Tau mass and leptonic branching fractions measurements at FCC-ee(Z)

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We estimate the uncertainties on the experimental measurements of the tau mass and the tau leptonic branching fractions at FCC-ee at the Z peak. These measurements can be used to test the Standard Model lepton universality.

This work has been performed within the FCC collaboration.

1 Tau mass and tau leptonic branching fractions measurements at FCC-ee(Z)

We summarize the estimate of the FCC-ee experimental precision on the measurements of the tau mass and the tau leptonic branching fractions, which have been documented in an FCC internal note [1][1]. These measurements can be used to test the Standard Model lepton universality. We assume that FCC-ee will observe at the Z peak $N_Z^{\text{FCC}} = 6{\cdot}10^{12}$ Z decays [2], corresponding to $2.0{\cdot}10^{11}$ tau pairs, and to an integrated luminosity of $\mathscr{L}_{\text{int}}^{\text{FCC}} = 210\,\text{ab}^{-1}$.

1.1 Tau mass

Recently, the Belle II collaboration reported the most precise measurement of the tau mass, $1777.09 \pm 0.08 \pm 0.11$ MeV/c^2 [3]. The systematic uncertainties have been substantially reduced with respect to the previous B-factories' measurements, and the total uncertainty is smaller than the uncertainties of the measurements performed at the tau pair production threshold [4, 5]. The Belle II statistical uncertainty of 0.08 MeV/c^2 (45 ppm) has been obtained with $175{\cdot}10^6$ tau pairs (190 fb^{-1} of integrated luminosity), and could be improved to 1.3 ppm with $2.0{\cdot}10^{11}$ tau pairs at FCC-ee, without taking into account the larger efficiency that can be expected at FCC-ee from the comparison of LEP versus B-factories tau measurements. Rescaling the statistical uncerytainty of the OPAL tau mass measurement [6] to number of Z decays expected at FCC-ee gives an estimated statistical precision of 0.9 ppm. The Belle II leading systematic uncertainty of 0.07 MeV/c^2 (39 ppm) is related to the knowledge of the beam energy, and is expected to be significantly smaller at FCC-ee, where the beam energy can be known with 1 ppm precision. The other Belle II leading systematic uncertainty of 0.06 MeV/c^2 (34 ppm) is related to the understanding of the charged tracks reconstructed momentum scale, which can probably be calibrated with 2 ppm precision at FCC-ee by matching the measured J/ψ mass to its world average, presently known to 2 ppm. Belle II reports systematics related to the estimator bias (0.03 MeV/c^2), to the choice of the fit function of the pseudo-mass distribution (0.02,MeV$/c^2$), to the detector material (0.03 MeV/c^2), and to the modeling of ISR, FSR and tau decay (0.02 MeV/c^2), for a total of 29 ppm. We expect that these systematics may be reduced by a factor 3 to 10 ppm at FCC-ee, which we take as the estimated precision of the measurement of the tau mass at FCC-ee.

1.2 Tau leptonic branching fractions

ALEPH measured the tau leptonic branching fractions $\mathscr{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)$ and $\mathscr{B}(\tau^- \to e^- \bar{\nu}_\mu \nu_\tau)$ with a precision of about 0.44% (0.40% statistical and 0.19% systematic), using $5.9{\cdot}10^6$ Z decays. The extrapolated statistical precision at FCC-ee with $6{\cdot}10^{12}$ Z decays amounts to 4.0 ppm. The measurement is complex and reducing the systematic uncertainties is challenging. We guess that at FCC-ee the ALEPH systematic uncertainty may be reduced by a factor 10 to 0.019%, 100% correlated between the muon and the electron tau decay modes, and that would set the estimated precision at FCC-ee.

1.3 Lepton universality test with the tau leptonic branching fractions

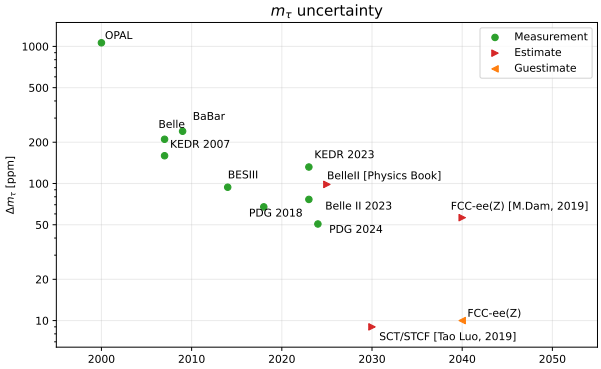
Figure 1 reports the status and prospects of the lepton universality test with the tau leptonic branching fractions and its tau-related input measurements (tau mass, tau lifetime [1] and tau leptonic branching fractions).

2 References

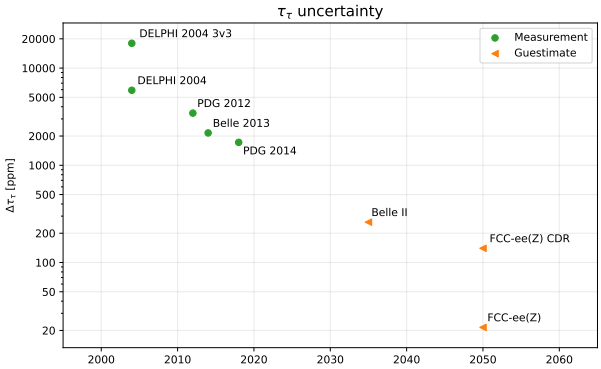
[1] A. Lusiani, *Tau Physics Prospects at FCC-ee*, FCC note, 2023, DOI: 10.17181/9bkm6-h8906, URL: https://doi.org/10.17181/9bkm6-h8906.

[2] P. Janot et al., *Integrated Luminosities and Sequences of Events to Be Used in the Mid-term Report*, CDS 20sa7-xkt23, CERN-FCC, 2023, DOI: 10.17181/20sa7-xkt23.

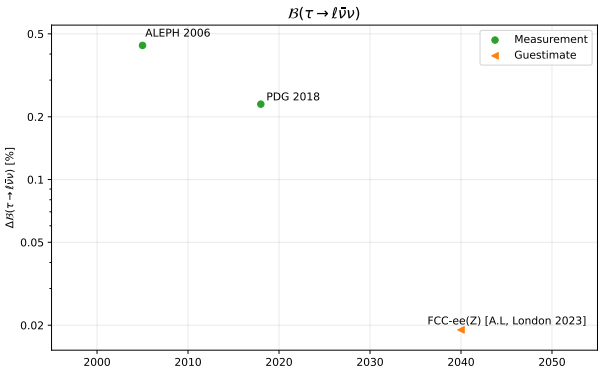
[1] Document in development, content restricted as of 20 October 2024, will eventually become public.



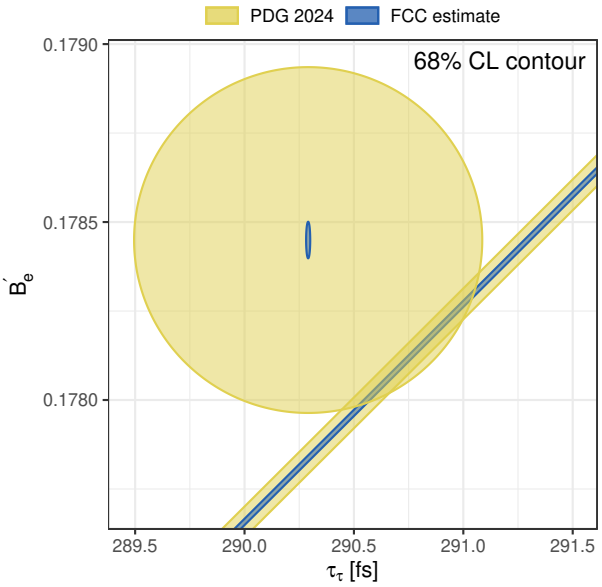
(a) Tau mass.



(b) Tau lifetime.



(c) Tau leptonic branching fractions.



(d) Lepton universality test using the tau mass, lifetime and leptonic branching fractions measurements. The test using the measurements reported in PDG 2024 is reported in yellow (lighter), and the estimated test at FCC-ee is reported in blue (darker). B'_e denotes the average between the measured branching fraction $\mathcal{B}(\tau^- \to e^- \bar{\nu}_\mu \nu_\tau)$ and its Standard Model prediction using the measured branching fraction $\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)$.

Figure 1: Status and prospects of the lepton universality test using tau measurements. The dates of the future measurements are speculative and mainly chosen for plotting purposes.

[3] I. Adachi et al., Belle II, *Measurement of the τ-lepton mass with the Belle II experiment*, Phys. Rev. D **108** (2023) 032006, DOI: 10.1103/PhysRevD.108.032006, arXiv: 2305.19116 [hep-ex].

[4] M. Ablikim et al., BESIII, *Precision measurement of the mass of the τ lepton*, Phys. Rev. D **90** (2014) 012001, DOI: 10.1103/PhysRevD.90.012001, arXiv: 1405.1076 [hep-ex].

[5] V. V. Anashin et al., *Experiments with the KEDR Detector at the e^+e^- Collider VEPP-4M in the Energy Range $\sqrt{s}$ = 1.84–3.88 GeV*, Phys. Part. Nucl. **54** (2023) 185, DOI: 10.1134/S1063779623010033.

[6] G. Abbiendi et al., OPAL, *A Measurement of the tau mass and the first CPT test with tau leptons*, Phys. Lett. B **492** (2000) 23, DOI: 10.1016/S0370-2693(00)01022-4, arXiv: hep-ex/0005009.