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Charm Particle Production by Neutrinos

by

N. P. Samios

Brookhaven National Laboratory

Upton, N. Y.

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MASTER

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Today I am going to discuss further evidence, indeed confirmation of the existence of the Λ_c^+ (2260) and Σ_c^{++} (2424) charm baryons, as well as the observation of the D^{*+} (2000) charm meson, these states all being produced by neutrino interactions. In addition I will briefly review the status of $(\mu^- e^+)$ di-lepton neutrino production in bubble chambers, especially as it affects charm production.

The specifics of the first experiment, in simple liquids, H_2 and D_2 at relatively low neutrino energies 0-20 Gev are shown in Fig. 1. The main point is that there is a sample of 5,000 charge current neutrino events and 35 strange particle events and as I will shortly show 2 baryon charm events. In Fig. 2, the fine resolution of this device and technique is demonstrated where W , the recoil hadron mass, is plotted and where the neutron and Δ^{++} peaks are clearly seen. The first example of baryon charm production is shown in Fig. 3 and has been published in Phys. Rev. Lett. 34, 1125 (1975). I remind you that this was a clear example of $\Delta S = -\Delta Q$, the reaction being $\nu p \rightarrow \mu^- \Lambda_c^+ \pi^+ \pi^- \pi^-$. There is only one strange particle, transverse momentum is balanced, with alternate explanations being at the 10^{-4} level. The pertinent masses are Λ_c^+ ($\Lambda_c^+ \pi^+ \pi^- \pi^-$) = 2260 MeV and the Σ_c^{++} ($\Lambda_c^+ \pi^+$) = 2426 MeV. The second event is shown in Fig. 4 and has been published in Phys. Rev. Lett. 42, 197 (1979). In this instance the reaction occurred on a neutron (in deuterium), the reaction fitting $\nu n \rightarrow \mu^- \bar{K}^0 \pi^- \pi^+ p$, all alternate

hypotheses being less than 1% probable. The exciting feature is that the $K^0 \pi^-$ mass is consistent with $K^{*}(892)$, thereby fixing the K_S as a $\bar{K}^0$ i.e. $S = -1$, again an example of $\Delta S = -\Delta Q$. The hadronic mass $M(\bar{K}^0 \pi^- \pi^+ p) = 2254 \pm 10$ MeV is that of the Λ_c^+ in this case decaying via a K^0 mode. This second event clearly confirms the existence of the Λ_c^+ (2260).

The second experiment which I will discuss involves the study of neutrino interactions at higher energies, 10-100 GeV, but in a Ne/H₂ mixture. The particulars are shown in Fig. 5, the main data comparing ≈ 200 di-lepton events and 3,000 charge particle events. The first results of the $\mu^- e^+$ study have been published in Phys. Rev. Lett. 39, 62 (1977). The present status is a yield of 204 $\mu^- e^+$ events from a sample of 83,000 charge current events. This corresponds to a corrected production rate of $\approx .5\%$. These events are accompanied by 43 V^0 's (a clear excess over the 12 event expected randomly). The corrected V^0 rate is $\mu^- e^+ V^0 / \mu^- e^+ \approx .6$. If neutral and charged strange particles are produced at equal rates this would correspond to ≈ 1.2 strange particles per event, in good agreement with charm production. A summary of a wide variety of experiments on this subject is shown in Table I. The main point is that the sum of all other experiments is similar to the BNL-Columbia results. If one examines the x, y distribution for the BNL-Columbia di-lepton events as shown in Fig. 6, one notes the excess at small x , corresponding to a 37% sea contribution and 1.4 strange particles per event, in agreement with the above rate expectation. In summary one would conclude that the di-lepton events have all the characteristics of charm production.

I will now turn to a discussion of the non-leptonic decay of charm particles. As noted earlier, $\approx 3,000$ strange particle events have been accumulated, slightly more K^0 's than Λ^0 's. With two thirds of the data, the $D^0 \rightarrow K^0 \pi^+ \pi^-$ was evident,

Fig. 7, and Phys. Rev. Lett. 41, 73 (1978), inclusively produced via the reaction $\nu\text{Ne} \rightarrow \mu^- D^0 + \text{anything}$. A similar search for an inclusive production of Λ_c^+ production with its subsequent decay into $\Lambda\pi^+$ showed an excess of 20 events, a 2σ effect at the expected mass, Fig. 8. It is clear then inclusive studies at high energies and in complex liquids are not likely to be the most productive means in deciphering charm particle production; it works for the D^0 and gives some evidence for the Λ_c^+ but the latter is far from overwhelming. As such we have exploited the mass difference between two charm particles, one decaying into the other via a pion emission. There is the well known example of $D^{*+} \rightarrow D^0 \pi^+$ which has a small $Q = 5$ MeV value. Therefore, we have taken the ≈ 40 events in the D^0 signal, Fig 7, and combined it with a single π^+ , at the same time performing the same procedure above and below the D^0 mass as control regions. In Fig 9a, one sees a cluster of 6 events at a mass difference of 146 MeV for the D^0 region with an absence of such an excess in the control region, Fig 9b. We attribute this effect to the well known D^{*+} to D^0 decay.

Of greater interest is the application of this same procedure to the baryon charm possibilities. The particular sequence exploited to date has been

In essence we have observed 7 examples of (a) with an expected background of one event and 3 examples of (b) again with a background of one event. Summing this gives a total of ten (10) events where two (2) are expected, a quite significant result. The two dimensional distribution of $M(\Lambda\pi^+)$

versus $\Delta m [(\Lambda \pi^+ \pi^+) - (\Lambda \pi^+)]$ is shown in Fig. 10 for the observed events, the expected number of events as deduced from non-correlated M , Δm distributions and the resultant Poisson probabilities. The effect is striking; even for this one channel. Similar conclusions with less data are reached with channel (b), as noted earlier the signal here consisting of 3 events. The effective mass distribution for the Λ_c^+ in $\Lambda \pi^+$ and $\Lambda \pi^+ \pi^+ \pi^-$ for both these channels is shown in Fig 9c for these events were the mass difference Δm has between .162 and .172 Gev. The excess of 10 events is clearly observable. In the sample consisting of the $\Lambda \pi^+ \pi^+ \pi^-$ final states, one of the events is elastic and very similar in its characteristics to the first BNL event. A picture of this event is shown in Fig. 11 where the fast μ^- is seen to traverse the chamber in the forward direction, the Λ^0 is observed to decay and the three positive and one negative pions are seen to interact in the chamber. The kinematics fit exceedingly well for the reaction $\nu p \rightarrow \mu^- \Sigma_c^{++}; \Sigma_c^{++} \rightarrow \Lambda_c^+ \pi^+$ and $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+ \pi^+$. The derived masses, from the above events are $\Lambda_c^+ = 2257 \pm 10$ Mev and $\Sigma_c^{++} = 168 \pm 5$ Mev. The decay modes observed to date for the Λ_c^+ are therefore $\Lambda \pi^+, \Lambda \pi^+ \pi^+ \pi^-$ and $\bar{K}^0 p \pi^+ \pi^-$.

My final comment has to do with production rates. If one considers the (10-2) $\Sigma_c^{++} \rightarrow \Lambda_c^+$ events and corrects for; lifetime + Λ^0 neutral decay modes (x3); other possible charged decay modes (x2); estimate of Λ_c^+ / Σ_c^+ production (x3) and $\Lambda_c^+ \rightarrow$ decay modes with neutrals (x2), one obtains a rate of $8 \times 2 \times 3 \times 2 \times 2$ events out of total of 75,000 charged current events or $\approx 1/3 \%$ Λ_c^+ production - quite reasonable.

In summary I would say that the existence of the $\Lambda_c^+, \Sigma_c^{++}$ is in good shape, with their respective masses being quite well measured, as well as clear indication of several decay modes for the Λ_c^+ . The rates and properties of leptonic as well as non-leptonic modes are in good agreement with these expected of charmed particles. The remaining task is to now find the host of other expected states, especially the Ξ, Ξ^* and Ξ_c 's.

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TABLE I

 $\nu^- e^+$ From Other Experiments

Experiment	$\langle E_\nu \rangle$	Liquid	Events	ν_{obs}^a	$\nu^- e^+ / \nu^-$
	BcV		Observed	Observed	Rate (%)
Gargamelle (11) CERN PS	1-3	Freon	14 $\nu^- e^+$	3	
Wisconsin-CERN-Hawaii-Berkeley (12) Fermilab 15 foot B.C., E28	~ 30	21% He	17 $\nu^- e^+$	11	0.6 ± 0.3
Columbia-Brookhaven Fermilab 15 foot B.C., E53	~ 30	64% He	166 $\nu^- e^+$	33	0.5 ± 0.15
Berkeley-Seattle-LBL-Hawaii (6) Fermilab 15 foot B.C., E172	~ 30	64% He	6 $\nu^- e^+$	1	0.34 ± 0.23 $- 0.13$
Fermilab-LBL-Hawaii (13) Fermilab 15 foot B.C., E546	~ 30	50% He	40 $\nu^- \nu^+$	5	0.43 ± 0.16
BEUC Narrow band (14) CERN SPS	~ 75	60% He	11 $\nu^- \nu^+$ 3 $\nu^- e^+$	6 2	0.7 ± 0.3
BEUC Wide band (15) CERN SPS	~ 30	60% He	21 $\nu^- e^+$	6	0.5 ± 0.17
GARGAMELLE Wide band (16) CERN SPS	~ 30	Freon Propane	46 $\nu^- \nu^+$	6	0.7 ± 0.2

^a ν_{obs} stand for $K_S^0 \rightarrow \nu^+ + \nu^-$ or $\Lambda^0 \rightarrow p + \nu^-$ decays

140

144

40 others

33 BNL-Columbia

BNL - 7' Chamber

Cnops, Connolly, Kahn, Kirk, Murtagh, Palmer,

Tanaka and Samios

$\nu(H_2, D_2)$

Volume = $9m^3$ (Fiducial $6m^3$)

Plates: 4 2" S.S. (2IM.Fp)

Kinematics - low energy

few missing particles.

(80% of all events

uniquely identified)

H_2	200 k pix	400 events	} analyzed
D_2	550 k pix	2300 events	
	450 k pix	1300 "	found
		<u>1000</u> "	expected
		5,000	

35 Strange particle events ($\Lambda^0 \rightarrow p\pi^-$

$K_S^0 \rightarrow \pi^+\pi^-$

$\Sigma^+ \rightarrow \pi^+\nu$ 1

2/3 nothing missing

i.e. $\nu n \rightarrow \mu^- \Lambda^0 K^+$ (8)

$\nu p \rightarrow \mu^- \Lambda^0 K^+ \pi^+$ (6)

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

BNL - Columbia Experiment: 15' Chamber. FNAL

ν_{μ} Ne - H₂ 60% mixture

28 tons

$l_R = 40\text{cm}$

9RL ϕ

$l_{m+} = 120\text{ cm}$

3IL ϕ

134 k pix = 106,000 c.c. events

$\nu_{\mu} N \rightarrow \mu^{-} + \text{anything}$

Reaction	Measured	Fraction
$\nu_{\mu} N \rightarrow \mu^{-} + \dots$	2,000	2%
$\nu_{\mu} N \rightarrow \mu^{-} \nu^0 + \dots$	3,000	50%
$\nu_{\mu} N \rightarrow \mu^{-} e^{+} + \dots$	200	70%
$\nu_{\mu} e^{-} \rightarrow \nu_{\mu} e^{-}$	11	100% $\sin^2 \theta_{\omega_3} = .2^{+.16}_{-.08}$
$\nu_e N \rightarrow e^{-} \dots$	180	25%
$\bar{\nu}_e N \rightarrow e^{+}$	30	25%

BNL - Cnops, Connolly, Kahn, Kirk, Murtagh, Palmer, Tanaka and Samios

Columbia: Baltay, Caroumbalis, French, Hibbs, Hylton, Kalelkar, Shastri

FIGURE 5

$$\nu_{\mu} + N \rightarrow \mu^{-} e^{+} + X$$

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

EXPECT

.142 .152 .162 .172 .182 .192 2.02

AM

 Δm

M

.142   .152   .162   .172   .182   .192   2.02

 Δm

FIGURE 10

FIGURE 11