Evidence of the coalescence of partons in experiments on heavy ion collisions

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The deviation from linear dependence of the dispersion on the multiplicity, observed in the experiments of the EMUO1 collaboration, as a result of variation of the rapidity interval has been explained on the basis of the model with parton recombination $2 \to 1$.

New experimental data, from the EMUO1 collaboration at CERN, on the multiplicity distributions in various rapidity intervals of particles with a charge of unity in the collisions of heavy ions with emulsion have been recently published. In these experiments 14.6*A*-GeV ^{16}O and ^{28}Si beams, 60*A*-GeV ^{16}O beam, and 200*A*-GeV ^{16}O and ^{32}S beams were used.[1]

The observable linear dependence between the distribution dispersion and the average multiplicity was explained by the absence of a correlation during the production of particles in the rapidity space.[1,2] Large rapidity "windows," however, caused a noticeable disruption of the linear dependence, which was attributed to the negative correlation between the particles from the beam center and those from the beam fragmentation region.

We propose a model[3,4] which describes this phenomenon both qualitatively and quantitatively. This model can be described as follows: in a parton cascade with the production $1 \to 2$, the inverse process, the $2 \to 1$ recombination, can simultaneously occur. This recombination becomes appreciable if the parton density is large in the region of interaction of the colliding ions.

An independent parton production in the $1 \to 2$ cascade leads, as we know,[5] to a negative binomial distribution (NBD) with the generating function $G^{\mathrm{OBD}}(z,\tau)$:

$$G^{\mathrm{NBD}}(z,\tau) = \left(\frac{z}{z-(z-1) < n(\tau) > /m}\right)^m, \qquad (1)$$

where τ is the parameter of the cascade evolution, m is the initial number of partons, and $\langle n \rangle$ is the average parton multiplicity.

If the dispersion of the kth order, σ_k, is defined as

$$\sigma_k = \{< (n- < n >)^k >\}^{1/k},$$

it is easy to see that for the negative binomial distribution

$$\sigma_2 = \{< n >^2 /m- < n >\}^{1/2},$$

$$\sigma_3 = \{2 < n >^3 /m^2 - 3 < n >^2 /m+ < n >\}^{1/3}, \quad n \geq m.$$

For $\langle n \rangle \gg 1$ we have σ_2, $\sigma_3 \propto \langle n \rangle$, which was, in fact, observed[1] in small (central) rapidity intervals. Upon extending the interval the number of participating partons increases, and we can expect the $2 \to 1$ recombination to occur.

The parton recombination is introduced by analogy with the classical model of particle collisions in an ideal gas.[6] The probability ν for recombination of a single parton with any other parton of n partons in a time $\Delta\tau \ll 1$ is given by

$$\nu = R/L,$$

where R is the mean radius of interaction of the colliding ions, and L is the mean free path of a parton, $L = 1/\sigma N$. Here σ represents the average scattering cross section of a parton and N denotes the parton density in the region of interaction. We have effectively a two dimensional picture because of the Lorentz contraction in the direction of the initial beam.

We can then express the interaction "area" $S_{\rm int}$ in the form

$$S_{int} = A^{2/3}\pi r^2(s),$$

where A is the atomic weight of the incident ion, and $r(s)$ is the interaction radius of a single nucleon. Assuming that in the first approximation

$$r(s) = r_0 \ln(s/s_0), \quad r_0 = \text{const}, \quad s_0 = 1 \;\Gamma \uparrow \mathrm{B}^2,$$

we find

$$N = d/\pi r_0^2, \quad d = n/\{A^{2/3}\ln^2(s/s_0)\}.$$

Since in dimension $\sigma \propto s^{-1/2}$, we can finally write

$$\nu \propto n/\{A^{1/3}\sqrt{s}\ln(s/s_0)\}.$$

The probability ν_{n+1} for the transition in the cascade ($n+1$ parton $\to$ n partons) for $\Delta\tau \ll 1$ can then be expressed in the form[6]

$$\nu_{n+1} = (n+1)\nu/2.$$

As a result, we obtain an equation for the generating function $G(z,\tau) = \Sigma P_n(\tau) z^n$ for the cascade $1 \to 2 \oplus 2 \to 1$ (Ref. 4)

$$\dot{G}(z,y) = z(z-1)\{G'(z,y) - \alpha(y)G''(z,y)\}, \tag{2}$$

where the dot (prime) denotes differentiation with respect to $y(z)$, $y = \delta\ln(s/\Lambda^2)$, and

$$\alpha(y) \propto \exp(-y/2\delta)/\{A^{1/3}(y-y_0)\}, \quad y_0 = \delta\ln(s_0/\Lambda^2). \tag{3}$$

Here $\Lambda = 0.2$ GeV, and $\delta = (\ln\langle n(s) >^{\bar{p}p}_{\rm tcsp} - \ln 1.93)/\ln(s/s_0) \simeq 0.225$ for energies in the range 5–900 GeV (Ref. 4).

Expression (1) is a solution of Eq. (2) for $\alpha = 0$. In the case $\alpha =$ const $\neq 0$, Eq. (2) has, in the limit $\tau \to \infty$, a steady-state solution in the form of a Poisson distribution with $\sigma_2 = \langle n \rangle^{1.2} = \alpha^{-1/2}$ (Ref. 3).

We note that in the experiments of the EMUO1 collaboration the rapidity intervals changed when the energy $\sqrt{s^*}$ and A were held constant ($A = 16$ in Fig. 1). It thus follows from (3) that $\alpha =$ const.

On the other hand, it is easy to see from the evaluation of the rapidity η that

$$\eta_{max} \cong \ln\sqrt{s^*/m_N^2} \cong \ln\sqrt{s^*/s_0} = (y - y_0)/2\delta.$$

The given values of s^* and A therefore uniquely determine the value of a and the maximum size of the rapidity "window." Equation (2) will then determine the rapidity evolution of the cascade $2 \to 2 \oplus 2 \to 1$ from zero to $\eta_{\rm max}$ for constant:

$$G_\eta(z,\eta) = 2\delta z(z-1)\{G'(z,\eta) - \alpha G''(z,\eta)\}.$$

The negative binomial distribution will accordingly change to a Poisson distribution at large values of η and the lower the value of α (which corresponds to a higher energy for a fixed value of A), the later the deviation from the negative binomial distribution will become noticeable.

From Eq. (3) we can easily determine the ratio of the values of α (50:18:8) with $A = 16$ for the experimental energies $P_{\rm lab} = 14.6$, 60, and 200 GeV/c, respectively. Numerically solving Eq. (4) for various values of α, we find the dependence $\sigma_2(\langle n\rangle)$ for these α. We need now to find just one value of α, for which the theoretical curve would coincide with the experimental (which can be achieved by means of a fit), in order to be able to make predictions for *any energy and any value of A*! The calculated $\sigma_2(\langle n\rangle)$ dependences are compared with the experimental results in Fig. 1.

In summary, the model of classical cascade with parton recombination according to the type of collision of molecules in an ideal gas can describe *quantitatively* the

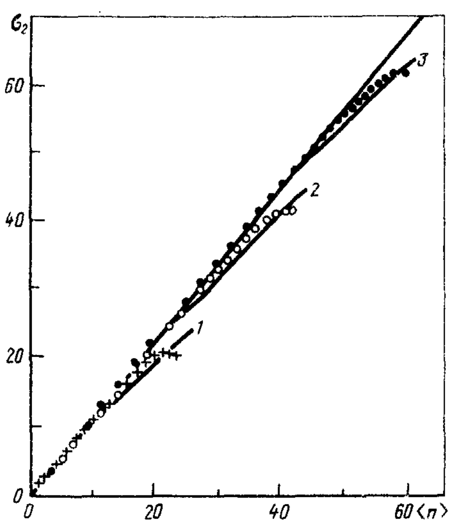

FIG. 1. The dispersion σ_2 versus the average multiplicity $\langle n\rangle$ upon variation of the rapidity intervals. Experimental points: 14.6A GeV (+), 60A GeV (○), and 200A GeV (●).[1] The theoretical curves 1–3 were calculated from Eq. (4) for $\alpha = 5\times10^{-3}$, 1.8×10^{-3}, and 0.8×10^{-3}, respectively. The straight line corresponds to the negative binomial distribution for $m = 0.76$.

dispersion as a function of multiplicity observed in heavy ion collisions upon varying the rapidity intervals.

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