

On behalf of the
CMS Collaboration



Search for Fermionic Partners at CMS

Charles Dietz
National Taiwan University

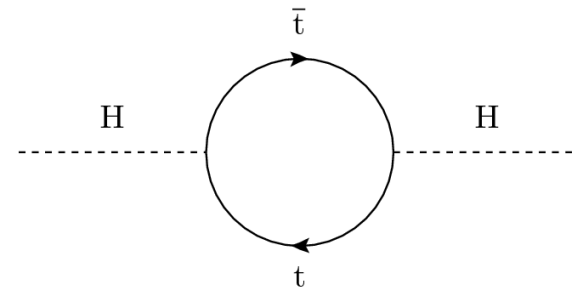
Lake Louise Winter Institute - February 17th, 2015

OUTLINE

- **Why Fermionic Partners?**
- **Search for Vector-like Quarks**
- **Recent CMS Analyses**
- **Summary of CMS Results**
- **Conclusion**

Why Fermionic Partners?

- SM Higgs boson discovery at 125 GeV
 - Higgs mass stabilization mechanism still unknown
- **Fourth generation (4G) quarks strongly disfavored** by EW data and Higgs boson cross-section measurements
- However Vector-Like Quarks (VLQ) do not obtain their mass via Yukawa couplings
- **Many models predict VLQ**
 - Little Higgs
 - Extra Dimensions
 - Composite Higgs
- **VLQ are not chiral** and can play a role in **canceling divergence in Higgs boson mass**
- There is also space for **new fermions!**



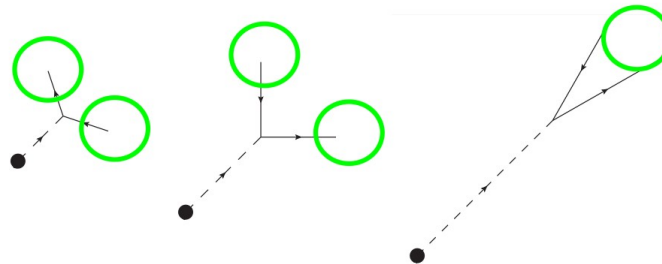
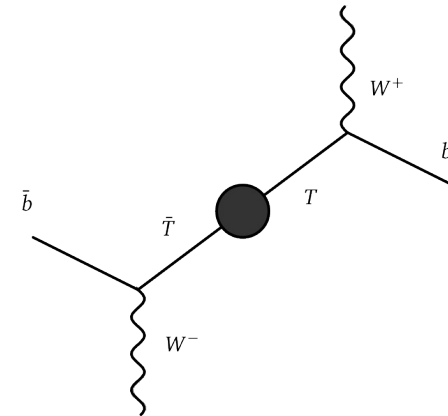
Search for VLQ at CMS

- Searches focused on pair-produced $B(-1/3)$ and $T(2/3)$
- Preferential mixing with third generation

$$T \rightarrow bW, T \rightarrow tH, T \rightarrow tZ$$

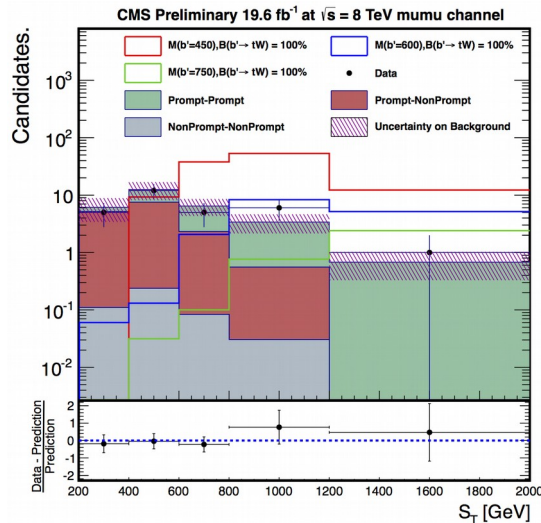
$$B \rightarrow tW, B \rightarrow bH, B \rightarrow bZ$$

- Opened the gate to many studies in the **leptonic**, **semileptonic** and **all-hadronic** final states along with **inclusive search** strategies
- **VLQ expected to be heavy** (>700 GeV), thus use of advanced **boosted objects taggers**
 - W/Z-tag
 - Top-tag
 - Higgs-tag



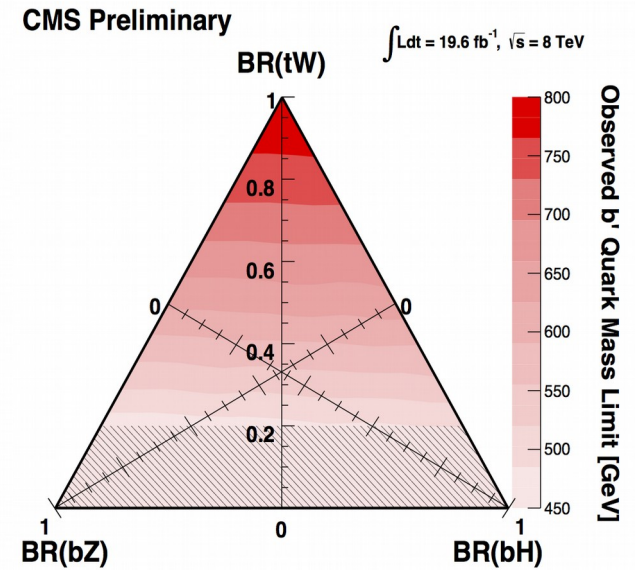
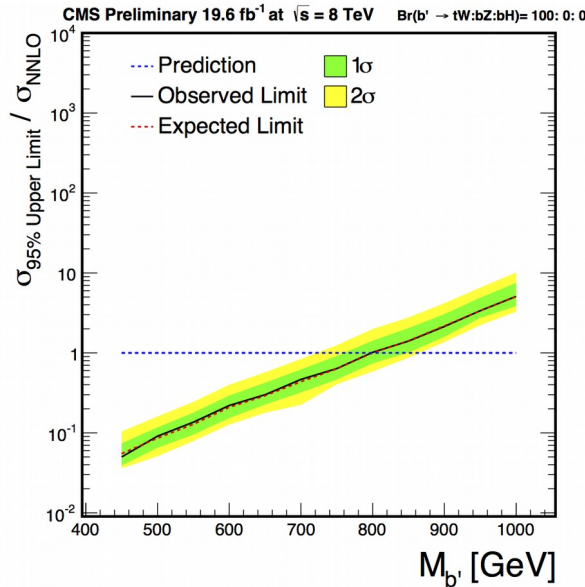
Search for B in same-sign dilepton final state

CMS-B2G-12-020



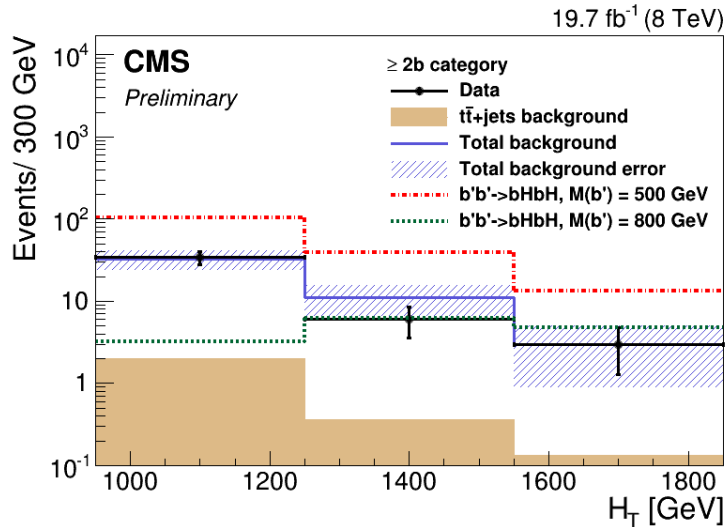
- $BB \rightarrow tWtW / tWbH / bHbH \rightarrow bWWbWW$
- ≥ 4 jets + same-sign dilepton ($ee, e\mu, \mu\mu$)
- $S_T > 200$ GeV $S_T = \sum p_T(\text{jets}) + \sum p_T(\text{leptons}) + \text{MET}$
- Background from prompt and non-prompt leptons and misidentified charges

- **Mainly sensitive to $BB \rightarrow tWtW$**
- **Exclude masses $< 464-800$ GeV at 95% C.L. with 19.6fb⁻¹ at 8 TeV**

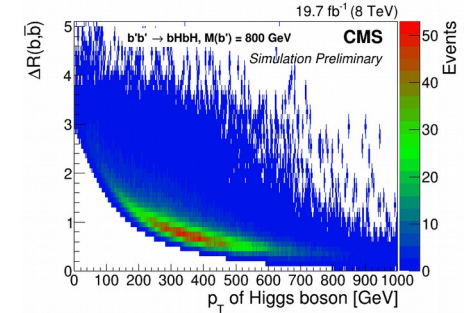


B → bH with boosted Higgs

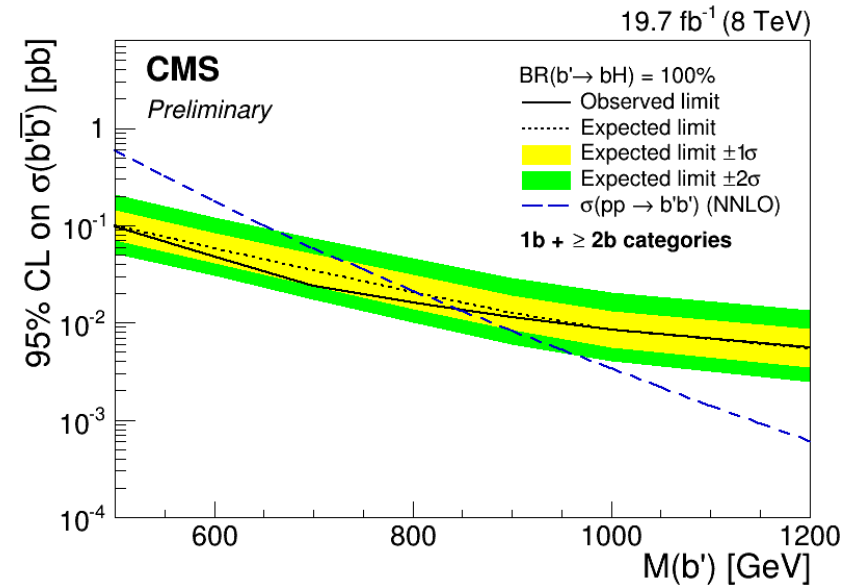
CMS-B2G-14-001



- **BB → bHbH with H → bb**
- **≥ 2 Higgs-tag + ≥ 1 b-tag**
- **Higgs-tagger based on N-subjettiness and double b-tagging**
- **1 and 2 b-tags categories**



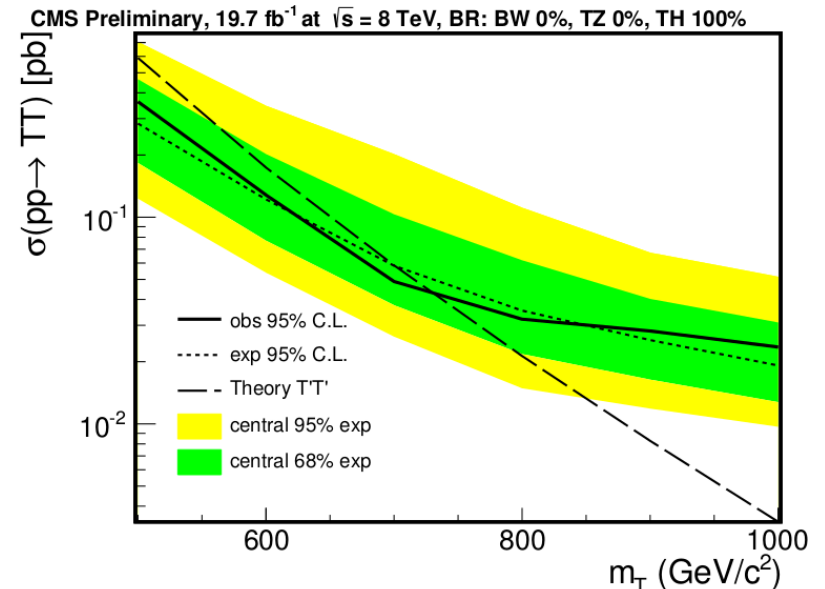
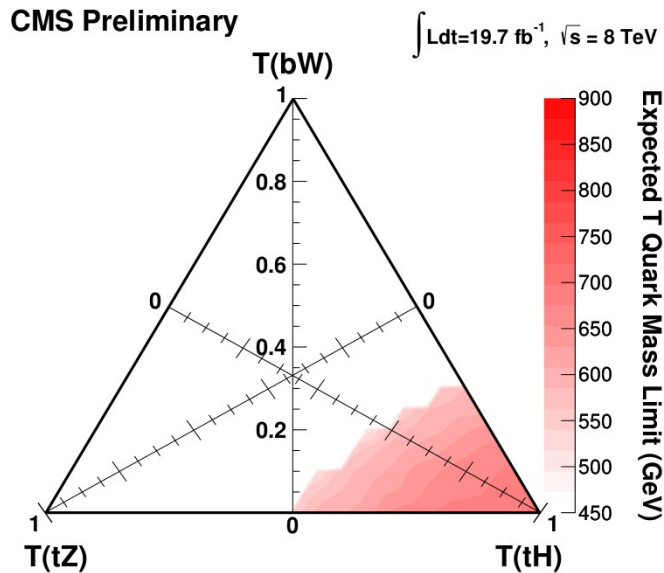
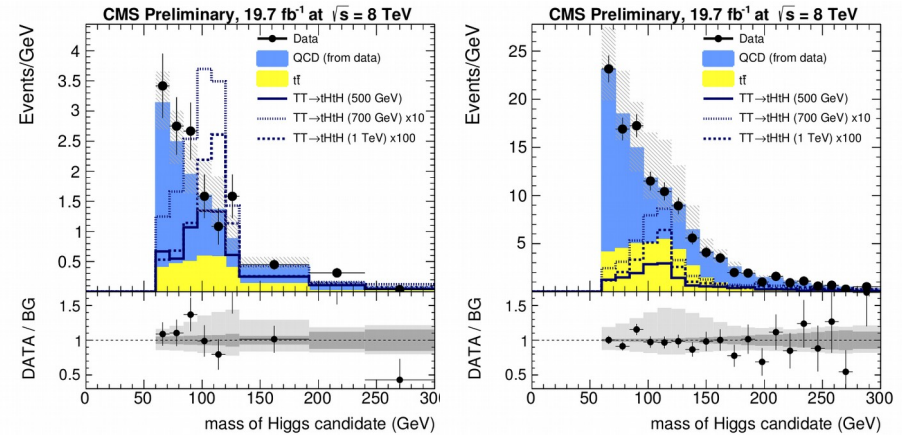
- **QCD multijet background dominant, estimated from sideband region**
- **Better sensitivity than leptonic channel**
- **Exclude masses < 846 GeV at 95% C.L. with 19.6fb⁻¹ at 8 TeV**



$T \rightarrow tH$ in all-hadronic final states

CMS-B2G-14-002

- Events with ≥ 1 Top-tag & ≥ 1 Higgs-tag
- $H_T > 720$ GeV with ≥ 1 CA15 jet with $p_T > 150$
- Dominant background from QCD multijet, estimated from tagger-inverted sidebands
- Exclude mass < 747 GeV at 95% C.L. with 19.7fb^{-1} at 8TeV



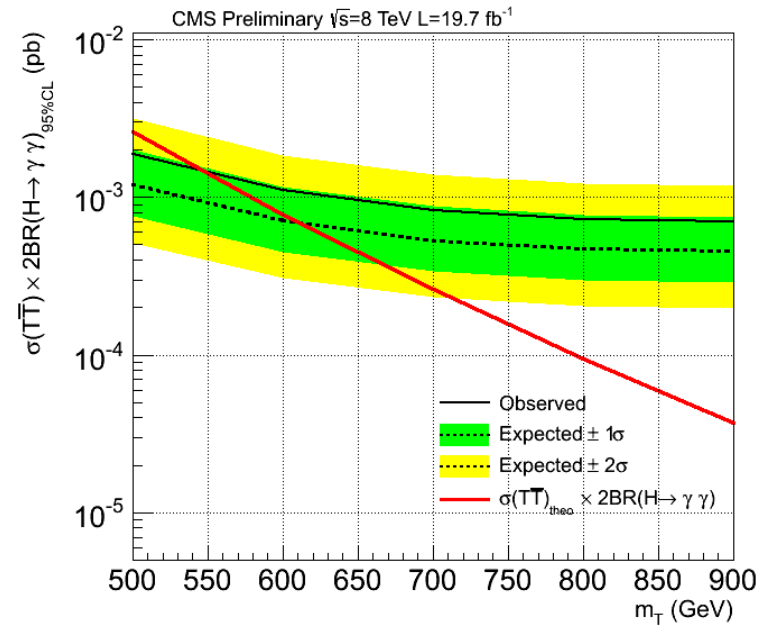
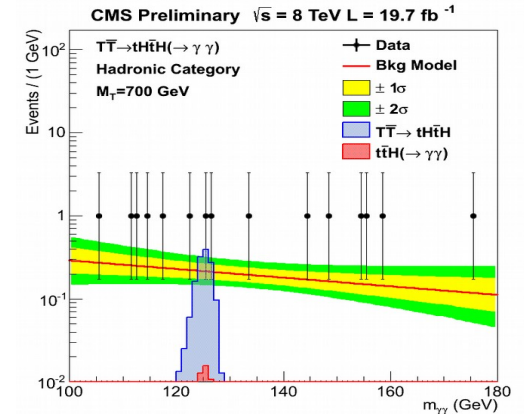
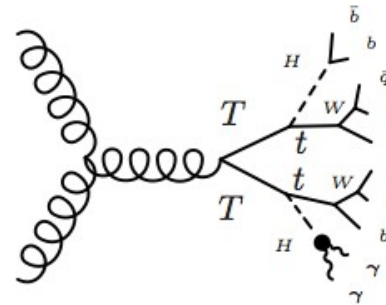
T → tH with H → γγ

CMS-B2G-14-003

- 2 photons + large hadronic activity
- W-decay: hadronic and leptonic channels

Variable	Hadronic channel	Leptonic channel
$p_T(\gamma_1)$	$> \frac{3}{4}m_{\gamma\gamma}$ GeV	$> \frac{1}{2}m_{\gamma\gamma}$ GeV
$p_T(\gamma_2)$	35 GeV	25 GeV
n_{jets}	≥ 2	≥ 2
H_T	≥ 1000 GeV	≥ 770 GeV
leptons	0	≥ 1
b tags	≥ 1	-

- Background is obtained by fitting the observed diphoton mass distributions
- Exclude mass < 540 GeV at 95% C.L. with 19.7fb⁻¹ at 8TeV

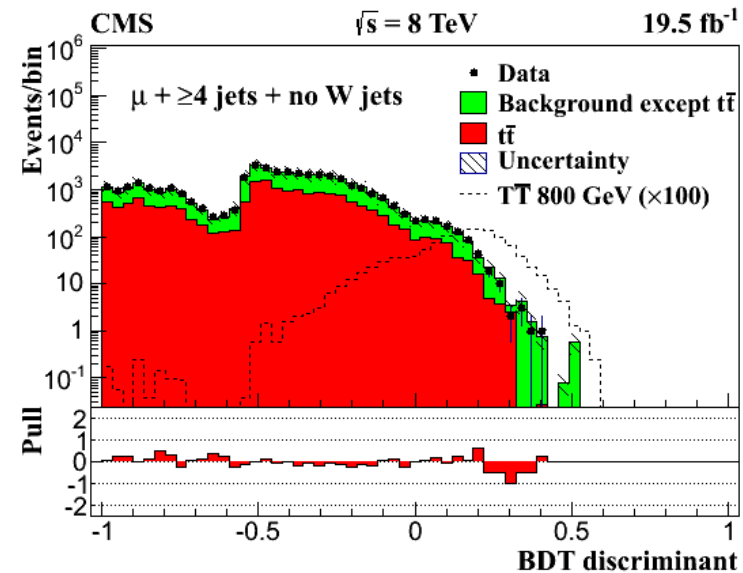
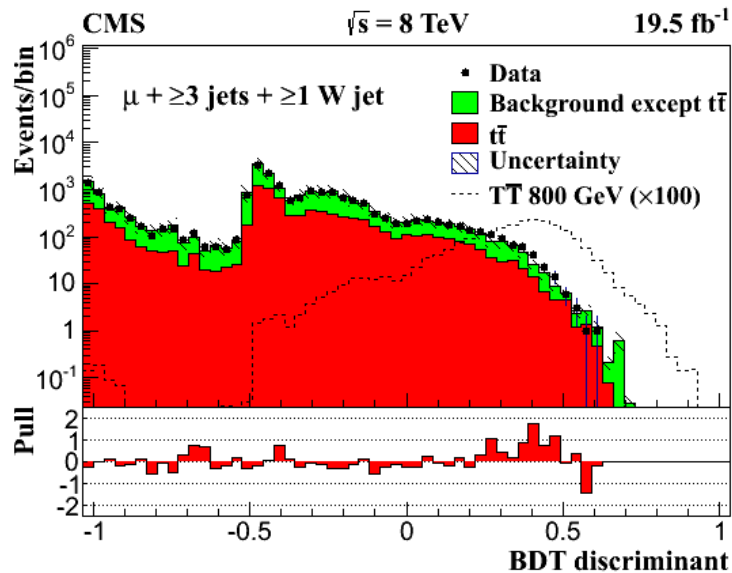


Inclusive search for vector-like T

CMS-B2G-12-015

- Signal assumed to be a mixture of $T \rightarrow bW / tH / tZ$
- Consider many combinations of objects:
 - **lepton+jets**: select one lepton (from the $W \rightarrow l'$ decays) + jets
 - **multilepton**: look for opposite-sign dileptons + jets, same-sign dileptons + jets, and trilepton + jets
- Feed shapes and counting information into a BDT

Physics Letters B 729 (2014) 149

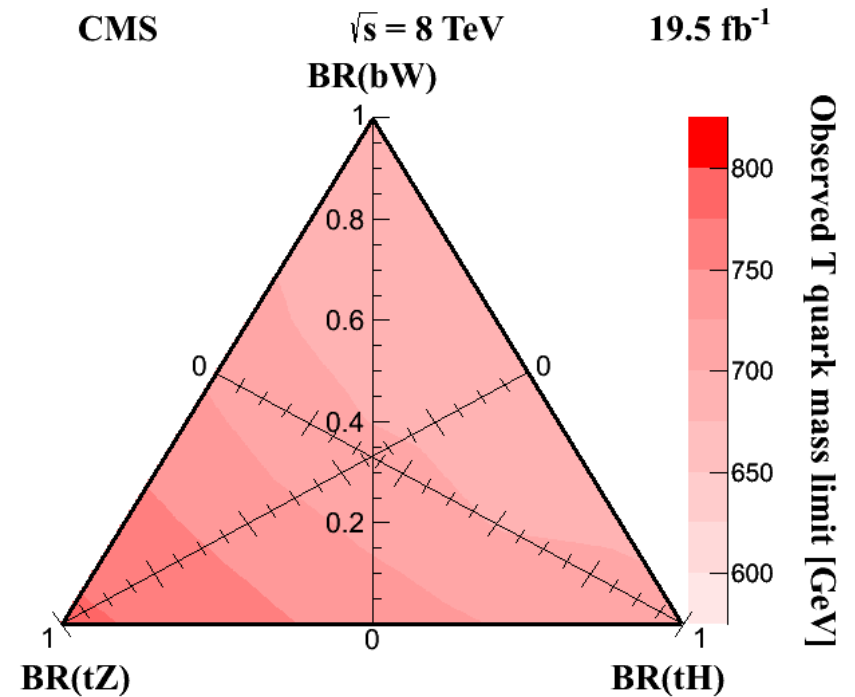
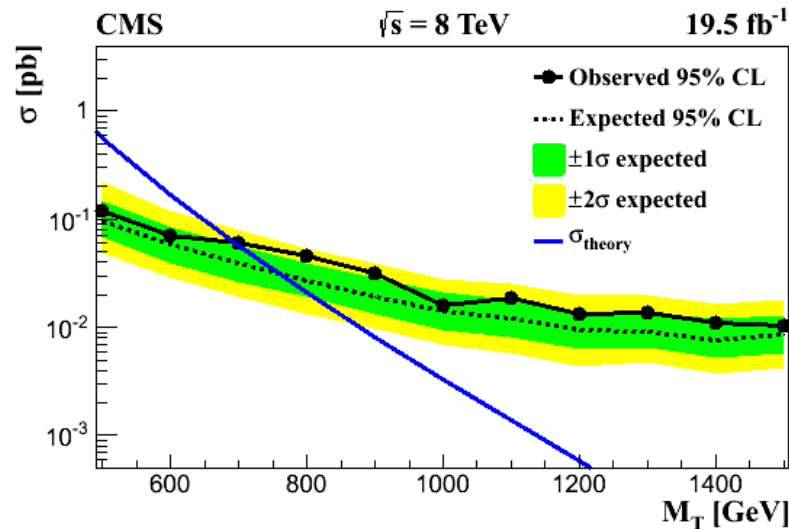


Inclusive search for vector-like T

CMS-B2G-12-015

Physics Letters B 729 (2014) 149

Benchmark is $T \rightarrow bW(0.5) / tH(0.25) / tZ(0.25)$



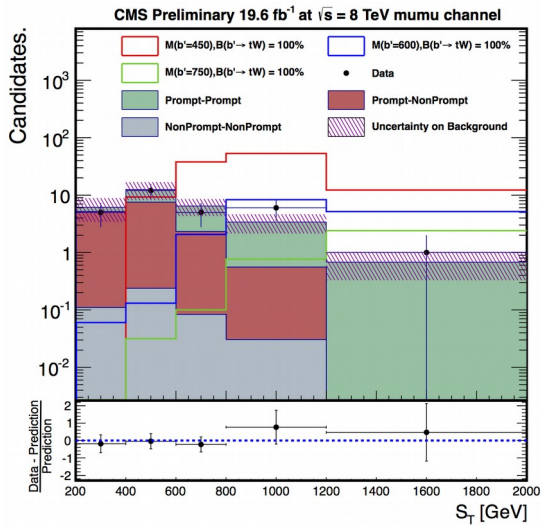
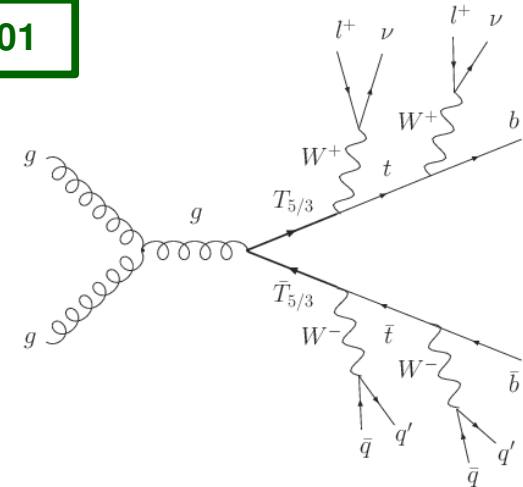
Exclude masses $< 687\text{-}782 \text{ GeV}$ at 95% C.L. for $T \rightarrow bW / tH / tZ$

T(5/3) in same-sign dilepton channel

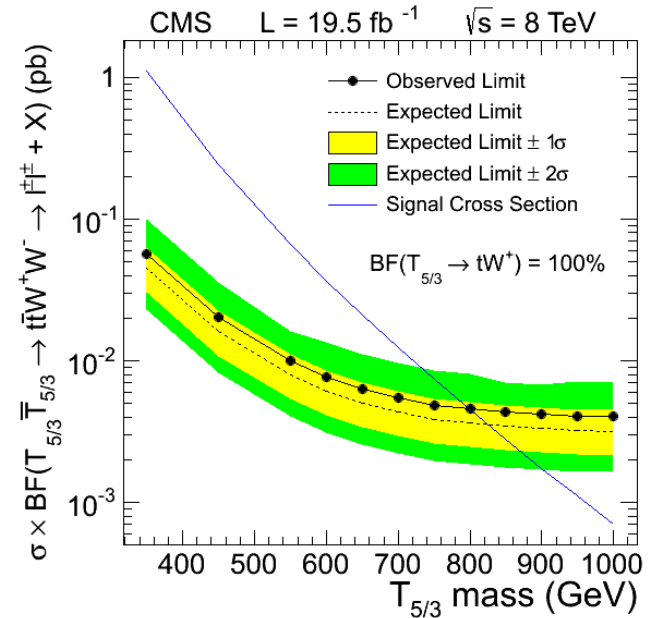
CMS-B2G-12-012

Phys. Rev. Lett. 112 (2014) 171801

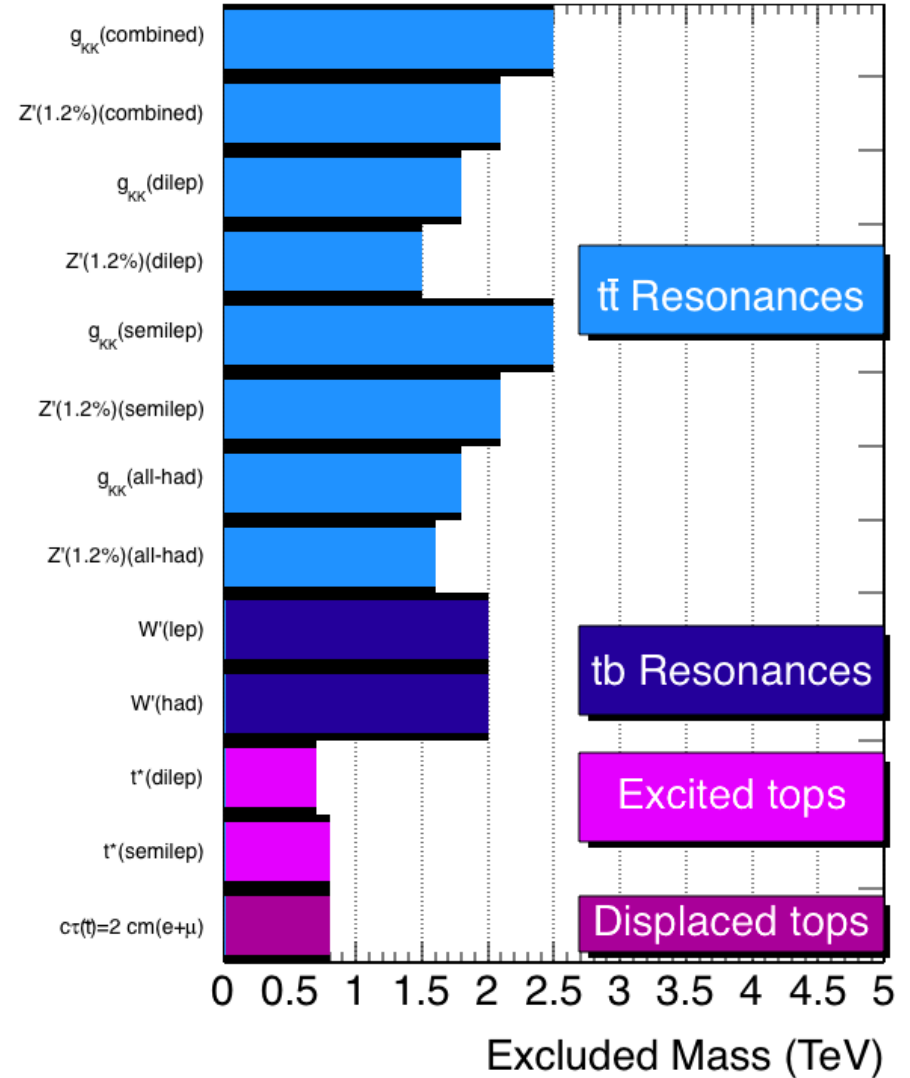
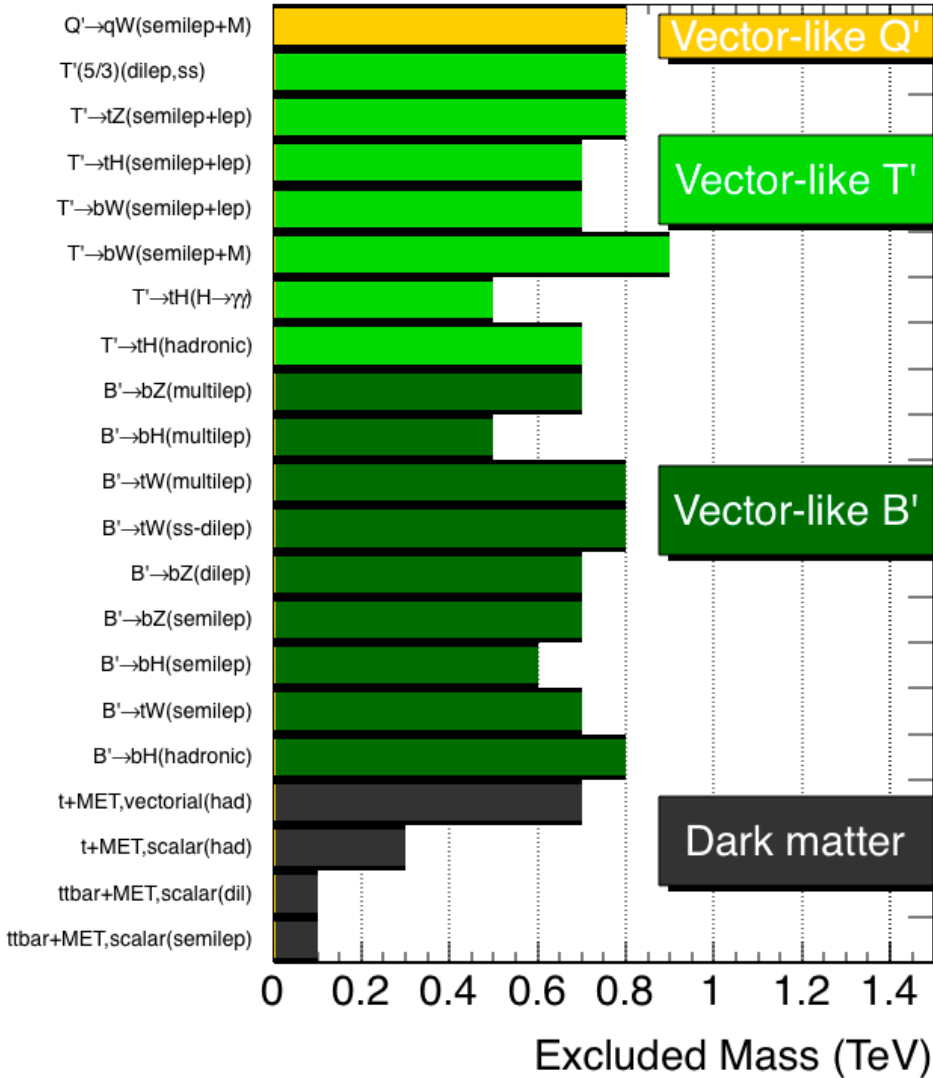
- 2 same-sign isolated leptons with $p_t > 30$ GeV
- ≥ 5 constituents [Top-jet = 3, W -jet = 2 , AK5 jet, lepton]
- $H_T > 900$ GeV
- Three categories ee, e μ , $\mu\mu$



- Dominant background from non-prompt leptons
- Exclude masses < 800 GeV at 95% C.L. with 19.6fb^{-1} at 8 TeV



CMS Searches for New Physics Beyond Two Generations (B2G) 95% CL Exclusions (TeV)



CONCLUSION

- Numerous searches for fermionic partners at CMS with the 8 TeV data recorded in 2012
- **No deviation from SM observed** so far, several new limits set on VLQ masses and cross-sections
- **Combination papers to come** for B and T searches at 8 TeV in CMS
- LHC Run 2
 - **13 TeV** starting this year
 - enhanced VLQ production, including **single production**
 - **early results will quickly be competitive**

All CMS public results available online at:

cms.web.cern.ch/news/cms-physics-results