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THE STUDY OF THE TENSOR ANALYZING POWER IN CUMULATIVE PARTICLE PRODUCTION ON A POLARIZED DEUTERON BEAM AT THE DUBNA SYNCHROPHASOTRON*

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An experiment on studying the tensor analyzing power of cumulative (subthreshold) hadron production reactions using a polarized deuteron beam has been proposed. Pions, kaons and antiprotons are assumed to be detected as secondary particles at a 0° angle in the kinematic region forbidden for a free nucleon-nucleon collision. The study of the tensor analyzing power for these reactions gives us information about the deuteron spin structure at short internucleonic distances, correspondind to high (≥ 0.2 GeV/c) nucleon momenta in the deuteron. A scheme of the experiments is presented, and the event rate is estimated.

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

Изучение тензорной анализирующей способности реакций рождения кумулятивных частиц на пучке поляризованных дейтронов синхрофазотрона в Дубне

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Предложен эксперимент по изучению тензорной анализирующей способности реакций рождения кумулятивных (подпороговых) адронов на пучке поляризованных дейтронов. В качестве вторичных частиц предполагается регистрировать $\pi^{\pm}$, $\bar{p}$ и $K^{\pm}$, рожденные под углом 0° в кинематической области, запрещенной при рассеянии свободных нуклонов. Изучение тензорной анализирующей способности этих реакций дает информацию о спиновой структуре дейтрона на малых межнуклонных расстояниях, соответствующих большим внутренним (≥ 0,2 ГэВ/с) импульсам нуклонов в дейтроне. Представлена схема эксперимента и проведены оценки скорости набора статистики.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

The study of cumulative particle production has been carried out at the Dubna Synchrophasotron and other accelerators from the beginning of the 70 th [1—4]. As usual, by cumulative particles [5] are meant particles produced in the fragmentation region of one of the colliding particles beyond the kinematic limit of free nucleon-nucleon collisions.

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Interest in the study of cumulative reactions arises from the fact that these reactions give us information about a high momentum component (≥ 0.2 GeV/c) in fragmenting nuclei. This internal momentum corresponds to small internucleonic distances (≤ 1 fm). At such small distances (less than the nucleon size) the use of nucleon as a quasi-particle for describing nuclear properties seems to be groundless, and the effects of manifestation of non-nucleon degrees of freedom in nuclei could be expected [6—8]. In deep inelastic scattering of leptons this internal momentum corresponds to the region of the Bjorken variable $x_b \geq 1$, where the cross sections are too small [10]. This leads to the well-known difficulties if one tries to use leptons as a probe for the investigation of nuclear properties at short distances. But at the same time the coincidence of the deuteron wave function square extracted from the data on deuteron fragmentation on proton [10] and from the experiments on electron collisions on deuteron [11], shows the possibility of using hadronic probes for studying nuclear structure [12].

It is obvious, that the study of the spin degree of freedom in cumulative particle production can give us more detailed information about nuclear matter at short distances and about reaction mechanisms. First experiments of such kind were the measurements of cumulative proton polarization for fragmentation of unpolarized nuclei [13]. The most precise experiments have shown that this value is small (5—10%) [14] and can be explained by produced proton rescattering [14,15]. However, for the nuclear structure investigation experiments on nuclear fragmentation in a definite spin state, i.e., experiments on studying spin effects on polarized nuclei fragmentation into cumulative hadrons, seem more adequate. For this purpose the deuteron nucleus is of the particular interest as more studied from the experimental (static characteristics, form factors and so on) and theoretical points of view. It should be noted that beams of polarized deuterons with a high enough energy ($p_0 \geq 2$ GeV/(c u)) are already available in Dubna and are planned to be obtained in KEK (Japan) and RHIC (US). Experiments with polarized deuterons allow us to separate contribution from the S and D components in the deuteron wave function. In particular, it is clearly seen from the expressions (valid for the nucleon model via an impulse approximation) for the fragmentation cross section σ (unpolarized deuteron), tensor analyzing power (T_{20}) and polarization transfer coefficient (κ) for tensor and vector polarized deuteron fragmentation into proton (at an angle of 0°):

$$\sigma \sim u^2(k) + w^2(k), \tag{1}$$

$$T_{20} = \frac{2u(k)w(k) - w(k)^2/\sqrt{2}}{u^2(k) + w^2(k)}, \tag{2}$$

$$\kappa = \frac{u^2(k) - w^2(k) - u(k)w(k)/\sqrt{2}}{u^2(k) + w^2(k)}. \tag{3}$$

In these equations u and w denote S and D waves in the deuteron and k is its internal momentum.

The values of T_{20} and κ for protons as a secondary particle have been studied at Saclay and for a wider internal momentum region at Dubna. At present there are some data for T_{20} in the region $0 \leq k \leq 1.0$ GeV/c and for κ in the region $0 \leq k \leq 0{,}6$ GeV/c [12,16,17,18]. A simple correlation between T_{20} and κ following from (2) and (3) is not confirmed by the experimental data [12]. The final state interaction was taken into account to describe these data [19], but a full agreement with the experimental data was not achieved. In the region $k \geq 0.8$ GeV/c the value of T_{20} is more close to the asymptotics predicted by the model [20] taking into account colour clusters in deuteron core. So, the fragmentation of polarized deuterons to protons gives us experimental evidence of including colour forces in description of the bound *NN*-system at short distances. The study of the polarized deuteron fragmentation to cumulative hadrons with quark contents other than in protons can give additional important information for understanding nuclear structure at short distances. For this purpose we propose to measure the tensor analyzing power of the following reactions:

$$\mathbf{d} + A \to \pi^{\pm}(0^{\circ}) + X, \tag{4}$$

$$\mathbf{d} + A \to K^{\pm}(0^{\circ}) + X, \tag{5}$$

$$\mathbf{d} + A \to \bar{p}(0^{\circ}) + X, \tag{6}$$

Interest in these reactions is explained by the following:

- the final state interactions change with changing the type of secondary particle, and so it provides us additional information about this background process;
- detected particles have a different quark composition. This helps us to make choice between different models which take into account non-nucleon degrees of freedom in nuclei;
- the registration of secondary particles at a zero angle leads to simplifying of the expression for cross section and allows us to avoid corrections due to the presence of vector polarization in a primary deuteron beam;

The possibility of using the reactions of polarized deuteron fragmentation to π mesons was discussed in [21], and there were predicted considerable spin effects for momentum region of cumulative production. The calculations of the tensor analyzing power for reactions (4—5) have been performed by Tokarev [22] on the base of his covariant approach. The results of these calculations shown in Fig.1 clearly demonstrate the sensibility of T_{20} to deuteron description at short distances. From these figures one can see that the presence of the core in internucleon forces changes strongly the tensor analyzing power dependence on secondary particle momentum in the cumulative region.

The measurements are planned to be carried out on a slow extraction polarized deuteron beam at the Dubna Synchrophasortron. The beam parameters are the following:

- the intensity is $2 \cdot 10^{9}$ **d**/burst;
- the burst duration is about 500 ms;

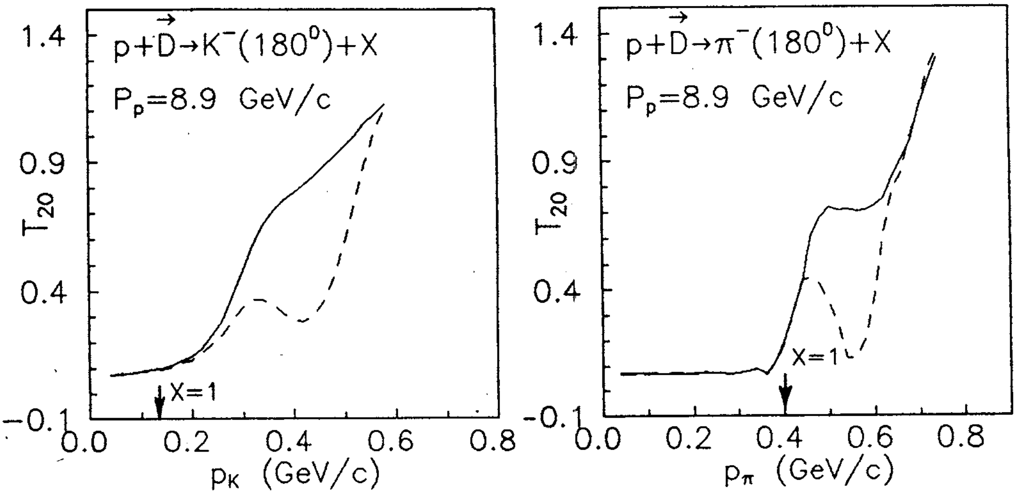

Fig.1. The tensor analyzing power T_{20} calculated by M.Tokarev [22]. Solid line — RDWF without core, dashed line — RDWF with core. The arrows denote the left boundary ($X = 1$) of cumulative production region for pions and kaons

- the tensor polarization of the deuteron beam for plus and minus alignments: $pp^+_{zz} \cong$ $\cong 0.60$ and $pp^-_{zz} \cong -0.75$. The polarization sign changes with each accelerator cycle (9s).

The value of the analyzing power (T_{20}) of reactions (1) is extracted from the measurement of the deuteron fragmentation cross sections ($\sigma^{\pm}$) at different tensor alignments of the deuteron beam as follows

$$T_{20} = \frac{2\sqrt{2}(\sigma^+ - \sigma^-)}{p^+_{zz}\sigma^- - p^-_{zz}\sigma^+}. \qquad (7)$$

As a spectrometer we are planning to use a beam line and the SPHERE setup (see Fig.2). The angular acceptance of the beam line is $0.4 \cdot 10^{-3}$ sr at a momentum bite of $\delta p/p = 2.5\%$. It is planned to use the following targets:

- a liquid hydrogen (deuterium) target 100 cm in size (7 g/cm^2);
- carbon targets with up to 25 g/cm^2 thickness.

For particle identification it is suggested to use the following setup:

- a high resolution Time-Of-Flight system (counters S_{TOF1}, S_{TOF2}) with a 77 m flying base
- Cherenkov counters for a π, K separation.

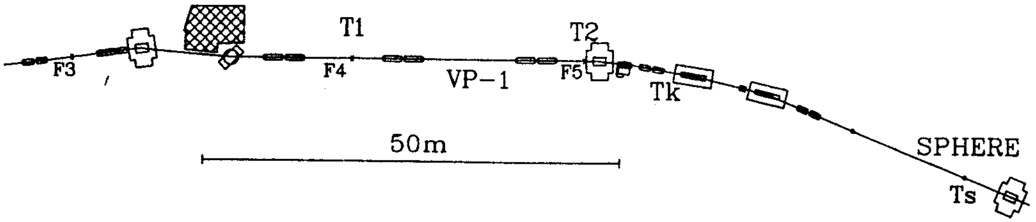

Fig.2. The beam line to the SPHERE spectrometer

The target is placed at the focus F3 for reactions with π and $\bar{p}$ and at the focus F5 for K mesons to decrease kaons losses due to a short decay length of kaon.

The degree of subthreshold (degree of cumulativity) for reactions (4—6) can be changed in two ways. In the first case one can change the deuteron momentum p_d while the beam line momentum for secondary particles p_h is fixed. In the second way the channel momentum (p_h) should be changed and the deuteron momentum (p_d) should be fixed. It is convenient to use the relativistic invariant scale variable X for experimental data representation in both cases. This variable commonly known as a cumulative number is widely used for experimental data analysis on nuclear fragmentation. In its meaning it is a minimum target mass (measured in nucleon mass units) in the rest frame of a fragmenting nucleus needed to obey the 4-momentum conservation law for particle production with a given momentum and mass in a proton-nucleus collision. The relativistic invariant expression looks like [1]:

$$X = \frac{(P_{II}P_1) + \Delta/2}{(P_{II}P_I) - (P_IP_1) - m_n^2 - m_n m_2}, \tag{8}$$

where P_I and P_{II} are the 4-momenta per nucleon of colliding fragmenting and other non-fragmenting primary nuclei, respectively; P_1 is the 4-momentum of an inclusively studied particle; m_n is the nucleon mass; m_1 is the produced particle mass; m_2, the additional particle mass needed to satisfy the quantum numbers conservation laws in the studied reaction and $\Delta = = 2m_n m_2 + m_1^2 - m_2^2$. In the beam fragmentation region the scale variable X is defined by the following expression:

$$X = \frac{m_n E_1 + \Delta/2}{p_1 p_0 \cos(\Theta_1) - E_1 E_0 + E_0 m_n - m_n^2 - m_n m_2}, \tag{9}$$

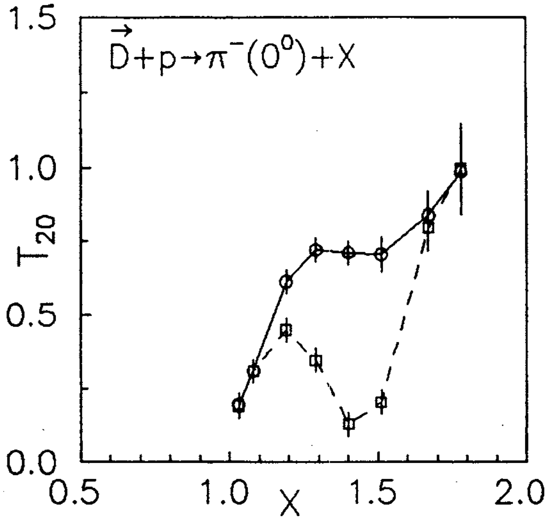

Fig.3. The value of tensor analyzing power with errors for ten-day run statistics. Solid and dashed lines demonstrate a waiting behaviour of T_{20} for two kinds of internucleon forces. We reproduced this cirves using calculations [22] and hypothesis of conservation of the form of $T_{20}(x)$-dependence in the scale of cumulative variable X

where E_0, p_0 are beam energy and momentum; E_1, p_1 are the same vulues for a studied particle and Θ_1 is the studied particle emission angle. The inclusive invariant cross-sections of the cumulative particles vs X can be presented in the following parametrization:

$$d\sigma \sim EXP(-X/\langle X\rangle). \tag{10}$$

The slope parameter $\langle X\rangle$ weakly depends on collision energy from 3—4 GeV/nucleon [1,2,3]. This is also confirmed in experiments on the fragmentation of polarized deuterons to protons [12,16,17,18]. The count rate was estimated using the channel and beam parameters introduced before and the cross sections for unpolarized deuteron fragmentation to cumulative hadrons. The expected experimental results are shown in Fig.3 with the statistical errors obtained in ten-day exposition for two kinds of nuclear forces at short distances. From this figure one can see that the statistical errors allow us to distinguish between internucleon forces with and without core. As is seen from this example, we can make a choice of the internucleon forces (with and without core, for instance) for available beam time using the proposed experimental approach.

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