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MISSING-MASS SPECTRUM NEAR 960 MEV FROM $\pi^- p \rightarrow n + (\text{mm})$

L. Holloway, B. Huld[†], U. Koetz^{††}, U. Kruse, M. Jordan, D. Mortara
L. Nodulman, R. Wojslaw
University of Illinois at Urbana-Champaign*
Urbana, Illinois 61801

S. Bernstein, S. Margulies, D. McLeod
University of Illinois Chicago Circle
Chicago, Illinois 60680

Reported by D. Mortara

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ABSTRACT

Supporting evidence for structure near 960 MeV in the reaction $\pi^- p \rightarrow n + (\text{missing-mass})$ at 2.5 GeV/c is presented.

A neutron counter hodoscope has been used as the principle constituent of a high-resolution, missing-mass spectrometer at Argonne. The resolution of the spectrometer is based largely on a precise measurement of the neutron momentum (time-of-flight or TOF) and angle, which in turn is achieved on the basis of a 20 meter distance of the neutron counters from the target. The TOF of the neutron is measured with an rms resolution of ± 0.85 ns compared to a typical TOF of 100-180 ns. This yields a momentum resolution $\Delta p_n/p_n \approx 0.015 p_n/E_n$ (GeV units). At a momentum-transfer (squared) of 0.3 (GeV/c)^2 to the neutron, the above yields $\Delta p_n/p_n \approx 0.8\%$. The polar angle of the neutron with respect to the beam is measured to ± 1.6 mr (rms) by the 11 cm wide counters. The uncertainty in the location of the interaction in the target does not enter significantly into the angular error. The beam parameters (angle and momentum) are determined to ± 0.8 mr and $\pm 0.2\%$ respectively. The combined effect of these errors is a typical rms missing-mass resolution of 2-4 MeV. The resolution of the spectrometer has been demonstrated in a measurement of the ω^0 width (7.7 ± 1.0 MeV) reported elsewhere.

One of the experiments using this spectrometer has been a measurement of the missing-mass spectrum produced by 2.5 GeV/c π^- mesons on a hydrogen target. The reaction observed is $\pi^- + p \rightarrow n + \text{missing-mass}$, where the neutral missing mass is composed of two and only two charged particles plus possible neutral particles. The directions of the charged particles are measured in spark chambers downstream of the target. The mass and momentum transfer acceptance are shown in Figure 1.

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[†] Present address: 15 Alpine St., Cambridge, Massachusetts

^{††} Present address: DESY, 2 Hamburg 52, Notkestieg 1, Germany

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Figure 1. The experimental acceptance is shown on a Chew-Low plot. The left and right edges correspond to the extreme angles of the neutron counter hodoscope (57° and 45° respectively). The bottom edge corresponds to the maximum neutron time-of-flight (185 ns).

In order to maximize uniformity of acceptance we confine our discussion to data in the region $0.22 \leq |t| \leq .38$ $(\text{GeV}/c)^2$ momentum transfer to the neutron. Events from the reaction $\pi^- p \rightarrow \pi^- \pi^+ n$ are excluded. The missing mass spectrum for this $|t|$ interval, shown in Figure 2, includes an ω^0 peak, a second peak near 960 MeV, and weak evidence for a peak near 935 MeV. A closer examination of the region around 960 MeV is motivated by a recent report from a somewhat similar experiment.*

As might be concluded from the signal:noise ratio in the ω^0 region, the data sample contains many entries not properly belonging to this mass spectrum. These entries arise from neutrons not originating in the target. For these entries, the neutron TOF and angle are uncorrelated with the track directions observed in the spark chambers. This fact can be employed to remove some of the background. Due to the finite Q -value in the $\omega^0 \rightarrow \pi^+ \pi^- \pi^0$ decay, not all

* D.L. Cheshire, R.W. Jacobel, R.C. Lamb, F.C. Peterson, E.W. Hoffman, A.R. Garfinkel, PRL 28, 520 (1972).

angles of the charged pions are possible. Removal of events with charged track directions inconsistent with $(\text{missing-mass}) \rightarrow \pi^+\pi^-\pi^0$ reduces this background by a factor of ~ 2 in the region of the ω^0 . This can be seen from the shaded region in Figure 2.

Figure 2. The missing-mass spectrum for $.22 \leq |t| \leq .38 \text{ (GeV/c)}^2$. The $\pi^+\pi^-\pi^0$ final state is excluded. The hatched area shows the sample kinematically consistent with a $\pi^+\pi^-\pi^0\pi^0$ final state in the region of the ω^0 .

The presence of this large contamination of unphysical entries with essentially random neutron TOF's can also be used to study the shape of the background spectrum near suspected peaks. The procedure used is to select events with neutron TOF's outside that corresponding to the selected momentum-transfer interval, and randomly redistribute these TOF's into the above interval. Then a new missing-mass corresponding to the new TOF is calculated. We refer to the spectrum generated in this fashion as the control sample. The data and control sample for the region around 960 MeV are shown in Figure 3. It is seen that the control sample does not show a peak near 960 MeV.

Figure 3. The control sample spectrum discussed in the text and a portion of the Fig. 2 spectrum. The curve is the result of a fit of the spectrum to two Breit-Wigner curves with resolution folded in, and a background shape determined by the control sample. The background curve is shown on the control sample. Data above 980 MeV are not used in the fit.

In order to make more quantitative statements, we assume that the control sample provides both the background shape and shape of the acceptance at the upper end of the spectrum. The acceptance is seen to fall off linearly above 967.5 MeV, and subsequently we appropriately scale up the data in the five bins in the interval 967.5 - 980.0 MeV. The control sample is then fitted with a quadratic polynomial. This polynomial is used with a parameterized normalization to fit a background to the actual spectrum. As in the case of the ω^0 , the requirement of kinematic consistency can help remove background. Of course, the lower the Q-value in the decay, the more restricted are the charged π directions. A potential decay might be $\pi^+\pi^-\eta^0$, and it is seen in Figure 4 that requiring consistency with this decay mode greatly enhances the signal near 960 MeV, and also makes the second peak near 935 MeV more prominent. Once again the control sample can be used to find a background shape by demanding the same consistency for it. Using a background determined by the control sample, we find in a fit to the data of Figure 4 for two peaks:

$$\begin{aligned} M_1 &= 968. \pm 1.0 \text{ MeV}, & \Gamma_1 &= 6.3 \pm 3.5 \text{ MeV}, \\ M_2 &= 936. \pm 2.5 \text{ MeV}, & \Gamma_2 &= 2.0 \pm 3.8 \text{ MeV}. \end{aligned}$$

The errors are statistical. The χ^2 is 46 for 45 degrees of freedom. Leaving out the lower peak does not appreciably change the higher peak parameters, and yields a χ^2 of 66 for 48 degrees of freedom (6% confidence level). Assuming no peaks yields a χ^2 of 97 for 51 degrees of freedom.

The most probable non-statistical source which could produce an effect similar to that observed is an "edge" effect, i.e. some misunderstood contribution or depletion of events near the edge of an experimental acceptance (See Figure 1). However we do not believe that this is the case here, for the following reasons:

- (1) The "edge" in this experiment is caused by the angular range of acceptance of the neutron counter hodoscope. Artificial edges generated by ignoring elements of the hodoscope covering the extreme angles of acceptance do not cause new peaks in the missing-mass spectrum.
- (2) In the identical experimental configuration, no such edge effect was observed at a beam momentum of 4.5 GeV/c.
- (3) The observed effect is correlated with the charged particle directions observed in the spark chambers, i.e. the effect is enhanced by requiring a low-Q decay. There seems no reason to associate these charged particle directions with the neutron angles for false contributions to the missing-mass spectrum.

Figure 4. The subset of the data for Figure 3 which is consistent with decay $\pi^+ \pi^- \eta^0$. The curves have the same definition as in Figure 3.

We feel the above constitutes evidence for a peak at 968 MeV and only weak evidence for a second lower mass peak. Despite the kinematic consistency with a $\pi^+\pi^-\eta^0$ decay mode,* we do not believe that the upper peak corresponds to the η' for two reasons: (1) the mass is 10 MeV removed from the η' , and the ω^0 mass gives an absolute mass calibration to ± 2 MeV, and (2) the signal is 25-35% of the ω^0 in the same $|t|$ interval; a $\pi^+\pi^-\eta^0$ decay mode with η' branching ratios would imply a η' cross section comparable to the ω^0 .

In an attempt to provide further confirmation of the peak(s) observed, another run has just been completed at Argonne using a 3.5 GeV/c π^- beam. In the preliminary analysis of a comparable amount of data, no evidence is seen for any peak near 960 MeV. Thus the only recent experiments reporting new peaks in this region are near 2.5 GeV.

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* Other decays may produce similar geometries; we have since calculated that 80% of an isotropic $\eta\pi^0$ ($\eta \rightarrow \pi^+\pi^-\pi^0$) decay would pass the kinematic consistency test used.