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Measurement of the B_c^+ meson lifetime using the $B_c^+ \to J/\psi\mu^+\nu X$ decays

LUCIO ANDERLINI on behalf of the LHCb COLLABORATION
Università di Firenze and INFN, Sezione di Firenze - Sesto Fiorentino (FI) Italy

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Summary. — Using $2\,\mathrm{fb}^{-1}$ of data collected in 2012 at $\sqrt{s} = 8\,\mathrm{TeV}$, the LHCb Collaboration measured the lifetime of the B_c^+ meson studying the semileptonic decays $B_c^+ \to J/\psi\mu^+\nu X$. The result, $\tau_{B_c^+} = 509 \pm 8 \pm 12\,\mathrm{fs}$, is the world's best measurement of the B_c^+ lifetime.

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1. – Introduction

The B_c^+ meson is the ground state of a $(\bar{b}, c)$ bound system. Being composed of two different heavy quarks it is a unique state in the Standard Model, offering an excellent laboratory to test both QCD and weak interaction. Indeed, being an open-favoured state, B_c^+ cannot decay through strong or electromagnetic interactions making weak interaction the only possible decay mechanism. Theoretical predictions indicate that 70% of the total decay width of the B_c^+ meson is due to c-quark decays, 20% to b-quark decays and 10% to weak annihilation [1].

Experimentally, the B_c^+ meson was discovered at the Tevatron in 1998 [2], where the CDF and D0 Collaborations observed three decays of the B_c^+ meson: the non-leptonic $B_c^+ \to J/\psi\pi^+$ decay and the semileptonic $B_c^+ \to J/\psi\mu^+\nu$ and $B_c^+ \to J/\psi e^+\nu$ decays.

The LHC experiments contributed significantly to improve this picture by observing a number of new decays. Many of the observed decays have a J/ψ in the final state, plus several mesons, for example LHCb and CMS reported the observation of the decay $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ [3, 4]. LHCb also reported the observation of the decays $B_c^+ \to J/\psi K^+K^-\pi^+$ and $B_c^+ \to J/\psi 3\pi^+2\pi^-$ [5, 6].

Other important observations reported by LHCb include the decay channels $B_c^+ \to \psi(2S)\pi^+$ [7], $B_c^+ \to J/\psi D_s^+$, and $B_c^+ \to J/\psi D_s^{*+}$ [8].

The decay $B_c^+ \to B_s^0\pi^+$, observed by LHCb, represents the first observation of a B_c^+ decay due to a $c \to s$ transition [9].

In this paper, a recent LHCb measurement of the B_c^+ lifetime, leading to the world's most precise result, is summarized [10].

2. – Lifetime measurement with the semileptonic decay channel $B_c^+ \to J/\psi \mu^+ \nu_\mu X$

The lifetime of the B_c^+ meson is an important quantity for both theory and experiments. Many models describing heavy-quark properties can be used to predict the B_c^+ lifetime, the more precise is the knowledge of this quantity, the more theoretical models are constrained.

Experimentally, the uncertainty on the lifetime results in an uncertainty on the selection efficiency of criteria based on the B_c^+ flight distance. Since these criteria are very powerful in rejecting background, most of B_c^+ analyses rely on them and are affected by lifetime uncertainty. In most of the analyses described above, the uncertainty on the world average for the B_c^+ lifetime is actually a dominant systematic uncertainty, so that a precise measurement of the B_c^+ lifetime will improve the precision on most of the results reported.

LHCb has recently measured [10] the lifetime of the B_c^+ meson by studying the semileptonic decay channel $B_c^+ \to J/\psi \mu^+ \nu_\mu X$, with the J/ψ reconstructed as a muon pair. The large branching fraction and the very clear experimental signature (a 3-muon vertex), allow this analysis to be performed with a cut-based decay-time-unbiased selection, avoiding the need to measure the acceptance as a function of the decay time, introducing the largest systematic uncertainty in most of the lifetime measurements.

On the other hand, when studying partially reconstructed decays background rejection is more difficult because the selection cannot rely on a mass peak. In the case of $B_c^+ \to J/\psi \mu^+ \nu_\mu X$, the invariant mass of the $J/\psi \mu^+$ combination lies in a range between 3.2 and $6.25\,\mathrm{GeV}/c^2$ and the shape of the distribution depends on the form factors of the decay, for which no experimental measurement is available.

A correction, named k-factor, between the $J/\psi \mu^+$ combination rest frame and the B_c^+ rest frame, needed to calculate the *proper* decay time and therefore the lifetime. The k-factor correction is applied on a statistical basis in bins of the mass reconstructed for the $J/\psi \mu^+$ combination. The shape of the k-factor distribution is determined using simulation and is affected by: i) form factor model of the B_c^+ decay; ii) model of acceptance and efficiency as a function of the kinematic variables; iii) feed-down decays, where the final state $J/\psi \mu^+$ is reached through an intermediate state, *e.g.* $B_c^+ \to \psi(2S)(\to J/\psi \pi^+ \pi^-)\mu^+ \nu_\mu$.

Background is dominated by events in which a real J/ψ from a b-hadron decay is associated to a hadron misidentified as a muon. This background source, named for brevity *misidentification background*, is modeled with a data-driven technique requiring an accurate characterization of the PID performance of the LHCb detector.

Other non-negligible background sources are due to decay candidates with a fake J/ψ and candidates obtained combining a J/ψ with a muon, but not from the same vertex (combinatorial background).

The B_c^+ lifetime is obtained through a two-dimensional fit on the joint distribution of $M(J/\psi \mu^+)$ and t_{ps}, the decay time reconstructed in the $J/\psi \mu^+$ rest frame. The statistical model, superimposed to the collected data, is shown in fig. 1.

The result,

$$\tau_{B_c^+} = 509 \pm 8\ (\mathrm{stat}) \pm 12\ (\mathrm{syst})\ \mathrm{fs}, \tag{1}$$

is the world's best measurement of the B_c^+ lifetime, with an uncertainty halved with respect to the world average. The systematic error is dominated by the uncertainties on

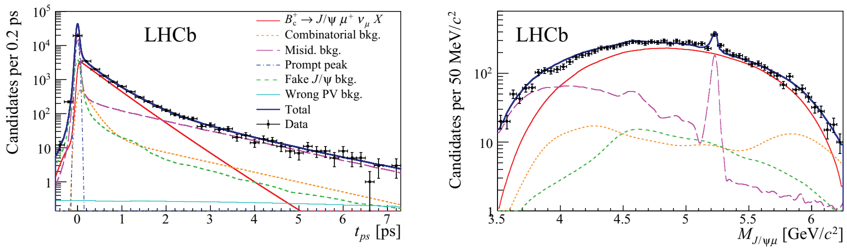

Fig. 1. – Data model for the $B_c^+ \to J/\psi\mu^+\nu_\mu X$ decays used in the B_c^+ lifetime measurement. On the left, the model is projected on the reconstructed pseudo-proper decay time; on the right, on the invariant mass of the $J/\psi\mu^+$ combination.

the background ($\pm$ 10 fs), and signal ($\pm$ 5 fs) models, where the latter includes theoretical uncertainties on form factors and branching fractions of the feed-down decays.

Further improvements on the precision of the lifetime measurement are expected studying the hadronic decay channel $B_c^+ \to J/\psi\pi^+$ where systematic uncertainties are largely uncorrelated with those affecting the measurement presented above.

3. – Conclusion and outlook

The excellent performance of the LHC and of the detectors has allowed the LHC experiments to reach several achievements in the field of B_c^+ physics.

The world's best measurement of lifetime was presented here together with the first observation of a $c \to s$ transition in a B_c^+ decay. Several other decay channels [4-7, 11] have been observed for the first time and their relative decay branching fraction measured.

Between the IFAE meeting and the preparation of these proceedings new exciting results have been obtained. LHCb has published the measurement of the ratio of B_c^+ branching fraction to $J/\psi\pi^+$ and $J/\psi\mu^+$, using a data sample corresponding to an integrated luminosity of 1 fb^{-1} [12]. The ATLAS Collaboration has published the observation of an excited B_c^+ meson state decaying to $B_c^+\pi^+\pi^-$ [13].

In 2015, the LHC experiments will restart data-taking of the pp collisions at 13–14 TeV. Higher luminosity and larger B_c^+ production cross-section are expected and therefore many unobserved B_c^+ decay channels are expected to become accessible. Observed decays will be used as high-statistics control channels and studied for precision measurements.

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