g_1 and ΔG at a future pEIC

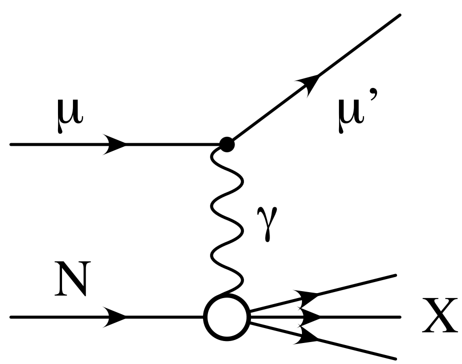
Ernst Sichtermann
Lawrence Berkeley National Laboratory

In collaboration with Abhay Deshpande, Jechiel Lichtenstadt, and others

2nd EIC workshop at JLab, March 15-17, 2004.

Introduction/Motivation

The setting is, of course, deep-inelastic scattering:



with the usual kinematic variables,

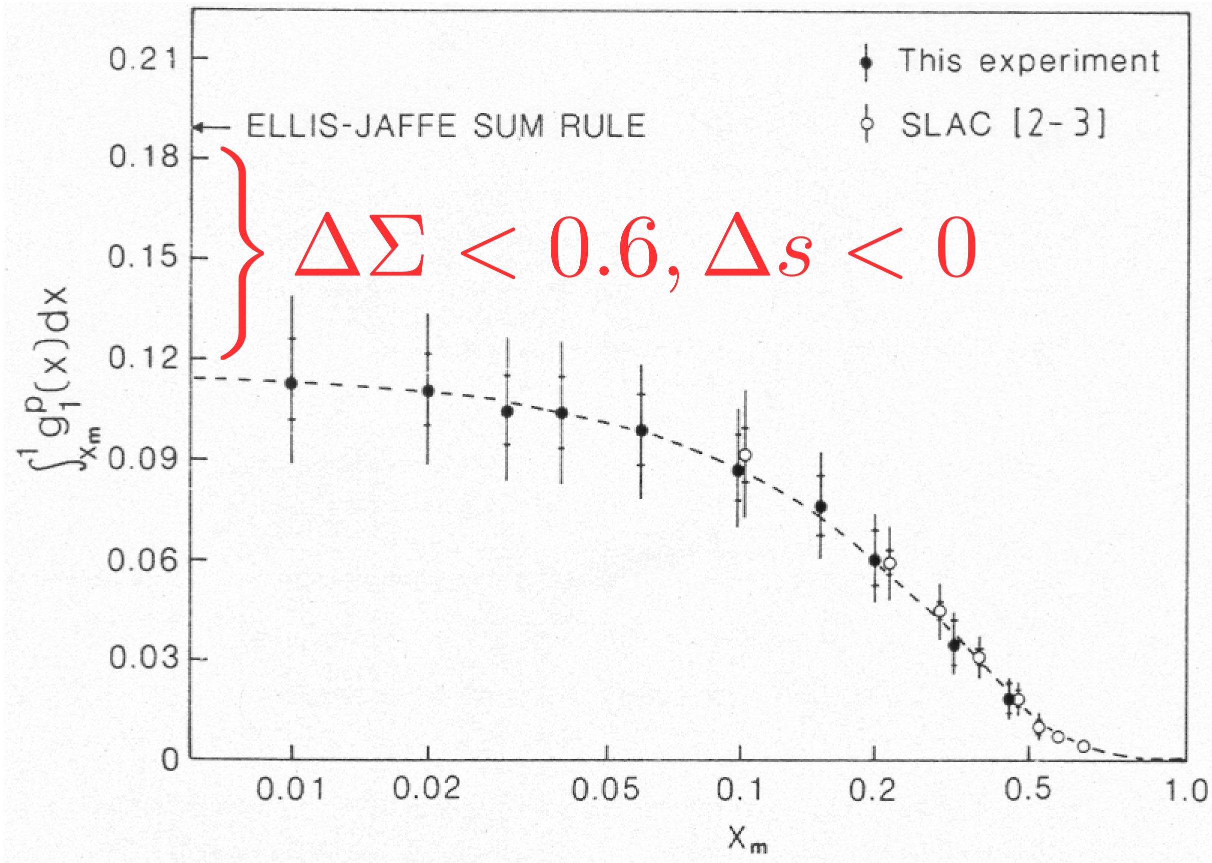
$$Q^2 = -q^2, \qquad x = \frac{-q^2}{2P \cdot q}, \qquad y = \frac{P.q}{P.p}$$

The spin structure function g_1 is the analogon of the \`usual' (spin-averaged) structure function F_2.

Important differences are:

- measurement as an asymmetry $A_1 \sim g_1/F_1$
- need for absolute polarization measurements
- depolarization of the photon $D \sim y$

SURPRISE when first measured *over an extended kinematic range:*

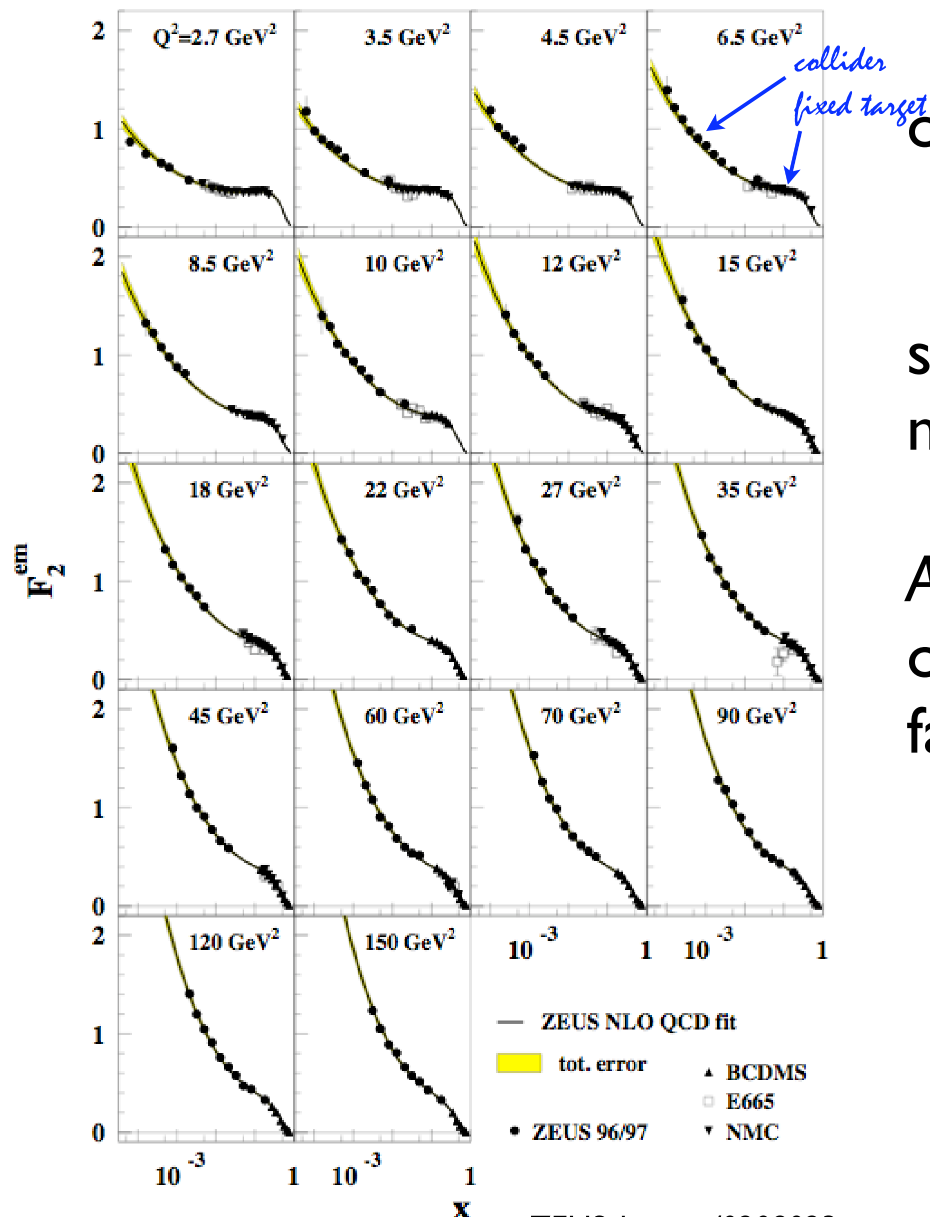


EMC: J.Ashman et al, Nucl. Phys. B328, 1 (1989)

The surprise persists (data confirmed) with important caveats:

- the unmeasured region at small x?
- the role of gluon polarization and angular momenta,
- remaining assumptions on quark-flavor symmetry.

The rise of the spin-averaged structure function at HERA:



ZEUS: hep-ex/0208023

occurs in the collider regime,

$$x < 10^{-3}, \quad Q^2 > 3\,\mathrm{GeV}$$

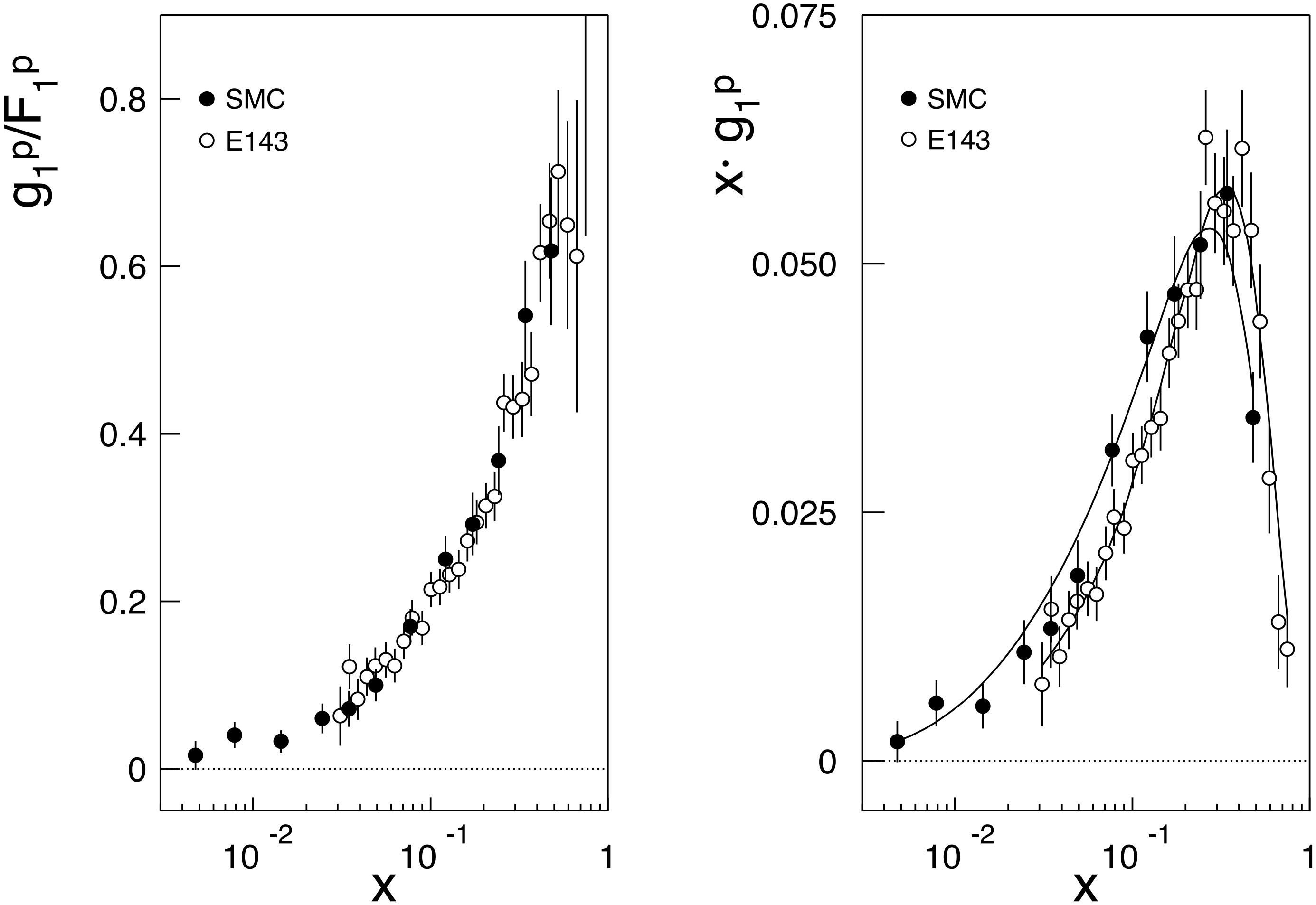
so far *inaccessible* to spin measurements.

Assumptions on extrapolation over this region should at least face the question:

At what scale Q^2*?*

Note that 4+ bins per decade in x or scale is common-place in spin-averaged measurements.

Violations of Bjorken scaling,



are *non-negligible* at the present uncertainty in spin-measurements. That is, the covered kinematic region is measured with fair *inclusive* precision.

Extrapolations over the unmeasured region cause the limiting uncertainties in the (first) moments,

SMC: PRD58 (1998):

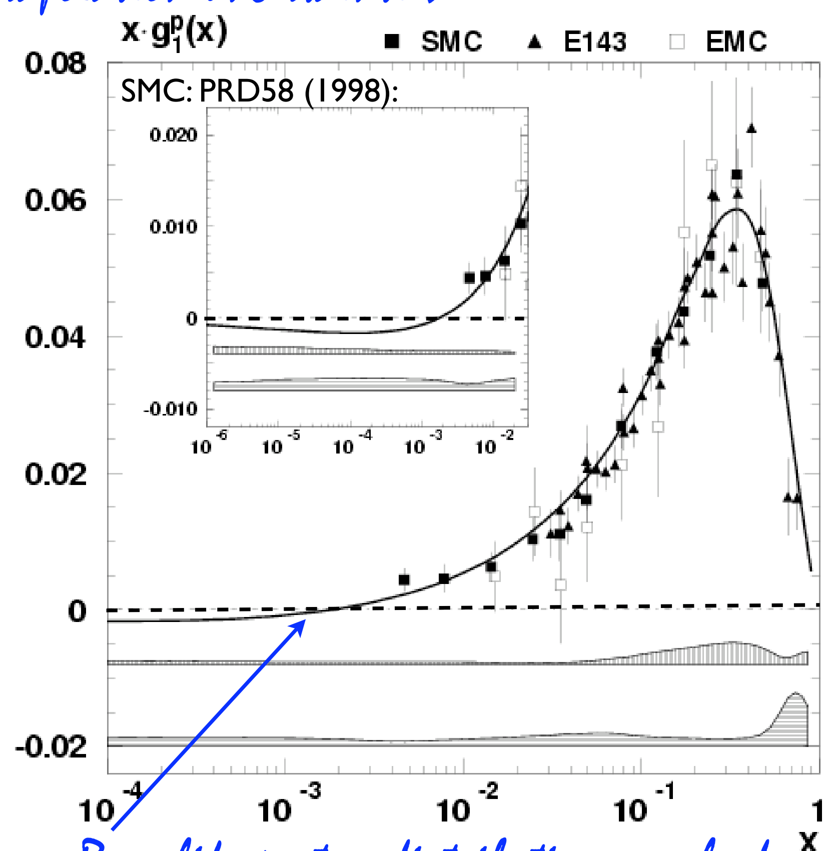
$\Gamma_1(Q_0^2)$	World $Q_0^2 = 5\ \mathrm{GeV}^2$
Proton	$0.121 \pm 0.003 \pm 0.005 \pm 0.017$
Deuteron	$0.021 \pm 0.004 \pm 0.003 \pm 0.016$
Neutron	$-0.075 \pm 0.007 \pm 0.005 \pm 0.019$

extrapolation uncertainties

statistics and systematics of the measured range

in part because of scale uncertainties.

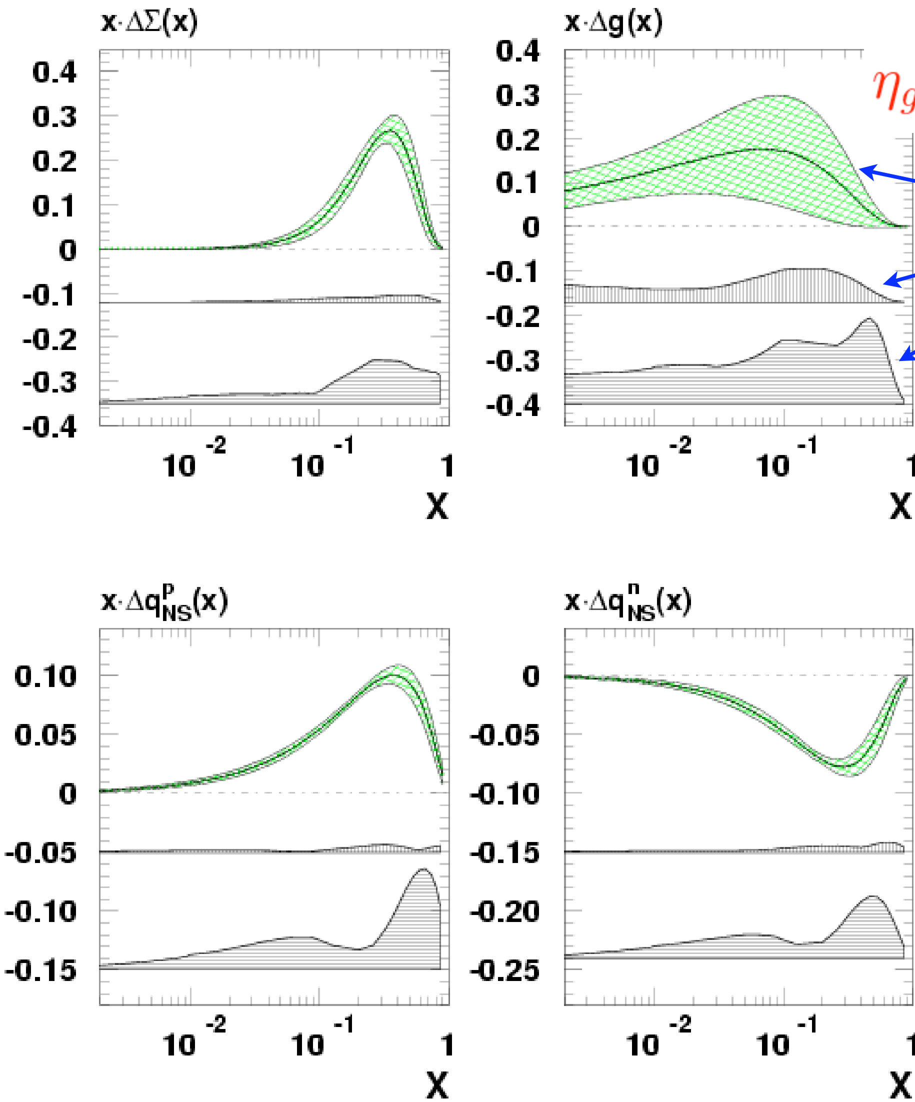
And, of course, model uncertainty exists as well (at least at the modest scales accessible to experiment).



Regge-like parton distributions, evolved from their (assumed) initial scale of 1 GeV^2 to a scale of 10 GeV^2

Gluons and small-x go together. The extrapolation uncertainties in spin reflect mostly on inadequate knowledge of the gluon helicity:

$$\eta_g = 0.99 \,{}^{+1.17}_{-0.31}\,(\mathrm{sta}) \,{}^{+0.42}_{-0.22}\,(\mathrm{sys}) \,{}^{+1.43}_{-0.45}\,(\mathrm{th})$$



SMC: PRD58 (1998)

Onto some detail of this (the SMC pQCD) analysis...

Features of the SMC pQCD analysis (~1998):

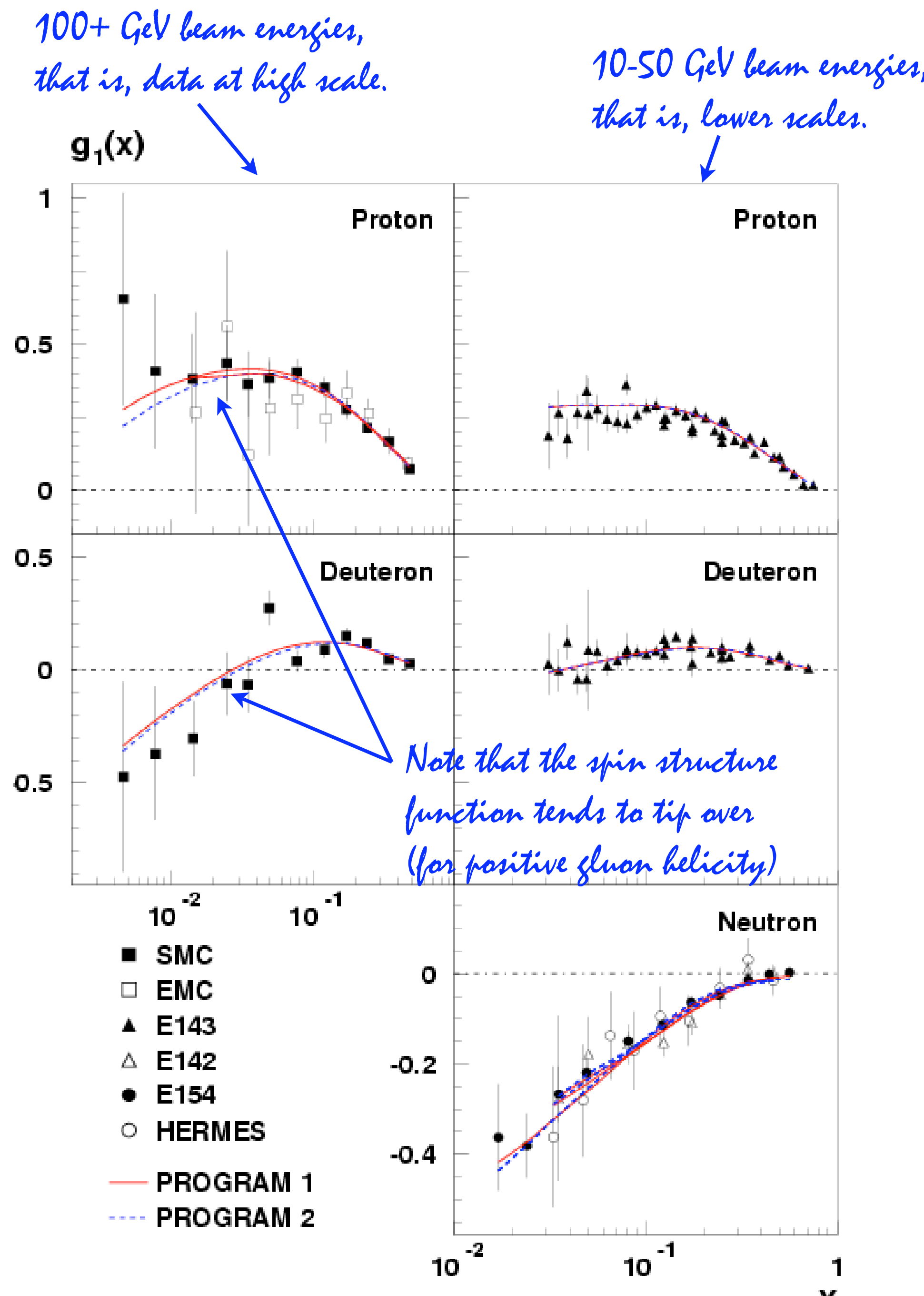
- DGLAP evolution,
- helicity pdfs of the form:

$$\Delta f(x) = \eta \cdot x^{\alpha} \cdot (1-x)^{\beta} \cdot (1 + Ax + \rho\sqrt{x})$$

  for gluon, singlet quark, and p,n non-singlet quark helicity distributions,
- main results in the AB scheme

$$\Delta\Sigma_{\overline{\rm MS}}(Q^2) = \Delta\Sigma_{\rm AB} - n_f \frac{\alpha(Q^2)}{2\pi} \Delta g(Q^2)$$

- initial scale $Q^2 = 1\,\mathrm{GeV}^2$ for most results
- good description of existing data, $\chi^2 = 126/(133-9)$
- a fairly complete set of tests, checks, and uncertainty estimates.



SMC: PRD58 (1998)

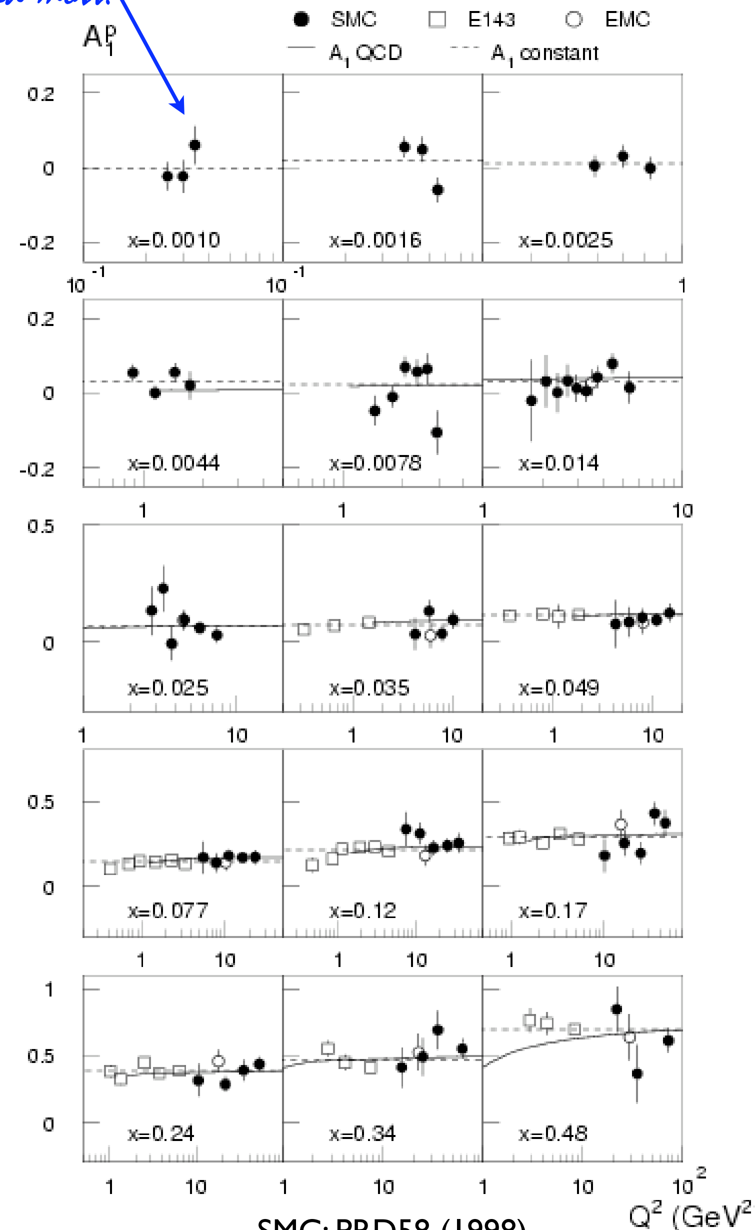
Features of the SMC pQCD analysis (~1998):

$$\Delta g(x) = \eta_g \; x^{\alpha} \cdot (1-x)^4$$

eta positive, alpha negative, correlation negative with a corr. coefficient of 0.85.

	I	$I_{\overline{MS}}$
$\tilde{\chi}^2$	126	123
n_{data}	133	133
n_{par}	9	10
$\tilde{p}$ [%]	43	50
η_Σ	0.38 ± 0.03	0.19 ± 0.05
α_Σ	1.20 ± 0.28	-0.48 ± 0.10
β_Σ	4.08 ± 0.60	3.29 ± 0.37
A_Σ	–	-13.8 ± 1.4
η_g	0.99 ± 0.43	0.25 ± 0.24
α_g	-0.70 ± 0.21	0.33 ± 1.27
α^p_{NS}	-0.15 ± 0.08	-0.19 ± 0.08
β^p_{NS}	1.42 ± 0.22	1.35 ± 0.21
A^p_{NS}	–	–
α^n_{NS}	0.01 ± 0.12	0.06 ± 0.14
β^n_{NS}	2.48 ± 0.48	2.59 ± 0.50
norm.	–	–

Note that there is basically no lever arm in Q^2 at small x, that is, the scale dependence is constrained least where it is needed most.



SMC: PRD58 (1998)

1998 is not 2004:

- new data, in particular from E155 (~50 GeV beam):
  - E155 deuteron improves the 'attitude' of existing data
  - proton data needs a normalization (target pol.), and
  - a slightly modified functional form for the non singlet proton,

Trade off large-x beta parameter for detail (A) at intermediate x

$$\Delta q^{\rm NS} = \eta^{\rm NS}\left(\frac{g_A}{g_V}, \frac{F}{D}\right) \quad x^{\alpha} \cdot (1 + Ax) \cdot (1 - x)^4$$

- *minimal*, if any, improvement in the *statistical* uncertainty in gluon helicity parameters

Expected future *inclusive* data from, say, COMPASS is not expected to cause significant improvement in the gluon helicity parameters either.

1998 is not 2004 (continued):

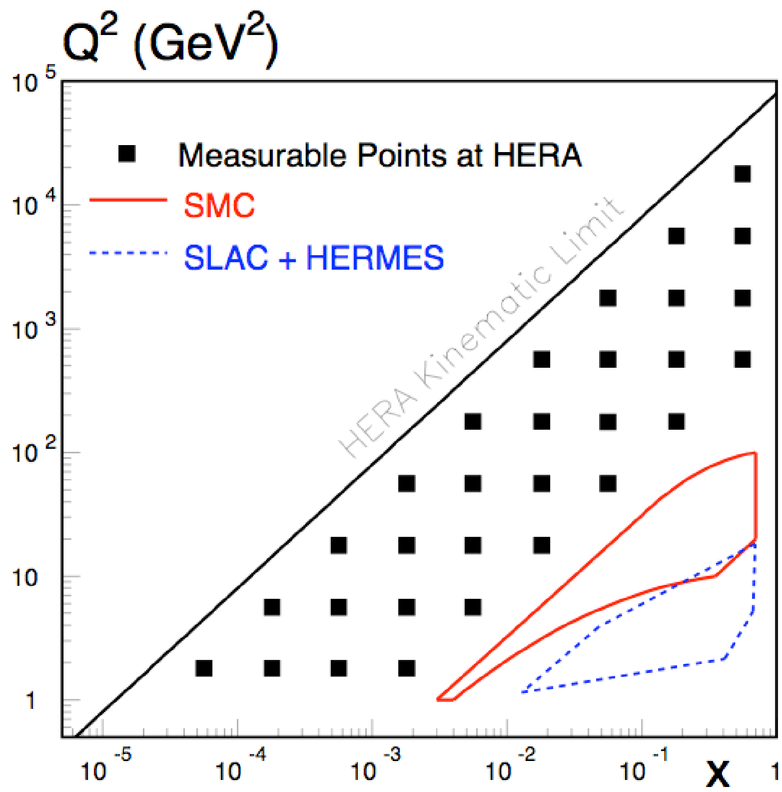
	G	G^{x2}	$G_{\overline{MS}}$	$G^{x2}_{\overline{MS}}$
$\tilde{\chi}^2$	213	213	208	210
n_{data}	185	185	185	185
n_{par}	10	10	11	11
$\tilde{p}$ [%]	3	3	4	4
η_Σ	0.39 ± 0.02	0.39 ± 0.02	0.20 ± 0.03	0.20 ± 0.03
α_Σ	1.60 ± 0.18	1.59 ± 0.20	-0.34 ± 0.08	-0.37 ± 0.07
β_Σ	3.79 ± 0.32	3.81 ± 0.34	2.71 ± 0.20	2.67 ± 0.16
A_Σ	–	–	-10.6 ± 0.9	-10.7 ± 0.9
η_g	1.07 ± 0.62	1.15 ± 0.61	0.53 ± 0.17	0.52 ± 0.16
α_g	-0.78 ± 0.17	-0.79 ± 0.16	1.87 ± 0.97	1.41 ± 0.82
α^p_{NS}	-0.59 ± 0.08	-0.58 ± 0.08	-0.52 ± 0.09	-0.49 ± 0.05
A^p_{NS}	20.1 ± 7.8	18.5 ± 7.2	16.8 ± 6.6	15.9 ± 5.9
α^n_{NS}	-0.07 ± 0.10	-0.06 ± 0.10	-0.08 ± 0.10	-0.08 ± 0.10
β^n_{NS}	1.81 ± 0.34	1.83 ± 0.35	1.88 ± 0.36	1.91 ± 0.35
norm.	1.08 ± 0.02	1.08 ± 0.02	1.10 ± 0.02	1.10 ± 0.02

Inclusion of COMPASS like inclusive data makes little difference for the gluon helicities; the inclusive fixed target era has ended.

However, 2004 is not 2012-2020 either. *Combined* analyses, including e.g. (future) RHIC polarized pp data (0.01 < x < 0.1), are only starting.

How well may a future collider do?

Most studies with reasonable first detail have focussed on polarized HERA so far.



Note the fairly coarse binning; this turned out to be a tedious aspect in making estaimtes for EIC.

General scheme:

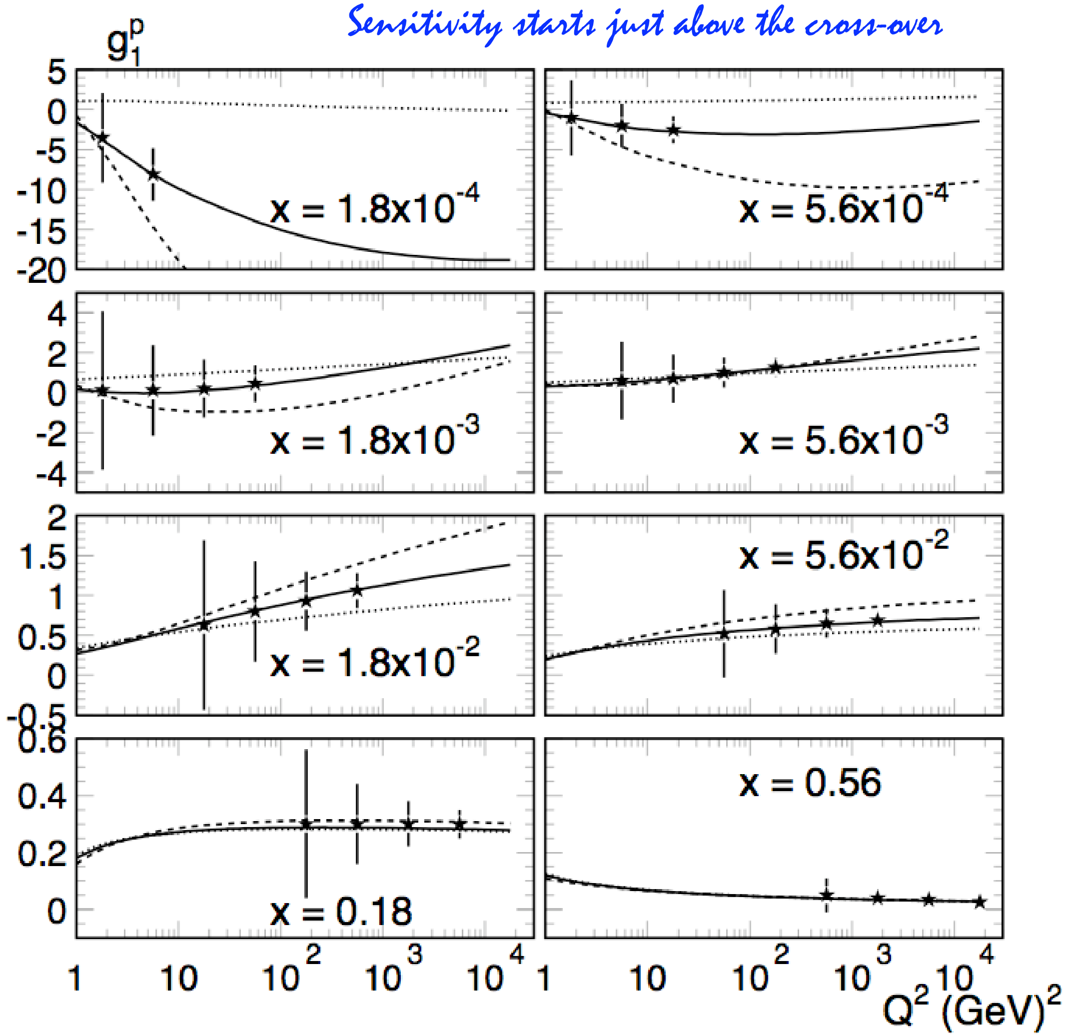
Extrapolate the pQCD pdfs into the unmeasured x-range, and evolve them to the corresponding scales Q^2

Estimate the expected precision on the spin observables (asymmetries), taking into account the detector acceptance, beam polarizations, depolarization, etc.

Refit the existing data, adding artificial polarized data to estimate the expected squeeze of uncertainties.

Anticipate systematics, experimental and theoretical.

Sensitivity starts just above the cross-over



A De Roeck et al, Eur.Phys.J.C6:121-131 (1999).

EIC expected improvement in statistical uncertainty on ΔG with $\mathcal{L} = 100\,\mathrm{pb}^{-1}$ analyzed data:

~3 5 on 250 GeV
~4 10 on 250 GeV
~7 20 on 250 GeV

with respect to the present uncertainty of ~0.5

- better knowledge of the gluon helicity is feasible, both in terms of normalization and - with high beam energies - in coverage.