PROCEEDINGS OF SCIENCE

Open charm hadron production and spectroscopy at LHCb

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Measurements for open charm hadron production and spectroscopy at LHCb and future prospects are presented. The LHCb detector is designed for the observation of heavy flavour decays with a fully instrumented forward coverage that is unique among the LHC experiments. These features, with the prolific charm production in $\sqrt{s} = 7$ TeV proton-proton collisions, make LHCb ideally suited to perform precise measurements of charm production and spectroscopy that test QCD in this new energy regime.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes, France

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PoS(EPS-HEP2011)302

1. Charm spectroscopy

After the discovery of D and D_s ground states, the QCD potential models [1] were able to predict successfully the masses of many excited charmed mesons. In 2003 the observations of two new narrow states, $D^*_{s0}(2317)$ [2] and $D_{s1}(2460)$ [3], with masses consistently lower than expectations, raised considerable interest in the spectroscopy of heavy mesons. Recently the B-factories observed new D_J [4] and D_{sJ} [5] states decaying to $D^{(*)}\pi$ and $D^{(*)}K$ systems respectively (Table 1).

	Mass (GeV/c^2)	Width (GeV/c^2)	Decay mode
$D(2550)$	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	$D^{*+}\pi^-$
$D^*(2600)$	$2608.7 \pm 2.4 \pm 2.5$	$96 \pm 6 \pm 3$	$D^0\pi^+$, $D^+\pi^-$, $D^{*+}\pi^-$
$D(2750)$	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$	$D^{*+}\pi^-$
$D^*(2760)$	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$	$D^0\pi^+$, $D^+\pi^-$
$D^*_{s1}(2710)$	$2710 \pm 2^{+12}_{-7}$	$149 \pm 7^{+39}_{-52}$	D^0K^+, $D^+K^0_S$, $D^{*+}K^0_S$
$D^*_{sJ}(2860)$	$2862 \pm 2^{+5}_{-2}$	$48 \pm 3 \pm 6$	D^0K^+, $D^+K^0_S$, $D^{*+}K^0_S$
$D_{sJ}(3040)$	$3044 \pm 8^{+30}_{-5}$	$239 \pm 35^{+46}_{-42}$	$D^{*+}K^0_S$

Table 1: Masses and widths of the D_J and D_{sJ} mesons recently observed at the B-factories.

The LHCb detector [6] at the Large Hadron Collider is a single arm spectrometer designed to study the properties of charm and beauty hadrons. Using 320 pb^{-1} of data collected in 2011, large samples of $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$ and $D^{*+} \to D^0\pi^+$ are reconstructed and combined with π^+, K^+ and $K^0_S \to \pi^+\pi^-$. The resulting $D^{(*)}\pi$ and $D^{(*)}K$ mass spectra show that the LHCb experiment has the potential to carry out a programme of charm spectroscopy with the same sensistivity as the B-factories. With the total integrated luminosity recorded in 2011, we will be able to confirm the observations of D_J and D_{sJ} resonances (Table 1) and establish their quantum numbers.

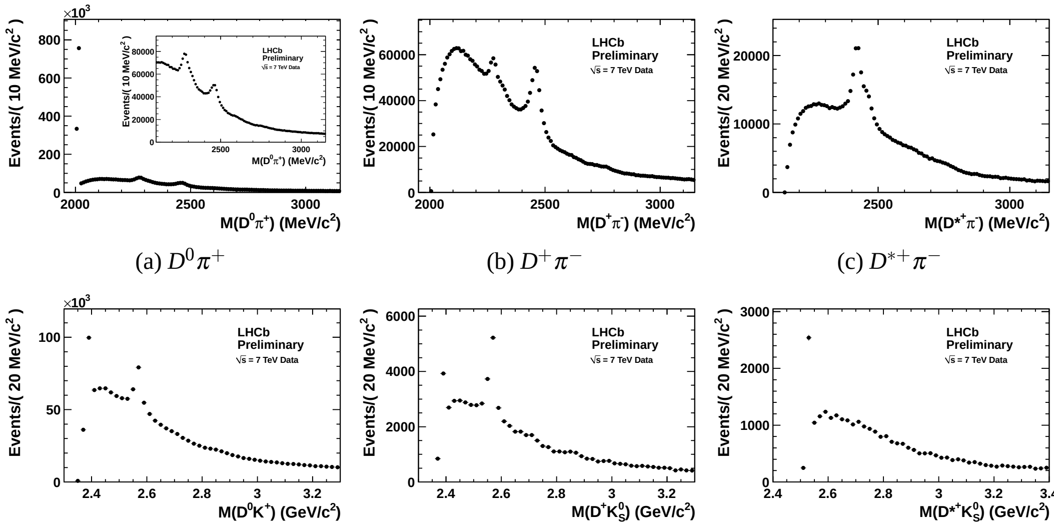
1.1 D_J spectroscopy

The $D^0\pi^+$ (Fig. 1a) and $D^+\pi^-$ (Fig. 1b) mass spectra show similar features except for the large $D^{*+} \to D^0\pi^+$ peak at the $D^0\pi^+$ threshold (the $D^{*0} \to D^+\pi^-$ decay is forbidden due to the insufficient phase-space). The two spectra have prominent peaks corresponding to $D^*_2(2460)^+$ and $D^*_2(2460)^0$ respectively. The $D^0\pi^+$ mass spectrum shows a peak at about 2.3 GeV/c^2 due to the feed-down of decays from the $D_1(2420)^+$ and $D^*_2(2460)^+$ to $D^{*0}\pi^+$ where the D^{*0} goes to $D^0\pi^0$ and the π^0 is missing in the reconstruction. Similarly, $D^+\pi^-$ shows feed-down peaks due to the decays of the $D_1(2420)^0$ and $D^*_2(2460)^0$ to $D^{*+}\pi^-$ where the D^{*+} decays to $D^+\pi^0$.

The $D^{*+}\pi^-$ mass distribution (Fig. 1c) shows a prominent $D_1(2420)^0$ peak with a shoulder on the right side corresponding to the $D^*_2(2460)^0$ signal.

1.2 D_{sJ} spectroscopy

The D^0K^+ and $D^+K^0_S$ mass spectra are shown in Figs. 1d -1e. They present similar features. The single bin peaks at 2.4 GeV/c^2 results from decays of $D_{s1}(2536)^+$ to $D^{*0}K^+$ or $D^{*+}K^0_S$ in which the π^0 or γ from the D^* decay is missed. We also observe prominent narrow signals due to the $D^*_{s2}(2573)^+$. The $D^{*+}K^0_S$ distribution (Fig. 1f) shows a narrow peak at threshold due to the $D_{s1}(2536)^+$ meson.



(a) $D^0\pi^+$ (b) $D^+\pi^-$ (c) $D^{*+}\pi^-$

(d) D^0K^+ (e) $D^+K^0_S$ (f) $D^{*+}K^0_S$

Figure 1: $D^{(*)}\pi$ *(top)* and $D^{(*)}K$ *(bottom)* mass distributions. The inset plot shows an expanded view of the $D^0\pi^+$ high mass region.

2. Charm production

2.1 D^0 production asymmetry

CP violation studies must account for any initial state asymmetry. Here we present the first measurement of $A_P(D^0)$, the production asymmetry of prompt D^0 mesons within the LHCb acceptance [7], in pp collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV. The analysis uses the full dataset of 37 pb^{-1} collected by LHCb in 2010. Selections are applied to provide a sample of $D^0 \to K^-\pi^+$ candidate decays and samples of $D^{*+} \to D^0\pi_s^+$ candidate decays, with $D^0 \to K^-\pi^+, K^+K^-$ and $\pi^+\pi^-$. The raw asymmetries A_{RAW} for a D^0 final state f can be written as:

$$A_{RAW}(f) = A_{CP}(f) + A_D(f) + A_P(D^0) \tag{2.1}$$

$$A_{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_P(D^0) + A_D(\pi_s) \tag{2.2}$$

where A_{CP} is the intrinsic physics CP asymmetry and A_D is the detection asymmetry due to the detector response for charge conjugate final state particles. It can be shown [7] that:

$$A_{RAW}(K^-\pi^+) - A_{RAW}(K^-\pi^+)^* + A_{RAW}(K^-K^+)^* = A_P(D^0) + A_{CP}(K^-K^+) \tag{2.3}$$

$$A_{RAW}(K^-\pi^+) - A_{RAW}(K^-\pi^+)^* + A_{RAW}(\pi^-\pi^+)^* = A_P(D^0) + A_{CP}(\pi^-\pi^+) \tag{2.4}$$

Taking the average of $A_{CP}(K^-K^+) = (-0.23 \pm 0.17)\%$ and $A_{CP}(\pi^+\pi^-) = (+0.20 \pm 0.22)\%$ as inputs, the system of equations 2.3-2.4 is over-constrained. $A_P(D^0)$ is evaluated by solving the system with a Bayesian minimization. Figure 2 shows $A_P(D^0)$ as evaluated in one-dimensional bins of p_T and η separately. No significant dependence is seen within the present statistical uncertainties. Therefore a weigthed average is performed to yield a result $A_P(D^0) = (-1.08 \pm 0.32_{\text{stat.}} \pm 0.12_{\text{syst.}})\%$. The largest systematic uncertainty is related to effects from the trigger mass window and differences between the offline and trigger mass resolutions.

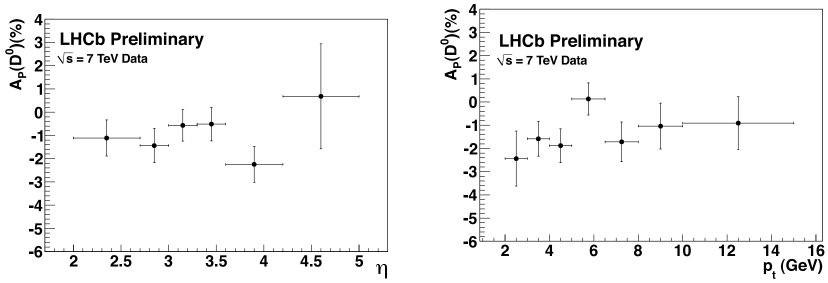


Figure 2: Measured charm production asymmetry in bins of η *(left)* and p_T *(right)*.

2.2 Open charm production asymmetry cross-section

Open charm production in pp collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV has been studied with the LHCb detector using an integrated luminosity of 1.81 nb^{-1} [8]. Cross-sections have been determined for D^0, D^{*+}, D^+, and D_s^+ in bins of transverse momentum and rapidity in the region $0 < p_T < 8$ GeV/c and $2 < y < 4.5$. The results are in a good agreement both in shape and absolute normalisation with theoretical predictions. A direct comparison of D_s^+ and D^+ gives the cross-section ratio as $\sigma(D^+)/\sigma(D_s^+) = 2.32 \pm 0.27_{\text{stat.}} \pm 0.26_{\text{syst.}}$. We find a total $c\bar{c}$ cross-section to produce c-flavoured hadrons ï£ijin the full phase space of $\sigma(pp \to c\bar{c}X) = 6.10 \pm 0.93$ mb.

Updated results based on a larger 2010 dataset will be released soon.

3. Summary

LHCb is an excellent experiment for charm spectroscopy and production measurements with emerging results and a bright future.

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