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Precision study on R_D and R_K

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Summary. — We evaluate first the impact of τ leptonic decay on the distribution $\bar{B} \to D\mu\bar{\nu}_\mu$. This allowed us to suggest kinematical cuts to disentangle almost completely the effect of the τ decay. In the second part we discuss the radiative correction to the process $B \to K\ell^+\ell^-$. By mean of esplicit calculation we obtain this effect for different benchmark and we compare them with the choices made in the analysis for R_K.

1. – Motivation

Lepton Flavour Universality (LFU) is one of the strongest prediction of Standard Model (SM). It is based on the fact that the interaction between the gauge vectors and leptons is independent of the leptonic family itself.

A great interest arises in testing LFU. This can be done comparing processes which involve different family of leptons. The most known ratios which are used to do so are $R_{D^{(*)}}$ and $R_{K^{(*)}}$, defined as

$$R_{D^{(*)}} = \frac{\mathcal{B}(\bar{B} \to D\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\mu\bar{\nu}_\mu)}, \tag{1}$$

$$R_{K^{(*)}}[q^2_{\rm min}, q^2_{\rm max}] = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\Gamma(B^+\to K^+\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{\mathrm{d}\Gamma(B^+\to K^+e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}. \tag{2}$$

The former is a charged current transition which in the SM can happen at tree-level, while the latter is a neutral-current transition which can take place in the SM only at loop level due to the fact that neutral currents are flavour-diagonal also for quarks.

What is interesting is that in both types of transitions there are discrepancies between SM expectation and the experimental measures: this could be due to either the presence of New Physics or to some SM effects not correctly taken in account so far.

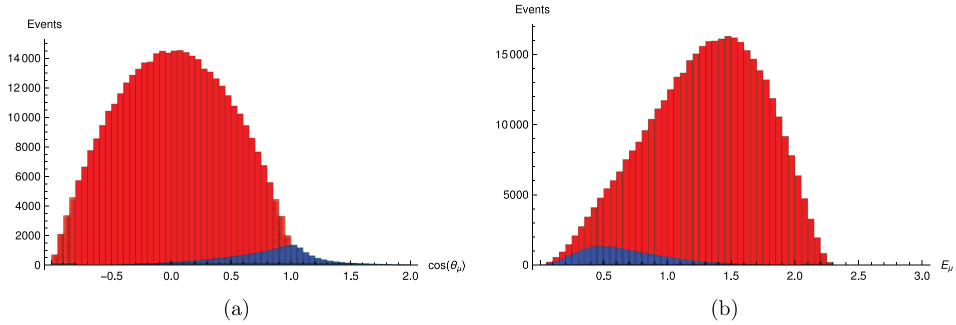

Fig. 1. – Histogram of $4 \cdot 10^5$ events. The red area represents the $1\nu + 3\nu$ events, while the blue area only the 3ν events.

In the following we focus on R_D and R_K: our approach is to perform for both of them an analytical calculation, within the SM, still not present in the literature, and analysing its effect on the present value of R_D and R_K.

2. – Impact of the leptonic τ decay on the distribution $\bar{B} \to D\mu\bar{\nu}_\mu$

According to the SM, the prediction for R_D is [1]: $R_D^{\rm SM} = 0.300 \pm 0.008$. On the experimental side there are two measurements of R_D performed by Babar [2] and Belle [3] collaboration; they are: $R_D^{\rm BaBar} = 0.440 \pm 0.058 \pm 0.042$ and $R_D^{\rm Belle} = 0.375 \pm 0.064 \pm 0.026$. The comparison between SM prediction and measures for R_D gives a discrepancy of $\sim 1.9\sigma$. In principle this difference is not so appealing, but it appears also when we substitute the D meson with the D^*. In fact in the latter case a discrepancy between SM prediction and the combined measures of R_{D^*} is of about $\sim 4\sigma$. From that we can conclude that all the processes based on the transition $b \to c\ell\bar{\nu}_\ell$ are interesting to be studied.

Our idea is to study the impact of τ leptonic decays to the distribution $\bar{B} \to D\mu\bar{\nu}_\mu$: in fact when the leptonic decay $\tau \to \mu\bar{\nu}_\mu\nu_\tau$ happens, the process $\bar{B} \to D\tau\bar{\nu}_\tau$ can be exchanged by experiments for $\bar{B} \to D\mu\bar{\nu}_\mu$.

What can immediately be noticed is that in $\bar{B} \to D\tau(\to \mu\bar{\nu}_\mu\nu_\tau)\bar{\nu}_\tau$ case there is a richer set of angular variables to study with respect to the $\bar{B} \to D\mu\bar{\nu}$ case. For our purpose we define the following two observables: θ_μ, the angle of the μ with the D, and E_μ, the energy of the μ in the $\bar{B}$ rest frame. We developed the analitycal calculation for the full differential decay width of the process and we implemented it in EOS [4] to get pseudo-events according to our calculation.

In fig. 1(a) we show the histogram of our events with respect to $\cos\theta_\mu$. What can be shown is that a cut at $\cos\theta_\mu \sim 1$ is not enough to disentangle completely the 1ν and the 3ν case. On the other hand, if we look at fig. 1(b) we can see that a cut at $E_\mu \sim 1\,\text{GeV}$ can be really useful: to be more quantitative this cut reduces the number of 3ν events by a factor of 6. Even more, from this distribution it is possible to develop a modelled PDF which can be used to subtract completely the 3ν background from the 1ν events [5].

3. – Radiative correction to the process $B \to K\ell^+\ell^-$

So far the ratio R_K has been measured only by LHCb collaboration. Their measurement reads [6] $R_K^{\rm LHCb} = 0.745^{+0.090}_{-0.074} \pm\ 0.036$, while within the SM the expectation is

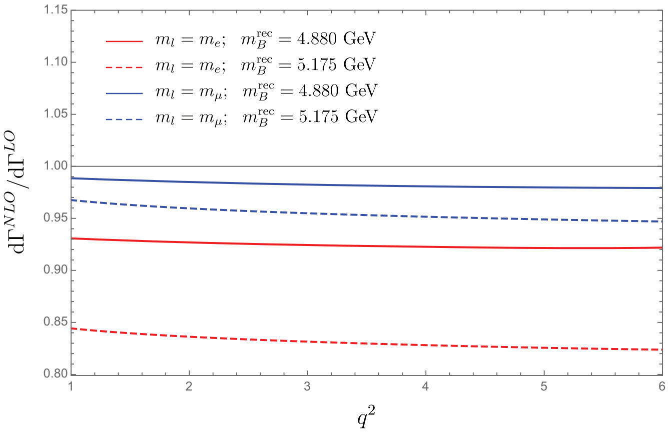

Fig. 2. – Relative impact of radiative correction in $B \to K\ell^+\ell^-$ for $q^2 \subset [1,6]\,\mathrm{GeV}^2$, for different values of m_l and different cuts on the reconstructed mass of the B meson, m_B^{rec}.

$R_K^{\mathrm{SM}} = 1$. This leads to a discrepancy of $\sim 2.6\sigma$, which is interesting to be investigated. In particular we want to study in details the impact of radiative correction to the process $B^+ \to K^+\ell^+\ell^-$.

From a theoretical point of view this calculation is very clean: we have to consider real emission of one photon from all the external particles. One of the first aspect of this process is that the emission from the mesons does not mix with the emission from the leptons: this allows us to treat them separately.

What we had to do to perform the calculation is regulating soft and collinear divergences. For doing this we introduce two regulators: the collinear divergence is regulated by m_l, the lepton mass itself, while the soft divergence can be related to the cut applied in the analysis on the reconstructed mass of the B meson, m_B^{rec}.

After performing the calculation we checked first that the tail of the J/Ψ peak does not affect the region $q^2 \subset [1,6]$ GeV^2, which is the one taken in account by the experiments. Then we also checked numerically that the emission from the mesonic leg is well below the 1% level, so it is subleading with respect to the emission from the lepton pair.

Our results are encoded in fig. 2: we can see that for specific benchmark the effect of radiative correction can be sizeble, due to interplay of m_l and m_B^{rec}. However, given the choice made in [6], we have that the effect for the electron and the muon case are less significative, leading to a shift in the central value of R_K of $\Delta R_K = 3\%$ [7]. The LHCb collaboration takes in account this effect using PHOTOS [8]: by explicit comparison we find that our effect for ΔR_K is in agreement with it to the 1% level of accuracy.

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