

SUSY Searches in ATLAS & CMS

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US ATLAS Physics Workshop

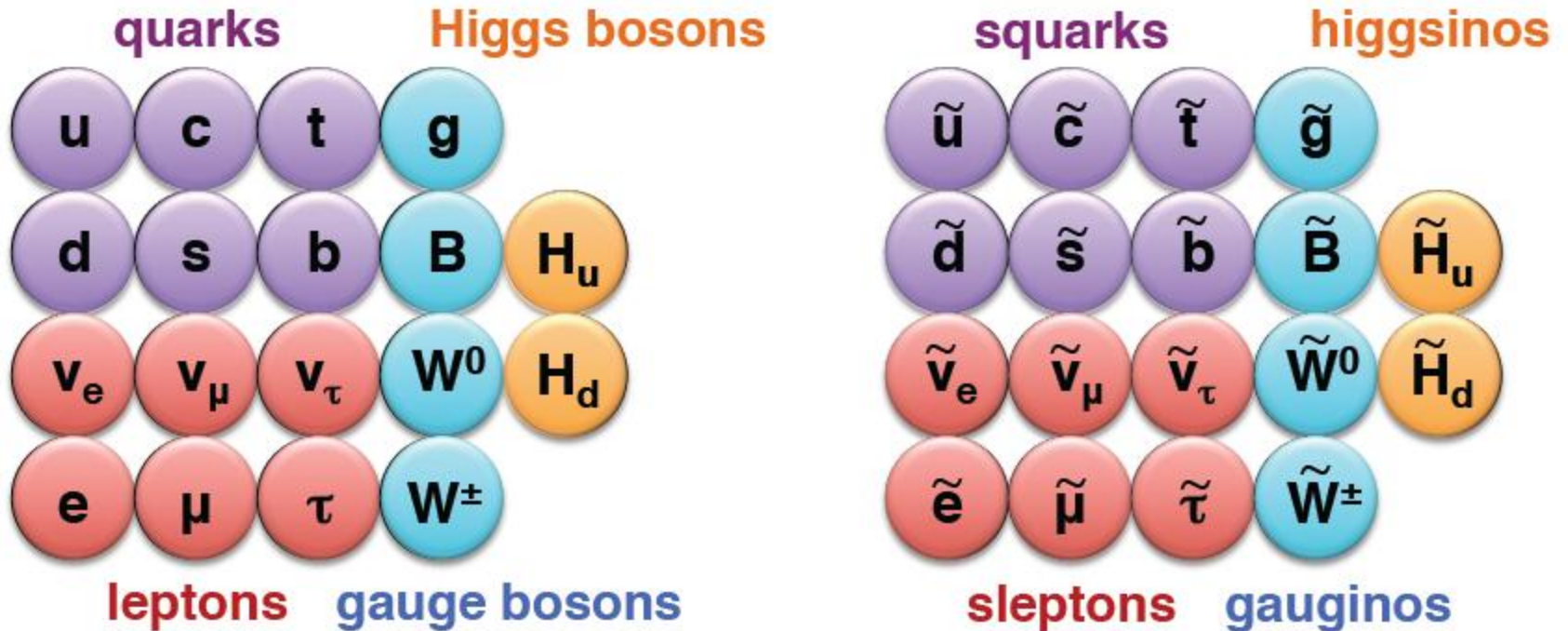
July 15th 2013

Overview

- Introduction
- Status of 8 TeV data analysis Talk by Antoine Marzin
 - gluino & 1st/2nd generation squarks
 - 3rd generation (top & bottom) squarks
 - electroweak SUSY (chargino, neutralinos, sleptons)
 - R-Parity Violating & Gauge Mediated scenarios
- Outlook
 - other possible searches with 8 TeV data
 - looking forward to ~ 14 TeV

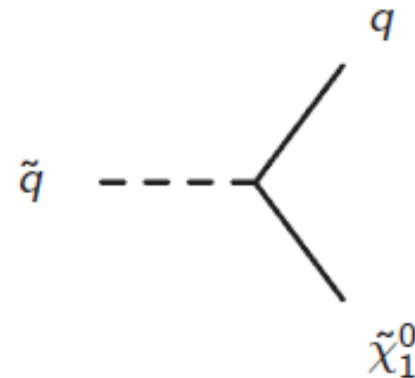
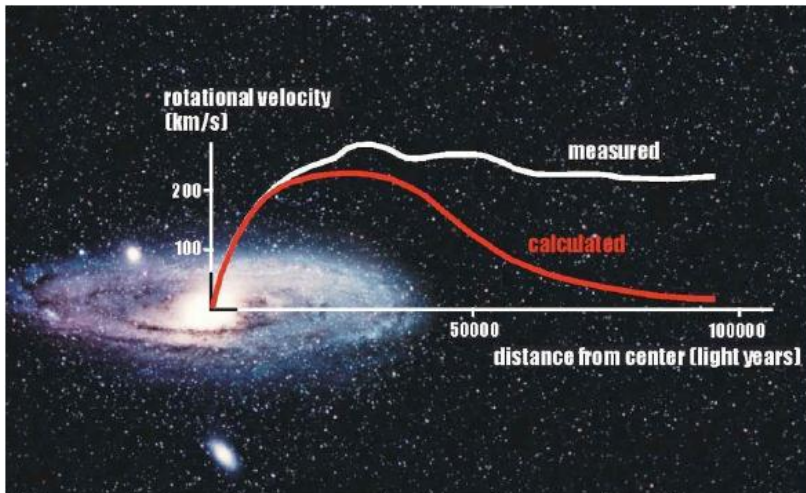
Introduction

Supersymmetry (SUSY)



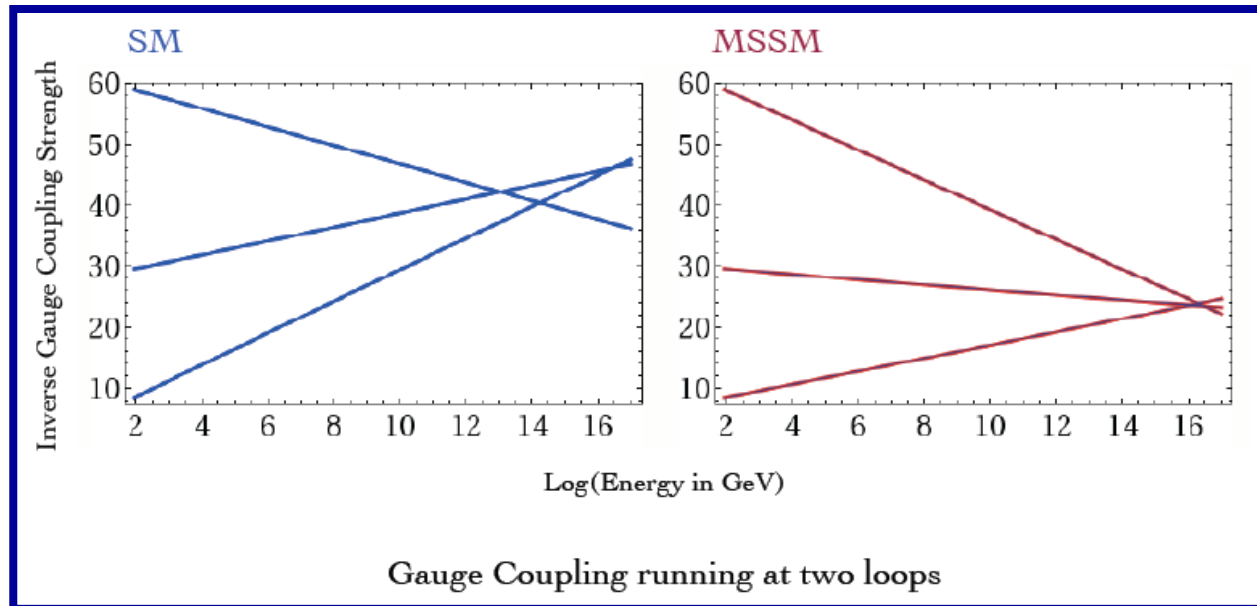
Why Searching for SUSY?

- Can explain WIMP Dark Matter
 - stable neutralino from R-Parity Conservation
 - E_T^{miss} signature at LHC



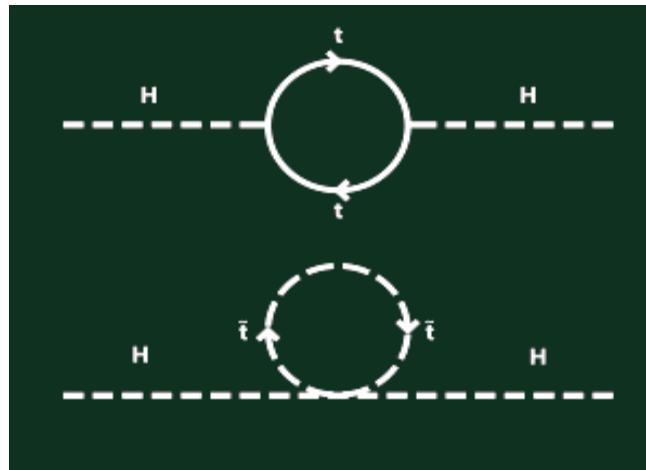
Why Searching for SUSY?

- Fundamental symmetry of space-time
 - super string theories (gravity)
- Gauge-Coupling Unification



Why Searching for SUSY?

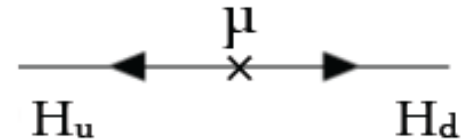
- Naturalness
 - solution to hierarchy problem
 - new physics accessible at LHC



Natural SUSY

For less than 10% fine-tuning...

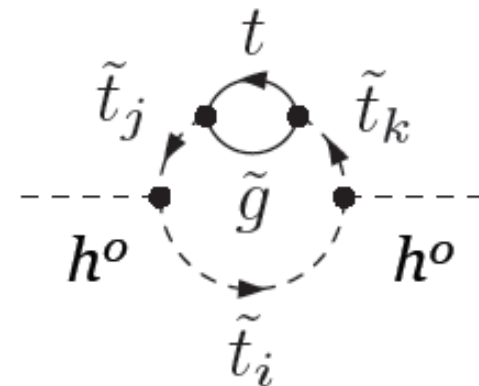
Tree-level: Higgsino $< \sim 250$ GeV



One loop: stop $< \sim 600$ GeV

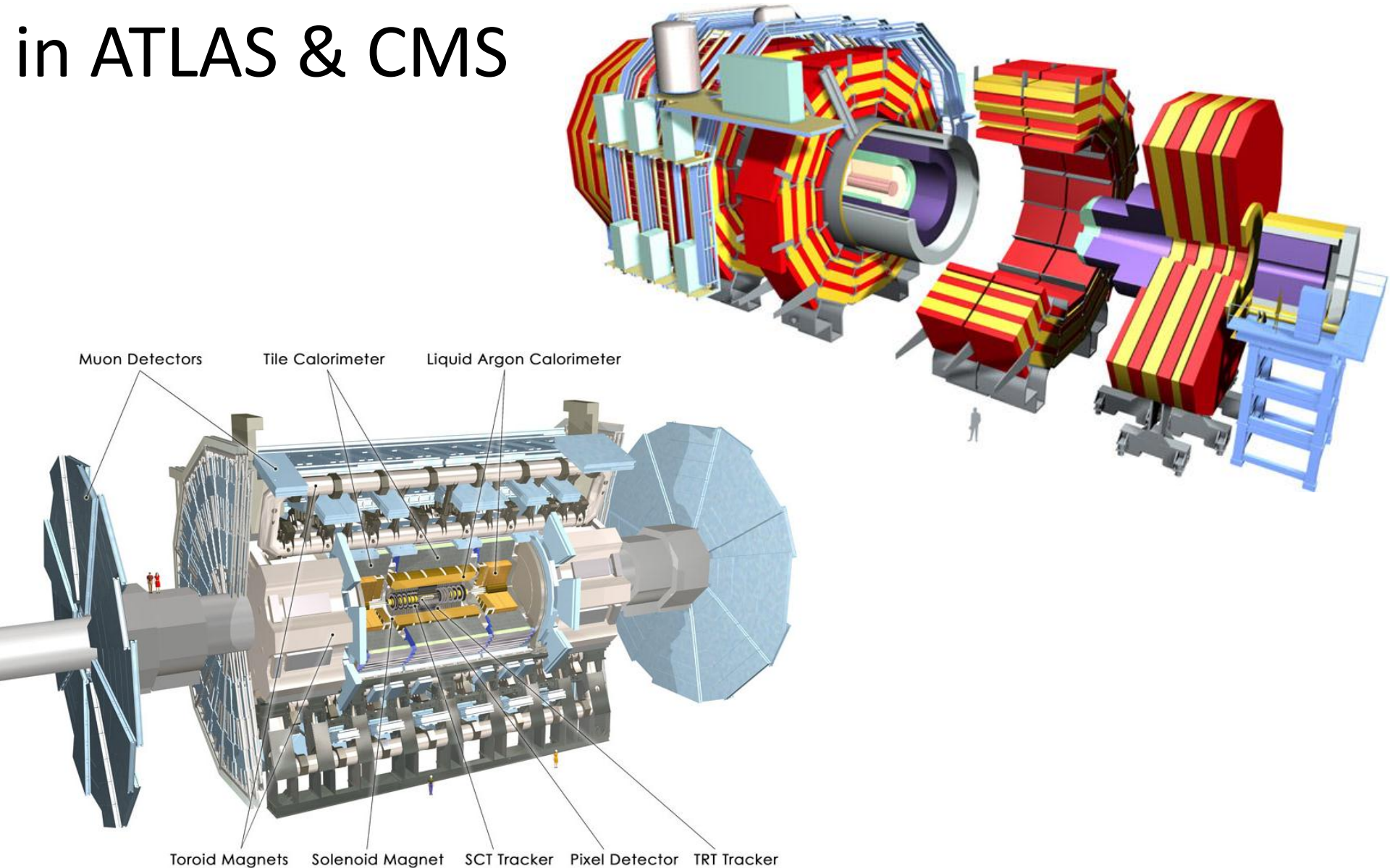


Two loops: gluino $< \sim 1.4$ TeV

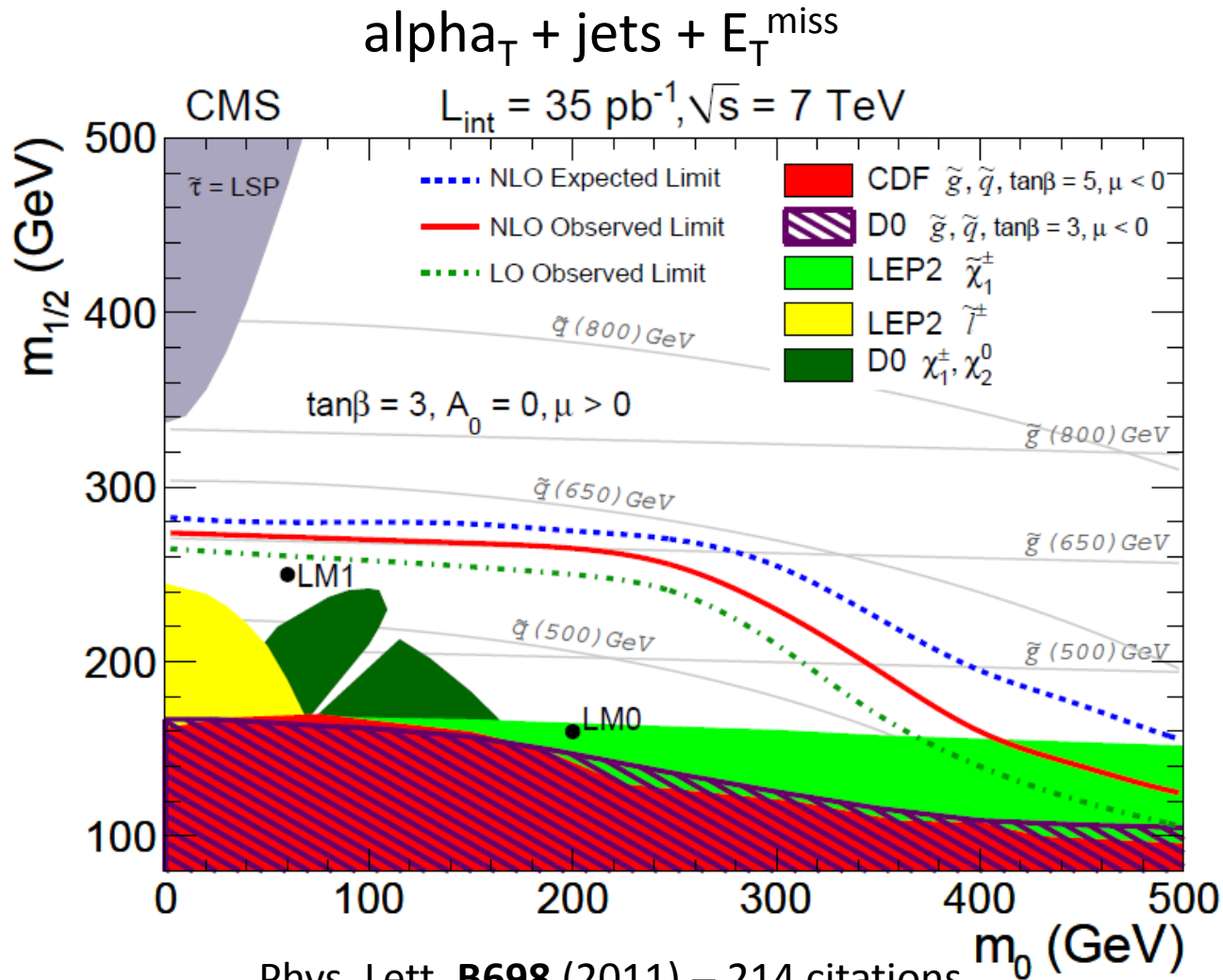


*[Dimopoulos & Giudice \(1995\)](#)

Brief history of SUSY searches in ATLAS & CMS

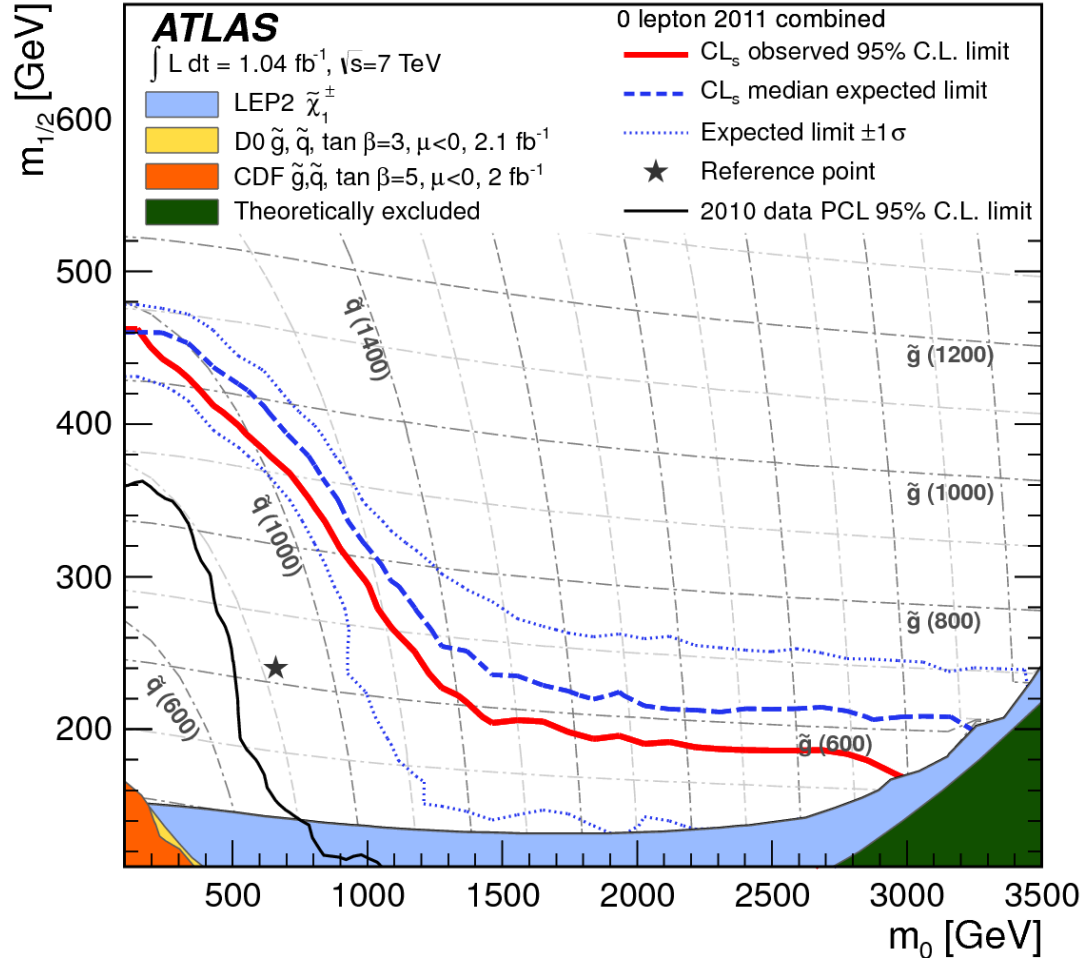


The very first SUSY result! (2010)



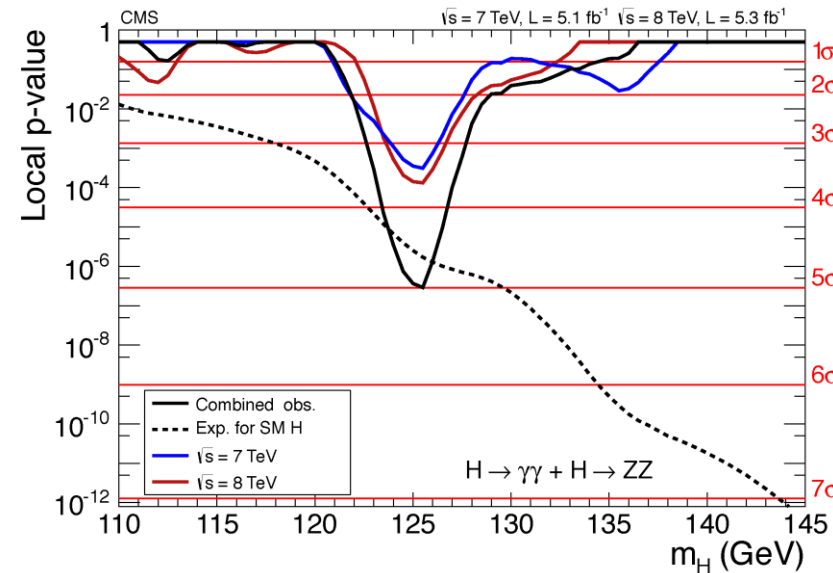
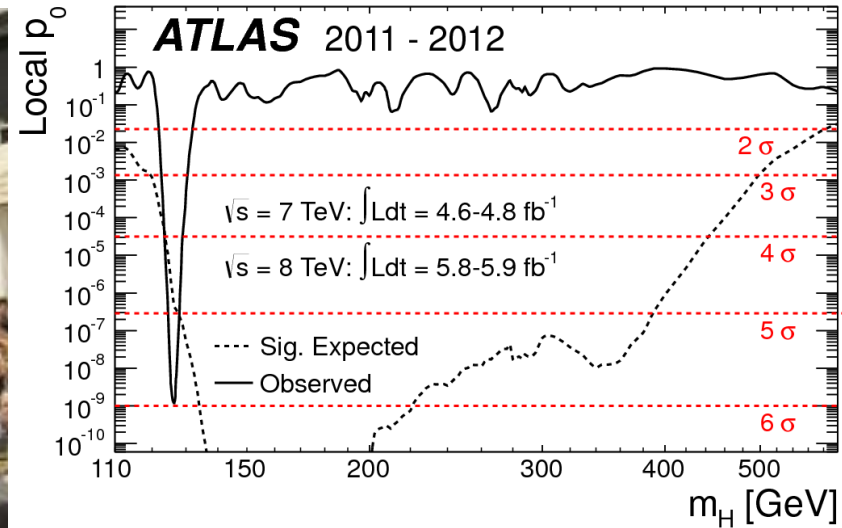
MET + jets + 0 lepton (1 fb^{-1})

MSUGRA/CMSSM: $\tan\beta = 10, A_0 = 0, \mu > 0$



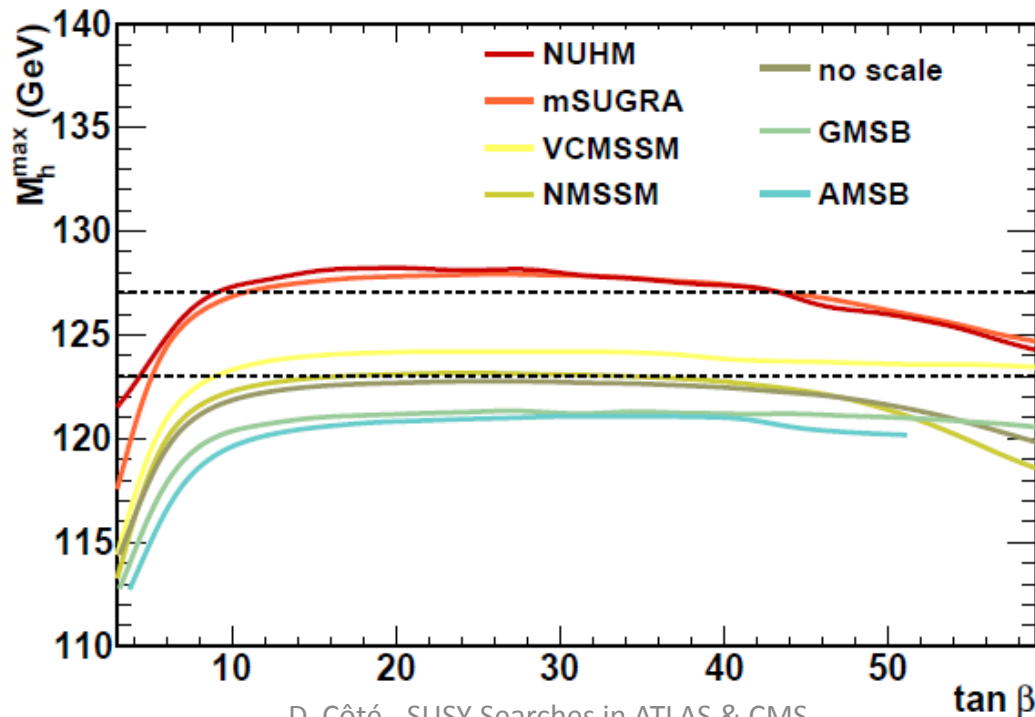
Phys. Lett. **B710** (2012) – 263 citations

Higgs Discovery: July 4th 2012

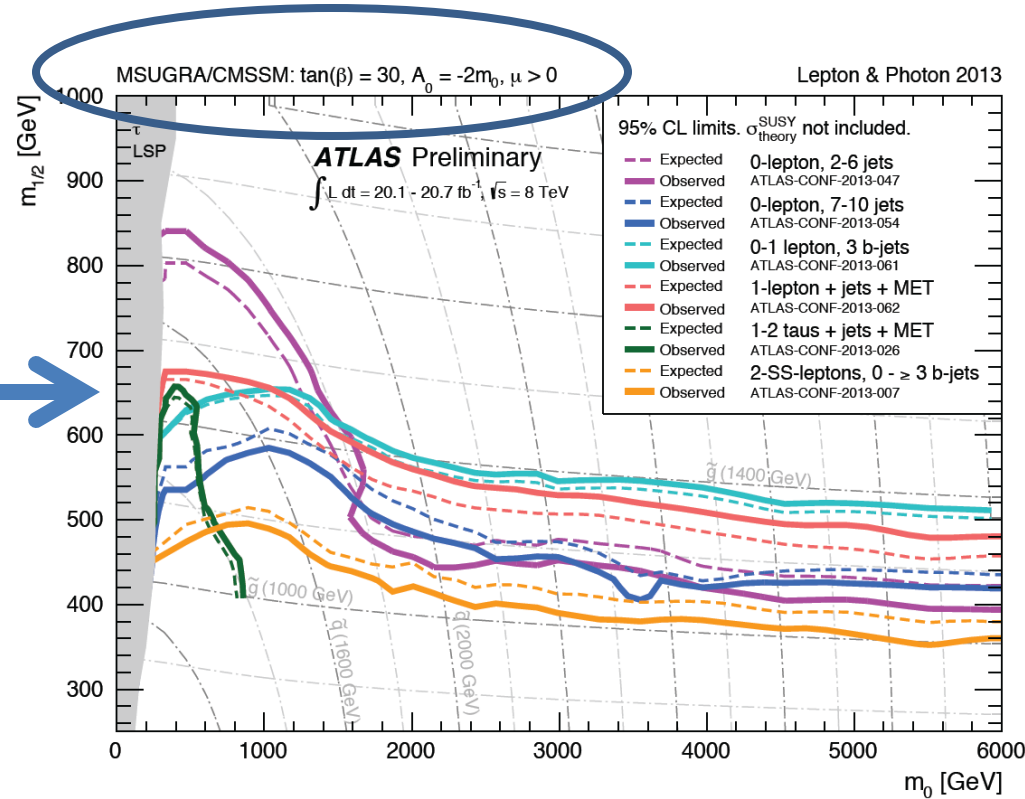
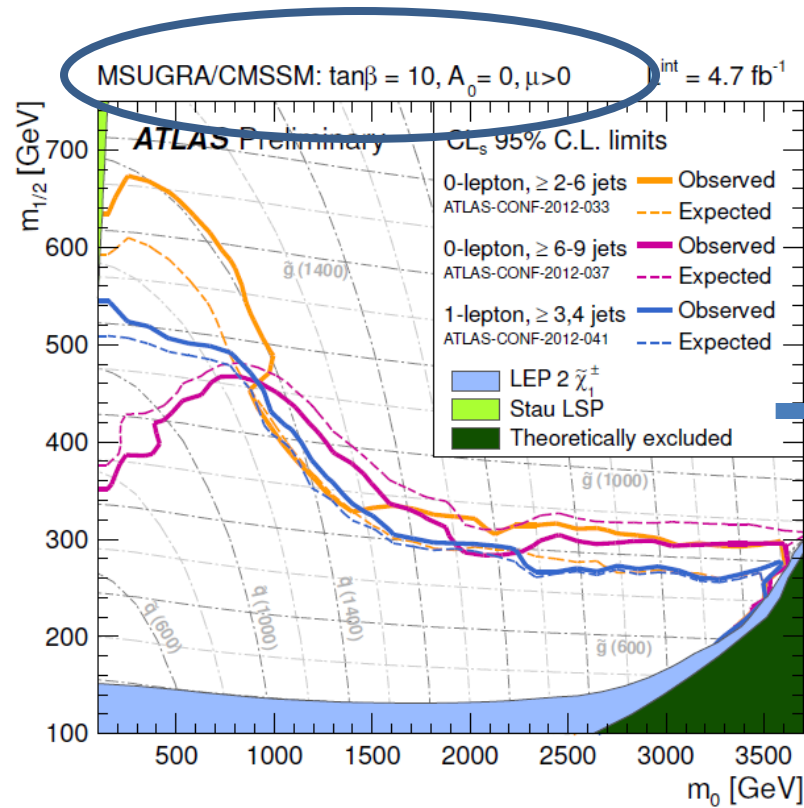


Impact of $m_H = 125.5$ GeV

- Higgs discovery encourages the SUSY use case
- Measured value $m_H \approx 125.5$ GeV required adjustments of some SUSY models



Higgs-aware mSUGRA



Models like mSUGRA are not statistically excluded, but are no longer the main focus.

Status of 8 TeV data analysis

Model	e, μ, τ, γ Jets	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference			
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	\tilde{q}, \tilde{g} 1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-tba
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	\tilde{g} 1.1 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-054
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	\tilde{q} 740 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	\tilde{g} 1.3 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0 \rightarrow q\tilde{q}W^\pm\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	\tilde{g} 1.18 TeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}, m(\tilde{\tau}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-tba
	$\tilde{g}\tilde{g} \rightarrow q\tilde{q}q\ell(\ell\ell)\tilde{\chi}_1^0\tilde{\chi}_1^0$	2 e, μ (SS)	3 jets	Yes	20.7	\tilde{g} 1.1 TeV	$m(\tilde{\chi}_1^0)<650 \text{ GeV}$	ATLAS-CONF-2013-007
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	\tilde{g} 1.24 TeV	$\tan\beta < 15$	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	\tilde{g} 1.4 TeV	$\tan\beta > 18$	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	0	Yes	4.8	\tilde{g} 1.07 TeV	$m(\tilde{\chi}_1^0)>50 \text{ GeV}$	1209.0753
	GGM (wino NLSP)	1 $e, \mu + \gamma$	0	Yes	4.8	\tilde{g} 619 GeV	$m(\tilde{\chi}_1^0)>50 \text{ GeV}$	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	1 b	1 b	Yes	4.8	\tilde{g} 900 GeV	$m(\tilde{\chi}_1^0)>220 \text{ GeV}$	1211.1167
GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	\tilde{g} 690 GeV	$m(\tilde{H})>200 \text{ GeV}$	ATLAS-CONF-2012-152	
Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{g})>10^{-4} \text{ eV}$	ATLAS-CONF-2012-147	
3 rd gen. \tilde{g} med.	$\tilde{g}\tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	\tilde{g} 1.25 TeV	$m(\tilde{\chi}_1^0)<600 \text{ GeV}$	ATLAS-CONF-2013-tba
	$\tilde{g}\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	\tilde{g} 1.14 TeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}$	ATLAS-CONF-2013-054
	$\tilde{g}\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.34 TeV	$m(\tilde{\chi}_1^0)<400 \text{ GeV}$	ATLAS-CONF-2013-tba
	$\tilde{g}\tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	\tilde{g} 1.3 TeV	$m(\tilde{\chi}_1^0)<300 \text{ GeV}$	ATLAS-CONF-2013-tba
3 rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	\tilde{b}_1 100-630 GeV	$m(\tilde{\chi}_1^0)<100 \text{ GeV}$	ATLAS-CONF-2013-053
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow t\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{b}_1 430 GeV	$m(\tilde{\chi}_1^0)=2m(\tilde{t}_1)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	1-2 e, μ	1-2 b	Yes	4.7	\tilde{t}_1 167 GeV	$m(\tilde{\chi}_1^0)=55 \text{ GeV}$	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	\tilde{t}_1 220 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W) - 50 \text{ GeV}, m(\tilde{t}_1) < m(\tilde{t}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	\tilde{t}_1 150-440 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{t}_1) - m(\tilde{t}_1^\pm) = 10 \text{ GeV}$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	\tilde{t}_1 150-580 GeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}, m(\tilde{t}_1) - m(\tilde{t}_1^\pm) = 5 \text{ GeV}$	ATLAS-CONF-2013-053
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	\tilde{t}_1 200-610 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	\tilde{t}_1 320-660 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	\tilde{t}_1 500 GeV	$m(\tilde{\chi}_1^0)>150 \text{ GeV}$	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.7	\tilde{t}_2 520 GeV	$m(\tilde{t}_1) = m(\tilde{t}_1^\pm) + 180 \text{ GeV}$	ATLAS-CONF-2013-025
EW direct	$\tilde{\chi}_{1,R}^+\tilde{\chi}_{1,R}^-, \tilde{\ell} \rightarrow \tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$ 85-315 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	ATLAS-CONF-2013-049
	$\tilde{\chi}_{1,R}^+\tilde{\chi}_{1,R}^-, \tilde{\chi}_1^0 \rightarrow \tilde{\ell}\nu(\tilde{\ell}\bar{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^0$ 125-450 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\ell}, \bar{\nu}) = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_{1,R}^+\tilde{\chi}_{1,R}^-, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}\nu(\tilde{\tau}\bar{\nu})$	2 τ	0	Yes	20.7	$\tilde{\chi}_1^0$ 180-330 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\tau}, \bar{\nu}) = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_{1,R}^+\tilde{\chi}_{1,R}^0 \rightarrow \tilde{\ell}_L\nu_L(\tilde{\nu}_L), \tilde{\ell}\tilde{\nu}_L(\tilde{\nu}_L)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^0$ 600 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, m(\tilde{\ell}, \bar{\nu}) = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_{1,R}^+\tilde{\chi}_2^0 \rightarrow W^\pm\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^0, \tilde{\chi}_2^0$ 315 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0$, sleptons decoupled	ATLAS-CONF-2013-035
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^+$ prod., long-lived $\tilde{\chi}_1^\pm$	0	1 jet	Yes	4.7	$\tilde{\chi}_1^\pm$ 220 GeV	$1 < \tau(\tilde{\chi}_1^\pm) < 10 \text{ ns}$	1210.2852
	Stable, stopped \tilde{g} R-hadron	0-2 e, μ	0	Yes	4.7	\tilde{g} 985 GeV		1211.1597
	Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	22.9	\tilde{g} 857 GeV		
	GMSB, stable $\tilde{\tau}$	1-2 μ	0	-	15.9	$\tilde{\tau}$ 385 GeV	$m(\tilde{\chi}_1^0)=100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{\tau}) < 100 \text{ s}$	ATLAS-CONF-2013-tba
	Direct $\tilde{\tau}\tilde{\tau}$ prod., stable $\tilde{\tau}$ or $\tilde{\ell}$	1-2 μ	0	-	15.9	$\tilde{\tau}$ 395 GeV	$5 < \tan\beta < 50$	ATLAS-CONF-2013-tba
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{g}$, long-lived $\tilde{\chi}_1^0$	2 γ	0	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	$m(\tilde{\tau})=m(\tilde{\ell})$	ATLAS-CONF-2013-tba
	$\tilde{\chi}_1^0 \rightarrow q\tilde{q}$ (RPV)	1 e, μ	0	Yes	4.4	\tilde{q} 700 GeV	$0.4 < \tau(\tilde{\chi}_1^0) < 2 \text{ ns}$	1304.6310
						$1 \text{ mm} < c\tau < 1 \text{ m}, \tilde{g}$ decoupled	1210.7451	
RPV	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu$	2 e, μ	0	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	$\lambda'_{111}=0.10, \lambda_{132}=0.05$	1212.1272
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	0	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	$\lambda'_{111}=0.10, \lambda_{11(2)33}=0.05$	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	\tilde{q}, \tilde{g} 1.2 TeV	$m(\tilde{q})=m(\tilde{g}), c\tau_{LSP} < 1 \text{ mm}$	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	0	Yes	20.7	$\tilde{\chi}_1^0$ 760 GeV	$m(\tilde{\chi}_1^0)>300 \text{ GeV}, \lambda_{121}>0$	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tau\tau\tilde{\nu}_\tau, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	0	Yes	20.7	$\tilde{\chi}_1^0$ 350 GeV	$m(\tilde{\chi}_1^0)>80 \text{ GeV}, \lambda_{132}>0$	ATLAS-CONF-2013-036
	$\tilde{g} \rightarrow q\tilde{q}$	0	6 jets	-	4.6	\tilde{g} 666 GeV		1210.4813
$\tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow b s$	2 e, μ (SS)	0-3 b	Yes	20.7	\tilde{g} 880 GeV		ATLAS-CONF-2013-007	
Other	Scalar gluon	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M^* scale 704 GeV	$m(\chi) > 80 \text{ GeV}$, limit of $\sim 687 \text{ GeV}$ for D8	ATLAS-CONF-2012-147

√s = 7 TeV full data
√s = 8 TeV partial data
√s = 8 TeV full data

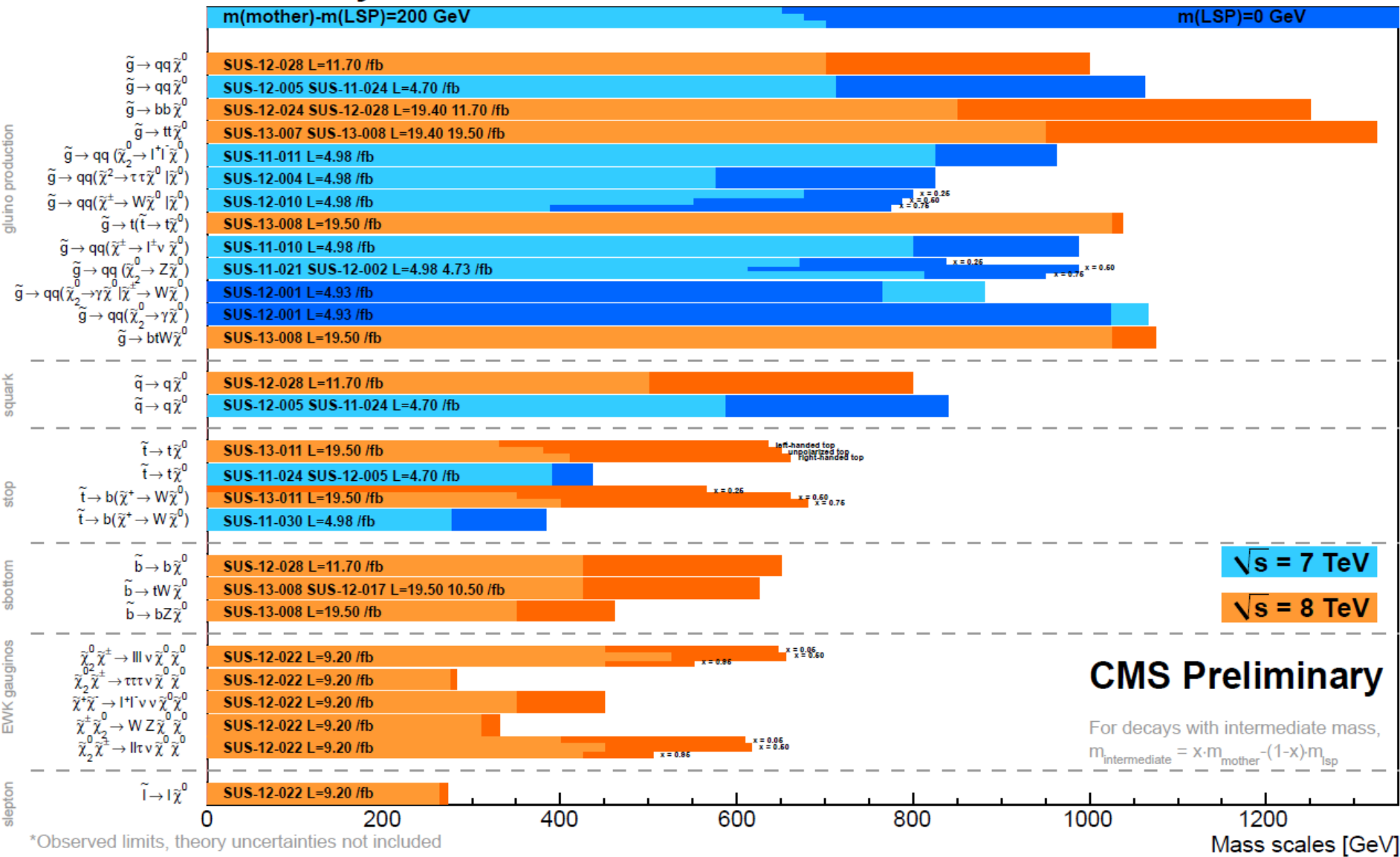
10^{-1} 1 Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

See: <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>

Summary of CMS SUSY Results* in SMS framework

LHCP 2013

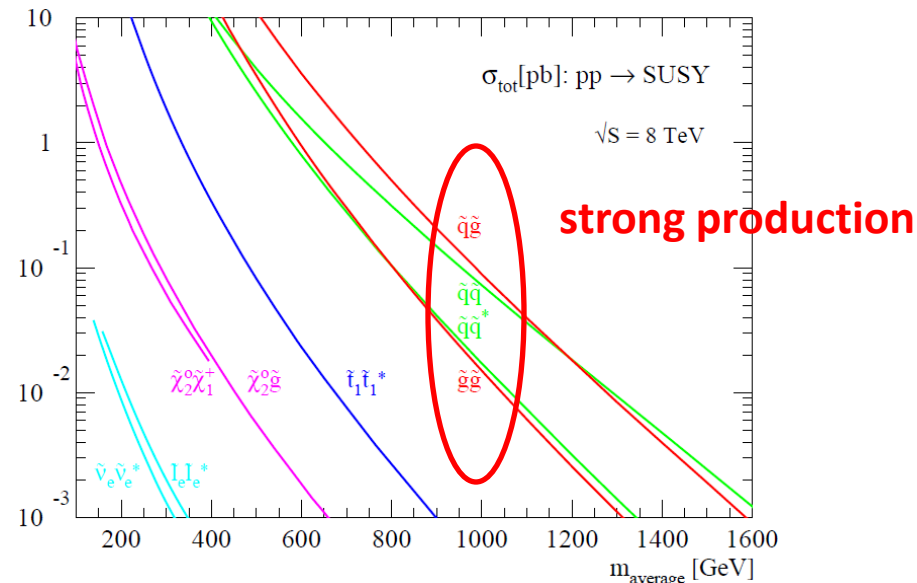


*Observed limits, theory uncertainties not included
 Only a selection of available mass limits
 Probe *up to* the quoted mass limit

See: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

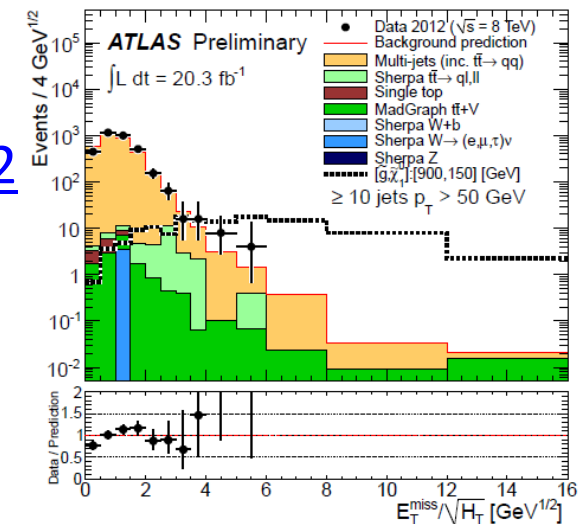
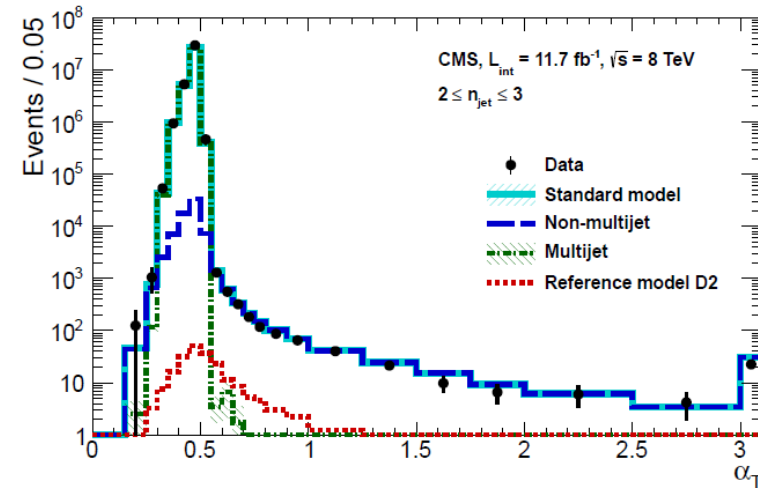
Status of 8 TeV data analysis

- gluino & 1st/2nd generation squarks
- 3rd generation (top & bottom) squarks
- electroweak SUSY (chargino, neutralinos, sleptons)
- R-Parity Violating & Gauge Mediated scenarios



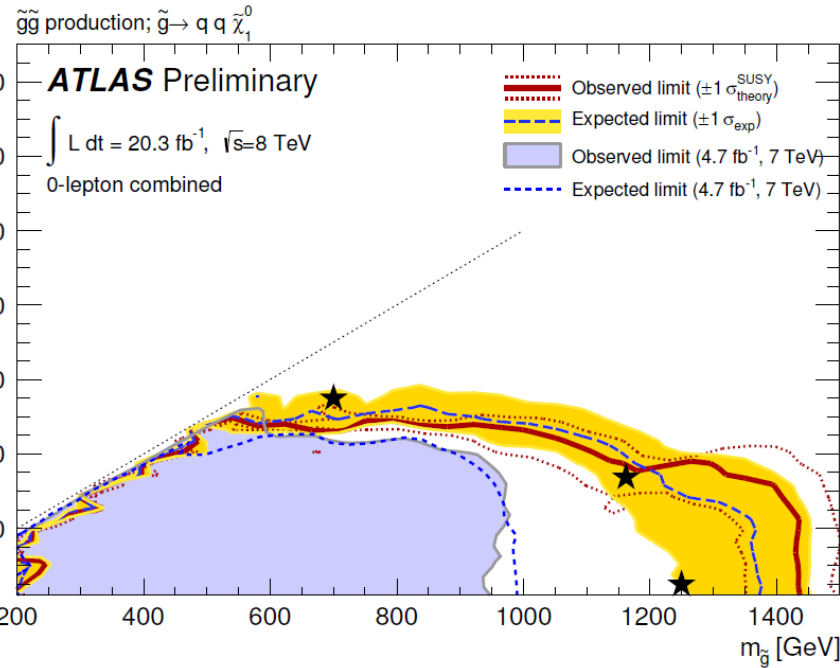
Inclusive searches for gluino & squarks

- Motivations for light gluino:
 - SUSY naturalness
 - gauge coupling unification
- Recent results:
 - ATLAS (20 fb⁻¹)
 - 0 lepton + 2-6 jets + E_T^{miss} [2013-047](#)
 - 0 lepton + 7-10 jets [2013-054](#)
 - 1 lepton (hard/soft) + jets + E_T^{miss} [2013-062](#)
 - 2 same-sign leptons + 0-3 b-jets [2013-007](#)
 - tau + jets + E_T^{miss} (GMSB) [2013-026](#)
 - CMS (11 fb⁻¹)
 - alpha_T + 0-4 b-jets [SUS12-028](#)

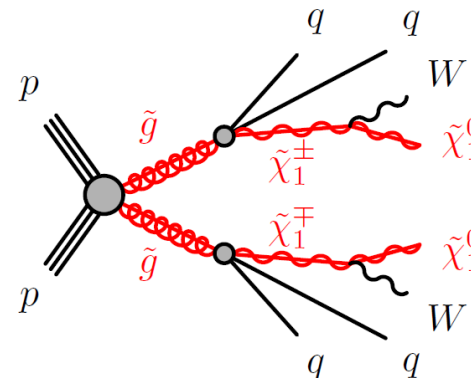
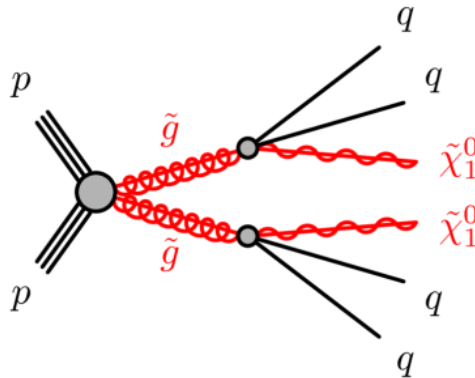
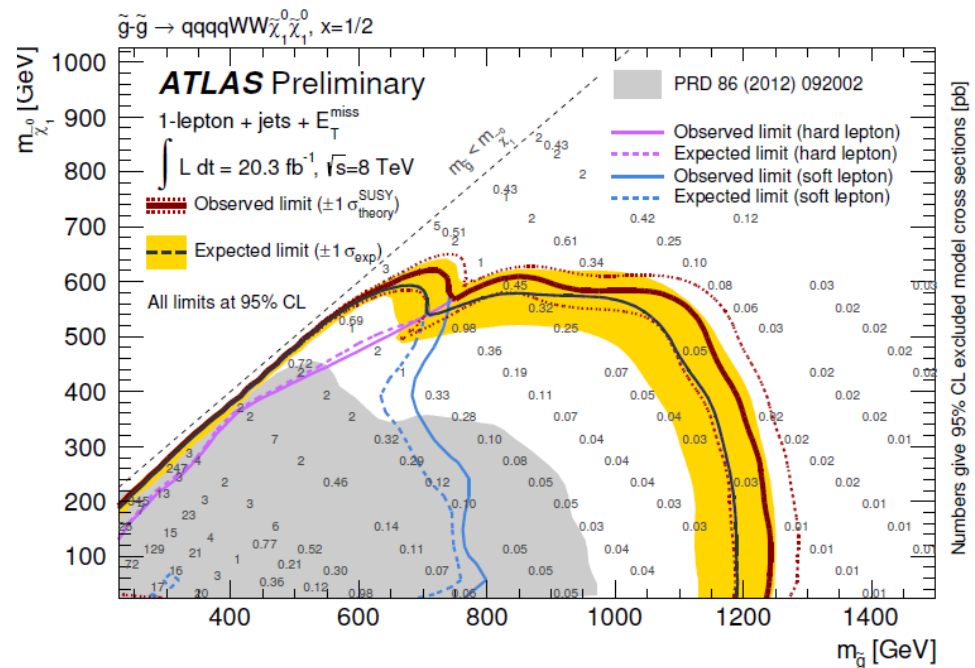


Limits on gluino \rightarrow squark

0 lepton + 2-6 jets + E_T^{miss}

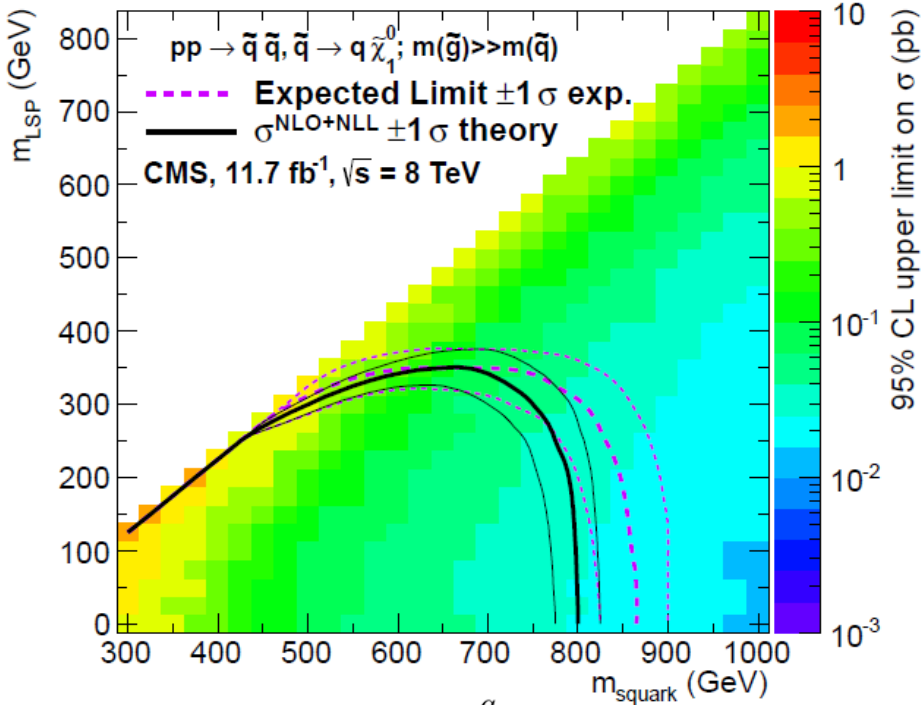


1 lepton (hard/soft) + jets + E_T^{miss}

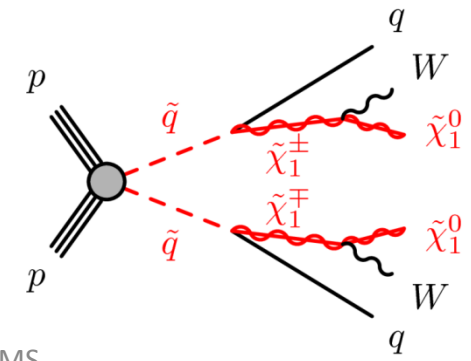
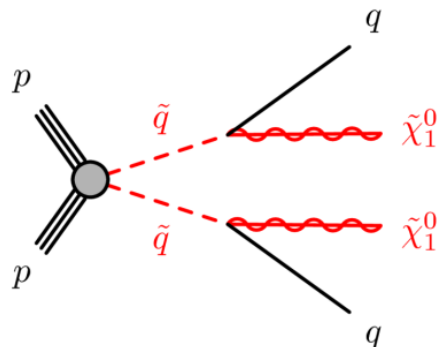
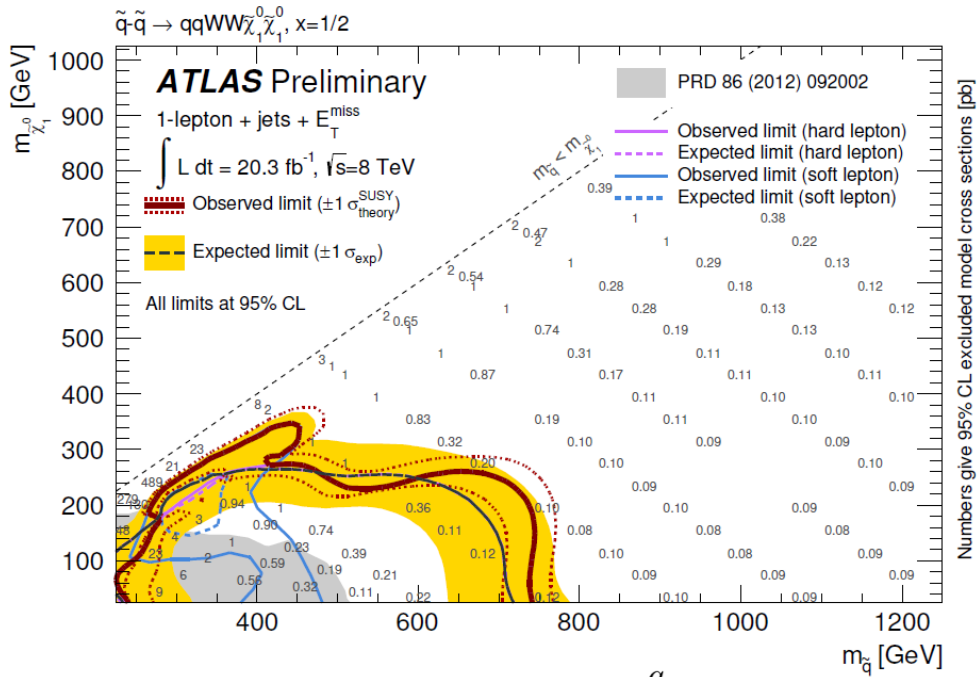


Limits on direct squark

alpha_T + 0-4 b-jets

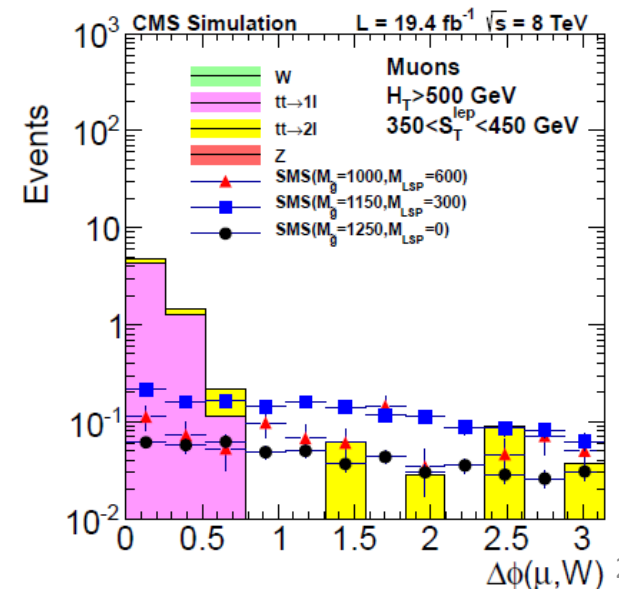
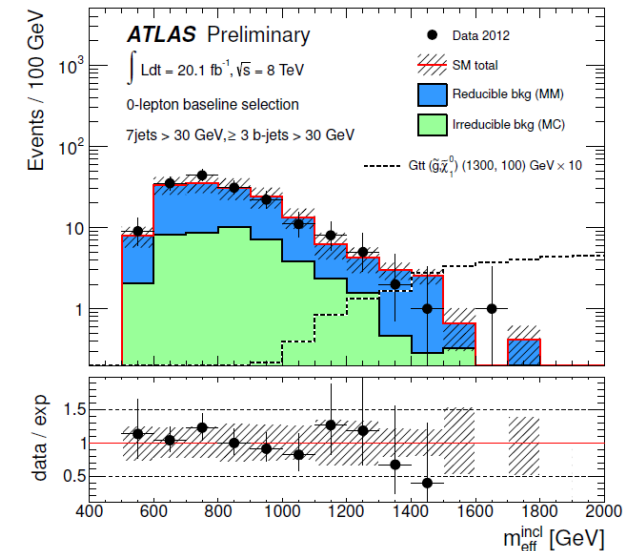


1 lepton (hard/soft) + jets + E_T^{miss}

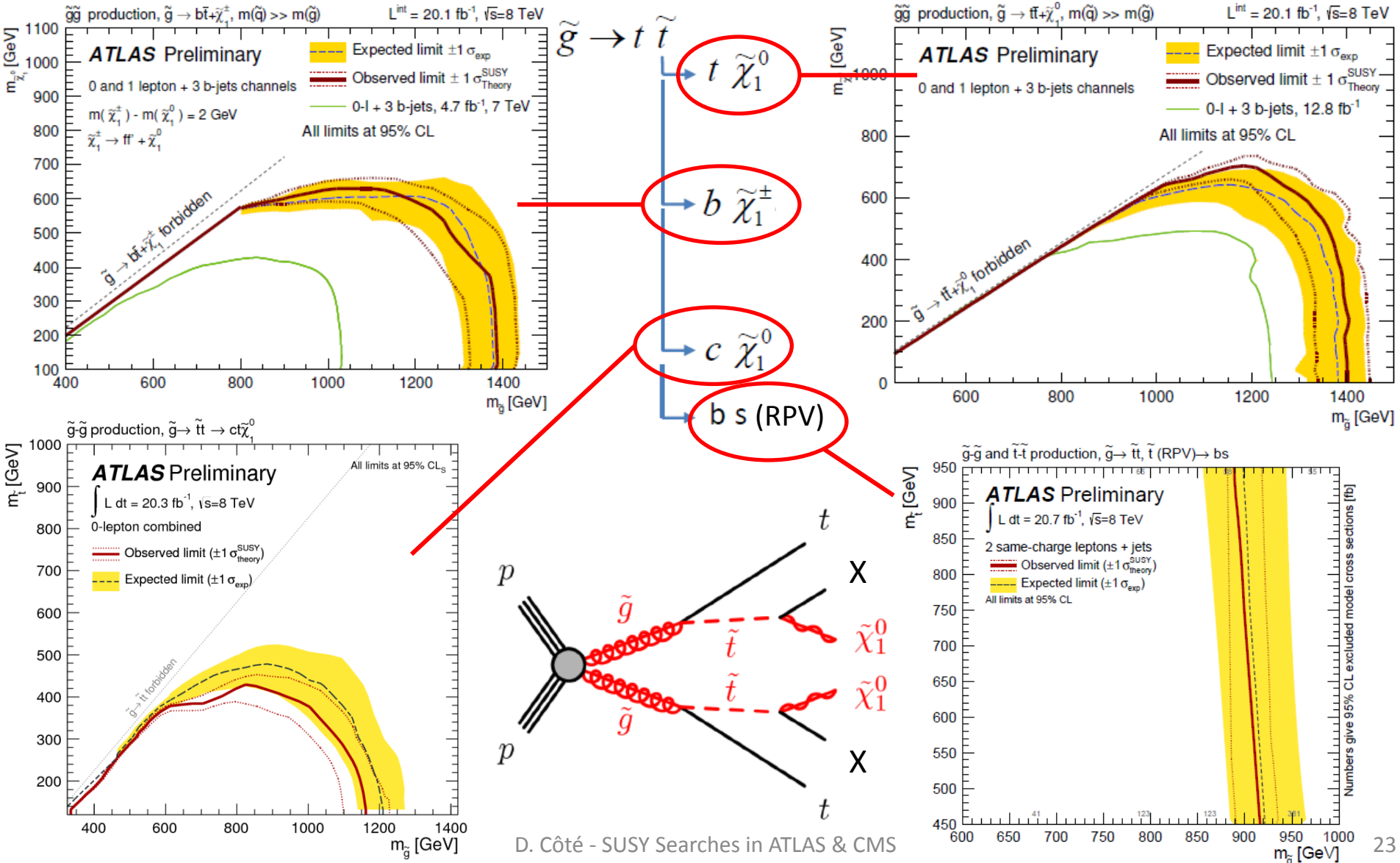


gluino \rightarrow stop/sbottom

- Motivations:
 - gluino & stop light in Natural SUSY
 - sbottom_L related to stop_L by SU(2)_L
 - then BF(gluino \rightarrow stop/sbottom) \approx 100%
- Recent results:
 - ATLAS (20 fb⁻¹)
 - 0/1 lepton + 3 b-jets + E_T^{miss} [2013-061](#)
 - 0 lepton + 2-6 jets + E_T^{miss} [2013-047](#)
 - 0 lepton + 7-10 jets [2013-054](#)
 - 2 same-sign leptons + b-jets [2013-007](#)
 - CMS (19.5 fb⁻¹)
 - H_T + 1-3 b-jets + ETmiss [SUS12024](#)
 - 1 lepton + b-jets + ETmiss [SUS13007](#)
 - 2 leptons same-sign + b-jets [SUS12017](#)
 - 3 leptons + b-jets [SUS13008](#)

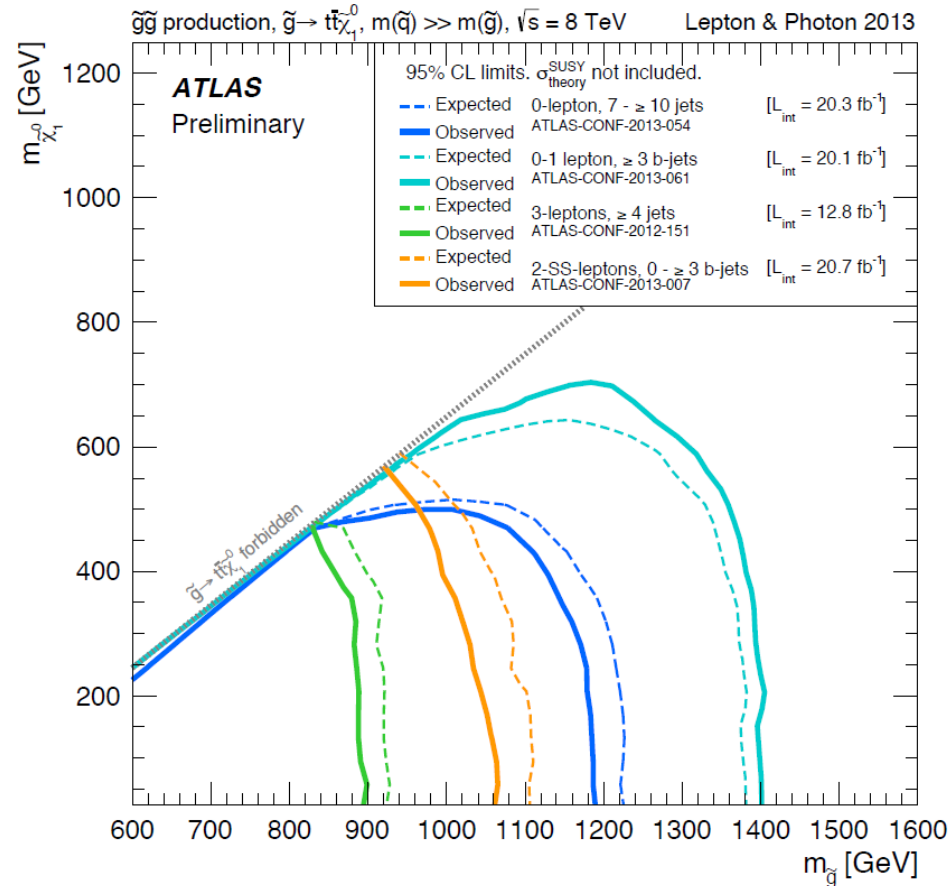
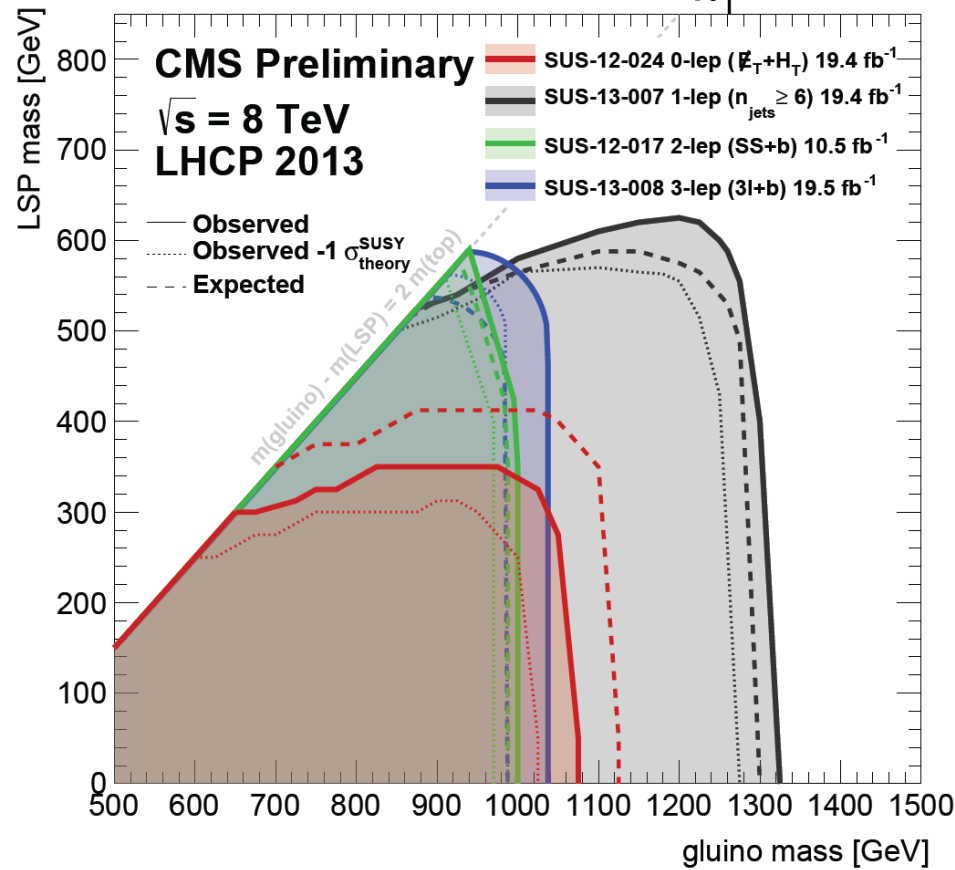


Limits on several gluino \rightarrow stop decays



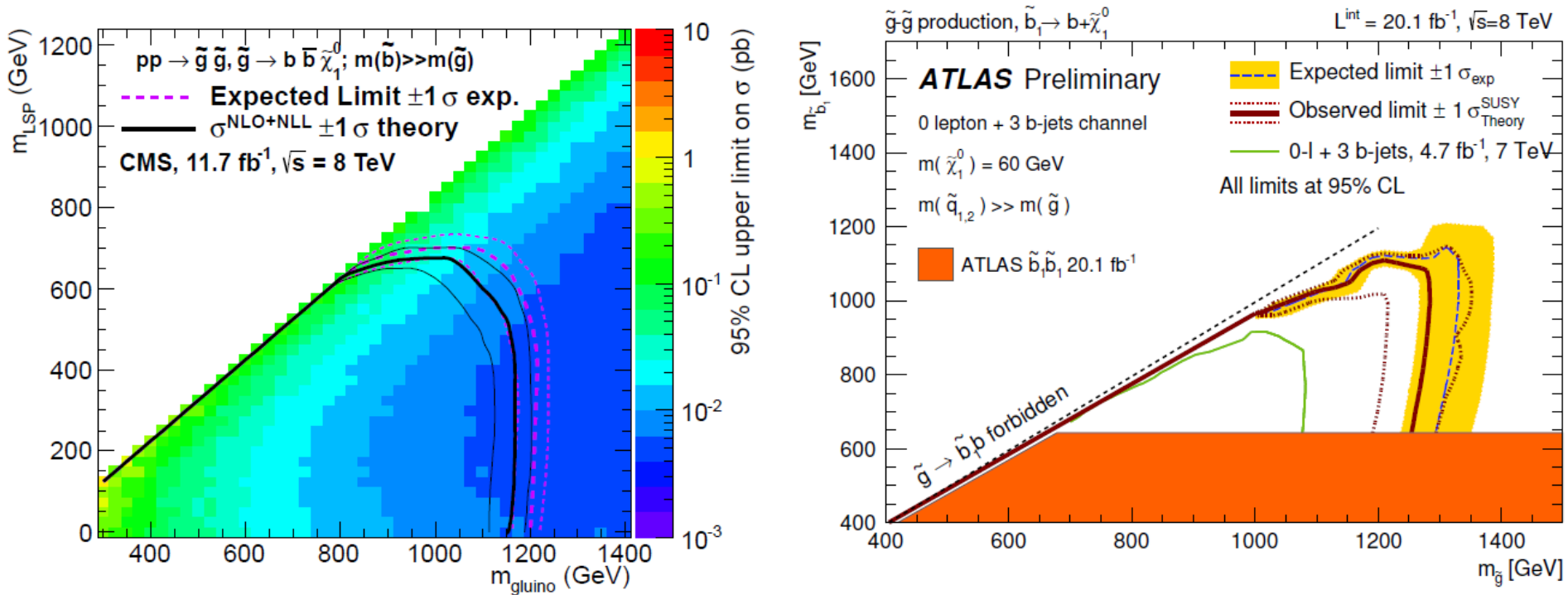
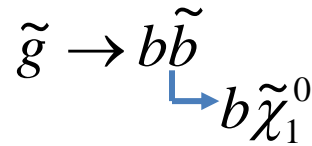
Limits on gluino $\rightarrow t\bar{t}\chi_1^0$

$\tilde{g}\text{-}\tilde{g}$ production, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$



Excluding $m_{\text{gluino}} < \sim 1.3 \text{ TeV}$ for $m_{\chi_1^0} < \sim 600 \text{ GeV}$

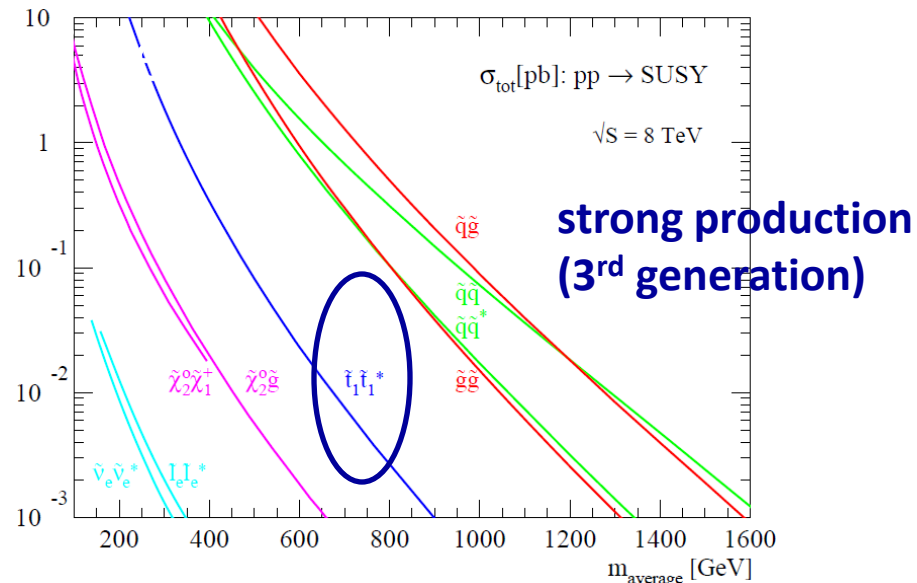
Limits on gluino $\rightarrow b\bar{b}\chi_1^0$



Excluding $m_{\tilde{g}} < \sim 1.2 \text{ TeV}$ for $m_{\tilde{\chi}_1^0} < \sim 600 \text{ GeV}$,
 similarly for on-shell sbottom ($m_{\tilde{s}_{\text{bottom}}} < m_{\tilde{g}}$) and off-shell sbottom* ($m_{\tilde{s}_{\text{bottom}}} > m_{\tilde{g}}$).

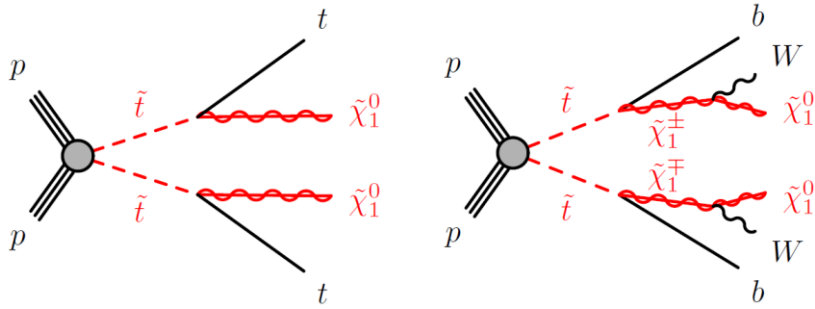
Recent Results

- gluino & 1st/2nd generation squarks
- 3rd generation (top & bottom) squarks
- electroweak SUSY (chargino, neutralinos, sleptons)
- R-Parity Violating & Gauge Mediated scenarios



Direct stop production

- Light stop motivated by Naturalness



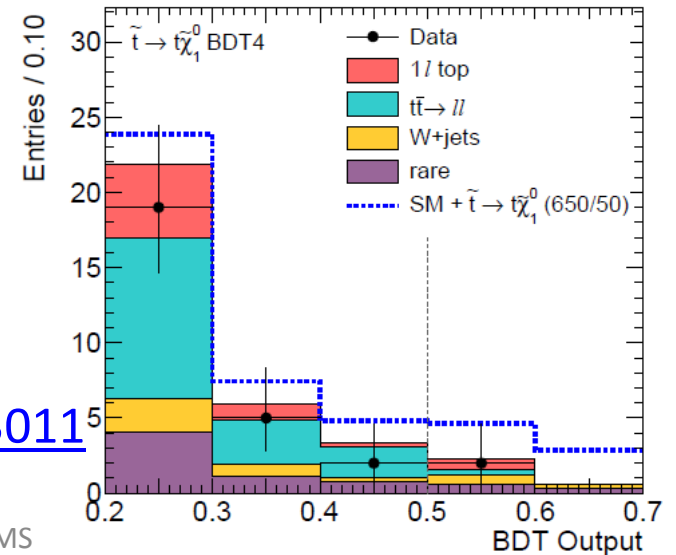
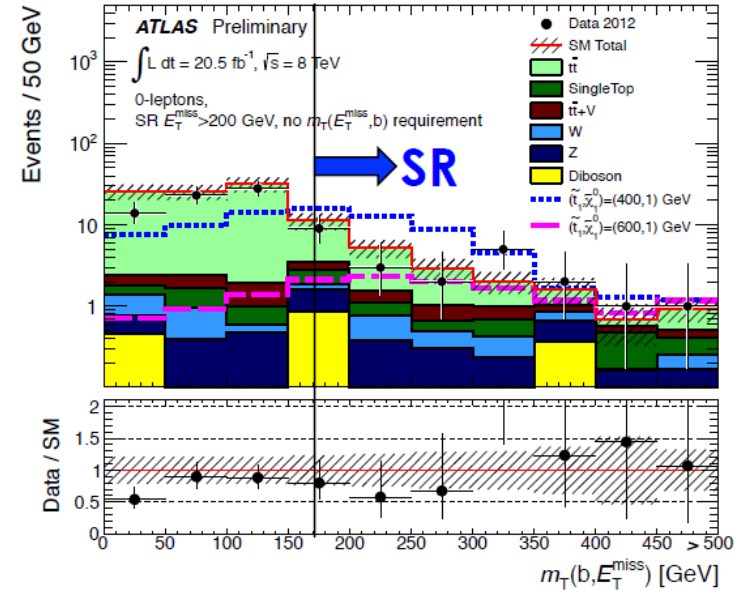
- Recent results :

– ATLAS (20 fb⁻¹)

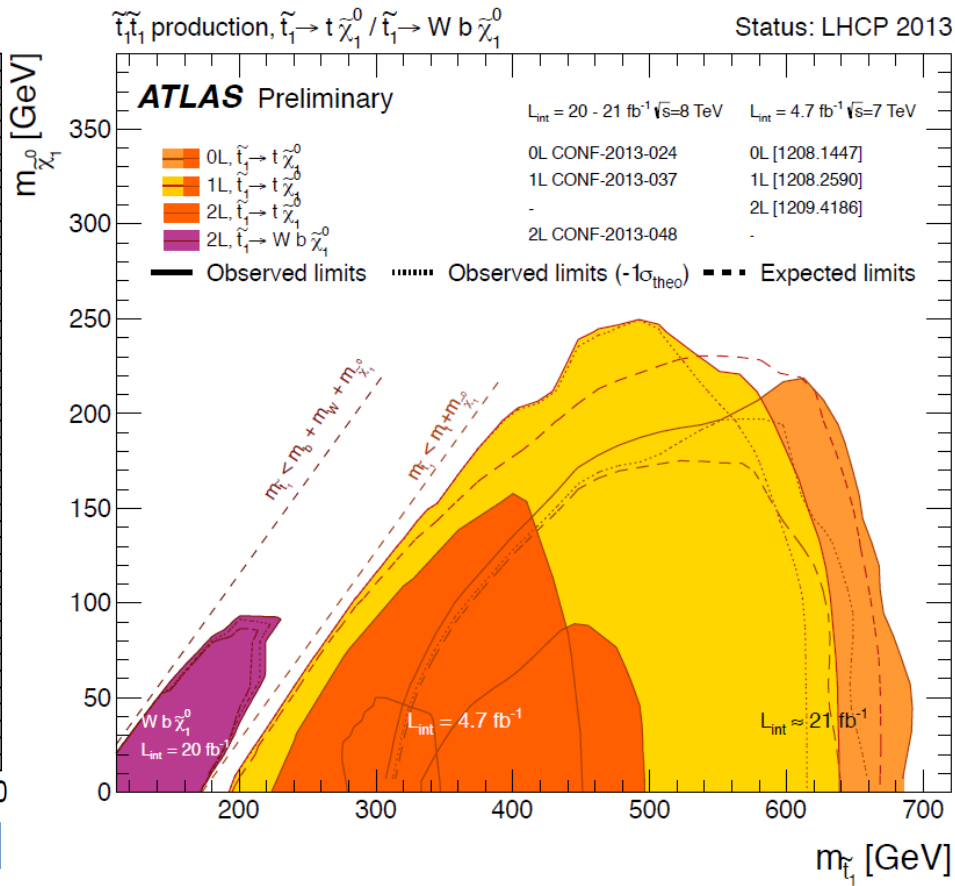
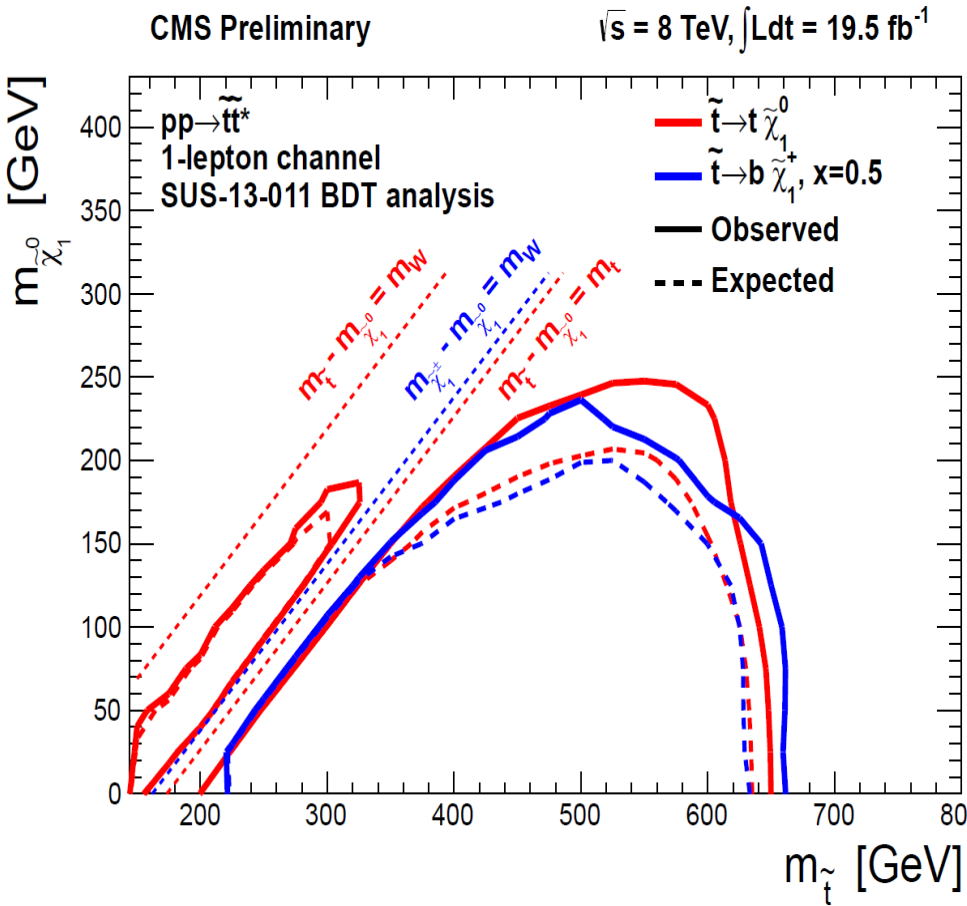
- 0 lepton + 6 (2 b-)jets + E_T^{miss} [2013-024](#)
- 1 lepton + 4 (1 b-)jets + E_T^{miss} [2013-037](#)
- 2 leptons + jets + E_T^{miss} [2013-048](#)
- Z + b-jet + jets + E_T^{miss} [2013-025](#)

– CMS (19.5 fb⁻¹)

- 1 lepton + 4 (1 b-)jets + E_T^{miss} (BDT) [SUS13011](#)



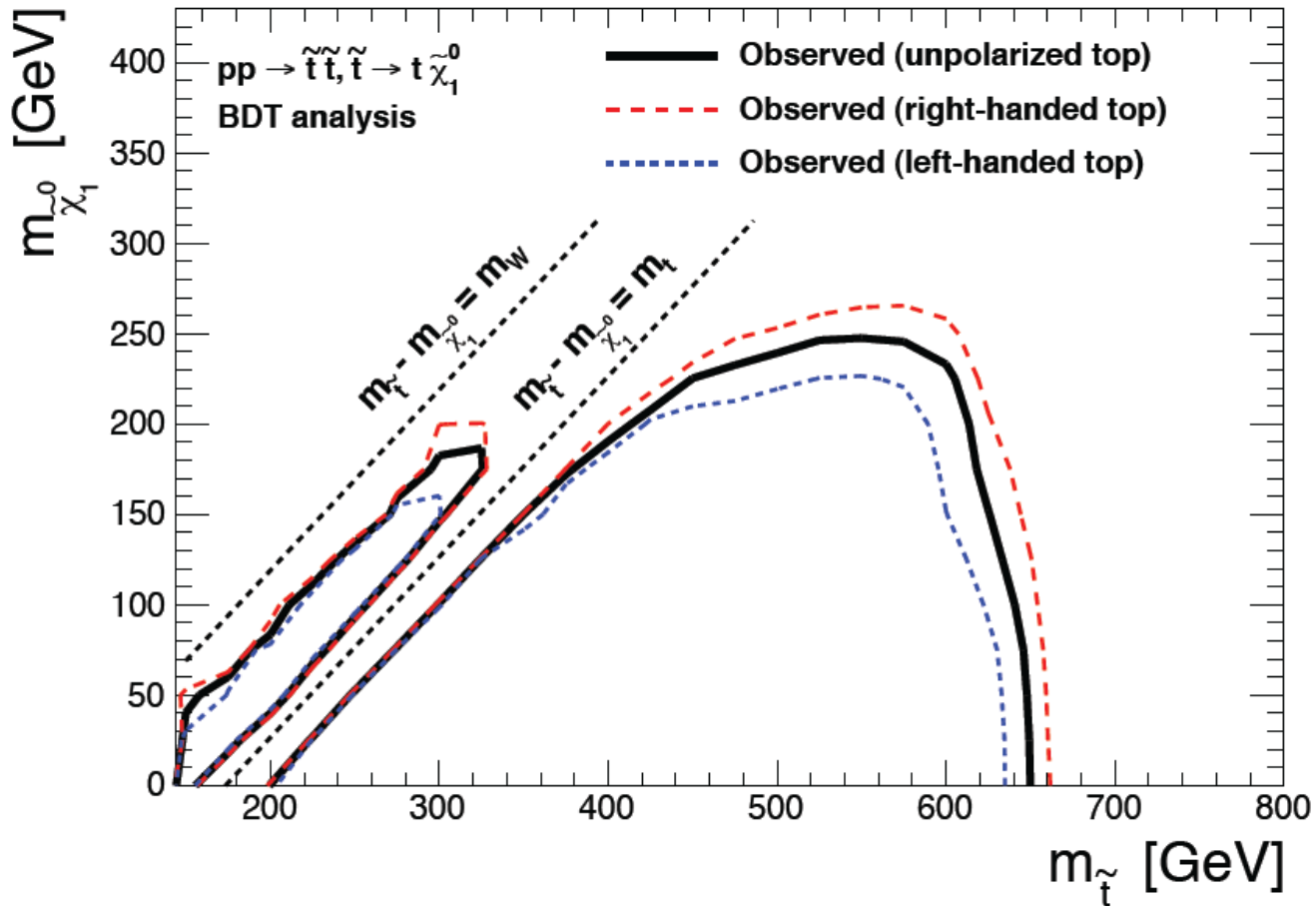
Limits on stop \rightarrow top/bW χ^0_1



stop polarization

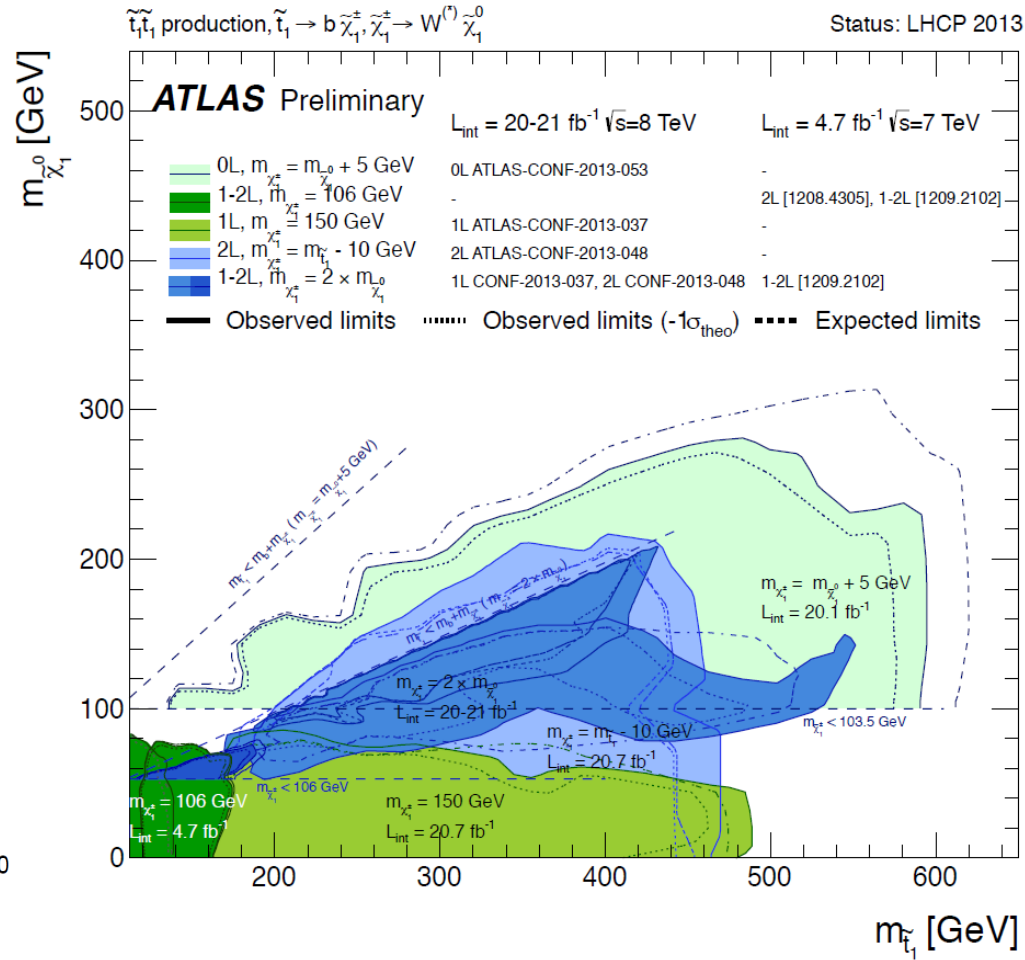
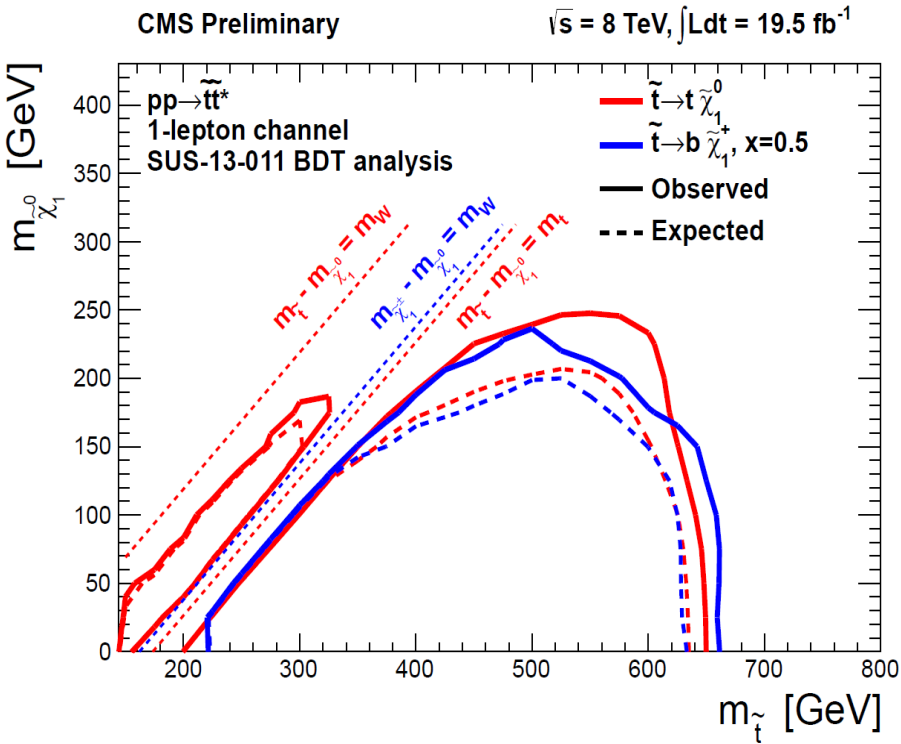
CMS Preliminary

$\sqrt{s} = 8 \text{ TeV}, \int \mathcal{L} dt = 19.5 \text{ fb}^{-1}$



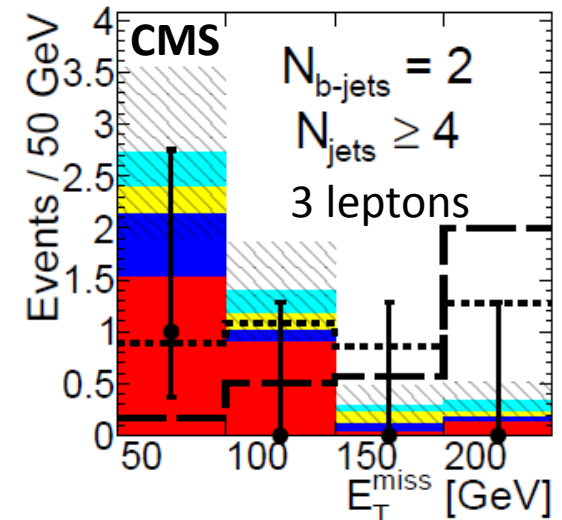
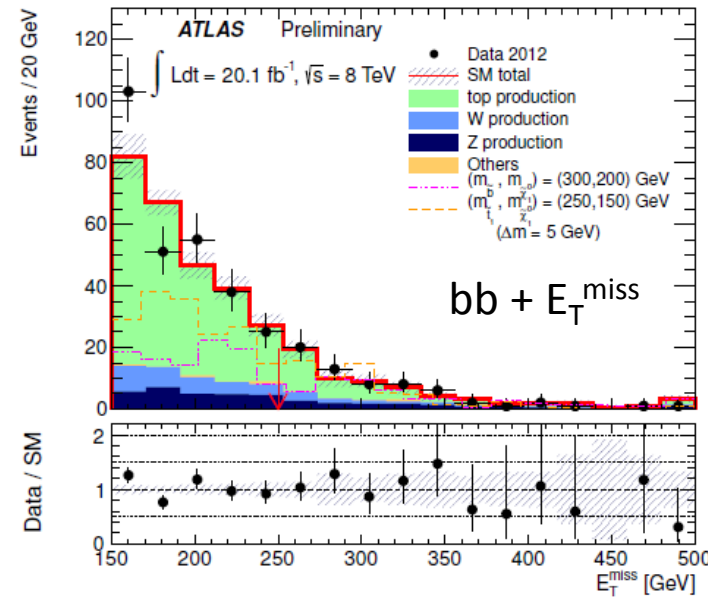
Impact of polarization on limit: ± 20 GeV in 1-lepton channel.
 No impact in 0-lepton channel.

Limits on $\text{stop} \rightarrow b \chi^\pm$



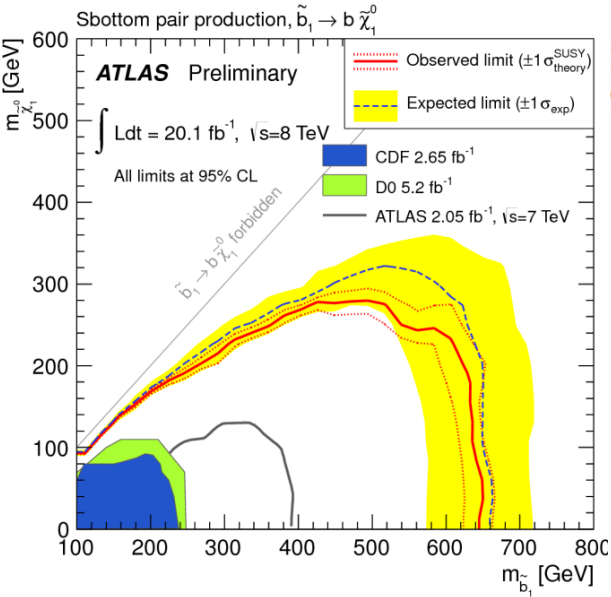
Direct sbottom production

- Light stop motivated by Naturalness
 - sbottom_L related to stop_L by SU(2)_L
- Recent results:
 - ATLAS
 - 0 lepton + bb + E_T^{miss} [2013-053](#)
 - 0/1 lepton + 3 b-jets + E_T^{miss} [2013-061](#)
 - 2 same-sign leptons + b-jets + E_T^{miss} [2013-007](#)
 - CMS
 - alpha_T + 0-4 b-jets [SUS12-028](#)
 - 2 leptons same-sign + b-jets [SUS12-017](#)
 - 3 leptons + b-jets [SUS13-008](#)

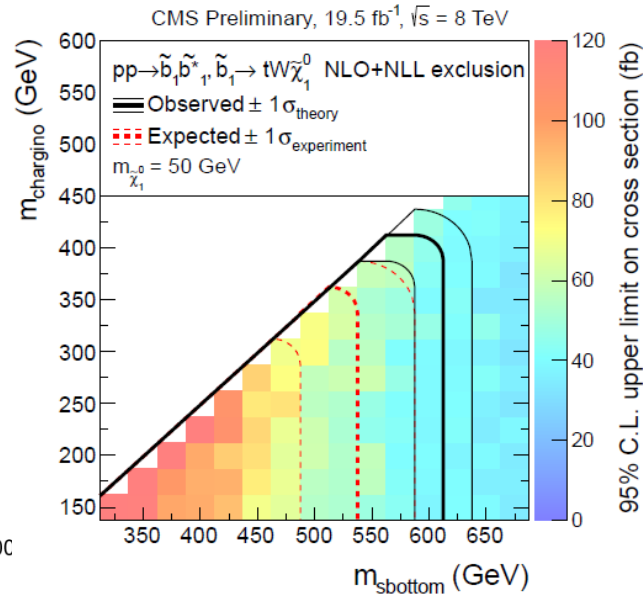


Direct sbottom limits

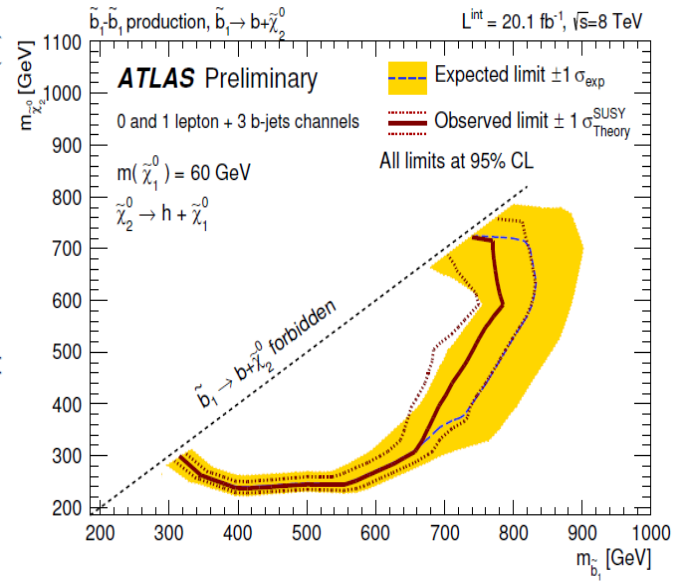
$bb + E_T^{\text{miss}}$



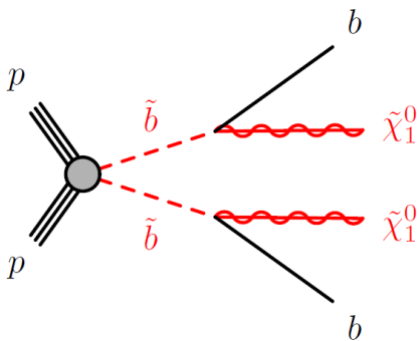
2L SS + b-jet



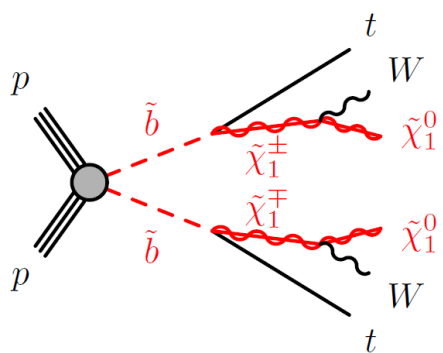
0/1L + 3 b-jets + E_T^{miss}



sbottom $\rightarrow b \tilde{\chi}_1^0$



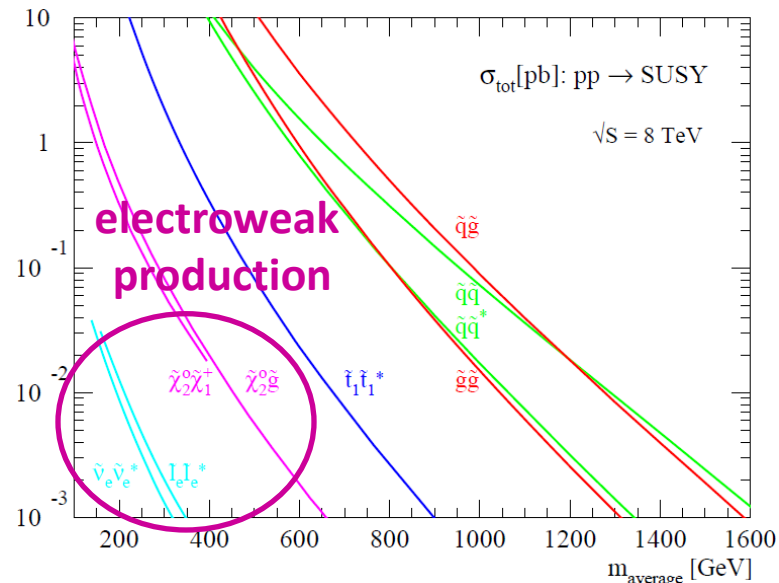
sbottom \rightarrow top $\tilde{\chi}_1^\pm$



sbottom $\rightarrow b \tilde{\chi}_2^0$
 $\rightarrow b h(bb) \tilde{\chi}_1^0$

Recent Results

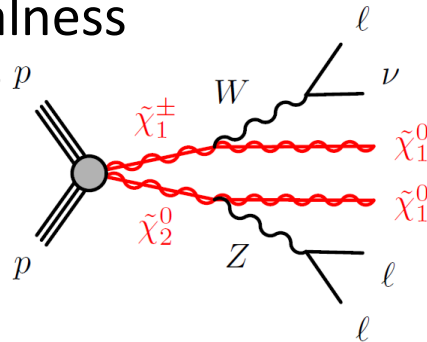
- gluino & 1st/2nd generation squarks
- 3rd generation (top & bottom) squarks
- electroweak SUSY (chargino, neutralinos, sleptons)
- R-Parity Violating & Gauge Mediated scenarios



Electroweak SUSY production

- Light neutralino/chargino motivated by:

- SUSY Naturalness
- Dark Matter



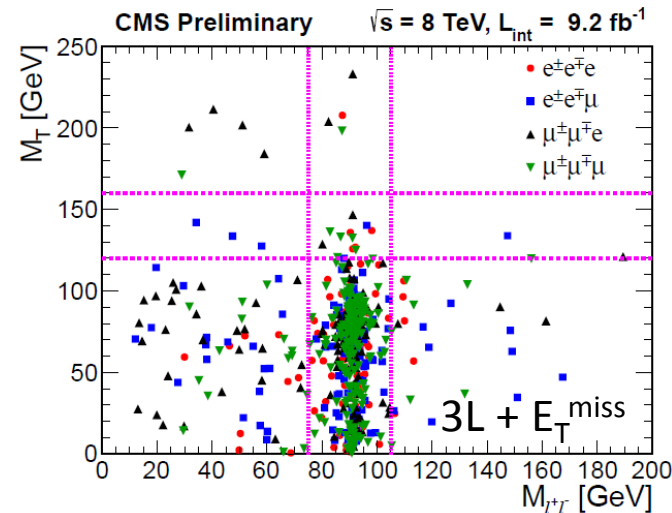
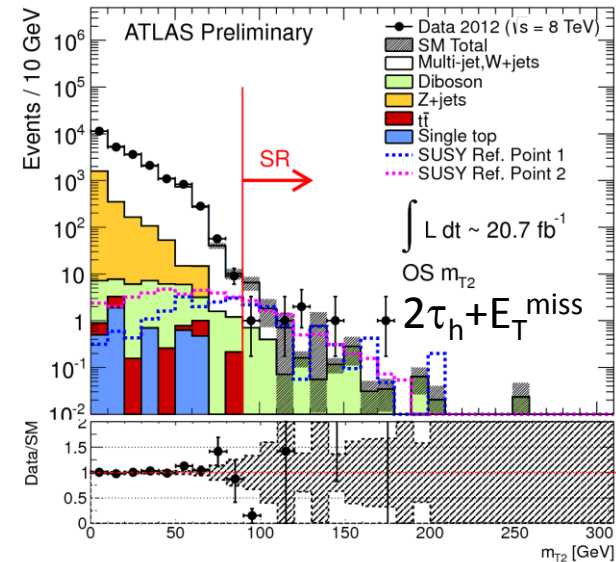
- Recent results:

- ATLAS

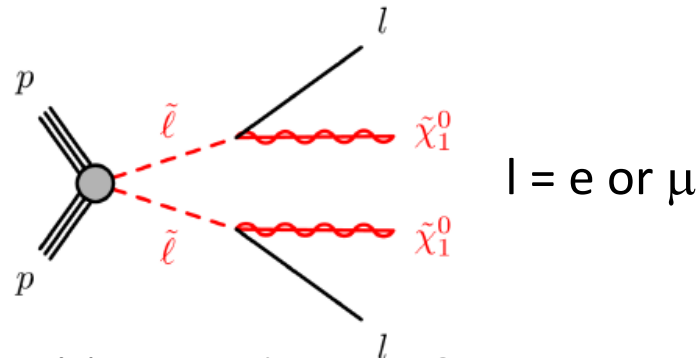
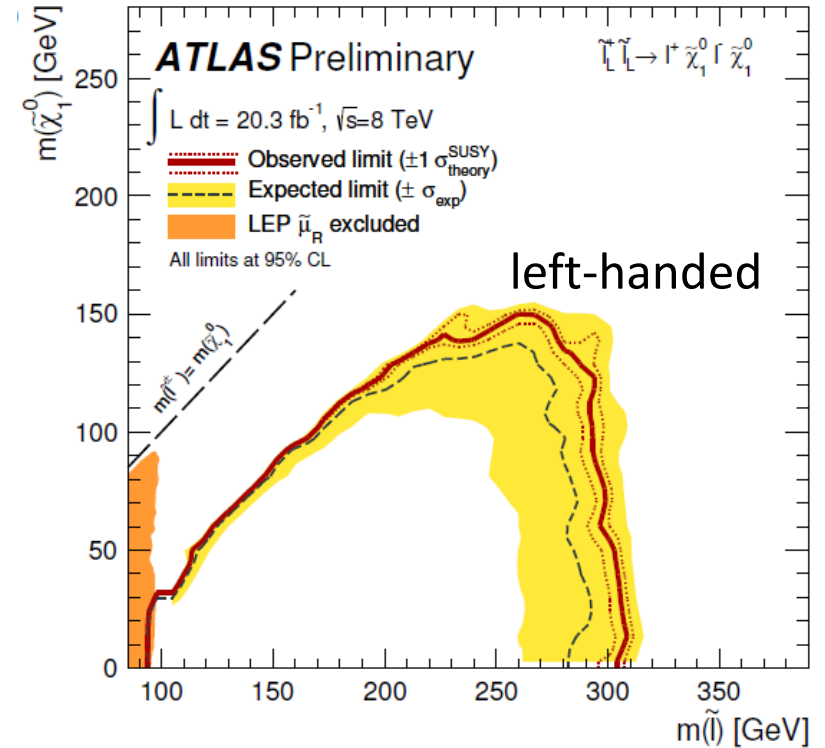
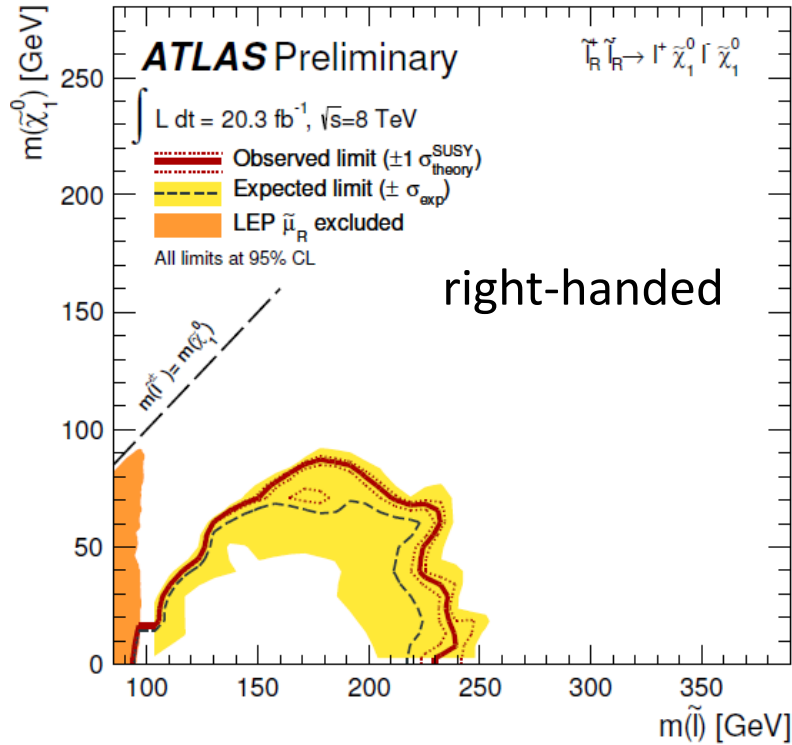
- 2 leptons (e/μ) + E_T^{miss} [2013-049](#)
- 2 τ + E_T^{miss} [2013-028](#)
- 3 leptons (e/μ) + E_T^{miss} [2013-035](#)
- 4 leptons + E_T^{miss} [2013-036](#)

- CMS

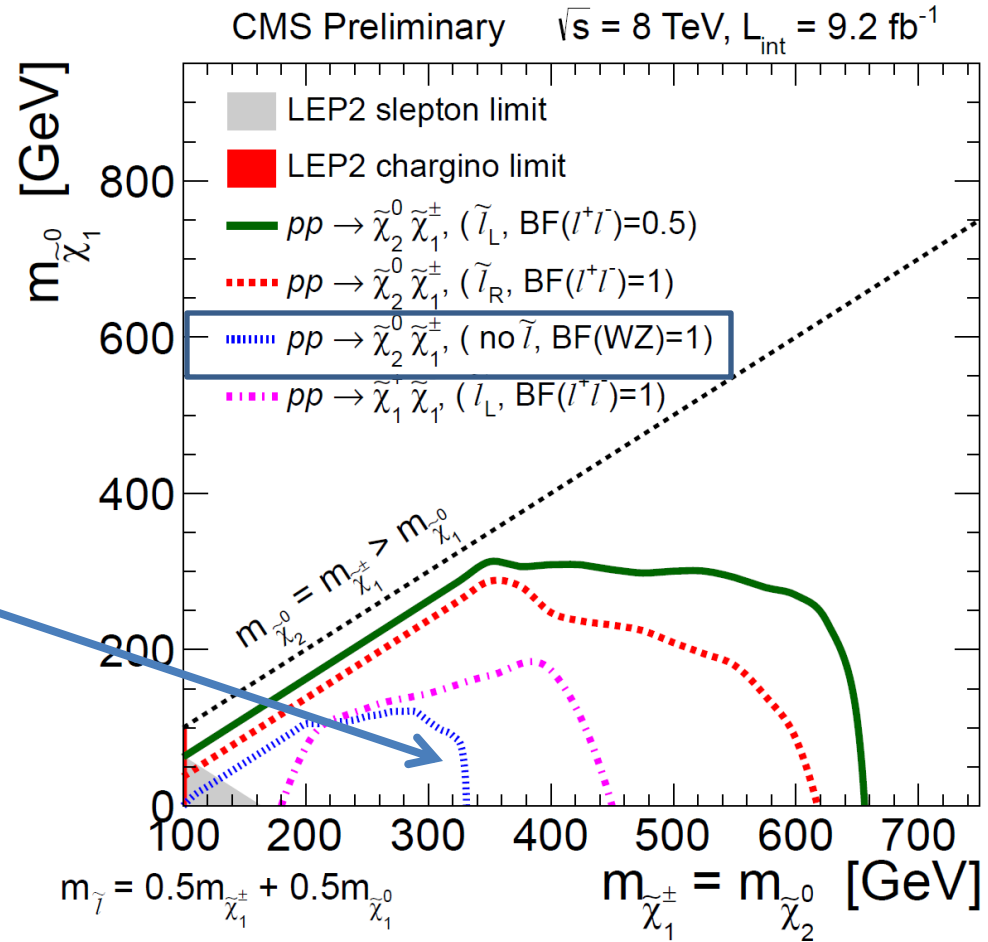
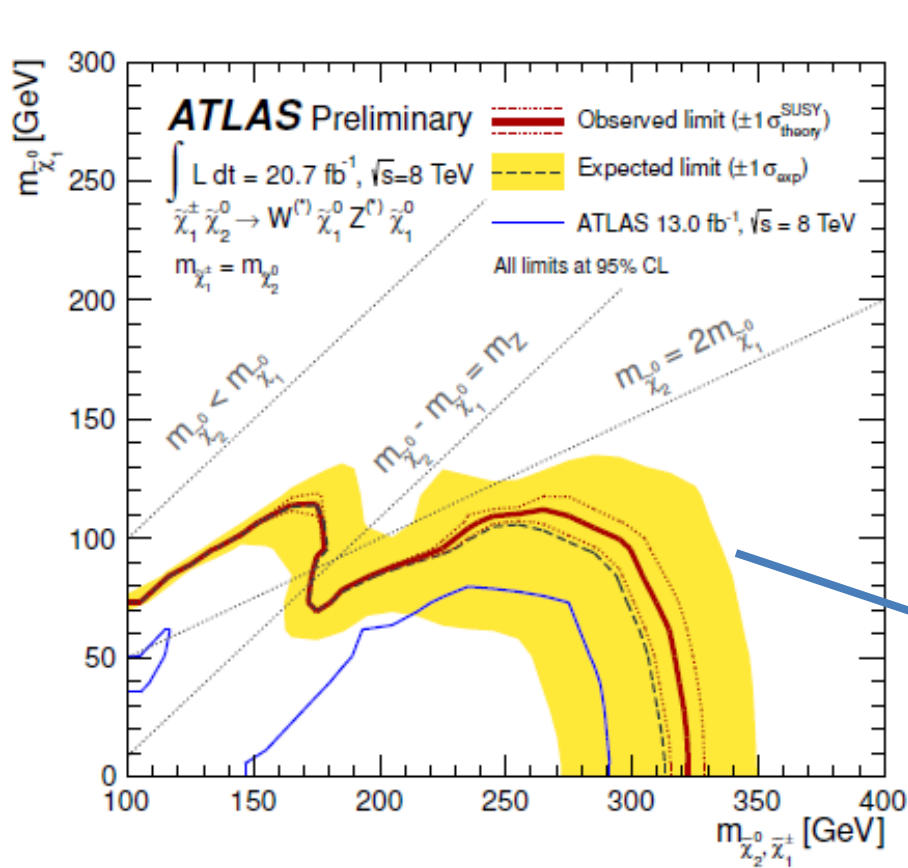
- 2,3,4 leptons + E_T^{miss} [SUS12022](#)



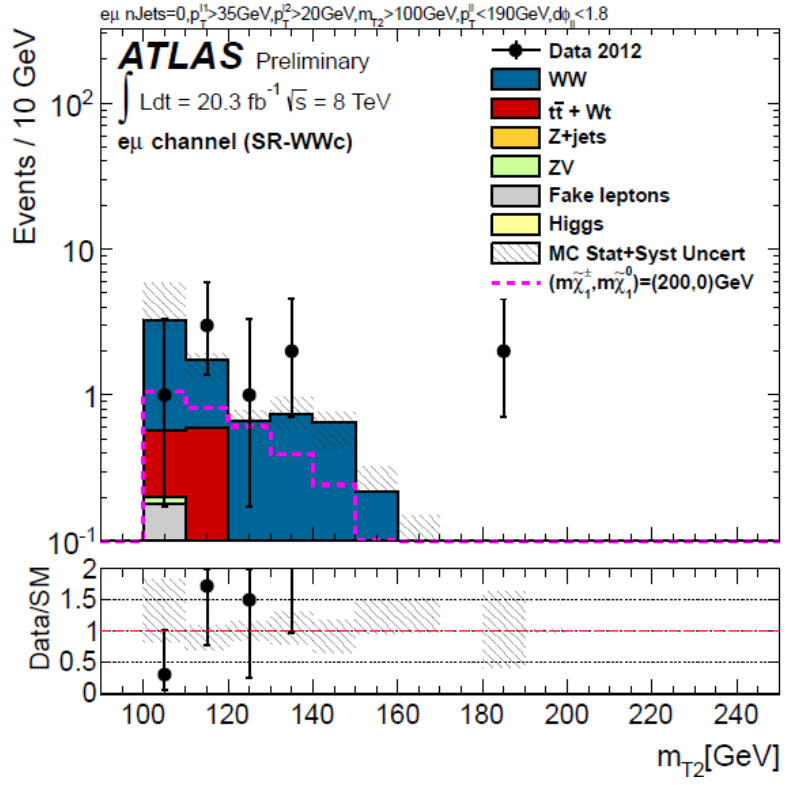
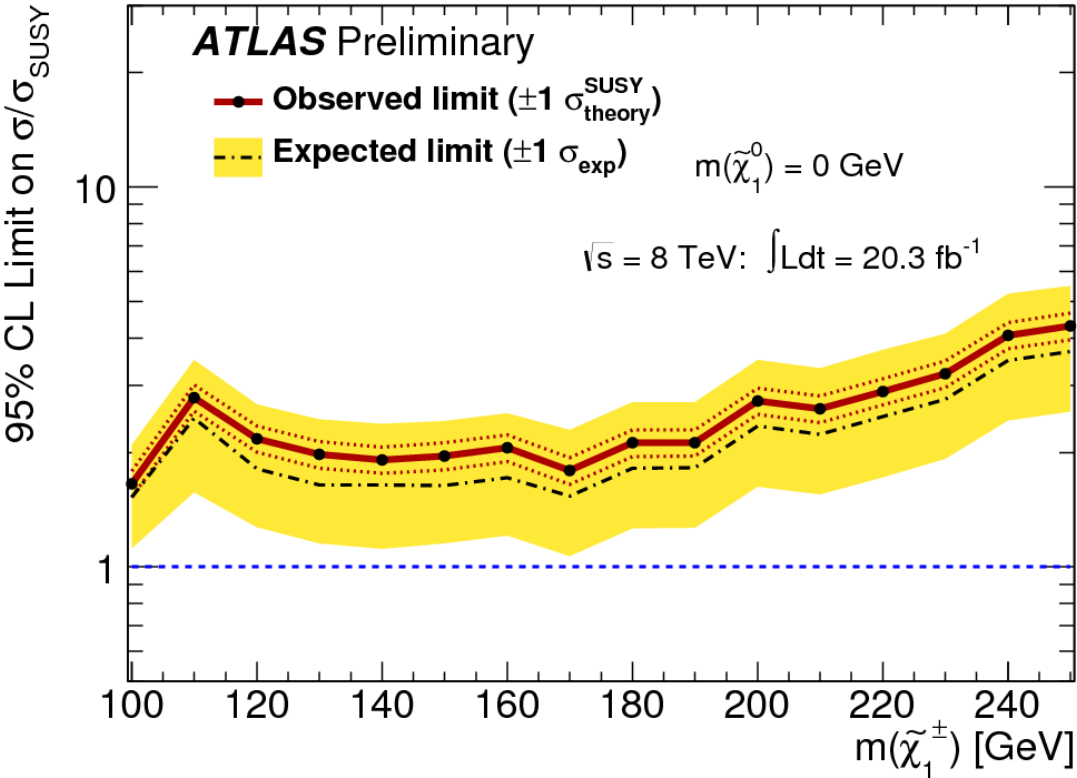
direct sleptons production



Limits on $\chi^0_2 \chi^\pm_1$



Limited sensitivity to $\chi^+_1 \chi^-_1 \rightarrow W^+W^- + E_T^{\text{miss}}$

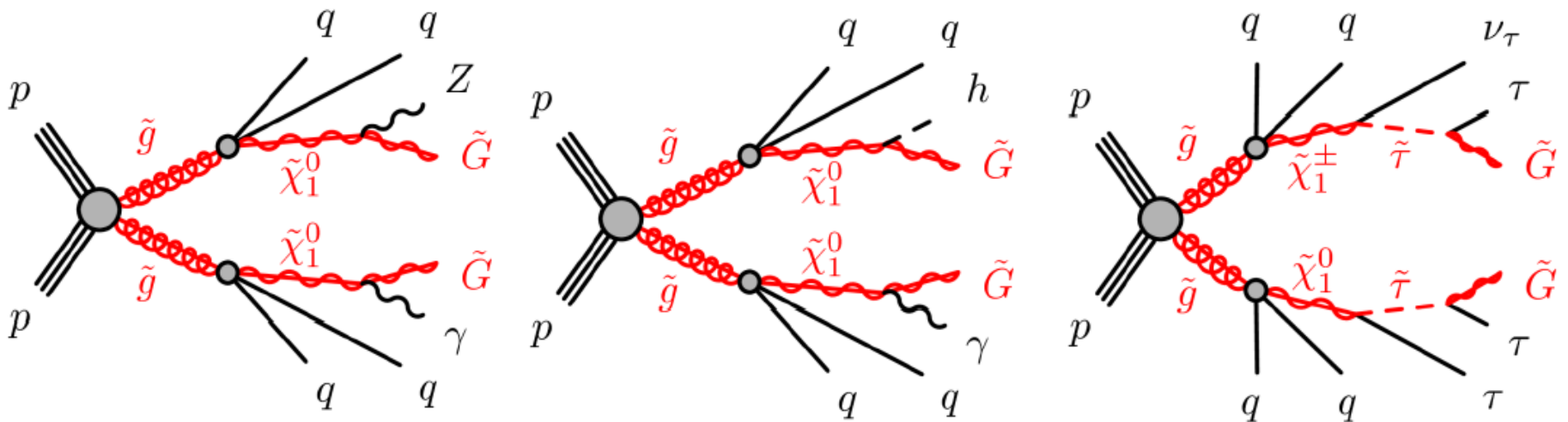


Recent Results

- gluino & 1st/2nd generation squarks
- 3rd generation (top & bottom) squarks
- electroweak SUSY (chargino, neutralinos, sleptons)
- **R-Parity Violating & Gauge Mediated scenarios**

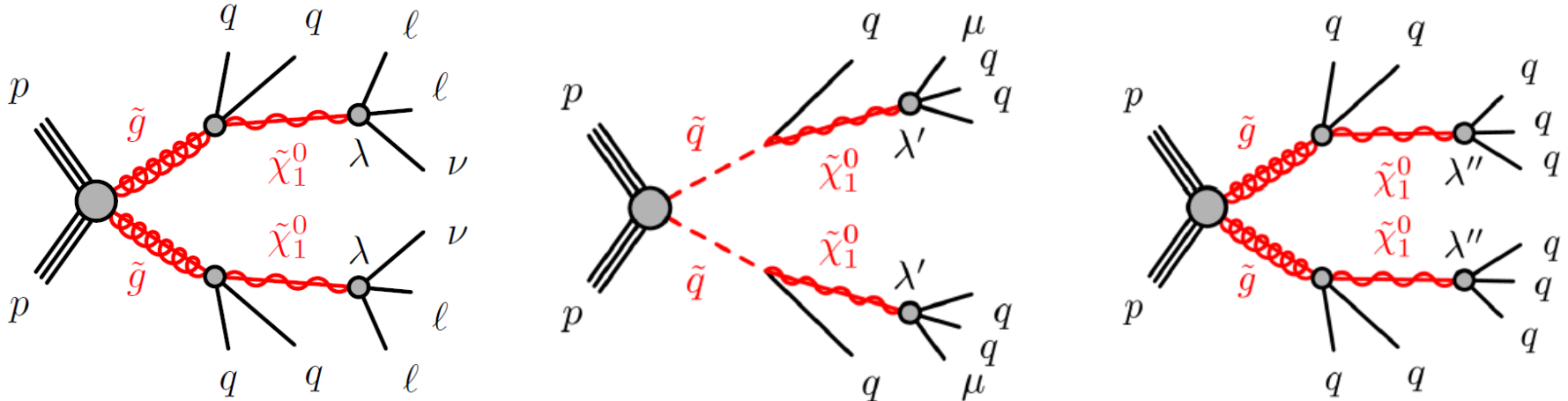
Gauge Mediation

Talk by Andrew Kuhl

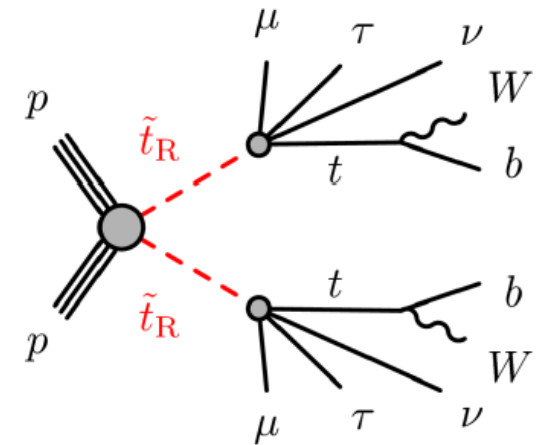


- SUSY production as usual: gluino, squarks, electroweak
- Lightest Supersymmetric Particle is the Gravitino (G)
- Phenomenology driven by NLSP particle & decay
 - $\chi_1^0 \rightarrow \gamma G$
 - $\chi_1^0 \rightarrow Z/h G$
 - $\text{stau} \rightarrow \tau G$
 - etc.

R-Parity Violation

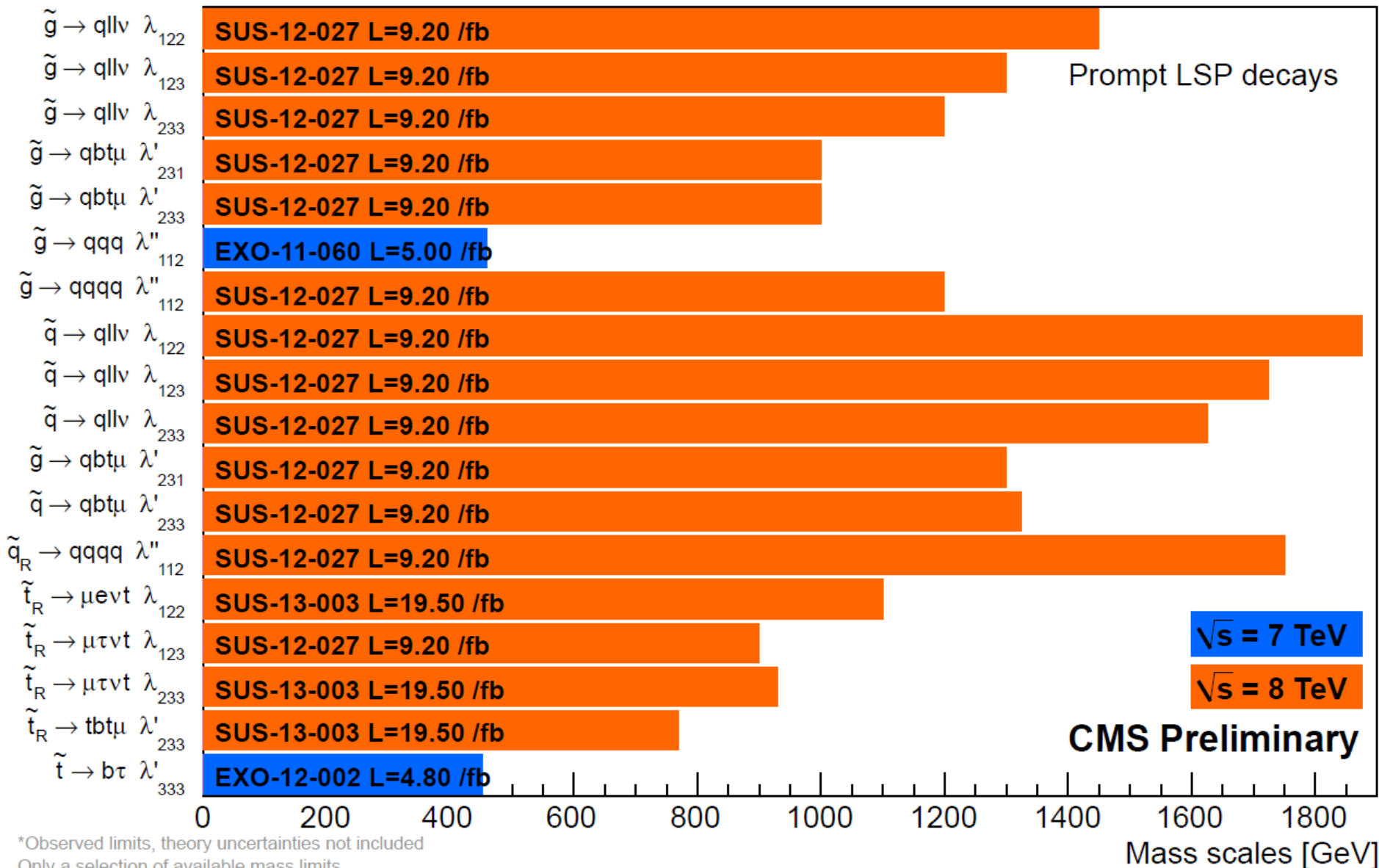


- R-Parity conservation is not necessary for viable SUSY models
 - SUSY production as usual*: gluino, squarks, electroweak ()
 - Lightest Supersymmetric Particle is not stable:
 - give up on SUSY Dark Matter
- Recent results with 20 fb^{-1} :
 - ATLAS
 - 4 leptons + MET ($e/\mu/\tau$, target leptonic λ) [2013-036](#)
 - 0 lepton + 7-10 jets (re-interpretation) [2013-054](#)
 - 2 leptons same-sign + 3 b-jets (re-interpretation) [2013-007](#)
 - CMS
 - 3 leptons + b-jets [SUS12027](#), [SUS13003](#)
 - 4 leptons [SUS13010](#)



Summary of CMS RPV SUSY Results*

LHCP 2013



*Observed limits, theory uncertainties not included

Only a selection of available mass limits

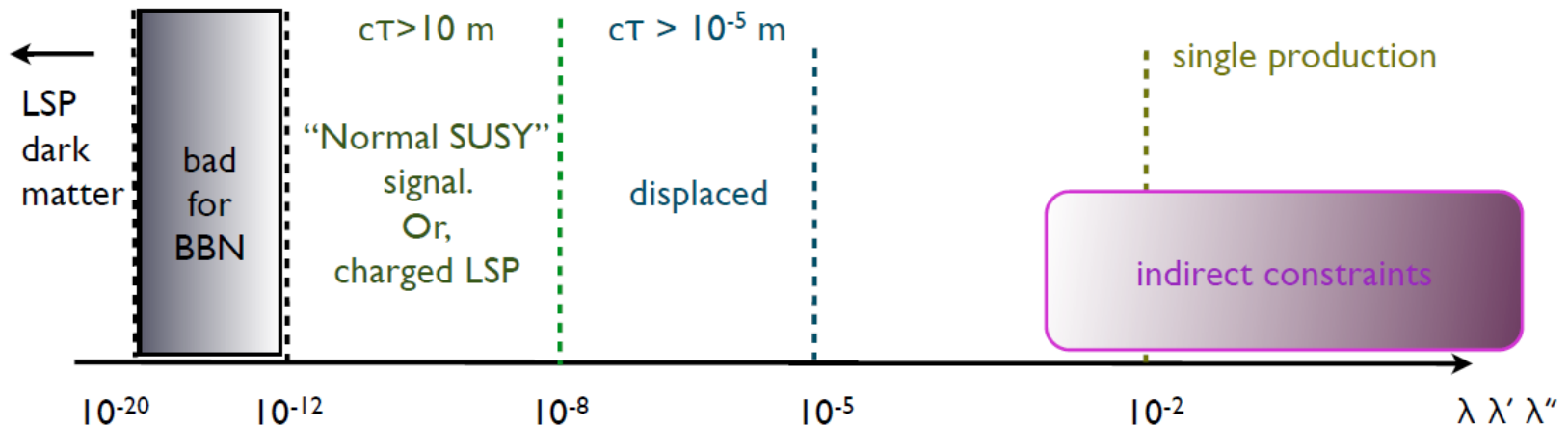
Probe *up to* the quoted mass limit

See: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

Long-lived particles

Talk by Antonio Boveia
Talk by Antoine Marzin

- Gauge Mediated and RPV scenarios with weak couplings can produce long-lived particles
 - stau \rightarrow (like heavy muon) $\rightarrow \tau G$
 - gluino \rightarrow (R-hadron) $\rightarrow qqq$
 - etc.



Outlook



So we have not found SUSY...

What does it mean? What is coming up?

Impact of LHC on SUSY phenomenology

- In spite of their null results, the ATLAS & CMS searches have transformed the landscape of SUSY phenomenology
 - mSUGRA → Natural SUSY
 - emergence of simplified models
 - generalization of model parameters
 - mSUGRA (4.5 par) → Neutralino pMSSM (19 par)
 - GMSB (4.5 par) → GGM → Gravitino pMSSM (20 par)

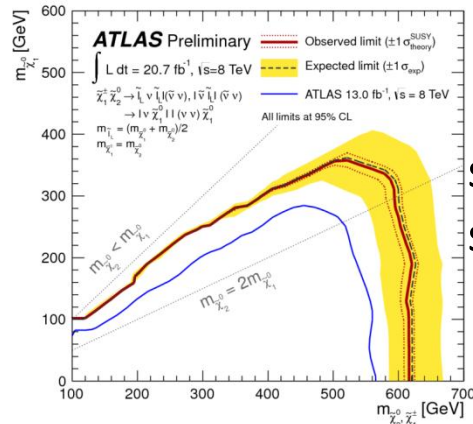
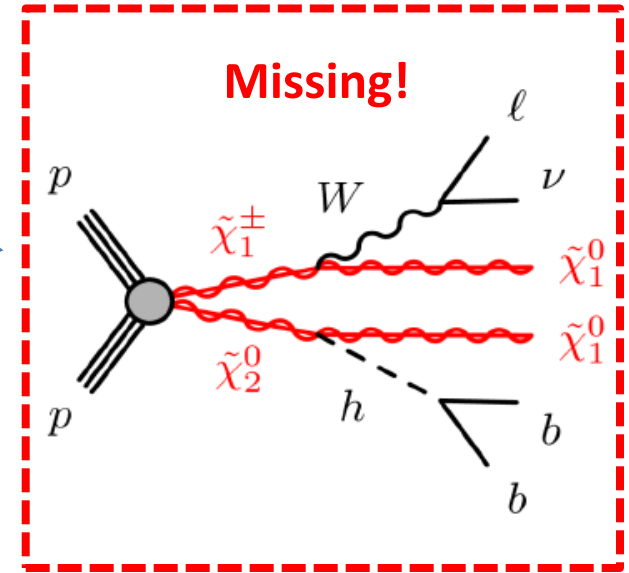
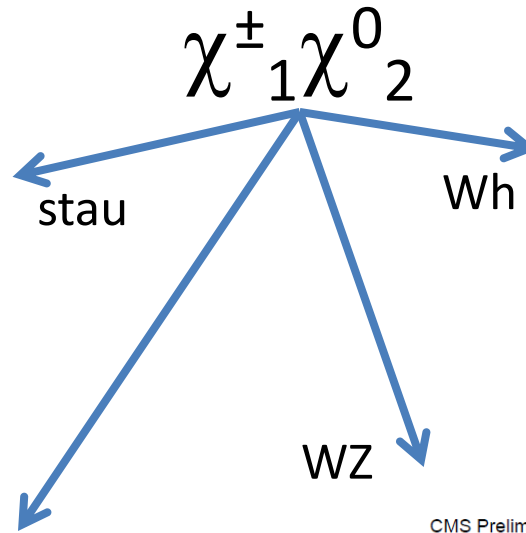
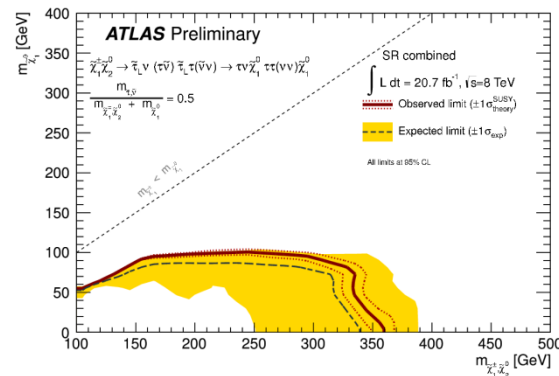
see talk by
Tom Rizzo

pMSSM interpretations by CMS: [SUS-12-024](#), [SUS-12-030](#)

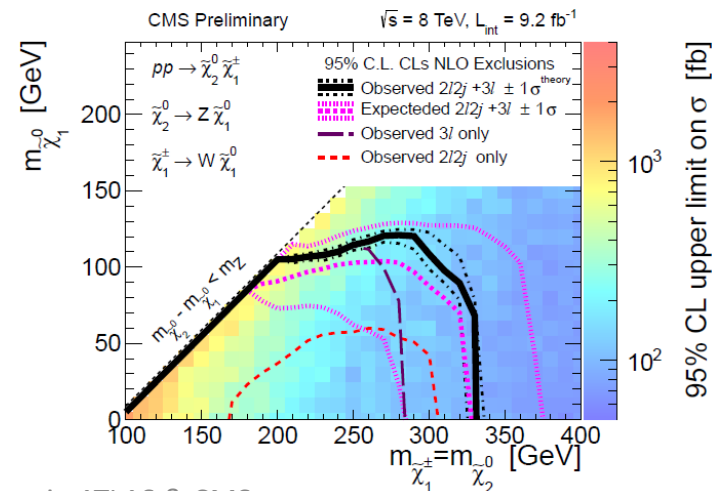
Other searches at 8 TeV



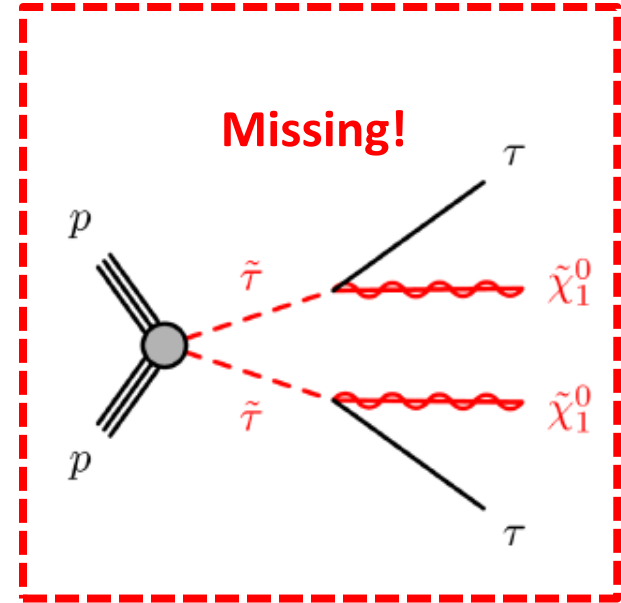
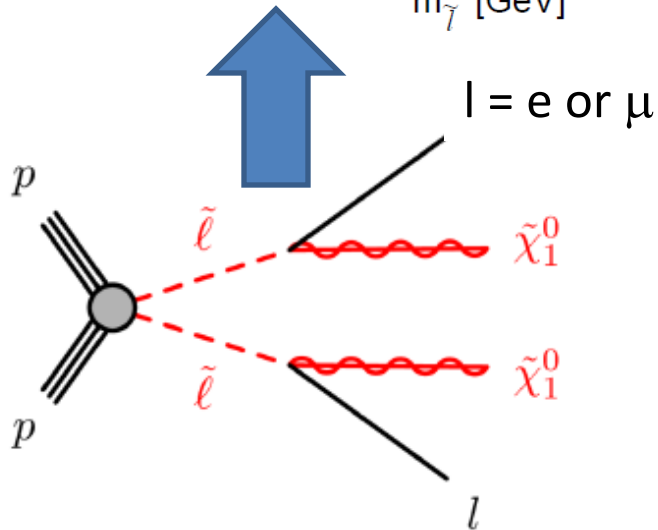
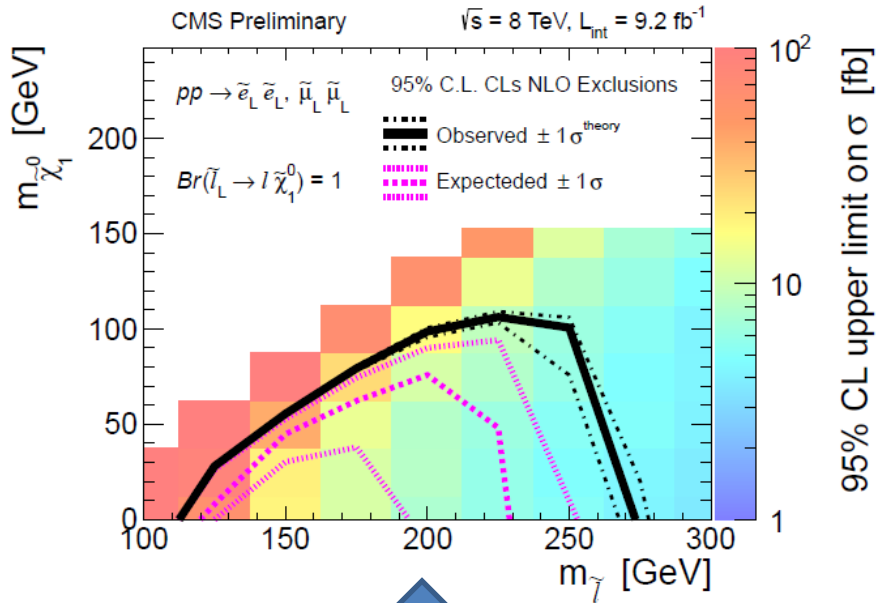
Gauginos decay via Higgs



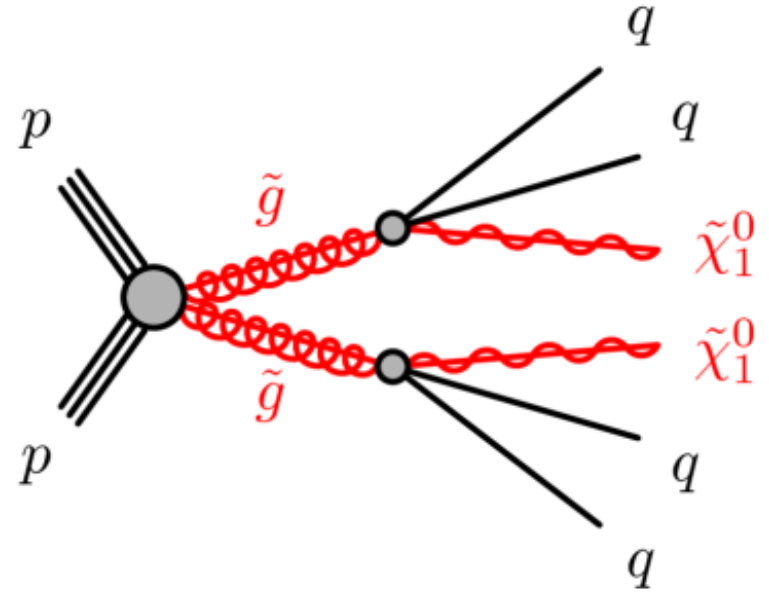
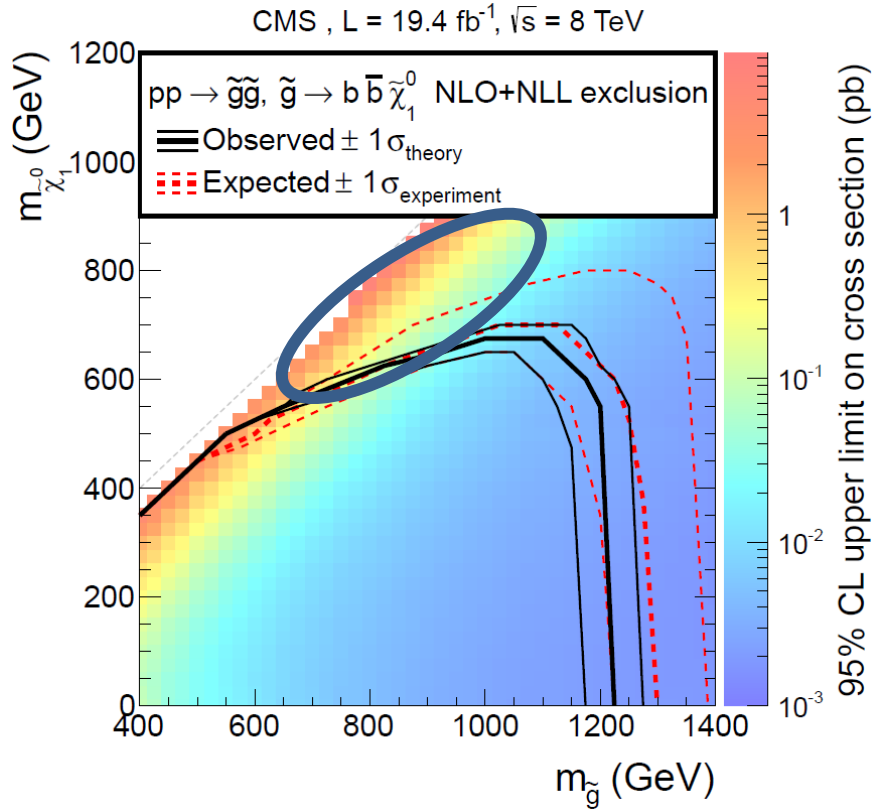
selectron
 smuon



direct stau production

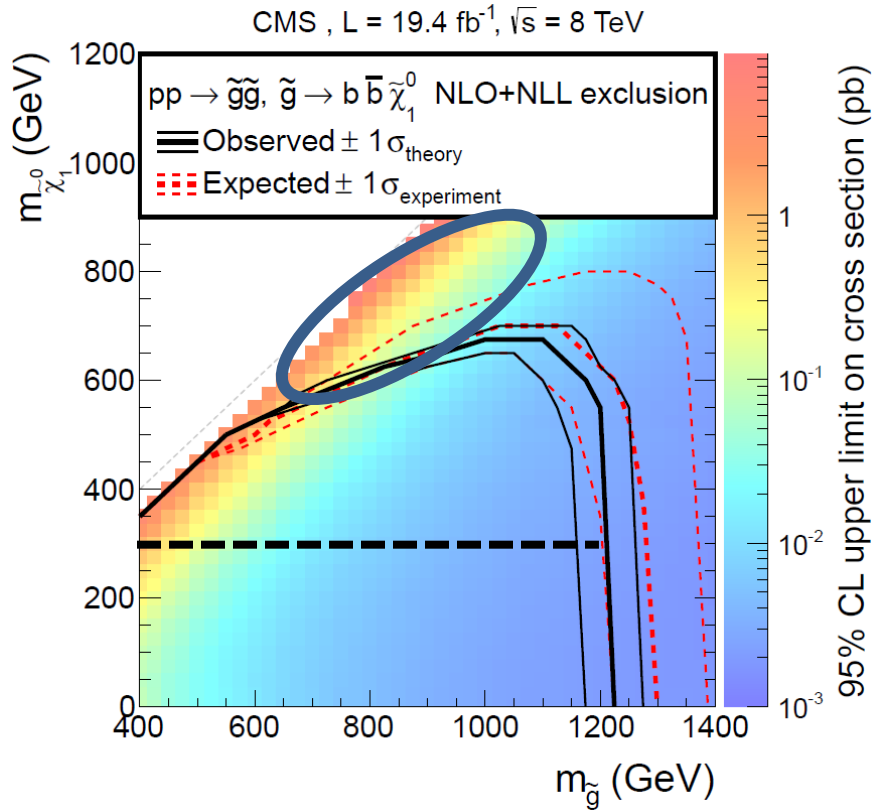


compressed spectra: strong production



Loss of sensitivity with small $\Delta M(\text{gluino}, \chi_1^0)$ or $\Delta M(\text{squark}, \chi_1^0)$ in simplified models.

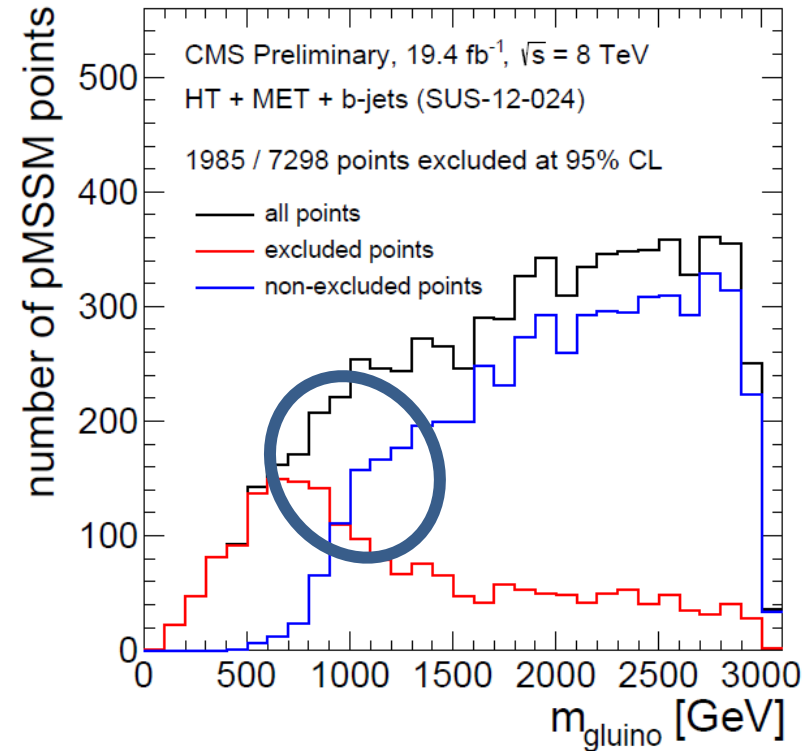
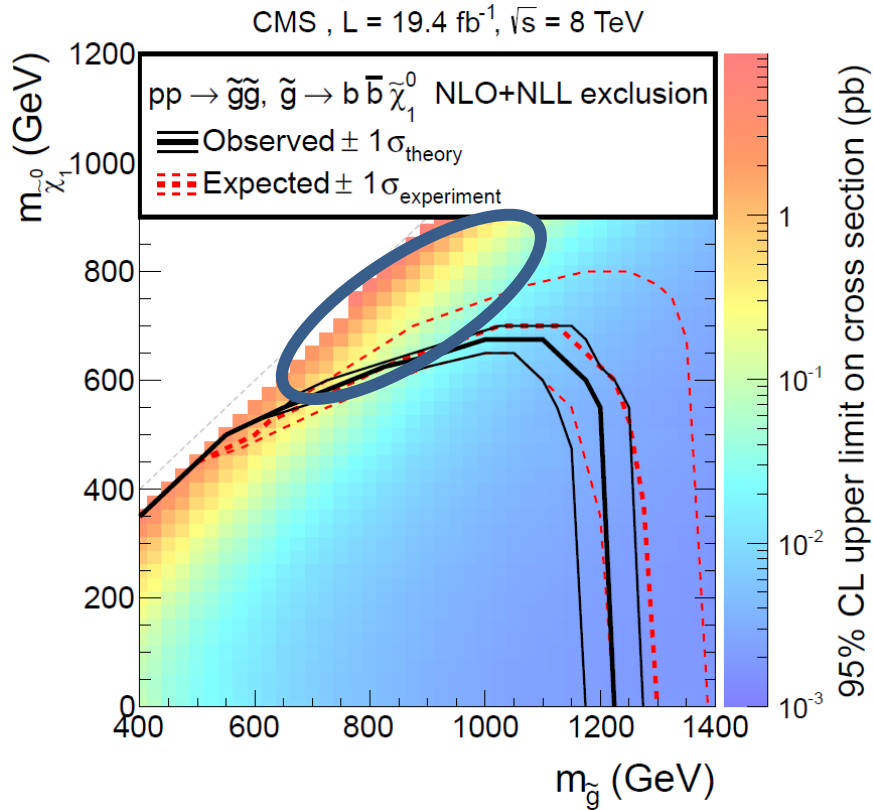
compressed spectra: strong production



Not really affecting $m_{\tilde{\chi}_1^0} < \sim 300 \text{ GeV}$
 stipulated by light Higgsino
 in Natural SUSY.

Loss of sensitivity with small $\Delta M(\text{gluino}, \tilde{\chi}_1^0)$ or $\Delta M(\text{squark}, \tilde{\chi}_1^0)$ in simplified models.

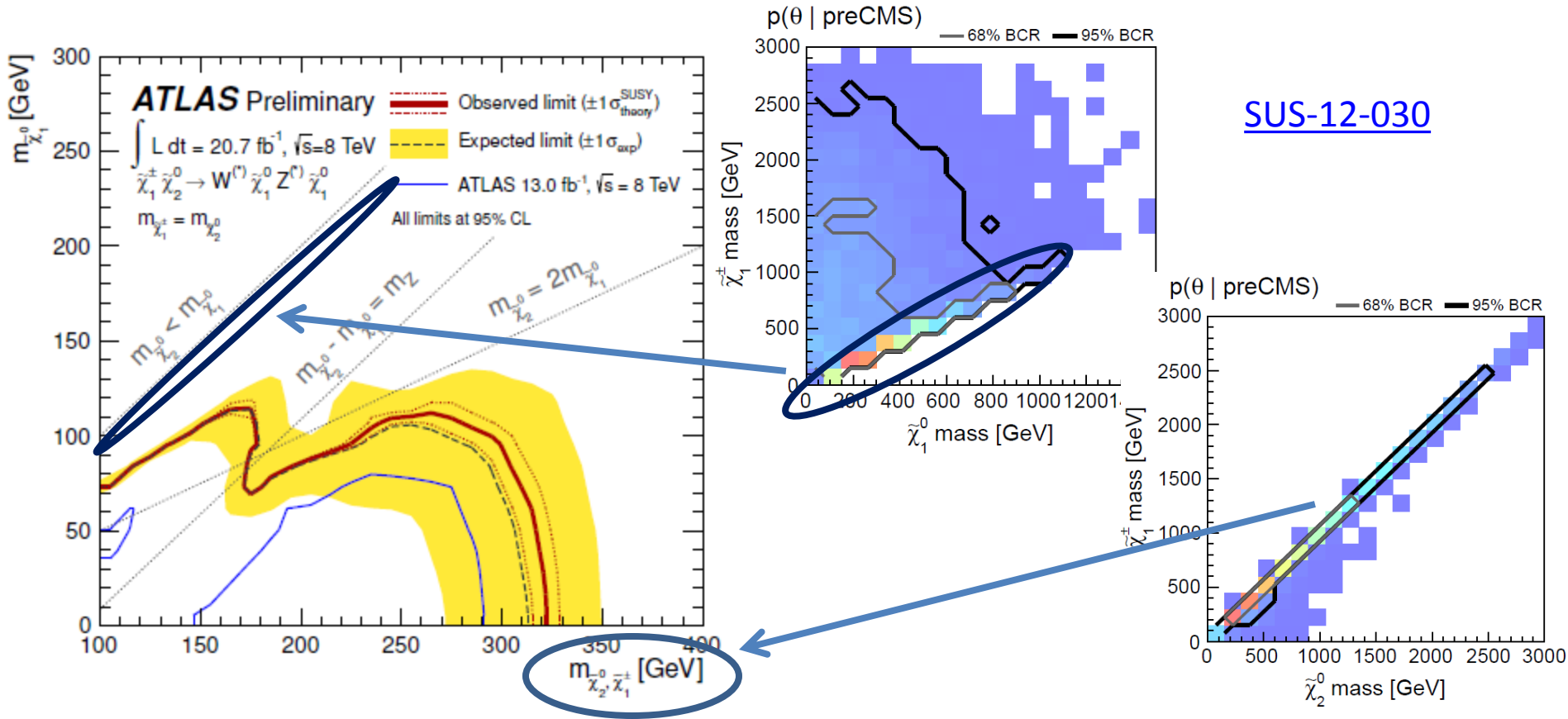
compressed spectra: strong production



These scenarios are observed in viable pMSSM models,
but they don't have a special motivation otherwise.

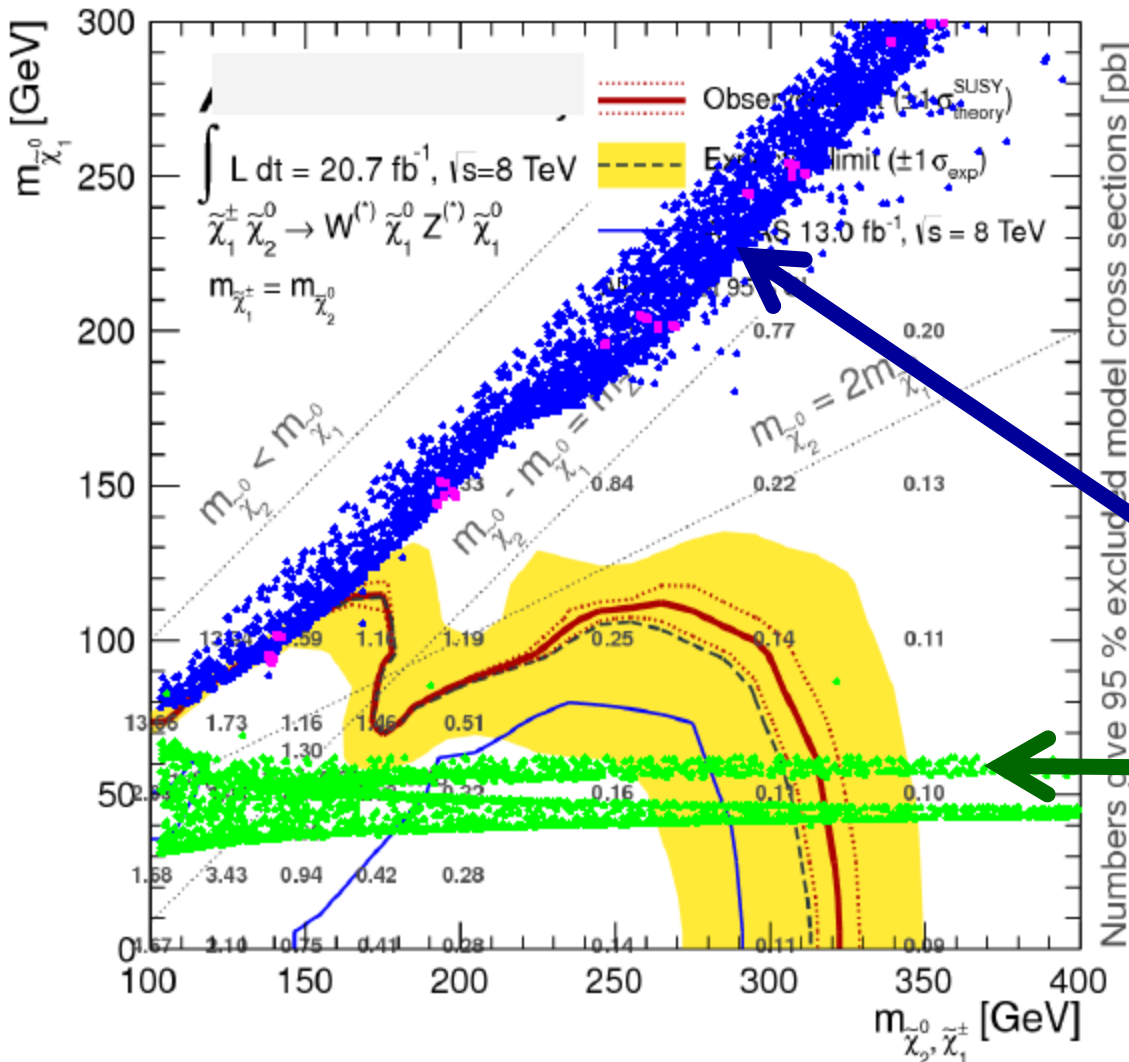
compressed spectra: gauginos

[SUS-12-030](#)



Very compressed $\Delta m(\tilde{\chi}_{1^\pm}, \tilde{\chi}_1^0)$ from pure Wino or Higgsino state arise naturally in the pMSSM because M_1 , M_2 and μ are un-correlated.

compressed spectra: gauginos

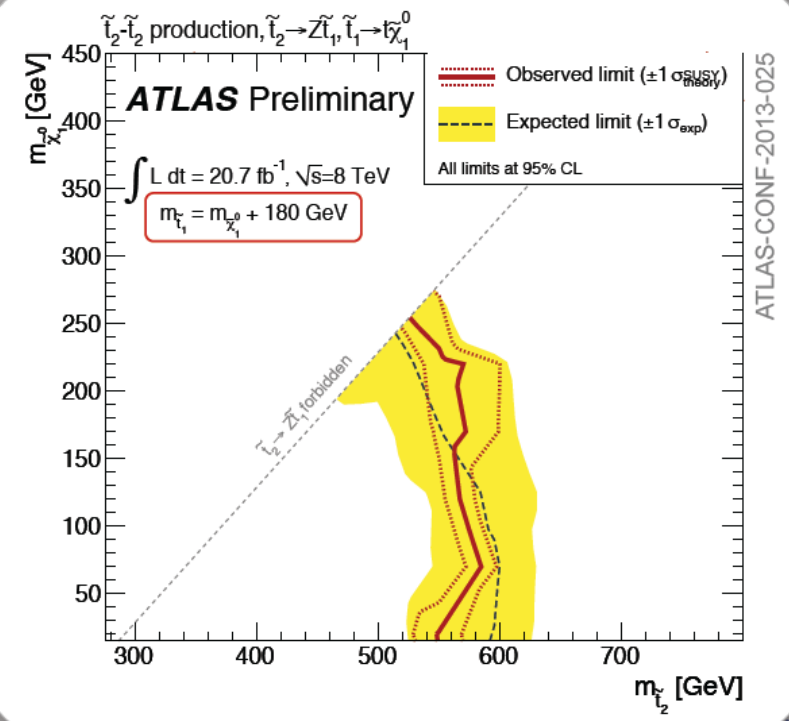
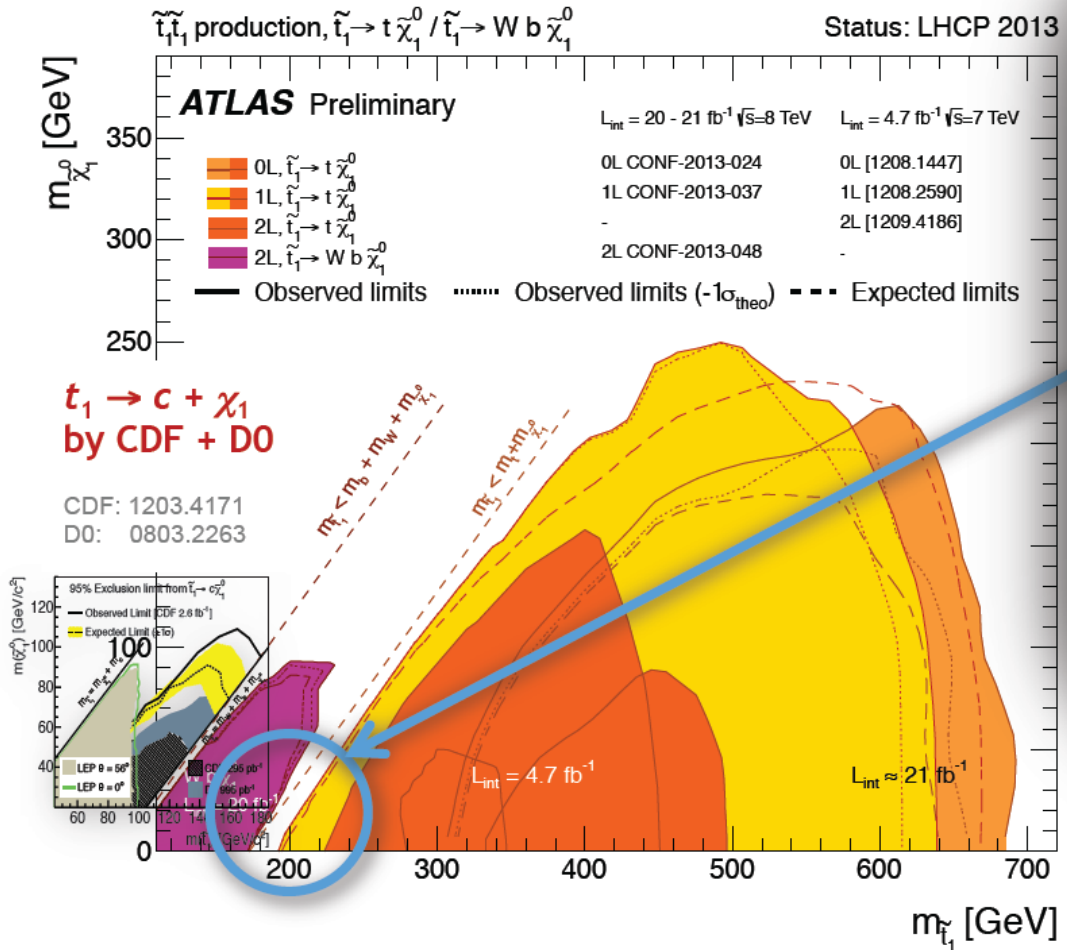


Compressed spectra with small $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ or small $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ are also motivated by dark matter relic density constraints.

Well-tempered neutralino population in pMSSM scans.

$Z \rightarrow \chi\chi$ and $h \rightarrow \chi\chi$ poles.

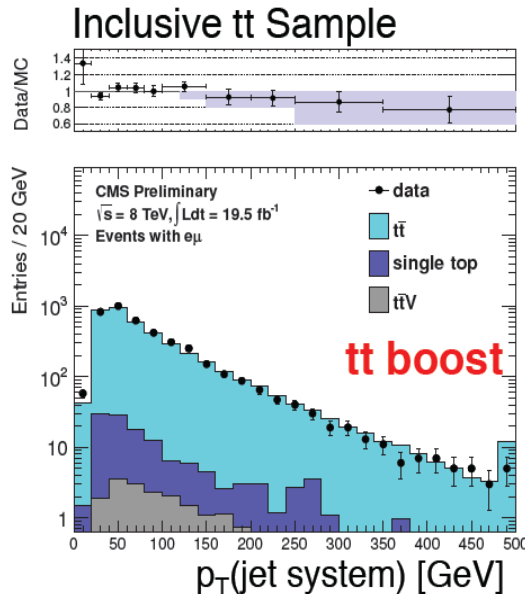
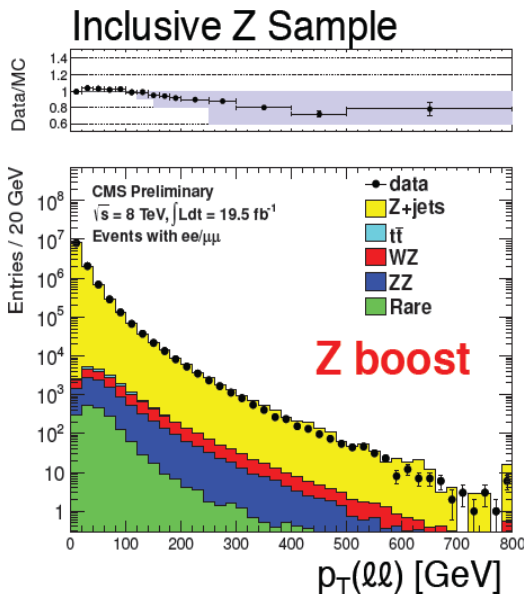
direct stop near $m_{\text{stop}} \approx m_{\text{top}}$



compressed spectra: impact of ISR

credits: B. Hooberman

- Signal efficiency in the small ΔM region depends on ISR
- Validate with data/MC comparisons in Z+jets and tt samples
 - Different initial state partons \rightarrow consistent results

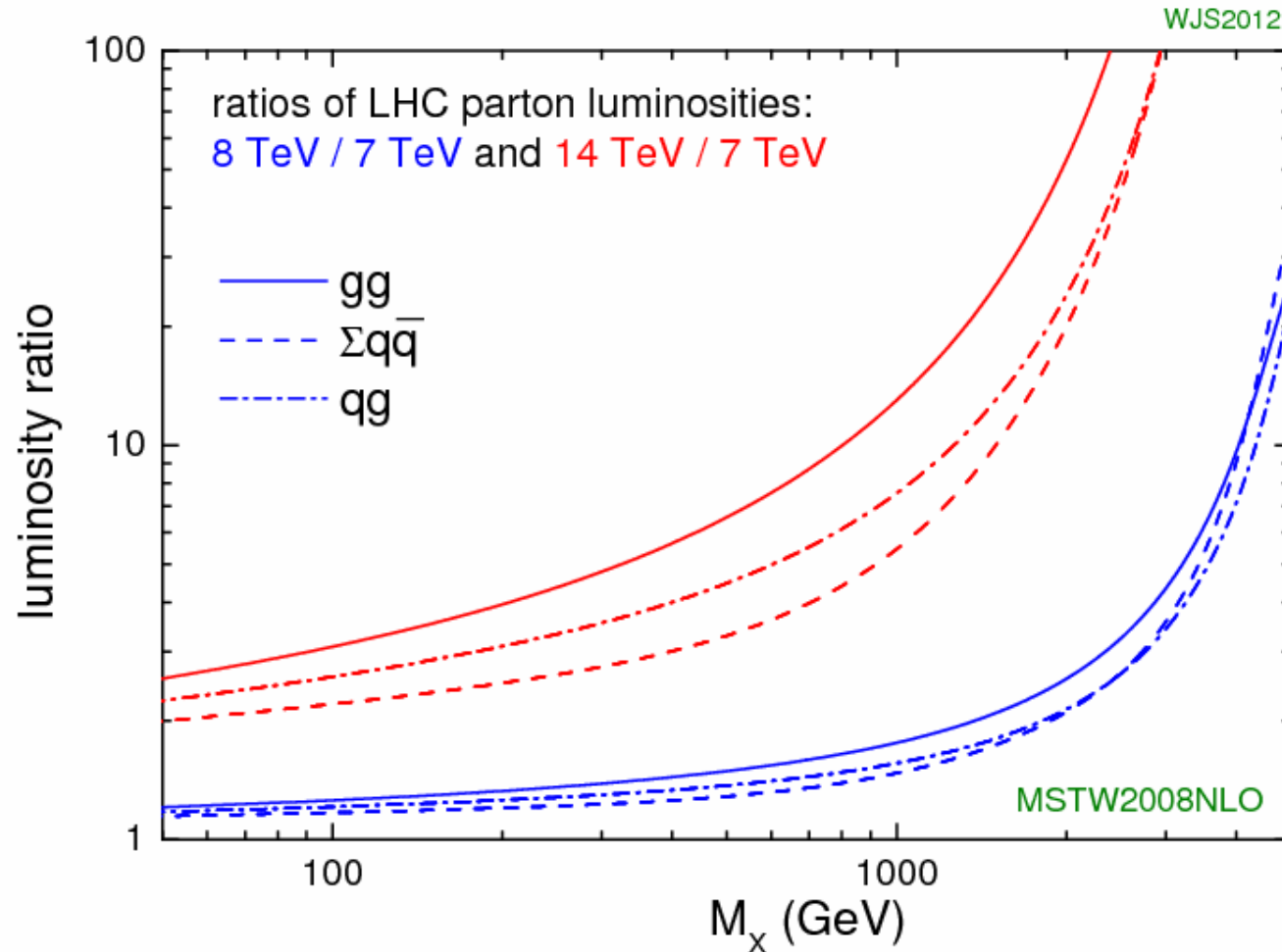


ATLAS also estimates ISR systematic uncertainties by varying normalization and factorization scales with Madgraph+pythia.

- **CMS tuning of madgraph MC tends to overestimate ISR \rightarrow extract corrections and reweight the signal MC events**

14 TeV

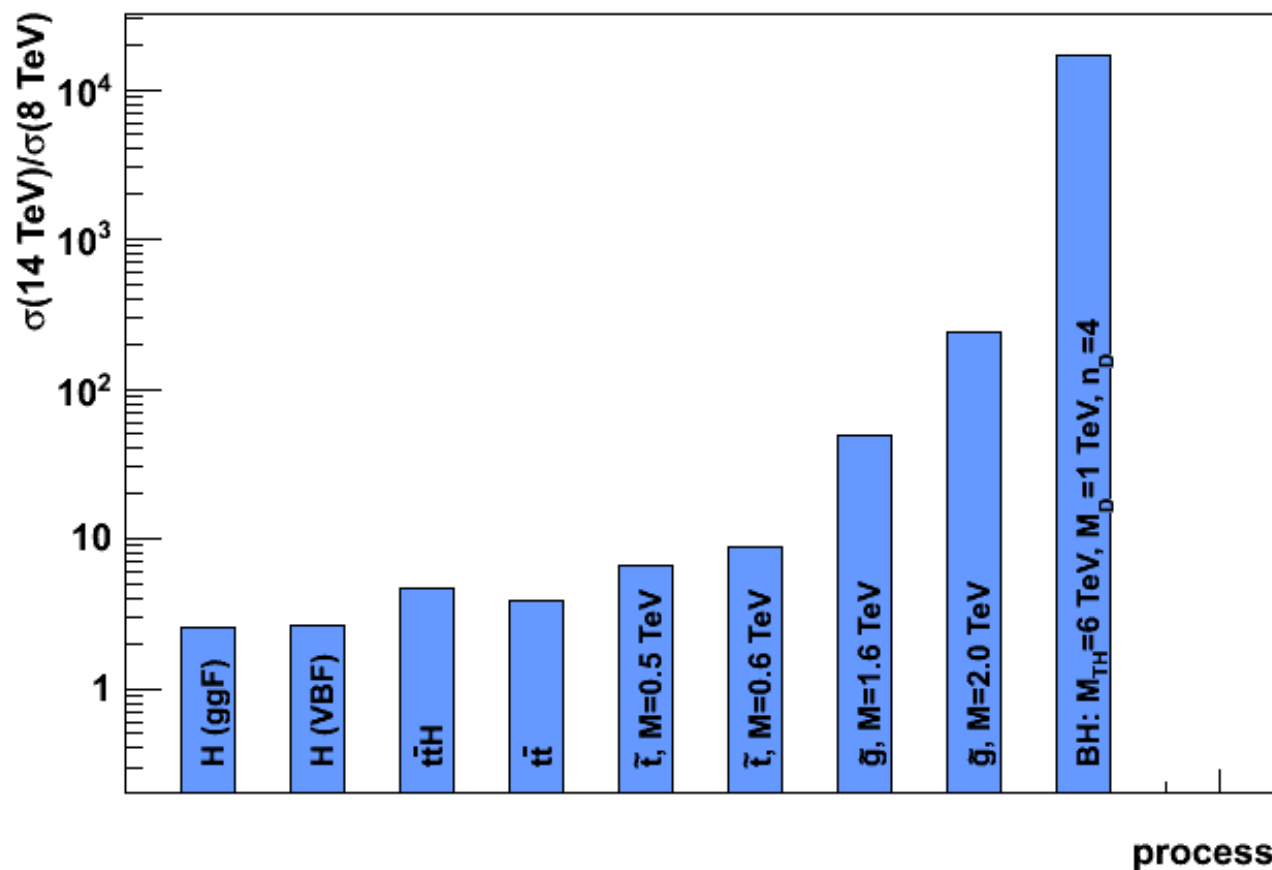
Cross-section increase at 14 TeV



Large sensitivity increase to heavy particles from higher LHC energy!

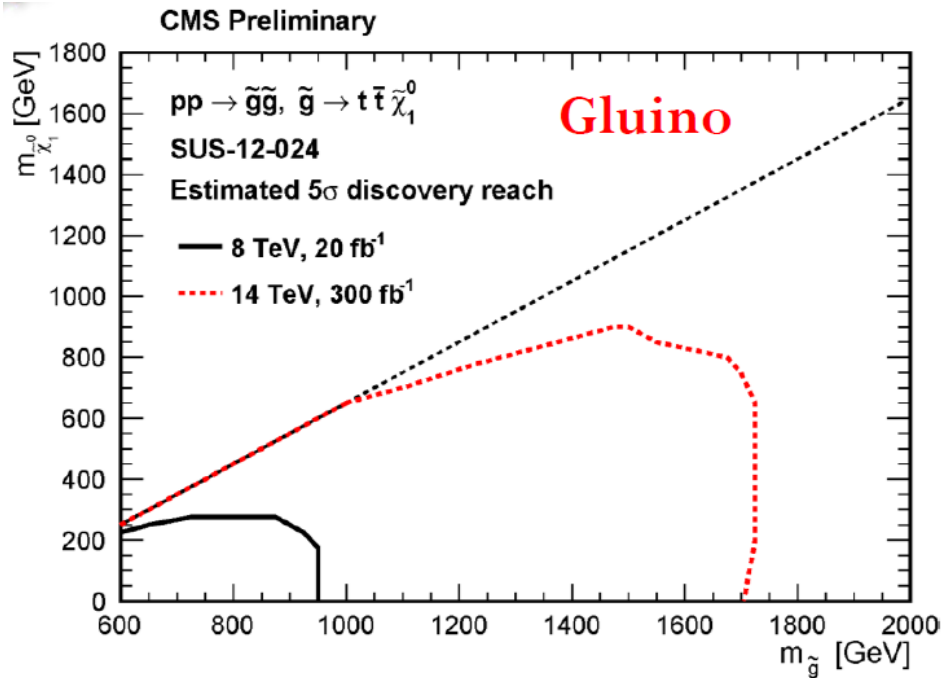
SUSY cross-section increase at 14 TeV

ratio of 14 TeV to 8 TeV cross sections at the LHC

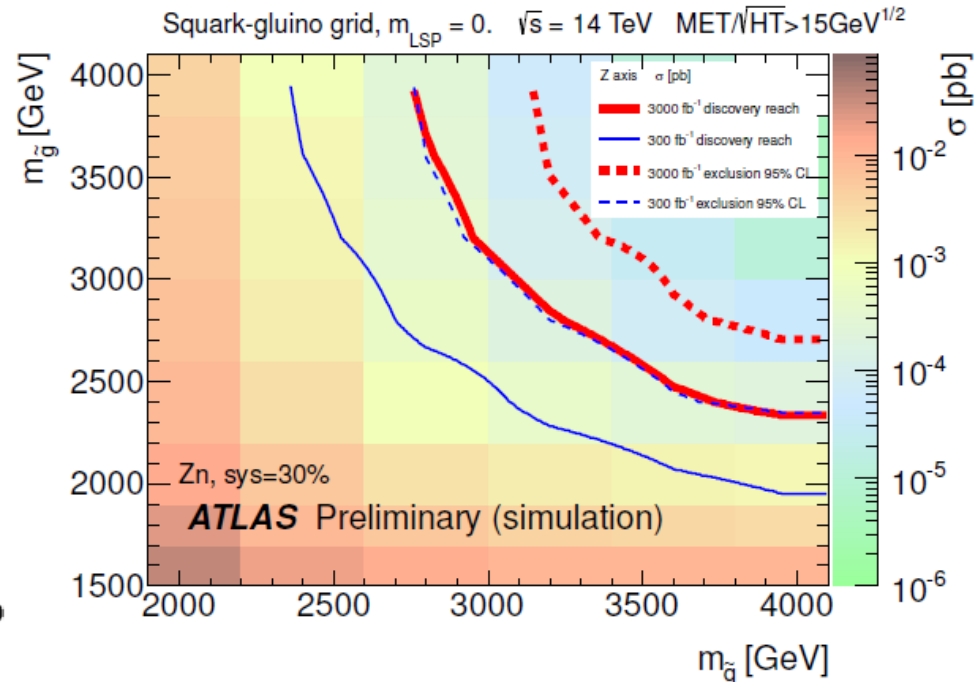


- Expect rapid progress on gluino sensitivity when the LHC re-starts.
- Lower-mass sparticles will also benefit from increased luminosity over time.

gluino reach at 14 TeV



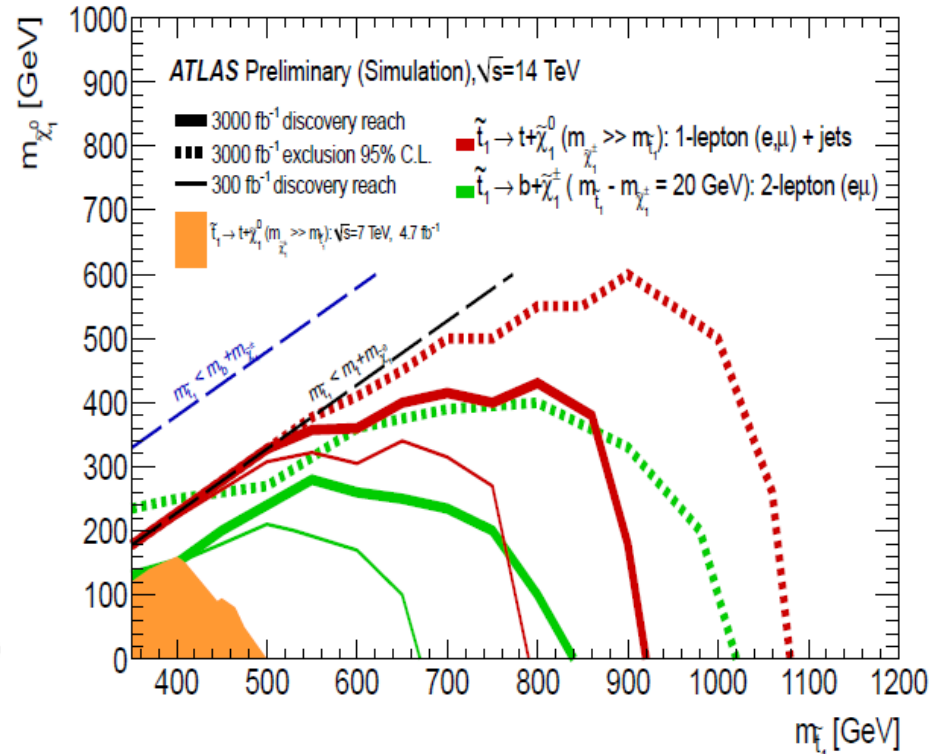
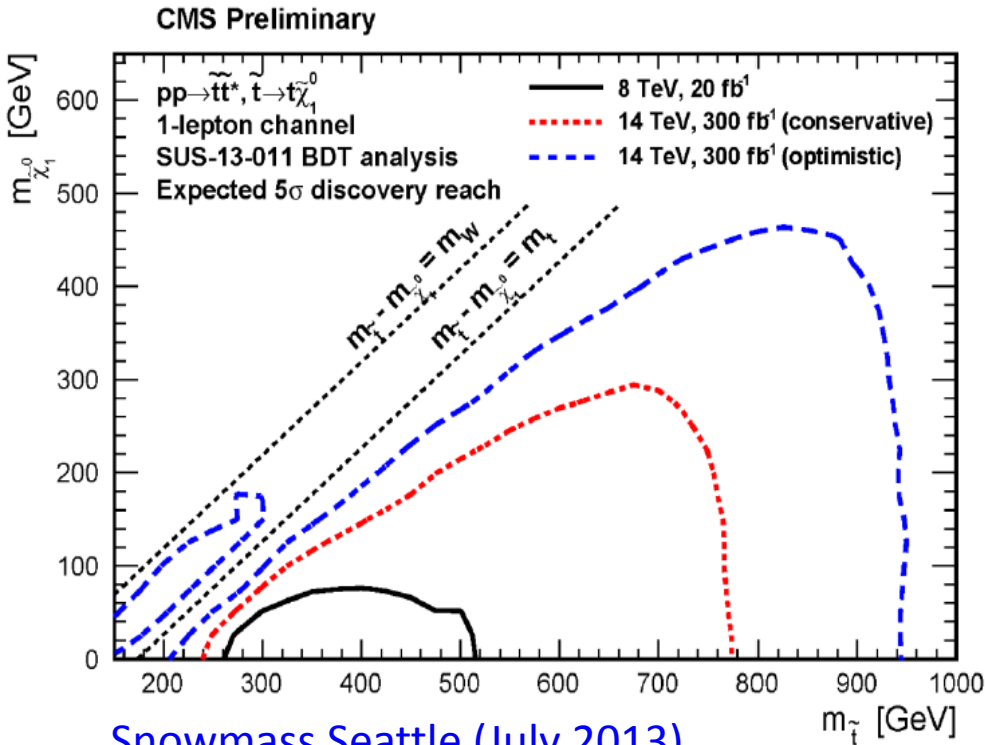
[Snowmass Seattle \(July 2013\)](#)



[ATLAS contribution to European Strategy for Particle Physics Open Symposium \(October 2012\)](#)

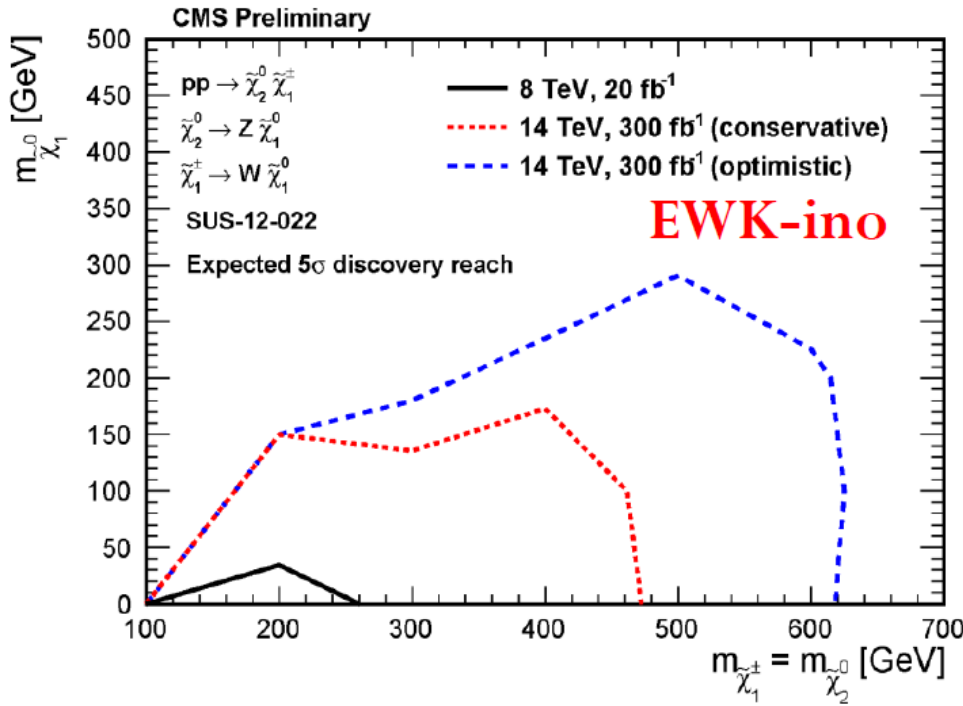
- Current estimates based on projections of 8 TeV analyses.

direct stop reach at 14 TeV

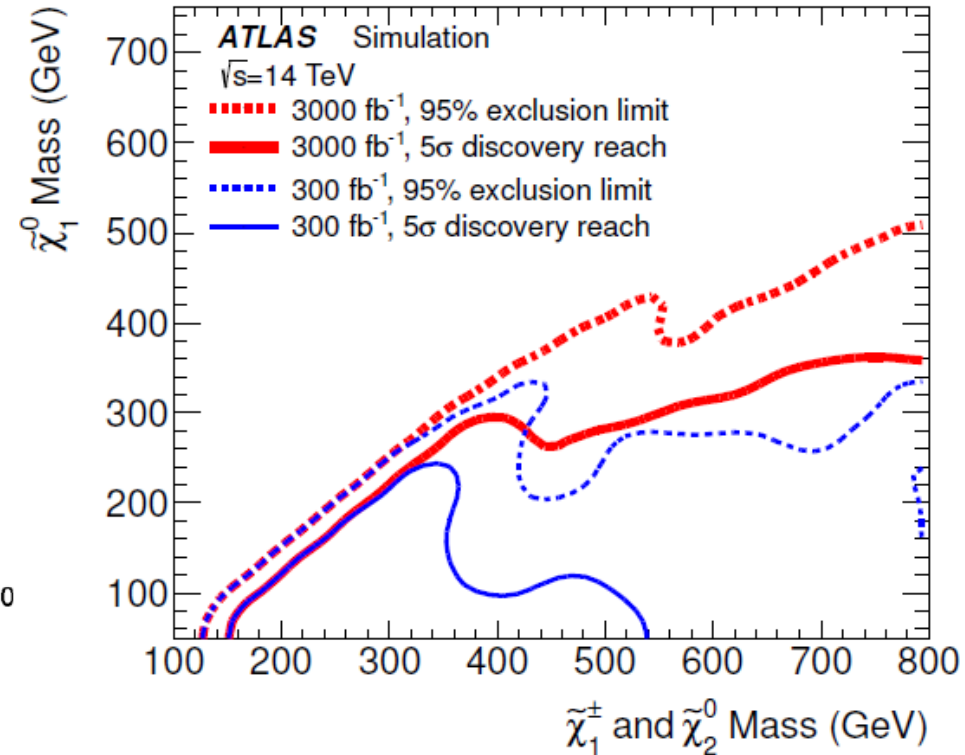


- Current estimates based on projections of 8 TeV analyses.

direct gaugino reach at 14 TeV



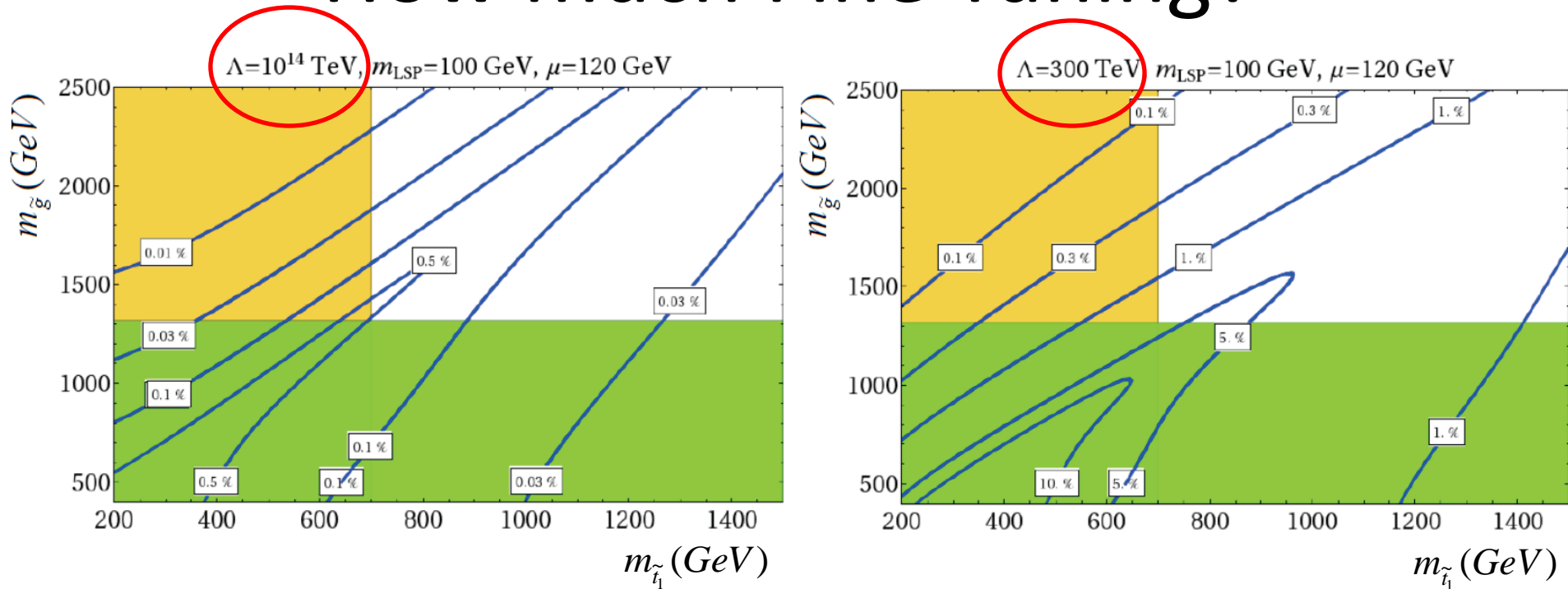
[Snowmass Seattle \(July 2013\)](#)



[Letter Of Intent for ATLAS upgrade Phase-II](#)

- Current estimates based on projections of 8 TeV analyses.

How much Fine Tuning?



Fine-tuning from stop and gluino depends on the choice of Λ , making it possible to go to higher masses.

$$m_Z^2 = -2(m_{h_u}^2 + |\mu|^2)$$

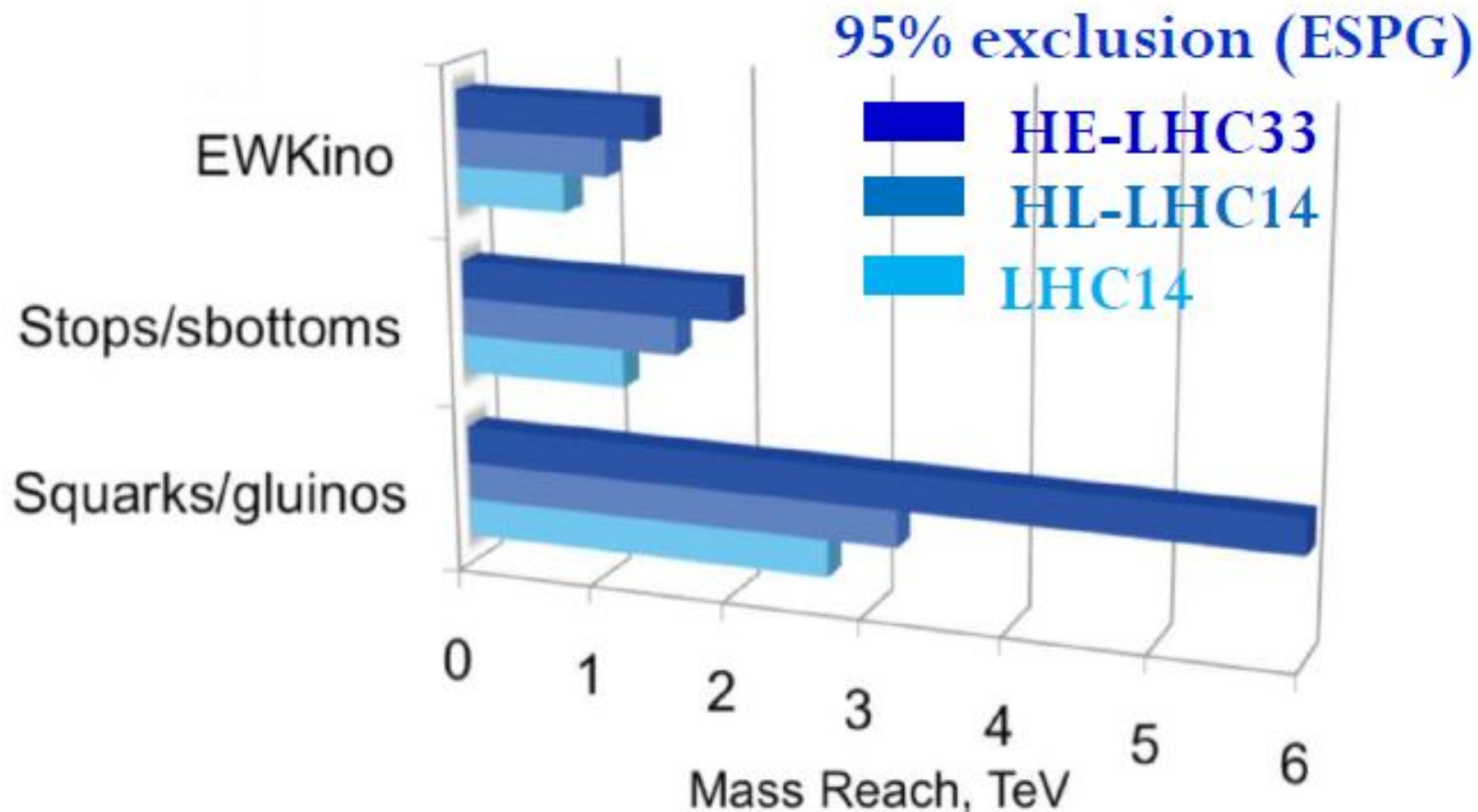
$$\delta m_{h_u}^2 = -\frac{3y_t^2}{4\pi^2} m_t^2 (1 + a^2/2) \log \frac{\Lambda}{m_{\tilde{t}}}$$

...but the Higgsino bounds are robust!

$$\delta m_{\tilde{t}}^2 = -\frac{8\alpha_s}{3\pi} M_3^2 \log \frac{\Lambda}{m_3}$$

SUSY reach at future colliders (CMS)

[Snowmass Seattle \(July 2013\)](#)

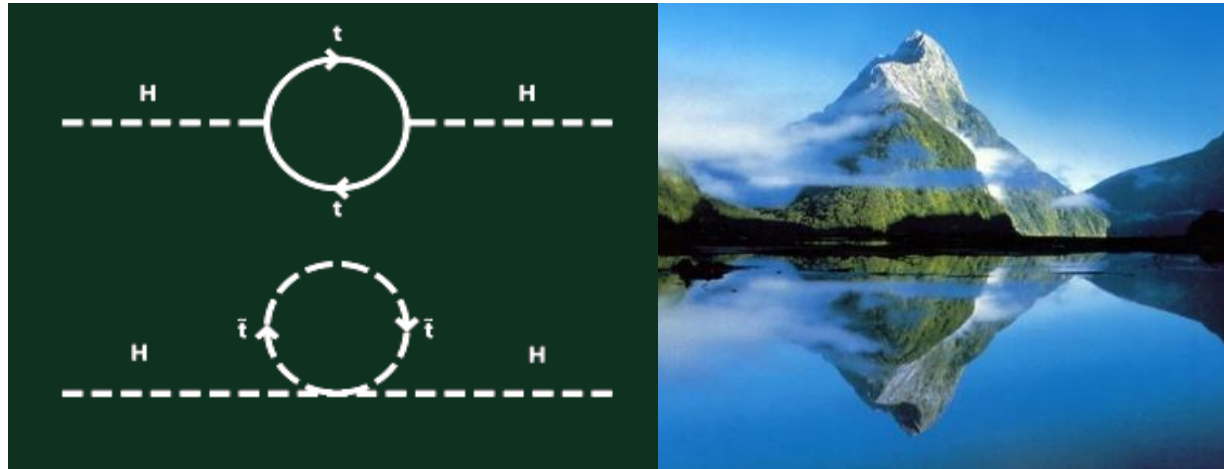


Conclusions

- Fascinating times to search for supersymmetry
 - tremendous effort by ATLAS & CMS
- No evidence for SUSY so far...
 - still possible to hide signals in 7-8 TeV datasets
 - sensitivity boost at 14 TeV and high luminosity
- Emphasis on Natural SUSY
 - but we'll leave no stone unturned...

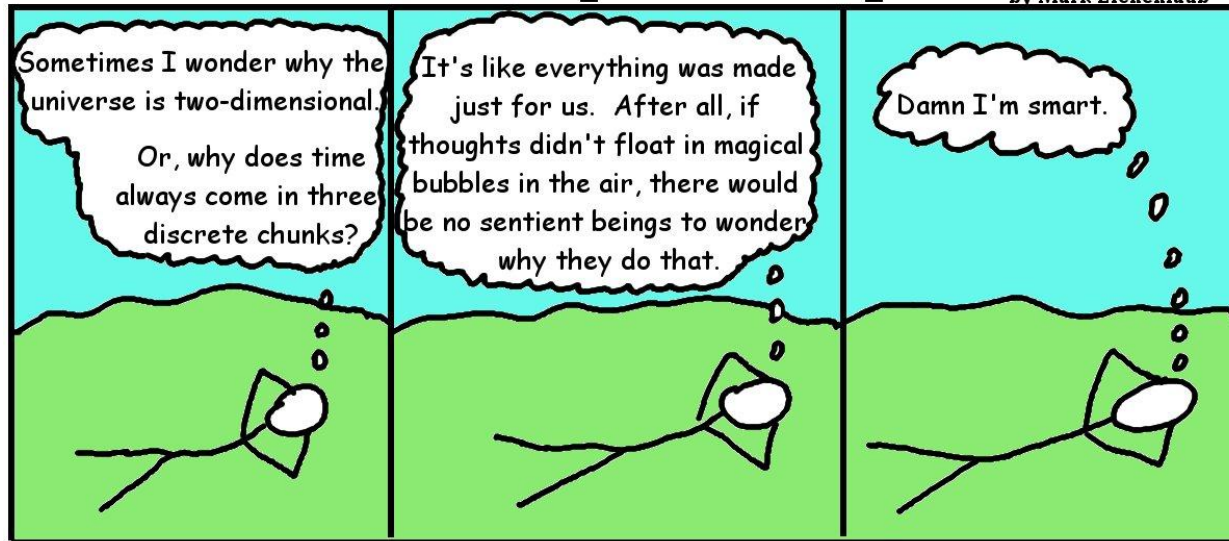
The absence of evidence may not be evidence of absence!

Naturalness



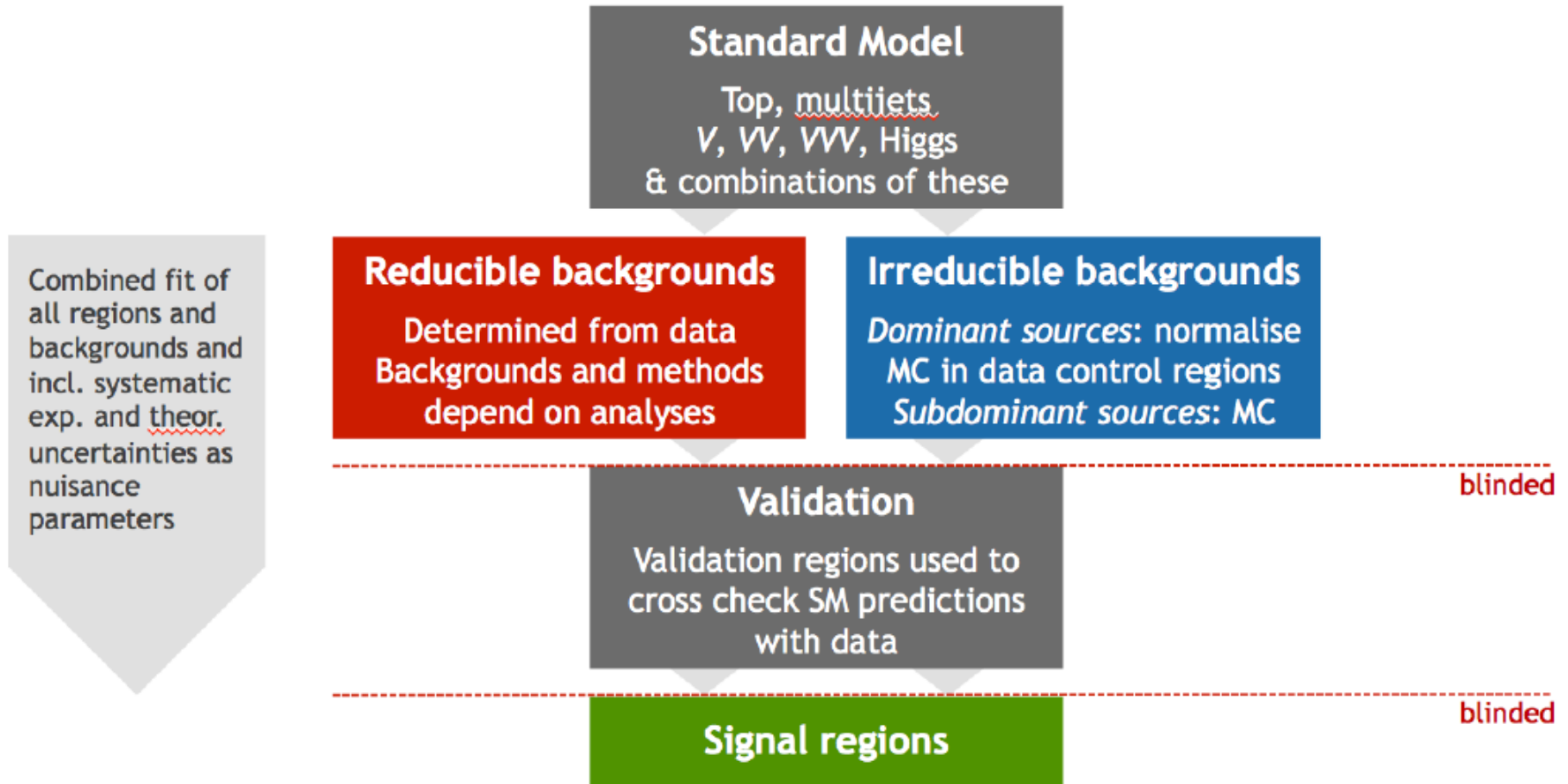
WGP "Anthropic Principle"

by Mark Eichenlaub

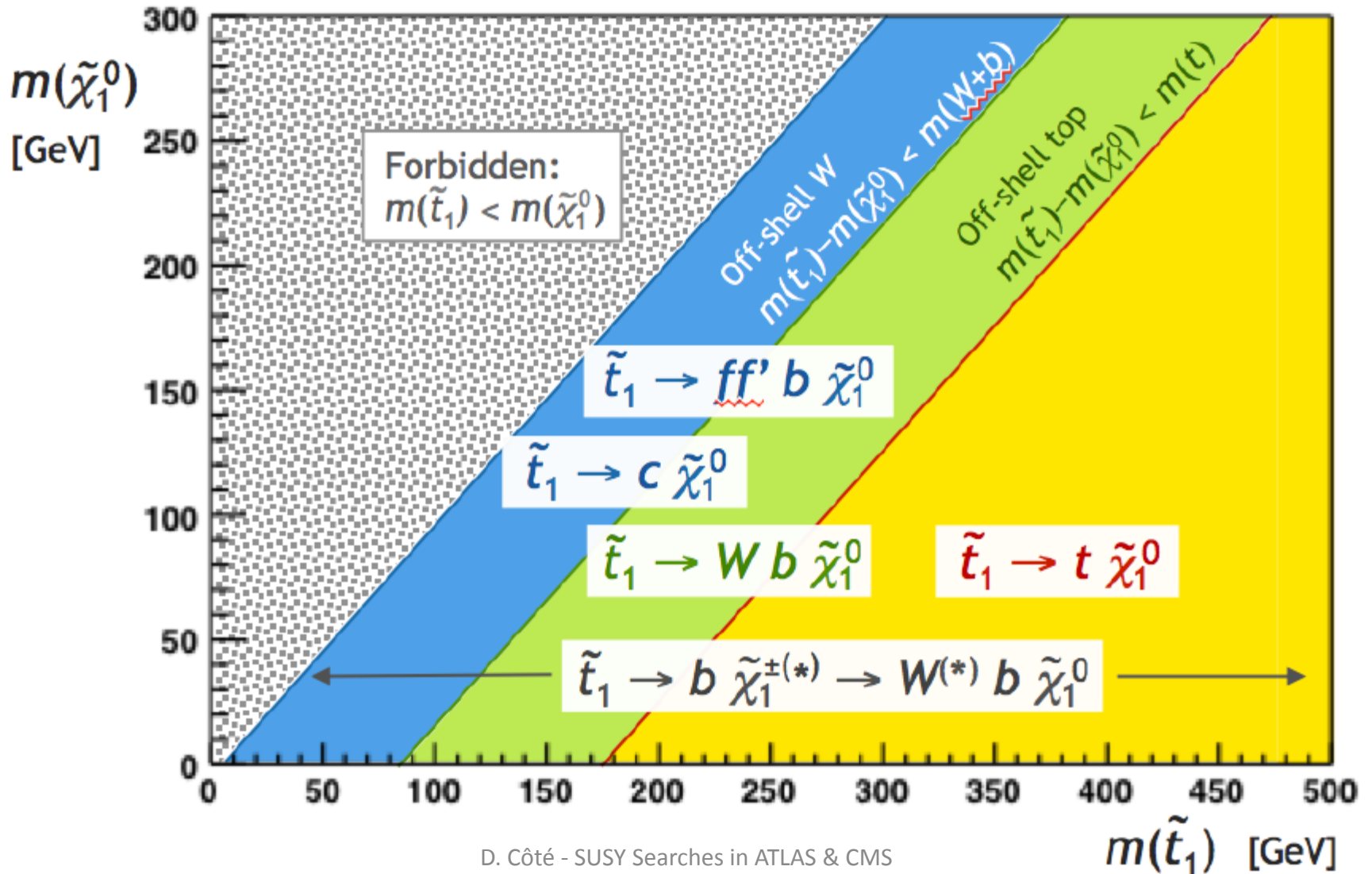


Backup Material

Typical SM Background Estimation



decay modes of the stop to χ_1^0



Definition of SUSY Fine-Tuning

$$M_Z^2 = -2\mu^2 + 2 \frac{m_{H_d}^2 - t_\beta^2 m_{H_u}^2}{t_\beta^2 - 1}$$

$$Z_i = \frac{\partial(\log M_Z^2)}{\partial(\log p_i)} = \frac{p_i}{M_Z^2} \frac{\partial M_Z^2}{\partial p_i}$$

$$\Delta = \max(|Z_i|)$$

One choice: stability of EW scale (identified by M_Z) w.r.t. model parameters.
(Traditional approach from Ellis *et al.*, Barbieri & Giudice.)