Angular correlations of charged particles in proton-nucleon inelastic collisions at 200 GeV/c

M. G. Antonova, E. G. Boos, A. A. Goryachikh, A. A. Loktionov, P. V. Morozova, N. P. Pavlova, V. B. Slyusareva, Zh. S. Takibaev, M. A. Tashimov, N. S. Titova, and I. Ya. Chasnikov

Institute of High-Energy Physics, Kazakh Academy of Sciences

N. P. Bogachev

Joint Institute for Nuclear Research

F.G. Lepekhin and B.B. Simonov

Leningrad Institute of Nuclear Physics, USSR Academy of Sciences

V. G. Bogdanov, N. A. Perfilov, and Z. I. Solov'eva

Radium Institute

M.I. Adamovich, N.A. Dobrotin, V.G. Larionova, M.I. Tret'yakova, S.P. Kharlamov, and M.M. Chernyavskiĭ

P. N. Lebedev Physics Institute

K. I. Alekseeva

Nuclear Physics Institute, Moscow State University

S. A. Azimov, A. I. Bondarenko, K. G. Gulamov, V. V. Lavkov, V. Sh. Navotnyĭ, V. I. Petrov, T. T. Riskiev, T. P. Trofimova, L. P. Chernova, and G. M. Chernov

Physico-technical Institute, Uzbek Academy of Sciences
Alma-Ata–Leningrad–Moscow–Tashkent Collaboration

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The distribution with respect to the quantity $y = -\ln \tan(\theta/2)$ is presented for pp interactions. The distributions of the rapidity intervals occupied by different numbers of particles yield indications of the correlations of the particles with respect to rapidity in the pionization region.

We present here experimental data concerning the structure and substructure of individual showers. Elementary inelastic interactions of 200 GeV/c protons with nucleons were investigated with the aid of nuclear emulsions. The emulsions were irradiated in the Batavia accelerator. The criteria for the selection of the elementary acts and the experimental conditions of the experiment are briefly described in the first papers.[1,2]

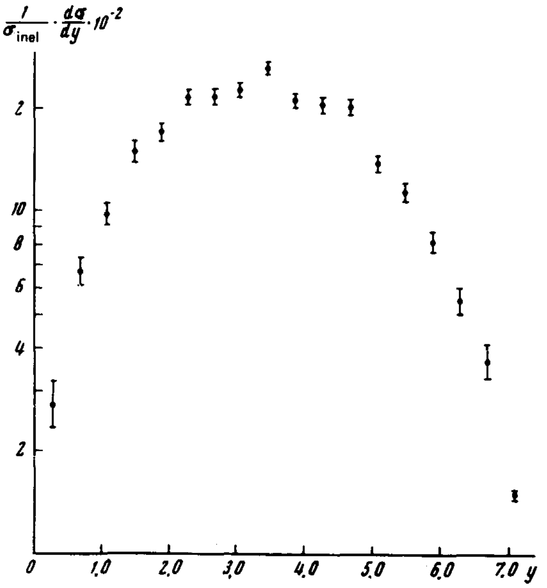

FIG. 1. Plot of $(1/\sigma_{\text{inel}})(d\sigma/dy)$ against y.

Figure 1 shows the experimental distribution of the secondary charged particles with respect to the quantity $y = -\ln\tan(\theta/2)$, where θ is the angle between the particle emission direction and the primary-proton momentum in the lab system. We shall call the quantity y "rapidity," since at 200 GeV the value of y practically coincides for most particles with the rapidity $(1/2)\ln[(E+p_\parallel)/(E-p_\parallel)]$, where E is the total energy and $p_\parallel$ is the longitudinal momentum of the secondary particles. This distribution is an inclusive distribution of the rapidities of the secondary charge particles in the reaction

$$p + p \rightarrow n \text{ charged particles} + \text{all}.$$

The ordinates represent the ratios of the inclusive cross section $d\sigma/dy$ to the inelastic cross section σ_{inel}.

The distribution takes the following form: it increases when y increases to $y = 2$ and decreases starting with $y = 4.65$; in the region $2 \leqslant y \leqslant 4.65$ the cross section is independent of y within the limits of errors. The cross sections of the pp interaction at 200 GeV/c in the interval $2 \leqslant y \leqslant 4.65$ agree with the cross sections[3] of the pp interactions at momenta 500–1500 GeV/c. This form of the distribution is attributed to the action of the pionization and fragmentation of the interacting particles. The pionization process is characterized, in accordance with the multi-peripheral model, by a uniform rapidity distribution of the particles.

It is easy to show that when the particles have a uniform distribution with respect to rapidity in the interval (0–1), the intervals of kth order between particles at a distribution density in the form

$$\frac{dw}{d\Delta_{kn}} \sim \Delta_{kn}^{k-1}(1-\Delta_{kn})^{n-k}, \qquad (1)$$

where Δ_{kn} is the interval between particles i and $i+k$ in a shower of multiplicity n. Indeed, if the particles fall uniformly and independently in the rapidity interval (0,1), then the probability that the particle will fall in the interval from y to $y+dy$ is dy. The integral probability of the particle having a rapidity smaller than y is y. It follows from geometrical considerations that the probability of two particles having rapidities that differ by an amount Δ_{kn} is $dw = (1-\Delta_{kn})d\Delta_{kn}$. The additional probability that the particle $k-1$ will fall in the interval Δ_{kn} and the particle $n-1-k$ will not fall in the interval Δ_{kn} is therefore determined by formula (1).

Inasmuch as the particle rapidity distribution is uniform in the pionization region, we can expect the observed condensations and rarefactions in the rapidity distributions of the individual showers to be connected, on the one hand, with random fluctuations described by the distribution density (1). On the other hand, they may be connected with correlations with respect to the rapidity, due to dynamics of the processes, for example clustering of the particles. Then the distributions with respect to Δ_{kn} will differ from (1). In this case the presence of small rapidity intervals between the particles will characterize the tendency to condensation of several particles, in the presence of very large intervals will characterize the tendency to condensation of particles into rapidity groups.

To compare the distributions of secondary-particle showers with respect to Δ_{kn} with formula (1), we change over to relative rapidities in the pionization region. Then the kth interval between particles $i+k$ and i is equal to

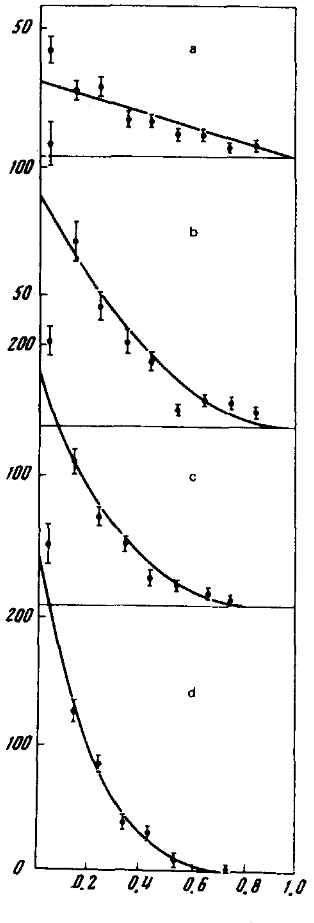

FIG. 2. Distributions of the interval Δ_{kn} for $k=1$ and $n_\tau = 2$ (a), $n_\tau = 3$ (b), $n_\tau = 4$ (c), and $n_\tau = 5$ (d). The solid curves show the distributions given by (1).

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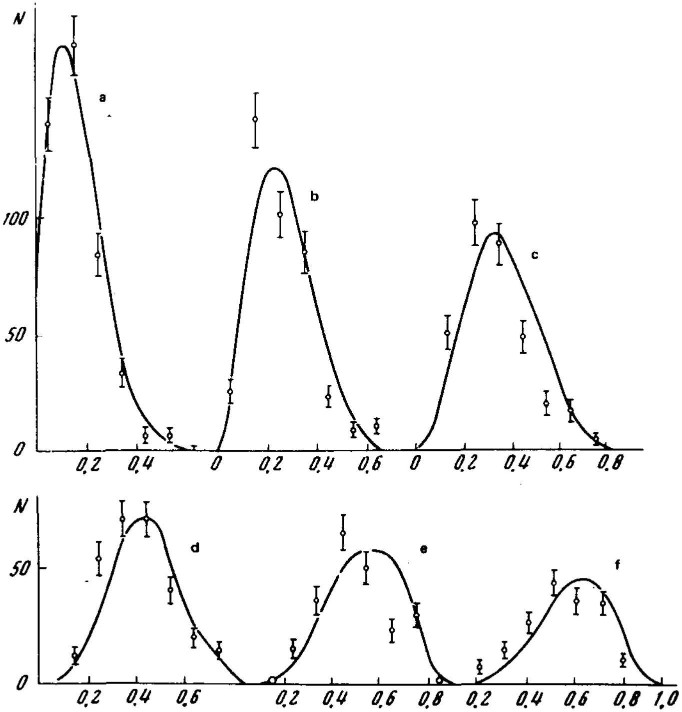

FIG. 3. Distributions of the intervals Δ_{kn} for $n_\tau = 10$ and $k = 2$ (a), $k = 3$ (b), $k = 4$ (c), $k = 5$ (d), $k = 6$ (c), and $k = 10$ (f). Solid curves—distributions (1).

$$\Delta_{kn} = \frac{y_{i+k} - y_i}{y_a - y_b}, \tag{2}$$

where $y_a = 4.65$ and $y_b = 2.0$ are the limits of the pionization region. In this case, in the comparison of (1), $n = n_\tau$ denotes the number of particles falling in the pionization region.

Figure 2 shows a comparison of the experimental distributions of the intervals between neighboring particles ($k = 1$) with (1) for different values of n_τ. As seen from the figure, at $n_\tau = 2, 3, 4$, the distributions rise more steeply towards smaller Δ_{kn} than the distributions (1), thus evidencing the presence of correlations between particles with close values of the rapidity. When n_τ exceeds 5, the experimental distributions coincide fully with the distributions (1).

Figure 3 shows the distributions for $n_\tau = 10$ and different k from 2 to 7, as well as the corresponding interval distributions (1) into which the segment (0, 1) is broken up by the random points. From a comparison of the distributions it follows that the experimental distributions at $k = 4, 5, 6$, and 7 are shifted slightly towards smaller Δ_{kn}. It is possible that this indicates the presence of correlations of the corresponding number of particles generated in the pionization process.

We can consider analogously the condensations and rarefactions of particles with respect to rapidity in the entire shower, assuming that the rapidities of the particles inside the shower are uniformly distributed between y_1 and y_n. To this end it is necessary to determine

$$\Delta_{kn} = \frac{y_{i+k} - y_i}{y_n - y_1} \tag{3}$$

and compare the distribution with respect to these Δ_{kn} with the distribution

$$\frac{dw}{d\Delta_{kn}} \sim \Delta_{kn}^{k-1} (1 - \Delta_{kn})^{n-2-k}. \tag{4}$$

Preliminary data indicate that no correlations appear inside the shower between the small number of particles, but there is a tendency for a correlation of a large number of particles to appear.

In conclusion, we are grateful to the management and staff members of NAL (Batavia, Ill.) and V.A. Nikitin for collaboration in the organization of the experiment.

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[3] Pisa—Stony Brook—ISR Collaboration, Report to the XVI International Conf. on High Energy Physics, Batavia, 1972.
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