PROCEEDINGS OF SCIENCE

Study of rare and suppressed processes in B meson decays with ATLAS

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The large amount of Heavy Flavor data collected by the ATLAS experiment is potentially sensitive to New Physics, which could be evident in processes that are naturally suppressed in the Standard Model. The most recent result on the search for the rare decay $B_s^0(B_d^0) \to \mu^+\mu^-$ is presented. Recent results are also presented on the angular distribution parameters A_{FB} and F_L describing the decay $B_d^0 \to \mu^+\mu^- K^* \to \mu^+\mu^- K^+\pi^-$. The accuracy obtained from data collected in 2011 is comparable to the best previous measurement in the region $q^2(\mu^+\mu^-) > 16$ GeV^2.

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1. Limit on $BR(B_s^0 \to \mu^+\mu^-$ decay.

The Standard Model (SM) predicts the $BR(B_s^0(5366) \to \mu^+\mu^-) = (3.23 \pm 0.27) \cdot 10^{-9}$ [1, 2, 3, 4]. The branching fraction might be substantially enhanced by non-SM heavy particles in the loop diagrams. Upper limits on this branching fraction have been presented by D0[5], CDF[6] collaborations. The LHCb collaboration recently reported first evidence for this decay with $BR = (3.23^{+1.4\ +0.5}_{-1.2\ -0.3}) \cdot 10^{-9}$ [7]. The CMS collaboration also reported a measurement of $BR(B_s^0 \to \mu^+\mu^-) = 3.0^{+1.0}_{-0.9} \cdot 10^{-9}$ [8]. Previous ATLAS result was based on half of the 2011 ATLAS dataset with integrated luminosity $L_{int} = 2.4\,\text{fb}^{-1}$ in pp-collisions at $\sqrt{s} = 7\,\text{TeV}$ [9].

This note represents an update to the full 2011 ATLAS dataset with integrated luminosity $L_{int} = 4.9\,\text{fb}^{-1}$ and with improvements in the analysis [10]. The ATLAS experiment [11] at the LHC is a general purpose particle detector covering almost the full solid angle around the pp collision point with layers of tracking detectors, calorimeters and muon tracking chambers. This analysis is based on events selected by a dimuon trigger. Events with a pair of opposite-sign muons, with transverse momenta $p_T > 4$ GeV for both muons were acquired during the 1-st half of the 2011 data taking period. Due to increase of instantaneous luminosity in the 2-nd half of the 2011 data taking campagne, the p_T threshold was marginally increased. The effect of this modification was studied on B^+ Monte-Carlo (MC) sample and found to be negligible.

The following requirements were applied in offline selection of B_s^0 candidates:

- requested two combined muons (reconstructed in Inner detector and in Muon spectrometer), both in pseudorapidity interval $|\eta| < 2.5$ and with transverse momentum $p_T > 4\,\text{GeV}$, with at least 1 hit in Pixel detector, 6 hits in SCT and 9 hits in TRT detector in muon track;
- decay vertices were formed by $\mu^+\mu^-$, accepted events with $\chi^2/NDF < 2.0$;
- B_s^0 candidates with $p_T > 8$ GeV and with effective mass of dimuon in interval $(4.0 < m(\mu^+\mu^-) < 8.5$ GeV) were selected for analysis.

Preliminary signal mass band was defined in interval $(5.066, 5.666)\,\text{GeV}$ and two side bands, $(4.766, 5.066)\,\text{GeV}$ and $(5.666, 5.966)\,\text{GeV}$. There are 390000 B_s^0 candidates after preselection.

$B^+ \to J/\psi K^+$ events were used for normalization, with $J/\psi \to \mu^+\mu^-$ and extra charged track with $p_T > 2.5\,\text{GeV}$ was taken with kaon mass (without identification). Three charged particles were fitted to a common vertex. Efficiencies for B^+ and B_s^0 detection were estimated from MC.

Detailed studies of random dimuon background in the sample of B_s^0 candidates and background from B-meson decays into two charged hadrons (misidentified as muons) were performed. Description of efficiency calculation and background (BG) subtraction can be found in [10], including reweighting of MC events to correct difference between data and MC in (p_T, η) bins. In order not to correlate the reweighting procedure with the yield measurement, only candidates with odd event numbers in the ATLAS dataset are used to determine the reweighting procedure, while the remaining sample is used for the yield measurement. A combination of ten discriminative variables was worked out, and an optimization procedure with Boosted Decision Trees (BDT) technique was applied aiming the best possible significance of the signal [10]. The MC describing the background was used only to train the BDT for the rejection of the background. A half of side-band data was used to optimize the value of the cut applied on the BDT output, and to define the optimal range

in mass for the search region. When the full analysis procedure was finalized and fixed, then the access to B_s^0 candidates with even event numbers in the dataset was opened. The remaining 50% of the side-band data was used to fit the background and interpolate in the search region. The result of $BR(B_s^0 \to \mu^+\mu^-)$ estimation is presented in Fig.1.

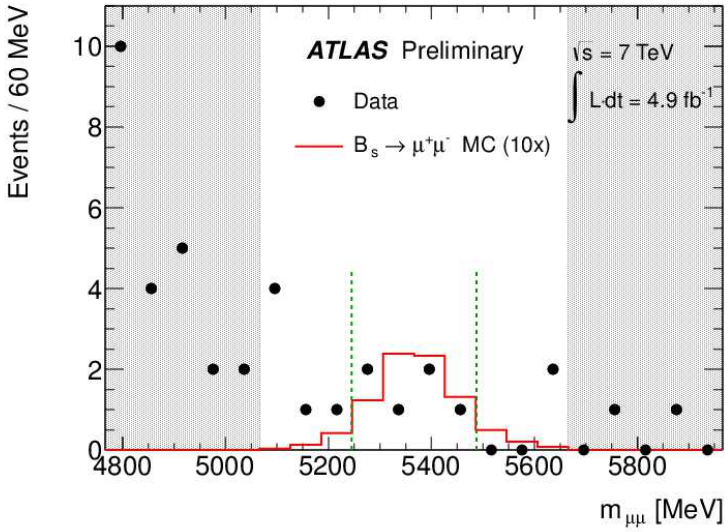

Figure 1: Invariant mass spectrum of oppositely charged muon candidate pairs for selected B_s^0 candidates after unblinding (taking even events), 6 events are counted in the signal region. Expected BG is 6.8 events. The observed limit $BR(B_s^0 \to \mu^+\mu^-) < 1.5(1.2) \cdot 10^{-8}$ at 95%(90%) Conf. Level. The plot also indicates the signal (continuous line) as predicted by Monte Carlo assuming $BR(B_s^0 \to \mu^+\mu^-) = 3.5 \cdot 10^{-8}$ (scaled by a factor 10). The signal region (two dashed vertical green lines) corresponds to the optimized Δm cut and the side bands used in the analysis are shown (grey areas).

2. A measurement of the forward-backward asymmetry A_{FB} and the fraction of the K^{*0} longitudinal polarisation F_L in the decay $B_d^0(5280) \to K^{*0}\mu^+\mu^-)$ decay.

Within the SM this decay occurs via loop diagrams that mediate the transition $b \to sl^+l^-$ and therefore has a small $BR = (1.06 \pm 0.1) \cdot 10^{-6}$ [12]. Angular distributions and amplitudes are sensitive to possible new physics beyond the SM. The objective of this analysis are measurements of the forward-backward asymmetry A_{FB} and the fraction of the K^{*0} longitudinal polarization F_L in the $B_d^0 \to \mu^+\mu^- K^{*0}(890)$ decay as a function of the dimuon invariant mass. This measurement was previously performed by BaBar[13], Belle[14], CDF[15] and LHCb[16, 17]. This analysis uses $4.9\,\text{fb}^{-1}$ of data from pp-collisions at $\sqrt{s} = 7\,\text{TeV}$ collected in 2011 [18]. The dimuon trigger is described above. The muon candidates are required to have $|\eta| < 2.5$ and a common vertex satisfying $\chi^2/NDF < 10$. The invariant mass of the dimuon pair is calculated from the ID tracks refitted accounting for the common B_d vertex.

Muons are considered as being in barrel, if they have $|\eta| < 1.05$, or Endcap otherwise. Muon pairs are classified as BB if both muons are in the Barrel, BE if one of them is in Barrel and other in Endcap, EE if both muons are in Endcap(s). Regions in dimuon mass are excluded which cover

3σ around the J/ψ mass, the width of excluded regions are ± 116, ± 159, ± 226 MeV for BB,BE and EE categories, respectively. Corresponding values for $\psi(2s)$ exclusion are ± 131, ± 189, ± 234 MeV.

The $K^* \to K^+\pi^-$ candidates are reconstructed from all pairs of oppositely charged particles with $p_T > 0.5\,\text{GeV}$ and $|\eta| < 2.5$ which are not identified as muons. Pions and kaons are not identified. For each pair two different mass hypotheses are tested, and the track combination with the invariant mass closer to the value of the K^* mass is considered as the K^* candidate. The candidates are accepted if they fulfill requirement $846 < m(K^{+-}\pi^{-+}) < 946$ MeV. Four tracks are fitted to a common vertex for each combination.

Kinematic variables:

- q^2 of the dimuon system;
- θ_L is the angle between the μ^+ and the direction opposite to the B_d in the dimuon rest frame;
- θ_K is the angle between the K^+ and the direction opposite to the B_d direction in the K^{*0} rest frame;
- ϕ is the angle between the plane defined by the two muons and the plane defined by the kaon-pion system in the B_d rest frame

The differential decay rate is projected from the four kinematic variables into the 2-dimensional distributions $d^2\Gamma/dq^2dcos(\theta_L)$ and $d^2\Gamma/dq^2dcos(\theta_K)$ by integrating over the two other variables.

Mass-angular simultaneous fit was done. To take into account angular detector endciencies due to trigger, event reconstruction and the selection cuts, the angular signal distributions are weighted by acceptance maps. The maps are constructed using Monte Carlo with full detector simulation and reconstruction. The probability mass density function for the signal is modelled as a Gaussian function with mass m_i and per-candidate error δm_i and the probability density function for the background as an exponential. The values of the K^{*0} longitudinal polarization fraction F_L and of the lepton forward-backward asymmetry A_{FB} are extracted, averaged in the q^2 bins. q^2 bins corresponding to J/ψ and $\psi(2s)$ regions are excluded. Results are shown and compared with other experiments and SM predictions in Fig.2 and Fig.3.

3. Summary

Upper limit on $BR(B_s^0 \to \mu^+\mu^-)$ measured using 4.9 fb^{-1} of integrated luminosity collected at $\sqrt{s} = 7\,\text{TeV}$ by the ATLAS experiment. The measured limit is $15 \cdot 10^{-9}$ at 95% confidence level, it is less strict in comparison with LHCb and CMS results, which include analysis of the data collected at $\sqrt{s} = 8$ TeV. The analysis of the data collected by ATLAS at 8 TeV, with an integrated luminosity close to 20 fb^{-1}, is in preparation.

Using $4.9\,\text{fb}^{-1}$ of integrated luminosity acquired at $\sqrt{s} = 7$ TeV, $B_d^0 \to \mu^+\mu^- K^{*0}(890)$ decays have been reconstructed and the angular distribution of their final state particles measured, excluded events with $m(\mu^+\mu^-)$ close to J/ψ and $\psi 2s$) masses. Forward-backward asymmetry A_{FB} and the K^{*0} longitudinal polarization F_L have been measured as a function of the dimuon mass squared q^2. The results obtained on A_{FB} and F_L are mostly consistent with theoretical predictions and

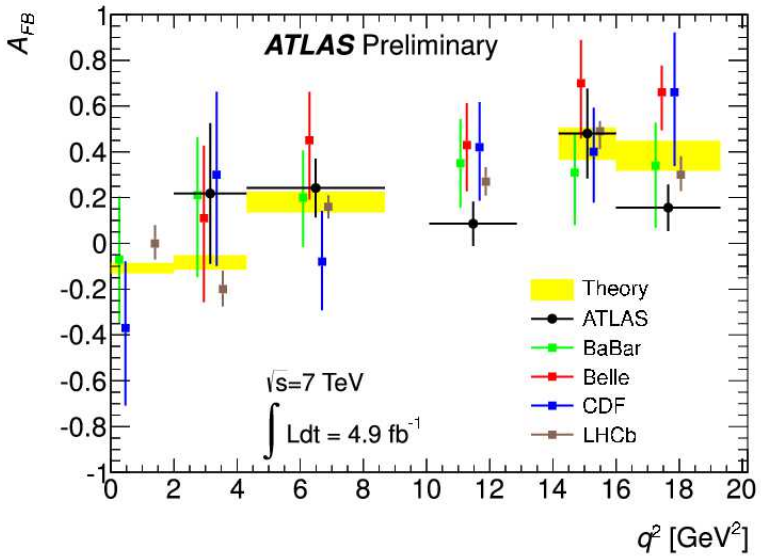

Figure 2: Compilation of forward-backward asymmetry A_{FB} measurements.

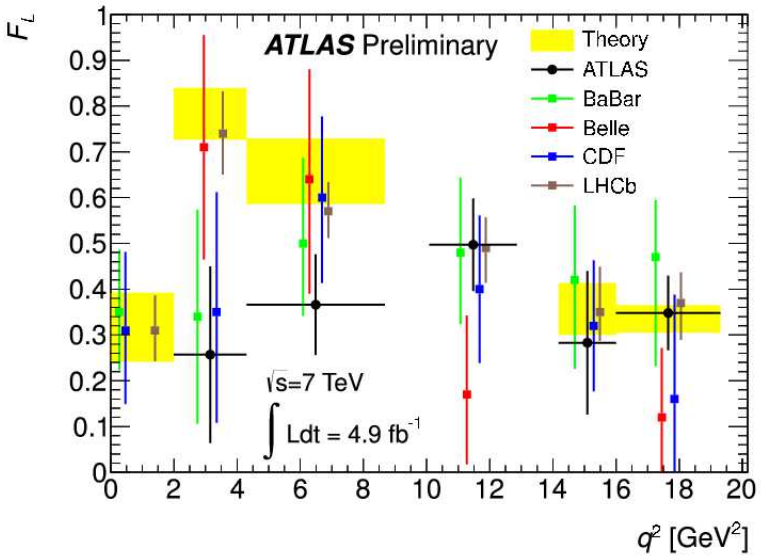

Figure 3: Compilation of K^{*0} polarization measurements.

measurements performed by other experiments. The results for F_L in the low q^2 bins slightly deviate from the Standard Model expectations.

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