# Sensitivity on the electromagnetic dipole moments of the tau-lepton at the CLIC

M. A. Hernández-Ruíz[1*], A. A. Billur[2], M. Köksal[3] and A. Gutiérrez-Rodríguez[4]

**1** Unidad Académica de Ciencias Químicas, Universidad Autónoma de Zacatecas, Apartado Postal C-585, 98060 Zacatecas, México.
**2** Deparment of Physics, Cumhuriyet University, 58140, Sivas, Turkey.
**3** Deparment of Optical Engineering, Cumhuriyet University, 58140, Sivas, Turkey.
**4** Unidad Académica de Física, Universidad Autónoma de Zacatecas, Apartado Postal C-580, 98060 Zacatecas, México.
* mahernan@uaz.edu.mx

November 18, 2018

*Proceedings for the 15th International Workshop on Tau Lepton Physics, Amsterdam, The Netherlands, 24-28 September 2018*
scipost.org/SciPostPhysProc.Tau2018

## Abstract

In this paper we established model independent bounds on the anomalous magnetic and electric dipole moments of the tau-lepton using the process $\gamma\gamma \to \tau^+\tau^-$. We use data collected with the future $e^+e^-$ linear collider such as the CLIC at $\sqrt{s} = 380, 1500, 3000$ GeV, and we consider systematic uncertainties of $\delta_{sys} = 0\%, 3\%, 5\%$. The theory predictions are a very good prospect for probing the dipole moments of the tau-lepton at the future $e^+e^-$ linear collider at the $\gamma\gamma$ mode.

# 1  Introduction

In this work, using $\gamma\gamma \to \tau^+\tau^-$ reaction we establish model independent sensitivity estimates on the dipole moments $a_\tau$ and $d_\tau$ of the tau-lepton. The high center-of-mass energies what has been proposed for the Compact Linear Collider (CLIC) make it an appropriate machine to probe the anomalous magnetic (MM) and electric dipole (EDM) moments which are more sensitive to the high energy and high luminosity of the collider.

For our study we consider the following parameters of the CLIC: $\sqrt{s} = 380$, 1500, 3000 GeV, $\mathcal{L} = 10$, 50, 100, 300, 500, 1000, 1500, 2000, 3000 fb$^{-1}$, with systematic uncertainties of $\delta_{sys} = 0\%$, 3%, 5%. We obtain strong sensitivity in comparison to the bounds given by the DELPHI, L3, OPAL, BELLE, and ARGUS Collaborations [1, 2, 3, 4, 5].

This paper is organized as follows: In Section 2, we present the total cross section and the electromagnetic dipole moments of the tau-lepton for the $\gamma\gamma \to \tau^+\tau^-$ reaction. In section 3, the results. In section 4, we give our conclusion.

# 2  The process $\gamma\gamma \to \tau^+\tau^-$

To calculate the $\gamma\gamma \to \tau^+\tau^-$ total cross section, the corresponding Feynman diagrams are given in Fig. 1. We determine sensitivity estimates on the electromagnetic dipole moments of the tau-lepton $a_\tau$ and $d_\tau$ via the two-photon process [6]. The future Collider CLIC can produce very hard photons at high luminosity in Compton backscattering of laser light off high energy $e^+e^-$ beams.

$$(1) \qquad\qquad\qquad (2)$$
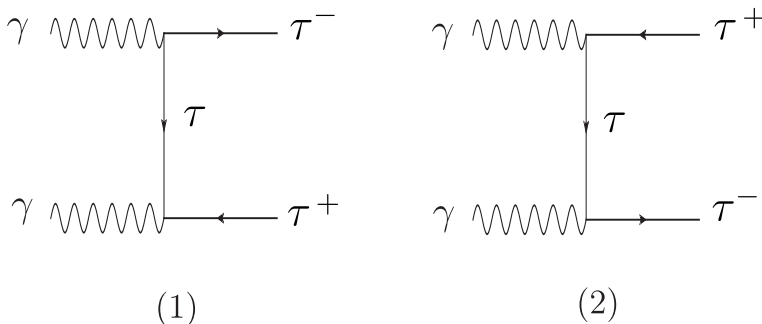
Figure 1: The Feynman diagrams for the process $\gamma\gamma \to \tau^+\tau^-$.

The electromagnetic current between on-shell tau-lepton and the photon is given by [7, 8, 9, 10]

$$\begin{aligned}
\Gamma_\tau^\alpha &= eF_1(q^2)\gamma^\alpha + \frac{ie}{2m_\tau}F_2(q^2)\sigma^{\alpha\mu}q_\mu + \frac{e}{2m_\tau}F_3(q^2)\sigma^{\alpha\mu}q_\mu\gamma_5 \\
&\quad + eF_4(q^2)\gamma_5\left(\gamma^\alpha - \frac{2q^\alpha m_\tau}{q^2}\right),
\end{aligned} \qquad (1)$$

the $q^2$-dependent form factors $F_{1,2,3,4}(q^2)$ have interpretations for $q^2 = 0$: $F_1(0) = Q_\tau$ is the electric charge; $F_2(0) = a_\tau$ is anomalous MM and $F_3(0) = \frac{2m_\tau}{e}d_\tau$ with $d_\tau$ the EDM. $F_4(q^2)$ is the anapole form factor. $e$ is the charge of the electron, $m_\tau$ is the mass of the tau-lepton, $\sigma^{\alpha\mu} = \frac{i}{2}[\gamma^\alpha, \gamma^\mu]$ represents the spin 1/2 angular momentum tensor, and $q = p' - p$ is the momentum transfer.

The spectrum of Compton backscattered photons to the process $\gamma\gamma \to \tau^+\tau^-$ is given by

$$f_\gamma(y) = \frac{1}{g(\zeta)}[1 - y + \frac{1}{1-y} - \frac{4y}{\zeta(1-y)} + \frac{4y^2}{\zeta^2(1-y)^2}], \tag{2}$$

where

$$g(\zeta) = (1 - \frac{4}{\zeta} - \frac{8}{\zeta^2})\log(\zeta + 1) + \frac{1}{2} + \frac{8}{\zeta} - \frac{1}{2(\zeta + 1)^2}, \tag{3}$$

and

$$y = \frac{E_\gamma}{E_e}, \quad \zeta = \frac{4E_0 E_e}{M_e^2}, \quad y_{max} = \frac{\zeta}{1 + \zeta}. \tag{4}$$

$E_0$ is energy of the incoming laser photon while for $E_e$ is initial energy of the electron beam before Compton backscattering, and $E_\gamma$ is the energy of the backscattered photon.

The total cross section can be written as,

$$\sigma = \int f_\gamma(x) f_\gamma(x) d\hat{\sigma} dE_1 dE_2. \tag{5}$$

Now, we present the total cross section as a polynomial in powers of $F_2$ and $F_3$ for the process $\gamma\gamma \to \tau^+\tau^-$.

- For $\sqrt{s} = 380\,GeV$.

$$\begin{aligned}
\sigma(F_2) &= \left[(9914034)F_2^4 + (81889)F_2^3 + (81382)F_2^2 + (111)F_2 + 38.75\right](pb), \\
\sigma(F_3) &= \left[(9736246)F_3^4 + (82619)F_3^2 + 38.75\right](pb).
\end{aligned} \tag{6}$$

- For $\sqrt{s} = 1500\,GeV$.

$$\begin{aligned}
\sigma(F_2) &= \left[(1.54 \times 10^8)F_2^4 + (84288)F_2^3 + (88058)F_2^2 + (17.5)F_2 + 6\right](pb), \\
\sigma(F_3) &= \left[(1.54 \times 10^8)F_3^4 + (88124)F_3^2 + 6\right](pb).
\end{aligned} \tag{7}$$

- For $\sqrt{s} = 3000\,GeV$.

$$\begin{aligned}
\sigma(F_2) &= \left[(6.17 \times 10^8)F_2^4 + (91348)F_2^3 + (87216)F_2^2 - (1.21)F_2 + 1.97\right](pb), \\
\sigma(F_3) &= \left[(6.17 \times 10^8)F_3^4 + (88327)F_3^2 + 1.97\right](pb).
\end{aligned} \tag{8}$$

## 2.1 Bounds on the $a_\tau$ and $d_\tau$ through $\gamma\gamma \to \tau^+\tau^-$ at the CLIC

We now proceed with our numerical analysis of the total cross section $\sigma_{NP}(\gamma\gamma \to \tau^+\tau^-) = \sigma_{NP}(\sqrt{s}, F_2, F_3)$, as well as of the electromagnetic dipole moments of the tau-lepton, here the free parameters are $\sqrt{s}$, $\mathcal{L}$, $F_2$ and $F_3$. For this purpose, we use the usual formula for the $\chi^2$ function [11, 12, 13, 14]:

$$\chi^2 = \left( \frac{\sigma_{SM} - \sigma_{NP}(\sqrt{s}, F_2, F_3)}{\sigma_{SM}\delta} \right)^2,  \qquad (9)$$

$\sigma_{NP}(\sqrt{s}, F_2, F_3)$ is the total cross section which includes contributions to the SM and new physics, $\delta = \sqrt{(\delta_{st})^2 + (\delta_{sys})^2}$, $\delta_{st} = \frac{1}{\sqrt{N_{SM}}}$ is the statistical error, $\delta_{sys}$ is the systematic error and $N_{SM}$ is the number of signal expected events $N_{SM} = \mathcal{L}_{int} \times BR \times \sigma_{SM}$, $\mathcal{L}_{int}$ is the integrated CLIC luminosity.

## 3  Results

In this section we presented a set of figures, which illustrate our results. The total cross sections $\sigma_{\gamma\gamma \to \tau^+\tau^-}(\sqrt{s}, F_2, F_3)$ it was obtained as a function of the anomalous couplings $F_2$ and $F_3$ with the center-of-mass energies of $\sqrt{s} = 380$ GeV, $\sqrt{s} = 1500$ GeV and $\sqrt{s} = 3000$ GeV. The total cross section sample a strong dependence on the anomalous paramaters $F_2$, $F_3$, and the center-of-mass energy of the collider $\sqrt{s}$ as they are show in Figures 2-4.

In Figures 5-7 indicate allowed regions at 95% C.L. in the plane $(F_2 - F_3)$ for the process $\gamma\gamma \to \tau^+\tau^-$ during the first, second and third stage of operation of the CLIC, where assumed fixed center-of-mass energies are $\sqrt{s} = 380$ GeV, $\sqrt{s} = 1500$ GeV, and $\sqrt{s} = 3000$ GeV with luminosities $\mathcal{L} = 10\,fb^{-1}$, $\mathcal{L} = 100\,fb^{-1}$, and $\mathcal{L} = 500\,fb^{-1}$, in Figure 5; likewise $\mathcal{L} = 100fb^{-1}$, $\mathcal{L} = 500fb^{-1}$, and $\mathcal{L} = 1500fb^{-1}$ in Figure 6; while, $\mathcal{L} = 100fb^{-1}$, $\mathcal{L} = 500fb^{-1}$, $\mathcal{L} = 3000fb^{-1}$ in Figure 7, and systematic uncertainties of $\delta_{sys} = 0\%, 3\%, 5\%$ [1, 15].

These results that we get for the process $\gamma\gamma \to \tau^+\tau^-$ at the CLIC could increase the sensitivity on anomalous electromagnetic dipole moments of tau-lepton with respect to the existing experimental bounds by two orders of magnitude. The best sensitivities obtained on $a_\tau$ and $d_\tau$ ware $-0.00012 \leq a_\tau \leq 0.00014$ and $|d_\tau(ecm)| = 7.445 \times 10^{-19}$ [6].

Furthermore, there has been extensive theoretical work done in new physics beyond de Standard Model that contributes to dipole moments of tau-lepton: Left-right symmetric model [16], $E_6$ superstring models [17], simplest little Higgs model [18], and 331 model [19]. Other limits on the MM and EDM of the $\tau$-lepton are reported in Refs. [11, 12, 13, 20, 21, 22, 23, 24].
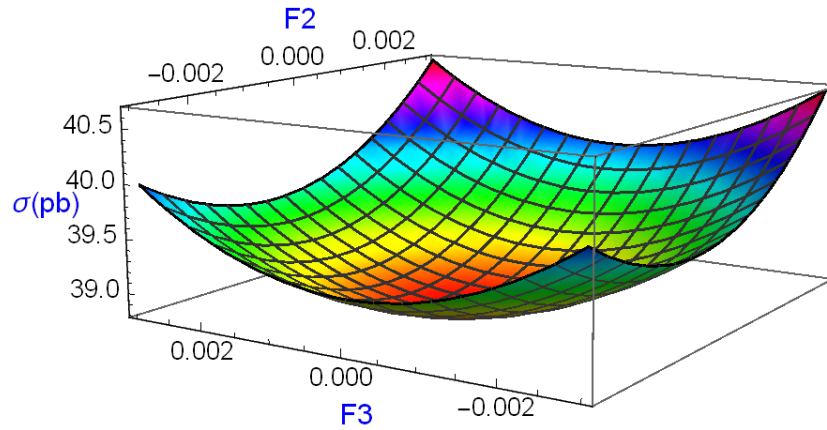
Figure 2: The total cross sections of the process $\gamma\gamma \to \tau^+\tau^-$ as a function of $F_2$ and $F_3$ for center-of-mass energy of $\sqrt{s} = 380$ GeV.
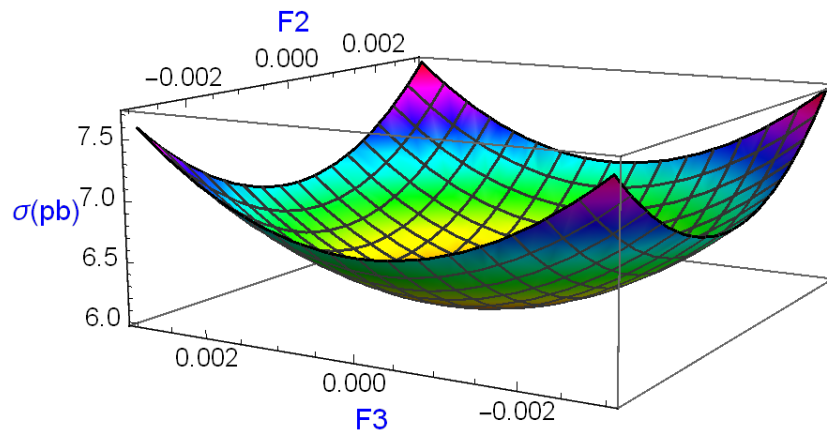
Figure 3: The same as in Figure 2, now for $\sqrt{s} = 1500$ GeV.
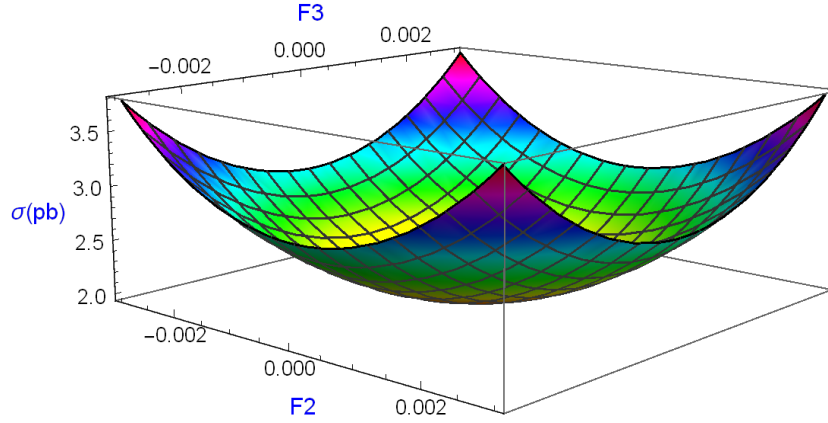
Figure 4: The same as in Figure 3, now for $\sqrt{s} = 3000$ GeV.
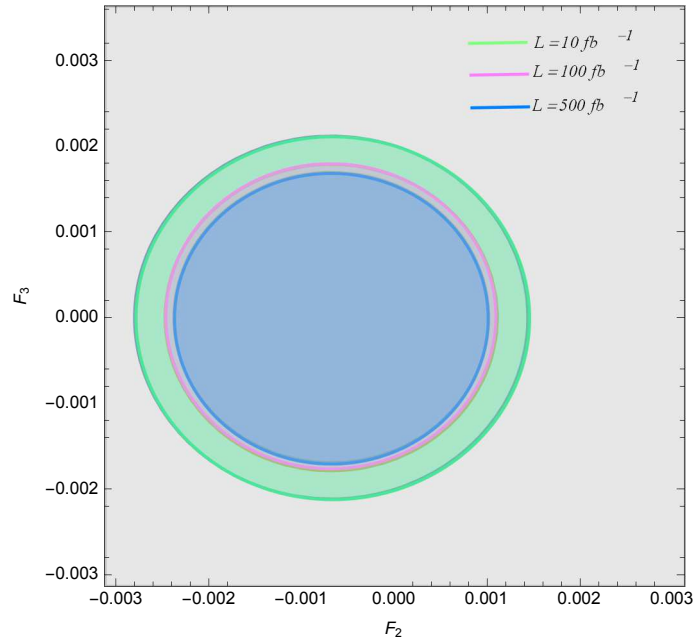
Figure 5: Bounds contours at the 95% C.L. in the $(F_2 - F_3)$ plane for the process $\gamma\gamma \to \tau^+\tau^-$ with the $\mathcal{L} = 10, 100, 500\, bf^{-1}$ and for center-of-mass energy of $\sqrt{s} = 380$ GeV.
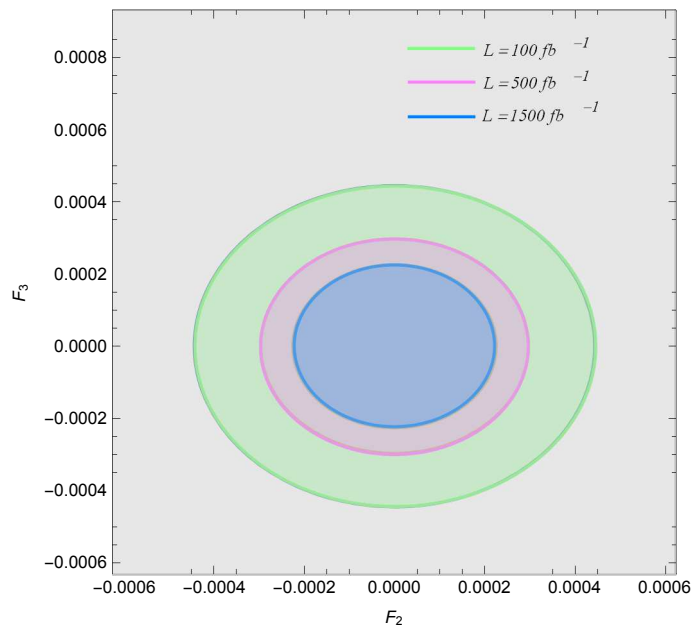
Figure 6:   The same as in Figure 5, now for $\mathcal{L} = 100, 500, 1500 \, bf^{-1}$ and for center-of-mass energy of $\sqrt{s} = 1500$ GeV.
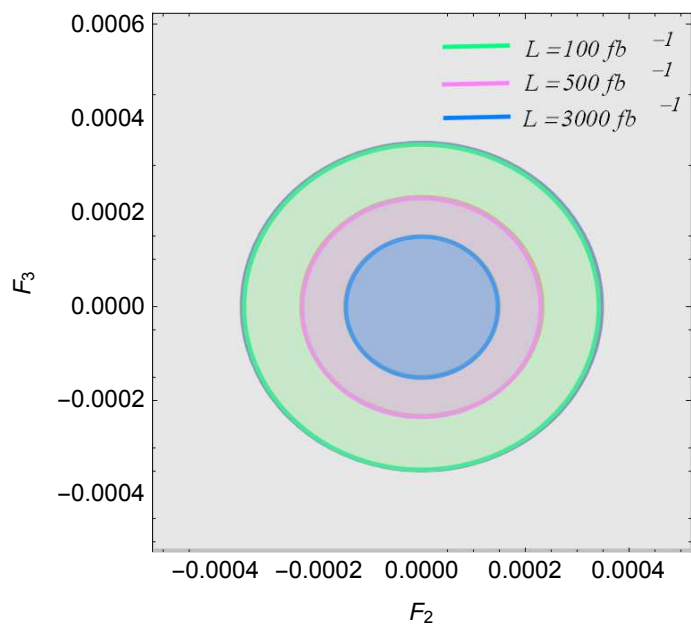
Figure 7: The same as in Figure 6, now for $\mathcal{L} = 100, 500, 3000 \, bf^{-1}$ and for center-of-mass energy of $\sqrt{s} = 3000$ GeV.

# 4 Conclusion

In conclusion, we have shown that the $\gamma\gamma \to \tau^+\tau^-$ process at the CLIC leads to an improvement in the existing sensitivity estimates on the $a_\tau$ and $d_\tau$. We present an optimistic scenario regarding the potencial precision, energy, and luminosity that may be achievable at the future $e^+e^-$ colliders. For the process $\gamma\gamma \to \tau^+\tau^-$ we obtain $3.466 \times 10^2$ for the upper sensitivity and $0.764 \times 10^2$ for the lower sensitivity, showing an improvement when compared to the results published by the DELPHI and BELLE Collaborations [1, 4].

# Acknowledgements

M. A. H. R. and A. G. R. acknowledges support from SNI and PROFOCIE (México).

# A References

# References

[1] J. Abdallah, *et. al.*, [DELPHI Collaboration], *Eur. Phys. J.* **C35**, 159 (2004).

[2] M. Acciarri, *et. al.*, [L3 Collaboration], *Phys. Lett.* **B434**, 169 (1998).

[3] K. Ackerstaff, *et. al.*, [OPAL Collaboration], *Phys. Lett.* **B431**, 188 (1998).

[4] K. Inami, *et al.*, [BELLE Collaboration], *Phys. Lett.* **B551**, 16 (2003).

[5] H. Albrecht, *et al.*, [ARGUS Collaboration], *Phys. Lett.* **B485**, 37 (2000).

[6] M. Köksal, A. A. Billur, A. Gutiérrez-Rodríguez and M. A. Hernández-Ruíz, Phys. Rev. D **98** (2018) no.1, 015017.

[7] S. Eidelman and M. Passera, *Mod. Phys. Lett.* **A22**, 159 (2007);

[8] J. A. Grifols and A. Méndez, *Phys. Lett.* **B255**, 611 (1991);

[9] R. Escribano and E. Massó, *Phys. Lett.* **B395**, 369 (1997);

[10] C. Giunti and A. Studenkin, *Rev. Mod. Phys.* **87**, 531(2015).

[11] M. Köksal, S. C. Inan, A. A. Billur, M. K. Bahar, Y. Özgüven, arXiv:1711.02405 [hep-ph].

[12] Y. Özgüven, S. C. Inan, A. A. Billur, M. Köksal, M. K. Bahar, *Nucl. Phys.* **B923**, 475 (2017).

[13] A. A. Billur, M. Köksal, *Phys. Rev. D89*, 037301 (2014).

[14] I. Sahin and M. Koksal, JHEP **03**, 100 (2011).

[15] P. Achard, *et al.*, [L3 Collaboration], *Phys. Lett.* **B585**, 53 (1998).

[16] A. Gutiérrez-Rodríguez, M. A. Hernández-Ruíz and L.N. Luis-Noriega, *Mod. Phys. Lett.* **A19**, 2227 (2004).

[17] A. Gutiérrez-Rodríguez, M. A. Hernández-Ruíz and M. A. Pérez, *Int. J. Mod. Phys.* **A22**, 3493 (2007).

[18] A. Gutiérrez-Rodríguez, *Mod. Phys. Lett.* **A25**, 703 (2010).

[19] A. Gutiérrez-Rodríguez, M. A. Hernández-Ruíz, C. P. Castañeda-Almanza, *J. Phys.* **G40**, 035001 (2013).

[20] S. Eidelman, D. Epifanov, M. Fael, L. Mercolli, M. Passera, *JHEP* **1603**, 140 (2016).

[21] A. Gutiérrez-Rodríguez, M. A. Hernández-Ruíz, L. N. Luis-Noriega, *J. Phys. Conf. Ser.* **37**, 25 (2006).

[22] M. Passera, *Nucl. Phys. Proc. Suppl.* **169**, 213 (2007).

[23] M. Passera, *Phys. Rev.* **D75**, 013002 (2007).

[24] A. Gutiérrez-Rodríguez, *et al.*, *Nucl. Phys. Proc. Suppl.* **253-255**, 202 (2014).