

## The exclusive backgrounds for rare muonic B-decays

Exclusive  $B$  decays with small branching fraction  $O(10^{-5})$  have to be studied separately since they are not included in standard Monte Carlo generators like PYTHIA and Evt-Gen<sup>1</sup>. These rare  $B$  decays may contribute to the background in three different ways. The most important background results from two-body hadronic decays which due to misidentification and mass resolution may peak in the dimuon invariant mass in the signal region. Next three- and four-body semileptonic decays where a hadron is misidentified as a muon may yield dimuon masses that due to resolution effects may leak into the signal region. The third source results from combinatorial background of a muon from a rare decay together with a muon from the primary vertex or from another semimuonic  $B$  decay in the same event<sup>2</sup>.

Before applying the signal selection criteria the contribution from exclusive backgrounds is much smaller than the contribution from combinatorial background. But since some of the exclusive decays have topologies which are similar to the signal, the background rejection is expected to be less effective on this background. Thus a more thorough investigation of these modes is necessary. Table 1 presents the most important backgrounds from such exclusive decays.

N	background Channel	BR Measurement or SM Predictions	Experiment			Ref.
			ATLAS	LHCb	CMS	
1.	$B_{d,s}^0 \rightarrow K\pi, \pi\pi, KK$	$\sim 2 \times 10^{-5}$	Significant			[1]
2.	$\Lambda_b \rightarrow p\pi^-$ $\Lambda_b \rightarrow pK^-$	$< 5 \times 10^{-5}$ 90% C.L. $< 5 \times 10^{-5}$ 90% C.L.		Not significant		[1] [1]
3.	$B_d^0 \rightarrow \pi^- \mu^+ \nu_\mu$ $B_s^0 \rightarrow K^- \mu^+ \nu_\mu$	$(6.8 \pm 0.8) \times 10^{-5}$ $\sim 7 \times 10^{-5}$		Not significant		[1] [2]
4.	$B^+ \rightarrow J/\psi (\mu^+ \mu^-) K^+$ $B^+ \rightarrow J/\psi (\mu^+ \mu^-) \pi^+$ $B_c^+ \rightarrow J/\psi (\mu^+ \mu^-) \pi^+$	$\sim 6 \times 10^{-5}$ $\sim 0.3 \times 10^{-5}$ $\sim 20 \times 10^{-5}$	Potentially significant			[1] [1] [3]
5.	$B \rightarrow (\pi, K, \gamma) \mu^+ \mu^-$	$10^{-7} - 10^{-8}$		Not significant		[1, 10]
6.	$B_c^+ \rightarrow J/\psi (\mu^+ \mu^-) \mu^+ \nu_\mu$ $B_c^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu$	$\sim 30 \times 10^{-5}$ $< 10 \times 10^{-5}$	Potentially significant			[8] [8]
7.	$B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu$	$\sim 0.1 \times 10^{-5}$		Not significant		[8]

Table 1: The most important backgrounds from rare  $B$ -decays.

Let's consider an exclusive background from two-body hadronic decays  $B_{d,s}^0 \rightarrow K\pi, \pi\pi, KK$ . If the pions/kaons are misidentified as muons these decays will give a peaked background in or near the signal region. Since  $K$ -mesons are heavier than  $\mu$ , the peak will be shifted towards lower masses, and the invariant mass resolution of the detector will decide whether these channels will contribute to the background or not. CMS and LHCb have resolution  $\sigma_{B \rightarrow \mu\mu}^{CMS} = 36$  MeV [6] and  $\sigma_{B \rightarrow \mu\mu}^{LHCb} = 18$  MeV [5], respectively, which is expected to be sufficient to make this effect negligible. Figure 1c) shows the

<sup>1</sup>However these packages have mechanisms to include some additional channels, for example in the phase space approach.

<sup>2</sup>This is particularly important for  $B$ -decays with three muons in the final state, e.g.  $B_c^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu$ .

invariant misidentified kaons mass distribution for the decay  $B_s^0 \rightarrow K^+K^-$  and dimuon mass distribution from  $B_s^0 \rightarrow \mu^+\mu^-$  signal in CMS detector simulation [7] confirming the above assertion. ATLAS has resolution  $\sigma_{B \rightarrow \mu\mu}^{ATLAS} \approx 80$  MeV [4] which is probably not good enough to render this background source negligible. But for the case of the decay in flight (when both final states hadrons decay to muons), the rate can be reduced somewhat by a strict requirement on the muon track fit quality and on the matching of inner-detector and muon spectrometer track in ATLAS.

The exclusive background from two-body hadronic  $\Lambda_b$ -decays are negligible small for all detectors [5, 7]. For these decays we can take into account the effective proton identification and large mass shift. In addition, the  $\Lambda_b$ -baryons production cross-section is order smaller than the production cross-section of  $B$ -mesons at LHC energies.

The dimuon invariant mass spectrum from the three- and four-body decays of  $B_{d,s}^0$ - and  $B^\pm$ -mesons have kinematic end-points which are close to the  $B_s^0$  signal window, and due to limited resolution some events may leak into the window. In particular the channels  $B_d^0 \rightarrow \pi^-\mu^+\nu_\mu$  and  $B_s^0 \rightarrow K^-\mu^+\nu_\mu$  should be studied more closely as there is no third charged lepton coming from the secondary vertex, and thus the isolation cut will not reduce this background. CMS and LHCb have concluded that their contribution is negligible because of high mass resolution [7], whereas full ATLAS simulation results pointed on the small, but non-negligible contribution for three-body decays. On The fig. 1 a) (CMS full detector simulation results) and b) (ATLAS full detector simulation results) we can see the illustration of this assertion for  $B_s^0 \rightarrow K^-\mu^+\nu_\mu$  decay.

The four-muonic resonant and nonresonant decays of the  $B_c^+$ -meson may contribute a potentially important source of background for all detectors [5, 7, 8] since the mass of  $B_c^+$  is larger than the masses of  $B_{d,s}^0$  mesons such that the kinematic endpoint is shifted closer to the signal region. For the LHCb after, full detector simulation and after all necessary signal selection criteria there was a background of approximately 80 events per  $\text{fb}^{-1}$  in the mass window  $\pm 60$  MeV around the  $B_s^0$ . This is at least two times greater than the signal from  $B_s^0 \rightarrow \mu^+\mu^-$  in this area. However this decay produce only a small contribution to the inclusive background in the signal region [5]. In CMS this has channel has been concluded not to contribute to the background [7].

Rare muonic radiative and semi-muonic decays as a background for rare muonic decays based on the ATLAS detector properties [8] has also been studied. The results of this study using the theoretical matrix element [10] are shown in Figure 1d). As can be seen from the figure, the background contribution from these channels is small. For rare semimuonic decays we find the same result.

## References

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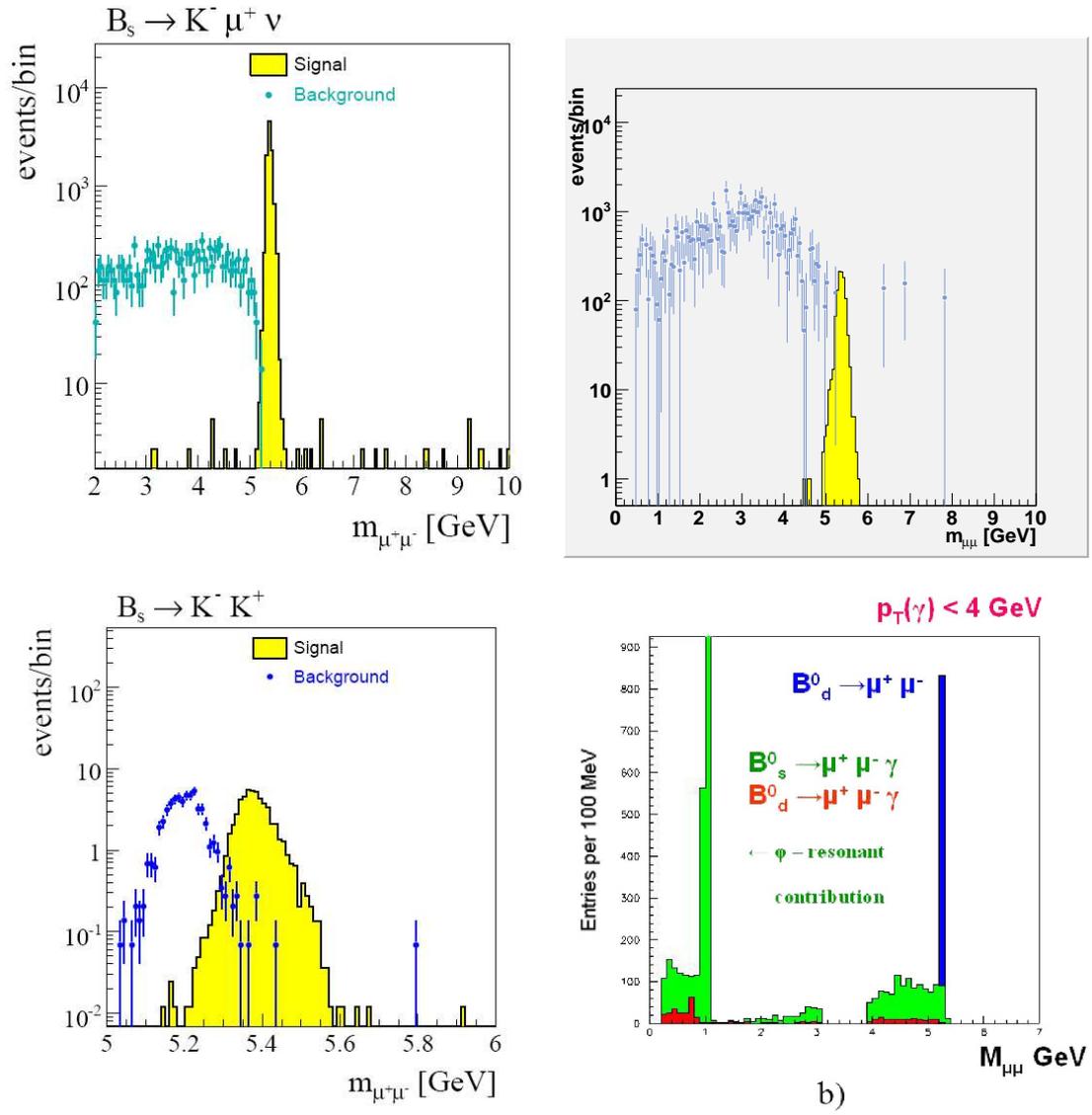


Figure 1: ...

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