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The dipole representation of vector meson electroproduction beyond leading twist

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Abstract

We link the recent computation beyond leading twist of the impact factor of the transition $\gamma_T^* \to \rho_T$ performed in the light-cone collinear approach, to the dipole picture by expressing the hard part of the process through its Fourier transform in coordinate space. We show that in the Wandzura–Wilczek approximation the impact factor up to twist 3 factorises in the wave function of the photon combined with the distribution amplitudes of the ρ-meson and the colour dipole scattering amplitude with the t-channel gluons. We show also that beyond the Wandzura–Wilczek approximation, the hard contribution of the amplitude still exhibits the signature of the interaction of a single colour dipole with the t-channel gluons. This result allows a phenomenological approach of the helicity amplitudes of the leptoproduction of vector meson, by combining our results to a dipole/target scattering amplitude model.

1. Introduction

At asymptotical energies, the understanding of hadronic scattering processes is a longstanding question, which can be addressed in perturbative QCD when a hard scale, generically denoted as Q^2, justifies the applicability of perturbation theory. In this so-called perturbative Regge limit, in which $s \gg -t \sim Q^2 \gg \Lambda_{QCD}^2$, the scattering amplitude is dominated by the exchange of

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reggeised gluons (named gluonic reggeons) in the t-channel. This regime is governed by the BFKL equation, derived in the leading order approximation (LLA) in Refs. [1–4] in the k_T-factorisation framework.

In the same kinematics, a dipole representation [5] was proposed, and its dynamics was studied at LLA [6–8]. In this picture, the degrees of freedom are coloured dipoles. The scattering of two colourless objects (heavy meson for example, or virtual photon, called generically onium) is then described completely in terms of these dipoles, and does not involve the notion of reggeisation. The equivalence with the BFKL description was shown at large N_c in Refs. [9,10].

At even higher energies, since the growing of partonic densities should be limited due to unitarity arguments, many theoretical investigations have been made in order to resum perturbative sub-series which contribute to the scattering amplitude, which could be responsible for the required non-linearities leading to recombination effects between partons. This includes the *Generalised Leading Log Approximation*, which takes into account any *fixed* number n of t-channel exchanged reggeons [11–14], and the *Extended Generalised Leading Log Approximation* (EGLLA) [15–19], in which the number of reggeon in t-channel is not conserved. In EGLLA, the simplest new building block is the triple $\mathbb{P}$omeron vertex [17,16,18,20].

In the Wilson line formalism, non-linear equations were derived [21–24], based on the concept of factorisation of the scattering amplitude in rapidity space and on the extension of the operator product expansion technique to high-energy Regge limit. Its simplest version, the Balitsky–Kovchegov (BK) equation, was derived independently by Kovchegov [25,26] in the dipole model. The triple $\mathbb{P}$omeron vertex is the BUILDING block responsible for non-linearities in the BK equation. Its complete expression beyond large N_c, known in EGLLA [18], was rederived based on the Wilson line formalism in [27] in a very compact way. Similarly the Wilson line approach, the Colour Glass Condensate (CGC) [28–36] leads to an equivalent set of non-linear equations.

The dipole model itself has been the basis of many studies in order to unitarise the theory [8,37,38]. As for other models, it can describe both the $\mathbb{P}$omeron and the $\mathbb{O}$dderon [39] degrees of freedom [40]. Besides its dynamics at large s, the dipole representation of the probe has been used to build observables sensitive to saturation effects. In particular, the geometrical scaling [41] is a natural consequence of saturation. In the dipole representation, a simple model was introduced by Golec-Biernat and Wüsthoff (GBW) [42,43] for describing the total $\gamma^* p$ cross-section [42] as well as diffractive events [43]. The basic idea is to describe the γ^*–p interaction at small x as the scattering of a $q\bar{q}$ pair (a dipole), formed long before the scattering off the proton (in a non-symmetric frame where the nucleon is at rest) and characterised by a transverse size r and by a relative fraction α of longitudinal momentum carried by the quark and the antiquark. The total cross-section is then

$$\sigma_{T,L}\big(x, Q^2\big) = \int d^2\underline{r} \int_0^1 d\alpha \, \big|\Psi_{T,L}(\alpha, \underline{r})\big|^2 \hat{\sigma}\big(x, \underline{r}^2\big), \tag{1}$$

with $r = |\underline{r}|$, and where $\Psi_{T,L}$ is the photon wave function for the transverse (T) and longitudinally polarised (L) photons. The saturation dynamics is implemented in a simple functional form for the effective dipole cross-section $\hat{\sigma}(x, r)$ which encodes the interaction of the $q\bar{q}$ dipole with a nucleon,

$$\hat{\sigma}\big(x, r^2\big) = \sigma_0 \left\{1 - \exp\left(-\frac{r^2}{4R_0^2(x)}\right)\right\}, \quad R_0(x) = \frac{1}{\text{GeV}} \left(\frac{x}{x_0}\right)^{\lambda/2}. \tag{2}$$