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Search for narrow structures in $p\bar{p}\pi^+$ and $\Lambda\bar{p}\pi^\pm$ systems

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We have performed a high-statistics search for narrow meson states ($\Gamma \leq 30$ MeV) produced in $\pi^- p$ interactions at 16 GeV/c and decaying into $p\bar{p}\pi^+$ or $\Lambda\bar{p}\pi^\pm$. This is the first systematic search in channels requiring exchange of exotic mesons. The cross section for production of such states is ruled out at the 95% confidence level with upper limits ranging from ~ 10 nb at 2.3 GeV to ~ 40 nb at 2.8 GeV.

Recent experimental searches for narrow baryonium or baryon-antibaryon ($B\bar{B}$) states[1–5] have failed to confirm previous claims for the existence of such states.[5–7] It is now apparent that, if four-quark ($qq\bar{q}\bar{q}$) states coupling to $B\bar{B}$ exist and are produced at moderate cross sections via meson or baryon exchange processes, they are likely to be broad with $\Gamma \geq 150$ MeV.[8] For such $B\bar{B}$ states one can plausibly assume that the diquark (antidiquark) system within the resonance is in a color antitriplet (triplet) state, leading to rapid decay into $B\bar{B}$ channels via a $q\bar{q}$ pair creation. How then can one find a more exotic and possibly narrow four-quark state with the diquark in a color-sextet state? It was pointed out by Chan[9] and Jaffe[10] that likely channels for production of such multiquark states are, in fact, those in which only exotic exchanges are allowed.

We present in this paper results of a search for narrow baryonium states in exotic-exchange channels

$$\pi^- p \rightarrow (p\bar{p}\pi^+)_f X^- \tag{1}$$

and

$$\pi^- p \rightarrow (\Lambda\bar{p}\pi^+)_f X^0 \ , \tag{2}$$

where the subscript f denotes a system produced forward along the beam. Note that production of the forward system in reaction (1) [(2)] requires an $I=2$ [$I=\frac{3}{2}$] exotic-meson exchange. We present in addition results of a search for a manifestly exotic system, an $I=\frac{3}{2}$ strange meson, in

$$\pi^- p \rightarrow (\Lambda\bar{p}\pi^-)_f X^{++} \ . \tag{3}$$

Data for this study come from an experiment performed at the BNL Multiparticle Spectrometer (MPS) with a π^- beam at 16 GeV/c impinging on a 60-cm-long liquid-hydrogen target. The trigger required a fast forward proton, identified on line, and a multiplicity of three or more tracks around the target (see Ref. 1 for a schematic layout of our experiment). The present statistics correspond to a total integrated beam flux of 62 nb^{-1}, obtained from a sample of 2.7×10^6 proton-trigger events.

The off-line selection process for reactions (1), (2), and (3) required the presence of a negative track with momentum greater than 3 GeV/c identified as a nonpion by a Čerenkov counter. In addition, for reactions (2) and (3), we have required identification of a V^0, satisfying the Λ hypothesis. In order to purify further our data sample, we have made additional cuts on the data. The uncut events of reaction (1) contain a background from low-momentum recoil protons which have been incorrectly designated as π^+'s. Therefore, we have required that $-t > 0.6$ (GeV/c)^2. In addition, we have required that $0.9 < M^2(X^-) < 3.1$ GeV^2; the lower limit reflects the minimum possible mass for X^- (threshold for $\pi^- n$), and the upper limit results from our view that the events in which the $p\bar{p}\pi^+$ system is produced peripherally are likely to have relatively low $M^2(X^-)$. Similarly, since the systems X^0 and X^{++} in reactions (2) and (3) should contain at least a kaon and a nucleon, we have made two selections on the data based on the following missing-mass squares: MM^2(off $\Lambda\bar{p}$) > 1.5 GeV^2 and MM^2(off $\Lambda\bar{p}\pi^\pm$) > 1.5 GeV^2. We emphasize that the fast forward proton in all the reactions has been uniquely identified by two Čerenkov counters. The background events from misidentification of the remaining tracks are likely to be small. In any case, the background events merely reduce the effective sensitivity of the upper limits we quote in this paper and cannot mask the presence of any narrow structures in our data.

We show in Fig. 1 the t' ($= t_{\max} - t$) distributions for reactions (1), (2), and (3), where t is the square of the four-momentum transfer from the beam to the forward system. The shaded histogram in Fig. 1(a) corresponds to the events with $M(p\bar{p}\pi^+) < 2.3$ GeV, a region likely to be richer with the peripheral processes. The effect of our finite experimental acceptance on the observed t' distributions has been determined from Monte Carlo events. We see that the experimental t' distributions fall off faster than the acceptance indicated by the dashed curves in the figure, showing a clear peripheral behavior consistent with the presence of exotic-meson exchanges in reactions (1) and (2).

We display in Fig. 2 the distributions in $M(p\bar{p}\pi^+)$ and $M(\Lambda\bar{p}\pi^\pm)$, where the t' is restricted to be less than 0.6 (GeV/c)^2 for reaction (1) and less than 1.0 (GeV/c)^2 for reactions (2) and (3). No significant

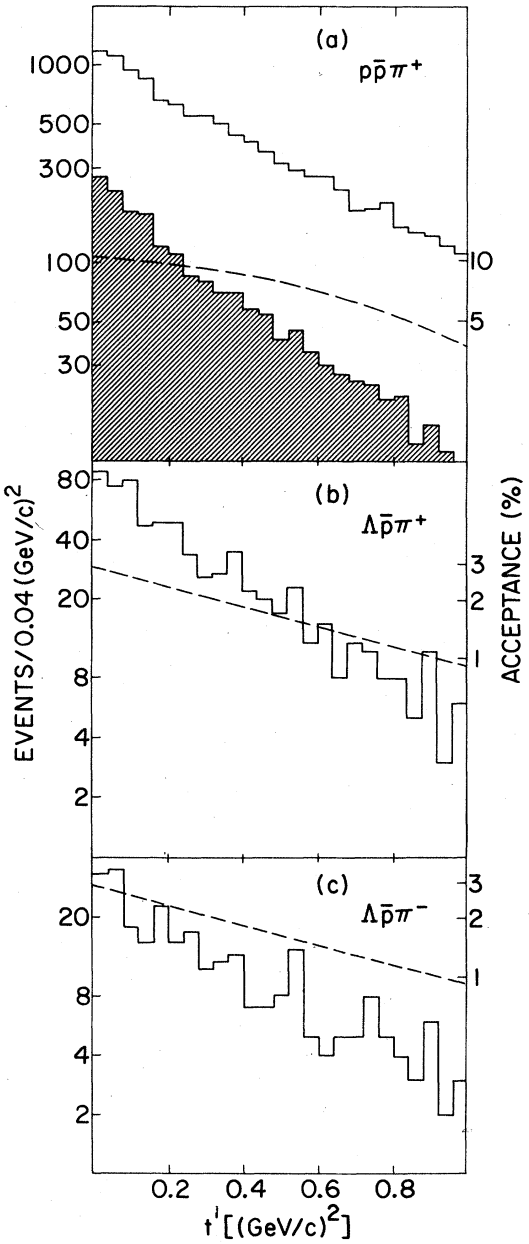

FIG. 1. t' distributions for $p\bar{p}\pi^+$, $\Lambda\bar{p}\pi^+$, and $\Lambda\bar{p}\pi^-$ systems. The dashed curves indicate our estimate of the acceptance as a function of t'. The shaded histogram in (a) corresponds to the events with $M(p\bar{p}\pi^+) < 2.3$ GeV.

narrow structure with $\Gamma \lesssim 30$ MeV is seen in any of the mass spectra. The rms mass resolutions range from 8 MeV at threshold to about 15 MeV at 2.8 GeV for all three reactions. The dotted curves are our estimate of the experimental mass acceptance from Monte Carlo events generated with an e^{5t} production distribution for the forward systems and with isotropic distributions for the decay angles. We esti-

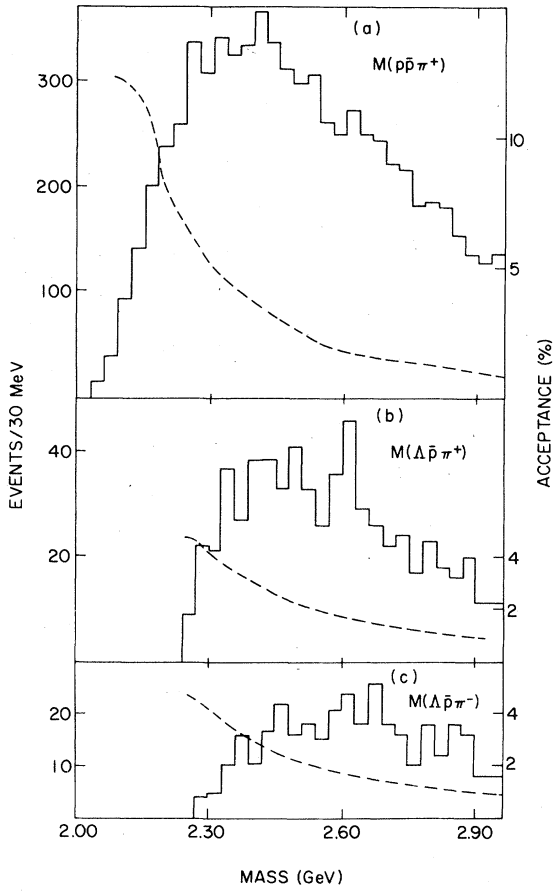

FIG. 2. Mass spectra for $p\bar{p}\pi^+$, $\Lambda\bar{p}\pi^+$, and $\Lambda\bar{p}\pi^-$ systems. See text for the cuts applied on these data. The dashed curves indicate our overall acceptance as a function of the effective mass.

mate that the visible sensitivities are 1.5 events/nb for $M(p\bar{p}\pi^+)$ at 2.5 GeV and 0.5 events/nb for $M(\Lambda\bar{p}\pi^\pm)$ at the same mass. We show in Fig. 3 the 2σ upper limits (95% confidence level) for production of a narrow object with $\Gamma \leq 30$ MeV. In particular, the upper limits for a state at ~ 2.5 GeV are seen to be less than 20 nb for all three reactions.[11]

In summary, we have searched for narrow structures in the $p\bar{p}\pi^+$ and $\Lambda\bar{p}\pi^+$ systems in the region of production where exotic-meson exchanges are likely to dominate, and also in an explicitly exotic system $\Lambda\bar{p}\pi^-$. The 95% upper limits for structures with $\Gamma \leq 30$ MeV are generally much less than 20 nb for

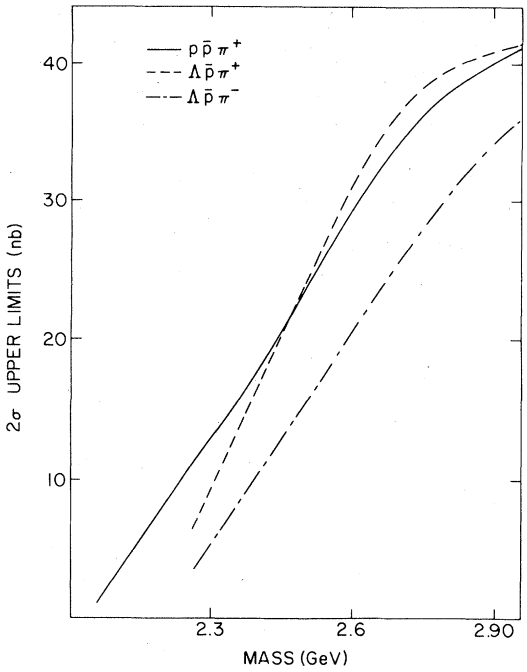

FIG. 3. 2σ upper limits (95% confidence level) for a state with $\Gamma < 30$ MeV decaying into the $p\bar{p}\pi^+$, $\Lambda\bar{p}\pi^+$, and $\Lambda\bar{p}\pi^-$ systems.

masses up to 2.5 GeV.

With the introduction of the color degree of freedom in quarks, an exciting possibility emerged for color-exotic multiquark states. However, these states do not seem to couple readily to nucleons, making it difficult to observe in conventional production channels. Our paper represents the first systematic attempt to look for such states in the exotic-meson *exchange* channels. We conclude that, if such states exist at all, their observation in the channels studied here would require an experiment sensitive to a cross section of perhaps a few nanobarns.

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