Precision measurements of b hadron lifetimes at LHCb

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Precision lifetime measurements of B^+, $B^0$and B_s^0mesons and the Λ_b^0baryon are presented. The hadrons are required to decay into a final state containing a J/ψ resonance. The used dataset represents an integrated luminosity of 1 fb^{-1}. The average decay times are measured to be $\tau_{B^+\to J/\psi K^+} = 1.637 \pm 0.004 \pm 0.003$ ps, $\tau_{B^0\to J/\psi K^{*0}} = 1.524 \pm 0.006 \pm 0.004$ ps, $\tau_{B^0\to J/\psi K_s^0} = 1.499 \pm 0.013 \pm 0.005$ ps, $\tau_{\Lambda_b^0\to J/\psi \Lambda} = 1.415 \pm 0.027 \pm 0.006$ ps and $\tau_{B_s^0\to J/\psi \phi} = 1.480 \pm 0.011 \pm 0.005$ ps, where the first uncertainty is statistical and the second systematic. Furthermore lifetime ratios are determined.

1 Introduction

In the framework of the Heavy Quark Expansion (HQE) [1–3] the decay rate of a hadron containing a heavy quark (b,c) can be expressed in a power series of the inverse of the heavy quark mass. Calculating the ratio of lifetimes, many terms with a large theory uncertainty cancel. In the first order the lifetime of all hadrons is the same, nevertheless there are expected to be deviations at higher orders due to the kinematic and chromomagnetic operators. These effects can be tested with precision measurements of lifetimes and the ratio of lifetimes. Theory predictions are $\tau_{B^+}/\tau_{B^0} = 1.063 \pm 0.027$, $\tau_{B_s^0}/\tau_{B^0} = 1.00 \pm 0.01$ and $\tau_{\Lambda_b^0}/\tau_{B^0} = 0.86 - 0.95$ [4–16].

In all studied decay modes the decay time distribution is fitted with a single exponential function. The decay rate of the B_s^0 is due to the non vanishing decay width difference $\Delta\Gamma_s$ not purely exponential and therefore in this channel the effective lifetime is measured. The effective lifetime depends on the mixture of the B_H and B_L eigenstates in the sample and is thus decay mode specific.

2 Measurement

In the following the important steps of the lifetime measurement[17] are summarized.

All investigated decay modes have a J/ψ in the final state and the selection of the J/ψ is in all decay modes the same. Events are triggered if two oppositely charged muons are found which can be combined to a J/ψ vertex. No requirement on the displacement of both of the muons or the J/ψ vertex to the primary vertex is made. Therefore at this stage the selection efficiency is uniform as a function of the b hadron decay time. In addition to this so called unbiased trigger there is also a trigger requiring that the J/ψ vertex is spacially separated from the primary vertex. The efficiency of this trigger is determined by comparing the measured decay time distributions of both triggers.

Offline selection cuts are chosen to minimize any possible systematic bias on the decay time distribution. A detailed study on simulated data is performed to investigate the effect of every single reconstruction step and selection cut.

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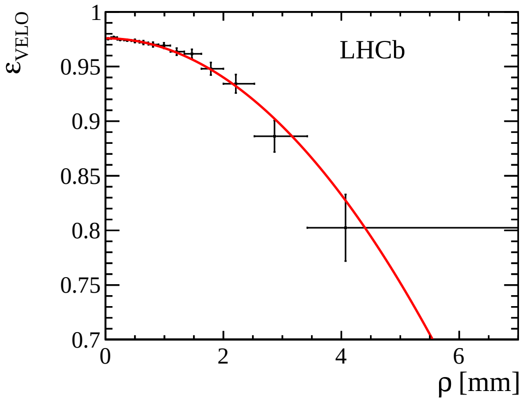

Figure 1 – Measured track reconstruction efficiency in the VELO sub detector vs. the distance of a track to the beam axis (ρ). The red line is the result of an unbinned maximum likelihood fit of a quadratic function.

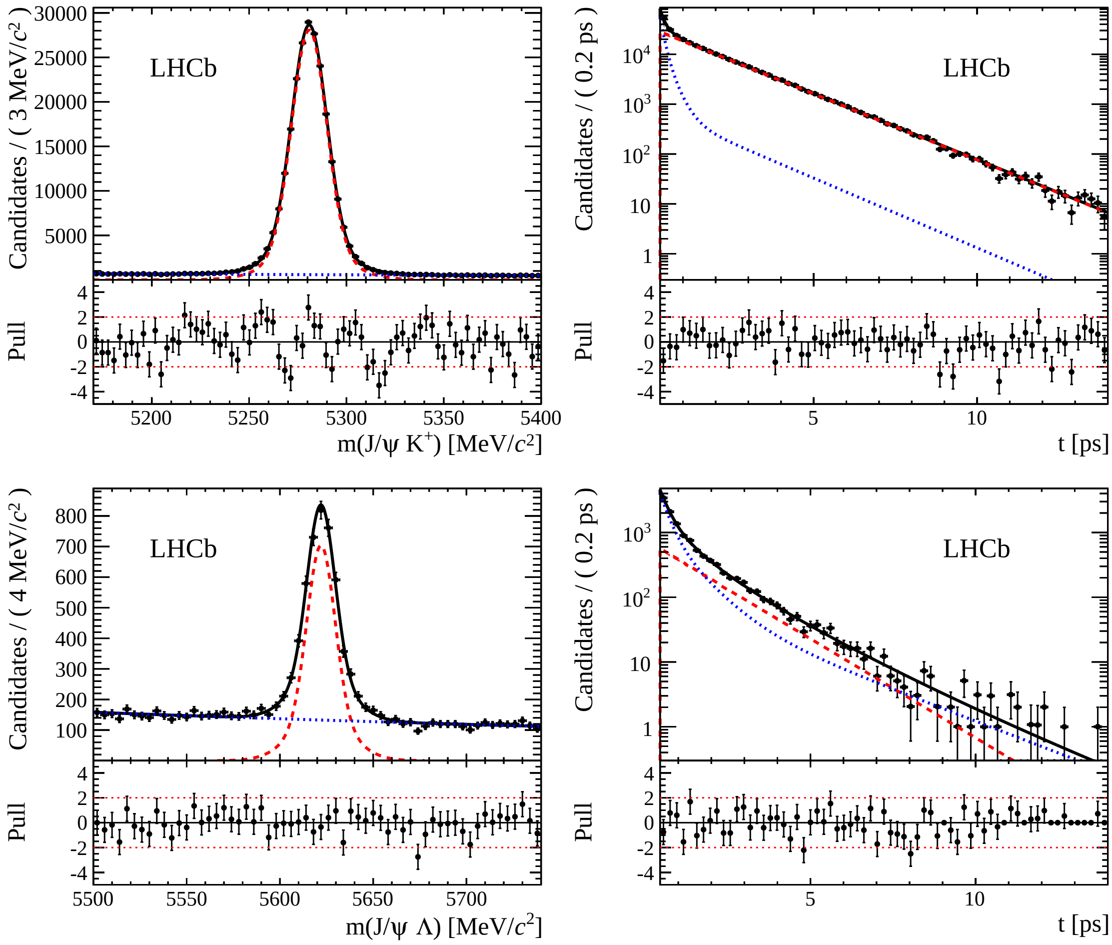

Figure 2 – Decay time (right) and mass (left) distribution of two of the decay channels. The total fit (black line) and also its signal (red) and background (blue) components are sown.

It is found that for tracks with a large distance to the beam axis the track reconstruction efficiency is significantly smaller, which introduces the most significant bias. The drop in efficiency can be explained by constraints applied in the pattern recognition code to match computer timing requirements of the online and offline software. This effect is purely geometrical and its size can be parametrized by a single parameter, namely the distance of closest approach of the track to the beam axis.

Using a data driven Tag and Probe technique this dependency is measured in the high statistics $B^+ \to J/\psi\, K^+$ decay channel. The measured efficiency is shown in Fig. 1. Events are then weighted in all channels according to the inverse of the product of the predicted inefficiencies for each daughter particle.

These corrections are purely data driven. Simulation was however used to test the correction method and to check for any potential biasing effect in the reconstruction or selection. After optimizing the selection no single large bias can be identified and the final measured lifetime in simulation is within the statistical uncertainty in agreement with the generated one.

The numbers of reconstructed signal candidates with this unbiased selections for the different channels are 229,000 ($B^+ \to J/\psi\, K^+$), 71,000 ($B^0 \to J/\psi\, K^{*0}$), 17,000 ($B^0 \to J/\psi\, K^0_s$), 19,000 ($B^0_s \to J/\psi\, \phi$) and 4,000 ($\Lambda^0_b \to J/\psi\, \Lambda$).

The lifetime is extracted using an unbinned maximum likelihood fit in 2D (decay time, mass). The mass shape of the signal is the sum of two Gaussian functions, whereas the background is modeled with an exponential function. The weighted decay time distribution for the signal is an exponential function convoluted with a single Gaussian to describe the decay time resolution (45 fs). For events from the biased trigger the function is multiplied by its decay time dependent acceptance function. The decay time dependence of the background is modeled by the sum of three exponential functions. The fits to the mass and decay time distribution of the largest and the lowest statistic channel are shown in Fig. 2.

Table 1: Lifetime measurements of different b hadron decay channels. The first uncertainty shown is statistical and the second systematic.

Lifetime	Value [ps]
$\tau_{B^+\to J/\psi\, K^+}$	$1.637 \pm 0.004 \pm 0.003$
$\tau_{B^0\to J/\psi\, K^{*0}}$	$1.524 \pm 0.006 \pm 0.004$
$\tau_{B^0\to J/\psi\, K^0_s}$	$1.499 \pm 0.013 \pm 0.005$
$\tau_{\Lambda^0_b\to J/\psi\, \Lambda}$	$1.415 \pm 0.027 \pm 0.006$
$\tau_{B^0_s\to J/\psi\, \phi}$	$1.480 \pm 0.011 \pm 0.005$

3 Results and Conclusions

The results from the lifetime measurement[17] are shown in Tab. 1. With this the lifetime ratios follow to be $\tau_{B^+\to J/\psi\, K^+}/\tau_{B^0\to J/\psi\, K^{*0}} = 1.074 \pm 0.005 \pm 0.003$, $\tau_{B^0_s\to J/\psi\, \phi}/\tau_{B^0\to J/\psi\, K^{*0}} = 0.971 \pm 0.009 \pm 0.004$ and $\tau_{\Lambda^0_b\to J/\psi\, \Lambda}/\tau_{B^0\to J/\psi\, K^{*0}} = 0.929 \pm 0.018 \pm 0.004$.

A difference in the lifetime of particles and anti-particles would deduce CPT violation. The samples are split up and the lifetime is measured in each sample independently. The ratios are $\tau_{B^+\to J/\psi\, K^+}/\tau_{B^-\to J/\psi\, K^-} = 1.002 \pm 0.004 \pm 0.002$, $\tau_{\Lambda^0_b\to J/\psi\, \Lambda}/\tau_{\overline{\Lambda}^0_b\to J/\psi\, \overline{\Lambda}} = 0.940 \pm 0.035 \pm 0.006$ and $\tau_{B^0\to J/\psi\, K^{*0}}/\tau_{\overline{B}^0\to J/\psi\, \overline{K}^{*0}} = 1.000 \pm 0.008 \pm 0.009$ and thus consistent with unity.

Several effects are estimated in the systematic uncertainty. The most significant contributions are due to the uncertainty of the reconstruction efficiency measurement, the sample size of the simulated data and the acceptance measurement of the biasing trigger. Calculating the ratio of lifetimes several uncertainties cancel.

Independently, a measurement of the lifetime ratio Λ^0_b/B^0 has been performed[18]. Fitting directly the ratio large uncertainties due to the acceptance directly cancel in first order. The lifetime ratio is measured to be $\tau_{\Lambda^0_b\to J/\psi\, pK^-}/\tau_{B^0\to J/\psi\, \pi^+K^-} = 0.974 \pm 0.006 \pm 0.004$. Combining the results of both papers gives $\tau_{\Lambda^0_b\to J/\psi\, X} = 1.468 \pm 0.009 \pm 0.008$ ps.

In all decay channels these are the most precise single measurements. They are consistent with previous measurements and theoretical predictions.

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