ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1-95-7

B.Kuehn[1], C.F.Perdrisat[2], E.A.Strokovsky

CORRELATIONS BETWEEN POLARIZATION OBSERVABLES IN INCLUSIVE DEUTERON BREAKUP

Submitted to «ЯФ»

[1]Permanent address: 01326 Dresden, Dresdner Str.57, Germany
[2]The College of William and Mary, Williamsburg, VA 23185, USA

1995

1. Introduction

Many experimental and theoretical investigations of the structure of the deuteron have been undertaken recently, with the goal of probing the deuteron wave functions at short distances or large internal momenta of its constituents. Progress has been achieved[1-3] especially in the measurement of cross section data and polarization observables for the inclusive deuteron breakup $A(d,p)X$ for beam momenta up to $9\,GeV/c$. Cross sections have been measured for internal momenta up to $k=0.9\,GeV/c$ in the infinite momentum frame; the tensor analyzing power T_{20} is now available up to $k=0.8\,GeV/c$ and the polarization transfer coefficient up to $k=0.5\,GeV/c$.

The interpretation of these data is normally based on two main assumptions: **(1)** the laboratory momentum $\vec{p}_{fr}$ (or $\vec{q}_{fr}$ in the deuteron rest frame) of the detected fragment proton is in one-to-one correspondence with the relative momentum of the deuteron constituents $\vec{q}$, which is the argument of the DWF in the Schroedinger equation in momentum space. This assumption justifies treating the argument of the DWF *as an observable*; it corresponds to the "frozen momentum" assumption of the impulse approximation (IA). **(2)** The spin state of the detected proton remains unchanged in the reaction; therefore it is the same as defined by the wave function of the incident deuteron. Here and in our talk[6] this assumption is called *"frozen proton spin"* in the (d,p) breakup reaction.

Examination of the data available indicate that these simple assumptions are violated to some degree. Additional features of the process have to be considered: for example, one might include additional angular momentum components in the DWF (which arise as a result of the relativization of the DWF in some approaches or appear in models with non-spherical 6q-bags), or one might involve more complicated reaction mechanisms beside the IA, with or without particle production and (or) spin-flip transitions. More stringent tests of the above assumptions are expected when additional data from the backward elastic dp reaction, become available.

We will demonstrate that data, as well as theoretical predictions for the polarization observables, show a considerable amount of internal consistency when examined in a form independent of the DWF, as a κ_0 - T_{20} correlation plot.

The theoretical background necessary to introduce this presentation is developed in section 2. Application of the presentation to the dp breakup data and to various theoretical predictions is presented in section 3. Section 4 contains our conclusions and a proposal for further experimental investigations of the dp breakup reaction.

2. The κ_0 - T_{20} correlation circle

Within the IA the observables of the reaction are related to the deuteron wave function (*DWF*) components u and w as follows:

$$T_{20}=\frac{1}{\sqrt{2}}\frac{2\sqrt{2}uw-w^2}{u^2+w^2}\quad,\quad \kappa_0=\frac{u^2-w^2-uw/\sqrt{2}}{u^2+w^2}\quad,\quad d\sigma/dq_{fr}\sim u^2+w^2 \qquad (1-3)$$

where T_{20} is the tensor analyzing power of the reaction and κ_0 is the ratio of the proton-fragment polarization to the polarization of the vectorially polarized incident deuteron. Relations (1-3) can be inverted in order to express u and w in terms of the observables κ_0, T_{20} and $d\sigma$; *in this sense the DWF is an observable.*

Because the three observables $d\sigma/dq_{fr}$, T_{20} and κ_0 are related with the two DWF components u and w, eqs.(1-3) form an overdetermined set of equations for u and w and only two of the equations are independent in fact[4].

Relations (1-3) show that both polarization observables depend only upon the ratio of the D over S wave functions, $x=w(q)/u(q)$:

$$T_{20}=\frac{1}{\sqrt{2}}\frac{2\sqrt{2}x-x^2}{1+x^2}\quad,\quad \kappa_0=\frac{1-x^2-x/\sqrt{2}}{1+x^2} \qquad (4-5)$$

Eliminating x from equations (4,5) leads to a quadratic relationship between the observables T_{20} and κ_0:

$$\frac{\kappa_0^2}{9/8}+\frac{(T_{20}+1/2\sqrt{2})^2}{9/8}=1 \qquad (6)$$

In other words the single parameter δ would describe **both** values κ_0 and T_{20} if the experimental data were on the circle (6).

If the data do not stay on the circle, they still can be parametrized as in the case of the Argand plot, namely introducing a second parameter η in analogy with the inelasticity parameter of the Argand-plot analysis:

$$\tilde{A} = \frac{(\eta\, e^{2i\delta} - 1)}{2i} \quad , \quad \eta . sin2\delta = 2\chi = \frac{2\sqrt{2}}{3}\kappa_0 \quad , \quad \eta\, cos2\delta = 1 - 2\tau \qquad (11)$$

3. Discussion of the experimental data

The observables $d\sigma/dq_{fr}, T_{20}$ and κ_0 were measured [1,2] as functions of proton momentum q_{fr} with various targets at several energies E_d of the deuteron beam (polarized and unpolarized). It has been possible to extract an empirical momentum density (EMD) of the nucleon in the deuteron using eq.(3). The main results are as follows: (1) the EMD is almost independent of the deuteron energy, of the target and of the type of hadronic reaction (see [1,2]); (2) the EMD extracted from the inclusive deuteron-breakup data [1] versus k agrees very well with the one determined from the inclusive (e, e') experiment [5], as it is seen from Fig.2a. Both of them disagree with the standard wave function calculations in the region $250 \leq k \leq 650\ MeV/c$. At the same time, they are in striking agreement [7] with the EMD calculated from the cross sections of elastic backward dp scattering, obtained with the help of an expression found in ref.[8]. (3) Polarization observables are also largely independent on the target and initial energy.

From Fig.2a alone one could conclude that at high k values ($k \geq 600\, MeV/c$) the agreement between the observed EMD and the calculated EMD is restored in spite of the fact that the very notion of wave function is questionable at such high internal momenta. But one immediately realizes that such a conclusion is premature, when one takes into account the polarization observables T_{20} and κ_0 (Fig.2b,c): actually one finds agreement between all data sets and standard calculations *only for* $k \leq 150\, MeV/c$; a drastic disagreement is seen beyond this region.

More complicated models, taking into account various additional contributions to the reaction mechanism, result in a partial success for a given observable, but not for the whole set of observables.

In Fig.1 data taken from ref.[2] are shown. The data are on the circle only for $k < 100\, MeV/c$. Therefore the spin structure of the reaction matrix element is different from that expected with "frozen proton spin" and the 2-component DWF. Two alternatives are considered here:

1. some spin-dependent mechanisms result in important corrections to the IA.
2. While the spin structure of the matrix element is determined, as in the IA, by the DWF, the wave function itself has an additional P-wave component related, for example, with an $N - N^*$ component of the deuteron; the parity of this N^*-resonance must then be opposite to that of proton.

One possible example of the 1-st alternative was analysed by Lykasov [9]; his prediction is rather close to the data up to $q_{fr} \sim 300\, MeV/c$; at higher momenta the calculated trajectory deviates strongly from the experimental one on the κ_0-T_{20} plot (Fig.1, solid line). Perdrisat and Punjabi[11] have calculated $d\sigma$, T_{20} and later κ_0 for the deuteron breakup on protons within the standard non-relativistic picture, namely: (i) the full NN amplitude taken from the phase shift analysis (including all spin dependent terms) was used, (ii) all possible single and double scattering graphs and the relevant interference terms were taken into account[11]. The results were presented for the full case and for the case when only single scattering graphs were kept but in both cases the full NN amplitude was used. The corresponding trajectories on the κ_0-T_{20} plot are shown on the Fig.3a as well (solid and dashed lines respectively, Bonn potential). One sees that single scattering graphs with the full NN amplitude result in a trajectory close to the data up to q_{fr} about 200 MeV/c; than it approaches the circle (6). The full set of graphs, including the double scattering terms, results in a trajectory closer to the experimental one up to $q_{fr} \sim 300\, MeV/c$. Unfortunately not all components of the NN amplitude are known from the phase shift analysis sufficiently well; these uncertainties as well as other approximations described in ref.[11] do not allow to get reasonable results in the most interesting region of q_{fr} above approximately 300 MeV/c. The results of ref.[11] can be interpreted as strong indications on an important influence of the spin-dependent multiple scattering amplitudes on the polarization observables in the deuteron breakup; in other words, the reaction mechanism determines the behaviour of the polarization observables in an important way. It is also an indication of the unsufficient level of our knowledge of the NN amplitude at intermediate energies.

The 2-nd alternative could be related with the problem of relativization of the deuteron wave function[12]. In particular, methods suggested in refs. [13,14] result in additional components of the DWF which destroy the relation (6) in general. Still, for specific kinematics, for example in the case of the "collinear" one, the components corresponding to the orbital momenta different from 0 and 2 can disappear, as can be seen in the case of the approach[13], thus conserving the equation of the circle. As an example of consequences of relativistic effects, the IA results obtained by Tokarev[14] are shown on Fig.3b. Unfortunately, they disagree with the experiment: the trajectory calculated for the same energy at which the data shown at the Fig.3b were obtained are far from the data (long-dashed line), but the calculations at much higher energy are going through the data points (solid line); the trajectory calculated for an extremely high energy is almost undistinguishable from the circle (6). Therefore in the ultra-relativistic case this method of relativization[14] does not change the standard $S-$ and $D-$ structure of the DWF.

Another realization of the 2-nd alternative can be motivated from quark models of the deuteron, where a pre-existing N^*N $P-$wave with negative parity N^* baryon can appear. We compare in Fig.3c the experimental data with a wave function with N^*N admixture as suggested by Gross and Buck[15]. To calculate the κ_0 and T_{20} with this DWF we used formulae suggested by A.P.Kobushkin[16] within the IA picture. These are similar to eqs.(1,2) but include two new P-wave components: spin singlet and triplet. As usual, the "frozen proton spin" assumption was used. We see that the additional components can result in a strong deviation from the circle ($\lambda = 1$ case). The calculated trajectory is closer to the data when the $P-$wave is stronger (compare the curves labelled as $\lambda = 1$ and $\lambda = 0$).

Concluding this Section we would like to stress that for this N^*N P-wave in the DWF the $N^*(1535)$ S'_{11} is a good candidate as the lowest mass negative parity baryon. Such components arise, for example, in 6q-models with non-spherical 6q-configurations[17]. Therefore it would be interesting to search for the N^*N component in the deuteron using the fact that the lowest N^* with negative parity has rather large (up to 50%) branching ratio for its decay into $\eta + N$. This decay mode could be a suitable trigger signature for such a search.

4. Conclusions

The $\kappa_0 - T_{20}$ correlation expressed by the relation (6) is a consequence of the 2-component structure of the DWF and the "frozen proton spin" assumption for the reaction mechanism. Therefore the $\kappa_0 - T_{20}$ plot contains an important information about the spin structure of the matrix element of reactions like breakup, when an incident particle is broken into two "constituents" with spin configurations $1 \rightarrow 1/2 + 1/2$ or $1/2 \rightarrow 1 + 1/2$; this information is rather model-independent. The deuteron breakup considered here is the simplest example of such reactions. Other reactions of this type are $(^3He, d)$ breakup, $dp \rightarrow ^3He + \pi^0, \eta$, $\pi^+ + t \rightarrow dp$ etc. which can be analysed in the same way.

The present-day data on polarization observables tell us that the spin structure of the breakup matrix element is drastically different from the one initially assumed. This may be due to 2 reasons (perhaps both are relevant):

1. the DWF has additional P-wave (N^*N) components,
2. single scattering graphs are unsufficient to explain the deviation from the circle (6): one must take into account both spin-flip and non-spin-flip parts of the NN amplitude together with complicated (multiple scattering, triangle etc.) graphs in order to explain the observed behaviour of T_{20} and κ_0.

Therefore the old question: *do we study the deuteron structure or the breakup mechanism?*, is related with the older one: *does the DWF consist of more than 2 components?*. If we would be able to answer the latter, we would have an answer for the first. Therefore more spin observables for the *dp* interactions are desirable, either in breakup or in backward elastic scattering. Comparison of data from different reactions in the $\kappa_0 - T_{20}$ plot will be useful to determine the spin structure of the DWF. Also new experiments aimed at the search for the P-wave component of the DWF would be very informative.

Acknowledgments

We are grateful to our colleagues for their interest and useful discussions of the topics considered in this paper: N.M. Piskunov, A.P. Kobushkin, V.P. Ladygin, M.P.Rekalo.

The work was financially supported in part by grant N^o 93-02-3961 of the Russian Foundation for Fundamental Researches, by grant N^o RFU000 of the International Science Foundation and by grant PHY-91-11942 from the U.S. National Science Foundation.

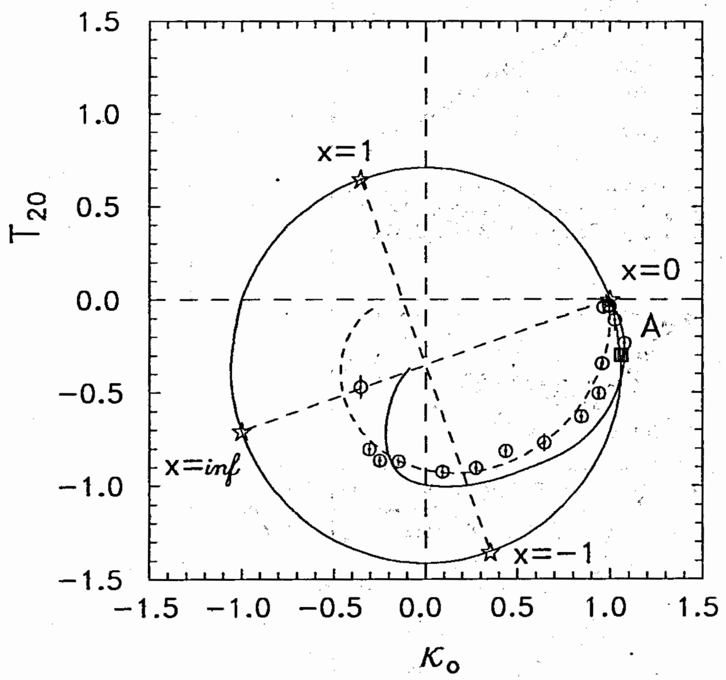

Fig.1 κ_0-T_{20} plot with the circle corresponding to eq.(6). The data points were obtained at Saclay[1]; their fitted trajectory is shown by the shortest-dashed line. The QCD-motivated asymptotic point[10] is shown by full square; the solid curve represents Lykasov's results[9]. The stars mark the points where the ratio $x = A_2/A_0$ (see eqs.(1'-3') is equal to 0, $\pm\infty$, +1 and −1.

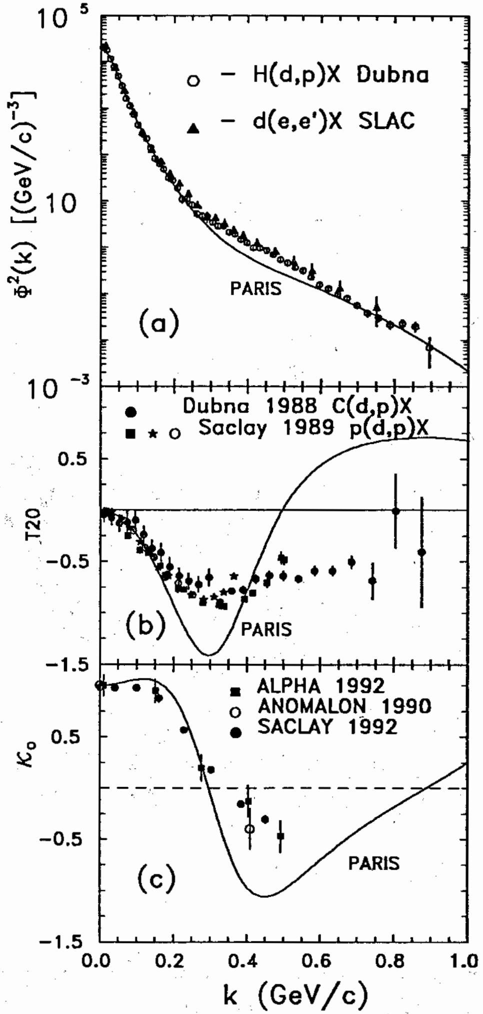

Fig.2 Observables measured for the deuteron breakup on protons and carbon. **(a)** The EMD extracted from data[1, 5] versus the light cone variable k, see[12, 14]. **(b)** T_{20} data from refs.[2] versus k. **(c)** κ_0 data versus k from refs.[2, 3]. Results of calculations within IA with Paris DWF are shown by solid lines.

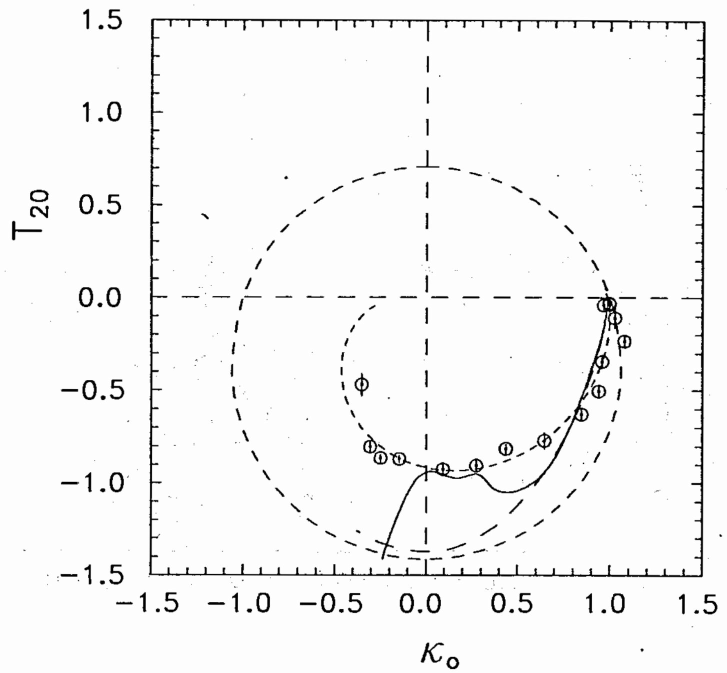

Fig.3a The same plot as on Fig.1 with results from ref.[11] obtained with DWF based on Bonn $N-N$ potential. Solid line: full calculation, dashed line: only single scattering graphs are taken into account (in both cases the full NN - amplitude was taken).

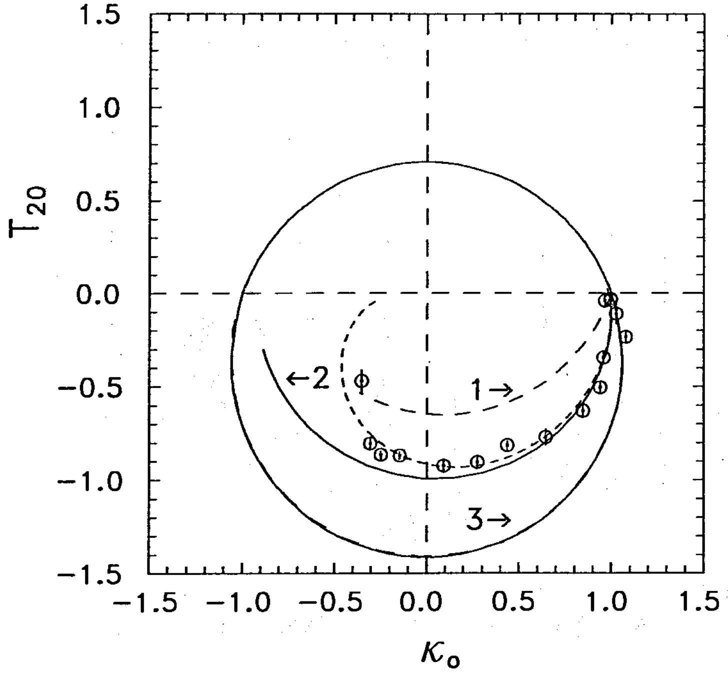

Fig.3b
κ_0-T_{20} plot with trajectories calculated by Tokarev[14] for incident deuteron kinetic energies 2.1 GeV (1), 4.45 GeV (2) and about $2 \cdot 10^4$ GeV (dashed line (3) coincinding with the circle).

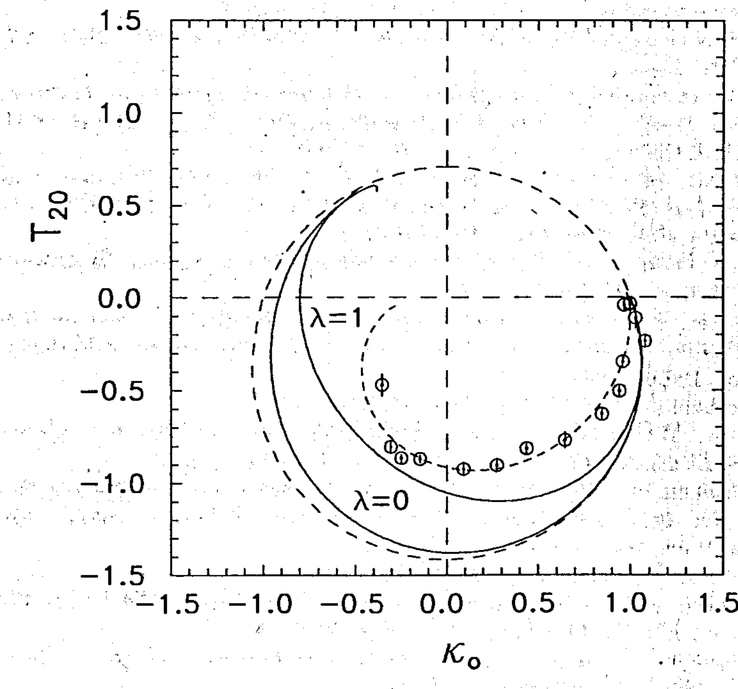

Fig.3c The same κ_0-T_{20} plot with trajectories calculated including the P-wave admixture as explained in text. Parameter λ was introduced in ref.[15]; it corresponds to pseudovector ($\lambda = 0$) and pseudoscalar ($\lambda = 1$) πNN coupling.

References

1. V.G.Ableev et al, *Pis'ma ZhETF* **37** (1983) 196; *Nucl. Phys.* **A393** (1983) 491, **A411** 541(E); *Pis'ma ZhETF* **45** (1987) 467; *JINR Rapid Comm* **1[52]-92** (1992) 10; *Few Body Systems* **8** (1990) 137; C.F. Perdrisat et al, *Phys. Rew. Lett.* **59** (1987) 2840; V. Punjabi et al, *Phys. Rev.* **C39** (1989) 608;
2. V.Punjabi et al, *Phys. Rev.* **C39** (1989) 608; V.G.Ableev et al, *Pis'ma ZhETF* **47** (1988) 558; *JINR Rapid Comm* **4[43]-90** (1990) 5; E. Cheung et al, *Phys. Lett.* **B284** (1992) 210; I.Atanasov et al, in: *Proc. of the 10-th Internat. Symp. on High Energy Spin Physics, Nov. 9-14 1992, Nagoya*, ed. by T.Hasegawa, H.Horikawa, A.Masaike, S.Sawada, Univ. Acad. Press, Inc., Tokyo, p.537.
3. T.Dzikowsky et al, in:*Proc. of Int. Workshop "Dubna-Deuteron-91"*, JINR, **E2-92-25** (1992) 181.
4. V.G.Ableev et al, *Book of contributions, XIII Intern. Conference on Few-Body Problems in Physics, Jan. 5-11 1992, Adelaide, Australia* p.52, ed. by I.R.Afnan, R.T.Cahill. E.Cheung et al, *Phys. Lett.*, *B284* (1992) 210;
5. I.Sick, D.Day, J.S.McCarthy, *Phys. Rev. Lett.* **45** (1980) 871; P.Bosted at al, *Phys. Rev. Lett.* **49** (1982) 1380; D. Day et al, *Phys. Rev. Lett.* **43** (1979) 1143; J.S.McCarthy et al, *Phys. Rev.* **C13** (1976) 712.
6. B.Kuehn, C.Perdrisat and E.A.Strokovsky, talk at the International Symposium Dubna - Deuteron-93, Dubna, 1993.
7. C.F.Perdrisat, V.Punjabi, in: *Proceedings of the XI Internat. Seminar on High Energy Physics Problems, Sept. 7-12 1992, Dubna*, p.491, ed. by A.M.Baldin, V.V.Burov, Dubna, 1994.
8. A.P.Kobushkin *J. Phys. G: Nucl. Phys.* **12** (1986) 487.
9. G.I.Lykasov, M.G.Dolidze, *Z. Phys.* **A336** (1990) 339; see also G.I.Lykasov, *Physics of Elenentary Particles and Atomic Nuclei*, **24** (1993) 140
10. A.P.Kobushkin, in: *Proc. of the 10-th Internat. Symp. on High Energy Spin Physics, Nov. 9-14 1992, Nagoya*, ed. by T.Hasegawa, H.Horikawa, A.Masaike, S.Sawada, Univ. Acad. Press, Inc., Tokyo.
11. C.F. Perdrisat, V.Punjabi, *Phys. Rev.* **C42** (1990) 608.
12. B.L.G.Bakker, L.A.Kondratyuk, M.V.Terent'ev, *Nucl. Phys.* **B158** (1979) 497; H.Leutwyler, J.Stern, *Ann. Phys. (N.Y.)* **112** (1978) 94; A.P.Kobushkin, V.P.Shelest, *Physics of Elementary Particles and Atomic Nuclei* **14** (1983) 1146; V.A.Karmanov, *ibid* **19** (1988) 525.
13. V.A.Karmanov, talk presented at *Int. Symp. DUBNA - DEUTERON'93, September 14-18 1993, Dubna.*
14. M.V.Tokarev, private comm.; see also review M.A.Braun, M.V.Tokarev, *Physics of Elementary Particles and Atomic Nuclei*, **22** (1991) 1237.
15. W.Buck, F.Gross, *Phys. Lett.* **63B** (1976) 286.
16. A.P.Kobushkin, in: *14th Int. IUPAP Conf. on Few Body Problems in Physics. Contributed papers.*, p.99 ed. by Franz Gross, The College of William and Mary, Williamsburg and CEBAF Newport News, Virginia, U.S.A. 1994.
17. V.G. Neudachin, I.T. Obukhovsky, Yu.F. Smirnov, *Physics of Elementary Particles and Atomic Nuclei* **15** (1984) 1165 and references therein.

Received by Publishing Department
on January 13, 1995.

Кюн Б., Педриса Ч.Ф., Строковский Е.А.

E1-95-7

Корреляции между поляризационными наблюдаемыми в реакции инклюзивного развала дейтрона

Обсуждается связь тензорной анализирующей способности T_{20} и коэффициента передачи спина κ_0 в реакции развала дейтрона $^1H\,(d,p)\,X$ под 0° с волновой функцией дейтрона (ВФД). Показано, что если: (а) ВФД имеет общепринятую двухкомпонентную S + D структуру и (б) механизм реакции таков, что спин регистрируемого протона не изменяется при развале дейтрона, то обе наблюдаемые T_{20} и κ_0 являются функциями отношения D/S и связаны уравнением окружности на плоскости $\kappa_0 - T_{20}$. Эта корреляция между двумя поляризационными наблюдаемыми не зависит от конкретной модели ВФД с двухкомпонентной структурой.

Экспериментальные данные уходят от $\kappa_0 - T_{20}$ окружности, свидетельствуя о том, что по меньшей мере одно из указанных общепринятых предположений не выполняется. Мы обсуждаем две возможности объяснения экспериментальных данных: (1) ВФД имеет дополнительные компоненты, например N^*N P-волну, (2) дополнительные спин-зависимые интерферирующие вклады в механизм реакции приводят к изменению спина детектируемого протона в процессе реакции. В качестве возможного способа проверки 1-й возможности предлагается провести поиск η-распада $N^*(1535)$ бариона с отрицательной четностью из N^*N-компоненты волновой функции основного состояния дейтрона.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1995

Kuehn B., Perdrisat C.F., Strokovsky E.A.

E1-95-7

Correlations between Polarization Observables in Inclusive Deuteron Breakup

The tensor analyzing power T_{20} and the spin transfer coefficient κ_0 for the deuteron break[illegible] reaction $^1H\,(d,p)\,X$ at 0° and at high energy are functions of the D/S ratio of the deuteron [illegible] function (DWF) and are related by the equation of a circle in the $\kappa_0 - T_{20}$ plane if (i) the deut[illegible] wave function has the commonly accepted S- and D-component structure, and (ii) the mechan[illegible] of the breakup reaction does not change the spin of the detected proton. This correlation of the [illegible] polarization observables is independent of any model of the deuteron wave function with 2-compon[illegible] structure.

The experimental data deviate from the $\kappa_0 - T_{20}$ circle, indicating that at least one of the ab[illegible] assumptions is not fullfilled. Two assumptions are discussed to explain this deviation: (i) the DWF [illegible] additional components, for example an N^*N P-wave, (ii) complicated spin dependent interfe[illegible] [illegible]s change the spin of the detected proton. We suggest an experimental way to verify the fi[illegible] of these assumptions by searching for the η-decay of the negative parity N^* (1535) baryon of a [illegible] component in the deuteron ground-state.

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