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STUDY OF THE SHORT-RANGE ^{3}He STRUCTURE FROM THE $dd \to {}^3$Hen REACTION

V.P.Ladygin, N.B.Ladygina

An experiment on studying of the tensor analysing power $C_{0,NN,0,0}$ and spin correlation $C_{N,N,0,0}$ due to the transverse polarization of both initial particles from the $dd \to {}^3$Hen reaction has been proposed. Those polarization observables are very sensitive to the short-range ^{3}He structure. This experiment is proposed to be done at the LHE Accelerator Complex using both a polarized deuteron beam and a polarized deuterium target.

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

Изучение структуры ^{3}He на малых расстояниях в реакции $dd \to {}^3$Hen

В.П.Ладыгин, Н.Б.Ладыгина

Предложен эксперимент по изучению тензорной анализирующей способности $C_{0,NN,0,0}$ и спиновой корреляции $C_{N,N,0,0}$, связанной с нормальной поляризацией обеих начальных частиц в реакции $dd \to {}^3$Hen. Эти поляризационные наблюдаемые очень чувствительны к структуре ^{3}He на малых расстояниях. Этот эксперимент предлагается провести на ускорительном комплексе ЛВЭ с использованием как поляризованного пучка дейтронов, так и поляризованной дейтериевой мишени.

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1. Introduction

We propose to measure the polarization observables in the $dd \to {}^3$Hen reaction using a polarized deuteron beam and a polarized target [1]. The main goal of the experiment is to explore the short-range ^{3}He spin structure at distances unreachable using electromagnetic probes.

This reaction belongs to the same class of processes as the deuteron-proton backward elastic scattering intensively investigated in the last years at Saclay and Dubna [1, 3]. Within One-Nucleon-Exchange (ONE) approximation the polarization observables of this reaction are very sensitive to the ^{3}He spin structure at small distance. Using of both a polarized target and a beam could allow one to extend sufficiently the number of possible experiments and to separate the ^{3}He structure from the reaction mechanism using different relative orientations of the initial deuteron spins.

2. Physical Motivation

The momentum distributions of spectator extracted from inclusive [4] ^{3}He(e, e')X and exclusive [5] ^{3}He(e, ep)d and ^{3}He(e, ep)pn data, taking into account corrections due to final state interaction (FSI) and meson exchange currents (MEC) [6] and from breakup A(^{3}He, p)X data at zero angle [7] within relativistic impuls approximation (RIA) [8] are in good accordance. On the other hand, the momentum distributions obtained from the exclusive measurements of the ^{3}He(p, 2p)d and ^{3}He(p,pd)p reactions [9] and inclusive measurements of the A(^{3}He, d)X breakup reaction [7], demonstrating a good agreement with each other, show an enhancement of extracted momentum density over calculations performed within RIA using a Faddeev calculation of the wave ^{3}He function [10] starting from momentum of spectator in the rest frame of ^{3}Heq > 150 MeV/c. This discrepancy can be explained as the poor knowledge of the ^{3}He structure at large momenta, as the importance of the reaction mechanisms.

The short-range spin structure of ^{3}He has not been investigated so widely as the momentum distribution to date. The results of experiment with a polarized ^{3}He target and polarized protons performed at 290 MeV at TRIUMF [11] indicate that analysing powers A_{no}, A_{on} and A_{nn} are close to the IA predictions for the $^3\overrightarrow{\mathrm{He}}(\vec{p}, 2p)$ reaction. For the $^3\overrightarrow{\mathrm{He}}(\vec{p}, pn)$ there is a strong disagreement with these predictions. This discrepancy can be related as with FSI, as with non-adequate knowledge of the ^{3}He structure at small distances. Polarized electron scattering on a polarized ^{3}He target $^3\overrightarrow{\mathrm{He}}(\vec{e}, e')X$ also can be used to study different components of the ^{3}He wave function [12]. To describe the experimental results [13] obtained at different relative orientations of electron and ^{3}He spin, it is necessary to take into account FSI and MEC in addition to the IA approach.

These difficulties in the interpretation of existing data require performing the new polarization experiments with ^{3}He. But the number of possible reactions for this purpose is limited by the absence of the polarized ^{3}He beam of high intensity and polarimeters to measure the ^{3}He polarization.

We propose to measure the spin observables in the $dd \to {}^3$Hen reaction which are sensitive to the ^{3}He and deuteron wave functions at short distances. The cross section of this reaction at high energies was measured at SATURNE [14]. At low energies this reaction is used to reconstruct the D/S ratio and parameter D_2 of the ^{3}He [15]. Low energy polarimeter based on this reaction works currently at SATURNE [16].

We propose to measure the polarization observables in the $dd \to {}^3$Hen reaction in the collinear geometry, when ^{3}He and beam deuteron have the same direction of the momentum in the center of mass. Under these kinematical conditions the contribution of one from two diagrams required by the symmetry in the initial state is strongly suppressed (a few orders of magnitude) by the rapid decreasing of the deuteron and ^{3}He wave functions versus spectator momenta. This occasion simplifies the analysis of the polarization phenomena for this reaction [1].

Tensor analysing powers due to the polarization of the beam deuteron can be expressed as:

$$C_{0,NN,0,0} = \frac{1}{2}\frac{\omega_2^2 - 2\sqrt{2}u_2\omega_2}{u_2^2 + \omega_2^2}. \tag{1}$$

In case of polarized beam, tensor analysing power is mostly defined by the ^{3}He wave function (Fig.1).

The expression for the spin correlation $C_{N,N,0,0}$ when both the deuterons are transversally polarized has the following form:

$$C_{N,N,0,0} = -\frac{4}{9}\frac{u_1^2 - \omega_1^2 - u_1\omega_1/\sqrt{2})}{u_1^2 + \omega_1^2}\frac{(u_2^2 - \omega_2^2 - u_2\omega_2/\sqrt{2})}{u_2^2 + \omega_2^2}, \tag{2}$$

where u_1, ω_2 and u_2, ω_2 are the S– and D–waves of the deuteron and the ^{3}He, respectively. The sign of this observable is negative at small relative momenta of the initial deuterons, which is easy to understand. Since two protons in the ^{3}He must have opposite directions of spins due to the Pauli principle, the maximal yield of ^{3}He will be in case of opposite orientations of the initial deuteron spins. Spin correlations due to the normal polarization of both the deuterons are presented in Fig.2. Calculations are performed using ^{3}He and deuteron wave functions from Refs. [10–17], respectively.

Considered observables ($C_{0,NN,0,0}$ and $C_{N,N,0,0}$) are sensitive to the ^{3}He structure at initial momenta of the deuteron 0.7–3.0 GeV/c that corresponds to high relative momenta

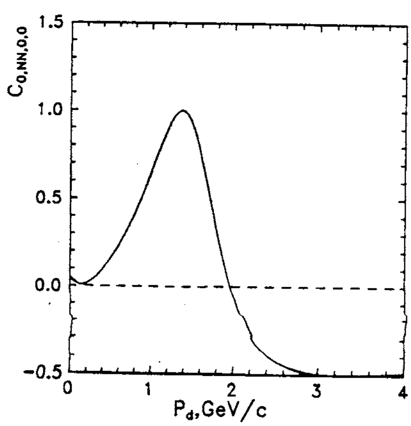

Fig.1. The tensor analysing power $C_{0,NN,0,0}$ due to the polarization of the beam deuteron. Dashed line — without D wave in ^{3}He, full line — with D-wave

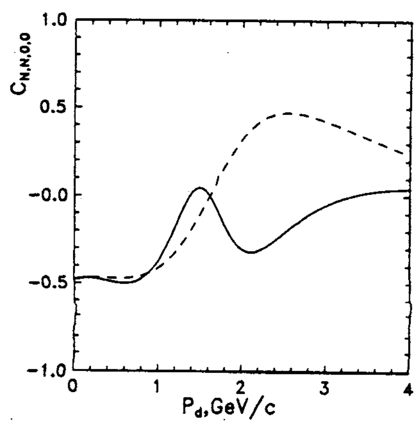

Fig.2. The vector spin correlations for $dd \to {}^3Hen$ reaction due to the transverse polarization of both the deuterons. Lines are as in Fig.1.

of the *dp* pair in the ^{3}He. In this range the relativistic effects, as well as additional to the ONE reaction mechanisms (for instance, Δ excitation on the intermediate state) start to be very sufficient and must be taken into account in addition to simple ONE.

Two deuterons in the initial state for this reaction give a lot of possibilities to study polarization effects in the first scattering. The next step in the studying of this reaction could be the measurement of *T*-odd observables like $C_{L,NS,0,0}$ which are defined by the reaction mechanisms additional to ONE. This measurement could allow one to correctly extract the spin structure of the ^{3}He. In principle, this experiment could be done using the polarized deuteron target and the extracted polarized deuteron beam of new superconducting accelerator Nuclotron in Dubna with specific orientations of spins of the initial particles.

3. Experimental Studying of the $dd \to {}^3He\pi$ Reaction

We propose to use the spectrometer to measure the spin correlation parameters $C_{N,N,0,0}$ in the *dp* backward elastic scattering [18], $dp \to {}^3He\pi^0$ and $dp \to {}^3He\eta^0$ [19, 20].

To select the ^{3}He it is necessary to add to the equipment the system of charge particle identification. The measurement of ^{3}He momenta and separation from the prime beam will be achieved by the system of 3 magnets (the magnet of polarized terget and 2 bending magnets). The momentum resolution of $\approx 1\%$ will be enough to separate the $dd \to {}^3He n$ process from channels with possible pion production. Using of the time-of-flight information at the trigger level will provide the selection of the particles of specific kind, reducing sufficiently the data taking time.

To measure the spin correlation $C_{N,N,0,0}$ we propose to use Moveable Polarized Target (MPT) installed recently in LHE, JINR and used for $\Delta\sigma_{L,T}$ experiment [21]. To study the $dd \to {}^3He n$ process it is necessary either to replace the $C_3H_8O_2$ by the $C_3D_8O_2$ in the existing target or to use the ^{6}LiD polarized target. Parameters of polarized targets one can find in Refs. [22, 23].

To separate the ^{3}He from background we propose to use the time-of-flight and charge identification systems. The main source of background is the break-up of the deuterons on the target material, since the ^{3}He from $dd \to {}^3He n$ has the rigidity close to the rigidity of the proton with a half of momenta of the initial deuteron. The ratio of background protons to ^{3}He is approximately $10^4 - 10^5$. Note in case of using of the $C_3D_8O_2$ the yield of protons will be more than 5 times higher than for ^{6}LiO target. The next background process is the quasi-free $NN \to d\pi$ and in case of using of $C_3D_8O_2$ target we have 10 times more deuterons than for ^{3}LiO target.

During experiment we propose to reduce the high voltage on the scintillator counters and proportional chambers to suppress the single charged particles rate. The momentum analysis will provide the separation of the $dd \to {}^3He n$ from the quasi-free $dN \to {}^3He\pi$ process.

The intensity of the deuteron beam is limited by MTP (10^8 deuterons per spill). The number of events per spill can be expressed as:

$$N_{event} = N_d \cdot \rho \cdot L \cdot N_A \cdot f_D \frac{d\sigma}{d\Omega} \cdot \Delta\Omega , \tag{3}$$

where N_d is the number of deuterons per spill, ρ is the density of the target, L is its length, f_D is the dilution factor of the target, N_A is the Avogadro number, $\Delta\Omega$ is the solid angle ($5 \cdot 10^{-3}$), $\frac{d\sigma}{d\Omega}$ is the cross section of the process taken from Ref. [14].

The error bars for polarization observables can be estimated as:

$$\Delta C_{N,N,0,0} \approx \frac{1}{3P_zP_T} \frac{1}{\sqrt{N_{event}}} ,$$

$$\Delta C_{0,NN,0,0} \approx \frac{1}{P_{zz}} \frac{1}{\sqrt{N_{event}}} ,$$

in case of good selection of events from the $dd \to {}^3\mathrm{He}n$.

Under typical parameters of the polarized deuteron beam at Dubna Synchrophasotron ($P_z = 0.45 - 0.50$ and $P_{zz} = 0.80$) and number of useful events 10000 per point we can estimate the error bars for $C_{N,N,0,0}$ as 0.017 and for $C_{0,NN,0,0}$ as 0.013, respectively.

The ratio of useful events in case of using of the ^{6}LiD and $C_3D_8O_2$ targets is approximately a factor of 3. Using of ^{6}LiD target will be especially important at $P_d \geq 2.0$ GeV/c. Under typical conditions of the Dubna Synchrophasotron the point at $P_d = 2.5$ GeV/c will take about 2(6) hours in case of 5 cm of ^{6}LiD($C_3D_8O_2$) target length. Calculations based on ONE give the beam request approximately 16(48) hours for $P_d = 3$ GeV/c.

4. Conclusion

We propose to measure spin correlation parameter $C_{N,N,0,0}$ and tensor analyzing power $C_{0,NN,0,0}$ in the $dd \to {}^3\mathrm{He}n$ process, which are most sensitive to the ^{3}He short-range spin structure at LHE Accelerator Complex using polarized deuteron beam and polarized deuteron terget.

From two considered polarized deuteron tergets (propane-diol and ^{6}LiD) the ^{6}LiD is more preferable for this experiment from the point of view of higher factor of merit as well as less rate from the background processes.

The terget also can be used to study the *T*-odd effects for this process as well as to search for the $\Delta\Delta$-dibaryon state in the reaction $\vec{d}(\vec{d}, d)X$ [24] and as ^{6}Li polarized target to study the $(^6\vec{\mathrm{Li}}, \vec{p})$ process [25] in the future.

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