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EDM observables for τ production with polarized beams

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Abstract. The Tau-lepton electric dipole moment (EDM) can be measured at Super B/Flavor factories operating with polarized electron beams at energies near and on top of the Υ resonances. In particular, new CP-odd observables, independent from others already considered, will allow to put stringent bounds on the τ EDM.

1. Introduction

The first clue to physics beyond the standard model (SM) has been found in neutrino physics [1]. However, other new phenomena beyond the well tested SM are expected both from the theory and experimental evidence. The physics of CP violation, particularly in the leptonic sector, is one of them. The time reversal odd EDM for fermions, specially the electron and the neutron, has been extensively investigated and strong limits were established at the level of 10^{-26} ecm. For the τ the present EDM bound is weaker [2]: -0.22 ecm $< \text{Re}(d_\tau^\pm) \times 10^{16} < 0.45$ ecm (95% C.L.). Within the SM the CP-violation is introduced by the CKM mechanism where the EDM is generated at three loops. Thus, any experimental signal coming from a CP-odd observable related to the EDM would point to beyond the SM physics where the EDM can be easily generated at 1-loop. For new physics models with an energy scale Λ the fermion mass dependence of the EDM can be stronger than m_f/Λ . Then, for heavy fermions (such as the τ lepton), the bounds on the EDM can be more competitive than the bound on the electron-EDM: the ratio $m_e/m_\tau \simeq 1/3.5 \times 10^3$ can well compensate a few orders of magnitude in the bounds for these leptons. The statistics for the τ physics is dominated nowadays by the high luminosity of the B factories. In the future, these will be superseded by the proposed Super B/Flavor factories [3]. These facilities may also operate with polarized beams and new physics phenomena could be accessible. We present in this paper new CP-odd observables, related to the τ pairs produced at low energies with polarized beams, that may lead to competitive results with the present bounds for the τ -EDM.

2. Polarized beams and the EDM.

The $e^+ e^- \rightarrow \tau^+(s_+) \tau^-(s_-)$ cross section has, at lowest order, contributions coming from γ or Υ exchange in the s-channel. These originate in the SM and, to first order in the EDM, the diagrams are shown in Fig. 1.

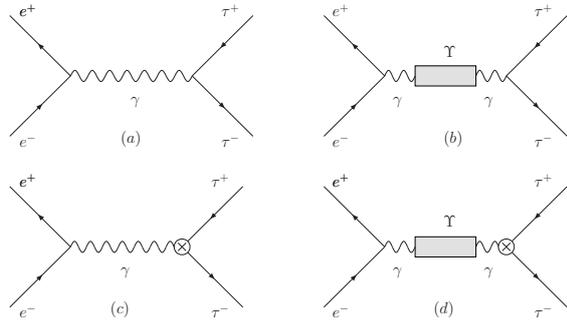


Figure 1. Diagrams (a) direct γ exchange (b) Υ production (c) EDM in γ exchange (d) EDM at the Υ -peak.

For longitudinally polarized electron beams the τ -EDM modifies the angular distribution for the cross section. The normal -to the scattering plane- polarization (P_N) of each τ is the only spin linear component which is T -odd. For CP-conserving interactions, the CP-even term $(s_+ + s_-)_N$ of P_N only gets contribution through the combined effect of both an helicity-flip transition and the presence of absorptive parts, which are both suppressed in the SM. For a CP-violating interaction, such as an EDM, the $(s_+ - s_-)_N$ CP-odd term gets a non-vanishing value without the need of absorptive parts. P_N is also parity even (P) so any observable sensitive to the EDM will need in addition a P -odd contribution. In our case this comes from the longitudinally polarized electrons and opens the possibility to study new observables. Polarization along the directions x, y, z are called transverse (T), normal (N) and longitudinal (L), respectively. Let us first consider the τ -pair production (diagrams (a) and (c) in Fig. 1). More details can be found in [4]. We assume that the τ production plane and direction of flight can be fully reconstructed, which is the case for both τ 's decaying semileptonically [5]. For the electron beam polarized with helicity λ the cross section for the process $e^+e^-(pol) \rightarrow \gamma \rightarrow \tau^+\tau^- \rightarrow h^+\bar{\nu}_\tau h^-\nu_\tau$ is [6]:

$$\frac{d^4\sigma^S}{d\Omega_{h^+} d\Omega_{h^-}} \Big|_\lambda = \frac{\pi^2\alpha^2\beta}{32\pi^2s} Br_+ Br_- \times \left\{ \frac{\lambda}{\gamma} [n_-^* + n_+^*]_x + \lambda \gamma\beta [n_-^* - n_+^*]_y \frac{2m_\tau}{e} \text{Re}\{d_\tau^\gamma\} + \frac{4}{3\gamma} [n_-^* - n_+^*]_z \frac{2m_\tau}{e} \text{Im}\{d_\tau^\gamma\} \right\} \quad (1)$$

where β and γ are the τ velocity and dilation factor respectively, $Br_\pm = Br_{\tau^\pm \rightarrow h^\pm \nu_\tau}$ and we have integrated the neutrinos in the final state and the production angles for the τ -pair. We can see in this equation that the normal (y) polarization carries the information on $\text{Re}\{d_\tau^\gamma\}$. Integrating in angles except in the azimuthal ones and subtracting for different helicities leaves only the real part of the τ -EDM:

$$\frac{d^2\sigma^S}{d\phi_- d\phi_+} \Big|_{Pol(e^-)} = \frac{1}{2} \left(\frac{d^2\sigma^S}{d\phi_- d\phi_+} \Big|_{\lambda=1} - \frac{d^2\sigma^S}{d\phi_- d\phi_+} \Big|_{\lambda=-1} \right) = \frac{\pi\alpha^2\beta}{32s} Br_+ Br_- \times \left(\frac{\alpha_- \cos \phi_- - \alpha_+ \cos \phi_+}{\gamma} + \beta\gamma(\alpha_- \sin \phi_- + \alpha_+ \sin \phi_+) \frac{2m_\tau}{e} \text{Re}\{d_\tau^\gamma\} \right) \quad (2)$$

We define the following azimuthal asymmetry:

$$A_N^\mp = \frac{\sigma_L^\mp - \sigma_R^\mp}{\sigma} = \alpha_\mp \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \text{Re}\{d_\tau^\gamma\} \quad (3)$$

where

$$\sigma_L^\mp = \int_0^{2\pi} d\phi_\pm \left[\int_0^\pi d\phi_\mp \frac{d^2\sigma^S}{d\phi_- d\phi_+} \Big|_{Pol(e^-)} \right] = Br_+ Br_- \alpha_\mp \frac{(\pi\alpha\beta)^2\gamma}{8s} \frac{2m_\tau}{e} \text{Re}\{d_\tau^\gamma\} \quad (4)$$

$\sigma_R^\mp = -\sigma_L^\mp$ and is defined as σ_L^\mp but the second integral limits are $(\pi, 2\pi)$. All other terms except the suppressed contributions coming from the CP-even term of P_N are eliminated along in this procedure. To eliminate the spurious CP-even terms we consider:

$$A_N^{CP} = \frac{1}{2} (A_N^+ + A_N^-) = \alpha_h \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \text{Re} \{d_\tau^\gamma\} \quad (5)$$

This CP-odd observable is proportional to the τ -EDM. All these ideas can also be applied for e^+e^- collisions at the Υ peak. Here, the τ pair production is mediated by the Υ resonances and the resonant diagrams (b) and (d) of Fig. 1 dominate the process. This has been discussed in ref.[4]. The main result is that the τ pair production at the Υ peak introduces the same τ polarization matrix as the direct one with γ exchange (diagrams (a) and (c)) except for a the overall multiplicative factor $H(M_\Upsilon^2) = -i \frac{3}{\alpha} Br(\Upsilon \rightarrow e^+e^-)$ in the cross section. Besides, at the Υ peak, the interference of diagrams (a) and (d) plus the interference of diagrams (b) and (c) is exactly zero and so it is the interference of diagrams (a) and (b). Thus, the only contribution proportional to the EDM comes with the interference of diagrams (b) and (d), while diagram (b) squared gives the leading contribution to the cross section. Finally we obtain no changes in the asymmetries we have already computed. If we measure these observables we can put direct bounds on the τ -EDM. We assume a set of integrated luminosities for high statistics B /Flavor factories and we consider the decay channels $\pi^\pm \bar{\nu}_\tau$ or $\rho^\pm \bar{\nu}_\tau$ (*i.e.* $h_1, h_2 = \pi, \rho$) for the traced τ^\pm , while we sum up over $\pi^\mp \nu_\tau$ and $\rho^\mp \nu_\tau$ hadronic decay channels for the non traced τ^\mp . The bounds for the τ -EDM that can be set in different scenarios are:

$$\begin{aligned} |\text{Re} \{d_\tau^\gamma\}| &\leq 4.4 \cdot 10^{-19} \text{ ecm, Babar + Belle at } 2ab^{-1} \\ |\text{Re} \{d_\tau^\gamma\}| &\leq 1.6 \cdot 10^{-19} \text{ ecm, SuperB/Flavor factory, 1 yr running, } 15ab^{-1} \\ |\text{Re} \{d_\tau^\gamma\}| &\leq 7.2 \cdot 10^{-20} \text{ ecm, SuperB/Flavor factory, 5 yrs running, } 75ab^{-1} \end{aligned} \quad (6)$$

These limits would improve the [2] bounds by two orders of magnitude. These observables allow for an independent analysis of the EDM bounds from what has been done with other high and low energy data.

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