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Lesya Shchutska and Renato Quagliani, Institute of Physics, EPFL

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Since several years, a consistent pattern of possible deviations from the standard model of particle physics has been building up in studies of the *B* mesons decays involving leptons. One of the most striking measurement was done in flavour changing neutral current channels where the best theoretical precision is achieved, showing a 3.1 standard deviation discrepancy to the standard model and leading to a lot of debate in the scientific community and beyond. However, the latest measurement from the LHCb experiment, carried out with the data collected between 2011–2018 while employing new data analysis techniques, restore the lepton universality in these transitions. The important updates are also done in semileptonic B meson decays at LHCb and high-energy searches with tau leptons at CMS.

1 History behind

Precision measurements of rare processes in particle physics traditionally have been paving the road towards insights about the nature of the fundamental interactions and of the building blocks of matter. Several times in the history of scientific breakthroughs unexpected experimental results led to new theoretical proposals culminating in building the complete theory of the Standard Model of particle physics (SM). As of 10 years now, this theory is complete after the discovery of the Higgs boson by the ATLAS and CMS experiments at CERN, and there is no clear guidance where a new discovery in particle physics might come from.

In this context, a series of deviations from the theory in *B* meson decays has led to a lot of excitement in the particle physics community, as it could signify a beginning of the exploration of so sought for beyond the Standard Model physics, as discussed in detail in Ref. [1]. The picture is formed with several different measurements in the decays corresponding to a $b \to s\ell\ell$ transition, which is forbidden at the lowest-order level and can happen only via processes involving exchange of the heavy virtual particles. Thus the predicted properties of such a process could be easily modified by a presence of new, yet undiscovered, particles. The deviations are seen in the angular distributions and differential branching fractions of the decays corresponding to the $b \to s\mu^+\mu^-$ transition, which can be rather precisely measured experimentally, e.g. at the LHCb, but the theoretical predictions of which still have rather large uncertainties. Finally, the particular interest was gathered by the results of the measurement of the so-called *R* variable, which represents a normalized ratio of branching fractions $\mathcal{B}$ of the *B* meson decays to a final state with two muons and of these to two electrons:

$$R_X = \frac{\mathcal{B}(B\to X_s\mu^+\mu^-)}{\mathcal{B}(B\to X_s e^+e^-)} / \frac{\mathcal{B}(B\to X_s J/\psi_{\to\mu^+\mu^-})}{\mathcal{B}(B\to X_s J/\psi_{\to e^+e^-})}, \quad (1)$$

where X_s is one hadron carrying strangeness or a combination of hadrons. To achieve better experimental precision, an additional normalization factor known to be equal to 1, is added to the definition of the R_X variable. In the SM, this ratio is expected to be equal to 1 with high precision, thanks to the equal interaction strength between the force carriers and three families of matter particles, leptons in this case. This property is called *lepton universality*.

The reported patterns of anomalies included lower than expected branching fractions of the decays involving muons in the final state, and R_X for several possibilities of *X* lower than 1. Finally, the latest R_K value was measured to be below 1 by slightly more than 3 standard deviations, adding up with other decay modes going in the same direction.

2 New lepton universality test in $b \to s\ell^+\ell^-$

Recently, a new LHCb result with a simultaneous measurement of the R_K and R_{K^*} in two kinematical regimes each has been released [2, 3], accompanied by a dedicated CERN seminar. All four measurements are found to be close to 1 and compatible with the SM at the level of 0.2 standard deviations as shown in Fig. 1.

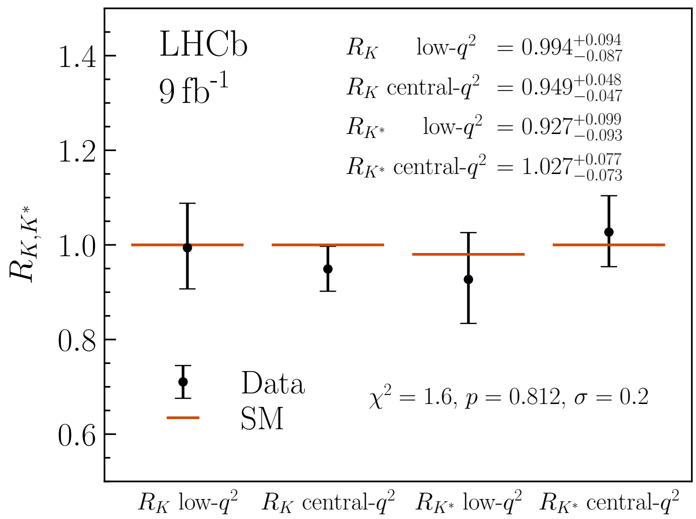

Figure 1: Measured R-values for $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}\ell^+\ell^-$ decays in two kinematical regimes each, ℓ represents e or μ. Adapted from [3].

The reason for such a qualitative change in the picture is a better understanding of the detector performance with measurement of the electrons. The new analysis employed new multivariate techniques for the electron identification in the detector, which led to realize that the contribution from misidentifying a hadron as an electron in this measurement could be important. In such cases, the abundant *B* decays, as e.g. $B \to K^+K^+K^-$ or $B \to K^+\pi^+\pi^-$ could mimic a rare signal mode of $B \to K^+e^+e^-$, and modify the measured rate of this process. A dedicated method has been developed in order to estimate the contribution of such processes with a result for the $B \to K^+e^+e^-$ decay mode shown in Fig. 2. Due to the peaking structure of this background, it has been contributing to enhance the measured yield in the electron mode, as is shown in Fig. 3. Similar contributions of such a background is found in other analyzed decay modes. After its

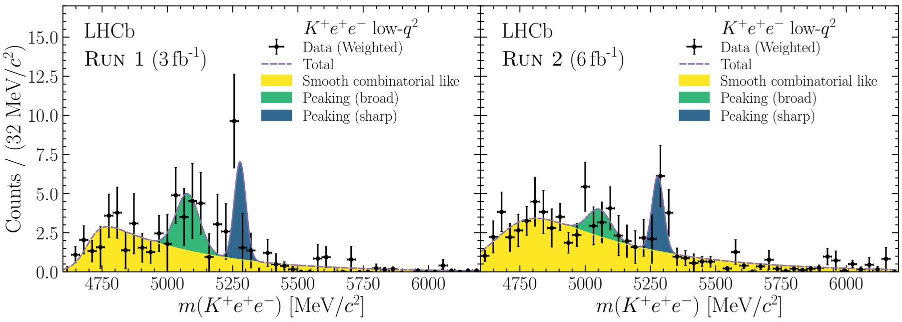

Figure 2: Estimated contribution of the background from processes where at least one hadron is misidentified as an electron in the $B^+ \to K^+e^+e^-$ decay mode. Adapted from [3].

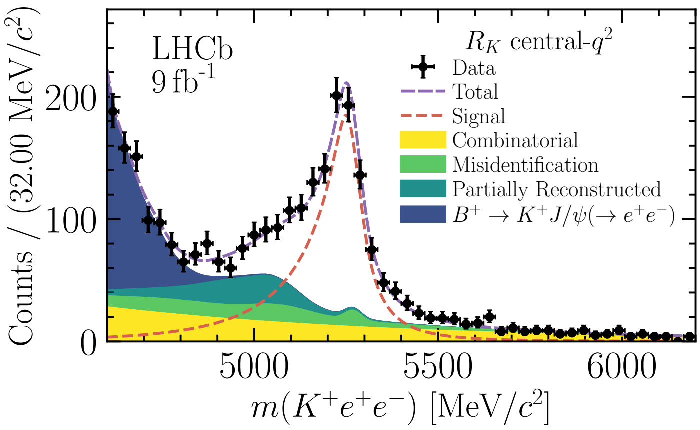

Figure 3: Mass distribution in the $B^+ \to K^+e^+e^-$ decay mode, with the results of the fit overlaid. Contributions of various backgrounds are shown as extracted from the fit. Adapted from [3].

inclusion to the fit model, the measured lepton universality comes back in line with the SM expectation.

Now, the LHCb detector is set up to collect one order of magnitude more data than previously, which would allow to push the lepton universality measurements to a new level of precision. It is not excluded that the effect is still there but not at the magnitude which was reported previously.

3 New measurements in semileptonic *B* decays

Another transition, challenging lepton universality, is a much more abundant $b \to c\ell\nu$ process, for which several experiments provided measurements of the ratios $R(D)$ and $R(D^*)$, defined as

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)} \text{ where } \ell = e \text{ or } \mu.$$

These measurements hint that there might be a difference in fundamental interactions of third generation of leptons, τ, and their lighter counterparts, electrons and muons. Recently, LHCb released a new combined measurement of $R(D)$ and $R(D^*)$ [4], which is shown together with previous results as well as with a new world average in Fig. 4. While the new individual measurements are compatible with the SM at the level of about 2 standard deviations (σ), the world average remains away from the theory prediction by more than 3.2 σ.

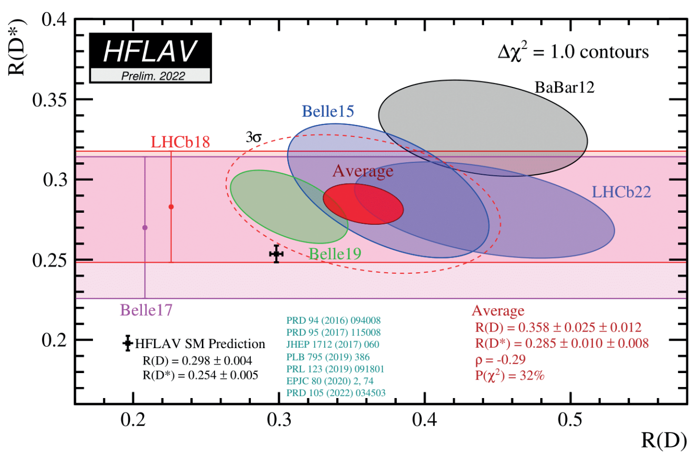

Figure 4: The world status of R(D) and R(D) measurements compiled by the HFLAV collaboration including the latest result from the LHCb collaboration marked as “LHCb22”.*

4 High-energy tau leptons

The flavor anomalies have stirred an interest to look for a direct production of particles which could lead to perceived different interaction strength of the three lepton families, with a specific interest to the third generation of fermions. Recently, CMS has released a preliminary result [5] based on the full available dataset, where the search for leptoquarks (LQ) coupling to a τ lepton and a b quark in different LQ production scenarios has been presented. In some LQ scenarios, an excess with a significance of 3.4 σ above the SM expectation is observed in the data, as shown in Fig. 5.

ATLAS collaboration has also performed a search for LQ in the final states with tau leptons and *b* jets [6], however the observed results are consistent with the expectations, and no excess is reported.

5 Future prospects

The large experiments at the LHC have restarted their data-taking, and are expecting to significantly increase the amount and quality of the dataset available for the analysis. While one piece of the puzzle has been resolved, and came

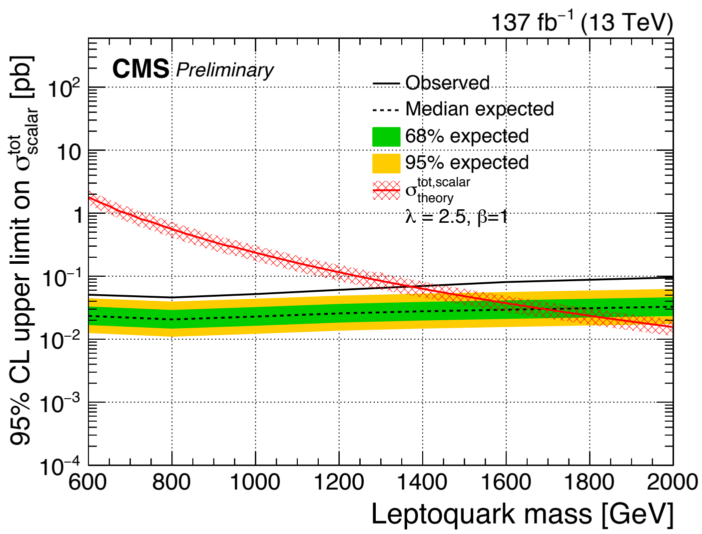

Figure 5: The observed and expected upper limit on the total cross section of a scalar LQ signal with λ = 2.5 at 95 % confidence level. The inner (green) band and the outer (yellow) band indicate the regions containing 68 and 95 %, respectively, of the distribution of limits expected under the background-only hypothesis. Adapted from [6].

back to the SM prediction, quite a few other measurements, such as differential branching fraction of exclusive $b \to s\ell\ell$ transitions, their angular distributions, as well as $R(D^{(*)})$ observables, require further studies, complemented with the direct searches for the new particles at the ATLAS and CMS experiments. Given the interest of the community to these measurements, we can expect new results with larger dataset in the near future.

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