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EVIDENCE FOR PRODUCTION AND DECAY OF SUPERNUCLEUS

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The existence of charmed particles, including the lightest baryon Λ_c^+ [1], is well established now. But the possibility of forming the analogous to hypernuclei bound states of Λ_c^+ with nucleons, i.e., supernuclei [2], is still a question. According to the theoretical estimates [3-7] their existence is highly probable.

At the scanning of photoemilsion exposed to 70 and 250 GeV protons at the IHEP and the FNAL there have been found five candidates to the supernuclear decay [8]. Their characteristics and preliminary analysis are presented in refs. [8,9]. The analysis of possible sources of background [10] has shown that 4 events could be explained through the inelastic interactions of shower particles and that the only source of background for the fifth event (250 GeV proton) is the annihilation of slow $\bar{p}$. The expected number of such annihilations, in case we take into account the yield of annihilation stars with visible energy release 0.3-1.3 GeV [11], is $\sim 3 \cdot 10^{-2}$. The secondary scanning of primary-stars vicinity to a distance of ~3 mm has enabled to detect in this event a vee with opening angle of $(1.23\pm0.03)\cdot 10^{-2}$ rad. The vertex point of the vee is estimated by the geometrical method to be $(6.3\pm2.8)\mu$m * away from the primary star. Figure 1 presents the photomicrograph and the scheme of this event (A - the primary star vertex, B - the vertex of the secondary star with tracks 1-6, C- the vertex of the vee with legs V1 and V2). The characteristics of this event are presented in Table 1. The characteristics of the vee legs and of the secondary star tracks are given in Table 2.

According to the measurements of multiple scattering and ionization the track V1 is most probably a K-meson. Due to this the vee can be interpreted as a decay of $\overline{D^\circ}$-meson into $K^+\pi^-$ (invariant mass $M_{K\pi}=1.62^{+0.13}_{-0.12}$ GeV) or into $K^+\pi^-\pi^\circ$ occurring after $\sim 0.3\cdot 10^{-14}$s. The $\overline{D^\circ}$-meson could be produced in pair with Λ_c^+ which decayed within the supernucleus in the point B.

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* We present a weighted mean value over 23 measurements. The error is defined with taking into account the correlation of separate measurements.

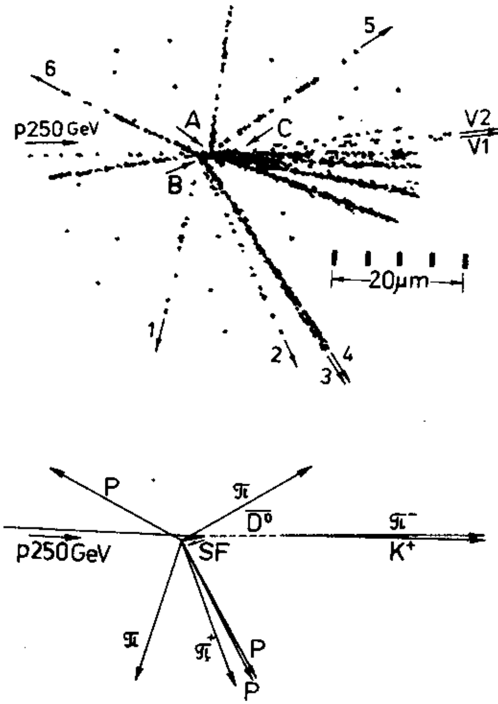

Fig.1. The photomicrograph and the scheme of the event, A - the primary star vertex, B - the vertex of the secondary star with tracks 1-6, C - the vertex of the vee with legs V1 and V2.

The probability of vee being a e^+e^--pair is negligibly small - $\sim 6\cdot 10^{-10}$. The background due to K°_s and Λ° decays and the diffraction dissociation $n \to p\pi^-$ $(n\to n\pi^+\pi^-)$ /12/ does not exceed $\sim 9\cdot 10^{-4}$. Thus, the expected number of events imitating the decays of a supernucleus and of a neutral charmed particle does not exceed $\sim 3\cdot 10^{-5}$.

In case the secondary star is produced by the supernuclear decay, among the decay products there should be a strange particle which can be neutral: Λ° or $\overline{K^\circ}$. The experimental data are not inconsistent with the assumption that this event is a supernuclear decay with invisible Λ° (in case one assumes that there occurs a $\overline{K^\circ}$ emission, the energy release in the secondary star will exceed the mass difference of Λ_c^+ and a nucleon). The secondary star has been kinematically analysed under the assumption that Λ° is the only invisible supernuclear decay product. There has been also estimated the Λ_c^+ binding energy in the supernucleus B_c ($B_c = M_{cn} + M_{\Lambda_c^+} - M_{SF}$, where M_{cn} is the mass of the core-nucleus; $M_{\Lambda_c^+} \sim 2.27$ GeV, the Λ_c^+ mass; M_{SF}, the invariant mass of the decay products, depending on the supernuclear momentum P_{SF}) and the supernuclear decay time t_{SF}.

The analysis shows that the kind of the supernucleus is defined by charges of the pions leaving the emulsion stack (tracks 1 and 5), but the positive values of B_c stipulating the existence of supernucleus, appear to be independent of them. There are only three possibilities.

Table 1. Event characteristics

Primary star	Connecting track			Secondary star		
Type of disintegration	Range $R, \mu m$	Dip angle θ^{o}	Azimuth angle ϕ^{o}	Visible energy release E_{vis}, MeV	Total longitudinal momentum of charged particles $P_{ch\parallel}$, MeV/c	Total transverse momentum of charged particles $P_{ch\perp}$, MeV/c
6+12p	1.8±0.5	0±18.0	192±8.9	998±21	190±122	532±42

Table 2. Characteristics of vee legs and of secondary star tracks

No.	$R, \mu m$	θ^{o}	ϕ^{o}	Ionization I/I_0	$p\beta$ MeV/c	Identity	Energy T_{kin}, MeV
1	> 74620	18.5±1.0	63.6±0.5	0.94±0.08	362±18	π	270±16
2	32560±650	14.2±1.0	102.3±0.5	1.47±0.12	74±6	π^{+}	48.0±1.1
3	291±5	-43.4±1.5	109.8±1.5	–	–	p	6.9±0.4
4	8790±120	-43.7±1.0	110.0±0.5	–	79±11	p	49.0±1.5
5	>65200	58.0±1.0	201.1±0.5	1.08±0.07	160±15	π	101±11
6	20710±130	-32.6±1.0	322.8±0.5	3.76±0.31	115±9	p	79.8±1.8
V1	> 54000	-6.0±1.0	358.8±0.2	0.94±0.01	840±70	K	576±58
V2	> 54000	-6.0±1.0	359.5±0.2	1.00±0.03	9760±1670	π	9630±1670

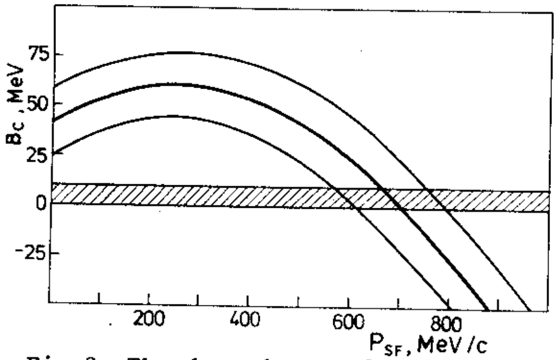

Fig.2. The dependence of Λ_c^+ binding energy B_c on supernuclear momentum P_{SF} for decay ${}^4_c Be \rightarrow \Lambda^\circ \pi^+ \pi^+ \pi^- ppp$.

1) $\pi^+\pi^-$. In this case the decay of supernucleus ${}^4_c Be \rightarrow \Lambda^\circ \pi^+\pi^+\pi^- ppp$ occurs due to the decay $\Lambda_c^+ \rightarrow \Lambda^\circ \pi^+\pi^+\pi^-$. The dependence of B_c on P_{SF} is shown in Fig.2. According to estimations[4-7] B_c is of the same order of magnitude as Λ° binding energy in hypernuclei with identical core-nuclei. Due to this we assumed the possible B_c values to be in the range of 0-10 MeV (the hatched area in Fig.2). These B_c values correspond to $t_{SF} \sim (2.4-5.3)\cdot 10^{-14}$ s. Since the core-nucleus (3p) is unstable the most probable interpretation suggests the emission of k neutrons ($k \geq 1$): ${}^{4+k}_{c} Be \rightarrow \Lambda^\circ \pi^+\pi^+\pi^- ppp + kn$.

2) $\pi^-\pi^-$. The interpretation of this event ${}^4_c He \rightarrow \Lambda^\circ \pi^+\pi^-\pi^- ppp$ assumes the supernuclear decay due to the weak interaction of Λ_c^+ with neutron $\Lambda_c^+ n \rightarrow \Lambda^\circ p \pi^+ \pi^- \pi^\circ$ with subsequent charge exchange $\pi^\circ n \rightarrow \pi^- p$. The invariant mass $M_{\pi p}$ (tracks 5 and 6) is equal to 1224.5±12.2 MeV. At the same P_{SF} values $B_c({}^4_c He)$ will be equal numerically to $B_c({}^4_c Be) - 5.92$ MeV. The interval $B_c = 0-10$ MeV corresponds to $t_{SF} \sim (2.9-4.4)\cdot 10^{-14}$s.

3) $\pi^+\pi^+$. The decay of supernucleus ${}^{6+k}_{c} C \rightarrow \Lambda^\circ \pi^+\pi^+\pi^+ pppnn + kn (k \geq 1)$ occurs due to the weak interaction of Λ_c^+ with proton $\Lambda_c^+ p \rightarrow \Lambda^\circ n \pi^+\pi^+\pi^\circ$ with subsequent charge exchange $\pi^\circ p \rightarrow \pi^+ n$. The presence of at least two neutrons and of Λ° does not allow one to estimate quantitatively the B_c and t_{SF} but it is not inconsistent with the possibility of B_c being positive. The addition of k neutrons is caused by the same reasons as in case 1). The versions 2) and 3) assume the pion charge exchange and therefore they are less probable.

A vee from the Λ° decay which was searched for in the limits of the Λ° hyperon emission angles corresponding to $B_c = 0-10$ MeV, was not found. However the probability of decay $\Lambda^\circ \rightarrow p\pi^-$ in the scanned area does not exceed ~18%. Besides, the emission angles of Λ° could be other than the searched for ones if even one neutron only has been emitted in supernuclear decay. Due to this the fact that we have not found Λ° does not contradict to the considered interpretation.

Thus, there exist serious reasons to interprete this event as the production of the bound state of charmed baryon Λ_c^+ with nucleons, i.e., of a supernucleus $_c\mathrm{Be}(_c\mathrm{He},\ _c\mathrm{C})$:

$$p + \mathrm{Ag, Br} \rightarrow {}_c\mathrm{Be}({}_c\mathrm{He},\ {}_c\mathrm{C}) + \overline{D^{\circ}} + X$$
$$\overline{D^{\circ}} \rightarrow K^{+}\pi^{-}(\pi^{\circ})$$
$${}_c\mathrm{Be}({}_c\mathrm{He},\ {}_c\mathrm{C}) \rightarrow \Lambda^{\circ}\pi^{+}\pi^{\pm}\pi^{\mp}ppp + kn\,(k \geq 0)$$

decaying after $\sim(2\text{-}5)\cdot 10^{-14}$ s.

We hope, the found event will be a stimulus for further investigations aimed at final clarification of the problem of supernuclear existence.

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