Search for exotic heavy quark partners

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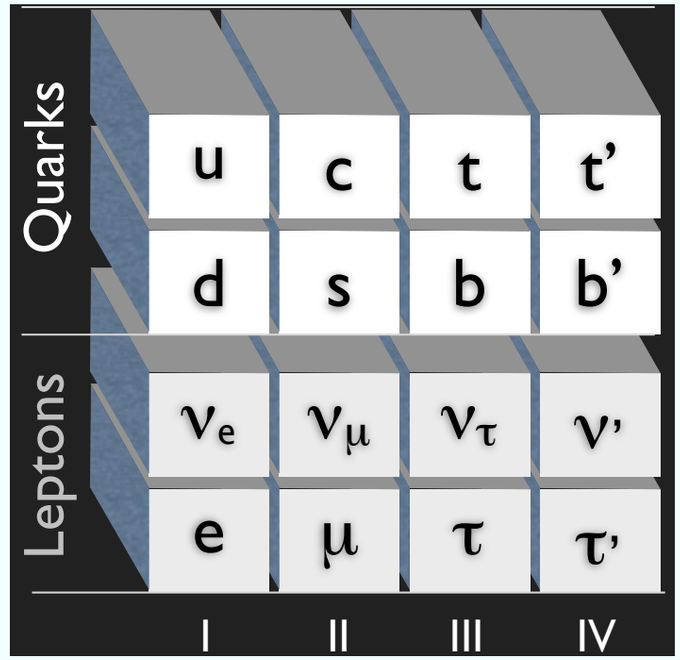
Introduction

- Many models beyond the Standard Model (SM) predict new heavy quarks
- Standard Model 4th generation (SM4): simplest extension
  - it can explain some CP-violation anomalies in B-physics
  - enhanced CP-violation ⇒ universe baryon asymmetry
  - hierarchy problem, dynamical electroweak symmetry breaking, ...
  - LEP constraints on $Z \to \nu\nu$ ⇒ heavy 4th generation neutrino
  - precision EW data favor $|m_{t'} - m_{b'}| < m_W$



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- Vector-like quarks (*non-chiral*) predicted in many models beyond the SM:
  - extra dimensions, little Higgs models, composite Higgs models, ...
  - they can also include a charge 5e/3 quark T
  - unlike SM4, vector-like quarks are less constrained
  - tree-level flavor-changing neutral-current coupling allowed

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- topologies predicted by these models also interesting as benchmarks

Analyses presented

- B2G-12-004: search for heavy quarks decaying to tW or tZ
  - *5.0 fb^{-1} at $\sqrt{s}$ = 7 TeV*
  - *JHEP 01 (2013) 154 - arXiv:1210.7471*

- B2G-12-012: search for top partners with charge 5e/3
  - *19.6 fb^{-1} at $\sqrt{s}$ = 8 TeV*
  - *Physics Analysis Summary (PAS)*

- EXO-11-098: inclusive search for a sequential 4th generation of quarks
  - *5.0 fb^{-1} at $\sqrt{s}$ = 7 TeV*
  - *Phys. Rev. D 86, 112003 (2012) - arXiv:1209.1062*

- SUS-12-027: b′ interpretation of the results from the RPV SUSY search with three or more leptons and b-tagged jets
  - *9.2 fb^{-1} at $\sqrt{s}$ = 8 TeV*
  - *Physics Analysis Summary (PAS)*

Search for Q→tV

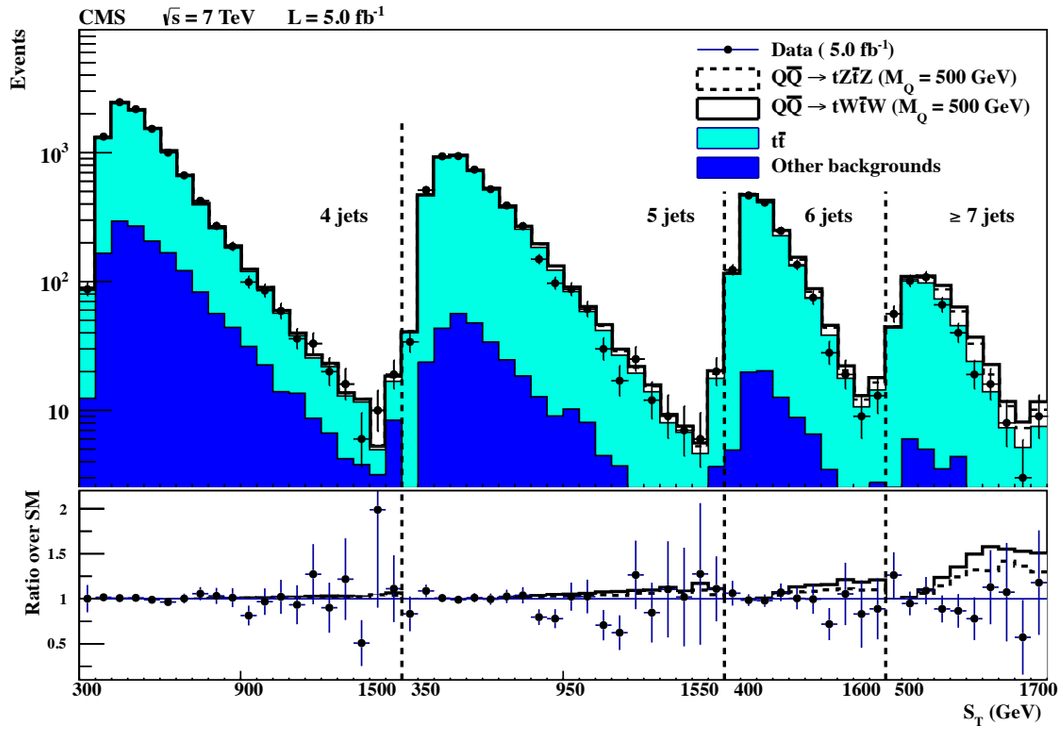
- search for heavy down(up)-type quarks decaying to tW (tZ)
  - *QQ → tWtW → bWWbWW and QQ→ tZtZ → bWZbWZ*

Event selection

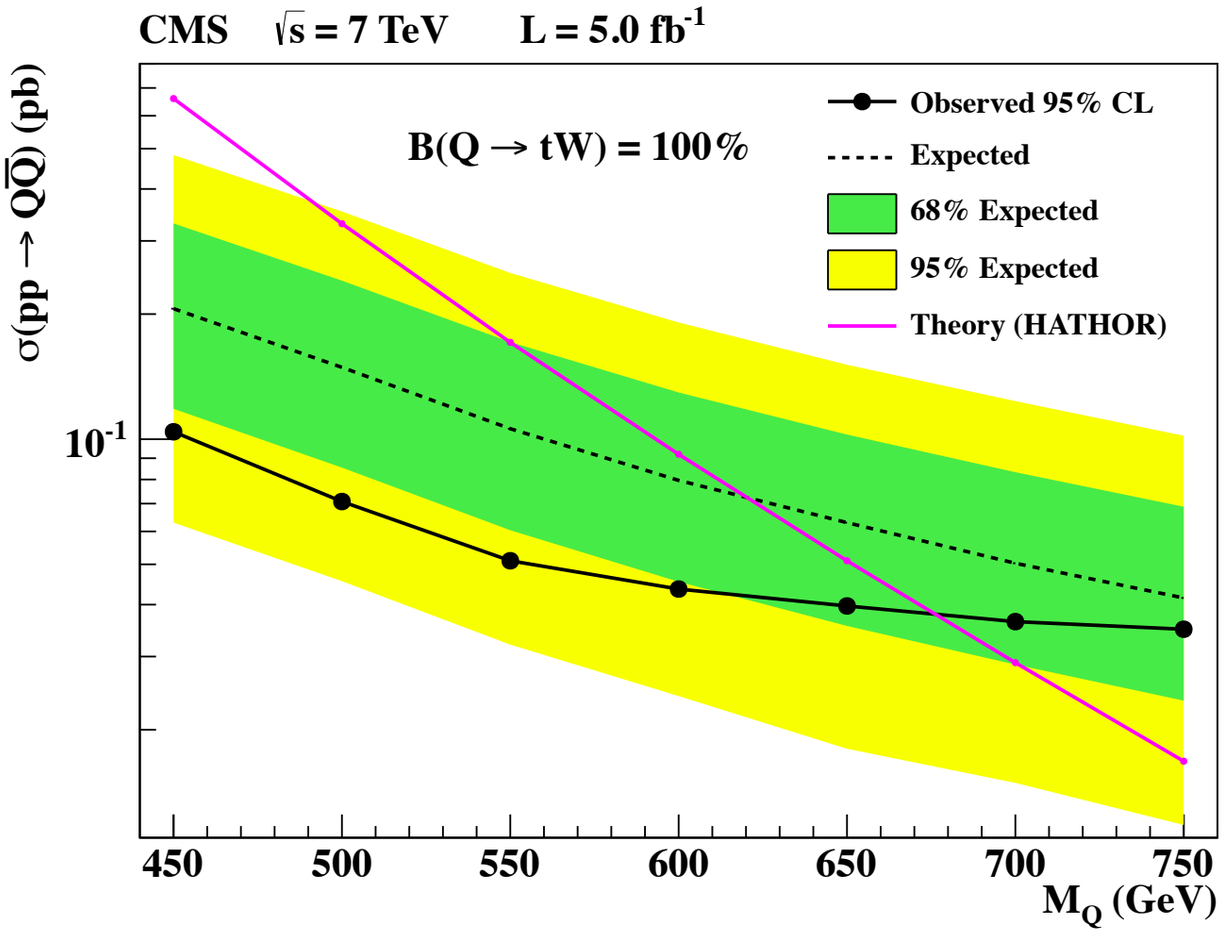
- 1 isolated electron (muon) with p_T > 35 (42) GeV and |η|< 2.5 (2.1)
- at least 4 jets with p_T > 100, 60, 50, 35 GeV with at least 1 b-tagged jet
- missing E_T (E_T^{miss}) > 20 GeV

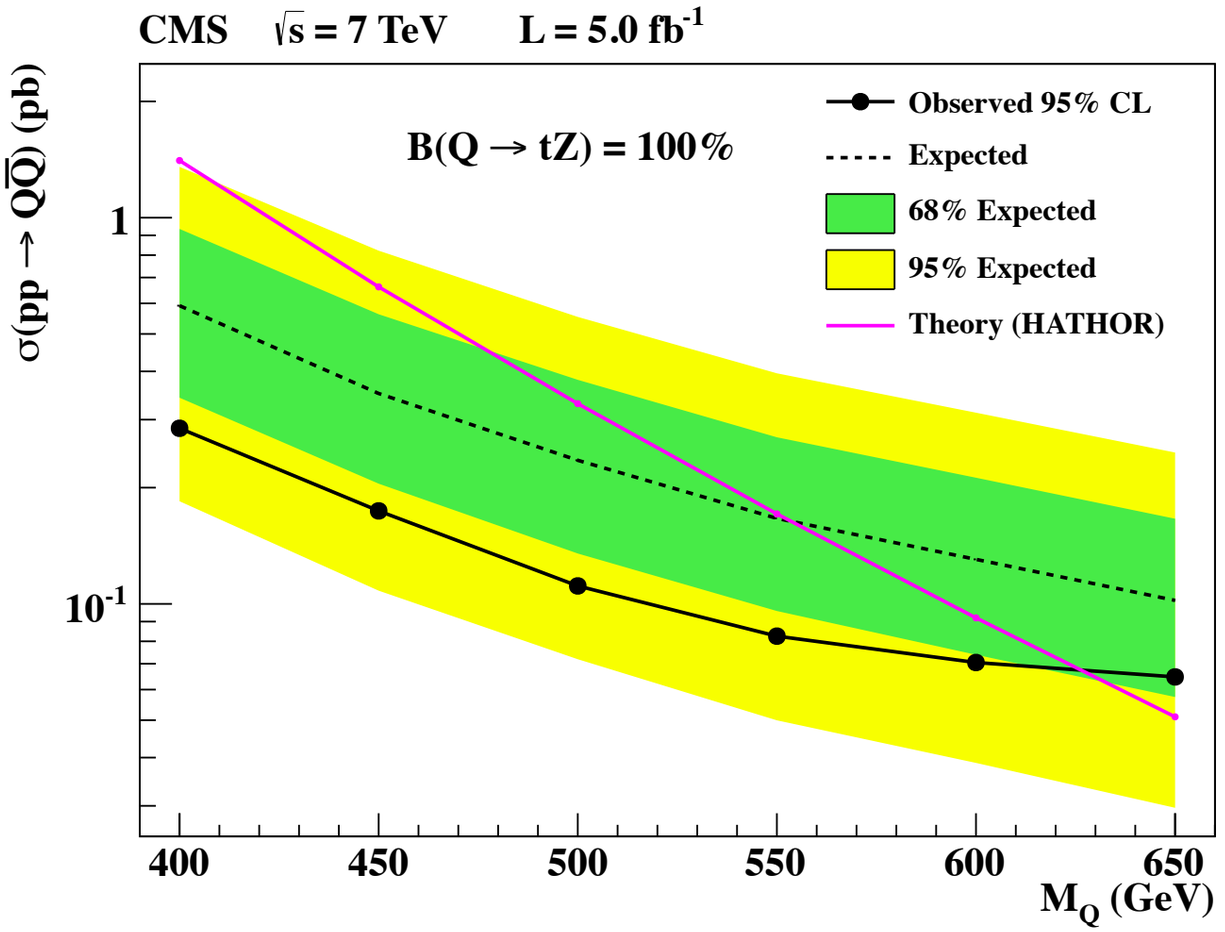
- 5.0 fb^{-1} of data at $\sqrt{s}$ = 7 TeV used
- data fitted to the S_T distribution as a function of the jet multiplicity

S_T: scalar sum of lepton and jets p_T and E_T^{miss}



Search for Q→tV (II)

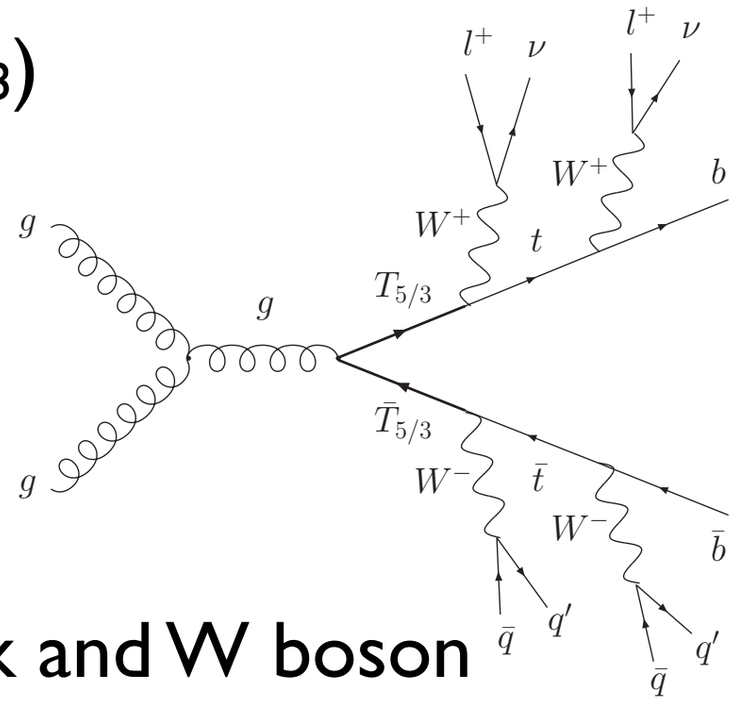




- **down-type Q**: M_Q > **675** GeV assuming BR(Q→tW) = 1
- **up-type Q**: M_Q > **625** GeV assuming BR(Q→tZ) = 1

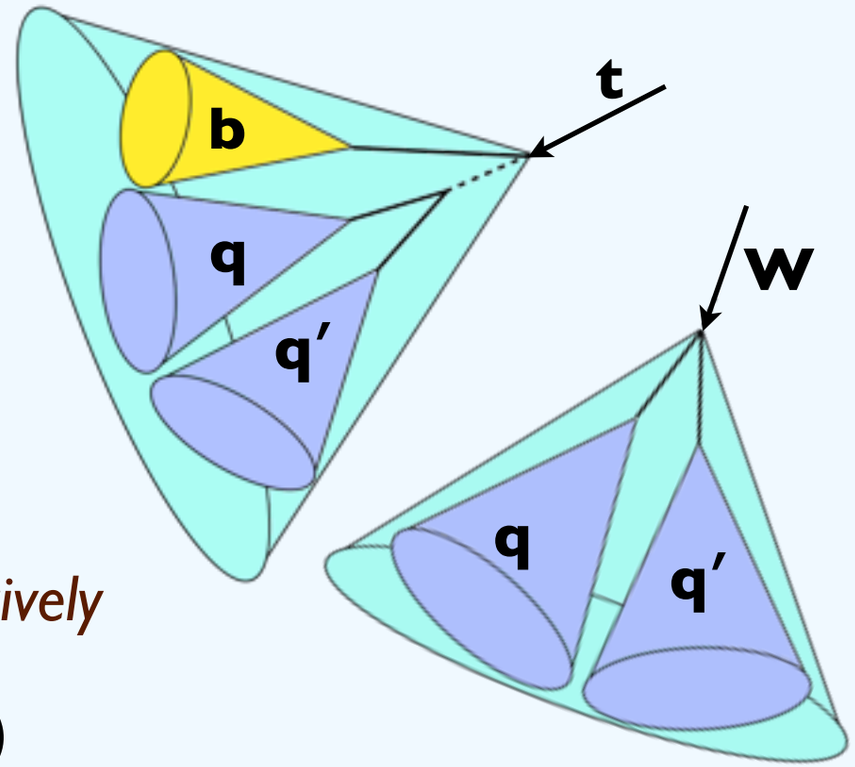
Search for $T_{5/3}$

- search for heavy top partners with charge 5e/3 ($T_{5/3}$)
- same-sign dilepton channel (ee, eμ, μμ)
- 19.6 fb^{-1} of data at $\sqrt{s}$ = 8 TeV used
- Cambridge-Aachen (CA) jets for boosted top quark and W boson



Event selection

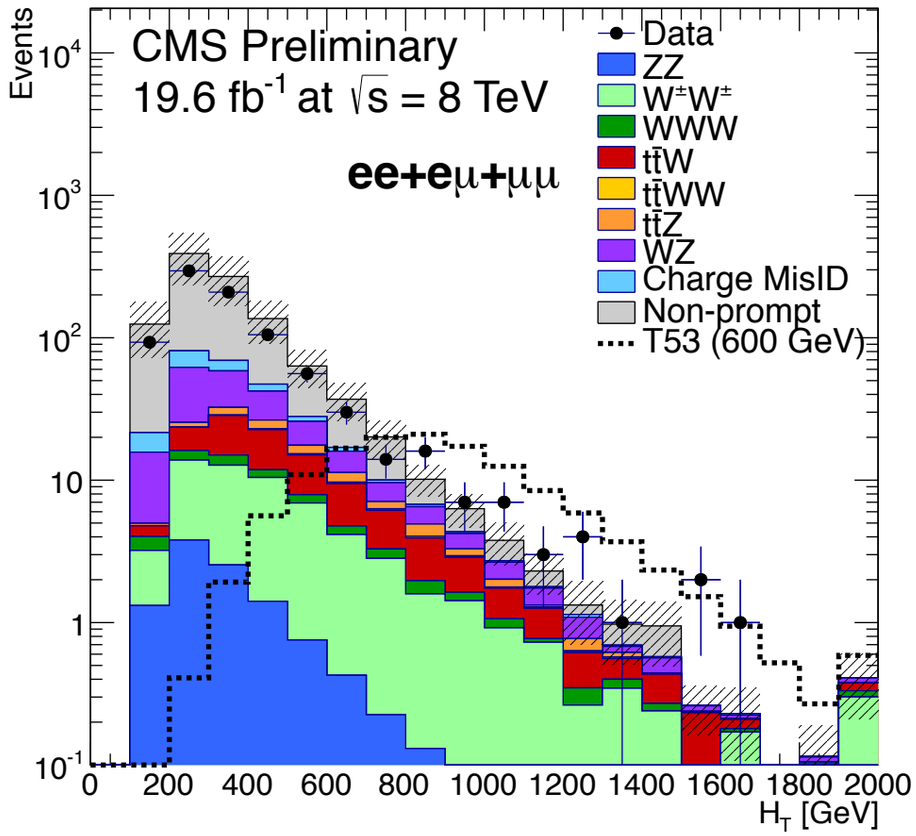
- 2 isolated same-sign leptons p_T > 30 GeV
- quarkonia and Z boson vetoes
- at least 5 constituents
  - *CA W and top jets count as 2 and 3 constituents respectively*
- H_T > 900 GeV (*scalar sum of leptons and jets p_T*)

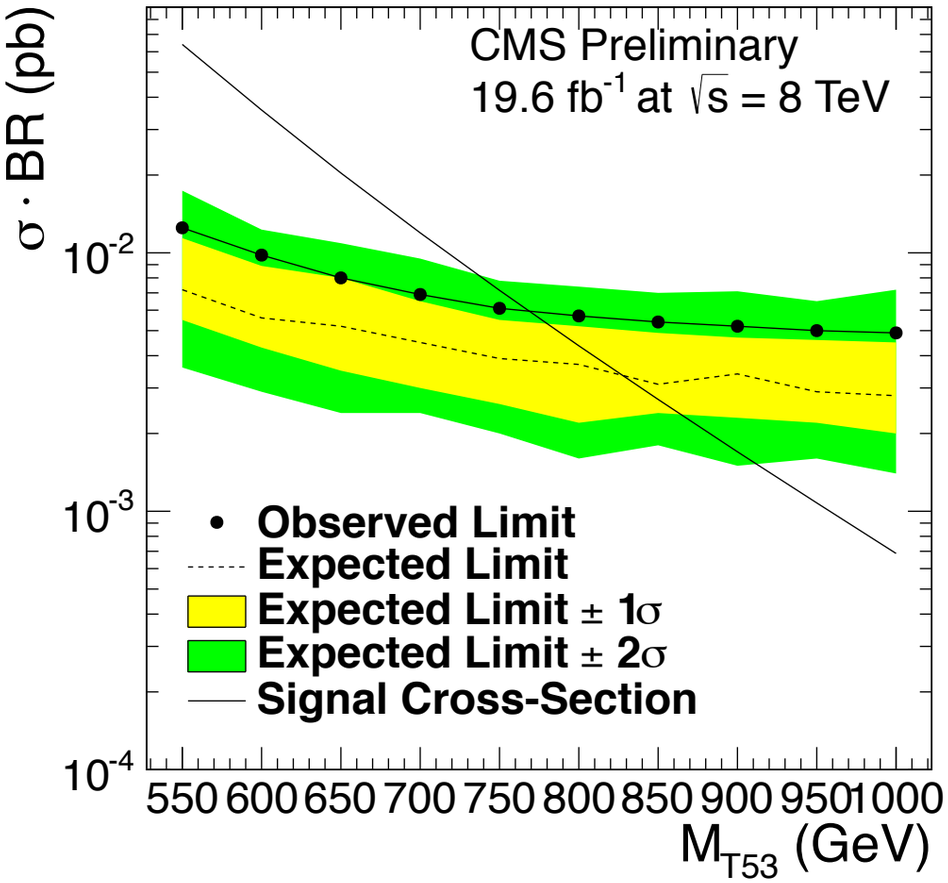


Search for $T_{5/3}$ (II)

- expected and observed yields for the three channels:

	PSS MC	Non-Prompt	Charge Mis-ID	Total Expected	Observed
ee	0.7 ± 0.2	1.9 ± 1.2	0.06 ± 0.02	2.6 ± 1.3	0
eμ	1.9 ± 0.4	0.6 ± 0.9	0.05 ± 0.01	2.5 ± 1.0	6
$\mu\mu$	1.3 ± 0.3	0.2 ± 0.6	-	1.5 ± 0.7	5
All	3.9 ± 0.8	2.6 ± 1.8	0.1 ± 0.02	6.6 ± 2.0	11





- $M_{T5/3} >$ **770** GeV assuming BR($T_{5/3} \rightarrow tW$) = 1

Inclusive t′ and b′ search

- inclusive search for t′ and b′
  - *t′t′, b′b′ and t′b, tb′, t′b′*

$$V_{CKM}^{4\times4} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \sqrt{A} & \sqrt{1-A} \\ 0 & 0 & -\sqrt{1-A} & \sqrt{A} \end{pmatrix}$$

- unitary CKM with $A = |V_{tb}|^2 = |V_{t'b'}|^2$ and degenerate b′ and t′ masses

t′ → bW

b′ → tW → bWW

→

- $t'b \to bWb$
- $t'\bar{t}' \to bWbW$
- $b't \to tWbW \to bWWbW$
- $b't' \to tWbW \to bWWbW$
- $b'\bar{b}' \to tWtW \to bWWbWW$

final states with 2 b-jets and 1 to 4 W bosons

- 3 channels defined according to the number of W bosons in the final state:
  - *single lepton channel*
  - *same-sign (SS) dilepton channel*
  - *trilepton channel*
- 5.0 fb^{-1} of data at $\sqrt{s}$ = 7 TeV used

Inclusive t′ and b′ search (II)

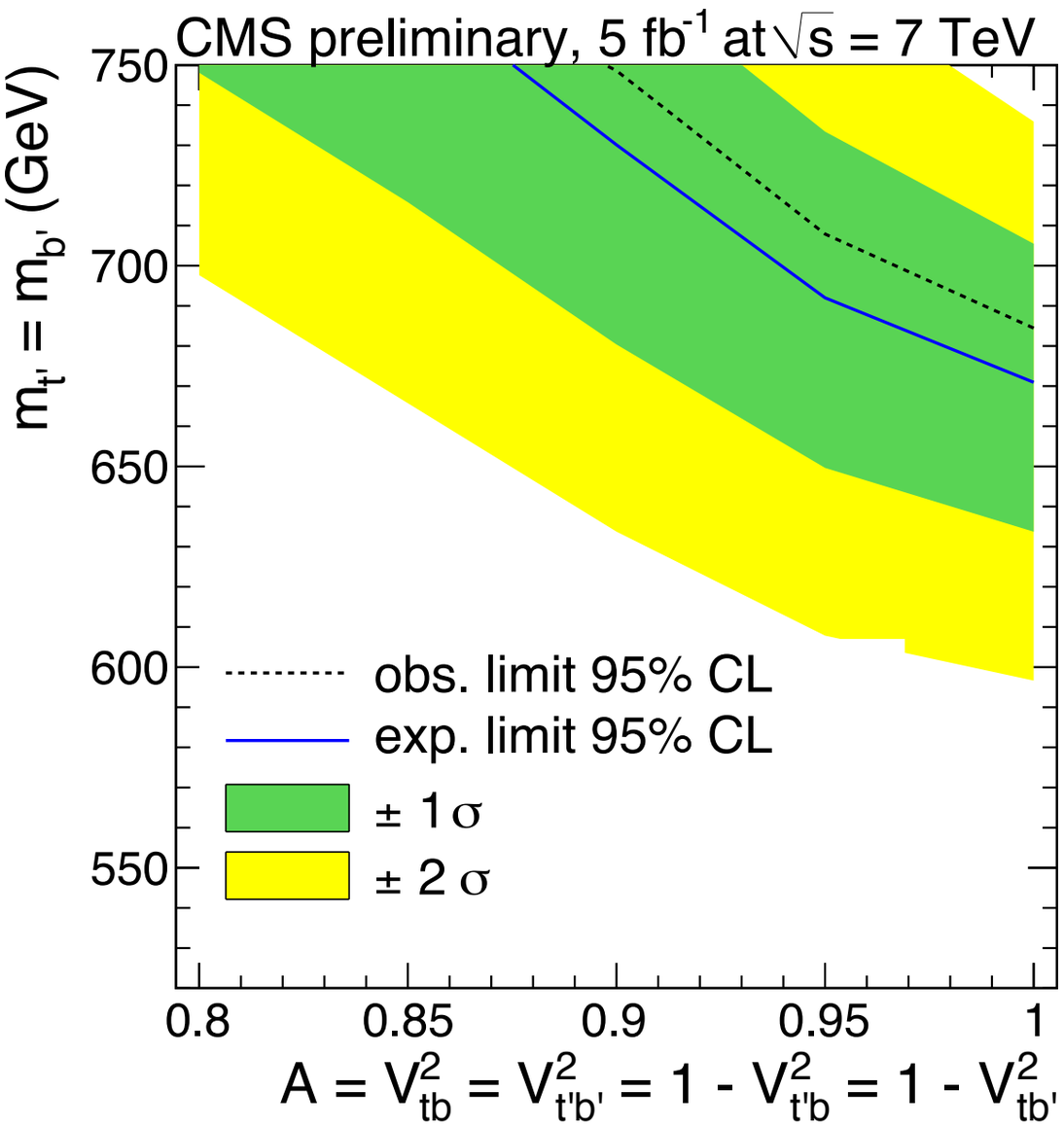
Single lepton channel

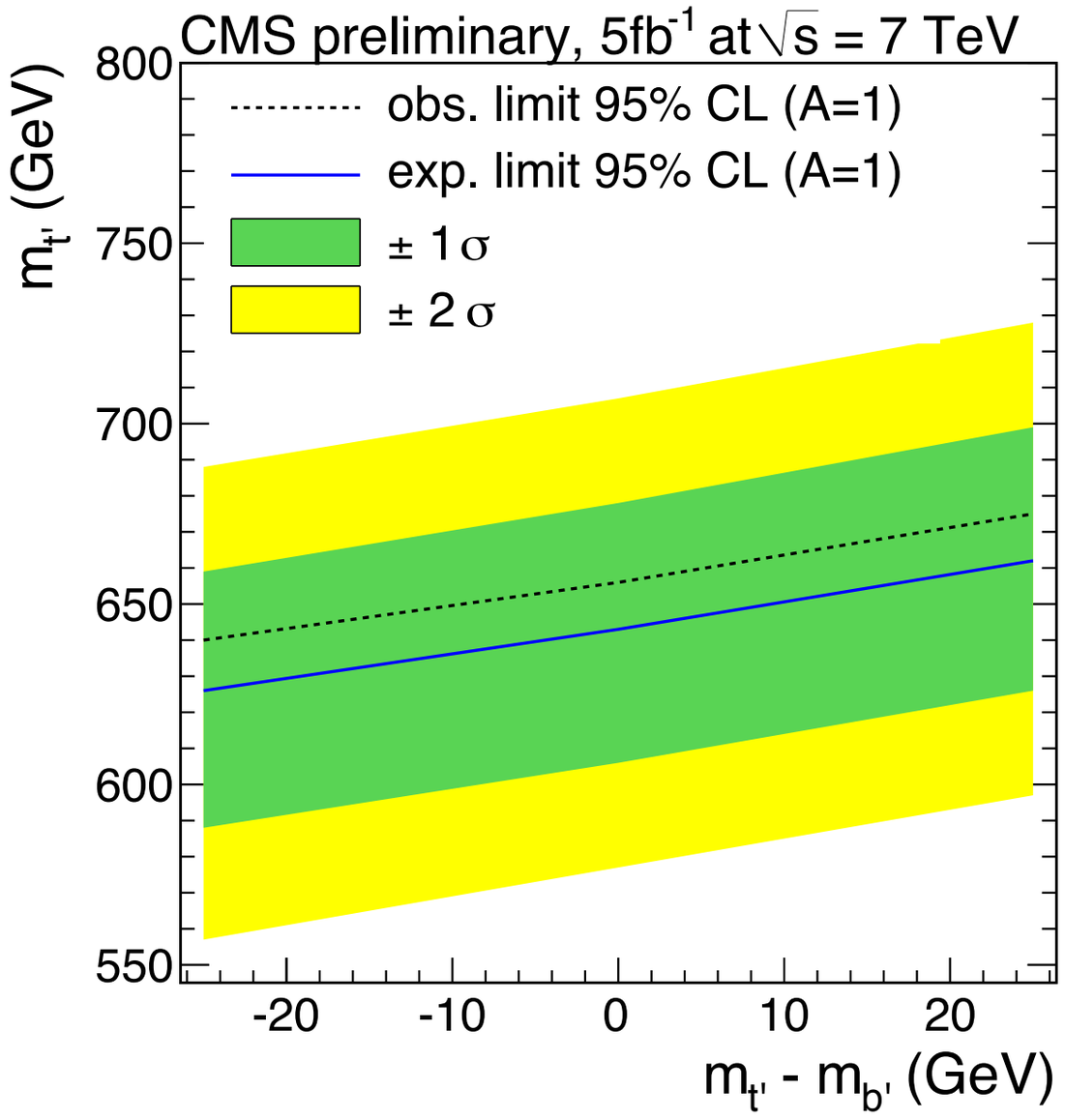
- exactly one isolated electron or muon $p_T > 40$ GeV and $|\eta| < 2.5$ (2.1)
- missing $E_T > 40$ GeV
- events subdivided into exclusive categories based on:
  - *number of b-tagged jets (exactly one or two)*
  - *number of W candidates (exactly one, two, three or at least four)*
- W candidate: dijet pair with 74.7 GeV < M_{jj} < 93.9 GeV

Same-sign dilepton and trilepton channels

- 2 SS leptons or 3 leptons with $p_T > 20$ GeV (40 GeV for the leading)
- missing $E_T > 40$ GeV
- at least 4 (2) jets for the dilepton (trilepton) channel

Inclusive t′ and b′ search (III)





- **for A=1 and $M_{t'}=M_{b'}$**: $M_{t'} = M_{b'}$ > **685** GeV
- **for $|m_{t'} - m_{b'}| = 25$ GeV**: corresponding limit shifts by about ±20 GeV

b′ from inclusive RPV susy search

- search for anomalous production of events with at least 3 isolated leptons
- 9.2 fb^{-1} of data at $\sqrt{s}$ = 8 TeV used

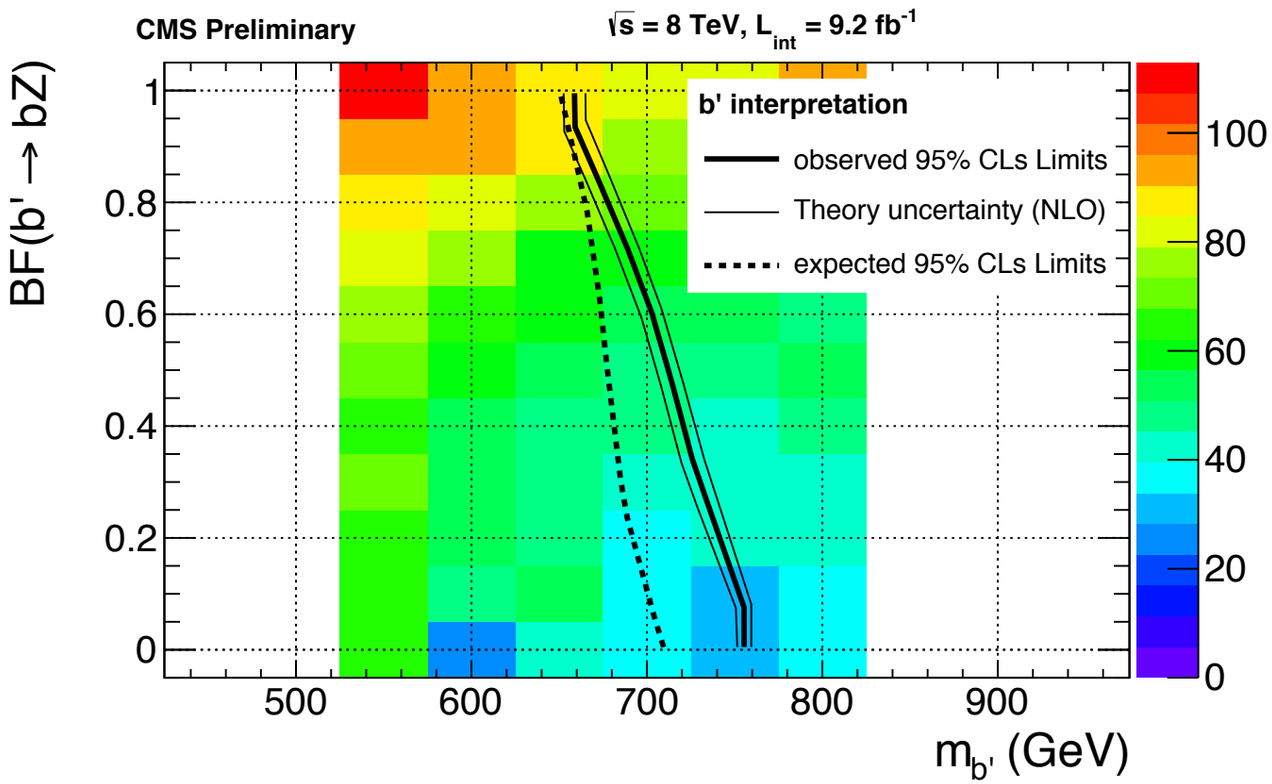
Event selection

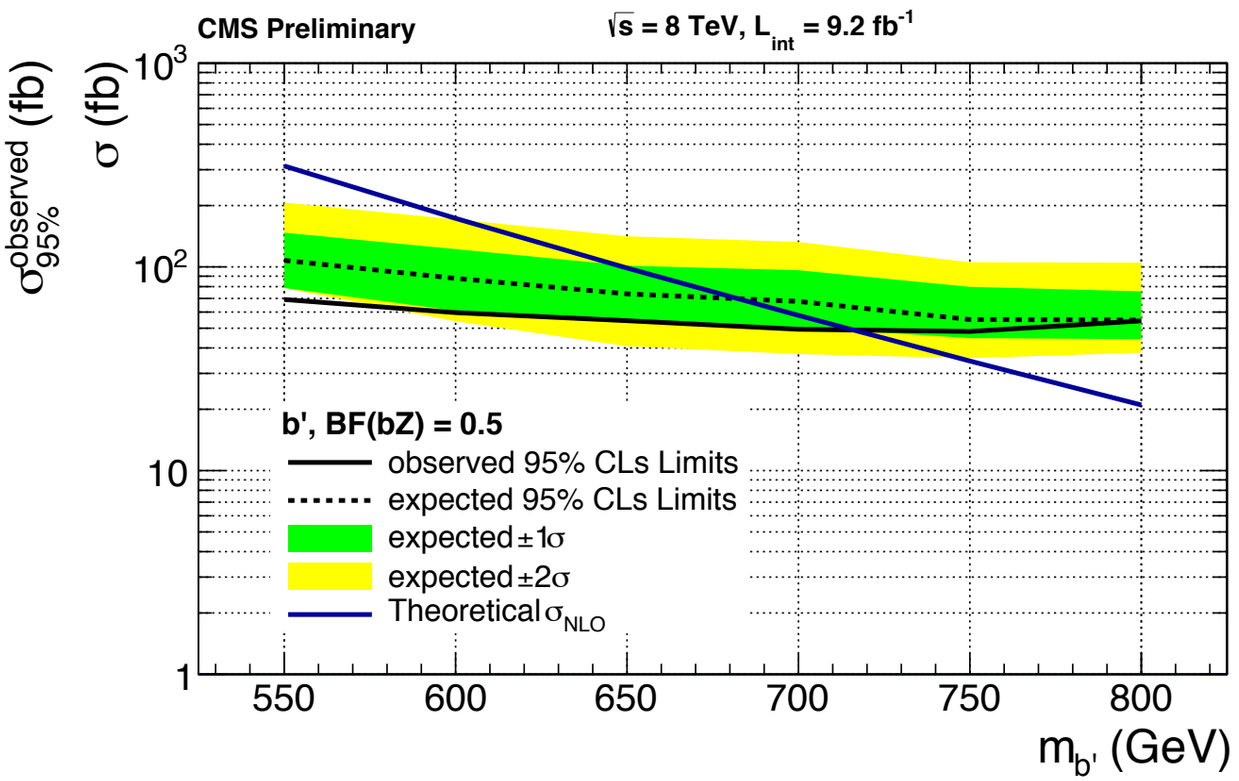
- at least 3 isolated leptons p_T > 10 GeV (20 GeV for the leading)
  - *maximum one hadronic-τ*
- jets are requested to have p_T > 30 GeV
- events classified according to:
  - *number of opposite-sign same-flavor lepton pairs*
  - *whether at least one lepton pair has M_{ll} within [75, 105] GeV (onZ event)*
  - *number of reconstructed taus and b-jets*
  - *S_T (scalar sum of $E_T$miss and jets and leptons p_T)*

- **240 channels**: 90 with three leptons and 150 with four leptons

b′ from inclusive RPV susy search (II)

- **b′b′→bZbZ**: channels with 3 leptons, 2 OSSF, no tau, ≥1 b-jet and onZ
- **b′b′→tWtW** :channels with 4 leptons, 1 OSSF, no tau, ≥1 b-jet + offZ
- $BR(b' \to tW) = 1 - BR(b' \to bZ)$





- **for BR(b′→bZ) = 0.5**: $M_{b'}$ > **718** GeV

Summary

- Many BSM models predict a fourth generation of fermions
- CMS performed the search for new heavy quarks in several decay channels
  - *no evidence of new physics*
- Four analyses have been presented:
  - B2G-12-004: search for Q→tV
    limits: **675** (**625**) GeV for down(up)-type quarks
  - B2G-12-012: search for $T_{5/3}$
    limits: **770** GeV
  - EXO-11-098: inclusive b′ and t′ search
    limits: **685** GeV for degenerate b′ and t′ masses
  - B2G-12-012: b′ from inclusive RPV susy search
    limits: **718** GeV for BR(b′→bZ) = 0.5

BACKUP

SM4 and the125 GeV Higgs

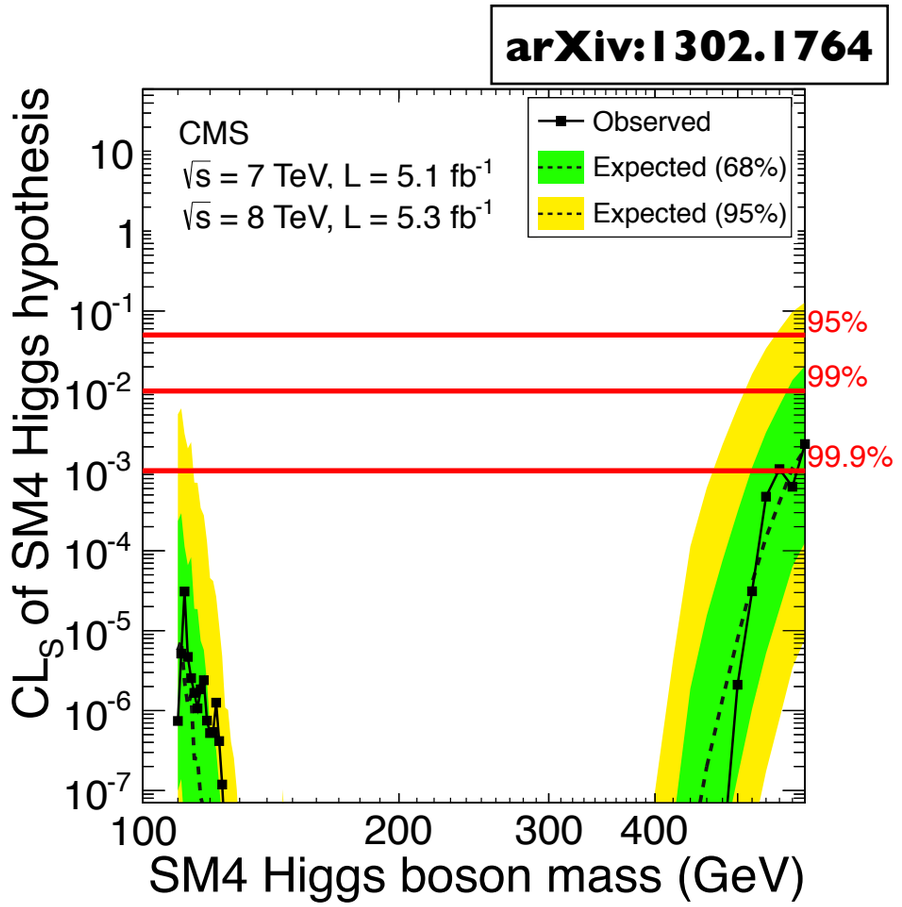
- the presence of a 4th generation would impact the Higgs production cross section and decay branching fractions

- direct search exclude SM Higgs up to 600 GeV except for the mass range 122-128 GeV where a new particle with mass ~125 GeV was observed

- several papers showed the ~125 GeV Higgs is not compatible with SM4

- also CMS has excluded SM4 Higgs in the mass range 110-600 GeV at 99% CL
  - $m_{l4} = m_{\nu 4} = mb' = 600$ GeV
  - $mt' - mb' \sim O(50)$ GeV

the existence of a chiral 4th generation is **NOT** ruled out but only the most simple extension SM4



The CMS detector