Supplementary material for LHCb-PAPER-2019-013

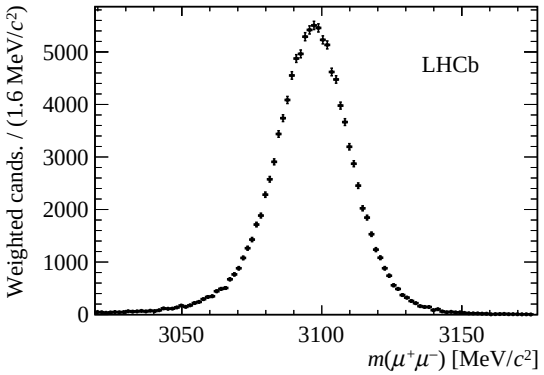

Figure 1: Background-subtracted distribution of the $\mu^+\mu^-$ invariant mass from selected $B_s^0 \to J/\psi K^+K^-$ decays.

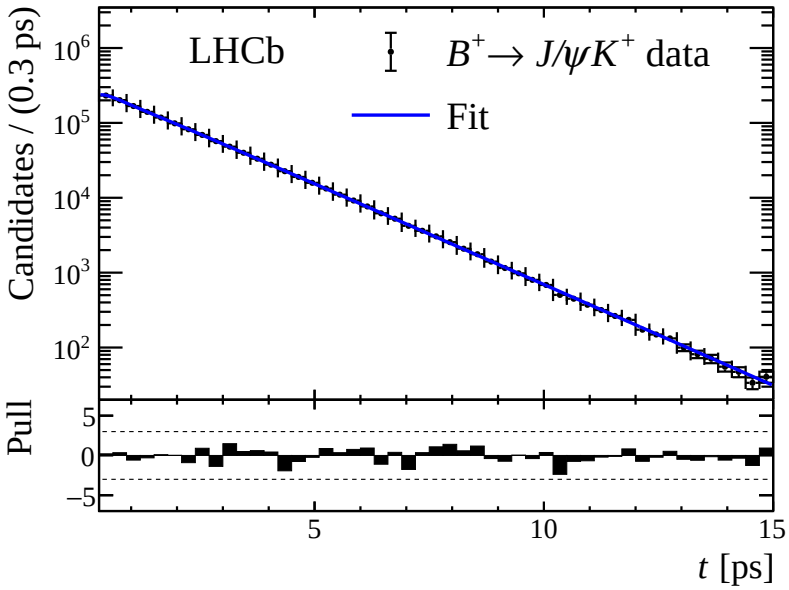

Figure 2: Projection of the fit to the decay-time distribution of $B^+ \to J/\psi K^+$ candidates. The blue line shows the fit function and the black points the data.

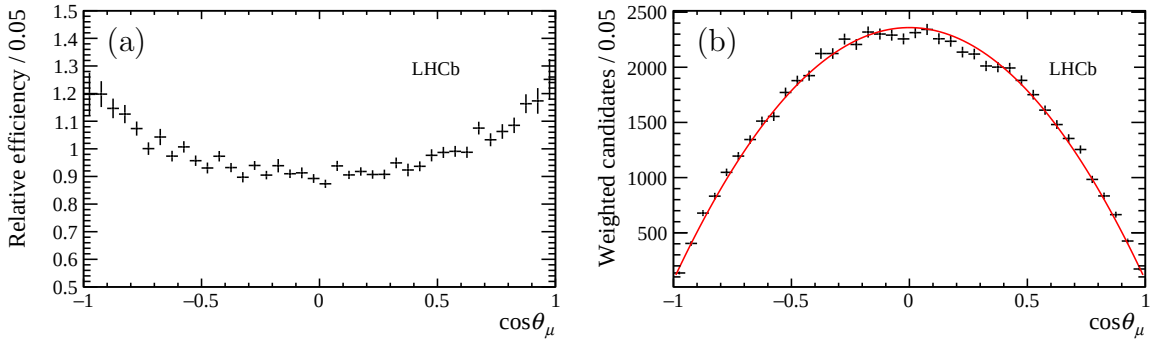

Figure 3: (a) Ratio of the simulated $\cos\theta_\mu$ distribution with the theoretical distribution ($\sin^2\theta_\mu$) for simulated $B^+ \to J/\psi K^+$ decays in the pseudorapidity range 2–2.5. (b) Distribution of efficiency-corrected and background-subtracted $\cos\theta_\mu$ for selected $B^+ \to J/\psi K^+$ decays in the pseudorapidity range 2–2.5. The red line shows the fit projection using $f(\cos\theta_\mu) = a(1+b\cos^2\theta_\mu)$.

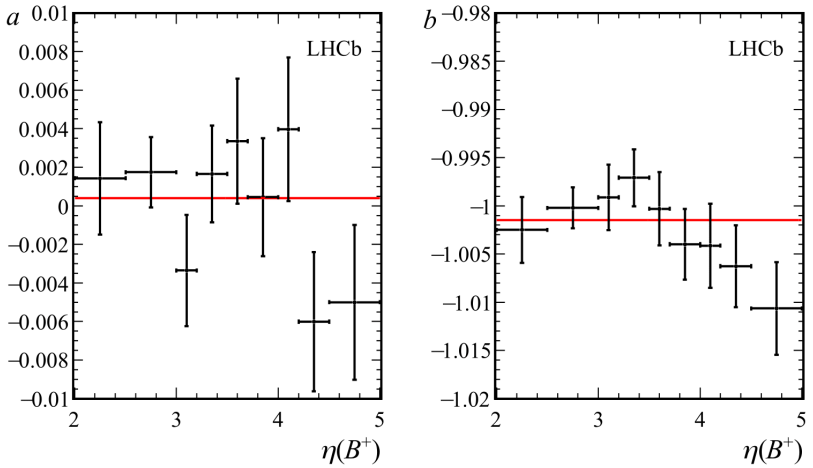

Figure 4: Values of the (left) a and (right) b parameters, obtained from a fit to the $\cos\theta_\mu$ distributions of $B^+ \to J/\psi K^+$ candidates with the function $f(\cos\theta_\mu) = a(1 + b\cos^2\theta_\mu)$, as a function of $\eta(B^+)$. The red line shows the result of a χ^2 fit of a constant line to the points. A consistency of a with a constant and b with -1 indicates a perfect efficiency correction.

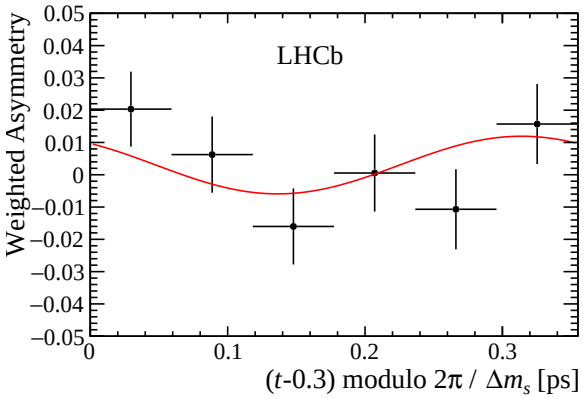

Figure 5: Observed *CP* asymmetry in data (black points) folded in one B_s^0 oscillation period. Per-event angular-dependent weights are applied to data to enhance the projection. The weights are calculated as $w(\Omega) = \frac{(f_1(\Omega)\cdot N_1 + f_2(\Omega)\cdot N_2) - (f_3(\Omega)\cdot N_3 + f_7(\Omega)\cdot N_7)}{(f_1(\Omega)\cdot N_1 + f_2(\Omega)\cdot N_2) + (f_3(\Omega)\cdot N_3 + f_7(\Omega)\cdot N_7)}$, where the individual terms are defined in Ref. [1]. The PDF (red line) was produced using pseudoexperiments with inputs from the baseline fit result, where the angular efficiency, decay-time efficiency and time-resolution effects are taken into account and perfect tagging is assumed. To account for tagging effects, the resulting distribution is multiplied by the average dilution, $(1 - 2\langle\omega_{\rm tag}\rangle)$, obtained by applying the tagging calibration on the data sample.

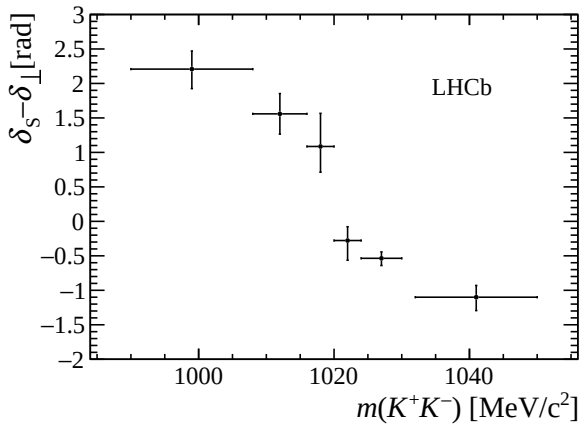

Figure 6: Phase difference $\delta_S - \delta_\perp$ in bins of $m(K^+K^-)$. The statistical and systematic uncertainties are summed in quadrature.

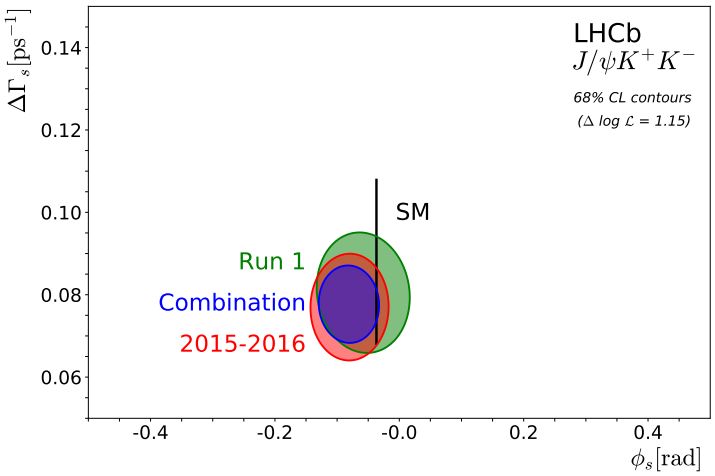

Figure 7: Regions of 68% confidence level in the ϕ_s-$\Delta\Gamma_s$ plane for the Run 1 (in green) and Run 2 (in red) $B_s^0 \to J/\psi K^+K^-$ measurements and a combined contour (in blue). The ϕ_s [2] and $\Delta\Gamma_s$ [3] predictions are indicated by the thin black rectangle.

Results of the combination of the Run 1 and Run 2 $B_s^0 \to J/\psi K^+K^-$ LHCb analyses. The corresponding correlation matrix is given in Table 1.

$$\begin{aligned}
\phi_s &= -0.081 \pm 0.032\,\text{rad}\,, \\
|\lambda| &= 0.994 \pm 0.013\,, \\
\Gamma_s &= 0.6572 \pm 0.0023\,\text{ps}^{-1}\,, \\
\Delta\Gamma_s &= 0.0777 \pm 0.0062\,\text{ps}^{-1}\,, \\
\Delta m_s &= 17.694 \pm 0.042\,\text{ps}^{-1}\,, \\
|A_\perp|^2 &= 0.2489 \pm 0.0035\,, \\
|A_0|^2 &= 0.5195 \pm 0.0034\,, \\
\delta_\perp - \delta_0 &= 2.87 \pm 0.11\,\text{rad}\,, \\
\delta_\parallel - \delta_0 &= 3.153 \pm 0.079\,\text{rad}, \\
\Gamma_d &= 0.6590 \pm 0.0016\,\text{ps}^{-1}.
\end{aligned}$$

Table 1: Correlation matrix of the combined Run 1 and Run 2 measurements of $B_s^0 \to J/\psi K^+K^-$, including statistical and systematic correlations.

	ϕ_s	$\lvert\lambda\rvert$	Γ_s	$\Delta\Gamma_s$	Δm_s	$\lvert A_\perp\rvert^2$	$\lvert A_0\rvert^2$	$\delta_\perp - \delta_0$	$\delta_\parallel - \delta_0$	Γ_d
ϕ_s	1.00	0.10	−0.02	−0.03	0.02	0.01	−0.01	0.07	0.00	0.01
$\lvert\lambda\rvert$		1.00	0.04	−0.04	−0.05	0.03	−0.02	−0.04	0.03	−0.01
Γ_s			1.00	−0.35	0.04	0.28	−0.17	0.01	0.01	0.39
$\Delta\Gamma_s$				1.00	−0.01	−0.62	0.40	−0.05	−0.01	0.04
Δm_s					1.00	0.01	−0.01	0.62	0.02	0.00
$\lvert A_\perp\rvert^2$						1.00	−0.67	0.03	0.01	−0.02
$\lvert A_0\rvert^2$							1.00	−0.06	−0.06	0.01
$\delta_\perp - \delta_0$								1.00	0.28	0.00
$\delta_\parallel - \delta_0$									1.00	−0.01
Γ_d										1.00

Results of the combination of all LHCb measurements of ϕ_s. The corresponding correlation matrix is given in Table 2.

$$\begin{aligned}
\phi_s &= -0.042 \pm 0.025\,\text{rad} \\
|\lambda| &= 0.993 \pm 0.010 \\
\Gamma_s &= 0.6563 \pm 0.0021\,\text{ps}^{-1} \\
\Delta\Gamma_s &= 0.0813 \pm 0.0048\,\text{ps}^{-1} \\
\Delta m_s &= 17.694 \pm 0.042\,\text{ps}^{-1} \\
|A_\perp|^2 &= 0.2476 \pm 0.0032 \\
|A_0|^2 &= 0.5204 \pm 0.0033 \\
\delta_\perp &= 2.88 \pm 0.11\,\text{rad} \\
\delta_\parallel &= 3.152 \pm 0.079\,\text{rad} \qquad (1) \\
\Gamma_d &= 0.6592 \pm 0.0016\,\text{ps}^{-1}
\end{aligned}$$

Table 2: Correlation matrix of the combined LHCb ϕ_s measurements, including statistical and systematic correlations.

	Γ_s	$\Delta\Gamma_s$	$\lvert A_\perp\rvert^2$	$\lvert A_0\rvert^2$	$\delta_\parallel$	$\delta_\perp$	ϕ_s	$\lvert\lambda\rvert$	Δm_s	Γ_d
Γ_s	1.00	−0.17	0.16	−0.08	0.00	0.00	−0.01	0.03	0.03	0.48
$\Delta\Gamma_s$		1.00	−0.50	0.32	0.00	−0.04	−0.03	−0.02	0.00	−0.03
$\lvert A_\perp\rvert^2$			1.00	−0.64	0.00	0.03	0.01	0.02	0.00	0.03
$\lvert A_0\rvert^2$				1.00	−0.06	−0.05	−0.01	−0.02	−0.01	−0.01
$\delta_\parallel$					1.00	0.28	0.00	0.02	0.02	−0.01
$\delta_\perp$						1.00	0.05	−0.03	0.62	0.00
ϕ_s							1.00	0.06	0.02	0.00
$\lvert\lambda\rvert$								1.00	−0.04	0.00
Δm_s									1.00	0.01
Γ_d										1.00

References

[1] LHCb collaboration, R. Aaij *et al.*, *Measurement of CP violation and the B_s^0 meson decay width difference with $B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi \pi^+\pi^-$ decays*, Phys. Rev. **D87** (2013) 112010, arXiv:1304.2600.

[2] CKMfitter group, J. Charles *et al.*, *Current status of the standard model CKM fit and constraints on $\Delta F = 2$ new physics*, Phys. Rev. **D91** (2015) 073007, arXiv:1501.05013, updated results and plots available at http://ckmfitter.in2p3.fr/.

[3] M. Artuso, G. Borissov, and A. Lenz, *CP violation in the B_s^0 system*, Rev. Mod. Phys. **88** (2016) 045002, arXiv:1511.09466.