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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Measurement of heavy flavor properties at CMS

Muhammad Alibordi for the CMS Collaboration

Abstract

Measurements of lifetimes in the decay channels $B^0 \to J/\psi K^*$, $B^0 \to J/\psi K^0_s$, $B^0_s \to J/\psi \pi^+\pi^-$, $B^0_s \to J/\psi \phi$, $\Lambda^0_b \to J/\psi \Lambda^0$ and $B^+_c \to J/\psi \pi^+$ and polarization for Λ_b in $\Lambda_b \to J/\psi \Lambda$ decays are presented. Data has been collected by Compact Muon Solenoid Experiment(CMS) in p-p collision at centre of mass energy at $\sqrt{s} = 8$ TeV corresponding to an integrated luminosity of 19.7 fb^{-1} for the former and $\sqrt{s} = 7$ and 8 TeV corresponding to an integrated luminosity 5 fb^{-1} and 19.7 fb^{-1} respectively for the later. The measured values of lifetimes in μm are $c\tau_{B^0 \to J/\psi K^*(892)^0} = 453.0 \pm 1.6$ (stat) ± 1.8 (syst), $c\tau_{B^0 \to J/\psi K^0_s} = 457.8 \pm 2.7$ (stat) ± 2.8 (syst), $c\tau_{B^0_s \to J/\psi \phi} = 443.9 \pm 2.0 (stat) \pm 1.5$ (syst), $c\tau_{B^0_s \to J/\psi \pi^+\pi^-} = 502.7 \pm 10.2$ (stat) ± 3.4 (syst), $c\tau_{\Lambda^0_b \to J/\psi \Lambda^0} = 442.9 \pm 8.2$ (stat) ± 2.8 (syst), $c\tau_{B^+_c \to J/\psi \pi^+} = 162.3 \pm 7.8 \pm 4.2$ and the Λ^0_b polarization $P = 0.00 \pm 0.06(stat) \pm 0.06(syst)$ along with asymmetry parameter $\alpha_1 = 0.14 \pm 0.14$ (stat) ± 0.10 (syst).

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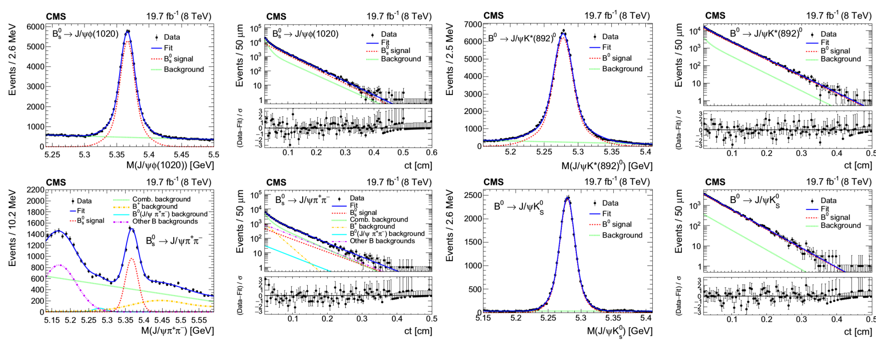
1 Introduction

The quantum chromodynamics (QCD) based Heavy Quark Expansion (HQE) framework describes the decay rates for the corresponding decays of $B^0 \to J/\psi K^*$, $B^0 \to J/\psi K_s^0$, $B_s^0 \to J/\psi \pi^+\pi^-$, $B_s^0 \to J/\psi \phi$, $\Lambda_b^0 \to J/\psi \Lambda^0$ and $B_c^+ \to J/\psi \pi^+$ which can be a critical probe to the non-perturbative aspects of QCD. A detailed account of the theory of lifetimes can be found here [1]. While measuring the lifetimes of other b hadrons mentioned above a different approach has been followed for the measurement of B_c^+ lifetime. First the decay width difference between B_c^+ and B^+ has been measured and then from the decay width difference the B_c^+ lifetime has been extracted by using precisely known B^+ ($\to J/\psi K^+$) lifetime. The study of polarization measurement in the decays of $\Lambda_b \to J/\psi \Lambda$ is very important source of strong interaction effects in hadronic decays. The main parameters in the signal model was the polarization, P of Λ_b and the parity violating asymmetry parameter in the decay of $\Lambda \to p\pi^-$ [2, 3, 4]. The analysis of lifetime and polarization measurements have been performed using data collected by CMS. CMS is a Large Hadron Collider (LHC) based experiment comprises coaxial cylindrical subdetectors. The innermost subdetector is silicon pixel and strip tracker. It is followed by an electromagnetic calorimeter (ECAL) which is composed of lead tungstate ($PbWO_4$) scintillating crystal. The ECAL is surrounded by brass and scintillator sampling hadron calorimeter (HCAL). These subdetectors are inside of a superconducting solenoid of inner diameter 6 m provides a 3.8 T magnetic field. Finally muon chamber subdivided into drift tubes (DT), resistive plate chambers (RPC) and cathode strip chambers (CSC) are located outside of the solenoid [5, 6].

Indian Institute Of Technology, Madras, Chennai-600036, Tamil Nadu, India
e-mail: muhammad.muhammad.alibordi@cern.ch

2 Event Reconstruction

For lifetime measurements of $B^0 \to J/\psi K^*$, $B^0 \to J/\psi K_s^0$, $B_s^0 \to J/\psi\pi^+\pi^-$, $B_s^0 \to J/\psi\phi$, $\Lambda_b^0 \to J/\psi\Lambda^0$ and $B_c^+ \to J/\psi\pi^+$ decay channels the J/ψ is reconstructed from oppositely charged muons which are required to have $p_t > 7.9$ GeV, $|\eta| < 2.2$, a distance of closest approach of muons to the event vertex < 0.5 cm originating from common vertex with a χ^2 probability > 0.5 %. The invariant mass of the dimuons are chosen ±5 times the experimental mass resolution of the world average J/ψ mass [1]. Apart from J/ψ other final state candidates in different decay modes are reconstructed from tracks and the b hadrons are formed by combining the J/ψ with tracks. All are required to originate from a common vertex. For the polarization measurement of $\Lambda_b \to J/\psi\Lambda$ the J/ψ is reconstructed from muon objects whereas $\Lambda \to p\pi^-$ from pairs of oppositely charged tracks. The Λ_b candidates are formed by combining muon objects and tracks within the mass window $5.40 < m_{J/\psi\Lambda} < 5.84$ GeV.



(a) (b)

Fig. 1: ct and mass distributions for B^0 and B_s^0, the curves are projections of the fit to the data, signal, background and both [1].

3 Fit model, Result and systematics

3.1 Fit and Results

For the measurement of lifetimes in different decay channels a simultaneous unbinned extended maximum likelihood fit has been performed using b hadron mass, ct and ct uncertainty as input parameters. The signal for mass fit is modeled as one or two Gaussians. The background is fit with a polynomial or exponential depending upon decay channels. For the ct distribution the signal is modeled with an exponential convolved with detector resolution where as background is described by a superposition of exponentials convolved with the resolution. The σ_{ct} distributions are modeled with two gamma functions for signal and two exponentials for background convolved with a Gaussian function.

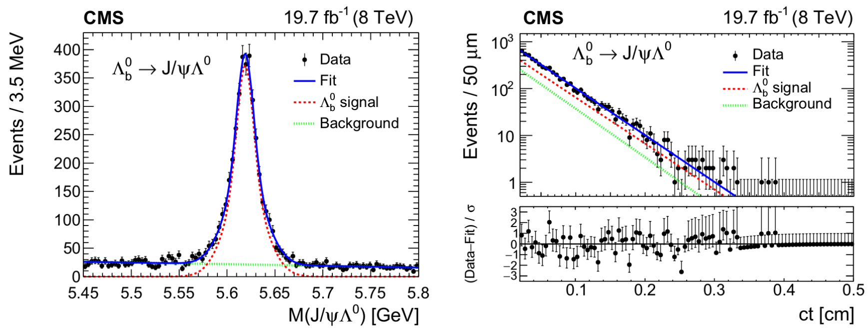
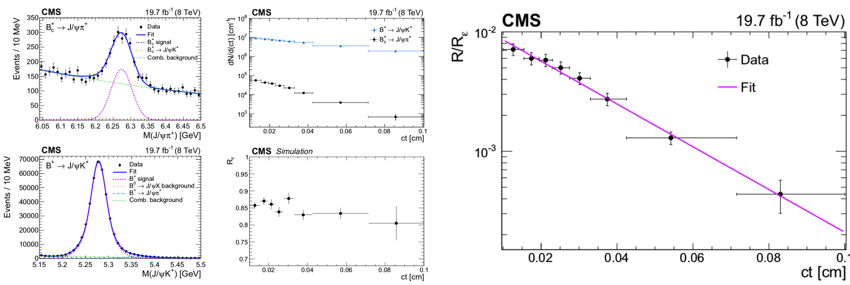


Fig. 2: The mass and *ct* distribution of Λ_b in the decay channel of $\Lambda_B^0 \to J/\psi\Lambda^0$, the curves are projections of the fit to the data, signal, background and both [1].

The fitted distributions of B^0, B_s^0 and Λ_b at centre of mass energy $\sqrt{s} = 8$ TeV are shown in fig. 1, 2 and results in μm corresponding to these channels are,

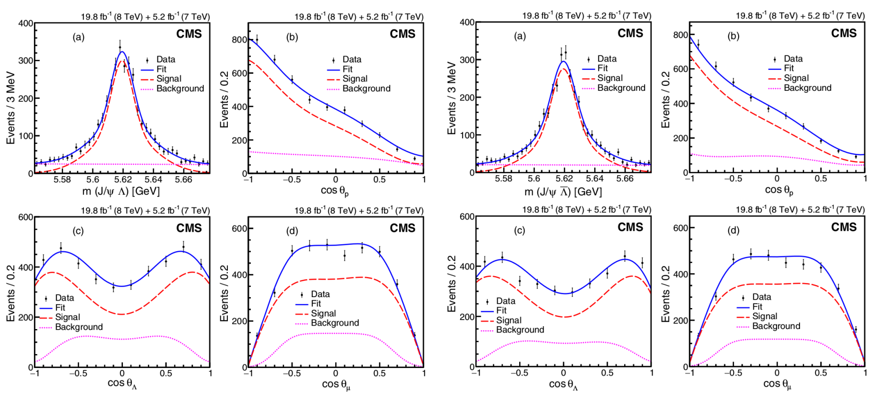
$$\begin{aligned} c\tau_{B^0\to J/\psi K^*(892)^0} &= 453.0 \pm 1.6(\text{stat}) \pm 1.8(\text{syst}) \\ c\tau_{B^0\to J/\psi K_s^0} &= 457.8 \pm 2.7(\text{stat}) \pm 2.8(\text{syst}) \\ c\tau_{B_s^0\to J/\psi\phi(1020)} &= 443.9 \pm 2.0(\text{stat}) \pm 1.5(\text{syst}) \\ c\tau_{B_s^0\to J/\psi\pi^+\pi^-} &= 502.7 \pm 10.2(\text{stat}) \pm 3.4(\text{syst}) \\ c\tau_{\Lambda_b^0\to J/\psi\Lambda^0} &= 442.9 \pm 8.2(\text{stat}) \pm 2.8(\text{syst}) \end{aligned} \tag{1}$$

The fitted efficiency corrected *ct* distribution of the ratio of B_c^+ to B^+ gives decay width difference $\Delta\Gamma = 1.24 \pm 0.09$ ps^{-1} in fig. 3. From the known lifetime of B^+ the extracted lifetime of B_c^+ is $c\tau_{B_c^+\to J/\psi\pi^+} = 162.3 \pm 7.8 \pm 4.2\ \mu$m.



(a) (b)

Fig. 3: Mass and efficiency distributions for B_c^+, B^+ (a) and ratio of the B_c^+ to B^+ efficiency corrected ct distribution (b) [1].



(a) (b)

Fig. 4: The fitted mass distribution and fitted cosines of all three angles $(cos\theta_\Lambda, cos\theta_p, cos\theta_\mu)$ are plotted. Plots for both Λ_b (a) and $(\bar{\Lambda}_b)$ (b) are shown [2].

For the measurement of polarization, the Λ_b polarization P, and the angular decay parameters α_1, α_2, and γ_0 are determined. The results are obtained from an unbinned maximum likelihood fit to the $J/\psi\Lambda$ invariant mass distribution and the three angular variables $\Theta_3 = (cos\theta_\Lambda, cos\theta_p, cos\theta_\mu)$ are shown in fig. 4 . The extracted signal yields from both $J/\psi\Lambda$ and $J/\psi\bar{\Lambda}$ was 6000 and the measured values for different parameters are $P = 0.00 \pm 0.06 \pm 0.06$, $\alpha_1 = 0.14 \pm 0.14 \pm 0.10$, $\alpha_2 = -1.11 \pm 0.04 \pm 0.05$, $\gamma_0 = -0.27 \pm 0.08 \pm 0.11$ and the values of helicity amplitudes are,

$$
\begin{aligned}
|T_{++}|^2 &= 0.05 \pm 0.04(stat) \pm 0.04(syst) \\
|T_{+0}|^2 &= -0.10 \pm 0.04(stat) \pm 0.04(syst) \\
|T_{-0}|^2 &= 0.51 \pm 0.03(stat) \pm 0.04(syst) \\
|T_{--}|^2 &= 0.52 \pm 0.04(stat) \pm 0.04(syst)
\end{aligned} \tag{2}
$$

3.2 Systematic uncertainties

For lifetime measurements common systematic uncertainties were statistical uncertainty in the Monte Carlo samples, modeling of the mass distribution shape and also channel specific uncertainties depending upon selection of reconstruction and fitting. Monte Carlo statistical uncertainty contributed much among other uncertainties, in $B^0 \to J/\psi K_s^0$ decays it is of 2.4 μm and in $\Lambda_b^0 \to J/\psi \Lambda^0$ decays it has the value of 2.3 μm. Uncertainties arising for *ct* range regulation and *S*-wave contamination is absent in all decay modes except $B_s^0 \to J/\psi\phi$. Modulation in *ct* accuracy contributes almost same number ∼1.3-1.4 μm in all cases. The measured values for polarization(P), asymmetry parameter(α_1), longitudinal polarization(α_2) and its related parameter(γ_0) in $\Lambda_b^0 \to J/\psi\Lambda^0$ decays are reconstruction wise biased by 5.7, 9.8, 2.0 and 9.1 respectively up to the order 10^{-2}. The γ_0 was systematically uncertain by 5.0×10^{-2} due to the angular distribution used for the background fit. The angular efficiency contributed systematic uncertainty in α_2 measurement at 3.0×10^{-2}. There are sources of uncertainties in the polarization measurement such as the weighting procedure for asymmetry parameter α_Λ.

4 Summary

The measurement of lifetimes for b hadrons in the channels $B^0 \to J/\psi K^*$, $B^0 \to J/\psi K_s^0$, $B_s^0 \to J/\psi\pi^+\pi^-$, $B_s^0 \to J/\psi\phi$, $\Lambda_b^0 \to J/\psi\Lambda^0$ and $B_c^+ \to J/\psi\pi^+$ and the polarization in the decays of $\Lambda_b^0 \to J/\psi\Lambda^0$ has been briefly described. The measurement of Λ_b^0 lifetime is compatible with measured values from other experiments in the same channel. The B_c^+ lifetime is in agreement with LHCb [7] and more precise than CDF [8] and D0 [9]. For the polarization measurement α_2 is compatible with -1, which implies a Λ of a positive-helicity state from Λ_b is suppressed. The measured value of α_1 is also consistent with LHCb [10] and ATLAS [11].

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