Searches for New Resonances Decaying to Third Generation Quarks at CMS

Petar Maksimovic
Johns Hopkins

PHENO 2017

The layout of this talk

- Many BSM models predict such resonances

  - composite Higgs, warped extra dimensions, etc.

- Many results to cover, focus on recent results with top quark(s) in final state

- Channels with large top BR: $t \to b\nu\ell$ and $t \to b(q\bar{q}')$

- $Z' \to t\bar{t}$ (semileptonic + hadronic)   B2G-16-015

- $W' \to tb$ (semileptonic + hadronic)   B2G-17-010   B2G-16-019

- $Z' \to tT' \to t(bW)$ (hadronic)   B2G-16-013

Z' → ttbar

- Three boosted channels:

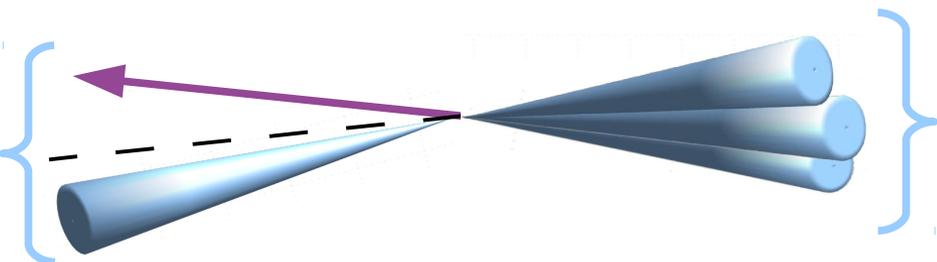 - Dileptons

    lepton + b jet
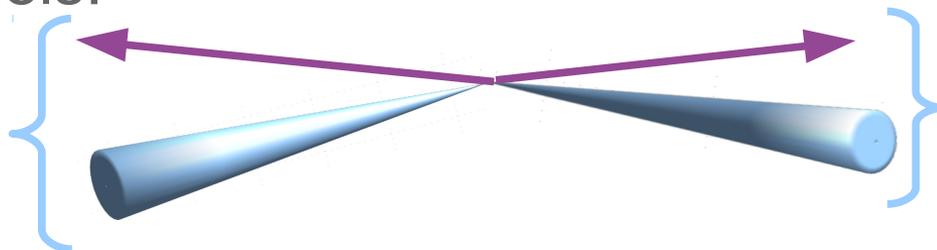
    lepton + b jet
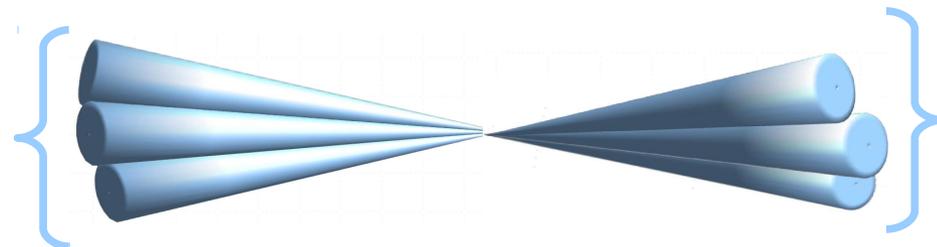
  - Semileptonic

    lepton + E_T^{miss} + b jet

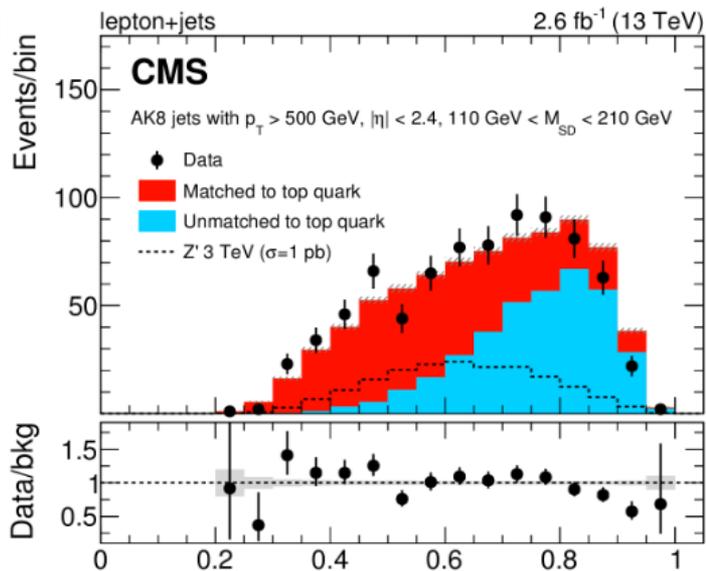   merged into a single top jet
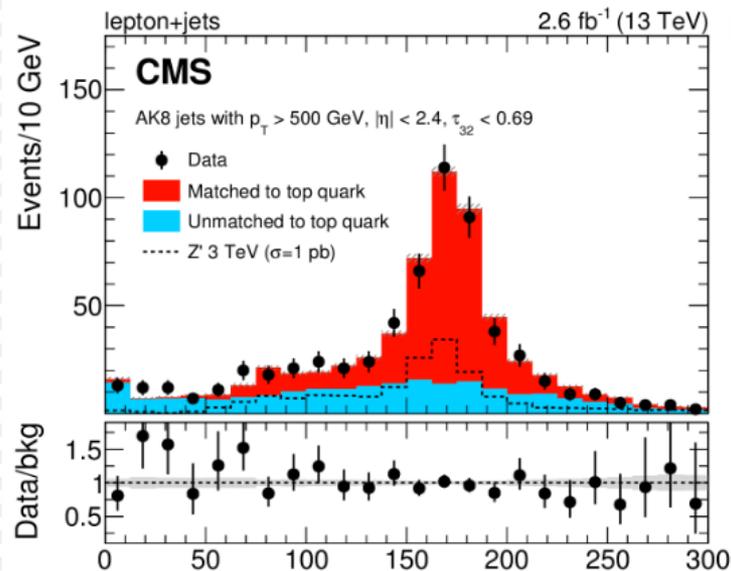
  - All-hadronic

    top jet

    top jet

- Isolation specially handled

- Top tagging tools are by now quite mature

Z' → ttbar: top tagging variables
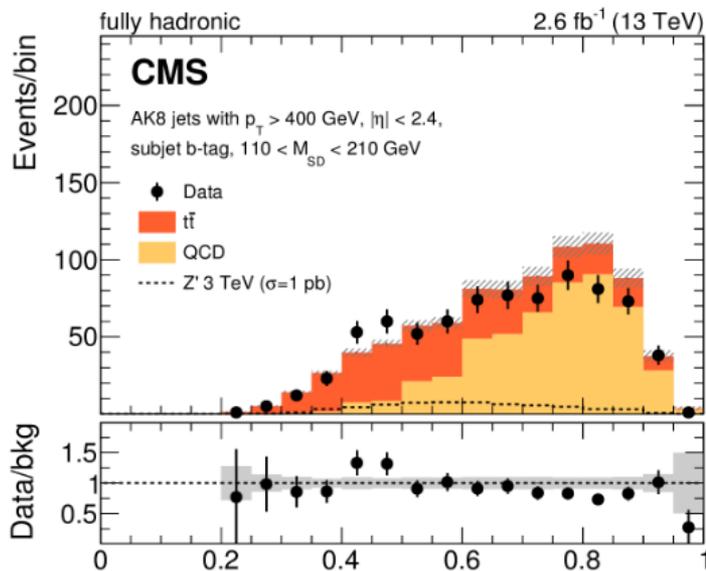
Semileptonic

Fully hadronic

N-subjettiness τ_{32}
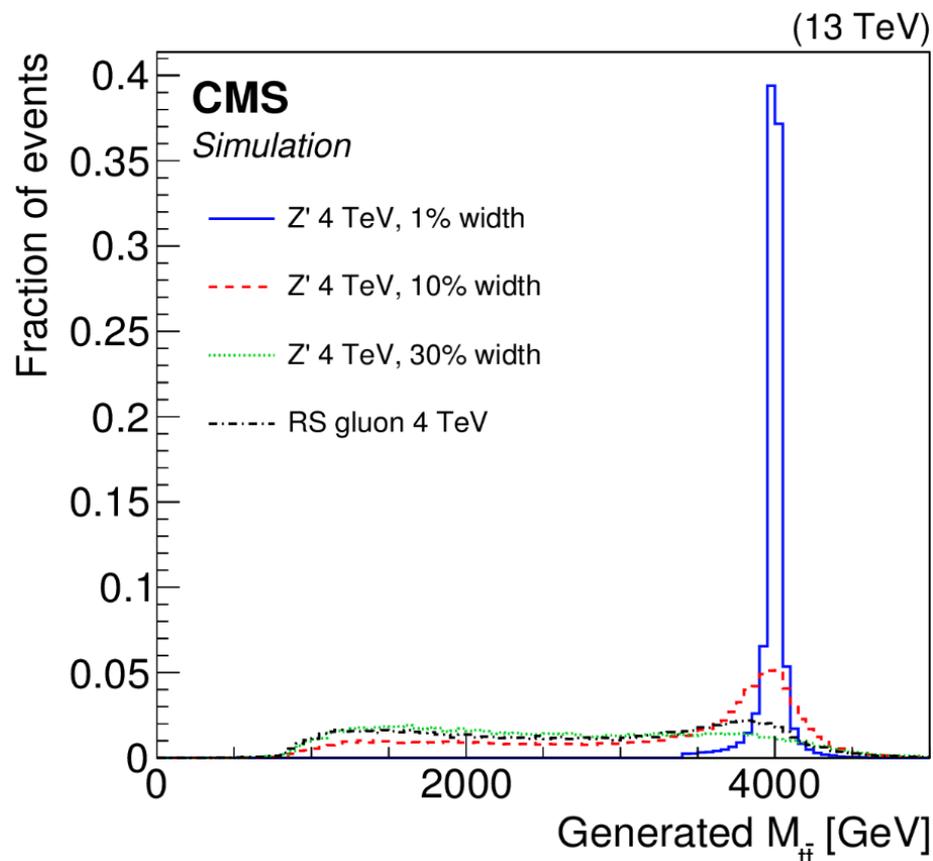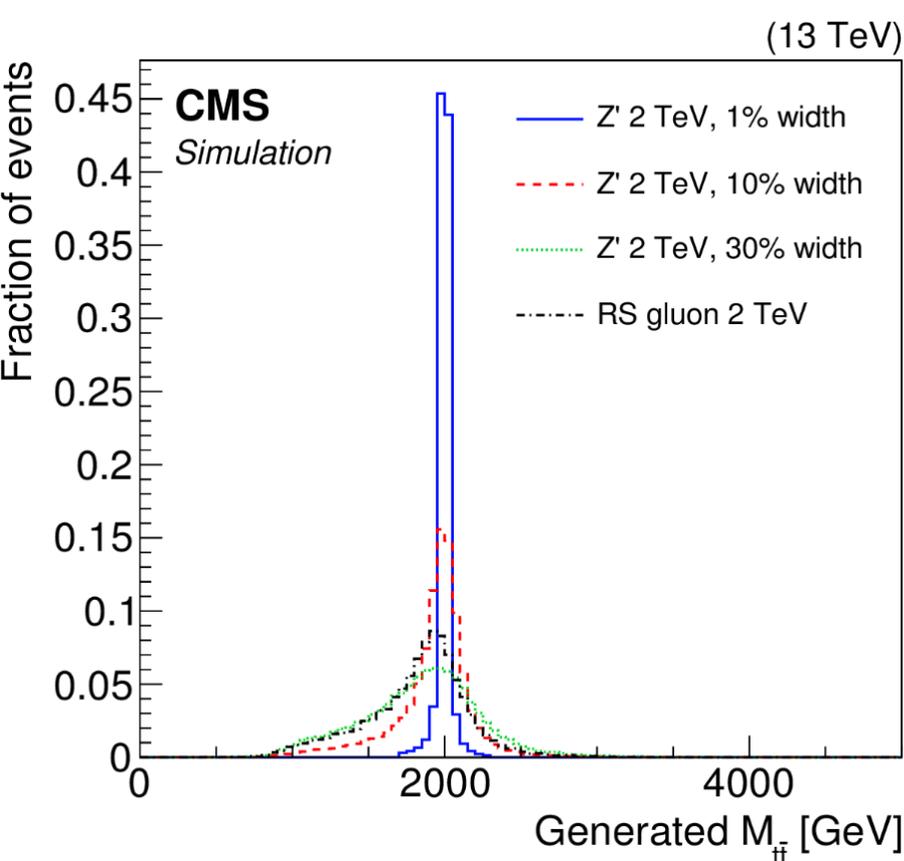
Top Jet Soft Drop mass
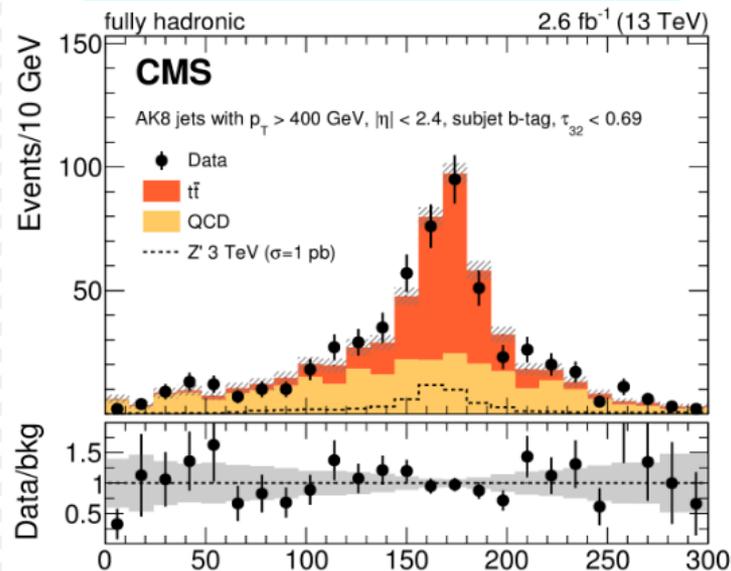
Z' → ttbar: signal shapes

- At high Z' masses, large widths result in very long tail
  - (may need to rethink strategy for higher masses)

B2G-16-015
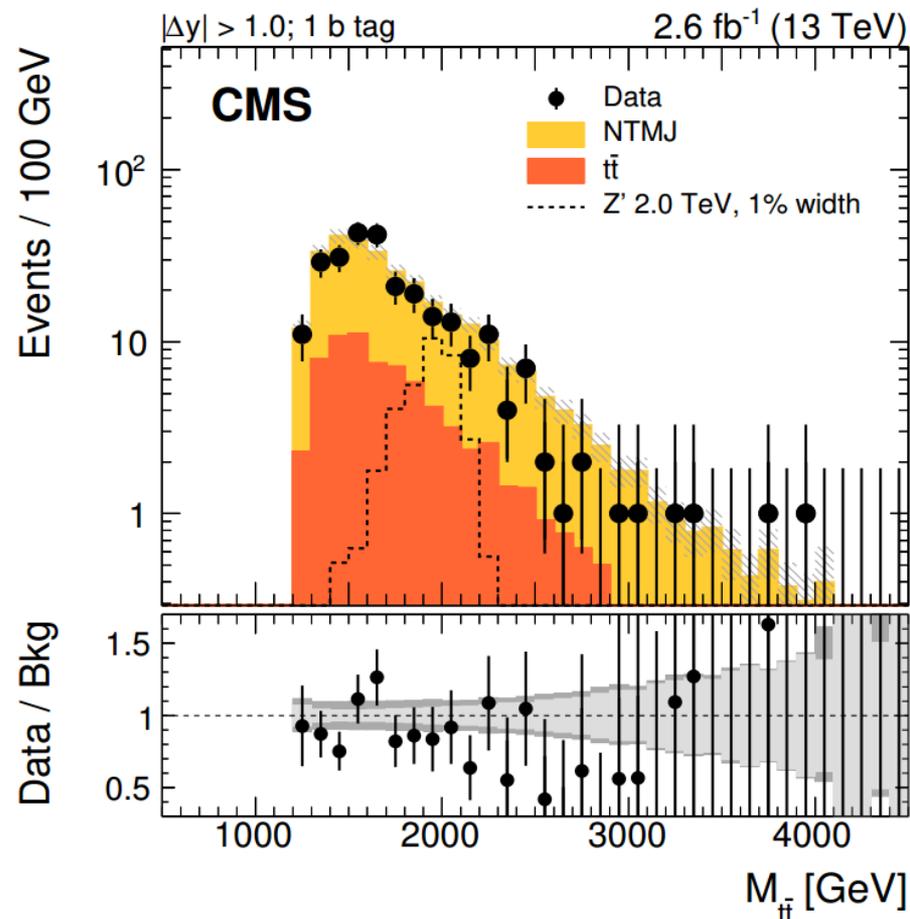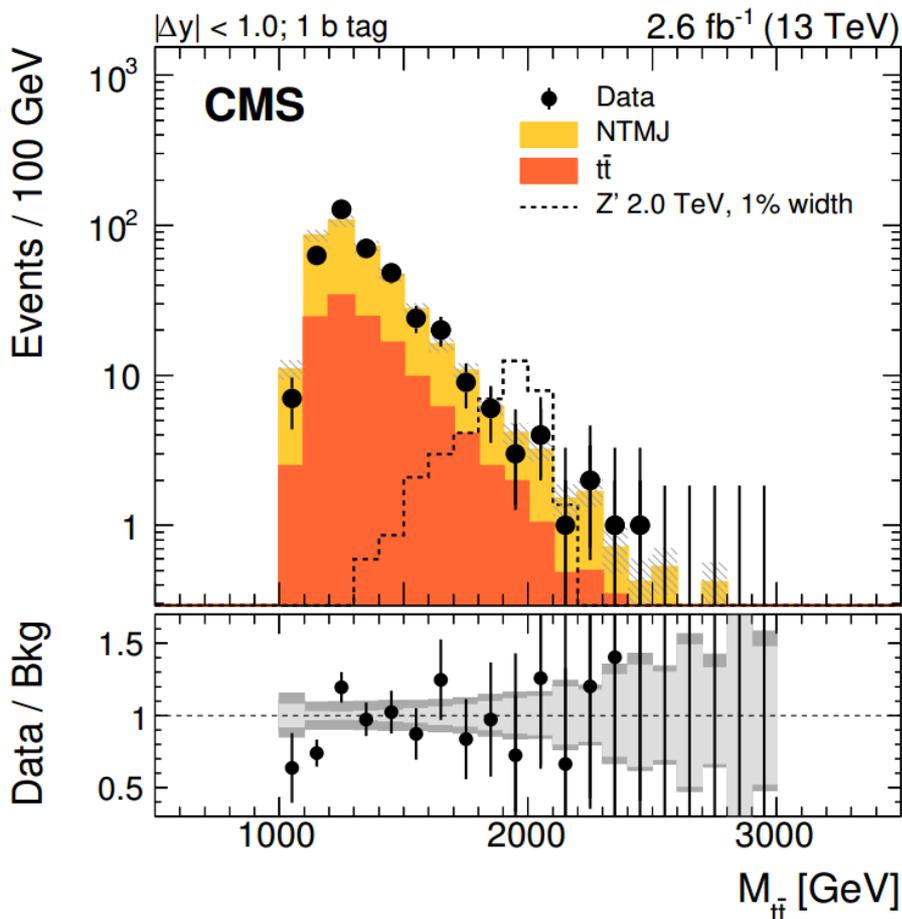
Z' → ttbar: hadronic

- Divided according to # of subjet b-tags (0,1,2), and $\Delta y_{t\bar{t}}$
- Main bkg: QCD (not-top multijet), derived from data

B2G-16-015

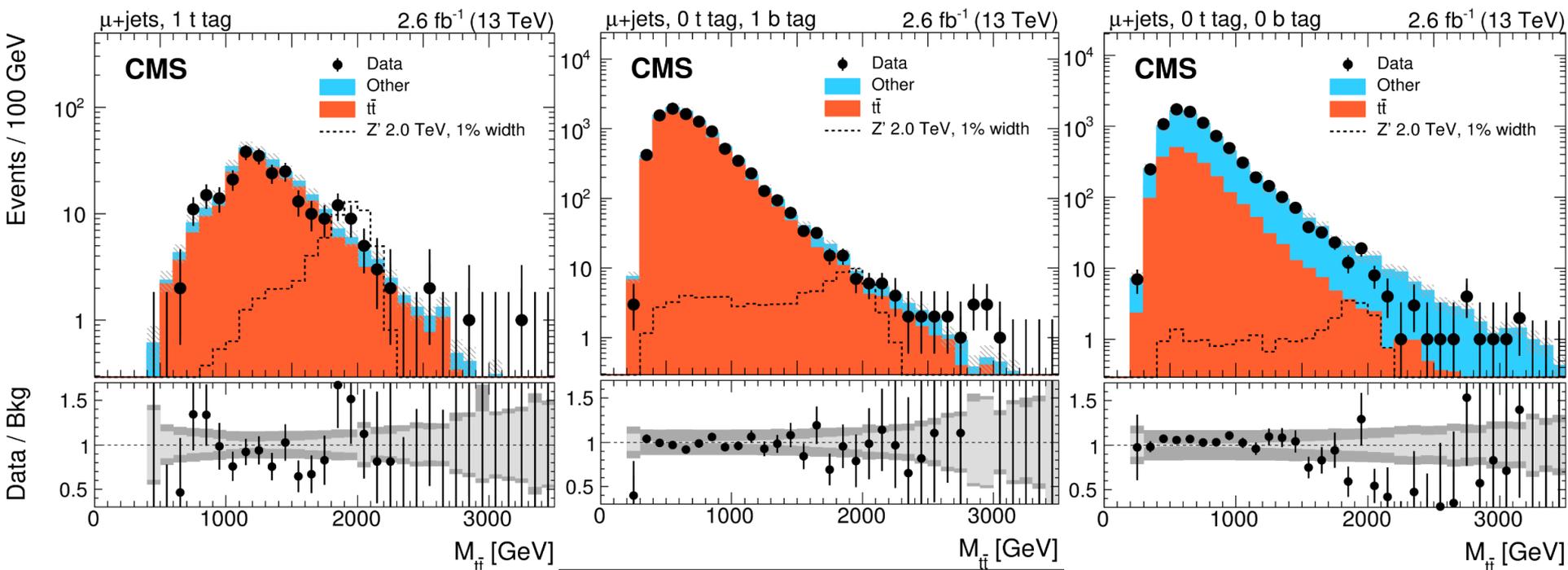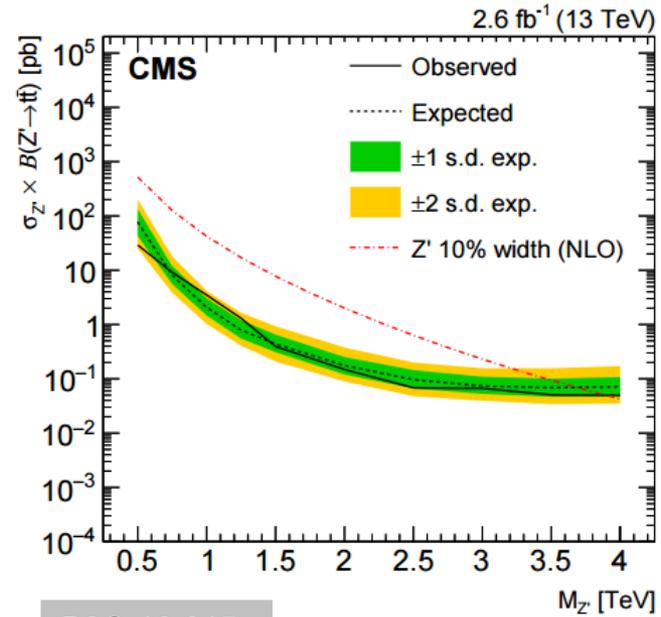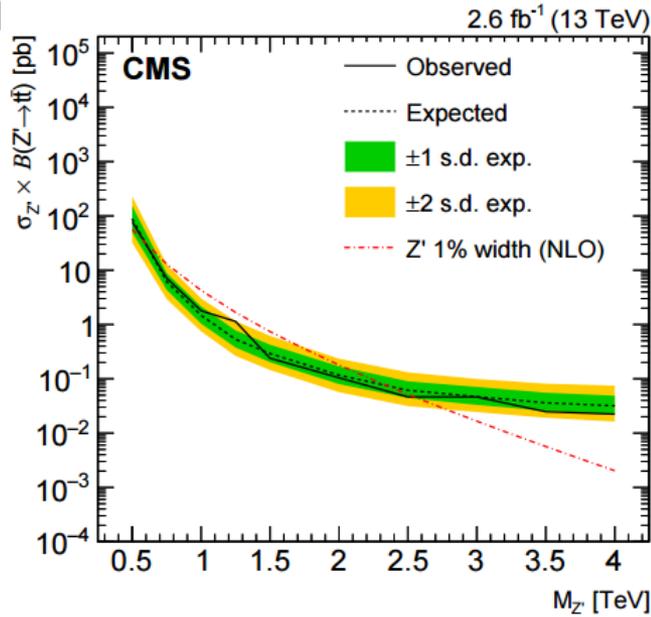# Z' → ttbar: semileptonic

- Divided into e and μ, and

  according to # of b-tags and top tags
- Main bkg: $t\bar{t}$:
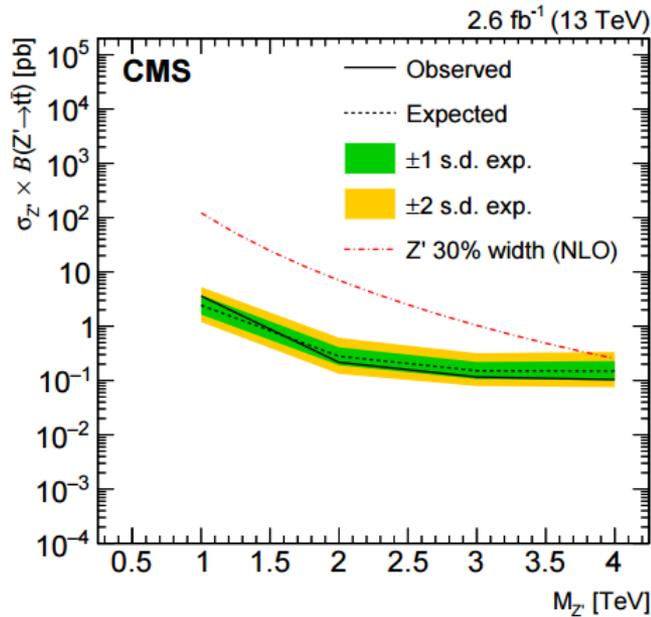 - template from simulation floating in final fit

B2G-16-015

Z' → ttbar: limits

Narrow

Wider

Very Wide

RS gluon

B2G-16-015
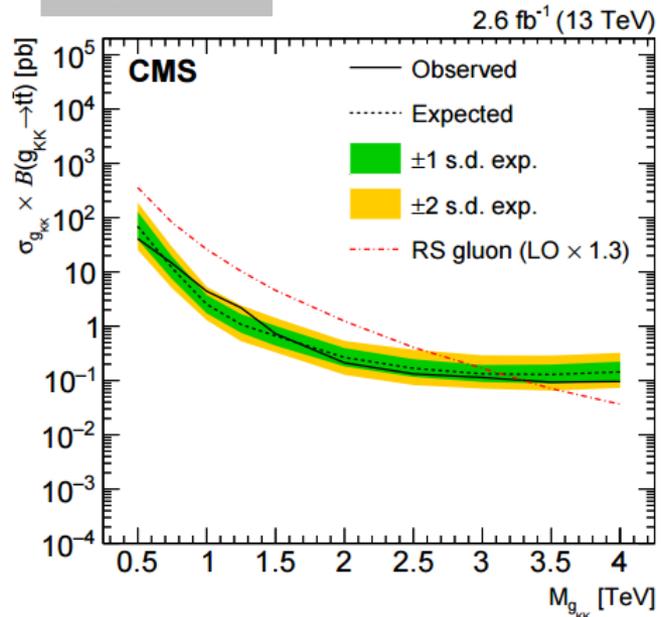
W' → tb

- Semileptonic channel

- All-hadronic channel

energetic b jet

top jet

energetic b jet

lepton + E_T^{miss} + b jet
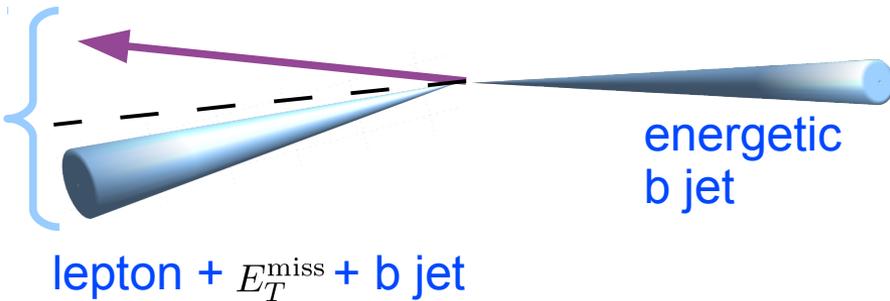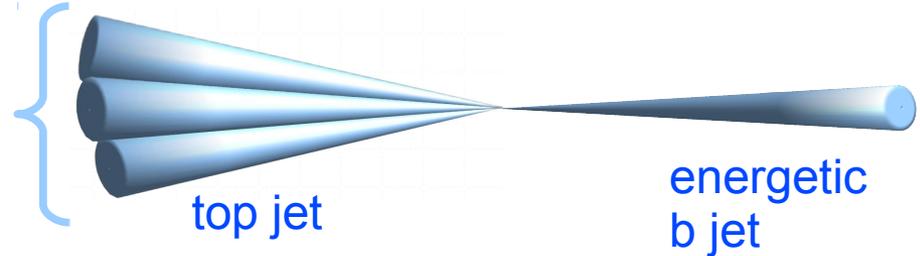
- Similar to $Z' \to t\bar{t}$, except only one boosted top

  - trickier (larger QCD background)

- Hadronic: b-tagged jet + top-tagged jet

  - QCD est. from data

2.55 fb^{-1} (13 TeV)

CMS
Preliminary

B2G-16-009

- data
- QCD
- $t\bar{t}$
- Single top
- 1 σ background uncertainty
- W'$_R$ at 1400 GeV
- W'$_R$ at 2000 GeV
- W'$_R$ at 2600 GeV

Counts per 100 GeV

(Data-Bkg)/σ

M_{tb} (GeV)

W' → tb semileptonic: improvements

- Finer event classification

  - Type B:
  $$p_T^{\text{top}} > 650 \text{ GeV}$$
  $$p_T^{j1+j2} > 700 \text{ GeV}$$

  ℓ

  energetic b jet

  E_T^{miss}

  "top"

  b jet

  B2G-17-010

  - Type A = ($p_T^{\text{top}} > 250$ GeV & $p_T^{j1+j2} > 350$ GeV) but !Type B
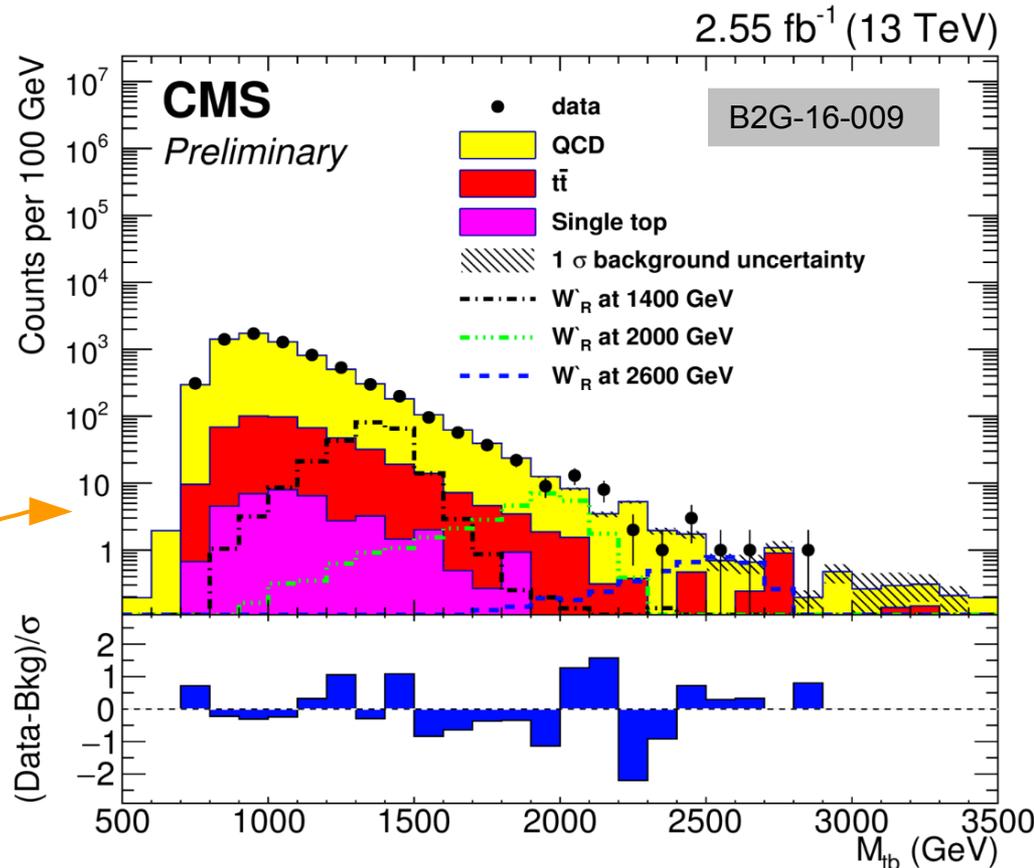
W' → tb

- Hadronic:

  - limits on 2015 data similar to Run 1
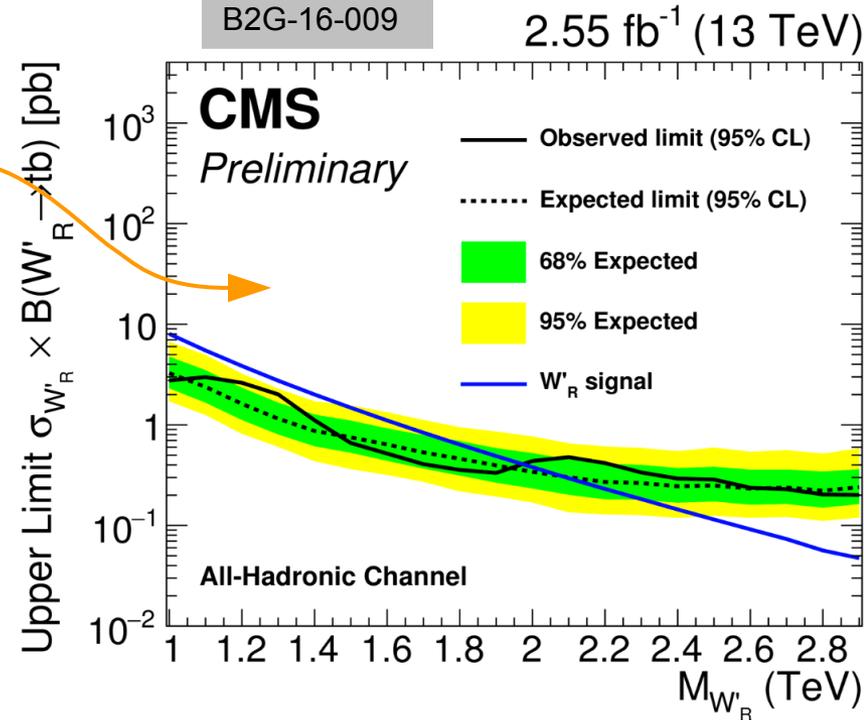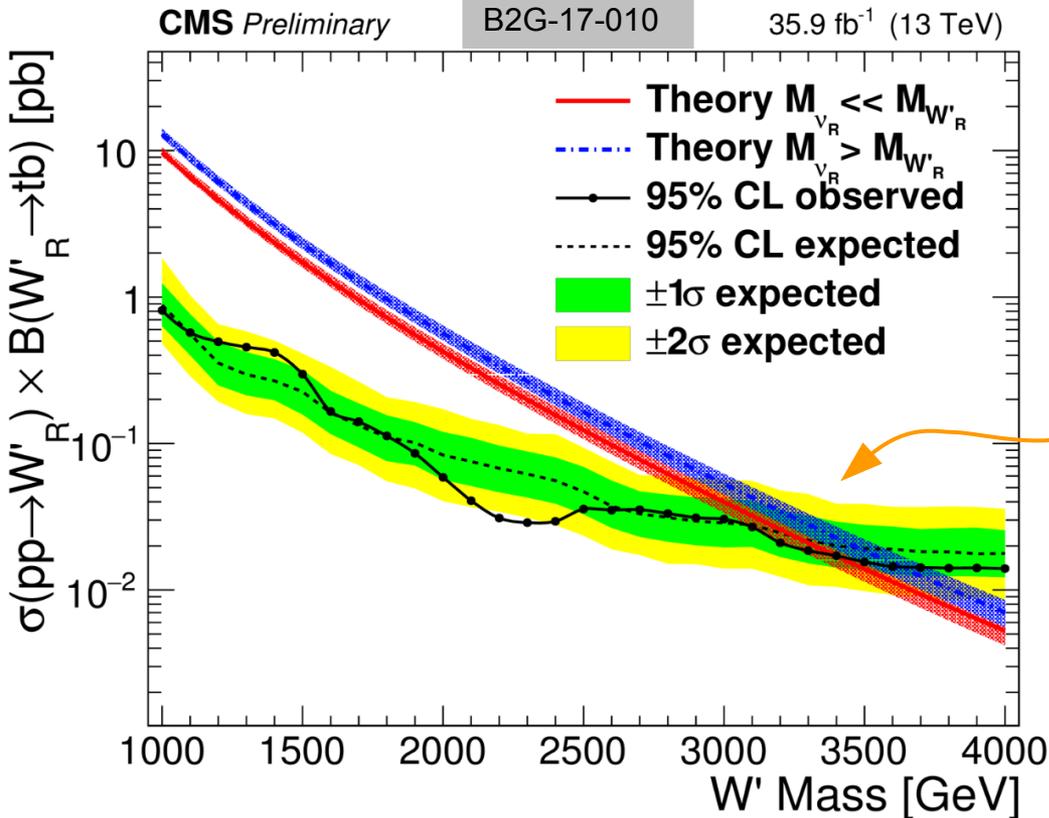
- Semileptonic:

  - full 2016 dataset
  - improved analysis strategy
  - limits at ~ 3.3-3.5 TeV !

W' – generalized couplings

$$\mathcal{L} = \frac{V_{q_i q_j}}{2\sqrt{2}} g_w \bar{q}_i \gamma_\mu (a^R_{q_i q_j}(1 + \gamma^5) + a^L_{q_i q_j}(1 - \gamma^5)) W' q_j + \text{H.c.}$$

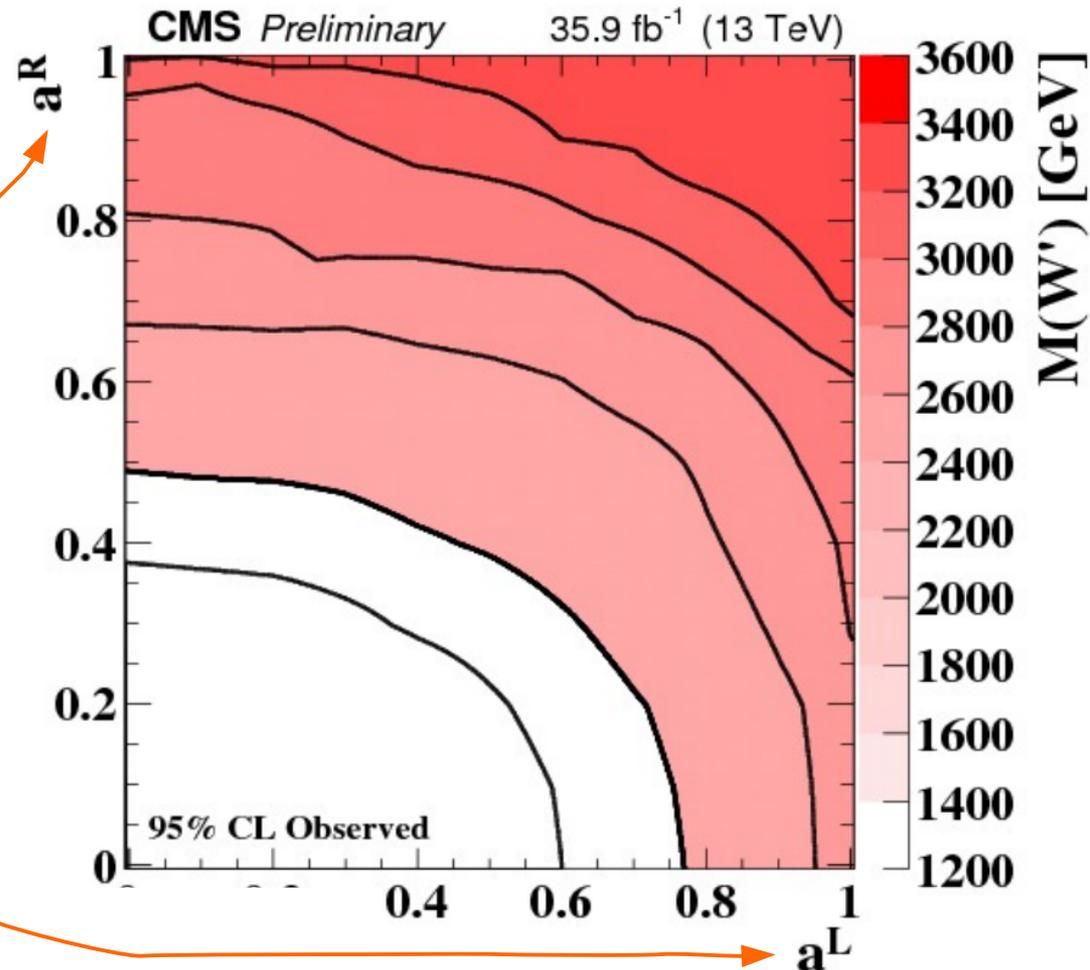- Both W'_R and W'_L could contribute

- *Mass* limits can be interpreted as a function of both couplings: $a^R_{tb},\ a^L_{tb}$

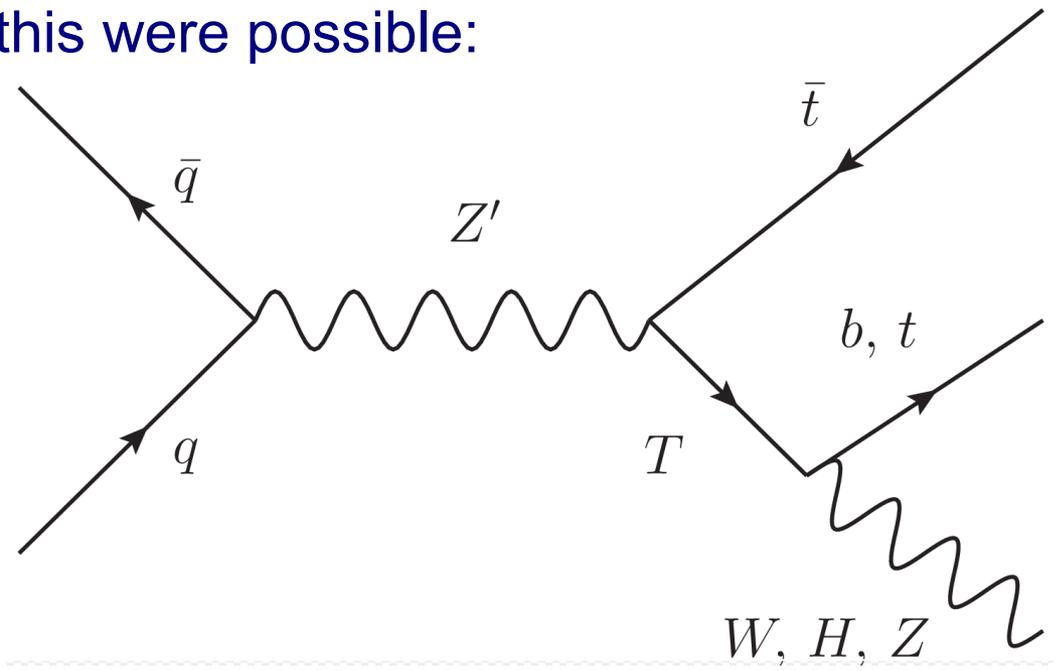# Z' → tT'

- But what if there are 3rd generation VLQ?

  - i.e. if something like this were possible:

  - e.g.,

$$Z' \to tT' \to t(bW)$$
$$\to t(tZ)$$
$$\to t(tH)$$

- If kinematically allowed, $Z' \to tT'$ would dominate $Z' \to t\bar{t}$

- There's a loophole in $Z' \to t\bar{t}$ limits!

Z' → tT' → t(bW) reconstruction

- "Mercedes sign" topology:

Large
T' mass
(kills $t\bar{t}$)

top jet:
- large R
- high pt
- top mass window
- τ_{32} (3-prong)

b-tagged
jet

W jet:
- large R
- W mass window
- τ_{21} (2-prong)

- Divide events by # of
  subject b-tags in top jet =
  total 1 or 2

Z' → tT' : also capture ttH and ttZ

- "Mercedes sign" topology:

Large T' mass (kills $t\bar{t}$)

top jet:
- large R
- high pt
- top mass window
- τ_{32} (3-prong)

b-tagged jet

- Divide events by # of subject b-tags in top jet = total 1 or 2

W jet:
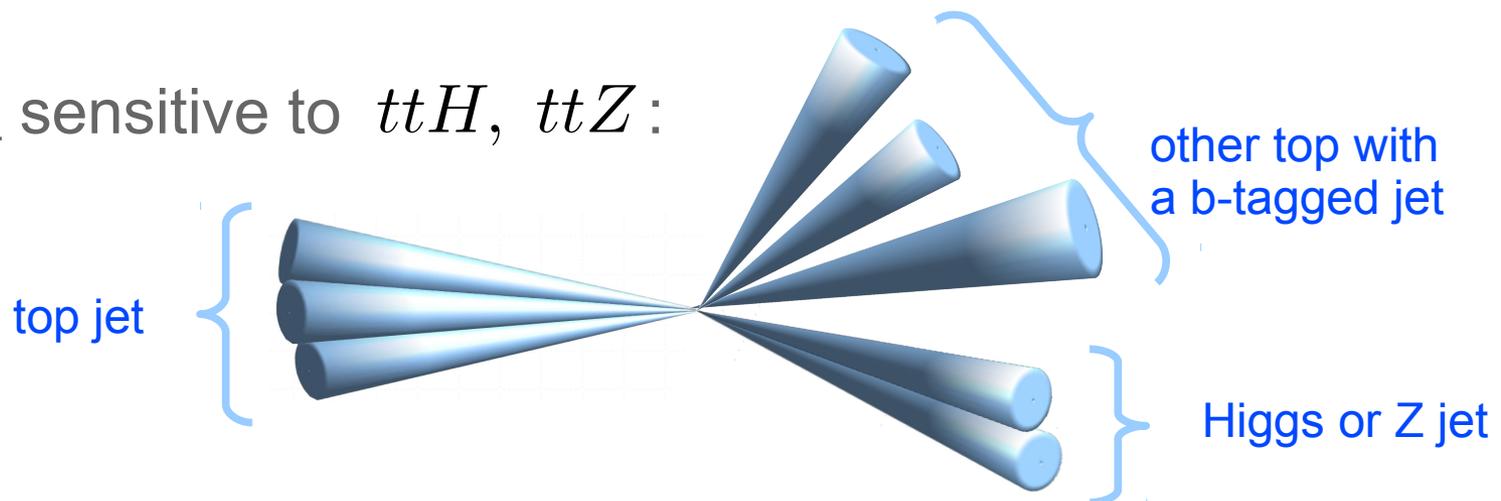- large R
- W mass window
- τ_{21} (2-prong)
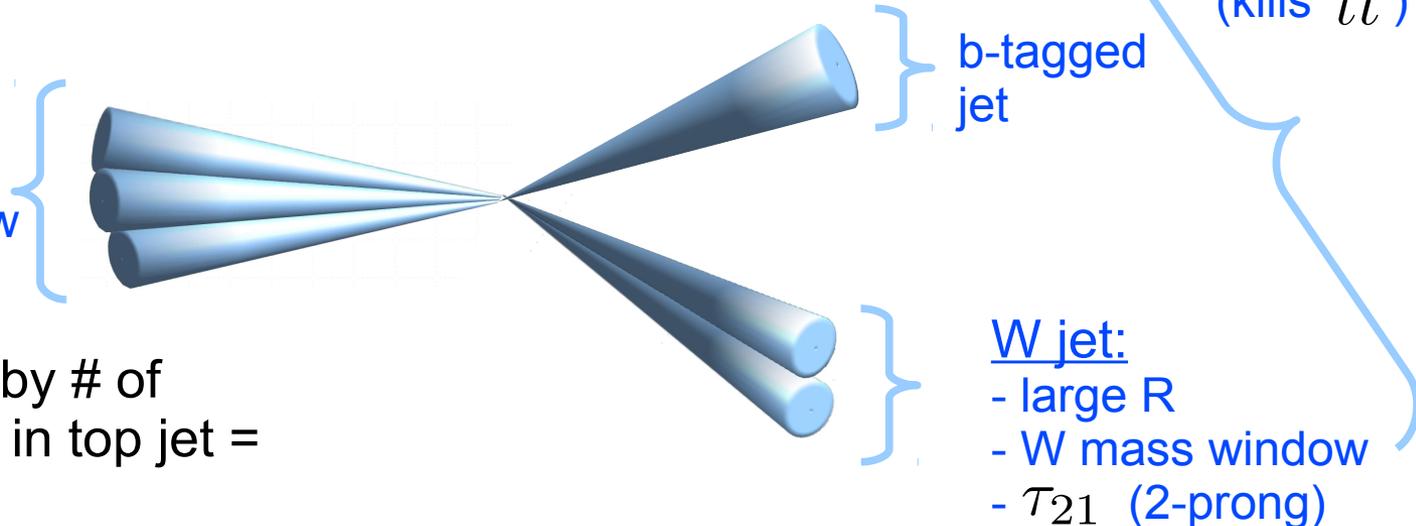
- <u>Also</u> sensitive to ttH, ttZ :

other top with a b-tagged jet

top jet

Higgs or Z jet

Z' → tT' : data in signal region
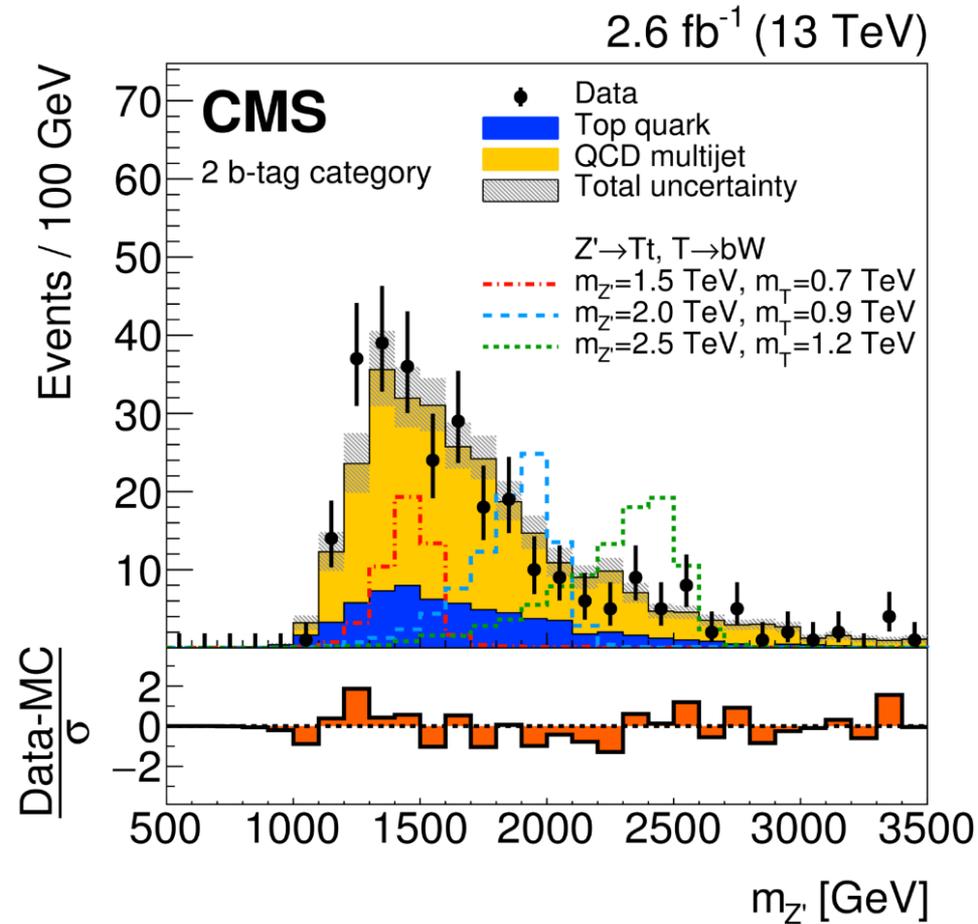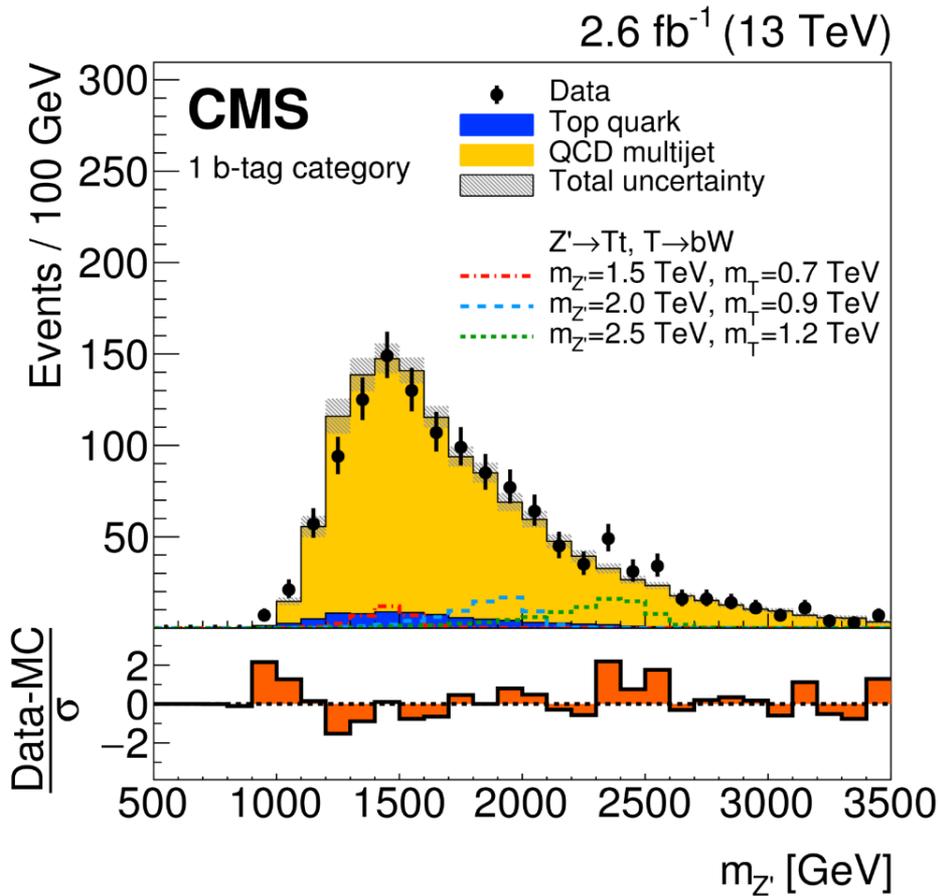
- 2b-tag category dominates: ~ same signal efficiency, but much less background

Z' → tT' : limits for various Z' and T' masses
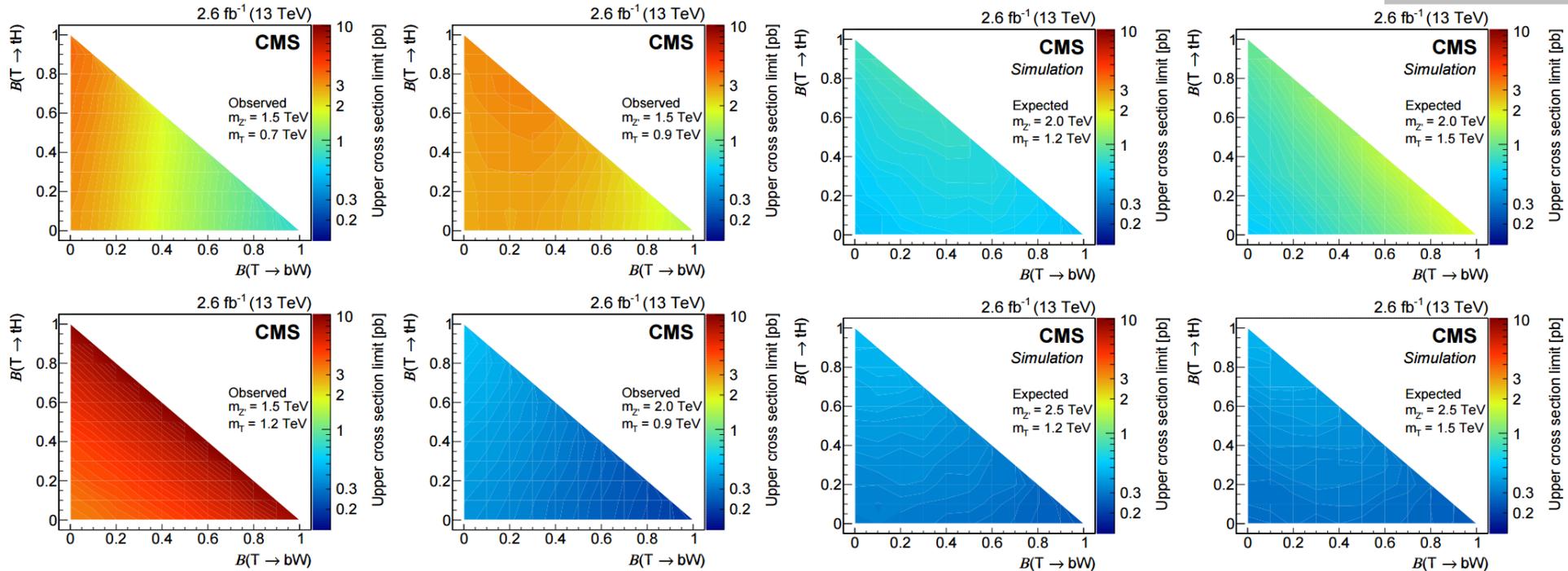
- Limits in 4D! Each plane is $\mathcal{B}(T \to bW)$ $vs.$ $\mathcal{B}(T \to tH)$
  - $\mathcal{B}(T' \to tZ) = 1 - \mathcal{B}(T \to bW) - \mathcal{B}(T \to tH)$

B2G-16-013

- Low Z' masses limits worse (higher): lower top jet boost
- Worst for small $m_{Z'} - m_{T'}$ (top barely boosted!)
- bW corner more sensitive

Z' → tT' : limits for fixed T' mass (1.2 TeV)

- Model 1: Composite Higgs
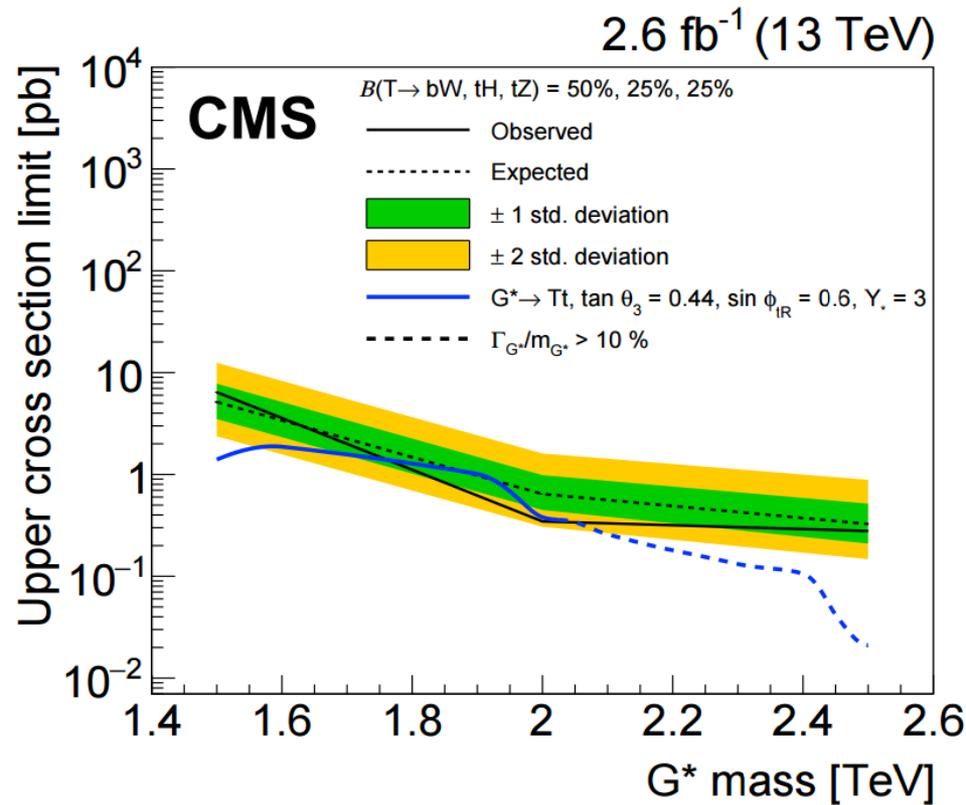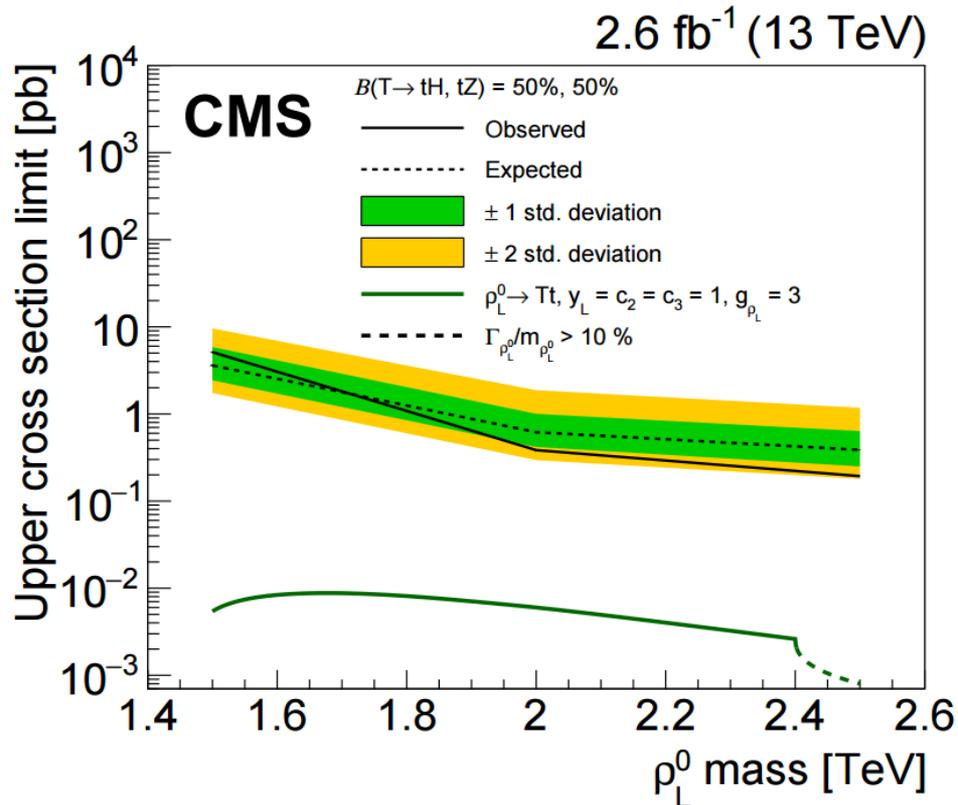 - $Z' \equiv \rho_L^0$
  - T' branching fractions:

$$bW : tH : tZ = 0\% : 50\% : 50\%$$

- Model 2: Warped Extra Dim.
  - $Z' \equiv G^*$ (KK gluon)
  - T' branching fractions:

$$bW : tH : tZ = 50\% : 25\% : 25\%$$

Conclusions

- CMS has a broad program of searches for $t\bar{t}$, and tb resonances

- Traditional analyses performing well

- Improvements (e.g. W' $\to$ tb) still possible and could yield large benefits

- New searches!
  - Z' $\to$ tT'
  - many similar channels interesting

BACKUP MATERIAL

Searches tt, tb, tT resonances, ...

Z' → tT' : background estimate

- Two categories: 1b-tag + 2b-tags

- Simulation: