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COHERENT MESON PRODUCTION IN THE dp → ^{3}HeX REACTION*

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Effects due to polarizations of both colliding particles have been analyzed in terms of two independent amplitudes which in the general case define the spin structure of amplitude of the $dp \to {}^3\mathrm{He}X$ ($X = \pi^0, \eta^0$) reaction in the collinear geometry. Energy dependence of spin-correlation parameters and polarization transfer coefficients are predicted using the moduli of amplitudes extracted from experimental data. The values of these polarization observables at threshold are predicted.

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

Когерентное рождение мезонов в реакции $dp \to {}^3\mathrm{He}X$

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В терминах двух независимых амплитуд, которые в общем случае определяют спиновую структуру амплитуды реакции $dp \to {}^3\mathrm{He}X$ ($X = \pi^0, \eta^0$) в коллинеарной геометрии, рассмотрены эффекты, связанные с поляризацией сталкивающихся частиц. Предсказывается энергетическая зависимость спиновых корреляций и коэффициентов передачи поляризации при использовании значения модулей амплитуд, извлеченных из экспериментальных данных. Предсказываются величины этих поляризационных наблюдаемых на пороге.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

Meson production and absorption is a manybody problem as in principle all nucleons will be involved. On the one hand, this process requires the participation of at least two nucleons, since the process $\pi N \to N$ ($\eta N \to N$) is kinematically forbidden on a free nucleon and strongly suppressed in nuclei by momentum conservation; on the other hand, one has a sensitivity to large-momentum components in the relative wave function of the nucleons due to the large transferred momentum and therefore may have a sensitivity

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The pion absorption on two nucleons is the dominant mode. The isoscalar absorption is stronger by an order of magnitude than the isovector one. This mechanism dominates mainly via an intermediate ΔN state and masks the NN-correlations. But information about NN-correlations may be obtained from studying the processes, when pion is absorbed on the isovector pairs of nucleons, which is not mediated by the Δ resonance or from measurements of polarization observables, which depend on interferences between diagrams with $N\Delta$ and NN intermediate states.

We consider the $dp \to {}^3\text{He}\pi^0(\eta^0)$ reaction in the collinear kinematics, when ^{3}He is produced at $\theta_\tau = 0°$ or at $\theta_\tau = 180°$ in the CMS. There are only two independent complex amplitudes to describe the $dp \to {}^3\text{He}\pi^0$ under these kinematical conditions. The measurements of the differential cross section and both cross section and tensor analyzing power T_{20} [1]—[4] for forward and backward π^0 production in CMS give the possibility of extracting the moduli of these amplitudes for collinear kinematics. To perform an amplitude analysis and reconstruction of the partial-wave amplitudes in the collinear geometry it is necessary to measure such polarization observables as deuteron-proton spin correlations between both polarized particles.

The $dp \to {}^3\text{He}\eta^0$ reaction has the same spin structure. Due to the large η^0 mass, 3-body mechanisms play more sufficient role for this process than for pion absorption.

Measurement of the spin correlations (in addition to measured cross section [2] and T_{20} [5]) could allow one to perform an amplitude and partial-wave analysis for this reaction.

Performance of these experiments is possible at Dubna, SATURNE, TRIUMF using polarized beams and targets.

2. The $dp \to {}^3\text{He}X$ ($X = \pi, \eta$) Reaction in Collinear Geometry

In the general case there are 6 complex amplitudes to describe the $dp \to {}^3\text{He}\pi^0(\eta^0)$ reaction. But one gets only 2 independent complex amplitudes A and B for these processes in collinear geometry [6].

Expressions for cross section, tensor analyzing power and spin correlation parameters have the following form through these amplitudes:

$$N^{-1}\frac{d\sigma^0}{d\Omega} = |A|^2 + 2|B|^2, \tag{1}$$

$$C_{0,NN,0,0} = \frac{|A|^2 - |B|^2}{|A|^2 + 2|B|^2}, \tag{2}$$

$$C_{L,L,0,0} = \frac{-2\cdot|B|^2}{|A|^2 + 2|B|^2}, \tag{3}$$

$$C_{N,N,0,0} = \frac{-2\cdot \mathrm{Re}BA^*}{|A|^2 + 2|B|^2}, \tag{4}$$

$$C_{N,SL,0,0} = \frac{-3\cdot \mathrm{Im}BA^*}{|A|^2 + 2|B|^2}, \tag{5}$$

where L is longitudinal, N is normal and S is sideways polarization of particles. (Here we follow notations used in ref. [7]):

Note, that coefficients of polarization transfer from deuteron to ^{3}He are related with spin-correlation coefficients as:

$$C_{0,L,L,0} = -C_{L,L,0,0} \quad C_{0,N,N,0} = C_{N,N,0,0} \quad C_{0,SL,N,0} = C_{N,SL,0,0}.$$

For coefficients of polarization transfer from proton to ^{3}He one can obtain:

$$C_{L,0,L,0} = 2\cdot C_{L,L,0,0} + 1,$$

$$C_{N,0,N,0} = -(C_{L,L,0,0} + 1). \tag{6}$$

Also, the observables $C_{N,N,0,0}$, $C_{N,SL,0,0}$ and $C_{0,NN,0,0}$ are related as follows:

$$2\cdot C^2_{N,N,0,0} + \frac{8}{9}C_{N,SL,0,0} + \frac{(4C^2_{0,NN,0,0} - 1)^2}{9} = 1. \tag{7}$$

One can mention that even in the case when A and B are in phase, what means $\mathrm{Re}AB^* = \pm|A|\cdot|B|$ and $C_{N,SL,0,0} = 0$, it is necessary to perform the measurement of the $C_{N,N,0,0}$ to obtain the relative sign of the moduli of A and B. Note that the spin correlations $C_{N,SL,0,0}$ and $C_{N,N,0,0}$ are the most informative polarization observables because they are the interference terms of two amplitudes in contrast with the others and can be more sensitive to short-range NN-correlations.

3. Polarization Observables for $dp \to {}^3\mathrm{He}X$ ($X = \pi, \eta$)

From π absorption on ^{3}He near threshold, it is known that S-wave pions are absorbed mainly on a pairs of nucleons with isospin $T = 0$ and $T = 1$.

In order to get agreement with measured tensor analyzing power T_{20} at threshold of the $dp \to {}^3\mathrm{He}\pi^0$ reaction [4], using realistic wave functions of deuteron and ^{3}He with D-waves, and the S-wave $\pi^-\ {}^3\mathrm{He} \to nd$ branching ratio, the authors [6] could extract numerical values of g_0 and g_1 coupling constant. Using these values one can predict the values of other polarization observables defined above.

Using completely symmetrical ^{3}He and deuteron wave functions one can obtain the value of $C_{N,N,0,0} = 0.333 \pm 0.026$. For realistic wave functions with D-waves one gets $C_{N,N,0,0} = 0.289 \pm 0.023$. $C_{L,L,0,0}$ is close to zero for both cases.

The value of $C_{N,N,0,0}$ can be predicted up to sign ambiguity, but the negative value of $C_{N,N,0,0}$ at threshold is more favourable, when g_0 and g_1 are assumed to have the same sign in order to avoid a strong suppression of the n—d branching ratio. One can see also that $C_{N,N,0,0}$ is very sensitive to short-range NN-correlations. At higher energies the P-wave contribution dominates and masks NN-correlations. It is necessary to include in calculations also the 3-body mechanisms [8].

We would like to note that the $dp \to {}^3\mathrm{He}\eta^0$ reaction having the same spin structure is also defined by two amplitudes in collinear kinematics. In the two-body absorption approach [9] the η-meson at threshold can also be absorbed on the pairs of nucleons with isospin $T = 0$ and $T = 1$.

If we neglect the D-waves in the deuteron and ^{3}He, difference between $S^*$and S-waves in the ^{3}He and ω, η exchange diagrams, A and B amplitudes of the $dp \to {}^3\mathrm{He}\eta^0$ process will correspond to pure π- and ρ-contributions, respectively. The relative phase between A and B amplitudes corresponds to the mixing parameter between π- and ρ-exchange graphs. The spin correlation $C_{N,N,0,0}$ takes the following form:

$$C_{N,N,0,0} = (0.694 \pm 0.052) \cdot \cos\delta, \tag{8}$$

where the $\cos\delta$ is mixing parameter between π- and ρ-contributions.

Of course, for correct description of this process it is necessary to add to this simplified model 3-body mechanisms [10], strong FSI due to large complex η^3He scattering length [11] and so on.

These questions are discussed in more detail in ref. [12].

4. Conclusions

Polarization observables of the pion absorption and production are very sensitive to the *NN*-correlation function, in particular to its short-range part, in contrast to the cross section.

Measurements of $C_{N,N,0,0}$ and $C_{N,SL,0,0}$ (in addition to T_{20} and differential cross section) realize the program of full experiment in the case of collinear kinematics (for $dp \to {}^3\mathrm{He}\pi^0$ and $dp \to {}^3\mathrm{He}\eta^0$ reactions).

At threshold, where two-body absorption of pions dominates, from measurement of $C_{N,N,0,0}$ it is possible to remove the sign uncertainty between g_0 and g_1 coupling constants.

Measurements of $C_{N,N,0,0}$ for $dp \to {}^3\mathrm{He}\eta^0$ could clarify: the role of three-body mechanisms in the meson absorption and production; the role of π, ρ, η, ω exchanges; possibility of existence of quasi-bound η^3He state.

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