# A MODEL FOR STRONG INTERACTIONS AT HIGH ENERGY BASED ON CGC/SATURATION APPROACH AND THE BFKL POMERON*

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We develop a consistent approach to describe soft interactions at high energy based on the BFKL Pomeron and CGC/saturation. We build a two-channel model, in which the opacity is determined by the exchange of the dressed BFKL Pomeron. The Green function of the Pomeron is calculated in the framework of CGC/saturation approach. Having eight parameters, we obtained a good description of the experimental data at high energies ($W \geq 0.546$ TeV).

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## 1. Introduction

The strong interaction at high energies is one the most difficult and thankless problems of high energy physics. The root of this problem is in the embryonic stage of our understanding of non-perturbative QCD. Traditionally, we consider the strong interaction at high energy as a typical example of the processes that occur at long distances, where the unknown confinement of quark and gluons plays a crucial role making all our theoretical efforts to treat these processes fruitless. As a result, the description of these processes is the arena of high energy phenomenology based on Pomeron calculus [1].

Our approach is to attempt to describe soft interactions by adopting well established aspects of QCD [2] and extending these to the region of soft interactions (low $Q^2$).

## 2. Theoretical input

In this section, we briefly review our model which successfully describes diffractive [3, 4] and inclusive cross sections [5]. The main ingredient of our model is the BFKL [6] Pomeron Green function that we obtained using a

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CGC/saturation approach [7]. We determined this function from the solution of the non-linear Balitsky–Kovchegov equation [8] using the MPSI approximation [9] to sum enhanced diagrams, shown in Fig. 1 (a). It has the following form:

$$G^{\rm dressed}\left(T\right) \;=\; a^2(1-\exp\left(-T\right)) + 2a(1-a)\frac{T}{1+T} + (1-a)^2 G\left(T\right)$$

$$\text{with}\quad G\left(T\right) = 1 - \frac{1}{T}\exp\left(\frac{1}{T}\right)\Gamma_0\left(\frac{1}{T}\right), \tag{2.1}$$

$$T\left(s,b\right) \;=\; \phi_0 S\left(b,m\right) e^{0.63\lambda\ln(s/s_0)} \quad\text{with}\quad S\left(b,m\right) = \frac{m^2}{2\pi}e^{-mb}. \tag{2.2}$$

In the above formulae, $a = 0.65$. This value was chosen, so as to obtain the analytical form of the solution of the BK equation. $m$ is a non-perturbative parameter, which characterizes the large impact parameter behavior of the saturation momentum, as well as the typical size of dipoles that take part in the interaction. The value of $m = 5.25$ GeV in our model supports our main assumption that the BFKL Pomeron calculus, based on a perturbative QCD approach, is able to describe the soft physics, since $m \gg \mu_{\rm soft}$, where $\mu_{\rm soft}$ is the natural scale for soft processes ($\mu_{\rm soft} \sim \Lambda_{\rm QCD}$ and/or pion mass).

Our first attempt to describe data at the LHC, based on the principles mentioned above [3], was a one-channel model (*i.e.* we did not take into account the small mass diffractive production) and had disappointing overall results.

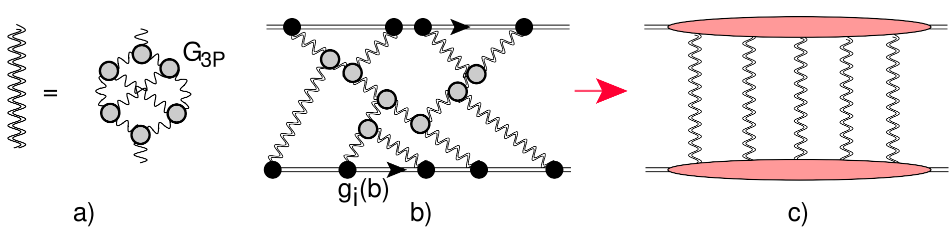


Fig. 1. (a) shows the set of the diagrams in the BFKL Pomeron calculus that produce the resulting (dressed) Green function of the Pomeron in the framework of high energy QCD. In (b), the net diagrams which include the interaction of the BFKL Pomerons with colliding hadrons are shown. The sum of the diagrams reduces to (c) after integration over positions of $G_{3\mathbb{P}}$ in rapidity.

Consequently, we extended our formalism to a two-channel model [4] which also allows us to calculate the diffractive production in the region of small masses. In this model, we replace the rich structure of the produced diffractively states by the single state with the wave function $\psi_{\rm D}$.

The Good–Walker [10] formalism for the two-channel case allows us also to calculate the low-mass diffractive states.

A simple solution to the unitarity equation at high energies has the eikonal form with an arbitrary opacity $\Omega_{ik}$, where the real part of the amplitude is much smaller than the imaginary part

$$A_{i,k}(s,b) = i\left(1 - \exp\left(-\Omega_{i,k}(s,b)\right)\right) . \tag{2.3}$$

The expressions for the physical observables in the Good–Walker formalism are given in [4]. These include the components responsible for diffraction in the small-mass region.

In the eikonal approach, we parametrize the arbitrary functions $\Omega_{ik}\left(s,b\right)$ (opacity) in the form

$$\Omega_{ik}\left(s,b\right) = \int d^2b' d^2b'' g_i\left(m_i, b'\right)\, g_k\left(m_k b''\right)\, G^{\mathrm{dressed}}\left(T\left(Y, \vec{b} - \vec{b}' - \vec{b}''\right)\right) . \tag{2.4}$$

The summation of the 'net' diagram is then given by the following simplified expression (see Ref. [11] for details):

$$\Omega\left(s,b\right)_{i,k} \;=\; \int d^2b' \;\; \frac{g_i\left(\vec{b}'\right)\, g_k\left(\vec{b} - \vec{b}'\right)\, \widetilde{G}^{\mathrm{dressed}}\left(T\right)}{1 \,+\, 1.29\, \widetilde{G}^{\mathrm{dressed}}\left(T\right)\left[g_i\left(\vec{b}'\right) + g_k\left(\vec{b} - \vec{b}'\right)\right]}\,, \tag{2.5}$$

where

$$\widetilde{G}^{\mathrm{dressed}}\left(T\right) = \int d^2b\, G^{\mathrm{dressed}}\left(T\left(Y, b\right)\right) . \tag{2.6}$$

The coefficient 1.29 results from the extraction of the value of $G_{3\mathbb{P}}$ from the CGC/saturation approach.

## 3. Diffraction production in the region of large mass

In this section, we also include, in the process of diffraction production, the mechanism of production that originates from the dressed Pomeron and has been discussed in Section 2.

For a single diffraction, the large mass contribution can be written as

$$\begin{aligned}
\sigma_{\mathrm{sd}}^{\mathrm{large\ mass}} &= 2\int d^2b\Big\{\alpha^6\, A^{\mathrm{sd}}_{1;1,1} e^{-2\Omega^{\mathrm{D}}_{1,1}(Y;b)} + \alpha^2\beta^4 A^{\mathrm{sd}}_{1;2,2}\, e^{-2\Omega^{\mathrm{D}}_{1,2}(Y;b)} \\
&+ 2\alpha^4\, \beta^2 A^{\mathrm{sd}}_{1;1,2}\, e^{-\left(\Omega^{\mathrm{D}}_{1,1}(Y;b) + \Omega^{\mathrm{D}}_{1,2}(Y;b)\right)} + \beta^2\alpha^4\, A^{\mathrm{sd}}_{2;1,1} e^{-2\,\Omega^{\mathrm{D}}_{1,2}(Y;b)} \\
&+ 2\,\beta^4\alpha^2 A^{\mathrm{sd}}_{2;1,2} e^{-\left(\Omega^{\mathrm{D}}_{1,2}(Y;b) + \Omega^{\mathrm{D}}_{2,2}(Y;b)\right)} + \beta^6\, A^{\mathrm{sd}}_{2;2,2} e^{-2\,\Omega_{2,2}(Y;b)}\Big\}\,,
\end{aligned} \tag{3.1}$$

where

$$\Omega^{\rm D}_{i,k}\left(Y;b\right)=\int d^2b'\frac{g_i\left(\vec{b}'\right)\,g_k\left(\vec{b}-\vec{b}'\right)\,\bar{G}^{\rm dressed}\left(T\right)}{\left(1+1.29\,\bar{G}^{\rm dressed}\left(T\right)\left[g_i\left(\vec{b}'\right)+g_k\left(\vec{b}-\vec{b}'\right)\right]\right)^2}\,, \tag{3.2}$$

$$A^{\rm sd}_{i;k,l}\left(Y,Y_{\rm max},Y_{\rm min};b\right)=\int d^2b'\sigma_{\rm diff}\left(Y,Y_{\rm max},Y_{\rm min},1/m\right)d^2b'\,g_ig_kg_l$$
$$\times S_{\mathbb{P}}\left(b',m_i\right)\,S_{\mathbb{P}}\left(\vec{b}-\vec{b}',m_k\right)S_{\mathbb{P}}\left(\vec{b}-\vec{b}',m_l\right)\,, \tag{3.3}$$

where $Y=\ln\left(s/s_0\right)$, $Y_{\rm max}=\ln\left(M^2_{\rm max}/s_0\right)$ and $Y_{\rm min}=\ln\left(M^2_{\rm min}/s_0\right)$. $M_{\rm max}$ and $M_{\rm min}$ are the largest and smallest mass produced in the diffractive processes. Equation (3.1) has simple physical meaning: each term is the product of probability to produce a mass diffractively from the dressed Pomeron (term $\exp\left(-\sum\Omega\right)$) and the probability of the process of single diffraction, from the dressed Pomeron ($A_{i;k,l}$).

For the double diffraction production at large mass, we have

$$\sigma^{\rm large\ mass}_{\rm dd}=\int d^2b\Big\{\alpha^4\,A^{\rm dd}_{1,1}\,e^{-2\Omega^{\rm D}_{1,1}(Y;b)}+2\alpha^2\,\beta^2 A^{\rm dd}_{1,2}\,e^{-2\Omega^{\rm D}_{1,2}(Y;b)}$$
$$+\beta^4\,A^{\rm dd}_{2,2}e^{-2\Omega^{\rm D}_{2,2}(Y;b)}\Big\}\,, \tag{3.4}$$

$$A^{\rm dd}_{i,k}=\int d^2bg_ig_kS^{i,k}_{\rm DD}\left(b\right)\sigma_{\rm dd}\left(Y\right)\,, \tag{3.5}$$

where

$$S^{i,k}_{\rm DD}\left(b\right)=\int d^2b'S_p\left(b',m_i\right)\,S_p\left(\vec{b}-\vec{b}',m_k\right)\,. \tag{3.6}$$

The expressions for $\sigma_{\rm diff}\left(Y,Y_{\rm max},Y_{\rm min},r\right)$ and $\sigma_{\rm dd}$ are given in [4]

## 4. Fitting to experimental data

There are eight phenomenological parameters, which need to be determined by fitting to the experimental data: $\phi_0,\lambda$ and $m$, $g_i$ and $m_i$ $(i=1,2)$, as well as $\alpha$. We determine these parameters by fitting to the experimental data on total, inelastic and elastic cross sections, single and double diffractive production cross sections, and the slope of the forward elastic differential cross section. The value of the minimal energy for data that we use is $W=0.546$ TeV, as starting from this energy the CGC/saturation approach, is able to describe the data on inclusive production in proton–proton collisions (see Ref. [12]).

The fitted parameters are tabulated in Table I.

The quality of the fit can be judged from Fig. 2.

TABLE I

Fitted parameters of the model.

| Model | $\lambda$ | $\phi_0$ | $g_1$ [GeV$^{-1}$] | $g_2$ [GeV$^{-1}$] | $m$ [GeV] | $m_1$ [GeV] | $m_2$ [GeV] | $\beta$ |
|---|---|---|---|---|---|---|---|---|
| 2 channel | 0.38 | 0.0019 | 110.2 | 11.2 | 5.25 | 0.92 | 1.9 | 0.58 |

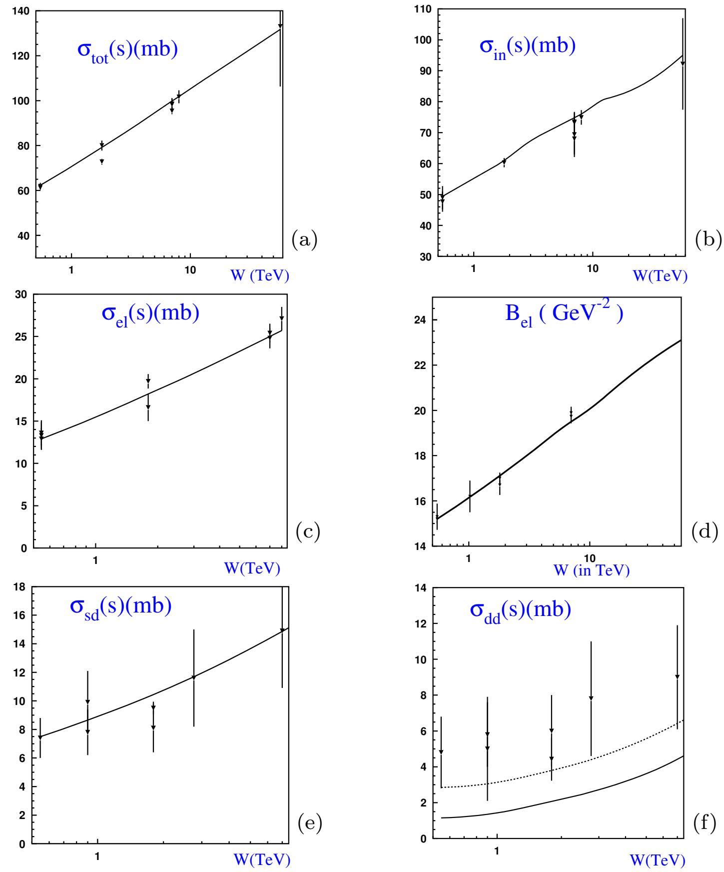


Fig. 2. Comparison with the experimental data: the energy behavior of the total (a), inelastic (b), elastic cross sections (c), as well as the elastic slope ($B_{\rm el}$, (d)), and single diffraction (e) and double diffraction (f) cross sections. The solid lines show our present fit. The data has been taken from Ref. [13] for energies less than the LHC energy. At the LHC energy for total and elastic cross section, we use TOTEM data [14], and for single and double diffraction cross sections, data are taken from Ref. [15]. The dotted line in (f) is discussed in [4].

## 5. Conclusions

We have shown that a consistent model, based on BFKL Pomeron and the CGC/saturation approach, can be built. We have demonstrated that this model successfully describes data for the high energy hadron scattering. In addition, we hope that this paper provides credence to the arguments that the matching with long-distance physics (where the confinement of quarks and gluons is essential) can be reached within the CGC/saturation approach without requiring that the soft Pomeron should appear (as a Regge pole).

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