# Mean multiplicities of the final hadron states in neutrino–nuclear interactions at $\langle E_\nu \rangle = 8.7$ GeV (The E-128 Experiment)

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This paper presents the results of an analysis of the mean multiplicities of the charged particles in the interactions of a neutrino with the nuclei of photographic emulsions when the values of the square of the invariant mass of the hadron system are $W^2 = 1-20$ GeV$^2$. The experimental data are in good agreement with a calculation using the parton–hadron cascade model. A logarithmic growth of the mean multiplicity with increasing $W^2$ is observed. © *1996 American Institute of Physics.* [S1063-7761(96)00208-9]

An important characteristic of the final hadron states in hard scattering processes is the mean multiplicity of the charged hadrons. This characteristic has been studied in $e^+e^-$ and $pp$ interactions,[1,2] deeply inelastic lepton-scattering from nucleons,[3–6] and Drell–Jahn processes.[7] The distributions of the events over the multiplicity of the charged particles are global characteristics, reflecting the dynamics of the interaction process. Therefore, the mean multiplicities have been studied in different particle beams in experiments based on various techniques and over a wide range of the kinematic variables. The importance of such studies is determined by the possibility of verifying the universality of the characteristics of the final hadronic states in various processes, which, generally speaking, is a consequence of the single-jet mechanism of hadron generation in processes with large virtual states. Because there is no universal model for the interaction of charged particles with nuclei, various phenomenological models are used for calculating the mean multiplicities.

This paper presents the results of a study of the mean multiplicities of the final hadron states in inclusive scattering processes of a neutrino from the nuclei of a photographic emulsion (mean atomic weight $\langle A \rangle = 80$), obtained in the E-128 experiment on the U-70 accelerator of IFVÉ.[8] The experimental results are compared with calculations using a simple intranuclear cascade model including the concept of the participation of the nucleus in the formation of the final hadronic system[9] as well as using a parton–hadron cascade model based on a multiperipheral pattern of strong interactions.[10]

An analysis was made of 670 neutrino reactions in the charged-current process

$$\nu N \rightarrow \mu^- X,$$

where $N$ is a nucleon of an atom of the target and $X$ is a final hadron state. All these events were selected according to the criterion of neutrino energy ($E_\nu > 3$ GeV) and muon momentum ($|\mathbf{p}_\mu| > 0.5$ GeV/$c$). In this case, the condition is also imposed of a momentum cutoff for each particle ($|\mathbf{p}| > 200$ MeV/$c$), with the goal of isolating only the relativistic particles. The mean neutrino energy for this sample was $\langle E_\nu \rangle = 8.66 \pm 1.72$ GeV, the mean square momentum transferred from the lepton vertex to the hadronic system was $\langle Q^2 \rangle = 2.08 \pm 0.67$ GeV$^2$, and the square of the invariant mass of the hadronic system, $W^2$, varied from 1 to 20 GeV$^2$ (Fig. 1).

The mean multiplicity of the particles in our experiment amounted to $\langle n \rangle = 3.30 \pm 0.21$ for a mean value of $\langle W^2 \rangle = 10.5 \pm 1.4$ GeV$^2$ (Fig. 2). This result is in agreement with the value $\langle n \rangle = 3.17 \pm 0.02$ measured in an experiment on the SKAT bubble chamber in the same region of variation of $W^2$. Calculations (accuracy $\approx 10\%$) give $\langle n \rangle = 5.6$ in terms of the simple intranuclear cascade model and

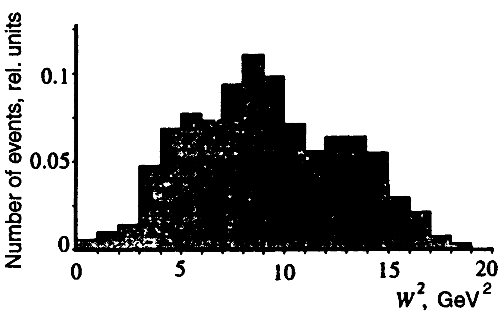


FIG. 1. Distribution of the number of events in the reaction $\nu N \rightarrow \mu^- X$ as a function of the square of the invariant mass of the hadron system.

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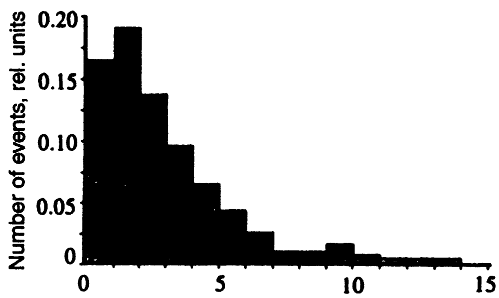


FIG. 2. Distribution of the number of events over the multiplicity of charged relativistic particles.

$\langle n\rangle = 3.6$ in the parton–hadron cascade model. The latter result describes our experimental data fairly well, within the limits of error.

Figure 3 shows the mean multiplicity as a function of the invariant mass of the final hadronic state. A logarithmic increase of $\langle n\rangle$ with increasing $W^2$ is observed in the entire range of variation of the kinematic variable $W^2$. A linear approximation of this dependence by the relationship $\langle n\rangle = A + B \ln W^2$ gives values of the coefficients of $A = 1.07 \pm 0.05$ and $B = 1.32 \pm 0.11$. For comparison, the results of the linear approximation of the dependence of $\langle n\rangle$ on $\ln W^2$ obtained in other neutrino experiments are presented in Table I. Broadening the dynamic range of $W^2$ to the values $\langle W^2\rangle \sim 100$ GeV$^2$ increases the mean multiplicity to $\langle n\rangle = 5.16 \pm 0.20$.[11] In this case, the logarithmic character of the growth of the mean multiplicity with increasing $W^2$ is maintained.

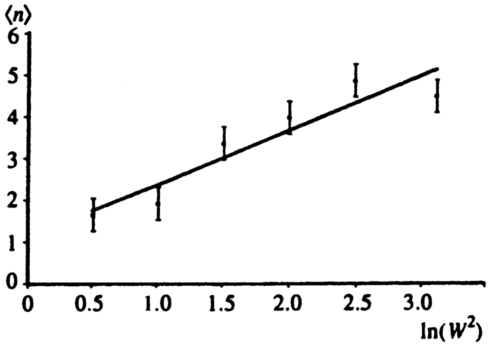


FIG. 3. Mean multiplicity of charged hadrons vs invariant mass of hadronic system.

TABLE I. Values of the parameters for the linear approximation of the dependence of the mean multiplicity on $\ln W^2$.

| Experiment | $E_\nu$, GeV | $A$ | $B$ |
|---|---|---|---|
| $\nu$-Em (Ref. 13) | 50 | $1.92 \pm 0.68$ | $1.19 \pm 0.23$ |
| $\nu$-Ne (Ref. 13) | 50 | $1.27 \pm 0.13$ | $1.20 \pm 0.05$ |
| $\nu$-$p$ (Ref. 4) | 30 | $-0.05 \pm 0.11$ | $1.43 \pm 0.04$ |
| $\nu$-$CF_3Br$ (Ref. 11) | | | |
| $\langle n_+\rangle$ | 8 | $0.15 \pm 0.09$ | $0.84 \pm 0.05$ |
| $\langle n_-\rangle$ | 8 | $-0.49 \pm 0.06$ | $0.63 \pm 0.04$ |

Note. Em is photographic emulsion; $\langle n_+\rangle$ and $\langle n_-\rangle$ are the mean multiplicities of positively and negative charged particles.

Only a very weak dependence of the mean multiplicity of the charged hadrons on the square of the transferred momentum $Q^2$ was observed in our experiment for $W^2 > 10$ GeV$^2$. This result is general even for other neutrino–nuclear experiments.[11–13] Moreover, the data on the mean multiplicities of relativistic particles for neutrino interactions coincide with the results obtained when studying quite different processes—hadronic interactions[2,14] and $e^+e^-$ annihilation.[1] Our data confirm this general tendency in the region of small $Q^2$ and $W^2$, where experimental results are very sparse (see, for example, Ref. 11).

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