Inclusive production in a QCD and N=4 SYM motivated 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 \( W = 7 \text{TeV} \). The original version of our model (GLMM) only summed a particular class of Pomeron diagrams (enhanced diagrams). We believe that this was the reason for our failure to describe the 7\( \text{TeV} \) inclusive LHC data. We have developed a new approach (GLM) that also includes the summation of the semi-enhanced diagrams. This contribution is essential for a successful description of the inclusive distributions, which is presented here.

Traditionally, inclusive hadron production at high energies has been considered a typical example of a soft process. Due to our lack of understanding of QCD at long distances, such processes are studied in the framework of high energy phenomenology based on soft Pomeron 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 the LHC data. In this letter we show that this impression is incorrect, and that models based on soft Pomeron interactions are capable of reproducing the inclusive LHC data. We have developed a new approach (GLM) where the Green’s function of the Pomeron, obtained by the summation of the enhanced diagrams\[17\], is equal to

\[
\frac{1}{\sigma_{NSD}} \frac{da}{dy} = \frac{1}{\sigma_{NSD}(Y)} \left\{ a_{P \cdot P} \left( \int d^2 b \left( \alpha^2 G_1(b, Y/2 + y) + \beta^2 G_2(b, Y/2 + y) \right) \right) \right. \\
\quad \left. \times \int d^2 b \left( \alpha^2 G_1(b, Y/2 + y) + \beta^2 G_2(b, Y/2 + y) \right) \\
\quad - a_{P \cdot R} \left( \alpha^2 g_1^R + \beta^2 g_2^R \right) \int d^2 b \left( \alpha^2 G_1(b, Y/2 + y) + \beta^2 G_2(b, Y/2 + y) \right) e^{\Delta R(Y/2+y)} \right. \\
\quad + \int d^2 b \left( \alpha^2 G_1(b, Y/2 + y) + \beta^2 G_2(b, Y/2 + y) \right) e^{\Delta R(Y/2-y)} \right\}.
\]

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

\[
G_i(b, Y) = \left( g_i(b) \gamma \right) G_{enh}(y) / \left( 1 + \left( G_{3\gamma} \gamma \right) g_i(b) G_{enh}(y) \right),
\]

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

\[
G_{enh}(Y) = 1 - \exp \left( \frac{1}{T(Y)} \right) \frac{1}{T(Y)} \Gamma \left( 0, \frac{1}{T(Y)} \right).
\]

In Eq. (2) and Eq. (3) we denote (see Refs.\[14,18\] for details):

\[
g_i(b) = g_i S_i(b) = \frac{g_i}{4\pi} m_i^3 b K_1(m_i b) ; \quad T(Y) = \gamma e^{\Delta P Y} ; \quad \gamma^2 = \int d^2 k G_{3\gamma}.
\]
between $y$ and $Q$ is the ratio produced in the decay of the minijet. As we shall see below, the only parameter that determines the inclusive spectra took the numerical values of these parameters from Ref. [18].

Enhanced diagrams were summed. Ref. [18]) provides a much better description of the data than we obtained in our previous attempt [16], where only the final version of our approach which includes the contributions of enhanced, semi-enhanced and net diagrams (see Fig. 1) provides a much better description of the data than we obtained in our previous attempt [16], where only the final version of our approach which includes the contributions of enhanced, semi-enhanced and net diagrams.

The triple Pomeron vertex $G_3 P$ and the parameters $\alpha$ and $\beta$, which determine the decomposition of the proton wave function into its GW components, $\Psi_{proton} = \alpha \Psi_1 + \beta \Psi_2$, 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: $a_1 P^P$ and $a_1 P R$, 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 only parameter that determines the inclusive spectra is the ratio $Q_0/Q$.

We need these parameters to calculate the pseudo-rapidity $\eta$, which we use instead of the rapidity $y$. The relation between $y$ and $\eta$ is well known (see Ref. [28])

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

with the Jacobian

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

Using Eq. (3) and Eq. (5) we can re-write Eq. (1) in the form

$$ \frac{1}{\sigma_{NSD}} \frac{d\sigma}{d\eta} = h(\eta, Q_0/Q) \frac{1}{\sigma_{NSD}(Y)} \left\{ a_{1PP} \left( \int d^2b \left\{ \alpha^2 G_1 \left( b, Y/2 - y(\eta, Q_0/Q) \right) + \beta^2 G_2 \left( b, Y/2 - y(\eta, Q_0/Q) \right) \right\} \right) \\
\times \int d^2b \left\{ \alpha^2 G_1 \left( b, Y/2 + y(\eta, Q_0/Q) \right) + \beta^2 G_2 \left( b, Y/2 + y(\eta, Q_0/Q) \right) \right\} \right) \\
- a_{1PR} \left( \alpha^2 g_1^R + \beta^2 g_2^R \right) \left\{ \alpha^2 \int d^2b \left\{ \alpha^2 G_1 \left( b, Y/2 - y(\eta, Q_0/Q) \right) + \beta^2 G_2 \left( b, Y/2 - y(\eta, Q_0/Q) \right) \right\} e^{\Delta_R(Y/2+y)} \\
+ \int d^2b \left\{ \alpha^2 G_1 \left( b, Y/2 + y(\eta, Q_0/Q) \right) + \beta^2 G_2 \left( b, Y/2 + y(\eta, Q_0/Q) \right) \right\} e^{\Delta_R(Y/2-y)} \right\} \right\}. $$

We extract the three new parameters: $a_{1PP}$, $a_{1PR}$ 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. 2a); and (b) fitting all inclusive data for $W \geq 546$ GeV (see Fig. 2b). 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 the table. As stated, all other parameters were taken from Ref. [18].

Fig. 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 version of our approach which includes the contributions of enhanced, semi-enhanced 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.
FIG. 2: The single inclusive density versus energy. The data were taken from Refs.[1–3] and from Ref.[29]. The fit to the CMS data is plotted in Fig. 2a, while Fig. 2b presents the description of all inclusive spectra with $W \geq 546\text{GeV}$.

| Data | $a_P$ | $a_{FP}$ | $Q_0/Q$ |
|------|-------|----------|---------|
| CMS  | 0.39  | 0.186    | 0.427   |
| All  | 0.413 | 0.194    | 0.356   |

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

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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