Notas de Física Vol. III - Nº 26

ANGULAR CORRELATION IN THE π-μ-e DECAY OF COSMIC RAY MESONS[§]

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Rio de Janeiro, D. F.

(Received 20th November, 1957)

Experiments at Columbia[1] and Chicago[2] have shown an angular correlation in the π-μ-e decay with accelerator produced π^+-mesons. We have studied the same angular distribution for cosmic ray produced π^+-mesons. The π-μ-e decays which we have measured were produced in a stack of 600 μm emulsions having a total volume of

§ This work was principally supported by the joint program of the O.N.R. and the A.E.C. The work was also materially assisted by funds from the Graduate School, University of Minnesota. Published in Il Nuovo Cimento 6, 63 (1957).

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22.4 liters. The exposure was made in a balloon flight in Minnesota at a geomagnetic latitude of 56° on September 18, 1956. The flight had a duration of 8 hours at an altitude of 116.000 feet. Because of the possible depolarization effect of external magnetic fields, we have investigated the magnetic field in the gondola and find that the magnetic field did not exceed the earth's field of 0.5 gauss throughout the emulsion stack.

A portion of the stack was scanned under 10x15 power with the requirement that π-μ decay be complete in one emulsion. Measurements were made on those events in which the end of the μ-meson was at least 30 μm from either emulsion surface in the processed emulsion. The second requirement was imposed in order to insure reliable observation of the decay electron regardless of its direction of motion. If such a criterion is not imposed, some electrons will be missed; in addition because of the geometry, the probability of missing will be greater for electrons moving forward with respect to the direction of the μ-meson before it comes to rest. Since this latter direction is highly correlated with the initial direction of the μ-meson originating from the π-μ decay, a loss of these electrons could give rise to an artificial backwards asymmetry. We have measured the space angle θ between the direction of the emission of the μ and that of its decay electron for 2117 events satisfying the prescribed conditions. In only 7 cases we were unable to find the electron track. The resultant angular distribution is shown in Fig. 1.

The mean value of cos θ was -0.011 ± 0.013. Other investigators have expressed their results in terms of the value of a in the expression $dN/d\Omega = (1 + a \cos \theta)$, where $dN/d\Omega$ is the number of events per unit solid angle as a function of θ. In this expression the constant <u>a</u> is 3 times the average value of the cos θ. Our results, therefore, give a = - 0.03 ± 0.04, in marked contrast to the values which have been measured for machine-made π^+-mesons. These are tabulated in Table I.

TABLE I

Values of «a» determined for machine-made π^+ mesons

	«a»	Accelerator in which the mesons were produced	
Columbia (1)	- 0.16 ± 0.03	Columbia	~ 400 MeV
Chicago (2)	- 0.17 ± 0.04	Chicago	~ 450 MeV
Göttingen (3)	- 0.09 ± 0.04	Chicago	~ 450 MeV
Rochester (4)	- 0.19 ± 0.055	Cosmotron	~ 2000 MeV

The great discrepancy between our result and the average machine result suggests some systematic difference between the experiments. The possibilities which we have considered are the following:

1) Magnetic field conditions.
2) Depolarization due to chemical effects such as anomalous muonium formation.
3) Energy of collisions in which the π^+ are produced.
4) Possible difference between cosmic ray primaries and laboratory protons.
5) The presence in our experiment of a large quantity of local matter in which the mesons are produced.

I. MAGNETIC FIELD CONDITIONS

The magnetic field in our experiment was ~0.5 gauss mainly in the plane of the emulsion. It was shown by the Columbia experiment that the mesons that show the asymmetry precess at a rate of $1.35\cdot10^4$ rad s^{-1} G^{-1}. This rate of precession produces a negligible depolarization in our magnetic field, unless anomalous muonium formation takes place.

II. DEPOLARIZATION DUE TO CHEMICAL EFFECTS SUCH AS ANOMALOUS MUONIUM FORMATION.

It is known that the asymmetry is sensitive to the material in which the μ^+ is brought to rest [1,2]. Small changes in composition of the emulsion or water content could perhaps catalyze muonium formation which would make the asymmetry decrease. This possibility cannot be ruled out, but it should be pointed out that all accelerator experiments with G-5 emulsion exposed at approximately 70° F have shown the asymmetry. These were the conditions of exposure in our experiment. Furthermore, the value of the mean range of the μ-mesons in our emulsion (602 ± 4 μm) indicates that the density during exposure is typical of that normally encountered.

III. ENERGY OF COLLISIONS IN WHICH THE π^+ ARE PRODUCED

We investigated the origin of 50 low energy $\pi^{\pm}$ which were created and brought to rest in the same emulsion sheet. The $\pi^{\pm}$-mesons that are brought to rest in the stack are mainly those with energies less than 100 MeV (range ≈ 10 cm). It is known that the energy spectrum of $\pi^{\pm}$ varies only slowly with the number of shower particles in the star. It is, therefore, plausible to assume that the 50 stars investigated are fairly representative of the origin of the π^+-mesons measured in our experiment. The mean number of charged shower particles N, for the stars was five, and 65% and three or more fast charged shower particles. The slow pion was not counted as a shower particle. The number of $\pi^{\pm}$ produced therefore was approximately $(\bar{N}_s+1)$. This situation is completely different from Columbia and Chicago whose production is single, and Brookhaven where multiple production of three or more mesons is small.

IV. POSSIBLE DIFFERENCE BETWEEN COSMIC RAY PRIMARIES AND LABORATORY PROTONS.

The difference between the accelerator result and the cosmic ray result may be due to some inherent difference in the nature of the pion producing particle. As Yang and Lee[5] have suggested, particles may exist which differ in handedness from laboratory particles. Even if there is no such fundamental difference between cosmic ray protons and laboratory protons, the null result for the cosmic ray asymmetry may arise because of the fact that in cosmic ray events neutrons and pions as well as protons can give rise to meson production. In accelerator experiments the pion producing particles have been protons. Of the primary cosmic ray nucleons possessing energy in excess of 1 GeV, ~14% are neutrons, which occur as constituents of α-particles and heavier nuclei. Further, as the cosmic ray beam progresses down through the atmosphere (or emulsion), the percentage of neutron primaries for meson producing events increases. Neutrons can make π^+ in multiple production in collision with neutrons as well as with protons in the target nucleus.

V. THE PRESENCE IN OUR EXPERIMENT OF A LARGE QUANTITY OF LOCAL MATTER IN WHICH THE MESONS ARE PRODUCED.

The 22.4 liter stack in which our mesons were produced weighed 300 pounds. The large amount of local matter leads to the followig effects:

a) Many of the pion producing particles are no longer primary cosmic rays as discussed in Sect. IV.

b) Pions emitted over a range of angles in the center of mass system can be brought to rest in our stack. In a small emulsion stack exposed to cosmic rays only pions emitted in the backwards direction in the C system will be stopped.

c) Because of the large average path of pions in our stack (approximately 10 cm), many of these pions will have suffered nuclear scattering before coming to rest.

VI. CONCLUSION

If we assume that all π^+-mesons are identical, it appears that one must accept our result as a consequence either of a large statistical fluctuation or a peculiar chemical effect which was present in our case but absent in all of the accelerator experiments. On the other hand if more than one kind of π^+-mesons is presumed to exist, a different mixture may have been selected in our experiment than that so far observed in accelerator investigations. Such a selection might result if some basic property of the π^+-meson was influenced by the nature of the pion producing particles, by the angle of emission of the meson in the center of mass system of the colliding nucleons, or by processes such as nucler scattering which occurs before the pion is brought to rest.

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