# Failure to Observe a Meson Decaying into $\pi^+\pi^0$ in the Reaction $\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$ with 968-MeV/$c$ Incident $\pi^+$*

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In a search for a meson decaying into $\pi^+\pi^0$, we have studied the reaction $\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$ at an incident pion momentum near 1 BeV/$c$. The dipion mass spectrum of almost 7000 events shows no statistically significant bumps, giving an upper limit of approximately 0.1 mb (99% confidence) for a meson with a width narrower than our dipion mass resolution (about $\pm 10$ MeV).

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There are strong suggestions, in $SU_3$,[1] quark,[2] and Regge-pole[3] theories, of an $I=1$, $S=0$, scalar meson in the mass region below the $\rho$. Several indications of a meson with a mass in the 550–600-MeV region and decaying into $\pi^\pm\pi^0$ (the "$\zeta$") were reported[4,5] some time ago, but in other experiments no clear resonance below the $\rho$ dipion mass spectrum has been seen. Metzger[6] has compiled about 16 000 events from various reactions, covering nine different experiments and 11 bombarding energies, and finds about a 1-standard-deviation excess over background in the 550–600-MeV mass region.

In an attempt to confirm the early indications or to set an appreciably smaller upper limit on the production cross section for such a meson, we have obtained almost 7000 events in the reaction $\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$. This reaction and the bombarding momentum were chosen to correspond to the case where the largest effect had been claimed.[4] Our dipion mass resolution ($\pm 10$ MeV) is appreciably narrower than previously obtained.

In this experiment the angles of both $\gamma$ rays and both charged tracks are observed in a very large solid angle detector, but without magnetic field for momentum analysis. The experimental equipment consisted chiefly of a central hydrogen target surrounded by a cylindrical spark chamber. The spark chamber was composed of thin aluminum plates surrounded by cylinders of stainless-steel-clad lead. Protons and kaons in the beam were rejected by a liquid Čerenkov counter. The spark chamber was triggered when a beam particle or any of its charged secondaries did not traverse the anticoincidence counter following the hydrogen target; to minimize possible bias, a more selective trigger was not used. The approximately 4.5 radiation lengths of lead plates served to detect the $\gamma$'s from the $\pi^0$ and gave range information on the charged tracks. The details of construction and operation of the equipment are given elsewhere.[7]

155 000 pictures were scanned for those events where, in addition to the incoming beam pion, two charged tracks and two $\gamma$'s were detected. The 8700 candidates selected were measured on Hydel measuring devices and the digitized results recorded on IBM punch cards for analysis by a reconstruction program.

Using the 4-vector of the incoming pion, the mass and angles for each outgoing particle, and the constraint that the invariant mass of the two $\gamma$'s be that of a $\pi^0$, a 1C (one-constraint) fit to the reaction hypothesis $\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$ was made. In making the 1C fit, the following scheme was adopted. Since a charged track could be assigned either the proton mass or pion mass assignments, there are in general two kinematic solutions possible. That solution was selected which gave momentum values for the outgoing particles closest to being consistent with the known kinematic lower bounds, namely, the observed ranges of the charged

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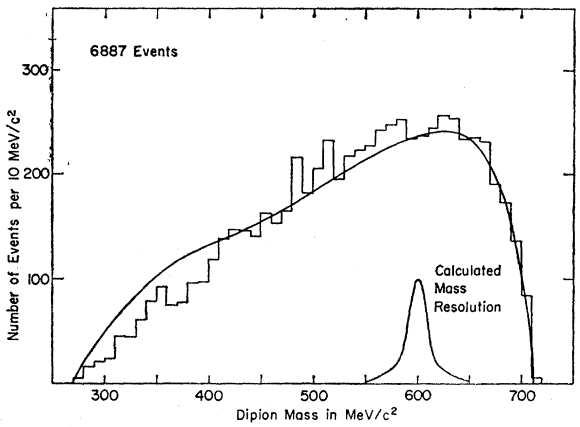


FIG. 1. Histogram of the dipion invariant mass. The smooth curve is the prediction from the simple $N^*$ model described in the text. The inset is the average dipion invariant-mass resolution as determined from Monte Carlo-generated events.

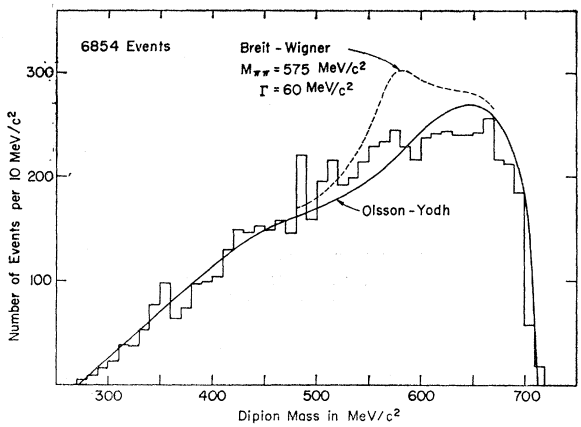


FIG. 2. Histogram of the dipion invariant mass plotted with detection weights. Smooth curve is the Olsson-Yodh prediction. Dashed curve represents a dipion resonance having a 60-MeV/$c^2$ width and centered at 575 MeV/$c^2$.

tracks and about 6-MeV/$c$ minimum laboratory momentum for the $\gamma$ rays. Monte Carlo studies for the correct mass assignment showed that less than 1% of the time could a better fit be made with the rejected solution.

6887 events made acceptable fits to the reaction hypothesis.[8] The square of the digamma mass for those events before iteration to the $\pi^0$ mass has a full width at half-maximum (FWHM) corresponding to 32 MeV and agrees well with the Monte Carlo prediction. The location of the peak was used as a check on the beam momentum and gave a value of 972±9 MeV/$c$. This is in agreement with the value 968±14-MeV/$c$ half-width at half-height obtained by a range measurement on 800-MeV/$c$ time-of-flight separated protons.

Figure 1 shows a histogram of dipon mass for these fitted events. The smooth curve is a Monte Carlo prediction for events produced through the $N^*(1236)$ $\pi$ intermediate state normalized to the number of experimental events. The chamber detection efficiency is included in this curve. The $N^*$ events were generated as a three-body phase-space-weighted Breit-Wigner distribution in the nucleon-pion invariant mass, with $\Gamma=100$ MeV and center at 1220 MeV corresponding to the approximate experimental values. The number of $N^{*++}$ to $N^{*+}$ events were generated in the ratio 9/4 in accordance with isospin invariance, and our experimental angular distribution of the $N^{*++}$, 1160 MeV $\leq M(\pi^+p)\leq$1280 MeV, was used for both channels. The inset in Fig. 1 shows the expected average dipion mass resolution; the FWHM is about 20 MeV.

[8] When allowance for an expected background of about 9% in the measured data is made, this number of fits is in good agreement with the Monte Carlo results. Background is based on the cross section for greater than 1 neutral given by C. Gensollen, P. Grunet, R. Barloutaud, A. Leveque, and J. Meyer, *Proceedings of the Sienna International Conference on Elementary Particles and High-Energy Physics, 1963*, edited by G. Bernardini and G. P. Puppi (Societa Italiana di Fisica, Bologna, 1963), Vol. 1, p. 84; and also in Ref. 6.

To remove any distortion in the mass spectrum because of a variation in the detection efficiency among the different events, a weight equal to the inverse of the average detection probability for the class of equivalent events was calculated for each event. Equivalent events are all those which differ by any of the following: rotation about the beam axis; angles of $\gamma$ decay from the $\pi^0$; and origin of the event in the hydrogen target. The average detection probability for all fitted events was 33%. This agrees with the calculated result using the Monte Carlo-generated events for the simple $N^*$ model described. For this $N^*$ model, more than 98% of the events will be detected with more than 2% efficiency, so it is expected that less than 2% of all data configurations would not be detected.

On this basis, a total cross section of 9.2±0.8 mb is obtained, where the error includes estimates of the possible systematic effects in beam contamination, expected fraction of true events making an acceptable fit, background contamination, bubbling in the hydrogen target, spark-chamber failure, and scanning losses. This number agrees with a bubble-chamber value of 9.2±0.6 and is about 1 standard deviation below a counter value of 10.2±0.5, both of which are at nearby energies.[9]

Figure 2 shows a histogram of the dipion masses where the fitted events are plotted with their weights. Thirty-three events had weights greater than 20 and were not plotted; they were spread over the whole spectrum, so that no bias comes from their exclusion. No statistically significantly fine structure is visible in Figs. 1 and 2.

The smooth curve in Fig. 2 is the Olsson-Yodh prediction. The dashed curve on top of this is the type of peak that might have been expected on the basis of the first substantial evidence[4] for the controversial $\zeta$

[9] Both previous values of the total cross section are given in J. F. Detoeuf, Y. Ducros, J. P. Merlo, A. Stirling, B. Thevenet, L. van Rossum, and J. Zsembery, Phys. Rev. 134, B228 (1964).

meson at about 575 MeV/$c^2$. About 520 weighted events above background are thus expected; the data show only about 40 net weighted events above the Olsson-Yodh curve within the mass region 540–610 MeV/$c^2$. If the theoretical curve were an exact representation of the background, this observed excess would amount to about 1 standard deviation and would correspond to a cross section of 0.06 mb.

No bumps of the size and location reported by others[5] in this region are observed in these data. For a peak narrower than our experimental resolution, our upper limit (99% confidence level) on cross section is about 0.1 mb.

We conclude that there is no evidence for a meson created in $\pi^+p$ at 968 MeV/$c$ and decaying into $\pi^+\pi^0$.

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# Backward Photoproduction of $\pi^0$ in the Region of the $P_{33}$ Pion-Nucleon Resonance

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The $\pi^0$ photoproduction cross section has been measured at 180° for photon energies from 220 to 380 MeV, in steps of 20 MeV, by detecting the recoil proton at 0°. The statistical accuracy of the measurements varies between 3 and 7%, depending on the energy. Absolute cross sections have been deduced from a comparison of the measurements with electron-proton scattering. The experimental data are compared with theoretical results calculated from fixed-momentum-transfer dispersion relations. Special attention is paid to the prediction of the multipoles at the first resonance, namely, $E_{1+}^{3/2}$, $M_{1+}^{3/2}$, and $E_{0+}^{\pi^0}$ to obtain agreement with experiment.

## I. INTRODUCTION

UNTIL recently the experimental information about $\pi^0$ photoproduction from the proton in the region of the first pion-nucleon resonance $\Delta(1236)$ has been very limited. The functional dependence on the photon energy $E$ or the production angle $\theta$ (in the c.m. system) has been established in the threshold region and only in a few other cases. There are recent and old data available from the counter experiments done at Moscow,[1] Glasgow,[2] and from the work with emulsion plates at Munich,[3] which give the first three coefficients $A$, $B$, and $C$ of the expansion of the differential cross section (in the c.m. system)

$$d\sigma(E,\theta)/d\Omega = A + B\cos\theta + C\cos^2\theta + D\cos^3\theta + \cdots \quad (1)$$

up to $E=240$ MeV. At higher energies, measurements[2–4] at $\theta=90°$ yielded the energy dependence of $A$ in the region of the first pion-nucleon resonance. But all other data do not give sufficient information for the asymmetry coefficients $B$ and $D$. The present measurements yield data in a kinematical region especially suited for a further check of the existing theories. Furthermore,

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