

Study of a Pair of π^+ , π^- Mesons with Unusual Characteristics

By Beatriz Roederer and Juan Roederer*

During calibration of a block of Ilford G-5 emulsions, exposed at an altitude of 29 km during a flight over Italy ("Mantua" grid square), we found a pair of ionization tracks close to the level of minimal ionization. Following careful measurements, we noted that we were dealing with a pair of π mesons, originating in the center of the block and directed upward, in the opposite direction to that of the impinging cosmic radiation. The angle between the two tracks seems to be less than 0.014 rad, which separation is due to scattering.

One track runs at 7 cm inside the block and then leaves at one edge; the other leaves after 2 cm. Both are practically horizontal. We made careful ionization and scattering measurements, in order to determine the mass and energy of both particles. For ionization measurements we used the method of Fowler and Perkins.¹ The calibration curve given in Ref. 1 was verified with protons and π mesons, which gave coinciding results for proton ranges greater than 2 cm. The measurements carried out on both tracks are summarized in Table 1. Since we could not reach the end of each track, we shall assume that we are dealing with a pair of π^+ , π^- mesons.

Table 1. Measurements of Two Tracks in an Emulsion (g is the coefficient of the gap distribution curve,¹ and g_0 corresponds to a "plateau" of ionization)

	Distance from origin, cm	g/g_0	$p\beta$ as determined by scattering	Mass	Energy (Mev) at the point of production
Track 1	0	1.14 ± 0.03	160 ± 30	π	105 ± 10
	1.6	1.17 ± 0.03			
Track 2	0	1.05 ± 0.04	290 ± 50	π	134 ± 6
	4.1	1.14 ± 0.03			
	6.1	1.19 ± 0.03	180 ± 30		

The interesting fact, as regards this pair of mesons of such low energy, is the very small angle noted in the laboratory (L) system. It is easy to show that this angle, once transformed to a center-of-mass (c.m.) system (corresponding to the particle or particles which produced the pair) having a velocity β_0 , would

continue to be very small, except in a short interval around $\beta_0 = \beta_{\pi_1} = 0.82$ and $\beta_0 = \beta_{\pi_2} = 0.86$.

Nevertheless, it is precisely in this area, for which the mesons could have been emitted with arbitrary angles in a c.m. system, that the kinetic energy of both particles in the c.m. system cancels out, as can be judged within the accuracy achieved. As a consequence, if we find no process for the production of the pair by which β_0 comes out at 0.82–0.86, we must conclude that this pair of low-energy π mesons was emitted in a c.m. system which is markedly collimated forward.

THE PRODUCTION PROCESS

We shall make the following hypotheses regarding the production process.

(1) *Disintegration into two bodies of a neutral particle in flight.*—The neutral particle has a mass of $550 \pm 10 m_e$, and $Q = 2 \pm 5$ Mev. The energy of the primary must be 241 Mev. Therefore we cannot be dealing with the disintegration of a θ^0 meson.

(2) *Disintegration of τ^0 in flight.*—Since in all cases the energy in the c.m. system of the charged π mesons from the disintegration of τ^0 unquestionably is very different from zero, both pions should have been emitted precisely in the forward direction and the π^0 backward, also in the c.m. system. In this special case we can figure out the kinematics of the disintegration exactly. We obtain the following values for the energy of the pions in the c.m. system: $E_{\pi_1} = 9.8$ Mev, $E_{\pi_2} = 17.5$ Mev and $E_{\pi_0} = 53.2$ Mev. The maximum permissible angle between the charged pions would be 0.03 rad. In the L system, τ^0 would have an energy $E_\tau = 166$ Mev, and neutral pion $E_{\pi_0} = 0.2$ Mev. While this process is possible, the probability that the required geometrical conditions would occur simultaneously is extremely small.

(3) $n + n \rightarrow n + n + \pi^+ + \pi^- + (\pi^0)$.—*A priori* we could object to this hypothesis, since when a neutron leaves a nucleus it leaves behind a β -active nucleus; however, at the origin of the pair in question we observe no electron track.† The minimum energy needed, in the L system, for the production of a pair of charged mesons under the conditions of the phenomenon we

Original language: Spanish.

* Comisión Nacional de Energía Atómica, Buenos Aires, Argentina.

† Only the Ag^{109} nucleus is changed to another stable nuclide, as long as there is a secondary collision with the emission of another neutron.

are observing is approximately 1.2 Gev (without allowing for the Fermi energy of the neutron which is used as a target). This result was obtained by supposing that the particle which compensates the momentum of the π^+ , π^- pair in the c.m. system is one π^0 , or one or both neutrons; in either case, the result is the same. It is very difficult to account for the origin of a neutron which has so much energy and passes through the block in a direction opposite to that of the primary cosmic radiation. In addition, the maximum energy of the π^+ , π^- pair in the c.m. system would be only 31 Mev; the marked collimation provides one more argument against the $n+n$ process.

(4) $\gamma + n \rightarrow n + \pi^+ + \pi^-$.—Disregarding, in the first instance, the Fermi energy, we obtained in the L system an energy E_γ of 523 Mev for the photon, and a final energy of $E_n \simeq 7$ Mev for the neutron. This means that, after impact, the neutron would probably still be within the nucleus. Considering now the Fermi energy of 22 Mev and the most favorable geometric conditions possible, we obtain $E_\gamma = 505$ Mev and $E_n \simeq 8$ Mev. The absence of β activity could therefore be accounted for satisfactorily if we assumed that the pair was produced by a photo-phenomenon. Despite these facts, by which the existence of hypothesis $\sigma + n$ seems acceptable, the fact remains that the pair would have had to be emitted markedly collimated forward in the c.m. system (with an energy of 160 Mev).

(5) $\bar{\theta}^0 + n \rightarrow \pi^+ + \pi^- + \Lambda^0$.—Disregarding, in the first instance, the Fermi energy of the neutron we obtain, in the L system, $E_\theta = 210$ Mev and $E_\Lambda \simeq 1$ Mev. We are left with a marked collimation of the pair in

the c.m. system. The Fermi energy will modify E_θ by a few Mev, but will not affect E_Λ . Assuming a marked nuclear interaction for the $\bar{\theta}^0$, we could account for the collimation of the pions on the basis of a collision with marked angular momentum. However, the small energy of the Λ^0 (which will favor its binding to the remaining nucleus) and the absence of any β decay constitute two arguments against hypothesis (5).

Finally, we exclude the possibility of the scattering of a pion at 180° , since only track 1 could have originated in an incoming pion (within the margin of error), but this one seems to be precisely the least energetic.

We conclude, therefore, that it is very difficult to interpret this phenomenon in terms of any one of the common mechanisms of collision or of disintegration of the known and unstable particles. It should be noted that the phenomenon is similar to those discovered by H. Yagoda² and E. Friedlaender.³ If we assumed that a neutral particle is disintegrated into two bodies, both authors obtain a mass, for the primary, which is close to $600m_e$; this value would be comparable to the $550m_e$ obtained for our phenomenon under hypothesis (1).

ACKNOWLEDGEMENTS

Our thanks are due to Drs. M. Ceccarelli and K. Gottstein (Max Planck Institute Für Physik, Göttingen) for their valuable suggestions.

REFERENCES

1. H. Fowler and D. H. Perkins, *Phil. Mag.*, **46**, 587 (1955).
2. H. Yagoda, *Phys. Rev.*, **98**, 103 (1955).
3. E. Friedlaender, *Nuclear Phys.*, **1**, 363 (1956).