SUSY or not, what is the evidence? Status and perspectives of collider searches – Part IIB

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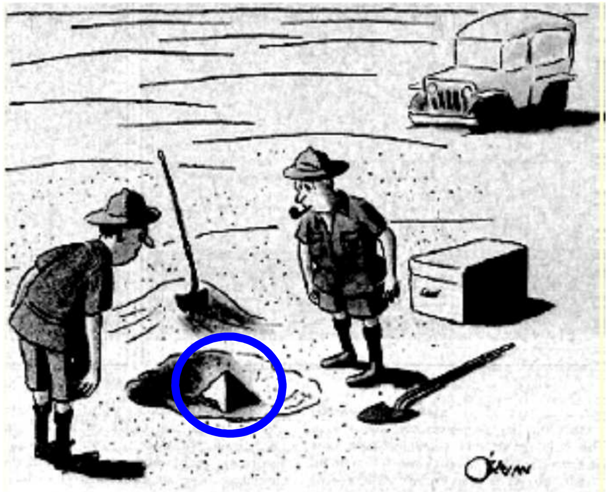


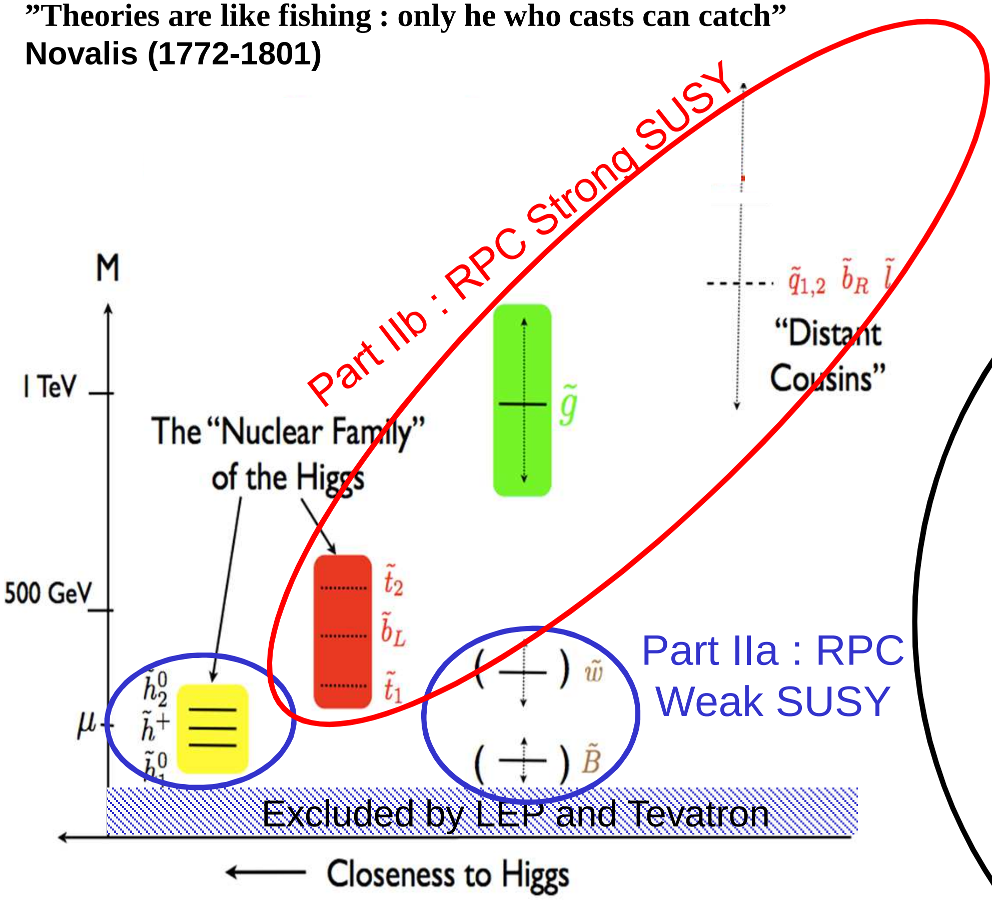
"This could be the discovery of the century. Depending, of course, on how far down it goes"

Part II (3 lectures + 2 exercises)
Direct SUSY searches at LHC

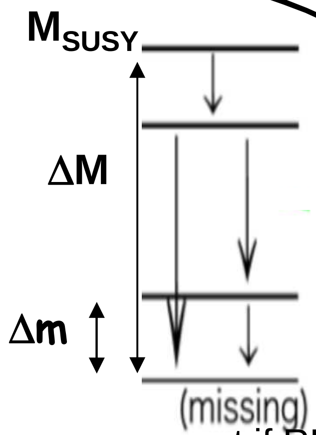
W 30-Oct	Th 31-Oct	Fr 01-Nov
--	Lecture IIA **Exercise 1**	Lecture IIC **Exercise 2**
Lecture IA Lecture IB	**Exercise 1** Lecture IIB	**Exercise 2** Lecture III

Lecture Part II

”Theories are like fishing : only he who casts can catch”
Novalis (1772-1801)



Part IIc: R-Parity Violated, Long-Lived Particles, beyond MSSM



or not if RPV

1. Low Δ**m**, tiny RPV, weak coupling to $\tilde{G}$
   Long Lived or meta-stable sparticles
2. ‘Sizeable’ RPV
   Multileptons, No Z, jet resonances, LFV
3. MSSM Extensions?
   Scalar Gluon
4. Un-natural SUSY ?

Lecture Part IIB

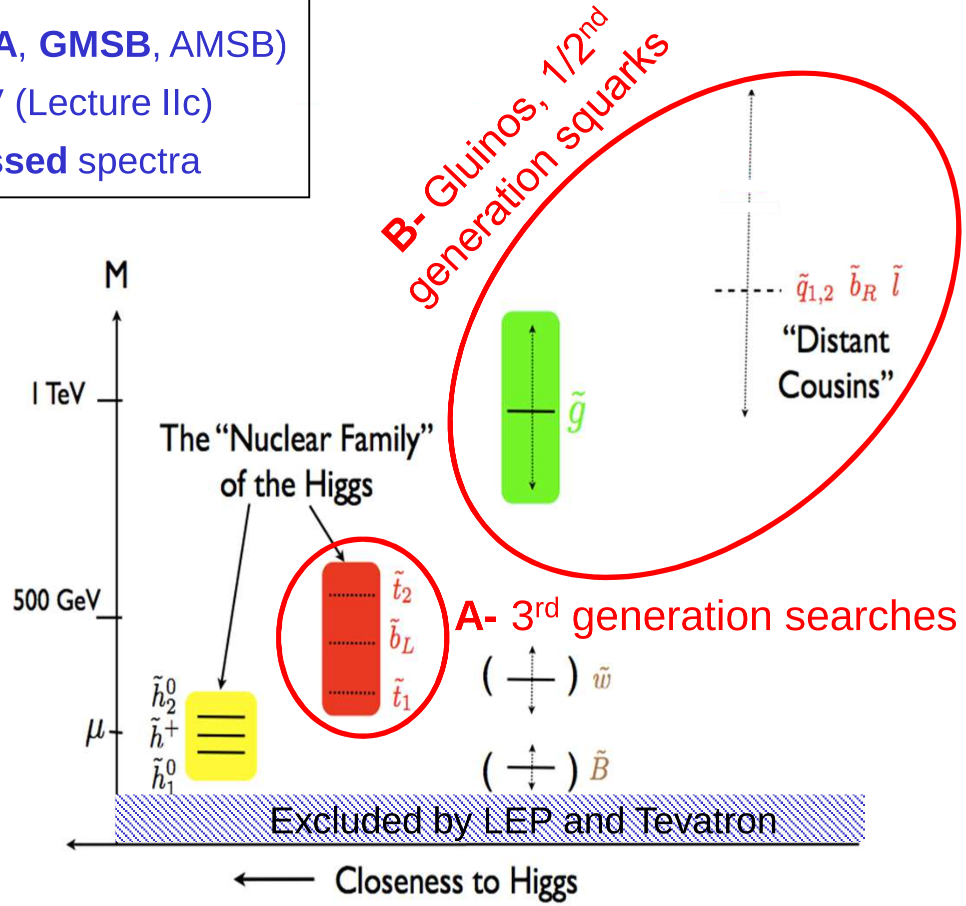
Part IIb : RPC Strong Production SUSY

Theory Unknowns:

1- SUSY Breaking (**SUGRA**, **GMSB**, AMSB)

2- RPC (**here**) vs RPV (Lecture IIc)

3- **Open** or **compressed** spectra



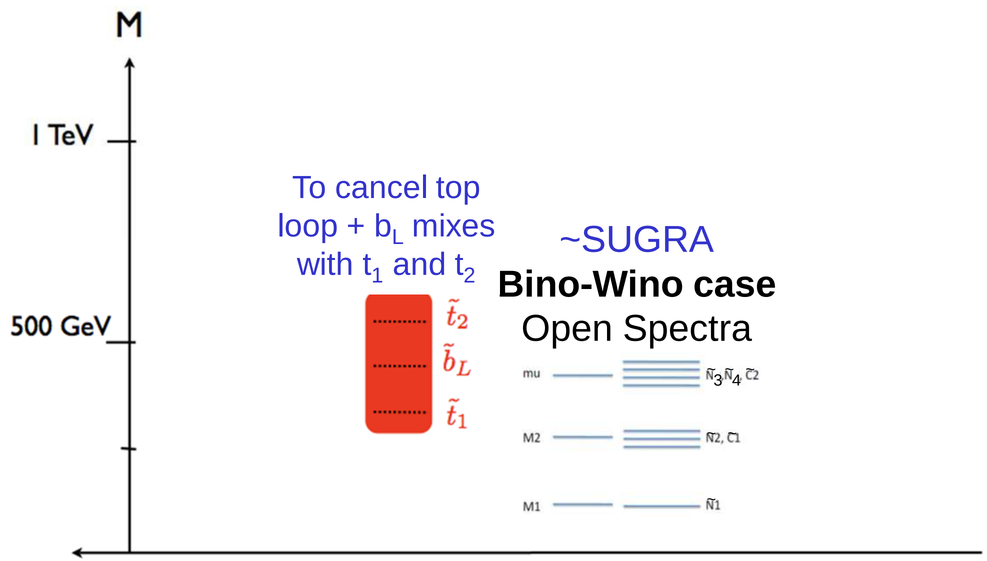
3^{rd} generation squark searches

Theory Unknowns:

1- SUSY Breaking (**SUGRA**, **GMSB**, AMSB)

2- RPC (**here**) vs RPV (Lecture IIc)

3- **Open** or **compressed** spectra



SUGRA

SUGRA, GMSB

$\tilde{b}_L$

$\tilde{b}_L \tilde{b}_L$ → bbN1N1 → 2b+MET

$\tilde{b}_L \tilde{b}_L$ → ttC1C1 → 2b+4W+MET

$\tilde{b}_L \tilde{b}_L$ → bbN2N2 → 2b+2H(bb)+MET

$\tilde{t}_1$

$\tilde{t}_1 \tilde{t}_1$ → 2t+MET, 2W+2b+MET, 2c+MET

m_{t1} $> m_t + m_{N1}$ $> m_b + m_W + m_{N1}$ $> m_c + m_{N1}$

$\tilde{t}_1 \tilde{t}_1$ → bbC1C1 → 2b+2W+MET

$\tilde{t}_2$

$\tilde{t}_2 \tilde{t}_2$ → 2Z2t_1 → 2Z2t+MET

Look at each case individually. Mixed case discussed in lecture III (pMSSM)

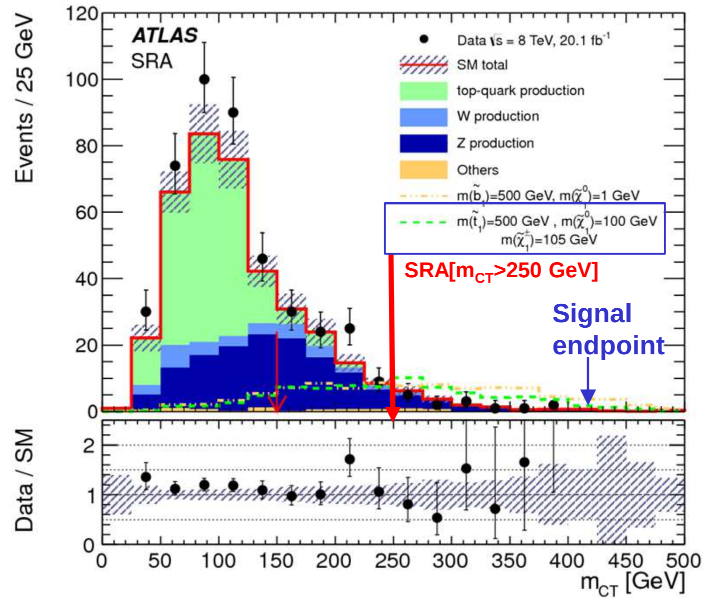
Sbottom (1)

1308.2631

$\tilde{b}_L\tilde{b}_L \to bb\tilde{\chi}_1^0\tilde{\chi}_1^0 \to$ 2b+MET

❑ Design an exclusive 2b-jet + MET analysis

Requirements	SRA	
Etmiss [GeV] >	**150**	**Trigger**-driven
Pt (j1) [GeV] >	**130**	
Pt (j2) [GeV] >	**50**	**Pile-up**-driven
Lepton and 3rd jet veto		
MET/Meff >	**0.25**	**QCD**-killer
$\Delta\phi$ (jet-MET) >	**0.4**	
N(bjets)=	**2 Tight (ε=0.6)**	
M_{CT} [GeV] >	**150,200,250,300,350**	**Discriminating var.** [m_{CT}(ttbar)<135 GeV]
m_{bb}[GeV] >	**200**	



Background determination :

- **Z(vv)bb**: Control Region with Z→ll mass constraint + 2 b-jets
- top, Wb: Control Region with =1 lep + 2 bjets + MET> 100 GeV
- QCD: jet smearing method (cf. 0lepton)

N_B [m_{CT}>250 GeV] = 15.8 ± 2.8 (14 obs)

→Error dominated by stat in Control Regions

Another signal region (SRB) exists for compressed spectrum:

- Remove m_{CT} and m_{bb} cuts which kills the signal, ask a 3rd jet (ISR) and H_T(wo 3 leading jets)<50 GeV

Sbottom (2)

1308.2631

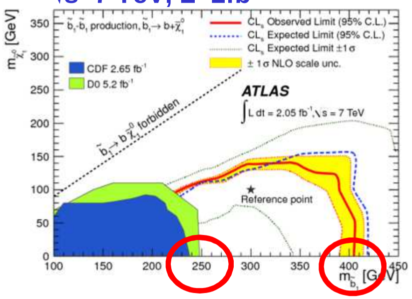
$\tilde{b}_L\tilde{b}_L \rightarrow bb\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow 2b+MET$

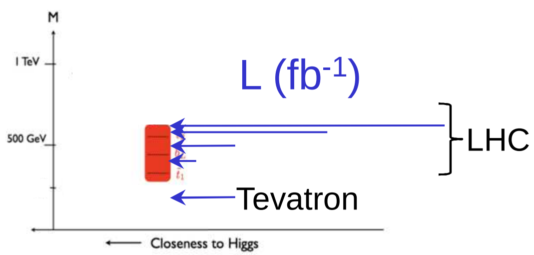
❑ Gradually improve mass limits with luminosity

- Reoptimise the signal regions for each luminosity

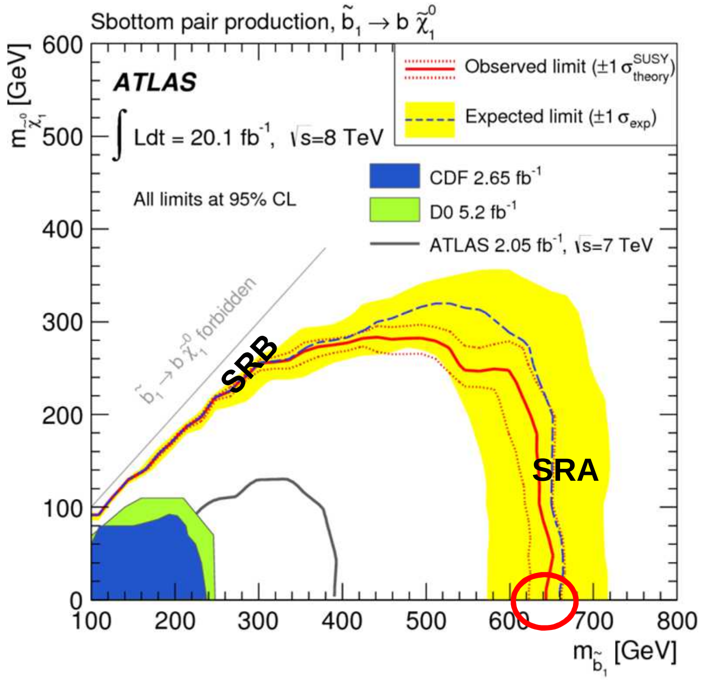
Only 2 sparticles: sbottom, LSP

$\sqrt{s}$=7 TeV, L=2fb^{-1}

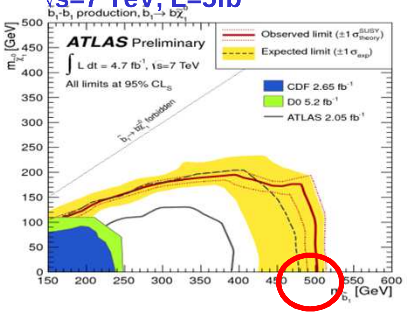




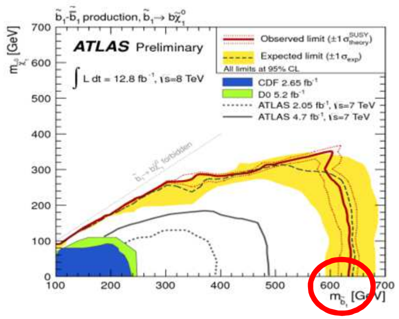
Final LHC Run I: $\sqrt{s}$=8 TeV, L=20fb^{-1}



$\sqrt{s}$=7 TeV, L=5fb^{-1}



$\sqrt{s}$=8 TeV, L=12fb^{-1}



Reaching upper mass limits of the natural SUSY spectrum for m(N1)<250 GeV

Sbottom (3)

CMS-PAS-SUS-13-013, ATLAS-CONF-2013-007

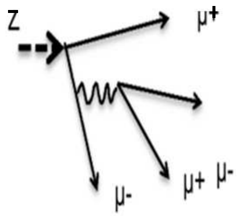
❑ Design a 2 lepton same sign analysis

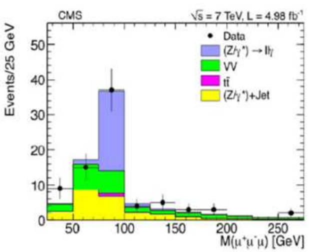
$\tilde{b}_L \tilde{b}_L \rightarrow t t \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow$ 2b+4W+MET

- Assume at least 2 leptonic W gives a high probability to have 2 lepton same sign
  - ✓ Multipurpose final state for RPC Strong SUSY (see later)
- Remove SM background which compensate for low leptonic branching ratio

Remaining background

Charge mis-identification





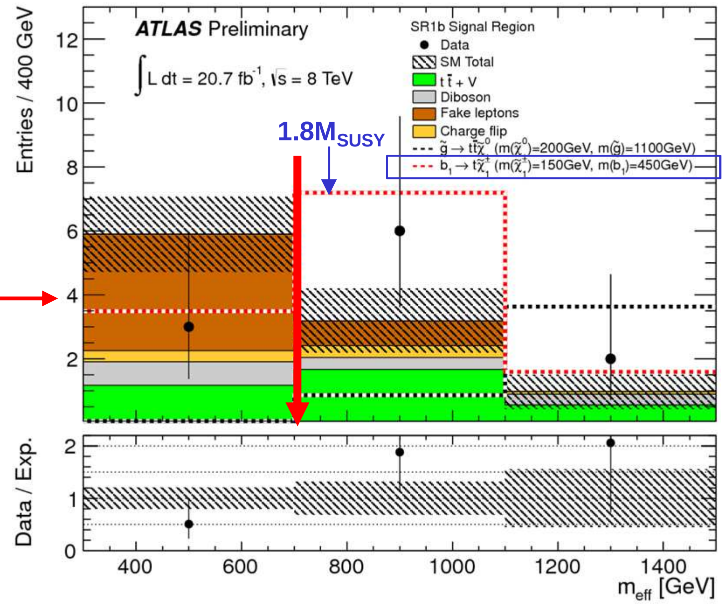
ttbar + W or Z : σ~0.1 pb

1 Real +1 Fake lepton (jets)

Signal Regions

Signal region	N_{b-jets}	Signal cuts (discovery case)
SR0b	0	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, $m_{eff} > 400$ GeV
SR1b	≥1	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, $m_{eff} > 700$ GeV
SR3b	≥3	$N_{jets} \geq 4$, -

After all cuts



N_B [SR1b] = 3.7 ± 1.6 (8 obs)

Sbottom (4)

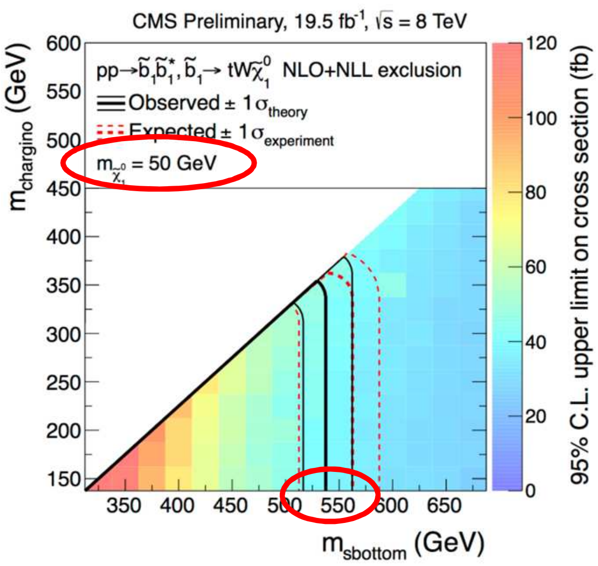
CMS-PAS-SUS-13-013, ATLAS-CONF-2013-007

❑ Results depends on χ_1^0 and $\chi_1^{+/-}$ masses

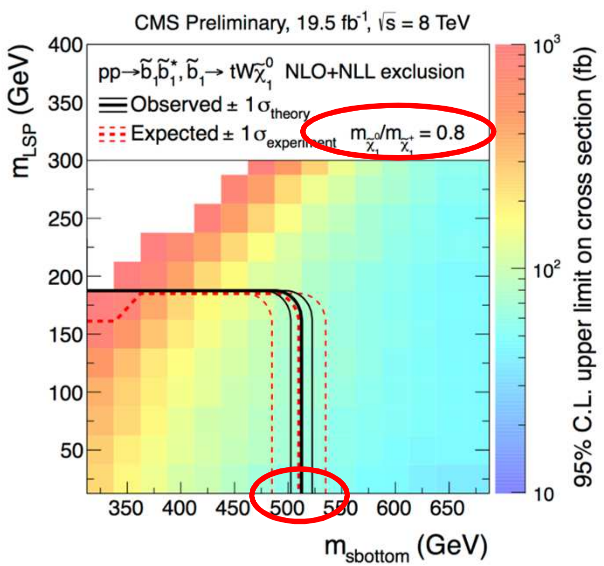
$\tilde{b}_L\tilde{b}_L \rightarrow tt\ \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow$ 2b+4W+MET

- Several assumptions are chosen
- Limits quite robust at m($\tilde{b}$)<500 GeV

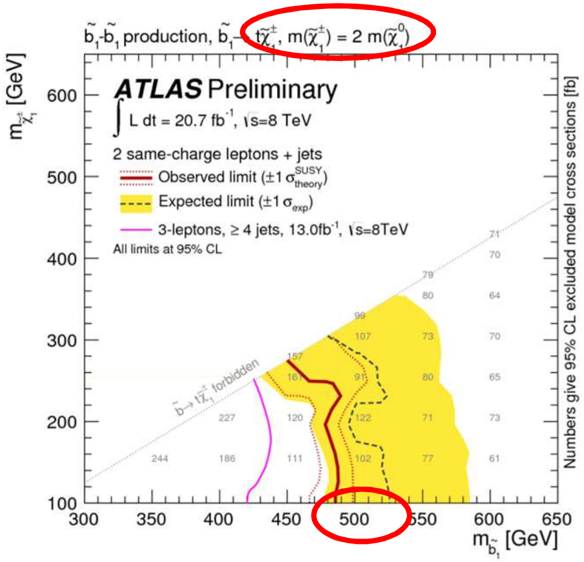
Fixed N1 mass



C1-N1 close-by



C1-N1 far



Reaching upper masses of the natural SUSY spectrum

Sbottom (5)

ATLAS-CONF-2013-061

$\tilde{b}_L\tilde{b}_L \rightarrow bb\,\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow$ 2b+2H(bb,WW)+MET

❑ Design a ≥3 b + jets + MET analysis

- Since H→bb is ~60%.
  - ✓ Multipurpose final state for RPC Strong SUSY (See later)
- Remove most of SM background especially ttbar

Remaining background

Irreducible :

- ttbar+H/Z(bb) : σ~0.1 pb
- ttbar+b/bb : σ~0.1 pb

➔ Estimated w Monte Carlo

Reducible :

- ttbar with τ-jet, c-jet mistagged as a b-jet

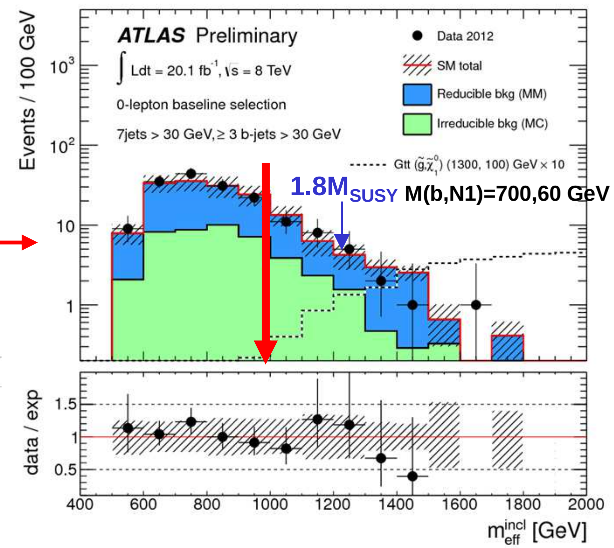
➔ Estimated w matrix method

Signal Regions (0-1l)

0-ℓ region	N jets	p_T jets [GeV]	E_T^{miss} [GeV]	m_{eff} [GeV]
SR-0l-4j-A	≥ 4	> 30	> 200	m_{eff}^{4j} > 1000
SR-0l-4j-B	≥ 4	> 50	> 350	m_{eff}^{4j} > 1100
SR-0l-4j-C	≥ 4	> 50	> 250	m_{eff}^{4j} > 1300
SR-0l-7j-A	≥ 7	> 30	> 200	m_{eff}^{incl} > 1000
SR-0l-7j-B	≥ 7	> 30	> 350	m_{eff}^{incl} > 1000
SR-0l-7j-C	≥ 7	> 30	> 250	m_{eff}^{incl} > 1500

1-ℓ region	N jets	E_T^{miss} [GeV]	m_T [GeV]	m_{eff}^{incl} [GeV]	$E_T^{miss}/\sqrt{H_T^{incl}}$ [$GeV^{1/2}$]
SR-1l-6j-A	≥ 6	> 175	> 140	> 700	> 5
SR-1l-6j-B	≥ 6	> 225	> 140	> 800	> 5
SR-1l-6j-C	≥ 6	> 275	> 160	> 900	> 5

After all cuts



N_B [SR-0l-7j-A] =22.5 ± 6.9 (22 obs)

Sbottom (6)

ATLAS-CONF-2013-061

❑ Results depends on $\chi_{1,2}^0$ masses

$\tilde{b}_L\tilde{b}_L \rightarrow bb\,\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow$ 2b+2H(bb,WW)+MET

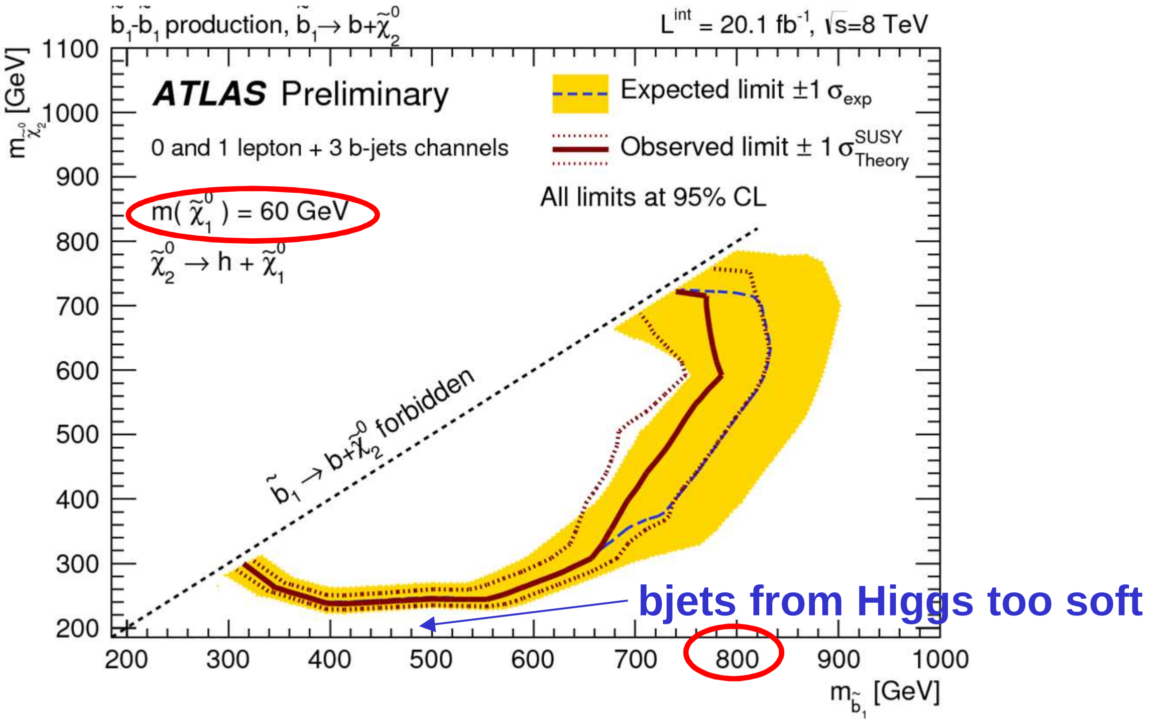
- Chose to fix LSP to a low mass (60 GeV)
- This results is also applicable to Z→bb *(BR=15% instead of 57%)*

ΔM (χ_2^0-χ_1^0)

340

240

140

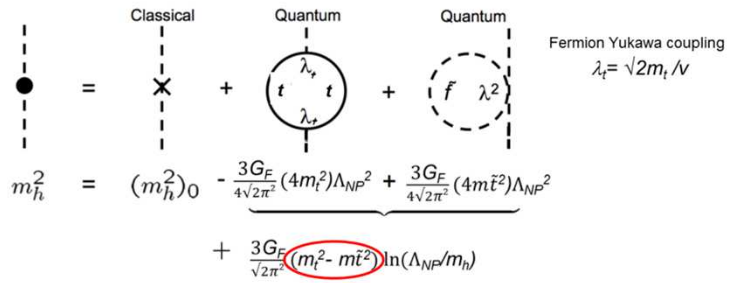


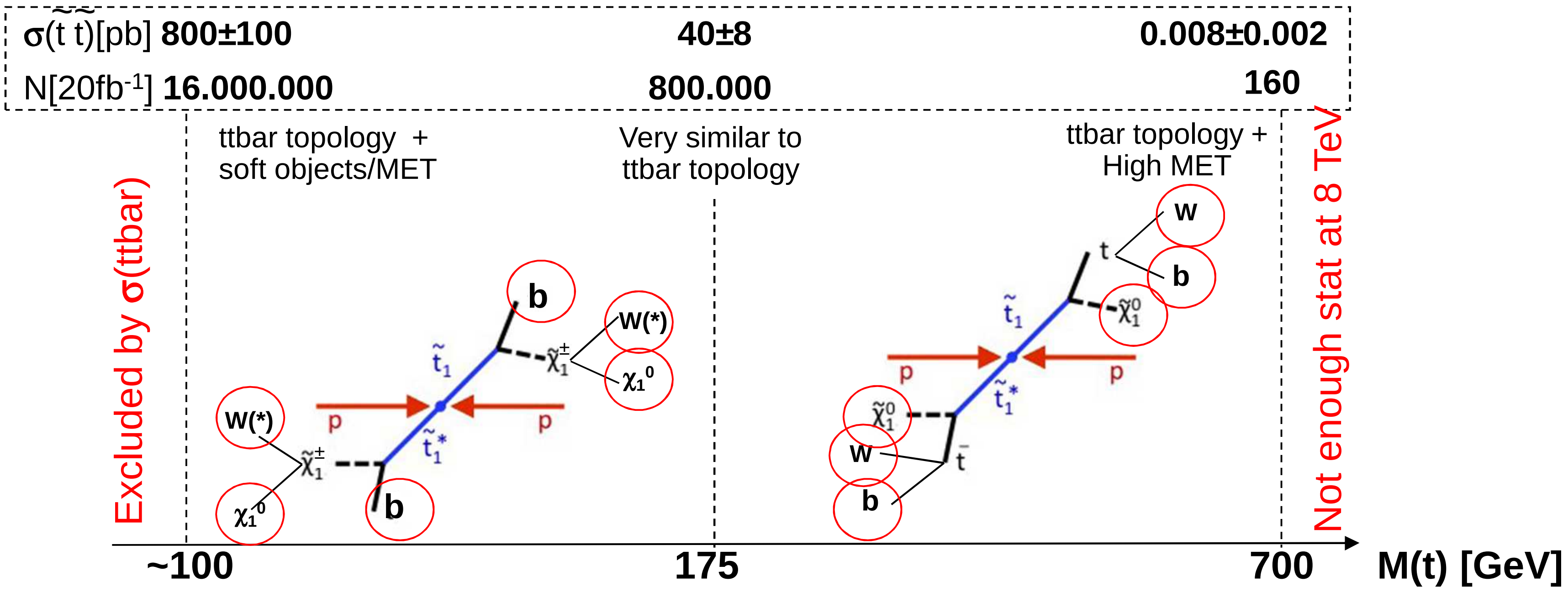
Again quite strong limit !

Stop (1)

One of the most motivated searches

- Most pressing contribution to m_H divergence
- Tension btw naturalness and m_H~126 GeV
- ➔ Results on stop put huge constraints on theory!
- Experimental challenge: remove ttbar σ~240pb



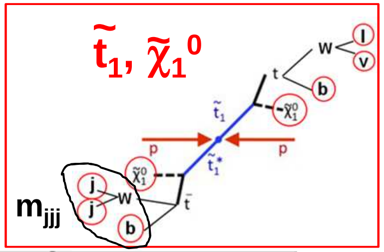


Before LHC start no constraints on stop !

Stop (2)

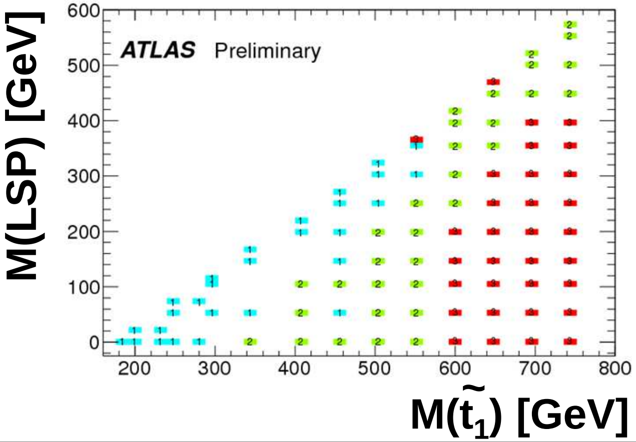
ATLAS-CONF-2013-037, 1308.1586

- **Take most powerful analysis 1l + 4j + ≥1b-jet**
  - Design very carefully SR (discriminant var.+ phase space regions)



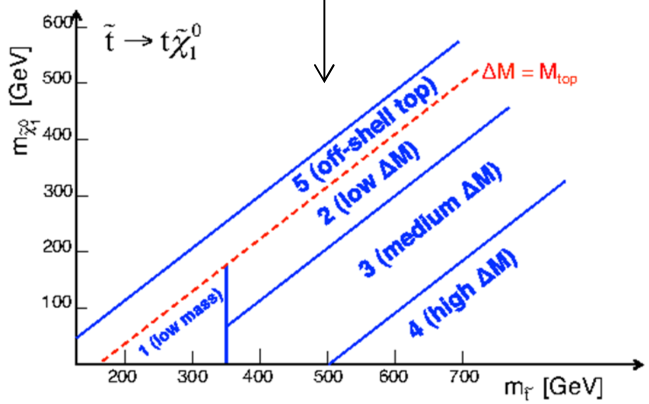
ATLAS

Requirement	SRtN1_shape 1(low)	SRtN2 2(med)	SRtN3 3(high)
$\Delta\varphi(\text{jet}_1, \vec{p}_T^{\text{miss}}) >$	0.8	-	0.8
$\Delta\varphi(\text{jet}_2, \vec{p}_T^{\text{miss}}) >$	0.8	0.8	0.8
E_T^{miss} [GeV] >	100(*)	200	275
$E_T^{\text{miss}} / \sqrt{H_T}$ [GeV$^{1/2}$] >	5	13	11
m_T [GeV] >	60(*)	140	200
m_{eff} [GeV] >	-	-	-
am_{T2} [GeV] >	-	170	175
m_{T2}^{τ} [GeV] >	-	-	80
m_{jjj}	Yes	Yes	Yes
$N^{\text{iso-trk}} = 0$	-	-	-
Number of b-jets ≥	1	1	1
p_T (leading b-jet) [GeV] >	25	25	25
p_T (second b-jet) [GeV] >	-	-	-



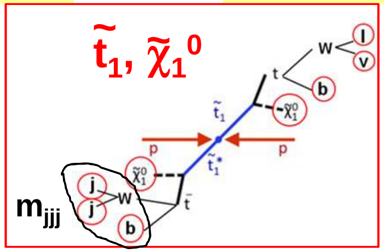
CMS

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



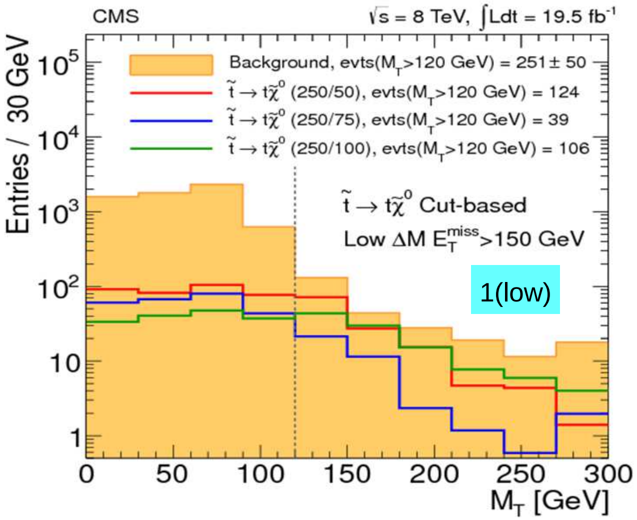
Stop (3)

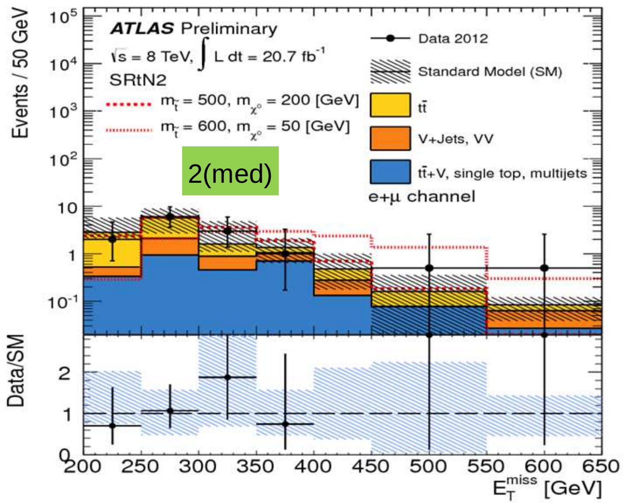
ATLAS-CONF-2013-037, 1308.1586

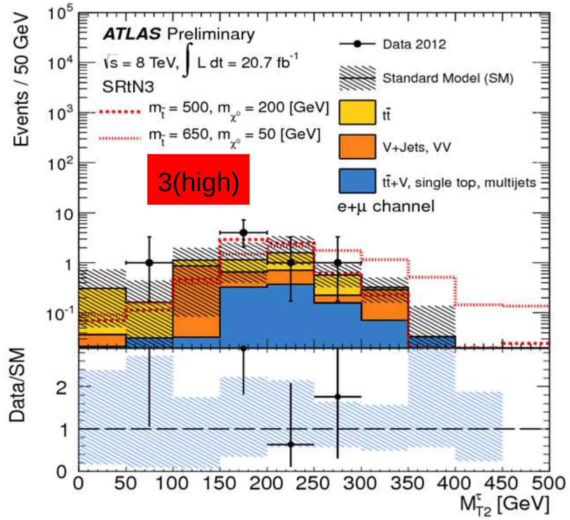


❑ Look at the results in Signal Regions

- Dominated by tt→WWbb→lνlνbb events
  - ✓ where one lepton is τ_{had} or is not rec./identified





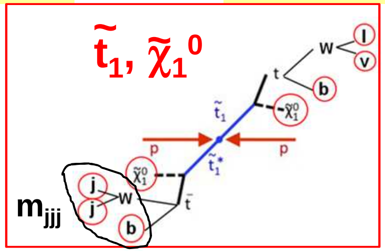


	Low DM 1(low)	Med DM 2(med)	High DM 3(high)
ATLAS	262+/-34 (235)*	13+/-3 (14)	5+/-2 (7)
CMS (Cut-based, Higher MET)	11.5+/-3.6 (9)		4.7+/-1.4 (2)

* mT>140 GeV, MET>150 GeV

Stop (4)

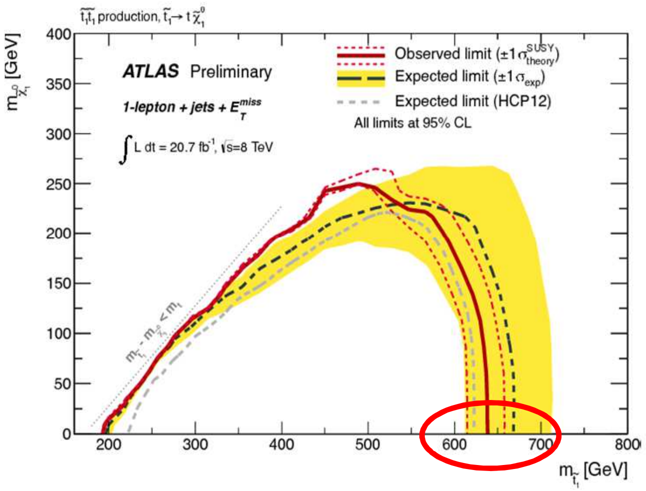
ATLAS-CONF-2013-037, 1308.1586

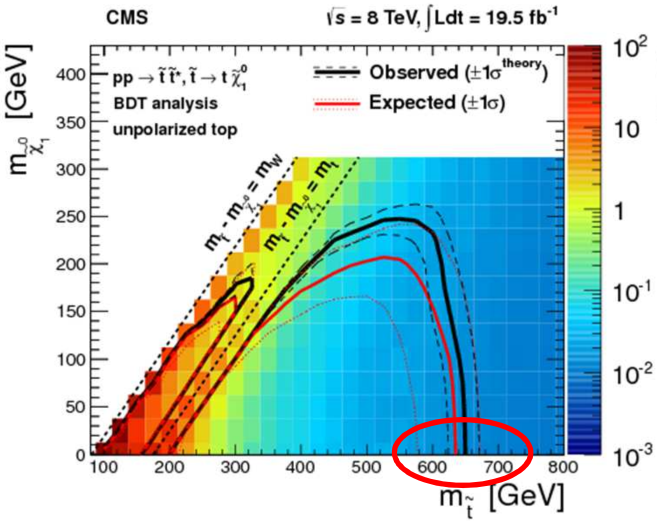


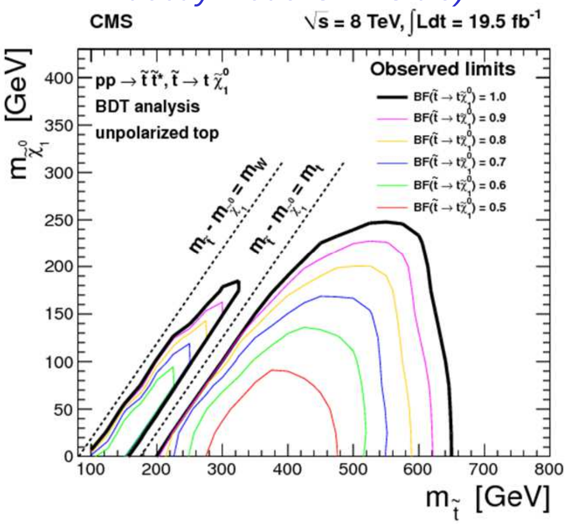
❑ Set limits on the $\tilde{t}_1 \rightarrow t\ \tilde{\chi}_1^0$ scenario

- Cover nicely the allowed phase space
- ATLAS and CMS obtain very similar limits

Impact of BR(t→tN1) hypothesis *(assume the other decay mode is invisible)*



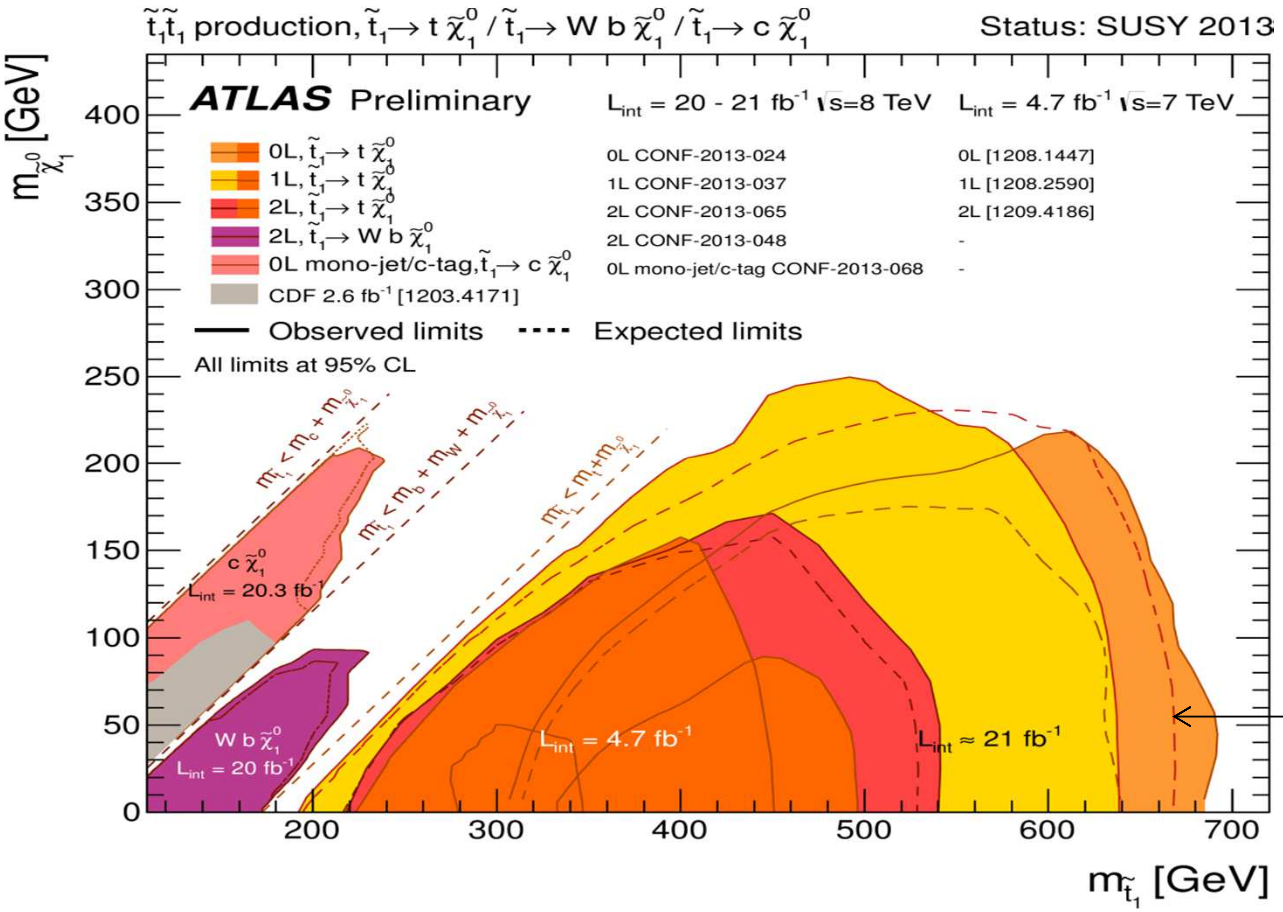




Cover a wide range of the region allowed by naturalness (SUGRA-like)

Stop (5)

❑ **General limit on $\tilde{t}_1 \rightarrow$ t/Wb/c + $\tilde{\chi}_1^0$**



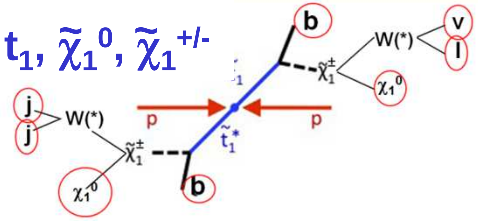
0 l + 6 jets +MET helps to increase the limit at high stop masses

Stop (6)

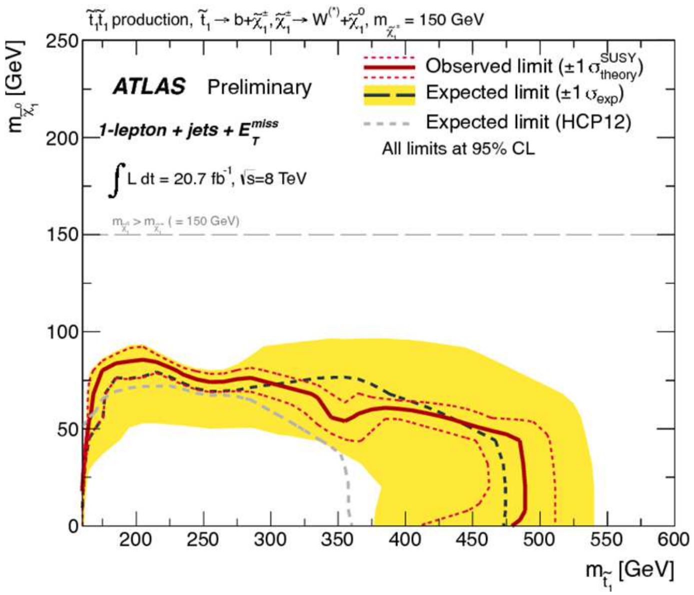
1308.1586, ATLAS-CONF-2013-037

❑ Can reuse the analysis 1l + 4j + ≥1b-jet

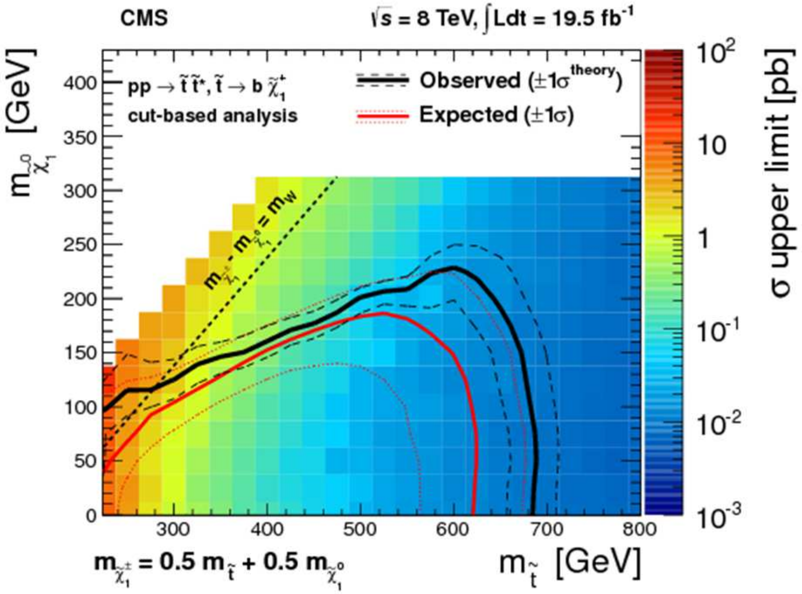
- Similar signal regions but with lower cuts and wo mjjj requirement
- Results interpretation depends on ($\tilde{t}_1$), m(C1) and m(N1)
  - ✓ Need an hypothesis on m(N1) or m(C1).



m(C1) fixed



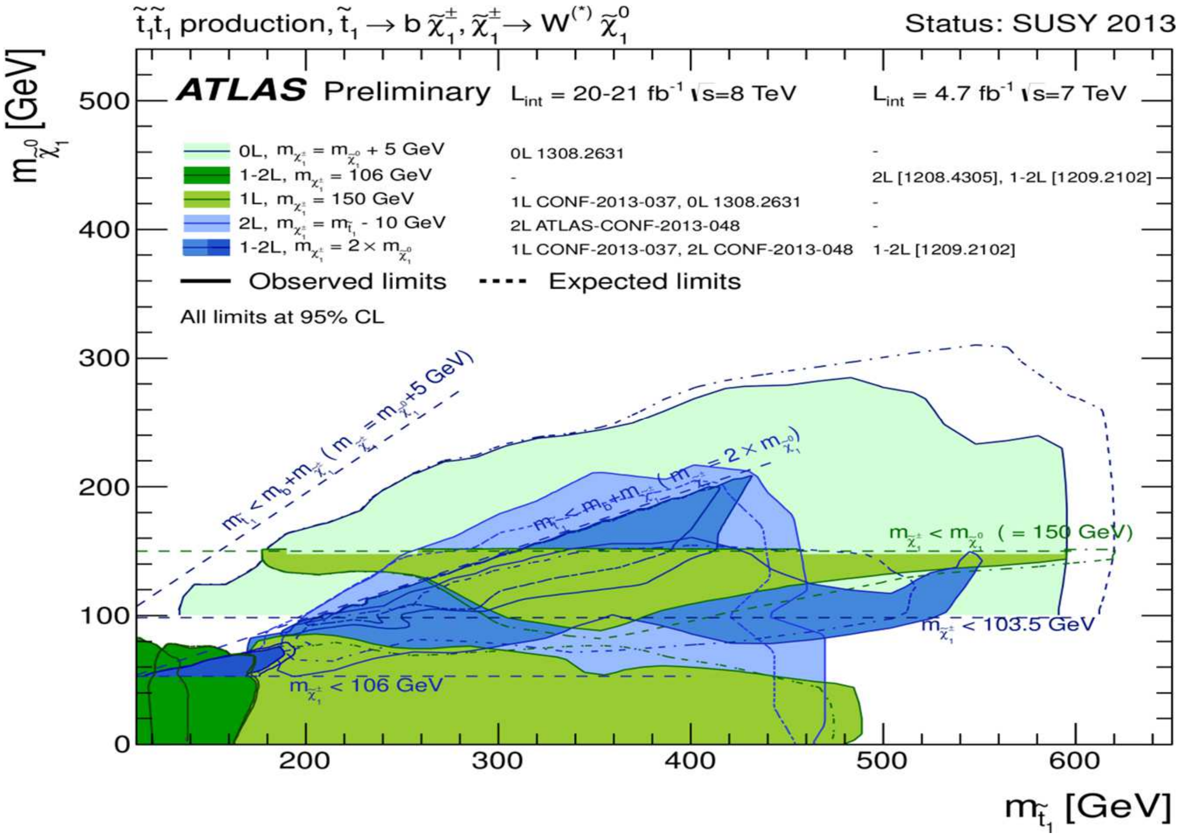
m(C1) half way from m($\tilde{t}_1$) and m(N1)



Access the models with enough energy for lepton, DM(C1-N1)>50 GeV

Stop (7)

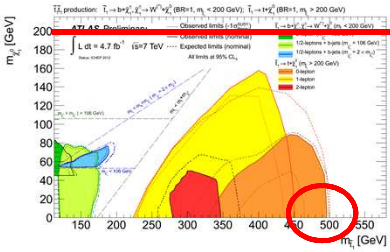
- **Limit on $\tilde{t}_1 \rightarrow b\ \tilde{\chi}_1^{+/-} \rightarrow W^{(*)}\ \tilde{\chi}_1^0$**
  - Compressed C1-N1 case covered by 0l + 2b-jets + MET *[Direct sbottom analysis]*
  - Compressed $\tilde{t}_1$-C1 case covered by a 2l (+jets) + MET analysis



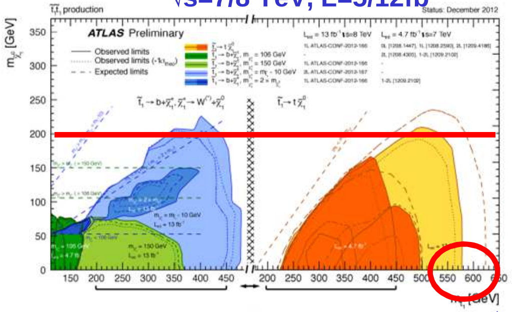
Stop (8)

❑ Lot of progress in one year

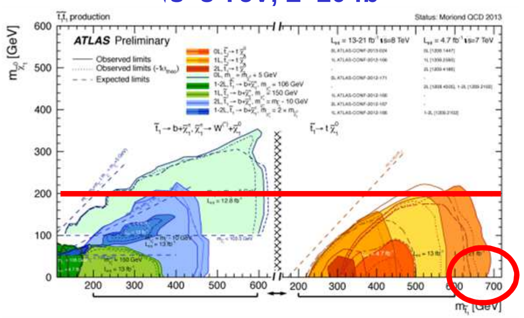
FIRST LIMITS (July2012) ! √s=7 TeV, L=5fb^{-1}



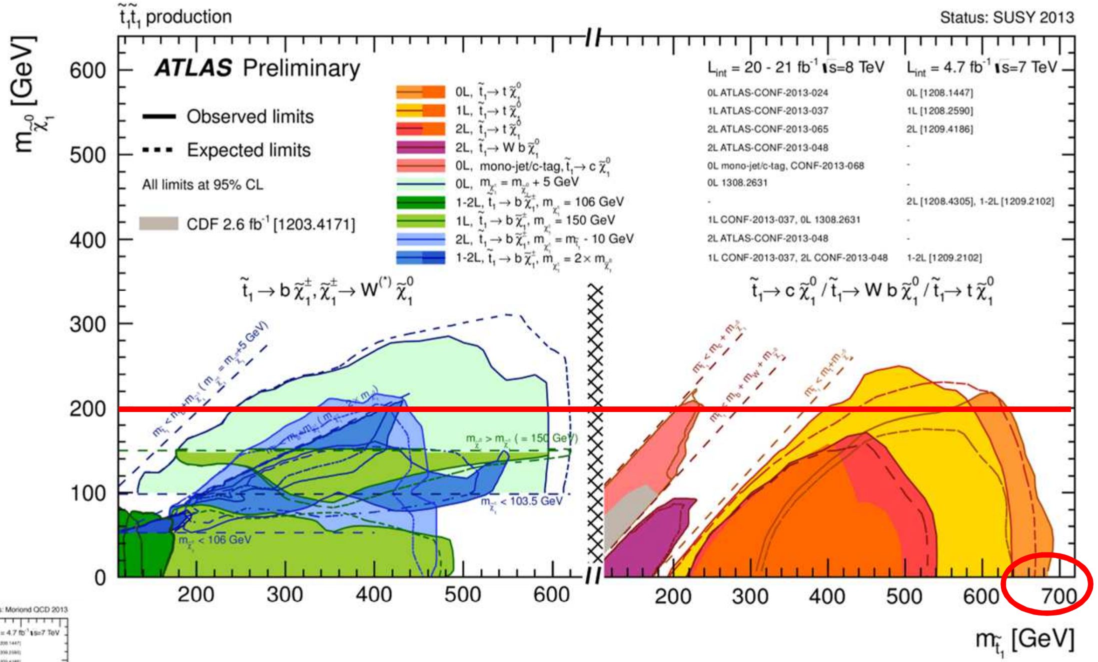
√s=7/8 TeV, L=5/12fb^{-1}



√s=8 TeV, L=20 fb^{-1}



Final LHC Run I: √s=8 TeV, L=20fb^{-1}



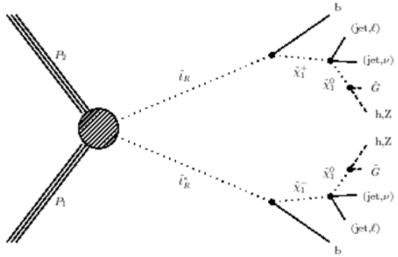
"If you cover the white then RPC Weak scale SUSY is probably dead" R. Barbieri (ICHEP2012)

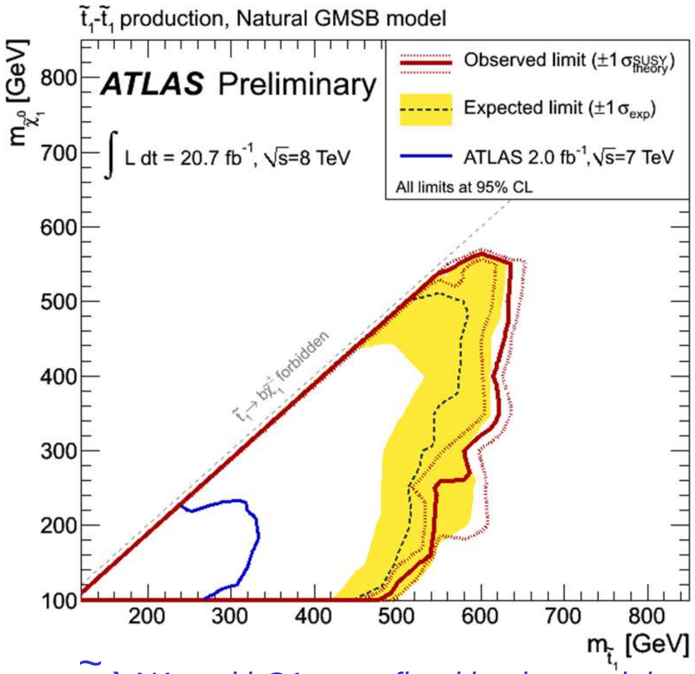
Stop (9)

ATLAS-CONF-2013-025, CMS-PAS-SUS-13-002

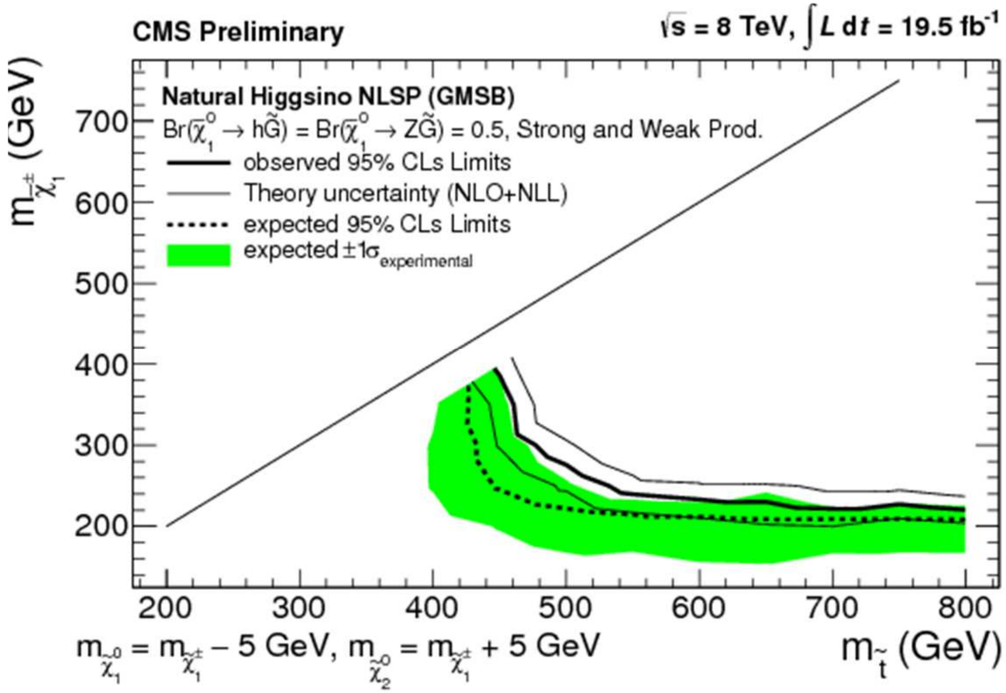
❑ A word on GMSB

- If N1 is NLSP and Higgsino-like it will decay via Z, H
- Final state: ttZZ/HH or bWZZ/bWHH





t̃→tN1 and bC1 rates fixed by the model

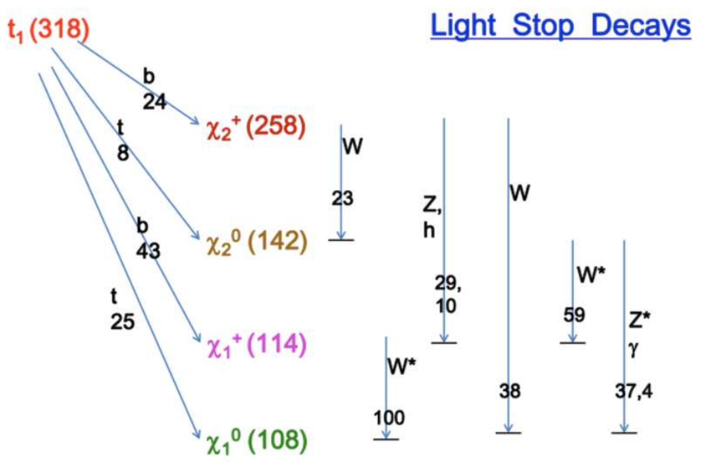


Limit a bit weaker: m(stop)> 500 GeV

Summary on 3rd generation squark

❑ Change paradigm with LHC results

- Plan vanilla scenarios for ‘natural’ stop and sbottom almost all excluded
  - ✓ Open a second SUSY crisis after no Higgs found at LEP2
  - ✓ Generate lots of new ideas to evade these constraints
- Clearly the situation can be more complex and signal may still hide (See Lecture IIc, III)



Is the naturalness guide not applicable to Higgs ? Slightly fine-tuned SUSY at the corner ?

Gluino, 1/2nd generation squarks

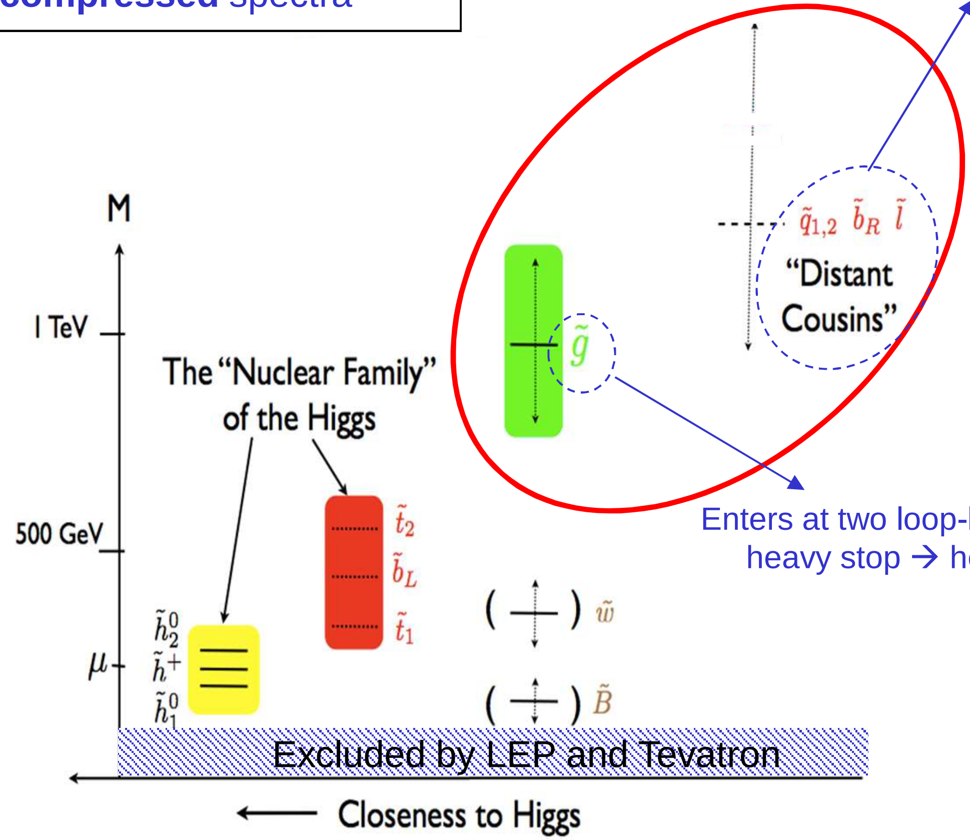
Theory Unknowns:

1- SUSY Breaking (**SUGRA**, **GMSB**, AMSB)

2- RPC (**here**) vs RPV (Lecture IIc)

3- **Open** or **compressed** spectra

O(10)TeV without problem for naturalness, yielding a decoupling solution to the SUSY flavor and CP problem. Slepton discussed in EWK SUSY (Lecture IIa)



Enters at two loop-level to protect the stop mass. If heavy stop → heavy gluino (and vice verse).

Gluino, 1/2nd generation squarks (1)

N (Signal Regions)

❑ Massive LSP = $\tilde{\chi}_1^0$ **48 (ATLAS)**

- Squark/gluino cascade : *0 lepton + 1-10 jets + MET (or MET/√H_T)*
- Squark/gluino cascade + leptonic gaugino/slepton decay : *1 soft-hard lepton (e μ) + jets +MET*
  2leptons (e μ) same sign + jets +MET
- Squark/gluino cascade + tops (bottoms) : *0-1 lepton + 3b + jets + MET*
  0lepton + 7-8-9 jets (inc. 1-2b) + jets + MET

❑ ~Massless LSP = $\tilde{G}$ **12 (ATLAS)**

- Squark/gluino cascade in GMSB/GGM : *2 opp. Sign leptons + jets +MET (Z or non Z)*
  (1)2taus + jets +MET
  γ+H→bb +jets+MET
  $\gamma\gamma$+jets +MET

Gluino, 1/2nd generation squarks (2)

ATLAS-CONF-2013-047

❑ 'Standard' 0lepton + jets + MET searches : Most inclusive !

- 0lepton : highest branching ratios generally in $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ and $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$
- Design 10 (inclusive) signal regions to cover most of the phase space

	Requirement	Channel									
		A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
		L	M	M	T	M	T	–	L	M	T
Trigger	E_T^{miss}[GeV] >	160									
Pile-up	$p_T(j_1)$ [GeV] >	130									
Pile-up	$p_T(j_2)$ [GeV] >	60									
Pile-up	$p_T(j_3)$ [GeV] >	–		60		60		60	60		
Pile-up	$p_T(j_4)$ [GeV] >	–		–		60		60	60		
Pile-up	$p_T(j_5)$ [GeV] >	–		–		–		60	60		
Pile-up	$p_T(j_6)$ [GeV] >	–		–		–		–	60		
QCD rejection	$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ >	0.4 (i = {1, 2, (3 if $p_T(j_3)$ > 40 GeV)})				0.4 (i = {1, 2, 3}), 0.2 (p_T > 40 GeV jets)					
QCD rejection	$E_T^{miss}/m_{eff}(Nj)$ >	0.2	–[a]	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
M_{Eff}	m_{eff}(incl.) [GeV] >	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

Tight (t) and Medium/Loose (l, m) signal regions

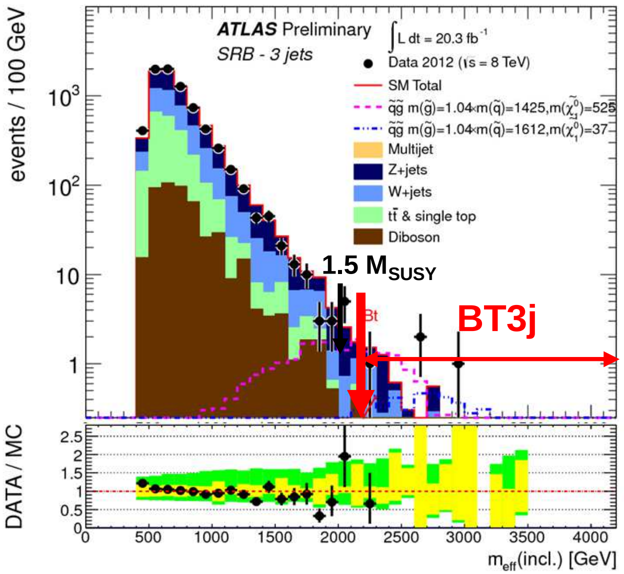
Gluino, 1/2nd generation squarks (3)

ATLAS-CONF-2013-047

❑ Energy frontier search with the 3 tighest signal regions

- 0lepton : highest branching ratios generally in $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ and $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$

SUSY model: $m_{\tilde{g}} = m_{\tilde{q}}$ = 1.4 TeV, $m_{\chi_1^0}$=0.5TeV



Signal Region	≥3j	≥4j	≥6j
Diboson	–	–	–
Z/γ^*+jets	0.2 ± 0.5	$0.0^{+0.6}_{-0.0}$	0.4 ± 0.6
W+jets	1.6 ± 1.2	0.7 ± 0.9	0.7 ± 0.5
$t\bar{t}$(+EW) + single top	0.6 ± 0.7	0.9 ± 0.9	1.7 ± 1.4
Multi-jets	–	–	–
Total bkg	2.4 ± 1.4	1.6 ± 1.4	2.9 ± 1.8
Observed	4	0	5
$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	0.33	0.12	0.41
$S^{95}_{\rm obs}$	6.7	2.4	8.3
$S^{95}_{\rm exp}$	$5.8^{+2.9}_{-1.8}$	$3.3^{+2.1}_{-1.2}$	$6.5^{+3.0}_{-1.9}$
p_0 (Z_n)	0.34 (0.4)	0.50 (0.0)	0.22 (0.8)

Dominated by ttbar+jets

50-100% error

Compatible with background

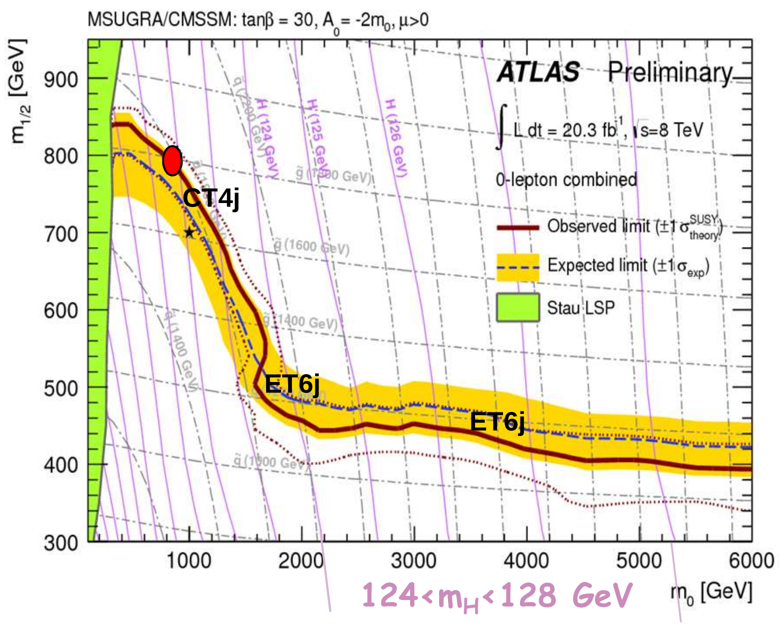
Gluino, 1/2nd generation squarks (4)

ATLAS-CONF-2013-047

❑ Interpretations for high M_{SUSY}, large $\Delta M/M_{SUSY}$

- Use tight signal regions == Energy frontier limit
- For each point take the signal region that gives the best expected limit

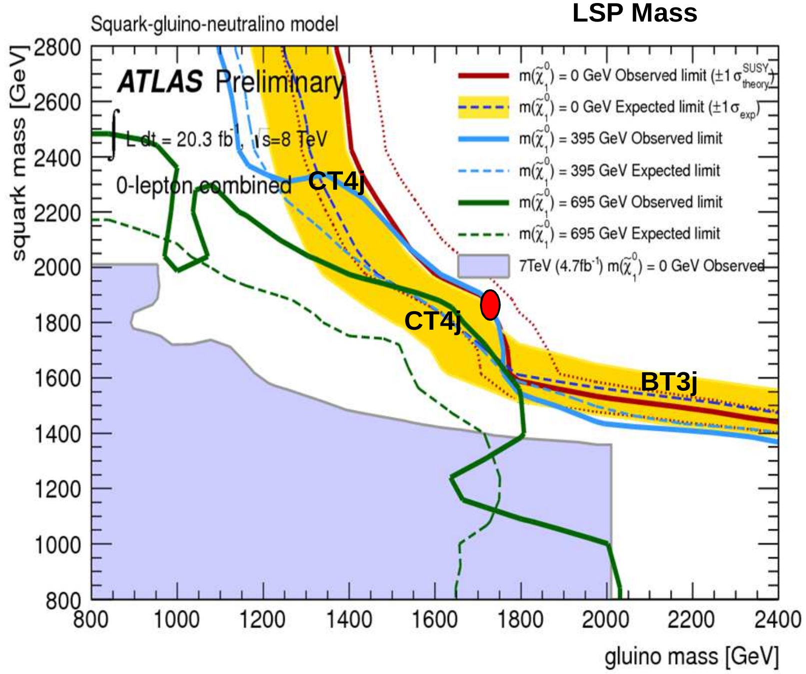
Very Constrained Model (105 parameters →5)



m_0 = Universal Scalar masses at GUT Scale

$m_{1/2}$ = Universal Fermion masses at GUT scale

Only 3 sparticles: gluino, degenerate squark 1rst,2nd gene., LSP



For m(squarks)=m(gluinos) and m(LSP)<400 GeV, set limit at ~1.7 TeV

Gluino, 1/2nd generation squarks (5)

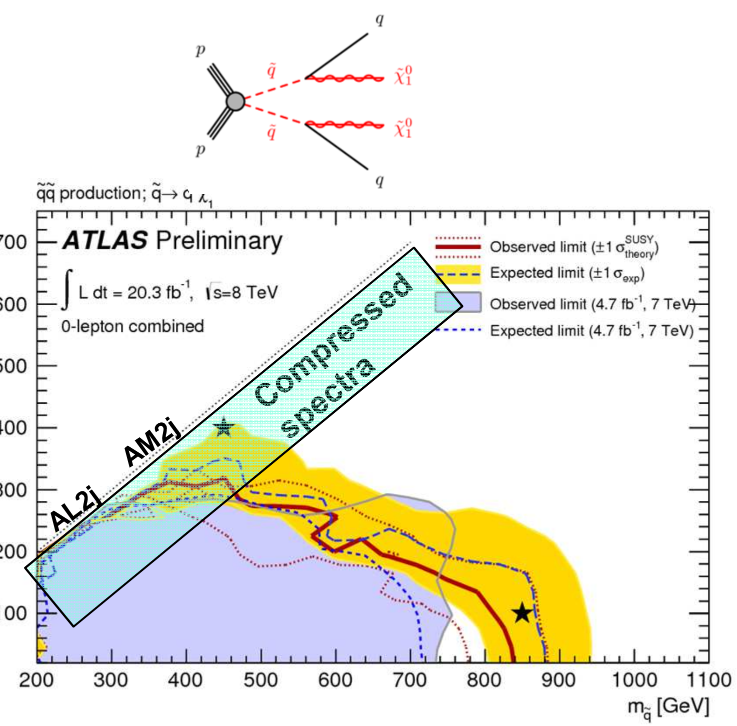
ATLAS-CONF-2013-047

❑ Low $\Delta M/M_{SUSY}$ ('compressed spectra')

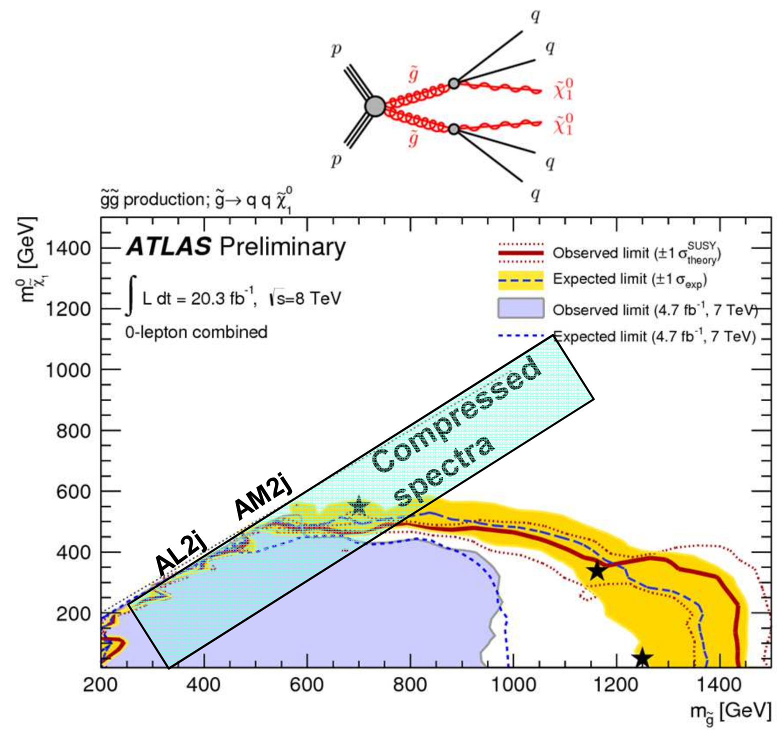
M_{Eff}=MET+H_T~1.8(M_{SUSY}^2-M_{LSP}^2)/M_{SUSY}

- Use loose/medium signal regions for compressed regions ($m_{SUSY} \approx m_{LSP}$)
  - ✓ In this region, jets from gluinos/squarks very light, i.e relax M_{Eff} cuts.
- Sensitive to Initial State Radiation (ISR) jets boosted by heavy particle production

Only 2 sparticles : degenerate squark 1rst,2nd gene., LSP



Only 2 sparticles: gluino, LSP



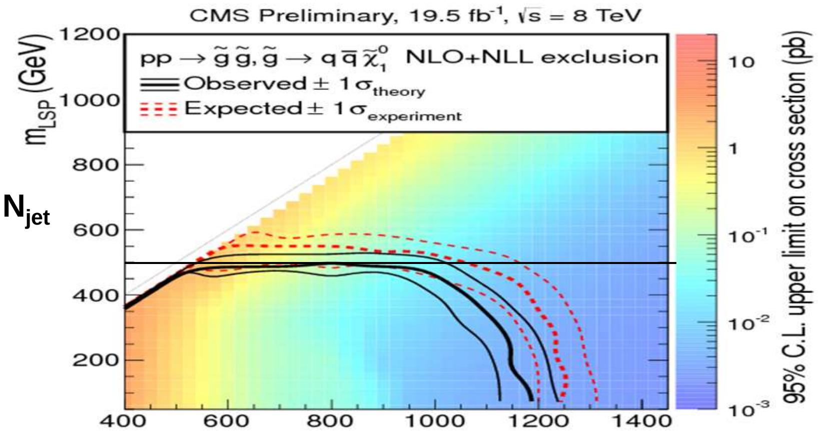
Significantly less stronger limits M(LSP)<300/500 GeV

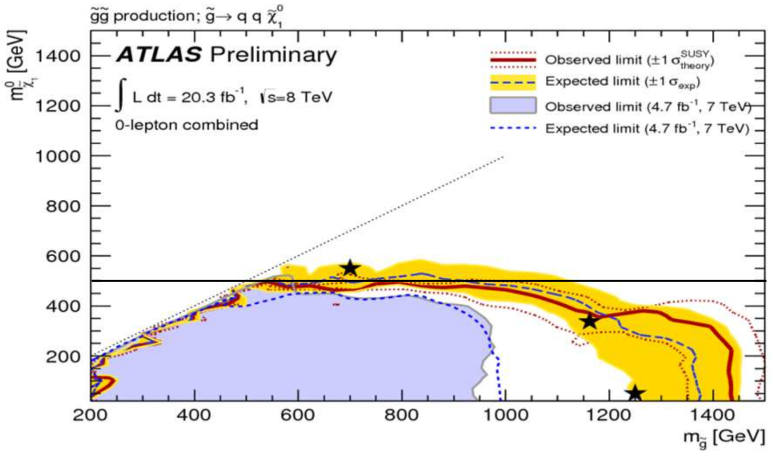
Gluino, 1/2nd generation squarks (6)

CMS-PAS-SUS-13-012

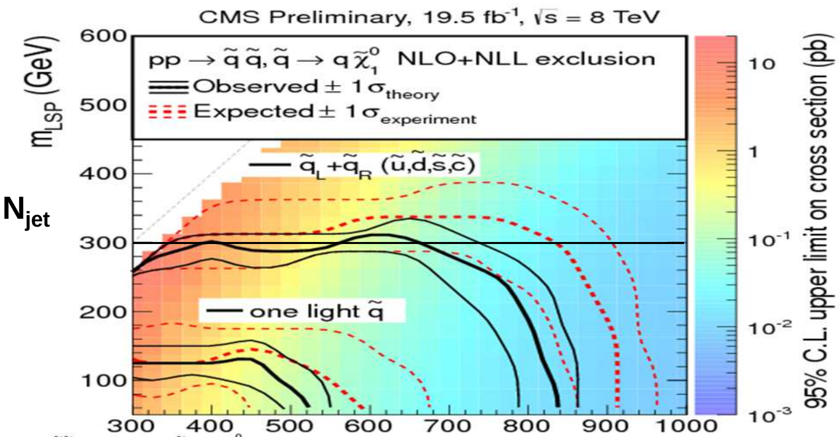
❑ Other discriminating variables can be used

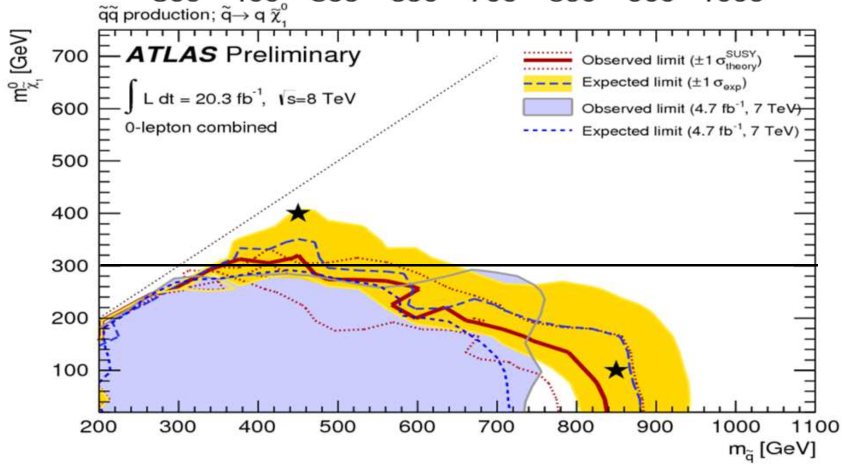
MHT, N_{jet}





MHT, N_{jet}





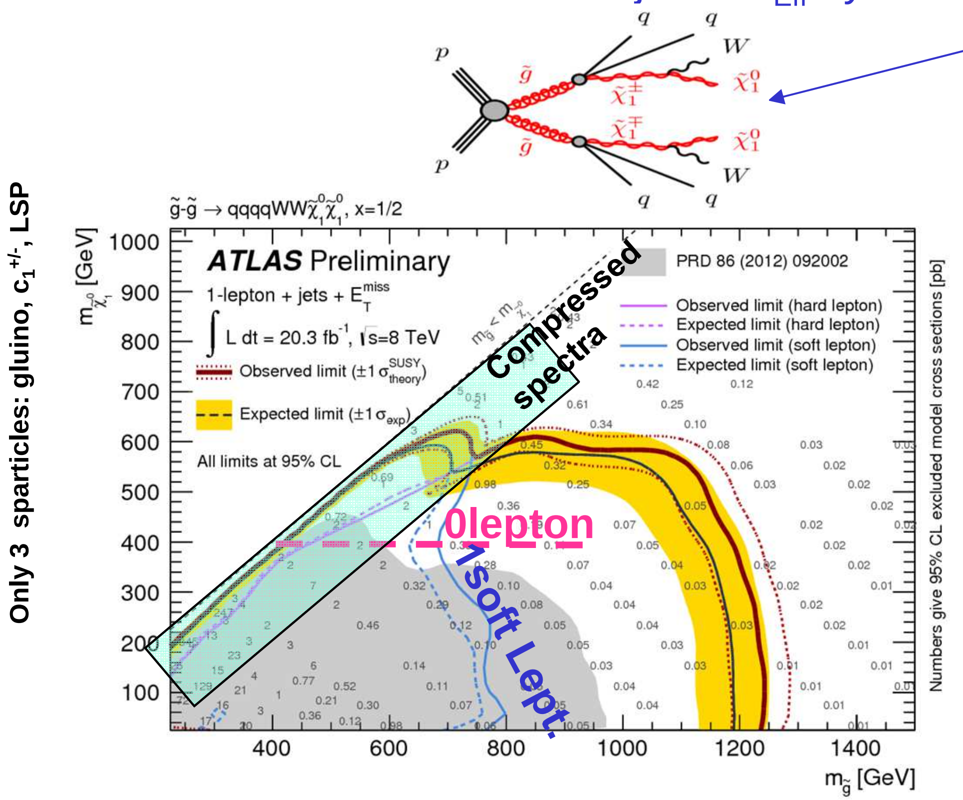
Comparable limits

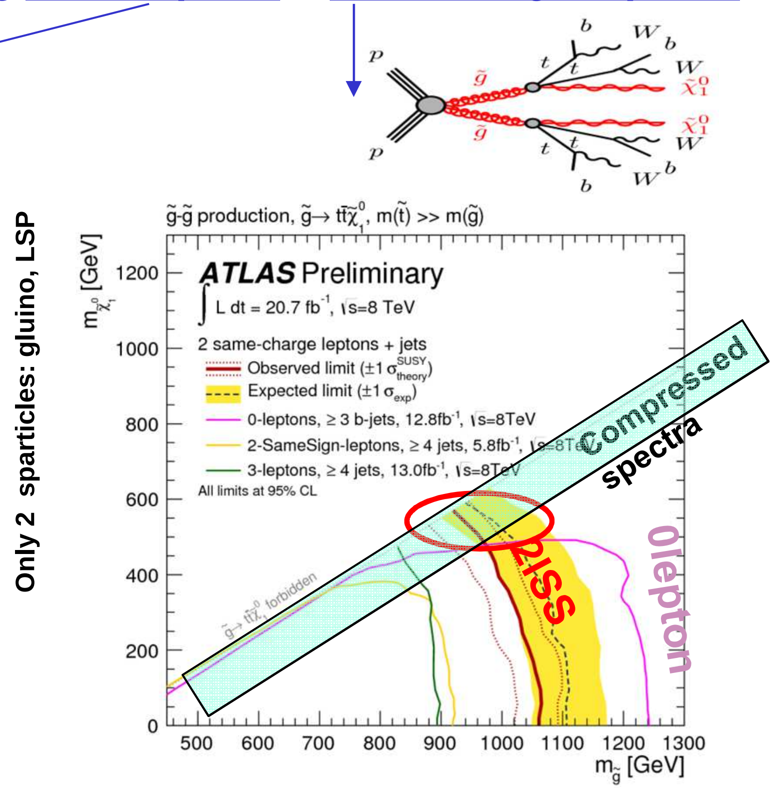
Gluino, 1/2nd generation squarks (7)

ATLAS-CONF-2013-062, ATLAS-CONF-2013-007

❑Low $\Delta M/M_{SUSY}$ ('compressed spectra') – Part II

- Develop dedicated analysis using ISR jet : "Monojet" (see later)
- Will also analyse delayed trigger with lower threshold
- Relax kinematic constraints on jets / M_{Eff} by asking **1soft lepton** or **2 same-sign leptons**



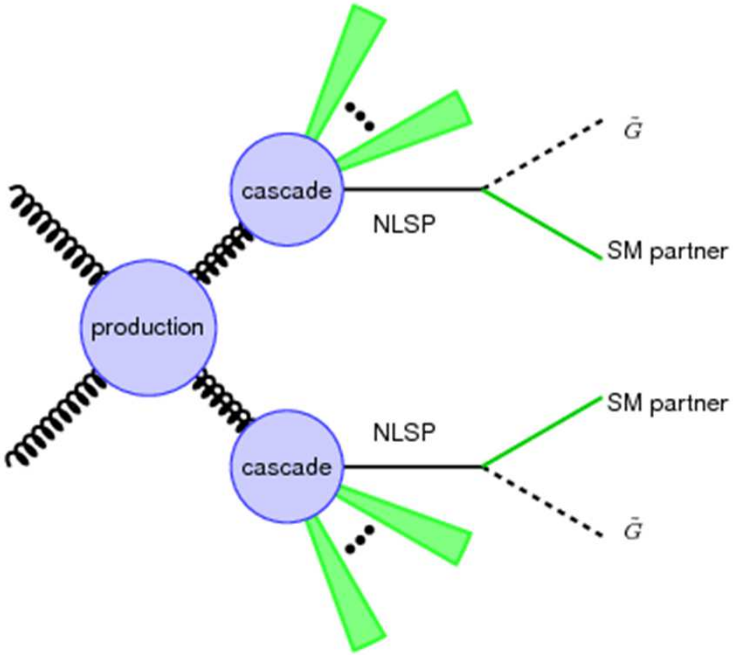


Can reach M(LSP) ~ 600 GeV !

Gluino, 1/2nd generation squarks (8)

❑ Assume now LSP is the gravitino (GMSB)

- Next-to-Lighest LSP (NLSP) determines the event final states
- Enhance multi-leptonic / photonic signature (0/1/2 leptons +jets +MET analyses also strong)



JHEP 02 (2012) 115

NLSP type	Relevant final states (+MET)
bino	$\gamma\gamma$, γ+jets
wino	$\gamma\ell$, $\gamma\gamma$, γ+jets, ℓ+jets, jets
Z-rich higgsino	$Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell'^+\ell'^-)$, SS dileptons, jets
h-rich higgsino	b-jets, SS dileptons, jets
chargino	SS dileptons, OS dileptons, ℓ+jets, jets
slepton	multileptons, SS dileptons, OS dileptons, ℓ+jets, jets
squark/gluino	jets
stop	SS dileptons, OS dileptons, b-jets, ℓ+jets, $\ell + b$-jets, $t\bar{t}$, jets
sbottom	b-jets, jets

Next slides **Discussed Before** **See Natural searches later**

------ Watch out the m(gluino)=1 TeV line

Have covered pretty much all signatures for gluino originated cascade !

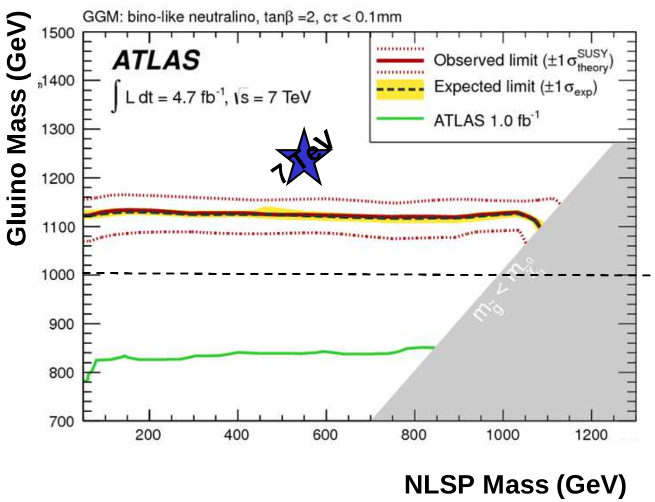
Gluino, 1/2nd generation squarks (9)

1209.0753, ATLAS-CONF-2012-144, ATLAS-CONF-2012-152, 1211.1167

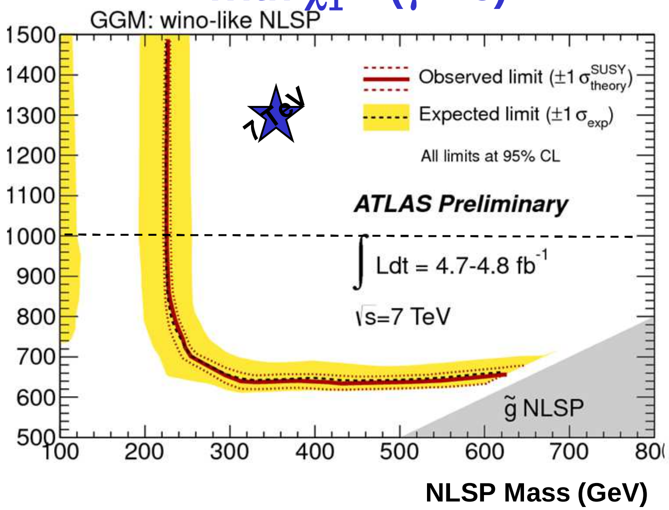
❑ NLSP = $\tilde{\chi}_1^0$

- Add MET to all signature in brackets
- All results still with 5 fb^{-1} of data

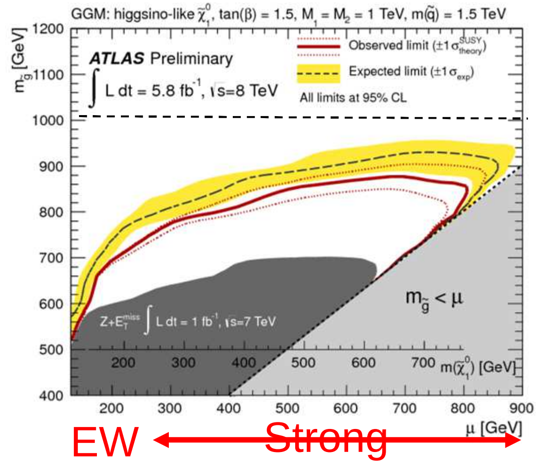
χ_1^0-bino like ($\gamma\gamma$)

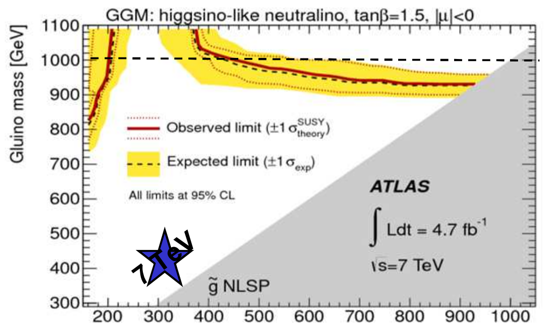


χ_1^0-wino like degenerate with $\chi_1^{+/-}$ (γ + e)



χ_1^0-Higgsino like (Z+jets, H→bb+jets)





NLSP Mass (GeV)

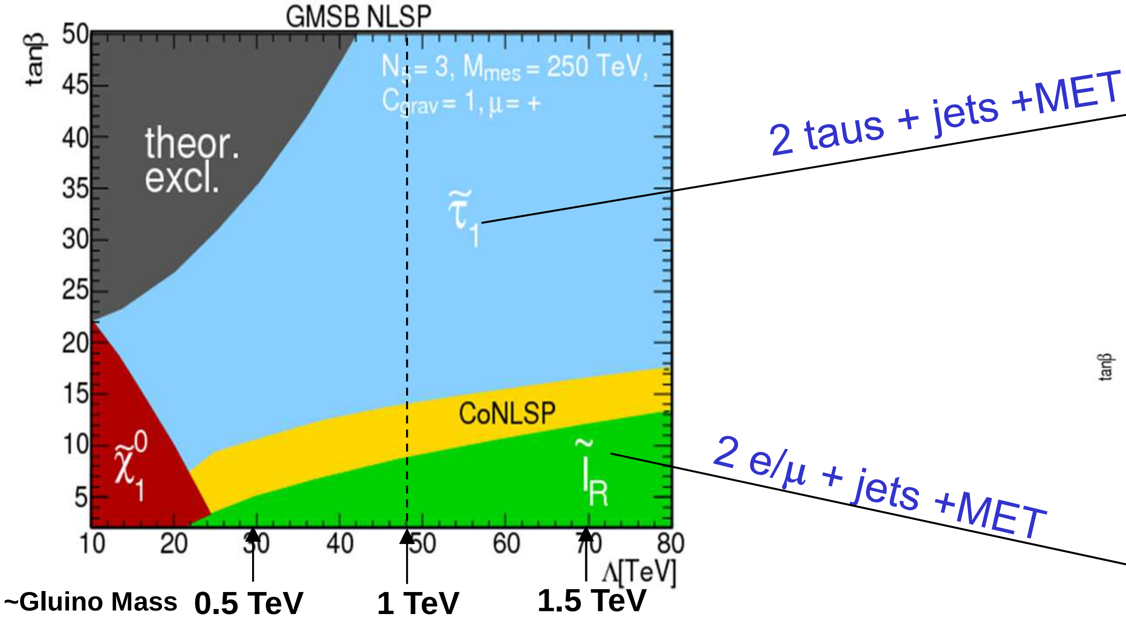
Expect to constraint gluino above 1 TeV with 20 fb^{-1} (Work in Progress)

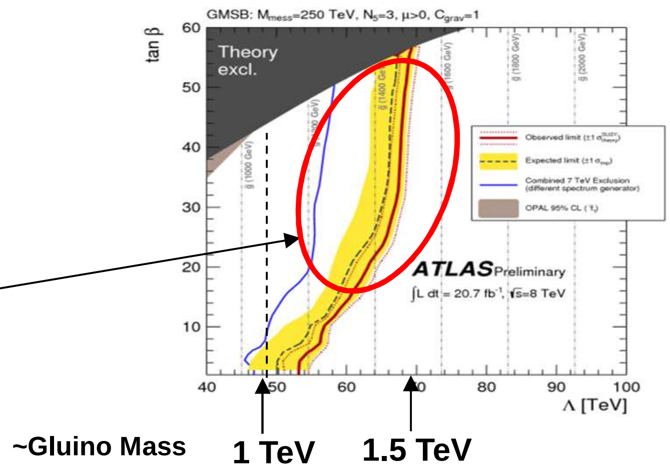
Gluino, 1/2nd generation squarks (10)

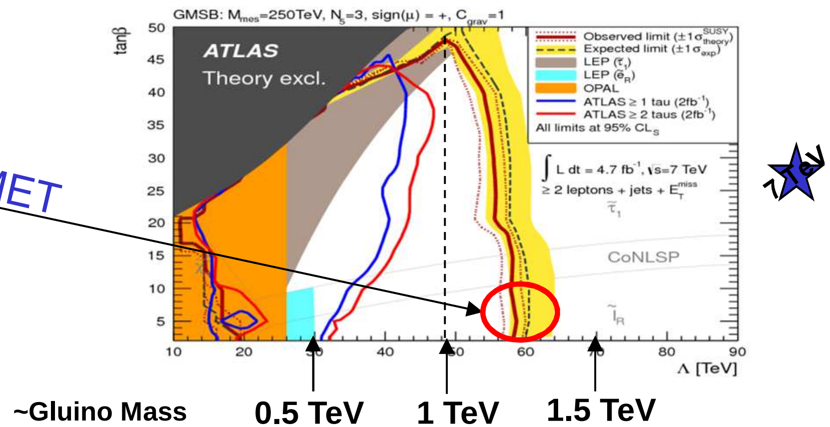
ATLAS-2013-026, 1208.4688

❑ NLSP = slepton

- Can enhance the number of taus if stau NLSP* and other leptons if selectron/smuon NLSP
- Can combine all flavor (e, μ, τ)



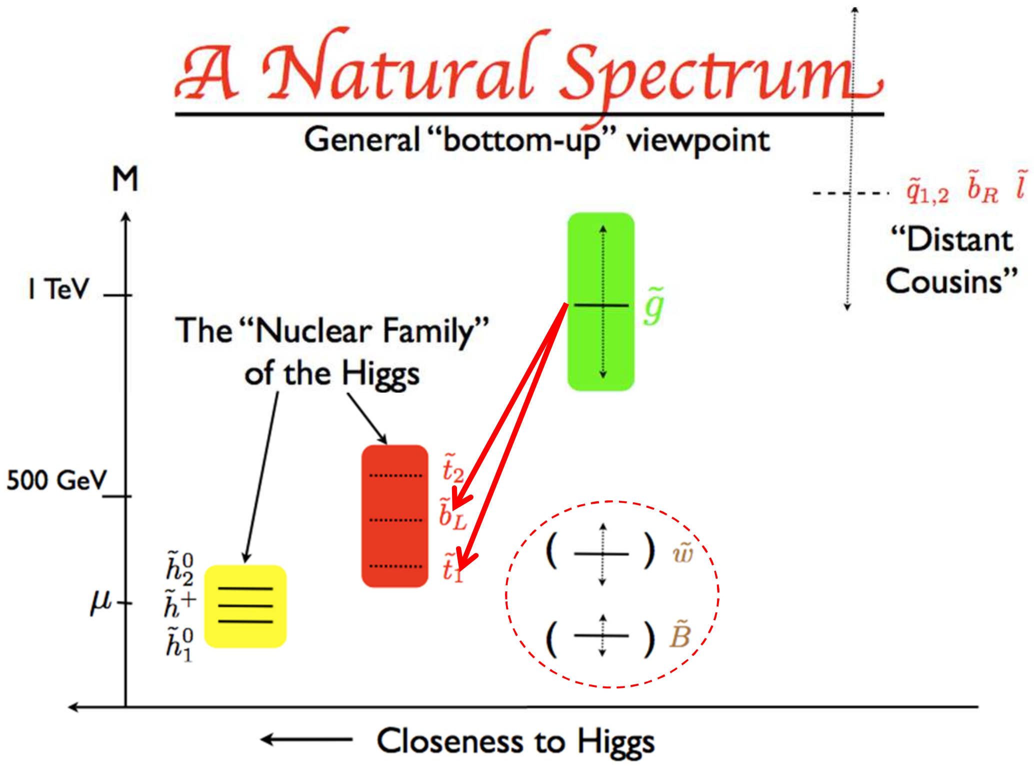


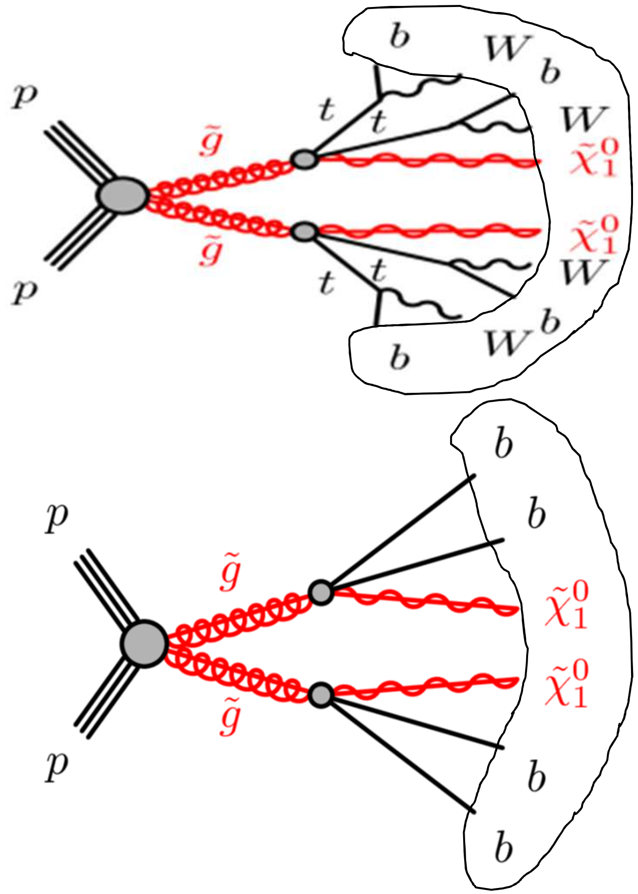


* Stau can be also be light if large mixing

Gluino→3rd generation squarks (1)

❑ **Gluino mediated stop and sbottom** (natural/inclusive)

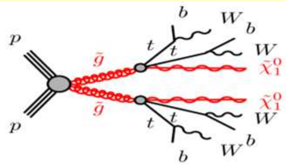




Gluino→3rd generation squarks (2)

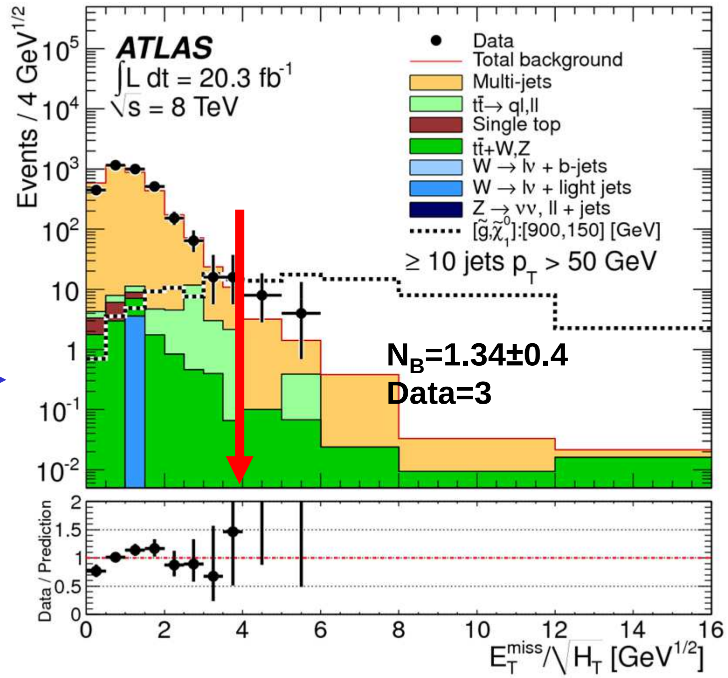
ATLAS-CONF-2013-061, 1308.1841, ATLAS-CONF-2013-007

- top killer analyses for $\tilde{g}\tilde{g} \rightarrow tttt\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow$ 4b+4W+MET



- ttbar = 2b → Ask for 3b *[see before]*
- ttbar leptonic = 2 opp. Charged lepton → Ask for 3 leptons or 2 same sign lepton *[see before]*
- ttbar hadronic = 6 jets + no MET → Ask for **0lepton + 7-10 jets + MET/$\sqrt{H_T}$**

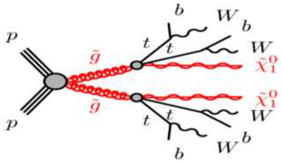
- 6-jet trigger p_T(jet)>50 GeV
- Develop 0 – 1 – 2 bjet analysis
- Template method to control Multijet background
  - ✓ MET resolution ~ $\sqrt{H_T}$, independent on Njet
- Example with 10jets p_T(jet)>50 GeV



Gluino→3rd generation squarks (3)

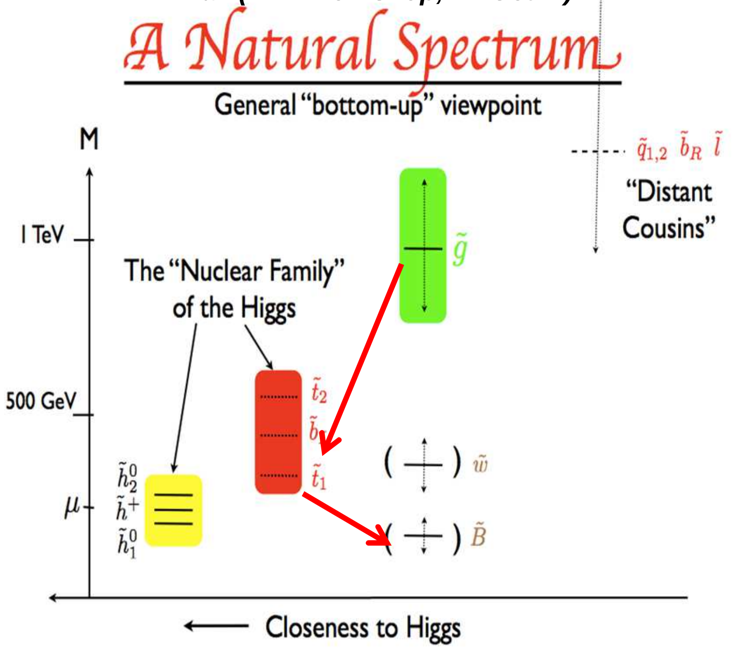
ATLAS-CONF-2013-061, 1308.1841, ATLAS-CONF-2013-007

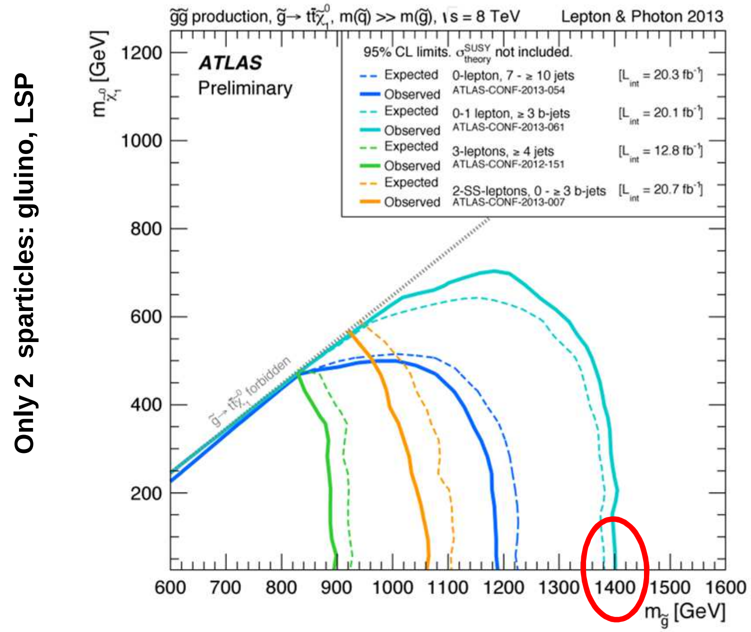
- **top killer analyses for $\tilde{g}\tilde{g} \rightarrow tttt\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow$ 4b+4W+MET**



  - ttbar = 2b → Ask for 3 b [**Strongest**]
  - ttbar leptonic = 2 opp. Charged lepton → Ask for 3 leptons or 2 same sign lepton [**Compressed**]
  - ttbar hadronic = 6 jets + no MET → Ask for 0lepton + 7-10 jets [**Not competitive here**]

L. Hall (LBL Workshop, 21-Oct11)



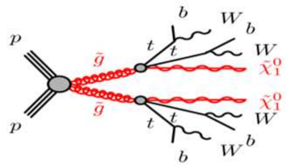


Very strong limit on this natural signature m(g)<1400 GeV

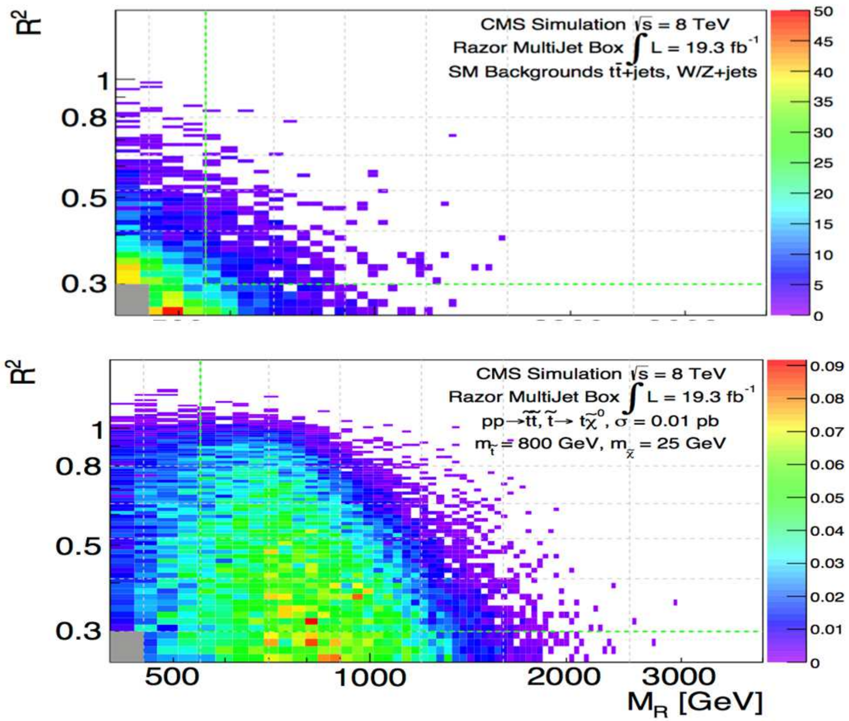
Gluino→3rd generation squarks (4)

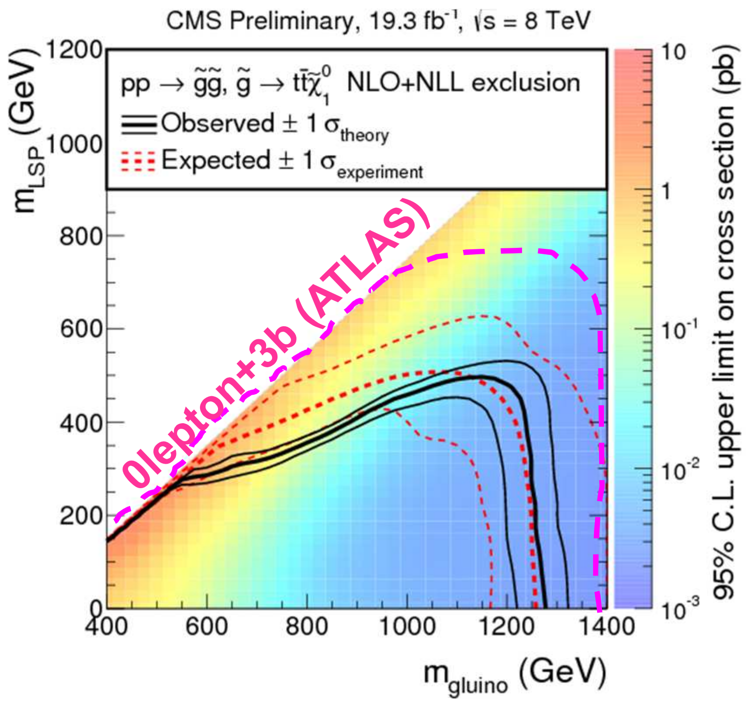
CMS-PAS-SUS-13-004

- **top killer analyses for $\tilde{g}\tilde{g} \rightarrow tttt\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow$ 4b+4W+MET**
  - Razor variable as discriminant in 0lepton + ≥2 b-jet analysis



Requirements				
Box	lepton	b-tag	kinematic	jet
2b-Jet	none	≥ 2 b-tag	$(M_R > 400$ GeV and $R^2 > 0.25)$ and $(M_R > 550$ GeV or $R^2 > 0.3)$	2 or 3 jets



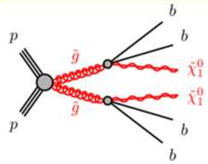


Similar limits obtained whatever the discriminating variables

Gluino→3rd generation squarks (5)

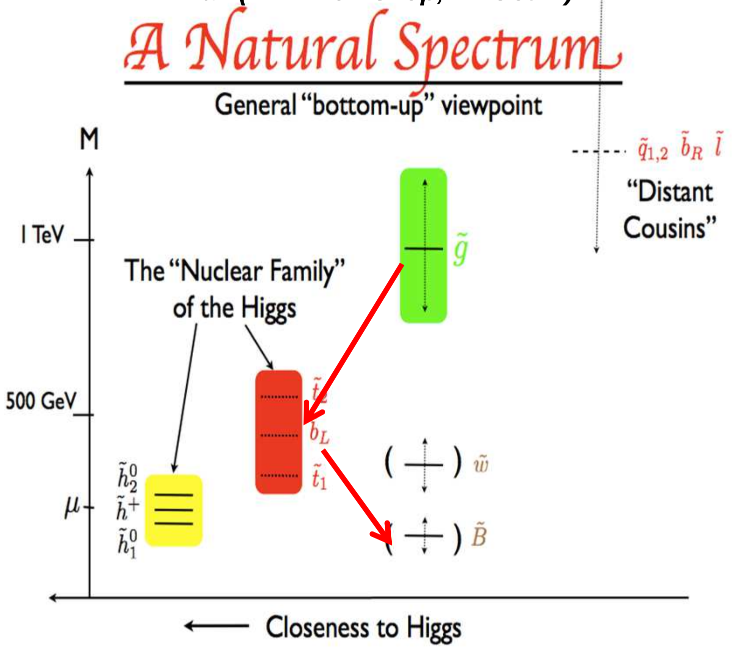
ATLAS-CONF-2013-061, CMS-PAS-SUS-13-004

❑ top killer analyses for $\tilde{g}\tilde{g} \rightarrow bbbb\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow$ 4b+4W+MET

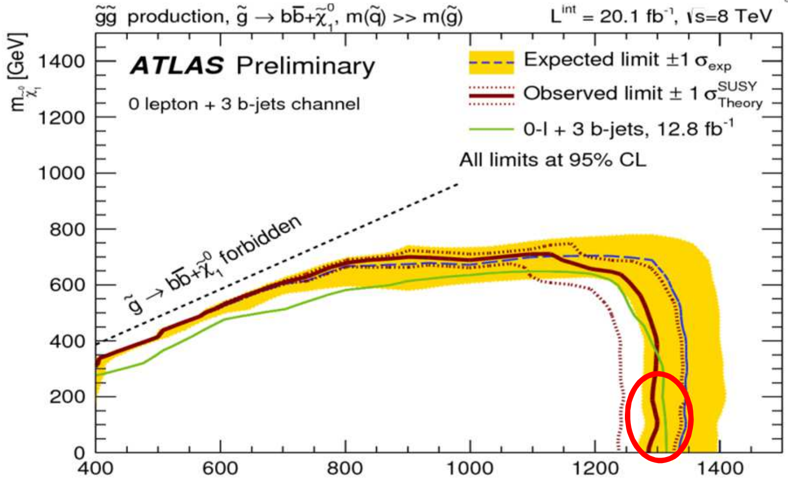


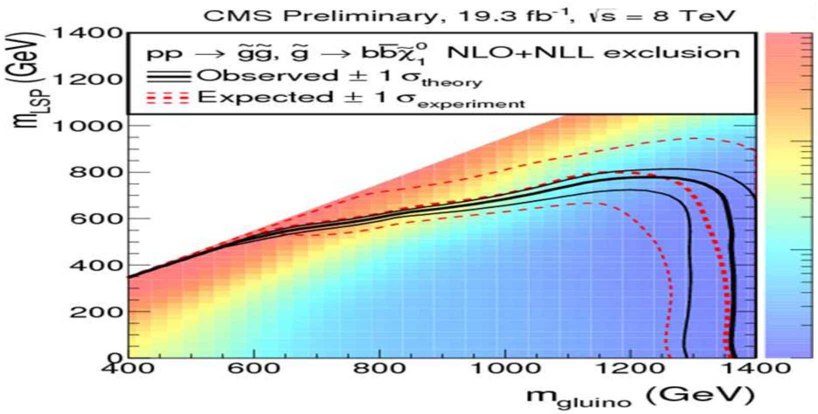
- ttbar = 2b → Ask for 3 b
- Razor variable also very powerful

L. Hall (LBL Workshop, 21-Oct11)



Only 2 sparticles: gluino, LSP

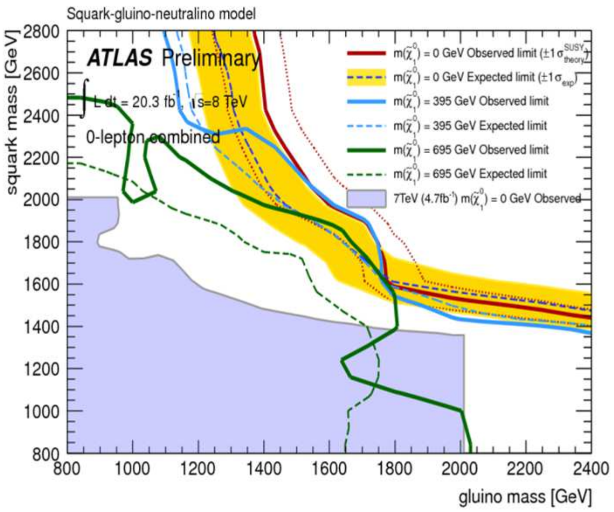




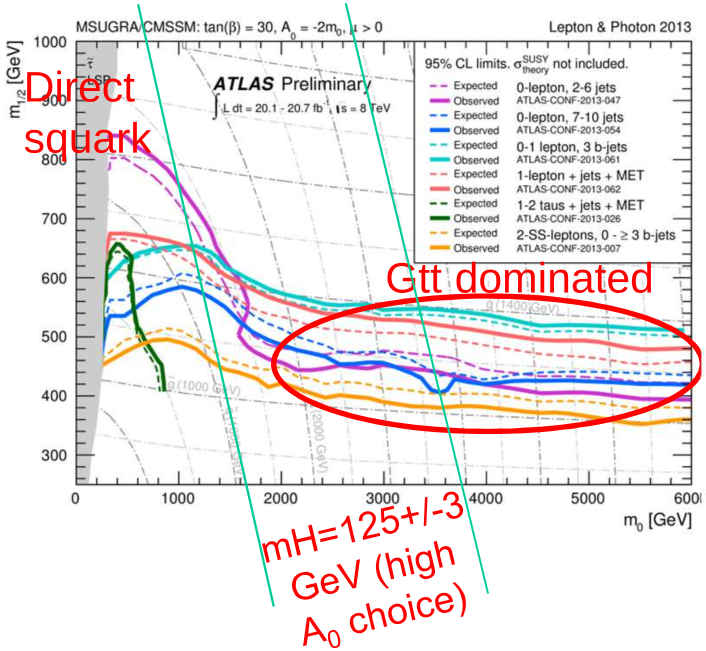
Very strong limit on this natural signature m(g)<1300 GeV

Summary on gluino, $\tilde{q}_{1,2}$

Inclusive-like



SUGRA-like



GMSB-like : m($\tilde{g}$)> 1TeV

NLSP type	Relevant final states (+MET)
bino	$\gamma\gamma$, γ+jets
wino	$\gamma\ell$, $\gamma\gamma$, γ+jets, ℓ+jets, jets
Z-rich higgsino	$Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell^+\ell^-)$, SS dileptons, jets
h-rich higgsino	b-jets, SS dileptons, jets
chargino	SS dileptons, OS dileptons, ℓ+jets, jets
slepton	multileptons, SS dileptons, OS dileptons, ℓ+jets, jets
squark/gluino	jets
stop	SS dileptons, OS dileptons, b-jets, ℓ+jets, ℓ + b-jets, $t\bar{t}$, jets
sbottom	b-jets, jets

Previous slides

Discussed Before

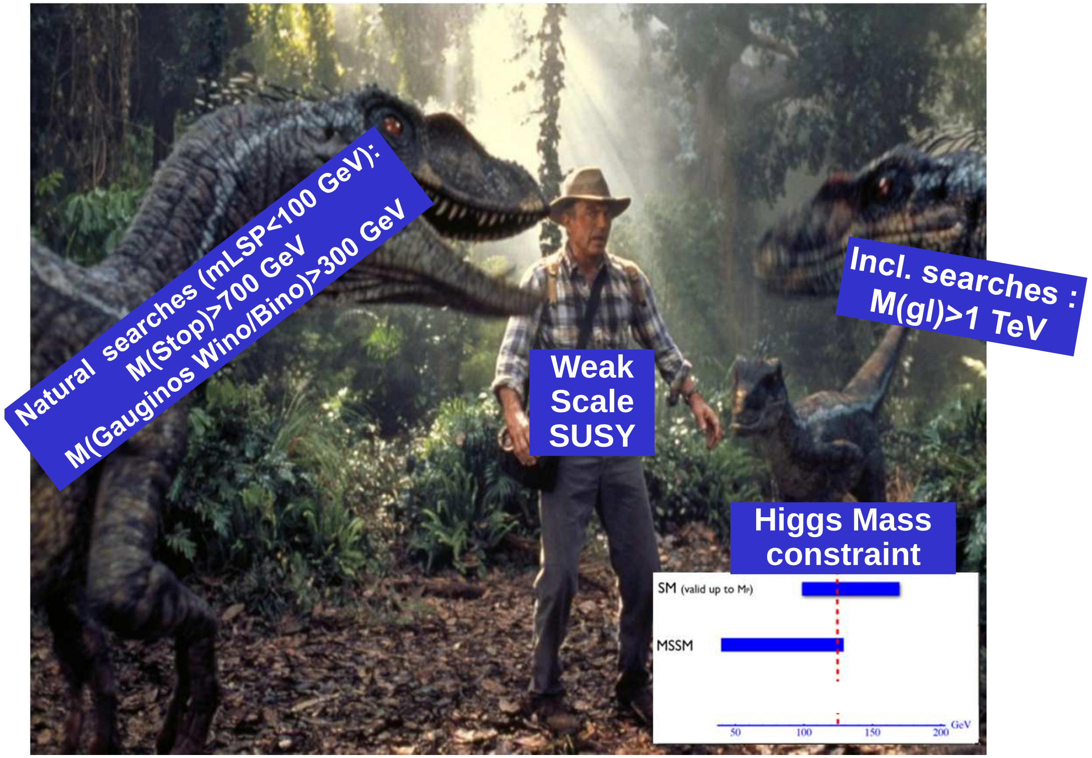
See Natural searches later

Limits on gluino are quite strong.

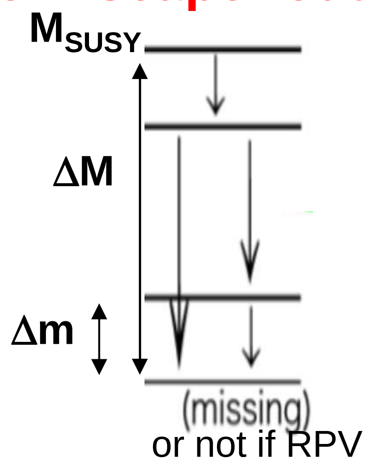
Limit on 1rst/2nd squark generation weaker *(or many assumptions)*

Conclusions

Plan vanilla MSSM is in danger !



Other Escape routes



3. Low Δ**m**, tiny RPV, weak coupling to $\tilde{G}$
   Long Lived or meta-stable sparticles
4. 'Sizeable' RPV
   Multileptons, No Z, jet resonances, LFV
5. MSSM Extensions?
   Scalar Gluon

Still viable if :

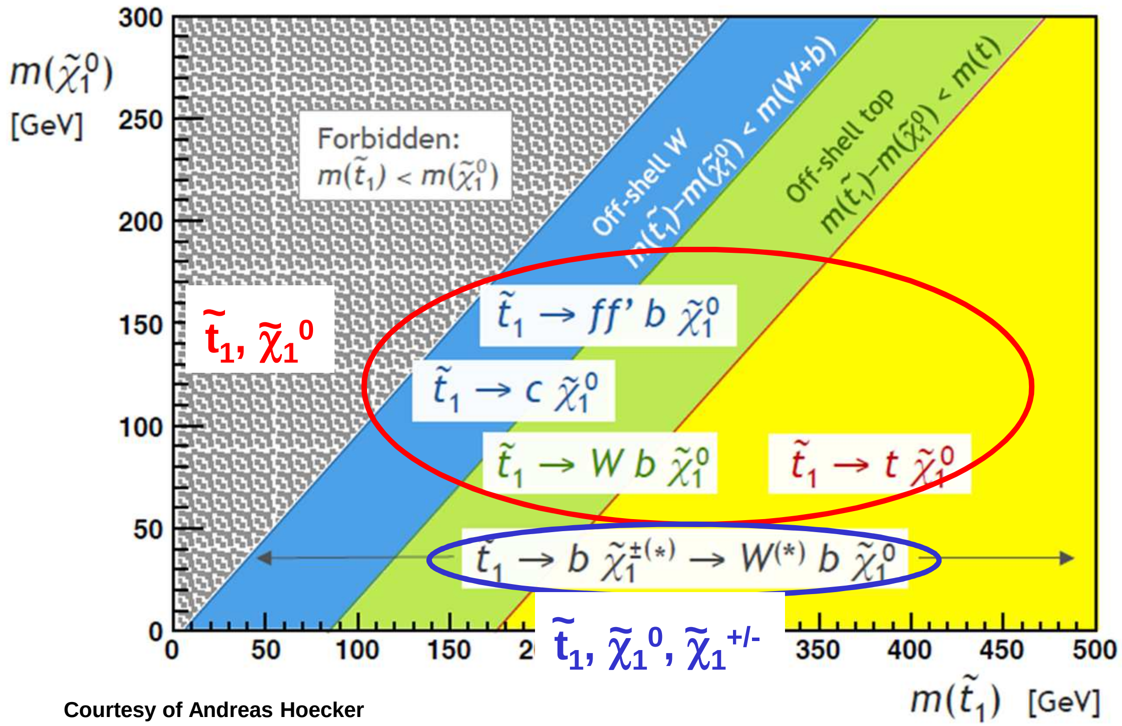
-- compressed scenario (limits are weaker) ⟶ ISR/Monojet-like analysis, delayed trigger
-- complicated SUSY spectrum (intricate decay chains) ⟶ pMSSM systematic scan
-- a new electroweak singlet is added(relax Higgs constraints) ⟶ not fully explored yet
-- N=2, hard at low luminosity ($c_1^+ c_1^- \rightarrow WW$), ...

SPARE

Stop (2)

❑ An extensive experimental research program

Large spectrum of possible stop decays. Effort so far concentrated on simplified models with 100% BRs to chosen final state. Studies of handedness dependence performed.



Courtesy of Andreas Hoecker

Dedicated effort pioneered in Summer 2012

Signature-based analyses:

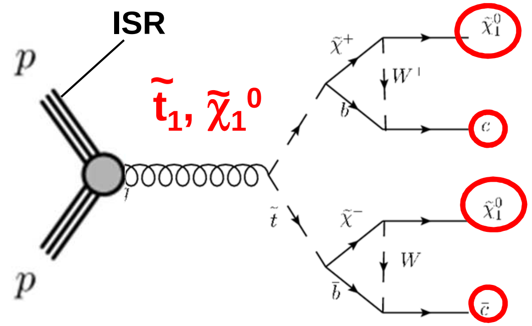
- 0 lepton + 2 *b*-jets + MET
- 0 lepton + 6 (2*b*) jets + MET
- 1 lepton + 4 (1*b*) jets + MET
- 2 leptons (+ jets) + MET
- GMSB / $\tilde{t}_2$ search with add. *Z*

Stop (5)

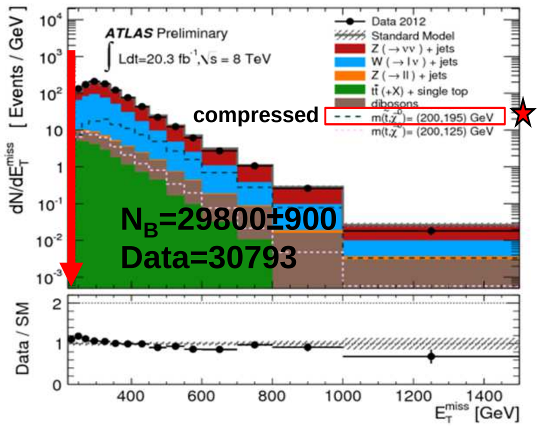
ATLAS-CONF-2013-068

❑ Analysis with Charm and ISR

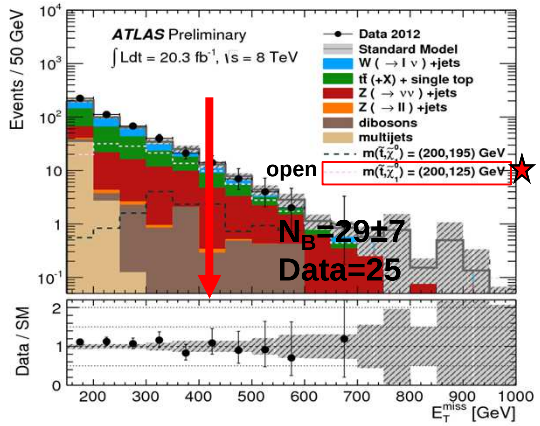
- A small corner of the phase space ($m_c+m_{N1} < m_{t1} < m_b+m_W+m_{N1}$)
- Trigger on ISR + Two complementary approaches

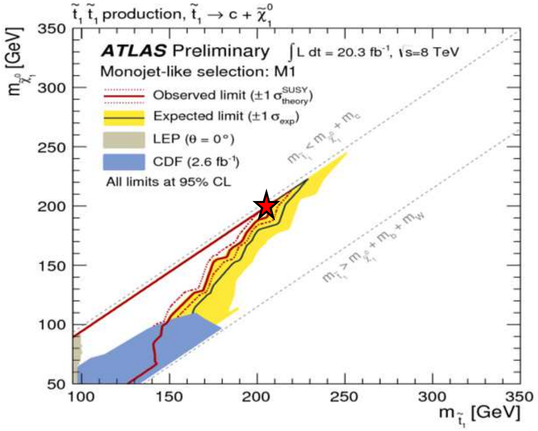


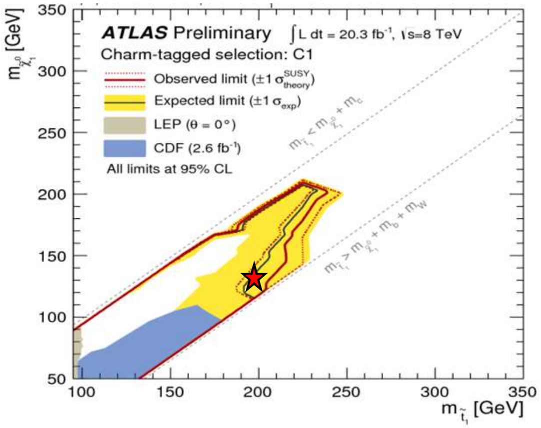
"Monojet "(≤3 jets)

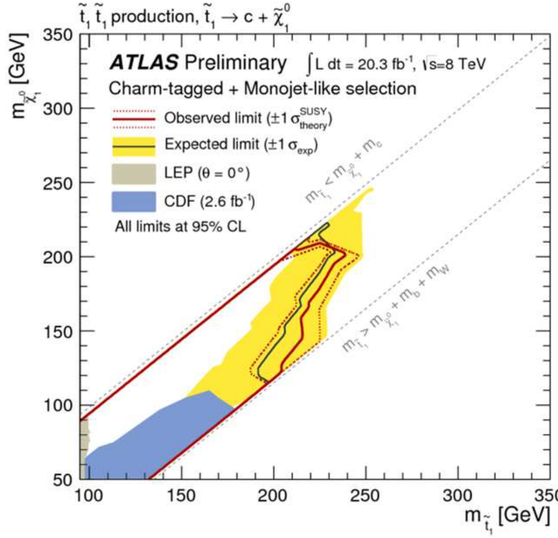


c-tag4th jet (>3 jets)





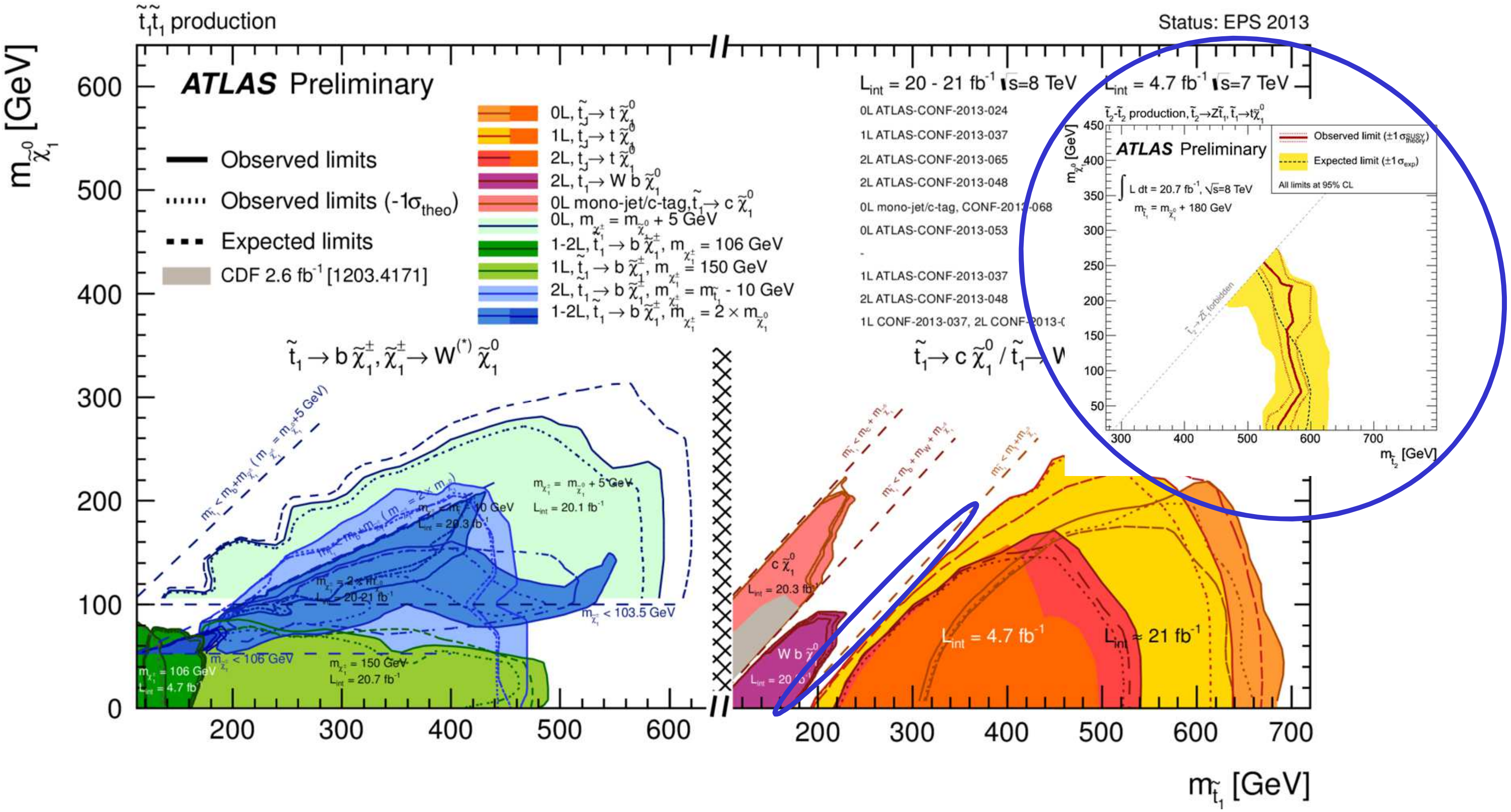




Stop (9)

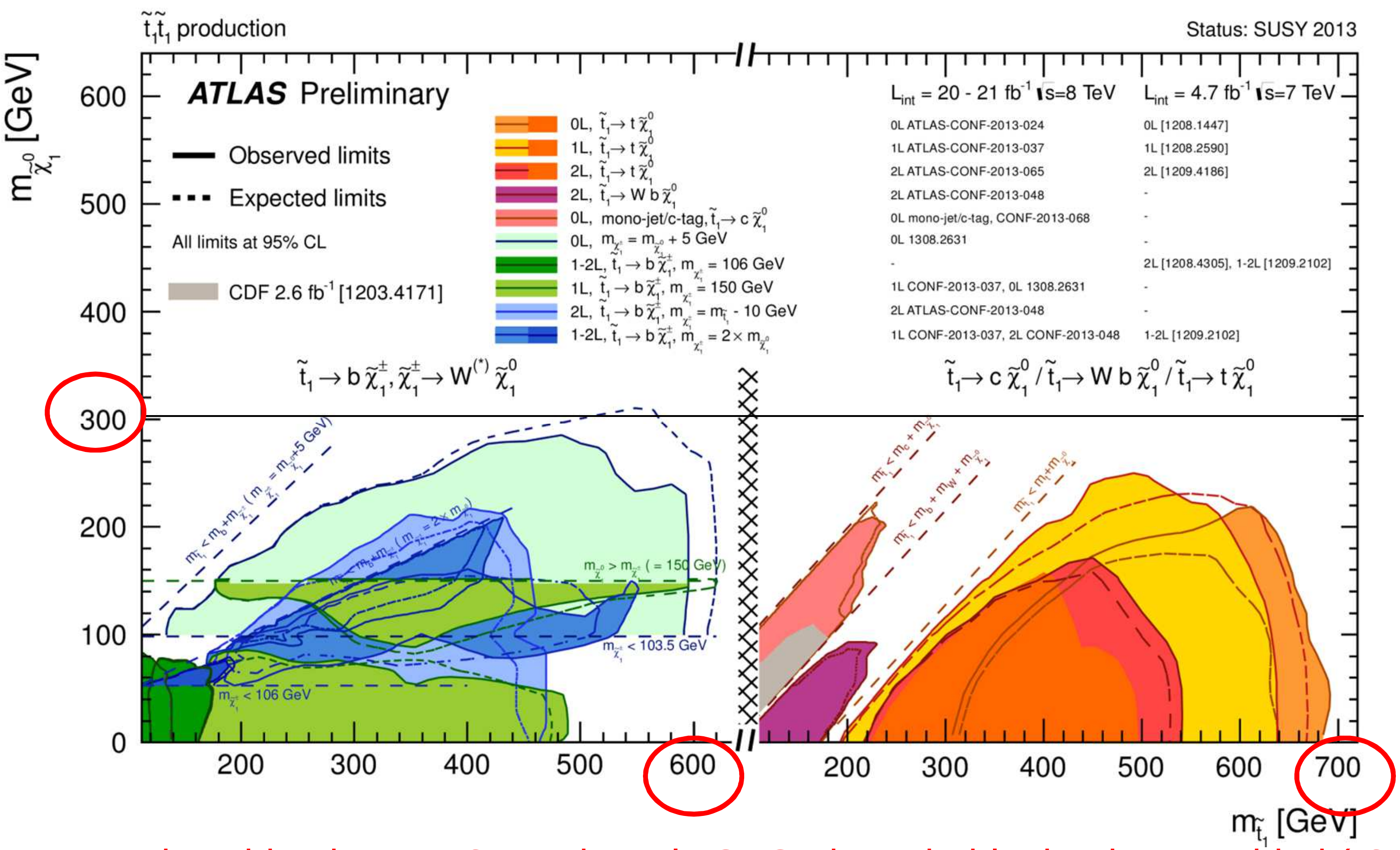
ATLAS-CONF-2013-025

- ❑ **Possible to cover unaccessible regions: stop2→stop1+Z**



Stop (10)

- **Current summary at 8 TeV (Still in progress)**



“If you cover the white then RPC Weak scale SUSY is probably dead” R. Barbieri (ICHEP2012)

Multivariate (MVA) for SUSY ?

- Usefulness considerations …
  - MVA less useful in case of strongly varying signal predictions and inclusive search
  - MVA classification useful in presence of several not too strongly correlated variables
  - Useful in case of bad signal to background ratio in signal region
  - Less useful in case of one or two very strong variables with little correlation
  - Maybe: analyses that strongly benefit from more statistics are good use cases for MVA classification, while analyses depending mostly on highest CM energy are less so
  - MVA training requires supervision by a signal model: useful if good generic or specific signal model exists

- Looking at the current SUSY analyses …
  - Probably not much needed for: inclusive 0/1-lepton, multijet, monojet, photon/tau + jets + MET searches → driven by highest effective mass tails with good S/B ratio
  - However, compressed scenarios in these analyses might be an MVA use case
  - Potentially useful for direct stop / gaugino / slepton searches
  - Probably not so useful for RPV scenarios (?)

Andreas Hoecker – SUSY and MVA ?