Brief Reports

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Search for $\mu^{\mp}\pi^{\pm}$ mass enhancements in neutrino- and antineutrino-deuterium charged-current interactions

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A search for $\mu\pi$ mass enhancements was made using the CERN bubble chamber BEBC, filled with deuterium, exposed to wide-band neutrino and antineutrino beams. From a sample of 15 275 neutrino and 11 100 antineutrino charged-current events, no significant $\mu\pi$ mass enhancement is observed. Upper limits are quoted.

An indication for an enhancement near 430 MeV in the $\mu^{\pm}\pi^{\mp}$ mass spectra was reported by Ramm[1] in charged-current neutrino and antineutrino interactions with nucleons and in K_L^0 decay. The neutrino and antineutrino interactions were observed in two heavy-liquid (propane and freon) bubble-chamber experiments at the CERN Proton Synchrotron.

In a recent paper Ballagh *et al.*[2] reported a search for $\mu^{\pm}\pi^{\mp}$ mass enhancements in neutrino and antineutrino interactions in the 15-ft Fermilab heavy-liquid (neon-hydrogen mixture) bubble chamber, exposed to wide-band beams. The analysis was performed using 8444 neutrino and 1367 antineutrino events. A structure near 430 MeV was observed (at the same mass of the enhancement reported by Ramm) but, with the experimental resolution taken into account, its significance is only about 1 standard deviation. Therefore, the authors believed that the enhancement found in their data is compatible with a statistical fluctuation. No other enhancement was observed in the $\mu\pi$ mass spectra.

In this Brief Report, we present a search for mass enhancements in the muon-pion mass spectra in neutrino and antineutrino charged-current interactions with deuterium. A structure in the $\mu\pi$ mass spectrum could be due to the decay of a short-lived massive neutral lepton.[3] In order to be observed in a bubble-chamber experiment, the neutral heavy leptons should be produced in neutrino interactions, and should subsequently decay in the semileptonic channel $\mu\pi$. If the neutral-heavy-lepton mean life is smaller than about 10^{-12} sec, such events do not differ topologically from usual charged-current events.

The data were obtained in an experiment performed at the CERN SPS, exposing the Big European Bubble Chamber (BEBC), filled with deuterium, to wide-band neutrino beams produced by 400-GeV protons. Details of the experiment are given in Ref. 4. We recall only that (i) because of the selection criteria used to identify charged-current events, all muons which enter in the mass combinations have a momentum greater than 4 GeV/c, and (ii) almost all charged kaons and all protons with a momentum greater than 1.0 GeV/c are labeled as pions.

In the present analysis 15 275 neutrino and 11 100 antineutrino charged-current (CC) events were used. The $\mu\pi$ invariant-mass distributions were analyzed using only those mass combinations for which both the muon and the pion had a fractional momentum error $\Delta p/p$ smaller than 5%. The number of mass combinations which survive these cuts decreases with increasing $\mu\pi$ mass. For instance, for the

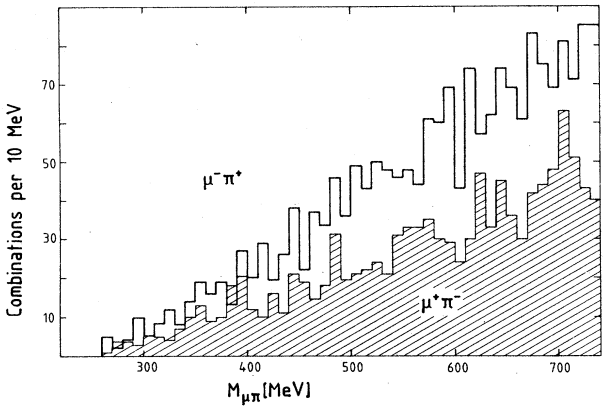

FIG. 1. Invariant-mass distributions for $\mu^+\pi^-$ and $\mu^-\pi^+$ in 10-MeV bins.

$\mu^+\pi^-$ system, the survival rate is 86% at a mass of 0.43 GeV, 80% at 2.0 GeV, and approximately 60% around 6.0 GeV. The overall passing rate is 80 (75)% of the $\mu^+\pi^-$ ($\mu^-\pi^+$) combinations.

The errors on the $\mu\pi$ invariant mass were computed starting from the errors on the measured tracks. Then, the mass resolution as a function of the $\mu\pi$ mass was computed: the resolution [full width at half maximum (FWHM)] is 10 MeV at a mass of 0.43 GeV, 30 MeV at a mass around 2.0 GeV, and approximately 100 MeV at a mass around 4.0 GeV.

The mass scale and the mass resolution have been checked using vees (K_S^0 and Λ). The masses of K_S^0 and Λ determined from the unconstrained effective-mass distributions of the $\pi^+\pi^-$ and $p\pi^-$ pairs are 497.2 ± 0.7 MeV and 1115.9 ± 0.3 MeV, respectively. The mass resolution (FWHM) for the $\pi^+\pi^-$ system computed as mentioned above at a mass around 500 MeV is 9 MeV, which is in good agreement with the experimental resolution determined from K_S^0 decays.[5]

The experimental $\mu\pi$ invariant-mass distributions are shown in Figs. 1 and 2 in 10- and 50-MeV bins, respectively. No significant $\mu\pi$ mass enhancement is visible.

If a neutral heavy lepton is produced and decays into the $\mu\pi$ channel, a fast pion with a relatively large transverse momentum should be observed. In order to reduce the background, cuts on the pion momentum and on the pion transverse momentum have been applied. The new mass spectra (not shown) do not show significant enhancements.

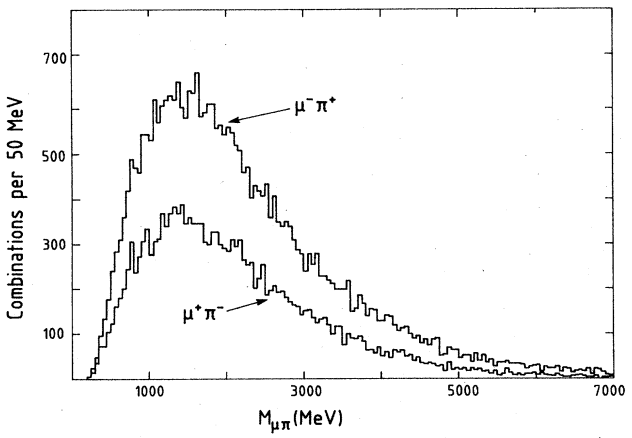

FIG. 2. Invariant-mass distributions for $\mu^+\pi^-$ and $\mu^-\pi^+$ in 50-MeV bins.

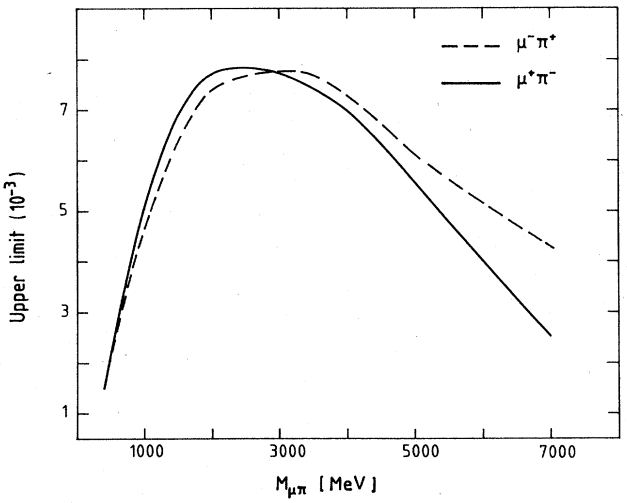

FIG. 3. Upper limits per CC event, at a level of 3 standard deviations, for narrow $\mu^+\pi^-$ and $\mu^-\pi^+$ enhancements as a function of the $\mu\pi$ invariant mass.

Even if no enhancements are directly visible in the $\mu\pi$ mass spectra, we analyzed with special care the mass region around 0.43 GeV and also around 1.6–1.8 and 1.9 GeV.[6] In particular, we analyzed the behavior of the momentum p, of the transverse momentum p_t, and of the polar and azimuthal angles of the pion with respect to the $\mu\pi$ system for the above-mentioned mass regions and for neighboring mass regions. No differences are present between the behavior of these quantities for the chosen $\mu\pi$ mass regions and the behavior of the same quantities for neighboring masses.

In order to estimate upper limits for possible $\mu\pi$ enhancements, we proceeded in the following way.[2] At a given value m of the $\mu\pi$ mass, the data were rebinned in a bin k, with a width equal to the mass resolution at that mass. Upper limits, at a level of a 3 standard deviations, were computed as $3\sqrt{2N_K}/(0.8\times N_{CC}\times F)$, where N_K is the number of mass combinations in the bin k, F takes account of losses in the mass combinations due to the cut in momentum error, N_{CC} is the number of CC events, and the 0.8 factor arises from the tails of the assumed Gaussian peaks. Figure 3 shows our experimental upper limits per CC event for narrow $\mu^+\pi^-$ and $\mu^-\pi^+$ enhancements as a function of the mass. The upper limits vary from 8.0×10^{-3} to 1.5×10^{-3} as a function of the $\mu\pi$ mass: at 0.43 GeV they are 1.5×10^{-3} for both $\mu^+\pi^-$ and $\mu^-\pi^+$ masses.

In conclusion, we found no evidence for narrow enhancements in the $\mu\pi$ invariant-mass spectra in the 0.3–7-GeV mass region. The 3-standard-deviation upper limits are shown in Fig. 3. Because of our larger statistics and better mass resolutions, our upper limits are about an order of magnitude better than those obtained in previous experiments.

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[1]C. A. Ramm, Phys. Rev. D **26**, 27 (1982).
[2]H. C. Ballagh *et al.*, Phys. Rev. D **29**, 1300 (1984).
[3]See, for instance, C. N. Leung and J. L. Rosner, Phys. Rev. D **28**, 2205 (1983), and references therein.
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