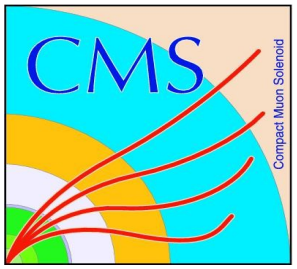


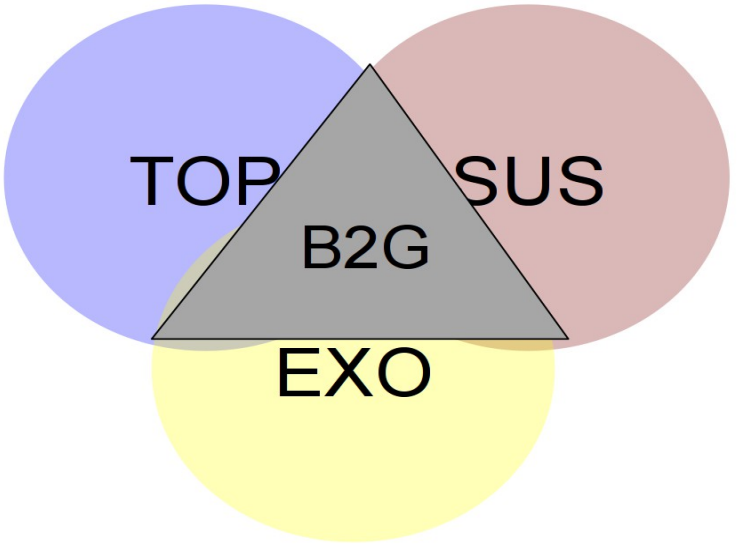
Universität Hamburg

New Physics with Top Quarks at CMS

Ivan Marchesini
on behalf of the CMS Collaboration
LHCP 2014, New York

Introduction

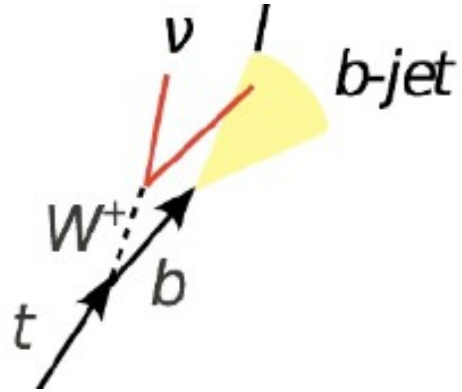
- Searches within "**Beyond 2 Generations**" group:
  - **non-SUSY searches** mostly with top quarks
  - intersection of Top, Susy, Exotic physics
  - challenging final states: involved in development of **cutting edge reconstruction techniques**

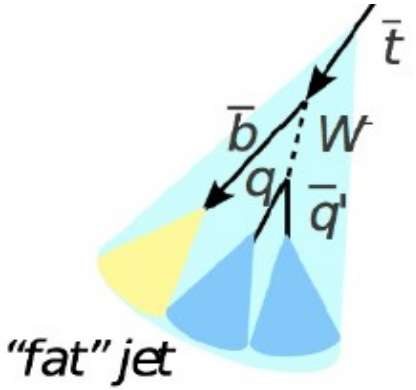


- Personal selection with focus on recent results. More at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Analysis Techniques

Boosted regime: **classical selection methods fail**





➔leptons close to jets

➔decay products from heavy particles **merged into large fat-jets**
➔Cambridge-Aachen (CA) jets R=0.8/1.5
➔**jet substructure**

Substructure Tools

[CMS-PAS-JME-13-006/007, CMS-PAS-BTV-13-001]

Top Taggers:

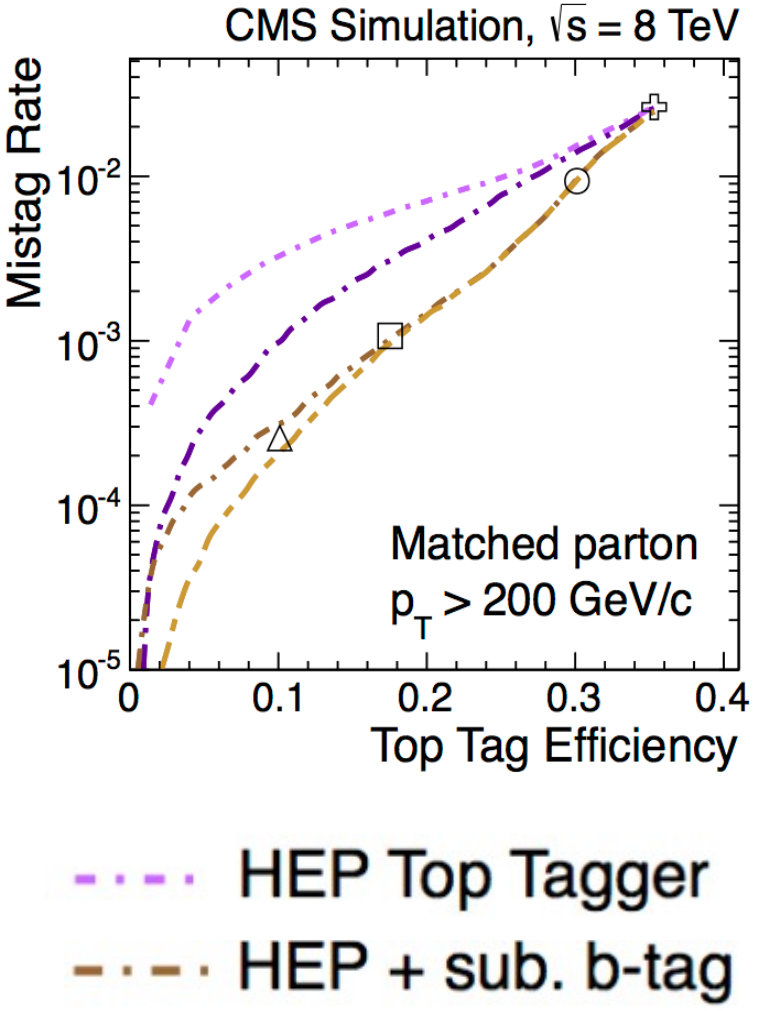
- **CMS Top Tagger**, based on **CA8 jets**
- **HEP Top Tagger**, uses **CA15 jets**

  - substructure: ≥ 3 subjets
  - jet and subjets mass requirements (top and W masses)

W/Z/H-Tagging based on **CA8 jets**:
substructure=2 subjets + mass cut

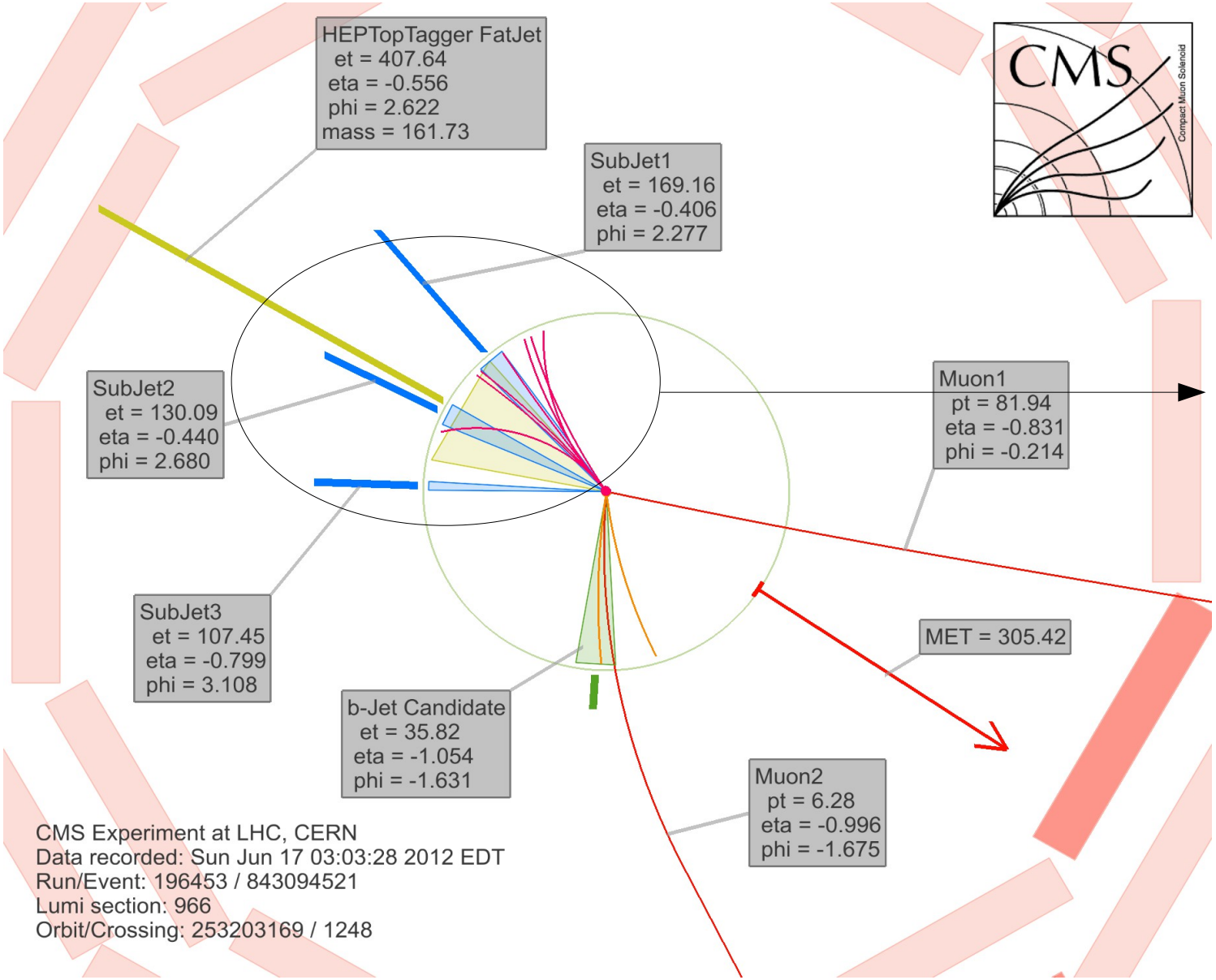
Subjet b-tagging:

- displaced tracks and secondary vertices (SV) within subjet to build b-discriminator
- improves top-tagging + **H→bb tagging**



Substructure Tools

[CMS-PAS-JME-13-006/007, CMS-PAS-BTV-13-001]



Semileptonic ttbar event display

hadronic decay:

- **3 HEP Top Tagger subjets**
  substructure + mass requirements to tag top
- **displaced tracks + SV** within one subjet:
  b-tag

BSM Resonances

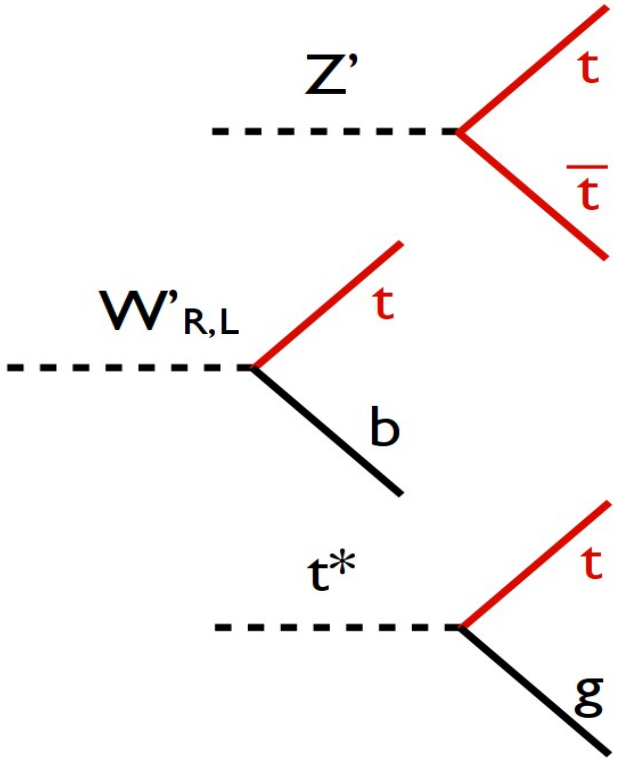
New Physics: BSM Resonances

- **Resonances in BSM models**:

  Z'→tt, W'→tb, t*→tg

- Predicted in **many models**:

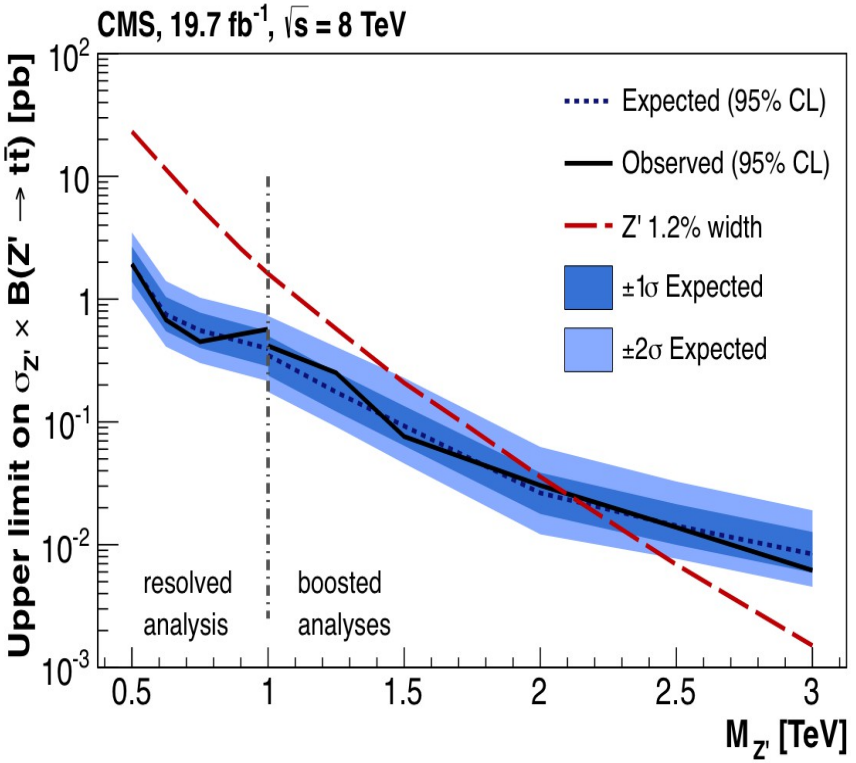
  - extended gauge sectors
  - top-colour condensates
  - warped extra dimensions
  - Kaluza-Klein excitations
  - compositeness: excited top quarks



Resonances→ttbar

[Phys. Rev. Lett. 111, 211804]

- **Boosted full hadronic**:
  - 2 back-to-back high-p_T jets
  - both **CMS top-tagged**
- **Boosted semi-leptonic**:
  - high-p_T CA8 jet (hadronic decay)
  - **lepton** (e, μ): **no isolation** required
  - n b-tag event categories
- **Resolved semi-leptonic**:
  - 4 jets, **isolated lepton**, E_T^{miss}

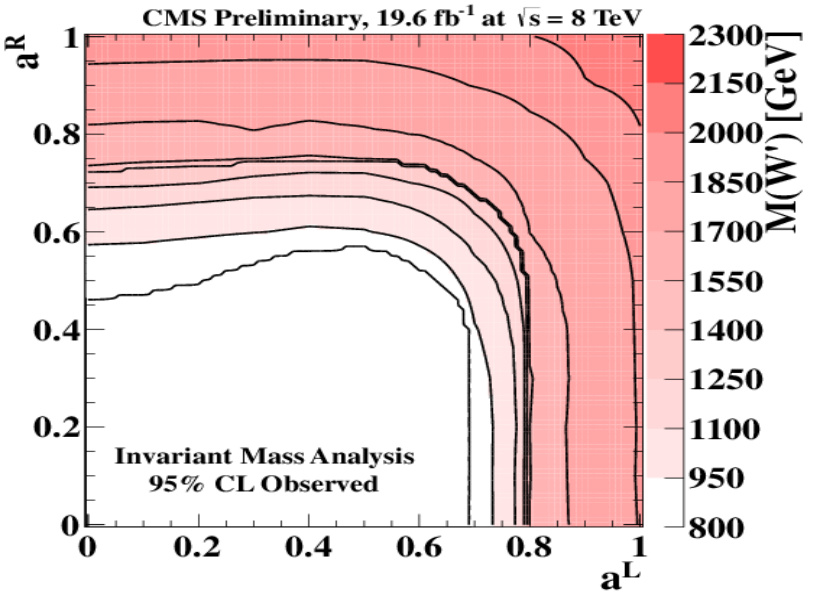


- Bump-hunt search in M_{tt}
- **Various theory models considered**: limits between 2.1-2.5 TeV

W'→tb Resonances

[hep-ex:1402.2176, accepted by JHEP]

- Top leptonic decay:
  - one **isolated lepton** (e, μ)
  - 2 jets, one b-tagged
- **Observable M(tb)**:
  - top candidate+highest-p_T jet
- Both **left- and right-handed W'** couplings considered:
  - accounted left-handed interference with SM
- Limits for W'_R: m> 2.03 TeV

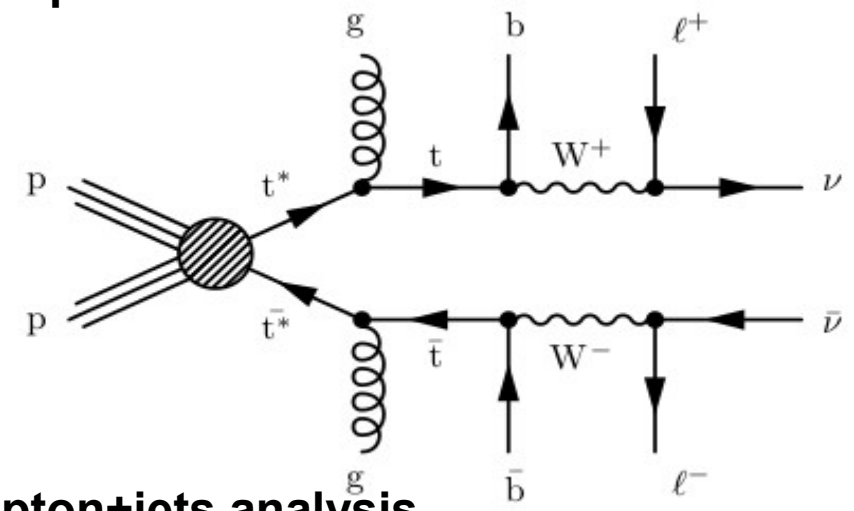


Excited Top Quarks

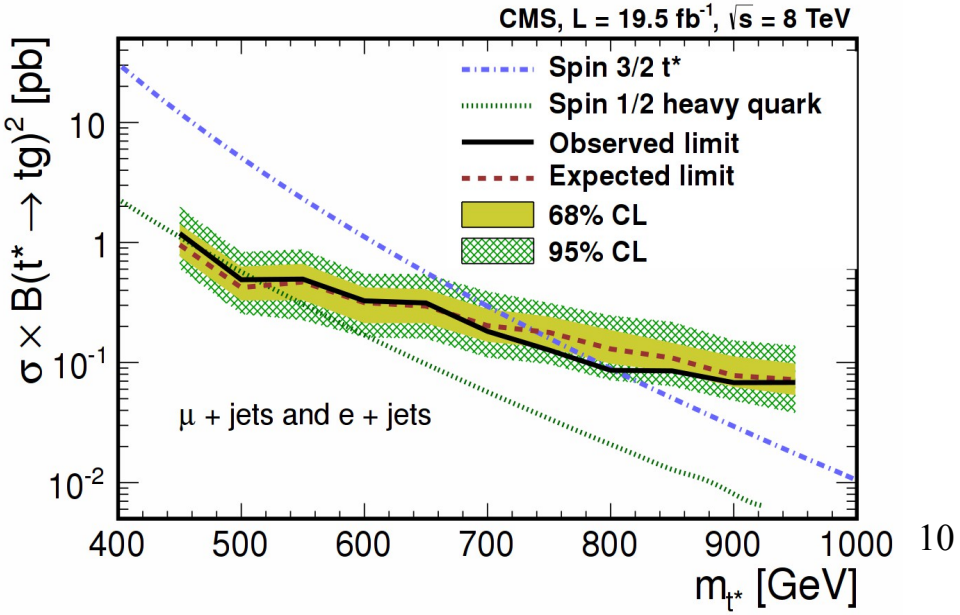
[hep-ex:1311.5357 (sub. to JHEP), CMS-PAS-B2G-12-008]

- ttbar signature + ≥2 jets
- **Lepton+jets**:
  - one isolated lepton (e, μ)
  - ≥6 jets, one b-tagged
- **Di-lepton**:
  - two isolated leptons (e, μ)
  - 2 b-tagged jets
  - 2 non b-tagged jets
- **Mass t* reconstruction**:
  - from objects in final state
- Limits from M_{t^*} shape for different models: $m_{t^*} < 803$ GeV for spin-3/2 t*

Di-lepton



Lepton+jets analysis



VLQ Searches

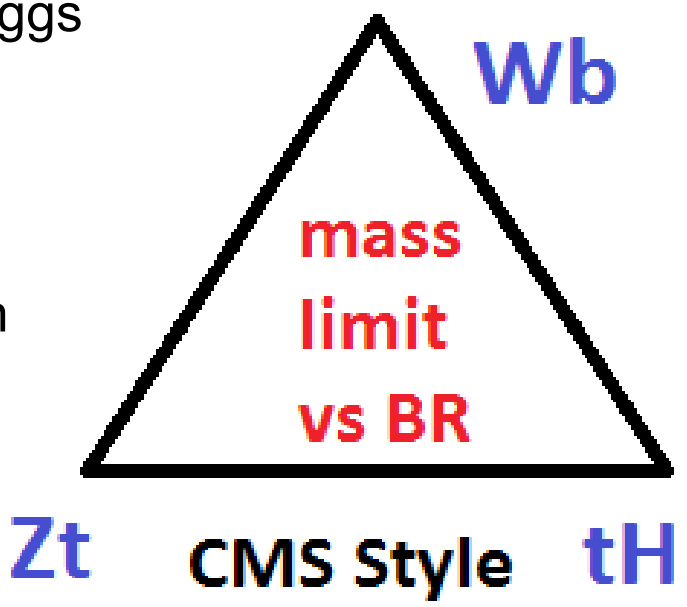
New Physics: Vector-Like Quarks

- **Minimal SM extension with 4th generation** of quarks replicating SM ones **excluded** after Higgs discovery

- Still interesting:
  - **vector-like quarks**
    L- and R-handed chiralities transformed in the same fashion under SU(2)⊗U(1)

- Predicted by many models:
  - Little-Higgs models
  - composite Higgs models
  - warped extra dimensions

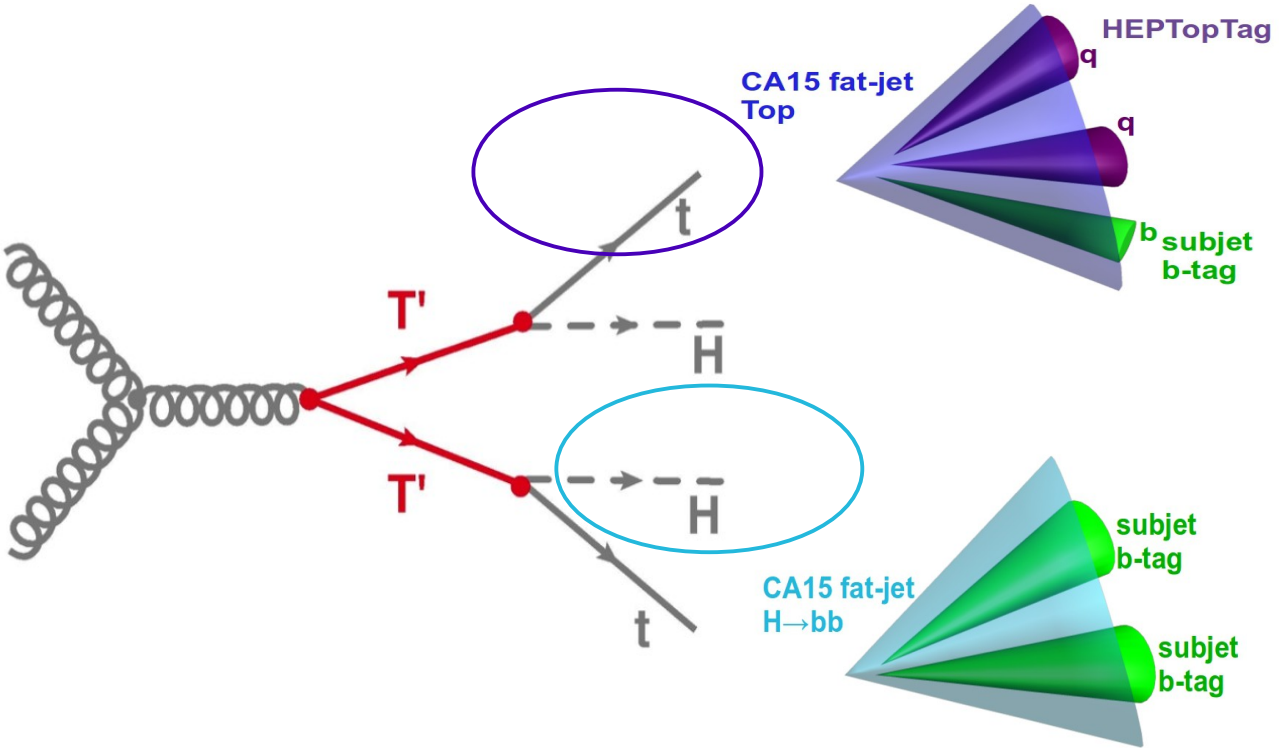
- Current results for **pair production**



Decays:
Top-like T': T'→Wb, Zt, Ht
Bottom-like B': B'→tW, bH, bZ

Fully Hadronic T'→tH, H→bb

[CMS-PAS-B2G-14-002]



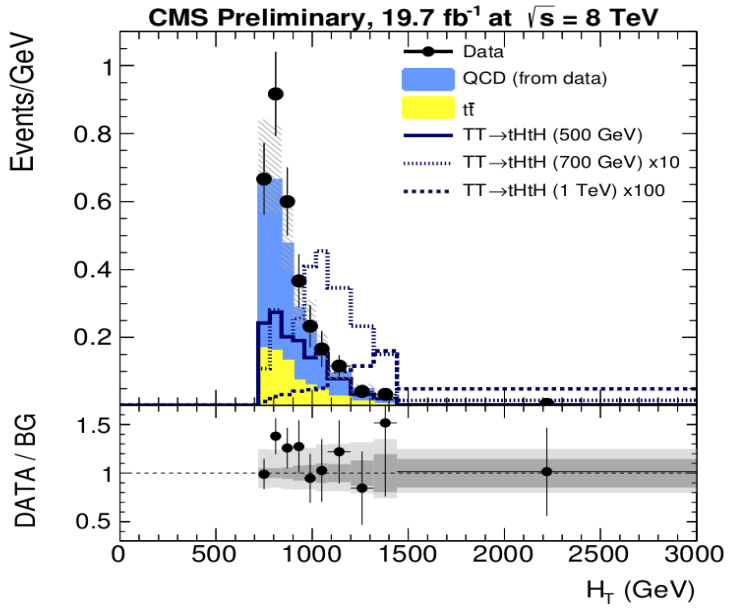
- Use of **most advanced substructure**:
  - → **HEPTopTagger**
  - → **subjet b-tagging** (**first time**)
- Increase acceptance:
  - → ≥ 1 top-tag and ≥ 1 Higgs-tag

top-tag:
HEPTopTagger
subjet b-tagging

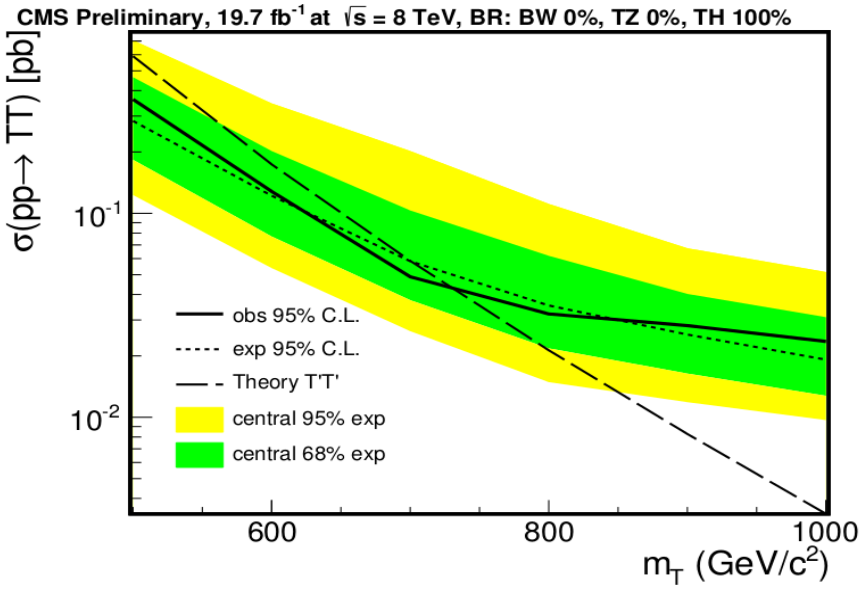
Higgs-tag, H→bb:
2xsubjet b-tagging
jet-mass > 60 GeV

Fully Hadronic T'→tH, H→bb
[CMS-PAS-B2G-14-002]

- Two observables **combined in Likelihood: $H_T = \sum p_T^{jets}$ and M_{Higgs}**
- ==1 and ≥2 Higgs-tags categories
- Use of substructure: **QCD background** reduced to the level of **ttbar**



H_T, ≥2 Higgs-tags bin



- Limits **competitive with leptonic final states**: obs. limit 747 GeV

T' in Leptonic Final States

[Phys. Lett. B 729 (2014) 149]

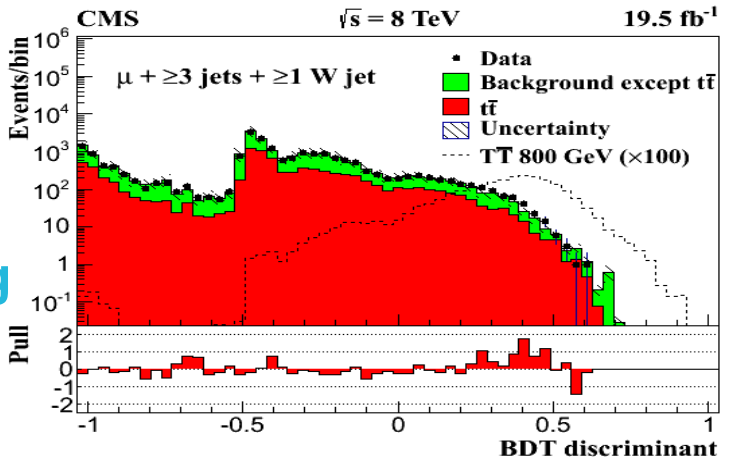
Single lepton:
multivariate analaysis
substructure

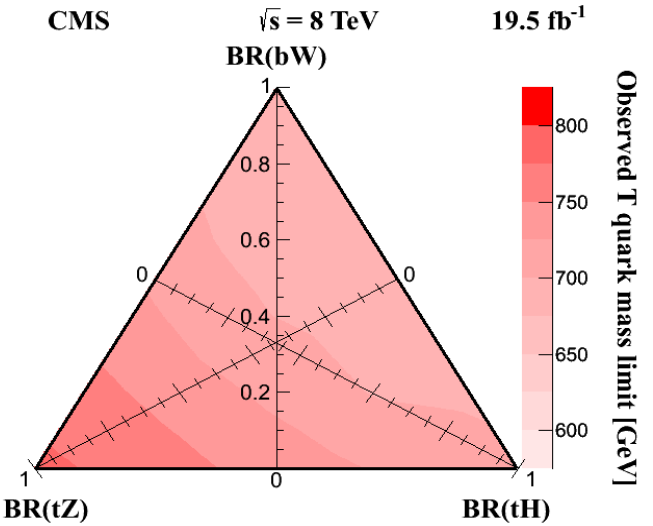
- two event categories: with or without **W-tag**
- **top-tagging** applied
- **boosted decision tree BDT**:
  - multiplicity/p_T of reconstructed objects (lepton, jets, tagged jets...)
  - N of b-, W- and top-tags

Multilepton:

- **counting experiment**
- event categories:
  - two/three leptons
  - opposite/same-sign di-leptons

BDT discriminant, single μ channel





final combined limit up to 782 GeV

B' VLQ Searches

[CMS-PAS: B2G-12-019, B2G-12-021, B2G-13-003]

Decays:
Bottom-like B': B'→tW, bH, bZ

Single lepton (e, μ)

- ≥4 AK5 jets, ≥1 b-tagged
- categories: number of **V-tags** (V=W/Z/H)
- limits based on $S_T = p_T^{lept} + p_T^{miss} + \sum p_T^{jets}$

Di-lepton

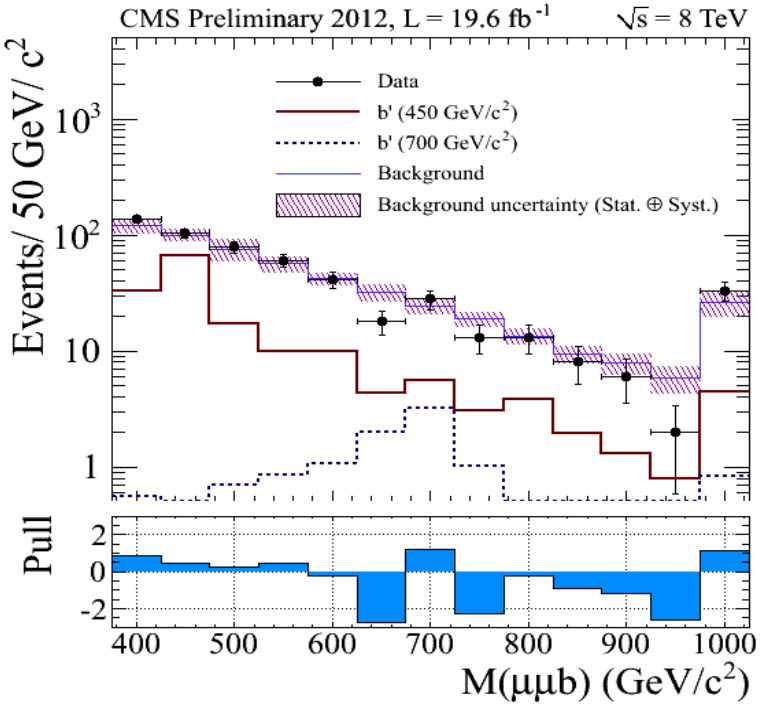
- opposite-sing leptons, from $Z \rightarrow l^+l^-$
- require Z mass + 1 b-tag
- limits from $M_{B'}$, $B' = Z \rightarrow l^+l^- + b\text{-}jet$

Multi-lepton

Event categories:

- opposite-sign/same-flavor lepton pairs:
  - number
  - on/off-shell Z
- hadronic tau candidate
- b-tag
- magnitude of S_T

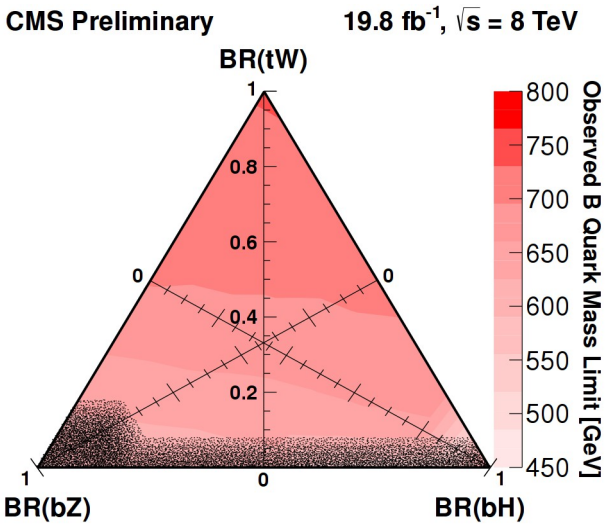
Mass B' candidate, di-lepton



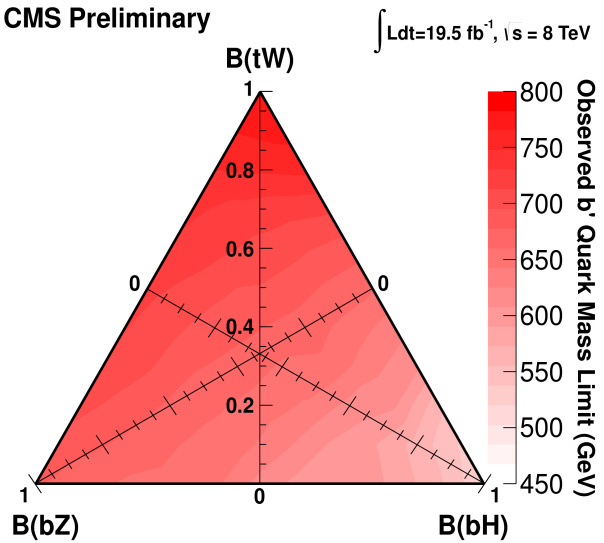
B' VLQ: Results

[CMS-PAS: B2G-12-019, B2G-12-021, B2G-13-003]

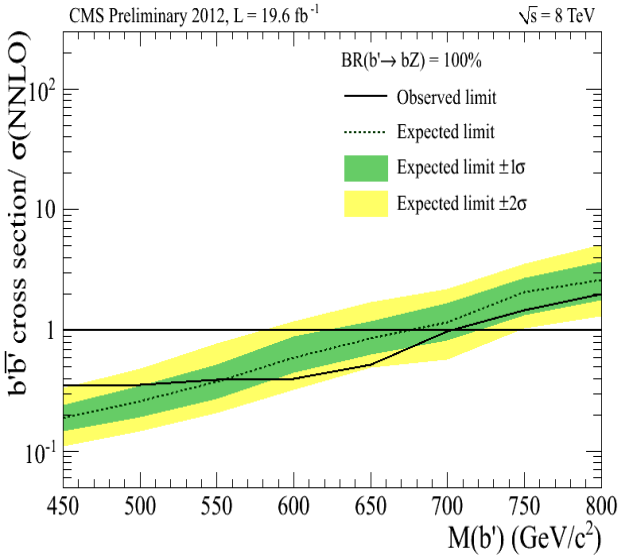
Single lepton



Multi-lepton



Di-lepton



final limit up to 732 GeV

final limit up to 785 GeV
competitive also in bZ corner

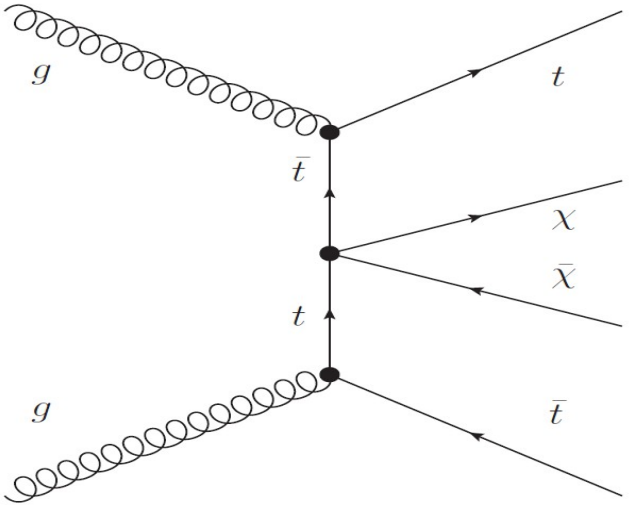
Contributes to bZ corner:
obs limit B'→bZ = 700 GeV

Other Searches with Tops

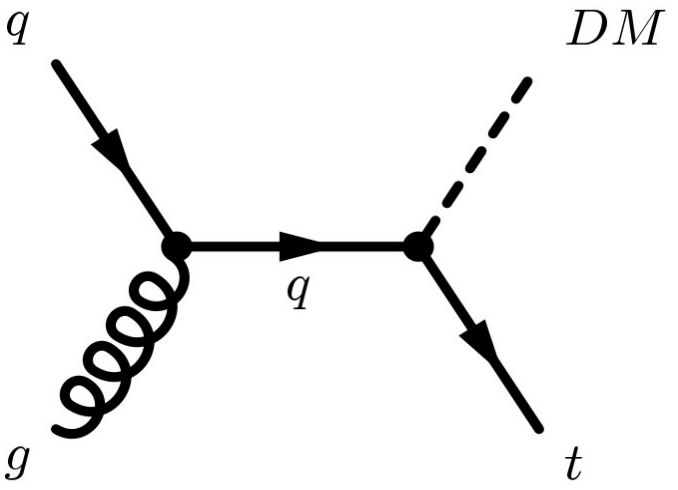
Dark Matter Searches

[CMS-PAS-B2G-13-004, CMS-PAS-B2G-12-022]

- **Di-lepton analysis**
  - DM particle is a **Dirac particle** interacting with quarks via **contact interaction**



- **Monotop analysis**
  - DM produced through **FCNC** diagrams
  - both **vector or scalar DM** boson possible: limits for both options

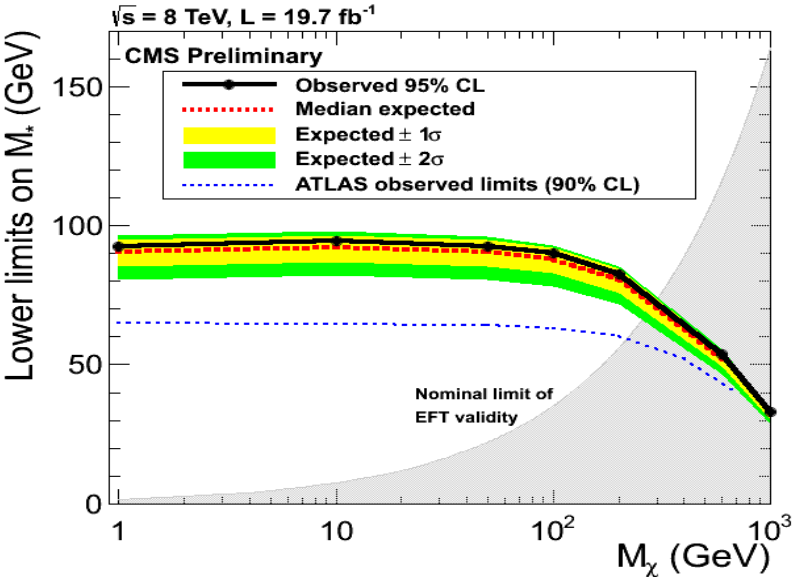


Dark Matter Searches

[CMS-PAS-B2G-13-004, CMS-PAS-B2G-12-022]

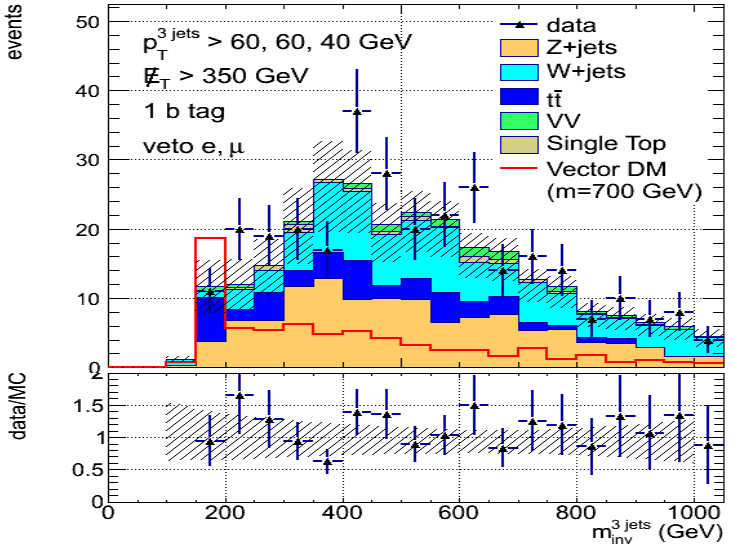
Di-lepton analysis

- ≥ 2 jets
- **E_T^{miss} > 320 GeV**
- **limits on the interaction scale M_***



Monotop analysis

- **hadronic top**: ==3 jets, M_{jjj}<250 GeV
- **E_T^{miss} > 350 GeV**
- 1 b-tag, no isolated leptons (e, μ)
- **M_{DM} limit: 327 GeV (scalar), 655 GeV (vector)**



Conclusions

- Rich **complexity of final states** investigated
- **Single VLQ production** searches effort started
- Boosted topologies: cutting edge **substructure** techniques
- No excess observed, but set **limits in so far unexplored regions**
- Current focus is preparation for 13 TeV

- Results not shown:
  - **T5/3 Top Partners** *[Phys. Rev. Lett. 112 (2014) 171801]*
  - **Barion Number Violation** *[Physics Letters B 731 (2014) 173]*
  - **Displaced Superymmetry** *[CMS-PAS-B2G-12-024] L. Vanelderen's talk*

Additional Slides

New Physics: Vector-Like Quarks

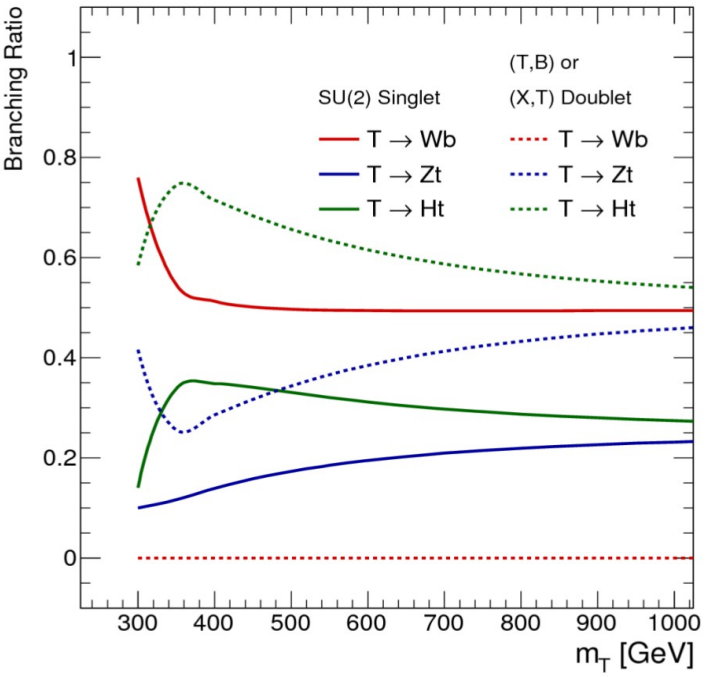
- **Sequential 4th generation** of quarks replicating SM ones **excluded** after Higgs discovery

- Still interesting:
  - **vector-like quarks**
    L- and R-handed chiralities transformed in the same fashion under SU(2)⊗U(1)

  - **quarks with exotic charges** (5/3)
    do not contribute significantly to the Higgs cross-section

- Predicted by many models:
  - Little-Higgs models
  - composite Higgs models
  - warped extra dimensions

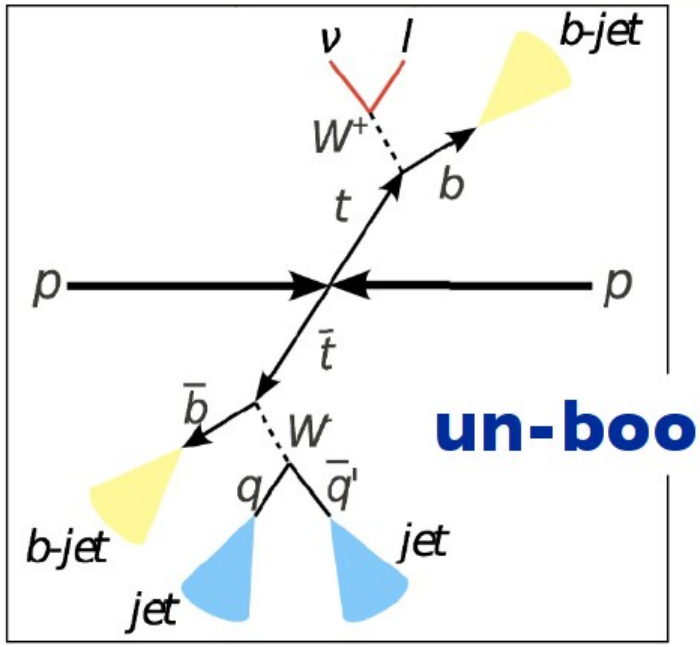
- Current results for **pair production**



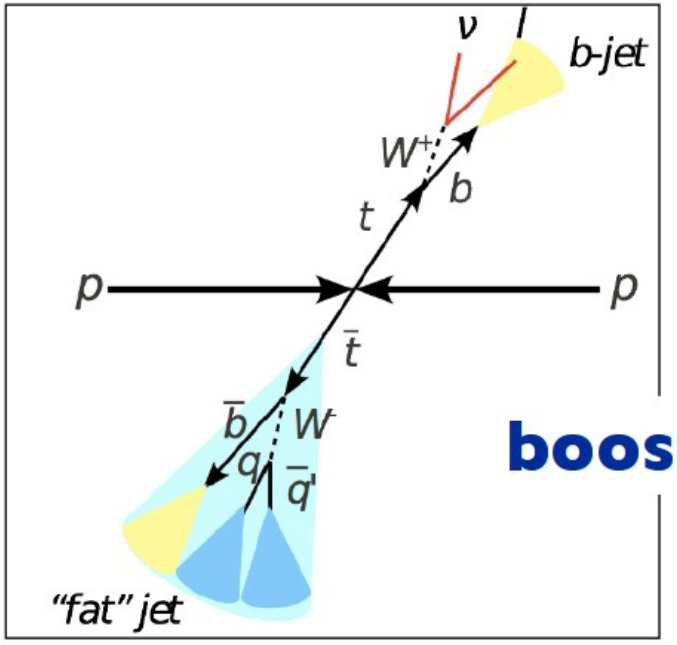
Decays:
Top-like T→Wb, Zt, Ht
Bottom-like B→tW, bH, bZ

Analysis Techniques

Boosted regime: **classical selection methods fail**



un-boosted



boosted

➔isolated leptons
➔multiple, **well separated jets**
➔Anti-kt jets R=0.5

➔leptons close to jets
➔decay products from heavy particles **merged into large fat-jets**
➔Cambridge-Aachen (CA) jets R=0.8/1.5
➔**jet substructure**

Substructure Tools

[CMS-PAS-JME-13-006/007, CMS-PAS-BTV-13-001]

Top Taggers:

- **CMS Top Tagger**, based on **CA8 jets**
- **HEP Top Tagger**, based on larger **CA15 jets**: smooth transition from low-p_T to boosted regime

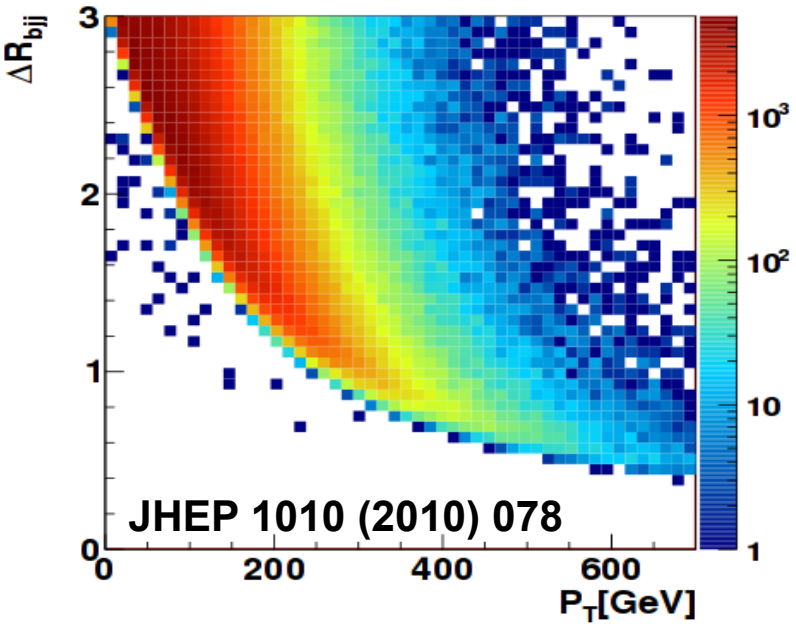
  - substructure: ≥ 3 subjets
  - jet and subjets mass requirements (top and W masses)

W/Z/H-Tagging based on **CA8 jets**: substructure=2 subjets + mass cut

Subjet b-tagging:

- full **dedicated commissioning** of b-tagging in the boosted regime
- displaced tracks and secondary vertices (SV) within subjet to build b-discriminator
- improves top-tagging + **H→bb tagging**

Spread top decay products vs p_T



Resonances

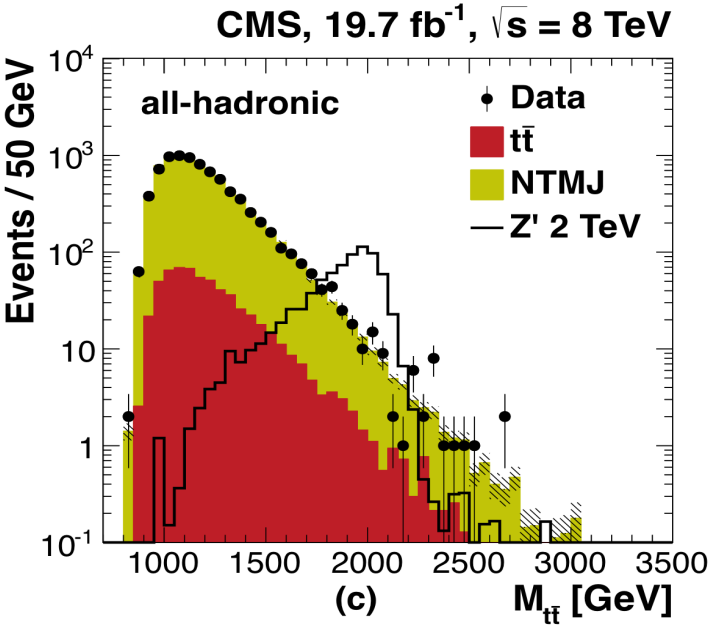
Resonances→ttbar

[Phys. Rev. Lett. 111, 211804]

Full hadronic:
- 2 back-to-back high-p_T jets
- both **CMS top-tagged**
- main background: **QCD**
  - data-driven estimation from signal-depleted regions (**anti-tag**)

Boosted semi-leptonic:
- high-p_T CA8 jet (hadronic decay)
- **non-isolated lepton** (e, μ)
- suppress QCD: cuts on $\mathbf{p_T^{rel}}$(lep,jet), $\Delta\mathbf{R}$(lep,jet), E_T^{miss}
- n b-tag event categories

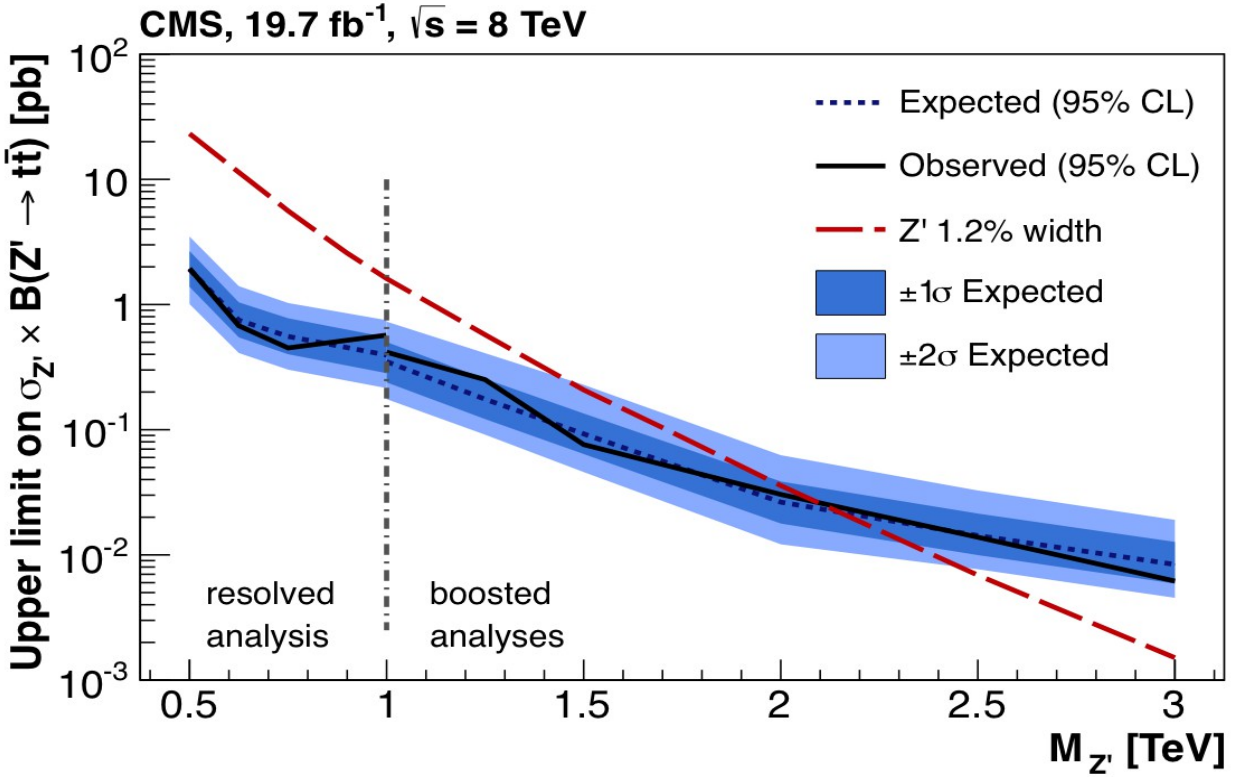
Resolved semi-leptonic:
- 4 jets, **isolated lepton**, E_T^{miss}



M_{tt} from hadronic analysis

Resonances→ttbar: limits

[Phys. Rev. Lett. 111, 211804]

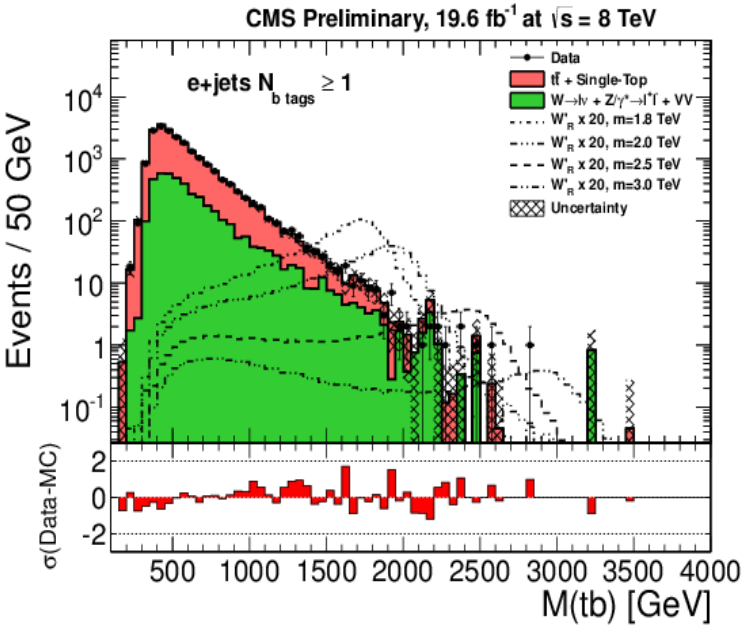


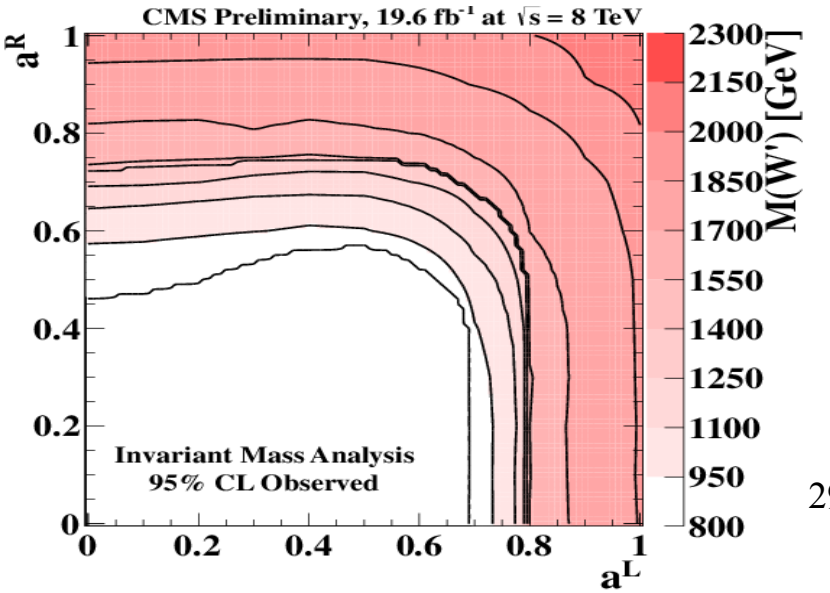
- Set limits based on **M_{tt} distributions**, combining three analyses.
- **Various theory models considered**:
  - narrow topcolor Z': m>2.1 TeV
  - topcolor Z' with 10% width: m>2.7 TeV
  - RS Kaluza-Klein gluon: m> 2.5 TeV

W'→tb Resonances

[hep-ex:1402.2176, accepted by JHEP]

- Top leptonic 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:
  - accounted left-handed interference with SM
- Limits for W'_R: m> 2.03 TeV





Excited Top Quarks

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

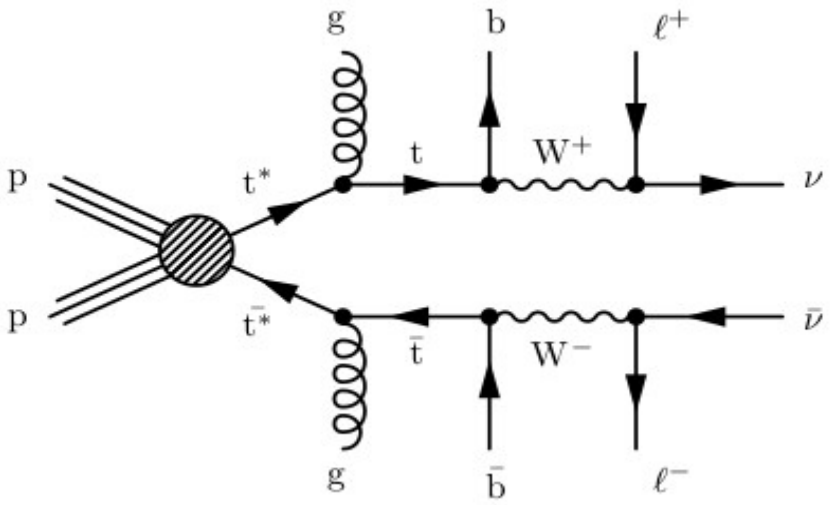
- ttbar signature + ≥2 jets

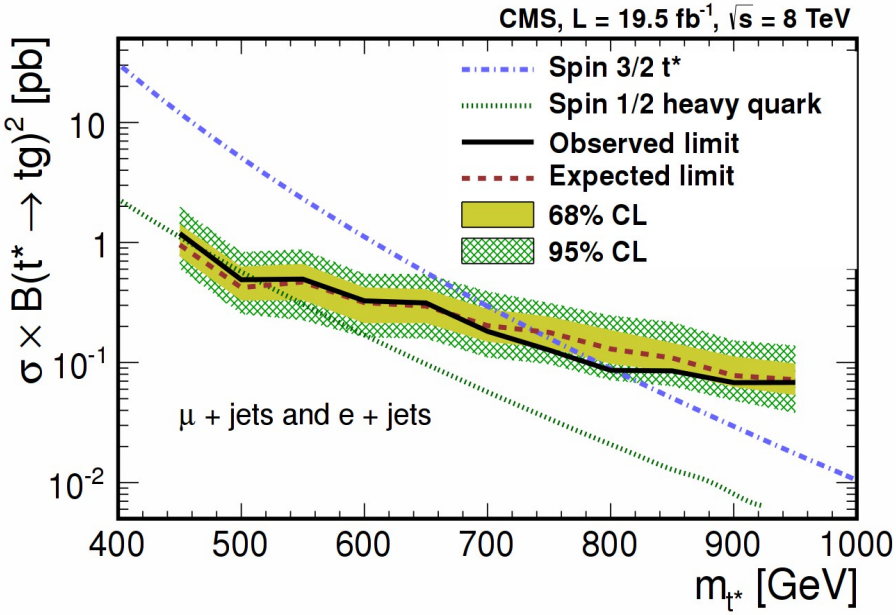
- **Lepton+jets**:
  - one isolated lepton (e, μ)
  - ≥6 jets, one b-tagged

- **Di-lepton**:
  - two isolated leptons (e, μ)
  - 2 b-tagged jets
  - 2 non b-tagged jets

- **Mass t* reconstruction**:
  - m(lνb)=m(qqb)=m_t
  - m(lνbg)=m(qqbg)=m_{t^*}, where m_{t^*} is a free parameter

- Limits from M_{t+jet} shape for different models: m_{t^*} < 803 GeV for spin-3/2 t*

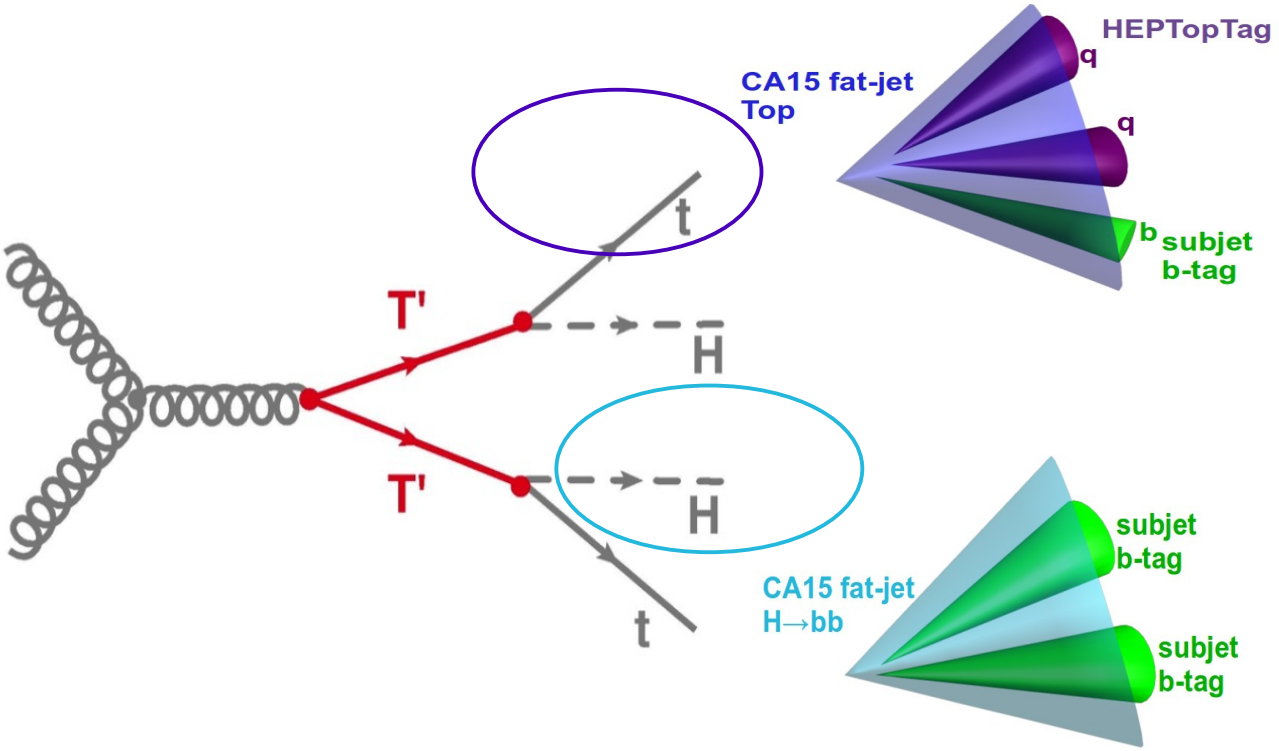




VLQ Searches

Full Hadronic T→tH

[CMS-PAS-B2G-14-002]



top-tag:
HEPTopTagger
subjet b-tagging

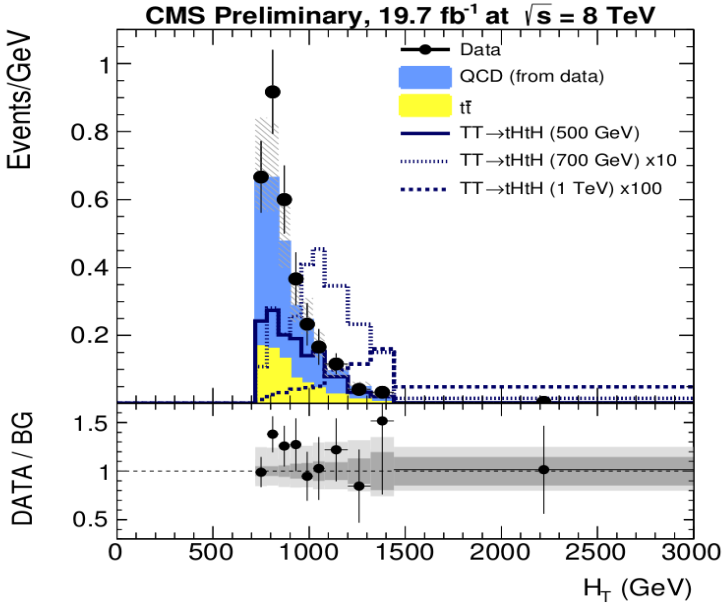
Higgs-tag, H→bb:
2xsubjet b-tagging
jet-mass > 60 GeV

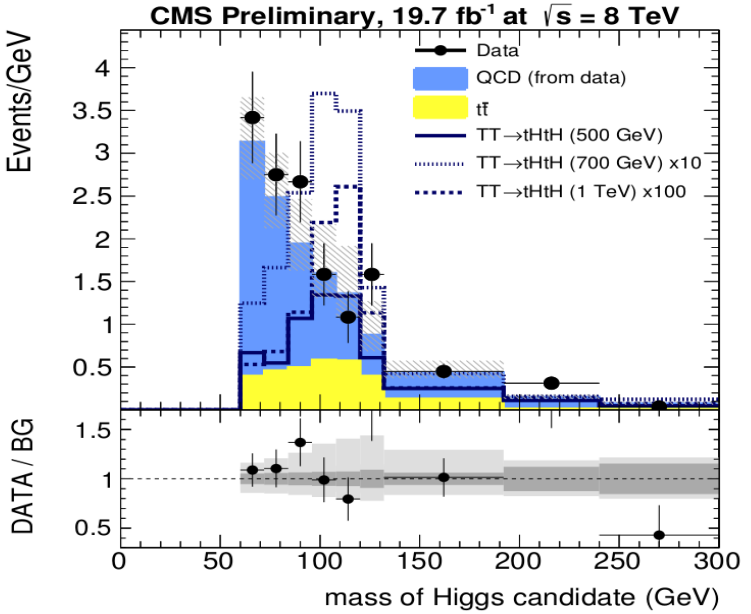
- Focusing on **large H_T** region, **boosted** final state
- Use of **most advanced substructure**:
  - **HEPTopTagger**
  - **subjet b-tagging** (first time)
- Increase acceptance:
  - ≥ 1 top-tag and ≥ 1 Higgs-tag
  - ≥ 2 Higgs-tags as very signal-enriched event category

Full Hadronic T→tH

[CMS-PAS-B2G-14-002]

- Use of substructure: **QCD background** reduced at the level of **ttbar**
- Two observables **combined in Likelihood: H_T and MHiggs**
- ==1 and ≥2 Higgs-tags categories



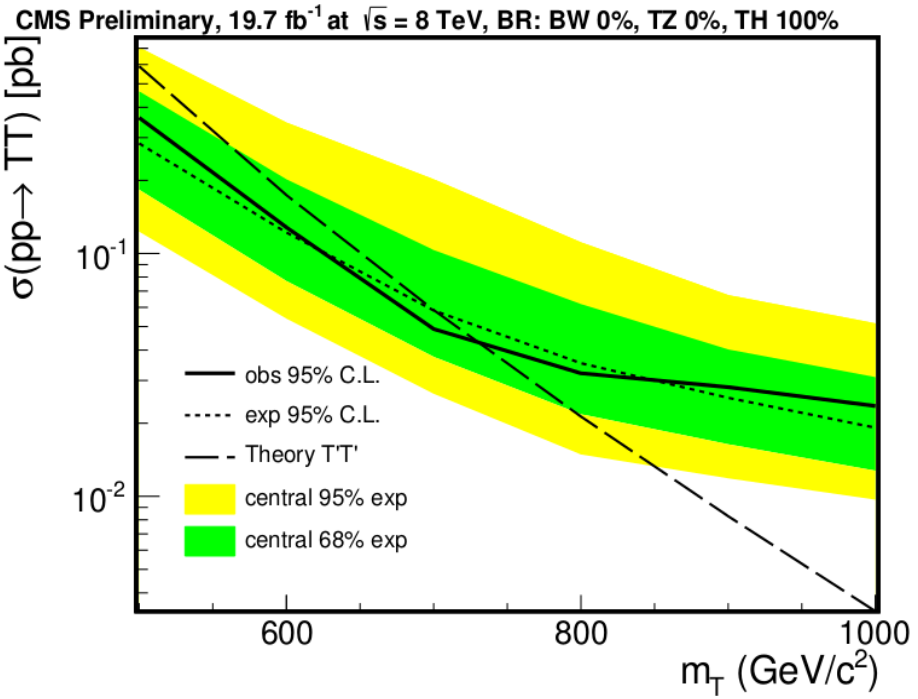


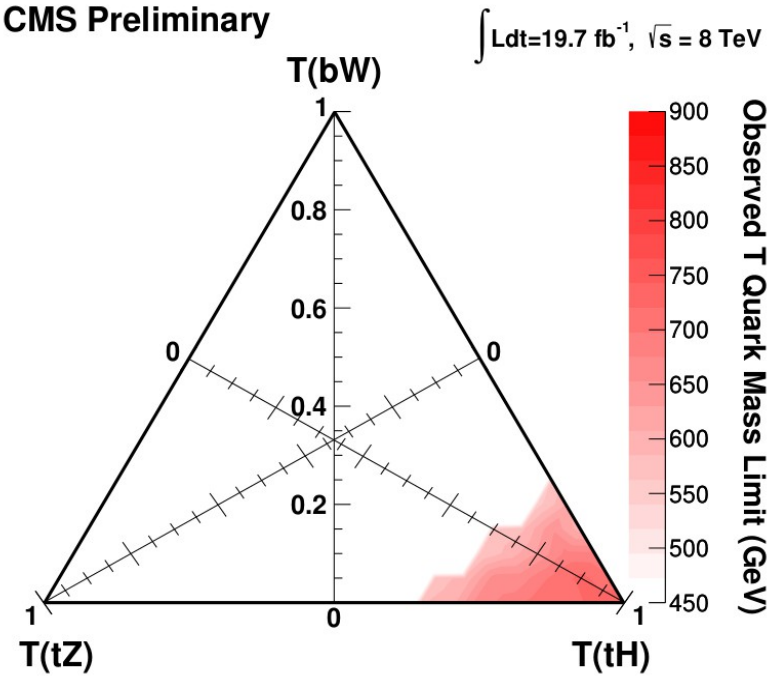
≥2 Higgs-tags bin

Full Hadronic T→tH

[CMS-PAS-B2G-14-002]

- Limits competitive with leptonic final states: obs. limit 747 GeV
- Optimized for T→tH final state, but cross-section limits provided also for mixtures with T→tZ and T→bW decays





T: Lep.+Jets and Multilept.

[Phys. Lett. B 729 (2014) 149]

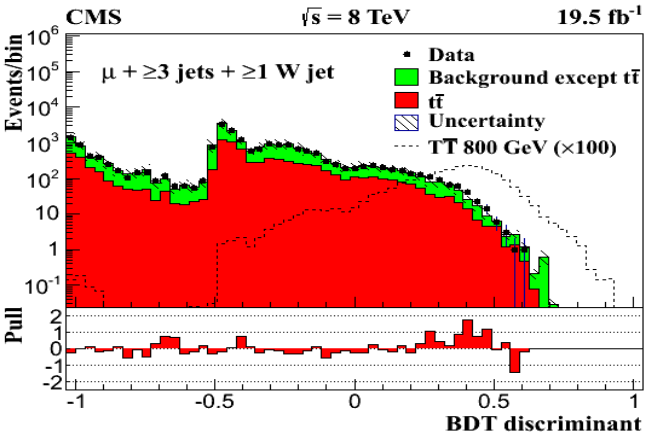
Single lepton:
multivariate analysis
substructure

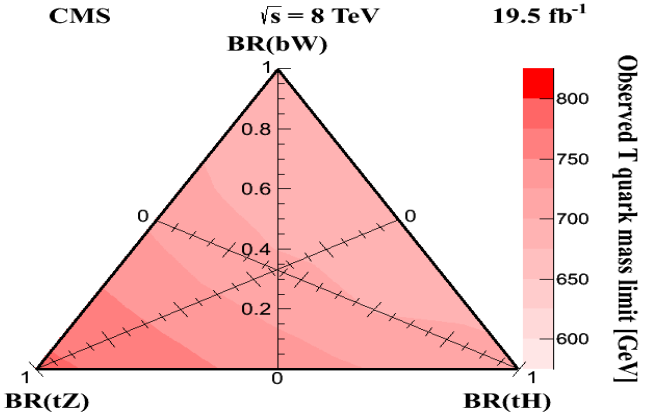
- two event categories: with or without **W-tag**
- **top-tagging** applied
- observables combined in BDT:
  - multiplicity/p_T of reconstructed objects (lepton, jets, tagged jets...)
  - N of b-, W- and top-tags

Multilepton:

- ➔ counting experiment
- ➔ event categories:
  - two/three leptons
  - OS dilepton or SS

BDT discriminant, single μ channel



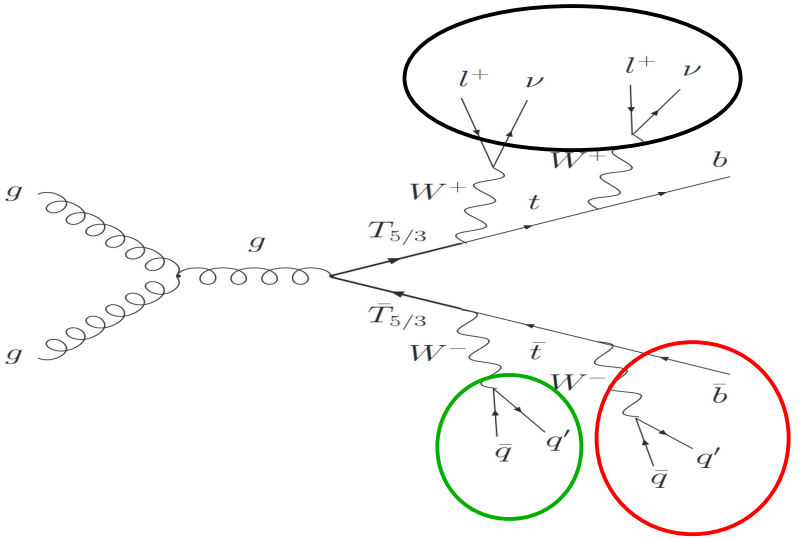


final combined limit up to 782 GeV

T5/3 Top Partners

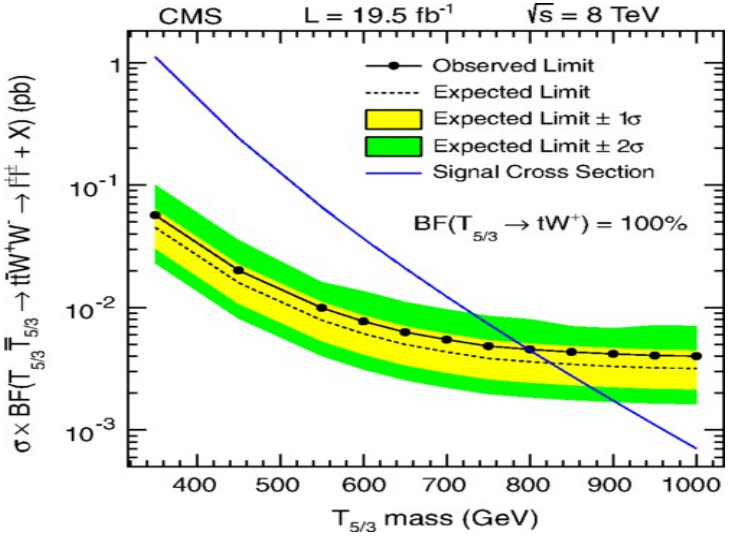
[Phys. Rev. Lett. 112 (2014) 171801]

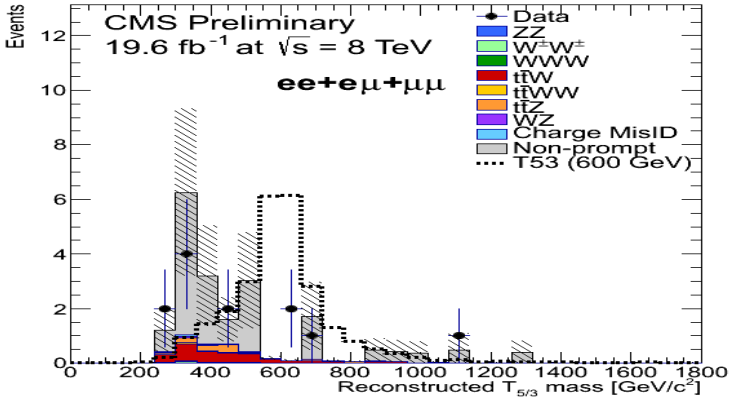
- Signal:
  - pair-produced **T with charge 5/3**
  - not contributing to Higgs coupling to gluons: not excluded by SM Higgs BR
  - BR 100% **T→tW**



- Selection:
  - two **same sign leptons**
  - **top-tagging**
  - **W-tagging**

- Limits from event yields: 800 GeV





reconstruction of T mass from all channels

Bottom Partners: Lepton+Jets

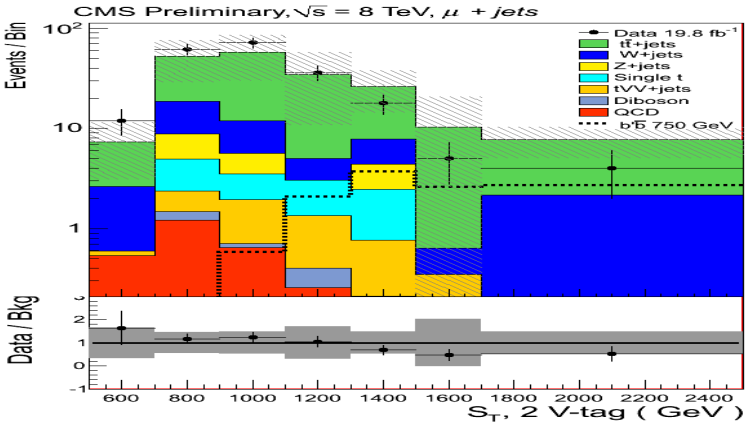
[CMS-PAS-B2G-12-019]

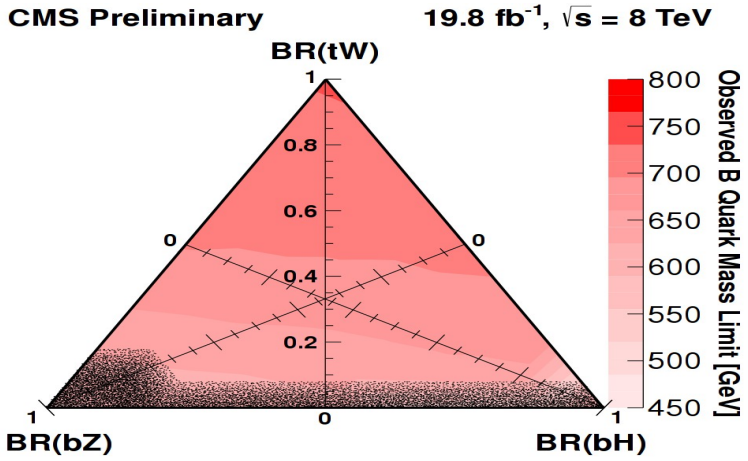
- Selection:
  - **single muon or electron**
  - ≥4 AK5 jets, ≥1 **b-tagged**
  - event categories based on number of **V-tags** (V=W/Z/H)

- Limits based on S_T distribution:

$$S_T = p_T^{lept} + p_T^{miss} + \sum p_T^{jets}$$

S_T distribution, for 2 V-tag category





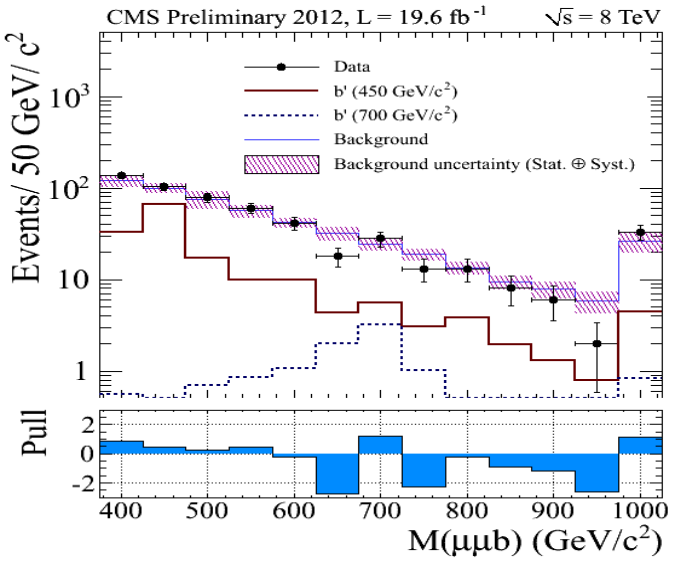
final limit up to 732 GeV

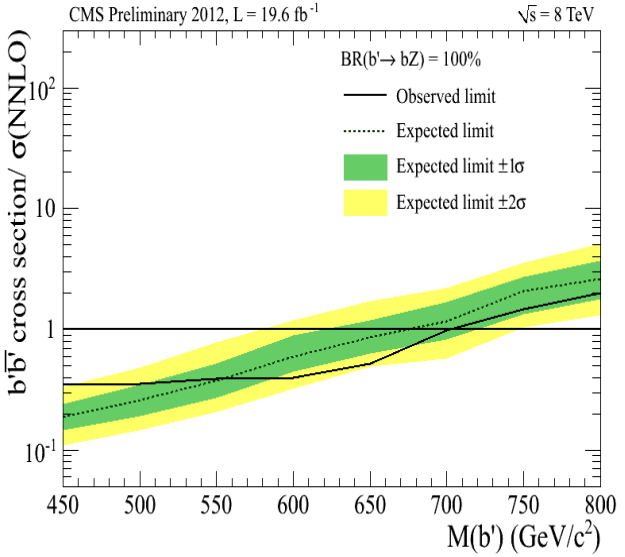
Bottom Partners: Dilepton+Jets

[CMS-PAS-B2G-12-021]

- Selection:
  - OS leptons, from $Z \rightarrow l^+l^-$
  - 60 GeV < M_{ll} < 120 GeV
  - $p_T(ll)$> 150 GeV
  - 1 b-tag
  - M_B from $Z \rightarrow l^+l^-$+high-p_T b-jet

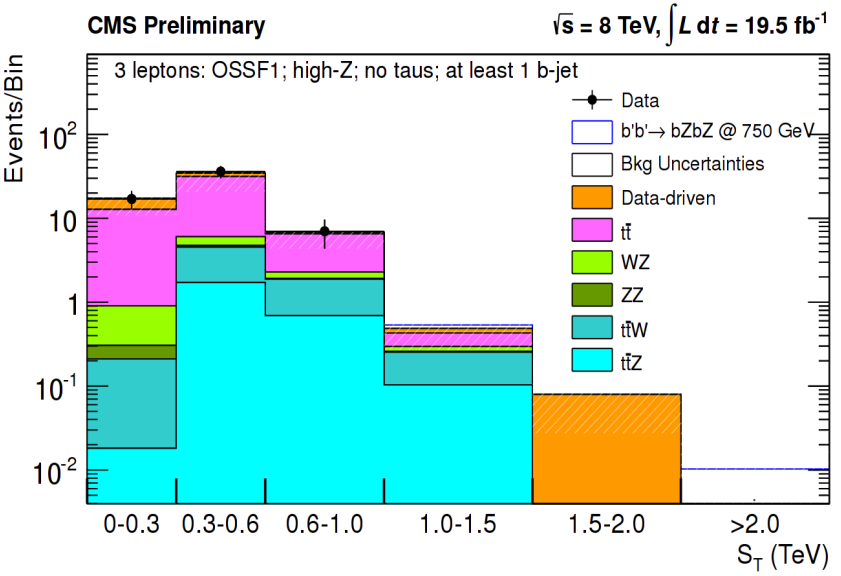
- obs(exp) limit $B \rightarrow bZ$ = 700 (680) GeV



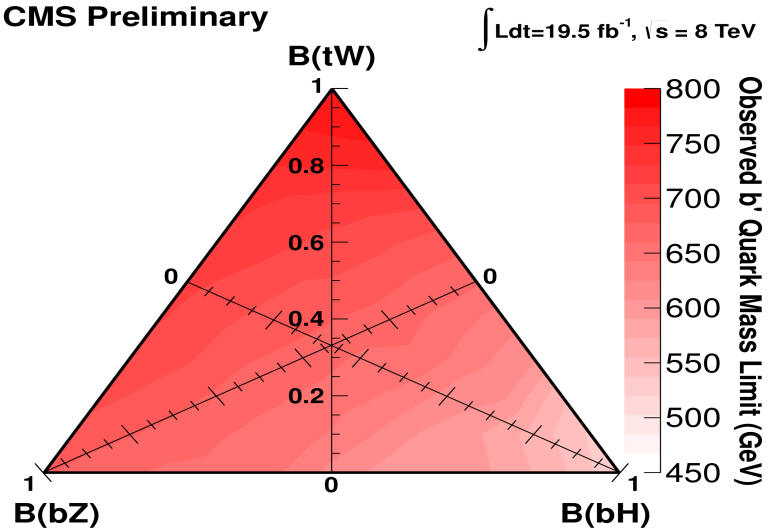


Bottom Partners: Multilepton
[CMS-PAS-B2G-13-003]

- Events categorized according to:
  - number of OSSF lepton pairs
  - if OSSF pair, whether on/off Z
  - presence of hadronic tau candidates
  - presence of b-tagged jets
  - magnitude of ST



- Limits between 520-785 GeV from counting experiment combining different categories

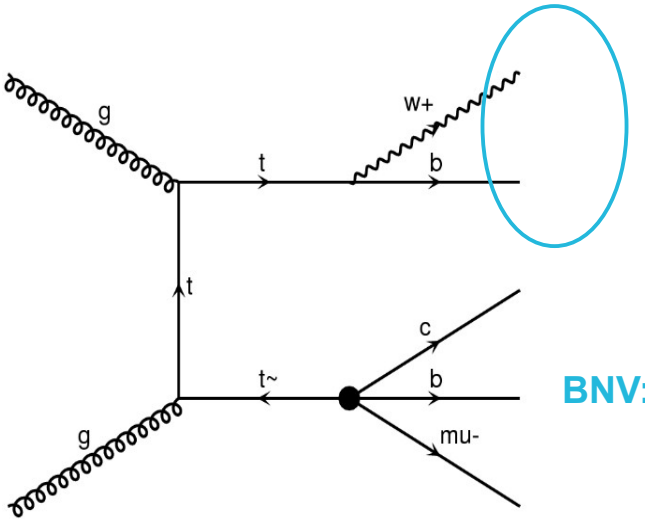


Other Searches with Tops

Barion Number Violation

[Physics Letters B 731 (2014) 173]

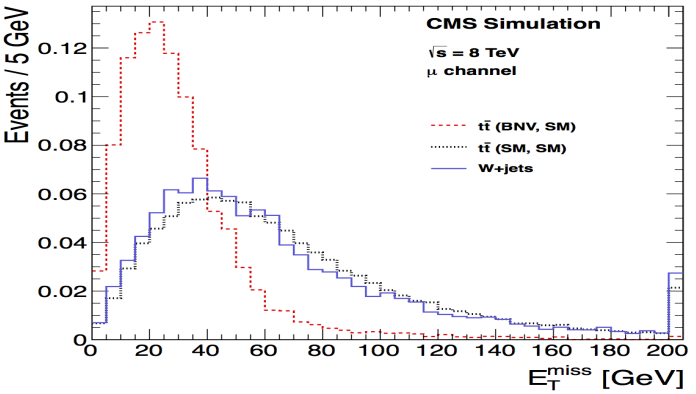
- Occurring in Susy, GUTs, black hole physics, ...
- Already studied in nucleons, mesons, tau, Z systems
- BNV decay channels: t→bcμ, t→bue



- Selection strategy:
  - 1 isolated lepton (e, μ)
  - no E_T^{miss}
  - ≥ 5 jets, ≥ 1 b-tag
  - χ^2 < 20, where:

$$\chi^2 = \sum_i \frac{(x_i - \bar{x}_i)^2}{\sigma_i^2}$$

BNV t-quark mass
Hadronic t-quark mass
W boson mass



- BR limits:

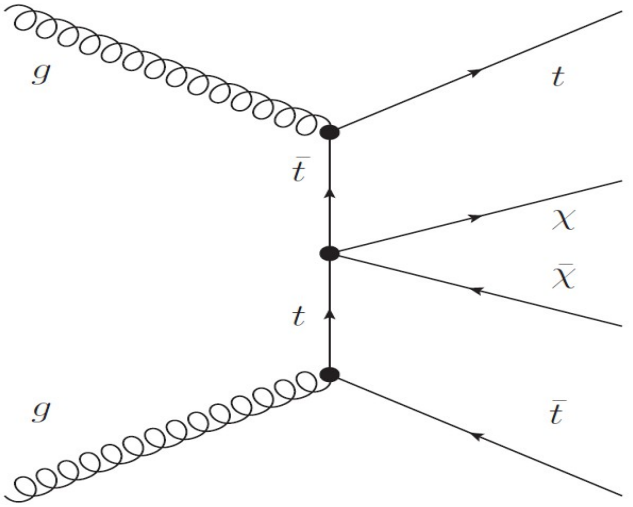
	95% CL Upp. lim.	Exp. lim.	68% exp. lim. range
Muon ch.	0.0016	0.0029	[0.0017, 0.0042]
Electron ch.	0.0017	0.0031	[0.0018, 0.0045]
Combined	0.0015	0.0029	[0.0016, 0.0042]

Dark Matter Searches

[CMS-PAS-B2G-13-004, CMS-PAS-B2G-12-022]

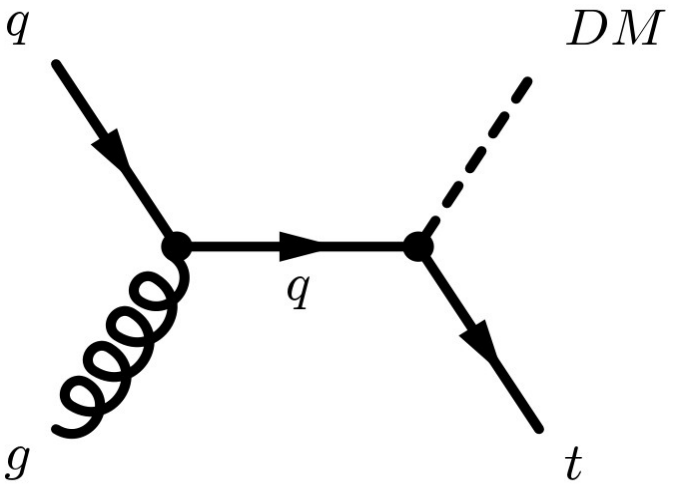
Di-lepton analysis

- DM particle is a **Dirac particle** interacting with quarks via **contact interaction**
- coupling proportional to quark mass: search in the top channel convenient!



Monotop analysis

- DM produced through **FCNC** diagrams
- both **vector or scalar DM** boson possible: limits for both options
- no monojet event observed: DM particle may couple to third generation quarks!

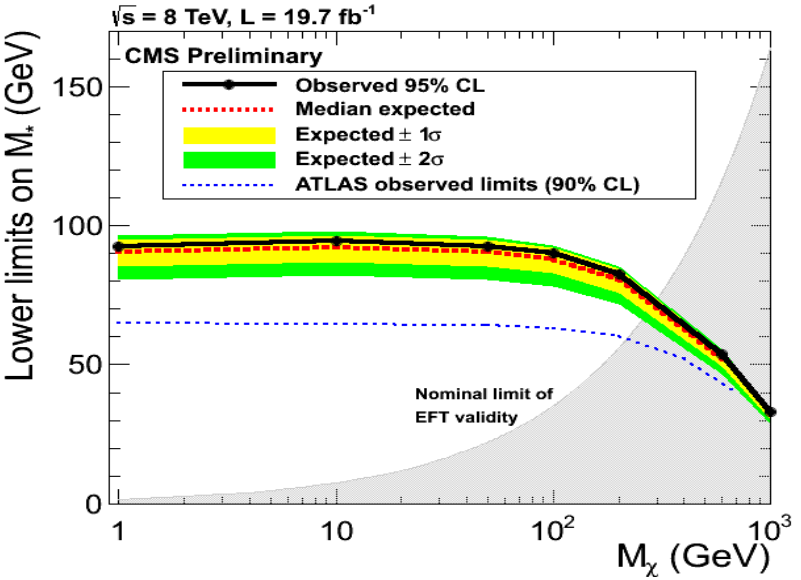


Dark Matter Searches

[CMS-PAS-B2G-13-004, CMS-PAS-B2G-12-022]

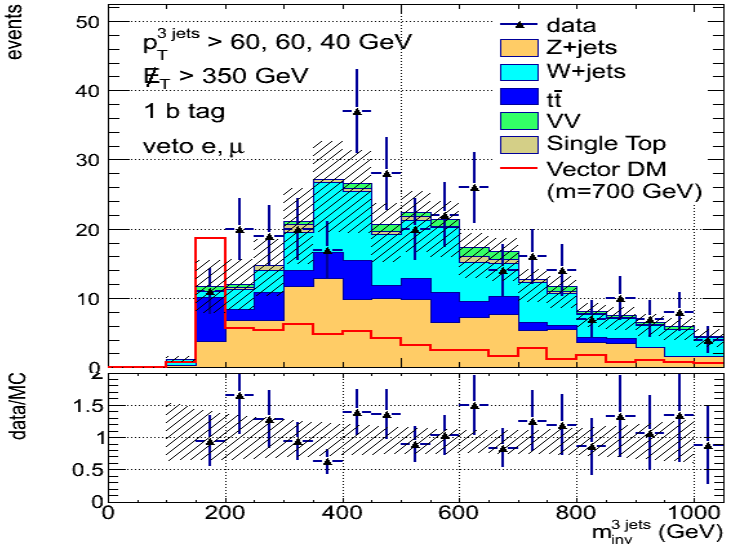
Di-lepton analysis

- two leptons, ≥ 2 jets
- ET^{miss} > 320 GeV
- Σp_T leading jets < 400 GeV (agains tt)
- m_{ll} > 20 GeV, $|m_{ll}$ -91| < 15 GeV (against DY)
- $\sum p_T$ leptons > 120 GeV, $\Delta\phi_{ll}$ < 2
- limits on the interaction scale M_*



Monotop analysis

- hadronic top: ==3 jets, M_{jjj}<250 GeV
- 1 b-tag, no isolated leptons (e, μ)
- data-driven backgrounds:
  - QCD: 0 b-tag sample
  - W+jets, Z+jets: isolated muons
- M_{DM} limit: 327 GeV (scalar), 655 GeV (vector)



Displaced Superymmetry

[CMS-PAS-B2G-12-024, theory arXiv:1204.6038v1]

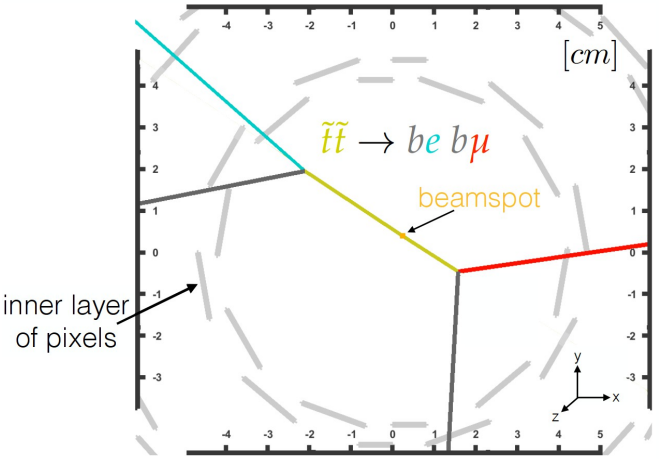
- Typical searches for non-prompt signatures focus on very long lifetimes: here **⟨cτ⟩ ~100 μm - 1 cm**

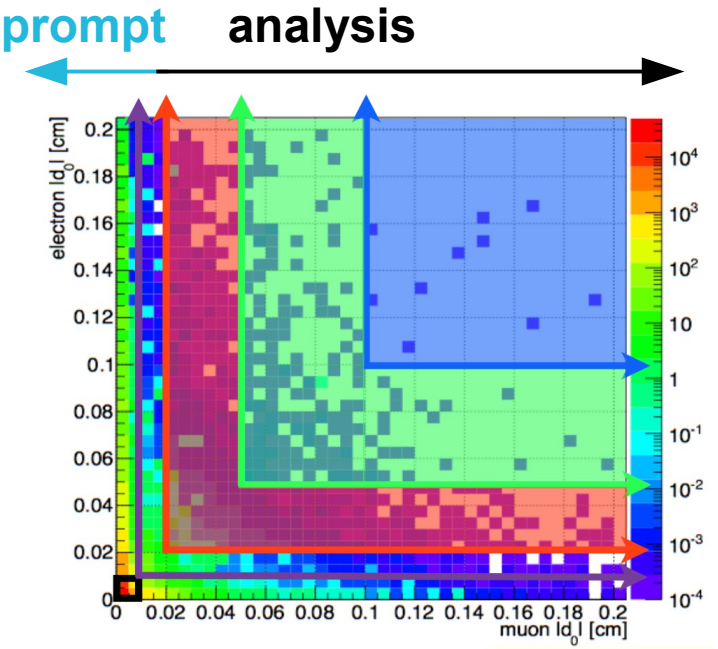
- General search:
  - selections on leptons
  - no selections aimed at jets, MET, b-tagging
  - interpretation: **RPV long-lived LSP stop**

- Event selection:
  - muon trigger
  - good quality, **OS, isolated e, μ pair**

- **⟨cτ⟩ correlates to impact parameter $|d_0|$**
  - signal regions : 200μm<$|d_0|$<2cm
  - control regions : $|d_0|$< or >100μm

- QCD data-driven estimation from SS/anti-isolated regions





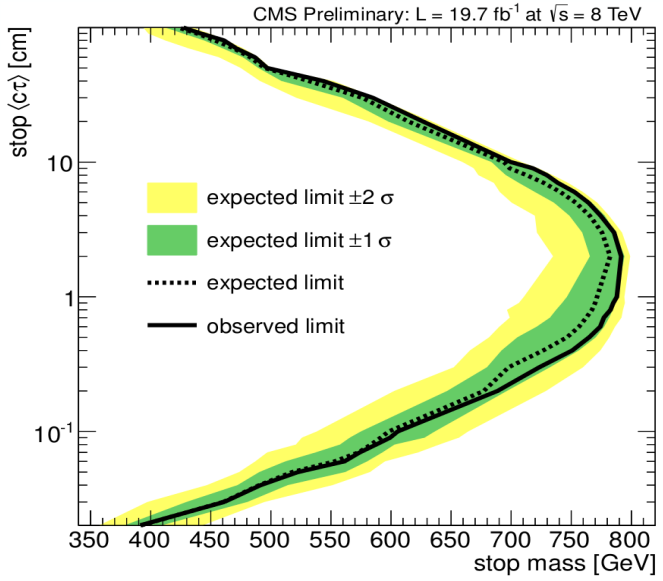
Displaced Superymmetry

[CMS-PAS-B2G-12-024, theory arXiv:1204.6038v1]

- Very pure signal regions:

	$0.02\ \text{cm} < \lvert d_0 \rvert < 0.05\ \text{cm}$	$0.05\ \text{cm} < \lvert d_0 \rvert < 0.1\ \text{cm}$	$\lvert d_0 \rvert > 0.1\ \text{cm}$
Total expected background	$18.0 \pm 0.5 \pm 3.8$	$1.01 \pm 0.06 \pm 0.30$	$0.051 \pm 0.015 \pm 0.010$
Observation	19	0	0
$pp \to \tilde{t}_1 \tilde{t}_1^*$			
$M = 500\ \text{GeV}, \langle c\tau \rangle = 1\ \text{mm}$	$30.1 \pm 0.7 \pm 1.1$	$6.54 \pm 0.34 \pm 0.24$	$1.34 \pm 0.15 \pm 0.05$
$M = 500\ \text{GeV}, \langle c\tau \rangle = 1\ \text{cm}$	$35.3 \pm 0.8 \pm 1.3$	$30.3 \pm 0.7 \pm 1.1$	$51.3 \pm 1.0 \pm 1.9$
$M = 500\ \text{GeV}, \langle c\tau \rangle = 10\ \text{cm}$	$4.73 \pm 0.30 \pm 0.17$	$5.57 \pm 0.32 \pm 0.20$	$26.27 \pm 0.70 \pm 0.93$

dominant region



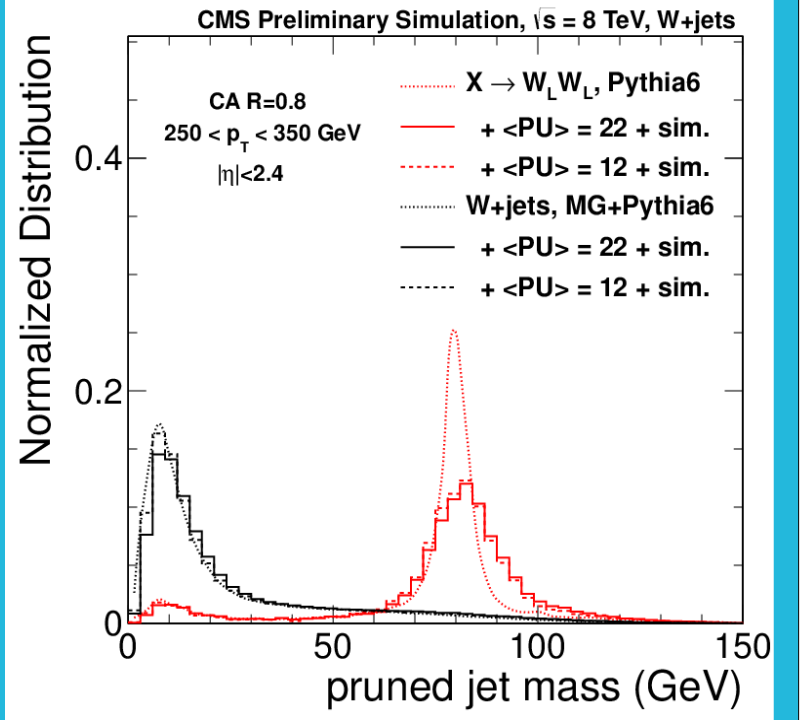
- Excellent exclusion limits for optimized $\langle c\tau \rangle$ region

- Limitiations:
  - short $\langle c\tau \rangle$: prompt backgrounds
  - long $\langle c\tau \rangle$: signal acceptance

W-Tagging
[CMS-PAS-JME-13-006]

- Based on **jet mass pruning** (*Ellis, Vermillion, Walsh [arXiv:0903.5081], [CMS-PAS-SMP-12-019]*): **remove soft clusters**.

- Starting with Cambridge-Aachen jets, distance parameter 0.8 (CA8).
- Recluster jet and apply **requirements when merging clusters** *i* and *j* into cluster *p*. Veto soft and large angle recombinations, removing softer cluster if:
  - $z=min(p_T^i,p_T^j)/p_T^p<0.1$
  - $\Delta R^{ij}>D_{cut}=0.5xm^{orig}/p_T^{orig}$.



m_{pruned} for signal/background MC with/without detector effects, pile-up

W-tagging:
•2 pruned subjets
•pruned jet mass [60,100] GeV

W-Tagging: Additional Observables

- Pruning can be combined with additional observables:

→ **mass-drop**

mass-drop $\mu = m_1/m_{jet}$
m_1 is the highest mass pruned subjet

W-Tagging: Additional Observables

- Pruning can be combined with additional observables:

  - **mass-drop**
  - N-subjettiness τ_N: τ_2/τ_1 used for W-tagging

probability that jet is composed by N subjets

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

$d_0 = \sum_k p_{T,k} R_0$, and R_0 is the original jet radius

W-Tagging: Additional Observables

- Pruning can be combined with additional observables:
  - **mass-drop**
  - N-subjettiness τ_N: τ_2/τ_1 used for W-tagging
  - also examined: Qjet volatility Γ_{QJet}, generalized energy correlation function C_2^{β}

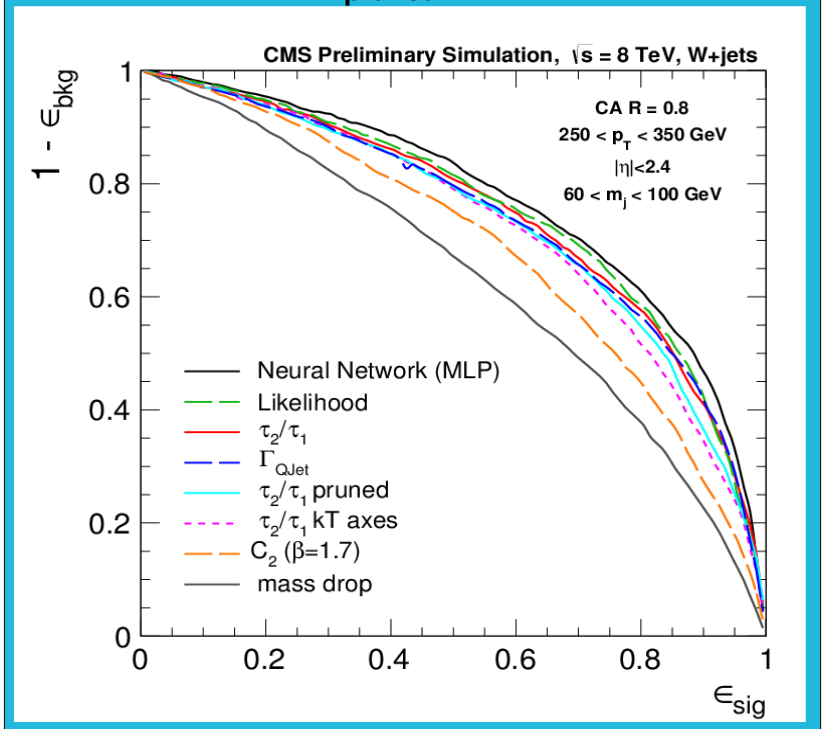
W-Tagging: Additional Observables

- Pruning can be combined with additional observables:
  - **mass-drop**
  - N-subjettiness τ_N: τ_2/τ_1 used for W-tagging
  - also examined: Qjet volatility Γ_{QJet}', generalized energy correlation function C_2^{β}

- **N-subjettiness** shows the best single discriminating power.

- Observables are correlated: moderate improvement with **multivariate combination**.

60 GeV < m_{pruned} < 100 GeV

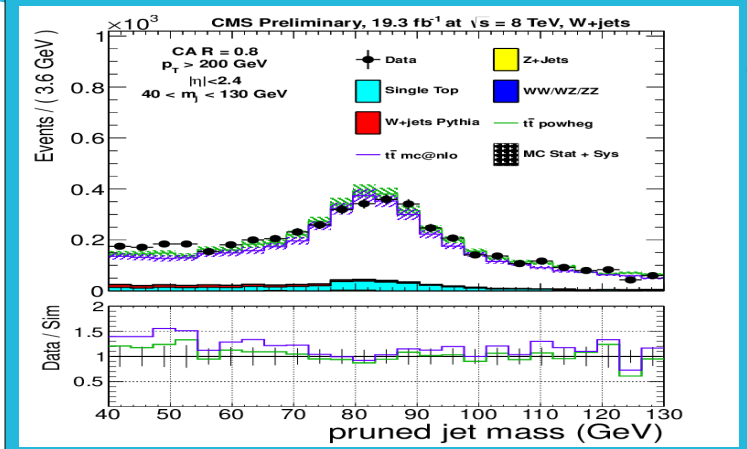


W-tagging ROC curves
single substructure observables and their combinations

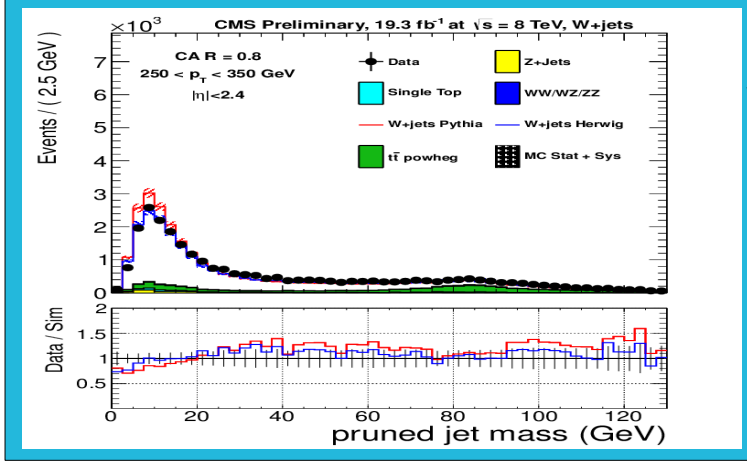
efficiency: H→WW, m_H = 600 GeV
mistag: QCD

W-Tagging: MC vs Data

- Detailed **data/MC comparisons** for all subtructure observables
- **Different topologies and generators** considered



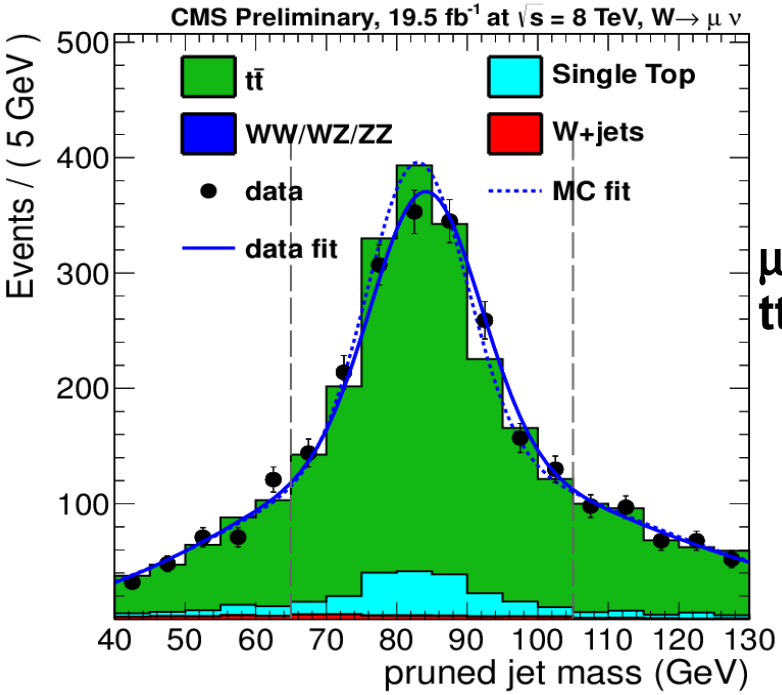
ttbar (signal)
powheg
mc@nlo



leptonic W+jets (backgr.)
Pythia
Herwig

general good agreement, more in the backup

- **Scale factors** (SF) to correct for residual discrepancies



μ+jets ttbar

peak position W candidate (mass scale):
- **data: 84.5±0.4 GeV**
- **MC: 83.4±0.4 GeV**

SF (m_{pruned} cut + τ_2/τ_1<0.5):
- **0.905 ± 0.08**

Top-Tagging

Based on **JHU top-tagger** (*Kaplan et al [PRL 101 (2008) 142001]*):

- start with **CA8 jets**
- **reverse clustering sequence** and examine clusters pairwise
- clusters are **splitted** if:

$$\Delta R > 0.4 - 0.0004 \times p_T^C$$

p_T^C is the parent cluster p_T

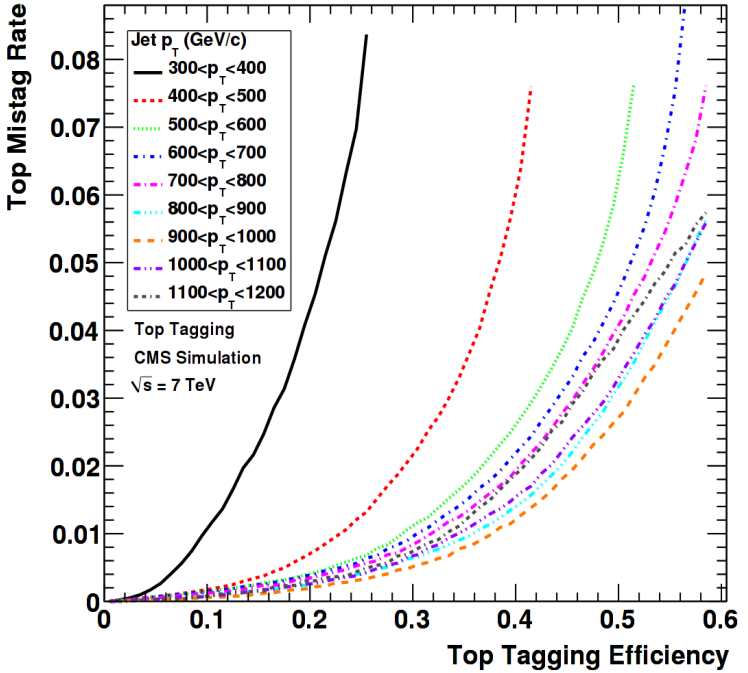
- **low p_T clusters** removed if:

$$p_T < 0.05 \times p_T^{jet}.$$

Top-tagger requirements:

- **$140 < m_{jet} < 250$ GeV**
- **$N_{subjets} \geq 3$**
- **Min pairwise mass > 50 GeV**

ROC Curves

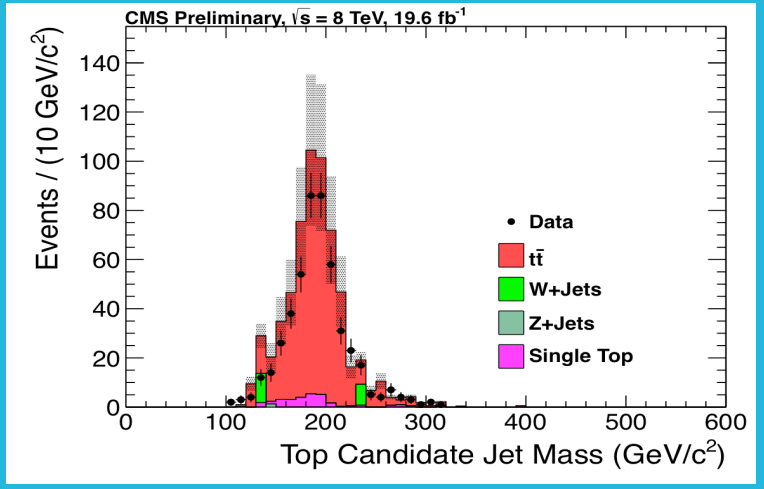


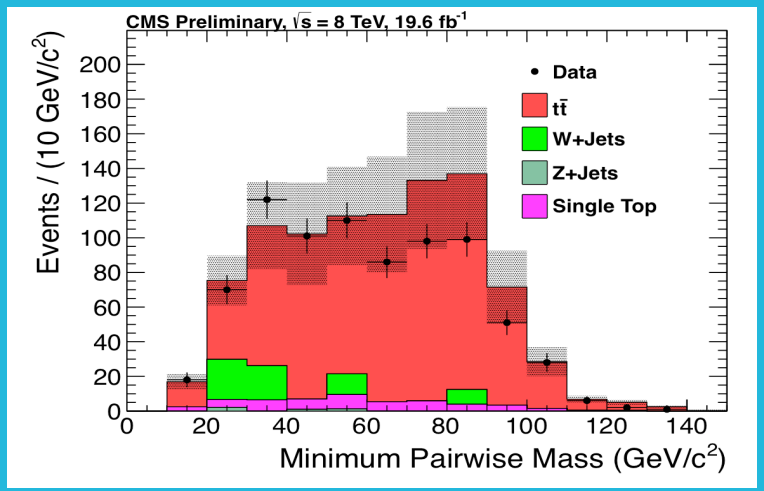
top-mistag (QCD) vs efficiency in simulation [CMS-PAS-JME-10-013]

Performance

[CMS-PAS-B2G-12-005]

μ+jets: semileptonic ttbar events

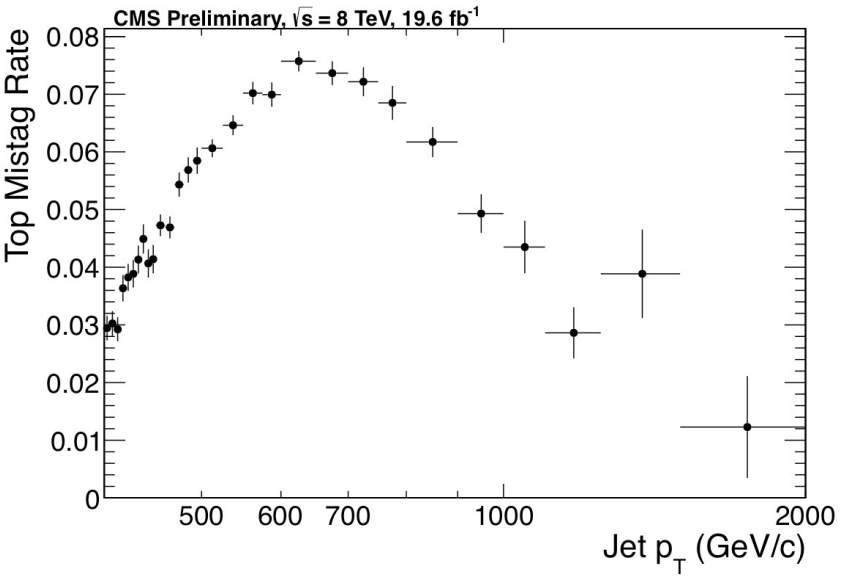




top-tagging data/MC scale factor derived from selection efficiency of hadronic top candidate: 0.93±0.04

Mistag rate can be measured from data, using **anti-tag method**:

- ➔ two high-p_T jets, p_T >400 GeV
- ➔ anti-tag one jet, inverting min pairwise mass requirement
- ➔ top-tag of other jet is a mistag

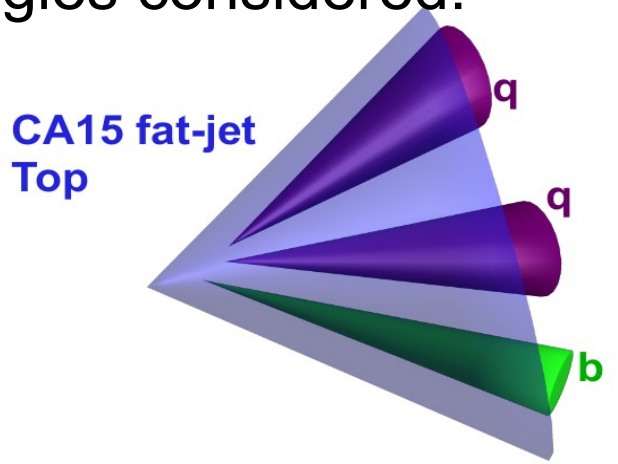


B-Tagging in Boosted Topologies
[CMS-PAS-BTV-13-001]

- B-tagging at CMS traditionally developed on **isolated AK5 jets** (anti-k_T, R=0.5), mostly suitable for the **non-boosted regime**.
- The work now presented is the first study at LHC dedicated to b-tagging in the boosted regime. Two topologies considered:

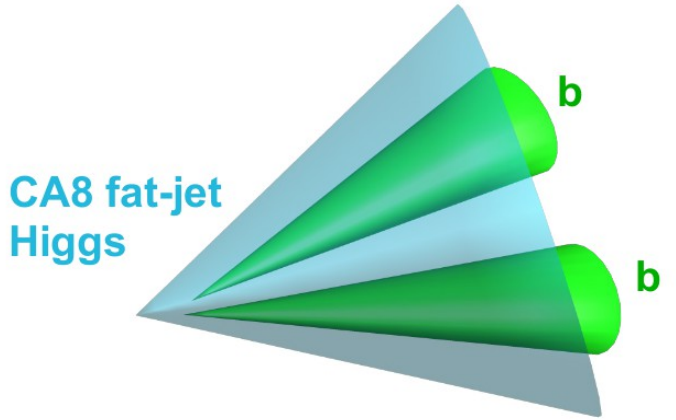
Boosted top, hadronic decay:

→**top decay selected using HEPTopTagger [JHEP 1010 (2010) 078], based on CA15 jet collection**



Boosted Higgs→bb̄:

→**2 b-jets clustered together in large fat-jet**
→**studies based on CA8 collection**



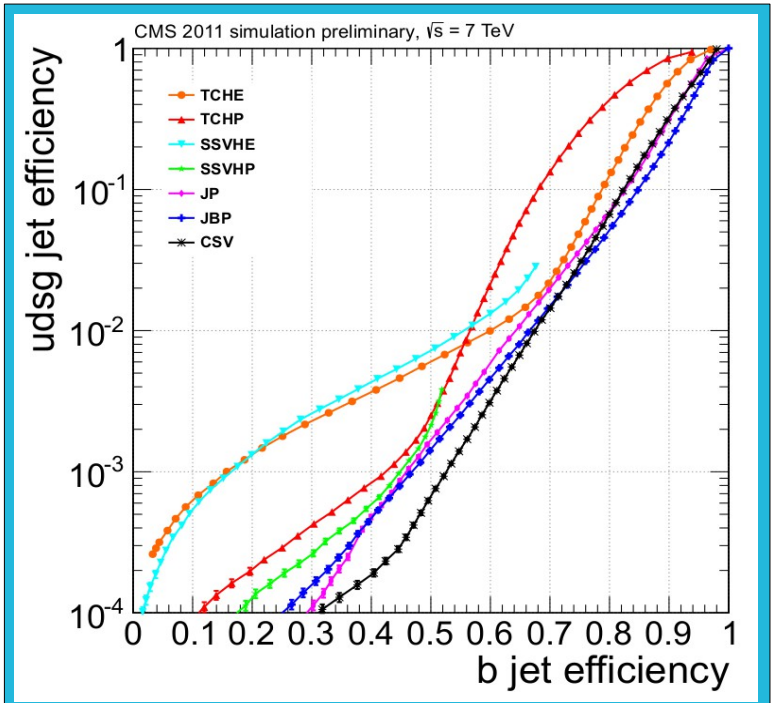
B-Quark Signatures

Life-time b-hadron → jets with:
- **secondary vertex**
- **tracks with large impact parameter**

Large mass, ~5 GeV

Fragmentation function:
- **high p_T of the b-hadron relatively to jet p_T**

B-decay produces often leptons: soft muon or electron within jet

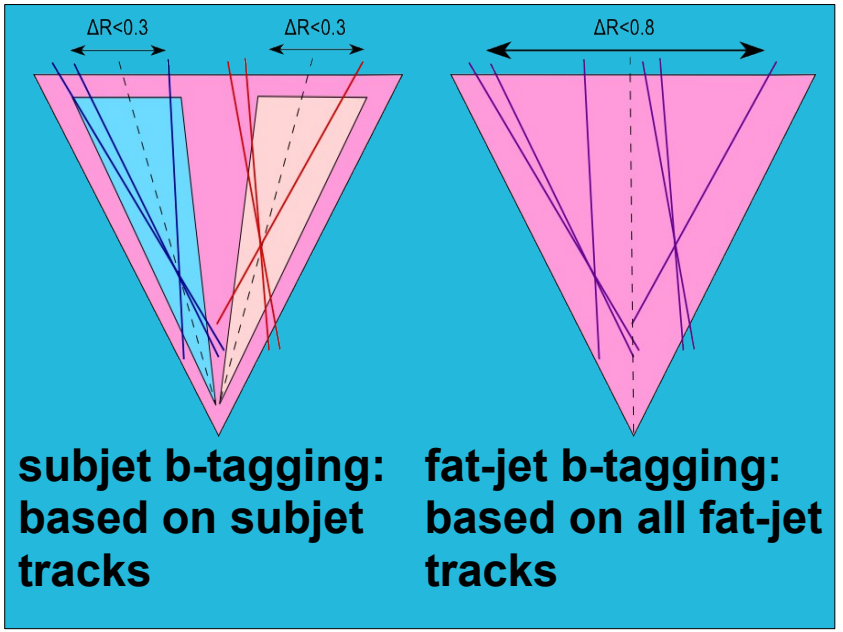


b-tagging algorithms ROC curves [JINST 8 (2013) P04013]

- Several taggers implemented at CMS. Boosted studies based on the **Combined Secondary Vertex** **CSV** tagger:
  - likelihood ratio combination of **secondary vertex + single track information**;
  - currently the best tagger in CMS, improvements ongoing.

Boosted B-Tagging Scenarios

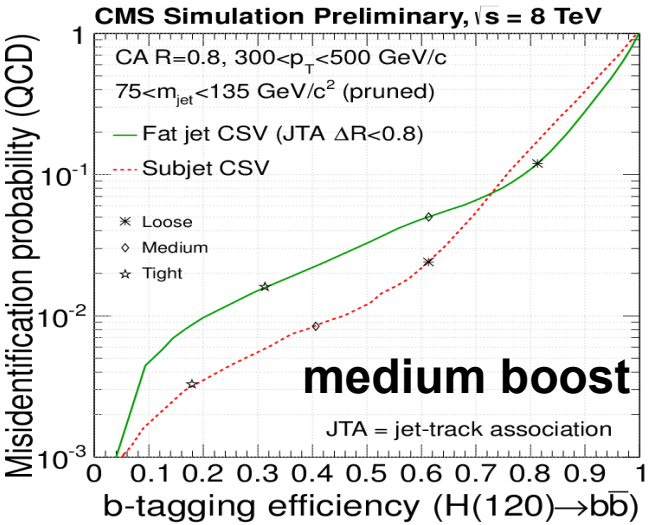
- Different scenarios considered for boosted topologies:
  - **subjet CSV**:
    - CSV b-tagger applied to subjets (**2 b-tags for Higgs-tagging, ≥1 for top-tagging**)
  - **fat-jet CSV**:
    - CSV b-tagger applied to the Higgs/top candidate fat-jet

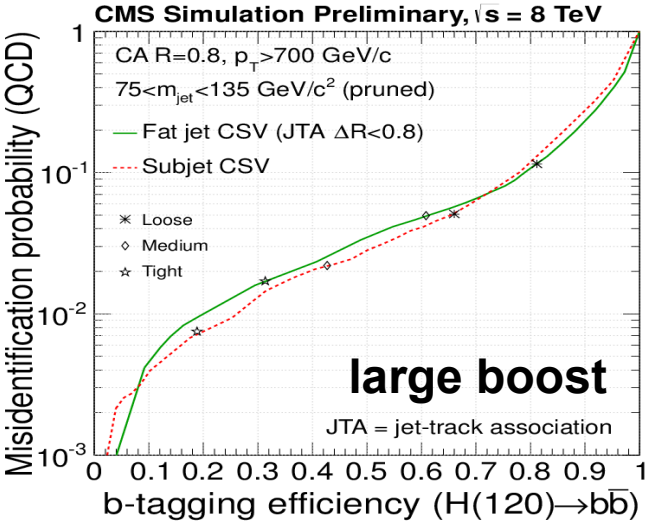


Subjet b-tagging generally performs better: chosen as **default technique**

Fat-jet b-tagging suitable at **very high p_T** where subjets start to merge

e.g. Higgs channel





Subjet B-Tagging Validation on Data

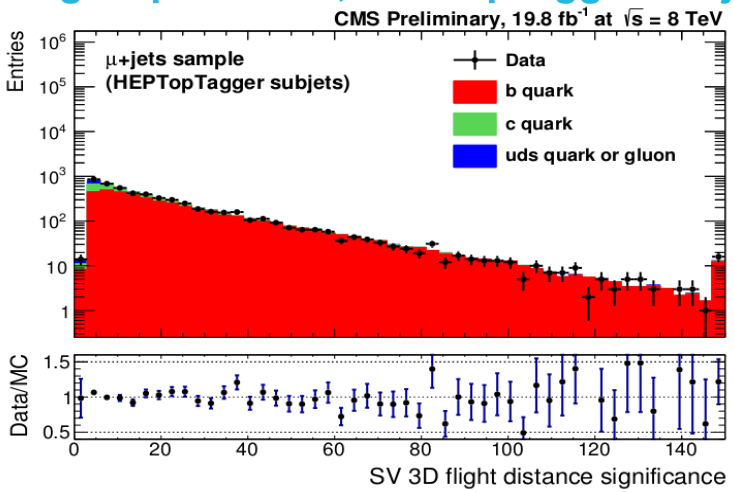
Control sample boosted top:

- **μ+jets, semileptonic ttbar**
- HEPTopTagger to select hadronic decay

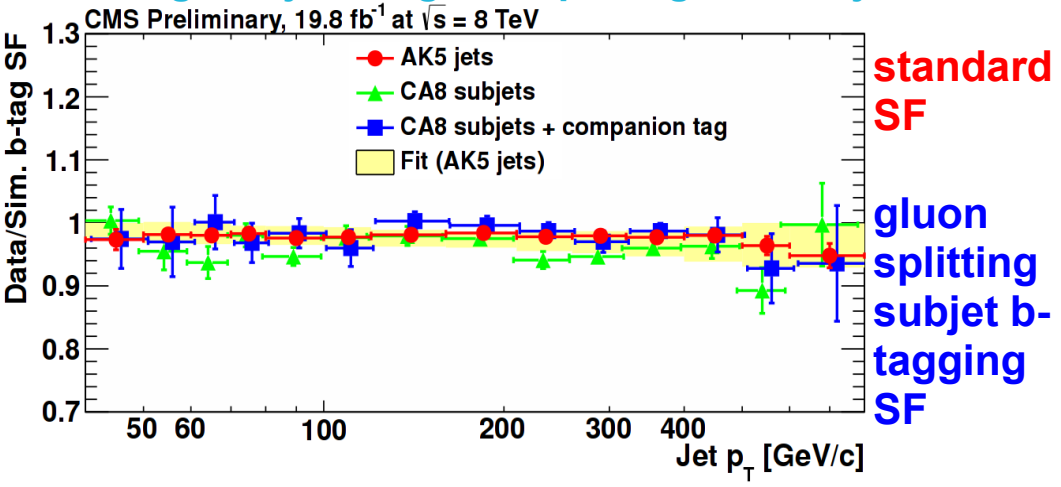
Boosted Higgs: challenging definition of the control sample

- similar topology: **gluon splitting jets**, two closeby b's
- selection: high p_T CA8 jet with 2 pruned subjets
- enrich in gluon-splitting requiring soft-muon within subjets cone

e.g. Top channel, HEPTopTagger subjets



e.g. subjets of gluon splitting CA8 fat-jets



- **Good data/MC agreement for b-tagging observables.**
- **All observables cross-checked (backup).**

- **SF~1, compatibly with SF for standard b-tagging in the non-boosted regime, for both channels.**
- **Nothing pathological in the boosted regime.**