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New Physics searches with Heavy Flavour observables at ATLAS

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New and recent results from the programme of studies in electroweak physics with open beauty performed by the ATLAS experiment [1] are presented. Flavour-Changing-Neutral-Current (FCNC) processes are sensitive to New Physics contributions, in particular through additional electroweak loop amplitudes. The angular analysis of the decay of $B_d \to K^* \mu\mu$ for a number of angular coefficients are measured as a function of the invariant mass squared of the di-muon system for data collected by the ATLAS experiment at a centre-of-mass energy $\sqrt{s}$ = 8 TeV. A comparison is made to theoretical predictions, including for the observable P_5', for which there has been recent tension between theory and experiments.

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1. Introduction

The $b \to sl^+l^-$ 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. Contrary to $B^0_{(s)} \to \mu\mu$ decays, the $b \to sl^+l^-$ transitions do not have any helicity suppression. This means that 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. Possible contributions from NP processes 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. The total lagrangian L, which includes NP contributions, can then be written as:

$$L = L_{SM} + \sum_i c_i \frac{O_i}{\Lambda^2_{NP}} \tag{1.1}$$

where L_{SM} represents the SM lagrangian and c_i are complex coefficients (called Wilson coefficients) related to the strength of the interaction. In the SM all c_i coefficients are zero. Any significant discrepancy would then be a hint of NP contributions.
Several decay topologies involving mesons and baryons that contain b-quark belong to this category. One of the most interesting channels is $B_d \to K^{*0}\mu^+\mu^-$, where only the $K^{*0} \to K^+\pi^-$ decay mode is considered. The SM predicts a branching ratio of $\approx 4.5 \times 10^{-7}$, and the full kinematic of the decay can be described by three angles (θ_L, θ_k and ϕ) and the invariant mass squared q^2 of the two muons in the final state. The differential decay rate is then described as a function of the three angles mentioned above and q^2, as shown in Equation 1.2

$$\begin{aligned}\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_L \mathrm{d}\cos\theta_K \mathrm{d}\phi \mathrm{d}q^2} = \frac{9}{32\pi}\Bigg[& \frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_L \\ & -F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi \\ & +S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi \\ & +S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi \\ & +S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Bigg].\end{aligned} \tag{1.2}$$

Here F_L is the fraction of longitudinally polarised K^* mesons and the S_i are angular coefficients. These angular parameters are functions of the real and imaginary parts of the transversity amplitudes of B_d decays into $K^*\mu^+\mu^-$.

The measurement of the differential decay rate as a function of q^2 and the three angles introduced above, allows to extract F_L and S_i parameters and to use them to compute the so-called optimised observables $P_{1,2,3}$ and P'_i ($i = 4,5,6,8$). The advantage of using these variables is that they are independent, at the first order, from the form-factors involved in the calculation [2], that are the main source of theoretical uncertainties in the computation. It is then possible to directly relate the values of the optimised observables to the Wilson coefficients c_i in Equation 1.1.

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The most complete analysis has been performed by the LHCb Collaboration [3], where the branching ratio and the three angles have been measured simultaneously and the full set of parameters extracted. Also the CMS Collaboration performed a similar measurement [4, 5], but only a subset of the parameters describing the differential decay amplitude has been extracted (namely 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).

2. ATLAS results

The angular analysis performed by the ATLAS Collaboration [6] used the full dataset collected at $\sqrt{s} = 8$ TeV corresponding to an integrated luminosity of 20.3 fb^{-1}. The final state is made of two oppositely charged muons ($p_T > 3.5$ GeV and $|\eta| < 2.5$) and two tracks ($p_T > 0.5$ 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. A cut on the fitted vertex to have a $\chi^2/n.d.f. < 2$ is applied in order to reject the combinatorial background. Two invariant mass windows are chosen around the K^{*0} and the B_d^0 candidate (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 have 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 invariant mass shape for the signal is modelled with a double Gaussian and the background with an exponential function for the combinatorial background (i.e. random combinations of muons and tracks passing the selection criteria) and double or triple Gaussian distributions for 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 as shown in Figure 1 (left). 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 GeV^2 is considered. The distribution of the invariant mass of the $K\pi\mu\mu$ system in the whole q^2 range is shown in Figure 1 (right).

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 $P_{4,5,6,8}'$ (once at a time) are finally 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 $cos\theta_L$. Figure 2 shows the value of two of the optimised variable, P_4' (left) and P_5' (right), 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 [3] and Belle [7] collaborations.

With the exception of the P_4' and P_5' measurements in $q^2 \in$[4.0, 6.0] GeV^2 and in $q^2 \in$[2.0, 4.0] GeV^2 respectively, there is good agreement between theory and measurement. The deviation, relative to SM calculations, observed for P_4' and P_5' is consistent with the deviation reported by the LHCb

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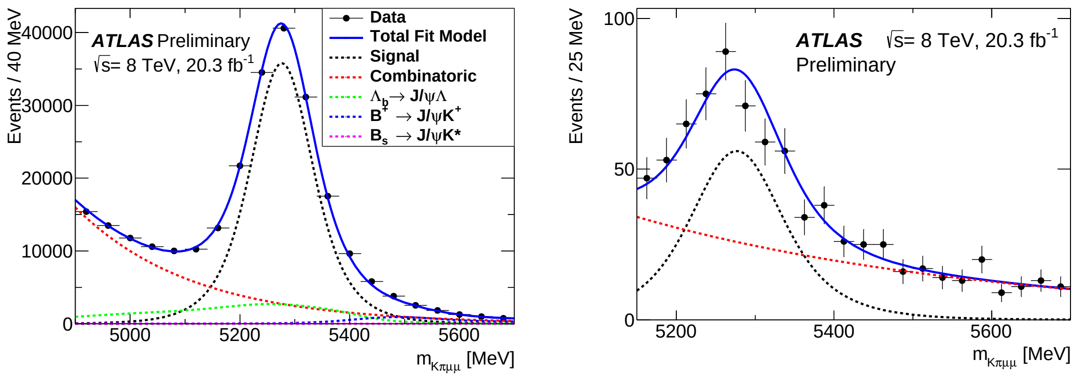

Figure 1: (Left) Control sample fits to the $K\pi\mu\mu$ invariant mass distributions for the K^*J/Ψ region. The data are shown as points and the total fit model as the solid lines. The dashed lines represent (black) signal, (red) combinatorial background, (green) Λ_b background, (blue) B^+ background and (magenta) B_s^0 background. (Right) The distribution of $m_{K\pi\mu\mu}$ obtained for $q^2 \in [0.04, 6.0]$ GeV. The (blue) solid line is a projection of the total p.d.f., the (red) dashed line represents the background, and the (black) dashed line represents the signal component. These plots are obtained from a fit using the folding scheme described in the text.

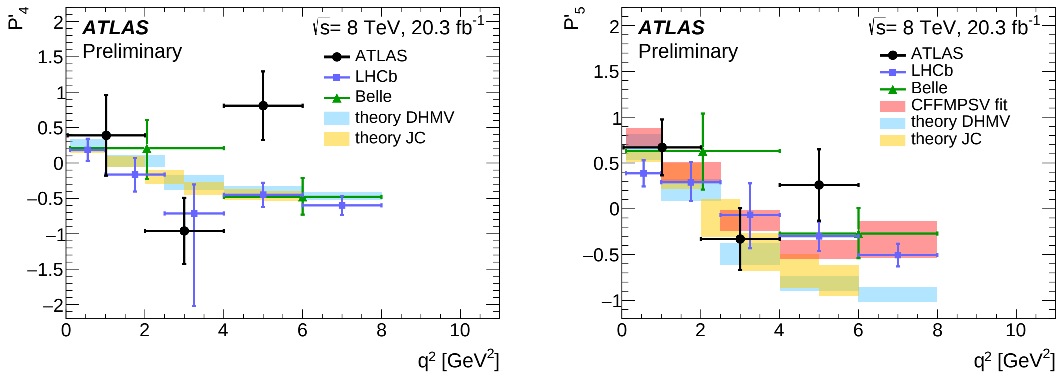

Figure 2: The measured values of P_4' (left) and P_5' (right) as a function of q^2 compared with predictions from the theoretical calculations described in [2, 8, 9] and with results from LHCb [3] and Belle [7] collaborations. In both plots, statistical and total uncertainties are shown for the data, i.e. the inner mark indicates the statistical uncertainty and the total error bar the total uncertainty including systematic ones.

Collaboration [3] and it is approximately 2.5 (2.7) standard deviations away from the calculation of DHMV [2]. The deviations are less significant for the other calculation and the fit approach. All measurements are found to be within three standard deviations of the range covered by the different predictions. Hence, including experimental and theoretical uncertainties, the measurements presented here are found to be in accordance with the expectations of the SM contributions to this decay

3. Conclusions

The results of the angular analysis of the $B_d^0 \to K^{*0}\mu^+\mu^-$ decay obtained by the ATLAS Collaboration are presented in this report. The values of the measured angular parameters, as a function of the di-muon system invariant mass q^2, are compared with several theoretical predictions and other experiments. No significant deviations above the level of three standard deviations with respect to the theoretical predictions were found. The measurements are still dominated by the statistical uncertainty.

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