Search for new resonances coupling to third generation quarks at CMS

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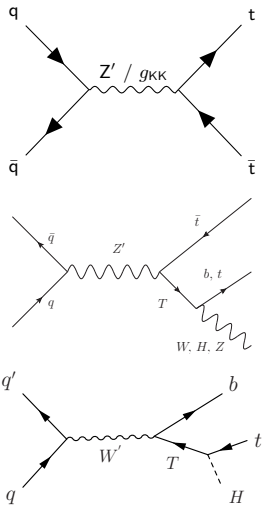
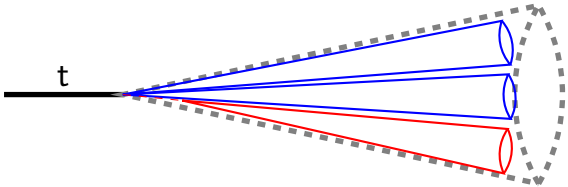
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Introduction

- third generation quarks as window to new physics
- interesting decay signatures can be used to distinguish from standard model processes
- heavy vector bosons
  - $Z' \rightarrow t\bar{t}$
- intermediate decays via vector-like partners
  - $Z' \rightarrow Tt$, $T \rightarrow tH$, tZ, bW
  - $W' \rightarrow tB$ / Tb, $T/B \rightarrow t/b + H$
- decays to bosons covered in 'Searches for heavy resonances decaying into Z, W and Higgs bosons at CMS'
- heavy resonances and vector-like quarks assumed at TeV scale



Jet substructure techniques



See talk about
'New jet tagging techniques at CMS'
for recent developments

- searches for decay of very heavy particles
  - decay products are boosted
  - subsequent decays are collimated
  - can be captured in a large R jet
- use jet substructure techniques to identify
  - groomed jet mass, e.g. softdrop mass
  - N-subjettiness: measure for a jet to have $\leq N$ subjets
  - subjet b-tagging

Softdrop criterion

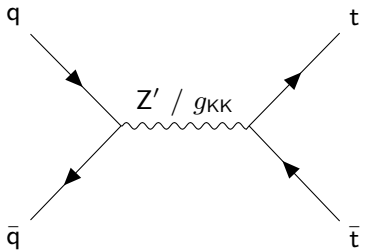
$$\frac{\min\left(p_{\mathrm{T},1}, p_{\mathrm{T},2}\right)}{p_{\mathrm{T},1} + p_{\mathrm{T},2}} > z\left(\Delta R_{1,2}/R_0\right)^{\beta}$$

N-subjettiness

$$\tau_N = \frac{1}{d}\sum_i p_{\mathrm{T,i}} \min\left(\Delta R_{1,i}, \Delta R_{2,i}, \ldots \Delta R_{N,i}\right)$$

Search for resonant tt production in proton-protoncollisions at $\sqrt{s}$=13 TeV

- Combination of searches in multiple channels
  - all hadronic
  - semileptonic
  - dileptonic
- Probing different mass-to-width hypotheses for Z′
  - probing scenarios from sharp resonant case to broad non-resonant case
  - $\Gamma/m_{Z'} = 1\%, 10\%, 30\%$
- Interpretation of signal as Randall-Sundrum gluon g_{KK} possible



Heavy $Z' \to t\bar{t}$

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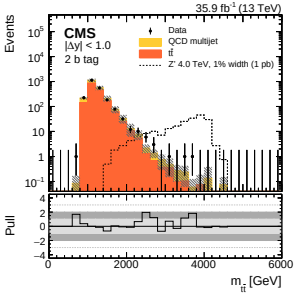
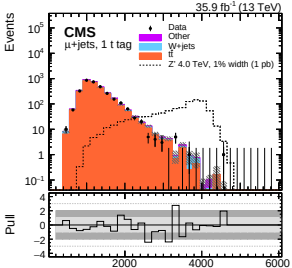
all hadronic channel

- two top tagged jets (softdrop + N-subjettiness)
- categories in $|\Delta y|$ and number of subjet b-tags
- QCD background estimated using anti-tag and probe method

semileptonic channel

- one lepton and two jets
- BDT trained to separate W+jets
- categories based on BDT score and presence of top tagged jet





Heavy $Z' \to t\bar{t}$

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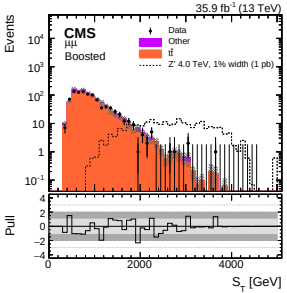
dileptonic channel

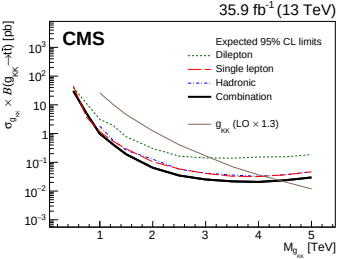
- two opposite charge leptons and two jets
- at least one b tagged jet
- categories in $\Delta R_{\text{sum}} = \Delta R(l_1, j) + \Delta R(l_2, j)$
- S_{T} used as sensitive variable

$$S_{\text{T}} = \sum_{i=1}^{\text{jets}} p_{\text{T},i} + \sum_{i=1}^{\text{leptons}} p_{\text{T},i} + p_{\text{T}}^{\text{miss}}$$

combination

- combination of three statistically independent channels
- enhanced sensitivity compared to individual searches





Heavy $Z' \to t\bar{t}$

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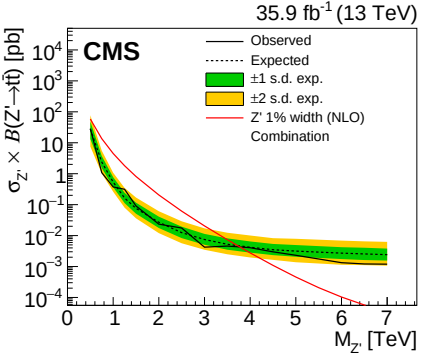
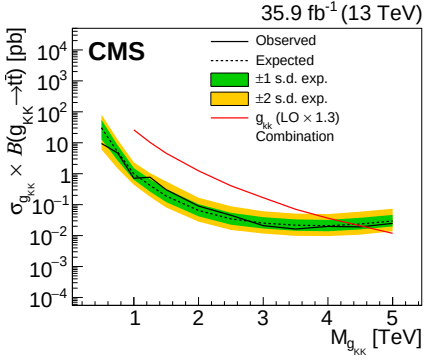
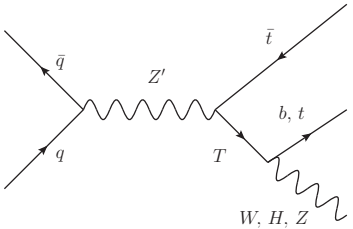




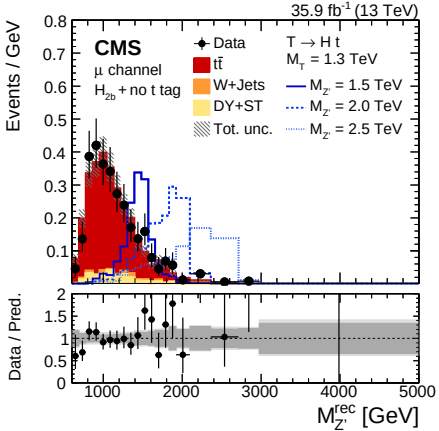
Signal	mass limit [TeV]
Z' (1% width)	3.8
Z' (10% width)	5.25
Z' (30% width)	6.65
g_{KK}	4.55

Search for a heavy resonance decaying to a top quark and a vector-like top quark in the lepton+jets final state in pp collisions at $\sqrt{s} = 13$ TeV

- exploring new models with couplings to vector-like quarks
- complementing 'Searches for vector-like quarks at CMS'
- multiple categories covering different possible decay modes (T $\rightarrow$ bW, tZ, tH)
  - optimized for T $\rightarrow$ tZ, tH
- jet tagging of boosted W/Z/H
- signal interpreted in extra dimensional and composite benchmark models



- categories based on softdrop mass, N-subjettiness ratios and subjet b-tags
  - Higgs tag with 2 subjet btags H_{2b} } T → tH
  - Higgs tag with 1 subjet btag H_{1b}
  - Z/W tag T → tZ / bW
- sub categories based on presence of top tagged jet
- use reconstructed Z′ mass M_Z' as sensitive variable
- $t\bar{t}$ and W+jets backgrounds constrained using dedicated control regions
  - invert softdrop mass criteria of Higgs and Z/W tag
  - 0 or 2 b-tags



Heavy $Z' \to Tt$

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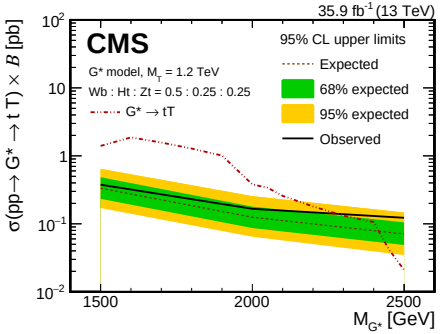
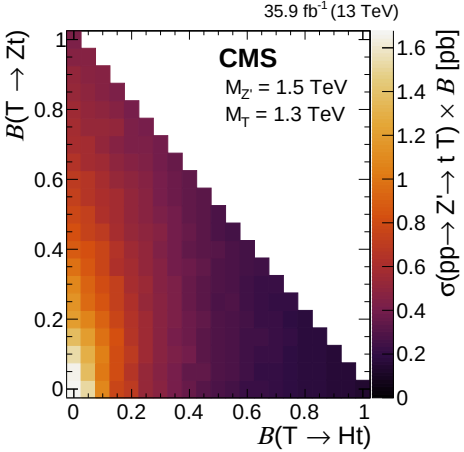
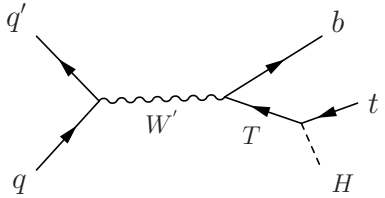


G^*	mass limit [TeV]
$m_T = 1.2$ TeV	[1.5, 2.3]
$m_T = 1.5$ TeV	[2.0, 2.4]

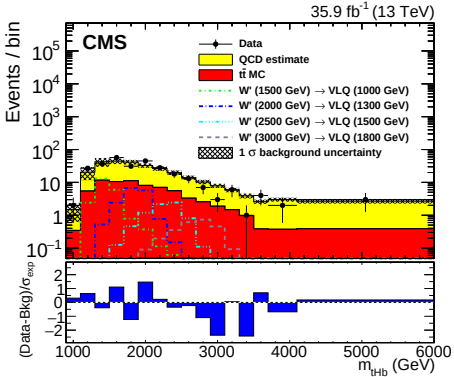


Search for a W boson decaying to a vector-like quark and a top or bottom quark in the all-jets final state

- target T/B → t/b + H decay mode
- jet tagging of boosted t and H
- scan different scenarios of $m_{W'}/m_{VLQ}$



- require top, Higgs and b tagged jets
  - top tagging: softdrop, N-subjettiness and subjet b-tag
  - Higgs tagging: softdrop and double b-tag
- use reconstructed W′ mass M'_{W} as sensitive variable
- control regions defined using anti-tags
- QCD background estimated from data in control regions



Heavy W′ → tB/Tb

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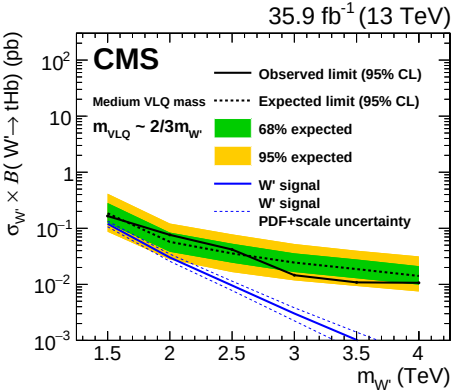
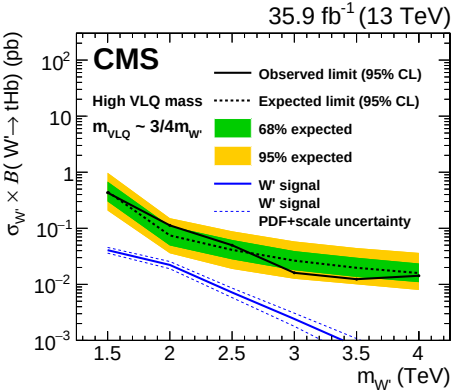
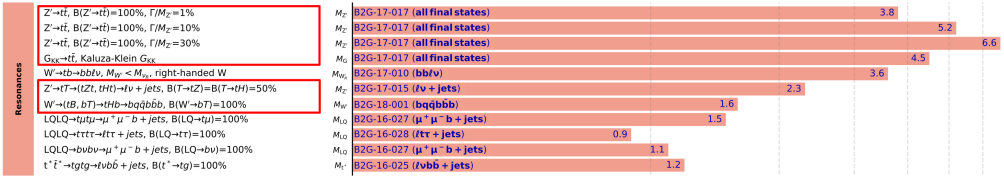




Summary

- combination of $Z' \to t\bar{t}$ searches
- exploring intermediate decays via vector-like quarks
  - search for $Z' \to Tt$
  - search for $W' \to tB/Tb$
- only part of the full picture of searches for heavy resonances coupling to third generation of quarks



Outlook

- Looking forward to new results exploring the combined datasets of 2016, 2017 and 2018
- Exploring new tagging algorithms and jet substructure techniques