



# 3rd generation SUSY searches at CMS



**Michael Sigamani**

(on behalf of the CMS collaboration)

**2014 Phenomenology Symposium**  
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# Hadronic stops

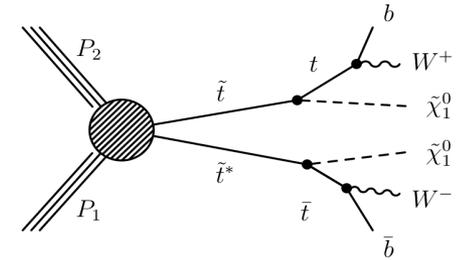
## Search: Top-squark pair production in multi-jet events

### Main bkg: $T\bar{T}$ (with $W \rightarrow l \nu$ ), $Z + \text{jets}$ (with $Z \rightarrow \nu \bar{\nu}$ )

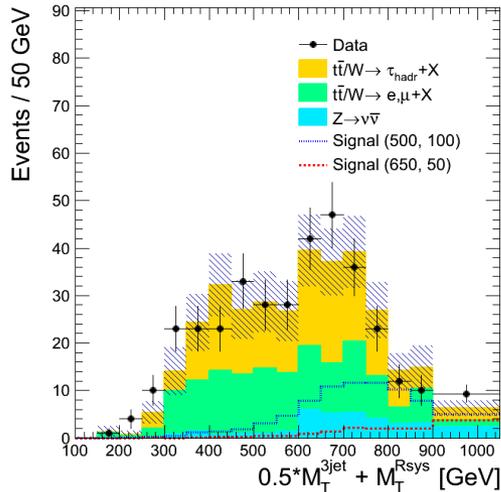
1) Tag two top quarks per event: One full-reconstruction and one partial-reconstruction  $\rightarrow$  increase signal efficiency (slide 14)

2) Then utilize topological variables ( $m_{T2}$ ,  $m_T^{3j}$ ,  $m_T^{\text{R syst}}$ ) to increase S/B

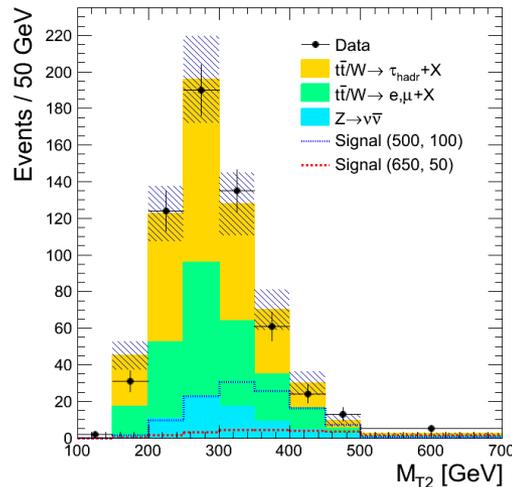
CMS-PAS-SUS-13-015



CMS Preliminary,  $L = 19.4 \text{ fb}^{-1}$ ,  $\sqrt{s} = 8 \text{ TeV}$



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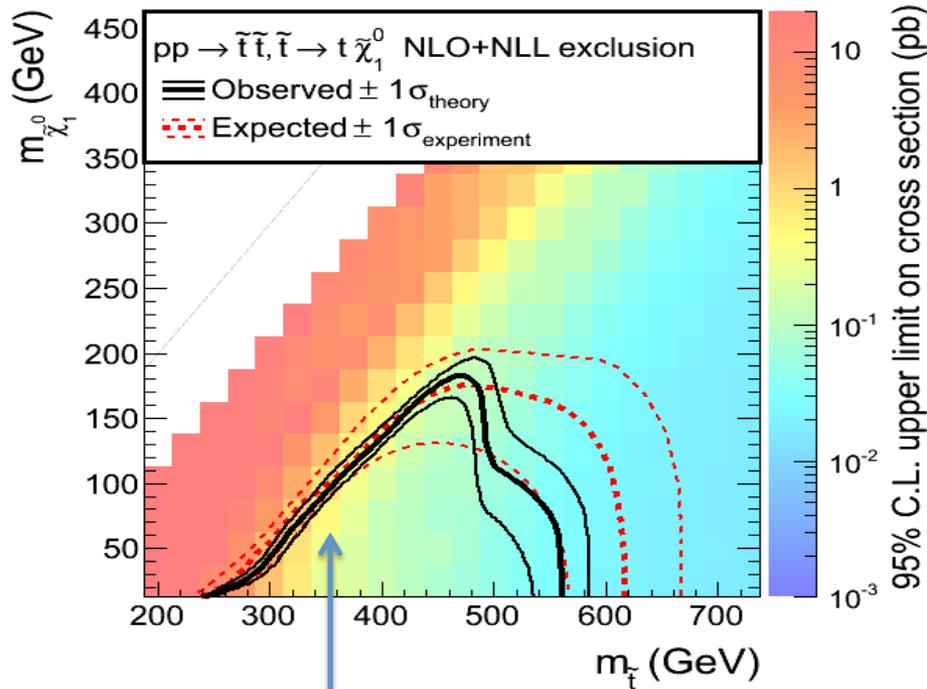


Variable	Cut
$N_{\text{jets}}$	$\geq 5$ ( $p_T > 30 \text{ GeV}$ & $ \eta  < 2.4$ )
$N_{\text{bjets}}$	$\geq 1, \geq 2$
$E_T^{\text{miss}}$	$\geq 200, \geq 350 \text{ GeV}$
$m_{T2}$	$\geq 300 \text{ GeV}$
$0.5 * m_T^{3j} + m_T^{\text{R syst}}$	$\geq 500 \text{ GeV}$

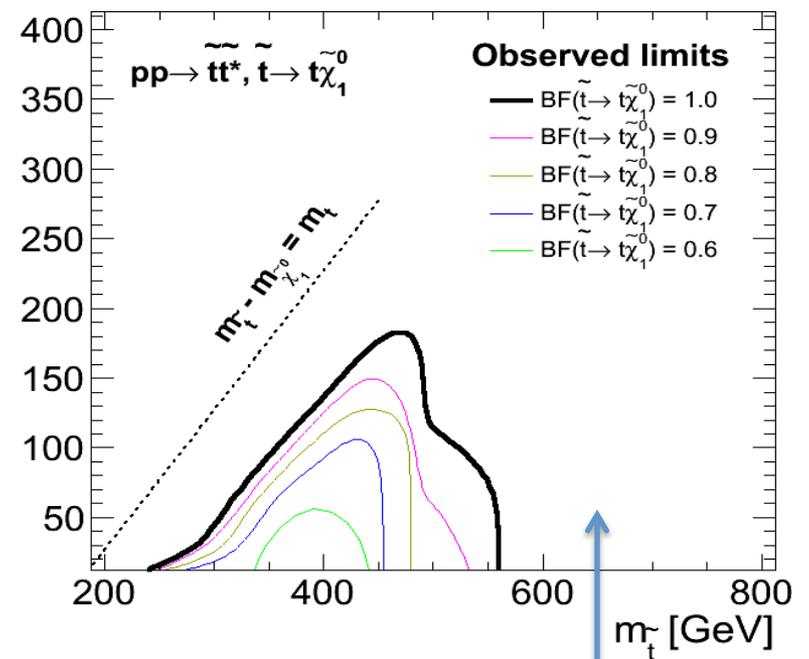
# Hadronic stops

The production of top squarks with mass less than 535 GeV is excluded at 95% confidence-level for small LSP masses less than 10 GeV

CMS Preliminary,  $19.4 \text{ fb}^{-1}$ ,  $\sqrt{s} = 8 \text{ TeV}$



CMS Preliminary,  $L = 19.4 \text{ fb}^{-1}$ ,  $\sqrt{s} = 8 \text{ TeV}$



Assume 100% BF

Results based on assumption that search has no acceptance if one stop decays in a different mode

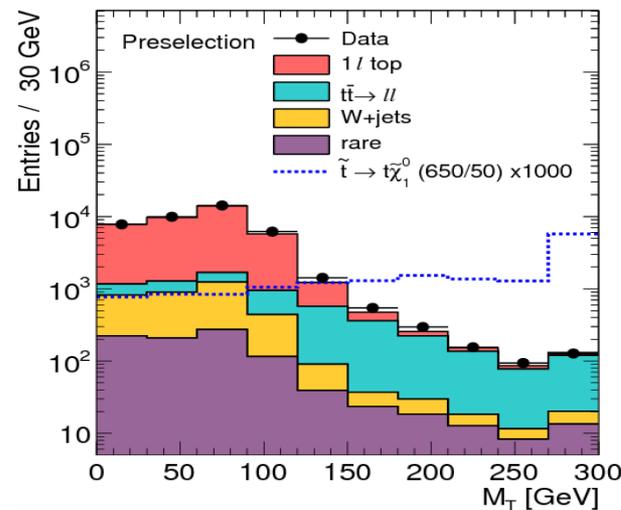
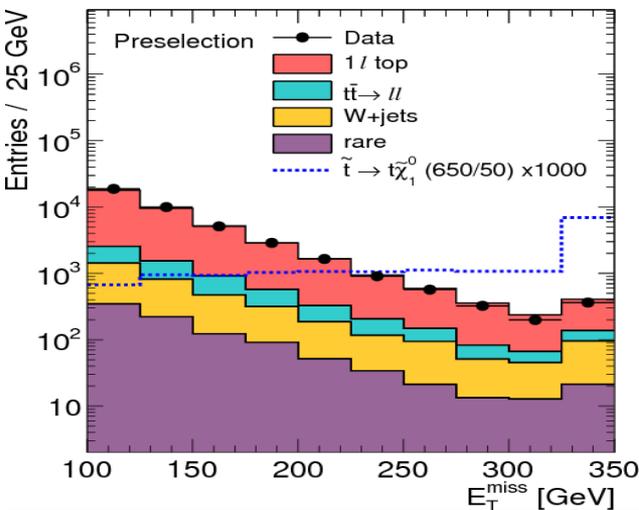
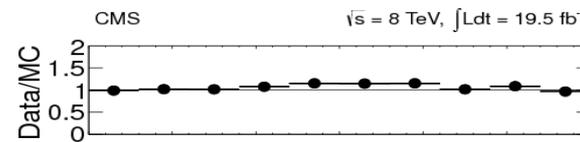
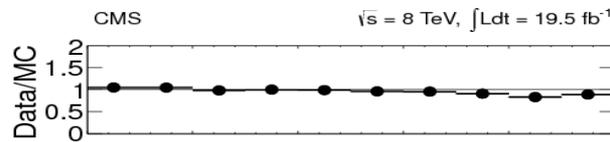
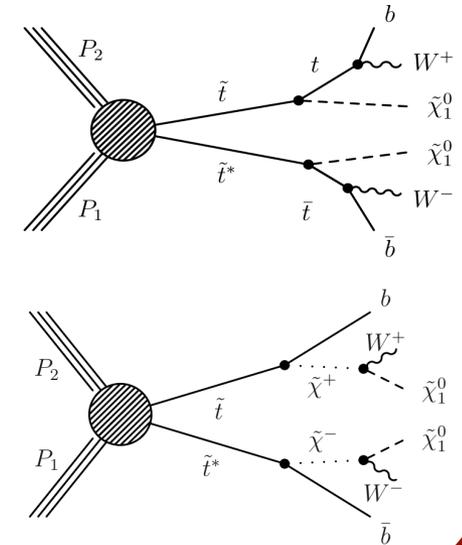
# 1-lepton stops

Search: Top-squark pair production in single lepton channel

Main bkg:  $T\bar{T}$  (di-lepton),  $W + \text{jets}$ , Drell-Yan, QCD, single top, di/tri-boson

1) Use a multivariate (BDT) approach to search for an excess over SM bkg. and cross check results with cut and count method

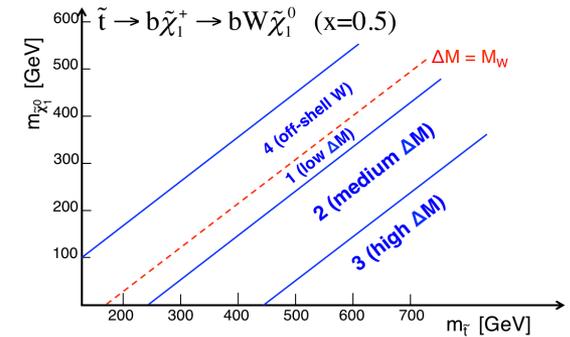
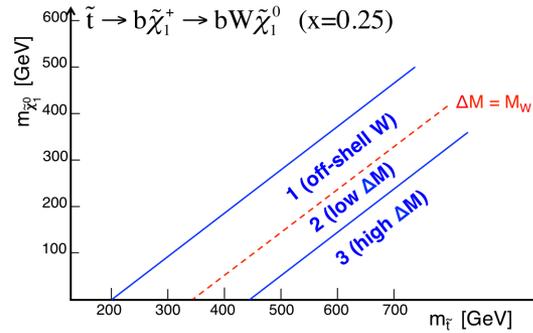
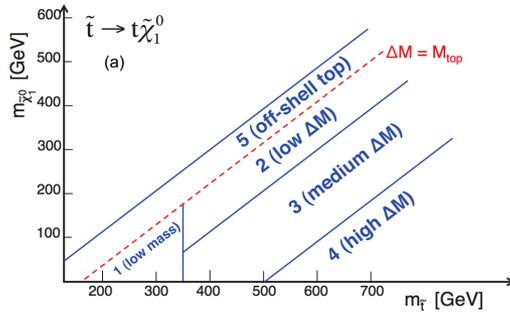
CMS-PAS-SUS-13-011



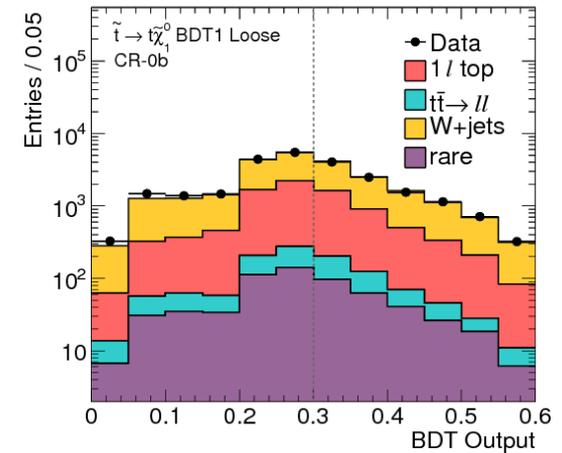
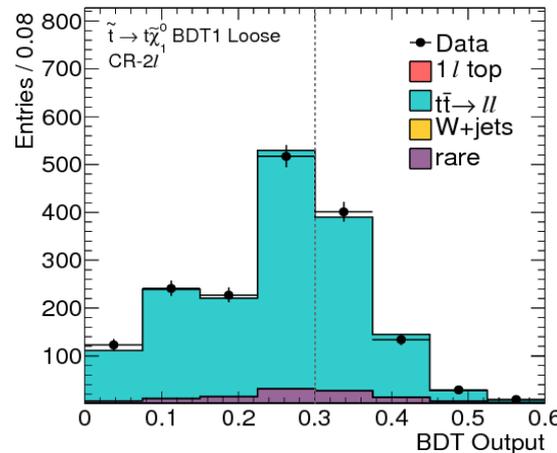
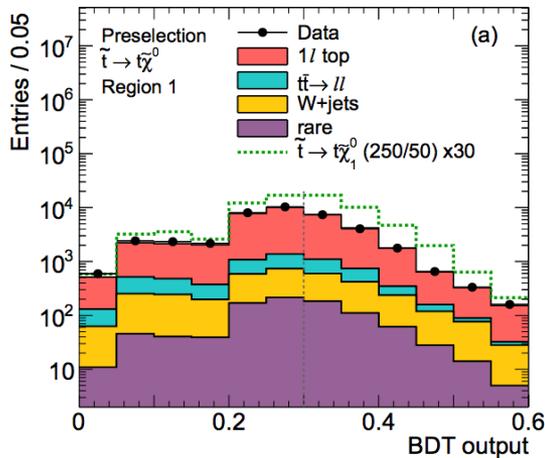
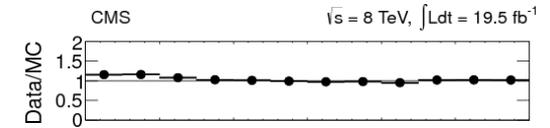
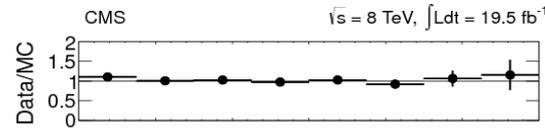
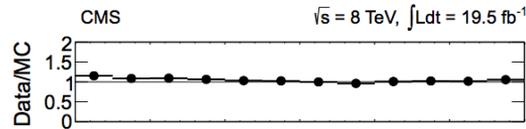
Variable	Cut
$N_{\text{jets}}$	$\geq 4$ ( $p_{T>30}$ GeV, $ \eta  < 2.4$ )
$N_{\text{bjets}}$	$\geq 1$
$E_{T}^{\text{miss}}$	$\geq 100$
$m_T$	$\geq 120$ GeV

# 1-lepton stops

18 BDT-based SRs and 16 cut-based SRs according to  $\Delta M(M_{\text{STOP}}, M_{\text{LSP}})$



Bkg estimation: Normalize MC to data in mT-peak region (50-80 GeV) and extrapolate to tail





# Stops with Higgs/Z

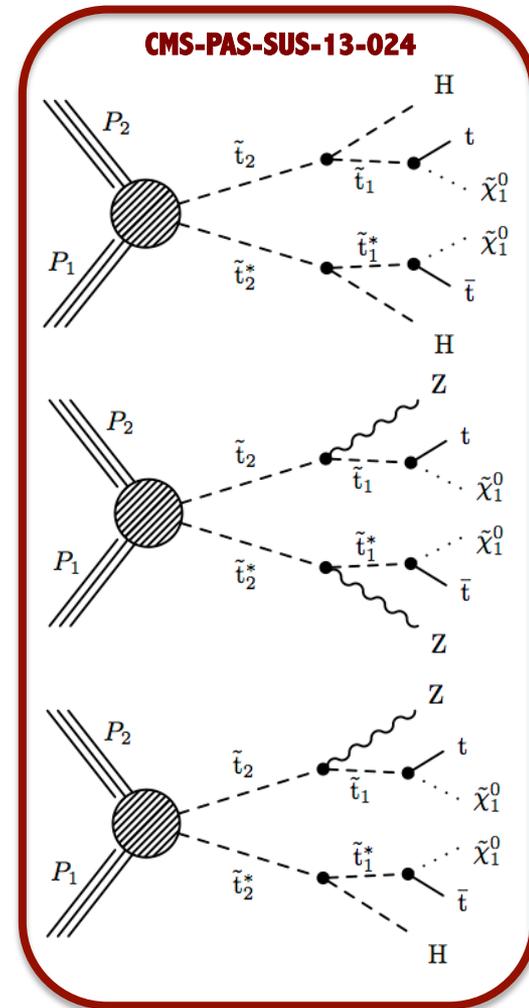
NEW

Search: Top-squark ( $t_2$ ) pair production decaying with:  
 $t_2 \rightarrow H t_1$  or  $t_2 \rightarrow Z t_1$

Main bkg:  $TTbar$

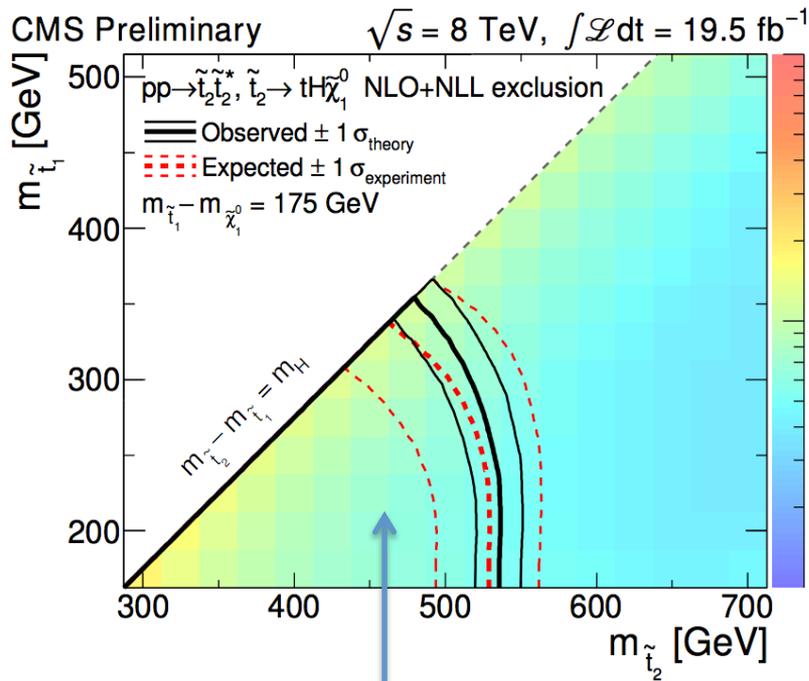
- 1)  $t_1$  and  $t_2$  are eigenstates of  $t_{L/R}$   $\rightarrow$  usually search for lighter  $t_1$  eigenstate (see earlier slides)
- 2i) Analysis targets the region:  $m(t_1) - m(\chi_1^0) \sim m(\text{top})$
- 2ii) Region not currently covered by CMS stops searches

$N_\ell$	Veto	$N_{b \text{ jets}}$	$N_{\text{jets}}$	$E_T^{\text{miss}}$ [GeV]	Additional requirements [GeV]
1	track or $\tau_h$	$= 3$ $\geq 4$	$\geq 5$ $\geq 4$	$\geq 50$	$m_T > 150$ $m_T > 120$
2 OS	extra $e/\mu$	$= 3$ $\geq 4$	$\geq 5$ $\geq 4$	$\geq 50$	$(N_{bb} = 1 \text{ with } 100 \leq m_{bb} \leq 150), N_{bb} \geq 2$
2 SS	extra $e/\mu$	$= 1$ $\geq 2$	$[2, 3], \geq 4$	$[50, 120], \geq 120$	for low/high- $p_T$ : $H_T \in [200, 400], \geq 400$
$\geq 3$	—	$= 1$ $= 2$ $\geq 3$	$[2, 3], \geq 4$ $\geq 3$	$[50, 100], [100, 200], \geq 200$	for on/off-Z: $H_T \in [60, 200], \geq 200$



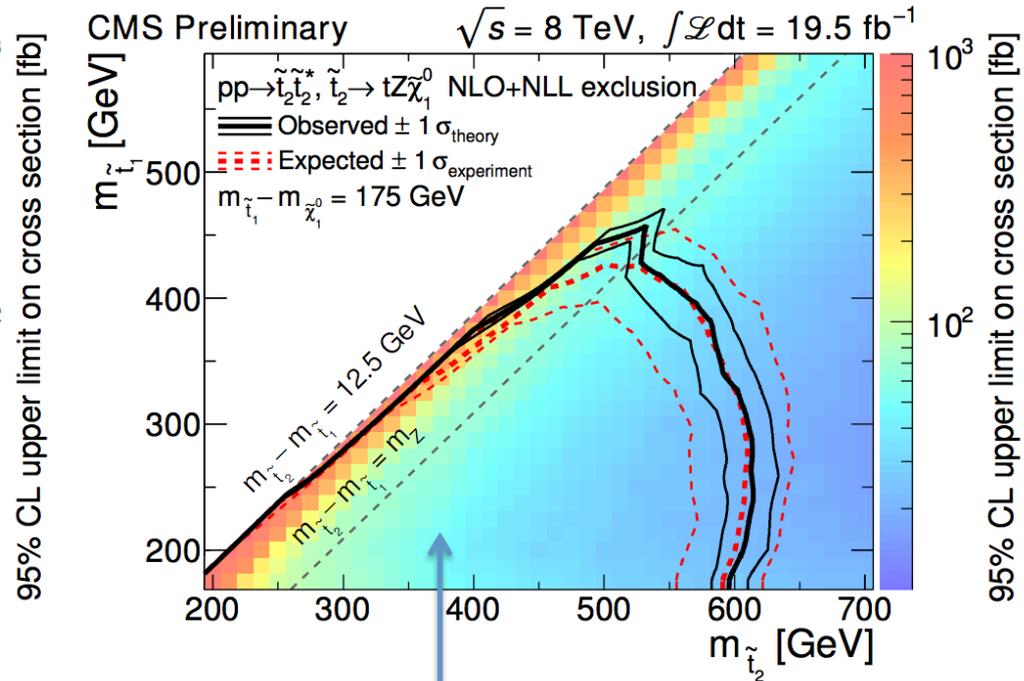
# Stops with Higgs/Z

Top-squarks with masses  $M(\tilde{t}_2)$  up to around 575 GeV for  $M(\tilde{t}_1)$  masses up to around 400 GeV are excluded at the 95% confidence level



$t_2 \rightarrow H t_1$  with  $t_1$  decaying to top plus LSP

Driving force in limit plot is 3 lepton SR



$t_2 \rightarrow Z t_1$  with  $t_1$  decaying to top plus LSP

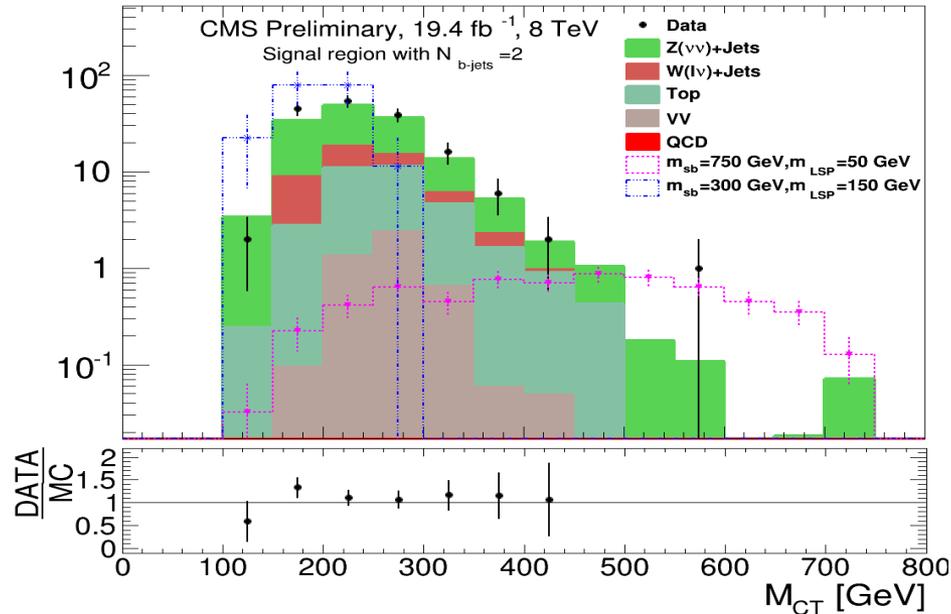
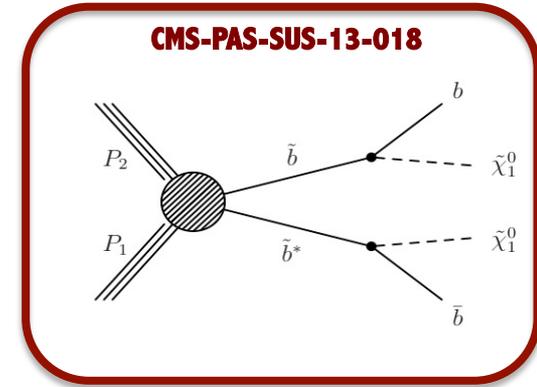
# Direct sbottoms

NEW

Search: Direct sbottom squark pair production decaying to b-quark + LSP

Main bkg:  $Z \rightarrow \nu \nu + \text{jets}$ ,  $T\bar{T} + \text{jets}$ ,  $W \rightarrow l \nu$

1) Construct 2D analysis in 8 bins of  $N_{\text{bjet}}$  and  $m_{\text{CT}}^2$  where:  
 $m_{\text{CT}}^2(\text{jet}_1, \text{jet}_2) = [E_{\text{T}}(\text{jet}_1) + E_{\text{T}}(\text{jet}_2)]^2 - [p_{\text{T}}(\text{jet}_1) - p_{\text{T}}(\text{jet}_2)]^2$

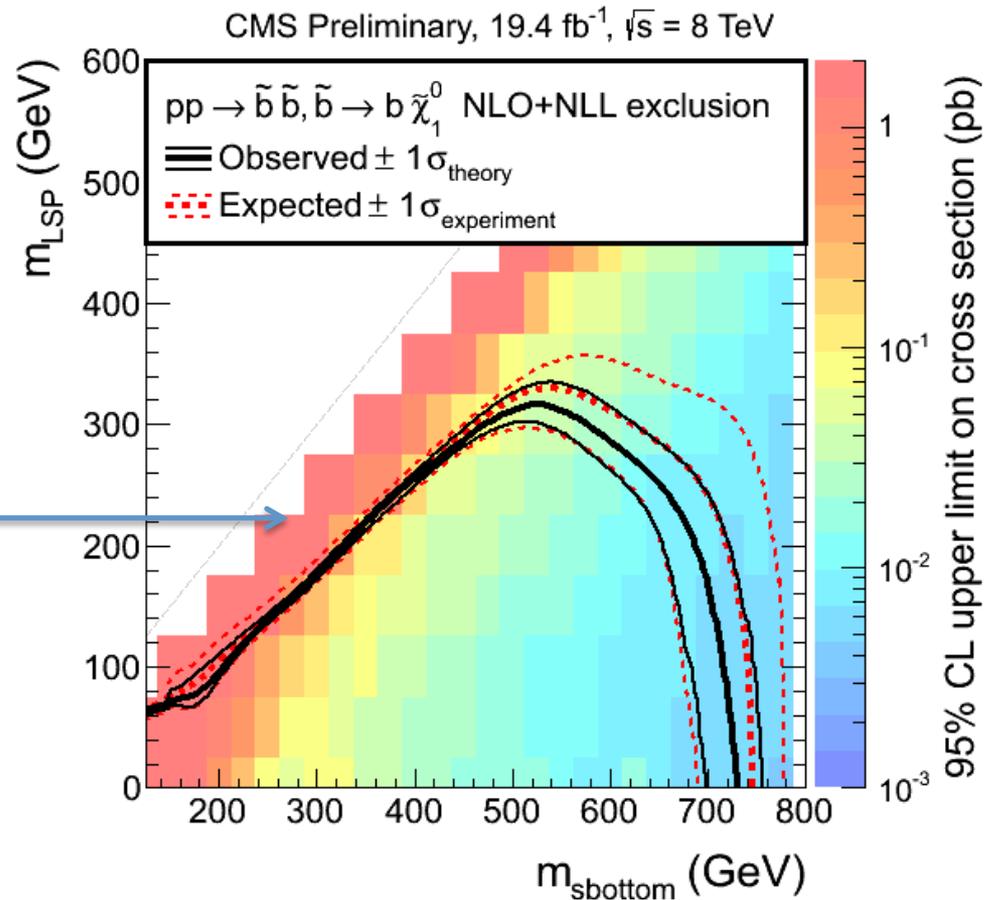


Variable	Cut
$N_{\text{jets}}$	2 ( $p_{\text{T}} > 70 \text{ GeV}$ & $ \eta  < 2.4$ )
$N_{\text{bjets}}$	[1, 2]
$E_{\text{T}}^{\text{miss}}$	$\geq 175 \text{ GeV}$
$H_{\text{T}}$	$\geq 250 \text{ GeV}$
$m_{\text{CT}}^2$	[0, 250, 350, 450, $\infty$ ] GeV

# Direct sbottoms

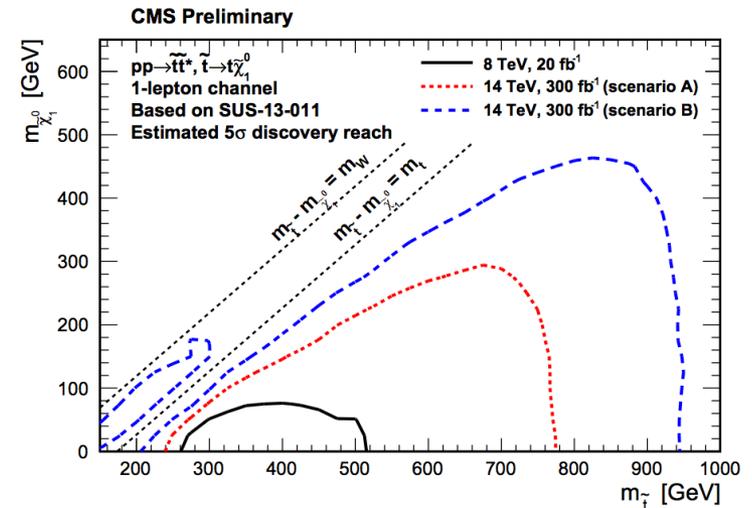
Bottom-squark mass values up to around 700 GeV for LSP masses less than 50 GeV are excluded at the 95% confidence level

With new search bins (with one ISR + 1 or 2 b-jets) expect the analysis to become more sensitive to the compressed region (near the diagonal)



# Summary

- **Wide range of SUSY searches for 3rd generation particles covered at CMS**
  - Collected around 20 fb<sup>-1</sup> of pp data at  $\sqrt{s}$ =8 TeV in 2012 and performed searches for third generation squarks.
- **No significant excess over expected SM bkg observed so far**
  - Have set top-squark lower limits at around 700 GeV
  - Have set bottom-squark lower limits at around 750 GeV
  - Have only covered direct production in this talk, can see here: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS> for full range of CMS 3G SUSY public material
- **LHC Run2 will start soon at  $\sqrt{s} = 13\text{TeV}$** 
  - Discovery potential for top-squark masses will be at around 1 TeV with 300 fb<sup>-1</sup> @  $\sqrt{s} = 14\text{TeV}$
  - Future Sensitivity Studies for SUSY searches at CMS at 14 TeV: <http://arxiv.org/pdf/1310.0781v1.pdf>



**Thank You**

## SUS-13-015: Top-tagger references

- [28] D. E. Kaplan, K. Rehermann, M. D. Schwartz, and B. Tweedie, “Top Tagging: A Method for Identifying Boosted Hadronically Decaying Top Quarks”, *Phys. Rev. Lett.* **101** (2008) 142001, doi:10.1103/PhysRevLett.101.142001, arXiv:0806.0848.
- [29] T. Plehn, M. Spannowsky, M. Takeuchi, and D. Zerwas, “Stop Reconstruction with tagged tops”, *JHEP* **1010** (2010) 078, doi:10.1007/JHEP10(2010)078, arXiv:1006.2833.
- [30] D. E. Kaplan, K. Rehermann, and D. Stolarski, “Searching for direct stop production in hadronic top data at the LHC”, *JHEP* **1207** (2012) 119, doi:10.1007/JHEP07(2012)119, arXiv:1205.5816.

## Kinematic variable definitions

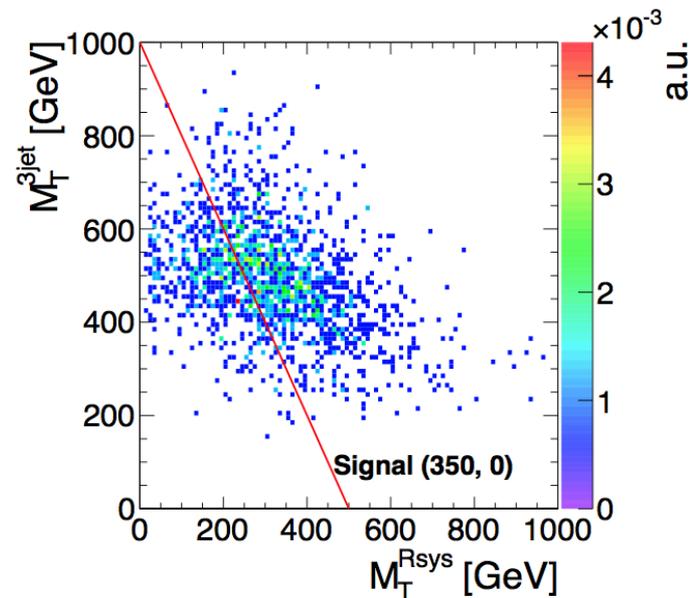
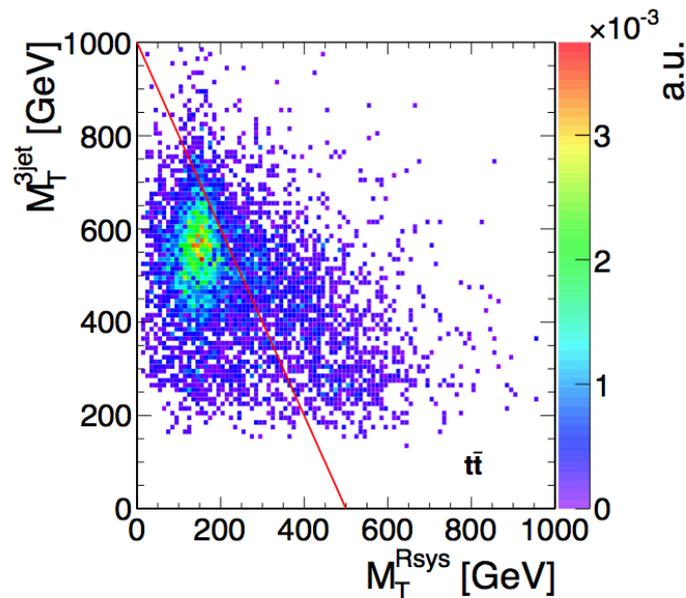
$M_T^{3\text{-jet}}$  is the transverse mass of the fully reconstructed top quark tri-jet system and the  $\vec{p}_T^{\text{miss}}$  vector given by

$$(M_T^{3\text{-jet}})^2 = (m^{3\text{-jet}})^2 + 2(E_T^{3\text{-jet}} p_T^{\text{miss}} - p_T^{3\text{-jet}} p_T^{\text{miss}} \cos \Delta\phi), \quad (2)$$

$m_T^{\text{Rsys}}$  is the transverse mass of the identified partial top decay products in the Rsys and the  $p_T^{\text{miss}}$  vector (3)

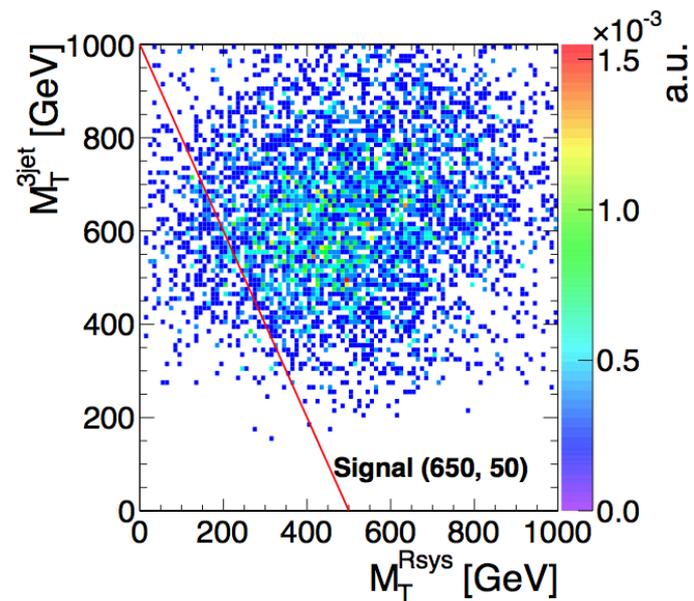
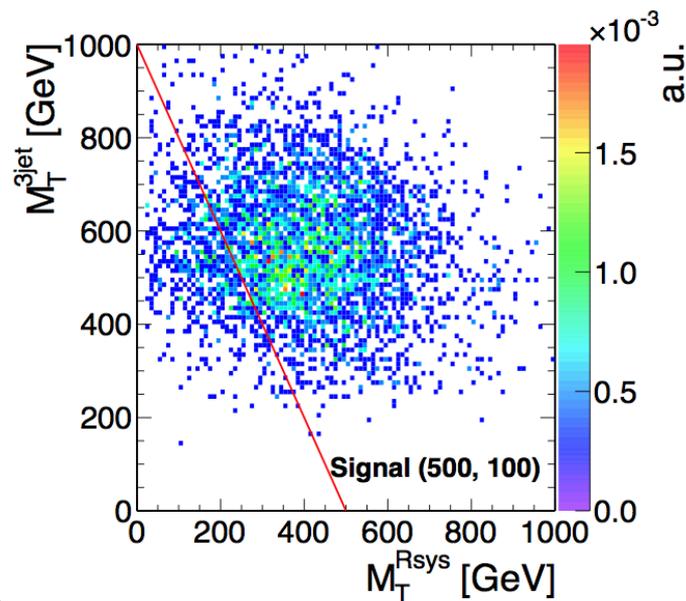
**ADDITIONAL  
MATERIAL**

SUS-13-015:  
Topological variable  
correlation plots



CMS Simulation,  $L = 19.4 \text{ fb}^{-1}$ ,  $\sqrt{s} = 8 \text{ TeV}$

CMS Simulation,  $L = 19.4 \text{ fb}^{-1}$ ,  $\sqrt{s} = 8 \text{ TeV}$



ADDITIONAL  
MATERIAL

SUS-13-015:  
Event yields (MC)

	$p_T^{\text{miss}} > 200 \text{ GeV},$ $N_{\text{b-jets}} \geq 1$	$p_T^{\text{miss}} > 350 \text{ GeV},$ $N_{\text{b-jets}} \geq 1$	$p_T^{\text{miss}} > 200 \text{ GeV},$ $N_{\text{b-jets}} \geq 2$	$p_T^{\text{miss}} > 350 \text{ GeV},$ $N_{\text{b-jets}} \geq 2$
$t\bar{t}$	$153.8 \pm 5.7$	$18.9 \pm 2.0$	$63.4 \pm 3.7$	$6.3 \pm 1.2$
$W \rightarrow \ell\nu$	$22.9 \pm 2.9$	$5.8 \pm 1.4$	$3.9 \pm 1.2$	$1.1 \pm 0.6$
$Z \rightarrow \nu\bar{\nu}$	$25.0 \pm 1.2$	$8.4 \pm 0.6$	$4.6 \pm 0.5$	$1.3 \pm 0.2$
QCD	$1.1 \pm 0.6$	$0.0^{+0.5}_{-0.0}$	$0.0^{+0.5}_{-0.0}$	$0.0^{+0.5}_{-0.0}$
single top	$17.5 \pm 3.9$	$5.2 \pm 2.1$	$7.0 \pm 2.5$	$1.8 \pm 1.2$
$t\bar{t}Z$	$7.8 \pm 0.4$	$2.3 \pm 0.2$	$4.2 \pm 0.3$	$1.4 \pm 0.2$
$t\bar{t}W$	$2.4 \pm 0.2$	$0.3 \pm 0.1$	$1.1 \pm 0.2$	$0.1 \pm 0.1$
ZZ	$0.8 \pm 0.2$	$0.3 \pm 0.1$	$0.2 \pm 0.1$	$0.0^{+0.1}_{-0.0}$
WZ	$0.5 \pm 0.2$	$0.1 \pm 0.1$	$0.1 \pm 0.1$	$0.0^{+0.1}_{-0.0}$
WW	$0.8 \pm 0.3$	$0.1 \pm 0.1$	$0.3 \pm 0.2$	$0.0^{+0.2}_{-0.0}$
Total (no QCD)	$231.5 \pm 7.6$	$41.2 \pm 3.3$	$84.7 \pm 4.6$	$12.0 \pm 1.8$
Data	254	45	83	15
Signal (350, 0)	$162.8 \pm 7.2$	$11.3 \pm 1.9$	$84.4 \pm 5.2$	$7.5 \pm 1.5$
Signal (500, 100)	$83.2 \pm 1.7$	$33.7 \pm 1.1$	$48.1 \pm 1.3$	$19.8 \pm 0.8$
Signal (650, 50)	$22.4 \pm 0.4$	$15.8 \pm 0.3$	$13.1 \pm 0.3$	$9.3 \pm 0.2$

ADDITIONAL  
MATERIAL

# SUS-13-011:

## Kinematic variables used In event selection

Selection	$\tilde{t} \rightarrow t\tilde{\chi}_1^0$			$\tilde{t} \rightarrow b\tilde{\chi}^+$		
	BDT	Cut-based		BDT	Cut-based	
		Low $\Delta M$	High $\Delta M$		Low $\Delta M$	High $\Delta M$
$E_T^{\text{miss}}$ (GeV)	yes	> 150, 200, 250, 300	> 150, 200, 250, 300	yes	> 100, 150, 200, 250	> 100, 150, 200, 250
$M_{T2}^W$ (GeV)	yes		>200	yes		>200
$\min \Delta\phi$	yes	>0.8	>0.8	yes	>0.8	>0.8
$H_T^{\text{ratio}}$	yes			yes		
Hadronic top $\chi^2$	(on-shell top)	<5	<5			
Leading b-tagged jet $p_T$ (GeV)	(off-shell top)					>100
$\Delta R(\ell, \text{leading b-tagged jet})$				yes		
Lepton $p_T$ (GeV)				yes (off shell W)		

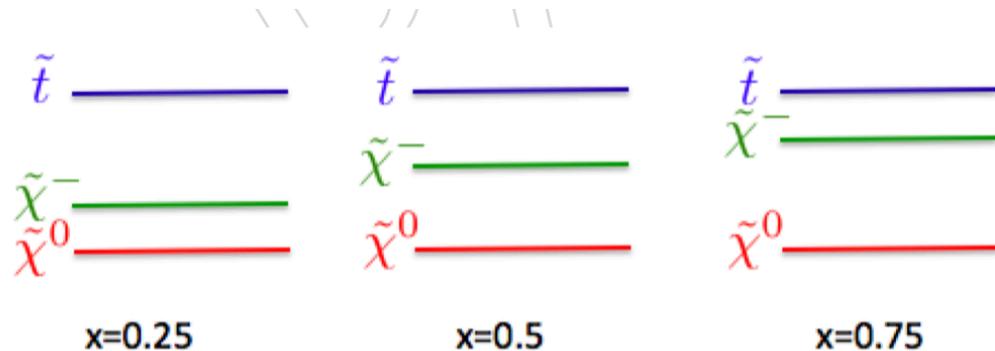


Figure 2: The stop-chargino-neutralino mass spectra for the three choices of the parameter  $x$  considered in this work.

**ADDITIONAL  
MATERIAL**

**SUS-13-024:**  
Kinematic variables  
(3 lepton SR)

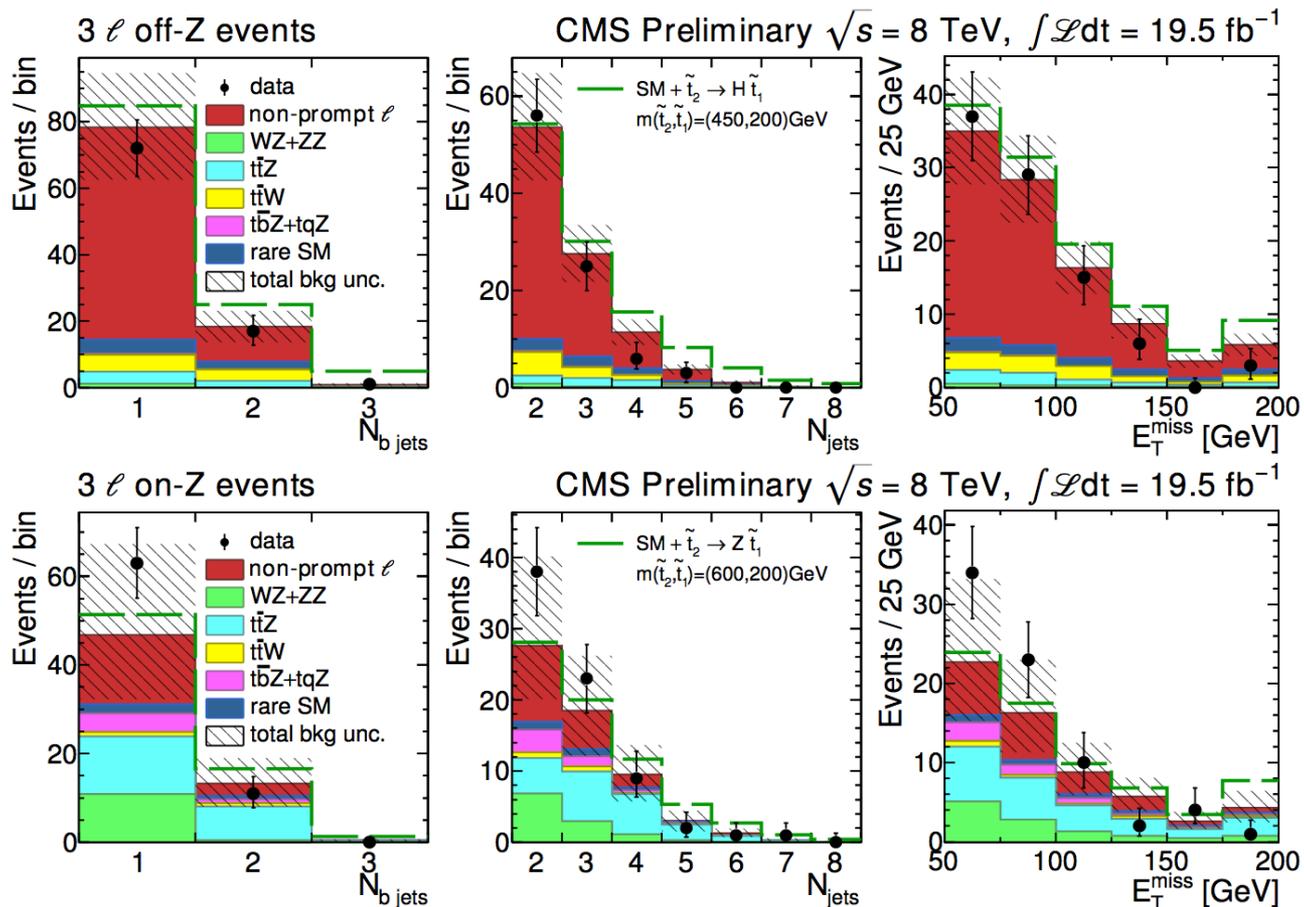


Figure 4: Observed data events and predicted SM background for the event sample with at least three leptons as a function of the number of jets, number of b jets and  $E_T^{\text{miss}}$  are shown for events that do not contain (off-Z), top row, or contain (on-Z), bottom row, an opposite-sign-same-flavor pair that is a Z boson candidate. The distribution for the models  $\tilde{t}_2 \rightarrow H\tilde{t}_1$  where  $m_{\tilde{t}_2} = 450$  GeV and  $m_{\tilde{t}_1} = 200$  GeV and  $\tilde{t}_2 \rightarrow Z\tilde{t}_1$  where  $m_{\tilde{t}_2} = 600$  GeV and  $m_{\tilde{t}_1} = 200$  GeV are stacked on top of the backgrounds in the top and bottom rows respectively. The last bin in the histograms includes overflow events. The shaded bands correspond to the estimated uncertainties on the background which are calculated on the per bin basis.

**ADDITIONAL  
MATERIAL**

- [55] D. Tovey, “Supersymmetric particle mass measurement with boost-corrected constransverse mass”, *JHEP* **03** (2010) doi:10.1007/JHEP03(2010)030.
- [56] G. Polesello and D. Tovey, “On measuring the masses of pair-produced semi-invisibly decaying particles at hadron colliders”, *JHEP* **04** (2008) doi:10.1088/1126-6708/2008/04/034.