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Dimuon decays and rare B decays prospects from CMS

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B hadrons are an ideal tool for advancing our current understanding of the flavour sector of the Standard Model (SM), and searching for effects originating from physics beyond the SM, thanks to the large production rate and the fact that B hadrons are relatively easy to trigger on and identify due to their long lifetime and high mass. In this talk, first CMS results on di-muons at proton-proton collisions at $\sqrt{s} = 7$ TeV are presented, and CMS prospects for the rare decay $B_s^0 \to \mu^+\mu^-$ are reviewed.

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1. Introduction

The rare leptonic decays $B^0_{s(d)} \to \mu^+\mu^-$ have a highly suppressed rate in the Standard Model (SM), since they involve a flavour-changing neutral current $b \to s(d)$ transition, they require an internal quark annihilation within the B meson and they are helicity suppressed [1]. The branching ratios predicted by the SM are (3.86 $\pm$ 0.15) $\times 10^{-9}$ for B_s and (1.06 $\pm$ 0.04) $\times 10^{10}$ for B_d. Any branching ratio measurement higher than SM one is a potentially sensitive probe of physics

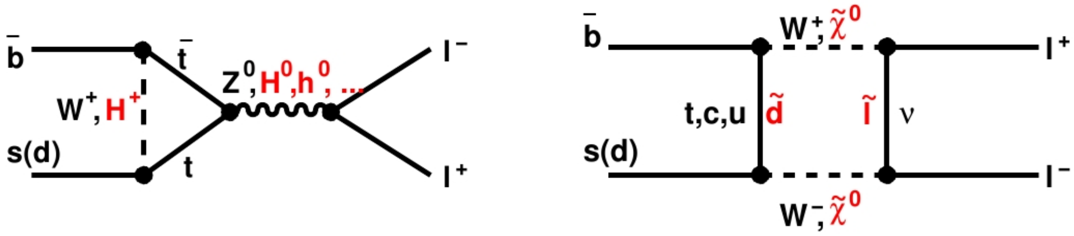

Figure 1: Illustration of the rare decays $B^0_{s(d)} \to \mu^+\mu^-$. In the SM, these decays proceed through $W^\pm$ and Z^0 bosons in Z-penguin (*left*) and box (*right*) interactions. The box diagram is suppressed by a factor of $m^2_W/m^2_t \approx 0.2$ with respect to the Z-penguin diagram.

beyond the SM. In the minimal supersymmetric extension of the Standard Model (MSSM) and in supersymmetric models with modified minimal flavour violation (MFV) at large $\tan(\beta)$ values, the branching fraction for these decays can be enhanced, especially at large $\tan(\beta)$ [2][3][4]. $B^0_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ decays can be enhanced separately even at low $\tan(\beta)$ in specific models containing leptoquarks [5] and supersymmetric models without R-parity conservation [6]. In the MSSM, the branching fraction enhancement for $B^0_s \to \mu^+\mu^-$ can be, depending on the model, proportional up to $\tan^6(\beta)$, which provides a good sensitivity to $\tan(\beta)$. There is significant interest in using the decay mode $B^0_s \to \mu^+\mu^-$ to "measure" the key parameter $\tan(\beta)$ of the MSSM and to constrain other extensions of the SM.

So far, neither CDF nor D0 have found evidence for the decay, because of their limited data sample. Their current best upper limits at 90% C.L. are about 4.7×10^{-8} and 7.5×10^{-8} respectively.

2. CMS first months of data taking

CMS[7] is now at its first year of collision data taking at the LHC. The two main sub-detectors for muons in CMS are the inner tracker and the outer muon stations. The inner tracker, composed by pixel and silicon strips, is designed to measure the track transverse momentum (p_T) and for vertex reconstruction. Three different sub-detectors are used for the muon identification and reconstruction: drift tube (DT) and cathode strip chambers (CSC) in the barrel, resistive plate chambers (RPC) and CSC in the endcaps. The CMS azimuthal coverage for tracks and muons is $|\eta| < 2.4$ where η is the pseudorapidity.

The muon reconstruction and trigger efficiencies have been measured with data-driven techniques like the Tag & Probe. This method looks for well known reconstructed resonances, like the

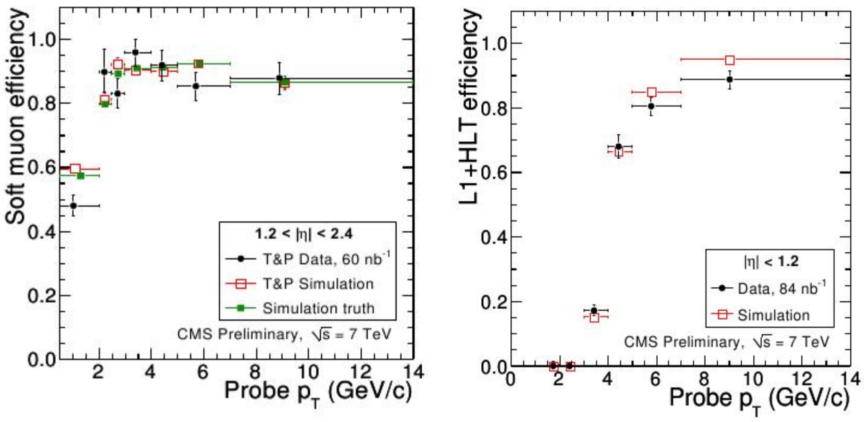

Figure 2: Examples of Tag & Probe reconstruction (*left*) and trigger (*right*) efficiencies as a function of the probe muon p_T [8].

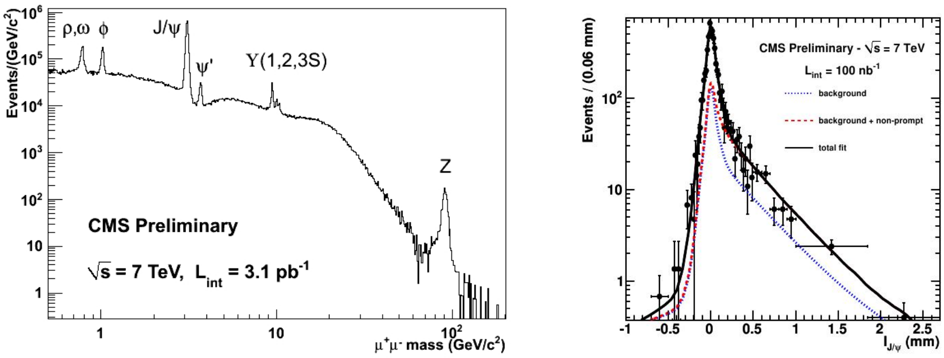

Figure 3: Full invariant-mass spectrum of opposite-sign muon pairs. The bin size is chosen to be 1% of the mass (*left*). Measured pseudodecay length distribution and likelihood fit result for J/ψ mesons reconstructed in the barrel [9] (*right*).

J/ψ mesons; with a well reconstructed muon (the tag) it tests if the second muon (the probe) is found. The efficiency is the fraction of passing probes (Fig.2).

Furthermore, it has been possible to check the tracker mass resolution for di-muon resonances (Fig. 3, left). For narrow resonances, the resolution varies from a width of 20 MeV for J/ψ mesons reconstructed in the barrel, to 100 MeV for Υ mesons reconstructed in the endcaps. Another important property for the tracker is the vertex reconstruction: the possibility to separate vertices of non-prompt dimuons from B hadrons and prompt dimuons originating from the primary vertex (Fig. 3, right).

3. Prospects for $B_s^0 \to \mu^+\mu^-$ branching ratio measurement

This section shows a simulation study of the measurement of the $B_s^0 \to \mu^+\mu^-$ branching ratio, that could be possible after one year of data acquisition. This simulation study uses a relative normalization to the well-measurable decay $B^\pm \to J/\psi K^\pm$, to avoid a dependence on the uncertainties

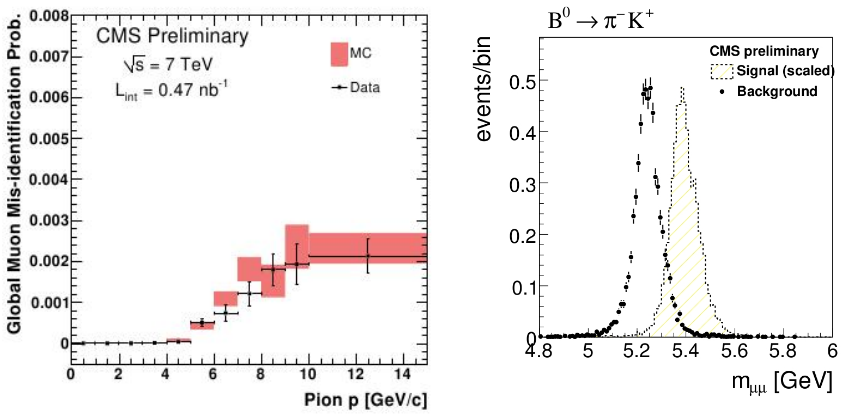

Figure 4: Muon misidentification probability for pions [8] (*left*). Background $m_{\mu\mu}$ distribution before the application of muon identification, for the channel $B^0 \to \pi^- K^+$ [10] (*right*).

in the $b\bar{b}$ production and luminosity measurements [10]. Furthermore many systematic errors cancel to first order when deriving the upper limit normalizing to a similar decay channel measured in data.

The background sources that mimic the signal topology can be grouped into three categories. First, $q\bar{q}$ events (where $q = b, c$) with $q \to \mu X$ (prompt or cascade) decays of both q-hadrons. Second, minimum bias QCD events where a true muon is combined with a hadron misidentified as a muon (Fig. 4, left) via punch-through or in-flight decay of a hadron. Third, rare B^0, B^+, B_s^0 and Λ_b decays (Fig. 4, right).

This analysis is not primarily targeted at the initial very low-luminosity startup period of the LHC but requires at least 1.0 fb^{-1}. Therefore the trigger strategy is based on an instantaneous luminosity of at least a few 10^{33} cm^{-2}s^{-1}. A transverse momentum requirement of $p_T > 3$ GeV is applied to the two triggering muons. These muons are fit to a common decay vertex, requiring a $\chi^2/ndf < 10$. The ratio between the decay length of the B_s^0 and its error must be larger than three and the angle α between the reconstructed di-muon momentum vector and the vector from the primary to the decay vertex has to fulfill $\cos\alpha > 0.9$.

For the offline event selection, variables related to the primary vertex, the muon candidates, and the B_s^0 candidate with its associated secondary vertex are calculated. If more than two muon candidates are found, the pair with the smallest $\eta\phi$ separation is chosen. For both muons, $p_T > 4$ GeV and $|\eta| < 2.4$ are required. The B_s^0 candidates are formed by vertexing the two muon candidates. The B_s^0 candidate is required to fulfill $p_T > 5$ GeV. The mass resolution distribution, obtained on a fully simulated signal sample, is fit with two Gaussians and its width is $\sigma = 53.0 \pm 1.4$ MeV. Signal events are distinguished by two muons originating from the same secondary vertex while the muons in $b\bar{b} \to \mu^+\mu^- + X$ events stem from separate vertices. Vertexing the two muons therefore provides a powerful handle in this background reduction. The transverse momentum vector of the B_s^0 candidate must be close to the direction of the secondary vertex from the primary vertex: the cosine of the opening angle between the two vectors must fulfill $\cos\alpha > 0.9985$. The flight length significance of the B_s^0 candidate is an excellent handle against prompt combinatorial background. The significance of the (unsigned) flight length l_{3D} is defined as l_{3D}/σ_{3D}, where σ_{3D} is the error on

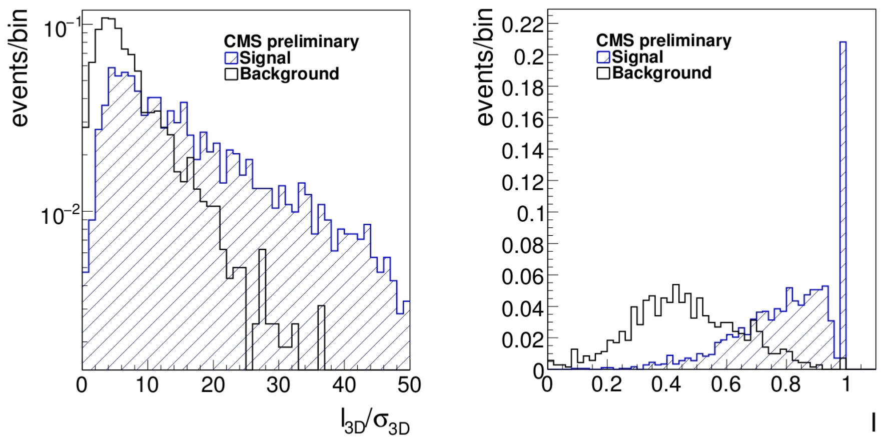

Figure 5: Flight length significance(*left*) and isolation I (*right*), for signal and the main background: $b\bar{b} \to \mu^+\mu^- + X$.

	Signal	$b\bar{b} \to \mu^+\mu^- + X$ background
Description	Efficiency	Efficiency
Trigger	0.171	0.016
Good events	0.130	0.013
Mass cut	0.130	6.15×10^{-4}
Pointing angle	0.095	6.63×10^{-5}
Flight distance	0.055	6.10×10^{-6}
Vertex fit	0.052	2.51×10^{-6}
Isolation	0.024	4.61×10^{-8}
Signal window $M_{B_s^0} \pm 100$ MeV	0.023	7.82×10^{-9}

Table 1: Event efficiency for the offline selection. The events are counted in the mass interval $4.8 < m < 6.0$ GeV and are normalized to a luminosity of 1.0 fb^{-1}.

the flight length (Fig. 5, left). In high-p_T gluon-splitting events the $b\bar{b}$ quark pair moves closely together due to their boost, and the two decay vertices of the resulting B-hadrons cannot be well separated in all cases, therefore mimicking a common secondary vertex. However, because of the other hadrons in semileptonic decays of both B-hadrons, the hadronic activity around the di-muon direction is enhanced compared to the signal decay. This is exploited in isolation requirements. The isolation I is determined from the B_s^0 candidate transverse momentum and charged tracks with $p_T > 0.9$ GeV in a cone with radius $r = 1.0$ around the di-muon direction as follows:

$$I = \frac{p_T(B_s^0)}{p_T(B_s^0) + \sum_{trk} |p_T|} \tag{3.1}$$

where all track parameters are evaluated at the origin (Fig. 5, right).

The most important selection criteria have been optimized in a grid search for best upper limit. Table 1 summarizes the evaluated efficiencies for signal and for the largest background source: $b\bar{b} \to \mu^+\mu^- + X$. The total cumulative selection efficiency for signal events is $\varepsilon_S = 0.023$ and the background reduction factor is $\varepsilon_B = 7.82 \times 10^{-9}$. With this selection, the first 1.0 fb^{-1} of integrated

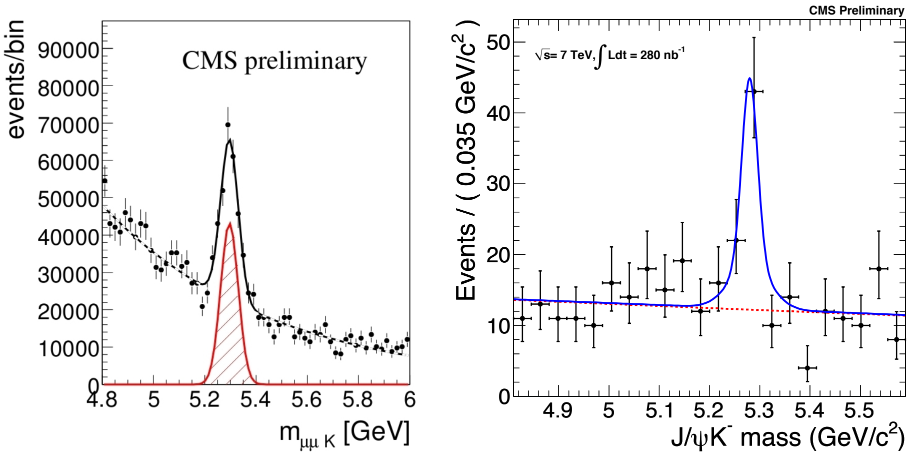

Figure 6: Normalization decay $B^{\pm} \to J/\psi K^{\pm}$ for $L = 1$ fb^{-1} simulation data (*left*) and with 280 nb^{-1} real data (*right*). A constraint on the J/ψ invariant mass is applied in the real data plot.

luminosity will yield $n_S = 2.36$ signal events and $n_B = 5.07$ background events in the mass window $m_{B_s^0} \pm 100$ MeV, where we have combined contributions from $\mu\mu$ pairs and misidentified μh pairs. Additional background events in the mass window arise from rare B-decays. The contribution of these events is $n_{rare} = 1.45$, for a total background expectation of $n_{total} = 6.53$. The estimated combined statistical and systematic uncertainties of the background are 37% and for the signal efficiency error 18%, respectively.

The normalization decay $B^{\pm} \to J/\psi K^{\pm}$ (Fig. 6) has a large and well-measured branching fraction with only one additional track in the final state compared to the signal decay. However, the hadronization of the B^+ meson can be different from the B_s^0 meson, affecting for instance the isolation variable. The large statistics of this normalization sample will allow a detailed comparison of the detector performance and analysis selection efficiencies in data and Monte Carlo (MC) simulation. It will also allow the reweighting of the B^+ transverse momentum spectra so that the MC simulation reproduces the data. The decay $B^{\pm} \to J/\psi K^{\pm}$ is reconstructed using requirements as similar to the signal mode as possible; the B^+ decay vertex is reconstructed using only the two muons and no mass-constraint on the J/ψ mass is applied.

The total selection efficiency for normalization signal events is $\varepsilon_{tot,N} = (1.57 \pm 0.074) \times 10^{-2}$, resulting in a total number $n_N = 3.30 \times 10^4$ of events for $L = 1.0$ fb^{-1}.

The upper limit at the 90% C.L. [10] is

$$\mathscr{B}(B_s^0 \to \mu^+\mu^-) = \frac{N(n_{obs}, n_B, n_S)}{N(B^{\pm} \to J/\psi K^{\pm})} \frac{f_u}{f_s} \frac{\alpha_B^+}{\alpha_{B_s^0}} \frac{\varepsilon_{B^+}^{trig}}{\varepsilon_{B_s^0}^{trig}} \frac{\varepsilon_{B^+}^{ana}}{\varepsilon_{B_s^0}^{ana}} \mathscr{B}(B^{\pm} \to J/\psi K^{\pm}) \mathscr{B}(J/\psi \to \mu^+\mu^-) \tag{3.2}$$

where $\alpha_{B_s^0}$ (α_B^+) is the generator-level acceptance for signal (normalization) events, $\varepsilon_{B_s^0}^{trig}$ ($\varepsilon_{B^+}^{trig}$) is the trigger efficiency for signal (normalization) events, $\varepsilon_{B_s^0}^{ana}$ ($\varepsilon_{B^+}^{ana}$) is the analysis efficiency for signal (normalization) events, and $\mathscr{B}(B^{\pm} \to J/\psi K^{\pm}) = (1.007 \pm 0.035) \times 10^3$ and $\mathscr{B}(J/\psi \to \mu^+\mu^-) = (5.930.06) \times 10^2$, and finally $f_s = (10.5 \pm 0.9)\%$ and $f_u = (40.2 \pm 0.9)\%$.

From eq. 3.2 the resulting upper limit on the branching fraction is given by

$$\mathscr{B}(B_s^0 \to \mu^+\mu^-) \leq 1.6 \times 10^{-8} \tag{3.3}$$

While this upper limit is about four times above the SM expectation, it allows already constraints on new physics models with the first 1.0 fb^{-1} of integrated luminosity.

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