First Measurement of the Tensor-Polarized Structure Function b_1^d

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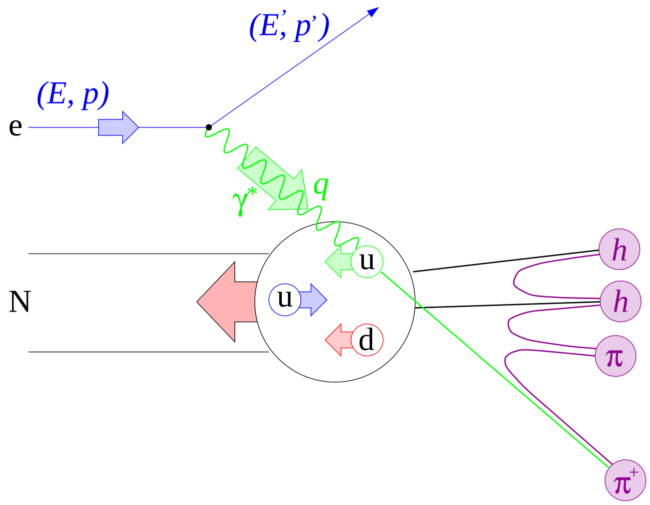
On behalf of the HERMES Collaboration

- Introduction on b_1
- The HERMES set-up
- HERMES b_1^d measurement
- Results
- Conclusions

Polarized DIS



Kinematics :

$$Q^2 \overset{lab}{=} 4EE' \sin^2(\tfrac{\theta}{2})$$
$$\nu \overset{lab}{=} E - E'$$
$$x \overset{lab}{=} \frac{Q^2}{2m\nu}$$
$$y \overset{lab}{=} \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k}$$

Cross section:

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

- lepton tensor

$$\mathbf{L}_{\mu\nu} = \mathbf{k}_\mu \mathbf{k}'_\nu + \mathbf{k}_\nu \mathbf{k}'_\mu + \mathbf{g}_{\mu\nu}\mathbf{k}\cdot\mathbf{k}' + \mathbf{m}\epsilon_{\mu\nu\lambda\sigma}\mathbf{q}^\lambda \mathbf{s}^\sigma$$

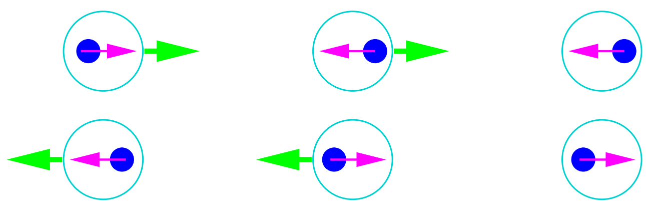
- hadronic tensor

$$\begin{aligned}
\mathbf{W}_{\mu\nu} = & - \mathbf{F_1}\,\mathbf{g}_{\mu\nu} + \mathbf{F_2}\frac{\mathbf{p}_\mu \mathbf{p}_\nu}{\nu} \\
& + \mathbf{i}\epsilon_{\mu\nu\lambda\sigma}\frac{\mathbf{q}^\lambda}{\nu}\left[\mathbf{g_1}\,\mathbf{s}^\sigma + \frac{\mathbf{g_2}}{\nu}\left((\mathbf{pq})\mathbf{s}^\sigma - (\mathbf{sq})\mathbf{p}^\sigma\right)\right] \\
\text{(for spin 1)} & - \mathbf{b_1}\,\mathbf{r}_{\mu\nu} + \frac{1}{6}\mathbf{b_2}\left(\mathbf{s}_{\mu\nu} + \mathbf{t}_{\mu\nu} + \mathbf{u}_{\mu\nu}\right) \\
& + \frac{1}{2}\mathbf{b_3}\left(\mathbf{s}_{\mu\nu} - \mathbf{u}_{\mu\nu}\right) + \frac{1}{2}\mathbf{b_4}\left(\mathbf{s}_{\mu\nu} - \mathbf{t}_{\mu\nu}\right)
\end{aligned}$$

The structure function b_1^d

In the quark parton model it measures the difference in the quark momentum distributions of helicity 1 and 0 targets.

q^+ q^- q^0



	Proton	Deuteron
$\mathbf{F_1}$	$\frac{1}{2}\sum_f e^2[q^+ + q^-]$	$\frac{1}{3}\sum_f e^2[q^+ + q^- + q^0]$
$\mathbf{g_1}$	$\frac{1}{2}\sum_f e^2[q^+ - q^-]$	$\frac{1}{2}\sum_f e^2[q^+ - q^-]$
$\mathbf{b_1}$	$--$	$\frac{1}{2}\sum_f e^2\left[2q^0 - (q^- + q^+)\right]$

$\mathbf{F_2, b_2}$ $\quad F_2 = 2x\,\frac{(1+R)}{(1+\gamma^2)}\,F_1 \qquad b_2 = 2x\,\frac{(1+R)}{(1+\gamma^2)}\,b_1$

$\mathbf{g_2, b_3, b_4}$ higher twist contributions

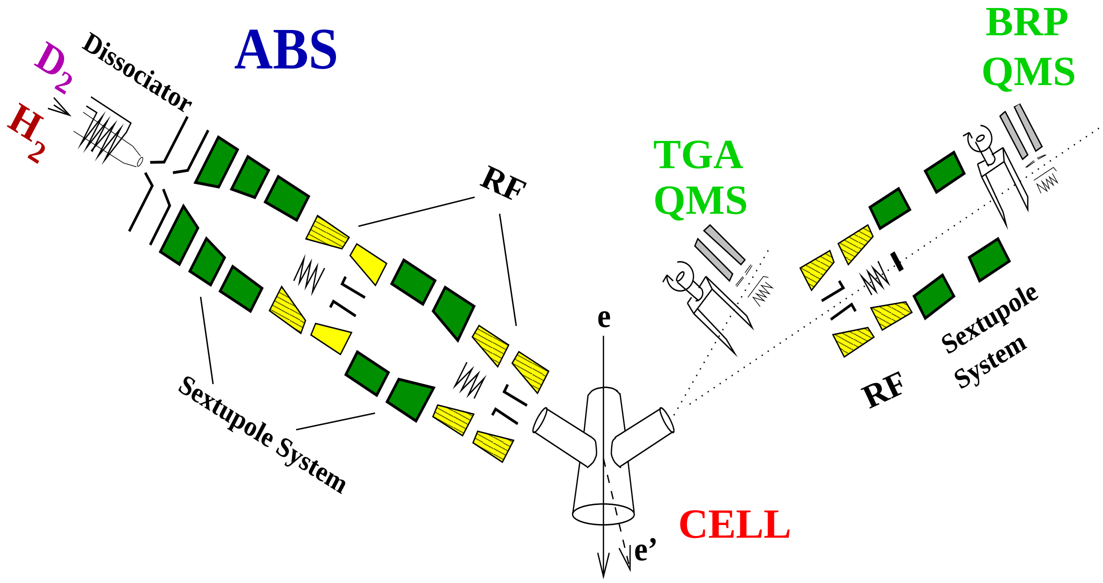
if b_1^d is exactly zero

$$q^0 = \frac{q^+ + q^-}{2} \quad \Rightarrow \quad \frac{1}{3}\sum_f e^2[q^+ + q^- + q^0] = \frac{1}{2}\sum_f e^2[q^+ + q^-]$$

$$\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{g_1}{F_1}$$

HERMES polarized target

Gaseous target



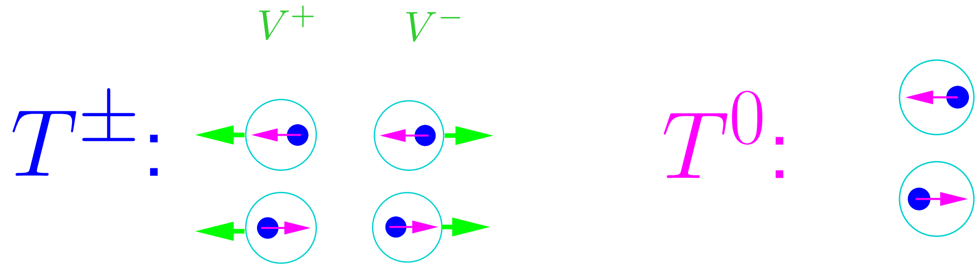
- ABS Atomic Beam Source
  dissociator plus beam optic with spin selectors

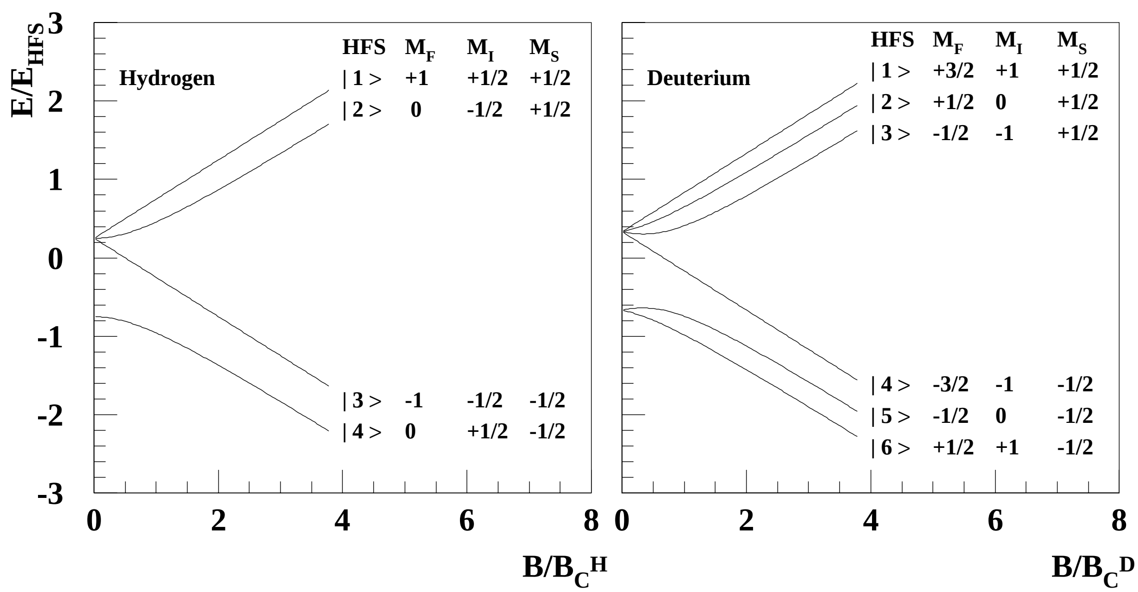
- Cell
  concentrates the target gas along the beam line
  (gain of $\sim$ 100 in the effective target density)

Target polarization reversed every 90 sec and continuously monitored

- TGA Target Gas Analyzer
  measures atomic and molecular abundances
- BRP Breit-Rabi Polarimeter
  measures atomic polarization
  (from the population in each of the hyperfine states)

Target polarization





Polarization	Injected state		V	T
Vector $+$	$\|1> + \|6>$	N^+	1	1
Vector $-$	$\|3> + \|4>$	N^-	-1	1
Tensor $\pm$	$\|3> + \|6>$	$N^\pm$	0	1
Tensor 0	$\|2> + \|5>$	N^0	0	-2

$$V = \frac{N^+ - N^-}{N^+ + N^- + N^0} \qquad \lesssim 1\%$$

$$T = \frac{N^+ + N^- - 2N^0}{N^+ + N^- + N^0} = \frac{N^\pm - 2N^0}{N^\pm + N^0} \qquad \sim 83\%$$

Cross sections

$$\sigma_{\rm meas} = \sigma_U \left[1 + P_B V A_{||} + \frac{1}{2} T A_T \right] \qquad \sigma_U = \frac{\sigma^+ + \sigma^- + \sigma^0}{3}$$

Vector asymmetry $(P_B = 1)$

Polarization	V	T	Cross section
Vector +	1	1	$\sigma^+ \sim \sigma_U \left[1 + V A_{\|\|} + \frac{1}{2} T A_T\right]$
Vector -	-1	1	$\sigma^- \sim \sigma_U \left[1 - V A_{\|\|} + \frac{1}{2} T A_T\right]$

$$V A_{||} = \frac{\sigma^+ - \sigma^-}{2\sigma_U} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \left[1 + \frac{1}{2} T A_T \right] \sim \frac{g_1}{F_1} \cdot D_\gamma V$$

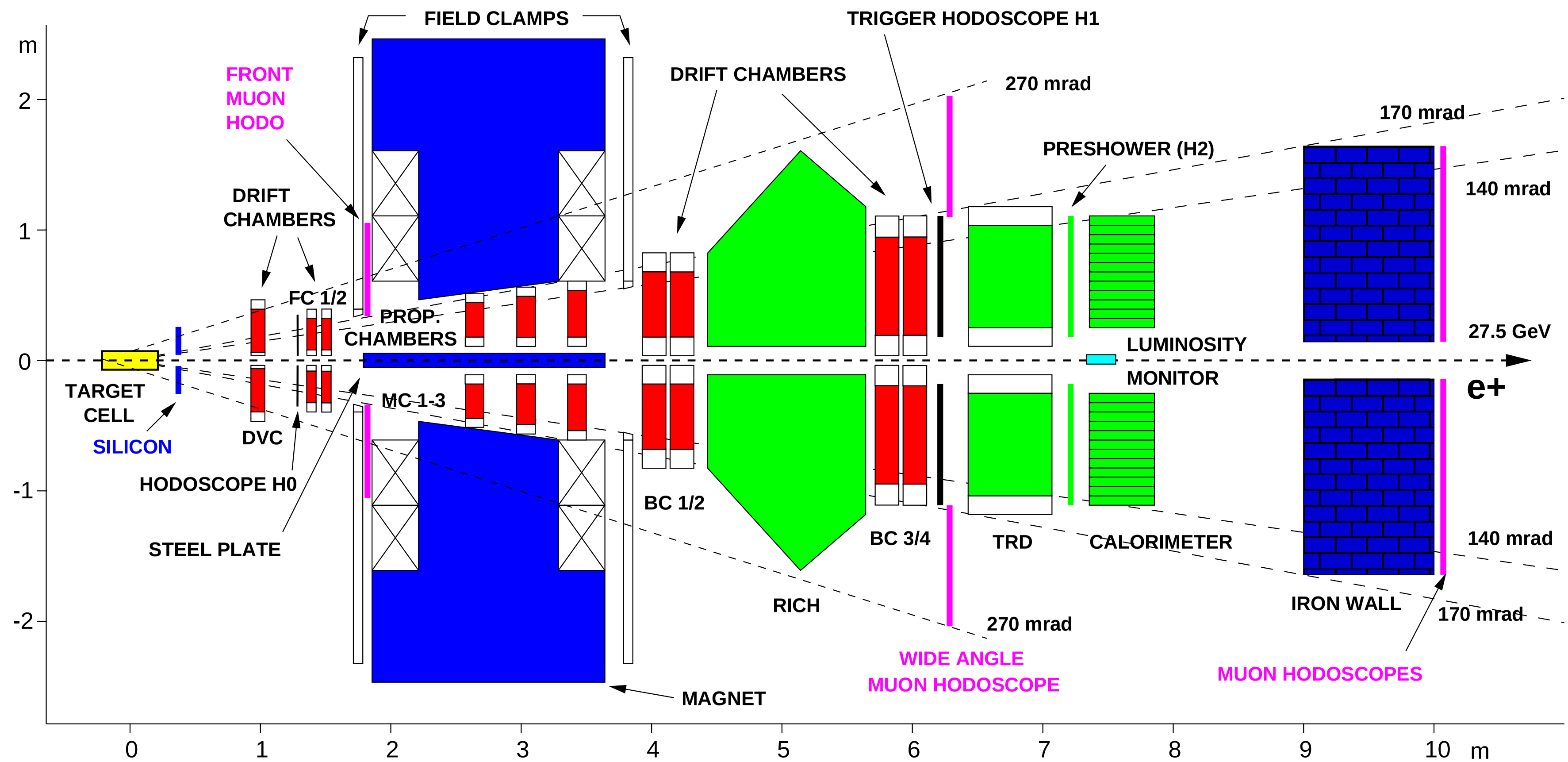
Tensor asymmetry (No P_B, No D_γ)

Polarization	V	T	Cross section $(P_B = 1)$
Vector + & -	~ 0	1	$\sigma^- + \sigma^+ \sim \sigma_U \left[1 + T A_T\right]$
Tensor 0	0	-2	$\sigma^0 \sim \sigma_U \left[1 - T A_T\right]$
Tensor $\pm$	0	1	$\sigma^\pm \sim \sigma_U \left[1 + \frac{1}{2} T A_T\right]$

$$T A_T = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{3\sigma_U} \sim -\frac{2}{3} \frac{b_1}{F_1} \cdot T$$

$$\mathrm{Cross-check} \qquad A_T = 2 \cdot \frac{\sigma^\pm - \sigma^0}{3\sigma_U}$$

HERMES spectrometer



Tracking

Drift chambers

$\delta p/p = 1.0 \div 2.0\%$

$\delta\theta \leq 0.6$ mrad

Particle ID

TRD, Preshower, Calorimeter

e ID eff. $= 98\ \%$

hadron cont. $\leq 0.5\ \%$

Luminosity monitor

Bhabha scattering

DATA

DATA 1 month of data taking in August 2000
$\sim$ 1.5 mill. polarized DIS events

Beam 62 % with negative polarization
38 % with positive polarization

for each target mode the opposite beam helicities are summed together, thus averaging out Bhabha and vector asymmetries from any residual electron and vector polarization in the target

Kinematic range

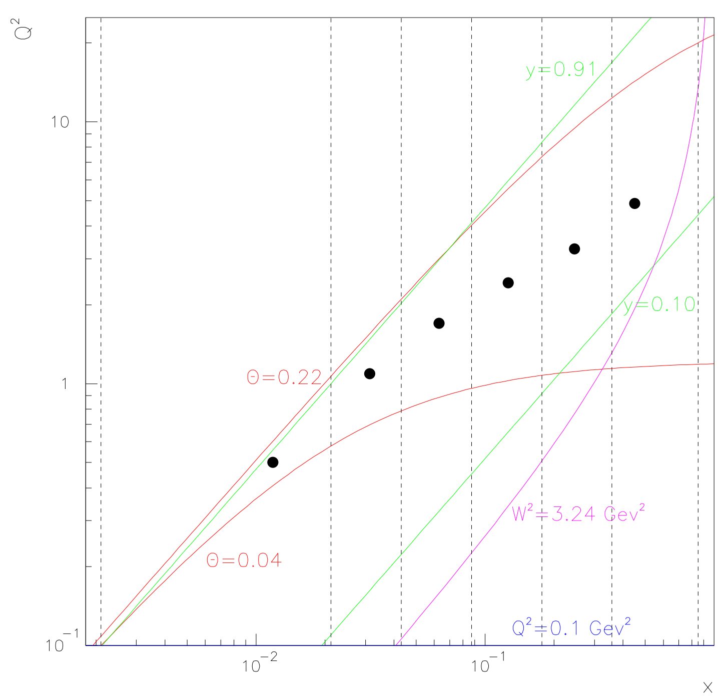
6 x-bins scheme over

$0.002 < x < 0.85$

$Q^2 > 0.1$ GeV ^{2}

$0.1 < y < 0.91$

$W^2 < 3.24$ GeV ^{2}



DATA

For each event

- quality requirement
- particle ID
- DIS requirements

$\Downarrow$

N^+, N^-, N^0: number of DIS events in the [x, y] bin

For each [x, y] bin and spin state

- subtraction of background arising from charge symmetric processes
- calculate the asymmetry

$$A_T = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{(\sigma^+ + \sigma^-) + \sigma^0} = \frac{1}{T} \cdot \frac{\left[\frac{N^+}{L^+}\right] + \left[\frac{N^-}{L^-}\right] - 2\left[\frac{n^0}{L^0}\right]}{\left[\frac{N^+}{L^+}\right] + \left[\frac{N^-}{L^-}\right] + \left[\frac{n^0}{L^0}\right]}$$

T: target polarization $(T < 1)$

L^+, L^-, L^0: dead-time corrected luminosities

- apply radiative corrections

Radiative background

$$A_T^{\text{meas}} = \frac{\Delta\sigma^{\text{pol}} + \text{RCs}^{\text{pol}}}{\sigma^{\text{unpol}}(1 + \text{RCs}^{\text{unpol}})}$$

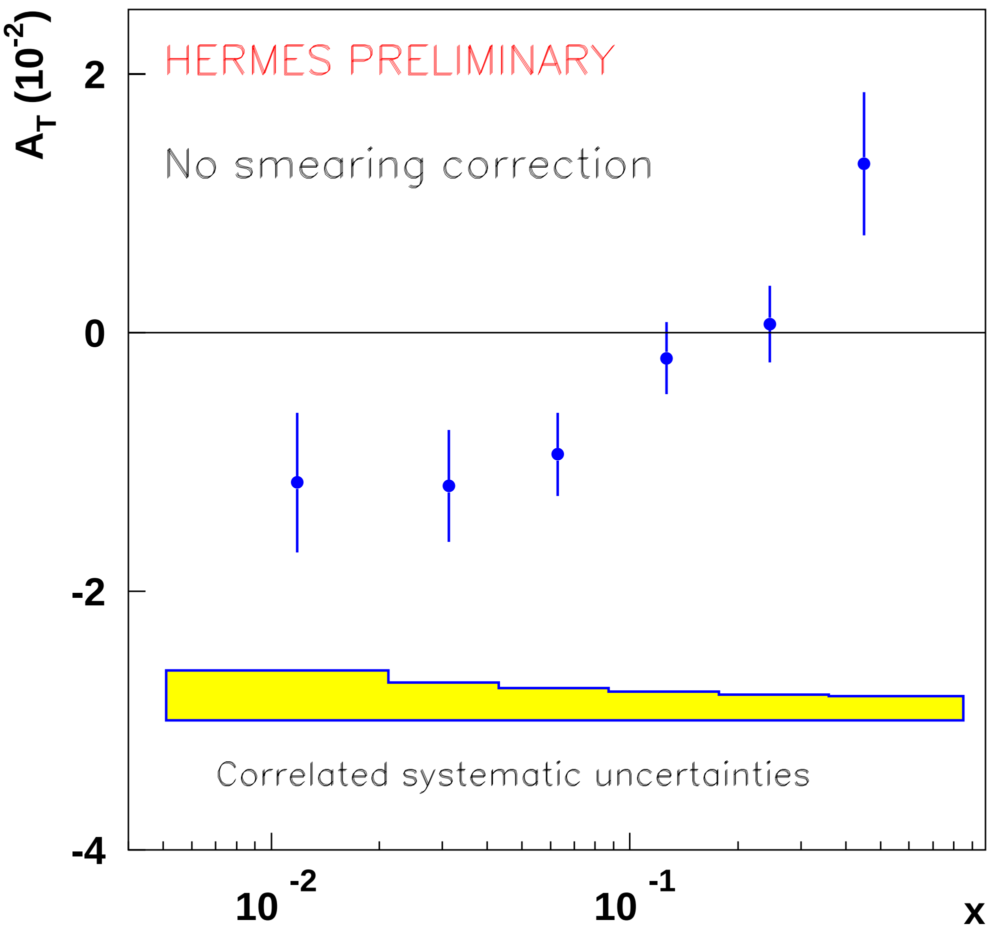
$$A_T^{\text{Born}} = \left[A_T^{\text{meas}} \cdot \left(1 + \frac{\sigma_{\text{bg}}^{\text{unpol}}}{\sigma_0^{\text{unpol}}} \right) - \frac{\sigma_{\text{bg}}^{\text{pol}}}{\sigma_0^{\text{unpol}}} \right]$$

where

- σ_0^{unpol} = unpolarized Born cross section
- $\sigma_{\text{bg}}^{\text{un}}$ = unpolarized radiative tails
  well known, give a negligible systematic uncertainty
- $\sigma_{\text{bg}}^{\text{pol}}$ = polarized radiative tails
  - $\sigma_{\text{bg}}^{\text{el}}$ from quadrupole elastic moment of Deuteron
    Kobushkin and Syamtomov parameterization
    Phys. At. Nucl. 58 (1995) 1477
  - $\sigma_{\text{bg}}^{\text{qel}}$ zero
  - $\sigma_{\text{bg}}^{\text{dis}}$ zero (for the moment)

Corrections computed from POLRAD

Tensor asymmetry



Systematic uncertainty dominated by the small difference in the target density between the four injection modes

A_T is less than 2 %

$$A_{||} = A_{||}^{\mathrm{meas}} \cdot \left[1 + \frac{1}{2} T A_T \right]$$

The bias on $A_{||}$ then can be bound to be less than $[0.5 \div 1]$ %

b_1^d structure function

Assuming:

- $F_1^d = \frac{1+\gamma^2}{2x(1+R)} \cdot F_2^d$ $\qquad$ $F_2^d = F_2^p \cdot \left(1 + \frac{F_2^n}{F_2^p}\right)$

  $\frac{F_2^n}{F_2^p}$: NMC fit, Nucl. Phys. B371 (1992) 3

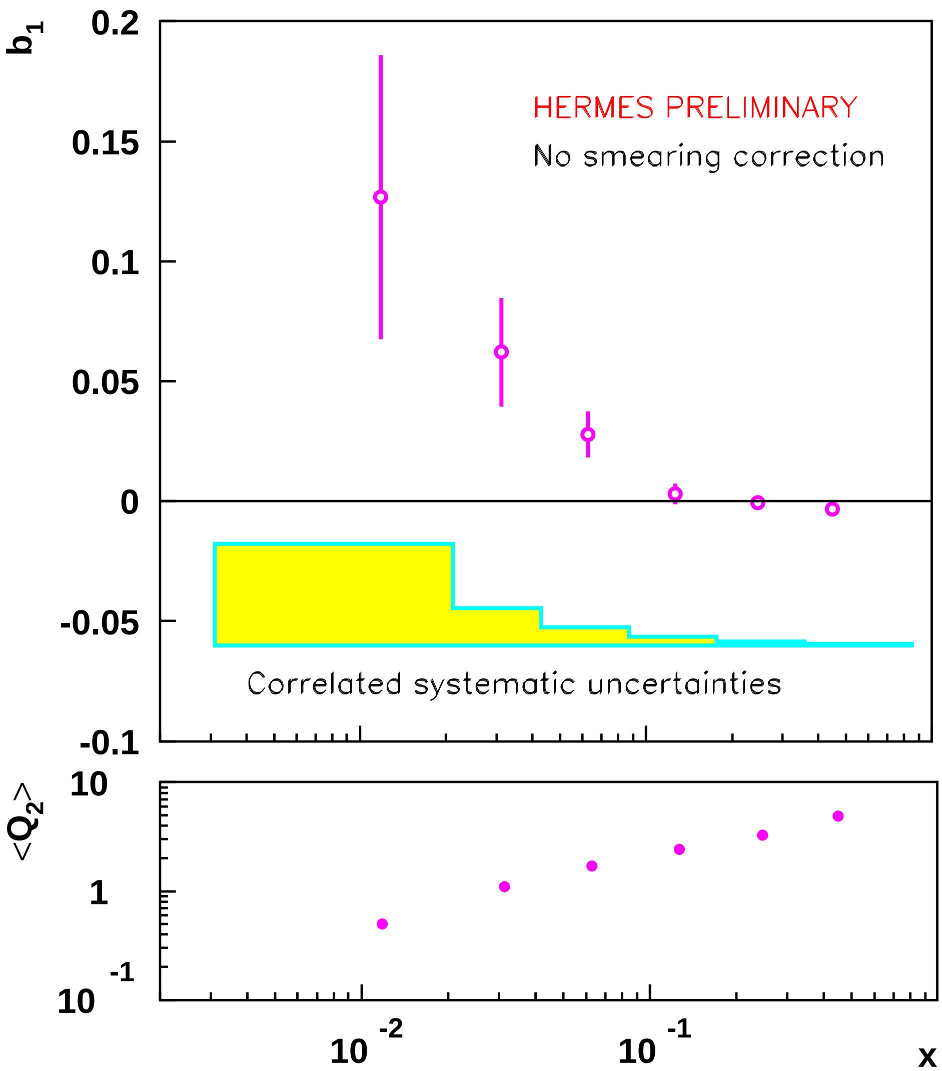
  F_2^p: ALLM97 Abramowicz and al., hep-ph 9712415

  $\mathbf{R} = \sigma_\mathbf{L}/\sigma_\mathbf{T}$ Whitlow and al., Phys. Lett. B250 (1990) 193

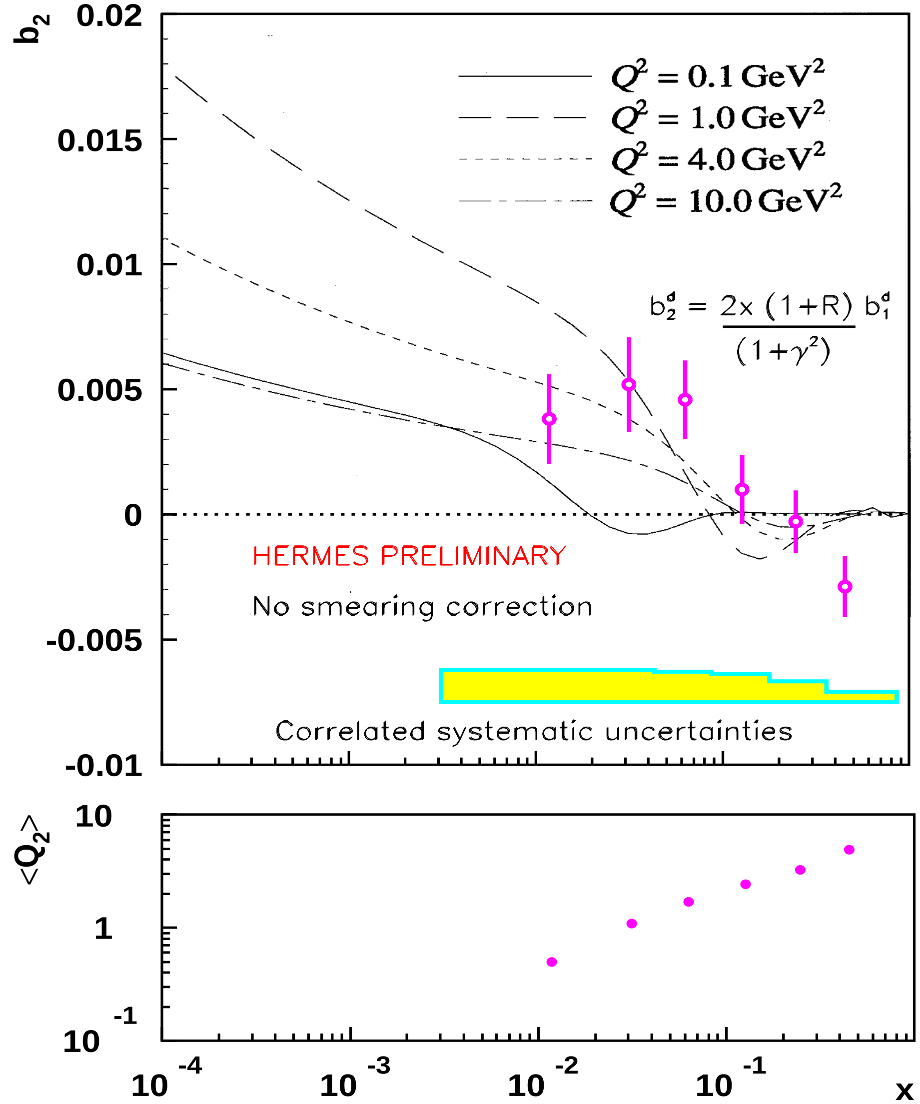
- no higher twist effects (b_3, $b_4 = 0$)

- negligible DIS radiative tails

$$b_1 = -\frac{3}{2} \cdot A_T \cdot F_1^d$$



b_2^d structure function



- H. Khan and P. Hoodbhoy, Phys. Rev. C44 (1991) 1219
  $b_1^d \lesssim 10^{-4}$
- F. E. Close and S. Kumano, Phys. Rev. D42 (1990) 2377
  $\int b_1(x)dx = 0$
- M. Strikman, Hughes and Cavata, World Scientific, Singapore (1995)
- N. N. Nikolaev and W. Schafer, Phys. Lett. B398 (1997) 245
- J. Edelmann, G. Piller, W. Weise, Phys. Rev. C57 (1998) 3392
- K. Bora and R. L. Jaffe, Phys. Rev. D57 (1998) 6906
  b_1^d significantly different from zero at low x

Conclusions

- for the first time the b_1^d structure function is measured

- HERMES measures that the polarized structure function b_1^d is different from zero in the kinematic range

  $0.002 < x < 0.85 \qquad 0.1 < y < 0.91$

- there is an indication for a rising b_1^d at low-x, as predicted by the recent double-scattering models

- any bias on $A_{||}$ from tensor asymmetry was find to be less than $[0.5 \div 1]$ % in the HERMES kinematic range

- Outlook:
  - refine systematic study to further reduce uncertainty
  - unfolding of b_1^d including smearing effects