New physics searches with b-hadrons at the ATLAS experiment

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Flavour changing neutral currents and precision measurements of CP violation are investigated by the ATLAS experiment as probes to new physics beyond the standard model. This talk presents the most recent results on the search for the rare decay $B_s^0 \to \mu^+\mu^-$, as well as the latest update on the study of the various angular amplitudes contributing to flavour tagged $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decays. The latter analysis measures the CP-violating phase ϕ_s, as well as the average B_s meson lifetime Γ_s and the decay width difference $\Delta\Gamma_s$.

1 Introduction

The searches with b-hadrons can present indirect evidence for new physics and show the size of new effects. They are complementary to direct searches. The talk presents the most recent results on the search for the rare decay $B_s^0 \to \mu^+\mu^-$ [1] and the latest update on the study of the various angular amplitudes contributing to flavour tagged $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decays [2]. Both results are based on the integrated luminosity of 4.9 fb^{-1}, collected in 2011 for pp data at $\sqrt{s} = 7$ TeV.

2 Search for $B_s^0 \to \mu^+\mu^-$ rare decay

The decay $B_s^0 \to \mu^+\mu^-$ is highly suppressed in the standard model (SM) and therefore is of particular interest in the search for new physics. The existence of new hypothetical particles may change the branching fraction for this decay and, thus, demonstrate the presence of new physics. The SM predicts the branching fraction for the $B_s^0 \to \mu^+\mu^-$ decay to be $(3.23 \pm 0.27) \cdot 10^{-9}$ [3]. The CMS and LHCb common results with all RUN-1 collected data show evidence for $\mathscr{B}(B_s^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \cdot 10^{-9}$ [4, 5, 6]. The ATLAS [7] experiment sets the upper limit $\mathscr{B}(B_s^0 \to \mu^+\mu^-) < 2.2 \cdot 10^{-8}$ at 95% C.L. with half of the integrated 2011 luminosity (2.4 fb^{-1}) [8].

A new analysis was performed with the data in the di-muon invariant mass region from 5066 to 5666 MeV removed from the analysis until the procedures for event selection, as well as for the signal and limit extractions were completely defined.

The $B_s^0 \to \mu^+\mu^-$ branching fraction is measured with respect to the prominent reference decay $B^\pm \to J/\psi K^\pm$. The branching fraction can be written as $\mathscr{B}(B_s^0 \to \mu^+\mu^-) = N_{\mu^+\mu^-} \times \text{SES}$, where single-event sensitivity SES $= \frac{\mathscr{B}(B^{\pm}\to J/\psi K^{\pm})}{N_{J/\psi K^{\pm}}} \cdot \frac{f_u}{f_s} \cdot R_{A_\epsilon}$, $N_{\mu^+\mu^-}$ and $N_{J/\psi K^{\pm}}$ are the event numbers of the corresponding decays, $\frac{f_u}{f_s}$ is relative b-quark hadronisation probability of $B^{\pm}$ and B_s^0, taken from previous measurements, and R_{A_ϵ} is the acceptance and efficiency ratio for the two decays. A limit on $\mathscr{B}(B_s^0 \to \mu^+\mu^-)$ is derived by assuming $\mathscr{B}(B^0 \to \mu^+\mu^-)$ to be negligible.

Monte Carlo simulated event samples were adjusted by an iterative re-weighting procedure with re-weighting based on simulation, followed by a data driven re-weighting. This procedure uses the comparison of MC events to the sample of $B^{\pm} \to J/\psi K^{\pm}$ events in collision data. Only candidates with odd event numbers are used in the re-weighting procedure, while the remaining sample is used for the yield measurement. The weights are cross-checked on the $B_s^0 \to J/\psi\phi$ control channel.

Only events containing candidates for $B_s^0 \to \mu^+\mu^-$ and $B^{\pm} \to J/\psi K^{\pm}$ are retained for this analysis. The sidebands for signal events are [4766, 5066] and [5666, 5966] MeV. For the reference channel, the signal region is [5180, 5380] MeV and sidebands are [4930, 5130] and [5430, 5630] MeV. After preselection, approximately $3.9 \cdot 10^5$ $B_s^0 \to \mu^+\mu^-$ and $2.5 \cdot 10^5$ $B^{\pm} \to J/\psi K^{\pm}$ candidates are obtained in the signal regions.

Two categories of background are considered: a continuum with smooth dependence on the di-muon invariant mass, and various sources of resonant contributions, most of which come from the $B_{(s)}^0 \to h^+h'^-$ decays (with h being a kaon or pion) when both daughters are misidentified as muons in the detector. The combinatorial background from $b\bar{b} \to \mu^+\mu^- X$ decays provides a reasonable description for event variables, used for background suppression, in sidebands. The contribution of the resonant background is estimated from MC.

The Boosted Decision Tree (BDT) algorithm was found to be the best performing discrimination between the signal and background events. It uses 13 variables. Distributions from $B^{\pm} \to J/\psi K^{\pm}$ events simulated with MC are compared to data after the side-band background subtraction for all discriminating variables and variables used in the preselection. The optimisation procedure aims at selecting the best performing BDTs and obtaining the final selection cuts in the BDT output variable q and in the invariant mass window Δm. The signal region is defined as $\pm\Delta m$ centred around a mass of 5366.33 MeV. The optimization is performed by maximizing the estimator $P = \frac{\epsilon}{1+\sqrt{B}}$, where ϵ is the signal efficiency and B is the number background events selected. The 2-dimensional optimization on the BDT output requirement and the signal region width is performed on the signal MC sample and the odd-numbered data events from sidebands. The optimization gives a maximum P value of 0.0145 with BDT output > 0.118 and $|\Delta m| < 121$ MeV.

The branching fraction for the reference channel is calculated as a product of $\mathscr{B}(B^{\pm} \to J/\psi K^{\pm}) = (1.016 \pm 0.033) \cdot 10^{-3}$ and $\mathscr{B}(J/\psi \to \mu^+\mu^-) = (5.93 \pm 0.06)\%$. The ratio $\frac{f_u}{f_s}$ is taken from $\frac{f_s}{f_d} = 0.256 \pm 0.020$ using $\frac{f_d}{f_u} = 1$. The ratio R_{A_ϵ} is evaluated using MC samples and found to be $0.267 \pm 1.8\% \pm 6.9\%$. The reference channel yield $N_{J/\psi K^{\pm}}$ is determined from a multi-dimensional unbinned extended maximum likelihood fit to the distribution of the invariant-mass of the $\mu^+\mu^- K^{\pm}$ system and its event-by-event uncertainty. The combined result for $N_{J/\psi K^{\pm}}$ gives 15214 even-numbered events with an uncertainty $\pm 1.1\%$ (stat.) and $\pm 2.4\%$ (syst.). The SES value is obtained as $(2.07 \pm 0.26) \cdot 10^{-9}$.

To extract the upper limit on the $\mathscr{B}(B_s^0 \to \mu^+\mu^-)$ the standard implementation of the CLs method in ATLAS is used. Before unblinding the signal region, the expected number of background events in this region is found to be 6.75. After unblinding, 6 events are counted in the signal region and used in CLs analysis. The observed CLs as a function of $\mathscr{B}(B_s^0 \to \mu^+\mu^-)$ is shown in Fig. 1a. The observed limit is $\mathscr{B}(B_s^0 \to \mu^+\mu^-) < 1.5(1.2) \cdot 10^{-8}$ at 95% (90%) CL.

3 CP violation parameter ϕ_s and $\Delta\Gamma_s$ from angular amplitudes of $B_s^0 \to J/\psi\phi$ decay

New phenomena beyond SM may alter CP violation in B-decays. A channel $B_s^0 \to J/\psi\phi$ is expected to be sensitive to new physics contributions. CP violation in this channel occurs due to interference between direct decays and decays with B_s^0—$\bar{B}_s^0$ mixing, characterized by Δm_s of heavy (B_H) and light (B_L) mass eigenstates, and is measured by the weak phase ϕ_s. It is small in SM: the predicted value is $\phi_s = -0.0368 \pm 0.0018$ rad [9]. The width difference $\Delta\Gamma_s = \Gamma_H - \Gamma_L$ is not expected to be significantly affected by new physics and is useful for the SM prediction test. The average decay width is $\Gamma_s = (\Gamma_H + \Gamma_L)/2$.

Previous ATLAS measurement of ϕ_s, Γ_s and $\Delta\Gamma_s$ from fully reconstructed decays $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ with only statistical CP states separation with 4.9 fb^{-1} is published in [10]. The results are updated with the flavour tagged time-dependent angular analysis [2].

The determination of the initial flavor of neutral B-mesons can be inferred from the B-meson that is produced from another b-quark in the event. The calibration of the method is performed in events containing the decays $B^\pm \to J/\psi K^\pm$.

Several methods are available to infer the flavor of the opposite-side b-quark. First, the measured charge of a muon from semileptonic decay of the B-meson provides a strong separation power and it can be enhanced by considering a weighted sum of the charge q_i of the tracks in the cone ΔR around muon:

$$Q_\mu = \frac{\sum_i^{N_{\rm tr}} q_i \cdot (p_T^i)^k}{\sum_i^{N_{\rm tr}} (p_T^i)^k},$$

where $k = 1.1$, number of tracks $N_{\rm tr}$ includes tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$, $\Delta R = 0.5$. If no muon is present, a b-tagged jet is required in the event, which is seeded from calorimeter clusters with an energy threshold of 10 GeV and a minimum b-tag weight of -0.5. The jet is reconstructed using the anti-k_t algorithm with a cone size 0.6. The jet charge $Q_{\rm jet}$ is defined similar to Q_μ, where the sum is over the tracks associated with the jet. In both cases, the tracks associated with the signal decay products are excluded from the sum.

Candidates for $B_s^0 \to J/\psi\phi$ decays are selected by following requirements: no displaced vertex or time cuts applied in the trigger or offline; J/ψ mass window adapted separately for barrel and endcap regions; ϕ mass window of 22 MeV; kaons $p_T > 1$ GeV; B-vertex fit quality χ^2/d.o.f. < 3. In total, 131k B_s^0 candidates within $5.15 < m(B_s^0) < 5.65$ GeV are used in the fit.

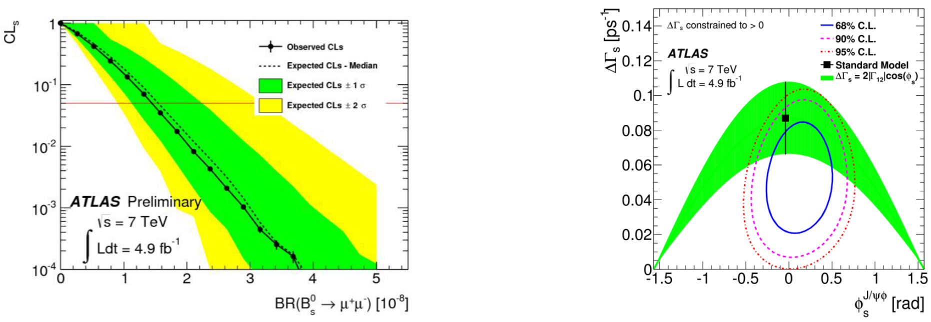
An unbinned maximum likelihood fit is performed on the selected events to extract the parameters of the $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay. The fit uses reconstructed mass and proper time with the uncertainties, the tag probability and the transversity angles $\Omega(\theta_T, \psi_T, \phi_T)$, defined in the rest frames of $J/\psi(\theta_T, \phi_T)$ and $\phi(\psi_T)$. The likelihood function includes the combination of signal and background probability density functions. The full simultaneous maximum likelihood fit contains 25 free parameters. The number of signal B_s^0 mesons extracted from the fit is 22670 ± 150. The solution with $\Delta\Gamma_s > 0$ is considered.

The results for physics parameters are

$$\phi_s = 0.12 \pm 0.25\,(\text{stat.}) \pm 0.05\,(\text{syst.})\,\text{rad},$$

$$\Delta\Gamma_s = 0.053 \pm 0.021\,(\text{stat.}) \pm 0.010\,(\text{syst.})\,\text{ps}^{-1},$$
$$\Gamma_s = 0.667 \pm 0.007\,(\text{stat.}) \pm 0.004\,(\text{syst.})\,\text{ps}^{-1},$$
$$|A_{\parallel}(0)|^2 = 0.220 \pm 0.008\,(\text{stat.}) \pm 0.009\,(\text{syst.}),$$
$$|A_0(0)|^2 = 0.529 \pm 0.006\,(\text{stat.}) \pm 0.012\,(\text{syst.}),$$
$$\delta_{\perp} = 3.89 \pm 0.47\,(\text{stat.}) \pm 0.11\,(\text{syst.})\,\text{rad}.$$

The values are consistent with those obtained in the untagged analysis [10] and reduce the statistical uncertainty on ϕ_s by 40%. The fit demonstrates sensitivity to the strong phase $\delta_{\perp}$. Likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane are presented in Fig. 1b. The results are consistent with the values predicted in the standard model.



(a) (b)

Figure 1: (a) Observed CL$_s$ as a function of $\mathscr{B}(B_s^0 \to \mu^+\mu^-)$. (b) Likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane.

4 Conclusions

ATLAS results from the full 2011 data for pp collisions at 7 TeV (4.9 fb^{-1}) are obtained for new physics searches in the rare decay $B_s^0 \to \mu^+\mu^-$ selection and $B_s^0 \to J/\psi\phi$ decay parameters measurement. The flavour tagged time dependent angular analysis is used for $B_s^0 \to J/\psi\phi$ improving on the previous ATLAS measurement without tagging. All results are consistent with the predictions of the standard model.

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