

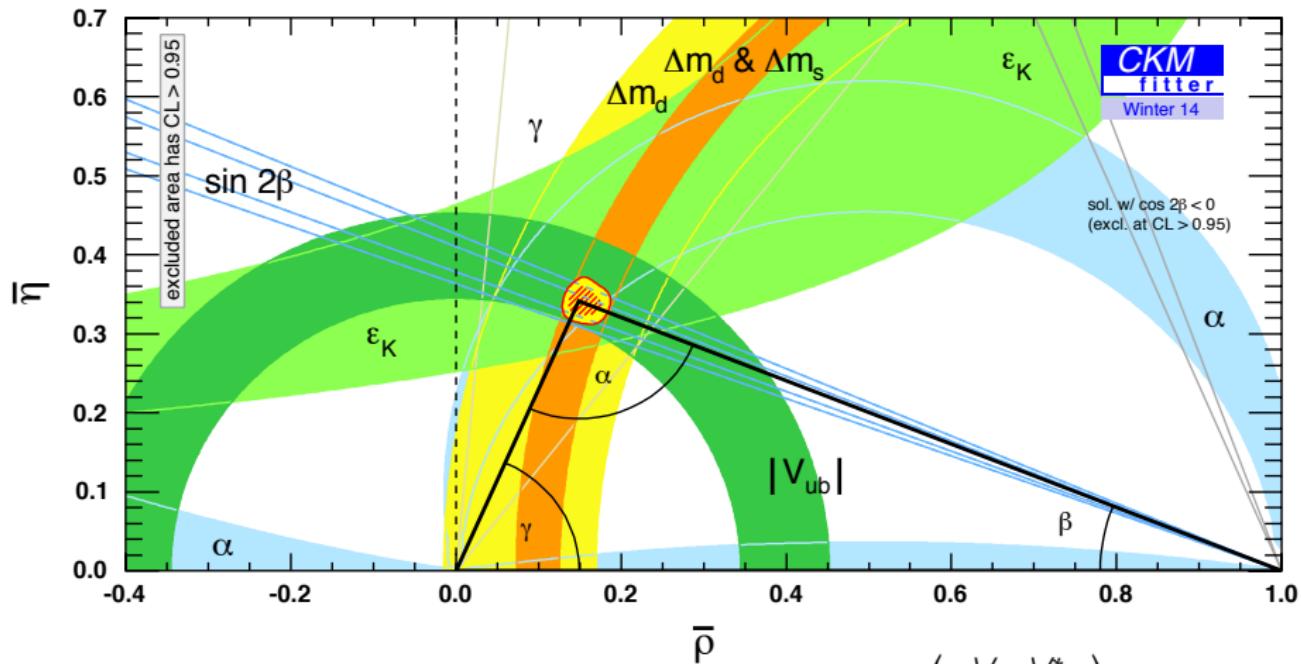
Measurement of CP violation in $B \rightarrow J/\psi K_s^0$ decays at LHCb

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CP violation in the SM quark sector

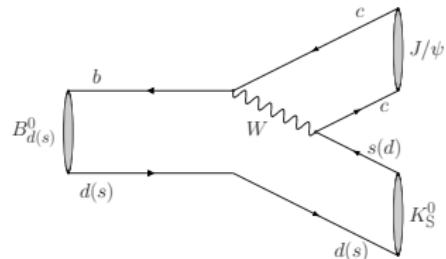
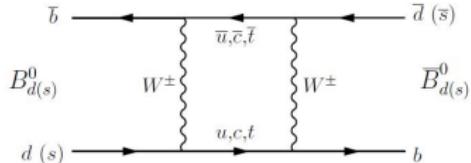


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \quad \beta = \arg \left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right)$$

- ▶ current world average: $\sin 2\beta = 0.679 \pm 0.020$

Time dependent CP asymmetry

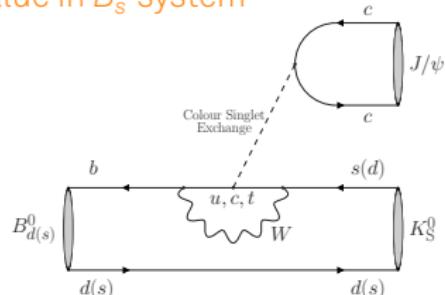
- ▶ CP violation in the interference between direct decay and decay after mixing



$$A(t) \equiv \frac{\Gamma(\bar{B}(t) \rightarrow J/\psi K_S^0) - \Gamma(B(t) \rightarrow J/\psi K_S^0)}{\Gamma(\bar{B}(t) \rightarrow J/\psi K_S^0) + \Gamma(B(t) \rightarrow J/\psi K_S^0)} = \frac{S \sin(\Delta m t) - C \cos(\Delta m t)}{\cosh(\Delta \Gamma t/2) + A_{\Delta \Gamma} \sinh(\Delta \Gamma t/2)}$$

- ▶ floating, constrained to HFAG values
- ▶ fixed to zero in B^0 system, constrained to HFAG value in B_s^0 system
- ▶ trivial in B^0 system, floating in B_s^0 system

- ▶ loop diagram suppressed in $B^0 \rightarrow J/\psi K_S^0$
- ▶ enhancement in $B_s^0 \rightarrow J/\psi K_S^0$ enables to control penguin topologies



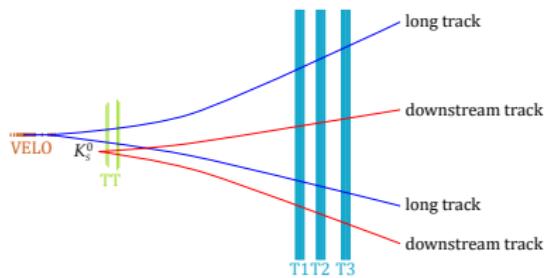
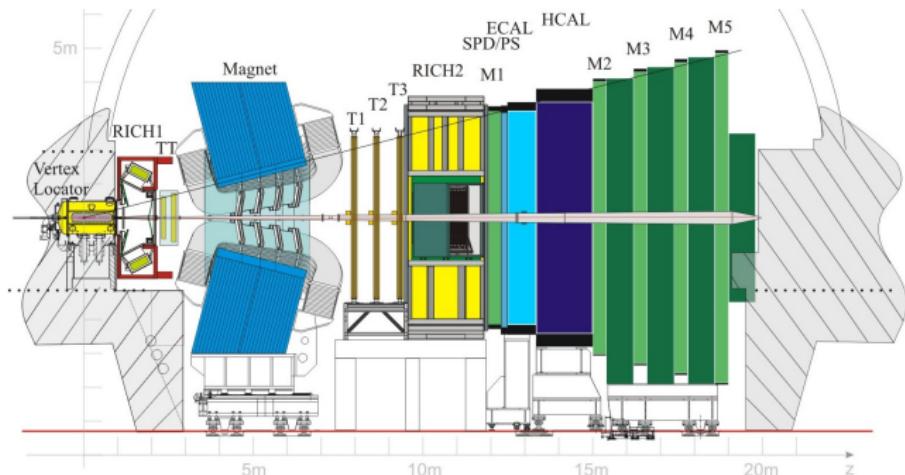
Current status

- ▶ no previous measurement of CP violation in $B_s^0 \rightarrow J/\psi K_s^0$
- ▶ previous measurements of LHCb and of B factories in $B^0 \rightarrow J/\psi K_s^0$

| Experiment | $S(B^0 \rightarrow J/\psi K_s^0)$ | $C(B^0 \rightarrow J/\psi K_s^0)$ |
|--|---|---|
| BaBar Phys. Rev. D 79 (2009) | $0.657 \pm 0.036 \text{ (stat)} \pm 0.012 \text{ (syst)}$ | $0.026 \pm 0.025 \text{ (stat)} \pm 0.016 \text{ (syst)}$ |
| Belle Phys. Rev. Lett. 108 (2012) | $0.670 \pm 0.029 \text{ (stat)} \pm 0.013 \text{ (syst)}$ | $0.015 \pm 0.021 \text{ (stat)} \pm^{0.023}_{0.045} \text{ (syst)}$ |
| LHCb (1 fb^{-1}) Phys. Lett. B 721 (2013) | $0.73 \pm 0.07 \text{ (stat)} \pm 0.04 \text{ (syst)}$ | $0.03 \pm 0.09 \text{ (stat)} \pm 0.01 \text{ (syst)}$ |

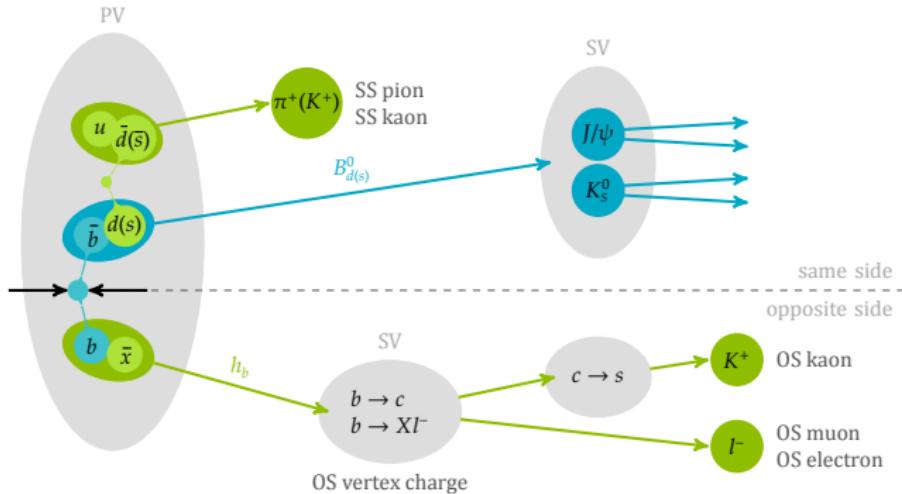
- ▶ new LHCb measurement using 3 fb^{-1} of pp -collisions
- ▶ final states $J/\psi \rightarrow \mu^+ \mu^-$ and $K_s^0 \rightarrow \pi^+ \pi^-$

LHCb Detector



- ▶ single-arm spectrometer ($2 < \eta < 5$)
- ▶ decay time resolution ~ 45 fs
- ▶ momentum resolution $\Delta p/p = 0.4 \% - 0.6 \%$
- ▶ impact parameter resolution $\sim 20 \mu\text{m}$

Flavour Tagging



- ▶ Tagging performance quantities
 - ▶ tagging efficiency ε_{tag}
 - ▶ mistag fraction ω
 - ▶ tagging power $\varepsilon_{\text{tag}}(1 - 2\omega)^2 = \varepsilon_{\text{tag}}D^2 \sim 3\%$

Flavour Tagging Calibration

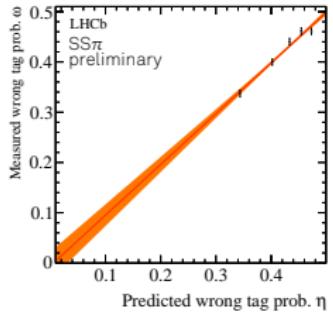
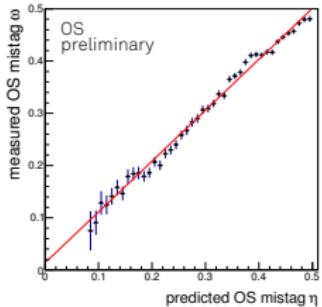
- ▶ linear calibration function

$$\omega = p_0 + p_1(\eta - \langle \eta \rangle)$$

- ▶ mistag asymmetry

$$\Delta\omega = \omega^{\bar{B}^0} - \omega^{B^0} = \Delta p_0 + \Delta p_1(\eta - \langle \eta \rangle)$$

- ▶ OS calibration using $B^+ \rightarrow J/\psi K^+$ decays
- ▶ SS π calibration using $B^0 \rightarrow J/\psi K_S^0$ decays



Measurement of CP violation in $B^0 \rightarrow J/\psi K_S^0$

LHCb-PAPER-2015-005 (to be submitted soon)

Improvements in $B^0 \rightarrow J/\psi K_s^0$ analysis



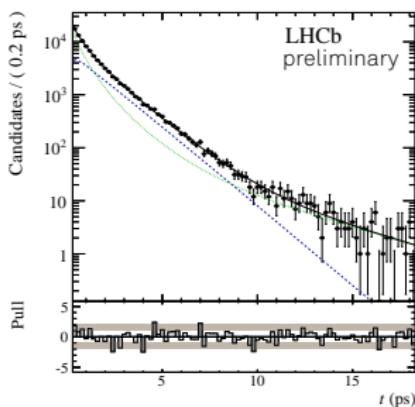
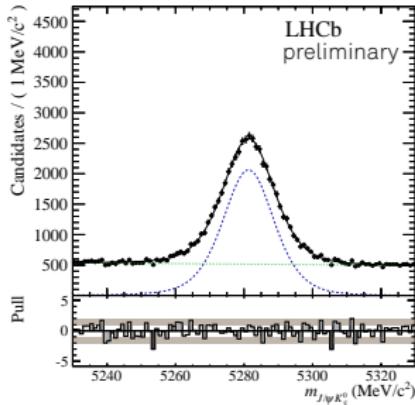
- ▶ Flavour Tagging
 - ▶ $\varepsilon_{tag} D^2 = (2.38 \pm 0.07) \%$ (OS in previous LHCb analysis)
 - ▶ $\varepsilon_{tag} D^2 = (3.02 \pm 0.05) \%$ (OS + SS π in this analysis) $\Rightarrow 27\%$ increase
- ▶ 14 % signal efficiency increase with additional trigger
- ▶ improved selection strategy
 $\Rightarrow 41\,560 \pm 270$ tagged signal candidates

Selection



- ▶ cut-based selection
- ▶ signal efficiency of each requirement above 99%
- ▶ cuts on kinematics and fit qualities
- ▶ almost all cut values different for downstream and long track events
- ▶ PID requirement to suppress Λ_b/Λ
- ▶ decay time significance τ/σ_τ of K_s^0

Fit setup



- ▶ seven dimensional PDF
 - ▶ mass, decay time, decay time error, tags and mistag estimates (OS and SS π)
- ▶ simultaneous fit in 24 disjoint categories
- ▶ 83 floating parameters including **S** and **C**
- ▶ constrained in fit: Δm_d , flavour tagging parameters and production asymmetry

$$\mu = \frac{R_{\bar{B}^0} - R_{B^0}}{R_{\bar{B}^0} + R_{B^0}}$$

Phys. Lett. B 739 (2014)

- ▶ adapted to momentum and pseudorapidity distribution
- ▶ accounting for $\sqrt{s} = 7/8$ TeV difference
- ▶ correcting for CP violation in $K^0 - \bar{K}^0$ mixing and K_S^0 regeneration

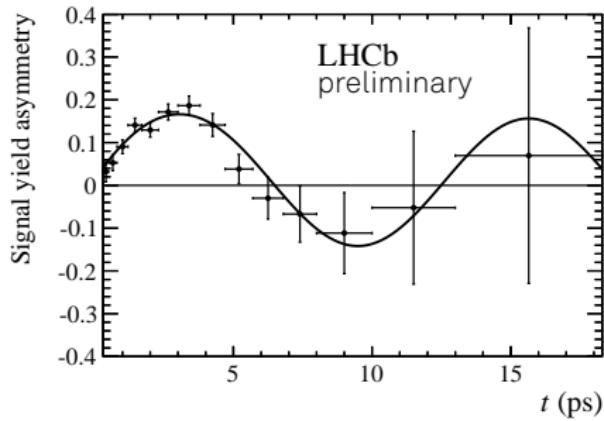
Systematic uncertainties



| Origin | σ_S | σ_C |
|---|----------------|-----------------|
| Background Tagging Asymmetry | 0.0179 (2.5 %) | 0.0015 (4.5 %) |
| Tagging calibration | 0.0062 (0.9 %) | 0.0024 (7.2 %) |
| $\Delta\Gamma_d$ | 0.0047 (0.6 %) | — |
| Δm_d | — | 0.0034 (10.3 %) |
| Fraction of wrong PV component | 0.0021 (0.3 %) | 0.0011 (3.3 %) |
| z-scale | 0.0012 (0.2 %) | 0.0023 (7.0 %) |
| Upper decay time acceptance | — | 0.0012 (3.6 %) |
| Low decay time acceptance | — | — |
| Decay time resolution calibration | — | — |
| Decay time resolution offset | — | — |
| Correlation between mass and decay time | — | — |
| Production asymmetry | — | — |
| Sum | 0.020 (2.7 %) | 0.005 (15.2 %) |

Results (preliminary)

- ▶ precise time-dependent CP violation measurement



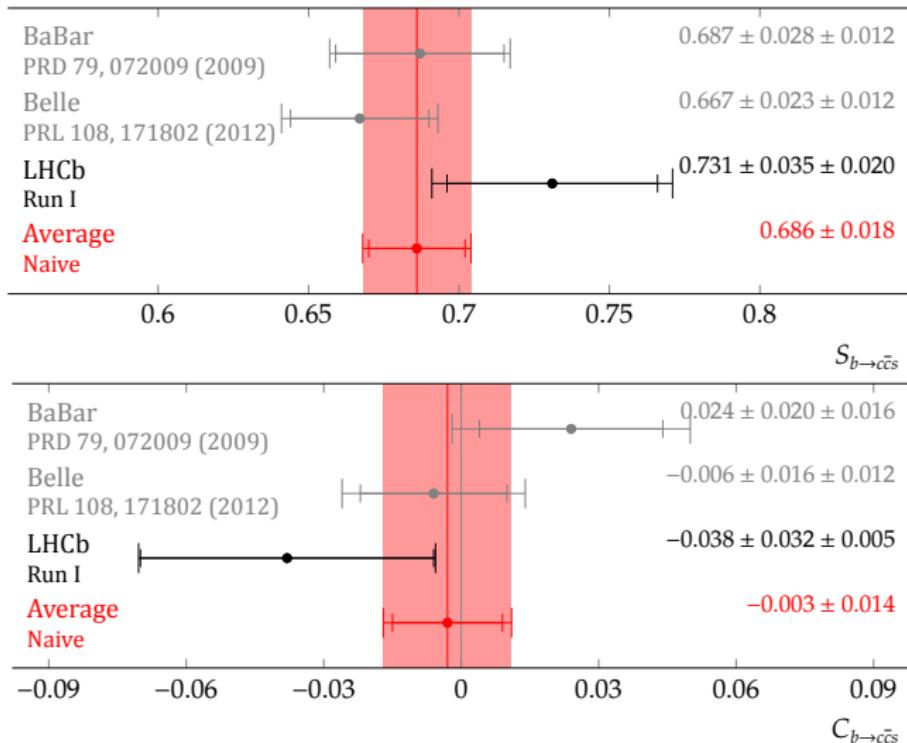
$$S(B^0 \rightarrow J/\psi K_S^0) = 0.731 \pm 0.035 \text{ (stat)} \pm 0.020 \text{ (syst)}$$

$$C(B^0 \rightarrow J/\psi K_S^0) = -0.038 \pm 0.032 \text{ (stat)} \pm 0.005 \text{ (syst)}$$

$$\rho(S,C) = 0.483$$

Results II

- precise CP violation measurement in $B^0 \rightarrow J/\psi K_S^0$



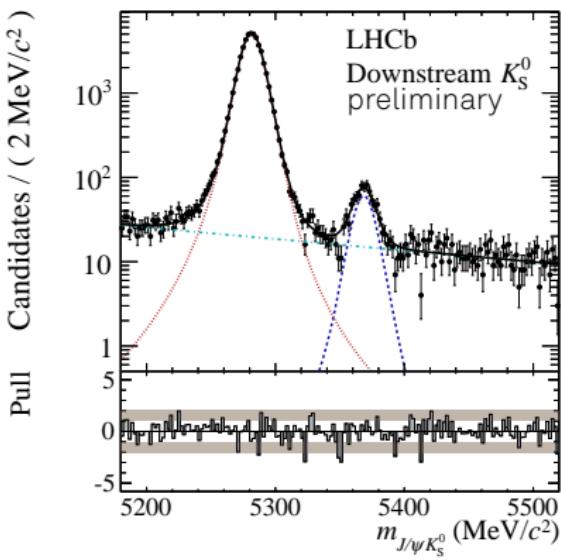
Search for CP violation in the decay

$$B_s^0 \rightarrow J/\psi K_s^0$$

LHCb-PAPER-2015-005 (to be submitted soon)

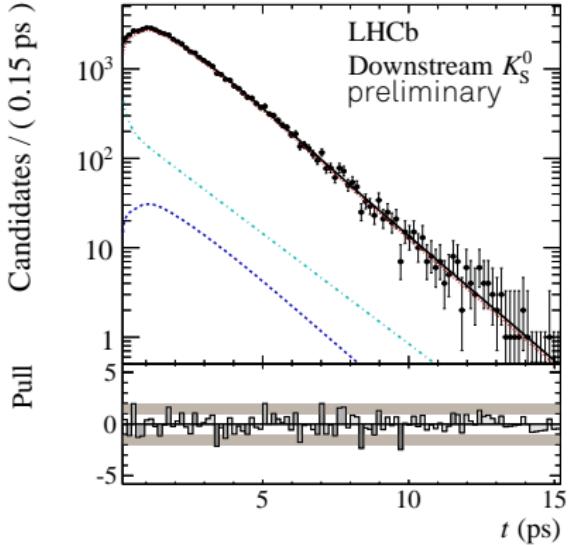
Overview

- ▶ motivation: constrain higher order hadronic corrections to $\sin 2\beta$
- ▶ related to $B^0 \rightarrow J/\psi K_s^0$ via U-spin symmetry
- ▶ 100 x fewer B_s^0 than B^0 candidates



- ▶ $5180 \text{ MeV}/c^2 < m < 5520 \text{ MeV}/c^2$
- ▶ two-stage neural net
 - ▶ eliminate $B \rightarrow J/\psi K^*$
 - ▶ suppress combinatorial bkg
- ▶ OS + SSK tagger
- ▶ simultaneous fit in six categories
- ▶ five floating CP observables
 - ▶ $A_{\Delta\Gamma}, S, C$ of B_s^0 system
 - ▶ S, C of B^0 system

Results (preliminary)



- ▶ significant systematics from
 - ▶ mass model ($A_{\Delta\Gamma}$)
 - ▶ decay time resolution ($A_{\Delta\Gamma}$, S, C)
 - ▶ decay time acceptance ($A_{\Delta\Gamma}$)
 - ▶ tagging calibration (S, C)
 - ▶ mass-time correlation (S, C)

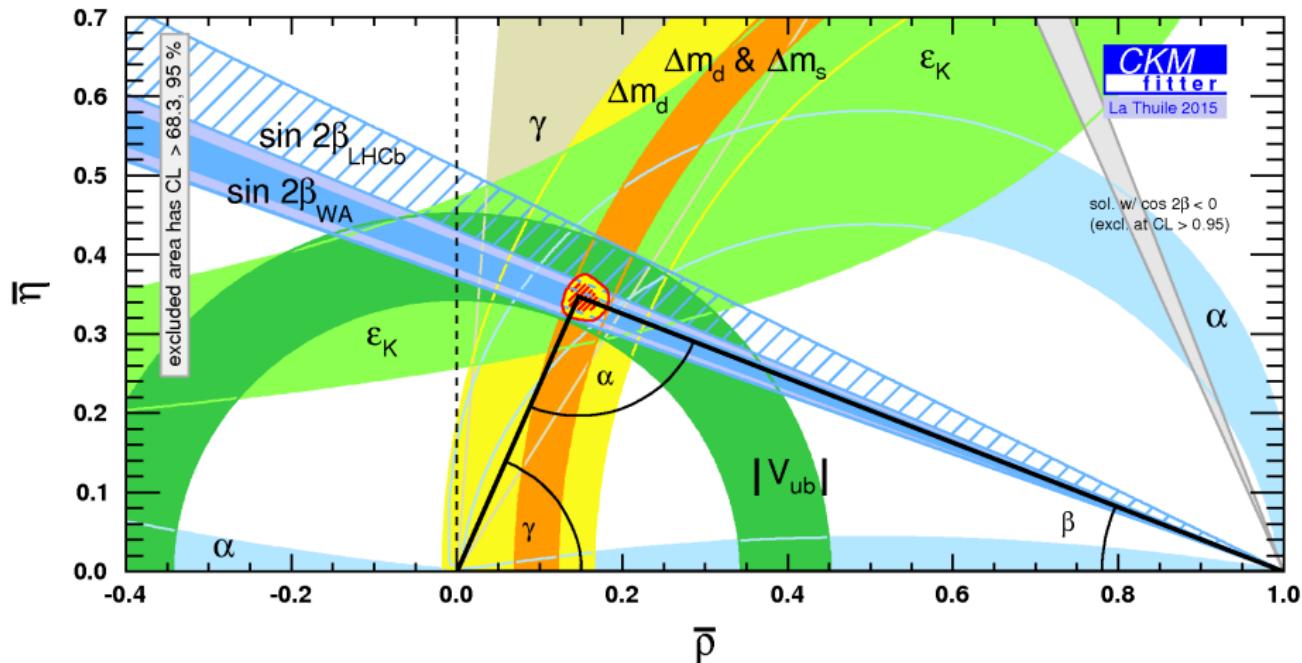
- ▶ first measurement of time-dependent CP violation in $B_s^0 \rightarrow J/\psi K_s^0$

$$A_{\Delta\Gamma}(B_s^0 \rightarrow J/\psi K_s^0) = 0.49 \pm ^{0.77}_{0.65} \text{ (stat)} \pm 0.06 \text{ (syst)}$$

$$S(B_s^0 \rightarrow J/\psi K_s^0) = -0.08 \pm 0.40 \text{ (stat)} \pm 0.08 \text{ (syst)}$$

$$C(B_s^0 \rightarrow J/\psi K_s^0) = -0.28 \pm 0.41 \text{ (stat)} \pm 0.08 \text{ (syst)}$$

Conclusion



- ▶ precise measurement of $\sin 2\beta$ by LHCb
 - ▶ expected sensitivity for Run II: $\sigma(\sin 2\beta) \sim 0.015$ [CERN-LHCC-2012-007](#)
- ▶ first step towards control of penguin pollutions using $B_s^0 \rightarrow J/\psi K_S^0$