Searches with Boosted Objects @ ATLAS and CMS

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On behalf of the ATLAS and CMS Collaborations

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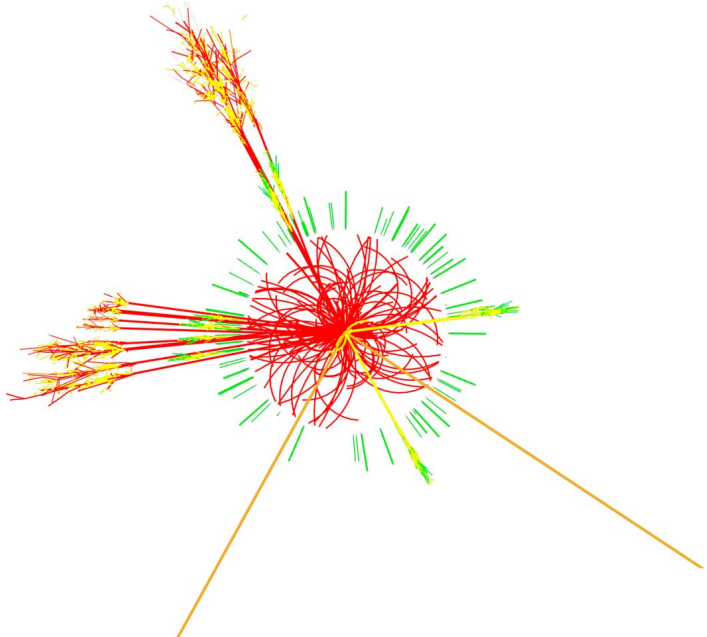


Exploring the TeV-Regime...

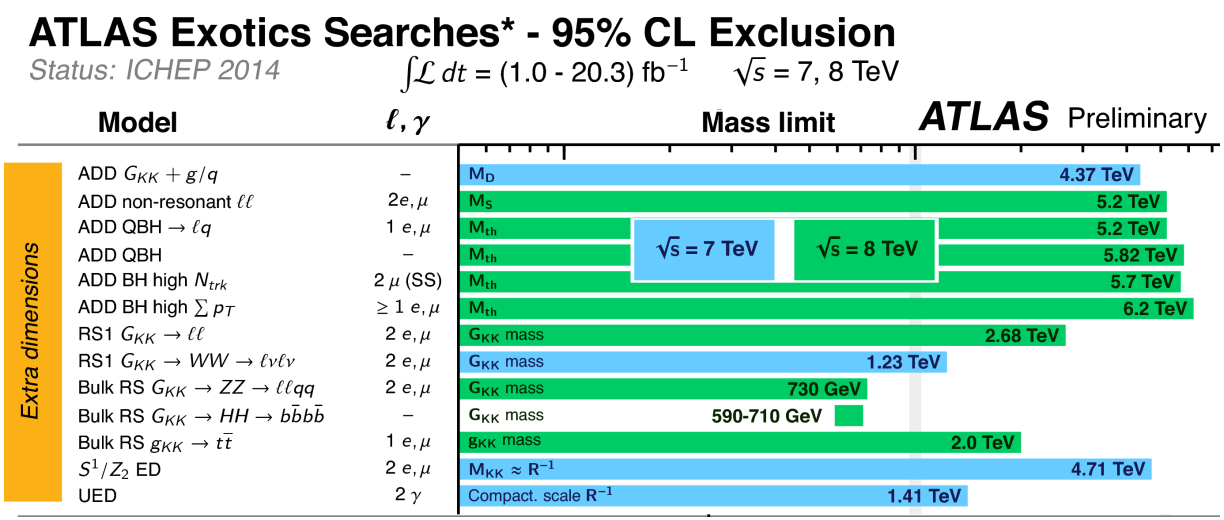
LHC opens up an unprecedented energy range:

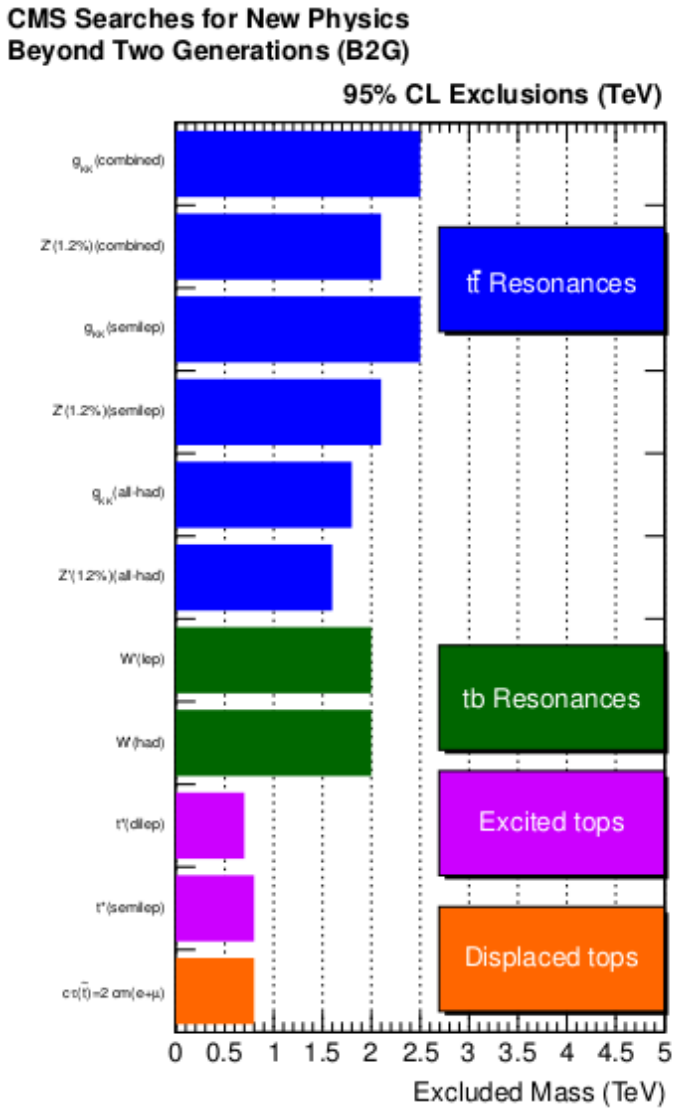
- Run-I: 8 TeV (2012), 7 TeV (2010-2011)
- Run-II: 13-14 TeV (from 2015)

Search for New Physics at the TeV-scale!

- Highly energetic particles in final state
  $\Rightarrow$ Unique **boosted** signatures

New reconstruction techniques evolving quickly!





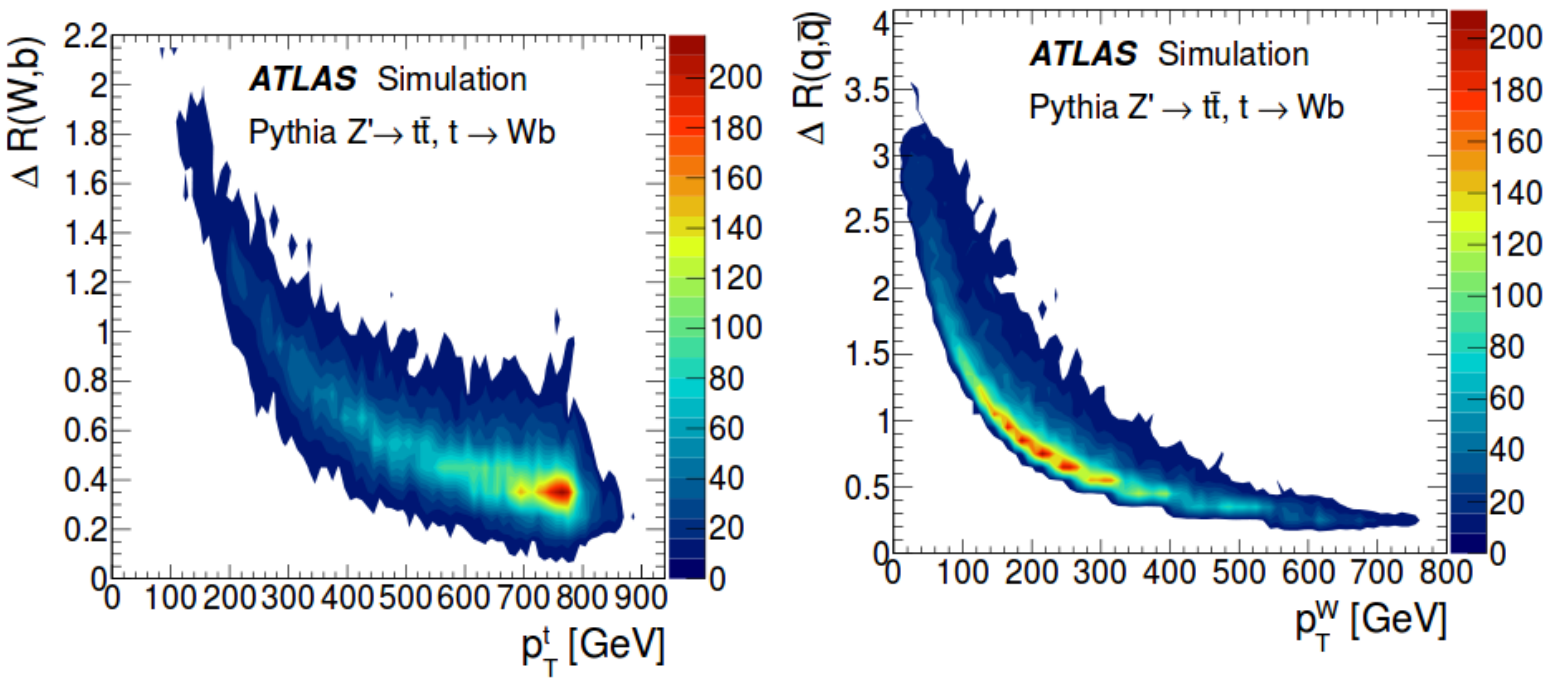
Boosted Signatures (1)

- **Boosted** means transverse momentum $\gtrsim$ 2 times mass
- Decay products collimated in direction of mother particle
- Angular separation $\Delta R(a, b)$* for products of boosted decay X $\rightarrow$ a b

Rule of thumb

$$\Delta R(a, b) \approx 2m^X / p_T^X$$

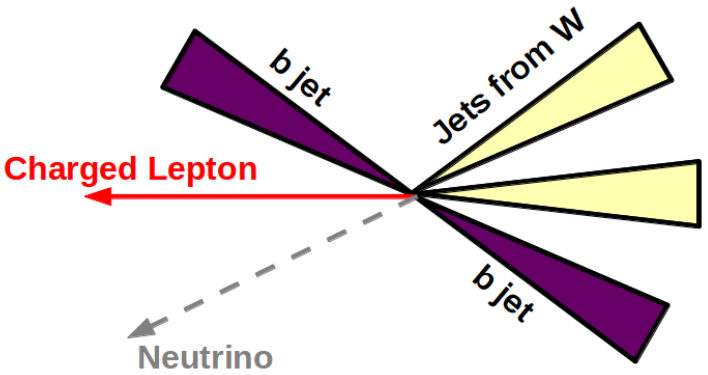
ATLAS-CONF-2012-065

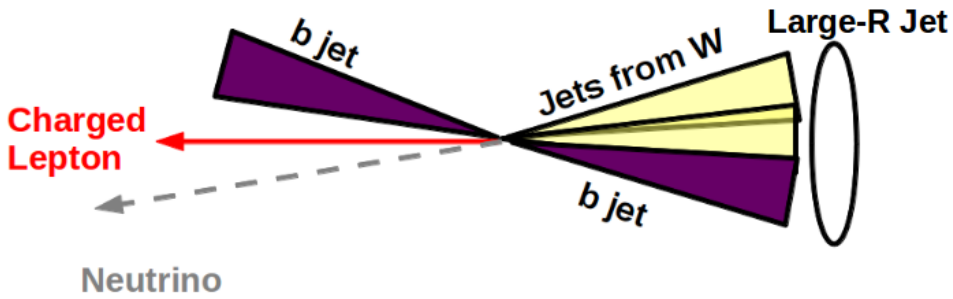


*$\Delta R(a, b) = \sqrt{\Delta\eta(a, b) + \Delta\phi(a, b)}$

Boosted Signatures (2)

Example: $t\bar{t} \to Wb\ W\bar{b} \to bq\bar{q}\ b\ell\nu$





low p_T^{top} ⟶ high p_T^{top}

Consequences

- Hadronic decay products merge into single jet
  ⇒ Reconstruct as one **large-R jet** comprising all decay products
  ⇒ Analyse its **substructure**
- Lepton close to (or even inside) jets
  ⇒ Modify **lepton isolation** criteria
- Separation below calorimeter resolution
  ⇒ Explore track-based reconstruction

Overview

Large-R jet with substructure

- Jet algorithms and substructure variables
- Grooming techniques

Searches with boosted top quarks

- Resonances decaying to $t\bar{t}$
  - 1ℓ+jets channel ATLAS [ATLAS-CONF-2013-052], CMS [CMS-PAS-B2G-12-006]
  - All-hadronic channel ATLAS [JHEP 01(2013) 116], CMS [CMS-PAS-B2G-12-005]
- Top Tagging ATLAS [ATLAS-CONF-2013-084], CMS [CMS-PAS-JME-13-007]
- Searches for $W' \to tb$ ATLAS [arXiv:1408.0886], CMS [CMS-PAS-B2G-12-009]
- Search for direct $\tilde{t}_1\tilde{t}_1$ production ATLAS [arXiv:1407.0583],[arXiv:1406.1122], CMS [CMS-PAS-SUS-13-015]

Searches with boosted bosons

- Search for mono-W/Z ATLAS [CERN-PH-EP-2013-158]
- Resonances searches with boosted W,Z
  - Dijet Resonances with Boosted Bosons CMS [CMS-EXO-12-024]
  - Diboson Resonance Search (semileptonic) ATLAS [ATLAS-CONF-2014-039], CMS [CMS-EXO-13-009]
- Search for vector-like $b' \to Hb$ CMS [CMS-PAS-B2G-14-001]

Top-partner searches (boosted tops + boosted bosons)

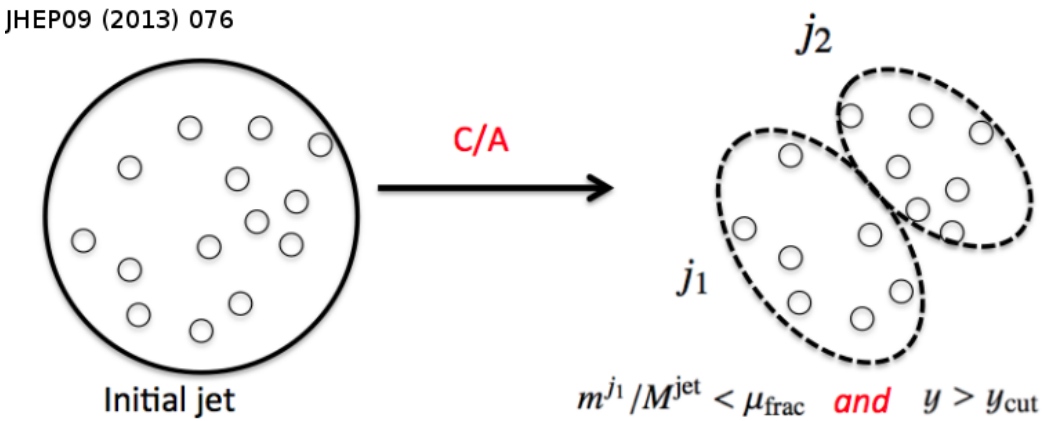
[ATLAS-CONF-2013-060], [CMS-B2G-12-012], [CMS-B2G-12-015], [CMS PAS B2G-14-002]

Large-R Jets and Substructure

- Jets built from **clusters of calorimeter cells** or **tracks** in the Inner Detector
- **Pairwise recombination** over several iterations (sequential algorithms)
- **Three major algorithms** used in ATLAS and CMS:
  - **k_T**: clusters soft, nearby particles first
  - **Cambridge-Aachen (C/A)**: like k_T but angular information only
  - **Anti-k_T**: clusters hard particles first

  } substructure information
- "Radius" parameter R determines average jet size
  - ATLAS: R = 0.4, 1.0, 1.2, 1.5
  - CMS: R = 0.5, 0.8, 1.5
- Take any large-R jet and recluster with k_T or C/A to analyse substructure

Example: Mass*-drop Tagger for boosted bosons
Look for symmetric splitting into massive subjets

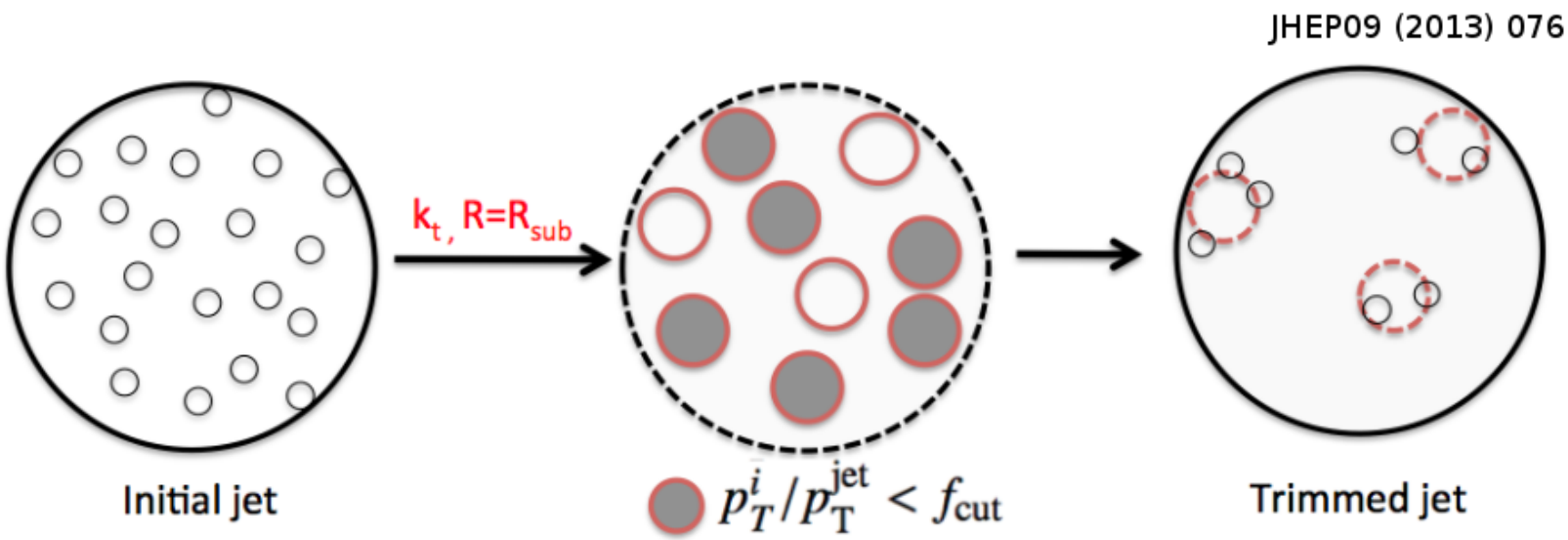


*Jet mass = Mass of the sum of four-momenta of all jet constituents

Jet Grooming (1)

- Large-R jets more susceptible to contaminations from Underlying Event and pile-up
- Soft radiation dilutes jet substructure
- **Grooming to remove soft, wide-angle contaminations!**
- Various algorithms available:
  - Trimming: Krohn, Thaler, Wang [arXiv:0912.1342]
    Widely used in ATLAS
  - Pruning: Ellis, Vermillion, Walsh [arXiv:0903.5081]
    Widely used in CMS
  - Filtering: Butterworth, Davison, Rubin, Salam [arXiv:0802.2470]
    HEPTopTagger uses filtering-like approach

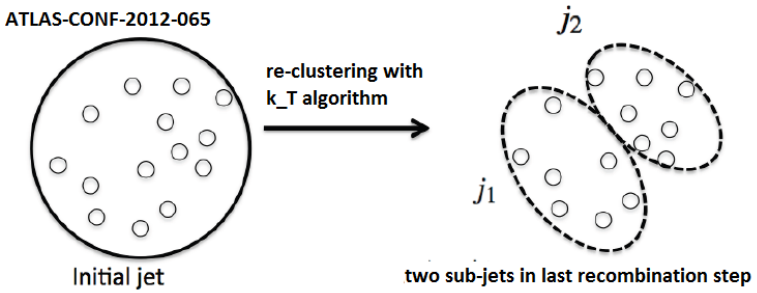
Example: Trimming (ATLAS: $R_{sub} = 0.3, f_{cut} = 0.05$)



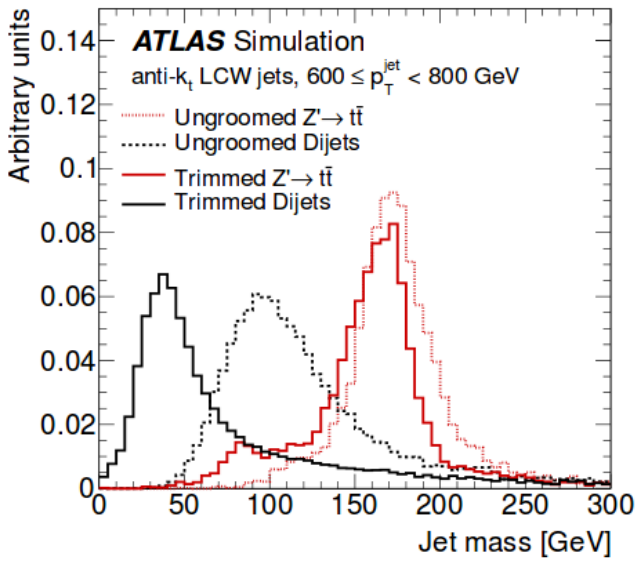
Jet Grooming (2)

Example: **Jet mass** and **first k_T-splitting scale $\sqrt{d_{12}}$** in $Z' \to t\bar{t}$ events

- $\sqrt{d_{12}} = \min(p_{T1}, p_{T2})\Delta R_{12}$
- Calculated from the two proto-jets of last k_T recombination step
- Expect $\sqrt{d_{12}} \approx m_t/2$ for $t \to Wb$



ATLAS-CONF-2012-065



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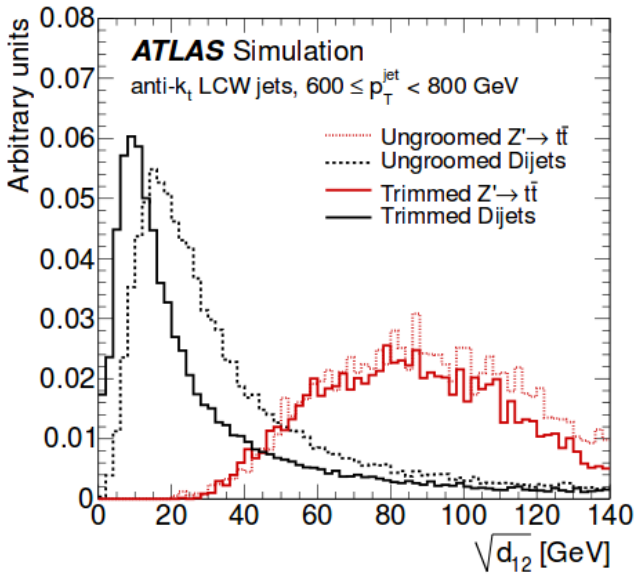

Significantly improves mass resolution and hence discrimination against QCD jets!

Searches with boosted top quarks

- Resonances decaying to $t\bar{t}$
  - 1ℓ+jets channel [ATLAS-CONF-2013-052], CMS [CMS PAS B2G-12-006]
  - All-hadronic channel ATLAS [JHEP 01(2013) 116], CMS [CMS PAS B2G-12-005]
- Top Tagging ATLAS [ATLAS-CONF-2013-084], CMS [CMS-PAS-JME-13-007]
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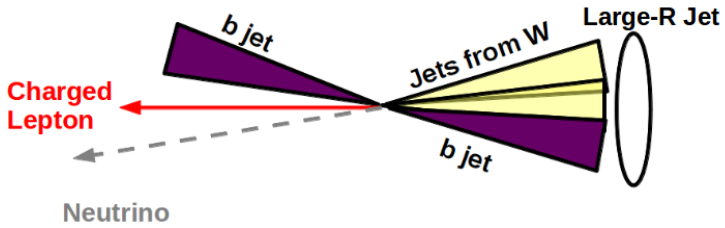
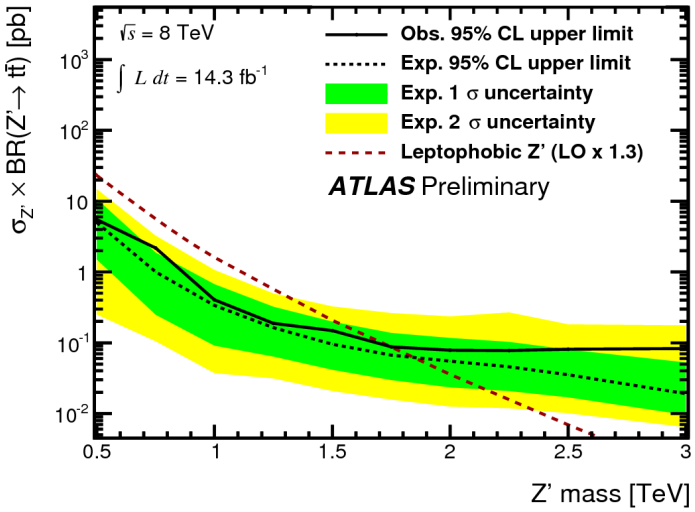
$t\bar{t}$ Resonance Search 1ℓ+jet

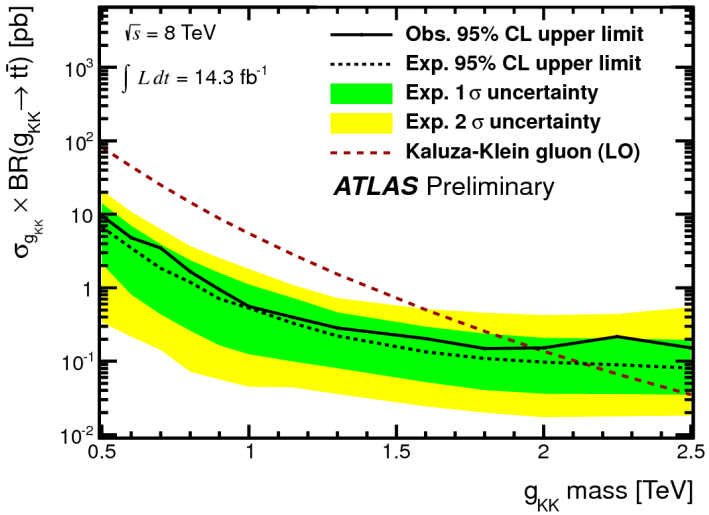
$\int Ldt = 14$ fb^{-1}, $\sqrt{s} = 8$ TeV [ATLAS-CONF-2013-052]

- **Hadronic decay**:
  Trimmed anti-k_T R=1.0 jets, $p_T > 300$ GeV
  Top-tagging: m>100 GeV and d_{12} >40 GeV
- **Leptonic decay**: Mini-isolation



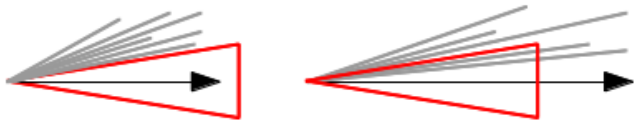
- **Combine with resolved channel** for optimal sensitivity over $m_{t\bar{t}}$ range
- Benchmark models:
  - Top-colour Z' with relative width 1.2%
    Exclude mass < 1.8 TeV at 95% CL
  - KK gluon with relative width 15.3%:
    Exclude mass < 2.0 TeV at 95% CL





Lepton Isolation

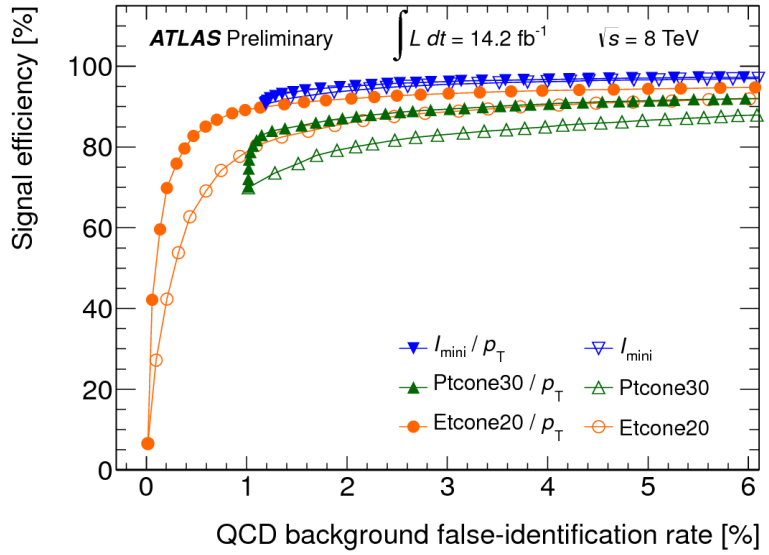
[ATLAS-CONF-2013-052]



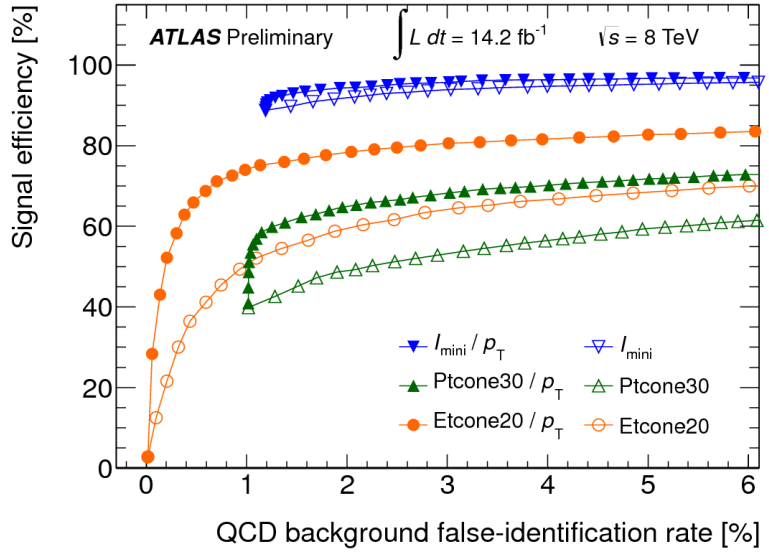
a) Fixed-cone isolation:
Cut on $\sum p_T$ ($\sum E_T$)
in cone with **fixed radius R**

b) Mini-isolation:
Cut on $\sum p_T$ ($\sum E_T$)
in cone with **radius R=k/p_T^l**

$m_{Z'} = 1$ TeV



$m_{Z'} = 2$ TeV

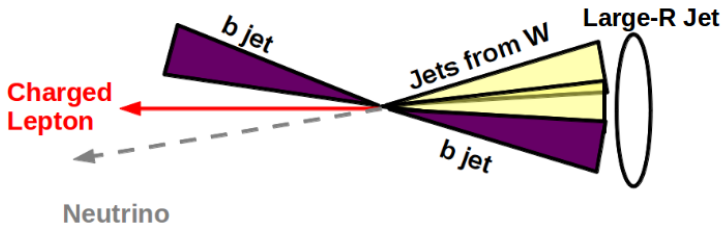


Mini-isolation provides stable performance over different p_T ranges with signal efficiency close to 100%!

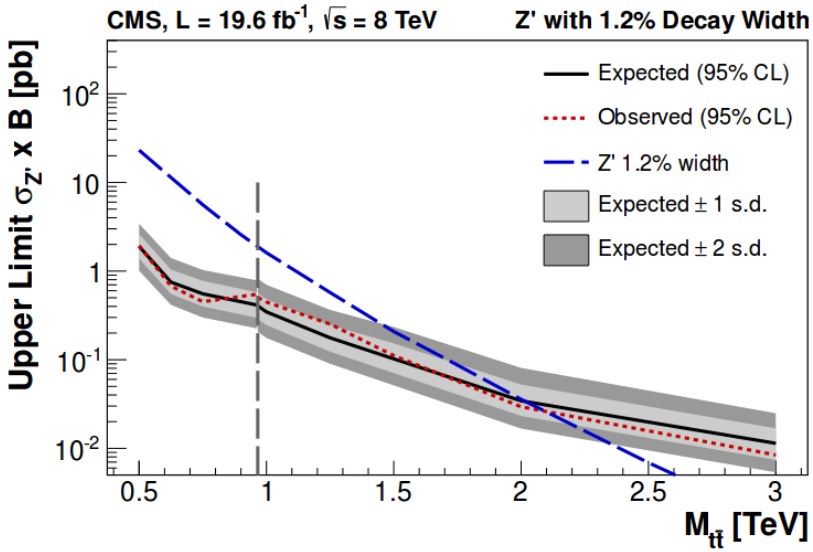
$t\bar{t}$ Resonance Search 1ℓ+jet

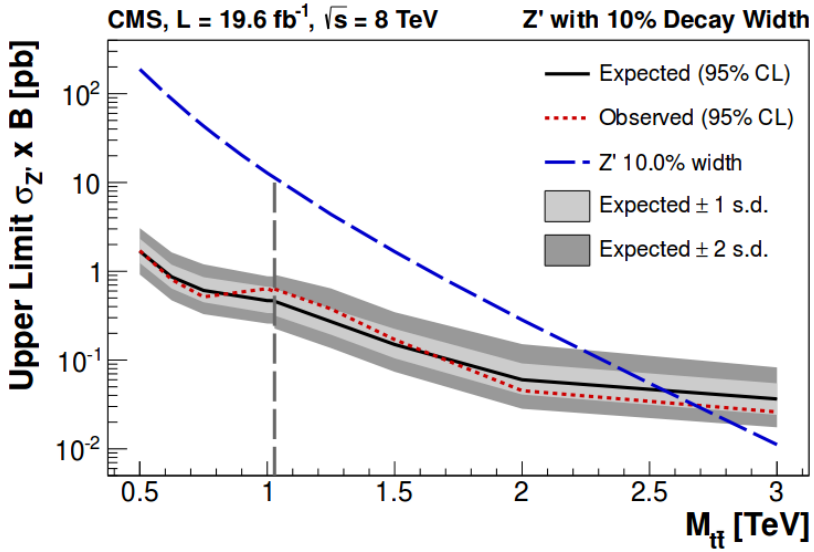
$\int Ldt = 19.7$ fb^{-1}, $\sqrt{s} = 8$ TeV [CMS PAS B2G-12-006]

- **Event selection**
  - $\geq$ 2 C/A R=0.5 jets, $p_T^{lead} > 150$ GeV
  - No dedicated top tagging
    Low multi-jet bkgr due to leptonic decay!
  - No lepton isolation
  - Cuts on $\Delta R(\ell, \text{jet})$ and $p_T^{rel}(\ell, \text{jet})$



- **Combine with resolved channel** for optimal sensitivity over $m_{t\bar{t}}$ range
- Benchmark models:
  - Top-colour Z' with relative width 1% (10%)
    Exclude mass $<$ 2.1 TeV ($<$2.7 TeV) at 95% CL
  - KK gluon with relative width 20%:
    Exclude mass $<$ 2.5 TeV at 95% CL





$t\bar{t}$ Resonance Search (all-hadronic)

$\int Ldt = 4.7$ fb^{-1}, $\sqrt{s} = 7$ TeV — ATLAS [JHEP 01(2013) 116]

$\int Ldt = 19.6$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS PAS B2G-12-005]

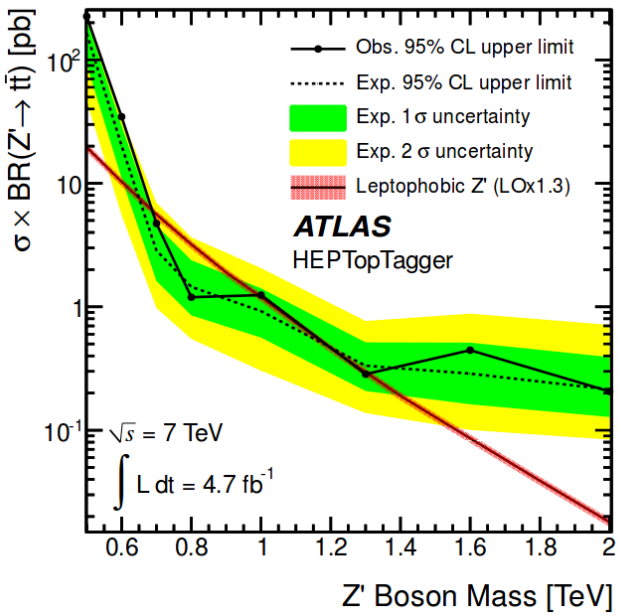
- Simple dijet event structure
  $\Rightarrow$ Require two top tagged large-R jets
- More sophisticated taggers needed against multi-jet bkgr

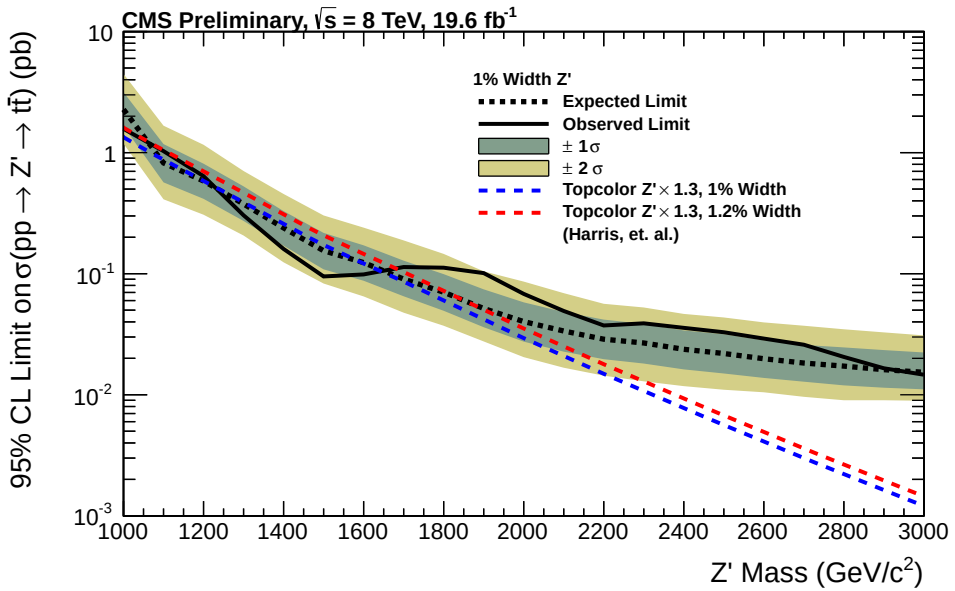
ATLAS

- HEPTopTagger (moderate p_T)
- Top Template Tagger (high p_T)

CMS

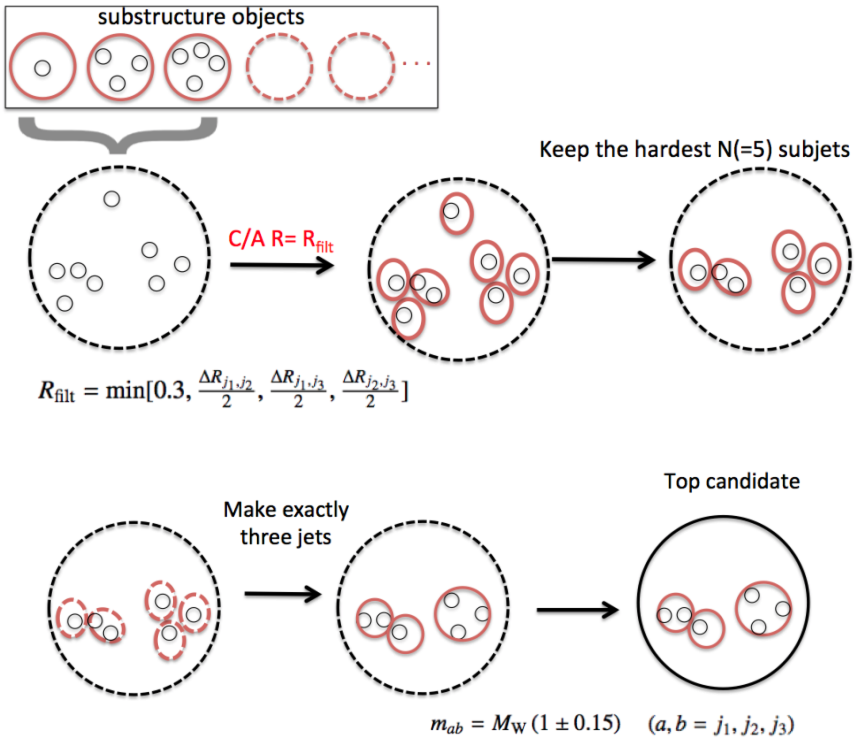
- CMS Top Tagger
- Combination with 1ℓ+jets channel in [CMS-B2G-13-001]





HEPTopTagger [ATLAS-CONF-2012-065]

- Algorithm by Plehn, Spannowsky, Takeuchi [arXiv:1111.5034]
- Several modified version available (e.g. track-based version for very high boosts)
- Combines several techniques (mass-drop, filtering, ...)

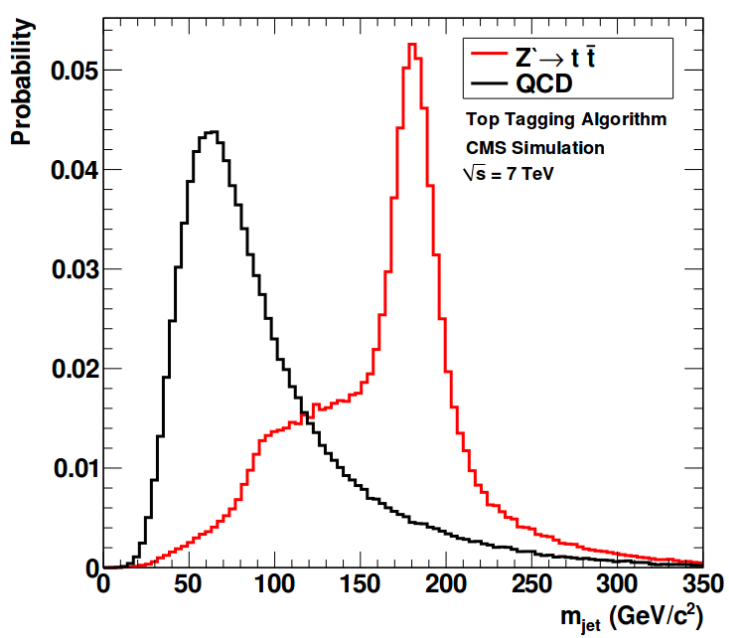


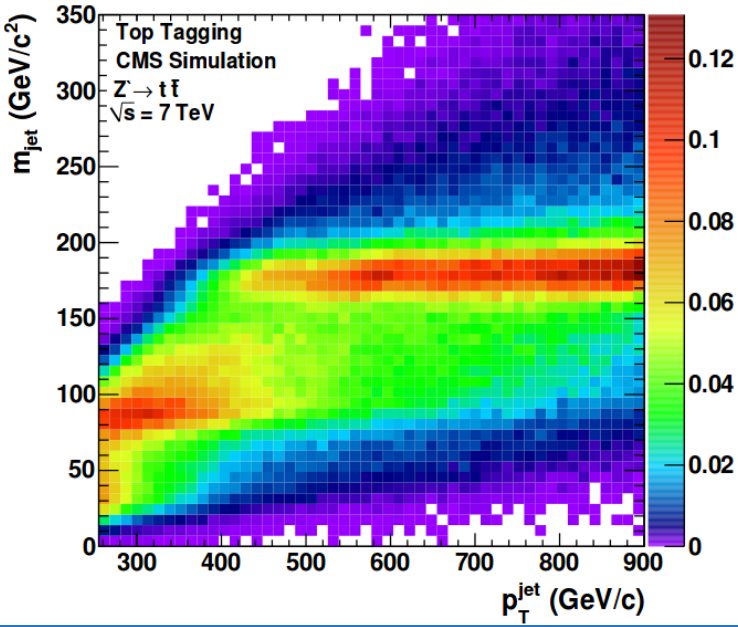
- Recluster large-R jet (typically C/A with R=1.5) using small radius R_{filt}
- Keep only 5 hardest subjets
  $\Rightarrow$ Discard soft, wide-angle radiation but keep FSR
- Recluster to get 3 subjets and apply cuts, e.g. on W mass window

Top Tagging in CMS [CMS PAS JME-10-013]

Algorithm based on **JHU top tagger**
Kaplan, Rehermann, Schwartz, Tweedie
[PRL 101/142001 (2008)]

- Start from C/A jets with R=0.8
- Undo clustering step by step until 3 or 4 subjets with sufficient p_T and angular separation
- Require smallest pair-wise mass close to W mass
- Require overall jet mass close to top mass





Search for $W' \rightarrow tb$

$\int Ldt = 20.3$ fb^{-1}, $\sqrt{s} = 8$ TeV — ATLAS [arXiv:1408.0886]

$\int Ldt = 19.7$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS PAS B2G-12-009]

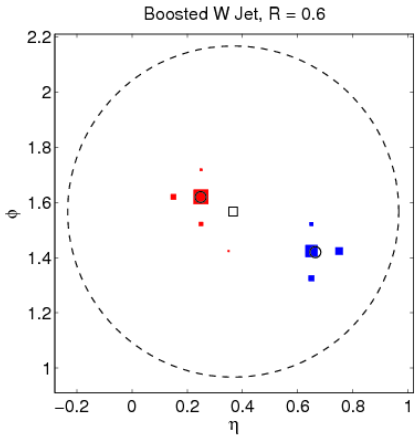
- **Heavy W partner** predicted by numerous SM extensions (GUTs, extra-dimension models, technicolour and Little Higgs models)
- Consider **only fully hadronic decays**: $W' \rightarrow tb \rightarrow qqbb$

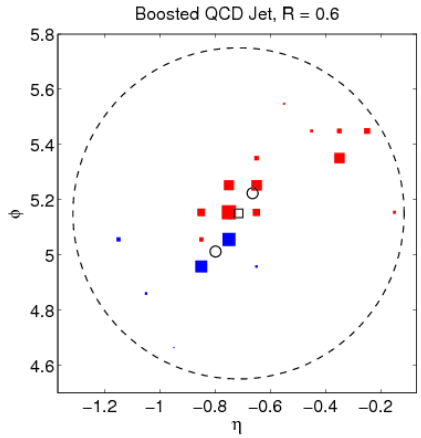
ATLAS: **W' Top Tagger**

- Single anti-k_T R=1.0 trimmed jet with p_T >350 GeV
- Cuts on three substructure variables: d_{12}, τ_{32}, τ_{21}

CMS

- CMS Top Tagger
- **Nsubjettiness ratio**: τ_{32} <0.55
- See Appendix (slide 29 for more details)





Measure how compatible jet substructure is with "N subjets" hypothesis

Ratios $\tau_{21} = \tau_2/\tau_1$, $\tau_{32} = \tau_3/\tau_2$ powerful discriminants against multijet bkgr

Search for $W' \rightarrow tb$

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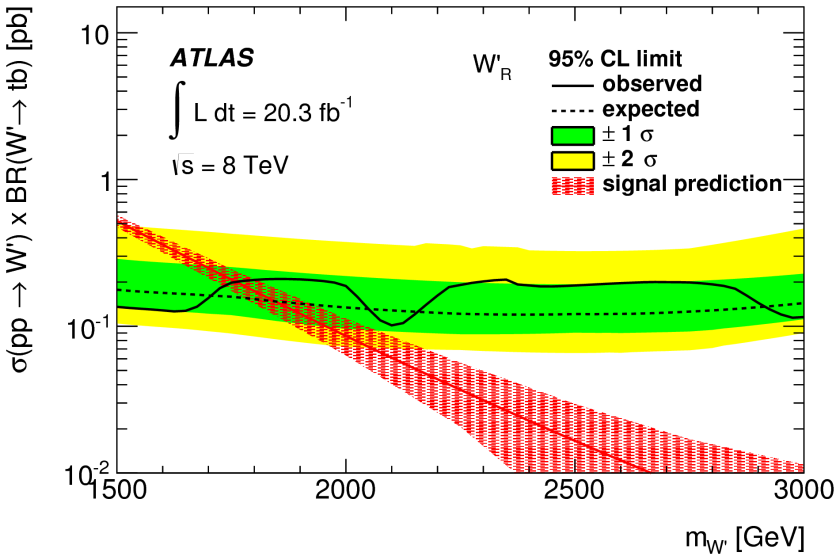
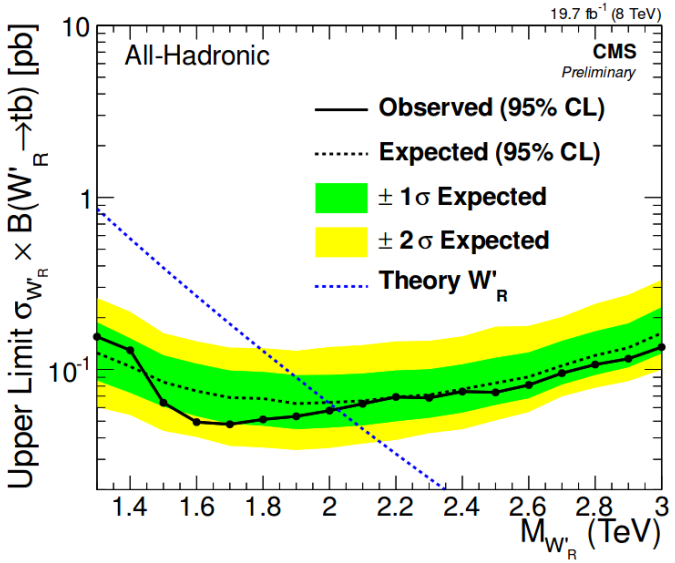




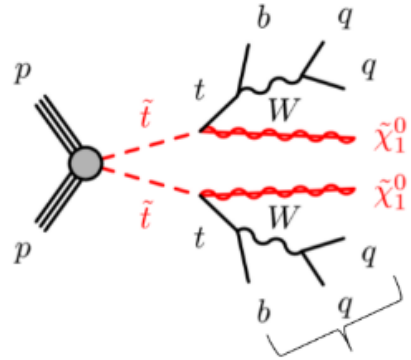
Searches for Direct $\tilde{t}_1\tilde{t}_1$ Production

$\int Ldt = 20.1$ fb^{-1}, $\sqrt{s} = 8$ TeV

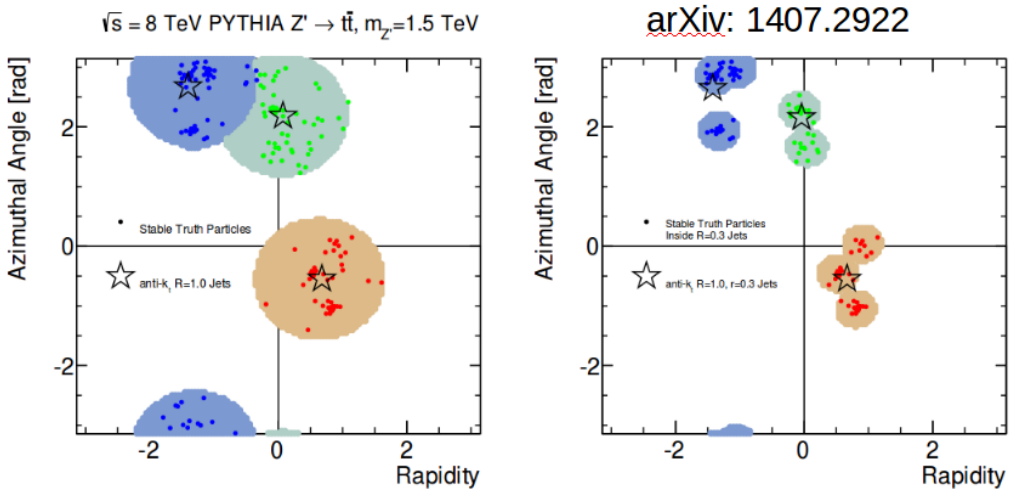
ATLAS [arXiv:1406.1122]

0-lepton channel: **Jet reclustering**

- Large-R (0.8, 1.2) anti-k_T jets built from anti-k_T 0.4 jets with p_T >25 GeV
- Need to calibrate only one jet collection
- p_T cut on input jets acts like trimming



Top jet

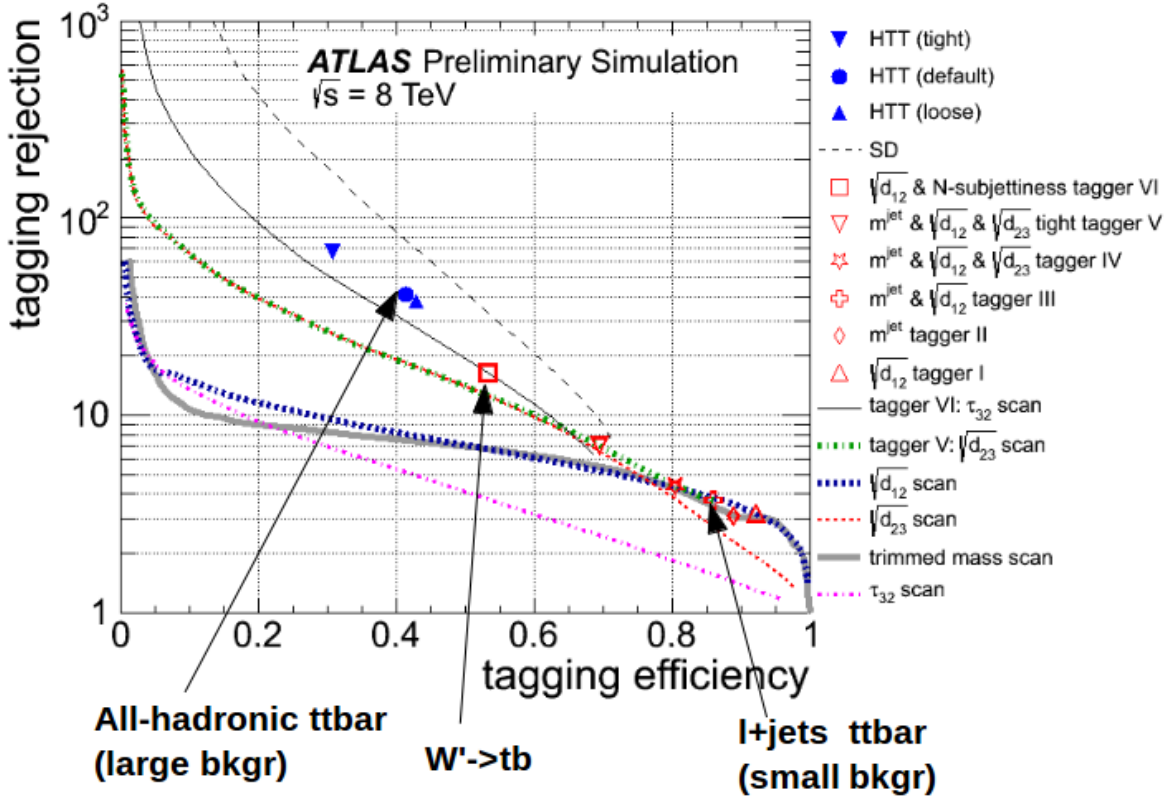


0-lepton CMS search [CMS-PAS-SUS-13-015] using 3 anti-k_T 0.5 jets within $\Delta R = 1.5$ as hadronic top

ATLAS search [arXiv:1407.0583] in 1-lepton channel using trimmed anti-k_T 1.0 jets

Comparison of Top Taggers ATLAS [ATLAS-CONF-2014-003]

- Numerous variables (and combinations thereof) for boosted top identification
- Different top taggers suited for different final states



On-going efforts to classify and compare taggers

⇒ **Define optimal strategies for Run-II!**

Searches with boosted bosons

- Resonances searches with boosted W, Z
  - Dijet Resonance Search with Boosted Bosons [CMS-EXO-12-024]
  - Diboson Resonance Search (semileptonic)
    [ATLAS-CONF-2014-039],[CMS-EXO-13-009]
- Search for mono-W/Z ATLAS [PRL 112,041802 (2014)]
- Vector-like b' quark decaying to boosted Higgs CMS [CMS-PAS-B2G-14-001]

Dijet Resonance Search with Boosted Bosons

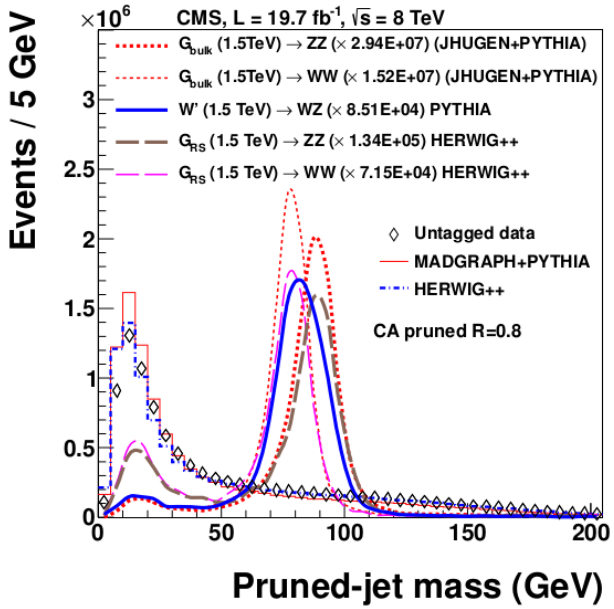
$\int Ldt = 19.7$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS-EXO-12-024]

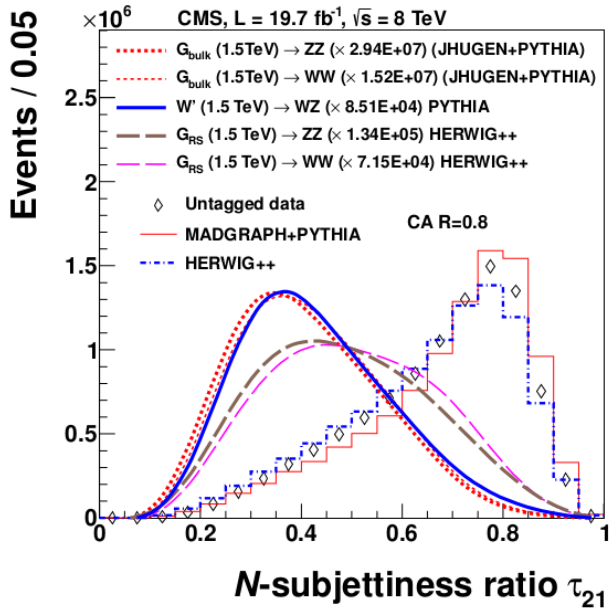
Searches for resonances decaying to qW,qZ or WW,WZ,ZZ

- **Excited quarks** $q* \rightarrow qW(qZ)$: Exclude mass $<$ 3.2 TeV ($<$2.9 TeV) at 95% CL
- **RS1 graviton** $G_{RS} \rightarrow WW$: Exclude mass $<$ 1.2 TeV at 95% CL
- **Heavy W-partner** $W' \rightarrow WZ$: Exclude mass $<$ 1.7 TeV at 95% CL

Boosted bosons decaying hadronically $\Rightarrow$ **Simple dijet event structure!**
Boson tagging:

- Mass cut on pruned C/A R=0.8 jets: 70 GeV$< m_{jet} <$100 GeV
- Cut on $\tau_{21} = \tau_2/\tau_1$: $\tau_{21} < 0.5$ (high-purity), $0.5 < \tau_{21} < 0.75$ (low-purity)



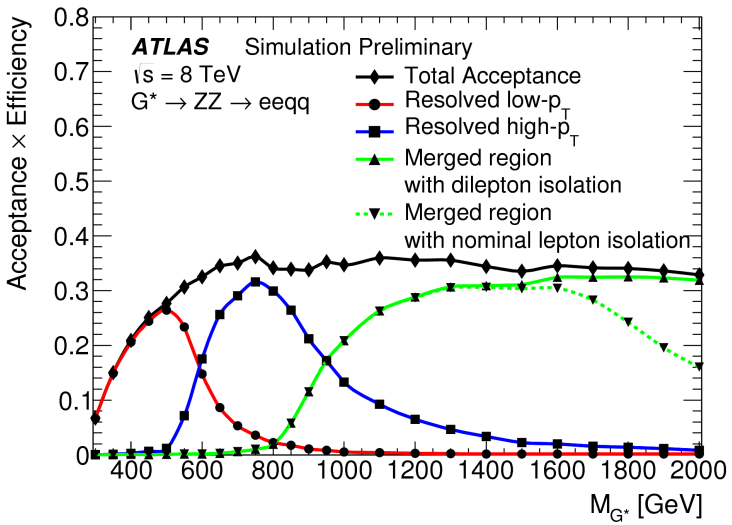


Diboson Resonance Search (semileptonic)

$\int Ldt = 20$ fb^{-1} at $\sqrt{s} = 8$ TeV — ATLAS [ATLAS-CONF-2014-039]

Resonances decaying to WZ,ZZ with one decay $Z \to \ell^+\ell^-$

- **"Bulk" RS graviton**: Exclude masses below 740 GeV at 95% CL
- **W′ boson**: Exclude masses below 1590 GeV at 95% CL

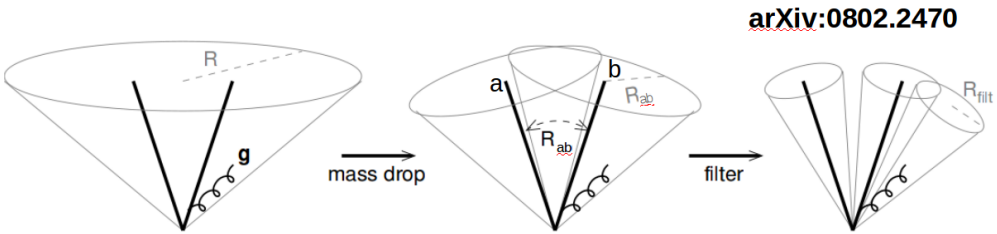


Lepton isolation

- Subtract track of other lepton if within 0.3 isolation cone
- Drop calorimeter-based isolation if $\Delta R(\ell^+\ell^-) < 0.25$

Boosted hadronic boson:

- C/A R=1.2 jet with mass-drop filtering algorithm optimised for bosons

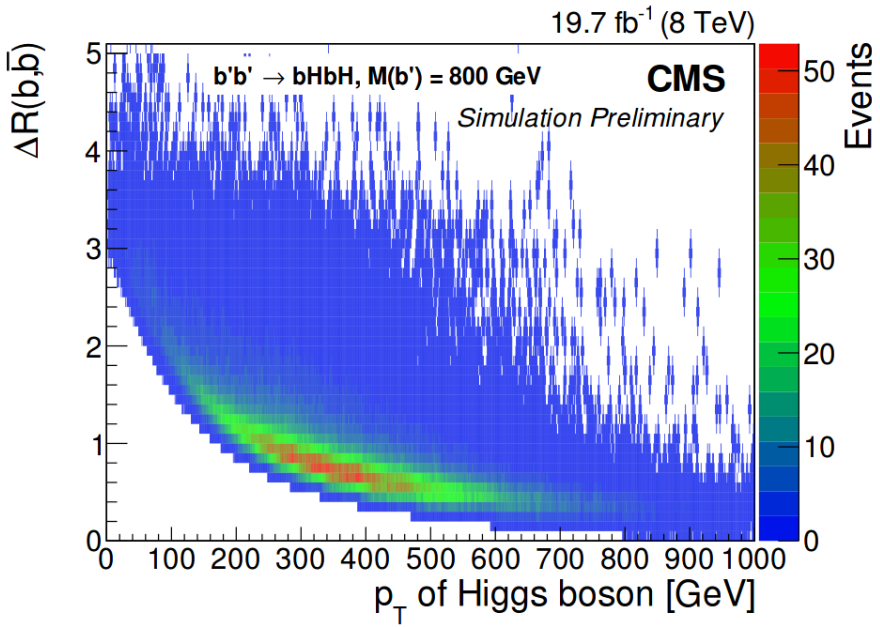


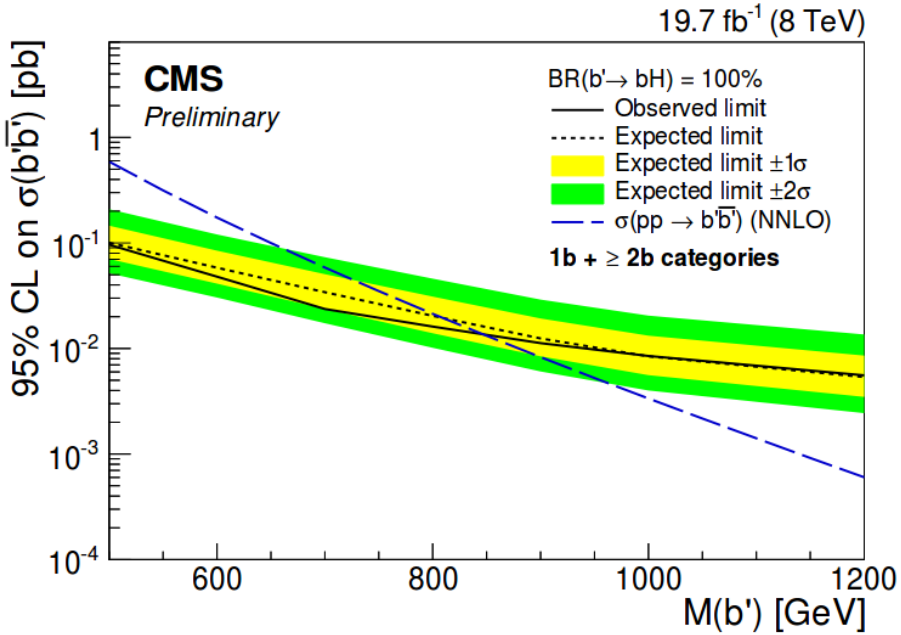
Same boson tagging applied by ATLAS [PRL 112,041802 (2014)] in DM search
Similar search by CMS [CMS-EXO-13-009] using boson tagging techniques as in all-hadronic search (slide 20)

Search for a Vector-like b' Quark decaying to Hb

$\int Ldt = 19.7$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS-PAS-B2G-14-001]

- Pair production of vector-like b' quark
- Consider decays $b' \to Hb$ with $H \to b\bar{b}$
- **Only feasible because boosted techniques help reduce multi-jet bkgr**
- Rely on both "Higgs-Tagging" and b-tagging
- **Higgs Tagging**:
  - Pruned C/A R=0.8 jets with p_T >300 GeV
  - 2-subjettiness: τ_2/τ_1 <0.5
  - 2 b-tagged subjets with ΔR >0.3





Top-partner searches (boosted tops + boosted bosons)

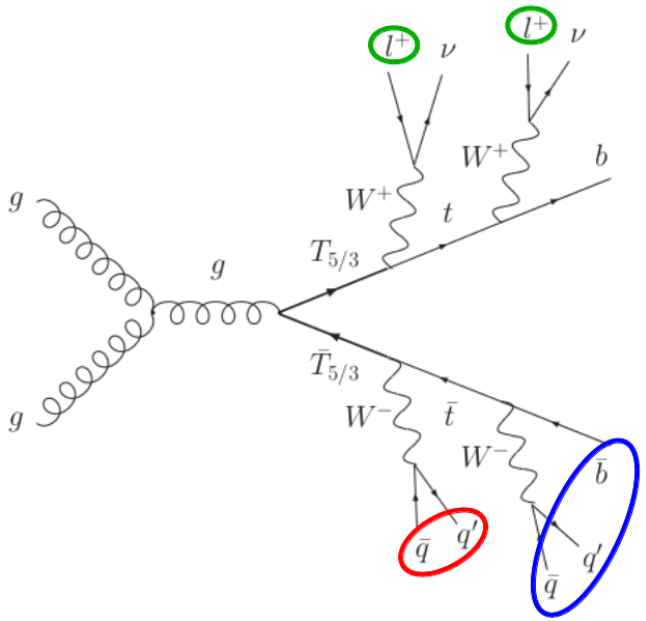
[ATLAS-CONF-2013-060], [CMS-B2G-12-012], [CMS-B2G-12-015], [CMS PAS B2G-14-002]

Top partners predicted by many extensions to the Standard Model
to address the problem of quadratic divergences in quantum-loop corrections to the Higgs boson mass (**hierarchy problem**)

Charge 5/3e Top Partner (same-sign dilepton)

$\int Ldt = 19.5$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS-B2G-12-012]

- Predicted by e.g. in **Composite Higgs** models
- Pair production of $T_{5/3}$ with decay $T_{5/3} \to W^{\pm} t \to W^{\pm} W^{\pm} b$
- Exclude mass $<$ 800 GeV at 95% CL



- **Boosted hadronic tops**:
  CMS Top Tagger
- **Boosted hadronic W**:
  Pruned C/A 0.8 jets;
  Exactly 2 subjets, m_{jj} close to m_W
- **Lepton isolation**:
  (Relative) fixed-cone isolation

Similar search in same-sign dilepton final state by ATLAS [ATLAS-CONF-2013-051] using mini-isolation but no further boosted techniques

Vector-like T-Quark with charge 2/3

$\int Ldt = 14.3$ fb^{-1}, $\sqrt{s} = 8$ TeV ATLAS [ATLAS-CONF-2013-060],[ATLAS-CONF-2013-018]

$\int Ldt = 19.5$ fb^{-1}, $\sqrt{s} = 8$ TeV CMS [CMS-B2G-12-015],[CMS PAS B2G-14-002]

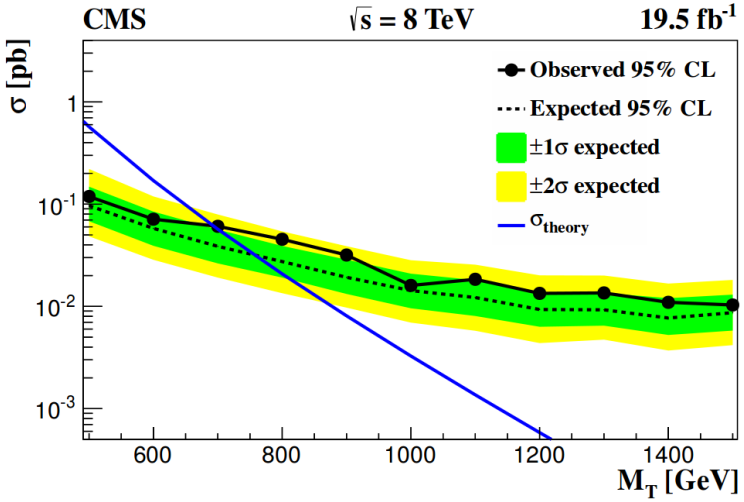
Decay channels: T → Wb (dominant), T → tZ, T → tH

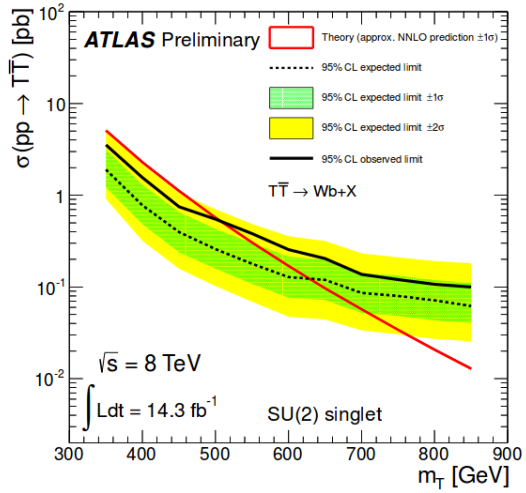
CMS: Incl. search with ≥1 lepton

- **Hadronic W**: Pruned C/A R=0.8 (p_T >200 GeV,$m \in$[60,130] GeV)
- **Hadronic top**: CMS Top Tagger

ATLAS: T → Wb with ≥1 lepton

- **Hadronic W**: Anti-k_T R=0.4 jet (p_T >250 GeV,$m \in$[60,120] GeV)
- **Mini-isolation** (on the μ)





CMS: Allhadronic T → tH search

- **Hadronic top**: HEPTopTagger
- **H(b$\bar{\text{b}}$)**: Higgs- and b-tagging

ATLAS: Allhadronic T → tH search

No dedicated substructure techniques

Summary and Outlook

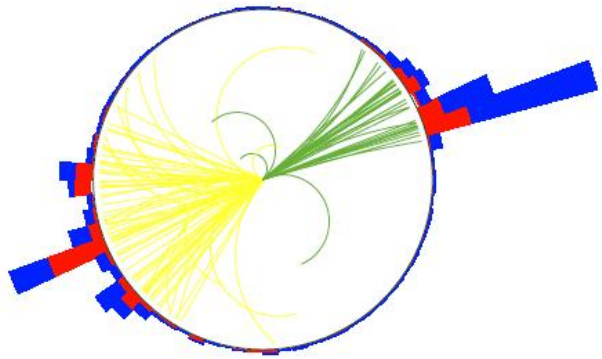
Number of searches using boosted techniques has grown fast in recent years...

- Wide range of techniques already on the market
- Right choice depends on final state, kinematic regime, backgrounds, etc.

... and still continues to grow!

- LHC center-of-mass energy will almost double to 13 TeV next year
  - Exploring new techniques (in particular track-based)
  - Intense collaboration with phenomenologists
  - Detector resolution is the limit...
- Boosted techniques also find their way into SM measurements (e.g. ATLAS [CERN-PH-EP-2014-123], see talk by M. Kuze)

Boosted objects may be the key to New Physics!



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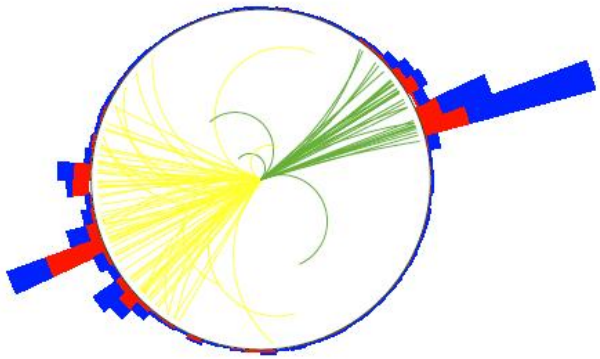


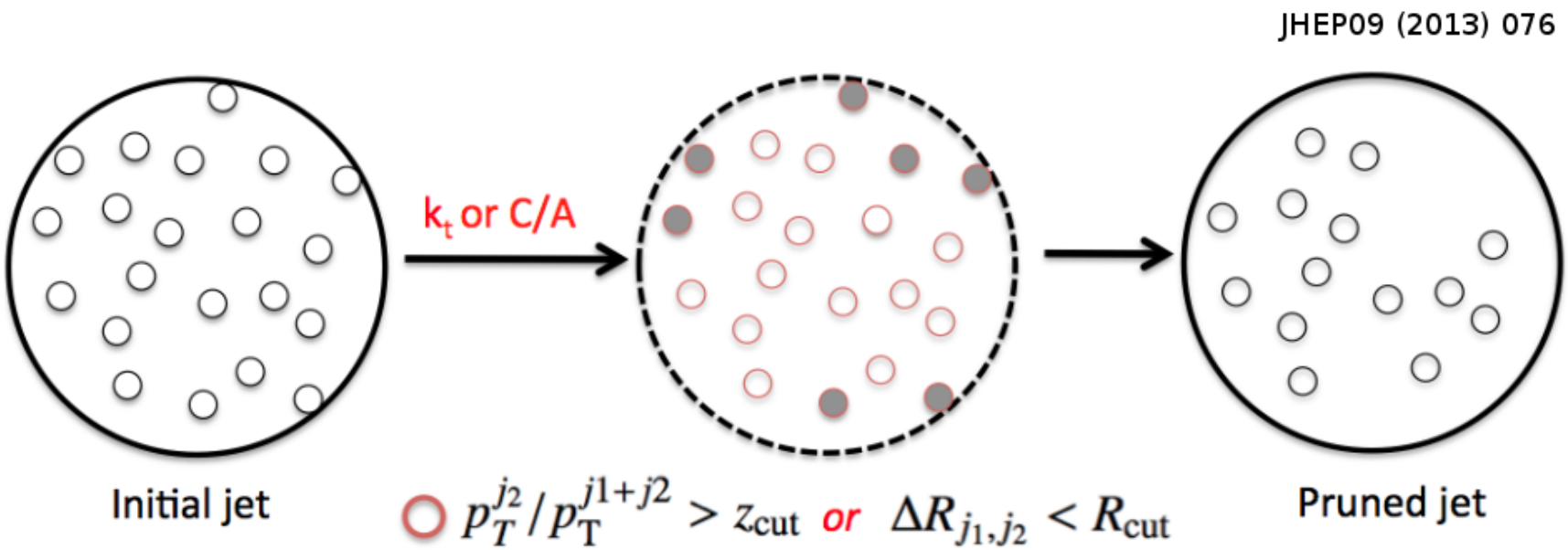
THANK YOU!

BACKUP

Jet Grooming (1)

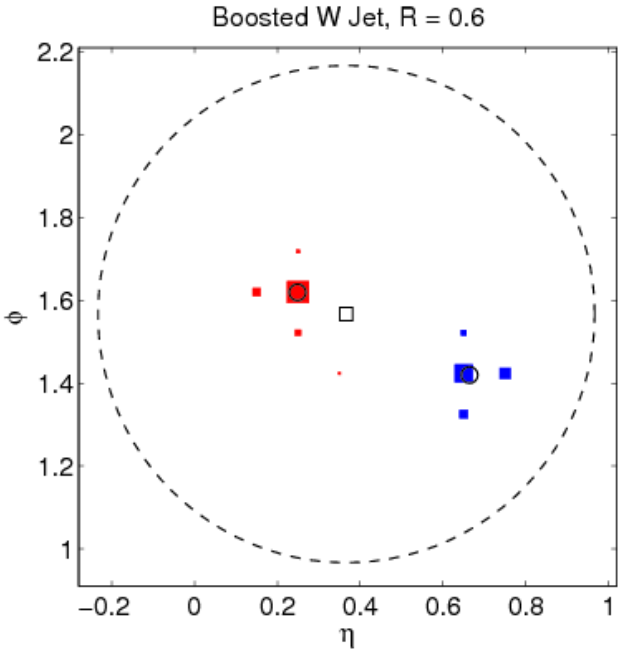
- Large-R jets more susceptible to contaminations from Underlying Event and pile-up
- Soft radiation dilutes jet substructure
- **Grooming to remove soft, wide-angle contaminations!**
- Various algorithms available:
  - Trimming: Krohn, Thaler, Wang [arXiv:0912.1342]
    Widely used in ATLAS
  - Pruning: Ellis, Vermillion, Walsh [arXiv:0903.5081]
    Widely used in CMS
  - Filtering: Butterworth, Davison, Rubin, Salam [arXiv:0802.2470]
    HEPTopTagger uses filtering-like approach

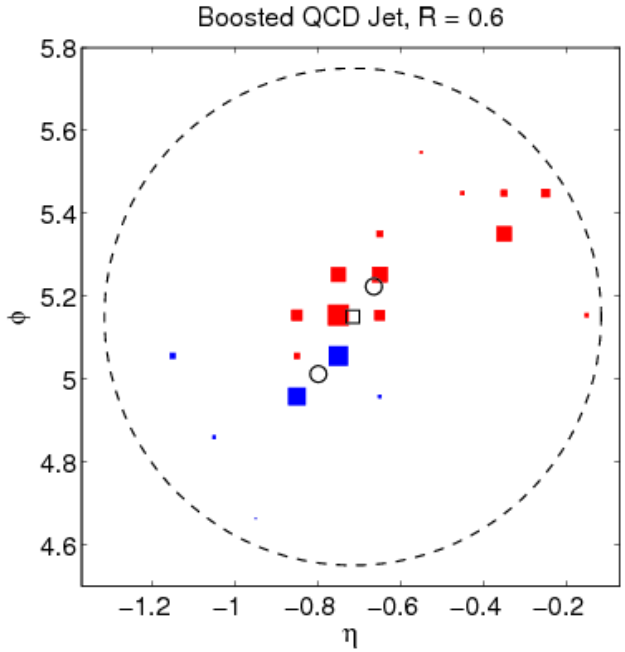
Example: Pruning (CMS: $z_{cut} = 0.1, R_{cut} = 0.5 \cdot m_{jet}/p_T$)



- Re-cluster large jet of radius R_0 with k_T algorithm until N subjets
- $\tau_N = 1/d_0 \cdot \sum_k p_{T,k} \min(\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{N,k})$
- Where $d_0 = \sum_k p_{T,k} \cdot R_0$ and k runs over all constituents

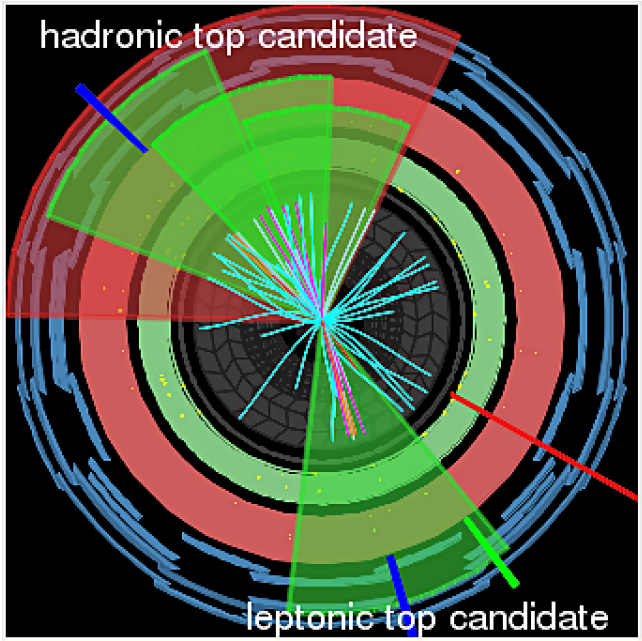
Measure how compatible jet substructure is with "N subjets" hypothesis

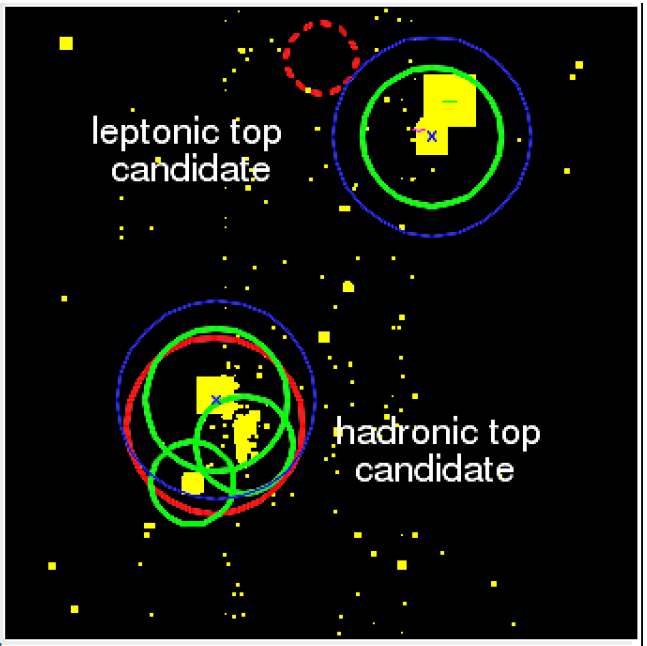


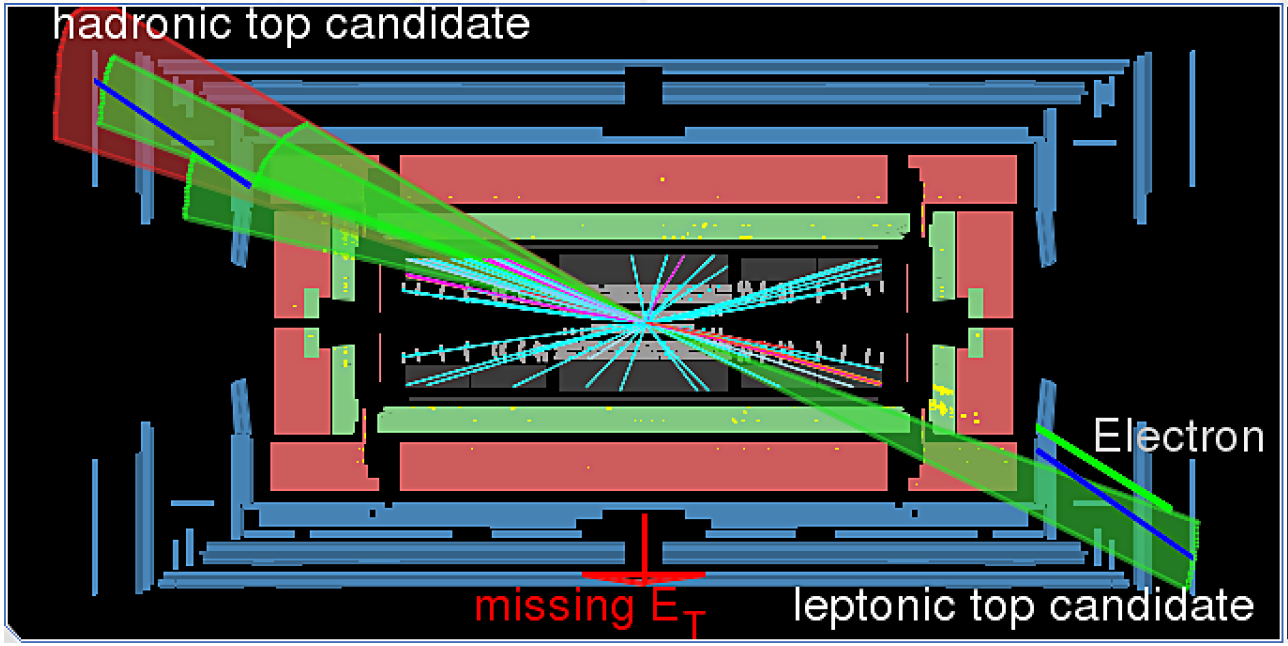


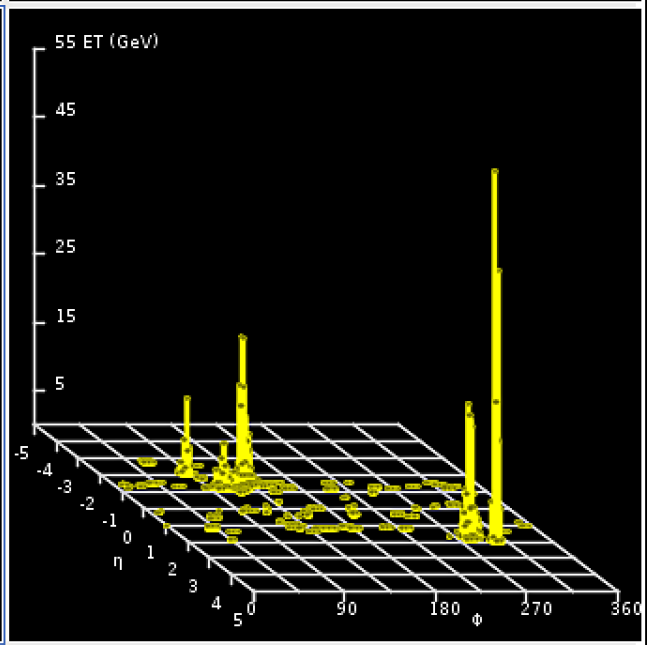
Ratios $\tau_{21} = \tau_2/\tau_1$, $\tau_{32} = \tau_3/\tau_2$ powerful discriminants against multijet bkgr

ATLAS event display: $t\bar{t} \rightarrow e$+jets

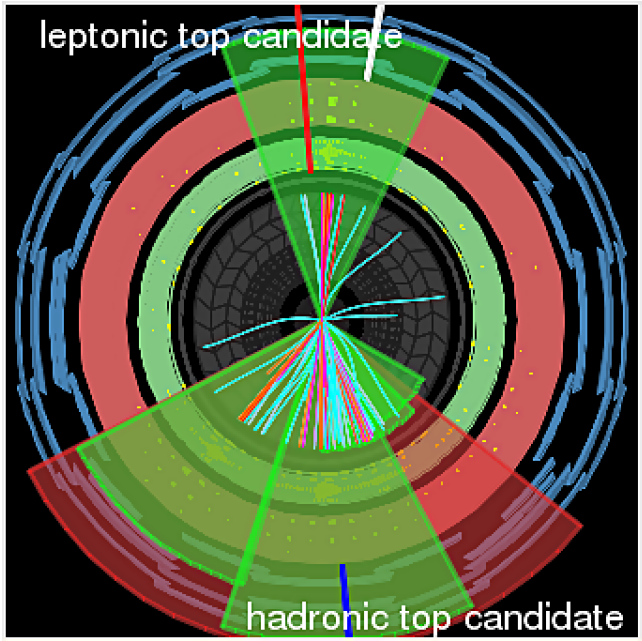


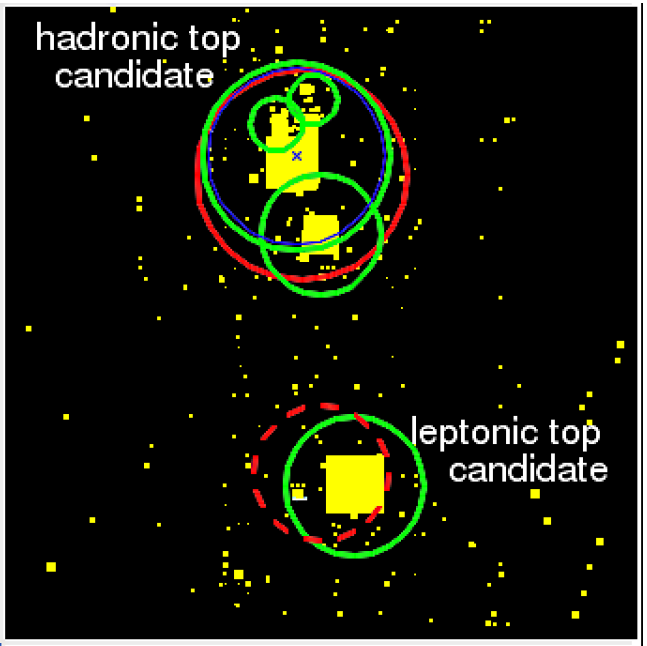


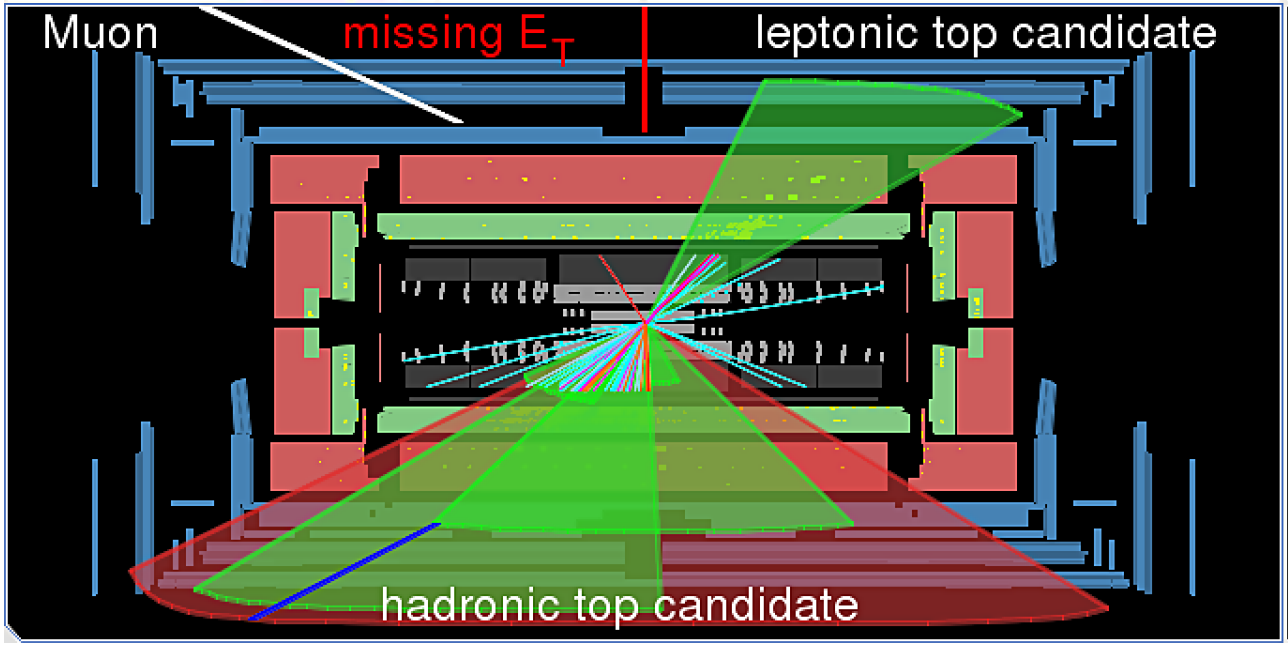


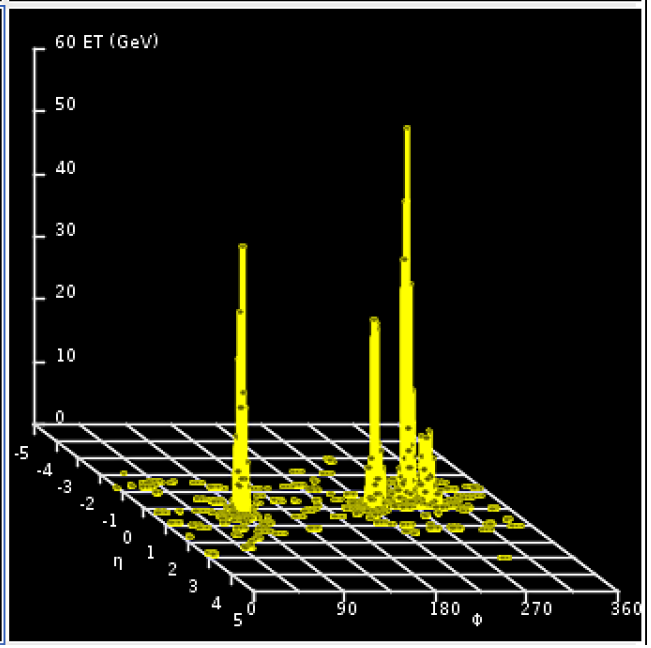


ATLAS event display: $t\bar{t} \rightarrow \mu$+jets









Benchmark Models for $t\bar{t}$ Resonance Searches

Various BSM models predict resonances in the $m_{t\bar{t}}$ spectrum

Warped extra-dimensions (Randall-Sundrum)

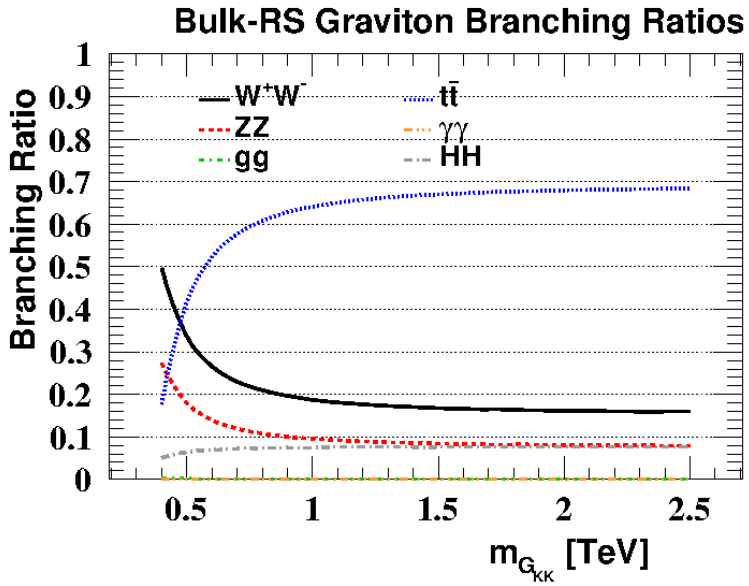
- **Kaluza-Klein (KK) gluon (g_{KK})**
  Spin-1, width: 10–40%
- **KK/Bulk-RS graviton (G_{KK})**
  Spin-2, width: 3–6%

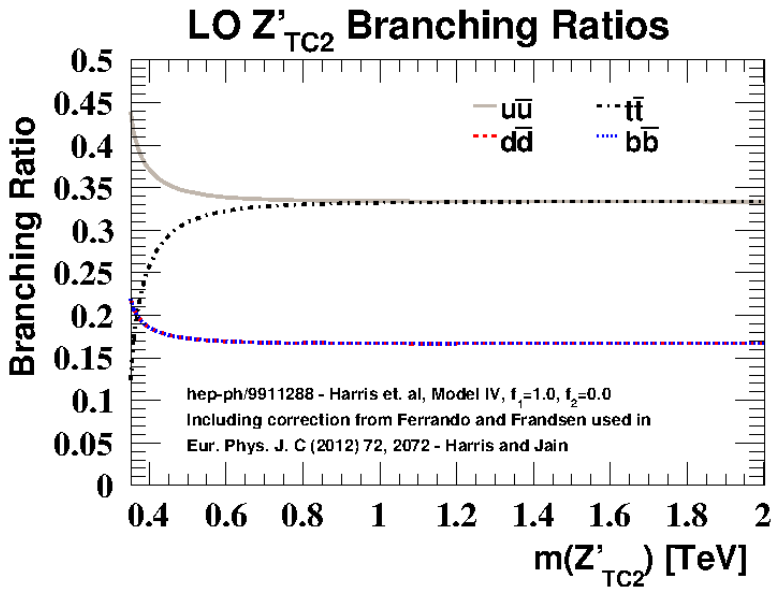
Top-colour (TC) model:

- **Leptophobic TC Z' boson (Z′)**
  Spin-1, width: 1.2%

Searches in all decay channels:

- All-hadronic
- 1 lepton+jets
- (Dileptonic)





Searches for Direct $\tilde{t}_1\tilde{t}_1$ Production

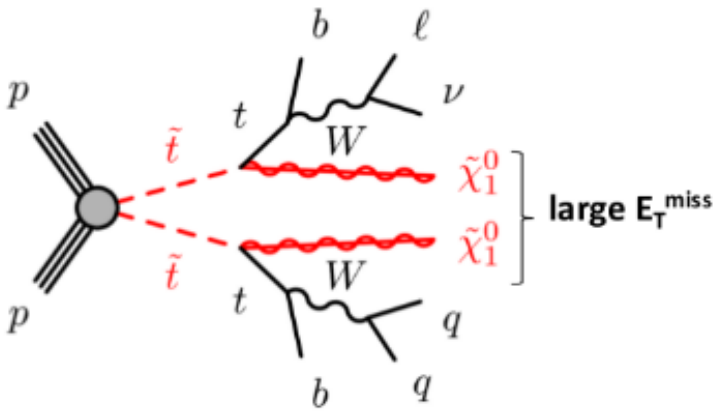
$\int Ldt = 20.1$ fb^{-1}, $\sqrt{s} = 8$ TeV ATLAS [arXiv:1407.0583,arXiv:1406.1122]

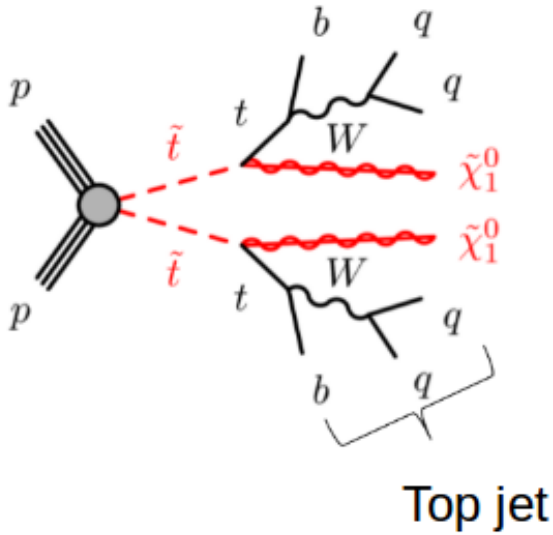
1-lepton channel

- $\geq$1 anti-k_T R=1.0 trimmed jet with p_T >270 GeV, m >75 GeV
- Modified rel. cone lepton isolation
- Sensitive for $m_{\tilde{t}_1}$ >600 GeV

0-lepton channel: **Jet reclustering**

- Large-R (0.8, 1.2) anti-k_T jets built from anti-k_T 0.4 jets with p_T >25 GeV
- Need to calibrate only one jet collection
- p_T cut on input jets acts like trimming





Similar 0-lepton search by CMS [CMS-PAS-SUS-13-015] using three anti-k_T 0.5 jets within $\Delta R = 1.5$ as a hadronic top

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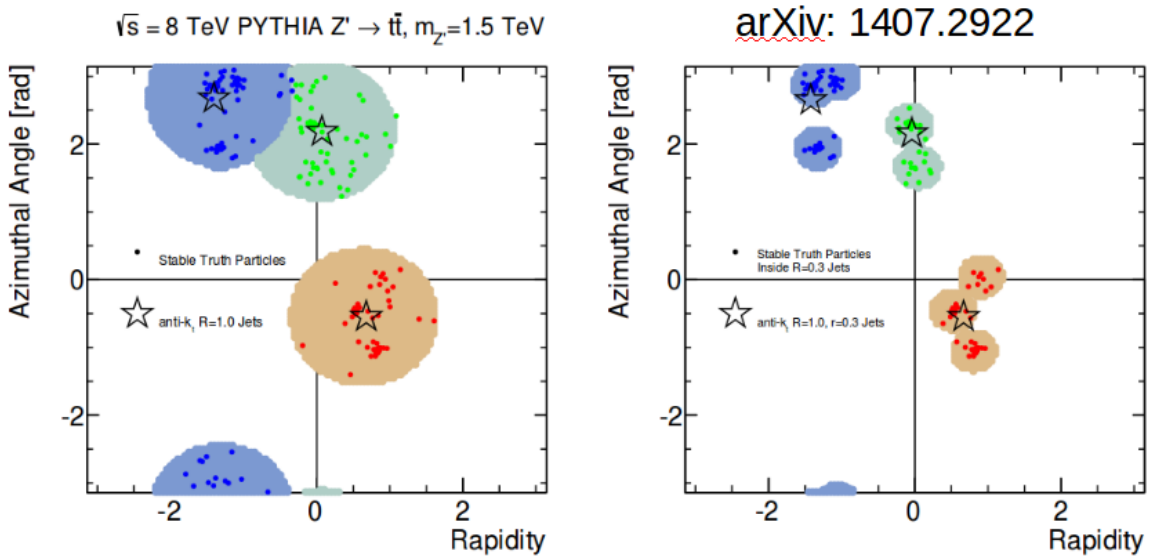

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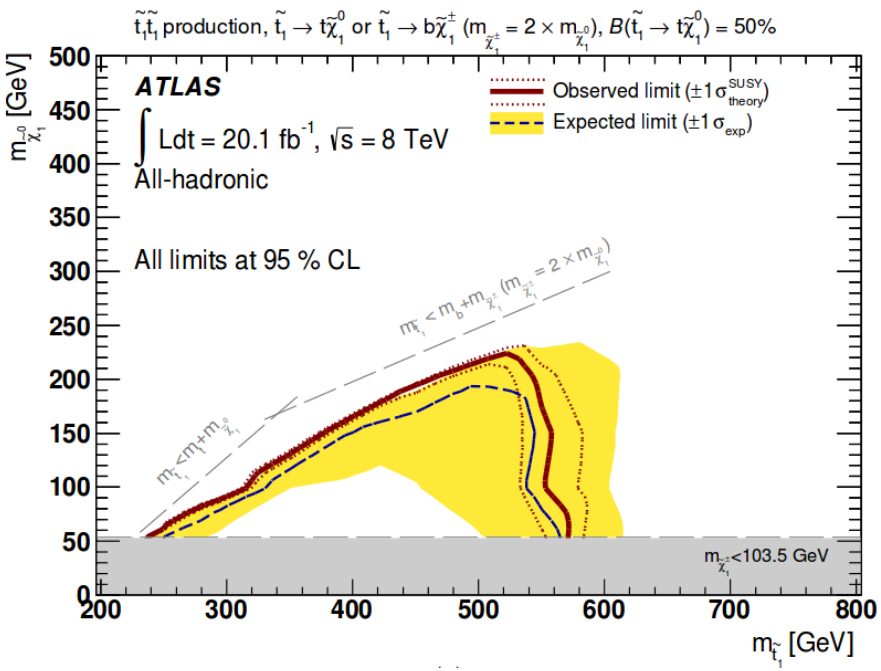

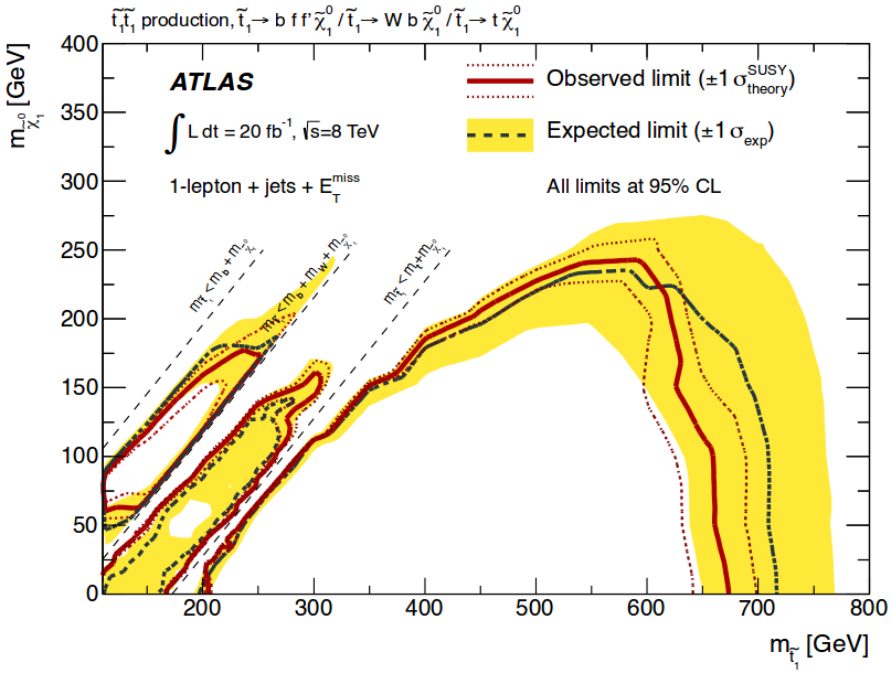

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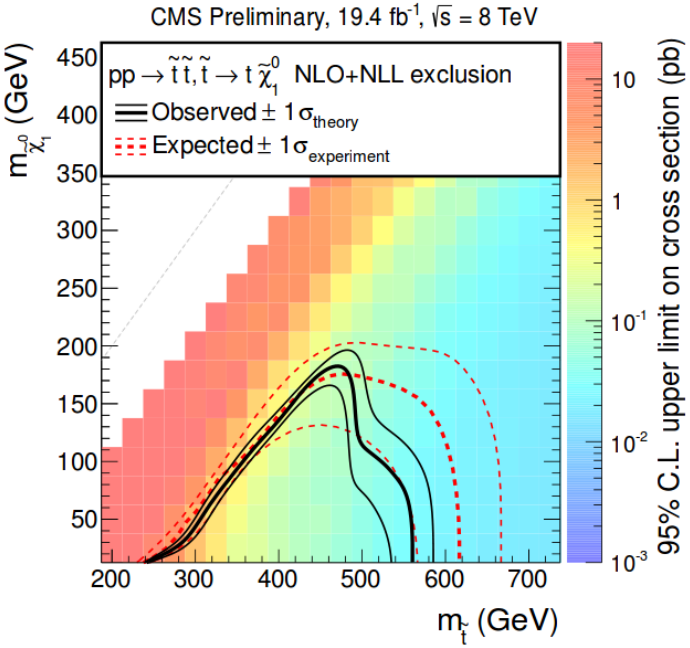
$\int Ldt = 20.1$ fb^{-1}, $\sqrt{s} = 8$ TeV

CMS [CMS-PAS-SUS-13-015]

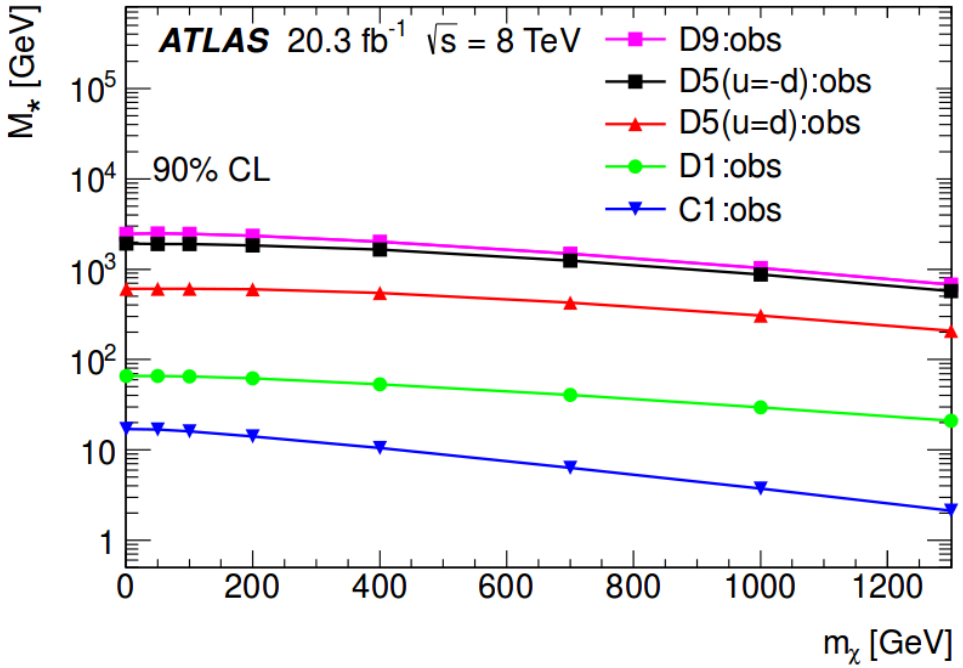


Search for mono-W/Z

$\int Ldt = 20.3$ fb^{-1} at $\sqrt{s} = 8$ TeV

ATLAS [PRL 112,041802 (2014)]

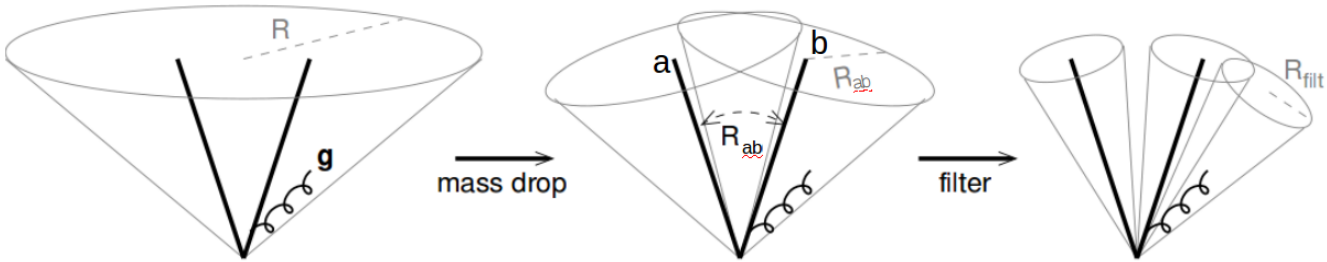
- Dark Matter pair production with associated hadronic W/Z
  90% exclusion limits on effective theory mass scale M_*
- Pair production with Higgs as mediator (not shown here)



Boson tagging:

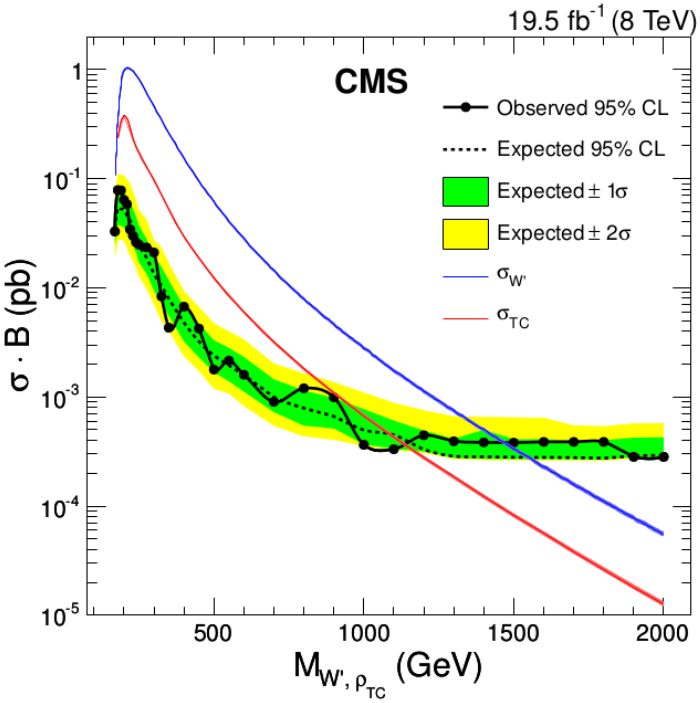
- $\geq$1 C/A 1.2 jet with p_T >250 GeV
- Mass-drop (see slide 6) and filtering
- Jet mass window cut around boson mass

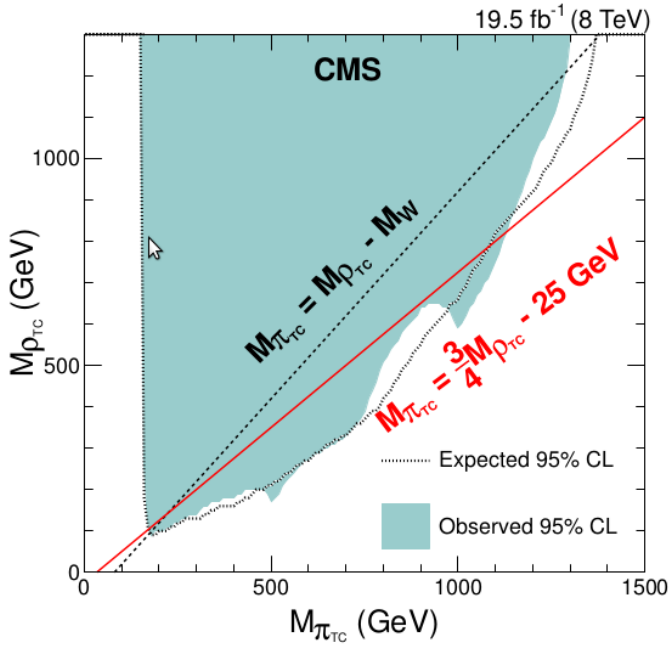
arXiv:0802.2470



Search for $W' \to WZ$ (leptonic) [CMS-EXO-12-025]

- Using $\int Ldt = 19.7$ fb^{-1} at $\sqrt{s} = 8$ TeV
- Leptonic decays $Z \to ll$, $W \to l\nu$ where $l = e, \mu$
- Modify selection for leptons from $Z \to$ Increase high-mass sensitivity!
  - e: Loosen requirements on matching between track and EM cluster
  - μ: Loosen requirements on number of detector hits
  - μ: Subtract contribution from close-by second μ in isolation cone
- Benchmark models:
  - Heavy W partner: W'; Low-scale technicolour models



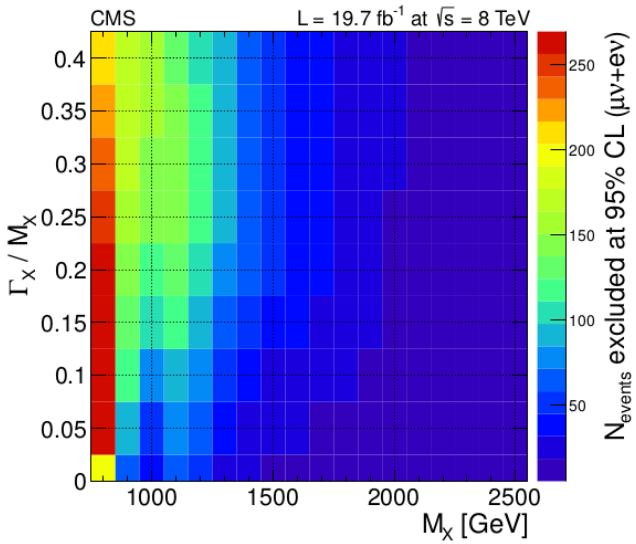


Diboson Resonance Search (semileptonic)

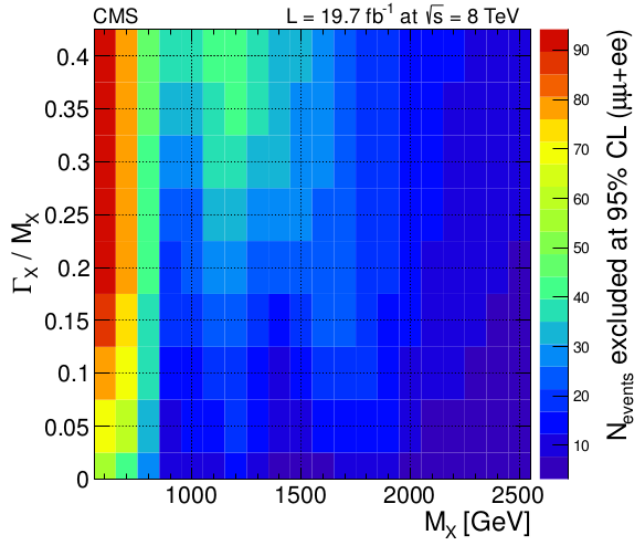
$\int Ldt = 19.7\ \text{fb}^{-1}, \sqrt{s} = 8\ \text{TeV}$ CMS [CMS-EXO-13-009]

- Searches for resonances in WW, WZ, ZZ final states
- Semileptonic boson decays:
  - Boosted hadronic boson: like all-hadronic boson search
  - Lepton isolation: relative pt-cone 0.3 isolation
- Benchmark models:
  - Generic resonances with different masses and widths
  - "Bulk" RS graviton
- Combination with all-hadronic channel to increase sensitivity

$WW \to e\nu + \mu\nu$

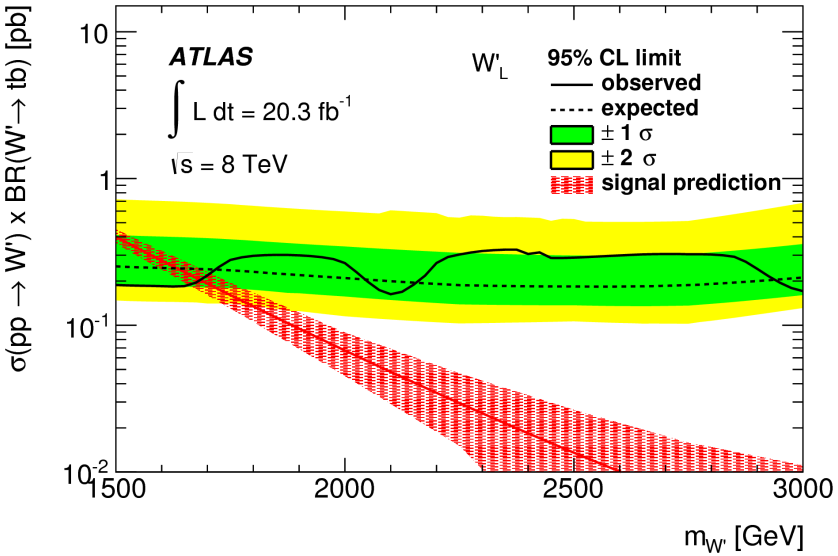


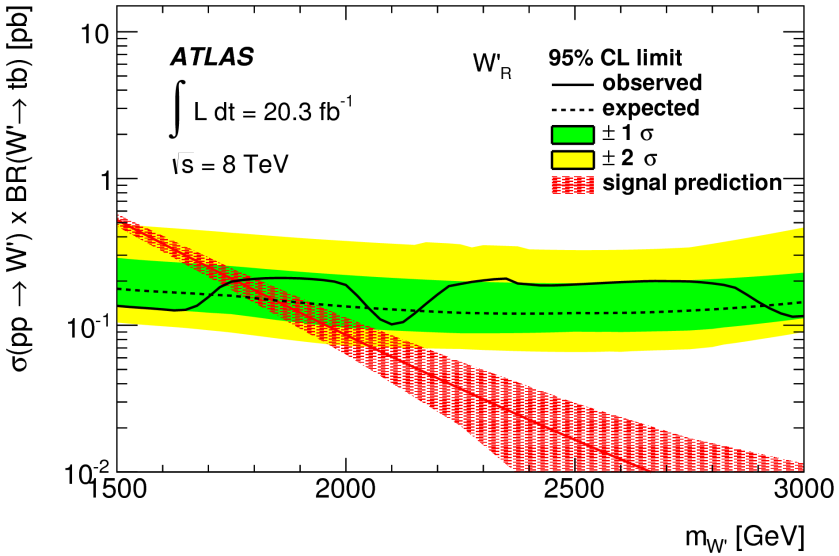
$ZZ \to ee + \mu\mu$

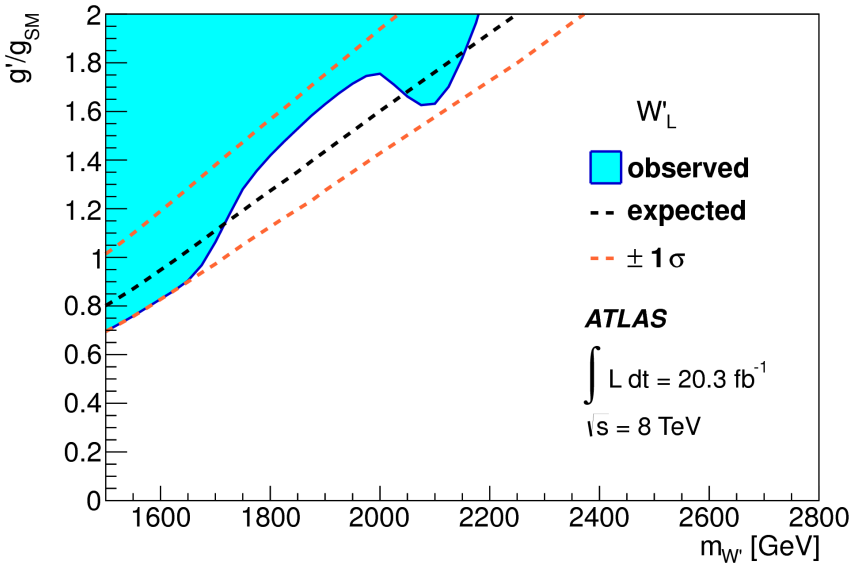


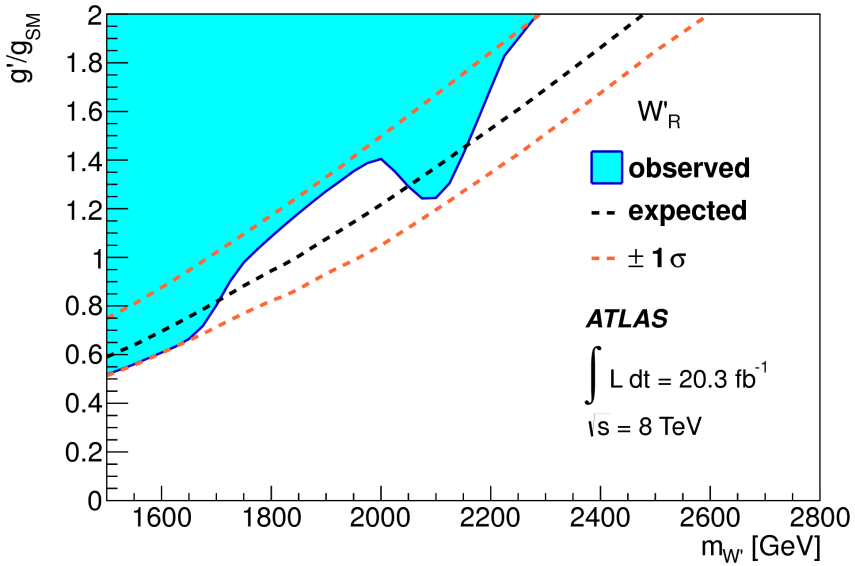
Search for $W' \to tb$: ATLAS Limits

$\int Ldt = 20.3\ \text{fb}^{-1}, \sqrt{s} = 8\ \text{TeV}$ ATLAS [arXiv:1408.0886]









Vector-like T-Quark with charge 2/3

$\int Ldt = 14.3$ fb^{-1}, $\sqrt{s} = 8$ TeV — ATLAS [ATLAS-CONF-2013-060]

$\int Ldt = 19.5$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS-B2G-12-015],[CMS PAS B2G-14-002]

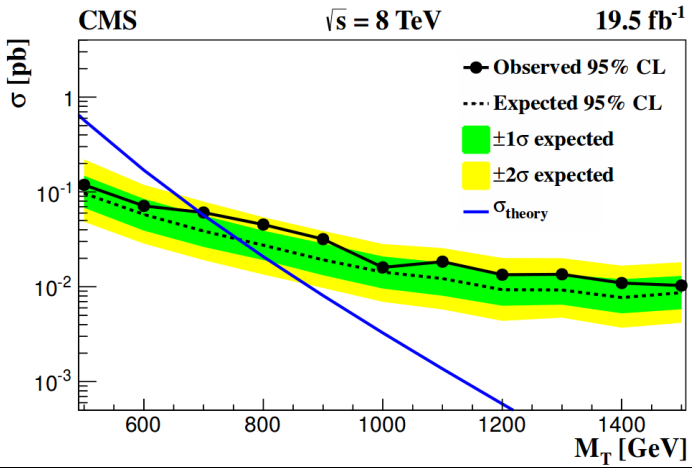
- Predicted by Little Higgs and extra-dimension models
- Vector couplings to W,Z (evading constraints from EW measurements)
- Decay channels: $T \to Wb$, $T \to tZ$, $T \to tH$

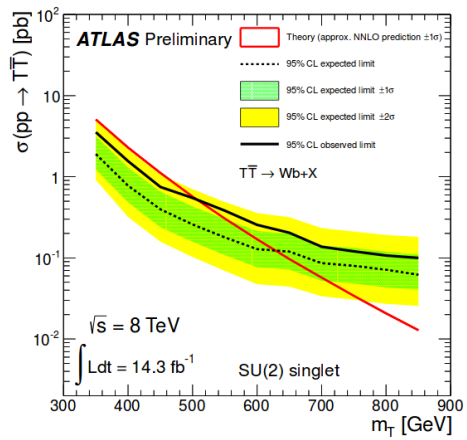
CMS: Incl. search with $\geq$1 lepton

- **Hadronic W**: Pruned C/A 0.8 jet (p_T >200 GeV,$m \in$[60,130] GeV)
- **Hadronic top**: CMS Top Tagger
- Using relative cone isolation with R=0.4(0.3) for μ (e)

ATLAS: $T \to Wb$ with $\geq$1 lepton

- **Hadronic W**:
  - $\mathbf{W}_{\mathbf{had}}^{\mathbf{typel}}$: Single anti-$k_T$ 0.4 jet (p_T >250 GeV,$m \in$[60,120] GeV)
  - $\mathbf{W}_{\mathbf{had}}^{\mathbf{typell}}$: Dijet system ($\Delta R(j,j) < 0.8$, p_T^{jj} >200 GeV)
- Mini-isolation (μ), fixed 0.3 cone (e)





Vector-like T-Quark with charge 2/3

$\int Ldt = 14.3$ fb^{-1}, $\sqrt{s} = 8$ TeV — ATLAS [ATLAS-CONF-2013-060]

$\int Ldt = 19.5$ fb^{-1}, $\sqrt{s} = 8$ TeV — CMS [CMS-B2G-12-015],[CMS PAS B2G-14-002]

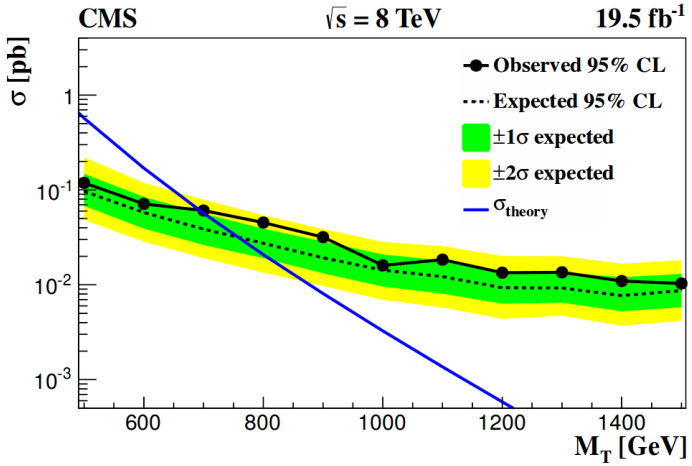
- Predicted by Little Higgs and extra-dimension models
- Vector couplings to W,Z (evading constraints from EW measurements)
- Decay channels: $T \to Wb$, $T \to tZ$, $T \to tH$

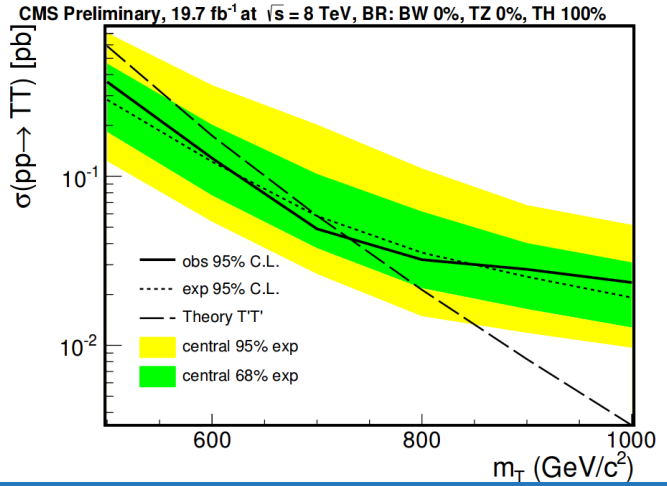
CMS: Incl. search with $\geq$1 lepton

- **Hadronic W**: Pruned C/A 0.8 jet (p_T >200 GeV, $m \in$[60,130] GeV)
- **Hadronic top**: CMS Top Tagger
- Using relative cone isolation with R=0.4(0.3) for μ (e)

CMS: Allhadronic T $\to$ tH search

- **Hadronic top**: HEPTopTagger with R=1.5, 1 b-tagged subjet
- **H($b\bar{b}$)**: Filtered C/A 1.5 jets, $m(jb1, jb2)$ >60 GeV
- Both R=0.3 subjets b-tagged





Vector-like T-Quark with charge 2/3

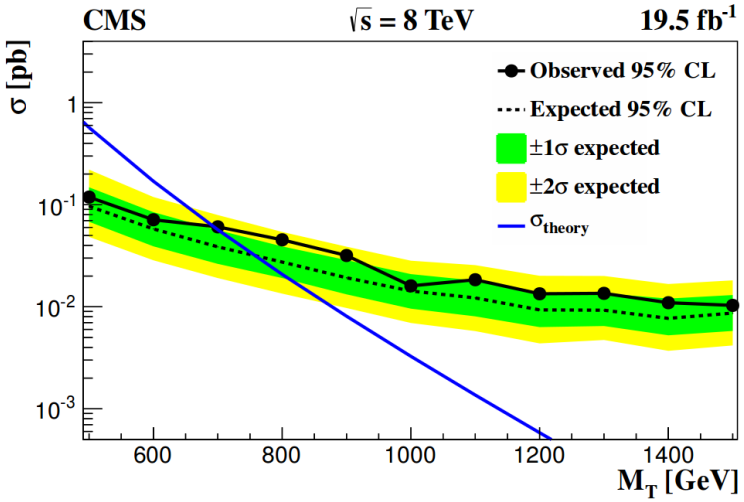
$\int Ldt = 14.3\ \text{fb}^{-1}$, $\sqrt{s} = 8$ TeV ATLAS [ATLAS-CONF-2013-060],[ATLAS-CONF-2013-018]

$\int Ldt = 19.5\ \text{fb}^{-1}$, $\sqrt{s} = 8$ TeV CMS [CMS-B2G-12-015],[CMS PAS B2G-14-002]

Decay channels: T → Wb, T → tZ, T → tH

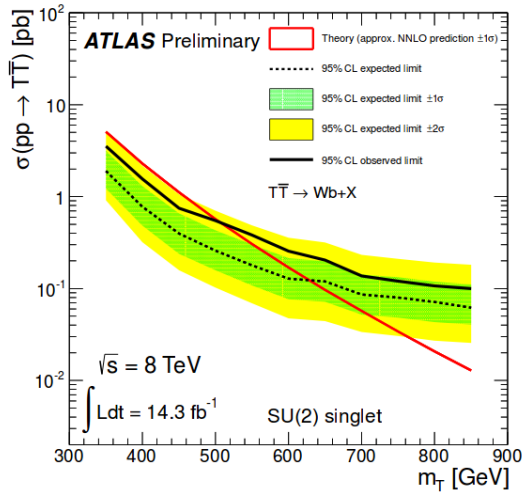
CMS: Incl. search with ≥1 lepton

- **Hadronic W**: Pruned C/A R=0.8 (p_T >200 GeV, $m \in$[60,130] GeV)
- **Hadronic top**: CMS Top Tagger



ATLAS: $T \to Wb$ with ≥1 lepton

- **Hadronic W**: Anti-k_T R=0.4 jet (p_T >250 GeV, $m \in$[60,120] GeV)
- Mini-isolation (on the μ)



CMS: Allhadronic T → tH search

- **Hadronic top**: HEPTopTagger
- **H(bb̄)**: Higgs- and b-tagging

ATLAS: Allhadronic T → tH search

No dedicated substructure techniques