Краткие сообщения ОИЯИ №4(67)-94 *JINR Rapid Communications №4(67)-94*
УДК 539.128.2

TENSOR ANALYZING POWER T_{20} FOR $d^{\uparrow} + {}^{12}C \rightarrow p + X$ AT $\Theta_p = 0°$ IN THE REGION OF HIGH INTERNAL MOMENTA IN THE DEUTERON*

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The tensor analyzing power T_{20} for the reaction $d^{\uparrow} + {}^{12}C \rightarrow p(0°) + X$ has been measured in the region of proton internal momenta k in light-cone dynamics up to 1 GeV/c. Measurements have been carried out with Dubna polarized deuteron beam at deuteron momenta up to 9 GeV/c. The results show that as the internal momentum increases the T_{20} tends to approach the value obtained by the calculation based on the reduced nuclear amplitude method in which the quark degrees of freedom were taken into account.

The investigation has been performed at the Laboratory of High Energies, JINR.

Тензорная анализирующая способность T_{20} для реакции $d^{\uparrow} + {}^{12}C \rightarrow p + X$ при $\Theta_p = 0°$ в области высоких внутренних импульсов в дейтроне

Черных Е.В. и др.

Тензорная анализирующая T_{20} способность реакции $d^{\uparrow} + {}^{12}C \rightarrow p(0°) + X$ измерена в области внутренних импульсов протона k в динамике светового фронта вплоть до 1 ГэВ/с. Измерения были выполнены на пучке поляризованных дейтронов с импульсом до 9 ГэВ/с. Результаты измерений показывают, что по мере роста внутреннего импульса T_{20} стремится к пределу, полученному в расчетах, основанных на методе редуцированных ядерных амплитуд, учитывающем кварковые степени свободы.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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*This work was supported by the Russian Fund of the Fundamental Investigations (grant No.93-02-3961) and the Japan Society for the Promotion of Science (JSPS).

The investigation of the deuteron structure at small internucleonic distances (high internal momenta) is one of the most interesting subjects in nuclear physics. At that case the wave functions of two nucleons in the deuteron overlap each other largely and the quark-gluon degrees of freedom would be expected to emerge rather than the nucleon-meson degrees of freedom. The internal structure of the deuteron has been studied at short distances in the reactions $d + A \to p + X$ at 0° [1—7], $\gamma d \to pn$ [8], inelastic [9] and elastic ed scattering at a large angle [10] and dp elastic backward scattering [11]. In particular, in the breakup reaction $d + A \to p + X$ it has been studied at the shortest internucleonic distances. So using 8.9 GeV/c unpolarized deuteron beam, the Dubna group [1] measured the cross section of the forward breakup reaction $d + \mathrm{C} \to p + X$ at the internal momenta in light cone dynamics k up to 1 GeV/c. The momentum spectrum obtained in the experiment was not reproduced by the models using conventional wave functions [12] [13]. On the contrary, the model with hybrid deuteron wave function [1,14] which includes a small amount of six-quark admixture described the data satisfactorily. This model also described T_{20} data obtained in the experiments at Saclay [2] and Dubna [3]. In accordance with maximum deuteron beam momenta available at Saclay (3.5 GeV/c) and Dubna (9.1 GeV/c) the breakup deuteron reaction can be studied up to internal momenta k about 0.54 GeV/c and 1.04 GeV/c, respectively. The first measurements of T_{20} performed at Dubna by ALPHA group [3] contained fairly large errors at k higher than 700 MeV/c. Recently new measurements of T_{20} have been performed by the ANOMALON group at Dubna with smaller errors [4]. T_{20} up to k = 825 MeV/c found to be still negative and more similar to the QCD prediction than to the calculations with conventional wave functions. However, a crucial test should be made at higher internal momenta where the calculations with conventional wave functions give considerably different values of T_{20} against the QCD prediction.

Another important spin observable in the breakup reaction is the polarization transfer coefficient κ_0; $\kappa_0 = V_p / V_d$ where V_p is the polarization of the emitted proton and V_d is the vector polarization of the deuteron. This observable has been measured in the region of internal momenta k up to 550 MeV/c [5—7], where its value has turned close to zero that contradicts the predictions of NN-potential models at the impulse approximation approach. For more complete information on the deuteron wave function at small internucleonic distances, further polarization experiments have been required.

In this paper we report the results of tensor analyzing power T_{20} measurement for the reaction $d^{\uparrow} + {}^{12}C \rightarrow p + X$ by detecting the protons emitted at the forward angles $\Theta_p \leq 1.3°$ at deuteron momenta from 6.0 GeV/c to 9.0 GeV/c. The experiment was performed at the Synchrophasotron of the Joint Institute for Nuclear Research using tensor polarized deuteron beam provided by POLARIS ion source [15]. POLARIS possesses ability to operate either in the vector polarization mode or the tensor polarization one and repeat pulse by pulse any combination in three polarization states «+», «0», «-» where «+» and «-» denote positive and negative polarization states and «0» denotes unpolarized state. A negligible depolarization at the Synchrophasotron was confirmed experimentally in the vector polarization mode [16]. For T_{20} data taking we used «+» and «-» polarization states in the tensor polarization mode. Typical beam intensity was $\sim 2 \cdot 10^9$ deuterons/pulse. The values of the deuteron beam polarization components were measured by detecting dp elastic scattering at 3 GeV/c with the fast two arm beam line polarimeter ALPHA [16]. The polarization measurement was carried out before and after the measurement of T_{20} and it was confirmed that the beam polarization remained stable. The T_{20} measurements under the same kinematic conditions were repeated with intervals of several hours. Reproduction of the values of T_{20} gives another confirmation of deuteron polarization stability within the measurement time. The tensor and admixture vector polarizations of the beam were

$$p_{zz}^{+} = +0.543 \pm 0.013(\text{stat.}) \pm 0.022(\text{syst.}),$$

$$p_{z}^{+} = 0.222 \pm 0.007(\text{stat.}) \pm 0.004(\text{syst.})$$

for «+» polarization state and

$$p_{zz}^{-} = -0.709 \pm 0.013(\text{stat.}) \pm 0.028(\text{syst.}),$$

$$p_{z}^{-} = 0.200 \pm 0.010(\text{stat.}) \pm 0.004(\text{syst.})$$

for «-» polarization state. To estimate the systematical errors for measured p_z and p_{zz} values we took total uncertainties for the known dp elastic scattering analyzing powers A_y and A_{yy} [17]. T_{20} for the reaction $d^{\uparrow} + {}^{12}C \rightarrow p(0°) + X$ is derived from the differential cross section defined by the formulae,

$$\sigma^{\pm} = \sigma^{0}\left(1 - \frac{1}{2}\rho_{20}^{\pm}\,\mathrm{T}_{20}\right), \qquad (1)$$

where σ^{+} and σ^{-} are the cross sections for positive (+) and negative (-) aligned beams, σ^{0} is that for an unpolarized beam and $\rho_{20} = p_{zz}/\sqrt{2}$ is the beam alignment in spherical form. Then T_{20} is reduced to

$$\mathrm{T}_{20} = \frac{2(n^{+} - n^{-})}{n^{+}\rho_{20}^{-} - n^{-}\rho_{20}^{+}}, \qquad (2)$$

where n^{+} and n^{-} are counts of the detected protons normalized by the deuteron beam intensities for positive (+) and negative (-) alignments. The experiment has been performed at 4.5, 6.5 and 7.5 GeV/c of beam line momenta for the emitted protons. To vary the internal momentum k at fixed beam line momentum we changed the momentum of the incident deuterons.

Table 1. Kinematic conditions of data taking

No.	P_d(GeV/c)	P_L(GeV/c)	$k_{\parallel}$(GeV/c)	$q_{\parallel}$(GeV/c)
1	9.00	7.50	0.814	0.493
2	8.90	7.50	0.855	0.505
3	8.70	7.50	0.949	0.528
4	9.00	6.50	0.455	0.347
5	8.41	6.50	0.600	0.416
6	8.00	6.50	0.725	0.464
7	7.80	6.50	0.806	0.497
8	9.00	4.50	0.000	0.000
9	6.85	4.50	0.299	0.252
10	5.97	4.50	0.524	0.382

Table 1 shows the set of kinematical conditions, under which we took the data: these are incident deuteron momentum P_d and beam line momentum P_L. Corresponding values of internal momentum $k_{\parallel}$ and momentum of proton in the deuteron rest frame $q_{\parallel}$ are also given in Table 1. The longitudinal component of q is obtained by the Lorentz transformation of the laboratory proton momentum:

$$q_{||} = \gamma(P_{||} - \beta E_p) \tag{3}$$

with $\gamma = E_d / m_d$ and $\gamma\beta = P_d / m_d$, where $P_{||} = P_p \cos\Theta_p \sim P_p$; P_p and E_p, P_d and E_d are the momenta and energies of proton and deuteron, respectively. The momentum k called internal momentum in light-cone dynamics is expressed by the following formula (see [14] and other references therein)

$$k^2 = \frac{m_\perp^2}{4\alpha(1-\alpha)} - m_p^2 \tag{4}$$

with $m_\perp^2 = k_\perp^2 + m_p^2$, where $k_\perp$ is the transverse momentum of the proton. The light-cone variable α [18] is the part of the deuteron momentum carried by the proton in the infinite momentum frame and is expressed by $\alpha = (E_p + P_p)/(E_d + P_d)$. When the light-cone variable α is not close to 1/2, the transverse momentum $k_\perp$ (~0.04 GeV/c) can be neglected and then k^2 is reduced to

$$k^2 \cong \frac{m_p^2}{4\alpha(1-\alpha)} - m_p^2 . \tag{5}$$

This expression was used in the analysis except the point at $k \cong 0$, where k was calculated by equation (4) with $k_\perp = 44$ MeV/c as the mean weighted value of $k_\perp$ estimated by the acceptance at the focus F3.

The stripping reaction $d^\uparrow + {}^{12}C \rightarrow p + X$ occurred in a carbon target located at the beam line focus F3 (see Fig.1). The target was 30 cm (50 g/cm^2) along the beam and 6 cm across while the beam spot at F3 did not exceed 3 cm. The beam position at F3 was under control by the multiwire ionization beam profilemeter and was found stable within ±1 mm in the data taking time. The quadrupole magnet located 4.5 m downstream F3 accepted the particles emitted at angle $\Theta_p \leq 1.3°$. The beam line consisting of bending magnets B1—B3 and quadrupole magnets selected the particles having the required momentum; the momentum bite of the beam line was ±2%. For particle identification, the two independent TOF counter systems were used. The TOF counters were placed at F4 (S_{TOF1}), F5 (S_{TOF2}) and F7(S_{TOF3}). The particles having passed through the beam line were detected by the magnetic spectrometer ANOMALON [19] located at F7. The spectrometer (Fig.1) was composed of an analyzing magnet (SP-40) and 9 MWPCs with a wire spacing of 1mm (PC3-5) and 2mm (PC1,2,6—9).

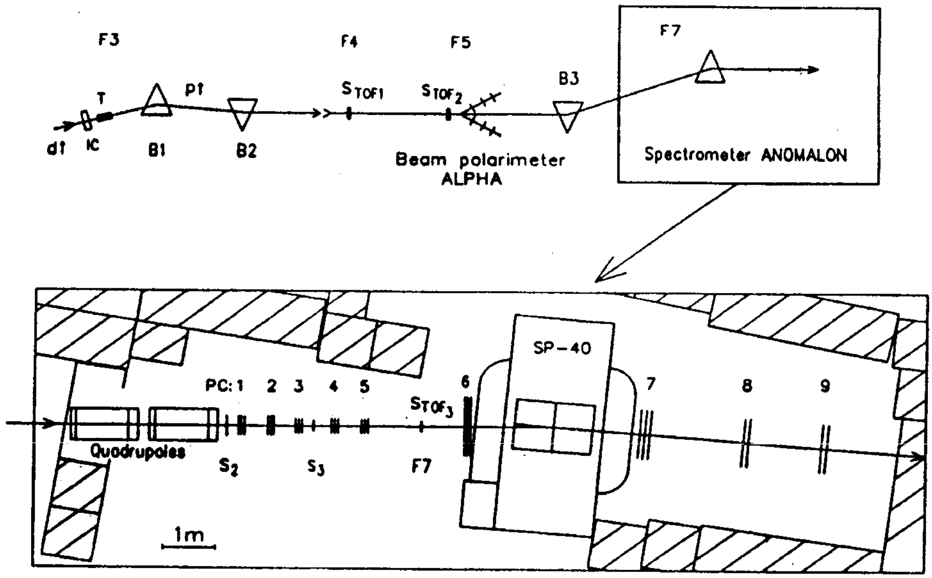

Fig.1. Schematic layout of the beam line and the spectrometer ANOMALON. B denotes the bending magnets. F3, F4, F5 and F7 are the focusing points

The first 7 MWPCs had 3 planes (X, U, V) and the two last ones (PC8,9) had 2 planes (X,Y). A momentum resolution of spectrometer was equal to 0.76% for 7.5 GeV/c protons. The deuteron beam intensity was measured by an ionization chamber (IC) placed in front of the carbon target (see Fig.1).

The event trigger logic of data acquisition was made according to

$$(\mathrm{N1 \cdot M1 \cdot S2 \cdot S3}) \cdot (\mathrm{TX1 \cdot TX2}).$$

N1, M1, S2 and S3 were trigger counters located at F7, four-fold N1·M1·S2·S3 coincidences formed a beam particle signal. All trigger and TOF counters were made of plastic scintillators 8 to 10 mm thick. TX1 and TX2 were TOF counters using Phillips XP2020 photomultipliers: the former was located at F4 and the latter at F7. These TOF counters were used to suppress the deuteron events at the stage of fast trigger. To select the proton events the final particle identification was carried out by another TOF counter system using Hamamatsu photomultipliers (H2431): the start timing signal of TDC was fed from TOF counter N1 located at F7, and the stop timing signals were sent from two TOF counters N2 at F4 and M2 at F5. This system gave us two TOF timings: one was between F4 and F7 (~70 m) called T2 and the other was between F5 and F7 (~45 m) called T3. In the off-line analysis the correlation of T2 and T3 was examined and the

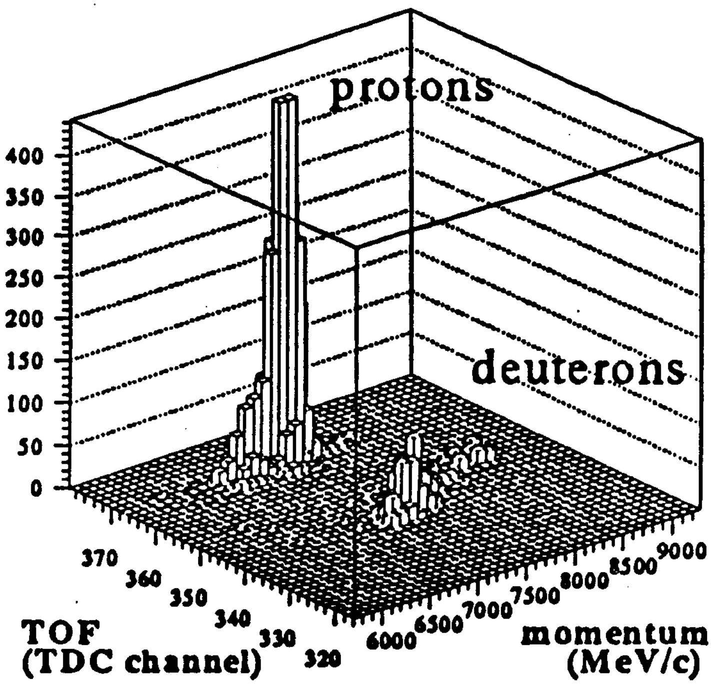

Fig.2. The two-dimensional plot of TOF and the momentum for the detected events of data set No.3 (Table 1). In the TOF time scale one digit of TDC corresponds to 220 ps/channel

uncorrelated events were discarded. A typical two-dimensional plot of TOF (T2) and the momentum for the events having passed through the correlation check is shown in Fig.2 for data set No.3 in Table 1. As one can see protons are clearly separated from the deuterons.

Dividing the events of each set of data typically into three to five bins of k with bites of 50 to 80 MeV/c, we derived the T_{20} values. The T_{20} values of the same k bins but for different deuteron beam momentum P_d are displayed in Fig.3. One can conclude that there is no indication of that T_{20} depends on P_d . The events for the same k bins were combined and the T_{20} values were calculated. The combined T_{20} values are shown in Table 2 as a function of k, q and α. The indicated systematic errors are dominantly originated from uncertainty of the analyzing power of elastic dp scattering [17]. The obtained values of T_{20} are plotted in Fig.4 with the data of other groups and theoretical calculations. In the region where other group's data and ours overlap, the data are in good agreement with each other. Our data in the

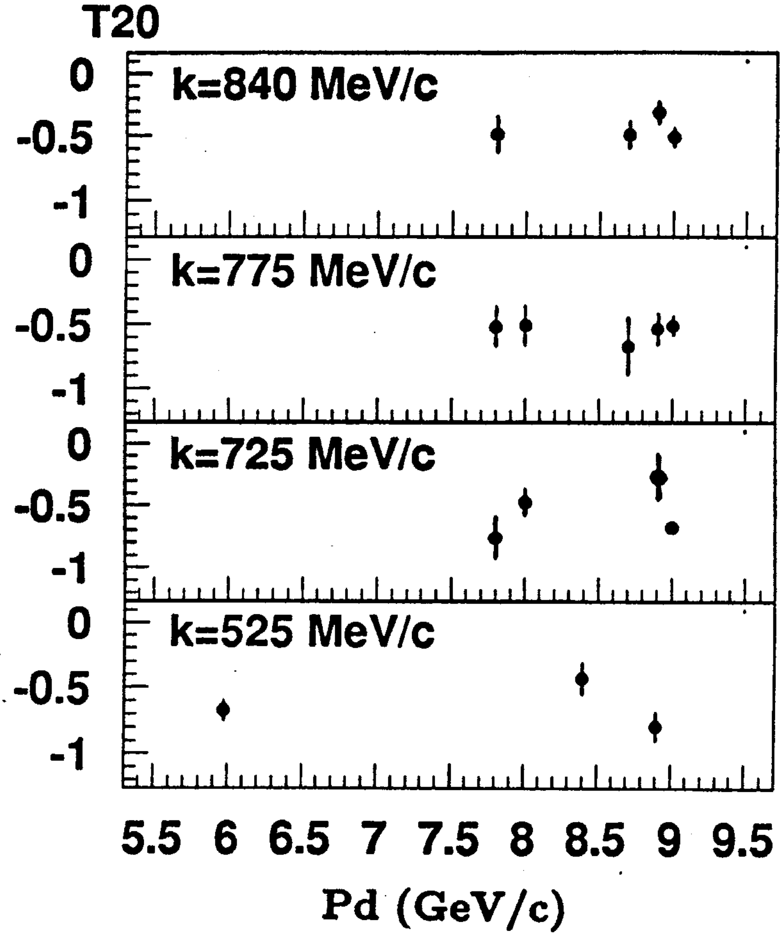

Fig.3. T_{20} for the same k bins at different deuteron beam momenta P_d . The errors bars display statistical errors

high internal momentum region, $k > 850$ MeV/c, show a tendency of approaching of T_{20} to the QCD motivated asymptotic prediction ($T_{20} \to -0.3$) [20] based on the reduced nuclear amplitude (RNA) method [21], as the arrow with the dashed line 5 in Fig.4 shows. Curves 1, 2 and 3 are the results of the calculation [22] by relativistic treatment using conventional wave functions: 1— spectator mechanism (SM) with the Reid soft core wave function, 2 — SM including final state interaction (FSI) with the Reid soft core wave function, 3 — SM including final state interaction with the Paris wave function. They indicate the change of the sign of T_{20} at

Table 2. T_{20} as a function of k, q and α

k (MeV/c)	δk (MeV/c)	q (MeV/c)	α	T_{20}±stat.±sys.
47	7	47	0.500	−0.083±0.027±0.003
275	10	235	0.640	−0.833±0.057±0.033
325	11	269	0.664	−0.810±0.047±0.032
375	12	301	0.686	−0.790±0.072±0.032
425	13	330	0.706	−0.600±0.056±0.024
475	14	358	0.726	−0.583±0.049±0.023
525	15	383	0.744	−0.663±0.053±0.027
575	17	406	0.761	−0.572±0.060±0.023
625	19	427	0.777	−0.506±0.062±0.020
675	21	447	0.792	−0.570±0.093±0.023
725	23	465	0.806	−0.601±0.057±0.024
775	25	481	0.818	−0.520±0.053±0.021
840	29	500	0.833	−0.453±0.048±0.018
920	35	521	0.850	−0.400±0.063±0.016
1000	38	539	0.864	−0.351±0.116±0.014

δk denotes uncertainty of k due to our momentum resolution for breakup protons

k below 950 MeV/c. On the contrary, our results show that T_{20} still remains negative even at k = 1000 MeV/c. Curve 4 is the result of the calculation with allowance for the composite 6-quark component [23].

To conclude: we have measured the tensor analyzing power T_{20} for the reaction $d^{\uparrow} + {}^{12}C \rightarrow p(0^{\circ}) + X$ in the region of proton internal momenta of light-cone dynamics up to 1 GeV/c. The results have shown a tendency that T_{20} is approaching the asymptotic prediction ($T_{20} \rightarrow -0.3$) obtained in the calculation based on the reduced nuclear amplitude method in which the quark degrees of freedom are taken into account.

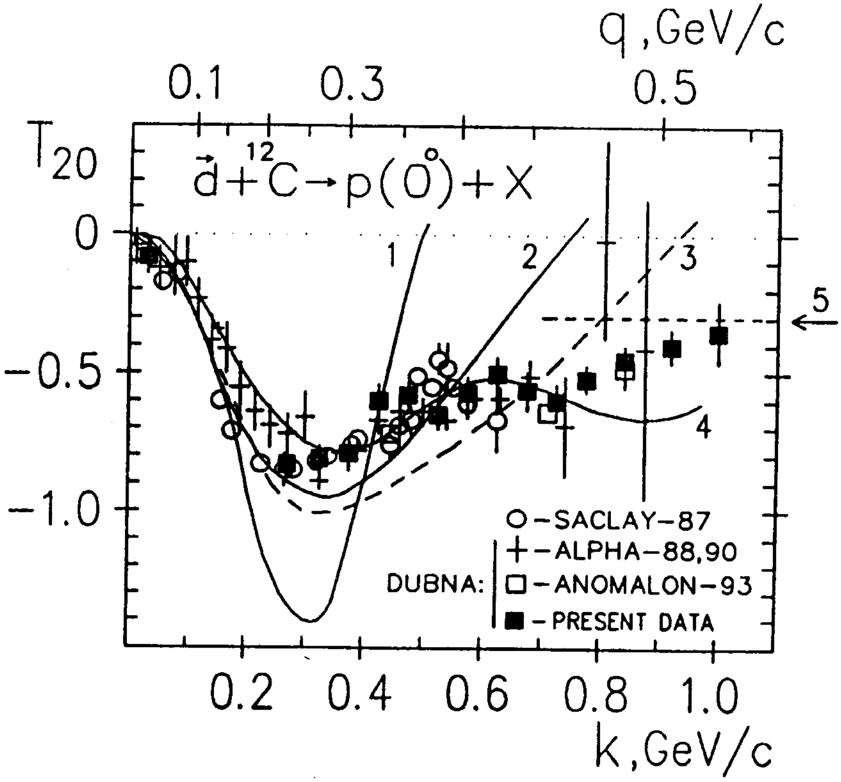

Fig.4. T_{20} as a function of k and q. Hatched squares are the present results. Open circles are from [2]. Crosses and open squares are Dubna data from [3] and [4], respectively. The errors are statistical. The curves and arrow are explained in the text

Acknowledgments

We would like to thank the staff of the engineering departments at LHE, JINR for maintaining the polarized deuteron beam running in good condition and Prof.I.Golutvin and Dr.V.Khabarov for their kind attention and support of our activity. We appreciate assistance of many who provided a technical support of these measurements among whom are A.Litvinenko, A.Khrenov, Z.Motina and P.Kulinich. We thank directorates of JINR and LHE, JINR for a manifold support of this experiment.

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Received by Publishing Department
on September 21, 1994.