Search for a narrow resonance in the $pp\pi^-$ system

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Preliminary results of the analysis of the $pp\pi^-$ system produced in the reaction $pp \rightarrow pp\pi^-\pi^+$ reveal a resonance with a mass $M \approx 2.06$ GeV and a width < 15 MeV. The mass spectrum of the system $pp\pi^-$, which can have any quantum numbers, including those forbidden in the np system, has been investigated for the first time. The observed resonance in the $pp\pi^-$ mass spectrum is in agreement with the quark models, and it confirms the recently proposed explanation of the peculiar features in the low-energy pionic double charge exchange on nuclei.

There is an apparent interest for exotic states, including low-mass dibaryons, which might be considered as six-quark systems. Most of the dedicated search for dibaryons performed so far involved the NN or $N\Delta$ coupled states.[1] These experiments have not led to any positive and unambiguous results, which is not surprising, in our view, since there are no reliable theoretical arguments in favor of a small width of dibaryon structures which can decay into two, colorless, three-quark clusters. One could have expected a small width of $T=2$ dibaryons with a mass $M \leqslant m_p + m_\Delta$. It follows, however, from quark models (see, e.g., Ref. 2) that $T=2$ states are expected to have masses that exceed the total mass of N and Δ. The experimental search for $T=2$ states in the reactions $\pi^- d \rightarrow \pi^+ X^-$ (Ref. 3) and $pp \rightarrow \pi^- X^{+++}$ (Ref. 4) have also indicated negative results.

It was pointed out in Refs. 2 and 5 that low-lying resonances (with a mass of only 50–100 MeV above the total mass of $NN\pi$) and narrow resonances with $T=0$ and quantum numbers $J^P = 0^-, 2^-$ can exist. These resonances cannot decay into two nucleons as a result of strong interactions, and they decay into two nucleons and a pion.

In this paper we present preliminary results of the experimental search for narrow structures in the $pp\pi^-$ mass spectrum, which was initiated by the predictions of quark models.[2,5] We studied a simple reaction relevant to this case, $pp \rightarrow pp\pi^-\pi^+$. We should emphasize that none of the previous dedicated experimental studies of dibaryons can either confirm or rule out the existence of the $pp\pi^-$ resonances which are not linked with the NN channel (see, e.g., Ref. 1).

The experiment was carried out at the ITEP accelerator. The proton energy of the storage ring was chosen to be $T_p = 920$ MeV ($\sqrt{s} = 2.29$ GeV). The protons scattered elastically at an angle of 3° by the internal beryllium target were formed by a magnetic field into a beam with $\Delta p/p \leqslant 5 \times 10^{-3}$ and intensity $\sim 0.5 \times 10^6$ particles/cycle. The beam protons were detected by scintillator counters which measured the time of flight

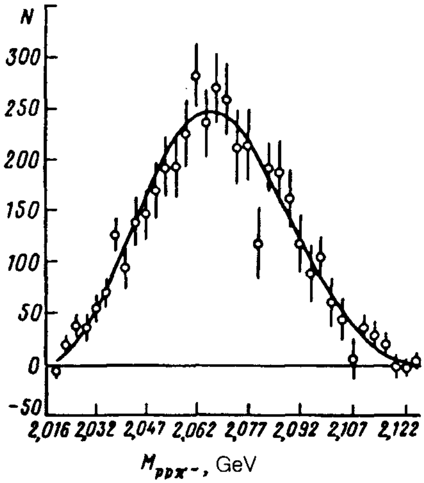

FIG. 1. Distribution of events in the reaction $pp \rightarrow pp\pi^-\pi^+$ as a function of the $pp\pi^-$ invariant mass.

and determined the effective region of the target. The measurements were performed with two different targets: CH_2 (2.78 g/cm^2) and ^{12}C (3.52 g/cm^2); the data given below are the result of a differential experiment. The scintillator counter which measured the total amplitude of the signals from the particles passing through it was installed next to the target; it allowed to discriminate the events with two or fewer relativistic particles produced in the target.

The secondary particles were detected by 36 thick scintillator counters ($\approx 200 \times 200 \times 200$ mm) which covered a solid angle of $4° < \Theta < 24°$, $0° < \phi < 360°$. Measurements of the energy of the secondary particles and their identification were done by the time-of-flight method and by measuring their energy release.

The signal detected from the $\mu^+ \rightarrow e^+$ decay of the pion stopped in the counter was considered to be the criterion of the positive charge of the pion. The particular features of the procedure are described in Ref. 6.

The events were recorded when at least three of the 36 counters were triggered. Experimental conditions allowed us to measure the invariant masses of the $pp\pi$ system up to $M_{pp\pi} = 2.12$ GeV. About 10^{11} protons passed through the counter and $\sim 10^7$ events were recorded on the magnetic tape. The events with two protons and one pion of a particular charge were selected. For further analysis we selected the events for which the squared missing mass of the $pp\pi$ system was equal to the squared pion mass; the FWHM of the corresponding distribution was about 0.02 GeV^2. It was also necessary to establish a correspondence between the amplitude in the counter placed next to the target and the energy released by the particles detected in the event. The number of events selected for the analysis was ~ 7000 for the CH_2 target and ~ 1000 for the ^{12}C target.

The distribution of events as a function of the $pp\pi^-$ invariant mass is shown in Fig. 1. The curve represents the Monte Carlo simulations which take into account the phase space and the constraints imposed by the experimental setup. The curve is normalized to the total number of events. There are no statistically significant devia-

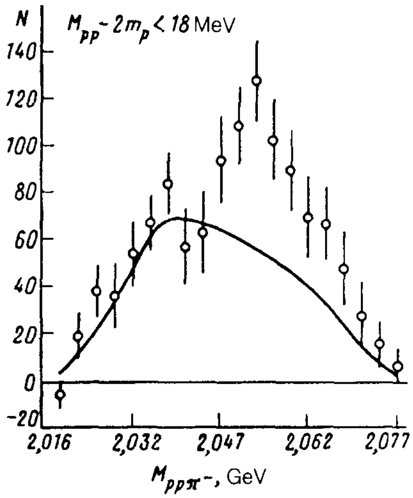

FIG. 2. The same as in Fig. 1 except for the constraint $M_{pp}<2m_p+18$ MeV.

tions of the experimentally measured distribution from the phase space curve.

If the spin and parity of the $pp\pi^-$ system are $J^P=0-$, the two protons are found in the relative S-wave. In this case strong effects should arise from the pp final-state interaction: The number of events with a small invariant mass of the pp subsystem (the Migdal–Watson effect) should increase significantly. The distribution $d\Gamma/dM_{pp}$ in the $pp\pi^-$ decay of the 0^- resonance was calculated in Ref. 7. Similar effects should also take place in the nonresonance background. However, in the region where M_{pp} is small the contribution of the 0^- resonance (if it exists) must be enhanced. There is an excess of events of the reaction $pp\rightarrow pp\pi^+\pi^-$ above the phase space curve at $M_{pp}<2m_p+\Delta m$, where $\Delta m=15$–20 meV. From the arguments advanced above it seems logical to search for a $pp\pi^-$ resonance by analyzing the events enriched by the S-wave between the two protons, i.e., at small invariant masses of the pp subsystem.

Figure 2 shows the distribution of events as a function of $M_{pp\pi^-}$ with the additional constraint $M_{pp}<2m_p+\Delta m$, where $\Delta m=18$ MeV. We point out that the variation of Δm in the range $10<\Delta m<20$ MeV does not change the result. In principle, as follows from Ref. 7, it would be desirable to restrict M_{pp} even more, and to choose the region in which the Migdal–Watson effect is most pronounced (say, $\Delta m\sim 3$–5 MeV). However, for the particular experiment this would mean an essential loss of the statistics, and hence an increase of errors. The solid curve in Fig. 2 corresponds to the phase space which is constrained by the same M_{pp} cutoff; the efficiency of the setup is taken into account. The normalization of the phase space curve is not arbitrary. It is made on the basis of the data plotted in Fig. 1. In other words, for comparison with the experimental data the curves in Figs. 1 and 2 were multiplied by the same number obtained from the normalization to the total number of events shown in Fig. 1.

In Fig. 2 we see a peak at $M_{pp\pi^-}\approx 2.06$ GeV with a width ~ 15 MeV. The energy resolution of the experimental setup is ~ 10 MeV in this region of invariant masses. The cross section corresponding to the excess of events at 2.06 GeV is estimated to be on the order of 1 μb, which is $\sim 2\%$ of the total cross section of the reaction.[8] Similar structures in the $pp\pi^+$ mass spectrum are absent, in agreement with the negative results of the experimental search for dibaryons with $T=2$.

The singularity in the $pp\pi^-$ invariant mass spectrum observed in this experiment should be compared with the s-channel singularity observed in the pionic double charge exchange on nuclei at $T_\pi \approx 50$ MeV. The peaks in the forward cross sections with a width ~20–30 MeV were observed in different experiments (Refs. 9–11 and the bibliography cited in Ref. 12), and are clearly seen for nuclei from ^{12}C to ^{56}Fe. In Refs. 12–15 this phenomenon is explained in terms of the resonance discussed here, and under the assumption that such a resonance exists in nuclei, where it can be produced at nucleon pairs. The parameters of the 0^- resonance imbedded in the nuclear medium are:[12] $M=2065$ MeV, $\Gamma=5$–10 MeV, and $\Gamma_{NN\pi} \approx 0.5$ MeV. Similar assumptions allow us to explain the highly excited state of the nucleus with $E \approx m_\pi + 50$ MeV and $\Gamma < 40$ MeV, observed in the reaction $A(\pi,\pi\pi)A^*$ upon selection of events produced as a result of interaction with nucleon clusters in the nuclei.[16]

In this experiment we have obtained new evidence, free from additional assumptions, of the existence of a narrow, low-mass dibaryon resonance with $T=0$ and probably with $J^P=0^-$.

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