$\mathcal{CP}$ violating phase ϕ_s and penguin pollution in $B_s^0 \to J/\psi K^+K^-$

Carlos Vázquez Sierra*, on behalf of the LHCb collaboration

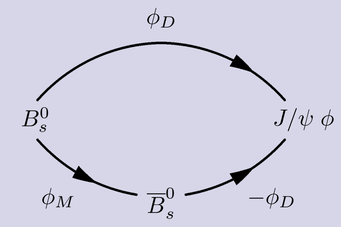
* Universidade de Santiago de Compostela, Santiago de Compostela, Spain

LHCC Open Session, CERN, Switzerland, 4th March 2015

1. $\mathcal{CP}$ violating phase ϕ_s in $B_s^0 \to J/\psi K^+K^-$

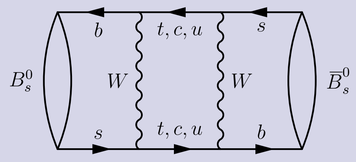
Mixing-induced violating $\mathcal{CP}$ phase:

$$\phi_s = \phi_M - 2\phi_D$$



Theoretical uncertainty on ϕ_s mainly due to penguin contributions δ^{P}:

$$\phi_s^{\mathrm{SM}} = -2\beta_s + \delta^{\mathrm{P}}$$



where $-2\beta_s$, with CKM matrix elements, is:

$$-2\beta_s = -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -36.3^{+1.6}_{-1.5}\ \mathrm{mrad}^{[1]}$$

New Physics (NP) processes can modify the value of ϕ_s if new particles contribute to box diagrams:

$$\phi_s^{\mathrm{LHCb}} = -2\beta_s + \delta^{\mathrm{P}} + \delta^{\mathrm{NP}}$$

The phase $-2\beta_s$ is predicted very **precisely** $\Rightarrow$ sensitive to BSM (Beyond Standard Model) physics, specially non-MFV (Minimal Flavour Violation) scenarios, accessible even if this NP is at **high energy scales**!

$B_s^0 \to J/\psi K^+K^-$ is a *golden* decay for ϕ_s measurement

$\Downarrow$

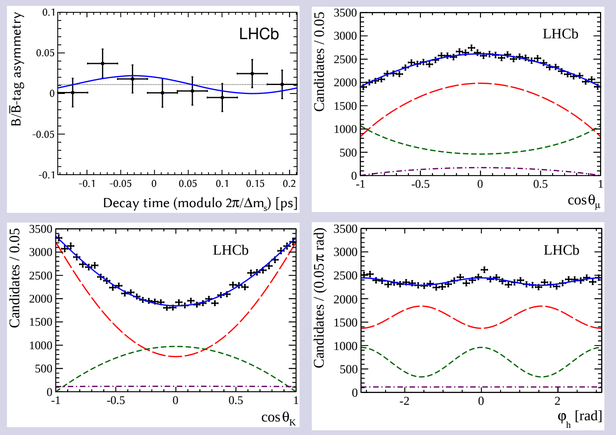
$B_s^0 \to J/\psi K^+K^-$ is a probe for New Physics

$\Downarrow$

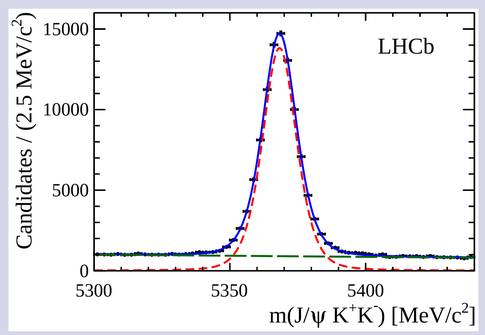
Penguin phase δ^{P} should be estimated[2]

2. Results with 3 fb^{-1} in $B_s^0 \to J/\psi K^+K^-$

Precision measurement of $\mathcal{CP}$ violation in $B_s^0 \to J/\psi K^+K^-$ decays using 3 fb^{-1} of LHCb collected data[3]



$\mathcal{CP}$ asymmetry as a function of shifted decay time and decay angles.
Red: $\mathcal{CP}$-even, green: $\mathcal{CP}$-odd, purple: S-wave.



Fit to m($J/\psi K^+K^-$): 95690 $B_s^0 \to J/\psi K^+K^-$ candidates.

World's most precise measurement of ϕ_s
Measured independently for each polarisation state of K^+K^- $\Rightarrow$ no polarisation dependence

$$\phi_s = -0.058 \pm 0.049\ (\mathrm{stat}) \pm 0.006\ (\mathrm{syst})\ \mathrm{rad}$$
$$\Gamma_s = 0.6603 \pm 0.0027\ (\mathrm{stat}) \pm 0.0015\ (\mathrm{syst})\ \mathrm{ps}^{-1}$$
$$\Delta\Gamma_s = 0.0805 \pm 0.0091\ (\mathrm{stat}) \pm 0.0032\ (\mathrm{syst})\ \mathrm{ps}^{-1}$$

Combined result including $B_s^0 \to J/\psi\pi^+\pi^-$ measurements[4]:

$$\phi_s = -0.010 \pm 0.039\ \mathrm{rad}$$

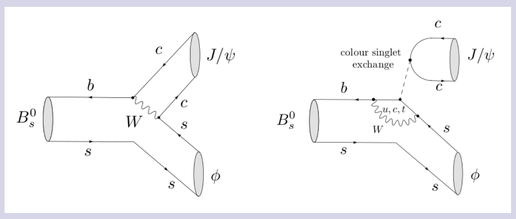
$\Rightarrow$ Excellent agreement with SM! ($-2\beta_s = -0.0363^{+0.0016}_{-0.0015}$ rad[1])
$\Rightarrow$ Experimental senstivity requires to distinguish possible δ^{NP} from δ^{P}

3. Methodology of penguin pollution control

In the framework described in [2], penguin pollution can be measured using observables from a $b \to c\bar{c}d$ decay, and assuming approximate $SU(3)$ flavour symmetry it is possible to apply these results on ϕ_s ($b \to c\bar{c}s$). Two possible control channels can be used in a separated way:

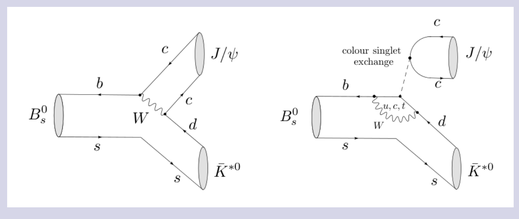
$\Rightarrow$ Using $B_s^0 \to J/\psi \bar{K}^{*0}$ decay as control channel:

$B_s^0 \to J/\psi K^+K^-$ ($b \to c\bar{c}s$) decay



Penguins suppressed to tree level by $\lambda^2 \simeq |V_{us}|^2 \simeq 0.22^2$

$B_s^0 \to J/\psi \bar{K}^{*0}$ ($b \to c\bar{c}d$) decay

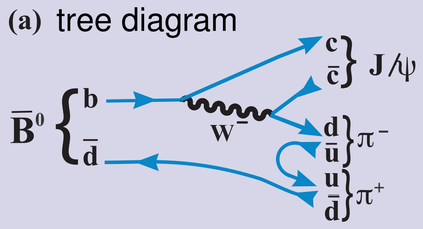


Penguins not suppressed to tree level!

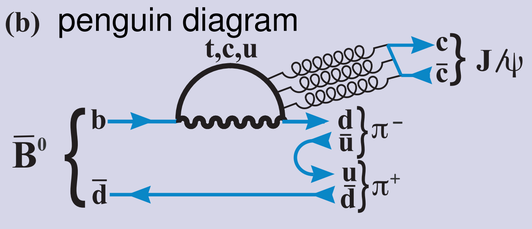
Branching ratio, polarization fractions from angular analysis and direct $\mathcal{CP}$ violation are needed for δ^{P} calculation. Branching ratio and polarization fractions are combined (separately for each final polarization state) in order to construct a unique untagged observable.

$\Rightarrow$ Using $B^0 \to J/\psi\rho^0$ decay as control channel:

(a) tree diagram



(b) penguin diagram



A time dependent Dalitz analysis is performed using data from $B^0 \to J/\psi\rho^0$ ($b \to c\bar{c}d$) decay: penguin phase δ^{P} can be calculated from measuring the mixing-induced $\mathcal{CP}$ violating phase β observable in this channel.

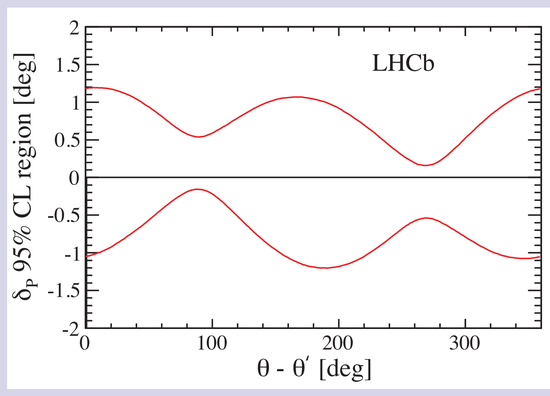
4. Measurement of penguin pollution phase δ^{P}

The penguin phase δ^{P} has been measured in $B^0 \to J/\psi\rho^0$ decay[5]:

$$|\delta^{\mathrm{P}}| < 0.02\ \mathrm{rad\ at\ 95\%\ CL}$$

Note that this value is **half** the uncertainty in ϕ_s phase!

The value of δ^P is also limited by $SU(3)$ symmetry breaking effects.
The dependence at 95% CL as a function of the difference between *penguin* strong phases of $b \to c\bar{c}s$ and $b \to c\bar{c}d$ transitions ($\theta - \theta'$) is shown:



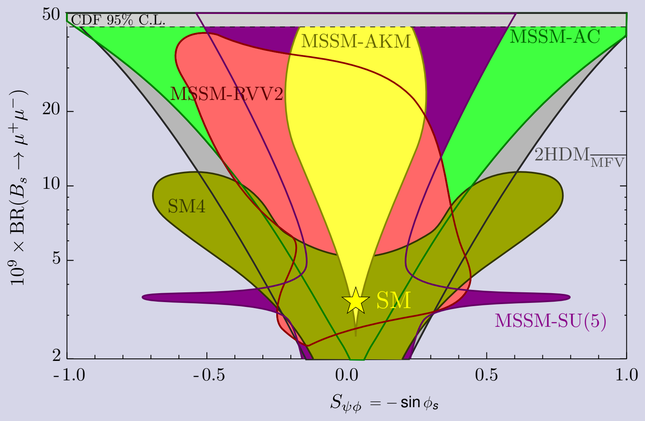
The dependency shown here is obtained **fixing** a $SU(3)$ breaking factor related to the ratio of *penguin* strong amplitudes between both type of b transitions shown before. Here, both amplitudes are **fixed** to be the same. This behaviour scales **linearly** with the $SU(3)$ breaking factor mentioned before.

Results obtained from $B^0 \to J/\psi\rho^0$ analysis are **consistent** with theoretical estimations.

The penguin phase δ^{P} measurement in $B_s^0 \to J/\psi \bar{K}^{*0}$ decay using 3 fb^{-1} of data is still ongoing, but is almost **finished**. A previous publication where 370 pb^{-1} of data is analysed is available[6].

5. Implications in searches of New Physics (NP)

$\mathcal{CP}$ violating phase ϕ_s can be measured with **high precision** combining results from $B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi\pi^+\pi^-$ decays. In the future, results from additional decay modes as $\bar{B}_s^0 \to D_s^+ D_s^-$ decay will be also included in this combined measurement[7].
$\mathcal{CP}$ violating phase ϕ_s is **very sensitive** to possible BSM NP scenarios[8], such as LHT (Littlest Higgs model with T-parity), non-MFV in SUSY-breaking lagrangian, ED (Extra Dimension), etc.



Several NP scenarios could contribute to NP observations via ϕ_s measurements

$\Downarrow$

Possible δ^{NP} contributions should be disentangled from δ^P contributions which have to be properly estimated

References

[1] J. Charles et al., "Predictions of selected flavour observables within the Standard Model", Phys. Rev. D84 (2011) 033005, arXiv:1106.4041.
[2] K. De Bruyn, R. Fleischer, "A Roadmap to Control Penguin Effects in $B_d^0 \to J/\psi K_S^0$ and $B_s^0 \to J/\psi\phi$", arXiv:1412.6834.
[3] LHCb collaboration, "Precision measurement of *CP* violation in $B_s^0 \to J/\psi K^+K^-$ decays", LHCb-PAPER-2014-059, arXiv:1411.3104.
[4] LHCb collaboration, "Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \to J/\psi\pi^+\pi^-$ decays", LHCb-PAPER-2014-019, arXiv:1405.4140.
[5] LHCb collaboration, "Measurement of the CP-violating phase β in $B^0 \to J/\psi\pi^+\pi^-$ decays and limits on penguin effects", LHCb-PAPER-2014-058, arXiv:1411.1634.
[6] LHCb collaboration, "Measurement of the $B_s^0 \to J/\psi \bar{K}^{*0}$ branching fraction and angular amplitudes", Phys. Rev. D 86, 071102(R) (2012), arXiv:1208.0738.
[7] LHCb collaboration, "Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \to D_s^+ D_s^-$ decays", Phys. Rev. Lett. 113, 211801 (2014), arXiv:1409.4619.
[8] D. M. Straub, "New physics searches in flavour physics", arXiv:1107.0266.