PROCEEDINGS OF SCIENCE

Search for New Physics in $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ at LHCb

Olivier Leroy* **for the LHCb Collaboration**
CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
E-mail: Olivier.Leroy@in2p3.fr

We discuss the potential to meaure mixing-induced CP violation in the channels $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ channels with the LHCb detector. For a data-set corresponding to $2\,\mathrm{fb}^{-1}$, the expected sensitivity to the CP violating weak phases is 0.03 rad for $B_s^0 \to J/\psi\phi$ and 0.08 rad for $B_s^0 \to \phi\phi$.

12th International Conference on B-Physics at Hadron Machines - BEAUTY 2009
September 07 - 11 2009
Heidelberg, Germany

*Speaker.

 http://pos.sissa.it/

PoS(BEAUTY 2009)011

1. Introduction

Within the Standard Model, the decay $B_s^0 \to J/\psi\phi$ is dominated by $\overline{b} \to \overline{c}c\overline{s}$ quark level transitions, as represented in Figure 1 (left), with a weak phase $\Phi_D = \arg(V_{cb}V_{cs}^*)$[1]. The B_s^0 meson can also oscillate to a $\overline{B}_s^0$ before decaying to $J/\psi\phi$, with a weak phase $\Phi_M = 2\arg(V_{ts}^* V_{tb})$ (Figure 2). The interference between both processes gives rise to a CP violating weak phase $\phi_s^{J/\psi\phi} = \Phi_M - 2\Phi_D = -2\beta_s$, where $\beta_s = \arg\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right)$ is the smallest angle of the "b$-$s unitarity triangle". The indirect determination via global fits to experimental data gives $2\beta_s = (0.0360^{+0.0020}_{-0.0016})$ rad [2]. The direct measurement of this phase is one of the key goals of the LHCb experiment. Indeed, $\phi_s^{J/\psi\phi}$ is one of the CP observables with the smallest theoretical uncertainty in the Standard Model, and New Physics could significantly modify this prediction. Both CDF and DØ have recently observed an interesting deviation of $\sim 2\sigma$ significance with respect to the Standard Model value [3].

The $B_s^0 \to \phi\phi$ decay is dominated by b$\to$s gluonic penguins represented in Figure 3, which carry the same weak phase as the B_s^0–$\overline{B}_s^0$ mixing diagram. Therefore, within the Standard Model, the CP violating phase in this decay vanishes, i.e. $\phi^{\phi\phi} = 0$. In presence of New Physics however, we have[2]:

$$\phi_s^{J/\psi\phi} = -2\beta_s + \Phi_M^{NP}\,, \tag{1.1}$$

$$\phi^{\phi\phi} = \Phi_M^{NP} + \Phi_D^{NP}\,. \tag{1.2}$$

So the measurement of both, $\phi_s^{J/\psi\phi}$ and $\phi^{\phi\phi}$, allows to probe New Physics in the B_s^0–$\overline{B}_s^0$ mixing box (Φ_M^{NP}) and in b$\to$s penguin diagrams (Φ_D^{NP}).

$B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ are pseudo-scalar to vector-vector decays. The final state is a superposition of 3 polarizations amplitudes (A_0, $A_\parallel$ and $A_\perp$), and an angular analysis is required to disentangle statistically the CP-odd and CP-even components. The phases of the polarization amplitudes are denoted by δ_0, $\delta_\parallel$ and $\delta_\perp$ and are conserved under CP transformation. The three decay product angles are shown in Figure 4, in the transversity basis, for $B_s^0 \to J/\psi\phi$. In the case of $B_s^0 \to \phi\phi$, the helicity basis is used instead, to treat on the same footing both ϕ mesons.

The decay rate of $B_s^0 \to J/\psi\phi$ (or $B_s^0 \to \phi\phi$) is a function of five observables (the proper time, the initial B_s^0 flavour and the three decay angles) and eight physics parameters: the weak phase ($\phi_s^{J/\psi\phi}$ or $\phi^{\phi\phi}$), the mass and width difference between B_s^0 mass eigenstates (Δm_s and $\Delta\Gamma_s$), the width of the B_s^0 (Γ_s), two amplitudes and two strong phases [4]. The possibility to account for a KK S-wave contribution in the $B_s^0 \to J/\psi K^+K^-$ decay is discussed in [5].

In the rest of this document, we explain how to trigger and select the $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ channels at LHCb, how to tag the initial B_s^0 flavour and how to fit the weak phases.

2. Trigger and selections

2.1 $B_s^0 \to J/\psi\phi$

The $B_s^0 \to J/\psi\phi$ channels together with two control channels ($B^0 \to J/\psi K^{*0}$ and $B^+ \to J/\psi K^+$), is triggered and selected in a uniform way, in order to extract the mistag rate (defined in Section 3)

[1] The possible small penguin contribution (same figure, right) is neglected here and discussed further in [1]

[2] Assuming New Physics affects only the loop processes.

PoS(BEAUTY 2009)011

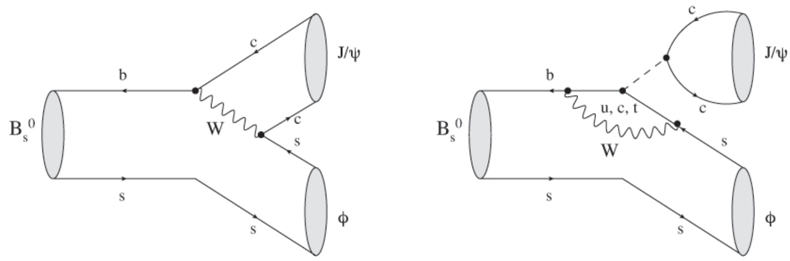

Figure 1: Feynman diagrams contributing to the decay $B_s^0 \to J/\psi\phi$, within the Standard Model. Left: tree; right: penguins.

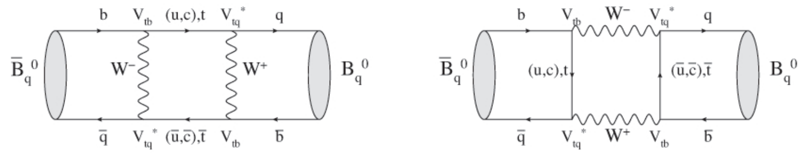

Figure 2: Feynman diagrams describing the B_q–$\overline{B}_q$ mixing, within the Standard Model (q=s,d).

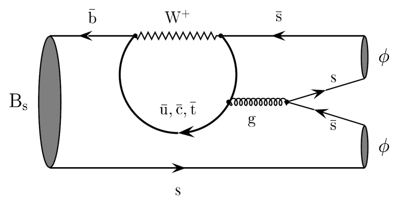

Figure 3: Feynman diagrams describing the $B_s^0 \to \phi\phi$ decay, within the Standard Model.

without applying large corrections. The trigger and selections are designed to maximize the sensitivity to $\phi_s^{J/\psi\phi}$ while avoiding large proper time and angular acceptance corrections [6]. The J/ψ is reconstructed from its decay to two muons, while the ϕ is reconstructed from two kaons. In Table 1, we give for the $B_s^0 \to J/\psi\phi$ decay as well as for the two control channels, the annual yield assuming $2\,\mathrm{fb}^{-1}$ of data, and the background over signal ratio for the two kinds of background: background from B decays (long lived) and non-B decay background (prompt, mostly charm). We expect 117 000 $B_s^0 \to J/\psi\phi$ per $2\,\mathrm{fb}^{-1}$. The total trigger efficiency is $\sim 70\%$. The background is dominated by prompt events, since no cut which can bias the lifetime is used. The B_s^0 mass resolution is $16\,\mathrm{MeV}/c^2$; the average proper time resolution is 38 fs. The proper time acceptance is flat. The distribution of mass and proper time for the prompt and long-lived background are given in Figures 5 and 6, respectively. The angular acceptances for the three transversity angles are given in Figure 7. The distortions (below 8%) come mainly from the LHCb geometrical detector acceptance.

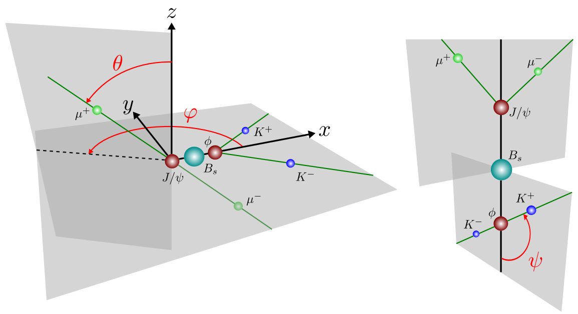

Figure 4: Angle definition in the transversity basis: θ is the angle formed by the positive lepton (ℓ^+) and the z axis, in the J/ψ rest frame. The angle φ is the azimuthal angle of ℓ^+ in the same frame. In the ϕ meson rest frame, ψ is the angle between $\vec{p}(K^+)$ and $-\vec{p}(J/\psi)$.

Channel	Event yield	B_{Pr}/S	B_{LL}/S
$B_s^0 \to J/\psi(\mu\mu)\phi(KK)$	117 k	1.6	0.5
$B^0 \to J/\psi(\mu\mu)K^{*0}(K\pi)$	489 k	5.2	1.5
$B^+ \to J/\psi(\mu\mu)K^+$	942 k	1.6	0.3

Table 1: Untagged event yield for selected and triggered events after $2\,\mathrm{fb}^{-1}$, background over signal ratio estimated in a $\pm 50\,\mathrm{MeV}/c^2$ mass window for the prompt and the long-lived components.

2.2 $B_s^0 \to \phi\phi$

For the $B_s^0 \to \phi\phi$ channel, both ϕ mesons are reconstructed from two kaons [7]. The B_s^0 mass resolution is $12\,\mathrm{MeV}/c^2$, the proper time resolution 43 fs and the total trigger efficiency is $\sim 22\%$, since there is no muon in the final state. The branching ratio of $B_s^0 \to \phi\phi$ has been recently updated by the CDF collaboration [8] and is: $\mathscr{B}(B_s^0 \to \phi\phi) = [24 \pm 2.1(\mathrm{stat}) \pm 2.7(\mathrm{syst}) \pm 8.2(\mathrm{BR})] \times 10^{-6}$. Assuming this value, we expect 6 200 untagged $B_s^0 \to \phi\phi$ events per $2\,\mathrm{fb}^{-1}$ of data. The background over signal ratio is estimated from a sample of inclusive $b\bar{b}$ to be below 0.8 at 90% CL.

3. Flavour tagging

The flavour tagging algorithm and its calibration in LHCb are described in [9, 6]. It is characterized by a mistag rate ($\omega = W/(W+R)$), a tagging efficiency ($\varepsilon_{\mathrm{tag}} = (W+R)/(W+R+U)$) and an effective tagging efficiency $\varepsilon_{\mathrm{eff}} = \varepsilon_{\mathrm{tag}}(1-2\omega)^2$, where W, R and U denotes the number of events wrongly tagged, correctly tagged and untagged. Within each event, all available information is used and combined using a neural network. The combined flavour tagging performance are summarized in Table 2 for $B_s^0 \to J/\psi\phi$, $B^0 \to J/\psi K^{*0}$, $B^+ \to J/\psi K^+$ and $B_s^0 \to \phi\phi$.

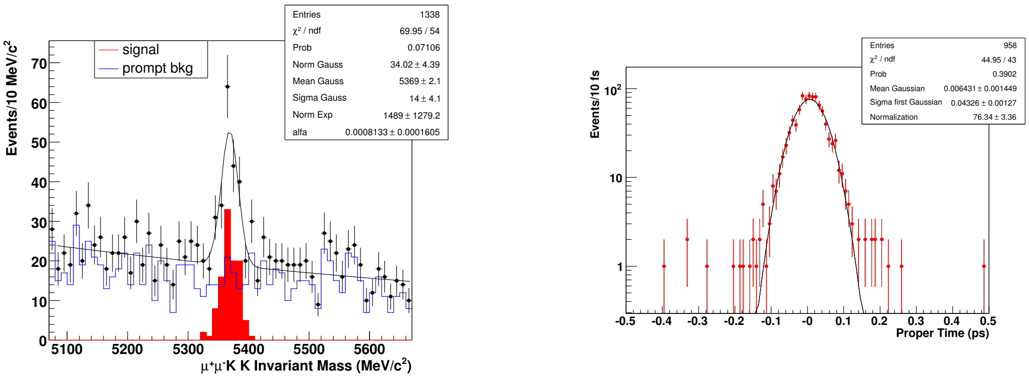

Figure 5: $B_s^0 \to J/\psi\phi$ candidates in a sample of inclusive prompt $J/\psi(\mu\mu)$ events: invariant mass (left) and proper time distribution for the prompt component, where the true signal events have been removed (right) [10].

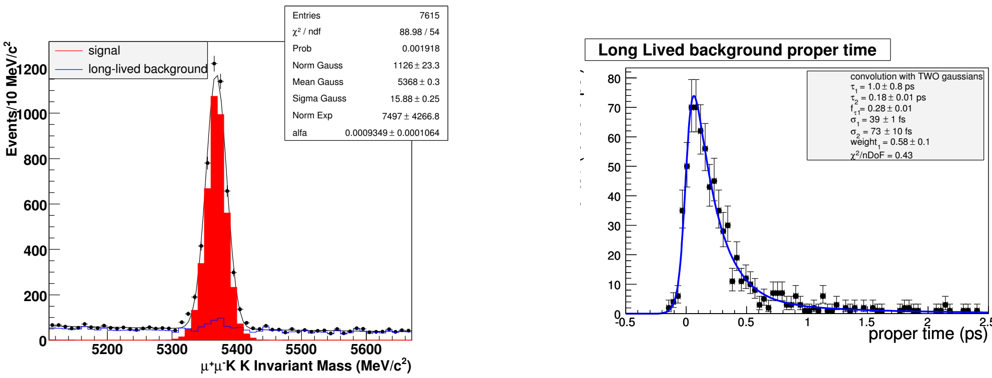

Figure 6: $B_s^0 \to J/\psi\phi$ candidates in a sample of inclusive $B_{u,d,s} \to J/\psi X$ events: invariant mass (left) and proper time distribution for the long-lived background component (right) [10].

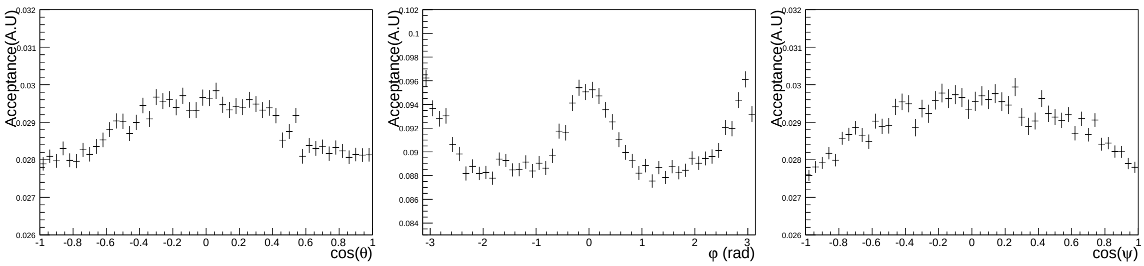

Figure 7: Angular acceptance for reconstructed, selected and L0-triggered $B_s^0 \to J/\psi\phi$ events ($\cos\theta$, ϕ and $\cos\psi$ angles). The plots are zero-suppressed [10].

4. Fits and systematics

The details of the fitting procedure to determine the 8 physics parameters from the observables are given in [11, 12, 13] for $B_s^0 \to J/\psi\phi$ and in [7] for $B_s^0 \to \phi\phi$. Here we summarize the $B_s^0 \to J/\psi\phi$ fitting procedure. The eight physics parameters $\{\phi_s^{J/\psi\phi}, \Gamma_s, \Delta\Gamma_s, R_\perp, R_0, \delta_\perp, \delta_\parallel, \Delta m_s\}$ are determined by an unbinned likelihood fit to six physical observables (mass, proper time, initial flavour and three transversity angles), taking into account 18 detector parameters. The total PDF is the sum of the

Channel	$\varepsilon_{\rm tag}^{\rm comb}$ [%]	$\omega^{\rm comb}$ [%]	$\varepsilon_{\rm eff}^{\rm comb}$ [%]
$B_s^0 \to J/\psi(\mu\mu)\phi(KK)$	55.71 ± 0.17	33.27 ± 0.21	6.23 ± 0.15
$B^0 \to J/\psi(\mu\mu)K^{*0}(K\pi)$	53.60 ± 0.15	35.48 ± 0.19	4.52 ± 0.11
$B^+ \to J/\psi(\mu\mu)K^+$	52.76 ± 0.14	35.48 ± 0.18	4.45 ± 0.10
$B_s^0 \to \phi\phi$	~ 60	~ 30	~ 9.6

Table 2: Combined flavour tagging efficiency, mistag and effective tagging efficiency for $B_s^0 \to J/\psi\phi$, $B^0 \to J/\psi K^{*0}$, $B^+ \to J/\psi K^+$ and $B_s^0 \to \phi\phi$ events. For $B_s^0 \to \phi\phi$, only rough estimates are given.

Parameter	Variation	$\lvert\phi_s^{\rm wrong} - \phi_s^{\rm true}\rvert/\phi_s^{\rm true}$
Angular distortions	$\pm 5\%$	7%
Proper time resolution	(38 ± 5) fs	6%
Mistag	$(34 \pm 1)\%$	7%

Table 3: Relative systematic variation on $\phi_s^{J/\psi\phi}$ (column 3), due to parameter variations (columns 1 and 2).

signal PDF plus two PDFs for modelling the prompt and the long-lived background. The proper time resolution, angular acceptance and mistag fraction are taken into account. The projections of data and fitted probability density function on the transversity angles and on the proper time can be found in Figure 8. The fitted PDFs and data show very good agreement. Using hundreds of toy Monte Carlo experiments, the statistical sensitivity of $\phi_s^{J/\psi\phi}$ is estimated to be 0.03 rad, for a dataset corresponding to $2\,{\rm fb}^{-1}$. A summary of the systematic effects is given in Table 3. No limiting systematic uncertainty has been identified. Figure 9 shows the statistical uncertainty on $\phi_s^{J/\psi\phi}$ versus the integrated luminosity. The Tevatron line is the combined CDF/DØ uncertainty in 2009 scaled to $18\,{\rm fb}^{-1}$, as expected for the Tevatron by the end of Run 2.

For $B_s^0 \to \phi\phi$, the statistical uncertainty is estimated to be 0.08 rad. The channel is expected to be statistics limited, therefore no exhaustive systematic studies have been performed so far.

5. Conclusions

The $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ channels will allow LHCb to probe possible New Physics effects in B_s^0–$\overline{B}_s^0$ box diagram and in b→s gluonic penguins diagrams. We have presented the work-plan to perform the measurement of the CP-violating weak phases in both channels. With $2\,{\rm fb}^{-1}$ of data, we expect a statistical sensitivity on $\phi_s^{J/\psi\phi}$ of 0.03 rad and on $\phi^{\phi\phi}$ of 0.08 rad. Should $\phi_s^{J/\psi\phi}$ be as large as the value currently preferred by the Tevatron data, it can be confirmed by LHCb with 5σ significance with only $0.2\,{\rm fb}^{-1}$ of data. A large value of $\phi_s^{J/\psi\phi}$ would be clear evidence for physics beyond the Standard Model.

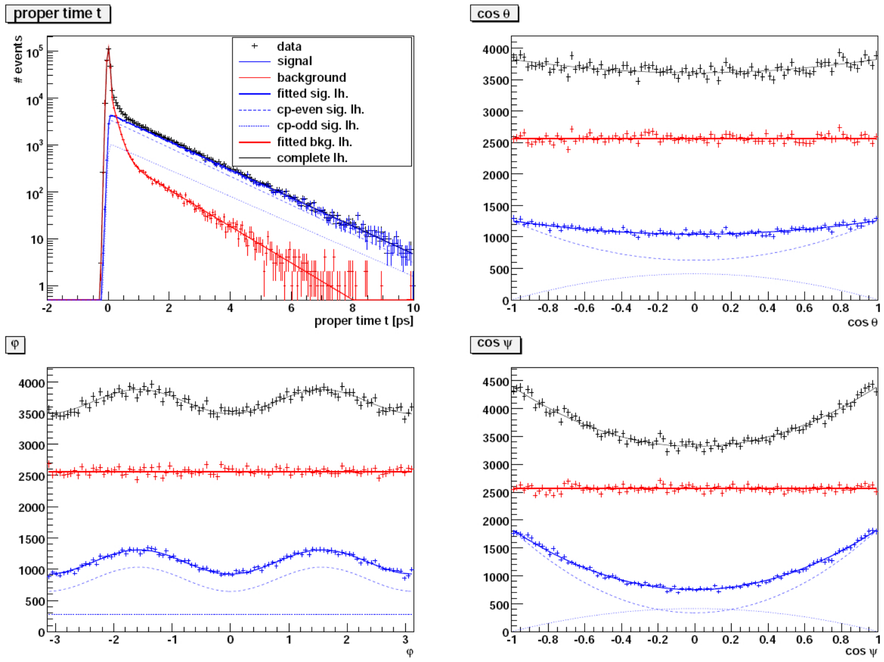

Figure 8: The projections of data and fitted signal PDF including both the angular and proper time acceptance effects, in a sample of toy MC events, including prompt and long-lived backgrounds. Also shown are the CP-even (dashed) and the CP-odd (dotted) signal components [12].

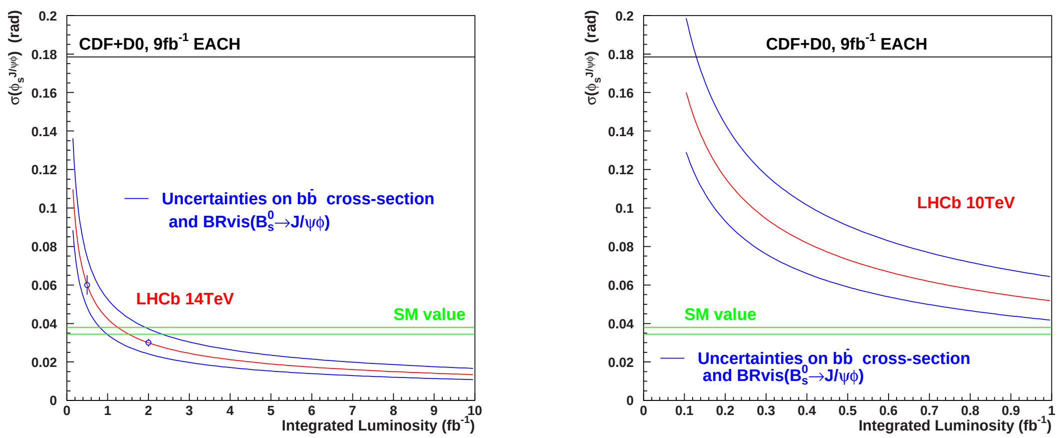

Figure 9: Red line: Statistical uncertainty on $\phi_s^{J/\psi\phi}$ versus the integrated luminosity. Blue line: uncertainties coming from the $b\bar{b}$ cross-section and the visible branching ratio on $B_s^0 \to J/\psi(\mu\mu)\phi(KK)$. The green band is the Standard Model value: $2\beta_s = (0.0360^{+0.0020}_{-0.0016})$ rad [2]. Left: from 0 to 10 fb^{-1}, assuming a centre-of-mass energy of 14 TeV. Right: zoom between 0 and 1 fb^{-1}, assuming a centre-of-mass energy of 10 TeV, as is expected for the early running of the LHC [14].

References

[1] H. Boos, T. Mannel and J. Reuter, "The gold-plated mode revisited: $\sin(2\beta)$ and $B^0 \to J/\psi K_S^0$ in the Standard Model", Phys. Rev. D 70, 036006 (2004);
S. Mishima, "Study of penguin pollution in the $B^0 \to J/\psi K_S^0$ decay", arXiv:hep-ph/0703193v1 (2007);
H. N. Li and S. Mishima, "Penguin pollution in the $B^0 \to J/\psi K_S^0$ decay", JHEP 0703, 009 (2007).
S. Faller, R. Fleischer and T. Mannel, "Precision physics with $B_s^0 \to J/\psi\phi$ at the LHC: The quest for New Physics", arXiv:0810.4248v1 [hep-ph] (2008).
M. Gronau and J. L. Rosner, "Doubly CKM-suppressed corrections to CP asymmetries in $B^0 \to J/\psi K_S^0$", arXiv:0812.4796 [hep-ph] (2008).

[2] J. Charles *et al.* (CKMfitter group), Eur. Phys. J. C41, 1-131 (2005), hep-ph/0406184, updated results and plots available at http://ckmfitter.in2p3.fr/

[3] CDF colaboration, "First flavor-tagged determination of bounds on mixing-induced CP violation in $B_s^0 \to J/\psi\phi$ decays", Phys. Rev. Lett. 100, 161802 (2008).
CDF collaboration, "An updated measurement of the CP violating phase $\phi_s^{J/\psi\phi}$", CDF/ANAL/BOTTOM/PUBLIC/9458 (2008).
DØ collaboration, "Measurement of B_s^0 mixing parameters from the flavor-tagged decay $B_s^0 \to J/\psi\phi$", Phys. Rev. Lett. 101, 241801 (2008).
CDF and DØ collaborations, "Combination of DØ and CDF results on $\Delta\Gamma_s$ and the CP-violationg phase $\beta_s^{J/\psi\phi}$", CDF/PHYS/BOTTOM/CDFR 9787, DØ note 59-28-CONF (2009).

[4] A. Dighe *et al.*, "Angular distribution and lifetime difference in $B_s^0 \to J/\psi\phi$ decays", arXiv:hep-ph/951136v1 (1995).

[5] P. Clarke *et al.*, "Determination of β_s in $B_s^0 \to J/\psi KK$ decays in the presence of a KK S-wave contribution", JHEP09 074 (2009) and LHCb-PUB-2009-007 (2009).

[6] M. Calvi *et al.*, "Calibration of flavour tagging with $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{*0}$ control channels at LHCb", LHCb-PUB-2009-020 (2009).

[7] S. Amato *et al.*, "LHCb's sensitivity to New CP-violating Phases in the Decay $B_s^0 \to \phi\phi$", LHCb note 2007-047 (2007).

[8] CDF colaboration, "First evidence for $B_s^0 \to \phi\phi$ decay and measurements of branching ratio and A_{CP} for $B^+ \to \phi K^+$ CDF collaboration, PhysṘevĹett .95, 031801 (2005).

[9] M. Calvi *et al.*, "Flavour tagging algorithms and performances in LHCb", LHCb note 2007-058 (2007).

[10] M. Calvi *et al.*, "Lifetime unbiased selection of $B_s^0 \to J/\psi\phi$ and related control channels: $B^0 \to J/\psi K^{*0}$ and $B^+ \to J/\psi K^+$", LHCb-PUB-2009-025 (2009).

[11] T. du Pree *et al.*, "Methods for angular analyses of $B \to J/\psi V$", LHCb-PUB-2009-024 (2009).

[12] C. Langenbruch *et al.*, "Fit of the decay $B_s^0 \to J/\psi\phi$", LHCb-PUB-2009-028 (2009).

[13] S. Vecchi *et al.*, "Systematic studies on the B_s^0 proper time measurement for the determination of the mixing phase ϕ_s in the channel $B_s^0 \to J/\psi\phi$", LHCb-PUB-2009-021.

[14] LHCb Collaboration, "Roadmap for selected key measurements of LHCb", LHCb-PUB-2009-029 and arXiv:0912.4179, (2009).