The measurement of the tensor structure function $b_1^d$ of the deuteron with the HERMES-experiment

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for the HERMES-collaboration

Euresco Conference:

Electromagnetic Interactions with Nucleons and Nuclei

Santorini, Oct. 8, 2003
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**DIS on a Spin-1 target at HERMES**

Longitudinally polarized $e^+$-beam (27.6 GeV) hits polarized internal gaseous deuterium target:
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**The HERMES spectrometer**

- **Acceptance:** $40 < \theta < 220$ mrad
- **Momentum resolution:** $\frac{\delta p}{p} = 2\%$; Angular resolution: $0.3 - 0.6$ mrad;
- **Calorimeter:** $\frac{\delta E}{E} = \frac{(5.1 \pm 1.1)}{\sqrt{E[GeV]}} \%$
- **PID:** RICH, TRD, preshower, calo
- **Efficiency of electron ID:** 98-99 $\%$
- **Hadron contamination:** $< 1\%$
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**Polarized atomic deuterium target**

Deuteron (Spin-1):

$$m = -1 \quad 0 \quad +1$$

polarizations:

**vector**

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

**tensor**

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

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

HERMES target: Atomic Beam Source + gas analyzing system

Special:

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

<table>
<thead>
<tr>
<th>target state</th>
<th>injected</th>
<th>$V$</th>
<th>$T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>vector +</td>
<td>$n^+$</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>vector −</td>
<td>$n^-$</td>
<td>−1</td>
<td>+1</td>
</tr>
<tr>
<td>tensor +</td>
<td>$n^+ + n^-$</td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>tensor −</td>
<td>$n^0$</td>
<td>0</td>
<td>−2</td>
</tr>
</tbody>
</table>

⇒ High $T$
(at $V=0$)
reachable

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Structure functions in the Quark Parton Modell

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

Structure functions:

<table>
<thead>
<tr>
<th>Spin-$\frac{1}{2}$</th>
<th>Spin-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1 = \frac{1}{2} \sum q e_q^2 (q^\uparrow + q^\downarrow)$</td>
<td>$F_1 = \frac{1}{3} \sum q e_q^2 (q^\uparrow + q^\downarrow + q^0)$</td>
</tr>
<tr>
<td>$g_1 = \frac{1}{2} \sum q e_q^2 (q^\uparrow - q^\downarrow)$</td>
<td>$g_1 = \frac{1}{2} \sum q e_q^2 (q^\uparrow - q^\downarrow)$</td>
</tr>
<tr>
<td>$b_1 = \frac{1}{2} \sum q e_q^2 (2q^0 - (q^\uparrow + q^\downarrow))$</td>
<td></td>
</tr>
</tbody>
</table>
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**Tensor asymmetry $A_T$ from HERMES-data**

- Cyclic alternation of target injection mode

  $$\Rightarrow$$ measured cross sections $\sigma^{\uparrow\downarrow}$, $\sigma^{\uparrow\uparrow}$, $\sigma^0$  \hspace{1cm} (\sigma^\pm)

  $b_1$ not sensitive to beam polarization $P_B$ \Rightarrow sum up!

- 

  $$\sigma = \sigma_{\text{unpol}} \left[ 1 + P_B V A_\parallel + \frac{1}{2} TA_T \right]$$

  $$\left( \sigma_{\text{unpol}} = \frac{1}{3} \cdot (\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow} + \sigma^0) \right)$$

- Inclusive tensor asymmetry:

  $$A_T := \frac{(\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}) - 2\sigma^0}{3\sigma_{\text{unpol}}} = -\frac{2}{3} b_1 \frac{b_1}{F_1}$$

- Inclusive vector asymmetry:

  $$A_\parallel := \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{2\sigma_{\text{unpol}}} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \cdot \left[ 1 + \frac{1}{2} TA_T \right] \sim \frac{g_1}{F_1}$$
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Results: tensor asymmetry $A_T$

- $A_T = \mathcal{O}(1\%) \Rightarrow$ Impact on $g_1$ small
- $x \to 0$: $|A_T| > |A_\parallel|$
The measurement of the tensor structure function $b_1^d$ with the HERMES-experiment

Results: tensor structure function $b_1^d$

- $b_1^d \gg \mathcal{O}(10^{-3}..10^{-4})$ (older models)
- $x \to 0$: $b_1^d \nearrow$, here even $b_1^d > g_1^d$
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$b_1^d, b_2^d$ and model calculations

$O(b_1^d) \leftarrow \checkmark$ latest model calculations

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

$\leftarrow$ 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 $\Rightarrow$

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

The measurement of the tensor structure function $b_d^1$ with the HERMES-experiment

Summary

- **First measurement** of the tensor structure function $b_d^1(x, Q^2)$ of the deuteron with the HERMES-experiment due to special features of the gaseous HERMES target

- Tensor asymmetry $A_T = \mathcal{O}(1\%) \Rightarrow$ small impact on $g_1$ measurement

- $b_d^1$ large for small $x$!

- Measured $b_d^1$ in good agreement with latest model calculations

- Interpretation of $b_1$:
  - Reason for $b_1 \neq 0$: double-scattering mechanisms
  - Measure for the deviation of the nucleus from a trivial bound state of p and n
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**The HERMES-target**

![Diagram of the HERMES-target](image)

Hyperfine splitting in a magnetic field for deuterium:

\[
\begin{align*}
F = \frac{3}{2} & : m_F = +3/2, +1/2, -1/2, -3/2 \\
F = \frac{1}{2} & : m_F = -1/2, +1/2
\end{align*}
\]

\[
E/E_{\text{HFS}} = \frac{x_{\text{HFS}}}{x} = \frac{(1 - B/B_D)}{(1 - x_{\text{HFS}})}
\]

where

\[
x = \frac{B}{B_D}
\]

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**Structure functions and interaction**

x-section for DIS:

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

Leptonic and hadronic tensor each separable in

{symmetric}, spin independent and

[anti-symmetric], spin dependent part $\Rightarrow$

$$L_{\mu\nu} W^{\mu\nu} = L_{\{\mu\nu\}} W^{\{\mu\nu\}}(F_1, F_2, b_1, b_2, b_3, b_4) + \text{unpolarized}$$

$$+ i L_{[\mu\nu]} W^{[\mu\nu]}(g_1, g_2) \text{ polarized inclusive x-section}$$

$\Rightarrow b_1$ not sensitive to beam polarization

(but implicitly dependent on target spin)

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**Leptonic and hadronic tensor**

\[
L^\mu\nu = \{\mu\nu\} + i[L^{[\mu\nu]}(s)]
\]

- spin independent and \{symmetric\}
- spin dependent and [anti symmetric]

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

\[
+ \{\mu\nu\}(b_1, b_2, b_3, b_4)
\]

implicitly dependent on target spin
(additionally and only for Spin-1)
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Kinematic region at HERMES

For the inclusive $g_1$- und $b_1$ analysis:
$0.002 < x < 0.85$, $0.1 \text{GeV}^2 < Q^2 < 20 \text{GeV}^2$

$b_1$: 6 bins in $x$