Angular analysis of the decay $B_0 \rightarrow K^* \mu\mu$ with the CMS detector

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Abstract. The Flavour Changing Neutral Current decay, $B_0 \rightarrow K^* \mu^+\mu^-$ is very sensitive to New Physics contributions through its observables like the muon forward-backward asymmetry, the fraction of $K^*$ longitudinal polarization, and the differential branching fraction. These parameters, as reported from previous experiments, remain so far consistent with SM prediction. We will report the recent results from CMS on these parameters using the 20 fb$^{-1}$ data collected during 2012.

Introduction

Rare decays are those processes that are highly suppressed according to the Standard Model (SM) predictions. These decays are an excellent laboratory to probe SM, since an eventual new physics contribution would have an amplitude comparable with the expected one and it would considerably modify the features of the process. The CMS Collaboration gave its significant contribution to the study of two rare decays within the heavy flavour physics: the $B^0_d$ (or $s$) $\rightarrow \mu\mu$ decays [1] and the $B^0 \rightarrow K^*(892)^0 \mu^+\mu^-$ decay [2]. Here only the latter decay analysis is reported.

The flavour changing neutral current decay $B^0 \rightarrow K^*(892)^0 \mu^+\mu^-$ is particularly fertile for new phenomena searches thanks to the modest theoretical uncertainties, due to the semileptonic final state. Furthermore, this decay is forbidden at tree level and the leading order diagrams that mediate this process are the box and penguin ones. This fact makes this decay channel very sensitive to virtual contributions of new particles.

In this three body decay, there are two angular parameters that have small theoretical uncertainties: the forward-backward asymmetry of the muons, $A_{FB}$, and the $K^{*0}$ longitudinal polarization fraction, $F_L$. These parameters, along with the differential branching fraction $dB/dq^2$, can be determined as a function of the dimuon invariant mass squared, $q^2$, and compared with the SM expectations.

Analysis

The CMS collaboration performed this analysis [2] using data collected from proton-proton collisions at the Large Hadron Collider (LHC) with the Compact Muon Solenoid (CMS) experiment in 2012 at a center-of-mass energy of 8 TeV. The analyzed dataset corresponds to an integrated luminosity of 20.5 ± 0.5 fb$^{-1}$.

Angular parametrization

The considered final state contains two opposite charged muons and a kaon and a pion as the decay products of the $K^{*0}$. Three angular variables are defined to describe completely the decay: the angle between the kaon momentum and the direction opposite to the $B^0$ in the $K^{*0}$ rest frame, $\theta_K$, the angle between the positive (negative) muon momentum and the direction opposite to the $B^0$ ($\bar{B}^0$) in the dimuon rest frame, $\theta$, and the angle between the plane containing the two muons and the plane containing the kaon and the pion, $\phi$. 
Contribution from spinless $K\pi$ combination is present, although the $K\pi$ invariant mass is imposed to be consistent with the $K^{*0}$ one. The fraction of S-wave contribution is parametrized as $F_S$ and the interference contribution between S-wave and P-wave is $A_S$.

The angular distribution of the decay is then:

$$
\frac{1}{\Gamma} \frac{d^3\Gamma}{d\cos\theta_K d\cos\theta_q dq^2} = \frac{9}{16} \left[ \left( \frac{2}{3} F_S + \frac{4}{3} A_S \cos\theta_K \right)(1 - \cos^2\theta_q) + (1 - F_S) \right] \left[ 2 F_L \cos^2\theta_K (1 - \cos^2\theta_q) + \frac{1}{2} (1 - F_L)(1 - \cos^2\theta_K)(1 + \cos^2\theta_q) + \frac{4}{3} A_{FB}(1 - \cos^2\theta_K) \cos\theta_q \right]
$$

where the dependence on $\phi$ is integrated out, since the $A_{FB}$ and $F_L$ parameters do not depend on it.

### Control samples and background events

The range of $q^2$ considered goes from 1 GeV$^2$ to 19 GeV$^2$ and it is divided in nine bins of different width. The fifth and the seventh bins correspond to the mass resonances of $J/\psi$ and $\psi'$. The former one contains mass square values in the range $8.68 < q^2 < 10.09$ GeV$^2$ and the events here contained are used as normalization sample, to normalize the branching fraction measurement. The latter resonance bin covers a range with $12.86 < q^2 < 14.18$ GeV$^2$ and its events are used as control sample.

After the selection cuts and the $K^{*0}$ mass requirement, a further cut is applied to reduce the contribution of resonant events with $q^2$ out of the resonance bin, due to a photon radiation from one of the muons. The background in the final sample is then mostly the combinatorial one. The small contribution from the remaining resonant-event background is taken into account as a systematic uncertainty.

### Fit algorithm

In order to extract the values of the angular parameters and the signal and background yield, a simultaneous unbinned maximum likelihood fit to the $B^0$ reconstructed mass, to the $\cos\theta_K$ and to the $\cos\theta_q$ distributions is performed for each $q^2$ bin.

The $p.d.f.$ used to fit the data is

$$
\text{PDF}(m, \theta_K, \theta_q) = \gamma_S^C \left[ S^C(m)S^K(\theta_K, \theta_q)e^K(\theta_K, \theta_q) \right] + \gamma_M \frac{f^M}{1 - f^M} S^M(m)S^K(-\theta_K, -\theta_q)e^K(-\theta_K, -\theta_q) + \gamma_B \frac{B(m)B^K(\theta_K, \theta_q)}{B^K(\theta_q)}
$$

where the first contribution corresponds to the correctly-tagged signal events, the second one to the wrongly-tagged signal events, where the pion track and the kaon track are misidentified, and the third contribution correspond to background events.

The parameters $\gamma_S^C$ and $\gamma_B$ are the yields of correctly tagged signal events and background events, respectively, and are free parameters in the fit. The parameter $f^M$ is the fraction of signal events that are mistagged and is determined from MC simulation. The signal mass probability functions $S^C(m)$ and $S^M(m)$ are each the sum of two Gaussian functions and describe the mass distribution for correctly tagged and mistagged signal events, respectively. In the fit, there is one free parameter for the mass value in both signal functions, while the other parameters (four Gaussian $\sigma$ parameters and two fractions relating the contribution of each Gaussian) are obtained from MC simulation. The function $S^K(\theta_K, \theta_q)$ describes the signal in the two-dimensional space of the angular observables and corresponds to Eq. 1. The combination $\gamma_B \frac{B(m)B^K(\theta_K, \theta_q)}{B^K(\theta_q)}$ is obtained from $B^0$ sideband data and describes the background in the space of $(m, \theta_K, \theta_q)$, where the mass distribution is an exponential function and the angular distributions are polynomials ranging from second to fourth degree, depending on the $q^2$ bin and the angular variable. The functions
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Results

The fit results are plotted in figure 1 and compared with the SM expectations [3, 4]. Controlled theoretical predictions are not available near the resonance regions.

The results are also combined with those obtained from the analysis on the data collected at $\sqrt{s} = 7$ TeV [5]. This combination is compared with the results from previous measurements [6, 7, 8, 9, 10] in figure 2.

Conclusions

The angular analysis of the $B^0 \to K^* \mu^\pm \mu^\mp$ decay has been presented. The measured values of $A_{FB}$, $F_L$ and of the differential branching fraction $dB/dq^2$ are compatible with the SM predictions. Since the experimental uncertainty is dominated by the statistical error, a great precision improvement is expected repeating this analysis with more statistics. A recent LHCb measurement [11] shows a discrepancy with the expectations and this raises great interest in this analysis.

$\epsilon_C(\theta_K, \theta_l)$ and $\epsilon_M(\theta_K, \theta_l)$ are the efficiencies in the 2D space of the angular observables for correctly tagged and mistagged signal events, respectively.

FIGURE 1. Results of the measurement of $F_L$ (top left), $A_{FB}$ (top right) and $dB/dq^2$ (bottom) versus $q^2$. The statistical uncertainty is shown by inner error bars, while the outer error bars give the total uncertainty. The vertical shaded regions correspond to the $J/\psi$ and $\psi'$ resonances. The other shaded regions show the SM prediction as a continuous distribution and after rate-averaging across the $q^2$ bins (SM) to allow direct comparison to the data points.
FIGURE 2. Results of the measurement of $F_L$ (top left), $A_{FB}$ (top right) and $d\beta/dq^2$ (bottom) versus $q^2$. Only the total uncertainty is shown. The vertical shaded regions correspond to the $J/\psi$ and $\psi'$ resonances.

REFERENCES