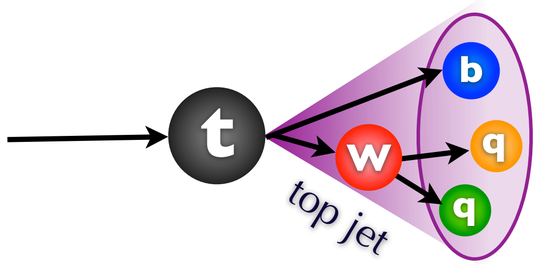
Searches for new resonances decaying to at least one top quark in pp collisions at a center-of-mass energy of 13 TeV



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2021 Meeting of the APS Division of Particles and Fields (DPF 2021)
12 July - 14 July, 2021.
Florida State University

Heavy resonance decaying to at least one top quark

Many physics models beyond the Standard Model predict heavy new particles preferentially decaying to at least one top quark

1. Heavy resonances which decay directly to standard model particles (including top and bottom quarks)

Examples:

$Z' \rightarrow tt$, $W' \rightarrow tb$, excited quarks ($b^* \rightarrow tW$, $t^* \rightarrow tg$),

leptoquarks ($LQ \rightarrow t\tau$, $LQ \rightarrow t\mu$)

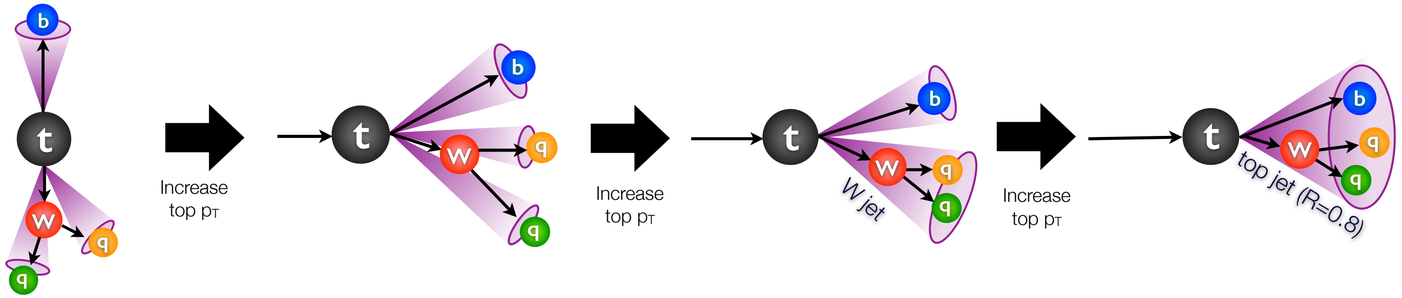
2. Heavy resonances which decay to new intermediate particles which then decay to standard model particles

Examples:

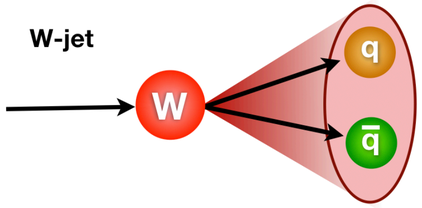
$Z' \rightarrow tT$, $Z' \rightarrow TT$, $W' \rightarrow Tb/Bt$ (T a new hypothetical heavy fermion) CMS-PAS-B2G-20-002

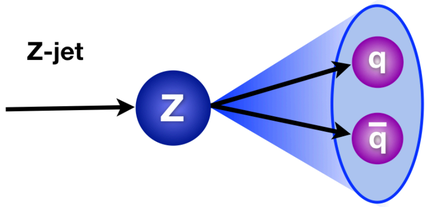
In this talk, I will present the most recent searches in these categories.

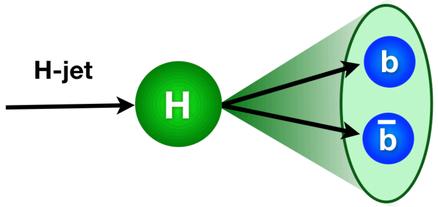
Jet-tagging Menu

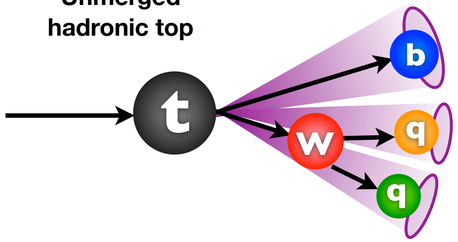


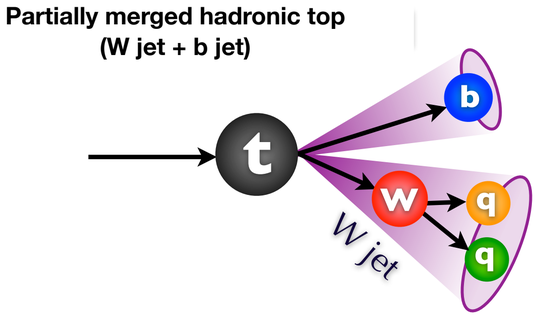
A schematic showing the way in which the subjets of a top quark decay merge with increasing p_T

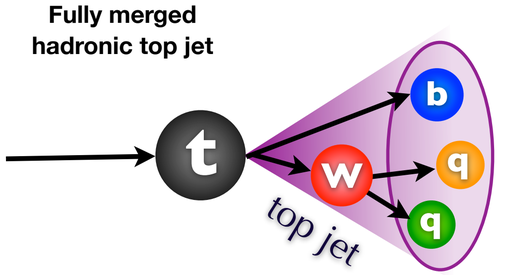


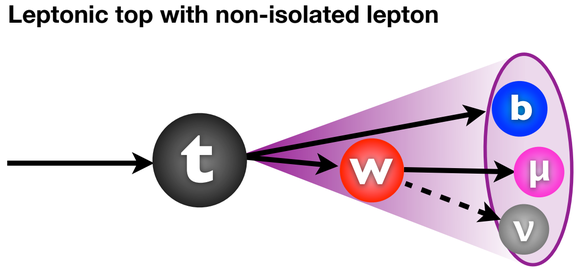








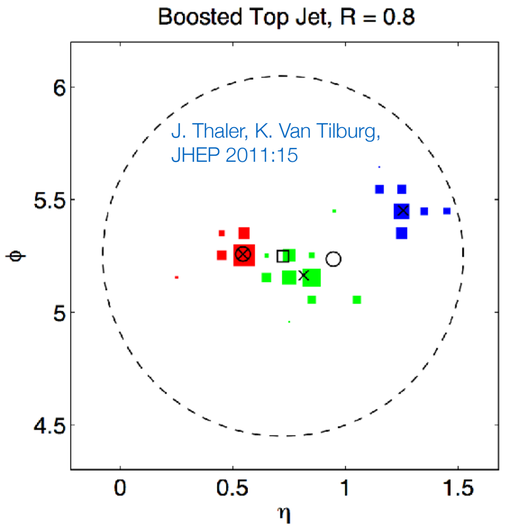


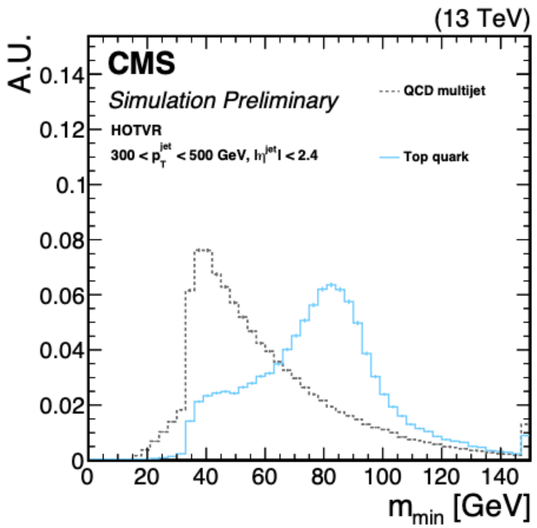


Use of jet substructure to tag partially or fully merged jets

Jet tagging tools

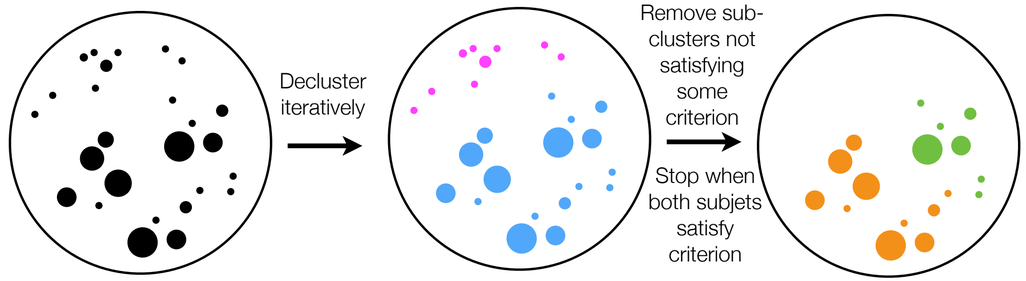
- Jet grooming
  - Soft-drop algorithm (modified mass drop algorithm)
  - Improve mass discrimination and resolution
- N-subjettiness algorithm.
  - The consistency between the jet energy deposits and the number of assumed subjets, *N, is* τ_N
  - Better discrimination by using ratios (ex. τ_3/τ_2)





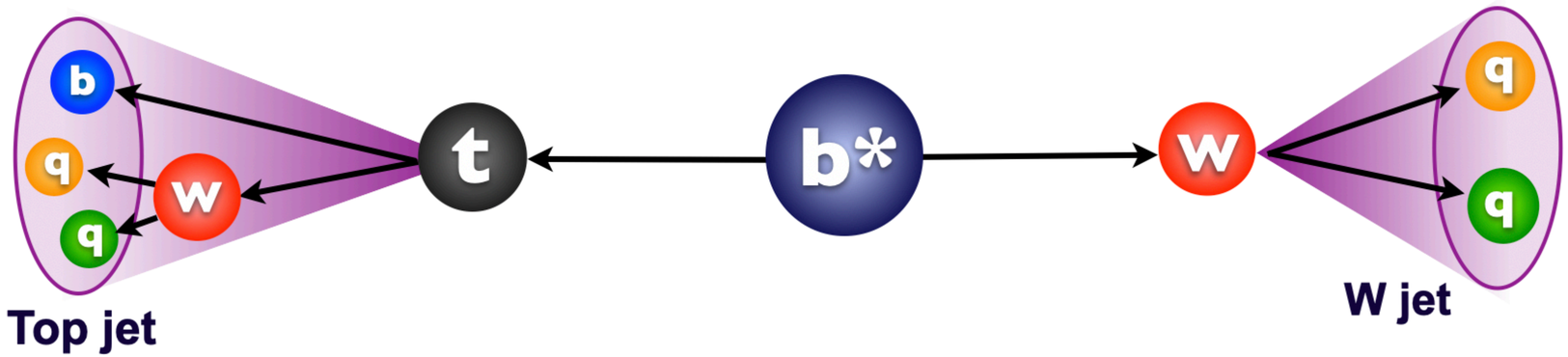
Novel Top tagger:

- DEEPAK8
  - Deep Neural Network approach
  - Inputs: Jet constituent particle kinematic and angular information, track information, and secondary vertex information.
- HOTVR(Heavy Object Tagger with Variable R)
  - Jet size varies up to $\Delta R = 1.5$
  - Allows the use of jet substructure tools for lower momentum tops
  - Tag jets using HOTVR mass, Nsubjets, minimum subjet pairwise mass, subjet pT ratio, and τ_3/τ_2



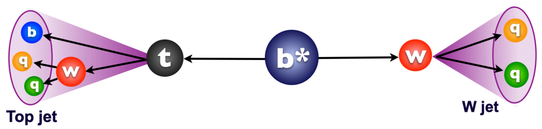
Resonance decaying to a top and W in hadronic state

- Search for a heavy resonance which decays to a top quark and a W boson at center-of-mass energy of 13 TeV .
- The production of an excited bottom quark, b*, is used as a benchmark when setting limits on the cross section for a heavy resonance decaying to a top quark and a W boson.
- All-Hadronic final state considered.



http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-19-003/index.html

Event Selection

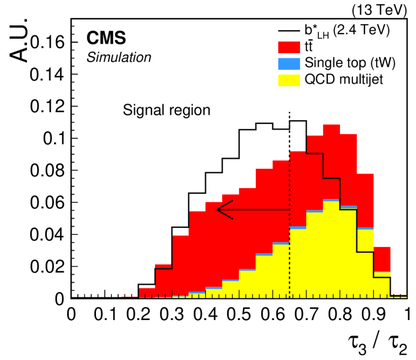


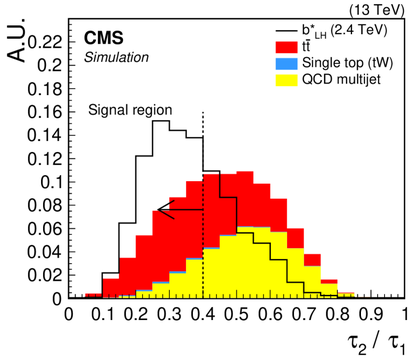
- Search uses the full CMS Run-2 data (2016-18) corresponding to an integrated luminosity of 137 fb^{-1} .

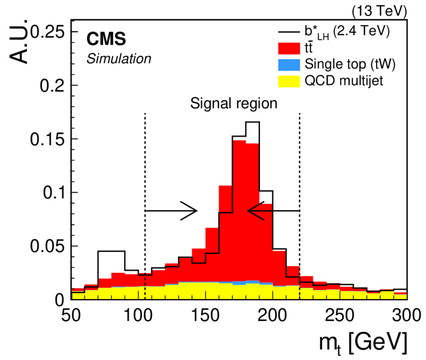
- Require two well-separated (back-to-back) AK8 jets with $p_T > 400$ GeV and $|\eta| < 2.4$.

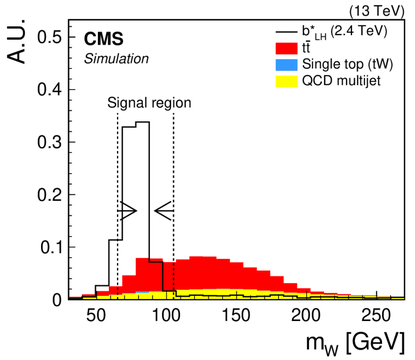
- Top tagging:
  - Soft-drop groomed jet mass
  - N- subjettiness ratio τ_3/τ_2 (< 0.65)
  - B-tagged subjet (DeepCSV algorithm)

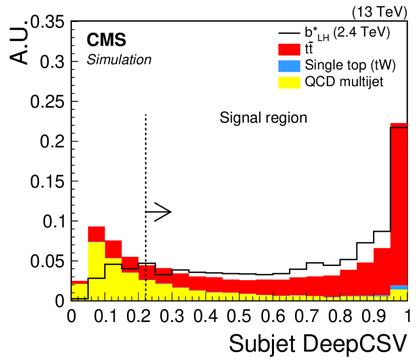
- W tagging:
  - Soft-drop groomed jet mass
  - N-subjettiness ratio τ_2/τ_1 (< 0.4)











CMS-B2G-19-003

Search Information

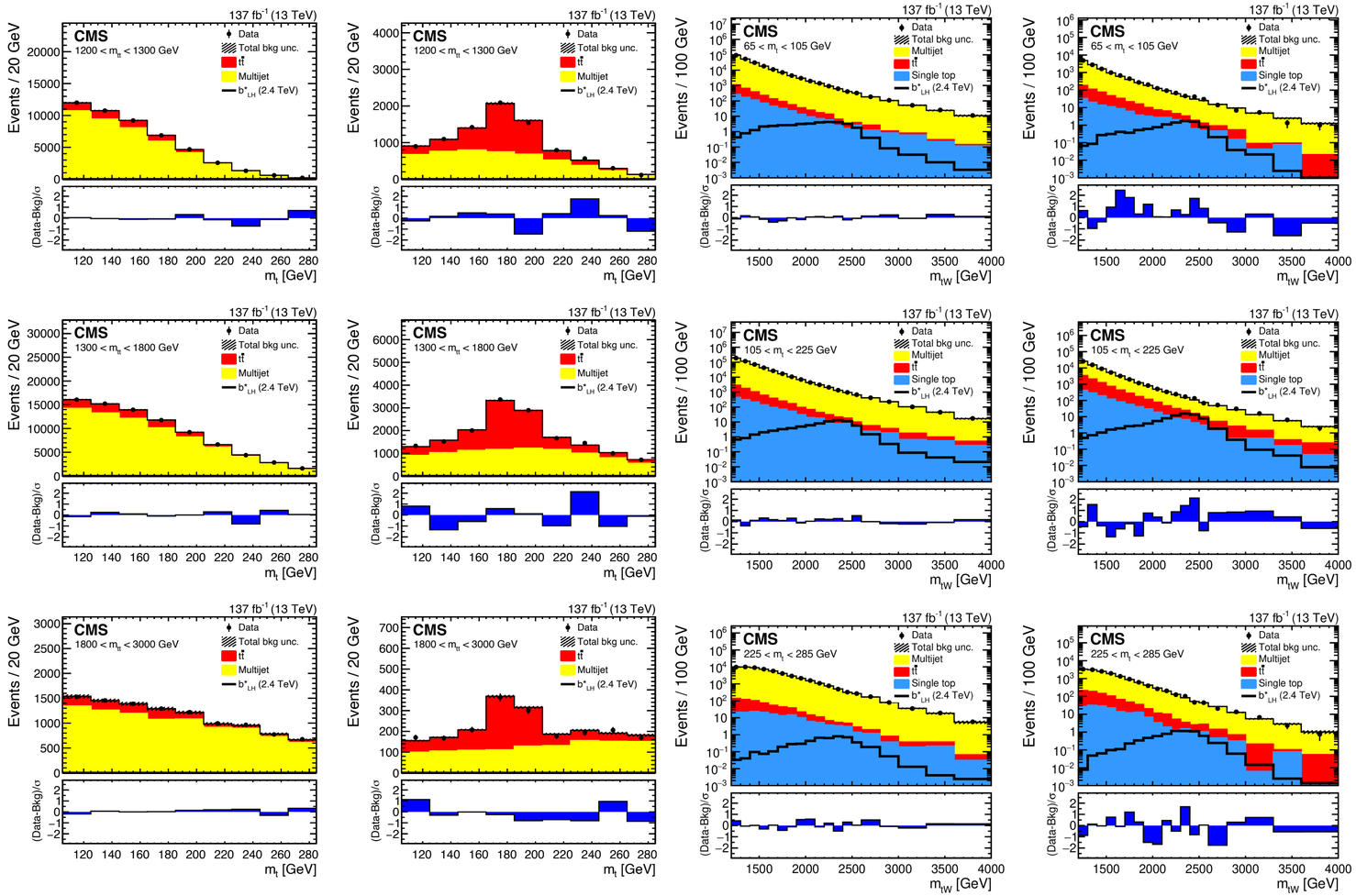
Backgrounds:

- QCD Multijet
  - Dominant
  - Estimated using data-driven control regions
- Top quark pair production
  - Estimated with both data and simulation
- Single Top
  - MC simulation

Search:

- (m_{tW}, m_t) and (m_{tt}, m_t) distribution are used in a simultaneous binned maximum likelihood fit to data.

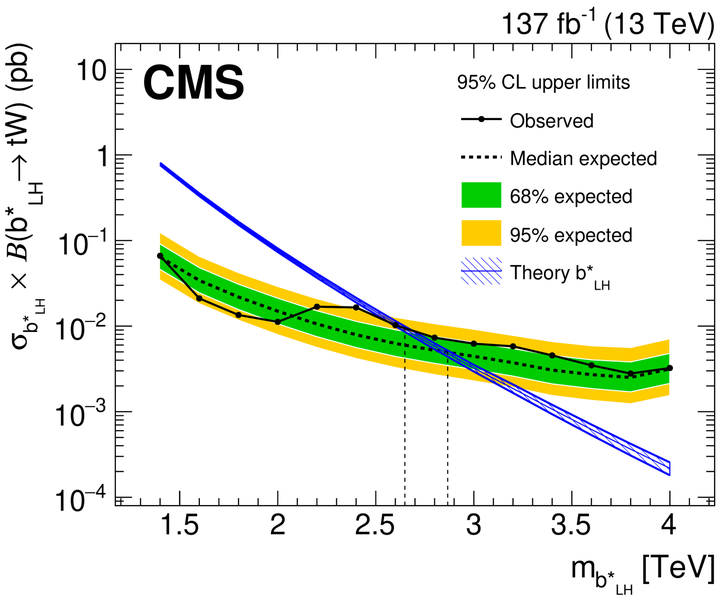
(m_{tt}, m_t) CMS-B2G-19-003 (m_{tW}, m_t)

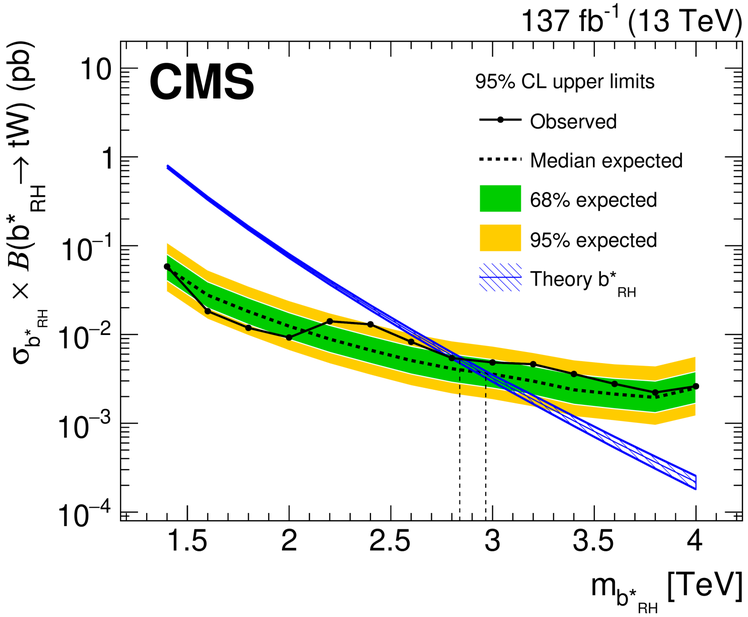


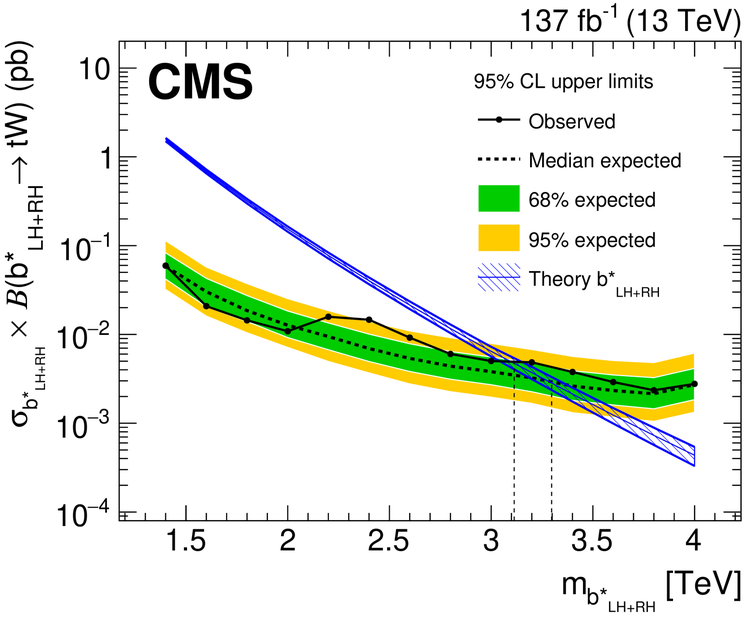
Results

- No significant excess above the standard model background is observed.
- Limits set on the production cross section for left-handed (LH), right-handed (RH), and vector-like chiralities (LH+BH) are excluded at 95% confidence level for masses below 2.6, 2.8, and 3.1 TeV, respectively.

CMS-B2G-19-003



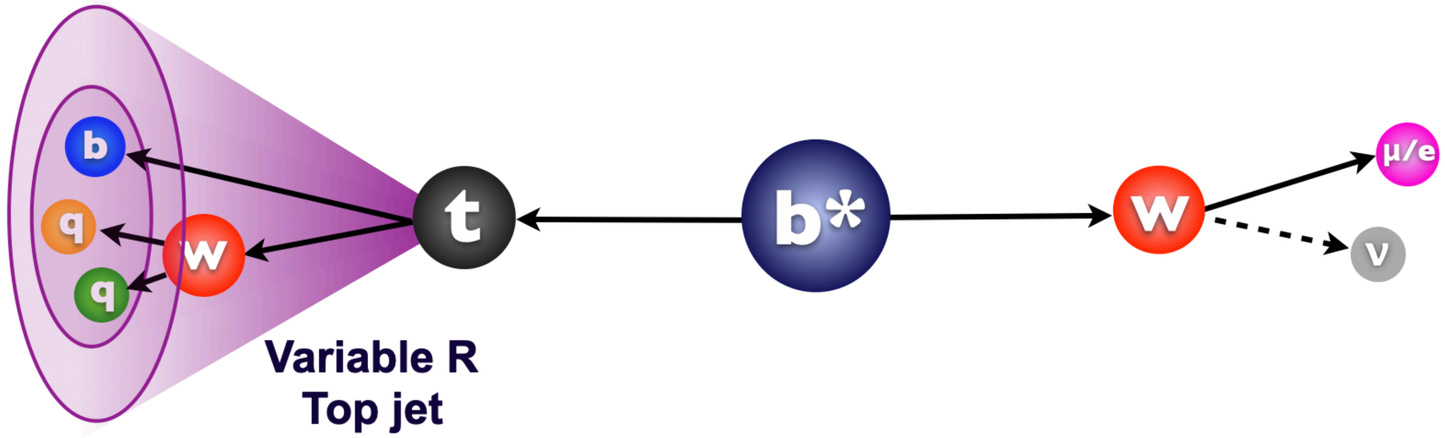




These are the most stringent limits on the b* quark mass to date, extending the previous best mass limits by almost a factor of two.

Resonance decaying to a top and W in lepton+jet state

- Search for a heavy resonance which decays to a top quark and a W boson at center-of-mass energy of 13 TeV.
- An excited bottom quark “b*” model is used as a benchmark
- Lepton+jets final state considered.
  - Hadronic top decay
  - W-boson decays to a muon or electron and a neutrino



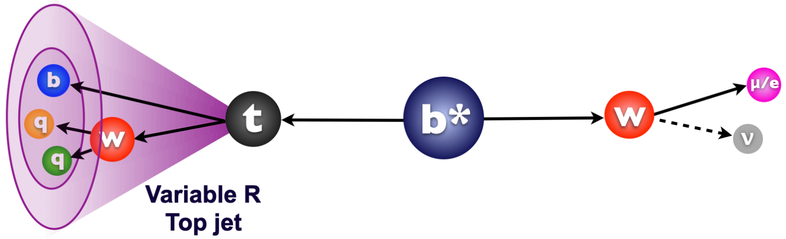
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G-20-010/index.html

Event Selection

- Analyzed data were collected by the CMS experiment between 2016 and 2018 (full Run-2 data) and correspond to an integrated luminosity 137 fb^{-1}.

- Final state consists of 1 lepton, missing transverse momentum, and 1 top-tagged jet with high transverse momentum
    - Lepton in the final state allows the use of lepton triggers with lower p_T thresholds than jet triggers

- Top tag - Heavy Object Tagger with Variable R (HOTVR) algorithm is employed for the identification of collimated t decays
    - Variable R allows one to maintain efficiency at low p_T

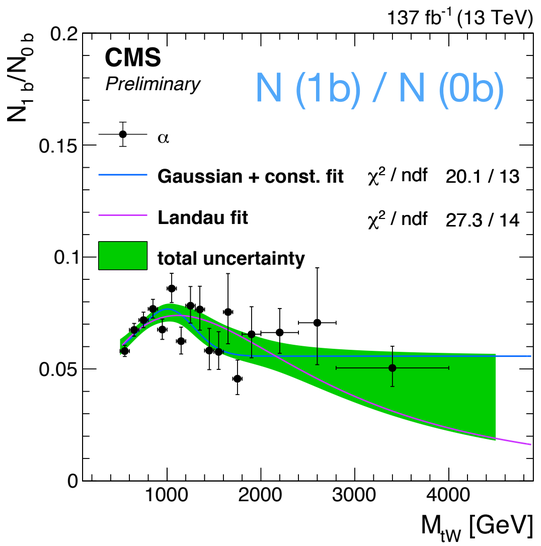


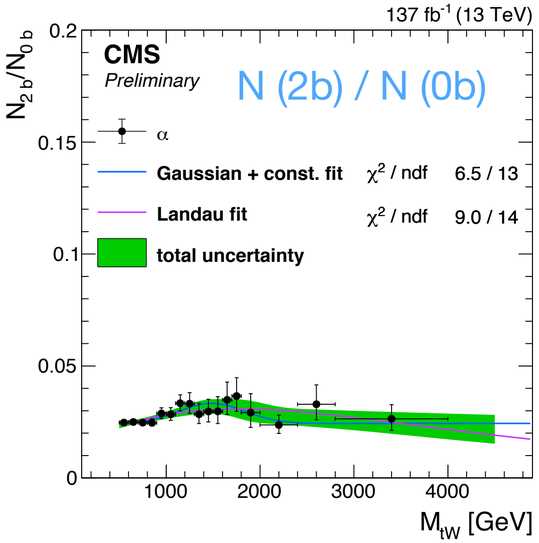
- Neutrino is reconstructed using the W mass as a constraint.

- How much “signal-like” the event is by exploiting the signal’s angular and kinematic properties.

- Categorize events based on number of b-tagged jets (N_{btags})

Search Information





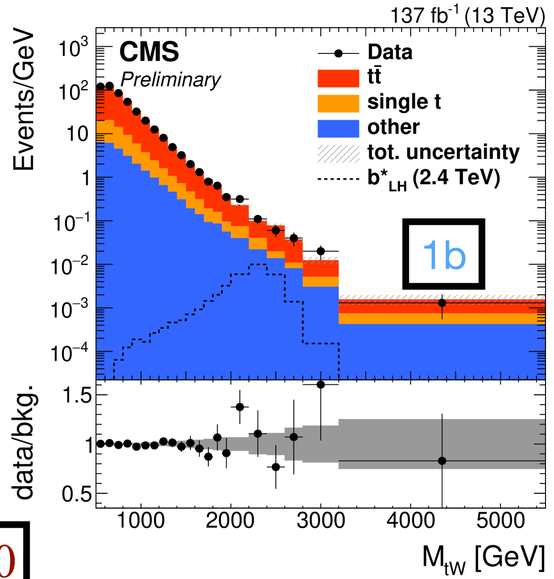
Backgrounds

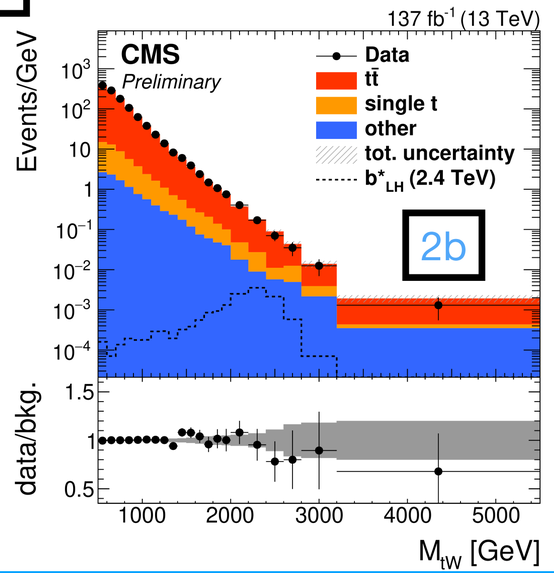
- Top quark pair production
  - Control region: 2 b-tag category is used to constrain systematic uncertainties associated with simulation
- Single Top
  - MC simulation
- Non-Top
  - Dominantly W/Z+jets and diboson with misidentified t jets
  - Estimated with data using the 0 b-tag category
  - Transfer function (alpha method)

Search

- Binned maximum likelihood fit
- b* mass is reconstructed from the tW mass

CMS-PAS-B2G-20-010

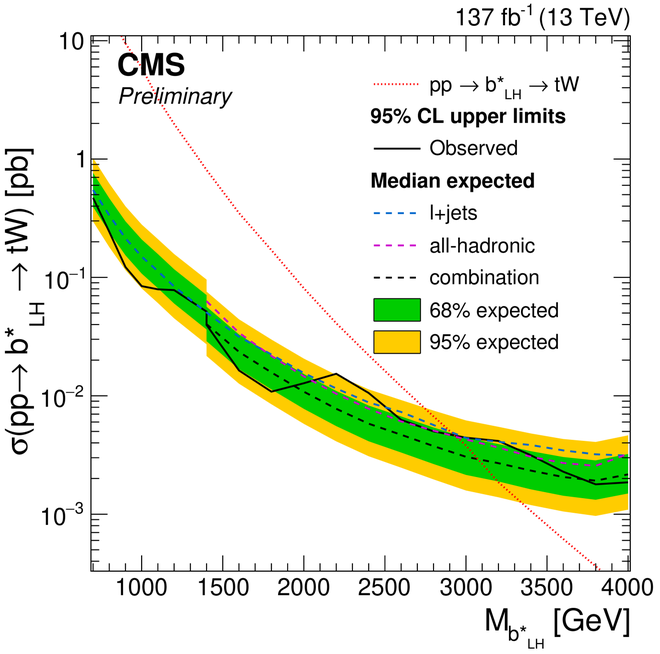


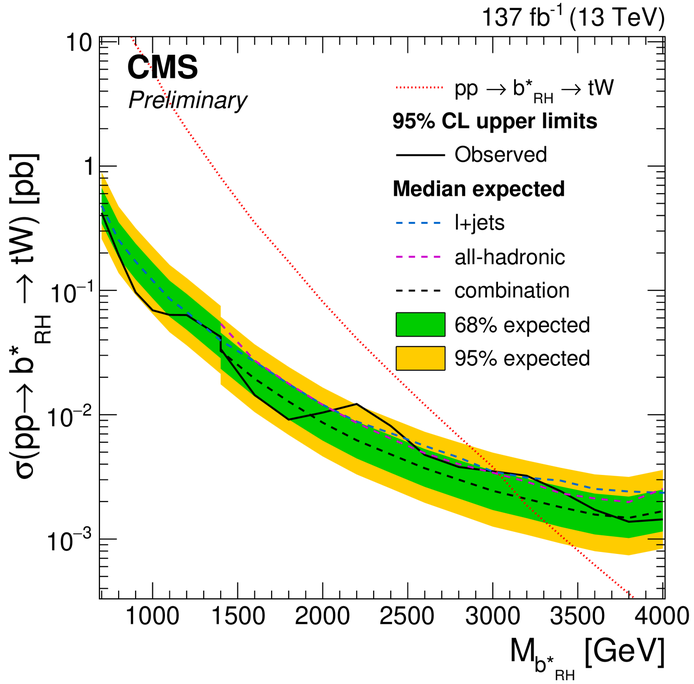


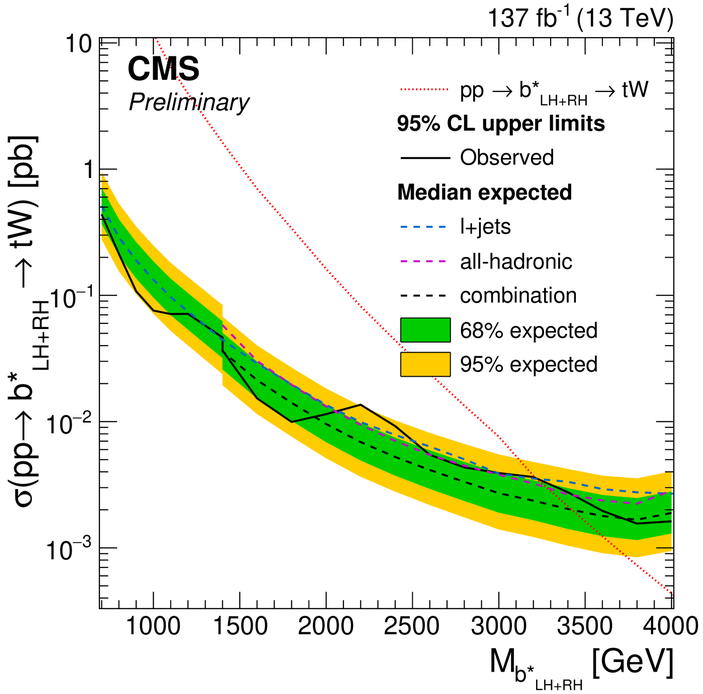
Results

- No significant excess above the standard model background is observed.
- Limits set on the production cross section for left-handed (LH), right-handed (RH), and vector-like chiralities (LH+BH) are excluded at 95% confidence level for masses below 2.6, 2.8, and 3.1 TeV, respectively
- Lepton+jets results are combined with the all-hadronic analysis

CMS-PAS-B2G-20-010



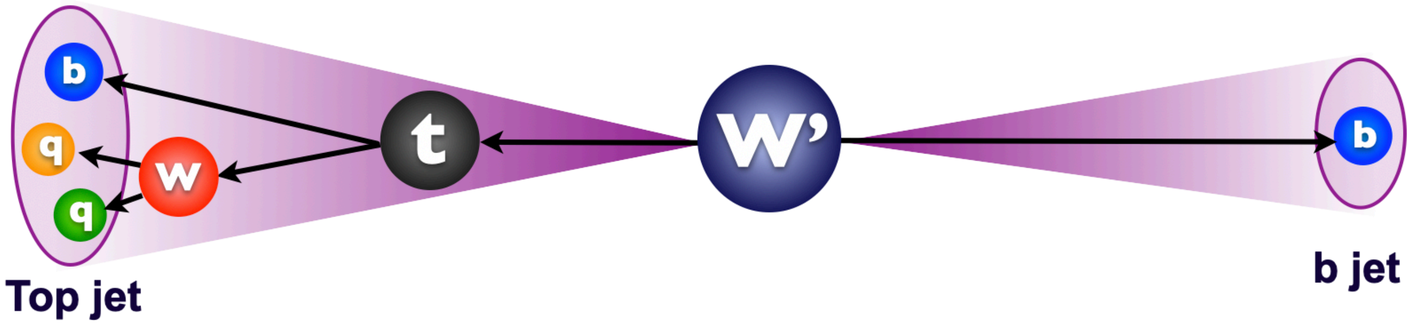




These are the most stringent limits on the b* quark mass to date, extending the previous best mass limits by almost a factor of two.

W' bosons decaying to a top and bottom in the hadronic state

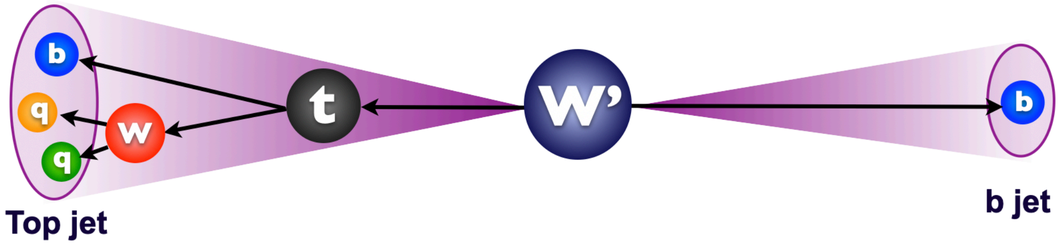
- W' boson, spin-1 gauge boson, is predicted in numerous models including Little Higgs, extra dimensional, and left-right symmetric models.
- A search is performed for W' bosons decaying to a top and a bottom quark in proton-proton collisions at a center-of-mass energy of 13 TeV.
- Hadronic final state considered.



http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-20-005/index.html

Event Selection

- Analyzed data were collected by the CMS experiment between 2016 and 2018 (full Run-2 data) and correspond to an integrated luminosity 137 fb^{-1}.
- Event with at least one AK8 and one AK4 jet is required, both with $p_T > 550$ GeV and $|\eta| < 2.4$, and which are separated by $\Delta R > 1.2$
- Reject pairwise top - make sure there is no heavy AK8 jet near the AK4 jet
- Top tag:
  - DeepAK8 top-tagger is used for t tagging of AK8 jets.
- b-tag:
  - DeepJet (DNN-based tagger) is used for b-tagging of AK4 jets



Search Information

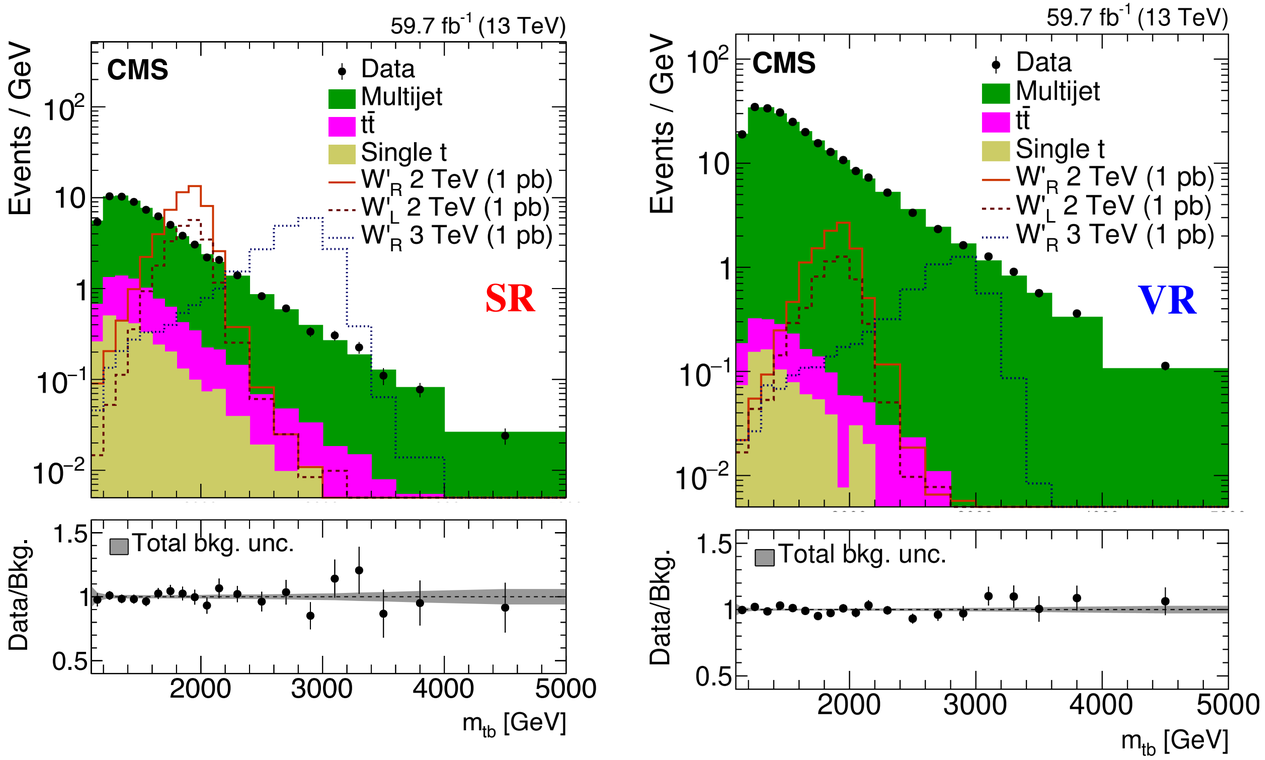
Backgrounds

- QCD Multijet
  - Dominant
  - Data-driven background estimation
    - Control region used to estimate the multi jet background in the signal region and validated in another orthogonal region directly on data.
- Top quark pair production
  - Estimated with simulation and validated with data

Search

- The signal and expected background m_{tb} distribution are compared with data.
- Binned maximum likelihood fit of reconstructed W′ mass.

CMS-B2G-20-005

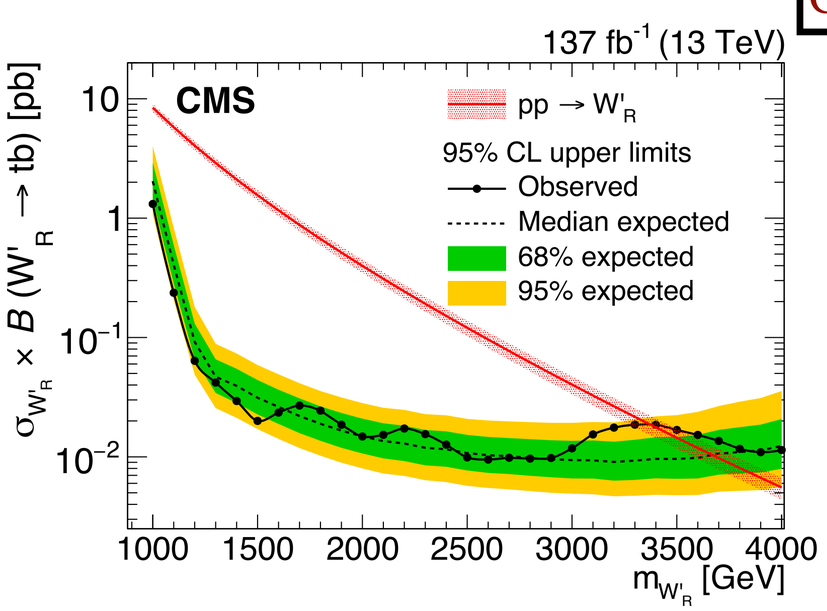


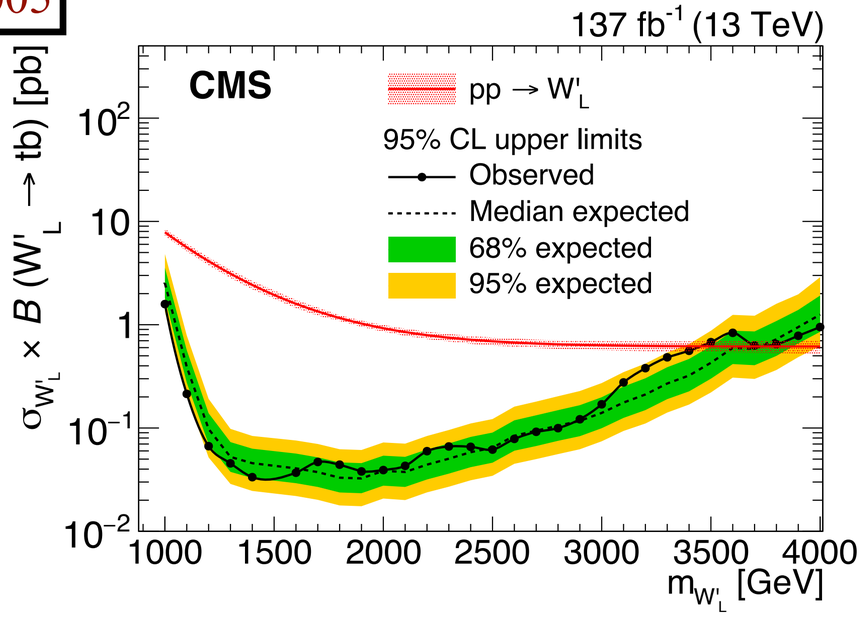
Results

- No significant excess above the standard model background is observed.

- Limits set on the production cross section for both left-handed and right-handed W′ bosons
  - Both excluded for masses below 3.4 TeV at 95% confidence level

CMS-B2G-20-005





The most stringent limits to date on W' bosons decaying to a top and a bottom quark in the all-hadronic final state are obtained.

Summary

- All those three analysis were performed with data collected by the CMS experiment between 2016 and 2018 (full Run-2 data) at 13 TeV, corresponding to an integrated luminosity 137 fb^{-1}.
- No significant excess found in CMS Run-2 data.
- The most stringent limits to date on W′ bosons decaying to a top and a bottom quark, or b* quark mass are obtained.
- Broad search program at CMS for heavy BSM particles decaying to third generation quarks can be found at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Back Up

Useful link for those analysis are here:

$Z' \rightarrow t\bar{t}$: http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-17-017/index.html

$W' \rightarrow$ tb : http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-20-005/index.html

b* $\rightarrow$ tW : http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-19-003/index.html

$W' \rightarrow$ Tb/Bt : http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G-20-002/index.html

$Z' \rightarrow$ tT : http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-17-015/index.html

$Z' \rightarrow$ TT : http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-18-005/index.html

LQ $\rightarrow$ tτ : http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-16-028/index.html