

Search for new resonances coupling to third generation quarks at the CMS experiment

*Jordan Damgov (Texas Tech University)
on behalf of the CMS Collaboration*

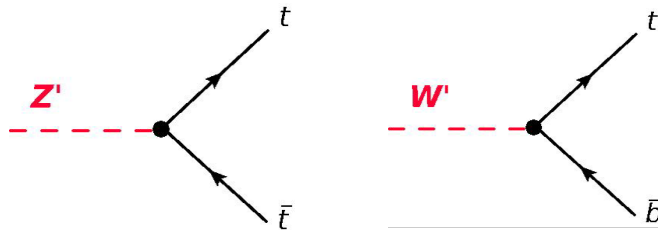
**Lake Louise Winter Institute 2017
Lake Louise Canada , February 19-26, 2017**

Introduction

❖ Many BSM models predict **new resonances** by adding new gauge field, extending the Higgs sector or considering extra-dimensions

- Randall-Sundrum (RS) gravitation,
- Kaluza-Klein (KK) excitation of gluons,
- Composite Higgs models,
- Colorons,
- ...

➤ *Many of the heavy new particles preferably couple to tops*



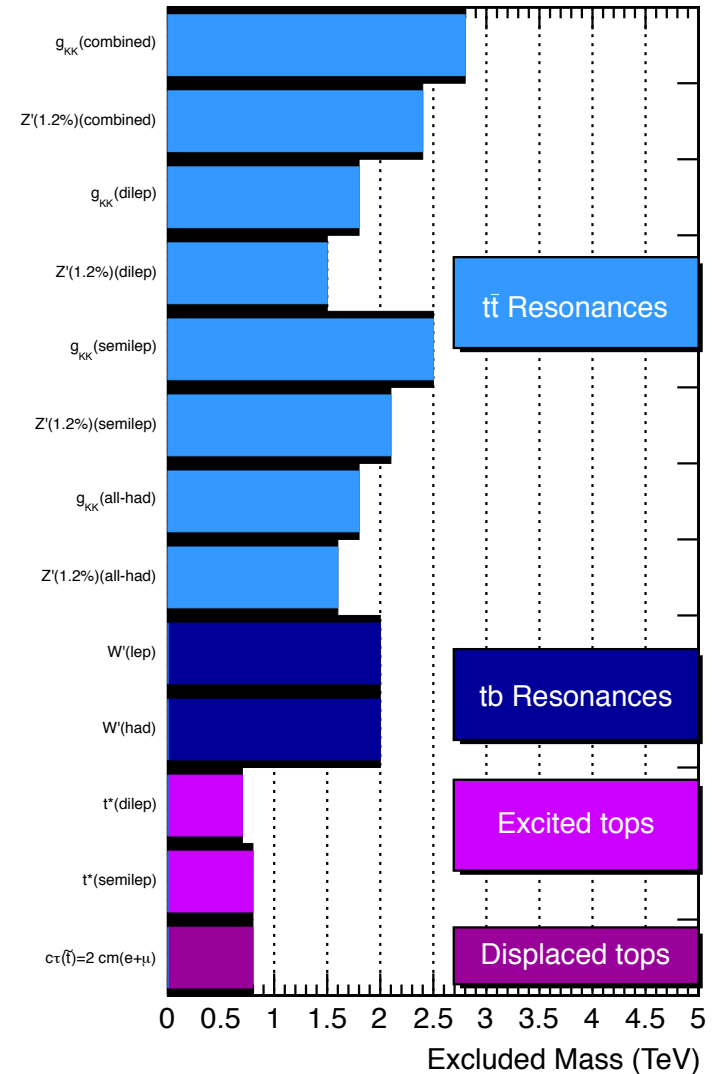
8TeV run:

➤ Stringent limits on various models

13 TeV run:

➤ Parton luminosities for heavy particle production increased a lot

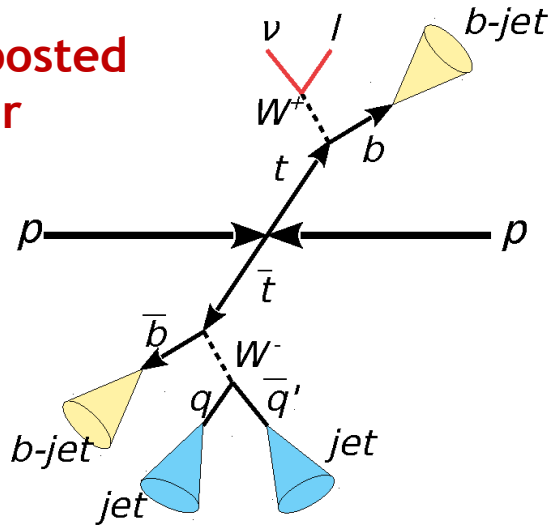
Limits from 8TeV run



Boosted Top topology

- ❖ Top quarks originated from heavy resonance decays are produced with a **large boost**

Non-boosted top pair



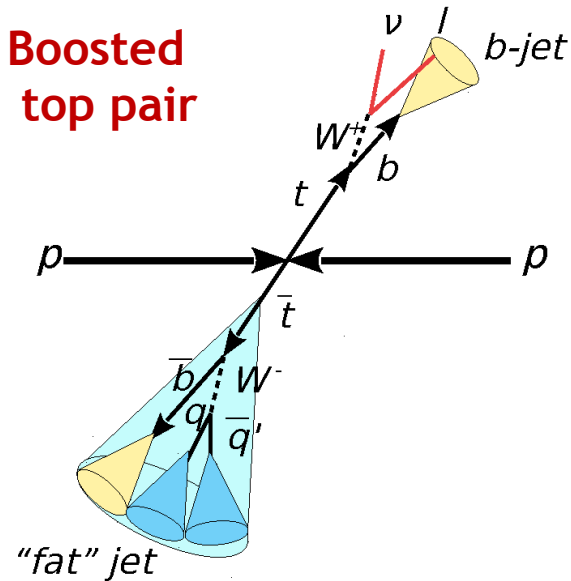
Hadronically decaying top:

3 well separated jets (one b-jet)

Leptonically decaying top:

One b-jet, isolated lepton,
missing transverse energy
from neutrino

Boosted top pair



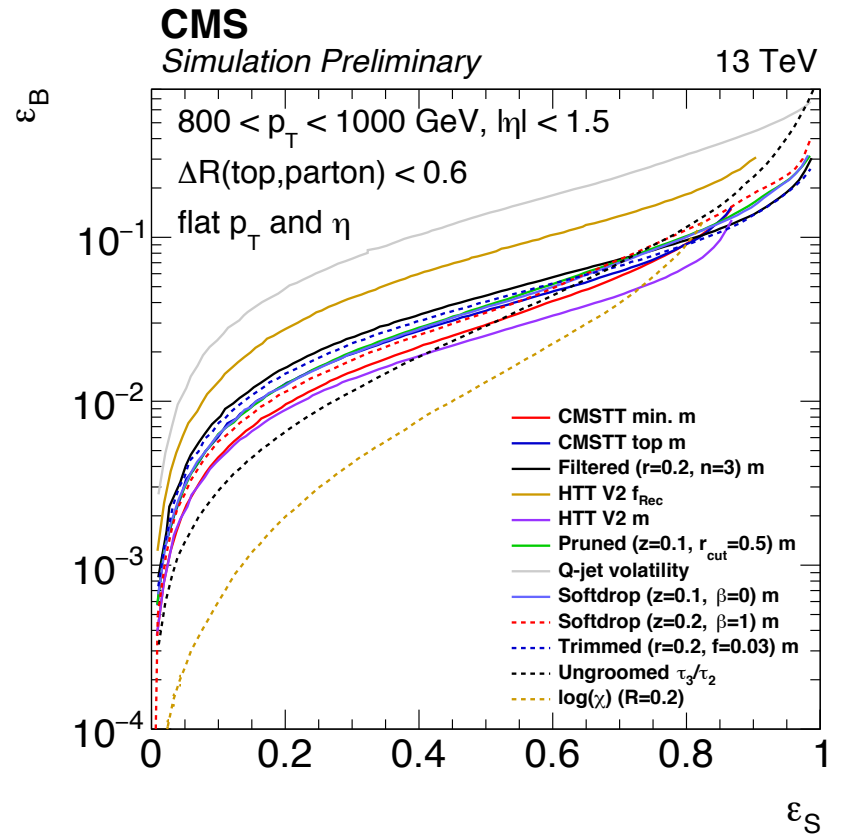
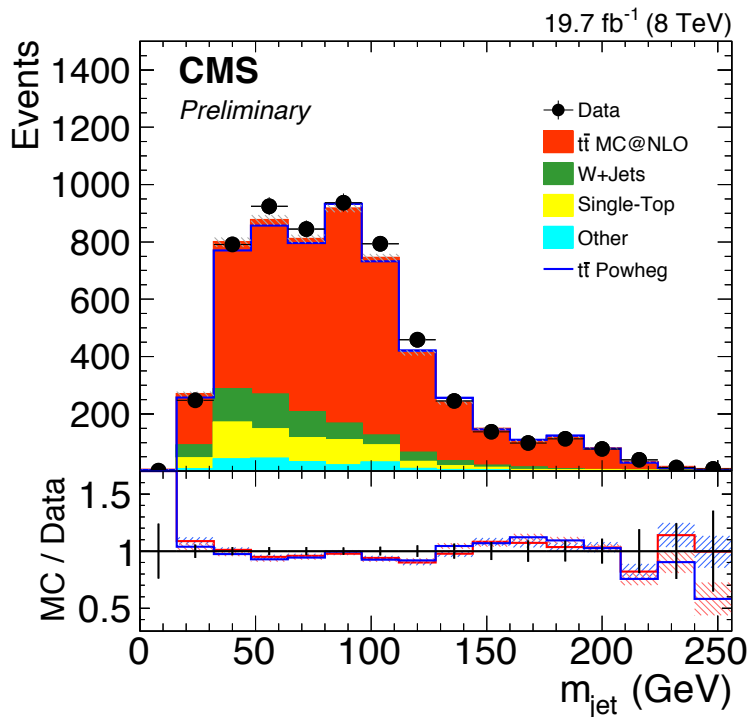
Hadronically decaying top:

One merged jet \rightarrow top tagging

Leptonically decaying top:

One b-jet, $E_{T,miss}$, non-isolated
lepton

- ❖ Top tagger inspects the substructure of hadronic decays of the top quarks
- ❖ Large variety of discriminating variables are studied within CMS



✓ Validation is performed with the 8 TeV

Top-tagging: reconstruct fat jets (AK8) and look at substructure (subjets)

n-subjettiness τ_3/τ_2

- is the jet more 3- or 2-subjet-like ?
- typical value : $\tau_3/\tau_2 < 0.69$

soft-drop mass m_{SD}

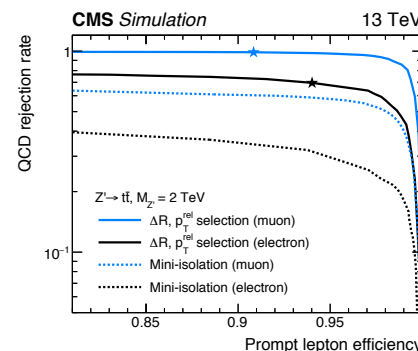
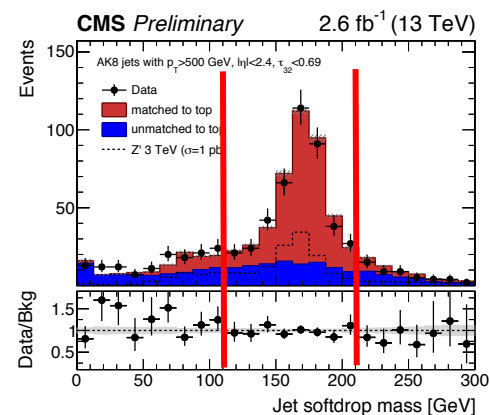
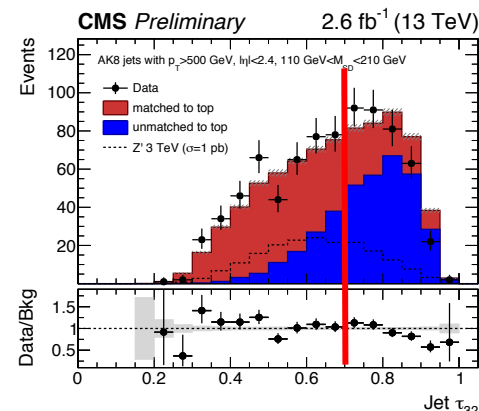
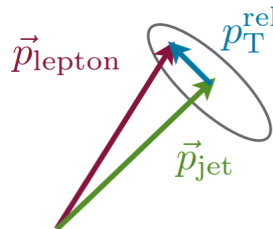
- mass of the groomed jet
- removes soft and wide angle radiations
- typical value : $110 < m_{SD} < 210$ GeV

b-tagging : use properties of b-hadrons

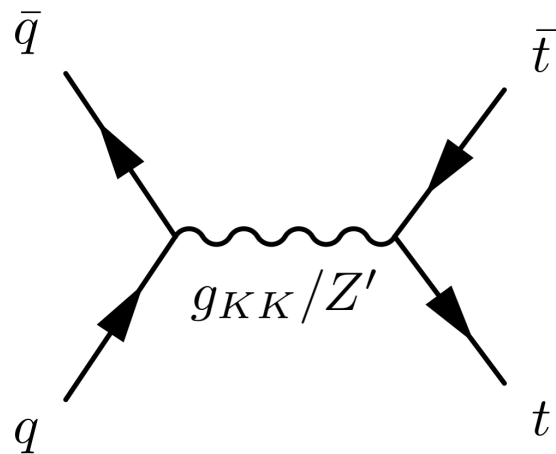
- track impact parameter
- secondary vertex

Lepton isolation:

- Modified - using 2D rejection cut
- $\Delta R(\mu/e, j) > 0.4$ or
- $p_T^{rel}(\mu/e, j) > 20$ GeV



tt resonances



Semi-leptonic channel:

- Lepton $p_T > 50$ GeV, $E_{T,miss}$ and two jets
- Search for large-R jets with top-tag

Reconstruct invariant tt mass by reconstructing t_{had} and t_{lep}

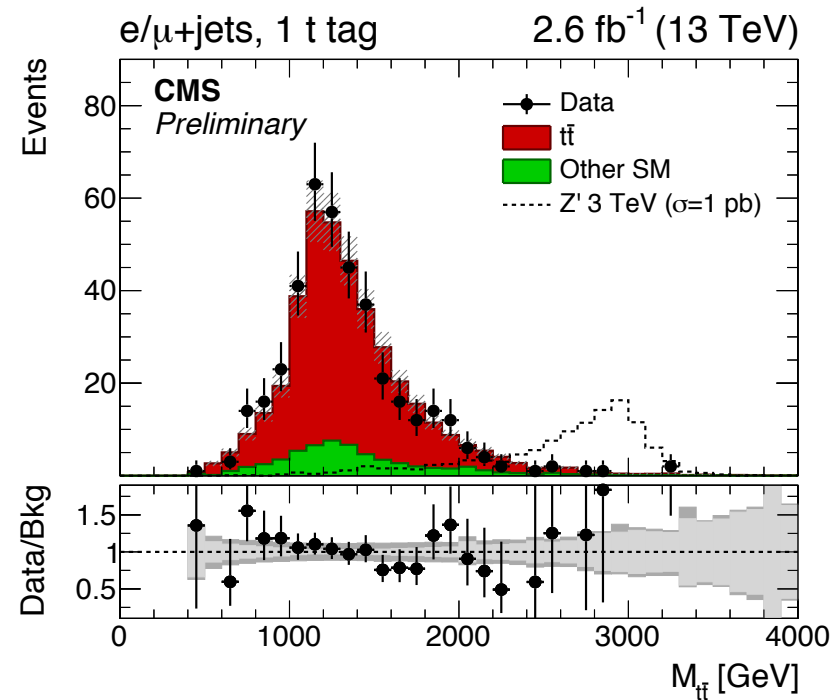
- ✓ Choose best hypothesis with minimal

$$\chi^2 = \left(\frac{M_{lep} - \bar{M}_{lep}}{\sigma_{M_{lep}}} \right)^2 + \left(\frac{M_{had} - \bar{M}_{had}}{\sigma_{M_{had}}} \right)^2$$

Hadronic channel:

- 2 leading jets $p_T > 500$ GeV, top-tagged
- Scalar sum of jets p_T : $HT > 1000$ GeV
- $|\Delta\phi(j_1, j_2)| > 2.1$ rad

Events are split into categories by the number of top-tag, b-tag and rapidity gap between two AK8 jets

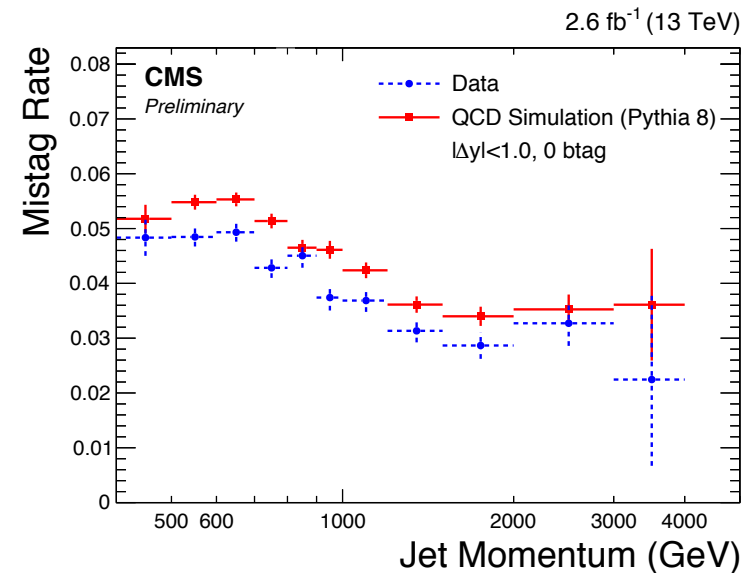
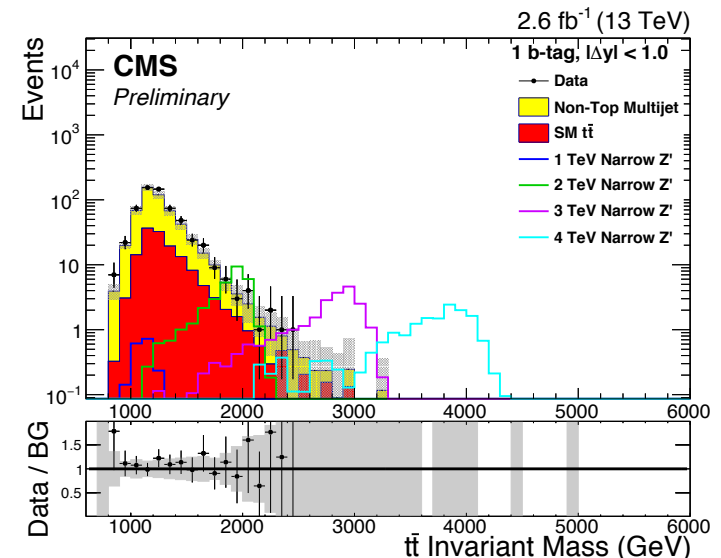


Semi-leptonic channel

- tt uses simulation with additional correction factors
- W +jets is constraint by fitting the background-only hypothesis to data in multiple categories based on lepton flavor and number of t - and b -tagged jets

Hadronic channel:

- **Multi-jets:** using data driven technique. Top-tag mistag rate is evaluated and used to predict the background contribution by extrapolation from control region
- tt - taken from the simulation; allowed to vary within the uncertainties during the limit setting



tt resonances - limits

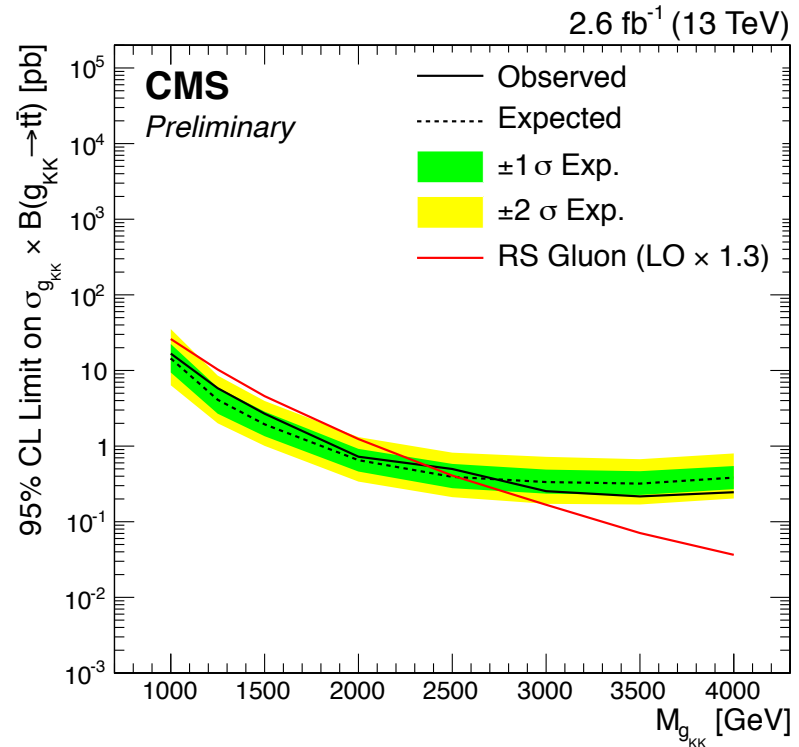
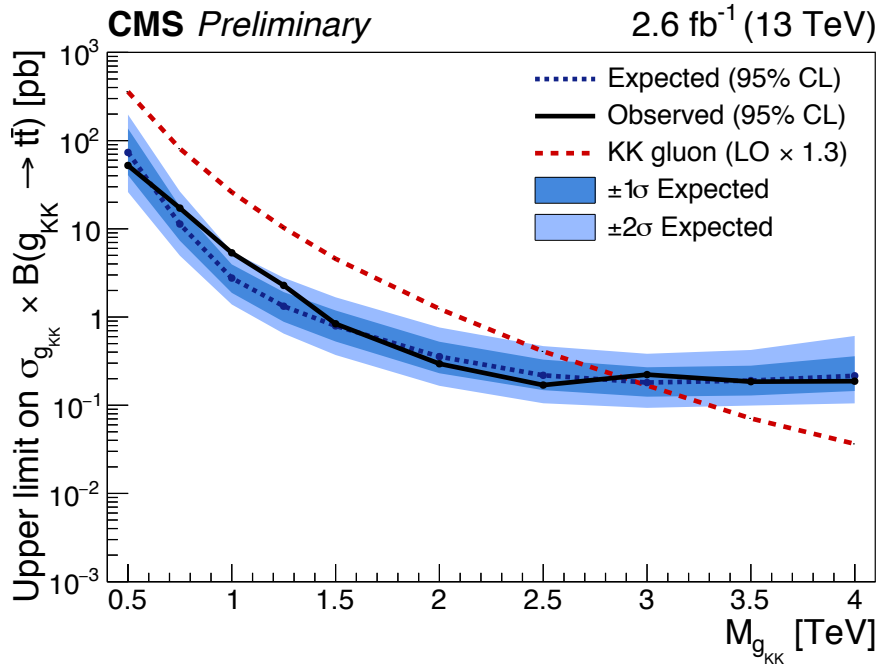
CMS-PAS-B2G-15-002

CMS-PAS-B2G-15-003

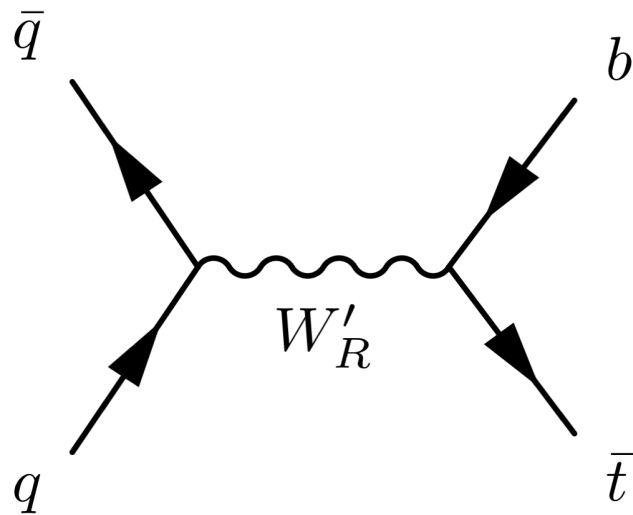
Limits at 95% CL are set for four BSM scenarios:

- ❖ Z' boson with relative width of 1, 10, 30%
- ❖ KK excitation of a gluon in the Randal-Sundrum model

Signal	Leptonic	Hadronic
Narrow Z'	[0.6-2.3] TeV	[1.4-1.6] TeV
Wide Z'	[0.5-3.4] TeV	[1.0-3.3] TeV
Extra wide Z'	[0.5-4.0] TeV	[1.0-3.8] TeV
KK gluons	[0.5-2.9] TeV	[1.0-2.4] TeV



W' resonances



Only right-handed interaction searched for

➤ W'_R resonance with narrow width (3%)

❑ Semi-leptonic channel:

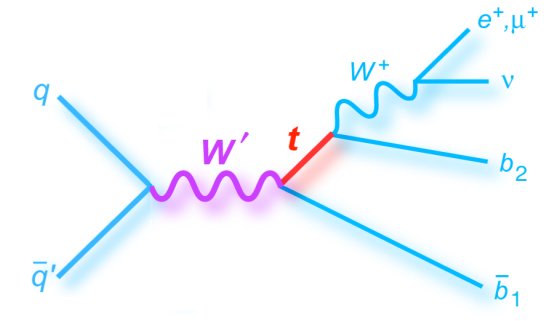
- lepton $p_T > 180$ GeV
- at least 2 jets of which at least 1 b-tagged jet
- p_T top > 250 GeV

❑ Hadronic channel:

- at least 2 jets with $p_T > 350$ GeV - one top-tagged and one b-tagged
- b-jet $m_j < 70$ GeV

➤ W' mass reconstruction:

- ✓ Semi-leptonic: lepton, $E_{T,miss}$, 2 jets
- ✓ hadronic: 2 leading jets



$W' \rightarrow t b$: backgrounds

CMS-PAS-B2G-16-009

CMS-PAS-B2G-16-017

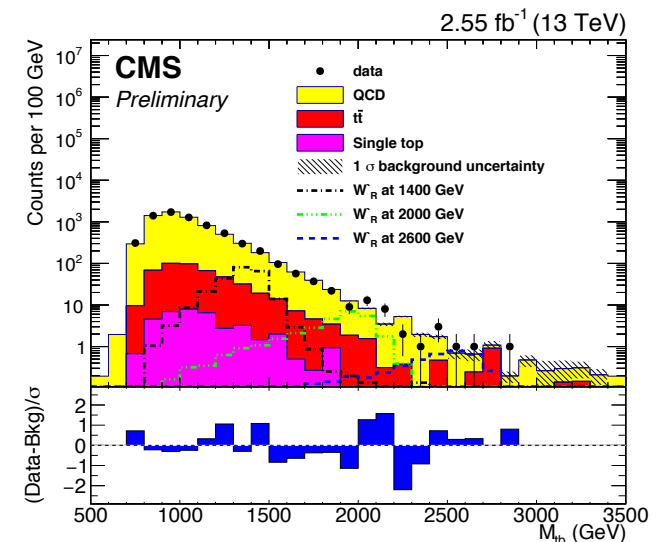
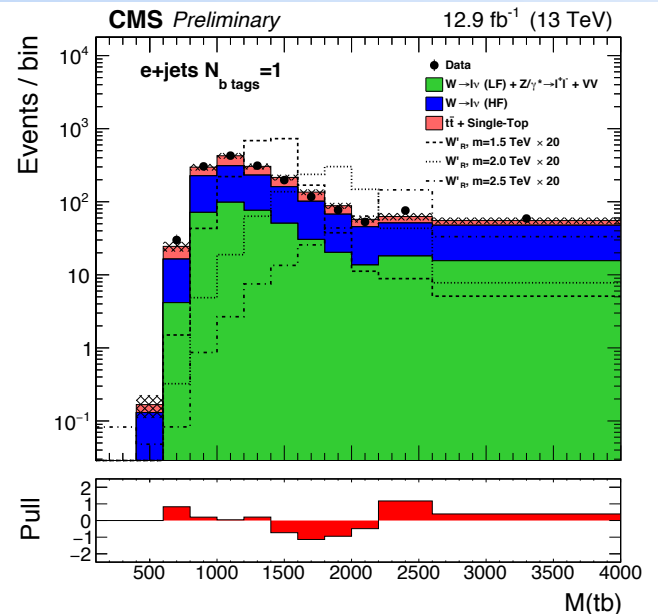
Semi-leptonic channel:

W+Jet initially is taken from the simulation, then check and corrections are derived from a control region with 0 b-tagged jets and relaxed selection. Separate corrections are derived for light and heavy flavor W+jets using iterative procedure.

Hadronic channel:

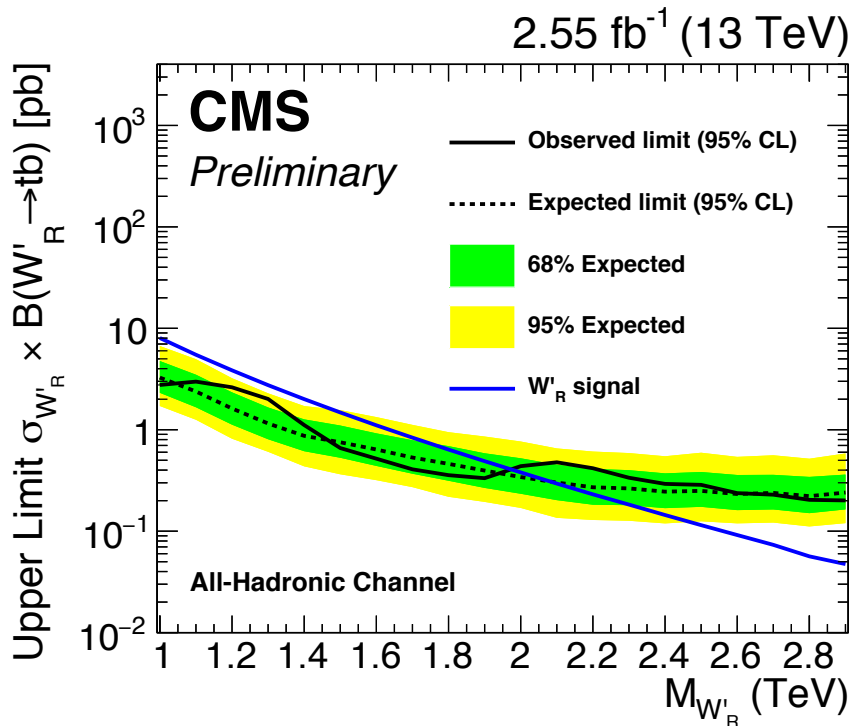
QCD multijet is derived from data. Average b-tag rate (p_T, η) is estimated from control region with m_{SD} (50,170) and $\tau_3/\tau_2 > 0.75$

ttbar background: Both channels take it from simulation; the prediction is checked in data in control region(s) - orthogonal to the signal selection



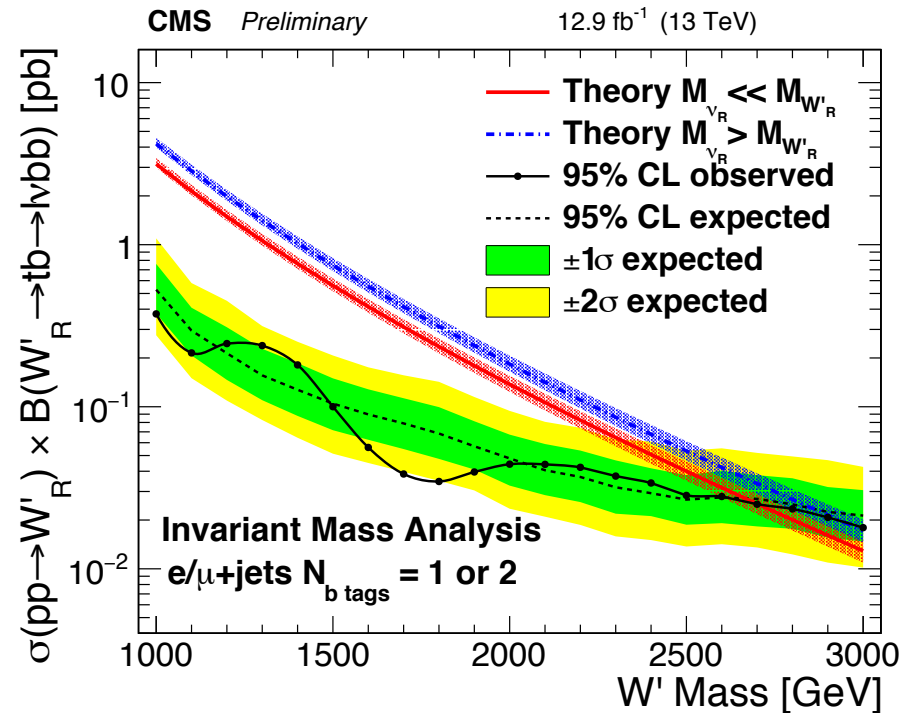
Hadronic $W' \rightarrow tb$

Exclusion at 95% CL:
[1.0 - 2.0] TeV

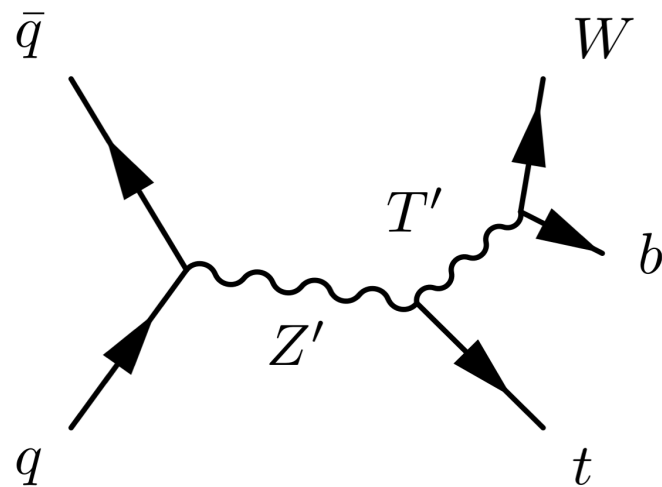


Leptonic $W' \rightarrow tb$ with 12.9 fb⁻¹ of 2016 data

Exclusion at 95% CL:
[1.0 - 2.67] TeV



Z' resonances



$Z' \rightarrow tT' (T' \rightarrow Wb) - \text{hadronic}$

CMS-B2G-16-013

First of its kind at LHC

❖ Three-jet topology

❖ Boosted top quark

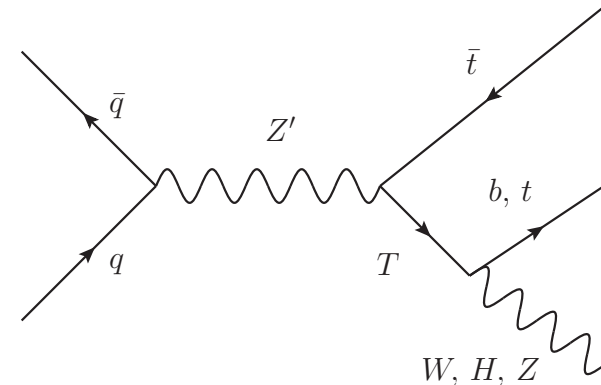
- ❖ AK8 jet with $p_T > 400$ GeV and
- ❖ soft drop mass 110 - 210 GeV
- ❖ N-subjetines: $\tau_3/\tau_2 < 0.86$

❖ Boosted W-jet

- ❖ AK8 jet with $p_T > 200$ GeV
- ❖ Soft drop mass 70-100 GeV
- ❖ N-subjetines: $\tau_2/\tau_1 < 0.6$

❖ b-jet

- ❖ AK4 jet with $p_T > 100$, $|\eta| < 2.4$
- ❖ b-tag with “Combined Secondary Vertex v2 “ algorithm



Events categorization:
✓ 2 b tag category
✓ 1 b tag category

❖ Reconstructed invariant mass of the T' is required to be larger than 500 GeV

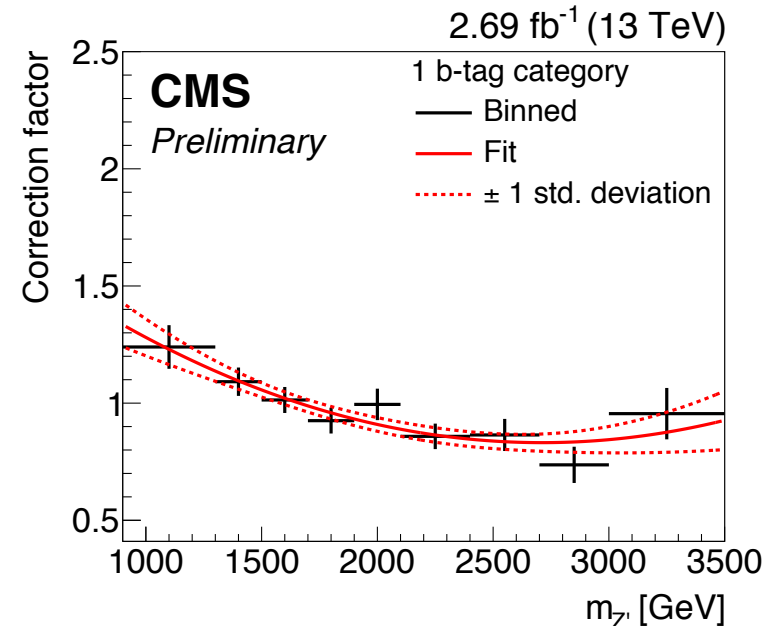
Dominant backgrounds: QCD multijets and top production (tt and single top)

- ❑ **QCD multijets:** derived from data
 - ❑ Estimated with events from a control region
 - ❑ Shape correction derived from the simulation
 - ❑ Normalization derived from data

- ❑ **Top production:** using simulation
 - ❑ Correction factors for DATA/simulation

QCD control regions: inverted b tag on AK4 jet:

Selection	SR 1 b tag	SB for 1 b tag	SR 2 b tag	SB for 2 b tag
1 t tag and 1 W tag	✓	✓	✓	✓
Subjet b tag on t-tagged jet	Veto	Veto	✓	✓
1 AK4 jet, $p_T > 100$ GeV, $\Delta R(t/W\text{-jet}, \text{jet}) > 0.8$	✓	✓	✓	✓
b tag on AK4 jet	✓	"loose" Veto	✓	"loose" Veto
$m_T > 500$ GeV	✓	✓	✓	✓

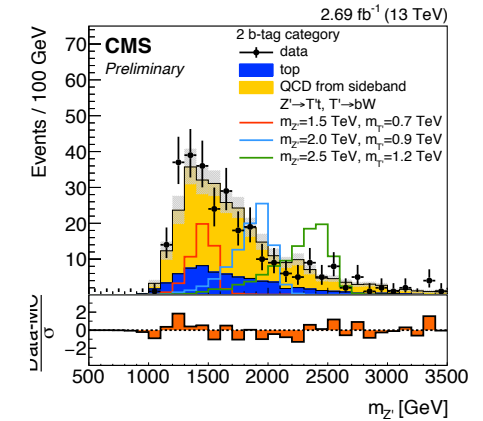
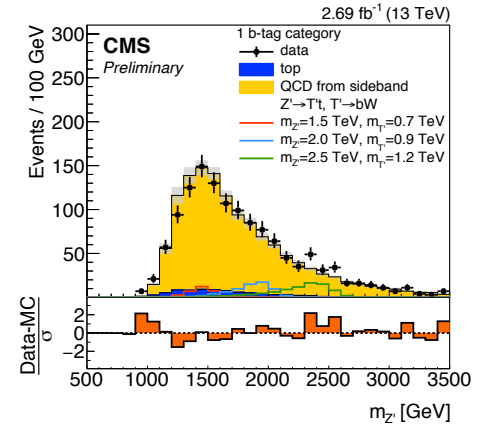
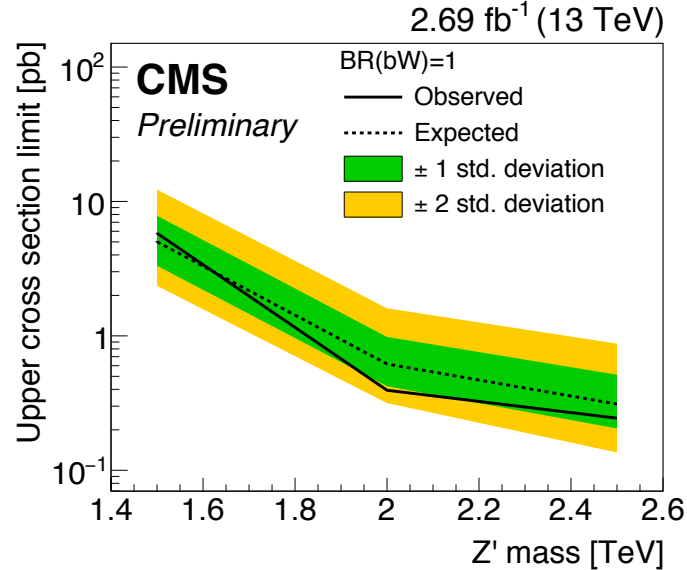
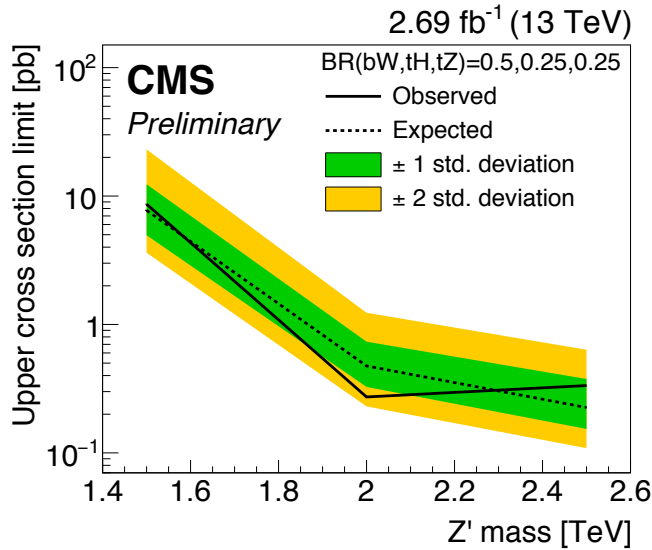


$Z' \rightarrow tT'$ ($T' \rightarrow bW$) limits

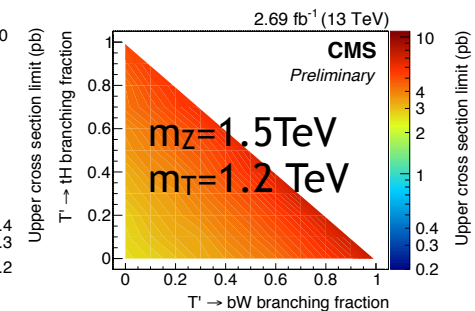
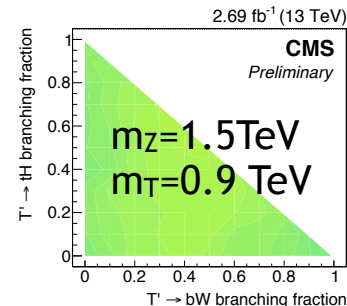
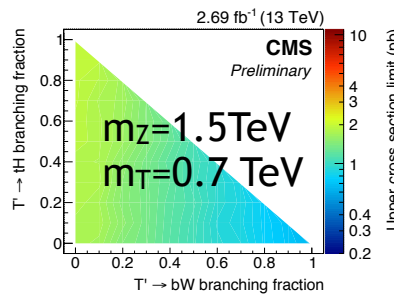
CMS-B2G-16-013

Cross section limit at 95% CL:

- $bW/tH/tZ$ - 50/25/25% - warped extra-dimension
- bW - 100%



2D limits for different T' and Z' masses and branching fractions of T' to bW and tH



Summary

- New heavy resonances searched at CMS at 13 TeV
 - ✓ $Z' \rightarrow tt$: semi-leptonic and hadronic channels
 - ✓ $W' \rightarrow tb$: leptonic and hadronic channels
 - ✓ $Z' \rightarrow tT'$ ($T' \rightarrow bW$) hadronic channel

- No sign of new physics

- Run II (2016) data already under process - stay tuned !