

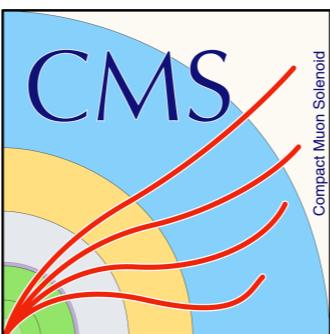
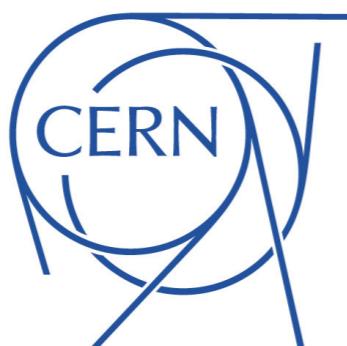
Measurement of the CP violating weak phase ϕ_s in the
 $B_s^0 \rightarrow J/\psi\phi \rightarrow \mu^+\mu^-K^+K^-$ decay process using the data collected by
CMS in proton-proton collision at $\sqrt{s} = 13$ TeV

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CMS public result : [here](#)
e-Print : [here](#)

Motivation (Rev. Mod. Phys., 88, 045002)

The source of CP violation in the Yukawa sector of SM:

- complex phase in CKM matrix, sensitive to new physics
- **overconstrain** the CKM unitarity triangle as many way as possible to look for new physics.
- the $B_s^0 \rightarrow J/\psi\phi \rightarrow \mu^+\mu^-K^+K^-$ comprises $b \rightarrow c\bar{c}s$ transition, and the resulting weak phase is given by,

$$\phi_s \simeq -2\beta_s, \quad \beta_s = \arg \left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right)$$

Current status of the precise values obtained from global fit,

$$\phi_s = -36.98^{+0.81}_{-0.70} \text{ mrad}, \quad \Delta\Gamma_s = 0.091 \pm 0.013 \text{ ps}^{-1}$$

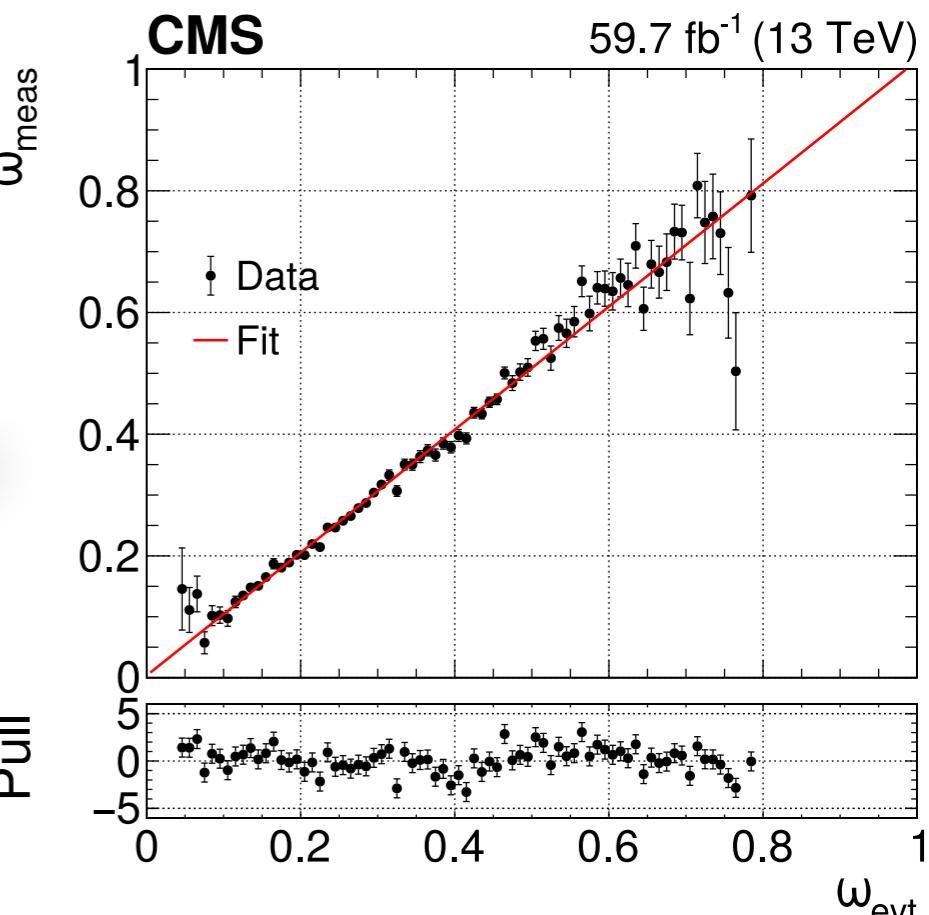
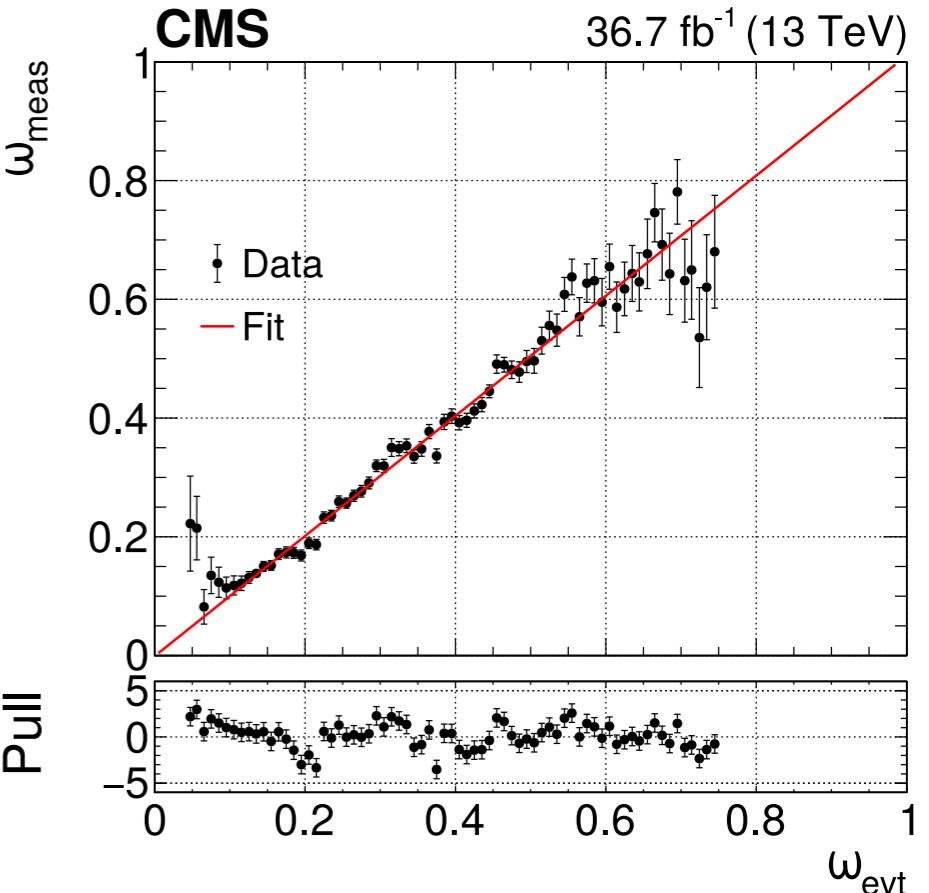
Identification of flavor specific modes

Distinguish B_s^0 and \bar{B}_s^0 at the time of production

Opposite Side taggers: exploit the decay products of the other b quark produced in the event with some figures of merit

- $\epsilon_{\text{tag}} = N_{\text{tag}}/N_{\text{total}}$: tagging efficiency;
- $\omega_{\text{tag}} = N_{\text{tag,wrong}}/N_{\text{tag}}$: per-event mistag probability evaluated with a DNN;
- $P_{\text{tag}} = \epsilon_{\text{tag}}(1 - 2\omega_{\text{tag}})^2$: tagging power.

Dataset	$\epsilon_{\text{tag}}(\%)$	$\omega_{\text{tag}}(\%)$	$P_{\text{tag}}(\%)$
2017	$(45.7 \pm 0.1)\%$	$(27.1 \pm 0.1)\%$	$(9.6 \pm 0.1)\%$
2018	$(50.9 \pm 0.1)\%$	$(27.3 \pm 0.1)\%$	$(10.5 \pm 0.1)\%$



Analysis

- The best B_s^0 vertex is obtained from a **Kalman Vertex** fit with the four tracks (μ^+, μ^-, K^+, K^-), and a biological evolution inspired Genetic Algorithm is used to optimize the physics selections.
- To extract the weak phase and decay width difference a multidimensional fit is employed to perform the time dependent angular analysis with three angles ($\cos\theta_T, \cos\psi_T, \phi_T$) defined in the transversity basis.
- The negative log likelihood of the unbinned multidimensional extended maximum-likelihood fitter is,

$$-\ln \mathcal{L} = - \sum_{i=0}^{N_{\text{evt}}} \ln P_i + N_{\text{tot}} - N_{\text{evt}} \ln N_{\text{tot}}, \quad P_i : \text{event pdf}, \quad N_{\text{evt}} = 65500$$

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- P_i includes signal model, background model and the proper time and angular efficiencies.

$$P_{\text{sig}} = \epsilon(ct) \epsilon(\Theta) [\tilde{\mathcal{F}}(\Theta, ct, \alpha) \otimes G(ct, \sigma_{ct})] P_{\text{sgn}}(m_{B_s^0}) P_{\text{sig}}(\sigma_{ct}) P(\xi)_{\text{sig}}$$

$$P_{\text{bkg}} = P_{\text{bkg}}(\cos\theta_T, \phi_T) P_{\text{bkg}}(\cos\psi_T) P_{\text{bkg}}(ct) P_{\text{bkg}}(m_{B_s^0}) P_{\text{bkg}}(\sigma_{ct}) P(\xi)_{\text{bkg}}$$

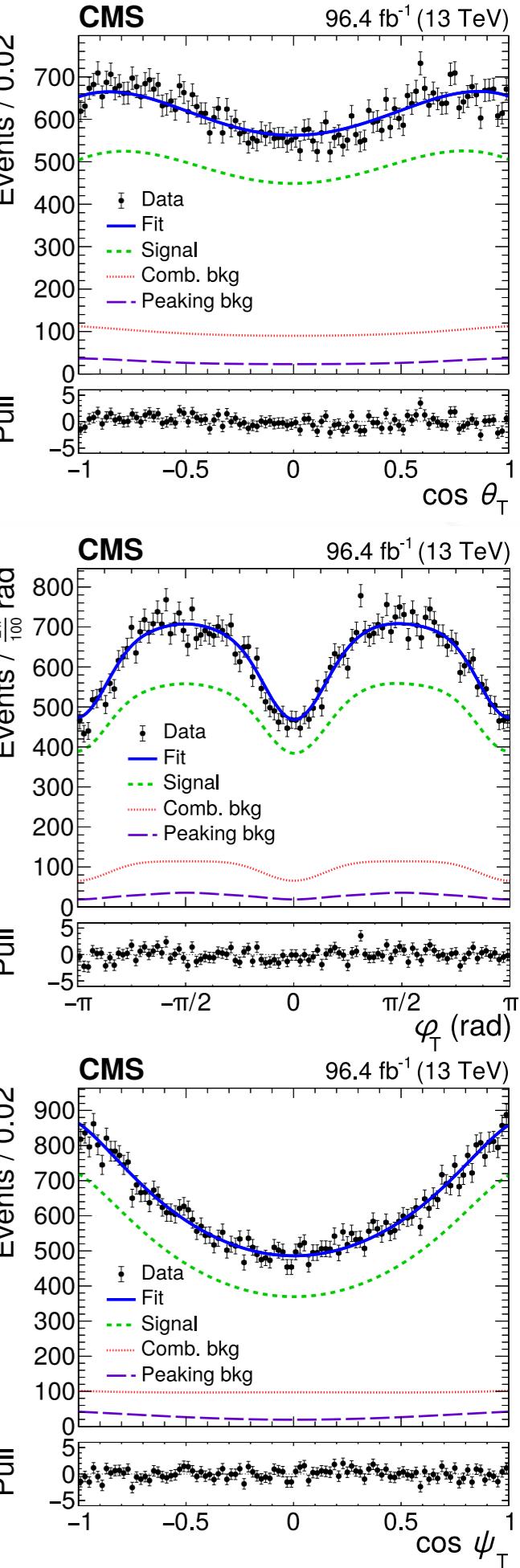


Table of systematic uncertainties

	ϕ_s [mrad]	$\Delta\Gamma_s$ [ps $^{-1}$]	Δm_s [\hbar ps $^{-1}$]	$ \lambda $	Γ_s [ps $^{-1}$]	$ A_0 ^2$	$ A_\perp ^2$	$ A_s ^2$	$\delta_{ }$ [rad]	δ_\perp [rad]	$\delta_{s\perp}$ [rad]
Statistical uncertainty	50	0.014	0.10	0.026	0.0042	0.0047	0.0063	0.0077	0.12	0.16	0.083
Model bias	7.9	0.0019	—	0.0035	0.0005	0.0002	0.0012	0.001	0.020	0.016	0.006
Angular efficiency	3.8	0.0006	0.007	0.0057	0.0002	0.0008	0.0010	0.002	0.006	0.015	0.015
Proper decay length efficiency	0.3	0.0062	0.001	0.0002	0.0022	0.0014	0.0023	0.001	0.001	0.002	0.002
Proper decay length resolution	2.5	0.0008	0.015	0.0009	0.0005	0.0007	0.0009	0.007	0.006	0.025	0.022
Data/simulation difference	0.6	0.0008	0.004	0.0003	0.0003	0.0044	0.0029	0.007	0.007	0.007	0.028
Flavor tagging	0.1	$<10^{-4}$	0.001	0.0002	$<10^{-4}$	0.0003	$<10^{-4}$	$<10^{-3}$	0.001	0.003	0.001
Sig./bkg. ω_{evt} difference	3.0	—	—	—	0.0005	—	0.0008	—	—	—	0.006
Model assumptions	—	0.0008	—	0.0046	0.0003	—	0.0013	0.001	0.017	0.019	0.011
Peaking background	0.3	0.0008	0.011	$<10^{-4}$	0.0002	0.0005	0.0002	0.003	0.005	0.007	0.011
<i>S-P</i> wave interference	—	0.0010	0.019	—	0.0005	0.0005	—	0.013	—	0.019	0.019
Total systematic uncertainty	9.6	0.0067	0.028	0.0082	0.0024	0.0048	0.0044	0.016	0.028	0.045	0.047

Results

The obtained final results at $\sqrt{s} = 13 \text{ TeV}$ are,

$$\begin{aligned}\phi_s &= -11 \pm 50 \text{ (stat)} \pm 10 \text{ (syst) mrad} \\ \Delta\Gamma_s &= 0.114 \pm 0.014 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1}\end{aligned}$$

consistent with the absence of CP violation in the mixing-decay interference. The $\sqrt{s} = 13 \text{ TeV}$ results are further combined with $\sqrt{s} = 8 \text{ TeV}$ results, the obtained combined results are,

$$\begin{aligned}\phi_s &= -21 \pm 45 \text{ mrad} \\ \Delta\Gamma_s &= 0.1073 \pm 0.0097 \text{ ps}^{-1}\end{aligned}$$

The two-dimensional likelihood contours at 68% CL in the ϕ_s - $\Delta\Gamma_s$ plane is consistent with current SM prediction.

