Addendum

LHCb Collaboration

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Addendum: Observation of double charm production involving open charm in pp collisions at $\sqrt{s} = 7$ TeV

The LHCb collaboration

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JHEP03(2014)108

The production of J/ψ mesons accompanied by open charm hadrons, and of pairs of open charm hadrons in pp collisions at a centre-of-mass energy of 7 TeV has been reported in ref. [1]. For all measured production cross-sections the inclusion of charge conjugate processes was implied, so that e.g., $\sigma_{\mathrm{J}/\psi\mathrm{D}^0}$ is the sum of production cross-sections for $\mathrm{J}/\psi\,\mathrm{D}^0$ and $\mathrm{J}/\psi\,\overline{\mathrm{D}}^0$. The inclusion of charge conjugate states was applied also for the reference input prompt charm production cross-sections from ref. [2]. The results have been compared with single (SPS) and double (DPS) parton scattering predictions [3–9].

M. H. Seymour and A. Siódmok [10] have pointed out that for DPS predictions the basic factorization equation, see eq. (1.1) from ref. [1], requires modifications to account for the cross-section including charge conjugation. For this case the equation reads as

$$\sigma^{\mathrm{DPS}}_{\mathrm{C}_1\mathrm{C}_2} = \alpha \frac{\sigma_{\mathrm{C}_1} \times \sigma_{\mathrm{C}_2}}{\sigma^{\mathrm{DPS}}_{\mathrm{eff}}}, \tag{1}$$

where $\alpha = \frac{1}{4}$ if C_1 and C_2 are identical and non-self-conjugate (e.g. $\mathrm{D}^0\mathrm{D}^0$), $\alpha = 1$ if C_1 and C_2 are different and either C_1 or C_2 is self-conjugate (e.g. $\mathrm{J}/\psi\,\mathrm{D}^0$), and $\alpha = \frac{1}{2}$ otherwise. Table 1 summarises the DPS predictions with this scheme. With such corrections, the production cross-sections, predicted by the DPS approach are unchanged for the $\mathrm{J}/\psi\,\mathrm{C}$ case, but decrease by a factor of two for the CC case.

Figure 1 shows the ratios $\mathcal{R}_{\mathrm{C}_1\mathrm{C}_2}$ defined as

$$\mathcal{R}_{\mathrm{C}_1\mathrm{C}_2} \equiv \alpha' \frac{\sigma_{\mathrm{C}_1} \times \sigma_{\mathrm{C}_2}}{\sigma_{\mathrm{C}_1\mathrm{C}_2}}, \tag{2}$$

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Mode	$\sigma^{\rm DPS}$
	[nb]
$J/\psi\, D^0$	146 ± 39
$J/\psi\, D^+$	60 ± 17
$J/\psi\, D_s^+$	24 ± 7
$J/\psi\, \Lambda_c^+$	56 ± 22
	[μb]
D^0D^0	1.0 ± 0.25
D^0D^+	0.85 ± 0.2
$D^0D_s^+$	0.33 ± 0.07
$D^0\Lambda_c^+$	0.75 ± 0.25
D^+D^+	0.17 ± 0.05
$D^+D_s^+$	0.14 ± 0.03
$D^+\Lambda_c^+$	0.32 ± 0.12

Table 1. Estimates for the production cross-sections of the $J/\psi\, C$ and CC modes in the LHCb fiducial range given by the double parton scattering approach.

where α' is defined similarly to α in eq. (1) for the $J/\psi\, C$ and CC cases. When considering $C\overline{C}$ production, $\alpha' = \frac{1}{4}$ is used for the $D^0\overline{D}^0$ and D^+D^- cases and $\alpha' = \frac{1}{2}$ for the other $C\overline{C}$ modes.

For the $J/\psi\, C$ and CC cases these ratios have a clear interpretation in the DPS approach [6–8] as the effective cross-section of eq. (1) which should be the same for all modes. For the $C\overline{C}$ case, neglecting the contribution from $c\bar{c}c\bar{c}$ production, the ratio $\mathcal{R}_{C_1C_2}$ is related by a model-dependent kinematical factor to the total charm production cross-section and should be independent of the final state under consideration. The values for the effective DPS cross-section calculated from the $J/\psi\, C$ cross-section are in good agreement with the value measured in multi-jet production at the Tevatron $\sigma_{\rm eff}^{\rm DPS} = 14.5 \pm 1.7\,^{+1.7}_{-2.3}$ mb [11]. The agreement in the CC case is also reasonable.

JHEP03(2014)108

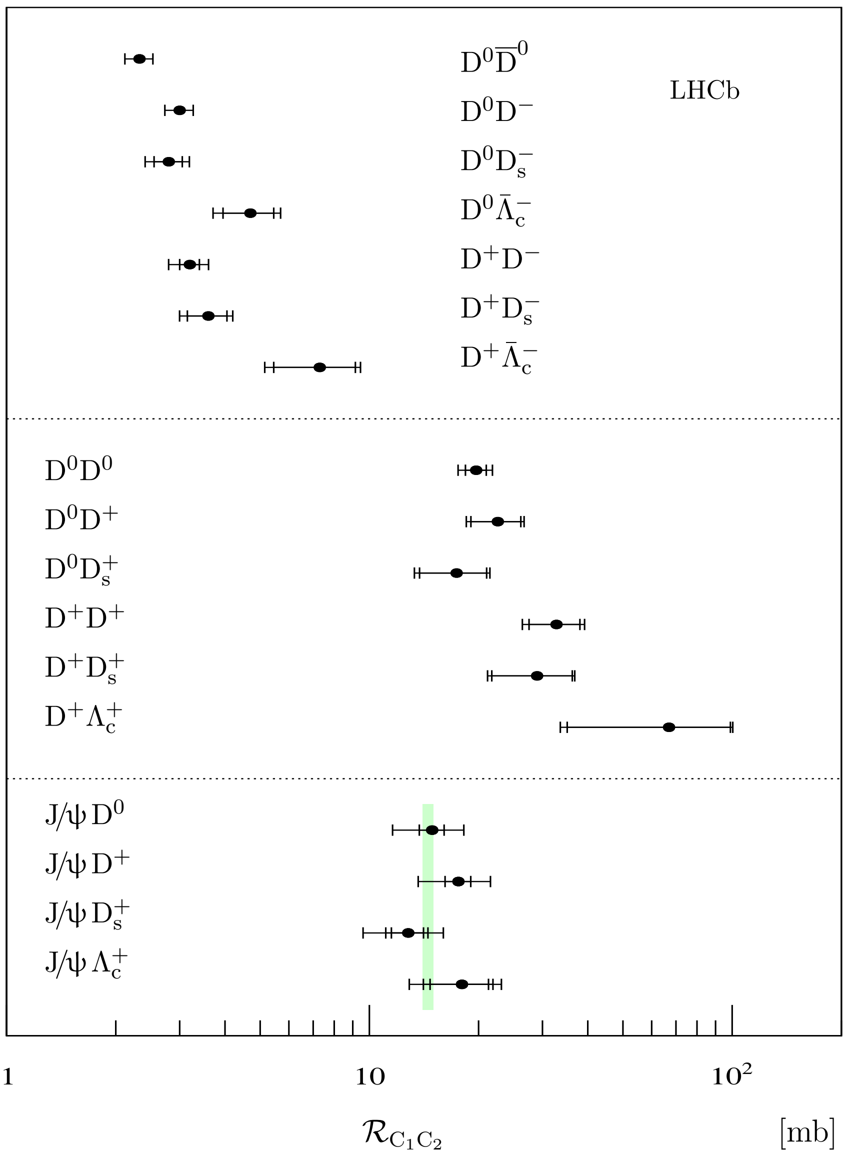

Figure 1. Measured ratios $\mathcal{R}_{\mathrm{C_1C_2}}$ (points with error bars) in comparison with the expectations from DPS using the cross-section measured at Tevatron for multi-jet events (light green shaded area). The inner error bars indicate the statistical uncertainty whilst the outer error bars indicate the sum of the statistical and systematic uncertainties in quadrature. For the $\mathrm{J}/\psi\,\mathrm{C}$ case the outermost error bars correspond to the total uncertainties including the uncertainties due to the unknown polarization of the prompt J/ψ mesons.

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JHEP03(2014)108

The LHCb collaboration

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JHEP03(2014)108

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JHEP03(2014)108

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JHEP03(2014)108