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Forward Drell-Yan plus backward jet as a test of BFKL evolution

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We study Drell-Yan plus jet events where the gauge boson is produced in the forward direction of one of the colliding protons and a jet is produced in the forward direction of the second proton. The resulting large rapidity difference between the final states then opens up the phase space for BFKL evolution. First numerical results on partonic level are provided.

1 Introduction

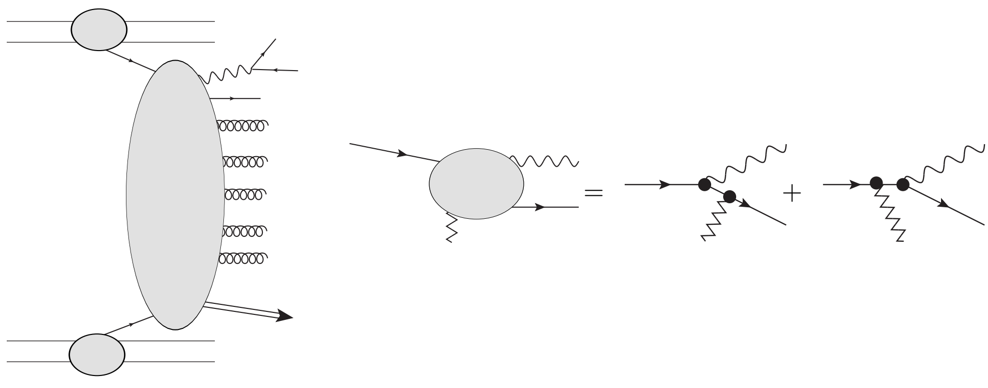
Due to its large center of mass energy the LHC allows for the study of forward physics using methods of perturbative QCD. Among them we find forward production of different systems such as high p_T jets [1], heavy quark pairs [2] and Drell-Yan (DY) processes where a virtual photon or Z boson decays into a pair of leptons [3, 4]. The study of these type of processes is interesting as they allow to probe parton distribution functions at very small values of x which have not been reached in so-far collider experiments. They therefore provide a possibility to test formalisms which have been especially developed for the description of small x processes and which go beyond the standard formulation in terms of collinear factorization by including additional small x enhanced contributions. The starting point of such studies is given by BFKL evolution which resums small x logarithms on the level of partonic scattering amplitudes at leading logarithmic (LL) [5] and next-to-leading-logarithmic (NLL) [6] accuracy. In addition, since small x evolution ultimatively leads to high parton densities, such processes may further allow for the observation of saturation effects which require an extension of the BFKL formalism, see *e.g.* [7].

While studies of inclusive observables provide strong hints for the presence of BFKL evolution in small x data, see *e.g.* [9], a proper identification of relevant effects at small x is hard to achieve. Cancellations between different final states minimize the sensitivity to the particular feature of the employed method and deviations from inclusive evolution equations due to small x effects may be partly hidden into the chosen initial conditions. It is therefore necessary to turn to the study of more exclusive observables to distinguish different effects at small x. Among these exclusive observables there is a class of events where the entire dependence of the process on the non-perturbative dynamics is treated within conventional collinear factorization.

These observables typically involve hard events in the forward region of both scattering protons, while the large difference in rapidity between the hard final states opens up the phase space for BFKL evolution. Among the best explored processes of this type are 'Mueller-Navelet' jets which consist of a high p_T-jets in the forward regions of each proton. Currently this process is one of the few examples where a complete NLL BFKL description exists [8]. In contrast to naïve expectations, the result reveals a strong dependence on the next-to-leading order corrections to the jet impact factors. At the same time, the numerical differences between the NLL resummed result and a pure collinear NLO result remain rather small for a large class of observables.

This observation motivates the study of a new type of forward-backward observable, where a DY pair is produced in the forward direction of one of the particles instead of a jet. The hope is that this observable is able to better distinguish between standard NLO results and NLL BFKL resummed predictions and allows to identify universal features of BFKL evolution. Even though the large virtuality of the photon and/or the mass of the Z diminishes at first the value of the strong coupling constant α_s, the rapidity difference between lepton pair and backward jet remains large at the Large Hadron Collider, $\Delta Y < 7$ and a study of BFKL evolution appears meaningful. In addition, study of new final states may also trigger new theoretical efforts for an improved definition of impact factors and lead to the identification of new BFKL observables. In the following we present some partial results of our study, which are currently restricted to the partonic level. For details we refer to our paper in preparation [10].

2 The leading-order DY impact factor



(a) (b)

Figure 1: a) A large difference in rapidity between the forward gauge boson (γ^*, Z) and the backward jet opens up the phase space for BFKL evolution. b) The leading order DY impact factor is obtained as the sum of two effective diagrams where the t-channel gluon carries eikonal polarizations.

In the current study we restrict to the LO impact factor, where relevant diagrams can be found in Fig. 1.b. A complete NLO study seems possible using Lipatov's effective action [11] which is currently explored at NLO [12]. The leading order impact factor reads

$$\Phi_{Zq} = \frac{c_f \alpha_s \sqrt{N_c^2 - 1}}{\pi \boldsymbol{k}^2 N_c} \left[\frac{z\boldsymbol{k}^2\big((1-z)^2+1\big) + 2M^2(1-z)z}{D_1 D_2} - \frac{M^2 z(1-z)}{D_1^2} - \frac{M^2(1-z)z}{D_2^2} \right]$$

$$D_1 = (\boldsymbol{q} - z\boldsymbol{k})^2 + (1-z)M^2 \qquad D_2 = \boldsymbol{q}^2 + (1-z)M^2 \tag{1}$$

Here M denotes the mass of the Z boson and the virtuality of the photon respectively, while c_f yields the coupling of the gauge boson to the quark. $\boldsymbol{q}$ and $\boldsymbol{k}$ are the transverse momenta of the final state gauge boson and initial gluon, while z is the momentum fraction of the initial quark momentum carried on by the gauge boson.

3 Preliminary numerical results at partonic level

The above impact factor carries a logarithmic singularity if the final state quark turns to be soft. After convolution of the impact factor with the BFKL Green's function, this corresponds to the limit $z \to 1$. To avoid this singularity we study ratios of angular coefficients $\mathcal{C}_n = \langle \cos n\phi \rangle$, where ϕ denotes the azimuthal angle between the jet and the gauge boson.

In a preliminary study, see Fig. 2, which restricts to the partonic level and conformal part of the NLO BFKL kernel, we use a fixed value $z = 0.9$ while the QCD coupling is taken at the Z-scale. As in the jet-jet case we find that the best convergence of the BFKL prediction is achieved for ratios which do not contain the angular coefficient $\mathcal{C}_0$. A complete study at hadronic level faces additional complications. Even though formally finite, the limit $z \to 1$, which is naturally encountered once the convolution with parton distribution functions is included, leads to large contributions which can even cause negative results for some of the angular coefficients. The study of these effects and their appropiate treatment as well as the inclusion of the running coupling corrections of the NLO BFKL Green's function is currently in progress.

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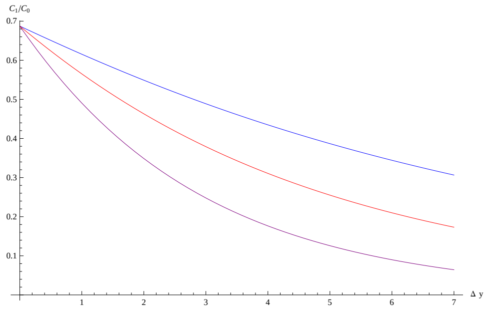
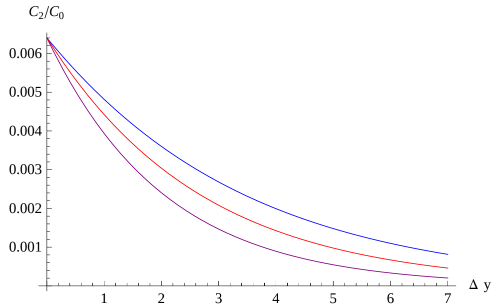
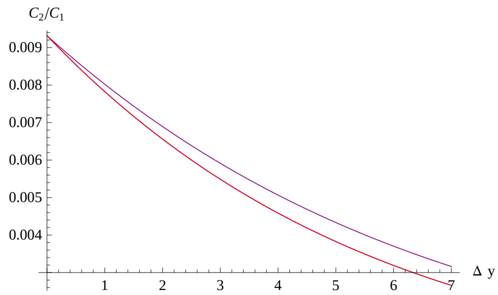


(a)



(b)



(c)

Figure 2: Ratios of angular coefficients $\mathcal{C}_1/\mathcal{C}_0$, $\mathcal{C}_2/\mathcal{C}_0$ and $\mathcal{C}_2/\mathcal{C}_1$ versus $\Delta y = |y_Z - y_{\rm jet}|$ on partonic level with $\alpha_s(M_Z^2)$ and $z = 0.9$. The transverse momentum of the Z-boson is taken to be $\boldsymbol{q} = 2$ GeV while jets with transverse momenta $\boldsymbol{p} > 20$ GeV are considered. The dependence on Δy is described by the LL (purple), NLL (blue) and NLL RG improved (see [13] for details) (red) BFKL Green's function

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