Production of $c\bar{c}$ pairs at LHC: k_t-factorization and double-parton scattering

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We discuss charm production at LHC. The production of single $c\bar{c}$ pairs is calculated in the k_t-factorization approach. We use several unintegrated gluon distributions from the literature. Differential distributions for several charmed mesons are presented and compared to recent results of the ALICE and LHCb collaborations. Some missing strength can be observed. Furthermore we discuss production of two $c\bar{c}$ pairs within a simple formalism of double-parton scattering (DPS). Surprisingly large cross sections, comparable to single-parton scattering (SPS) contribution to $c\bar{c}$ production, are predicted for LHC energies.

1 Introduction

The cross section for open charm production at the LHC is very large. Different mesons are measured [1, 2]. Some other experiments are preparing their experimental cross sections. Different theoretical approaches for heavy quark production are used in the literature. In the present communication we present briefly some results for charmed meson production within k_t-factorization approach. A more detailed analysis will be presented elsewhere [3]. Similar analysis within next-to-leading order aproach was presented very recently [4]. Previously we have used the k_t-factorization approach for charm production at the Tevatron [5] and for non-photonic electron production at RHIC [6, 7]. The k_t-factorization approach was also successfully used for beauty [8] and top [9] quark (antiquark) inclusive production.

Recently we have made first estimates for the production of two $c\bar{c}$ pairs [10, 11]. We have considered both double-parton scattering (DPS) mechanism [10] as well as single-parton scattering (SPS) mechanism [11]. By comparison of contributions of both mechanisms we come to the conclusion that the production of two $c\bar{c}$ pairs is a favourite place to study and identify double-parton scattering effects. The double-parton scattering was studied recently for different high-energy processes.

2 Inclusive charmed meson production

In the leading-order (LO) approximation within the k_t-factorization approach the quadruply differential cross section in the rapidity of Q (y_1), in the rapidity of $\bar{Q}$ (y_2) and in the transverse

momentum of Q ($p_{1,t}$) and $\bar{Q}$ ($p_{2,t}$) can be written as

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_{1,t} d^2 p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{ij\to Q\bar{Q}}|^2} \tag{1}$$

$$\delta^2 \left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}\right) \mathcal{F}_i(x_1, \kappa_{1,t}^2) \mathcal{F}_j(x_2, \kappa_{2,t}^2) ,$$

where $\mathcal{F}_i(x_1, \kappa_{1,t}^2)$ and $\mathcal{F}_j(x_2, \kappa_{2,t}^2)$ are so-called unintegrated gluon (parton) distributions. The unintegrated parton distributions are evaluated at: $x_1 = \frac{m_{1,t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(y_2)$, $x_2 = \frac{m_{1,t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(-y_2)$, where $m_{i,t} = \sqrt{p_{i,t}^2 + m_Q^2}$.

The hadronization is done in the way explained in Ref.[6]. In Fig. 1 we show two examples how we describe LHC experimental data [1, 2]. There seems to be some strength missing. A possible explanation of that observation will be discussed in the next section.
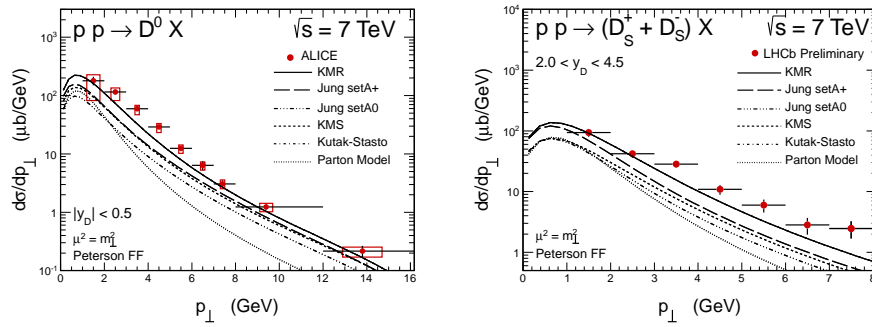

Figure 1:   Two examples of transverse momentum distribution of charmed mesons compared to ALICE (left panel) and LHCb (right panel) experimental data. The calculations were done for different unintegrated gluon distributions.

3   Production of two $c\bar{c}$ pairs

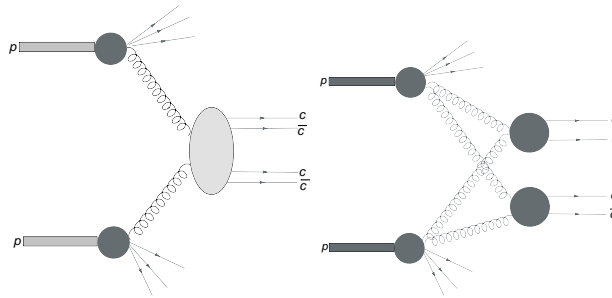Two possible mechanisms of the production of two $c\bar{c}$ pairs are shown in Fig. 2.

Figure 2:   SPS (left) and DPS (right) mechanisms of $(c\bar{c})(c\bar{c})$ production.

The cross section for differential distribution in a simple double-parton scattering in leading-order collinear approximation can be written as

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_{1t} dy_3 dy_4 d^2 p_{2t}} = \frac{1}{2\sigma_{eff}} \frac{d\sigma}{dy_1 dy_2 d^2 p_{1t}} \cdot \frac{d\sigma}{dy_3 dy_4 d^2 p_{2t}} \tag{2}$$

which by construction reproduces the formula for integrated cross section [10]. This cross section is formally differential in 8 dimensions but can be easily reduced to 7 dimensions noting that physics of unpolarized scattering cannot depend on azimuthal angle of the pair or on azimuthal angle of one of the produced c ($\bar{c}$) quark (antiquark). This can be easily generalized by including QCD evolution effects [10].

In Fig. 3 we compare cross sections for the single $c\bar{c}$ pair production as well as for single-parton and double-parton scattering $c\bar{c}c\bar{c}$ production as a function of proton-proton center-of-mass energy. At low energies the conventional single $c\bar{c}$ pair production cross section is much larger. The cross section for SPS production of $c\bar{c}c\bar{c}$ system is more than two orders of magnitude smaller than that for single $c\bar{c}$ production. For reference we show the proton-proton total cross section as a function of energy. At higher energies the DPS contribution of $c\bar{c}c\bar{c}$ quickly approaches that for single $c\bar{c}$ production as well as the total cross section.
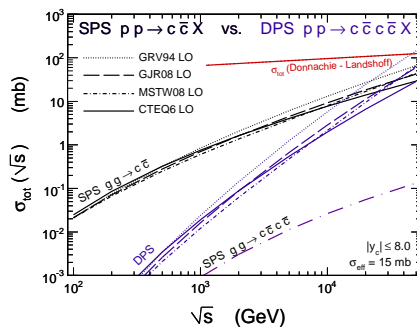

Figure 3: Total LO cross section for single $c\bar{c}$ pair and SPS and DPS $c\bar{c}c\bar{c}$ production as a function of center-of-mass energy.

In Ref.[10] we have also considered several correlation observables between different c quarks and $\bar{c}$ antiquarks. Particularly interesting are correlations between c-c and $\bar{c}$-$\bar{c}$. Two examples are shown in Fig. 4. We show both terms: when $c\bar{c}$ are emitted in the same parton scattering ($c_1\bar{c}_2$ or $c_3\bar{c}_4$) and when they are emitted from different parton scatterings ($c_1\bar{c}_4$ or $c_2\bar{c}_3$). In the latter case we observe a long tail for large rapidity difference as well as at large invariant masses of $c\bar{c}$.

In Ref.[11] we have calculated cross section for $c\bar{c}c\bar{c}$ production in single-parton scattering in high-energy approximation. In Fig. 5 we compare the SPS contribution with the DPS one. Clearly the SPS contribution at large rapidity difference between cc or $\bar{c}\bar{c}$ is much smaller than the DPS contribution.

In Ref.[10] we have discussed that the sum of transverse momenta of two c (or two $\bar{c}$) has a hard tail. This is of course not an observable. In Fig. 6 we show instead distribution in transverse momentum of the $D^0 D^0$ pair (or $\bar{D}^0 \bar{D}^0$ pair) for the rapidity interval relevant for
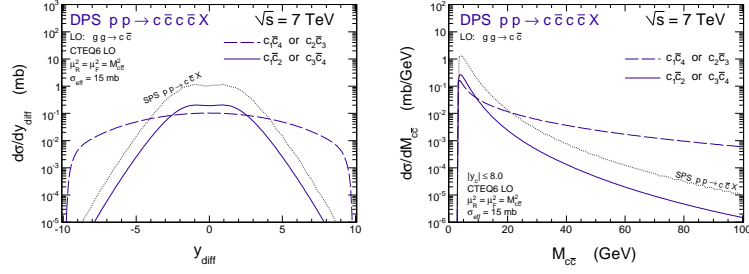
Figure 4: Distribution in rapidity difference (left panel) and in invariant mass of the $c\bar{c}$ pair (right panel) at $\sqrt{s} = 7$ TeV.
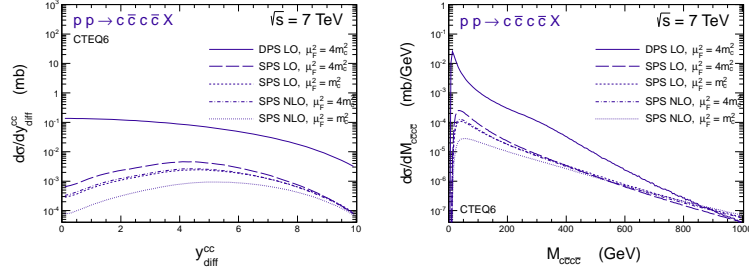

Figure 5: Comparison of SPS and DPS contributions for two correlation distributions.

a given experiment. This distribution has surprisingly long tail. For comparison we show transverse momentum distribution of one D^0 (or $\bar{D}^0$).
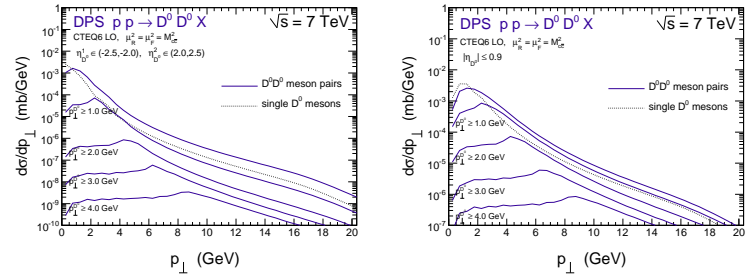

Figure 6: Transverse momentum distribution of the $D^0 D^0$ (or $\bar{D}^0 \bar{D}^0$) pairs for the rapidity interval of ATLAS or CMS (left) and ALICE (right) experiments for different cuts on transverse momenta of each meson in the pair. The distribution in transverse momentum of single D^0 is shown for comparison (dashed line). All distributions are shown for $\sqrt{s} = 7$ TeV.

4 Summary

We have presented our selected new results for charmed meson production at LHC. Results of our calculation have been compared with recent ALICE and LHCb experimental data for transverse momentum distribution of D mesons. There seems to be a missing strength, especially for the LHCb kinematics.

One of possible explanation is a presence of double-parton scattering contributions. Therefore the second topic discussed during the conference was the production of two $c\bar{c}$ pairs. We have compared energy dependence of the DPS contribution to the $c\bar{c}c\bar{c}$ production with that for the $c\bar{c}$ production. The cross section for two pair production grows much faster than that for single pair production. At high energies the two cross sections become comparable. We have also discussed some correlation observables that could be used to identify double-parton scattering contribution. The rapidity difference is one of the good examples.

We have also estimated corresponding single-parton scattering contributions in a high energy approach. The latter turned out to be much smaller than the double-parton scattering contributions.

In summary, we have found that the production of two $c\bar{c}$ pairs is one of the best places to study and identify double-parton scattering effects. For example a good possibility would be to measure two $D^0 D^0$ or two $\bar{D}^0 \bar{D}^0$ mesons. The LHCb collaboration has started already such studies [12].

5 Acknowledgements

References

[1] B. Abelev et al. (ALICE Collaboration), JHEP **01** (2012) 128.

[2] LHCb Collaboration, LHCb-CONF-2010-013.

[3] R. Maciuła and A. Szczurek, a paper in preparation.

[4] B.A. Kniehl, G. Kramer, I. Schienbein and H. Spiesberger, arXiv:1202.0439 [hep-ph].

[5] M. Łuszczak and A. Szczurek, Phys. Rev. **D73** (2006) 054028.

[6] M. Łuszczak, R. Maciuła and A. Szczurek, Phys. Rev. **D79** (2009) 034009.

[7] R. Maciuła, A. Szczurek and G. Ślipek, Phys. Rev. **D83** (2011) 054014.

[8] H. Jung, M. Kraemer, A.V. Lipatov and N.P. Zotov, arXiv:1111.1942.

[9] A.V. Lipatov and N.P. Zotov, Phys. Lett. **B704** (2011) 189.

[10] M. Łuszczak, R. Maciuła and A. Szczurek, Phys. Rev. **D85** (2012) 094034, arXiv:1111.3255 [hep-ph].

[11] W. Schäfer and A. Szczurek, Phys. Rev. **D85** (2012) 094029, arXiv:1203.4129 [hep-ph].

[12] R. Aaij et al. (LHCb Collaboration), arXiv:1205.0975 [hep-ex].