Multiplicity distribution of secondary particles on nuclei at energies 200 and 800 GeV

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Results are presented of an investigation of the multiplicity of secondary particles on nuclei. The average multiplicities are equidistant with increasing energy. The maxima of the distributions for heavy nuclei are strongly shifted to the right, so that it is possible to separate, even at energies as low as ~ 1 TeV, the diffraction and non-diffraction mechanisms of secondary particle generation.

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The study of the multiplicity of hadron production in interactions of hadrons with nuclei makes it possible to obtain new information on the dynamics of strong interactions. All the collisions with the system produced in the first act and with the leading particle occur in nuclear matter even before the final state has been formed, so that the nucleus can serve as an analyzer of the space-time evolution of the process. Of course, we must have a set of data obtained with different targets, and at different energies. The experimental data were obtained in the Tskhra–Tskaro High-Mountain Laboratory. In the experiments are used cosmic hadrons which constitute, as is well known, 30% $\pi^{\pm}$ mesons and 70% nucleons. The experimental setup was described in detail in Refs. 1 and 2.

After the exposure time (15 000 h of operation of the installation), we selected for the analysis 265, 417, and 703 events on CH_2, Al, and Cu respectively with $n_s \geqslant 3$ and with energy 100 GeV (46 events for all the targets with $n_s = 2$). The target thicknesses ranged from 0.05 to 0.15 nuclear ranges. The thickness choice was governed by the requirement that no large systematic errors be introduced in the experiment by secondary collisions of the produced particles and by electron-photon cascades caused by the γ quanta of the π^0-meson decay. The estimated energy of each event included in the statistical material is based on data of an ionization calorimeter. The entire obtained material is broken up into two energy intervals, 100–400 GeV and >400 GeV. In Table I we give the number of registered events N, the average measured energy E_0, the average multiplicity of the secondary particles $\langle n_s \rangle$, and the average multiplicity $\langle n_s \rangle_m$ measured by us, the absolute systematic error in the estimate of the multiplicity of the secondary particles, and a number of parameters that are related to the multiplicity of the secondary particles.

The largest amount of information, however, is provided by the distribution of the multiplicity of the secondary particles $W(A)$, shown in Fig. 1. Before we proceed to analyze the data, however, let us discuss the systematic effects that were taken into account by us. Some of the effects, such as the loss of particles from the narrow peak as a result of the spatial resolution of the tracks in the wide-gap spark chambers, loss

TABLE I.

A	E_0, GeV	N	$\langle n_s \rangle_m$	Δn_s	$\langle n_s \rangle$	R_A	R'_A	$\langle n_s \rangle / \sqrt{D}$
CH_2	220 ± 15	192	9.2 ±0.3	0.4 ± 0.4	9.6 ± 0.5	1.25 ± 0,07	1.68 ± 0.09	2.1 ± 0.1
10.1	750 ± 40	73	11.7 ±0.5	1.2 ± 0.5	12.9 ± 0.9	1.23 ± 0.08	1.52 ± 0.10	2.1 ± 0.2
Al	220 ± 10	327	10.3 ±0.3	1.0 ± 0.5	11.3 ± 0.6	1.46 ± 0,08	1.98 ± 0.11	2.1 ± 0.1
27	860 ± 70	90	14.5 ±0.8	1.2 ± 0.5	15.7 ± 0.9	1.78 ± 0.09	1.80 ± 0.12	2.0 ± 0.2
Cu	210 ± 10	584	12.4 ± 0.3	0.8 ± 0.5	13.2 ± 0.6	1.71 ± 0.08	2.32 ± 0.11	2.0 ± 0.1
63.5	730 ± 40	119	17.6 ± 1.2	0.3 ± 0.5	17.9 ± 1.3	1.70 ± 0.14	2.10 ± 0.18	1.8 ± 0.2
—	200	876	–	–	13.3 ± 0.3	1.74 ± 0.04	2.36 ± 0.06	1.6 ± 0.04
70	1000	55	–	–	19.2 ± 1.8	1.76 ± 0.19	2.23 ± 0.24	1.4 ± 0.2

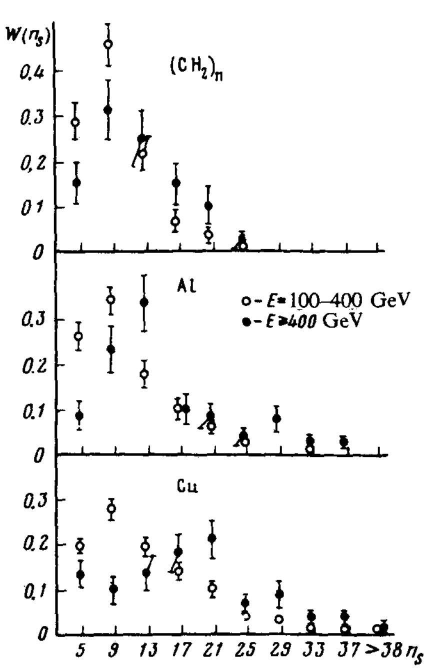

FIG. 1. Distribution of multiplicity on the nuclei CH_2, Al, and Cu.

of particles of the broad cone, the scanning efficiency, the efficiency of registration of many particles, and many other less significant effects all lead to loss of particles. Some of the effects, such as repeated interactions, electron–positron pairs, gray tracks, accompanying particles, the leading charged particles, and selection of events with $n_s \geqslant 3$, all lead to an increase of the multiplicity of the secondary particles. As a result, the combined correction is small, 3–7%. In the final result we also took into account the errors that arise in the estimates of the systematic correction. Thus, we arrive at the conclusion that neither the estimate of the average errors nor the presented distributions contain systematic distortions. From the analysis of the data listed in Table I we draw the following conclusions. 1) The multiplicity of the produced particles on nuclei increases equidistantly with energy: $\langle n_s \rangle_{E_2} / \langle n_s \rangle_{E_1} = 1.35$; 1.39; 1.36 for CH_2, Al, Cu, respectively. We note that for *PP*, interactions $\langle n_{ch} - 2 \rangle_{800} / \langle n_{ch} - 2 \rangle_{200} = 1.53$. 2) The quantity $R_A \equiv \langle n_s \rangle / \langle n_{ch} \rangle$ does not change with energy in the interval 200–800 GeV, and its dependence on the atomic nucleus can be expressed by the relation $R_A = (0.60 \pm 0.06) + (0.48 \pm 0.04)\bar{\nu}$, where $\bar{\nu} = \sigma_p^{\text{in}} / \sigma_A^{\text{in}} A$ is the average number of collisions in the nucleus. 3) As already noted, $\langle n_s \rangle$ is the multiplicity of production of particles on nuclei (the leading particle and δ nucleons have been excluded), so that a more physically consistent value of the average multiplicity of the produced particles on nuclei and nucleons is $R'_A = \langle n_s \rangle_A / \langle n_{ch} - 2 \rangle_p$. R'_A reveals a consistent tendency to decrease for all nuclei (unfortunately, the corroborating statistics are still scanty). If such a tendency is preserved further, then this will reflect an increase of the "transparency" of nulcear matter to the fast produced particles with increasing energy. If we assume the aforementioned decrease of R'_A with energy, then we can expect $R'_A \approx 1$ at $E \approx 10^5$ TeV. 4)

The quantity $\langle n_s \rangle / \sqrt{D}$ does not depend on the energy and is equal to 2 with good accuracy, for all targets. Here $D = \langle n_s^2 \rangle - \langle n_s \rangle^2$. We note that for emulsion data[3] (see Table I) this ratio is much less than 2. This emphasizes the need for using pure targets. This is even more pronounced when the distributions are investigated. The presence of an impurity amounting to six nuclei in a nuclear emulsion leads to a smearing of the true distributions. Figure 1 leads to the following conclusions: 1) A strong difference between the distribution on light, medium, and heavy nuclei at 800 GeV, which manifests itself in the fact that the maxima of the distributions W_{max} shift rapidly to the right, from which follows the possibility of distinguishing between the diffraction and non-diffraction production of secondary particles. On copper nuclei, even at 800 GeV, a tendency was noted for such a discrimination. Unfortunately, the statistics of this result are small, but for $n_s(W_{max}) = 19$ the probable value for diffraction production is 3–5 and does not depend on energy. This gives grounds for hoping that even at the energies of the modernized Batavia accelerator it will be possible not only to separate completely these two components, but also to distinguish the maxima due to branching. 2) If we compare the distributions on CH_2 and on Cu nuclei at 800 GeV, then they show (qualitatively!) that the average number of constituent quarks that take part in the interaction agrees with the predictions of Ref. 5.

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