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The study of the rare decays $B^0_{(s)} \to \mu^+\mu^-$ at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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The flavour-changing neutral currents of the rare decays $B^0_{(s)} \to \mu^+\mu^-$ provide a favourable environment to observe new physics. This contribution summarises the study of these rare decays, using the 2015 and 2016 data collected by the ATLAS detector. Their branching ratios are measured relative to the reference decay mode $B^\pm \to J/\psi K^\pm$, which has a well-measured branching fraction $\mathcal{B}(B^\pm \to J/\psi K^\pm) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)$. The event yields of the reference and the rare-decay channels are extracted employing the unbinned maximum likelihood fit approach. Run 2 (2015+2016) and Run 1 ATLAS measurements are combined. The combined result is consistent with the Standard Model prediction within 2.4 standard deviations in the $\mathcal{B}(B^0_s \to \mu^+\mu^-)$-$\mathcal{B}(B^0 \to \mu^+\mu^-)$ plane.

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The rare decays $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ are strongly suppressed in the Standard Model (SM). However, their branching fractions are precisely predicted [1] to be $(3.66 \pm 0.14) \times 10^{-9}$ and $(1.03 \pm 0.05) \times 10^{-10}$, respectively. Therefore, indirect searches for new physics can be performed by measuring the branching ratios of these rare decays $B^0_{(s)} \to \mu^+\mu^-$. A measurement [2] of the branching fractions is performed at a centre-of-mass energy of 13 TeV, using 36.2 fb^{-1} of LHC Run 2 data, collected during the years of 2015 and 2016 by the ATLAS detector [3]. The branching ratios are measured relative to the reference decay mode $B^\pm \to J/\psi(\to \mu^+\mu^-)K^\pm$, which has a well-measured branching fraction [4] defined as the product of $\mathcal{B}(B^\pm \to J/\psi K^\pm) = (1.010 \pm 0.029) \times 10^{-3}$ and $\mathcal{B}(J/\psi \to \mu^+\mu^-) = (5.961 \pm 0.033)\%$.

Selected events are required to have two muons, one with $p_{\mathrm{T}} > 4$ GeV and the other with $p_{\mathrm{T}} > 6$ GeV. The dimuon invariant mass is required to be in the range of 4 GeV to 8.5 GeV. The defined signal mass region has a width of 360 MeV and starts at 5166 MeV. The region is kept blinded until the final event selection and the signal yield extraction are fully defined. A Boosted Decision Tree (BDT) is trained on the sideband data to suppress the dominant background contribution from continuum $b\bar{b} \to \mu^+\mu^- X$ events. The low dimuon invariant mass sideband is contaminated by the partially reconstructed decays. These decays involve processes like $b \to c\mu^-\bar{\nu} \to s(d)\mu^+\mu^-\nu\bar{\nu}$ cascades, $B \to J/\psi\mu^+X$, B^+_c decays and semileptonic b-hadron decays where a hadron in the final state is misidentified as a muon. A small contribution of $B \to hh'$, where the two hadrons are misidentified as muons, peaks in the signal region with an amount of 2.9 ± 2.0 events, after a tight muon selection is applied.

The yield in the normalisation channel is obtained by an unbinned extended maximum likelihood fit to the invariant mass of the $J/\psi K^\pm$. The fit involves four components: $B^\pm \to J/\psi K^\pm$ decays and Cabibbo-suppressed $B^\pm \to J/\psi\pi^\pm$ decays, where both are parametrised using the sum of Johnson S_U [5] and Gaussian functions, the partially reconstructed B-hadron decays described by the combination of Fermi-Dirac and exponential functions, and the non-resonant background modelled by an exponential function. All parameters, except for the normalisation, are determined from simulation. The result of the fit is shown in Figure 1 (left). The number of extracted $B^\pm \to J/\psi K^\pm$ candidates is found to be 334 351 with a statistical uncertainty of 0.3% and a systematic uncertainty of 4.8%.

An efficiency ratio $\epsilon(B^\pm \to J/\psi K^\pm)/\epsilon(B^0_s \to \mu^+\mu^-)$ is extracted from Monte Carlo. It takes into account the differences in the acceptance, trigger, reconstruction and selection efficiencies in the normalisation channel relative to the signal channel. The ratio is estimated to be 0.1176 ± 0.0009 (stat.) $\pm$ 0.0047 (syst.), in a fiducial volume defined by p^B_{T}[1] > 8 GeV and $|\eta^B| > 2.5$.

The $B^0_{(s)} \to \mu^+\mu^-$ signal yields are extracted from an unbinned maximum likelihood fit to the dimuon invariant mass in four BDT bins. The invariant mass distribution of the signal is described by a double-Gaussian function centred at the B^0 and B^0_s, respectively. The result of the fit in the most sensitive BDT bin is shown in Figure 1 (middle). The total number of signal events returned by the fit is $N_s = 80 \pm 22$ for $B^0_s \to \mu^+\mu^-$ and N_d = -12 $\pm$ 20 for $B^0 \to \mu^+\mu^-$, in agreement with the SM predictions of 91 and 10 for N_s and N_d, respectively.

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

A branching ratio of $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.21^{+0.96}_{-0.91}\ \text{(stat.)}^{+0.49}_{-0.30}\ \text{(syst.)}) \times 10^{-9}$ is obtained and an upper limit of $\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.3\times10^{-10}$ at 95% CL is set, employing a Neyman construction [6]. The likelihoods of this measurement and that of Run 1 [7] are combined, resulting in branching fractions of $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8^{+0.8}_{-0.7}) \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.1 \times 10^{-10}$ at 95% CL. The combined measurement is in agreement with the SM at the level of 2.4σ. The individual and combined results are shown in Figure 1 (right).

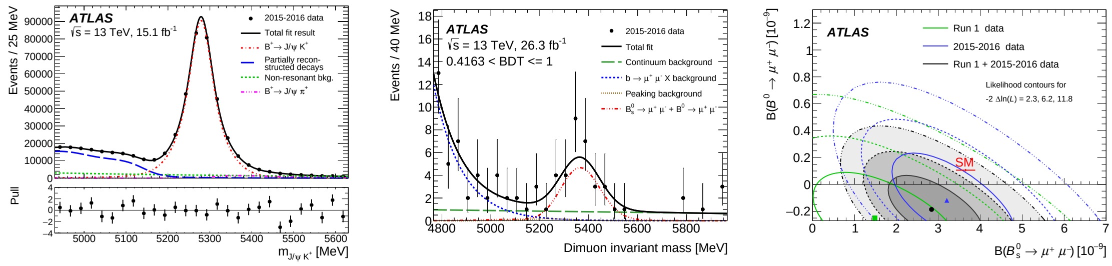

Figure 1: (left) Result of the fit to the $J/\psi K^\pm$ invariant mass distribution for all $B^\pm$ candidates in half of the data events. The lower panel of the plot shows the bin-by-bin pulls for the fit, where the pull is defined as the difference between the data point and the value obtained from the fit function, divided by the error from the fit. (middle) Dimuon invariant mass distributions in the unblinded data, in the highest interval of BDT output. (right) Likelihood contours for the combination of the Run 1 and 2015-2016 Run 2 results (shaded areas). The contours are obtained from the combined likelihoods of the two analyses, for values of -2Δln(L) equal to 2.3, 6.2 and 11.8. The contours for the individual Run 2 2015-2016 [2] and Run 1 [7] results are overlaid. The SM prediction with its uncertainty is included. Figures are taken from [2].

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