Search for new resonances coupling to third generation quarks at CMS

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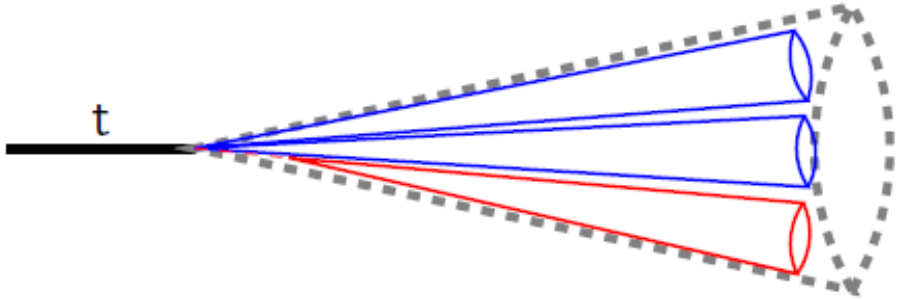
Introduction



Searching for heavy particles

- Their decay products are boosted
  - Subsequent decays are collimated, e.g. top quarks → can be captured in a jet with a large solid angle
  - Peculiar signature of investigated decay helps the discrimination with Standard Model processes

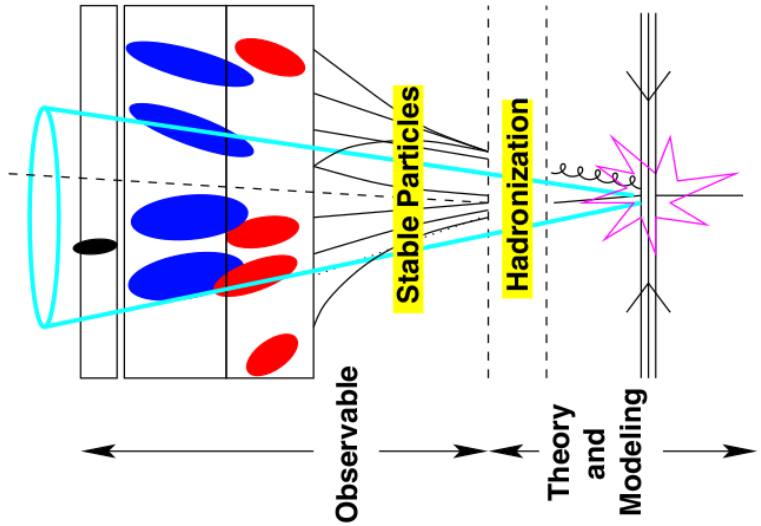
Third generation: a highway to New Physics

- Potential preferred fermions to couple for Beyond Standard Model particles
  - Considering final states with 3rd generation quarks is an optimal choice

Jet substructures

Measure of solid angle in CMS coordinate system

ΔR



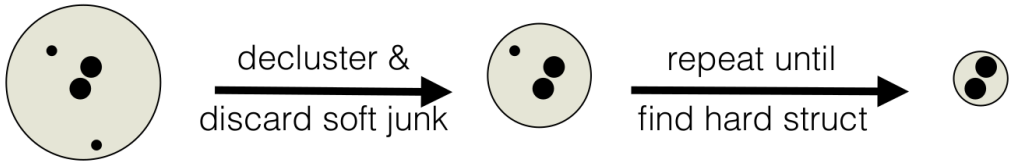
Defining jets

A conic composite object with a definite angular opening constructed performing a definite algorithm (anti-k_T in CMS)

- ΔR = 0.4 → AK4 jets (associated to quark hadronization)
- ΔR = 0.8 → AK8 jets (associated to boosted decay)

AK8 jet substructure techniques to tag decay products

- Jet mass grooming techniques to improve the mass estimates of jets



Soft Drop (SD) technique → defines m_{SD}

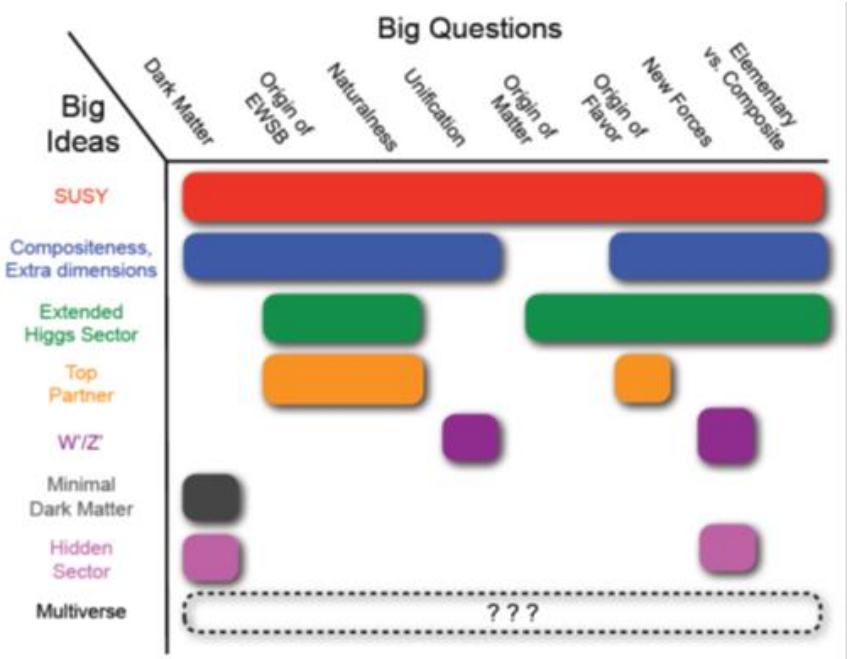
More reliable estimates can be used to identify jet origin (i.e., a resonance)

- Metrics measuring the degree of compositeness of a jet based on spacial distribution
  - N-subjettiness τ_N : compatibility with N AK4-subjets pattern
    Ratios $\tau_{NN'}$ indicates which structure is more compatible with jet substructure

  Substructure strongly depending on the "mother" particle

- *b*-tagging subjets inside an interesting jet: top/Higgs decay signature

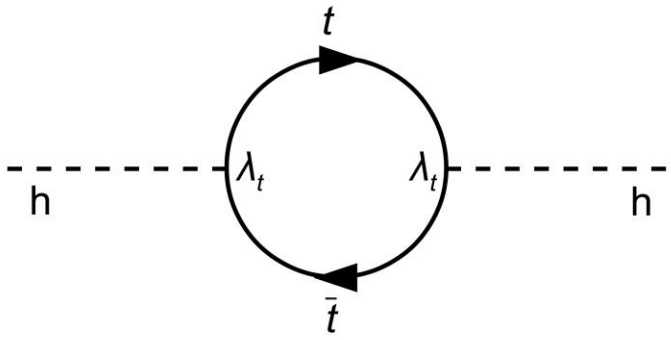
Beyond the Standard Model



Different scenarios having a look Beyond Standard Model (BSM)

- Expansions of SM guage symmetry group
  - New extra dimensions
  - Compositeness (more fundamental particles)

  considered here
- SM fermions acquire excited states
- New bosonic resonances compare: W', Z', G* (massive gluon)
  - Can be accompanied with a new composite fermionic sector
    - Vector-like quarks (VLQs) → transform as vectors under EW symmetry group
      Mass terms permitted in BSM Lagrangian
      Not excluded by Higgs sector experiments
    - Heavy bosons decay in VLQs
- New models address the hierarchy problem
  - New Physics preferentially couples with 3rd generation quarks
    Top quark plays a key role in Higgs mass corrections

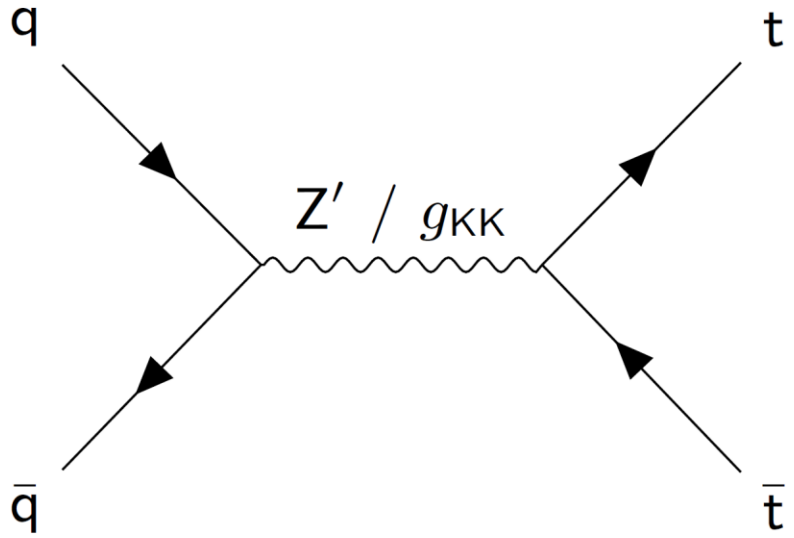


Z' → ttbar

JHEP 04 (2019) 031 - Overview

Search for a massive ttbar resonance

- probing scenarios from sharp resonant case to broad non-resonant case
- peak width/$m_{Z'}$ = 1%, 10%, 30%
- boosted decay products

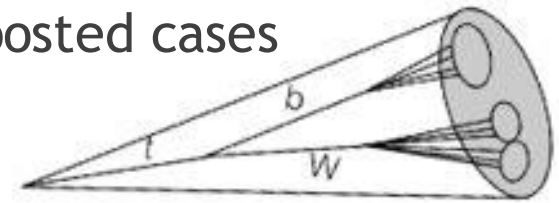


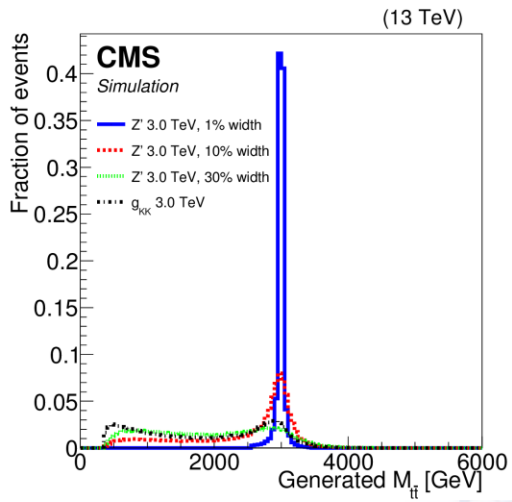
Categories combined for different ttbar scenarios

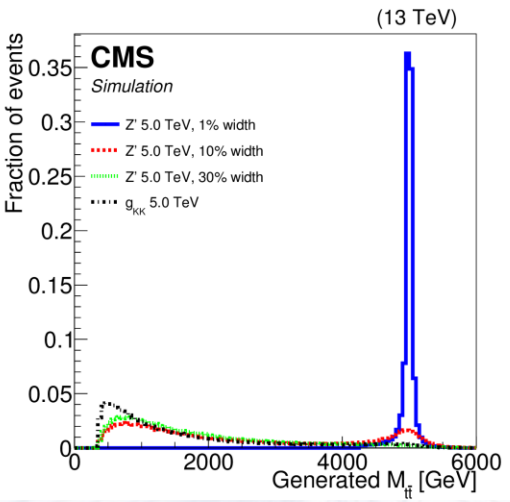
- all hadronic: tt → all jets
- semileptonic: tt → jets + 1 leptonic couple
- dileptonic: tt → jets + 2 leptonic couples

Both boosted and not boosted topology for top decay

- top tagging algorithm for boosted cases $m_{SD} \subset$ top peak, 3-prong τ_{32}







Z' → ttbar

JHEP 04 (2019) 031 - All hadronic channel

Two t-tagged AK8 jets

- p_T > 400 GeV, $|\Delta\varphi|$ > 2.1

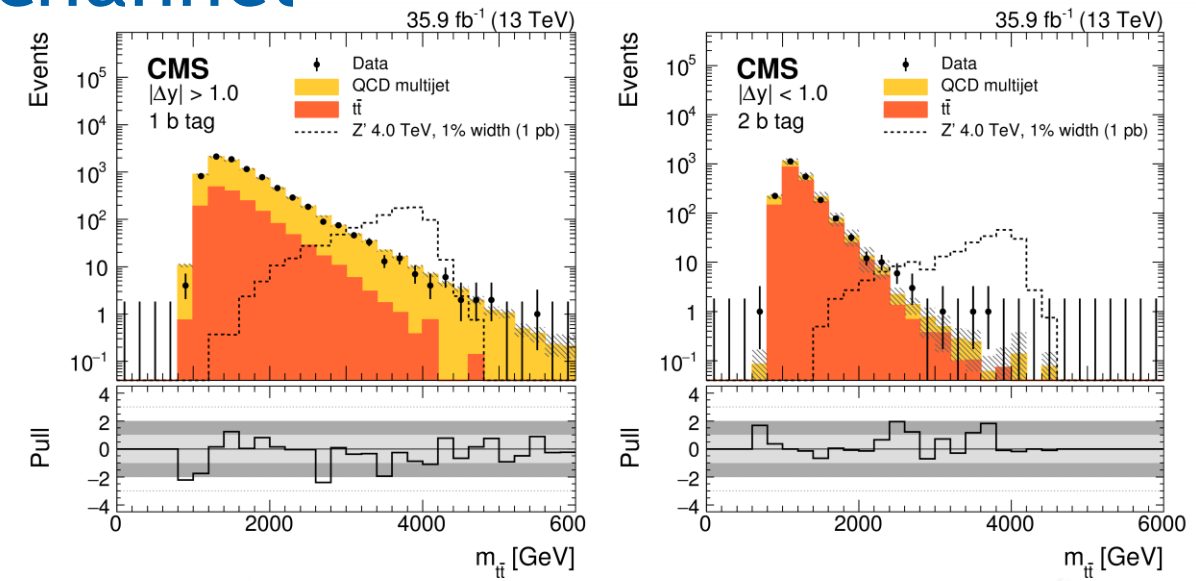
Categorisation of events in signal- and background-enriched regions

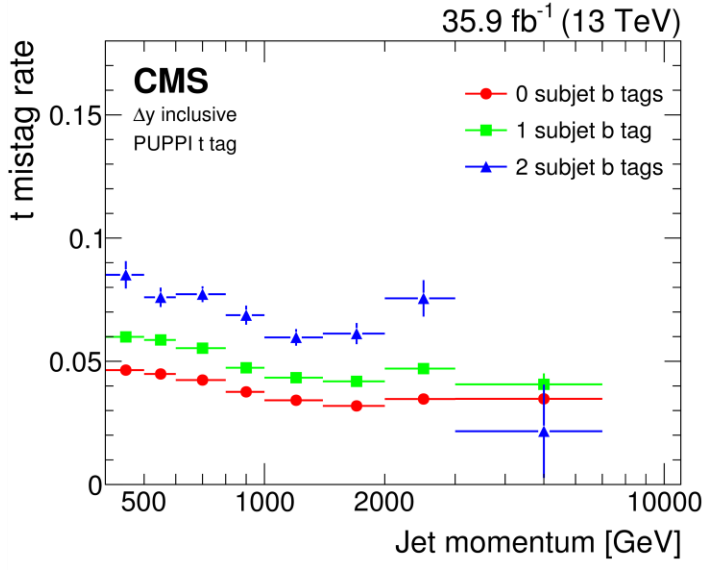
- number of *b*-tagged subjets in AK8 jets
- two regions in $|\Delta y|$ between selected jets

Background estimation

- QCD multijets contribution estimated with top mistag rate estimated in data
  - anti-tag a jet (reverting τ_{32} request) and evaluate t-tagging of second jet
- Others evaluated with MC simulations

m_{ttbar} as sensitive quantity to fit





Z' → ttbar

JHEP 04 (2019) 031 - Semileptonic channel

1 muon (electron) and 2 AK4 jets

- leptons: p_T > 55 (80) GeV
  relaxed isolation request wrt any AK4 jets
- leading AK4 jet: p_T > 150 (180) GeV

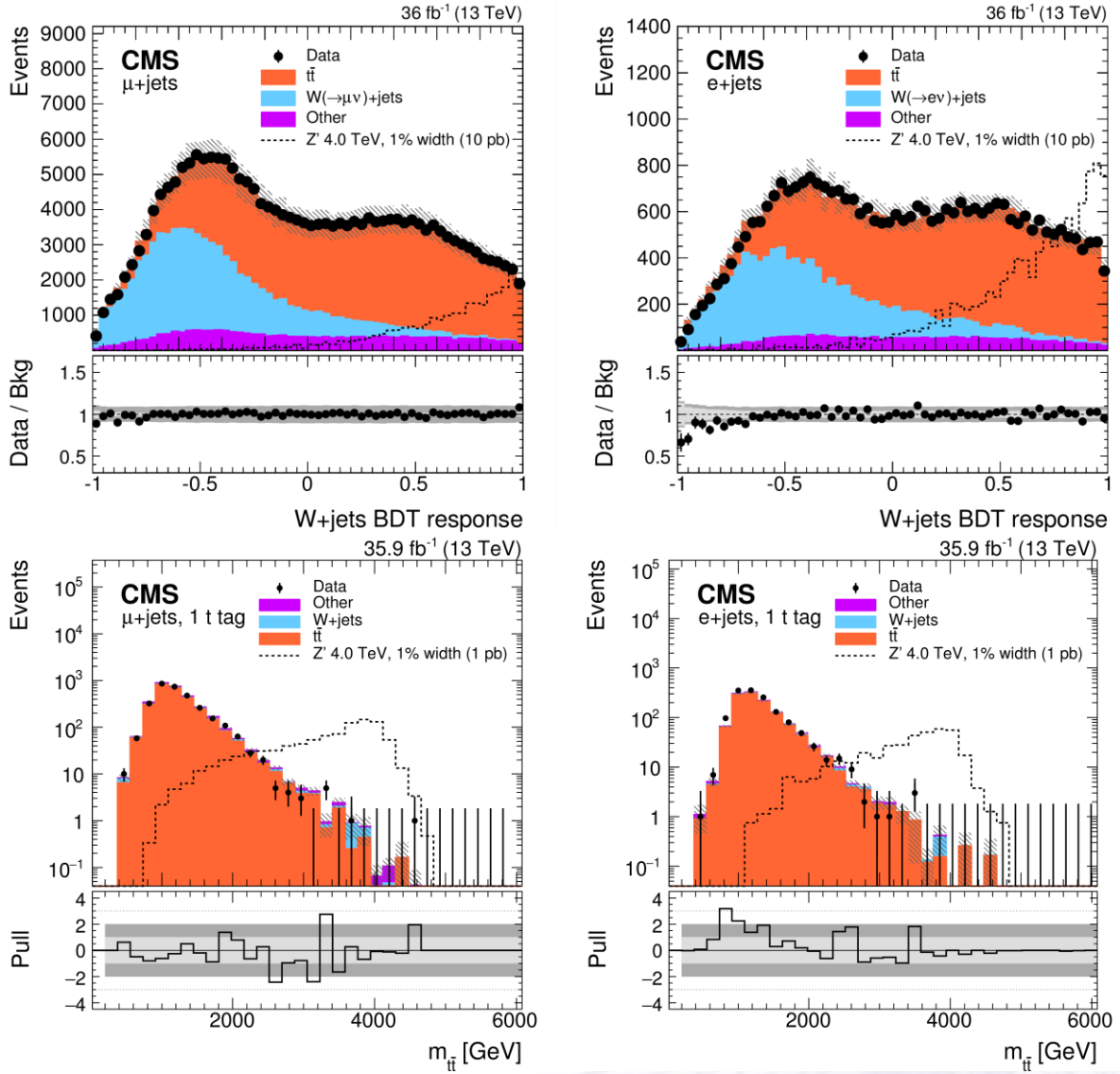
Background estimation

- W+jets contribution estimated with
  Boosted Decision Trees (BDT) score
- Others evaluated with MC simulations

Categorisation of events in signal- and background-enriched regions

- Number of t-tagged AK8 jets
- BDT score

m_{ttbar} as sensitive quantity to fit



Z' → ttbar

JHEP 04 (2019) 031 - Dileptonic channel

Two opposite charge leptons and two AK4 jets

- High p_T leptons (ee, μe, μμ)
- Leading AK4 jets, at least one b-tagged

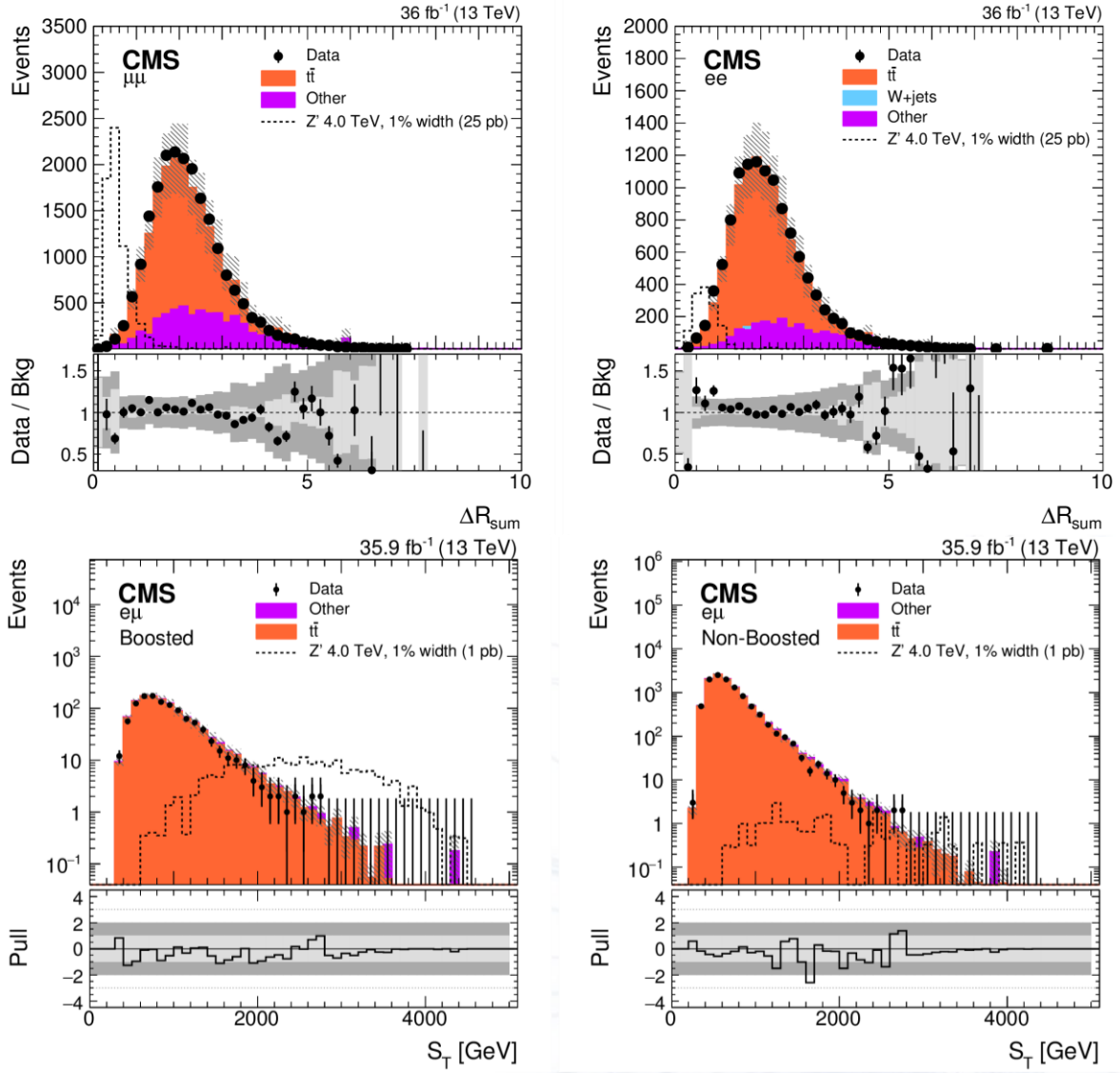
Categorisation of events in signal- and background-enriched regions

- Two regions in $|\Delta R(l, j)|_{min}$ (boosted and not)

Background estimation

- Evaluated with MC simulations
- QCD multijets contribution reduced with 2D cut on leptons
  - $|\Delta R(l, j)|_{min} > 0.4$, $p_{T,rel}(l, j) > 15$ GeV

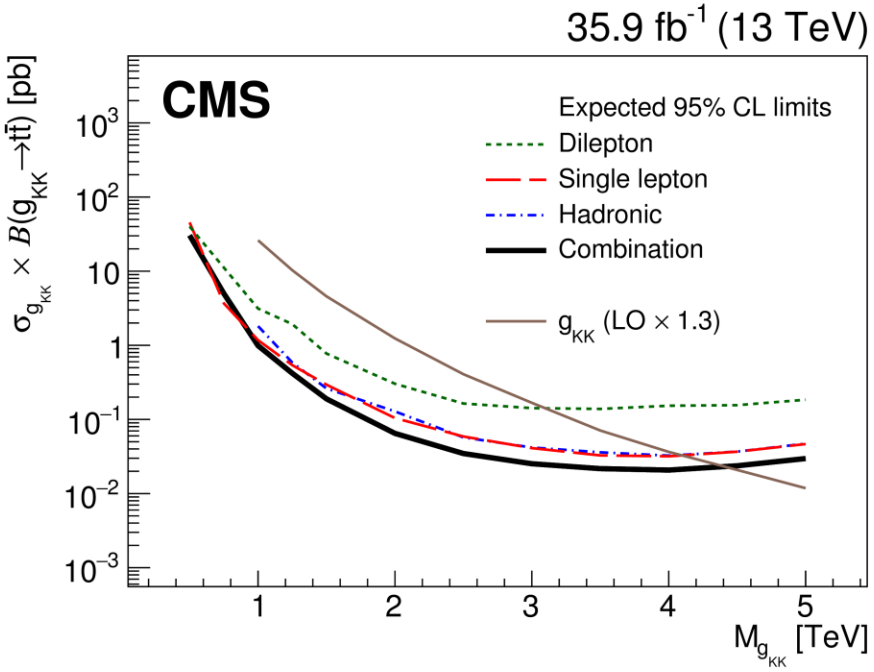
Total p_T sum of the event (S_T) as most signal-sensitive quantity to fit

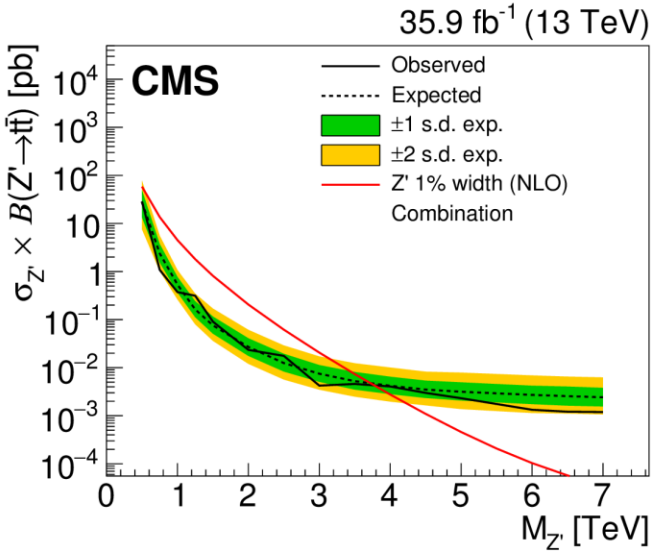


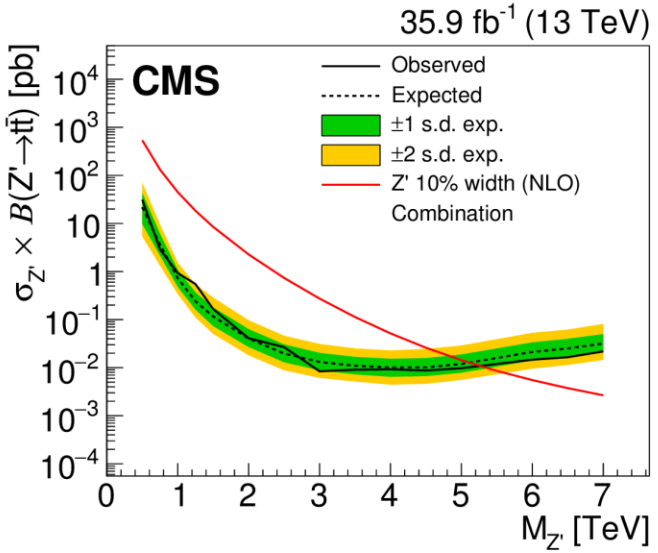
Z' → ttbar

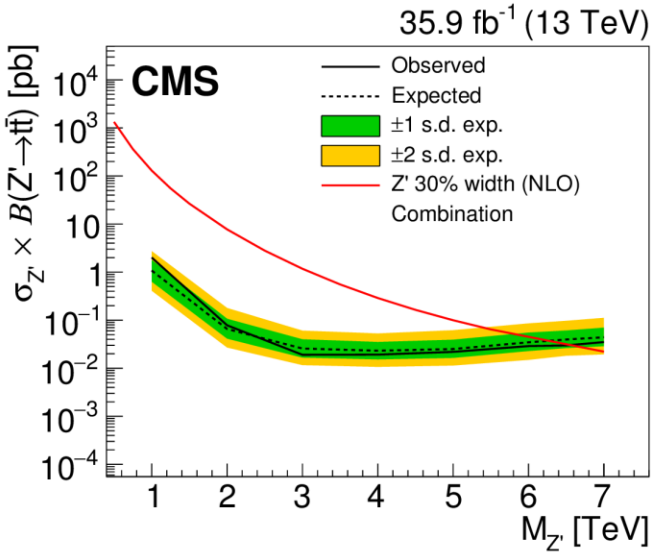
JHEP 04 (2019) 031 - Combination and results

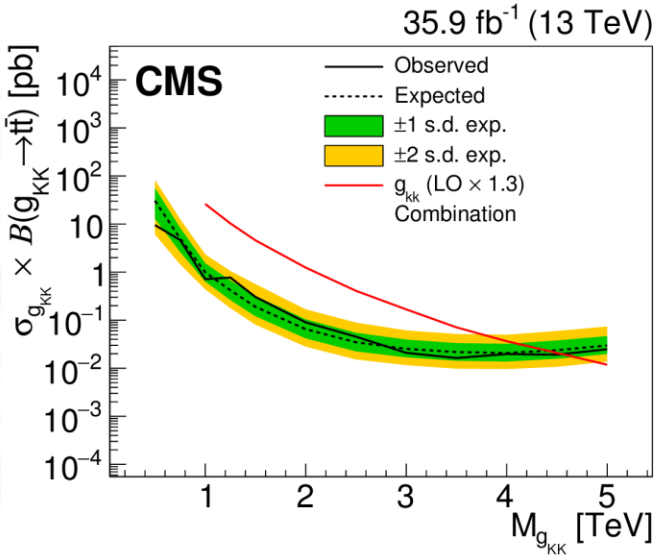
Combination of the three statistically independent channels performed









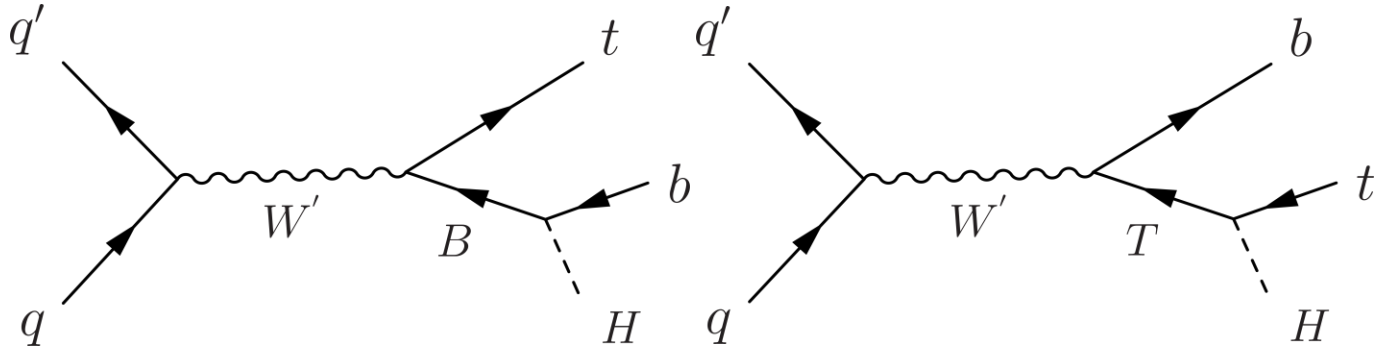


Heavy W' → tB/Tb → tbH

JHEP 03 (2019) 127 - Overview

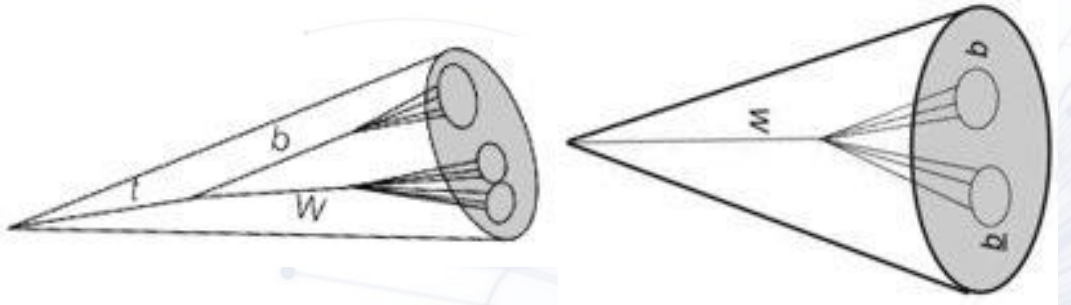
First search of this type with LHC data

- W' decaying in VLQs (T, B)
  - All jets final states
- Several scenarios in ($m_{W'}$, m_{VLQ}) investigated
- Couplings fixed to enhance likelihood of the chain decay



Highly boosted decay products

- Jets from decays with different substructure
- Tagging combination strategy to distinguish signal from SM multijet processes
  - Top: $m_{SD} \subset$ top peak, 3-prong τ_{32}, 1 b-tagged subjet
  - Higgs: $m_{SD} \subset$ Higgs peak, double-b-tag substructure



Heavy W' → tB/Tb → tbH

JHEP 03 (2019) 127 - Analysis

Event selection

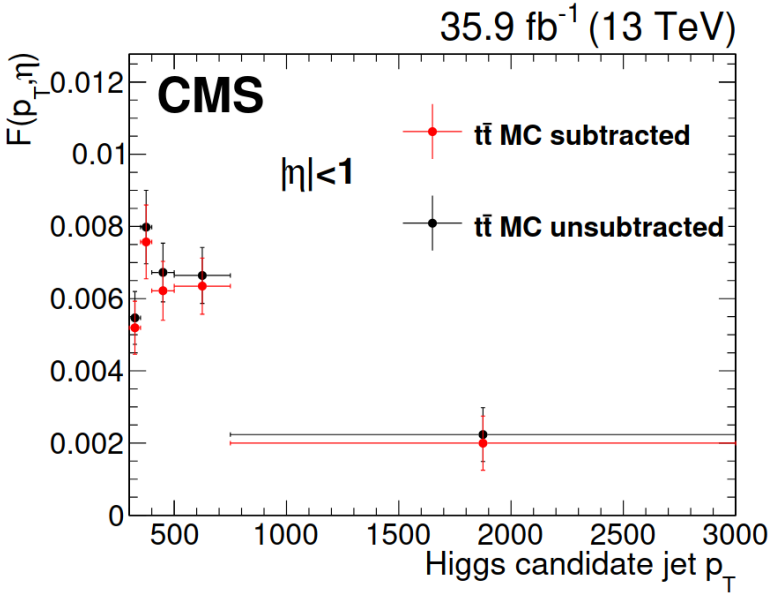
- Presence of Higgs-, top- and b- tagged jets
- Antitags define control regions

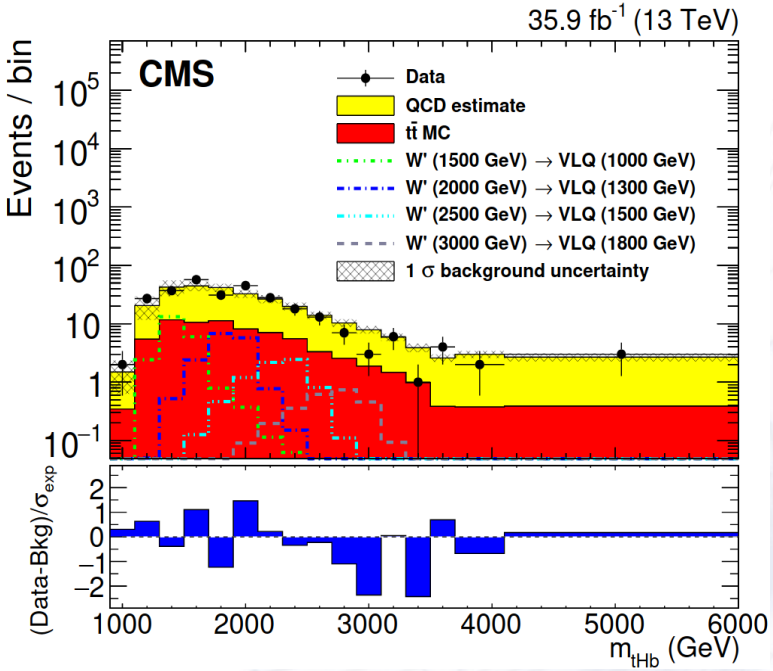
Background estimation

- QCD multijet: Data-driven method
  Transfer function $F(p_T, \eta)$ fail-to-pass
  Higgs tagging derived in top-antitag region
- ttbar: template from MC simulation
- b-antitag defines validation regions

Fit procedure

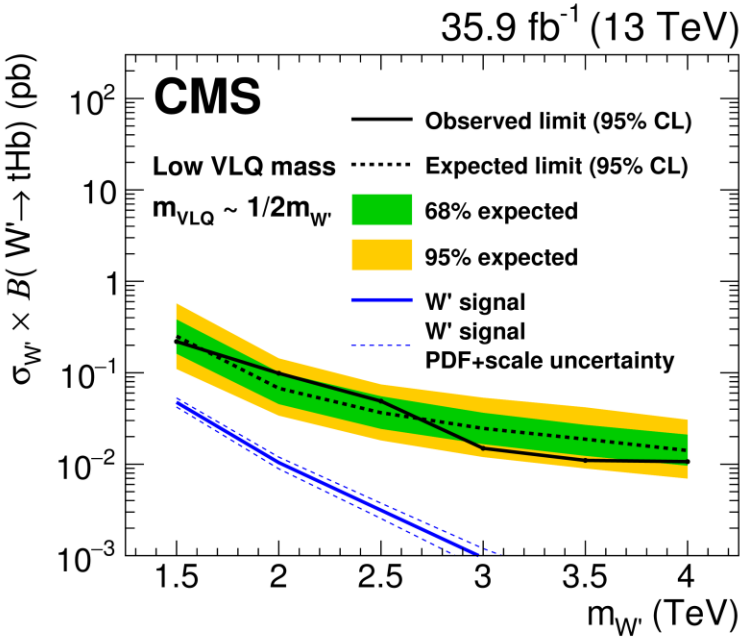
- Performed on reconstructed $m_{W'} = m_{tbH}$
- Limits imposed on cross section × BR

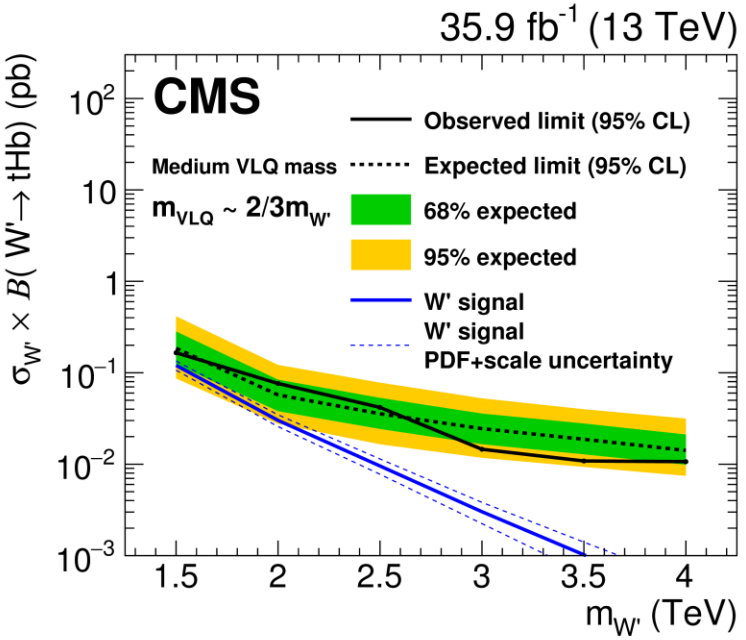


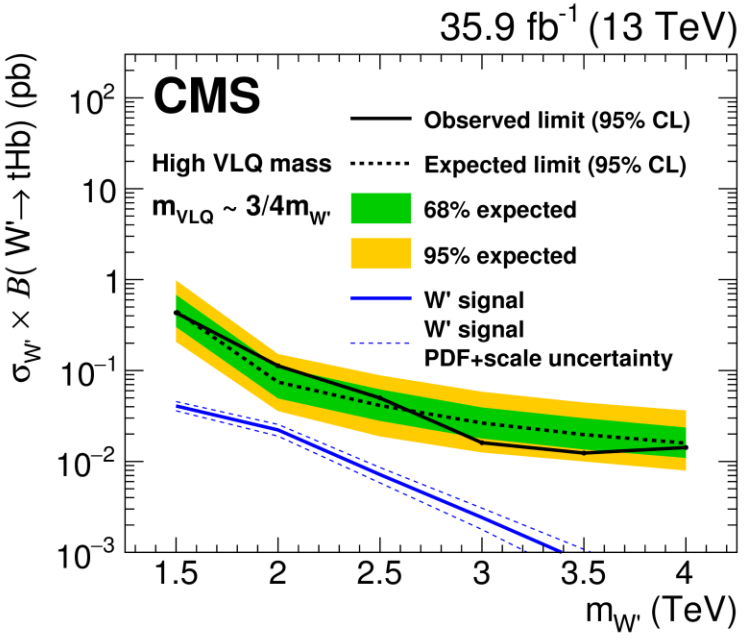


Heavy W' → tB/Tb → tbH

JHEP 03 (2019) 127 - results







Z' → tT → ttH/ttZ/tbW

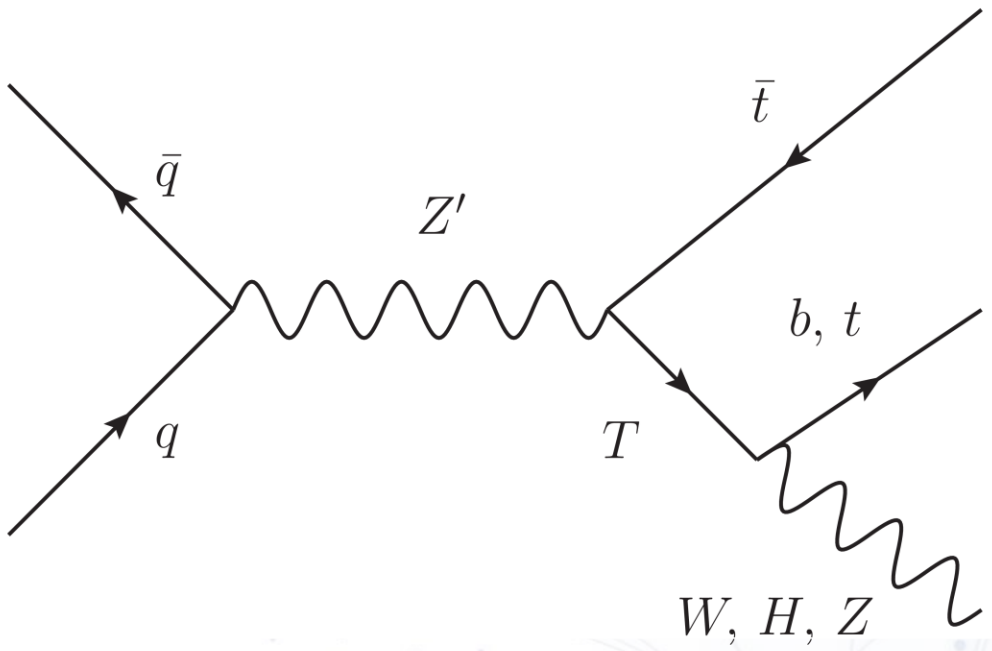
Eur. Phys. J. C 79 (2019) 208 - Overview

Investigating several new models

- Searching for heavy resonances decaying to VLQs
  - Lepton + jets final states (EW decay)
- Multiple categories for different possible decays
  - T → bW, tZ, tH **optimized for these**

Boosted decay products

- Jet tagging based on hadronic substructure
  - Mistag rate and efficiencies estimated with data
  - W, Z: $m_{SD} \subset m_{W/Z}$, 2-prong τ_{32}
  - H: $m_{SD} \subset m_{H}$ peak, 1 or 2 b-tagged subjets
  - hadronic top: $m_{SD} \subset m_{W/Z}$ peak, 2-prong τ_{21}



Z' → tT → ttH/ttZ/tbW

Eur. Phys. J. C 79 (2019) 208 - Analysis and results

Event selection

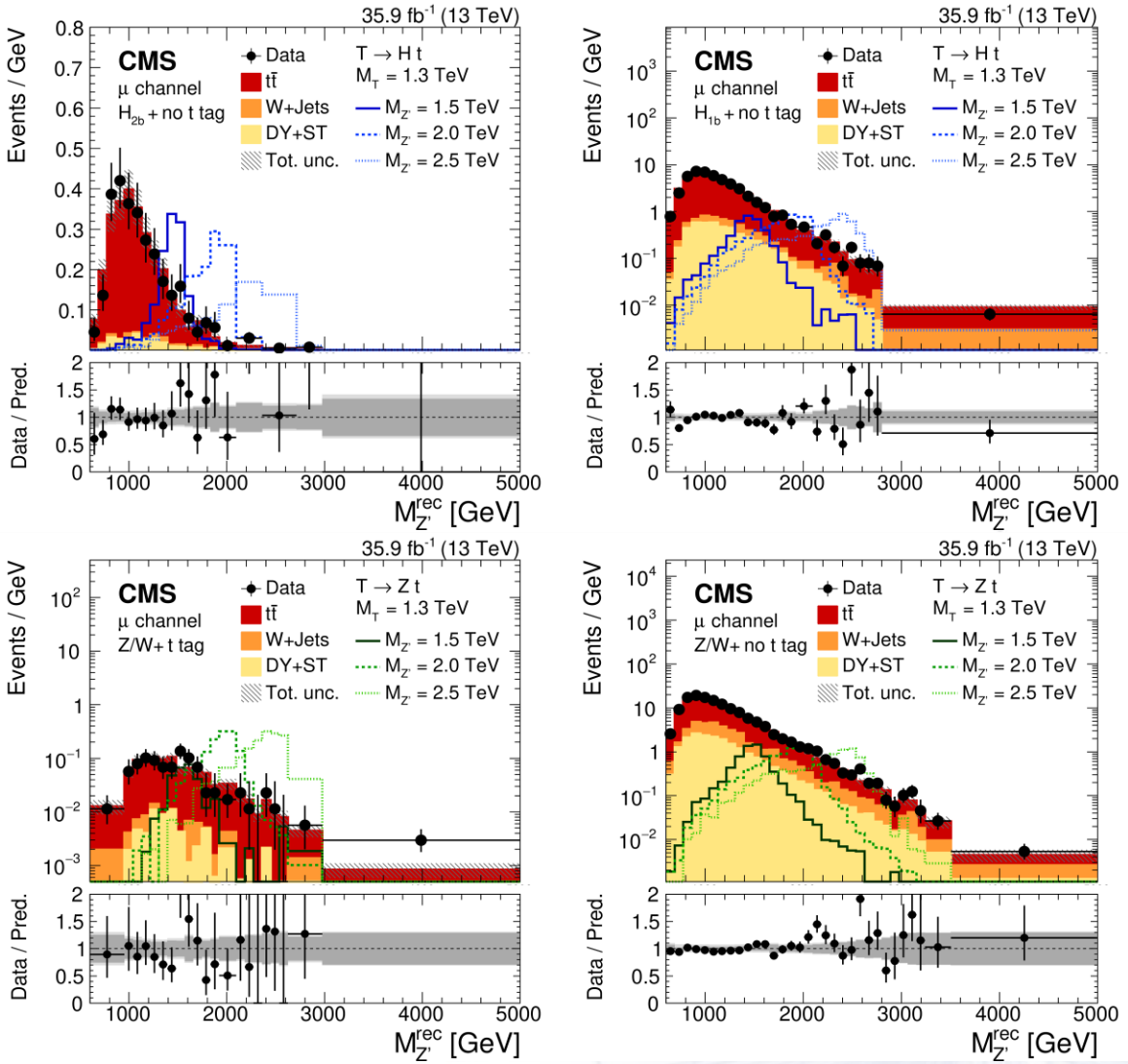
- Presence of at least one H/W/Z-tagged jet
- Need to maximise the signal efficiency
  - Passed H/W/Z tagger categorises the event
  - Subcategories based on presence/absence of a top-tagged jet

Background estimation

- ttbar and W + jets estimated with simulations and constrained with dedicated control regions

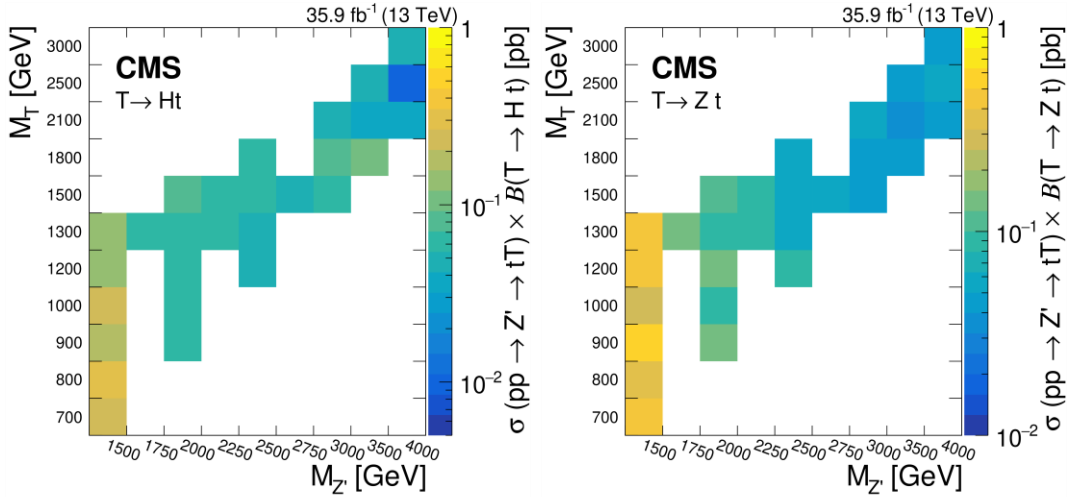
Fit procedure

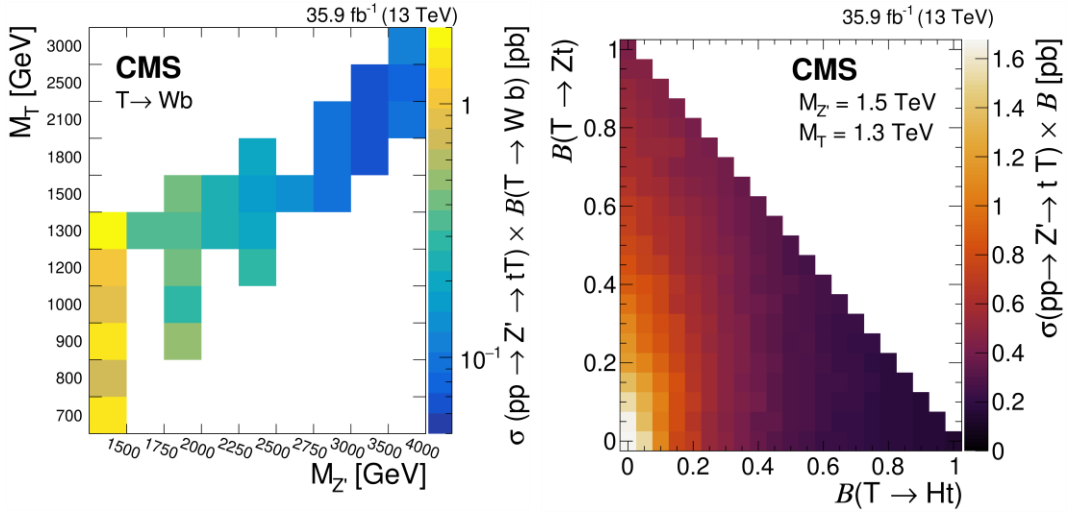
- Performed on reconstructed $m_{Z'}$
- Limits extracted for different (m_T, $m_{Z'}$) values and several Z' interpretations

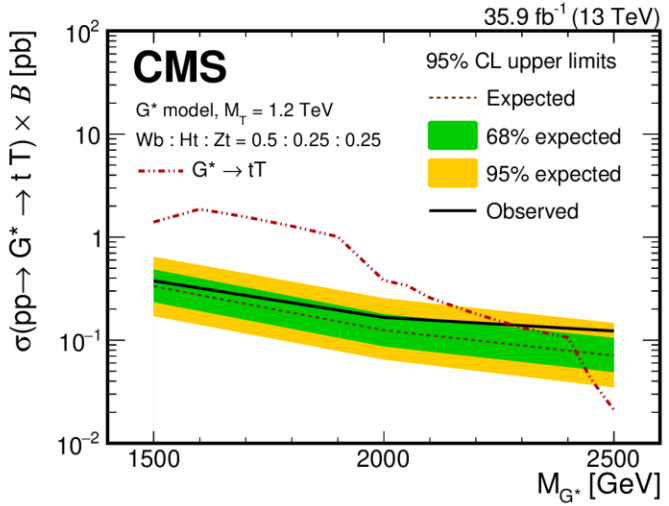


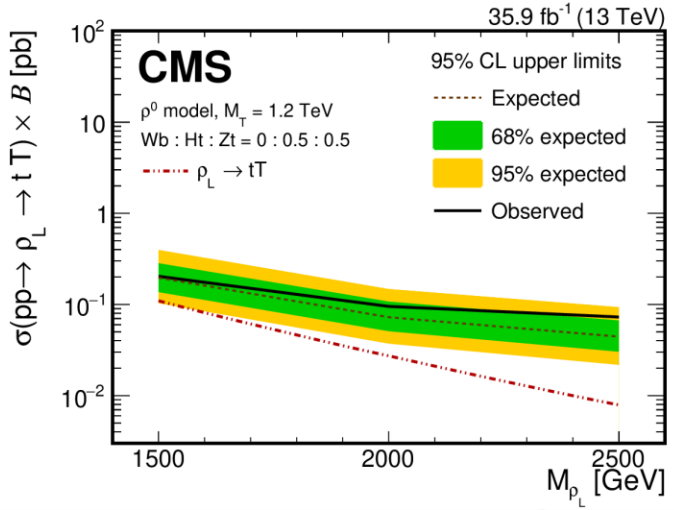
Z' → tT → ttH/ttZ/tbW

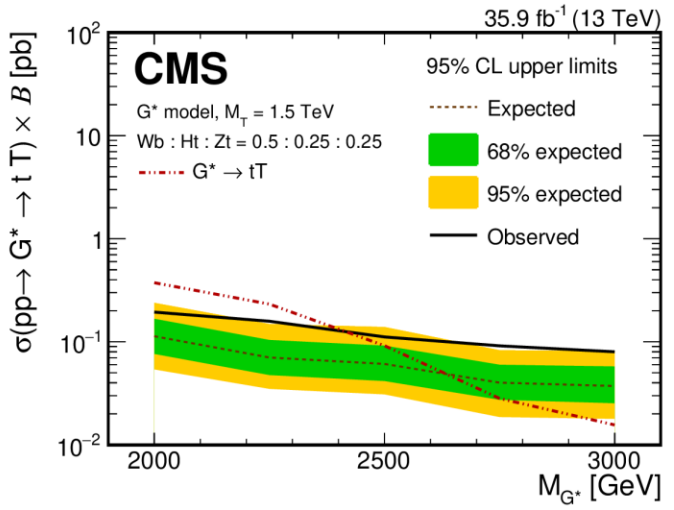
Eur. Phys. J. C 79 (2019) 208 - Results

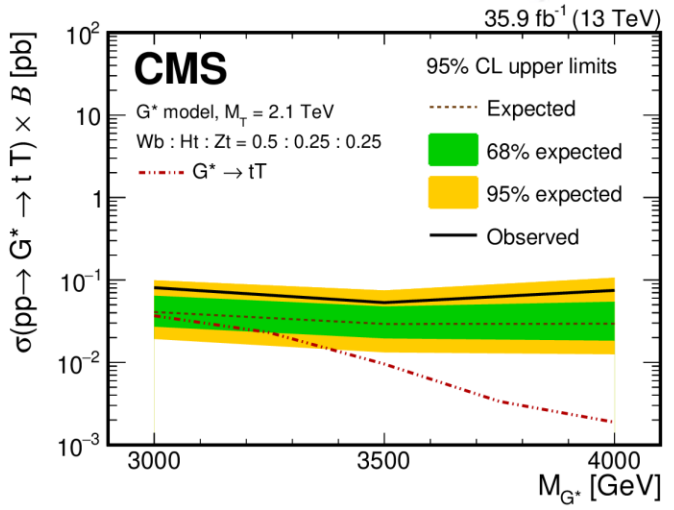








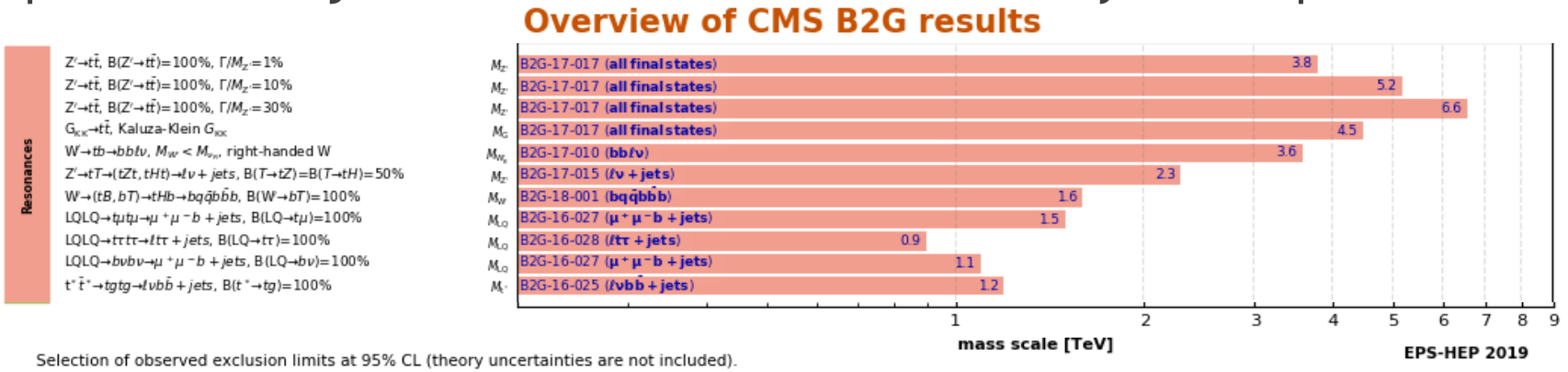




Conclusions

Searching for heavy new particles nowadays

- 3rd generation quarks as portal to New Physics
- Different new models and processes investigated
  - Compositeness, extra dimensions
  - Heavy bosons → VLQs and SM quarks
- Tagging techniques based on jet substructure enhance sensitivity to new processes



Selection of observed exclusion limits at 95% CL (theory uncertainties are not included).

For the future

- Development of tagging algorithms with jet substructure techniques dedicated to new searches
- New results expected from the combined 2016, 2017 and 2018 dataset

Thank you for your attention!