

# Search for heavy $T'$ quarks and third generation leptoquarks with the CMS detector

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# Outline



## **Search for heavy $T'$ quarks decaying to top and Higgs with substructure methods**

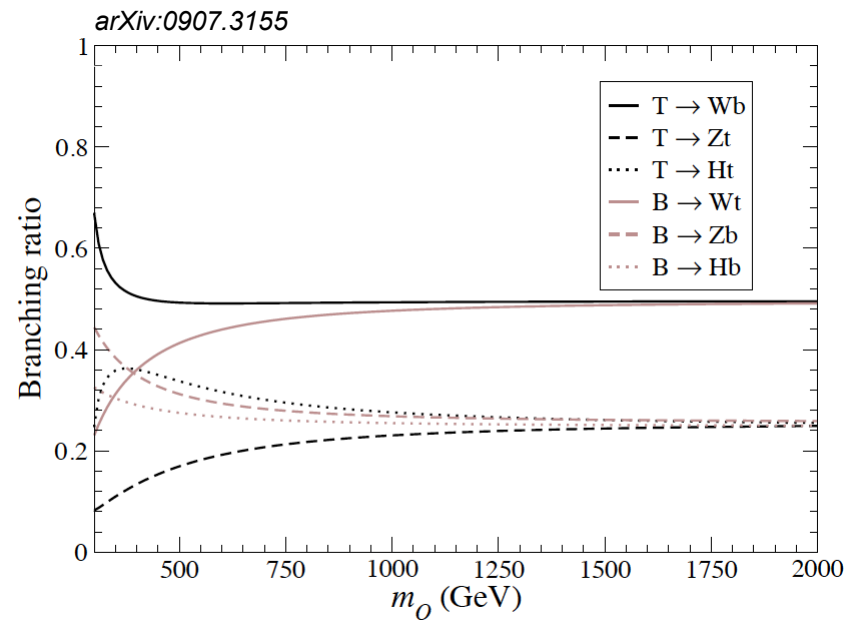
- motivation
- selection
- data-driven estimation of QCD multijet-background
- results

## **Search for third-generation leptoquarks decaying into top and tau**

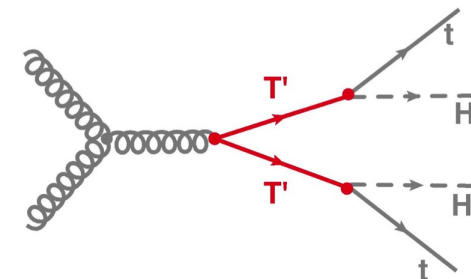
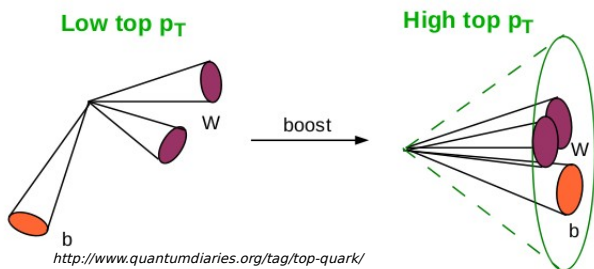
- motivation
- pre-selection & selections
- results

Search for  $T' \rightarrow t H$

- existence of chiral fourth generation of quarks highly unlikely due to the discovery of a Standard Model Higgs boson  
**but** vector-like fourth generation is possible
  - vector-like: both chiralities same transformation under  $SU(2) \times U(1)$
- predicted by many extensions of the Standard Model (extra dimensions, little Higgs Models, composite Higgs models)
- possible decay modes:
  - $T' \rightarrow bW, T' \rightarrow tH, T' \rightarrow tZ$
  - $B' \rightarrow tW, B' \rightarrow bH, B' \rightarrow bZ$
- searches are performed in almost all final states by ATLAS and CMS
- **this analysis:** pair production of T' quarks ( $Q=2/3e$ ), **all possible fully hadronic decay modes** considered



- optimized for  $T' \rightarrow tH$  with  $H \rightarrow bb$ , fully hadronic channel
- $T'$  massive new particles
  - boosted decay products
  - substructure tools needed



## □ HEP Top Tagger (*arXiv:1112.4441*)

- Cambridge-Aachen jet with  $\Delta R=1.5$  top tagged if
  - $140 \text{ GeV} < m_{\text{jet}} < 250 \text{ GeV}$
  - $p_T > 200 \text{ GeV}$
  - cuts on pairwise subjet mass

## □ Subject b-tagging (*CMS PAS BTV-13-001*)

- b-tagging algorithm applied on subjets of Cambridge-Aachen jets with  $\Delta R=1.5$
- $H \rightarrow bb$  identified through two b-tagged subjets
  - **Higgs-tag**

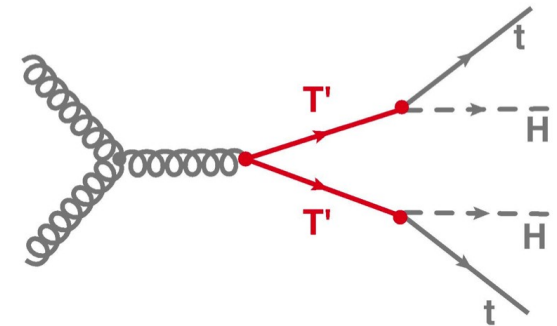
see talk Emanuele Usai "Jet Substructure, W- and Top-tagging in CMS"

full data sample 2012,  $E_{\text{CMS}} = 8 \text{ TeV}$ ,  $L = 19.7 \text{ fb}^{-1}$

$$H_T = \sum_{\text{jets}} |\vec{p}_T|$$

□ pre-selection:

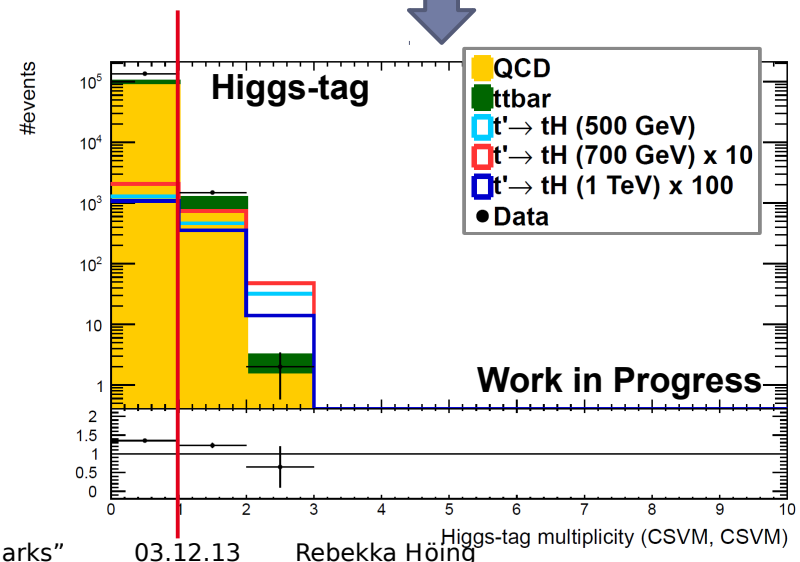
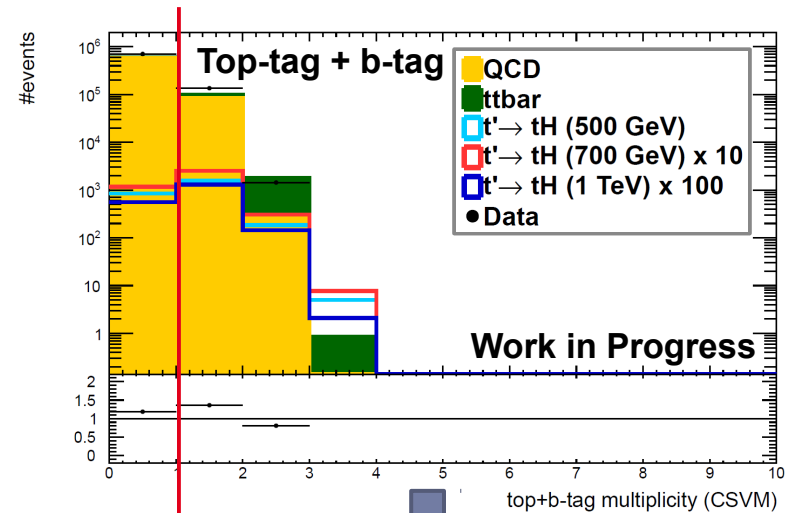
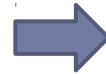
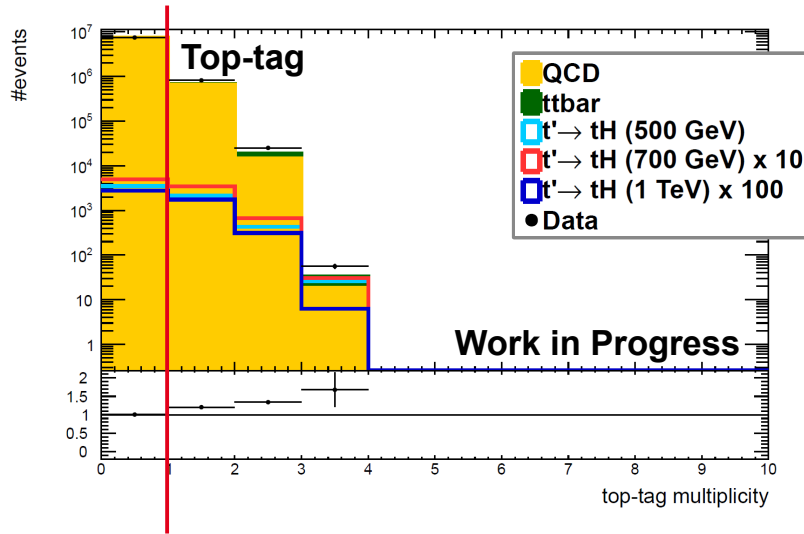
- $H_T$  based trigger,  $H_T > 1000 \text{ GeV}$
- at least two jets (Cambridge Aachen,  $\Delta R = 1.5$ ),  $p_T > 150 \text{ GeV}$ ,  $|\eta| < 2.5$



□ substructure tools:

- at least one HEP top-tag
- at least one subjet of the top-tagged jet is b-tagged
- at least one Higgs-tagged jet (different jet than the top-tagged jet)

# Control plots



- signal: 100% BR  $T' \rightarrow tH$
- top-tagging, b-tagging and Higgs-tagging largely reduce backgrounds
- QCD multijet-production still main background  
→ data-driven background estimation

- ABCD-method

- changed cuts:

- veto Higgs-tag
- HEP Top Tagger (invert mass requirements)

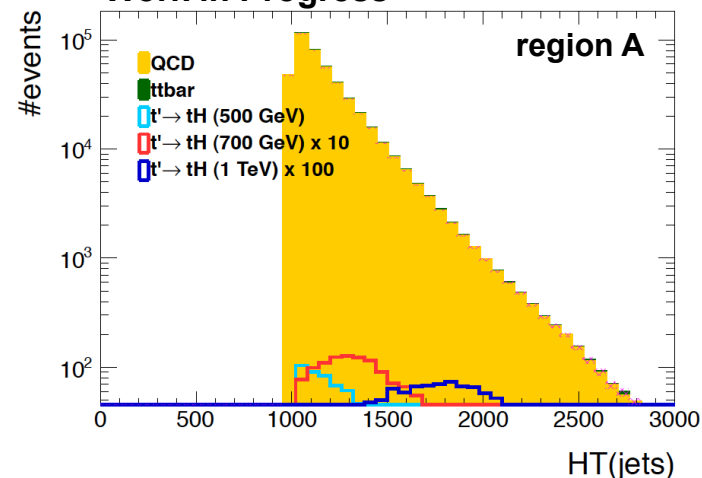
	invert top-tag	apply top-tag
veto Higgs-tag	A	B
apply Higgs-tag	C	D

- regions A, B and C:

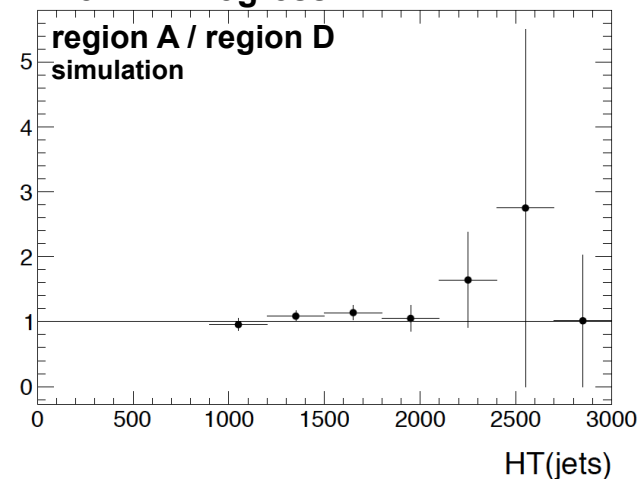
- QCD enriched sidebands
- little signal contamination
- subtraction of ttbar background

- shape of QCD in signal region taken from region A, yield taken from ABCD-method:  $yield_D = yield_B / yield_A * yield_C$

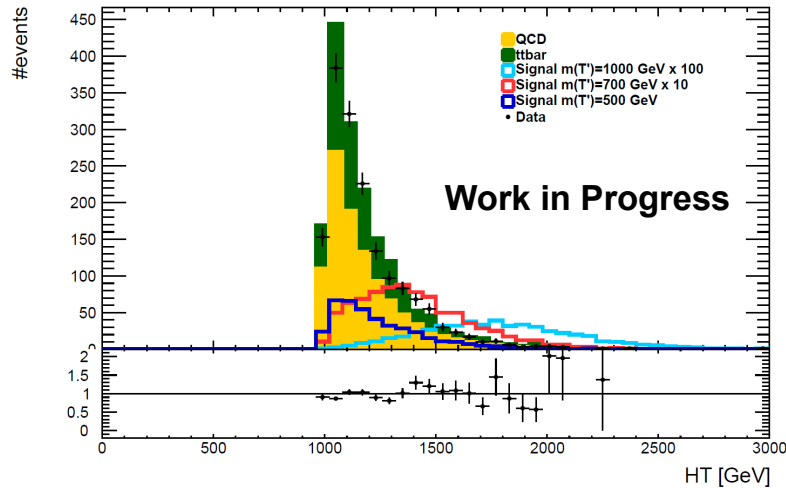
## Work in Progress



## Work in Progress





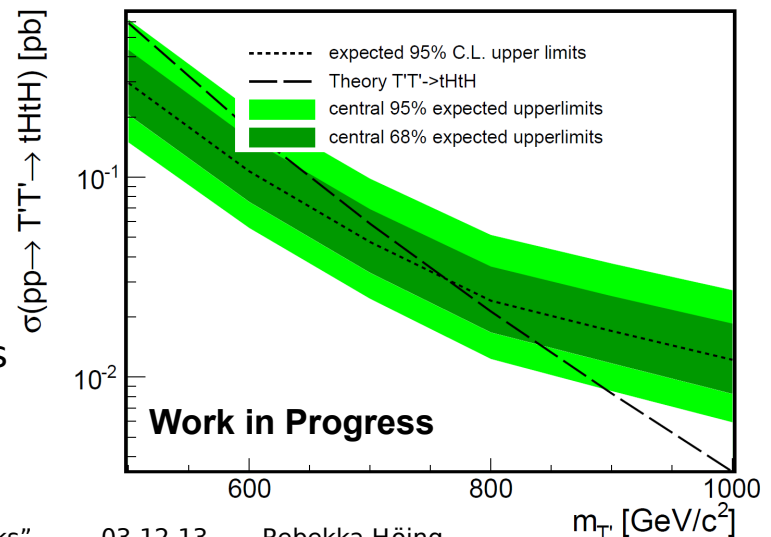


- $H_T$  distribution after event selection
- data-driven estimation of QCD background
- main backgrounds:  $t\bar{t}$ -production, QCD multijet-production
- good separation between signal and background  
→ distribution can be used in limit setting procedure
- no excess over the Standard Model expectation observed

□ preliminary limit, ad-hoc assumptions for systematic uncertainties

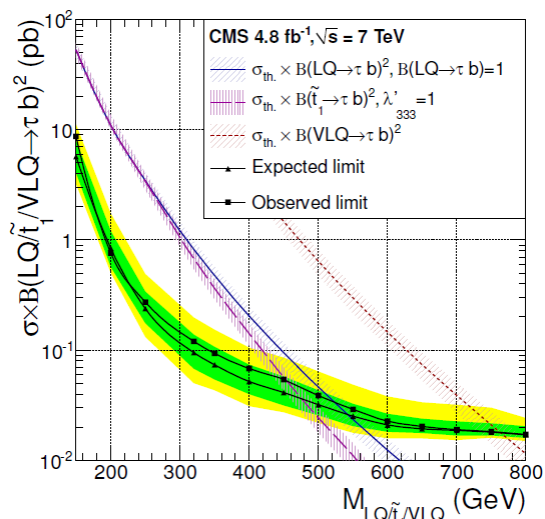
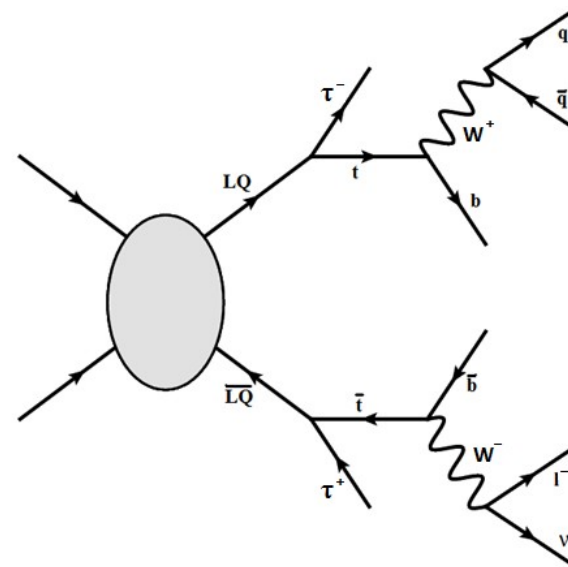
□ **next steps:**

- scan over branching ratios
- final estimation of systematic uncertainties
- include single  $T'$  production



Search for  $LQ_3 \rightarrow t \tau$

- bosons which decay into a lepton and a quark  
 → three generations of leptoquarks  
 → decays to fermions of same generation  
 favored due to constraints on FCNC and other rare processes
- predicted by many extensions of the SM (GUT, technicolor, compositeness)
- LHC: pair production through gluon-gluon fusion and quark-antiquark annihilation



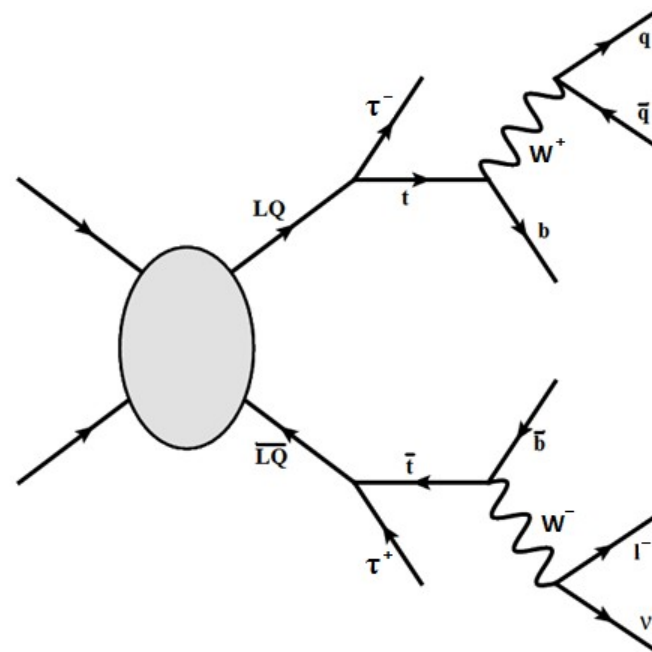
arXiv: 1210.5629

- high mass limits on first- and second- generation leptoquarks set by ATLAS and CMS
- searches for third-generation leptoquarks only performed in the channels  $b+\tau$  and  $b+\nu_\tau$ , no one ever looked in **channel  $t+\tau$**

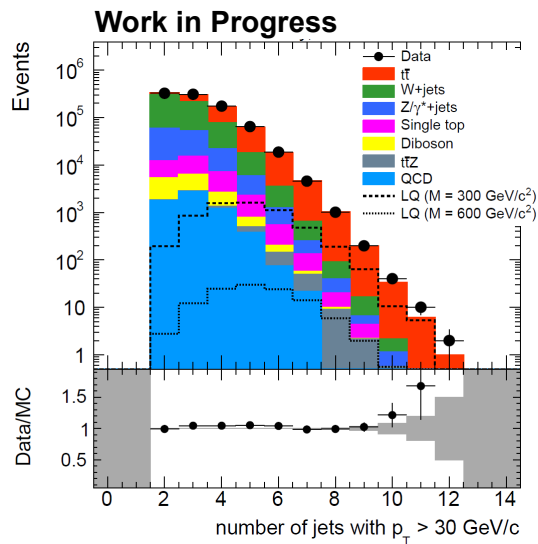
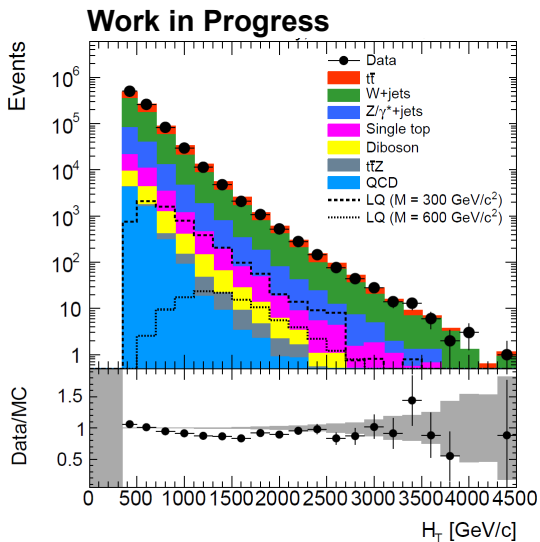
full data sample 2012,  $E_{\text{CMS}} = 8 \text{ TeV}$ ,  $L = 19.7 \text{ fb}^{-1}$

$$H_T = \left( \sum_{\text{jets, leptons}} |\vec{p}_T| \right) + \cancel{E}_T$$

- isolated muon/electron trigger
- $H_T > 350 \text{ GeV}$
- at least one central tau with  $p_T > 20 \text{ GeV}$ , hadronic decay
- at least two central jets with  $p_T > 50 \text{ GeV}$
- muon channel:
  - at least one central muon with  $p_T > 35 \text{ GeV}$
- electron channel:
  - at least one central electron with  $p_T > 30 \text{ GeV}$
  - veto against tight muons

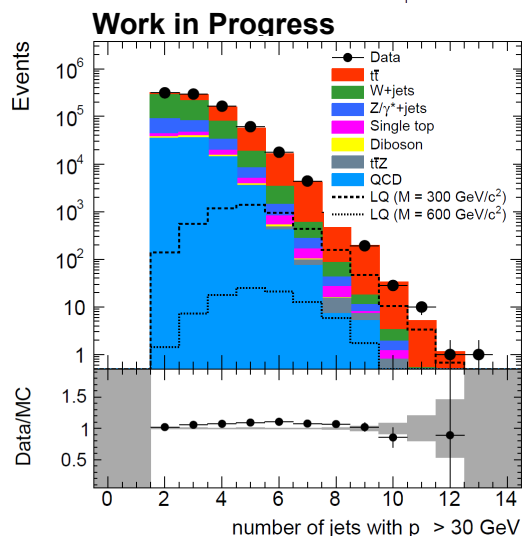
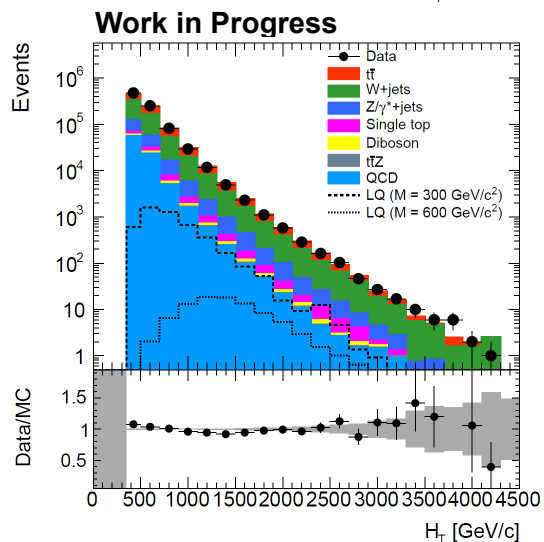


muon channel



- data and MC agree well
- main backgrounds: ttbar-production, W+jets-production (mostly fake taus) and Z+jets-production
- ttbar-production particularly important with increasing number of jets

electron channel



- perform final selection based on one muon/electron, two jets,  $H_T$  and  $\cancel{E}_T$
- expected limits calculated with theta ([www.theta-framework.org](http://www.theta-framework.org))
- based on best expected limits

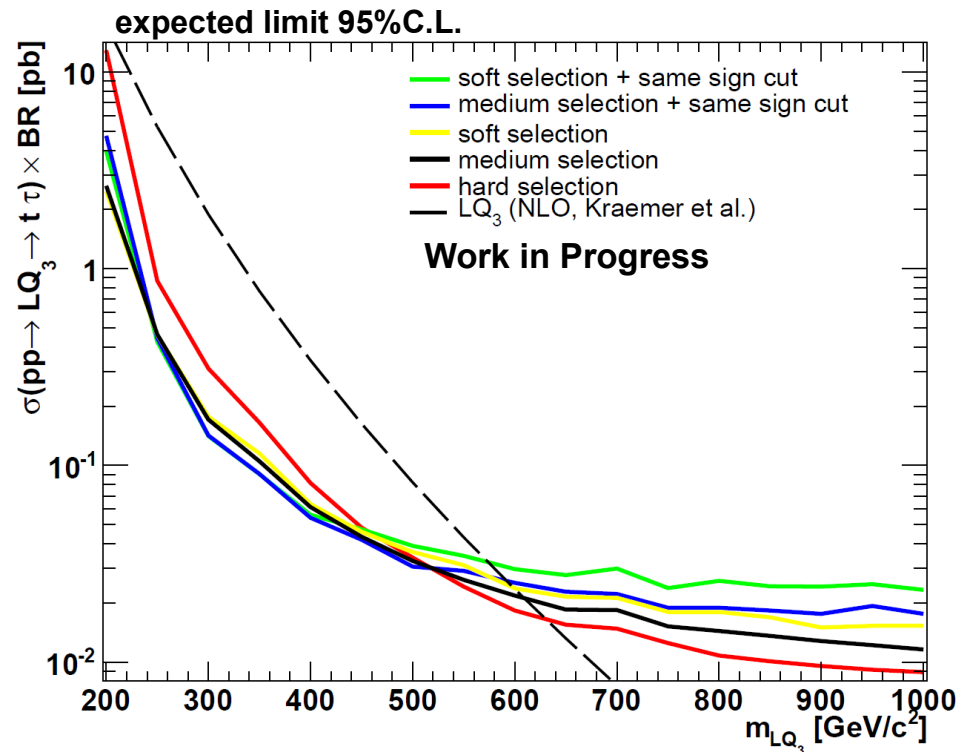
➔ medium and hard selection

## □ medium selection

- at least one tau lepton candidate
- leading jet  $p_T > 100$  GeV
- third jet with  $p_T > 30$  GeV
- $H_T > 400$  GeV
- $\cancel{E}_T > 50$  GeV

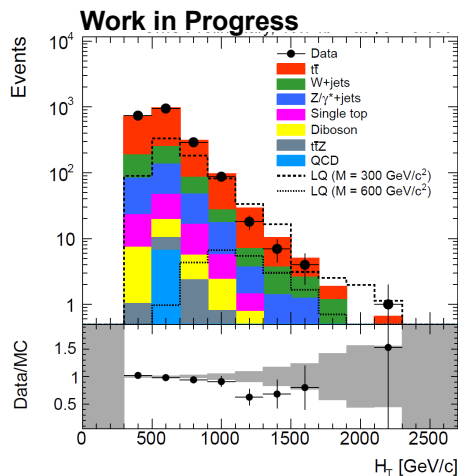
## □ hard selection

- medium selection
- leading jet  $p_T > 150$  GeV
- second and third jet  $p_T > 50$  GeV
- $H_T > 700$  GeV
- $\cancel{E}_T > 100$  GeV

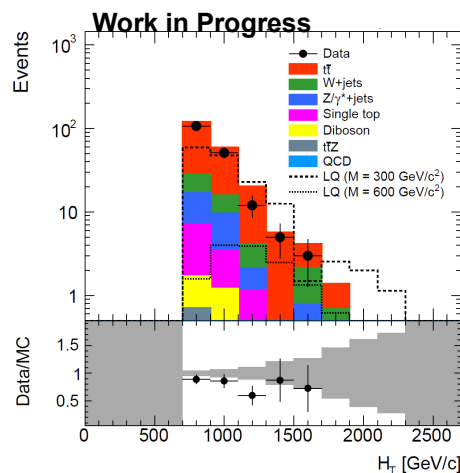


muon channel

## medium selection

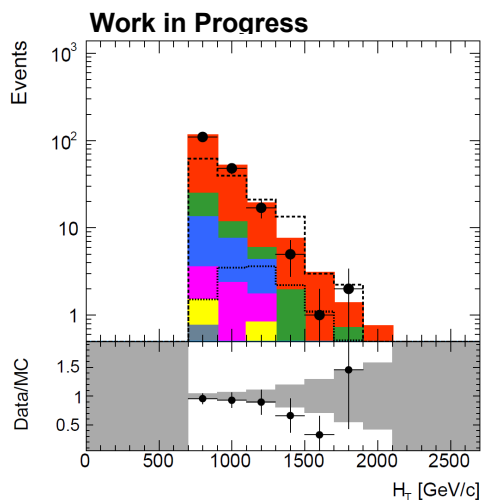
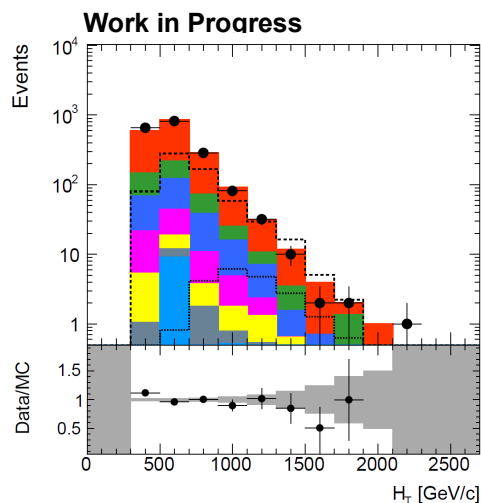


## hard selection



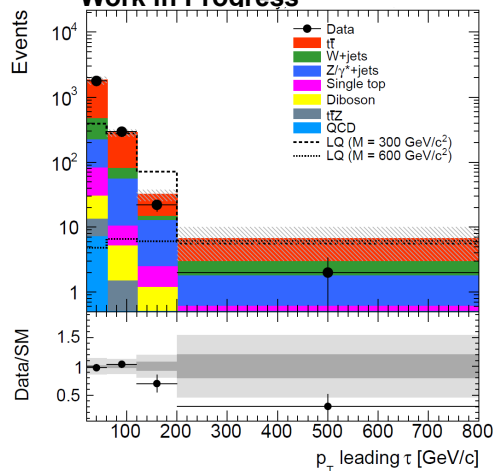
- measured tau fake rate scale factors in  $W$ +jets sideband, corrections applied
- data and MC agree well
- main background:  $t\bar{t}$ -production

electron channel

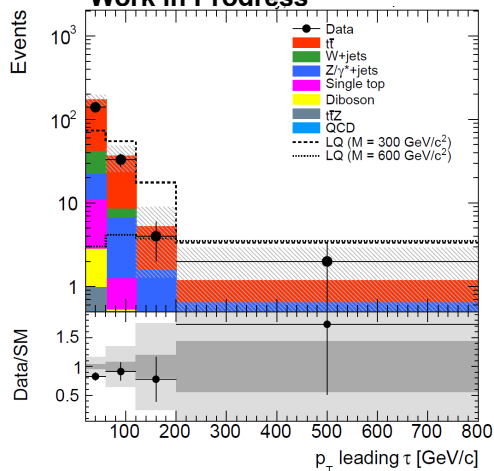


muon channel

## medium selection Work in Progress



## hard selection Work in Progress

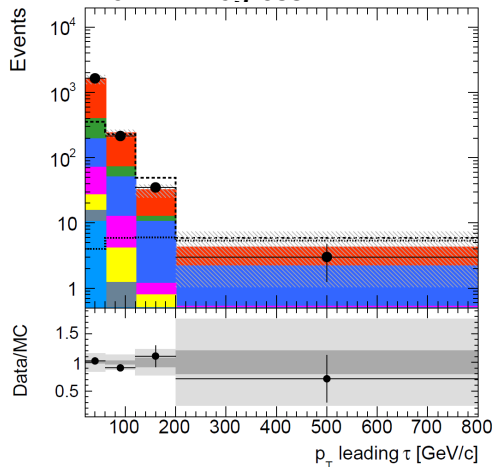


□  $p_T$  distribution of leading tau lepton:

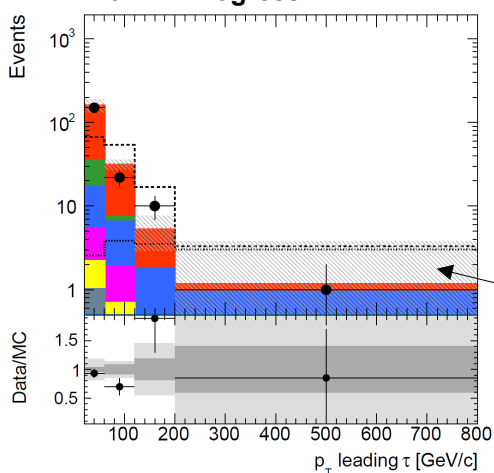
- good separation between signal and background
- high sensitivity for different leptoquark masses

electron channel

## Work in Progress



## Work in Progress

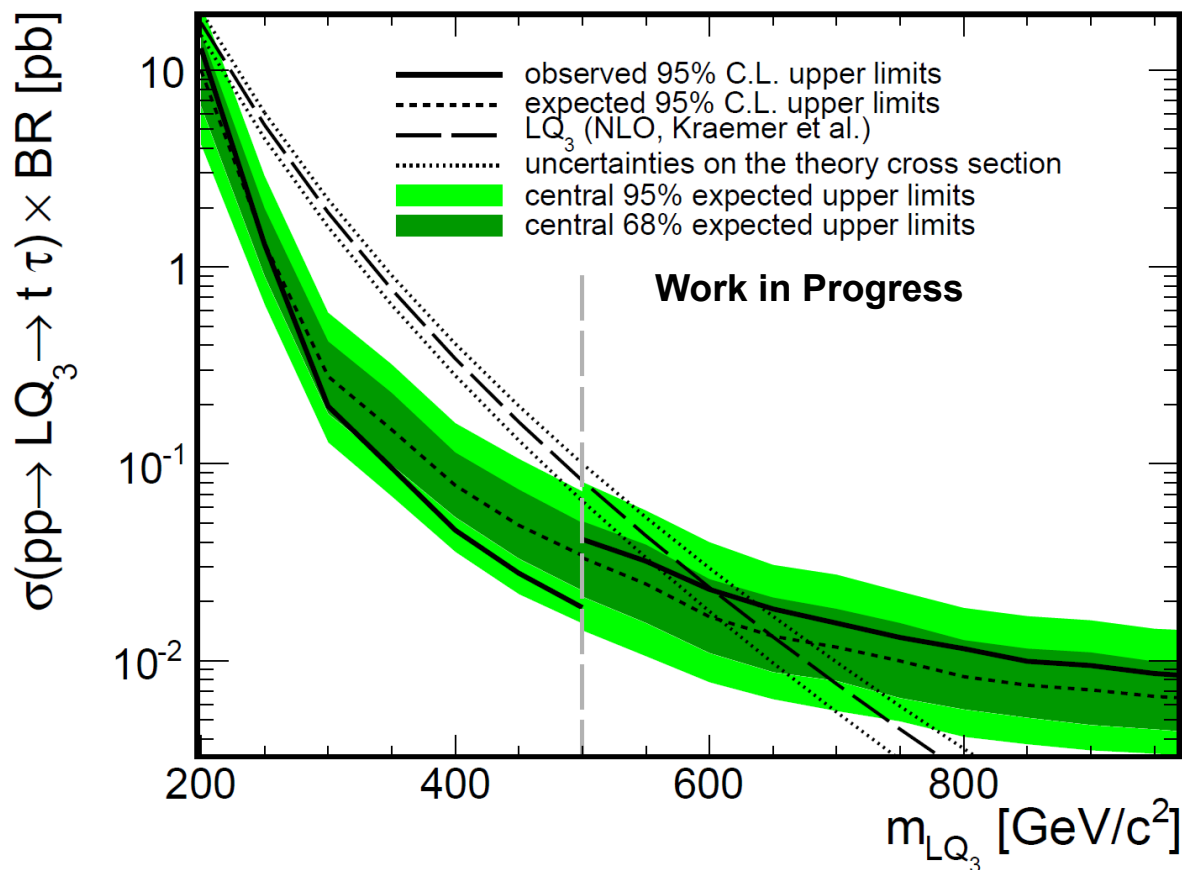


➔ can be used in limit setting procedure

□ no excess over the Standard Model expectation observed

statistical and systematic uncertainties

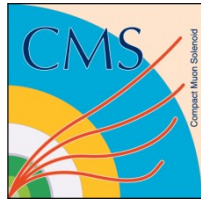




- limits calculated with the theta framework ([www.theta-framework.org](http://www.theta-framework.org))
- all systematic and statistical uncertainties are taken into account



# Summary



- presented two searches for new physics in the top quark sector
- first results in these channels
- search for  $T' \rightarrow tH, tZ, bW$ 
  - extensive use of substructure techniques make search in full hadronic state possible
- search for  $LQ_3 \rightarrow t \tau$ 
  - challenging experimental signature
- official publication of both analyses expected soon