Production of a New Hadron in 300-GeV Proton Interactions*

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We report the production of a new neutral hadron with a lifetime $\sim 10^{-13}$ sec in a 300-GeV proton interaction in nuclear emulsion.

The recently observed narrow resonances[1-3] at 3.1 and 3.7 GeV have been attributed to the meson and it has been suggested[4,5] that they are composed predominantly of charmed quark and antiquark constituents. The properties of these particles have been studied through SU(4) and from these calculations the existence of other charmed hadrons[4,5] has also been estimated (with masses approximately between 1 and 4 GeV). These charmed particles are expected to be produced in pairs just like strange particles via strong or electromagnetic interactions and singly in neutrino interactions. The lightest of these charmed particles should decay only through weak interactions with a lifetime in the range of 10^{-11} to 10^{-14} sec, either nonleptonically into ordinary baryons and mesons or leptonically into zero-charm hadrons plus an $e\nu$ or $\mu\nu$ pair.

One of the ways to detect these charmed particles is through their decaying tracks which are generally very short as the lifetime is 10^{-11} to 10^{-14} sec. The shortest track in the bubble chamber is a few millimeters, and these short decaying tracks have not been found[6] in bubble chamber films, which means that their lifetime is shorter than 10^{-11} sec. On the other hand, photographic emulsion detectors have by far the highest spatial resolution of any particle detector. They can resolve events separated in space by a few microns so that decays of particles of mean lives in the range 10^{-11} to 10^{-14} sec should be readily observable. Thus nuclear emulsions are the only detectors where one can hope to see the massive charmed particles through their decay mechanism.

In order to make an effort to look for these new hadrons, we used a small stack of G-5 emulsions which was exposed to a 300-GeV proton beam parallel to the plane of the emulsion, with a flux density of 5×10^3 particles/cm^2. By scanning along the primary tracks which were picked up at about halfway up from the bottom of the pellicle and at a distance of 0.5 cm from the edge of the plate, we observed[6] about 800 events in about 230 meters of track length. By using this technique we have almost completely eliminated the background events and have reduced the number of events with large multiplicities which are generally found by area scanning, and the analysis of these large-multiplicity events is sometimes not simple. For our preliminary scanning, we looked very carefully under high magnification at each of these 800 events for a distance of about 500 μm downstream from the vertex, for any single scatterings, any interactions, and any neutral-particle decays. The scanning efficiency for neutral particles which decay into two or more particles (even number of charged-prong events) as well as the scanning efficiency for observing charged particles which decay into three or more particles (odd number of charges) is almost 100%. We also looked for anomalous decays of any neutral and charged particles produced in the primary interaction. The details of these findings will be published elsewhere.[7] We are interested to report here a new hadron which we believe may be the first evidence for the production of the charmed hadron produced in the 300-GeV proton beam.

The event $(1+4)p$ as seen in the plane of plate No. 20 is shown in Fig. 1, with one short black prong and four shower particles with one "V." The distance of the "V" from the vertex O, where the primary proton interacts, is only 194 μm. The whole event is clearly seen in the plane of

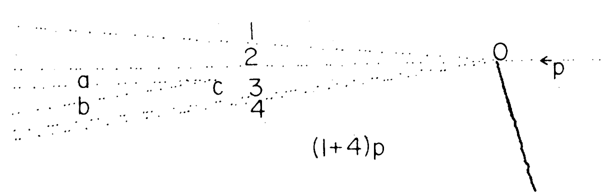

FIG. 1. Projection drawing of the primary event $(1+4)p$ produced by 300-GeV proton at the vertex O, with a produced "V" at point C. The distance $OC = 194$ μm.

one emulsion pellicle. The secondary hadron tracks, numbers 1, 2, 3, and 4, make space angles of 41×10^{-3}, 1×10^{-3}, 80×10^{-3}, and 58×10^{-3} rad with the direction of the primary particle. The opening angle of the V (i.e., angle between tracks a and b) is relatively large, 34.9×10^{-3} rad. The angle between the direction of flight of the neutral particle (line OC) and the incident direction of the proton is 53×10^{-3} rad. The production of the vertex of the V is very near the direction of the primary track and it extends back to the main interaction at O. The angles between the direction of flight of the neutral particle and tracks a and b are 8.7×10^{-3} and 26.2×10^{-3} rad, respectively. We also looked for another V in the forward direction of the primary interaction but did not find any. We may also point out that there was no other primary or secondary interaction in the neighborhood of this event. We also checked the upper and lower emulsion plates (numbers 19 and 21) near the coordinates of this event for any other interactions, but there was none. We followed track b which is 8.6 mm in length in plate No. 20. It is a low-energy typical electron track with momentum value of only 75 MeV/c as calculated by the scattering technique. Track a is about 12.5 mm in this plate and is a high-energy track. It was followed in the other plates for scattering measurements and is a typical track produced by a hadron. Different scattering techniques[8] were used to determine its momentum, which is 9.1 GeV/c.

The general location and the characteristics of the two tracks a and b produced by V, when compared to the whole event, leave no doubt that this V is an integral part of this event. We used the following check points to confirm further that these two tracks a and b represent only an electron and a hadron, respectively: (a) The tracks a and b cannot be produced from a Dalitz electron pair because the distance OC is too large for the energies calculated here. (b) Tracks a and b are not due to an electron pair from π^0 decay as the ratio of energy partition between the two particles is $\sim10^{-2}$ which is too far apart to be an electron pair. (c) The behavior of track a when followed in different plates for the measurements of ionization density and the energy by multiple scattering is not at all like an electron track. (d) The high-energy track a, if it were due to an electron, should produce typical electron pairs due to bremsstrahlung along its path, but we did not find any. (e) The rather large opening angle of the V indicates that the high-energy track a with momentum ~ 9 GeV/c could not have been produced by an electron along with another low-energy electron track b.

On the basis of the above facts, we feel that track a is produced by a hadron (π, K, or p) and track b by a low-energy electron with minimum ionization. Because of the presence of an electron at vertex C along with a hadron, there has to be a third particle, a neutrino. Its short decay distance from the vertex and all the other features of this event suggest that this event is a three-body leptonic decay ($Ke\nu$, $\pi e\nu$, or $pe\nu$) of a neutral hadron with a short lifetime. The existence of a neutrino is further confirmed from the transverse-momentum imbalance between tracks a and b which necessitates the presence of a third neutral particle. Because the direction and momentum of the neutrino are unknown, we can only approximate the mass value of the new hadron (say particle "L"). If we consider that the neutrino is produced in the laboratory system at right angles to the direction of the high-energy particle a (suppose a pion) then the mass of the particle L will be ~1.25 GeV and the lifetime $\tau\simeq x/c\gamma\sim10^{-13}$ sec. If the neutrino is produced in the backward direction of track a, then the mass of particle L will be greater than 1.25 GeV and the value of γ will decrease from 7 to lower values which will increase the value of the lifetime. The mass of particle L will increase further if the track a is due to a kaon or a proton, instead of a pion. Thus, in this event the presence of (i) a very short distance of the decay path length and (ii) a detectable low-energy electron and a high-energy hadron, with the above complete analysis, indicate that the production of particle L may be considered here as the production of a charmed particle with leptonic decay.

Our search for new particles is being continued and there is some evidence for the production of more new particles. These events are being analyzed now very carefully and will be reported.[7]

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Measurement of the Regeneration Phase in Carbon from 4 to 10 GeV/c*

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A regeneration experiment exploring K_S-K_L interference in the decay modes $K_{S,L} \to \pi^+\pi^-$ and $K_{S,L} \to \pi^\pm l^\mp \nu$ ($l=\mu$ or e) has been performed at the Brookhaven National Laboratory alternating-gradient synchrotron. The regeneration phases in carbon obtained from the time-dependent charge asymmetry of the K_{e3} and $K_{\mu 3}$ modes are in good agreement and yield a combined result $\varphi_f \equiv \arg i[f(0)-\bar{f}(0)] = -40.9° \pm 2.6°$ at the average K^0 momentum of 7.5 GeV/c.

Since the discovery of CP nonconservation,[1] the phenomenon of coherent K_S regeneration from an initially pure K_L beam has been exploited in a number of experiments[2] designed to measure the phase φ_{+-} of the CP-nonconservation parameter,[3]

$$\eta_{+-} \equiv \langle \pi^+\pi^- | T | K_L \rangle / \langle \pi^+\pi^- | T | K_S \rangle = |\eta_{+-}| \exp(i\varphi_{+-}). \tag{1}$$

The principal limitation in this type of experiment arises from the uncertainty of the regeneration phase, φ_ρ, which enters directly in any interference of the K_L and regenerated K_S amplitudes.

After traversing a block of matter (the regenerator), a pure $|K_L\rangle$ beam is transformed into a coherent mixture $\psi = a|K_L\rangle + b|K_S\rangle$. The regeneration amplitude, defined at the exit face of the regenerator for the undeflected beam, is

$$\rho \equiv b/a = |\rho| \exp(i\varphi_\rho) = \frac{i\pi NL[f(0)-\bar{f}(0)]}{P_K} \, \frac{1-\exp[(i\Delta m - \Gamma_s/2)LM_K/P_K]}{-(i\Delta m - \Gamma_s/2)LM_K/P_K}, \tag{2}$$

where N is the atomic density, L is the length of the regenerator, P_K is the K momentum, and f ($\bar{f}$) is the K^0- ($\bar{K}^0$-) nucleus forward scattering amplitude. In the determination of φ_ρ, the poorest known part is $\varphi_f \equiv \arg i[f(0)-\bar{f}(0)]$.

Several methods have been employed for the determination of φ_f.[4] The method followed here utilizes the time-dependent charge asymmetry in the decay modes $K_{L,S} \to \pi^\pm l^\mp \nu$, where l is either a muon or electron. The charge asymmetry after a regenerator is defined by $\delta(\tau) \equiv [\Gamma_+(\tau) - \Gamma_-(\tau)]/[\Gamma_+(\tau)+\Gamma_-(\tau)]$, where Γ_+ (Γ_-) refers to positive (negative) leptonic decay rate, and is given to sufficient accuracy for the present discussion by

$$\delta(\tau) = 2\chi|\rho| \exp[-(\Gamma_S+\Gamma_L)\tau/2]\{\cos(\Delta m\tau + \varphi_\rho) + \alpha\cos(\Delta m\tau + \varphi - \varphi')\} + \delta_L. \tag{3}$$