Towards Mapping the Proton unintegrated Gluon Distribution in Dijets Correlations in Real and Virtual Photoproduction at HERA

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Abstract

It is discussed how the dijet azimuthal correlations in DIS and real photoproduction at HERA probe the unintegrated gluon distribution in the proton. The correlation function shows a strong dependence on kinematical variables. We discuss a possible interplay of perturbative and nonperturbative effects.

1 Introduction

The jet studies are known to be a good tool to test perturbative QCD effects. It was pointed out already some time ago that dijet production in DIS could be a method to study the onset of BFKL dynamics both in photo- and electroproduction. Unfortunately in practice, due to unavoidable cuts on transverse momenta of jets, one samples rather large values of the gluon longitudinal momentum fraction $x_g$, where it is not completely clear what is the underlying dynamics and in particular what unintegrated gluon distribution should be used.

This presentation is based on Ref. [3] where we have discussed the jet production beyond the familiar collinear approximation and have focused on how more exclusive and more differential jet production observables probe the unintegrated gluon distribution. Based on the unintegrated gluon distributions found recently [4] from the phenomenological analysis of $\sigma^{\gamma^* p}$ we have explored dijet azimuthal correlations.
2 The formalism

At the parton level the total cross section for quark-antiquark dijet production $\gamma^* + p \rightarrow j_1 + j_2 + X$ can be written in a compact way as:

$$\sigma_{T/L}(x, Q^2) = \int d\phi \int p_{1,\perp,\min}^2 \int p_{2,\perp,\min}^2 \frac{f_g(x_g, \kappa^2)}{\kappa^4} \tilde{\sigma}_{T/L}(x, Q^2, \vec{p}_{1,\perp}, \vec{p}_{2,\perp}),$$

where $x$ and $Q^2$ are standard kinematical variables. In the formula above $f_g(x_g, \kappa^2)$ is the unintegrated gluon distribution and $\vec{\kappa}$ is the transverse momentum of the exchanged gluon. It is related to the quark/antiquark jet transverse momenta $\vec{p}_{1,\perp}$ and $\vec{p}_{2,\perp}$ as:

$$\vec{p}_{2,\perp} = \vec{\kappa} - \vec{p}_{1,\perp}, \quad \kappa^2 = p_{1,\perp}^2 + p_{2,\perp}^2 + 2p_{1,\perp}p_{2,\perp}\cos\phi.$$ (2)

We have written explicitly lower cuts on the transverse momenta of jets in (1). The indices $T$ and $L$ refer to transverse and longitudinal photons, respectively. The auxilliary quantities $\tilde{\sigma}_{T/L}$ introduced in (1) are given explicitly in [3].

The gluon momentum $\kappa$ is responsible for the jets being not exactly back-to-back in contrast to the conventional collinear approximation to leading order. In the following we limit ourselves to the region of $x_g \sim 1$, where the jets are dominantly produced from the quark box on the very top of the gluonic ladder.

The following simple two-component Ansatz was adopted in [4]

$$f_g(x_g, \kappa^2) = F_{\text{soft}}(\kappa^2) \frac{\kappa_s^2}{\kappa^2 + \kappa_s^2} + F_{\text{hard}}(x_g, \kappa^2) \frac{\kappa_{\text{h}}^2}{\kappa^2 + \kappa_{\text{h}}^2}$$

for unintegrated gluon distribution. The parameters $\kappa_s$ and $\kappa_{\text{h}}$ determine the scale of the transition from the hard to soft gluon region [4]. The details concerning both components can be found in [4].

The hard perturbative component is calculated from known conventional DGLAP parametrizations as derivative [4]. The results presented in this note and in [3] were obtained based on a recent MRST98 LO parametrization [6].

The two-component structure (3) of the unintegrated gluon distribution leads to interesting consequences for the dijet azimuthal correlations.

3 Results

Here for illustration only two examples will be discussed. A more complete analysis can be found in [3].
The cross section for the dijet production strongly depends on cuts imposed on kinematical variables. In order to better demonstrate the effect of coexistence of perturbative and nonperturbative effects we have imposed cuts on kinematical variables in the so-called hadronic center of mass (HCM) system. In the present purposefully simplified analysis we impose the cuts on the parton level and avoid extra cuts in the laboratory frame.

In Fig.1, we present \( \frac{d\sigma}{d\phi}(\gamma^* p \rightarrow j_1 j_2) \) as a function of HCM azimuthal angle between jets for two different values of photon virtuality \( Q^2 = 4 \) GeV\(^2\) (left panel) and \( Q^2 = 16 \) GeV\(^2\) (right panel) for a series of Bjorken-\( x \). In this calculation, we have restricted the transverse momenta of jets to \( p_{HCM}^{1,\perp}, p_{HCM}^{2,\perp} > p_{t,\text{cut}} = 4 \) GeV and summed over light flavours \( u, d \) and \( s \). One can observe a strong dependence of the azimuthal angle decorrelation pattern on Bjorken \( x \).

A closer inspection of both panels simultaneously leads to the conclusion that averaging over a broad range of \( Q^2 \) would to a large extent destroy the effect as it involves automatically averaging over a certain range of \( x_g \), the most crucial variable for the effect to be observed.

The experimental identification of the effects discussed here requires good statistics in the data sample. In practice [3], one averages over broader range of Bjorken \( x \), photon virtuality and jet transverse momenta. Most of the effects are then washed out and the information about the small-\( x \) dynamics is to a
Figure 2: The cross section for $\gamma p \rightarrow \text{"two jet"}$ (solid) and \"one jet\" (dashed) cases as a function of $\gamma p$ CM energy. In this calculation $p_{t,cut} = 4$ GeV.

In the model in Ref.[4] the total (real) photoproduction cross section at energies $W < 100$ GeV is dominated by the soft component. Only at very high, not yet available, energies the hard component would dominate. At \"intermediate\" energy available at HERA, the two components coexist and their fraction is a smooth function of initial $\gamma p$ energy. In principle, the same stays true for the dijet production and has interesting consequences for the jet azimuthal correlations $^{3}$.

There is another interesting prediction of the two-component model. Let us concentrate on the cases (events) with one hard ($p_\perp > p_{t,cut}$) jet and one soft ($p_\perp < p_{t,cut}$) \"jet\". In this single jet event $x_\gamma < 1$, because the transverse momentum of the single quark(antiquark) jet is compensated by a transverse momentum of a much softer gluon. We shall call such cases \"one jet\" events for simplicity. Let us compare the rate of such \"one jet\" events to the previously discussed cases of two hard jets in photoproduction. As an example in Fig.2 we compare the cross section for the two cases with the lower cut on transverse momentum $p_{t,cut} = 4$ GeV. Firstly, we observe that the cross section for both cases are of similar order. Furthermore we observe a significantly stronger rise of the cross section for the \"one jet\" case than for the \"two jet\" case. This is related to different $x_g$ and $\kappa$ sampled in both cases. For example for $W = 100$ GeV and $p_{t,cut} = 4$ GeV in the \"one jet\" case $<x_g> \approx 0.01$ is substantially lower than in the \"two jet\" case $<x_g> \approx 0.02$. Both numbers are, however, substantially larger than average $<x_g> \approx 0.005$ sampled in the case of total.
cross section. The effect of $\kappa$ is more complicated as averaged $\kappa$ strongly depends on $\phi$ for the "two jet" case. The interplay of the two effects ($x_g$ and $\kappa$) causes $f_g$ to be sampled differently in the "one jet" and "two jet" cases. This, potentially allows the possibility of a further nontrivial test of $f_g$. It would be valuable to compare the present predictions with the predictions of standard (collinear) NLO approach.

4 Conclusions

Based on the recent model determination of the unintegrated gluon distribution in the proton we have explored the impact of the soft gluon component and the onset of the perturbative regime on the dijet azimuthal correlations. We have predicted a strong dependence of the azimuthal correlation pattern on Bjorken $x$, photon virtuality and the cut on the jet transverse momenta. The effects in the electroproduction could be verified now at HERA, provided a careful differential ($x, Q^2$, transverse momentum cut) studies of the dijets are made.

It would be important to compare the results of the model discussed here with the result of the standard collinear approach to understand the potential of such a dijet study to shed more light on the low-$x$ dynamics which has been studied up to now in rather inclusive processes. Finally, we have found that the study of the energy dependence of the "one jet" (defined in the text) cross section would be a new test of unintegrated gluon distributions.

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