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at KEK

Tensor Structure Function b_1 of the Deuteron measured with High-Energy Electron Scattering by HERMES

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‘First Measurement of the Tensor Structure Function b_1 of the Deuteron’

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

Non-zero b_1 indicates nuclear effects,

b_1 is zero if the deuteron simply consists of a proton and neutron in relative S-state.

Contents

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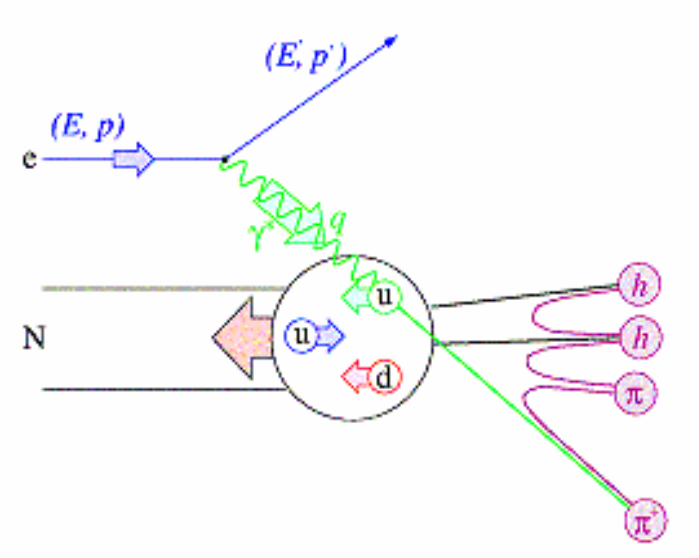
   Tensor Asymmetry A_{ZZ},
   Tensor Structure Function b_1
2. First Measurement at HERMES
   - Polarized Deuterium Target
3. Experimental Results – discovery of non-zero b_1
4. Theoretical models
5. Conclusions

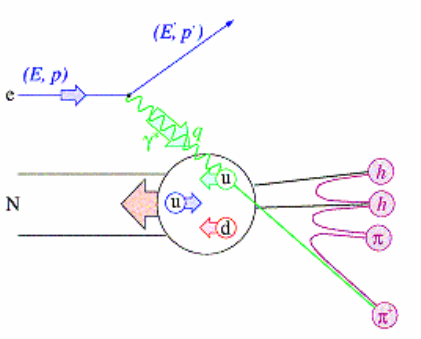
Deep Inelastic Scttering

High-Energy Electron Beam

28 GeV



Electron-Quark Elastic Scattering



Cross section:

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

- hadronic tensor

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

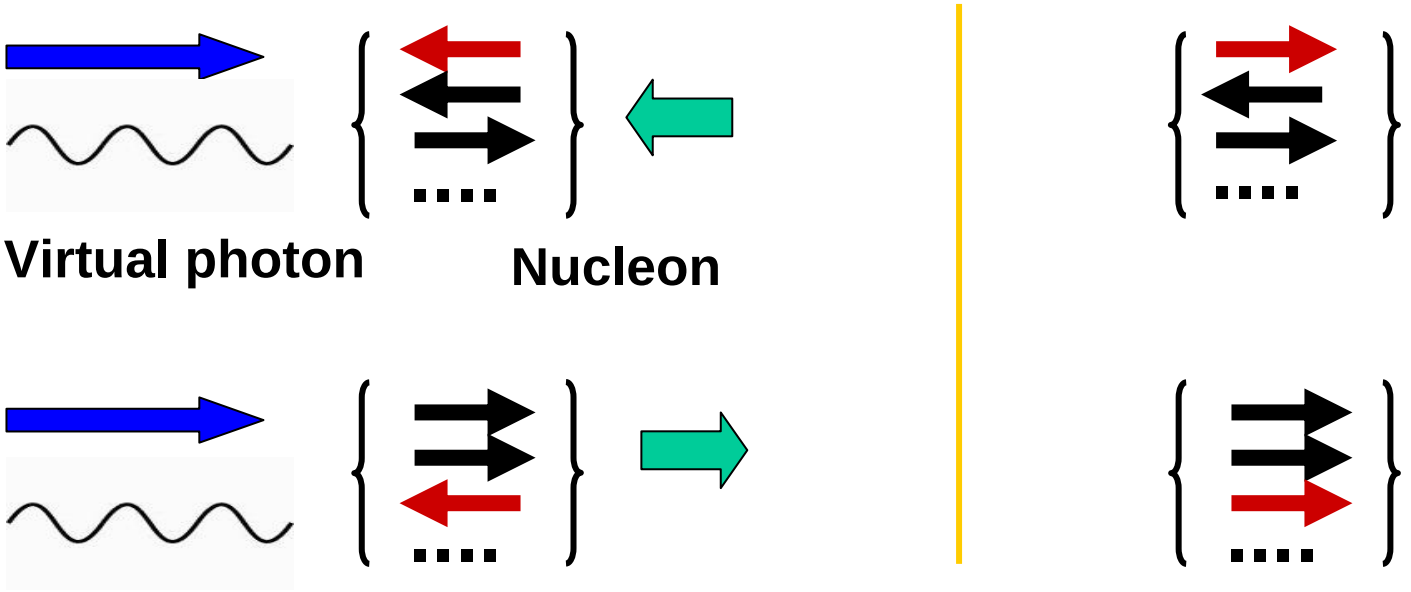
$$\text{(for spin 1)} \quad - b_1 r_{\mu\nu} + \frac{1}{6}b_2 (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) + \frac{1}{2}b_3 (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2}b_4 (s_{\mu\nu} - t_{\mu\nu})$$

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

Double-spin asymmetry

$$\vec{e} + \vec{N} \rightarrow e' + X$$

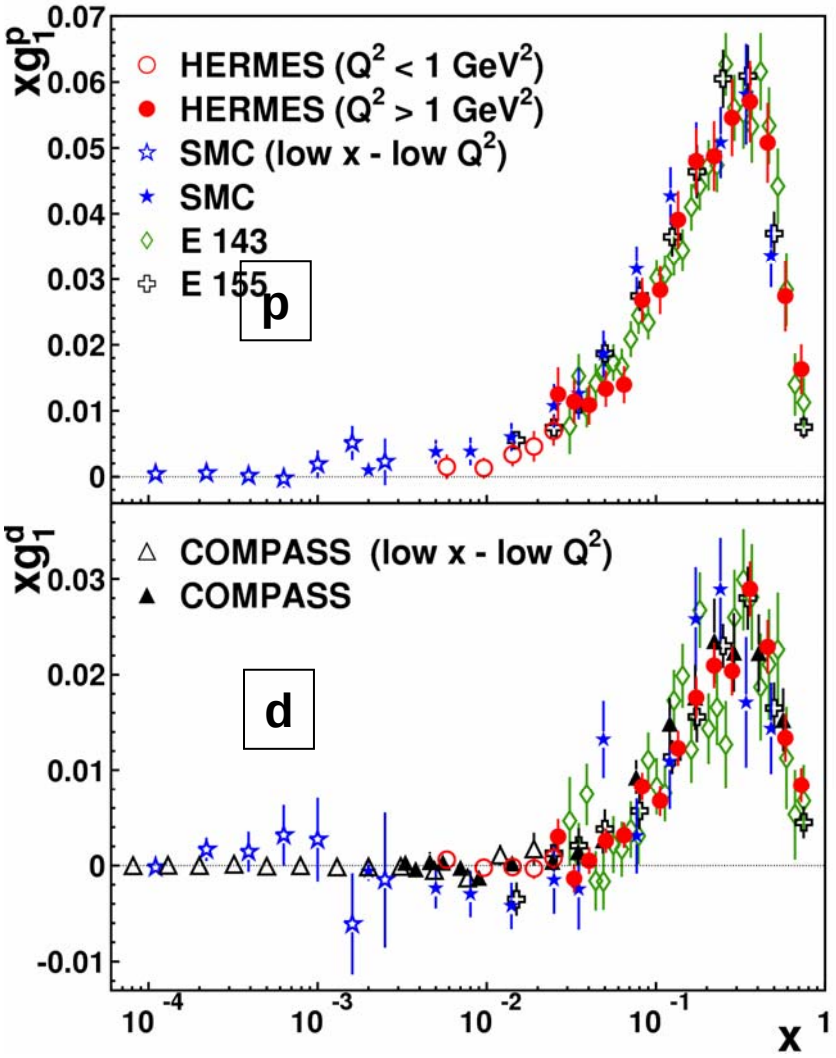
Beam and target, both polarized



$$A_1(x,z) = \frac{\sigma^{\rightarrow}_{\leftarrow}(x) - \sigma^{\rightarrow}_{\rightarrow}(x)}{\sigma^{\rightarrow}_{\leftarrow}(x) + \sigma^{\rightarrow}_{\rightarrow}(x)}$$

$g_1(x_B,Q^2)$ from Lepton-Nucleon Deep Inelastic Scattering

$g_1(x,Q^2)$



and also semi-inclusive data

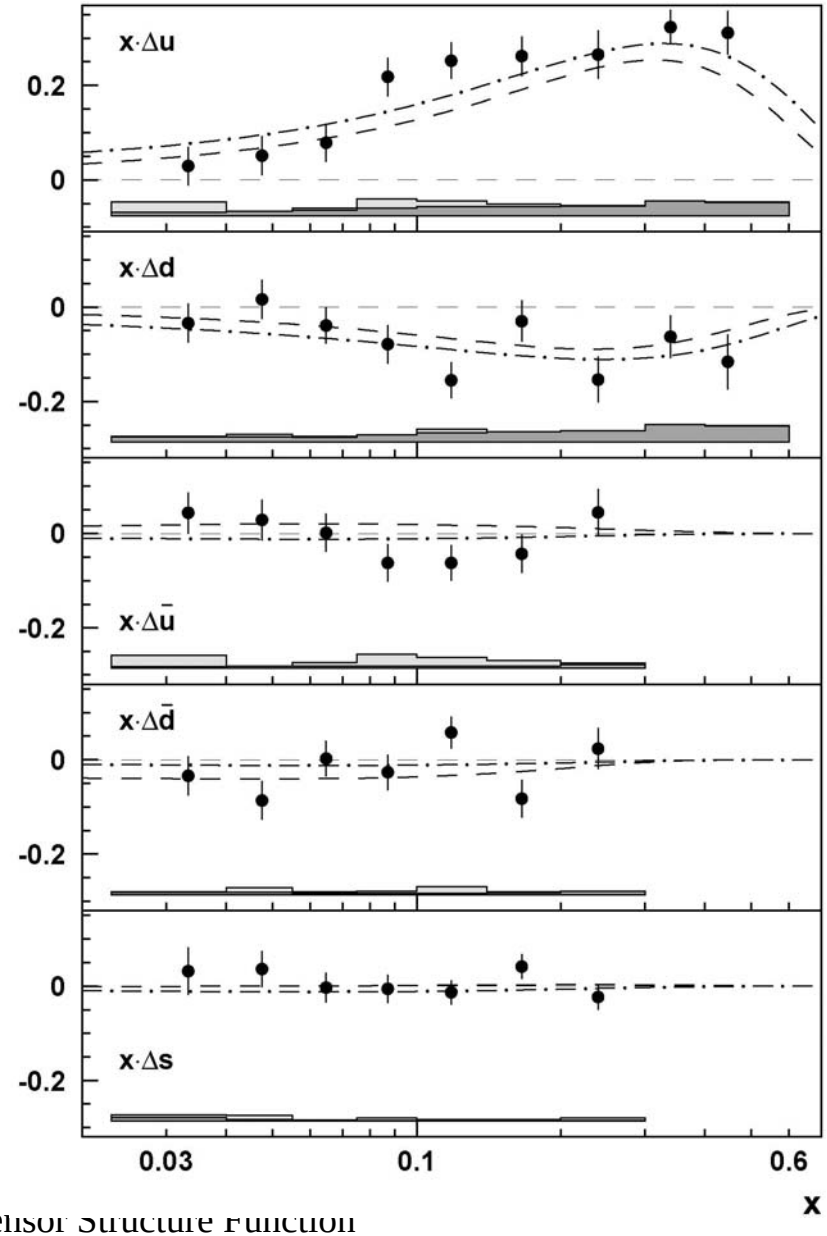
Flavor Separation

$\Delta u, \Delta d, ..$

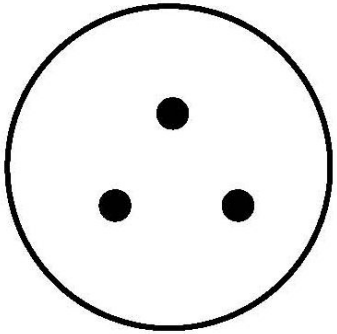
$\Delta u(x) > 0,$

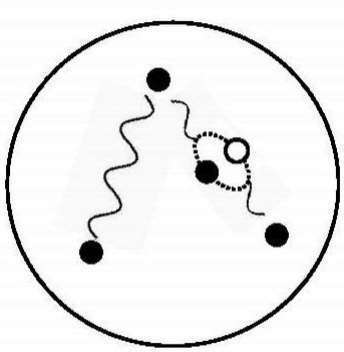
$\Delta d(x) < 0$

Study of helicity distributions has well advanced.



‘Proton Spin Problem’ since EMC 1988

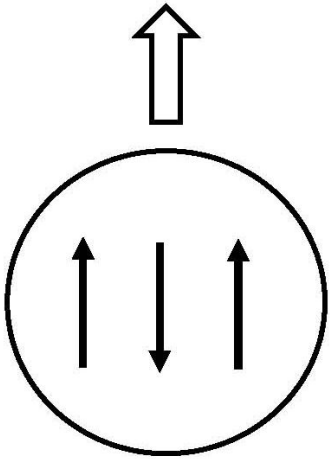


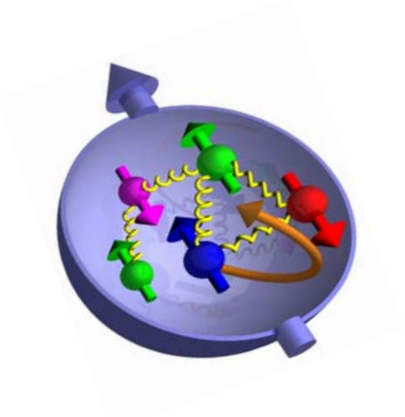


valence quarks

sea quarks

gluons



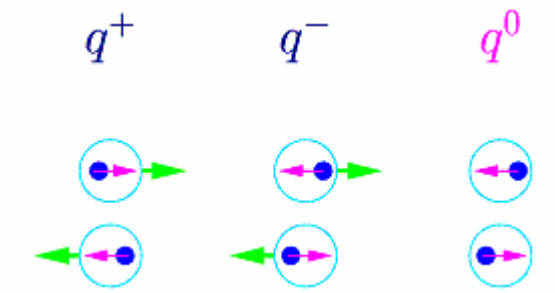


$$\Delta u = \frac{4}{3}, \Delta d = -\frac{1}{3}$$

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + < L_q > + < L_g >$$

Tensor structure function b_1

'Difference in quark distributions between helicity 0 and average of non-zero helicity states of the deuteron.'



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:

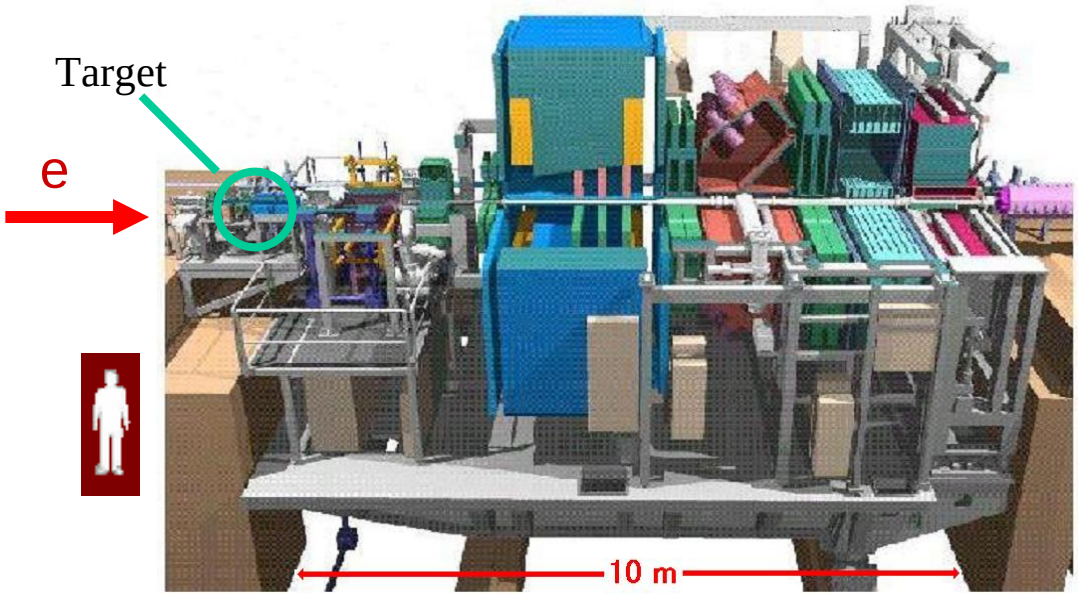
1. Physics of b_1 D-state, double scattering, shadowing, etc.
2. $\frac{g_1}{F_1} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$ is valid if $b_1 = 0$ *i.e.* $q^0 = \frac{q^+ + q^-}{2}$

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

The Detector, Targets, Beam

HERMES at DESY-HERA

- 27.6 GeV Polarized Electron / Positron Beam
- A Wide Acceptance Detector
- Hadron Identification with RICH
- Polarized Gas Internal Targets ^{3}He, H, D, ...



H $P_H = 0.824$ $(\pm 4.2\%)$

D $P_D = 0.844$ $(\pm 4.4\%)$

$P_B = 0.53$ $(\pm 3.4\%$ for H)

$(\pm 1.9\%$ for D)

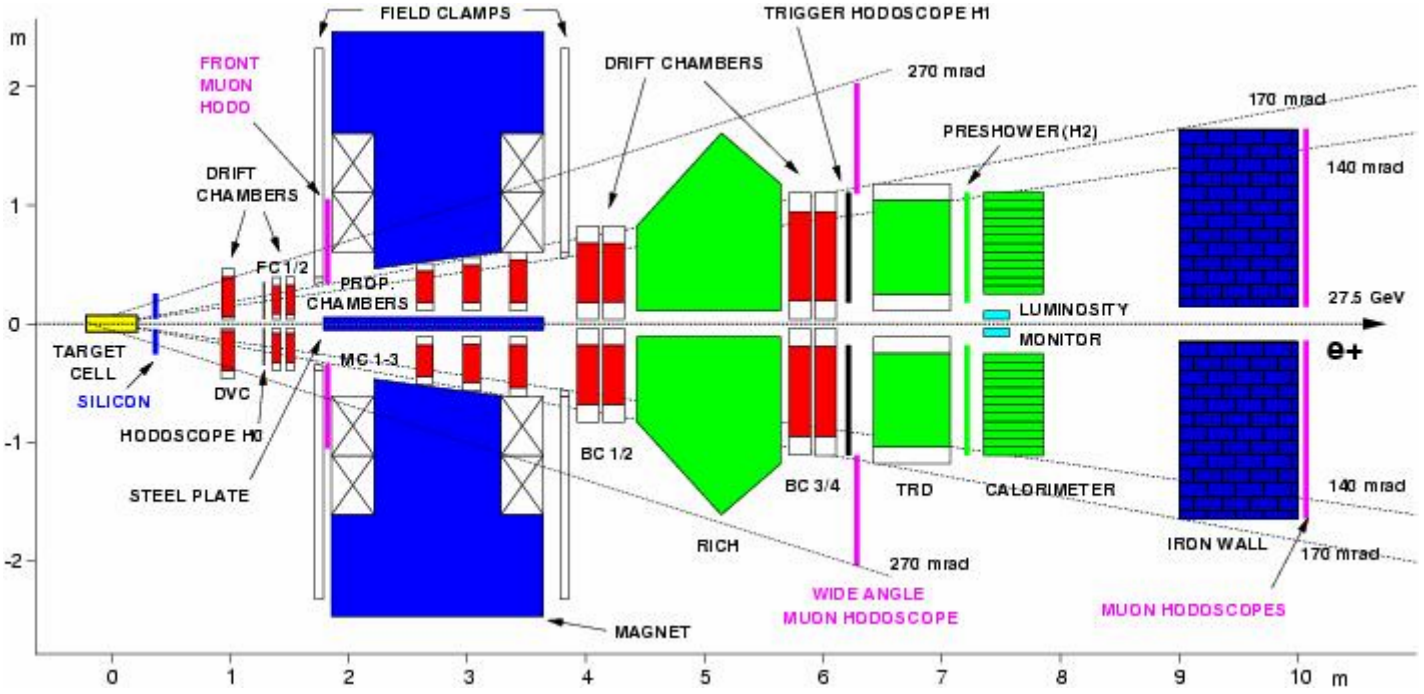
$Q^2 > 1\,\mathrm{GeV}^2$, $W^2 > 10\,\mathrm{GeV}^2$,

$y = \nu / E < 0.85$, $0.2 < z = E_h / \nu < 0.8$,

$x_F \approx 2p_L / W > 0.1$

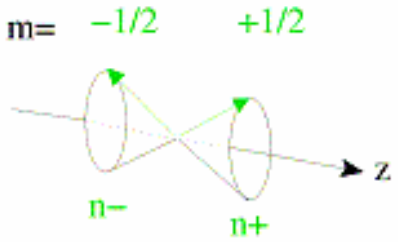
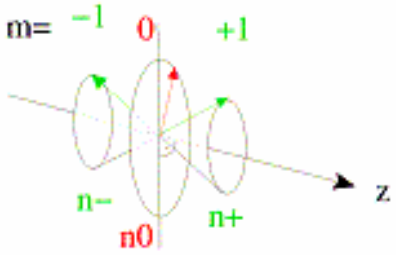
HERMES Spectrometer

Positron 27.6 GeV, longitudinally polarized, ~53%



- Deuteron, longitudinally polarized, 76 - 85%
- resolution: $\delta p/p \sim 2\%$, $\delta\theta < 1$ mrad
- particle ID: lepton ID with $\varepsilon \sim 98\%$, hadron contamination <1%

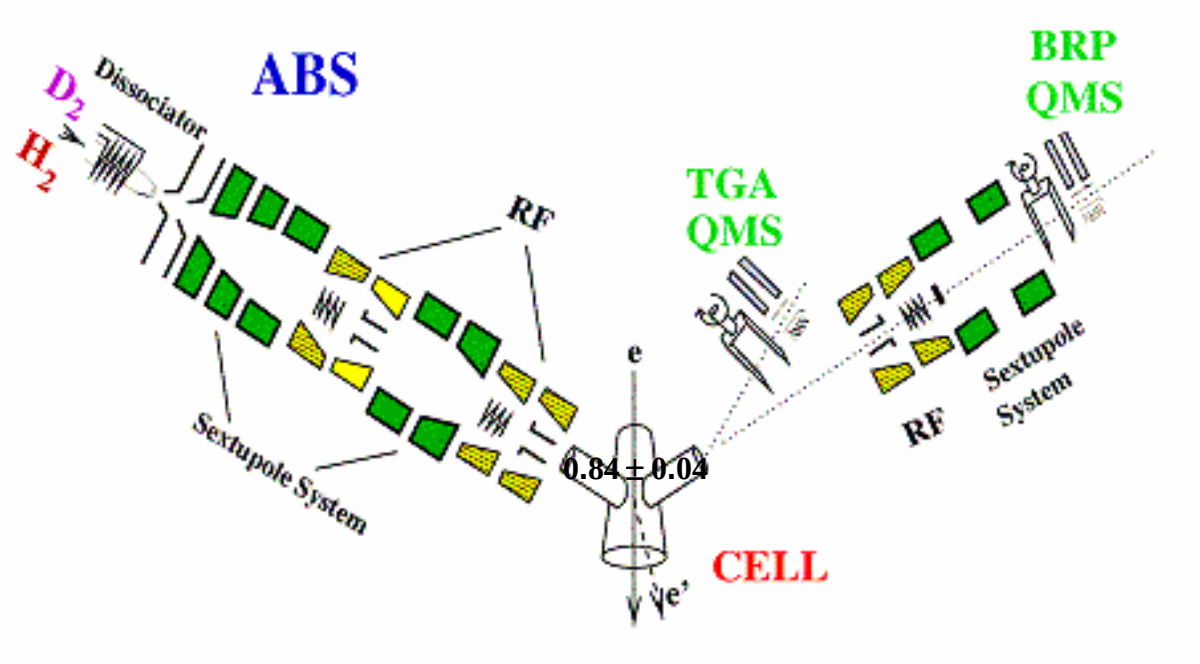
Vector and Tensor Polarization

	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



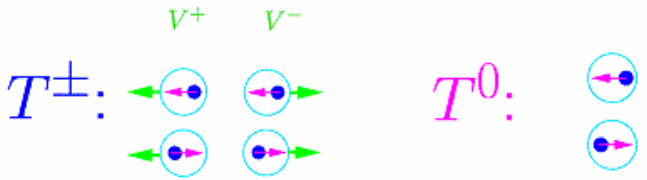
Atomic beam method

- 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

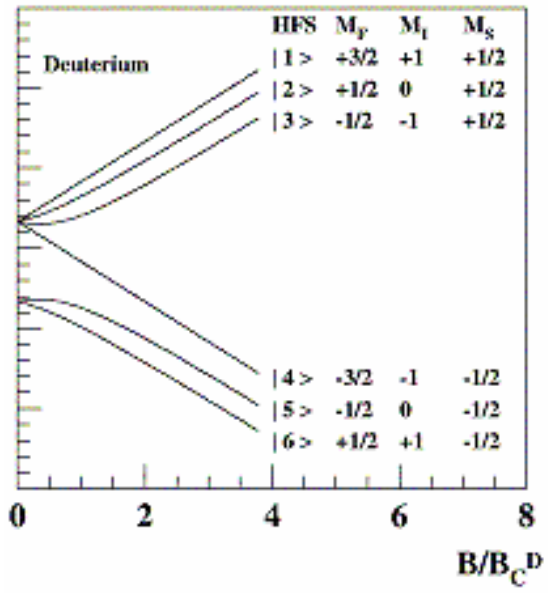
80% of theoretical maximum

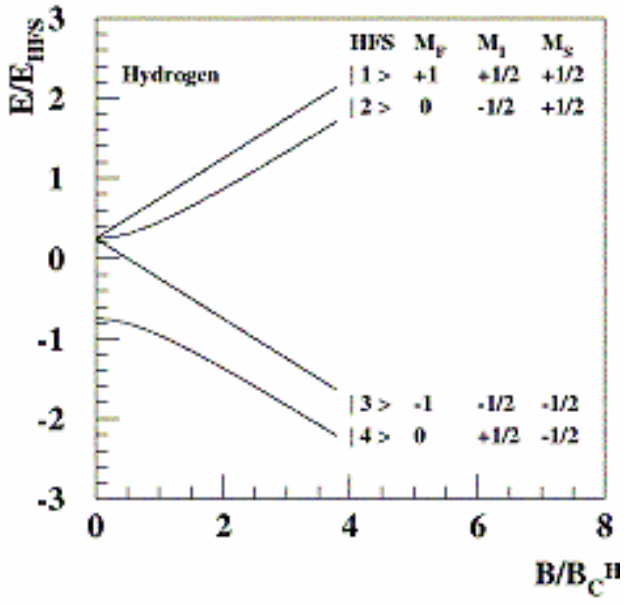
Target polarization reversed every 90 sec and continuously monitored



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:

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

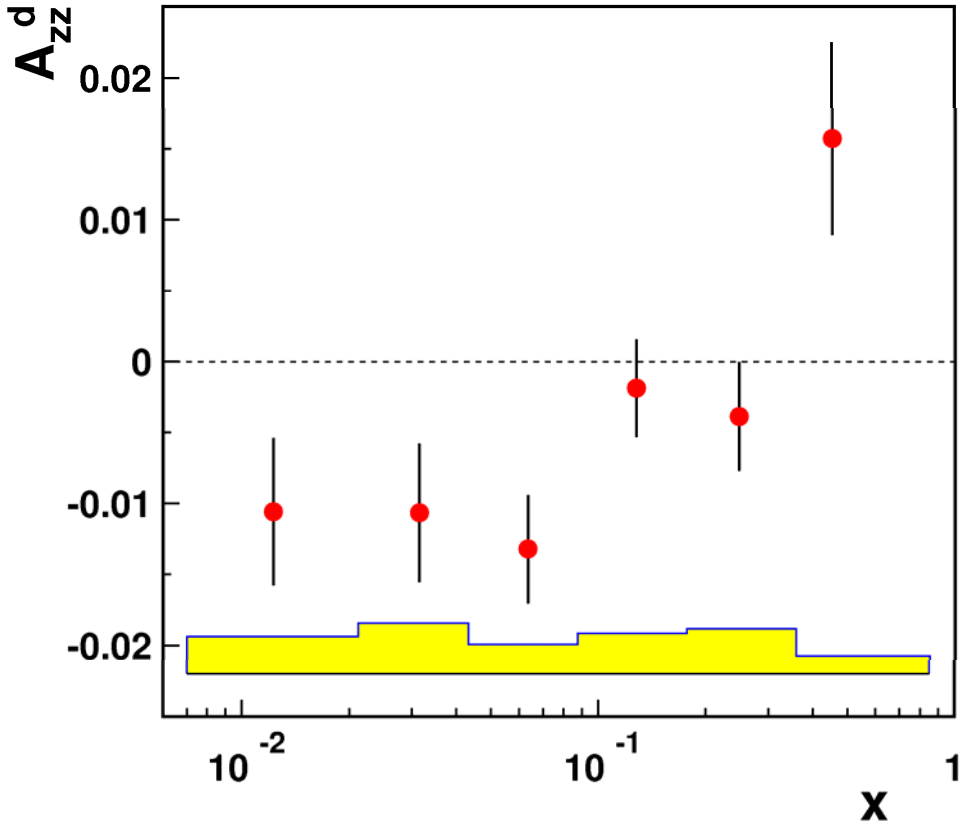
$$A_{zz} = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{\sigma^+ + \sigma^- + \sigma^0} \approx -\frac{2}{3}\frac{b_1}{F_1}$$

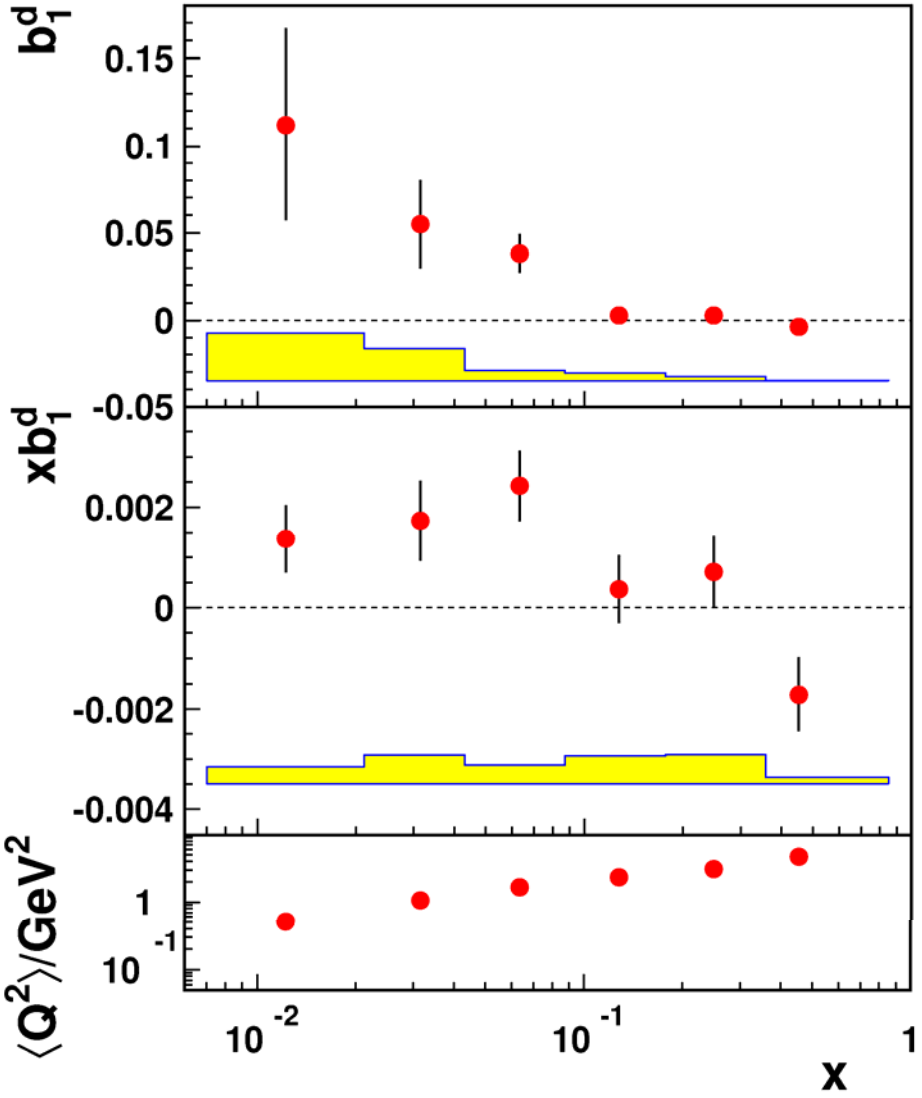
b_1 can be extracted from A_{zz}

E = 27.6 GeV

L = 42 pb^{-1}

3.2 million deep inelastic scattering events
0.01 < <x> < 0.45, 0.5 GeV² < <Q²> < 5 GeV²


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



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

Theoretical Works : 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 b_1 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. Non-zero A_{zz} was discovered.

- 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%.