

STATUS OF THE NLO CORRECTIONS TO THE PHOTON IMPACT FACTOR*

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(Received June 21, 2002)

We present the status of the programme of calculating the next-to-leading order corrections to the virtual photon impact factor. In particular, we discuss new results for the transversely polarized photon. We briefly outline the definition of infrared finite terms and the subtraction of the leading logarithmic parts.

PACS numbers: 12.38.Bx, 14.70.Bh

1. Introduction

The total cross section for the scattering of two highly virtual photons, having virtualities Q_1^2 and Q_2^2 at large centre-of-mass energy s ($s \gg Q_1^2, Q_2^2$) is an excellent testing ground for the applicability of perturbative QCD in the Regge limit [1, 2]. If the energy is high enough to expect the validity of the Regge limit but not too high in order to suppress unitarity corrections we expect the $\gamma^*\gamma^*$ cross section to be described by the BFKL [3] equation.

Besides $\gamma^*\gamma^*$ scattering we are interested in understanding the γ^*p cross section or the structure function $F_2(x, Q^2)$ at small values of $x = Q^2/s$. At large values of Q^2 we can describe the contribution from the photon side in perturbation theory, which might allow us to get insight into the non-perturbative nature of the proton. Furthermore, we are able to study the interplay between the hard and the soft pomeron from the point of view of perturbative QCD. In addition, we may force a situation that is believed to be purely perturbative in γ^*p scattering as well when we consider

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

[†] Supported by the EU TMR-Network “QCD and the Deep Structure of Elementary Particles”, contract number FMRX-CT98-0194 (DG 12-MIHT).

the production of forward jets at HERA [4, 5], similar to the production of Mueller–Navelet jets in pp scattering [6]. The coupling of the BFKL ladder to the relevant jet production vertex at NLO is currently under study [7].

To leading logarithmic accuracy (LLA) the predicted cross section, based on the BFKL equation, rises too quickly with increasing s . The situation is very different at NLO. The calculation of NLO corrections to the BFKL Kernel was initiated in [8] and finally completed in [9, 10]. The corrections were first seen to be very large. However, their size is under control when additional collinear logarithms are taken into account [11, 12] or when the kinematical conditions are forced to avoid these extra logarithms (rapidity vetoes) [13, 14]. The NLO corrections tend to lower the power rise of cross sections to values that seem to be compatible with the data [15, 16]. These studies, however, can at best be viewed as an estimate of higher order corrections since they do not take care of higher order corrections to the coupling between external particles, virtual photons in the $\gamma^*\gamma^*$ case, and the NLO BFKL ladder.

In order to make reliable predictions, being consistent to NLO, the NLO corrections to the coupling of virtual photons to the exchanged BFKL ladder, described by the impact factor, has to be taken into account. These corrections are currently under study [17–19] and the status of this work is reviewed in this contribution.

2. The calculational programme

We focus our discussion on the example of $\gamma^*\gamma^*$ scattering which may serve as the canonical example for a scattering process in perturbative QCD at very high energy. As a result of Regge factorization, always assumed at very high energy, we can write down the total cross section for $\gamma^*\gamma^*$ scattering as (*cf.* Fig. 1)

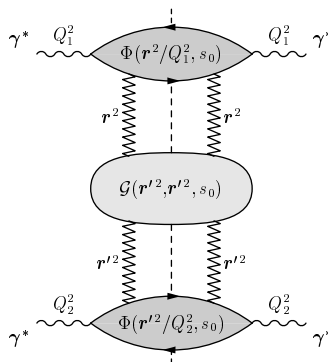


Fig. 1. Regge factorization of the $\gamma^*\gamma^*$ scattering process.

$$\sigma_{\gamma^*\gamma^*}(s) = \Phi_{\gamma^*} \otimes \mathcal{G}_\omega \otimes \Phi_{\gamma^*}, \quad (1)$$

where $\mathcal{G}_\omega(\mathbf{r}^2, \mathbf{r}'^2, s_0)$ is the Green's function for the exchange of two reggeized gluons, projected into the colour singlet state, obtained as a solution of the (NLO) BFKL equation. Φ_{γ^*} is the impact factor for virtual photons under discussion. At leading order, this impact factor (Fig. 2) is calculated from cut quark box diagrams: the virtual photon splits into a $q\bar{q}$ -pair and the reggeized gluons from the t -channel couple to the $q\bar{q}$ pair in all possible ways. At NLO we have virtual corrections to the leading order diagrams

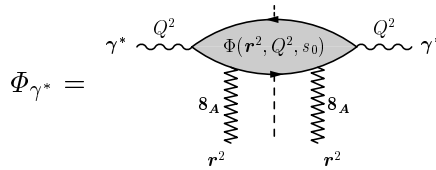


Fig. 2. The γ^* impact factor.

as well as contributions with an additional gluon in the intermediate state (Fig. 3) and the impact factor at NLO would look like

$$\Phi_{\gamma^*}^{(1)} = \int \frac{dM_{q\bar{q}}^2}{2\pi} d\phi_{q\bar{q}} 2 \operatorname{Re} \Gamma_{\gamma^* \rightarrow q\bar{q}}^{(1)} \Gamma_{\gamma^* \rightarrow q\bar{q}}^{(0)} + \int \frac{dM_{q\bar{q}g}^2}{2\pi} d\phi_{q\bar{q}g} \left| \Gamma_{\gamma^* \rightarrow q\bar{q}g}^{(0)} \right|^2. \quad (2)$$

The terms $\Gamma_{\gamma^* \rightarrow q\bar{q}}^{(0)}$, $\Gamma_{\gamma^* \rightarrow q\bar{q}}^{(1)}$ and $\Gamma_{\gamma^* \rightarrow q\bar{q}g}^{(0)}$ are the particle-particle-reggeon vertices that naturally appear at amplitude level as a result of Regge factorization. dM_i^2 and $d\phi_i$ denote the invariant mass and the phase space of the respective intermediate states $i = q\bar{q}, q\bar{q}g$.

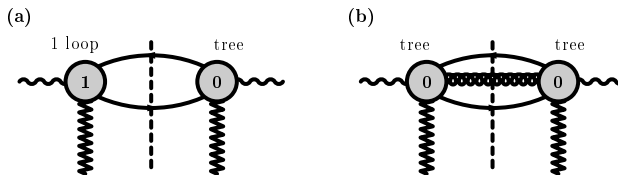


Fig. 3. Contributions to the γ^* -impact factor at NLO.

The virtual corrections $\Gamma_{\gamma^* \rightarrow q\bar{q}}^{(1)}$ have been calculated in [17]. We have expressed all loop integrals in analytic form as an expansion in $\varepsilon = (4-D)/2$, quite in contrast to [20] where all integrals are kept as they are. For the real corrections, we considered the square of the particle-reggeon vertex $|\Gamma_{\gamma^* \rightarrow q\bar{q}g}^{(0)}|^2$, which has been calculated in [18] for longitudinally polarised

virtual photons. In [19] we complete the real corrections by adding the contributions from transversely polarised photons. The real corrections have been considered in [21] as well, but not in a very suitable form for the task of finally evaluating the impact factor.

However, calculating the amplitudes as they are does not quite complete the task. The individual contributions are still infrared divergent and have to be combined in order to get the expected cancellation that has been shown previously [22]. At the same time, one has to consider the subtraction of leading logarithmic terms. These are present in the virtual corrections and proportional to the well-known LLA gluon trajectory function. In the real contribution to the impact factor they arise as the additional gluon is emitted with a large rapidity separation to the $q\bar{q}$ -pair. Both of these LLA-terms are individually infrared divergent as well as the emitted gluon becomes soft. In [19] we have extracted the infrared divergent contributions from real and virtual corrections and defined suitable subtraction terms. The difference of our result and the respective subtraction term is finite upon integration over the gluon phase space. Re-adding the subtracted terms with the integrations over the gluon phase space performed, explicitly allows us to exhibit the infrared divergences and cancel them successfully against those from the virtual corrections. The subtraction of the leading logarithmic terms induces a scale s_0 which can be translated into a rapidity cutoff beyond which the emitted gluon will belong to the leading logarithmic term. However, since the particular choice of this scale is arbitrary, the NLL impact factors will depend on it. This dependence was irrelevant at LLA, since a change in the scale

$$\ln \frac{s}{s_0} = \ln \frac{s}{s_1} + \ln \frac{s_1}{s_0} = \ln \frac{s}{s_1} + \text{NLLA} \quad (3)$$

is of higher order w.r.t. the LLA. These NLLA terms are now taken care of and may be phenomenologically important.

3. Outlook and conclusions

Besides the above discussion of the NLO impact factor, our calculations have the potential to give further insight into the photon wave function picture. This picture, in conjunction with the saturation model has been applied successfully to the description of both deep-inelastic and diffractive scattering cross sections at HERA, *e.g.* [23, 24]. First steps in this direction have been done in [18], showing that an extension of the current picture to a higher $q\bar{q}g$ Fock-state of the virtual photon is in principle possible. Further steps in this direction include a consistent treatment of infrared divergences in configuration space and remain to be done.

In order to complete the calculation of the impact factor we have to calculate the phase space integrals over the remaining infrared finite terms, defined in [19]. We will express the phase space integrals in terms of a set of standard integrals. For first phenomenological applications this might best be done numerically.

With these results we will be able to calculate the $\gamma^*\gamma^*$ cross section to NLL accuracy. In combination with the NLO jet vertex [7] there will be an interesting variety of phenomenological applications for the NLO BFKL equation.

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