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Time dependent CP-violation measurements and related studies in B_s^0 decays at LHCb

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First time-dependent measurements with the LHCb experiment are presented using $36\,\mathrm{pb}^{-1}$ data collected during the 2010 data taking at the LHC. The B_s^0 mixing frequency is measured to be $\Delta m_s = 17.63 \pm 0.11(stat.) \pm 0.04(syst.)\,\mathrm{ps}^{-1}$. A flavour tagged time-dependent angular analysis using $B_s^0 \to J/\Psi\Phi$ decays allows to derive confidence regions in the $\phi_s^{J/\Psi\Phi}$-$\Delta\Gamma_s$ plane. The branching ratios of two penguin decays with potential sensitivity on ϕ_s are measured. The effective $B_s^0 \to K^+K^-$ lifetime is determined to be $\tau_{B_s^0\to K^+K^-} = 1.440 \pm 0.096 \pm 0.010\,\mathrm{ps}$.

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1. Introduction

LHCb is a dedicated flavour physics experiment to search for New Physics through precision measurements in the heavy flavour sector. It is designed as a single arm forward spectrometer covering a pseudorapidity range of $2 < \eta < 5$. A full description of the detector can be found in [1]. The good decay time resolution of the LHCb detector allows a wide range of precise time-dependent measurements. Some preliminary results of these measurements will be presented in the following. All results are obtained from the first run of LHC during 2010 at $\sqrt{s} = 7$TeV center-of-mass energy, where LHCb collected about $36\,\mathrm{pb}^{-1}$ of data.

2. Measurement of the $\mathrm{B_s^0}$ oscillation frequency

The meson flavour eigenstates in the $\mathrm{B_s^0}$ system, $\mathrm{B_s^0}$ and $\mathrm{\bar{B}_s^0}$ differ to the mass eigenstates $\mathrm{B_L}$ and $\mathrm{B_H}$. As a consequence mixing between the flavour eigenstates is possible. The mixing frequency Δm_s is determined by the mass difference of the mass eigenstates $\Delta m_s = m_H - m_L$. In order to measure the mixing frequency the knowledge of the flavour of the initial $\mathrm{B_s^0}$ meson is necessary ("tagging"). The tagging algorithms were calibrated in an independent analysis exploiting high statistics $B^0 \to D^{*-}\mu^+\nu_\mu$ and $B^0 \to J/\Psi K^+$ modes to maximize the effective tagging power $\varepsilon_{\mathrm{eff}} = \varepsilon_{\mathrm{tag}} D^2$, where $\varepsilon_{\mathrm{tag}}$ is the tagging efficiency and $D = (1-2\omega)$ the tagging dilution, determined by the mistag probability ω. The total tagging power of the tagging algorithms used in the Δm_s measurement is $\varepsilon_{eff} = 3.8 \pm 2.1\%$. The measurement of Δm_s is performed using in total 1350 $\mathrm{B_s^0}$ candidates reconstructed in four different decay modes shown in table 2. Figure 1 shows the invariant mass distribution for the mode with highest statistics. The mixing frequency is determined in a common two dimensional fit (mass and decay time) to these four decay modes. The measured oscillation frequency is $\Delta m_s = 17.63 \pm 0.11(stat.) \pm 0.04(syst.)\,\mathrm{ps}^{-1}$ with a 4.2 σ significance. Figure 1 shows the mixing frequency as function of the measured decay time modulo $\frac{2\pi}{\Delta m_s}$. More details can be found in [2].

decay mode	#signal candidates
$B_s \to D_s^-(\Phi\pi^-)\pi^+$	515 ± 25
$B_s \to D_s^-(K^*K)\pi^+$	338 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)\pi^+$	283 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)3\pi$	245 ± 46

Table 1: Decay modes used for Δm_s measurement

3. CP analysis of $B_s^0 \to J/\Psi\Phi$

A key channel to measure CP-violation in the $\mathrm{B_s^0}$ system is $B_s^0 \to J/\Psi\Phi$. The interference between mixing and decay gives rise to a CP-violating phase $\phi_s^{J/\Psi\Phi}$ which is precisely calculated within the Standard Model by global fits to experimental data: $\phi_s^{J/\Psi\Phi} = 0.0363 \pm 0.0017$rad [3]. Additional New Physics particles contributing to the mixing diagram would directly affect the measured value of $\phi_s^{J/\Psi\Phi}$.

$B_s^0 \to J/\Psi\Phi$ is a pseudo-scalar to vector-vector decay with three different final states with different

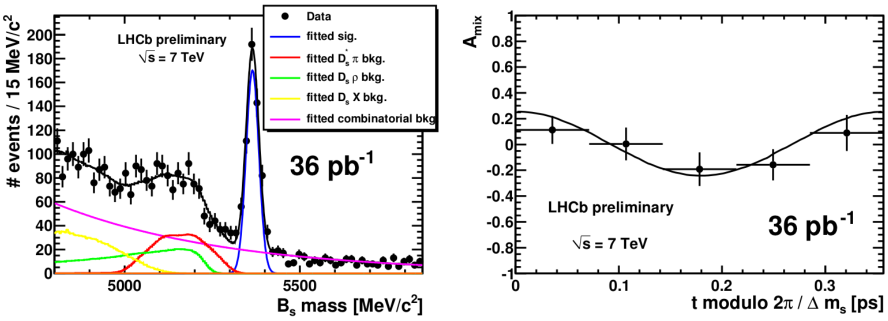

Figure 1: Left: Invariant mass distribution of reconstructed $B_s \to D_s^-(\Phi\pi^-)\pi^+$ candidates. Right: Mixing asymmetry as function of decay time modulo $\frac{2\pi}{\Delta m_s}$.

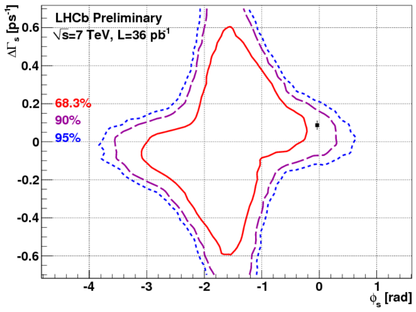

Figure 2: Two dimensional confidence intervals in the $\phi_s^{J/\Psi\Phi}$-$\Delta\Gamma_s$ plane.

relative angular momentum. The decay can be described by three polarization amplitudes $A_0(t)$, $A_\parallel(t)$ and $A_\perp(t)$ which correspond to CP even and CP odd eigenstates for $t = 0$. A 3 dimensional angular analysis is used to statistically disentangle the CP eigenstates, using the so called "transversity basis" $\Omega = \{\phi, \psi, \theta\}$ as described in [4]. A likelihood fit to mass, decay time and transversity angles is performed to determine $\phi_s^{J/\Psi\Phi}$ and the decay width difference of the $\mathrm{B_s^0}$ mass eigenstates $\Delta\Gamma_s = \Gamma_L - \Gamma_H$. The full 2010 data set consisting of 757 ± 25 signal events is used. The total tagging power for $B_s^0 \to J/\Psi\Phi$ was found to be $\varepsilon_{eff} = 2.2 \pm 0.5\%$. With the available statistics a meaningful point estimate for $\phi_s^{J/\Psi\Phi}$ is not possible. Instead the Feldman-Cousins method is used to derive two-dimensional confidence contours in the $\phi_s^{J/\Psi\Phi}$-$\Delta\Gamma_s$ plane, shown in figure 2. The contours show the statistical uncertainty only. The systematic uncertainties of the flavour tagging calibration and the mixing frequency are used as constraints in the fit and thus contribute to the statistical uncertainties. Other systematic effects have no significant influence on the confidence regions.

A one dimensional interval is derived from the contours resulting in $\phi_s^{J/\Psi\Phi} \in [-2.7, -0.5]$ rad at 68% CL. More details can be found in [5].

4. Other interesting channels for CP measurement

Additional to $B_s^0 \to J/\Psi\Phi$ there are pure penguin decays which are potentially interesting to measure the CP violating phase ϕ_s. LHCb makes the first observation of $B_s^0 \to K^*\bar{K}^*$ and measures the branching ratio to $BR(B_s^0 \to K^*\bar{K}^*) = (1.95 \pm 0.47(stat.) \pm 0.29(syst.)) \cdot 10^{-5}$ [7]. In addition the branching ratio of the decay $B_s^0 \to J/\Psi K^*$ is determined to $BR(B_s^0 \to J/\Psi K^*) =$

$(3.5^{+1.1}_{-1.0}(stat.)\pm 0.9(syst.))\cdot 10^{-5}$ [6]. An additional interessting mode in this context is $B_s^0 \to J/\Psi f_0$. More details can be found in an article in these proceedings.

5. Lifetime measurement of $B_s^0 \to K^+K^-$

The measurement of the $B_s^0 \to K^+K^-$ lifetime can be used to put constraints on New Physics contributing to the $\mathrm{B_s^0}$ mixing. The decay time distribution is given by $\hat{\Gamma}(B_s^0 \to K^+K^-) = R_H e^{-\Gamma_H t} + R_L e^{-\Gamma_L t}$ where R_H and R_L are the fractions of the heavy and light mass eigenstates. $B_s^0 \to K^+K^-$ is primarily sensitive to the width of the short-lived light state of the $\mathrm{B_s^0}$. Comparing the measurement with a lifetime obtained from a flavour specific decay allows to extract $\Delta\Gamma_s$.

Two different independent lifetime measurements are performed at LHCb. One absolute measurement taking into account decay time acceptance effects introduced by the selection requirements and a measurement relative to the $B_0 \to K^+\pi^-$ decay where lifetime biasing effects cancel. Both approaches give consistent results and the combined measured lifetime is $\tau_{B_s^0\to K^+K^-} = 1.440 \pm 0.096 \pm 0.010\mathrm{ps}$ [8].

6. Summary

Several time-dependent measurement using the 2010 LHC data set were presented showing LHCb's excellent performance. The $\mathrm{B_s^0}$ mixing frequency was measured with competitive sensitivity to previous results. The first LHCb measurement of the CP violating phase in $B_s^0 \to J/\Psi\Phi$ allowed to determine confidence regions in the $\phi_s^{J/\Psi\Phi}$-$\Delta\Gamma_s$ plane. With the larger 2011 data set a updated result of $\phi_s^{J/\Psi\Phi}$ was published being the most exact measurement of this quantity [9]. In addition some other decay channels were presented which can be used to measure CP-violation in the $\mathrm{B_s^0}$-meson system.

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