

New physics searches with heavy flavour with the ATLAS experiment

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Abstract. Flavour changing neutral currents and precision measurements of CP violation are investigated by the ATLAS experiment at the Large Hadron Collider at CERN as probes to physics beyond the Standard Model. This paper presents recent update of flavour tagged time-dependent analysis of $B_s \rightarrow J/\psi \phi$, angular analysis of $B_d \rightarrow K^* \mu^+ \mu^-$ and a search for the rare decay $B_s^0 \rightarrow \mu^+ \mu^-$ with measurement of upper limit on its branching fraction. All analyses use 4.9 fb^{-1} of integrated luminosity collected in 2011 at centre-of-mass energy of 7 TeV and the results are in agreement with Standard Model predictions.

1. Introduction

The production of b -hadrons at the Large Hadron Collider (LHC) provides excellent opportunities for indirect searches for new physics. Various rare decay modes occur in Standard Model (SM) as loop diagrams and are sensitive to contributions of physics beyond SM, mainly as a result of the interference with SM diagrams.

The ATLAS experiment [1] is a general purpose detector consisting of an inner tracker, calorimeters and a muon spectrometer. The Inner Detector (ID) detects tracks of charged particles and consists of pixel, silicon strip and transition radiation subdetectors embedded in a 2 T solenoidal magnetic field. Surrounding the ID there are electromagnetic and hadronic calorimeters and the Muon Spectrometer (MS) with toroidal magnetic field.

The ATLAS trigger consists of a hardware-based Level-1 trigger and a 2-staged High Level Trigger (HLT). The muon trigger at Level-1 is based on pattern search for different p_T thresholds in the MS. The regions of interest around these patterns are then used as seeds for the HLT reconstruction, matching information from both the MS and ID.

2. Flavour tagged time dependent angular analysis of $B_s^0 \rightarrow J/\psi \phi$

Events for this measurement [2] are triggered by di-muon triggers searching for $J/\psi \rightarrow \mu^+ \mu^-$ candidates with p_T thresholds of 4 GeV for both muons or 4 GeV and 2 GeV for the first and second muon, respectively. The candidates for $\phi \rightarrow K^+ K^-$ are reconstructed from tracks with $p_T > 1 \text{ GeV}$ and $|\eta| < 2.5$ not identified as muons and each combination of J/ψ and ϕ is fitted to a common vertex (fixing the di-muon invariant mass to the J/ψ mass). Candidates are accepted if the invariant mass of hadronic track pairs falls within a small range around ϕ mass and if the criteria on vertex fit quality and number of ID hits for tracks are met.

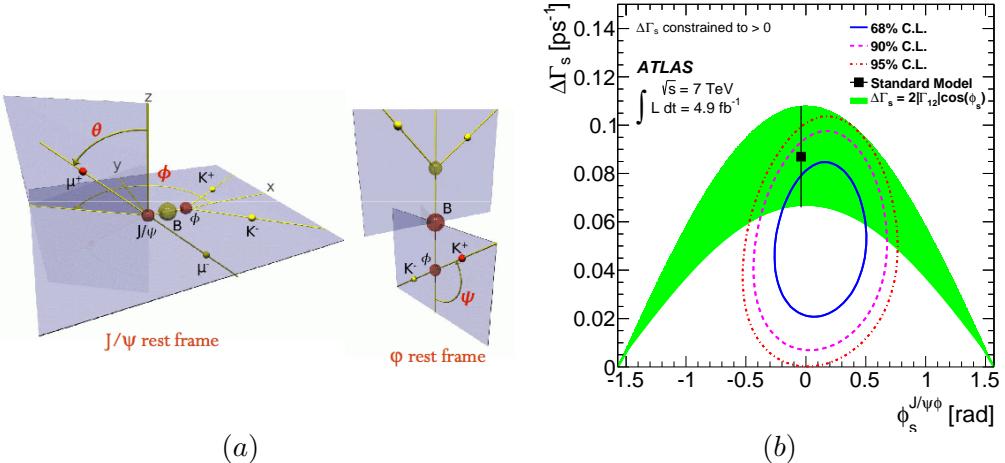


Figure 1. $B_s^0 \rightarrow J/\psi \phi$ analysis: (a) definition of transversity angles, (b) the 68% and 95% likelihood contours in $\phi_s - \Delta\Gamma_s$ plane (statistical errors only) with the theoretical prediction of mixing-induced CP violation [2].

This updated analysis includes Opposite-Side Tagging to determine the initial flavour of B -mesons. To calibrate the method, decays $B^\pm \rightarrow J/\psi K^\pm$ are used: the flavour of B^\pm at production is known from the kaon charge.

An unbinned maximum likelihood fit is performed on selected events to extract parameters of the signal decay. The likelihood function is defined as a combination of probability density functions \mathcal{F}_s for signal, \mathcal{F}_{B^0} for B^0 background contribution and \mathcal{F}_{bkg} for other backgrounds as

$$\ln \mathcal{L} = \sum_{i=1}^N \{ \ln(w_i f_s \mathcal{F}_s(m_i, t_i, \Omega_i) + f_s f_{B^0} \mathcal{F}_{B^0}(m_i, t_i, \Omega_i) + (1 - f_s(1 + f_{B^0})) \mathcal{F}_{\text{bkg}}(m_i, t_i, \Omega_i)) \},$$

where N is the number of candidates, w_i is weighting factor to account for trigger efficiency, f_s is fraction of signal candidates, and f_{B^0} is fraction of peaking B^0 events. Values of reconstructed mass m , proper decay time t , their uncertainties σ_m and σ_t , tag probability and transversity angles $\Omega = (\theta_T, \psi_T, \phi_T)$, as defined in Fig. 1 (a), are measured from data for each event.

The full fit has 25 free parameters and it extracted 22670 ± 150 signal candidates. The fitted values of weak phase ϕ_s , $B_s - \bar{B}_s$ width difference $\Delta\Gamma_s$ and other physical parameters [2] are

$$\begin{aligned} \phi_s &= 0.12 \pm 0.25 \text{ (stat.)} \pm 0.05 \text{ (syst.) rad} \\ \Delta\Gamma_s &= 0.053 \pm 0.021 \text{ (stat.)} \pm 0.010 \text{ (syst.) ps}^{-1} \\ \Gamma_s &= 0.677 \pm 0.007 \text{ (stat.)} \pm 0.004 \text{ (syst.) ps}^{-1} \\ |A_{||}(0)|^2 &= 0.220 \pm 0.008 \text{ (stat.)} \pm 0.009 \text{ (syst.)} \\ |A_0(0)|^2 &= 0.529 \pm 0.006 \text{ (stat.)} \pm 0.012 \text{ (syst.)} \\ \delta_\perp &= 3.89 \pm 0.47 \text{ (stat.)} \pm 0.11 \text{ (syst.) rad}. \end{aligned}$$

Figure 1 (b) shows the likelihood contours in $\phi_s - \Delta\Gamma_s$ plane, together with the SM expectations. The values are consistent with those obtained in the previous untagged analysis [3] and the overall uncertainty on ϕ_s is reduced by 40% with respect to the untagged analysis.

3. Angular analysis of $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$ with subsequent $K^{*0} \rightarrow K^+ \pi^-$ decay can be described by four kinematic variables: the invariant mass q^2 of the di-muon system and three angles defining configuration of the final state, θ_L is the angle between μ^+ and direction opposite to B^0 in

di-muon rest frame, θ_K is the angle between K^+ and direction opposite to B^0 in K^{*0} rest frame, and ϕ is the angle between di-muon and K^{*0} planes [4].

Signal candidates are selected using single and di-muon triggers with different p_T thresholds (mainly $p_T > 4$ GeV or 6 GeV). Decay candidates are reconstructed from two muons and a pair of oppositely charged tracks with $p_T > 0.5$ GeV. Based on Monte Carlo (MC) optimisation, cuts on lifetime significance τ/σ_τ , pointing angle (angle between the B_d^0 momentum and the vector between the primary vertex and the reconstructed B_d^0 vertex) and $p_T(K^{*0})$ are applied to suppress the combinatorial background. In order to remove the resonant background, events with di-muon mass within 3σ from the J/ψ and $\psi(2S)$ peaks are excluded.

Because statistics is insufficient to study the fully differential decay rate, the K^{*0} longitudinal polarisation fraction F_L and the muon forward-backward asymmetry A_{FB} are extracted from projections into 2-dimensional distributions (integrating over ϕ and θ_L or θ_K) as

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2 d \cos \theta_K} = \frac{3}{2} F_L(q^2) \cos^2 \theta_K + \frac{3}{4} (1 - F_L(q^2))(1 - \cos^2 \theta_K)$$

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2 d \cos \theta_L} = \frac{3}{4} F_L(q^2)(1 - \cos^2 \theta_L) + \frac{3}{8} (1 - F_L(q^2))(1 + \cos^2 \theta_L) + A_{FB}(q^2) \cos \theta_L.$$

Results of an unbinned maximum likelihood fit in five q^2 bins are shown in Fig. 2, together with comparison with the SM predictions.

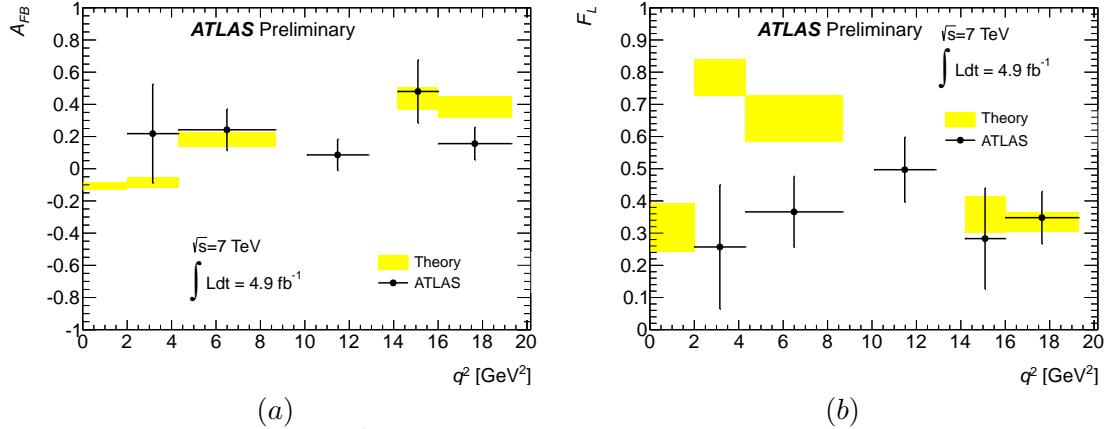


Figure 2. Results of $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$ analysis: (a) forward-backward asymmetry A_{FB} and (b) fraction of longitudinally polarised K^0 mesons F_L , with statistical and systematic uncertainties added in quadrature. The SM predictions calculated for limits of small and large values of q^2 are also shown [4].

4. Search for $B_s^0 \rightarrow \mu^+ \mu^-$

The $B_s^0 \rightarrow \mu^+ \mu^-$ branching fraction \mathcal{B} is measured as a relative branching ratio with a reference decay $B^\pm \rightarrow J/\psi K^\pm$ in order to minimize systematic uncertainties [5].

To select signal decay candidates, two muons with $p_T > 4$ GeV are required at the Level-1 trigger and a loose cut on their invariant mass are applied at the HLT to select B_s^0 or J/ψ . A preselection is made requiring a good quality of tracks and reconstructed vertices and minimal numbers of hits in the ID subdetectors. Similar cuts are applied to reference channel candidates, leaving approximately 3.9×10^5 signal and 2.5×10^5 reference channel candidates in the signal region ($5066 \text{ MeV} < m_{\mu^+ \mu^-} < 5666 \text{ MeV}$).

Two categories of background are considered: the resonant background due to B decays to hadrons misidentified or decaying to muons are simulated and results are included in the

computation of expected background yield for the upper limit extraction. The combinatorial background is studied with the $b\bar{b} \rightarrow \mu^+\mu^-X$ MC sample. To improve the agreement of MC simulation with data, a generator level re-weighting procedure is applied (correcting for generator filter biases) and a data-driven re-weighting is performed using half of the reference channel data (avoiding bias to extraction of the reference channel and background yield).

The selection criteria are chosen by performing a 2D optimization of the signal window width and a Boosted Decision Tree (BDT) discriminant, using signal MC and half of the side-band data. Thirteen variables based on the kinematic properties of decay products, vertices and tracks in underlying event are used as inputs to the BDT. The residual combinatorial background in the signal region is determined from interpolation of side-bands using the other half of data.

The estimated number of background events in the signal region is 6.75, the total number of events observed after unblinding is 6. Figure 3 shows the invariant-mass distribution of selected candidates and the behaviour of the observed confidence level (CL_s [6]). The upper limit of branching fraction is extracted using the CL_s method and the observed value is $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 1.5 \times 10^{-8}$ (at 95% CL).

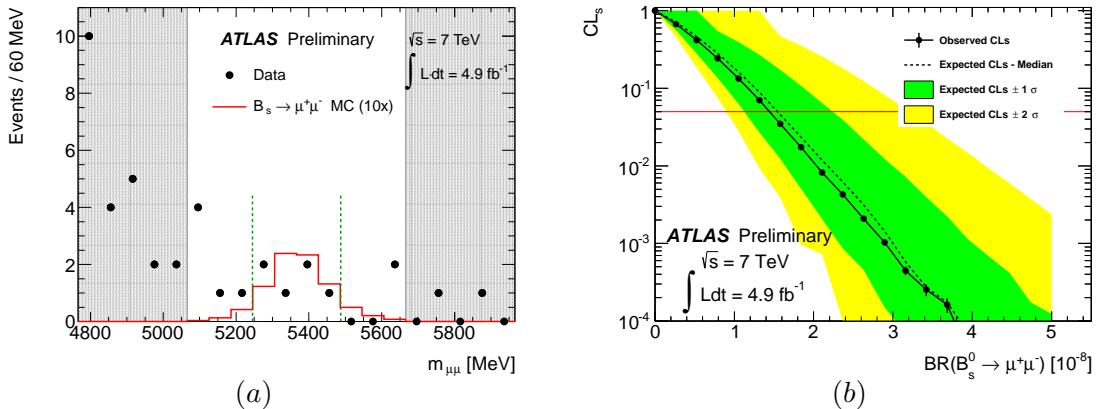


Figure 3. (a) Invariant-mass distribution of $B_s^0 \rightarrow \mu^+\mu^-$ candidates for data and MC (scaled by a factor of 10) in signal region (dashed vertical lines) and side-bands (grey areas). (b) Observed CL_s as a function of branching ratio of $B_s^0 \rightarrow \mu^+\mu^-$. The 95% limit is indicated by the red line, green and yellow bands correspond to the $\pm 1\sigma$ and $\pm 2\sigma$ range of background-only pseudo-experiments with median of expected CL_s given by the dashed line [5].

5. Conclusions

Presented analyses of rare b -hadron decays show no deviations from the SM. They are, however, limited by small statistics of 2011 dataset. Measurements will be soon updated using the 2012 dataset (21.7 fb^{-1} at centre-of-mass energy of 8 TeV) and with data which will be collected in the future LHC runs.

Acknowledgments

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