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High-Energy Asymptotics of Photon–Photon Collisions in QCD [1]

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Abstract

The high-energy behaviour of the total cross section for highly virtual photons, as predicted by the BFKL equation at next-to-leading order (NLO) in QCD, is presented. The NLO BFKL predictions, improved by the BLM optimal scale setting, are in excellent agreement with recent OPAL and L3 data at CERN LEP2.

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Photon–photon collisions, particularly $\gamma^*\gamma^*$ processes, play a special role in QCD [1], since their analysis is much better under control than the calculation of hadronic processes which require the input of non-perturbative hadronic structure functions or wave functions. In addition, unitarization (screening) corrections due to multiple Pomeron exchange should be less important for the scattering of γ^* of high virtuality than for hadronic collisions.

The high-energy asymptotic behaviour of the $\gamma\gamma$ total cross section in QED can be calculated [2] by an all-orders resummation of the leading terms: $\sigma \sim \alpha^4 s^\omega$, $\omega = \frac{11}{32}\pi\alpha^2 \simeq 6 \times 10^{-5}$. However, the slowly rising asymptotic behaviour of the QED cross section is not apparent since large contributions come from other sources, such as the cut of the fermion-box contribution: $\sigma \sim \alpha^2 (\log s)/s$ [1] (which although subleading in energy dependence, dominates the rising contributions by powers of the QED coupling constant), and QCD-driven processes.

The high-energy asymptotic behaviour of hard QCD processes is governed by the Balitsky–Fadin–Kuraev–Lipatov (BFKL) formalism [3, 4]. The highest eigenvalue, ω, of the BFKL equation [3] is related to the intercept of the QCD BFKL Pomeron, which in turn governs the high-energy asymptotics of the cross sections: $\sigma \sim s^{\alpha_{I\!P}-1} = s^\omega$. The BFKL Pomeron intercept in the leading order (LO) turns out to be rather large: $\alpha_{I\!P} - 1 = \omega_{LO} = 12 \ln 2\,(\alpha_S/\pi) \simeq 0.55$ for $\alpha_S = 0.2$ [3]. The next-to-leading order (NLO) corrections to the BFKL intercept have recently been calculated [5], but the results in the $\overline{\mathrm{MS}}$–scheme have a strong renormalization scale dependence. In Ref.[6] we used the Brodsky–Lepage–Mackenzie (BLM) optimal scale setting procedure [7] to eliminate the renormalization scale ambiguity. (For other approaches to the NLO BFKL predictions, see Refs.[8, 6] and references therein.) The BLM optimal scale setting resums the conformal-violating β_0-terms into the running coupling in all orders of perturbation theory, thus preserving the conformal properties of the theory. The NLO BFKL predictions, as improved by the BLM scale setting, yields $\alpha_{I\!P} - 1 = \omega_{NLO} =$ 0.13–0.18 [6].

The photon–photon cross sections with LO BFKL resummation was considered in Refs. [4, 9, 10]. Although the NLO impact factor of the virtual photon is not known, one can use the LO impact factor of [2, 4, 10], assuming that the main energy-dependent NLO corrections come from the NLO BFKL subprocess rather than the photon impact factors [11, 12].

Fig compares the LO and BLM scale-fixed NLO BFKL predictions $\sigma \sim \alpha^2 \alpha_S^2 s^\omega$ [6, 11, 12] with recent LEP2 data from OPAL[13] and L3[14]. The spread in the curves reflect the uncertainty in the choice of the Regge scale parameter, which defines the beginning of the asymptotic regime: $s_0 = Q^2$ to $10Q^2$ for LO BFKL and $s_0 = Q^2$ to $4Q^2$ for NLO BFKL, where Q^2 is the mean virtuality of the colliding photons. One can see from Fig. that the agreement of the NLO BFKL predictions [11, 12, 6] with the data is quite good. We also note that the NLO BFKL predictions are consistent [12] with data recently presented by ALEPH[15]. In contrast, the NLO quark-box contribution [16] underestimates the L3 data point at $Y \equiv \log(s_{\gamma\gamma}/\langle Q^2\rangle) = 6$ by more than 3 standard deviations. The sensitivity of the NLO BFKL results to the Regge parameter s_0 is much smaller than in the case of the LO BFKL. The variation of the predictions in the value of s_0 reflects uncertainties from uncalculated subleading terms. The parametric variation of the LO BFKL predictions is so large that it can neither be ruled out nor confirmed at the energy range of LEP2.

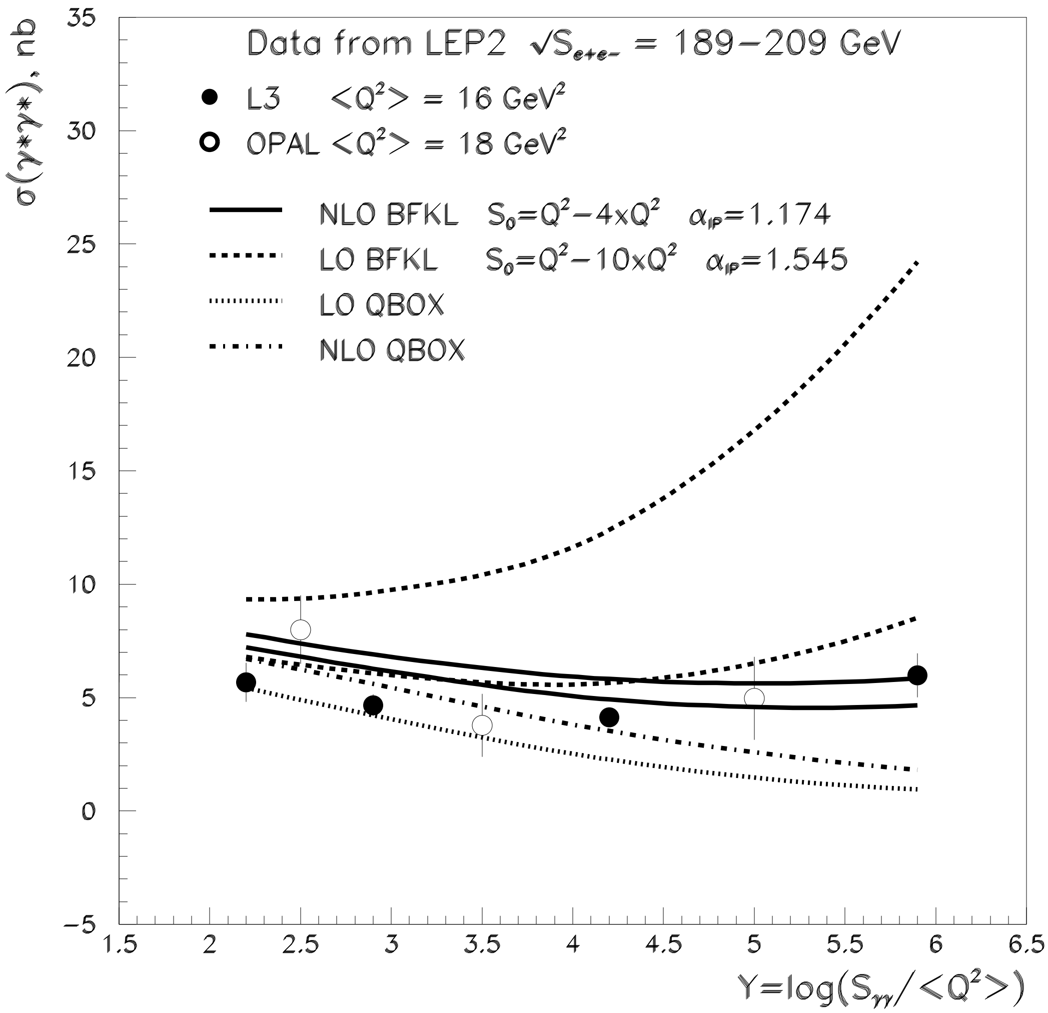

Figure 1: The energy dependence of the total cross section for highly virtual photon–photon collisions predicted by the NLO BFKL theory[11, 12, 6] compared with OPAL[13] and L3[14] data from LEP2 at CERN. The solid curves correspond to the BLM scale-fixed NLO BFKL predictions. The dashed curve shows the LO BFKL prediction. (Both predictions include the quark-box contribution). The BFKL predictions are shown for two different choices of the Regge scale, LO BFKL: $s_0 = Q^2$–$10Q^2$, NLO BFKL: $s_0 = Q^2$–$4Q^2$.

The NLO BFKL phenomenology is consistent with the assumption of small unitarization corrections in the photon–photon scattering at large Q^2. Thus one can accommodate the NLO BFKL Pomeron intercept value 1.13–1.18 [6] predicted by BLM optimal scale setting. In the case of hadron scattering, the larger unitarization corrections [17] lead to a smaller effective Pomeron intercept value, about 1.1 [18].

In summary, highly virtual photon–photon collisions provide a very unique opportunity to test high-energy asymptotics of QCD. The NLO BFKL predictions for the $\gamma^*\gamma^*$ total cross section, with the renormalization scale fixed by the BLM procedure, show good agreement with the recent data from OPAL[13] and L3[14] at CERN LEP2.

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