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Search for Neutral Mesons near 1 GeV/c^2

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In a study of the missing-mass spectrum near 1 GeV in the reaction $\pi^- + p \rightarrow \text{MM} + n$ at three incident momenta near 2 GeV, we find no evidence for the recently reported narrow neutral mesons at 940, 963, and 1033 MeV.

Evidence for the existence of three new narrow neutral mesons with masses of 940, 963, and 1033 MeV was recently presented in this journal.[1,2] The experiment, by a collaboration from Iowa State University, Argonne National Laboratory, and Purdue University (IAP) consisted of a study of the missing-mass spectrum for the reaction $\pi^- + p \rightarrow \text{MM} + n$ at an incident momentum of 2.4 GeV. The reported cross sections for the three new resonances were comparable to that of the well-established $\eta'(958)$. In earlier publications[3,4] we reported on our study of the missing-mass region near 1 GeV in the same reaction but at incident momenta close to threshold. We found no evidence for any of the new mesons; however, there remains the possibility that their cross sections near threshold could be small compared to that of the η'. As the existence of these mesons could have far-reaching implications for meson classification schemes, we performed a new experiment at the Rutherford Laboratory at incident momenta near 2 GeV in order to confirm or otherwise the findings of the IAP collaboration.

Our apparatus, which is very similar to that of the IAP experiment, is described in detail elsewhere.[3] An array of neutron counters situated near 0° in the laboratory a few meters downstream from a liquid-hydrogen target detects the recoil neutrons whose energy is measured by time of flight. Lead-scintillator sandwich counters surrounding the target are used to define final-state particle multiplicities and topologies for charged particles and γ rays. The only modifications to the experimental setup consisted in moving the neutron counter array from 6.15 to

TABLE I. Main features of this experiment (ICS) compared to the IAP one (Refs. 1 and 2). The reaction is $\pi^- + p \to \mathrm{MM} + n$.

	ICS	IAP
Incident momentum (GeV)	2	2.4
Neutron angle (deg)	1.4–6	1.0–5.3
$-t$ at η' mass (GeV^2)	0.08	0.05
Sensitivity[a]	80	4[b]
Solid angle for charged particles	3.95π	$\sim 4\pi$
Solid angle for γ rays	3.25π	1.2π
Azimuthal bins for charged particles	20 bins, 18° each	16 bins, 22.5° each
Azimuthal bins for γ rays	20 bins, 18° each	
Mass resolution at η' (FWHM) (MeV)	13.5	8.6

[a]Number of events predicted for $d\sigma/dt = 10\ \mu\mathrm{b/GeV}^2$.
[b]Private communication with Dr. R. C. Lamb.

7.15 m from the target and increasing the number of neutron counters from six to ten. In order to ensure that any observed enhancement in the missing-mass spectrum was not due to instrumental effects, we collected data at three central momenta near 2 GeV. For each central momentum setting, hodoscopes in the incident beam spectrometer determined five momentum bins, so that we covered the incident momentum range $1.93 \leq p_1 \leq 2.08$ GeV in fifteen partly overlapping bins each 0.77% wide, full width at half-maximum (FWHM). A particular missing-mass value is uniquely determined by a relation between p_1 and the neutron momentum p_4. Therefore any instrumental structure at fixed time of flight would appear at a different missing mass depending on p_1. The shift in the missing-mass value for fixed time of flight is 35 MeV between the two extreme p_1 values.

The new narrow neutral mesons reported in Refs. 1 and 2 were observed in final states with specific charged-particle multiplicities and topologies. The angular cuts applied by the above authors reflected the geometry of the counters surrounding the target and it was not possible to reproduce them exactly in our experiment. However, we can approximate their particle multiplicities and topologies sufficiently well so as to make a meaningful comparison. In Table I we summarize the most important features of the two experiments. As can be seen our experiment has 20 times the sensitivity of the IAP one, while our resolution in missing mass is somewhat larger. The γ detection system covers a larger solid angle in our experiment and the azimuthal information allows us to identify π^0 decays. Our incident momentum corresponds to a c.m. energy around 2160 MeV, compared to 2325 MeV for the IAP experiment. The difference between the two experiments in the four-momentum transfer squared t for a missing mass of 960 MeV is very small and in both cases we have $t \simeq t_{\min}$. The mass resolution of our apparatus at a mass of 960 MeV is 13.5 ± 2 MeV (FWHM) and is dominated by uncertainties in the momentum of the recoil neutron due to the length of the hydrogen target and neutron counters (29.4 and 30 cm, respectively) and the intrinsic timing of the neutron counters and associated electronics (2.0 nsec FWHM). The neutron counters were checked for the neutron energy of interest (~45 MeV) by observing η production at an incident momentum of 743 MeV. The resulting mass spectrum without any decay selections is shown in Fig. 1(a). We find a mass of $548.4 \pm (0.4, 1.0)$ MeV for the η, where the first error is statistical and the second systematic. The efficiency of the 30-cm-long counters, at a bias of 8 MeV (electron equivalent), was predicted[5] to be about 20%. Using this value we find the differential cross section for forward η production at 743 MeV to be 11 ± 2 mb/GeV^2, in agreement with other measurements.[6]

An important test of the sensitivity of our experiment is the observation of the η' meson. In Fig. 1(b) we show the missing-mass spectrum at an incident momentum of 2 GeV for events containing at least four γ rays. This selection is primarily sensitive to the decays $\eta' \to \pi^0 + \pi^0 + \eta$ and $\eta' \to \pi^+ + \pi^- + \eta$ ($\eta \to 3\pi^0$ or $\pi^0 + \gamma + \gamma$), and it was chosen by comparing Monte Carlo predictions of expected η' signals in various final decay configurations to the measured backgrounds in the same configurations. Our Monte Carlo simulation in-

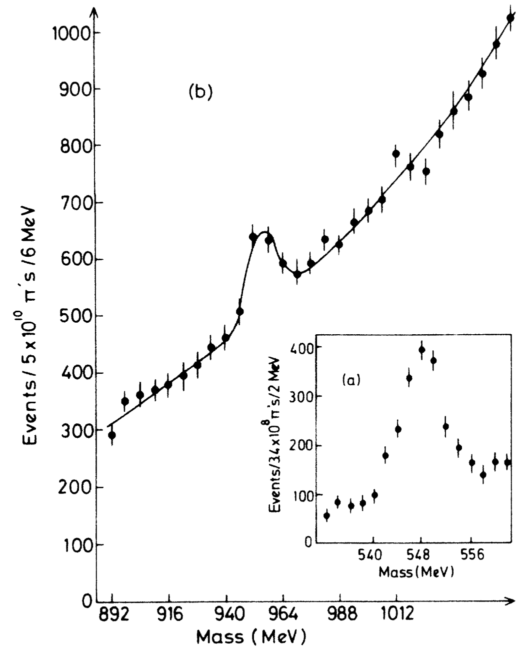

FIG. 1. (a) Missing-mass spectrum at 743 MeV incident momentum; η signal with no decay selections. (b) Missing-mass spectrum at 2 GeV incident momentum. Only events with at least four γ rays in the final state have been retained. This signature is 20% efficient for the η' meson decays and maximizes the signal-to-background ratio. The curve is a fit by a Gaussian and a third-order polynomial.

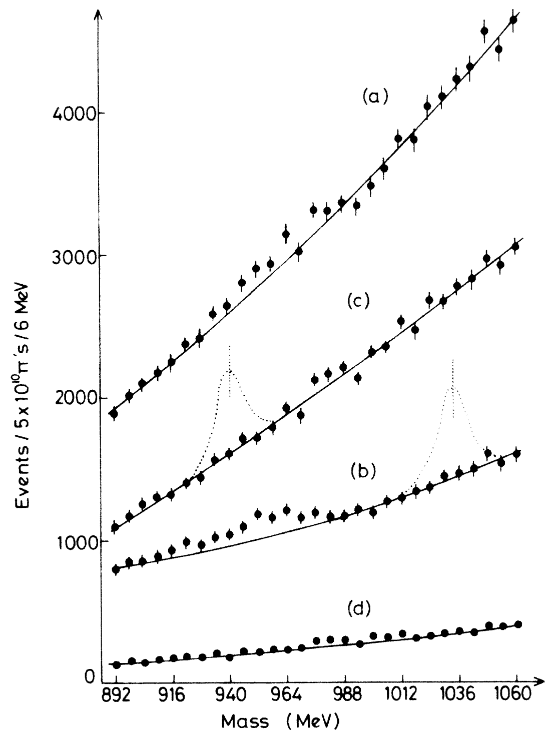

FIG. 2. Missing-mass spectrum at 2 GeV incident momentum: Curve a, events with two charged particles and any number of γ's. One charged particle has $6 \leq \theta \leq 35°$ and the other $35 \leq \theta \leq 130°$. Curve b, subset of a where all events with γ's are rejected and the azimuthal separation for the charged particles is $144 \leq \varphi \leq 180°$. Mainly populated by the final state $\pi^+\pi^-n$. Curve c, difference between a and b. Curve d, subset of a where $0 \leq \varphi \leq 36°$. The curves are fits by fourth-order polynomial to the data in the region 892 to 992 and 994 to 1060 MeV. The dotted lines represent the signals expected from the IAP experiment as described in the text with errors from their uncertainty in the cross sections.

dicates that it contains $(20 \pm 5)\%$ of the total η' signal and maximizes the signal-to-background ratio. Using the above efficiency we find the differential cross section $d\sigma/dt$ for $\pi^- + p \rightarrow \eta' + n$ at 2 GeV and $t = -0.08$ GeV$^2 \simeq t_{\rm min}$ to be 0.22 ± 0.07 mb/GeV^2, in agreement with other measurements.[7] We have fitted the missing-mass spectrum with a Gaussian and a third-order polynomial and find for the mass and width of the observed signal $954 \pm (1.5, 2.8)$ MeV and 13.0 ± 3.5 MeV. On the basis of the decay, cross-section, mass, and width information we identify the observed signal with the η' resonance.

The neutral mesons at 940 and 963 MeV in the IAP experiment were observed in final decay configurations involving two charged particles and any number of γ's. One of the charged particles had a polar angle to the beam of $3 \leq \theta \leq 17°$ while the other had $17 \leq \theta \leq 130°$. The 940-MeV meson also appeared in a subset of the above configuration which could not be populated by pure $\pi^+\pi^-n$ final states. Curve a, Fig. 2, shows our result for the missing-mass spectrum with two charged particles and any number of γ's in the final state. We require one charged particle to lie in the range $6 \leq \theta \leq 35°$ and the other in the region $35 \leq \theta \leq 130°$. Curve b, Fig. 2, presents the subset of curve a where we veto all events with γ's and require the azimuthal separation between the two charged particles to be $144 \leq \varphi \leq 180°$. This subset is mainly populated by $\pi^+\pi^-n$. Curve c, Fig. 2, shows the difference between curves a and b, i.e., events with two charged particles and any number of γ's but with $\pi^+\pi^-n$ excluded. Finally, curve d, Fig. 2, shows the subset of the data in curve a for which the azimuthal separation between the two charged particles is $0 \leq \varphi \leq 36°$.

Our curves a and d are to be compared directly with Figs. 3(b) and 3(c) of Ref. 1. In order to investigate any structure in the missing-mass spectrum we have excluded the region $922 \leq M \leq 944$ MeV and fitted a third-order polynomial to the remaining mass bins. In curves a, c, and d we find no evidence for narrow neutral states. An excess of events is seen above background in the pure $\pi^+\pi^-n$ subset of curve b and this accounts almost entirely for the excess seen in curve a. This enhancement could be associated with the S^* meson.[4-8] The authors of Ref. 1 do not present the mass spectrum for the subset of their data which is mainly $\pi^+\pi^-n$. We suggest that the two bumps identified as $M(940)$ and δ in their Fig. 3(b) may be due to statistical fluctuations around the wide enhancement which we observe in our data near 960 MeV.

Our Monte Carlo simulation predicts that the decay configuration in curve c, Fig. 2, is 30% efficient for detecting isotropic $\pi^+\pi^-\pi^0$ final states. The authors of Ref. 1 suggest that the narrow state at 940 MeV, for which they quote a differential cross section of 0.52 ± 0.16 mb/GeV^2, might decay mainly into $\pi^+\pi^-\pi^0$. The above cross section combined with the detection efficiency of our setup would lead to 1400 ± 400 events above background in curve c. We cannot make a similar calculation for the claimed state at 963 MeV as the authors do not suggest any dominant decay mode. However, in our data, there is clearly no evidence for any narrow resonance at this mass.

In Ref. 2 the same authors claim the presence of an enhancement in the missing-mass spectrum at 1033 MeV. This appears in a decay selection with two charged particles of which one has $6.5 \leq \theta \leq 17°$ and the other $17 \leq \theta \leq 130°$. The azimuthal separation is $169 \leq \varphi \leq 180°$. The authors claim that this selection is kinematically most favorable for the $\pi^+\pi^-n$ final state but cannot exclude the presence of one or more neutral pions. Our decay selection in curve b, Fig. 2, approximates the above cuts and the data show no evidence of any narrow enhancement around 1033 MeV. Our Monte Carlo estimate of the detection efficiency in Fig. 2(b) for isotropic $\pi^+\pi^-n$ final states with a 2π mass of 1033 MeV is about 65%. Assuming that the resonance of Ref. 2, for which the authors quote a differential cross section of 0.30 ± 0.09 mb/GeV^2, decays entirely into $\pi^+\pi^-n$ we would expect to see about 1500 ± 500 events above background in curve b.

We conclude that the subsets of our data which approximate the charged-particle multiplicity and topology cuts of the IAP experiment are inconsistent with the presence of narrow neutral mesons at 940, 963, and 1033 MeV.

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