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MEASUREMENT OF POLARIZATION TRANSFER AND THE TENSOR ANALYZING POWER IN POLARIZED DEUTERON BREAK-UP WITH DEUTERON MOMENTA UP TO 9 GeV/c*

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1.Introduction

The experimental study of deuteron fragmentation in A(d,p) reactions using relativistic deuteron beams has shown for the first time [1] significant deviation of the differential cross sections over the $0.3 \leq k \leq 0.6$ GeV/c range of internal momenta from the ones calculated assuming the impulse approximation and the use of popular NN-potentials. This phenomenon can be explained more or less successfully by different models both using traditional nucleon-meson approaches and taking into account non-nucleon(quark) degrees of freędom.Nevertheless,the use of reactions with unpolarized deuterons in experiments oriented to analyse deuteron structure at small distances, does not allow a conclusive discrimination to be done between different types of models. The observation of the behaviour of spin observables at deuteron disintegration gives complementary information to advance in the study of deuteron structure. Accessibility of polarized deuterons with a momentum of up to 9 GeV/c at the Dubna Synchrophasotron gave rise to the measurement of the tensor analyzing power T_{20} and the polarization transfer coefficient æ(the ratio of proton polarization to the vector polarization of deuteron) at the break-up of relativistic deuterons.It was made at maximum internal momenta available nowadays.

Presenting the data obtained with relativistic deuterons, we use the momentum k defined in the infinite momentum frame(IMF) as follows

$$k = \sqrt{\frac{m^2 + k_T^2}{4\alpha(1-\alpha)} - m^2}, \; \alpha = \frac{E_p + p_p^l}{E_d + p_d^l}, \; \vec{k}_T = \vec{p}_p^{\,T}, \; p_d^T = 0, \qquad (1)$$

where m is the proton mass; $E_p, \vec{p}_p$ and $E_d, \vec{p}_d$ are the energies and the momenta of the proton-spectator and the deuteron in the lab.frame, l and T denote longitudinal and transverse components of the momenta.

2.Experiment

The measurements were performed at the Dubna polarized deuteron facility including the beam line of polarized deuterons with a momentum up to 9GeV/c at an intensity of 10^9 deuterons per burst and two experimental setups ALPHA and ANOMALON[2]. Two symmetrical arms of ALPHA form a high energy polarimeter[3] used in this experiment to measure the vector and tensor components of deuteron polarization. The atomic beam type source of polarized deuterons POLARIS[4] can operate in two modes. In the vector mode it produced a deuteron beam with a pure vector polarization $P_d = p_z$ =0.52-0.54 . In the tensor mode the polarization of the deuteron beam changed from $p_{zz}^+ = 0.611 \pm 0.024$ to $p_{zz}^- = -0.766 \pm 0.018$ at reversing of the polarization sign.

The measurements of p_z and p_{zz} were made by ALPHA polarimeter with a liquid hydrogen target (0.3m long) as an analyzer. The latest data [5] were used for an analyzing power of the elastic scattering reaction $^1H(\vec{d},d)p$ at $T_d = 1.6 GeV$. The sign of polarization can be changed with each accelerator cycle via changing of the radiofrequency regime of POLARIS.

A general layout of the experiment and the ANOMALON setup modified in a wide aperture polarimeter is shown in fig.1. The carbon target T1 (30cm thick) was located at the focus F3 of the extracted deuteron beam, where its dimensions are $10mm(H) \times 20mm(V)$.The breakup protons were separated from the deuteron beam by bending them by 5° (a less bent deuteron beam ended up at the beam stopper) and transported by the 100m long beam line to the analyzing target T2 at the focus F7. The 1m long liquid hydrogen target was used to analyze the vector polarization of breakup protons by measuring pp-elastic scattering asymmetry.

To measure the k-dependence of polarization transfer from the deuteron to the breakup proton, the beam line was tuned to transport breakup protons with a fixed momentum p_p=4.5GeV/c. The momentum acceptance of the beam line was ±2.5%. To vary the internal proton momenta k from the minimum (~ 0) to the maximum measured value (550MeV/c) the deuteron beam momentum p_d changed from 9 to 5.8GeV/c. This method of studying of the æ(k) -dependence does not allow one to control a possible æ-dependence on deuteron momentum which is supposed by one of the relativization models of the deuteron wave function[6]. However, this method is economical of time in so far as it excludes beam tuning time losses, when passing from one k-point to another.It is not less important that the polarization of breakup protons is measured for all k-points at a fixed momentum.

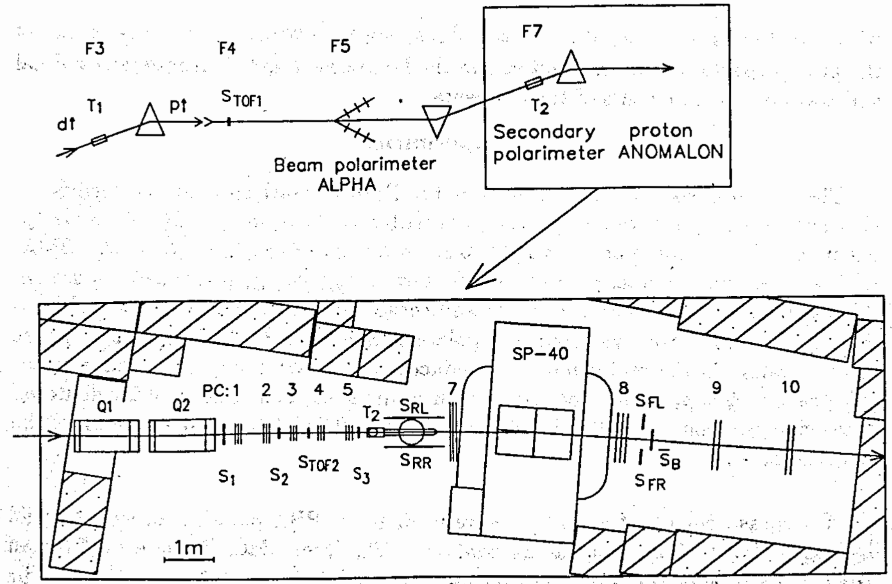

Fig.1. Layout of the experimental setup ANOMALON

The differential cross section of the breakup reaction at 0° changes by four orders of magnitude with increasing k from 0 to 550MeV/c. To keep the counting rate at the focus F7 within a reasonable limit, the beam intensity varied accordingly. The minimum rate of proton scattering events was about 1-2 events per burst at k=550MeV/c and the polarized deuterons intensity of 10^9. Inelastically scattered deuterons are the main background component in the focus F7. The deuteron flux is comparable to the proton flux at k=400MeV/c and increases by order of magnitude for each 150MeV/c increasing of k. The time-of-flight(TOF) analysis with a 70m long flight path (between F4 and F7) was used for proton identification. A proton signal from the TOF separator was used in the fast trigger logic to reject deuterons.

The polarization of breakup protons was determined by measuring pp-elastic scattering asymmetry. The selection of elastic scattering events was based on comparison of the scattering angle and the momentum of scattered particle. The system of proportional chambers P1-10 (fig.1) with a wire spacing of 2mm and 1mm(P3,4,5) was used to reconstruct the particle trajectories and to measure the momentum of forward scattered particles. Signals from the recoil counters S_{RL}, S_{RR} disposed at the right and left sides of the hydrogen target were inserted in the trigger logic to reject the main part of inelastic events. The events with the horizontal projection of scattering angle $\theta_{xz} \leq 30mrad$ were also rejected at the trigger level by the antibeam counter S_B. The forward trigger counters S_{FR}, S_{FL} determined the upper limit of $\theta_{xz} = 120mrad$.

So, the trigger option was

$$Tr = S_{beam} \times (S_{FR} \times S_{RL} + S_{FL} \times S_{RR}) \times \bar{S}_B \times S_{TOF},$$

where S_{beam} is a coincidence signal of three beam counters and S_{TOF} is a TOF-separator signal. The momentum resolution for scattered protons was 1.8% at a deviation angle of 80mrad in the SP-40 magnet.

The tensor analyzing power T_{20} of the polarized deuteron breakup reaction can be defined by measuring a ratio of yields of breakup protons at two different alignments of a deuteron beam

$$T_{20} = \frac{2\sqrt{2}(1 - \frac{N_+}{N_-})}{p_{zz}^+ - p_{zz}^- \frac{N_+}{N_-}},$$

where N_+, N_- are the proton yields at 0° for the values of p_{zz}^+ and p_{zz}^- of the polarized deuteron alignment. So, for measuring T_{20} only the beam part of the ANOMALON setup was used to measure the ratio of proton fluxes at the focus F7 at 'plus' and 'minus' alignments of deuterons directed on to the carbon target T1 at the focus F3. The beam line momentum was fixed at 6.5GeV/c. The three values of deuteron momentum P_d=9.0,8.0 and 7.7GeV were used to measure T_{20} at internal momenta k=445, 710 and 835 MeV/c.

3. æ-data analysis

The differential cross section of proton scattering with polarization P_p and momentum p_p by the target with an analyzing power A_y is given by the equation

$$\sigma_{pol}(\theta,\phi,q) = \sigma_o\{1 - A_y(\theta,q)P_p(q)cos\phi\}, \qquad (2)$$

where σ_o is the cross section for unpolarized protons; θ, ϕ are the polar and azimuthal angles of scattering. In accordance with (2), the polarization of protons can be defined by means of measuring the left-right asymmetry of scattering

$$A(\theta,p_p) = \frac{\frac{N_L}{\epsilon_L<cos\phi>_L} - \frac{N_R}{\epsilon_R<cos\phi>_R}}{\frac{N_L}{\epsilon_L} + \frac{N_R}{\epsilon_R}},$$

$$P_p(p_p) = \frac{A(\theta,p_p)}{A_y(\theta,p_p)}$$

where $N_{L,R}$ are the numbers of events counted in the left and right parts of the polarimeter with the efficiencies $\epsilon_{L,R}$; $< cos\phi >_{L,R}$ are the cosines averaged over $N_{L,R}$ events. The ANOMALON polarimeter has a marked difference between efficiencies of the left and right parts of its aperture due to the asymmetry brought in the SP-40 analyzing magnet. To exclude the necessity of $\epsilon_{L,R}$ control, one can measure the scattering asymmetry separately for the left and right parts by changing the deuteron spin orientation from the up(+) to down(-) direction

$$A_{L,R} = \frac{\frac{N^+_{L,R}}{<cos\phi>_{L,R}} - \frac{N^-_{L,R}}{<cos\phi>_{L,R}}}{N^+_{L,R} + N^-_{L,R}}.$$

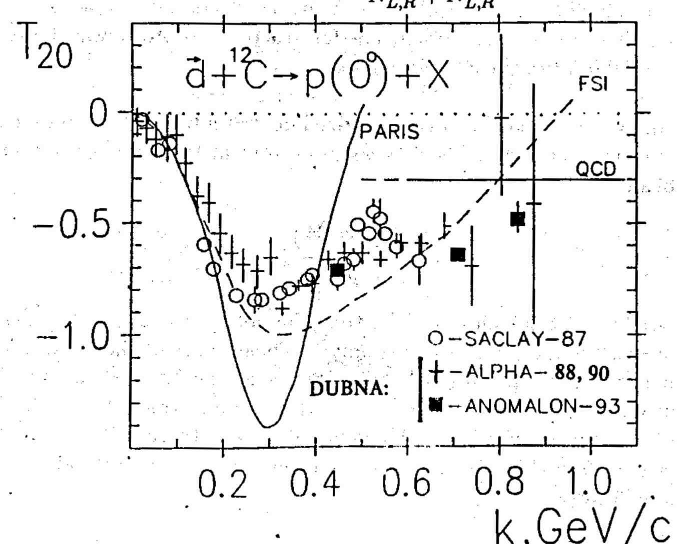

Fig.2. Analyzing power T_{20} vs. internal momenta k. Saclay(SACLAY-87) and Dubna(ALPHA-88,90) data are from Refs.[8] and [9],respectively. Curves show the prediction of Paris IA, FSI calculations[10] and the prediction of the QCD model[11]

In the program analysis of the data we use the 4-momentum scale,t.The collected elastic events were divided into t-intervals of 0.01(GeV/c)^2 between 0.08 and 0.30(GeV/c)^2. The values of polarizations for different t-bins calculated on the basis of elastic events collected in the left and right parts of the polarimeter are respectively equal to

$$P_L(t) = \frac{A_L(t)}{A_y(t)} \text{ and } P_R(t) = \frac{A_R(t)}{A_y(t)}.$$

The analyzing power for pp-elastic scattering $A_y(\theta,p_p)$ at p_p=4.5GeV/c was obtained according to Spinka et al.[7].

The polarization P_p of breakup protons was calculated as a mean weighted value of polarizations P^L_p and P^R_p extracted by the least square fit of $P_L(t)$ and $P_R(t)$ over the various t-bins.

In the case of purely vector polarized deuterons, the coefficient of polarization transfer is the ratio of two quantities

$$æ(k) = \frac{P_p(k)}{P_d}.$$

Taking into account that the polarization of breakup protons at $p_p = 0.5p_d$ should be equal to the deuteron polarization in accordance with relation of S and D state portions of the deuteron wave function at k=0,the value of æ can be determined as

$$æ(k) = \frac{P_p(k)}{P_p(0)}. \qquad (3)$$

We extracted æ in this way.

4.Results

The newly obtained T_{20} points are displayed in fig.2 together with the data obtained so far in Saclay([8]-Saclay-87) and Dubna([9]-ALPHA-90). The data are compared with the IA prediction for the Paris deuteron wave function and the infinite momentum frame(IMF) calculation taking into account NN-rescattering and pseudoscalar meson exchange between the final states[10]. The prediction of the QCD approach[11] which supposes an asymptotic regime with the fixing of T_{20} at the level close to -0.3, also is shown here. The two first points overlap on the k-scale with the data [8] and show a good quantitative accordance with them. The last point at k=835GeV/c clarifies the k-dependence at the highest measured momenta and shows that the $T_{20}(k)$-behaviour is likely to confirm the QCD-motivated prediction.

The experimental values of æ are shown in table 1 and displayed in fig.3.

Table 1

$k(GeV/c)$	æ±δæ(stat.)
0.030 ± 0.020	1.0 (fixed value)
0.186 ± 0.025	0.696 ± 0.064
0.271 ± 0.029	0.272 ± 0.071
0.375 ± 0.033	-0.190 ± 0.078
0.520 ± 0.043	-0.109 ± 0.128
0.550 ± 0.045	-0.039 ± 0.167

The uncertainty of internal momenta k is determined by the momentum acceptance of the beam line. The systematic error in the æ-data connected with the deuteron polarization measurement and with the uncertainty of the proton elastic scattering analyzing power is excluded by the accepted normalization of the æ-data (3). The uncertainty of this normalization stipulated by a deviation of k from 0 and by an admixture of the D-state at $k \leq 0.03$GeV/c should not exceed 2%. This uncertainty and the statistical error of δæ$= \pm 0.05$ at $k = 0.03$ determine the systematic error at other k-points: $\delta æ(k)_{syst} = 0.055 æ(k)$.

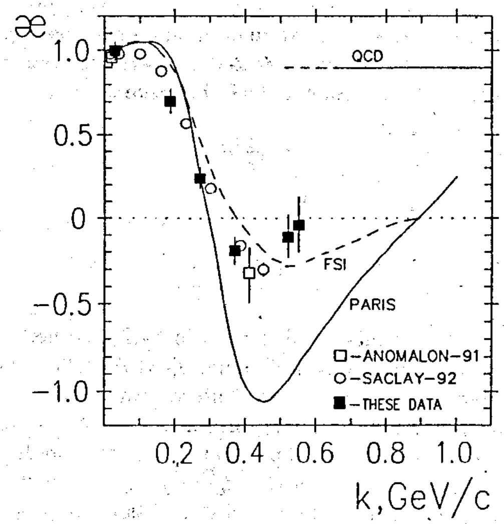

Fig.3. Polarization transfer æ$= \frac{P_p}{P_d}$ vs. internal momenta k. Our earlier ANOMALON-91 data and SACLAY-92 data are from Ref.[12] and Ref.[13]

The presented æ-data are compared (fig.3) with the earlier ANOMALON-91 data[12] and Saclay-92 data obtained for the reaction $^1H(\vec{d},\vec{p})X$ with a 3.5GeV/c polarized deuteron beam[13]. Up to k=400GeV/c the all data sets are in good agreement with each other and in general agree with the calculations. However, a disagreement with the Paris IA prediction out of the error bars can be observed starting with $k \simeq 150$GeV/c,where the inclusive cross section and T_{20} are in fine agreement with the IA. Apparently, the spin observable like æ is more sensitive to rescattering and FSI phenomena. Including FSI in the calculation remarkably improves agreement with the data at $k \geq 300$GeV/c.

The region of $k = 100 - 200$GeV/c can be also attractive to check the speculation of some approaches to the relativization of the deuteron wave function[6] which predict the æ-dependence at fixed k on deuteron momenta. Comparison of the Dubna and Saclay data is likely not to confirm this.

The last points of our data at k=520 and 550GeV/c demonstrate stopping of decreasing æ. One can suppose two possible tendencies of the æ-behaviour with further increasing internal momentum. The first one is to remain close to a zero level. The second tendency is to cross zero from below much earlier than predicted by the Paris WF and display the further behaviour as motivated by the QCD approach[11] which predicts an asymptotic value of æ=0.9.

Conclusion

The new results of measurement of the tensor analyzing power T_{20} and the polarization transfer coefficient æ in the inclusive deuteron breakup reaction $^{12}C(\vec{d},\vec{p})X$ are presented. At high internal momenta T_{20} demonstrates a slow change from -0.7 to a level of -0.5 which contradicts the IA predictions of NN-potential models. The QCD-motivated approach based on the consideration of color cluster configurations in deuteron[11], evidently is more successful to explain the T_{20}-data at high internal momenta. The polarization transfer was measured at intradeuteron momenta up to k=550 MeV/c,where the values of æ close to zero were observed. Disagreement with IA estimates is evident here. The FSI calculations[10] qualitatively predicted such behaviour. An advancement to higher k will make it possible to verify the proposed FSI models at quantitative level and to test an alternative QCD-approach for the description of deuteron spin structure at short internucleonic distances.

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Измерение передачи поляризации и тензорной анализирующей способности при стриппинге поляризованных дейтронов с импульсом до 9 ГэВ/с

Представлены новые экспериментальные результаты для передачи поляризации κ и анализирующей способности T_{20} в реакции $^{12}C(d, p)X$ при 0°. Измерения были выполнены на дубненском комплексе поляризованных дейтронов. При высоких внутренних импульсах протона в дейтроне ($k \geq 300$ МэВ/с) поведение этих наблюдаемых не согласуется с предсказаниями импульсного приближения, основанными на реалистических NN-потенциалах. Данные сопоставлены с расчетами ряда других моделей, предсказывающих поведение κ и T_{20} при высоких k.

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Measurement of Polarization Transfer and the Tensor Analyzing Power in Polarized Deuteron Break-Up with Deuteron Momenta up to 9 GeV/c

New experimental results for polarization transfer, κ, and the analyzing power, T_{20}, in $^{12}C(d, p)X$ at 0° are presented. The measurements have been performed at the Dubna polarized deuteron facility. At high intrinsic momenta of proton in deuteron ($k \geq 300$ MeV/c) the behaviour of these observables is in disagreement with the impulse approximation predictions based on the realistic NN-potentials. The data are compared with calculations of some other models predicting the high k behaviour of κ and T_{20}.

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

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