Tensor analyzing power A_{yy} in deuteron inclusive breakup at large P_t and spin structure of deuteron at short internucleonic distances.

V.P.Ladygin[1,†], L.S. Azhgirey[1], S.V. Afanasiev[1], V.V. Arkhipov[1], V.K. Bondarev[1,2], Yu.T. Borzounov[1], G.Filipov[1,3], L.B. Golovanov[1], A.Yu. Isupov[1], A.A. Kartamyshev[4], V.A. Kashirin[1], A.N. Khrenov[1], V.I. Kolesnikov[1], V.A. Kuznezov[1], A.G. Litvinenko[1], S.G. Reznikov[1], P.A. Rukoyatkin[1], A.Yu. Semenov[1], I.A. Semenova[1], G.D. Stoletov[1], A.P. Tzvinev[1], N.P. Yudin[5], V.N. Zhmyrov[1] and L.S. Zolin[1]

(1) *Joint Institute for Nuclear Researches, 141980 Dubna, Russia*
(2) *St.-Petersburg State University, 198350 St.-Petersburg, Russia*
(3) *Institute of Nuclear Research and Nuclear Energy, 1784 Sofia, Bulgaria*
(4) *Russian Scientific Center "Kurchatov Institute", 123182 Moscow, Russia*
(5) *Moscow State University, 117234 Moscow, Russia*

† *E-mail: ladygin@sunhe.jinr.ru*

The A_{yy} data for deuteron inclusive breakup off hydrogen, beryllium and carbon at the deuteron momenta 4.5-9.0 GeV/c and large P_t of emitted protons are presented. The large values of A_{yy} independent of initial energy and target mass reflect the sensitivity of the data to the deuteron spin structure. The data obtained at fixed x_F and plotted versus P_t clearly demonstrates the dependence of the deuteron spin structure at short internucleonic distances on 2 variables. The data are compared with the calculations using CD-Bonn and Karmanov deuteron wave functions.

Deuteron inclusive breakup (d, p)

The interest to the (d, p) reaction at relativistic energies is due to mostly to the possibility to observe

- the manifestation of the non-nucleonic degrees of freedom;
- relativistic effects in the simplest bounded system.

Large amount of the polarization data obtained at a zero degree last years can be interpreted from the point of view NN^* configurations in the deuteron, where relativistic effects are taken into account by the minimal relativization scheme with the dependence of the deuteron structure on **single variable** k. In addition the considering of multiple scattering is required to obtain the agreement with the data.

(*A.P.Kobushkin et al.*).

Deuteron inclusive breakup (d, p)

On the other hand,

- it was shown that T_{20} data for the pion-free deuteron breakup process $dp \to ppn$ in the kinematical region close to that of backward elastic dp scattering depended on the incident deuteron momentum in addition to k.

  (*L.S. Azhgirey et al., Phys. Lett. B 391 (1997) 22;*

  L.S. Azhgirey et al., Yad. Fiz.61 (1998) 494.)

- the recent measurements of the tensor analyzing power A_{yy} of deuteron inclusive breakup on nuclear targets have demonstrated a significant dependence on the transverse secondary proton momentum p_T being plotted at a fixed value of the longitudinal proton momentum.

  (*S.V. Afanasiev et al., Phys. Lett. B 434 (1998) 21;*

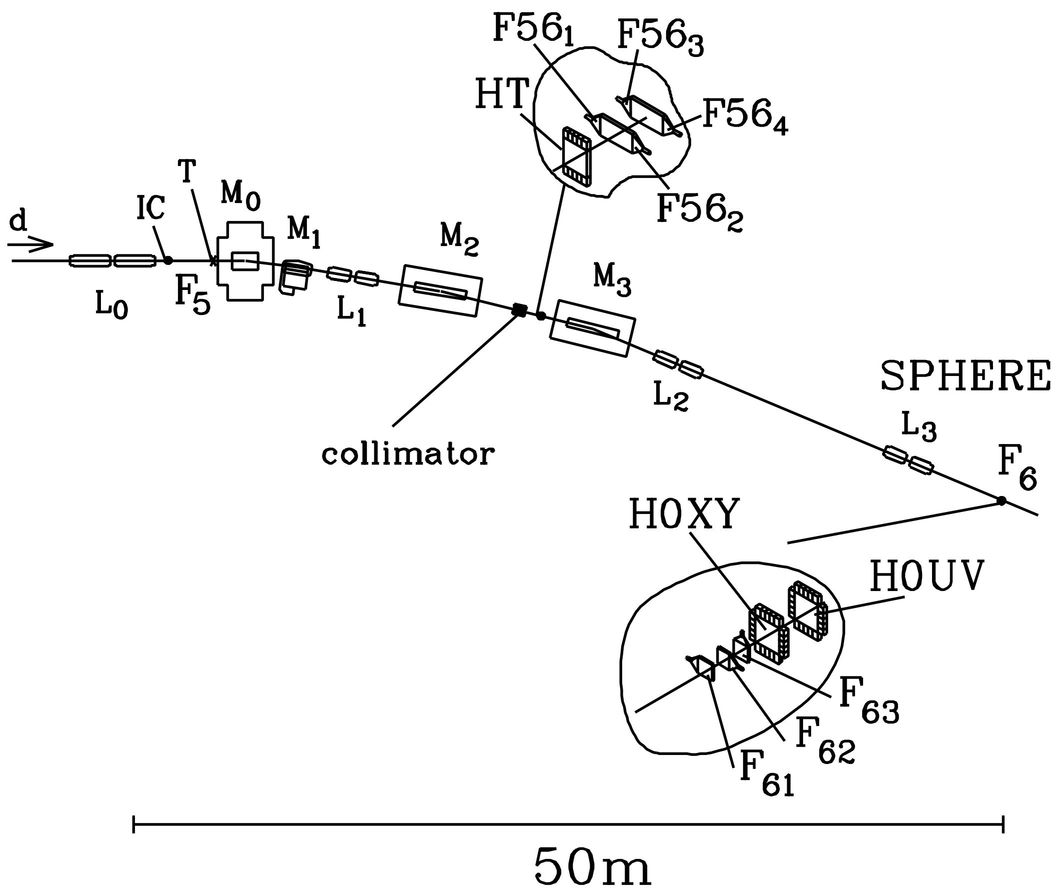
  V.P. Ladygin et al., Few-Body Systems 32 (2002) 127;

  L.S. Azhgirey et al., Yad. Fiz. 66 (2003) 719;

  L.S. Azhgirey et al., Phys.Lett.B 595 (2004) 151.)

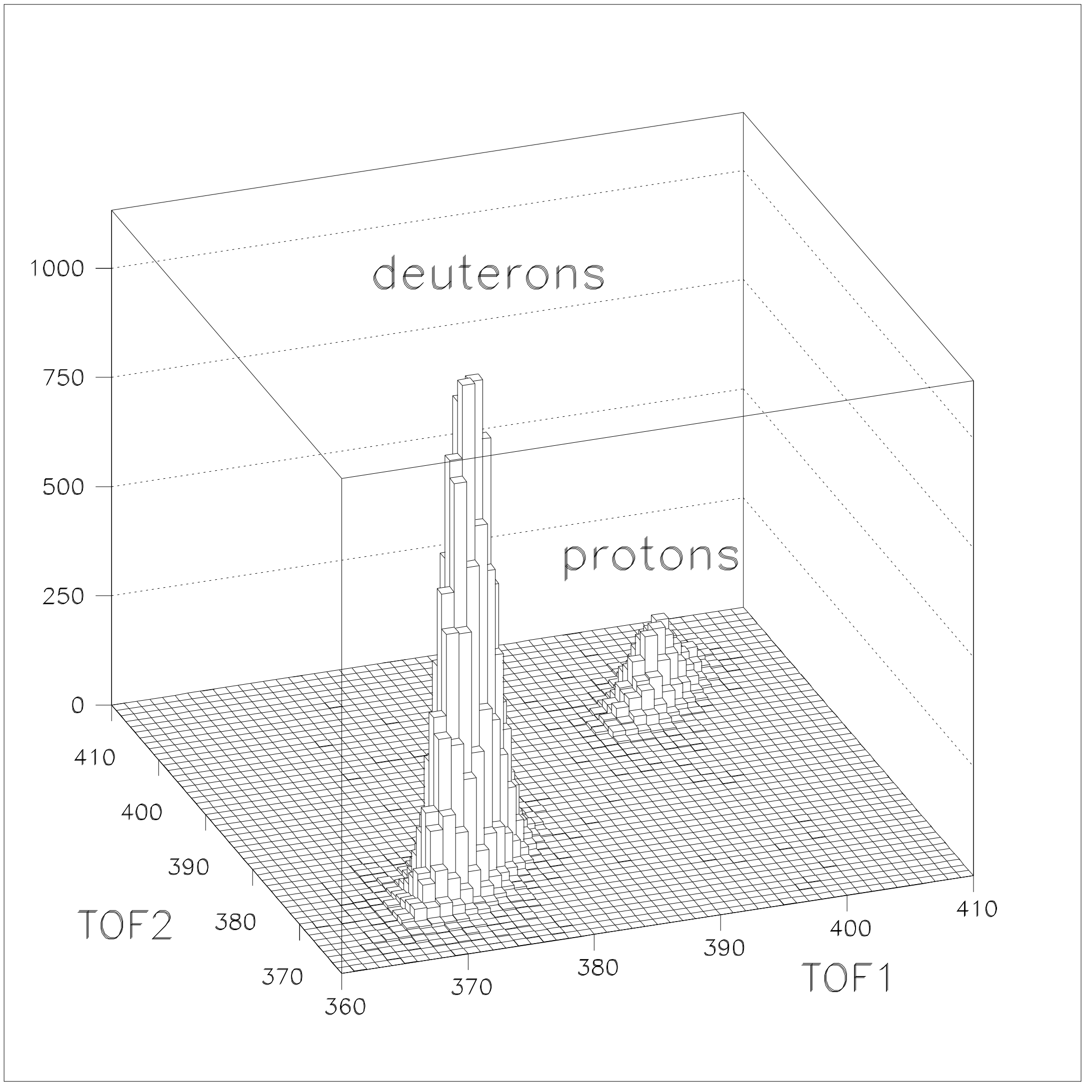
This forces one to suggest that description of this quantity requires an **additional independent variable, aside from k.**

SETUP



- Initial momentum: 9 GeV/c
- Polar angle: 85, 130, 160 mr
- Target: 7,16 cm of carbon or 30 cm of hydrogen
- Polar angle acceptance: ± 8 mr
- Momentum acceptance: $\sim \pm 2\%$
- TOF base: ~ 34m

Particles Identification



Tensor polarization from $dA \to p(0^\circ)X$ reaction

At proton momentum $P_p \sim 2/3 \cdot P_d$ $|T_{20}| \sim 0.85$

$p_{zz}^{+} = 0.798 \pm 0.002(stat) \pm 0.040(syst)$
$p_{zz}^{-} = -0.803 \pm 0.002(stat) \pm 0.040(syst)$

L.S. Zolin et al., JINR Rapid Comm. **2[88]-98**, *27 (1998).*

Vector polarization from quasielastic pp scattering

At 4.5 GeV/c/nucleon and 8° analyzing power $A_{CH_2} \sim 0.12$

$p_{z}^{+} = 0.231 \pm 0.014(stat) \pm 0.012(syst)$
$p_{z}^{-} = 0.242 \pm 0.014(stat) \pm 0.012(syst)$.

L.S. Azhgirey et al., PTE **1** *51 (1997) [Instr. and Exp. Tech.* **40**, *43 (1997)];*

L.S. Azhgirey et al., Nucl.Inst.and Meth. in Phys.Res. **A497**, *340 (2003).*

Evaluation of the analyzing powers

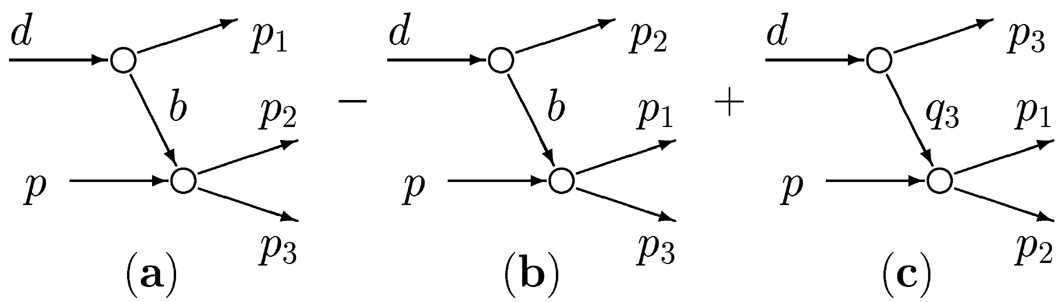
The tensor A_{yy} and vector A_y analyzing powers were calculated from the yields of secondary particles n^+, n^- and n^0 for different states of the beam polarization after correction for dead time of the setup, by means of the expressions

$$
\begin{aligned}
A_{yy} &= 2 \cdot \frac{p_z^- \cdot (n^+/n^0 - 1) \ - \ p_z^+ \cdot (n^-/n^0 - 1)}{p_z^- p_{zz}^+ - p_z^+ p_{zz}^-}, \\
A_y &= -\frac{2}{3} \cdot \frac{p_{zz}^- \cdot (n^+/n^0 - 1) \ - \ p_{zz}^+ \cdot (n^-/n^0 - 1)}{p_z^- p_{zz}^+ - p_z^+ p_{zz}^-},
\end{aligned}
$$

where p_z and p_{zz} are the vector and tensor polarizations of the beam, respectively.

Feynman diagrams describing (d, p) process

The mechanism of the deuteron fragmentation (d, p) can be represented by the Feynman diagrams.



Here d is the incoming deuteron, p is the target proton, p_1 is the detected proton, b is the virtual (off-shell) nucleon, and p_2, p_3 are nucleons.

In addition to nucleons, one or more pions may be produced at low vertices.

Diagram (a) corresponds to the case where the detected proton results from deuteron stripping, and at the low vertex elastic np scattering takes place.

In diagrams (b) and (c) the low vertices correspond to the charge exchange np and elastic pp scatterings, respectively.

Calculations

The analyzing power $T_{\kappa q}$ of the (d,p) reaction is given by the expression

$$T_{\kappa q} = \frac{\int d\tau \, Sp\{\mathcal{M} \cdot t_{\kappa q} \cdot \mathcal{M}^{\dagger}\}}{\int d\tau \, Sp\{\mathcal{M} \cdot \mathcal{M}^{\dagger}\}}, \tag{1}$$

where $d\tau$ is the phase volume element, $\mathcal{M}$ is the reaction amplitude, and the operator t_{2q} is defined by

$$< m \,|\, t_{\kappa q} \,|\, m' >= (-1)^{1-m} < 1\, m\, 1 \, - m' \,|\, \kappa\, q >,$$

with the Clebsh-Gordan coefficients $< 1\, m\, 1 \, - m' \,|\, \kappa\, q >$.

The amplitude for the reaction ${}^1H(d,p)X$ in the light-front dynamics is

$$\mathcal{M}_a = \frac{\mathcal{M}(d \to p_1 b)}{(1-x)(M_d^2 - M^2(k))} \mathcal{M}(bp \to p_2 p_3), \tag{2}$$

where $\mathcal{M}(d \to p_1 b)$ is the amplitude of the deuteron breakup on a proton-spectator p_1 and an off-shell particle b, and $\mathcal{M}(bp \to p_2 p_3)$ is the amplitude of the reaction $bp \to p_2 p_3$ (in the case of diagram (a), and with evident replacements of indices for diagrams (b) and (c)). The ratio

$$\psi(x, p_{1T}) = \frac{\mathcal{M}(d \to p_1 b)}{M_d^2 - M^2(k)} \tag{3}$$

is the wave function in the channel $(b,\, N)$ given by Eq.(1); here p_{1T} is the component of the momentum p_1 transverse to the z axis. The light-front variables $p_T \equiv p_{1T}$ and x (the fraction of the deuteron longitudinal momentum taken away by the proton in the infinite momentum frame) are given above. The quantity $M^2(k)$ is given by

$$M^2(k) = \frac{m^2 + p_{1T}^2}{x} + \frac{b^2 + p_{1T}^2}{1-x}, \tag{4}$$

where b^2 is the four-momentum squared of the off-shell particle b.

Relativistic DWF

The relativistic deuteron wave function in the light front dynamics is determined by six invariant functions $f_1, ..., f_6$ instead of two ones in the non-relativistic case, each of them depending on two scalar variables k and $z = cos(\widehat{\mathbf{kn}})$ and has the following form:

$$\psi(\mathbf{k},\, \mathbf{n}) = \frac{1}{\sqrt{2}}\sigma f_1 + \frac{1}{2}\left[\frac{3}{k^2}\mathbf{k}(\mathbf{k}\cdot\sigma) - \sigma\right] f_2$$
$$+\frac{1}{2}\left[3\mathbf{n}(\mathbf{n}\cdot\sigma) - \sigma\right] f_3 + \frac{1}{2k}[3\mathbf{k}(\mathbf{n}\cdot\sigma) + 3\mathbf{n}(\mathbf{k}\cdot\sigma) - 2\sigma(\mathbf{k}\cdot\mathbf{n})] f_4$$
$$+\sqrt{\frac{3}{2}}\frac{i}{k}[\mathbf{k}\times\mathbf{n}] f_5 + \frac{\sqrt{3}}{2k}[[\mathbf{k}\times\mathbf{n}]\times\sigma] f_6, \qquad (5)$$

where $\mathbf{k}$ is the momentum of nucleons in the deuteron in their rest frame, $\mathbf{n}$ is the unit normal to the light front surface, and σ are the Pauli matrices. The quantities $\mathbf{k}$ and $\mathbf{n}$ are defined by

$$x = \frac{E_p + p_{pl}}{E_d + p_d}, \quad k = \sqrt{\frac{m_p^2 + \mathbf{p}_T^2}{4x(1-x)} - m_p^2}, \qquad (6)$$

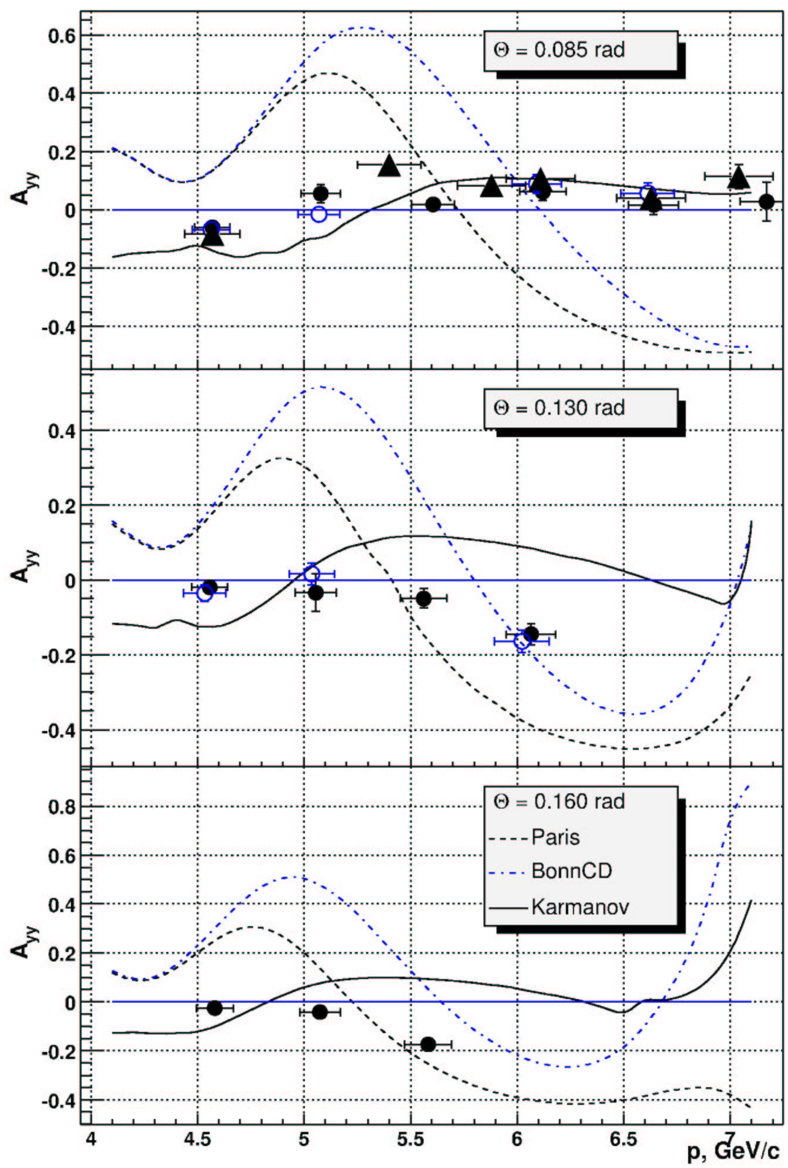
$$(\mathbf{n}\cdot\mathbf{k}) = (\frac{1}{2} - x)\cdot\sqrt{\frac{m_p^2 + \mathbf{p}_T^2}{x(1-x)}}, \qquad (7)$$

where E_d and p_d are the energy and the momentum of the incoming deuteron, respectively, p_{pl} is the longitudinal component of $\mathbf{p}_1$, and m_p is the mass of the nucleon. $\mathbf{n}$ is directed opposite to the beam direction, i.e. $\mathbf{n} = (0,\ 0,\ -1)$.

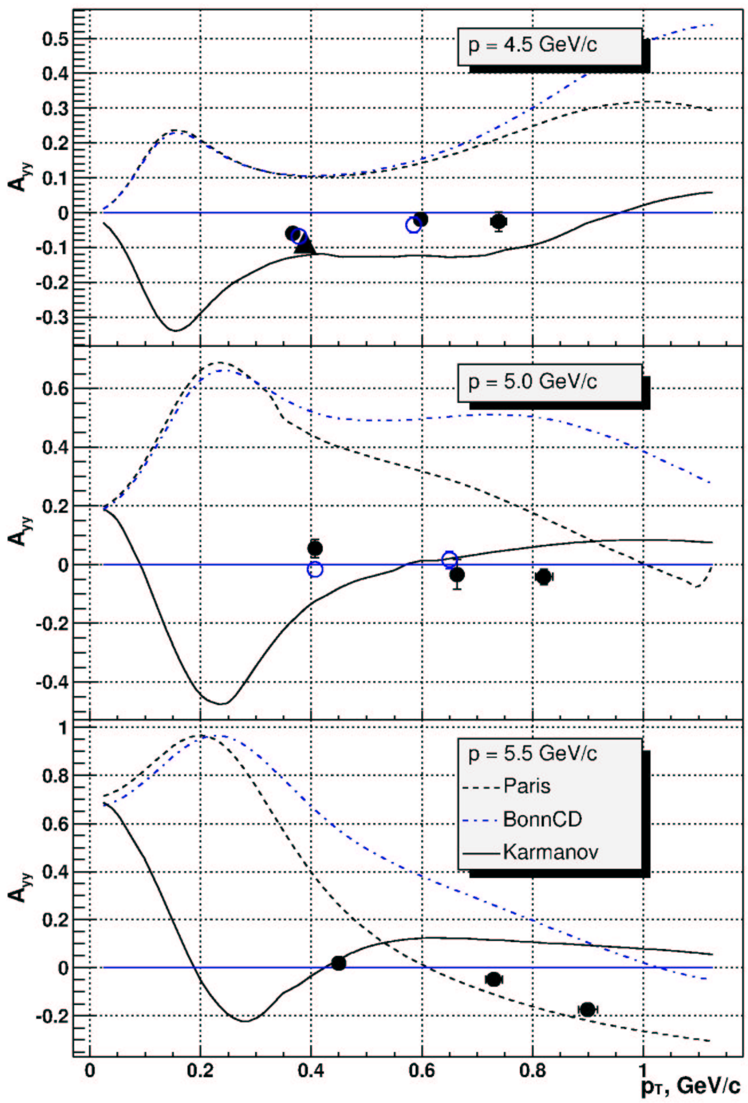
Nonrelativistic DWF (relativised in minimal scheme) :

f_1 and f_2 components depending on k variable only.

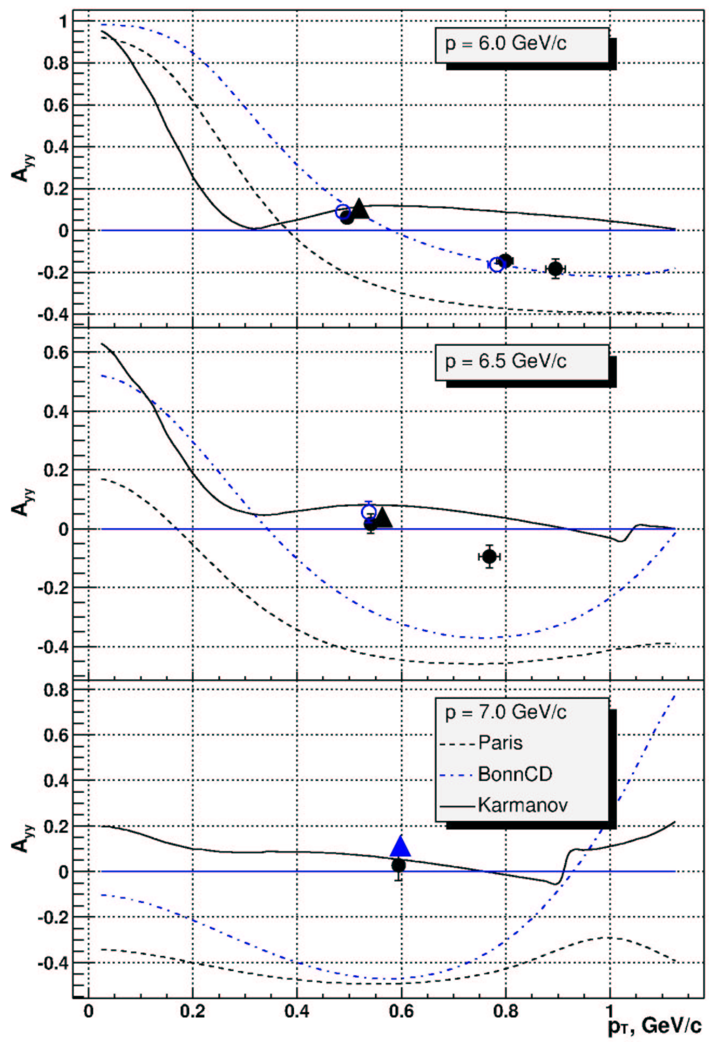
Angular dependence of A_{yy}



P_t dependence of A_{yy} at 4.5-5.5 GeV/c



P_t dependence of A_{yy} at 6.0-7.0 GeV/c



Conclusions

- The tensor analyzing power A_{yy} of the reactions $^{1}H(d,p)X$ and $^{12}C(d,p)X$ has been measured at an initial deuteron momentum of 9 GeV/c and proton emission angles of 85, 115, 130, 145 and 160 mr in the laboratory. The range of measurements corresponds to transverse proton momenta between 0.4 and 0.9 GeV/c.
- The A_{yy} data from the present experiment at 85 mr are in good agreement with the data obtained earlier [**?**].
- The A_{yy} data demonstrate an approximate independence on the A-value of the target, as it was pointed previously [**?**].
- The proton momentum dependences of A_{yy} at the fixed values of proton emission angles and the transverse proton momentum dependences of A_{yy} at the fixed values of longitudinal proton momentum fractions are in a better agreement with calculations using Karmanov's relativistic deuteron wave function instead of standard non-relativistic deuteron wave functions. While a quantitative description is not always achieved, the results obtained favours the description of the relativistic deuteron structure with a function depending on more than one variable.
- Additional measurements of A_{yy} and other polarization observables at different initial deuteron momenta and various p_T and x are strongly desirable to provide the necessary experimental base to develop relativistic models describing the short-range structure of deuteron.

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