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ABSTRACT

We report recent results from an analysis of 100,000 pictures of the Fermilab 15 ft. bubble chamber filled with heavy neon and exposed to the double horn focused, wideband ν_μ beam. We have found 164 dilepton ($\mu^- e^+$) events with 33 vees, in good agreement with the GIM model of charm production. We have also observed the production of the charmed D^o meson, followed by the decay $D^o \rightarrow K^o \pi^+ \pi^-$, at a rate of (0.7 ± 0.2)% of all charged current events. We have carried out searches for charm changing neutral current processes and for heavy lepton production, both with negative results; the upper limits obtained in these searches are given.

INTRODUCTION

We present recent results from a study of ν_μ interactions in heavy neon. The experiment was carried out at Fermilab using the two-horn focused wideband muon neutrino beam and the 15 ft. chamber filled with a heavy neon-hydrogen mixture (64 atomic % neon). A total of 150,000 pictures was taken with an average of 10^{13} 400 GeV protons per pulse on the neutrino target. The interaction length for hadrons is 125 cm, so that hadrons typically interact, while muons leave the chamber without interaction, and can thus be identified on the scan table. Electrons are easily identifiable through visible bremsstrahlung, since the radiation length is 40 cm. Some previous publications from this experiment are given in Ref. 1.

DILEPTON PRODUCTION

We have previously published results on dilepton production from the first 50,000 pictures of our exposure. We have now analyzed 100,000 pictures, corresponding to about 60,000 charged current neutrino interactions. In this sample, we have found 164 events with a μ^-, an e^+ and anything else. The e^+ is required to have two signatures and a momentum over 300 MeV/c. With these cuts, the background from asymmetric Dalitz pairs is a few percent. The μ^- is identified as the fastest negative leaving track. No momentum cut is made. From a comparison of interacting and noninteracting tracks of both signs, the background due to fake μ^- (hadron punch-through) is determined to be about 10%. After correcting for these backgrounds, scan efficiency (∿90%), and e^+ identification efficiency (∿85%), we obtain a dilepton rate of

$$R = \frac{\nu_\mu + Ne \rightarrow \mu^- + e^+ + \ldots}{\nu_\mu + Ne \rightarrow \mu^- + \ldots} = (0.5 \pm 0.15)\%.$$

This rate is calculated using half of our events for which we have an accurate normalization. Figure 1 shows the momentum distribution of the e^+ and μ^-, and also the total visible energy.

We have examined the 164 μ^-e^+ events for associated $K_S \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$ decays. We find 33 such vees (25 events with a single vee, 4 with a double vee), consisting of 20 unambiguous K^o's, 3 unambiguous Λ's, and 10 K/Λ ambiguities. From half of our events, this corrsponds to a neutral strange particle rate of 0.6 ± 0.2 per dilepton event, in good agreement with the GIM model of charm production by neutrinos. From our 60,000 charged current events, we find that 6% have a visible vee. At that rate, we would expect 10 vees in 164 μ^-e^+ events, whereas we actually see 33. The data on dilepton production from other bubble chamber experiments is summarized in Table I for neutrinos and Table II for antineutrinos. Both the rate for dilepton production and the number of neutral strange particles per event are consistent with the results of the Columbia-BNL experiment.

Figure 2 shows the K^oe^+ effective mass from 19 μ^-e^+ events with a single K^o. The data are not in good agreement with the distribution expected from the $K^oe^+\nu_e$ decay of a spin zero D^+ meson at 1868 MeV. However, the distribution is consistent with a calculation by Barger et al.(2) assuming a $K\pi e\nu$ decay.

OBSERVATION OF $D^o \to K^o\pi^+\pi^-$

We have measured all events with vees in about 80,000 pictures, corresponding to 46,000 charged current events with a muon momentum over 2 GeV/c. We obtain good 2 or 3 constraint fits for 1815 $K_S \to \pi^+\pi^-$ and 1367 $\Lambda \to p\pi^-$. Correcting for branching ratios and detection efficiencies, this corresponds to a $(K^o + \overline{K}^o)$ rate of (13.6 ± 1.5)% of all charged current events, and a $(\Lambda^o + \Sigma^o)$ rate of (5.0 ± 0.5)%.

Figure 3 shows the $K_S\pi^+\pi^-$ mass distribution, indicating a peak in the mass region of the charmed D^o meson seen at SPEAR.(3) The best fit to a polynomial background plus a Gaussian, shown by the curve, gives the following parameters:

$$M = 1850 \pm 15 \text{ MeV}, \quad \sigma = 20 \pm 8 \text{ MeV}$$

corresponding to 64 events above a background of 180, with a statistical significance of four standard deviations. The width is consistent with our experimental mass resolution of 20 MeV. No corresponding peak is apparent near the D mass in the events without a μ^-. This is consistent with the prediction of the GIM model that the charm charging neutral current interactions are absent. If the peak were due to K^* production, then one might expect it to be present in events both with and without a μ^-.

Correcting for branching ratios and detection efficiencies, we obtain a rate

$$\frac{\nu_\mu + Ne \to \mu^- + D^o + \ldots,\ D^o \to K^o\pi^+\pi^-}{\nu_\mu + Ne \to \mu^- + \ldots} = (0.7 \pm 0.2)\%.$$

Figure 4 shows the distribution in Z, the fraction of the hadronic energy carried by the D^o. We have used the visible hadronic energy for each event, correcting for our estimate of the energy lost due to missing neutrals or charged tracks that interact close to the vertex and therefore fail to reconstruct. The solid lines represent all of the events in the D^o region of the $K^o\pi^+\pi^-$ mass distribution, while the dashed lines give the contribution from the background under the D^o, obtained by using control regions above and below the D^o.

LIMITS ON CHARM CHANGING NEUTRAL CURRENTS

We have looked for charm changing neutral currents in both production and decay processes. We have found no evidence for charm changing neutral currents in either search, and present the following upper limits.

a) Charm production via neutral currents, $\nu_\mu + Ne \rightarrow \nu_\mu + C + \ldots$, where C is any charmed particle, followed by the semileptonic decay $C \rightarrow e^+ + \nu_e + \ldots$ The signature for this process is an event with an e^+ with any number of additional hadrons but no μ^-. We have 28 such events, most of which are consistent with being $\bar{\nu}_e$ interactions with a fast leading e^+, while the e^+ from charm decay has a soft e^+ (see Figure 1a for the momentum distribution of the e^+ from the μ^-e^+ events). Using the expected e^+ momentum distribution from charm decay (Figure 1a) and for $\bar{\nu}_e$ interactions, we obtain a 90% confidence level upper limit on charm charging neutral currents by comparing with the number of μ^-e^+ events which are presumably due to charged current charm production, of

$$\frac{\text{Charm production by NC}}{\text{Charm production by CC}} \leq 8\%$$

Note that the semileptonic branching ratio cancels out in this limit.

b) Charm changing neutral currents in the decay process $C \rightarrow \text{hadrons} + e^+ + e^-$, compared to the charged current decay $C \rightarrow \text{hadrons} + e^+ + \nu_e$, where C is any charmed particle produced in the reaction $\nu_\mu + Ne \rightarrow \mu^- + C + \ldots$, The signature for the neutral current decay is an event with three leptons, i.e. $\mu^- + e^+ + e^- +$ hadrons. We observe no such events with $m(e^+e^-) \geq 600$ MeV, to be compared to 164 μ^-e^+ events, which are presumably due to charged current semileptonic charm decays. Using a calculation by Shrock(4) to correct for losses due to the $m(e^+e^-) \geq 600$ MeV cut, we obtain the 90% confidence level upper limit of

$$\frac{\text{Charm changing Neutral Currents}}{\text{Charm changing Charged Currents}} \leq 2\%$$

LIMITS ON HEAVY LEPTON PRODUCTION AND CHECK ON $\nu_e - \nu_\mu$ UNIVERSALITY

In the first 50,000 pictures we observed

$\nu_e + Ne \rightarrow e^- + \text{hadrons}$	187 ± 14 events
$\bar{\nu}_e + Ne \rightarrow e^+ + \text{hadrons}$	28 ± 6 events

Using a Monte Carlo program we have calculated the ν_e/ν_μ and the $\bar{\nu}_e/\nu_\mu$ flux ratios using measured K/π ratios at the neutrino target (note that overall flux normalizations cancel out in these ratios). Comparing the numbers of ν_e and $\bar{\nu}_e$ interactions with the number of ν_μ interactions in this sample (27,600) and using the calculated flux ratios we obtain the following cross section ratios:

$$\sigma(\nu_e)/\sigma(\nu_\mu) = 0.9 \pm 0.3$$

$$\sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu) = 1.2 \pm 0.4$$

These ratios are consistent with 1.0, the value expected from $\nu_e - \nu_\mu$ universality.

We can use these events to set upper limits on heavy lepton production via the process $\nu_\mu + Ne \to L^\pm +$ hadrons followed by the decay of $L^\pm$, the heavy lepton, $L^\pm \to \nu + e^\pm + \overset{(-)}{\nu}$. The signature for this process is an event with $e^\pm$ with any number of hadrons but no muon, like the 187 e^- and the 28 e^+ events. We now assume $\nu_e - \nu_\mu$ universality and subtract the expected number of ν_e and $\bar{\nu}_e$ interactions from the observed number of events to obtain the 90% confidence level upper limits

$$\frac{\nu_\mu + Ne \to L^- + \ldots,\ L^- \to e^- + \ldots}{\nu_\mu + Ne \to \mu^- + \ldots} \leq 3 \times 10^{-3}$$

$$\frac{\nu_\mu + Ne \to L^+ + \ldots,\ L^+ \to e^+ + \ldots}{\nu_\mu + Ne \to \mu^- + \ldots} \leq 1 \times 10^{-3}$$

The rate of heavy lepton production as a function of the heavy lepton mass $m(L^\pm)$, as well as the heavy lepton decay rate into $e^\pm\nu\bar{\nu}$ have been calculated by Carl Albright et al.(5) Comparing our upper limits with these calculations we conclude that

a) Muon type heavy leptons that couple with the usual V-A interactions to the usual quarks must be heavier than

$$m(L^-) \geq 7.5 \text{ GeV}$$

$$m(L^+) \geq 9.0 \text{ GeV}$$

b) The recently discovered 1.9 GeV heavy lepton, the τ, does not have the quantum numbers of the muon; i.e. the coupling strength of the ν_μ to the τ is less than 0.025 of the ν_μ to μ^- coupling strength. Alternately, if the τ is not a member of the same multiplet as the μ but there is a mixing between the μ and the τ, then our results imply a limit on the mixing angle of $\tan^2\phi \leq 0.025$.

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References

1. C. Baltay et al., Phys. Rev. Lett. 39, 62 (1977).
   A.M. Cnops et al., Phys. Rev. Lett. 40, 144 (1978).
   C. Baltay et al., Phys. Rev. Lett. 41, 73 (1978).
2. V. Barger et al., Phys. Rev. D16, 746 (1977).
3. G. Goldhaber et al., Phys. Rev. Lett. 37, 255 (1976).
4. R. Shrock, private communication.
5. C.H. Albright, J. Smith, and J.A.M. Vermaseren, State Univ. of New York at Stonybrook Report No. ITP-SB-77-43, and C.H. Albright and C. Jarlskog, Nucl. Phys. B84, 467 (1975).

TABLE I

Dilepton Production by Neutrinos in Bubble Chambers

Experiment	$\langle E_\nu \rangle$ BeV	Liquid	Events Observed	Vees* Observed	$\mu^- e^+/\mu^-$ Rate (%)
Gargamelle CERN PS	1-8	Freon	14 $\mu^- e^+$	3	
Wisconsin-CERN-Hawaii-Berkeley Fermilab 15 foot B.C., E28	∿30	21% Ne	17 $\mu^- e^+$	11	0.8 ± 0.3
Columbia-Brookhaven Fermilab 15 foot B.C., E53	∿30	64% Ne	164 $\mu^- e^+$	33	0.5 ± 0.15
Berkeley-Seattle-LBL-Hawaii Fermilab 15 foot B.C., E172	∿30	64% Ne	6 $\mu^- e^+$	1	$0.34^{+0.23}_{-0.13}$
Fermilab-LBL-Hawaii Fermilab 15 foot B.C., E460	∿30	50% Ne	9 $\mu^- \mu^+$	1	
BEBC Narrow band CERN SPS	∿75	60% Ne	11 $\mu^- \mu^+$ 5 $\mu^- e^+$	6 2	0.7 ± 0.3
BEBC Wide band CERN SPS	∿30	60% Ne	21 $\mu^- e^+$	6	0.5 ± 0.17
Fermilab-Michigan-IHEP-ITEP Fermilab 15 foot B.C., E180	∿30	64% Ne	6 $\mu^- e^+$	1	1 ± 1/2

*Vees stand for $K_s^o \rightarrow \pi^+ + \pi^-$ or $\Lambda^o \rightarrow p + \pi^-$ decays

TABLE II

Dilepton Production by Antineutrinos in Bubble Chambers

Experiment	$\langle E_{\bar{\nu}} \rangle$ BeV	Liquid	Events Observed	Vees* Observed	μ^+e^-/μ^+ Rate, %
Fermilab-Michigan-IHEP-ITEP Fermilab 15 foot B.C. E180	∿30	21% Ne	$\leq 1\ \mu^+e^-$	0	$\leq 0.5\%$
Berkeley-Seattle-LBL-Hawaii Fermilab 15 foot B.C. E172	∿30	64% Ne	$4\ \mu^+e^-$	2	$0.15 {+0.14 \atop -0.08}$
Fermilab-Michigan-IHEP-ITEP Fermilab 15 foot B.C. E180	∿30	64% Ne	$12\ \mu^+e^-$	7	0.22 ± 0.07

*Vees stand for $K_s^o \to \pi^+ + \pi^-$ or $\Lambda^o \to p + \pi^-$ decays.

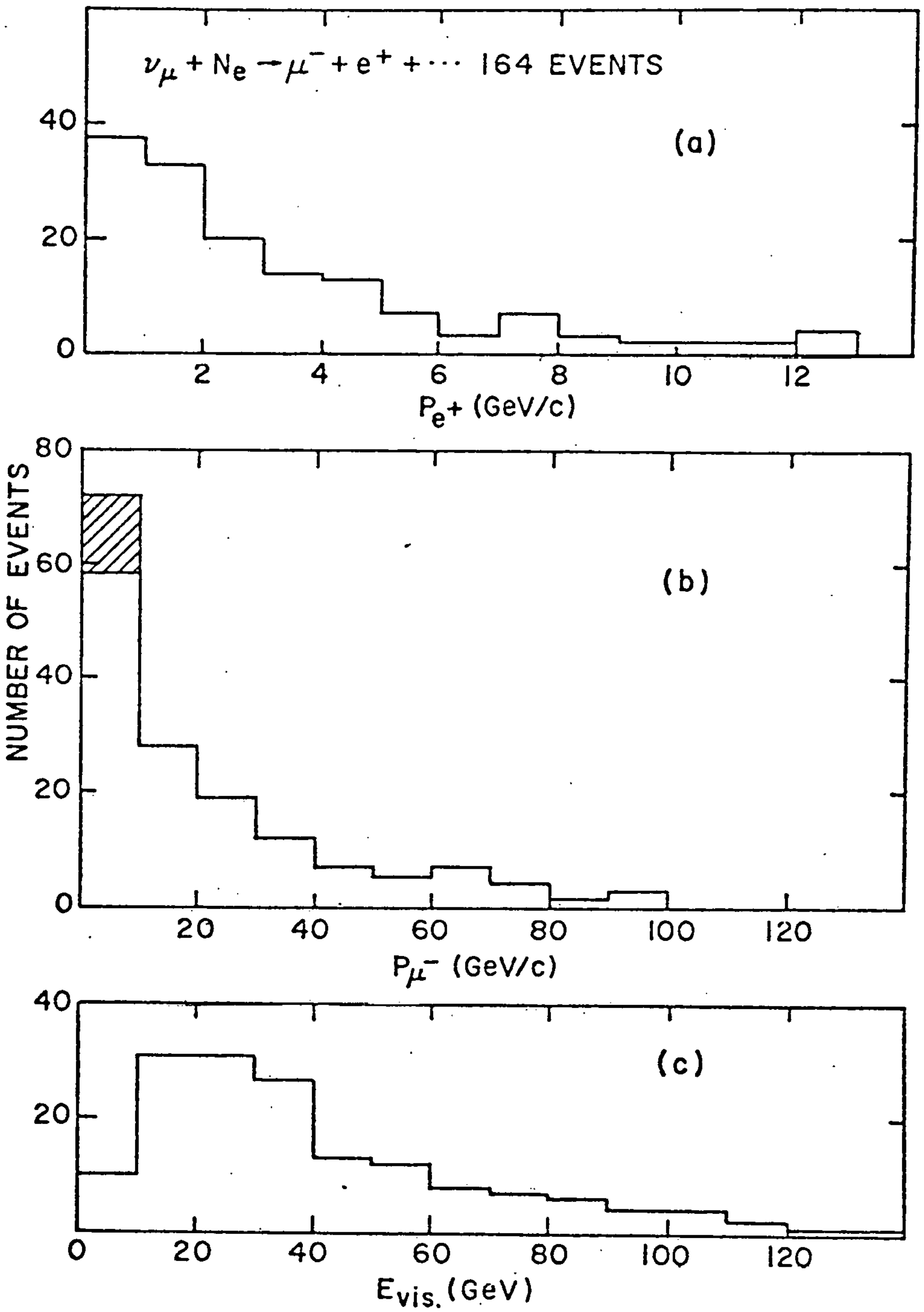

Fig. 1 Momentum of a) the e^+, and b) the μ^-, the dilepton sample. The shaded events are the background from hadron punchthrough. c) The total visible energy.

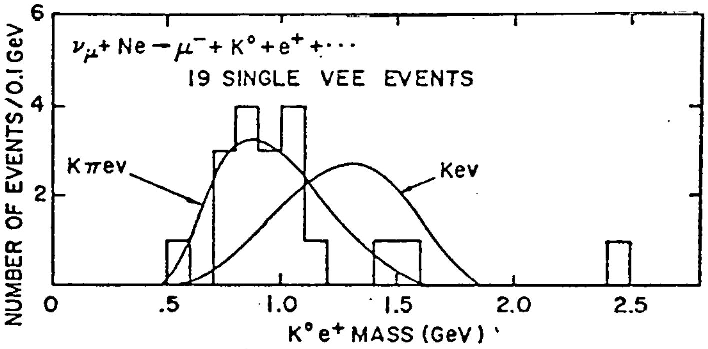

Fig. 2 K^O e^+ mass from dilepton sample.

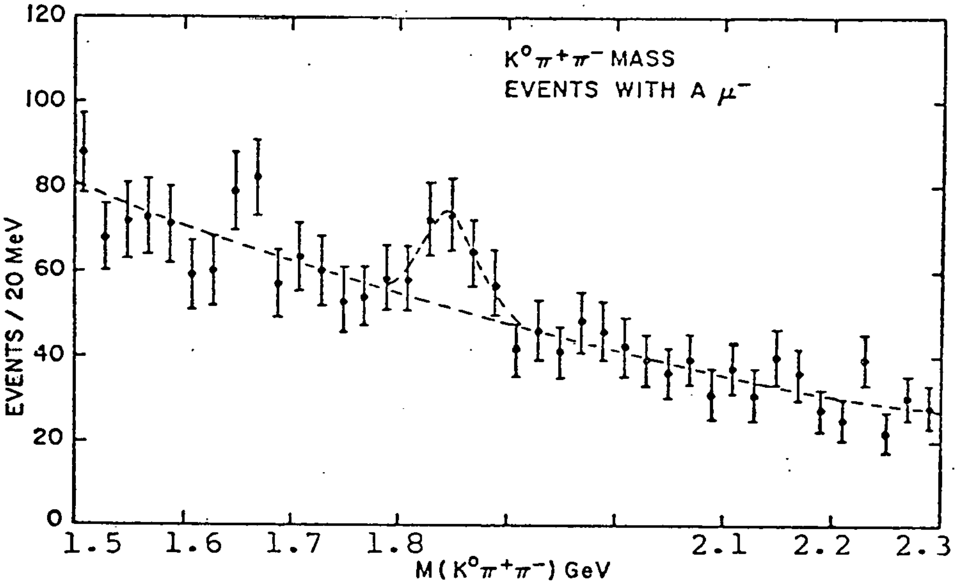

Fig. 3 $K^O\pi^+\pi^-$ mass from charged current events.

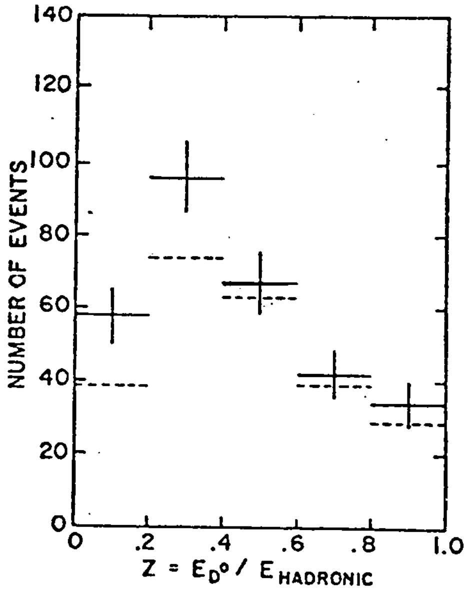

Fig. 4 Distribution of Z of the D^O.