Note on the Energy Distribution of Produced Particles in Multiple Particle Production

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Abstract

We discuss an energy distribution of produced particles in multiple particle production which describes the rapidity density distributions by accelerator experiments. We show that the distribution does not describe well those of simulated events by QGSJET code at high energies.

1. Introduction

The code of nuclear interaction model QGSJET[1] is widely used in the simulations to follow high energy cosmic-ray phenomena in the atmosphere. Therefore it is not meaningless to examine in detail what kind of multiple particle production the model predicts at high energies. In order to discuss the characteristics of multiple particle production, it is convenient to examine the energy distribution of produced particles because important parameters to describe multiple particle production, such as multiplicity and inelasticity, are derived from it.

In this paper we produce artificial events of $p-p$ collisions by QGSJET code at various energies of $10^{12} \sim 10^{20}$ eV, and discuss what kind of formula of the energy distribution describes the pseudo-rapidity density distributions of produced particles.

2. Notes on the energy distribution

2.1. *Energy distribution of produced particles in multiple particle production*

In our previous work[2] we examined violation of the Feynman scaling law assuming following type of the energy distribution for *charged* produced particles,

$$\frac{dN}{dxdp_T} = aD\frac{(1-a'x)^d}{\sqrt{x^2+\left(2\mu/\sqrt{s}\right)^2}}\, g(p_T) \tag{1}$$

with $x = 2p_{||}/\sqrt{s}$, $\mu = \sqrt{p_T^2+m^2}$, $D = (d+1)/3 = 1.67$ and $d = 4.0$. The quantities x and $p_{||}$ are those in the center-of-mass system. The transverse momentum

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of a produced particle, p_T, is distributed as

$$g(p_T)dp_T = (p_T/p_0)\ \exp(-p_T/p_0)\ d(p_T/p_0) \tag{2}$$

which gives the average value $< p_T >= 2p_0$.

Following comments are worth mentioning. are given in Ref.[2].

(1) At $a = a' = 1$ and $\sqrt{s} \to \infty$, we have

$$\frac{dN}{dx} = D\frac{(1-x)^d}{x}. \qquad \text{(the scaling function)} \tag{3}$$

The distribution is one of the empirical formulae to describe the energy distribution of *charged* produced particles in low energy region where the Feynman scaling law is valid.[3]

(2) The parameters a (≥ 1) and a' (≥ 1), called scaling violation parameters, represent enhancement and suppression of the scaling function in the central region and in the forward region, respectively. Navarra *et al.* point out that the the formula emerges in a natural way from the information theory approach.[4]

(3) The rapidity and pseudo-rapidity distributions, dN/dy and $dN/d\eta$ are obtained easily from eq.(1).

(4) The (pseudo-)rapidity distribution with suitable values of the scaling violation parameters describes the experimental data in satisfactory way at the energies of $\sqrt{s} = 53,\ 200,\ 546,$ and 630 GeV.[5] And the incident energy dependence of the scaling violation parameters shows that the Feynman scaling law is violated more strongly as the incident energy increases.

3. Pseudo-rapidity density distributions by QGSJET

We produced artificial events of multiple particle production using QGSJET code in CORSIKA6.05 INTTEST mode. The sampled incident energies are 10^{12}, $10^{13}, \cdots, 10^{20}$ eV, and the number of events is 10^4 at respective incident energies. Our concern is all inelastic events which includes single diffractive, double diffractive and non-diffractive events. Fig. 1 is the pseudo-rapidity density distribution of charged produced particles in $p-p$ collisions (all inelastic events) with incident energies of $10^{12}, 10^{13}, \cdots, 10^{20}$ eV.

3.1. Fit to the distribution of eq.(1)

We examine whether eq.(1) reproduces the distribution of the simulated events or not. The values of the scaling violation parameters are those determined by the experimental data in the energy region of $\sqrt{s} = 10 \sim 630$ GeV. We found that eq.(1) does not reproduce the distributions of simulated events. Eq.(1) with suitable values of the scaling violation parameters reproduces the distribution of simulated events fairly in low energy region. But agreement becomes worse as the incident energy increases.

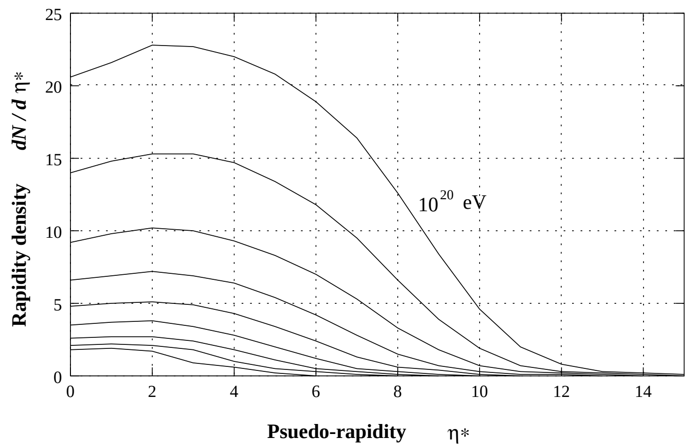

Fig. 1. Rapidity density distributions of charged produced particles at various incident energies of 10^{12}, 10^{13}, $\cdots$, 10^{20} eV. The nuclear interaction model is QGSJET. The sampled events are all inelastic events, including the leading particle.

Fig. 2 shows the distribution of 10^{20} eV. The chain lines with the scaling violation parameters in Ref.[2] and the dotted lines with the adjusted value for a and various values for a'.

3.2. Alternative formula to describe the energy distribution

We tried to find a formula of x-distribution which reproduces the pseudo-rapidity distributions of simulated events by trial and error. Following distribution reproduces the pseudo-rapidity density at 10^{20} eV fairly well.

$$\frac{dN}{dxdp_T} = \frac{b \;\mathrm{Min}\left(\frac{1}{1+b'x}, \frac{1}{1+\sqrt{b'x}}\right)}{\sqrt{x^2+(\mu/\sqrt{s})^2}}\; g(p_T) \qquad (4)$$

where b and b' are the adjustable parameters. However reproduction is poor at 10^{12}, 10^{13} and 10^{14} eV. Furthermore the distribution at 10^{12} eV is not consistent with the scaling function at $x > 0.1$.

4. Summary and discussion

(i) We studied the energy distribution of produced particles on the nuclear interaction model QGSJET, using artificial events produced by QGSJET code at 10^{12}, 10^{13}, ..., 10^{20} eV. We showed the following points.
(1) The energy distribution of produced particles by QGSJET cannot be described by the empirical formula eq.(1) which describes the experimental data at $\sqrt{s} = 53,\ 200,\ 546$ and 630 GeV. We discussed in Ref.[2] that the distribution stays between those of Model 1 and Model 2.

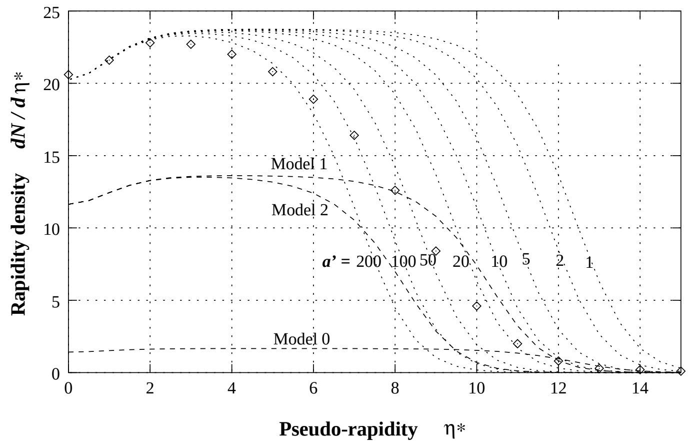

Fig. 2. Rapidity density distribution of charged produced particles at 10^{20} eV. The chain curves are those with the scaling violation parameters in Ref.[2], *e.g.* Model-0($a = 1.0$, $a' = 1.0$), Model-1(8.19, 8.19) and Model-2(8.19, 67.1), and the dotted curves are those of the adjusted value for a and several values for a' (attached to the curves).

(2) The energy distribution of produced particles by QGSJET can be described by the formula eq.(6) fairly well. But we have to say that unified description over the wide energy region of $10^{12} \sim 10^{20}$ eV is not satisfactory.
(ii) In the present analysis we did not take into account the energy dependence of $< p_T >$. As one can see in eq.(1), p_T appears dominantly in the term $a'x$ as

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

That is, the energy dependence of $< p_T >$ is absorbed in the energy dependence of a'. It is interesting to see that $a \propto E_0^{0.125}$ and $a' \propto E_0^{0.25}$ in Ref.[2], but the energy dependence of $< p_T >$ is as small as $\propto E_0^{0.026}$ in QGSJET model.

References

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