"Critical" surfaces in the phase space of particles inclusively generated in hadron-hadron collisions

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In the study of single-particle inclusive distributions of charged π mesons in $\pi^- p$ interactions, the "critical" surfaces, which determine the boundary of the regions with significantly different characteristics (in particular, angular distributions) of the generated particles, were observed in the phase space of the isolated particle. A new kinematic variable is introduced.

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Investigation[1,2] of inclusive reactions in the $\pi^- p$ interactions at 5 and 40 GeV/c in the "light-front" variables[3] showed that at certain small values $\xi^{\pm} = \tilde{\xi}^{\pm}$ maxima are observed in the invariant differential cross sections $(\xi^{\pm}/\pi)\, d\sigma/d\xi^{\pm}$, which are clearly defined for light particles such as π mesons (see Fig. 1).[1)] The corresponding values of $\tilde{\xi}^{\pm}$ are given in Ref. 2.

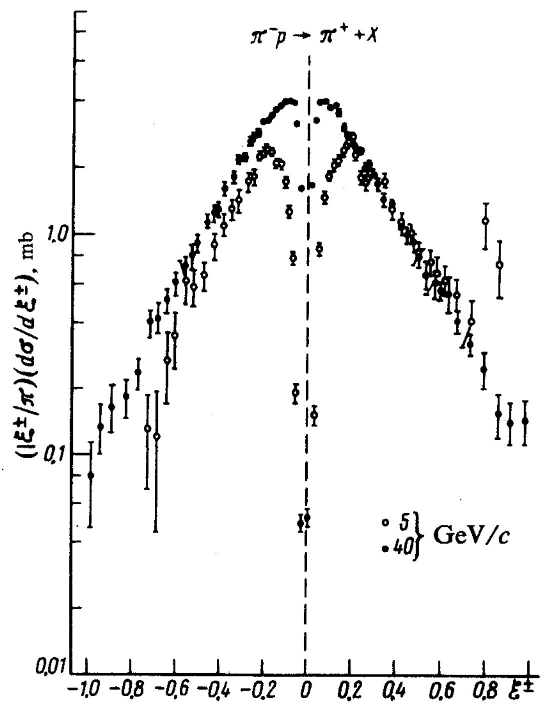

FIG. 1.

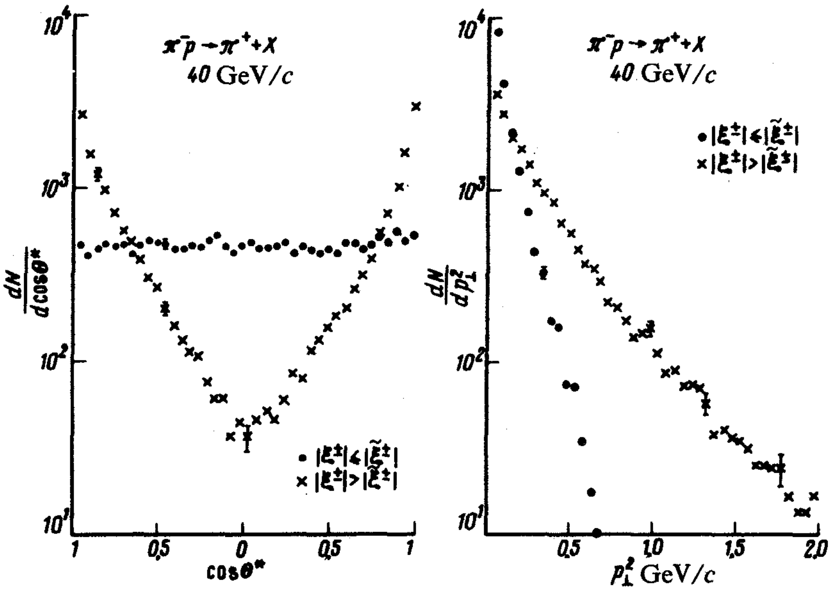

FIG. 2. Angular distributions in the c.m. system (a) and the $p_\perp^2$ distributions (b) for the π^+ mesons with $|\xi^+| < |\xi^\pm_{cr}|$ (•) and $|\xi^\pm| > |\xi^\pm_{cr}|$ (x). The number of events in the corresponding intervals of $\cos\theta$ and $p_\perp^2$ are plotted on the Y axis.

To determine the nature of these peaks, we investigated the angular and $p_\perp^2$ distributions of the inclusively generated $\pi^\pm$ mesons in the $\pi^- p$ interactions at 40 GeV/c in the regions $|\xi^\pm| < |\tilde{\xi}^\pm|$ and $|\xi^\pm| > |\tilde{\xi}^\pm|$. The results for the π^+ mesons are shown in Fig. 2. It can be seen that the angular distribution of particles with $|\xi^\pm| > |\tilde{\xi}^\pm|$ is sharply anisotropic in contrast to the almost isotropic distribution of particles with $|\xi^\pm| < |\tilde{\xi}^\pm|$. In addition, the slopes of the $p_\perp^2$ distributions differ greatly. The average values of $\langle p_\perp^2 \rangle$ in these two regions also differ substantially.

We note that the surfaces of the constant $\xi^\pm$ are paraboloids

$$p_z^c = (p_\perp^{c^2} + m_c^2 - \xi^{\pm^2} s)/(-2\xi^\pm \sqrt{s})$$

in the phase space of the isolated particle. Therefore, the surfaces

$$p_z^c = (p_\perp^{c2} + m_c^2 - \tilde{\xi}^{\pm 2} s)/(-2\tilde{\xi}^\pm \sqrt{s})$$

in the phase space of the particle c separate two groups of particles with significantly different characteristics. We call these surfaces and the values $\tilde{\xi}^\pm$ corresponding to them "critical" by analogy with the critical values of the thermodynamic parameters at which the phase transitions occur.

If we consider the phase space as a constant-curvature space occurring in the upper field of the hyperboloid $p^{c2} = m_c^2$, which determines the mass surface of the produced particle c, then the combinations $(p_0^c \pm p_z^c, \mathbf{p}_\perp^c)$ define the orispherical coordinate system in it (see, e.g., Refs. 4 and 5). In view of this, a possible theoretical interpretation of the obtained results may evolve as a result of using the techniques[5-7] developed in the study of the collective motion of this hyperboloid.

For further analysis of the inclusive reactions in the "light-front" variables, we introduced a new kinematic variable

$$\zeta^{\pm} = \mp \ln |\xi^{\pm}|,$$

where the upper sign, like in the previous case,[1,2] refers to the particles with $p_z^c > 0$ and the lower sign refers to the particles with $p_z^c < 0$ in the center-of-mass system.

The experimental data for invariant differential cross sections $(1/\pi)(d\sigma/d\zeta^{\pm})$ in the reactions $\pi^- + p \to \pi^+ + X$ at 5 and 40 GeV/c are shown in Fig. 3. The maxima are also observed in these distributions at $\zeta^{\pm} = \tilde{\zeta}^{\pm} = \zeta^{\pm}_{\rm cr}$. However, the region $|\xi^{\pm}| < |\tilde{\xi}^{\pm}|$ changes to the region $|\zeta^{\pm}| > |\tilde{\zeta}^{\pm}|$ and vice versa. Notice that in the regions $|\zeta^{\pm}| > |\zeta^{\pm}_{\rm cr}|$ the experimental distributions for the two values s_1 and s_2 of the square of the total energy in the c.m. system (which correspond to the momenta of the incident π^- mesons at 5 and 40 GeV/c, respectively) are almost parallel curves that are separated from each other by the distance

$$\Delta^{\pm} \approx 1/2 \ln(s_2/s_1)$$

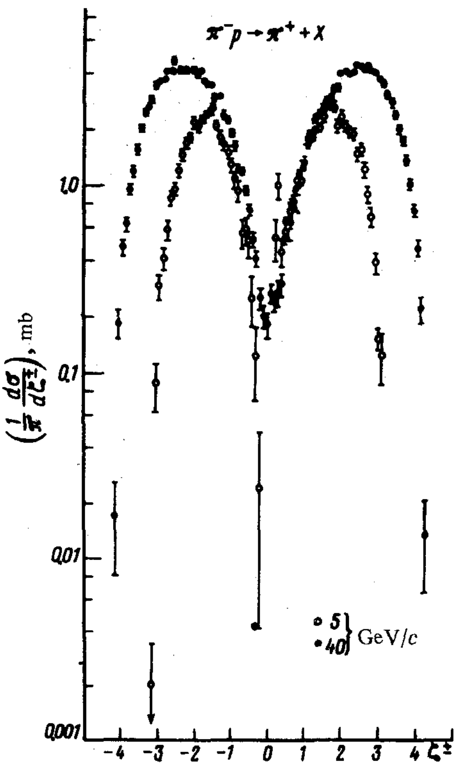

FIG. 3.

on the ζ scale. It would be of great interest to verify this relationship for other energies and other generated particles. Later we shall discuss these problems in detail.

This analysis leads us to suspect that this breakdown of the phase space by the "critical" surfaces could be a general property of all high-energy hadron-hadron reactions. It would be of great interest to investigate this effect in deep inelastic lepton-hadron processes and in the nucleus-nucleus collisions.

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[1)]In the c.m. system $\xi^{\pm} = \pm(E^c \pm p_z^c)/\sqrt{s}$, where E^c and p_z^c are the energy and longitudinal component of the particle momentum c, respectively, in the reaction $a+b\rightarrow c+X$.

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