Sensitivity estimates on anomalous couplings of the tau-lepton in pp, e^-p and e^+e^- colliders

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Abstract

We explore the discovery prospect of the pp, e^-p and e^+e^- colliders at the LHC, FCC-he and CLIC for model-independent sensitivity estimates on the dipole moments of the τ-lepton $\tilde{a}_\tau$ and $\tilde{d}_\tau$. We consider the channels $pp \to p\tau^+\tau^-\gamma p$, $e^-p \to e^-\tau^+\tau^-\gamma p$ and $e^+e^- \to e^+\tau^+\tau^-\gamma e^-$. Bounds on the dipole moments of the τ-lepton $\tilde{a}_\tau$ and $\tilde{d}_\tau$ are obtained: $\tilde{a}_\tau = (-0.00674, 0.00658)$, $|\tilde{d}_\tau(\mathrm{ecm})| = 3.6925 \times 10^{-17}$ [LHC]; $\tilde{a}_\tau = (-0.00265, 0.00246)$, $|\tilde{d}_\tau(\mathrm{ecm})| = 1.4379 \times 10^{-17}$ [FCC-he] and $\tilde{a}_\tau = (-0.00128, 0.00105)$, $|\tilde{d}_\tau(\mathrm{ecm})| = 6.4394 \times 10^{-18}$ [CLIC]. The sensitivity of CLIC show a potential advantage compared to those from LHC and FCC-he.

1 Introduction

The study of the τ-lepton by the ATLAS and CMS Collaborations at the Large Hadron Collider (LHC) has developed significantly in recent years and now represents a very active physics program.
The future ep colliders, such as the Large Hadron Electron Collider (LHeC) [1] and the Future Circular Collider Hadron Electron (FCC-he) [2, 1, 3, 4], are a hybrid between the pp and e^+e^- colliders and will complement the physics program of the LHC.
In this work, we have based our study on three phenomenological analyses for finding physics beyond the Standard Model (BSM) at present and future colliders in order to compare the electromagnetic properties of the τ-lepton. We consider pp collisions at the LHC with 13, 14 TeV and luminosities 10, 30, 50, 100, 200 fb^{-1}. Another scenario is the FCC-he with 7.07, 10 TeV and $\mathcal{L} = 100, 300, 500, 700, 1000\, fb^{-1}$. The CLIC at CERN is another option with 1.5, 3 TeV and assumed luminosities 100, 300, 500, 1000, 1500, 2000, 3000 fb^{-1}.

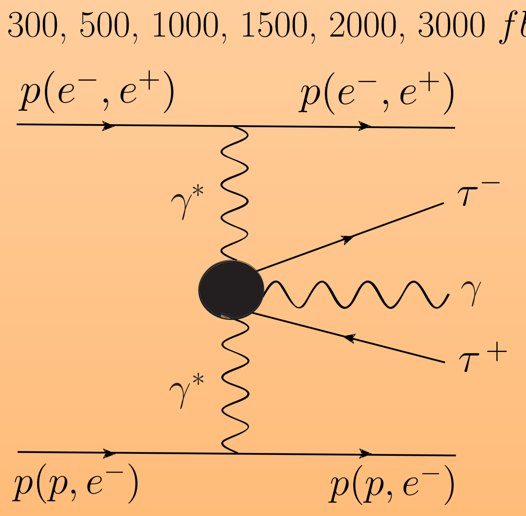

FIGURE 1: A schematic diagram for the processes $pp(e^-p, e^+e^-) \to p\tau\bar{\tau}\gamma p(e^-\tau\bar{\tau}\gamma p, e^+\tau\bar{\tau}\gamma e^-)$.

2 The total cross-sections in pp, e^-p and e^+e^- colliders

The most general expression for the vertex of interaction $\tau\bar{\tau}\gamma$ is given by [5, 6, 7, 8]:

$$\Gamma^\alpha_\tau = eF_1(q^2)\gamma^\alpha + \frac{ie}{2m_\tau}F_2(q^2)\sigma^{\alpha\mu}q_\mu + \frac{e}{2m_\tau}F_3(q^2)\sigma^{\alpha\mu}q_\mu\gamma_5 + eF_4(q^2)\gamma_5\left(\gamma^\alpha - \frac{2q^\alpha m_\tau}{q^2}\right) \tag{1}$$

We evaluate the total cross-sections $\sigma(pp \to p\tau\bar{\tau}\gamma p)$, $\sigma(e^-p \to e^-\tau\bar{\tau}\gamma p)$ and $\sigma(e^+e^- \to e^+\tau\bar{\tau}\gamma e^-)$ and to probe the dipole moments $\tilde{a}_\tau$ and $\tilde{d}_\tau$, with the potential of LHC, FCC-he and CLIC based $\gamma^*\gamma^*$ colliders . Furthermore, in order to suppress the backgrounds and optimize the signal sensitivity, we impose the following kinematic basic acceptance cuts for $\tau^+\tau^-\gamma$ events at the LHC, FCC-he and CLIC:

$$\begin{aligned} p^\gamma_t &> 20GeV, \quad |\eta^\gamma| < 2.5, \\ p^{\tau^+,\tau^-}_t &> 20GeV, \quad |\eta^{\tau^+,\tau^-}| < 2.5, \\ \Delta R(\tau^-, \gamma) &> 0.4, \\ \Delta R(\tau^+, \tau^-) &> 0.4, \\ \Delta R(\tau^+, \gamma) &> 0.4. \end{aligned} \tag{2}$$

2.1 Cross-section of the $pp \to p\gamma^*\gamma^*p \to p\tau^+\tau^-\gamma p$ signal at the LHC

The total cross-section of the $pp \to p\gamma^*\gamma^*p \to p\tau^+\tau^-\gamma p$ signal as a function of the anomalous parameters κ and $\tilde{\kappa}$ are given in Figs. 2 and 3.

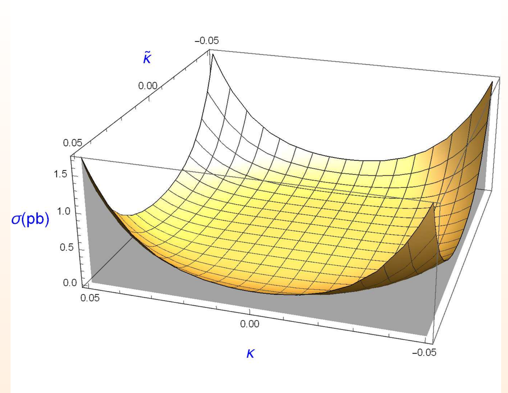

FIGURE 2: The total cross-sections of the process $pp \to p\tau\bar{\tau}\gamma p$ as a function of κ and $\tilde{\kappa}$ for center-of-mass energy of $\sqrt{s} = 13TeV$ at the LHC.

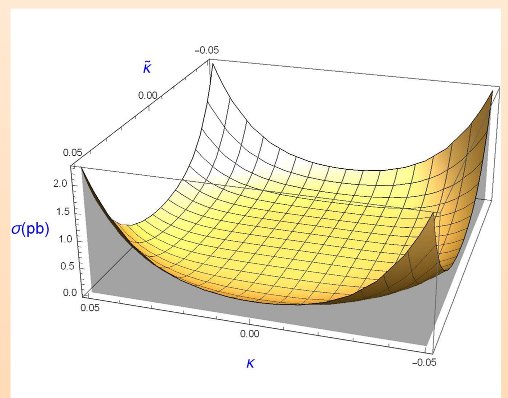

FIGURE 3: Same as in Fig. 2, but for center-of-mass energy of $\sqrt{s} = 14TeV$.

2.2 Cross-section of the $e^-p \to e^-\gamma^*\gamma^*p \to e^-\tau^+\tau^-\gamma p$ signal at FCC-he

The total cross-section of the process $e^-p \to e^-\gamma^*\gamma^*p \to e^-\tau^+\tau^-\gamma p$ as a function of the two independent anomalous couplings κ and $\tilde{\kappa}$, with 7.07 and 10 TeV at FCC-he is given in Figs. 4 and 5.

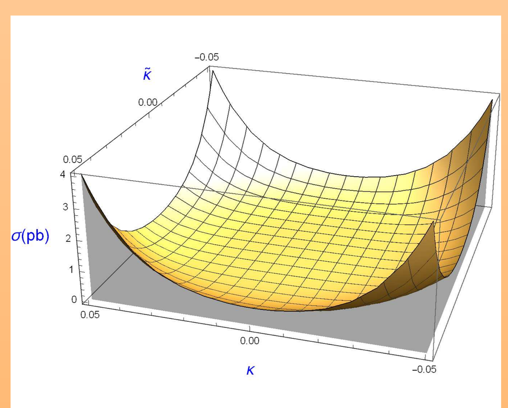

FIGURE 4: The total cross-sections of the process $e^-p \to e^-\tau\bar{\tau}\gamma p$ as a function of κ and $\tilde{\kappa}$ for center-of-mass energy of $\sqrt{s} = 7.07TeV$ at the FCC-he.

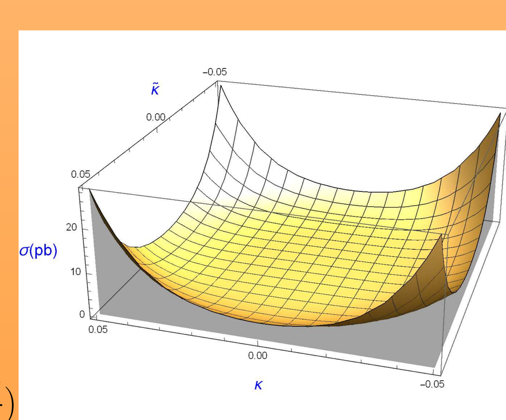

FIGURE 5: Same as in Fig. 4, but for $\sqrt{s} = 10TeV$.

2.3 Cross-section of the $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\tau^+\tau^-\gamma e^-$ signal at CLIC

The total cross-section for the $e^+e^- \to e^+\gamma^*\gamma^*e^- \to e^+\tau^+\tau^-\gamma e^-$ processes at CLIC is given in followings figures:

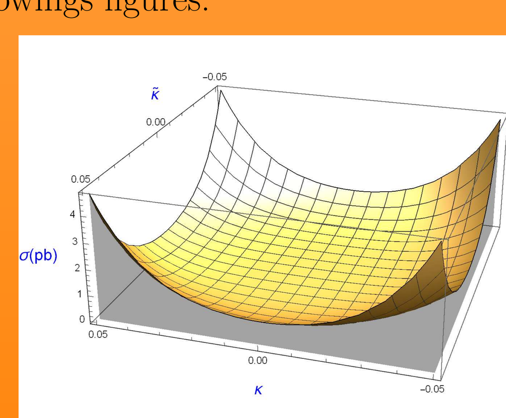

FIGURE 6: The total cross-sections of the process $e^+e^- \to e^+\tau\bar{\tau}\gamma e^-$ as a function of κ and $\tilde{\kappa}$ for center-of-mass energy of $\sqrt{s} = 1.5TeV$ at the CLIC.

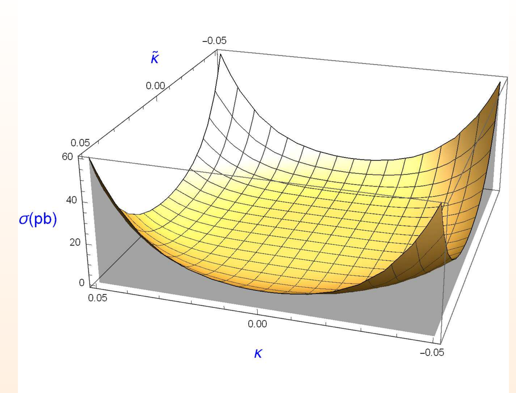

FIGURE 7: Same as in Fig. 17, but for $\sqrt{s} = 3TeV$.

$$-0.052 < a_\tau < 0.013, \quad 95\%\mathrm{C.L}, \quad \mathrm{DELPHI} \tag{3}$$

$$-0.052 < a_\tau < 0.058, \quad 95\%\mathrm{C.L}, \quad \mathrm{L3} \tag{4}$$

$$-0.068 < a_\tau < 0.065, \quad 95\%\mathrm{C.L}, \quad \mathrm{OPAL} \tag{5}$$

$$-2.2 < Re(d_\tau(10^{-17}ecm)) < 4.5, \quad 95\%\mathrm{C.L}, \quad \mathrm{BELLE} \tag{6}$$

$$-0.22 < d_\tau(10^{-16}ecm)) < 0.45, \quad 95\%\mathrm{C.L}, \quad \mathrm{DELPHI} \tag{7}$$

$$|Re(d_\tau(10^{-16}ecm))| < 3.1, \quad 95\%\mathrm{C.L}, \quad \mathrm{L3} \tag{8}$$

$$|Re(d_\tau(10^{-16}ecm))| < 3.7, \quad 95\%\mathrm{C.L}, \quad \mathrm{OPAL} \tag{9}$$

3 Conclusions

In conclusion, with 300 fb^{-1} of data that will be collected by LHC, a sensitivity of $\tilde{a}_\tau = (-0.0067, 0.0065)$, 95% C.L. can be achieved for the τ-lepton, and $|\tilde{d}_\tau| = 3.692 \times 10^{-17}$ecm, 95% C.L. can be achieved for the EDM. In the case of the FCC-he, with 1000 fb^{-1}, it is possible to obtain a sensitivity of $\tilde{a}_\tau = (0.00265, 0.00246)$ and $|\tilde{d}_\tau| = 1.437 \times 10^{-17}$ecm at 95% C.L.. While for the CLIC, the projections with 3000 fb^{-1} of data that will be collected are $\tilde{a}_\tau = (0.00128, 0.00105)$ and $|\tilde{d}_\tau| = 6.439 \times 10^{-18}$ecm, at 95% C.L.. The precision of the τ-lepton is about 39% of the SM prediction. Thus, in this framework and with the large amount of data collected at current and future colliders, BSM can be constrained much better than before. In summary, the future CLIC at high energy and high luminosity should provide the best sensitivity on the MDM and EDM of the τ-lepton and shows a potential advantage compared to those from LHC and FCC-he [9].

Acknowledgments

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