Search for stop and sbottom pair production at the LHC using the CMS detector

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on behalf of the CMS collaboration

Outline:

- **Physics motivation**
- **Single lepton searches for:**
  - **Gluino induced stop production**
  - **Direct stop production**

  [searches for sbottoms will be covered in other CMS talks]
- **Summary and conclusions**

European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS, CULTURE & SPORTS
MANAGING AUTHORITY
Co- financed by Greece and the European Union

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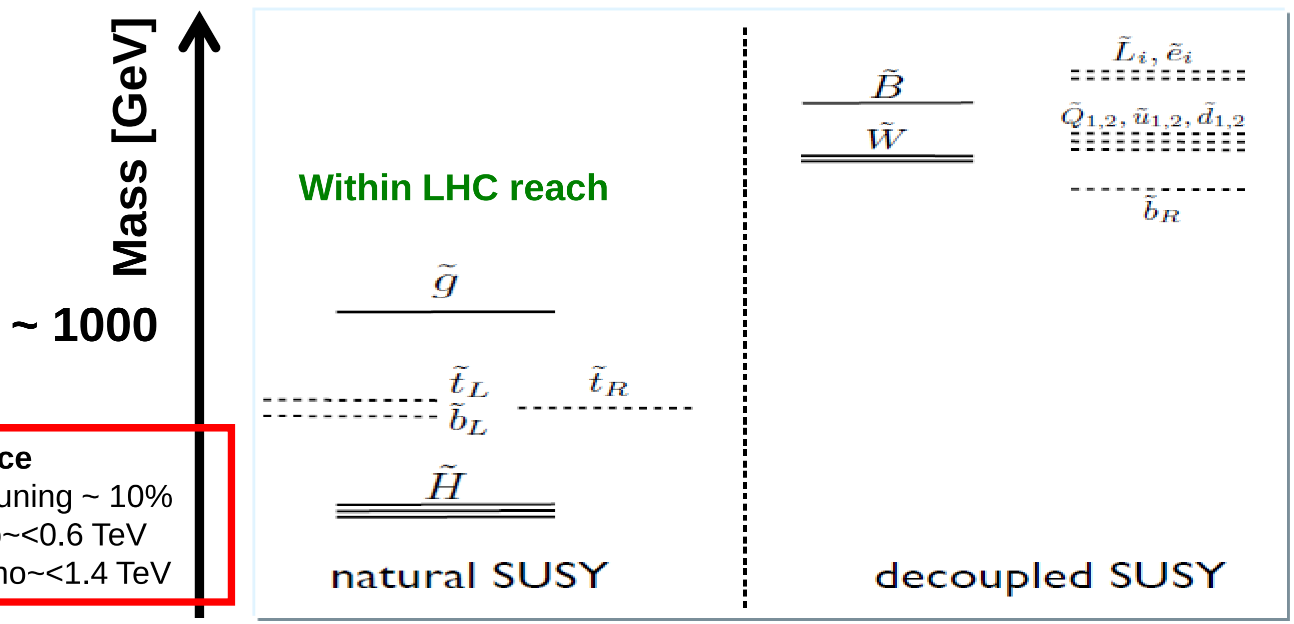
EUROPEAN SOCIAL FUND

Co-funded by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF).

Physics motivation

Physics motivation

- **Experimental results show no evidence of SUSY**
  - **Constrained SUSY models cornered – though not excluded yet**
- **Motivation for SUSY at the EWK scale: naturalness**
  - **Top/ bottom squarks [3G] and gluino masses at ~TeV scale**



Giudice
Fine tuning ~ 10%
Mstop~<0.6 TeV
Mgluino~<1.4 TeV

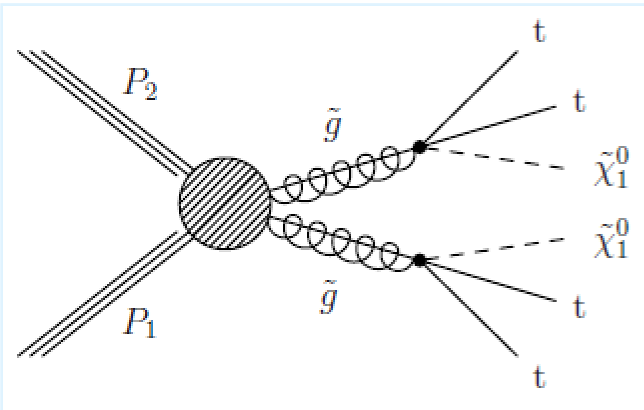
Papucci, Ruderman, Weiler
hep-ph 1110.6926

Barbieri et al.
hep-ph 9512388

Physics motivation (II)

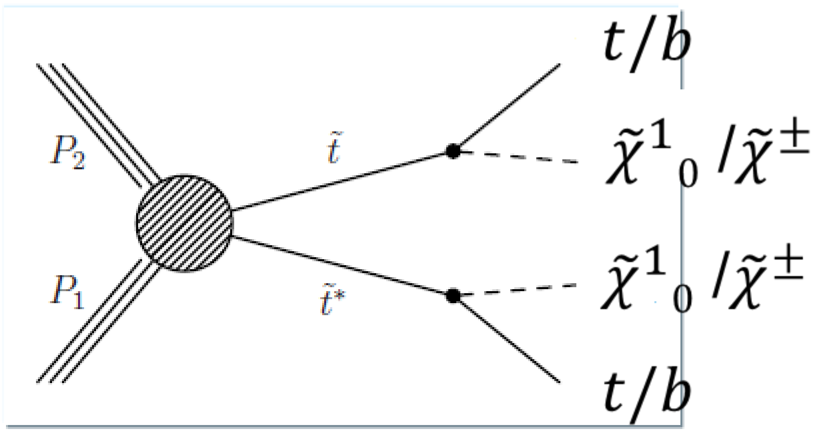
- **stop production:**

Gluino induced production



$\tilde{g} \to t\tilde{t} \to tt\tilde{\chi}^1{}_0 \to bW\tilde{\chi}^1{}_0$

Direct production



$\tilde{t} \to t\tilde{\chi}^0{}_1 \to bW\tilde{\chi}^1{}_0$

$\tilde{t} \to b\tilde{\chi}^{\pm} \to bW^{\pm}\tilde{\chi}^1{}_0$

- **Leptonic channels [through W decay] important BR**
  - **1lep: ~40% for the indirect production, ~30% for the direct prod.**
- **I'll speak about the single lepton searches**

Gluino induced stop search

CMS-SUS-13-007

Gluino induced stop search

- 1lep: Largest BR; sensitivity competitive to all hadronic
- Selection:
  - 1 isolated lepton [e/ μ] → **Dominant bkg: ttbar + jets**
  - Njts≥6 , Nbjets≥2
- Two independent searches using different data–driven background estimation methods
  - Δφ method [DP]:
    - SM – SUSY discrimination based on the angle between W and lepton
    - Binned in N_{bjets} and S_T^{lep},; S_T^{lep} = (p_T[lep] + MET) > 250 GeV
  - Lepton spectrum method [LS]:
    - Predict ME_T distribution for SM background from the lepton p_T spectrum
    - Binned in ME_T ; ME_T>250 GeV for different H_T thresholds

Δφ: Strategy & EWK bkg estimation

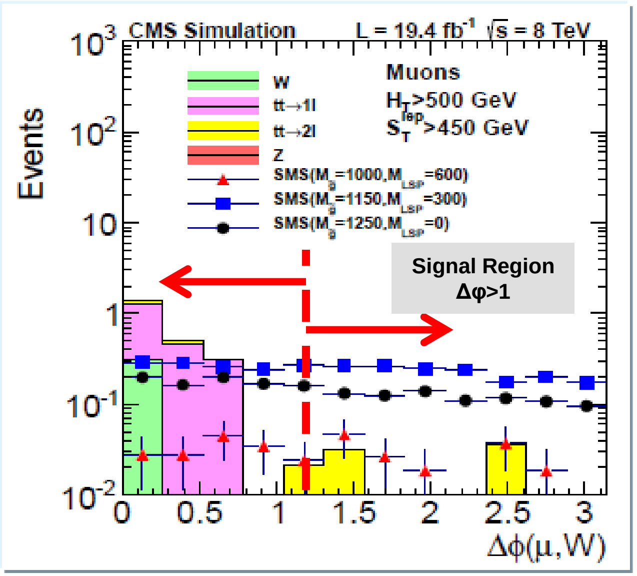
- Require $\Delta\phi>1$ [$\Delta\phi<1$ control region]
- Define translation factor R_{CS}:

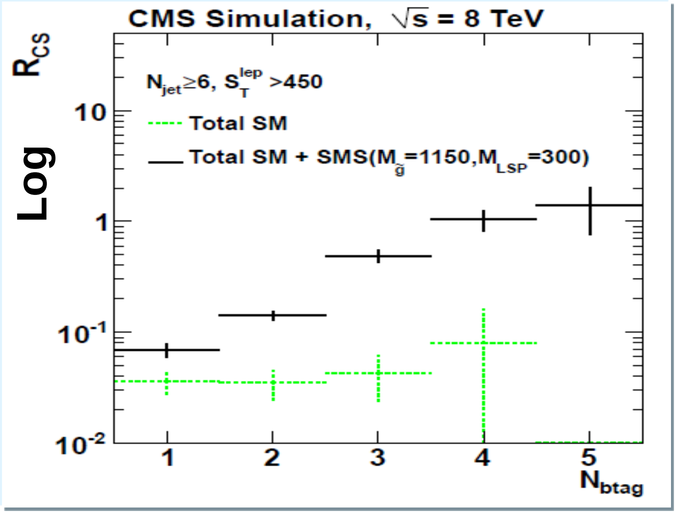
$$R_{CS} = \frac{N_{signal}}{N_{control}} = \frac{\text{Number of events with } \Delta\phi(W,l) > 1)}{\text{Number of events with } \Delta\phi(W,l) < 1)}$$

- R_{CS} dependance on N_{bjets} very weak
  - measure in data in N_b=1, use in N_b=2,≥3
  - k_{CS} [MC] for residual differences
- Prediction:

$$N_{signal}(N_b \geq 3) = R_{CS}(N_b = 1) \cdot \kappa_{CS}(N_b \geq 3) \cdot N_{control}(N_b \geq 3)$$

- Potential presence of signal drastic effect on R_{CS}





CMS-SUS-13-007

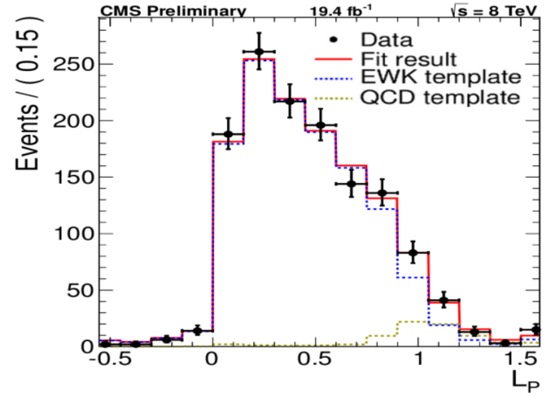
Δφ: QCD Bkg estimation

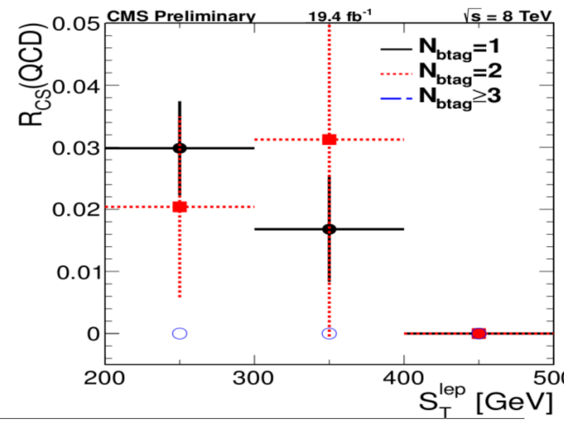
- **QCD background small compared to other bkgs**
  - **negligible in the muon channel**
- **Estimate QCD contribution using well tested method**
  [PRL (2011) 107:02180, CMS-SUS-11-015, CMS-SUS-12-010]
  - **Invert electron id variables and estimate QCD shape from anti-selected data sample**
  - **Binned likelihood fit in Lp to estimate total QCD**

$$L_P = \frac{\vec{P}_T(l)\cdot\vec{P}_T(W)}{|\vec{P}_T(W)|^2}$$

    - **EWK template from MC**
  - **Calculate R_{CS}[QCD] from anti-selected data**
- **N_{QCD}<5% of total data, negl. for Δφ>1**
  - **subtract contribution in control region**
- **Prediction in electron channel:**

$$N_{SMest.}(\Delta\phi(W,l)>1) = R_{CS}^{EWK}\cdot\left(N_{data}(\Delta\phi(W,l)<1) - N_{QCD}(\Delta\phi(W,l)<1)\right)$$





CMS-SUS-13-007

Dphi: Method validation and results

- **All ingredients of the analysis tested in bkg dominated sample [$3 \le N_{jets} \le 5$] in data**

Control sample [$3 <= N_{jets} <= 5$]

L=19.4 fb^{-1}

		S_T^{lep} [GeV]	control reg. data	prediction	observation
$N_b=2$	Muons	[250,350]	632	41.94± 5.63	59
		[350,450]	188	8.51± 2.39	11
		> 450	71	2.46± 1.32	1
	Electr.	[250,350]	548	34.23±5.37	30
		[350,450]	174	5.11±1.85	8
		>450	61	5.57±2.14	1
$N_b \ge 3$	Muons	[250,350]	59	3.88±0.81	5
		[350,450]	25	1.09±0.44	0
		> 450	7	0.26±0.21	0
	Electr.	[250,350]	70	3.91±0.92	2
		[350,450]	12	0.32±0.16	2
		>450	4	0.32±0.24	0

Stat. uncertainties only

Good agreement between prediction and observed data [☺]

Results @ 19.4 fb^{-1}

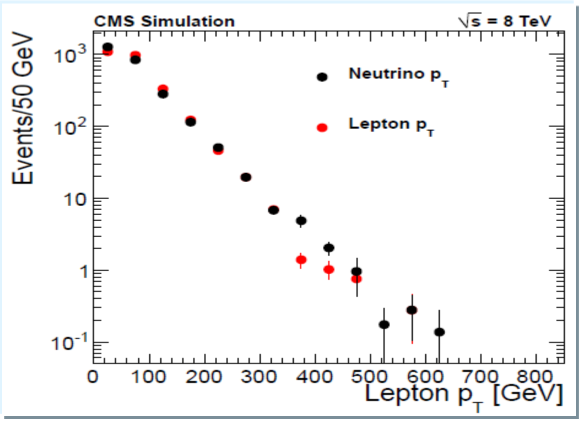
		S_T^{lep} [GeV]	control reg. data	prediction	observation
$N_b=2$	Muons	[250,350]	141	6.00 ± 2.40 (2.23)	9
		[350,450]	24	1.37 ± 1.19 (1.12)	2
		>450	9	0.0 ± 0.66 (0.66)	0
	Electr.	[250,350]	112	3.83 ± 1.84 (1.75)	9
		[350,450]	28	2.74 ± 2.02 (1.86)	2
		>450	9	0.0 ± 0.42 (0.42)	0
$N_b \ge 3$	Muons	[250,350]	28	1.92 ± 0.95 (0.84)	0
		[350,450]	13	0.57 ± 0.58 (0.52)	0
		>450	2	0.0 ± 0.22 (0.22)	0
	Electr.	[250,350]	45	1.89 ± 1.03 (0.94)	4
		[350,450]	7	0.85 ± 0.80 (0.70)	0
		>450	0	0.0 ± 0.08 (0.08)	0

total uncertainty (stat unc)

Observed data agree with SM expectations [☹]

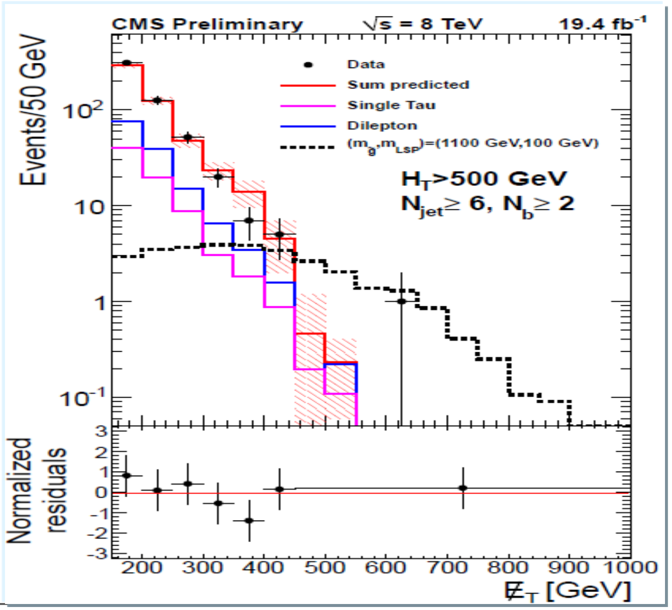
LS: Strategy, bkg estimation & results

- **Main background: 1-lep ttbar**
- **Estimate ME_T distribution for 1l events from the lepton p_T spectrum**
  - **Residual differences→correction from MC**
- **tt(ll) & *τ→l* bkgs estimated separately**



Results @ 19.4 fb^{-1}

$\not\!\!E_T$:	[150,250)	[250,350)	[350,450)	≥ 450 GeV
$1\ \ell$	$304.0\pm17.4\pm16.4$	$49.9\pm7.7\pm6.0$	$13.4\pm4.8\pm3.1$	$0.3^{+1.9+0.8}_{-0.3-0.3}$
Dilepton	$54.7\pm4.2\pm9.0$	$9.6\pm1.5\pm4.4$	$2.3^{+1.3+1.0}_{-0.7-0.6}$	$0.1^{+1.8+1.8}_{-0.1-0.1}$
Single tau	$60.1\pm2.1\pm5.1$	$11.8\pm0.9\pm3.6$	$2.7\pm0.5\pm1.9$	$0.3\pm0.1\pm0.1$
Z+jets (from MC)	$0.5\pm0.1\pm0.5$	<0.1	<0.1	<0.1
QCD multijet	$1.6\pm3.1\pm3.1$		$0.0\pm1.2\pm1.2$	
Total (predicted):	$419.3\pm18.0\pm19.4$	$71.3\pm7.9\pm8.3$	$18.4^{+5.0+3.8}_{-4.9-3.7}$	$0.7^{+2.6+2.0}_{-0.3-0.3}$
Data (observed), **total** (μ, e):	**437** (237, 200)	**72** (38, 34)	**12** (7, 5)	**1** (0, 1)
SMS ($m_{\tilde{g}} = 1150$ GeV, $m_{LSP} = 500$ GeV)	5.1 ± 0.2	5.6 ± 0.2	3.7 ± 0.2	3.0 ± 0.2
SMS ($m_{\tilde{g}} = 1100$ GeV, $m_{LSP} = 100$ GeV)	6.5 ± 0.3	7.6 ± 0.3	7.3 ± 0.3	9.1 ± 0.3

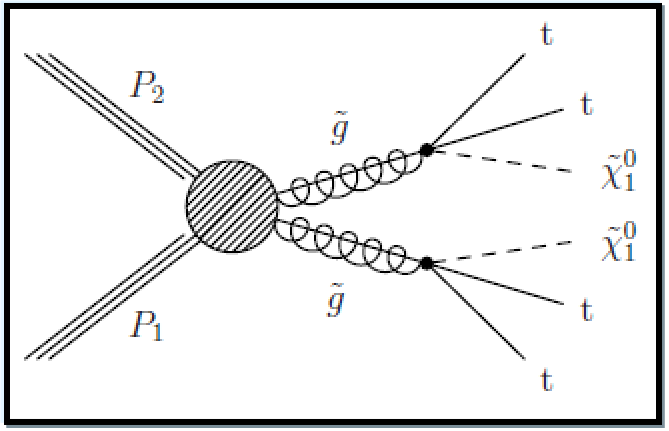


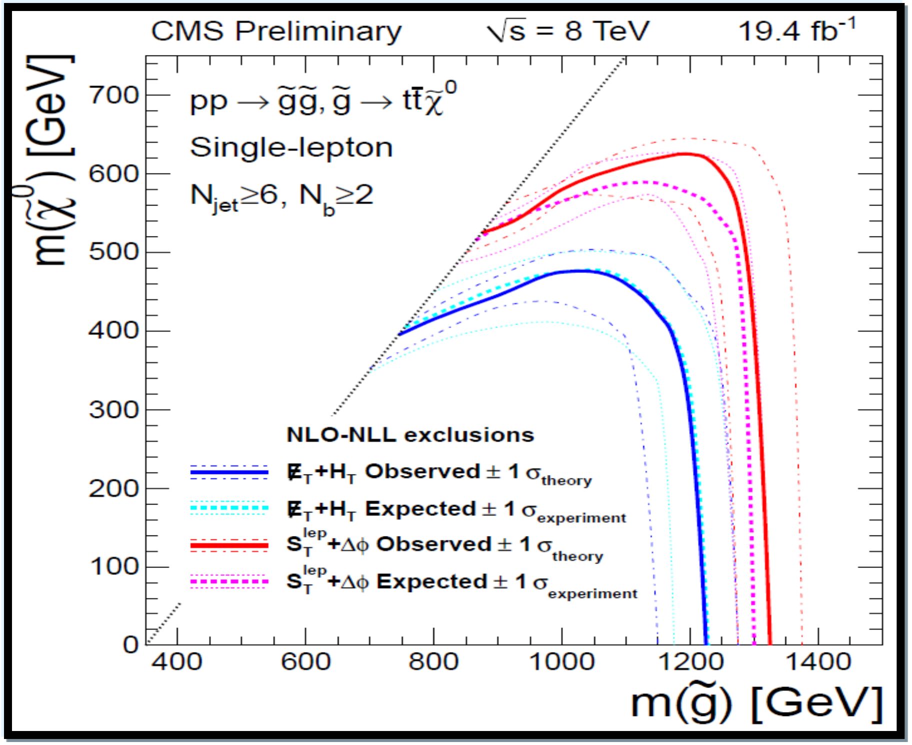
Observed data agree with SM expectations [☹]

CMS-SUS-13-007

Interpretation in $\tilde{g} \to t\tilde{t} \to tt\tilde{\chi}^1{}_0$

- **Limits set for gluino induced stop production**
- **Simultaneous fit over all search bins**
  - **LS: select HT region with best expected limit**



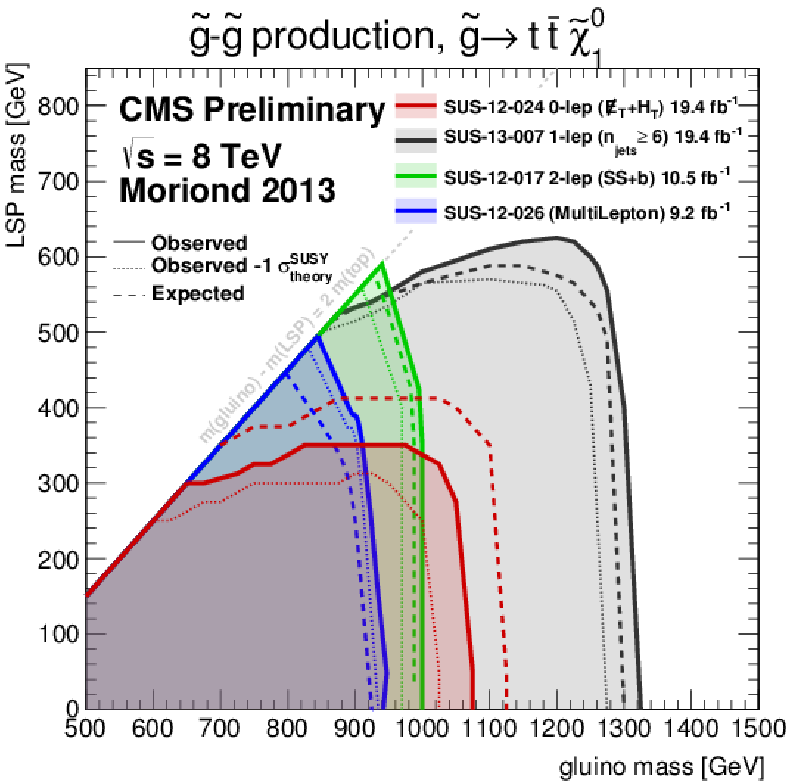


Exclude gluino mass ~1280 GeV for $\tilde{\chi}_0$ ~ 570 GeV

CMS-SUS-13-007

Interpretation in $\tilde{g} \rightarrow t\tilde{t} \rightarrow tt\tilde{\chi}^1{}_0$

- **Summary of the CMS searches based on the lepton multiplicity**



– **Single lepton search [19.4 fb^{-1}] most competitive results**

– **2lep, SS [10.5 fb^{-1}] quite sensitive if gluino and LSP masses are compressed due to low MET requirement [details in Manfred's presentation]**

– **All hadronic search [19.4 fb-1] details Robert's presentation**

Excluded M_{gluino} ~ 1280 GeV and M_{lsp} ~ 570 GeV

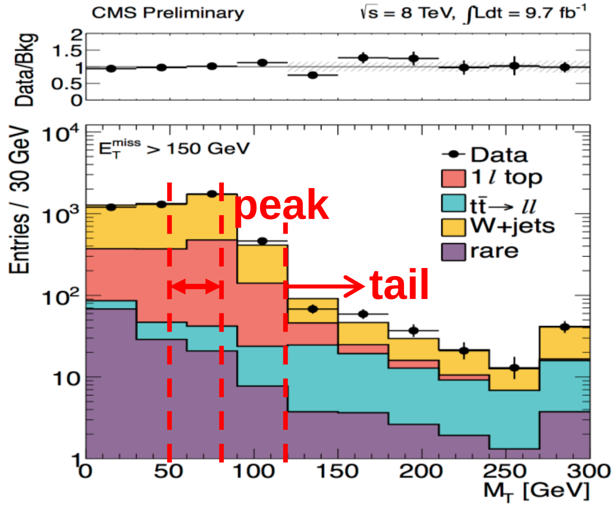
Direct stop search

CMS-SUS-12-023

Direct stop search: strategy

- **Event selection:**
  - 1 isolated lepton [e/μ], $N_{jets}\geq4$, $N_{bjets}\geq1$
  - ME_T>150 GeV [suppress QCD]
  - $M_T(l,ME_T) \gg M_W$ [suppress tt(1l) & W+jets]
  - Veto events with additional isolated track [suppress tt(2l)]
- **Search is performed in different ME_T and M_T regions**
- **Bacground estimation**
  - Bkg shapes from MC
  - Estimate scale factors from data using the "peak-to-tail" method
    - Normlalize MC to data in MT-peak region: 50-80 GeV
    - Extrapolate results in MT-tail region

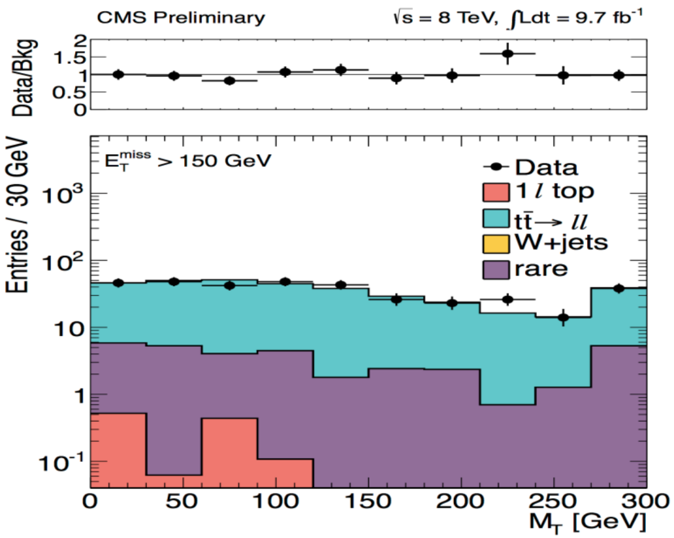
W+jets validation, N_b=0



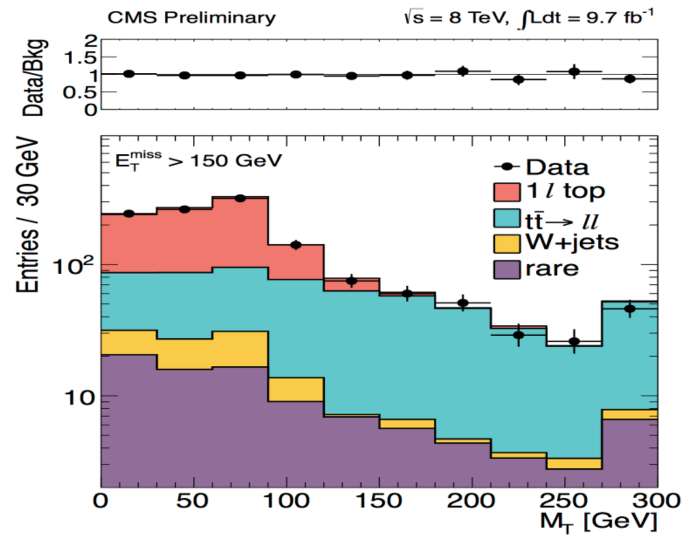
Direct stop search: strategy

- **Background estimation methods validated in control regions in data:**
  - **4 CRs: W+jets, Z+jets, tt(ll), tt(l) + tt(ll)**

tt(2l) validation, N_{lep}=2



tt(2l), tt(lτ) validation, 1 iso track

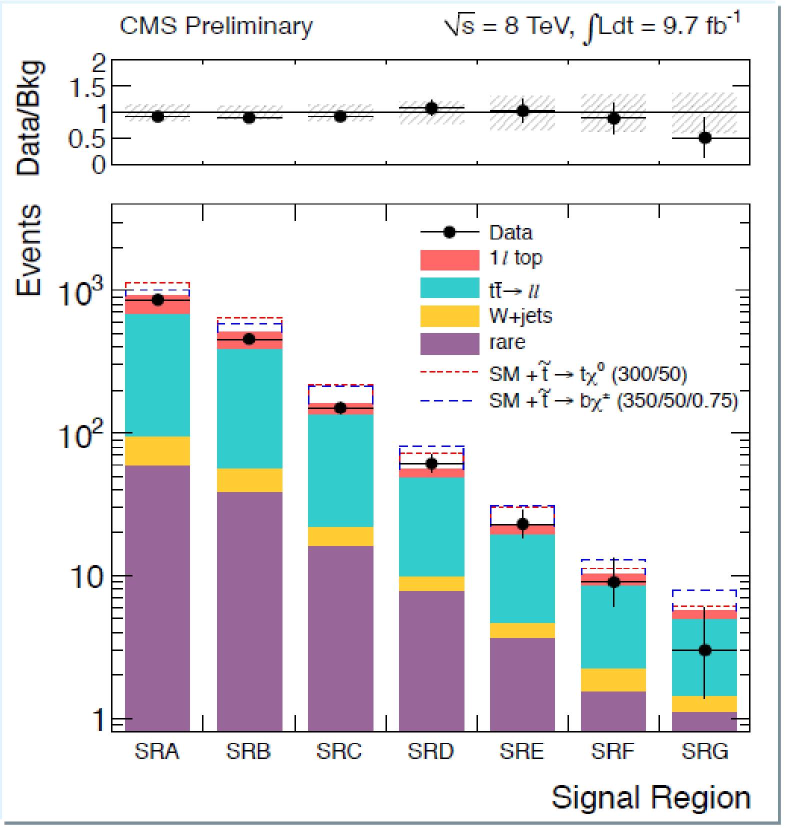


- **Systematic uncertainties / process derived from these control regions**

Direct stop search: results

- **Search performed in different ME_T and M_T regions**

Results @ 9.7 fb^{-1}



Sample	SRA	SRB	SRC	SRD	SRE	SRF	SRG
Minimum M_T [GeV]	150	120	120	120	120	120	120
Minimum E_T^{miss} [GeV]	100	150	200	250	300	350	400
Total background	927 ± 138	504 ± 65	161 ± 26	56 ± 12	22 ± 7	10 ± 3	5.7 ± 2.2
Data	861	456	150	61	23	9	3

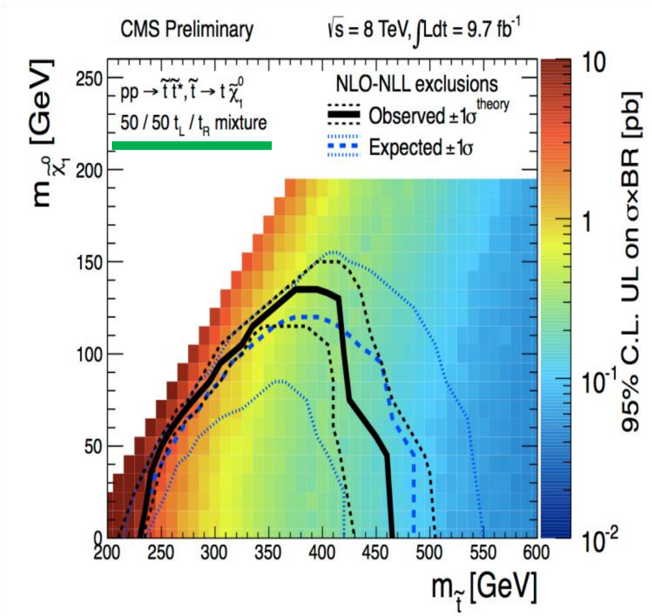
Observed data agree with SM expectations [☹]

CMS-SUS-12-023

Direct stop search: interpretation

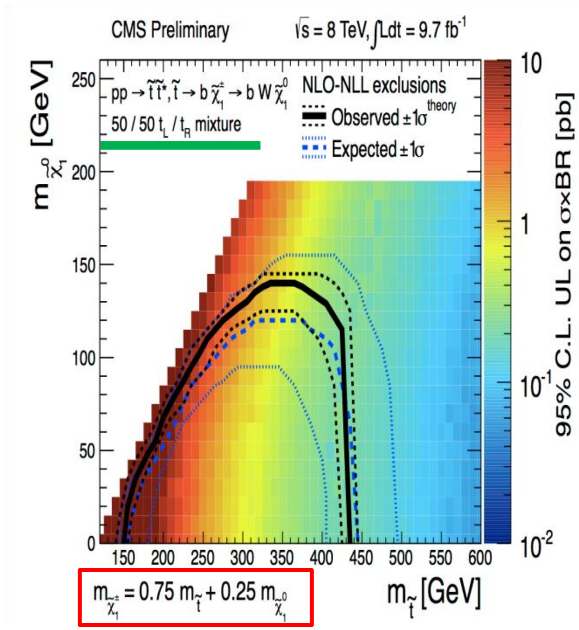
Direct stop production → 2 decay modes

$\tilde{t} \rightarrow t\tilde{\chi}^0{}_1 \rightarrow bW\tilde{\chi}^1{}_0$

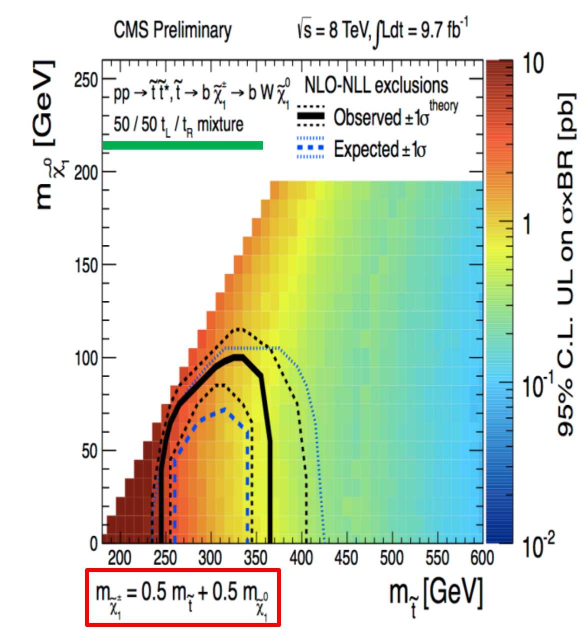


Exclude stop masses ~230-430 GeV for $\tilde{\chi}_0$ < ~110 GeV

$\tilde{t} \rightarrow b\tilde{\chi}^{\pm} \rightarrow bW^{\pm}\tilde{\chi}^1{}_0$



Exclude stop masses ~160-420 GeV for $\tilde{\chi}_0$ < ~120 GeV



Exclude stop masses ~260-340 GeV for $\tilde{\chi}_0$ < ~80 GeV

Summary

Summary

- **Naturalness requires light gluinos, stops and sbottoms**
  - **[probably] within LHC reach**
- **Several searches [based on lepton multiplicity] for direct and indirect stop/sbottom production in CMS**
  - **No excess found so far ☹**
- **Limits in m_{gluino}, m_{lsp}, m_{stop} tightend**
  - **M_{gluino} ~<1280 GeV, M_{stop}~< 500 GeV [~10-20% fine tuning]**
- **Natural SUSY constrained, but not dead!**
  - **various other SUSY scenarios:**
    - **Compressed spectra, RPV,..**
- **More analyses under way for 2013. Stay tuned!**

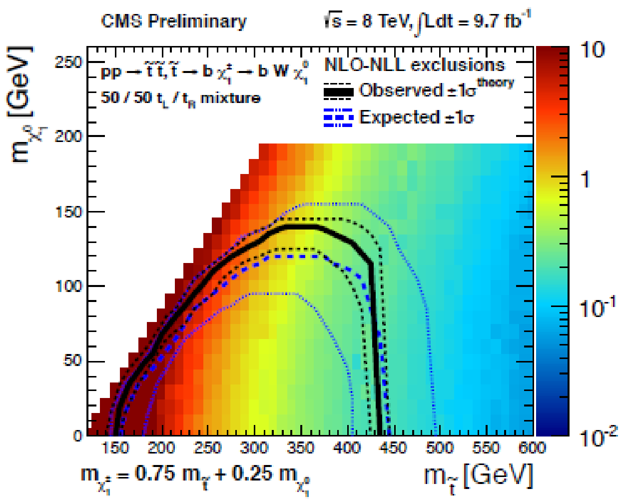
CMS SUSY results:

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

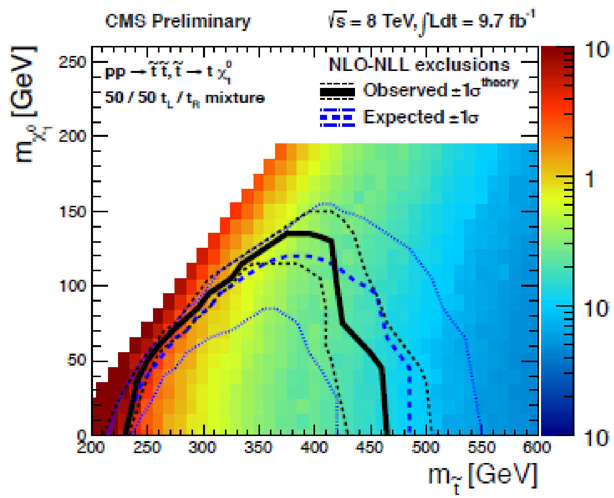
Additional material

CMS vs. ATLAS comparison

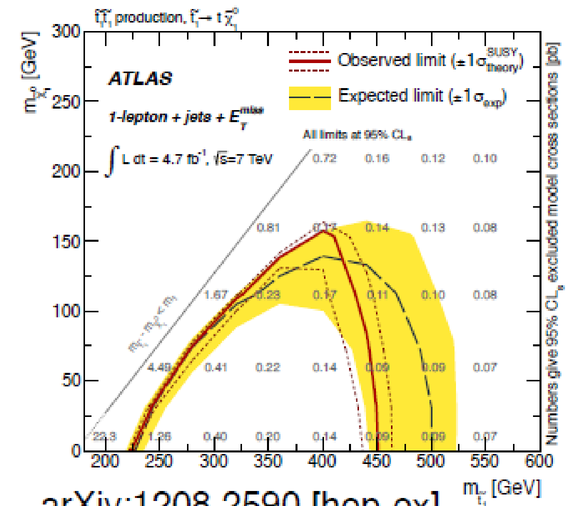
$\tilde{t} \rightarrow b\chi^{\pm}$ x = 0.75



$\tilde{t} \rightarrow t\chi^{0}$



$\tilde{t} \rightarrow t\chi^{0}$



arXiv:1208.2590 [hep-ex]

- When correcting for luminosity and √s, the ATLAS limit covers more of the $\tilde{t} \rightarrow t\,\chi^0$ space for 2 reasons:
  - 1) Different signal model: CMS signal model has **unpolarized tops** from $\tilde{t} \rightarrow t\,\chi^0$. ATLAS signal model has **top quarks which are mostly right-handed**. This choice increases the large lepton p_T and $M_T(\ell,MET)$ acceptance because it causes the lepton to be emitted preferentially parallel to the top boost. **We estimate the size of this effect to be ~25%**.
  - 2) Tuned kinematical requirements: The most important one appears to be the **hadronic top reconstruction**. This is not currently implemented in the CMS analysis in order to **maintain sensitivity to both the $\tilde{t} \rightarrow t\,\chi^0$ and $\tilde{t} \rightarrow b\,\chi^{\pm}$ decay modes**.