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CPV results from time-dependent analysis of $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$

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The $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay constitutes an excellent candidate to search for New Physics in the field of *CP* violation, and LHCb is the only current experiment capable of fully studying this channel. The first observation of this mode and the determination of its polarization fractions and time-integrated *CP* asymmetries are reviewed. The first time-dependent study aimed at measuring the mixing-induced *CP*-violating phase $\phi_s^{d\bar{d}}$ in this mode is also presented.

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1. Introduction

The $B_s^0 \to K^{*0}(892)\overline{K}^{*0}(892)$ decay (hereafter $K^{*0}(892)$ is referred to as K^{*0}) is sensitive to the *CP*-violating weak phase $\phi_s^{d\bar{d}}$, which arises in the interference between B_s^0 mesons decaying directly to $K^{*0}\overline{K}^{*0}$ and those decaying after $B_s^0 - \overline{B}_s^0$ oscillation. This phase is close to zero in the Standard Model (SM) and a deviation from this value would hint the presence of New Physics (NP). This mode has been discussed to be a golden channel for these kind of studies [1–7] for two main reasons. Firstly, it proceeds at leading order in the SM via a loop (penguin) transition, making the decay amplitude sensitive to new heavy particles entering the loop and affecting $\phi_s^{d\bar{d}}$. Secondly, the theoretical uncertainty on this phase due to higher order SM contributions can be controlled using the U-spin related channel $B^0 \to K^{*0}\overline{K}^{*0}$.

The LHCb detector [8, 9] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. This experiment is currently the only one able to measure $\phi_s^{d\bar{d}}$ in the $B_s^0 \to K^{*0}\overline{K}^{*0}$ mode, thanks to its excellent vertexing and tracking capabilities that allow to resolve the fast $B_s^0 - \overline{B}_s^0$ oscillations. The signal candidates are reconstructed in the final state $K^{*0}(\to K^+\pi^-)\overline{K}^{*0}(\to K^-\pi^+)$. Being this a pseudoscalar to vector-vector decay, an angular analysis is needed to disentangle the three existing polarisation amplitudes, A_L^{VV}, $A_\parallel^{VV}$ and $A_\perp^{VV}$. Experimentally, the presence of spurious partial waves from similar decays, which interfere with the signal mode, requires the inclusion of more amplitudes in the formalism. In order to measure $\phi_s^{d\bar{d}}$, the B_s^0 decay time distribution has to be studied and a flavour tagging algorithm has to be used to separate between B_s^0 and $\overline{B}_s^0$ at production time.

This document reviews the LHCb analyses corresponding to the first observation of the $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay and the measurement of its polarisation fractions and time-integrated *CP* asymmetries. It also presents the current status of the first study aimed at measuring the $\phi_s^{d\bar{d}}$ phase in $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ decays.

2. First observation of the $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay

The $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay was observed for the first time at LHCb [11], from a data sample corresponding to an integrated luminosity of 35 pb^{-1} obtained from proton-proton collisions at $\sqrt{s} = 7$ TeV.

The $K\pi$ pairs were constrained to have an invariant mass within a window of ± 150 MeV$/c^2$ around the K^{*0} nominal mass. As shown in Figure 1, a visible S-wave component was found, corresponding to the substitution of either one or both K^{*0} candidates by a scalar $K\pi$ pair. However, due to the limited statistics, this component was not further treated in the analysis.

An angular study, considering only the three vector-vector amplitudes, was performed to determine the polarisation fractions of the $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay. These measurements were updated in the next analysis reviewed in this document.

3. Measurement of polarisation fractions and time-integrated *CP* asymmetries

The second LHCb analysis of this decay [12] used a larger data sample of 1 fb^{-1} obtained from proton-proton collisions at $\sqrt{s} = 7$ TeV. Three additional S-wave amplitudes, A^{SS}, A^{SV} and

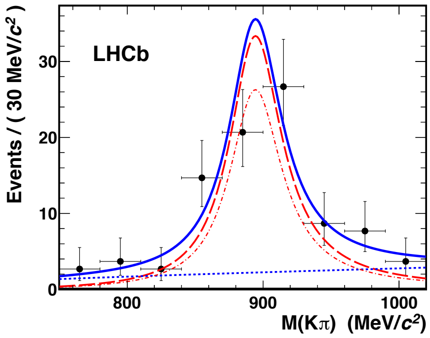

Figure 1: Background subtracted $K^+\pi^-$ and $K^-\pi^+$ combination [11]. The solid blue line represents the whole model, while the pure $B_s^0 \to K^{*0}\overline{K}^{*0}$ component is represented by a dashed-dotted red line. The blue dotted line represents the double S-wave and the dashed red line indicates the overall $B_s^0 \to K^{*0}X$ contribution.

A^{VS} (where S stands for scalar and V for vector), were considered in this occasion. When rotating into *CP* eigenstates, the last two amplitudes are rewritten as $A^{S+} \equiv 1/\sqrt{2}(A^{VS}+A^{SV})$ and $A^{S-} \equiv 1/\sqrt{2}(A^{VS}-A^{SV})$.

An angular analysis including the $K^+\pi^-$ and $K^-\pi^+$ invariant mass distributions was performed to determine the amplitude structure of the decay. The results are shown in Table 1 and the corresponding plots in Figure 2.

Complementary to the angular analysis, the accessible flavour-untagged and time-integrated *CP* asymmetries were determined. They correspond to triple-products, $\mathscr{A}_T$, and S-wave induced direct *CP*-asymmetries, $\mathscr{A}_D$ [10], all of which are expected to be negligible within the SM framework. These asymmetries were found to be compatible with zero, as can be seen in Table 2. No attempt was done to measure $\phi_s^{d\bar{d}}$, given the limited statistics of the data sample.

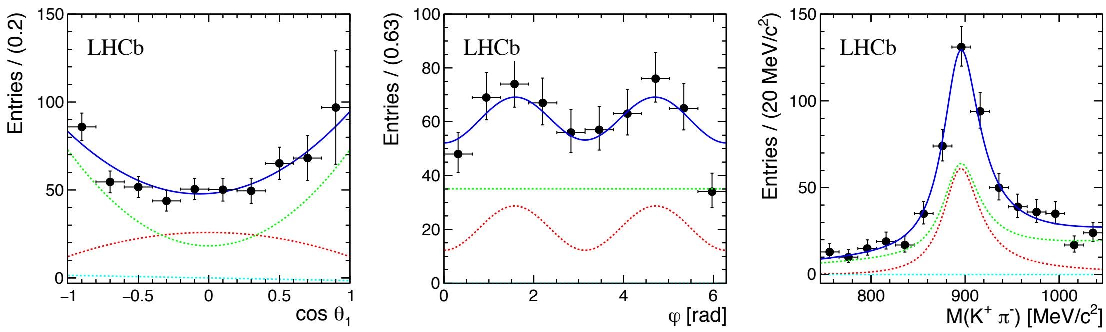

Figure 2: Projections in two angular variables (left and center) and one mass variable (right) of background subtracted and acceptance corrected data, along with the fit model (solid blue line) [12]. The $B_s^0 \to K^{*0}\overline{K}^{*0}$ component is represented by a dashed red line, the S-wave by a dashed green line and the $A^{S+}A_L^{VV}$ interference term by a dashed light-blue line.

Parameter	Value ± stat. ± syst.	Parameter	Value ± stat. ± syst.
f_L^{VV}	$0.201 \pm 0.057 \pm 0.040$	$\delta_{\parallel}^{VV}$	$5.31 \pm 0.24 \pm 0.14$
$f_{\parallel}^{VV}$	$0.215 \pm 0.046 \pm 0.015$	$\delta_{\perp}^{VV} - \delta^{S+}$	$1.95 \pm 0.21 \pm 0.04$
$\|A^{S+}\|^2$	$0.114 \pm 0.037 \pm 0.023$	δ^{S-}	$1.79 \pm 0.19 \pm 0.19$
$\|A^{S-}\|^2$	$0.485 \pm 0.051 \pm 0.019$	δ^{SS}	$1.06 \pm 0.27 \pm 0.23$
$\|A^{SS}\|^2$	$0.066 \pm 0.022 \pm 0.007$		

Table 1: Results of the angular and $K\pi$ invariant mass fit to $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ events including six polarisation amplitudes [12].

Parameter	Value ± stat. ± syst.	Parameter	Value ± stat. ± syst.
$\mathscr{A}_T^1$	$0.003 \pm 0.041 \pm 0.009$	$\mathscr{A}_D^1$	$-0.061 \pm 0.041 \pm 0.012$
$\mathscr{A}_T^2$	$0.009 \pm 0.041 \pm 0.009$	$\mathscr{A}_D^2$	$0.081 \pm 0.041 \pm 0.008$
$\mathscr{A}_T^3$	$0.019 \pm 0.041 \pm 0.008$	$\mathscr{A}_D^3$	$-0.079 \pm 0.041 \pm 0.023$
$\mathscr{A}_T^4$	$-0.040 \pm 0.041 \pm 0.008$	$\mathscr{A}_D^4$	$-0.081 \pm 0.041 \pm 0.010$

Table 2: Measured triple products and S-wave induced direct *CP* asymmetries [12].

4. Measurement of the $\phi_s^{d\bar{d}}$ phase in $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ decays

The first LHCb analysis aimed at measuring $\phi_s^{d\bar{d}}$ in the $B_s^0 \to K^{*0}\overline{K}^{*0}$ mode uses 1 fb^{-1} of data from proton-proton collisions recorded at $\sqrt{s} = 7$ TeV and 2 fb^{-1} recorded at $\sqrt{s} = 8$ TeV. With the goal of maximising the sensitivity on this phase, the analysis follows the approach of studying within a common framework the main $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ modes contributing in a wide $K\pi$ mass window, from 750 MeV/c^2 to 1600 MeV/c^2. The considered quasi-two-body decays correspond to the possible combinations of scalar (such as the $K_0^*(1430)^0$ resonance), vector (such as the K^{*0} resonance) and tensor (such as the $K_2^*(1430)^0$ resonance) $K\pi$ components. For illustration, Figure 3 shows the two-body mass spectrum of selected events within the large mass window.

One advantage of this extended approach is that the shape and size of the large S-wave component can be better determined. A second and more important consideration is that these channels share, at leading order in the SM, the same electroweak decay structure. This supports the approximation of using only one $\phi_s^{d\bar{d}}$ phase for all them, consequently increasing the available statistics and, therefore, the sensitivity on this phase.

After performing an event selection, more than 6000 signal candidates (LHCb preliminary) are found, as measured from a four-body mass fit whose result is visualised in Figure 4. The $\phi_s^{d\bar{d}}$ phase is measured through a flavour-tagged time-dependent angular and $K\pi$ mass fit to the background subtracted data sample. The previous model, which considered the 6 helicity amplitudes that are needed to describe the $B_s^0 \to K^{*0}\overline{K}^{*0}$ and the S-wave contributions, has to be upgraded in order to account for a total of 19 helicity amplitudes, which arise from the inclusion of the aforementioned scalar, vector and tensor components. The variation of the efficiency with respect to all the involved variables is accounted for during fitting, as well as the effect of the decay time resolution. The LHCb tagging algorithms provide for this modes an effective tagging power (defined as the fraction

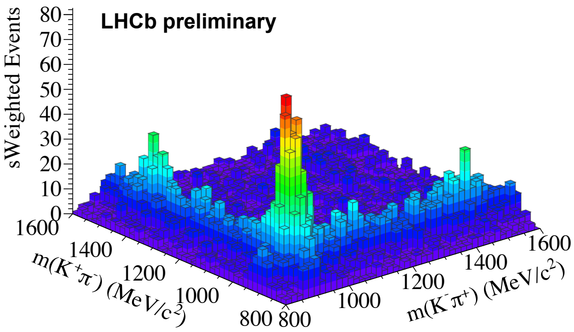

Figure 3: Background subtracted two-body mass distribution of $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ events.

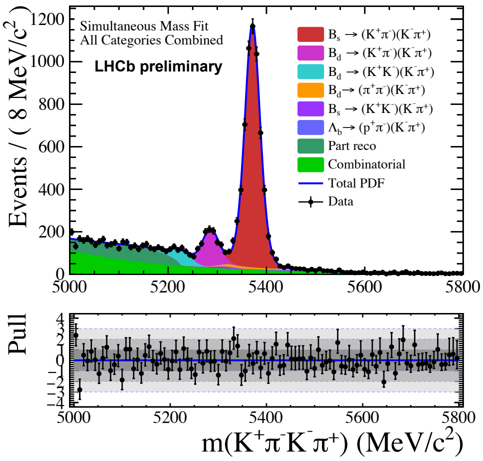

Figure 4: Four-body mass data distribution.

of correctly tagged events) close to 5% (LHCb preliminary).

The statistical uncertainty on $\phi_s^{d\bar{d}}$ obtained from the fit is less than 0.2 rad (LHCb preliminary). This analysis is currently under internal review by the LHCb Collaboration. Public results are to be expected soon.

5. Summary

The $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay mode is a golden channel in the search for New Physics in *CP* violation, specially when its *CP* violating weak phase $\phi_s^{d\bar{d}}$ is measured through a flavour-tagged and time-dependent analysis. The LHCb Collaboration has observed this mode and performed an angular analysis to determine its polarisation fractions. The *CP* asymmetries accessible from an untagged and time-integrated study have been measured and found to be compatible with the SM expectations. The first analysis aimed at measuring $\phi_s^{d\bar{d}}$ in $B_s^0 \to K^{*0}\overline{K}^{*0}$ performs a combined study of $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ decays to scalar, vector and tensor $K\pi$ pairs to increase the data sample size, which has a direct impact in the sensitivity that can be reached on $\phi_s^{d\bar{d}}$. This analysis is currently under internal review by the LHCb Collaboration and its results are expected soon.

References

[1] R. Fleischer, *Extracting CKM phases from angular distributions of B(d,s) decays into admixtures of CP eigenstates*, Phys. Rev. **D60** (1999) 073008, arXiv:hep-ph/9903540

[2] R. Fleischer and M. Gronau, *Studying new physics amplitudes in charmless $B_{(s)}$ decays*, Phys. Lett. **B660** (2008) 212, arXiv:0709.4013

[3] M. Ciuchini, M. Pierini, and L. Silvestrini, *$B_s^0 \to K^{(*)0}\bar{K}^{(*)0}$ decays: The Golden channels for new physics searches*, Phys. Rev. Lett. **100** (2008) 031802, arXiv:hep-ph/0703137

[4] S. Descotes-Genon, J. Matias, and J. Virto, *Penguin-mediated $B_{d,s} \to VV$ decays and the $B_s - \bar{B}_s$ mixing angle*, Phys. Rev. **D76** (2007) 074005, arXiv:0705.0477, [Erratum: Phys. Rev.D84,039901(2011)]

[5] S. Descotes-Genon, J. Matias, and J. Virto, *An analysis of $B_{d,s}$ mixing angles in presence of New Physics and an update of $B_s \to K^{0*}\bar{K}^{0*}$*, Phys. Rev. **D85** (2012) 034010, arXiv:1111.4882

[6] B. Bhattacharya, A. Datta, M. Imbeault, and D. London, *Measuring β_s with $B_s \to K^{0(*)}\bar{K}^{0(*)}$ – a Reappraisal*, Phys. Lett. **B717** (2012) 403, arXiv:1203.3435

[7] B. Bhattacharya, A. Datta, M. Duraisamy, and D. London, *Searching for new physics with $\bar{b} \to \bar{s}$ $B_s^0 \to V_1V_2$ penguin decays*, Phys. Rev. **D88** (2013), no.~1 016007, arXiv:1306.1911

[8] LHCb collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, JINST **3** (2008) S08005

[9] LHCb collaboration, R. Aaij *et al.*, *LHCb detector performance*, Int. J. Mod. Phys. **A30** (2015) 1530022, arXiv:1412.6352

[10] A. Datta and D. London, *Triple-product correlations in $B \to V_1V_2$ decays and new physics*, Int. J. Mod. Phys. **A19** (2004), no.~15 2505, arXiv:hep-ph/0303159

[11] LHCb collaboration, R. Aaij *et al.*, *First observation of the decay $B_s^0 \to K^{*0}\overline{K}^{*0}$*, Phys. Lett. **B709** (2012) 50, arXiv:1111.4183

[12] LHCb collaboration, R. Aaij *et al.*, *Measurement of CP asymmetries and polarisation fractions in $B_s^0 \to K^{*0}\overline{K}^{*0}$ decays*, JHEP **07** (2015) 166, arXiv:1503.05362