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Search for vector-like quarks, $t\bar{t}$ and t+b resonances

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on behalf of the ATLAS & CMS Collaborations

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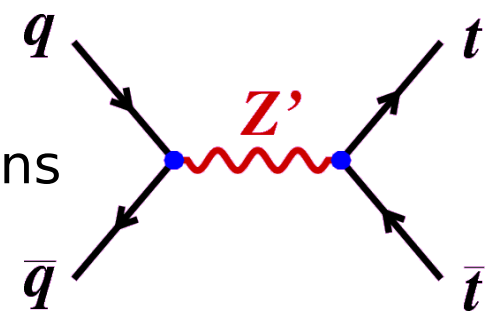
Introduction

Many new particles connected to top quarks:

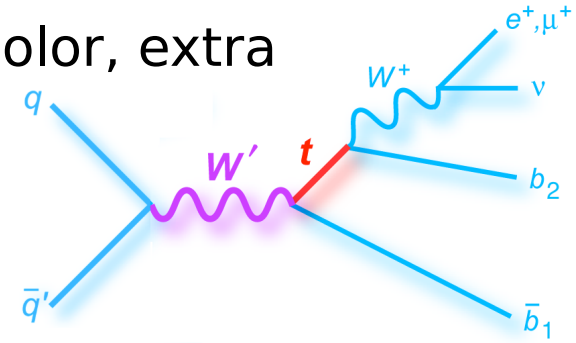
- **Resonances decaying to $t\bar{t}$**

  Different models predict such resonances:
  topcolor Z', Kaluza Klein excitations, heavy Higgs bosons



- **Resonances decaying to t+b**

  W' bosons predicted in Little Higgs models, technicolor, extra dimensions



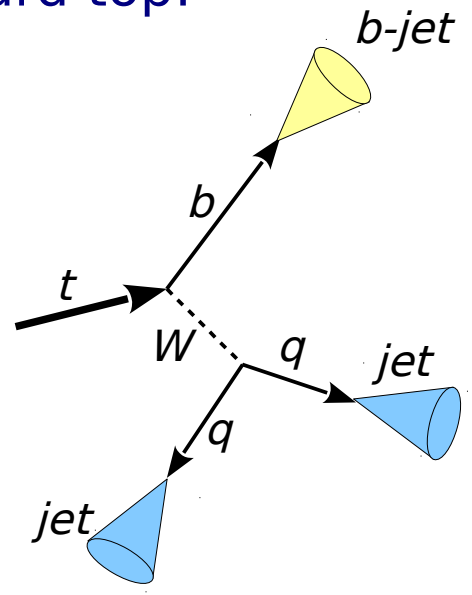
- **Vector-like quarks**
  - Pair-produced T or B
  - Possible decays: T→b+W, T→t+H, T→t+Z

    B→t+W, B→b+H, B→b+Z
  - Also heavy quarks with exotic charges (5/3, -4/3) possible

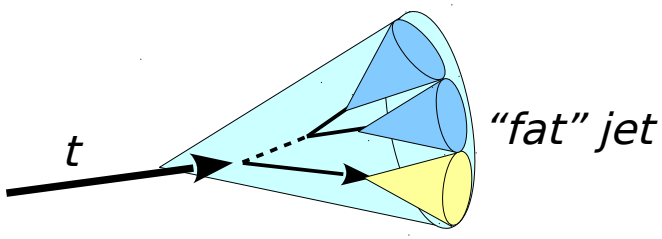
Analysis Techniques

Top quarks from heavy resonances → heavy high-p_T objects

Standard top:



Boosted top:



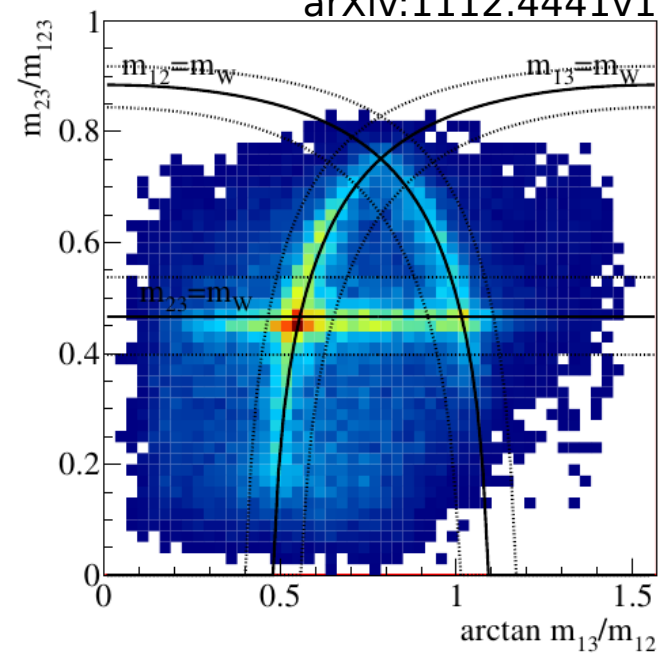
Boosted tops require new reconstruction techniques → **top tagging**

Substructure Tools

HEP Top Tagger

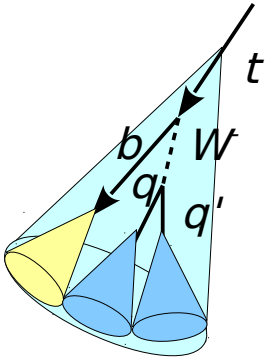
- Cambridge-Aachen jets with R=1.5
- Filtered subjets
- Cuts on masses and mass ratios

arXiv:1112.4441v1



CMS Top Tagger (based on Johns Hopkins Tagger)

- Cambridge-Aachen jets with R=0.8
- At least 3 subjets
- Subjet combinations compatible with W and top mass



W, Z and Higgs tagging: similar to top tagging, 2 instead of 3 subjets

Search for $t\bar{t}$ resonances

Full Hadronic

Event topology:

- 2 back-to-back high-p_T top quarks

ATLAS (JHEP 01(2013) 116 (7 TeV)):

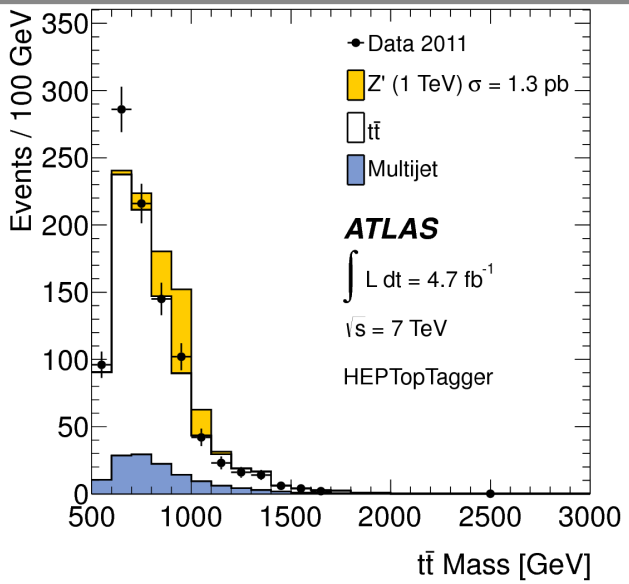
- Two HEP Top tags or Top Template Tagger
  - Template Tagger: Check compatibility of energy flow inside a jet with top signature
- Combined with b tagging

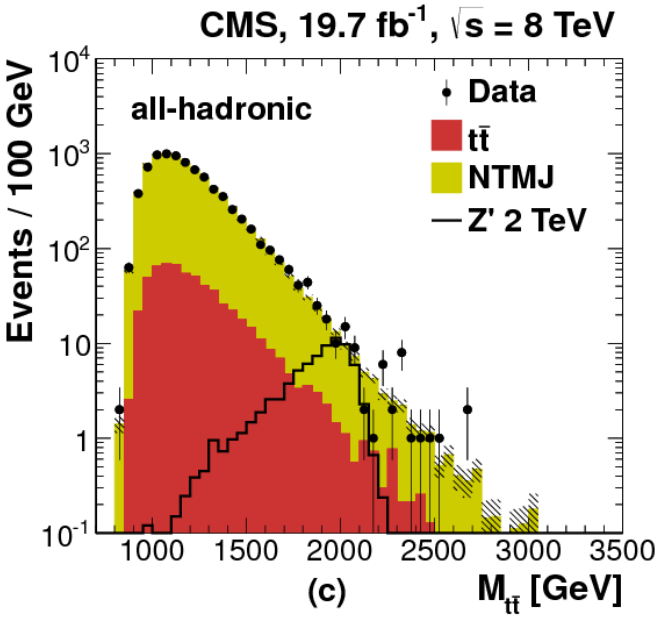
CMS (Phys. Rev. Lett. 111 (2013) 211804):

- 2 CMS top tags

Common in both analyses:

- Background from inverted tagging regions

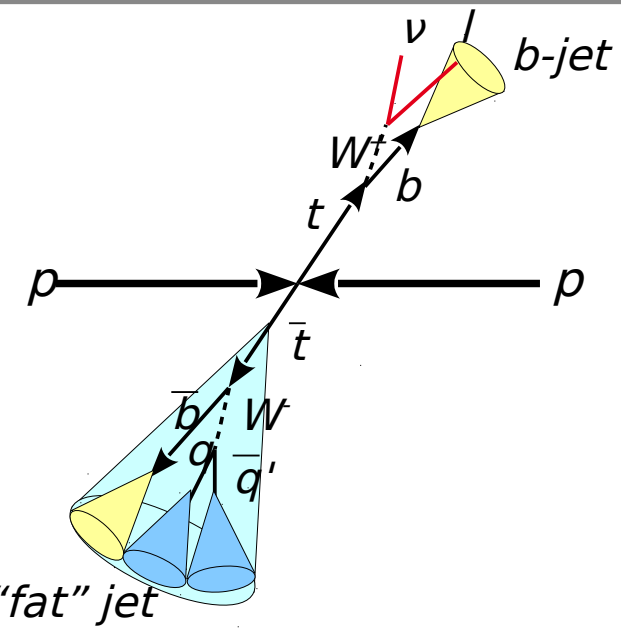




Lepton+Jets

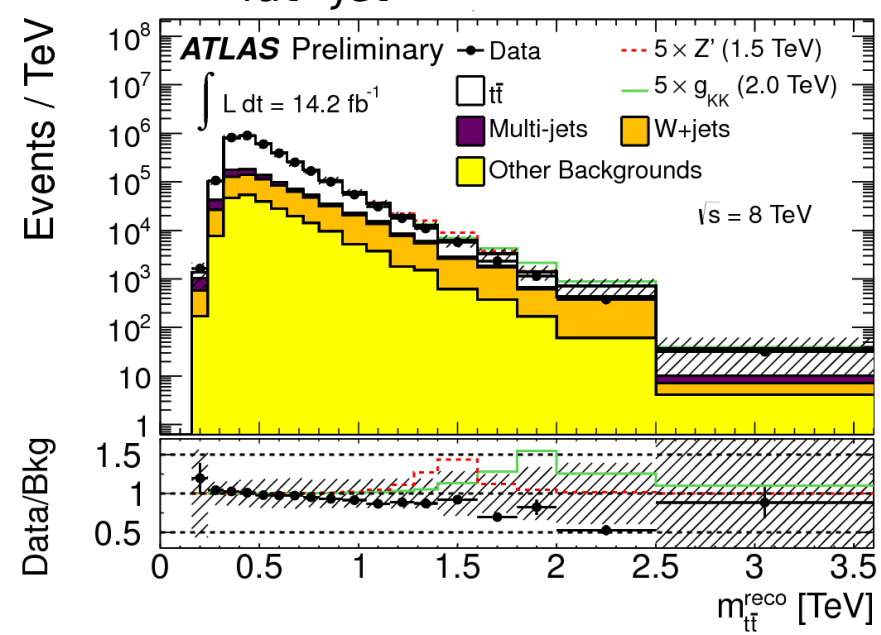
Signature:

- One “fat jet”
- One lepton (e or μ), close to other jet, requires alternative isolation requirements



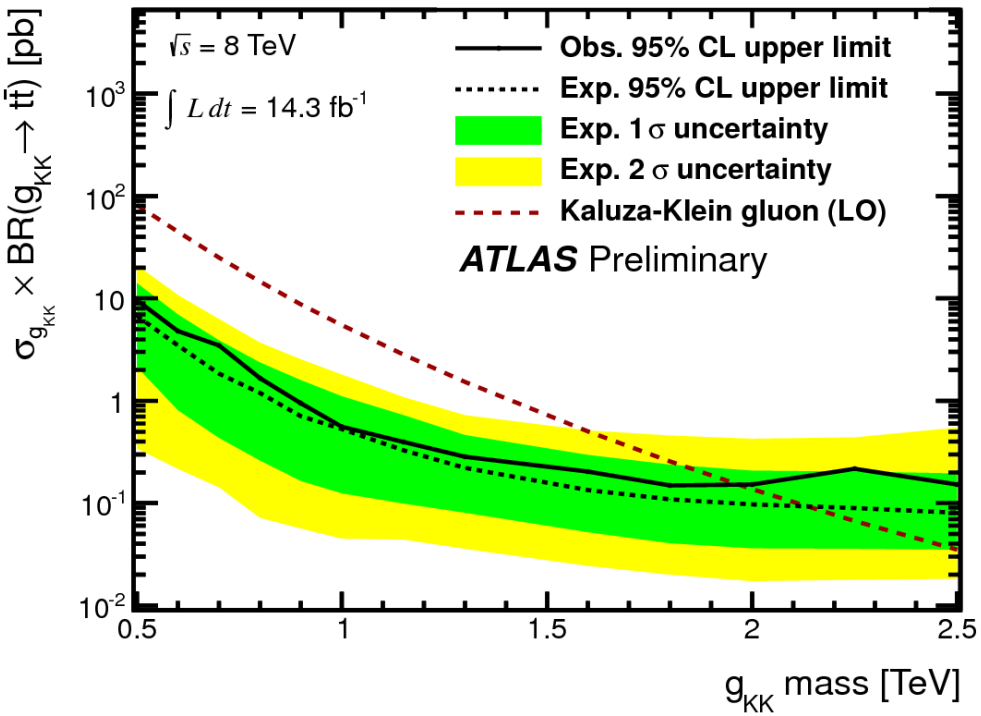
Two analyses from ATLAS (ATLAS-CONF-2013-052) and CMS (Phys. Rev. Lett. 111 (2013) 211804)

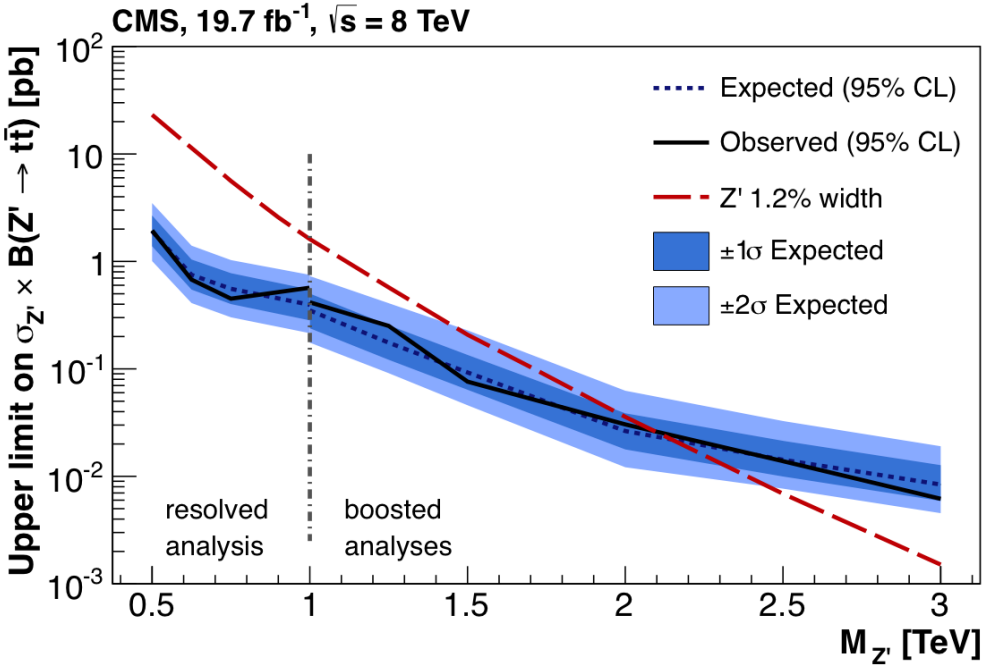
- ATLAS: 1 lepton with “mini isolation”, E_T^{miss}, 1 jet with R=0.4, one jet with R=1.0 and substructure cuts
- CMS: 1 lepton with 2D cut on p_T^{rel}(jet,l) and ΔR(jet,l), E_T^{miss} cut, 2 or more normal jets with R=0.5
- Combined with resolved analysis (4 jets, isolated l, E_T^{miss})



Limits

Derive limits from fits to $M_{t\bar{t}}$ distribution





95% C.L. limits on various theory models:

- Narrow Topcolor Z': m>2.1 TeV
- Topcolor Z' with 10% width: m>2.7 TeV
- RS Kaluza-Klein gluon: m>2.5 TeV

Search for t+b resonances

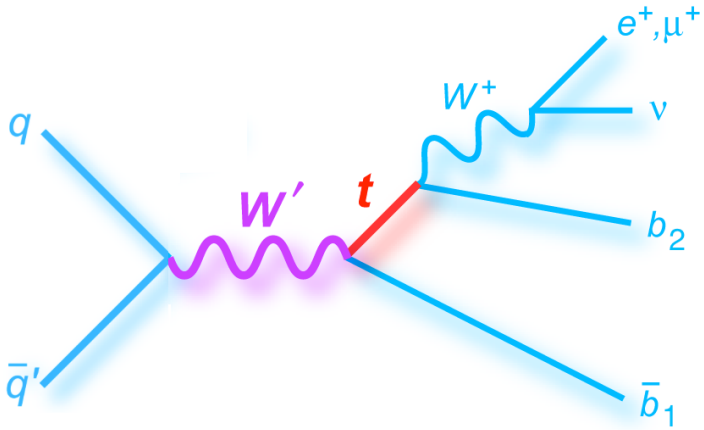
Analysis Strategy

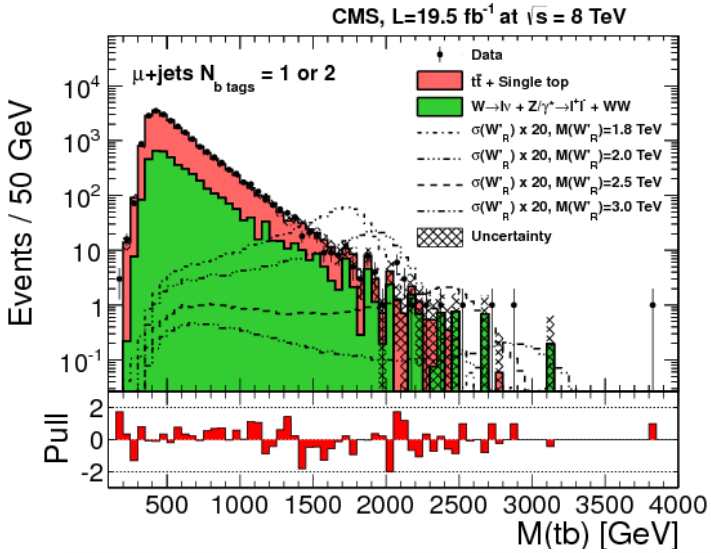
ATLAS (ATLAS-CONF-2013-050):

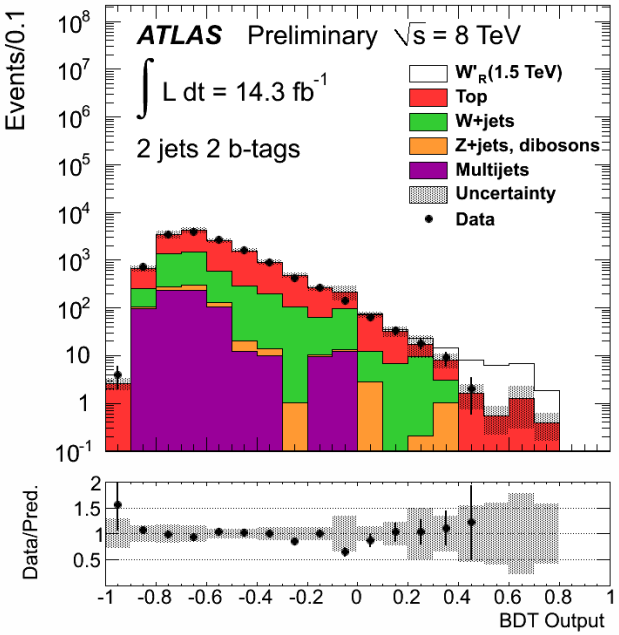
- One e or μ
- 2 or 3 jets, 2 b tags
- BDTs used for signal discrimination

CMS (hep-ex:1402.2176 (accepted by JHEP)):

- One e or μ
- At least 2 jets, 1 b-tag
- M_{tb} used for signal discrimination





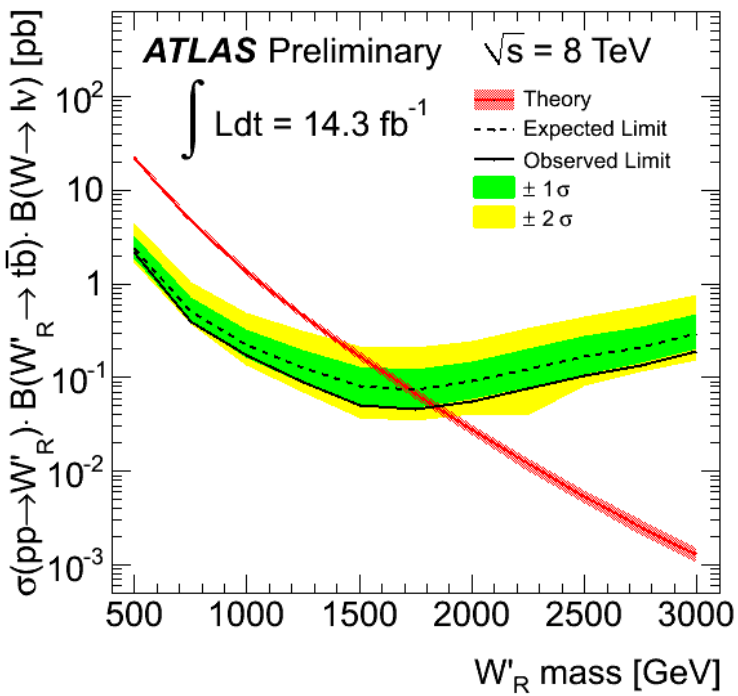


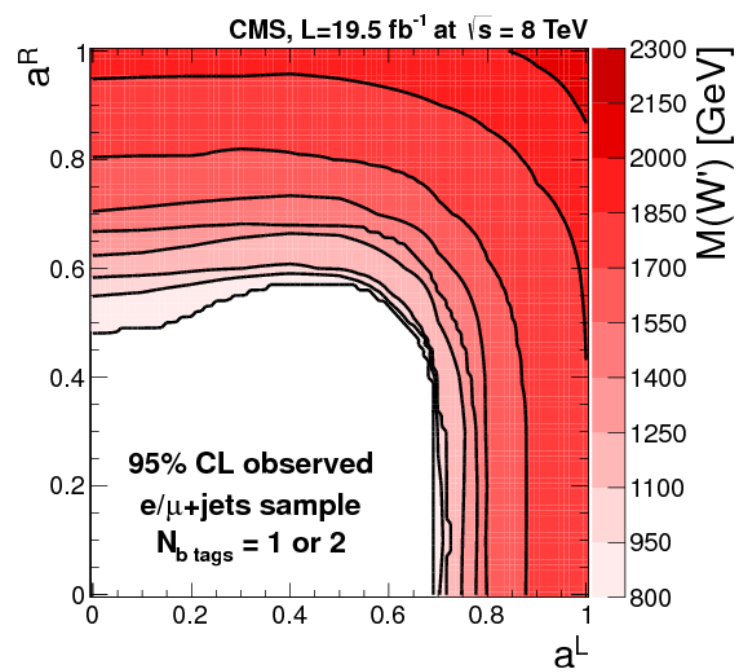
Limits

- Left and right handed W' couplings considered

$$\mathcal{L} = \frac{V_{f_i f_j}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu \left(a^{\mathrm{R}}_{f_i f_j} (1+\gamma^5) + a^{\mathrm{L}}_{f_i f_j} (1-\gamma^5) \right) \mathrm{W}'^{\mu} f_j + \mathrm{h.c.}$$

- Left handed W' interferes with SM single top (considered by CMS in combined MC simulation of SM single top and W')





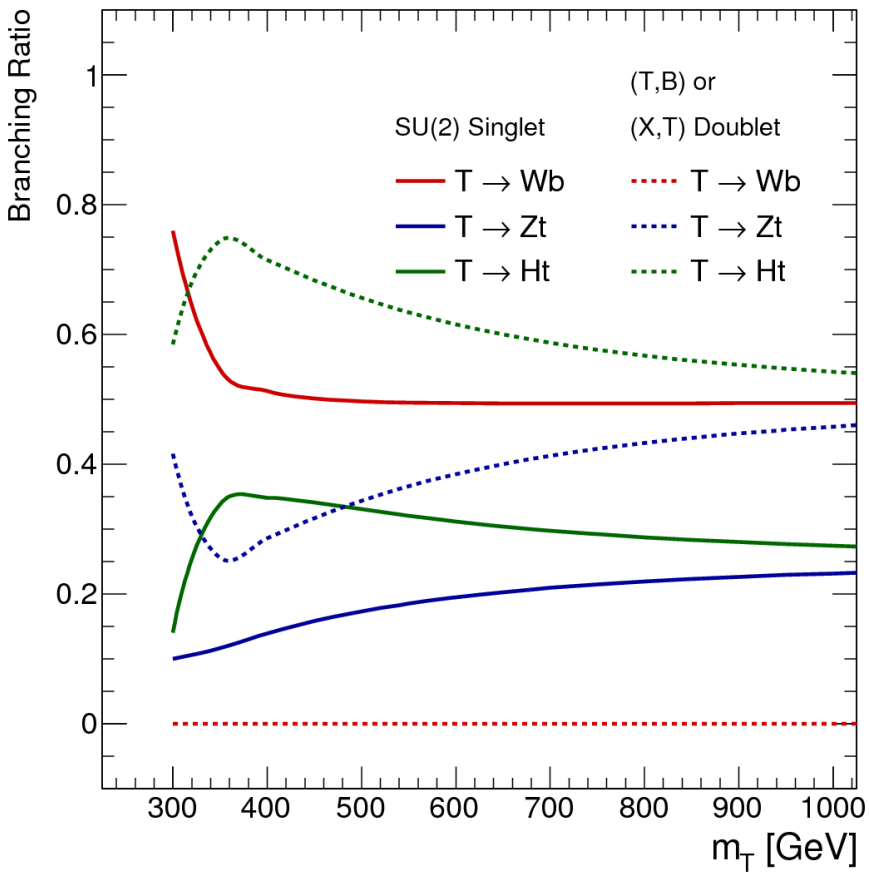
Search for vector-like quarks

VLQ Searches

- Chiral 4th generation basically excluded after Higgs discovery
- But: vector-like quarks independent from Higgs sector still allowed
- Various decay channels and signatures:

  T→b+W, T→t+H, T→t+Z,

  B→t+W, B→b+H, B→b+Z
- Also possible:
  top partners with charge 5/3



Latest available searches:

ATLAS: T→Ht (ATLAS-CONF-2013-018), T→Zt (ATLAS-CONF-2013-056), T→Wb (ATLAS-CONF-2013-060), T/B inclusive in (same-sign) di-lepton (ATLAS-CONF-2013-051), B and T(5/3) in same-sign di-lepton (ATLAS-CONF-2012-130)

CMS: T inclusive (Physics Letters B 729 (2014) 149), B in l+jets (PAS-B2G-12-021), B in di-lepton (B2G-12-019), B in multi-lepton (B2G-13-003), T(5/3) search (PAS-B2G-12-012)

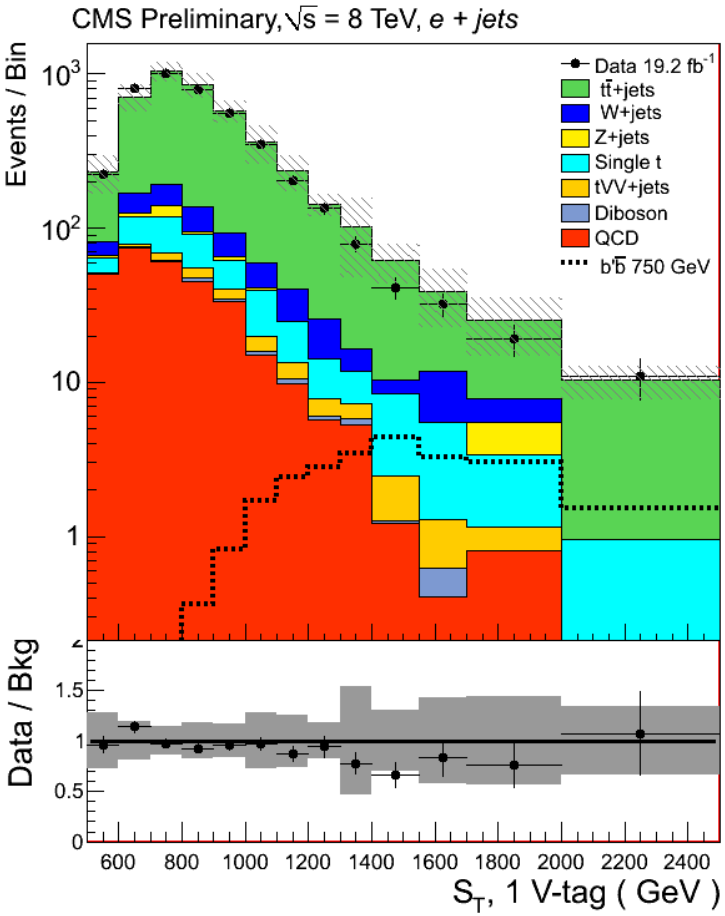
Search Strategy

General strategy in most analysis:

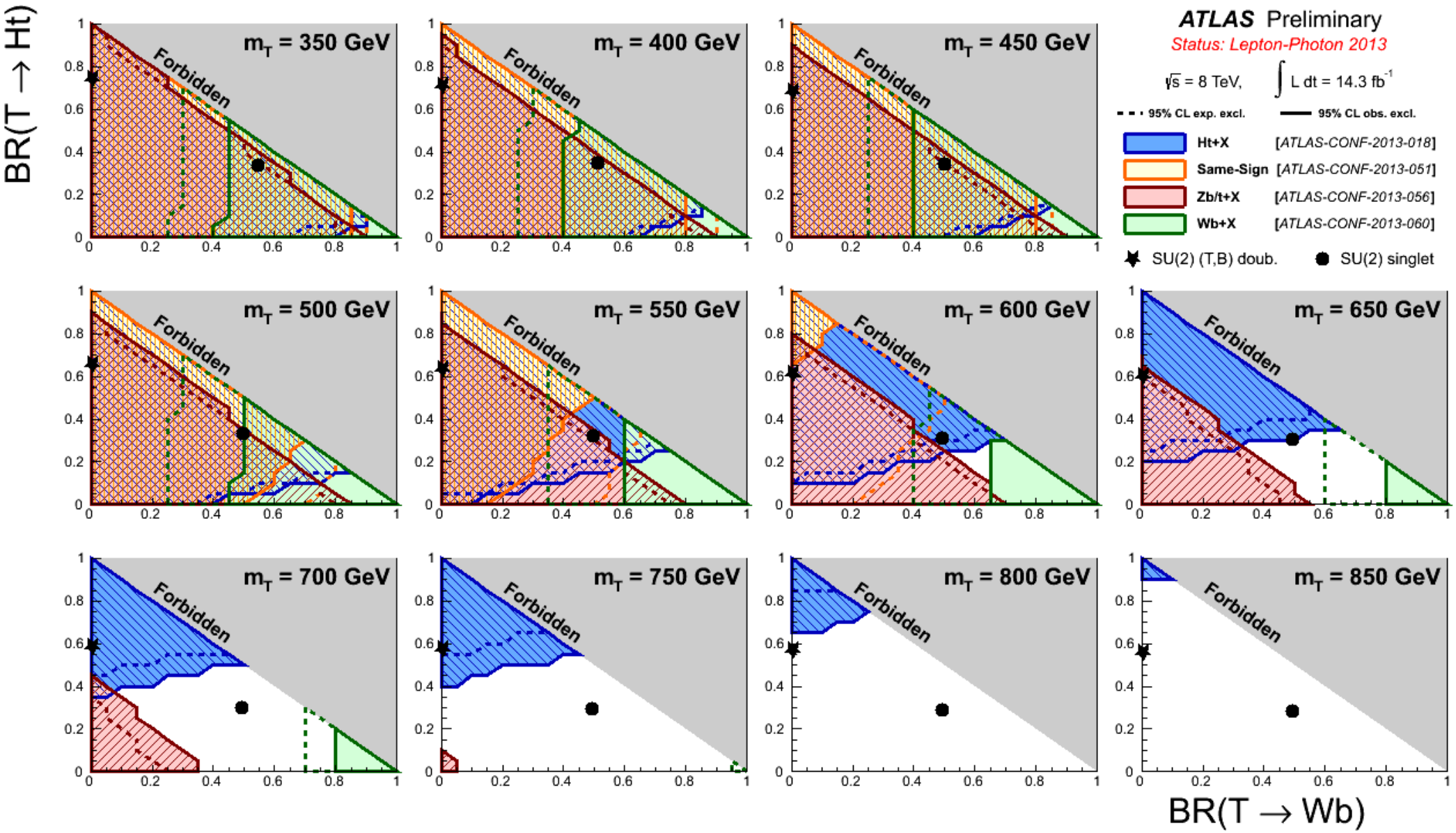
- Select at least one charged lepton
- Several jets
- Various number of b-tags
- In case of several leptons: different search regions for same-sign and opposite-sign lepton pairs
- Extract limits from likelihood fit to H_T/S_T variable or from counting events in high H_T/S_T region.

V tagging used in CMS l+jets B search (PAS B2G-12-019):

- Classify events according to number of W, Z or Higgs tags



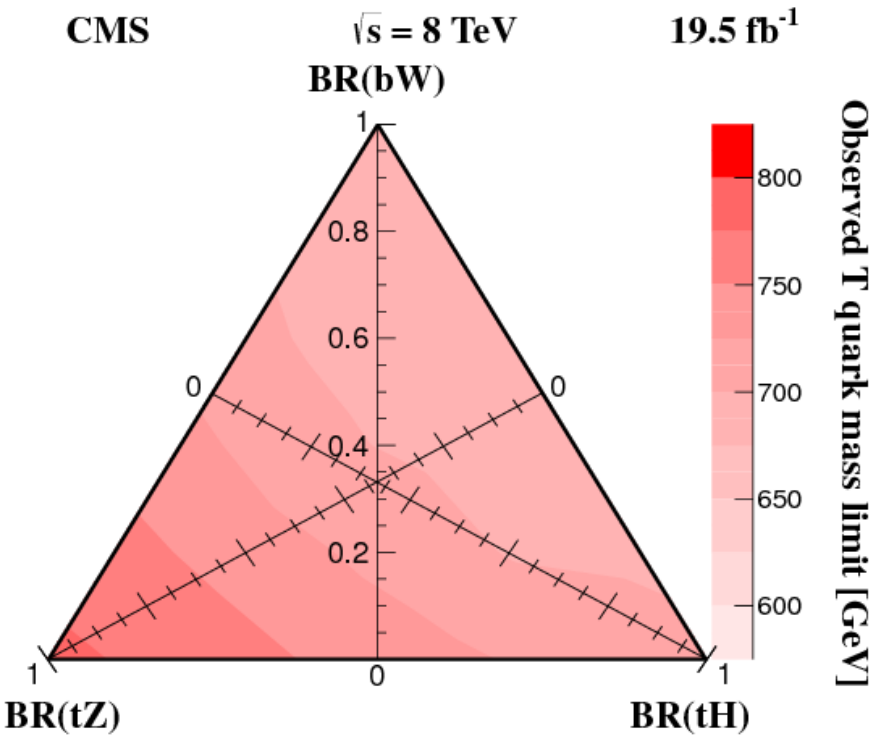
ATLAS Results



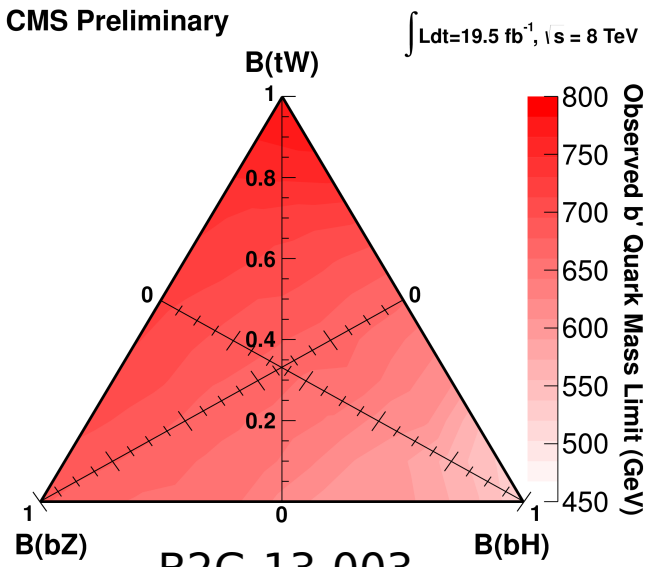
CMS Results

No excess observed in data

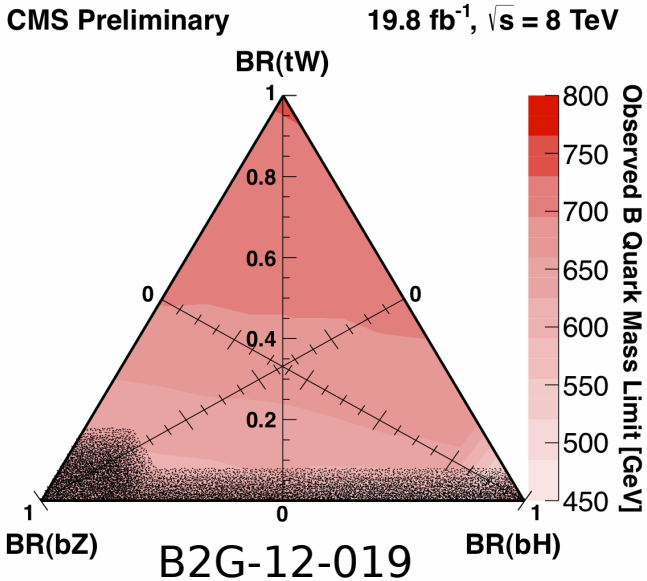
VLQ B and T can be excluded up to masses between 600-800 GeV



Physics Letters B 729 (2014) 149



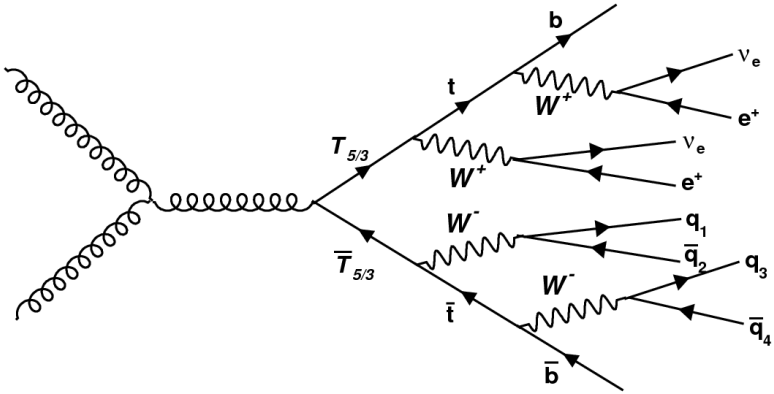
B2G-13-003



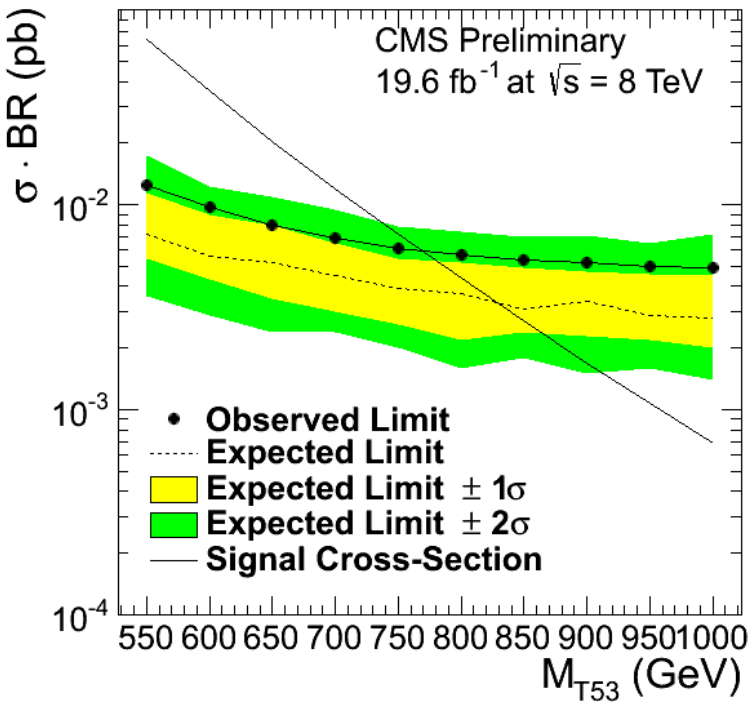
B2G-12-019

T(5/3) Searches

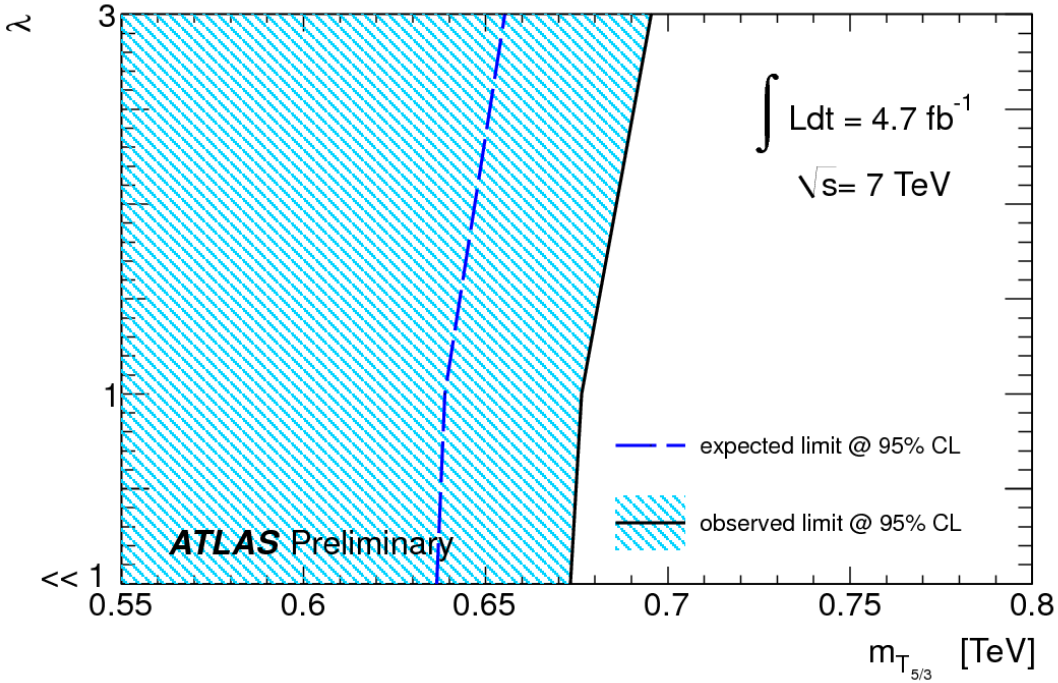
- Searches performed in same-sign di-lepton events with high jet multiplicity, b tags and high H_T and E_T^{miss}
- Top and W tagging applicable
- Exotic top partners with charge 5/3 can be excluded up to m=770 GeV at 95% C.L.



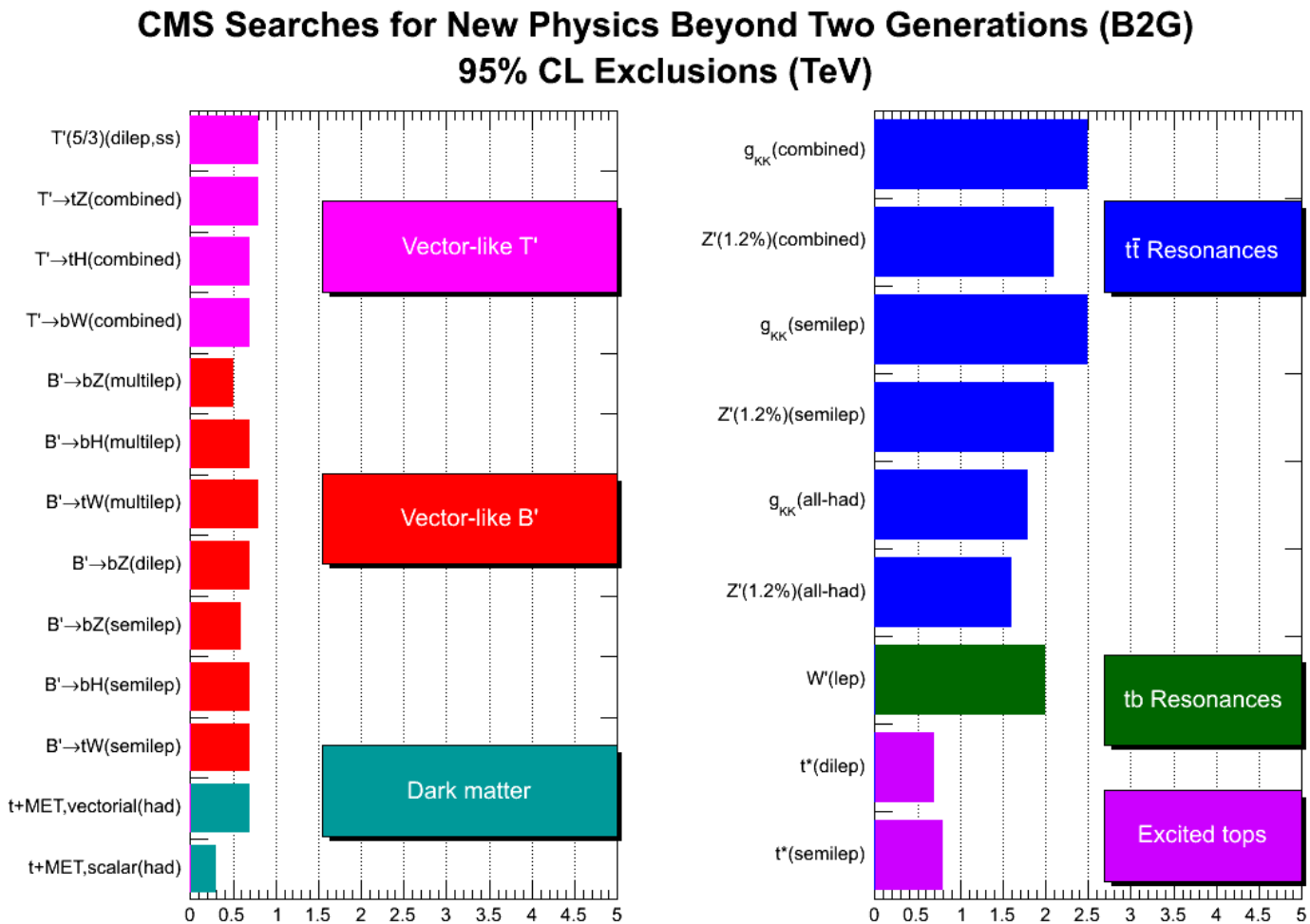
B2G-12-012



ATLAS-CONF-2012-130



Conclusion



Many searches performed by ATLAS and CMS for New Physics with top quarks.

No excess observed with first LHC runs.