Jahn, R. J. Morrison, F. V. Murphy, and D. E. Yount, Phys. Rev. Lett. 23, 1256 (1969); 25, 609 (1970).
[30]H. Satz and D. Schildknecht, Phys. Lett. 36B, 85 (1971).
[31]P. L. Jain, SUNY Buffalo report (unpublished).
[32]P. L. Jain, Z. Ahmad, R. D. Malucci, M. J. Potoczak, and B. Girard, Nuovo Cimento Lett. 4, 601 (1972).
[33]K. Fujikawa, Phys. Rev. D 4, 2794 (1971).
[34]A functional form for $\sigma_{ph}(K)$ is found by using the data on Cone *et al.* (Ref. 35) to facilitate the integration of Eq. (11). The integration over E' is performed (via CDC 6400 computer) by using the method of Gaussian quadrature (GQ). Special attention is given to the variable limits which result from the introduction of K as a variable. We then integrate over each angular interval, again using GQ. The integral cross section versus q^2 is obtained by first changing variables in Eq. (11) ($\Omega \to q^2$) and integrating (via GQ) from q^2 to q_{max}^2. The integral is found not to be sensitive to the value of q_{max}.
[35]A. A. Cone, K. W. Chen, J. R. Dunning, Jr., G. Hartwig, N. F. Ramsey, J. K. Walker, and R. Wilson, Phys. Rev. 156, 1490 (1967).
[36]C. M. Hoffman, A. D. Liberman, E. Engles, Jr., D. C. Imrie, P. G. Innocenti, R. Wilson, C. Zajde, W. A. Blanpied, D. G. Stairs, and D. Drickey, Phys. Rev. Lett. 22, 659 (1969).
[37]J. D. Bjorken and E. A. Paschos, Phys. Rev. 185, 1975 (1969).
[38]S. D. Drell, D. J. Levy and T.-M. Yan, Phys. Rev. Lett. 22, 744 (1969).
[39]E. A. Paschos, in *High Energy Physics*, edited by K. T. Mahanthappa, W. D. Walker, and W. E. Brittin (Colorado Associated Univ. Press, Boulder, 1970), p. 125.
[40]H. Moreno and J. Pestieau, Phys. Rev. D 5, 1210 (1972).
[41]P. V. Landshoff and J. C. Polkinghorne, Nucl. Phys. B28, 240 (1971).
[42]V. Rittenberg and H. R. Rubinstein, Phys. Lett. 35B, 50 (1971).
[43]J. J. Sakurai and D. Schildknecht, Phys. Lett. 40B, 121 (1972).
[44]M. Breidenbach and J. Kuti, MIT report, 1972 (unpublished).
[45]C. W. Gardiner and D. P. Majumdar, Phys. Rev. D 2, 151 (1970); 2, 2040 (1970).
[46]S. J Brodsky, F. E. Close, and J. F. Gunion, Phys. Rev. D 5, 1384 (1972).
[47]S. J. Brodsky and J. Pumplin, Phys. Rev. 182, 1994 (1969); K. Gottfried and D. R. Yennie, *ibid.* 182, 1595 (1969).
[48]W. T. Meyer *et al.*, Phys. Rev. Lett. 28, 1344 (1972).

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Four-Pion Decay of the f^0 Meson*

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A search for the $\pi^+\pi^+\pi^-\pi^-$ decay mode of the $f^0(1260)$ has been made in 7.87-GeV/c $\pi^+ d$ interactions. We find no evidence for this decay. The ratio of this decay mode relative to the dipion decay mode of the f^0 is consistent with zero and less than 3.3 % with 90% confidence.

There have recently been several reports of a small but statistically significant 4π decay mode of the f^0. Ascoli *et al.*,[1] obtained a corrected ratio for $F = f^0 \to \pi^+\pi^+\pi^-\pi^-/f^0 \to \pi\pi$ of $(7 \pm 4)\%$ from a 5.1-GeV/c $\pi^- p$ experiment, while Oh *et al.*,[2] reported the ratio to be $(7 \pm 2)\%$ from a 7-GeV/c $\pi^- p$ experiment. On the other hand, the most recent results by Bardadin-Otwinowska *et al.*,[3] from a study of 8-GeV/c $\pi^+ p$ interactions, show little evidence for the four-pion decay of the f^0. They obtain a ratio $F = (2.2^{+4.5}_{-2.2})\%$, consistent with zero. The Meson Spectroscopy Table of the Particle Data Group[4] gives a world average of $F = (6.1 \pm 1.5)\%$. Our data, presented below, are in agreement with a null result.

The results are obtained from a 0.6-μb event exposure of the BNL 80-in. deuterium bubble chamber exposed to a beam of 7.87-GeV/c π^+ mesons. Only events with a spectator proton identifiable on the scanning table have been selected. The channels relevant to the present work are

(a) $\pi^+ d \to p_s p\pi^+\pi^-$ $(-t \leq 10m_\pi^2)$ (963 events),
(b) $\pi^+ d \to p_s p\pi^+\pi^-\pi^+\pi^-$ $(-t \leq 10m_\pi^2)$ (92 events),

where p_s denotes a visible spectator proton and $(-t \leq 10 m_\pi^2)$ implies that only peripheral events have been selected for analysis. This peripherality requirement reduces the nonresonant background in the f^0-mass region. (In this paper the momentum transfer $-t$ is always calculated between the incident π^+ and outgoing bosonic system.) Figure 1 presents the 2π and 4π mass spectra with these restrictions. While a large f^0 signal is visible ($\sigma \approx 120$ μb) in the $\pi^+\pi^-$ spectrum, the existence of a signal in the 4π spectrum is dubious. Our results are consistent with a zero four-pion branching ratio for the f^0.

For the purpose of the present study, we have selected the f^0-mass region to be $1.18\ \text{GeV}/c^2 \leq m_{f^0} \leq 1.34\ \text{GeV}/c^2$. This choice seems prudent, since the four-pion spectrum is rapidly rising in the vicinity of $1.4\ \text{GeV}/c^2$ in a manner atypical of any type of phase space which we have been able to generate, but which could be indicative of ρ' production.[5] A larger f^0 region would enhance the 4π contribution in an artificial way. Figure 2 exhibits the momentum transfer $(-t)$ distributions for the f^0 region for the 2π and 4π events. In the latter group, only 4 events are in the f^0 region, all with $-t \leq 10 m_\pi^2$. With such a small sample of events in the f^0 region of the 4π spectrum, it is difficult to assess a background subtraction. From an examination of Fig. 2(b), it would appear that at least one of these events is background. To determine the number of $\pi^+\pi^-$ decays of the f^0 in the above mass and $-t$ regions, we note, from Fig. 2, that there is a maximum of 173 events of this type. Furthermore, we estimate from Fig. 1 that at least 70% of these are f^0 events. Isotopic spin conservation requires that the $\pi^0\pi^0$ decay be $\frac{1}{3}$ of the total dipion f^0 decay (our data agree with this figure to within one standard deviation). Us-

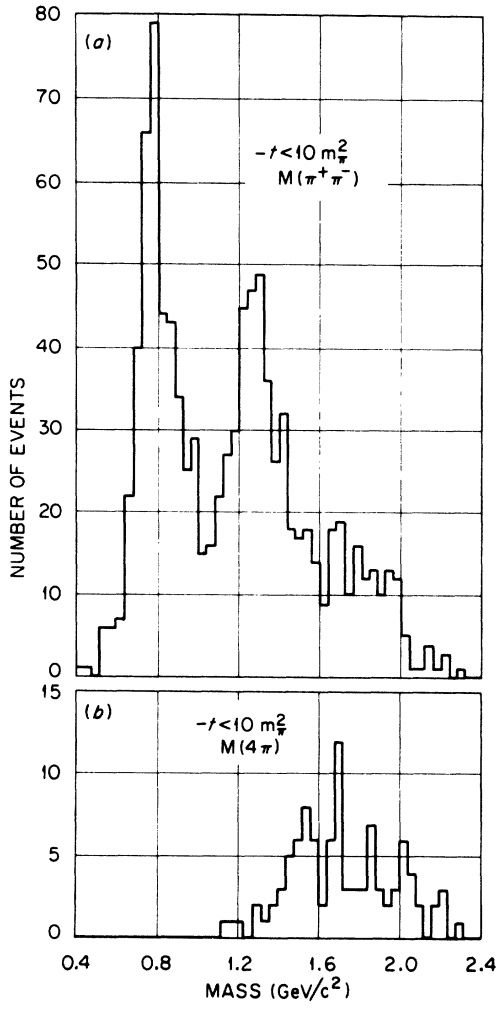

FIG. 1. (a) Dipion mass spectrum from reaction $\pi^+ d \to pp\pi^+\pi^-$ at 7.87 GeV/c, with $(-t)_{\pi^+,\pi^+\pi^-} \leq 10 m_\pi^2$. (b) Four-pion mass from reaction $\pi^+ d \to pp\pi^+\pi^-\pi^-\pi^+$ at 7.87 GeV/c, with $(-t)_{\pi^+,4\pi} \leq 10 m_\pi^2$.

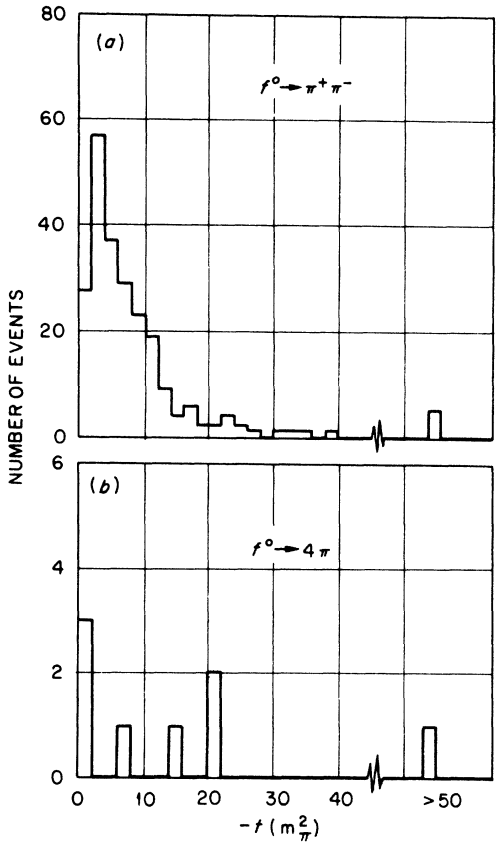

FIG. 2. Momentum-transfer distributions for events in the mass region $1.18 - 1.34\ \text{GeV}/c^2$ for (a) dipion events; (b) four-pion events.

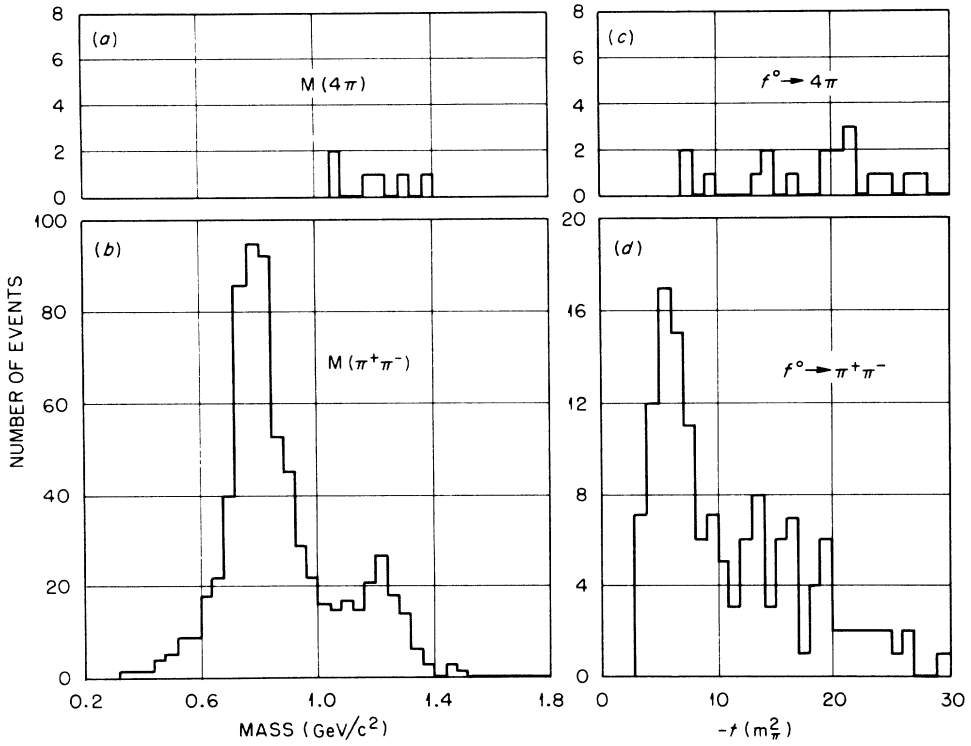

FIG. 3. For 3.29-GeV/c π^+d interactions: (a) 4π mass spectrum for the $pp\pi^+\pi^+\pi^-\pi^-$ final state with $(-t)_{\pi,4\pi} \leq 10\, m_\pi{}^2$. (b) 2π spectrum for the $pp\pi^+\pi^-$ final state with $(-t)_{\pi,4\pi} \leq 10\, m_\pi{}^2$. (c) Momentum-transfer distribution for 4π events in the f^0 region. (d) Momentum-transfer distribution for 2π events in the f^0 region.

ing these criteria,

$$F = \frac{f^0 \to 2\pi^+ 2\pi^-}{(f^0 \to \pi^+\pi^-) + (f^0 \to \pi^0\pi^0)}$$

$$= 0.017^{+0.010}_{-0.017}.$$

Finally, we display in Fig. 3 the corresponding data available from a 3.29-GeV/c π^+d experiment utilizing the 20-in. BNL bubble chamber for which each event corresponded to a cross section of 1.33 μb. Again there is no compelling evidence for any 4π decay of the f^0, and the branching ratio, F, is consistent with the above determination.

Our conclusion, from Fig. 2, is that the ratio of the decay of the f^0 into 4 charged pions relative to its decay into 2 pions ($\pi^+\pi^-$ and $\pi^0\pi^0$) is consistent with zero and has an upper limit of 3.3% with 90% confidence.

It should be pointed out that these results were obtained from a deuterium-target experiment and that we have ignored any possible effects resulting from final-state interactions, which could conceivably differ in the 2π and 4π channels.

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[1]G. Ascoli *et al.*, Phys. Rev. Lett. 21, 1712 (1968).

[2]B. Y. Oh *et al.*, Phys. Rev. D 1, 2494 (1970).

[3]M. Bardadin-Otwinowska *et al.*, Phys. Rev. D 4, 2711 (1971).

[4]Particle Data Group, Phys. Lett. 38, 1 (1972).

[5]G. Smadja *et al.*, in *Experimental Meson Spectroscopy – 1972*, Proceedings of the Third International Conference, Philadelphia, 1972, edited by Kwan-Wu Lai and Arthur H. Rosenfeld (A.I.P., New York, 1972), p. 349.