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INCLUSIVE PRODUCTION OF HADRONS IN ν_μNe AND $\bar{\nu}_\mu$Ne INTERACTIONS [⊕]

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ABSTRACT

Data on the inclusive production of hadrons in ν_μNe and $\bar{\nu}_\mu$Ne interactions are presented and compared with the corresponding quantities obtained in $\pi^\pm$Ne interactions. With 224 νNe and 219 $\bar{\nu}$Ne events, no differences are seen which would distinguish the hadronic states created by pions and neutrinos.

INTRODUCTION

In this paper we present preliminary data on the inclusive production of hadrons in ν_μNe and $\bar{\nu}_\mu$Ne interactions. We compare our results with those obtained in $\pi^\pm$Ne interactions and find that within statistics we can discern no differences. A similar conclusion was previously reported for ν_eNe and $\bar{\nu}_e$Ne interactions.(1)

The data reported here come from a study of neutrino interactions in the Fermilab 15-foot bubble chamber filled with a 64% neon - 36% hydrogen (atomic) mixture. Thus $\gtrsim$ 96% of the interactions occur on Ne. We neglect a small hydrogen background. The radiation and interaction lengths are 39 cm and $\sim$ 1.4 m, respectively. For each interaction we require a noninteracting leaving track with momentum greater than 4 GeV/c that is identified as a muon by the EMI with likelihood,(2) $\mathcal{L} > 5$, and that the total visible energy be greater than 10 GeV. From measurements of the charged secondaries, the neutrino energy was reconstructed using the method of p_T balance in the ν-μ plane to correct the total

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hadronic momentum.[3] We can reliably identify protons in the momentum range $0.2 \lesssim p \lesssim 1.0$ GeV/c. Protons with $p \gtrsim 1.0$ GeV/c will be included in the positive ("minimum-ionizing, non-muon") secondary tracks, N_+. Thus, assuming that $K^\pm$ contamination is negligible,[4,5] the N_+ distribution contains pions and fast protons, while the negative track distribution, N_-, contains pions only. We also require that there be ≥ 1 pion (i.e., one or more tracks which cannot be identified as protons). Since there are few events with hadronic invariant mass $W > 10$ GeV, we restrict ourselves to $1 \lesssim W \lesssim 10$ GeV. This leaves 224 ν_μ and 219 $\bar{\nu}_\mu$ events. In comparing with $\pi^\pm$Ne interactions at 10.5 GeV/c[5] ($\sqrt{s} = 4.4$ GeV) we make the further restriction $3 < W < 6$ GeV, leaving 112 ν_μ and 100 $\bar{\nu}_\mu$ events.

RESULTS

In Fig. 1 and Table I we give the average multiplicity of positive and negative particles combined, $\langle N_\pm \rangle = \langle N_+ \rangle + \langle N_- \rangle$ as a function of W and Q^2. Within the statistical significance of these data we observe no dependence of the average multiplicity on Q^2 for fixed W intervals. Similar conclusions have been obtained in ep, μp, νp and $\bar{\nu}$p interactions.[6] In Fig. 2a we show the dependence of $\langle N_\pm \rangle$ on W for $\nu(\bar{\nu})$Ne interactions and compare it with $\pi^\pm$Ne interactions[5,7] and note that within statistics the W dependence is similar. In Fig. 2b we give the dependence of the average multiplicity of produced negative particles, $\langle N_-^{Pr} \rangle$, where

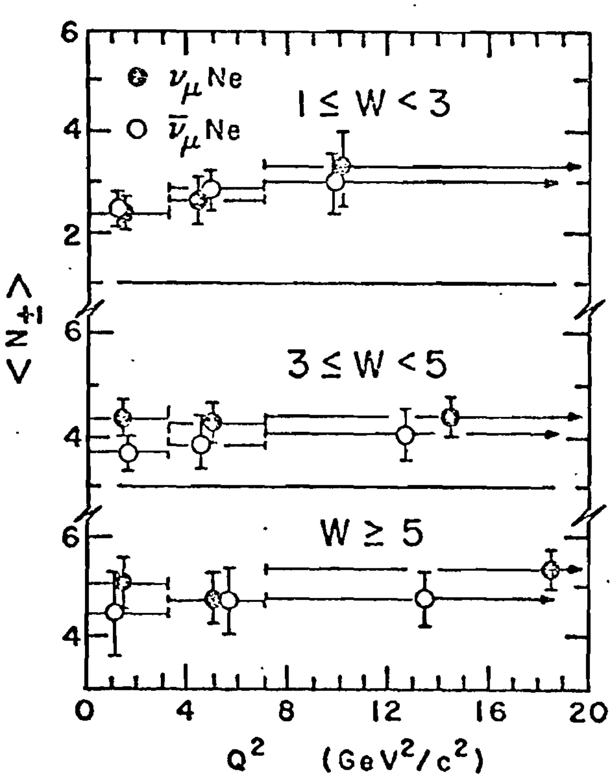

Fig. 1. The average multiplicity as a function of Q^2 for different values of W.

Table I. The average multiplicity, $< N_{\pm} >$, as a function of Q^2 and W for a) ν_μNe and b) $\bar{\nu}_\mu$Ne interactions.

a)

Q^2 (GeV^2/c^2) / W (GeV)	1.0 - 3.0	3.0 - 5.0	≥ 5
0 - 3	2.39 ± 0.15	4.25 ± 0.37	5.05 ± 0.57
3 - 7	2.71 ± 0.40	4.15 ± 0.38	4.63 ± 0.50
≥ 7	3.33 ± 0.76	4.27 ± 0.24	5.66 ± 0.25
≥ 0	2.56 ± 0.18	4.23 ± 0.18	5.34 ± 0.21

b)

Q^2 (GeV^2/c^2) / W (GeV)	1.0 - 3.0	3.0 - 5.0	≥ 5
0 - 3	2.42 ± 0.16	3.61 ± 0.32	4.45 ± 0.86
3 - 7	2.80 ± 0.33	3.90 ± 0.37	4.61 ± 0.63
≥ 7	3.00 ± 0.71	4.05 ± 0.37	4.78 ± 0.36
≥ 0	2.49 ± 0.14	3.81 ± 0.20	4.67 ± 0.30

$< N_-^{Pr} > = \left[\sum_{N_- \geq 1} N_- \cdot \sigma_{N_-} \right] \Big/ \left[\sum_{N_- \geq 1} \sigma_{N_-} \right]$ for ν and positive hadron beams and $< N_-^{Pr} > = \left[\sum_{N_- \geq 2} (N_- - 1) \cdot \sigma_{N_-} \right] \Big/ \left[\sum_{N_- \geq 2} \sigma_{N_-} \right]$ for $\bar{\nu}$ and negative hadron beams. This has the effect of removing the negative charge given to the hadron system by the beam particle, which we assume to be a W^- for $\bar{\nu}_\mu$ interaction. In most hadron-nucleus interaction experiments, the inelastic interactions in which there is only one charged particle have considerable elastic contamination. Thus, the above definition uses only data which do not have such background. From Fig. 2b, it is seen that $\langle N_-^{Pr} \rangle$ in neutrino-neon interactions has the same W dependence as $\langle N_-^{Pr} \rangle$ in hadron-nucleus interactions.[5,7,8] We note that $\langle N_-^{Pr} \rangle$ is free of possible proton contamination which might be present in $N_\pm$.

In an earlier publication[7] we showed that there is a universal relationship between the dispersion $D_-^{Pr} = \left[\langle N_-^{Pr^2} \rangle - \langle N_-^{Pr} \rangle^2 \right]^{1/2}$ versus $\langle N_-^{Pr} \rangle$ for hadron-nucleus interactions, and we see from Fig. 3 that our neutrino-neon data are consistent with this conclusion. While it is not generally understood, it appears that the universal relationship between D_-^{Pr} and $\langle N_-^{Pr} \rangle$ holds for various projectiles and targets.

Several authors[5,7,9] have pointed out that hadron-nucleus interactions approximately satisfy KNO scaling.[10] In Fig. 4 we add our $\nu(\bar{\nu})$Ne data to a compilation of πNe and πC interactions[7] and find that νNe interactions are also consistent with approximate KNO scaling.

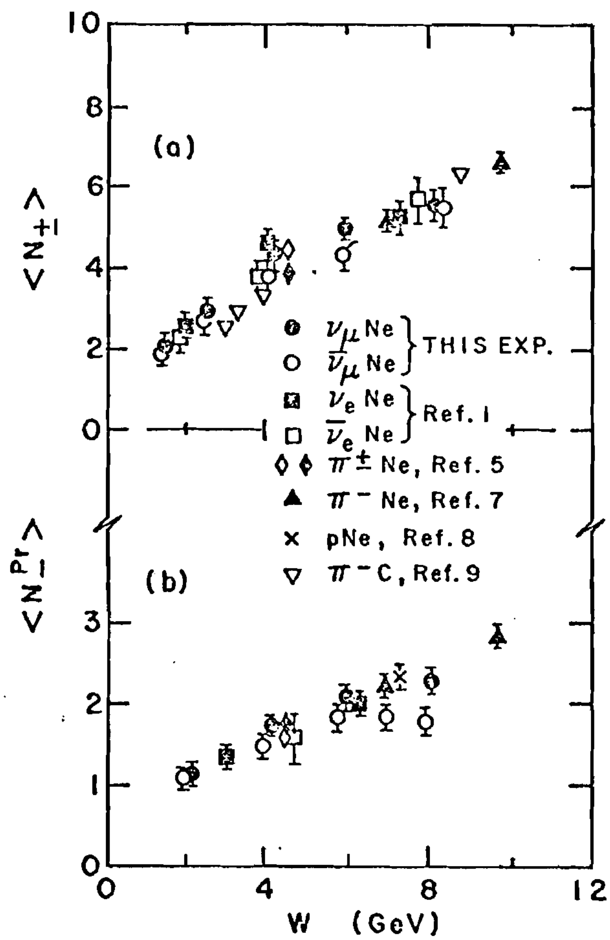

Fig. 2. Comparison of average multiplicities of charged hadrons as a function of W (or $\sqrt{s}$) for neutrino (antineutrino) and hadron-induced interactions.

We now turn to the production of protons in neutrino-neon interactions. In Fig. 5 we give the invariant inclusive cross section of protons observed in ν_μNe and $\bar{\nu}_\mu$Ne interactions (combined) and note that there is good agreement with $\pi^\pm$Ne and π^-C interactions.[5,11] The average multiplicity of slow protons ($0.2 \lesssim p \lesssim 0.8$ GeV/c) for νNe and $\bar{\nu}$Ne combined in the range $3 < W < 6$ GeV is $\langle N_p \rangle = 0.68 \pm 0.08$ which agrees well with $\langle N_p \rangle = 0.76 \pm 0.04$ for $\pi^\pm$Ne interactions at 10.5 GeV/c. Thus the

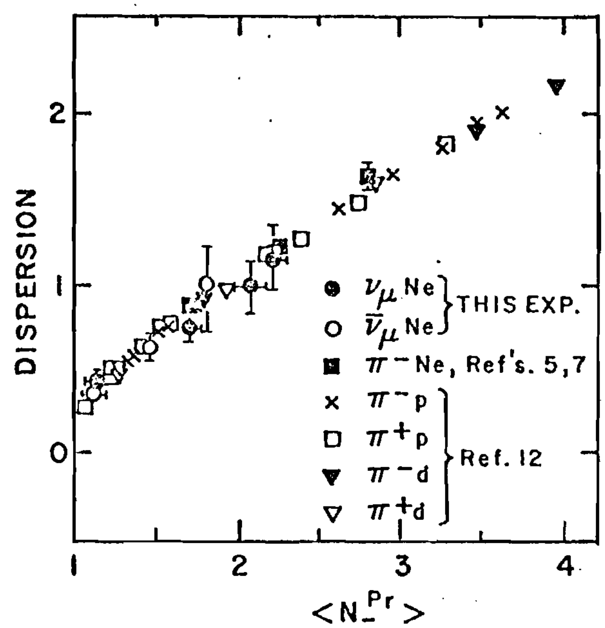

Fig. 3. Comparison of dispersion versus average multiplicity of produced negative particles for $\nu(\bar{\nu})$Ne, $\pi^{\pm}$Ne, $\pi^{\pm}$d, and $\pi^{\pm}$p interactions.

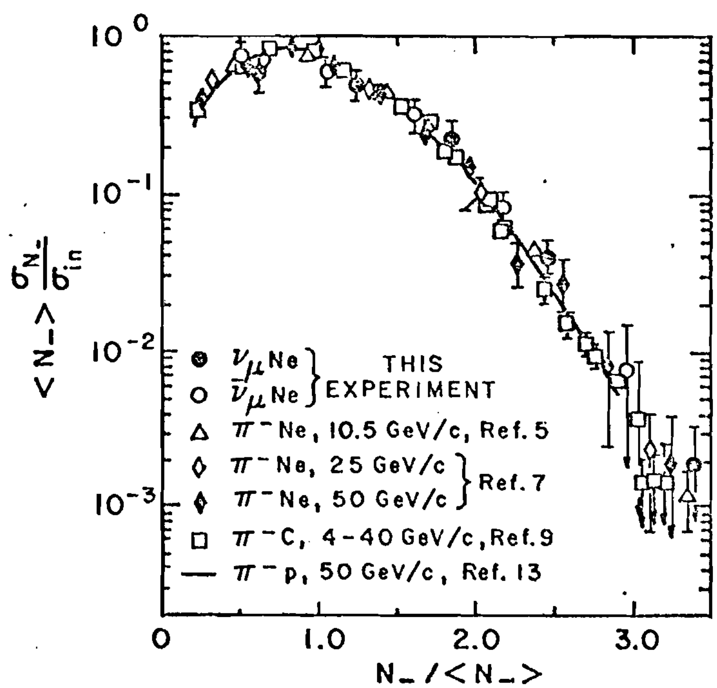

Fig. 4. Comparison of KNO scaling variable for $\nu(\bar{\nu})$Ne interactions and hadron interactions.

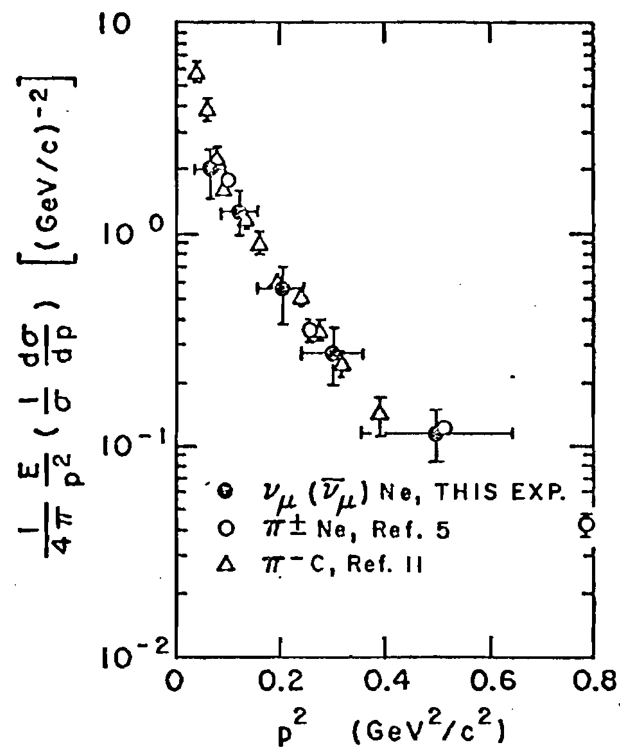

Fig. 5. Inclusive cross section of identified protons in $\nu_\mu(\bar{\nu})$Ne, $\pi^\pm$Ne and π^-C interactions.

slow protons produced in νNe and πNe interactions are similar. In $\pi^\pm$Ne interactions it has also been observed[(5)] that there is an excess of positive charge for fast minimum-ionizing secondaries and this has been interpreted as resulting from unidentified fast protons. The positive excess has been determined by applying charge symmetry and taking the difference $<N_\pm>_{\pi^+ Ne} - <N_\mp>_{\pi^- Ne} \equiv <N_p^f>_\pi$. We can see from Table II that a similar result is obtained for $\nu_\mu(\bar{\nu}_\mu)$Ne interactions for the region 3 < W < 6 GeV, by using $<N_\pm>_{\nu Ne} - <N_\mp>_{\bar{\nu} Ne} = <N_p^f>_\nu$. This suggests that there is also an excess of fast protons in neutrino-neon interactions which is quantitively similar to the excess observed in πNe interactions.[(5)]

In Table III we give the average transverse momentum of negative pions produced in νNe and $\pi^\pm$Ne interactions.[(5)] For neutrino interactions, the average transverse momentum is defined with respect to the direction of the total visible hadronic momentum. Within errors, we obtain good agreement between νNe and πNe interactions.

TABLE II. Difference $\langle N_\pm \rangle_{\nu Ne} - \langle N_\mp \rangle_{\bar{\nu} Ne}$ as compared to $\pi^\pm$Ne data.

$\nu_\mu(\bar{\nu}_\mu)$Ne Interactions, $3 \le W \le 6$ GeV	
$\langle N_+ \rangle_{\nu Ne} - \langle N_- \rangle_{\bar{\nu} Ne}$	$= 0.69 \pm 0.13$
$\langle N_+ \rangle_{\bar{\nu} Ne} - \langle N_- \rangle_{\nu Ne}$	$= 0.13 \pm 0.14$
$\pi^\pm$Ne Interactions, $\sqrt{s} = 4.4$ GeV[5]	
$\langle N_+ \rangle_{\pi^+ Ne} - \langle N_- \rangle_{\pi^- Ne}$	$= 0.78 \pm 0.04$
$\langle N_+ \rangle_{\pi^- Ne} - \langle N_+ \rangle_{\pi^+ Ne}$	$= 0.46 \pm 0.03$

TABLE III. Average transverse momenta of negative pions in $\nu_\mu(\bar{\nu}_\mu)$Ne interactions at $3 < W < 6$ GeV and $\pi^\pm$Ne interactions at 10.5 GeV/c.[5]

Reaction	$\langle p_\perp \rangle$ (MeV/c)
$\nu_\mu Ne \to \pi^- + \ldots$	315 ± 16
$\pi^+ Ne \to \pi^- + \ldots$	309 ± 4
$\bar{\nu}_\mu Ne \to \pi^- + \ldots$	307 ± 16
$\pi^- Ne \to \pi^- + \ldots$	348 ± 4

CONCLUSION

We find that within statistics the inclusive characteristics of hadrons produced in ν_μNe and $\bar{\nu}_\mu$Ne interactions are similar to those observed in $\pi^\pm$Ne interactions.

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REFERENCES

1. T.H. Burnett et al., "Neutrino-77", ed. M. A. Markov et al. (Nauka-Moscow), Vol. II, p. 132 (1978).
2. R.J. Cence et al., Nucl. Inst. and Meth. 138, 245 (1976); G. Lynch, LBL Phys. Note 808 (1975).
3. The total visible hadronic momentum is increased in magnitude to balance the momentum transverse to the ν direction in the $\mu\nu$ plane. We have verified that no distortion which could affect any of our conclusions results from this procedure. See H. Rudnicka, University of Washington Internal Report VTL-HEP-58 (1978).
4. M. Derrick et al., Phys. Rev. D17, 1 (1978).
5. W.M. Yeager et al., Phys. Rev. D16, 1294 (1977).
6. See, for example, J.W. Chapman et al., Phys. Rev. Lett. 36, 124 (1976); C. del Papa et al., Phys. Rev. D13, 2934 (1976); C.K. Chen et al., Preprint DESY 77/69 (1977); K. Bunnell et al., Preprint SLAC-PUB-2061 (1977), and Ref. 4.
7. B.S. Yuldashev et al., VTL-PUB-48 (1978), to be published in Acta Phys. Pol. B9 (1978).
8. D.J. Miller and R. Nowak, Lett. Nuovo Cimento 13, 39 (1975).
9. S.A. Azimov et al., Nucl. Phys. B107, 45 (1976).
10. Z. Koba, H.B. Nielsen and P. Olesen, Nucl. Phys. B40, 317 (1970).
11. S.A. Azimov et al., Sov. J. Nucl. Phys. 23, 519 (1976).
12. Data for $\pi^{\pm}p$ and $\pi^{\pm}d$ interactions are taken from A. Wroblewski, Proc. of VIII Inst. Symposium on Multiparticle Reactions, Kayserberg (1977).
13. G.A. Akopjanov et al., Nucl. Phys. B75, 401 (1974).