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Charm production and rare charm decays at LHCb

PoS(ICHEP2012)343

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During 2010 and 2011 the LHCb experiment has collected a dataset corresponding to an integrated luminosity of 1 fb^{-1} in proton-proton collisions at $\sqrt{s} = 7$ TeV. We present studies of double charm production, D_S^+ production asymmetry and a search for the $D^0 \to \mu^+\mu^-$decay.

36th International Conference on High Energy Physics,
July 4-11, 2012
Melbourne, Australia

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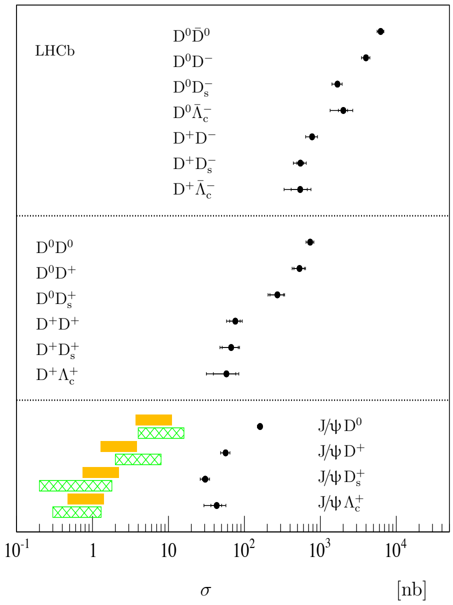

Figure 1: Cross section of the different double charm channels. The leading order gg-fusion predictions are shown in yellow (filled) [5] and green (hatched) [7].

1. Double charm production

The production of double $c\bar{c}$ is expected to come from higher order gluon diagrams, for J/ψ with a strong color octet contribution. It could be enhanced by the charm content of the proton or by double parton scattering (DPS). The naïve DPS prediction[1] is: $\frac{\sigma_{C_1}\sigma_{C_2}}{\sigma_{C_1C_2}} \approx 15$ mb [1], where C_i, $i = 1,2$, is an open charm meson or J/ψ and $\sigma_{C_1C_2}$ is the cross-section of their simultaneous production.

$\sigma(J/\psi J/\psi)$ was measured in 2010 data with an integrated luminosity of 38 pb^{-1} [2], requiring the two J/ψ's to come from a common vertex. The statistical significance of the double J/ψ signal is larger that 6σ. The analysis was performed in the rapidity range $2 < y < 4.5$ and for $p_T < 10$ GeV/c and gave the result $\sigma(J/\psi J/\psi) = 5.1 \pm 1.0 \pm 1.1$ nb, where the first uncertainty is the statistical and the second uncertainty is the systematic one. The result is consistent with the theoretical predictions from prompt LO CSM of 4.1 ± 1.2 nb [3] and DPS of 2 ± 1 nb [4].

The cross-sections $\sigma(J/\psi C)$, $\sigma(J/\psi \overline{C})$, $\sigma(CC)$, $\sigma(C\overline{C})$ and $\sigma(\overline{CC})$, where C is an open charm meson and both J/ψ and C are coming from the same primary vertex, were measured in 2011 data with 355 pb^{-1}[6]. This is the first observation of these kind of double charm events at a hadron collider. Most of the channels are observed with a significance lager than 5σ. The results are illustrated in Fig. 1 and 2. The cross-sections are larger than LO gg-fusion predictions. The naïve DPS prediction on the other hand works well for the $J/\psi C$ modes while for CC the predictions are too low which could be an effect of fragmentation.

[1] In the case $C_1 = C_2$ there is an additional factor 2.

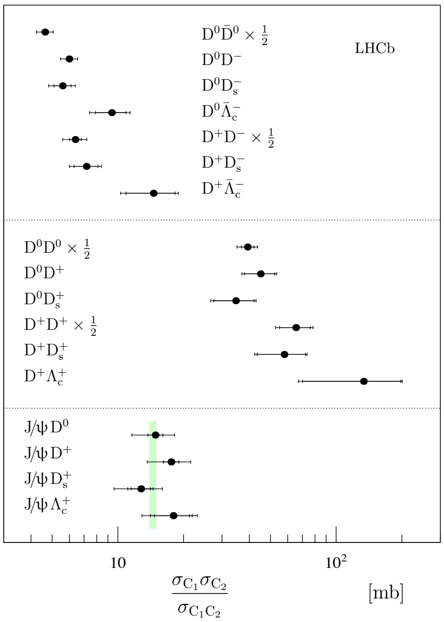

Figure 2: $\frac{\sigma_{C_1}\sigma_{C_2}}{\sigma_{C_1C_2}}$ for the different double charm channels. The value for the naïve DPS prediction is shown in green (filled stripe) [1].

2. D_S^+ meson production asymmetry

Following earlier measurements of the open charm cross-sections [8], a measurement of the $D_s^+ - D_s^-$ production asymmetry $A_P = \frac{\sigma(D_s^+)-\sigma(D_s^-)}{\sigma(D_s^+)+\sigma(D_s^-)}$ at 7 TeV has been made [9].

The quark production should be symmetric, but hadronization may not be, leading to a non zero asymmetry. In this analysis, we use 1 fb^{-1} of 2011 data. The analysis makes use of the decay $D_s^+ \to \phi(K^+K^-)\pi^+$ and its charge conjugate. A crucial point here is to determine the π^+/π^- detection asymmetry. For this we use D^{*+}-tagged $D^0 \to K^-\pi^+\pi^-\pi^+$ decays, but reconstruct only two of the three pions and compare with the result where we use all three pions. Data taken with opposite magnet polarities are combined in order to reduce systematic uncertainties. The analysis is performed in the range $2 < y < 4.5$, $p_T > 2$ GeV/c and leads to the result $A_P = (-0.33 \pm 0.22 \pm 0.10)$ %, consistent with theory prediction [10, 11]. The results are also shown versus y and p_T in Fig. 3, where they are also split into datasets of opposite magnetic field polarity showing no significant difference. The main systematic uncertainties are due to the modeling of the background shape in the D_s^+ mass spectrum and to the statistical uncertainty on the efficiency (0.06 % each).

2.1 Search for $D^0 \to \mu^+\mu^-$

The search for the $D^0 \to \mu^+\mu^-$decay at LHCb is based on a dataset of 0.9 fb^{-1}of pp collisions in LHC at $\sqrt{s} = 7$ TeV [12]. An additional sample of about 79 pb^{-1}was also used in order to optimize the selection but not used in the final analysis. Pairs of opposite side muons were selected to form D^0 candidates, which were required to come from a $D^{*+} \to D^0\pi^+$decay. After a first selection based on standard geometrical and kinematic variables, a Boosted Decision Tree (BDT) was built in order to reject the combinatorial background. A large background to

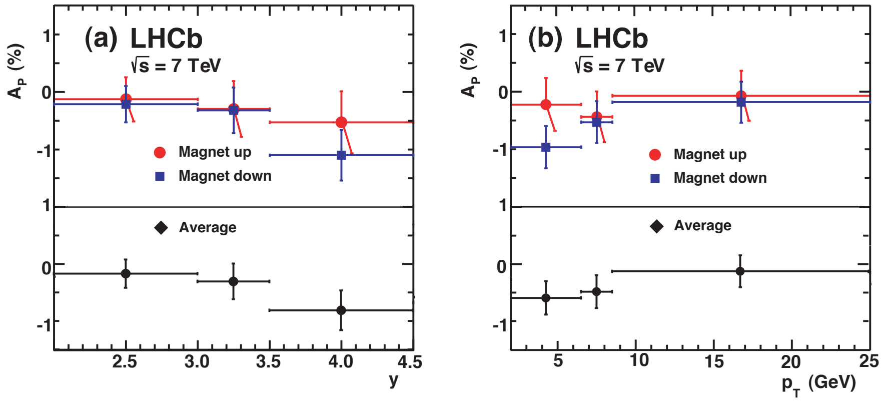

Figure 3: The $D_s^+ - D_s^-$ production cross-section asymmetry plotted versus y (left) and p_T (right). Red (upper panels, round symbol) and blue (upper panels, rectangular symbols) correspond to opposite dipole magnet polarities. The average of the two is shown in the lower panels.

this decay is the $D^0 \to \pi^+\pi^-$with both pions mis-identified into muons. This background was estimated by measuring the mis-ID probability directly on data $D^0 \to K^-\pi^+$decays. The double mis-ID probability was estimated to be $p(D^0 \to \pi^+\pi^- \to \mu\mu) = (27.3 \pm 3.4 \pm 2.0) \cdot 10^{-6}$. The $D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$decay was also exploited as normalisation channel, after being selected with the same selection as the signal, with the exception of the muon identification. The $D^0 \to \pi^+\pi^-$yield was estimated with a 2-dimensional fit to the distribution in the ΔM versus invariant mass plane. The signal and normalisation channel efficiencies were estimated from MC simulations and corrected for data-MC discrepancies. The estimate of the $D^0 \to \mu^+\mu^-$signal yield was also done in the 2D ΔM-M_{D^0} plane. The projection of the $D^0 \to \mu^+\mu^-$fit along the D^0 candidate invariant mass is shown in Fig. 4(a). As no significant signal was observed, the upper limit to the $D^0 \to \mu^+\mu^-$branching fraction was estimated with the CLs method to be: $\mathscr{B}(D^0 \to \mu^+\mu^-) < 1.3(1.1) \times 10^{-8}$ at 95 (90)% CL. In Fig. 4(b) is shown the CLs value as a function of the $D^0 \to \mu^+\mu^-$branching fraction and the expected values and bands. This limit is still several orders of magnitude far from the SM predictions but constrains various NP models.

3. Summary

LHCb is an excellent environment for charm production measurements in the forward region. In this paper we showed that double charm modes are observed in hadron collisions for the first time showing strong hints for double parton scattering. The measured $D_s^+ - D_s^-$ production asymmetry is in agreement with theory. A new and more stringent limit to the $D^0 \to \mu^+\mu^-$decay was placed, constraining even more New Physcis parameters.

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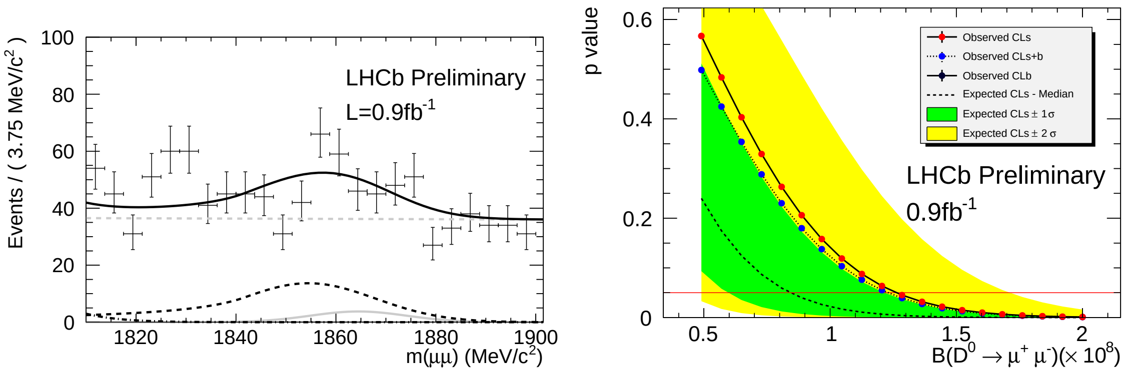

(a) (b)

Figure 4: (a) Invariant mass distribution for $D^0 \to \mu^+\mu^-$candidates, projected from the $M_D, \Delta M$ plane, and the fit to the distribution: the black line is the total fit function composed of the combinatorial background (light grey dashed line), $D^0 \to \pi^+\pi^-$mis-identified background (dark dashed line), $D^0 \to K^-\pi^+$mis-identified background (dash-dotted line) and the signal $D^0 \to \mu^+\mu^-$(light grey continuous line). In (b) the CLs value as a function of the $D^0 \to \mu^+\mu^-$branching fraction as obtained with the CLs method is shown; the red line shows the upper limit to the branching fraction at 95 % CL [12].

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