# Results and prospects for di-muon final states at LHCb

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Final states of rare decays with di-muons have a very high trigger efficiency in LHCb and will provide some of the most promising analyses for new physics. With the 2010 data from the LHC the focus will be on the search for the decays $B_s \to \mu^+\mu^-$ and $D^0 \to \mu^+\mu^-$ as well as a first angular analysis of $B_d \to K^*\mu^+\mu^-$. The first data collected by LHCb have been used to start the validation of some key aspects of these analyses. In this context, the LHCb capabilities in constraining new physics models through the studies of rare decays are discussed.

## 1 Introduction

Decays of heavy flavour mesons which proceed via flavor changing neutral currents (FCNC) are forbidden at the tree level in the Standard Model (SM). As a consequence, they are heavily suppressed and form an excellent probe to search for new physics (NP) as virtual new particles can enter in the loop processes. Rare decays with di-muons in the final state are of particular interest for LHCb as they have a very high trigger efficiency. Here, the LHCb potential for the search of new physics in $B_s \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-$ and $B_d \to K^*\mu^+\mu^-$ is discussed. The first data collected by LHCb (about 14 nb$^{-1}$) at a center-of-mass energy of 7 TeV, have been used to start the validation of the key aspects of these analyses. In particular, the performance of the muon trigger, muon identification, tracking and vertexing has been demonstrated using mainly $J/\psi \to \mu^+\mu^-$ and $K_s \to \pi^+\pi^-$ samples.

## 2 Search for $B_s \to \mu^+\mu^-$

The helicity suppressed $B_s \to \mu^+\mu^-$ decay is due to very rare loop diagrams in the SM and its branching ratio (BR) is expected to be extremely small: $(3.6 \pm 0.4) \times 10^{-9}$ [1] but NP models such as for example supersymmetry could enhance it up to several orders of magnitude. The current best limits are achieved by CDF [2], BR$< 3.6 \times 10^{-8}$ at 90% confidence level (CL) (3.7 fb$^{-1}$), and D0 [3], BR$< 5.1 \times 10^{-8}$ at 95% CL (6.1 fb$^{-1}$). The LHCb event selection for this decay is based on a loose preselection to reject most of the background, followed by a multidimensional analysis based on three variables: the $\mu^+\mu^-$ invariant mass, and two likelihood variables, one describing the particle identification information and the second describing the geometrical information of the decay (impact parameter significance of the muons, $B_s$ proper time, impact parameter of the $B_s$, distance of closest approach between the two muons, muon isolation). The last step of the analysis consists of using a normalisation channel to derive the BR. Several $B_{u,d}$ channels are envisaged as $B_d \to K^+\pi^-$ or $B_u \to J/\psi\, K^+$. The use of these decays introduces a systematic uncertainty due to the poorly known hadronization rate ratio $f_{u,d}/f_s$ which can become dominant at high statistics [4]. A new method has been proposed recently to derive this ratio from data [5].

To validate the different analysis steps, a sample of more than 3500 $J/\psi \to \mu^+\mu^-$ events has been selected in the data. The $\mu^+\mu^-$ invariant mass resolution found is 16 MeV/c$^2$, which, given the fact that the tracking and alignement is not yet fully calibrated, is promising for the $B_s \to \mu^+\mu^-$ study. Same sign events have also been used to subtract background from data and study $J/\psi$ distributions like the vertex $\chi^2$ or the muon transverse momentum. The geometrical likelihood function has been validated using $K_s \to \pi\,\pi$ and $D^0 \to k\,\pi$ decays. A good agreement between data and simulation is visible. In the future, $B_{d,s} \to h\,h'$ decays, $h$ and $h'$ being charged kaons or pions, will be used as they are kinematically closer to the $B_s \to \mu^+\mu^-$ decay. Finally, the nominal preselection has been applied to data. The amount of

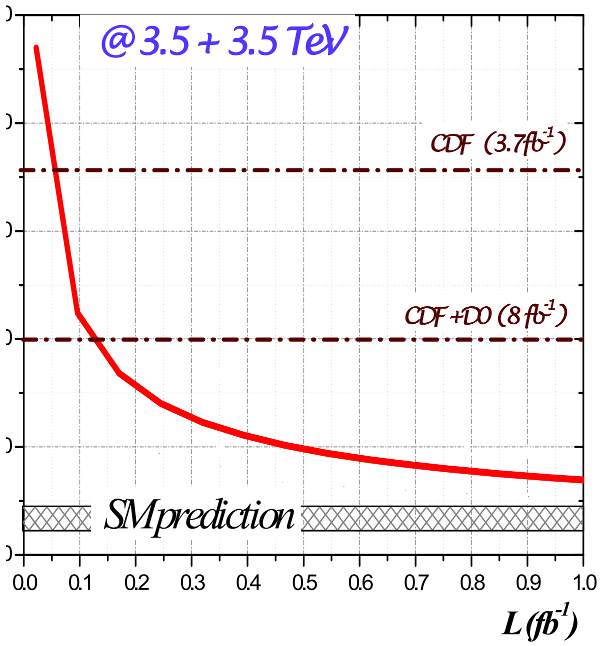


Figure 1: Exclusion limit at 90% CL for the measurement of BR($B_s \to \mu^+\mu^-$) at LHCb.

background found is well reproduced by the simulation.[1] The work done so far with the first data indicates that LHCb is in good shape to do physics analyses and that we can be confident in MC expectations. Figure 1 shows the expected BR exclusion at a confidence level of 90% as a function of the integrated luminosity up to 1 fb$^{-1}$. LHCb can improve the current Tevatron limit with 0.1 fb$^{-1}$ and will be able to exclude BR up to twice the SM prediction with the 2010/2011 data.

[1] These background events are not in the sensitive region and would be rejected by the geometrical likelihood.

# 3 Search for $D^0 \to \mu^+\mu^-$

$D^0 \to \mu^+\mu^-$ is a very rare decay as the SM predicts a branching ratio of $3\times10^{-13}$ [6]. However, in the Minimal Supersymmetric Standard Model (MSSM) with conserved R-parity it can be enhanced up to $10^{-6}$. The current best limit has been obtained by Belle [7]: BR($D^0 \to \mu^+\mu^-$) $<$ $1.4\times10^{-7}$ at 90% CL.

The analysis strategy in LHCb is very similar to the search for $B_s \to \mu^+\mu^-$. A loose selection is applied to look for $D^* \to D^0\pi$, $D^0 \to \mu^+\mu^-$, followed by a multivariate analysis based on kinematic and geometrical variables. The normalization is done with respect to the $D^0 \to \pi\pi$ channel. With 0.1 fb$^{-1}$, LHCb will be able to improve the Belle limit down to $4\times10^{-8}$ at 90% CL.

# 4 Study of the $B_d \to K^*\mu^+\mu^-$ decay channel

The decay $B_d \to K^*\mu^+\mu^-$ is fully described by three decay angles $\Theta_L, \Theta_K$ and $\phi$, and the di-muon invariant mass $q^2$. The angular distribution of this decay gives access to a number of observables sensitive to NP [8]. Among these observables, the forward-backward asymmetry $A_{FB}$ in the $\mu^+\mu^-$ rest frame as a function $q^2$ is of interest, in particular the $q^2$ value where $A_{FB}$ crosses zero, $s_0$. The value of $s_0$ can be precisely predicted in the SM thanks to the cancellation of the hadronic uncertainties at this point, and NP could give a sizeable deviation to this prediction.

LHCb is expected to collect 1400 events for 1 fb$^{-1}$ with a background to signal ratio of 0.2, to be compared with the $\mathcal{O}(100)$ events analysed by Babar, Belle and CDF each [9]. Two methods have been developed for LHCb to measure $s_0$. The first one uses a binned counting analysis and a linear fit to $A_{FB}$ around the crossing region, while the second one is based on a fit of the forward and backward distributions separately. Both methods give a sensitivity on $s_0$ of about 0.5 GeV$^2$ for 2 fb$^{-1}$. The LHCb sensitivity is also illustrated in Fig. 2 for 0.1 fb$^{-1}$ (left) and 1 fb$^{-1}$ (right) of data.

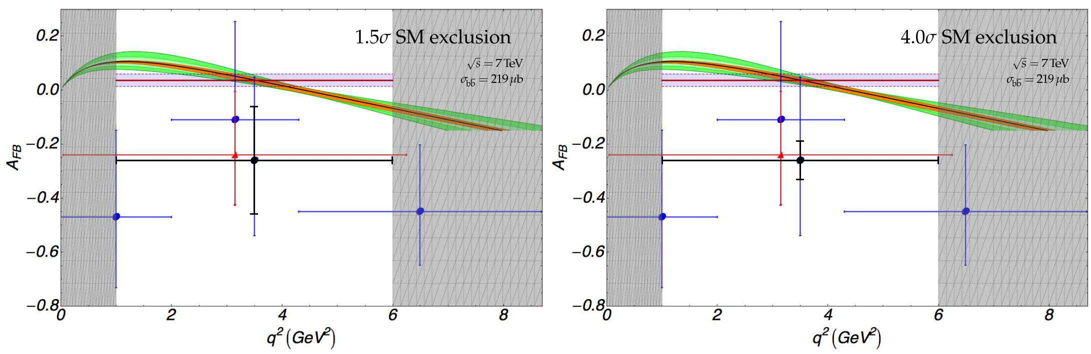


Figure 2: Precision with which $A_{FB}$ can be determined at LHCb from 0.1 fb$^{-1}$ (left) and 1 fb$^{-1}$ of data. The SM prediction is shown as a line surrounded by a grey area (theoretical uncertainty). The blue (dark grey) ellipses correspond to the Belle measurement, the red (light grey) triangle to the Babar measurement and the black circle is the LHCb expectation assuming the Belle $A_{FB}$ central value in the region from 1 to 6 GeV$^2$.

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