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OBSERVATION OF CHARMED BARYON PRODUCTION IN νp INTERACTIONS IN BEBC

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ABSTRACT

Two examples of charmed baryon production by neutrinos have been observed in BEBC filled with hydrogen. Both events fit uniquely the reaction $\nu p \rightarrow \mu^- p K^- \pi^+ \pi^+$ and thus apparently violate the $\Delta S = \Delta Q$ rule. None of the appropriate mass combinations is consistent with the mass values of the D^0 and D^+ mesons. However, for the mass combinations of the $p K^- \pi^+$ systems, values of $(2.285 \pm 0.005)\text{GeV}$ and $(2.280 \pm 0.003)\text{GeV}$ are found for event 1 and 2, respectively. These values agree with the mass of $(2.285 \pm 0.006)\text{GeV}$ for the Λ_c^+ charmed baryon determined recently in $e^+ e^-$ collisions at SLAC.

The production of charmed baryons has been observed in several experiments with ν , γ and hadronic beams as well as in e^+e^- collisions [1-10]. There are, however, some discrepancies in the results for the mass of the lowest lying state, the Λ_c^+ . In some experiments a value of ~ 2.26 GeV has been found, whereas others measure a value around 2.28 GeV.

In this letter we report on the observation of charmed baryon production in νp -interactions. Two events have been found, which apparently violate the $\Delta S = \Delta Q$ rule, having a single strange particle - a K^- - in the final state, and can only be interpreted as examples of Λ_c^+ production.

The data come from an exposure of the Big European Bubble Chamber (BEBC), filled with hydrogen, to the CERN neutrino wideband beam. Details of the experimental set-up have been given elsewhere [11]. The experiment yielded ~ 8000 charged current (CC) events. For this investigation, however, a reduced fiducial volume has been used to ensure that the distance between the interaction point and the chamber wall is at least 1 m. This rejects events with short tracks and allows momentum measurements with good accuracy. The CC events were required to have a visible energy E_{vis} greater than 5 GeV and a negative muon of at least 3 GeV/c momentum, identified by the two-plane External Muon Identifier (EMI). These cuts left a sample of ~ 5650 CC events.

Among these, the events were selected which yielded a 3-constraint fit with probability greater than 5% to a reaction containing a single strange particle with strangeness -1 in the final state [12]. If this strange particle was a K^- , it was required to have a momentum smaller than 5 GeV/c to have good particle identification either by ionisation (for momenta up to ~ 1 GeV/c) or by energy momentum conservation. If any other hypothesis also fitted the event with a probability $> 10^{-4}$, the event was rejected.

Four events have been found that fulfil these criteria. Two of them have been described in an earlier publication [11] as evidence for charmed meson production. The two other events, described here, have five outgoing tracks and both fit uniquely to the reaction

$$\nu p \rightarrow \mu^- p K^- \pi^+ \pi^+ . \quad (1)$$

In fig. 1 the first event is shown as an example. The kinematic characteristics of the produced particles as well as the method of their identification are listed, for the two events, in table 1.

In both events the fastest negative track is clearly identified as μ^- by the EMI. The proton is also unambiguously identified either by a secondary interaction (event 1) or by ionisation (event 2). In the first event one of the remaining positive tracks is identified as a pion by its characteristic $\pi \rightarrow \mu \rightarrow e$ decay chain (not seen in fig. 1). The other positive track is excluded to be a proton by ionisation. It shows an inelastic interaction followed by a backward scattering giving a 4-constraint fit to the reaction $\pi^+ p \rightarrow p \pi^+$. To the second negative track, with momentum of 2.5 GeV/c only the K^- mass hypothesis can be assigned to obtain a 3-constraint fit for the reaction (1).

In the second event, all tracks leave the bubble chamber without interacting. However, with the slowest positive track ($p = 950$ MeV/c) identified as a proton by ionization, only reaction (1) gives a 3-constraint fit to the event.

Both events have been measured several times. The average fit probabilities to reaction (1) are 62% and 40% for event 1 and 2, respectively. No other mass assignments were possible in any of the measurements.

Interpreting the two events as due to associated strange particle production would require an additional fast K^0 produced in the forward direction with a transverse momentum smaller than 30 MeV/c. In our sample of 359 K_s^0 none has a transverse momentum smaller than 35 MeV/c with respect to the neutrino direction.

If the negative hadron would be interpreted as a π^- instead of a K^- , then an additional π^0 would have to be produced with very unusual characteristics, to conserve energy and momentum. In addition to a

transverse momentum to the incident neutrino direction less than 30 MeV/c, this π^0 should have a momentum smaller than ~ 400 MeV/c. From the spectra of π^+ and π^- , the probability for a π^0 to have such characteristics is estimated to be $\sim 4 \times 10^{-3}$.

Thus the most probable explanation of the two events is that they correspond to an apparent $\Delta S = -\Delta Q$ reaction. As is well known, such a process is not allowed in a three quark model, but can occur if a d quark in the struck proton is converted into a charmed quark. If this charmed quark then decays into a strange quark, the overall reaction is apparently a $\Delta S = -\Delta Q$ process. Therefore the two events strongly indicate the production of a charmed particle. To check this hypothesis the invariant masses have been studied.

The effective mass of the total hadronic system is (2.808 ± 0.006) GeV and (2.791 ± 0.004) GeV for event 1 and 2, respectively. No mass combination is compatible with the D^0 or D^+ masses. However, mass values of (2.285 ± 0.005) GeV and (2.280 ± 0.003) GeV are obtained for the $pK^- \pi_2^+$ combinations in events 1 and 2, respectively. These values are in remarkably good agreement with the recently measured value of (2.285 ± 0.006) GeV for the Λ_c^+ mass at SLAC [7]. We interpret our two events as examples of Λ_c^+ charmed baryon production

$$\begin{aligned} \nu p &\rightarrow \mu^- \Lambda_c^+ \pi_1^+ \\ &\quad \searrow \\ &\quad pK^- \pi_2^+ \end{aligned} \quad (2)$$

A search for inclusive Λ_c^+ production has been made by investigating various effective mass combinations with many different cuts in the total sample of charged current events. No significant signal has been found in the $pK^- \pi^+$, pK^0 , and $\Lambda \pi^+ \pi^+ \pi^-$ mass distributions. However, it should be remembered that the identification of protons and charged kaons with momenta above ~ 1 GeV/c is not good except for the case of three-constraint fits.

In the $\Lambda \pi^+$ mass distribution there is a slight enhancement at the Λ_c^+ mass region, though statistically not significant. Selecting

only those $\Lambda\pi^+$ combinations where the π^+ is fast in the laboratory system by requiring

$$z(\pi^+) = E(\pi^+)/E(\text{hadr}) > 0.2$$

only few combinations are left and a Λ_c^+ signal may be present. This is shown in fig. 2. If these events are indeed due to Λ_c^+ production, one finds, correcting for unseen Λ decays,

$$\frac{\sigma[\nu p \rightarrow \mu^-(\Lambda_c^+ \rightarrow \Lambda\pi^+)X]}{\sigma(\nu p \rightarrow \mu^- X)} = (0.17 \pm 0.10)\%$$

for W greater 2.4 GeV, i.e. above Λ_c^+ production threshold.

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TABLE 1

Description of the two charmed baryon events of the reaction

Particle	Event 1		Event 2	
	Momentum (GeV/c)	Identification	Momentum (GeV/c)	Identification
μ^-	48.654 ± 1.613	EMI	10.348 ± 0.028	EMI
K^-	2.574 ± 0.011	Fit	2.514 ± 0.005	Fit
P	1.973 ± 0.015	Interaction	0.935 ± 0.005	Ionisation
π_1^+	1.255 ± 0.006	Fit	1.081 ± 0.003	Fit
π_2^+	0.225 ± 0.001	Decay	1.483 ± 0.005	Fit
$\langle \chi^2 \text{ probability} \rangle$	62%		40%	
E_ν (GeV)	54.051 ± 1.615		15.879 ± 0.029	
W (GeV)	2.808 ± 0.005		2.796 ± 0.005	
$M(pK^- \pi_2^+)$ (GeV)	2.285 ± 0.005		2.280 ± 0.003	

FIGURE CAPTIONS

Fig. 1 Photograph and drawing of the first of the two charmed baryon events. The reaction occurring is $\nu p \rightarrow \mu^- \Lambda_c^+ \pi^+$.
 $\Lambda_c^+ \rightarrow p K^- \pi^+$

Fig. 2 $\Lambda \pi^+$ mass distribution for the combinations with $z(\pi^+) = E(\pi^+)/E(\text{hadr}) > 0.2$.

Fig. 1

Fig. 2