Search for exotic Top quark partners and new Physics in Top-like final states

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CMS collaboration

Higgs and BSM Physics
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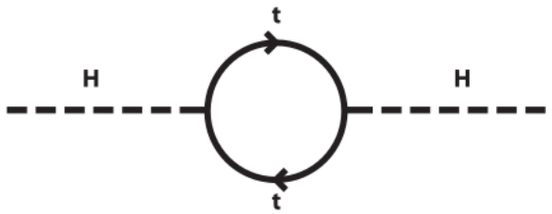
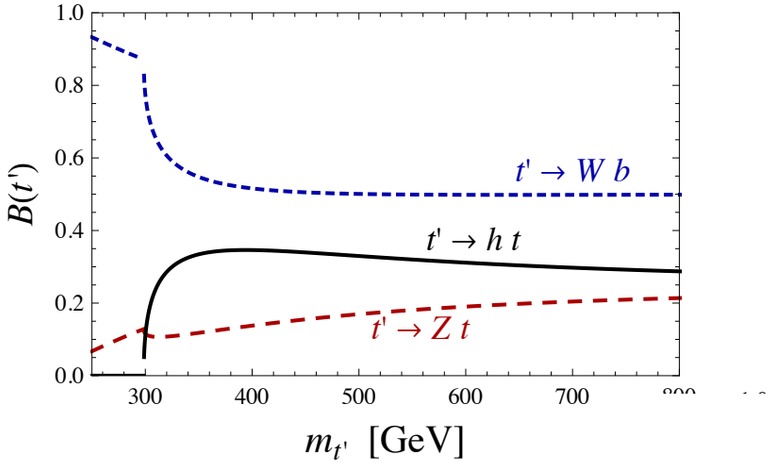
Introduction

- The LHC is a top quark factory
  - With large dataset many decay channels can be analyzed independently
- A perfect final state to probe new physics!
  - Unique event signatures
  - Can provide solution to the hierarchy problem without SUSY
  - Special techniques for top reconstruction can increase mass reach



- Top quark partners
  - Sequential Fourth fermion generation existence is disfavored by the discovery of Higgs boson, several other models exists
  - **Vector-like quarks:** Transforms as *(3,1,+2/3)* under $SU(3)_c \times SU(2)_W \times U(1)_Y$ would mix with the top quark Rakhi Mahbubani et.el, JHEP 0906:001 (2009)
  - **$T_{5/3}$ top partners:** Transforms as *(3,1,+5/3)* and strong sector respect the $SU(2)_L \times SU(2)_R \times U(1)_X$ Contino & Servant, JHEP 0806:026 (2008) Mrazek & Wulzer, Phys. Rev. D 81, 075006 (2010)



Branching fractions of t':
$(M_h = 125$ **GeV**, $\sin\theta_L = 0.1)$

- Top pair resonances
  - Models that predict enhanced couplings to the third generation of SM
  - **Z´, RS KK gluon production**
- t+b and t+jets resonances
  - **W´, t* decays**

Outline

- T and B vector-like pair
  - lepton+jets $t'\bar{t}' \to WbW\bar{b}, WbZ\bar{t}, WbH\bar{t}, HbZ\bar{t}, HbH\bar{b}, ZbZ\bar{b}$
  - trilepton $b'\bar{b}' \to WbW\bar{b}, ZbZ\bar{b}, WbZ\bar{b}$

CMS-PAS-B2G-12-015

- $T^{5/3}$ search $T^{5/3}T^{5/3} \to tWtW$

CMS-PAS-SUS-12-027

CMS-PAS-B2G-12-012

- Top pair resonances
  - Lepton + jets

CMS-PAS-B2G-12-006

  - All-hadronic

CMS-PAS-B2G-12-005

- T+b resonance $W' \to tb$

CMS-PAS-B2G-12-010

- Excited Top quarks $t^* \to t + g$

CMS-PAS-B2G-12-014

- Baryon number violating top

CMS-PAS-B2G-12-023

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Vector-like Quark

- At 7 TeV most heavy quark, Q searches assume 100% BR for a given channel
- Michael Peskin's slogan
  - Exclude Triangles not Points

https://indico.fnal.gov/getFile.py/access?contribId=49&resId=0&materialId=slides&confId=5256

$TT \to bWbW$

PLB.2012.10.038, EXO-11-099
$t'\bar{t}' \to l + jets$

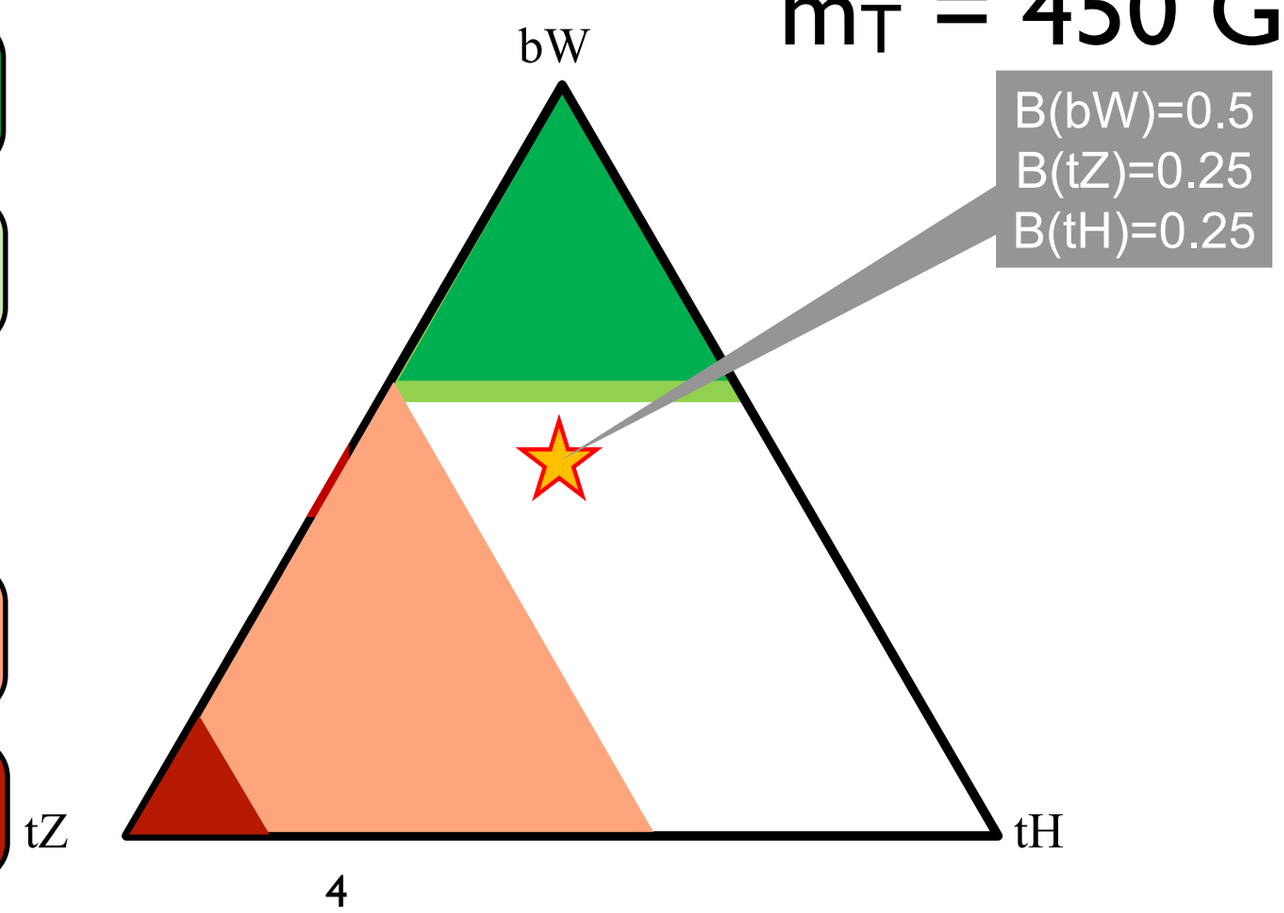
PLB.2012.07.959, EXO-11-050
$t'\bar{t}' \to dileptons$

$TT \to tZtZ$

JHEP05(2012)123
$t'\bar{t}' \to l + jets$

PRL.107.271802, EXO-11-005
$t'\bar{t}' \to trileptons$

m_T = 450 GeV

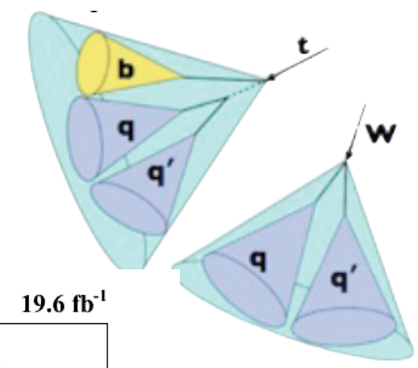


Inclusive vector-like T search

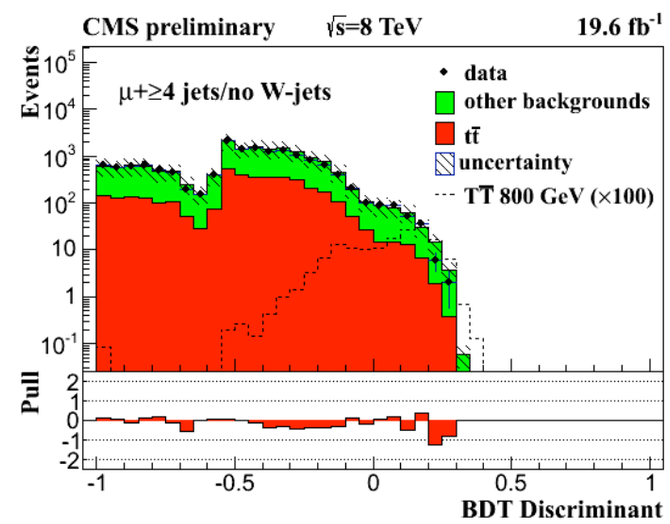
CMS-PAS-B2G-12-015

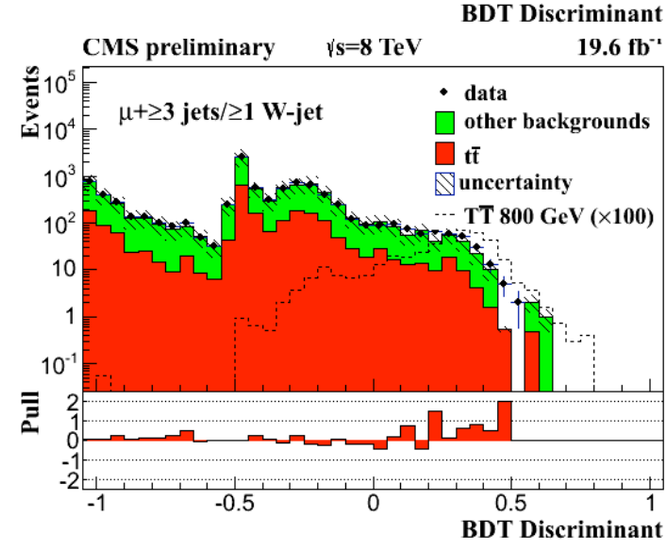
T→bW, tZ, tH (lepton+jets channel)

- Use CMS Top-tagger and W-tagger with pruned CA8 jets (CMS-PAS-JME-10-013)
  - top-tagging : p_T > 200 GeV, 140 < m_{jet} < 250 GeV, ≥3 subjets with minimum pairwise mass > 50 GeV
  - W-tagging: p_T > 200 GeV and 60 < m_{jet} < 130 GeV



- Categorize events depending on N_W
  - 1 lepton, (≥ 3 jets, ≥ 1 W) or (≥ 4 jets, = 0 W)
- Strategy: BDT
  - Training is done on highest discriminating power variables namely, N_{jets}, N_{btags}, H_T ...



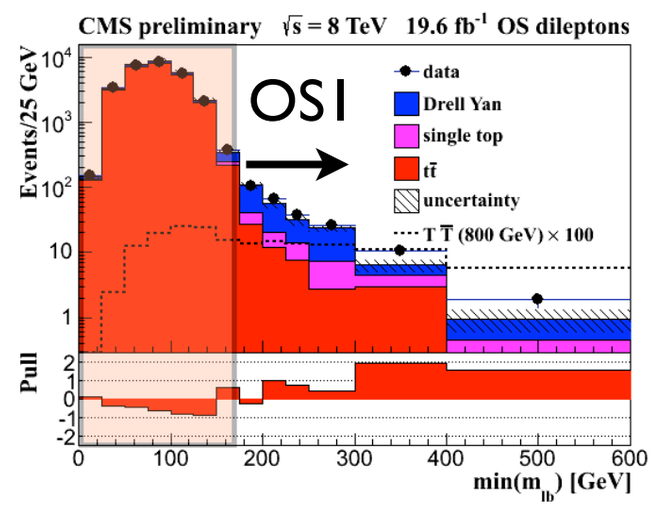


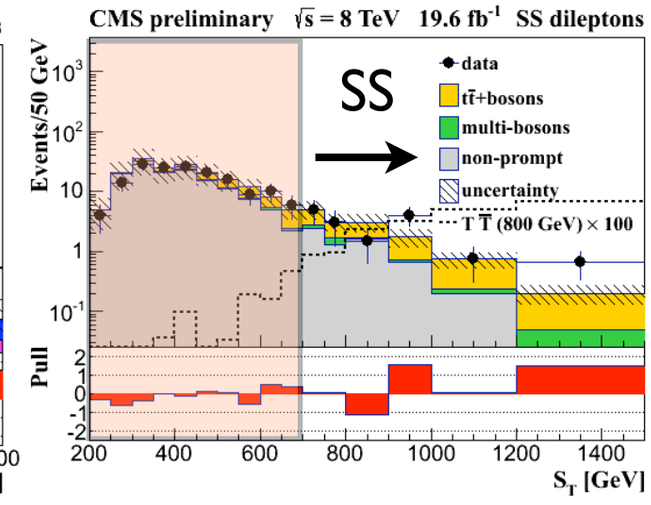
Inclusive vector-like T search

CMS-PAS-B2G-12-015

T→bW, tZ, tH (≥2 leptons+jets channel)

- Standard analysis categorized into four mutually exclusive channels
  - OS1 dilepton (dominant signal = T→bW)
    - ZVeto, 2 or 3 jets, H_T>300 GeV, S_T > 900 GeV and m_{lb} > 170 GeV
  - OS2 dilepton (dominant signal = T→tZ)
    - ≥ 5 jets, ≥ 1 b-tag, H_T>500 GeV, S_T > 1000 GeV
  - SS dilepton (dominant signal = T→tZ, tH)
    - ≥ 3 jets, S_T > 700 GeV
  - Trileptons (dominant signal = T→tZ, tH)
    - ≥ 3 jets, S_T > 700 GeV
- Strategy:
  - Binned Likelihood fit for 12 different channels
    - OS1, OS2, SS = ee, eμ, μμ
    - Trileptons = eee, μμμ+eeμ, μμμ





Backgrounds

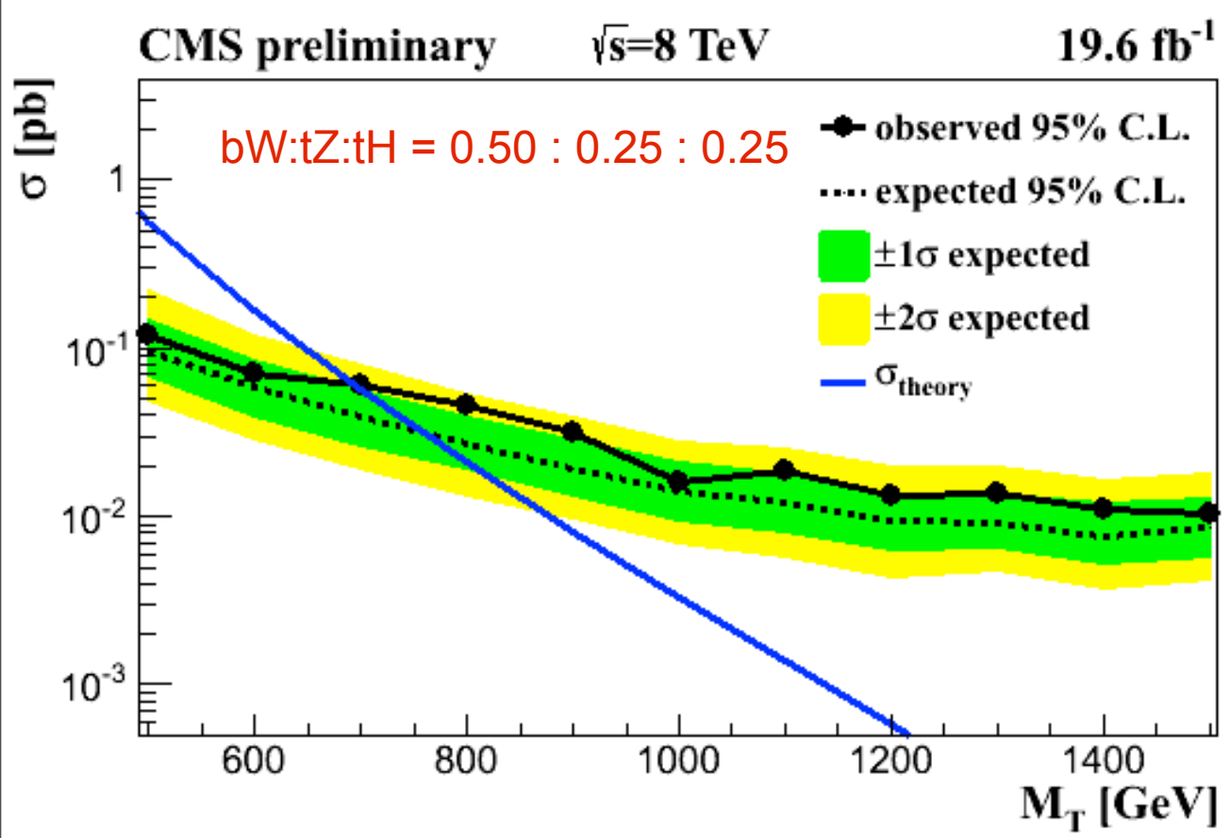
channel	OS1	OS2	SS	trileptons
tt̄	5.2±1.9	80 ±12	-	-
single top	2.5±1.3	2.0±1.0	-	-
Z	9.7±2.9	2.5±1.9	-	-
tt̄W	-	-	5.8 ±1.9	0.25±0.11
tt̄Z	-	-	1.83±0.93	1.84±0.94
WW	-	-	0.53±0.29	-
WZ	-	-	0.34±0.08	0.40±0.21
ZZ	-	-	0.03±0.00	0.07±0.01
WWW/WWZ/ZZZ/WZZ	-	-	0.13±0.07	0.08±0.04
tt̄WW	-	-	-	0.05±0.03
charge mis-ID	-	-	0.01±0.00	-
non-prompt	-	-	7.9 ±4.3	0.99±0.90
total background	17.4±3.7	84 ±12	16.5 ±4.8	3.7 ±1.3
data	20	86	18	2

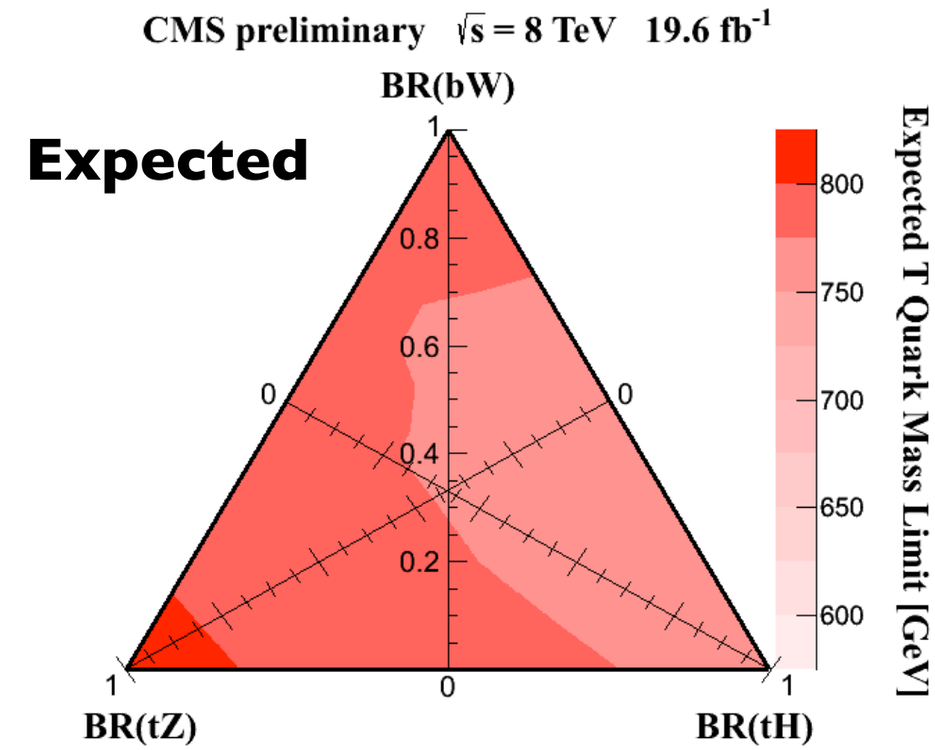
Inclusive vector-like T search

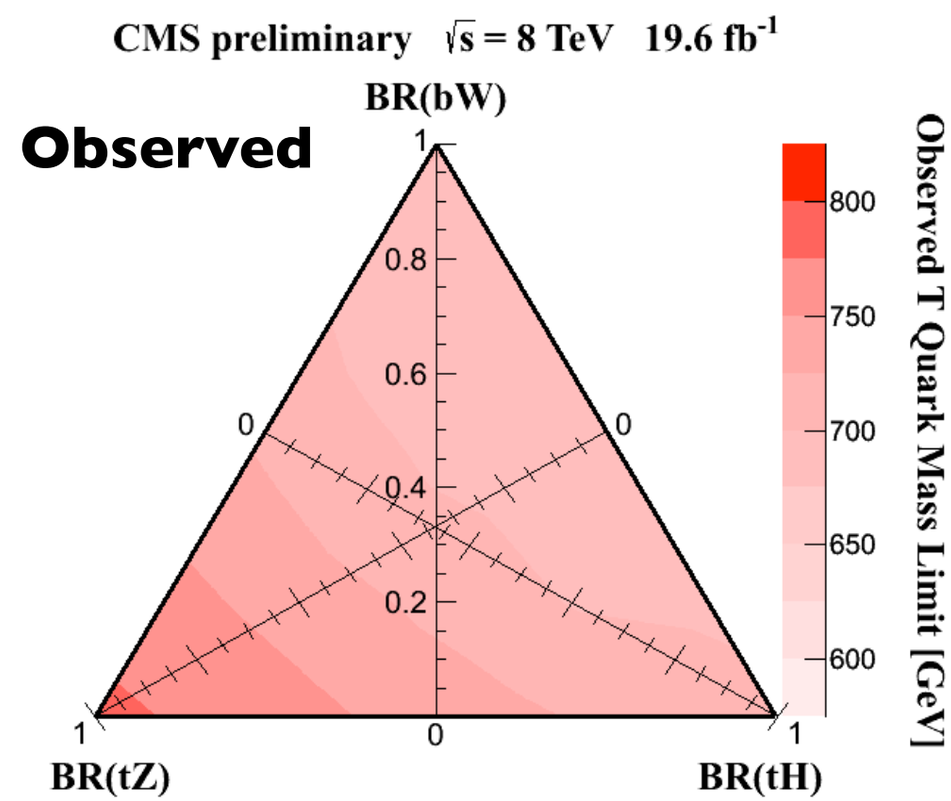
CMS-PAS-B2G-12-015

Combine limits

- For inclusive decay of T →bW, tZ, bH, a mass bound of [687, 782] GeV is set at 95% C.L for all possible branching fractions





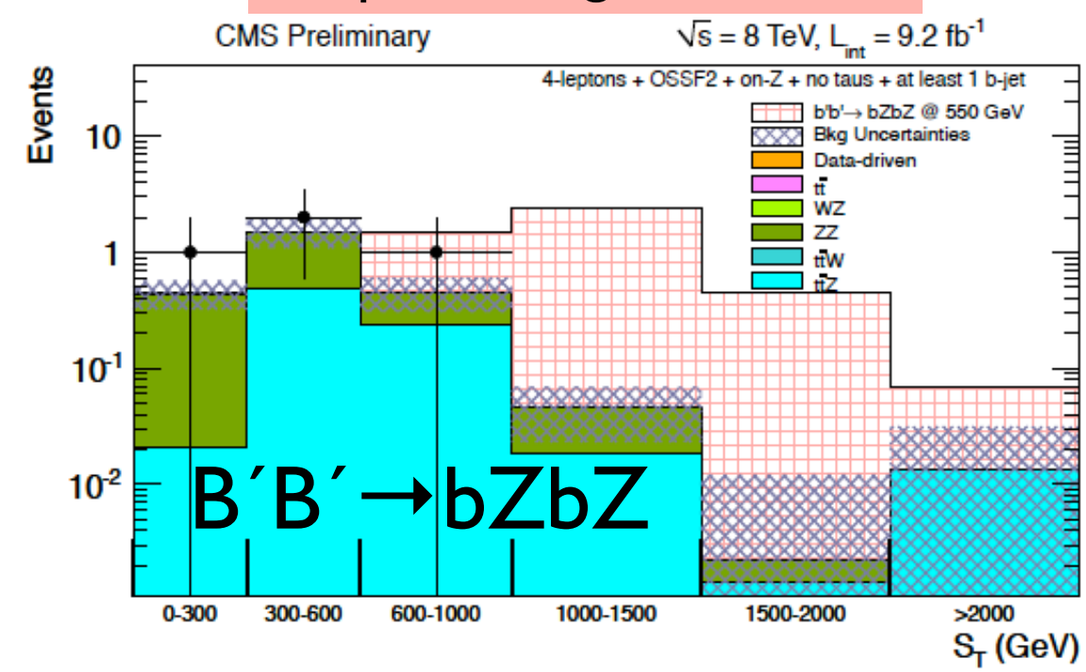


B´ search with multileptons

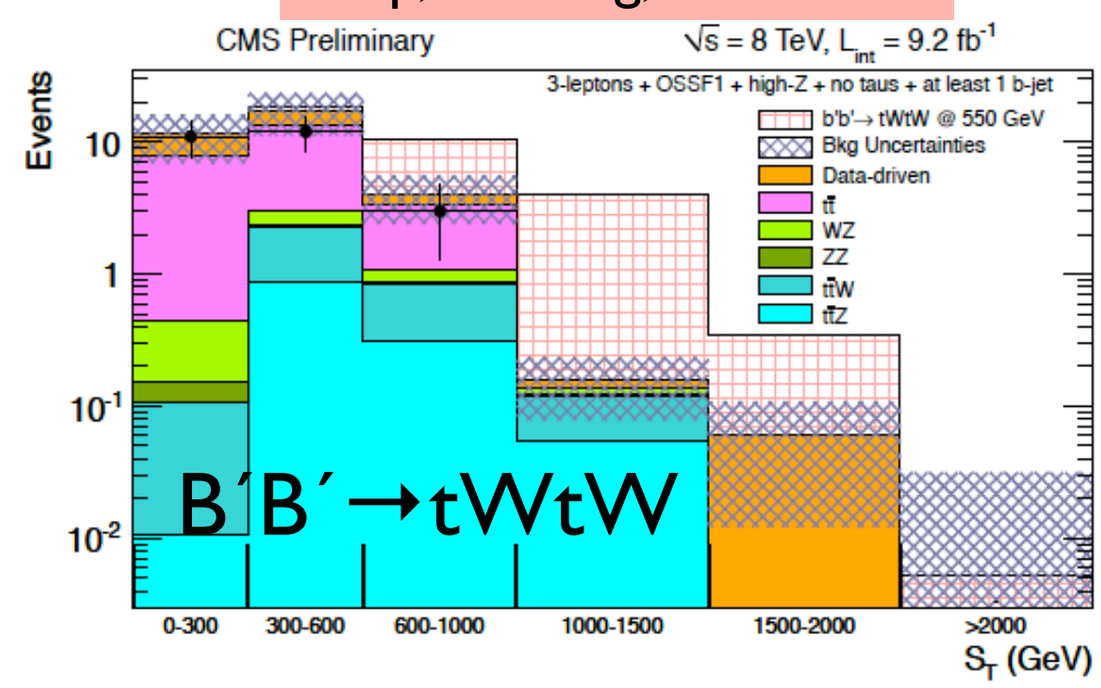
See talk by Thiago this morning → CMS-PAS-SUS-12-027

- Re-interpret search for RPV SUSY with ≥3 leptons as search for vector-like B´ quark
- Event selection:
  - ≥ 3 isolated leptons (τ_l = e or μ, ≤1 τ_h)
- Classification:
  - number of leptons, taus, b-jets
  - # of opposite-sign same flavor (OSSF)
    - OSSF0 = $\mu^+\mu^+e^-$
    - OSSF1 = $\mu^+\mu^-\mu^-$ and $\mu^+\mu^-e^-$
    - OSSF2 = $\mu^+\mu^-e^-e^+$
  - on/off Z: OSSF in Z window (75–105 GeV)?
  - Veto events with OSSF lepton-pair mass < 12 GeV (J/Psi, low mass DY and photon conv)
- Use S_T : $S_T = p_T^l + \Sigma p_T^{jet} + E_T^{miss}$
  - 240 exclusive channels

4 lep, ≥1b-tag, OSSF on Z



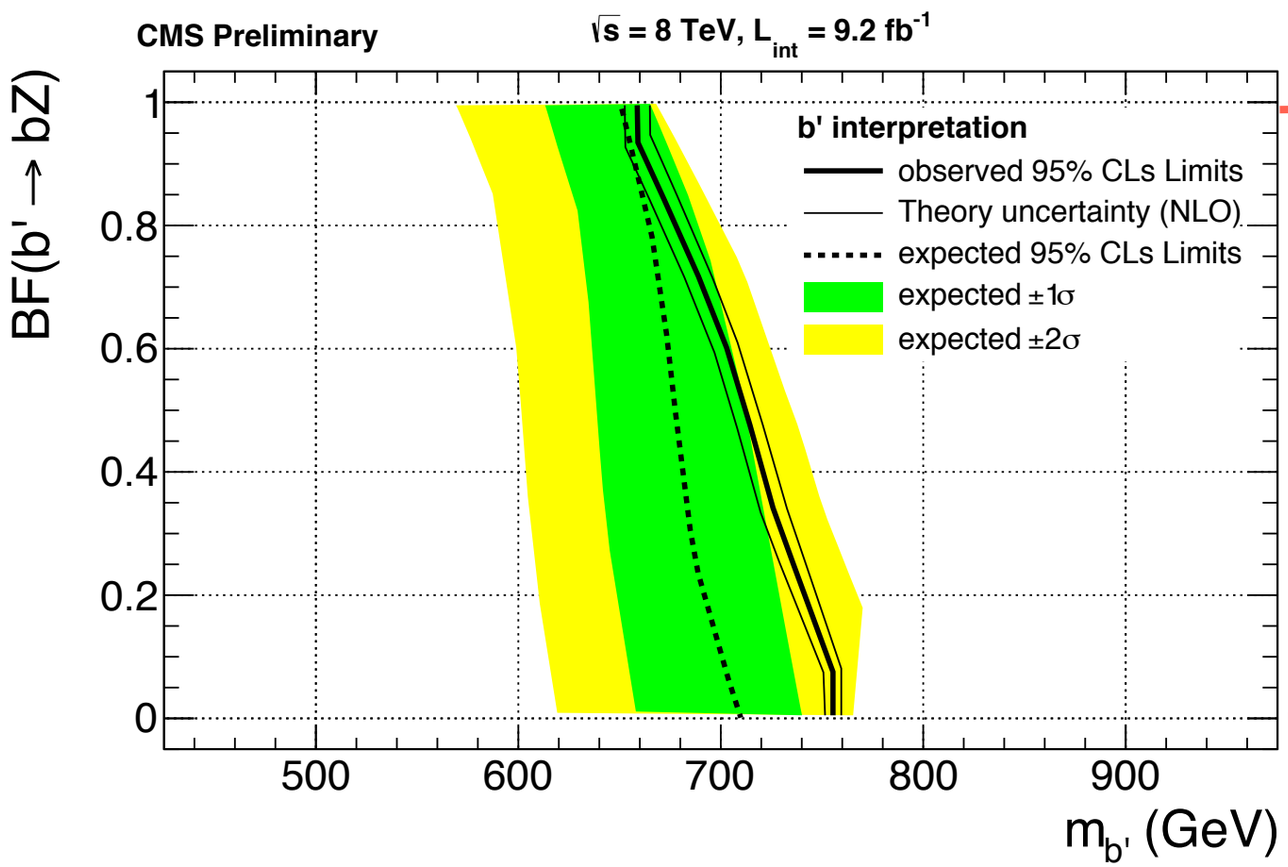
3 lep, ≥1b-tag, OSSF off Z

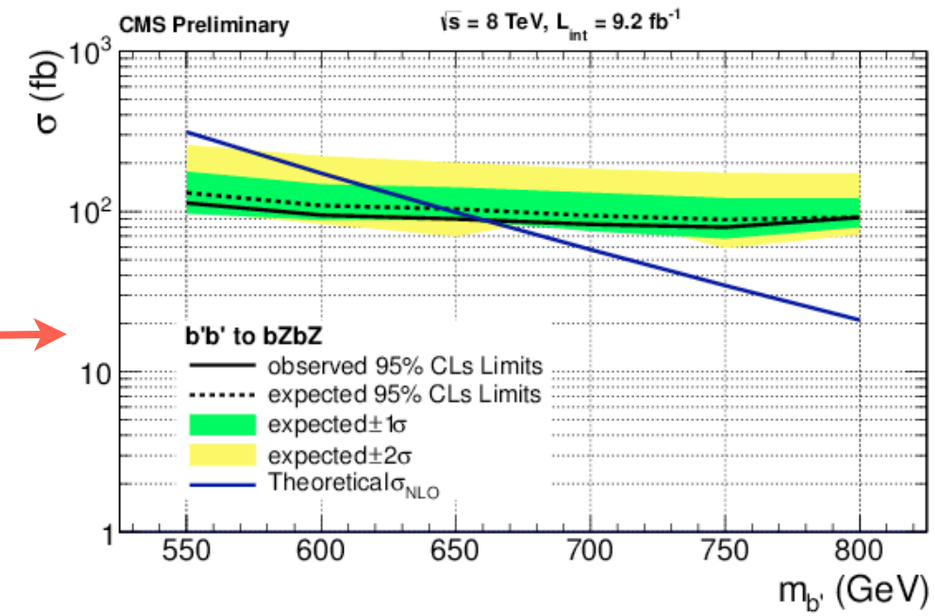


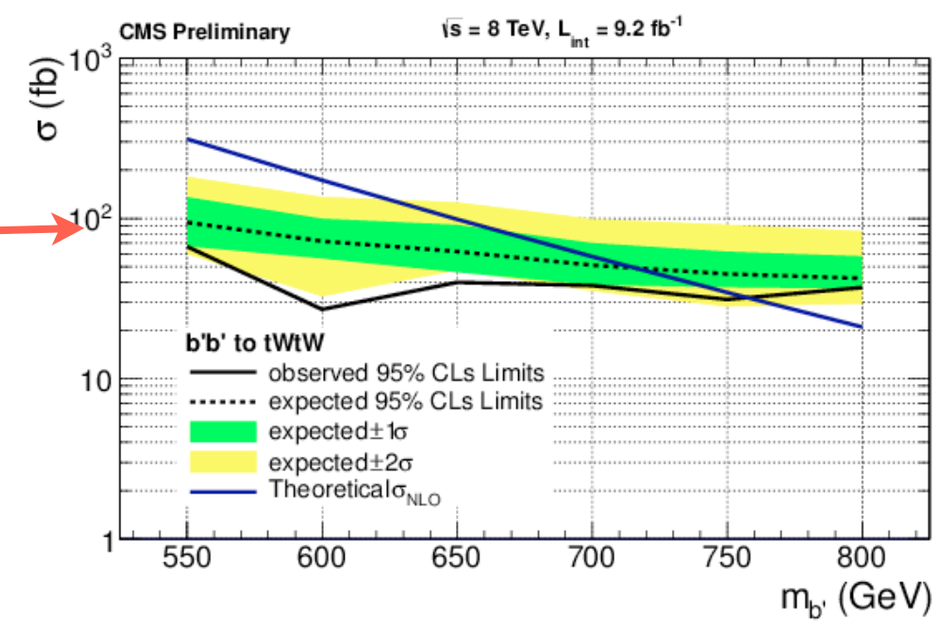
B´ search with multileptons

CMS-PAS-SUS-12-027

- Area on the left below the observed limits is excluded @ 95% CL







- Exclude B´ with 100% BR
  - B´→bZ: $m_{B'}$>660 GeV @ 95% CL
  - B´→tW: $m_{B'}$>760 GeV @ 95% CL

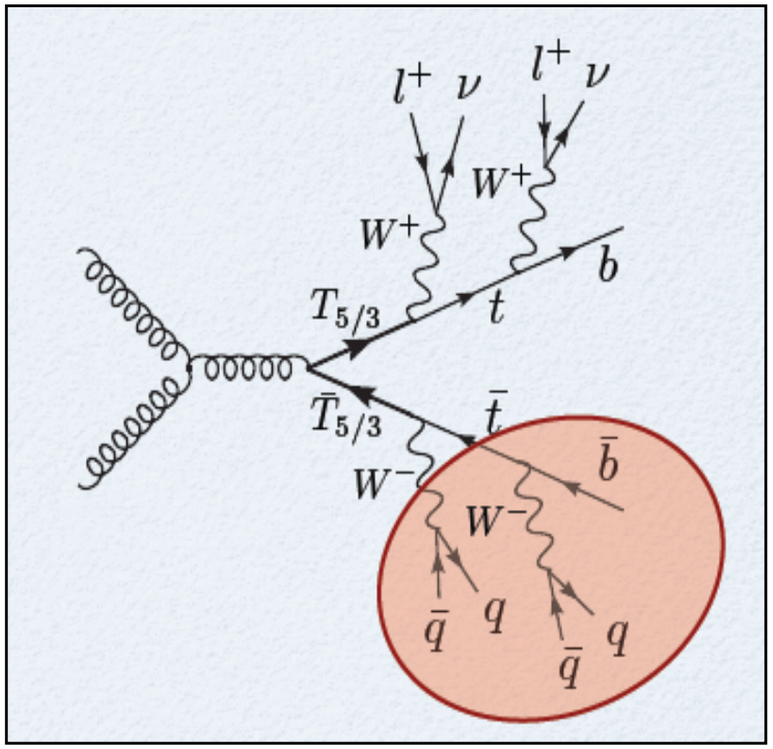
$T_{5/3}$ Top Partners

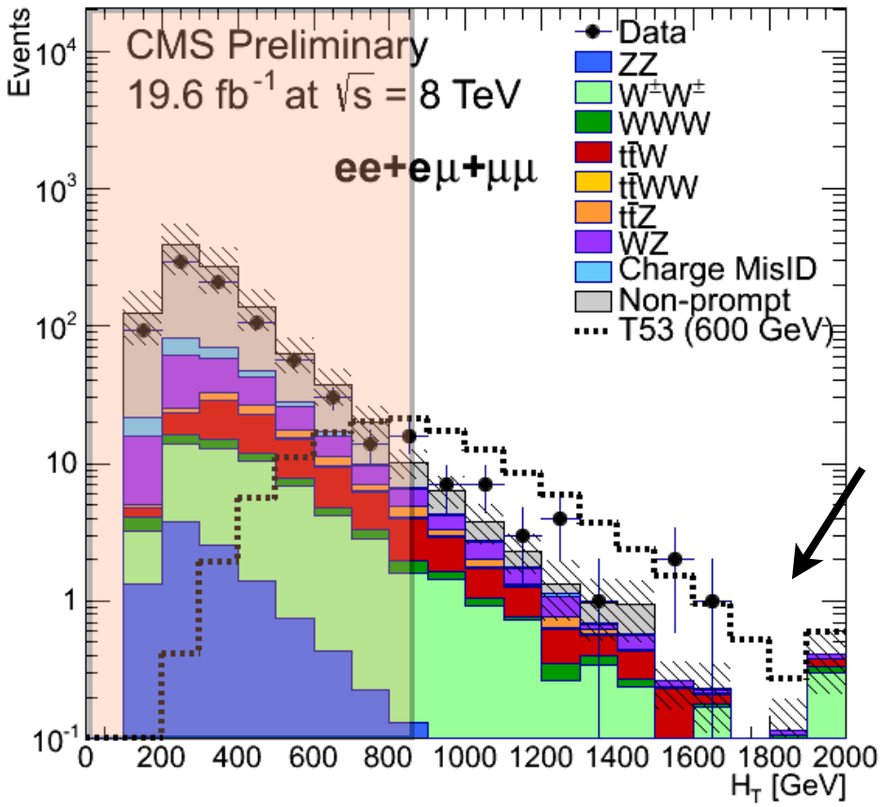
CMS-PAS-B2G-12-012

- Striking signature: same-sign dileptons

$$l^{\pm}l^{\pm} + 2b + 2W$$

- Hadronically decaying $T_{5/3}$ can be reconstructed
- Selection:
  - Two same-sign leptons (e or μ) with p_T > 30 GeV and $|\eta| < 2.4$
  - Vetos: Quarkonia, Dilepton and Trilepton Z boson
  - 5 or more "constituents" in addition to the two SS leptons
  - constituent=lepton, jet, W-tagged jet (2), or top-tagged jet (3)
    - Use W-tagger and HEP top-tagger with CA8 jets (CMS-PAS-JME-10-013)
  - S_T > 900 GeV





2 SS lep + ≥ 2 jets

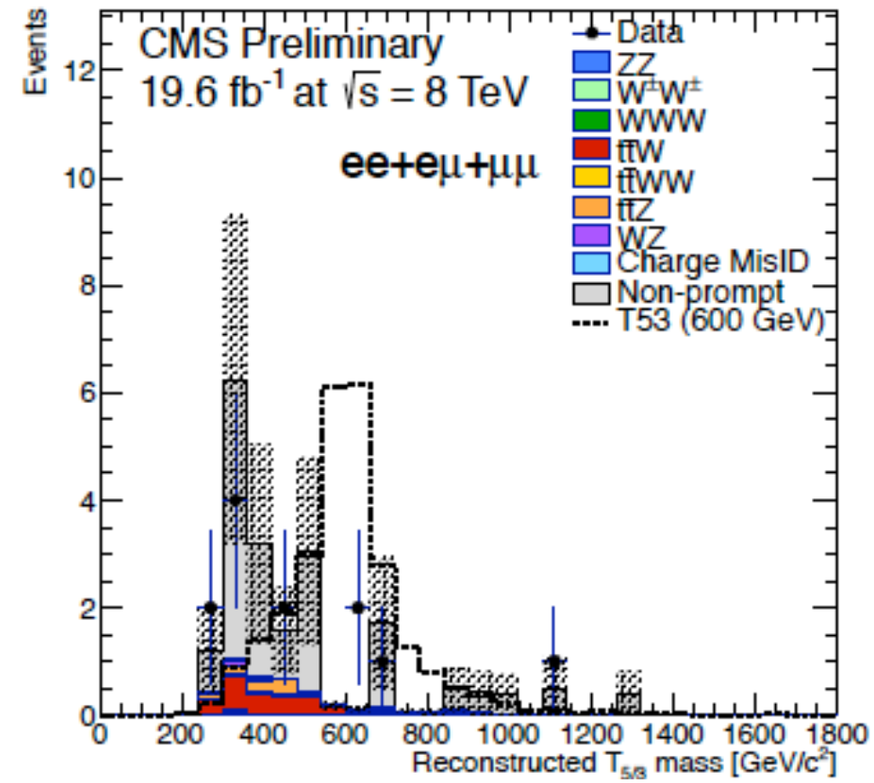
$T_{5/3}$ Top Partners

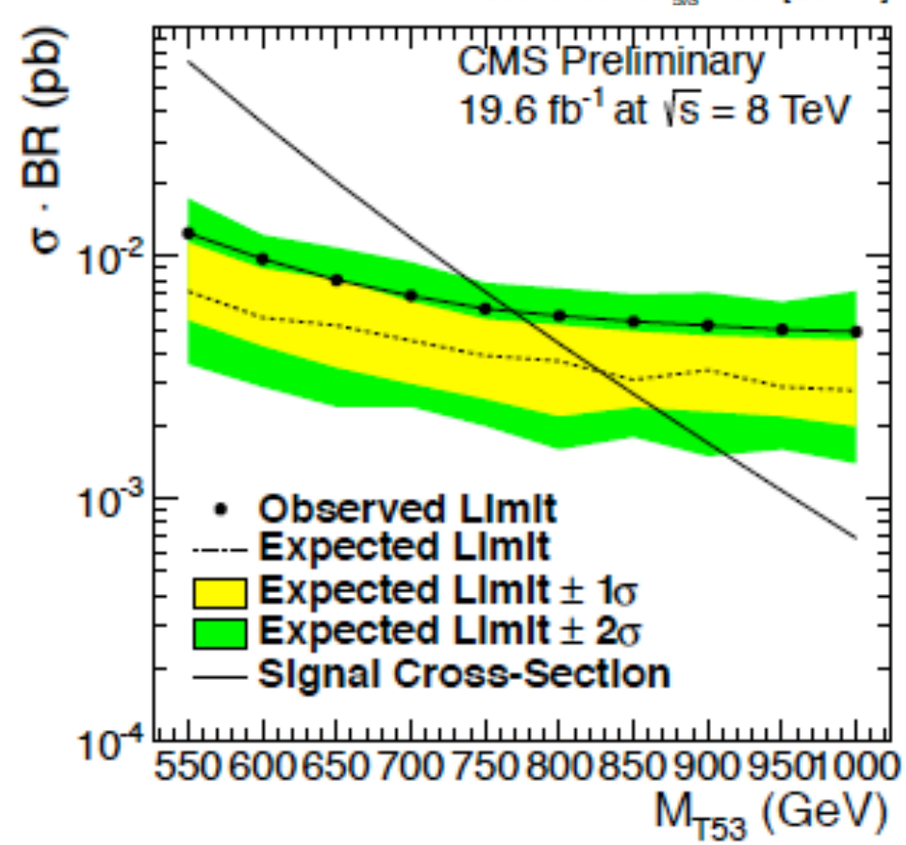
CMS-PAS-B2G-12-012

- **Strategy:** Mass reconstruction
- Backgrounds
  - Same-sign prompt leptons (WZ, ZZ, ttV, ttWW, $W^{\pm}W^{\pm}$)
  - Opposite sign prompt leptons with charge misidentification
  - Same sign non-prompt leptons (from heavy flavor or conversions)
- Systematic Uncertainty

Sample	JES	Pileup	Normalization	Trigger	Lepton Efficiency	Luminosity
WZ	6.6%	4.5%	17%	1.0%	1.0%	4.4%
ZZ	4.8%	2.4%	5.1%	1.0%	1.0%	4.4%
$W^{\pm}W^{\pm}$	3.0%	3.8%	50%	1.0%	1.0%	4.4%
WWW	4.1%	3.8%	50%	1.0%	1.0%	4.4%
$t\bar{t}$ W	4.4%	2.7%	32%	1.0%	1.0%	4.4%
$t\bar{t}$ Z	4.4%	3.4%	50%	1.0%	1.0%	4.4%
$t\bar{t}$ WW	4.7%	2.6%	50%	1.0%	1.0%	4.4%

Table 5: Systematic uncertainties for the background contributions that are obtained from simulation.



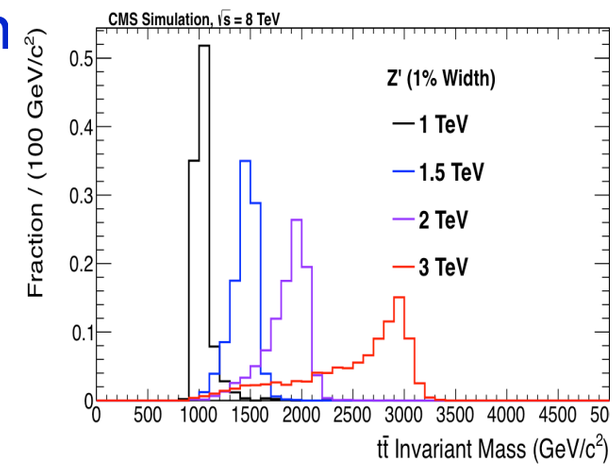


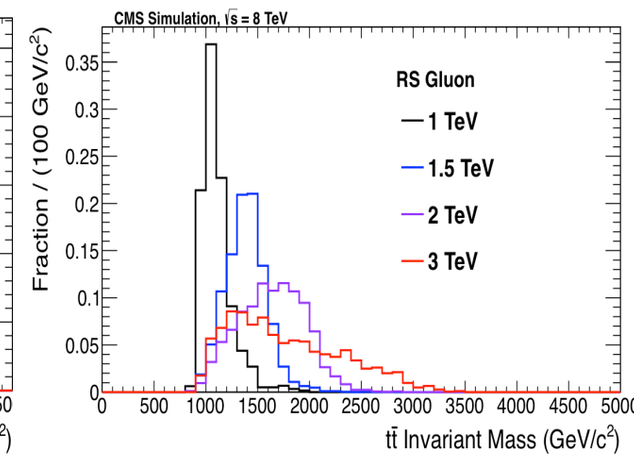
- Counting experiment
  - 6.9 ± 2.1 expected vs. 9 observed
  - Exclude the $T_{5/3}$ up to masses of 770 GeV

Top Pair $t\bar{t}$ Resonances (l+jets)

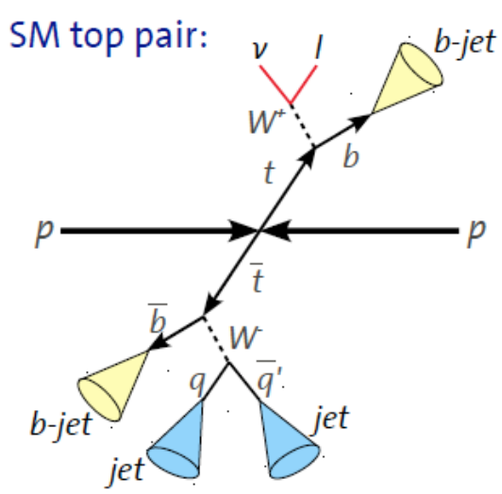
CMS-PAS-B2G-12-006

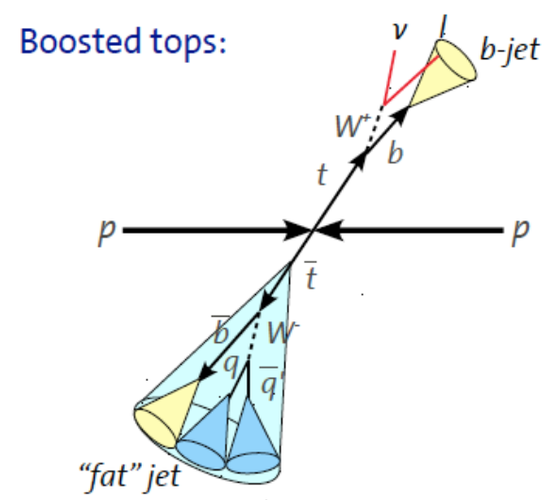
- Search for resonances in the m_{tt} spectrum
  - $Z' \rightarrow tt$:
    - Widths $\Gamma/m_{Z'}$ = 1%, 10%
  - RS KK gluon → tt:
    - Mass-dependent width





- **Two different analyses: threshold and boosted analysis**





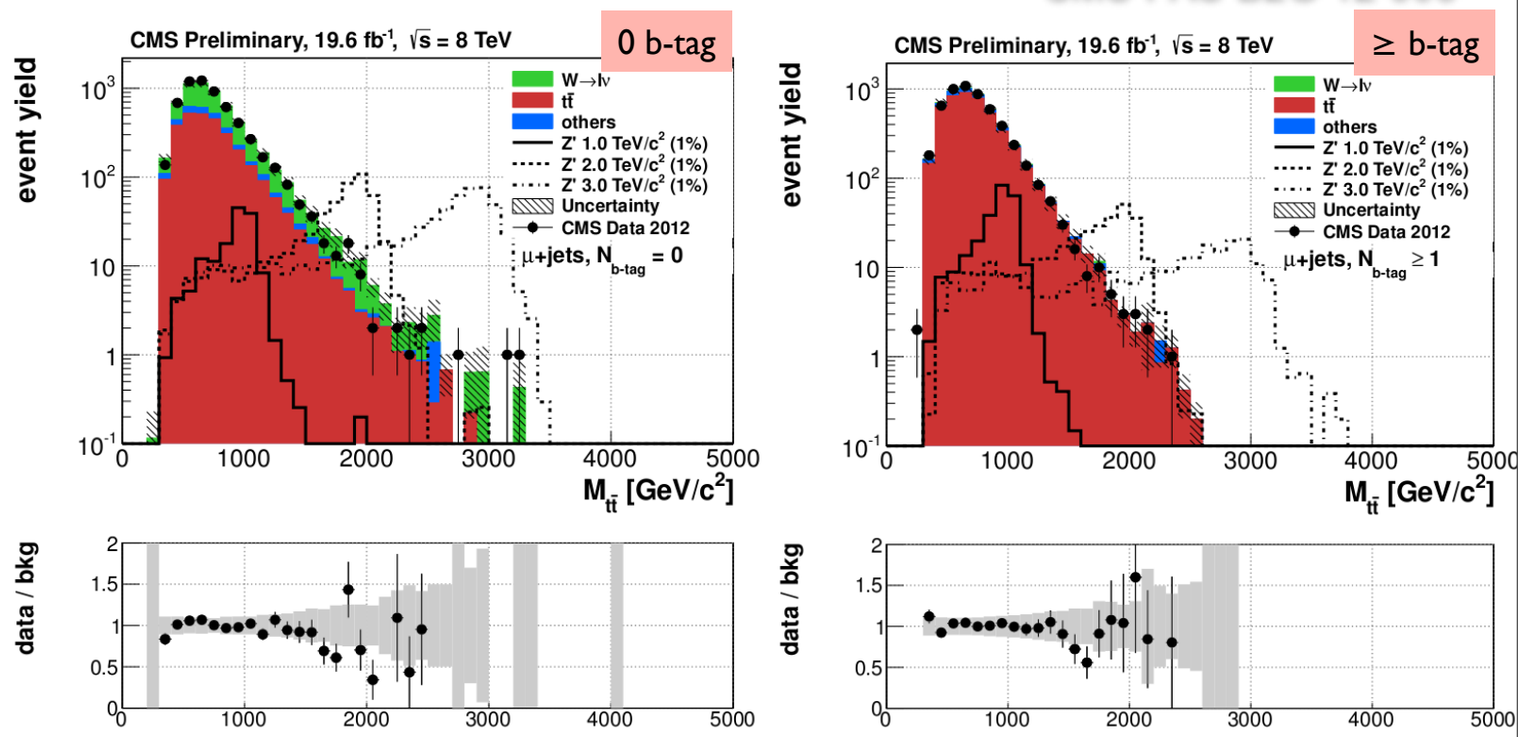
- One isolated charge lepton
- Missing E_T > 20 GeV
- ≥ 4 jets, ≥ 1b-tagged jet
  - 1st, 2nd, 3rd and 4th leading jet p_T>70, 50, 30, 30 GeV

- One (often non-isolated) lepton
- ≥ 2 jets, 0 or 1b-tagged jet
  - 1st and 2nd leading jet p_T>150, 50 GeV
  - Missing E_T > 50 GeV, H_T > 150 GeV

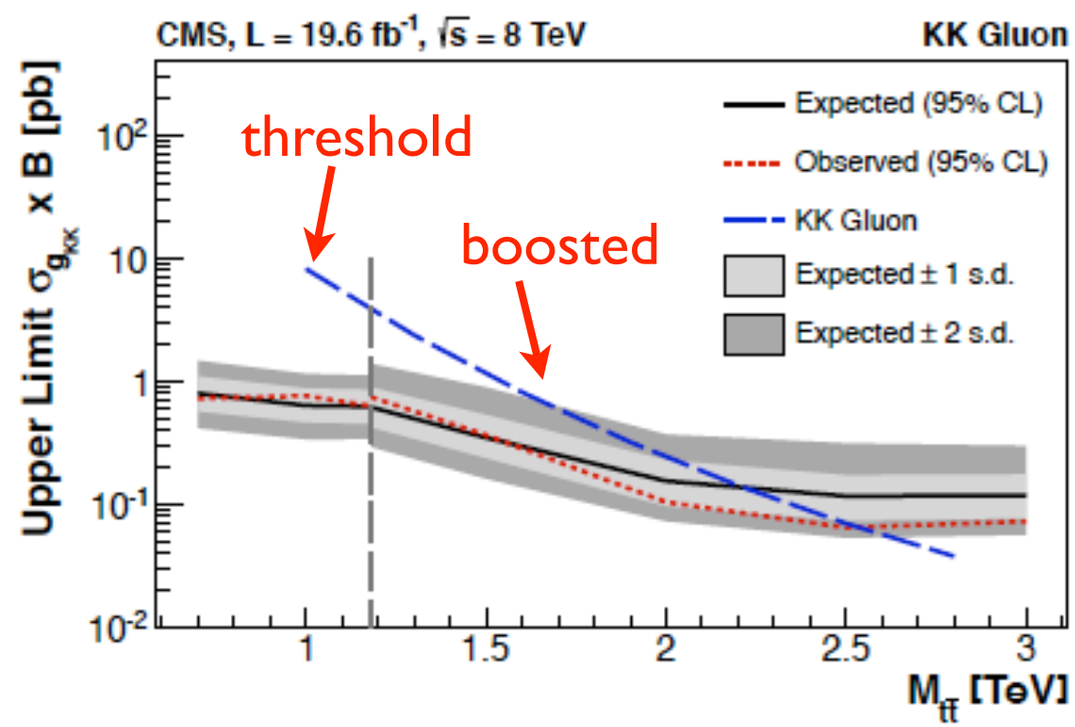
Top Pair Resonances (l+jets)

CMS-PAS-B2G-12-006

- **Strategy:** Mass reconstruction
  - Final discriminator used to set limits
    - 0 or ≥ 1b channel



- Transition region between threshold and boosted regimes at M ≈ 1 TeV
  - Corresponds to P_T(top) ≈ 350 GeV

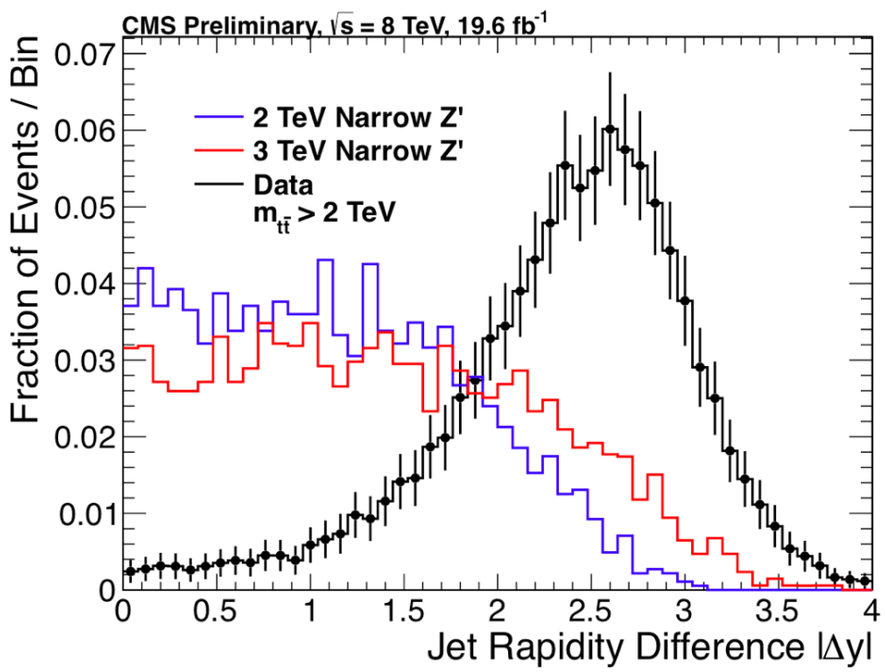


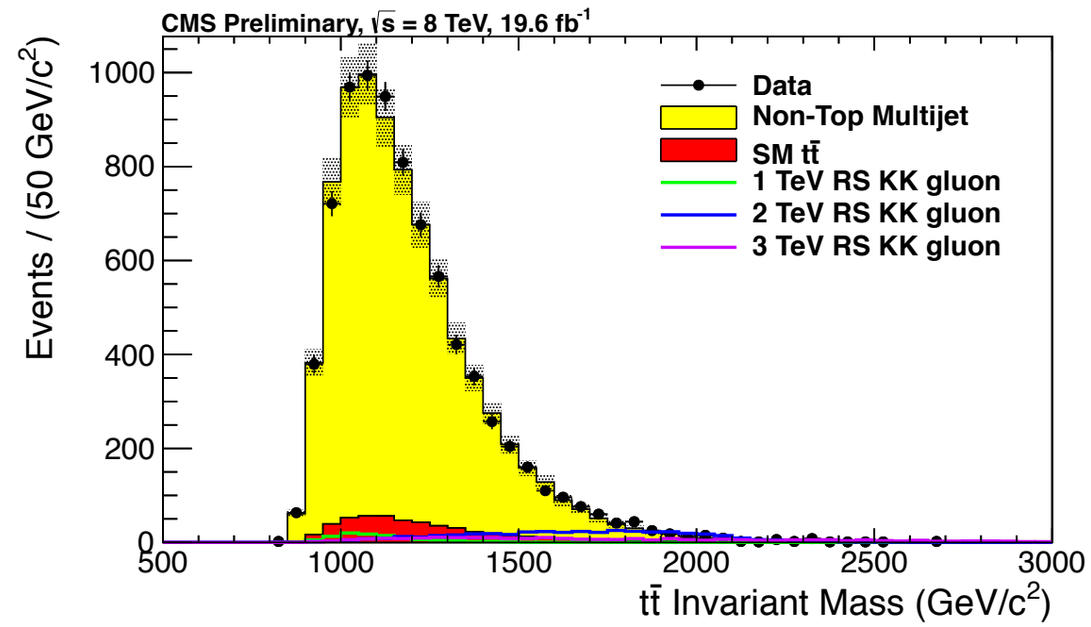
- Combined upper limits for narrow and wide resonances
  - Exclude gKK masses below 2.5 TeV
  - Exclude masses of narrow(wide) Z′ below 2.1(2.7) TeV

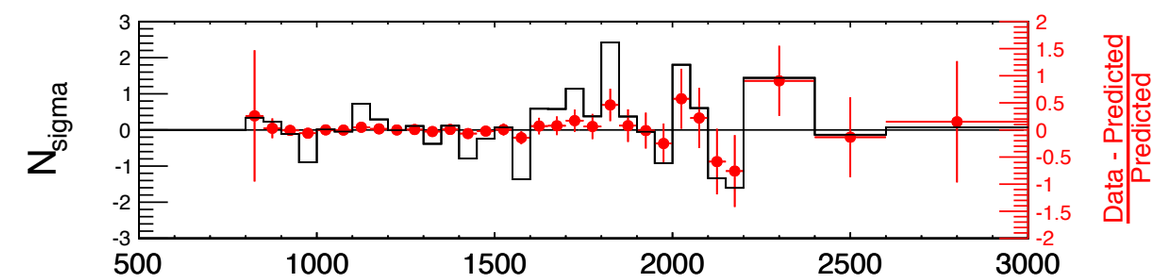
Top Pair Resonances(all hadronic)

CMS-PAS-B2G-12-005

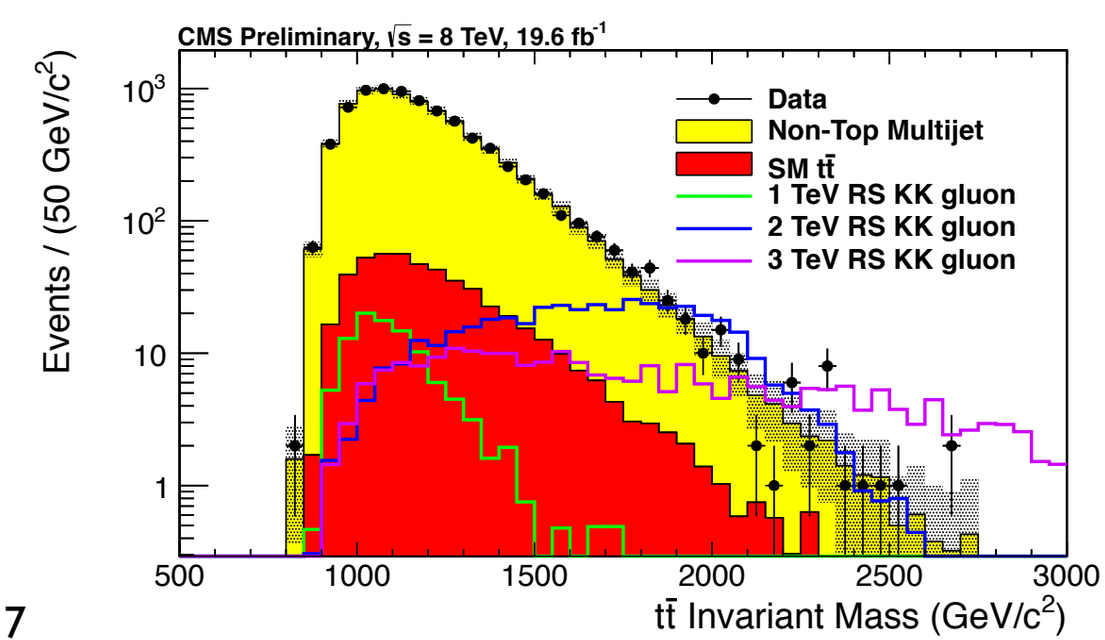
- CMS uses the JHU-based top tagger
- Dijet event topology
  - 2 jets p_T > 400 GeV
  - Rapidity separation $|\Delta y| < 1.0$
    - Enhances sensitivity at high mass







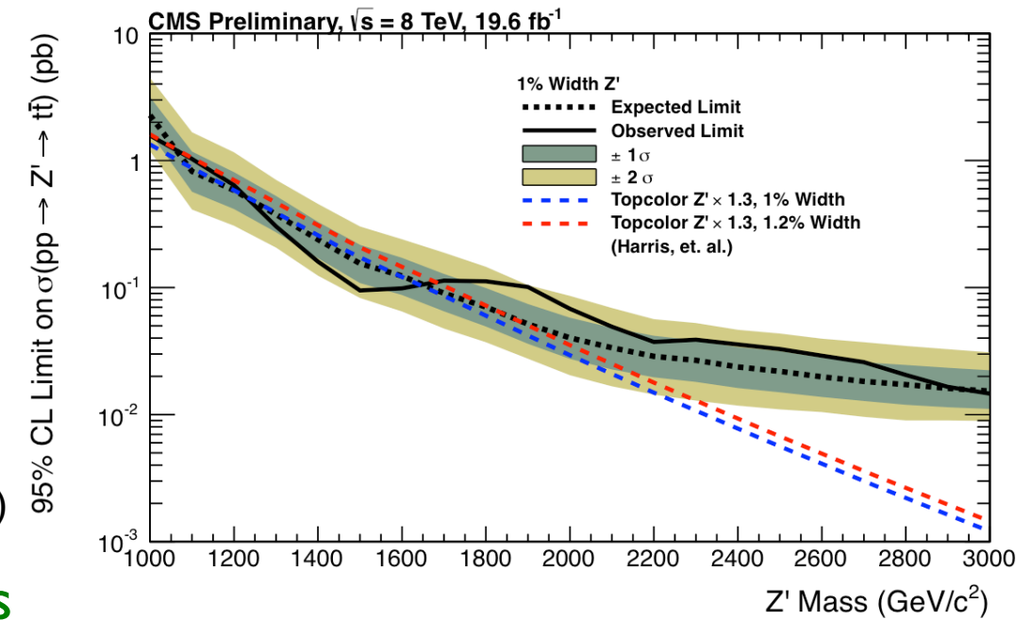
- Main background is multijet events
  - Determined from data using a mistag rate applied to loosened selection



Top Pair Resonances(all hadronic)

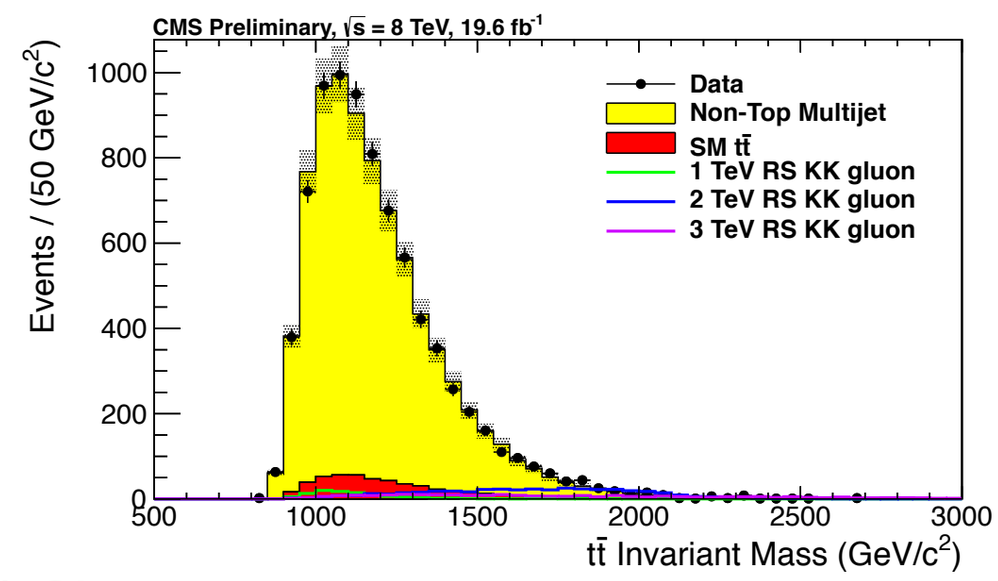
CMS-PAS-B2G-12-005

- Results
  - Narrow (1%) Z' exclusion to 1.65 TeV
  - Wide (10%) Z' exclusion to 2.35 TeV
  - RS KK gluon exclusion to 1.8 TeV



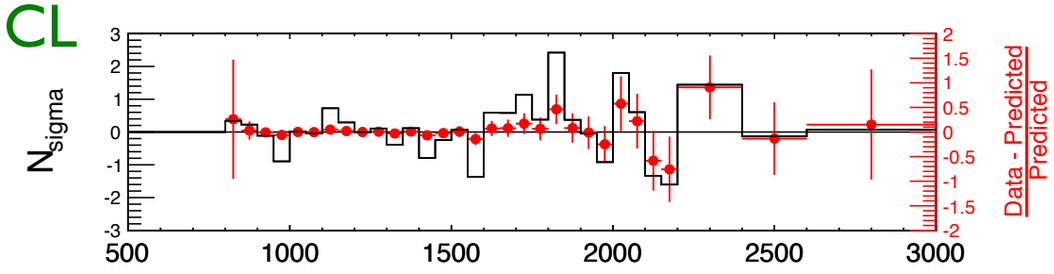
- Limit on general enhancement (arXiv:1103.2765)
  - use a simple counting experiment with events having m_{tt} > 1 TeV

Process	Events
SM $t\bar{t}$	507 ± 269
Non-Top Multijet	6602 ± 723
Total Background	7109 ± 771
Observed Data	6887
$t\bar{t}$ Efficiency	$(3.4 \pm 1.7) \cdot 10^{-4}$



- New result
  - set limit of ***S* < 1.79** (expect S < 2.29) at 95% CL

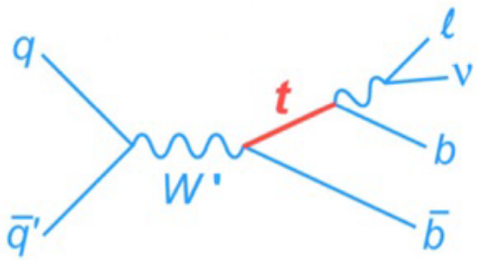
$$\mathcal{S} = \frac{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM+NP}}{dm_{t\bar{t}}} dm_{t\bar{t}}}{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM}}{dm_{t\bar{t}}} dm_{t\bar{t}}}$$



t+b resonance (W′→tb)

- Search for W′→tb in semiletopic channel

See talk by Thiago this morning → CMS-PAS-B2G-12-010

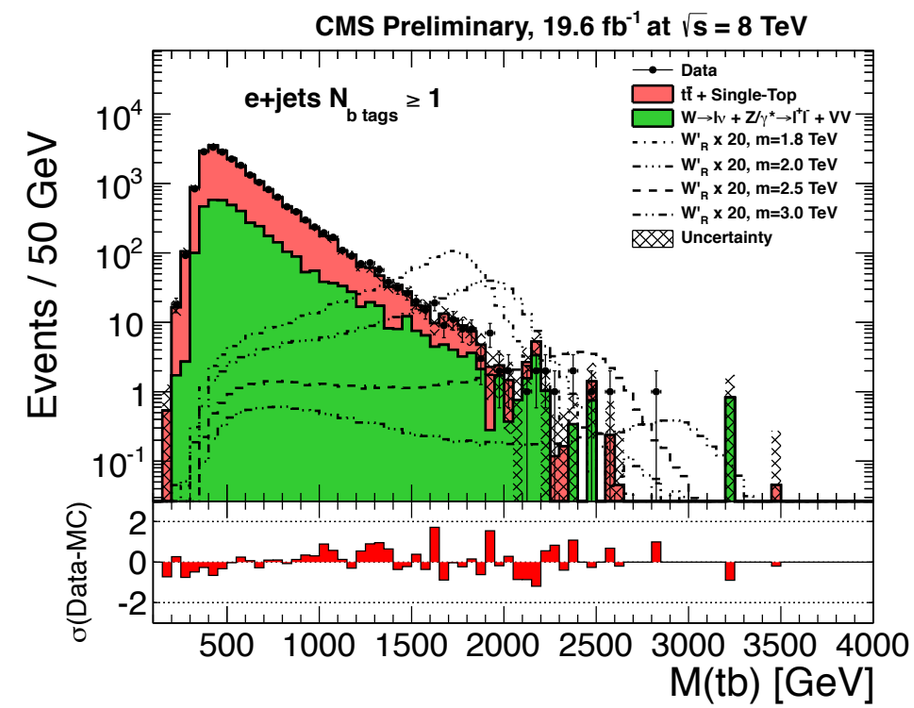


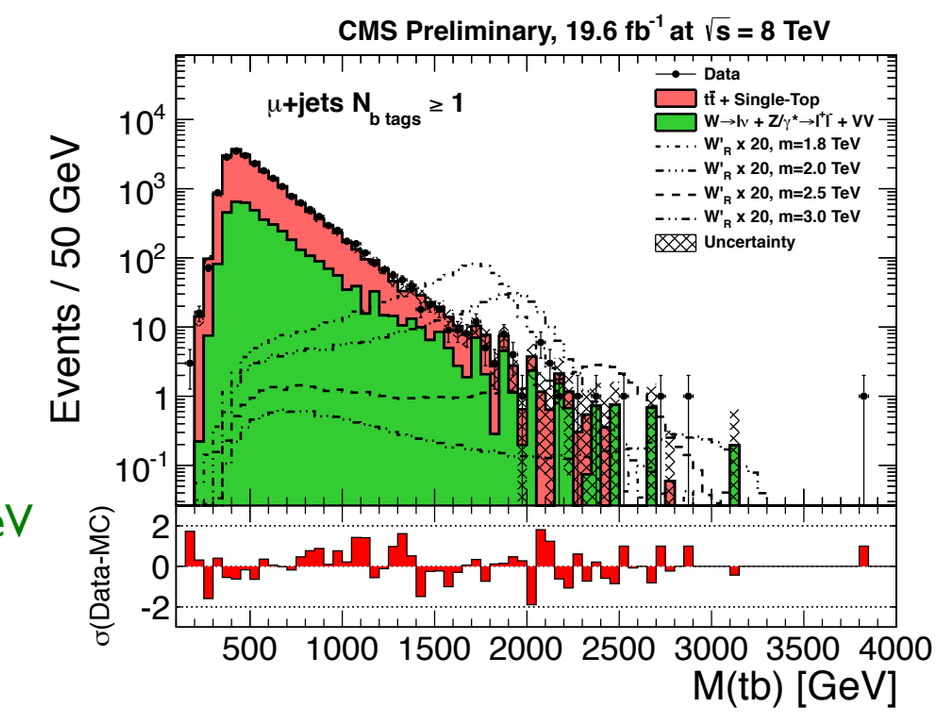
Complementary to W′→l ν

- An arbitrary combination of left- and right-handed couplings is allowed

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

- Event Selection
  - Isolated lepton(e/μ)
  - ≥2 jets with p_T > 120, 40GeV(≥1 b-jet)
  - Missing E_T > 20 GeV
- Mass reconstruction
  - m(l+ν) = m_W, m(j+l+ν) ↔m_{top}, m(top+another j)
- Additional selection
  - 130 < m_{top} < 210 GeV, p_T(top) > 85 GeV and $p_T(j_1, j_2)$ > 140 GeV
- Background modeling
  - Wjets: Shape from pre b-tag sample
  - ttbar: Data/MC ratio function for p_T(top) obtained from a ttbar enriched region and re-weight MC

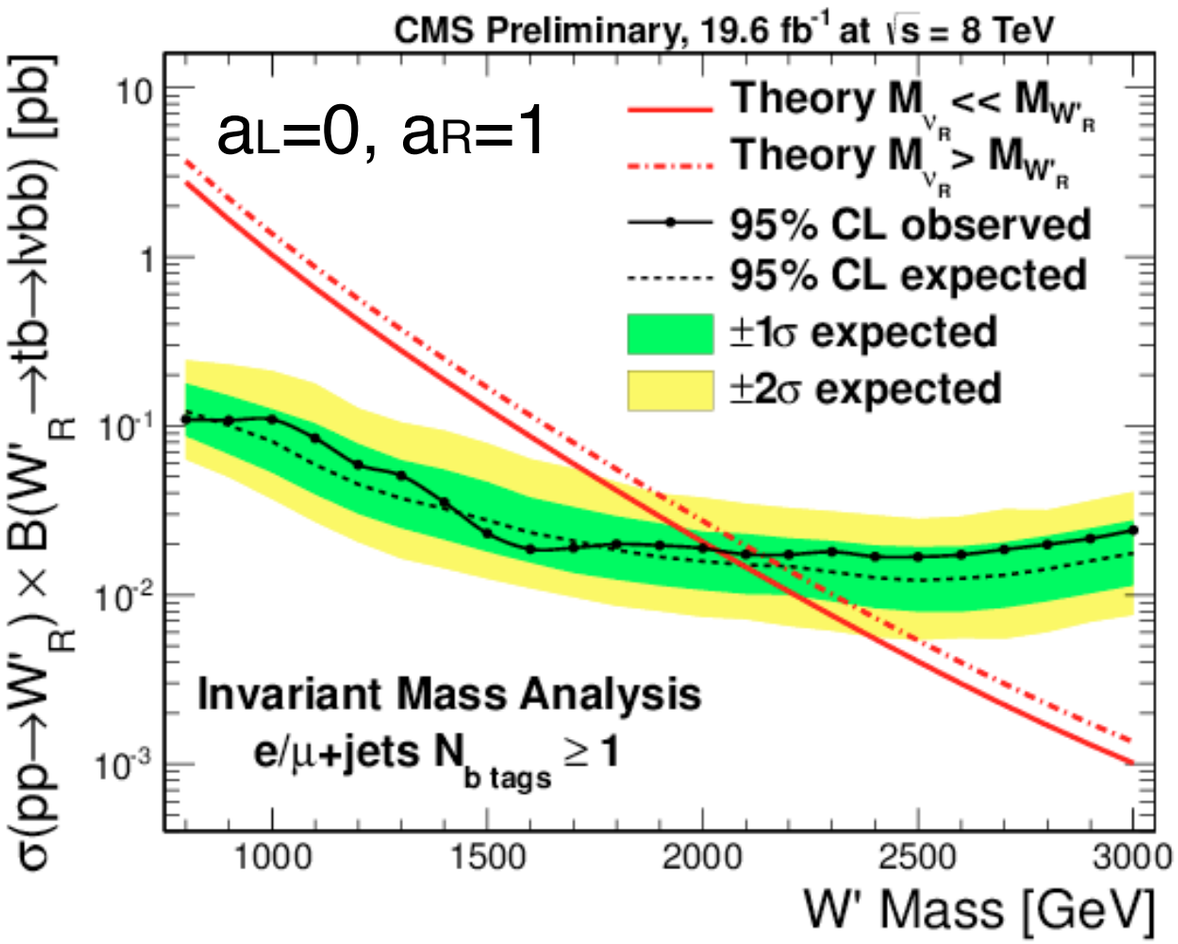


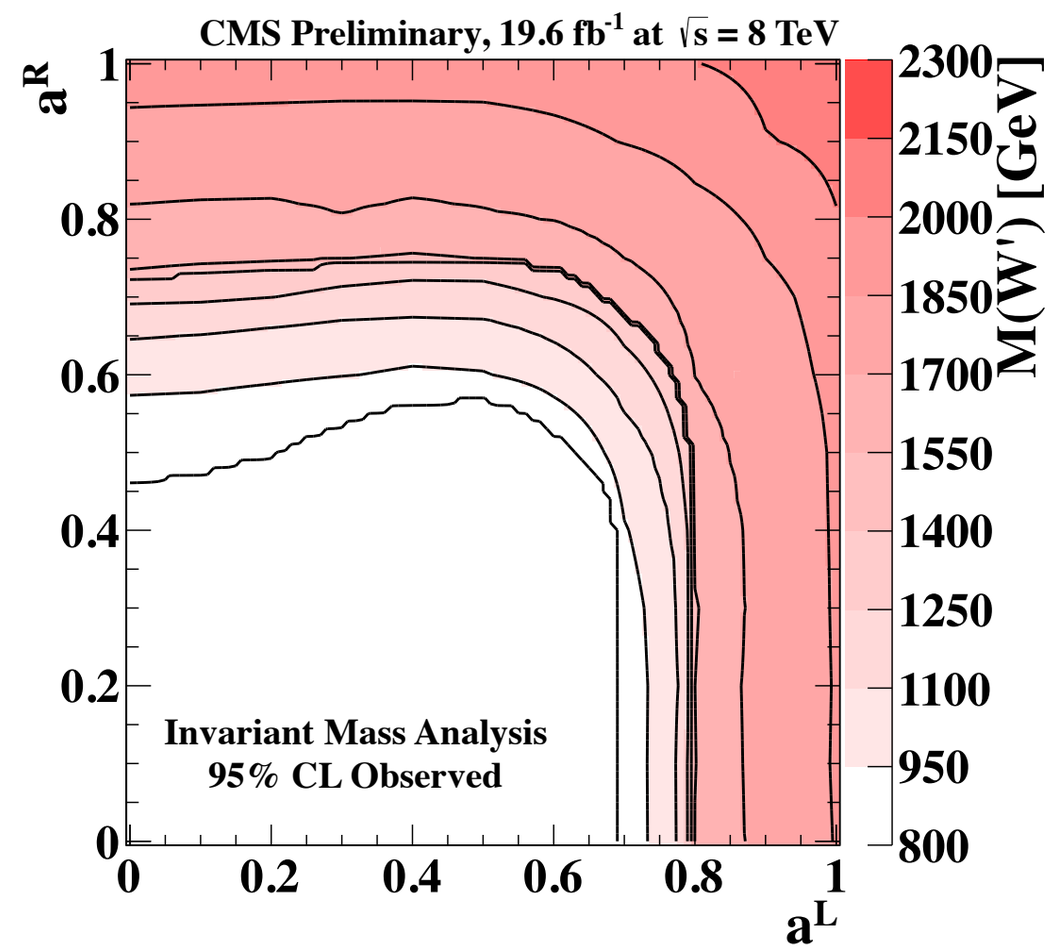


t+b resonance (W′→tb)

CMS-PAS-B2G-12-010

- For W′ bosons with right-handed couplings to fermions, we exclude masses below 2.03 TeV at 95% C.L.
- We also set limits on W′ masses for arbitrary left- and right-handed couplings

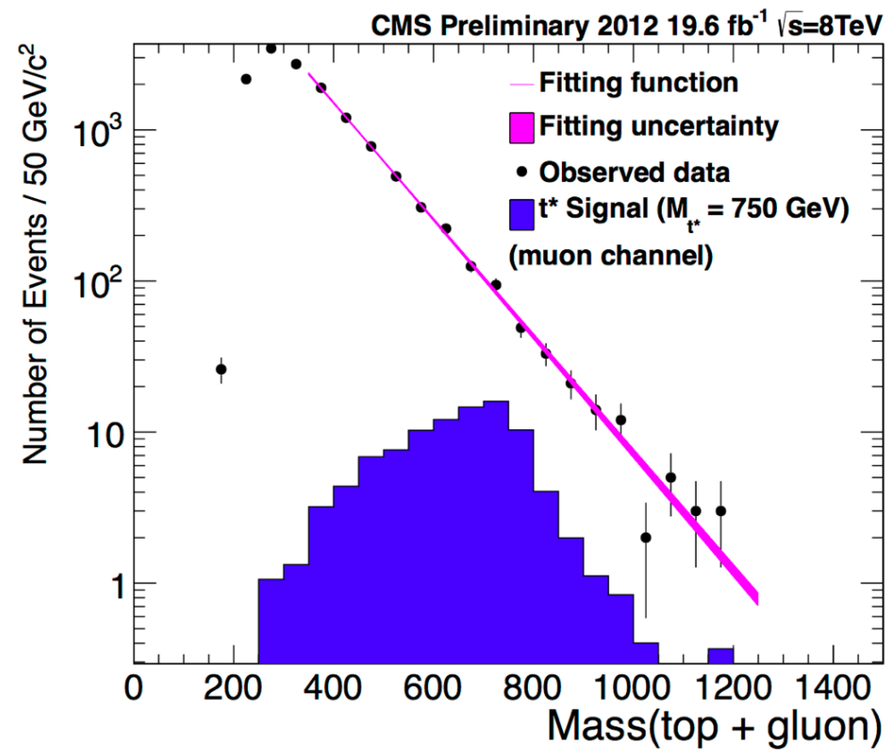


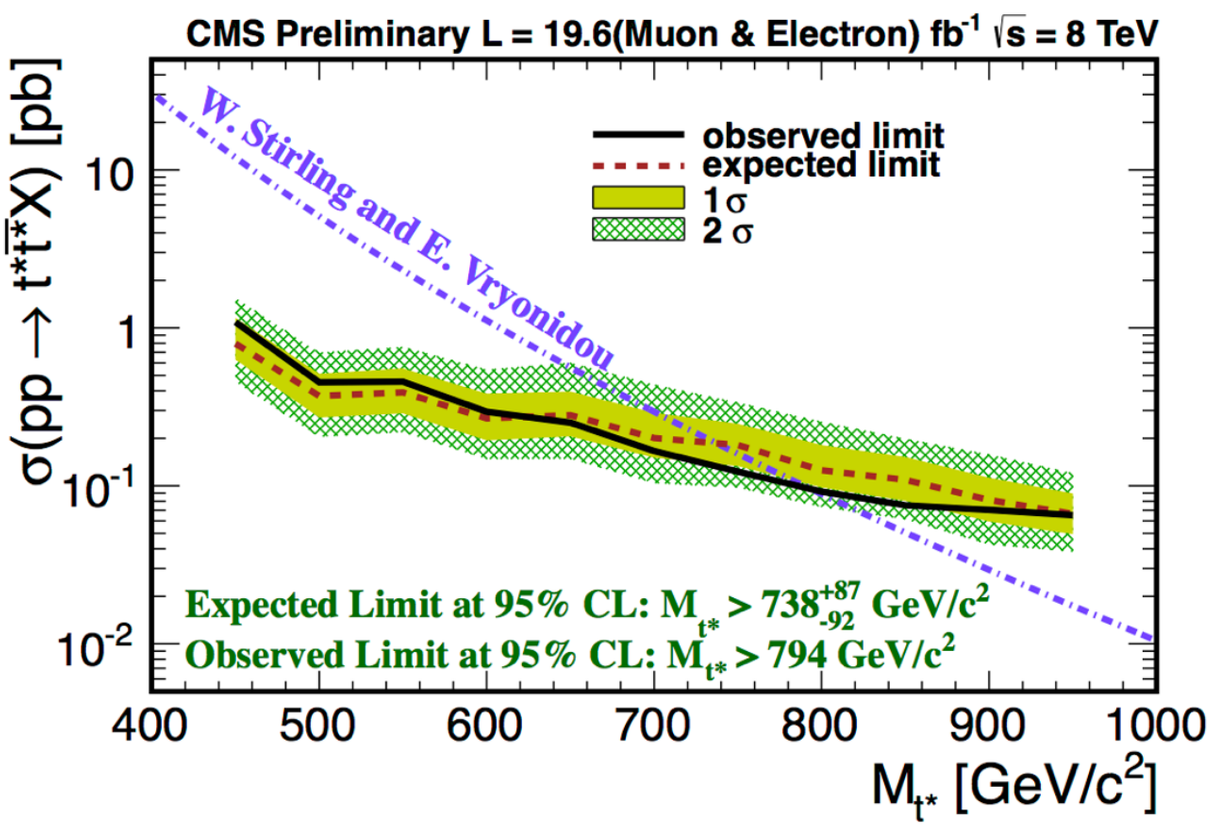


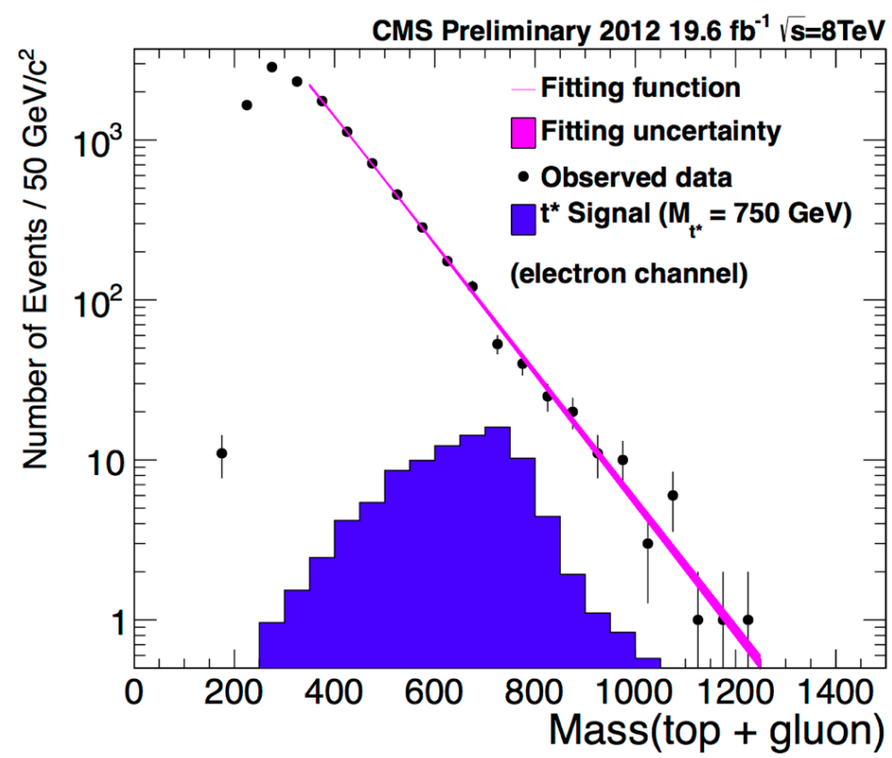
Excited Top Quarks

CMS-PAS-B2G-12-014

- Search for excited top quark $t^* \rightarrow t+g$
- Event Selection:
  - Isolated lepton(e/μ), missing E_T, ≥6 jets (1 b-jet)
- Kinematic constraints to reconstruct candidate t* mass
  - Distribution used in limit setting
- Exclude t* quarks > 794 GeV



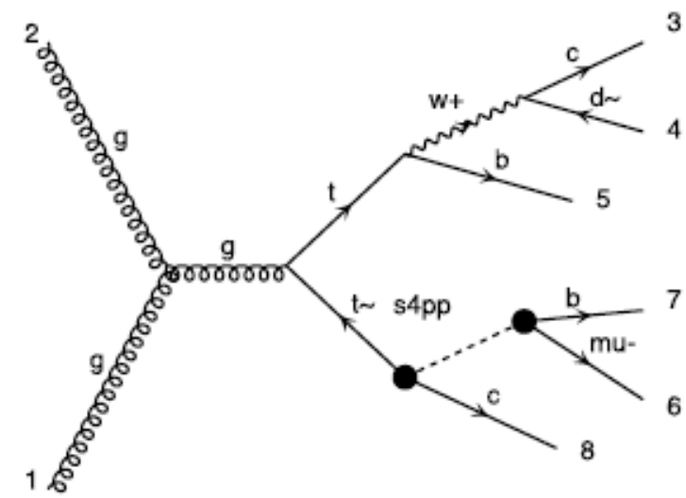




Baryon Number Violating Top

CMS-PAS-B2G-12-023

- Baryon number violation (BNV) : indication to new physics (SUSY, GUT, ...)
- Probing BNV in top-quark decay motivated by
  - Good identification of top events
  - Access to BNV at the quark level (before hadronization)
  - BNV at ~O(TeV) energy scale



$$pp \to t\bar{t} \to bW^{+}bc\mu^{-} \to bqq'bc\mu^{-}$$

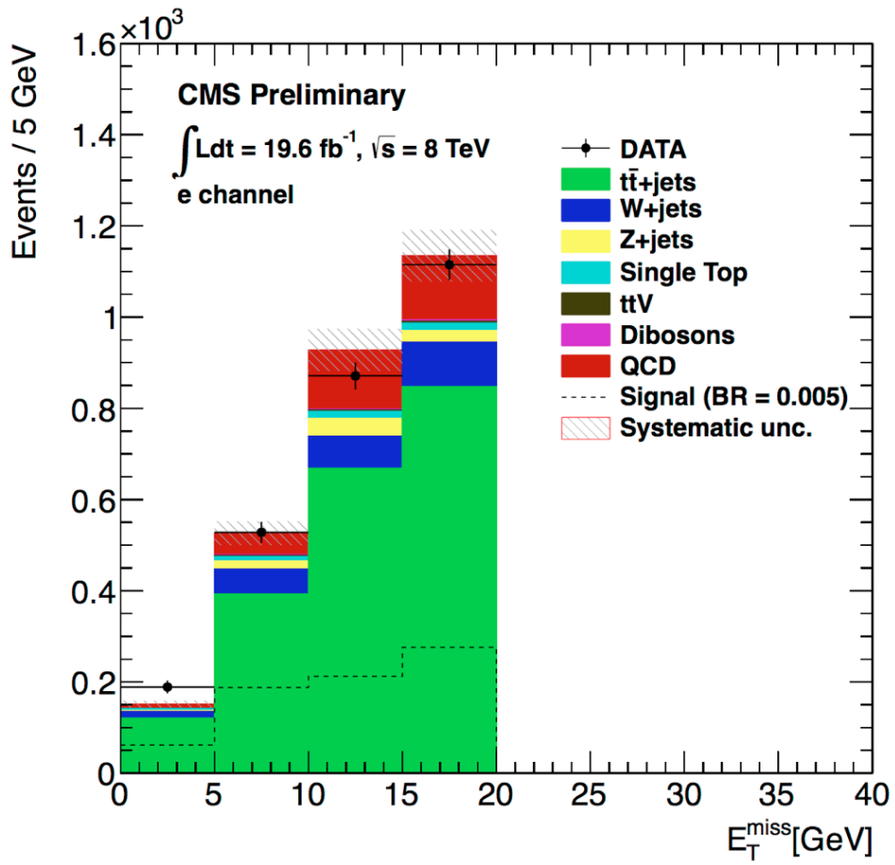
- Event Selection:
  - Isolated lepton(e/μ) with p_T>30(25) GeV
  - ≥5 jets p_T>30-70 GeV(1 b-jet)
  - Missing E_T < 20 GeV
  - Compatibility with SM-BNV ttbar decay

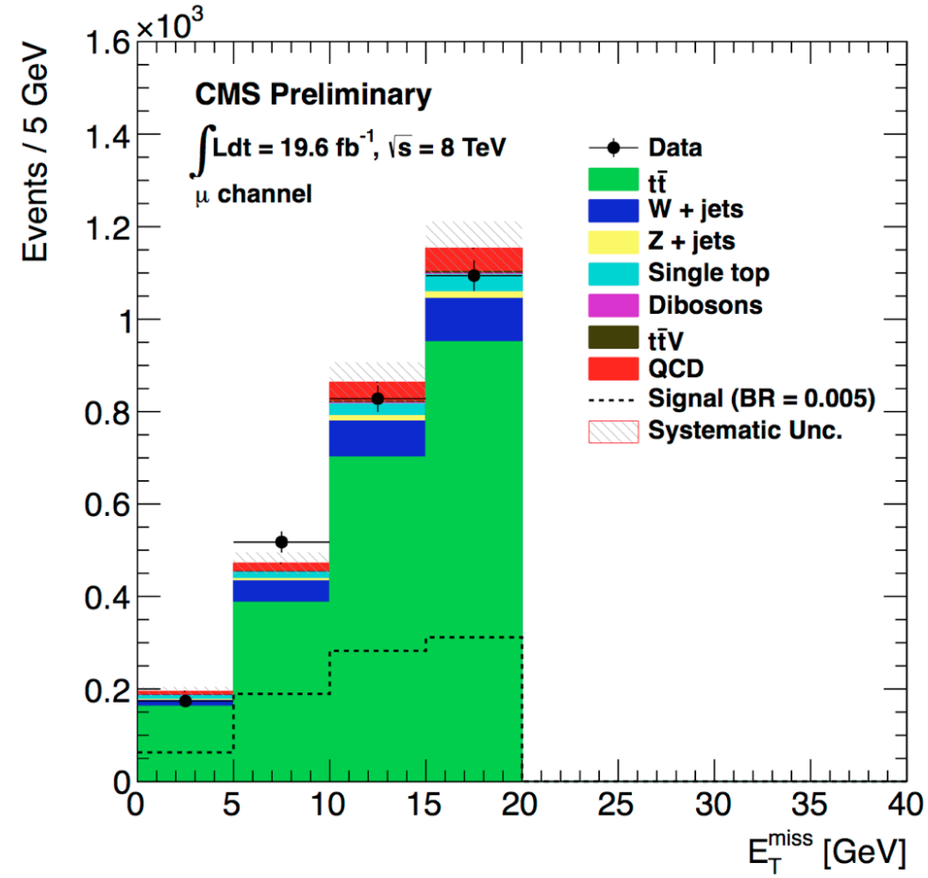
$$\chi^2 = \sum_i \frac{(x_i - \bar{x}_i)^2}{\sigma_i^2} \rightarrow \chi^2_{\min} < 20$$

- Strategy:
  - Look for BNV decay in tt events with a top→all-had decay
  - Enhance possible BNV decays of
    - **top→bcμ** or **top→bue**
  - Fix tt and Wt normalization using data
  - Likelihood fits to data after event selection with signal (BNV BR as a parameter) and background hypotheses

Baryon Number Violating Top

CMS-PAS-B2G-12-023





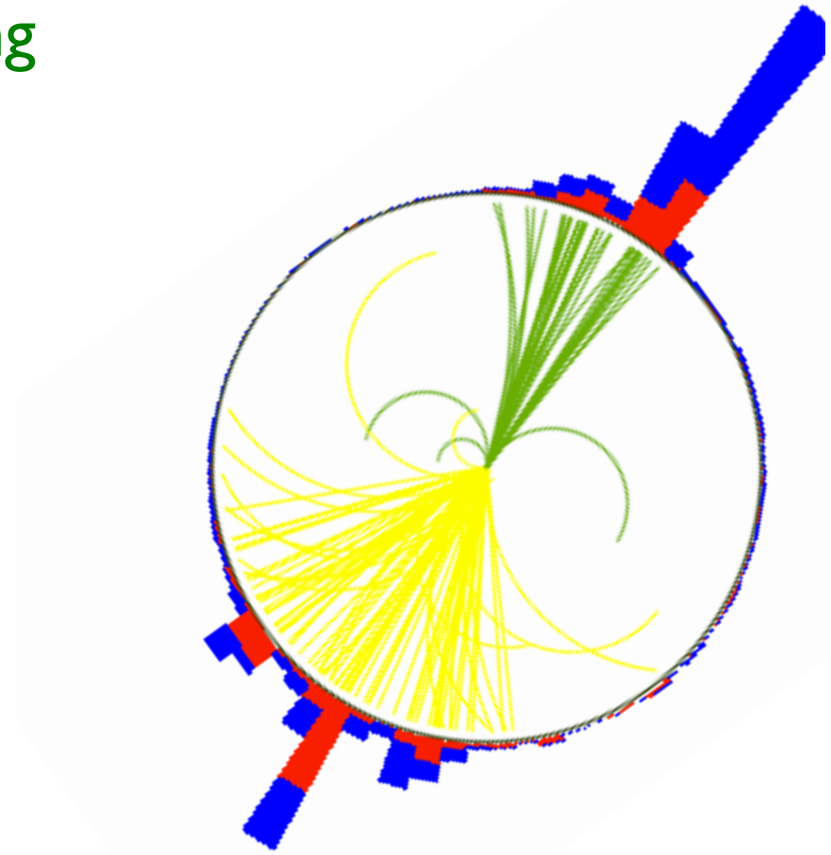
- Results: BF limits for BNV decay of top quarks into 1 lepton + 2 jets

	95%CL Obs. Limit	95%CL Exp. Limit	68%CL Exp. Limit Range
Muon	0.0016	0.0029	[0.0017, 0.0042]
Electron	0.0017	0.0031	[0.0018, 0.0045]
Combined	0.0015	0.0029	[0.0016, 0.0042]

Summary and Conclusions

- Many new analysis results related to top quark in final state from CMS are presented
  - Mass reach continues to increase, now setting multi-TeV scale exclusions!
  - We have reached the critical mass of ~650 GeV/c^2 at which fermion's weak interactions become non-perturbative

    M.S. Chanowitz, M.A. Furman, I. Hinchcliffe, Phys. Lett.B78, 285 (1978)



- These analyses benefit greatly from the use of substructure tools
  - Specialized reconstruction techniques to maintain sensitivity in the boosted regime
  - Will become even more critical during the next LHC run at higher energy!
- Many new results are awaited. Stay tuned!

Thank you

Backup

Status @ 7 TeV

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

- t´ pair search
  - lepton+jets channel $t'\bar{t'} \to WbW\bar{b} \to l\nu b\bar{b}q\bar{q}$ — PLB.2012.10.038, EXO-11-099
  - dilepton channel $t'\bar{t'} \to WbW\bar{b} \to l\nu bl\bar{\nu}\bar{b}$ — PLB.2012.07.959, EXO-11-050
- b´ search $b'\bar{b'} \to WtW\bar{t} \to bWWbWW$
  - lepton+jets channel — JHEP 01 (2013) 154, B2G-12-004
  - same sign dilepton + trilepton channel — JHEP05(2012)123
- Inclusive t´ and b´ search — Phys. Rev. D 86 (2012) 112003
  - singly produced
  - pair produced

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

- T vector like pair
  - lepton+jets $T\bar{T} \to tZ\bar{t}Z \to b\bar{b}WWZZ$ — JHEP 01 (2013) 154, B2G-12-004
  - trilepton channel — PRL.107.271802, EXO-11-005
- B vector-like pair $B\bar{B} \to bZ\bar{b}Z$ — CMS-PAS-EXO-11-066
- $T_{5/3}$ search $T^{5/3}T^{5/3} \to tWtW$ — CMS-PAS-EXO-12-003
- Baryon number violating top decays — CMS-PAS-B2G-12-002

Limits on Branching Fractions

$$max(B) = \sqrt{\frac{\max(\sigma)}{\langle\sigma\rangle}}$$

T mass	TT xsec	bW $max(\sigma)$	$max(B)$	tZ $max(\sigma)$	$max(B)$
400 GeV	1.406 pb	0.473 pb	0.58	0.48 pb	0.58
450 GeV	0.662 pb	0.246 pb	0.61	0.45 pb	0.82
500 GeV	0.330 pb	0.213 pb	0.80	0.48 pb	---
550 GeV	0.171 pb	0.148 pb	0.93	0.44 pb	---

PLB.2012.10.038, EXO-11-099

$t'\bar{t}' \rightarrow l + jets$

PRL.107.271802, EXO-11-005

$t'\bar{t}' \rightarrow trileptons$

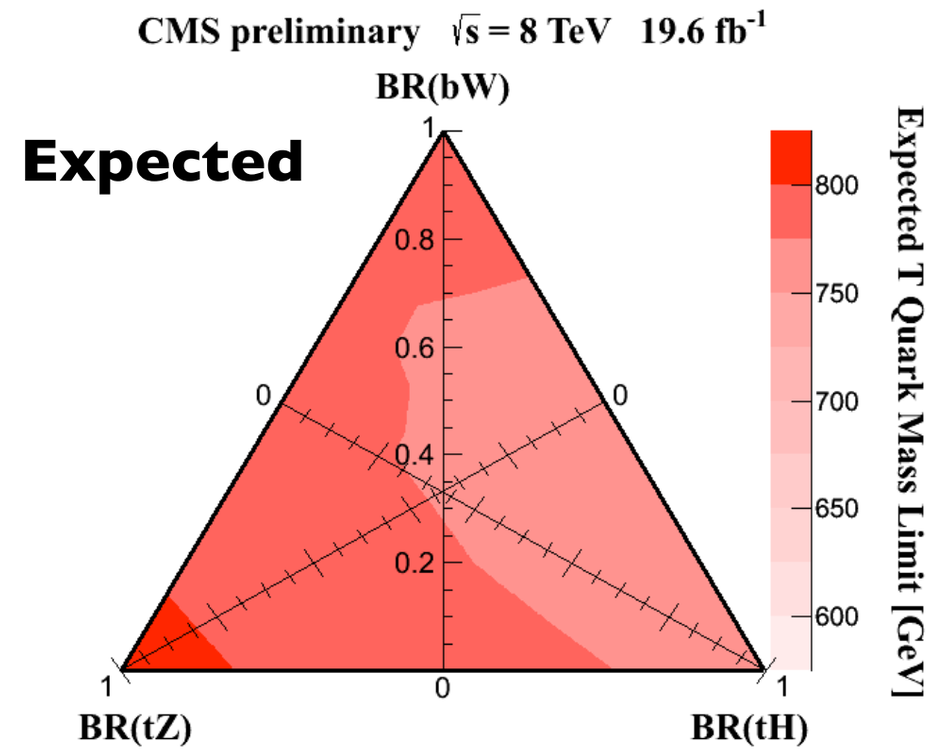
Inclusive vector-like T search

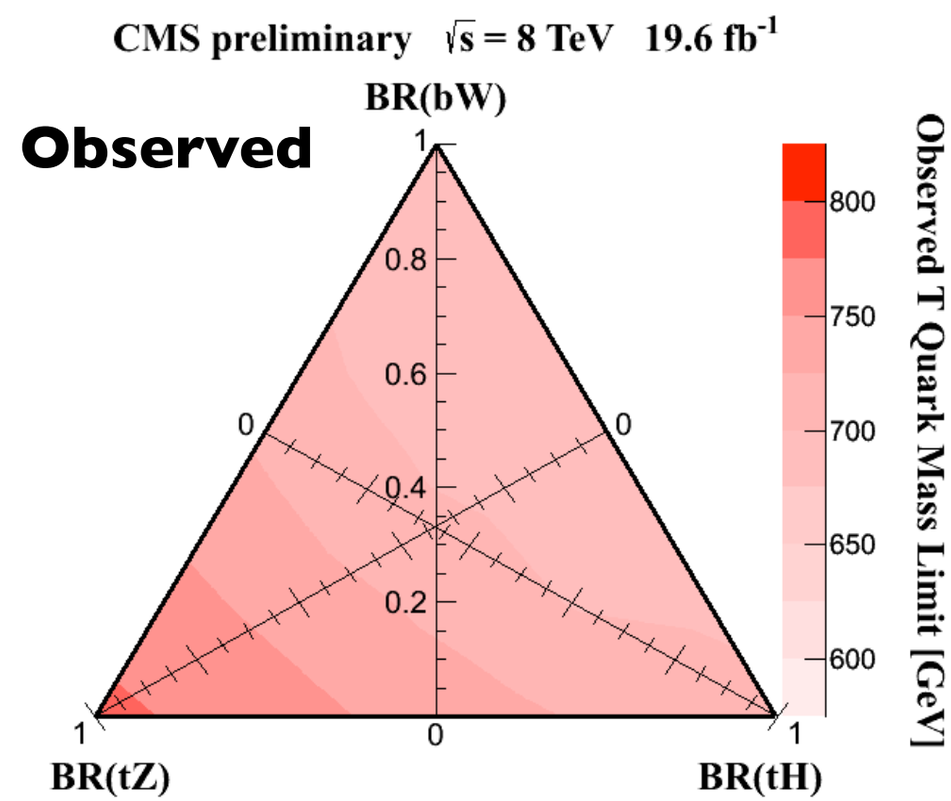
CMS-PAS-B2G-12-015

Combine limits

- For inclusive decay of T →bW, tZ, bH, a mass bound of [687, 782] GeV is set at 95% C.L for all possible branching fractions

Scenario	Branching Fractions T→bW	T→tH	T→tZ	expected limit (GeV)	observed limit (GeV)
(0)	0.5	0.25	0.25	773	696
(1)	0.0	0.0	1.0	813	782
(2)	0.0	0.2	0.8	798	766
(3)	0.0	0.4	0.6	790	747
(4)	0.0	0.6	0.4	783	731
(5)	0.0	0.8	0.2	773	715
(6)	0.0	1.0	0.0	770	706
(7)	0.2	0.0	0.8	794	758
(8)	0.2	0.2	0.6	786	739
(9)	0.2	0.4	0.4	777	717
(10)	0.2	0.6	0.2	767	698
(11)	0.2	0.8	0.0	766	694
(12)	0.4	0.0	0.6	786	734
(13)	0.4	0.2	0.4	776	705
(14)	0.4	0.4	0.2	766	693
(15)	0.4	0.6	0.0	762	690
(16)	0.6	0.0	0.4	779	703
(17)	0.6	0.2	0.2	771	693
(18)	0.6	0.4	0.0	769	687
(19)	0.8	0.0	0.2	779	695
(20)	0.8	0.2	0.0	777	689
(21)	1.0	0.0	0.0	785	700

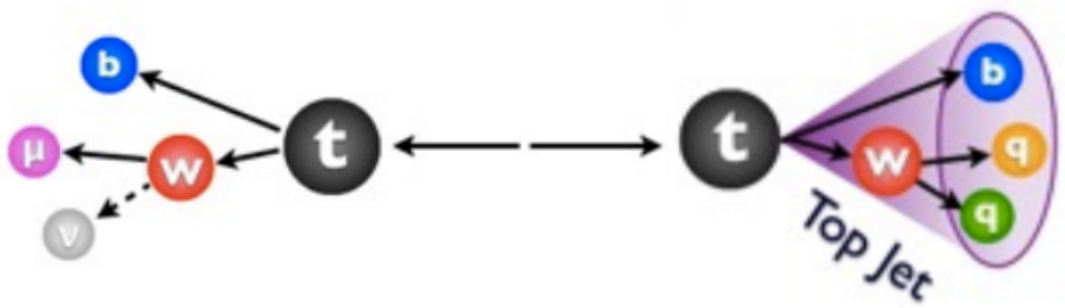


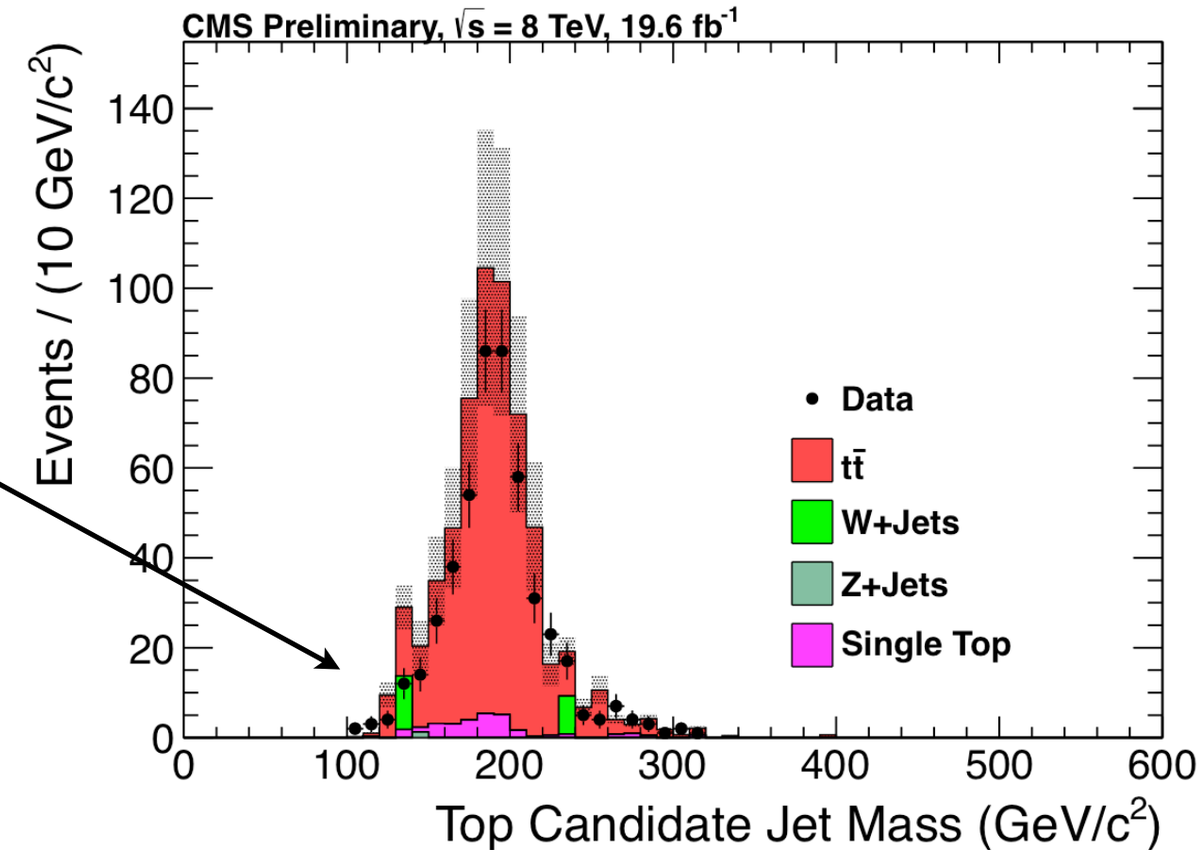


CMS Top Tagger

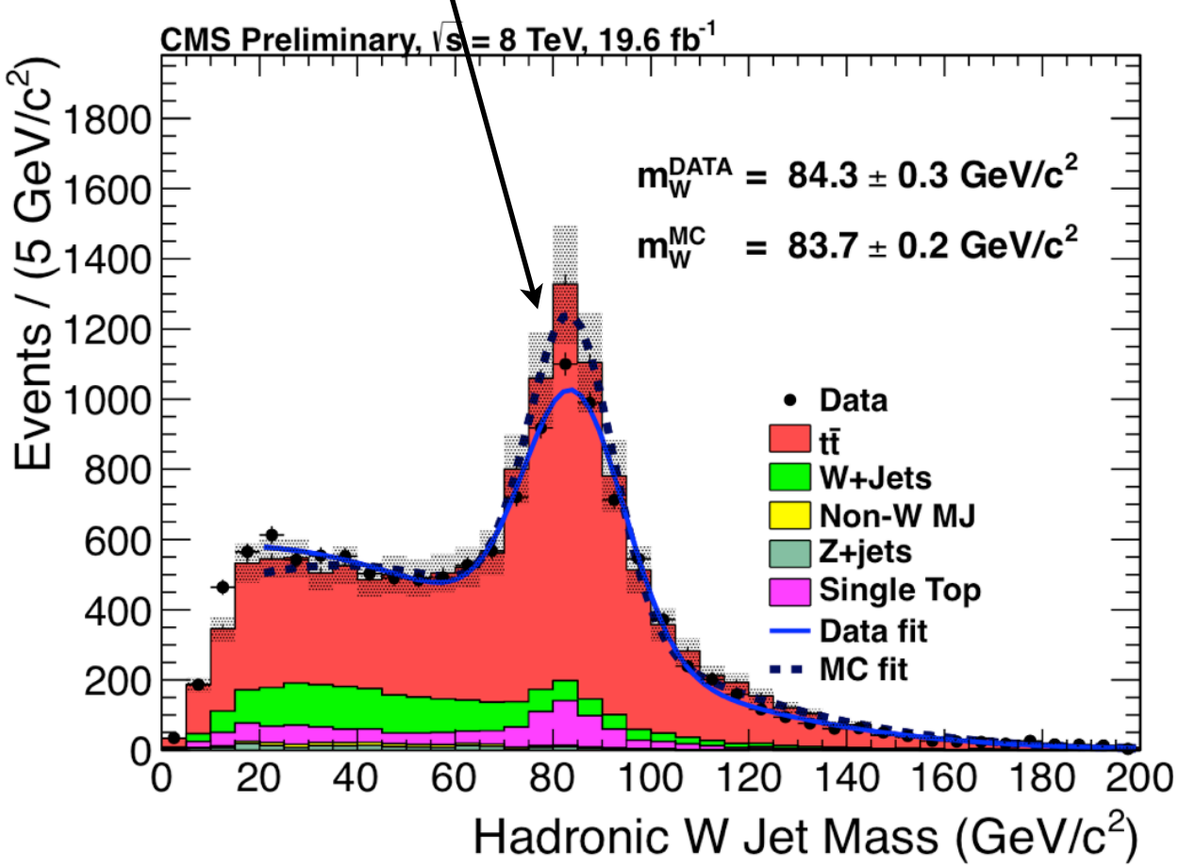
CMS-PAS-B2G-12-005

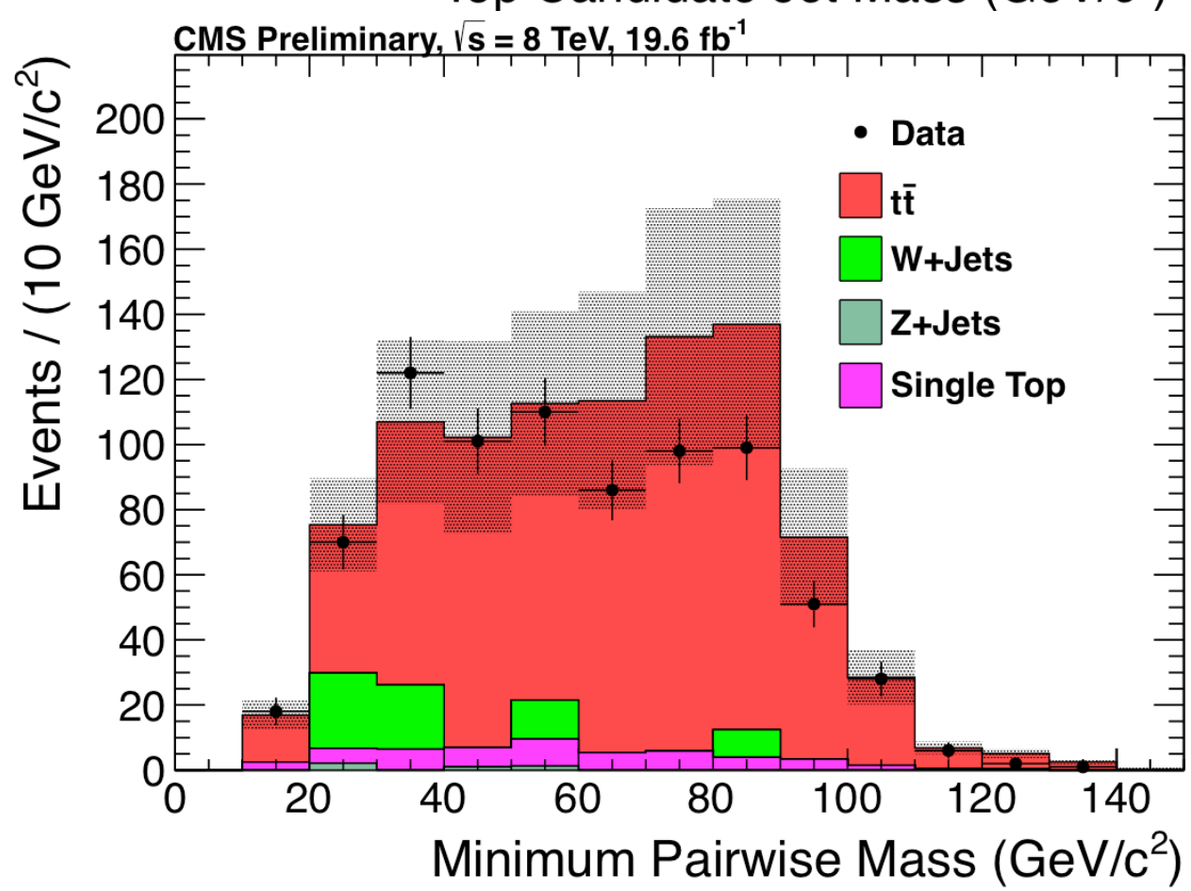
- Validated in a lepton+jets selection
  - Pure sample of $t\bar{t}$ events





- W mass peak serves as a calibration of the subjet energy scale





Top Pair Resonances(all hadronic)

CMS-PAS-B2G-12-005

	Process	$t\bar{t}$	NTMJ	RS KK gluon				
	Mass (TeV/c^2)			1	1.5	2	2.5	3
Systematic Source	**Variation**	**Effect of Systematic**						
Trigger Efficiency	2	2		2	2	2	2	2
Jet Energy Scale	$\sim \pm 5$	$^{+11}_{-15}$		$^{+15}_{-22}$	$^{+1.3}_{-3.5}$	$^{-4.5}_{-0.1}$	$^{-4.9}_{-0.1}$	$^{-3.0}_{-1.1}$
Jet Energy Resolution	$f(\eta)$			$^{-1.0}_{-0.3}$	$^{-0.4}_{+0.2}$	$^{-0.2}_{+0.3}$	$^{-0.4}_{+0.4}$	$^{-0.4}_{+0.3}$
Luminosity	± 4.4	4.4		4.4	4.4	4.4	4.4	4.4
Top Tagging Scale Factor	85.7 ± 7.8	8.4		8.4	8.4	8.4	8.4	8.4
NTMJ Determination	See Text		4.9					
NTMJ Closure Test	See Text		$^{+10.8}_{-8.7}$					
$t\bar{t}$ Cross Section	± 50	50						

	Process	Z′ (1% Width)				Z′ (10% Width)			
	Mass (TeV/c^2)	1	1.5	2	3	1	1.5	2	3
Systematic Source	**Variation**	**Effect of Systematic**							
Trigger Efficiency	2	2	2	2	2	2	2	2	2
Jet Energy Scale	$\sim \pm 5$	$^{+23}_{-26}$	$^{-1.9}_{-2.2}$	$^{-7.9}_{+2.4}$	$^{-14}_{+8.6}$	$^{+19}_{-23}$	$^{-0.9}_{-3.4}$	$^{-5.2}_{+2.1}$	$^{-7.5}_{+3.7}$
Jet Energy Resolution	$f(\eta)$	$^{+0.5}_{-0.1}$	$^{-0.3}_{+0.1}$	$^{-0.3}_{+0.1}$	$^{-0.5}_{+0.5}$	$^{+0.3}_{+0.1}$	$^{+0.0}_{+0.1}$	$^{-0.3}_{+0.2}$	$^{-0.4}_{+0.2}$
Luminosity	± 4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Top Tagging Scale Factor	85.7 ± 7.8	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
NTMJ Determination	See Text								
NTMJ Closure Test	See Text								
$t\bar{t}$ Cross Section	± 50								

B´ search with multileptons

CMS-PAS-SUS-12-027

- Event counts for 4 leptons

			0-τ, 0-b		1-τ, 0-b		0-τ, 1 + b		1-τ, 1 + b	
N_{OSSF}	onZ	S_T(GeV)	obs	exp	obs	exp	obs	exp	obs	exp
0	-	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$1000 < S_T < 1500$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$600 < S_T < 1000$ GeV	0	0 ± 0.009	0	0.01 ± 0.01	0	0.01 ± 0.02	0	0 ± 0.009
0	-	$300 < S_T < 600$ GeV	0	0.009 ± 0.01	0	0.6 ± 0.5	0	0.0007 ± 0.009	0	0.11 ± 0.07
0	-	$0 < S_T < 300$ GeV	0	0.004 ± 0.009	2	0.16 ± 0.08	0	0.0002 ± 0.009	0	0.14 ± 0.09
1	offZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
1	onZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
1	offZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0.007 ± 0.01	0	0 ± 0.009	0	0 ± 0.009
1	onZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0.01 ± 0.01	0	0.009 ± 0.01	0	0 ± 0.009
1	offZ	$1000 < S_T < 1500$ GeV	0	0.001 ± 0.009	0	0.06 ± 0.03	0	0.01 ± 0.01	0	0.001 ± 0.009
1	onZ	$1000 < S_T < 1500$ GeV	0	0.03 ± 0.02	0	0.05 ± 0.03	0	0.06 ± 0.04	0	0.02 ± 0.02
1	offZ	$600 < S_T < 1000$ GeV	0	0.02 ± 0.02	2	0.15 ± 0.05	0	0.03 ± 0.02	0	0.09 ± 0.05
1	onZ	$600 < S_T < 1000$ GeV	0	0.18 ± 0.06	0	0.7 ± 0.13	0	0.22 ± 0.13	0	0.32 ± 0.14
1	offZ	$300 < S_T < 600$ GeV	0	0.07 ± 0.02	1	0.7 ± 0.15	0	0.1 ± 0.06	0	0.47 ± 0.21
1	onZ	$300 < S_T < 600$ GeV	2	0.6 ± 0.17	5	4.7 ± 0.7	0	0.47 ± 0.25	1	0.7 ± 0.23
1	offZ	$0 < S_T < 300$ GeV	1	0.17 ± 0.05	9	4 ± 1.2	0	0.009 ± 0.01	0	0.19 ± 0.11
1	onZ	$0 < S_T < 300$ GeV	0	1.2 ± 0.38	18	18 ± 5.2	2	0.02 ± 0.02	2	0.37 ± 0.17
2	offZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$S_T > 2000$ GeV	0	0.001 ± 0.009	0	0 ± 0	0	0.01 ± 0.01	0	0 ± 0
2	offZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$1500 < S_T < 2000$ GeV	0	0.02 ± 0.01	0	0 ± 0	0	0.002 ± 0.009	0	0 ± 0
2	offZ	$1000 < S_T < 1500$ GeV	0	0.004 ± 0.01	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$1000 < S_T < 1500$ GeV	0	0.27 ± 0.06	0	0 ± 0	0	0.04 ± 0.02	0	0 ± 0
2	offZ	$600 < S_T < 1000$ GeV	0	0.04 ± 0.01	0	0 ± 0	0	0.04 ± 0.02	0	0 ± 0
2	onZ	$600 < S_T < 1000$ GeV	1	2.6 ± 0.5	0	0 ± 0	1	0.45 ± 0.14	0	0 ± 0
2	offZ	$300 < S_T < 600$ GeV	1	0.46 ± 0.1	0	0 ± 0	1	0.1 ± 0.06	0	0 ± 0
2	onZ	$300 < S_T < 600$ GeV	10	19 ± 3.8	0	0 ± 0	2	1.4 ± 0.39	0	0 ± 0
2	offZ	$0 < S_T < 300$ GeV	4	3.4 ± 0.9	0	0 ± 0	0	0.07 ± 0.03	0	0 ± 0
2	onZ	$0 < S_T < 300$ GeV	68	56 ± 13	0	0 ± 0	1	0.44 ± 0.12	0	0 ± 0
Total4	All	All	87	84 ± 19	37	29 ± 6.9	7	3.6 ± 1.1	3	2.5 ± 0.7

B´ search with multileptons

CMS-PAS-SUS-12-027

- Event counts for 3 leptons

			0-τ, 0-b		1-τ, 0-b		0-τ, 1 + b		1-τ, 1 + b	
N_{OSSF}	OSSF Mass	S_T(GeV)	obs	exp	obs	exp	obs	exp	obs	exp
0	-	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.2	0	0 ± 0.01	0	0 ± 0.2
0	-	$1500 < S_T < 2000$ GeV	0	0.01 ± 0.01	0	0.003 ± 0.2	0	0 ± 0.01	0	0.5 ± 0.48
0	-	$1000 < S_T < 1500$ GeV	0	0.07 ± 0.03	0	0.4 ± 0.22	0	0.6 ± 0.5	2	1.3 ± 0.9
0	-	$600 < S_T < 1000$ GeV	2	2.1 ± 1.2	17	9 ± 3.5	1	3.3 ± 1.6	23	20 ± 10
0	-	$300 < S_T < 600$ GeV	14	13 ± 5.7	129	134 ± 53	20	16 ± 6.5	206	186 ± 98
0	-	$0 < S_T < 300$ GeV	30	37 ± 10	555	581 ± 130	22	13 ± 5.9	150	150 ± 72
1	$m_{\ell^+\ell^-} > 105$ GeV	$S_T > 2000$ GeV	0	0.0005 ± 0.01	0	0 ± 0.2	0	0 ± 0.03	0	0 ± 0.2
1	$m_{\ell^+\ell^-} < 75$ GeV	$S_T > 2000$ GeV	0	0.002 ± 0.01	0	0 ± 0.2	0	0 ± 0.03	0	0 ± 0.2
1	onZ	$S_T > 2000$ GeV	0	0.12 ± 0.04	0	0.005 ± 0.2	0	0.01 ± 0.04	0	0 ± 0.2
1	$m_{\ell^+\ell^-} > 105$ GeV	$1500 < S_T < 2000$ GeV	0	0.08 ± 0.04	0	0.2 ± 0.2	0	0.06 ± 0.04	0	0.05 ± 0.05
1	$m_{\ell^+\ell^-} < 75$ GeV	$1500 < S_T < 2000$ GeV	1	0.02 ± 0.03	0	0 ± 0.2	0	0.06 ± 0.04	0	0 ± 0.2
1	onZ	$1500 < S_T < 2000$ GeV	2	0.5 ± 0.28	0	0.12 ± 0.08	0	0.11 ± 0.07	0	0.07 ± 0.05
1	$m_{\ell^+\ell^-} > 105$ GeV	$1000 < S_T < 1500$ GeV	0	0.46 ± 0.11	0	0.6 ± 0.28	0	0.15 ± 0.07	1	0.9 ± 0.6
1	$m_{\ell^+\ell^-} < 75$ GeV	$1000 < S_T < 1500$ GeV	0	0.41 ± 0.08	0	0.2 ± 0.12	0	0.16 ± 0.08	0	0.6 ± 0.6
1	onZ	$1000 < S_T < 1500$ GeV	6	7.6 ± 1.3	3	2.4 ± 0.5	1	1.6 ± 0.43	1	0.8 ± 0.6
1	$m_{\ell^+\ell^-} > 105$ GeV	$600 < S_T < 1000$ GeV	6	5.2 ± 1.2	12	8.5 ± 2.6	3	3.9 ± 1.5	13	9.8 ± 5.4
1	$m_{\ell^+\ell^-} < 75$ GeV	$600 < S_T < 1000$ GeV	2	4.7 ± 0.9	11	6.8 ± 2.5	0	3.3 ± 1.1	5	5.1 ± 2.8
1	onZ	$600 < S_T < 1000$ GeV	42	56 ± 7.6	48	35 ± 7.2	7	10 ± 2.7	10	6.5 ± 1.9
1	$m_{\ell^+\ell^-} > 105$ GeV	$300 < S_T < 600$ GeV	34	31 ± 5.3	149	170 ± 39	12	17 ± 6.1	80	73 ± 35
1	$m_{\ell^+\ell^-} < 75$ GeV	$300 < S_T < 600$ GeV	34	38 ± 6	139	128 ± 29	26	23 ± 9	87	81 ± 35
1	onZ	$300 < S_T < 600$ GeV	314	356 ± 45	1023	1219 ± 290	63	44 ± 8.1	131	132 ± 31
1	$m_{\ell^+\ell^-} > 105$ GeV	$0 < S_T < 300$ GeV	81	97 ± 9.5	799	761 ± 182	11	11 ± 4.6	50	41 ± 17
1	$m_{\ell^+\ell^-} < 75$ GeV	$0 < S_T < 300$ GeV	308	325 ± 36	4933	4208 ± 1033	31	35 ± 13	146	129 ± 38
1	onZ	$0 < S_T < 300$ GeV	2054*	2260 ± 213	24078	22191 ± 5517	57	67 ± 9.3	391	369 ± 87
Total3	All	All	2930	3239 ± 308	31896	29460 ± 7204	254	252 ± 59	1296	1211 ± 351

B´ search with multileptons

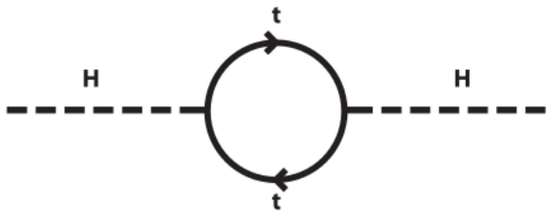
CMS-PAS-SUS-12-027

- Systematic Uncertainty

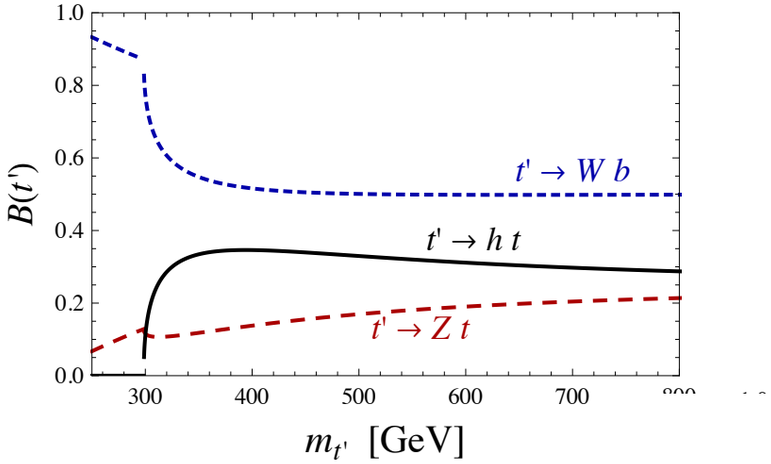
Source of Uncertainty	Uncertainty
Luminosity	4.5% [27]
PDF	14% [28]
Renormalization Scale	10% [28]
E_T^{miss} Res (E_T^{miss}): 0-50 GeV, 50-100 GeV, > 100 GeV	(-3%, +4%, +4%)
Jet Energy Scale $W^{\pm}Z$	0.5% (WZ)
B-Tag Veto (CSVM)	0.1% (WZ), 6% ($t\bar{t}$)
Muon ID/Isolation at 10 (100) GeV/c	11% (0.2%)
Electron ID/Isolation at 10 (100) GeV/c	14 % (0.6%)
$t\bar{t}$ xsec/fake rate	50%
WZ xsec	6%
ZZ xsec	12%

Introduction

- The LHC is a top quark factory
  - With large dataset many decay channels can be analyzed independently
- A perfect final state to probe new physics!
  - Unique event signatures
  - Can provide solution to the hierarchy problem without SUSY
  - Special techniques for top reconstruction can increase mass reach



- Top quark partners
  - Sequential Fourth fermion generation existence is disfavored by the discovery of Higgs boson, several other models exists
  - **Vector-like quarks:** Transforms as *(3,1,+2/3)* under $SU(3)_c \times SU(2)_W \times U(1)_Y$ would mix with the top quark Rakhi Mahbubani et.el, JHEP 0906:001 (2009)
  - **$T_{5/3}$ top partners:** Transforms as *(3,1,+5/3)* and strong sector respect the $SU(2)_L \times SU(2)_R \times U(1)_X$ Contino & Servant, JHEP 0806:026 (2008) Mrazek & Wulzer, Phys. Rev. D 81, 075006 (2010)



Branching fractions of t':
$(M_h = 125$ **GeV**, $\sin\theta_L = 0.1)$

- Top pair resonances
  - Models that predict enhanced couplings to the third generation of SM
  - **Z´, RS KK gluon production**
- t+b and t+jets resonances
  - **W´, t* decays**