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# THE DIPION SYSTEM IN THE REACTION $\pi^- p \rightarrow n\pi^0\pi^0$ AT 1.6 TO 2.4 GeV/c*

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## ABSTRACT

We report results from a high-statistics study of the reaction $\pi^- p \rightarrow n\pi^0\pi^0$ between 1.6 and 2.4 GeV/c, in which all the final-state particles were detected. The $2\pi^0$ mass spectrum exhibits a marked enhancement in the region of 800 MeV. In terms of I = 0, S-wave $\pi$-$\pi$ phase shifts, the data are consistent with the recently reported "Down-Down" solution above 800 MeV but are in disagreement below that dipion mass.

In principle, the study of the isoscalar (I = 0) dipion system below 1 GeV $\pi\pi$ mass is simplified by analyzing the $2\pi^0$ system, from which the effects of the I = 1, $\rho(765)$ are excluded.[1] However, because of the complexity of detecting and measuring the kinematics of neutral particles, experiments which study reactions such as

$$\pi^- p \rightarrow n\pi^0\pi^0 \tag{1}$$

have yielded inconsistent results.[2,3]

We report results from a high-statistics experiment, performed at the Berkeley Bevatron, to study reaction (1) at beam momenta of 1.59 to 2.39 GeV/c in 0.20-GeV/c intervals.[4] The prominent features of the experiment which minimized the systematic biases are:

1) identification of the final state by detecting the neutron and all the $\gamma$-rays from the $\pi^0$ decays. The kinematic variables of each of the particles were measured and an overconstrained (6-constraint, 3-vertex) kinematic fit was made to each event, using a modified version of the LBL bubble chamber program SQUAW;[5]

2) a high $\gamma$-ray detection efficiency over more than 90% of the entire $4\pi$ sr lab solid angle, and

3) an empirical check of systematic effects by comparing the differential cross sections for the 2-body final states, $n\pi^0$ and $n\eta$, measured with and without the neutron detector in the triggering logic.

The experimental setup is the same as described in a previous paper,[6] except for the addition of the neutron detector.[7] This detector consisted of 20 cylindrical plastic scintillation counters, each 8 in. in diameter and 8 in. long, located 15 ft from the target and subtending polar lab angles ($\theta_n$) from 12 to 72 deg with respect to the central beam ray. Each neutron counter had an additional counter mounted in front of it to veto charged particles. The neutron trigger was set to accept neutrons of velocity ($\beta$) in the region $0.17 \leq \beta \leq 0.84$, corresponding to invariant four-momentum-transfers to the nucleon ($-t_{p\rightarrow n}$) of 0.029 to 1.54 $(\mathrm{GeV}/c)^2$. The neutron timing resolution was $\pm 0.6$ ns.[7]

Data were collected in two different modes of electronic triggering conditions: 1) a neutron counter signal in coincidence with a neutral-final-state trigger and 2) a neutral-final-state trigger only. The latter data were used to determine partial cross sections for various neutral final states, as described in Ref. 8. Cross sections for reaction (1) are listed in Table I. They agree well with those of Crouch et al.[9]

The study of the dynamical properties of reaction (1) was made with the neutron-trigger data sample containing four visible showers in the spark chambers and no upstream shower-counter signal. The $\gamma$-ray energy measurement from spark counting was calibrated by an overconstrained kinematic fit of the 2-shower events to $n\pi^0$ and $n\eta$ final states. The 4-shower data sample consists of about 7400 events that fit reaction (1) with $\chi^2$ probability $\geq 5\%$. The data within the neutron counter acceptance region in t and $\theta_n$ have been corrected for neutron scattering in the chambers, neutron counter geometry, and detection efficiency.[7] Structure is evident in both the $n\pi^0$ and $\pi^0\pi^0$ mass plots. The dominant feature, at all values of t, is the peak in the $n\pi^0$ spectrum (not shown) corresponding to $\Delta^0(1236)$ production.[10] To isolate the $2\pi^0$ system from the effects of the $\Delta(1236)$, we cut out all events having at least one $n\pi^0$ combination in the broad mass band of 1100 to 1300 MeV. The $n\pi^0$ mass spectrum of the surviving events exhibits no resonant structure.

Figure 1 displays the combined data from the five beam momenta, with the $\Delta$-band events excluded. The t-distribution (Fig. 1a) is characterized by a pronounced peak at low t. The curve represents the prediction of "peripheral phase-space" (PPS) which is defined as $[(\text{phase-space}) \cdot (-t)/(t-\mu^2)^2 \cdot F(t)]$, where $\mu$ is the pion mass and

F(t) is the Dürr-Pilkuhn vertex factor[11] multiplied by Wolf's t-dependent form factor.[12,13] This expression, normalized to the number of events below 1 GeV dipion mass, fits the t-distribution very well in the peripheral region, $-t \leq 0.3\ (\mathrm{GeV}/c)^2$.

Figure 1b shows the $2\pi^0$ mass spectrum for the entire t region (4088 events). A marked enhancement in the 800-MeV region is clearly evident. The curve represents a crude approximation of the spectrum as the sum of phase space and PPS, the relative amounts being determined by a maximum-likelihood fit to the t-distribution and the mass spectrum at each momentum. Figure 1c shows the mass spectrum (1323 events) for events with $-t \leq 0.3\ (\mathrm{GeV}/c)^2$. The same structure is much more pronounced here, because the production of the enhancement is more peripheral than that of the background. The curve represents the PPS distribution normalized to the data below 1000 MeV but excluding the 700- to 900-MeV region.

The dipion decay angular distribution was studied with respect to the incident $\pi^-$ direction in the dipion rest frame, for events in the peripheral region. For all $2\pi^0$ masses below about 940 MeV, the decay distribution was consistent with isotropy outside the region corresponding to the $\Delta$-mass-band cut and hence is consistent with spin $J = 0$ for the dipion system.

To parametrize the peripheral data we assume the one-pion exchange (OPE) mechanism as a production model, using the Chew-Low equation[14] modified by the form factor F(t) defined above, and work in the physical region (since there are too few events to make a meaningful extrapolation to the pion pole). Cross sections (Table I) for this t-cut were determined by normalizing the neutron-counter data to the total $n\pi^0\pi^0$ cross sections, as outlined in Ref. 7. In the S-wave approximation, the $\pi\pi$ cross section is proportional to $\sin^2(\delta_0^0 - \delta_0^2)$, where $\delta_0^0$ ($\delta_0^2$) is the I = 0 (I = 2) S-wave phase shift. Details of the calculation are given elsewhere.[15]

A weighted average of $\sin^2(\delta_0^0 - \delta_0^2)$ from the five beam momenta is plotted as a function of $m_{\pi\pi}$ in Fig. 2. The error bars in each bin are purely statistical and do not include a systematic uncertainty in the overall normalization (± 6%) from our $n\pi^0\pi^0$ cross-section determination for $-t \leq 0.3$ $(\mathrm{GeV}/c)^2$. Our analysis does not extend beyond dipion mass of 940 MeV because of the presence of D-wave contribution, whose amount is difficult to determine due to the Δ(1236) cut.

For comparison, we show in Fig. 2 the recent phase-shift results of Protopopescu et al.[16] from an analysis of the $\pi^+\pi^-$ system. The "Down-Up" solution is clearly in disagreement with our data and can be ruled out completely—a conclusion consistent with that of Ref. 16. Within the normalization uncertainty, the "Down-Down" solution agrees quite well with our results for $M_{\pi^0\pi^0} \geq 800$ MeV but <u>not</u> with the results below 800 MeV.

The <u>same</u> conclusions follow if we compare only the shape of the mass spectrum in Fig. 1c with the shape predicted from the phase shifts of Ref. 16, using the Chew-Low equation[14] modified by F(t). The predicted shape is relatively insensitive to the choice of form factor, provided it fits the t-distribution (Fig. 1a). Thus, <u>regardless</u> of the particular parametrization used to obtain the phase shifts (assuming OPE), the structure observed in the mass spectra is not reproduced with the phase shifts of Ref. 16, other than the fall-off in the 800-1000 MeV region. Our results are therefore inconsistent with the conclusions from a recent experiment[3] at 8 GeV/c which measured only the shape of the $2\pi^0$ mass spectrum, where the authors conclude their measured shape to be consistent with the phase shifts of Ref. 16 above 650 MeV.

Finally, we also show in Fig. 2 the two phase-shift solutions at the K mass obtained by Sarker[17] from an analysis of $K \rightarrow 2\pi$ decays and the theoretical solutions (curves II and III) by Basdevant et al.[18] for the phase shifts just above threshold. Neither solution can be ruled out by our results.

We wish to thank Dr. S. Protopopescu, Dr. T. Lasinski, and Dr. E. Colton for fruitful discussions about $\pi$-$\pi$ scattering.

## FOOTNOTES AND REFERENCES

[*] Work done under the auspices of the U. S. Atomic Energy Commission.

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Table I. Cross sections for $\pi^- p \rightarrow n\pi^0\pi^0$.

| $P_{\pi^-}$ (GeV/c) | Total (μb) | $-t \lesssim 0.3$ (GeV/c)$^2$ [a] (μb) |
|---|---|---|
| 1.59 | 1310±100 | 325±30 |
| 1.79 | 1360±100 | 430±30 |
| 1.99 | 1390±90 | 335±30 |
| 2.19 | 1380±90 | 320±30 |
| 2.39 | 1140±70 | 225±15 |

[a] Δ - cut corrected for by the ratio of phase space with and without Δ-mass-bands.

# FIGURE CAPTIONS

Fig. 1. Data, with Δ(1236) mass-band events excluded (see text):

(a) t-distribution. The solid (dashed) histogram is for data with $M_{\pi^0\pi^0} < 1000$ MeV ($< 1400$ MeV). The curve represents peripheral phase space (PPS) for $M_{\pi^0\pi^0} < 1000$ MeV, normalized to the data in the solid histogram for $-t \leq 0.3$ $(\mathrm{GeV}/c)^2$;

(b)-(c) $2\pi^0$ mass spectrum for the t region indicated. The curve in (b) represents a combination of phase space and PPS (see text), while that in (c) represents PPS only. Both curves are normalized to the corresponding data below 1000 MeV but outside the 700- to 900-MeV region.

Fig. 2. Phase-shift results. The solid (dashed) curve above 550 MeV corresponds to the "Down-Down" ("Down-up") solution from Protopopescu et al.[16] Curves II and III are solutions II and III, respectively, from Basdevant et al.[18] The corresponding S-wave scattering lengths ($a_s^I$), in units of $m_\pi^{-1}$ are $a_s^0 = 0.16$ and $a_s^2 = -0.048$ for solution II and $a_s^0 = 0.60$ and $a_s^2 = 0.043$ for solution III. The dashed points at the K mass are from Sarker.[17]

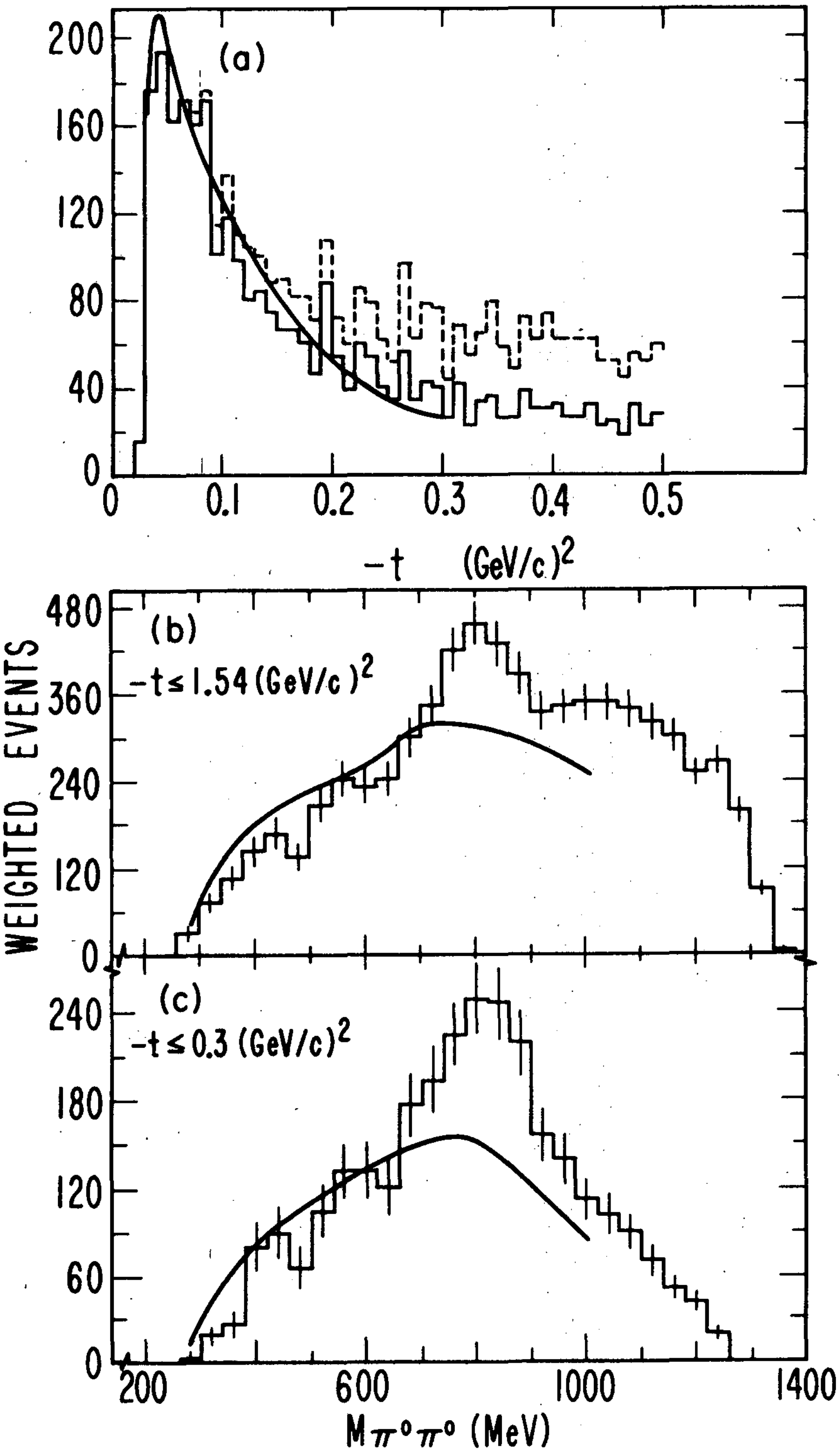

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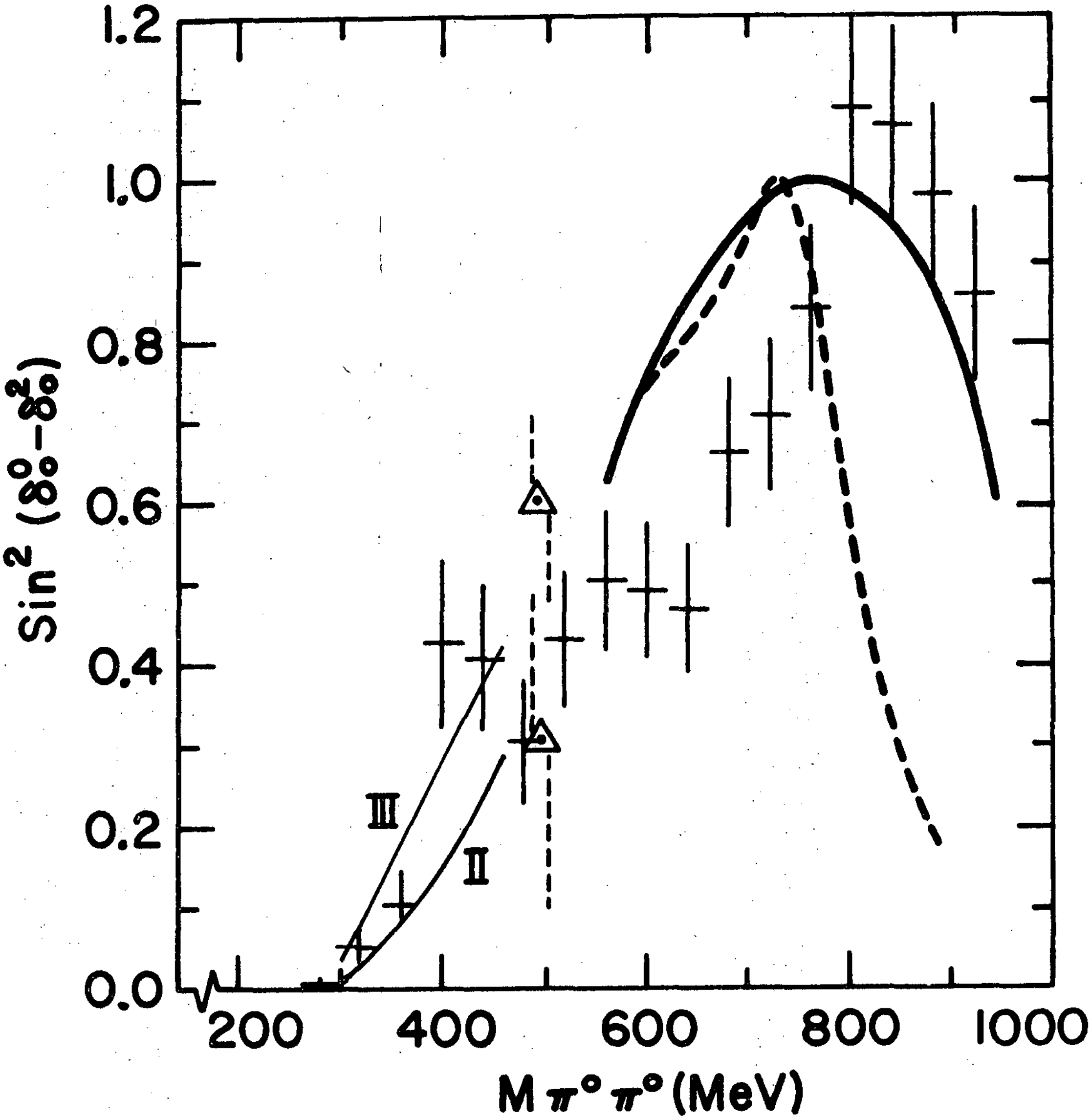
Fig. 1



XBL733-324

Fig. 2

Note added in Proof: In a very recent $\pi\pi$ phase shift analysis by Estabrooks, Martin et al[19], the authors present two solutions for $\delta_0^\circ$ in the region $M_{\pi\pi}$ = 450-1000 MeV. They conclude that solution 1 is the correct one when compared with the shape of the $\pi^\circ\pi^\circ$ mass spectrum of ref. 3. On the other hand, our results in Fig. 2 are consistent with solution 2 below the point where the two solutions cross over at $M_{\pi^\circ\pi^\circ}$ = 770 MeV, and solution 1 above this cross-over point. However, the validity of jumping from one solution to the other at the cross-over point may be questioned.[19] A prominent feature of their solution 2 is that $\delta_0^\circ$ is relatively constant between 450 and 650 MeV, at which point it starts rising sharply with increasing mass. This is the same behavior indicated in our phase-shift results in Fig. 2.

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