PROCEEDINGS OF SCIENCE

Lepton flavour universality in W boson decays

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The standard model (SM) predicts that the W boson decays equally to all three flavours of leptons, known as lepton flavour universality. Many studies have been performed to measure the rate at which the W boson decays to different flavors of leptons to test this accidental symmetry. Because of the high mass of the τ lepton, the measurement of the ratio between the branching fraction of W bosons in τ and μ channels is a good probe for physics beyond the SM. We report the results on lepton flavour universality from different experiments

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1. Introduction

There have been multiple studies probing the lepton flavour universality in W boson decays, with ATLAS studying the decay of on-shell W-bosons, while LHCb, Belle, and BaBar studying the same in B-meson decays through a virtual W-boson. The measurement of $R(D^{(*)}) = \mathcal{B}(B^0 \to D^*\tau^+\nu_\tau)/\mathcal{B}(B^0 \to D^*l^+\nu_l)$ by BaBar[6] in 2012 showed an excess of τ sparking interest in the topic. Since then, there have been several studies in LHCb[1] and Belle[2] and a detailed review [3] for the measurement of $R(D^{(*)})$ with further results available from ATLAS[4] on $R(\tau/\mu) = \mathcal{B}(W \to \tau\nu_\tau)/\mathcal{B}(W \to \mu\nu_\mu)$.

2. $R(\tau/\mu)$ measurement

The proton-proton (pp) collisions at the Large Hadron Collider (LHC) produce a large number of top and anti-top quark pair events ($t\bar{t}$). With the top quark almost exclusively decaying to an on-shell W boson and a bottom quark, the process provides a large sample of clean W bosons for the study of lepton flavour universality. ATLAS has conducted a study in the final state where both the W-bosons in $t\bar{t}$ events decay leptonically, referred to as di-leptonic $t\bar{t}$.

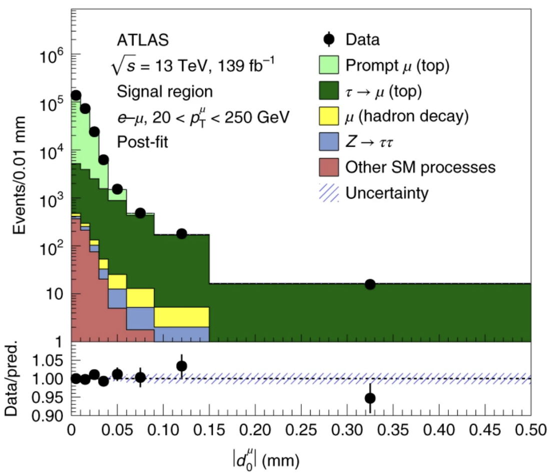

Figure 1: Transverse impact paramater distributions in the signal region for e-μ (left) and μ-μ (right) channels in one p_T bin [4],

The two charged leptons in the di-leptonic $t\bar{t}$ events are exploited in a tag and probe approach, where the tag lepton (electron or muon) is used to select the event and the probe lepton (muon) of opposite charge is used to perform the measurement. Selection criteria for the probe muon are chosen to avoid any bias between prompt or displaced muons. The normalization factors for the primary backgrounds, namely Drell-Yan and semi-leptonic $t\bar{t}$ events, are directly obtained from the data. A two-dimensional likelihood fit is performed using the transverse momentum p_T and transverse impact parameter d_0^μ distributions of the probe muon. The measured branching fraction for $\tau \to \mu\nu_\mu\nu_\tau$ [5] is used to extract $R(\tau/\mu)$. The value obtained for $R(\tau/\mu)$ is 0.992 ± 0.013, which is consistent with the SM expectation of unity.

3. $R(D^*)$ and $R(D)$ measurements

After the first measurement by BaBar[6] in 2012, Belle and LHCb have performed the measurement in multiple channels[1],[2]. Belle and BaBar exploit the $B\overline{B}$ pair production by operating at the $\Upsilon(4S)$ resonance, which almost exclusively decays into $B\overline{B}$. LHCb, on the other hand, is designed to study the B mesons produced at small angles to the beam line in pp collisons. BaBar has made the measurements in leptonically decaying τ channels, while LHCb and Belle have used both leptonically and hadronically decay channels in their measurements.

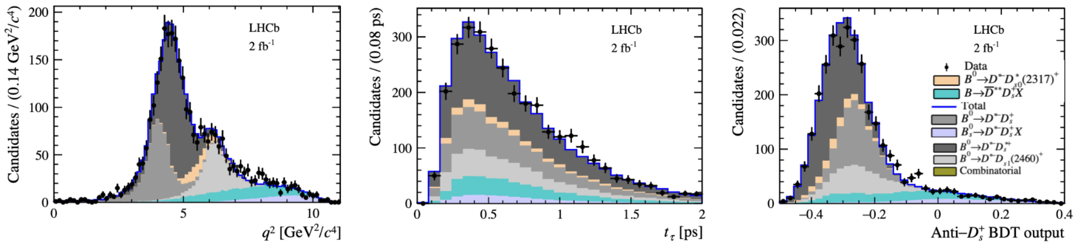

Figure 2: Distributions of q^2, decay time of the τ t_τ and anti-D_s BDT output at LHCb.

Belle and BaBar tag on a hadronically decaying B meson, with the D or D^* mesons produced in the leptonic decay of the second B meson. In contrast, LHCb exploits the displacement of B meson to select the events. Multidimensional likelihood fits are performed in squared missing mass $m^2_{miss} = (p(B^0) - p(D^*) - p(\mu))^2$, energy of charged lepton in the B rest frame and q^2 for leptonic, and hadronic τ at Belle2. Instead, distributions of q^2, decay time of the τ (t_τ) and a Boosted Decision Tree score suppressing D_s are used for the hadronic τ at LHCb. BaBar measured $R(D) = 0.440 \pm 0.058 \pm 0.042$ and $R(D^*) = 0.332 \pm 0.024 \pm 0.018$ that deviate from the SM by 3 standard deviations (σ). Belle measured $R(D) = 0.349 \pm 0.027 \pm 0.015$ and $R(D^*) = 0.298 \pm 0.011 \pm 0.007$; these are consistent with the SM prediction within 1σ. Lastly, the measurement by LHCb with hadronically decaying τ found $R(D^*) = 0.260 \pm 0.015 \pm 0.020$ in good agreement with the SM. The newer results are closer to, or in agreement with, the SM.

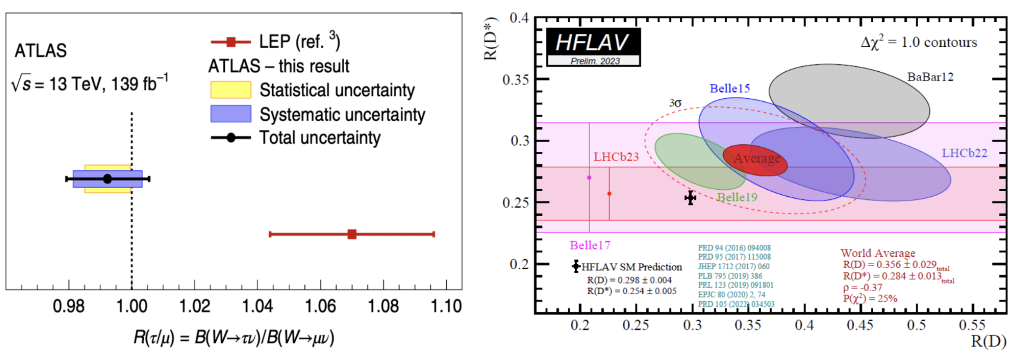

Figure 3: Results of $R(\tau/\mu)$ measurement from ATLAS and LEP [7] (left), and results of $R(D)$ and $R(D^*)$ measurements by LHCb, Belle and BaBar (right).

4. Conclusions

From Figure 3 we can see that the measurement by ATLAS for $R(\tau/\mu)$ shows a good agreement with SM expectation within uncertainty. In case of the $R(D^*)$ and $R(D)$ measurements, we find a discrepancy of about 2σ between the world average and SM value. It is also interesting to point out that the $R(D^*)$ result from LHCb in 2023[1] is consistent with the SM.

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