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Angular analysis of the $B_d^0 \to K^* \mu\mu$ at CMS and ATLAS

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Summary. — New Physics (NP) beyond the Standard Model (SM) can be revealed by analysing processes which are expected to occur with very low probability in the SM; among these, the flavour-changing neutral current (FCNC) decay $B_d^0 \to K^{*0}\mu^+\mu^-$ is particularly promising. Recent results from the LHCb Collaboration show that the expected values of the parameter P_5' differ by more than three standard deviations from the measurements in a well-defined interval of the dimuon invariant mass. The results of angular analyses performed by the ATLAS and CMS experiments at the LHC are here presented and compared with other experiments and several theoretical predictions.

1. – Introduction

$b \to sl^+l^-$ transitions are suppressed in the Standard Model (SM) and then very sensible to New Physics (NP) processes. These decays are forbidden at the lowest perturbative order and proceed through loops involving electroweak penguin diagrams. Possible NP contributions can modify not only the branching ratios of the decays, but also the angular distributions of the particles in the final state. They can be parameterised into the SM Lagrangian using the effective field theory approach. This approach allows to describe any NP contribution simply using higher-dimension operators O_i and the energy scale Λ_{NP} where NP phenomena should appear. Any significant discrepancy would then be a hint of NP contributions.

One of the most interesting channels is $B_d^0 \to K^{*0}\mu^+\mu^-$, where only the $K^{*0} \to K^+\pi^-$ decay mode is considered. The full kinematic of the decay can be described by three angles (θ_K, θ_L and ϕ) and the invariant mass squared q^2 of the two muons in the final state. The measurement of the differential decay rate as a function of q^2 and the three angles allows to extract specific parameters called P_i' (referred to in the following as optimised observables since they are independent, at the first order, of the form factors involved in the calculation) which can be directly related to the presence of NP phenomena. In the following, the measurements performed by the ATLAS and CMS Collaborations are presented.

2. – ATLAS and CMS results

The angular analysis has been performed by the ATLAS Collaboration [1] using the full dataset collected at $\sqrt{s} = 8\,\text{TeV}$ corresponding to an integrated luminosity of $20.3\,\text{fb}^{-1}$. The final state is made of two oppositely charged muons ($p_T > 3.5\,\text{GeV}$ and $|\eta| < 2.5$) and two tracks ($p_T > 0.5\,\text{GeV}$ and $|\eta| < 2.5$). The B_d^0 candidate is then reconstructed requiring a common vertex for the two muons and the two tracks and applying some quality cut to reject the combinatorial background. Two invariant mass windows are chosen around the K^{*0} and the B_d^0 candidates (846–946 MeV and 5150–5700 MeV, respectively) imposing that the two tracks are the kaon and the pion coming from the K^{*0} decay. A combination of several triggers based on one, two and three muons has been used to select the events. The efficiencies are calculated using polynomial functions to model the angular distributions of the signal in the three angles.

The signal yield and the parameters of interest (among them the P_i' parameters) are extracted using a two-steps fit procedure. First, an extended unbinned maximum likelihood fit on the $\mu\mu K\pi$ invariant mass is performed to extract the mass and the resolution on the mass of the B_d^0 candidate. Events with an invariant mass of the two muons and one track being close to D^* and B^+ masses are vetoed in order to reduce the contamination of the partially reconstructed decays. The fit on the signal has been validated using the resonant $B_d^0 \to J/\Psi K^{*0}$ and $B_d^0 \to \Psi(2S)K^{*0}$ decays. The second step is a fit on the distributions of $\cos\theta_k$, $\cos\theta_L$ and ϕ to extract the angular parameters as a function of q^2. Only the range in q^2 between 0.04 and $6\,\text{GeV}^2$ is considered.

Since the size of the sample is not sufficient to extract with reasonable precision all the parameters entering in the decay amplitude, a folding procedure, based on the (a)symmetry of the trigonometric functions, is applied in order to reduce the number of parameters extracted by the fit. F_L, P_1 and $P_{4,5,6,8}$ are the parameters extracted. The main systematic uncertainties on the measurement come from the background angular variables modelling and the partially reconstructed decays peaking in $\cos\theta_k$ and $\cos\theta_L$.

The same measurement has been performed by the CMS Collaboration based on

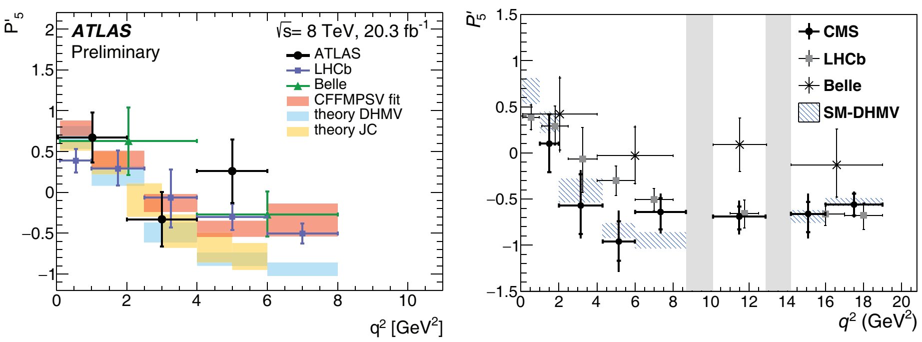

Fig. 1. – The measured values of P_5' as a function of q^2 made by ATLAS (left) and CMS (right). Both are compared with predictions from the theoretical calculations described in [1,3] and with results from LHCb [4] and Belle [5] Collaborations (in the left plot, Belle results are obtained combining electron and muon channels, while in the right plot, only the muon channel was used). Statistical and total uncertainties are shown for the data, *i.e.*, the inner mark indicates the statistical uncertainty and the total error bar the total shows the uncertainty including systematic ones.

proton-proton collisions at centre-of-mass energy $\sqrt{(s)} = 8\,\mathrm{TeV}$ corresponding to an integrated luminosity of $20.5\,\mathrm{fb}^{-1}$. The online event selection requires two muons with $p_T > 3.5\,\mathrm{GeV}$, forming a dimuon system with $p_T > 6.9\,\mathrm{GeV}$ and with vertex quality cuts. Offline selection cuts are applied to identify two tracks composing the K^* system, selected with $p_T > 0.8\,\mathrm{GeV}$ and forming a common vertex with the two muons. The mass assignment to the two tracks and the CP-state of the K^{*0} system is determined choosing the combination with a K^{*0} candidate mass closer to the PDG mass. About 13% of events have a wrongly assigned CP-state. The B_d^0 candidates must have $p_T > 8\,\mathrm{GeV}$ and $|\eta| < 2.2$. Similarly to ATLAS, a folding procedure is applied and the set of angular parameters is reduced to F_L, P_1 and P_5' for the P-wave component, and F_S, A_S, A_s^5 for the S-wave and interference components. Out of these 6 parameters, F_L, F_S, and A_S have been taken from a previous CMS analysis [2] based on the same dataset and selection cuts, while P_1 and P_5' are measured, and A_s^5 treated as a nuisance parameter.

The fit PDF is a function of the three angular parameters and the B_d^0 mass, and has two signal components, for correct and wrong CP-state events, respectively, and a background component. The efficiency of the selections and detector acceptance is described by a 3D kernel density estimator function measured on a Monte Carlo (MC) sample. This efficiency function multiplies the signal component of the PDF. The fit is performed in two steps: a first fit is performed on the data mass sidebands, using the background component of the PDF only, to extract the parameters of the background, and a second fit is performed on the full mass range, using the full PDF, to extract the parameters of the signal components. Several validation steps are used to test the fit procedure, on high-statistics MC, on data-like statistics MC and on data resonant control regions. Statistical uncertainties are determined with the Feldman-Cousins method. Systematic uncertainties are introduced to take into account any possible source of fit bias, and any effect introduced by the efficiency description. Figure 1 shows the value of one of the optimised variables, P_5', as a function of q^2 measured by ATLAS (left) and CMS (right) in comparison with the SM prediction and the measurements made by LHCb [4] and Belle [5] Collaborations. For both experiments, all P_i' parameters are compatible with the SM predictions and the measurements performed by the other experiments.

3. – Conclusions

The results of the angular analysis of the $B_d^0 \to K^{*0}\mu^+\mu^-$ decay from the ATLAS and CMS Collaborations are presented in this report. The values of the measured angular parameters, as a function of the dimuon-system invariant mass, are compared with several theoretical predictions and no significant deviation was found. The measurements are still dominated by the statistical uncertainty. The precision will be improved for both experiments with Run 2 data.

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