Torsion resonance decaying into $t\bar{t}b\bar{b}$ at LHC

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Motivation – Why Torsion?

➢ Standard Model does not include gravity.

➢ Some solutions like string theory predict a field usually associated with torsion.

➢ The main theoretical advantage is that torsion links the spin of the matter fields with space-time geometry.

➢ Effective approach to torsion treats it as a fundamental propagating field characterized by torsion mass ($M_{TS}$) and the coupling between torsion and SM fermions ($\eta$).

➢ The total Lagrangian of the theory includes $\mathcal{L}_{SM}, \mathcal{L}_{TS-matter}, \mathcal{L}_{TS-free}$.

➢ Due to the renormalization group running of the couplings, the interaction between the top quark and torsion may be, in principle, different from the interaction between torsion and the other fermions ($\eta_t \neq \eta_i$).
Torsion – Previous Limits

Limits from di-lepton ($ee, \mu\mu$) channel for different couplings strength

$\eta_f = \eta_t = \eta_{TS}$

Torsion with masses between 1.5 TeV and 2.8 TeV were excluded at 95% CL.
Torsion-top Coupling ($\eta_t$)

➢ The torsion-fermions interaction is not necessary universal because the renormalization group equations for different $\eta_i$ depend on the fermion Yukawa coupling.

➢ From simple assumptions, it is found that the solution of the renormalization group equation is

$$\eta_i(\mu) = \eta_i(\mu_0) \left(\frac{\mu}{\mu_0}\right)^{Ch_i/(4 \pi)^2}$$

where $\mu_0$ is the Plank scale, $\mu = 1$ TeV, $h_i$ are the Yukawa couplings and $C$ is a coefficient that depends on the gauge group.

Except for the top quark, the values of all $\eta_i$ at TeV scale are equal. The free parameters are torsion-top coupling ($\eta_t$), the couplings between torsion and all other SM fermions ($\eta_f$), and torsion mass ($M_{TS}$).

See detailed discussion in PRD 75, 034014 (2007), A. Belyaev, I. Shapiro, M. do Vale.
Torsion Production at LHC 13 TeV

\[ (p p \rightarrow TS \rightarrow t\bar{t}X) \]
For $\eta_t < \eta_f$, the increase of the torsion production is compensated by the decrease of $Br(TS \rightarrow t\bar{t})$. 

$pp \rightarrow TS \rightarrow t\bar{t}X$
Searching for New Physics – ATLAS Results

ATLAS searched for heavy particles decaying to pairs of top quarks using lepton-plus-jets events at 13 TeV with 3.2 fb\(^{-1}\) of data.

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<thead>
<tr>
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<th>e+jets</th>
<th>(\mu)+jets</th>
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<td>(tt)</td>
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<tr>
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Torsion Limits from $tt\bar{t}$ production

For $\eta_t = 0.1$, $M_{TS} > 1180$ GeV.

Torsion with masses up to $\sim 2600$ GeV are excluded, depending on the couplings $\eta_f$ and $\eta_{t'}$.

First limits on torsion parameters space with $tt\bar{t}$ LHC13 results.
Looking ahead: Searching for Torsion at next LHC runs

- The lepton-plus-jets channel is used to investigate the LHC13 potential to discovery torsion.
- Simulation: CALCHEP + PYTHIA + DELPHES
- Final state: electron + jets + MET

Semileptonic Background

- $t\bar{t}b$, $W$+jets, single top, QCD (multi-jets), $Z$+jets, diboson
- We estimate the non $t\bar{t}b$ background as $\sim20\%$ of $N_{t\bar{t}b}$
- The $t\bar{t}b$ LO cross-section is scaled to the measured $t\bar{t}b$ cross-section

$$\sigma_{t\bar{t}} = 818 \pm 8(stat) \pm 27(syst) \pm 19(lum) \text{ pb} \quad (\text{PLB 761, 2016})$$
Looking ahead: Searching for Torsion at next LHC runs

Signal Selection and Reconstruction

- 1 electron with $p_T > 30$ GeV and $|\eta| < 2.5$
- MET > 30 GeV
- Highly boosted top candidates

\[ \Delta R(jet, lepton) < 1.5, \quad p_T^{jet} > 400 \text{ GeV} \]
\[ \Delta \phi(jet, lepton) > 2.3, \quad \Delta \phi(jet_1, jet_2) > 1.5 \]

- Three jets events

\[ \chi^2 = \left[ \frac{m_{jj} - m_{th}}{\sigma_{th}} \right]^2 + \left[ \frac{m_{jj\nu} - m_{tl}}{\sigma_{tl}} \right]^2 \]
Looking ahead: Searching for Torsion at next LHC runs

The number of signal and backgrounds events is estimated from a likelihood fit

- Signal region: [900, 5000] GeV
- Shape analysis (likelihood fit)
- Background pdf is modeled as exponential
- Numerical pdf for signal
- The integrated luminosity is increased until $P\text{-value} < 3 \times 10^{-7}$
Discovery Potential at 13 TeV

- By the end of Run II, torsion with mass ~ 2.5 TeV could be observed.
- At Run III, masses up to ~ 3.0 TeV can be probed.
- With the luminosity expected for sLHC (3000 fb\(^{-1}\)), \(M_{TS} \sim 4\) TeV can be reached.
For $\eta_t = 0.1$, $M_{TS} > 1.52 \text{ TeV GeV (300 fb}^{-1})$

- Masses up to $\sim 3.0 \text{ TeV (100 fb}^{-1})$ and $\sim 3.5 \text{ TeV (300 fb}^{-1})$ can be excluded.
Summary

➢ New limits on torsion parameters from *ttbar* production were derived.

➢ The *ttbar* production at LHC may provide complementary information on torsion couplings, specially if the torsion-leptons coupling is weak.

➢ By the end of LHC run II (run III), a torsion with mass of 2.5 TeV (3.0 TeV) can be observed in the strong torsion-top coupling scenario.

➢ With 300 fb⁻¹ of data, torsion with masses up to 3.5 TeV can be excluded.

➢ For more details, see arXiv:1712.09632 [hep-ph].
Backup Slides
Expected reach for $\eta_t = 0.1$
Torsion action and symmetry

\[
S^{TS-\text{matter}}_{\text{non-min}} = i \int d^4 x \sqrt{g} \bar{\psi}^{(i)} \left( \gamma^\alpha \nabla_\alpha + i \eta \gamma^5 \gamma^\mu S_\mu - i m_i \right) \psi^{(i)},
\]

\[
S^{TS-\text{kin}}_{\text{tor}} = \int d^4 x \left\{ -\frac{1}{4} S_{\mu \nu} S^{\mu \nu} + \frac{1}{2} M_{TS}^2 S_\mu S^\mu \right\}
\]

Extra transformations related to torsion

\[
\psi \rightarrow \psi' = \psi e^{\gamma_5 \beta(x)}, \quad \bar{\psi} \rightarrow \bar{\psi}' = \bar{\psi} e^{\gamma_5 \beta(x)}, \quad S_\mu \rightarrow S'_\mu = S_\mu - \eta^{-1} \partial_\mu \beta(x)
\]

This symmetry implies that torsion \textit{has} to be a massive field.
Running couplings

\[ \eta_i(\mu) = \eta_i(\mu_0) \left( \frac{\mu}{\mu_0} \right)^{C\eta_i/(4\pi)^2}. \]

where \( \mu_0 = M_p = 10^{19} \text{ GeV}. \)

Theoretical constraint

\[ M_{TS} \gg m_i \eta_i \]