PoS PROCEEDINGS OF SCIENCE

Open charm production at LHCb

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Open charm production has been studied at $\sqrt{s}$ = 7 TeV with the LHCb detector at LHC. Production cross sections have been measured for D^0, D^{*+}, D^+ and D_s^+ mesons in bins of transverse momentum and rapidity in the region $0 < p_T < 8$ GeV/c and $2 < y < 4.5$ using integrated luminosity of 1.8 nb^{-1}. The results are compared to and are in good agreement with theoretical predictions and with Monte Carlo simulation based on the PYTHIA program, using the LHCb tuning. Extrapolating to the full phase space, the total open charm $c\bar{c}$ cross section is found to be $\sigma(pp \to c\bar{c}X)$ = 6.1 ± 0.9 mb. In addition the measurement of the D^0 production asymmetry is reported using the 2010 data sample with an integrated luminosity of 37 pb^{-1}. The production asymmetry amounts to $A_P(D^0) = (-1.08 \pm 0.32 \pm 0.12)\%$ and is the first evidence of a non-zero asymmetry in heavy flavor production at the LHC.

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1. Introduction

The LHCb detector is a single-arm forward spectrometer [1]. The detector is dedicated for flavor physics at the LHC and its main goal is the measurement of CP-violating observables and rare decays of heavy flavor to search for 'New Physics' beyond the Standard Model in the decays of b- and c- hadrons.

The following sub-detectors are extensively used in charm production and asymmetry measurements. The Vertex Locator (VELO) provides excellent primary vertex reconstruction. The tracking system before and after the magnet allows track reconstruction with momentum resolution of $\Delta p/p \approx$ 0.35–0.55%. Two Ring Imaging Cherenkov detectors (RICH) provide particle identification (PID) to distinguish charged kaons from pions.

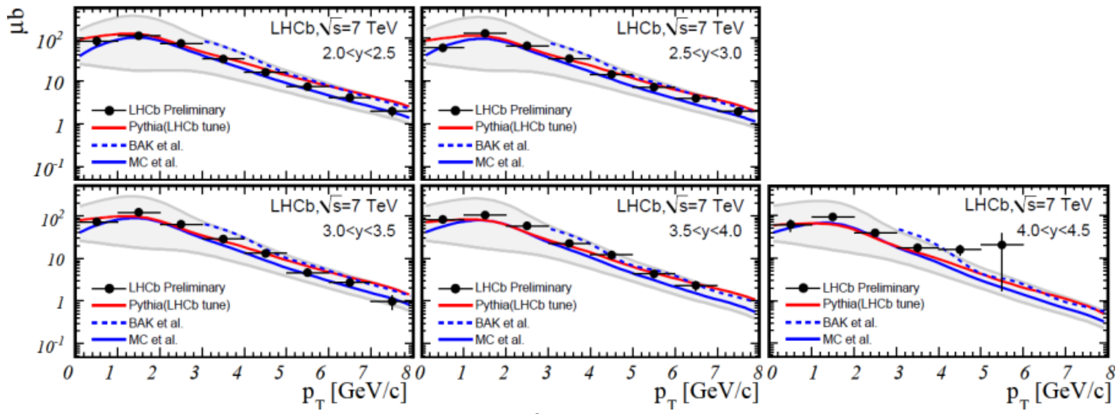
Currently, the LHC is working at a center-of-mass energy of 7 TeV and in 2010 LHC delivered an integrated luminosity of 42 pb^{-1} to LHCb of which about 90% was recorded. An early data set corresponding to an integrated lumiosity of 1.8 nb^{-1} is used for the cross section measurement in Section 2, whereas the full data set is used for the measurement of the production asymmetry reported in Section 3.

2. Open charm production cross section

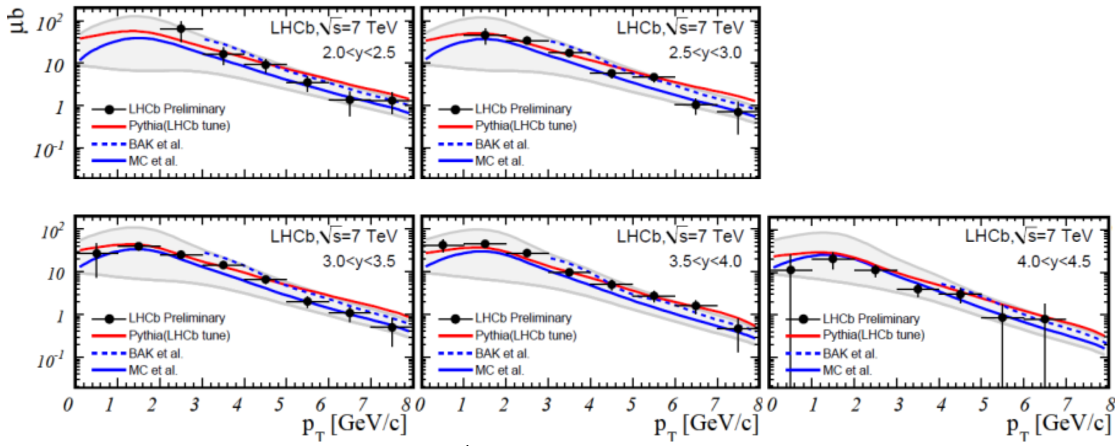
With the first data of 2010 LHCb measured the open charm production cross section of D^0, D^{*+}, D^+ and D_s^+ mesons. The measurement was performed at 7 TeV center-of-mass energy with the first 1.8 nb^{-1} of integrated luminosity [2]. This data were collected with a minimum bias trigger, which selects events with a minimum activity in calorimeter and one track reconstructed in the VELO detector or in the tracking stations. Compared to other LHC experiments LHCb provides the possibility to measure the cross section down to transverse momentum $p_{\mathrm{T}} = 0$ GeV and in the forward rapidity range. The double differential cross section was measured in 8 bins of p_T from 0 to 8 GeV and 5 bins of rapidity y from 2 to 4.5. Due to the relatively small data sample, the D_s^+ cross section is reported only single-differentially in p_{T} and rapidity. The following decay modes were studied: $D^0 \to K^-\pi^+$, $D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$, $D^+ \to K^+\pi^+\pi^-$ and $D_s^+ \to \varphi(K^+K^-)\pi^+$ including their charge conjugate modes.

The yields were determined by fitting the D meson mass distributions in bins of p_T and y. The secondary contribution of charm mesons produced in B decays was determined from fits to the impact parameter distribution of the charm mesons with the shapes of the prompt and secondary components fixed from Monte Carlo (MC) simulation. The acceptance and reconstruction efficiencies were determined from MC while the PID efficiencies for pions and kaons were determined from a calibration sample, containing $K_s \to \pi^+\pi^-$ and $\varphi \to K^+K^-$ decays.

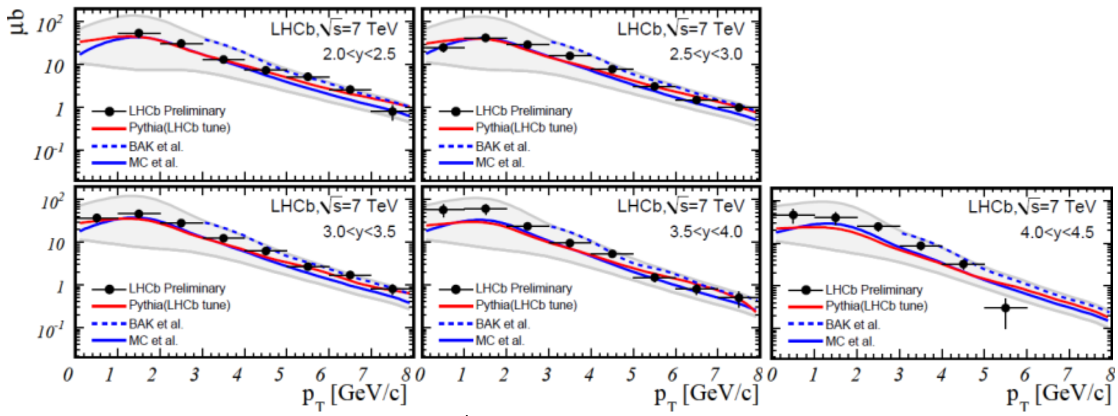
The main systematic uncertanties are the uncertainty on the integrated luminosity of the data sample, which is 10% [3], and the uncertainty of the tracking efficiency, which was determined from data to be 3% for high momentum tracks and 4% for the soft pion from D^{*+}.



(a) The $D^0(+\overline{D}^0)$ production cross section.

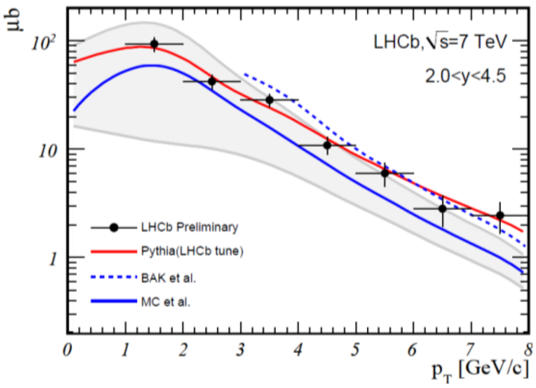


(b) The $D^{*+}(+D^{*-})$ production cross section.

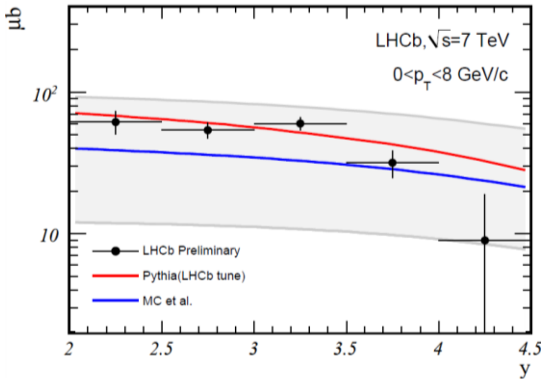


(c) The $D^+(+D^-)$ production cross section.

Figure 1: Double differential cross section of open charm production versus p_T and y. The data (black dots) are compared with LHCb tuning of PYTHIA (red solid line) and two theoretical predictions: MC et al. [4] (blue solid line) and BAK et al. [5] (blue dotted line). (a), (b) and (c) show the D^0, D^{*+} and D^+ cross section as a function of p_T for different rapidity ranges. The error bars include statistical and uncorrelated systematic errors. The correlated systematic errors are not shown and are 12%, 14% and 14% respectively.



(a)



(b)

Figure 2: Single differential cross section of $D_s^+(+D_s^-)$ production versus p_T (a) and rapidity (b). The correlated systematic error is not shown and amounts to 16%.

The measured cross sections in bins of p_{T} and y are shown in Figure 1 and Figure 2. The data are compared with two theories, namely MC et al. [4] based on improved fixed order next-to-leading order (NLO) with resummation of p_T logarithms to next-to-leading accuracy (FONLL), and BAK et al. [5] based on NLO calculations in the general-mass variable flavor-number scheme. In addition the data are compared to MC simulation based on the PYTHIA program, based on the LHCb tuning.

The results for various D meson species are integrated over the measured p_{T} and y range to determine the open charm production cross section. The fragmentation fractions for charm quark to hadronize into specific D meson are taken from e^+e^- collisions at the $\Upsilon(4S)$ resonance [7] are used to determine the open charm $c\bar{c}$ cross section in the same range. The combined average of the $c\bar{c}$ cross section in the LHCb acceptance, accounting for correlations between the errors, is determined to be 1.23 ± 0.19 mb. Extrapolating with PYTHIA to the full solid angle and full p_T range gives the result for the total $c\bar{c}$ cross section of 6.1 ± 0.9 mb.

3. D^0 production asymmetry

The LHC is a pp collider and an asymmetry may exist between D and $\overline{D}$ production due to the valence quarks in the proton [6]. Knowledge of this asymmetry is important for testing QCD models and crucial for future CP violation measurements in other D decays. The production asymmetry can be extracted by measuring the time-integrated asymmetries for untagged D^0 and tagged D^0 mesons in $D^{*+} \to D^0\pi^+$ decays.

The raw asymmetries for untagged and tagged D^0 decays to a final state f, $A_{CP}^{RAW}(f)$ and $A_{CP}^{RAW}(f)^*$, are defined as:

$$A_{CP}^{RAW}(f) = \frac{N(D^0\to f)-N(\overline{D^0}\to \overline{f})}{N(D^0\to f)+N(\overline{D^0}\to \overline{f})}, \qquad (1)$$

$$A_{CP}^{RAW}(f)^* = \frac{N(D^{*+}\to D^0(f)\pi^+)-N(D^{*-}\to \overline{D^0}(\overline{f})\pi^-)}{(D^{*+}\to D^0(f)\pi^+)+N(D^{*-}\to \overline{D^0}(\overline{f})\pi^-)}, \qquad (2)$$

where N(X) refers to the number of events reconstructed for decay X. Figure 3 shows the fits to the invariant mass distributions that were used to extract number of events.

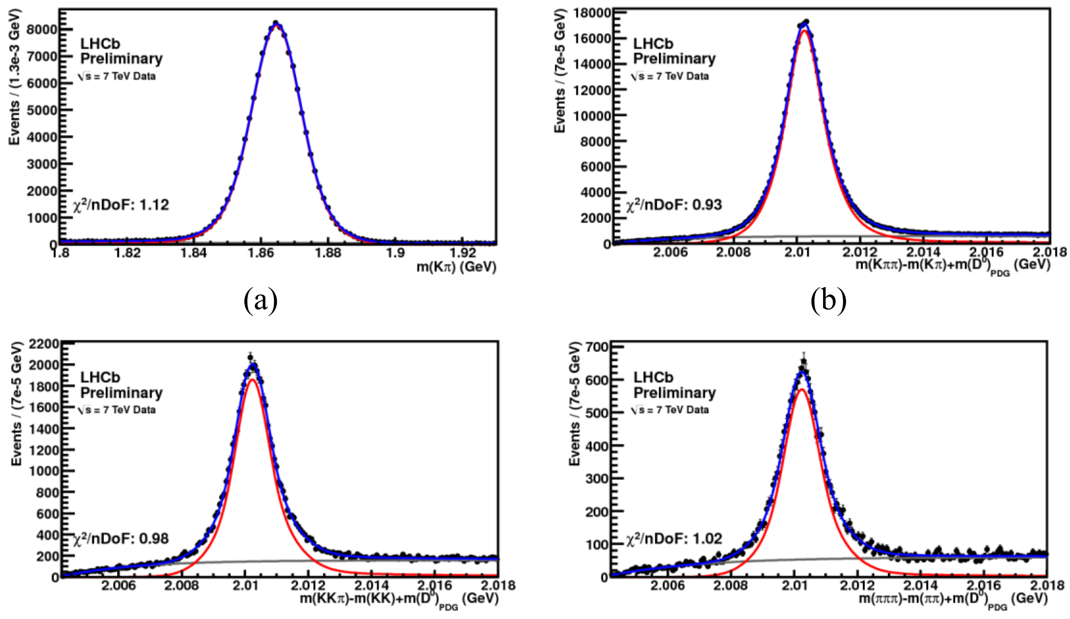


Figure 3: Invariant mass distributions for the decays: (a) $D^0 \to K^-\pi^+$,
(b) $D^{*+} \to (D^0 \to K^-\pi^+)\pi^+$, (c) $D^{*+} \to (D^0 \to K^-K^+)\pi^+$, (d) $D^{*+} \to (D^0 \to \pi^-\pi^+)\pi^+$.

The raw asymmetries can be written as a sum of various components that originate from physics and detector effects:

$$A_{CP}^{RAW}(f) = A_{CP}(f) + A_D(f) + A_P(D^0), \qquad (3)$$

$$A_{CP}^{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^*). \qquad (4)$$

Here $A_{CP}(f)$ is the direct CP asymmetry in $D \to f$ decays, whereas $A_D(f)$ and $A_D(\pi_s)$ are the detector induced asymmetries of selecting a D^0 meson and a soft pion from D^{*+} decay respectively, and $A_P(D^0)$ and $A_P(D^*)$ are production asymmetries.

From Eqs.(1-4) the following relations are obtained:

$$A_{CP}^{RAW}(K^-\pi^+) - A_{CP}^{RAW}(K^-\pi^+)^* + A_{CP}^{RAW}(K^-K^+)^* = A_P(D^0) + A_{CP}(K^-K^+),$$

$$A_{CP}^{RAW}(K^-\pi^+) - A_{CP}^{RAW}(K^-\pi^+)^* + A_{CP}^{RAW}(\pi^-\pi^+)^* = A_P(D^0) + A_{CP}(\pi^-\pi^+).$$

Taking the world average values of $A_{CP}(K^-K^+)$ and $A_{CP}(\pi^-\pi^+)$ as an input and solving this over-constrained system using Bayesian minimization the production asymmetry $A_P(D^0)$ is extracted.

The production asymmetry at LHCb was measured using the full 2010 data sample corresponding to an integrated luminosity of 37 pb^{-1}. The measurement was performed in bins of pseudo-rapidity η of the D^0 meson. Figure 4 shows the D^0 production asymmetry as a function of pseudo-rapidity. With the currently available data sample there is no evidence of a dependence on pseudo-rapidity. The total production asymmetry calculated as the weighted average over bins gives $A_P(D^0)$ = (–1.08 ± 0.32 ± 0.12)%. The first error is statistical with the fully propagated errors on the input quantities $A_{CP}(KK)$ and $A_{CP}(\pi\pi)$ taken into account, and the second error is the total systematic uncertainty.

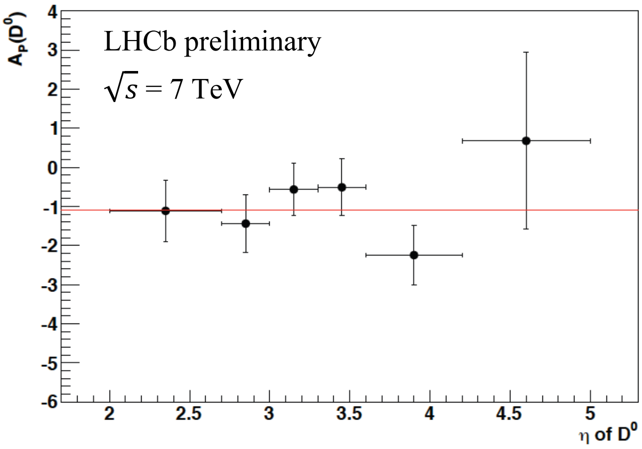


Figure 4: D^0 production asymmetry versus pseudo-rapidity.

4.Summary

The preliminary results for the open charm production cross sections and D^0 production asymmetry have been presented. The measured charm cross sections show good agreement with the theoretical predictions and with the LHCb tuning of PYTHIA. The D^0 production asymmetry was measured with the full 2010 data sample and shows first evidence of a non-zero asymmetry in heavy flavor production at the LHC.

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