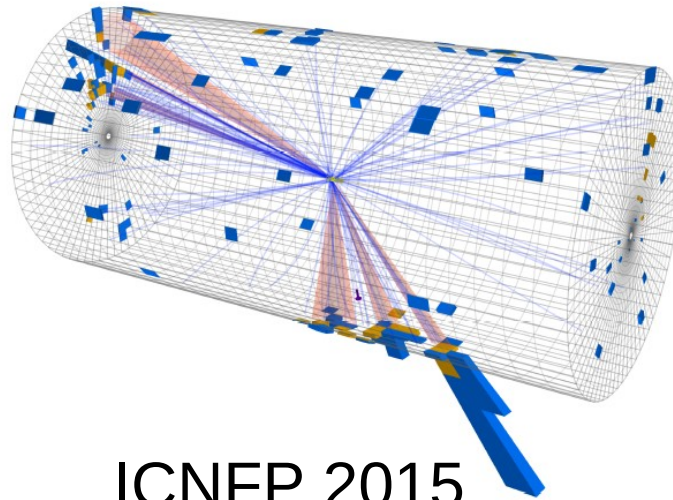


Beyond 2 Generations (CMS)

Giorgos Anagnostou,
On behalf of the CMS collaboration

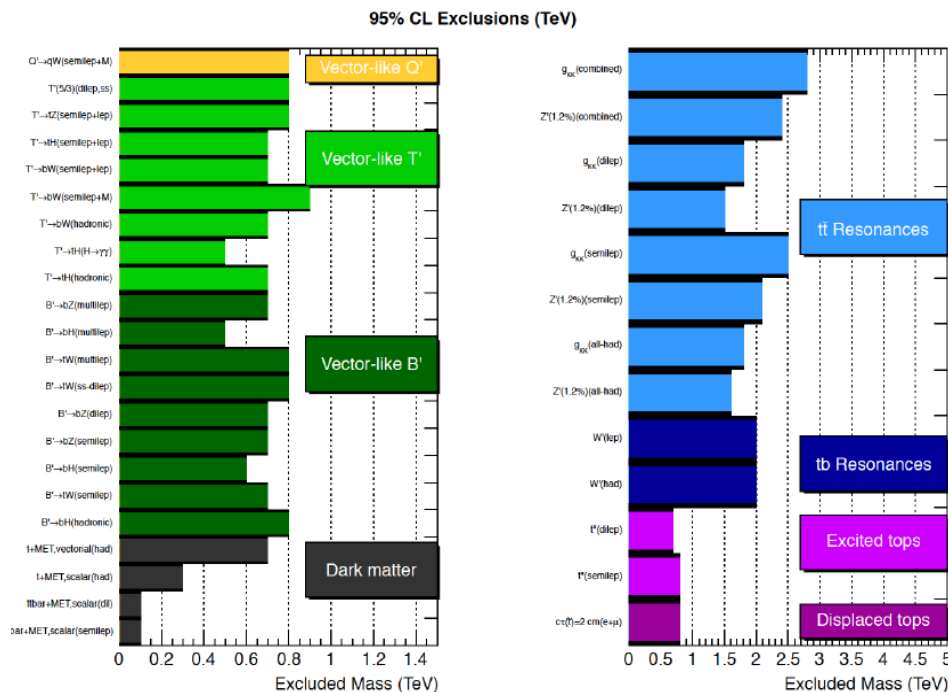


ICNFP 2015
4th International Conference on New Frontiers in Physics,
23-30 Aug 2015
Kolympari, Crete

Beyond Two Generations - CMS

Are there heavy top partners to keep the radiative corrections to Higgs mass at EWK scale? **Vector-like quarks**

CMS Searches for New Physics Beyond Two Generations (B2G)



Are there new resonances decaying to top quarks?
top pair/tb resonances

Excited top

Is dark matter coupled to top quarks?

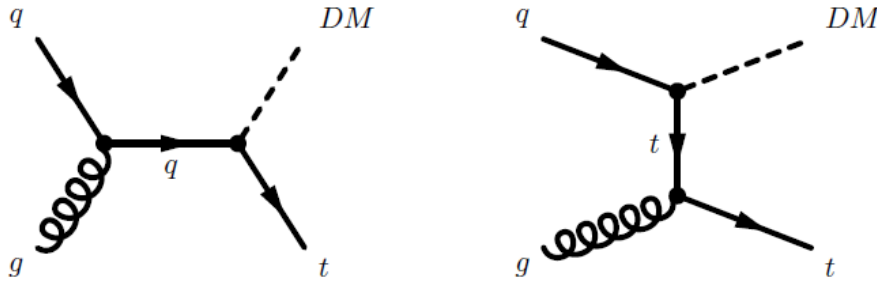
Dark matter searches

Has top quark a composite structure?

Dark matter - monotop

[PRL 114,101801 (2015)]

Invisible particle + a top quark, $t \rightarrow Wb \rightarrow b qq'$

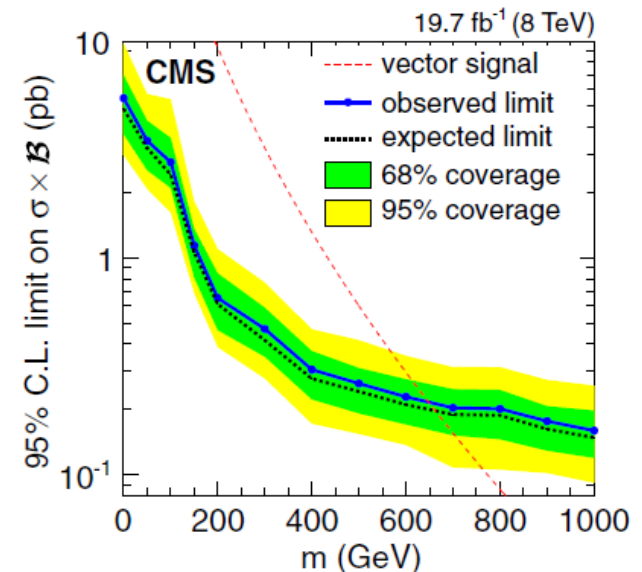
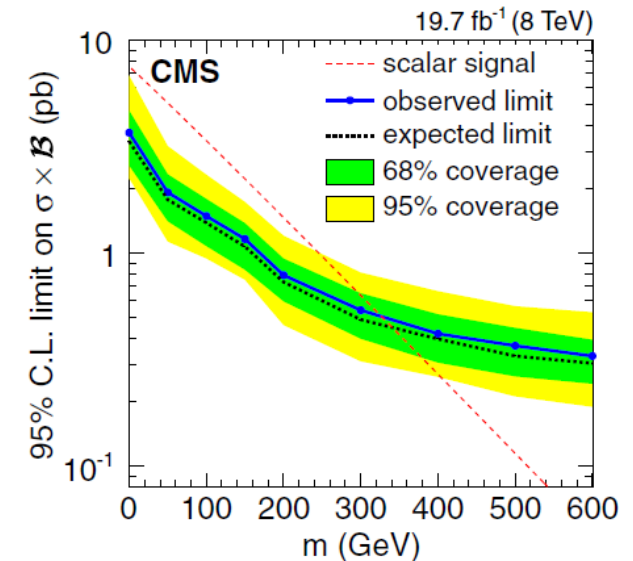


monotop analysis

3 jets, 1 btagged, large missing energy, lepton veto

Z+jets, W+jets from control regions
Signal & QCD multijet estimation
using a likelihood approach

Observed Limits: 330 GeV (scalar)
650 GeV (vector)



Dark matter with top pairs

[JHEP06,121 (2015)]

Scalar interaction of DM with quarks
Couplings proportional to quark mass

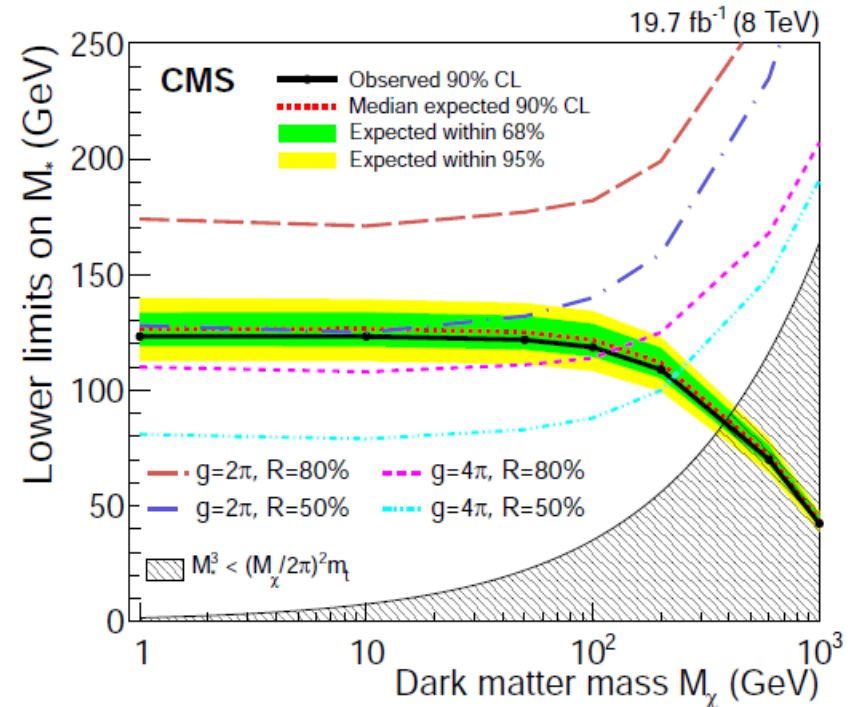
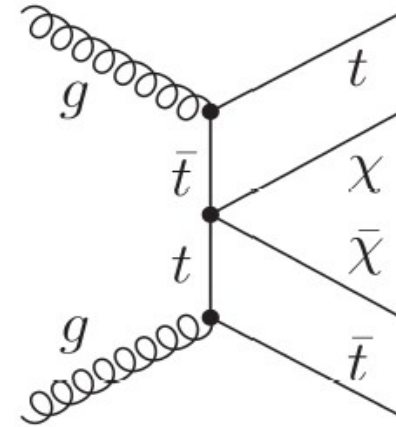
→ top pairs associated with dark matter

$$L_{\text{int}} = \frac{m_q}{M_*^3} \bar{q}q\bar{\chi}\chi$$

semileptonic analysis

$N_{\text{jets}} \geq 3$, 1 btagged, large
missing energy, isolated lepton

tt+jets, W+jets estimated
from control regions



Top pair resonances

arXiv:1506.03062

Collimated objects due to large boosts

dilepton analysis

non-isolated leptons + $N_{\text{jets}} \geq 2$

top pair irreducible background

lepton+jets analysis

Non isolated lepton + top quark tagging for hadronic top decay

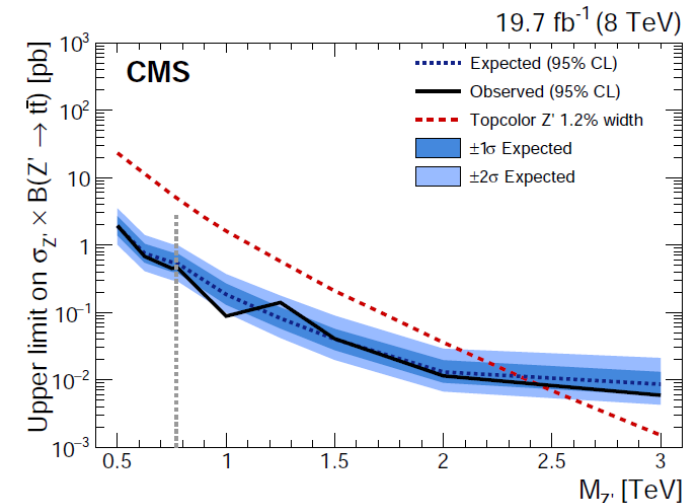
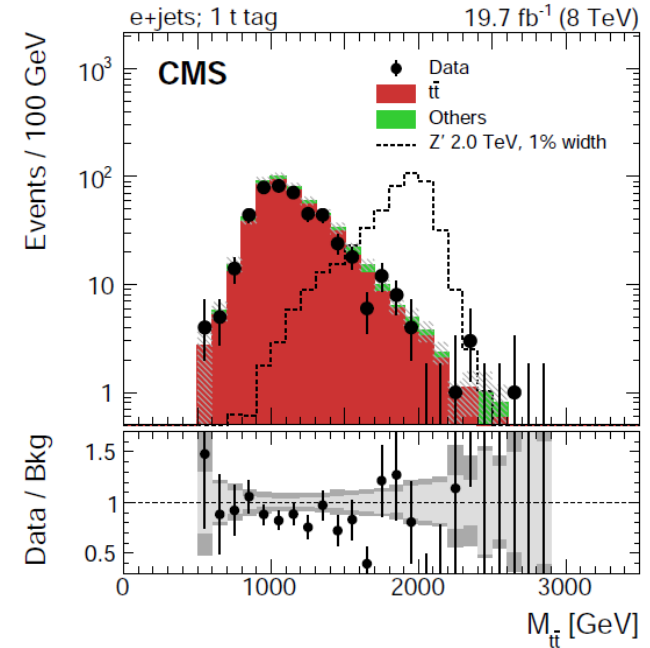
top pair continuum irreducible background

all-hadronic analysis

Selects events with di-jet topology

top-tagging with 2 tagged top jets

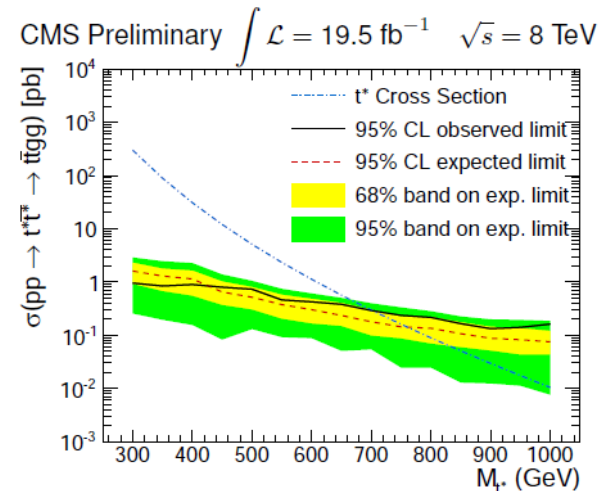
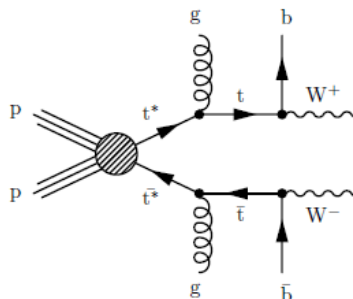
Observed Limits: 2.4 TeV Z' (1.2% width)
2.9 TeV Z' (10% width)
2.8 TeV KK gluon



Excited top, $pp \rightarrow t^*t^*$, $t^* \rightarrow t+g$

dilepton analysis [CMS-B2G-12-008]

2 isolated leptons, $N_{\text{jets}} \geq 2$, kinematic mass reconstruction of t^* pair, using equal pair mass assumption



lepton+jets analysis [JHEP 06, 125 (2014)]

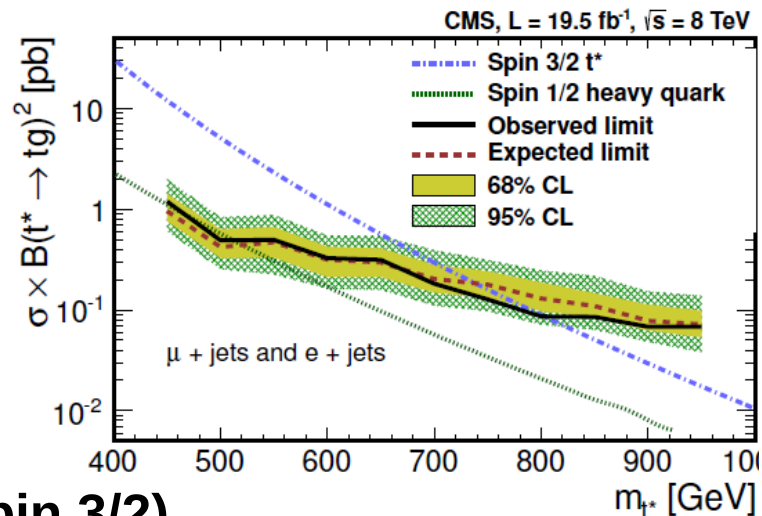
Isolated lepton, at least 6 jets

reconstruction of t^*t^* system using mass constraints:

$$m(l\nu bg) = m(q\bar{q}bg) = m_{t^*g}$$

Dilepton: 703 GeV (763 expected)

l+jets: 803 GeV (739 expected) for t^* (spin 3/2)



t+b Resonances

all-hadronic analysis [CMS-B2G-12-009]

dijet b-t-b topology with a top + b quark

Top tagging to suppress QCD multijet

lepton+jets analysis [JHEP 05, 108 (2014)]

isolated lepton, $N_{\text{jets}} \geq 2$

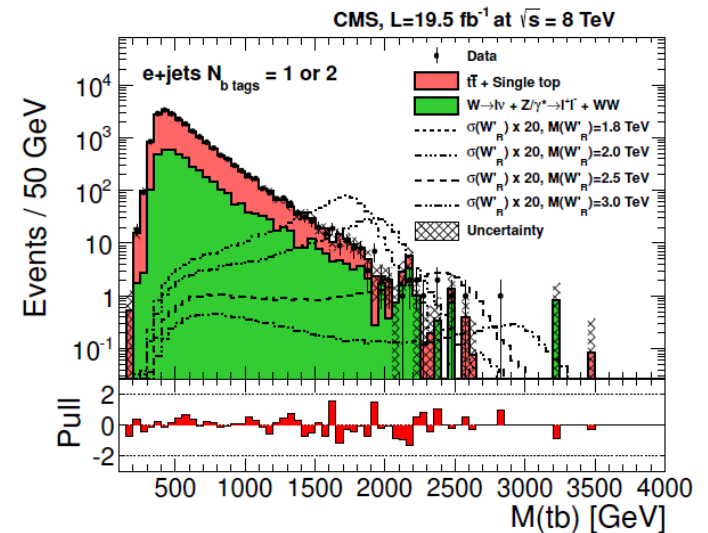
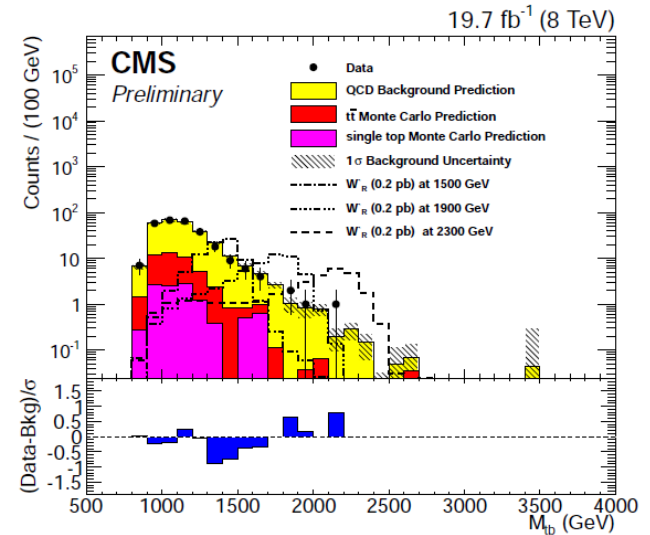
Decay $W' \rightarrow t b$, $t \rightarrow W b$, $W \rightarrow l \nu$ is fully reconstructable

Combinatorics reduced from top mass constraint

Limits: All-hadronic: 2.02 TeV (W_R')

l+jets: 2.05 TeV ,

Combined 2.15 TeV



Top partners with charge 5/3

[PRL 112, 171801 (2014)]

Exotic top partners with 5/3e charge

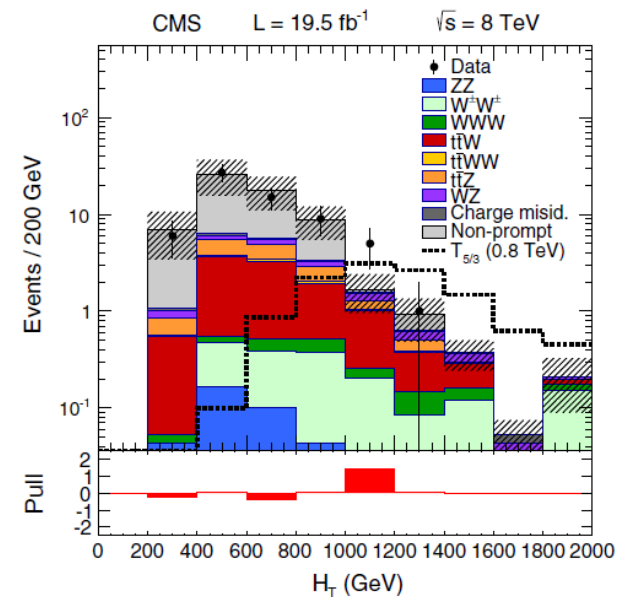
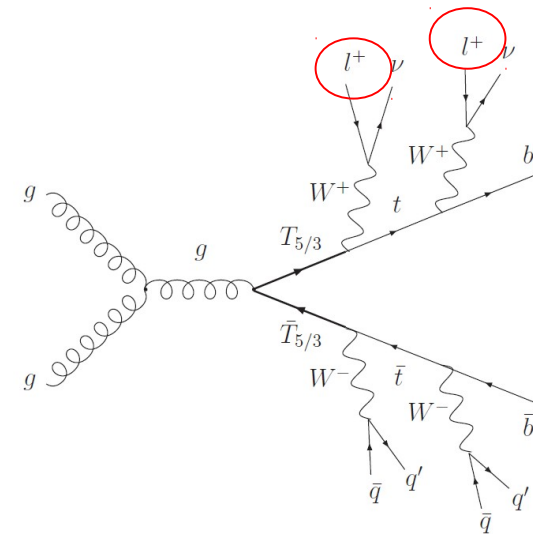
$T_{5/3}$ pair produced, $T_{5/3} \rightarrow t W$,

Same sign dilepton analysis

Top jet tagging, W jet tagging
2 isolated, same sign leptons

$N_{\text{constituents}} \geq 7$ (leptons, top & W subjects)
 $H_T > 700$ GeV

Limits: 800 GeV (830 expected)



Top partners with charge 2/3

[PLB 729, 149 2014)]

Top partners with $2/3e$ charge
Vector-like to evade constraints to 4th
generation of quarks and leptons

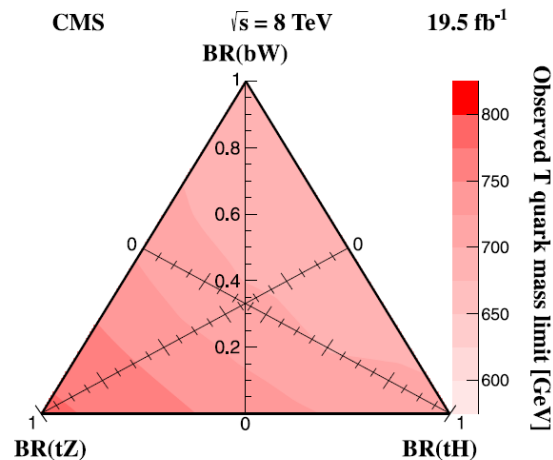
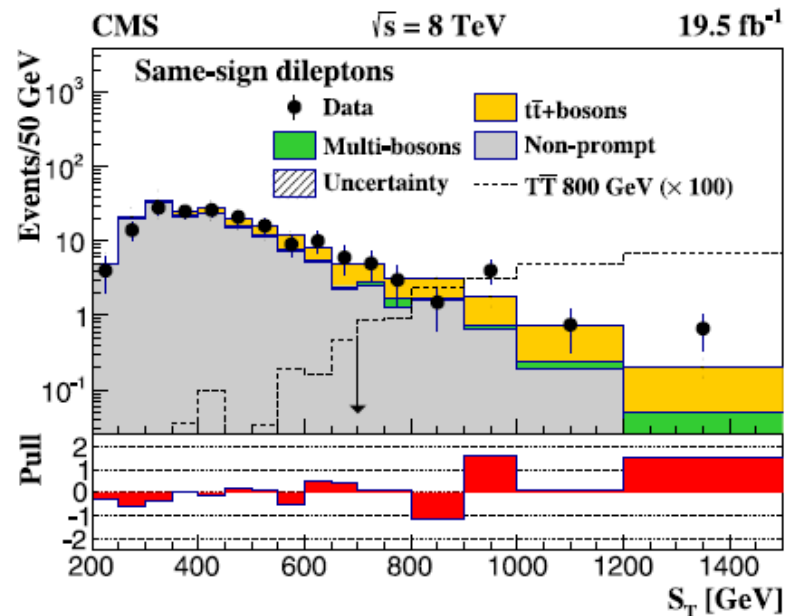
Pair produced, $T \rightarrow b W$, $t Z$, $t H$
W jet and top jet tagging

Inclusive lepton analysis

Isolated lepton + (3jets and 1 Wjet) or 4 jets
BDT used to extract signal

multilepton analysis

Opposite sign dileptons
Same sign dileptons
Trileptons

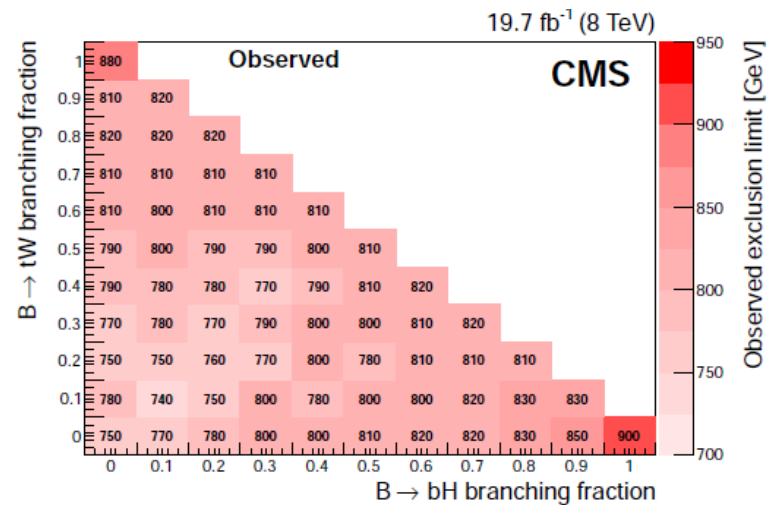
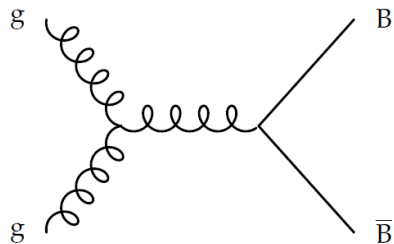


Limits: 687 – 782 GeV depending on BRs

B → tW, tZ, tH [B2G-13-006]

Heavy vector-like B quark

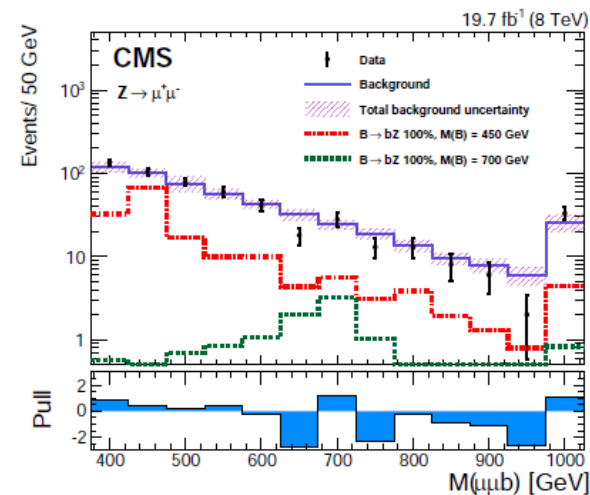
Charge (-1/3), pair produced,
 $B \rightarrow tW, bZ, bH,$



Limits: 740-900 GeV depending on BRs

Combination of 5 analysis

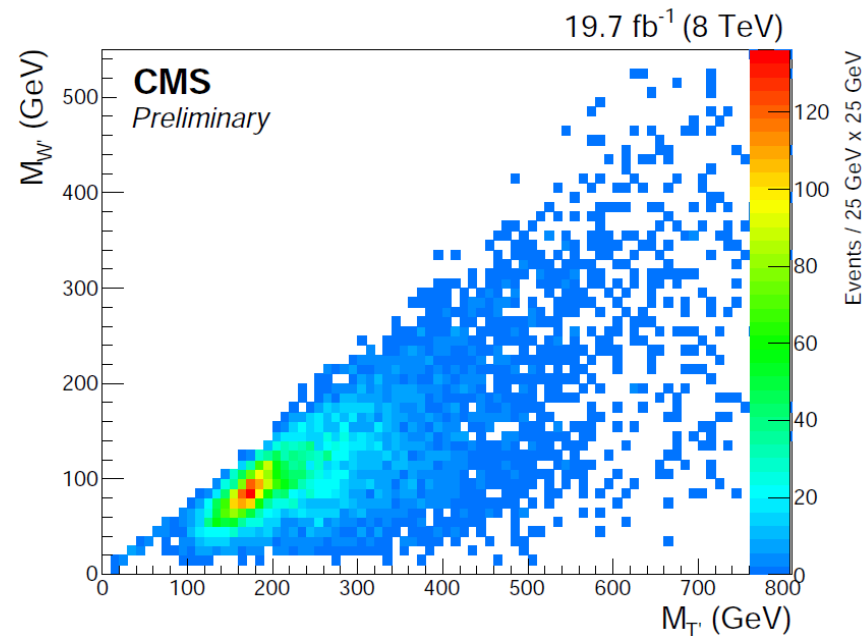
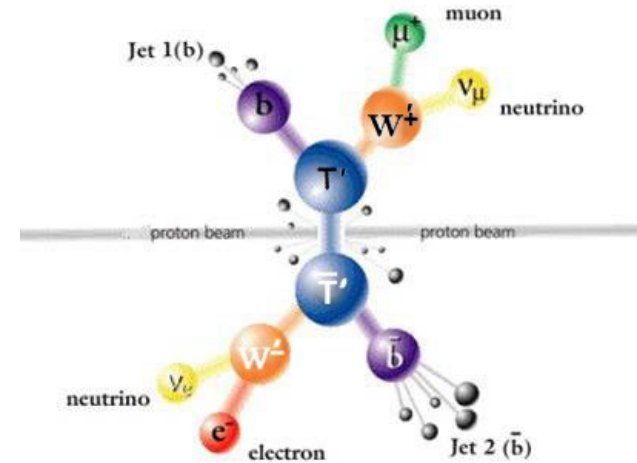
	Nleptons	Observable	Decays
Lepton+jet	1	S_T	tW
Same-sign dilepton	2	S_T	tW
Opposite-sign dilepton	2	M(l lb)	bZ
Multilepton	≥3	S_T	tW, bZ
All-hadronic	0	H_T	bH



Search in 2-dimensional mass space [B2G-12-025]

Search for anything decaying like dilepton top pairs.

Searching simultaneously for a new T' quark and W' Boson predicted by little Higgs model



2012 Dataset

2-dimensional mass reconstruction of both unknown particles in $[M_{T'}, M_{W'}]$ plane.

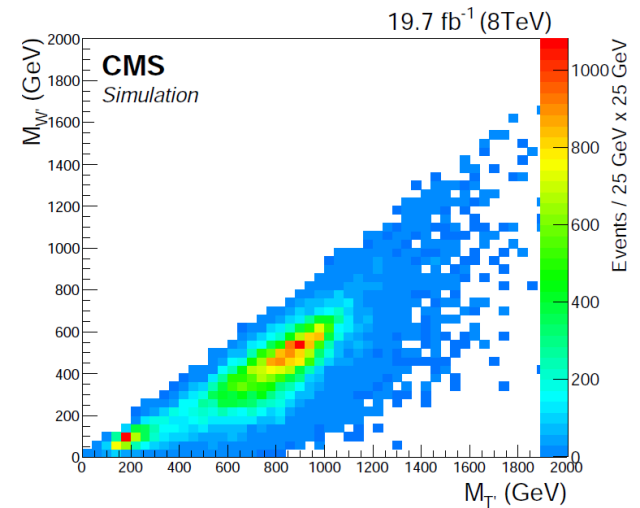
No assumptions for the $M_{T'}$ & $M_{W'}$ masses except event topology.

Search in 2-dimensional mass space(II) [B2G-12-025]

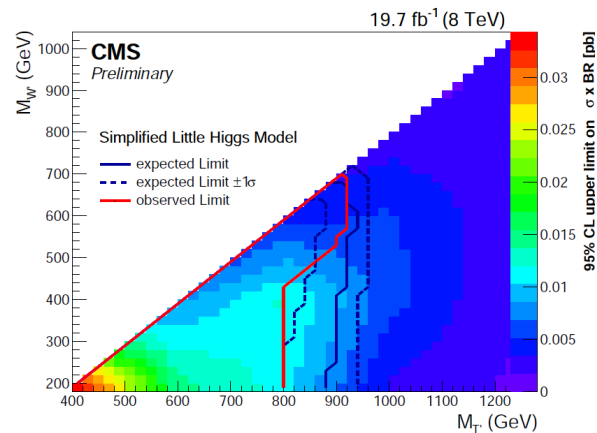
2 leptons, 2 jets & missing energy

2-dimensional mass reconstruction based on analytical solutions (mass constraints) & PDFs

Choose solution/combination most likely to originate from a p-p collision based on PDFs

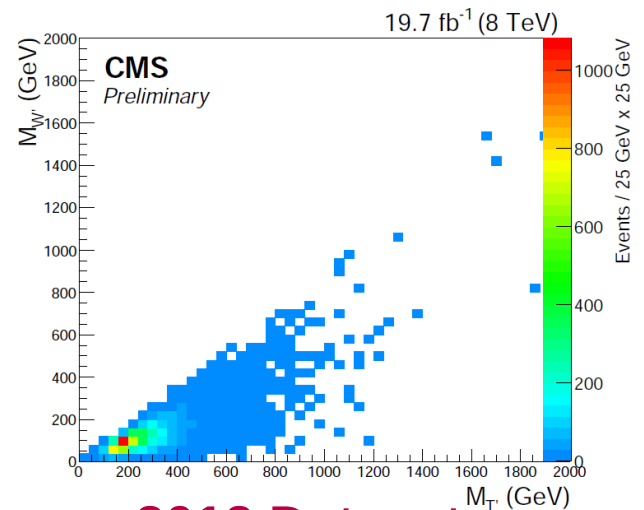


MC signal + background



Limits:

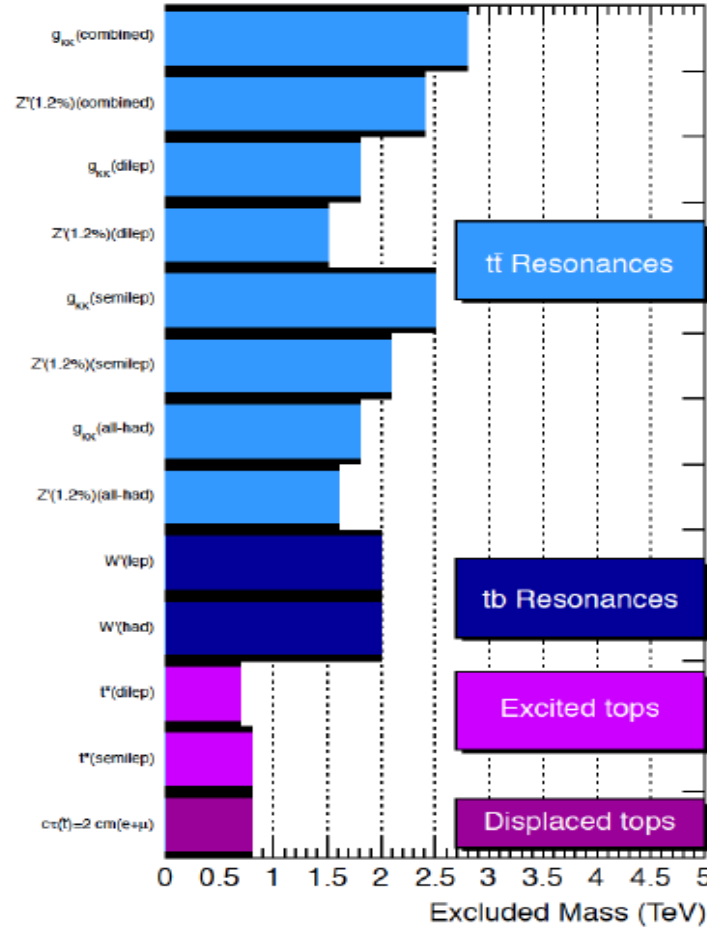
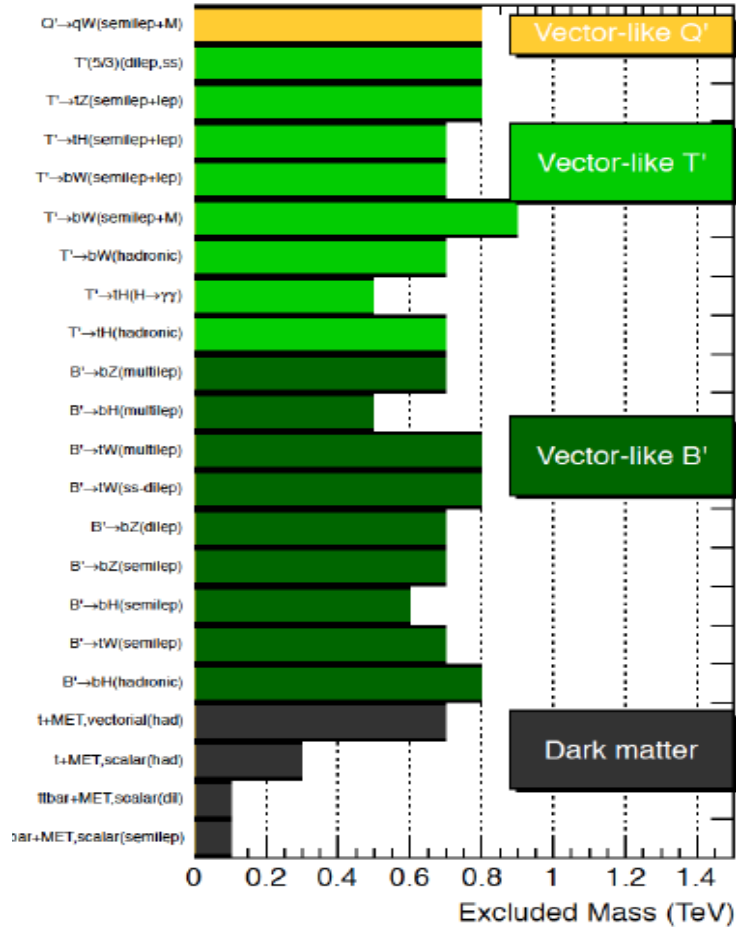
800 – 920 GeV for $M_{T'}$ depending on $M_{W'}$



2012 Dataset

B2G Results

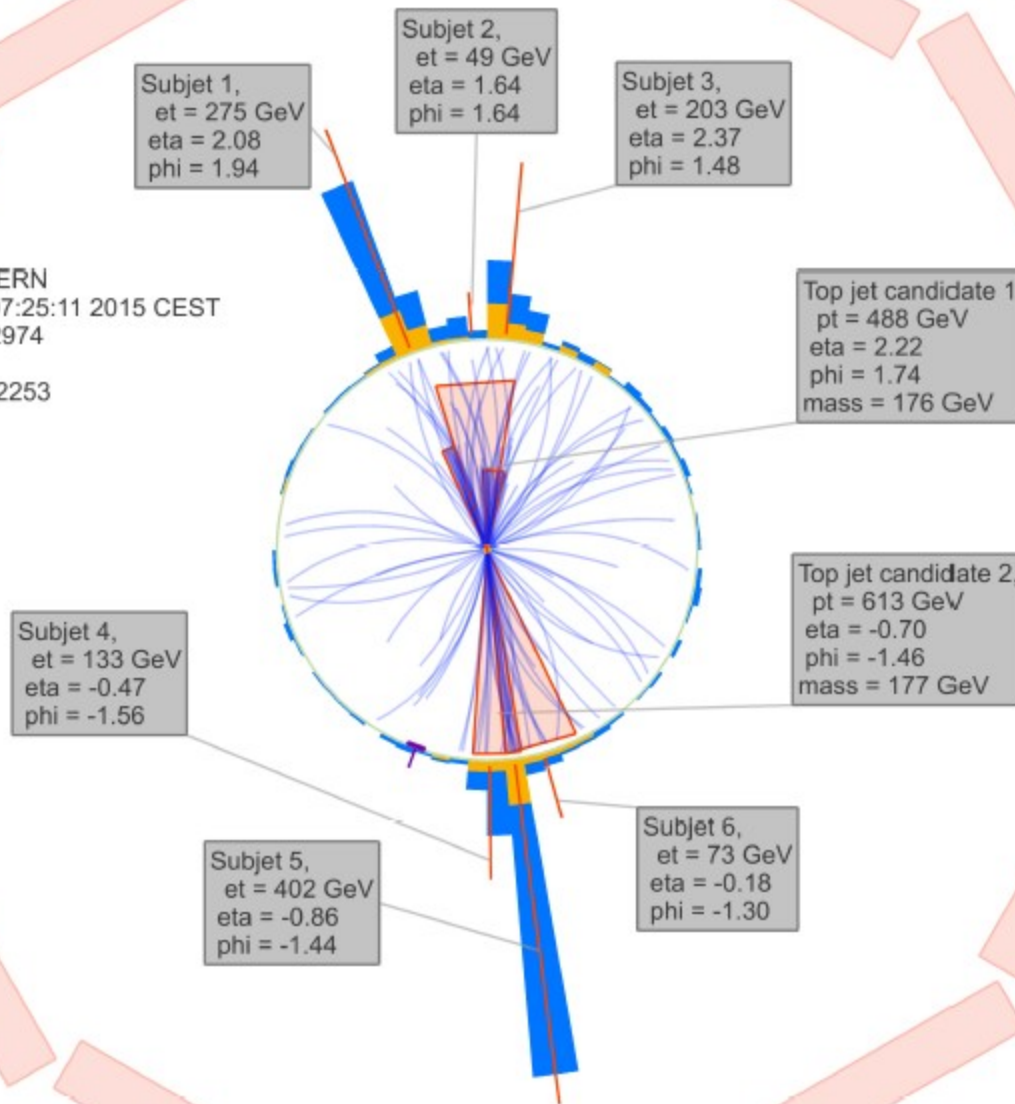
CMS Searches for New Physics Beyond Two Generations (B2G)
95% CL Exclusions (TeV)



Run 2 has started!



CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253



Top pair candidate @ 13 TeV

Back-up

Vector-like quarks (more)

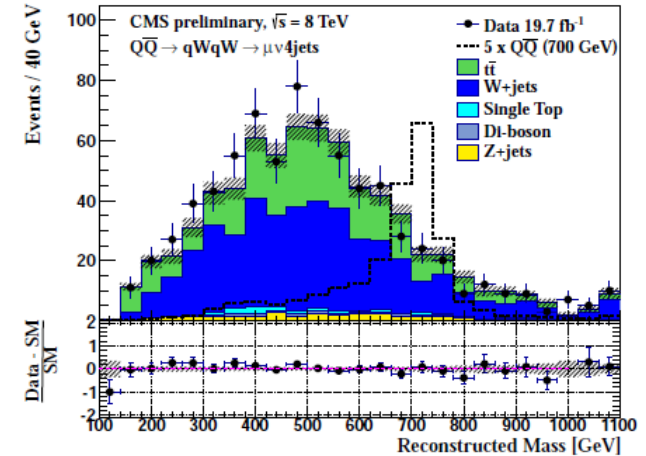
Single lepton + jets [CMS-B2G-12-017]

$$T\bar{T} \rightarrow bW^+ \bar{b}W^- \rightarrow bl\nu\bar{b}q\bar{q}'$$

$$Q\bar{Q} \rightarrow qW^+ \bar{q}W^- \rightarrow ql\nu\bar{q}q\bar{q}'$$

Single isolated lepton, $N_{\text{jets}} \geq 4$,
Mass reconstruction of T/Q pair

Limit: 912/788 GeV on T/Q-quark

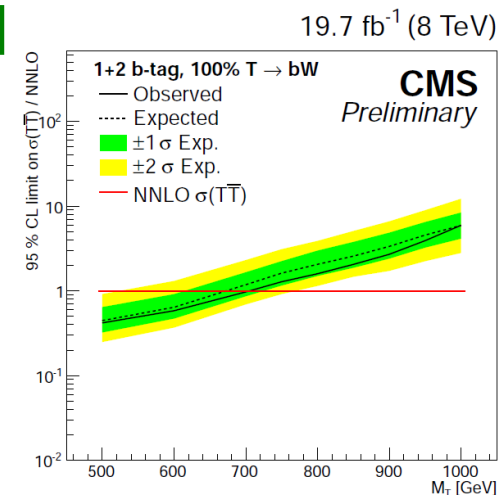


Fully hadronic analysis [CMS-B2G-12-013]

Pair produced $T \rightarrow W b$, fully hadronic
4 jets: 2 W-jets + 2 bjets

Mass reconstruction: minimizing mass difference of Wjet+bjets candidate pairs

Limit: 705 GeV (667 exp)



Top partners with charge 2/3 (more) [JHEP 06, 080 2015]

All-Hadronic channel

Pair produced, $T \rightarrow t H$, $H \rightarrow bb$

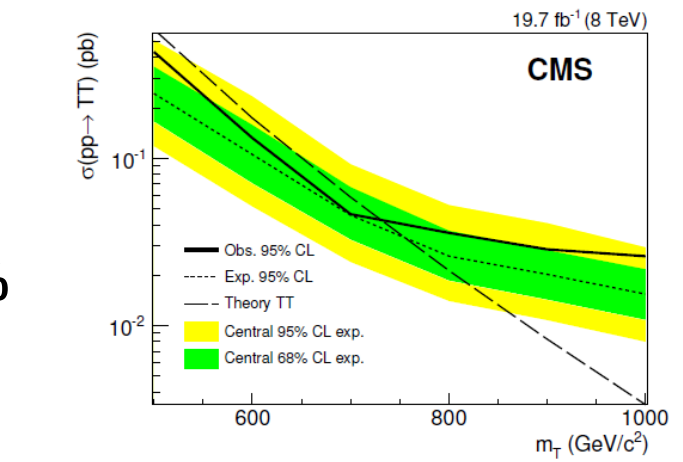
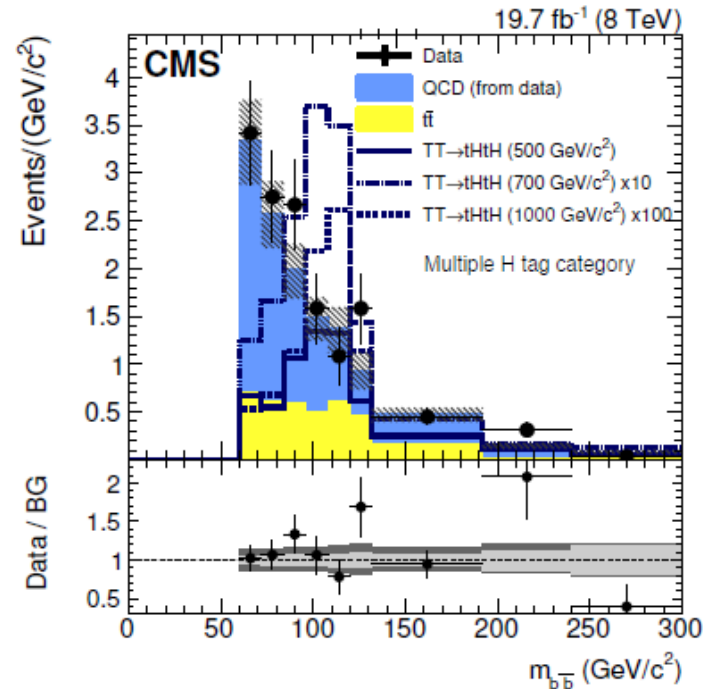
Top and Higgs tagging

Identification of:

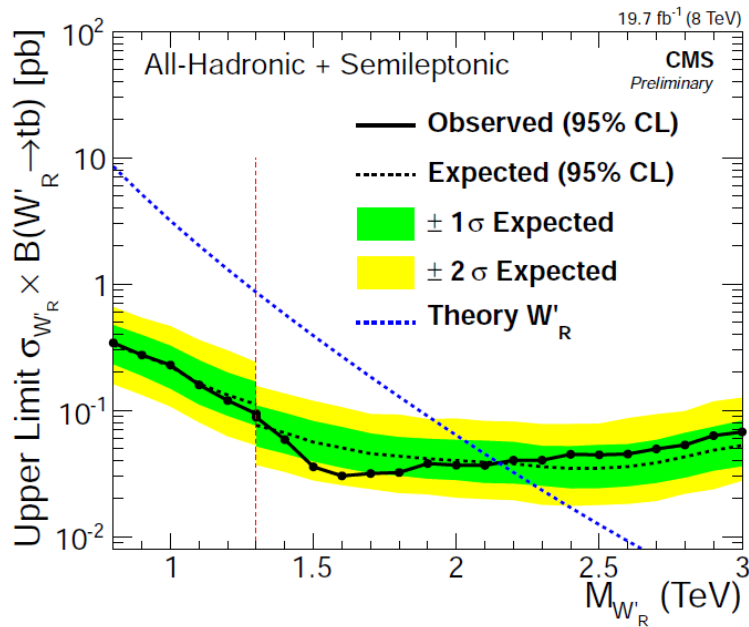
- boosted top quarks (top-tagging)
- Boosted Higgs bosons (higgs tagging)

Tagging Higgs bosons based on combination of jet substructure and b-tagging

Limits: 745 GeV (773 exp), $BR(T \rightarrow t H) = 100\%$



t+b Resonances (combination)



Combined results W'_R

