Search for Narrow $\bar{p}p$ States in the Reaction $\pi^- p \to p\pi^-\bar{p}p$ at 16 GeV/c

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This Letter carries out a sensitive (~5 events/nb) search for narrow $\bar{p}p$ states at the Brookhaven National Laboratory multiparticle spectrometer. No evidence is found for such states in the mass range 1900–2400 MeV/c^2 in the reaction $\pi^- p \to p\pi^-\bar{p}p$ at 16 GeV/c. In particular, the $\bar{p}p$ states at 2020 and 2200 MeV/c^2 previously reported in a CERN Ω-spectrometer experiment are not observed.

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In recent years narrow $N\bar{N}$ states have attracted much interest from both theorists and experimentalists, for they are the prime candidates for being four-quark bound states or baryonium. Several $\bar{p}p$ states with narrow widths ($\lesssim 24$ MeV/c^2) have been reported. Of these, two states with mass 2020 and 2200 MeV/c^2 have been seen with good statistical significance in only one experiment, a production experiment on $\pi^- p$ interactions at 9 and 12 GeV/c, carried out in 1977 at the CERN Ω spectrometer by Benkheiri *et al.*[1] A number of experiments have since looked for these two states in formation as well as other production processes, all with negative results.[2-4]

Our experiment is the first to search for these states in the same reaction as the Ω-spectrometer experiment with use of similar trigger techniques and acceptance.[1,5] The reaction studied is

$$\pi^- p \to (p_f \pi^-)(\bar{p} p_s), \tag{1}$$

where p_f (p_s) refers to a fast (slow) proton in the laboratory.

Our experiment was performed at the Brookhaven National Laboratory (BNL) multiparticle spectrometer (MPS) with a π^- beam at 16 GeV/c impinging on a 60-cm-long liquid-hydrogen (LH_2) target (see Fig. 1). The trigger required detection of a fast forward proton. It had good acceptance for a baryon-exchanged, fast $p\pi^-$ system going downstream of the target. The trigger elements included two planar proportional wire chambers, T_1 and T_2, and two scintillation-counter hodoscopes, H_5 and H_7, which were used to trigger on positive tracks with momenta between

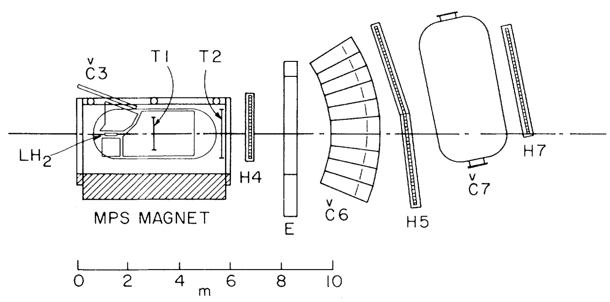

FIG. 1. Floor plan of the experiment. T_1 and T_2 are planar PWC's; E is a spark-chamber module; H_4, H_5, and H_7 are scintillation counter hodoscopes; C_3, C_6, and C_7 are Čerenkov counters. Also shown are the outlines of three groups of spark-chamber modules around the liquid-hydrogen target, LH_2.

8 and 12 GeV/c, and two Čerenkov counters, C_6 and C_7, with γ thresholds of 20 and 13, respectively. For proton identification the trigger utilized two sets of three-dimensional coincidence-matrix logic systems implemented via two random-access memories (RAM), RAM 1 and RAM 2.[6] The elements in the logic systems were (T_1, T_2, $H_5 \cdot \bar{C}_6$) in RAM 1 and ($T_1, T_2, H_7 \cdot \bar{C}_7$) in RAM 2. With these systems the efficiency for rejection of fast forward π^+ and K^+ was better than 99%. In addition, a multiplicity requirement around the target was imposed to select events with three or more charged tracks, but less than six hits in T_1. Particles associated with each event were detected with spark chambers on both sides as well as downstream of the target. A total of 3.4×10^6 proton triggers were recorded, and ~ 80% of them have been analyzed to date, corresponding to a raw sensitivity of 62 eV/nb.

Events have been processed in two stages. The first stage consists of a pattern-recognition and a crude momentum- and vertex-fitting program, yielding a total of 450 000, four-prong events. From this sample, we have selected for further processing 40 000 four-constraint (4C) candidates with missing momentum cuts of $|\Delta P_x| < 300$ MeV/c, $|\Delta P_y| < 200$ MeV/c, and $|\Delta P_z| < 1$ GeV/c. After these cuts the remaining sample shows a clear signal satisfying energy conservation for reaction (1). The second stage of our data-reduction chain consists of a fitting program designed to perform iterative fits to spark-chamber measurements and beam parameters simultaneously, where the parameters in the fit are the vertex position and the vector momentum of each track at the vertex plus kinematic constraints. The 40 000-event sample has first been processed

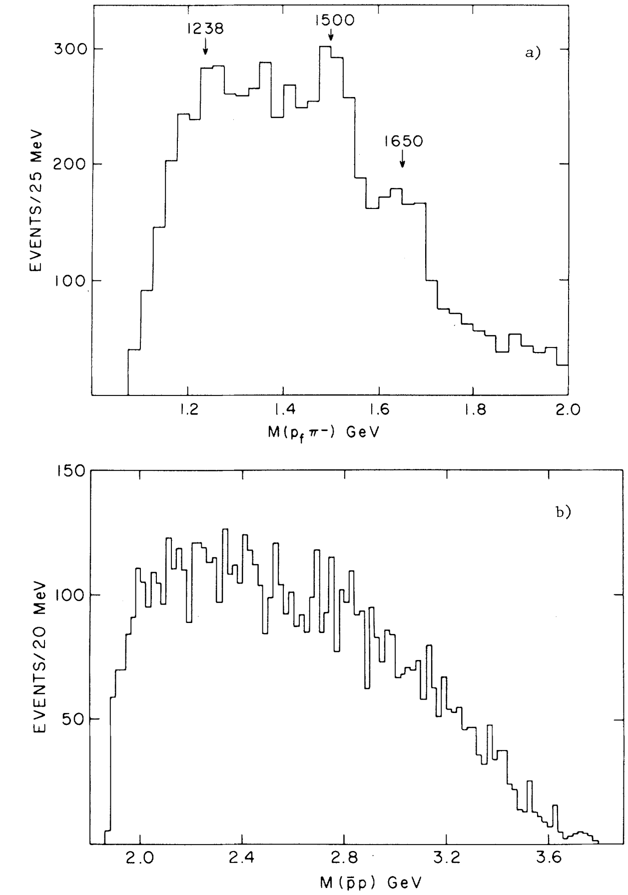

FIG. 2. (a) $M(p_f\pi^-)$ for the events of Reaction (1). (b) $M(\bar{p}p_s)$ for the events of Reaction (1).

through this program without the kinematic constraints (0C fits), and then with the 4C kinematic constraints for the hypothesis corresponding to Reaction (1). A total of ~7000 events survive the 4C fit for reaction (1) with acceptable χ^2. By examining the missing center-of-mass energy distribution[7] for the 0C fits with tighter cuts on $|\Delta P_x|$, $|\Delta P_y|$, and $|\Delta P_z|$, we conclude that the contamination from non 4C background in our final sample is less than 3%.

In Fig. 2(a) we present $M(p_f\pi^-)$ from our final ~ 7000-event sample. Although the background is substantial, $\Delta^0(1238)$ and $N^0(1520)$ are clearly produced in our data. Fig. 2(b) shows the effective mass of the recoil system $M(\bar{p}p_s)$ from the same sample. There is no evidence for the production of 2020- and 2200-MeV/c^2 states in our data. We have attempted to enhance the baryon-exchanged N^0 or Δ^0 production by selecting on $M(p_f\pi^-)$, on the corresponding t', and on the Jackson angle for the $\bar{p}p_s$ system. None of the cuts produced a signal at the two claimed $\bar{p}p$ states.

Our resolution for the $\bar{p}p_s$ system has been estimated from Monte Carlo (MC) events generated according to the observed resolution and efficiency of the MPS spark chambers, PWC's, and hodoscopes. These MC events correctly reproduce the observed missing momentum and energy distributions of our data. The mass resolution is obtained by examining the spread in mass after the MC events generated at a given $M(\bar{p}p_s)$ have been processed through our data reduction programs. We conclude that the mass resolution (rms) is better than 7 (11) MeV/c^2 at 2020 (2200) MeV/c^2, sufficient for us to have seen narrow states, had they been produced in our data. As an independent estimate of our mass resolution, we have checked that the four known masses of the final state $p_f\pi^- p p_s$ calculated for each particle from the remaining particles agree well with those of the MC events. Similarly, the difference in $\sqrt{s}$ between the initial and final states as observed in our data agrees well with that of the MC events.

The acceptance due to detector geometry, absorption in the LH_2 target, and program inefficiency as a function of $M(\bar{p}p_s)$ has been estimated using the same MC events. The acceptance for $M(\bar{p}p_s)$ at 2.02 GeV/c^2 is 23% with $M(p_f\pi^-)$ at $\Delta^0(1238)$, and 20% at $N^0(1520)$; for $M(\bar{p}p_s)$ at 2.20 GeV/c^2, it is 16% at $\Delta^0(1238)$ and 14% at $N^0(1520)$. Our estimate for the additional loss due to inefficiencies in the trigger components, χ^2 cut, etc., is 44%. Then the overall visible sensitivity of our present data for $M(\bar{p}p_s)$ at 2.02 GeV is 8.0 events/nb with $\Delta^0(1238)$ and 7.0 events/nb with $N^0(1520)$; for $M(\bar{p}p_s)$ at 2.20 GeV, it is 6.0 events/nb with $\Delta^0(1238)$ and 5.0 events/nb with $N^0(1520)$. These are to be compared with Benkheiri *et al.* with sensitivities in the 1–2-events/nb range. Our estimate of the sensitivities has less than 15% systematic errors.

Since the CERN Ω-spectrometer experiment observed the $\bar{p}p$ states most clearly with $M(p_f\pi^-)$ and Jackson angle (θ_J) cuts, we display in Figs. 3(a)-3(c) the $M(\bar{p}p_s)$ spectra selecting $\Delta^0(1238)$ [$1.175 < M(p_f\pi^-) < 1.30$ GeV/c^2], $N^0(1520)$ [$1.45 < M(p_f\pi^-) < 1.60$ GeV/c^2], and $\cos\theta_J < 0$. Again we see no evidence for the 2020- and 2200-MeV/c^2 states. The dotted histograms show our estimate of the peaks we should have seen, had they been produced with the cross sections quoted in Ref. 1 but reduced via $\sim P_{\rm lab}^{-2.5}$, a typical behavior of baryon-exchange processes. The absence of the $\bar{p}p$ states in our data corresponds to $\gtrsim 7$- and $\gtrsim 5$-

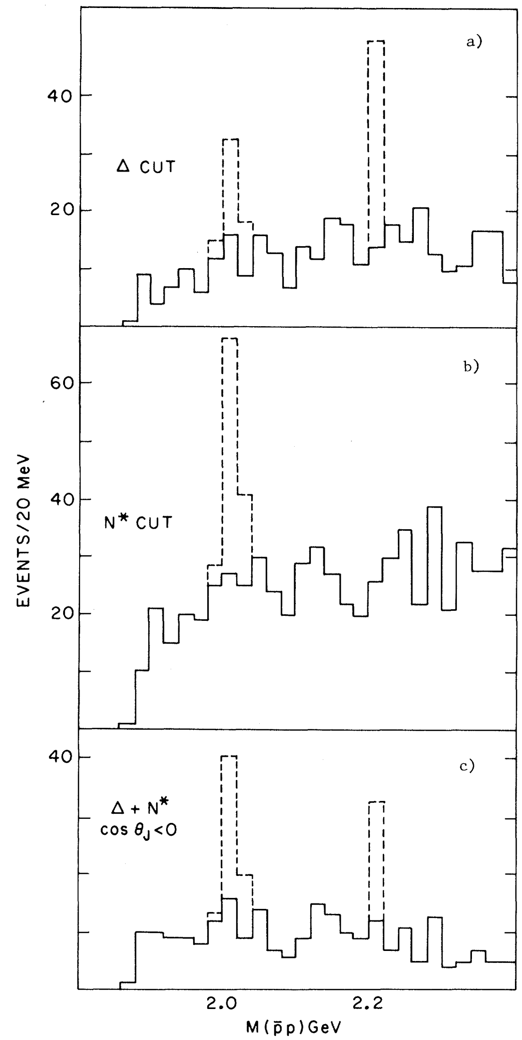

FIG. 3. $M(\bar{p}p_s)$ for the events with $M(p_f\pi^-)$ in the region of (a) $\Delta^0(1238)$, (b) $N^0(1520)$, and (c) Δ^0 plus N^0 with $\cos\theta_J < 0$. Dotted bins delineate the 2020- and 2200-MeV/c^2 peaks estimated from Ref. 1 as explained in the text.

standard-deviation discrepancies at 2020 and 2200 MeV/c^2, respectively. Our 2-standard-deviation upper limit cross sections are 3.0 nb for the 2.02-GeV/c^2 state (obtained by combining Δ^0 and N^0 events) and 2.0 nb for the 2.20-GeV/c^2 state (for Δ^0 events alone), to be compared with the cross sections reported by Benkheiri *et al.* of 36 ± 9 nb and 21 ± 5 nb, respectively, at 12 GeV/c.

In summary, we have obtained a clean ~7000-event sample of Reaction (1) with less than 3% background contamination from $\pi^- p$ interactions at 16 GeV/c. We do not observe narrow $\bar{p}p$ structures less than 30 MeV/c^2 wide in the mass range between 1900 and 2400 MeV/c^2. From the cross sections of the 12-GeV/c CERN data and the assumption of baryon exchange, we should have seen $\gtrsim 5$-standard-deviation signals at 2020 and 2200 MeV/c^2 in our data. We obtain for these states 2-standard-deviation upper limits (95% confidence level) of < 3 nb. We conclude, therefore, that our experiment contradicts the results of the CERN Ω-spectrometer experiment.

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