERA (to get ΔG).

g_1^p g_1^n





Curves for $Q^2 = 10$ GeV^2 500 pb^{-1} for p and 70$\%$ polarisation. ^{3}He assumed $p \uparrow p \downarrow n \uparrow$. Systematics $\lesssim$ statistics. NB Nucleon energy in $^3_2$He is 2/3 target, in $^2_1$H would be 1/2 target - compromises low x point.

Study different scenarios at small x IN A NEW KINEMATIC DOMAIN - i.e. discovery potential ! (EMC experience).

Asymmetries small ($\lesssim 10^{-3}$). Frequent polarisation changes needed OR half the bunches of $\uparrow$ and half $\downarrow$.

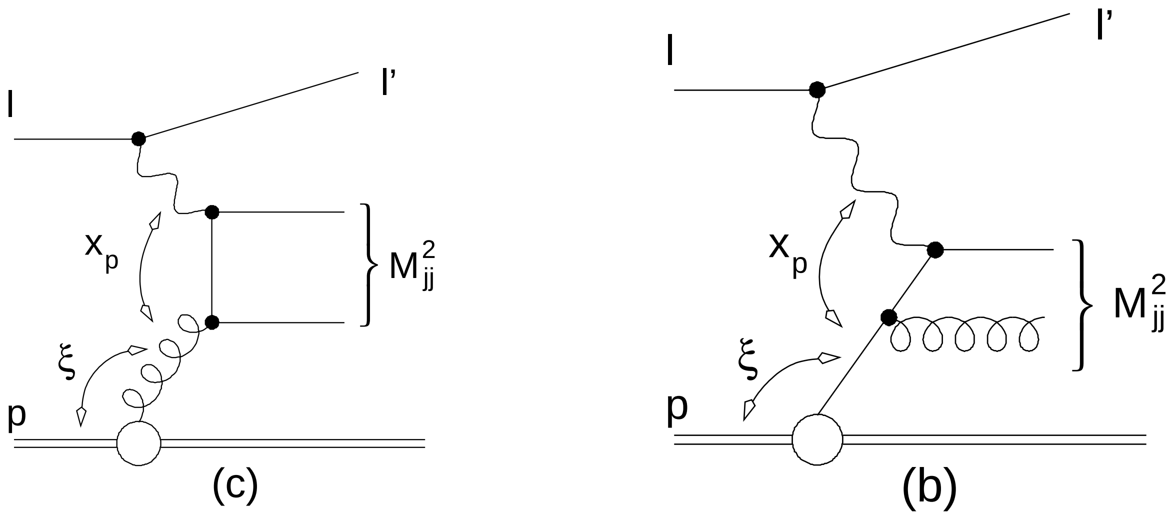
Possibility to do eA at the same time ?

1/3 bunches with $\uparrow$D 1/3 $\downarrow$D and 1/3 with ^{16}O.

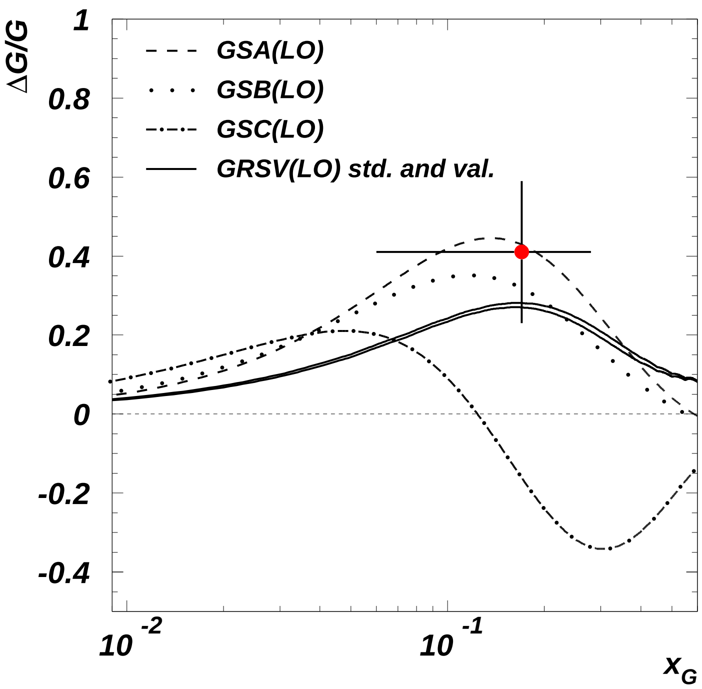
EXPERTS “Not Impossible !!” .

Direct measured of ΔG from DIJETS

Dijets come from boson-gluon fusion and QCD Compton Scattering. BGF sensitive to G but not QCDC.



First data from Hermes on asymmetries with 2 or more hadrons $p_t^{h1} > 1.5, p_t^{h2} > 0.5$ GeV.

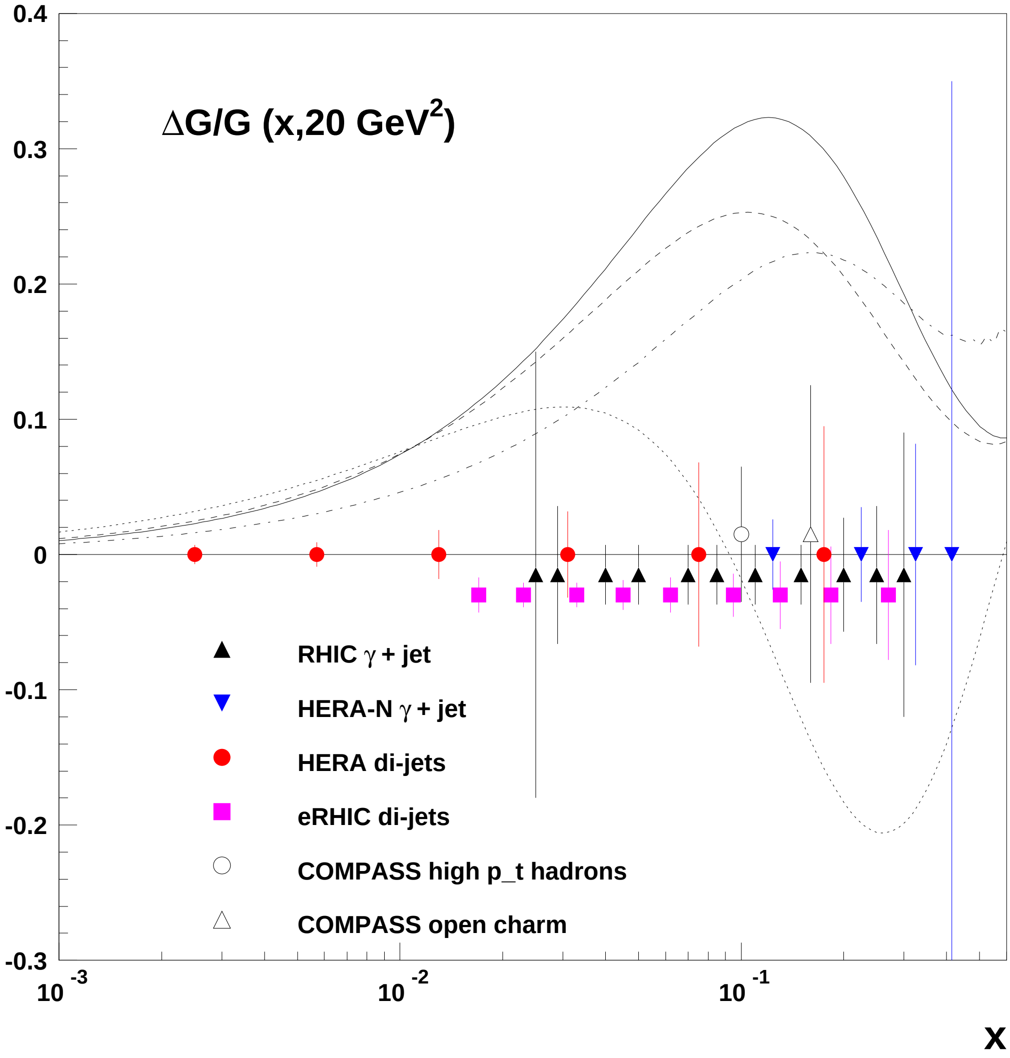


ΔG has expected sign. 1998-2000 data to come so that $\int_0^1 \Delta G dx$ should be measured.

Direct ΔG at HERA and other projects

Gaby Rädel, A. De Roeck

HERA 500 pb−1   eRHIC (EIC) 4 fb−1



large x range covered with HERA

ΔG from jets (high p_t hadrons)

large gluon contribution to p spin expected,

but large uncertainties of

$\int \Delta G(x)dx\ 1.0 \pm 0.3(stat) \pm 1.0(theory)$

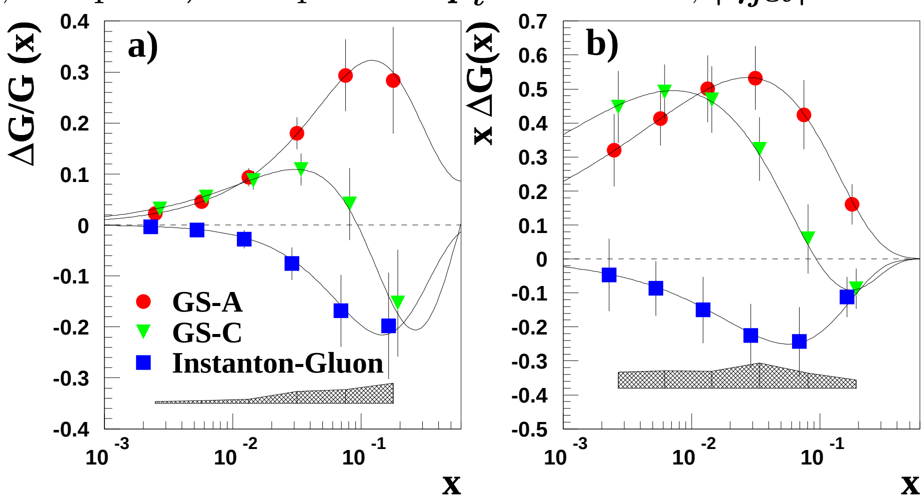
from present g_1 QCD analyses, due to lack of low x data

HERA would improve on this.

But direct measurements essential and possible:

Gaby Rädel, A. De Roeck

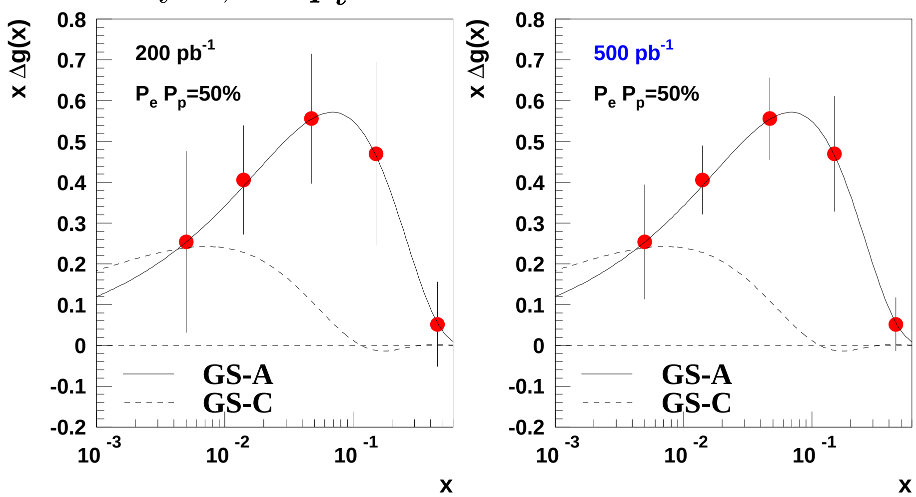
LO, 500 pb^{-1}, 70% pol. $\quad p_t^{jet} > 5$ GeV, $|\eta_{jet}| < 2.8$



(GS Gehrmann-Stirling, Instanton: Kochelev)

$\Rightarrow$ large x range covered $0.002 < x < 0.2$

NLO analysis, $\quad p_t^{jet} > 7$ GeV



SPIN PHYSICS IN CHARGED CURRENTS

Measure polarised asymmetries for charge current interactions with BOTH e^- and e^+.

$$A^{W^\mp} = \frac{d\sigma^{W^\mp}_{\uparrow\downarrow} - d\sigma^{W^\mp}_{\uparrow\uparrow}}{d\sigma^{W^\mp}_{\uparrow\downarrow} + d\sigma^{W^\mp}_{\uparrow\uparrow}} = \frac{\pm 2bg_1^{W^\mp} + ag_5^{W^\mp}}{aF_1^{W^\mp} + bF_3^{W^\mp}}$$

New structure functions appear which are sensitive to the quark spins - $g_5^{W^\mp}$ can be measured precisely (the kinematic factors work in our favour).

The kinematic factors are $a = 2(y^2 - 2y + 2)$ $b = y(2-y)$ NB $a >> b$ so the measured asymmetry

$$A^{W^\mp} \approx \frac{g_5^{W^\mp}}{F1^{W^\mp}}$$

where the structure functions are related to quark distributions in leading order by

$$g_5^{W^-} = \Delta u + \Delta c - \Delta\bar{d} - \Delta\bar{s}$$
$$g_5^{W^+} = \Delta d + \Delta s - \Delta\bar{u} - \Delta\bar{c}$$
$$F_1^{W^-} = u + c + \bar{d} + \bar{s}$$
$$F_1^{W^+} = d + s + \bar{u} + \bar{c}$$

CC asymmetries

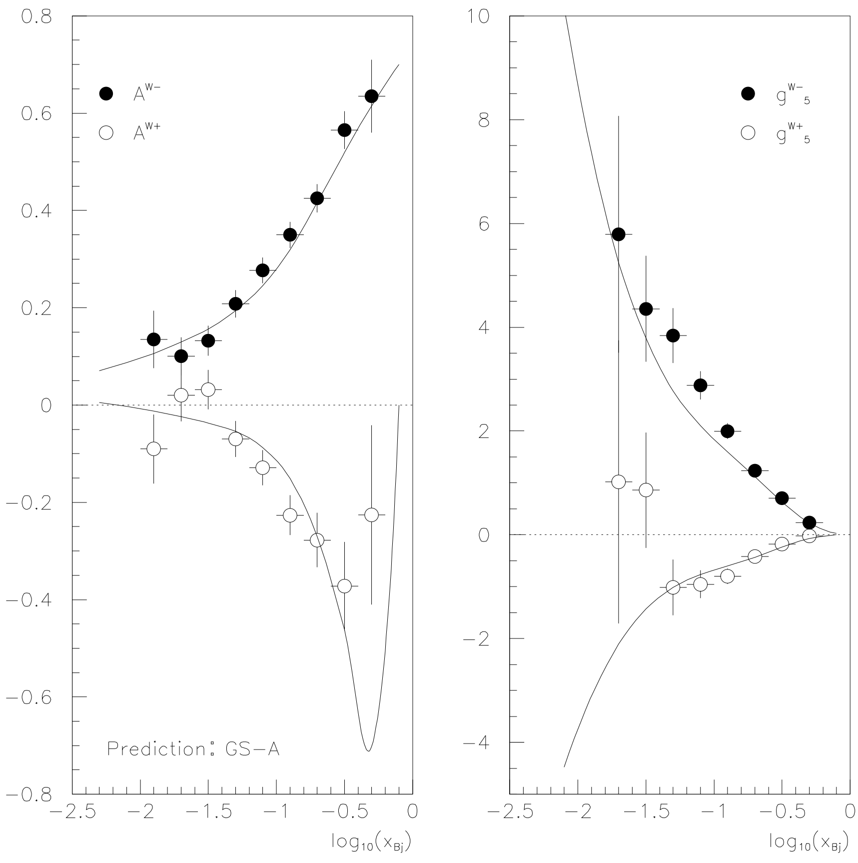
case $\vec{e}^-\vec{p} \rightarrow \nu_e X$:

$$g_5^{W^-} = \Delta u - \Delta\bar{d} + \Delta c - \Delta\bar{s}.... = \frac{1}{2x} g_4^{W^-}$$

case $\vec{e}^+\vec{p} \rightarrow \bar{\nu}_e X$:

$$g_5^{W^+} = -\Delta\bar{u} + \Delta d - \Delta\bar{c} + \Delta s.... = \frac{1}{2x} g_4^{W^+}$$

Contreras et al. DESY-proc 98-01

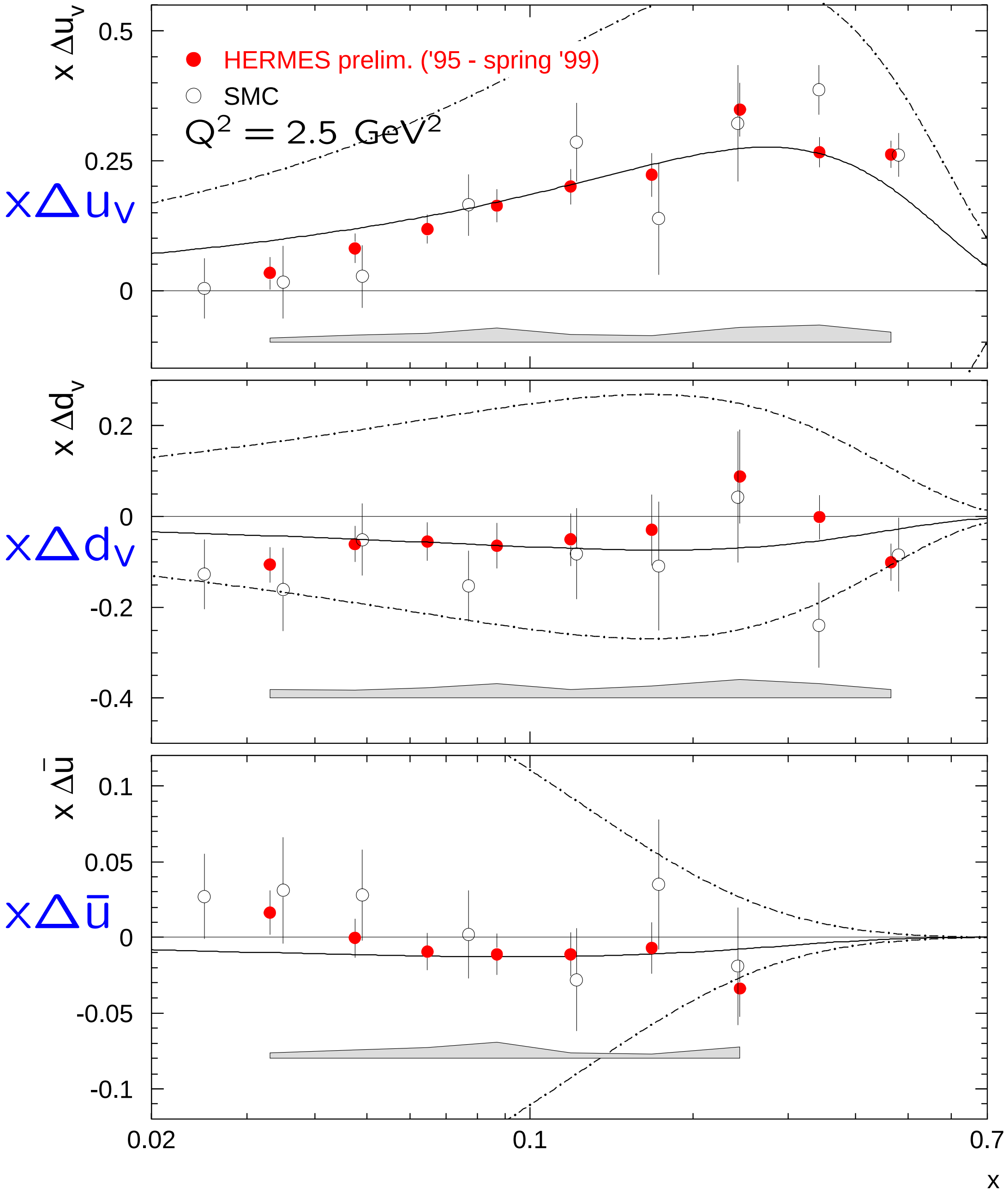


500 pb^{-1}

displacements due to detector effects

measurement looks very significant

Polarized Quark Distributions (LO)



flavour tagging:

$A_1(h^{\pm})$ on proton dominated by $\Delta u(x)$

$A_1(h^{\pm})$ on neutron dominated by $\Delta d(x)$

sensitivity to $\Delta\bar{u}$ and $\Delta\bar{d}$ $\lesssim$ 10% at $x < 0.2$

$\Delta\Sigma = 0.30 \pm 0.04 \pm 0.09$

[HERMES, PLB464(99)123]

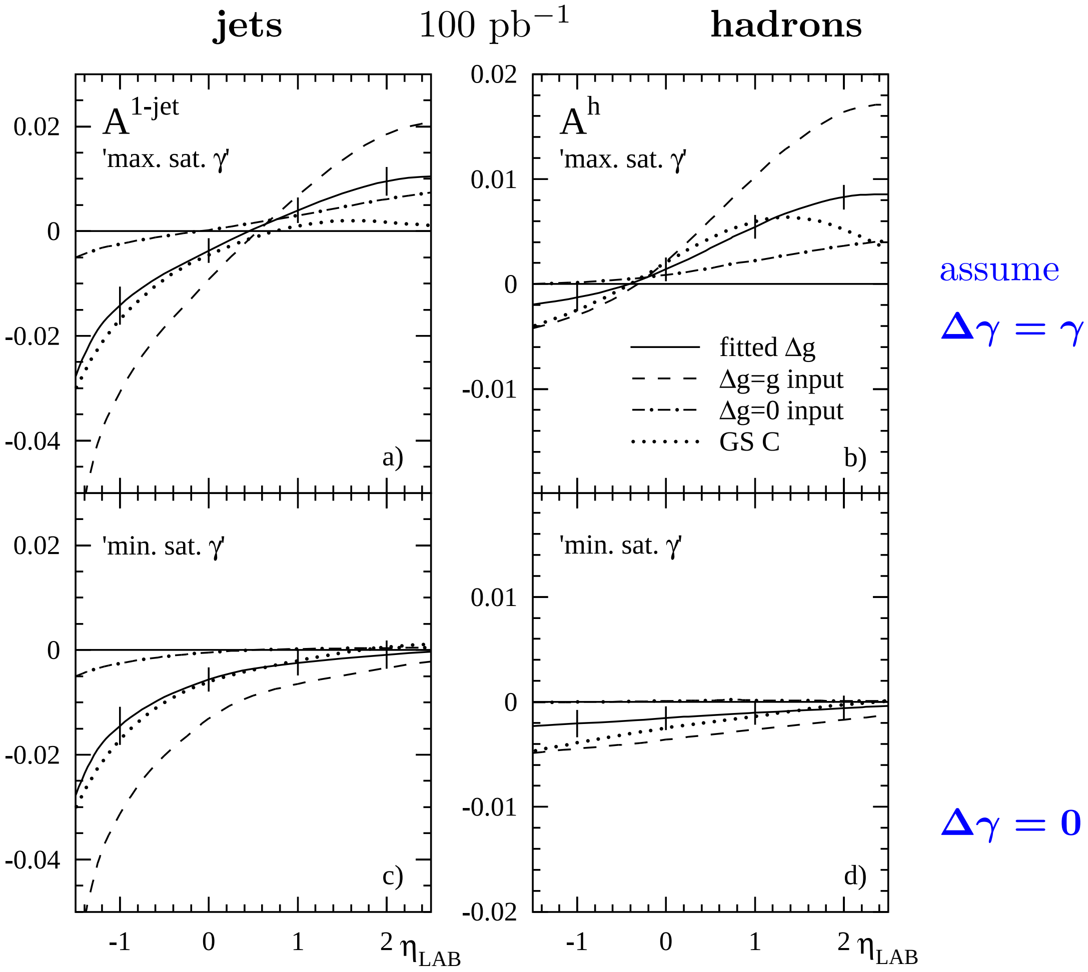
polarized quark sea not yet separated

solid lines: GSA LO
dashed lines: positivity limits
bands: HERMES syst. uncertainty

Photoproduction

asymmetries in jet or hadron production sensitive to ΔG,
but also to resolved photon structure $\Delta\gamma$

DESY proc 98-01 Butterworth et al.



very sensitive (stat. errors) to different scenarios for ΔG and $\Delta\gamma$

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also possible to measure Drell-Hearn-Gerasimov sum rule at high energies.

ADVANTAGE of DEUTERONS IN HERA.

Deuterons allow simultaneous measurement from proton (neutron) targets by tagging spectator neutron (proton).

Avoids the dilution from unpolarised nucleons. BUT need EFFICIENT tagging.

Physics with Deuterons is also interesting in its own right. since it allows the structure function of the neutron to be studied. i.e. the parton distribution functions of the neutron can be measured. and the detailed QCD studies already made on the proton to be extended to the neutron.

Allows a low energy run of HERA i.e. a direct measurement of F_L since the target protons and neutrons each have half of beam momentum (NB shadowing corrections).

Deuteron Targets are vital to study eA collisions in HERA. Deuteron is almost unbound (binding energy 2.2 MeV compared to 8 MeV average for bound nucleons). So deuteron represents an “average free” nucleon.

Physics with Unpolarised Deuterons - e.g start up.

QCD fits are better constrained - $F_2^p - F_2^n$ is a non-singlet structure function - reduces error on measurement of α_s . (Botje,Klein,Pascaud Future Physics at HERA page 40).

Comparison of charged and neutral currents allows $s - c$ to be measured with good accuracy - further constraining the QCD fits. (Blümlein,Klein Physics at HERA 1991 p. 107).

In NC interactions from a deuteron

$$F_2^N = \frac{(F_2^p + F_2^n)}{2} = \frac{5}{18}\Sigma - \frac{1}{6}x(s + \bar{s} - c - \bar{c})$$

where $\Sigma = u + \bar{u} + d + \bar{d} + s + \bar{s} + c + \bar{c}$ and

$$F_2^p = x\big(4/9(u+\bar{u}) + 1/9(d+\bar{d}) + 1/9(s+\bar{s}) + 4/9(c+\bar{c})\big)$$

$$F_2^n = x\big(4/9(d+\bar{d}) + 1/9(u+\bar{u}) + 1/9(s+\bar{s}) + 4/9(c+\bar{c})\big)$$

In charged current interactions

$$\frac{d^2\sigma^\pm}{dxdQ^2} = A(Y_+ W_2^\pm \mp Y_- x W_3^\pm) \text{ with } W_2^\pm = \Sigma$$

So that measuring $W_2^\pm$ from difference between e^+ and e^- in CC interactions and F_2^N in NC interactions

$$(s + \bar{s}) - (c + \bar{c}) = 6\big(\tfrac{5}{18}W_2^\pm - F_2^N\big)$$

Insert transparency showing Levman plot here (it refuses to dvips). This is a separate ps file sloantran20.ps

Insert transparency showing Badelek Kwiecinski plot here (it refuses to dvips). This is a separate ps file sloantran21.ps

Disadvantage of Deuterons

Nucleons have half the energy compared to running with protons in HERA. This may compromise the low x point.

Deuteron corrections (e.g.$\sim 5\%$ D state) are well undertood - SMC used D and HERMES D and ${}^{3}_{2}$He - nevertheless corrections are necessary.

Shadowing corrections need to be measured and these could compromise a low energy run.

CONCLUSIONS

Interesting physics comes from unpolarised deuterons in HERA. Polarised nucleons are even more interesting.

An understanding of the spin of the nucleon needs L_q (from DVCS, but how ?) and ΔG - HERA can contribute significantly.

Better measurement of ΔG

by Q^2 evolution - both experiment and theory errors will be reduced by a factor ~ 2 by HERA data.

by dijet production - gives a somewhat lower experimental error but theory error is uncertain. Need measurements from the complementary experiments HERA, COMPASS, HERMES and RHIC to understand the theory error on ΔG.

Excellent measurements of Δq become possible by measurements of asymmetries in charged current interactions.

First measurements of the quark and gluon contributions to the spin of the photon become possible.

Polarised high Q^2, CC interactions and the photon spin content means HERA is entering a new domain - discovery potential.