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HFAG 2016 and PDG 2016 τ lepton averages and $|V_{us}|$ determination from τ data

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Abstract

The HFAG-Tau sub-group has performed in 2016 two similar global fits on the τ lepton branching fractions measurements. One, unitarity constrained, has been published in the 2016 edition of the Review of Particle Physics [1] and a second one, without the unitarity constraint, is currently preliminary and is expected to be published soon on the HFAG 2016 report [2]. The resulting τ branching fractions are used to test the Standard Model lepton universality predictions and to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{us}|$.

Keywords: tau, lepton, lepton universality, lepton flavour violation, LFV, Vus, CKM

1. Introduction

We report in the following the preliminary results of the τ branching fraction fit prepared by the HFAG-Tau sub-group for the HFAG 2016 report. We also summarize the main differences between that fit and its unitarity constrained variant that has been included for the first time in the 2016 edition of the Review of particle physics [1]. Finally, we report elaborations of the preliminary HFAG 2016 results to test the Standard Model (SM) lepton universality and to compute the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{us}|$.

2. Branching fractions fits

A global fit of the available experimental measurements is used to determine the τ branching fractions, together with their uncertainties and statistical correlations. The measurements used in the fit consist of either τ decay mode branching fractions, labelled as Γ_i, or ratios of two τ decay mode branching fractions, labelled as Γ_i/Γ_j. A minimum χ^2 fit is performed for all the measured quantities. Some fitted quantities are constrained to be equal to the ratio of two other fitted quantities, as implicit in the notation just mentioned above, and some fitted quantities are constrained to be the sum of other fitted quantities, for instance $\Gamma_8 = B(\tau \to h^- \nu_\tau)$ is the sum of $\Gamma_9 = B(\tau \to \pi^- \nu_\tau)$ and $\Gamma_{10} = B(\tau \to K^- \nu_\tau)$. The symbol h is used to mean either a π or K. The fit χ^2 is minimized subject to all these above mentioned constraints for the HFAG 2016 version of the fit. An additional unitarity constraint is used for the PDG 2016 version of the fit, which requires that the sum of all non-overlapping τ branching fractions is equal to one. In computing the χ^2, all published statistical correlations are used, and a selection of measurements, particularly the most precise and the most recent ones, were studied to take into account the significant systematic dependencies from external parameters and common sources of systematic uncertainty. Therefore, following the HFAG methodology [3], no error scaling is performed unless a significant inconsistency is detected in the measurements. In the τ branching fraction fits, a scale factor of 5.44 has been applied to the published uncertainties of the two severely inconsistent measurements of $\Gamma_{96} = \tau \to KKK\nu$ by BABAR and Belle. The scale factor has been determined using the Particle Data Group procedure for the Review of Particle Physics. Additional details on the fit will be available in the forthcoming HFAG report [2].

The HFAG 2016 τ branching fractions fit has

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χ^2/d.o.f. = 137.3/123, corresponding to a confidence level CL = 17.84%. The procedure uses a total of 170 measurements to fit 135 quantities subjected to 88 constraints. The fit is statistically consistent with unitarity, and the unitarity residual is $1-\Gamma_{\rm All} = (0.0355\pm0.1031)\cdot 10^{-2}$.

2.1. Changes with respect to the HFAG 2014 fit

The following changes have been introduced with respect to the previous HFAG report [4].

Two old preliminary results have been removed:

- $\Gamma_{35} = B(\tau \to \pi K_S \nu)$, *BABAR* [5],
- $\Gamma_{40} = B(\tau \to \pi K_S \pi^0 \nu)$, *BABAR* [6].

They where announced in 2008 and 2009, respectively, but have not been published yet.

The Belle result on $\tau^- \to K^0_S(\text{particles})^- \nu_\tau$ [7] has been discarded, because it was determined that the published information does not permit a reliable determination of the correlations with the other results in the same paper. The correlations estimated for the HFAG 2014 report were inconsistent and made the covariance matrix of the results in the corresponding paper non positive-definite, as well as the overall correlation matrix for the branching ratio fit results. It has been found that the inconsistency had negligible impact on lepton universality and $|V_{us}|$ measurements.

The ALEPH result on Γ_{46} ($\tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$) [8] has been removed from the fit inputs, since it is the simply sum of twice $\Gamma_{47} = \pi^- K^0_S K^0_S \nu_\tau$ and $\Gamma_{48} = \pi^- K^0_S K^0_L \nu_\tau$ from the same paper, hence 100% correlated with them.

Several minor corrections have been applied to the constraints. All the the parameters corresponding to the measurements systematic biases and uncertainties and all the parameters appearing in the constraint equations have been updated to the PDG 2015 results [9].

2.2. Differences between the HFAG 2016 fit and the PDG 2016 fit

As is standard for the PDG branching fraction fits, the PDG 2016 τ branching fraction fit is unitarity constrained, while the HFAG 2016 fit is unconstrained.

The HFAG-Tau fit uses the ALEPH measurements of branching fractions defined according to the final state content of "hadrons" and kaons, where a "hadron" corresponds to either a pion or a kaon, since this set of results is closer to the actual experimental measurements and facilitates a more comprehensive treatment of the experimental results correlations [3]. The PDG 2016 fit on the other hand continues to use – as in the past editions – the ALEPH measurements of modes with pions and kaons, which correspond to the final set of published measurements of the collaboration. It is planned to eventually update the PDG fit to use the same ALEPH measurement set that is used by HFAG.

The HFAG 2016 fit, as in 2014, uses the ALEPH estimate for $\Gamma_{805} = B(\tau \to a_1^-(\to \pi^-\gamma)\nu_\tau)$, which is not a direct experimental measurement. The PDG 2016 fit uses the PDG average of $B(a_1 \to \pi\gamma)$ as a parameter and defines $\Gamma_{805} = B(a_1 \to \pi\gamma) \times B(\tau \to 3\pi\nu)$. As a consequence, the PDG fit procedure does not take into account the large uncertainty on $B(a_1 \to \pi\gamma)$, resulting in an underestimated fit uncertainty on Γ_{805}. Therefore, in this case an appropriate correction has to be applied after the fit.

3. Tests of lepton universality

We update the lepton universality tests using the HFAG 2016 preliminary results using the Standard Model predictions for the partial widths of a heavier lepton λ decaying to a lighter lepton ρ [10],

$$\Gamma(\lambda\to\nu_\lambda\rho\bar{\nu}_\rho(\gamma)) = \frac{B(\lambda\to\nu_\lambda\rho\bar{\nu}_\rho)}{\tau_\lambda} = \frac{G_\lambda G_\rho m_\lambda^5}{192\pi^3}\, f\left(\frac{m_\rho^2}{m_\lambda^2}\right) R_W^\lambda R_\gamma^\lambda\,,$$

where

$$G_\rho = \frac{g_\rho^2}{4\sqrt{2}M_W^2} \qquad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

$$R_W^\lambda = 1 + \frac{3}{5}\frac{m_\lambda^2}{M_W^2} \qquad R_\gamma^\lambda = 1 + \frac{\alpha(m_\lambda)}{2\pi}\left(\frac{25}{4} - \pi^2\right)$$

We use $R_\gamma^\tau = 1-43.2\cdot10^{-4}$ and $R_\gamma^\mu = 1-42.4\cdot10^{-4}$ [10] and M_W from PDG 2015 [9]. We use HFAG 2016 averages and PDG 2015 for the other quantities. Using pure leptonic processes we obtain

$$\left(\frac{g_\tau}{g_\mu}\right) = 1.0010 \pm 0.0015\,, \quad \left(\frac{g_\tau}{g_e}\right) = 1.0029 \pm 0.0015$$

$$\left(\frac{g_\mu}{g_e}\right) = 1.0019 \pm 0.0014\,.$$

Figure 1 shows the test of the SM prediction of the relation between the τ leptonic branching fractions $B_\ell = B(\tau \to \ell\bar{\nu}_\ell\nu_\tau)$, with $\ell = e, \mu$, the τ lifetime τ_τ, the τ mass m_τ, and the respective muon parameters,

$$B_{\tau\ell}^{\rm SM} = B_{\mu e}\frac{\tau_\tau}{\tau_\mu}\frac{m_\tau^5}{m_\mu^5}\frac{f_{\tau\ell}r_W^\tau r_\gamma^\tau}{f_{\mu e}r_W^\mu r_\gamma^\mu}, \quad \text{with } f_{\lambda\rho} = f\left(\frac{m_\rho^2}{m_\lambda^2}\right)\,.$$