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Sensitive Search for μ-Channel Production of New Meson Resonances in Exclusive Final States from 11.46-GeV/c π^+p Interactions

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A search has been performed for new meson resonances produced in a 208-event/μb π^+p experiment at 11.46 GeV/c utilizing the Stanford Linear Accelerator Center hybrid facility triggered on a fast forward proton. In the final states $p3\pi$, $pK\bar{K}\pi$, and $pp\bar{p}\pi$ no significant new structures are observed in either the charged- or neutral-meson system. Upper limits for the production and decay of meson resonances with widths less than 30 MeV and masses less than 3 GeV/c^2 are in the range 75–200 nb.

In this report we present the results of a search for new meson resonances produced by baryon exchange in a 208-event/μb sample of 11.46 GeV/c π^+p interactions. These baryon exchange reactions are part of a larger experiment which utilized the Stanford Linear Accelerator Center (SLAC) hybrid facility triggered on a forward K^+, K^-, proton or antiproton.

Meson production by baryon exchange processes has been a subject of interest for many years, particularly because of the predictions of states coupling mainly to $N\bar{N}$ channels. Such states were first proposed in connection with dual models[1] and more recently in quark models under the general name of baryonium.[2] These states in general are predicted to have narrow widths (< 30 MeV) and to decay into channels involving an $N\bar{N}$ pair. There have been several experiments from which results on u-channel reactions[3] have been published and in some cases narrow peaks have been observed.[4] Such states have not been unambiguously confirmed and overall their existence remains in doubt.

The results presented here come from an experiment conducted in the SLAC hybrid facility, a schematic of which is shown in Fig. 1(a). This apparatus is ideal for such a study in that the meson decay products are observed with an angular acceptance of 4π in the bubble chamber. Another advantage over a conventional bubble chamber is the improvement in resolution obtained by utilizing the proportional wire chamber (PWC) information and fringe field to supplement the bubble-chamber measurements of the fast forward

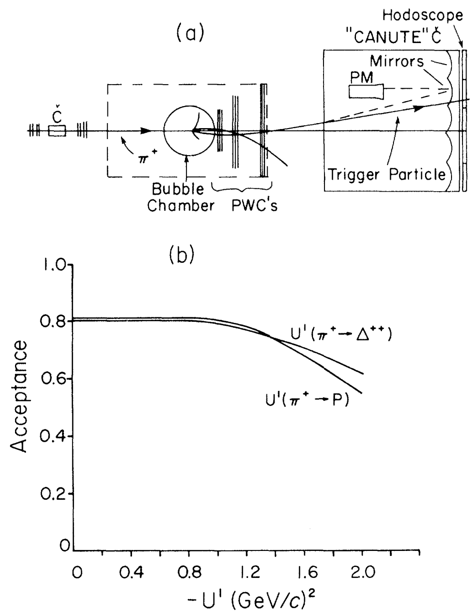

FIG. 1. (a) Schematic layout of the SLAC hybrid facility. (b) Acceptance of the apparatus for the reaction $\pi^+p \to p_F\pi^+\pi^-\pi^+$.

proton.

The incident beam was unseparated and positive pions were selected with use of a Čerenkov counter. The central detector was the 40-in hydrogen bubble chamber cycling at a rate of up to 12 cycles per second. A fast trigger of the system was initiated when an incident pion interacted producing a secondary particle which passed through the downstream system with a light signal in the high-pressure Čerenkov counter consistent with it being a K^+,K^-, proton, or antiproton. The Čerenkov detector had a pion threshold of 2.5 GeV/c and ten separate mirrors, each with its own hodoscope element. More than one secondary particle was allowed to pass through the downstream system. The fast trigger initiated the readout of all the PWC planes and Čerenkov information into an on-line computer. The computer was then used in the time available during bubble growth to analyze the information in order to decide whether to take a picture. As part of this analysis a crude vertex position was determined to ensure the interaction occurred in the hydrogen. In addition, all secondary tracks which passed through the downstream system were reconstructed utilizing the fringe field of the bubble chamber for momentum determination. A picture was taken if one of these particles had a momentum > 4.5 GeV/c and passed through, but did not produce light in the Čerenkov counter. A total of 1.2×10^6 pictures were taken, corresponding to 208 events/μb for 100% acceptance. All four-prong events on these pictures were then digitized on POLLY measuring machines and reconstructed with use of TVGP and SQUAW with the upstream and downstream PWC information being used to improve resolution. This sample of four-prong events is predominantly composed of t-channel meson production with a forward K^+ or K^-.

In order to study u-channel meson production we are forced to use events with constrained fits since we do not have an unambiguous particle identification with one Čerenkov. In particular, we have analyzed the following reactions:

$$\pi^+p \to p_F\pi_1^+\pi_2^+\pi^- \quad \text{(2352 events)}, \tag{1}$$

$$\pi^+p \to p_FK^+K^-\pi^+ \quad \text{(895 events)}, \tag{2}$$

$$\pi^+p \to p_F\bar{p}p_2\pi^+ \quad \text{(2502 events)}, \tag{3}$$

where the subscript F indicates a proton with momentum > 5 GeV/c which was required to be the trigger particle. These four constraint reactions are particularly clean and easy to select. Reaction 3 is the most difficult to analyze since with two protons in the final state the separation between the t channel and u channels is not complete. For example, a fast forward proton can be produced as a result of the π^+ peripherally producing a $p\bar{p}$ pair. These reactions contain not only the production of a fast forward proton at the pion vertex, but, in addition fast forward $\Delta^{++}(1238)$ production. Both of these processes show a characteristic peaking at low u', where u' is the four-momentum transfer squared from the beam pion to the nucleon system measured relative to the minimum possible. These u' distributions when fitted to the form $Ae^{-bu'}$ yield values of b in the range 4–8. The geometrical acceptance of the apparatus is large and uniform at low u' as is shown in Fig. 1(b). The actual sample of $p3\pi$ events has an average acceptance of 79%. This acceptance is similar for both forward proton and forward Δ^{++} production and this permits a search for both charged- and neutral-meson production, i.e.,

$$\pi^+p \to pM^+, \tag{4}$$

$$\pi^+p \to \Delta^{++}M^0. \tag{5}$$

These mesons are produced through an $N\bar{N}$ coupling with the simplest exchanges expected to be proton or $\Delta(1238)$ and are, therefore, ideal channels to look for baryonium. The $p\pi^+$ mass spec-

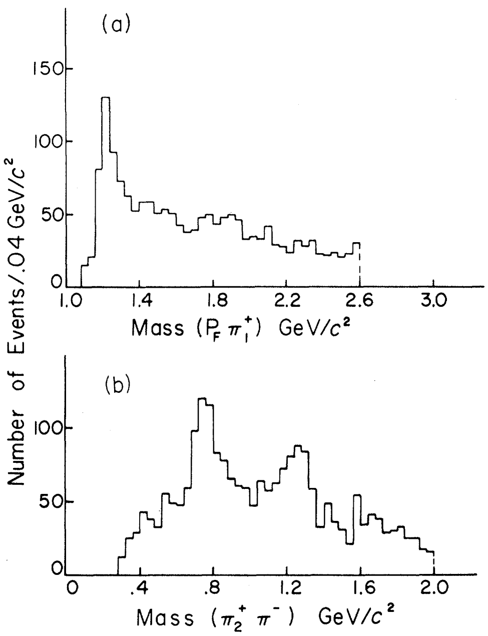

FIG. 2. (a) Effective-mass distribution of the $p_F\pi_1^+$ system from Reaction 1; (b) effective-mass distribution of the $\pi_2^+\pi^-$ system from Reaction 1.

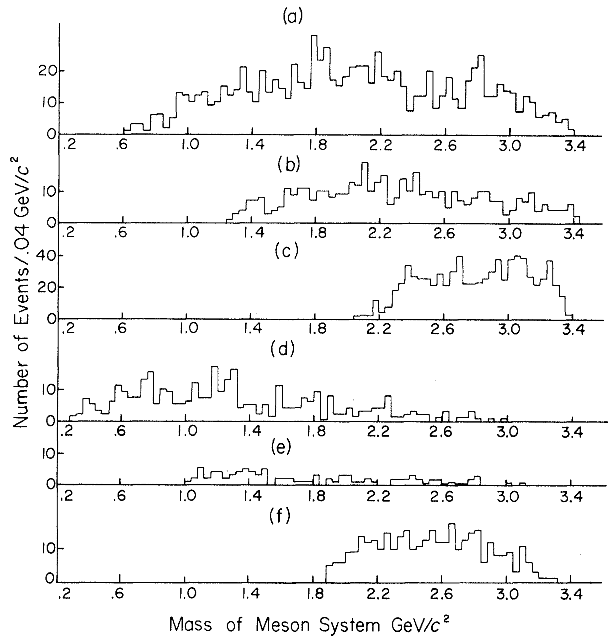

FIG. 3. Effective-mass distributions for M^+ and M^0 with $-u' < 0.5$ GeV/c^2 for (a) $\pi^+\pi^+\pi^-$ from Reaction 1 with $M(p_F\pi_1^+) > 1.4$ GeV/c^2; (b) $K^+K^-\pi^+$ from Reaction 2 with $M(p_F\pi^+) > 1.4$ GeV/c^2; (c) $p_2\bar{p}\pi^+$ from Reaction 3 with $M(p_F\pi^+) > 1.4$ GeV/c^2; (d) $\pi_2^+\pi^-$ from Reaction 1 with $M(p_F\pi_1^+) < 1.4$ GeV/c^2; (e) K^+K^- from Reaction 2 with $M(p_F\pi^+) < 1.4$ GeV/c^2; and (f) $\bar{p}p$ from Reaction 3 with $M(p_F\pi^+) < 1.4$ GeV/c^2.

trum for Reaction 1 is shown in Fig. 2(a) to illustrate the magnitude of Δ^{++} production. A similar spectrum is found in other reactions. We also observe resonance production in other two-particle spectra, for example, strong ρ and f production in the $\pi_2^+\pi^-$ system, (where the subscript 2 indicates the slower π^+), in Reaction 1, which is shown in Fig. 2(b). We have examined the M^+ and M^0 systems in the three reactions, making various cuts on, for example, u' and well-known resonances, such as ρ, f, and $K^*(890)$. In none of the spectra do we observe any significant new enhancement. Some typical mass distributions are shown in Fig. 3, where we have demanded that the u' to the nucleon system be <0.5 and for Reaction 4 we have excluded the Δ^{++}, and for the Reaction 5 we have selected the Δ^{++}, defined as $Mp\pi^+ < 1.4$ GeV. With these data corrected for acceptance and kinematical cuts we have determined upper limits at the 4-standard-deviation level for a $\sigma\times$(branching ratio). For the mass range <3 GeV/c^2 these upper limits are 175 (3π), 100 ($K\bar{K}\pi$), 200 ($p\bar{p}\pi$), 100 ($\pi\pi$), 75 ($K\bar{K}$), and 150 nb ($\bar{p}p$) for resonances with widths $\Gamma < 30$ MeV. Our experimental mass resolution in these systems varies with a σ between 13–17 MeV. For a resonance with a $\Gamma \sim 100$ MeV these limits would be 2.5 times larger. These results are similar to those obtained in an experiment searching for charge-2 mesons from π^-d interactions.[5] Our results do not conflict with the observation[4] by Benkheiri *et al.*,[4] of possible narrow states at 2.02 and 2.204 GeV in the $\bar{p}p$ system in an Omega Spectrometer experiment, because the production cross sections they observed were <50 nb. Claims of narrow enhancements with larger cross sections have been in either different reactions or at different energies and, therefore, cannot be compared directly.

In summary, we have set limits for new meson production with widths <30 MeV and masses <3 GeV/c^2 of 75–200 nb for three particular u-channel reactions in an experiment of 208-events/μb sensitivity. These limits apply to meson production by both $I=\frac{1}{2}$ and $\frac{3}{2}$ baryon exchange and for mesons with $I=1$ or 2 (Reaction 4) and $I=0$ or 1 (Reaction 5).

We would like to thank the staff of the Stanford Linear Accelerator Center who were instrumental in the construction and operation of the hybrid facility. We would also like to thank the person-

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Observation of Missing Energy Associated with $\mu^+\mu^-$ Produced in p-Fe Interactions

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In a study of interactions of 400-GeV protons in an iron calorimeter, we have observed $\mu^+\mu^-$ pairs associated with a significant amount of missing energy indicative of final-state neutrinos. This missing energy is not due to any instrumental effects, nor to any trivial sources like double $K\bar{K}$ (or $\pi\pi$) decay. Interpretation of these data as production of a $D\bar{D}$ pair followed by a double muonic decay leads to a model-dependent estimate of a total production cross section of the order of 7–20 μb.

Previously,[1] we have presented evidence for the production of prompt *single* muons in 400-GeV proton-iron interactions. A natural explanation of this phenomenon is the production and subsequent semileptonic decay of a short-lived heavy hadron, the most likely candidate being a charmed particle (e.g., $p + \mathrm{Fe} \to D + \bar{D} + \ldots$). That mechanism would also produce 2μ events from semileptonic decay of both hadrons which would be associated with missing energy due to the undetected companion neutrinos. In this Letter, we present evidence for the observation of such missing energy in association with hadronically produced $\mu^+\mu^-$ pairs, and relate it to the rate for our observed single-muon signal.[1]

The experimental apparatus has been described previously.[1-3] A 400-GeV proton beam was directed at an iron-scintillator calorimeter that served as target and "live beam dump," and which measured the total hadronic and electromagnetic energy of each interaction. The calorimeter, studied extensively with an unbiased sample of proton interactions,[2] gave a linear response over a range of 30 to 450 GeV, with a resolution of $\sigma/E = [(0.49\ \mathrm{GeV})/E]^{1/2}$. For the unbiased proton interactions, at the level of 1 part in 10^4 there was no low-energy tail (i.e., missing energy) beyond that of a normal Gaussian distribution. There was some rate-dependent high-energy tail due to pileup.[2]

The trigger for the 2μ data reported here preferentially selected hadronic interactions producing a μ^+ with $p_t \geqslant 0.75$ GeV/c. The cuts imposed on the hadronic shower and on the quality of the incident proton track were identical to those in Ref. 2, thus allowing a direct comparison

