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Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays with the CMS detector

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Summary. — The study of extremely rare or forbidden processes allows the indirect search for new physics through the comparison with the standard model expectations. The leptonic decays of B_s^0 and B^0 mesons are flavor changing neutral currents processes highly suppressed in the standard model, with small predicted branching fractions. A search for the rare decays $B_s^0(B^0) \to \mu^+\mu^-$ is performed in *pp* collisions at $\sqrt{s} = 7\,\mathrm{TeV}$, with a data sample corresponding to an integrated luminosity of $5\,\mathrm{fb}^{-1}$ collected by the CMS experiment at the LHC. The number of observed events is consistent with the background plus standard model signal expectation. The resulting upper limits on the branching fractions are $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.7 \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9}$ at 95% confidence level.

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1. – Introduction

The $B_s^0(B^0) \to \mu^+\mu^-$ decays are highly suppressed in the standard model (SM) due to three main factors: i) the flavor-changing neutral current transition $\mathrm{b} \to \mathrm{s(d)}$; ii) the helicity suppression factor m_μ^2/m_B^2; iii) the internal annihilation of the quarks within the B meson. The branching ratio of the two processes, predicted in the SM to be $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.23 \pm 0.27) \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \times 10^{-10}$ [1], can be significantly modified in several new physics scenarios, such as high $\tan\beta$ minimal supersymmetric extensions of the SM or extended Higgs sectors.

2. – Analysis

The CMS Collaboration carried out a simultaneous search for $B_s^0(B^0) \to \mu^+\mu^-$ decays performing an event-counting experiment in the dimuon mass region around the B_s^0 and B^0 masses. Monte Carlo (MC) simulations are used to estimate the background due to B decays. Combinatorial backgrounds are evaluated from the data in dimuon invariant mass ($m_{\mu\mu}$) sidebands. A normalization sample of $B^+ \to J/\psi\, K^+$ decays (with $J/\psi \to \mu^+\mu^-$) is used in order to remove uncertainties related to the $b\bar{b}$ production cross section and the integrated luminosity. The background level and the mass resolution depend on the pseudorapidity η of the reconstructed particles. The analysis is therefore perfomed in two independent channels: the "barrel" (if both of the muons have $|\eta| < 1.4$) and the "endcap" (if at least one muon has $|\eta| \geq 1.4$). The efficiencies are determined through MC simulation studies. To validate the simulation distributions, and to evaluate potential effects resulting from differences in the fragmentation of B^+ and B_s^0, a control sample of reconstructed $B_s^0 \to J/\psi\,\phi$ decays (with $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$) is used. The reconstruction of $B_s^0(B^0) \to \mu^+\mu^-$ candidates requires two oppositely charged muons that originate from a common vertex and have an invariant mass in the range $4.9 < m_{\mu\mu} < 5.9\,\text{GeV}$. The most discriminating variables are i) the 3D impact parameter of the B candidate with respect to the primary vertex (PV) of the event; ii) the angle between the dimuon momentum and the vector from the PV to the B candidate secondary vertex (SV); iii) the isolation, for which three variables are used: one based on the PV and two based on the SV isolation.

3. – Results

An analysis searching for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ has been performed with the CMS experiment for pp collisions at $\sqrt{s} = 7\,\text{TeV}$ [2]. A data sample corresponding to an integrated luminosity of $5\,\text{fb}^{-1}$ has been used. The branching fraction is evaluated according to the equation

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_s}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+),$$

where ε_{tot} is the total signal efficiency, $N_{obs}^{B^+}$ is the number of reconstructed $B^+ \to J/\psi\,K^+$ decays, $\varepsilon_{tot}^{B^+}$ is the total efficiency of B^+ reconstruction, $\mathcal{B}(B^+)$ is the branching fraction for $B^+ \to J/\psi\,K^+ \to \mu^+\mu^-K^+$ [3], f_u/f_s is the the fragmentation function ratio (measured by LHCb [4] in the $2 < |\eta| < 5$ region), and N_s is the background-subtracted number of observed $B_s^0 \to \mu^+\mu^-$ candidates in the signal window $5.30 < m_{\mu\mu} < 5.45\,\text{GeV}$. An analogous equation is used for $B^0 \to \mu^+\mu^-$, for the signal window $5.20 < m_{\mu\mu} < 5.30\,\text{GeV}$.

Six events are observed in the $B_s^0 \to \mu^+\mu^-$ signal windows (two in the barrel and four in the endcap), while two events are observed in the $B^0 \to \mu^+\mu^-$ barrel channel and none in the endcap channel. No eccess is measured over the number of expected MC signal plus background events. Including cross-feed between the B^0 and B_s^0 decays, the background-only p-value is 0.11(0.24) for $B_s^0(B^0) \to \mu^+\mu^-$, corresponding to 1.2(0.7) standard deviations. The p-value for the background plus SM signal hypotheses is 0.71(0.86) for $B_s^0(B^0) \to \mu^+\mu^-$. The resulting upper limits on the branching fractions, determined using the CLs method, are

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.7 \times 10^{-9} \quad (95\%\ \text{CL}),$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9} \quad (95\%\ \text{CL}).$$

These limits can be used to improve bounds on the parameter space for a number of potential extensions to the standard model.

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