Measurement of the $\tau \to e\bar{\nu}_e\nu_\tau$ and $\tau \to \mu\bar{\nu}_\mu\nu_\tau$ branching ratios at Belle II

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1 Motivation

The weak leptonic branching ratios can be calculated in the Standard Model (SM) to a high accuracy thanks to the fact that they only include weak and no strong interactions. Some of the fundamental parameters appearing in the prediction are the lepton masses m_ℓ and lifetimes τ_ℓ. The τ to $\ell = e, \mu$ branching ratios can be written as

$$B_{\tau\ell}^{SM} = B_{\mu e}\frac{\tau_\tau}{\tau_\mu}\frac{m_\tau^5}{m_\mu^5}\frac{F_{\tau\ell}}{F_{\mu e}}\left(1+\varepsilon'_{\tau\ell}\right) \quad (1)$$

Figure 1 shows the slight tension between the current measurements of the $\tau \to e\bar{\nu}_e\nu_\tau$

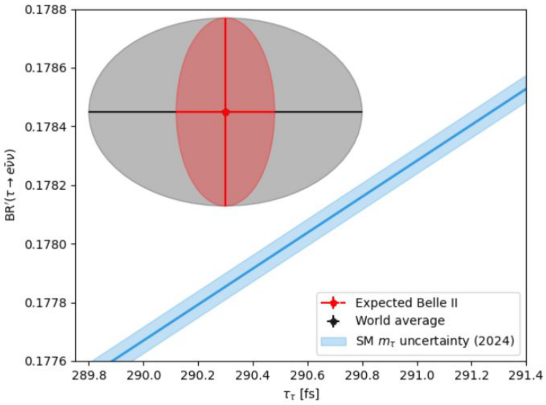

Abbildung 1: Test of relation 1

branching ratio and the tau lifetime τ_τ when comparing to the SM prediction (the blue band). But limited precision prevents any definite conclusion. Some of the greatest uncertainties affecting the result are the ones of the tau branching ratio, the tau mass and the tau lifetime (the muon parameters are some of the most precisely known).
The best single measurement of the $\tau \to e\bar{\nu}_e\nu_\tau$ and $\tau \to \mu\bar{\nu}_\mu\nu_\tau$ branching ratios dates back to 2005 by the ALEPH collaboration with data taken in 1993–94.

The aim of this doctoral project is to make a precision measurement of BR($\tau \to e\bar{\nu}_e\nu_\tau$) and BR($\tau \to \mu\bar{\nu}_\mu\nu_\tau$) with Belle II data and together with (hopefully) improved τ mass and lifetime to test the SM's prediction of the relation.

BR	PDG value	PDG rel. uncert.	ALEPH measurement	ALEPH rel. uncert.
$\tau \to e\bar{\nu}_e\nu_\tau$	(17.82 ± 0.04) %	0.22%	$(17.837 \pm 0.072 \pm 0.036)$ %	0.45%
$\tau \to \mu\bar{\nu}_\mu\nu_\tau$	(17.39 ± 0.04) %	0.23%	$(17.319 \pm 0.070 \pm 0.032)$ %	0.44%

2 Measurement strategy

The Belle II detector is located at the SuperKEKB, an asymmetric e^+e^- collider with a center-of-mass energy close to the $\Upsilon(4S)$ resonance. This allows production of a $\tau^+\tau^-$ pair which can further decay into leptons $(\tau \to e\bar{\nu}_e\nu_\tau)(\tau \to \mu\bar{\nu}_\mu\nu_\tau)$. The observed number of events from this decay topology can then be written as

$$\mathcal{N}_{e\mu} = \mathcal{B}(\tau \to e\bar{\nu}_e\nu_\tau) \times \mathcal{B}(\tau \to \mu\bar{\nu}_\mu\nu_\tau) \times \varepsilon_{e\mu} \times 2 \times \mathcal{L}_{int} \times \sigma_{\tau\tau}$$

where $\mathcal{N}_{e\mu}$ is the number of events observed, $\mathcal{B}(X \to Y)$ is the branching ratio of the decay $X \to Y$, $\mathcal{L}_{int}$ is the integrated luminosity, $\sigma_{\tau\tau}$ is the cross section of $e^+e^- \to \tau^+\tau^-$ at the beam energy and $\varepsilon_{e\mu}$ is the detection efficiency. To now calculate the branching ratio of i.e. the $\tau \to e\bar{\nu}_e\nu_\tau$ decay an inclusive measurement of $(\tau \to \mu\bar{\nu}_\mu\nu_\tau)(\tau \to X)$ is performed. Here X stands for any particles in any number. The number of events is then given by

$$\mathcal{N}_{X\mu} = \mathcal{B}(\tau \to \mu\bar{\nu}_\mu\nu_\tau) \times \mathcal{B}(\tau \to X) \times \varepsilon_{X\mu} \times 2 \times \mathcal{L}_{int} \times \sigma_{\tau\tau}$$

Then by exploiting $\mathcal{B}(\tau \to X) \equiv 1$ the branching ratio can be calculated as

$$\mathcal{B}(\tau \to e\bar{\nu}_e\nu_\tau) = \frac{\mathcal{N}_{e\mu}}{\mathcal{N}_{X\mu}} \times \frac{\varepsilon_{X\mu}}{\varepsilon_{e\mu}}$$

where knowledge of the efficiencies $\varepsilon_{e\mu}$, $\varepsilon_{X\mu}$ is obtained by comparing Data with a Monte-Carlo Simulation. By switching the non-inclusive side in the second observation to an electron decay ($\mathcal{N}_{eX}$) the branching ratio $\mathcal{B}(\tau \to \mu\bar{\nu}_\mu\nu_\tau)$ can be similarly obtained.