Abstract

We study new physics contributions to CP-violating anomalous couplings of top-quark in the context of top-pair production and their consequent decays into a pair of dilepton and b-jets at the Large Hadron Collider. An estimate of sensitivities to such CP-violating interactions would also be discussed for the pre-existing 13 TeV LHC data and its projections for the proposed LHC run at 14 TeV.

Introduction

- The matter-antimatter asymmetry of the universe is one of the greatest mysteries of modern physics.
- Observation of CP-violation [1] will help to understand the matter-antimatter asymmetry of the universe.
- The Standard-Model [2] is a very rich and successful phenomenology and allows a tiny amount of CP-violation which is not sufficient to explain the matter-antimatter asymmetry of the universe. This indicates the need to explore beyond SM theories.
- Direct CP-violation could be observed through the top induced processes which are abundant at the LHC.
- In this study, we consider top-pair production through the process $pp \rightarrow t\bar{t}$, where the top and anti-top-quark further decays semileptonically into $(bl^+\nu_l)$ and $(\bar{b}l^-\bar{\nu}_l)$.
- We study the CP-violating effects in the top-pair production by constructing the T-odd observables.
- The CP-violating asymmetry is constructed using the formula

$$A_{CP} = \frac{N(C_i > 0) - N(C_i < 0)}{N(C_i > 0) + N(C_i < 0)},$$

(1)

A non-zero value of asymmetry would be a clear indication of the presence of CP-violation.

Lagrangian and Process

- The following anomalous interaction term modifies the SM Lagrangian in the presence of T-odd interactions of top-quark with gluon

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

(2)

- The figure represents Feynman diagrams responsible for top-quark pair production at the LHC.

Observables

We consider the following T-odd correlations:

$$C_1 = \epsilon(p_b, p_{\bar{b}}, p_{l^+}, p_{l^-})$$
$$C_2 = \bar{q} \cdot (p_{l^+} - p_{l^-}) \epsilon(p_{l^+}, p_{l^-}, p_b + p_{\bar{b}}, \bar{q})$$
$$C_3 = \bar{q} \cdot (p_{l^+} - p_{l^-}) \epsilon(p_b, p_{\bar{b}}, p_{l^+} + p_{l^-}, \bar{q})$$
$$C_4 = \epsilon(p_b + p_{l^+}, p_b + p_{l^+}, p_l^-)$$
$$C_5 = \epsilon(p_b + p_{l^+}, p_{l^-} + p_{l^-}, p_b + p_{\bar{b}}, p_{l^+} - p_{l^-}).$$

(3)
**Results**

The Figures show possible \( d_g - \Lambda \) space allowed at 2.5 \( \sigma \) and 5 \( \sigma \) respectively for the given C.M. energy and Luminosities.

**13 TeV LHC Energy**

\[
\begin{align*}
\sqrt{s} = 13\, \text{TeV} \quad \int L = 36.1\, \text{fb}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 13\, \text{TeV} \quad \int L = 140\, \text{fb}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 13\, \text{TeV} \quad \int L = 1\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 13\, \text{TeV} \quad \int L = 3\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\end{align*}
\]

**HL-LHC (14 TeV LHC energy)**

\[
\begin{align*}
\sqrt{s} = 14\, \text{TeV} \quad \int L = 0.3\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 14\, \text{TeV} \quad \int L = 1\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 14\, \text{TeV} \quad \int L = 2\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\sqrt{s} = 14\, \text{TeV} \quad \int L = 3\, \text{ab}^{-1} \quad \frac{d_g}{d\Lambda} &\quad \text{(in GeV}^{-1}) \\
\end{align*}
\]

**Conclusions**

- The present study achieved stringent bounds on CP-violating anomalous couplings of the top-quark.
- We have presented 5\( \sigma \) sensitivities for 13 TeV C.M. energy at LHC with the integrated luminosities of 36.1 fb\(^{-1}\), 140 fb\(^{-1}\) and predicted that we can achieve 5\( \sigma \) sensitivity at 14 TeV LHC energy with projected luminosities of 0.3 ab\(^{-1}\), 1 ab\(^{-1}\), 2 ab\(^{-1}\) and 3 ab\(^{-1}\). The results are summarised in the following table.

<table>
<thead>
<tr>
<th>(\sqrt{s} ) (TeV)</th>
<th>( \int L ) dt</th>
<th>( \frac{d_g}{d\Lambda} ) (in GeV(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>36.1 fb(^{-1})</td>
<td>0.29 ( \times ) 10(^{-4})</td>
</tr>
<tr>
<td>14</td>
<td>140 fb(^{-1})</td>
<td>0.52 ( \times ) 10(^{-5})</td>
</tr>
<tr>
<td>14 (HL-LHC)</td>
<td>0.3 ab(^{-1})</td>
<td>0.39 ( \times ) 10(^{-5})</td>
</tr>
<tr>
<td>14 (HL-LHC)</td>
<td>1.0 ab(^{-1})</td>
<td>0.11 ( \times ) 10(^{-4})</td>
</tr>
<tr>
<td>14 (HL-LHC)</td>
<td>2.0 ab(^{-1})</td>
<td>0.13 ( \times ) 10(^{-4})</td>
</tr>
<tr>
<td>14 (HL-LHC)</td>
<td>3.0 ab(^{-1})</td>
<td>0.14 ( \times ) 10(^{-4})</td>
</tr>
</tbody>
</table>

Table: Sensitivity to CP-violating anomalous couplings at 3\( \sigma \) C.L. and 5\( \sigma \) C.L. in the process pp \( \rightarrow t\bar{t} \rightarrow (b\ell^+\nu_\ell)(\bar{b}\ell^-\bar{\nu}_\ell) \) at \(\sqrt{s} \) of 0.3 ab\(^{-1}\), 1 ab\(^{-1}\), 2 ab\(^{-1}\) and 3 ab\(^{-1}\).

**References**


J. D. Wells, [arXiv:1911.04604 [physics.hist-ph]].