Electromagnetic dipole moments of the τ-lepton at the ILC and CLIC

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Abstract

We quantify the anomalous magnetic moment and electric dipole moment of the τ-lepton through the process $e^+e^- \to \tau^+\tau^-\gamma$, within the ranges of energies and luminosities affordable at the future International Linear Collider (ILC) and the Compact Linear Collider (CLIC). The tau-lepton is a key particle in various Beyond the Standard Model (BSM) models and is considered a laboratory for many experimental or simulation aspects in searches for new physics. In particular, the tau-lepton anomalous couplings to bosons in the $\tau^+\tau^-\gamma$ and $\tau^+\tau^-Z$ vertices, have made the tau-lepton one of the most attractive particles for new physics searches.

1 Introduction

The anomalous electromagnetic dipole moments of charged leptons provide very precise tests of quantum electrodynamics. In addition, the Standard Model (SM) predictions can also be confronted with these properties, that is these particles can help both to test the SM and to find new physics. The study of the magnetic and electric dipole moments of the tau-lepton gains special interest due to a hint of possible new physics BSM.

The main purpose is to quantify the Anomalous Magnetic Moment (AMM) and the Electric Dipole Moment (EDM) of the τ-lepton through the process $e^+e^- \to \tau^+\tau^-\gamma$, framed in the $SU(4)_L \times U(1)_X$ electroweak model [1, 2, 3, 4], within the ranges of energies and luminosities affordable at the ILC and CLIC linear colliders.

2 The $SU(4)_L \times U(1)_X$ electroweak model

The $SU(4)_L \times U(1)_X$ electroweak model [1, 2, 3], and the minimal $SU(4)_L \times U(1)_X$ electroweak model [4]. The $SU(4)_L \times U(1)_X$ symmetry is a natural extension of the $SU(3)_C \times SU(3)_L \times U(1)_X$ symmetry. The leptonic structure for the $SU(4)_L \times U(1)_X$ model is given by Eq. (1).

$$\mathbf{f}_{aL} = (\nu_a, l_a, l_a^c, \nu_a^c)_L^T \sim (1, 4, 0), \quad a = e, \mu, \tau \tag{1}$$

where c denotes the electric charge of extra leptons, $\nu_L^c \equiv (\nu_R)^c$ and the charge conjugation of f_{aL} is

$$\mathbf{f}_{aR}^c = (f_{aL})^= (\nu_{aR}^c, l_{aR}^c, l_{aR}, \nu_{aR})^T. \tag{2}$$

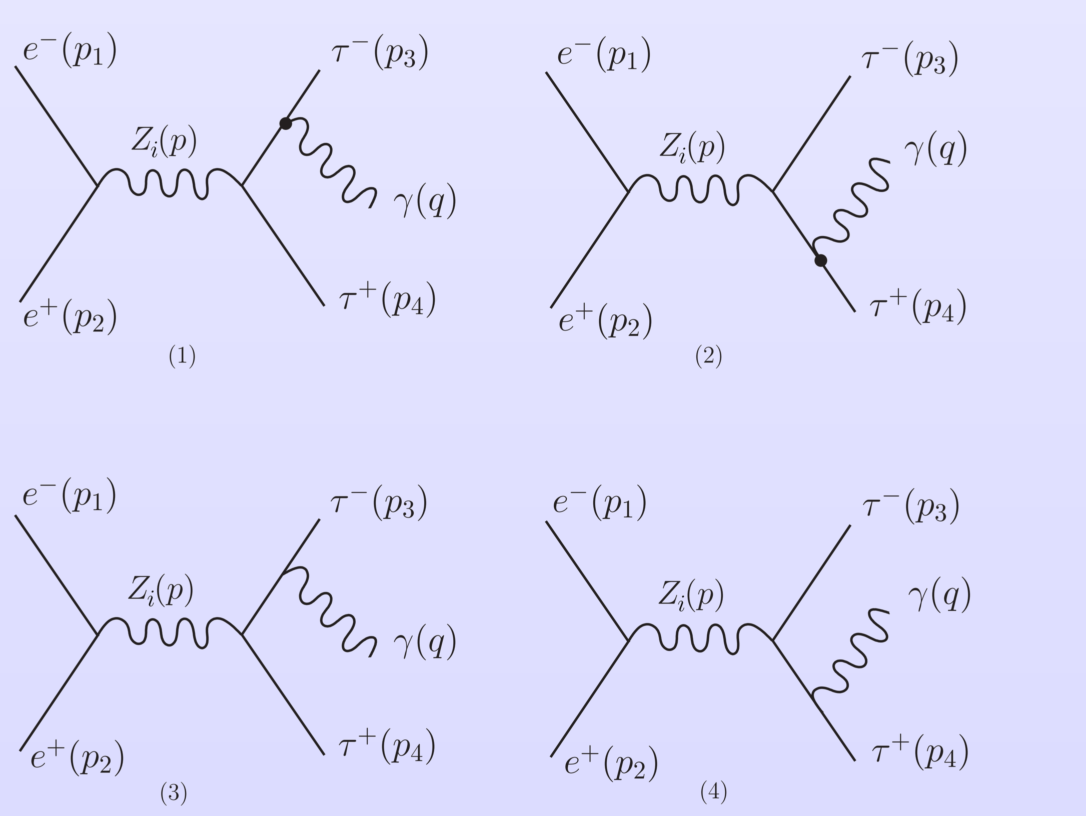

FIG. 1: The Feynman diagrams contributing to the signal process $e^+e^- \to \tau^+\tau^-\gamma$ when the Z_i vector bosons are produced on mass-shell. New physics (represented by a black circle) in the electroweak sector can modify the $\tau^+\tau^-\gamma$ couplings.

3 Cross-section for the reaction $e^+e^- \to \tau^+\tau^-\gamma$

We calculate the cross-section for the reaction $e^-(p_1)e^+(p_2) \to \tau^-(p_3)\tau^+(p_4)\gamma(q)$ using the neutral current lagrangian for the $SU(4)_L \times U(1)_X$ model for the Feynman diagrams of Fig. 1. Since the model predicts the existence of two new neutral gauge bosons Z_2 and Z_3, the respective transition amplitudes

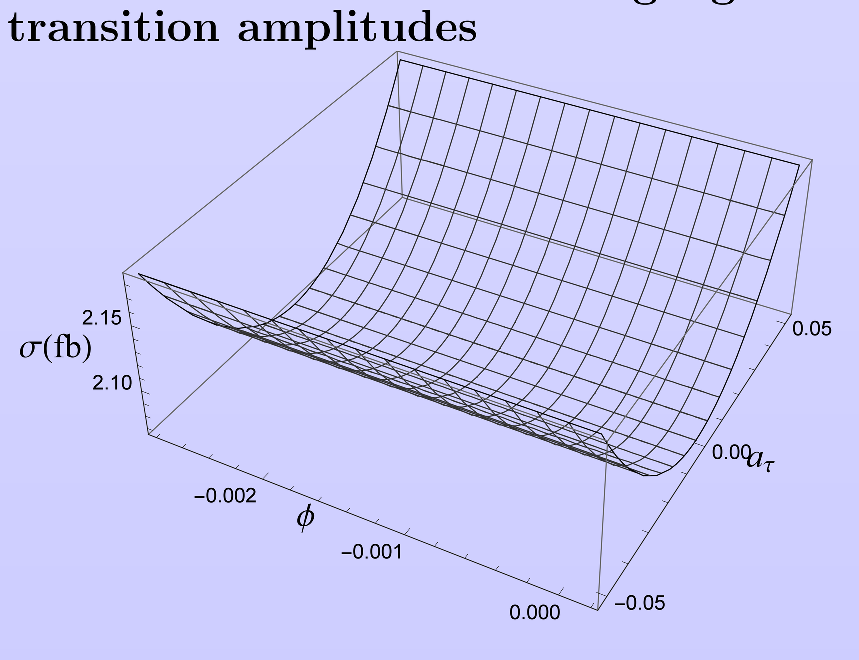

FIG. 2: The surface shows the shape for the cross-section of the process $e^+e^- \to \tau^+\tau^-\gamma$ as a function of AMM a_τ and the mixing angle ϕ with $\sqrt{s} = 3000$ GeV.

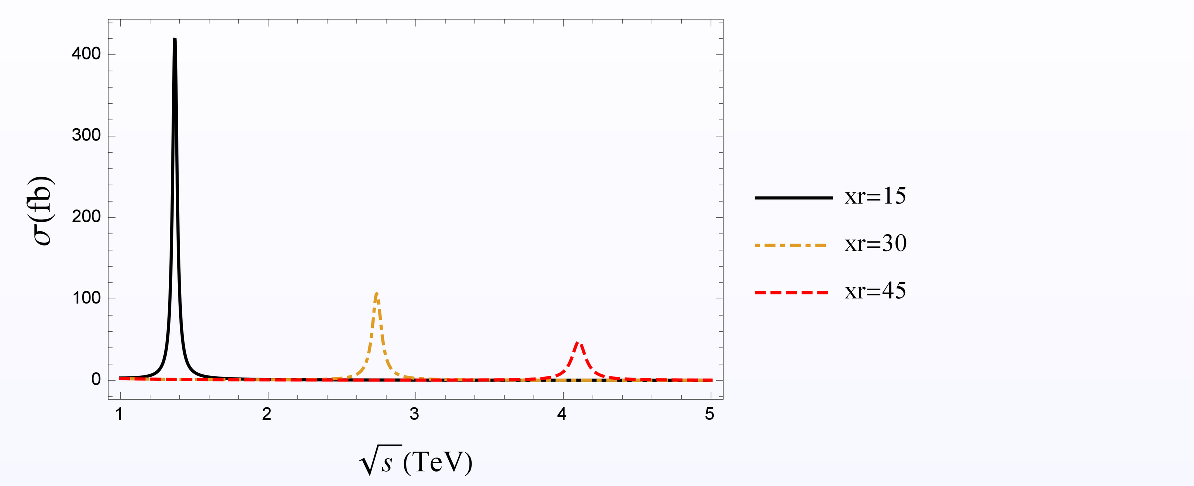

FIG. 3: The total cross-section of the production process $e^+e^- \to \tau^+\tau^-\gamma$ as a function of $\sqrt{s}$ for $x_r = 15$ (solid line), $x_r = 30$ (dot-dashed line) and $x_r = 45$ (dashed line).

4 Results and Conclusion

We consider the following pertinent approximations, (i) we approximate the mass of the two new neutral gauge bosons are of the same order, $M_{Z_2} \approx M_{Z_3}$. In this way, their decay rate is approximately of the same order $\Gamma_{Z_2} \approx \Gamma_{Z_3}$. (ii) The mass of Z_2, Z_3 bosons can be approximated as $M_{Z_{2,3}} = x_r M_{Z_1}$ with $x_r = \frac{M_{Z_2}}{M_{Z_1}}$, and the decay width of the Z_2, Z_3 bosons are approximated as: $\Gamma_{Z_{2,3}} = x_r \Gamma_{Z_1}$. The mass range of the new neutral gauge bosons investigated is $\mathcal{O}(1.3 - 3.9)$ TeV [5, 6], which is equivalent to $x_r\,\epsilon\,[15, 40]$.

TABLE 1: Benchmark parameters of the ILC and CLIC based e^+e^- colliders [7, 8, 9, 10].

ILC	$\sqrt{s}$(TeV)	$\mathcal{L}$(fb^{-1})
Phase I	0.250	10, 100, 250, 500, 1000
Phase II	0.5	10, 100, 250, 500, 1000
Phase III	1	10, 100, 250, 500, 1000
CLIC	$\sqrt{s}$(TeV)	$\mathcal{L}$(fb^{-1})
Phase I	0.380	100, 250, 500, 800, 1000
Phase II	1.5	100, 500, 1000, 2000, 3000
Phase III	3	100, 500, 1000, 3000, 5000

In our numerical analysis, we obtain the total cross-section for the $e^+e^- \to \tau^+\tau^-\gamma$ signal, that is $\sigma_{Tot} = \sigma_{Tot}(a_\tau, d_\tau, \sqrt{s}, x_r, \phi)$. Thus, in our numerical computation, we will assume that $\sqrt{s}$, x_r and ϕ are free parameters.

4.1 Conclusion

we have studied the phenomenology of the cross-section of the $e^+e^- \to \tau^+\tau^-\gamma$ signal, as well as the sensitivity on the AMM a_τ and the EDM d_τ of the tau-lepton in the model based on the $SU(4)_L \times U(1)_X$ symmetry. The sensitivity limits on the electromagnetic dipole moments were estimated for future e^+e^- linear colliders ILC and CLIC with center-of-mass energies of $\sqrt{s} = 250 - 3000$ GeV and integrated luminosities of $\mathcal{L} = 250 - 5000$ fb^{-1}. We find that the sensitivity bounds on the a_τ and d_τ at the ILC and CLIC at high energy and high luminosity can reach a sensitivity of the order of $\mathcal{O}(10^{-3} - 10^{-1})$ and $\mathcal{O}(10^{-17})$(ecm) at 95% C.L., respectively.

Our results do not appear outside the realm of detection in future experiments with improved sensitivity. In addition, a fiducial contribution is that our analytical and numerical results for the total cross-section have not been reported before in the literature and could be of relevance for the scientific community.

Acknowledgments

We acknowledge support of the Organizing Committee of the 41st International Conference on High Energy Physics (ICHEP 2022), Bologna, Italy.

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