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SPACE CORRELATIONS AND FINAL STATE INTERACTION IN THE DEUTERON AND HELIUM NUCLEI BREAK-UP REACTIONS

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The work in beams of accelerated nuclei opens new possibilities for studying the final state interaction (FSI). In particular, we can see the most sensible way of FSI observation through correlation effects in reactions of the lightest nuclei disintegration, as ^{2}H, ^{3}He and ^{4}He. The experimental data are presented on the angular correlations in the reactions $dp \to ppn$, $^3\text{He} \to dpp$ and $^3\text{He}p \to {}^3\text{He}pn$ in the region of 1—4 GeV per nucleon for different intervals of the momentum transfer. The strong asymmetry is connected with FSI. We discuss also FSI with virtual isobaric excitation.

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

Пространственные корреляции и взаимодействие в конечном состоянии в реакциях дезинтеграции ядра дейтерия и гелия

В.В.Глаголев и др.

Исследования в пучках ускоренных ядер открывают новые возможности изучения взаимодействия в конечном состоянии (ВКС). В частности, можно увидеть наиболее чувствительный путь наблюдения ВКС через корреляционные эффекты в реакциях дезинтеграции легких ядер, таких как ^{2}H, ^{3}He и ^{4}He. Представлены экспериментальные данные по угловым корреляциям для реакций $dp \to ppn$, $^3\text{He} \to dpp$ и $^3\text{He}p \to {}^3\text{He}pn$ в области энергий 1—4 ГэВ на нуклон для различных диапазонов переданных импульсов. Сильная асимметрия связана с ВКС. Обсуждается также ВКС с возбуждением виртуальных изобар.

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1. Introduction

The final state interaction (FSI) has been predicted many years ago [1]. There are a lot of results of the intermediate energy region, for example [2]. The acceleration of light nuclei opens new possibilities for space correlation studies on the 4π-detectors. In this work we, discuss the experimental results on pionless light nuclei disintegration at *dp*, ^{3}He*p* and ^{4}He*p* reactions in 1–4 A GeV region. The experiment was made in the 100 cm hydrogen bubble chamber at proton synchrotron of High Energy Physics Laboratory of the Joint Institute for Nuclear Research (Dubna). The fragmentation processes investigations in accelerated nuclei beams have an advantage because most of secondary particles are fast and good measurable.

The systematical errors are practically absent.

2. Experiment

The interactions of accelerated ^{2}H, ^{3}He and ^{4}He nuclei have been investigated on the pictures of 100 cm HBCh. All pionless channels except full disintegration have not more than one neutron and are kinematically defined. The cross sections of the reactions are listed in Table 1. The most of events (near 75000) were obtained for $dp \to ppn$ reaction and subdivided by direct and charge exchange (the neutron is the most fast nucleon in the rest deuteron system) channels.

All quantities in the following are to be understood with respect to the nuclei rest frame.

Table 1. Cross sections of the pionless reactions

No.	Reaction	Momentum per nucleon [GeV/c]	σ [mb]	Momentum per nucleon [GeV/c]	σ [mb]
1	$dp \to ppn$	1.67	37.2 ± 1.4		
2	$^3\text{He}p \to dpp$	4.5	7.29 ± 0.14		
3	$^3\text{He}p \to pppn$	4.5	6.90 ± 0.14		
4	$^4\text{He}p \to {}^3\text{He}pn$	2.15	12.6 ± 0.2	3.37	7.62 ± 0.13
5	$^4\text{He}p \to {}^3\text{H}pp$	2.15	12.28 ± 0.22	3.37	7.46 ± 0.18
6	$^4\text{He}p \to ddp$	2.15	1.53 ± 0.08	3.37	0.86 ± 0.06
7	$^4\text{He}p \to dppn$	2.15	9.91 ± 0.21	3.37	4.37 ± 0.14

3. Results and Discussion

3.1. *Rescattering and Coalescence.* In the frame of simple impulse approximation (IA) we wait factorization for two vertices of quasielastic scattering diagram and isotropic Treiman – Yang angular distribution. But it is working only up to 50—70 MeV/c Fermi motion momentum [3,4]. More full systematical investigations have led to observation of strong angular dependence on spectator momentum. Kinematics of the break-up reaction is presented in Fig.1. Here **k** is the momentum of the projectile proton, $\mathbf{p}_3$ is the momentum of the fast proton. The slowest nucleon we shall call a spectator nucleon. It is nucleon with $\mathbf{p}_1$ or $\mathbf{p}_2$ momentum. Further, we consider the angle between the spectator momentum $\mathbf{p}_s$ and transfer momentum **q**: $\cos\alpha = \dfrac{\mathbf{q}\cdot\mathbf{p}_s}{|\mathbf{q}|\cdot|\mathbf{p}_s|}$ [5].

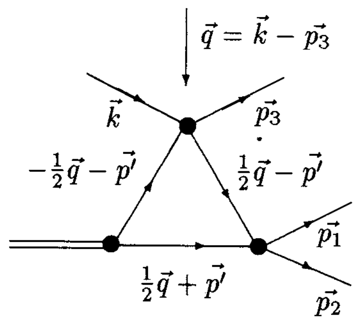

Fig.1. Kinematics of deuteron-proton break-up reaction

To summarize the information on the angular distribution, we use an asymmetry parameter expressed in the following form

$$A = \frac{N(\alpha < 90°) - N(\alpha > 90°)}{N(\alpha < 90°) + N(\alpha > 90°)}.$$

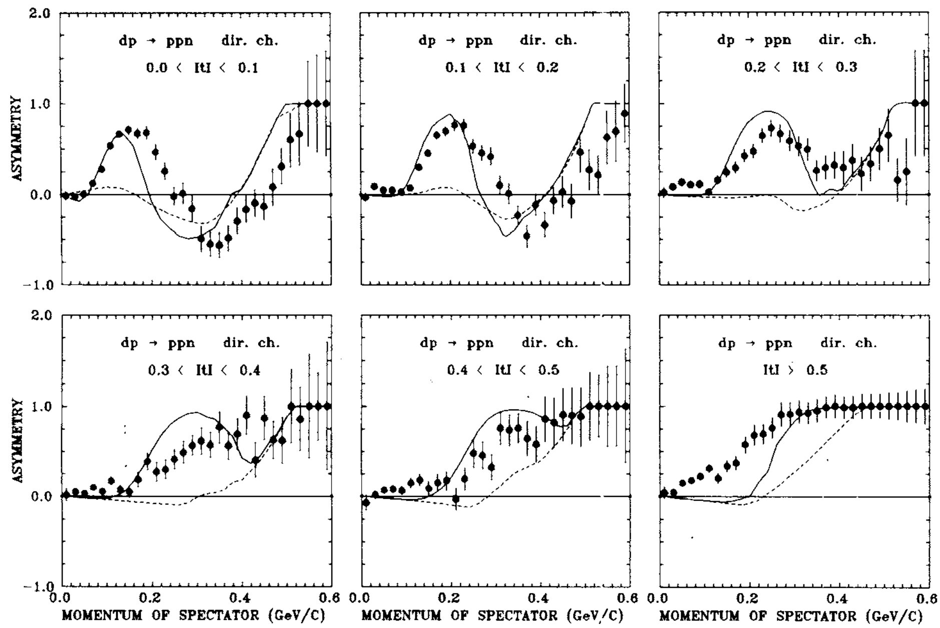

Fig.2. Momentum distributions of asymmetry parameter: the dashed and full lines correspond to contributions of IA diagrams and IA + FSI ($S + D$ wave DWF)

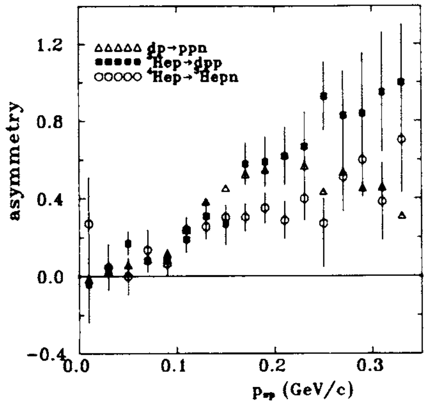

Fig.3. Momentum distributions of asymmetry parameter: $dp \to ppn$, $^3He p \to dpp$ and $^4He p \to {}^3He pn$ reactions

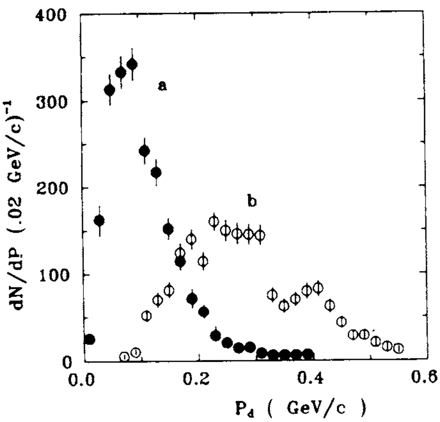

Fig.4. Momentum spectra of the deuterons for the $^3He p \to dpp$ reaction:
a) deuteron is the slowest particle
b) proton is the slowest particle

The A-parameter distribution for direct channel of $dp \to ppn$ reaction and theoretical curves are presented in Fig.2 over a wide region of the spectator momentum at different transfer momentum.

We see strong FSI correlations in the region 0.1–0.4 GeV/c.

Number of events in the ^{3}He and ^{4}Hep reactions is smaller than in dp ones. For this reason we may compare a behaviour of symmetry parameter only up to 350 MeV/c spectator momentum. This behavior is presented in Fig.3 for three different pionless reactions.

It is possible to make the conclusion that breakup mechanism of all light nuclei is the same.

Let us say some words about coalescence. For example, in the frame of close approximation the channels $^3He p \to {}^3He p$, $^3He p \to dpp$ and $^3He p \to$ $\to pppn$ have some correlation. The $^3He p \to dpp$ reaction has two groups of deuterons: slow (spectators) and fast (Fig.4). Just as for $^3He p \to pppn$ reaction there is significant asymmetry in cos α for neutron spectator ($A = 0.34 \pm 0.04$) and asymmetry is absent for proton spectator ($A = 0.04 \pm 0.03$) [6]. The deuteron spectra and correlations in ^{4}Hep reactions have the similar behavior [7]. We connect this correlations with a group of fast deuterons formed through coalescence.

3.2. *Isobaric Excitation.* Isobaric state excitation and interaction kind of $NN \to \pi NN \to$ $\to \Delta N \to NN$ inside of nuclei are another type of FSI. This influence we saw in $dp \to ppn$ reaction as strong magnification of high-energy tail of spectator momentum spectrum [5,8,9]. In Fig.5 are presented proton and neutron spectator spectra in the different angular intervals of backward hemisphere for this reaction.

The ratio of proton to neutron yields is 5 due to the two-step process with Δ-isobar in intermediate state for $dp \to ppn$ reaction [10]. Similar effects also take place in $^4He \to pX$ reaction [11] and are weakened with energy increase. In Fig.6 we demonstrate the experimental ratio of slow proton to neutron for the $dp \to ppn$ and $^4He p \to dppn$ reactions in different regions $x = \dfrac{T}{T_{max}}$ versus emission angle.

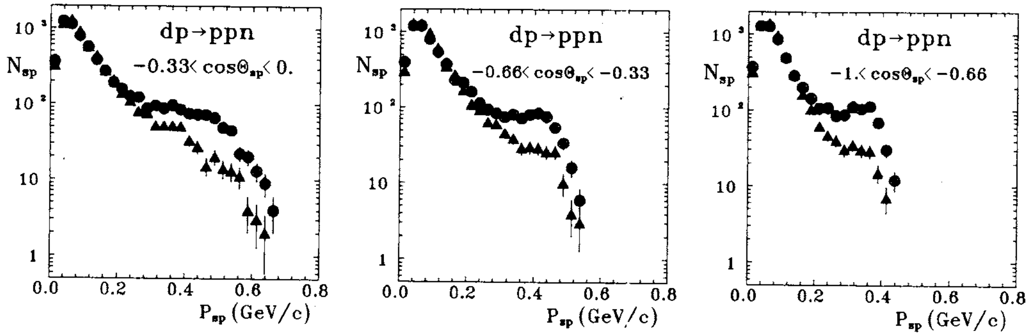

Fig.5. Spectra of *p*-spectator («O») and *n*-spectator («Δ») momenta

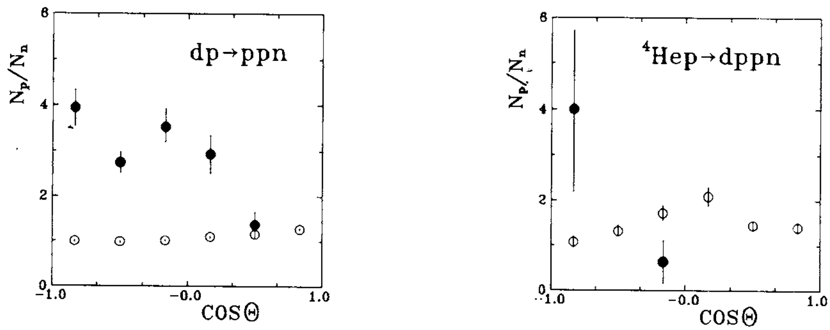

Fig.6. The proton-to-neutron ratio versus cos θ for $dp \to ppn$ and ^{4}He$p \to dppn$ reactions. Black circles relate to $x > 0.5$; open circles, to $x < 0.5$

Conclusions

Experimental investigations in the beams of accelerated nuclei in 4π geometry give the possibilities of studying different kinds of FSI. It is needed to take into account strong correlation and coalescence FSI effects in wide energy region and isobaric influence near thresholds of the corresponding isobars.

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