Measurement of Neutral-Meson Production in $\pi^- p \to \pi^- pX^0$ at 13.4 GeV/c

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We have measured, by the missing-mass technique, spectra of the neutral-meson system X^0 produced in $\pi^- p \to \pi^- pX^0$ at 13.4 GeV/c. The π^0, ρ^0, and ω^0 appear as well as a broad enhancement at 450 MeV and a narrow peak at 1280 MeV which is interpreted as the D^0. Most of the π^0 signal and the events around 450 MeV are correlated with N^{*+} production. The ρ^0 peak results primarily from A_1^--A_2^- decays. We find, however, that the ω^0 and D^0 are largely uncorrelated with N^{*+} or X^- resonances.

Spectroscopy of heavy mesons has received considerable attention over the past several years.[1] Numerous peaks, both narrow and broad, have been reported, but no coherent picture has emerged concerning their production, decay, quantum numbers, or systematics. This work was designed to measure the neutral-meson spectrum in the reaction $\pi^- p \to \pi^- pX^0$ in a kinematical region where decays from narrow high-spin, charged mesons ($X^- \to \pi^- X^0$) may be expected to appear.

The experiment, some aspects of which have been described previously,[2,3] was performed at Brookhaven National Laboratory. Beam pions having an average momentum of 13.4 GeV/c interacted with protons in a 61-cm-long liquid-hydrogen target. Three threshold Cherenkov counters distinguished these pions from the small (1.3%) fraction of beam kaons and antiprotons. The coordinates and the momentum of the beam were measured with three scintillator hodoscopes. The identities and momenta of the detected pions and protons were determined with the spectrometer system shown in Fig. 1.

Recoil protons were detected with a rotatable spectrometer consisting of four wire spark chambers and five vertically stacked scintillator modules. Each module contained a thin scintillator for measuring dE/dX and time of flight, a 29-cm-deep scintillator for determining the energy of stopping protons, and an anti-counter for rejecting particles which penetrated a module but did not stop in it. About 1% of the accepted events had a pion misidentified as a recoil proton after dE/dx, and time-of-flight measurements were required to be consistent with the values predicted from the measured energy. These events introduced no spurious structure in the X^0 spectrum. The spectrometer accepted protons with kinetic energies from 55 to 225 MeV, corresponding to a proton momentum transfer interval $0.10 < |t_{pp}| < 0.42$ (GeV/c)^2.

Pions scattered into the forward direction were detected with a spectrometer consisting of eight wire spark chambers and a magnet. These pions were identified with a threshold Cherenkov counter placed inside the magnet. The minimum momentum accepted by the spectrometer was 2.5 GeV/c and the pion scattering angles were limited to the region from 15 to 100 mrad. The momentum transfer from the beam to the scattered pion was confined therefore to the interval $0.04 < |t_{\pi\pi}| < 1.8$ (GeV/c)^2.

The trigger required the coincident detection of a beam pion, recoil proton, and scattered pion. The accidental trigger rate varied from 1.5 to 4.0%. Nearly all accidental events were rejected in the analysis by the requirement that the tracks of the detected particles meet at a vertex.

The resolution of the X^0 mass, discussed below, was dominated by the uncertainty in mea-

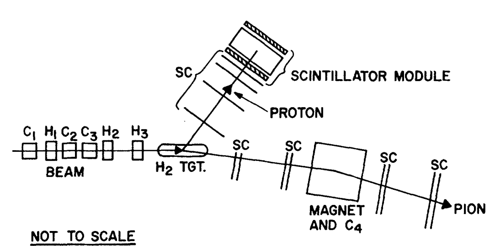

FIG. 1. Spectrometer system. C_1–C_4, threshold Cherenkov counters; H_1–H_3, beam hodoscopes. Spark chambers, denoted by SC. Beam magnets, trigger and veto counters, and scintillators that measure charge multiplicity, not shown.

surements of the momenta of the beam and scattered pions. The resolution of the beam momentum was 0.65% full width at half-maximum (FWHM). The fractional momentum resolution of the scattered pion was 1.8% (FWHM). Detailed information on resolution measurements is given elsewhere.[4]

At 13.4 GeV/c two sets of data were obtained, one with the proton spectrometer centered at 58° with respect to the beam, the other at 48°. The geometry and the field of the magnetic spectrometer remained constant. At 58°, 74 800 events passed all analysis requirements; approximately 18 000 of these being elastic-scattering events. At 48° the number of accepted events is 46 228 which are all inelastic.

Figure 2 displays the neutral-meson spectra for the two-proton spectrometer settings. These

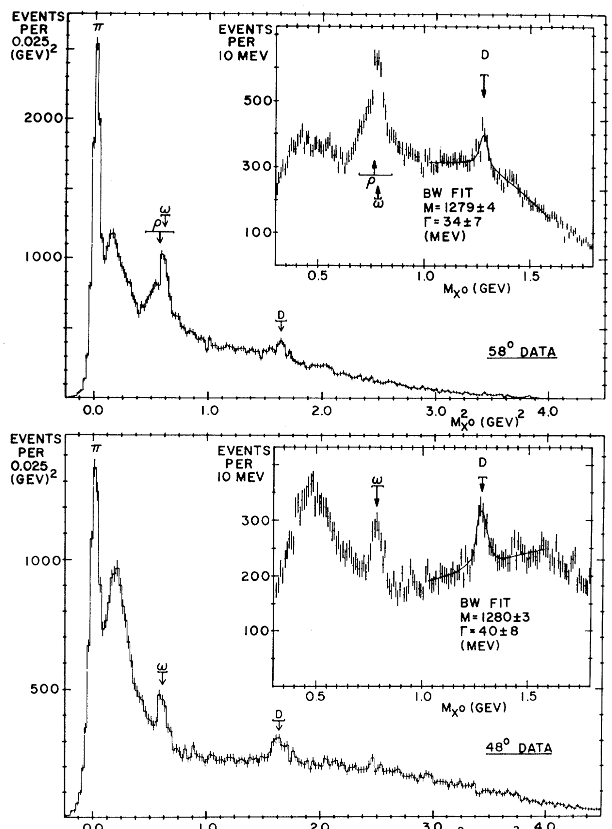

FIG. 2. Spectrum of X^0 in $\pi^- p \to \pi^- p X^0$. Data are shown for the two spectrometer settings, 58° and 48°. Mass plots (insets) are for the same data as the corresponding plots of X^0 mass squared. The fits of the peak at 1280 MeV are described in the text. Both fits have χ^2 probabilities larger than 40%. Bars above the arrows pointing to peaks in the spectra represent intrinsic widths folded with experimental resolution.

spectra have not been corrected for the limited geometric acceptance of the spectrometers. (Such a correction has been obtained by an approximate method.[4] The main effect of the correction is to flatten somewhat the background in the spectra without changing significantly their structure.) Elastic events, which are not of interest here, have been excluded from the 58° spectrum. As shown in Fig. 2, the 58° spectrum has a large π^0 signal, a broad enhancement at about 450 MeV, an asymmetric peak consistent with overlapping ρ^0 and ω^0 signals, and a narrow peak at 1280 MeV. The 48° spectrum shows the same structure except that little or no ρ^0 is present.

The X^0 mass resolution has been calculated from the uncertainty in the basic momentum and angle measurements and is in close agreement with the observed π^0 widths. The resolution is not a simple function of X^0 mass but depends strongly on the kinematic topology of the events. For this reason different mass resolutions are obtained in the two sets of data. For 58°, the average mass resolution at the ω^0 is 38 MeV (FWHM), and at the 1280 MeV peak, 27 MeV (FWHM). For the 48° data, these resolutions are 58 and 30 MeV, respectively. The ω^0 was fitted well in both spectra with a Gaussian curve having widths of 39 ± 5 MeV at 58° and 58 ± 8 MeV at 48°. These widths (FWHM) are in excellent agreement with the calculated resolution since the natural width of the ω^0 does not contribute appreciably to the measured width. The fitted ω^0 mass is 781 ± 2 MeV in the first spectrum and 786 ± 3 MeV in the second, which indicates that systematic errors in the mass scale are no larger than a few MeV. In these ω^0 fits, the ρ^0 was assumed to be present at 58° but absent in the 48° data. The resolution of X^- mass squared is equal to 0.11 GeV^2 (FWHM) and is nearly independent of X^- mass.

One of the surprising features of these spectra is the narrow peak at 1280 MeV. As shown in Fig. 2 a wide mass region about this peak is fitted well with a combination of a quadratic background and a nonrelativistic, S-wave, Breit-Wigner distribution broadened by the calculated resolution. The fits give a mass of 1280 ± 3 MeV and a natural width $\Gamma = 37 \pm 5$ MeV, where these numbers are statistically weighted averages from the fits to the two sets of data. Among the known mesons only the D^0 has parameters consistent with this measurement.[5] A bump of marginal statistical significance is seen in the 58° data at 1420 MeV,

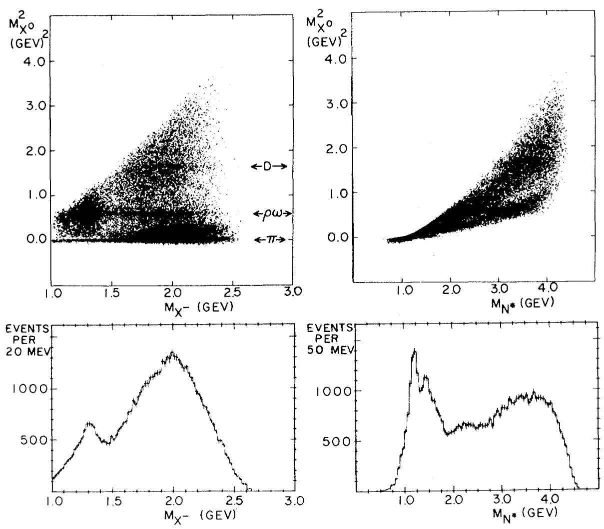

FIG. 3. Scatter plots with projections for the reaction $\pi^- p \to \pi^- p X^0$. Only shown are data for the proton spectrometer setting at 58°. $X^- = (\pi^- X^0)$; $N^* = (pX^0)$. Elastic events have been excluded. The geometric acceptance decreases rapidly at low and high X^- mass producing the broad triangular shape apparent in the X^- spectrum. The band of points along the lower right-hand corner of the plot of M_{N^*} versus $M_{X^0}{}^2$ results from $A_2{}^- \to \pi^- \rho^0$.

the mass of the E^0 meson. Copious production of f^0 and $A_2{}^0$ might be expected to occur at low momentum transfer between the beam pion and the neutral meson. This region of kinematics is excluded by our apparatus and hence the absence of large f^0 or $A_2{}^0$ signals is perhaps not surprising.

Figure 3 shows how structure in the X^0 spectrum is related to resonance production of the type $\pi^- p \to X^- p$ where $X^- \to \pi^- X^0$, and $\pi^- p \to \pi^- N^*$ where $N^* \to pX^0$. The π^0, ω^0, D^0, and the broad 450-MeV peak are distributed over extended regions of the X^- spectrum. (The region of X^- mass explored at 58° is $0.14 < M_{X^-} < 2.6$ GeV, while at 48° it is $1.5 < M_{X^-} < 3.0$ GeV.) These signals do not appear to originate from *narrow* X^- resonances decaying into $\pi^-\pi^0$, $\pi^-\omega^0$, or $\pi^- D^0$.[6] Events containing ρ^0 fall almost entirely into the X^- region from 1.0 to 1.4 GeV where a large peak is seen. This region includes the $A_1{}^-$ and $A_2{}^-$ whose dominant decay modes are $\pi\rho$. (The geometric acceptance decreases the A_1 signal in relation to the A_2.) The π^0 and the 450-MeV peak are limited to the N^* region below 1.8 GeV where copious N^* resonance production is seen. The prominent peaks in the N^* spectrum are primarily from $\Delta(1236)$ and $N^*(1470)$. The decay $N^* \to p\pi^0$ produces a π^0 signal, whereas $N^* \to p(\pi\pi)^0$ reflects into the X^0 spectrum from twice the pion mass to the mass difference between N^* and proton, thereby producing the broad, low-mass X^0 peak at 450 MeV. The ω^0 and D^0 do not appear to be correlated with N^* resonance production. The scatter plots at 48°, not shown here, are qualitatively similar to those at 48° except that the geometric acceptance excludes events with X^- mass below 1.5 GeV and allows the π^0, ω^0, and D^0 bands to extend to somewhat higher X^- mass.

Analysis of X^0 production, X^- mass spectra, and a detailed search for meson decays of the type $X^- \to \pi^- X^0$ at other beam energies are still in progress.

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[1]See, for example, *Meson Spectroscopy*, edited by C. Baltay and A. H. Rosenfeld (Benjamin, New York, 1968), and *ibid.* (Columbia Univ. Press, New York, 1970). In the 1970 volume the CERN Boson Spectrometer Group describes their apparatus for an investigation of the neutral meson spectrum (p. 557).

[2]D. Bowen *et al.*, Phys. Rev. Lett. 26, 1663 (1971).

[3]D. Bowen *et al.*, in *Phenomenology in Particle Physics*, edited by C. B. Chiu, G. C. Fox, and A. J. G. Hey (California Institute of Technology, Pasadena, Calif., 1971).

[4]R. Thun, Ph. D. thesis, State University of New York at Stony Brook, 1972 (unpublished).

[5]For a list of references on the D^0 meson see A. Rittenberg *et al.* (Particle Data Group), Rev. Mod. Phys. Suppl. 43, 1 (1971).

[6]Various cuts on N^* mass and on the momentum transfer between the different sets of detected particles have been made. No significant, *narrow* structure is seen in the X^- spectrum after any of these cuts. For further details see Ref. 4 where also the possible presence of *broad* ($\Gamma \geq 100$ MeV) X^- resonances, particularly $g^- \to \pi^-\pi^0$ and $\rho^-(1710) \to \pi^-\omega^0$, is discussed.