Effect of the nucleus on the average charged-particle multiplicities in high-energy neutrino interactions

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A comparative analysis of the average multiplicities of charged secondary particles in the interaction of neutrinos with emulsion nuclei and neon nuclei is reported. The average multiplicity of highly ionizing particles is observed to decrease sharply as $W^2 \to 40\ \text{GeV}^2$ in νEm interactions, in contrast with hEm interactions. A decrease of this sort cannot be explained quantitatively in the model of a parton-hadron cascade.

Research on inelastic interactions of leptons with nuclei at high energies can yield information about the multiple production of secondary hadrons in their space-time development.[1] A unique opportunity for research of this type is presented by hybrid experiments in which the target is a nuclear emulsion, in which all of the charged particles, up to the decay products of the target nucleus, are detected.

In this letter we are reporting data obtained in a hybrid experiment with a cryogenic-sensitivity nuclear emulsion inside the 15-foot Fermilab bubble chamber. The emulsion was exposed to a neutrino beam with a wide energy spectrum, up to 200 GeV. In the emulsion (with an average atomic weight $\langle A \rangle = 80$), we selected 206 charged-current neutrino interactions. For a comparative analysis we made use of neutrino data[3] from the 15-foot bubble chamber when filled with a neon-hydrogen mixture (64% neon atoms, $A = 20$). In the bubble chamber, 4000 charged-current interactions were selected. For the data of these samples, the average neutrino energy was $\langle E_\nu \rangle \sim 50$ GeV; the square of the quasimomentum transferred to the hardons, Q^2, reached 100 $(\text{GeV}/c)^2$; and the invariant mass of the hadron system ranged from 1 to 15 GeV. The details of the analysis and the selection of interactions are given in Ref. 3.

For comparison with the experimental data we carried out calculations based on models of an intranuclear cascade[4] (INC) and a parton-hadron cascade[1] (PHC) in a nucleus. The predictions based on the intranuclear-cascade model were obtained at a value $\mu^2 = 0.08\ \text{GeV}^2$ of the square transverse mass of the parton. This value determines its formation length $l_f = p/\mu^2$.

TABLE I.

	νEm		νNe	
	$\langle n_s \rangle$	$\langle n_g \rangle$	$\langle n_s \rangle$	$\langle n_g \rangle$
expt	5.16 ± 0.20	1.82 ± 0.16	4.70 ± 0.02	0.82 ± 0.02
INC	7.30	3.95	6.03	1.68
PHC	5.30	2.31	4.78	1.05

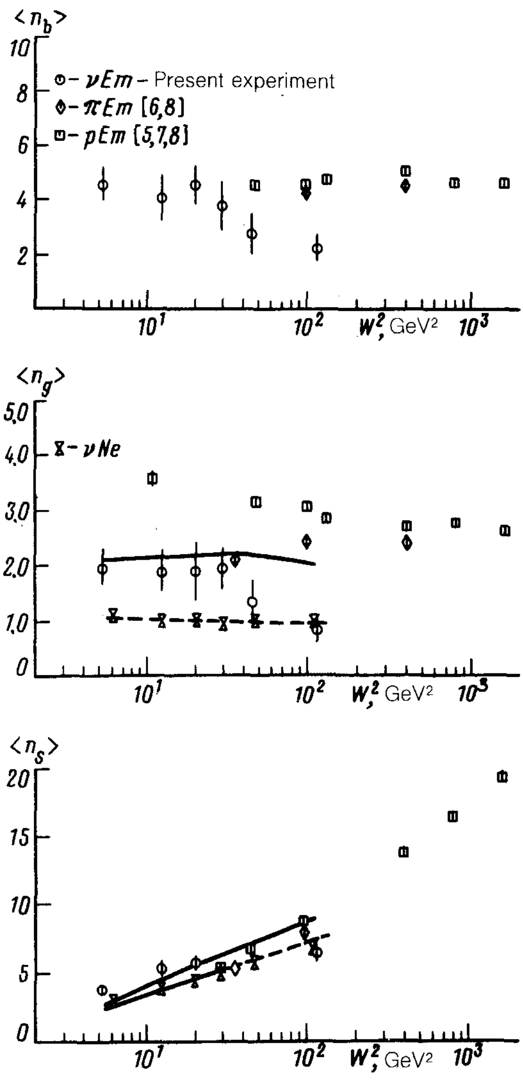

FIG. 1. W^2 dependence of the average multiplicities of various particles. a—b particles; b—g particles; c—s particles. The curves show predictions of the model of a parton-hadron cascade. Solid curves—for νEm interactions; dashed curves— for νNe interactions.

To study nuclear effects, we made use of the average multiplicities of particles of various types: relativistic *s* particles ($\beta > 0.7$), "gray" *g* particles ($0.2 < \beta < 0.7$), and "black" *b* particles ($\beta < 0.2$), which were evaporated by the excited nucleus.

Data on the average multiplicities of the charged secondary particles are listed in Table I.

It can be seen from this table that the average multiplicity of the *s* particles in *νEm* interactions is higher than that in *νNe* interactions. The increase in the multiplicity with increasing atomic number of the nucleus is evidence of an intranuclear cascade. Calculations based on the intranuclear-cascade model (with an error ~10%) fail to describe the experimental data. Calculations based on the model of a parton-hadron cascade are successful, within the error of the calculations (~10%), in describing the average multiplicities of both the *s* particles and the *g* particles in neutrino interactions.

Figure 1 shows the average multiplicities of (a) the *b* particles, (b) the *g* particles, and (c) the *s* particles versus the square of the invariant mass of the hadron block, W^2, in *νEm* and *νNe* interactions. Also shown here are data from hadron experiments[5-8] and predictions of the model of a parton-hadron cascade. The average multiplicity of the *b* and *g* particles in *νEm* interactions is observed to fall off sharply at $W^2 > 40$ GeV^2, while $\langle n_g \rangle$ for the *νNe* interactions depends only weakly on W^2. Note also that the average multiplicities of the highly ionizing paticles in *hEM* interactions are essentially independent of W^2 (Refs. 7 and 8).

In *νEm* interactions we see a slowing of the growth in $\langle n_s \rangle$ with increasing W^2, in contrast with the behavior in the *hEm* interactions.

A decrease in the average multiplicities of highly ionizing particles in *νEm* interactions is also observed in the behavior of $\langle n_b \rangle$ and $\langle n_g \rangle$ as functions of Q^2 and *Eν*.

At a qualitative level, the model of a parton-hadron cascade explains the decrease in the multiplicity of highly ionizing particles with increasing *Eν*, Q^2, and W^2 by the fact that a nucleus is excited only by those hadrons which are formed inside it, the number of which decreases with increasing energy transfer. However, quantitative calculations based on the model of a parton-hadron cascade predict values for the multiplicities of *s* and *g* particles which are too high; the discrepancy amounts to ~5 standard deviations for $\langle n_g \rangle$ at $W^2 > 40$ GeV^2.

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