PROCEEDINGS OF SCIENCE

Measurement of the CP Violating phase ϕ_s at LHCb.

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The precise measurement of CP violating phases is a key goal of the LHCb collaboration. This article presents the latest results for measurements of ϕ_s in the $B_s^0 \rightarrow J/\psi K^+K^-$ and $B_s^0 \rightarrow J/\psi \pi^+\pi^-$ channels and summarises the status of this measurement from other experiments.

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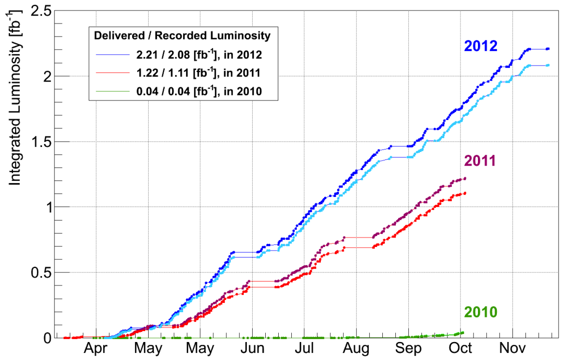


Figure 1: Plot showing the delivered/recorded luminosity for LHCb over 3 years of data taking[1].

1. Introduction

One of the unsolved puzzles of nature is the source of the matter-antimatter asymmetry. The Standard Model (SM) makes predictions for CP (Charge-Parity) violation which is a process that is needed for such an asymmetry. However, the amount of CP violation predicted is too small to explain the observable universe. The LHCb collaboration aims to test the SM predictions and search for new sources of CP violation. Over the course of two years the LHCb experiment collected over 3fb^{-1} of data from p-p collisions at 7 and 8TeV (Fig. 1). This article gives an overview of measurements of the CP violating phase ϕ_s with this data.

2. Phenomenology

CP violation in the Standard Model arises from a single complex phase in the CKM matrix. For decay modes involving $b \to c\bar{c}s$ quark transitions, CP violation arises from the interference between neutral meson mixing (Fig. 2b) and decay to a CP eigenstate (Fig. 2a). For modes where the initial meson is a B_s^0 or a $\bar{B}_s^0$ the measured phase is called ϕ_s. Neglecting penguin contributions, the weak phase can be expressed as follows:

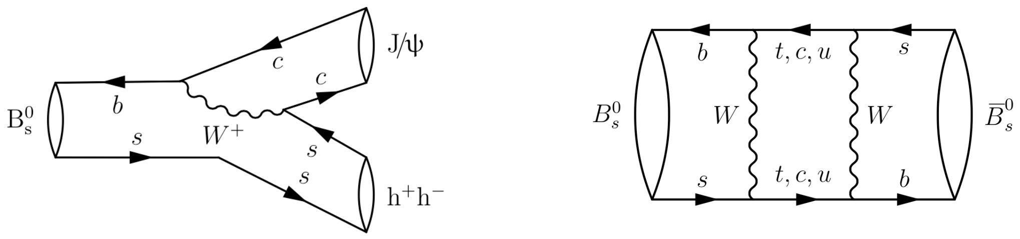
$$\phi_s^{SM} = 2arg\left(-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right) = -2\beta_s \tag{2.1}$$

$$\phi_s^{SM} = \phi_{Mixing} - 2\phi_{Decay} = -2\beta_s \tag{2.2}$$

This value is predicted to be small as $\phi_{Decay} = 0$, and $\phi_{Mixing} \approx 0$. New Physics can modify this leading to a measurable divergence from the SM prediction.

3. CP violation in $B_s^0 \to J/\psi K^+K^-$

This mode is often referred to as the Golden Mode for measurements of ϕ_s due to the high yield of events. This decay occurs via a pseudoscalar to vector-vector transition so to extract a measurement of ϕ_s an angular fit must be performed to separate the CP-even and CP-odd components. From a fit to the decay time and helicity angles (Fig. 3), values can be measured for Γ_s, $\Delta\Gamma_s$



(a) Tree level decay of $B_s^0 \to J/\psi K^+K^-$. (b) Neutral meson mixing ($B_s^0 - \bar{B}_s^0$).

Figure 2: Feynman diagrams describing $B_s^0 \to J/\psi h^+h^-$ decay and $B_s^0 - \bar{B}_s^0$ mixing.

(the average and difference in the decay widths of the heavy and light B_s^0 mass eigenstates) and ϕ_s. With 1fb^{-1} of data the results are[2]:

$$\Gamma_s = 0.663 \pm 0.005(\text{stat.}) \pm 0.006(\text{syst.})\text{ps}^{-1}$$
$$\Delta\Gamma_s = 0.100 \pm 0.016(\text{stat.}) \pm 0.003(\text{syst.})\text{ps}^{-1}$$
$$\phi_s = 0.07 \pm 0.09(\text{stat.}) \pm 0.01(\text{syst.})\text{rad}$$

Since this conference an updated measurement of Γ_s, $\Delta\Gamma_s$ and ϕ_s has been made with mode using the full 3fb^{-1} of data available [5].

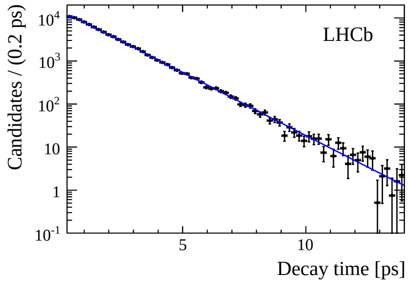
4. CP violation in $B_s^0 \to J/\psi\pi^+\pi^-$

Unlike the $B_s^0 \to J/\psi K^+K^-$ mode, the final state of this mode is mostly CP odd (> 97.7%). For this analysis two complementary methods were used; one method where the final state is assumed to be 100% CP odd so no angular analysis is needed and a time-dependent Dalitz analysis. Plots of the projection of the dipion recontructed mass and helicity angles are shown in Fig. 4. These methods result in a measurement of ϕ_s with 3fb^{-1} of data as[3]:

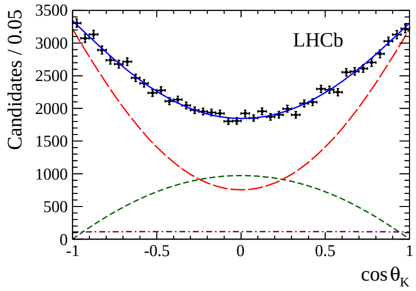
$$\phi_s = 0.070 \pm 0.068(\text{stat.}) \pm 0.008(\text{syst.})\text{ rad}$$

5. Summary

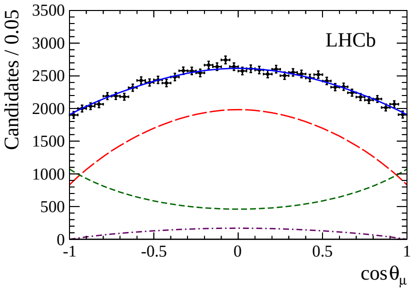
The LHCb Collaboration has made a significant contribution to the measurement of $\phi_s^{c\bar{c}s}$ through various channels. At the end of three years of data taking LHCb has provided the most precise measurement of this CP violating phase (Fig. 5). There will be an updated value of ϕ_s from $B_s^0 \to J/\psi K^+K^-$ using 3fb^{-1}, and a new combination including other modes. There is also work on measurements from new modes such as $B_s^0 \to \psi(2S)\phi$.



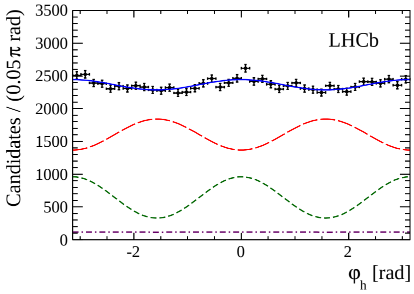
(a) Fit to the decay-time distribution(log scale).



(b) Fit to $\cos(\theta_K)$.



(c) Fit to $\cos(\theta_\mu)$.



(d) Fit to ϕ_h.

Figure 3: Plots showing the fit to the decay time and helicity angle distributions of $B_s^0 \to J/\psi K^+K^-$ decays. The blue line is the total signal contribution, which is composed of CP-even(long-dashed red), CP-odd (short-dashed green) and S-wave (dotted-dashed purple)[2].

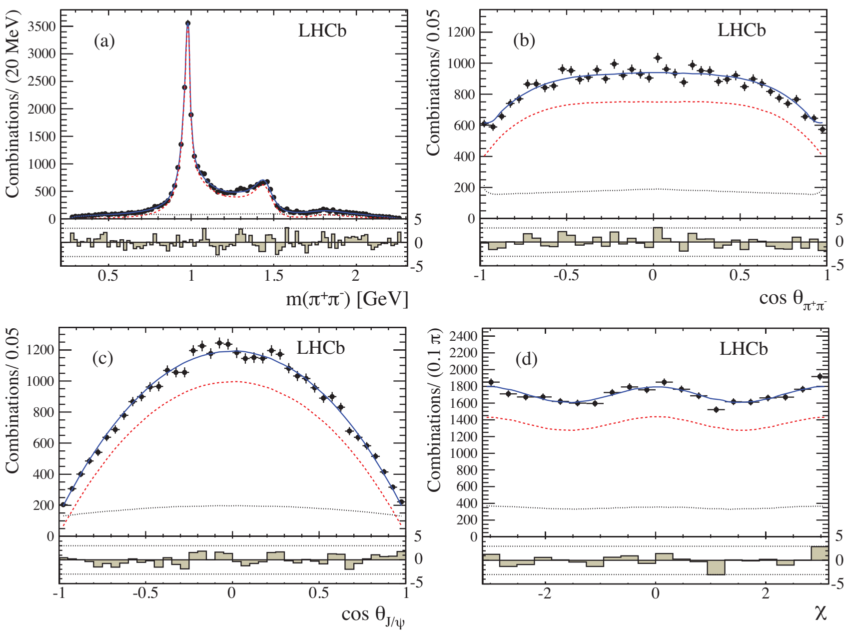
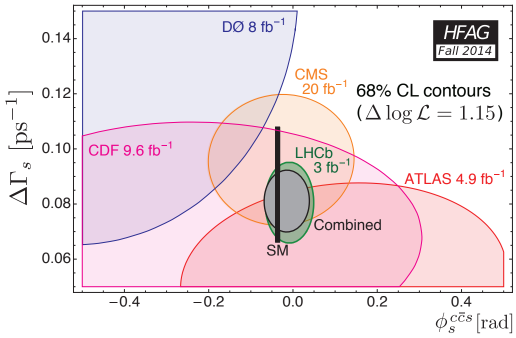
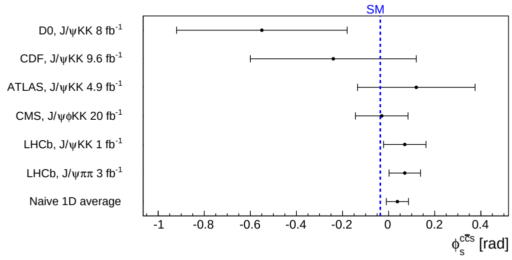


Figure 4: Projections of (a) $m(\pi^+\pi^-)$, and the three helicity angles (b) $\cos(\theta_{\pi\pi})$, (c) $\cos(\theta_{J/\psi})$ and (d) χ. The points with error bars are data, the signal fit is shown with a (red) dashed line, the background with a (black) dotted line, and the (blue) solid line represents the total[3].



(a) Comparison of ϕ_s vs $\Delta\Gamma$ measurements[4].



(b) Comparison of measurements of ϕ_s from $B_s^0 \to J/\psi(K^+K^-)/(\pi^+\pi^-)$ modes from different experiments.

Figure 5: Plots showing measurements of ϕ_s from different experiments and their combination.

References

[1] LHCb Operations, `http://lhcb-operationsplots.web.cern.ch/lhcb-operationsplots/index.htm`.

[2] Aaij, Roel and others, *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.D* **87** 112010 (2013)[`arXiv:1304.2600 [hep-ex]`].

[3] Aaij, Roel and others, *Measurement of the CP-violating phase ϕ_s in $\overline{B}_s^0 \to J/\psi\pi^+\pi^-$ decays*, *Phys.Lett* **B736**(2014) [`arXiv:1405.4140 [hep-ex]`].

[4] Heavy Flavour Averaging Group(HFAG), `http://www.slac.stanford.edu/xorg/hfag/osc/fall_2014/BETAS/hfag_Fall2014_DGsphis_zoom.pdf`.

[5] Aaij, Roel and others, *Precision measurement of CP violation in $B_s^0 \to J/\psi K^+K^-$ decays*, *Phys. Rev. Lett.* **114** 041801 (2015)[`arXiv:1411.3104 [hep-ex]`].