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Measurement of tensor polarization of deuterons from $^3He \to d + p$ breakup at internal momenta up to 0.4 GeV/c

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Abstract. The tensor polarization (ρ_{20}) of deuterons emitted in the $p\,(^3He, d)X$ reaction at 0° in the lab. system was measured at the Saturne National Laboratory in Saclay, using the SPES-4 spectrometer with the HYPOM polarimeter in the area of its focal plane. The momentum of the detected deuterons was kept fixed at 3.77 GeV/c, while the momentum of the ^3He beam was varied from 4.60 to 5.66 GeV/c, thus providing a range of internal momenta k of the deuteron inside the ^3He from 0 up to 0.4 GeV/c. The obtained data are compared with the theoretical predictions.

1. Introduction

Disintegration of the lightest nuclei is one of effective tools in studying of few-body problem. The inclusive measurements of $A(^3He, d)X$ and $A(^3He, p)X$ in the wide region of the fragments momenta were performed for the first time in Dubna [1]. The spin-dependent observables bring very important information concerning structure of the lightest nuclei. Corresponding observables were considered in Ref. [2].

Here we present results of the "double scattering" experiment, where the tensor polarization of deuterons, ρ_{20}, emitted at zero degree in the $p\,(^3He, d)X$ reaction with unpolarized ^3He was measured. It follows from the symmetry laws that only tensor longitudinal deuteron polarization is possible in the collinear kinematics when colliding particles are unpolarized.

The measurements were performed at the Saturne National Laboratory in Saclay, using the SPES-4 spectrometer [3] and the HYPOM polarimeter [4] located in the area of the SPES-4 focal plane (see Figs. 1,2). The polarimeter contained a LH_2 hydrogen target to use advantage of the large analyzing power T_{20} of the elastic dp scattering.

In the ^3He rest frame the deuteron-fragment has momentum $q \simeq 0$ when its momentum in the laboratory system is about of $p_d = 2/3p_{^3He}$. Our measurements were performed at $p_d > 2/3p_{^3He}$. To provide this region of measurements, the tune of the SPES-4 spectrometer, which transferred the deuterons produced in the $(^3He, d)X$ reaction to the analyzer (the HYPOM polarimeter), was kept at fixed momentum of 3.77 GeV/c, while the momentum of the ^3He beam was varied from 5.66 to 4.60 GeV/c.

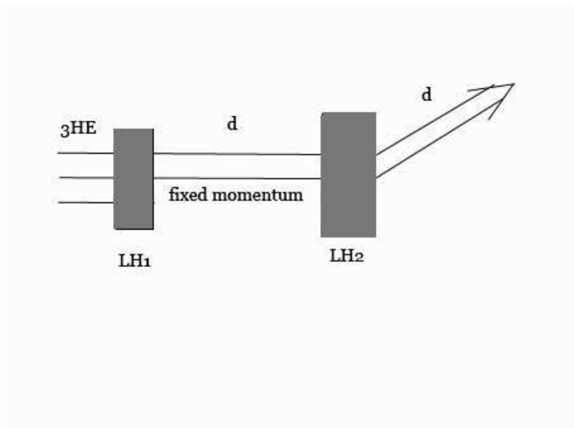

Figure 1. Main scheme of the experiment.

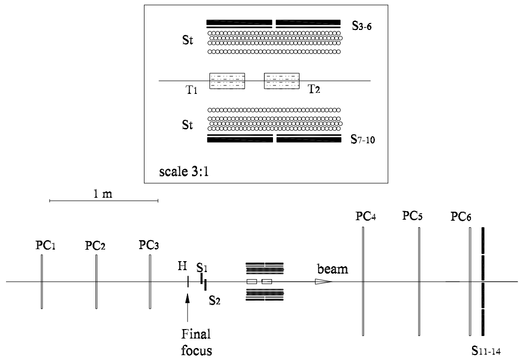

Figure 2. Schematic side view of the polarimeter. S_i – scintillator counters, PC_i – proportional chambers, T_i – LH_2-targets, St – straws.

Main difficulty of this experiment was that we had no alternate polarization and no azimuthal asymmetry when the polarization axes were parallel to momentum of secondary deuteron. The asymmetry produced by the tensor polarization of the deuterons emitted in the breakup of the unpolarized ^3He was measured by comparison of the t-dependence (the Mandelstam 4-momentum transfer squared) of the yields in the analyzing scattering with the "reference" yields, measured with up to a week time difference in calibrating runs with the fixed momentum (3.77 GeV/c) deuteron beam. In order to keep systematic errors at acceptable level, the time drifts of the setup offsets were investigated very carefully and then taken into account.

2. Experimental setup

To overlap wide secondary beam disribution the unique hydrogen target [6] was elaborated for this experiment. It contained two elements with dimensions 100x20x500 mm (xyz, z is along the beam direction) each. A tomographical picture of the target is shown in Fig. 3.

Velocities of particles transported from the first target to the polarimeter were measured by the SPES-4 TOF-system. It allowed to separate deuteron and tritons in the secondary beam and to find the average central momentum beam for each ^3He incident momenta, which proved to be, as a rule, lower than the declared value of 3.77 GeV/c.

The incident and outgoing tracks were detected in the HYPOM [4] multi-wire proportional chambers (MWPC). The recoil tracks were triggered by four sets of two scintillation counters (two up- and two downstream from the target) with a thickness of 3 and 10 mm, respectively. These counters were used also to evaluate recoil particle energies using $\Delta E - E$ method. The yz-projections of the recoil protons were detected by straw detectors.

3. Event reconstruction

Solid and azimuthal angles (θ, ϕ) were calculated using information from the front (projectiles) and rear (scattered particles) MWPCs. The yz-projections of recoil particle track $(z = a_s y + b_s)$ were measured by straws. To provide the narrow elastic peak, there were taken into account time drift of straw offsets and turns between different planes of straws. The procedure of the track reconstruction via straws is described in Ref. [5]. The interaction point was found using information from the front chambers and the straws (Fig. 3). The projectile momentum was calculated using formula $p = p_0(1 + ax)$. Here x is the deflection of track from the spectrometer axis in the focal plane, p_0 is average central momentum, measured by the TOF-system. Assuming two-body kinematics, the θ, ϕ, p values were used to find expected Mandelstam variable t, yz-angle projection (a'_s) and kinetic energy of recoil particle (T').

The elastic event separation, using interaction point (out of the target walls), $|a_s - a'_s|$ and $|T - T'|$ criteria, is shown in Fig. 4.

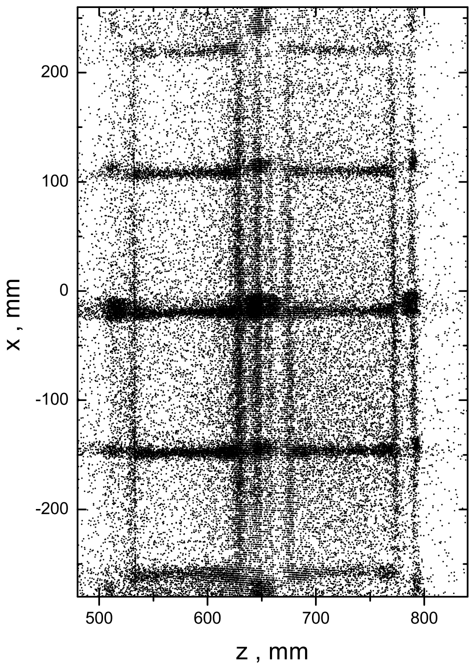

Figure 3. zx-distribution of interaction points.

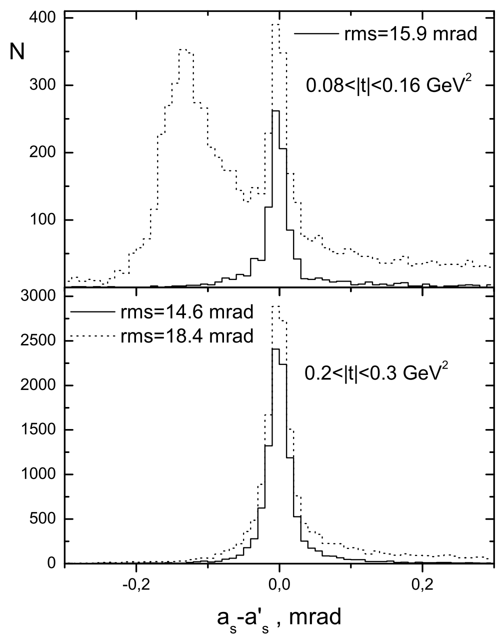

Figure 4. Elastic peak for different regions of 4-momentum transfer squared t. Solid histogram – $\Delta E/E$ cuts are switched on.

4. Calibration measurements

The maximum deuteron momentum, at which the analyzing power of the elastic scattering was well known, is 2.93 GeV/c [7]. Dealing with higher momenta of deuterons during the main measurement, the calibration measurements of analyzing power at 3.77 and 3.39 GeV/c were undertaken. It was found that T_{20} remained the same (within error bars) in the region of 2.9 – 3.8 GeV/c.

5. Measurement of the deuteron tensor polarization

When the longitudinal tensor polarization is only possible, we have:

$$\frac{\sigma(t)-\sigma^0(t)}{\sigma^0(t)} = \rho_{20}T_{20}(t) \tag{1}$$

and the azimuthal asymmetry is absent. The data of the calibration experiment were used for $\sigma^0(t)$. The parametrization of the analyzing power data [7] was used for $T_{20}(t)$. The interval $0.06 < -t < 0.34$ $(GeV/c)^2$ was considered for the analysis.

6. Results

For transition from measured momenta to internal momentum of deuteron in ^3He, we suppose that internal momentum is so called light front variable, k, firstly introduced by P.A.M. Dirac [8]. In the parallel kinematics k is related to the fragment momentum q in the nuclear rest frame by the following formulas [9]:

$$\begin{aligned} \alpha &= \frac{\sqrt{m_s^2+q^2}+q}{M} \\ M_{sf}^2 &= \frac{q^2+m_s^2(1-\alpha)+m_f^2\alpha}{\alpha(1-\alpha)} \\ k &= (\alpha-\frac{1}{2})M_{sf} - \frac{m_s^2-m_f^2}{2M_{sf}} \end{aligned} \tag{2}$$

where m_s is the mass of the spectator, m_f is the mass of the second fragment, M is the mass of the projectile. The obtained data are compared with a theoretical prediction based on the Plane Wave Impulse Approximation (PWIA) [2]. The parametrization of the S- and D-waves of the projection of ^3He wave function onto $(d+p)$-vertex was taken in Ref. [10]. In this approach the expression for deuteron tensor polarization has the form

$$\rho_{20}(k) = -\frac{2\psi_S(k)\psi_D(k)+\frac{1}{\sqrt{2}}\psi_D^2(k)}{\psi_S^2(k)+\psi_D^2(k)} \tag{3}$$

The experimental values of $\rho_{20}(k)$ together with theoretical curve (Eq. 3) are shown in Fig. 5. One can see that data agree well with prediction at $k < 0.2$ GeV/c.

Let us discuss the nature of deviation of experimental data from expectations at $k > 0.2$ GeV/c on base of comparison of deuteron momentum distributions in ^3He, obtained with electron and hadron probes. In Fig. 6 the spectra obtained with hadron probe [1], are shown together with recent data from the JLab Hall A experiment [11]. In perpendicular kinematics used in Ref. [11] the missed momentum, $p_m \simeq k$. The data [11] and described them curve [12] were multiplied by factor to compare with deuteron momentum distribution, obtained in Ref. [1]. One can see that data agree well except small region in vicinity of $k = 0.3$ GeV/c. The electron probe data are explained by PWIA with AV18 [13] potential and Final State Interaction (FSI). One can see the predominance of PWIA at $k < 0.2$ GeV/c. Our data confirm this predominance. Our point at the highest value of k apparently can be explained calculating T_{20} in framework of PWIA+FSI mechanism. The most difficult for explanation point is that at $k = 0.305$ GeV/c, because it is situated in region of maximum discrepancy between electron and hadron probe cross section data. It is possible that some additional mechanisms like intermediate pion rescattering [14] may be necessary to include in order to describe both the momentum spectra [1] and ρ_{20} in this region.

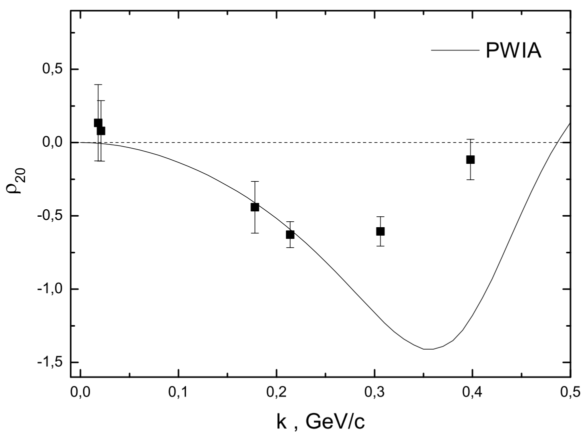

Figure 5. Deuteron tensor polarization versus its internal momentum in ^3He.

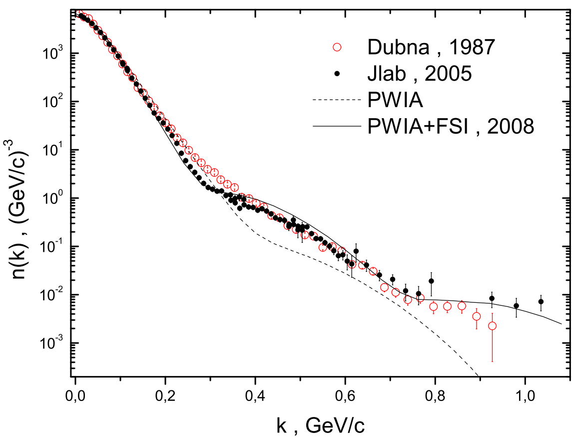

Figure 6. Momentum distribution of deuterons in ^3He, obtained with hadron and electron probes.

7. Conclusions

- The deuteron tensor polarization in the $p(^3He, d)X$ reaction has been measured at internal momenta of 0–0.4 GeV/c.
- At $k < 0.2\ GeV/c$ the data are agree well with the PWIA approach.
- At the highest value of k one can expect a good description in frameworks of the PWIA+FSI model. An additional mechanism should be incorporated to describe the data in vicinity of $k = 0.3\ GeV/c$.
- Comparison of deuteron momentum spectra, obtained in parallel and perpendicular kinematics, proves that the light front variable is a good one.

8. Acknowledgements

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