Limits on Exotic Bosons at LHC

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Outline

- Current limits on torsion parameter space
- Bilepton production at LHC
- Future works

Motivation – Why Torsion ?

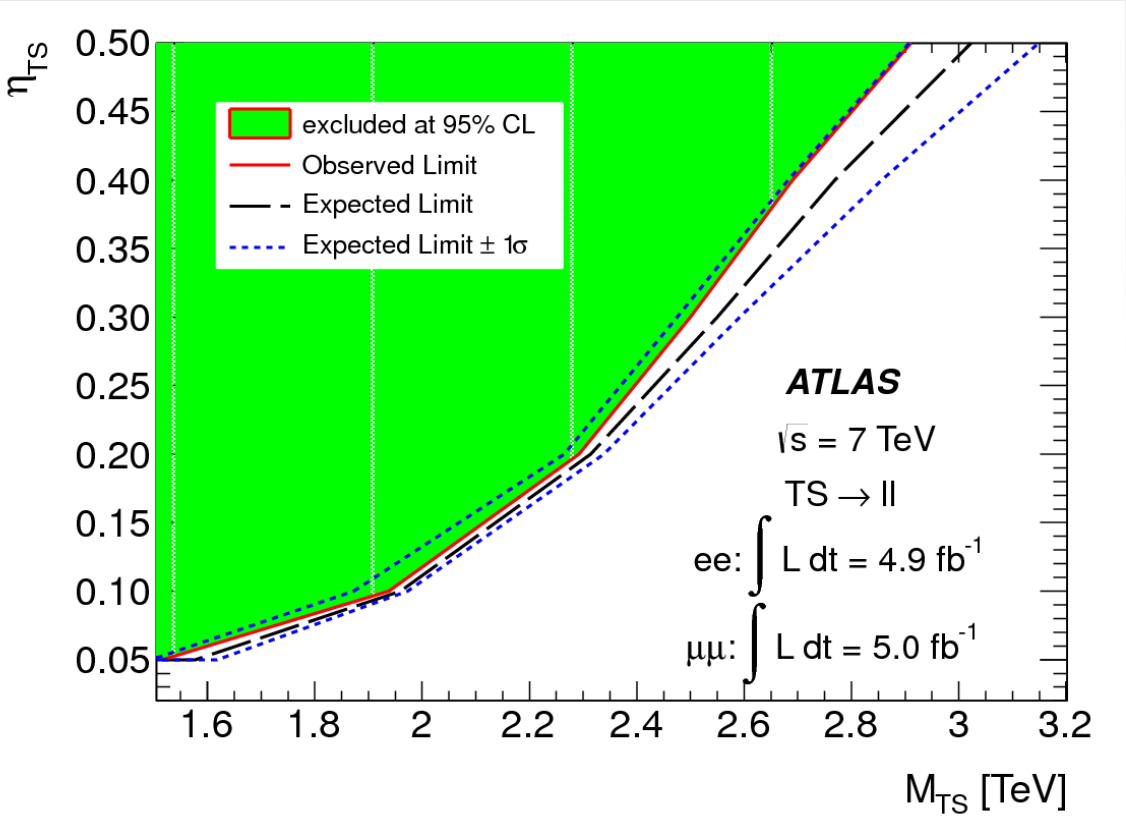
- Standard Model does not include gravity.
- Some solutions like string theory predict a field usually associated with *torsion*.
- The main theoretical advantage is that torsion links the spin of the matter fields with space-time geometry.
- Effective approach to torsion treats it as a fundamental propagating 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 **($\eta_f \neq \eta_t$).**

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

Torsion – Previous Limits

Limits from di-lepton (*ee*, μμ) channel for different couplings strength

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



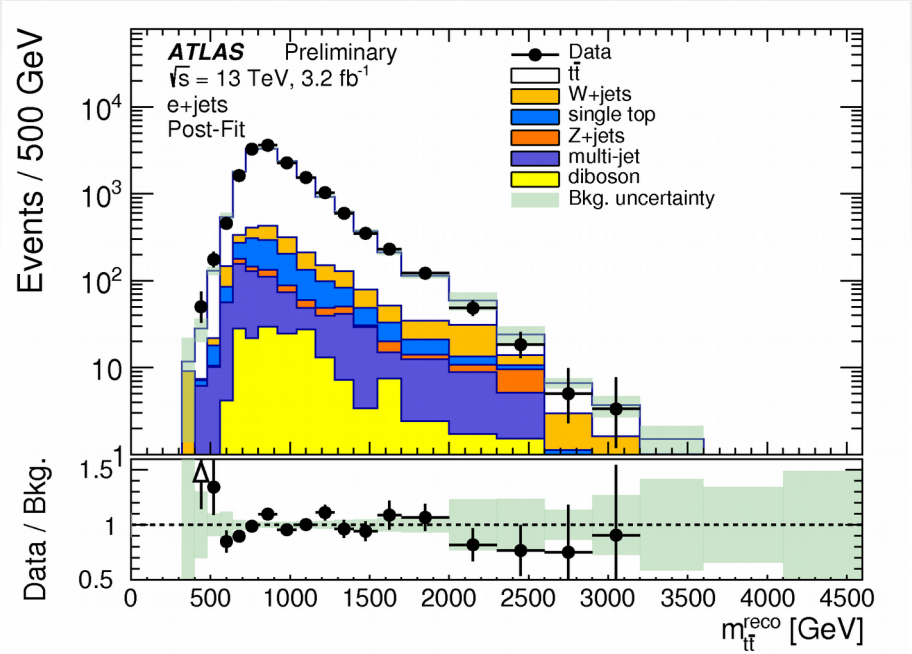
JHEP11 (2012) 138

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

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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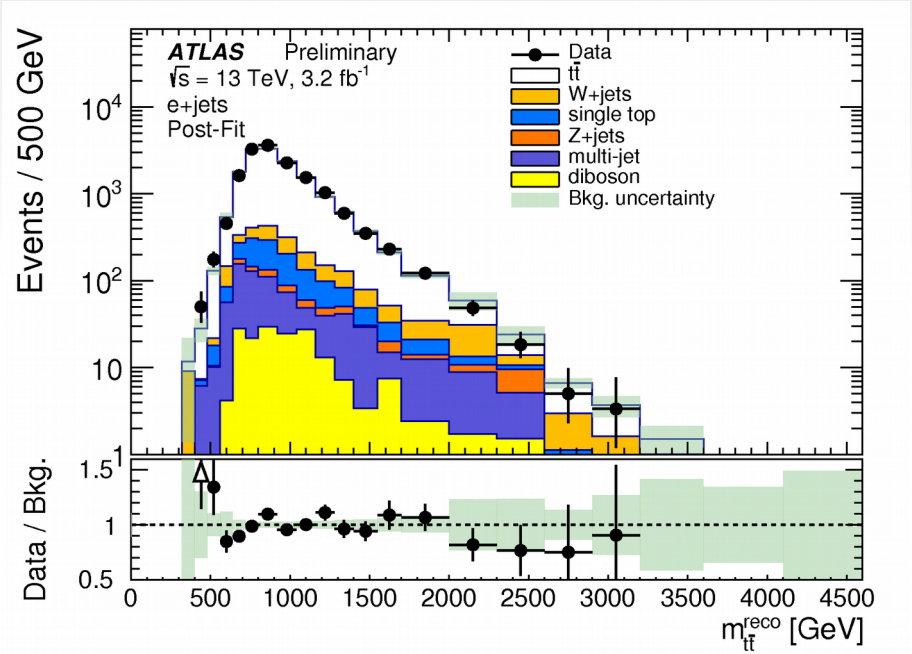
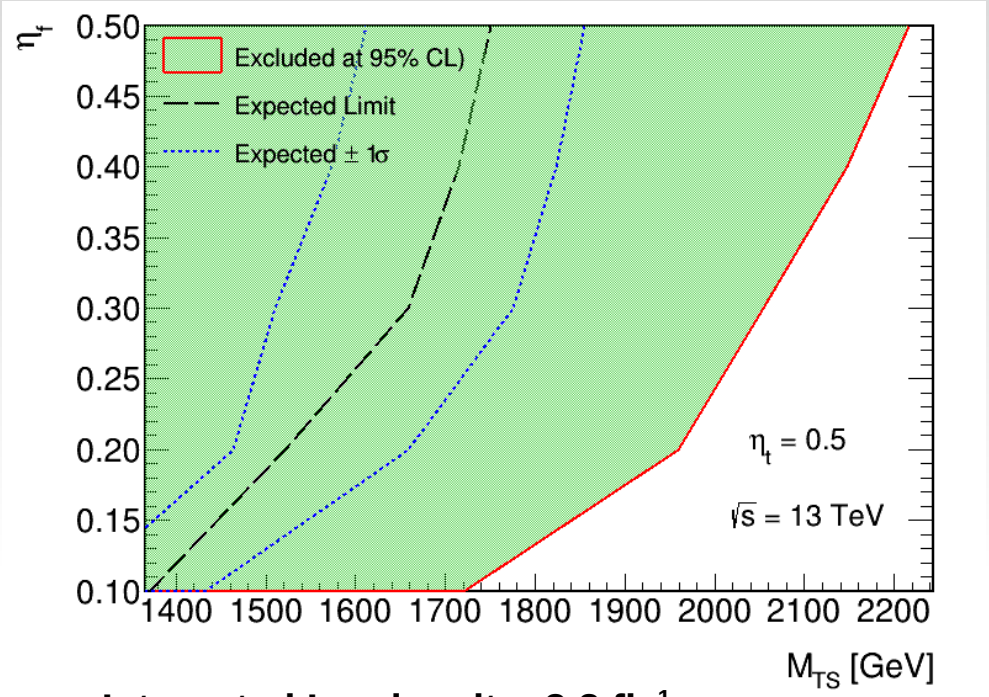
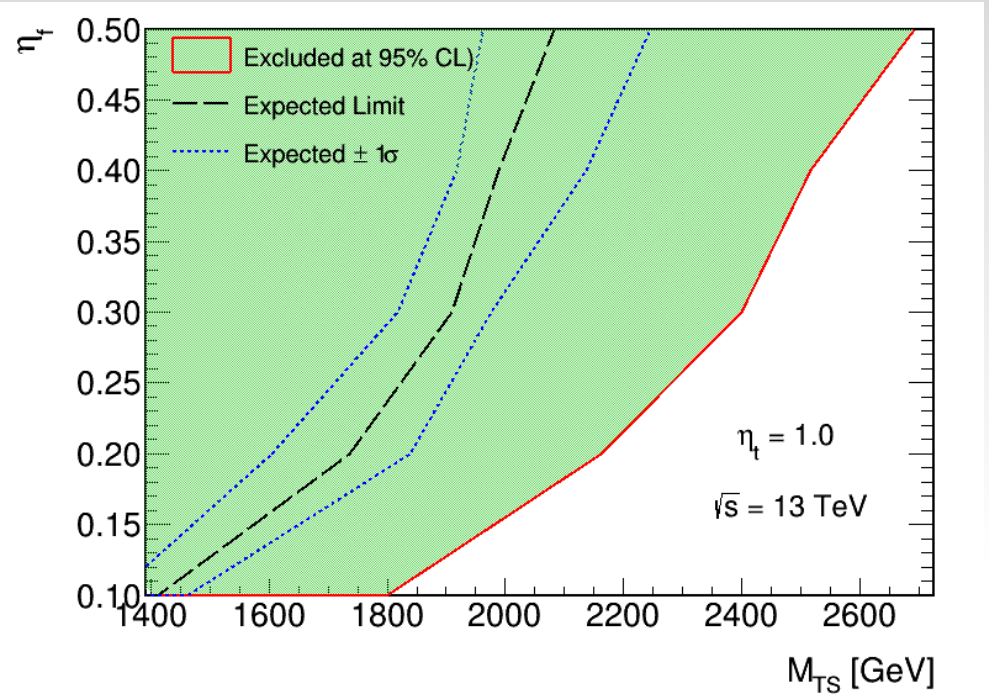


ATLAS-CONF-2016-014

Torsion Limits from *ttbar* production





Integrated Luminosity: 3.2 fb^{-1}

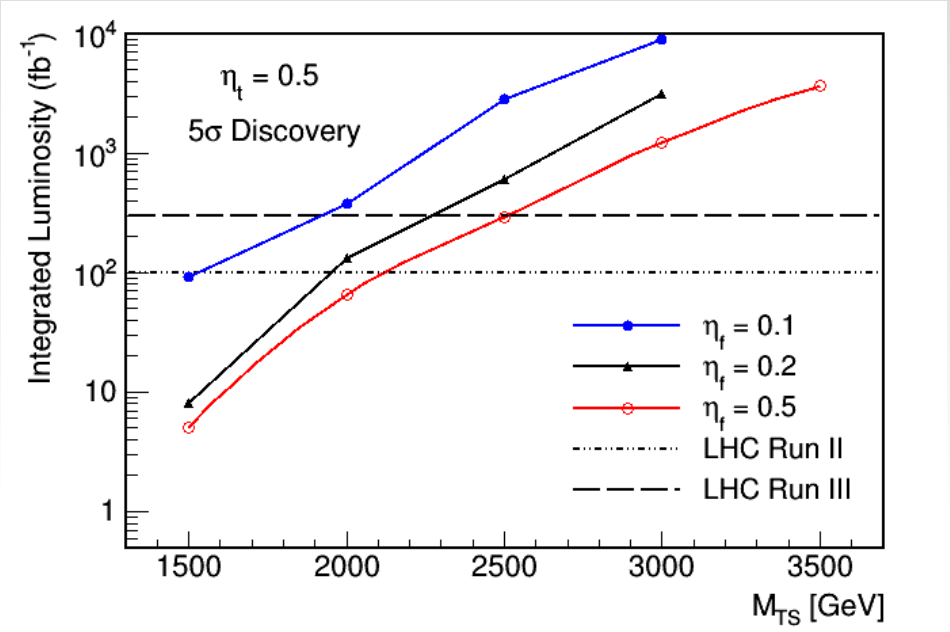
For $\eta_t = 0.1$, $M_{TS} > 1180$ GeV .

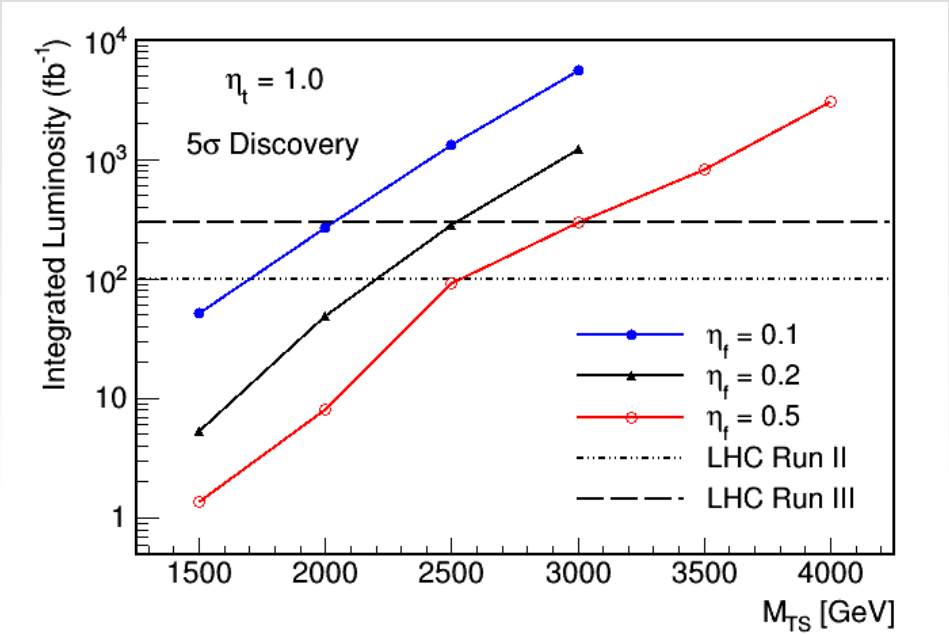
Torsion with masses up to ~ 2600 GeV are excluded, depending on the couplings η_f and η_t.

First limits on torsion parameters space with ttbar LHC13 results.

PRD 97, 075036 (2018).

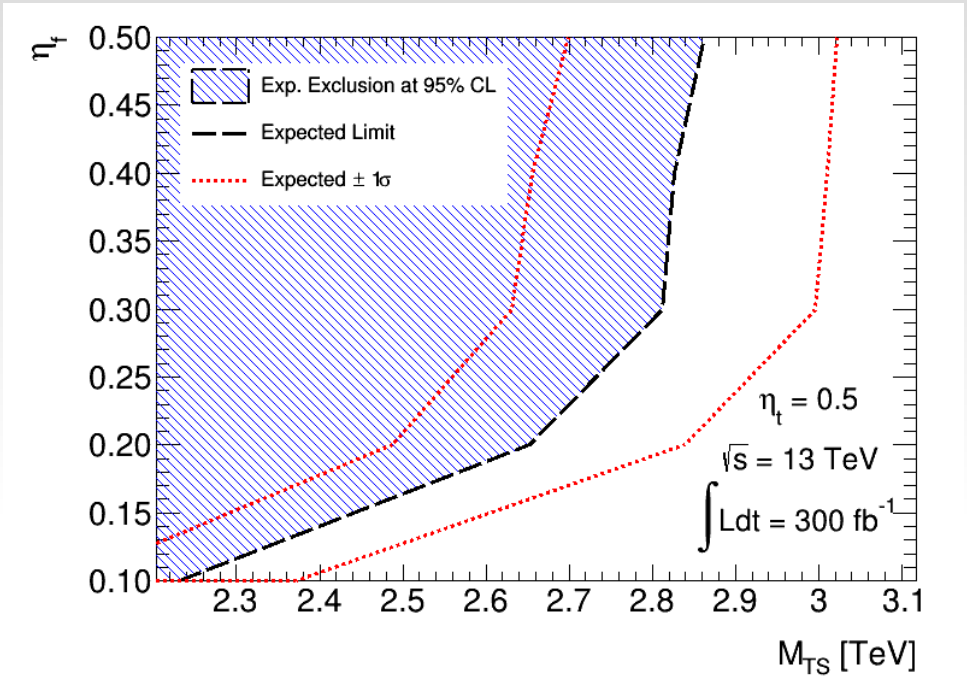
Discovery Potential

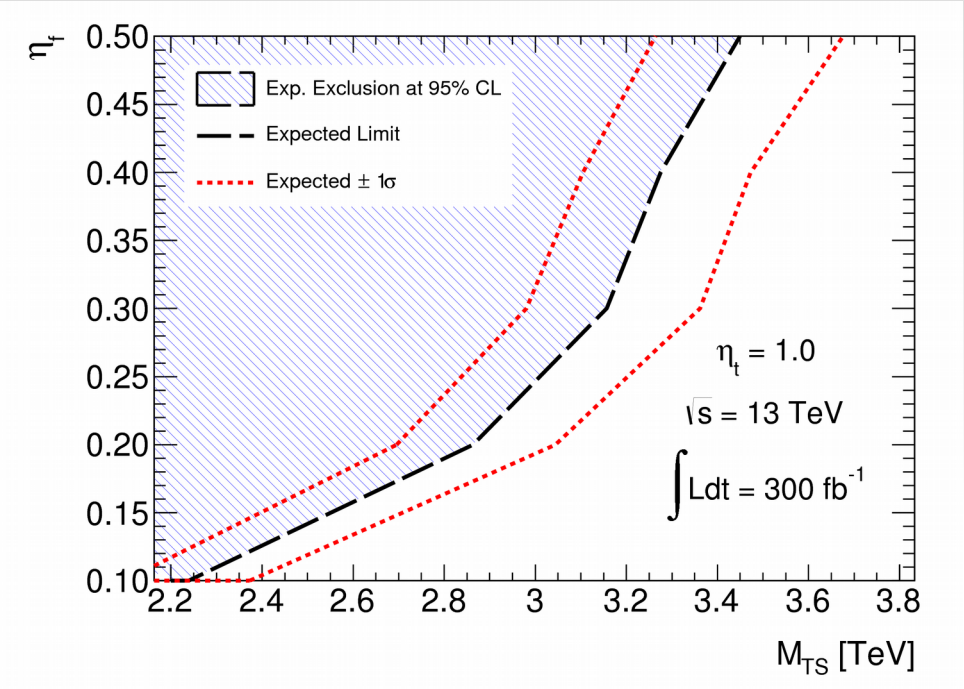




- By the end of Run II, torsion with mass ~ 2.5 TeV could be observed.
- At Run III, masses up to ~ 3.0 TeV can be probed.
- With the luminosity expected for sLHC (3000 fb^{-1}), M_{TS} ~ 4 TeV can be reached.

Expected Limits at 13 TeV





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

Vector Bosons in 331 Model

- Based on the gauge symmetry $SU(3)_C$ X $SU(3)_L$ X $U(1)_X$.
- Provides an elegant solution for the family replication problem of the SM. Nontrivial anomaly cancellation takes place between families.
- Lepton family number is not required to be conserved.
- It foresees a number of new gauge bosons (vectors and scalars).

Predictions: **Vector Bileptons $Y^{\pm\pm}$, $V^{\pm}$**
New neutral gauge boson Z'
Three new heavy Leptoquarks (Q_1,Q_2,Q_3)

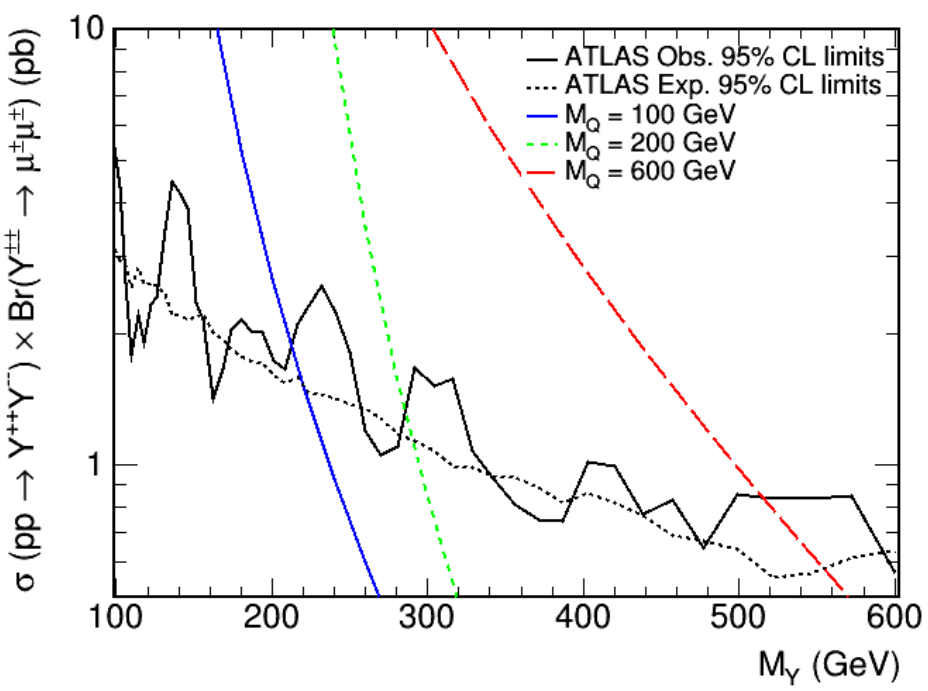
Bileptons are bosons with two units of leptonic number

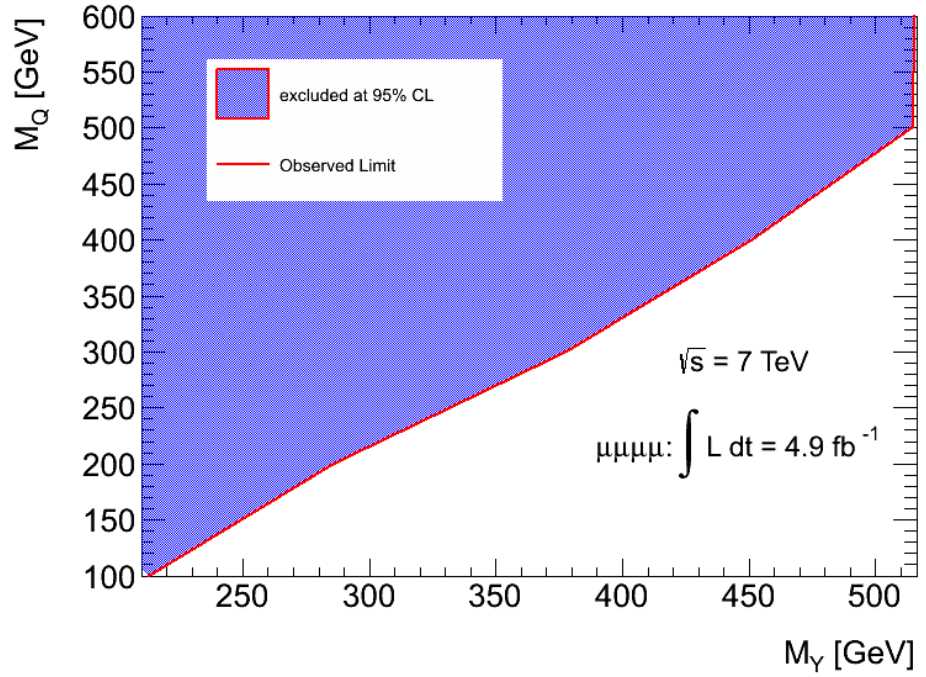
Decay Mode: $Y^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$

Bilepton production at LHC: $pp \rightarrow Y^{++}Y^{--} \rightarrow l^{\pm}l^{\pm}l'^{\mp}l'^{\mp}$

Exclusion Limits at 7 TeV (4μ production)

ATLAS collaboration limits on cross-section for doubly-charged higgs production are used to set 95% CL limits on bilepton mass.

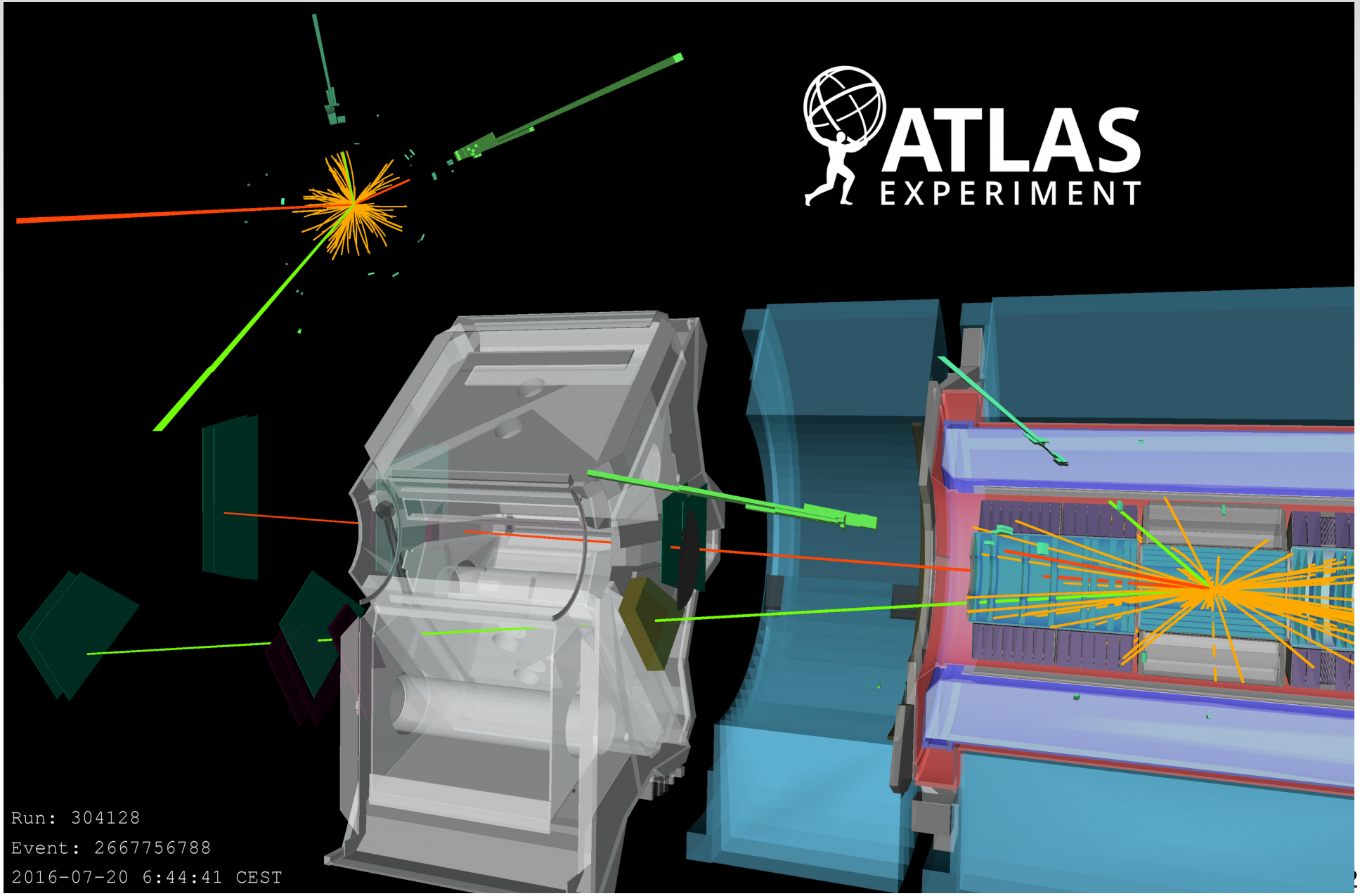




Bileptons with masses between 250 GeV and 550 GeV, depending on the exotic quark mass, are excluded.

PRD 94, 055020 (2016).

ATLAS Event – 13 TeV (2e2μ)



Current and Future Work I

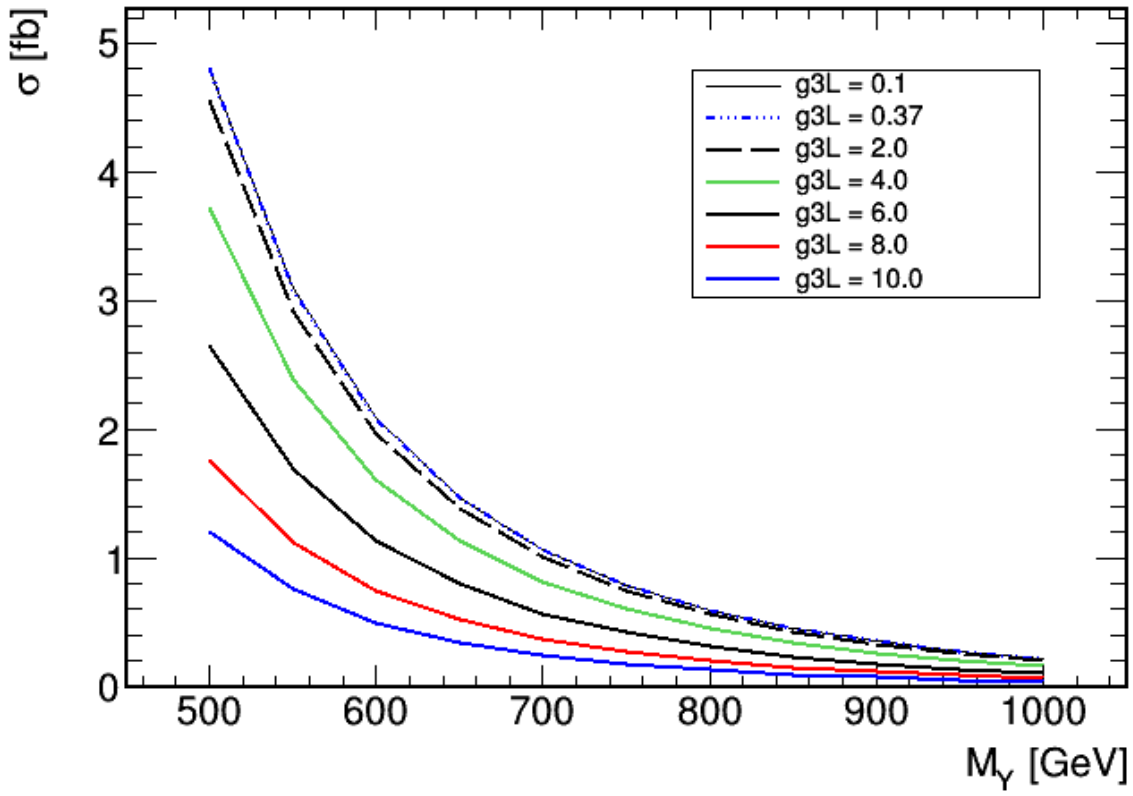
Combining different channels to constrain the 331 Model (different couplings)

$$Y^{\pm\pm} \to l^{\pm} l^{\pm}$$

$$V^{\pm} \to l^{\pm} \nu$$

$$Z' \to l^{+} l^{-}$$

$$l = (e, \mu)$$

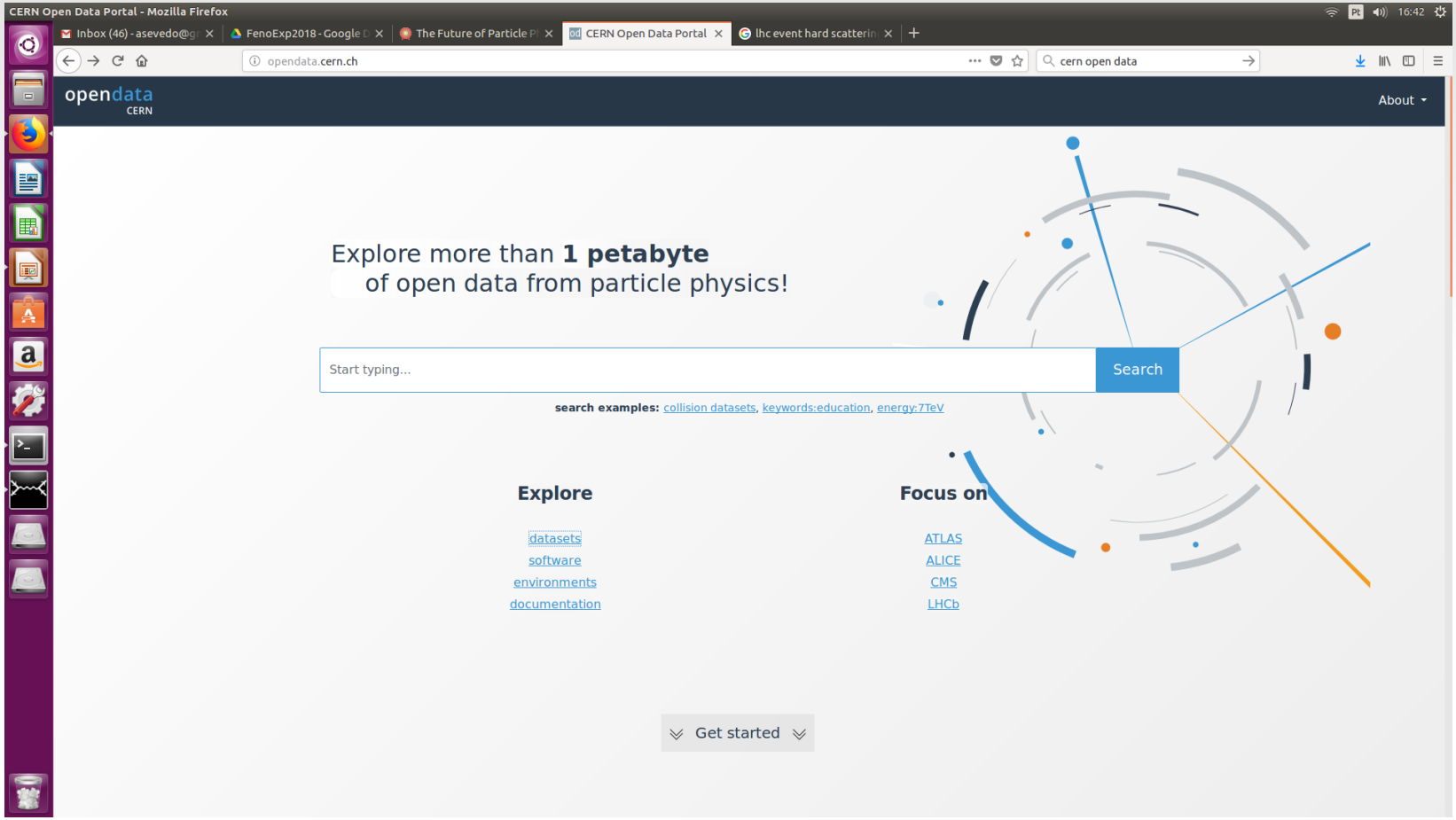


$$pp \to e^{+} e^{+} e^{-} e^{-} X$$

Current and Future Work II

Leptoquarks and CMS Open data

Explore final states with leptons, jets and missing transverse energy



"It was not easy. In fact, it was one of the most challenging research projects in my career."
Jesse Thaler

Backup Slides

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

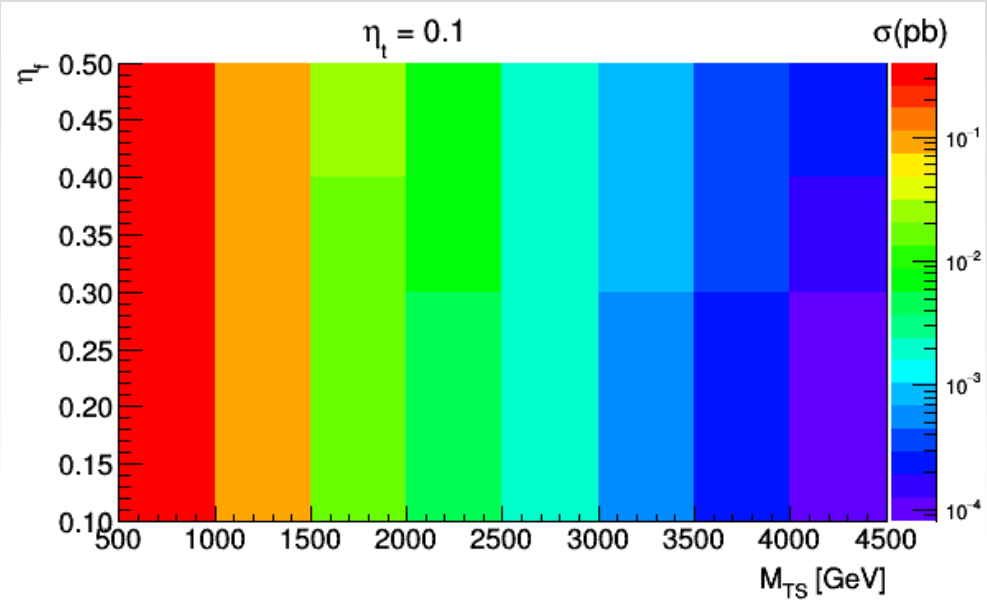
$$\eta_i(\mu) = \eta_i(\mu_0)\left(\frac{\mu}{\mu_0}\right)^{Ch_i/(4\pi)^2}$$

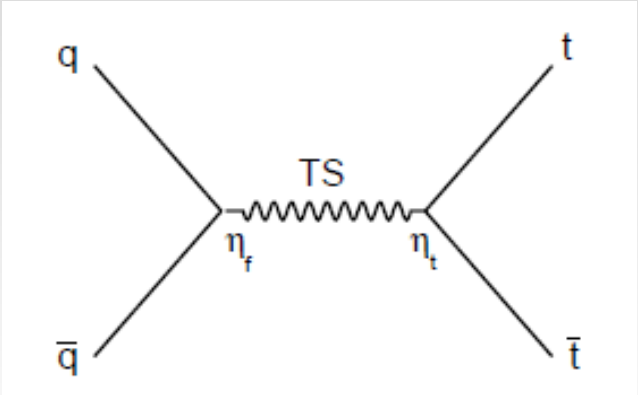
where μ_0 is the Plank scale, μ = 1 TeV, h_i are the Yukawa couplings and C is a coefficient that depends on the gauge group.

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}).

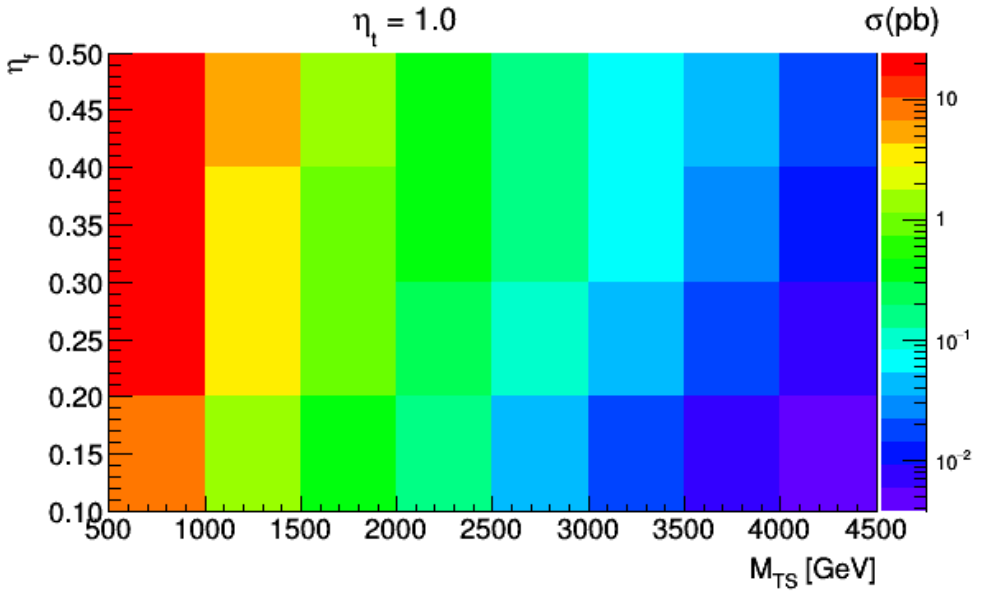
See detailed discussion in **A. Belyaev *et al*, PRD 75, 034014 (2007).**

Torsion Production at LHC 13 TeV $(pp \longrightarrow TS \longrightarrow t\bar{t}X)$

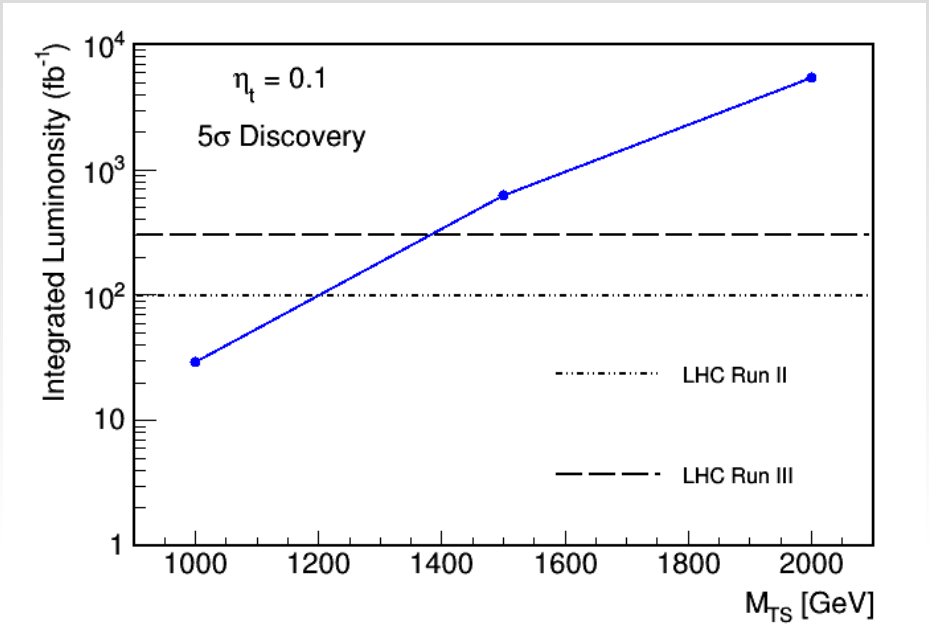


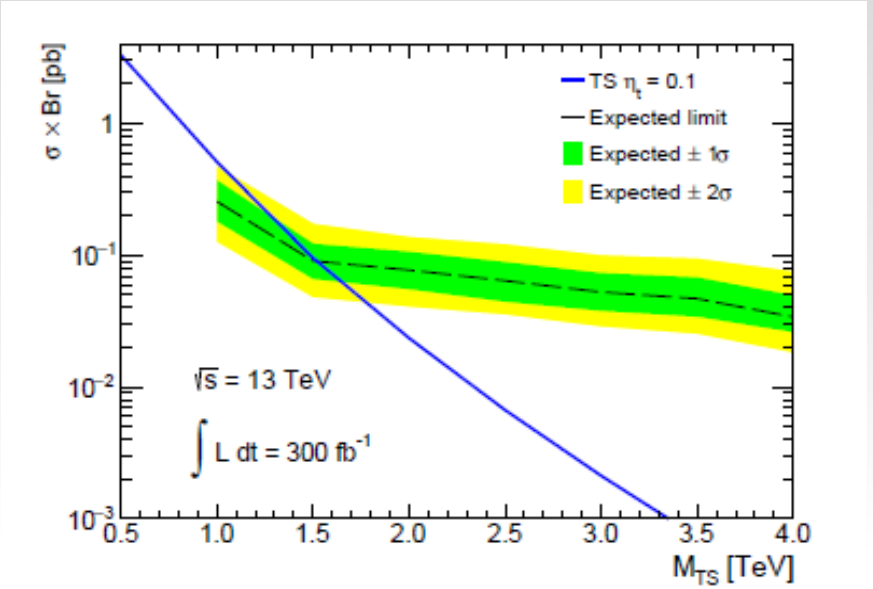


For $\eta_t < \eta_f$, the increase of the torsion production is compensated by the decrease of $Br(TS \longrightarrow t\bar{t})$.



Expected reach for $\eta_t = 0.1$





Torsion action and symmetry

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

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

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

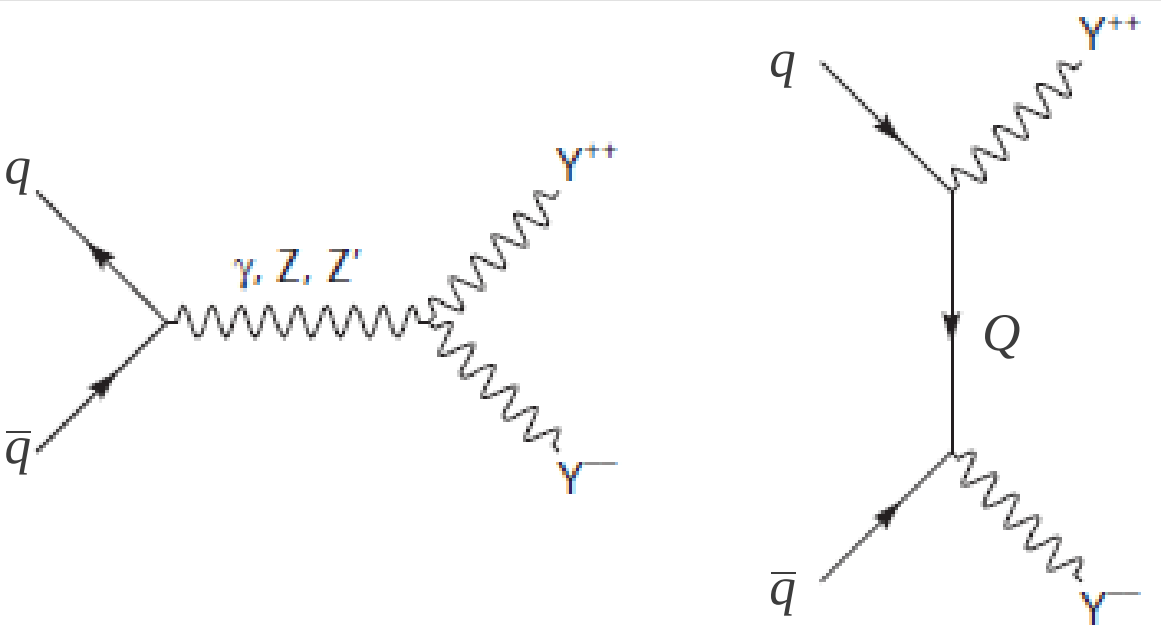
$$\eta_i(\mu) = \eta_i(\mu_0)\left(\frac{\mu}{\mu_0}\right)^{Ch_i/(4\pi)^2}.$$

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

Theoretical constraint

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

Bileptons Production

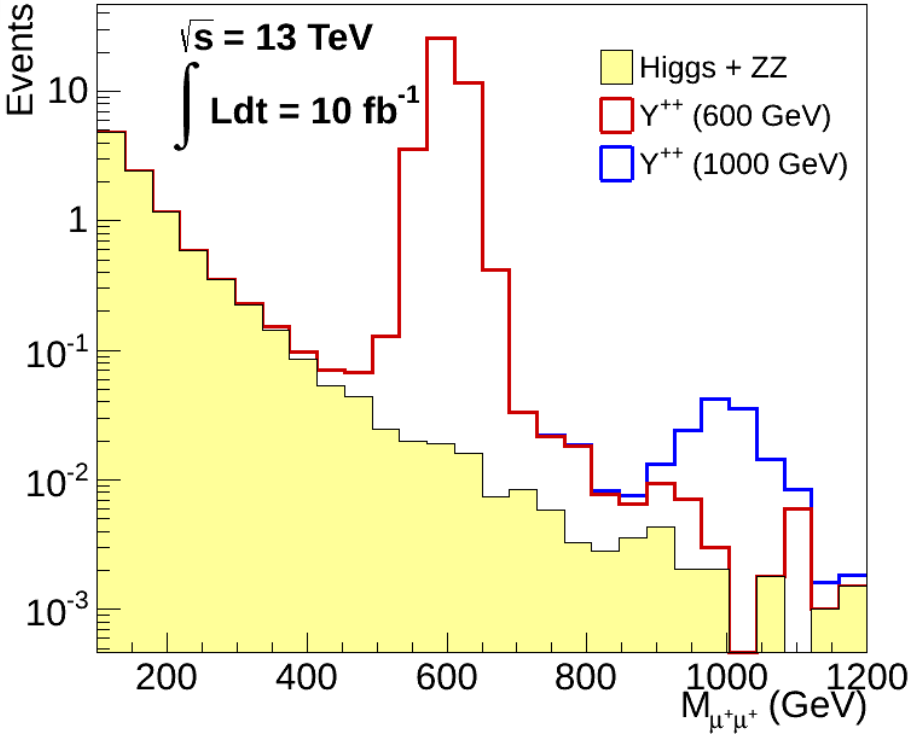


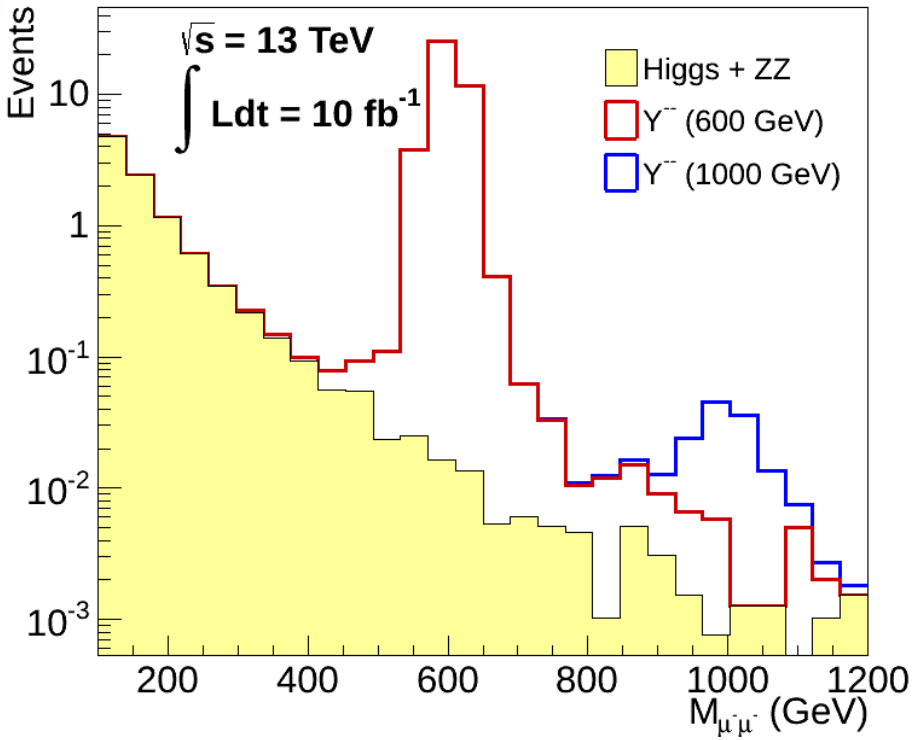
Bileptons at LHC Run II – 13 TeV

Event Selection
- At least four muons
- The two pairs must have opposite signs
- $|\eta| < 2.5$ and $p_T > 20$ GeV
- Trigger Efficiency: 80%
- Signal overall efficiency: ~ 60%

Background
- Higgs production
- ZZ production

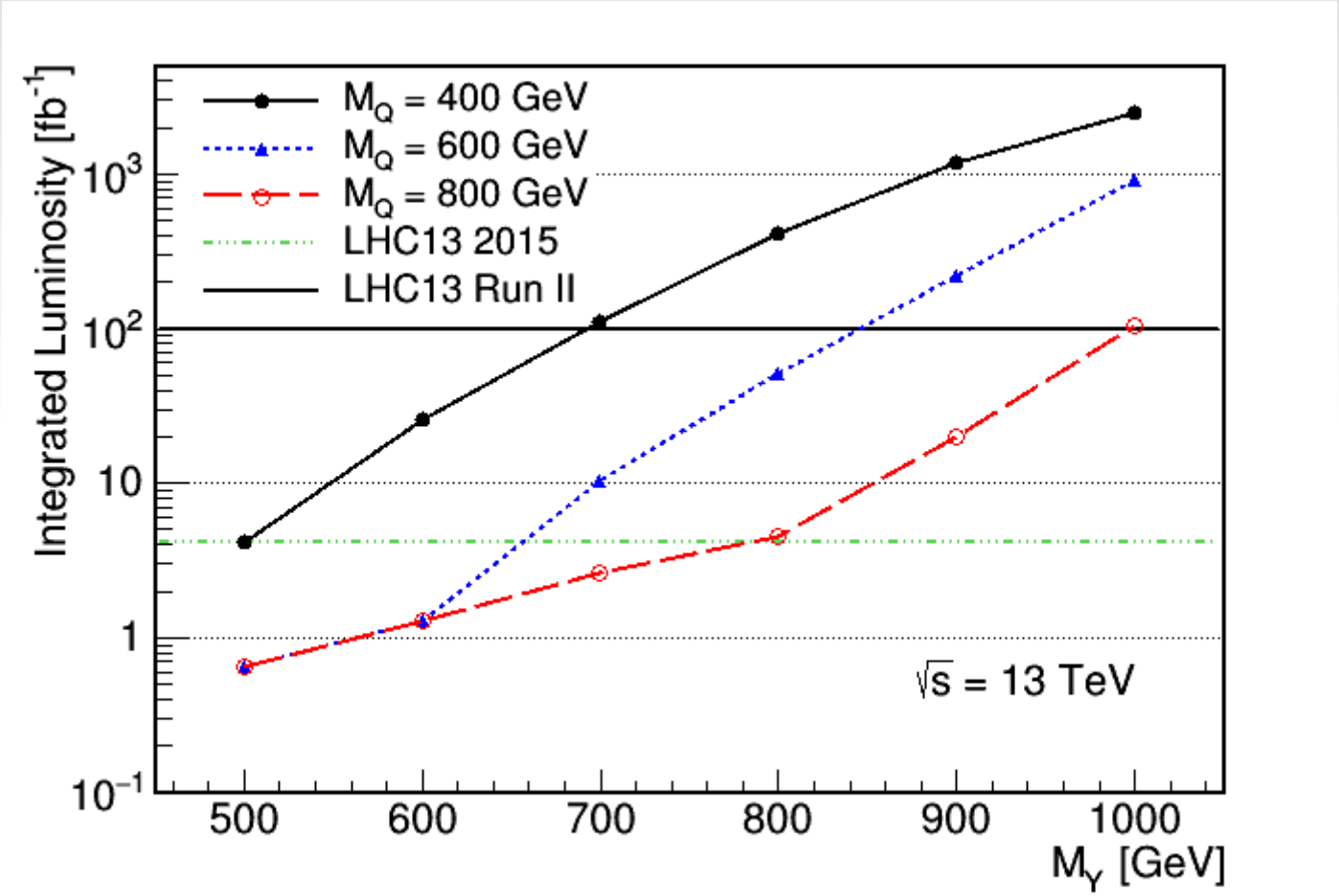
Higgs production only relevant for Mμμ < 500 GeV.





Discovery Potential

Minimal integrated luminosity needed to claim a discovery (13 TeV)



Bileptons masses up to 1 TeV can be probed with ~ 100 fb^{-1}.

PRD 94, 055020 (2016).