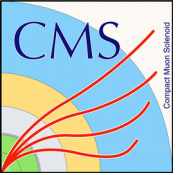


Search for heavy BSM particles coupling to 3rd generation quarks at CMS

Lucas Corcodilos on behalf of the CMS Collaboration
Johns Hopkins University
SUSY 2019

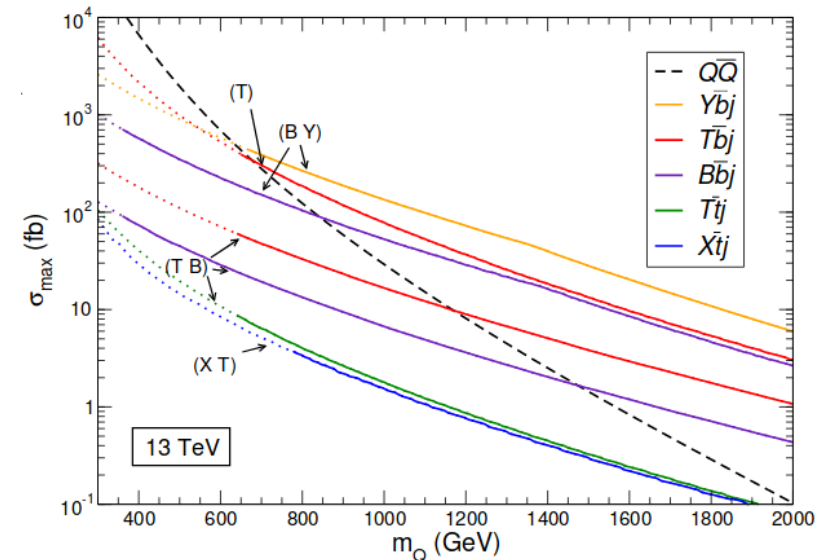


Beyond Two Generations (B2G) Program

- This talk on BSM physics coupling to third generation quarks
 - Even then, too many results to cover in a short time!
- Focus on most recent results using 35.9 fb⁻¹ of 2016 data taken at $\sqrt{s} = 13$ TeV
 - Will slow down where there's interesting work being done!

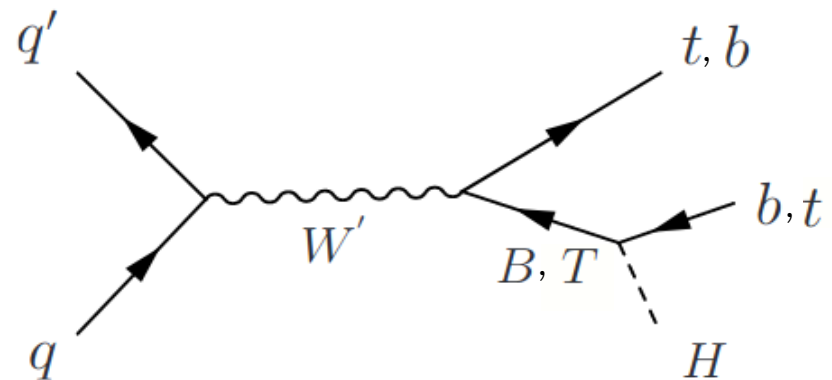
Vector-like Quarks (VLQs)

- Several analyses centered around existence of VLQs
- Chiral 4th gen. quarks constrained by Higgs cross section measurements
- Left and right handed components transform the same under SM EW symmetry
 - Gauge invariant mass term means masses are not determined by Yukawa couplings to Higgs!
- Predicted in many BSM scenarios
 - GUTs, extra dimensions, little higgs, etc



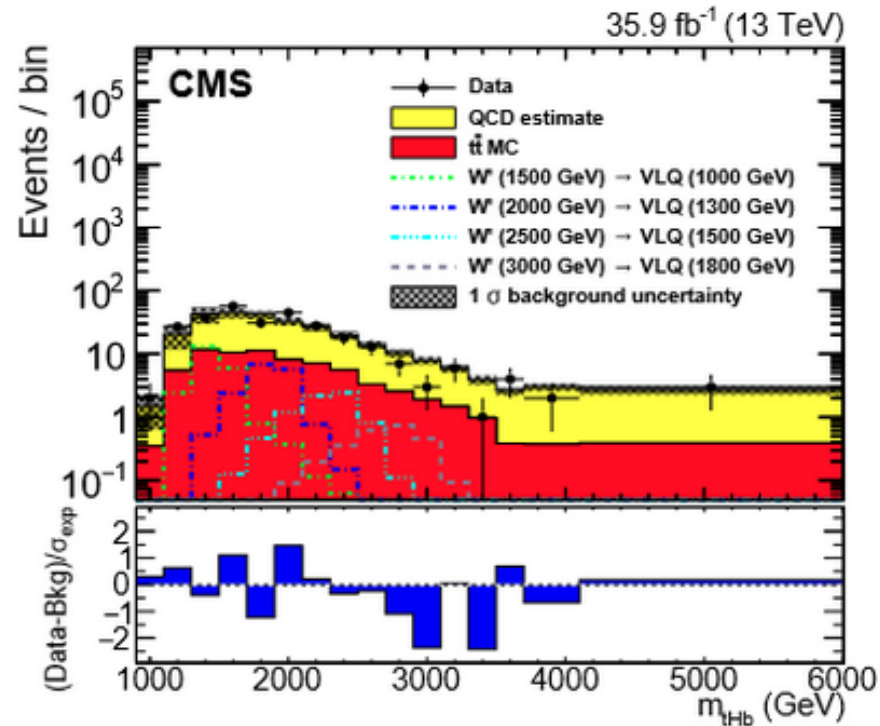
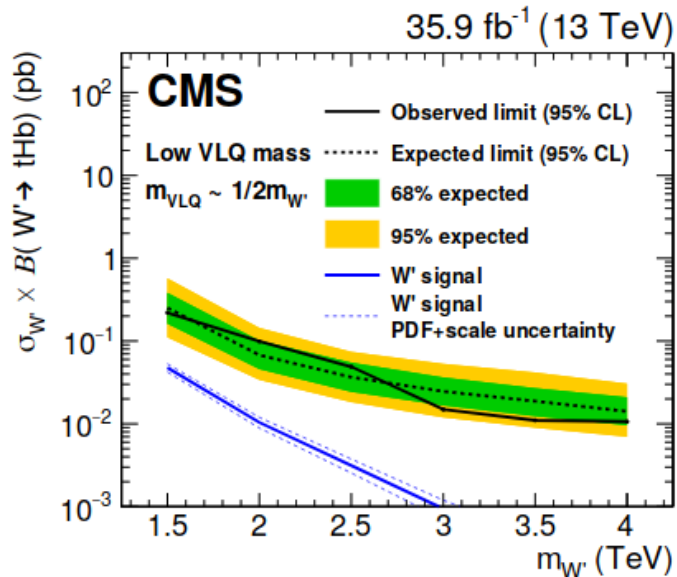
$W' \rightarrow tB$ or Tb – All Hadronic

- Proposed in models such as composite Higgs
- Tb or $tB \rightarrow tbH \rightarrow$ jets
 - Three boosted jets – one standard, two large-cone with sufficient separation between the three
 - Higgs to bb
- Background dominated by QCD multijet
 - Estimated from data in inverted top-tag selection
 - Transfer function between H-tag and H-antitag regions as a function of p_T and η
- $t\bar{t}$ contribution estimated from MC with MC-to-data corrections applied



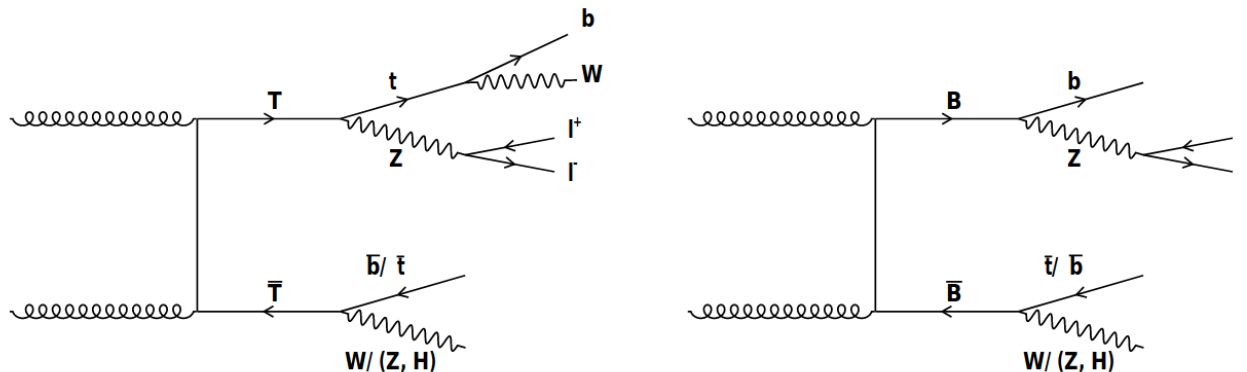
$W' \rightarrow tB$ or Tb – All Hadronic

- Bump hunt performed in m_{tHb} mass
- First limits set for W' in this channel
 - Different VLQ to W' mass ratios considered



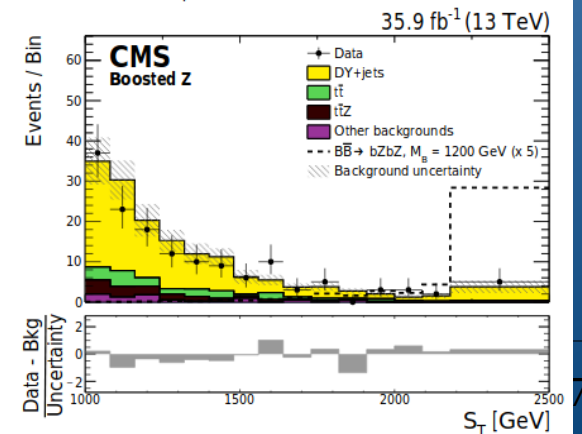
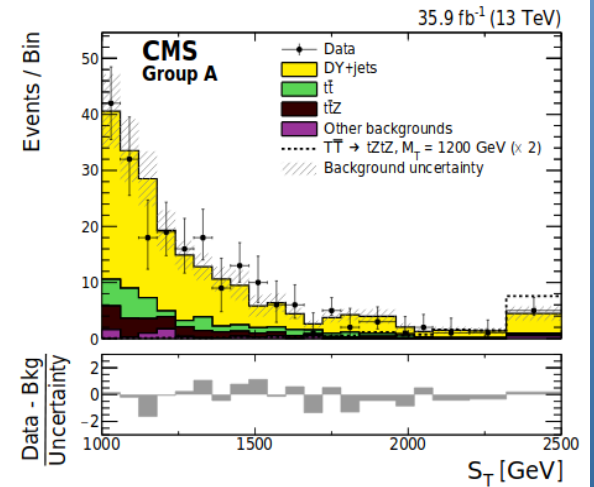
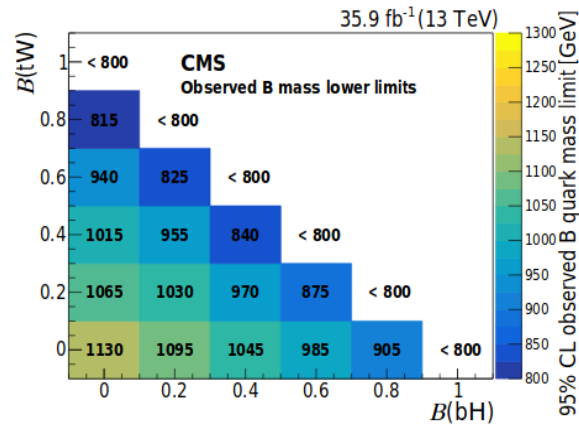
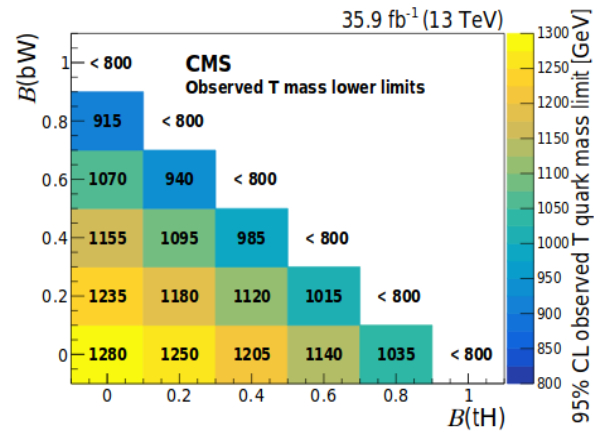
Pair VLQ Production – Semi-leptonic

- Production via strong force means cross-section is uniquely determined by mass of VLQ unlike model-dependent single VLQ production
- Slightly different topology for $T\bar{T}$ and $B\bar{B}$
 - Searches performed separately
- Categorize events based on number of successful tags of b, V, H, t
 - Fit simultaneously



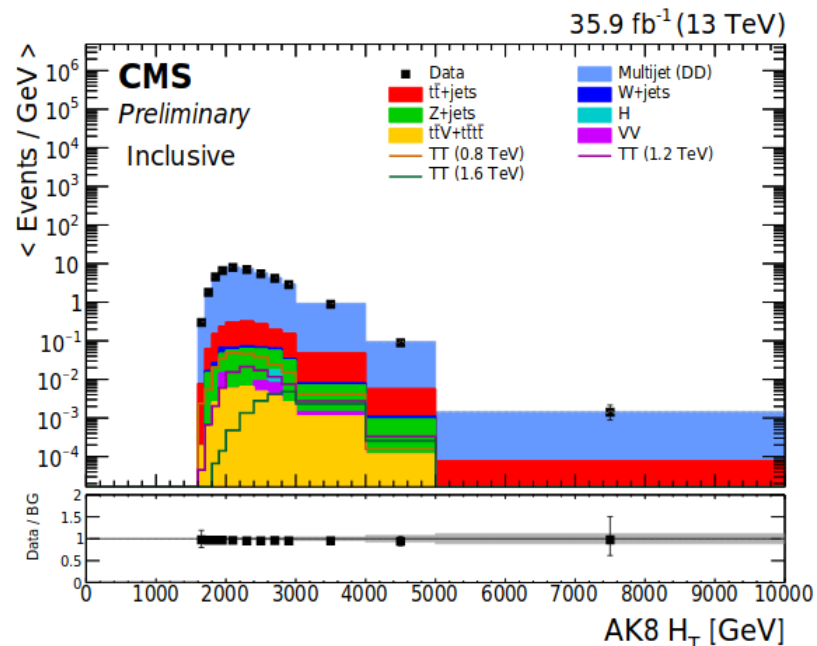
Pair VLQ Production – Semi-leptonic

- Search in S_T
 - Sum of H_T , p_T , and $p_{T\text{miss}}$
- Backgrounds include Z+jets, $t\bar{t}$, and $t\bar{t}Z$
 - Z+jets corrected from data from measurements in control region



Pair VLQ Production – Fully Hadronic

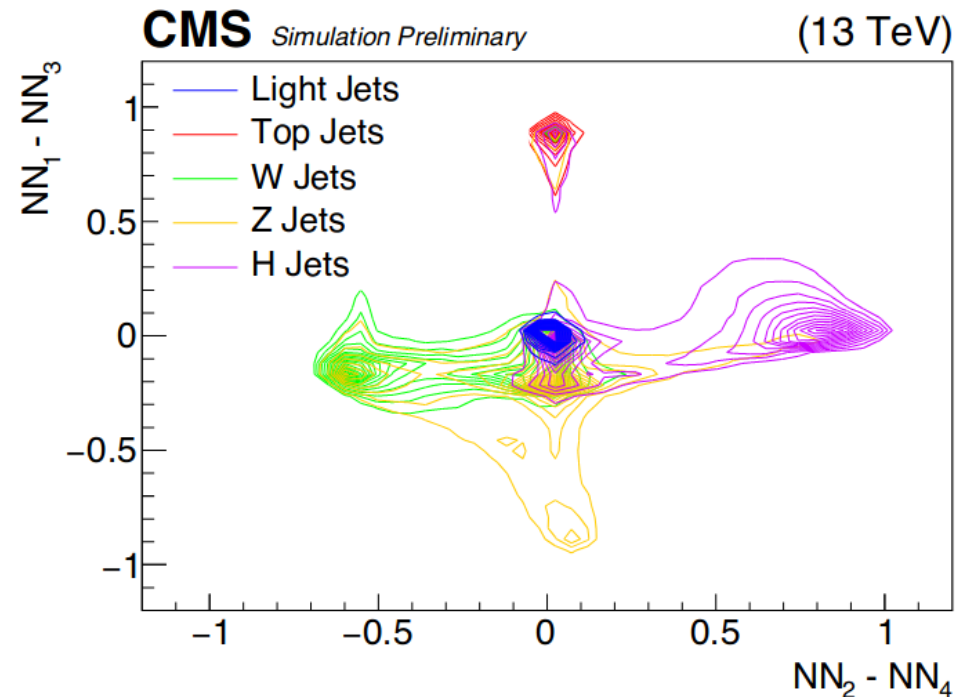
- $B \rightarrow tW, bZ, bH$ and $T \rightarrow bW, tZ, tH$
- NN-based search for all possible decays
 - Uses a multiclassifier technique (“BEST”) for object tagging
 - 126 signal region categories for all possible decays
- Background dominated by QCD multijet
 - Misidentification rates used for prediction



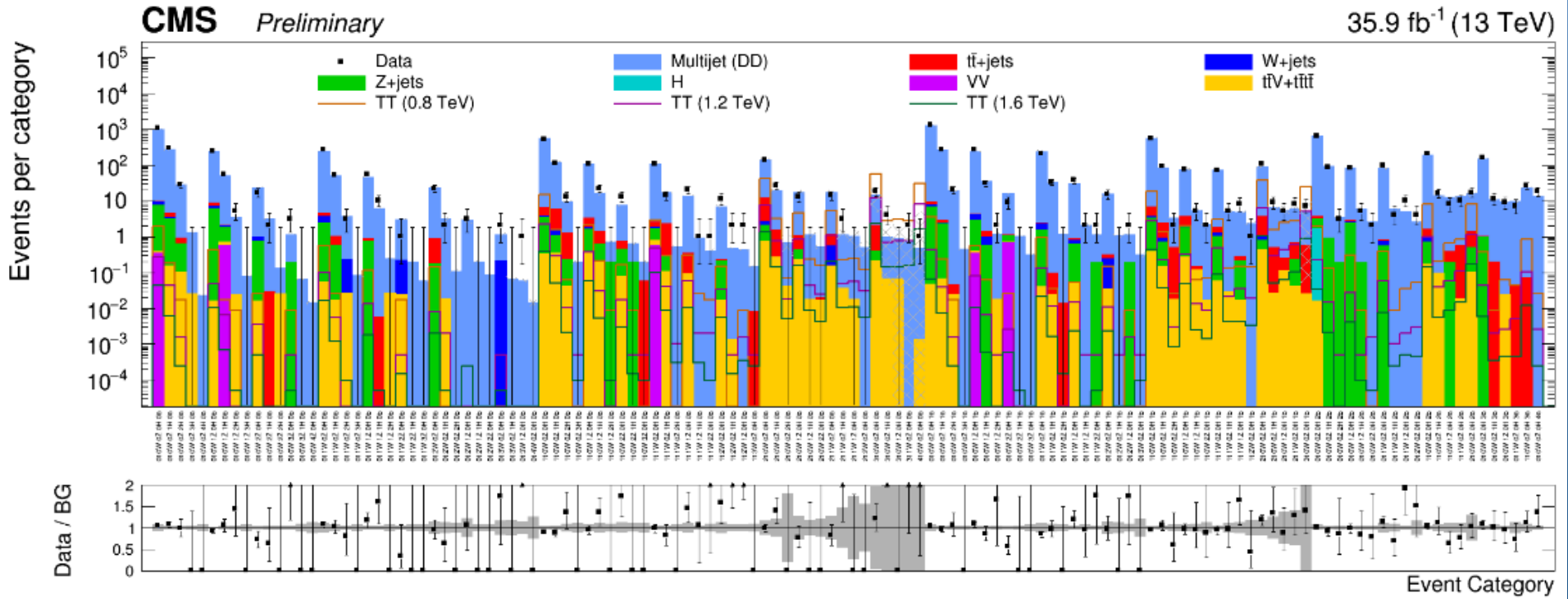
A Bit on BEST

- Boosted Event Shape Tagger
 - Classify hadronic decays of boosted heavy objects
 - Train on several kinematic distributions in boosted reference frames

- Uses a set of interesting observables
 - Fox-Wolfram Moments
 - Sphericity
 - Jet asymmetry

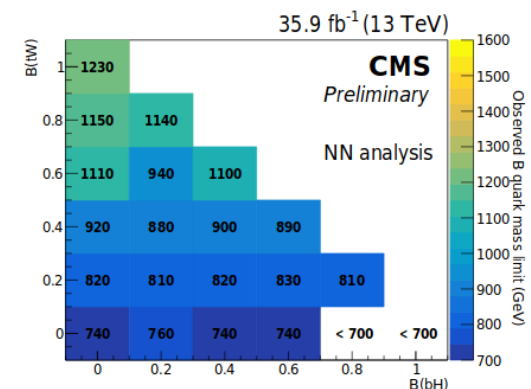
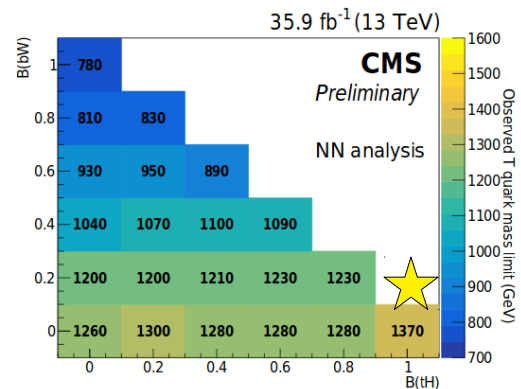
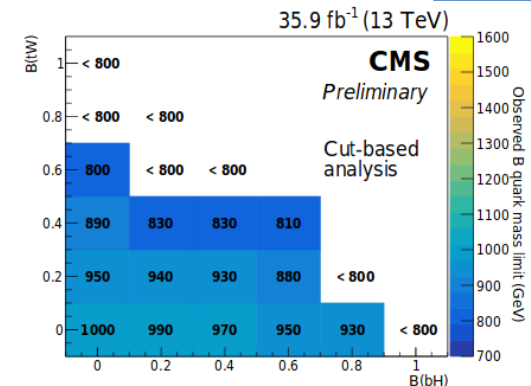
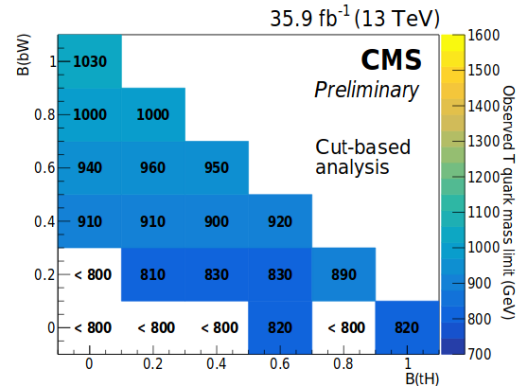


126 Different Categories



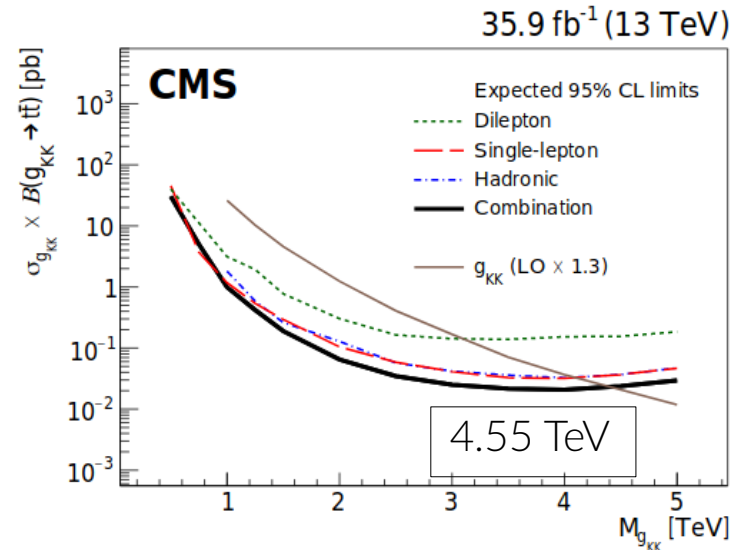
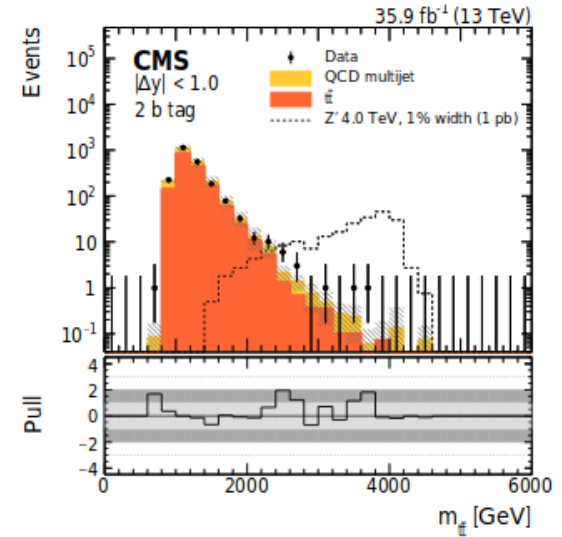
Pair VLQ Production – Fully Hadronic

- Set most stringent limits in this channel and now comparable to leptonic searches
- Compare to cut-based method
 - T: 1.03 TeV
- Compare to 8 TeV cut-based
 - T: 705 GeV



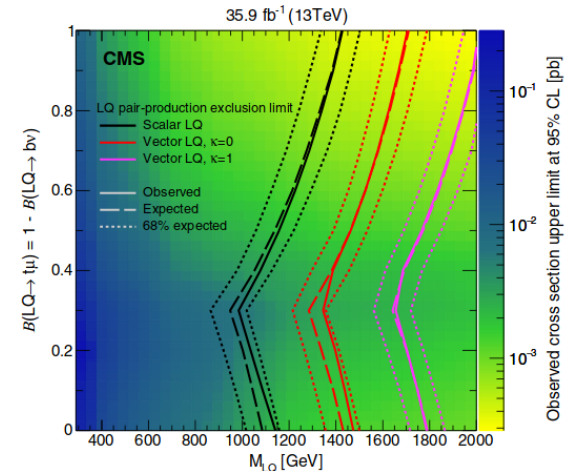
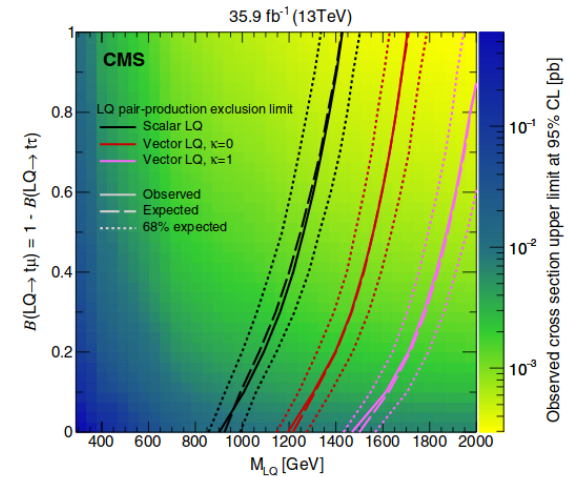
$$Z' \rightarrow t\bar{t}$$

- Considers three exclusive final states
 - Dilepton, single-lepton, and fully hadronic (from W decays)
- Background contributions change depending on the channel
 - Use simulation primarily except for QCD in fully hadronic channel
- Limits derived for leptophobic topcolor Z' and g_{KK}



Leptoquarks (LQs)

- Some of the largest measured deviations in SM predictions come from B-physics measurements and anomalous magnetic moment of the muon
 - Both can be explained by existence of LQs with large couplings to 3rd generation quarks
- One of the most recent studies was in LQ pair production to $t\mu$ (exclusively)
 - Probed all relevant couplings to LQs with charge $-1/3$ to 3rd gen quarks for first time
 - For vector LQ, excluded up to 1190 GeV for all possible combinations of branching fractions to $t\mu$, $t\tau$, and $b\nu$



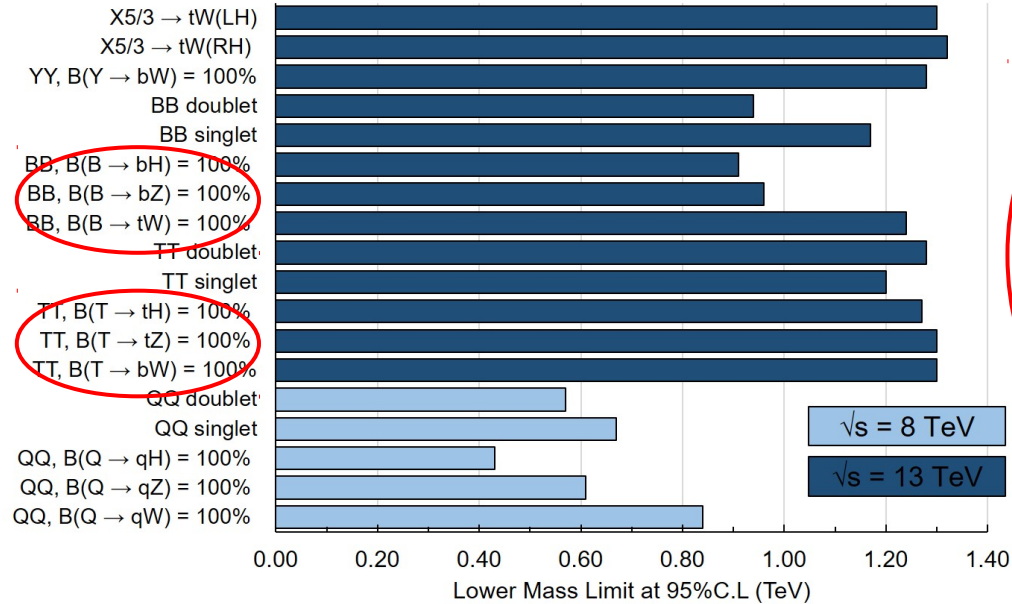
Summary

- Extensive program of searches looking for BSM coupling to 3rd generation quarks at CMS
 - Recent 2016 analysis results reviewed
- Signatures can be complex and require novel analysis techniques
 - Different analyses trying different techniques
- Exciting to learn from these and look forward to full Run II results ($\sim 137 \text{ fb}^{-1}$)!

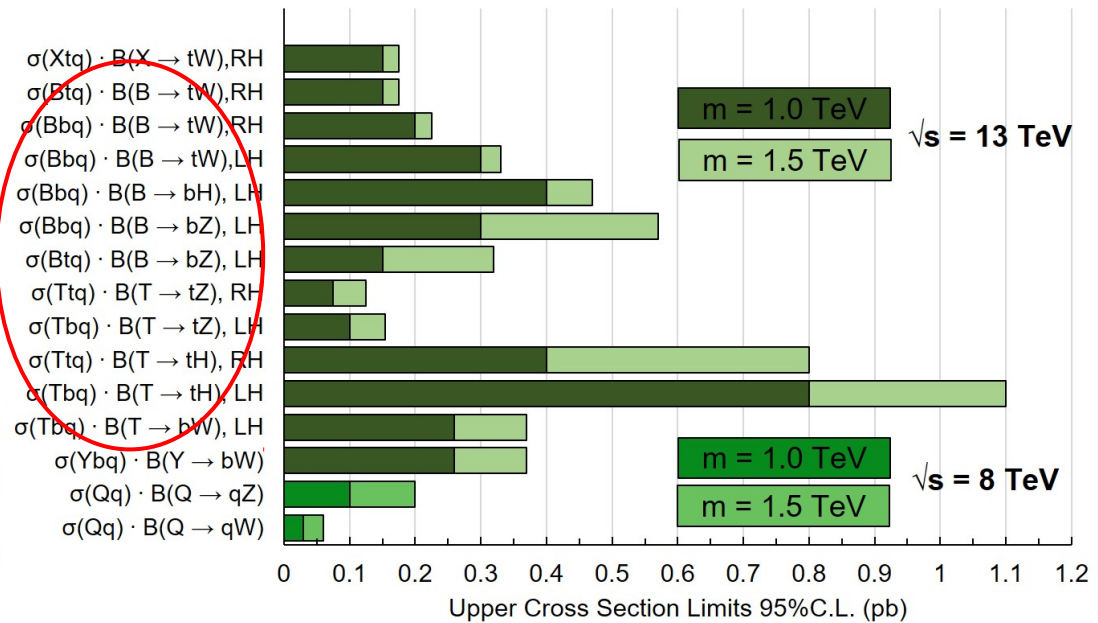
Backup

Beyond Two Generations (B2G) Program

Vector-like quark pair production

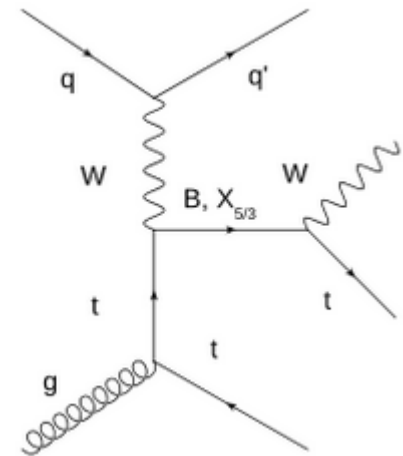
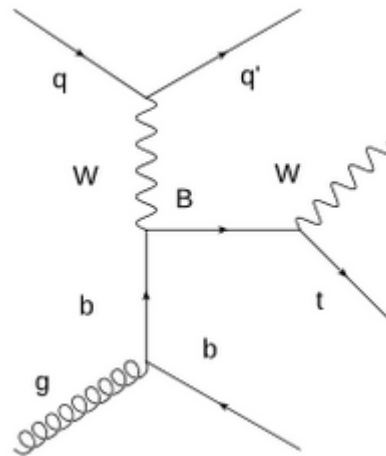


Vector-like quark single production



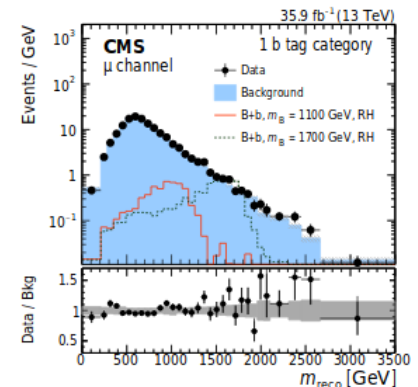
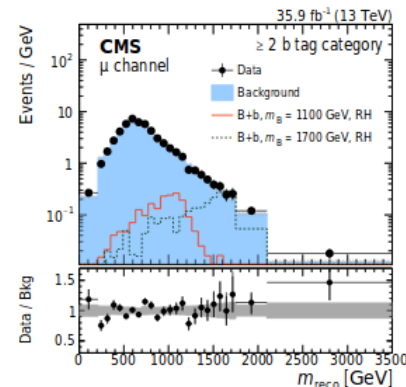
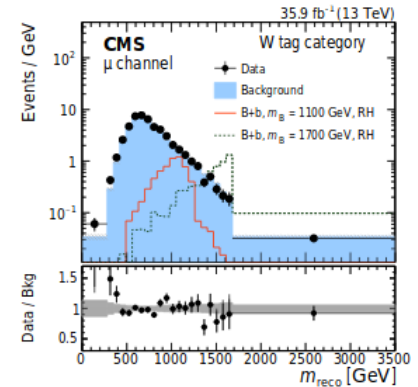
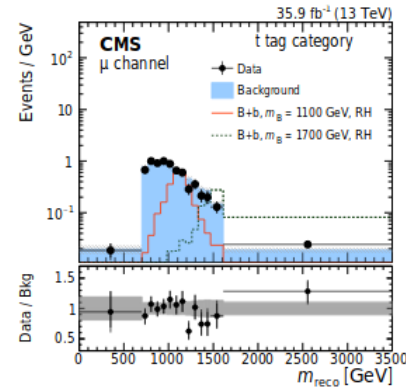
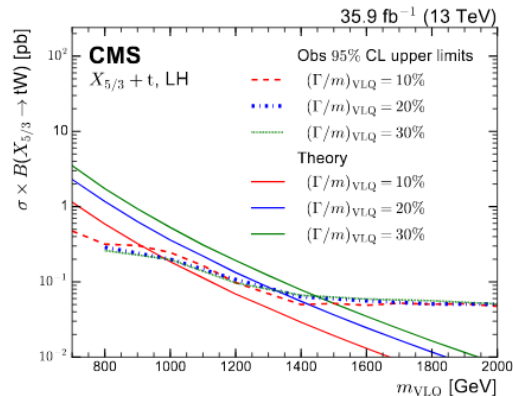
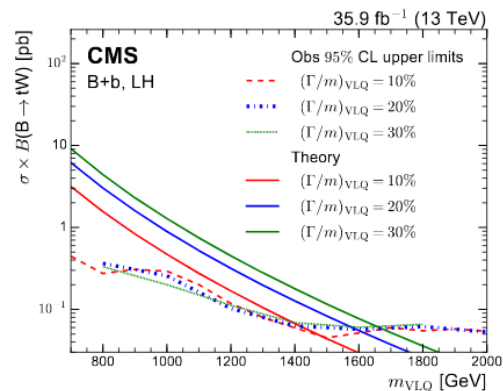
Single VLQ Production ($B \rightarrow tW$)

- Select for
 - Central: 1 AK8 jet, 2 AK4 jets, 1 lepton
 - Forward: 1 AK4 jet
- Assign jets based on maximum χ^2 of jet assignment
- Backgrounds include $t\bar{t}$, V +jets, single top, and multijet
 - Data driven estimate with selection of 0 jets in forward



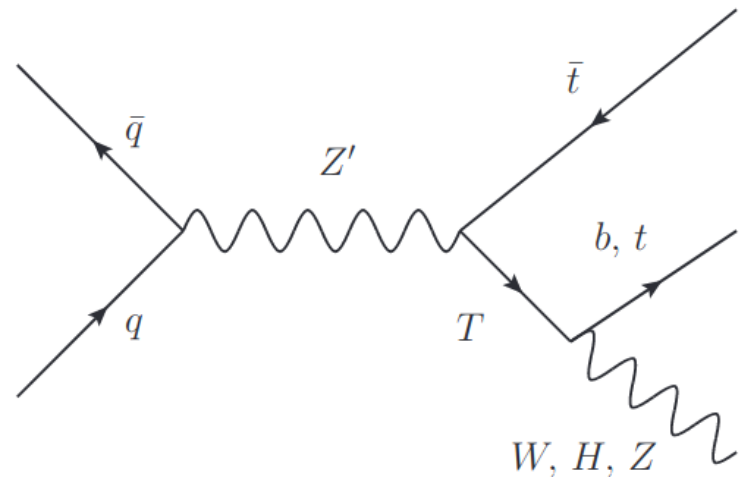
Single VLQ Production ($B \rightarrow tW$)

- Bump hunt in reconstructed mass
 - Simultaneously fit different tag categories
- Search between 700 and 2000 GeV
 - Mass exclusion up to 1.66 TeV



$$Z' \rightarrow t\bar{T}$$

- $t\bar{T} \rightarrow tZt, tHt, tWb \rightarrow$ lepton (from t) + jets
 - Two quarks, one boson
 - e +jets and μ +jets channels considered separately
- Boosted topology
 - Lepton-near-jet criteria used in place of conventional lepton isolation
 - $\Delta R(l,j) > 0.4$ or $p_{T,rel}(l,j) > 40$ GeV



$Z' \rightarrow t\bar{t}$

- Backgrounds include $t\bar{t}$, W +Jets, Drell-Yan, and single top
 - Constrained via simultaneous fit of regions categorized by number of t , H , b , and V tags
- Heavy spin-1 resonance G^*
 - $[1.5, 2.3]$ TeV, $M_T = 1.2$ TeV
 - $[2.0, 2.4]$ TeV, $M_T = 1.5$ TeV

