Search for Narrow $\bar{p}p$ States in the Reactions $\bar{p}p \to \bar{p}p\pi^0$ and $\bar{p}p\rho^0$ at 5 GeV/c

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A search for narrow $\bar{p}p$ states (width $\lesssim 20$ MeV/c^2) has been conducted in the Brookhaven National Laboratory multiparticle spectrometer. No significant structure has been observed in events where the $\bar{p}p$ system has been produced forward in the laboratory. Upper limit cross sections (95% confidence level) for $\bar{p}p$ masses below 2.2 GeV/c^2 are ≤ 0.12 μb and ≤ 0.22 μb for the final states $\bar{p}p\pi^0$ and $\bar{p}p\rho^0$, respectively.

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The existence of four-quark states has been of great interest during the past several years. If such objects exist, a prominent decay mode may be $\bar{p}p$. Two production experiments observed a narrow $\bar{p}p$ state near 1940 MeV/c^2, one with a γ beam[1] and the other with a p beam.[2] Another experiment performed at the CERN Ω spectrometer reported statistically significant narrow $\bar{p}p$ structures at 2020 and 2200 MeV/c^2.[3] The CERN experiment concentrated on the reaction $\pi^-p \to (p\pi^-)_f(\bar{p}p)_s$ at 9 and 12 GeV/c, where the $(\bar{p}p)_s$ system is produced by baryon-exchange with the $(p\pi^-)_f$ system going forward in the laboratory along the beam direction. Other experiments with similar or higher statistics have failed to confirm the existence of these states.[4]

An appropriate channel for production of these states is the baryon-exchange process

$$\bar{p}p \to (p\bar{p})_f X^0, \tag{1}$$

where $(\bar{p}p)_f$ is fast in the laboratory system and X^0 is the slow recoil system. We report in this paper the results of such a search for the $\bar{p}p$ states in Reaction (1). Our experiment is the first to have sufficient sensitivity to check for the existence of narrow $\bar{p}p$ states in Reaction (1).

The experiment was conducted at the Brookhaven National Laboratory multiparticle spectrometer (MPS) with a 5-GeV/c $\bar{p}$ beam incident on a 60-cm liquid-hydrogen target. The apparatus is shown in Fig. 1. The trigger required a fast forward proton (or K^+) with momentum $\gtrsim 1.2$ GeV/c. The identification utilized proportional multiwire chambers (PWC) T_1 and T_2, scintillation-counter hodoscopes H_7 and H_5, a high-pressure Čerenkov counter C_7 with threshold of 10, and a three-dimensional coincidence-matrix logic system implemented via two random-access memories[5] (RAM1 and RAM2). The elements in RAM1 were (T_1, T_2, H_5) and the elements in RAM2 were $(T_1, T_2, \bar{C}_7 \cdot H_7)$. With the coincidence of RAM1 and RAM2 we were able to reject more than 99% of the π^+'s with momentum greater than 1.8 GeV/c.

This experiment has inherent advantages over previous baryon-exchange searches of narrow $\bar{p}p$ states. In particular, compared to searches with higher-momentum meson beams,[3,4] the advantages are twofold: First, the beam momentum of 5 GeV/c favors the baryon-exchange process compared to a π^- beam at 12 GeV/c by a factor of 9 (if we assume the cross section varies as $P_{\text{beam}}^{-2.5}$); second, the four-momentum transfer

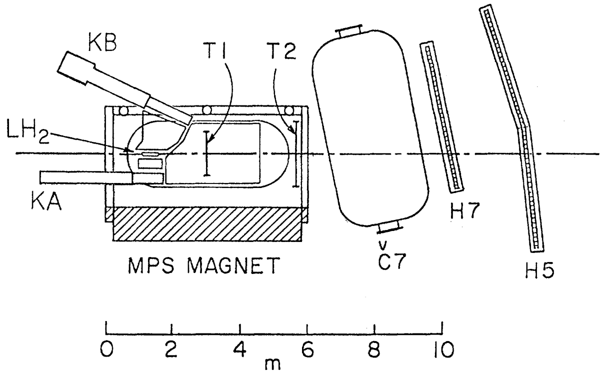

FIG. 1. Schematic diagram of the experimental layout. T_1 and T_2 are planar PWC's; H_7 and H_5 are scintillation-counter hodoscopes; C_7 is the high-pressure Čerenkov counter. All these elements have been used in the triggers. KA and KB are slow K^+ detectors not used in this experiment. The MPS magnet was set at 0.5 T (the direction of the field points into the paper).

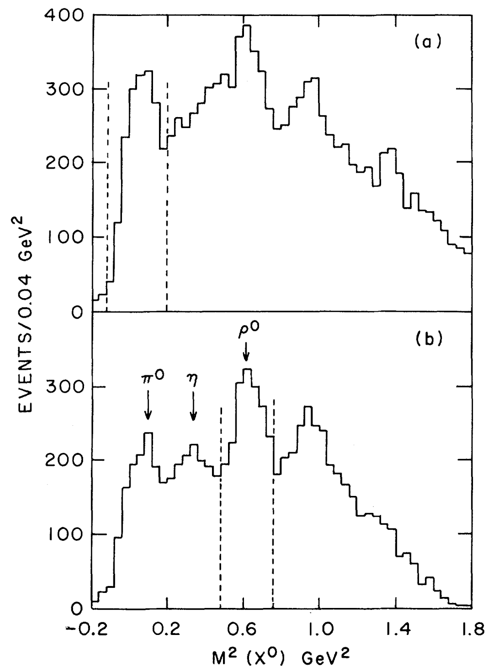

FIG. 2. (a) $M^2(X^0)$ for two-prong events with the assumption that the charged particles are p and $\bar{p}$; (b) $M^2(X^0)$ for $\bar{p}$ and p momentum greater than 1.8 GeV/c and two or more prongs.

from the $\bar{p}$ beam to the $\bar{p}p$ system can become positive, thus allowing for a closer approach to the baryon pole. This results in an additional enhancement factor of 3.2.[6] Thus, the total enhancement factor over a π-beam–induced reaction at 12 GeV/c is estimated to be ~30. Since the quoted cross section of the CERN experiment[3] is around 30 nb, the cross section for Reaction (1) is then expected to be around ~1 μb. Furthermore, the $\bar{p}p$ system goes forward in the laboratory allowing for easier detection and identification.

In this experiment a total of 7.7×10^5 triggers were recorded on magnetic tape corresponding to a raw sensitivity of 6.5 nb^{-1}. The data have been analyzed through our chain of MPS data-reduction programs. After pattern recognition, selected events were processed through 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. To select $\bar{p}p$ events, we have required that in addition to the forward-triggered positive particle, the fastest negative particle (>1.2 GeV/c) go through the high-pressure Čerenkov C_7 without light emission.

In Figs. 2(a) and 2(b) we show the missing mass squared, $M^2(X^0)$, recoiling off $\bar{p}p$ pairs. To select $\bar{p}p\pi^0$ events we have required that the events have two prongs with no additional tracks [Fig. 2(a)]. The background after selecting $-0.12 < M^2(X^0) < 0.16$ (GeV/c^2)^2 is less than 30%. To select $\bar{p}p\rho^0$ events we have required that the p and $\bar{p}$ tracks have momenta greater than 1.8 GeV/c, and we have allowed for two or more prongs. The tighter momentum requirement for p and $\bar{p}$ tracks reduces the background due to $\pi^-p\bar{n}$ and $\pi^+\bar{p}n$ events which tend to peak just below the ρ^0 region [see Fig. 2(a)]. Also, we have required two or more prongs in the selection in order to include the $\bar{p}p\pi^+\pi^-$ events where either one or both of the π's have been lost because of finite acceptance. We estimate that with a cut of $0.48 < M^2(X^0) < 0.76$ (GeV/c^2)^2 the non-ρ^0 background is less than 60% [see Fig. 2(b)]. We note that the ρ^0 signal clearly includes the ω^0 events.[7] Since we do not observe narrow structures, the nature of the background under π^0 and ρ^0 peaks is relatively unimportant; this background merely leads to higher upper limits.

The $\bar{p}p$-mass spectra are shown in Figs. 3(a) and 3(b) for the $\bar{p}p\pi^0$ and $\bar{p}p\rho^0$ events, respectively. No narrow enhancement is seen anywhere throughout the whole spectra.[8] The acceptances are shown as solid curves in Figs. 3(a) and (b). The experimental acceptance and the effective-mass resolution as a function of $M(\bar{p}p)$ have been calculated with use of Monte Carlo events gener-

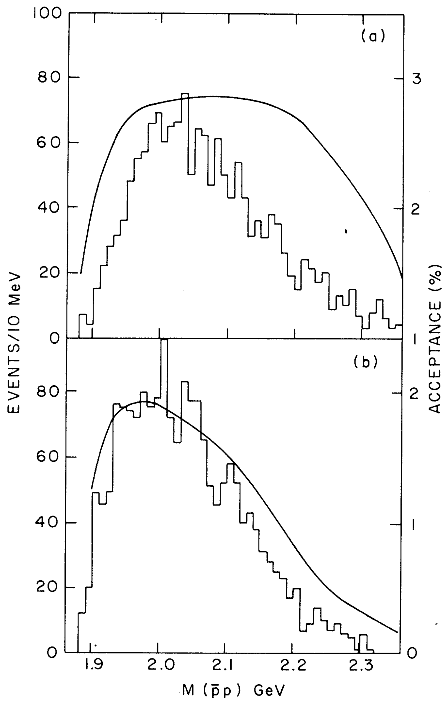

FIG. 3. $M(\bar{p}p)$ for (a) $\bar{p}p\pi^0$ events and for (b) $\bar{p}p\rho^0$ events. The solid curves are the estimates of our acceptance.

ated with the $\bar{p}p$ system having e^{3u} distributions (but isotropic in other variables). The effective-mass resolution (rms) is less than 5 MeV/c^2 near threshold and less than 15 MeV/c^2 near 2.2 GeV/c^2. It is seen that at the $\bar{p}p$ mass of 2.0 GeV/c^2 the acceptances are ~2.5% for π^0 events and ~2.0% for ρ^0 events, so that the visible sensitivities are ~160 and ~130 eV/μb, respectively. Therefore, at this mass the 2-standard-deviation (2σ) upper limits with 20-MeV/c^2 bins are ~0.12 μb for π^0 events and ~0.21 μb for ρ^0 events.[9] Table I lists 2σ upper limits (95% confidence level) for several $\bar{p}p$ masses with width ≤ 20 MeV/c^2.

In summary, we have searched for narrow $\bar{p}p$ states in Reaction (1), for X^0 in the π^0 or ρ^0 regions, with negative results. This reaction allows one to reach positive values of u and to observe production of $\bar{p}p$ states with low beam momentum. Given the cross sections quoted in the paper of Benkheiri *et al.*[3] for $\bar{p}p$ states at 2.02 and 2.2 GeV/c^2, we should have observed them with cross sections of ~1 μb. Instead, we find that 2σ upper limits are ≤ 0.12 μb for $\bar{p}p\pi^0$ and ≤ 0.22 μb for $\bar{p}p\rho^0$ final states.

TABLE I. Cross-section upper limits (95% confidence level) for narrow $\bar{p}p$ states ($\Gamma \lesssim 20$ MeV/c^2).

$M(\bar{p}p)$ (GeV/c^2)	$\bar{p}p(\pi^0)$ (μb)	$\bar{p}p(\rho^0)$ (μb)
1.9	0.07	0.20
2.0	0.12	0.21
2.1	0.10	0.22
2.2	0.07	0.22

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[6]To obtain this factor of 3.2 we compared $|u|_{\min}$ for reaction $\pi^- p \to \Delta^0(1236)\,\bar{p}p$ to that of reaction $\bar{p}p \to \bar{p}p\pi^0$ at 12 GeV/c assuming e^{3u}.

[7]Our missing-mass resolution is not sufficient for distinguishing ρ^0 from ω. The third peak at 1 GeV/c^2 could be due to η' or δ, or a reflection of Λ ($\bar{\Lambda}$) recoiling off $K^+\bar{p}$ ($K^- p$).

[8]We have chosen π^0 and ρ^0 events in this paper because they have better signal-to-background ratio than other $\bar{p}pX^0$ events. In any case, no narrow $\bar{p}p$ structures are seen with X^0 outside the π^0 and ρ^0 regions.

[9]There is an excess of $\lesssim 20$ events in a 10-MeV/c^2 bin at 2.01 GeV/c^2 for ρ^0 events [see Fig. 3(b)] corresponding to a cross section of $\lesssim 0.15$ μb, seven times smaller than the expected cross section of ~1 μb. In any event, the excess of $\lesssim 20$ events represents a 2σ effect, well within the statistical fluctuations.