3rd GENERATION SUSY SEARCHES AT CMS
DIS 2014, WARSAW

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on behalf of the CMS collaboration

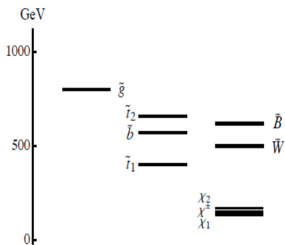April 28, 2014

Outline

Theoretical Motivation
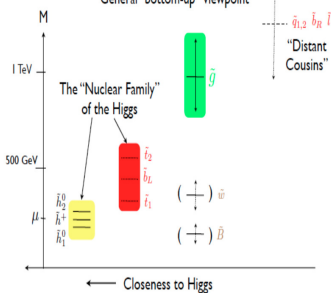
arXiv:1203.6227
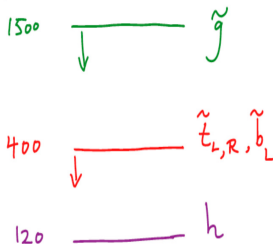
naturalness

- Higgs Mass is stabilized w.o. fine-tuning
- 3rd Gen (Stop) quarks can be lighter than all squarks due to large mixing
- Wino, Bino, other squarks & sleptons can be $\mathcal{O}(\text{TeV})$

3rd Gen Searches Strategies

R-Parity conserved

- SUSY particles created in pairs
- SUSY particles undergo in (long) cascades $\Rightarrow$ High p_T jets and/or ℓ
- LSP is stable $\Rightarrow \not{E}_T$ sign

R-Parity not-conserved

- SUSY part. can be created as "singles"
- LSP decays as well $\Rightarrow$ no $\not{E}_T$

Working with Simplified Models Sectrum

- Main kinematical properties are conserved
- Reduce the free parameters (masses & BR)
- Feasible to perform an analysis based on a "full" scan of the p.s.
- BR is typically assumed to be 100% for a given model
- Results are re-interpreted as upper limits on the $\sigma \times BR$ for each model
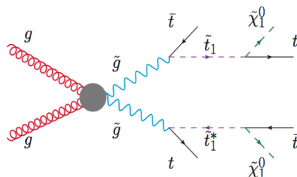
Production Mechanisms
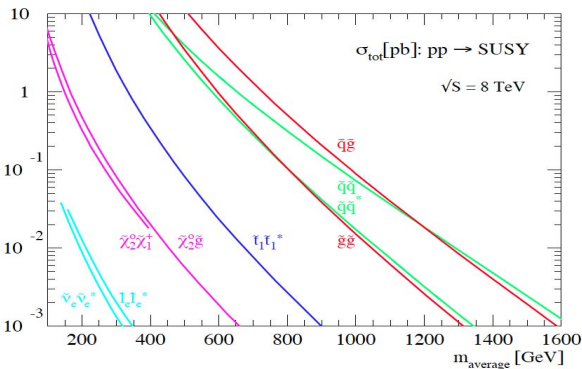
Direct production
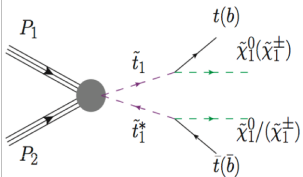
Gluino mediated production

CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons

SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC
CALORIMETER (ECAL)
~76k scintillating PbWO₄ crystals

PRESHOWER
Silicon strips
~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING
SOLENOID
Niobium-titanium coil
carrying ~18000 A

FORWARD
CALORIMETER
Steel + quartz fibres
~2k channels

HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Total weight   : 14000 tonnes
Overall diameter   : 15.0 m
Overall length   : 28.7 m
Magnetic field   : 3.8 T

| Parameter	Nominal	2012
$\sqrt{s}$	14 TeV	8 TeV
bunches	2808×2808	1374×1374
protons /bunch	1.15×10^{11}	1.7×10^{11}
spacing	25 ns (40 MHz)	50 ns (20 MHz)
$\mathcal{L}$ (cm^{-2} s^{-1})	10^{34}	7.7×10^{33}

CMS Integrated Luminosity, pp, 2012, $\sqrt{s} = 8$ TeV

Data included from 2012-04-04 22:37 to 2012-12-16 20:49 UTC

LHC Delivered: 23.30 fb^{-1}
CMS Recorded: 21.79 fb^{-1}
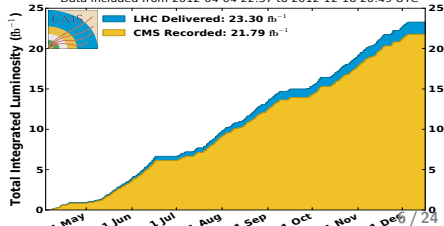
Gluino Mediated Searches

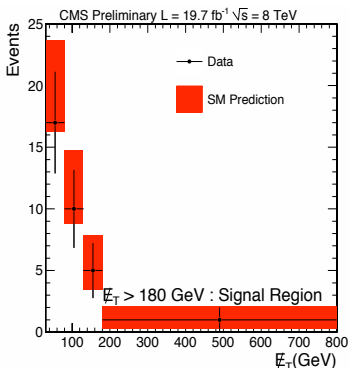| Final State	Analysis	Mode	
		$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	$\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$
$0 - \ell$	Multi-jets + $\not{E}_T$ (SUS-13-012)*	✓	
	Razor with b-jets (SUS-13-004)*	✓	✓
$1 - \ell$	Razor with b-jets (SUS-13-004)	✓	✓
	Multi (b) jets (SUS-13-007)	✓	
$> 1 - \ell$	SS -ℓ + jets (SUS-13-013)*	✓	✓
	OS-ℓ + multi (b) jets + $\not{E}_T$ (SUS-13-016)	✓	
	3-sℓ + b tag (SUS-13-008)		✓
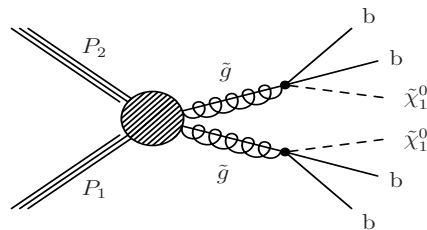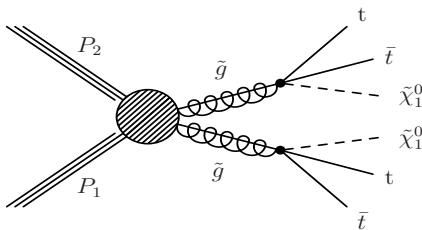
*See Niki Saoulidou's talk "Inclusive SUSY Searches @ CMS"

OS leptons, multi(b) jets and large $\not{E}_T$ ▸ SUS-13-016

Preselection : ≥ 2 OS-ℓ, ≥ 2 Jets, $\not{E}_T > 100$ GeV

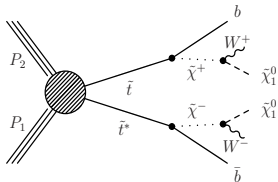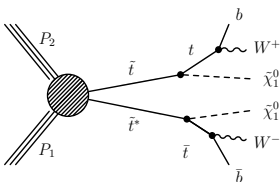*Signalregion* : $\not{E}_T > 180$ GeV, > 4 Jets, ≥ 2 b-tag Jets, Jet$_{1\,or\,2}^{|\eta|} < 1$
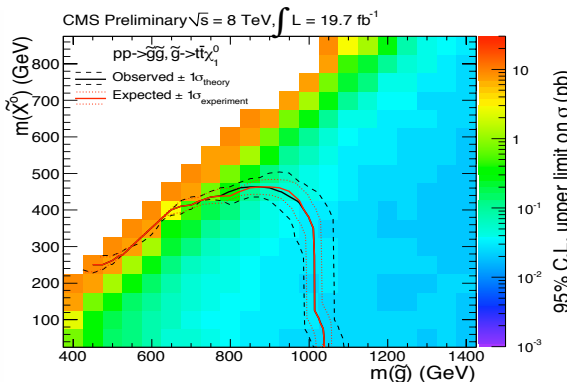
$m(\tilde{g}) \simeq 1$ TeV are excluded for $m(\tilde{\chi}_1^0) \approx 400$ GeV

Direct Stop Pair Production

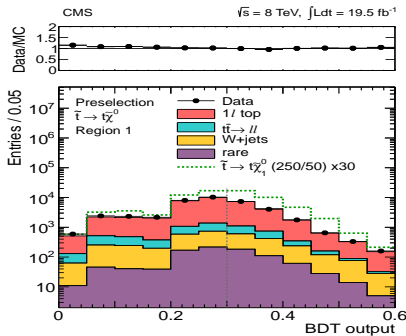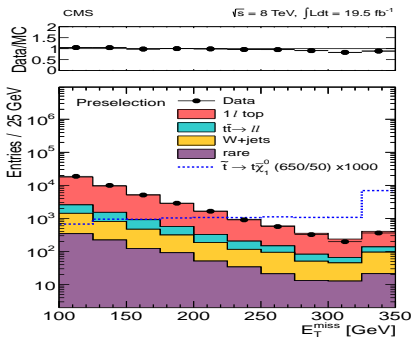| Final State	Analysis	Mode	
		$\tilde{t} \to t\tilde{\chi}_1^0$	$\tilde{t} \to b\tilde{\chi}_1^\pm$
$0 - \ell$	Multi-jets $+ \not{E}_T$ (SUS-13-015)	✓	
$1 - \ell$	1-ℓ + b-jet(s) $+ \not{E}_T$ (SUS-13-011)	✓	✓

Direct Stop in $1 - \ell + \not{E}_T$ ▸ SUS-13-011
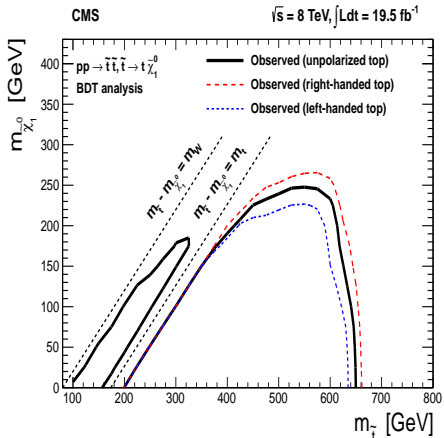
Cut & count and an BDT MVA method

Preselection : Exactly $1 - \ell$ (Iso), ≥ 4 Jets, $\geq 1b - \text{tag}$, $\not{E}_T > 100$ GeV
Variables : $\not{E}_T$, $\min\Delta\Phi$, M_{12}^W, H_T^{ratio}, $\ell\, p_T$, $\text{lead}_{\text{bjet}}^{\text{p}_T}$, $\Delta R(\ell, \text{lead}_{\text{bjet}}^{\text{p}_T})$...
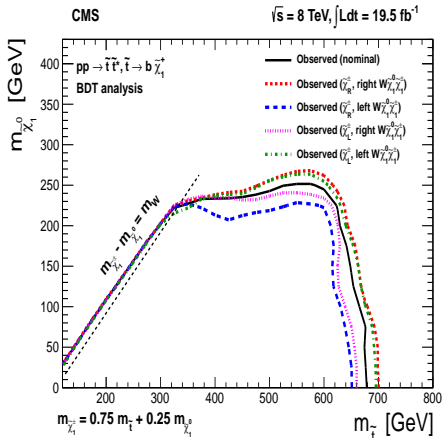Signal region : $M_T > 120$ GeV
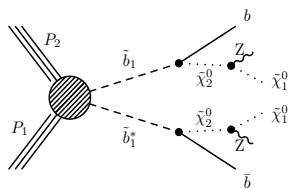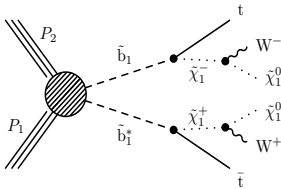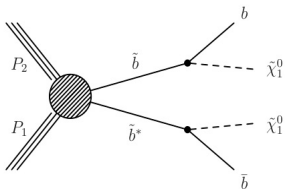
Direct Stop in $1 - \ell$ - Exclusion Plots

$m(\tilde{t}) \simeq 650~(600)$ GeV are excluded for $m(\tilde{\chi}_1^0) = 0~(\approx 240)$ GeV

$m(\tilde{t}) \simeq 675~(600)$ GeV are excluded for $m(\tilde{\chi}_1^0) = 0~(\approx 240)$ GeV

Direct Sbottom Pair Production

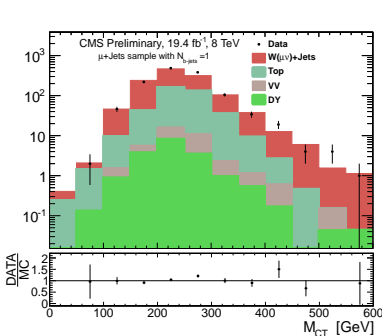| Final State	Analysis	Mode		
		$\tilde{b} \to b\tilde{\chi}_1^0$	$\tilde{b} \to tW\tilde{\chi}_1^0$	$\tilde{b} \to bZ\tilde{\chi}_1^0$
$0 - \ell$	(b) jets + H_T + $\not{E}_T$ (SUS-13-018)	✓		
$1 - \ell$	1-ℓ + b-jet(s) + $\not{E}_T$ (SUS-13-011)	✓	✓	
$> 1 - \ell$	SS -ℓ + jets + $\not{E}_T$ (SUS-13-013)		✓	
	3-ℓ + b-jets + $\not{E}_T$ (SUS-13-008)		✓	✓

Direct Sbottoms ▸ SUS-13-018

Use of boost-corrected contransverse mass

$$m_{CT} = \sqrt{[E_T(J_1) + E_T(J_2)]^2 - [\vec{p_T}(J_1) - \vec{p_T}(J_2)]^2}$$

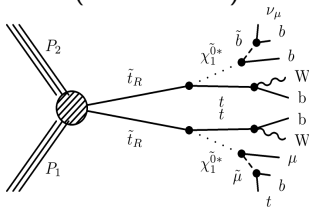Presel : == 2 jets, ≥ 1 b-tags, $H_T > 200$ GeV $\not{E}_T > 100$ GeV
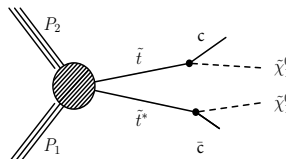Signal regions : 1 & 2 b-tags for $m_{CT} \times (<250, 350, 450, > 450)$ GeV
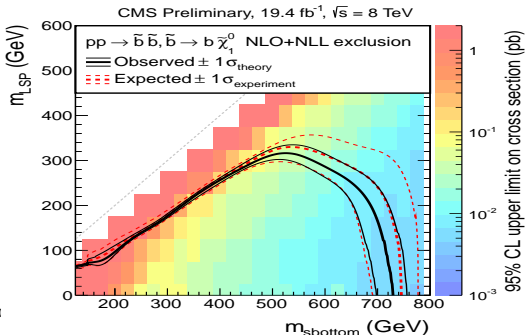
$m(\tilde{b}) \simeq 725\ (525)$ GeV are excluded for $m(\tilde{\chi}_1^0) = 0\ (\approx 300)$ GeV
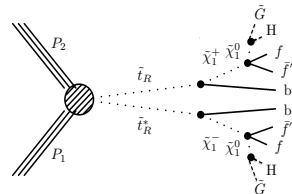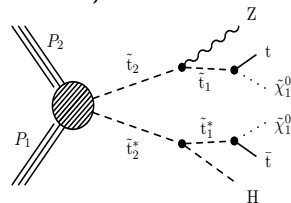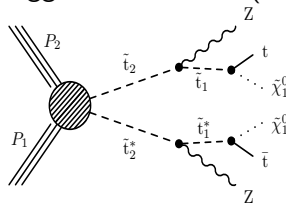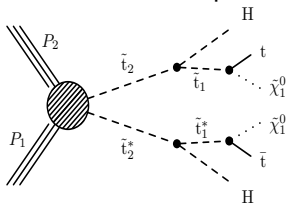
Other Searches

RPV Stop Search
(SUS-13-003)

Compressed spectrum
(SUS-13-009)

Stop with Higgs boson
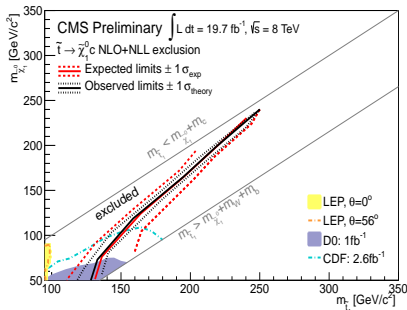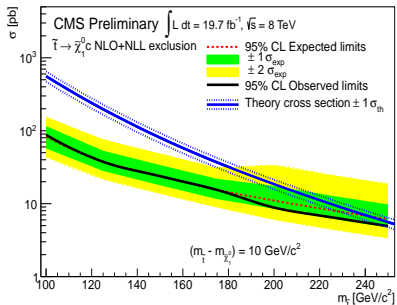(SUS-13-014)

Stop2 with Higgs and Z bosons (SUS-13-024)

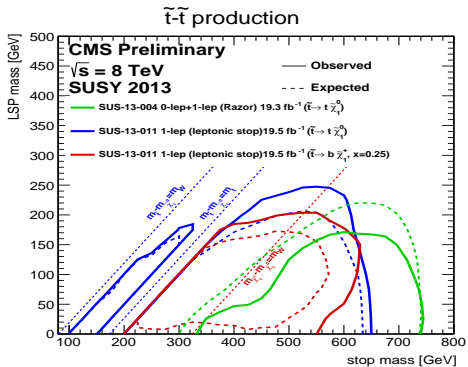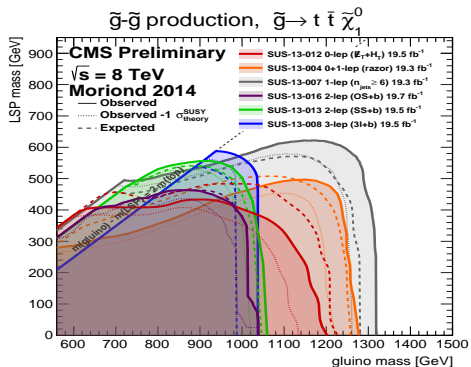# Direct Stops using monojet $+$ large $\not{E}_T$ ▸ SUS-13-009

Aims to $\tilde{t} \to c \, \tilde{\chi}_1^0$ when $\Delta M = m_{\tilde{t}_1}$ - $m_{\tilde{\chi}_1^0} < 80$ GeV (compressed region)

Variable	Cut (GeV)	$|\eta|$
Leading Jet	$p_T > 110$	< 2.4
NL Jet	$p_T > 60$	< 4.5
$\not{E}_T$	> 250	-

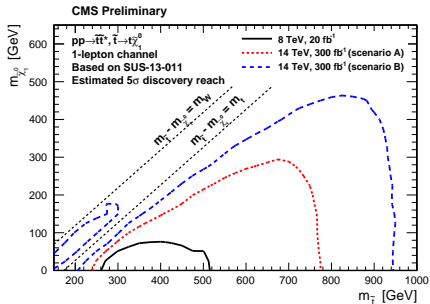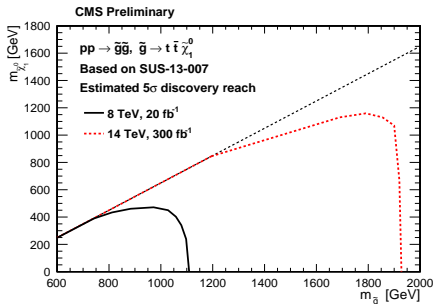$m_{\tilde{t}_1} < 250$ GeV are excluded if $\Delta M < 10$ GeV

The big picture

Summary

- Very competitive results for 3rd Gen. searches @ 8 TeV Run
- More than 12 approved analyses - many already published
- Full public results (▸ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS)
- CMS is preparing intensively for the 13 TeV Run (▸ Future studies)

BackUp

OS leptons, multi(b) jets and large $\not{E}_T$- Background Estimation

- CR : Invert either one of the two SR on the η of the two jets
- Extrapolation Factor : $R_{ext.} = \frac{N_{nb-jets,SR}}{N_{nb-jets,CR}}$ in bins of $\not{E}_T$
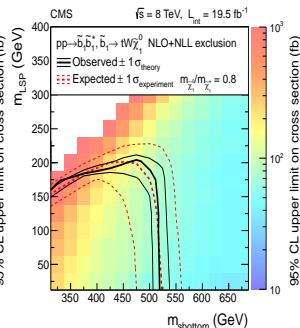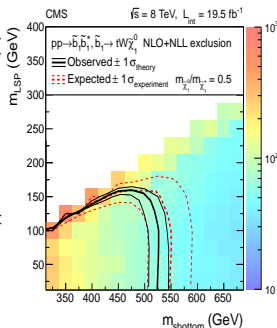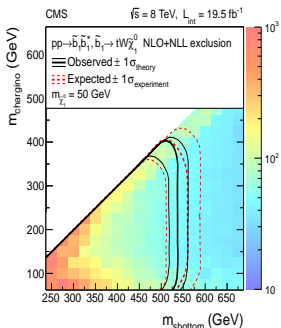- $N^{SR}_{Predicted} = R^{Obs,nb-jets=2}_{ext} \times N^{CR}_{Obs}$

Region	$\not{E}_T$(GeV)	Jets	Jets^{b-tag}	Jet $|\eta|$
Signal	> 180	> 4	> 2	Jet1 $|\eta| < 1$, Jet2 $|\eta| < 1$
Control	> 180	> 4	> 2	Jet1 $|\eta| \geq 1$ or Jet2 $|\eta| \geq 1$
Signal for R_{ext}	> 180	> 4	= 2	Jet1 $|\eta| < 1$, Jet2 $|\eta| < 1$
Control for R_{ext}	> 180	> 4	= 2	Jet1 $|\eta| \geq 1$ or Jet2 $|\eta| \geq 1$
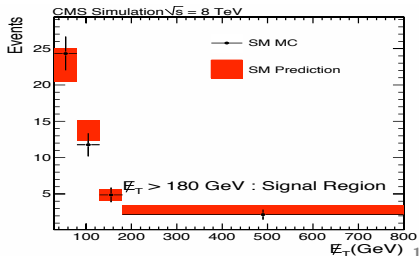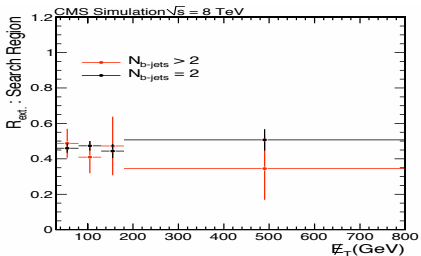
Direct Sbottoms with SS leptons ▸ SUS-13-013

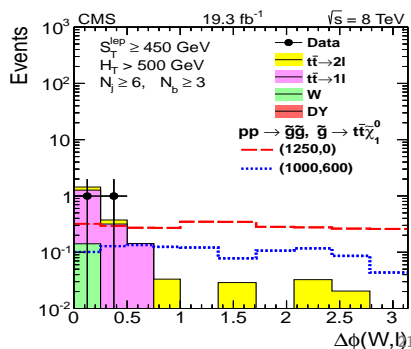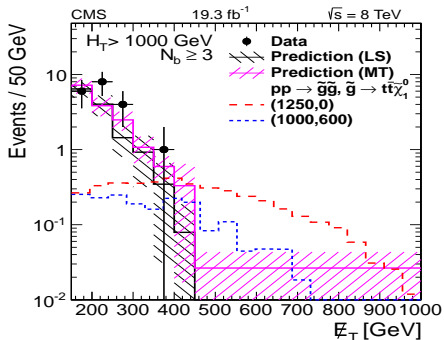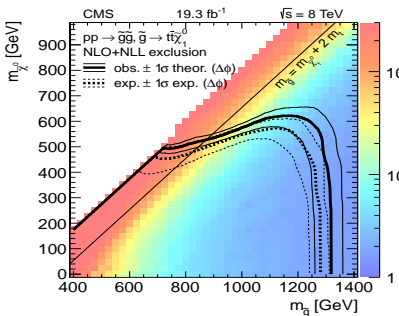| Variable	p_T (GeV) for low (high) p_T
Electrons / Muons	> 10 (20)
Jets	> 40
b-tagged Jets	> 40

$1 - \ell +$ multi(b) jets ● SUS-13-007

Models : 2+1 models depending if $m_{\tilde{g}} > (<) \; m_{\tilde{t}_1} \Rightarrow$ real/virtual $\tilde{t}$

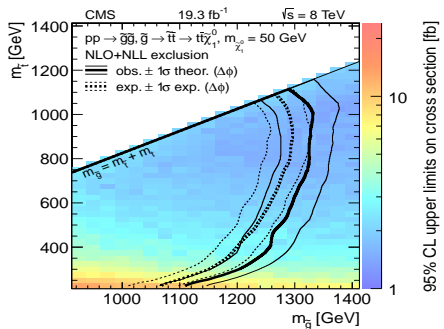Strategy : a) extract $\not{E}_T$ in high H_T (SR) b) $\Delta\Phi(W, \ell)$ in SR of $S_T = \not{E}_T + p_T^\ell$

Variable	Cut
leptons	1
Jets	≥ 3 && ≤ 5 (CR) , ≥ 6 (SR)
b-tag Jets	≤ 2 (CR), ≥ 3 (SR)
H_T	> 400 GeV

Exclusion limits

$m(\tilde{g}) \leq 1.3$ TeV are excluded

Direct Stop with multi-jets ▸ SUS-13-015

Variable	Cut
Jets	≥ 5, 1&2 > 70 GeV 3&4 > 50 GeV
b-tag Jets	≥ 1
$\Delta\Phi(\vec{p_{Tj}}, \vec{p_T^{miss}}), j = 1, 2, 3$	$> 0.5, > 0.5, > 0.3$
M_{T2}	≥ 300 GeV
$0.5 \cdot M_T^{3-jet} + M_T^{Rsys}$	≥ 500 GeV

CMS Preliminary, L = 19.4 fb^{-1}, $\sqrt{s}$ = 8 TeV
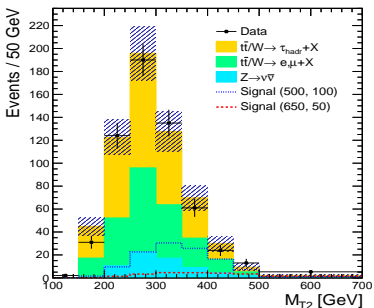
CMS Preliminary, L = 19.4 fb^{-1}, $\sqrt{s}$ = 8 TeV
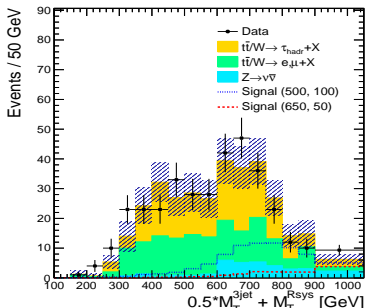
Direct Stop with multi-jets - Exclusion Plots