Fast pionization at very high energies

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It is shown that fast pionization—generation of mesons carrying a specified fraction of the total velocity—is dominant in the inclusive spectra of *pp* collisions. The *z* scaling associated with this process turns out to be a universal regularity. A new parametrization of the inclusive spectra at CERN ISR energies is proposed.

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As was recently established, the inclusive spectra in the CERN IRS energy range have a z-scaling shape[1]

$$\frac{1}{\bar{n}\,\sigma_{in}}\;\frac{d\sigma}{dz\,dk_T^2}\;\xrightarrow[Y\to\infty]{}\;f(z,\,k_T)\;, \qquad (1)$$

where $z = y/Y$, k_T is the transverse momentum, and $Y = \ln(\sqrt{s/m_p})$. In this paper we show that the z scaling is a universal law in the inclusive spectra of pp collisions, where the mesons with a fixed fraction of the total velocity dominate in the region of intermediate momenta.

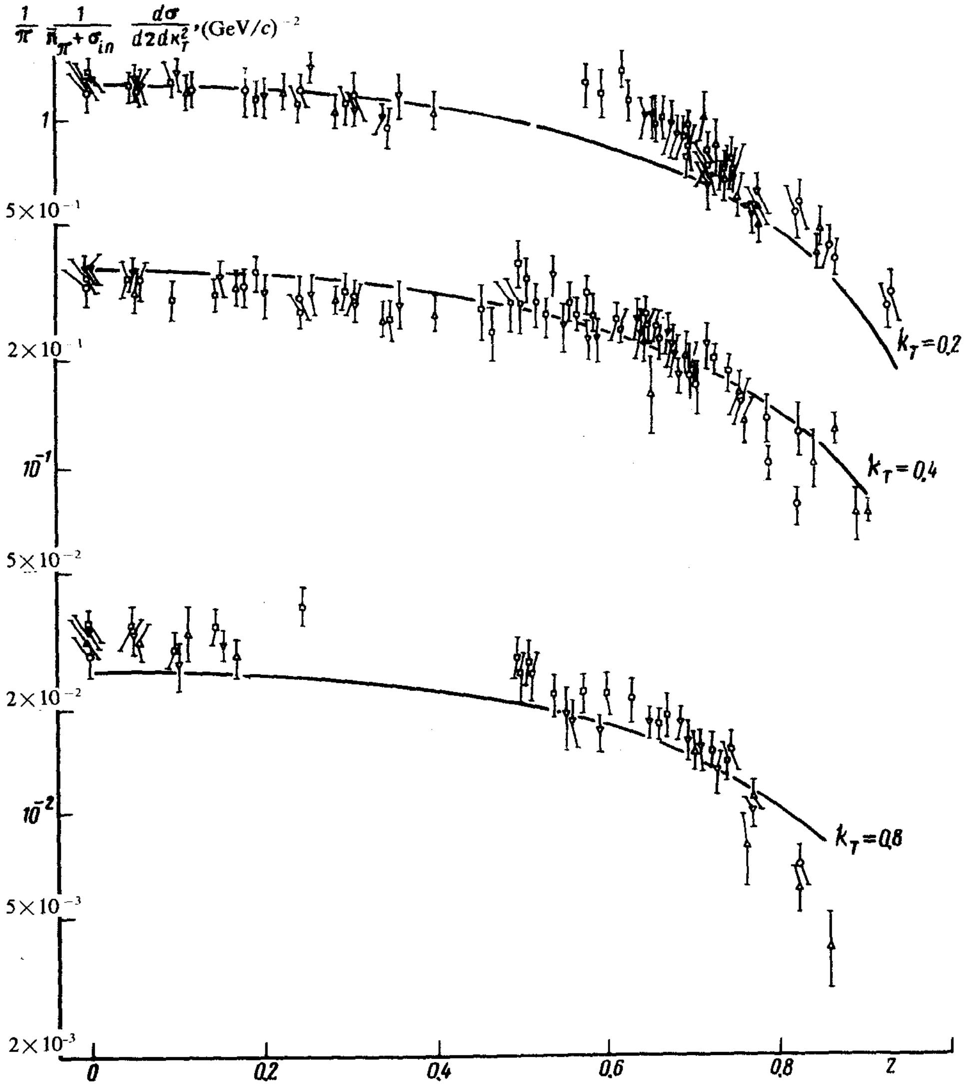

FIG. 1. The distribution of π^+ mesons normalized according to the relative velocity $z = y/Y$ and according to the transverse momentum k_T in the pp collisions. The solid lines correspond to the fit of the data in Refs. 3–6 according to Eq. (5) for the following energies in the c.m.s.: ○, 23.6 GeV; Δ, 30.6 GeV; ∇, 44.9 GeV; □, 52.8 GeV.

The general picture of this scaling can be clearly shown by constructing normalized distributions

$$\frac{1}{\bar{n}\sigma_{in}} \frac{d\sigma}{dz} \rightarrow f(z) = C(1 - z^2)^{\beta}, \tag{2}$$

where the specific choice of the z dependence is based on a fairly reasonable (although not proved rigorously) hypothesis that the Mueller-Kancheli diagrams are factorizable

TABLE I. Results of fitting according to Eqs. (2)–(5) of inclusive spectra and distributions according to the relative velocity in the pp collisions.

Equation	Region z	Region k_T GeV/c	GeV/c)$^{-2}$	B (GeV/c)$^{-1}$	C	β	χ^2/NPF	d	Δ	χ^2 NPF
					$pp \to \pi^+ X$ process					
(5)	0 – 0,9	0,1 – 0.8	6.63 ± 0,22	6.81 ± 0.07	–	0,92 ± 0,03	323/180			
(5)	0 – 0,4	0.2 – 0.8	6.42 ± 0,15	6.69 ± 0,05	–	2	159/179	0,46 ± 0.07	0.117 ± 0.004	0,5/3
(2)	0 – 0,4	–	–	–	0.67 ± 0,01	2	8/26			
					$pp \to \pi^- X$ process					
(5)	0 – 0,9	0.1 – 0.8	7.89 ± 0,29	7,04 ± 0,08	–	1,33 ±	337/161			
(5)	0 – 0.4	0.2 – 0,8	6,97 ± 0.14	6,77 ± 0.04	–	2	121/175	0,42 ± 0.06	0.087 ± 0.003	0.5/3
(2)	0 – 0.4	–	–	–	0.71 ± 0.01	2	9/25			
					$pp \to K^+ X$ process					
(5)	0 – 0.7	0.2 – 0.8	33.73 ± 3.96	6.74 ± 0.18	–	1,42 ± 0,09	94/88	0,41 ± 0,08	0.015 ± 0.006	0.4/3
(2)	0 – 0.3	–	–	–	0.42 ± 0,03	2	40/18			
					$pp \to K^- X$ process					
(5)	0 – 0.7	0.2 – 0.8	63,47 ± 8.63	7,36 ± 0,22	–	2,78 ± 0,11	96/80	0.34 ± 0.07	0.008 ± 0.0003	0.3/3
(2)	0 – 0.3	–	–	–	0,57 ± 0,04	2	22/16			

when the asymptotic form of the subenergies is saturated with singularities which guarantee an increase of the total cross sections of the form $\sigma_{\text{tot}} \sim Y^{\beta}$. It can be seen in Table I that z scaling for $\pi^{\pm}$ and $K^{\pm}$ mesons is fulfilled satisfactorily.

An increase of the effective size of the velocity region can be seen directly in the calculation of the relative dispersion

$$\delta z = \delta y / Y = d, \quad (\delta y)^2 = \frac{1}{\bar{n}\,\sigma} \int y^2 \left(\frac{d\sigma}{dy}\right) dy. \tag{3}$$

The data obtained according to relation (3) are given in Table I. Like in Eq. (2), the maximum values of β for all types of inclusive particles are reasonably close to the limiting value of $\beta = 2$.

Let us examine the relative contribution to σ_{inel} of different inclusive particles

$$\Delta_i = \Delta\sigma_i / \sigma_{in}, \tag{4}$$

where $\Delta\sigma_i$ is calculated from the saturtion of the inclusive sum rules by the ith kind of secondary particles. The results of fitting for the $\pi^{\pm}$ and $K^{\pm}$ mesons are given in Table I. The estimates taking into account the neutral particles and the fact that the leading particles carry away about half of the initial energy show that fast pionization accounts for approximately 70% contribution to the cross sections, i.e., it actually dominates at the attained energies.

Of particular interest is the fact that in the CERN ISR energy range the $\pi^{\pm}$ and $K^{\pm}$ spectra allow an astonishingly simple parametrization with a total factorization in longitudinal and transverse degrees of freedom:

$$\frac{1}{\bar{n}_i \sigma_{in}} \left(\frac{d\sigma}{dz\,dk_T^2}\right)_i = A_i \exp(-B_i \mu_T^2)(1 - z^2)^{\beta}; \tag{5}$$

here $\mu_T = (k_T^2 + \mu_i^2)^{1/2}$. The results of fitting, shown in Fig. 1 and in Table I, demonstrate that Eq. (5) is in good agreement with the data of CERN ISR.

A strong additional argument in favor of universality of the z-scaling picture of multiple hadron production is the fast increase of the average multiplicity predicted by Zachariasen *et al.*[2]

$$\bar{n} = (a \ln E_g + b)^3 , \tag{6}$$

where E_g is the permissible energy in the $\pi^{\pm}p, K^{\pm}p$, and pp collisions. A good agreement between Eq. (6) and the experimental data[1] indicates that the third power of the logarithm is entirely competitive with the traditional, purely logarithmic parametrization and power parametrization with respect to energy of the average multiplicity.

In conclusion, we note that the domination of fast pionization and the z-scaling shape of the inclusive spectra establish the most natural phenomenological base for a self-consistent picture of multiple production for the case of increasing total cross sections.

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