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POSSIBLE DIBARYON STATES PRODUCED IN ^{4}HE – PROTON INTERACTIONS

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INTRODUCTION

Interest in dibaryon states has been recently aroused because their existence can reflect the quark substructure of nucleons. The spectrum of six-quark states has been predicted, e.g., in the MIT bag model /1-3/ and in the string model /4/. It seems, however, that a more classical description of the available experimental data in terms of nucleon-meson physics cannot be rejected at present. The majority of experimental indications of non-strange dibaryon resonances comes from the analysis of nucleon-nucleon scattering data for different spin configurations /5/ and from γd and πd reactions /6,7/ . The lowest energy dibaryon state which is relatively well established experimentally is the state at 2140 - 2170 MeV. The nature of this state is still controversial, mainly because of the vicinity of the threshold for Δ-isobar production.

However, there are some theoretical indications of the existence of lower-lying states. A dibaryon state near 2040 MeV has been predicted, e.g., by Lichtenberg as a diquark-quadriquark structure of a six-quark system /8/ and by Mac Gregor at 2060 MeV in the rotational model /9/. Ferreira and Murguia claim that the assumption of the existence of the $^3P_1$ state with a mass of 2060 MeV significantly improves a theoretical description of πd scattering data in the low energy region /10/ . In this paper we have investigated dibaryon excitations in the ^{4}He nucleus. The production of two-nucleon states is expected to be more copious here than on a deuterium target due to relatively smaller distances between the nucleons.

The class of interactions involving two nucleons can be somewhat enriched by rejecting events with ^{3}He or triton in the final state. This is due to the fact that the interaction with only one nucleon often leaves a recoiling three-nucleon system intact. We decided to analyze a $^4\mathrm{He} \to dppn$ reaction channel. This channel has the above features and also a good experimental separation and the lack of pions which permits the experimental background to be simply estimated.

The method used here allows the low effective masses of the two nucleons to be analyzed. This region has been covered neither by the experiments with polarization information nor by the proton-proton total cross section measured with small steps and to a sufficient accuracy for proton laboratory momenta smaller than 1 GeV/c.

EXPERIMENT

The experiment has been performed using the 1 m hydrogen bubble chamber exposed to an external beam of 8.6 GeV/c α-particles at the Dubna proton synchrotron. Films were scanned for all topologies. About 44 thousand events (normalization of 3.5 μb/events) were measured and reconstructed in three dimensions using the CERN HYDRA Application Library. Some other results of the experiment have been published elsewhere [11,12].

The results presented are based on the statistics of 3234 events giving a fit to the $^4He p \to dppn$ reaction with a χ^2 probability greater than 5% and consistent with the estimated ionization on the tracks. In 2867 events the identification of the reaction was unique. To avoid the admixture of nonfitted $^4He p \to dppn\pi^0$ reaction, only events with missing mass smaller than 1.2 GeV/c were accepted.

A high percentage of unambiguously identified events is due to the kinematical configuration of the experiment with the incident alpha beam [13].

RESULTS

The two-nucleon effective mass distribution for the $^4He p \to dppn$ reaction is shown in fig. 1 for events with the proton (neutron) being the fastest particle in the helium rest system. The diagrams corresponding to these two classes of reactions, further referred to as "direct" (2346 ev.) and "charge exchange" (888 ev.) reactions channles, are shown in fig. 2 a and b, respectively. The mass of the two slowest nucleons in the helium rest frame has been calculated because it is natural to associate the fastest nucleon to the upper vertices of the diagrams.

The pn effective mass in the direct reaction has an exponentially decreasing shape. A fit with an exponential function leads to a 60% confidence level. The two-proton effective mass distribution does not exhibit the same behaviour. In this case the best description has been obtained by fitting the admixture of an exponential background and two Breit-Wigner functions with positions $M_1 = 2035 \pm 15$ MeV, $M_2 = 2137 \pm 15$ MeV and widths $\Gamma_1 = 30 \pm 23$ MeV and $\Gamma_2 = 59 \pm 20$ MeV (see the curve in fig. 1). In this fit the slope of the experimental background is found different from that in the direct channel. This can be connected with the fact that the $d\sigma/dt$ distributions are different for the $pn \to np$ reaction and nucleon-nucleon forward elastic scattering. The relation of the $d\sigma/dM$ and $d\sigma/dt$ distributions in elementary nucleon-nucleon scattering arises in a natural way if we assume that the background processes mainly proceed via the double scattering on two nucleons, and the deuteron acts as a spectator.

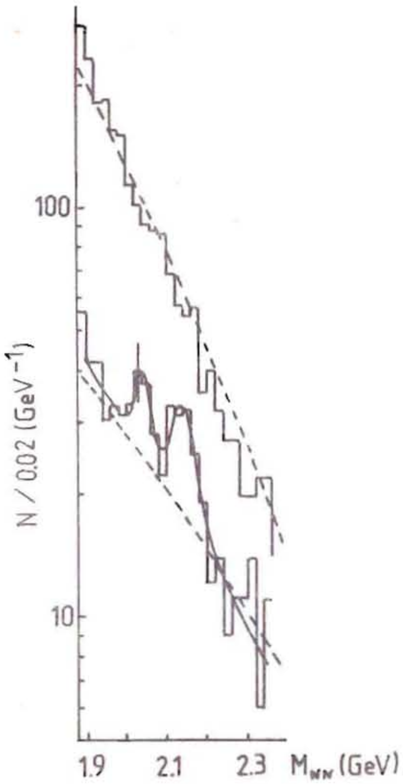

Fig. 1. Effective mass distributions of the two slowest nucleons in the helium rest frame for direct reaction channel (upper histogram) and charge exchange channel (lower histogram). Dashed lines are the prediction in the frame of the multiple scattering model (see text).

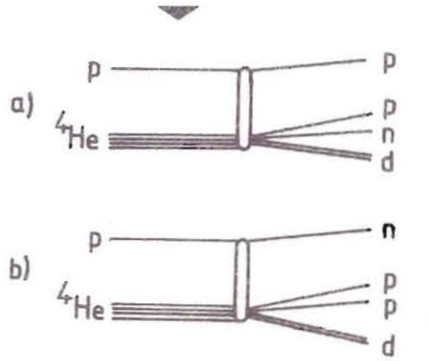

Fig. 2. Diagrams representing "direct" and "charge exchange" channels of the $^4He \to dppn$ reaction.

The validity of this model is confirmed by the fact that the deuteron momentum distribution observed in our data is spectator-like. Moreover, the slope of the four-momentum transfer distribution for $^4He p \to dppn$ is rather close to the value predicted in the multiple scattering model for the double scattering term. This means that it is equal to one half the slope in the elementary nucleon-nucleon scattering (for large enough t to neglect final state interactions).

We have used the expression obtained by Bertocchi and Bradamante et al. [14,15] for the proton-deuteron double scattering amplitude as a function of relative momentum $\vec{k} = (\vec{k}_1 - \vec{k}_2)/2$. Having in mind that the two-nucleon effective mass squared is approximately equal to

$$M^2 = (\vec{k}_1 - \vec{k}_2)^2 + 4m^2, \qquad (1)$$

we have found that

$$\frac{d\sigma}{dM} \sim e^{\frac{ab}{4(a+b)}M^2} , \qquad (2)$$

where a is the parameter of the helium single nucleon density in momentum space

$$\Psi(q) = A e^{-aq^2}, \qquad (3)$$

b is the slope of the nucleon-nucleon scattering cross section taken in the form

$$\frac{d\sigma}{dt} = C e^{-bt} . \qquad (4)$$

If a is much larger than b, the fall of the $d\sigma/dM$ distribution depends essentially on the value of parameter

$$\frac{d\sigma}{dM} \sim M \exp(-\frac{b}{4}M^2). \qquad (5)$$

Extrapolating the avaliable experimental data on nucleon-nucleon scattering to a momentum of 2.15 GeV/c, the b value has been found to be approximately 5.4 GeV^{-2} for nucleon-nucleon forward elastic scattering /16/ and approximately 3.5 GeV^{-2} for the $pn \to np$ charge exchange process /17/. This difference in the b values explains the difference in slopes of the background distributions. The dotted lines in fig. 1 are calculated according to formula (5).

We do not claim that the proposed mechanism for the background process is the only possible, e.g., the single scattering term leads to a steeper $d\sigma/dM$ dependence.

We have analyzed the decay angular distribution in the two-proton centre of mass frame. The shape of the angular distribution observed in the experiment does not contradict the resonance interpretation of the effect.

The question can arise why the bumps are seen in the charge exchange channel only. There are at least two possible reasons for easier detection of a signal in the proton-proton configuration than in the neutron-proton one: (i) The number of possible resonance states is obviously smaller in the pure isospin pp-state, (ii) The background of the quasi-elementary change exchange channel is several times smaller than the background of the more frequent direct reaction so a similar signal can be unseen there.

In the $dp \to ppn$ reaction at a 3.3 GeV/c deuteron momentum similar effects have been observed in the selected class of non-spectator events /18, 19/. To diminish the background, the cut on the momentum of the lowest nucleon in the deuteron system was applied.

We have therefore selected a similar sample for the $^4He p \to dppn$ reaction by choosing events where both proton momenta are large than 300 MeV/c in the ^4He rest frame. The shape of the corresponding mass distribution closely repeats the shape of the enchancements.

CONCLUSION

In the two-proton invariant mass in the $^4He p \to dppn$ reaction the structure has been observed, which cannot be explained in the frame of the simple multiple scattering model. The observed enchancements can be interpreted as a result of the production of dibaryon states with positions and widths $M_1 = 2035 \pm 15$, $\Gamma_1 = 30 \pm 23$, $\Gamma_2 = 2137 \pm 15$, $M_2 = 59 \pm 20$ MeV. The excess over the background is 3.0 ± 1.3 and 3.2 ± 1.3 standard deviations, respectively.

There are theoretical indications concerning both structures, but only the second one has been observed in several experiments. The position below production threshold and a rather small width seen in our experiment may be regarded as an argument in favour of the six-quark state interpretation.

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Возможные дибарионные состояния во взаимодействиях ядер ^{4}He с протонами

С помощью водородной пузырьковой камеры исследовались ^{4}He-p взаимодействия при импульсе падающих α-частиц 8,6 ГэВ/с. Использование пучка ускоренных ядер дало возможность провести полный кинематический анализ реакций с одной нейтральной частицей. Подробно изучена реакция ^{4}He ⟶ dppn . Выделены события перезарядки, которые характеризуются наличием быстрого нейтрона в системе покоя ^{4}He . В этих событиях в распределении по эффективным массам двух протонов наблюдены максимумы при 2035±15 и 2137±15 МэВ. Так как дейтрон в реакции ^{4}Hep→dppn имеет спектаторные характеристики, фоновые кривые рассчитаны в предположении двукратного рассеяния на нуклонах

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Possible Dibaryon States Produced in ^{4}He - Proton Interactions

^{4}He-p interactions have been investigated at an incident α-particle momentum of 8.6 GeV/c by a hydrogen bubble chamber. The use of a beam of accelerated nuclei makes it possible to carry out a total kinematical analysis of reactions involving one neutral particle. The reaction ^{4}Hep → dppn is studied in detail. Charge exchange events having a fast neutron in the ^{4}He rest system are selected. In these events for the effective mass distributions of two protons maxima are observed at 2035±15 MeV and 2137±15 MeV. As the deuteron in the reaction ^{4}Hep → dppn has spectator properties, the background curves are calculated on the assumption of double scattering on ^{4}He nucleons.

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

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