ABSTRACT

Measurements of b-hadron decays have greatly advanced our understanding of the Standard Model (SM), especially in its flavour sector and the study of Charge-Parity (CP) violation. The study of meson lifetimes plays a crucial role in testing the SM predictions, as deviations from expected values could indicate contributions from new physics beyond the SM. The effective lifetime of the B_s^0 meson in the decay $B_s^0 \to J/\psi K_S^0$ is measured using the data collected during 2016-2018 with the CMS detector at $\sqrt{s}$=13 TeV proton-proton collisions at the LHC, corresponding to an integrated luminosity of 140 fb^{-1}. The effective lifetime is determined by performing a two-dimensional unbinned maximum likelihood fit to the $J/\psi K_S^0$ invariant mass and proper decay time distributions. The resulting value is found to be 1.59 ± 0.07 (stat) ± 0.03 (syst) ps, which is the most precise measurement to date and is in good agreement with the expected value.

Low-momentum ("soft") muons, with transverse momentum below 10 GeV, are of critical importance in CMS analyses, playing a central role in both rare decay searches and muon identification studies. In particular, the search for the highly suppressed decay $D \to \mu^+\mu^-$, which proceeds via flavour-changing neutral currents forbidden at tree level in the SM, relies heavily on the efficient identification of soft muons. Precise background estimation is essential in this analysis, and dedicated muon fake rate measurements were performed to quantify the contribution from misidentified hadrons. These efforts led to a significant improvement in signal extraction, resulting in a 30% enhancement in sensitivity over the previous branching fraction limit. More broadly, maximizing muon selection efficiency while reducing contamination from long-lived light-flavour hadron decays is vital for improving the overall performance of rare decay measurements involving muons. To this end, multivariate analysis (MVA) techniques have been employed, demonstrating superior discrimination power over traditional methods. A new soft muon classifier, based on gradient-boosted decision trees (BDTs), has been developed for Run-3 and shows substantial improvement in signal-background separation compared to the Run-2 version. Its performance, evaluated using 2022 and 2023 data corresponding to 62 fb^{-1}, indicates a marked gain in muon identification efficiency. A detailed fake rate study was also carried out to characterize background contamination in this new classifier, ensuring robust and

reliable performance in current and future analyses.

The study of the $B_s^0 \rightarrow J/\psi K_S^0 K_S^0$ decay, a three-body decay, provides a rich environment for probing CP violation and understanding the dynamics of intermediate resonant states. This channel allows for a detailed study of the $J/\psi K_S^0$ and $K_S^0 K_S^0$ mass spectra, which may exhibit contributions from intermediate scalar, vector, or tensor resonances such as f0, ϕ, χ, f2', or Ψ states. With the increased statistics and enhanced low-mass-targeted triggers in Run-3 data, this study will benefit from a higher event yield, enabling a more precise and statistically significant analysis of the decay's resonance structures.