PROCEEDINGS OF SCIENCE

Limits on Torsion parameters from $t\bar{t}$ production at LHC

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Torsion models constitute a well known class of extended quantum gravity models. In this work, one investigates the phenomenological consequences of a torsion field interacting with top quarks at the LHC. A torsion field could appear as a new heavy state characterized by its mass and couplings to fermions. This new state would form a resonance decaying into a top anti-top pair. The latest ATLAS $t\bar{t}$ production results from LHC 13 TeV data are used to set limits on torsion parameters. The integrated luminosity needed to observe torsion resonance at the next LHC upgrades are also evaluated, considering different values for the torsion mass and its couplings to Standard Model fermions. Finally, prospects for torsion exclusion at the future LHC phases II and III are obtained using fast detector simulations.

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1. Introduction

The various SM extensions deal with one or more problems of the theory, but few of them try to incorporate quantum gravity. In fact, it is generally accepted that a consistent quantum gravity theory does not exist. In this scenario, the most realistic candidate to a universal theory would be the string theory, which induces gravitational interactions in the low energy limit. However, there is no perspective in near future that this theory could be verified experimentally. The alternative has been to apply effective approaches to the problem by considering natural extension of General Relativity (GR), assuming they might come from a still unknown fundamental theory. One of the most natural extensions of GR is the torsion gravity theory [1].

There are different approaches to treat the torsion field, but for the purpose of this paper, we consider the one where torsion is a fundamental propagating field, with a well-defined action and characterized by a mass and couplings between torsion and fermions [2]. As the torsion is taken as a dynamical field, it is incorporated into the SM along with the other vector fields. The coupling between torsion and fermions can be, in principle, non-universal. This possibility is explored in this paper.

We use the latest ATLAS $t\bar{t}$ production results to constrain torsion parameters assuming representative values for the torsion-top coupling. Limits on torsion from this channel, using LHC published data, are derived here for the first time. The torsion discovery potential at LHC Run II and III are also evaluated. Torsion decaying into $t\bar{t}$ at LHC was first investigated in [3], but the subsequent top decay and the final state reconstruction were not taken into account. In the present study, we go a step further in understanding the actual collider signature by considering measurable final states.

2. The Torsion Interactions

The interaction between a Dirac field and torsion, assuming that the metric is flat, is described by the following action [4]

$$S^{TS-matter}_{non-min} = i \int d^4x\, \bar{\psi}_{(i)} \left(\gamma^\mu \partial_\mu + i\eta_i \gamma^\mu \gamma^5 S_\mu - im_i \right) \psi_{(i)} , \tag{2.1}$$

where $\psi_{(i)}$ stands for each of the SM fermions, S_μ is a axial vector field and η_i is the non-minimal interaction parameter for the corresponding spinor. The spinor-torsion interaction enter the SM as interactions of fermions with the new axial vector S_μ, characterized by new dimensionless parameter, the coupling constants η_i.

The torsion-fermion interactions are not necessary universal since the values of the couplings η_i may not be the same for all fermions. The difference comes from the renormalization group equations for each η_i that depend on the Yukawa coupling for the corresponding fermion. The torsion-top coupling, denoted hereafter by η_t, may be different because of the potentially stronger running between the Planck and TeV scales. Hence, the free parameters of the theory include M_{TS}, the torsion-top coupling η_t and the coupling between torsion and all other SM fermions, denoted by η_f.

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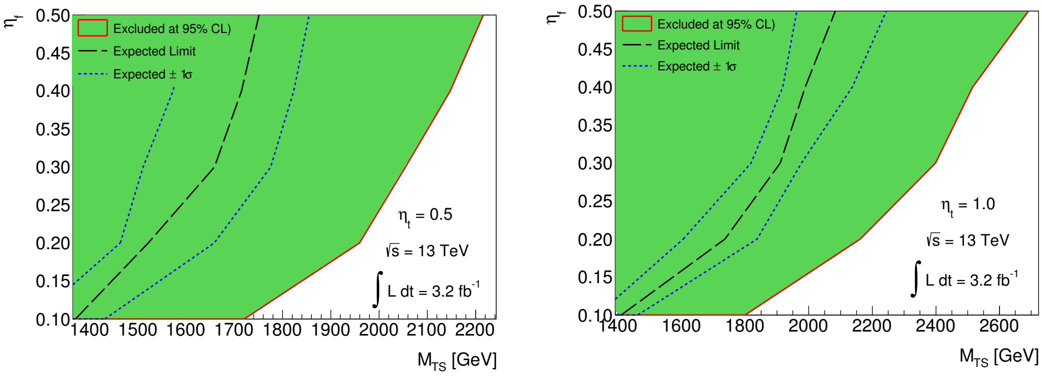
3. Observed Exclusion Limits

The ATLAS experiment has searched for heavy particles decaying into $t\bar{t}$ at center-of-mass energy of 13 TeV with a data sample corresponding to an integrated luminosity of 3.2 fb^{-1} [5]. The analysis selected events where the top and the anti-top quarks decay to W boson and bottom quarks ($t \to W^+b$, $\bar{t} \to W^-\bar{b}$), one of the W's decays to leptons and the other decays to quarks, forming the lepton-plus-jets topology. The number of selected events from data and from different SM processes estimated by the experiment, in the electron-plus jet channel (e + jets), and the torsion theoretical cross-sections calculated with CALCHEP event generator [6] are used to set limits on torsion mass and couplings. The ATLAS acceptance times efficiency in the e+jets channel is also used to calculate the number of torsion signal events. Upper limits on the signal cross-section are obtained by applying a Bayesian technique implemented in the MCLIMIT program [7, 8]. This approach assumes that the signal adds incoherently to the background. The inputs for the calculations are the number of events observed in data, the expected number of torsion events and the expected number of background events. The limit on the cross-section is translated in the lower limit on the torsion mass for each combination of η_f and η_t. Figures 1(a) and 1(b) show the 95% C.L. exclusion regions on the $M_{TS} \times \eta_f$ plane for $\eta_t = 0.5$ and $\eta_t = 1.0$, respectively.



(a) (b)

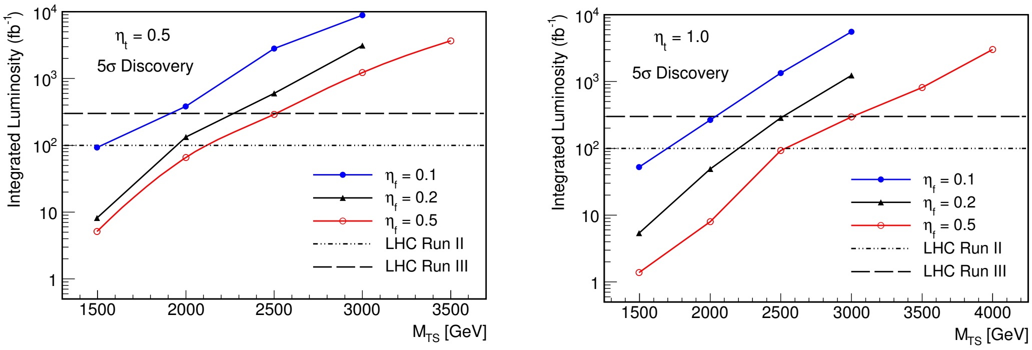
Figure 1: Exclusion region on $M_{TS} \times \eta_f$ plane for $\eta_t = 0.5$ (a) and for $\eta_t = 1.0$ (b), based on ATLAS 13 TeV resonance search. The red, long dashed black and dashed blue curves are the observed limits, expected limits and 1σ error bands, respectively. The green areas are excluded at 95% C.L.

In a scenario where torsion is strongly coupled to the top quark but the interaction with other fermions is weak ($\eta_f = 0.1$), the current data excludes torsion with a mass between 1700 and 1800 GeV. For the highest coupling values considered in this paper, the lower limit on torsion mass is pushed to $\sim$ 2700 GeV. For $\eta_t = 0.1$, the observed limit is $M_{TS} > 1200$ GeV.

4. Discovery Potential at Runs II and III

We have performed high mass $t\bar{t}$ resonance reconstruction and investigate the LHC potential to discover torsion at 13 TeV. A fast detector simulation using DELPHES[9] is performed to determine the efficiency for reconstructing the decaying tops from torsion and from SM processes. Jets are reconstructed using the anti-k_t algorithm. The missing transverse momentum E_T^{miss} is calculated from calorimeter cell energies.

The $t\bar{t}$ system is reconstructed from the hadronic top ($t \to Wb \to bq\bar{q}$) and from the semi-leptonic top ($t \to Wb \to be\nu_e$). The events are required to have exactly one electron with $p_T > 30$ GeV and pseudo-rapidity $|\eta| < 2.5$. Their missing transverse momenta are required to be greater than 30 GeV. The three jets from the hadronic top quark decay can be so collimated in the detector that they cannot be distinguished from each other and therefore are reconstructed as a single jet or two jets. Various selection criteria are applied to select the jets. A statistical test is performed for various torsion mass and coupling hypotheses, and for each one of them the minimal integrated luminosity needed to discover torsion is obtained. The results are shown in Fig. 2 for $\eta_t = 0.5$ and $\eta_t = 1.0$.



(a) (b)

Figure 2: Experimental sensitivity to observe a torsion signal at LHC 13 TeV. The plots (a) and (b) show the minimal discovering integrated luminosity as a function of M_{TS} for $\eta_t = 0.5$ and $\eta_t = 1.0$, respectively.

From Fig. 2 we can estimate that by the end of Run II, torsion with mass $\sim$ 1500 GeV can be observed at LHC if $\eta_t = 0.5$ and $\eta_f = 0.1$. The discovery reach of Run II (Run III) is $\sim$ 2500 GeV ($\sim$ 3000 GeV) if torsion is strongly coupled to quarks ($\eta_t = 1.0$, $\eta_f = 0.5$). In the high-luminosity LHC scenario ($\mathscr{L}$ = 3000 fb^{-1}), torsion mass up to $\sim$ 4000 GeV can be probed. For $\eta_t = 0.1$, the maximum discovery reach at LHC is $M_{TS} \sim 1700$ GeV.

5. Conclusions

Exclusion limits on torsion mass and couplings based on ATLAS $t\bar{t}$ results from LHC 13 TeV data are derived. Considering non-universal torsion-quarks couplings, torsion with masses between 1.2 TeV to 2.7 TeV are excluded at 95% CL. The LHC potential to observe torsion decaying into $t\bar{t}$ is also investigated. Taking into account the reconstruction and selection efficiencies of the decaying top quarks, it is found that torsion with mass up to $\sim$ 3.0 TeV can be observed by the end of Run III. The results also show that a torsion mass of 4.0 TeV set the maximum M_{TS} value that can be probed at LHC from $t\bar{t}$ production in the electron-plus-jets selection.

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