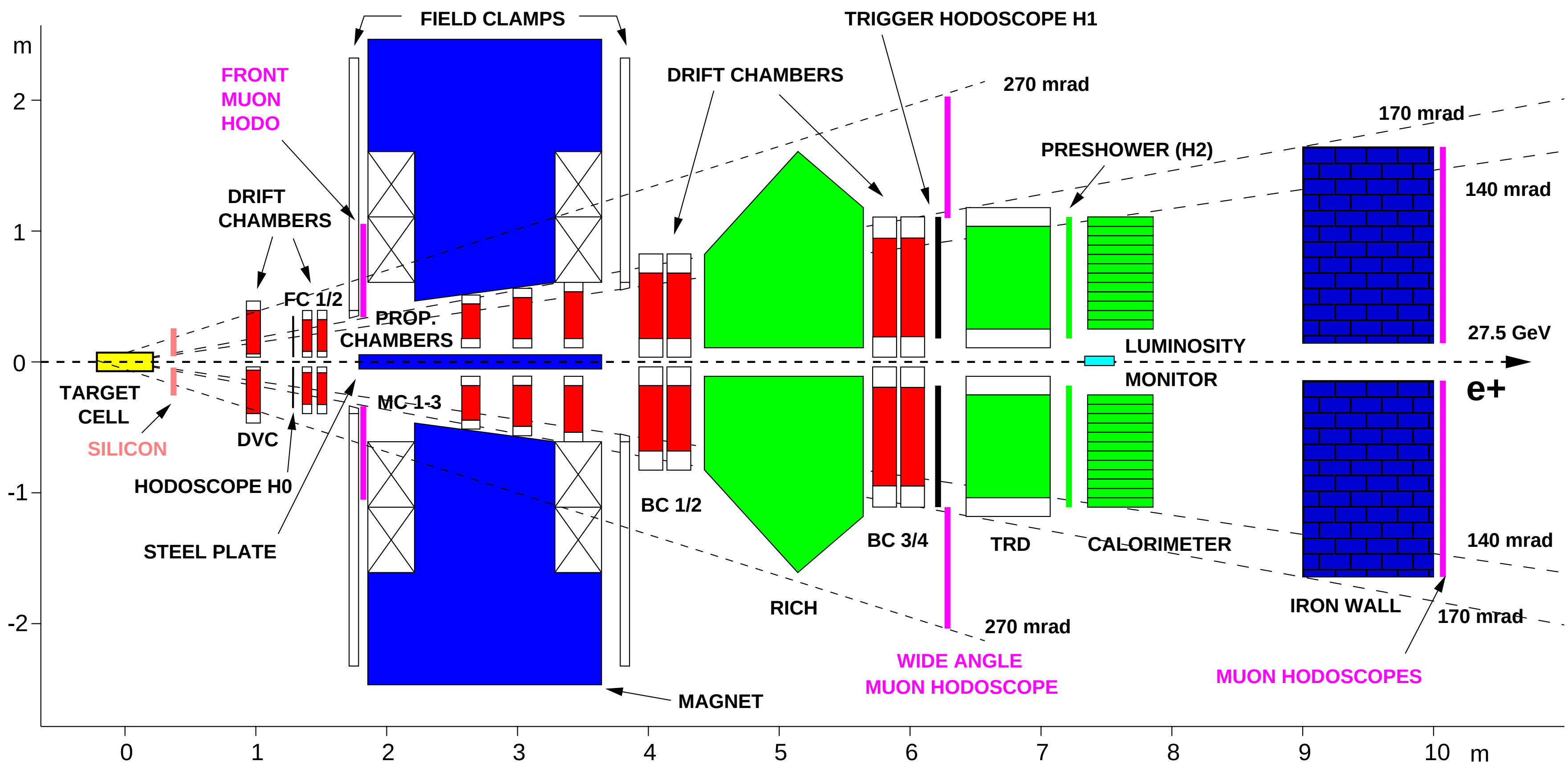
Measurement of the structure function g_1^d at HERMES and extraction of polarized parton distributions

Lara De Nardo

- ⋆ Measurement of g_1^d
  - ⋆ Systematic studies
- ⋆ Fits to g_1 world data

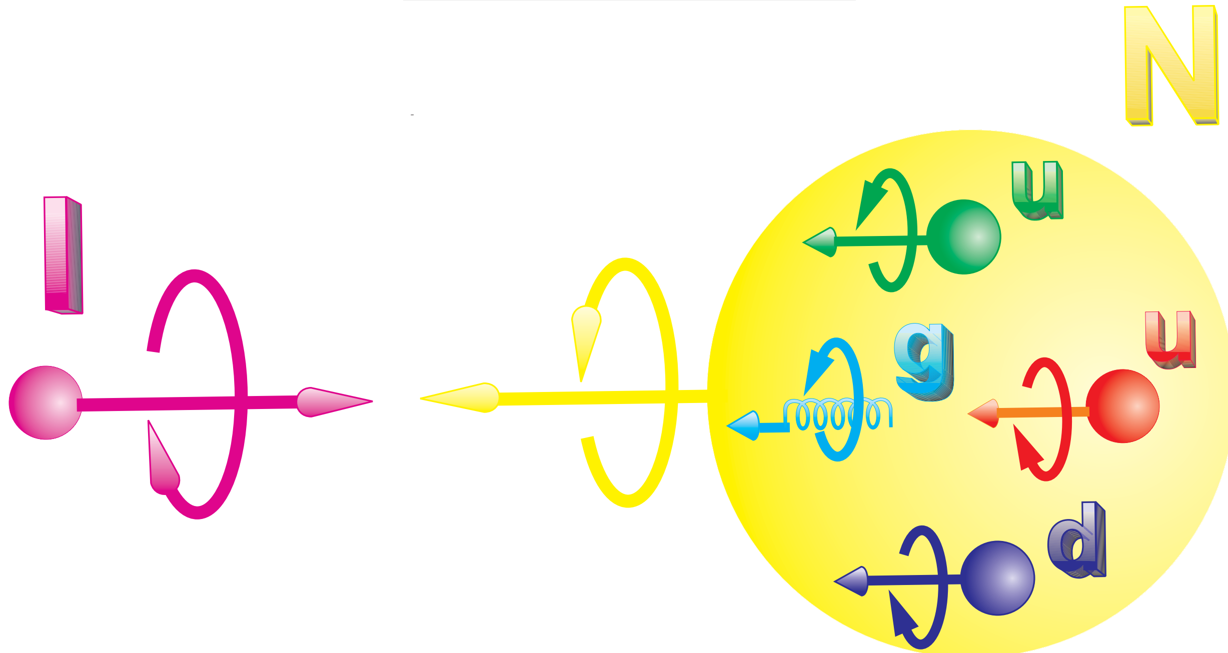
The HERMES Spectrometer



The HERMES experiment is located in the east section of the HERA accelerator ring.

The primary goal of HERMES is the study of the Spin Structure of the nucleons (protons and neutrons) and the contributions from the various fields ($\Delta\Sigma$, Δu, Δd, Δs, ΔG).

The nucleon's SPIN

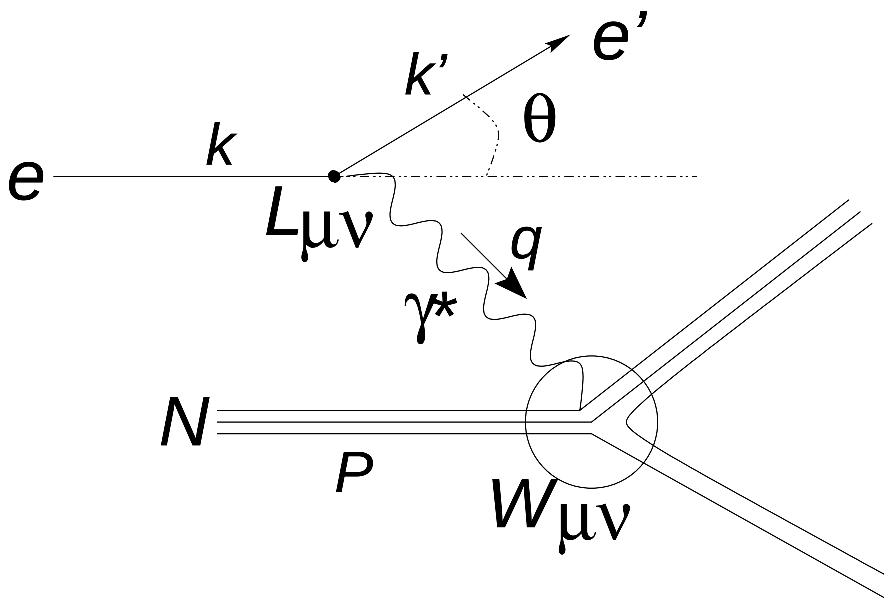


The EMC experiment at CERN discovered, in the late 80's, that the spin carried by the quarks is very small $\rightsquigarrow$ spin crisis

The nucleon's spin is probed with the scattering of polarized pointlike leptons off polarized nucleons in deep inelastic scattering

$$\frac{1}{2} = \frac{1}{2} \overbrace{\Delta\Sigma}^{HERMES} + \overbrace{\Delta G}^{HERMES} + L_q + L_G$$

Deep Inelastic Scattering



$Q^2 = 4EE' \sin^2\left(\frac{\theta}{2}\right)$ 4-momentum transfer

$x = Q^2/(2M\nu)$ momentum fraction carried by the struck parton

$y = (E - E')/E$ fraction of momentum transfer

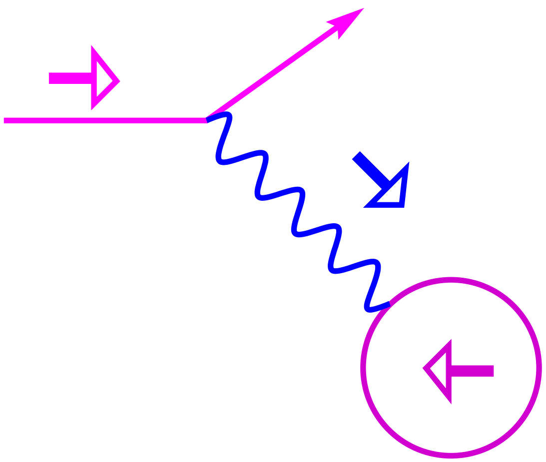
$$\frac{d^2\sigma}{d\Omega d\theta} = \frac{\alpha^2}{2M_p Q^4}\frac{E'}{E}\mathbf{L}_{\mu\nu}\mathbf{W}^{\mu\nu}$$

$$\mathbf{L}_{\mu\nu} = 2\left[k_\mu k'_\nu + k_\nu k'_\mu - (k\cdot k' - m_e^2)g_{\mu\nu} + i m_e \varepsilon_{\mu\nu\alpha\beta} s^\alpha (k-k')^\beta\right] \quad \text{exact in QED}$$

$$\mathbf{W}^{\mu\nu} = -g^{\mu\nu}\mathbf{F_1} + \frac{p^\mu p^\nu}{\nu}\mathbf{F_2} + \frac{i}{\nu}\epsilon^{\mu\nu\lambda\sigma} q_\lambda S_\sigma \mathbf{g_1} + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma} q_\lambda (p\cdot q S_\sigma - S\cdot q p_\sigma)\mathbf{g_2}$$

The hadronic tensor has to be parameterized introducing $\mathbf{F_1}$, $\mathbf{F_2}$ (unpolarized structure functions) and $\mathbf{g_1}$ and $\mathbf{g_2}$ (polarized structure functions).

The structure function g_1



In the quark parton model:

$$\mathbf{g_1}(x) = \frac{1}{2} \Sigma_f \, e_f^2 \, \Delta q_f(x)$$

$$\mathbf{g_1^d} = \frac{1}{2}(\mathbf{g_1^p} + \mathbf{g_1^n}) \left(1 - \frac{3}{2}\omega_d\right)$$

with $\omega_d = 0.05 \pm 0.01$

$$A_{||} = \frac{\sigma^{\leftrightarrows} - \sigma^{\rightrightarrows}}{\sigma^{\leftrightarrows} + \sigma^{\rightrightarrows}} = \frac{1}{P_b P_t} \frac{N^{\leftrightarrows} L^{\rightrightarrows} - N^{\rightrightarrows} L^{\leftrightarrows}}{N^{\leftrightarrows} L^{\rightrightarrows} + N^{\rightrightarrows} L^{\leftrightarrows}}$$ measured asymmetry

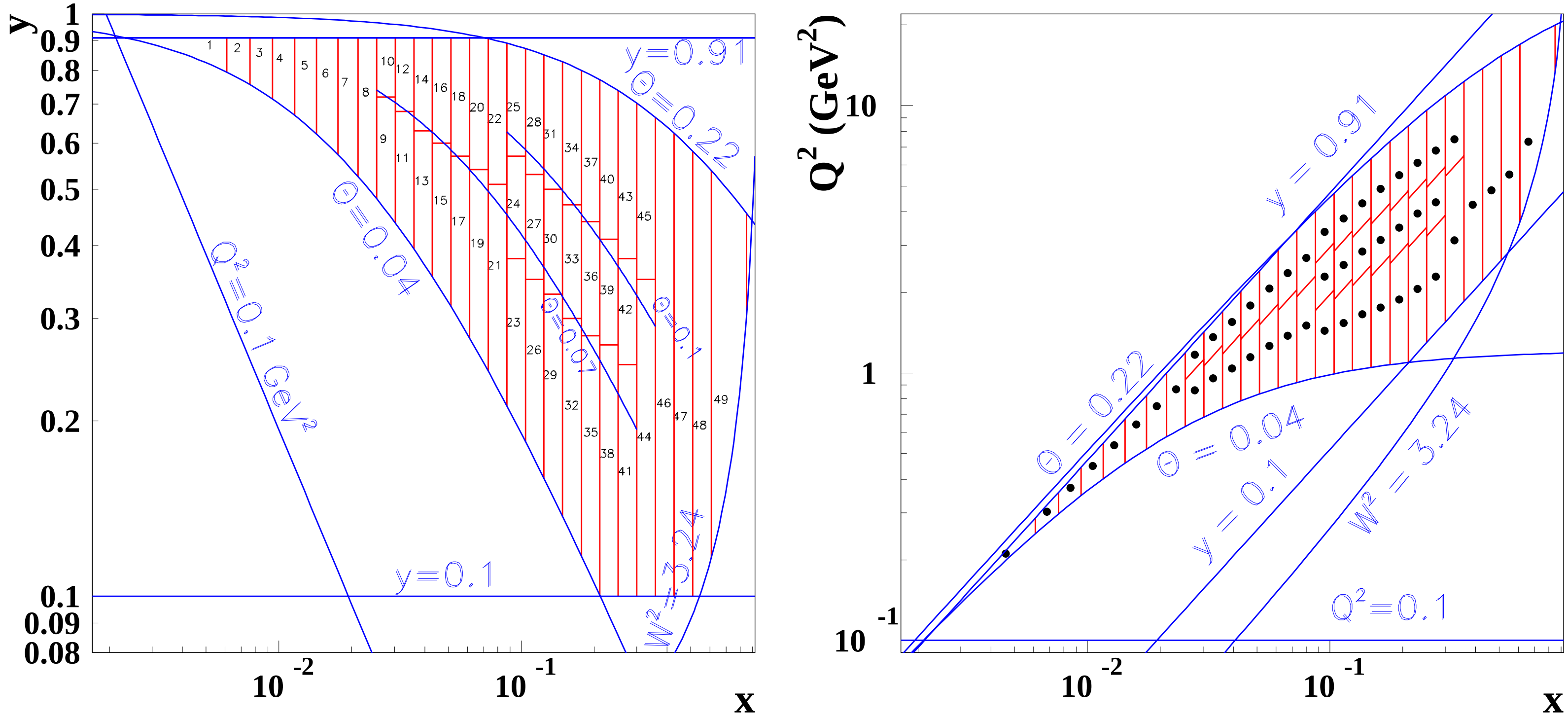
$$\frac{\mathbf{g_1}}{\mathbf{F_1}} = \frac{1}{1+\gamma^2} \left[\frac{A_{||}}{D} + (\gamma - \eta) A_2 \right]$$ structure function ratio

where D, γ, η are kinematic factors.

$$\mathbf{g_1} = \left(\frac{\mathbf{g_1}}{\mathbf{F_1}} \right)_{meas} \cdot \mathbf{F_1}^{param}$$ extraction of g_1

$$A_2 = \frac{\gamma(\mathbf{g_1} + \mathbf{g_2})}{\mathbf{F_1}}$$

The HERMES Kinematic Plane



Deuterium HERMES data from 1998 and 2000 to measure g_1^d

Events separated into 49 (x, Q^2) bins

1998 e^- d data set: 1.5M DIS events

2000 e^+ d data set: 9.7M DIS events!

Systematic Studies

Once the asymmetry is measured, the result has to be tested for

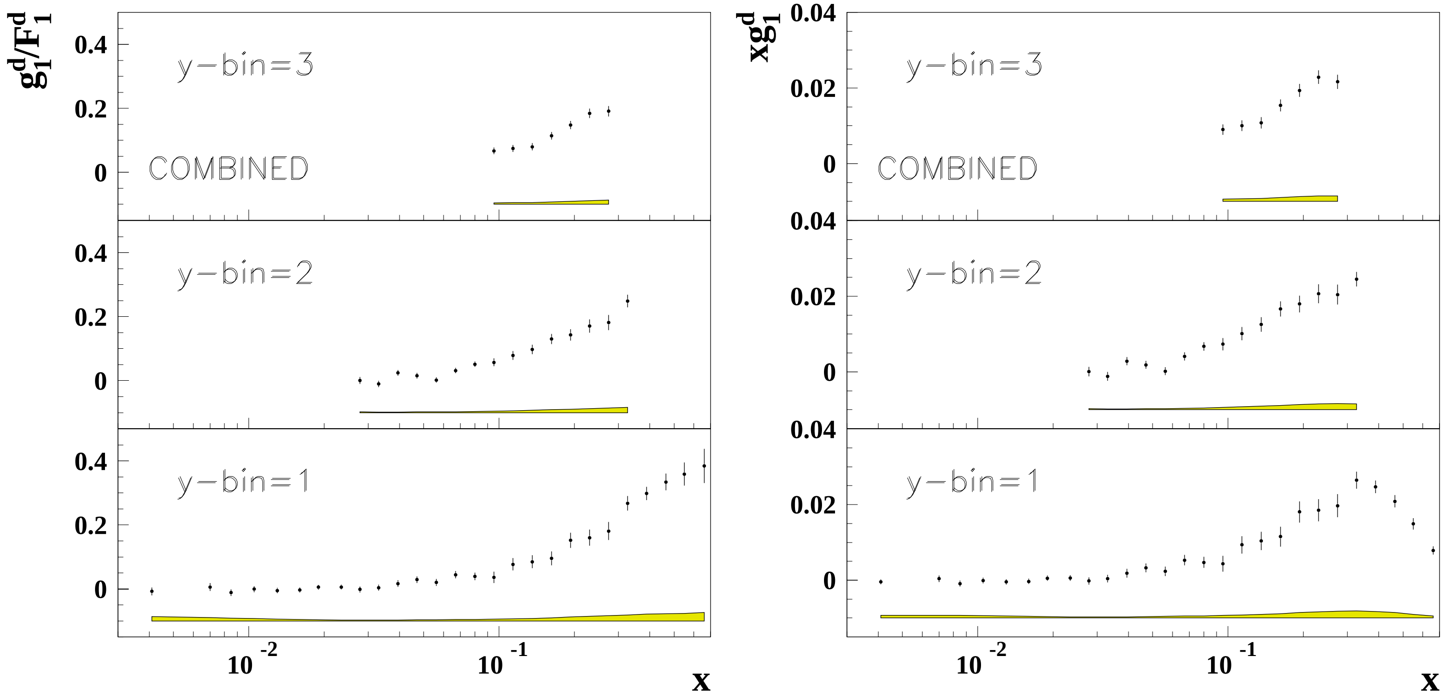
$\star$ cut variations

$\star$ dependences on time, current, target vertex position z_v, azimuthal angle φ, trigger efficiencies...

$\rightsquigarrow$ statistical tests

$\rightsquigarrow$ assessment of systematic uncertainties

Results and systematic uncertainties



Target Polarization	4%
Beam Polarization	2%
Extraction	$\leq$0.013
Normalization	$\leq$0.005
Alignment	$\leq$0.006
Hadronic background	$\leq$ 0.5%
A_2^d assumption	$\leq$ 1.8%
R (for g_1^d/F_1^d)	2.8-6.6%
R (for g_1^d)	2.7-14%
F_2^d	2.5%

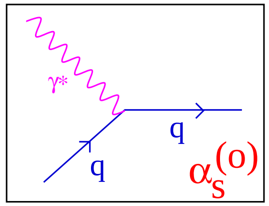
(No smearing corrections applied)

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

Much improved precision with respect

to previous experiments: 9.7+1.5M events!

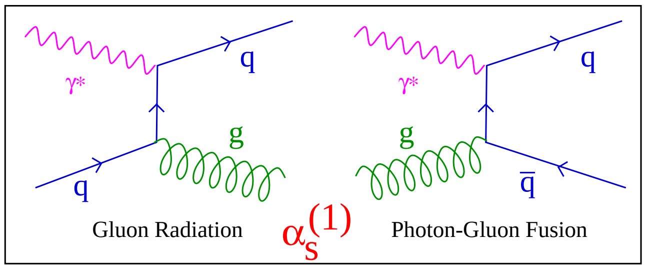
Beyond the Naive Parton Model



$\Longrightarrow$ No gluons

$$g_1^0(x) = \frac{1}{2}\sum e_q^2\, \Delta q(x)$$

$\Downarrow$



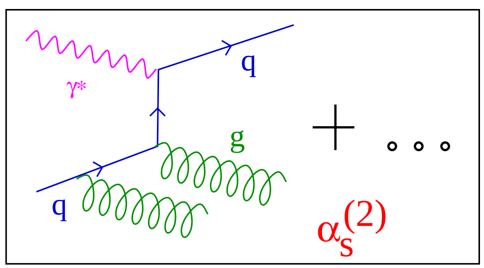
$\Longrightarrow$ Quarks are re-defined

with the inclusion of ΔG

(weak dependence)

$$g_1^{LO}(x, Q^2) = \frac{1}{2}\sum e_q^2\, \Delta q(x, Q^2)$$

$\Downarrow$



$\Longrightarrow$ g_1 becomes

explicitly ΔG dependent

$$g_1^{NLO}(x, Q^2) =$$
$$\frac{1}{2}\sum e_q^2\, \Delta q(x, Q^2) + \frac{\alpha_s}{2\pi}\, \frac{1}{2}\sum e_q^2 \left[\Delta q(x, Q^2) \otimes C_q + \Delta G(x, Q^2) \otimes C_G\right]$$

Splitting Functions and Evolution Equations

In NLO there are two independent NS distributions, plus $\Delta\Sigma$ and ΔG:

$$\begin{aligned} \Delta q^p_{NS} &= \tfrac{1}{2}\,(2\Delta u - \Delta d - \Delta s) \\ \Delta q^n_{NS} &= \tfrac{1}{2}\,(2\Delta d - \Delta u - \Delta s) \\ \Delta\Sigma &= \Delta u + \Delta d + \Delta s \end{aligned}$$

Their Q^2 dependence is regulated by the evolution equations:

$$\frac{d}{d\ln Q^2}\begin{pmatrix}\Delta\Sigma \\ \Delta G\end{pmatrix} = \frac{\alpha_s}{2\pi}\begin{pmatrix}P^S_{qq} & 2n_f P_{qG} \\ P^S_{Gq} & P_{GG}\end{pmatrix} \otimes \begin{pmatrix}\Delta\Sigma \\ \Delta G\end{pmatrix}$$

$$\frac{d}{d\ln Q^2}\Delta q_{NS} = \frac{\alpha_s}{2\pi} P^{NS}_{qq} \otimes \Delta q_{NS}$$

- Each distribution is parameterized at a starting Q^2_0:

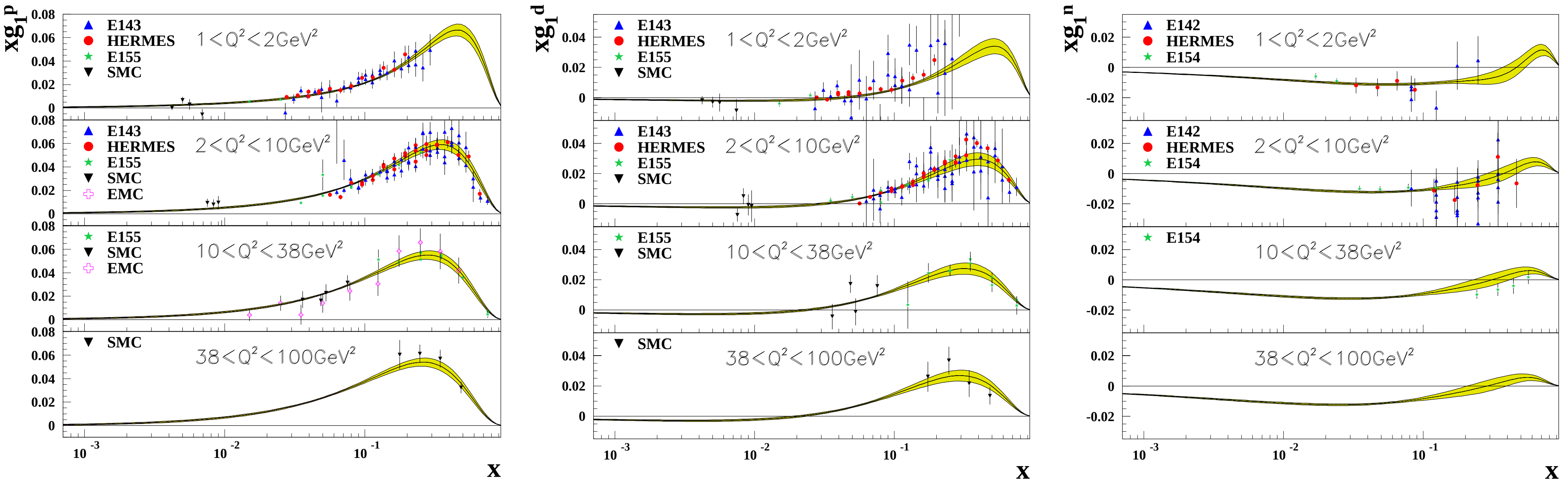
$$\Delta f = N_f\, \eta\, x^{\alpha}\, (1-x)^{\beta}\, (\, 1 + \gamma x + \rho\sqrt{x}\,)$$

- It is evolved at Q^2_{meas} using the evolution equations, where g_1^{calc} is calculated.
- The χ^2 is minimized:

$$\chi^2 = \sum_{\text{data}} \frac{(\mathbf{g_1}^{\text{meas}} - \mathbf{g_1}^{\text{calc}})^2}{\sigma^2_{\text{stat}}}$$

- The parameters α, β, γ... are evaluated.

Best fits

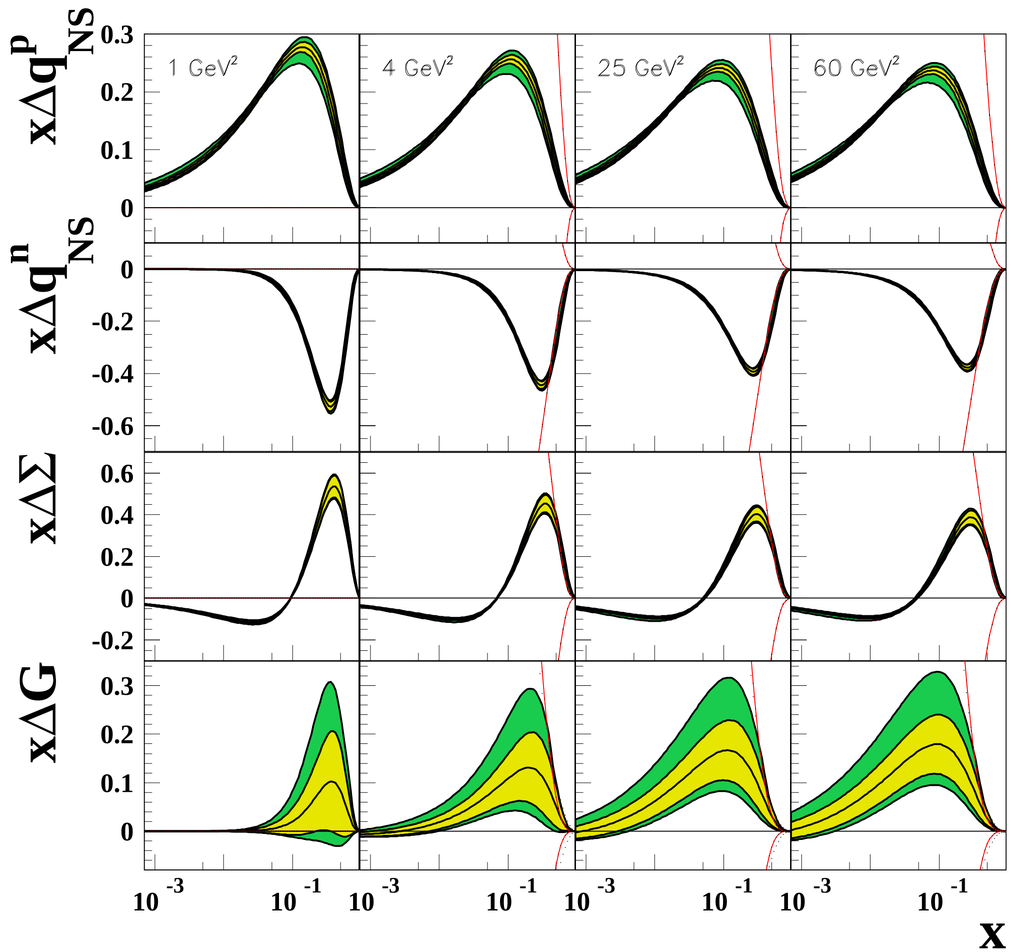


Statistical errors shown, obtained from the fits by propagating the errors on the parameters.

The bands are for the Q^2 values of 1,4,25,60 GeV^2, overlapped with data in the ranges shown.

Polarized Parton Distributions

Method implemented for propagating the errors on the parameters at any Q^2 by evolving the error bands.



The statistical error bands are very small for all distributions

Positivity limits (red) well respected

Gluons appear to be positive

Systematic bands: obtained by shifting each data set by $\pm 1\sigma_{syst}$

Conclusions

- ⋆ The deuteron structure function g_1^d has been measured with very high precision with data collected by the HERMES experiment in the years 1998 and 2000.

- ⋆ g_1 can be inverted to provide the polarized quark distributions and ΔG.
  - ⋆ Statistical and systematic error bands have been obtained.
  - ⋆ ΔG seems to be better constrained by data than before and shows a clear positive sign.