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Flavour anomaly updates from ATLAS and CMS

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The latest results on flavour anomaly from ATLAS and CMS are here presented. Four recent studies are discussed: the first CMS search for the $\tau \to 3\mu$ decay, the CMS angular analysis of the $B^+ \to K^+\mu^+\mu^-$ decay, and the $B^0 \to K^{*0}\mu^+\mu^-$ angular analyses by ATLAS and CMS, with respective HL–LHC projections. This last study is of particular interest, due to indications of discrepancy with respect to the Standard Model from previous measurements by LHCb and Belle. All results presented in these proceedings are in agreement with the Standard Model.

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1. Introduction

Lepton flavour universality (LFU) is a fundamental prediction of the Standard Model (SM). In models beyond the SM LFU can be violated by New Physics (NP) particles that couple differently to the various generations of leptons. In the last few years, hints of lepton universality violation have been observed in both tree–level and loop–level transitions, stimulating further studies from the experimental community.

The latest results on flavour anomaly from ATLAS and CMS are here presented. Section 2 presents the first CMS search for the $\tau \to 3\mu$ decays using τ leptons produced in D and B mesons. Section 3 describes the CMS angular analysis of the processes $B^+ \to K^+\mu^+\mu^-$. Section 4 at last presents the $B^0 \to K^{*0}\mu^+\mu^-$ angular analyses by ATLAS and CMS and the respective projections for HL–LHC.

2. Search for $\tau \to 3\mu$ with CMS

The decay of the tau lepton in three muons is a very rare Charged Lepton Flavour Violating decay allowed in the Standard Model by neutrino oscillation with a predicted branching faction of $\mathscr{B} \sim 10^{-14}$ [1], way smaller than experimentally accessible values. Many New Physics scenarios predict branching ratio enhancement up to the current experimental sensitivity of $\mathscr{B} \sim 10^{-8}$ [2]. This decay, with its clean three–muons final state, is experimentally very appealing. As today no statistically significant signal has been observed by BaBar [3], LHCb [4], ATLAS [5], and Belle [6], which set the most stringent limit at $\mathscr{B} < 2.1 \cdot 10^{-8}$ (90% CL). CMS recently presented in a preliminary result [7] its first search for the $\tau \to 3\mu$ decay using τ from D and B decays. The collaboration used pp collisions at $\sqrt{s} = 8$ TeV collected in 2016, corresponding to $\mathscr{L}_{\text{int}} = 33$ fb^{-1}.

Trimuons candidates are selected with a High Level Trigger that requires two muons plus one charged track with invariant mass in the range 1.60–2.02 GeV^2 and displacement from the beam spot by at least two standard deviations. The two muons candidates are required $p_T^{\mu_1,\mu_2} > 3.0$ GeV, while the charged track $p_T^{\mu_3} > 2.0$ GeV. The sum of charges of three muons must be ± 1. Events are then further selected offline requiring $\Delta R_{\eta,\phi} < 0.8$ and $|\Delta z| < 0.5$ cm for all muons pairs. A total of $1.0 \cdot 10^5$ trimuon candidates are selected in this way, assuming $\mathscr{B}(\tau \to 3\mu) = 10^{-7}$ the expected number of signal events is 64 (29) for $D \to \tau X$ ($B \to \tau X$). To separate signal from background a Boosted Decision Tree is trained with signal events from Monte Carlo simulations and background events from data sidebands.

Events are then classified in six mutually exclusive categories. First three categories are defined based on the trimuon mass resolution, as shown in Fig. 1, then two sub–categories are defined based on the BDT score, as shown in Fig. 2.

The signal yield is predicted by measuring the rate of $D_s \to \phi\pi \to \mu\mu\pi$ events, which are selected with the exact same trigger and event selection criteria (with the pion treated as if it were a third muon). The combined search for a peak at $m(3\mu) = m(\tau)$ is performed fitting simultaneously on the six categories. The plot shown in Fig. 3 combines all six mass distributions. No significant event excess is observed in the signal region and upper limits on $\mathscr{B}(\tau \to 3\mu)$ are therefore set. The observed combined upper limit at 90% CL is $8.8 \cdot 10^{-8}$, while the expected limit is $9.9 \cdot 10^{-8}$.

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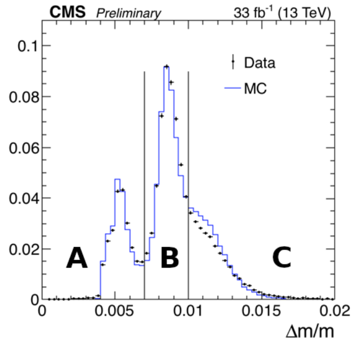

Figure 1: Trimuon mass resolution categories.

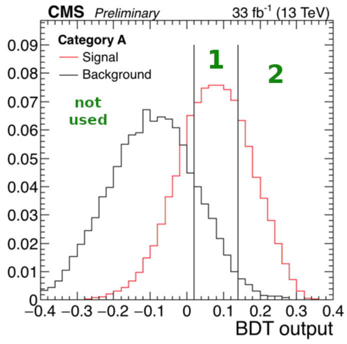

Figure 2: BDT score sub–categories.

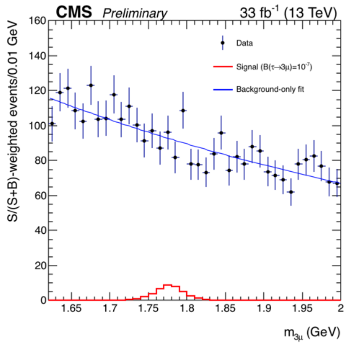

Figure 3: Final trimuon mass distribution. The expected signal for $\mathscr{B}(\tau \to 3\mu) = 10^{-7}$ is shown with a red line.

3. $\mathbf{B^+ \to K^+\mu^+\mu^-}$ angular analysis with CMS

The $B^+ \to K^+\mu^+\mu^-$ decay is a $b \to s\ell\ell$ Flavour Changing Neutral Current (FCNC) process, forbidden at tree level, mediated by electroweak loop and box diagrams. These amplitudes may interfere with non–SM contributions, altering the angular distribution of the final state. Angular analyses of this process have been previously performed by BaBar [8], Belle [9], CDF [10], and LHCb [11]-[12], no hints of beyond SM physics have been observed in any of these results.

CMS has studied the angular distribution of $B^+ \to K^+\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 8$ TeV, for a total integrated luminosity of $\mathscr{L}_{\text{int}} = 20.5$ fb^{-1} [13]. The $\mu^+\mu^-$ forward–backward asymmetry A_{AB}, and the parameter F_{H}, a measure of the contribution from (pseudo)scalar and tensor amplitude, have been measured in $q^2_{\mu\mu}$ bins in the range 1.0–22.0 GeV^2.

Events are selected with a displaced low–mass dimuon HLT. Muons are required $p_T^{\mu} > 3.5$ GeV, $|\eta^{\mu}| < 2.2$, $p_T^{\mu\mu} > 6.9$ GeV, $1.0 < m(\mu\mu) < 4.8$ GeV^2, while the kaon is required $p_T^{K^+} > 1.3$ GeV and $\text{DCA}_{xy}^{K^+}/\sigma_{\text{DCA}} > 3.3$. A displacement requirement of $L/\sigma_L > 10.6$ is also required. The differential decay rate $d\Gamma/d\cos\theta_\ell$ is parametrized as a function of $\cos\theta_\ell$, A_{FB} and F_{H}:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}(1-F_{\text{H}})(1-\cos^2\theta_\ell) + \frac{1}{2}F_{\text{H}} + A_{\text{FB}}\cos\theta_\ell \tag{3.1}$$

where θ_ℓ is the angle between the μ^- and the K^+ in the dimuon rest frame.

The final fit is performed over the full invariant mass range, resulting in 2286 ± 73 signal events. The A_{AB} and F_{H} measurement in the various $q^2_{\mu\mu}$ is reported in Fig. 4. The results are in good agreement with both the Standard Model prediction and previous measurements.

4. Status and prospective of $\mathbf{B^0 \to K^{*0}\mu^+\mu^-}$ angular analysis by ATLAS and CMS

$B^0 \to K^{*0}\mu^+\mu^-$ is described within the SM as a FCNC $b \to s\ell\ell$ process, where New Physics contributions can change the angular distribution. This process has become of particular interest after both LHCb [18] and Belle [19] saw a $\sim 3\,\sigma$ discrepancy from the SM prediction [20]-[21] on the P_5' observable at $q^2_{\mu\mu} \sim 6$ GeV^2. $P_5' = S_5/\sqrt{F_L(1-F_L)}$ is one of several angular parameters

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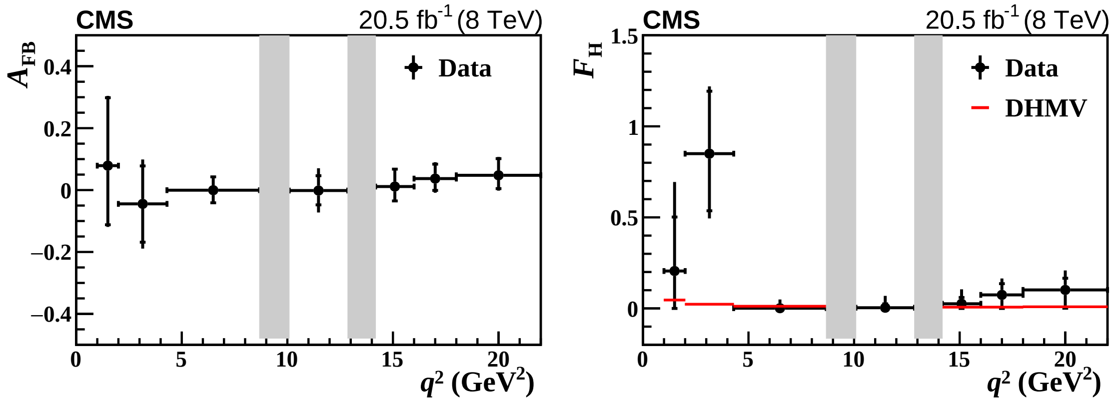

Figure 4: Results of the A_{AB} (left) and F_H (right) measurement in ranges of $q^2_{\mu\mu}$. The red lines show the DHMV Standard Model theoretical prediction [14]-[15].

in the LHCb parameterization, for which precise theoretical predictions are available for several $q^2_{\mu\mu}$ bins. Both ATLAS [16] and CMS [17] used their 8 TeV datasets to measure (among others) P'_5. CMS has extended a previous analysis [22] where it already measured the FB asymmetry of the muons A_{FB}, the K^{*0} longitudinal polarisation fraction F_L, the S–wave fraction A_S and the S/P–wave interference parameter F_S. In this new analysis CMS has measured P_1 and P'_5 in the $q^2_{\mu\mu}$ range 1.0–19.0 GeV^2 (with a veto on the J/ψ and ψ' resonances). ATLAS instead has performed its first measurement of the parameters P_1, P'_4, P'_5, P'_6 and P'_8 in the $q^2_{\mu\mu}$ range 1.0–6.0 GeV^2.

The event selection follows the same strategy for both experiment. Events are selected online with dedicated low–mass dimuon triggers and offline with kinematic requirements on the dimuon pair and charged tracks. B^0 candidates are selected with a lifetime cut of $L/\sigma_L > 12$ and several invariant mass constrains. The two CP–states $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$ and $\overline{B^0} \to \overline{K^{*0}}(\to K^-\pi^+)\mu^+\mu^-$ are distinguished assigning both mass hypotheses to the K^{*0} and choosing the closest to the PDG value. This technique leads to a mistag rate of $\sim 10\%$ for ATLAS and $\sim 14\%$ for CMS.

The signal yield amounts to a total of 348 candidates for ATLAS and 1397 for CMS. Since these yields are not large enough to fit the whole decay rate model, the decay rate is “folded” around certain angle values exploiting the odd symmetry of trigonometric functions (e.g. for P_1 and P'_5 the folding is around around $\phi = 0$ and $\theta_\ell = \pi/2$).

The ATLAS and CMS measurements of P'_5, alongside with existing measurements and the Standard Model theoretical prediction, are shown in Fig. 5. Both results are in excellent agreement with the SM, with the largest discrepancy being $\sim 2\sigma$ around $q^2_{\mu\mu} = 5$ GeV^2 in the ATLAS result. Even if all the other parameters show no deviations from SM predictions, the picture of P'_5 around $q^2_{\mu\mu} = 4.0$–8.0 GeV^2 is still not clear. On this regard ATLAS, CMS and LHCb have all planned Run–2 and HL–LHC analyses of $B^0 \to K^{*0}\mu^+\mu^-$.

4.1 HL–LHC projections for $\mathbf{B^0 \to K^{*0}\mu^+\mu^-}$ angular analysis by ATLAS and CMS

For this analysis both ATLAS and CMS provided HL–LHC projection in the HL/HE–LHC Yellow Report [23]. ATLAS has provided projections of $F_L, P_1, P'_4, P'_5, P'_6, P'_8$ for $\mathscr{L}_{INT} = 3000$ fb^{-1}. On P'_5 uncertainties are estimated to improve up to a factor $5 \sim 9$ with respect to Run–1, as shown in Fig. 6a, depending on the trigger scenario. CMS projected the measurement of P'_5 for

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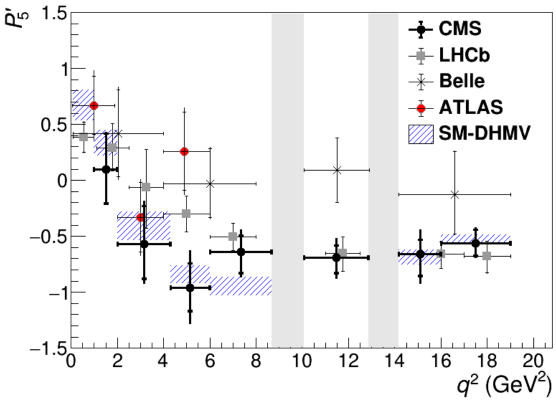
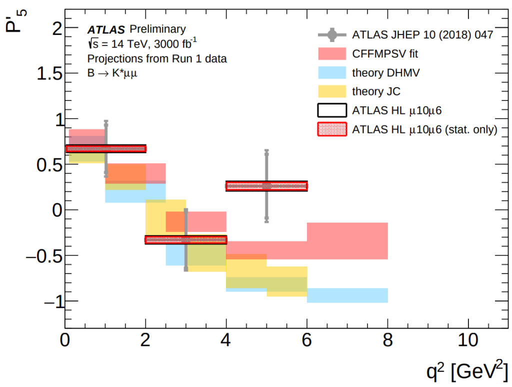
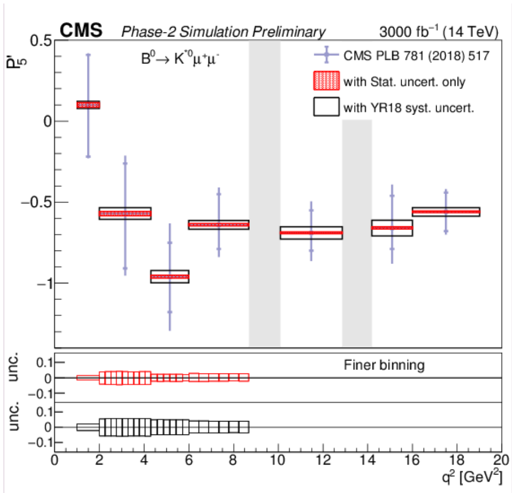


Figure 5: P_5' experimental state of the art and theory prediction.



(a) ATLAS projection.



(b) CMS projection. Lower pads represent the statistical (upper pad) and total (lower pad) uncertainties with the finer binning.

Figure 6: HL–LHC sensitivity projections for P_5'.

$\mathscr{L}_{\text{INT}} = 3000\ \text{fb}^{-1}$, quoting an improvement on the uncertainties up to a factor 15 with respect to Run–1, as shown in Fig. 6b. CMS has also highlighted the possibility to use finer $q^2_{\mu\mu}$ binning.

5. Summary

Four recent studies on flavour anomaly from ATLAS and CMS have been presented in these proceedings. First the first CMS search for the $\tau \to 3\mu$ decay, resulted in no excess observed and upper limits set at $\mathscr{B}(\tau \to 3\mu) < 8.8 \cdot 10^{-8}$ (90% CL). Second the CMS angular analysis of the $B^+ \to K^+\mu^+\mu^-$ decay, which measured the A_{FB} and F_{H} parameters. At last the $B^0 \to K^{*0}\mu^+\mu^-$ angular analyses by ATLAS and CMS have been presented, with respective HL–LHC projections. All results are in agreement with the Standard Model, albeit some tensions are observed by ATLAS in the P_5' parameter.

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