Alpha particles with large transverse momenta from nucleus-nucleus collisions at high energies

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In the transverse-momentum distribution of α particles produced in the relativistic nucleus-nucleus interactions the high-momentum tail can be naturally explained in the coalescence model, without appealing to "exotic" mechanisms.

Study of nucleus-nucleus interactions at high energies initially draws attention to those characteristics of the reaction products which might be considered odd and which therefore must be analyzed to see whether they provide clues of the formation of a new form of nuclear matter or whether they are a manifestation of "exotic" reaction

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mechanisms. One of these characteristics is the transverse-momentum (p_T) distribution of α fragments of a projectile nucleus in the interaction of ^{22}Ne nuclei at 4.1 GeV/nucleon with nuclei in emulsion.[1] A statistical base of more than 3300 α particles has revealed in this distribution the presence of a smoothly decaying high-momentum tail, beginning at $p_T \sim 0.8$ GeV/c (i.e., about 0.2 GeV/c per nucleon) and extending to 3 GeV/c. The same tail, although with a much smaller statistical base, was previously observed in the interaction of 2.9-GeV/nucleon light nuclei (^{12}C, ^{14}N, ^{16}O) with emulsion nuclei.[2]

To explain the transverse-momentum distribution of α particles, we used the coalescence model proposed in Refs. 3 and 4. The simplest version of the model of Ref. 4 is, as was shown in Ref. 5, the preferable version. This version is based on the fact that several (A_F) nucleons are produced, independent of each other, in the interaction of a fast particle or a nucleus with a nucleus. If the momenta of their relative motion are smaller than a certain p_0, which is a parameter of the model, these nucleons will coalesce to form a fragment with an atomic weight A_F. The differential cross section of the fragments with a momentum $\mathbf{p}_F$ can be expressed in terms of the differential cross section of the yield of nucleons with a momentum $\mathbf{p}_n = \mathbf{p}_F/A_F$:

$$E_F \frac{d^3\sigma_F}{d^3p_F} = C_F \left(E_n \frac{d^3\sigma_n}{d^3p_n} \right)^{A_F} , \tag{1}$$

$$C_F = \left(\frac{N_T + N_P}{Z_T + Z_P} \right)^{N_F} \frac{1}{A_F^2 \; N_F! \; Z_F!} \left(\frac{4\pi}{3} \frac{p_0^3}{m_p \sigma_{in}} \right)^{A_F - 1} , \tag{1a}$$

where A, N, and Z are the neutron and proton mass numbers, the indices F, T, and P refer to the fragment, the target and the incident nucleus, and σ_{in} is the cross section for the inelastic interaction of two nuclei.

Although the coalescence model has not been fully substantiated, we chose it for two reasons: (a) In many cases this model effectively describes the spectra of light particles from proton-nucleus and nucleus-nucleus interactions (see, e.g., Refs. 6 and 7); (b) the traverse-momentum distribution of fast protons produced in nucleus-nucleus interactions has a kink in approximately the same region of p_T (~ 0.2 GeV/c) as the distribution of α particles (momentum per nucleon). This is precisely what should take place in a coalescence model. As the initial data we used the proton distributions from Refs. 1, 2, and 7, which are approximately equal to each other, as can be seen from Fig. 1a. (The transverse-momentum distributions are known to depend only slightly on the energy and the species of the incident nucleus.[7]) Figure 1 shows the data on protons produced in the interaction of: (a) C, N, and O nuclei at 2.9 GeV/nucleon with the emulsion nuclei[2] (solid line); (b) α and C nuclei at 0.95, 1.75, and 2.9 GeV/nucleon with ^{12}C nuclei[7] (dashed line); and (c) 4.1-GeV/nucleon ^{22}Ne nuclei with the emulsion nuclei[1] (circles). Since the only distribution known experimentally[1] is the transverse-momentum distribution of α particles and not the double differential cross section, which must be known before Eq. (1) can be used, we had to switch from Eq. (1) to the relation which links $d\sigma/dp_T$ distributions for nucleons and α particles. We assumed that the transverse- and longitudinal-momentum distribu-

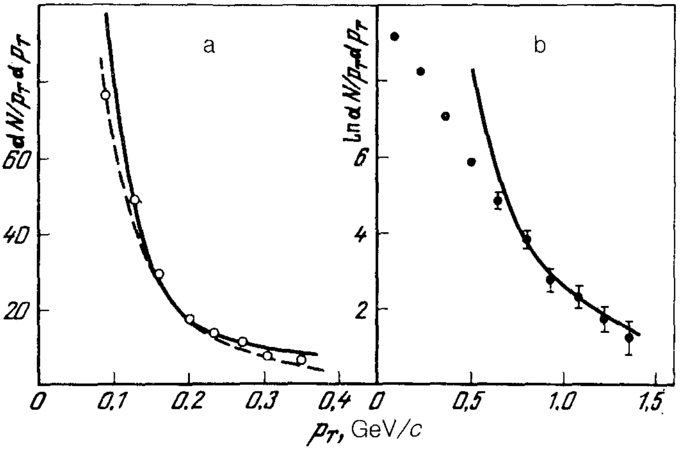

FIG. 1. (a) The p_T distribution of protons from nucleus-nucleus interactions (see the text proper); (b) comparison of the experimental data on the p_T distribution of α particles from the interaction of ^{22}Ne at 4.1 GeV/nucleon with the emulsion nuclei with the calculation based on the coalescence model (solid line). The scale is logarithmic.

tions factor out and that the longitudinal-momentum distribution can be approximated by a Gaussian curve with a characteristic parameter 70 MeV/c. These assumptions are in good agreement with the data of Ref. 7 for 2.9 GeV/nucleon, where the double differential cross sections were measured.

The results of the calculation of the $p_\perp$ distribution of α particles and their comparison with the experimental data are shown in Fig. 1b. We see that the high-momentum part of the spectrum, which is of greatest interest to us, is described well by the coalescence model, without appealing to exotic mechanisms. An agreement in absolute values of the cross sections is obtained at the parameter value $p_0 = 280$ MeV/c, which is close to the value 290 MeV/c obtained in the description of the deuteron and α-particle spectra in Ref. 7. In view of the large value of p_0, the following remarks are in order. Let us consider the graph in Fig. 2, which corresponds to the formation of a light fragment (for simplicity, let it be a deuteron). The rectangular block corresponds to the production of nucleons. If this block is assumed to be a constant, the amplitude which is compared in Fig. 2 is proportional to the wave function of the deuteron at the origin. We must therefore include here the parameters of order 200 MeV/c, which

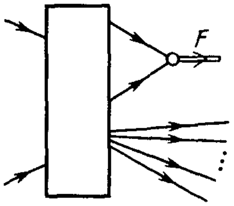

FIG. 2. Diagram showing the formation of a light fragment.

determine the behavior of the wave function at short ranges, i.e., at the nucleus-core level. Furtheremore, $\psi(0)$ is known to vanish for attainable potentials, which accounts for the fact that the result depends essentially on the behavior of the rectangular block. These circumstances should generally lead to the dependence of p_0 on the particle species, on the types of nuclei, and on the kinematic conditions of the experiment.

Differences between the spectra at low values of p_T may stem from the fact that other α-particle-production mechanisms contribute substantially here and the fact that at low values of p_T the important coherent effects and coalescence-model equations, which ignore these effects, become inapplicable.

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