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Prospects for $B_s^0 \to \mu^+\mu^-$ at CMS

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The Flavor Changing Neutral Current decay $B_s^0 \to \mu^+\mu^-$ is highly suppressed in the Standard Model, but its branching fraction could be significantly enhanced through contributions from new physics. At the LHC, this rare decay could be observed for the first time. In this contribution, the prospects for search for $B_s^0 \to \mu^+\mu^-$ with the CMS detector in a low luminosity LHC phase ($\mathscr{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}) are presented. In particular, some aspects of the experimental setup, the first and high level trigger selections, and the offline analysis are discussed.

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Contents

1. Introduction

In the Standard Model (SM) the decay mode $B_s^0 \to \mu^+\mu^-$ has a highly suppressed branching fraction of $(3.42 \pm 0.54) \times 10^{-9}$ [1] since it involves a $b \to s$ Flavor Changing Neutral Current (FCNC) transition, which is forbidden at tree level and occurs through higher-order diagrams. To date this decay has not been observed; upper limit on its branching fraction is a topic of frequent updates at Tevatron. Currently the best upper limit is from the CDF collaboration [2] with $\mathscr{B}(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}$ at 95% confidence limit (CL).

Since these processes are highly suppressed in the SM, they are potentially sensitive probes of physics beyond the SM. In the Minimal Supersymmetric extension of the SM (MSSM) the branching fraction for these decays can be substantially enhanced, especially at large $\tan\beta$ [3]. For MSSM with modified minimal flavor violation at large $\tan\beta$, the branching fraction can be increased by up to four orders of magnitude [4]. The decay mode $B_s^0 \to \mu^+\mu^-$ can be used to obtain a model-independent lower bound on the $\tan\beta$ parameter of the MSSM [5].

2. The CMS experiment

The Compact Muon Solenoid (CMS) [6] is a general purpose detector well suited for the study of B decays to muons, since it is composed by precise systems for muon reconstruction and identification. The key components for this analysis are the tracker and the muon system. The CMS tracker is an all-silicon detector, which is immersed in a magnetic field of 3.8 T and covers the pseudorapidity region $|\eta| < 2.6$. The tracker consists of two types of detectors. In the inner region, close to the interaction point, there is a pixel tracker for vertexing and effective pattern recognition in the high-track multiplicity environment at the LHC. This detector consists of 1440 modules, arranged into three barrel layers at radii $r = 4.4, 7.3, 10.2$ cm from the beampipe, and four endcap discs, two in each side. The hit resolution is 15-20 μm (in $r\phi - z$). In the outer region there is a strip tracker, which consists of 15148 modules distributed over 10 barrel layers (4 TIB + 6 TOB) and 12 discs (3 TID + 9 TEC) per side. The track reconstruction efficiency is about 99% for muons over most of the acceptance in $|\eta| < 2.4$, and the transverse momentum resolution for single muons with $p_T = 1-100$ GeV/c is in the range 0.7-3% for $|\eta| < 1.8$.

The CMS muon system, incorporated into the magnet return yoke, is also divided into a barrel ($|\eta| < 1.2$) and forward parts ($|\eta| < 2.4$). In the barrel region, where the neutron induced background and the muon rate is small, drift tube (DT) chambers are used. In the two endcaps cathode strip chambers (CSC) are deployed. In addition, resistive plate chambers (RPC) are used both in the barrel and endcap region: the excellent time resolution of RPC allows the unambiguous identification of the correct bunch crossing.

3. Event samples

The Monte Carlo (MC) event samples were generated with PYTHIA v6.227 [7] and passed through a full detector simulation. Five pile-up events on average were included, appropriate for a luminosity of $\mathscr{L} = 2\times10^{33}$ cm^{-2}s^{-1}. All signal and background events were selected from the generic QCD $2\to2$ subprocesses. The $b\bar{b}$ events in the samples represent a mixture of gluon-gluon fusion, flavor excitation, and gluon splitting subprocesses. The quark-antiquark annihilation component is negligible at the LHC. In the signal sample, B_s meson were forced to decay as $B_s^0 \to \mu^+\mu^-$. The muons were required to have transverse momentum $p_T(\mu)$ >3 GeV/c and pseudorapidity $|\eta(\mu)|$ <2.4.

The main challenge in the measurement of the $B_s^0 \to \mu^+\mu^-$ decay rate is background suppression. The considered sources of background in this analysis are non-resonant $q\bar{q}$ events ($q = b,c$) with $q \to \mu X$ decays of both q-hadrons, and rare B_d, B_u, B_s and Λ_b decays, comprising hadronic, semileptonic and radiative decays. The background samples contain two muons with $p_T(\mu)$ >3 GeV/c and $|\eta(\mu)|$ <2.4. For the QCD samples, the muon separation in azimuth and pseudorapidity $\Delta R(\mu\mu) = \sqrt{\Delta\phi^2+\Delta\eta^2}$ was required to be $0.3 < \Delta R(\mu\mu) < 1.8$.

4. The $B_s^0 \to \mu^+\mu^-$ online selection

The CMS detector has a two-level trigger structure. The first level trigger (L1) is based on information from the calorimeters and the muon system and reach an output rate of at most 100 kHz. B decays to muons are triggered by a single or dimuon trigger at level one. The threshold for inclusive isolated single muons is at $p_T(\mu)$ >14 GeV/c, for dimuon events both muons must have p_T >3 GeV/c, at the assumed luminosity (2×10^{33} cm^{-2}s^{-1}). The expected rates amount to 2.7 kHz and 0.9 kHz, respectively.

The high-level trigger (HLT) is a software trigger, running on a large processor farm. The HLT reduces the overall trigger rate by three orders of magnitude to about 150 Hz. Approximately 30 Hz are allocated to the inclusive single and dimuon channels, resulting in trigger thresholds of 19 (7) GeV/c for the single (di) muon trigger, respectively. Due to the limited time available for the trigger decision, dedicated algorithms are employed to speed up the track reconstruction by reducing the seed generation to specific regions of interest, e.g. in a cone around the L1 muon candidate direction, and making a partial or conditional track reconstruction. Already with six reconstructed

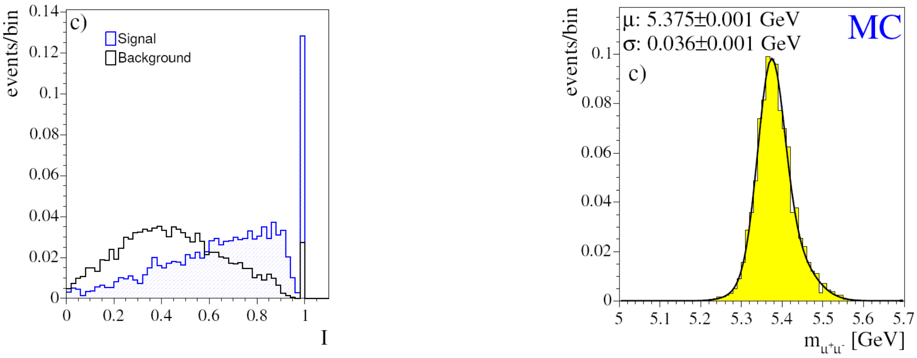

Figure 1: On the left the isolation distribution for signal and background MC events. On the right the dimuon mass distribution in signal MC events. The curve is a fit of two Gaussians, the displayed parameters indicate the mean and sigma of the reconstructed mass. The histograms are normalized to unity.

hits, both the efficiency and the resolution are comparable to the full tracking performance. The HLT selection algorithm for the $B_s^0 \to \mu^+\mu^-$ channel makes use of both regional and conditional tracking. Pixel seeds were considered only within cones around the L1 muon candidates, which have a $p_T(\mu) > 4$ GeV/c. Only tracks with at least six hits and transverse momentum resolution $<2\%$ were kept. Reconstructed tracks with opposite charge were paired and retained if their invariant mass falls into ±150 MeV/c^2 around the B_s^0 mass. The best track pair was fit to a common vertex and finally the event was retained only when the fit $\chi^2 < 20$ and the three-dimensional flight length l_{3d} >150 μm. With this selection, the event rate was estimated to be <1.7 Hz [8].

5. Offline analysis

The analysis selection was focused on the secondary vertex reconstruction, since this object is well measured and is separated from the primary vertex, as is expected in a decay of an isolated B_s^0 meson. The primary vertex was determined from all the tracks which have p_T >0.9 GeV/c. The B_s^0 candidates were formed by vertexing the two muon candidates, which had an angular separation $0.3 < \Delta R(\mu\mu) < 1.2$. The secondary vertex quality was required to be χ^2 <1.0. The transverse momentum vector of the B_s^0 candidate must be close to the displacement of the secondary vertex from the primary vertex: the cosine of the opening angle α between the two vectors had to be $\cos\alpha$ >0.995. The significance of the B_s^0 candidate flight length in the transverse plane was defined as l_{xy}/σ_{xy}, where σ_{xy} is the error on the flight length. In this analysis a significance l_{xy}/σ_{xy} >18.0 was requested.

The hadronic activity around the dimuon direction is expected to be small for the signal B_s^0 decays while, because of color reconnection, it is enhanced in high-p_T gluon splitting $b\bar{b}$ events. This was exploited in the isolation requirement: the isolation I (see Figure 1) was determined from the dimuon transverse momentum and charged tracks with p_T >0.9 GeV/c in a cone with half-radius $r = 1.0$ around the dimuon direction:

$$I \equiv \frac{p_T(\mu\mu)}{p_T(\mu\mu) + \sum_{trk}|p_T|}.$$

The isolation was required to be $I > 0.85$.

Figure 1 shows the mass resolution obtained from the dimuon invariant mass distribution of signal MC events. The distribution was fitted with two Gaussians and the quoted width (σ) was determined by the weighted mean of the two Gaussian widths.

Given the limited statistics of the background sample, no event remained after the application of all requirements. However, the absence of correlation to the other selection requirements allows a factorization of the isolation and the χ^2 requirements in the determination of the total background rejection factor. The dominant sources of uncertainties are the statistical component of the background samples, the impact of misalignment on the transverse flight length significance and the assumption of factorization cuts. Other contributions to the systematic error have been studied, such as the uncertainties on the L1 efficiency, the muon identification and the tracking efficiency. To summarize the uncertainty on signal efficiency is ±25%, while the background yield uncertainty is dominated by the statistical error and is $^{+160}_{-100}$%. The total selection efficiency for signal events is $\varepsilon_S = 0.016 \pm 0.002$ and the background reduction factor is $\varepsilon_B = 2.6 \times 10^{-7}$. The results extrapolation at 10 fb^{-1} of integrated luminosity gave a number of signal $n_S = 6.1 \pm 0.6 \pm 1.5$ and background $n_B = 13.8 \pm 0.3^{+22.3}_{-14.1}$ events selected in a window wide ±100 MeV/c^2 around the B_s^0 mass value. With these results, the upper limit on the branching fraction is $\mathscr{B}(B_s^0 \to \mu^+\mu^-) \leq 1.4 \times 10^{-8}$ at the 90% CL.

6. Conclusions

The search for $B_s^0 \to \mu^+\mu^-$ at the CMS experiment is a promising analysis that will allow tight constraints to be set on the MSSM. The feasibility of this search in a low luminosity phase has been presented. The upper limit on branching fraction that can be reached with 10 fb^{-1} of data collected is $\mathscr{B}(B_s^0 \to \mu^+\mu^-) \leq 1.4 \times 10^{-8}$ at 90% CL. The study described in this report is limited by the size of the background MC sample, which also induce large error in background prediction, and this limitation can be removed by analyzing large data samples.

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