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at Matsuyama

HERMES による 重陽子のスピン依存構造関数 g_1 および テンソル偏極構造関数 b_1 の測定

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A. Airapetian et al., HERMES Collaboration,
Phys. Rev. Lett. 95 (2005) 242001

‘First Measurement of the Tensor Structure Function $\boldsymbol{b_1}$ of the Deuteron’

Contents

1. Introduction to **Tensor Polarization** of **Deuterium,**
   Tensor Asymmetry A_{ZZ},
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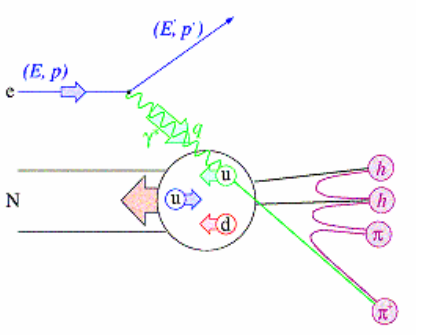


Cross section:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega\mathrm{d}E'} = \frac{\alpha^2}{Q^4}\frac{E'}{E}L^{\nu\mu}W_{\nu\mu}$$

- hadronic tensor

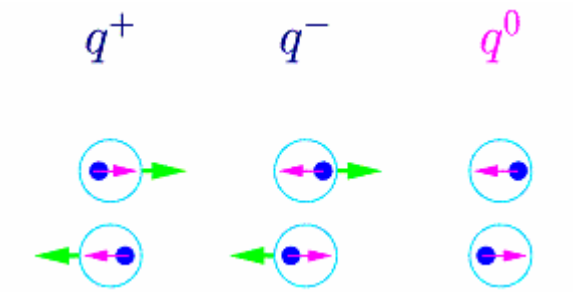
$$\begin{aligned} W_{\mu\nu} = & - F_1\, g_{\mu\nu} + F_2 \frac{p_\mu p_\nu}{\nu} \\ & + i\epsilon_{\mu\nu\lambda\sigma}\frac{q^\lambda}{\nu}\left[g_1\, s^\sigma + \frac{g_2}{\nu}\left((pq)s^\sigma - (sq)p^\sigma\right)\right] \end{aligned}$$

$$\begin{aligned} \text{(for spin 1)} \quad & - b_1\, r_{\mu\nu} + \frac{1}{6}b_2\,(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) \\ & + \frac{1}{2}b_3\,(s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2}b_4\,(s_{\mu\nu} - t_{\mu\nu}) \end{aligned}$$

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

Tensor structure function b_1

Difference in quark distributions in helicity 1 and 0 states of spin 1 target



3 leading-twist structure functions

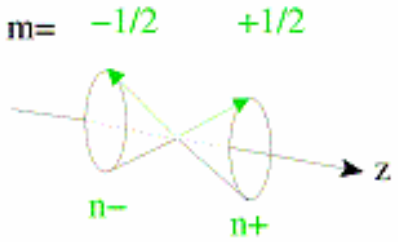
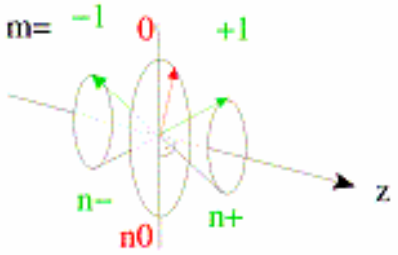
	spin 1/2	spin 1
	Proton	Deuteron
F_1	$\frac{1}{2}\sum_f e^2[q^+ + q^-]$	$\frac{1}{3}\sum_f e^2[q^+ + q^- + q^0]$
g_1	$\frac{1}{2}\sum_f e^2[q^+ - q^-]$	$\frac{1}{2}\sum_f e^2[q^+ - q^-]$
b_1	$--$	$\frac{1}{2}\sum_f e^2\,[2q^0 - (q^- + q^+)]$

Motivations:

1. Physics of b_1 D-state, double scattering, shadowing, etc.
2. $\frac{g_1}{F_1} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$ is valid if $b_1 = 0$ *i.e.* $q^0 = \frac{q^+ + q^-}{2}$

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

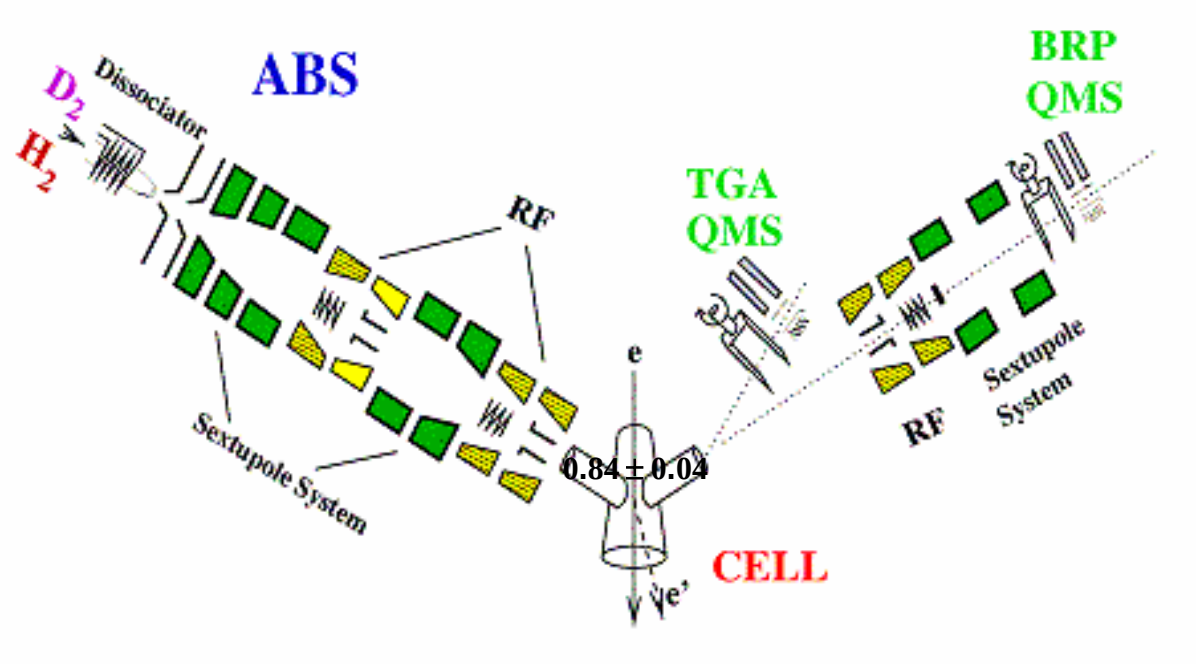
Vector and Tensor Polarization

	Spin-$\frac{1}{2}$ Nucleon	Spin-1 Deuteron
		
Vector polarisation	$P_z = \frac{n^+ - n^-}{n^+ + n^-}$ $\lvert P_z \rvert \leqq 1$	$P_z = \frac{n^+ - n^-}{n^+ + n^- + n^0}$ $\lvert P_z \rvert \leqq 1$
Tensor polarisation		$P_{zz} = \frac{(n^+ + n^-) - 2n^0}{n^+ + n^- + n^0}$ $-2 \leqq P_{zz} < 1$

n: atomic population

HERMES Polarized Gas Internal Target

Atomic Beam Source



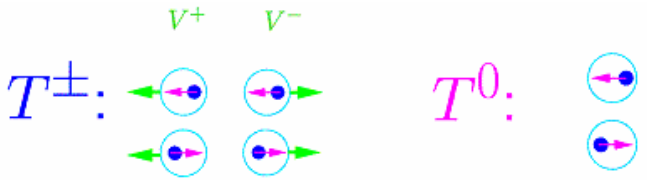
Atomic beam method

- ABS Atomic Beam Source
  dissociator plus beam optic with spin selectors
- Cell
  concentrates the target gas along the beam line
  (gain of ∼ 100 in the effective target density)

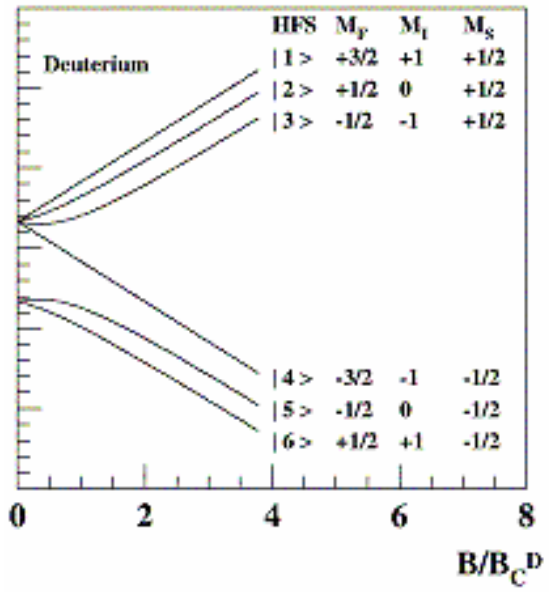
Vector Polarization
Tensor Polarization

80% of theoretical maximum

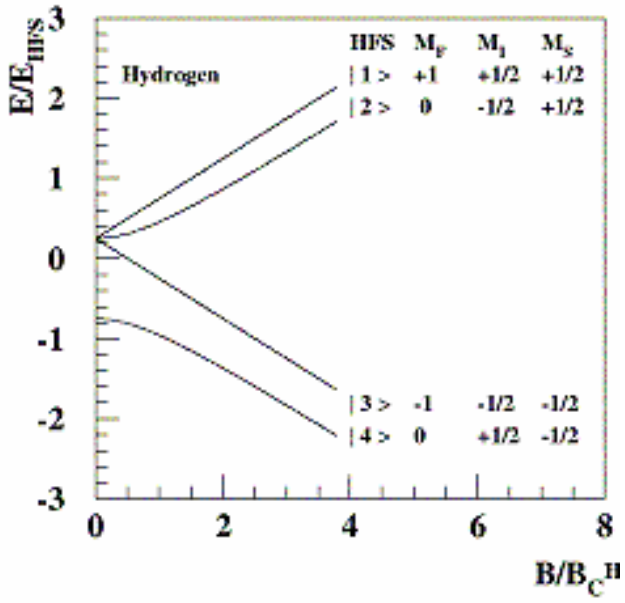
Target polarization reversed every 90 sec and continuously monitored



Deuterium Atom



Hydrogen Atom



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

Measurements:

$$\frac{\mathrm{d}^2\sigma_P}{\mathrm{d}x\mathrm{d}Q^2} \simeq \frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2}\left[1 - P_z P_B D A_1^{\mathrm{d}} + \frac{1}{2} P_{zz} A_{zz}^{\mathrm{d}}\right]$$

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

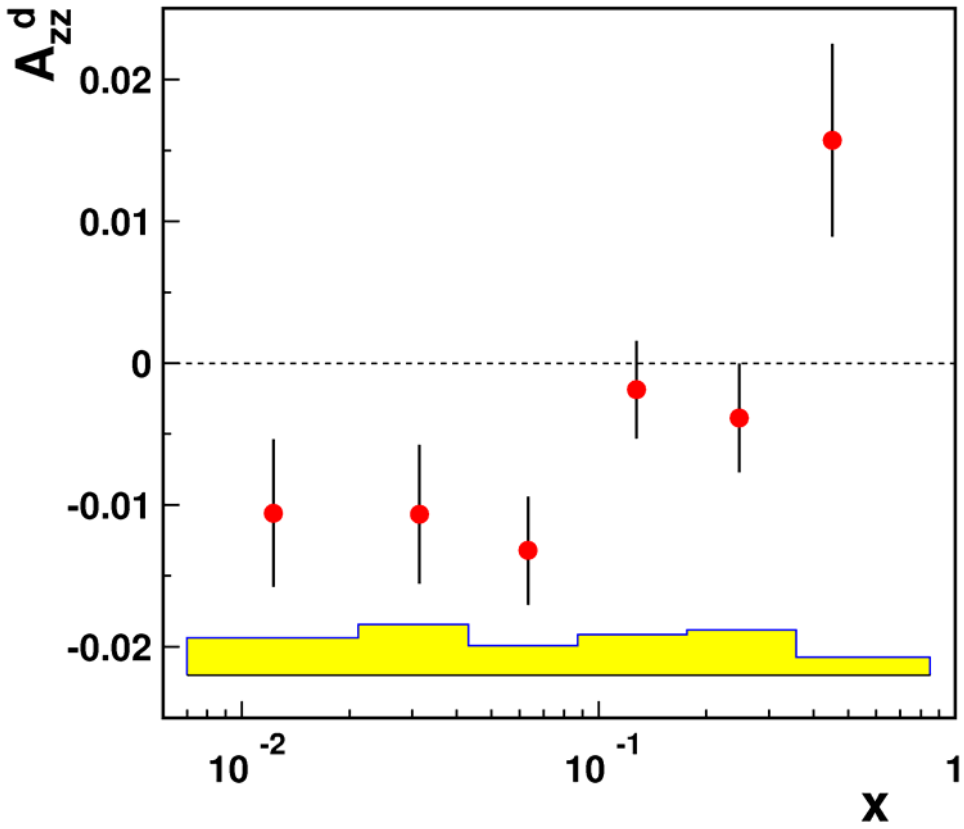
b_1 can be extracted from A_{zz}

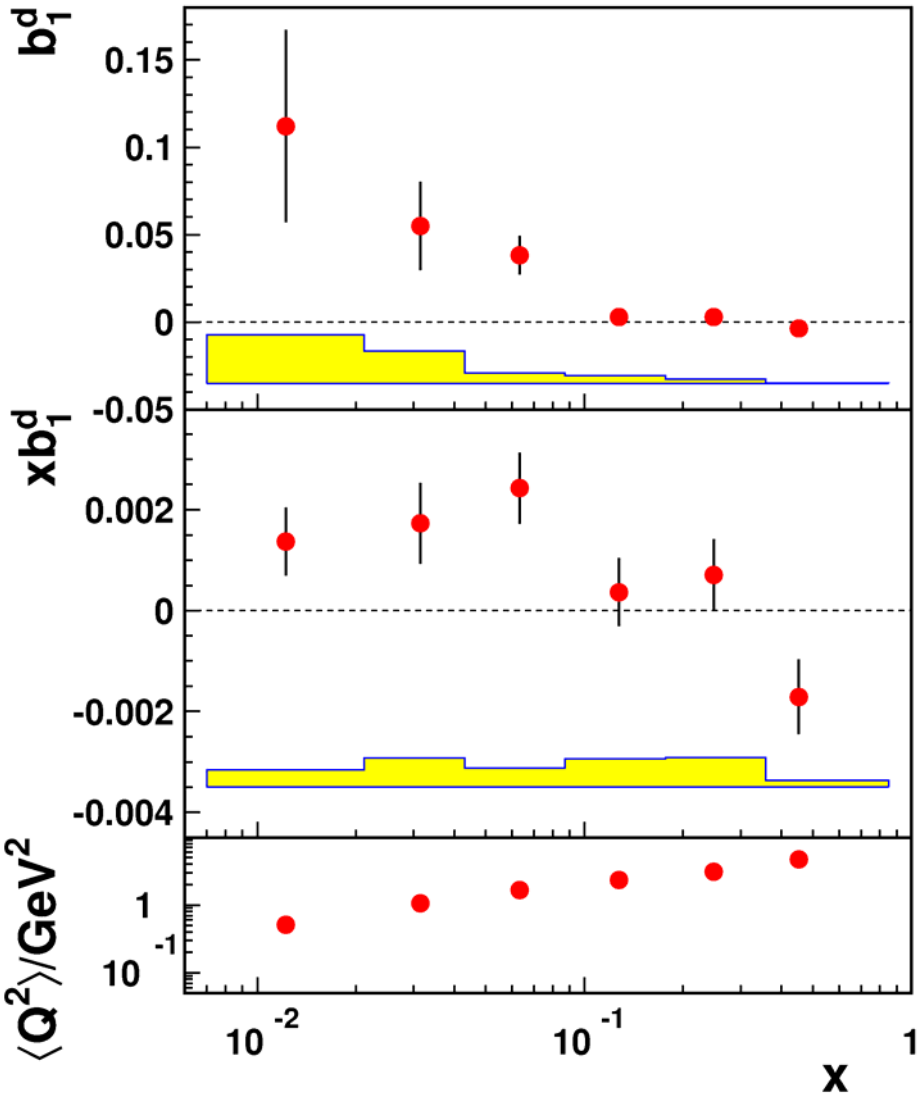
E = 27.6 GeV

L = 42 pb^{-1}

3.2 million deep inelastic scattering events

0.01 < <x> < 0.45, 0.5 GeV^2 < <Q^2> < 5 GeV^2


A_{zz}^{d}
0.02
0.01
0
-0.01
-0.02
10^{-2}
10^{-1}
1
x


b_1^d
0.15
0.1
0.05
0
-0.05
xb_1^d
0.002
0
-0.002
-0.004
$\langle Q^2 \rangle$/GeV^2
1
10^{-1}
10^{-2}
10^{-1}
1
x

Theoretical Works:

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

Tensor Structure Function b_1

Theory : Effects of nuclear binding & Fermi motion at x > 0.2

H. Kahn et al., Phys. Rev. C44, 1219 (1991)
A. Yu. Umnikov, Phys. Lett. B391, 177 (1997)

Theory: Coherent double-scattering

H. Khan et al., Phys. Lett. B298, 181 (1993)
N.N. Nikolaev et al., Phys. Lett. B398, 245 (1997)
J. Edelmann et al., Z. Phys. A357, 129 (1997)
J. Edelmann et al., Phys. Rev. C57, 3392 (1998)
K. Bora and R. Jaffe, Phys. Rev. D57, 6909 (1998)

Significant enhancement of b1 at small x_B:

→Close-Kumano sum rule violated ?

F.E. Close et al., Phys. Rev. D42, 2377 (1990)

→ sea quarks are tensor polarized ?

A.V. Efremov et al., Sov. J. Nucl. Phys. 36, 557 (1982)

Conclusions

- Quark distributions associated with **tensor polarization of deuterium** was measured with deep inelastic scattering. **Tensor asymmetry A_{ZZ} of deuterium** was measured for the first time by HERMES.

- Polarized gas internal target of HERMES with **atomic beam method** was essential for this measurement.

- As the result, **tensor structure function b_1** was obtained at $0.002 < x < 0.85$.
  Comparisons with theories now became possible.

- Effect on $A_{||}$ from tensor asymmetry was found to be less than 0.5 – 1.0%.