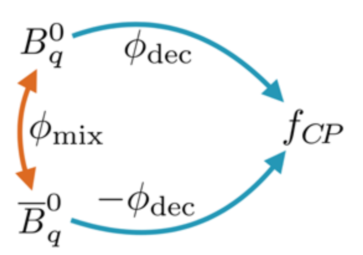
Time-dependent CP violation in B_s^0 decays at LHCb

What do we measure?

The Standard Model (SM) fails to predict the *matter-antimatter asymmetry* observed in the universe. We can search for sources of CP violation, for example by measuring the CP violation phase, ϕ_s.



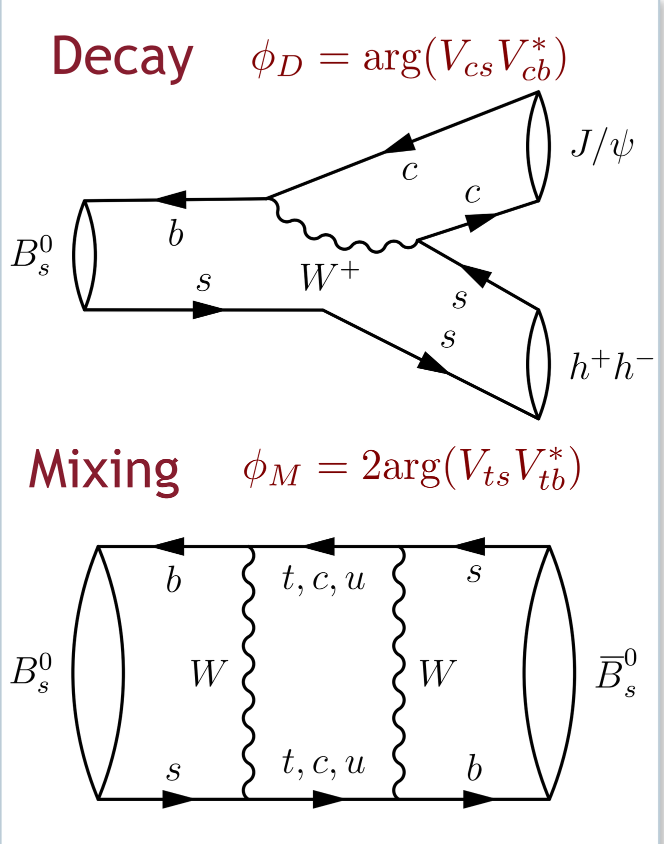
$$\phi_s = \phi_{\rm mix} - 2\phi_{\rm dec}$$

$$\phi_s^{s\bar{c}c} = -2\beta_s$$

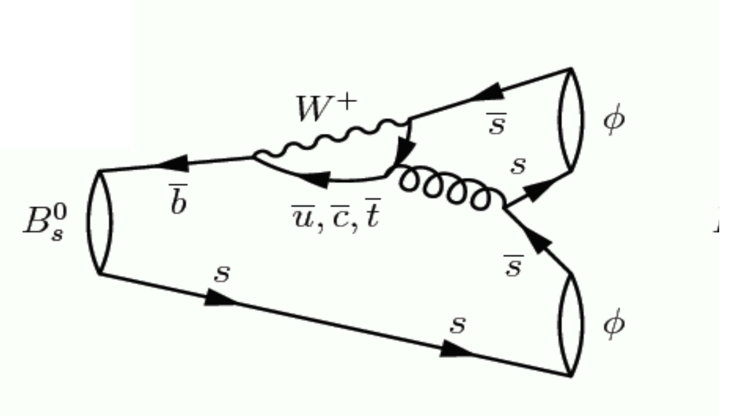
$$\beta_s \equiv \arg\left(\frac{-V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

A time-dependent angular analysis is necessary to disentangle the CP-even and CP-odd final states. For this we need:

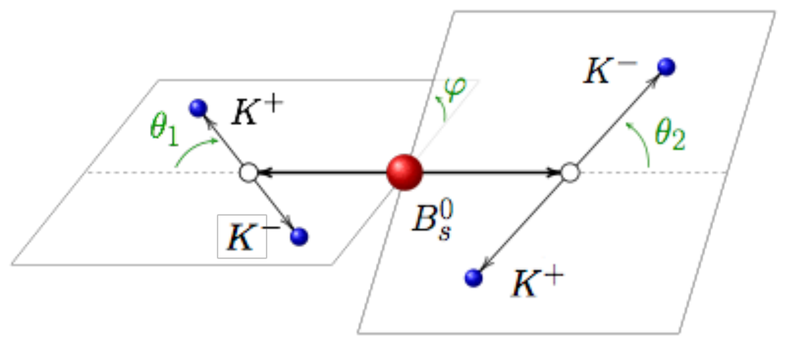
- Good *decay-time resolution* (typically ~45 fs at LHCb) to resolve fast flavour oscillations induced by B_s^0 mixing.
- *Angular acceptance* from non-uniform selection efficiency due to detector acceptance and kinematic selections.
- *Decay-time acceptance*.
- *Flavour tagging* of the B meson at production. (~5%)



$B_s^0 \to \phi\phi$



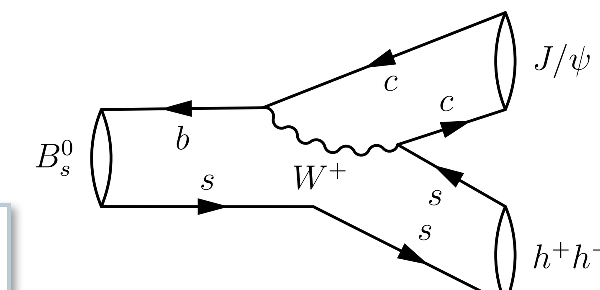
- $b \to s\bar{s}s$ transition forbidden at tree level.
- Measure $\phi_s^{s\bar{s}s}$ and $|\lambda|$.
- SM predictions: $\phi_s^{s\bar{s}s}$ in context of QCD factorisation close to zero by SM, with errors of a few %. [1,2]



Helicity angles

$B_s^0 \to J/\psi h^+h^-$

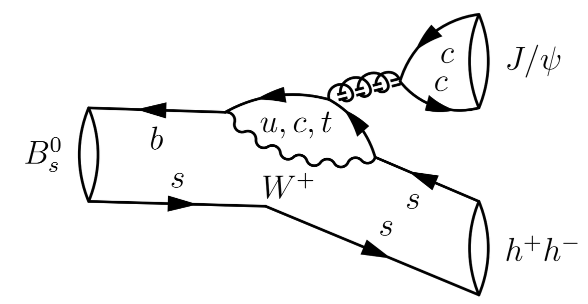
- h^+h^- is either K^+K^- (around m(ϕ)) or $\pi^+\pi^-$.
- $b \to s\bar{c}c$ transition.



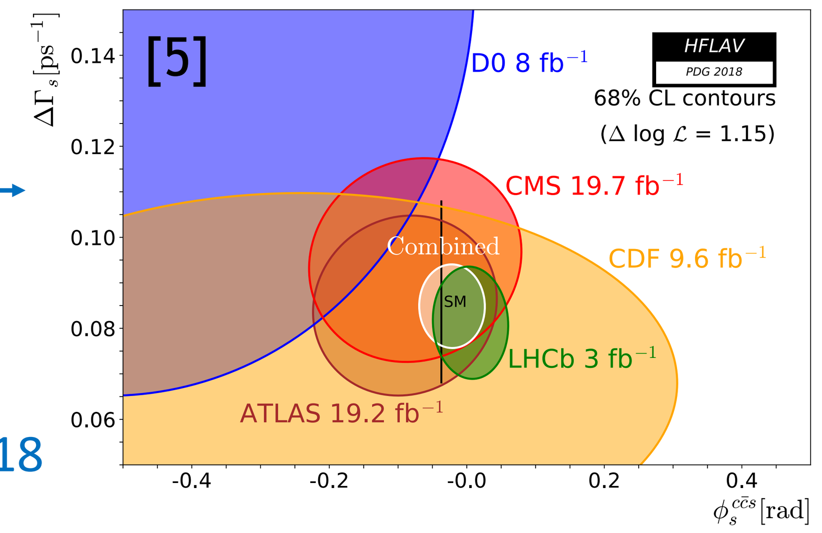
SM prediction: [4]

$$\phi_s^{s\bar{c}c\ \rm SM} = -36.9^{+1.0}_{-0.7}\ [\rm mrad]$$

- $B_s^0 \to J/\psi\,\pi^+\pi^-$ final state 97.7% CP-odd [3]. Measure $\Gamma_H - \Gamma_{B^0}$ and $\phi_s^{s\bar{c}c}$.
- $B_s^0 \to J/\psi\,K^+K^-$ final state CP-even/CP-odd mix. Measure $\Gamma_s - \Gamma_{B^0}$, $\Delta\Gamma_s$ and $\phi_s^{s\bar{c}c}$.



$\phi_s^{s\bar{c}c}$ experimental status: Summer 2018

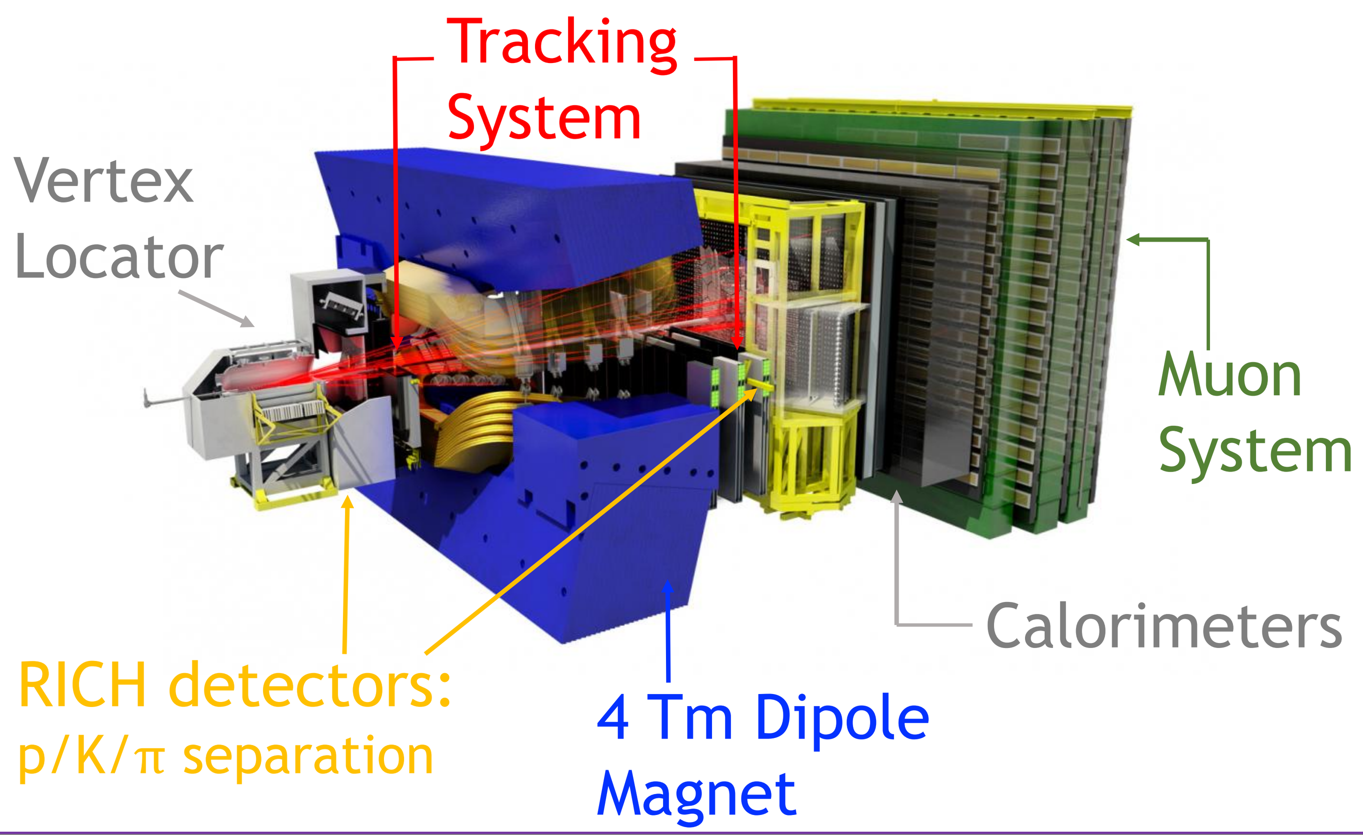


References

[1] arXiv:0810.0249
[2] Phys.Rev. D 80, 114026, 2009
[3] Phys. Rev. D **89**, 092006
[4] http://ckmfitter.in2p3.fr/www/results/plots_summer18/num/ckmEval_results_summer18.html
[5] www.slac.stanford.edu/xorg/hflav/osc/PDG_2018/
[5] LHCb-PAPER-2019-019 (preliminary!)
[6] LHCb-PAPER-2019-013 (preliminary!)
[7] arXiv:1903.05530
[8] Physics Letters B 762, 2016, Pages 253-262
[9] PhysRevLett.113.211801
[10] JHEP08(2017)037
[11] PhysRevLett.114.041801
[12] Physics Letters B 736, 2014, Pages 186-195
[13] www.cppm.in2p3.fr/~oleroy/pro/hfag/Spring2019/v5/ (preliminary!)

The LHCb Detector

- Forward spectrometer ($2 < \eta < 5$) to capture roughly 24% of $\bar{b}b$ pairs produced.
- 40 MHz collisions (~12 MHz visible interactions)
- Two level trigger: L0 hardware (12-1 MHz)
  HLT software (1-0.005 MHz)



Recent results

$B_s^0 \to \phi\phi$ (preliminary!) [6]

Run 1 (3.2 fb^{-1}) + 2015/6 (1.9 fb^{-1})

$$\phi_s^{s\bar{s}s} = -0.073 \pm 0.115 \pm 0.027\ [\rm rad]$$
$$|\lambda| = -0.99 \pm 0.05 \pm 0.01$$

- All results presented are in agreement with SM predictions.
- Experimental precision increased tremendously. LHCb producing the worlds most precise measurements of ϕ_s.
- More results including data taken in 2017 and 2018 at LHCb (~4[fb^{-1}]) to follow.

$B_s^0 \to J/\psi K^+K^-$(preliminary!) [7]

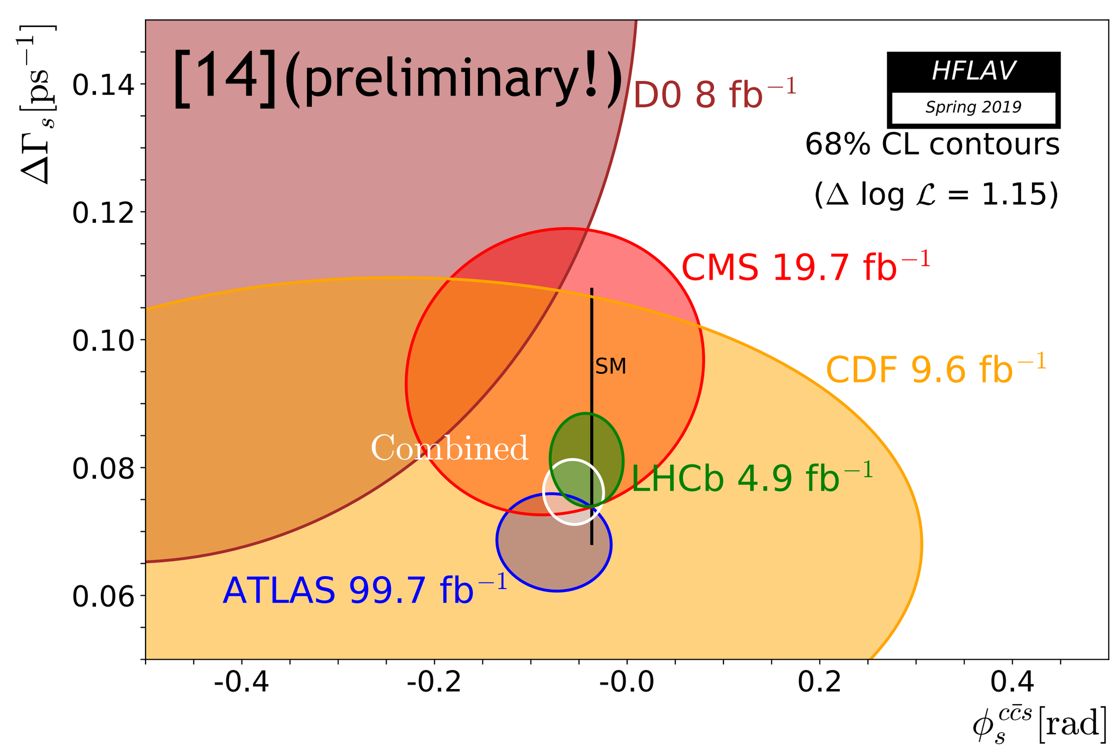
2015/6 (1.9 fb^{-1})

$$\phi_s^{s\bar{c}c} = -0.083 \pm 0.041 \pm 0.006\ [\rm rad]$$
$$|\lambda| = 1.012 \pm 0.016 \pm 0.006$$
$$\Gamma_s - \Gamma_d = -0.0041 \pm 0.0024 \pm 0.0015\ [\rm ps^{-1}]$$
$$\Delta\Gamma_s = -0.0772 \pm 0.0077 \pm 0.0026\ [\rm ps^{-1}]$$

$B_s^0 \to J/\psi\pi^+\pi^-$ [8]

2015/6 (1.9 fb^{-1})

$$\phi_s^{s\bar{c}c} = -0.057 \pm 0.060 \pm 0.011\ [\rm rad]$$
$$|\lambda| = 1.01^{+0.08}_{-0.06} \pm 0.03$$
$$\Gamma_H - \Gamma_{B^0} = -0.050 \pm 0.004 \pm 0.004\ [\rm ps^{-1}]$$



Combination [7-13]

$$\phi_s^{s\bar{c}c} = -0.040 \pm 0.025\ [\rm rad]$$
$$|\lambda| = 0.991 \pm 0.010$$
$$\Delta\Gamma_s = 0.0816 \pm 0.0048\ [\rm ps^{-1}]$$
$$\Gamma_s - \Gamma_{B^0} = -0.0024 \pm 0.0018\ [\rm ps^{-1}]$$

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