Prospects for rare and very rare B decays at LHCb

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Abstract

The prospects for the analysis of rare and very rare B decays at LHCb experiment are presented, with particular emphasis in the results that can be obtained with an initial integrated luminosity of $0.1\text{-}0.5\text{ fb}^{-1}$.

1 Introduction

Flavour Changing Neutral Currents (FCNC) have a pivotal role in the search of new physics (NP). In the Standard Model (SM) they appear at loop level and they are suppressed by the GIM mechanisms. New particles and interactions can enter in the loops and produce in some cases effects similar or larger in size to those of the SM. The large amount of $b\bar{b}$ pairs to be recorded in the LHCb experiment opens the door to explore NP via the FCNC in the B sector.

The LHCb has been designed specifically to trigger and identify exclusive B decays via its configurable trigger, its excellent momentum, vertex resolution and particle identification, to study CP violation and rare B decays (see proceedings by R. Vazquez and V. Gligorov). Among the most promising rare B decays studies to search for NP are the radiative decay $B_s \rightarrow \phi\gamma$, $B \rightarrow K^*\mu\mu$ and $B_s \rightarrow \mu\mu$. Some of these studies have already been performed at the B factories and Tevatron, and no discrepancy with the SM has been found so far. The large amount of data to be collected at LHCb will enlarge the range to search for NP.

2 Radiative decays

Among the most valuable probes of NP models are the FCNC transitions $b \rightarrow s\gamma$. The measurement of the inclusive ratio [1] [2] of the B_d meson is in agreement with the SM expectations and imposes stringent constraints on a variety of NP models [3] [4]. The inclusive BR cannot be measured at LHCb, but several exclusive measurements such as $B_s \rightarrow \phi\gamma$, are suitable for the LHCb detector capabilities. The SM predicts a left polarized photon in $b \rightarrow s\gamma$ transitions to the level of $O(m_s/m_b)$. In several extensions of the SM, the photon can acquire an appreciable right-handed component due to chirality flip in the transition [5] [6] without affecting the SM branching ratio. Photon helicity can be probed via mixing-induced CP asymmetries [7]. If the photon is not fully polarized, B and anti-B mesons can decay

to same final CP state f^{CP} . The time-dependent rate of $B_q(\bar{B}_q)$ is given by:

$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP}\gamma) \propto e^{-\Gamma_q t} \left(\cosh \frac{\Delta\Gamma_q t}{2} - A^\Delta \sinh \frac{\Delta\Gamma_q t}{2} \right) \quad (1)$$

$$\pm C \cos \Delta m_q t \mp S \sin \Delta m_q t \quad (2)$$

Contrary to the B_d , in the B_s system the measurable mass width difference $\Delta\Gamma_s/\Gamma_s$ opens the possibility to measure the coefficient A^Δ , which is related to the fraction of “wrongly” polarized photons. The measurement of A^Δ is therefore an indirect measurement of the photon polarization.

BaBar and Belle have measured the coefficients S and C in the exclusive decay $B \rightarrow K^*(K_s\pi^0)\gamma$ [8] with approximately 150 events, with a resolution on S of 40%. LHCb expects to collect and select $\sim 6(36)$ k events in 2 fb^{-1} of $B_s \rightarrow \phi\gamma$ ($B \rightarrow K^*\gamma$) with a B/S $\sim 0.5(0.7)$ [9]. The selected signal events have an invariant mass resolution of 91 MeV. The proper time oscillation of the B_s can be resolved with ~ 80 fs resolution, but it depends strongly on the topology of the decay. After the selection, the remaining background events are mostly $b\bar{b}$ events with an unresolved π^0 in the calorimeter. The acceptance as a function of the B_s proper time can be determined using control channels such as $B \rightarrow K^*\gamma$.

With 2 fb^{-1} of integrated luminosity, the A^Δ coefficient can be measured with 20% statistical uncertainty.

3 $B \rightarrow K^*\mu\mu$

The $B \rightarrow K^*\mu\mu$ decay proceeds mostly via an electroweak penguin diagram with a small BR $\sim 1.2 \cdot 10^{-6}$. Some NP scenarios predict a different muon distribution to the SM one. The differences are usually shown in the forward-backward asymmetry (A_{FB}) of the muon with respect the B direction in the dimuon mass rest frame as a function of the dimuon mass. In particular, the value of the dimuon mass at which the asymmetry is zero is predicted [10] in the SM to be $4.36^{+0.33}_{-0.31} \text{ GeV}/c^2$.

This channel is triggered with high efficiency at LHCb. The signal selection benefits from the low misidentification of muons, the great K/π separation of the RICH detector and the good invariant mass resolution ($\sim 14 \text{ MeV}$), that leads to a yield of 7k events in 2 fb^{-1} , with a background to signal ratio of ~ 0.5 in a 50 MeV window around the B mass. After the selection, the remaining background events are semileptonic B decays.

BaBar and Belle have measured the branching ratio of the $B \rightarrow K^*\mu\mu$, the A_{FB} and the K^* longitudinal polarization vs the dimuon mass, and fit the angular distributions to extract the Wilsons Coefficients [11], with a precision comparable to what can be obtained by the LHCb with less than 0.1 fb^{-1} . The precision of the zero crossing point of the asymmetry is expected to be 0.8 GeV^2 with 0.5 fb^{-1} and $0.5(0.3) \text{ GeV}^2$ at $2(10) \text{ fb}^{-1}$ [13]. In addition, with large statistics, LHCb can measure [14] the transversity amplitudes as a function of the dimuon mass via new observables [12].

4 $B_s \rightarrow \mu\mu$

The decay $B_s \rightarrow \mu\mu$ has been identified as a process where NP can contribute significantly. This is a very rare decay that proceeds mostly via a electroweak (and Higgs) penguin diagrams, other box diagrams mediated via W are suppressed by a factor $(M_W/m_t)^2$. Moreover the decay is helicity suppress by a factor $(m_\mu/m_{B_s})^2$. The SM predicts a branching ratio of $3.35 \pm 0.32 \cdot 10^{-9}$ with small theoretical error [15]. The decay is very sensitive to the presence of extra scalar sector, in particular to extra Higgs bosons. In the Minimum Supersymmetric Standard Model (MSSM), the BR is proportional to $\tan^6\beta$ [16]. For example, in reference [17], the authors have fit the present experimental results of electroweak and B physics precision observables, and taking into account the current limit in direct searches of the Higgs boson, to a particular realization of the MSSM; they found a best fit (mostly driven from the results of the $g-2$ experiment) that corresponds to $\tan\beta \sim 30$ and $M_A \sim 350 \text{ GeV}$, which will predict a $B_s \rightarrow \mu\mu$ BR of $\sim 10^{-8}$.

LHCb is very suitable for the search of this channel despite the huge background level. This decay is triggered very efficiently thanks to the muon triggers. The efficiency to identify muons is 95% with very low misidentification of pions as muons (0.5%). In addition, taking advantage of the excellent

vertex capabilities of the LHCb detector, the secondary vertex formed by the two muons, can be well separated from the primary vertex, reducing further the combinatorial background. Finally the excellent invariant mass resolution of 20 MeV, further reduces the background events under the mass peak. The total selection efficiency, computed in a MC signal sample, including the detector acceptance, trigger and selection efficiencies, is 10%.

The analysis is based on 3 variables: the invariant mass, and two likelihood variables, one compiling the particle identification information and the second one the geometrical information of the decay (impact parameter of the muons, B_s proper time, etc). The space defined by these variables is divided in bins. The estimated background and the expected signal events for a given BR in each of these bins are used to compute the exclusion and discovery potential of the LHCb via the determination of the confidence level of the signal and the background according with the method described in reference [18]. The main background has been identified as combinatorial semileptonic B decays, while the exclusive backgrounds such as $B \rightarrow hh$ (where h stands for hadron) and $B_c^+ \rightarrow J/\Psi \mu^+ \nu$ have been shown to be negligible. In 2 fb^{-1} we expect 23 signal events for the SM BR and 150 background events in the most sensitive region of the 3D space. The current limit of the BR (established by CDF with 2 fb^{-1} [19]) is $4.7 \cdot 10^{-8}$ at 90% CL. With no signal events observed with 0.1 fb^{-1} integrated luminosity, LHCb will set a 90% CL limit at $1.3 \cdot 10^{-8}$. With 0.5 fb^{-1} and no observed signal, LHCb should exclude a BR above the SM at 90% CL. To get an evidence (observation) of the SM BR $2(6) \text{ fb}^{-1}$ will be needed.

$B \rightarrow hh$ events can be used to calibrate the geometrical likelihood and the invariant mass of the signal distributions. Moreover, the control channels $B \rightarrow hh$ or $B^+ \rightarrow J/\Psi K^+$ can be used for normalization. The main systematic error comes from the uncertainty in the hadronization fraction between the B_s and the B_d mesons that is 13%.

5 Conclusions

The LHCb detector is in the last period of its commissioning. The large number of $b\bar{b}$ pairs to be produced in the LHC opens the possibility to study in detail FCNC in the B sector that have a large potential to discover NP beyond the SM. The most relevant studies are the wrong polarization of the photon in the $B_s \rightarrow \phi \gamma$; the angular distributions, in particular the A_{FB} of the $B \rightarrow K^* \mu \mu$, and the measurement of the BR of the very rare decay $B_s \rightarrow \mu \mu$. In the last two channels, LHCb results with an integrated luminosity above 0.1 fb^{-1} will improve on the current measurements, opening the door to a possible discovery of NP.

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