Search for the rare decays $B \to \mu^+\mu^-$ with the CMS detector

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I summarize here the results of a search for the rare decays $B^0 \to \mu^+\mu^-$ and $B^0_s \to \mu^+\mu^-$, based on a sample of data collected by the CMS detector from pp collisions at $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of 4.9 fb^{-1}. No excess of events over the expected background is observed. The resulting upper limits on the branching fractions are $\mathcal{B}(B^0_s \to \mu^+\mu^-) < 7.7 \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9}$ at 95 % confidence level.

1 Introduction

In the Standard Model (SM) of electroweak interaction the leptonic decays $B^0_{(s)} \to \mu^+\mu^-$ proceed through high order terms involving penguin or box diagrams. The decay rate is further depressed by the small values of the Cabibbo-Kobaiashi-Maskawa terms involved in the transition, $|V_{td(s)}|^2$, by the helicty related factor m^2_μ/m^2_B (where m_μ, m_B are the muon and B mesons masses respectively), and by the ratio $(f_b/m_B)^2$, where $f_b \sim 200MeV$ is the $B^0_{(s)}$ -meson decay constant parameterizing the contribution of the quark annihilation diagram. Therefore, very low decay rates are expected in the SM : $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-9}$ [1], where the uncertainty is due mostly to the limited knowledge of the f_B factors.

Several extension of the SM introduce new diagrams which can enhance the rates quite sizeably [2, 3, 4, 5]. Destructive interference, however, can also result in a further depression of the decay rates for some choice of the model parameters [6].

The CMS collaboration has performed a search [7] based on 4.9 fb^{-1} of data from pp interactions at $\sqrt{s} = 7$ TeV produced by the LHC collider. Thanks to the excellent operations of LHC, the high efficiency in track reconstruction and muon identification, and to the great accuracy in the reconstruction of charged particle trajectories, the results are competitive with those from the other LHC collaborations [8], [9], and from Tevatron experiments [10],[11]. I present below a brief description of this search.

2 Data analysis

The CMS detector is described at length elsewhere [12]. Muons with rapidity $|\eta| < 2.4$ are identified matching track segments from the inner silicon tracker with those reconstructed independently in the self-triggering muon chambers, placed in the return yoke of the solenoidal

3.8 T magnetic field. The muon identification efficiency for signal events is 70% in the barrel ($|\eta| < 1.4$) and 85% in the forward region.

A dimuon trigger was used, requiring a $\mu^+\mu^-$ pair with invariant mass $4.8 < m_{\mu\mu} < 6.0$ GeV: this interval includes the signal region and two side-bands used to subtract the combinatorial background. The other trigger requirements, (track quality, muon momenta in the plane orthogonal to the beam axis, p_T) were tightened as the luminosity increased. A sample of $B^+ \to K^+ J/\Psi(\to \mu^+\mu^-)$ was also selected to compute the normalization and the efficiency corrections. In addition, a control sample of $B_s \to \phi J/\Psi$ decays, with $\phi \to K^+K^-$ and $J/\Psi \to \mu^+\mu^-$ was selected to correct for potential differences in B^+ and B_s production and fragmentation.

Large samples of simulated events were produced, representing the signal, the normalization and control samples, and the background from rare B decays with one or two hadron misidentified as muons, like $B \to h\mu\nu_\mu$ or $B \to hh'$ $(h, h' = \pi, K, p)$. A detailed simulation of the CMS detector was used; simulated events were analysed as the real data, including trigger requirements.

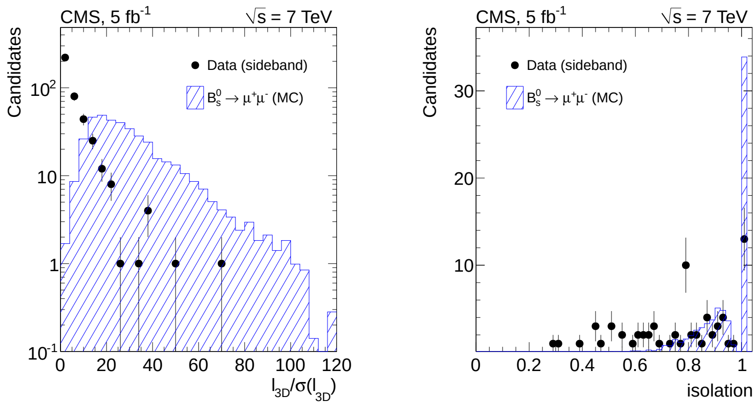

Figure 1: Rigth: $\ell_{3D}/\sigma(\ell_{3D})$; left : isolation parameter. Points with error bars: data side bands; histogram: signal Monte Carlo

At the analysis stage, a slightly tighter request was applied to the dimuon mass: $4.9 < m_{\mu\mu} < 5.9$ GeV. The two muons were combined to form a B candidate. Its trajectory was extrapolated back to the beam line to compute the projection δ_z of the distance of closest approach from each primary vertex (up to 30 collisions per event were registered) along the beam (z) axis. The muons were then assigned to the vertex with the minimum value of δ_z, and the vertex fit was repeated without the muons. Finally, a kinematic fit was applied to the two muon trajectories, requiring a common production point (secondary vertex). To select the signal, requirements were applied on the secondary vertex fit (χ^2/dof), on the transverse momentum of each muon and of the B candidate, on the 3D impact parameter of the B candidate (δ_{3D}) and on its significance ($\delta_{3D}/\sigma(\delta_{3D})$), on the significance of the distance between the secondary and the primary vertex ($\ell_{3D}/\sigma(\ell_{3D})$), and on the angle α between the B momentum and the line joining the primary to the secondary vertex. Three isolation requirements (I, d^0_{cs}, N_{close}) were also applied. Figure 1 shows for illustratrion the distributions of $\ell_{3D}/\sigma(\ell_{3D})$ and of the isolation parameter I for the simulated signal (histogram) and for the data side bands (points with error bars).

Simulated signal events and the data side bands were used to optimize the selections so as to obtain the best 95% C.L. exclusion limit assuming the SM branching ratios. A different set of cuts was applied in the barrell (both tracks with $|\eta| < 1.4$) and in the forward. The complete set of requirements applied at the analysis stage is summarized in tab. 1.

Variable	Barrell	Endcap	Units
$p_T(\mu_1)$	> 4.5	> 4.5	GeV
$p_T(\mu_2)$	> 4.0	> 4.2	GeV
$p_T(B)$	> 6.5	> 8.5	GeV
χ^2/dof	<2.2	<1.8	
δ_{3D}	< 0.008	< 0.008	cm
$\delta_{3D}/\sigma(\delta_{3D})$	< 2	< 2	
α	<50	<30	mrad
$\ell_{3D}/\sigma(\ell_{3D})$	> 13	> 15	
I	> 0.8	> 0.8	
d^0_{ca}	> 0.05	> 0.05	cm
N_{close}	< 2	< 2	

Table 1: Selection criteria applied at the analysis stage

A study performed in the simulated events and in the data normalization samples showed that the selection efficiency does not depend on the multiplicty of primary vertex (pileup). The efficiency for the signal was $(2.9 \pm 0.2) \times 10^{-4}$ in the barrell and $(1.6 \pm 0.2) \times 10^{-4}$ in the endcaps. A blind analysis was performed: the signal region, defined by $5.20 < m_{\mu\mu} < 5.45$, was not inspected until the completion of the study of the systematic uncertainties.

3 Results

The branching ratio was computed separately in the barrell and in the forward regions according to the formula:

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \frac{N_S}{N_{B^+}} \frac{f_u}{f_s} \frac{\epsilon^+}{\epsilon_s} \mathcal{B}(B^+ \to KJ/\Psi) \times \mathcal{B}(J/\Psi \to \mu^+\mu^-) \tag{1}$$

where N_S is the number of signal events after background subtraction, N_{B^+} is the number of events in the normaliztion sample ($82700 \pm 415o$ in the barrell and 23800 ± 1200 in the forward region), ϵ_s, ϵ^+ the corresponding efficiencies, $f_{u(s)}$ the probability that a b quark hadronizes to a $B^+(B_s)$ meson.

Figure 2 shows the search result: six events were found in the $B_s \to \mu^+\mu^-$ signal window, while 5.9 ± 0.8 background events were expected, and two in the $B^0 \to \mu^+\mu^-$ region, with an expected background of 2.0 ± 0.5. As no signal excess was observed , the following upper limits at 95% C.L. were computed:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 7.7 \times 10^{-9} \tag{2}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9} \tag{3}$$

These results include the systematic unertainties in acceptance and efficiency computation for the signal and normalization samples, those due to the limited knowledge of the production rates for the background from rare B decays, and the statistical error from side-band subtraction.

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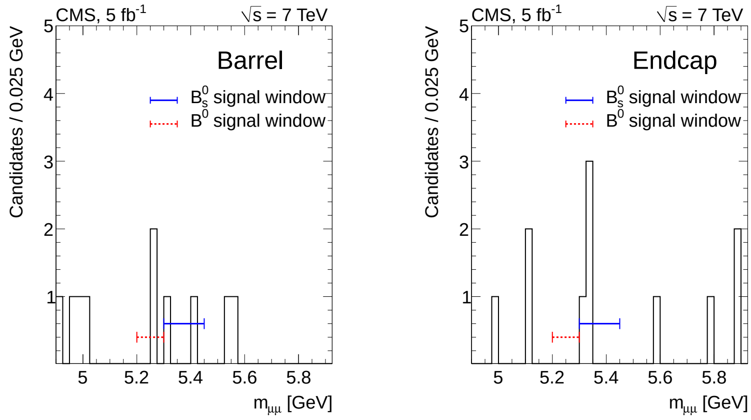

Figure 2: Dimuon invariant mass distributions in the barrel (left) and endcap (right) channels. The signal windows for B_s^0 and B^0 are indicated by horizontal lines.

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