

Top Partners

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Motivation

- The electroweak naturalness problem goes hand-in-hand with the large top-quark Yukawa coupling
- New physics related to top sector very well motivated
 - SUSY: stops
 - Little Higgs: vector-like $SU(2)$ singlet T'
 - Randall-Sundrum: Top KK-modes
 - Composite Higgs: higher reps for improved EWP fits
 - UV completions of RPV MFV SUSY

Phenomenology

- R-parity conserving SUSY - stops create MET-type topologies
- Not generic - many models with exotic quarks involve pure SM final states:
 - pair or single production - decays to Wb , Zt , Ht , Wt
 - also potentially flavor non-conserving
- There are a few existing studies that probe one or more of these topologies
- May affect Higgs physics (e.g. enhance di-photon rate)

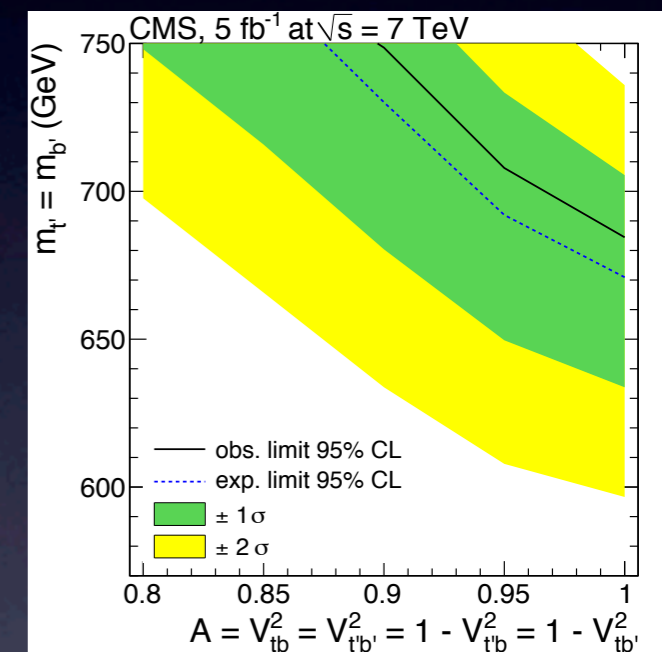
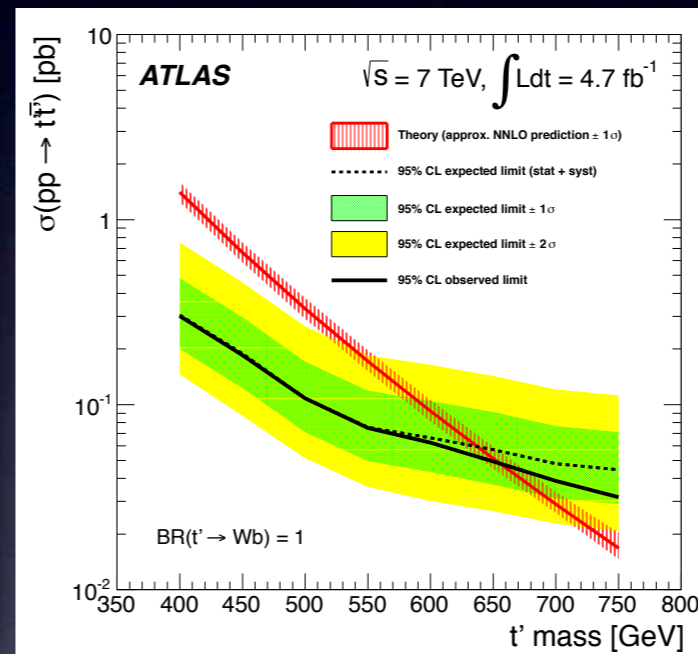
Chiral 4th generation

$$T' \rightarrow Wb$$

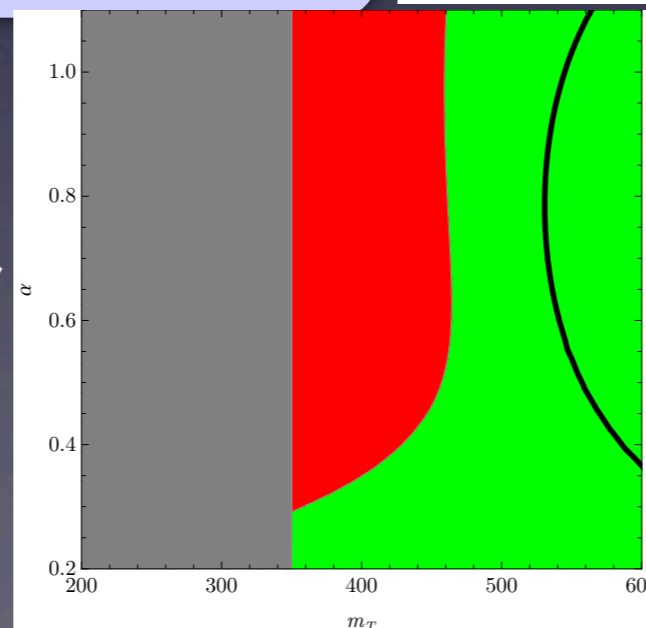
Straightforward SM extension - excluded by Higgs production rate/EWFP

utility: simplified model - re-cast for T' quarks with similar final states

Mode	ATLAS	CMS
$t' \rightarrow Wq$	350 (di-leptons) [20]	
$t' \rightarrow Wb$	656 (1+jets) [5]	570 (1+jets) [6] 557 (di-leptons) [7] 685 (inclusive) [8]
$b' \rightarrow Wt$	480 (1+jets) [9] 450 (ss leptons) [11] 670 (1+jets) [13]	675 (1+jets) [10] 611 (ss leptons) [12] 760 (multileptons+btag) [14]



recast limits on little Higgs type top-partner (CMS di-lepton):



Bounds on LH top partner considerably weaker over most parameter space (~450 GeV)

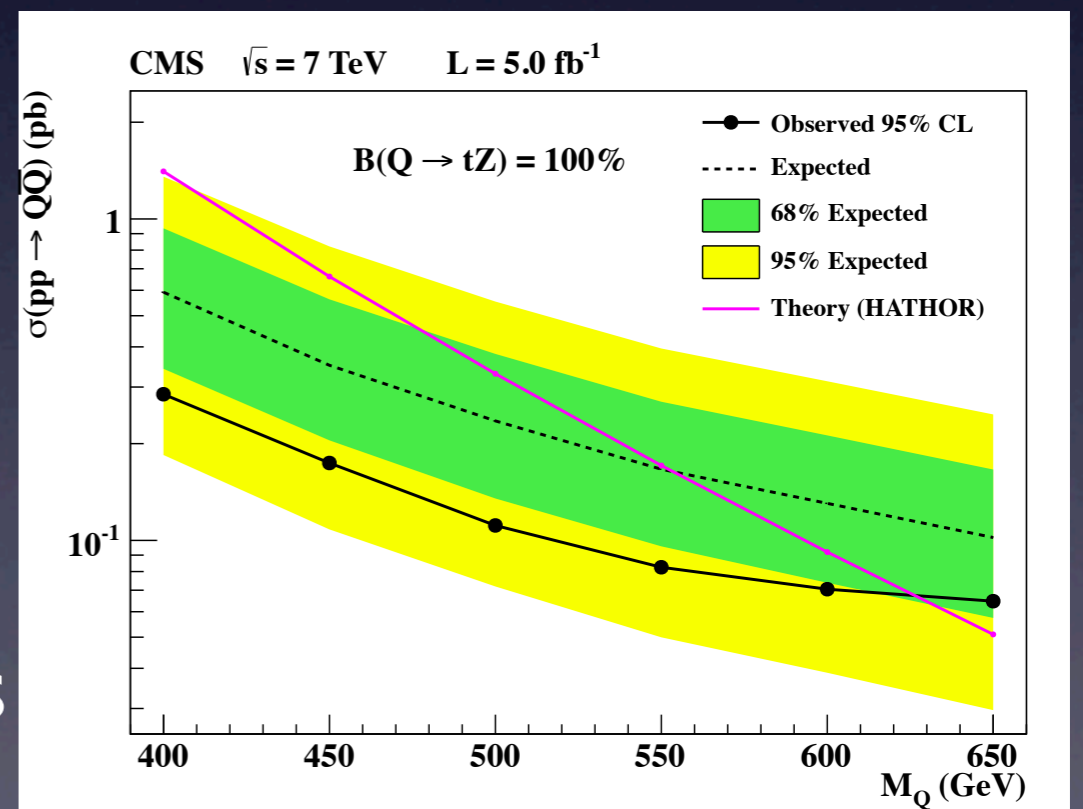
Vector-like T' quarks

Well motivated - KK quarks in Randall Sundrum models,
Little Higgs, MFV SUSY

Generally, multiple decay modes open - parameter space
not yet fully explored experimentally

Mode	ATLAS	CMS
$t' \rightarrow Zt$		625 (1+jets) [10]
		475 (multileptons) [15]
$b' \rightarrow Zb$	400 (di-leptons) [16]	660 (multileptons+btag) [14]

100% Zt final state presumed -
recast for bounds on realistic models



Chiral T' limits in 100% Wb final state also apply through recast

“Triangulating” T’ quarks

Many cases: total BF to bW , tZ , tH make up 100% of decays

Pair production rate set by QCD

Limits can be put in plane spanned by 2 BF’s:

Current optimized experimental searches:

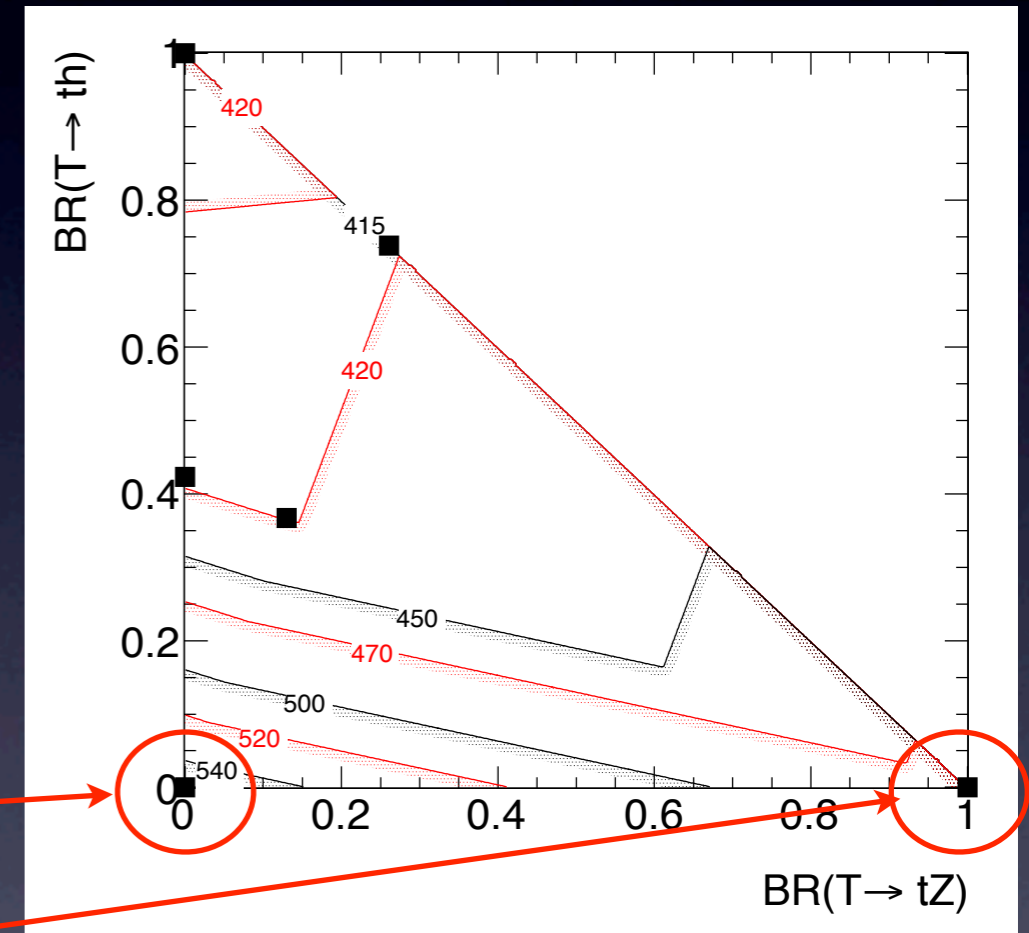
100% bW

100% tZ

Remaining points: interpretations of other searches for similar topologies

($b' \rightarrow Wt$ templates for Zt , Ht , and Wb)

Whiteson and Rao 1204.4504

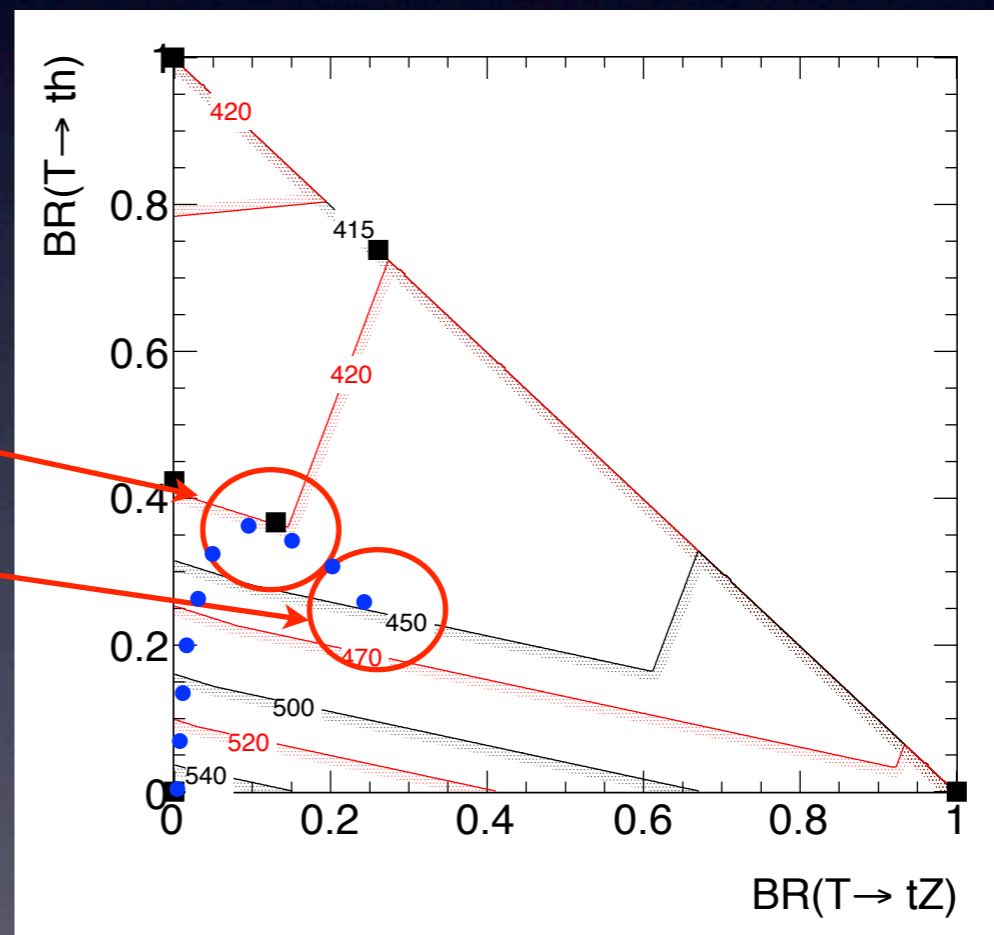
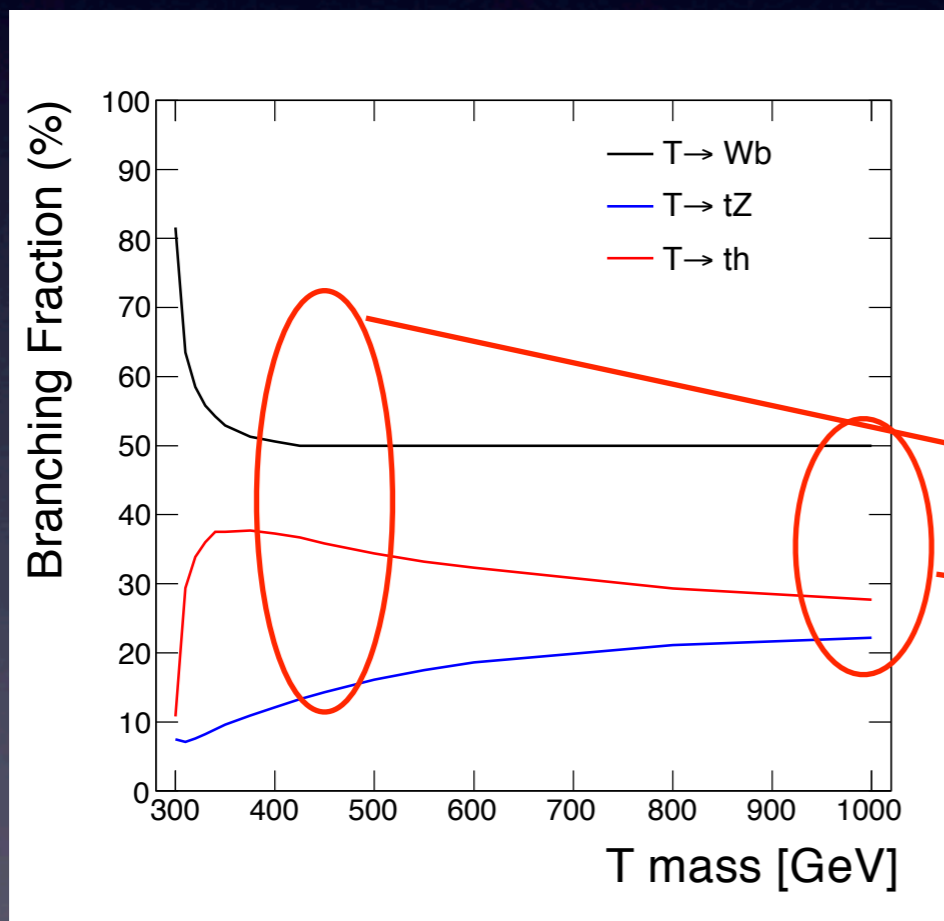


Common features

Certain regions are more generic

Models with T' - t mixing - Little Higgs T' , KK-tops, etc.

Class of T' models follow trajectory in BF triangle



High mass behavior fixed by Goldstone's theorem:
 $Br(Wb)=2Br(Zt)=2BR(Ht)=.5$

“Tetrahedralizing” T’s

T’ quarks may have substantial BF’s to other final states (i.e. exotica)

Reduces sensitivity in individual Wb , Zt , Ht channels

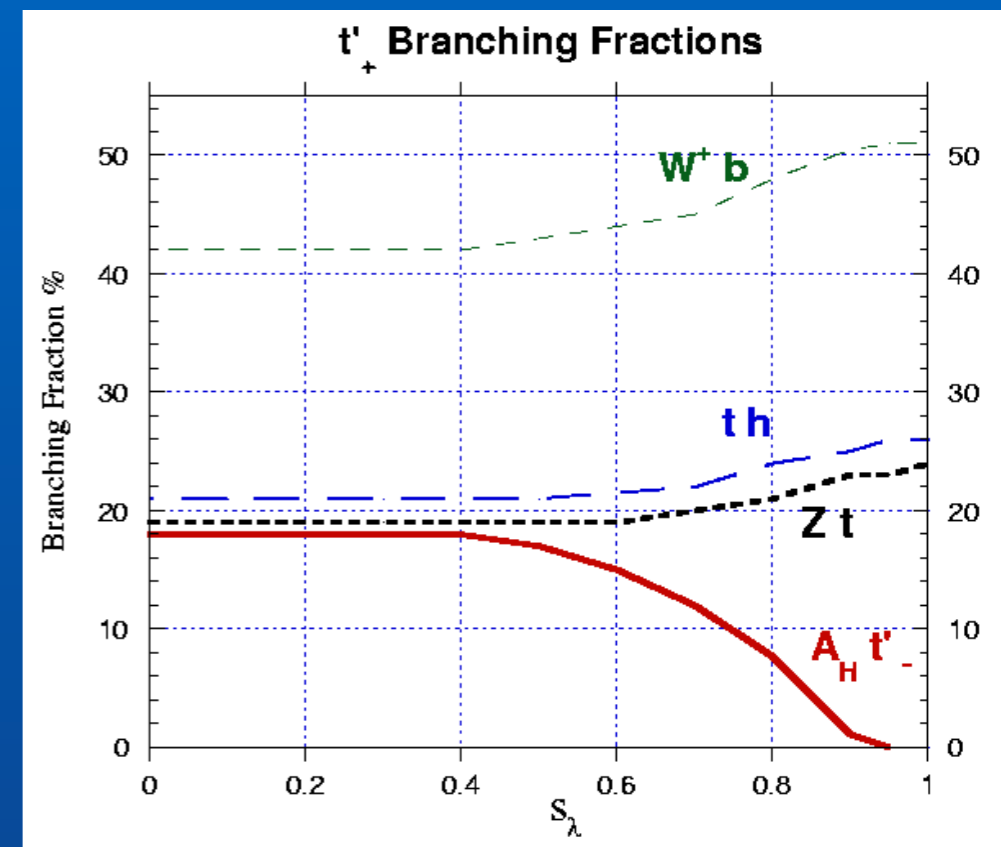
LHT: additional stop-like topology

$$T' \rightarrow \underbrace{A_H A_H t}_{\text{MET}}$$

Stop searches provide
complimentary coverage
(similar bounds ~ 400 GeV)

Extra dimensional models with SUSY:
top KK modes may have addn’l stop+LSP final state

Littlest Higgs w/ T-parity

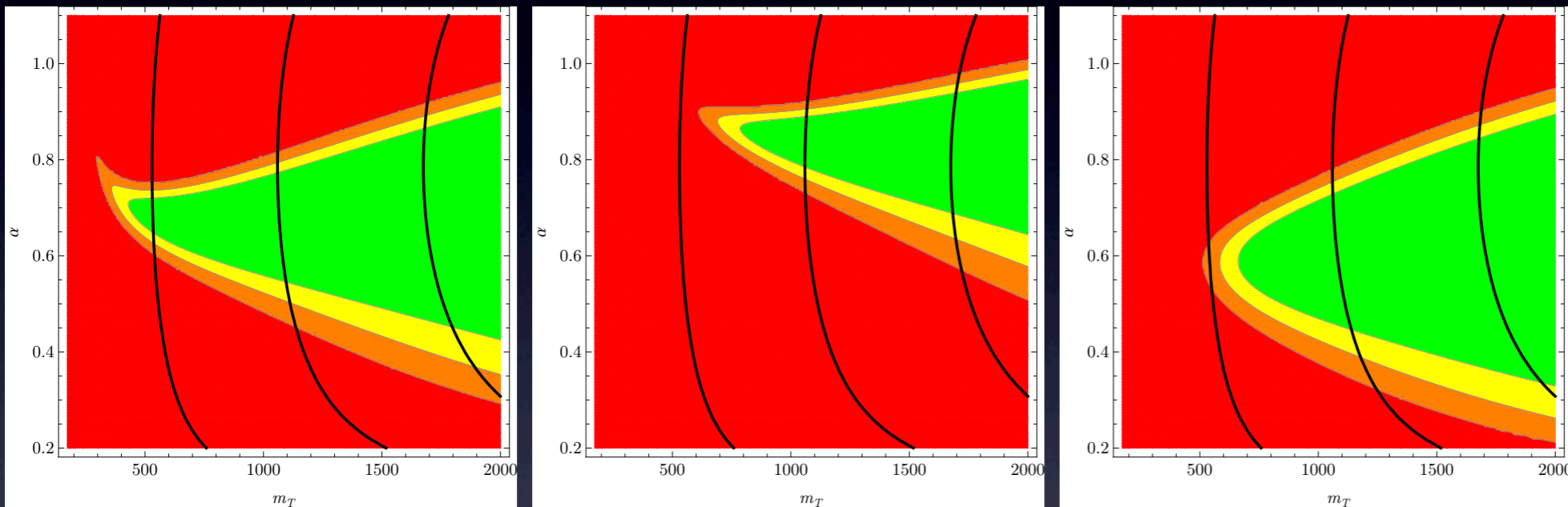


$s_\lambda \sim 1/\sqrt{2}$ preferred

Other constraints

SU(2)_L singlet T' (Little Higgs-like)

EWP constraints

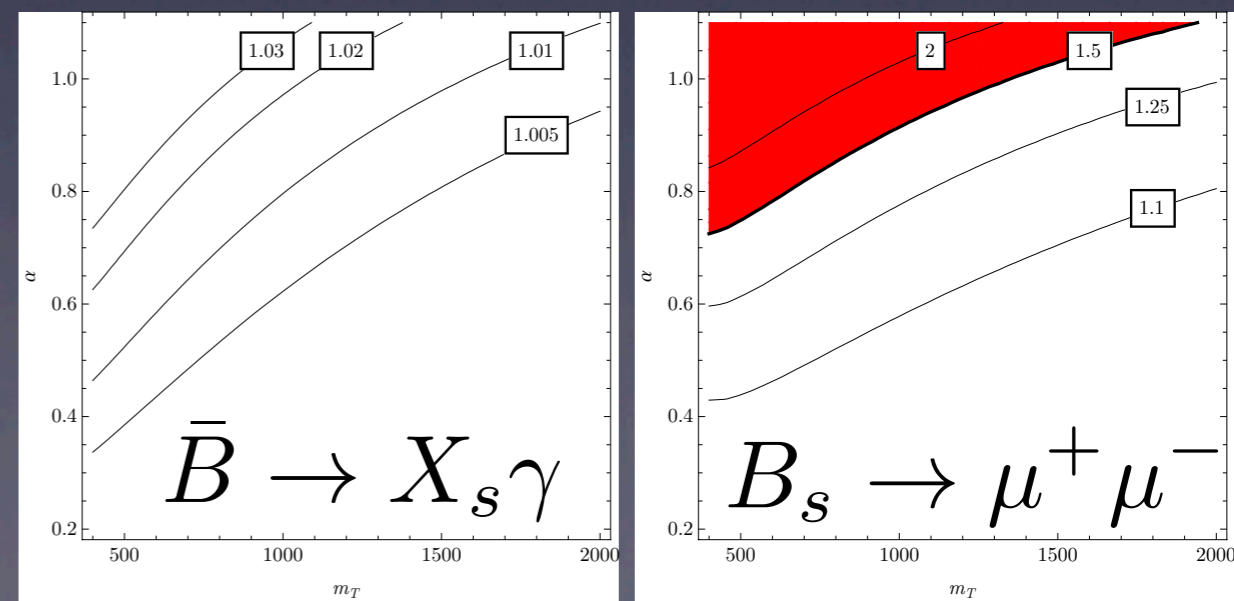


$$S_{UV} = \frac{4c_s m_W^2}{\pi g^2 f^2},$$
$$T_{UV} = -\frac{c_t m_W^2}{2\pi e^2 g^2 f^2}$$

Berger et. al. [205.0013]

3 plots demonstrate sensitivity to other new physics contributions

Flavor physics do not yet give competitive limits



Charge +5/3 T'

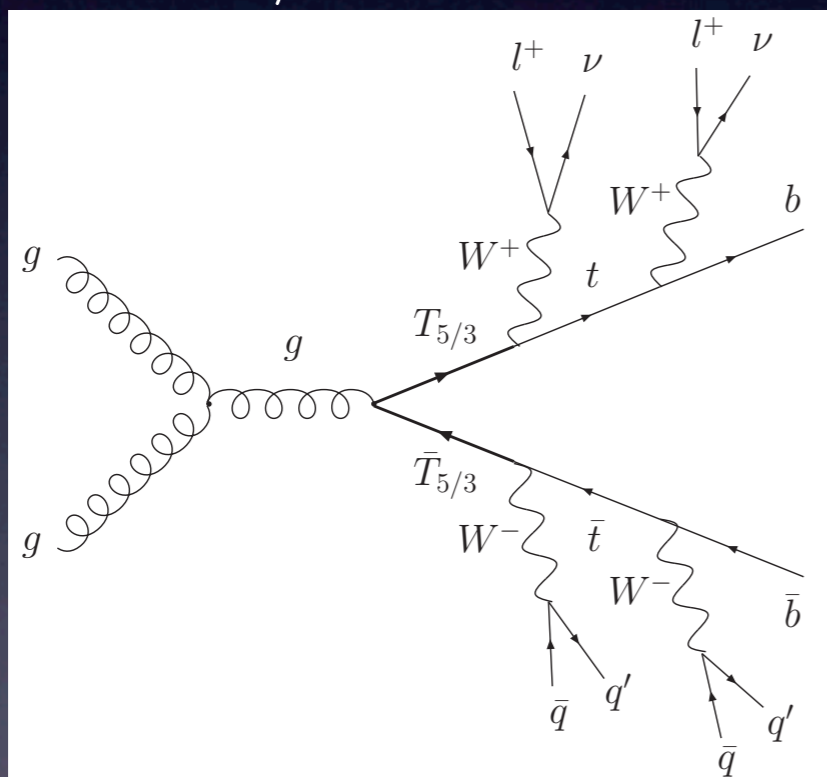
Predicted in composite Higgs/Randall sundrum models which address large corrections to Zbb vertex

Part of complete representation of custodial SU(2) symmetry

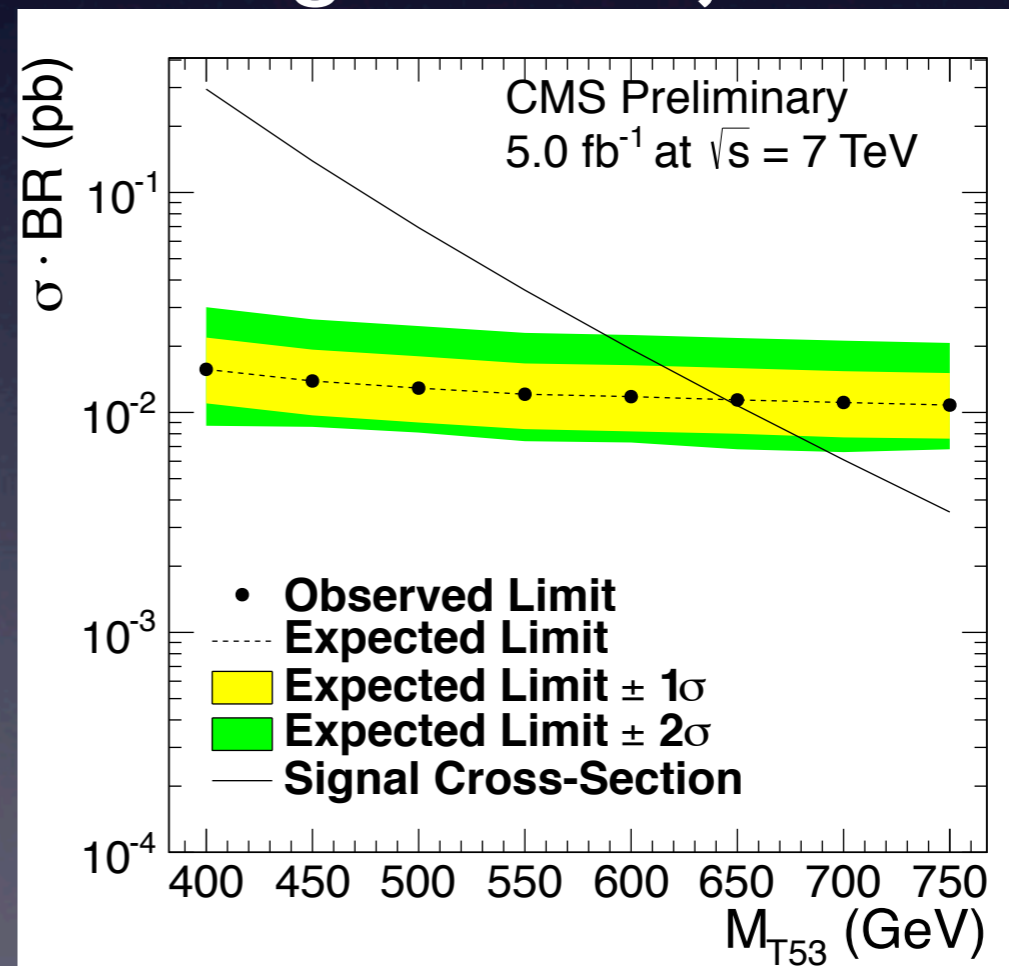
ρ -parameter *and* Zbb protected

same sign di-leptons aid in ttbar background rejection

$$T'_{5/3} \rightarrow Wt$$



Similar to b' topology



Flavor changing decays can reduce limits: Cacciapaglia et. al. 1211.4034

Other quarks in $SU(2)_c$ reps

A $Y_{-4/3}$ quark accompanies $T_{5/3}$ in same multiplet

$$Y_{-4/3} \rightarrow W^- b$$

b-quark jet charge difficult to measure
constrained by chiral 4th generation search
mass limit $m_Y \gtrsim 685$ GeV

Larger reps can have even more exotic charges (8/3, -7/3)

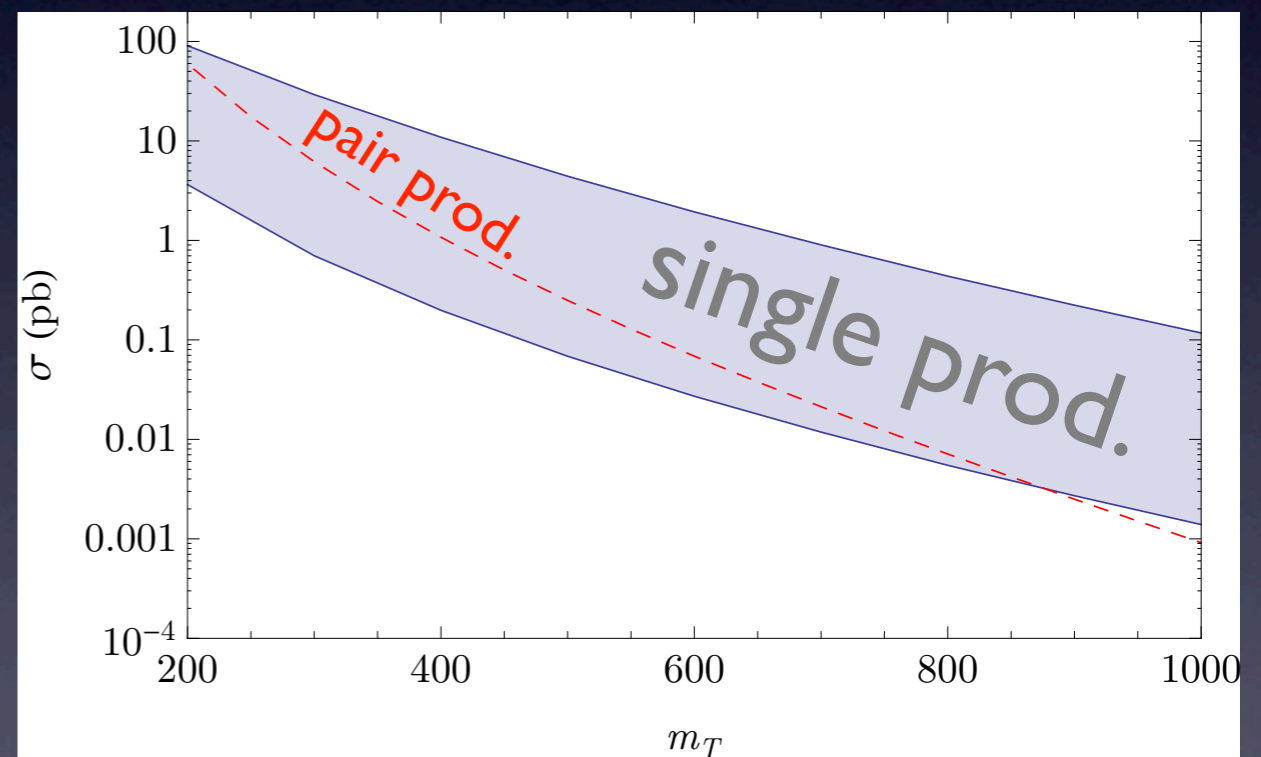
Single production

For larger masses kinematics rapidly cuts off pair production rate

Single production is in general more model dependent but can provide coverage in high mass regime

Little Higgs-like T' :

As mixing between top and heavy partner is varied, obtain wide range of SP rates

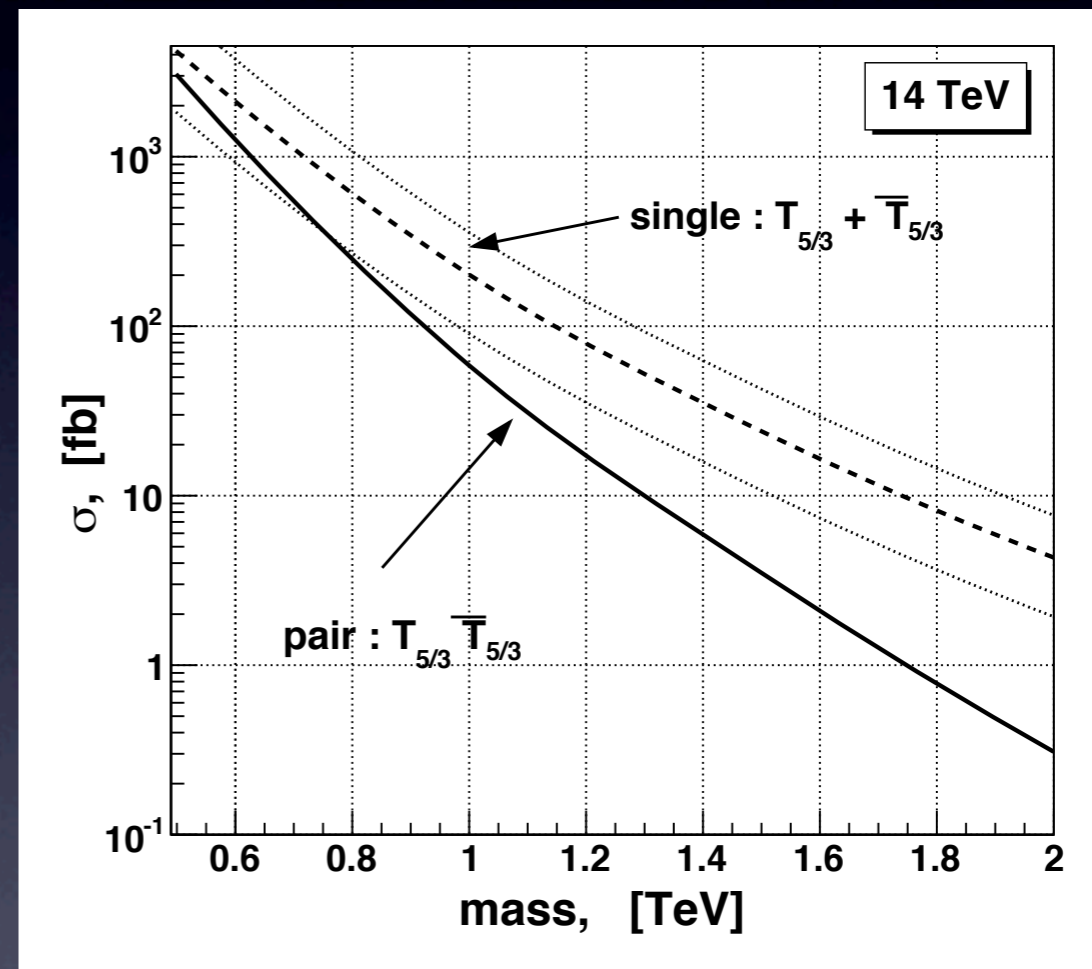
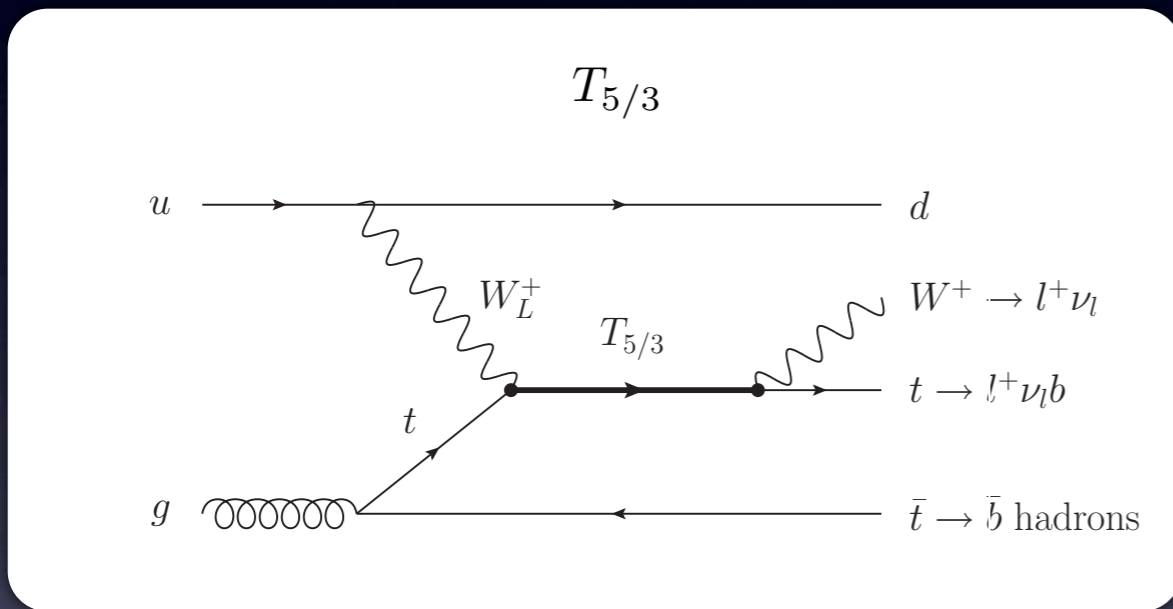


Berger et. al. [205.0013

7 TeV LHC

Can be providing
complementary constraints

Single production of other Top partners



Mrazek & Wulzer : 0909.3977

At high mass, single production extends discovery reach for custodial multiplets as well

Future Directions

- Current searches are piecemeal and are not optimized for many well-motivated scenarios
 - 100% Wb , 100% $Zt, T_{5/3}$ → Wt only direct searches
- Some T' quarks involve a stop-like MET topology
 - Little Higgs with T-parity, Randall-Sundrum SUSY
 - overlap with stop group - similar bounds - go beyond the triangle?
- Further exploration of single production channel limits