that their rejection does not appear justifiable. Their effect on the mean life is large, of course. The ratio of the decay rates of Ξ^0 and Ξ^- reported in this work is $0.51^{+0.15}_{-0.12}$. The $|\Delta I| = \frac{1}{2}$ rule predicts $\frac{1}{2}$ for this ratio. Other recently reported values of the Ξ^0 mean life are $(3.8^{+1.0}_{-0.7}) \times 10^{-10}$ sec by Jauneau et al.[7] and $(2.5^{+0.4}_{-0.3}) \times 10^{-10}$ sec by Hubbard et al.[2]

We wish to thank the hydrogen bubble chamber group at the Lawrence Radiation Laboratory and, in particular, Professor L. W. Alvarez, for their continuing friendly cooperation. We acknowledge gratefully many helpful discussions with Professor N. Byers, Professor M. Gell-Mann, and Dr. S. Fenster. Finally, we thank our scanners for their painstaking work.

---

*Work supported in part by the U. S. Atomic Energy Commission.

†Now at the University of California, San Diego, La Jolla, California.

[1]H. Schneider, Phys. Letters 4, 360 (1963); L. W. Alvarez, J. P. Berge, J. R. Hubbard, G. Kalbfleisch, J. Shafer, F. T. Solmitz, M. L. Stevenson, and S. Wojcicki (private communication); L. Jauneau, D. Morellet, U. Nguyen-Khac, A. Rousset, J. Six, H. H. Bingham, D. C. Cundy, W. Koch, M. Nikolić, B. Ronne, O. Skjeggestad, H. Sletten, A. K. Common, J. J. Esten, C. Henderson, C. M. Fisher, J. M. Scarr, R. H. Thomas, A. Haatuft, R. Møllerud, and K. Myklebost, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished); P. L. Connolly, E. L. Hart, G. Kalbfleisch, K. W. Lai, G. London, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, M. Gundzik, J. Leitner, and S. Lichtman, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished). These reports, along with portions of this work, have been reviewed by H. K. Ticho, Proceedings of the Conference on the Fundamental Aspects of Weak Interactions, Brookhaven National Laboratory, Upton, N.Y., September 1963 (unpublished).

[2]J. R. Hubbard, J. P. Berge, G. R. Kalbfleisch, J. B. Shafer, F. T. Solmitz, M. L. Stevenson, G. Wojcicki, and P. G. Wohlmut, University of California Radiation Laboratory Report No. UCRL-10819 (unpublished); and (to be published).

[3]T. D. Lee and C. N. Yang, Phys. Rev. 109, 1755 (1958).

[4]J. W. Cronin and O. E. Overseth, Phys. Rev. 129, 1795 (1963).

[5]N. Byers and S. Fenster, Phys. Rev. Letters 11, 52 (1963).

[6]M. Ademollo and R. Gatto, Phys. Rev. 133, B531 (1964).

[7]L. Jauneau, D. Morellet, U. Nguyen Khac, P. Petiau, A. Rousset, A. H. Bingham, D. C. Cundy, W. Koch, M. Nikolić, B. Ronne, O. Skjeggestad, H. Sletten, F. W. Bullock, A. K. Common, M. J. Esten, C. Henderson, F. R. Stannard, J. M. Scarr, J. Sparrow, A. G. Wilson, A. Halsteinslid, and R. Møllerud, Proceedings of the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished).

[8]S. Coleman and S. L. Glashow, Phys. Rev. Letters 6, 423 (1961).

OBSERVATION OF $f^0 \to 2\pi^0$ †

L. Sodickson, M. Wahlig, I. Mannelli,* D. Frisch, and O. Fackler
Laboratory for Nuclear Science and Department of Physics,
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 2 April 1964)

In a recent Letter, Frazer et al.[1] proposed that the f^0 meson is the neutral member of a 1^- triplet of which the $B^\pm$ mesons are the charged members. As one experimental test, they suggested looking for the decay mode $f^0 \to 2\pi^0$. If this decay mode exists, the spin of the f^0 must be even and the proposal cannot be correct.

We have observed the $f^0 \to 2\pi^0$ decay mode and conclude that the f^0 has even spin and positive parity. This agrees with earlier indications,[2] recently reinforced by Lee et al.[3]

We observe $f^0 \to 2\pi^0$ decays from forward-going f^0's produced in liquid hydrogen in the reaction $\pi^- + p \to f^0 + n$ at an incident pion momentum of 10 GeV/c. The four product gammas from $f^0 \to 2\pi^0 \to 4\gamma$ make showers in a 14-plate (5 radiation lengths) brass spark chamber. The spark chamber detects only those gamma rays produced within ±14° of the beam direction, and is protected by a scintillation counter which vetoes charged particles. Almost all of the remaining solid angle is covered by counters made up of alternate layers of lead and scintillator, which veto gamma rays as well as charged particles. This system is thus designed to be triggered only by events which yield only neutrals in the forward direction. This apparatus was used in high-energy $\pi^- + p \to \pi^0 + n$ elastic charge-exchange scattering survey at the Brookhaven AGS.

The geometry of the experiment was such that we could detect f^0's from the reaction $\pi^- + p \to f^0 + n$ if the f^0 was produced within ~10° of the forward direction and if the π's were emitted at angles between 60° and 120° in the center of mass of the f^0.

In this Letter we will use three coordinate systems. The quantities in the lab system will have no superscripts, those in the f^0 c.m. system will have a single asterisk superscript, and those in the $\pi^- - p$ c.m. system will have a double asterisk superscript.

The distribution of the number of f^0 decays as a function of the $\pi^- - p$ c.m. opening angle $\theta_{\pi\pi}^{**}$ between the two π's is strongly peaked at a minimum[4] opening angle given by $\sin(\theta_{\pi\pi m}^{**}/2) \simeq \beta_{\pi^0}^{*}/\gamma_{f^0}^{**}$, where $\gamma_{f^0}^{**}$ is the energy of the f^0 in natural units in the $\pi^- - p$ system and $\beta_{\pi^0}^{*}$ is the velocity of the π^0 in the f^0 c.m. system. This is just like the distribution of opening angles $\theta_{\gamma\gamma}$ near $\theta_{\gamma\gamma m}$ in the $\pi^0 \to 2\gamma$ decay. The f^0 from $\pi^- + p \to f^0 + n$ gives a minimum decay opening angle $\theta_{\pi\pi m}^{**} = 64°$ in the $\pi^- - p$ c.m. system for $p_{\pi^-} = 10$ GeV/c and $m_{f^0}c^2 = 1250$ MeV. This corresponds to a lab opening angle $\theta_{\pi\pi m} = 14°$ for an f^0 emitted in the forward direction.

For the symmetric f^0 decay corresponding to $\theta_{\pi\pi m}$ in the lab, i.e., at $\theta_{\pi_1^0}^{*} = \theta_{\pi_2^0}^{*} = 90°$ in the f^0 c.m. system, the π^0's from a forward-going f^0 have lab momenta $p_{\pi_1^0} = p_{\pi_2^0} \simeq p_{f^0}/2 \simeq 5$ GeV/c. For the most asymmetric decay we can observe from a forward-going f^0, corresponding to $\theta_{\pi_1^0}^{*} \simeq 60°$ the π^0's have $p_{\pi_1^0} \simeq 7.5$ GeV/c, $p_{\pi_2^0} \simeq 2.5$ GeV/c, and $\theta_{\pi\pi} = 1.14\theta_{\pi\pi m}$.

The strong peaking of the $\pi^0 \to 2\gamma$ opening angle $\theta_{\gamma\gamma}$ gives 50% of the decays in the range $\theta_{\gamma\gamma m} \leq \theta_{\gamma\gamma} \leq 1.16\theta_{\gamma\gamma m}$, where $\theta_{\gamma\gamma m} \cong 2/\gamma_\pi$, and allows us to use the bisector of the two γ's as the π^0 direction with fair accuracy. For $p_{\pi_1^0} = p_{\pi_2^0}$, we have $\theta_{\gamma\gamma m1} = \theta_{\gamma\gamma m2} = 3.1°$, and $\theta_{\pi\pi m} \simeq 5\theta_{\gamma\gamma m}$ for the completely symmetric case. Thus the $f^0 \to 2\pi^0$ events usually have two well-separated sets of gamma pairs. For the present analysis the $f^0 \to 2\pi^0$ opening angle $\theta_{\pi\pi}$ was taken to be just the angle between the bisectors of $\theta_{\gamma\gamma 1}$ and $\theta_{\gamma\gamma 2}$. No assumption was made about the f^0 direction since we are not attempting to measure the spin of the f^0 by the angular distribution of its decay π's.

The scanners measured only those 4γ events in which they thought they saw a pairing into two separated 2γ sets; these were about $\frac{2}{3}$ of the total 4γ events. Only the starting point of the shower caused by each γ was measured, and it was assumed that all γ's originated in the center of the hydrogen target. Thus for example the 2γ's from π^0's produced closer to the spark chamber are assigned a narrower opening angle than they have in fact. The error in angle from off-center production in the hydrogen target was at most ±6%.

In the upper histogram of Fig. 1 the number of events plotted as a function of $\theta_{\pi\pi}^{**}/\theta_{\pi\pi m}^{**}$ in the $\pi^- - p$ center-of-mass system shows a distinct peak just above $\theta_{\pi\pi}^{**}/\theta_{\pi\pi m}^{**} = 1$. The width of the peak has not yet been studied quantitatively, but seems reasonable considering the spread of $\theta_{\pi\pi}^{**}$ from the f^0, the width of the f^0 itself, and our angular resolution.

As cross checks, the data were replotted with various conditions on the sum of the $\pi^0 \to 2\gamma$ opening angles $\theta_{\gamma\gamma 1} + \theta_{\gamma\gamma 2}$. Under no circumstances should $2\pi^0$'s produced in the hydrogen by a 10-GeV/c π^- give $\theta_{\gamma\gamma 1} + \theta_{\gamma\gamma 2} < 2\theta_{\gamma\gamma m} = 6.2°$. The lower histogram shows the data surviving the cut $3° \leq \theta_{\gamma\gamma 1} + \theta_{\gamma\gamma 2} \leq 6°$. The few events left are primarily from $2\pi^0$ events produced in the veto scintillator about halfway between the target and the

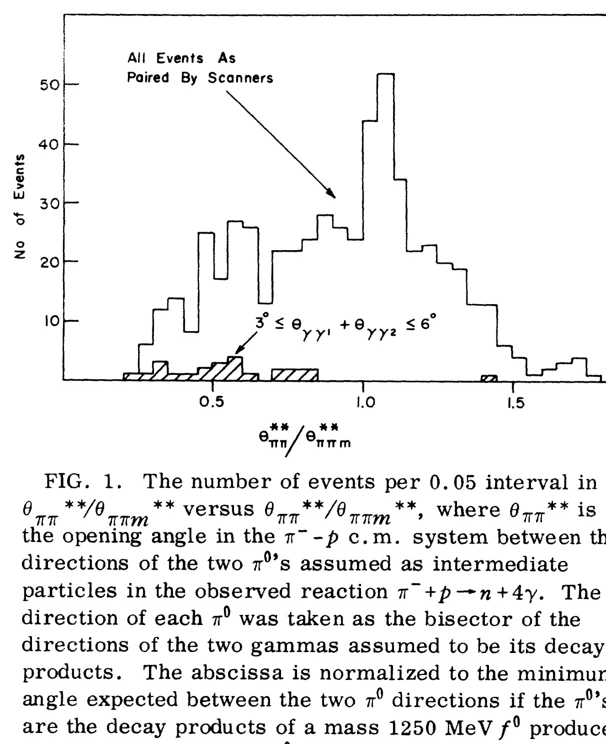

FIG. 1. The number of events per 0.05 interval in $\theta_{\pi\pi}^{**}/\theta_{\pi\pi m}^{**}$ versus $\theta_{\pi\pi}^{**}/\theta_{\pi\pi m}^{**}$, where $\theta_{\pi\pi}^{**}$ is the opening angle in the $\pi^- - p$ c.m. system between the directions of the two π^0's assumed as intermediate particles in the observed reaction $\pi^- + p \to n + 4\gamma$. The direction of each π^0 was taken as the bisector of the directions of the two gammas assumed to be its decay products. The abscissa is normalized to the minimum angle expected between the two π^0 directions if the π^0's are the decay products of a mass 1250 MeV f^0 produced in the reaction $\pi^- + p \to f^0 + n$. The analysis is done in the $\pi^- - p$ c.m. system to remove the dependence of the f^0 momentum on production angle. The lower histogram is the corresponding distribution for those events for which the sum of the π^0 decay opening angles is too small to come from the reaction $\pi^- + p \to n + 2\pi^0$.

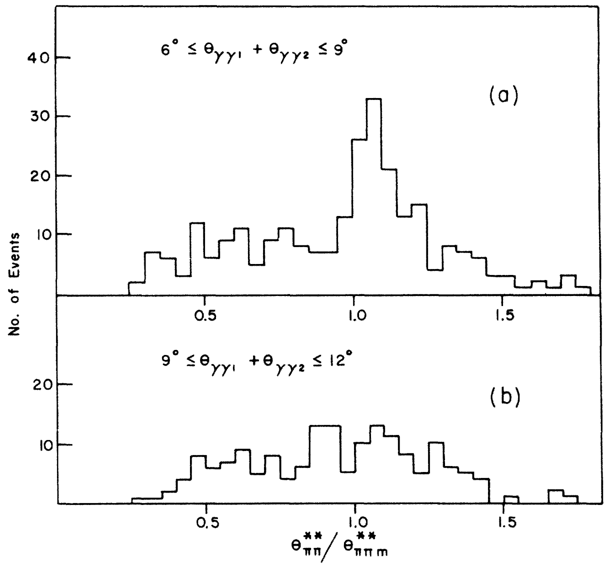

FIG. 2. Similar distributions when the sum of the decay opening angles of the two π^0's is between (a) 1.9 and 2.9 times the minimum opening angle for a 5-BeV/c π^0, and (b) 2.9 and 3.9 times the same minimum angle.

spark chamber.

The histogram in Fig. 2(a) shows the events left after the cut $6° \leq \theta_{\gamma\gamma 1} + \theta_{\gamma\gamma 2} \leq 9°$. Since for the most asymmetric f^0 decay observable here $\theta_{\gamma\gamma m 1} + \theta_{\gamma\gamma m 2} \simeq 1.3(2\theta_{\gamma\gamma m}) = 8.1°$, we expect most of the f^0's to survive this cut, as the events in the peak are seen to do despite the large reduction of the number of events outside the peak. If the γ's are mispaired purposely and reanalyzed, extremely few events survive this cut.

The histogram in Fig. 2(b) shows the events left after the cut $9° \leq \theta_{\gamma\gamma 1} + \theta_{\gamma\gamma 2} \leq 12°$. These can be from the tails of the $\theta_{\gamma\gamma}$ distributions, or caused by mispairing of gammas, or from a general inelastic background.

We conclude that the $f^0 \rightarrow 2\pi^0$ decay exists and the f^0 is restricted to even spin, to positive parity, and to even isospin if it is conserved in the decay.

We would like to thank Paul Mockett for suggesting the search for the f^0 decay with this equipment; E. Bonis, A. Buffington, T. Kan, P. Kirk, E. Shibata, S. Smith, L. Sompayrac, and especially L. Stinson, for crucial help in running the experiment and analyzing the data; and the AGS crew for constant support.

*NATO Fellow; on leave of absence from Pisa University, Pisa, Italy and Istituto Nazionale Fisica Nucleare, Sezione di Pisa, Pisa; present address: Istituto di Fisica, Pisa, Italy.

[1]W. R. Frazer, S. H. Patil, and N.-h. Xuong, Phys. Rev. Letters 12, 178 (1964).

[2]V. Hagopian and W. Selove, Phys. Rev. Letters 10, 533 (1963), and others listed in references 1 and 3.

[3]Y. Y. Lee, B. P. Roe, D. Sinclair, and J. C. Vander Velde, Phys. Rev. Letters 12, 178 (1964).

[4]Actually at this energy a π^0 going at 180° in the f^0 c.m. system is carried forward to 0° in the laboratory (giving $\theta_{\pi\pi} = 0$), but its γ's open too wide to be seen in the spark chamber.

ANISOTROPY OF PRIMARY COSMIC RADIATION AT THE EARTH

S. Standil and R. P. Bukata
Allen Physics Laboratory, The University of Manitoba, Winnipeg, Manitoba, Canada
(Received 10 March 1964)

This communication presents some results obtained in an experimental study of energetic, directionally selected muons at Winnipeg, Canada (longtitude 97.2°W, latitude 49.9°N, and altitude 236 meters). To the best of our knowledge the experimental method used is a new one. The results have been obtained during the present "quiet" part of the solar cycle (March 1963-February 1964) using two geometrically identical, equatorially mounted, narrow-angle muon telescopes. The two telescopes are mounted on a polar axis so that they and the polar axis are mutually perpendicular. (A telescope in the initial experiments consisted of two scintillators each 8.89 cm in diameter and 5 cm thick separated by 55.9 cm of lead, operated in coincidence.) The polar axis is rotated at the rate of one revolution per solar day in a sense opposite to that of the earth's rotation. Thus during a run the axis of each telescope lies in the plane of the celestial equator and is kept in a fixed orientation with respect to the projection of the earth-sun line in this plane (hereafter referred to as the PES line). The arrangement is thus such that 6 hours after one telescope has a given orientation with respect to the laboratory (and therefore the earth) the other telescope finds itself identically oriented. Because each tele-