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Measurement of B_c^+ Mass and Lifetime at LHCb

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The potential of measuring the B_c^+ mass and lifetime in LHCb using $B_c^+ \to J/\psi\pi^+$ channel is studied. With an integrated luminosity of 1 fb^{-1} collected at $\sqrt{s} = 14$ TeV in LHCb nominal condition, 310 events are expected with B/S less than 2. The statistical errors for mass and lifetime measurement are around 2 MeV/c^2 and 30 fs respectively.

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1. Introduction

LHCb is a forward detector dedicated to precise b physics measurements at LHC. The detailed description can be found elsewhere [1] and here only a brief detector performance is summarised. The LHCb vertex detector called vertex locator (VELO) is a silicon strip detector. The resolutions for the primary vertex position measurement is around 60 μm along the beam and 10 μm in the transverse direction. The good resolutions give opportunities to do precise lifetime measurements and the 25 μm resolution for impact parameter (for tracks with p_T around 3 GeV/c) helps to suppress prompt backgrounds which are the main backgrounds for b physics. The LHCb tracking system includes trigger tracker station (TT), tracking stations T1-T3, and it can measure long tracks that pass through VELO, TT, T1-T3 with an efficiency around 95% while the ghost rate is only 5%. $\delta p/p$ is about 0.5% for momentum measurement of long tracks. In LHCb, there are 2 level triggers, Level 0 trigger (L0) and High Level Trigger (HLT). L0 is the hardware trigger which includes both di-muon and single muon trigger relevant for the physics discussed here. HLT is the software trigger and it reduces the L0 output from 1MHz down to 2 kHz.

The B_c system consists of mesons formed by quarks $c\bar{b}$. The ground state particle is B_c^+[1]. Because the lifetime of top quark is too small to form bound states, B_c^+ is the unique double heavy-flavored meson in Standard Model and is stable for strong and electromagnetic interactions.

The main process for generating the B_c^+ mesons is through the gluon-gluon fusion process $gg \rightarrow B_c^+ + \bar{c} + b$. High energy gluons are needed to generate $b\bar{b}$ and $c\bar{c}$ pairs together and then the two heavy quarks c $\bar{b}$ combine into the meson by certain chance, thus the B_c^+ production rate is only 0.1% of other b meson production rates. The expected production cross-section is around 0.4 μb [2] for 14 TeV pp collision.

Due to the heavy masses of b and c quarks, precise calculations can be performed to predict the B_c^+ properties. So the B_c^+ particle is perfect for testing QCD theory. But after being discovered in 1998 by Tevatron [3], many properties of the B_c^+ meson still remain unknown, like the main decay modes together with their branching fractions, excited states, etc. The LHCb detector offers a possibility to study in detail these properties.

2. Event Selections

For current MC study, the decay channel $B_c^+ \rightarrow J/\psi\pi^+$ is used to measure the B_c^+ mass and lifetime. The event selections [4] are obtained from MC samples of B_c^+ signal decays generated by a dedicated B_c generator, BCVEGPY [5]. The underlying events, pile-up events and background events are generated with PYTHIA [6]. To reconstruct the B_c^+ meson, we first choose good tracks based on the χ^2 of the track fit and require their p_T to be greater than 0.5 GeV/c. Then a pair of two tracks with opposite charges and identified as μ are used to reconstruct the J/ψ candidates. We require these candidates with an invariant mass in the range from 3.04 to 3.14 GeV/c^2 and the vertex fit quality of χ^2/ndof < 9. After this, a track identified as pion from the rest of the selected good tracks is used to combine with J/ψ candidate and to reconstruct the B_c^+ meson with a vertex fit quality of χ^2/ndof < 12. The main backgrounds of these pre-selected B_c^+ are random combinations of real J/ψ and π from primary vertex and from other b decays. So additional impact

[1] If not specified, charge conjugate states are implied throughout this paper.

parameter requirements on J/ψ, π and B_c^+ are added to reduce prompt backgrounds. Further p_T selection criteria are added to reduce backgrounds from b decays. We require p_T of μ, π and B_c^+ to be greater than 1.0 GeV/c, 1.6 GeV/c and 5.0 GeV/c respectively. After all these selections, The total reconstruction efficiency including the trigger efficiency is found to be 1.0% and B/S (background over signal ratio) to be $1 \sim 2$(90% CL). With the assumptions that the cross-section of the B_c^+ is 0.4 μb and branching ratio of $B_c^+ \rightarrow J/\psi(\mu^+\mu^-)\pi^+$ is 1.3×10^{-3} [7], we estimate that 310 events are reconstructed for 1fb^{-1} of data at $\sqrt{s} = 14$ TeV.

3. The B_c^+ Mass Measurement

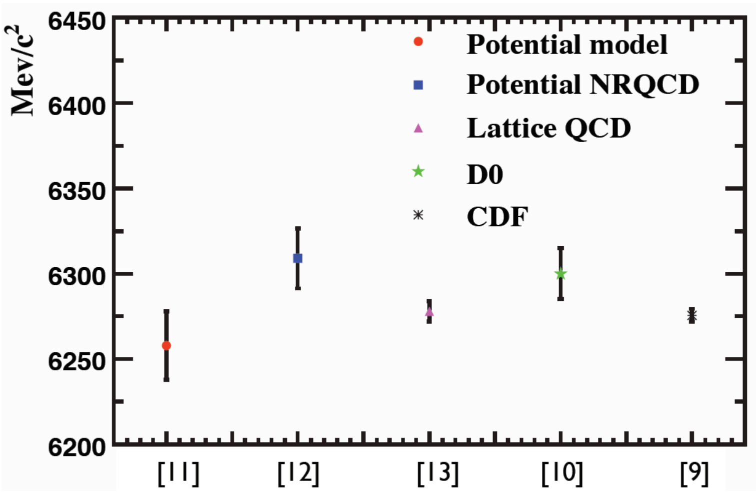

Figure 1: Measured and calculated masses of B_c^+. The first two computations are from different models while the third one is given by lattice QCD calculation. The last two are Tevatron measurements.

The bound states of the B_c system provide a rich spectrum of different excited states and thus an interesting window on the understanding of forces between heavy quarks. Below the threshold of decay into BD-pair 16 states are predicted [8], but currently, only the mass of B_c^+ is measured by CDF [9] and D0 [10]. The experimental results [9] [10] with theoretical values [11] [12] are shown in Figure 1. We can see that current measurements are compatible with theoretical calculations and the errors are of the same order as lattice QCD [13].

Figure 2 shows the mass distribution expected for 1 fb^{-1} of data obtained after applying selections described in [4]. The events are obtained from full detector simulation and background events from a simpler simulation which reproduces basic characteristics of the fully simulated events. The mass distribution is fitted with a Gaussian distribution for the signal and a linear function for the background part. In order to improve the B_c^+ mass resolution, J/ψ momentum is refitted by constraining the J/ψ mass to the nominal J/ψ mass [14]. The fit gives 6399.6 ± 1.7(stat.) MeV/c^2 which is in good agreement with the input value 6400 MeV/c^2.

4. The B_c^+ Lifetime Measurement

B_c^+ decay only through weak modes with three main processes. The first two are that $\bar{b}$ or c quark decays while the other quark stays as spectator. The third process is the annihilating decay to

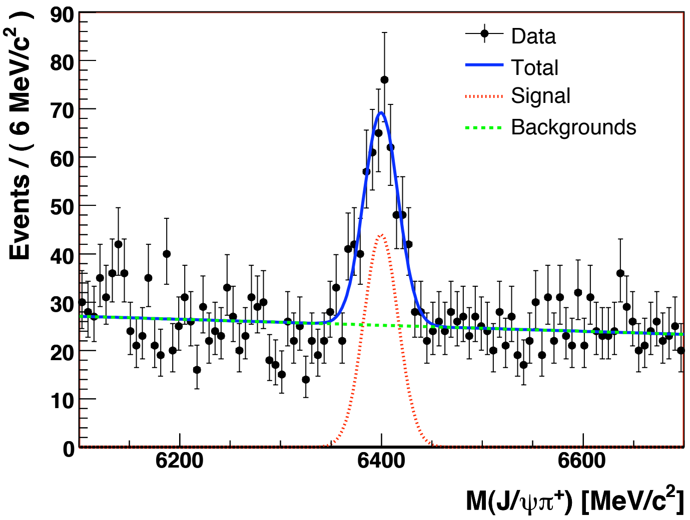

Figure 2: The B_c^+ mass distribution with fit results. The Gaussian distribution is used for signal fit and a linear function is used for background.

the W boson. After considering all the three processes and interferences between them, theoretical prediction by QCD sum rules gives 0.48 ± 0.05 ps [15] for the B_c^+ lifetime. Recent Tevatron results from CDF and D0 are $0.475^{+0.053}_{-0.049} \pm 0.018$ ps [16] and $0.448^{+0.038}_{-0.036} \pm 0.032$ ps [17] respectively using semileptonic decay mode $B_c^+ \to J/\psi \mu^+ \nu_\mu$, thus with rather large systematic errors due to the not reconstructed B_c^+ momentum. With a large sample, hadronic decay modes can be used to improve the measurements and theoretical predictions are also expected to improve.

For the lifetime measurement, the proper time and invariant mass distributions are fitted simultaneously. The mass function is the same one used for the mass measurement. For the proper time part, the background distribution will be obtained from the mass sideband data. For the current study, we generate the background proper time distribution with a standalone simulation as done for the mass distribution. The signal part of proper time distribution is described by an exponential function convoluted with the resolution function and multiplied by an acceptance function which accounts for the biases introduced by the triggers and event selections. For the current study, this efficiency function is taken from MC.

Possible systematic effects on the lifetime measurement are also studied. First, 10^4 sets of simple simulated experiments are analysed to see if the fit procedure biases the lifetime measurement . The pull results show a good agreement with the normal distribution. Effect from the B_c^+ p_T distribution is also studied because the real p_T distribution of B_c^+ is unknown and the difference between real data and simulation can induce possible bias. MC study is done by repeating the measurement using the $B^\pm$ p_T spectrum instead of B_c^+ spectrum. We found a bias around 0.023 ps. In order to reduce this bias, the B_c^+ lifetime will be measured using simultaneous fit over different p_T bins. By dividing the data set into two regions, $5 < p_T < 12$ GeV/c and $p_T > 12$ GeV/c, the bias is reduced to 0.004 ps. The fit results are shown in Figure 3, giving the measured lifetime to be 0.438 ± 0.027(stat.) ps with the input value 0.46 ps.

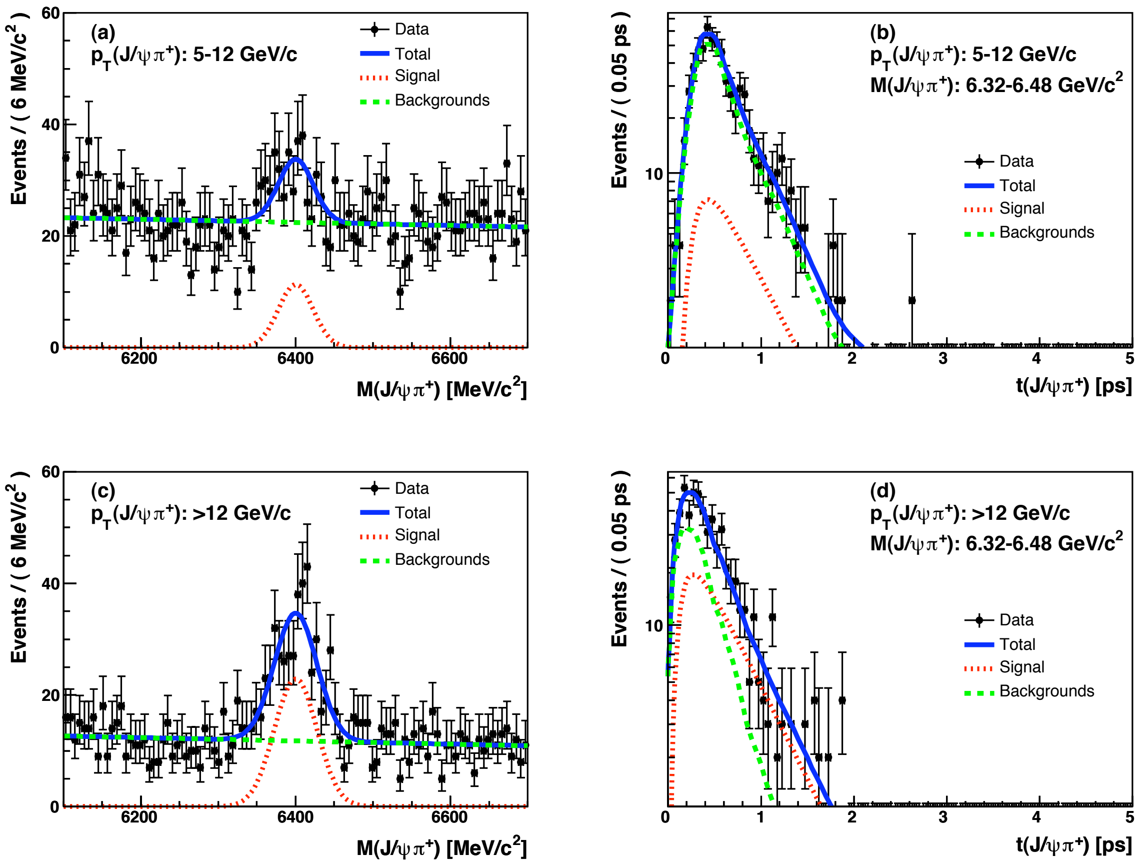

Figure 3: The left column shows the combined mass fit results. The right column shows the proper time distributions in the signal region.

5. Summary

B_c^+ mass and lifetime studies are performed based on the current LHCb simulation. We expect around 310 events for 1 fb^{-1} of data after all selections and triggers are applied with B/S around 2. From the selected B_c^+ samples, its mass can be obtained with a precision less than 2 MeV/c^2. For the lifetime, the mass and proper time distributions are fitted together over two p_T bins and the statistic error is expected to be below 30 fs. LHCb will also contribute to other interesting physics topics like the B_c excited states search and differential cross section measurements.

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