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

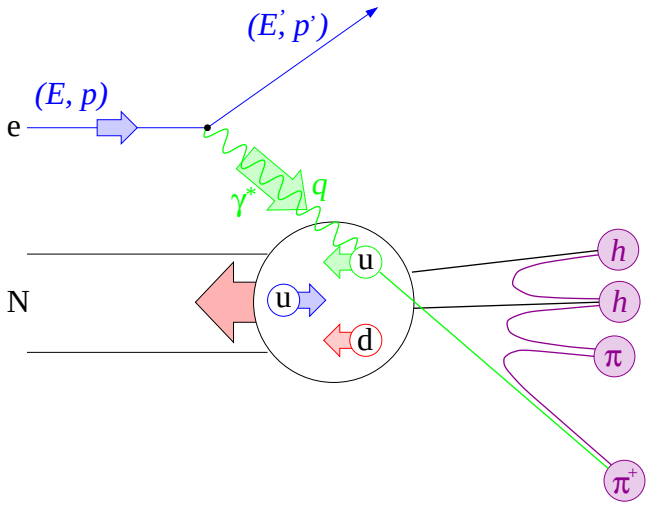
M. Contalbrigo
Ferrara University and INFN

September 9 - 2002
BNL - SPIN 2002

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

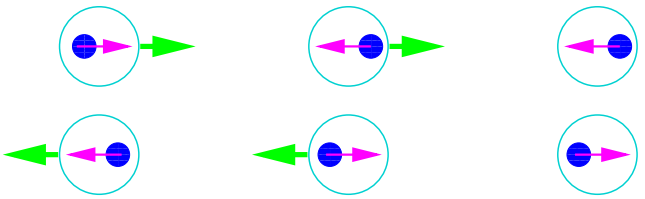
$$\mathbf{W}_{\mu\nu} = -\mathbf{F_1}\,\mathbf{g}_{\mu\nu} + \mathbf{F_2}\frac{\mathbf{p}_\mu\mathbf{p}_\nu}{\nu} + \mathbf{i}\epsilon_{\mu\nu\lambda\sigma}\frac{\mathbf{q}^\lambda}{\nu}\left[\mathbf{g_1}\,\mathbf{s}^\sigma + \frac{\mathbf{g_2}}{\nu}\left((\mathbf{pq})\mathbf{s}^\sigma - (\mathbf{sq})\mathbf{p}^\sigma\right)\right]$$

$$(\text{for spin } 1) \quad - \mathbf{b_1}\,\mathbf{r}_{\mu\nu} + \frac{1}{6}\mathbf{b_2}\left(\mathbf{s}_{\mu\nu} + \mathbf{t}_{\mu\nu} + \mathbf{u}_{\mu\nu}\right) + \frac{1}{2}\mathbf{b_3}\left(\mathbf{s}_{\mu\nu} - \mathbf{u}_{\mu\nu}\right) + \frac{1}{2}\mathbf{b_4}\left(\mathbf{s}_{\mu\nu} - \mathbf{t}_{\mu\nu}\right)$$

The structure function b_1^d

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

q^+ q^- q^0



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

$F_2,\ b_2$	$F_2 = 2x\,\frac{(1+R)}{(1+\gamma^2)}\,F_1$	$b_2 = 2x\,\frac{(1+R)}{(1+\gamma^2)}\,b_1$
$g_2,\ b_3,\ b_4$	higher twist contributions	

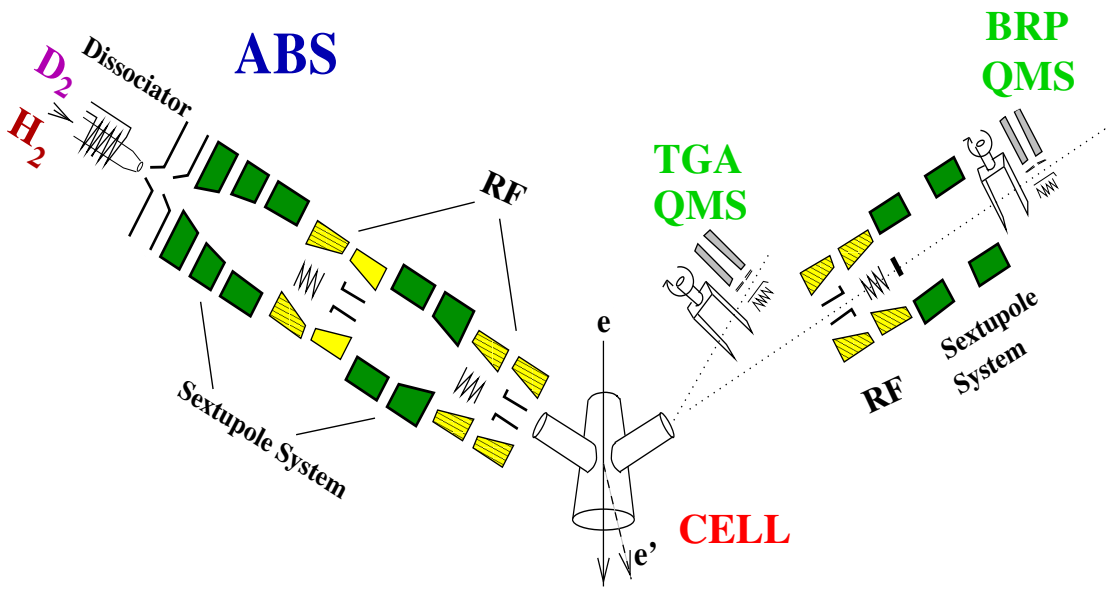
if b_1^d is exactly zero

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

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

HERMES polarized target

Gaseous target



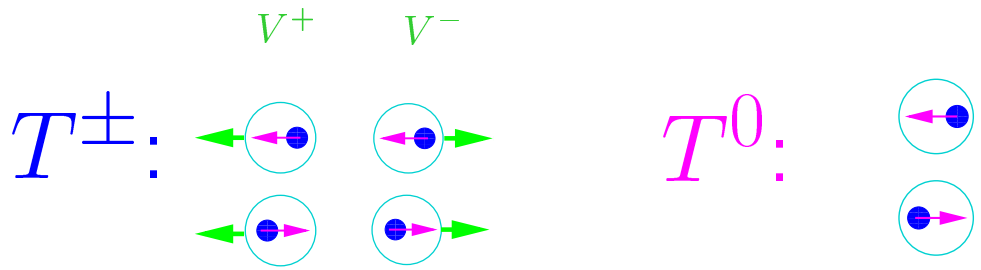
- ABS Atomic Beam Source
  dissociator plus beam optic with spin selectors

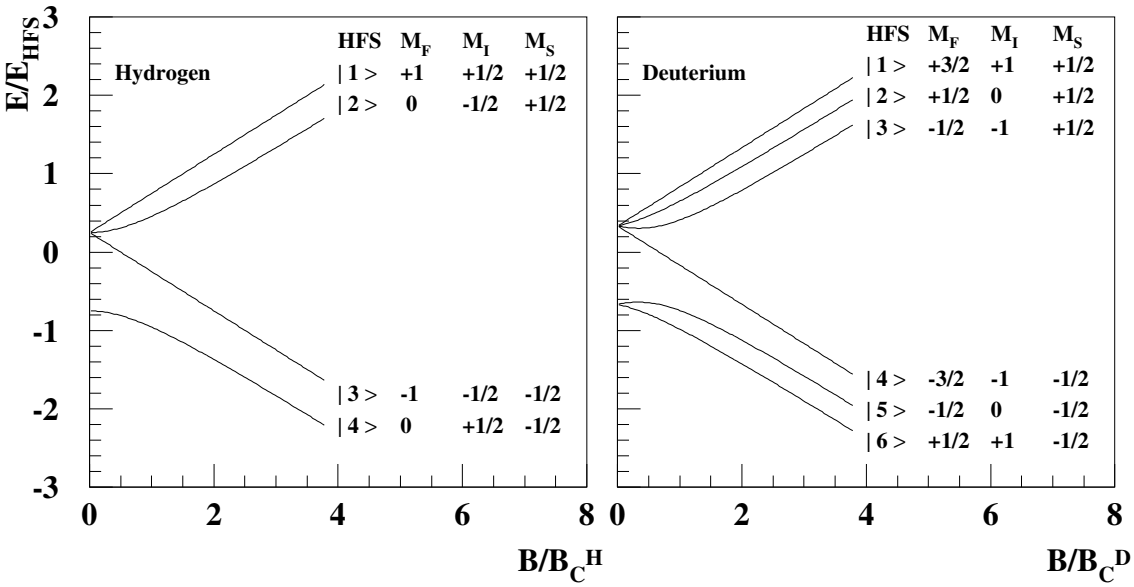
- Cell
  concentrates the target gas along the beam line
  (gain of $\sim$ 100 in the effective target density)

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 ±	$\|3>+\|6>$	$N^{\pm}$	0	1
Tensor 0	$\|2>+\|5>$	N^0	0	-2

$$T = \frac{N^+ + N^- - 2N^0}{N^+ + N^- + N^0} = \frac{N^{\pm} - 2N^0}{N^{\pm} + N^0}$$

Target polarization

b_1^d enters in the symmetric part of the hadronic tensor,
therefore is not sensitive to the beam polarization

no P_B no D_γ

This result bases on the excellent HERMES target performances

$< T > = \ 0.83 \pm 0.03$ $< V > = \ 10^{-2}$

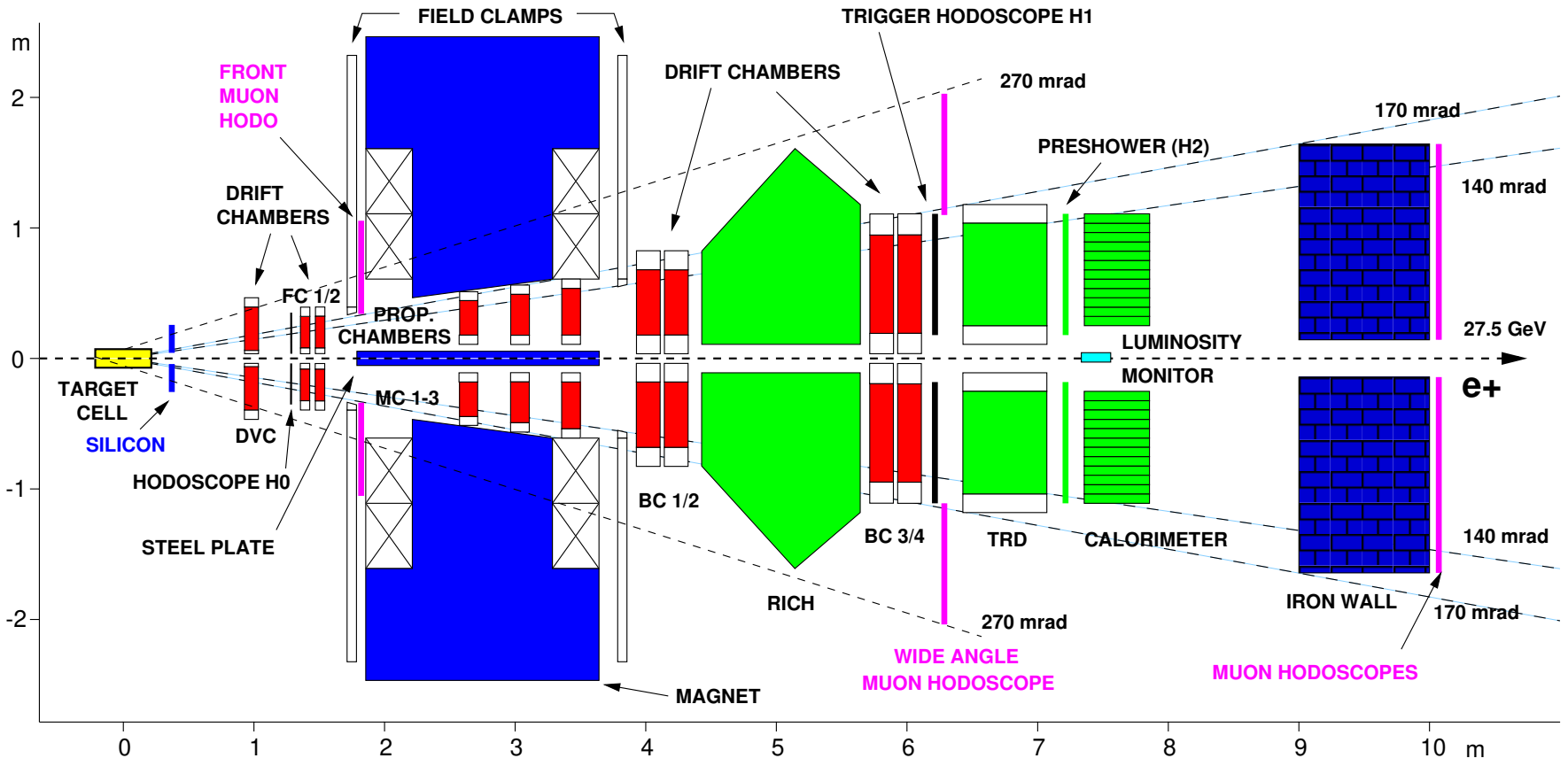
No dilution from non-polarizable substrate

Target polarization

$$\mathbf{P_t} \ = \ \alpha_0 \alpha_r \cdot \mathbf{P_a} \ + \ \alpha_0 (1 - \alpha_r) \cdot \mathbf{P_m}$$

- α_0 Atomic fraction entering the cell
- $\mathbf{P_a}$ Polarization of atoms
- α_r Atomic fraction which survives recombination
- $\mathbf{P_m}$ Residual polarization of recombined atoms

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

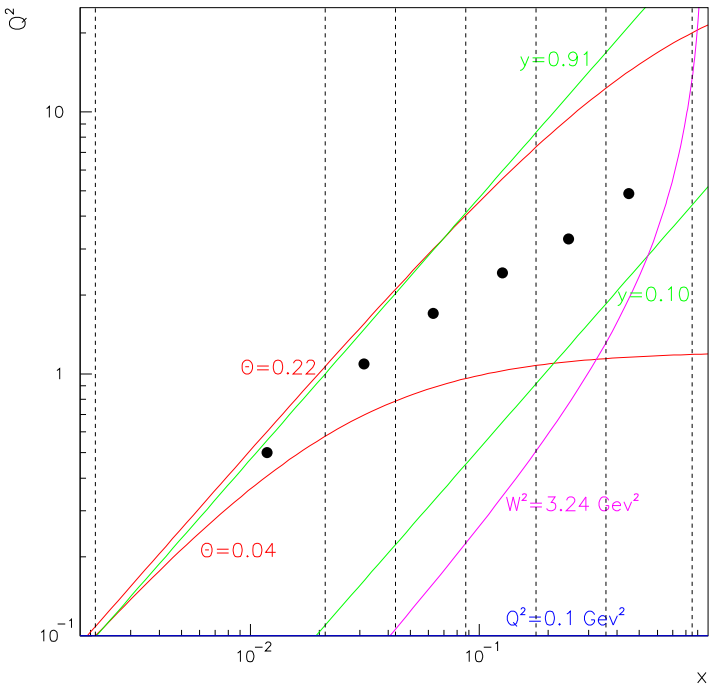
6 x-bins scheme over

$0.002 < x < 0.85$

$Q^2 > 0.1$ GeV^2

$0.1 < y < 0.91$

$W^2 < 3.24$ GeV^2



Cross sections

$$\sigma_{\rm meas} \;=\; \sigma_U \left[1 \;+\; P_B V A_{||} \;+\; \frac{1}{2} T A_T\right]$$

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

Unpolarized cross section $\qquad \sigma_U \;=\; \frac{\sigma^+ + \sigma^- + \sigma^0}{3}$

Vector asymmetry

$$A_{||} \;=\; \frac{\sigma^+ \,-\, \sigma^-}{2\sigma_U} \;=\; \frac{\sigma^+ \,-\, \sigma^-}{\sigma^+ \,+\, \sigma^-} \left[1 + \frac{1}{2} T A_T\right] \qquad \sim \frac{g_1}{F_1}$$

Tensor asymmetry

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

$$A_T \;=\; 2 \cdot \frac{\sigma^{\pm} - \sigma^0}{3\sigma_U}$$

Cross-check $\qquad \frac{(\sigma^+ + \sigma^-) - 2\sigma^{\pm}}{(\sigma^+ + \sigma^-) + \sigma^{\pm}} \;\sim\; 0$

DATA

For each event

- quality requirement
- particle ID
- DIS requirements

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

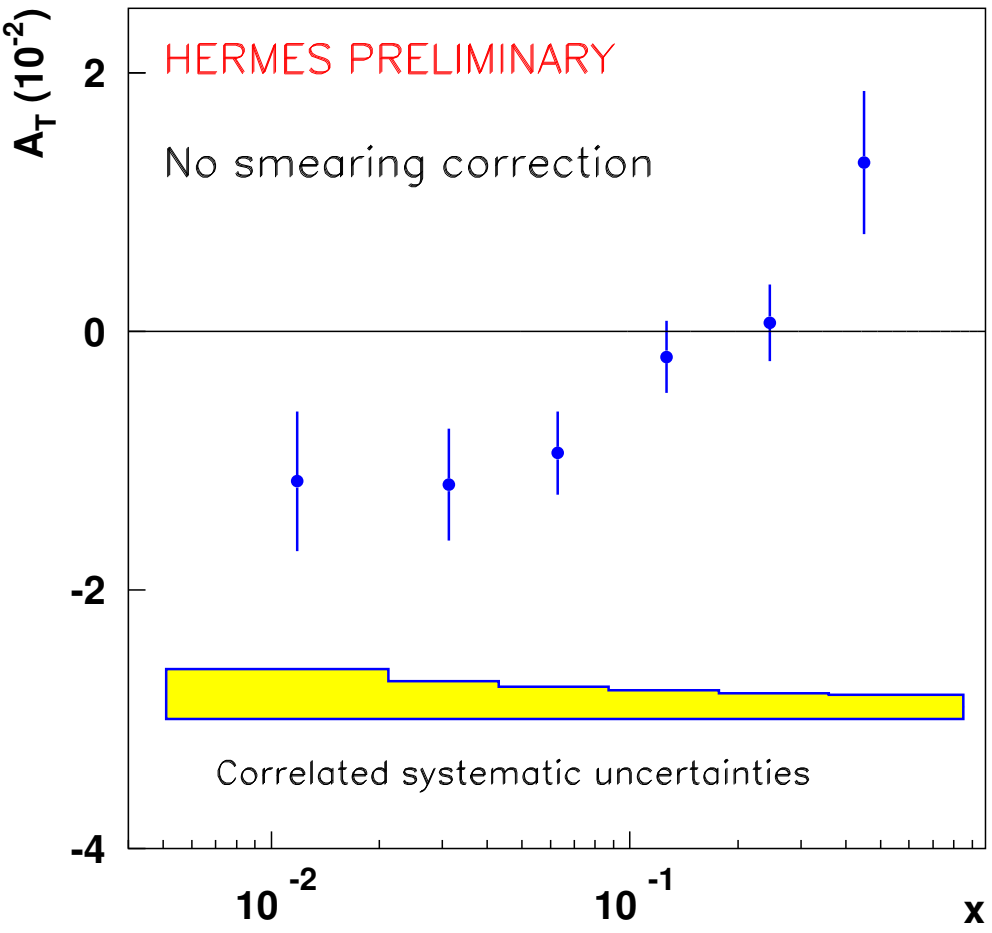
$$A_T^{\rm Born} = \left[A_T^{\rm meas} \cdot \left(1 + \frac{\sigma_{\rm bg}^{\rm unpol}}{\sigma_0^{\rm unpol}} \right) - \frac{\sigma_{\rm bg}^{\rm pol}}{\sigma_0^{\rm unpol}} \right]$$

where

- $\sigma_0^{\rm unpol}$ = unpolarized Born cross section
- $\sigma_{\rm bg}^{\rm un}$ = unpolarized radiative tails
  well known, give a negligible systematic uncertainty
- $\sigma_{\rm bg}^{\rm pol}$ = polarized radiative tails
  - $\sigma_{\rm bg}^{\rm el}$ from quadrupole elastic moment of Deuteron
    Kobushkin and Syamtomov parameterization
    Phys. At. NUcl. 58 (1995) 1477
  - $\sigma_{\rm bg}^{\rm qel}$ zero
  - $\sigma_{\rm bg}^{\rm dis}$ 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

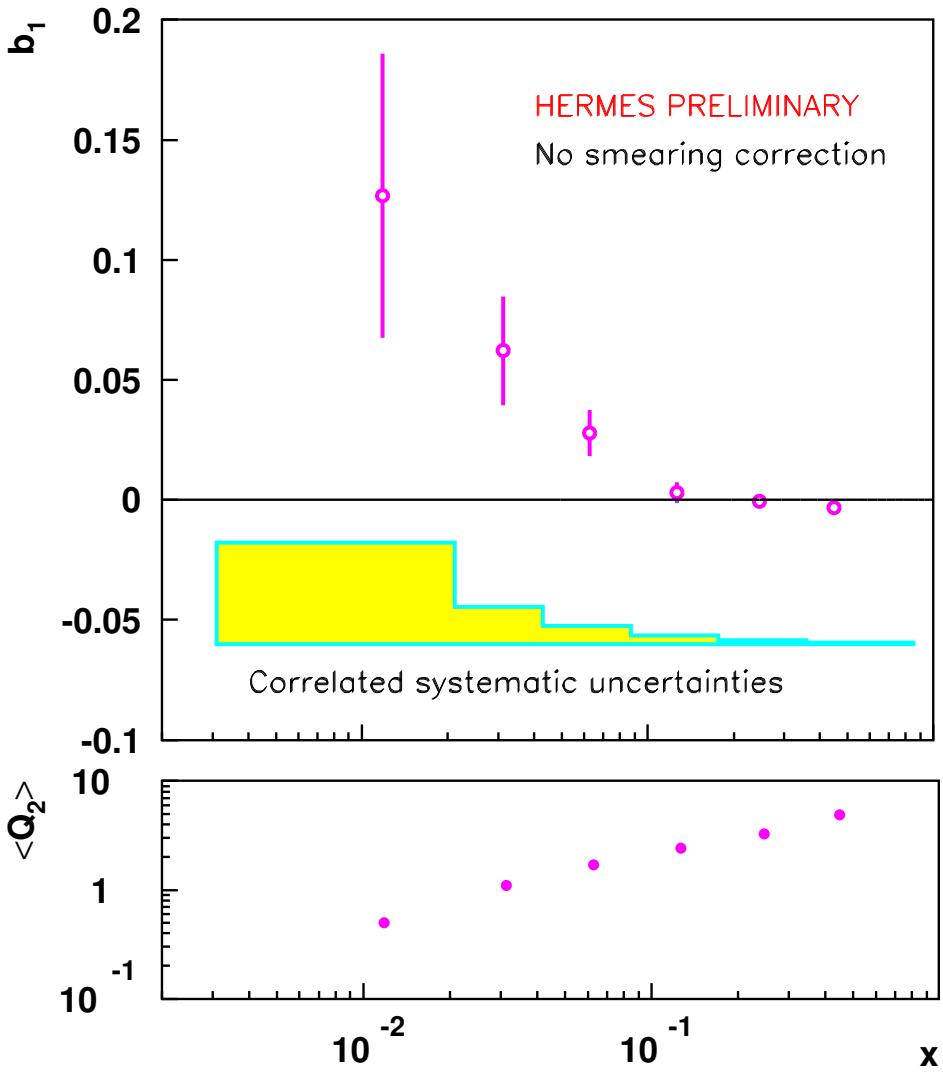
  F_2^p: ALLM97 Abramowicz and al., hep-ph 9712415

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

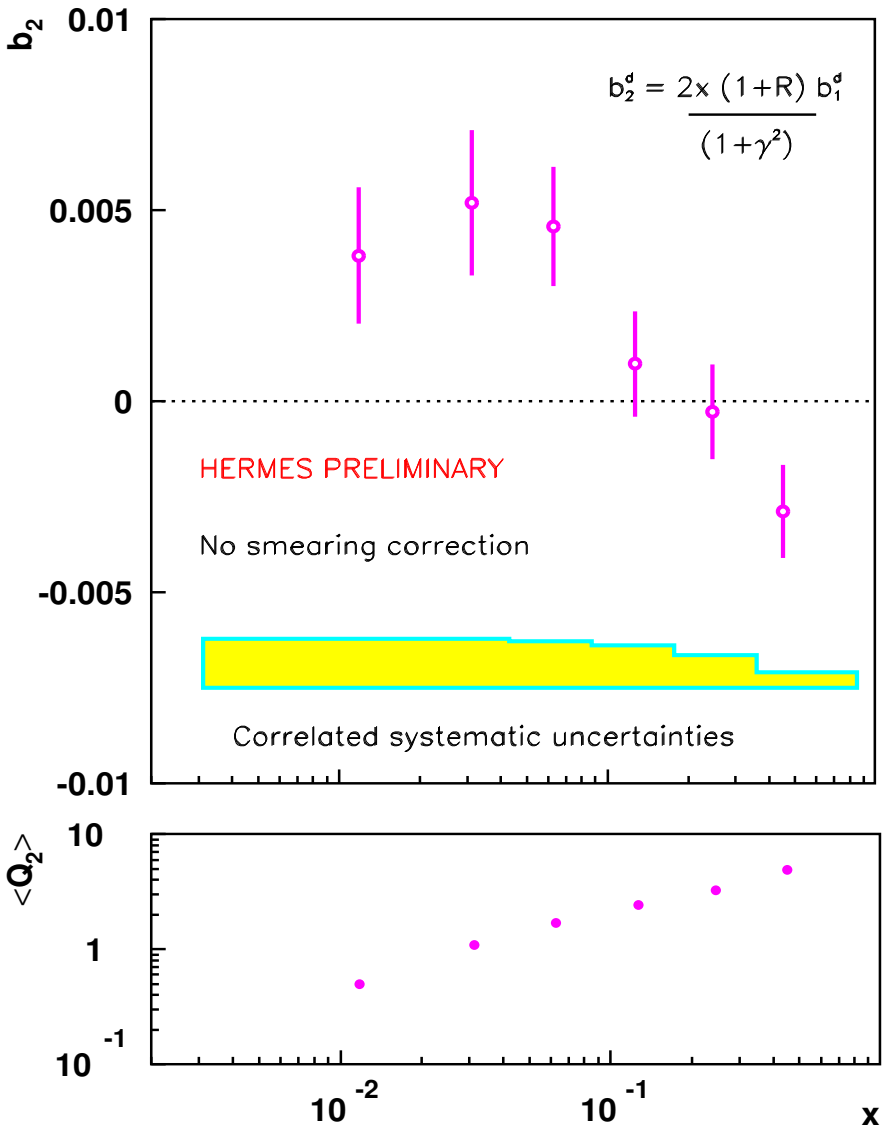
- no higher twist effects $(b_3,\, b_4 = 0)$

- negligible DIS radiative tails

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

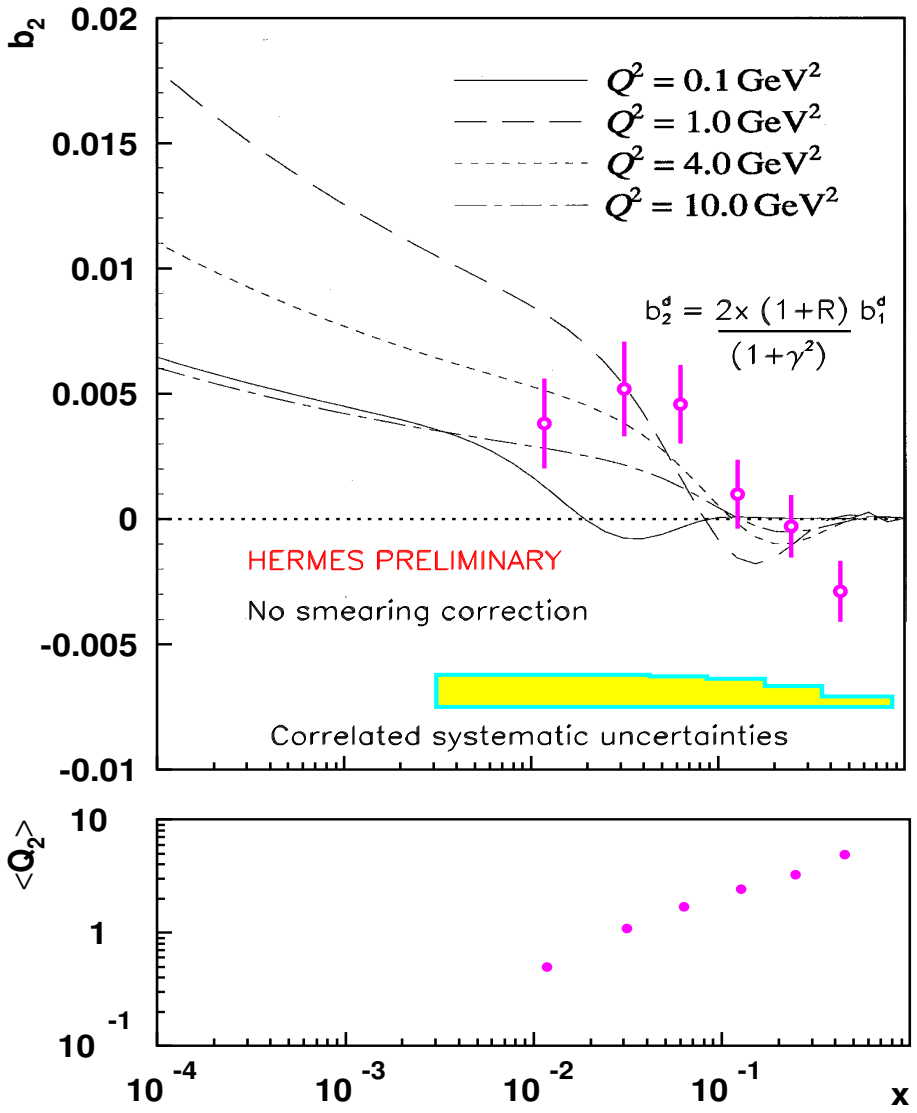


b_2^d structure function



- 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
  $\int b_1(x)dx = 0$
- N. N. Nikolaeva and W. Schafer, Phys. Lett. B398 (1997) 245
- J. Edelmann, G. Piller, W. Weise, Z. Phys. A357 (1997) 129
- K. Bora and R. L. Jaffe, Phys. Rev. D57 (1998) 6906
  b_1^d significantly different from zero at low x

b_2^d structure function



- 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 Deuterium target can be easily flipped between the three possible helicity states. It allows to measure b_1^d with two additional independent cross-checks.

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

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

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

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