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Measurement of the τ lepton electric dipole moment at BaBar

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Summary. — The search for a CP violation signature arising from an electric dipole moment of the τ lepton in the $e^+e^- \to \tau^+\tau^-$ reaction is currently in progress using $470\,\text{fb}^{-1}$ of data collected with the BaBar detector at the PEP II collider from 1999 to 2008. In this paper the EDM search analysis method will be illustrated.

PACS 14.60.Fg – Taus.
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The SM prediction for CP violation in the lepton sector is negligibly small and has never been observed so far. However, the presence of physics beyond the SM could introduce these effects at experimentally accessible levels [1], making any observation of CP violation in this sector a clear evidence of new physics. In some models such effects are expected to be enhanced for the τ leptons due to its very large mass compared to other leptons, since new bosons and Higgs strongly couple with heavy particles through quantum loop effects. The contribution from CP violating interactions in the τ pair production process can be parametrized at the leading order, in a model-independent way, using an electric dipole moment (EDM) of the τ lepton, d_τ. Some theoretical SM predictions are given in [2, 3]. Presently, the best bound on d_τ is from the Belle collaboration [4]. The Belle EDM analysis was performed using $29.5\,\text{fb}^{-1}$ of data, finding 95% confidence level limits of $-2.2 < \text{Re}(d_\tau) < 4.5(10^{-17}\,\text{e}\,\text{cm})$ and $-2.5 < \text{Im}(d_\tau) < 0.8(10^{-17}\,\text{e}\,\text{cm})$. The analysis discussed in the present paper will be based on all the data recorded by the BaBar detector [5] at the PEP-II asymmetric-energy e^+e^- storage rings operated at the SLAC National Accelerator Laboratory. An integrated luminosity of about $470\,\text{fb}^{-1}$ was collected.

Taking into account the EDM contribution in the Lagrangian, the cross section of the process: $e^+(\vec{p})e^-(-\vec{p}) \to \tau^+(\vec{k},\vec{S}_+)\tau^-(-\vec{k},\vec{S}_-)$, where $\vec{p}$ is the momentum vector of e^+, $\vec{k}$ is the momentum vector of the τ^+ and $\vec{S}_\pm$ are the spin vectors for $\tau^\pm$, all expressed in the center-of-mass frame, is proportional to the squared spin density matrix [6]: $\mathcal{M}^2_{\text{prod}} =$

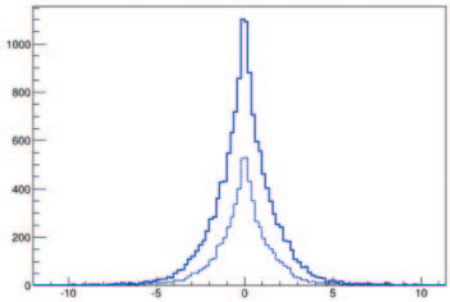

Fig. 1. – Real observable distribution for $\tau^+\tau^- \to \pi^+\pi^-\nu_\tau\bar{\nu}_\tau$ events. Dotted line is the background contribution.

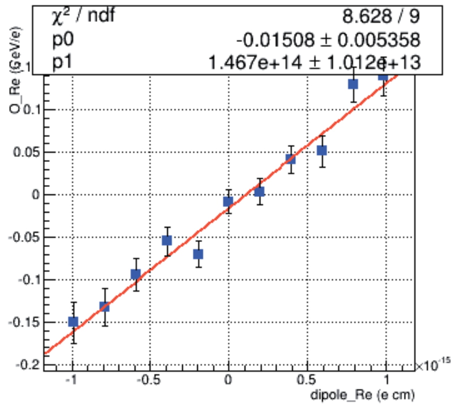

Fig. 2. – Correlations between $\langle O_{\mathrm{Re}}\rangle$ and $\mathrm{Re}(d_\tau)$ for the analysed MC sample.

$\mathcal{M}^2_{\mathrm{SM}}(\vec{k},\vec{S}_\pm) + \mathrm{Re}(d_\tau)\mathcal{M}^2_{\mathrm{Re}}(\vec{k},\vec{S}_\pm) + \mathrm{Im}(d_\tau)\mathcal{M}^2_{\mathrm{Im}}(\vec{k},\vec{S}_\pm) + |d_\tau|^2\mathcal{M}^2_{d^2}(\vec{k},\vec{S}_\pm)$. In addition to the standard term, the interference terms between the SM and the CP violating amplitudes $\mathcal{M}^2_{\mathrm{Re}}$ and $\mathcal{M}^2_{\mathrm{Im}}$, respectively related to the real and imaginary part of the d_τ, appear. For the EDM measurement we adopt the same method of Belle, the so-called optimal observable method [7], which maximizes the sensitivity to d_τ. The optimal observables are defined as

$$\mathcal{O}_{\mathrm{Re}} = \frac{\mathcal{M}^2_{\mathrm{Re}}}{\mathcal{M}^2_{\mathrm{SM}}}, \quad \mathcal{O}_{\mathrm{Im}} = \frac{\mathcal{M}^2_{\mathrm{Im}}}{\mathcal{M}^2_{\mathrm{SM}}}.$$

The mean values of these observables $\langle\mathcal{O}_{\mathrm{Re}}\rangle$ and $\langle\mathcal{O}_{\mathrm{Im}}\rangle$ are linear functions of d_τ: $\langle\mathcal{O}_{\mathrm{Re}}\rangle = a_{\mathrm{Re}} \cdot \mathrm{Re}(d_\tau) + b_{\mathrm{Re}}, \quad \langle\mathcal{O}_{\mathrm{Im}}\rangle = a_{\mathrm{Im}} \cdot \mathrm{Im}(d_\tau) + b_{\mathrm{Im}}$.

In order to extract the value of d_τ from the mean values of the observables measured on the data, we have to know the coefficients a_j and the offsets b_j. The parameters a_j and b_j are estimated from the correlations between $\langle\mathcal{O}_{\mathrm{Re}}\rangle$ ($\langle\mathcal{O}_{\mathrm{Im}}\rangle$) and $\mathrm{Re}(d_\tau)$ ($\mathrm{Im}(d_\tau)$) extracted by a full Monte Carlo (MC) simulation including the detector simulation with acceptance effects and event selection efficiency. In the MC different EDM values are introduced. With a $30\,\mathrm{fb}^{-1}$ MC sample the final state in which both τ's decay hadronically into

$\tau^{\pm} \to \pi^{\pm}\nu$ has been analysed so far. Distribution of the real optimal observable for this channel is shown in fig. 1. Dotted line is the background contribution, with a preliminarly event selection the purity of the sample is of about 50%. In fig. 2 the correlations between the real observable means $\langle O_{\mathrm{Re}} \rangle$ and $\mathrm{Re}(d_\tau)$ of this MC sample is shown. By fitting the linear correlation plot of fig. 2, the parameters a_{Re} and b_{Re} are obtained. The slope a_{Re} represents the real EDM sensitivity, the offset b_{Re} represent the difference from zero of the observable mean when $d_\tau = 0$. Sample purity is under improvement with a BDT multivariate analysis and the EDM sensitivity evaluation with the full MC sample is in progress.

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