Search for New Physics with rare decays of B^0, B^+ and B^0_s mesons at LHCb

Johannes Albrecht
CERN, Geneva, Switzerland
on behalf of the LHCb collaboration

1 Introduction

The rare processes $b \to s\ell^+\ell^-$ and $b \to s\gamma$ are flavour changing neutral currents that are forbidden at tree level in the Standard Model (SM). They can proceed via higher order electroweak (Z^0, γ) penguin or box diagrams. In extensions to the SM, new virtual particles can enter at loop level, leading to significant deviations form the SM predictions. These deviations may be the enhancement (or suppression) of branching fractions, where a good example, the search for the very rare decays $B^0_{(s)} \to \mu^+\mu^-$ is presented here[1]. They might also be observable in the modification of angular distributions, e.g. in $B^0 \to K^*\mu^+\mu^-$, or in the modification of CP or Isospin asymmetries such as those observable in the radiative decays $B^0 \to K^*\gamma$ and $B^0_s \to \phi\gamma$. The last presented probe for extensions to the SM is the search for Majorana neutrinos in same sign decays of $B^+ \to h^-\mu^+\mu^+$, where h^- represents a K^- or π^-. These rare decay processes provide a complementary approach to direct searches at the general purpose detectors and can provide sensitivity to new particles with masses up to higher scales than directly accessible.

At the time of the conference Physics at LHC 2011 (PLHC), June 2011, a published LHCb measurement of the search for the very rare decays $B^0_{(s)} \to \mu^+\mu^-$ using $37\,\text{pb}^{-1}$ existed [1]. The angular analysis of $B^0 \to K^*\mu^+\mu^-$ as well as the radiative decay measurements were in preparation for the EPS conference in July 2011. In the meantime, these three measurements have been performed using about $300\,\text{pb}^{-1}$ of data. Hence, this proceedings describes the existing measurements [2, 3, 4] rather than an outdated status at the time of PLHC. The Majorana neutrino search was presented for the first time at PLHC.

1.1 The LHCb Detector and data taking in 2010 and 2011

The LHCb detector is described in detail elsewhere [5]. The published searches for $B^0_{(s)} \to \mu^+\mu^-$ decays and for Majorana neutrinos were performed on a dataset

---

[1] In this proceedings, the inclusion of charge conjugate states are implicit.

corresponding to an integrated luminosity of about $37\,\mathrm{pb}^{-1}$, collected in 2010 at $\sqrt{s} = 7\,\mathrm{TeV}$. The main results described in sections 2, 3 and 4 are based on a dataset corresponding to an integrated luminosity of about $300\,\mathrm{pb}^{-1}$, collected in the first half of 2011. This luminosity was delivered by the LHC at instantaneous luminosities of $3 - 3.5 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 50% above the design luminosity of LHCb. At this instantaneous luminosity, LHCb collected more than $1\mathrm{fb}^{-1}$ of integrated luminosity in 2011.

2 Search for the very rare decays $B^0_{(s)} \to \mu^+\mu^-$

The SM prediction for the Branching Ratios (BR) of the decays $B^0_{(s)} \to \mu^+\mu^-$ have been computed [6] to be $BR(B^0_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$ and $BR(B^0 \to \mu^+\mu^-) = (0.10 \pm 0.01) \times 10^{-9}$. However, many extensions of the SM predict large enhancements to these BR. Before the LHC measurements of these BR, the most restrictive limits about a factor 13 above the SM prediction, measured by the CDF and D0 experiments. The measurements presented here use about $300\,\mathrm{pb}^{-1}$ of data. Assuming the SM branching ratio, about 3.4 (0.32) $B^0_s \to \mu^+\mu^-$ ($B^0 \to \mu^+\mu^-$) events are expected to be reconstructed and selected in the analyzed sample.

The first step of the analysis is a simple selection, which removes the dominant part of the background and keeps about 60% of the reconstructed signal events. Then, each event is given a probability to be signal or background in a two-dimensional probability space defined by the dimuon invariant mass and a multivariate discriminant likelihood. This likelihood combines kinematic and topological variables of the $B^0_{(s)}$ decay using a Boosted Decision Tree (BDT). The BDT is defined and trained on simulated events for both signal and background. The signal BDT shape is then calibrated using decays of the type $B^0_{(s)} \to h^+h'^-$, where $h^\pm$ represents a $K^\pm$ or $\pi^\pm$. These decays have an identical topology as the signal. The invariant mass resolution is calibrated with an interpolation of J/ψ, $\psi(2S)$ and $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ decays to two muons. The background shapes are calibrated simultaneously in the mass and the BDT using the invariant mass sidebands. This procedure ensures that even though the BDT is defined using simulated events, the result will not be biased by discrepancies between data and simulation.

The number of expected signal events is evaluated by normalizing with channels of known branching ratio. Three independent channels are used: $B^+ \to J/\psi K^+$, $B^0_s \to J/\psi\phi$ and $B^0 \to K^+\pi^-$. The first two decays have similar trigger and muon identification efficiency to the signal but a different number of particles in the final state, while the third channel has the same two-body topology but is selected with a hadronic trigger. The event selection for these channels is specifically designed to be as close as possible to the signal selection. The ratios of reconstruction and selection efficiencies are estimated from the simulation, while the ratios of trigger efficiencies on selected events are determined from data. The compatibility of the observed distribution of events with a given branching fraction hypothesis is computed using the CLs method [7].

The measured upper limit for the branching ratio is BR($B_s^0 \to \mu^+\mu^-$)$<$ 1.3 (1.6)$\times 10^{-8}$ at 90 % (95 %) confidence level (CL), while in the case of the B^0, the measured upper limit is BR($B^0 \to \mu^+\mu^-$)$<$ 4.2 (5.1) $\times 10^{-9}$ at 90 % (95 %) CL. A combination with the LHCb observations on the 2010 dataset results in BR($B_s^0 \to \mu^+\mu^-$)$<$ 1.2 (1.5) $\times 10^{-8}$ at 90 % (95 %) CL. The 95% CL limit on BR($B_s^0 \to \mu^+\mu^-$) is less than a factor 5 from the SM prediction.

3 Angular analysis of the decay $B^0 \to K^*\mu^+\mu^-$

The rare decay $B^0 \to K^*\mu^+\mu^-$ is a $b \to s$ flavour changing neutral current decay which is in the SM mediated by electroweak box and penguin diagrams. It can be a highly sensitive probe for new right handed currents and new scalar and pseudoscalar couplings. These NP contributions can be probed by fits to the angular distributions of the B^0 daughter particles. The most prominent observable is the forward-backward asymmetry of the muon system (A_{FB}). A_{FB} varies with the invariant mass-squared of the dimuon pair (q^2) and in the SM changes sign at a well defined point, where the leading hadronic uncertainties cancel. In many NP models the shape of A_{FB} as a function of q^2 can be dramatically altered.

The present analysis uses 309 pb^{-1} of data collected by the LHCb experiment during 2011 to measure A_{FB}, the fraction of longitudinal polarisation of the K^0, F_L, and the differential branching fraction, dB/dq^2, as a function of the dimuon invariant mass squared, q^2. There is good agreement between recent Standard Model predictions and the LHCb measurement of A_{FB}, F_L and dB/dq^2 in the six q^2 bins. In a $1 < q^2 < 6\,\mathrm{GeV}^2$ bin, LHCb measures $A_{FB} = 0.10 \pm 0.14 \pm 0.05$, to be compared with theoretical predictions of $A_{FB} = 0.04 \pm 0.03$. The experimental uncertainties are presently statistically dominated, and will improve with a larger data set. Such a data set would also enable LHCb to explore a wide range of new observables.

4 Radiative decays in LHCb

The precise measurement of the branching ratios, asymmetries or angular distributions of radiative decays are promising modes to test for New Physics. LHCb has measured the ratio of branching ratios of the radiative decays $B^0 \to K^*\gamma$ and $B_s^0 \to \phi\gamma$ using 340 pb^{-1} of data recorded in 2011 [4]. The obtained value for the ratio is $1.52 \pm 0.14(stat) \pm 0.10(syst) \pm 0.12(fs/fd)$. Using the HFAG value for BR($B^0 \to K^*\gamma$), BR($B_s^0 \to \phi\gamma$) has been found to be $(2.8 \pm 0.5) \times 10^{-5}$.

5 Search for Majorana Neutrinos

LHCb has performed a search for heavy Majorana neutrinos in the same sign decays $B^+ \to K^-\mu^+\mu^+$ and $B^+ \to \pi^-\mu^+\mu^+$ [8]. These decays are forbidden in the SM but allowed in models with a Majorana neutrino. No signal is observed in either channel and limits of $\mathrm{BR}(B^+ \to K^-\mu^+\mu^+) < 5.4 \times 10^{-8}$ and $\mathrm{BR}(B^+ \to \pi^-\mu^+\mu^+) < 5.8 \times 10^{-8}$ are set at the 95% confidence level. These improve the previous best limits by factors of 40 and 30 respectively.

6 Conclusion

The worlds tightest limit on the branching fraction of the decay $B^0_s \to \mu^+\mu^-$ is presented, using about $300\,\mathrm{pb}^{-1}$ of data collected by the LHCb experiment. This limit is less than a factor 5 above the SM prediction. The first LHCb measurement of the forward-backward asymmetry of the muons from $B^0 \to K^*\mu^+\mu^-$ decays is the most precise measurement of this quantity, in agreement with the SM prediction. A first measurement of the ratio of the branching fraction of $B^0 \to K^*\gamma$ and $B^0_s \to \phi\gamma$ is performed, opening the field to measure CP asymmetries in radiative decays in LHCb.

References

[1] The LHCb Collaboration, Phys. Lett. B 699 (2011) 330-340, arXiv:1103.2465

[2] The LHCb Collaboration, LHCb-CONF-2011-037 (2011)

[3] The LHCb Collaboration, LHCb-CONF-2011-038 (2011)

[4] The LHCb Collaboration, LHCb-CONF-2011-055 (2011)

[5] The LHCb Collaboration, *JINST* **3** (2008) S08005

[6] A.J. Buras, arXiv:1012.1447; E. Gamiz *et al*, Phys. Rev. D **80** (2009) 014503.

[7] A.L. Read, J. Phys. G 28 (2002) 2693; T. Junk, N.I.M. A 434 (1999) 435.

[8] The LHCb Collaboration, CERN-PH-EP-2011-156 (2011), arXiv:1110.0730