Search for three-baryon resonances in the mass spectrum of a pnn system in the $tp \to ppnn$ reaction at $p_t = 2.5$ GeV/c

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A search for three-baryon resonances B^3 in the mass spectra of $p_F nn$ and $p_S nn$ systems in the range 2.84–3.04 GeV in the $tp \to ppnn$ reaction at 2.5-GeV/c momentum of tritium nuclei was conducted. Clearly manifested structures were observed in the mass spectrum of the $p_F nn$ system at 2.94 and 3.01 GeV and in the mass spectrum of the $p_S nn$ system at 2.9 GeV. The resonance origin of these structures, however, is questionable, since they are satisfactorily described by the pole model.

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The study of excited states of nuclear matter has produced great interest lately. The existence of two-baryon resonances B^2 with masses of 2.1–2.5 GeV has been reported in a number of articles.[1] These resonances are interpreted as a 6-quark bags[2] or as rotational excitations of the $NN\pi$ system.[3] A generalization of these schemes to three-baryon systems makes it possible to predict to predict a number of three-baryon resonances B^3.[4]

The spherical, 9-quark bags[5] give sufficiently heavy resonances [for example, $M^{(3)}(I = 1/2, S = 1/2) = 3.52$ GeV]. The stretched rotating bags with a hidden color and 4 and 5 quarks at its ends $(q^4)_3 - (q^5)_{3^*}$ [3 and 3* denote irreducible SU$(3)_c$ group representations] are energetically more advantageous configurations (the minimum mass of the bags with $I = 1/2$ and $J^P = 1/2^-$, $3/2^-$, and $5/2^-$ is equal to 3.1 GeV).

The theoretical masses for the B^2 resonances are 100–200 MeV larger than those observed experimentally.[2] The quark models for the B^3 resonances evidently also require the same accuracy. The minimum mass of B^3, therefore, may be about 2.9 GeV.

The two-baryon resonances $^1D_2(2.14)$, $^3F_3(2.26)$, and $^1G_4(2.43)$ in the McGregor model[3] are explained as rotational excitations of the $NN\pi$ system with a mass $M_L^{(2)} = M^0_{(2)} + E^{(2)}_{rot} L(L+1)$, where $M^0_{(2)} = 2m_N + m_\pi = 2.02$ GeV and $E^{(2)}_{rot} = 0.02$ GeV. If the same rotational bands also exist in three-baryon $3N\pi$ systems, then $M_L^{(3)} = M^0_{(3)} + E^{(2)}_{rot} L(L+1)$, where $M^0_{(3)} = 3m_N + m_\pi = 2.96$ GeV, and $E^{(3)}_{rot}$ must be smaller because of an increase of the moment of inertia as a result of transition to a heavier system: $E^{(3)}_{rot}/E^{(2)}_{rot} \sim M^0_{(2)} R^2_{(2)} / M^0_{(3)} R^2_{(3)}$. Such systems must have a large radius $R \sim 1/m_\pi$. If the radius $R_{(2)}$ does not differ greatly from the radius $R_{(3)}$, then $E^{(3)}_{rot} / E^{(2)}_{rot} \approx 2/3$. Thus we obtain (in GeV): $M_1 = 2.99$, $M_2 = 3.04$, $M_3 = 3.12$, and

$M_4 = 3.23$. If $R_{(n)} \sim n^{1/3}$, just as in the case of nuclei, then the levels of the rotational band will be located closer to each other: $E^{(3)}_{rot}/E^{(2)}_{rot} \approx 0.5$.

By using an experimental material obtained as a result of exposure of the ITEP, 80-cm-diam, liquid-hydrogen bubble chamber to a separated beam of tritium nuclei with a 2.5-GeV/c momentum, we were able to search for three-baryon resonances. The purpose of this investigation was to analyze the mass spectrum of a three-baryon pnn system in the energy range 2.84–3.01 GeV in the $tp \to ppnn$ reaction. The investigated mass range is located below the formation threshold of an Δ isobar. The B^3 resonances in this range can decay to $3N$ or $3N + \pi$. If the B^3 resonance is below the $3N + \pi$ threshold, then it can decay only to three nucleons.

We obtained approximately 80,000 photographs and processed approximately 21,000 two-beam interactions. The details of the processing are given in Ref. 6.

As a result of processing, we identified 7956 events of the reaction

$$tp \to ppnn. \qquad (1)$$

Since the events with a slow secondary proton may be omitted in the scanning, we have included in the final analysis only the events with large secondary-proton momenta in the laboratory system

$$p_{min} = 0.2 \text{ GeV}/c. \qquad (2)$$

The cross section for the reaction (1) with the constraint (2) turned out to be equal to 28.8 ± 0.8 mb.

Figure 1 shows the mass spectra of the $p_F nn$ and $p_S nn$ systems for different intervals of the angle θ between the momenta of the secondary proton p_F and the primary proton in the tritium rest frame (p_F and p_S are the slow and fast protons in this frame). The spectrum in Fig. 1a has two sharply defined peaks at 2.94 and 3.01 GeV. As the angle θ decreases (Fig. 1b), the peak for 2.94 GeV vanishes [which is due primarily to selection of (2)], and the structure for 3.01 GeV broadens noticeably. The maxima in Figs. 1c and 1d, whose shape depends on the angle θ, can also be seen in the

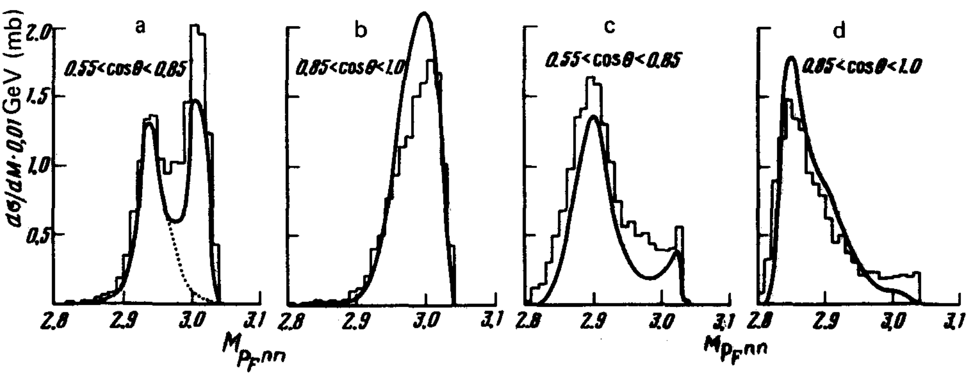

Fig. 1.

mass spectrum of $p_S nn$.

A sharp dependence of the peaks on the kinematic variables (in particular, the 2.94-GeV peak) evidently indicates that these peaks have a nonresonance nature. This was verified by comparing the experimental data with the results of a calculation within the framework of the pole model, which satisfactorily describes the main characteristics of the reaction (1) in an absolute normalization and without introduction of free parameters.[6]

The model is based on an incoherent sum of five pole diagrams with an exchange of a virtual proton or a virtual neutron. In the upper vertices of the diagrams selected the amplitudes of elastic *pp* and *pn* scattering on the mass surface, which were parameterized in the entire kinematically resolved region through the *NN*-scattering phases.[7] The vertex function of tritium decay to a virtual nucleon and a spectator *NN* pair is written in the lower sections of the diagrams in the form of an overlapping integral of the wave function of tritium with a wave function of the continuous spectrum of an *NN* pair. We assumed that tritium was in a totally symmetric ground state. The wave function of this state was determined in the parametrization[8] by solving the Faddeev equations in a separable approximation.[9] The wave function of an *NN* pair was written in the Yamaguchi separable approximation[10] with the Sitenko-Kharchenko parameters.[9]

A numerical calculation of the cross section for the reaction (1) in the relativistic phase volume, which was performed by using the Monte-Carlo method with an accuracy of $\sim 10\%$ and with allowance for the constraint (2), gave a value of 32 mb.

The solid curves in Figs. 1a–1d correspond to a total contribution of all five diagrams and the dotted curve corresponds to a contribution of the diagram with a virtual-proton exchange. The theoretical spectra have maxima in the same places as the experimental spectra. The maximum on the left-hand side in Fig. 1a, which is attributable, in particular, to a contribution of the diagram with a virtual-proton exchange, is associated with a sharp peak in the mass distribution of the *nn* system due to final-state interaction. The maximum at 2.85–2.9 GeV in Figs. 1c and 1d is attributable to the same causes. The maximum at 3.01 GeV in Figs. 1a and 1b occurs because of constraints associated with the small phase volume. Note that the quality of the theoretical description in this region is slightly poorer.

Thus, the structures in the mass spectra of three-baryon systems observed in this experiment apparently have a nonresonance origin. In the next stage of investigation it would be useful to study the spectra of three-baryon systems produced in the reaction (1) at higher energy in the same mass region. First, if B^3 resonances exist, then the cross section for their production at a given energy can be greatly suppressed by the $t_{\min}$ effect. Second, the constraints associated with a small phase volume vanish with increasing energy, and the background becomes smoother.

A more thorough theoretical analysis must be conducted in connection with the search for three-baryon resonances in the reaction (1). In particular, the interference and rescattering effects, which were disregarded in this calculation, can be significant in certain kinematic regions.

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