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Stars initiated by π^--mesons in photographic emulsions have been examined in order to determine the probability that such a meson will form a star of a specified number of prongs. Preliminary results have been previously published in abstract form[1]. Recently, Perkins[2] has made a similar study using cosmic ray data. When account is taken of his different method of tabulating recoils, his distribution is compatible with that given in this paper.

[1] F. L. Adelman and S. B. Jones, Phys. Rev. 75, 1468(A) (1949)

[2] D. H. Perkins, Phil. Mag., Ser. 7, Vol. XL, p. 601 (1949)

It may be noted that these results are potentially useful in connection with the possible existence of mesons of mass different from that of either π or μ-mesons, since a prong spectrum is expected to be characteristic of each meson type.

The opportunity to study a group of π^--mesons with essentially no contamination by μ^--mesons was afforded by the determination of the mass of the π^--meson which was made in this laboratory[3,4,5]. The apparatus, shown in

[3] E. Gardner, Phys. Rev. 75, 1468(A) (1949)

[4] A. S. Bishop, Phys. Rev. 75, 1468(A) (1949)

[5] C. M. G. Lattes, Phys. Rev. 75, 1468(A) (1949)

Fig. 1, selects a group of mesons in a small momentum range. The channel was designed to eliminate π^--mesons of undesired moments as well as positive mesons, and to minimize the number of μ^--mesons. For this work Ilford C.2 emulsions were used. The mesons were measured by the method of $H\rho$ and range described in earlier reports[3,4,6].

[6] E. Gardner and C. M. G. Lattes, Science, 107, 270 (1948)

In order to estimate the μ^--contamination, the prong spectrum of those mesons in the central part of the distribution of meson masses was compared with the spectrum of the remainder of the group. Since the μ^--mesons would be products of the decay of π^--mesons in flight, their apparent mass values are expected to be distributed throughout the entire mass spectrum. However, it was found that these two prong spectra agreed within the probable errors. From these results and the assumption that μ^--mesons do not initiate stars[7,8], it is concluded

[7] W. Y. Chang, Rev. Mod. Phys. 21, 166 (1949)

[8] Y. Goldschmidt-Clermont, D. T. King, H. Muirhead, D. M. Ritson, Proc. Phys. Soc. 61, 183 (1948)

that no more than one percent of the mesons included in the total prong spectrum are μ^--mesons.

In making this study, those events were termed stars in which at least one track could be discerned leaving the terminus of the meson with a well-defined direction. A star was considered to have a recoil as one of its prongs when at least one of its branches was a "heavy" track less than five microns in length, with a definite direction. However, a poorly defined group of grains, showing no preferred direction, was not considered a prong, but was called a "club". A "club" may, in fact, be a nuclear recoil, but this interpretation is not certain.

Mesons which ended within five microns of either emulsion surface were discarded in order not to include stars all of whose prongs might not be observable. Photomicrographs of typical meson events are shown in Fig. 2.

In this study 512 π^--mesons were observed to end in the emulsion. Their prong spectrum is shown in Fig. 3. The 137 mesons which appear in the first column did not initiate stars. Fifty-two of these formed "clubs", as indicated by the blacked-in portion of this column. A count was not made of "clubs" which were associated with stars of one or more prongs. Shading in the other columns indicates stars which had a recoil prong as one of its branches. It was found that 26.8 $\pm$ 2 percent of the π^--mesons ending in the emulsion do not initiate observable stars. For all mesons in this study, the average number of prongs per meson is 1.7 $\pm$ 0.1.

Earlier prong spectra, taken with a different geometry, indicate that there is no statistically significant difference between Eastman NTB, Ilford C.2, and Ilford C.3 emulsions, and that there is also no significant difference between 50 and 100 micron emulsion thicknesses.

The prong spectrum in an electron sensitive emulsion (Eastman NTB3) was studied by Ellen Grunwald at the suggestion of Dr. W. H. Barkas. By grain counting, she found that in 64 π^--meson stars, no protons of energy greater than 40 Mev (or heavier particles of corresponding grain density) were emitted. Her prong spectrum was consistent with ours within the poor statistics. This agreement was to be expected, since no particles were found of energy greater than that registered by Ilford C.2 emulsions (protons of 50-60 Mev). A few slow electrons were observed, but no high energy electrons were seen. Since low energy electrons often could not be reliably assigned to an event because of the heavy background of low energy electrons, no estimate of their frequency of occurrence is given here. This work is being continued by one of us (F. L. A.) using Ilford G.5 emulsion.

The decay of a π-meson at rest into a μ-meson has been observed in photographic emulsions[9]. A significant question has been whether this process

[9] C. M. G. Lattes, H. Muirhead, C. P. S. Occhialini, C. F. Powell, Nature 159, 694 (1947)

is restricted to positive mesons. In the more than 4000 π^--mesons that have been observed at this laboratory to end in the emulsion, only two events have been found (by Drs. W. H. Barkas and H. Bradner) which may be interpreted as negative π-μ decays. However, the possibility that these are stray π^+-mesons has not been ruled out; the probability is even larger that they are decays of π^--mesons which take place before the π^--meson comes to rest. It follows that, since the emulsion consists of discontinuous grains of AgBr and gelatin[10],

[10] J. H. Webb, Phys. Rev. 74, 511 (1948)

π^--mesons seldom, if ever, undergo π-μ decay either in gelatin, which consists of light elements, or in AgBr. This substantiates the assumption of Lattes et al[11] that the π-μ decays observed in cosmic ray photographic emulsions are decays

[11] C. M. G. Lattes, C. P. S. Occhialini, C. F. Powell, Nature 160, 486 (1947)

of positive mesons.

Among 3000 meson events, eleven "hammer" tracks were found. A photomicrograph of such an event is shown in Fig. 4. These "hammer" tracks are attributed to the emission of a Li^8 nucleus as a star prong[12]. The Li^8 decays

[12] C. Franzinetti and R. M. Payne, Nature 161, 735 (1948)

into Be^8 with a half life of 0.88 seconds and the Be^8 disintegrates into two alpha-particles of equal energies with a half life[13] of the order of 10^{-21} sec.

[13] Calculated from energy spread given by T. W. Bonner, J. E. Evans, C. W. Malich, J. R. Risser, Phys Rev. 72, 163 (1947)

The presence of these "hammer" tracks implies that the emission of fragments other than alpha-particles and nucleons might occur with significant probability. This conclusion is not inconsistent with the observation of deuterons and tritons in high energy nuclear reactions induced by the Berkeley 184-inch cyclotron[14].

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[14] K. Brueckner and W. M. Powell, Phys. Rev. 75, 1274 (1949)

Since it is extremely difficult to distinguish these heavier nuclei from alpha-particles in the emulsions used, and since an unknown number of neutrons is emitted from each star, the detailed calculation of the energy given up to the star by the meson is impracticable in most cases.

We are indebted to Professor Ernest O. Lawrence for his continued interest in this work. We also wish to thank Professor R. L. Thornton and Drs. Eugene Gardner and C. M. G. Lattes for much helpful discussion. The authors are very grateful to F. M. Smith and D. J. O'Connell for microscopic work, to A. J. Oliver for the photomicrographs, and to James Vale and the cyclotron crew for making the bombardments. This work was done under the auspices of the Atomic Energy Commission.

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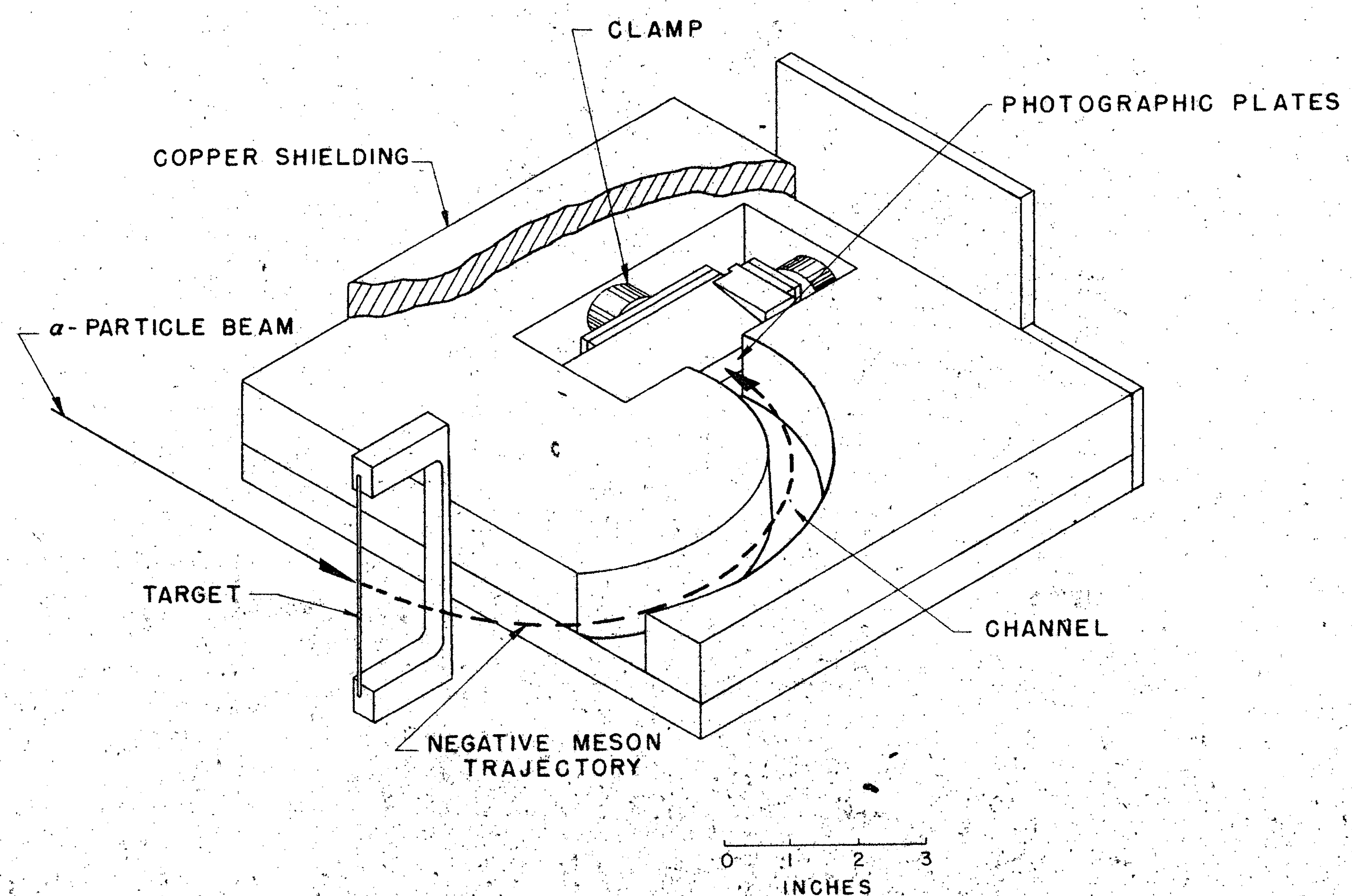

FIG. 1

SCHEMATIC DIAGRAM OF APPARATUS FOR OBSERVING π^--MESONS

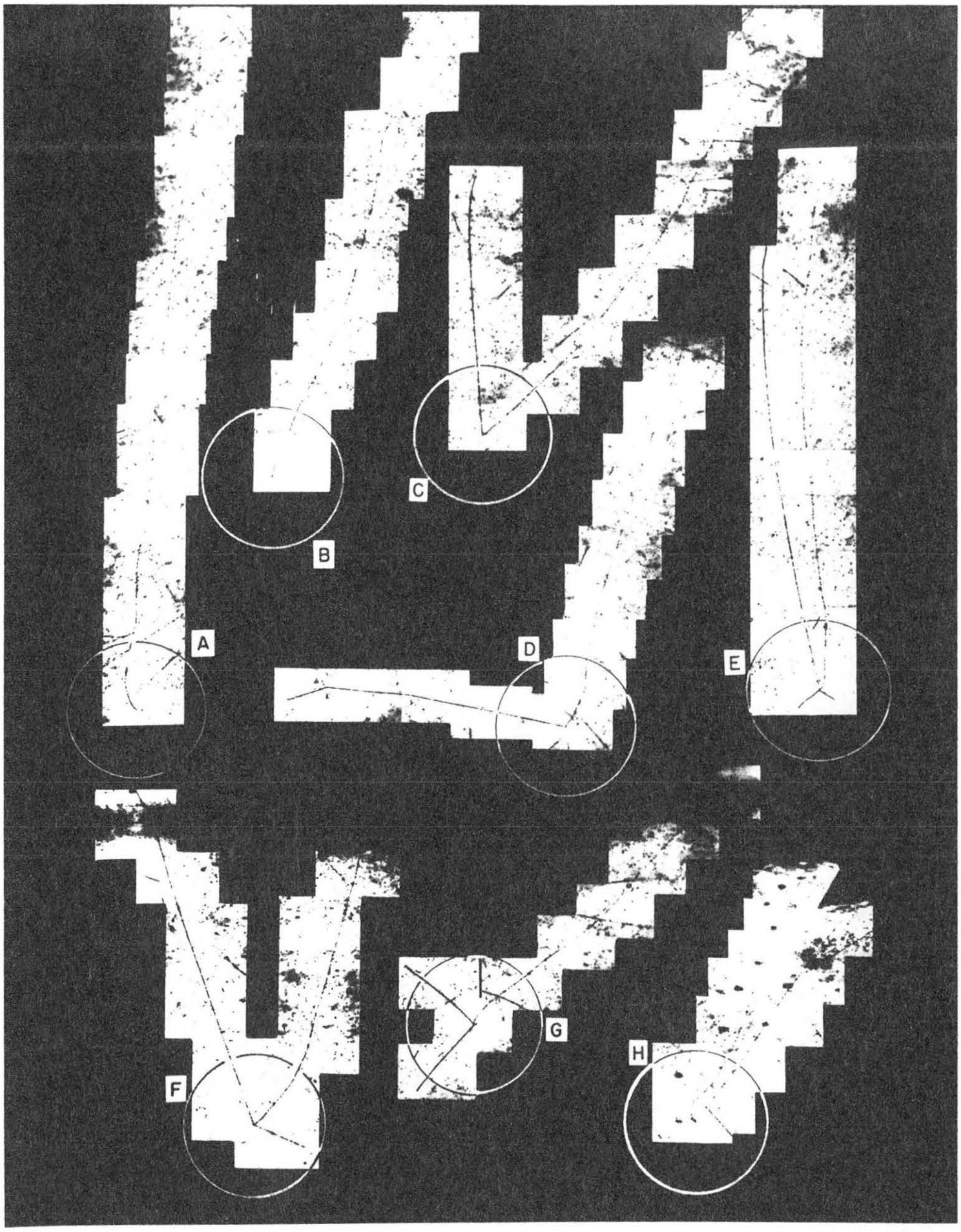

Fig. 2

Typical π^- -meson events. Mesons enter at top of each photomicrograph. Each circle is 100 microns in diameter. (A) Meson ending with no event associated; (B) Meson forming a "club"; (C) 1-prong star; (D) 1-prong star; (E) 3-prong star; (F) 2-prong star; (G) Star with 3 prongs, one of which is a recoil prong; (H) Star with 2 prongs, one of which is a recoil prong.

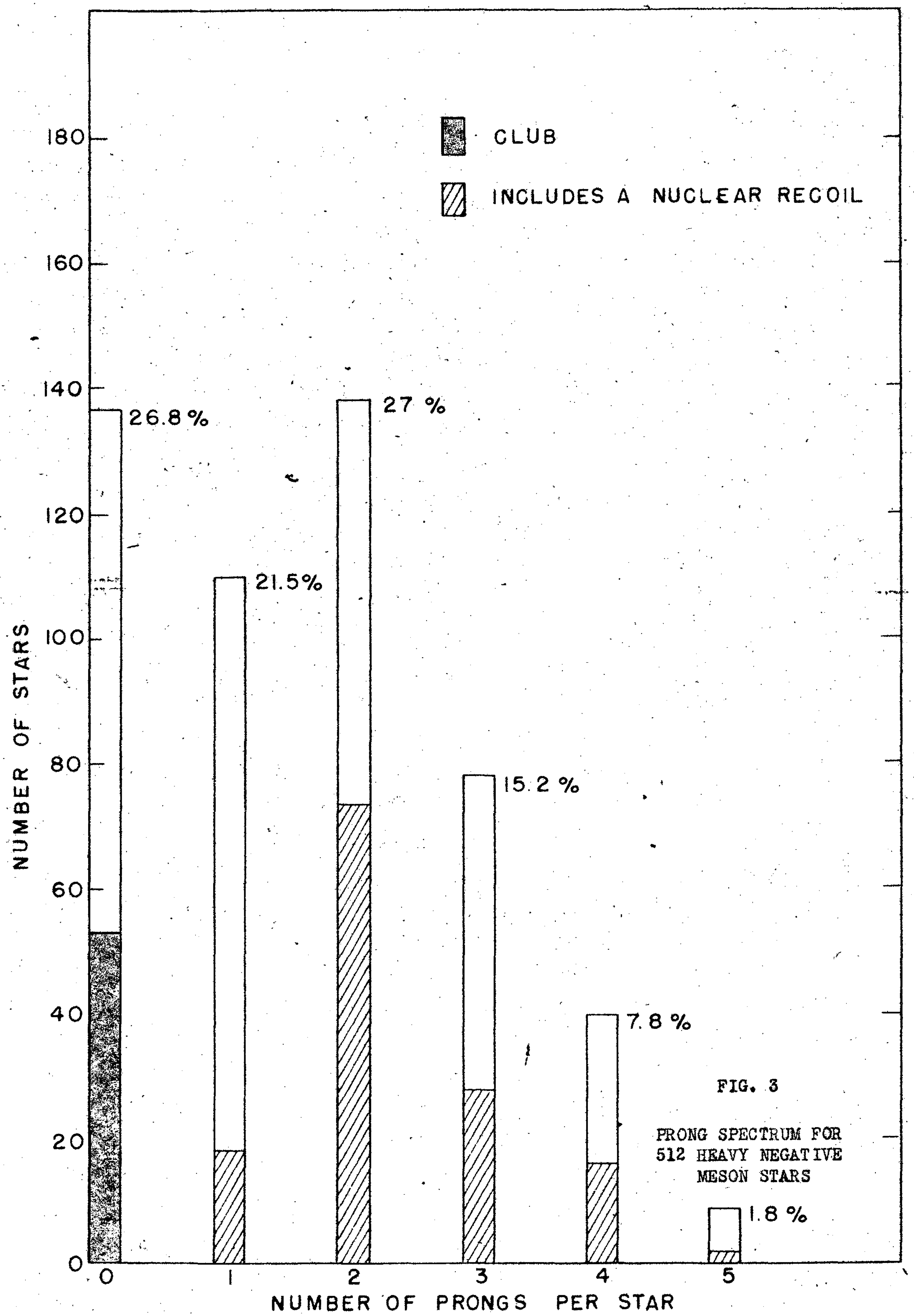

FIG. 3

PRONG SPECTRUM FOR 512 HEAVY NEGATIVE MESON STARS

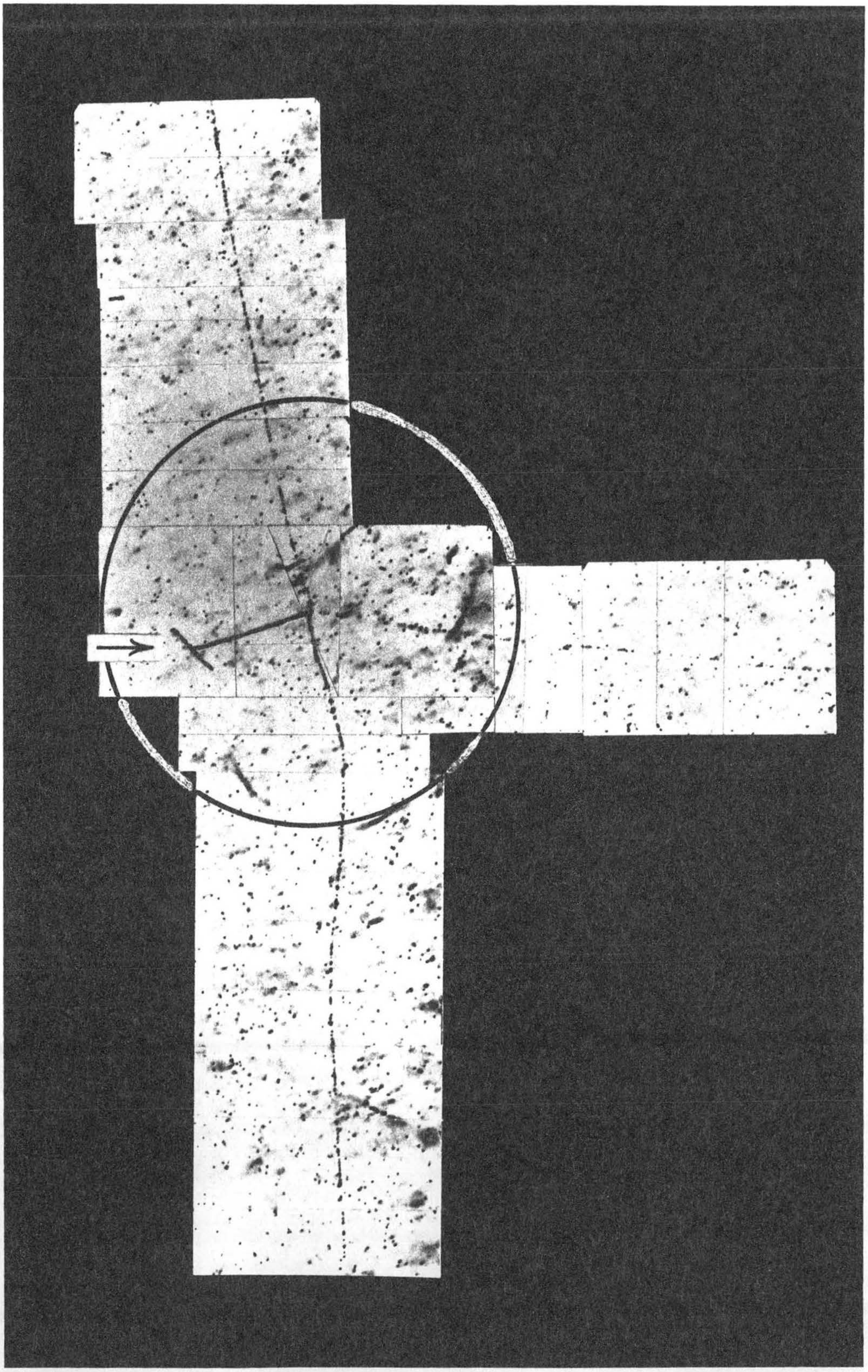

FIG. 4

"HAMMER" TRACK (A) FROM STAR INITIATED BY π^--MESON ENTERING FROM THE TOP