10 FCC tau polarisation

Contribution* by: S. Banerjee, Z. Was
Corresponding author: Z. Was [z.was@cern.ch]

SM parameters, such as the τ polarisation can be measured very precisely in τ decays. The phenomenology is quite similar to that of measurement of the $A_{\rm FB}$ parameter of the SM [1]. Details of the τ decay spectrum, as well as a good understanding of associated uncertainty, play an important role in this measurement of polarisation, because the spin of the τ lepton is not measured directly.

The distribution of hadronic final-state products in decays of a τ lepton needs to be evaluated to understand the substructure of the vertex. An important effect is related to bremsstrahlung, because the signature of every decay mode needs to take into account the final-state configurations with accompanying photons. Corresponding virtual corrections cancel the bulk of these effects and specialised programs, such as PHOTOS [2, 3], are useful.

Corresponding effects can be sizeable; even during the early stages of LEP preparations, it was found [4] that the corresponding corrections affect the slope of the π spectrum in $\tau^- \to \pi^-\nu$, for example. This translates to a 0.013 effect on τ idealised observable $A_{\rm pol}$. For more discussion and essential experimental context, see Ref. [5].

However, not all of the final-state photons can be associated with bremsstrahlung. For example, in the cascade decay $\tau^- \to \pi^-\omega\nu$, a subsequent decay of $\omega \to \pi^0\gamma$ contributes to the final state $\tau^- \to \pi^-\pi^0\gamma\nu$, coinciding with the radiative corrections to the final state of the $\tau^- \to \rho^-\nu$ decay channel. In this case, the photon originates from the $\omega \to \pi^0\gamma$ decay and is of non-QED bremsstrahlung origin.

The branching fractions for the $\tau^- \to \pi^-\omega\nu$ decay and for the $\omega \to \pi^0\gamma$ decay are 0.02 and 0.08, respectively [6]. Thus, the resulting decay channel $\tau^- \to \pi^-\pi^0\gamma\nu$ contributes 0.0015 of all τ decays.

Such contributions and subsequent changes of the hadronic decay energy spectrum in τ decays need to be understood for each spin-sensitive channel. Resulting deformation of $\tau^- \to \rho^-\nu$ decay spectra may mimic the contribution of the τ polarisation that can be obtained from future high-precision data analysis at the Belle II experiment.

This is the case when one of the τ decay channels mimics bremsstrahlung correction for the other one. The dynamics of the low-energy strong interactions are difficult to obtain from a perturbative calculation.

Another hint of the non-point-like nature of the τ vertex was explained in the corrections to the π energy spectra in the $\tau^- \to \pi^-\nu$ decay channel [7, 8]. Although at the lowest order, the spectrum is fully determined by the Lorentz structure of the vertex, and the real and virtual photonic corrections play an important role in the level of precision under discussion. The dominant part of the effects of the QED bremsstrahlung from point-like sources can be seen in Fig. 3 of Ref. [8], where the effects induced by hadronic resonances also play an important role.

The Belle II experiment is expected to collect 10^{11} τ lepton decays with $50\,\mathrm{ab}^{-1}$ of data,

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and the detector is extremely well-suited to study τ lepton physics. The backgrounds can be well-controlled in an electron–positron collider environment. We can expect that the τ decay spectra can be measured without large degradation, owing to a highly granular electromagnetic calorimeter with large fiducial coverage, as explained in the Belle II technical design report [9].

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