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Diffractive processes at the LHC within k_t -factorization approach

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August 9, 2017

Abstract

We discuss the single diffractive production of $c\bar{c}$ pairs and charmed mesons at the LHC. In addition to standard collinear approach, for a first time we propose a k_t -factorization approach to the diffractive processes. The transverse momentum dependent (the unintegrated diffractive parton distributions) in proton are obtained with the help of the Kimber-Martin-Ryskin prescription where collinear diffractive PDFs are used as input. In this calculation the transverse momentum of the pomeron is neglected with respect to transverse momentum of partons entering the hard process. The results of the new approach are compared with those of the standard collinear one. Significantly larger cross sections are obtained in the k_t -factorization approach where some part of higher-order effects is effectively included. Some correlation observables, like azimuthal angle correlation between c and \bar{c} , and $c\bar{c}$ pair transverse momentum distribution were obtained for the first time.

1 Introduction

Diffractive hadronic processes were studied theoretically in the so-called resolved pomeron model [1]. This model, previously used to describe deep-inelastic diffractive processes must be corrected for absorption effects related to hadron-hadron interactions. In theoretical models this effect is taken into account approximately by multiplying the diffractive cross section calculated using HERA diffractive PDFs

by a kinematics independent factor called the gap survival probability – S_G . Two theoretical groups specialize in calculating such probabilities [2, 3].

In this study we consider diffractive production of charm for which rather large cross section at the LHC are expected, even within the leading-order (LO) collinear approach [4]. On the other hand, it was shown that for the inclusive non-diffractive charm production the LO collinear approach is a rather poor approximation and higher-order corrections are crucial. Contrary, the k_t -factorization approach, which effectively includes higher-order effects, gives a good description of the LHC data for inclusive charm production at $\sqrt{s} = 7$ TeV (see e.g. Ref. [5]). This strongly suggests that application of the k_t -factorization approach to diffractive charm production is useful. Besides, the dipole approach is also often used to calculate cross section for diffractive processes. However, as we discussed in Ref. [6], it gives only a small fraction of the diffractive cross section for the charm production. This presentation is based on our recent study presented in [7]. Here we present only results at the quark/antiquark level.

2 A sketch of the theoretical formalism

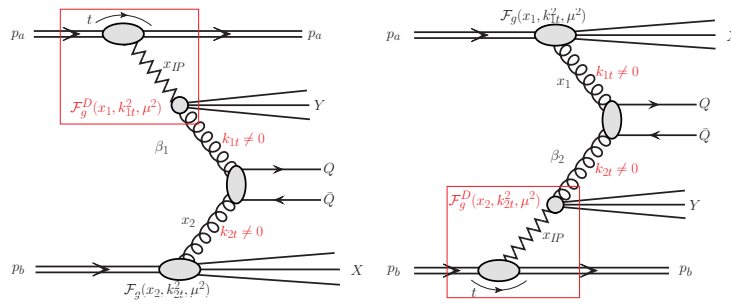


Figure 1: A diagrammatic representation for single-diffractive production of heavy quark pairs within the k_t -factorization resolved pomeron approach.

A sketch of the theoretical formalism is shown in Fig. 1. Here, extension of the standard resolved pomeron model based on the LO collinear approach by adopting a framework of the k_t -factorization is proposed as an effective way to include higher-order corrections. According to this model the cross section for a single-diffractive production of charm quark-antiquark pair, for both considered diagrams (left and right panel of Fig. 1), can be written as:

$$d\sigma^{SD(a)}(p_a p_b \rightarrow p_a c\bar{c} XY) = \int dx_1 \frac{d^2 k_{1t}}{\pi} dx_2 \frac{d^2 k_{2t}}{\pi} d\hat{\sigma}(g^* g^* \rightarrow c\bar{c}) \times \mathcal{F}_g^D(x_1, k_{1t}^2, \mu^2) \cdot \mathcal{F}_g(x_2, k_{2t}^2, \mu^2), \quad (1)$$

$$d\sigma^{SD(b)}(p_a p_b \rightarrow c\bar{c} p_b XY) = \int dx_1 \frac{d^2 k_{1t}}{\pi} dx_2 \frac{d^2 k_{2t}}{\pi} d\hat{\sigma}(g^* g^* \rightarrow c\bar{c}) \times \mathcal{F}_g(x_1, k_{1t}^2, \mu^2) \cdot \mathcal{F}_g^D(x_2, k_{2t}^2, \mu^2), \quad (2)$$

where $\mathcal{F}_g(x, k_t^2, \mu^2)$ are the "conventional" unintegrated (k_t -dependent) gluon distributions (UGDFs) in the proton and $\mathcal{F}_g^D(x, k_t^2, \mu^2)$ are their diffractive counter-

parts. The latter can be interpreted as a probability of finding a gluon with longitudinal momentum fraction x and transverse momenta k_t at the factorization scale μ^2 assuming that the proton which lost a momentum fraction x_{IP} remains intact.

Details of our new calculations can be found in Ref. [7].

3 Selected results

First, we show some selected examples of the results of the k_T -factorization calculation in Fig. 2. In Fig. 2 we show rapidity (left panel) and transverse momentum (right panel) distribution of c quarks (antiquarks) for single diffractive production at $\sqrt{s} = 13$ TeV. Distributions calculated within the LO collinear factorization (black long-dashed lines) and for the k_t -factorization approach (red solid lines) are shown separately. We see significant differences between results of the both approaches, that are consistent with the conclusions from similar studies of standard non-diffractive charm production (see *e.g.* Ref. [5]). Here we confirm that the higher-order corrections are very important also for the diffractive production of charm quarks.

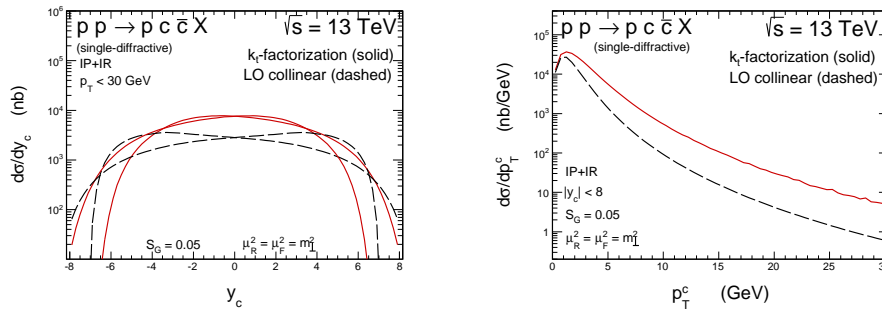


Figure 2: Rapidity (left panel) and transverse momentum (right panel) distributions of c quarks (antiquarks) for a single-diffractive production at $\sqrt{s} = 13$ TeV. Components of the $g(IP) - g(p)$, $g(p) - g(IP)$, $g(IR) - g(p)$, $g(p) - g(IR)$ mechanisms are shown.

Figure 3 shows the differential cross section as a function of $\log_{10}(x)$ where x is defined as the longitudinal momentum fraction of proton carried by the gluon from non-diffractive side (left panel) or as the longitudinal momentum fraction of proton carried by the diffractive gluon emitted from pomeron/reggeon on diffractive side (right panel). In the case of non-diffractive gluon (left panel) we see that for extremely small values of x the LO collinear predictions strongly exceed the ones of the k_t -factorization. This effect also affects the rapidity spectra in the very forward/backward regions (see Fig. 2) and is partially related to a very poor theoretical control of the collinear PDFs in the range of x below 10^{-5} .

In Fig. 4 we show again the rapidity (left panel) and transverse momentum (right panel) distributions of c quarks (antiquarks) calculated in the k_t -factorization approach. Here contributions from the pomeron and the reggeon exchanges are shown separately. The estimated sub-leading reggeon contribution is of similar size as the one of the leading pomeron. In the single-diffractive case the maxima of rapidity distributions for $g(IP) - g(p)$ and $g(p) - g(IP)$ (or $g(IR) - g(p)$ and $g(p) - g(IR)$)

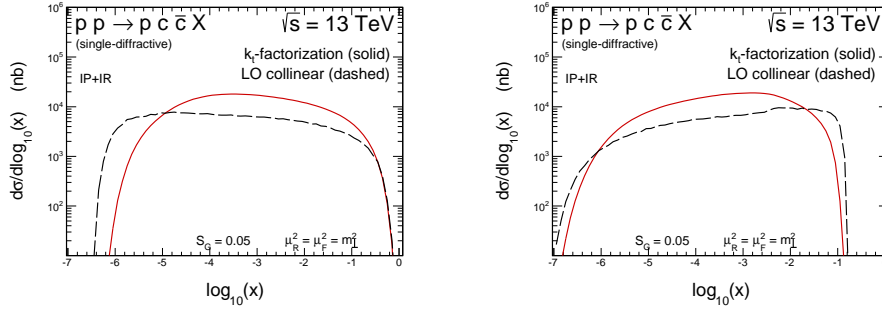


Figure 3: The differential cross section as a function of $\log_{10}(x)$ with x being the non-diffractive gluon longitudinal momentum fraction (left panel) and the diffractive gluon longitudinal momentum fraction with respect to the proton (right panel) for single-diffractive production at $\sqrt{s} = 13$ TeV. Results for the LO collinear (black long-dashed) and the k_t -factorization (red solid) approaches are compared.

mechanisms are shifted to forward and backward rapidities with respect to the non-diffractive case. This is related to the upper limit on diffractive gluon longitudinal momentum fraction ($x \leq x_{IP}$).

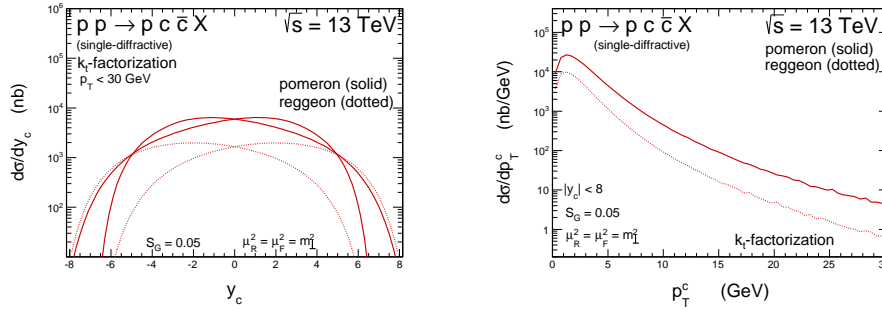


Figure 4: Rapidity (left panel) and transverse momentum (right panel) distributions of c quarks (antiquarks) for single-diffractive production at $\sqrt{s} = 13$ TeV calculated with the k_t -factorization approach. Contributions of the $g(IP) - g(p)$, $g(p) - g(IP)$, $g(IR) - g(p)$, $g(p) - g(IR)$ mechanisms are shown separately.

The correlation observables cannot be calculated within the LO collinear factorization but can be directly obtained in the k_t -factorization approach. The distribution of azimuthal angle $\varphi_{c\bar{c}}$ between c quarks and \bar{c} antiquarks is shown in the left panel of Fig. 5. The $c\bar{c}$ pair transverse momentum distribution $p_T^{c\bar{c}} = |\vec{p}_t^c + \vec{p}_t^{\bar{c}}|$ is shown in the right panel. Results of the full phase-space calculations illustrate that the quarks and antiquarks in the $c\bar{c}$ pair are almost uncorrelated in the azimuthal angle between them and are often produced in the configuration with quite large pair transverse momenta.

Figures 6 and 7 show the double differential cross sections as a functions of transverse momenta of incoming gluons (k_{1T} and k_{2T}) and transverse momenta of outgoing c and \bar{c} quarks (p_{1T} and p_{2T}), respectively. We observe quite large incident gluon transverse momenta. The major part of the cross section is concentrated in the region of small k_t 's of both gluons but long tails are present. Transverse

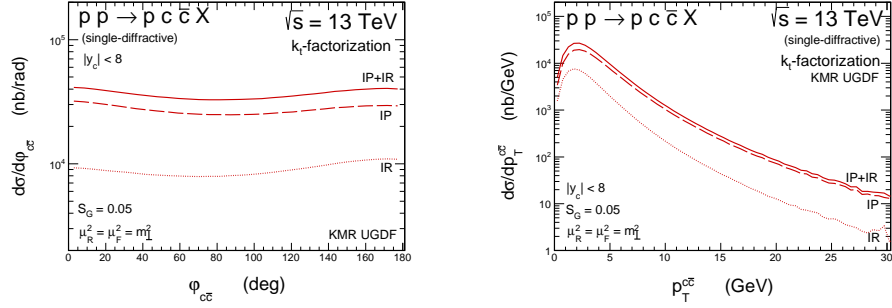


Figure 5: The distribution in $\phi_{c\bar{c}}$ (left panel) and distribution in $p_T^{c\bar{c}}$ (right panel) in the k_t -factorization approach at $\sqrt{s} = 13$ TeV.

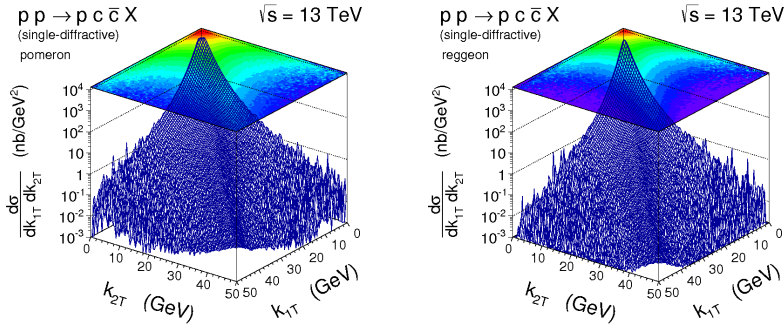


Figure 6: Double differential cross sections as a function of initial gluons transverse momenta k_{1T} and k_{2T} for single-diffractive production of charm at $\sqrt{s} = 13$ TeV. The left and right panels correspond to the pomeron and reggeon exchange mechanisms, respectively.

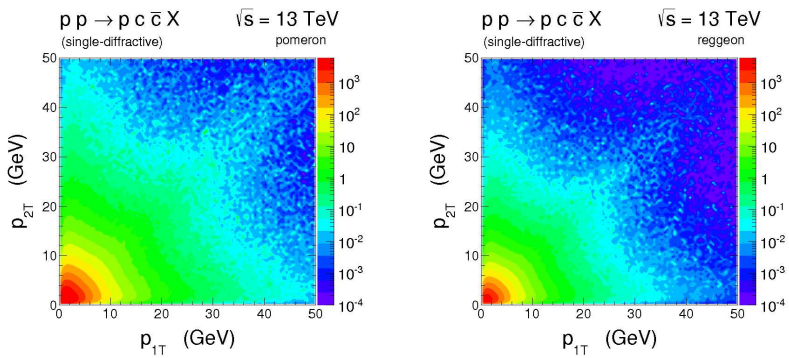


Figure 7: Double differential cross sections as a function of transverse momenta of outgoing c quark p_{1T} and outgoing \bar{c} antiquark p_{2T} for single-diffractive production of charm at $\sqrt{s} = 13$ TeV. The left and right panels correspond to the pomeron and reggeon exchange mechanisms, respectively.

momenta of the outgoing particles are not balanced as they were in the case of the LO collinear approximation.

4 Conclusions

Charm production is a good example where the higher-order effects are very important. For the inclusive charm production we have shown that these effects can be effectively included in the k_t -factorization approach [5]. In our approach we decided to use the so-called KMR method to calculate unintegrated diffractive gluon distribution (UDGD). Having obtained the UDGD we have performed calculations of several single-particle and correlation distributions. In general, the k_t -factorization approach leads to larger cross sections. However, the K -factor is strongly dependent on phase space point. Some correlation observables, like azimuthal angle correlation between c and \bar{c} , and $c\bar{c}$ pair transverse momentum distributions were obtained in [7] for the first time.

Acknowledgments

This work was partially supported by the Polish National Science Centre grant DEC-2013/09/D/ST2/03724 as well as by the Centre for Innovation and Transfer of Natural Sciences and Engineering Knowledge in Rzeszów.

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