Energy distribution of produced particles in multiple particle production at LHC energy

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Abstract: The energy distribution of charged produced particles at $\sqrt{s} = 630$ GeV is formulated by the data of UA5 Collaboration and P239 Collaboration. The data are concluded by our discussion to be the most probable ones. Based on the formula we discuss the rapidity density distributions of the produced particles and the surviving particles at LHC energy ($\sqrt{s} = 14$ TeV).

Introduction

The data of the energy distribution of produced particles at high energies are obtained by Chacaltaya Collaboration[1], UA5 Collaboration[2], UA7 Collaboration[3] and P238 Collaboration[4]. It is not simple to obtain a unified view on the energy distribution of produced particles at high energies from these data, because some of these data are not consistent one another and because they are presented in various ways; different incident energies ($\sqrt{s} = 53,\ 200,\ 546,\ 630$ and 900 GeV), different quantities (the rapidity and pseudo-rapidity density) and different observed particles (charged particles, π^0's and γ's), etc. (See Fig. 1.) Several authors, including the authors of the above collaborations, examined some (but not all) sets of these data for the purposes of their own interests. Their conclusions on the consistency (or inconsistency) of these data are not the same but confused. We have settled this confused situation and concluded that the most probable energy distribution of charged produced particles is between those by UA5 and P238 Collaborations at $\sqrt{s} = 630$ GeV.[5]

In this paper, based on the above conclusion, we formulate empirically the energy distribution of produced particles and discuss the rapidity density distribution of produced particles at LHC energy ($\sqrt{s} = 14$ TeV, equivalent to 10^{17} eV in the laboratory system). Large Hadron Collider, to be in operation in 2007, provides a good chance to examine the plausibility of nuclear interaction models, which are incorporated in the simulations to analyze the high energy cosmic-ray events, because the predictions by the respective models cannot be said to be converging at high energies.

Empirical formula of energy distribution of produced particles

We assume the energy distribution of charged produced particles of

$$\frac{dN}{dx^* dp_T} \equiv \frac{1}{\sigma_{inel}} \frac{d\sigma}{dx^* dp_T}$$

$$= aD \frac{(\ 1 - a' x^*\ )^d}{\sqrt{x^{*2} + (2\mu/\sqrt{s})^2}}\ g(p_T) \qquad (1)$$

with $x^* = 2p^*_{||}/\sqrt{s},\ d = 4,\ D = (d+1)/3$ and $\mu = \sqrt{p_T^2 + m_\pi^2}$.[1] The scaling violation parameters $a\ (\geq 1)$ and $a'\ (\geq 1)$ express the increase and the suppression of the particle density at $x^* = 0$

1. The quantities with an asterisk are those in the center of mass syestem.

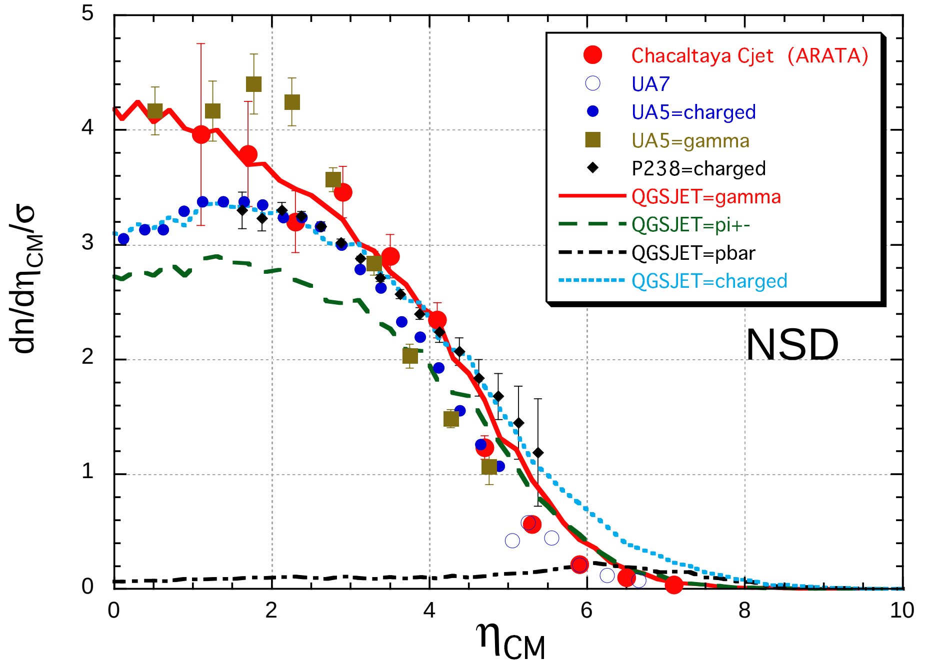

Figure 1: Rapidity density distributions of γ's and charged particles by the eperiments. The lines are for those by QGSJET[7] code of nuclear interactions at the energy $\sqrt{s} = 546$ GeV. One can see that the distributions of γ's by C-jets, UA5 and UA7 are consistent one another, and that the one of charged particles by P238 is consistent with that by QGSJET.

and in the forward region, respectively. (The case of $a = a' = 1.0$ corresponds to the Feynman scaling law.) The parameter values are to be adjusted by the experimental data. The transverse momentum (p_T) distribution is assumed as

$$g(p_T) = \delta(p_T - p_0)$$

where $\delta(x)$ is the Dirac's delta function. The parameter p_0 is dependent on the (pseudo-)rapidity so as to reproduce the experimental data of average p_T values by UA7 Collaboration[3], which decreases in the forward region. That is, we assume

$$p_0(\eta^*) = \frac{c}{1 + ae^{b(\eta^* - y_c)}} \quad (2)$$

where $a = 0.881$, $b = 1.15$, $c = 0.4$ (GeV/c), and $y_c = \ln(\sqrt{s}/M)$ (M : nucleon mass).

From eq.(1) we have

$$\frac{dN}{d\eta^* dp_T} = aD\left[1 - a'\frac{p_T}{\sqrt{s}}\left(e^{\eta^*} - e^{-\eta^*}\right)\right]^d$$

$$\times \frac{p_T\left(e^{\eta^*} + e^{-\eta^*}\right)}{\sqrt{p_T^2\left(e^{\eta^*} - e^{-\eta^*}\right)^2 + (2\mu)^2}} \quad (3)$$

because we have a relation

$$x^* = (p_T/\sqrt{s})(e^{\eta^*} - e^{-\eta^*})$$

Fig. 2 shows the pseudo-rapidity density distributions at $\sqrt{s} = 630$ GeV for several values of the parameter a', together with experimental data. The best-fit value of the parameter is $a' = 3.0$. Since we know that the Feynman scaling law violates gradually with energy, we express the scaling violation parameters as

$$a = \left(\frac{E_0}{A}\right)^{\alpha} \qquad a' = \left(\frac{E_0}{A}\right)^{\alpha'} \quad (4)$$

with $\alpha = 0.105$, $\alpha' = 0.159$ and $A = 200$ (GeV).

Fig. 3 shows the pseudo-rapidity density distributions of the produced charged particles and the surviving nucleons (charged), expected by the for-

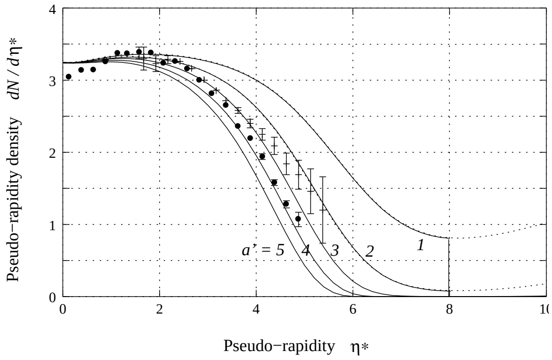

Figure 2: Pseudo-rapidity density distributions at $\sqrt{s} = 630$ GeV for the values of the scaling violation parameter $a' = 1, \ 2, \ \cdots, \ 5$. The experimental data are from UA5 Collaboration (circles) at $\sqrt{s} = 546$ GeV and from P238 Collaboration (crosses) at $\sqrt{s} = 630$ GeV. The sudden changes of the density distributions in the forward region, seen for the values of the parameter $a' = 1$ and 2, are due to the fact that the rapid decrease of p_T value causes the value x^* to decrease in the forward region.

mula eq.(3) at the energy $\sqrt{s} = 14$ TeV.[2] The surviving nucleons are assumed to have a flat energy distribution between $(1-K)\sqrt{s}/2$ and $\sqrt{s}/2$, which leads to the average inelasticity K.

Discussions

(i) The value of the parameter a' is determined by the pseudo-rapidity density distributions of charged particles by the data of UA5 Collaboration ($\sqrt{s} = 546$ GeV) and P238 Collaboration ($\sqrt{s} = 630$ GeV), which are the most probable ones at $\sqrt{s} = 630$ GeV, according to the discussions in our previous paper.[5] The value, however, reproduces poorly the pseudo-rapidity density distribution by UA5 Collaboration at $\sqrt{s} = 900$ GeV.[2] (See Fig. 4.)

The assumption of the delta function for the p_T distribution is rather brutal, but we cannot invent any appropriate distribution to describe the rapidity density distribution and the average p_T value in the forward region simultaneously and consistently.

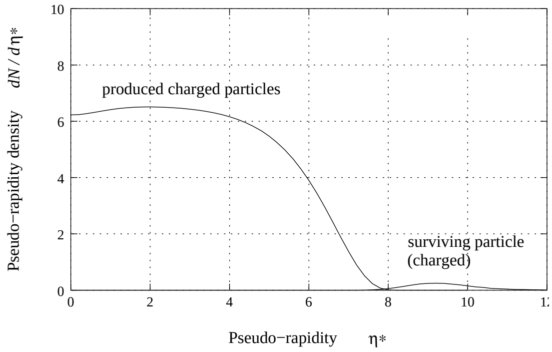

Figure 3: Pseudo-rapidity density distributions of the charged produced particles and the surviving particle (charged) at $\sqrt{s} = 14$ TeV (LHC energy) by the present model.

We note the following two points concerning the p_T distribution.
(1) A slight dip of the density distribution near $\eta^* = 0$, seen in the experimental data, is not reproduced in the present work but was reproduced in our previous work.[6]. Of course, it is due to the difference of the assumed p_T distributions, the delta function in the present work and the exponetial type in Ref.[6].
(2) It is interesting to see that the value of the parameter b in eq.(2) is quite near to 1, because we know the relation

$$< p_T > \equiv < p > sin\theta = 2 < p > \frac{e^{-\eta}}{1 + e^{-2\eta}}$$

$$\simeq 2 < p > \ e^{-\eta}$$

in the forward region. Note that the relation is obtained for the produced particles from a single emitting center, located in the forward region.

(ii) It is interesting to see the energy dependences of the characteristic features of multiple particle production by the present formula. Fig. 5 shows the energy dependences of the multiplicity of the charged produced particles and the total inelasticty, which are obtained by integrating eq.(1) with the values of the scaling violation parameters of eq.(4).

2. The charged multiplicity and the total inelasticity are $m = 83.5$ and $K = 0.318$, at $\sqrt{s} = 14$ TeV, respectively. See Discussion (ii).

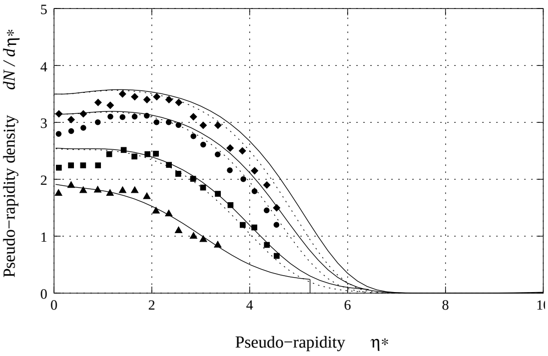

Figure 4: Pseudo-rapidity density distributions at $\sqrt{s} = 53,\ 200,\ 546,$ and 900 GeV, expected by the present formulation. The experimental data are from UA5 Collaboration; triangles ($\sqrt{s} = 53$ GeV), rectangles (200 GeV), circles (546 GeV), and diamonds (900 GeV), where the experimental errors are omitted to avoid a jam.

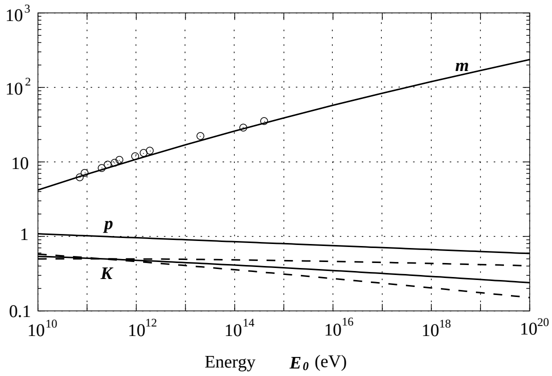

Figure 5: Energy dependences of the multiplicity (indicated as m), pion ratio (p) and the inelasticity (K). Open circles are the experimental data of the charged multiplicity. The chain lines are inelasticities for the cases of $\alpha' = 0.133$ (upper) and $\alpha' = 0.182$ (lower), while the difference is invisible for the multiplicity.

The total inelasticity is the one for which the effect of the particle composition is taken into account.[3] The cases of the values $\alpha' = 0.133$ (the best fit to the data by P238 Collaboration[4]) and 0.182 (UA5 Collaboration[2]) are also shown together in Fig. 5 for the inelasticity and the multiplicity. Note that the small difference of the characteristic features at $\sqrt{s} = 630$ GeV develops to large diffrence at higher energies for the inelasticity, but not for the multiplicity.

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3. We assume the ratio of charged pions among the charged produced particles is,

$$p(E_0) = \left(\frac{E_0}{A}\right)^{-\epsilon}$$

with $\epsilon = 0.0264$. The value is $p = 0.84$ at $\sqrt{s} = 546$ GeV, in accordance with the experimental data.[2]