Precision results on g_1^{p}, g_1^{d} and g_1^{n} and the first measurement of the tensor structure function b_1^{d} with the HERMES-experiment

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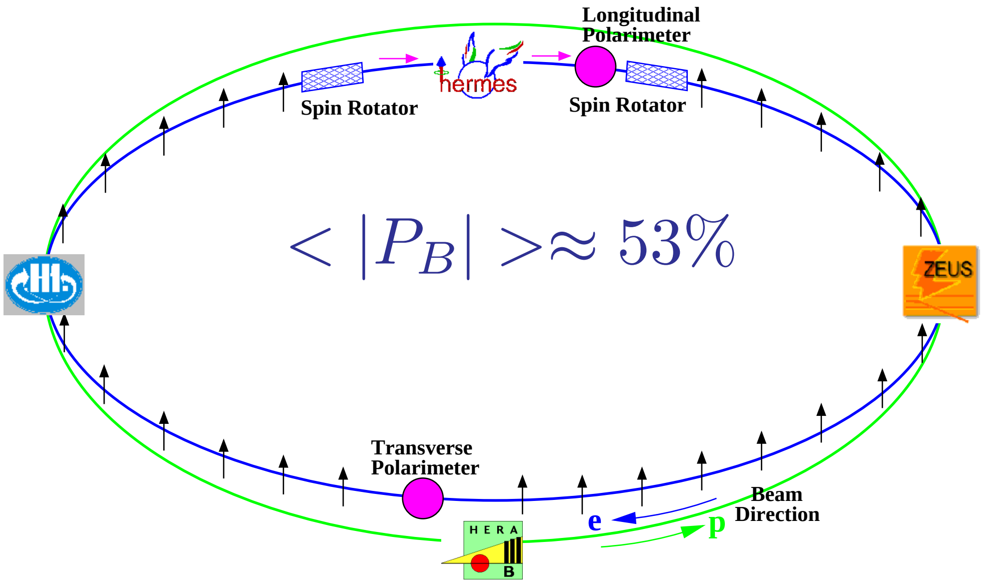
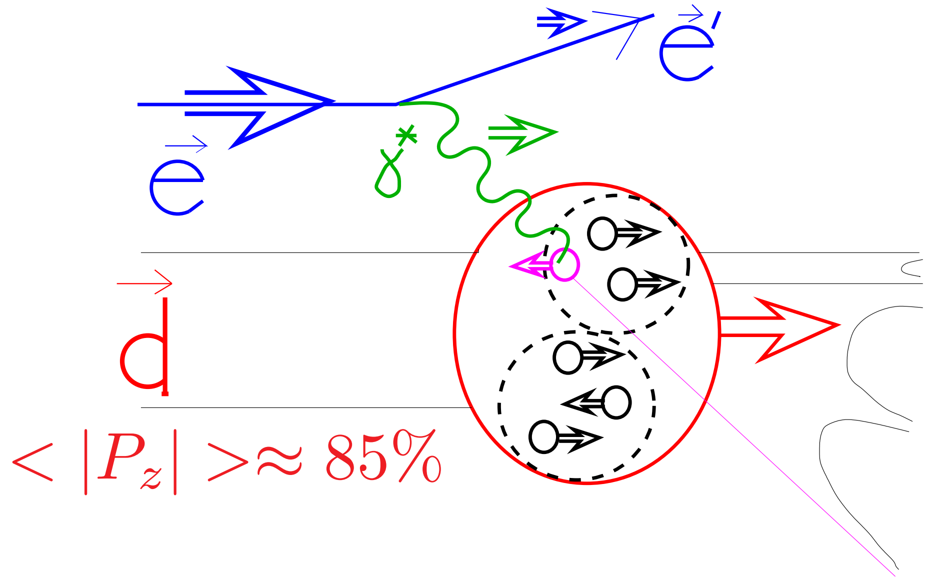
bmb+f - Förderschwerpunkt
HERMES
Großgeräte der physikalischen Grundlagenforschung

DIS on a fixed target at HERMES

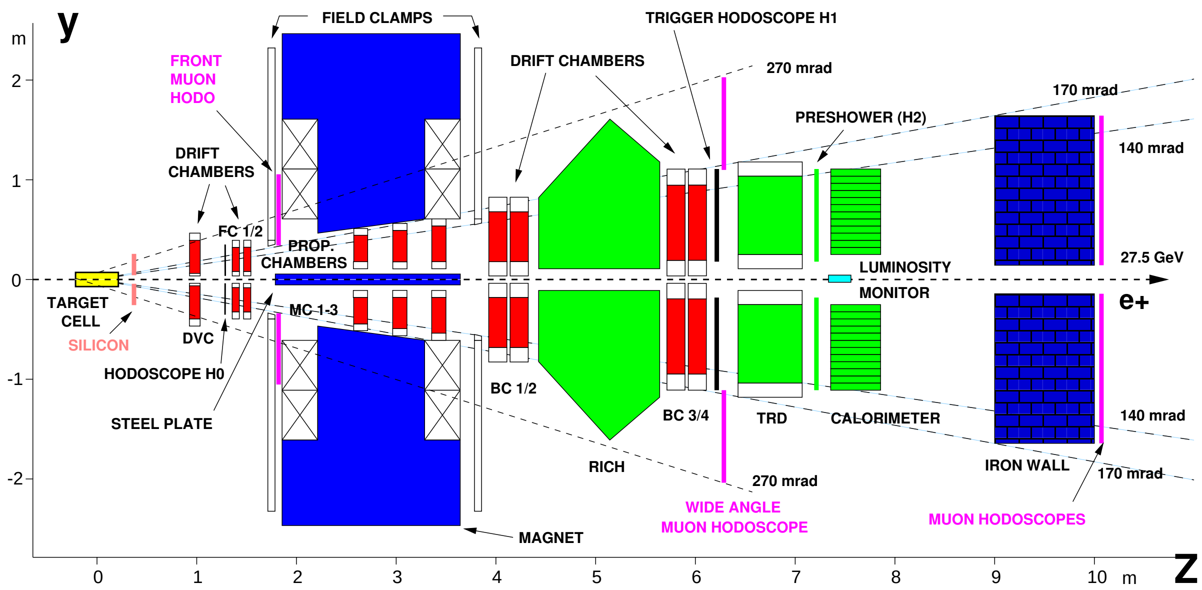


Longitudinally polarized e^+- (or e^--)beam (27.6 GeV) hits

polarized internal gaseous hydrogen or deuterium target:



The HERMES spectrometer

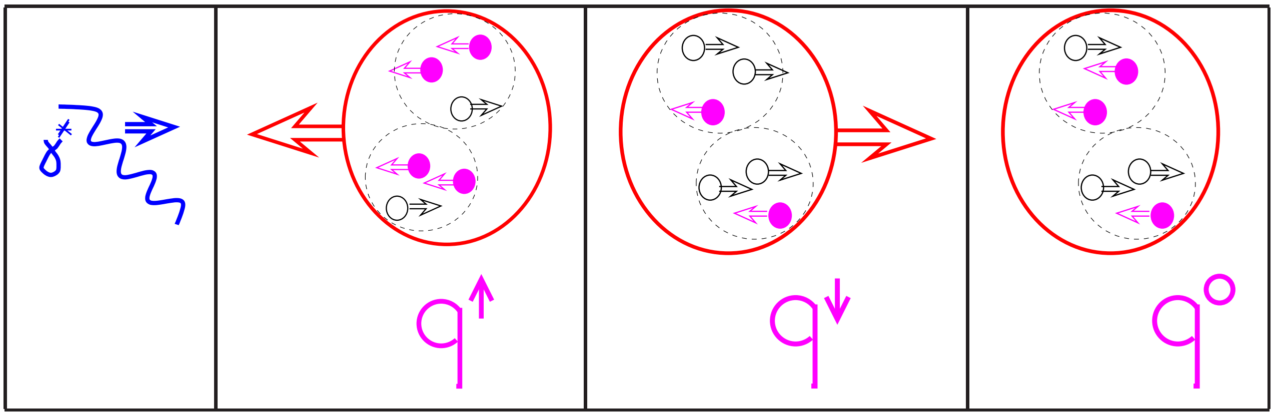


- Acceptance: $40 < \theta < 220$ mrad
- Momentum resolution: $\frac{\delta p}{p} \approx 2\%$;
  Angular resolution: $0.3 - 0.6$ mrad;
- Calorimeter: $\frac{\delta E}{E} \approx \frac{(5.1 \pm 1.1)}{\sqrt{E[\mathrm{GeV}]}}\%$

- PID: RICH, TRD, preshower, calo
- Efficiency of electron ID: 98-99 %
- Hadron contamination: $< 1\%$

Structure functions in the Quark Parton Modell

Quark densities $q(x, Q^2)$:



Structure functions:

Spin-$\frac{1}{2}$ (proton)	Spin-1 (deuteron)
$F_1 = \frac{1}{2} \sum_q e_q^2 \left(q^\uparrow + q^\downarrow \right)$	$F_1 = \frac{1}{3} \sum_q e_q^2 \left(q^\uparrow + q^\downarrow + q^0 \right)$
$g_1 = \frac{1}{2} \sum_q e_q^2 \left(q^\uparrow - q^\downarrow \right)$	$g_1 = \frac{1}{2} \sum_q e_q^2 \left(q^\uparrow - q^\downarrow \right)$
	$b_1 = \frac{1}{2} \sum_q e_q^2 \left(2q^0 - (q^\uparrow + q^\downarrow) \right)$

Inclusive asymmetries

- Measured cross section:

$$\sigma = \sigma_{\mathrm{unpol}} \left[1 + P_{\mathrm{B}} P_z A_{\parallel} + \frac{1}{2} P_{zz} A_{zz} \right]$$

- Inclusive vector asymmetry :

$$A_{\parallel} \quad := \quad \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{1}{P_{\mathrm{B}} P_z} \cdot \frac{\left(\frac{N^{\uparrow\downarrow}}{L^{\uparrow\downarrow}}\right) - \left(\frac{N^{\uparrow\uparrow}}{L^{\uparrow\uparrow}}\right)}{\left(\frac{N^{\uparrow\downarrow}}{L^{\uparrow\downarrow}}\right) + \left(\frac{N^{\uparrow\uparrow}}{L^{\uparrow\uparrow}}\right)}$$

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

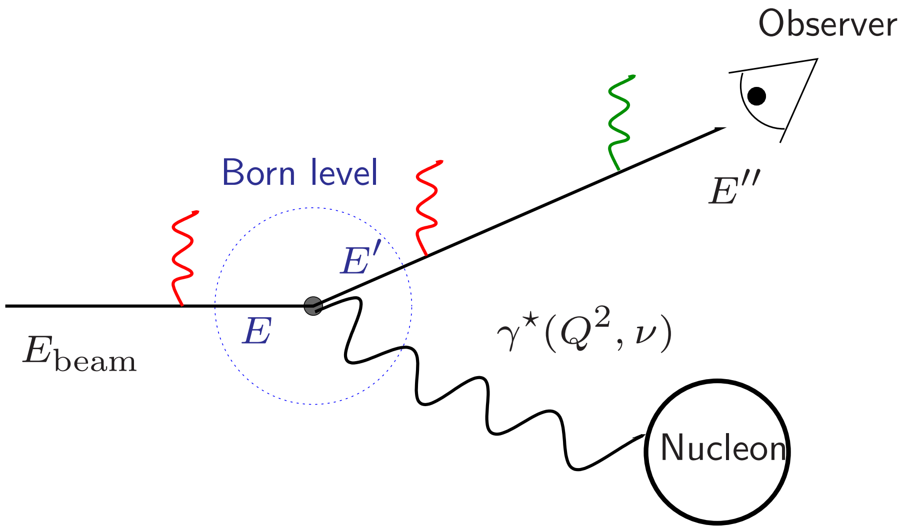
Kinematic variables:

$$\gamma = \frac{\sqrt{Q^2}}{\nu}, \qquad \eta = \eta(x, Q^2), \qquad D = \frac{P_{\gamma^\star}}{P_{\mathrm{B}}}$$

- Inclusive tensor asymmetry :

$$A_{zz} := \frac{(\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}) - 2\sigma^0}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow} + \sigma^0} = -\frac{2}{3} \frac{b_1}{F_1}$$

From the observed to the true bin



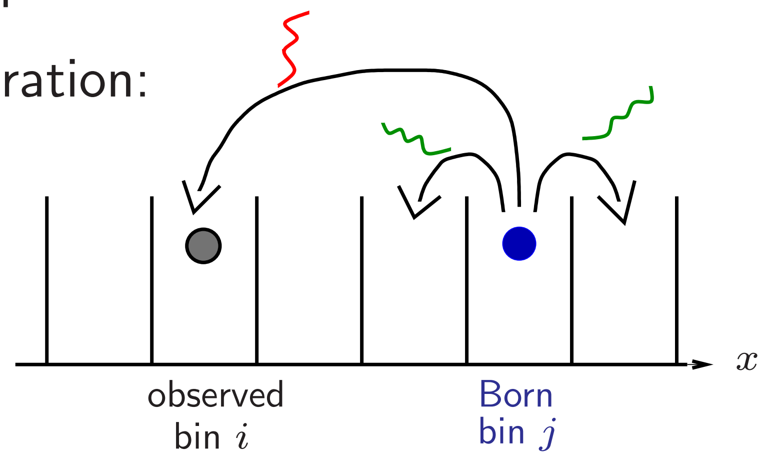
smearing

=

$\sum$ (radiative corrections + detector smearing)

bin

migration:

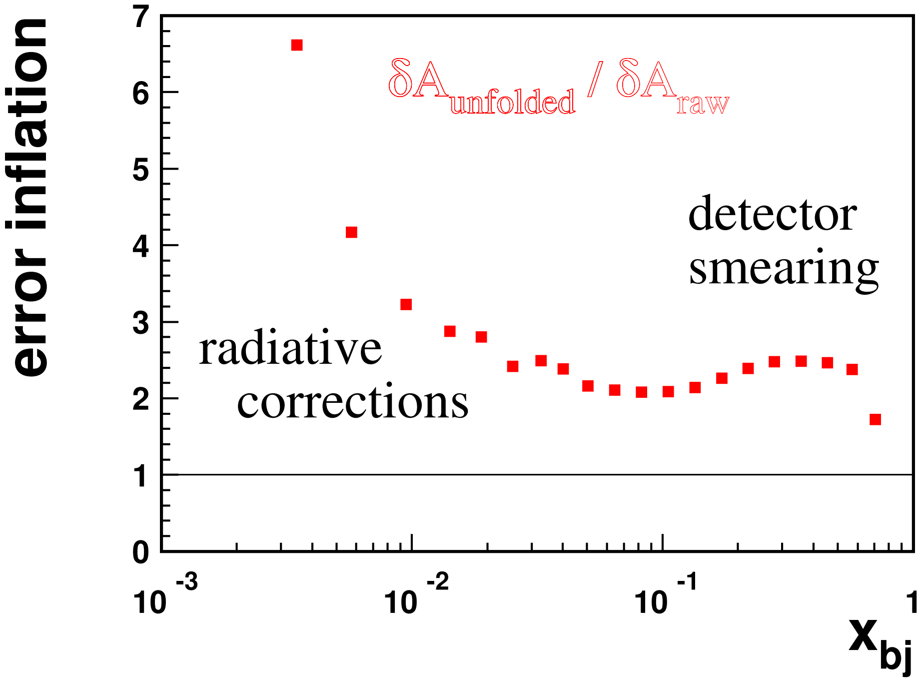


Unfolding procedure

- MC simulation of radiative corrections and detector
- Model-independent approach to calculate $A_{\parallel}^{\mathrm{Born}}$:

$$A_{\parallel}^{\mathrm{Born}} = A_{\parallel}^{\mathrm{meas}} \cdot \left(1 + \frac{\sigma_{\mathrm{unpol}}^{\mathrm{bg}}}{\sigma_{\mathrm{unpol}}^{\mathrm{Born}}}\right) - \frac{\sigma_{\mathrm{pol}}^{\mathrm{bg}}}{\sigma_{\mathrm{unpol}}^{\mathrm{Born}}}$$

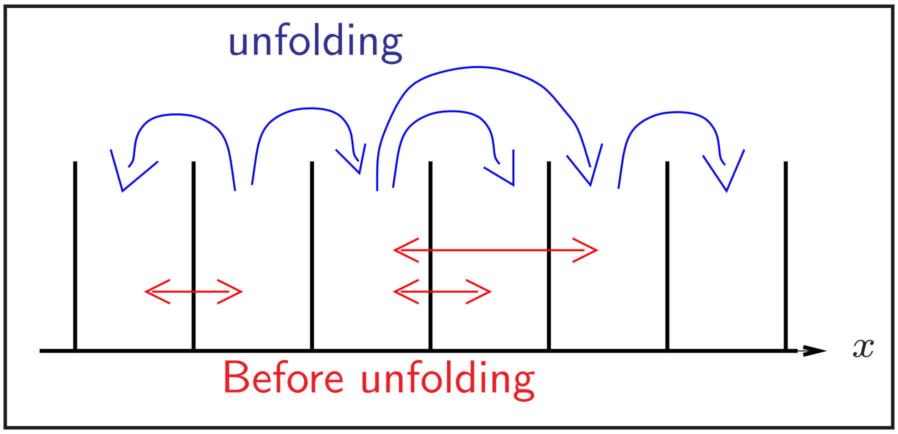
$$\delta A_{\parallel}^{\mathrm{Born}} = \delta A_{\parallel}^{\mathrm{meas}} \cdot \left(1 + \frac{\sigma_{\mathrm{unpol}}^{\mathrm{bg}}}{\sigma_{\mathrm{unpol}}^{\mathrm{Born}}}\right)$$



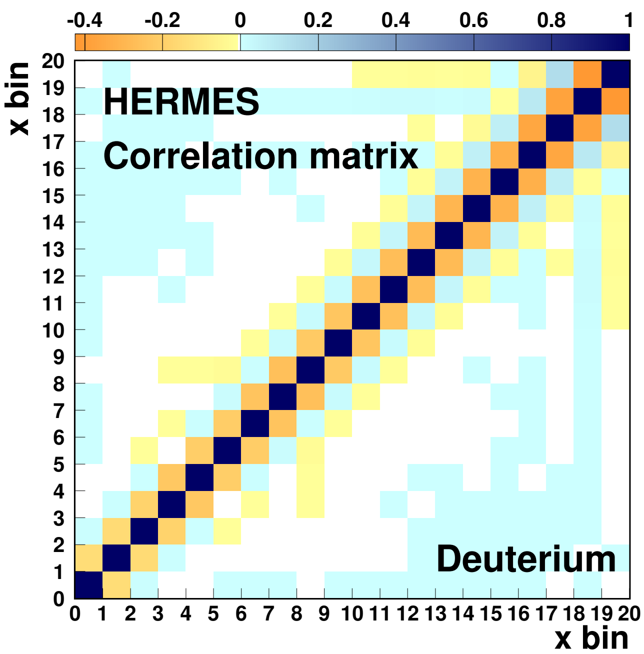
BUT...

Error correlation matrix

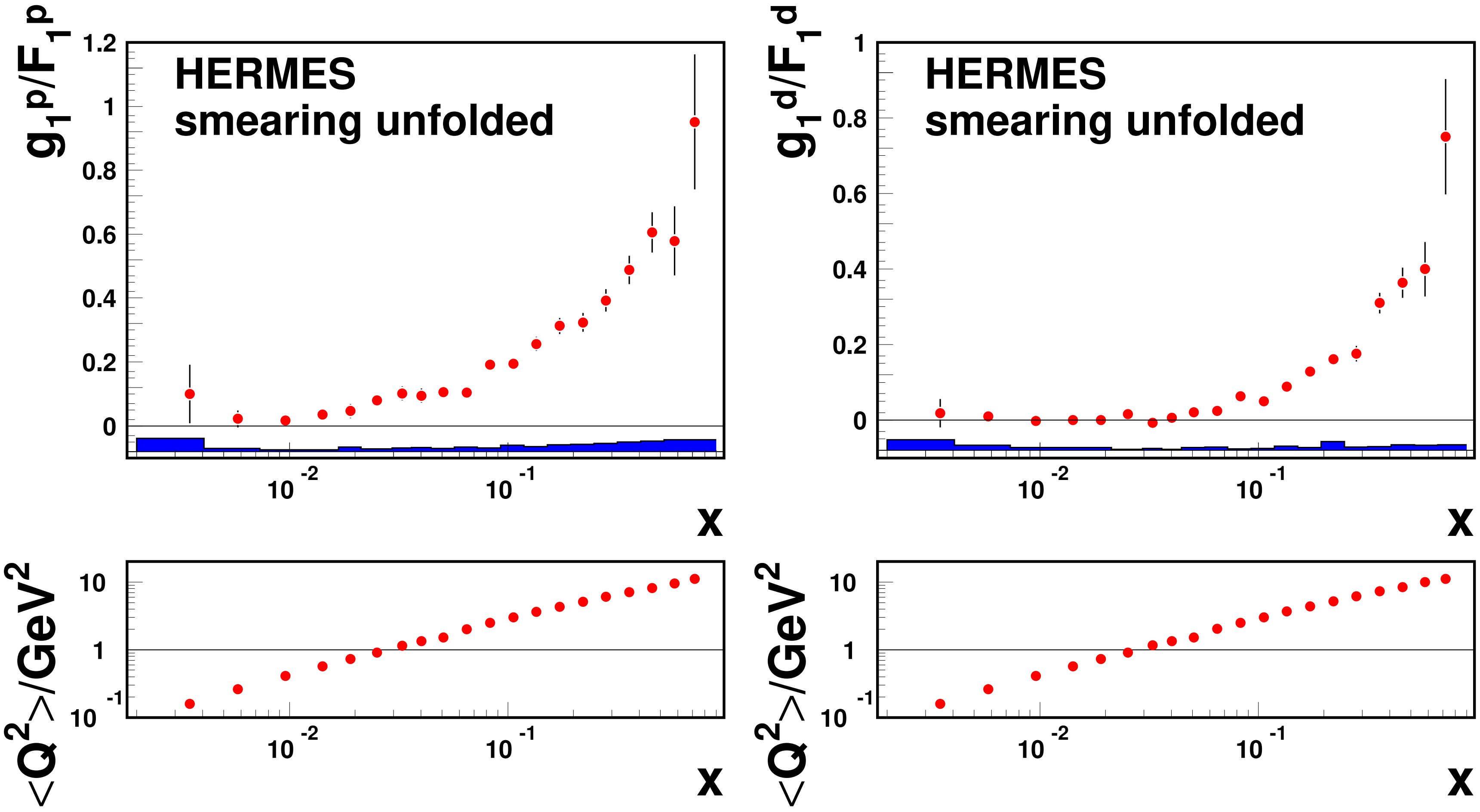
Unfolding removes systematic correlations between data points, correlating them statistically



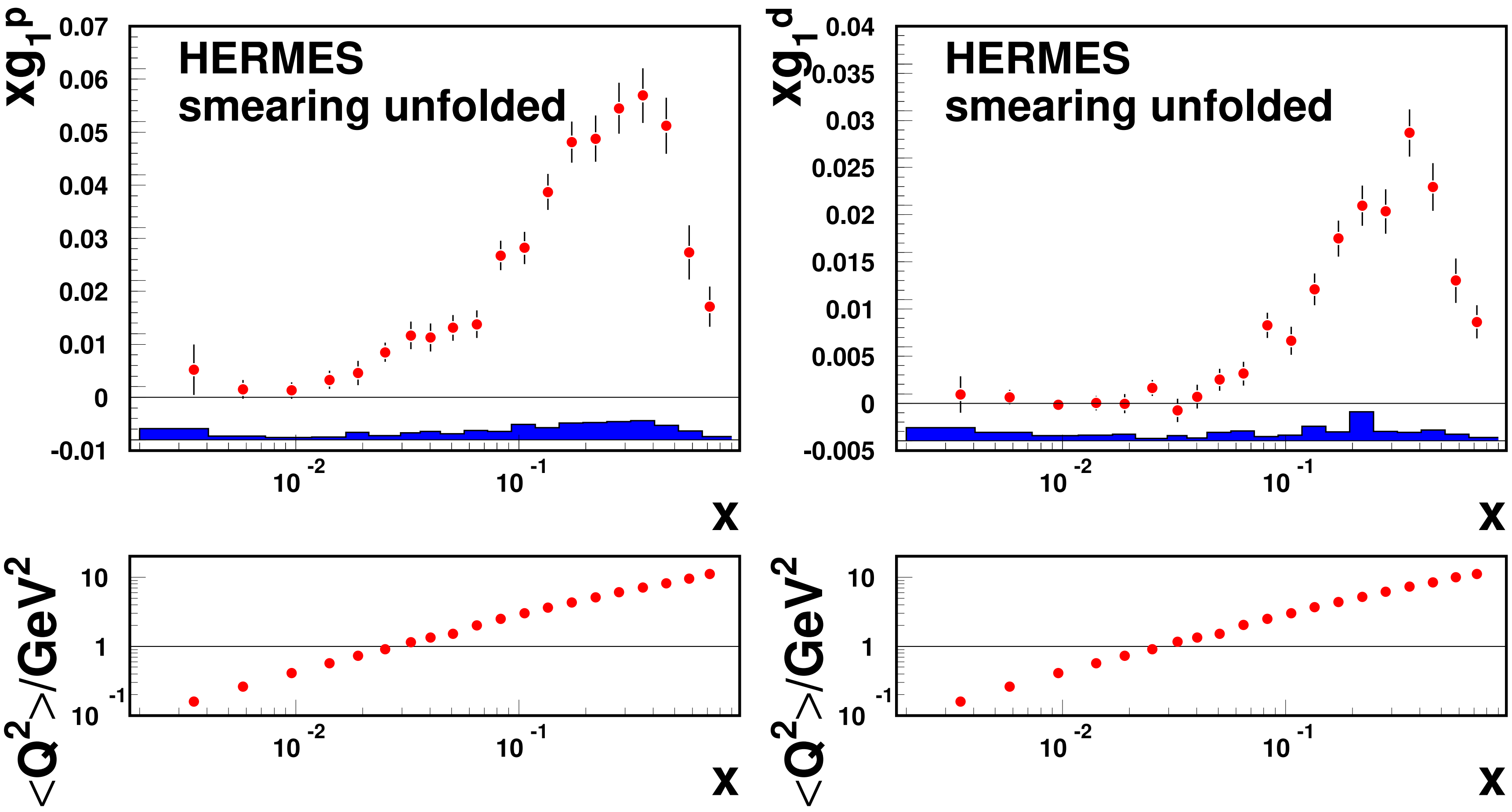
e.g. QCD fits, moments from HERMES measurement:
For correct interpretation and usage of error bars:
$\Rightarrow$ correlation matrix!



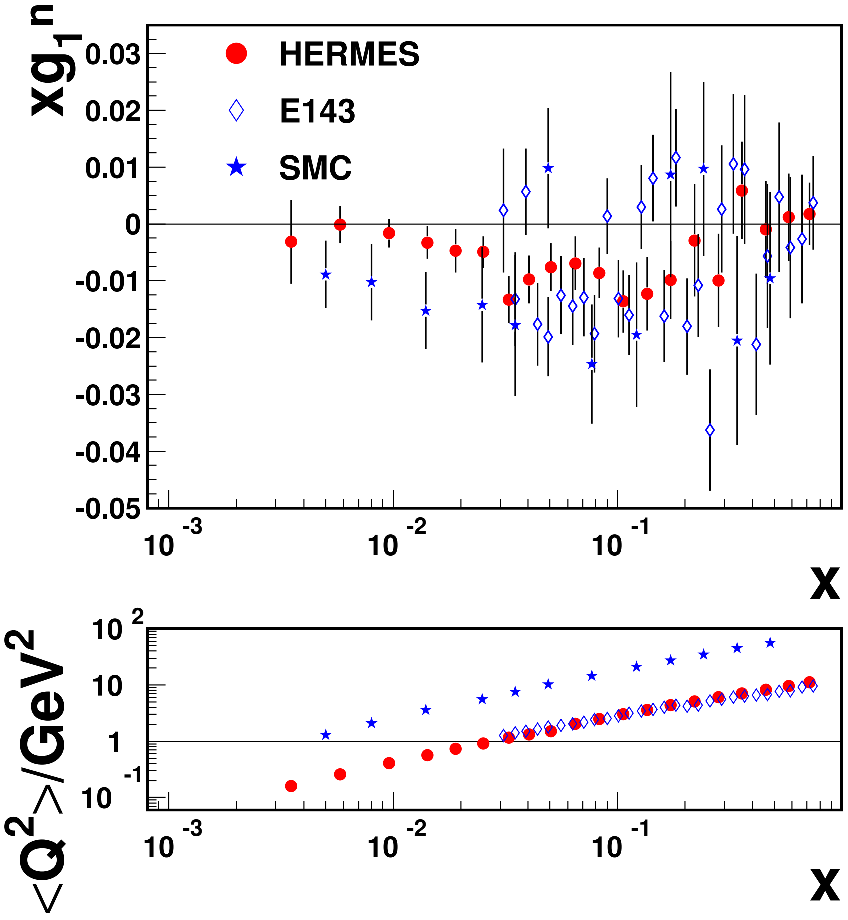
g_1/F_1 of the proton and of the deuteron



Spin structure function xg_1 of the proton and of the deuteron



Spin structure function xg_1 of the neutron

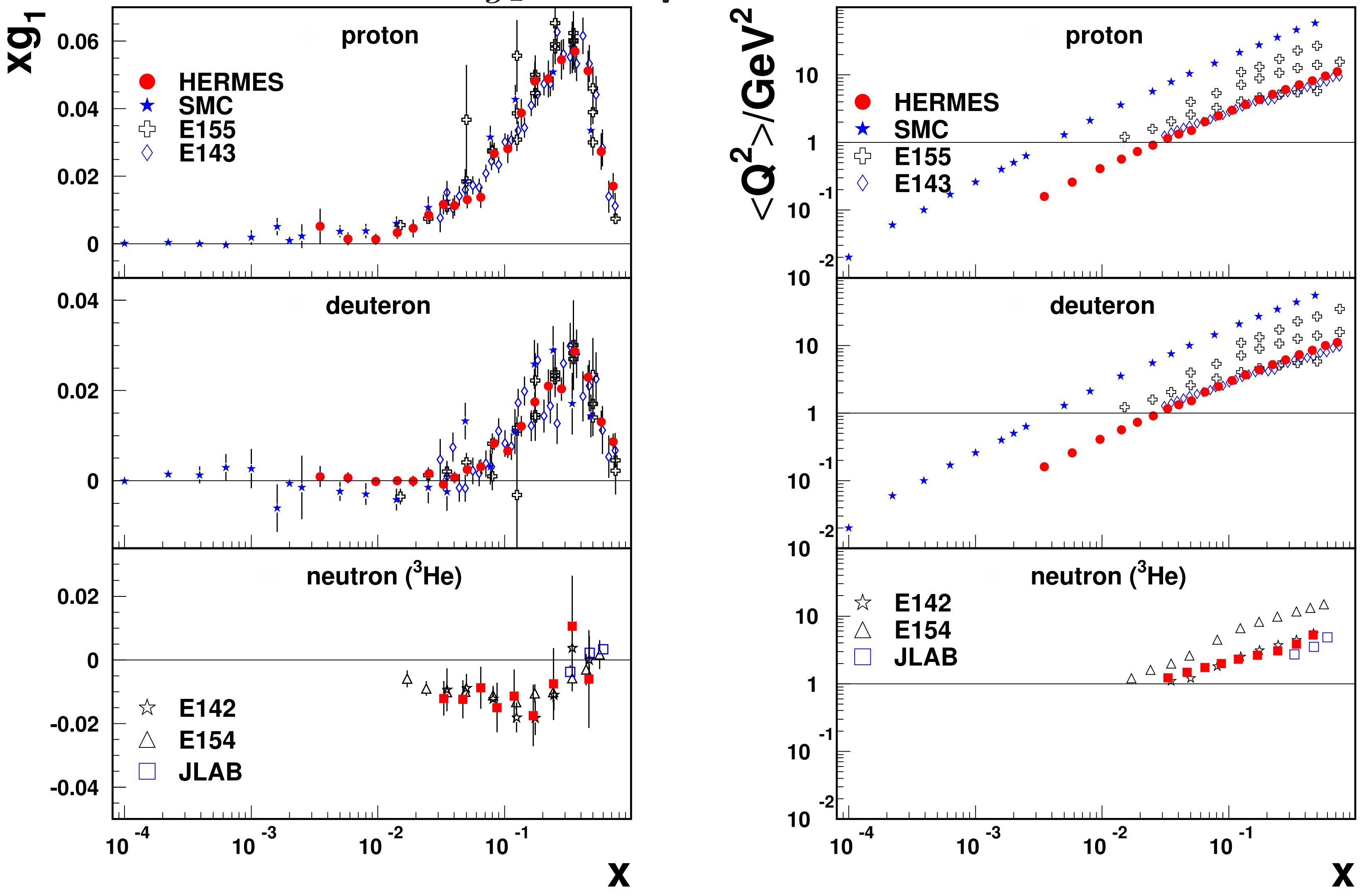


Extracted from

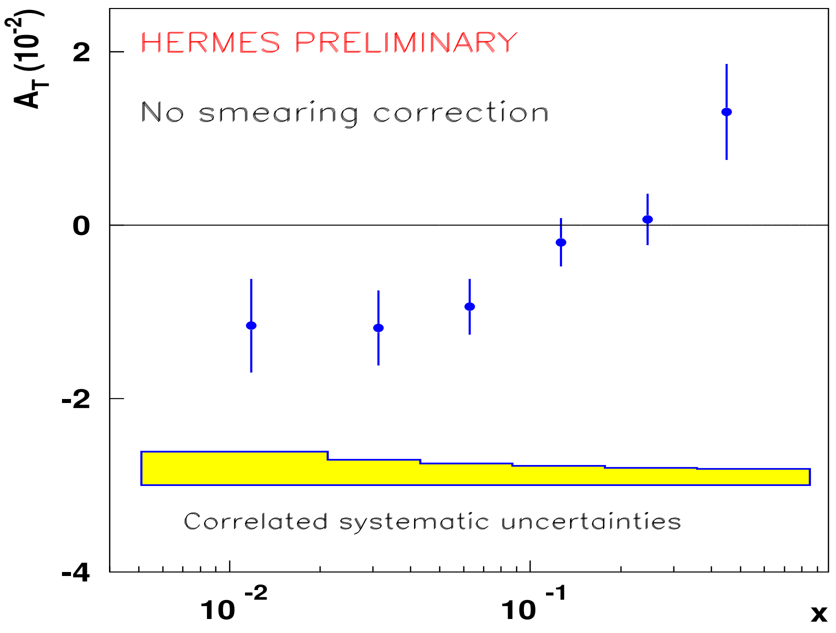
$$g_1^{\mathrm{d}} = \frac{1}{2}\left(1 - \frac{3}{2}\omega_D\right)(g_1^{\mathrm{p}} + g_1^{\mathrm{n}}),$$

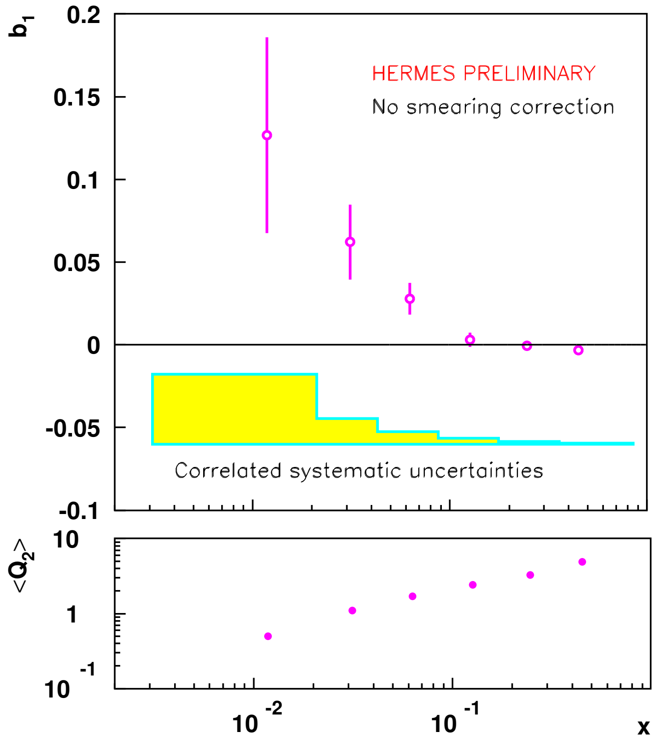
with $\omega_D = 0.058$

HERMES xg_1: Comparison to world data



Tensor asymmetry A_{zz} and tensor structure function b_1^{d}





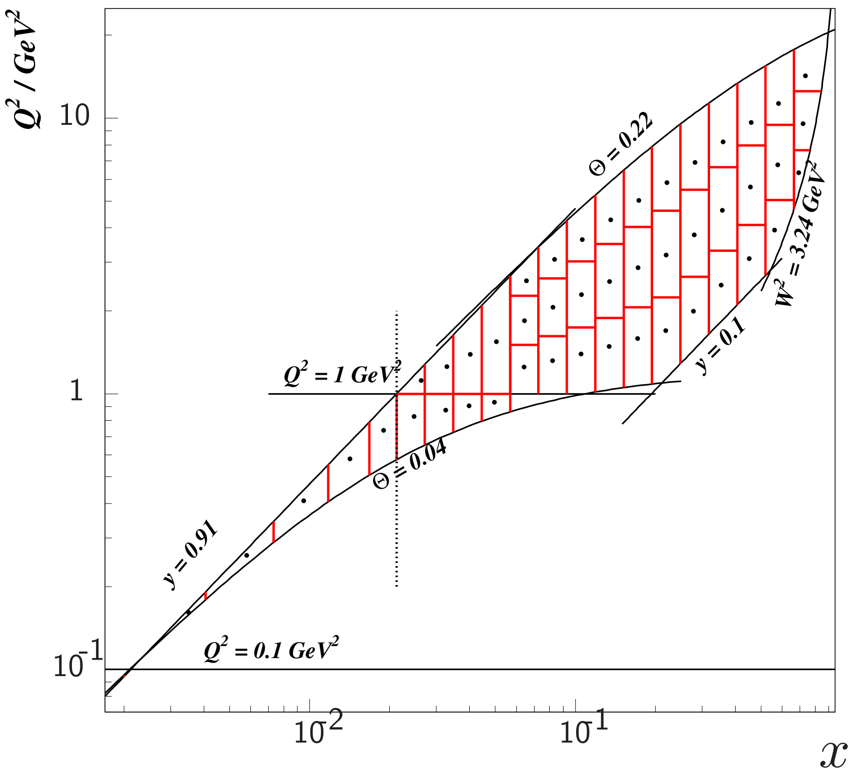
- HERMES: First measurement ever
- $A_{zz} = \mathcal{O}(1\%) \Rightarrow$ Impact on g_1 small
- $b_1^{\mathrm{d}} \gg \mathcal{O}(10^{-3}..10^{-4})$ (older models)
- HERMES publication including unfolding in preparation

Summary and outlook

- Smearing unfolding of inclusive HERMES asymmetries (proton and deuteron)
- Data points of spin structure function now systematically uncorrelated, but statistically correlated
  $\Rightarrow$ Correlation matrix for correct calculation of e.g. QCD fits and moments
- Spin structure function of the neutron from g_1^{p} and g_1^{d}
- To come: moments from unfolded HERMES data
- First measurement of tensor structure function b_1^{d} by HERMES: shows steep rise for small x
- To come: HERMES publications on spin and tensor structure function

A 2-dimensional binning in x and Q^2

- 46 bins in x and Q^2 (20 in x, at most 3 in Q^2):



- Benefit of binning in Q^2:
  - Higher average Q^2
  - Improvement of statistical power after unfolding (diagonal element of correlation matrix)
- $A_{\|}$ unfolded in x and Q^2, then Q^2-average of g_1/F_1

Covariance and correlation matrix

Covariance matrix for unfolded asymmetry:

$$\mathrm{cov}(j,i) = \sum_{k=1}^{n_{\mathrm{X}}} \frac{\partial A_{\mathrm{Born}}(j)}{\partial A_{\mathrm{X}}(k)} \frac{\partial A_{\mathrm{Born}}(i)}{\partial A_{\mathrm{X}}(k)} \delta A_{\mathrm{X}}^2(k)$$

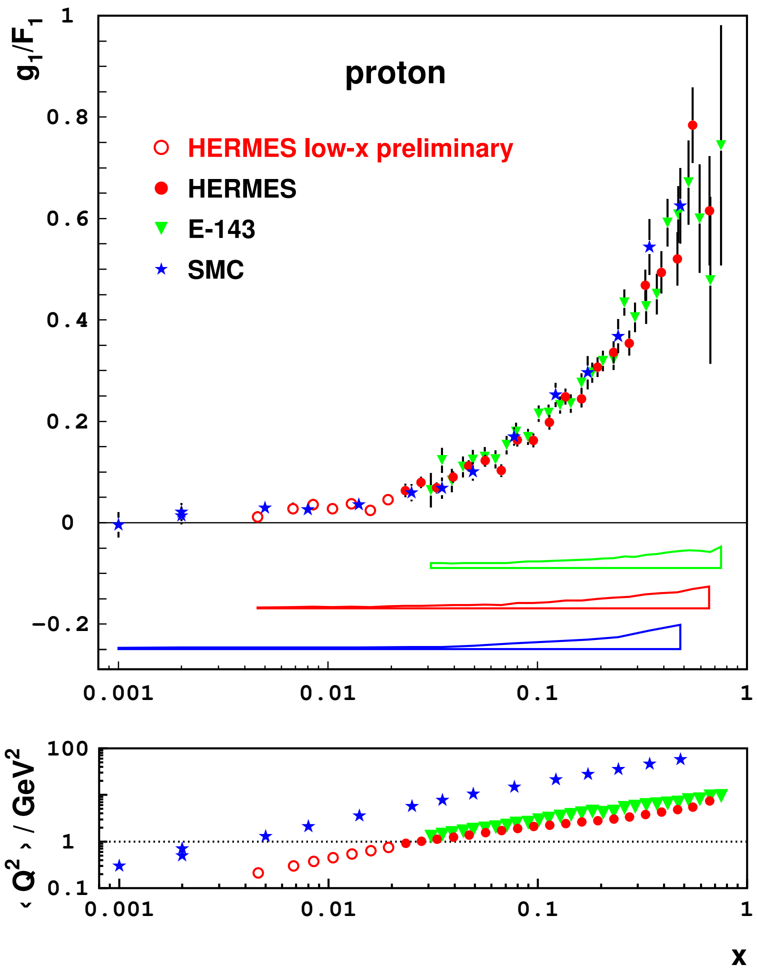
$\Rightarrow$ Correlation matrix:

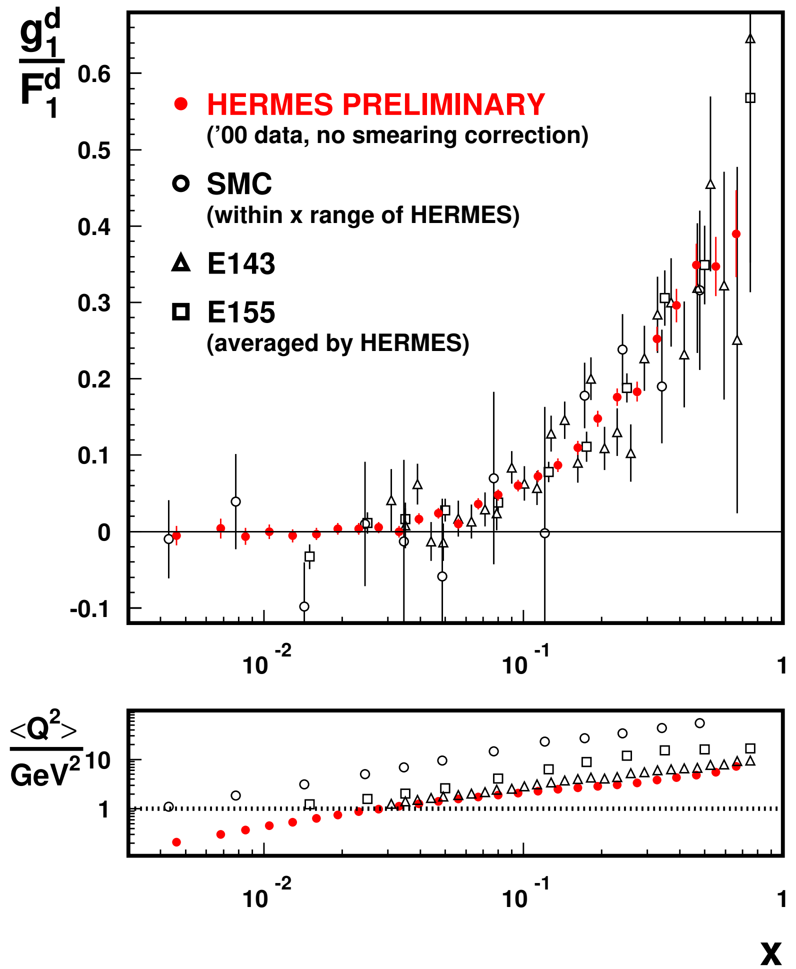
$$\mathrm{corr}(j,i) = \frac{\mathrm{cov}(j,i)}{\delta A_{\mathrm{Born}}(j)\delta A_{\mathrm{Born}}(i)}$$

with

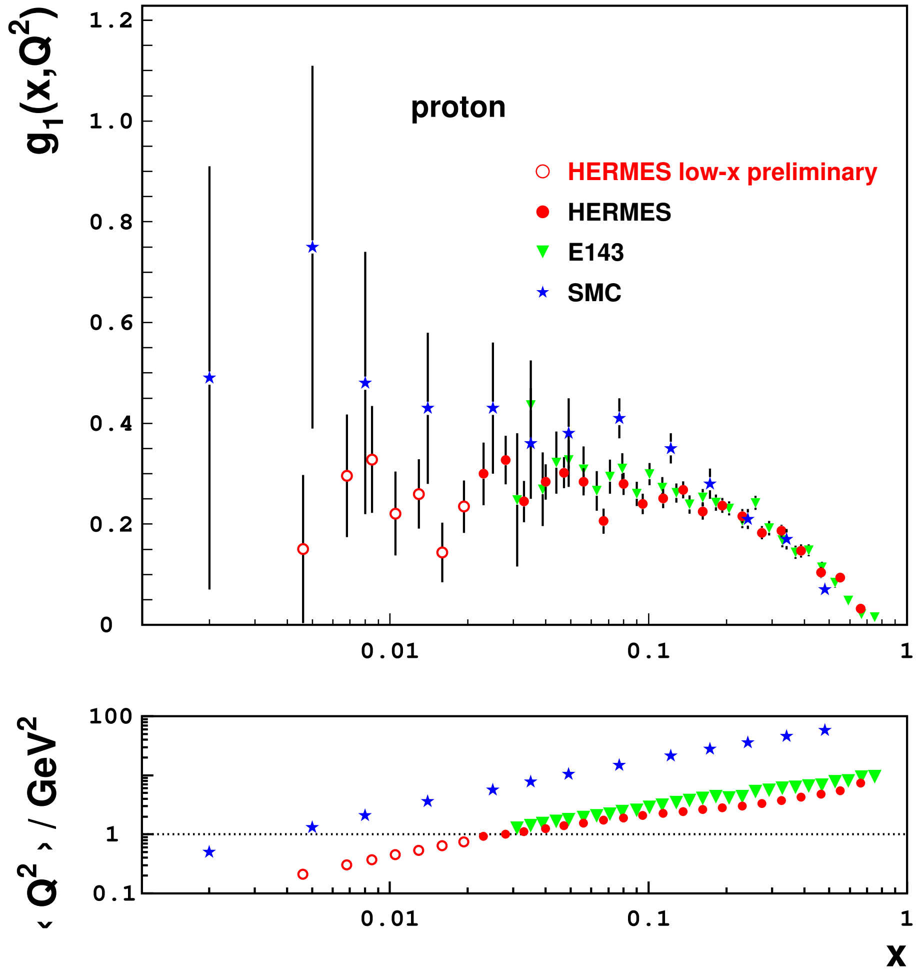
$$\begin{aligned} \mathrm{cov}(j,j) &= \delta A_{\mathrm{Born}}^2(j) \\ \mathrm{corr}(j,j) &= 1 \end{aligned}$$

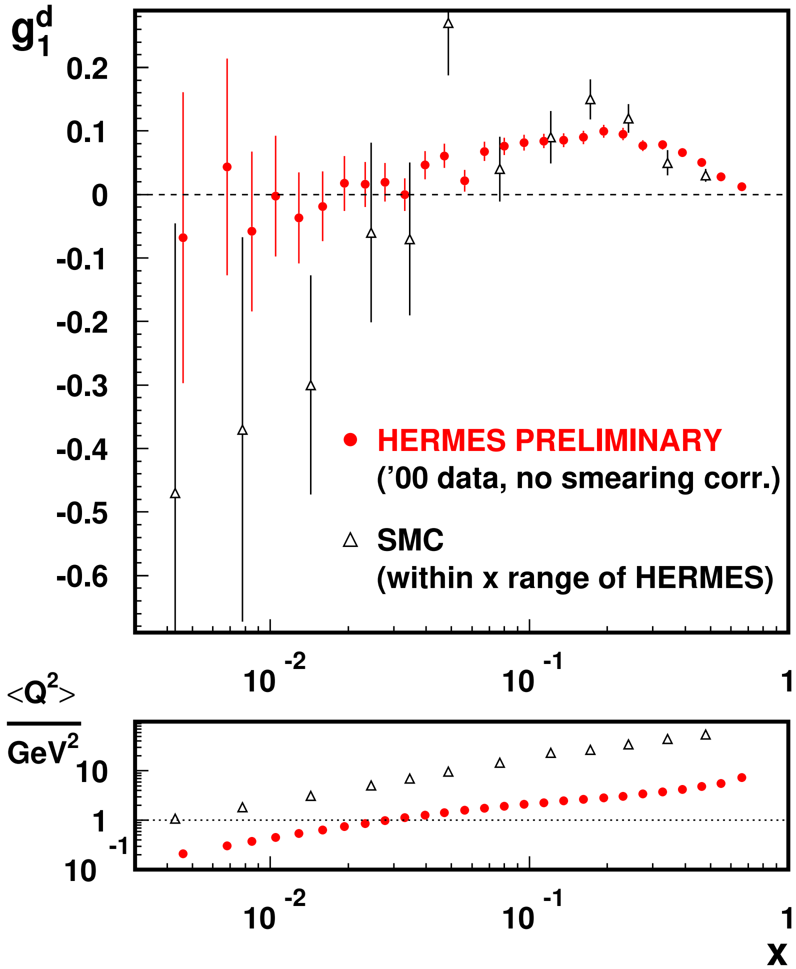
Old HERMES release: g_1/F_1 of the proton and of the deuteron



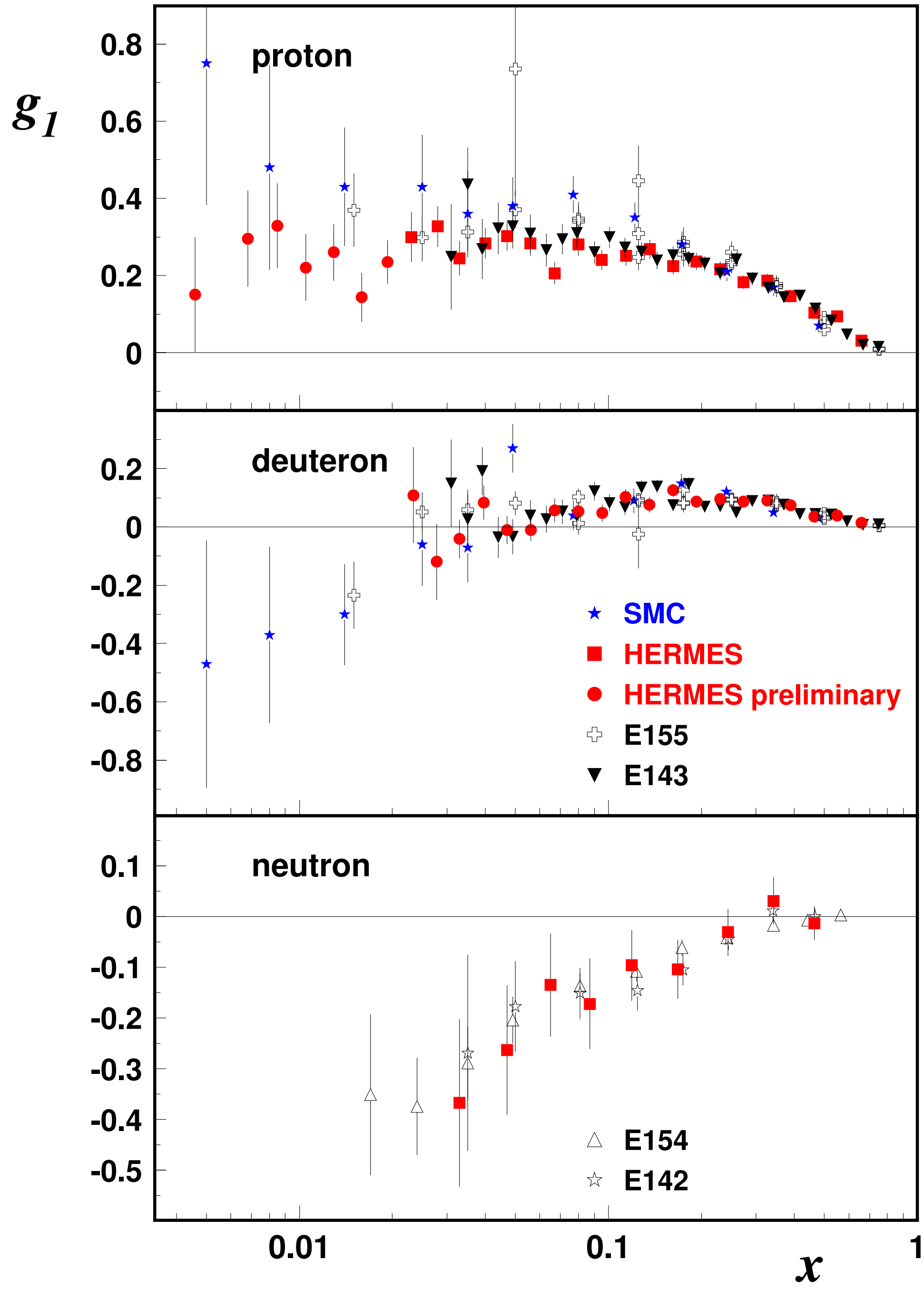


Old HERMES release: g_1 of the proton and of the deuteron





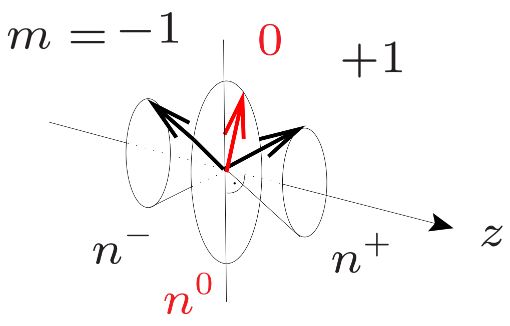
Old HERMES release: g_1 comparison to world data



Polarized atomic gas target

Proton: $m = \pm\frac{1}{2}$

Deuteron (Spin-1):



Polarizations:

vector $\boxed{V = \frac{n^+ - n^-}{n^+ + n^- + n^0}}$

tensor $\boxed{T = \frac{(n^+ + n^-) - 2n^0}{n^+ + n^- + n^0}}$

$|V| \leqq 1, \; -2 \leq T < 1$

HERMES target: ABS + gas analyzing system

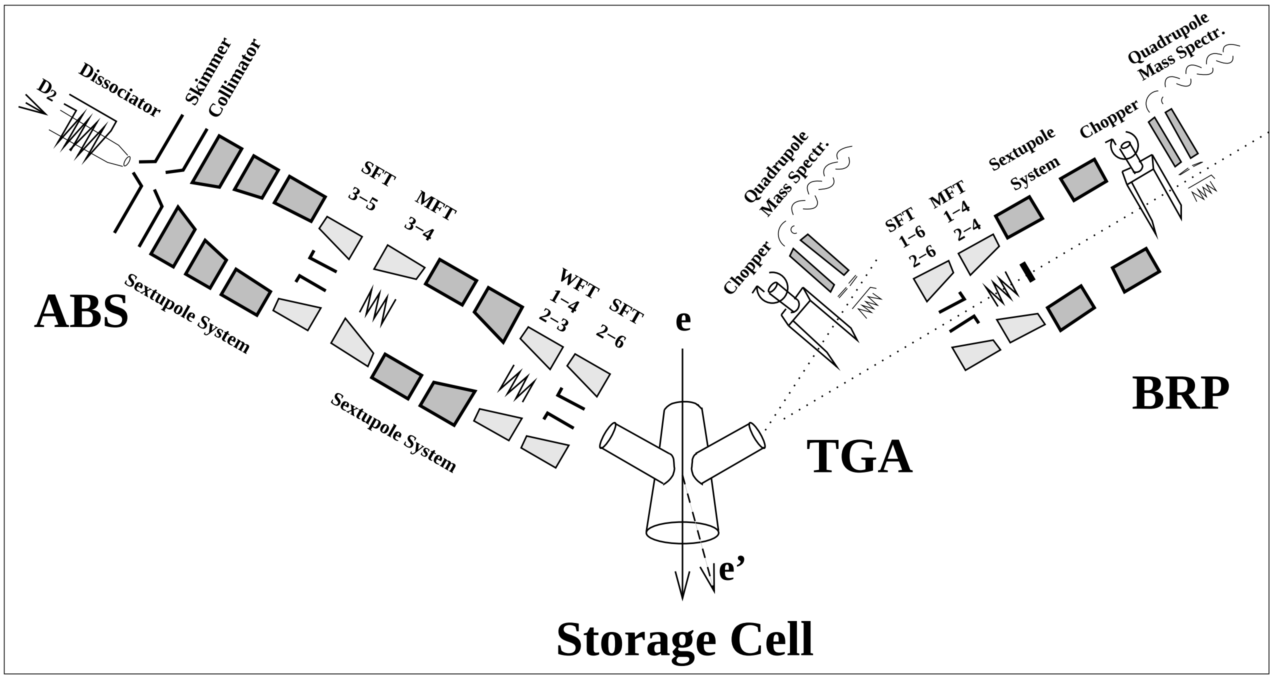
Special:

- Hyperfine states can be selected separately
- Negative T reachable!

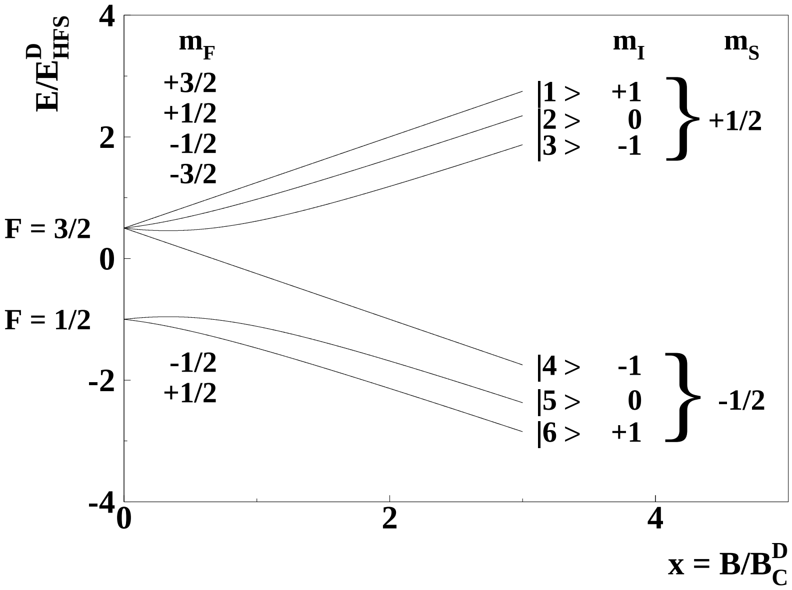
target state	injected	V	T
vector +	n^+	$+1$	$+1$
vector –	n^-	-1	$+1$
tensor –	n^0	0	-2

$\Rightarrow$ High T (at V=0) reachable

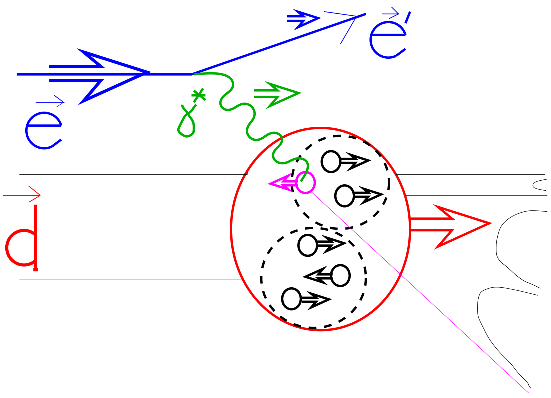
The HERMES-target



Hyperfine splitting in a magnetic field for deuterium:



Structure functions and interaction



x-section for DIS:

$$\left.\frac{d^2\sigma}{dE'd\Omega}\right|_{\text{Born}} = \frac{\alpha^2}{2MQ^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

Leptonic and hadronic tensor each separable in

{symmetric}, spin *in*dependent and

[anti-symmetric], spin dependent part ⇒

$$L_{\mu\nu}W^{\mu\nu} = \underbrace{L_{\{\mu\nu\}}W^{\{\mu\nu\}}(F_1, F_2, b_1, b_2, b_3, b_4)}_{\text{unpolarized}} + $$
$$+ \underbrace{iL_{[\mu\nu]}W^{[\mu\nu]}(g_1, g_2)}_{\text{polarized inclusive x-section}}$$

(⇒ b_1 not sensitive to beam polarization, but implicitly dependent on target spin)

Leptonic and hadronic tensor

$$L^{\mu\nu} = L^{\{\mu\nu\}} \quad + \quad iL^{[\mu\nu]}(s)$$

spin *in*dependent and {symmetric}

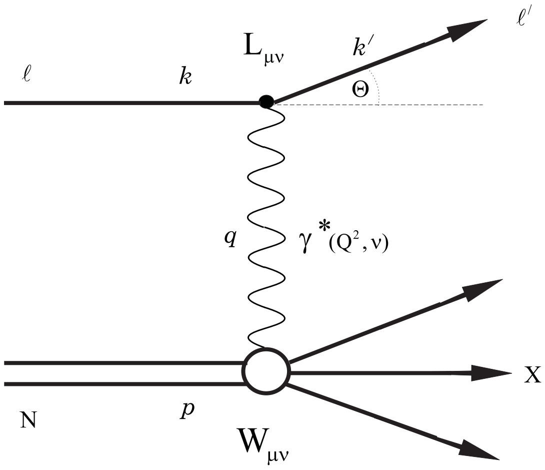
spin dependent and [anti symmetric]

$$W^{\mu\nu} = W^{\{\mu\nu\}}(F_1, F_2) \quad + \quad iW^{[\mu\nu]}(g_1, g_2) +$$

$$+W^{\{\mu\nu\}}(b_1, b_2, b_3, b_4)$$

implicitly dependent on target spin (additionally and only for Spin-1)

Deeply inelastic lepton nucleon scattering (inclusive measurement)



LORENTZ invariant kinematic variables

- square of four-momentum transfer

$$Q^2 = -q^2 \overset{\text{Lab.}}{\simeq} 2EE'(1-\cos\Theta)$$

- Bjørken scale variable

$$x = \frac{Q^2}{2\mathbf{pq}} = \frac{Q^2}{2M\nu} \qquad 0 \leq x \leq 1$$

- electron energy transferred to the nucleon

$$\nu = \frac{\mathbf{pq}}{M} \overset{\text{Lab.}}{\simeq} E - E'$$

- fraction of electron energy transferred to the nucleon

$$y = \frac{\mathbf{pq}}{\mathbf{pk}} \overset{\text{Lab.}}{=} \frac{\nu}{E} \qquad 0 \leq y \leq 1$$

Vector asymmetry in spin dependent DIS

Virtual photon asymmetries:

$$A_1(x) = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}} = \frac{g_1(x) - \gamma^2 g_2(x)}{F_1(x)}$$

$$A_2(x) = \frac{\sigma_{\mathrm{TL}}}{\sigma_{\mathrm{T}}} = \frac{\gamma(g_1(x) + g_2(x))}{F_1(x)}$$

$\Rightarrow$ write $A_{\|}$ as:

$$A_{\|} = D(A_1 + \eta A_2)$$

Used parameterizations

$$
\begin{aligned}
A_2 &\sim M_{\mathrm{p}} \frac{x}{\sqrt{Q^2}} \\
F_2^{\mathrm{p}} &= F_2^{\mathrm{p}}(\mathrm{ALLM}), \qquad F_2^{\mathrm{d}} = \frac{1}{2} F_2^{\mathrm{p}} \underbrace{(\frac{F_2^{\mathrm{n}}}{F_2^{\mathrm{p}}})}_{\mathrm{NMC}} \\
R &= R(1990)
\end{aligned}
$$

with

$$R = \sigma_{\mathrm{L}}/\sigma_{\mathrm{T}}$$

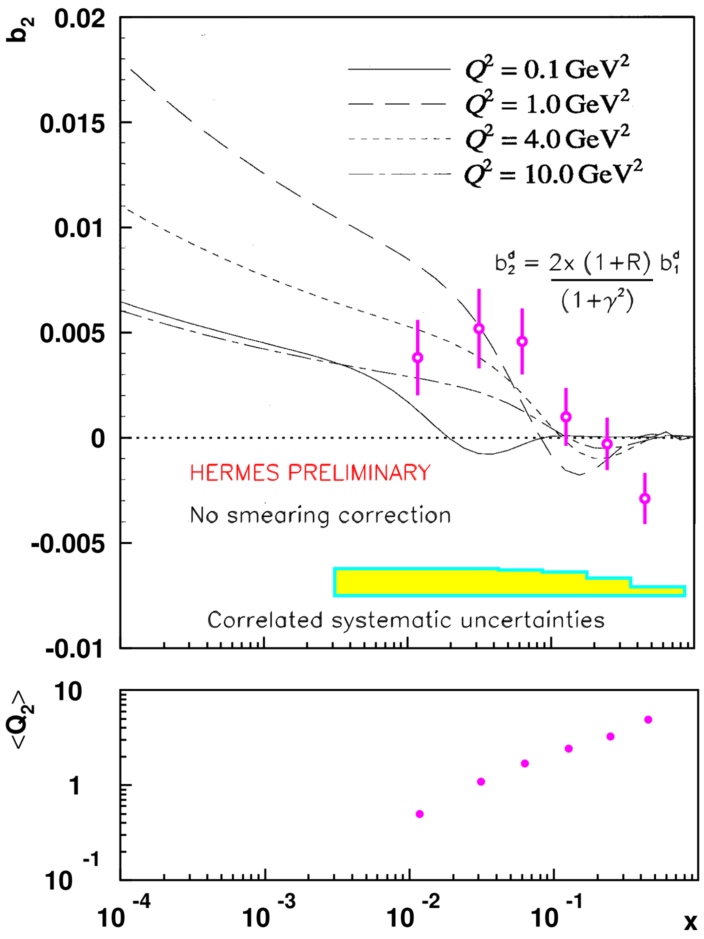
and using

$$F_1 = F_2 \frac{1+\gamma}{2x(1+R)}$$

Kinematic variables:

$$
\begin{aligned}
\gamma &= \frac{\sqrt{Q^2}}{\nu} \\
\eta &= \eta(x, Q^2) \\
D &= \frac{P_{\gamma^\star}}{P_{\mathrm{beam}}}
\end{aligned}
$$

$b_1^{\rm d}$, $b_2^{\rm d}$ and model calculations



$$\boxed{\mathcal{O}(b_1^{\rm d}) \overset{\surd}{\longleftrightarrow} \text{latest model calculations}}$$

- deuteron: D-state admixture
  $\Rightarrow$ el. quadrupole moment $\neq 0$

  $\hookrightarrow$ double scattering mechanisms with a significant contribution to b_1 at small x (e.g. Nikolaev *et al.*, *Phys. Lett.* B **398** (1997) 245)
- Callan-Gross relation $\Rightarrow$

$$b_2^{\rm d} = \frac{2x(1+R)}{1+\gamma^2} b_1^{\rm d}$$

Theory curves: Bora *et al.*, *Phys. Rev.* D **57** (1998) 6906