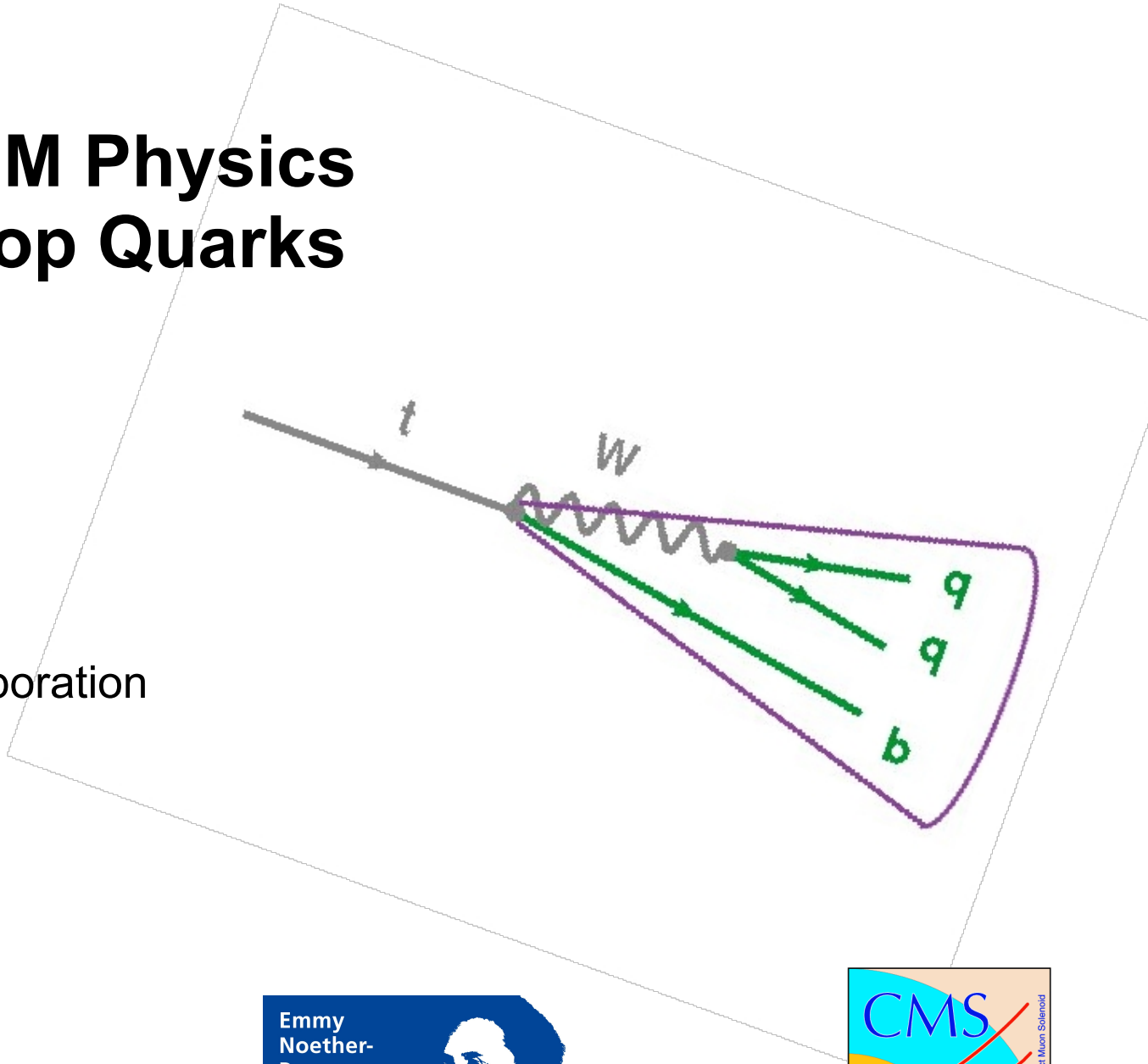
Searches for BSM Physics in Events with Top Quarks (CMS)



Rebekka Sophie Höing
On behalf of the CMS collaboration

SUSY 2014
Manchester, July 22nd 2014

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

CMS Compact Muon Solenoid

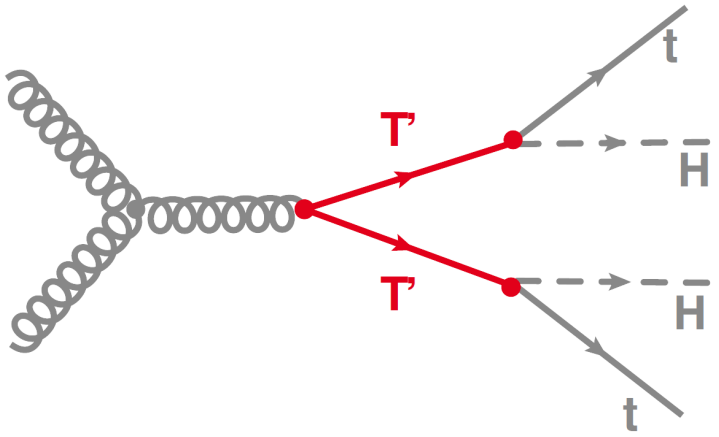
The Top Quark

- Top quark special due to its high mass
  - main responsible for hierarchy problem
  - strong Yukawa couplings to the Higgs boson → window to EWSB
- Top quark plays important role in many BSM models
  - Little Higgs Models
  - Composite Higgs Models
  - Extra dimensions...
- These models predict a number of new particles

  → Search results presented in this talk

BSM Searches in this Talk

- Vector-like quarks:
  - Same transformations under SU(2)⊗U(1) for L- and R-handed chiralities
  - Decay modes
    - T' → tH, T' → tZ, T' → bW
    - B' → bH, B' → bZ, B' → tW
  - Searches for pair produced T' and B' in all decay channels

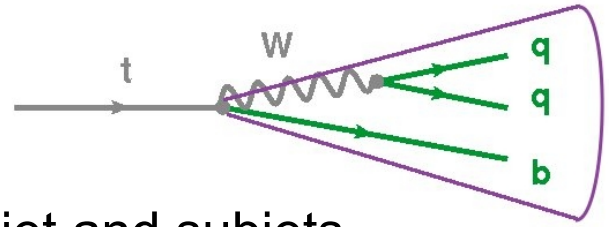


- Resonance searches:
  - Resonances of third generation quarks: Z', W' or Kaluza-Klein gluons
  - Excited top quarks

- Also covered in this talk: Searches for FCNC

Jet Substructure Tools

- **Top Tagging** CMS PAS JME-13-007
  - CMSTopTagger
  - HEPTopTagger



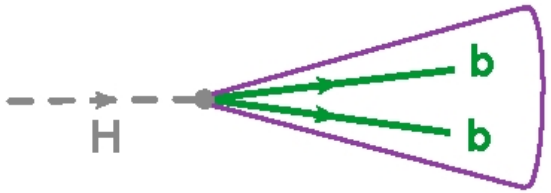
→ Identify 3 subjets

Apply W and top mass requirements on fat jet and subjets

- **Higgs/W/Z Tagging** CMS PAS JME-13-006

→ Identify 2 subjets

Apply mass cuts



- **Subjet b tagging** CMS PAS BTV-13-001

→ b-tagging discriminator from displaced tracks & secondary vertex info

Improves performance of top tagging and Higgs tagging

- **N-subjettiness**

→ τ_n:how consistent is jet with having n subjets?

Vector-Like Quarks

CMS PAS B2G-12-015

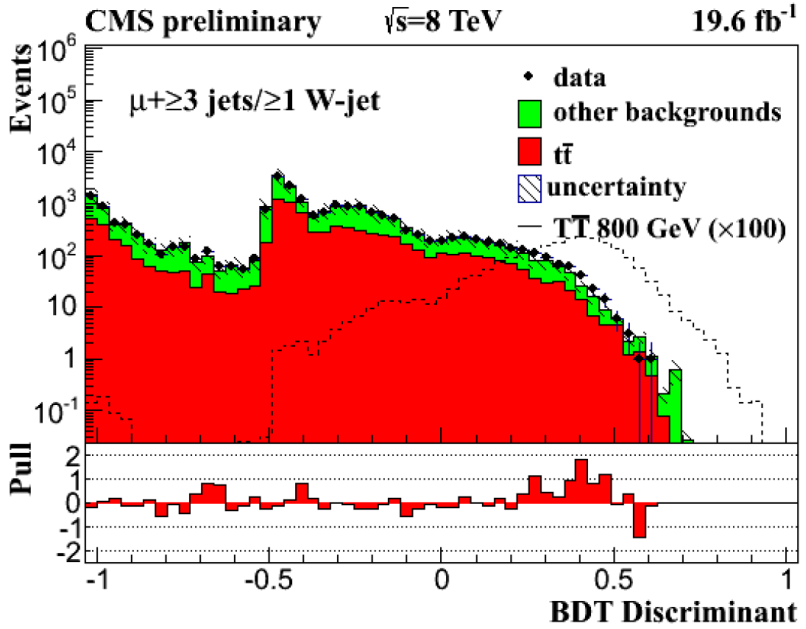
Inclusive Leptonic T' Search

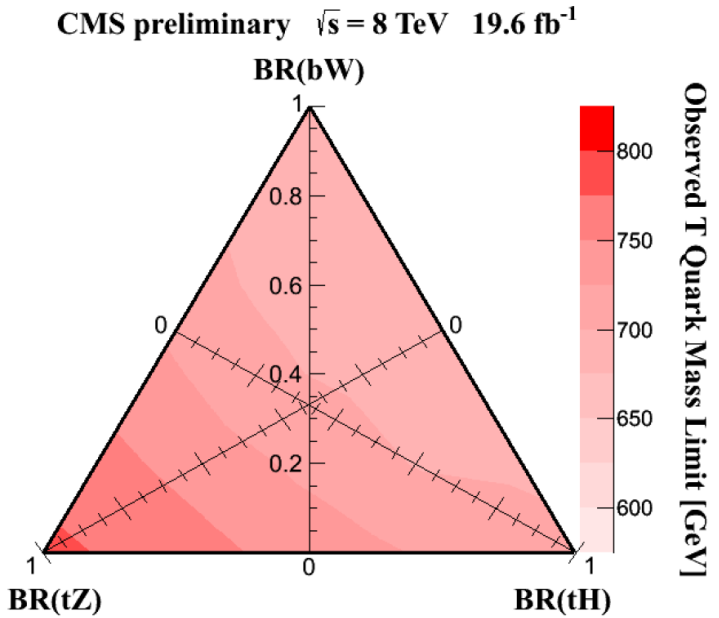
- Single lepton + jets BDT analysis
  - with/without W-tagged CA8 jet
  - BDT input variables:

    e.g. W-tag, b-tag & top-tag multiplicity

- Multilepton counting experiment
  - Opposite sign dilepton channel
  - Same sign dilepton channel
  - Trilepton channel

- Greatest sensitivity for T' → tZ decays
- Observed limits between 687 and 782 GeV

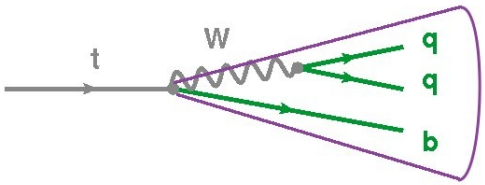




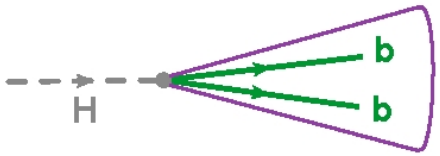
CMS PAS B2G-14-002

All-hadronic T' → tH (H → bb)

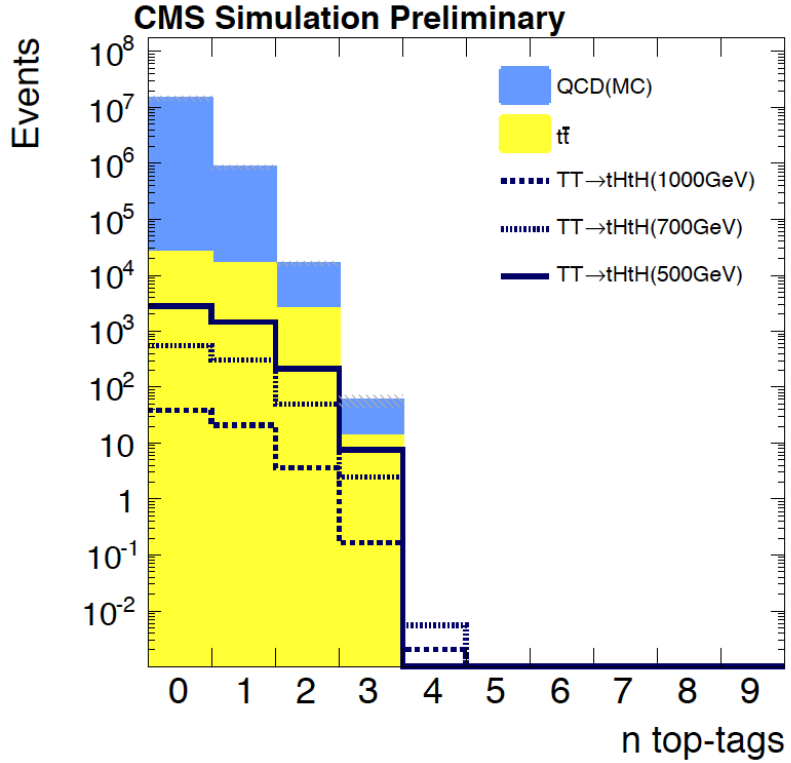
Select events with ≥ 1 top tags and ≥ 1 Higgs tags



Top-tagging:
- HEPTopTagger
- Subjet b-tag



Higgs-tagging:
- 2 subjet b tags
- Invariant mass of b jets > 60 GeV

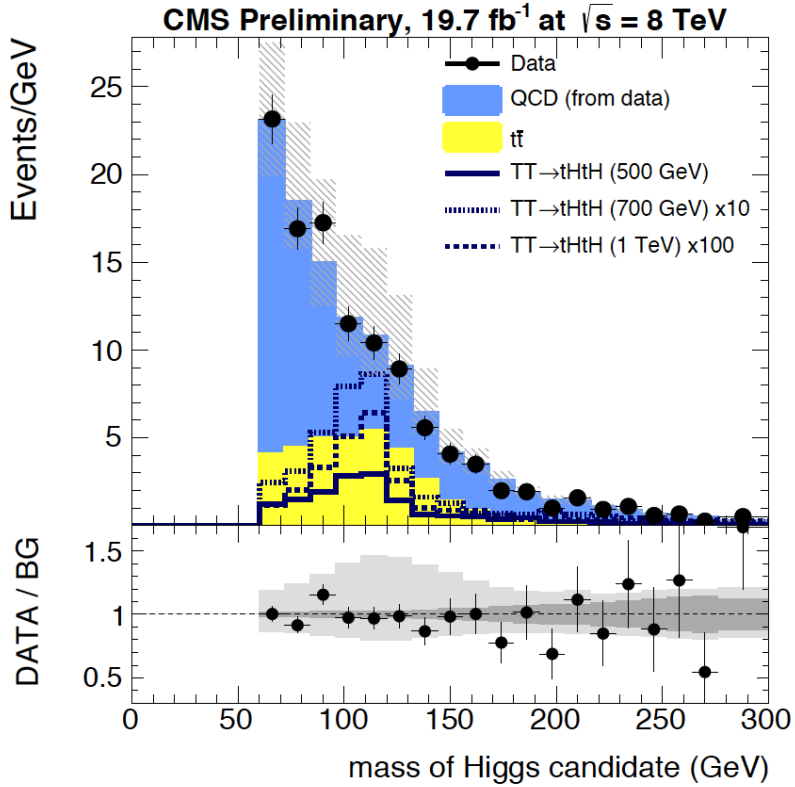


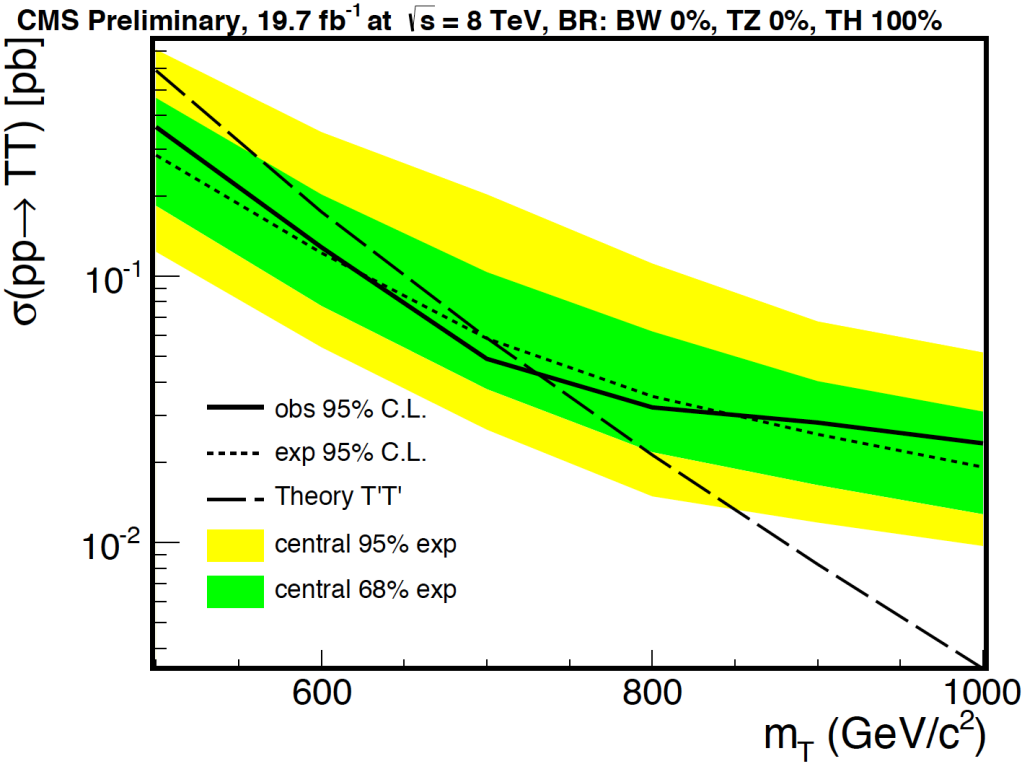
Backgrounds reduced very effectively using substructure tools

CMS PAS B2G-14-002

All-hadronic T' → tH (H → bb)

Sensitive variables: HT & Higgs candidate mass
→ Combine in likelihood ratio for limit setting



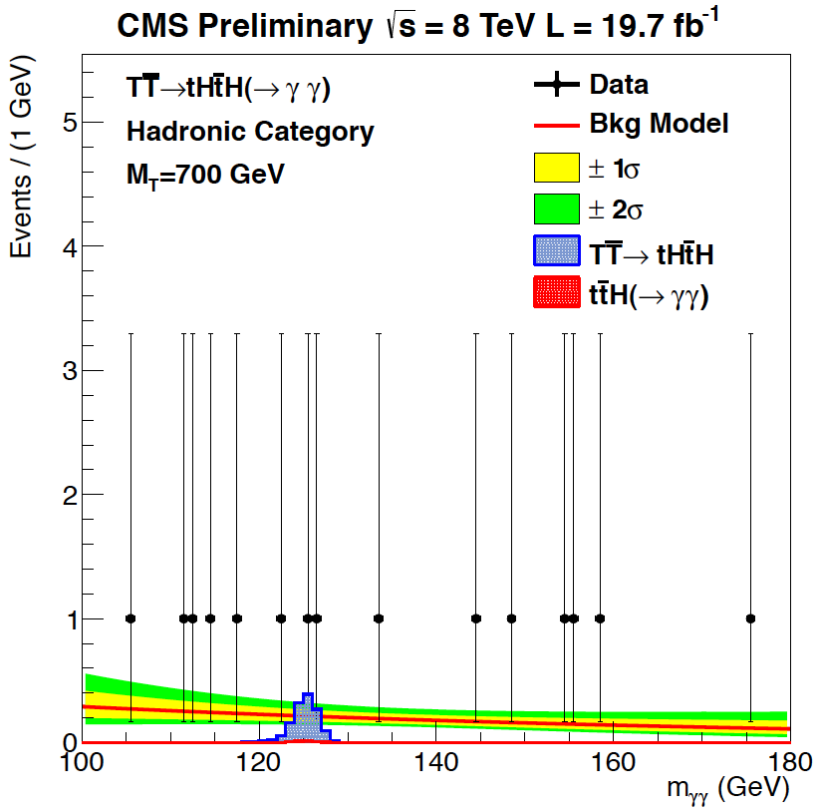


Mass limit for 100% T' → tH: Expected 701 GeV
Observed 747 GeV

CMS PAS B2G-14-003

T' → tH (H → γγ)

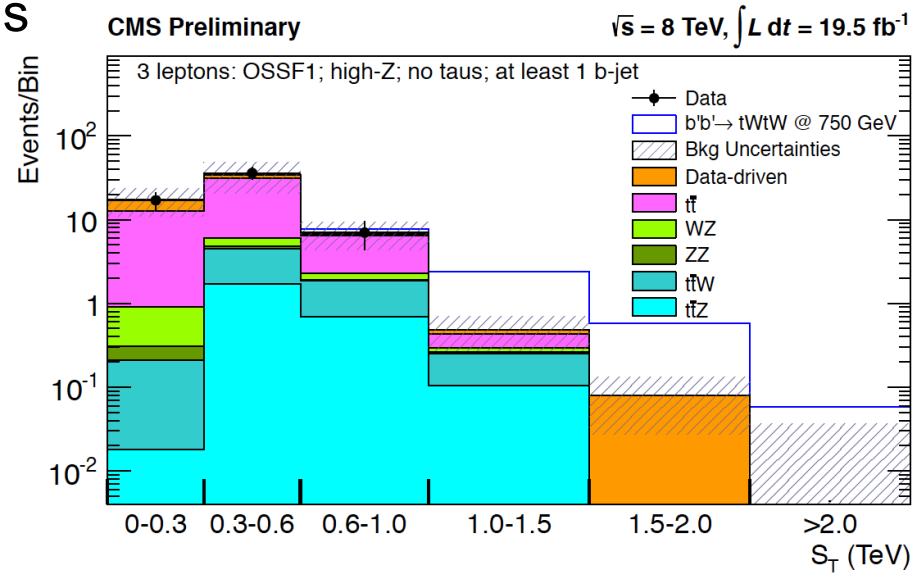
- At least one decay H → γγ: Precise Higgs-mass reconstruction
- Analysis in hadronic and leptonic channel
- Event selection:
  - 2 photons
  - 2 jets
  - Large H_T
  - 1 b-tag in hadronic channel
- Limit: 540 GeV observed
  607 GeV expected

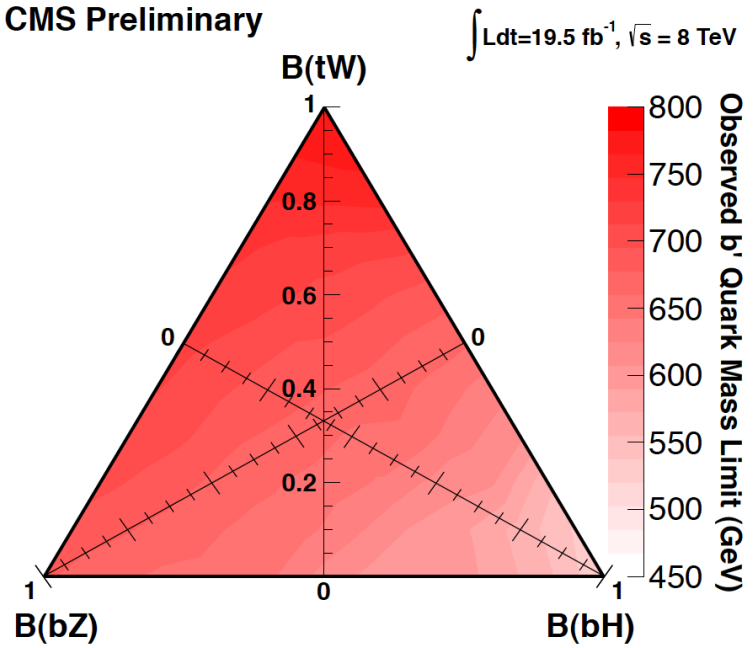


CMS PAS B2G-13-003

Multilepton B' Search

- Inclusive search in events with ≥ 3 leptons (including hadronic taus)
- Define multiple event categories by
  - Number of OSSF lepton pairs
  - Lepton pair on/off Z shell
  - Value of S_T
  - Presence of b-tags / hadronic taus
- Limits from counting experiments: 520-785 GeV



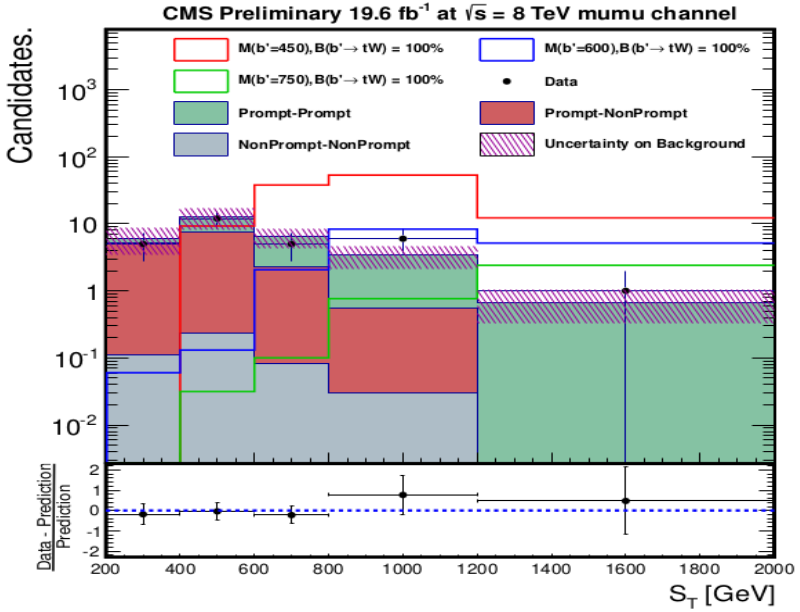


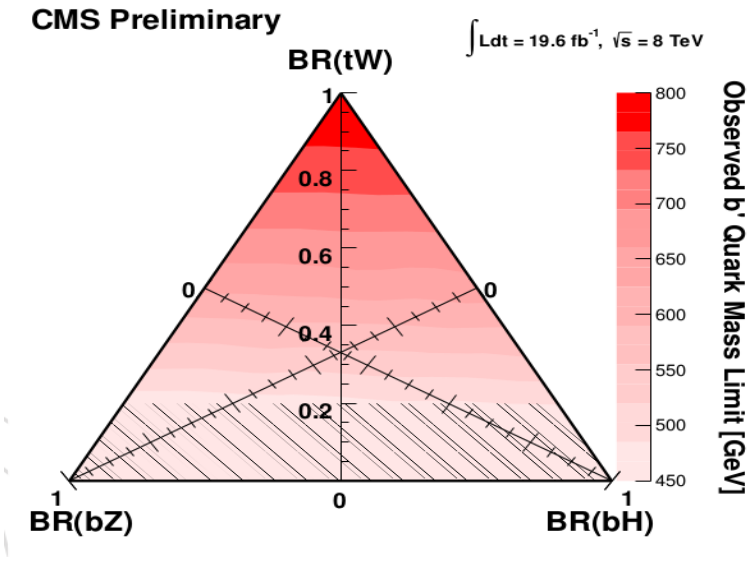
CMS PAS B2G-12-020

Leptonic B' → tW

- Analysis optimized for decays of B' → tW
- Event selection:
  - 2 same sign leptons
  - ≥ 4 jets
- Split events into categories according to S_T and lepton flavor
- Mass limit from S_T variable:

  800 GeV for 100% B' → tW





Resonance Searches

Phys. Rev Lett. 111, 211804

$t\bar{t}$ Resonances

- Search for resonances in $m_{t\bar{t}}$ spectrum
- Combination of three approaches:
  - **Resolved semi leptonic**

    Isolated lepton + 4 jets + $E_{T,miss}$
  - **Boosted semi leptonic**

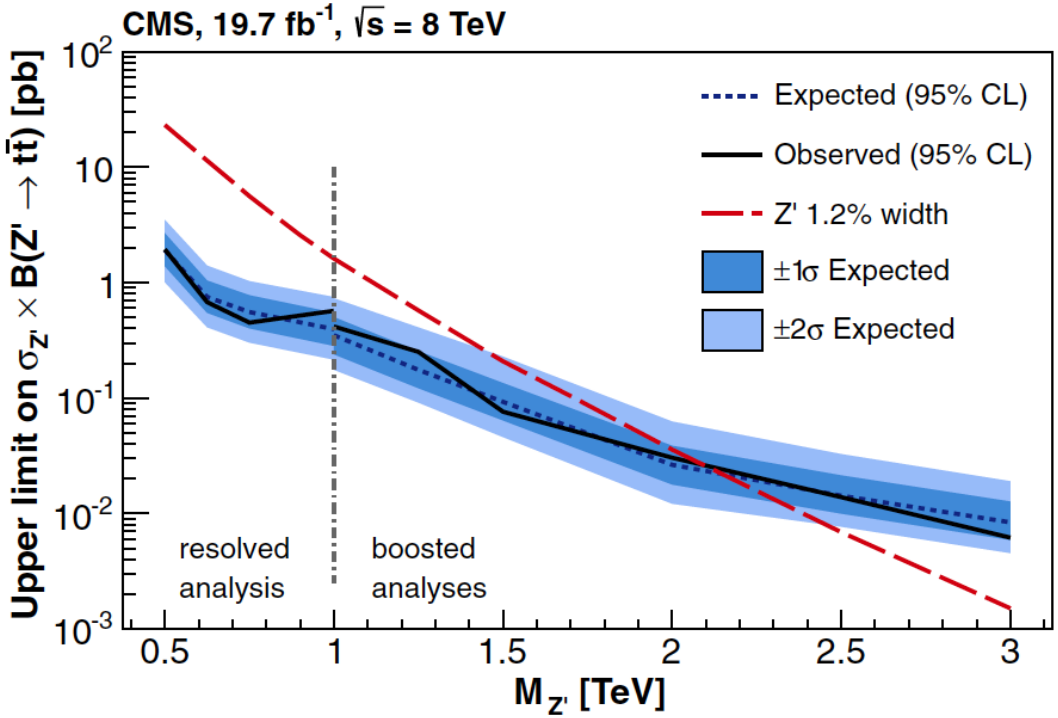
    1 lepton (no isolation required)

    1 high p_T CA8 jet

    Different b-tag categories
  - **Boosted hadronic**

    2 CA8 jets with CMS top-tag

    Back to back topology



Model	Observed Limit	Expected Limit
Z', $\Gamma_{Z'}/M_{Z'} = 1.2\%$	2.1 TeV	2.1 TeV
Z', $\Gamma_{Z'}/M_{Z'} = 10\%$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

CMS PAS B2G-12-009

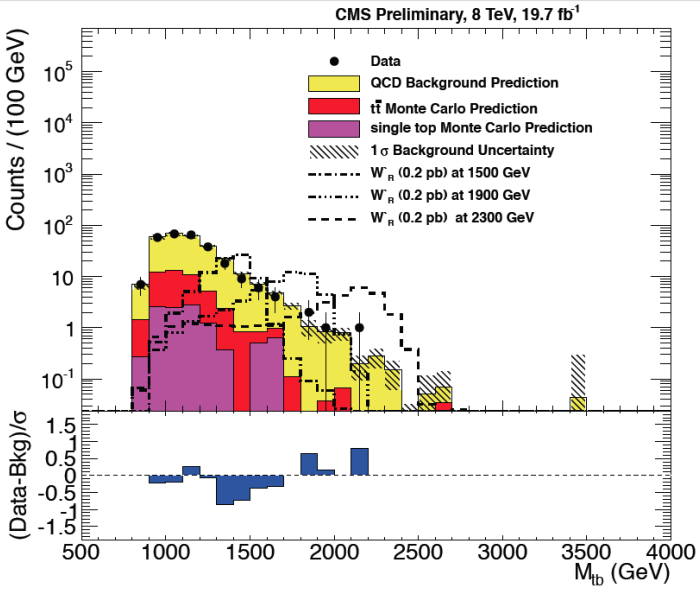
W' → tb (All-hadronic)

- Event selection:
  - **Top candidate**: CA8 jet (p_T > 450 GeV)

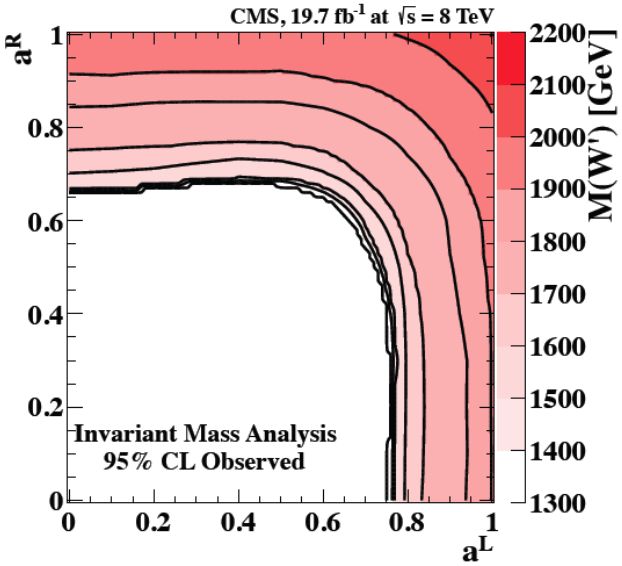
    CMS top tag & 1 subjet b-tag

    N-subjettiness τ_3/τ_2 < 0.55
  - **b candidate**: b-tagged jet

    p_T > 370 GeV & mass < 70 GeV
- Limit for 100% right handed couplings:
  - Expected: 1.99 TeV
  - Observed: 2.0 TeV
- Similar sensitivity as previous CMS search in leptonic channel: hep-ex:1402.2176
  - Expected: 2.02 TeV
  - Observed: 2.05 TeV



Limit on right & left handed coupling strength:



CMS PAS B2G-12-008,
hep-ex:1311.5357 (sub. to JHEP)

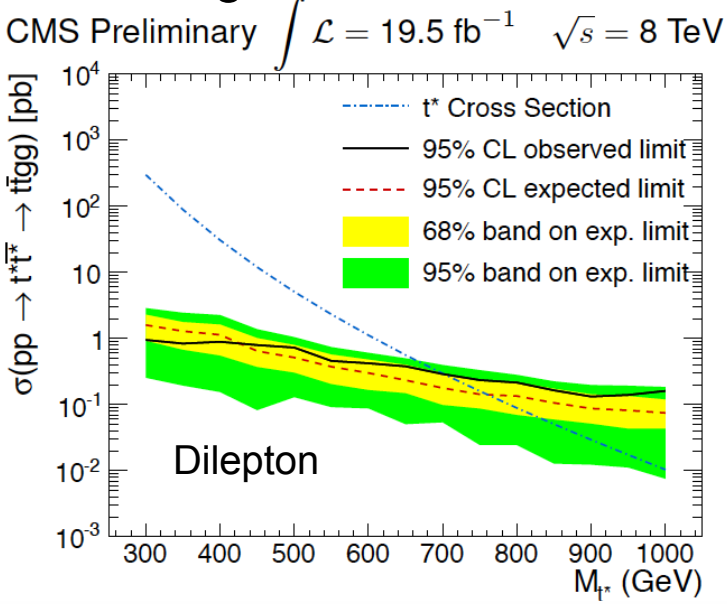
Excited Top Quarks

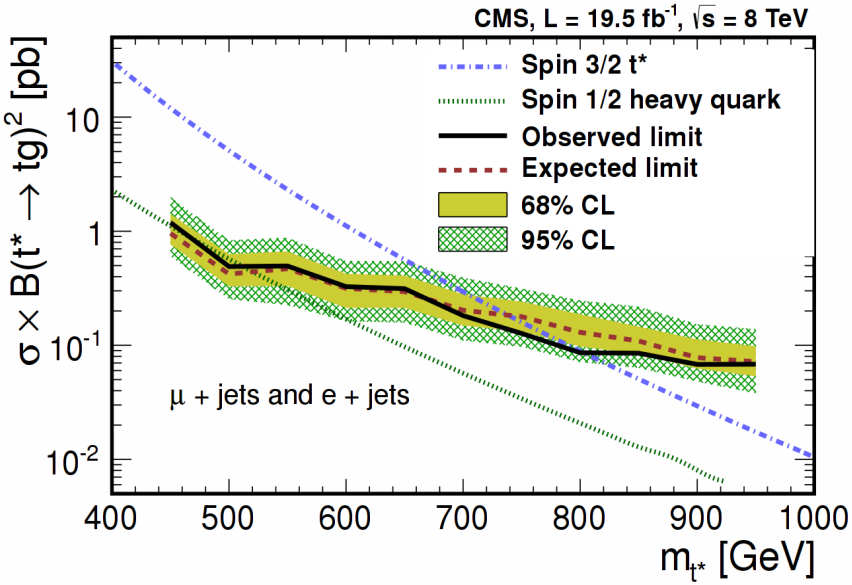
- Searches for pair production of top excitation t* → t + g
- Signature tt + jets difficult to model

  → distributions derived from data
- Dilepton event selection:
  - 2 isolated leptons
  - 4 jets with 2 b-tags
- Single lepton event selection:
  - 1 isolated lepton
  - ≥ 6 jets with ≥ 1 b-tag
- Limits on m(t*) from t + jet mass spectrum:

  Dilepton: 703 GeV

  Single lepton: 803 GeV





Flavor Changing Neutral Currents

CMS PAS TOP-14-003

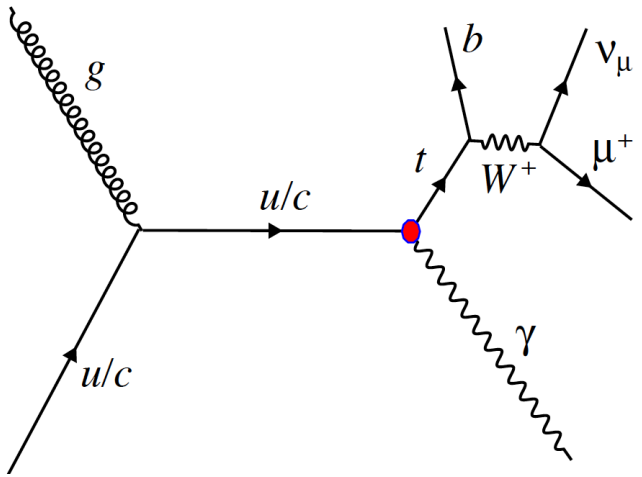
FCNC in Single Top

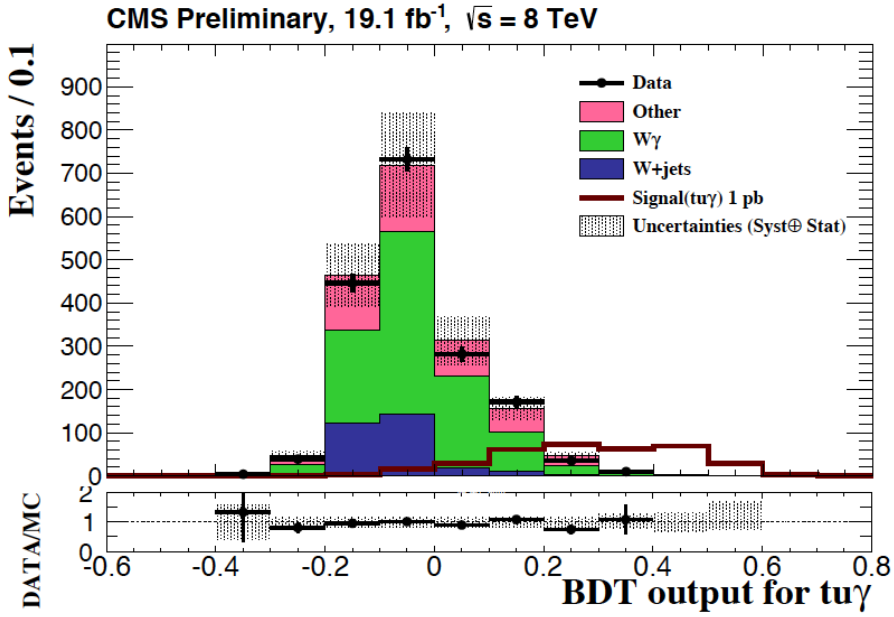
- Search for FCNC in tqγ vertices in single top

- Event selection:
  - 1 isolated high energy photon
  - 1 isolated muon + $E_{T,\,miss}$ > 30 GeV
  - ≥ 1 jet, ≤ 1 b-tags

- Limits from 8 variable BDT:

  $K_{tu\gamma} < 0.028$, $K_{tc\gamma} < 0.090$





PRL 112 (2014) 171802

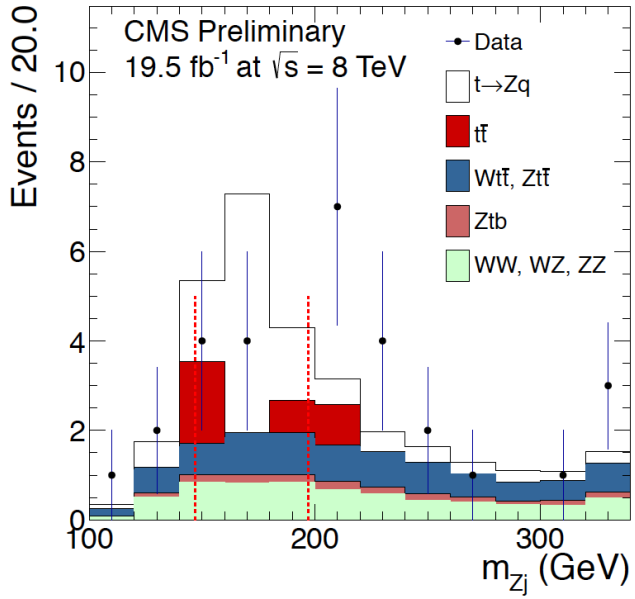
FCNC in top pair production

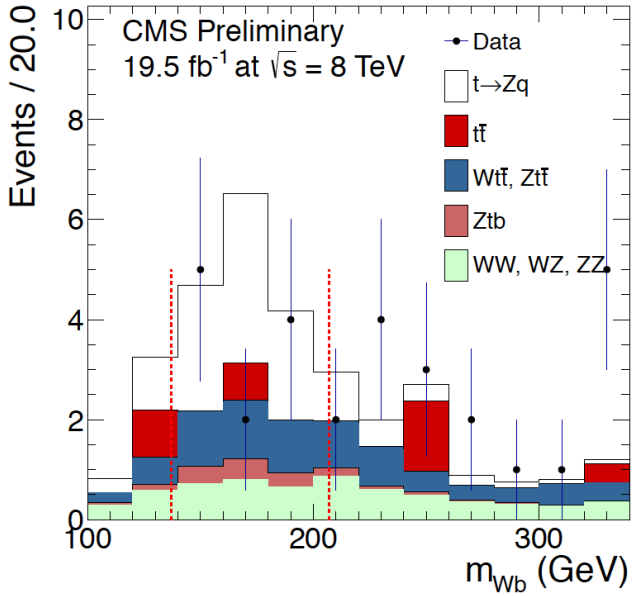
- Search for decays t → Zq
- Event selection:
  - 2 opposite sign leptons in Z-mass window + 3rd lepton
  - $E_{T,miss}$ > 30 GeV
  - ≥ 2 jets with exactly 1 b-tag
- Reconstruct top-mass from light jet + Z and b-jet + W

  → apply top mass window
- Limit on branching fraction of t → Zq (7 + 8 TeV combined):

  0.05% observed

  0.09% expected





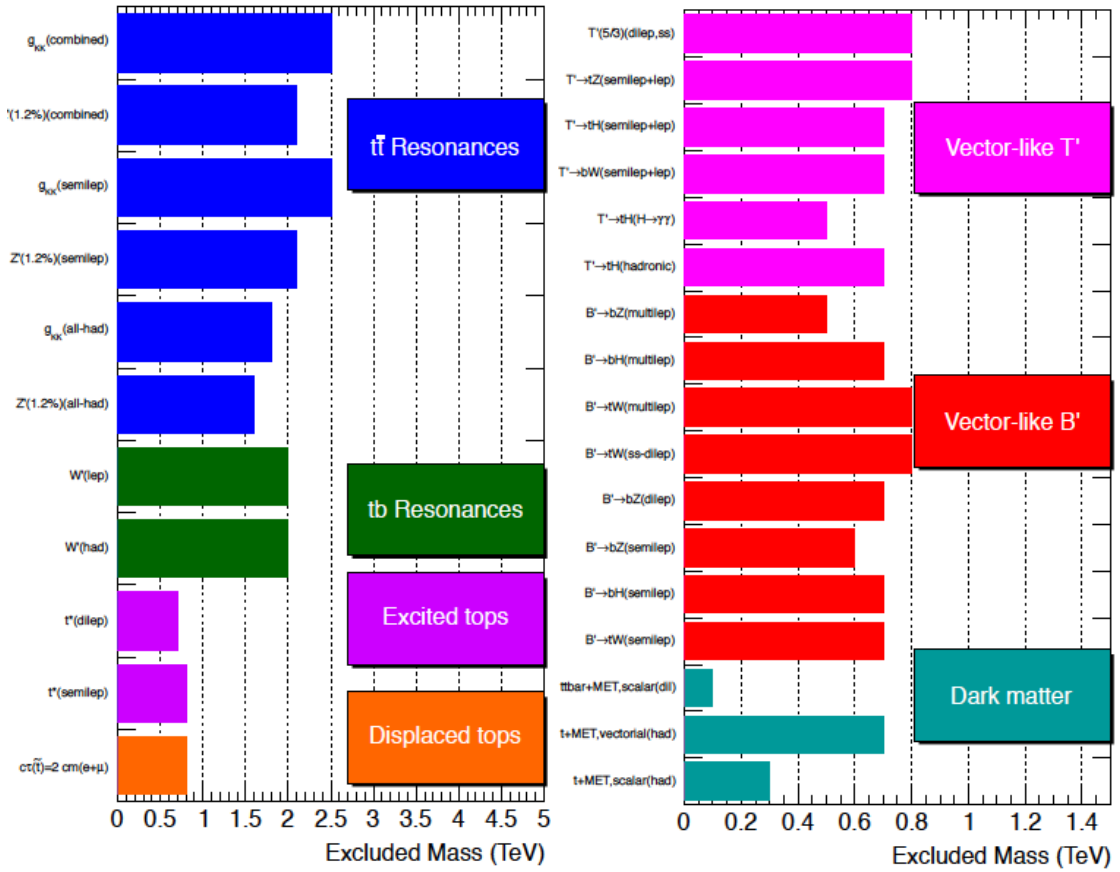
Summary

- Wide variety of new physics models tested in CMS analyses

  → even more results than covered in this talk

- Cutting edge substructure techniques to handle boosted topologies

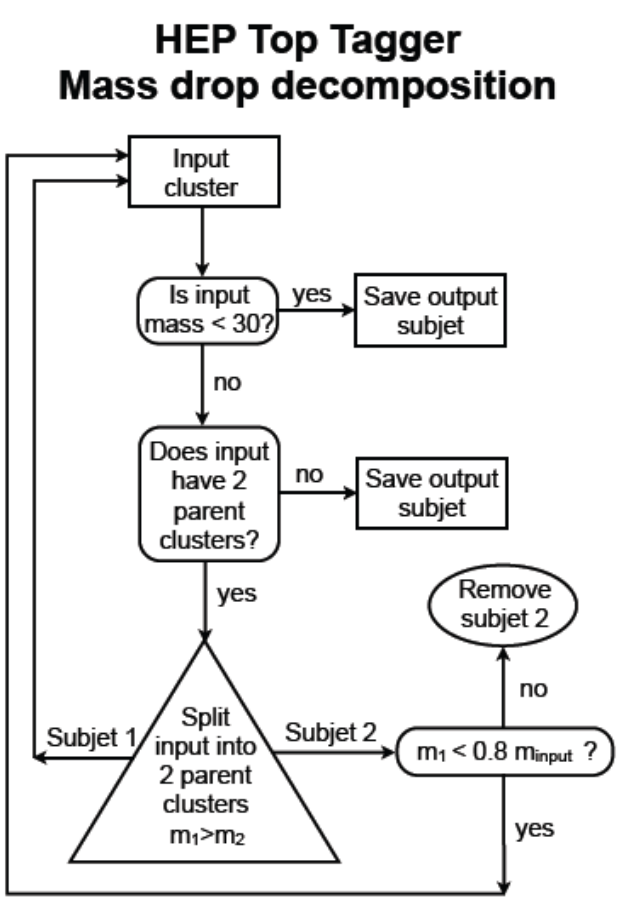
- No indications for new physics so far, but: limits in previously unexplored regions

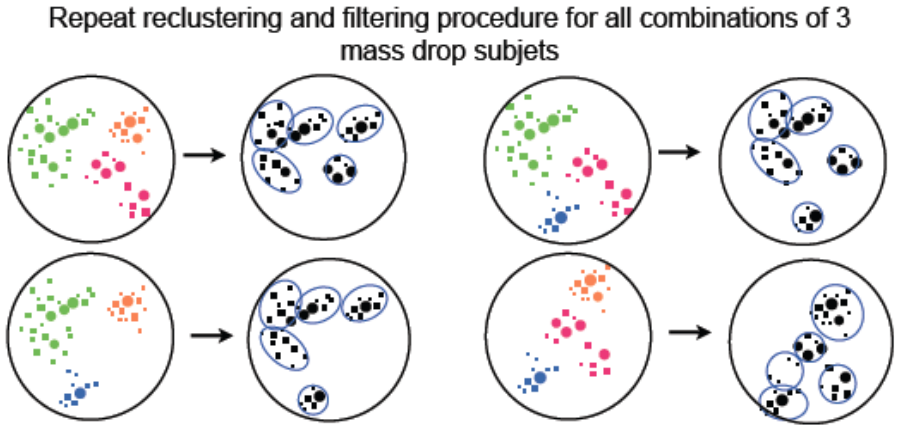


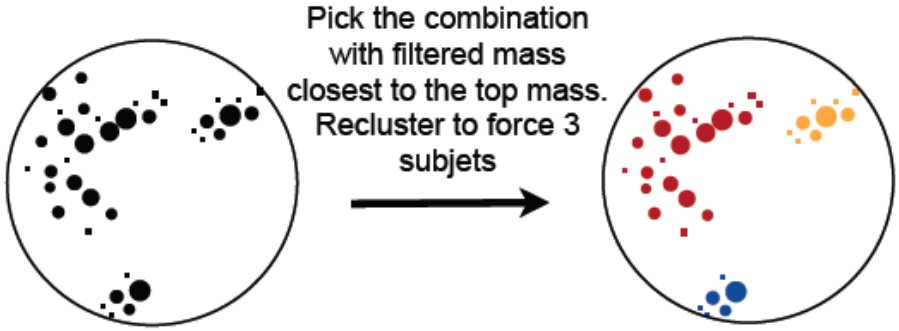
Focus now: Preparation for 13 TeV run
→ Exciting times still ahead

Backup

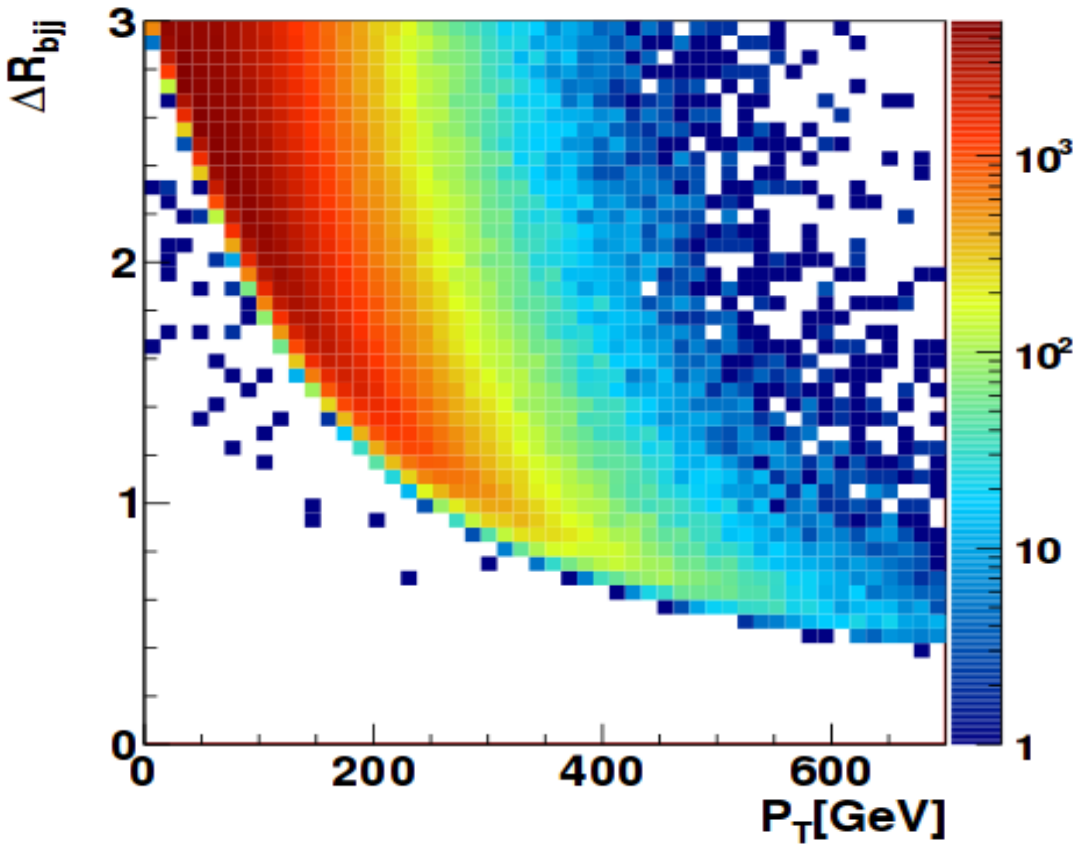
HEPTopTagger Mass decomposition



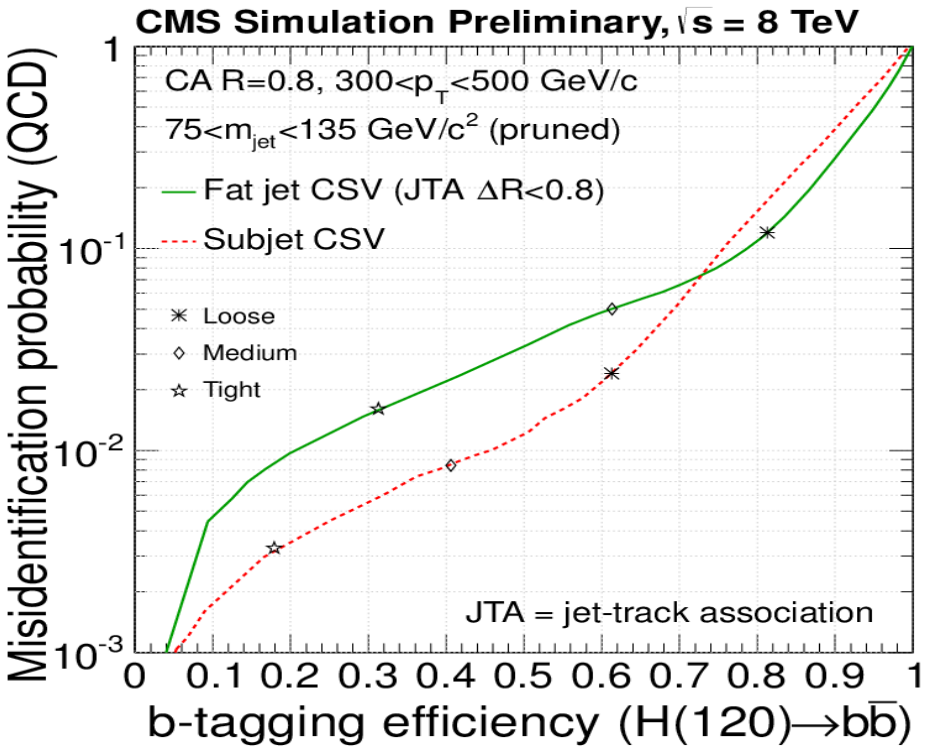


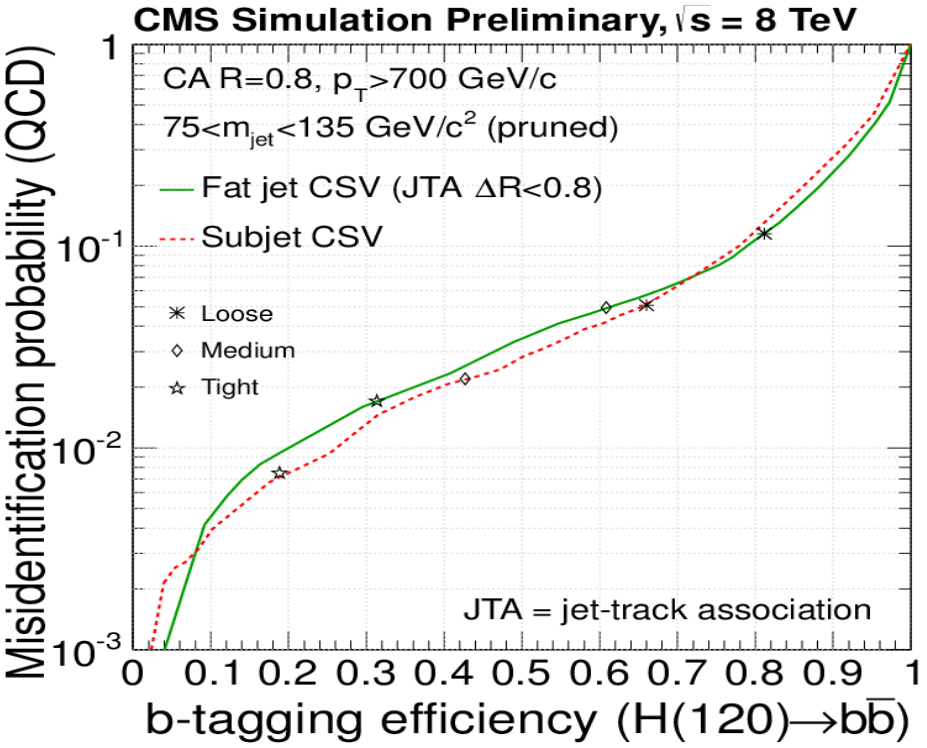


Jet Cone Size vs. jet pT



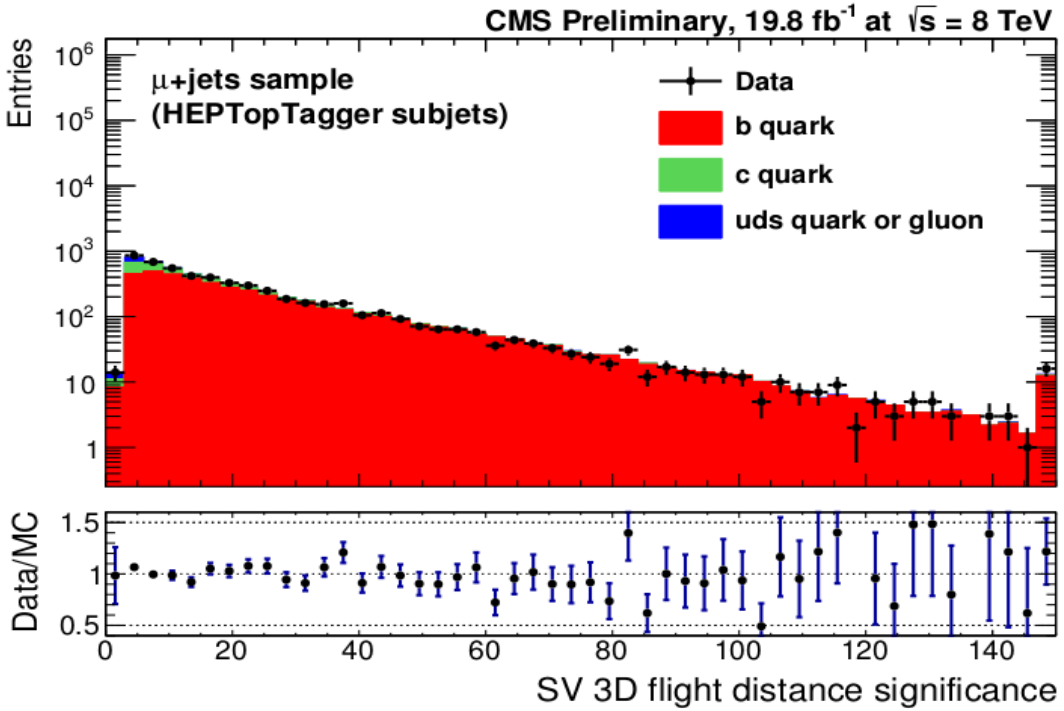
Subjet b-tagging



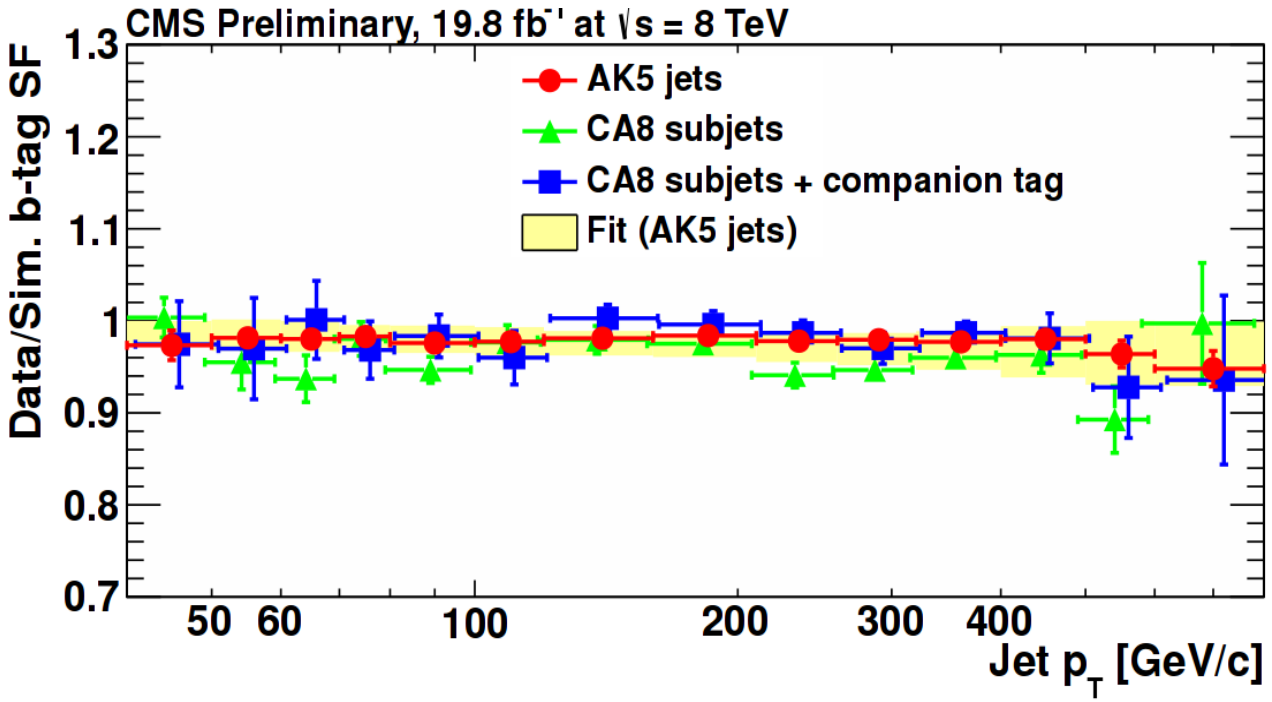


Subjet b-tagging outperforms fat jet b-tagging

Subjet b-tagging



- Good data/MC agreement for b-tagging observables.
- All observables cross-checked

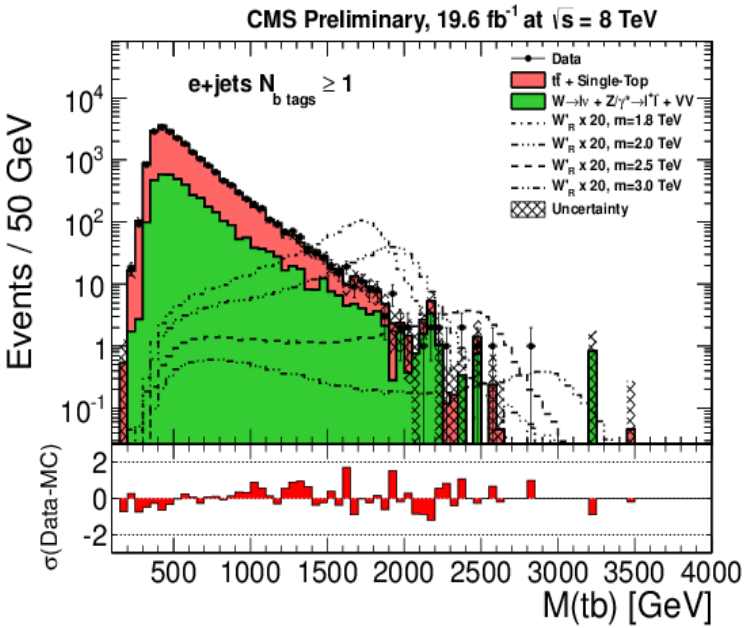


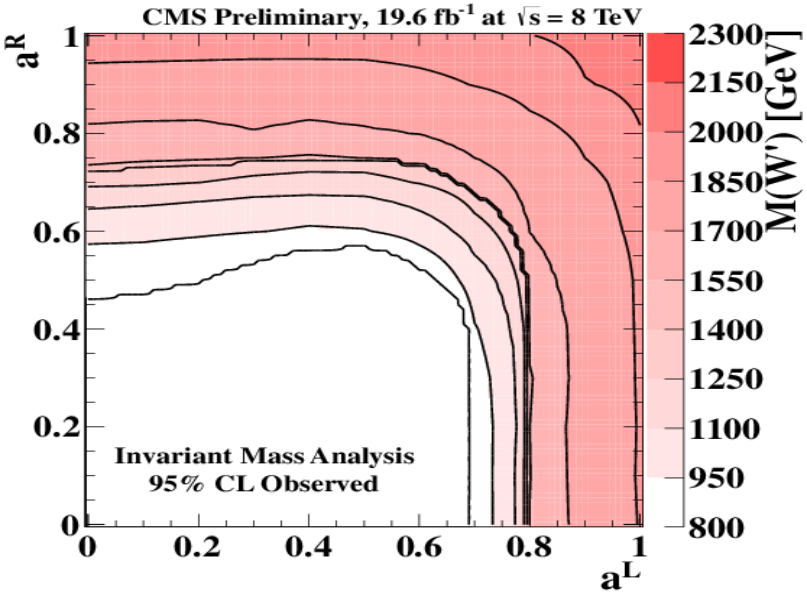
- SF~1, compatibly with SF for standard b-tagging in the non-boosted regime, for both channels.

hep-ex:1402.2176

Leptonic W' → tb

- Leptonic top decay:
  - one isolated lepton (e, μ)
  - 2 jets, one b-tagged
- Top reconstruction
  - $W = P_T^{miss} + lep$
  - W+jet closest to top mass
- Observable M(tb):
  - combine top with highest-p_T jet
- Both left- and right-handed W' couplings considered:
  - Accounting for left-handed interference with SM
- Limits for W'_R: m> 2.03 TeV

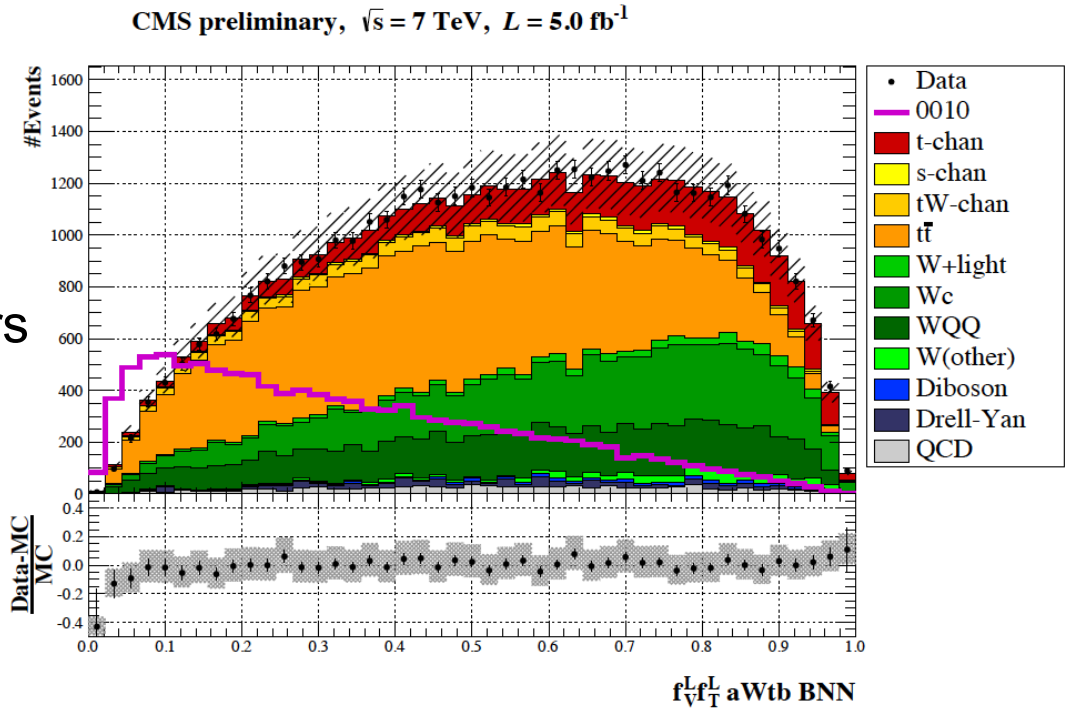




CMS PAS TOP-14-007

FCNC in Single Top

- Search for anomalous Wtb couplings in single top t-channel events
- Event selection
  - == 1 muon
  - 2 or 3 jets & 1 b-tag
- Bayesian Neural Networks in 3 tiers
  - QCD suppression
  - SM signal extraction
  - identify anomalous couplings



- 2D BNN discriminant used as input for limit setting
- Limits: $|f^L_T| < 0.09$

  $|f^R_V| < 0.34$
- Also limits on tcg/tug interactions

Dark Matter Searches

CMS PAS B2G-12-022

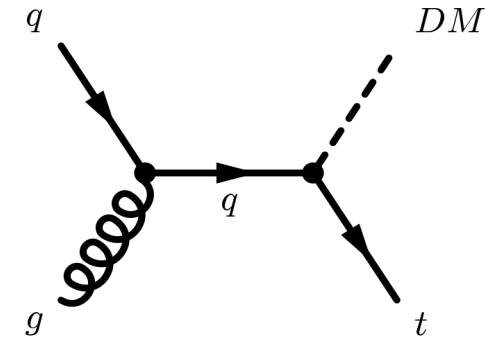
Monotop Search

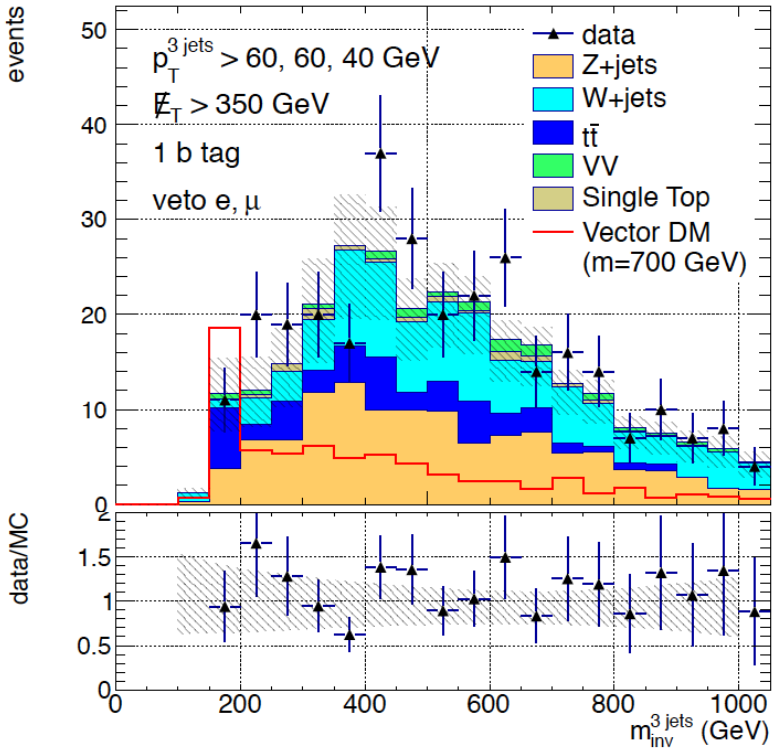
- Scalar or vector dark matter particle produced via FCNC

- Selection:
  - large $E_{T,miss}$ >350 GeV
  - hadronic top decay:
    - 3 jets
    - 1 b-tag
    - No isolated lepton
    - M_{jjj} < 250 GeV

- Limits: 327 GeV for scalar DM

  655 GeV for vectorial DM





CMS PAS B2G-13-004

Dilepton Dark Matter Search

- Search for Dirac fermion interacting via contact interaction
- Produced in association with top quark pair
- Event selection
  - $E_{T,\,miss} > 320$ GeV
  - 2 isolated leptons
  - 2 jets with $\Sigma p_T < 400$ GeV
- $\sigma > 0.09$ - 0.31 excluded for mass range of 1 GeV - 1 TeV
- Also set lower limits on interaction scale M_*