CP-violating anomalous interactions at Large Hadron Collider

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Abstract

In this study, we explore the effects of CP-violating anomalous interactions of the top-quark through the semileptonic decay modes of the top-quark arising due to pair-production of $t\bar{t}$ at the Large Hardon Collider. Predictions on the LHC sensitivities of the coupling strength to such CP-violating interactions would be discussed for the 13 TeV LHC data and for the future hadron collider with 14 TeV energy.

Introduction

The Standard-Model (SM) [1] of particle physics is a remarkably successful theory that explains most of the observations and data collected in experiments. However, SM is unable to explain CP-violation [2], leptogenesis [3] , bariogenesis [4], non-zero neutrino mass, etc. Therefore SM extensions are needed to explain some or all of these problems. The observed amount of CP-violation in the SM is too small to explain the current matter–antimatter asymmetry. Therein lies the importance of CP-violation searches because its presence would be a clear indication of physics Beyond-the-SM (BSM).

The present study explores the T-odd interactions of top-quark with gluon at the LHC and its luminosity intense varient, HL-LHC by constructing the effective Lagrangian of higher dimension which modifies the SM Lagrangian by the following additional term [5],

$$\mathcal{L}_{int} = -i\frac{g_s}{2}\left(\frac{d_g}{\Lambda}\right)\bar{t}\sigma_{\mu\nu}\gamma_5\, G^{\mu\nu}\, t, \tag{1}$$

with g_s, $G^{\mu\nu}$, d_g, Λ are the strong coupling constant, gluon field-strength tensor, interaction strength, energy scale of the CP -violation respectively and $\sigma_{\mu\nu} = 2i[\gamma_\mu,\gamma_\nu]$.

CP-odd correlations

We study the CP-properties of anomalous couplings in the context of top-quark via the top-pair production process $pp \to t\bar{t}$ followed by the semileptonic decay into $(bl^+\nu_l)(\bar{b}l^-\bar{\nu}_l)$ at the LHC with $\sqrt{S} = 13$ TeV and HL-LHC with $\sqrt{S} = 14$ TeV using the T-odd observables.

We work within the framework of Standard Model effective field theory (SMEFT) and consider the following admissible T-odd correlations induced by anomalous top-quark couplings:

$$\begin{aligned}
\mathcal{C}_1 &= \epsilon(p_b,p_{\bar{b}},p_{l^+},p_{l^-})\\
\mathcal{C}_2 &= \tilde{q}\cdot(p_{l^+}-p_{l^-})\ \epsilon(p_{l^+},p_{l^-},p_b+p_{\bar{b}},\tilde{q})\\
\mathcal{C}_3 &= \tilde{q}\cdot(p_{l^+}-p_{l^-})\ \epsilon(p_b,p_{\bar{b}},p_{l^+}+p_{l^-},\tilde{q})\\
\mathcal{C}_4 &= \epsilon(P,p_b-p_{\bar{b}},p_{l^+},p_{l^-})\\
\mathcal{C}_5 &= \epsilon(p_b+p_{l^+},p_{\bar{b}}+p_{l^-},p_b+p_{\bar{b}},p_{l^+}-p_{l^-}),
\end{aligned} \tag{2}$$

where $\epsilon(a,b,c,d) = \epsilon_{\mu\nu\alpha\beta}a^\mu b^\nu c^\alpha d^\beta$ with $\epsilon_{\mu\nu\alpha\beta}$ being the Levi-Civita symbol of rank 4. The significance of the above observables lies in the fact that they neither require any information about the spin of the produced particles nor the reconstruction of the produced top-quarks.

The CP-violation asymmetry for the respective observables presented in the above equation is obtained using the following formula,

$$\mathcal{A}_{CP} = \frac{N(\mathcal{C}_i > 0) - N(\mathcal{C}_i < 0)}{N(\mathcal{C}_i > 0) + N(\mathcal{C}_i < 0)}, \tag{3}$$

Results

Figure 1 – d_g vs. Λ for observable $\mathcal{C}_1$ at $\sqrt{S} = 13$ TeV energy at LHC for an integrated luminosity of (a) 36.1 fb^{-1} and (b) 140 fb^{-1} respectively.

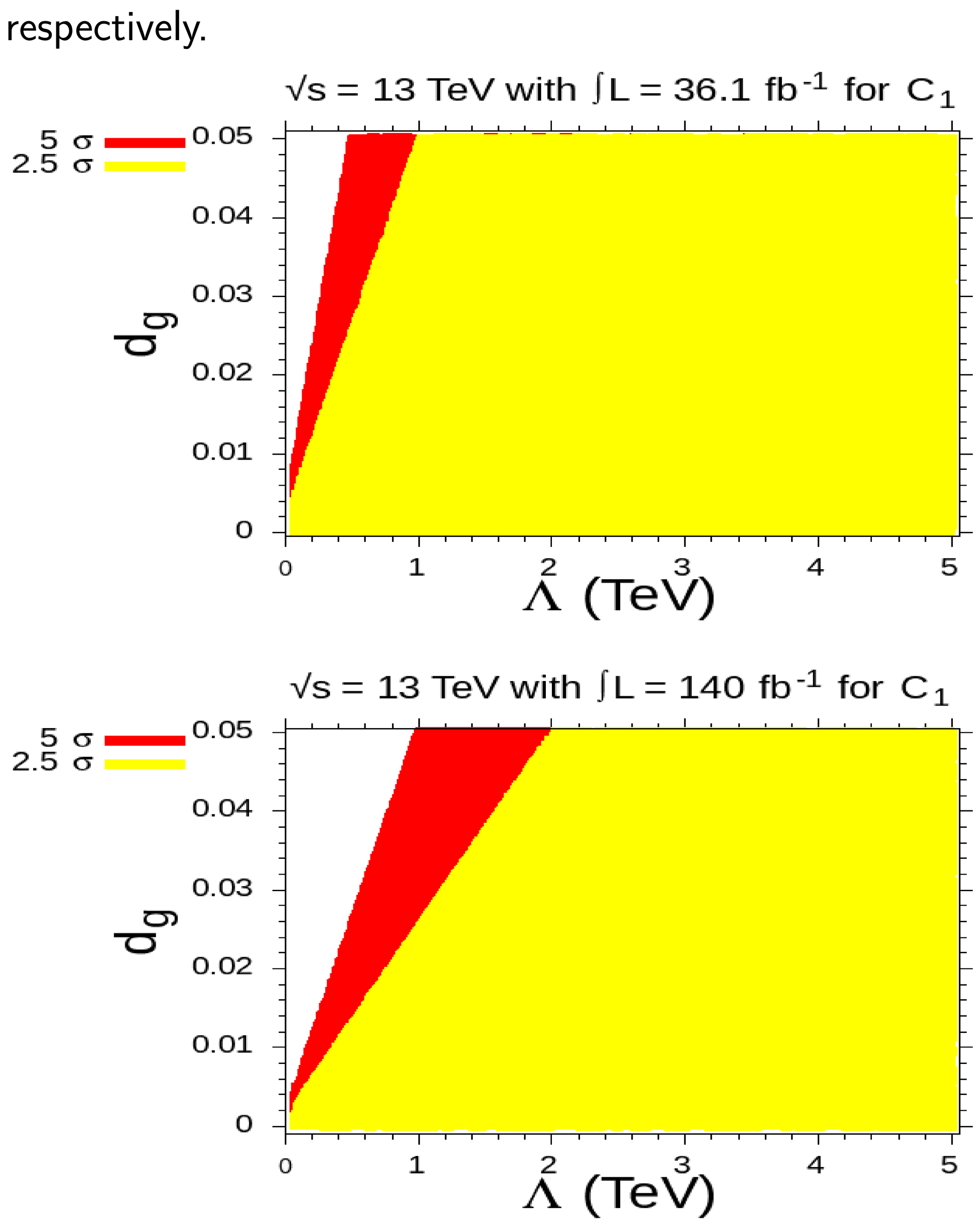


Figure 2 – d_g vs. Λ for observable $\mathcal{C}_1$ at $\sqrt{S} = 14$ TeV energy at LHC for an integrated luminosity of (a) 0.3 ab^{-1} and (b) 3 ab^{-1} respectively.

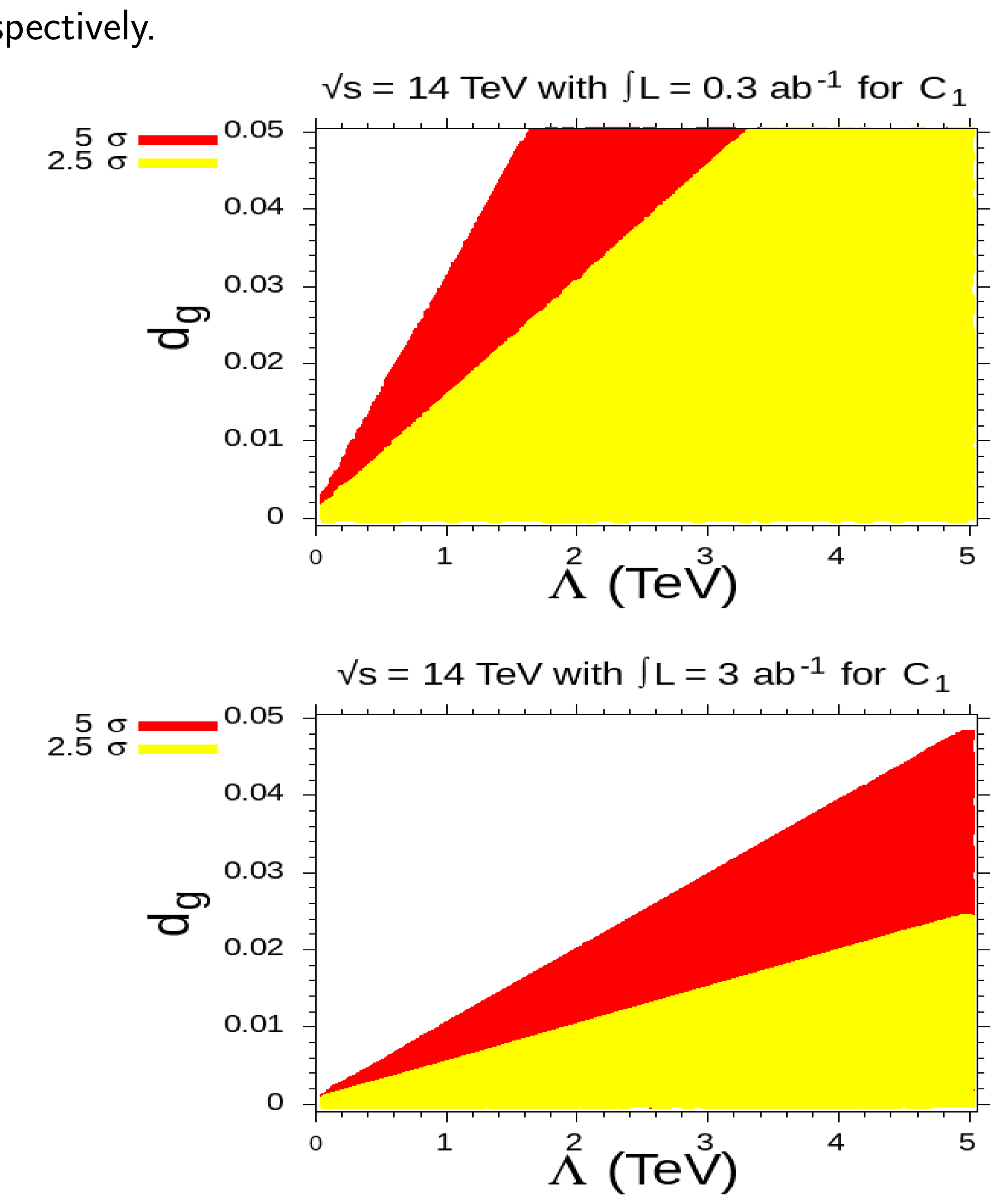
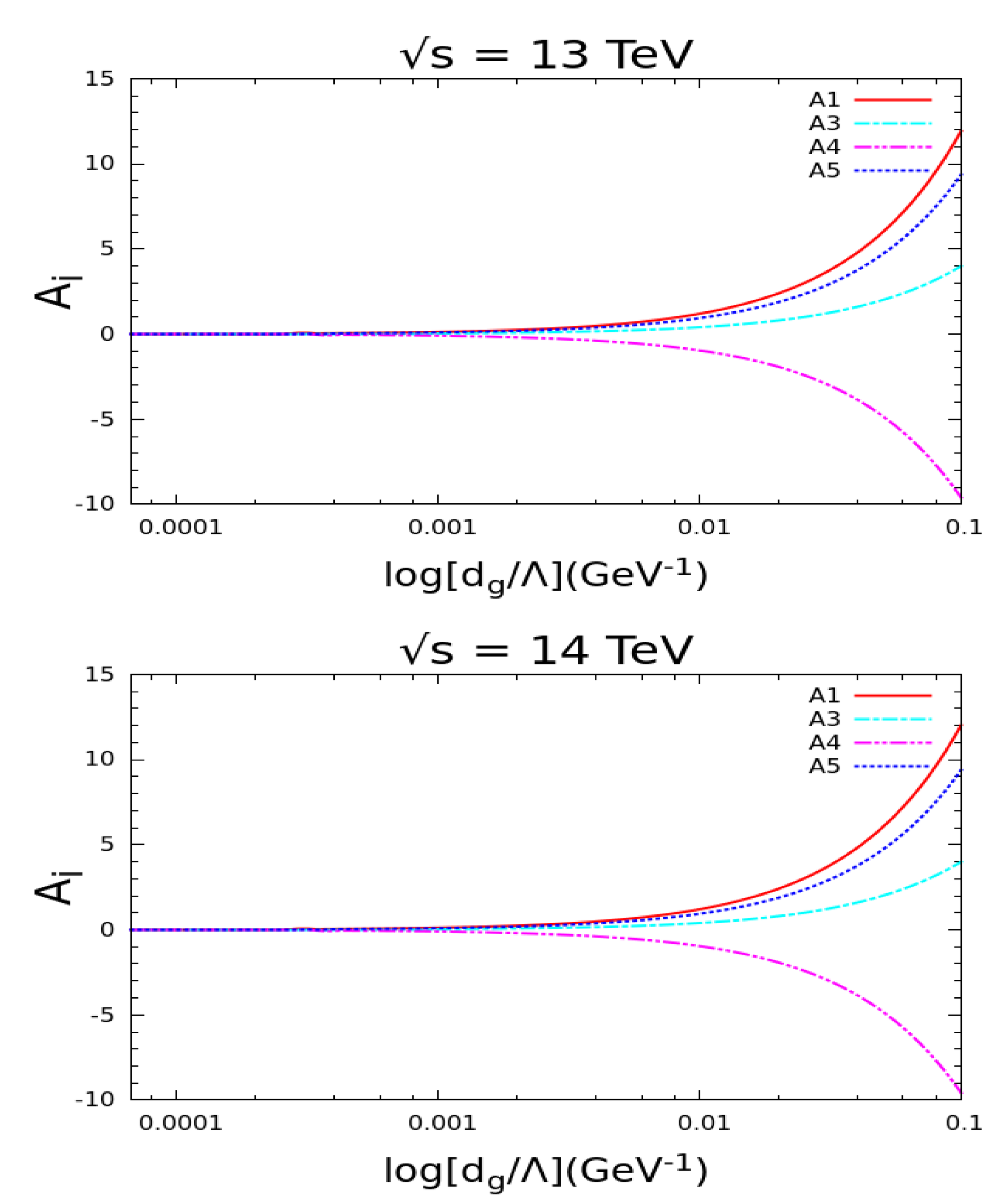


Figure 3 – Asymmetries vs. $\frac{d_g}{\Lambda}$ for $\sqrt{S} = 13$ TeV and 14 TeV energy at LHC.



Conclusions

- The largest asymmetry is A_1 which corresponds to the observable C_1.
- The upper bounds on $|\frac{d_g}{\Lambda}|$ for $\sqrt{S} = 13$ TeV with integrated luminosities of 36.1 fb^{-1}, 140 fb^{-1} would be of about $(0.29,0.05)\times 10^{-4}$ and $(0.6,0.2)\times 10^{-4}$ at 3 σ C.L. and 5 σ C.L. respectively.
- The corresponding bounds for High Luminosity LHC (HL-LHC) with $\sqrt{S} =$ 14 TeV for projected luminosities of 0.3 ab^{-1}, 3 ab^{-1} turned out to be of about $(0.04,0.14)\times 10^{-4}$ and $(0.06,0.1)\times 10^{-4}$ at 3 σ C.L. and 5 σ C.L. respectively.

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