

# Events of possible associative production of charmed particles in emulsions

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We observed two stars produced in emulsion by protons with  $p = 200 \text{ GeV}/c$ , in which a single electron is emitted practically from the center of the star and a particle with mass  $\sim 2 \text{ GeV}$  is produced simultaneously. The events can be interpreted as a manifestation of associative production of a charmed baryon and a charmed meson.

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1. One of the possible explanations of the properties of the recently discovered  $\Psi$  particles calls for the assumption that they are composite systems constructed of charmed quarks.<sup>11-51</sup> A direct consequence of this assumption is the statement that there exists in nature charmed mesons and baryons, which are produced associatively in strong and electromagnetic interactions.

According to estimates, the charmed mesons ( $M_c$ ) should have masses in the region  $2200 \text{ MeV}/c^2$ . For the charmed baryons ( $B_c$ ), the masses are less accurately determined, but at any rate they are larger than  $2 \text{ GeV}/c^2$  and perhaps reach  $3 \text{ GeV}/c^2$  and more.

The large masses of  $M_c$  and  $B_c$  lead to large values of the energy released in weak decays  $M_c$  and  $B_c$  (for the latter, if their mass is  $< 3200 \text{ MeV}/c^2$ ), and accordingly to lifetimes on the order of  $10^{-14}-10^{-15} \text{ sec}^1$  which is much shorter than the lifetime of strange particles. At accelerator energies (hundreds of GeV,  $\gamma \sim 10$ ), the ranges of these particles prior to the decay are quite small,  $\sim 3-30 \mu$ . This means that in leptonic decays of

$M_c$  or  $B_c$  the electron (positron) is emitted practically from the center of the star produced in the emulsion.

This characteristic circumstance was chosen by us to be the criterion for selecting events in the analysis of stars generated in nuclear emulsions of type BR-2 (layer dimension  $10 \times 20 \text{ cm}$ , thickness  $600 \mu$ ) by protons with  $p = 200 \text{ GeV}/c$  (bombardment with FNAL accelerator).

In the study of the momentum characteristics of  $pN$  interactions, we observed stars (of the type  $0+0+13p$  and  $0+0+10p$ ), in which a single high-energy electron is emitted from the interaction point with an uncertainty  $\leq 3 \mu$ . We measured for these stars the momenta of all the charged particles. Figure 1 shows the projection of the stars  $0+0+13p$ , while Figs. 2 and 3 show the diagrams of the target (a) and  $p_{\perp}$  (b) for these events. The electrons were identified by the momentum/ionization ratio and by the character of the energy loss. The

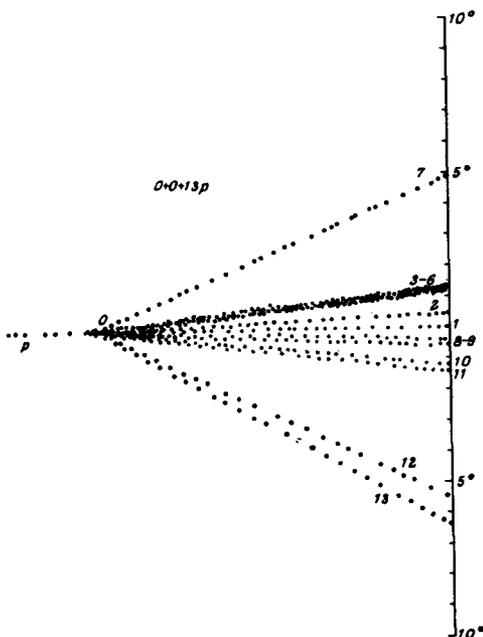


FIG. 1. Projection of the star  $0+0+13p$  on the emulsion plane.

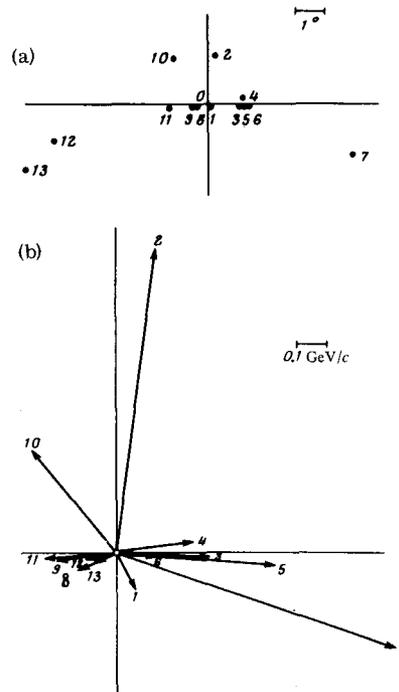


FIG. 2. Diagrams of the targets (a) and of  $p_{\perp}$  (b) for the events  $0+0+13p$  ( $O$  is the primary point).

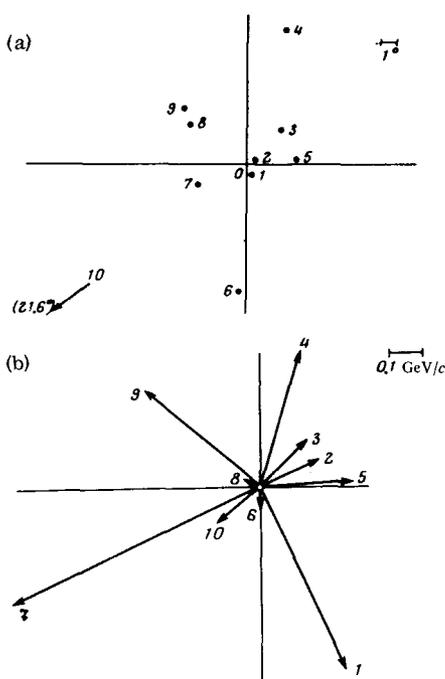


FIG. 3. Diagrams of the target (a) and of  $p_{\perp}$  (b) for the event  $0+0+0+10p$ .

momentum was determined by measuring the multiple scattering (the working emulsions had small distortions; the error in the momentum measurement over a track length  $\sim 5$  cm was 20–30% up to 100 GeV/c), and the ionization was measured relative to the primary-beam particle, namely 200 GeV/c protons (we henceforth denote the relative ionization by  $I$ ). When necessary, the tracks were continued into the neighboring layers up to lengths of 10 cm. We present below the characteristics of events and the events of the analysis.

### 3. Event I of type $0+0+13p$ (No. 4–20–305).

Particle No. 12 was identified as an electron. Measurements of the momentum along track No. 12 yielded the following results:

$$\begin{aligned} p\beta c_{12} &= 1.0 \pm 0.1 \text{ GeV} && \text{(first 30 mm),} \\ p\beta c_{12} &= 0.43 \pm 0.11 \text{ GeV} && \text{(next 3.6 mm),} \\ p\beta c_{12}'' &= 0.26 \pm 0.05 \text{ GeV} && \text{(next 6.2 mm).} \end{aligned}$$

$p\beta c_{12}''' = 0.023 \pm 0.006$  GeV after scattering through an angle  $14^\circ$ . The ionization produced by the star particle is  $I_{12} = 1.01 \pm 0.03$ , corresponding to the plateau.  $I_{12}''' = 1.0 \pm 0.5$  on the last section. We investigated in addition the track No. 13, which is nearest in angle to track No. 12. Measurements of the momentum and ionization have established that particle No. 13 is a pion.

Attention is called to the fact that in the same events there are two particles (No. 2 and No. 7) with  $p_{\perp} \sim \text{GeV}/c$ . A feature of this star is also the asymmetry of the forward emission of most particles in the c.m.s. ( $\theta_{\Lambda} < 2^\circ$  for 10 particles, see Fig. 2a). The total momentum of all the secondary charged particles is equal to

the primary momentum, within the limits of errors 10–15%.

4. Event II, of type  $0+0+10p$  (No. 4–20–079). Particle No. 8 was identified as an electron. The initial momentum is  $p\beta c_8 = 0.45 \pm 0.10$  GeV, the ionization is  $I_8 = 1.00 \pm 0.03$ , after 2.1 mm we have  $p\beta c_8' = 0.055 \pm 0.015$  GeV and an ionization  $I_8' = 1.01 \pm 0.03$ . Five single scattering through angles from 1 to  $3^\circ$  are observed along track No. 8 over a length of 6.5 mm.

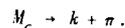
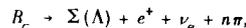
We investigated in addition track No. 9, which is the nearest to track No. 8. At  $p\beta c_9 = 4.8_{-0.9}^{+1.3}$  GeV, the ionization is  $I_9 = 0.88 \pm 0.03$ . In addition, track No. 9 was continued in five emulsions to  $l = 50$  mm. No energy losses or breaks were observed. Thus, particle No. 9 is not an electron.

In this event, two of the secondary particles (No. 1 and No. 7) have large  $p_{\perp}$  (0.8 and 0.6 GeV/c). The total momentum of all the charged secondary particles is  $\sim 100$  GeV.

5. The presence of single electrons emitted in the described event practically from the interaction point is quite unusual and can serve as a serious indication that their appearance is due to the decay of a heavy relatively short-lived particle ( $\tau < 10^{-15}$  sec in both cases).<sup>2)</sup> Similar characteristics, as noted above, are possessed by charmed particles. If we assume that  $B_c$  or  $M_c$  is produced in the described events, then evidence should also exist of the formation of  $M_c$  (and respectively  $B_c$ ) produced in a pair with it. There are definite confirmations of this assumption.

The typical decay mode of  $M_c$  is  $M_c \rightarrow k + \pi$ . If we assume in the case of star I that particles No. 2 and No. 7, which have large  $p_{\perp}$ , are products of  $M_c$  decay (a  $\pi$  or  $k$  meson respectively, or vice versa), then the corresponding invariant mass is 2.0–2.2 GeV/ $c^2$ . If we make an analogous assumption in the case of type II with respect to particles No. 1 and No. 7, which also have rather large  $p_{\perp}$ , then the corresponding invariant mass is 1.7–1.9 GeV/ $c^2$ .

In both cases, the invariant masses are close to the expected value of the  $M_c$  mass. This gives ground for assuming that the described events I and II are examples of associative production of a charmed baryon and a charmed meson, which presumably decay subsequently in accordance with the schemes



It is possible, however, that this is not the only interpretation. An analysis of the described events will be continued.

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<sup>1)</sup>There are also published indications of the existence of particles with lifetimes  $10^{-13}$ – $10^{-14}$  sec. <sup>[6,7]</sup>

<sup>2)</sup>The appearance of electrons from weak decays of known particles, or due to failure to observe one of the components of the Dalitz pair, was considered and was estimated as being of extremely low probability.

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