Exclusive and Rare B Decays in ATLAS

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The ATLAS experiment at LHC presented a variety of B-Physics results obtained by analyzing data collected during 2010 and 2011. B meson properties are investigated in the exclusive decays involving a J/ψ. A brief overview of these measurements is given; then, the blind analysis search for the decay $B_s \to \mu^+\mu^-$ is described.

1 Introduction

The ATLAS B-Physics program is mainly based on exclusive and rare B-hadron decays as they allow to perform interesting studies in the Heavy Flavor sector and to search for New Physics. Several measurements have been done by using proton-proton collisions at a center-of-mass energy of 7 TeV recorded with the ATLAS [1] detector at the LHC during 2010 and 2011. These measurements rely mainly on the Inner Detector (ID) tracker and on the Muon Spectrometer (MS) systems, which achieved very good performance despite the challenging pile-up conditions due to the high luminosity reached. Dedicated B-physics triggers based on di-muons were developed and were kept unprescaled without having to raise the $p_T(\mu)$ threshold.

2 Exclusive B mesons decays

B mesons in ATLAS are reconstructed in exclusive channels involving a J/ψ which further decays to a di-muon final state [2, 3, 4, 5, 6, 7]. The analysis of these decays is important to study the B meson properties, to test the theoretical predictions, or to be used as reference in future important measurements.

In particular, some decays serve as reference for other decay channels, like $B^\pm \to J/\psi K^\pm$ for $B_s \to \mu^+\mu^-$. The $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi(K^+K^-)$ decays are studied to evaluate B_d^0 and B_s^0 lifetimes; the latter allows the measurement of the B_s^0 mixing phase which generates CP violation. $B_d^0 \to J/\psi K_s^0(\pi^+\pi^-)$ and $\Lambda_b^0 \to J/\psi\Lambda^0(p^+\pi^-)$ serve to measure the lifetime ratio of Λ_b^0 and B_d^0, predicted by Heavy Quark Expansion (HQE) [8] and perturbative QCD. Also the study of the Λ_b^0 polarization is relevant to test these models. Finally, the study of $B_c^\pm \to J/\psi\pi^\pm$ is useful to probe heavy quark dynamics.

The J/ψ selection requires a pair of good quality oppositely charged tracks identified as muons fitted to a common vertex. Depending on the exclusive decay, the tracks belonging to the di-muon candidate and one or two additional tracks are again fitted to a common vertex; this time the di-muon tracks are constrained to the J/ψ world average mass while to the other tracks a mass hypothesis is assigned. All B hadron mass measurements agree with PDG values;

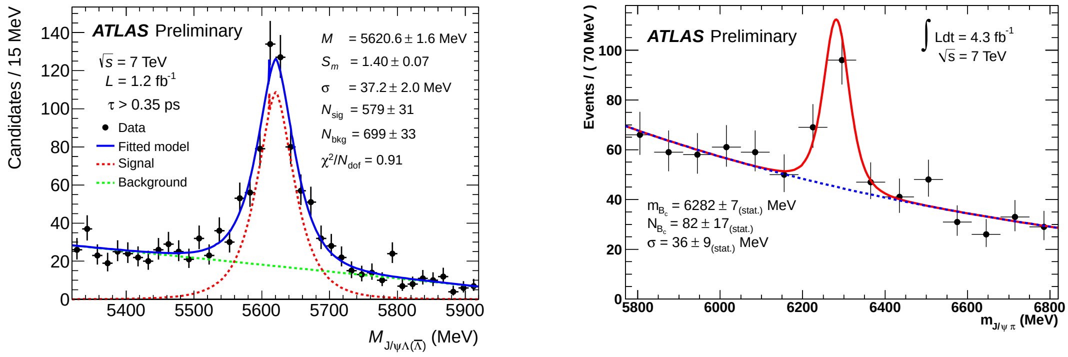

Figure 1: Invariant mass distributions of $\Lambda_b^0 \to J/\psi\Lambda^0(p^+\pi^-)$ and charge conjugate (left) and $B_c^\pm \to J/\psi\pi^\pm$ (right) candidates found in ATLAS data.

two examples of invariant mass distributions are shown in Figure 1 for $\Lambda_b^0 \to J/\psi\Lambda^0(p^+\pi^-))$ (left) [6] and for $B_c^\pm \to J/\psi\pi^\pm$ (right) [7] decays.

3 The $B_s \to \mu^+\mu^-$ decay

The $B_s \to \mu^+\mu^-$ decay is a Flavor Changing Neutral Current process involving a $b \to s$ quark transition. It is highly suppressed in the Standard Model picture and occurs at the lowest order through one-loop diagrams, so that the theoretical estimation of the branching ratio is $(3.55 \pm 0.28) \times 10^{-9}$ [9, 10]. Contributions from New Physics can significantly increase this branching ratio. Recently the CDF collaboration reported an excess of $B_s \to \mu^+\mu^-$ candidates [11] , which has not been confirmed by the latest results of the LHCb [12] and the CMS [13] collaborations.

The ATLAS analysis [14] is based on data collected up to July 2011 with stable LHC beams, corresponding to 2.4 fb^{-1} of integrated luminosity. In order to minimize the systematic uncertainties the $B_s \to \mu^+\mu^-$ branching ratio is normalized to the branching ratio of another high-yield B meson decay channel taken as reference; for this purpose the $B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm$ decay has been used. The expression of the $B_s \to \mu^+\mu^-$ branching ratio reads

$$Br(B_s \to \mu^+\mu^-) = \frac{N_{\mu\mu}}{N_{B^\pm}} \times R_{\alpha\epsilon} \times \frac{\mathcal{L}_{ref}}{\mathcal{L}_{\mu\mu}} \times \frac{f_u}{f_s} \times Br(B^\pm \to J/\psi K^\pm) \times Br(J/\psi \to \mu^+\mu^-) \quad (1)$$

where $R_{\alpha\epsilon} = \frac{\epsilon_{B^\pm}\alpha_{B^\pm}}{\epsilon_{\mu\mu}\alpha_{\mu\mu}}$ and for each decay mode, N is the number of observed events, ϵ and α are, respectively, the efficiencies and acceptances, $\mathcal{L}$ is the integrated luminosity and f_u/f_s is the relative p-p production rate of $B^\pm$and B_s mesons. In Equation 1 the luminosity factors cancel out since the same integrated luminosity has been used. Equation 1, when setting $N_{\mu\mu} = 1$, provides the so-called *Single Event Sensitivity* (SES). A blind search is performed, meaning that all the quantities entering the SES have been evaluated by excluding in the data sample the signal region, corresponding to a mass window of $\pm$ 300 MeV around the B_s mass, until the analysis was considered finalized and approved by the Collaboration.

Monte Carlo (MC) samples [1]were used to model both signal and reference channels. In particular, for each decay mode N is evaluated from data after background subtraction while the ratio $R_{\alpha\epsilon}$ is evaluated from MC; for the remaining quantities the values $\frac{f_u}{f_s} = 0.267 \pm 0.021$ [2] , and $Br(B^{\pm} \to J/\psi K^{\pm} \to \mu^+\mu^- K^{\pm}) = (6.01 \pm 0.21) \times 10^{-5}$ [17] are used. The main background is expected to originate from true di-muon events, dominated by (prompt) Drell-Yan pairs ($pp \to \mu^+\mu^-$) and non-prompt heavy flavor semi-leptonic decays ($pp \to b\bar{b} \to \mu^+\mu^- X$). To model this *continuum* background the data belonging to the sidebands of the signal region ($4766\ MeV < m_{\mu\mu} <5066\ MeV \bigcup 5666\ MeV < m_{\mu\mu} < 5966\ MeV$), as shown in Figure 2, were used. In order to avoid biases, the sidebands data have been split in 2 equal populated parts: one was used in the optimization of the cuts, the other for the estimation of the background in the signal region after the optimization. In addition, the irreducible background which originates from neutral B meson two-body decays with charged hadrons in final state misidentified as prompt muons[3], has been evaluated using MC and accounted in the upper limit extraction[4]. To improve the signal/background separation, the samples were split in three mass resolution categories ($\sigma_{m_{\mu\mu}} \sim 60/80/120\ MeV$) depending on the maximum absolute value of the muons pseudorapidity in the di-muon candidate, η_{max}. A multivariate analysis (MVA) has been used to combine the separation power of 14 different variables, selected according to their discriminating power and avoiding correlations; the chosen multivariate classifier was the Boosted Decision Tree (BDT) algorithm. In particular, these variables exploit the signal features, like the separation between the primary and the secondary vertex, the symmetry of the final state (pointing angle, impact parameters, etc.) and the B meson hadronization features

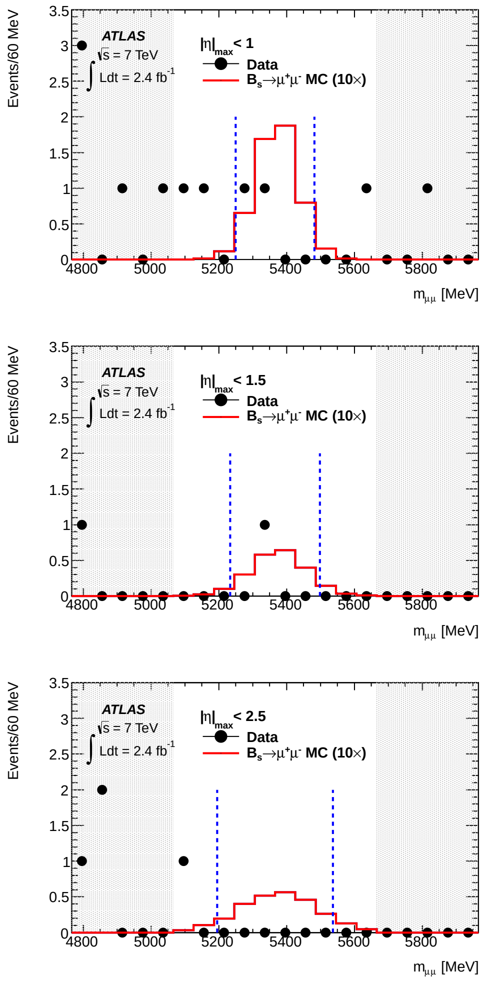

Figure 2: Invariant mass distributions for the three resolution categories (top to bottom).

[1]MC samples were corrected by using per event weights in order to account for the differences between B_s and B^+spectra and for the discrepancies found from comparison with data.

[2]This value is obtained from Reference [15] assuming $f_u = f_d$ (following Reference [16]) and no kinematic dependence of $\frac{f_u}{f_s}$.

[3]The probability to misidentify a final state hadron as muon either due to punch-through or decay in flight (*muon fake rate*) has been estimated to be $\sim 10^{-3}$.

[4]Additional sources of background have been estimated to be negligible.

(transverse momentum, isolation[5], etc). For each mass resolution category, the selection has been optimized as a function of the width of the search window in mass Δm and of the lower cut on the BDT output[6]. To obtain a limit at 95% CL, the estimator [18] $\mathcal{P} = \epsilon_S/(1+\sqrt{N_{bkg}})$ is maximized, where ϵ_S is the signal efficiency and N_{bkg} is the number of background events. To avoid the introduction of additional systematic uncertainties, the same BDT classification optimized on the $B_s \to \mu^+\mu^-$ signal has been used for the $B^\pm \to J/\psi K^\pm$ selection. For each resolution category, the invariant mass distribution is shown in Figure 2: each plot shows the invariant mass distribution for the selected candidates in data (dots) compared to the signal (continuous line) as predicted by MC, assuming a branching ratio 10 times greater than the SM expectation. The two vertical lines correspond to the optimized Δm cut, while the grey areas correspond to the sidebands used. No excess of events has been found, therefore an upper limit on the $B_s \to \mu^+\mu^-$ branching ratio is set. The observed limit, obtained by means of an implementation [19] of the $\mathrm{CL_s}$ method [20], is < 2.2 (1.9) $\times 10^{-8}$ at 95% (90%) CL.

4 Conclusions

The ATLAS Collaboration presented interesting results in the B-Physics sector, mainly concerning masses and lifetimes of various B hadrons, which allow to test the theoretical prediction, to perform future measurements of CP violation or to search for New Physics. For this purpose the $B_s \to \mu^+\mu^-$ decay has been studied and an upper limit has been set.

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[5]The isolation is track based, and the dependence on pile-up is reduced by using only tracks associated with the same primary vertex as the B candidate.

[6]The mass dependence of the BDT output has been checked with a test signal, where the signal mass has been shifted to the value of 6.5 GeV: no significant correlation between the two has been found.