PROCEEDINGS OF SCIENCE

ATLAS measurements of CP violation and rare decays processes with beauty mesons

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The ATLAS experiment at the Large Hadron Collider has performed precise measurements of mixing and CP violation in neutral B mesons, and also of rare processes happening in electroweak neutral B mesons decays. This contribution focuses on the latest results from ATLAS, including measurements of the branching fractions of $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ channels and of CP violation in the $B_s^0 \to J/\psi\phi$ channel.

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1. Introduction

Very rare decays of B mesons and CP violation in B_s^0 oscillations are expected to be sensitive to physics beyond the Standard Model (SM) with high precision. The ATLAS experiment [1] at the Large Hadron Collider (LHC) [2] has very rich B physics program that includes two searches for New Physics (NP): a measurement of the CP violation in the $B_s^0 \to J/\psi\phi$ channel and a measurement of the branching fractions of $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ channels.

2. CP-violating phase ϕ_s in $B_s^0 \to J/\psi\phi$ decay

In the SM, the CP violation appears due to the interference between a direct decay and a decay with $B_s^0 - \overline{B}_s^0$ mixing. A hint for NP can be observed in deviations of the CP-violating phase ϕ_s from its SM prediction: $\phi_s = -0.03696^{+0.00072}_{-0.00082}$ rad [3]. Other parameters like the decay width difference $\Delta\Gamma_s$ measured in $B_s^0 \to J/\psi\phi$ channel are not sensitive to NP, however the measurement is interesting to test the theory: $0.091 \pm 0.013\,\mathrm{ps}^{-1}$ [4]. The ATLAS Run 1 results are consistent with the SM prediction and other experiments results: $\phi_s = -0.090 \pm 0.078(\mathrm{stat.}) \pm 0.041(\mathrm{syst.})$ rad and $\Delta\Gamma_s = 0.085 \pm 0.011(\mathrm{stat.}) \pm 0.007(\mathrm{syst.})\,\mathrm{ps}^{-1}$ [5]. ATLAS Run 2 results use the proton-proton collision data at $\sqrt{s} = 13$ TeV collected between years 2015 and 2017 corresponding to an integrated luminosity of $80.5\,\mathrm{fb}^{-1}$. Data were collected with triggers based on the identification of a $J/\psi \to \mu^+\mu^-$ with muon transverse momentum (p_T) thresholds of 4 or 6 GeV. The results of Run 2 are combined with the Run 1 results using proton-proton collision data at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV.

The reconstructed Jpsi and psi particles can originate from the decay of either B_s^0 or $\overline{B}_s^0$, and the latter can oscillate before decaying. To infer the initial signal flavour, the opposite side tagging method (OST) is applied. OST extracts the probability of initial flavour via the p_T-weighted charge using the charge of tracks inside the cone around electron, muon or reconstructed b-jet object is used. This method is calibrated on self-tagging channel $B^\pm \to J/\psi K^\pm$. The total tag power (figure of merit of tagger performance) is 1.65 ± 0.01 %.

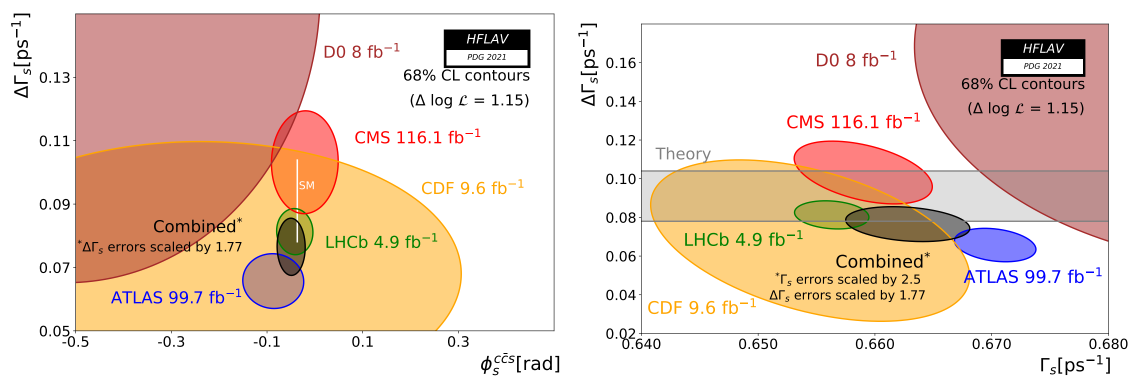

Figure 1: The individual 68% confidence-level contours of ATLAS, CMS, CDF, D0 and LHCb, their combined contour (black solid line and shaded area), as well as the SM predictions (white rectangle and grey box) [6].

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To extract the physical parameters of interest, ϕ_s, $\Delta\Gamma_s$, the average decay width Γ_s and the CP-state amplitudes with their phases, an unbinned maximum likelihood (ML) fit in five dimensions (mass m, lifetime t and angles ψ_T, ϕ_T, θ_T [7]). The results of the fit are combined with the ATLAS Run 1 results, yielding $\phi_s = -0.087 \pm 0.036(\text{stat.}) \pm 0.021(\text{syst.})\,\text{rad}$, the decay width difference $\Delta\Gamma_s = 0.0657 \pm 0.0043(\text{stat.}) \pm 0.0037(\text{syst.})\,\text{ps}^{-1}$ and average decay width $\Gamma_s = 0.6703 \pm 0.0014(\text{stat.}) \pm 0.0018(\text{syst.})\,\text{ps}^{-1}$ [7]. The combined results are in agreement with theory, but there are some tensions between experiments (see Figure 1).

3. Branching ratios of $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ decays

The direct decay of B^0 and B_s^0 to dimuons is highly suppressed in the SM, the predicted branching ratios are $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$ and $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-10}$ [8]. The experimental deviations from these values will suggest the existence of NP that can cntribute via a loop diagram. The ATLAS experiment provides the branching ratio measurements using data from the pp collisions at $\sqrt{s} = 13\,\text{TeV}$ collected during 2015 and 2016 corresponding to $36.2\,\text{fb}^{-1}$. The results are combined with the Run 1 results using proton-proton collision data at $\sqrt{s} = 7\,\text{TeV}$ and $\sqrt{s} = 8\,\text{TeV}$: $\mathcal{B}(B^0 \to \mu^+\mu^-) = 4.2 \times 10^{-10}$ at 95% confidence level (CL) and $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 0.9^{+1.1}_{-0.8} \times 10^{-9}$ [9].

The branching ratios are calculated using the formula:

$$\mathcal{B}\left(B^0_{(s)} \to \mu\mu\right) = N_{d(s)} \frac{\mathcal{B}\left(B^\pm \to J/\psi K^\pm\right) \times \mathcal{B}\left(\text{J}/\psi \to \mu\mu\right)}{N_{\text{J}/\psi K^\pm} \frac{\varepsilon_{\mu\mu}}{\varepsilon_{\text{J}/\psi K^\pm}}} \frac{f_u}{f_{d(s)}}, \tag{1}$$

where $\mathcal{B}\left(B^\pm \to J/\psi K^\pm\right)$ and $\mathcal{B}\left(\text{J}/\psi \to \mu\mu\right)$ are branching ratios known from PDG, $f_u/f_{d(s)}$ from HFLAV [6], $\varepsilon_{\mu\mu}/\varepsilon_{\text{J}/\psi K^\pm} = 0.1176 \pm 0.0009(\text{stat.}) \pm 0.0047(\text{syst.})$ is the ratio of reconstruction efficiencies estimated from MC and $N_{d(s)}$ and $N_{J/\psi K^\pm}$ are yields of $B^0_{(s)} \to \mu^+\mu^-$ and reference channel $B^\pm \to J/\psi K^\pm$ extracted from unbinned ML fit.

The continuum background is rejected by a 15-variable Boosted Decision Tree (BDT) which is trained and tested on data sidebands and simulated signal events. The other background contributions arise from partially reconstructed B-hadrons and mis-reconstruction $B^0_{(s)} \to hh'$ decays, where both hadrons are identified as muons. An unbinned ML fit to the $m_{\mu\mu}$ distribution is performed in four BDT intervals of constant signal efficiency to extract the signal yield. Due to the limited mass resolution, the peaks of $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ overlap and are statistically separated in the fit. The results were combined with ATLAS Run 1 measurements, resulting into branching ratios $\mathcal{B}\left(B_s^0 \to \mu\mu\right) = \left(2.8^{+0.8}_{-0.7}\right) \times 10^{-9}$ and upper limit of $\mathcal{B}\left(B^0 \to \mu\mu\right) < 2.1 \times 10^{-10}$ at 95% CL [10]. The results are combined with results obtained by the CMS and LHCb experiments with data collected between 2011 and 2016 leading to values $\mathcal{B}\left(B_s^0 \to \mu\mu\right) = \left(2.69^{+0.37}_{-0.35}\right) \times 10^{-9}$ and upper limit of $\mathcal{B}\left(B^0 \to \mu\mu\right) < 1.9 \times 10^{-10}$ at 95% CL [11].

4. Summary

Measurements of rare decays and CP-violation by the ATLAS collaboration have been presented. The results for $B^0_{(s)} \to \mu^+\mu^-$ agree with the SM and other measurements. There is no sign

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for the decay $B^0 \to \mu^+\mu^-$ in ATLAS data, but ATLAS will add data taken in 2017 and 2018 to the analysis (107 fb^{-1}). The ATLAS measurement of the CP-violating phase ϕ_s and the B_s^0 decay width difference $\Delta\Gamma_s$ provides a single measurement precision comparable to that of the LHCb experiment and reaches the sensitivity to test the SM prediction. About 60 fb^{-1} of data taken in 2018 will be added to the analysis in the future.

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