NLO BFKL in $\gamma^*\gamma^*$ collisions

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Abstract. We study in the BFKL approach the total hadronic cross section for the collision of two virtual photons for energies in the range of LEP2 and of future linear colliders. The BFKL resummation is done at the next-to-leading order in the BFKL Green’s function; photon impact factors are taken instead at the leading order, but with the inclusion of the subleading terms required by invariance under changes of the renormalization scale and of the BFKL scale $s_0$. We compare our results with previous estimations based on a similar kind of approximation.

Keywords: Cross section, hadronic; BFKL equation; photon photon, interaction.

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INTRODUCTION

The total hadronic cross section for the collision of two off-shell photons with large virtualities is a fundamental observable, since it is fully under the control of perturbative QCD. It is widely believed that this total cross section is the best place for the possible manifestation of the BFKL dynamics [1] at the energies of future linear colliders (for a review, see Ref. [2]). For this reason, many papers [3] have considered the inclusion of the BFKL resummation of leading energy logarithms. In a remarkable paper [4] (see also Ref. [5]), BFKL resummation effects have been taken into account also at the subleading order and evidence has been presented that the appearance of BFKL dynamics is compatible with experimental data already at the energies of LEP2 [6, 7]. In this work [8] we estimate the energy dependence of the $\gamma^*\gamma^*$ total hadronic cross section in an energy range which covers LEP2 and future linear colliders. The procedure we follow is approximate, since we use the singlet forward NLA BFKL Green’s function together with forward $\gamma^* \rightarrow \gamma^*$ impact factors at the leading order. However, in the impact factors we include the subleading terms required by the invariance of the full amplitude at the NLA under change of the renormalization scale and of the energy scale $s_0$ entering the BFKL approach.

THE $\gamma^*\gamma^*$ TOTAL CROSS SECTION: NUMERICAL ANALYSIS

The total hadronic cross section of two unpolarized photons with virtualities $Q^2_1$ and $Q^2_2$ can be obtained from the imaginary part of the forward amplitude. Following the procedure of Refs. [9], it is possible to write down the cross section with the inclusion
of NLO corrections in the Green’s function only, while keeping the impact factors at the LO. In fact, the requirement of invariance of the amplitude at the NLA under renormalization group transformation and under change of the energy scale $s_0$ allows to fix the $\mu_R$- and $s_0$-dependent terms in the NLO impact factors

$$A(s_0) = \chi(v) \ln \frac{s_0}{Q_1 Q_2}, \quad B(\mu_R) = \frac{\beta_0}{2 N_c} \ln \frac{\mu_R^2}{Q_1 Q_2}. \quad (1)$$

The details of the analytical calculation can be found in Ref. [8]. We use the series representation [9], that is one of the infinitely many possible ways, equivalent with NLA accuracy, to represent the total cross section. In the case of the $\gamma^* \gamma^* \to VV$ process [9], where $V$ stands for light vector meson ($\rho$, $\omega$, $\phi$), it turned out that the contribution to the amplitude from the kernel starts to dominate over that from the impact factors in the series from $n = 4$. This makes evident the fact that the high-energy behavior of the amplitude is weakly affected by the NLO corrections to the impact factor. Therefore, our approximated $\gamma^* \gamma^*$ total cross section should compare better and better with the correct result as the energy increases. In order to stabilize the perturbative series, it is necessary to resort to some optimization procedure, exploiting the freedom to vary the energy parameters, $\mu_R$ and $s_0$, without corrupting the calculation but at the next-to-NLA. We use both the principle of minimal sensitivity (PMS method) [10] and the Brodsky-Lepage-Mackenzie (BLM) method [11]: for some selected values of the energy $s$ in the region of interest the optimal scales $\mu_R$ and $s_0$ are found and the cross section is thus determined. Then, the curve giving the cross section vs the energy is obtained by interpolation.

In order to compare the theoretical prediction with the existing data from LEP2, we cannot neglect the contribution from LO quark box diagrams [12] which is of order $\alpha^2 (\ln s)/s$. On the other hand, the soft Pomeron contribution, if estimated within the vector-dominance model, is proportional to $\sigma_{\gamma^* \gamma^*} \sim (m_V^2/Q^2)^4 \sigma_{\gamma \gamma}$ and is therefore suppressed for highly virtual photons. We restrict ourselves to the case of a symmetric kinematics, which means the same virtuality $Q_1 = Q_2 \equiv Q$ for the two photons. This is the so-called “pure BFKL regime”, as opposite to the “DGLAP regime” realized for strongly ordered photon virtualities. In Fig. 1 (left) we summarize our results for the CERN LEP2 region: we show the NLO BFKL curves obtained by the PMS and the BLM methods, to which we added the contribution of the LO quark box diagrams. For comparison we put in this plot also the experimental data from CERN LEP2, namely three data points from OPAL [7] ($Q^2 = 18$ GeV$^2$) and four data points from L3 [6] ($Q^2 = 16$ GeV$^2$). We observe first of all that the difference between the two theoretical curves can be taken as an estimate of the systematics effects which underlay the optimization procedures adopted here. Then, the comparison with experimental data is acceptable, although within uncertainties which are large both on the theory and on the experiment side. Around the energy for which the condition for the BFKL resummation, $\bar{\alpha}_s Y \sim 1$, is satisfied, which in the present conditions corresponds to $Y \sim 5$, both the PMS and BLM curves agree with experimental data within the errors. Finally, we remark that the determination from Ref. [4] falls between our two curves from PMS and BLM methods. From the energy dependence of the NLO BFKL cross section determined through the PMS method at $Q^2 = 17$ GeV$^2$ we obtained also the “dynamical” Pomeron
intercept (minus 1) as a function of the energy.

The result is shown in Fig. 1 (right). In Fig. 2 we show the $Y$-behavior of the total cross section for $Q^2 = 20 \text{ GeV}^2$ ($n_f = 5$) in an energy region not explored by past and present experiments, but relevant for future colliders. We plot here the two curves obtained in the present work with the PMS and the BLM methods. The condition for the BFKL resummation, $\bar{\alpha}_s Y \sim 1$, corresponds here to $Y \sim 6$; around this energy the deviation between the PMS and the BLM methods is about 50%. This discrepancy can be taken as an estimate of the systematic uncertainty of this approach. We observe that our determination from the BLM method is in quite good agreement with the result of Ref. [4] (see Fig. 4 of that paper), obtained for the same kinematics.

CONCLUSIONS

We have found that, if suitable methods are used to stabilize the perturbative series, a smooth curve for the energy behavior of the cross section can be achieved. Our result in the CERN LEP2 region compares favorably with experimental data. Systematic effects coming from the optimization procedure are estimated by the comparison with two different methods. Our findings in the CERN LEP2 region are in agreement with the result of Ref. [4], where for the first time subleading BFKL effects were considered in the $\gamma^* \gamma^*$ total hadronic cross section. In comparison with the latter work, which deals with the same process under consideration in the present paper, the elements of novelty are the following:

- the optimization procedures to stabilize the perturbative series are performed on the amplitude itself and not on the NLO Pomeron intercept, which is not a physical quantity;
- the impact factors, although taken at the LO, contain the appropriate NLO terms, so that the dependence on the energy scales entering the process (the renormalization scale $\mu_R$ and the parameter $s_0$ introduced in the BFKL approach) is pushed to the next-to-NLA;
two optimization methods are used, thus having a control of systematic effects at work.

The numerical effect of the neglected subleading corrections to the impact factors cannot be quantified. We expected that it be modest in the second region of energy considered in this work. Here our prediction should be very close to the true NLO result. The final word will be said when the $\gamma^*\gamma^*$ cross section will be calculated fully in the next-to-leading approximation.

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