PROCEEDINGS OF SCIENCE

B_c production at LHCb

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The LHCb Collaboration presents preliminary results concerning searches for exclusive decays of B_c meson in the channels $B_c \to J/\psi\pi$ and $B_c \to J/\psi 3\pi$. The mass together with the relative cross-sections are reported.

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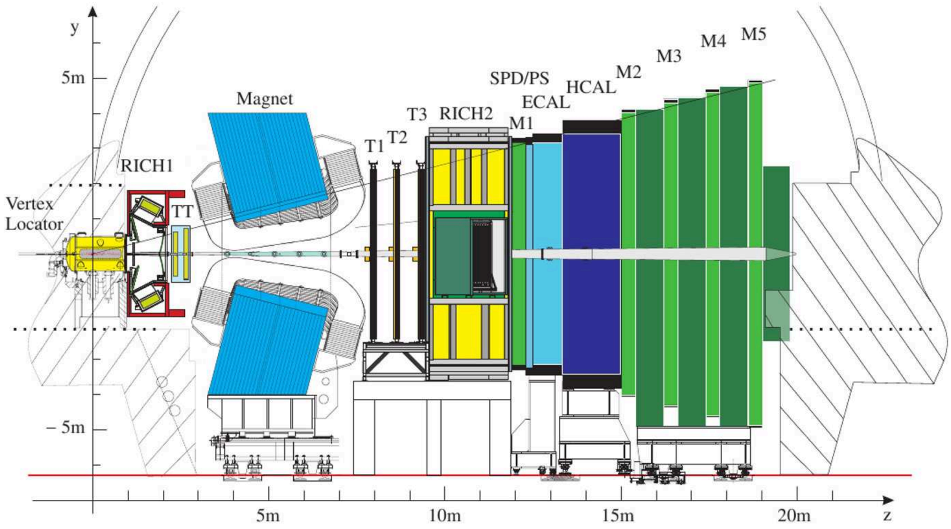


Figure 1: LHCb Experiment Detector.

1. Introduction

The nature of the B_c^+ (charge conjugate states are implied in this proceedings) is unique because it is the lightest state composed of heavy quarks of different flavors. Such bound states of b and c quarks, provide unique test of NRQCD, potential models, and searches for effects beyond the Standard Model.

All states below BD threshold decay via either weak decays of b or c quarks, weak annihilation or via radiative transitions into lower mass states. The study of mass and life-time of the ground (1S) state will provide excellent test of NRQCD [1], while radiative transitions of higher excitations into this ground state will be a good test of different potential models [2].

The first observation of the B_c^+ was reported by the CDF collaboration [3]. However, it is only recently that the B_c^+ has been observed with a significant number of events, in $p\bar{p}$ collisions at the Tevatron [4, 5], where reconstructed B_c^+ mesons in the decay mode $B_c^+ \to J/\psi\pi^+$ were used to measure the mass. The semileptonic decay mode $B_c^+ \to J/\psi l^+\nu$ was used for lifetime measurements [6, 7].

In these proceedings, we report on the recent results from LHCb using data accumulated in 2010, and in the early months of the 2011 run.

2. The LHCb experiment

The LHCb experiment [8] has been designed to study decays of b-hadrons from pp collisions at the LHC. The detector elements (Fig.1) are placed along the beam line of the LHC starting with the Vertex Locator (VELO), a silicon strip device that surrounds the proton-proton interaction region and is positioned 8 mm from the beam during collisions. It provides precise locations for primary pp interaction vertices, the locations of decays of long-lived particles, and contributes to the measurement of the track momenta. Other devices used to measure track momenta comprise a large area silicon strip detector (TT) located in front of 4 Tm dipole magnet and a combination of TT and straw drift chambers (OT) taken together as T-stations. Two Ring Imaging Cherenkov (RICH) detectors are used to identify charged hadrons.

Further downstream an Electromagnetic Calorimeter (ECAL) is used for photon detection and electron identification, followed by a Hadron Calorimeter (HCAL) and a system consisting of alternating layers of iron and chambers (MWPC and triple-GEM) that distinguishes muons from hadrons (MUON).

The LHCb setup covers the pseudo-rapidity interval of $1.9 < \eta < 4.9$ which is unique in the forward region for collider experiments. The primary vertex position resolution is ~ 10 μm in the transverse plane and ~ 60 μm along beam axis. The tracking system provides momentum resolution $\Delta p/p \sim 0.4-0.6\%$ and muon system performs muon identification with probability of $\sim 97\%$ providing wrong identification $h \to \mu$ at the level of $\sim 2\%$ only.

3. B_c^+ mass and cross-section ratio measurement in the decay $B_c^+ \to J/\psi\pi^+$.

This particular measurement uses a data sample collected at LHC at $\sqrt{s} = 7$ TeV between August and November 2010. It corresponds to an integrated luminosity of ~ 35 pb^{-1} for the mass [9] and ~ 33 pb^{-1} for cross-section measurements [10].

J/ψ candidates are formed from pairs of opposite sign muons that must have p_{T} larger than 900 MeV/c and have a good quality of the track fit ($\chi^2/\mathrm{ndf} < 4$). The muon identification is chosen such that the muon hypothesis is at least 10^3 more probable than that of a pion. The two muons are required to originate from a common vertex with good quality of the vertex fit. J/ψ candidates with a mass of ± 40 MeV/c^2 around the nominal J/ψ mass are combined with a charged track. The details of the selection procedure can be found in [10].

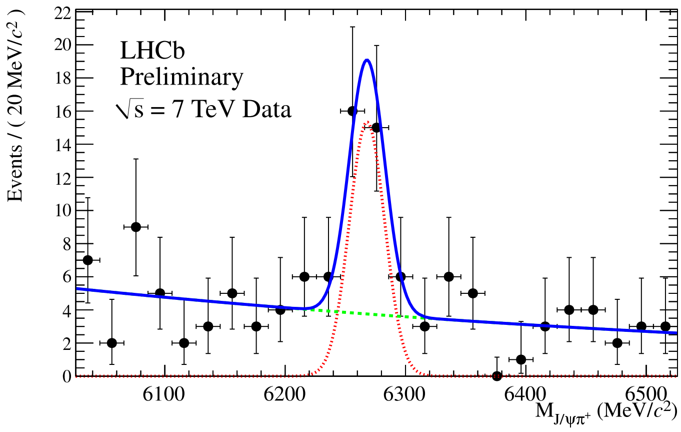
For the purpose of mass measurements, where a high signal purity is desired, only candidates with a measured proper time large than 0.3 ps are used. In addition, to maximise the statistics, all events are used no matter which trigger algorithm retained them. Most of the events have passed single- or di-muon triggers.

The mass spectrum of $J/\psi + \pi^\pm$ (Fig.2) was fitted with the combination of Gaussian (for the signal) and exponential for the background. The number of signal events 28 ± 7 was extracted from fit parameters.

Finally, the mass of B_c^+ was estimated to be $M(B_c^+) = 6268.0 \pm 4.0(\mathrm{stat}) \pm 0.6(\mathrm{syst})$ MeV/c^2. The systematics includes the contributions from the background and signal models (0.32 and 0.07 MeV/c^2 respectively), momentum calibration (0.23) and η dependence (0.44), energy loss corrections (0.11) as well as the alignment of the vertex detector (0.06).

Figure 2 (bottom) shows the comparison of this result with analogous measurements performed at Tevatron.

Fully reconstructed decays $B_c^+ \to J/\psi\pi^+$ were used to measure the ratio



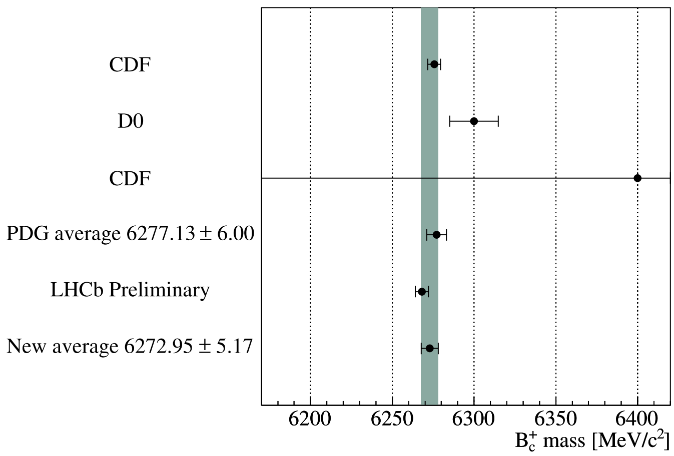


Figure 2: Invariant mass spectrum M$(J/\psi\pi^+)$ (top) and comparison of the LHCb B_c^+ mass measurement with those reported by Tevatron experiments (bottom).

$$\frac{\sigma(B_c^+) \times \mathrm{BR}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+) \times \mathrm{BR}(B^+ \to J/\psi K^+)} = \varepsilon_{\mathrm{rel}} \times \frac{N(B_c^+)}{N(B^+)} \tag{3.1}$$

for $p_{\mathrm{T}}(B_c^+, B^+) > 4$ GeV/c and $2.5 < \eta(B_c^+, B^+) < 4.5$.

The invariant mass distributions for B_c^+ and B^+ samples with the number of events 43 ± 13 for $B_c^+ \to J/\psi\pi$ signal and 3476 ± 62 for $B^+ \to J/\psi K^+$ normalization samples respectively are shown in Fig.3

Signal events were separated from background on a statistical basis using the sPlot technique [11], according to the probability density function used for the mass fits, and were grouped in bins of p_{T} and η. The efficiencies were computed from fully simulated Monte Carlo $B_c^+ \to J/\psi\pi^+$ and $B^+ \to J/\psi K^+$ samples. The number of efficiency-corrected signal events was found to be equal to 756 ± 286 for $B_c^+ \to J/\psi\pi^+$ and $35,029 \pm 984$ for $B^+ \to J/\psi K^+$.

Several sources of uncertainties were considered. The main systematic uncertainty is related to the selection requirement on the proper lifetime of the B_c^+ meson (> 0.3 ps) due to the uncertainty

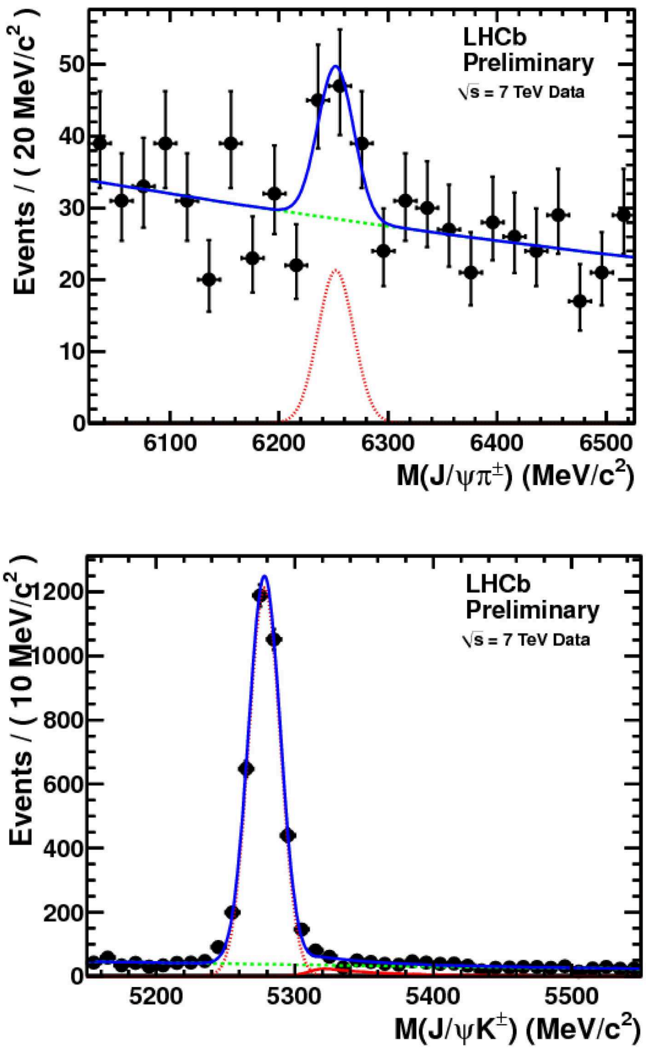


Figure 3: Invariant mass spectrum M$(J/\psi\pi^+)$ (top) and M$(J/\psi K^+)$ (bottom).

in the measured $\tau(B_c^+) = 0.453 \pm 0041$ ps [12].

Finally, the ratio is measured to be

$$\frac{\sigma(B_c^+) \times \mathrm{BR}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+) \times \mathrm{BR}(B^+ \to J/\psi K^+)} = (2.2 \pm 0.8_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}})\% \ .$$

4. First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

The branching ratio for this decay is expected to be 1.5 to 2.3 times higher than for $B_c^+ \to J/\psi\pi^+$ [13]. The search for this decay and determination of the relative rate $\mathrm{BR}(B_c \to J/\psi 3\pi)/\mathrm{BR}(B_c \to J/\psi\pi)$ was performed using a data sample of approximately 300 pb^{-1} collected with the LHCb detector in the first half of 2011 [14].

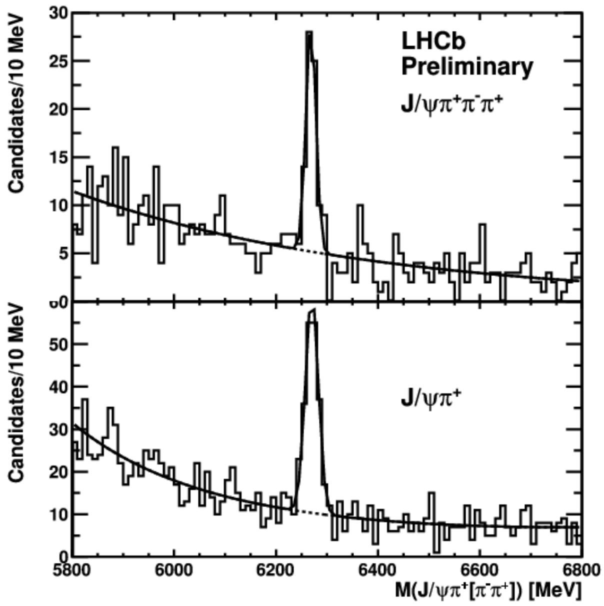


Figure 4: Invariant mass spectra M($J/\psi\pi^+\pi^-\pi^+$) (top) and M($J/\psi\pi^+$) (bottom).

Offline data analysis consists of two stages: preselection and use of signal-to background likelihood-ratio discrimination. Preselection explores muon and pion tracks selection, J/ψ construction, vertex fit requirements, proper decay time for B_c^+ candidate as well as $p_{\rm T}$ cuts for original and combined hadrons.

The final background suppression step is performed using likelihood-ratio method. The signal probability density functions (PDFs) of the most sensitive variables are obtained from $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ and $B_c^+ \to J/\psi\pi^+$ Monte Carlo simulation. The background PDFs are derived from the real data in far-sidebands around B_c^+ signal region [14].

The resulting mass spectra for $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ and $B_c^+ \to J/\psi\pi^+$ are shown in Fig.4. For one (three) pion final states the observed number of events is 163.1 ± 15.7 (58.2 ± 9.6).

This is the first observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ decay. The statistical significance of the signal is determined to be 6.8 standard deviations. Using efficiencies derived from fully simulated Monte Carlo samples, the relative rate was determined

$$\frac{\mathrm{BR}(B_c \to J/\psi 3\pi)}{\mathrm{BR}(B_c \to J/\psi\pi)} = (3.0 \pm 0.6_{\rm stat} \pm 0.4_{\rm syst})\%\ .$$

This result can be compared with the theoretical prediction 2.3 [13]. Invariant mass distributions for $\pi^+\pi^-\pi^+$ and $\pi^+\pi^-$ subsystems (Fig.5) are consistent with $B_c^+ \to J/\psi a_1^+(1260)$ and $a_1^+(1260) \to \rho^0\pi^+$ decay chain assumed in MC simulation.

5. Summary

The LHCb experiment reports preliminary results concerning B_c^+ meson based on the statistics collected in 2010 and in the early months of the 2011 run.

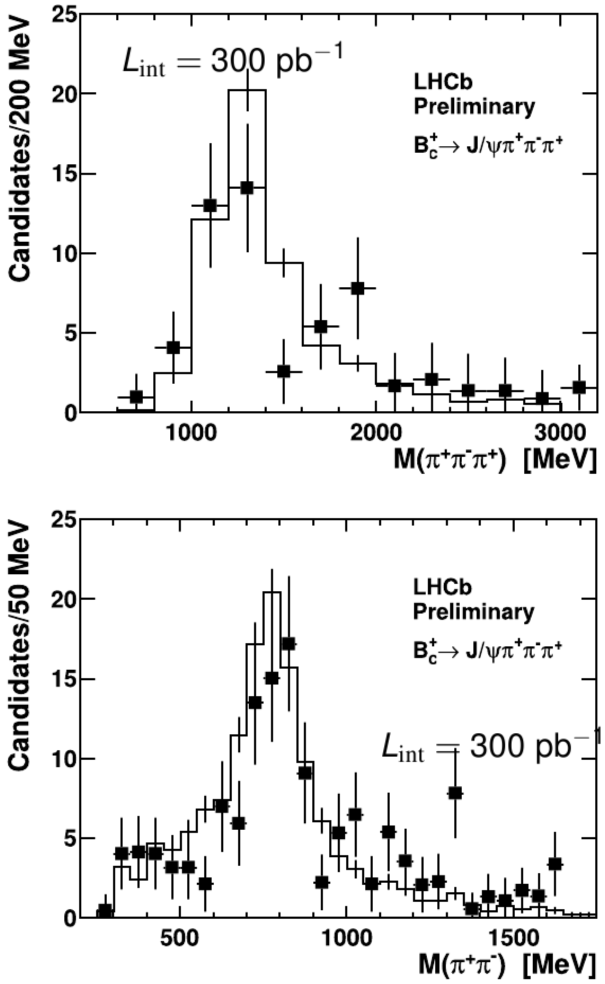


Figure 5: Sideband-subtracted data in the B_c^+ signal region with the signal MC simulation superimposed (histogram) for $M(\pi^+\pi^-\pi^+)$ (top) and $M(\pi^+\pi^-)$ (bottom).

The mass of B_c^+ meson observed in the decay channel $B_c^+ \to J/\psi\pi^+$, $J/\psi \to \mu^+\mu^-$ with statistic collected in 2010 run (~ 35 pb^{-1}) was found to be $M(B_c^+) = 6268.0 \pm 4.0(\text{stat}) \pm 0.6(\text{syst})$ MeV/c^2.

The relative cross-section determined with data sample of ~ 33 pb^{-1} was found to be

$$\frac{\sigma(B_c^+) \times \text{BR}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+) \times \text{BR}(B^+ \to J/\psi K^+)} = (2.2 \pm 0.8_{\text{stat}} \pm 0.2_{\text{syst}})\%\ .$$

LHCb has also reported the first observation of the decay $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ with a statistical significance for the signal of 6.8 standard deviations based on the data sample collected in early months of 2011 run (~ 300 pb^{-1}). The invariant mass of 3π system is consistent with the decay $B_c^+ \to J/\psi a_1^+(1260)$. The relative rate for two decay modes was determined to be

$$\frac{\text{BR}(B_c \to J/\psi 3\pi)}{\text{BR}(B_c \to J/\psi\pi)} = (3.0 \pm 0.6_{\text{stat}} \pm 0.4_{\text{syst}})\%\ .$$

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