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CHARM-ANTICHARM KINEMATICAL CORRELATIONS IN PHOTON-PROTON SCATTERING

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$c - \bar{c}$ correlations are calculated in the k_t-factorization approach. Different unintegrated gluon distributions (uGDF) from the literature are used. The results are compared with recent results of the FOCUS collaboration. The recently developed CCFM uGDF gives a good description of the data. Predictions for the HERA energies are presented.

1 Introduction

In recent years a lot of activity was devoted to the description of the photon-proton total cross section in terms of the unintegrated gluon distribution functions (uGDF) (see e.g.[1,2] and references therein). In some of the analyses also inclusive charm quark (or meson) were considered [3]. Although the formalism of uGDF is well suited for studying more exclusive observables, only very few selected cases were considered in the literature. A special example is azimuthal jet-jet correlations in photon-proton scattering [4]. Recently the FOCUS collaboration at Fermilab provided precise data for $c - \bar{c}$ correlations [5]. We analyze the $c - \bar{c}$ correlations in terms of uGDF available in the literature. While the total cross section depends on small values of x, the high-p_t jets and/or heavy quark production test gluon distributions at somewhat larger x. Only some approches are applicable in this region. In particular, we test results obtained with recently developed CCFM unintegrated parton distributions. This presentation is based on [6] where more details can be found.

2 Charm-anticharm correlations

The total cross section for quark-antiquark production in the reaction $\gamma + p \to Q + \bar{Q} + X$ can be written as [4]

$$\sigma^{\gamma p \to Q\bar{Q}}(W) = \int d\phi \int dp_{1,t}^2 \int dp_{2,t}^2 \int dz \, \frac{f_g(x_g,\kappa^2)}{\kappa^4} \cdot \tilde{\sigma}(W, \vec{p}_{1,t}, \vec{p}_{2,t}, z) \; . \qquad (1)$$

In the formula above $f_g(x,\kappa^2)$ is the unintegrated gluon distribution. The gluon transverse momentum is related to the quark/antiquark transverse momenta $\vec{p}_{1,t}$

and $\vec{p}_{2,t}$ as:

$$\kappa^2 = p_{1,t}^2 + p_{2,t}^2 + 2p_{1,t}p_{2,t}cos\phi \; . \tag{2}$$

Above we have introduced:

$$\tilde{\sigma}(W, \vec{p}_{1,t}, \vec{p}_{2,t}, z) = \frac{\alpha_{em}}{2} \, e_Q^2 \, \alpha_s(l^2)$$

$$\left\{ [z^2 + (1-z)^2] \left| \frac{\vec{p}_{1,t}}{p_{1,t}^2 + m_Q^2} + \frac{\vec{p}_{2,t}}{p_{2,t}^2 + m_Q^2} \right|^2 + \; m_Q^2 \left(\frac{1}{p_{1,t}^2 + m_Q^2} + \frac{1}{p_{2,t}^2 + m_Q^2} + \right)^2 \right\} \tag{3}$$

The unintegrated gluon distribution f_g is evaluted at

$$x_g = \frac{M_t^2}{W^2} \; , \tag{4}$$

where

$$M_t^2 = \frac{p_{1,t}^2 + m_Q^2}{z} + \frac{p_{2,t}^2 + m_Q^2}{1-z} \; . \tag{5}$$

The basic ingredient of our approach are unintegrated gluon distributions. Different models of uGDF have been proposed in the literature (see for instance [1,2]). The main effort has been concentrated on the small-x region. While the total cross section is the genuine small-x phenomenon (x $< 10^{-3}$), the production of charm and bottom quarks samples rather the intermediate-x region (x$\sim 10^{-2}$ - 10^{-1}) even at the largest available energies at HERA. It is not obvious if the methods used are appropriate for the intermediate values of x. In the present approach we shall present results for a few selected gluon distributions from the literature. For illustration we shall consider a simple BFKL [11], saturation model used to study HERA photon-proton total cross sections [12] (GBW), saturation model used recently to calculate particle production in hadron-hadron collisions [13] (KL). These three model approaches are expected to be valid for low values of x. At somewhat larger values of x all these models are expected to break. As in Ref.[10] we shall try to extend the applicability of the model by multiplying the model distributions by a phenomenological factor $(1-x)^n$.

The azimuthal correlation functions $w(\phi)$ defined as:

$$w(\phi) = \int dp_{1,t}^2 \int dp_{2,t}^2 \int dz \; \frac{f_g(x_g, \kappa^2)}{\kappa^4} \cdot \tilde{\sigma}(W, \vec{p}_{1,t}, \vec{p}_{2,t}, z) \; . \tag{6}$$

and normalized to unity for two energies of W = 18.4 GeV (FOCUS) and W = 200 GeV (HERA) are shown in Fig.1. The GBW-glue (thin dashed) gives too strong back-to-back correlations for the lower energy. Another saturation model (KL, [13]) provides more angular decorrelation, in better agreement with the experimental data. The BFKL-glue (dash-dotted) provides very good description of the data. The same is true for the CCFM-glue (thick solid) and resummation-glue (thin solid). The latter two models are more adequate for the lower energy. The renormalized azimuthal correlation function for BFKL, GBW and KL models are almost independent of the power n in extrapolating to larger values of x_g. In calculating the cross section with the CCFM uGDF for simplicity we have fixed the scale for $\mu^2 = 4\ m_c^2$. In the present calculations we have used exponential form factor with $b_e = 0.5$ GeV^{-1} (see [15]). For comparison in panel (b) we present predictions for $W = 200$ GeV. Except of the GBW model, there is only a small increase of decorrelation when going from the lower fixed-order energy region to the higher collider-energy region.

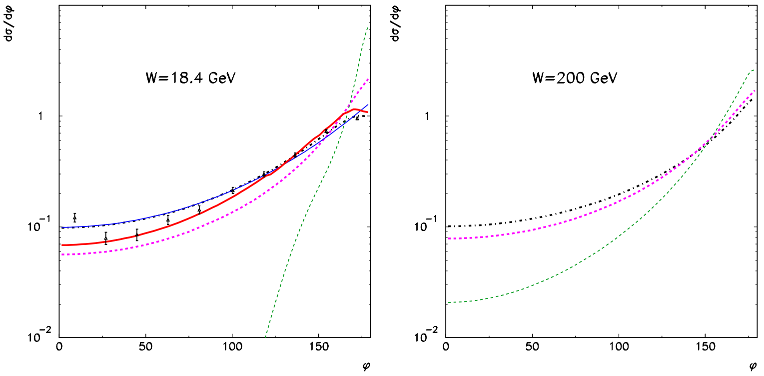

Figure 1. Azimuthal correlations between c and $\bar{c}$. The theoretical results are compared to the recent results from [5] (fully reconstructed pairs).

In the LO collinear approach the transverse momenta of two jets add up to zero. It is not the case for our LO k_t-factorization approach. In Fig.3 we present normalized to unity distribution in p_+^2, where $\vec{p}_+ = \vec{p}_1 + \vec{p}_2$. Due to momentum conservation, in our approach the sum of transverse momenta is directly equal to transverse momentum of the gluon ($\vec{p}_+ = \vec{\kappa}$). This means that the distribution in p_+^2 directly probes the transverse momentum distribution of gluons. The CCFM gluon distribution gives the best description of the FOCUS data [5]. We expect that this approach is suitable for $x > 0.01$. Although the other models give also reasonable description of the FOCUS data, one should remember that their application for the low energy data is somewhat unsure.

Not only azimuthal correlations are interesting. The formula (1) can be rewritten in the form

$$\sigma^{\gamma p \to Q\bar{Q}}(W) = \int dp_{1,t}^2 \int dp_{2,t}^2 \; w(p_{1,t}^2, p_{2,t}^2; W) \; , \qquad (7)$$

where the two-dimensional correlation function

$$w(p_{1,t}^2, p_{2,t}^2; W) = \int d\phi \; dz \; \frac{f_g(x_g, \kappa^2)}{\kappa^4} \cdot \tilde{\sigma}(W, \vec{p}_{1,t}, \vec{p}_{2,t}, z) \; . \qquad (8)$$

In Fig.2 we present two examples of $w(p_{1,t}^2, p_{2,t}^2)$ at W=18.4 GeV for different uGDF. As in Ref.[16] for GBW we have used the power n=7 in the extrapolating formula. While normalization is slightly dependent on the value of the power, the shape of the two-dimensional map is almost the same. The maps for different uGDF differ in details. The distribution for the GBW gluon distribution is concentrated along

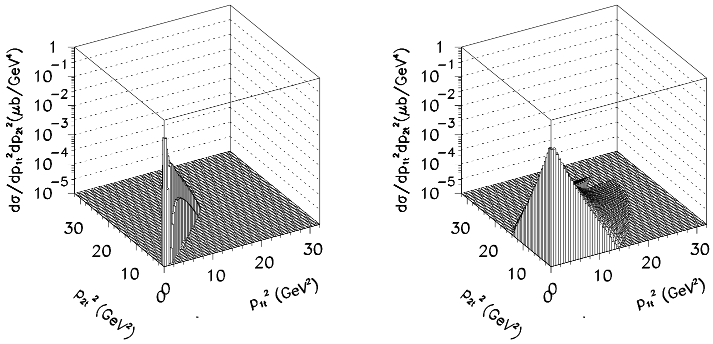

Figure 2. The two-dimensional maps $w(p_{1,t}^2, p_{2,t}^2)$ for W = 18.4 GeV: a) GBW and b) CCFM.

the diagonal $p_{1,t}^2 = p_{2,t}^2$ and in this respect resembles the familiar collinear LO result. The CCFM distribution has a sizeable strength at the phase-space borders for $p_{1,t}^2 \approx 0$ or $p_{2,t}^2 \approx 0$. Experimental studies of such maps could open a possibility to test models of uGDF in a more detailed differential way. In principle, such studies will be possible with HERA II runs at DESY.

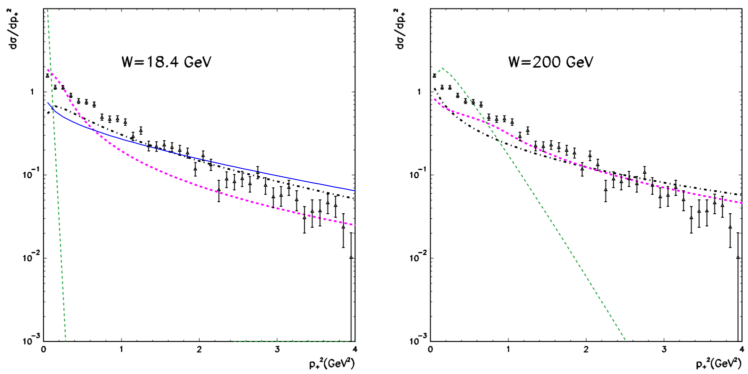

Figure 3. p_+^2 distribution of $c - \bar{c}$. The theoretical results are compared to the recent results from [5] (fully reconstruced pairs). The notation is the same as in Fig.1.

3 Summary

We have shown that analysis of kinematical correlations of charm quarks opens a new possibility to verify models of uGDF. The recently measured data of the FOCUS collaboration at Fermilab allows to study the unintegrated gluon distribution in the intermediate-x region. The recently developed unintegrated gluon (parton) distributions which fulfil the CCFM equation describe the data fairly well. Many models of uGDF from the literature are constructed rather for small values of x and its application in the region of somewhat larger x (x > 0.05) is questionable. It can be expected that the correlation data from the HERA II runs will give a new possibility to verify the different models of unintegrated gluon distributions in more detailed way.

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