Associated Production of Ξ^- with Two θ^0 Particles*

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A cosmic-ray event is described in which a negative cascade particle and two neutral heavy mesons appear to be produced in a single nuclear interaction above a cloud chamber. It is suggested that this event may be an example of the associated production of a Ξ^- particle with two θ^0 particles according to the scheme of Gell-Mann.

EXPERIMENTAL information concerning the associated production of unstable heavy particles was first obtained by Shutt and his collaborators at Brookhaven.[1] Using a hydrogen diffusion chamber in the 1.37-Bev π^- beam, these researchers have found that neutral or charged hyperons may be produced with neutral or charged K-mesons.

Recent data have shown that associated production occurs to some extent in cloud chambers triggered on penetrating showers[2] and in nuclear emulsions exposed to cosmic rays.[3] Here again the evidence is that hyperons are produced associated with heavy mesons.

In the 48-inch magnet cloud chambers operating in Pasadena (Fig. 1), we have obtained a photograph showing four V events (Fig. 2), all connected with a single penetrating shower origin. This event is produced by a primary particle of >4 Bev/c momentum and unknown sign of charge which enters from above and behind chamber 2. Only 6 mm above the top inside wall of chamber 3 the primary makes a high-energy nuclear interaction which produces the penetrating shower containing the four V-particles, all of which decay in chamber 3. There are no other tracks besides the primary in chambers 1 and 2, and all of the tracks in chambers 3 and 4 appear to result from the single interaction at the top of chamber 3.

In Fig. 3, the various decays are shown in an isometric projection of the tangents to the pertinent tracks at their decay points. All decay secondaries pass through the front of the apparatus except for FH and IK which travel down through chamber 4.

There are three V^0 decays, FGH, CDE, and IJK. The planes of both FGH and IJK pass through the origin within experimental error, the angles of noncoplanarity for O with respect to FGH and IJK being $2.8\pm4°$ and $0.5\pm1.4°$ respectively. Moreover, the lines of flight of the corresponding V^0 particles computed from measured momenta and assuming two-body decay also pass through O within experimental error.

However, plane CDE does not contain O, the angle of noncoplanarity being $7.8\pm1.5°$. Instead, CDE contains the decay point of a V^- particle, OAB, the measured angle of noncoplanarity being $0.2\pm1.3°$.

Information concerning the tracks pertinent to the interpretation of this event are given in Tables I and II. Momenta for FH and IK in chamber 3 were determined from curvature measurements in chamber 4 with correction for the lead absorber and brass chamber walls in between.

Both FGH and IJK must have light positive secondaries to be consistent with their estimated ionizations and measured momenta. Independently of any ionization estimates, the α and $P_-\sin\theta_T$ values exclude the possibility that FGH and IJK might be Λ^0 decays. Under the assumption of the decay

$$\theta^0\rightarrow\pi^++\pi^-+Q(\pi,\pi),$$

FGH gives

$$Q(\pi,\pi)=240\pm60 \text{ Mev}$$

from the measured momenta of the secondaries. The momentum of the positive secondary of IJK cannot be determined directly, but by assuming two-body decay and momentum balance we obtain from the momentum of the negative secondary

$$Q(\pi,\pi)=270\pm70 \text{ Mev.}$$

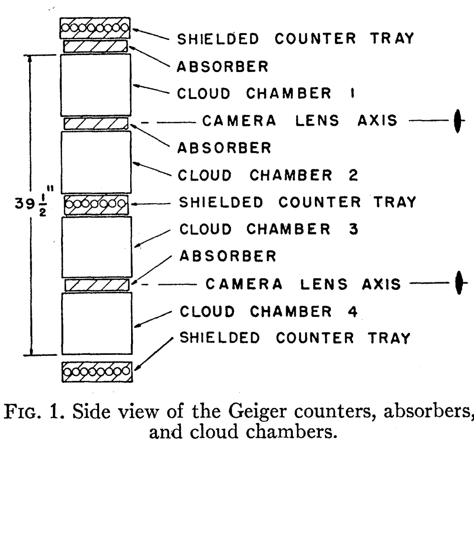

FIG. 1. Side view of the Geiger counters, absorbers, and cloud chambers.

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[1] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **98**, 121 (1955); Phys. Rev. **91**, 1287 (1953); and Phys. Rev. **93**, 861 (1954).

[2] Thompson, Burwell, Hugget, and Karzmark, Phys. Rev. **95**, 1576 (1954); J. D. Sorrels, Proceedings of the Fifth Annual Rochester Conference (Interscience Publishers, Inc., New York, 1955).

[3] Lal, Pal, and Peters, Proc. Indian Acad. of Sci. **38**, 398 (1953); Dahanayake, Francois, Fujimoto, Iredale, Waddington, and Yasin, Phil. Mag. **45**, 855 (1954).

Therefore, *FGH* and *IJK* are quite consistent with normal θ^0 decay where $Q(\pi,\pi)=214$ Mev.

The third V^0 decay, *CDE*, cannot be identified directly from the characteristics of its secondary tracks. However, the established coplanarity of this decay plane with the decay point of the V^- particle suggests strongly that it is the secondary of the well-known Ξ^- decay,

$$\Xi^- \rightarrow \Lambda^0 + \pi^- + Q(\Lambda^0,\pi),$$

and is thus a Λ^0 particle. The $Q(\Lambda^0,\pi)$ for the assumed Ξ^- decay can be computed from the roughly measured momentum of the negative secondary, *AB*, and the geometry of the event. The result is

$$Q(\Lambda^0,\pi)=95^{+100}_{-50} \text{ Mev},$$

which is consistent with previously measured values[4] of $\sim$66 Mev.

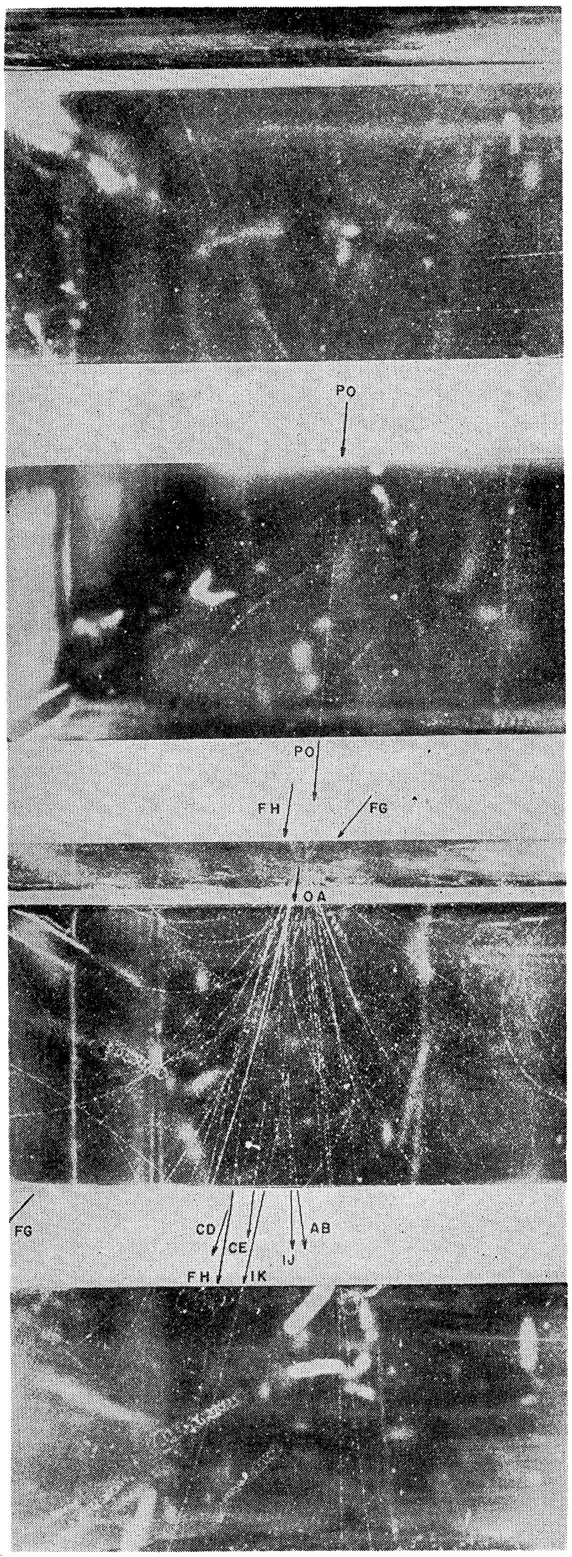

FIG. 2. Cloud-chamber photograph of a penetrating shower which includes two θ^0 decays (*FG*—*FH* and *IJ*—*IK*) and one Ξ^- decay (*OAB*) with its secondary Λ^0 (*CD*—*CE*).

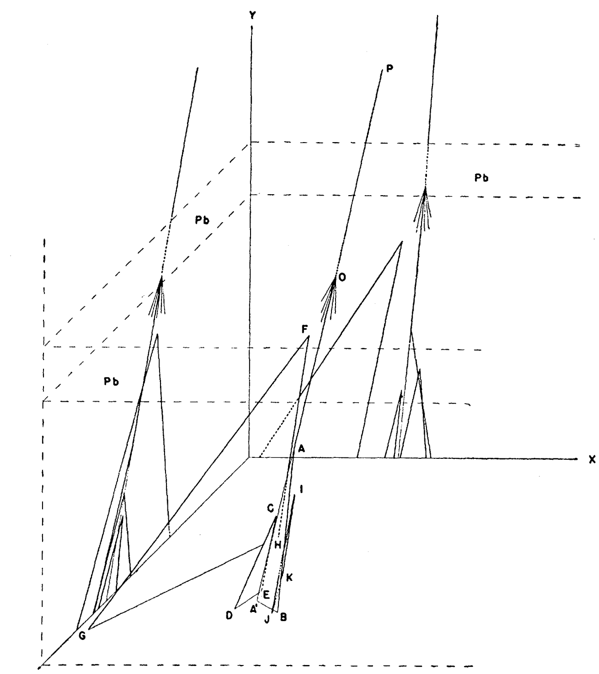

FIG. 3. An isometric view of the event in Fig. 2. All lines except *PO* are tangents to the tracks at the decay points. There is no detectable curvature in *PO* or *OA*. The primary *PO* makes a nuclear interaction at *O*, the origin of the penetrating shower, which produces four *V*-events. Decays *FGH* and *IJK* are identified as θ^0 decays from data in Tables I and II. Point *O* is coplanar with both θ^0 decay planes within experimental error. However plane *CDE* passes through *A* but not *O*, within errors of measurement. Thus *OAB*—*CDE* is interpreted as a cascade event. Other data summarized in the text and Tables I and II are consistent with the interpretation that *CDE* is the secondary Λ^0 of a Ξ^- event *OAB*. Tracks *FH* and *IK* penetrate through another cloud chamber (No. 4, Fig. 1) below the one shown in the figure.

[4] Arnold, Bellam, Lindeberg, and Van Lint, Phys. Rev. **98**, 838 (1955); W. B. Fretter and F. W. Friesen, Phys. Rev. **96**, 853 (1954); E. W. Cowan, Phys. Rev. **94**, 161 (1954).

TABLE I. Basic data.

Track	Charge	Measured momentum Mev/c	Estimated ionization times monimum	Estimated mass from ionization *vs* momentum in m_e	Best direction cosines[a] l	m	n
PO	?	>4000	<2	···	−0.0625	−0.9591	+0.2764
OA	−	>200	<2	···	−0.0756	−0.9579	+0.2773
OF	0	···	···	···	−0.3889	−0.9160	+0.0994
OI	0	···	···	···	−0.0211	−0.9612	+0.2748
AB	−	500^{+500}_{-250}	<2	<2000	+0.1489	−0.9165	+0.3714
AC	0	···	···	···	−0.1380	−0.9680	+0.2091
CD	−	>180	<2	···	−0.2222	−0.8716	+0.4368
CE	+	>180	<2	···	−0.1116	−0.9855	+0.1282
FG	+	520±150	<2	<1500	−0.5056	−0.7684	+0.3924
FH	−	920±220[b]	<2	<2800	−0.1992	−0.9759	−0.0895
IJ	−	>640	<2	···	+0.0671	−0.9083	+0.4131
IK	+	475±110[b]	<2	<1350	−0.2139	−0.9696	−0.1190

[a] Errors in measurement of direction cosines are less than ±0.015 for l and less than ±0.04 for n.
[b] These values are determined for chamber 3 from curvature measurements in chamber 4 with correction for the lead and brass in between.

TABLE II. Numerical results for the decays of Fig. 3. The values for α_a are computed for the four *V*-particle decays, *ABC*, *CDE*, *FGH*, and *IJK* from angles only. The values for α_p are computed from momentum measurements alone. The angle θ_T is the total included angle between decay secondaries. The values of $P_-\sin\theta_T$ listed in the fourth column must be less than 118 Mev/c for Λ^0 decay, which is not the case for *FGH* and *IJK*. *ABC* and *CDE* appear to be members of a cascade event and are therefore interpreted as Ξ^- and Λ^0 decays respectively. The noncoplanarity angles, δ, with assumed origins are all zero within experimental error. The Q value for *FGH* was obtained from θ_T and the momenta of the secondaries. The Q values in column 7 for both *ABC* and *IJK* were obtained from θ_T, the momentum of one measurable secondary in each case, and the transverse momentum about their lines of flight. The Q values in column 8 were obtained from the cascade relationship between *ABC* and *CDE* as described in the text.

Decay plane	1[a] α_a	2[b] α_p	3 θ_T degrees	4 $P_-\sin\theta_T$ Mev/c	5 Inter-pretation	6 δ Noncoplanarity angle degrees	7 Q values from momenta and geometry Mev	8 Q values from cascade geometry Mev
ABC	+0.5 ±0.1	···	19.2±1	160^{+160}_{-80}	Ξ^- decay	···	95^{+100}_{-50}	76±15
CDE	+0.5 ±0.3	···	20.0±2	>61	Λ^0 decay	0.2±1.0	···	32±10
FGH	−0.13±0.05	−0.29±0.26	35.4±1	535±125	θ^0 decay	2.8±4	240±60	···
IJK	−0.46±0.08	<−0.05	35.2±2	>370	θ^0 decay	0.5±1.4	270±70	···

[a] $\alpha_a=\sin(\theta_- - \theta_0)/\sin(\theta_- + \theta_0)$ for *ABC*, and $\alpha_a=\sin(\theta_- - \theta_+)/\sin(\theta_- + \theta_+)$ for *CDE*, *FGH*, and *IJK*.
[b] $\alpha_p=(P_+^2-P_-^2)/P_0^2$.

The momentum of the assumed Λ^0 can be obtained from transverse momentum balance with *AB*, but a more precise value can be obtained from the geometry of the Ξ^- decay if we assume the decay scheme

$$\Xi^- \rightarrow \Lambda^0 + \pi^- + 66 \text{ Mev}.$$

From the derived momentum of the Λ^0(792±50 Mev) and its decay geometry, we obtain for

$$\Lambda^0 \rightarrow p + \pi^- + Q(p,\pi)$$

a $Q(p,\pi)$ value of 32±10 Mev in agreement with the known value of 37 Mev. Conversely, if we assume that *CDE* is indeed a 37-Mev Λ^0 decay, we may calculate the momentum of the Λ^0 from geometrical factors only. From this new Λ^0 momentum and the geometry of the Ξ^- event, we obtain

$$Q(\Lambda^0,\pi) = 76 \pm 15 \text{ Mev},$$

in good agreement with the known value. Therefore, the decay dynamics are completely consistent with the interpretation that *CDE* is the secondary Λ^0 of a Ξ^- event *OAB*.

Since there is evidence of only one nuclear interaction which could produce these unstable particles, it appears that the Ξ^- was very probably produced in association with two θ^0 particles. Such a process is in direct agreement with the ideas presented by Gell-Mann.[5]

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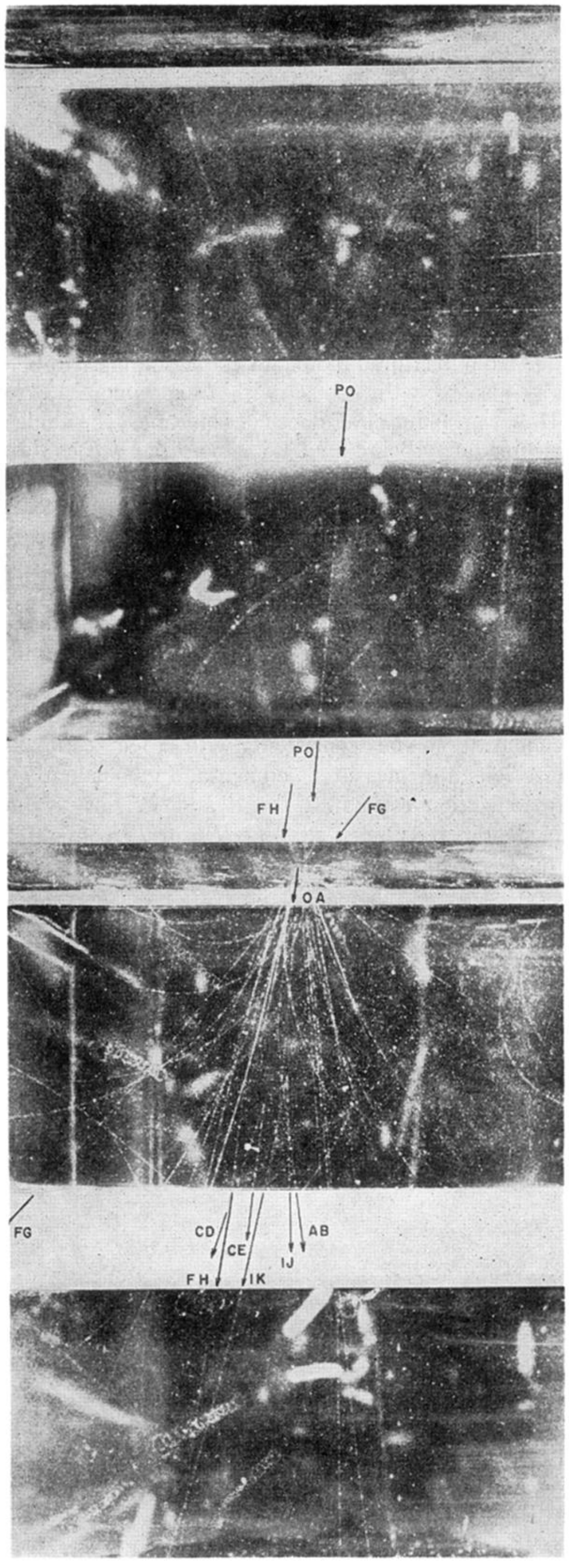
[5] M. Gell-Mann, Phys. Rev. **92**, 833 (1953); M. Gell-Mann and A. Pais, Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics (Pergamon Press, London, 1955).



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