ASPECTS OF THE UNITARIZED SOFT MULTIPOMERON APPROACH IN DIS AND DIFFRACTION

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We study in detail the main features of the unitarized Regge model (CFKS), recently proposed to describe the small-Q^2 domain. It takes into account a two-component description with two types of unitarized contributions: one is the multiple Pomeron exchanges contribution, interacting with the large dipole size configurations, and the other one consists on a unitarized dipole cross section, describing the interaction with the small size dipoles. We compare the resulting dipole cross section to that from the saturation model (GBW).

1 Introduction

The study of a new regime of QCD, that of high density of partons, has drawn much attention in the last years. The key discovery was the observation at HERA of the fast growth of parton densities (mainly gluons) as the energy increases in experiments of deep inelastic scattering. Taking $\sigma^{tot} \sim s^{\alpha(0)-1}$ ($F_2 \sim x^{-\alpha(0)+1}$), values of $\Delta \equiv \alpha(0) - 1$ in the range $0.1 - 0.5$ have been reported, depending on the virtuality Q^2 of the photon. However, some kind of saturation of this growing due to unitarity effects is expected, leading to the expected limit given by the Froissart bound ($\sigma \lesssim (\log s)^2$ as $s \to \infty$)[1].

Taking into account that the saturation phenomenon is required in a complete understanding of the high energy reactions, and that a consistent treatment of both inclusive and diffractive processes should be done, in this work we study derivative quantities using the Regge unitarized CFKS model [2,3]. In this hybrid model, both soft (multiperipheral Pomeron and reggeon exchanges) and hard (dipole picture) contributions are properly unitarized in an eikonal way with triple pomeron interaction also included. This approach describes the transition region and can be used as initial condition for a QCD evolution at high virtualities. The extrapolation to the higher-Q^2 domain is also performed here, checking the behaviour of the model without including QCD evolution. We discuss the similarities and/or connections with the phenomenological saturation model[4], stressing that a QCD evolution is required for a correct description of higher Q^2 in the inclusive case. For the diffractive case, such a procedure is not formally required, since the non-perturbative sector is dominant in this case.

2 The inclusive case

We start by briefly reviewing the CFKS approach. It interpolates between low and high virtualities Q^2, which are related to the dipole separation size, r, at the target rest frame, considering a two-component model[2,3]. Considering the unifying picture of the color dipoles, the separation into a large size (in[3] it is called L) and a small size (called S in[3]) components of the $q\bar{q}$ pair is made in terms of the transverse distance r between q and $\bar{q}$. The border value, r_0, is treated as a free parameter - which turn out to be $r_0 \sim 0.2$ fm. Hereafter we use the notation *soft* for the large size configuration and *hard* for the small size one.

The soft component considers multiple Pomeron exchanges (and reggeon f) implemented in a quasi-eikonal approach. It also includes the resummation of triple Pomeron branchings (the so-called fan diagrams). The initial input is a phenomenological Pomeron with fixed intercept $\alpha_P(0) = 1 + \varepsilon_{I\!P} = 1.2$ (further changes are due to absorptive corrections). In the impact parameter representation, the b-space, the Regge parametrization for the amplitude of the soft Pomeron exchange looks like:

$$\chi^{I\!P}(s,b,Q^2) \simeq \frac{C_{I\!P}}{R(x,Q^2)} \left(\frac{Q^2}{s_0 + Q^2} \right)^{\varepsilon_{I\!P}} x^{-\varepsilon_{I\!P}} \exp[-b^2/R(x,Q^2)] \,. \tag{1}$$

The resummation of the triple-Pomeron branches is encoded in the denominator of the amplitude $\chi^{n\,I\!P}$, i.e. the Born term in the eikonal expansion. Moreover, the corrected amplitude is eikonalized in the total cross section,

$$\chi^{n\,I\!P}(x,Q^2,b) = \frac{\chi^{I\!P}(x,Q^2,b)}{1 + a\chi_3(x,Q^2,b)} \,, \tag{2}$$

$$\sigma^{n\,I\!P}(x,Q^2,b) \simeq 1 - \exp\left[-\chi^{n\,I\!P}(x,Q^2,b)\right] \,, \tag{3}$$

where the constant a depends on the proton-Pomeron and the triple-Pomeron couplings at zero momentum transfer ($t = 0$).

The eikonalization procedure modifies the growth of the total cross section from a steep power-like behavior to a milder logarithmic increase. The total soft contribution is obtained by integrating over the impact parameter,

$$\sigma^{soft}(s,Q^2) = 4 \int d^2b \, \sigma^{soft}(s,Q^2,b) \,. \tag{4}$$

The hard component is considered in the color dipole picture of DIS. The dipole cross section, modeling the interaction between the $q\bar{q}$ pair and the proton, $\sigma^{dipole}(x,r)$, is taken from the eikonalization of the expression above $\chi^{n\,I\!P}(s,b,Q^2)$ already corrected by triple-Pomeron branching (the fan diagrams contributions). The corresponding cross section is extracted by considering the contributions coming from distances between 0 and $r_0 = 0.2$ fm, whereas for $r > r_0$ the contributions are described by the soft piece already discussed. In such small distances, perturbative QCD is expected to work. The total cross section considering this dipole cross section is expressed as:

$$\sigma_{tot}^{hard}(x,Q^2) = \int_0^{r_0} d^2r \int_0^1 d\alpha\, |\Psi_{\gamma^* q}^{T,L}(\alpha,r)|^2\, \sigma_{CFKS}^{dipole}(x,r)\,, \quad (5)$$

$$\sigma_{CFKS}^{dipole}(x,r) = 4 \int d^2b\, \sigma^{n\,I\!P}(x,Q^2,b,r)\,, \quad (6)$$

$$\sigma^{n\,I\!P}(x,Q^2,b,r) \simeq 1-\exp[-\,r^2\chi^{n\,I\!P}(x,Q^2,b)\,]\,, \quad (7)$$

where T and L correspond to transverse and longitudinal polarizations of a virtual photon, $\Psi_{\gamma^* q}^{T,L}(\alpha,r)$ are the corresponding wave functions of the $q\bar{q}$-pair.

The r^2 dependence is introduced in the Born term of the eikonal expansion, presented in the last expression above, in order to ensure the correct behavior determined by the color transparency. Thus a factor r^2 has been introduced in the eikonal of eq. (7).

The weight of each contribution (soft and hard) in the total cross section [and $F_2(x,Q^2)$] can be obtained, providing an analysis of the role played by each piece of the model:

$$R_{SOFT}(x,Q^2) = \frac{\sigma_{tot}^{soft}(x,Q^2)}{[\sigma_{tot}^{soft}(x,Q^2)+\sigma_{tot}^{hard}(x,Q^2)]}\,. \quad (8)$$

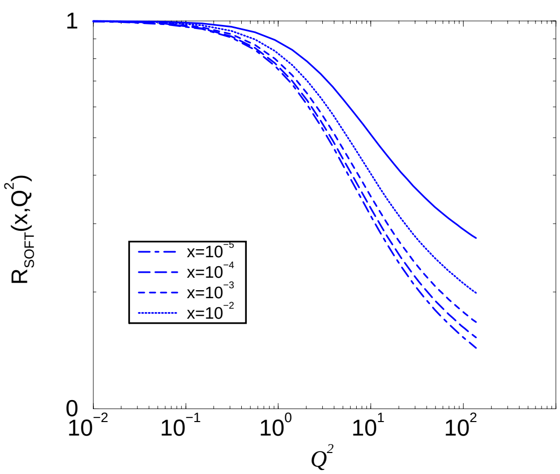

Figure 1. The ratio R_{SOFT} as a function of Q^2 at fixed momentum fraction x.

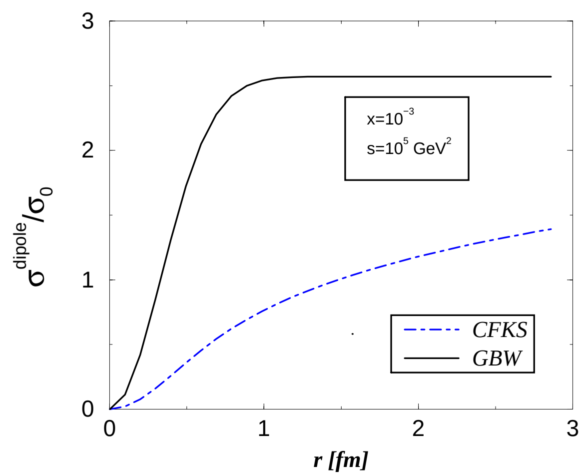

Figure 2. The dipole cross section from GBW and CFKS as a function of the transverse dipole separation r at fixed x (s).

Fig. 1 clearly shows that the soft piece is dominant at $Q^2 = 0.01$ and decreases as the virtuality grows. The behavior is monotonic, almost independent of the momentum fraction x.

An interesting issue is the relation between the dipole cross section coming from the CFKS model and the phenomenological one of G.-Biernat-Wüsthoff [4]. The GBW cross section is parametrized as:

$$\sigma^{GBW}(x,r) = \sigma_0 \left[1-\exp(-r^2/4R_0^2(x))\right]\,, \quad (9)$$

$$R_0^2(x) = \left(\frac{x}{x_0}\right)^{\lambda} \mathrm{GeV}^{-2}\,, \quad (10)$$

where $\sigma_0 = 23.03$ mb properly normalizes the dipole cross section. The remaining parameters are $\lambda = 0.288$ and $x_0 = 3.04\times 10^{-4}$, all of them determined from the small-x HERA data. The $R_0(x)$ is the main theoretical contribution, defining the saturation scale, which is related with the taming of the gluon distribution at small x (unitarity effects) [5]. The above expression has been used to describe both inclusive and diffractive structure functions, in good agreement with the experimental results. The comparison between this approach and the CFKS dipole cross section is shown in Fig. 2. The main feature of the GBW parametrization is that it ensures that the dipole cross section grows linearly with r^2 at small transverse separation, whereas it saturates at large size configurations. The picture emerging from the CFKS is slightly different, presenting a mild (logarithmic) increase with r, away from huge separation sizes that shifts the saturation scale up to very high virtualities. Although the continuous and smooth increasing with the radius, in the CFKS approach the cross section underestimates the GBW one for all r –one should take into account that in the CFKS model there is also a soft contribution–.

3 The diffractive case

The diffractive sector in the CFKS approach is constructed by a three-component model, using the AGK cutting rules to relate the elastic multiple scattering amplitude to the inelastic diffractive contribution. The first term comes directly from the soft piece, the second one from the triple-Pomeron (and the reggeon f) interaction and the last one from the hard (dipole) piece. The spectrum on β is introduced by hand, based on earlier soft and hard (pQCD) calculations.

The agreement of CFKS approach with data is remarkable even at high virtualities. In the saturation model [4], the reliability of the pQCD calculation is extended to smaller virtualities through the saturation scale $R_0(x)$.

As a final study, we have performed the calculation of the Q^2 logarithmic slope of the diffractive structure function $F_2^{D(3)}$. The motivation is that this observable is a potential quantity to distinguish soft and hard dynamics in diffractive DIS [6]. The saturation model produces a transition between positive and negative slope values at low $\beta = 0.04$ (upper plots), while it shows a positive slope for medium and large β. Instead, the CFKS approach presents a positive slope for the whole Q^2 and $x_{I\!P}$ ranges, flattening at large β, similarly as the non-saturated pQCD calculations [6].

4 Conclusions

A deeper understanding of the saturation phenomenon is required to perform reliable estimations for the current and forthcoming high energy reactions. The saturation scale, which sets the onset of the unitarity corrections, is found to be in the transition regime of low x and Q^2. In this domain, both Regge-inspired phenomenology and improved pQCD calculations (perturbative shadowing, higher twist), considering unitarity effects, are able to describe the data with high precision. The most advantageous ones are those describing in an unified way the inclusive processes as well as diffractive ones.

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