Mixing and CP-violation in the B_s^0 system at LHCb

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1 Introduction

Decays of neutral B mesons provide a unique laboratory to study CP-violation originating from a non-trivial complex phase in the CKM matrix. The relative phase between the direct decay amplitude and the amplitude of decay via mixing gives rise to time-dependent CP-violation, a difference in the proper decay time distribution of B-meson and anti-B-meson decays. The decay $B_s^0 \to J/\psi\phi$ is considered the golden mode for measuring this type of CP-violation in the B_s^0 system. In the Standard Model the CP-violating phase in this decay is predicted to be $\phi_s^{J/\psi\phi} \approx -2\beta_s$, where $\beta_s = arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$, V_{ij} being elements of the CKM matrix. The indirect determination via global fits to experimental data gives $2\beta_s = (0.0363^{+0.0016}_{-0.0015})$ rad [1]. New Physics contributions in $B_s^0 - \overline{B}_s^0$ mixing could alter this phase: $\phi_s \to \phi_s^{SM} + \phi_s^{NP}$ [2]. Therefore, a high precision measurement of ϕ_s allows us to indirectly search for and constrain any New Physics effects. The Tevatron experiments CDF and D0 have previously measured $\phi_s^{J/\psi\phi}$ [3] with a precision of ~ 0.5 rad.

The measurement is performed using an integrated luminosity of $36pb^{-1}$ of pp collision data recorded by the LHCb experiment at a centre-of-mass energy $\sqrt{s} =$ 7 TeV during 2010. The LHCb detector is a forward spectrometer at the Large Hadron Collider (LHC) at CERN and described in detail in [4]. The ϕ_s sensitivity profits from the large b-$\overline{b}$ cross section at the LHC, the excellent trigger, track reconstruction and particle identification efficiencies and decay time resolution of the detector.

2 Trigger and selection

Events are selected by a trigger system consisting of a hardware trigger which selects muon or hadron candidates with high transverse momenta, followed by a two stage software trigger. Two different classes of trigger are used: one which employs requirements on the impact parameter of tracks and another which only relies on a

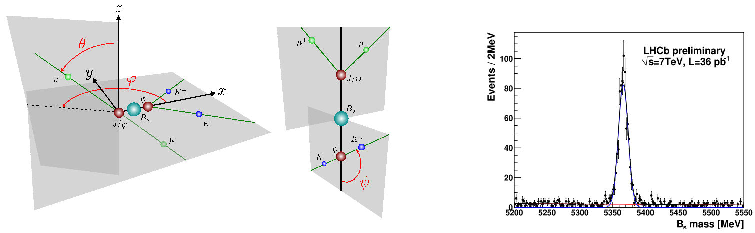
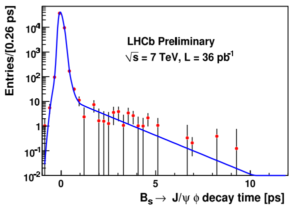


Figure 1: Left: Definition of the decay angles in the transversity frame: θ_{tr} is the angle formed by the positive lepton (μ^+) and the z-axis, in the J/ψ rest frame. The angle ϕ_{tr} is the azimuthal angle of μ^+ in the same frame. In the ϕ meson rest frame, ψ_{tr} is the angle between $\vec{p}(K^+)$ and $-\vec{p}(J/\psi)$. Right: Invariant mass distribution of selected $B_s^0 \to J/\psi\phi$ candidates. The fitted curves show the Gaussian signal and small background contribution.

confirmation in the muon system ("lifetime unbiased"). $B_s^0 \to J/\psi\phi$ candidates are reconstructed from $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ decays, using simple kinematic, tracking and vertex cuts to isolate the signal. B_s^0 candidates are required to have a decay time, $t \in [0.3, 14.0]$ ps. The lower cut suppresses a large combinatoric background which originates from prompt J/ψ production. We select a sample of 757 ± 28 B_s^0 signal candidates, of which 75% are associated with the lifetime unbiased trigger. Fig. 1 shows the invariant mass distribution of the $B_s^0 \to J/\psi\phi$ candidates. Full details of the selection can be found in [5].

3 Tagged analysis of $B_s^0 \to J/\psi\phi$

The decay $B_s^0 \to J/\psi\phi$ proceeds via a vector-vector intermediate state to a superposition of CP-even and CP-odd final states. The differential decay rate of a B_s^0 meson is described by a sum of six terms labeled by k (the K^+K^- S-wave component is ignored in this analysis and treated as a systematic uncertainty on the final result). Each term is a product of an angular function $f_k(\cos\theta_{tr}, \phi_{tr}, \cos\psi_{tr})$ and a time-dependent amplitude $h_k(t)$. $\Omega = \{\cos\theta_{tr}, \phi_{tr}, \cos\psi_{tr}\}$ are the 4-body decay angles in the transversity frame, defined in Fig. 1. $h_k(t)$ is expressed in terms of the CP-violating phase ϕ_s, the B_s^0 decay width Γ_s, the decay width difference between the B_s^0 mass eigenstates, the mixing frequency Δm_s and the complex amplitudes of the P-wave $(A_\parallel, A_\perp, A_0)$ at $t = 0$. The differential decay rates for a $\overline{B}_s^0$ meson are obtained by multiplying ϕ_s and $A_\perp$ by a factor -1. To disentangle these CP components and extract the phase $\phi_s^{J/\psi\phi}$ we perform with an unbinned maximum likelihood fit to the candidate invariant mass m, the proper decay time t, the initial B_s^0 flavour



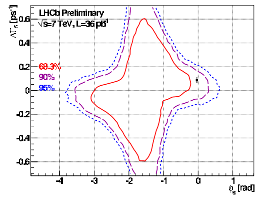


Figure 2: Left: Decay time distribution of background $B_s^0 \rightarrow J/\psi\phi$ candidates obtained with the sPlot [7] technique using the candidate mass as separating observable. The superimposed curve is the background decay time model convolved with the resolution model. The background model includes a prompt component and a long lived component, described by two exponential functions with different decay constants. Right: Feldman-Cousins confidence regions in the $\phi_s - \Delta\Gamma_s$ plane. The CL at the Standard Model point (black square) is 0.785 which corresponds to a deviation of "1.2σ".

q and decay angles Ω. The full description of the fitting technique can be found in [6].

To account for the finite decay time resolution of the detector, all time-dependent terms in the differential decay rate are convolved with a sum of three Gaussian functions with common mean and different widths. The parameters of this resolution function are determined using $B_s^0 \rightarrow J/\psi\phi$ candidates with measured decay time in the range $t \in [-1.0, 10.0]$ ps. This distribution is dominated by the prompt J/ψ production and is shown in Fig. 2 where the signal candidates have been subtracted using the sPlot [7] technique using the B_s^0 invariant mass. The effective time resolution is $\sigma_t = 50$ fs. To measure ϕ_s requires the determination of the flavour of the B_s^0 or $\overline{B}_s^0$ meson at production using dedicated algorithms which exploit properties of each event. The dilution due to imperfections of the flavour tag is $D = 1 - 2\omega$, where ω is the mistag probability. The flavour tagging algorithm has a finite efficiency ϵ_{tag}. For this analysis, we use only the oppositely signed (OS) flavour tagging which uses properties of the accompanying non-signal B-hadron decay. The optimization and calibration of the tagging is done using large statistics samples of $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow J/\psi K^{*0}$ and $B_0 \rightarrow D^*\mu\nu$ events. This gives an effective tagging efficiency $\epsilon_{eff} = \epsilon_{tag} D^2 = 2.2 \pm 0.5\%$.

4 Results

The 2010 data set does not constitute a sufficiently large sample of tagged signal events to constrain ϕ_s with a meaningful parabolic $\pm 1\sigma$ error. Therefore, the result of this analysis is presented as two-dimensional confidence level regions in the $\phi_s - \Delta\Gamma_s$ plane obtained using a likelihood ratio ordering, following the prescription of Feldman-Cousins (FC) [8]. Figure 2 shows the 68.3%, 90% and 95% FC confidence level contours in the $\phi_s - \Delta\Gamma_s$ plane. The contours exhibit a symmetry due to the two-fold ambiguity in the B_s^0 differential decay rate. We find that all studied systematic variations of the fitting conditions have an insignificant effect on the $\phi_s - \Delta\Gamma_s$ confidence contours. The dominant systematic uncertainties are due to relative uncertainty in the dilution from flavour tagging (7%), the decay time resolution (6%) and ignoring a possible S-wave contribution (11%). Therefore, the contours include only the statistical uncertainty, with the exception of the uncertainties due to flavour tagging calibration parameters and mixing frequency, which were floated in the likelihood fit. We find $\phi_s \in [-2.7, -0.5]$ rad at 68% CL and $\phi_s \in [-3.5,\ 0.2]$ rad at 95% CL when projecting the confidence level contours onto one dimension.

5 Conclusions and outlook

We have presented a tagged time-dependent angular analysis of $B_s^0 \to J/\psi\phi$ decays that allows us to constrain the CP-violating phase ϕ_s. In one dimension we find $\phi_s \in [-2.7, -0.5]$ rad at 68% CL. With the full 2011 dataset recorded at LHCb we expect the sensitivity on ϕ_s to be ~ 0.1 rad.

References

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