Evidence Against the Mass-500 Particle*

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The existence of a mass-500 particle was investigated by exposing a nuclear emulsion to cosmic rays at an altitude of 10 600 feet and geomagnetic latitude 39°. Particles of average range, 60 g/cm^2 of copper, were stopped in the emulsion and grain counted at a residual range of 1 cm. The available track length was such that the existence of a mass-500 particle would have been established on the basis of a single occurrence. About 1100 muons were found with no particles in the region of 500 electron masses being observed. This is not consistent with the abundance reported by Alikhanian *et al.*, since the probability of finding none, assuming their reported abundance, is 0.4%.

I. INTRODUCTION

THE existence of a cosmic-ray particle of about 540 electron masses was reported by Alikhanian *et al.*[1] Subsequently, several attempts were made to confirm the existence of such a particle but none has met with success.[2] The present experiment which utilizes nuclear emulsions, rather than cloud chamber and counter apparatus as in the Alikhanian experiment, is one such attempt.

The major features of this experiment are the following: (1) it is carried out at an altitude, geomagnetic latitude, and particle energy which almost exactly duplicates that in the Alikhanian experiment; (2) particles are detected by a method which would have established the existence of a mass-500 particle on the basis of a single occurrence; and (3) the nonoccurrence of such particles not only fails to confirm the reported abundance, but contradicts it.

II. EXPOSURE

A stack of 100 Ilford *G*-5 nuclear emulsion pellicles, each 3 in. by 5 in. by 600 microns was exposed on Mt. San Jacinto, California, from September 29 to October 19, 1957, at an altitude of 10 600 feet and geomagnetic latitude 39°. Alikhanian *et al.* worked at 10 600 feet and 36°. Copper was placed above the stack so that particles stopping in the center of the scanning region passed through an equivalent amount of absorbing material as did those in Alikhanian's experiment, i.e., 60 g/cm^2 of copper. This corresponds to an average momentum of 370 Mev/c for muons. The pellicles were shuffled and the stack kept upside down except during the exposure so that only particles which traversed the series of pellicles during the exposure time could be traced back through upon scanning.

Figure 1 shows the geometry of the exposure and the region scanned.

III. MEASUREMENT PROCEDURE

Area-scanning was carried out on 25 cm^3 of the stack for stopping particles that entered the field of view within 45° of the zenith. All particles that were not clearly protons, as judged by the grain density and scattering in the last three millimeters and the lack of a secondary, were followed back to the pellicle where the central region of depth was traversed closest to 1 cm residual range. There they were grain-counted; the average count was about 300 grains in 600 microns of track length. Each count was then corrected for dip, normalized to that for 1 cm residual range, and normalized to 1 for each scanner's average count. No attempt was made to reach a scanning efficiency of precisely 100% or to follow the angular criterion exactly; rather what was sought was an efficiency which was at least as great for mass-500 particles as for lighter particles since Alikhanian expressed the frequency of occurrence of the mass-500 particle relative to that of muons.

Particles entering the emulsion at its leading edge travelled an average of 4.3 cm, thus giving a track length sufficient for about 50 independent counts of 400 grains each on any possible mass-500 particle. Fluctuations of about 0.8 times the square root of the

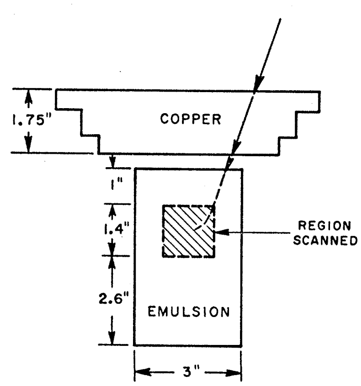

FIG. 1. Arrangement of emulsion stack and copper absorber during exposure on Mt. San Jacinto.

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[1] Alikhanian, Shostakovich, Dadain, Fedorov, and Deriagin, J. Exptl. Theoret Phys. U.S.S.R. **31**, 955 (1956) [translation: Soviet Phys. JETP **4**, 817 (1957)].
[2] For a summary of these experiments see *1958 Annual International Conference on High-Energy Physics at Cern*, edited by B. Ferretti (CERN, Geneva, 1958).

number of grains counted were expected due to statistics alone. This corresponds to an error of 12% in the mass inferred from any one count of 400 grains. A conclusive mass measurement was therefore possible on any particle entering from outside. In fact, any particles produced in the emulsion having a residual range greater than 2 cm would have been identified. All 15 of Alikhanian's mass-500 particles entered his apparatus from outside. Particles produced in the emulsion at less than one cm residual range were not grain-counted because the mass measurement would not have been conclusive and they were irrelevant to the findings of Alikhanian.

IV. RESULTS

Figure 2 is a histogram of the grain densities of the 1202 particles of less than proton mass which were found in the experiment. The standard deviation of the 1094 muon counts is 8%, of which 5% is due to statistics. The remaining contribution to the error is probably due to small variations in grain-counting criteria. The errors due to straggling, scattering, shrinking, and nonuniform development were negligible.

As a particle of 540 electron masses would have a grain density 1.36 times that of the muon at 1 cm residual range, Fig. 2 tentatively indicates that none of the particles observed in this experiment have that mass. To make this conclusive, the particles on each end of the tail were counted in another plate and the count normalized by the same procedure. This yielded an independent measurement of the mass which in every case confirmed the conclusion that the particle was a pion or a muon.

The grain densities of the 108 particles having characteristic π endings ($\pi-\mu-e$ decay and visible capture stars) are indicated by the shaded region in Fig. 2.

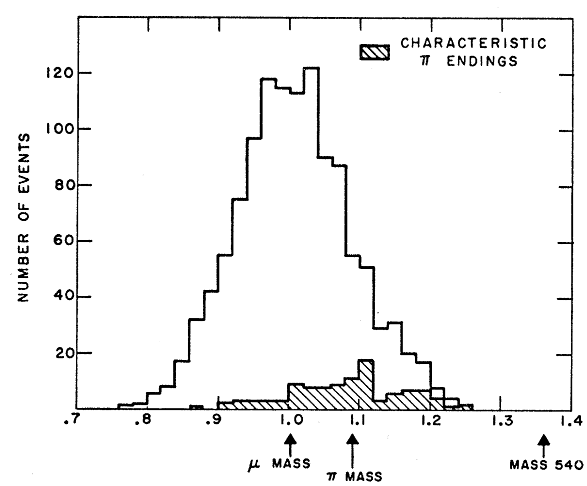

FIG. 2. Histogram of the grain density, relative to the average muon grain density, of the 1202 particles found of less than proton mass. The shaded area of the histogram represents 108 events which had characteristic π endings. All events above 1.185 and below 0.815 were grain-counted again at different residual ranges. In each case the additional grain-counting indicated that the particle was a muon or pion.

In order to make certain that mass-500 particles were not missed as a result of their incorrect identification as protons by the scanners, the following test was carried out: old plates were area-scanned under similar conditions in a region where there were both K and proton endings. Under the magnification used the secondaries were not visible, making identification depend on scattering and grain density. Ninety-two percent of the K mesons were identified as probable or possible K mesons. In scanning the mass-500 emulsions, care was taken not to overlook any K mesons and as the efficiency of the scanners at this mass was proven to be high, it is concluded that mass-500 particles were not overlooked as protons. The efficiency for finding mass-500 particles was actually higher than for other masses since many particles were followed back and grain-counted because they "looked interesting," despite being outside the angular criteria.

All possible K mesons were carefully examined under intermediate magnification for secondaries. As the minimum grain density was 24 grains per hundred microns, secondaries were fairly obvious, and in fact the majority of the muon secondaries were noticed without searching. If any doubt remained, the heavy particle was followed back and grain-counted. No K mesons were detected in the experiment.

Fifty positive pions were found with ranges which were at least 1 cm long using the same angular criterion as for the muons. The corresponding number for negative particles producing visible capture stars was 58. According to Fry,[3] 3.1% of negative muons stopping in G-5 emulsion produce stars with at least one prong longer than 10 microns. Assuming a positive excess of 20% for the muons, 15 capture stars were produced by negative muons and therefore 43 of the aforementioned 58 stars were due to negative pions. Assuming further that 30%[4] of all negative pions did not produce any visible capture star, the conclusion is that about 110 pions were found altogether.

There seems to be some disparity in the results of various workers with regard to the relative frequency of the production of K mesons. It should be pointed out that the ratio $K/\pi^{\pm}$ is not independent of the choice of the range or momentum or velocity interval in which both K and π mesons are selected. The exact dependence is still unknown. However, the various experiments performed in connection with this ratio indicate that, whatever the conditions were, the $K/\pi^{\pm}$ ratio is not larger[5,6] than 3% and very probably[7] varies be-

[3] W. F. Fry, Phys. Rev. **85**, 676 (1952).
[4] Beneventano, Carlson-Lee, Stoppini, Bernadini, and Goldwasser, Nuovo cimento **12**, 156 (1954).
[5] Amaldi, Fabri, Hoang, Lock, Scarci, Touschek, and Vitale, Suppl. Nuovo cimento **12**, 419 (1954).
[6] Bridge, Peyrou, Rossi, and Safford, Phys. Rev. **90**, 921 (1953).
[7] J. Hornbostel (private communication).

tween 0.4% and 1.5%. The result of the present experiment is therefore consistent with other experiments.

Alikhanian *et al.*, on the other hand, report a value of 8% for $K/\pi^{\pm}$. This value is still uncorrected[8] both for the difference in the lifetimes of the π and K mesons and the difference in the time of flight. The corrected value of Alikhanian should be 14% which is too large by at least a factor of five.

V. CONCLUSION

If the mass 540 existed in an abundance of one in every 200 muons, as claimed by Alikhanian, this experiment should have yielded five or six. The probability of finding none in that case is 0.4%. We thus conclude that the existence of the mass-500 in the abundance reported is not consistent with the present experiment

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[8] This has been kindly pointed out to us by Dr. J. Hornbostel.

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Further Evidence for a Variation in the Rate of Dense Extensive Air Showers with Solar Time*

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The variation in the rate of dense extensive air showers with solar time previously found in Dublin, Ireland has been confirmed using a similar apparatus situated in Mona, Jamaica. It is suggested that this and other variations in rate with solar time may possibly be due to a periodic change in the structure function of the showers.

In 1956 a variation in the rate of dense extensive air showers with solar time was reported.[1] It appeared to be correlated with the semidiurnal oscillations of the atmosphere. In order to corroborate the effect and to study it further, a similar (but completely new) apparatus was setup on the campus of the University College of the West Indies at Mona, Jamaica. A site on a tropical island was chosen because of the well known increase of the amplitude of the semidiurnal wave in the atmosphere near the equator. As in the previous experiment the apparatus consisted of 6 M units, each M unit being 3 small Geiger-Müller counters each of sensitive area 14 sq cm placed at the corners of a horizontal equilateral triangle of side 20 cm. A coincidence of the three counters provided a master pulse. The event was classed as an extensive shower if an unshielded tray of Geiger counters of area 2100 cm^2. placed some meters from the M unit was discharged, and as a local shower if not. Events in which two or more M units were discharged simultaneously were called multiple events. Considerable care was taken to exclude spurious variations in rate. All voltages (even heater voltages) were stabilized using a Servomex A.C.7 stabilizer which does not distort the wave form. The more critical voltages were then subjected to a further stabilization. Many precautions to avoid pickup were taken and the many tests applied failed to reveal its occurrence. The apparatus was tested at least twice a week. Finally the "local" events provided a monitor rate which showed no variation with time.

Figure 1 shows the rates averaged over two-hour periods of the "extensive" events plotted against solar time for the Dublin station for the period March, 1955 to March, 1956 and for the Jamaican station for the period August, 1957 to August, 1958. The average daily pressure variation at Mona is also shown. For the Dublin station the probability that the results could be due to chance assessed using a χ^2 test applied to 4-hourly averages is 0.003, or for the "multiple events," 0.002. The amplitude of the semidiurnal wave for the extensive events (calculated by the method of Chapman and Bartels[2]) is 13% with a probability that it could be due to chance of 0.0008.

For the Jamaican station the corresponding values

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[1] C. B. A. McCusker and B. G. Wilson, Nuovo cimento **10**, 188 (1956).

[2] S. Chapman and J. Bartels, *Geomagnetism* (Oxford University Press, Oxford, 1940), Vol. 2, p. 580.