PROCEEDINGS OF SCIENCE

Results from angular analyses of B-meson decays in CMS

Alessio Boletti[a,*] **on behalf of the CMS Collaboration**

[a] *Laboratório de Instrumentação e Física Experimental de Partículas (LIP)*
Av. Gama Pinto 2, Lisbon, Portugal

E-mail: alessio.boletti@cern.ch

The rare flavour-changing neutral current decays of the B mesons are among the most sensitive laboratories to probe the Standard Model and indirectly search for physics beyond it. In this report, a complete review of the analyses of the rare $b \to s\ell\ell$ decays performed by the CMS Collaboration is presented. In particular, three decays have been studied: $B^0 \to K^{*0}\mu\mu$, $B^+ \to K^+\mu\mu$, and $B^+ \to K^{*+}\mu\mu$. Finally, the projection of the analysis of the $B^0 \to K^{*0}\mu\mu$ decay channel to the HL-LHC data-taking is presented.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

[*] Speaker

https://pos.sissa.it/

PoS(ICHEP2022)694

1. Introduction

Indirect searches for physics beyond the Standard Model (SM) rely on precision measurements of the production and decay of SM particles that could be affected by those phenomena. One of the most promising type of decays is the family governed by $b \to sll$ flavour-changing neutral current (FCNC) transitions, which are forbidden at tree level and occur through higher-order penguin or box diagrams, according to the SM. For this reason, the study of these rare FCNC decays is very sensitive to possible contribution of phenomena beyond the SM.

The Compact Muon Solenoid (CMS) Experiment [1] at the Large Hadron Collider, has performed the analysis of three $b \to s\ell\ell$ decays: $B^0 \to K^{*0}\mu\mu$ [2, 3], $B^+ \to K^+\mu\mu$ [4], and $B^+ \to K^{*+}\mu\mu$ [5][1]. These analyses have been performed using the data collected in proton-proton collisions at centre of mass energy of 8 TeV, corresponding to an integrated luminosity of 20.5 fb^{-1}. In this report, these analyses are presented, together with the projection of the analysis of the neutral channel on the data that is expected to be collected by CMS in the HL-LHC runs [6]. The goal of these analyses is the measurement of the differential branching fraction and a set of parameters of the angular distribution of the final state, as a function of the invariant mass squared of the two-muon system, which is referred to as q^2.

2. The $B^0 \to K^{*0}\mu\mu$ decay

In the analysis of the $B^0 \to K^{*0}\mu\mu$ decay, the K^{*0} meson is reconstructed in the decay into $K^+\pi^-$. Three angular variables can be defined using the helicity angles identified by the direction of the final-state particles: $\cos\theta_K$, $\cos\theta_\ell$, and ϕ. The decay rate as a function of these angular variables can be written as an expansion of 3D spherical harmonics, and a set of eight angular parameters. Two analysis of this transition has been performed by CMS: in the first one [2] the angle ϕ was integrated out to simplify the analysis procedure and make it robust to low number of signal events, to measure the forward-backward asymmetry of the muons, A_{FB}, the fraction of longitudinally polarized K^{*0}, F_L, and the differential branching fraction; in the second analysis [3], the angles $\cos\theta_\ell$ and ϕ has been folded around the middle point of the range to simplify the decay rate and measure the parameters P_1 and P'_5. The q^2 spectrum has been divided in bins, in which the analysis is performed independently; two of the q^2 bins contain the resonant $B^0 \to K^{*0}J/\psi$ and $B^0 \to K^{*0}\psi(2S)$ decays, used as control and normalization channels. In the first (second) analysis, the angular parameters are extracted using a 3D (4D) fit to the B-candidate mass spectrum and the angular variables. The projections of the 4D fit in one of the q^2 bins are shown in Figure 1. The results of the two analyses are shown in Figures 2 and 3, respectively.

3. The $B^+ \to K^+\mu\mu$ decay

In the analysis of the $B^+ \to K^+\mu\mu$ decay [4], a single angular variable can be defined using the trajectories of the three final-state particles. The angular decay rate depends on two parameters: F_H and A_{FB}. Similarly to the analysis of the neutral channel described above, the q^2 spectrum is divided in bins, two dedicated to the resonant control channels, and the angular parameters are

[1]Charge conjugation is implied throughout the paper.

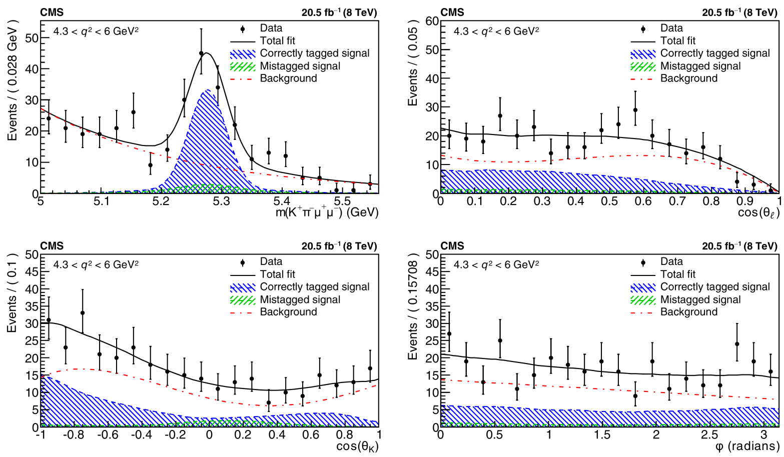

Figure 1: Projections of the fit to the $B^0 \to K^{*0}\mu\mu$ decay, in one of the q^2 bins. Figures from [3].

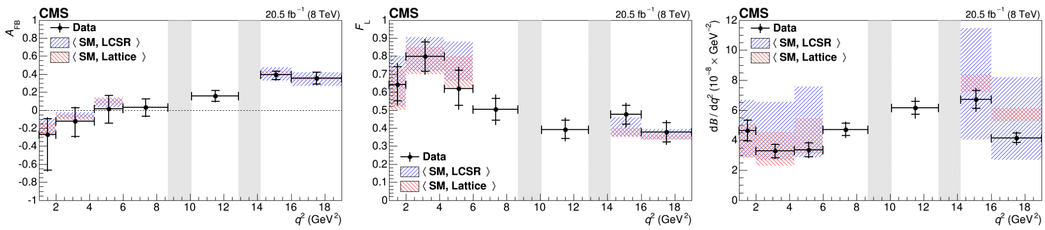

Figure 2: Results of the measurement of A_{FB} (left), F_L (centre), and the differential branching fraction (right). The internal error bar represents the statistical uncertainty, and the full bar represents the total one. The blue and red shaded areas represent the SM prediction. Figures from [2].

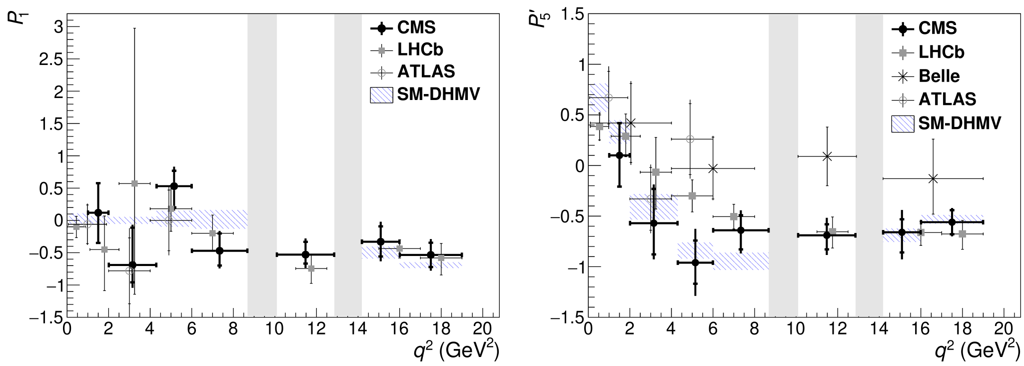

Figure 3: Results of the measurement of P_1 (left) and P_5' (right). The internal error bar represents the statistical uncertainty, and the full bar represents the total one. The blue shaded area represents the SM prediction. Results from other experiments are also shown. Figures from [3].

extracted using a 2D fit to the B-candidate mass and the angular variable. The projections of the fit in one of the q^2 bins are shown in Figure 4. The resulting parameters are shown in Figure 5.

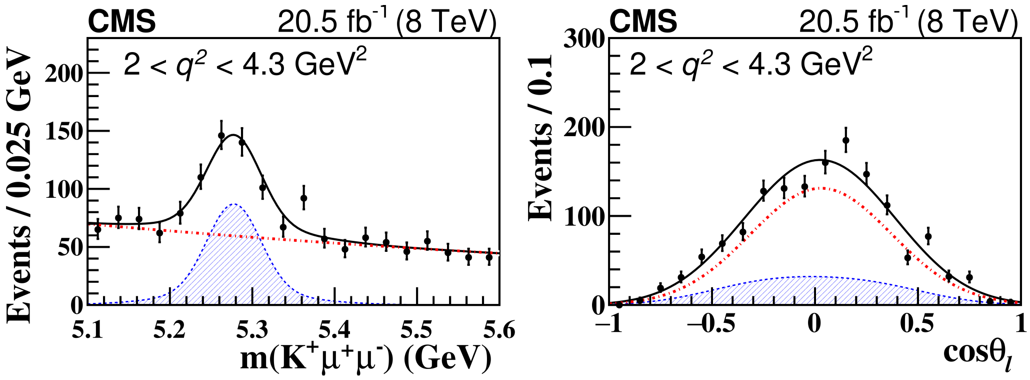

Figure 4: Projections of the fit to the $B^+ \to K^+\mu\mu$ decay, in one of the q^2 bins. Figures from [4].

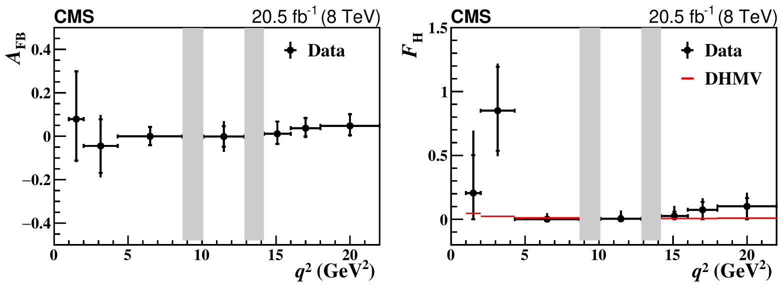

Figure 5: Results of the measurement of A_{FB} (left) and F_H (right). The internal error bar represents the statistical uncertainty, and the full bar represents the total one. The red lines represent the SM prediction for F_H, while A_{FB} is zero, according to the SM. Figures from [4].

4. The $B^+ \to K^{*+}\mu\mu$ decay

In the analysis of the $B^+ \to K^{*+}\mu\mu$ decay [5], the K^{*+} meson is reconstructed in the decay into $K_S\pi^+$, with the K_s decaying in flight in a pair of charged pions. The angular variables and decay rate of this channel are equivalent to the neutral one described above. However, the challenge introduced by the reconstruction of this decay chain, in which two displaced vertices (for the B^+ and K_s decays) need to be identified and reconstructed, reduce the number of signal events and the signal-to-noise ratio in the fitted dataset. The q^2 spectrum is divided in three bins, in addition to the two bins for the resonant control channels, and the ϕ variable is integrated out. The angular parameters A_{FB} and F_L are then extracted by fitting the 3D distribution of the B-candidate invariant mass and the two angular variables. The projections of the fit, for all the q^2 bins, are shown in Figure 6. The resulting parameters are shown in Figure 7.

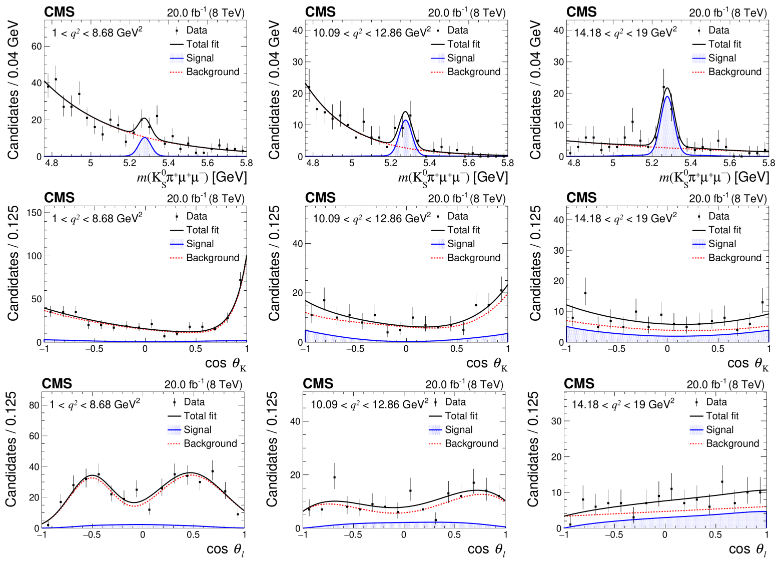

Figure 6: Projections of the fit to the $B^+ \to K^{*+}\mu\mu$ decay, in the three signal q^2 bins. Figures from [5].

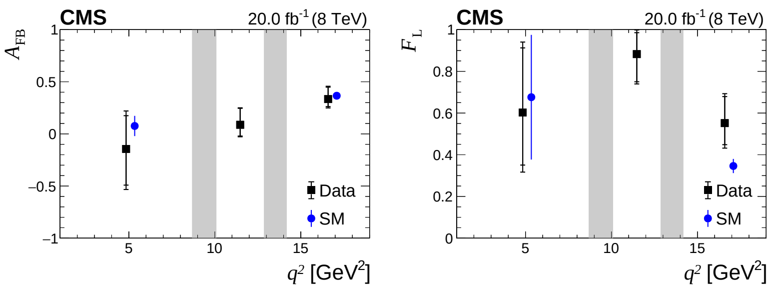

Figure 7: Results of the measurement of A_{FB} (left) and F_L (right). The internal error bar represents the statistical uncertainty, and the full bar represents the total one. The blue points represent the SM prediction. Figures from [5].

5. Projection of the $B^0 \to K^{*0}\mu\mu$ analysis to HL-LHC

A study has been performed to extrapolate the precision of the measurement of the P_5' parameter from the $B^0 \to K^{*0}\mu\mu$ analysis, to the expected data-taking conditions and integrated luminosity of HL-LHC [6]. The result obtained from the 8 TeV data analysis [3] is used as baseline for the extrapolation. Simulated MC samples are used to evaluate the impact of the Phase-II upgrade of the CMS detector on the B^0 candidate reconstruction efficiency and mass resolution. In Figure 8 (left), the expected improvement in mass resolution is shown as a function of q^2. The signal yield expected to be collected in the HL-LHC data-taking is computed and used to scale the uncertainties of the P_5' results of the 8 TeV analysis. The statistical uncertainty and some of the systematic ones are scaled according to the increase in signal yield. The other systematic uncertainties are reduced by a factor of two, assuming a general improvement in the analysis techniques. The resulting uncertainties are shown in Figure 8 (right), using the same central values of the 8 TeV analysis. The improved statistical precision would also allow for a finer bin definition in the q^2 spectrum. The bottom panels of Figure 8 (right) show the binning that would allow having similar statistical and systematic uncertainties for each bin.

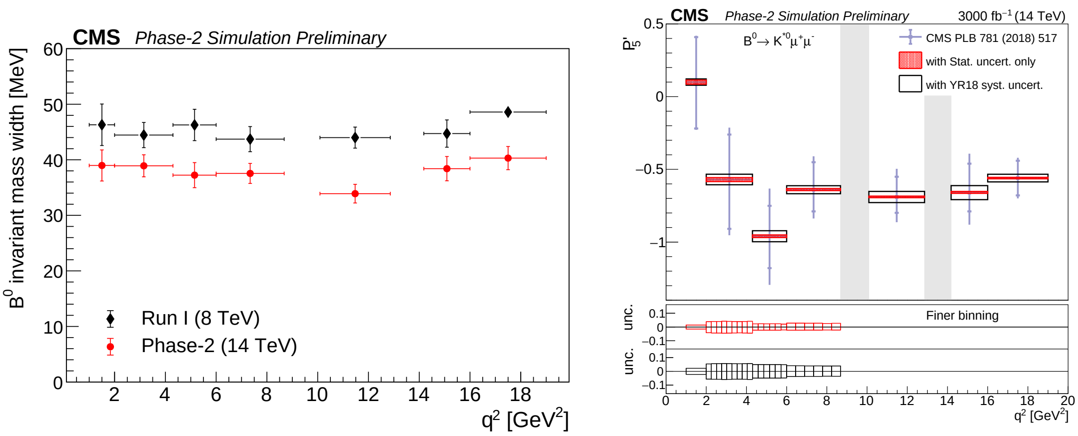

Figure 8: Left: The B^0 mass resolution, as a function of q^2, estimated with simulation of the Run 1 (black) and Phase-II (red) detector conditions. Right: Uncertainties of the measurement of P'_5, extrapolated to the HL-LHC data-taking. Figures from [6].

6. Conclusions

The class of FCNC $b \to s\ell\ell$ decays has been extensively studied using the data collected by CMS during the LHC Run 1 data taking. The results of the angular analysis of these transitions have been described in this report. In addition, the results of the $B^0 \to K^{*0}\mu\mu$ analysis have been projected to the dataset that CMS will collect during the HL-LHC data taking, estimating the precision that the experiment is expected to achieve on the measurement of P'_5 angular parameter.

References

[1] CMS Collaboration, JINST **3** (2008) S08004

[2] CMS Collaboration, Phys. Lett. B 753 (2016) 424

[3] CMS Collaboration, Phys. Lett. B 781 (2018) 517

[4] CMS Collaboration, Phys. Rev. D 98 (2018) no.11, 112011

[5] CMS Collaboration, JHEP **04** (2021), 124

[6] CMS Collaboration, CMS-PAS-FTR-18-033 (2018) `https://cds.cern.ch/record/2651298`

PoS(ICHEP2022)694