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The Search for Fourth Generation Top-Like Quarks (t') in the Lepton+Jets Channel at CMS

The CMS Collaboration
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4^{th} Gen. t' quarks in the lepton+jets channel

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Talk is based on material found in EXO-11-099

$$t'\bar{t}' \to bWbW \to bbjjl\nu$$

Search uses the 4.68 (4.60) fb^{-1} of data collected during 2011 at CMS in the e+jets (μ+jets) channel at $\sqrt{s} = 7\ TeV$.

Assumptions:

- is strongly pair produced
- has mass greater than top quark
- decays promptly.

Motivation

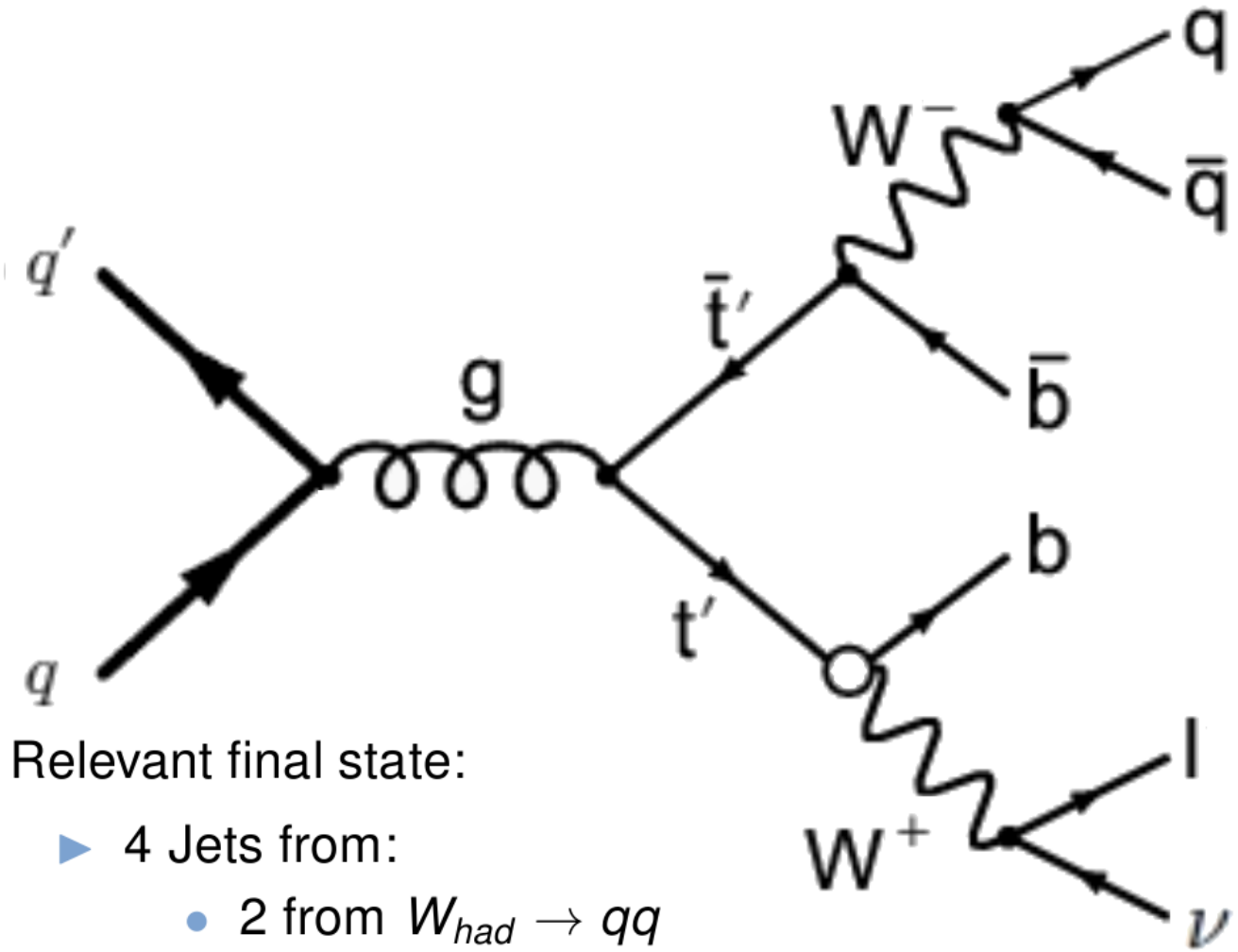
Fourth generation chiral quarks:

- Natural extension of Standard Model
- Consistent with precision electroweak measurements
- May allows sufficient *CP* violation to explain matter-antimatter asymmetry - highly constrained CKM matrix does not allow sufficient CP violation (only one *T* violating complex phase with 3 generations, measured to be very small)

Search is not limited to fourth generation chiral quarks - many BSM theories predict particles the same decay:

- May resolve 'naturalness' of Higgs predicted to be light - by cancelling quadratically divergent loop diagrams.

$t'\bar{t}' \to bWbW$



Relevant final state:

- 4 Jets from:
  - 2 from $W_{had} \to qq$
  - 2 b-jets
- 1 visible lepton and MET from:
  - $W_{lep} \to l\nu$

Constraints

Constraints on the pair produced t' mass:

- $m_{t'} > 404$ GeV direct search

  ATLAS arxiv:1202.3076
- $|m_{t'} - m_{b'}| < 50$ GeV from precision electroweak measurements

  (Kribs, PRD 76 075016 (2007) Eberhardt, Lenz, Rohrwild, PRD 82 095006 (2010))
- $m_{b'} > 611$ GeV direct search
  (CMS arXiv:1204.1088)

motivates our search:

$$t'\bar{t}' \to bWbW$$

in lepton+jets channel.

Selection criteria - *lepton + jets*

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Selection chosen to maximise $n_s/\sqrt{n_b}$.

- primary vertex
  - $|z| < 24$ cm , $|r| < 2$ cm
- lepton and MET
  - $pT > 35 - 42$ GeV to match trigger threshold
  - pseudorapidity $|\eta| < 2.5$ (2.1 for μ)
  - impact parameter of matched track $|d_{xy}| < 0.02$ cm, $|d_z| < 1$ cm
  - missing $p_T > 20$ GeV
- at least 4 jets with
  - $pT > 120, 90, 50(30), 35(30)$ GeV & $|\eta| < 2.4$ (μ+jets)
  - $\Delta R(l, jets) = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.3$ veto - avoids double counting leptonic jets
  - ≥ 1 jet is btagged (suppresses W+jets and QCD).

Event Yield: $e + jets$ @ 4.68 fb^{-1} & $\mu + jets$ @ 4.60 fb^{-1}

		e+jets events	μ+jets events
$\mathcal{L}$		4683 pb^{-1}	4601 pb^{-1}
data		4734	6448
background process	cross section		
$t\bar{t}$	165.8 pb	4000 ± 33	5536 ± 45
single t	33 pb	196 ± 3	316 ± 5
W+jets	30 μb	434 ± 13	709 ± 48
Z+jets	2.9 μb	46 ± 5	51 ± 6
WW,WZ,ZZ	67 pb	–	14 ± 1
multijets (QCD)		73 ± 3	5 ± 5
total background		4749 ± 36	6631 ± 67

e+jets and μ+jets optimised and studied independently.

$t\bar{t}$ background is irreducible:

- use 'fitted' mass and $H_T \equiv \sum p_T$(jets,MET,lepton) to discriminate against $t'\bar{t}'$ signal.

Event Reconstruction

Kinematic fitter reconstructs the fitted mass M_{fit} and H_T.
Measurements:

- Lepton momentum
- Neutrino p_T (calculated)
- Jets momenta

Fit unknowns:

- t' mass
- ν has 2 $p_{//}$ solutions
- 4 jets from $b, \bar{b}, W_{had}$ ($4!/2 \times 2 = 24$ combinations if consider only 4 leading jets)

Fit constraints:

- $M(W_{had} \to q\bar{q}) = M_W(80.4\ \text{GeV}) \quad = M(W_{lep} \to l\nu)$
- $M(W_{had} + b) \quad = \quad M_{fit}(\text{free param.}) = M(W_{lep} + b)$

Fit to constraints - get one χ^2 value for each combination.
Then pick 'best' combination that reconstructs the event.

Mass and H_T Reconstruction

Final state: 4 jets $+l\nu$ but also have initial/final state radiation.

Number of combs of assigning jets to partons ($\times 2\nu_{//}$ sol) :

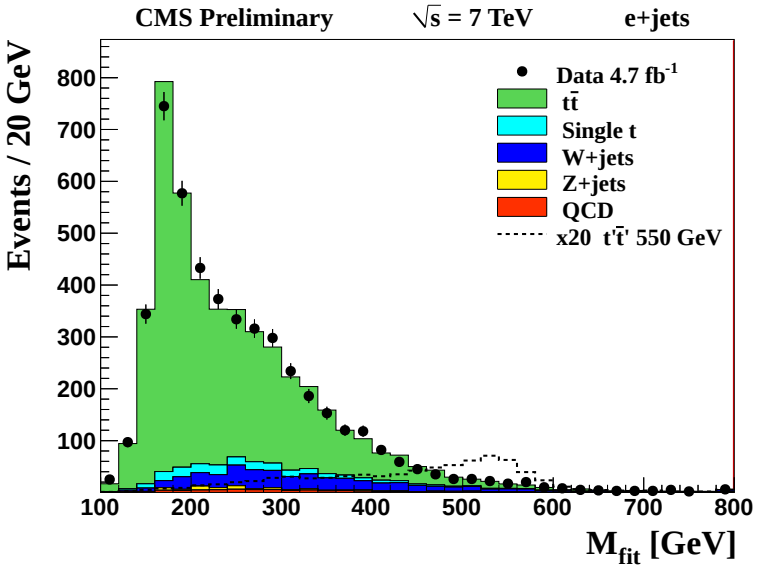
no of jets	combinations	1 b-tag
4	12	6
5	60	24
6	180	60

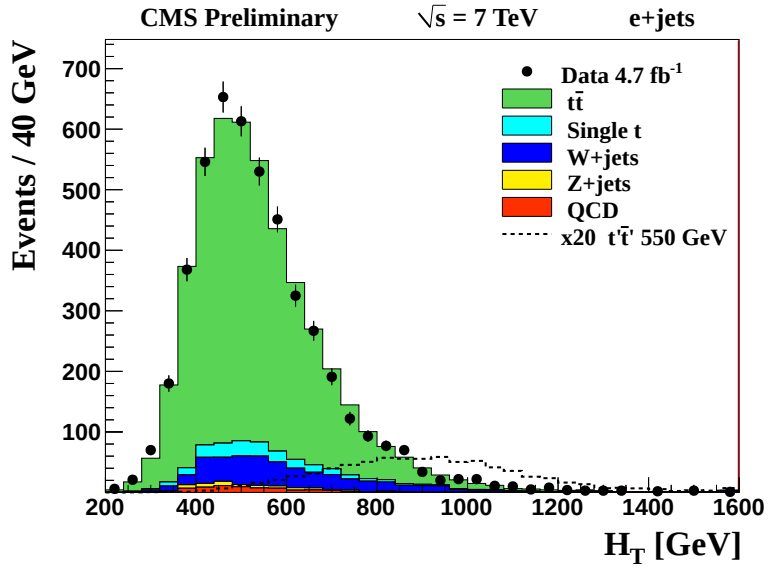
Studied 4,5,6 leading jets - 5 jets best compromise.

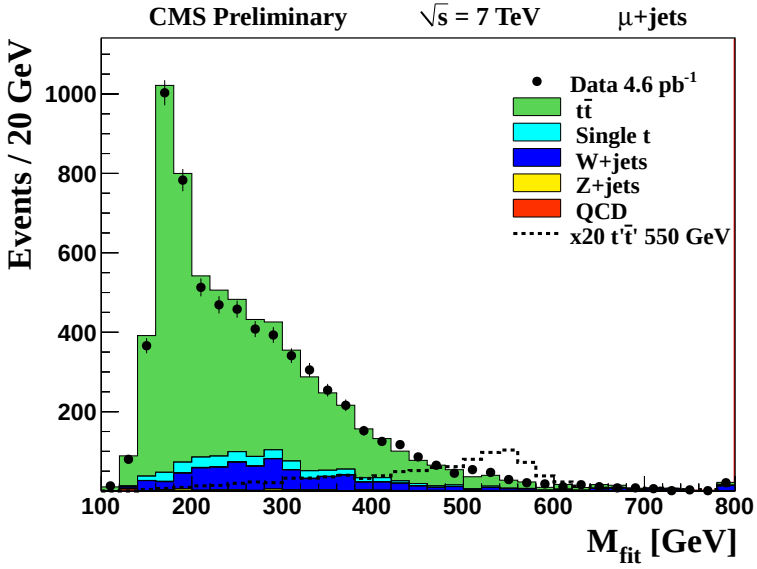
We take the Minχ^2 combination from the following set:

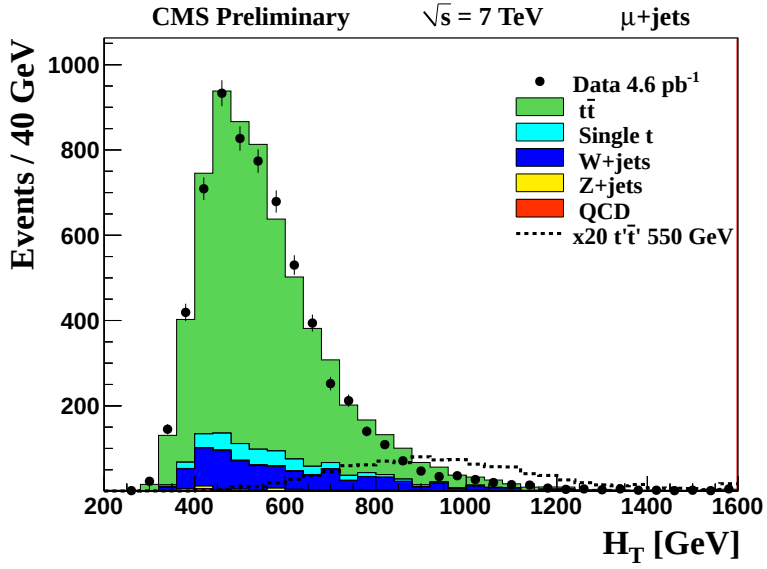
- all 4-jet combs out of the leading 5 jets, which have one btagged jet assigned to a bjet in the fitter hypothesis.

M_{fit} & H_T: $e+jets$@4.68 fb^{-1} , $\mu+jets$@4.60 fb^{-1}









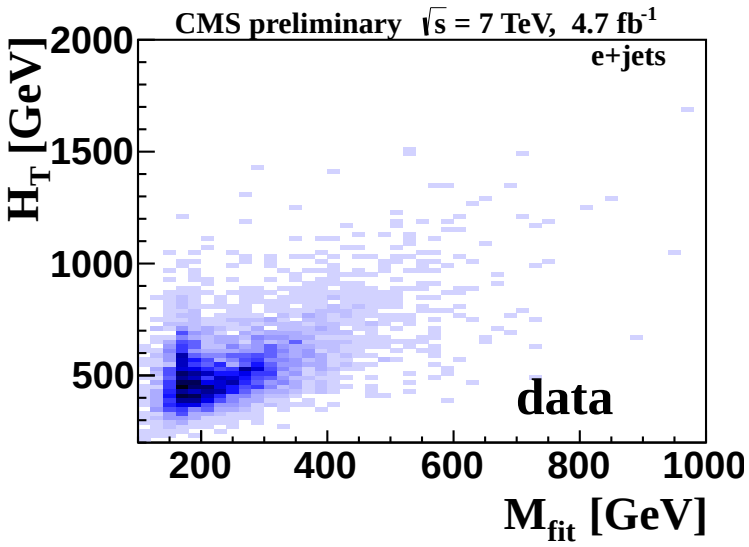
Procedure and Limit Computation

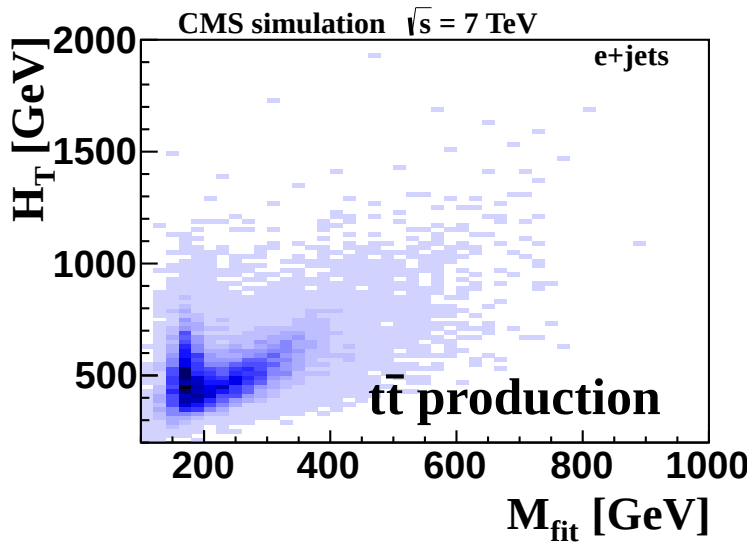
Statistical procedure:

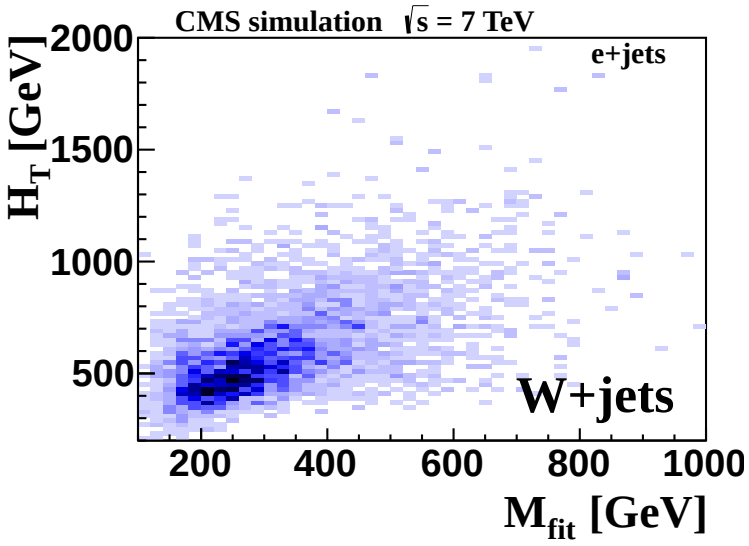
- Start with $2D$ histogram (M_{fit} *vs* H_T)
- Apply fit to $2D$ templates - this smooths out statistical uncertainty (used *only* in ordering)
- Order bins in descending $S/\sqrt{B}$ according to the fitted values - maximises signal and background separation
- Merge adjacent bins until have good statistics in both background and signal MC templates

These final templates are then compared to data (with uncertainties) by HistFactory, a limit calculator.

2D Distributions - *e*+jets







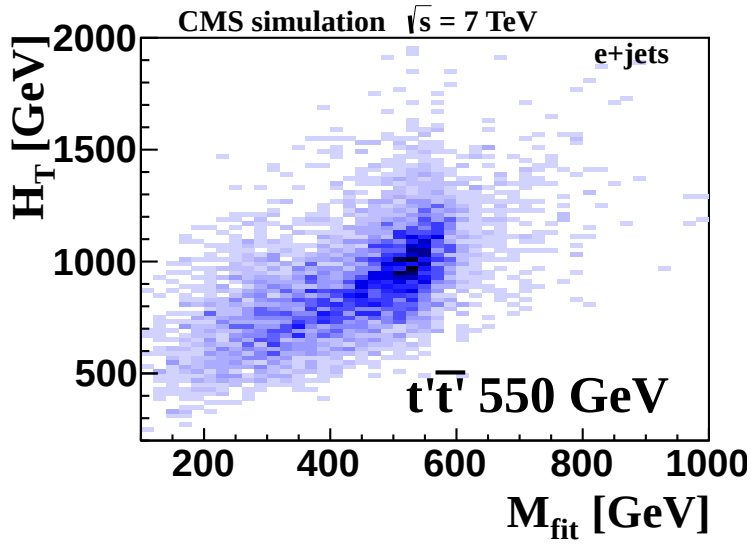
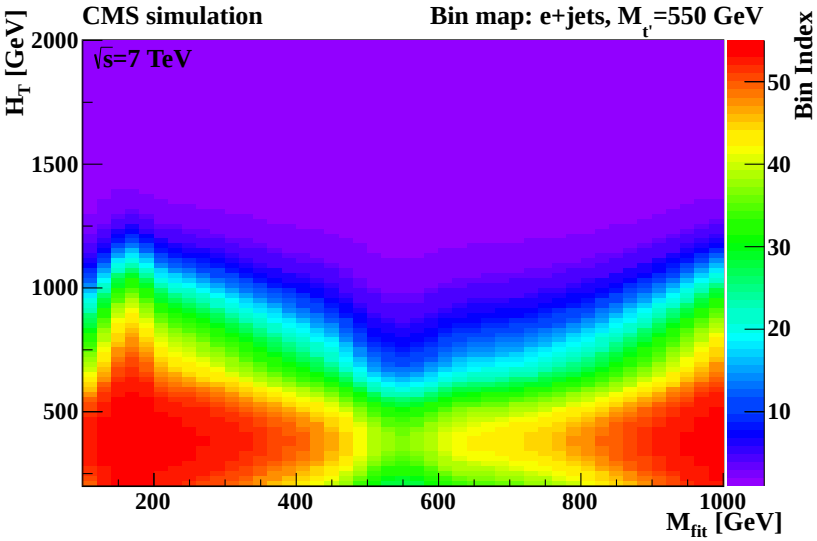


Figure: *e*+jets 2D plots using $\int \mathcal{L} = 4.68$ fb^{-1} (μ+jets similar).

2D Fit and Final Merged Templates - e+jets



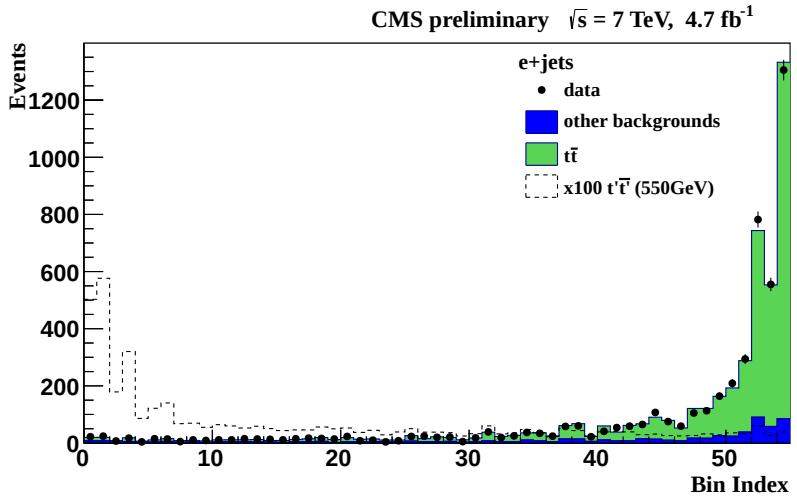


Figure: (left) e+jets 2D $S/\sqrt{B}$ plot using $\int \mathcal{L} = 4.68$ fb^{-1}. Each colour corresponds to one bin in the merged final templates (right).

(μ+jets similar)

Uncertainties

- $t\bar{t}$ cross section:
  - $158pb \pm 11\%$
- total electroweak (non $t\bar{t}$) background normalization - 50% uncertainty of sum of other backgrounds.
- integrated luminosity:
  - lumi known to $\pm 6\%$
- lepton selection efficiency:
  - data driven correction 1% (3%) for e+jets (μ+jets)
- b-tagging efficiency:
  - correction factor to match simulation and data applied to $t\bar{t}$ and $t'\bar{t}$ 5%
- jet energy scale:
  - JES corrected by CMS jet energy calibration constants $\pm 1\sigma(5\%)$
- jet energy and missing p_T resolution:
  - JER for simulation increased by $10 \pm 10\%$ to match resolution in data
  - MET varied accordingly.

Limits: e+jets 4.68 fb^{-1}, μ+jets 4.60 fb^{-1}

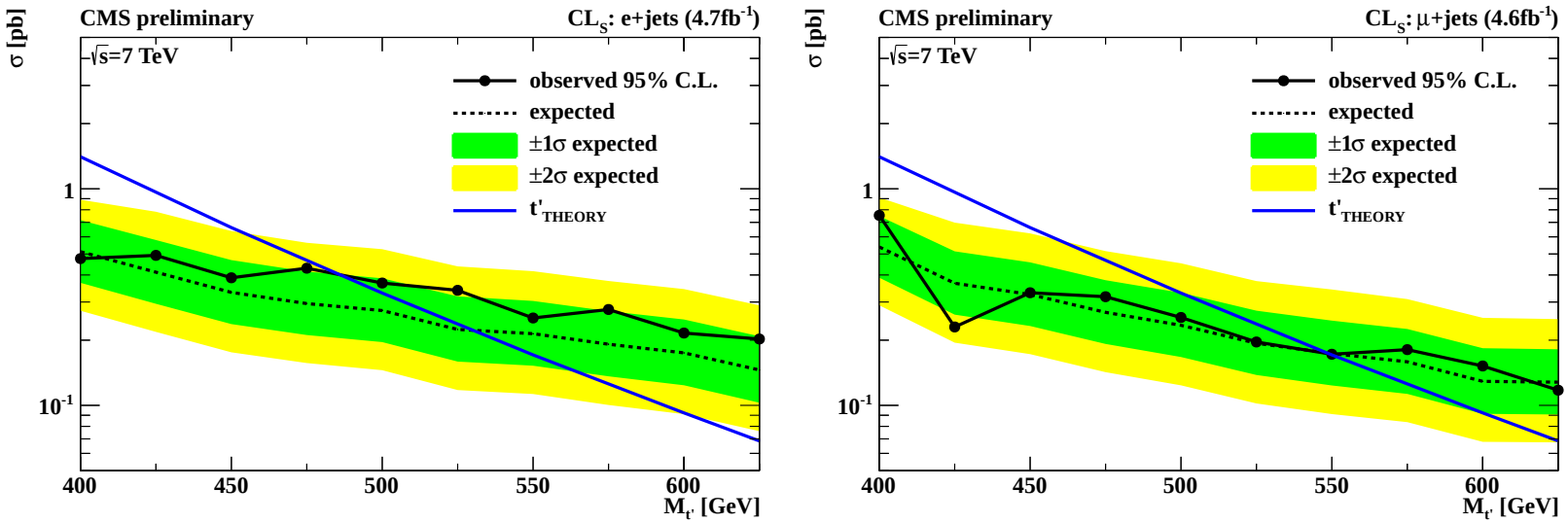


Figure: (left) $m_{t'} > 485$ GeV @ 95%CL in the e+jets channel (right) $m_{t'} > 550$ GeV @ 95%CL in the μ+jets channel.

Results: Combined Limit

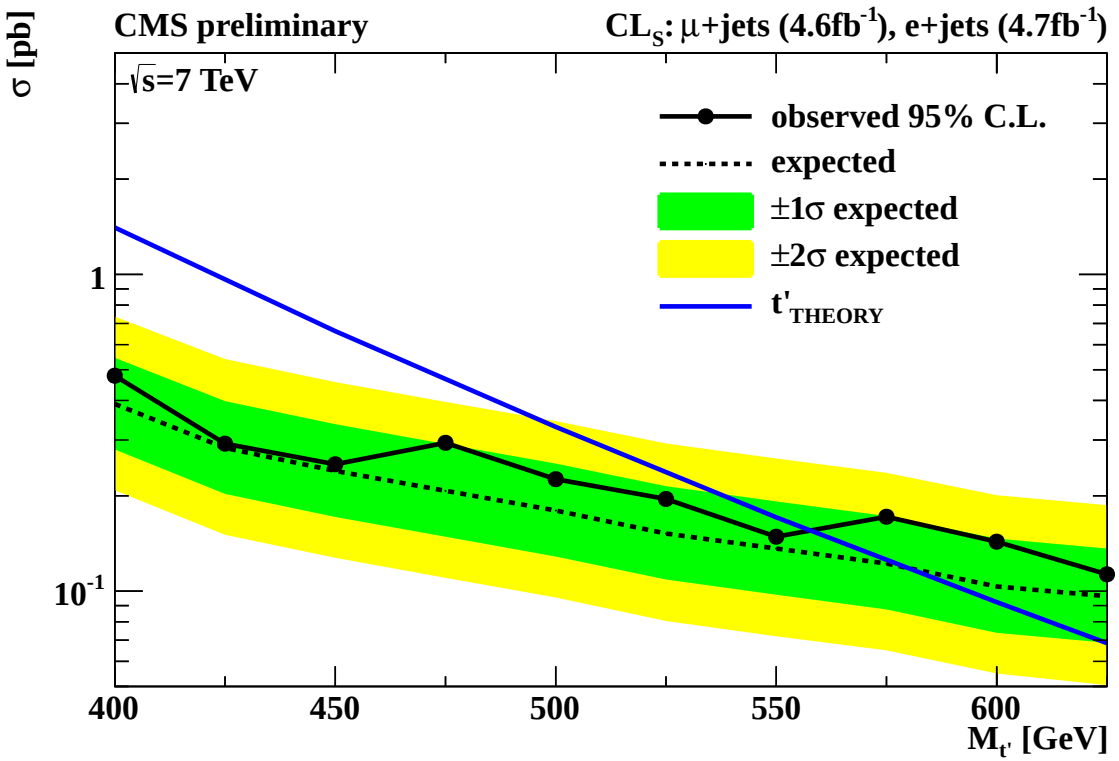


Figure: observed limit: $m_{t'} > 560$ GeV @ 95%CL (exp. 575 GeV)

For t' quark masses above 550 GeV the coupling of the t' to Higgs field becomes so large that perturbative theory starts to break down. M.S. Chanowitz, M.A. Furman, I. Hinchliffe, Phys. Lett. B78, 285 (1978).

$\to$ Makes theoretical extension to fourth generation non-trivial.

Final Comments

Searched for Fourth Generation Top-Like Quarks (t') in the Lepton+Jets Channel:

- exclusive decay $t' \to bW$
- strongly pair production
- used 4.68 fb^{-1} in $e + jets$ and 4.60 fb^{-1} in $\mu + jets$ channel
- $m_{t'} > 560$ GeV observed limit with 95% CL

$\to$ no excess over SM seen.