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Inclusive production in a model for soft interactions

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The results presented in this paper differ from our previous unsuccessful attempt to predict the rapidity distribution at $W = 7$ TeV. The original version of our model only summed a particular class of Pomeron diagrams (enhanced diagrams). We believe that this was the reason for our failure to describe the 7 TeV inclusive LHC data. We have developed a new approach that also includes the summation of the semienhanced diagrams. This contribution is essential for a successful description of the inclusive distributions, which is presented here.

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Traditionally, inclusive hadron production at high energies has been considered a typical example of a soft process. Because of our lack of understanding of QCD at long distances, such processes are studied in the framework of high-energy phenomenology based on soft Pomerons and their interactions. However, the first LHC data on hadron production [1–3] showed that the alternative approach, based on high-density QCD [4–11], is able to predict [12] and describe the main features of the inclusive experimental data at the LHC [13–15]. On the other hand, our first attempt [16] to predict the inclusive rapidity spectra based on a model of soft interactions [17] failed to describe the experimental data, possibly giving the impression that soft models are unable to depict LHC data. In this paper we show that this impression is incorrect, and that models based on soft Pomeron interactions are capable of reproducing the inclusive LHC data. In our two papers (see Refs. [17,18]) we have built a model for soft interactions. This model has the following features:

(i) Pomeron $\Delta_{IP} \approx 0.2$ and $\alpha'_{IP} \approx 0$.
(ii) It contains a large Good-Walker component.
(iii) The Pomeron interaction turns out to be weak.
(iv) Only the triple Pomeron vertex was taken into account.

It is interesting to note that this model reproduces the main qualitative property of high energy scattering in anti–de Sitter conformal field theory (AdS/CFT) correspondence for $N = 4$ supersymmetric Yang-Mills (SYM) in the region of large coupling constant. Indeed, in $N = 4$ SYM the intercept of the Pomeron is large and equal to $2 - 2/\sqrt{\lambda}$, while $\alpha'_{IP} = 0$ (see Ref. [19]). In this theory we only have a solution for $\lambda \gg 1$ with $\Delta_{IP} \approx 1$. However, attempts to describe deep inelastic scattering data [20] in $N = 4$ SYM lead to $\Delta \approx 0.2$. This value and small α'_{IP} should be compared with the typical values $\Delta_{IP} = 0.08$ and $\alpha'_{IP} = 0.25$ GeV^{-2} (see Ref. [21] and references therein). The large Δ_{IP} and small α'_{IP} are typical features of a new generation of soft interaction models [17,18,22,23]. A large Good-Walker component is one of the most qualitative features of the AdS/CFT approach, as in this approach the main contribution to the shadowing correction stems from elastic scattering and diffraction production [19,24]. The triple Pomeron vertex is small both in AdS/CFT correspondence approach and peturbative QCD, being of the order of $2/\sqrt{\lambda} \ll 1$[1] and α_s^2/N_c^2, respectively. We believe that the small size is necessary to provide a natural matching with peturbative QCD, where only this vertex contributes [25]. This is our justification for neglecting higher order vertices for Pomeron-Pomeron interactions in the model utilized here.

In our recent paper [18] we summed all essential Pomeron diagrams. Therefore, it is important, for consistency, to check whether our postulates are necessary for the description of the inclusive hadron production at the LHC.

The inclusive cross section can be calculated in Pomeron calculus [26] (see also Refs. [21,27–29]) using Mueller diagrams [30] shown in Fig. 1. They lead to the following expression for the single inclusive cross section:

$$\begin{aligned}\frac{1}{\sigma_{NSD}}\frac{d\sigma}{dy} = \frac{1}{\sigma_{NSD}(Y)}\Big\{ & a_{IPIP}\Big(\int d^2b(\alpha^2 G_1(b,Y/2-y) \\ & + \beta^2 G_2(b,Y/2-y)\Big)\times\int d^2b(\alpha^2 G_1(b,Y/2+y) \\ & + \beta^2 G_2(b,Y/2+y)) - a_{IPIR}(\alpha^2 g_1^{IR} + \beta^2 g_2^{IR}) \\ & \times\Big[\alpha^2\int d^2b(\alpha^2 G_1(b,Y/2-y) \\ & + \beta^2 G_2(b,Y/2-y))e^{\Delta_{IR}(Y/2+y)} \\ & + \int d^2b(\alpha^2 G_1(b,Y/2+y) \\ & + \beta^2 G_2(b,Y/2+y))e^{\Delta_{IR}(Y/2-y)}\Big]\Big\}. \end{aligned} \qquad (1)$$

In Eq. (1) $G_i(b, Y)$ denotes the sum of fan diagrams

[1]In AdS/CFT correspondence the Pomeron is the Reggeized graviton and there is no triple graviton interaction in flat space.

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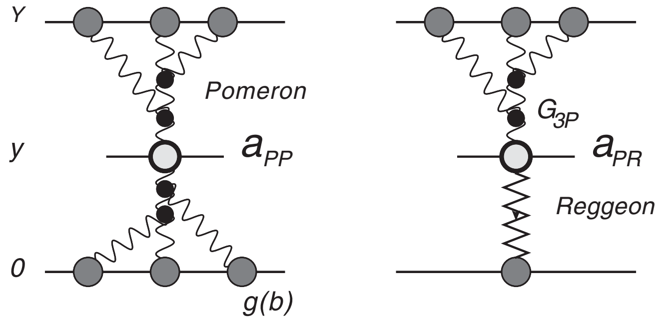

FIG. 1. The Mueller diagrams [30] for single inclusive cross section. The wavy bold line denotes the exact Pomeron Green's function of Eq. (3), which is the sum of the enhanced diagrams. The zigzag line stands for the exchange of a Reggeon.

$$G_i(b,Y)=(g_i(b)/\gamma)G_{\rm enh}(y)/(1+(G_{3IP}/\gamma)g_i(b)G_{\rm enh}(y)), \quad (2)$$

where the Green's function of the Pomeron, obtained by the summation of the enhanced diagrams [17], is equal to

$$G_{\rm enh}(Y) = 1 - \exp\left(\frac{1}{T(Y)}\right)\frac{1}{T(Y)}\Gamma\left(0, \frac{1}{T(Y)}\right). \quad (3)$$

In Eqs. (2) and (3) we denote (see Refs. [17,18] for details)

$$g_i(b) = g_i S_i(b) = \frac{g_i}{4\pi} m_i^3 b K_1(m_i b); \qquad T(Y) = \gamma e^{\Delta_{IP} Y};$$
$$\gamma^2 = \int d^2k G_{3IP}. \quad (4)$$

g_i denotes the Pomeron vertex of interaction with the i state at $b=0$; m_i is the parameter which determines the impact parameter dependence of this vertex; Δ_{IP} and Δ_{IR} are the Pomeron and Reggeon trajectory intercepts, respectively. The triple Pomeron vertex G_{3IP} and the parameters α and β, which determine the decomposition of the proton wave function into its Good Walker components, $\Psi_{\rm proton} = \alpha\Psi_1 + \beta\Psi_2$, have been discussed in Refs. [17,18]. In our calculations we took the numerical values of these parameters from Ref. [18].

In Eq. (1) we introduce two new vertices: a_{IPIP} and a_{IPIR}, which describe the emission of hadrons from Pomeron and from the secondary Reggeon (see Fig. 1). In practice, we have to deal with two more dimensional parameters Q and Q_0. Q is the average transverse momentum of the produced minijets, and $Q_0/2$ is the mass of the slowest hadron produced in the decay of the minijet. As we shall see below, the parameter that determines the shape of the inclusive spectra versus η is the ratio Q_0/Q.

We need this parameter to calculate the pseudorapidity η, which we use instead of the rapidity y. The relation between y and η is well known (see Ref. [31])

$$y(\eta, Q_0/Q) = \frac{1}{2}\ln\left\{\frac{\sqrt{\frac{Q_0}{Q}+1+\sinh^2\eta}+\sinh\eta}{\sqrt{\frac{Q_0}{Q}+1+\sinh^2\eta}-\sinh\eta}\right\}, \quad (5)$$

with the Jacobian

$$h(\eta, Q_0/Q) = \frac{\cosh\eta}{\sqrt{\frac{Q_0}{Q}+1+\sinh^2\eta}}. \quad (6)$$

Using Eqs. (5) and (6) we can rewrite Eq. (1) in the form

$$\frac{1}{\sigma_{NSD}}\frac{d\sigma}{d\eta} = h(\eta, Q_0/Q)\frac{1}{\sigma_{NSD}(Y)}\Big\{a_{IPIP}\Big(\int d^2b\{\alpha^2G_1(b, Y/2 - y(\eta, Q_0/Q)) + \beta^2G_2(b, Y/2 - y(\eta, Q_0/Q))\}$$
$$\times\int d^2b\{\alpha^2G_1(b, Y/2 + y(\eta, Q_0/Q)) + \beta^2G_1(b, Y/2 + y(\eta, Q_0/Q))\}\Big) - a_{IPIR}(\alpha^2g_1^R + \beta^2g_2^R)$$
$$\times\Big[\alpha^2\int d^2b\{\alpha^2G_1(b, Y/2 - y(\eta, Q_0/Q)) + \beta^2G_2(b, Y/2 - y(\eta, Q_0/Q))\}e^{\Delta_R(Y/2+y)}$$
$$+\int d^2b\{\alpha^2G_1(b, Y/2 + y(\eta, Q_0/Q)) + \beta^2G_2(b, Y/2 + y(\eta, Q_0/Q))\}e^{\Delta_R(Y/2-y)}\Big]\Big\}. \quad (7)$$

We extract the three new parameters: a_{IPIP}, a_{IPIR}, and Q_0/Q from the experimental inclusive data. We made two separate fits: (a) fitting only the CMS data at different LHC energies (see Fig. 2(a)); and (b) fitting all inclusive data for $W \geq 546$ GeV (see Fig. 2(b)). We choose only data in the central region of rapidity, as we have not included energy conservation, and therefore our model is inadequate to describe the data behavior in the fragmentation region. The values of fitted parameters are presented in Table I. As stated, all other parameters were taken from Ref. [18].

Figure 2 shows that the soft model based on the Pomeron approach is able to describe the behavior and the value of the inclusive production observed experimentally. Our predictions are shown in the same figure. We note that the final

TABLE I. Values of parameters for the fit of inclusive spectra.

Data	a_{IPIP}	a_{IPIR}	Q_0/Q	χ^2/d.o.f.
All	0.396	0.186	0.427	0.9
CMS	0.413	0.194	0.356	0.2

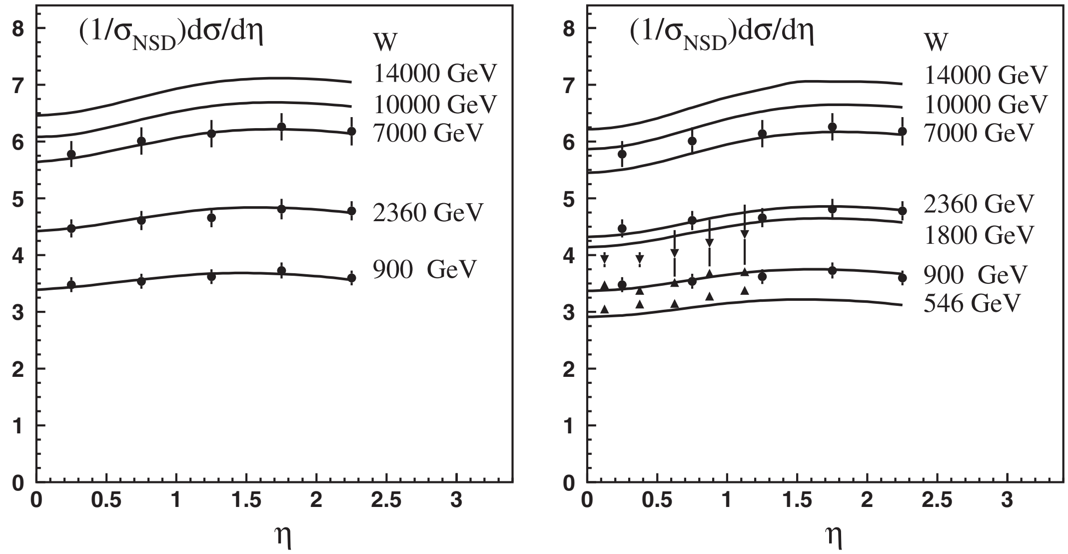

FIG. 2. The single inclusive density versus energy. The data were taken from Refs. [1–3] and from Ref. [32]. The fit to the CMS data is plotted in Fig. 2(a), while Fig. 2(b) presents the description of all inclusive spectra with $W \geq 546$ GeV.

version of our approach which includes the contributions of enhanced, semienhanced, and net diagrams (see Ref. [18]) provides a much better description of the data than we obtained in our previous attempt [16], where only enhanced diagrams were summed.

We believe that our description of the inclusive production presented here will be efficacious in calculations of other observables at high energies, such as correlations and multiplicity dependences.

Unfortunately, up to now, we are the only group that has attempted to describe inclusive production in the framework of a soft model. We hope that this effort will provide a background for other microscopic approaches based on high-density QCD.

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