



3rd GENERATION SUSY SEARCHES AT CMS

DEEP INELASTIC SCATTERING 2014, WARSAW

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on behalf of the CMS collaboration

April 30, 2014

Outline

- 1 Introduction
- 2 Gluino Mediated Searches
- 3 Direct Production Searches
- 4 Other Searches
- 5 Summary

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 $\Rightarrow \cancel{E}_T$ signatures

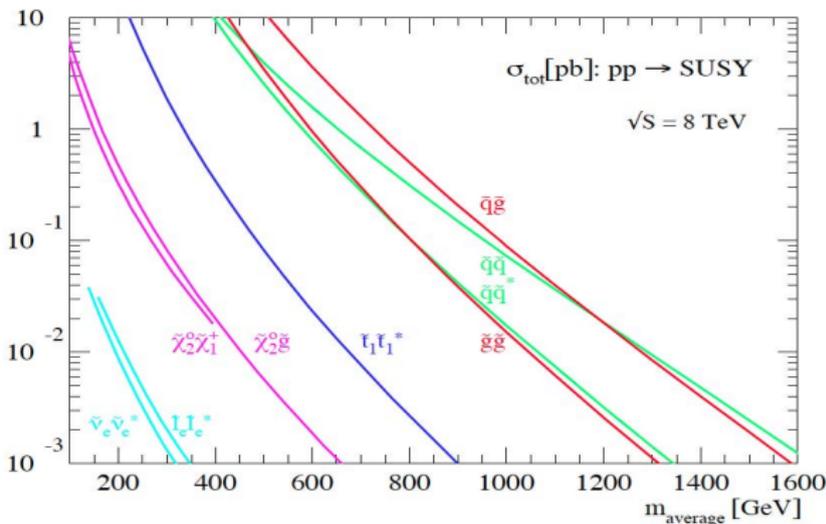
R-Parity not-conserved

- SUSY part. can be created "solo"
- LSP decays as well \Rightarrow no \cancel{E}_T

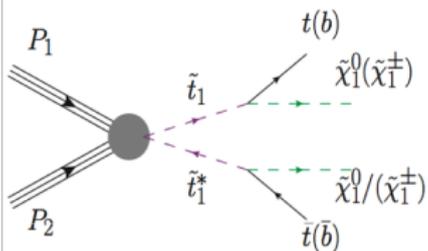
Working with Simplified Models Spectrum (bottom-up approach)

- 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 u.l. on the $\sigma \times BR$ for each model

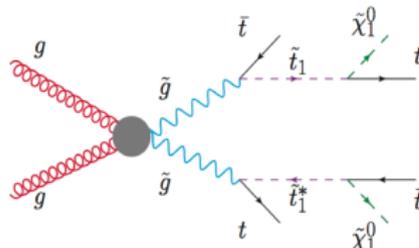
Production Mechanisms



Direct production



Gluino mediated production



CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A

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

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

SILICON TRACKER
Pixels (100 x 150 μm^2)
~1m² ~60M channels
Microstrips (80-180 μm)
~200m² ~9.6M channels

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

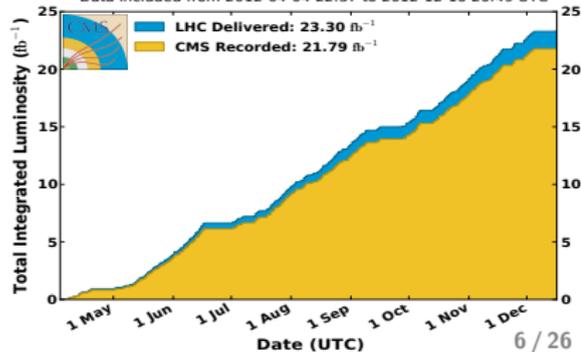
FRESHOWER
Silicon strips
~16m² ~137x channels

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

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

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

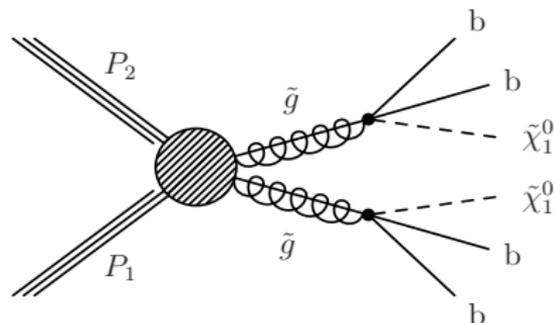
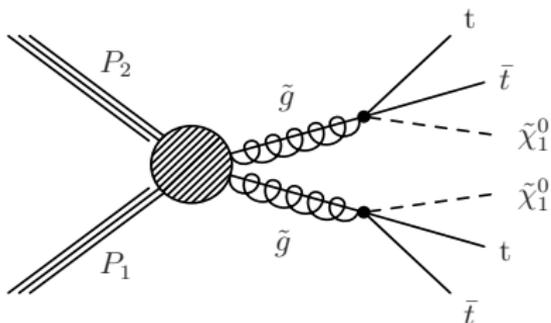
Data included from 2012-04-04 22:37 to 2012-12-16 20:49 UTC



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}

Glauino Mediated Searches

Final State	Analysis	Mode	
		$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$	$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$
$0 - \ell$	Multi-jets + \cancel{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 + \cancel{E}_T (SUS-13-016)	✓	
	3 ℓ + b-jets (SUS-13-008)		✓



*See Niki Saoulidou's talk "Inclusive SUSY Searches @ CMS"

OS leptons, multi(b) jets and large \cancel{E}_T

▶ SUS-13-016

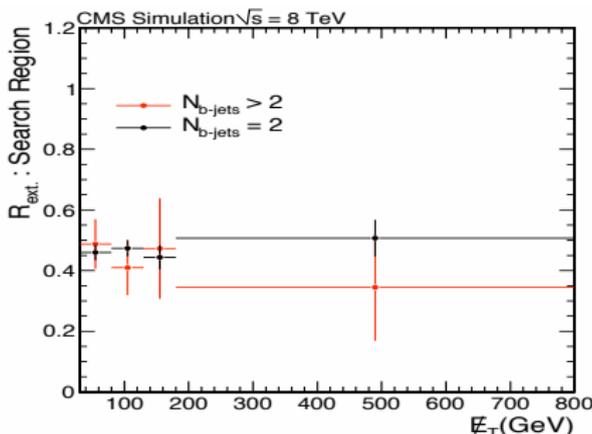
Preselection : OS- ℓ (Iso), ≥ 2 Jets ($p_T > 30$ GeV)

Signal Region : $\cancel{E}_T > 180$ GeV, > 4 Jets, > 2 b-tag Jets, $\text{Jet}_{1,2}^{|\eta|} < 1$

Control Region : Invert the η of either one of the two leading jets

Extrapolation Factor (Bkg estim) : $R_{ext.} = \frac{N_{nb-jets,SR}}{N_{nb-jets,CR}}$ in bins of \cancel{E}_T

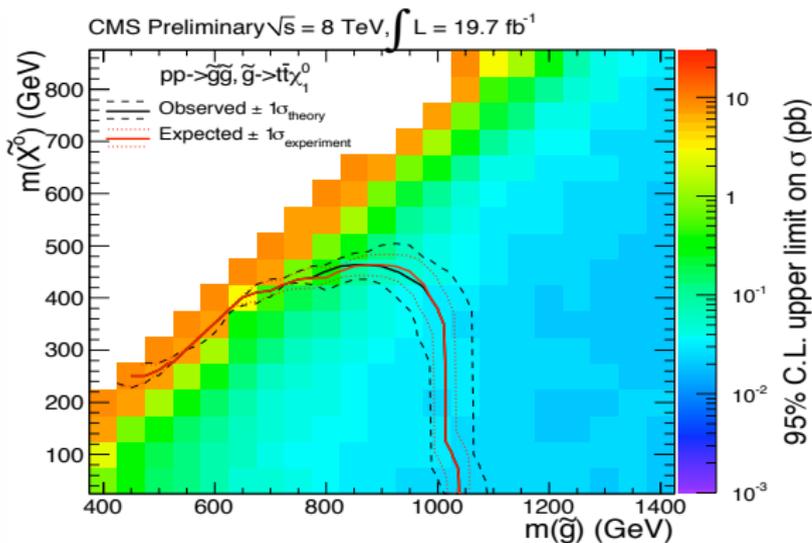
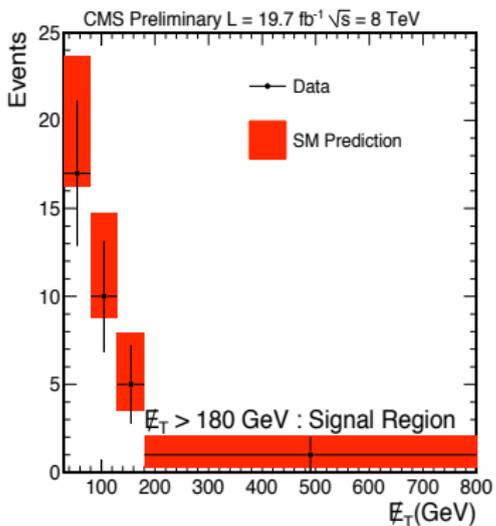
- Smooth as a function of \cancel{E}_T
- Almost invariant under the number of b-jets



OS leptons, multi(b) jets and large \cancel{E}_T

▶ SUS-13-016

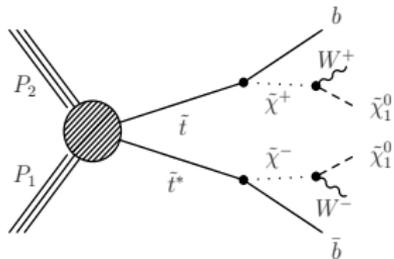
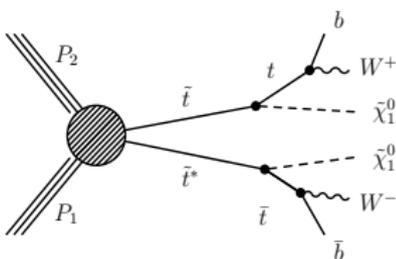
$$\text{Prediction @ SR : } N_{\text{Predicted}}^{SR} = R_{\text{ext}}^{\text{Obs}, nb-jets=2} \times N_{\text{Obs}}^{CR}$$



$m(\tilde{g}) \simeq 1 \text{ TeV}$ are excluded for $m(\tilde{\chi}_1^0) \approx 400 \text{ GeV}$

Direct Stop Pair Production

Final State	Analysis	Mode	
		$\tilde{t} \rightarrow t\tilde{\chi}_1^0$	$\tilde{t} \rightarrow b\tilde{\chi}_1^\pm$
$0 - \ell$	Multi-jets + \cancel{E}_T (SUS-13-015)	✓	
$1 - \ell$	$1 - \ell + \text{b-jet(s)} + \cancel{E}_T$ (SUS-13-011)	✓	✓



Direct Stop in $1 - \ell + \cancel{E}_T$ ▶ SUS-13-011

Cut & count and an BDT MVA method

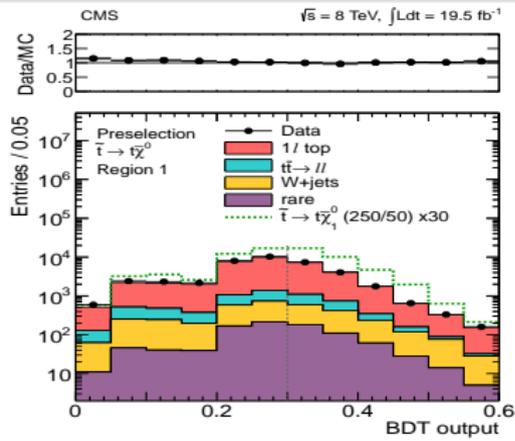
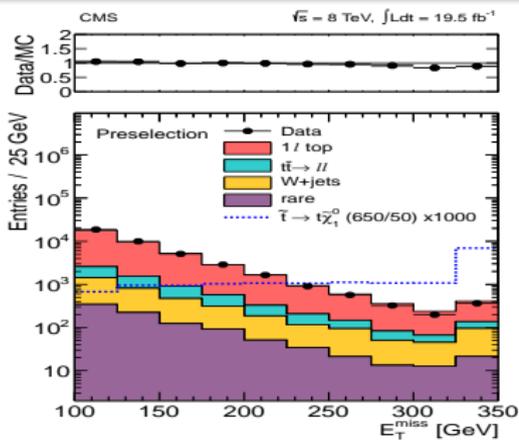
Preselection : 1 Isolated $-\ell$, ≥ 4 Jets, $\geq 1b$ - tag, $\cancel{E}_T > 100$ GeV

Variables : \cancel{E}_T , $\min\Delta\Phi$, M_{T2}^W , H_T^{ratio} , p_T^ℓ , $\text{lead}_{\text{bjet}}^{\text{PT}}$, $\Delta R(\ell, \text{lead}_{\text{bjet}}^{\text{PT}})$...

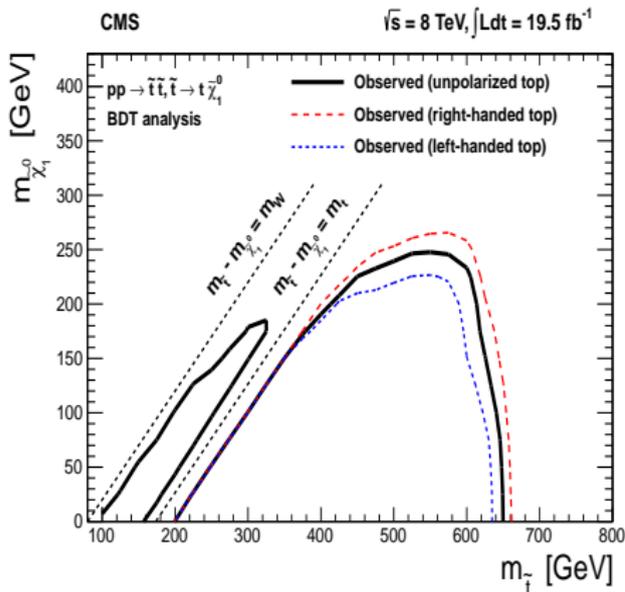
Signal Regions : always use $M_T > 120$ GeV

BDT : several ΔM Region + selection of optimal cut in MVA output

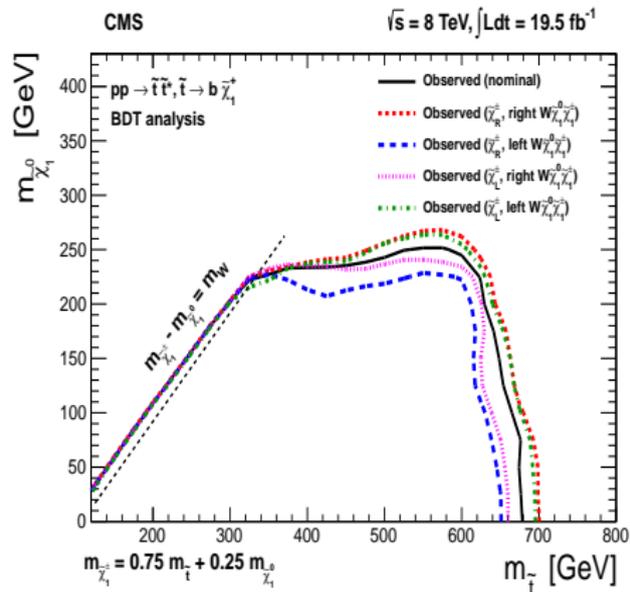
Cut Based : $2 \times \Delta M$ Regions + kinematic cuts (i.e. $\min\Delta\Phi > 0.8$)



Direct Stop in $1 - \ell$ - Exclusion Plots



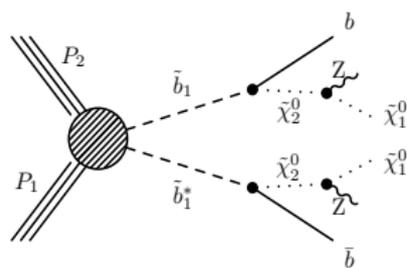
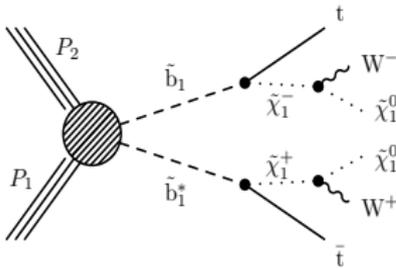
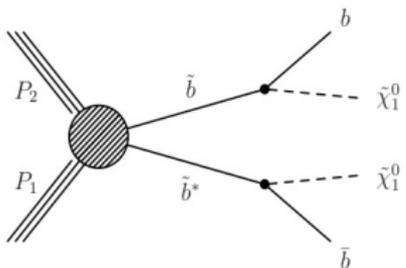
$m(\tilde{t}) \simeq 650$ (600) GeV are excluded
for $m(\tilde{\chi}_1^0) = 0$ (≈ 240) GeV



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

Direct Sbottom Pair Production

Final State	Analysis	Mode		
		$\tilde{b} \rightarrow b\tilde{\chi}_1^0$	$\tilde{b} \rightarrow tW\tilde{\chi}_1^0$	$\tilde{b} \rightarrow bZ\tilde{\chi}_1^0$
$0 - \ell$	b-jets + H_T + \cancel{E}_T (SUS-13-018)	✓		
$1 - \ell$	1-l + b-jet(s) + \cancel{E}_T (SUS-13-011)	✓	✓	
$> 1 - \ell$	SS -l + jets + \cancel{E}_T (SUS-13-013)		✓	
	3-l + b-jets + \cancel{E}_T (SUS-13-008)		✓	✓



Direct Sbottom in b-jets + H_T + \cancel{E}_T (SUS-13-018)

[SUS-13-018](#)

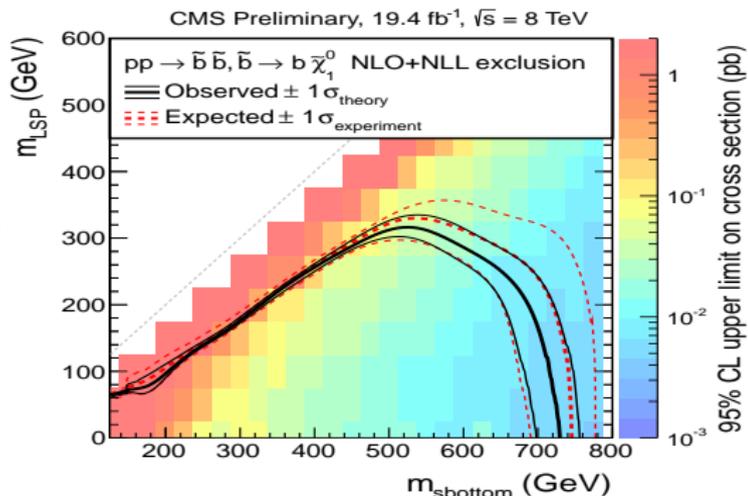
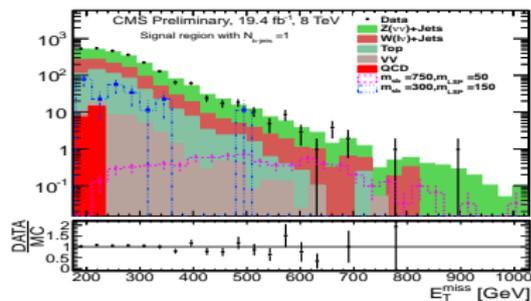
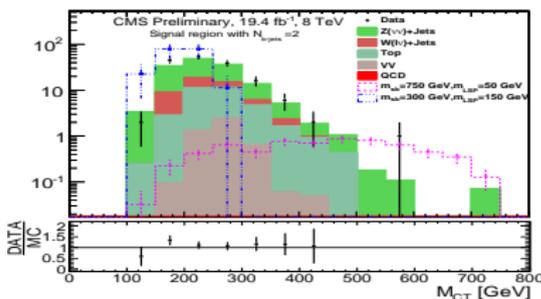
Use of boost-corrected transverse mass

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

Baseline : == 2 jets, ($p_T > 70$ GeV) ≥ 1 b-tags, $H_T > 250$ GeV

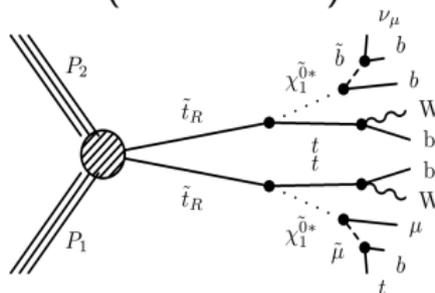
Signal enriched : $\cancel{E}_T > 175$ GeV, $\Delta\phi(J_1, J_2) < 2.5$, $M_T(\cancel{E}_T, J_2) > 200$ GeV

Search Regions : 1 & 2 b-tags for $m_{CT} \times$ (<250, 350, 450, > 450) GeV

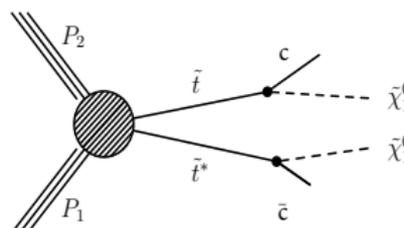


Other Searches

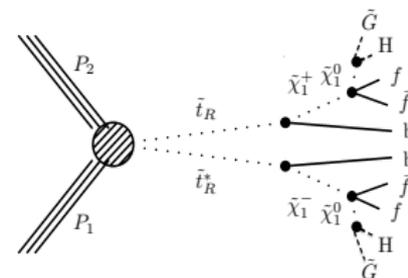
RPV Stop Search
(SUS-13-003)



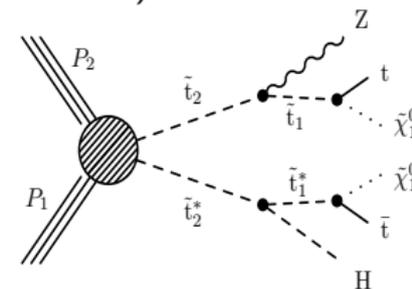
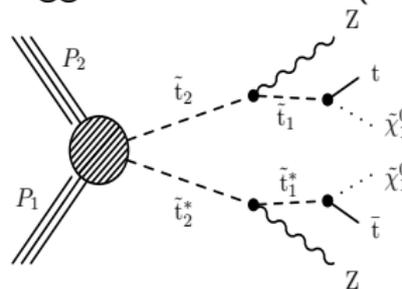
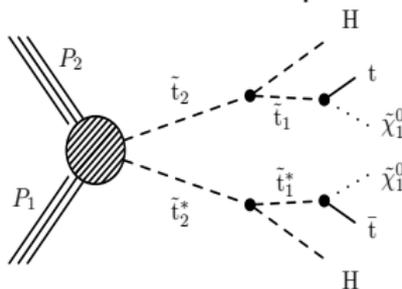
Compressed spectrum
(SUS-13-009)



Stop with Higgs boson
(SUS-13-014)



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



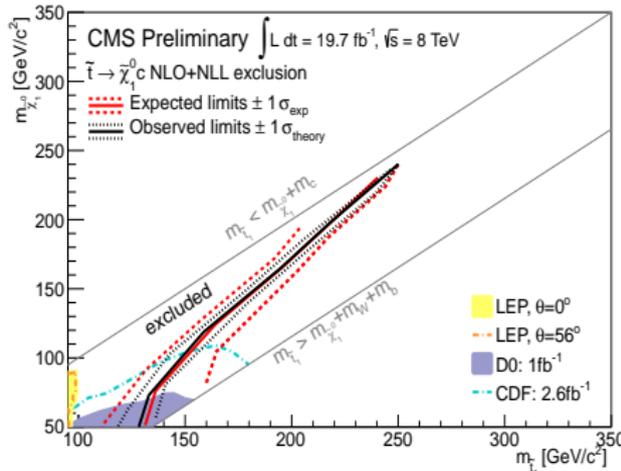
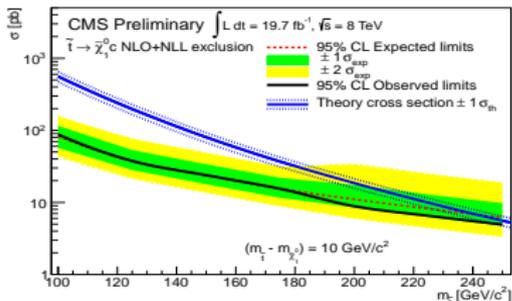
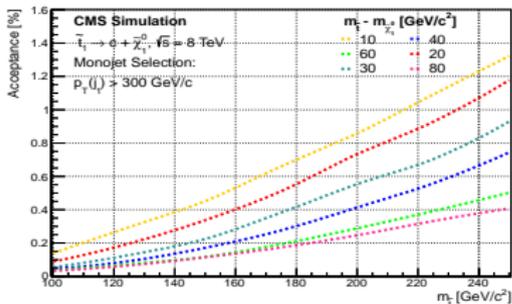
Direct Stops using monojet + large E_T

▶ SUS-13-009

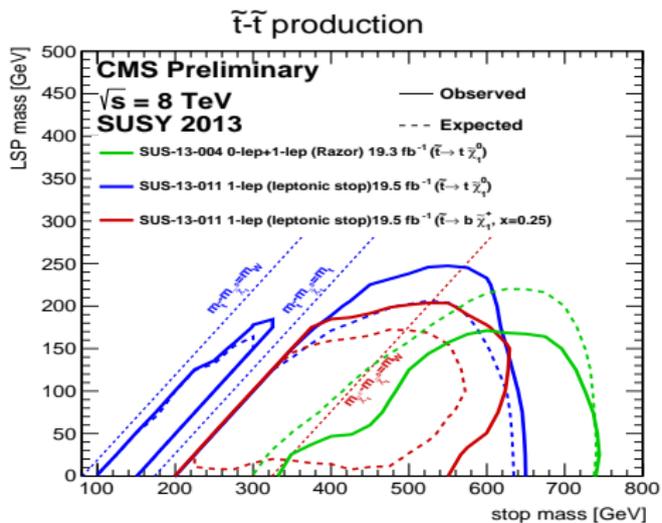
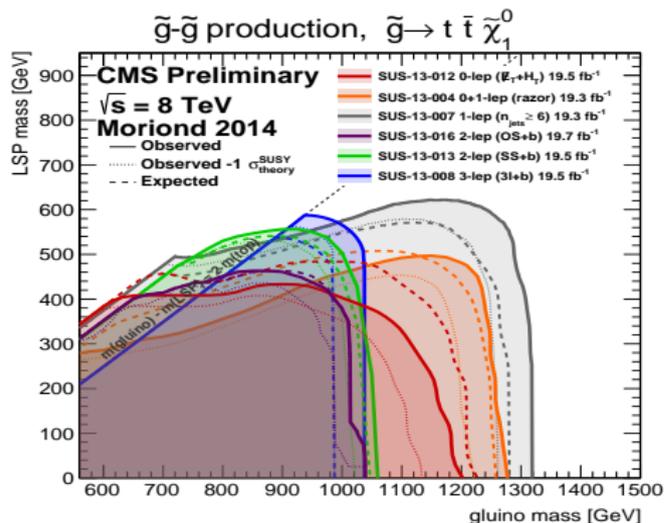
Aims to $\tilde{t} \rightarrow c \tilde{\chi}_1^0$ when $\Delta M = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < 80$ GeV (compressed Region)

Selection : 2 jets ($p_T^{J1} > 110, p_T^{J2} > 60$ GeV), veto on ℓs , $E_T > 250$ GeV

Signal Regions : $p_T^{J1} > 250, 300, 350, 400, 450, 500, 550$

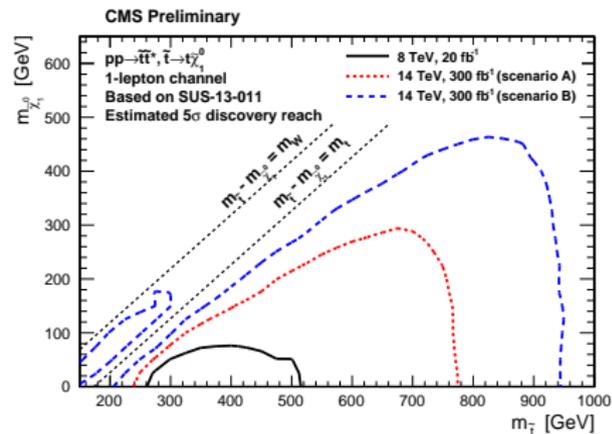
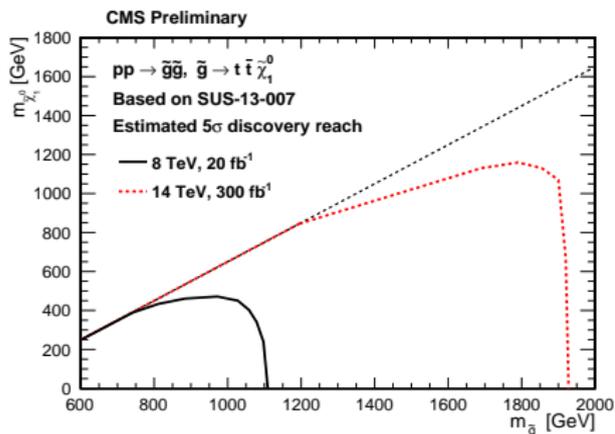


The big picture



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](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS)
- CMS is preparing intensively for the 13 TeV Run [▶ Future studies](#)



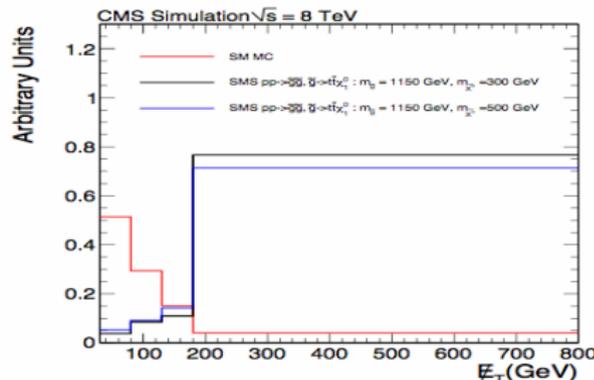
BackUp

OS leptons, multi(b) jets and large E_T

▶ SUS-13-016

Baseline Selection

Sample	Event Selection	Signal selection
tt	82171 ± 287	2.2 ± 0.7
Z + jets	1475456 ± 1215	0.0 ± 1.5
W + jets	26978 ± 164	0.0 ± 6.3
WW	1637 ± 44	0.0 ± 0.3
WZ	1364 ± 37	0.0 ± 0.1
ZZ	3129 ± 56	0.0 ± 0.2
ttW + jets	434 ± 3	0.2 ± 0.07
ttZ + jets	463 ± 3	0.2 ± 0.06
Total SM Bkg.	1591632 ± 1261	2.6 ± 6.5
$m_{\tilde{g}}=1000$ GeV $m_{LSP}=400$ GeV	28.2 ± 0.5	4.3 ± 0.2
$m_{\tilde{g}}=1150$ GeV $m_{LSP}=300$ GeV	9.8 ± 0.2	1.9 ± 0.1
$m_{\tilde{g}}=1150$ GeV $m_{LSP}=500$ GeV	9.5 ± 0.2	1.6 ± 0.1



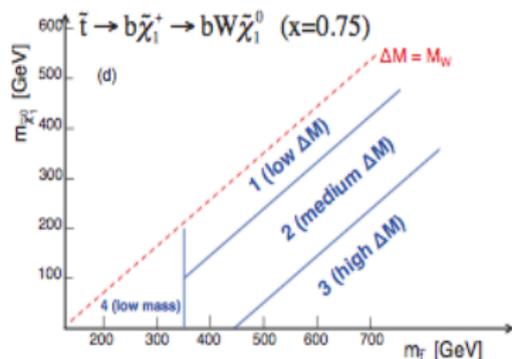
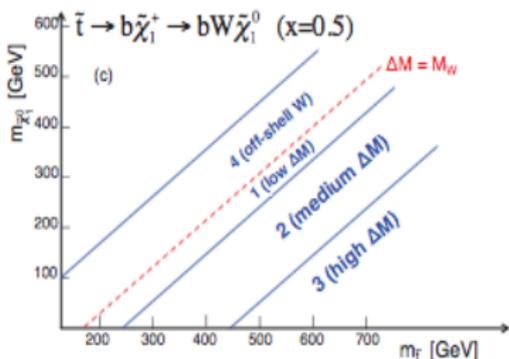
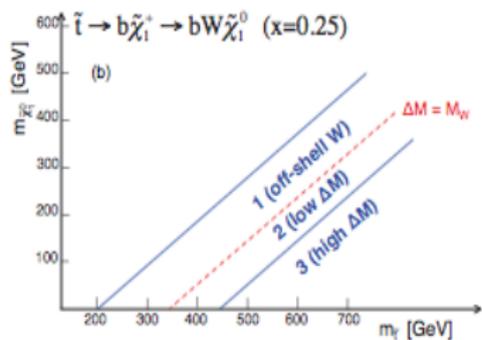
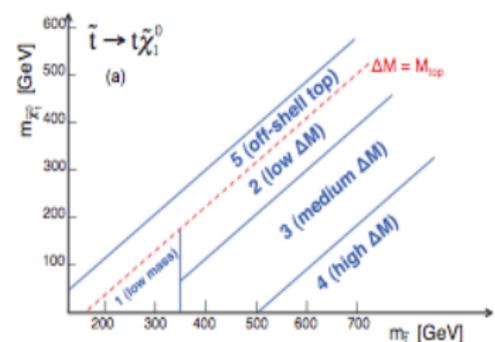
Systematics

Source	Uncertainty
Lepton triggers ($p_T > 20$ GeV)	6%
Lepton isolation, reconstruction and identification	4%
Luminosity	2.6%
b jet identification	14%
Jet energy scale and resolution	8%
PDF	2%
ISR	1-18%
Pileup effects	1%
Simulation statistics	2-30%
Total	17-39%

Direct Stop in $1 - \ell + \cancel{E}_T$

▶ SUS-13-011

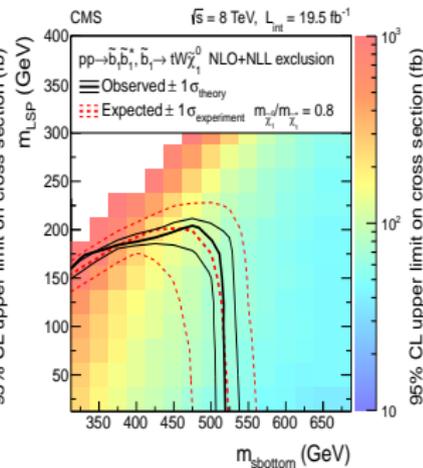
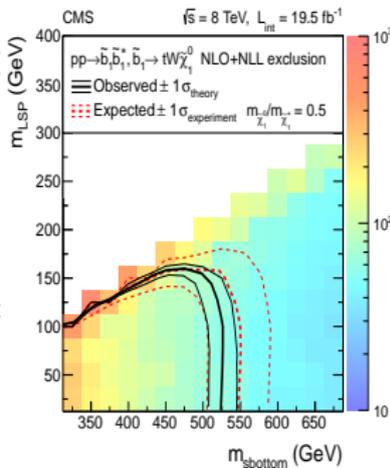
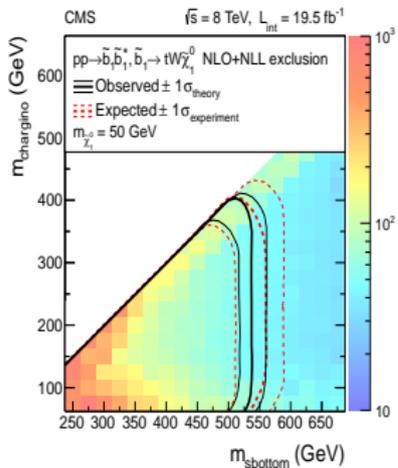
ΔM in DBT training



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



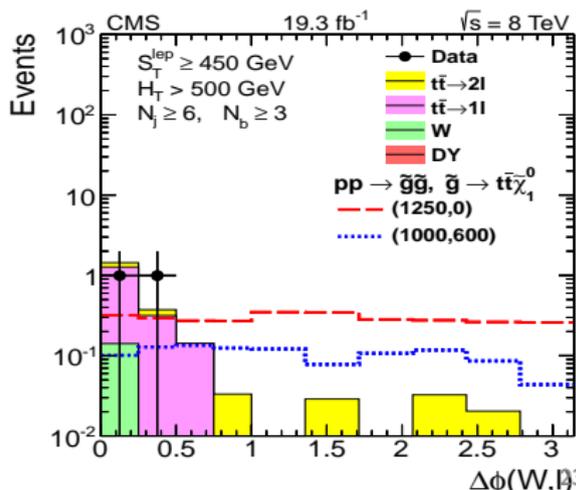
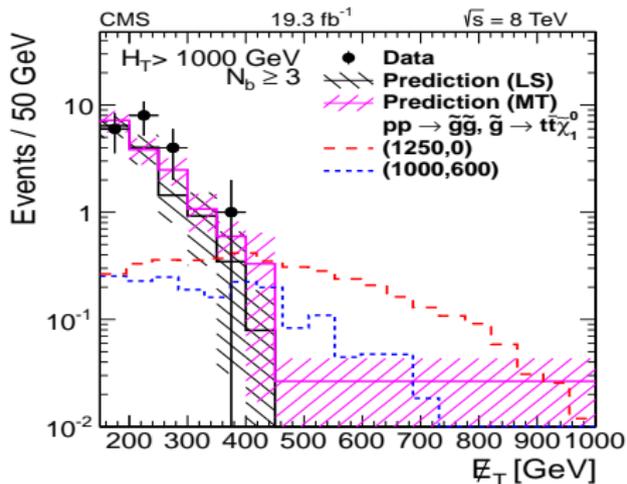
1 - ℓ + multi(b) jets

▶ SUS-13-007

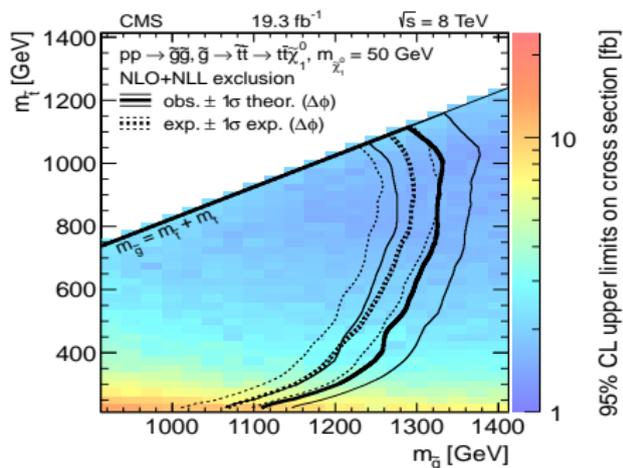
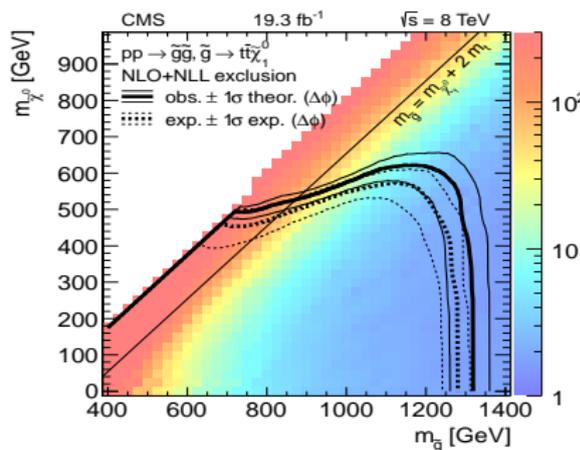
Models : 2+1 models depending if $m_{\tilde{g}} > (<) m_{\tilde{t}_1} \Rightarrow$ real/virtual \tilde{t}

Strategy : a) extract \cancel{E}_T in high H_T (SR) b) $\Delta\Phi(W, \ell)$ in SR of $S_T = \cancel{E}_T + p_T^\ell$

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



Exclusion limits



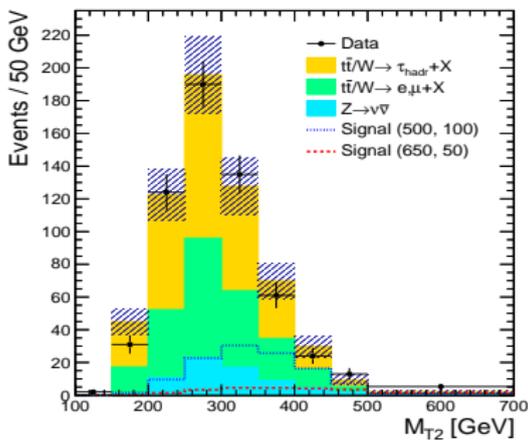
$m(\tilde{g}) \leq 1.3$ TeV are excluded

Direct Stop with multi-jets

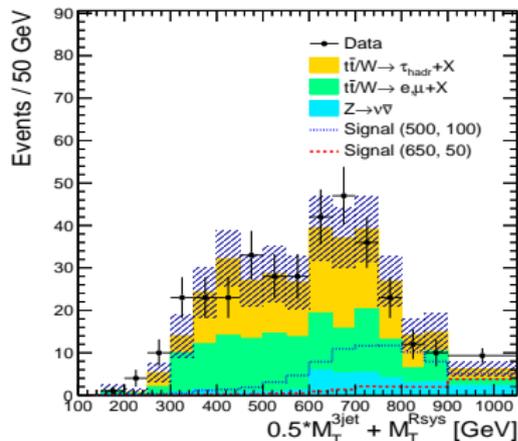
▶ SUS-13-015

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

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



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



Direct Stop with multi-jets - Exclusion Plots

