

B AND C SPECTROSCOPY AT LHCb

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We will present recent results in the field of b and c spectroscopy at LHCb, with particular attention to the latest studies on the $X(3872)$ quantum numbers and the B_c new decay modes and mass measurement.

1 Introduction

The production of mesons and baryons containing b and c quarks is copious at the LHC. The studies on the production and spectroscopy of these particles are important inputs to other measurements and bring valuable contributions to the thorough understanding of the mechanisms of QCD production^{1,2}. The LHCb detector³ has a unique geometry optimised for these studies, as it accepts 40% of all B hadrons produced in pp interactions. The detector is a single-arm forward spectrometer³ dedicated to flavour physics at the LHC. In the years from 2010 to 2012 LHCb has recorded an integrated luminosity of about 3 fb^{-1} of data at a center-of-mass energy of 7, 2.76 and 8 TeV with an efficiency of more than 90%. We discuss recent B_c and b -baryons results in Section 2 and 3, and the $X(3872)$ results in Section 4.

2 B_c physics

The B_c is the only B meson made of two “heavy” quarks and, as such, its properties are in between the charmonium and bottomonium states. It was first observed by CDF in 1998⁴ in the $J/\psi\ell^\pm\nu$ decay mode, and fully reconstructed the $J/\psi\pi^\pm$ mode⁵. At LHCb we already measured the B_c mass and production cross section in the latter channel using 40 pb^{-1} of data⁶. In the larger dataset we observed two new decay modes, $B_c^\pm \rightarrow \psi(2S)\pi^\pm$ and $B_c^\pm \rightarrow J/\psi D_s^{(*)\pm}$.

2.1 $B_c^\pm \rightarrow \psi(2S)\pi^\pm$ observation

In 1.1 fb^{-1} of data we observed 595 ± 29 $B_c \rightarrow J/\psi\pi^\pm$ and 20 ± 5 $B_c \rightarrow \psi(2S)\pi^\pm$ candidate events (as shown in Fig. 1, left and middle), selected using the Boost Decision Tree (BDT) technique⁷

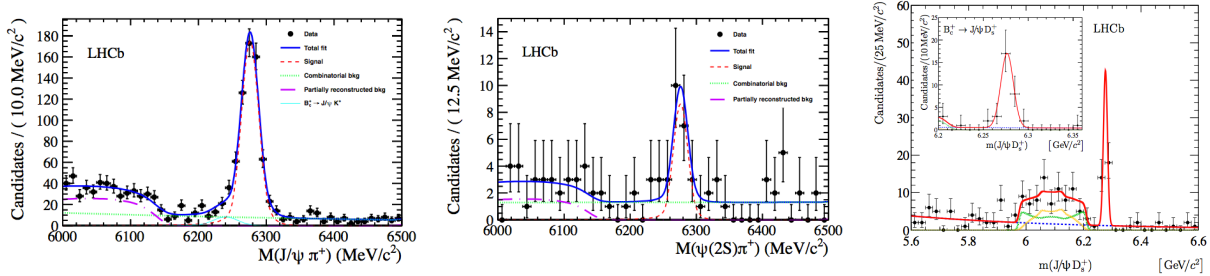


Figure 1: $J/\psi\pi^\pm$ (left), $\psi(2S)\pi^\pm$ (middle) and $D_s^{\pm(*)}\pi^\pm$ (left) invariant mass distributions. The inset in the leftmost figure is the fit in the region between 6.2 and 6.35 GeV/c^2 performed with different binning.

trained on the $B_c \rightarrow J/\psi\pi^\pm$ more abundant channel. The number of signal candidates is determined by fitting the $\psi(2S)\pi$ invariant mass distribution with a Crystal Ball function⁸ for the signal and an exponential function for the background. Partially reconstructed events and combinatorial background are also accounted for. We measured the ratio of $B_c^\pm \rightarrow \psi(2S)\pi^\pm$ to $B_c^\pm \rightarrow J/\psi\pi^\pm$ branching ratios by correcting for the relative reconstruction efficiencies and found the value of

$$\frac{B_c^\pm \rightarrow \psi(2S)\pi^\pm}{B_c^\pm \rightarrow J/\psi\pi^\pm} = 0.250 \pm 0.068(\text{stat}) \pm 0.014(\text{syst}) \pm 0.006(\mathcal{B}), \quad (1)$$

where the third uncertainty is due to the uncertainties on the branching ratios of J/ψ and $\psi(2S)$ in dimuons¹². The dominant source of systematic uncertainty is the one associated with the BDT selection, which amounts to 4.5%. The results are in good agreement with the theoretical predictions of 0.18 made by the relativistic quark model⁹.

2.2 $B_c^\pm \rightarrow J/\psi D_s^{(*)\pm}$ observation

Using the full dataset of $\simeq 3 \text{fb}^{-1}$ collected until 2012, we have observed the decays $B_c^\pm \rightarrow J/\psi D_s^{(*)\pm}$ for the first time¹⁰. The J/ψ is reconstructed in its dimuon decay, while the D_s^\pm is reconstructed through its decay into $\phi\pi$, followed by $\phi \rightarrow K^\pm K^\mp$. The decay $B_c^\pm \rightarrow J/\psi D_s^*$ appears in the $J/\psi D_s$ invariant mass as a satellite structure at smaller mass. The number of signal events for the two decays is determined by a fit to the $D_s^{\pm(*)}\pi$ invariant mass distribution, shown in Fig. 1 (right), using a double Crystal Ball for the D_s signal and the shapes obtained from the Monte Carlo of the distributions due to the $\mathcal{A}^{\pm\pm}, \mathcal{A}^{00}$ different amplitudes for the D_s^* . Using the $B_c^\pm \rightarrow J/\psi\pi^\pm$ as normalisation channel we can measure the ratio of branching ratios

$$\frac{B_c^\pm \rightarrow J/\psi D_s^\pm}{B_c^\pm \rightarrow J/\psi\pi^\pm} = 2.90 \pm 0.57(\text{stat}) \pm 0.24(\text{syst}), \quad (2)$$

$$\frac{B_c^\pm \rightarrow J/\psi D_s^{*\pm}}{B_c^\pm \rightarrow J/\psi D_s^\pm} = 2.37 \pm 0.56(\text{stat}) \pm 0.10(\text{syst}), \quad (3)$$

where the dominant systematic is the one associated with the knowledge of the branching ratio of $D_s^\pm \rightarrow \phi(\rightarrow K^\pm K^\mp)\pi^\pm$ ¹². These results are in good agreement with the simple factorisation approach but generally disagree with the other models¹⁰. Given the small Q value associated with this decay and the precise knowledge of the D meson mass differences¹¹ it is possible to obtain a precise measurement of the B_c mass, which is found to be $m(B_c^\pm) = 6276.26 \pm 1.44(\text{stat}) \pm 0.28(\text{syst}) \text{MeV}/c^2$, in excellent agreement with the previous LHCb result⁶ and with the world average¹².

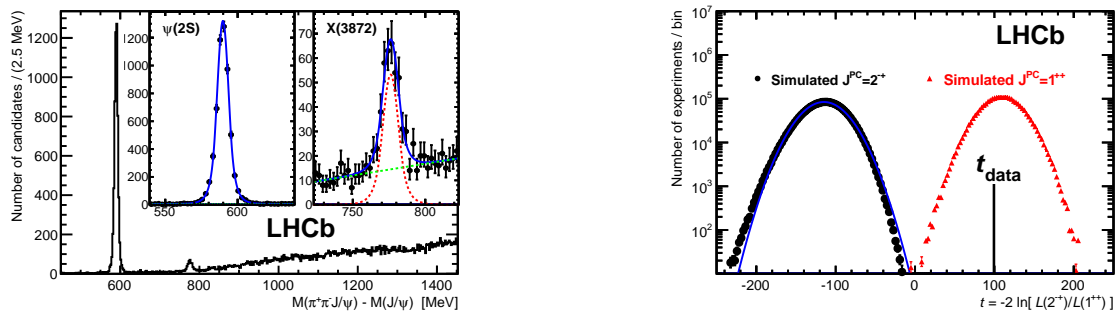


Figure 2: *Left*: Distribution of $m(J/\psi\pi^\pm\pi^\mp) - m(J/\psi)$ for $B^\pm \rightarrow J/\psi\pi^\pm\pi^\mp K^\pm$ candidates. The results of the fit around the $\psi(2S)$ and X masses are shown in the inserts. The solid blue, dashed red, and dotted green lines represent the total, signal, and background component, respectively. *Right*: Distribution of the test statistic for the simulated experiments with $J^{PC} = 2^{-+}$ (black circles) and with $J^{PC} = 1^{++}$ (red triangles). A Gaussian fit to the two distributions is overlaid (blue solid line). The value of the test statistic for the data, “ t_{data} ”, is shown by the solid vertical line.

3 B hadron masses

At LHCb we reconstructed three of the 16 b-baryons predicted ground states, namely the Λ_b^0 , Ξ_b^- and the Ω_b^- in their decays $J/\psi\Lambda^0$, $J/\psi\Xi^-$ and $J/\psi\Omega^-$ respectively. Using a minimal set of selections in 1 fb^{-1} of data we measured the masses¹³ of the above mentioned baryons, finding the values of

$$m(\Lambda_b^0) = 5619.53 \pm 0.13(stat) \pm 0.45(syst) \text{ MeV}/c^2, \quad (4)$$

$$m(\Xi_b^0) = 5795.8 \pm 0.9(stat) \pm 0.4(syst) \text{ MeV}/c^2, \quad (5)$$

$$m(\Omega_b^0) = 6046.0 \pm 2.2(stat) \pm 0.4(syst) \text{ MeV}/c^2, \quad (6)$$

with the dominant systematic uncertainty coming from the knowledge of the momentum scale. These results are in agreement with the previous measurements and with the world average¹².

4 X(3872) quantum numbers

The X(3872) (called X in the rest of the paper) has been the first exotic state to be discovered¹⁴ and by far the most abundant. Its mass just above the DD^* threshold still intrigues theorists and experimentalists who wonder about its real nature. After measuring the mass and the production cross section¹⁵, we have measured the X quantum numbers¹⁶, resolving the ambiguity observed by Belle between 1^{++} and 2^{-+} in favour of the former. In 1.1 fb^{-1} of data we have performed a five dimensional analysis of $313 \pm 26 B^+ \rightarrow XK^+$ decays, with $X \rightarrow J/\psi\pi^\pm\pi^\mp$ and $J/\psi \rightarrow \mu^\pm\mu^\mp$. The selection is optimised on the $B^\pm \rightarrow \psi(2S)K^\pm$ similar channel, and the signal is determined through a fit to the data using a Crystal Ball function for the signal and a linear function for the background, as shown in Fig. 2, left. A likelihood ratio test is performed to discriminate between the two quantum numbers hypotheses, which shows that the 1^{++} option is favoured and the 2^{-+} option is rejected at 8.4σ (see Fig. 2, right).

5 Conclusions

LHCb has a flourishing program in spectroscopy which is getting more and more interesting as more and more data are collected. Important results have already been achieved especially in exotic spectroscopy and more are expected in the near future.

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