Torsion resonance decaying into ttbar at LHC

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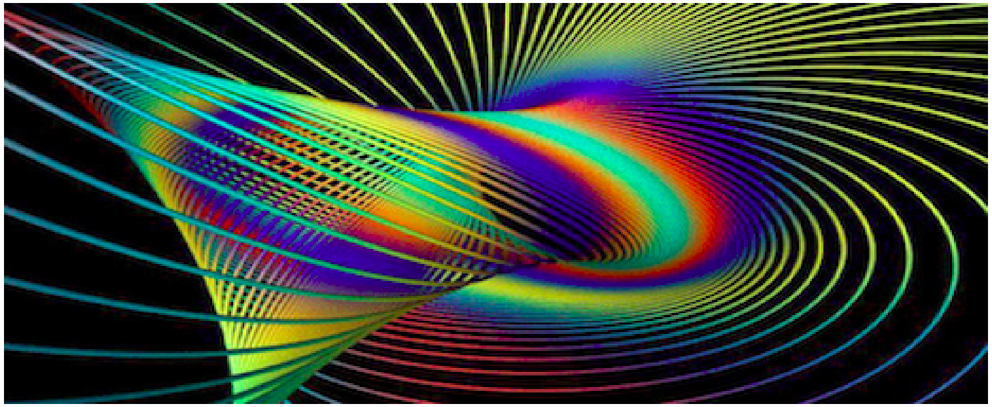
Motivation – Why Torsion ?

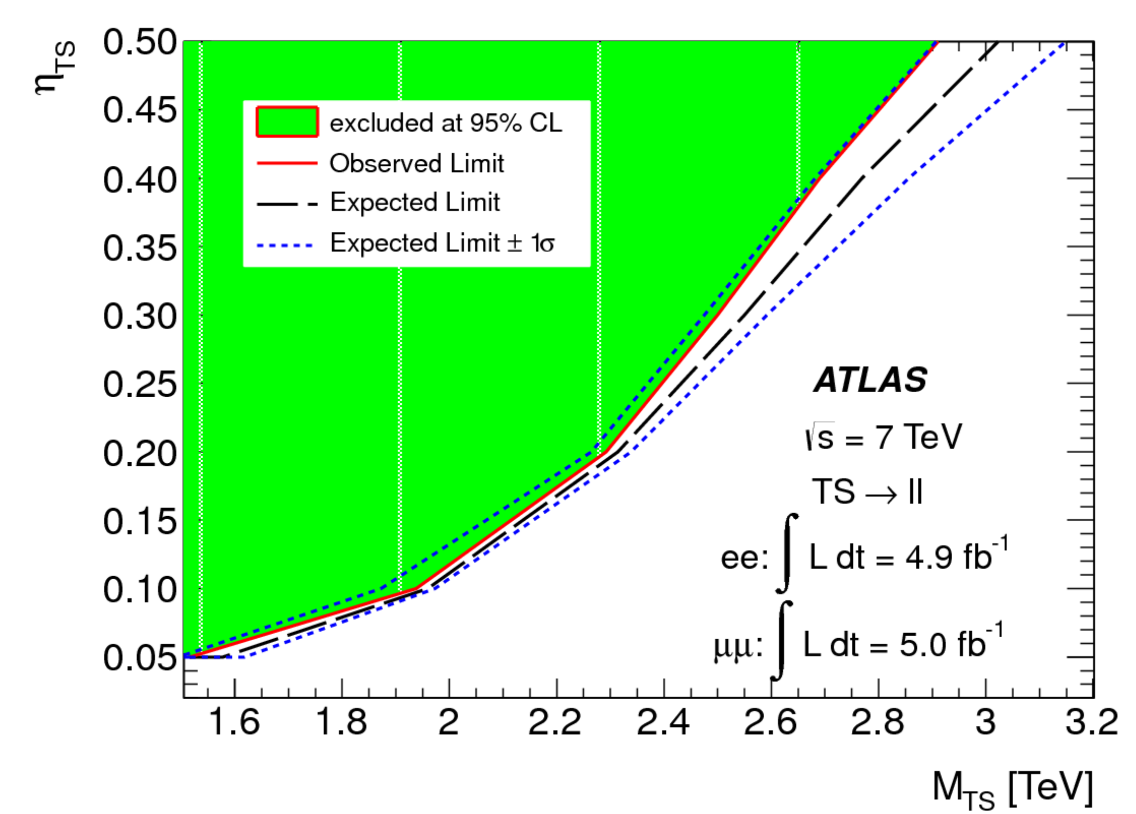
- Standard Model does not include gravity.
- Some solutions like string theory predict a field usually associated with *torsion*.
- The main theoretical advantage is that torsion links the spin of the matter fields with space-time geometry.
- Effective approach to torsion treats it as a fundamental propagating field characterized by torsion mass (M_{TS}) and the coupling between torsion and SM fermions (η).
- 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 **($\eta_f \neq \eta_t$)**.



Torsion – Previous Limits

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

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



JHEP11 (2012) 138

Torsion with masses between 1.5 TeV and 2.8 TeV were excluded at 95% CL.

Torsion-top Coupling (η_t)

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

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

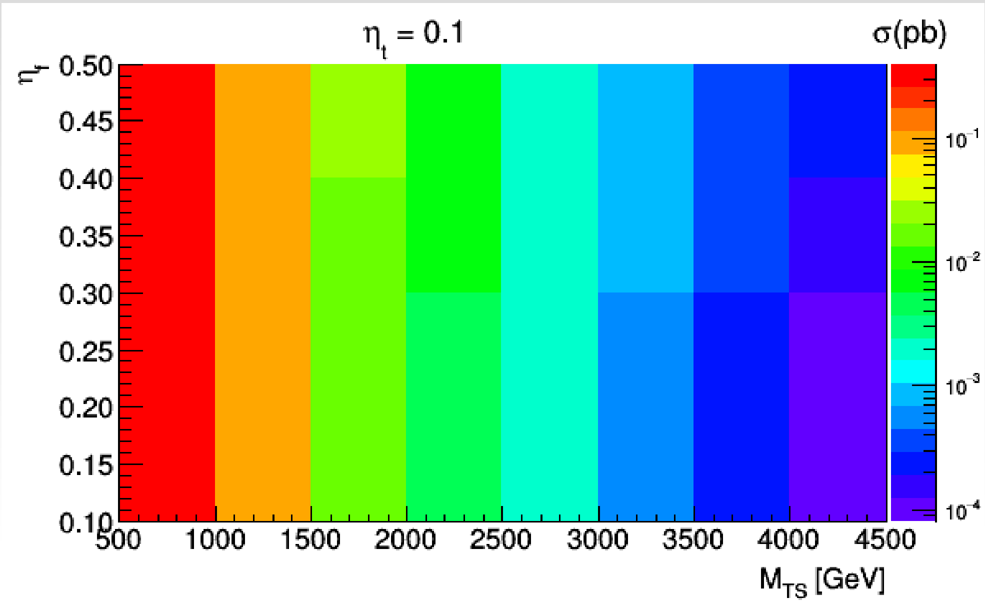
$$\eta_i(\mu) = \eta_i(\mu_0) \left(\frac{\mu}{\mu_0}\right)^{Ch_i/(4\pi)^2}$$

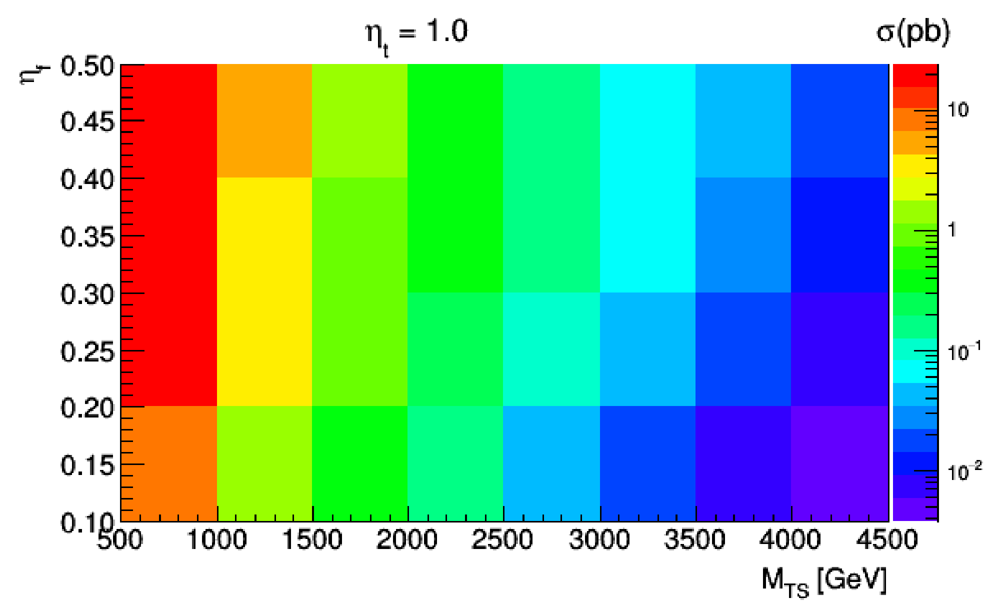
where μ_0 is the Plank scale, μ = 1 TeV, h_i are the Yukawa couplings and C is a coefficient that depends on the gauge group.

Except for the top quark, the values of all η_i at TeV scale are equal. The free parameters are torsion-top coupling (η_t), the couplings between torsion and all other SM fermions (η_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 $(pp \longrightarrow TS \longrightarrow t\bar{t}X)$





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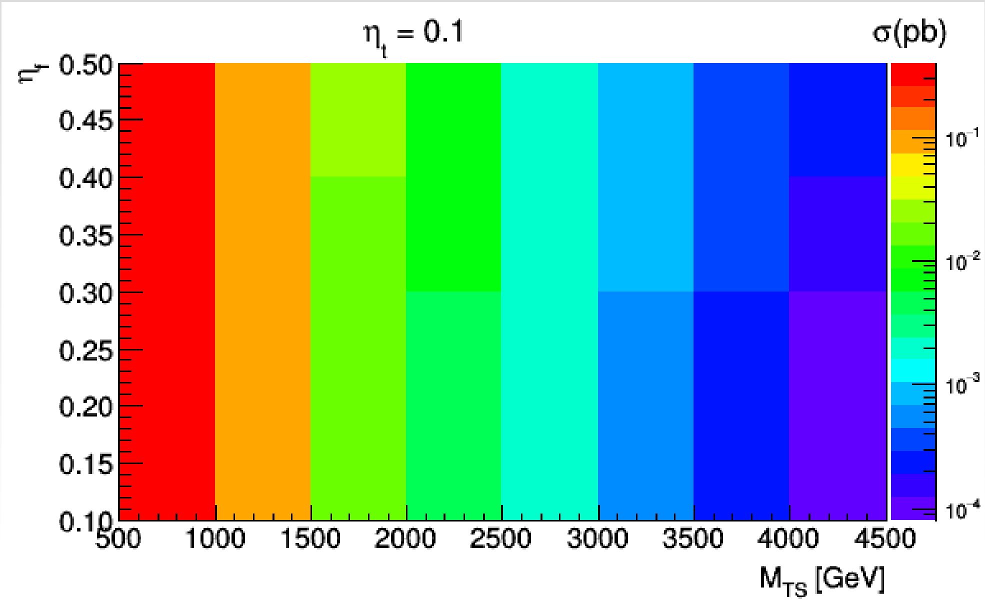
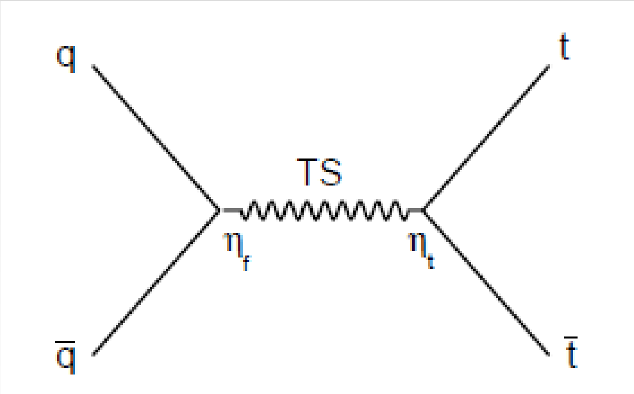
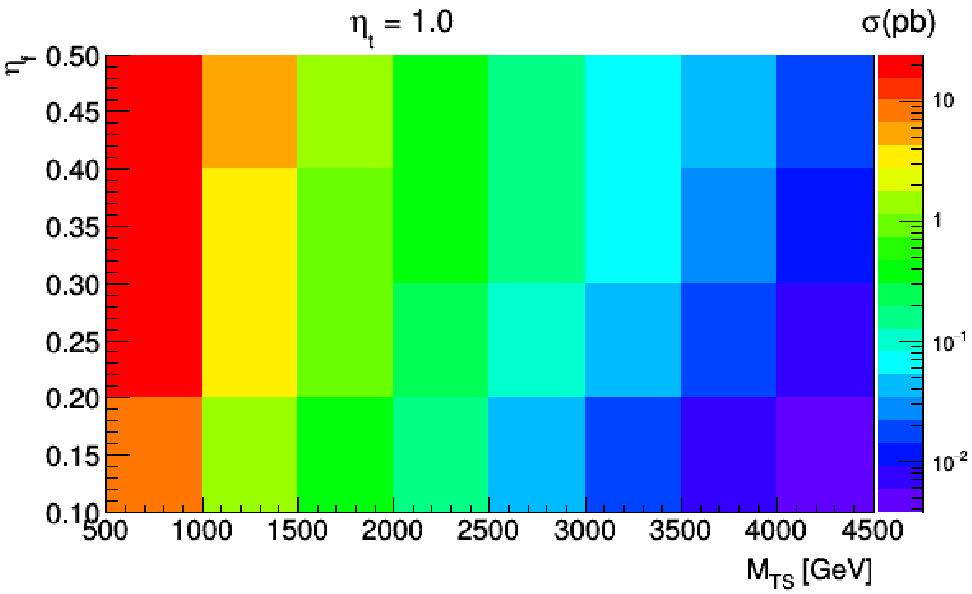




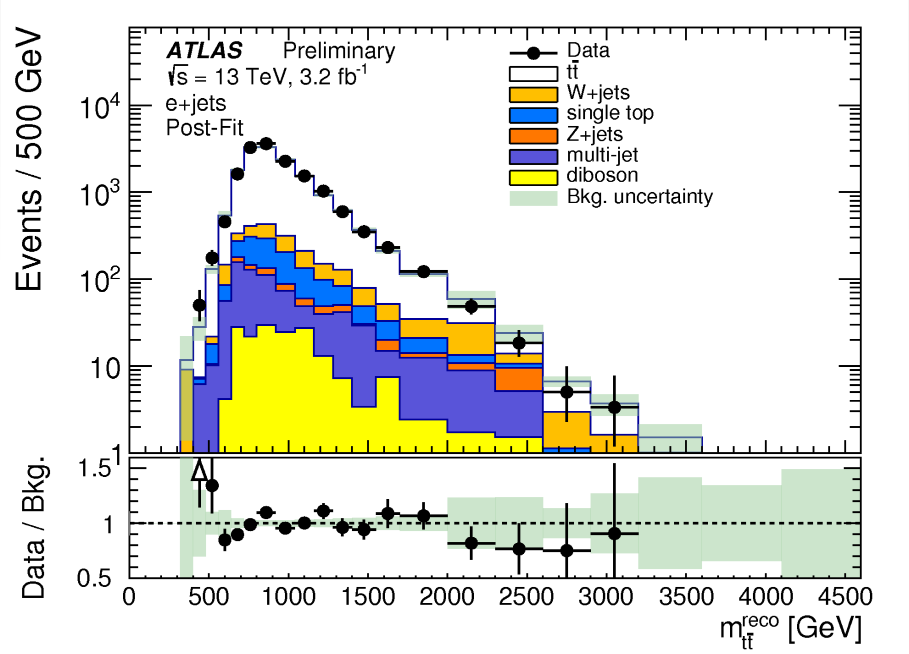
For $\eta_t < \eta_f$, the increase of the torsion production is compensated by the decrease of $Br(TS \longrightarrow t\bar{t})$.



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.

	e+jets	μ+jets
$t\bar{t}$	3000 ± 700	3000 ± 700
W+jets	200 ± 140	200 ± 40
Single top	190 ± 40	180 ± 40
Z+jets	33 ± 12	26 ± 12
Multi-jet	130 ± 70	19 ± 11
Diboson	46 ± 11	37 ± 8
Total	3700 ± 800	3400 ± 800
Data	3352	3074



ATLAS-CONF-2016-014

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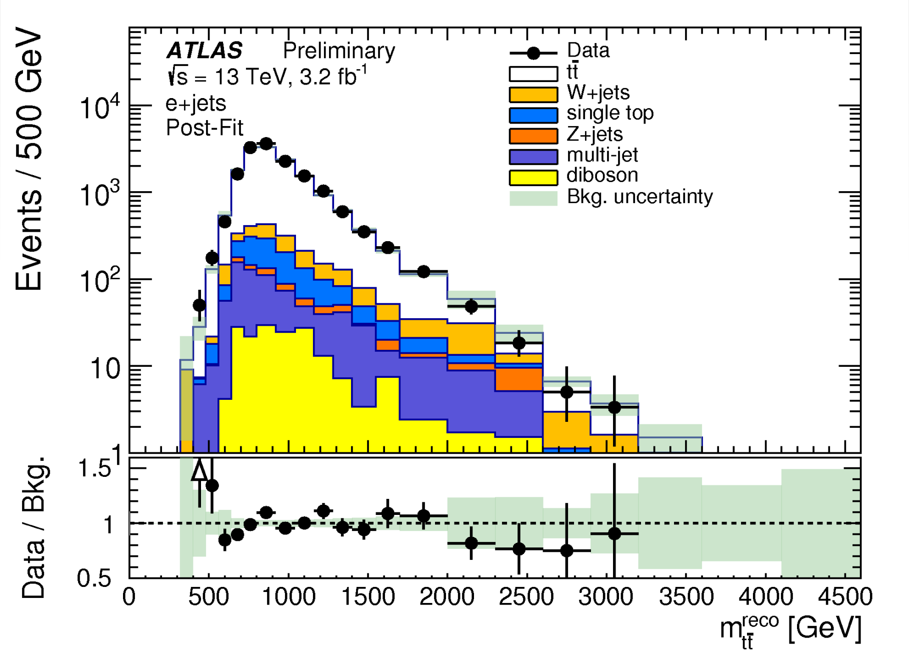

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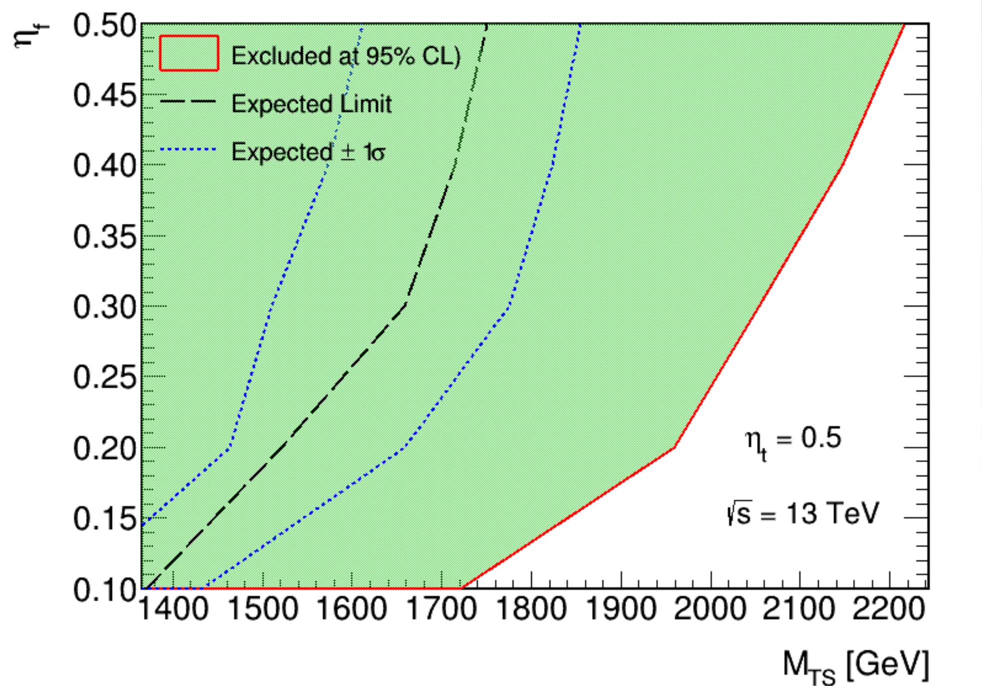
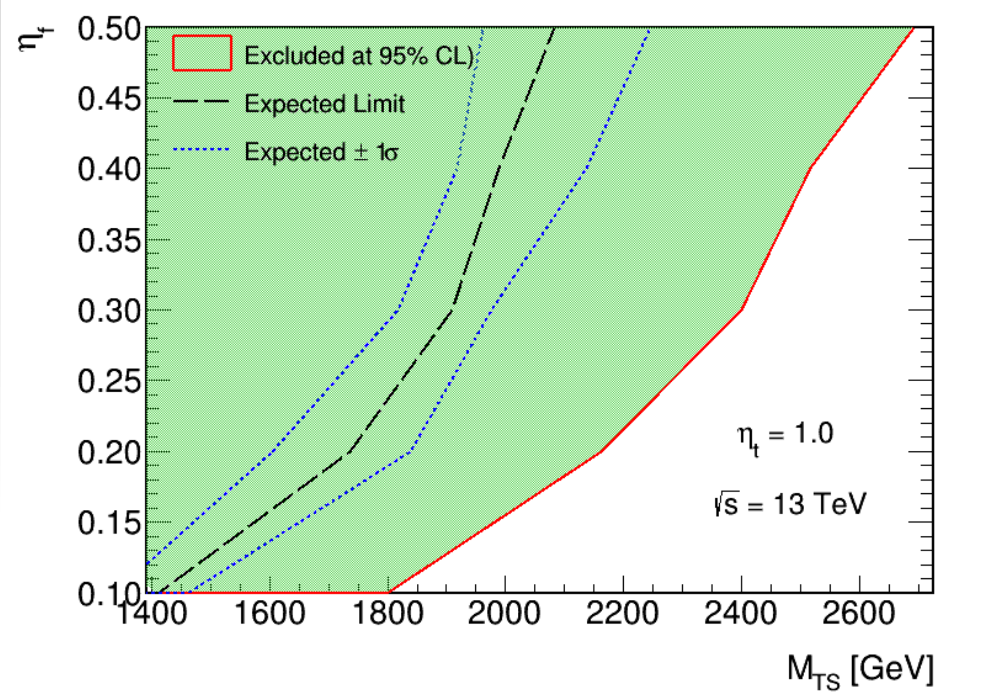
Torsion Limits from *ttbar* production





Integrated Luminosity: 3.2 fb^{-1}

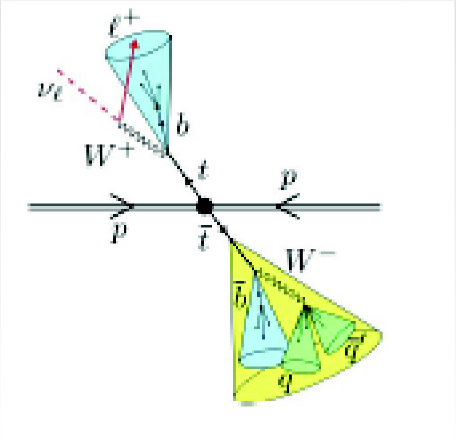
For $\eta_t = 0.1$, $M_{TS} > 1180$ GeV .

Torsion with masses up to ~ 2600 GeV are excluded, depending on the couplings η_f and η_t.

First limits on torsion parameters space with ttbar 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

- ***ttbar***, W+jets, single top, QCD (multi-jets), Z+jets, diboson
- We estimate the non *ttbar* background as ~20% of N_{ttbar}
- The *ttbar* LO cross-section is scaled to the measured *ttbar* cross-section

$$\sigma_{t\bar{t}} = 818 \pm 8(stat) \pm 27(syst) \pm 19(lum)\ \mathrm{pb}$$ (PLB 761, 2016)

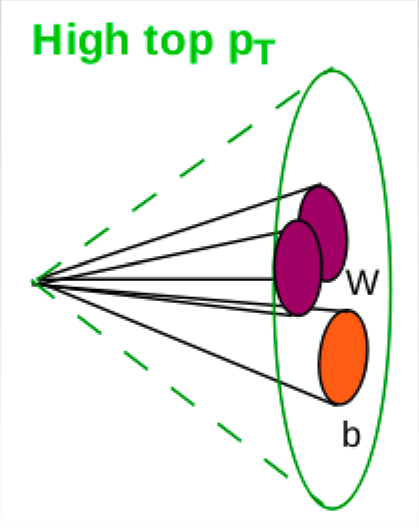
Looking ahead: Searching for Torsion at next LHC runs

Signal Selection and Reconstruction

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

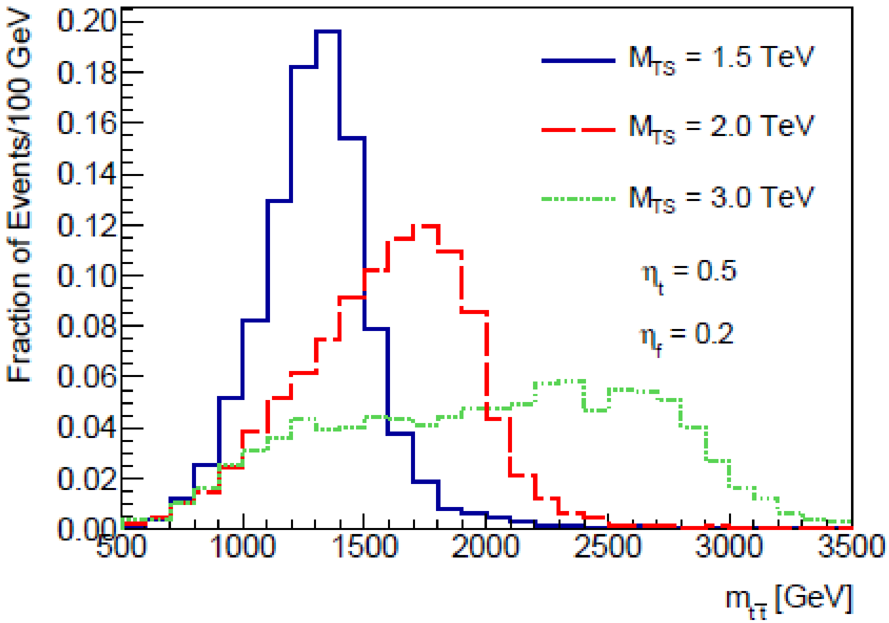
$$\Delta R(jet, lepton) < 1.5, \;\; p_T^{jet} > 400 \text{ GeV}$$

$$\Delta\phi(jet, lepton) > 2.3, \;\; \Delta\phi(jet_1, jet_2) > 1.5$$



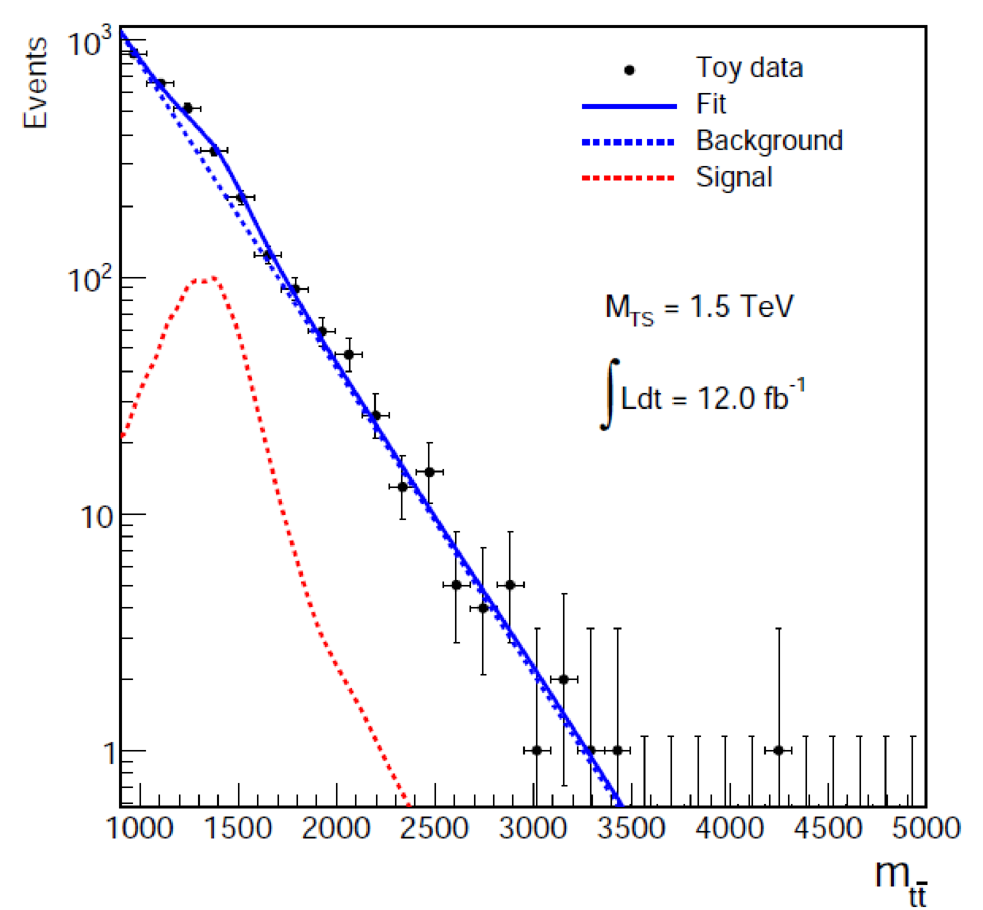
- Three jets events

$$\chi^2 = \left[\frac{m_{jj} - m_{th}}{\sigma_{th}}\right]^2 + \left[\frac{m_{jl\nu} - m_{tl}}{\sigma_{tl}}\right]^2$$



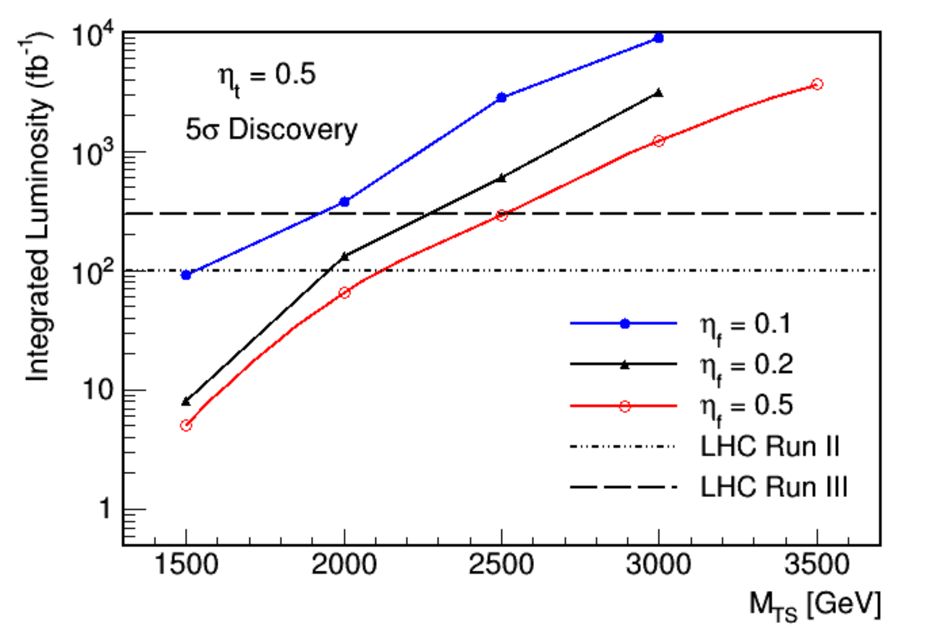
Looking ahead: Searching for Torsion at next LHC runs

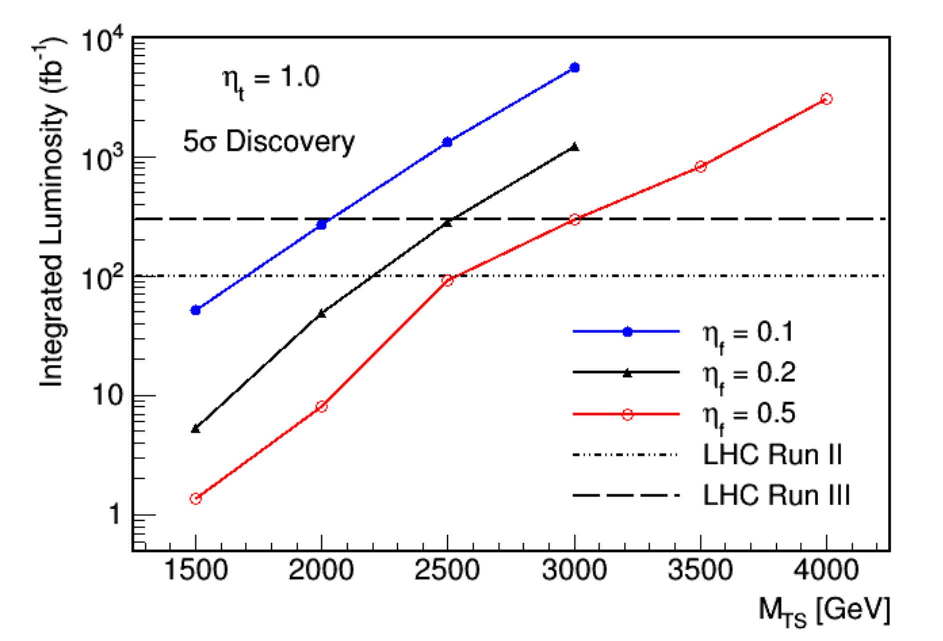
The number of signal and backgrounds events is estimated from a likelihood fit



- 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 - value* $< 3 \times 10^{-7}$

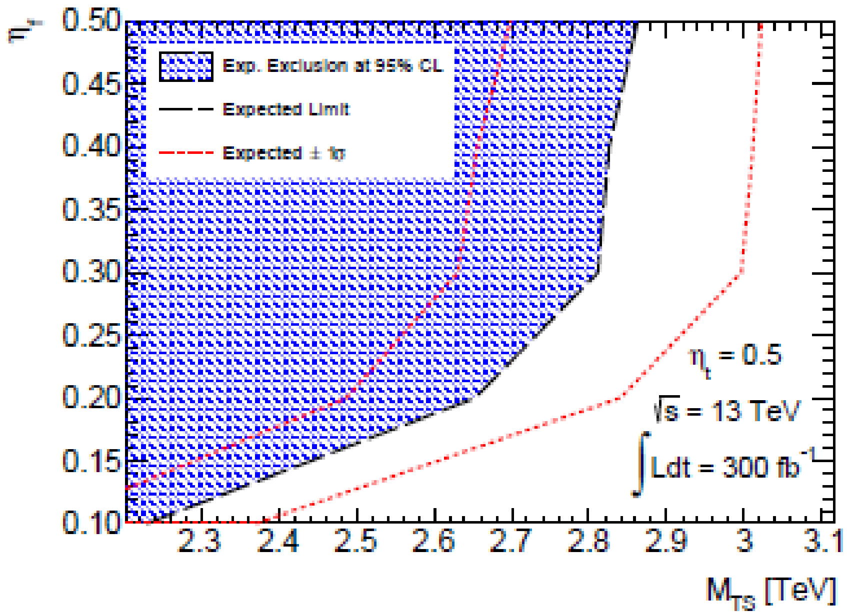
Discovery Potential at 13 TeV

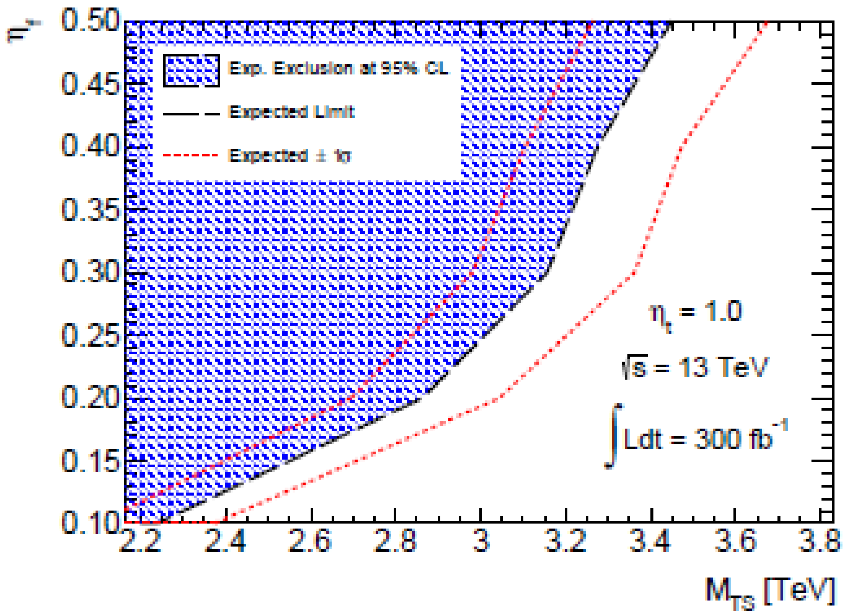




- By the end of Run II, torsion with mass ~ 2.5 TeV could be observed.
- At Run III, masses up to ~ 3.0 TeV can be probed.
- With the luminosity expected for sLHC (3000 fb^{-1}), M_{TS} ~ 4 TeV can be reached.

Expected Limits at 13 TeV





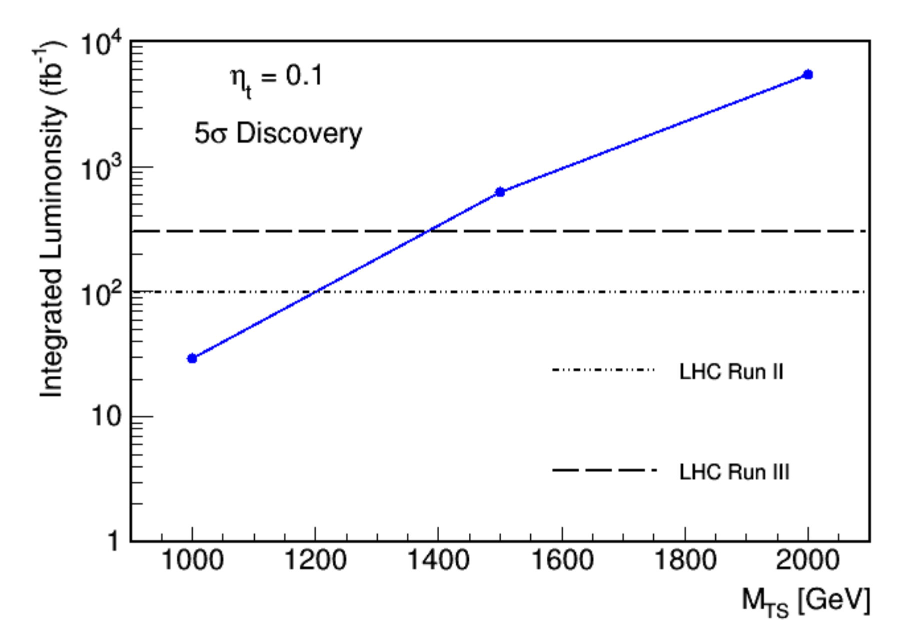
- For η_t = 0.1, M_{TS} > 1.52 TeV GeV (300 fb^{-1})
- Masses up to ~ 3.0 TeV (100 fb^{-1}) and ~ 3.5 TeV (300 fb^{-1}) can be excluded.

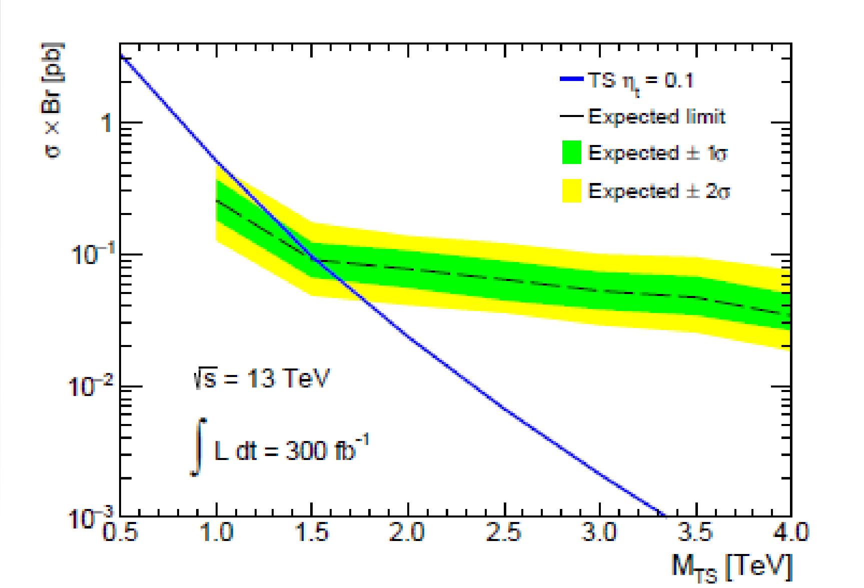
Summary

- 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^{-f} 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

$$\mathcal{S}_{non-min}^{TS-matter} = i \int d^4x \sqrt{g}\, \bar{\psi}_{(i)} \left(\gamma^\alpha \nabla_\alpha + \imath\, \eta_i \gamma^5 \gamma^\mu S_\mu - \imath\, m_i \right) \psi_{(i)} \,,$$

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

Extra transformations related to torsion

$$\psi \to \psi' = \psi\, e^{\gamma_5 \beta(x)}, \qquad \bar{\psi} \to \bar{\psi}' = \bar{\psi}\, e^{\gamma_5 \beta(x)}, \qquad S_\mu \to S'_\mu = S_\mu - \eta^{-1}\, \partial_\mu \beta(x)$$

This symmetry implies that torsion ***has*** to be a massive field.

Running couplings

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

where $\mu_0 = M_P = 10^{19}$ GeV.

Theoretical constraint

$$M_{TS} >> m_i \eta_i$$