Searches for Pair Production of Third Generation Squarks with the ATLAS Detector

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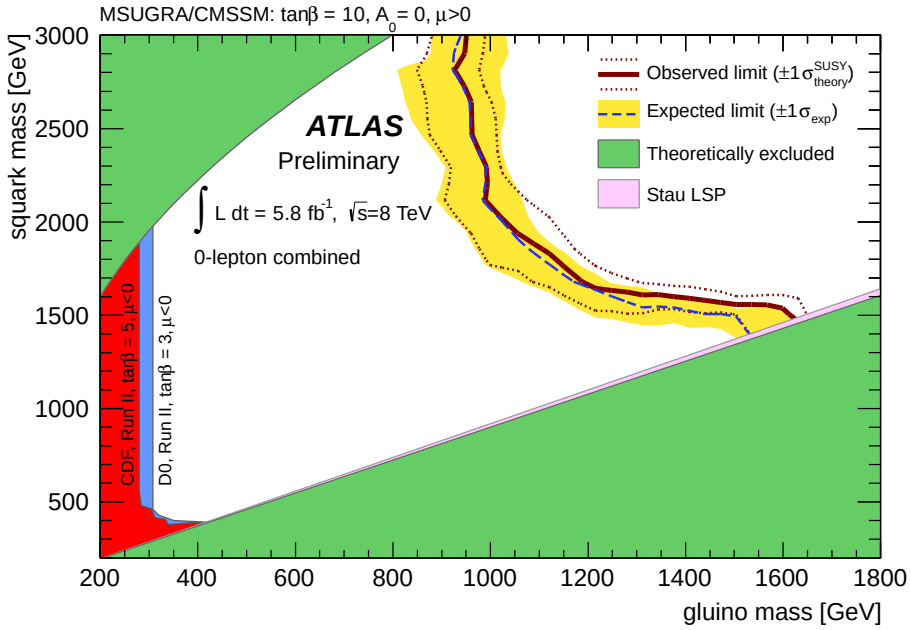
on behalf of the ATLAS Collaboration

Phenomenology Symposium

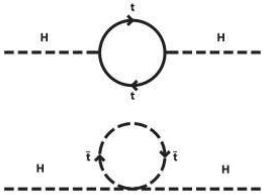
May 6, 2013

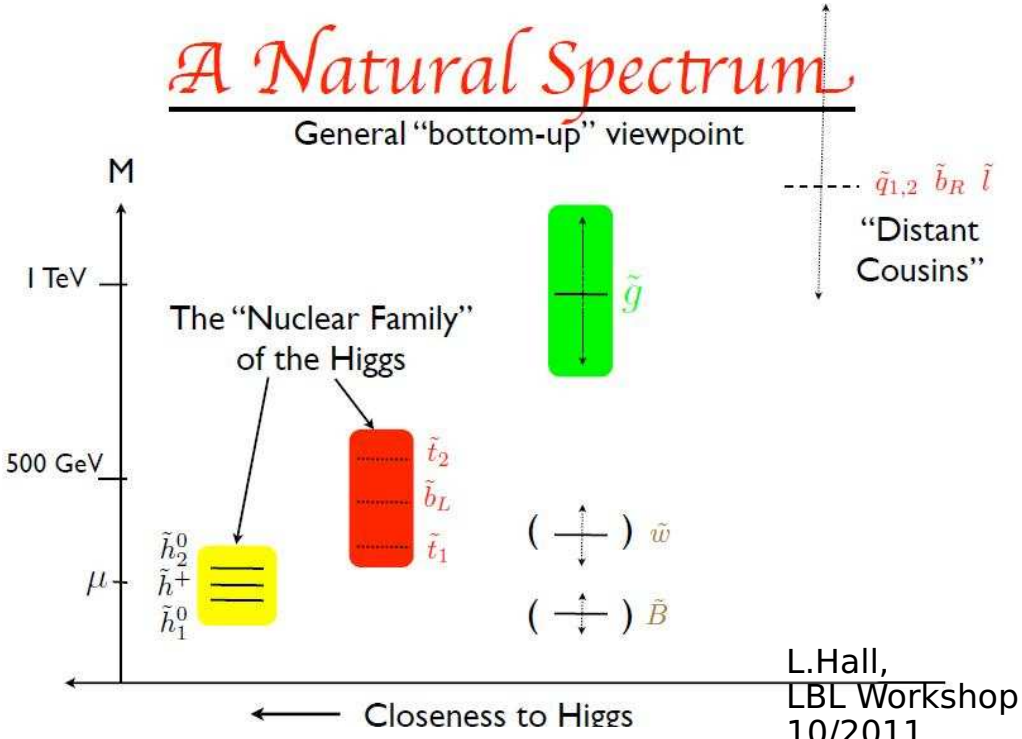
Seeking SUSY

- ***No sign of SUSY!***
  - many limits at $\gtrsim 1$ TeV
  - no light squarks or gluinos
- ***Allowed phase space strongly squeezed***
  - MSUGRA & CMSSM under pressure



- ***However, only the stop, sbottom, and gauginos need to be light!***
  - *Natural* SUSY
  - Higgs boson mass regularized by stop
  - For MSSM: large mixing in stop sector or heavy squarks

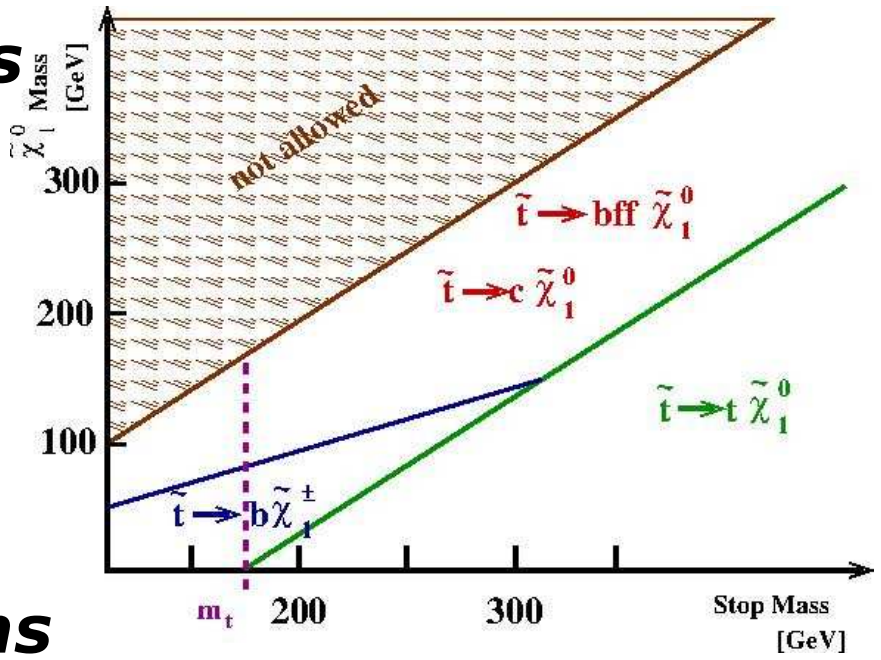


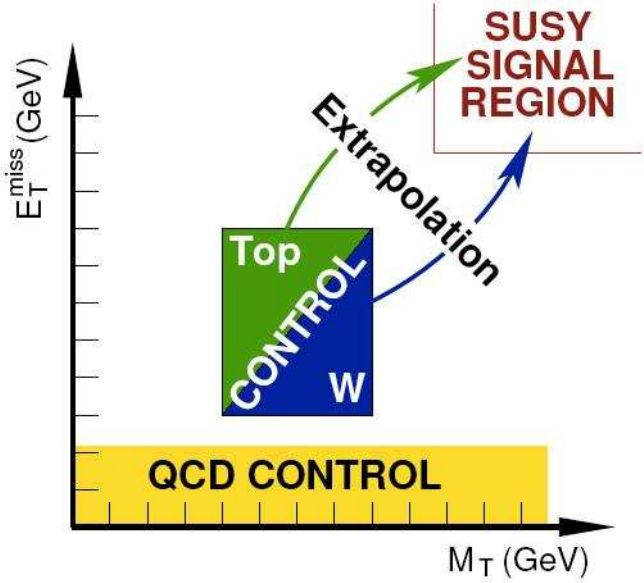


L.Hall, LBL Workshop 10/2011

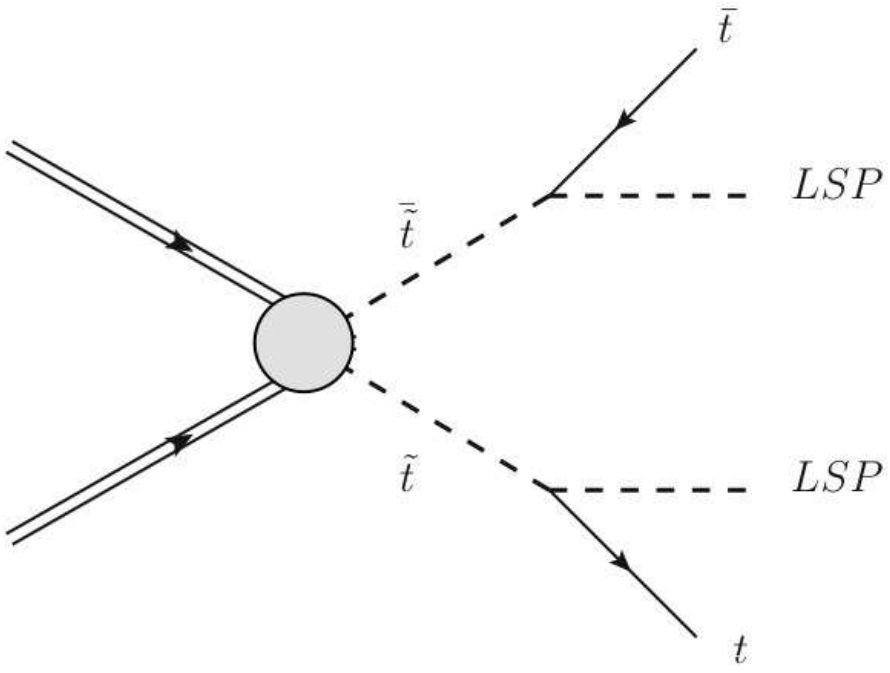
Analysis Strategy

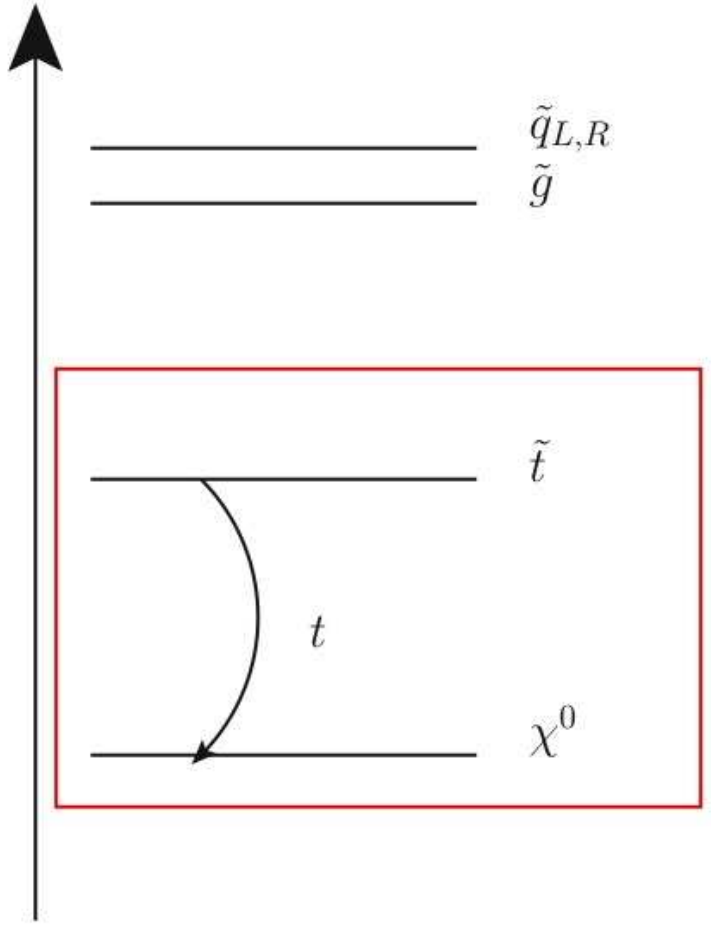
- ***Consider many decay channels and final states***
- ***"Cut & Count" methodology***
  - some analyses fit distributions
- ***Main background: $t\bar{t}$***
  - reject backgrounds using kinematics, event shapes, and *b*-tagging
- ***Define Signal & Control regions***
  - control regions normalize SM backgrounds to data
- ***Dominant uncertainties:***
  - jet energy scale & resolution
  - *b*-tagging
  - theory and simulation
- ***Interpret results***
  - typically assume 100% BR Simplified Models
  - publish values for external use (HEPData)





- **Consider $m_{\tilde{t}_1} > m_t + m_{\tilde{\chi}_1^0}$ so that $\tilde{t}_1 \to t + \tilde{\chi}_1^0$ is an available decay channel**
  - assume other squarks and gluino are much heavier
  - stop is essentially decoupled from the rest of SUSY





0-lepton $t\bar{t}$ Final State

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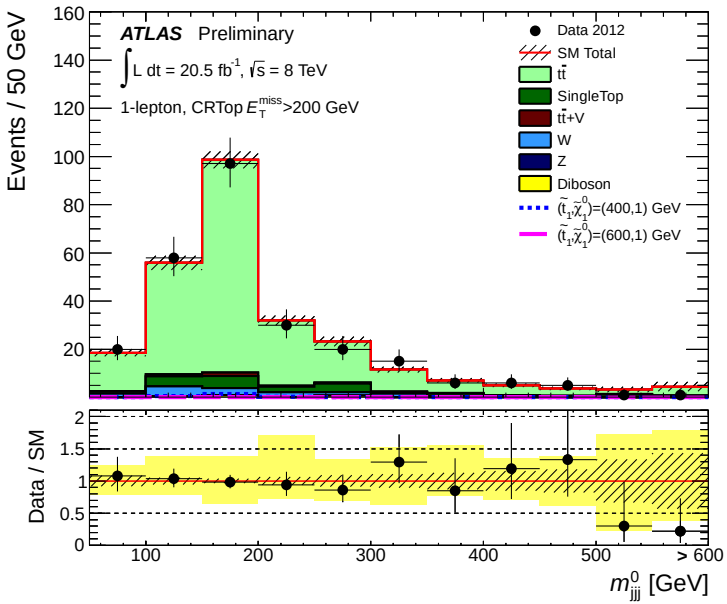
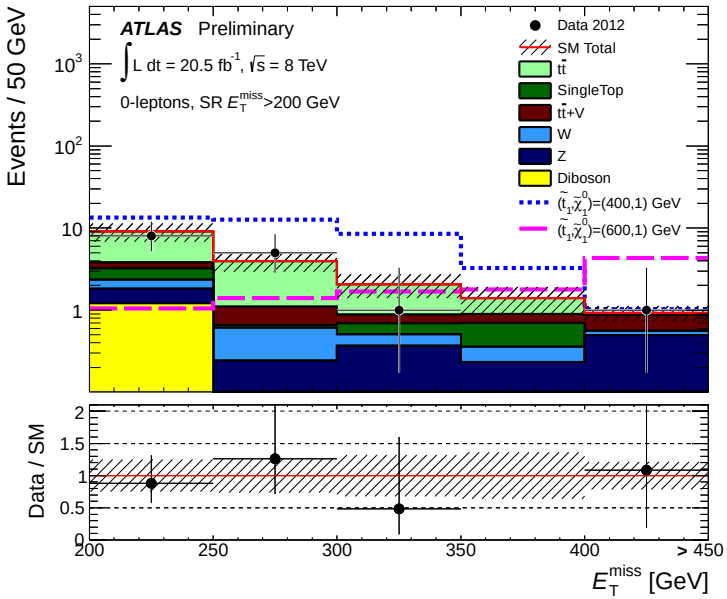
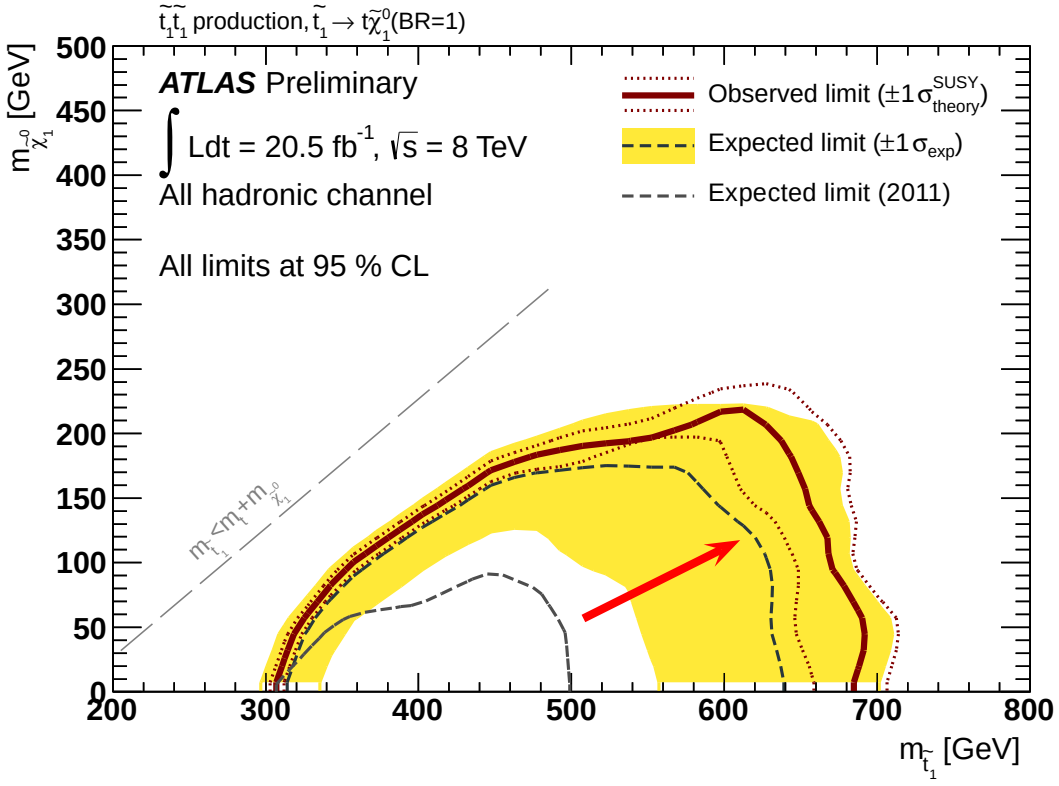


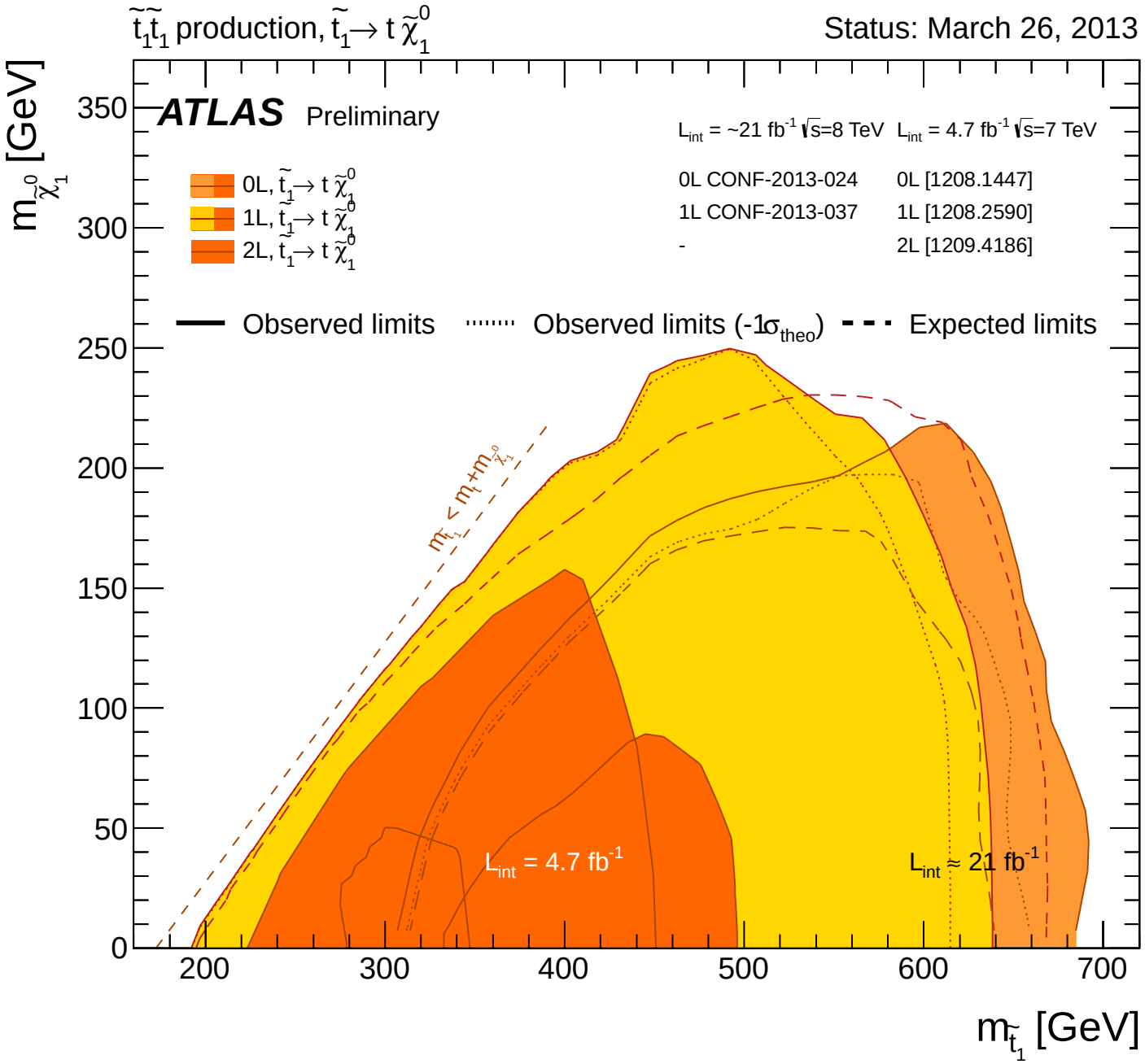




Number of events	SR1	SR2	SR3
Observed	15	2	1
Expected background	17.5 ± 3.2	4.7 ± 1.5	2.7 ± 1.2
Expected $t\bar{t}$	9.8 ± 2.6	1.9 ± 1.3	0.9 ± 0.7
Expected $t\bar{t} + W/Z$	1.7 ± 1.0	0.7 ± 0.4	0.51 ± 0.30
Expected Z+jets	2.1 ± 1.0	1.2 ± 0.5	0.8 ± 0.4
Expected W+jets	1.2 ± 0.8	0.32 ± 0.29	$0.19^{+0.23}_{-0.19}$
Expected single-top	1.5 ± 0.9	0.5 ± 0.4	$0.3^{+0.5}_{-0.3}$
Expected multijet	0.12 ± 0.12	0.01 ± 0.01	< 0.01
Expected diboson	1.2 ± 1.2	< 0.22	< 0.22

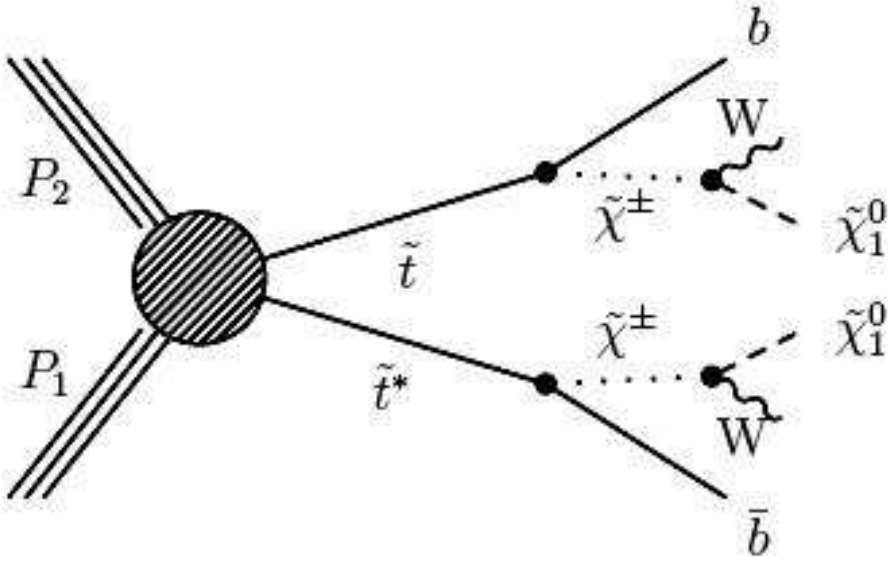
ATLAS-CONF-2013-024

$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ Summary



$\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$

- **Consider $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to W^{(\star)}\tilde{\chi}_1^0$**
  - mass of chargino is an additional degree of freedom



- ***Interpreted in terms of benchmark MSSM scenarios:***
  - gaugino universality: $m_{\tilde{\chi}_1^{\pm}} \sim 2 \times m_{\tilde{\chi}_1^0}$
  - stop–chargino mass degeneracy: $m_{\tilde{\chi}_1^{\pm}} \sim m_{\tilde{t}_1} - 10$ GeV
  - neutralino–chargino mass degeneracy: $m_{\tilde{\chi}_1^{\pm}} \sim m_{\tilde{\chi}_1^0}$
  - $m_{\tilde{\chi}_1^{\pm}} = 150$ GeV

1-lepton ≥ 1 b-jet Final State

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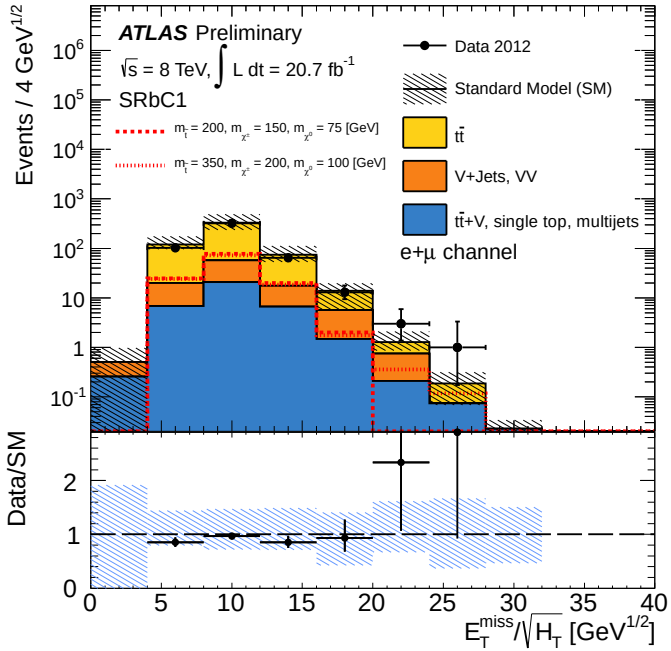
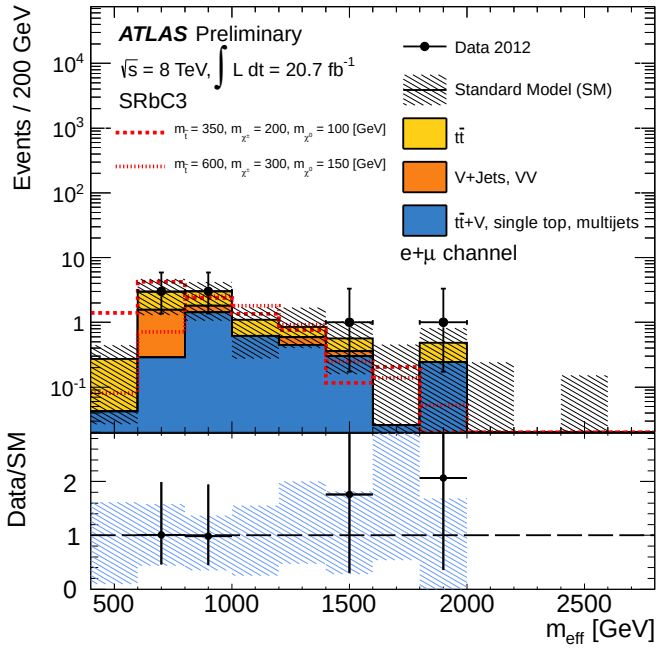
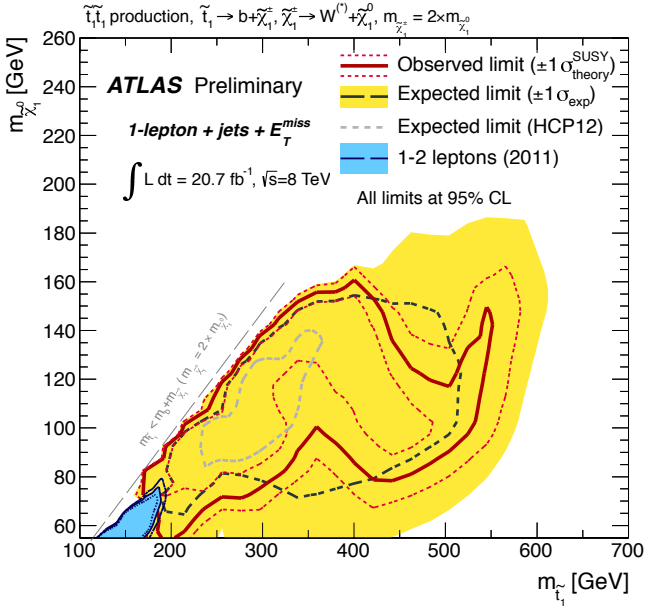
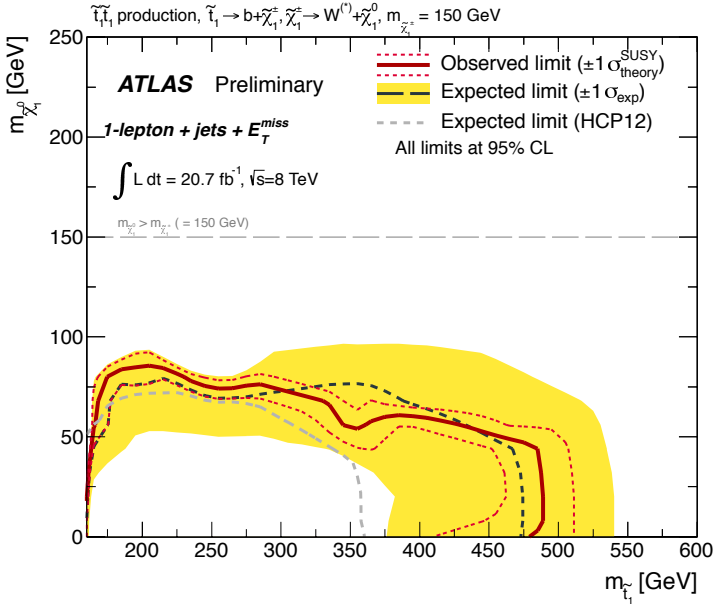




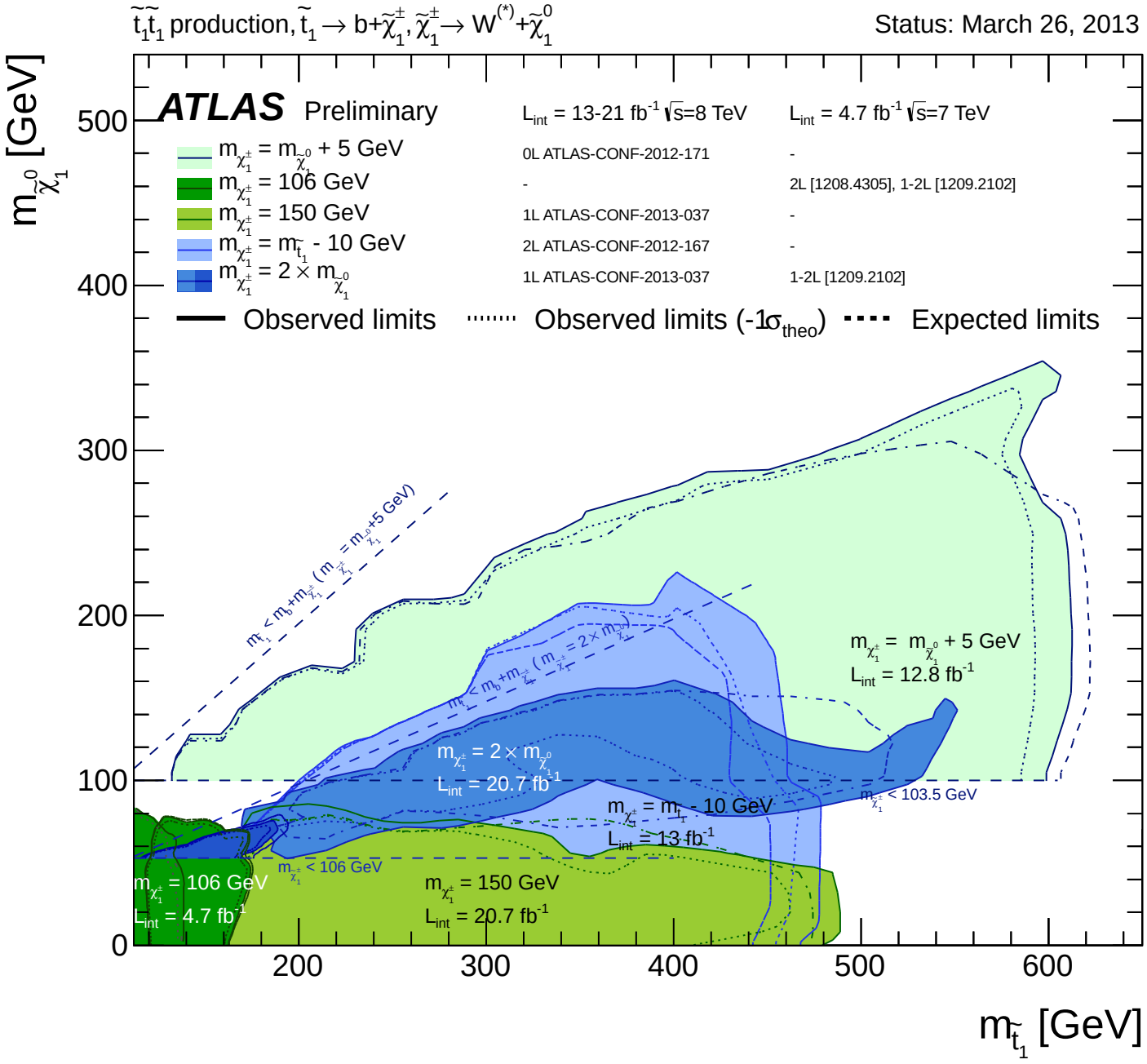




Requirement	SRtN1_shape	SRtN2	SRtN3	SRbC1	SRbC2	SRbC3
$\Delta\varphi(\text{jet}_1, \vec{p}_T^{\text{miss}}) >$	0.8	-	0.8	0.8	0.8	0.8
$\Delta\varphi(\text{jet}_2, \vec{p}_T^{\text{miss}}) >$	0.8	0.8	0.8	0.8	0.8	0.8
E_T^{miss} [GeV] >	$100^{(\star)}$	200	275	150	160	160
$E_T^{\text{miss}} / \sqrt{H_T}$ [GeV$^{1/2}$] >	5	13	11	7	8	8
m_T [GeV] >	$60^{(\star)}$	140	200	120	120	120
m_{eff} [GeV] >	-	-	-	-	550	700
am_{T2} [GeV] >	-	170	175	-	175	200
m_{T2}^{τ} [GeV] >	-	-	80	-	-	-
m_{jjj}	Yes	Yes	Yes	-	-	-
$N^{\text{iso-trk}} = 0$	-	-	-	Yes	Yes	Yes
Number of b-jets ≥	1	1	1	1	2	2
p_T (leading b-jet) [GeV] >	25	25	25	25	100	120
p_T (second b-jet) [GeV] >	-	-	-	-	50	90

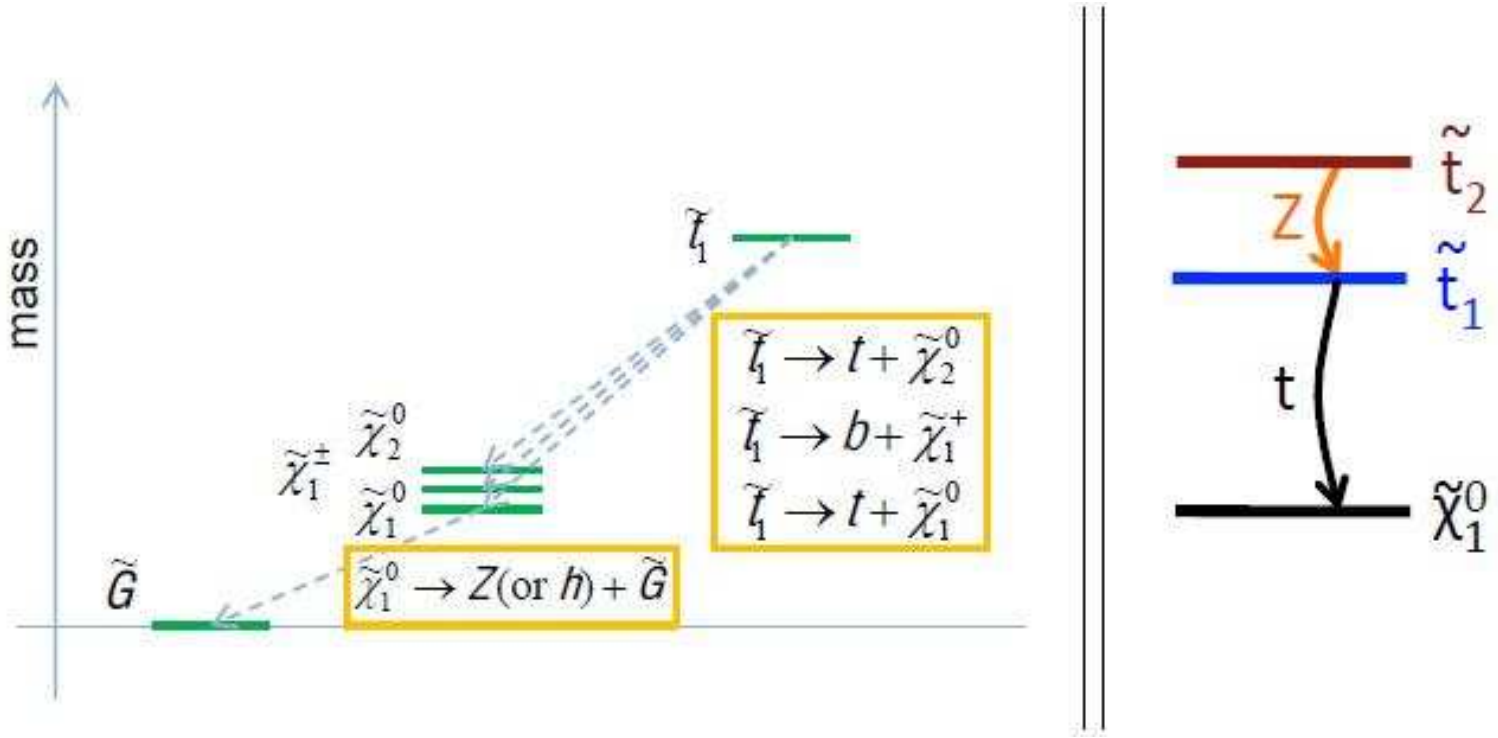
ATLAS-CONF-2013-037

$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$ Summary



$\tilde{t}_2 \to Z\tilde{t}_1 \to t\chi_1^0$

- ***Stop sector can also be explored in longer decay chains with $\tilde{t}_1$, $\tilde{t}_2$, and Z bosons***
  - explore alternative scenarios
    - natural gauge-mediated symmetry breaking (GMSB)
    - direct $\tilde{t}_2\tilde{t}_2^\star$ production
  - sensitivity in unexplored regions of parameter space such as $m_{\tilde{t}_1} \approx m_t + m_{\tilde{\chi}_1^0}$



≥ 2-leptons ≥ *1 b*-jet (Z+b)

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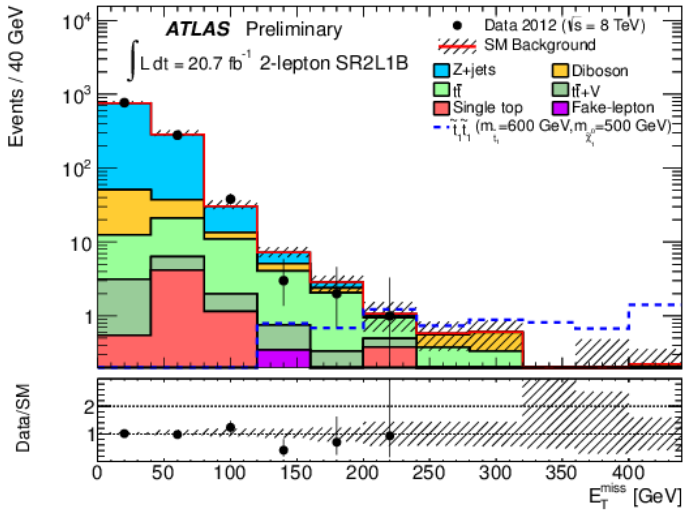

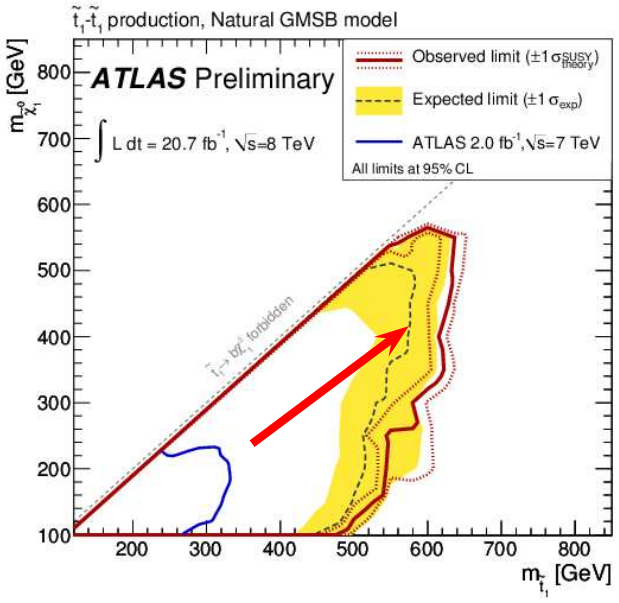

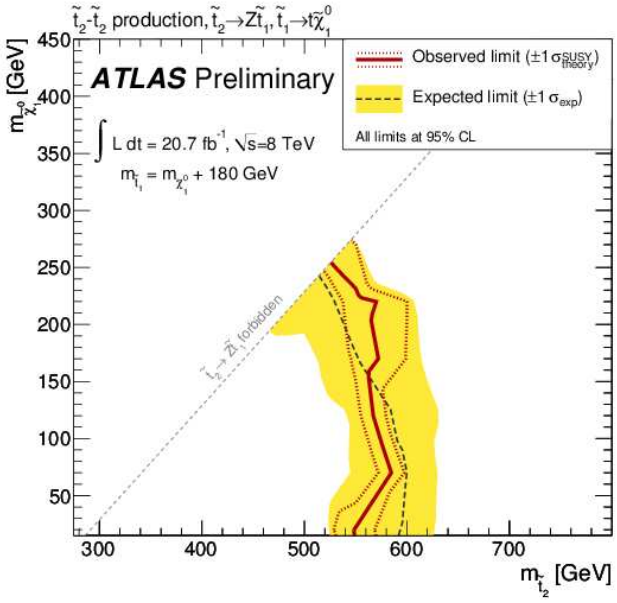

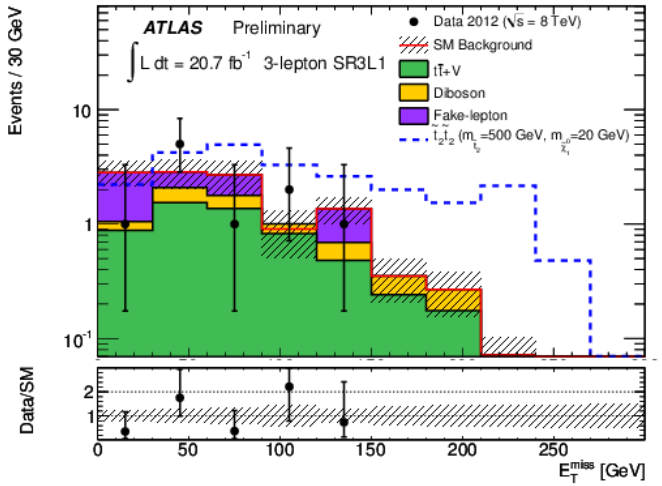

	SR2L1A	SR2L1B	SR2L2	SR3L1	SR3L2
N^{lepton}	2			≥ 3	
$\lvert m_{\ell\ell} - m_Z \rvert$	< 5 GeV	< 10 GeV	< 5 GeV	< 10 GeV	
$N^{b\text{-jets}}$	≥ 1			≥ 1	
N^{jets}	3, 4		≥ 5	≥ 5	
$p_{\text{T}}(\text{jet}_1)$	> 30 GeV			> 50 GeV	> 40 GeV
$p_{\text{T}}(\text{jet}_N)$	> 30 GeV			> 30 GeV	> 40 GeV
$E_{\text{T}}^{\text{miss}}$	> 160 GeV	> 200 GeV	> 160 GeV	> 60 GeV	
$p_{\text{T}}(\ell\ell)$	> 80 GeV	> 160 GeV	> 80 GeV	-	> 75 GeV
$\Delta\phi^{\ell\ell}$	< 1.5 rad			-	
$p_{\text{T}}(\ell_1)$	> 25 GeV			> 40 GeV	> 60 GeV

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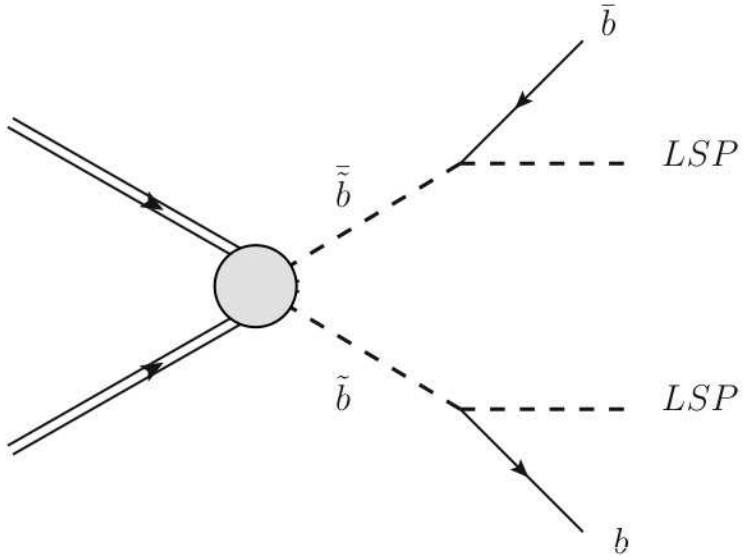
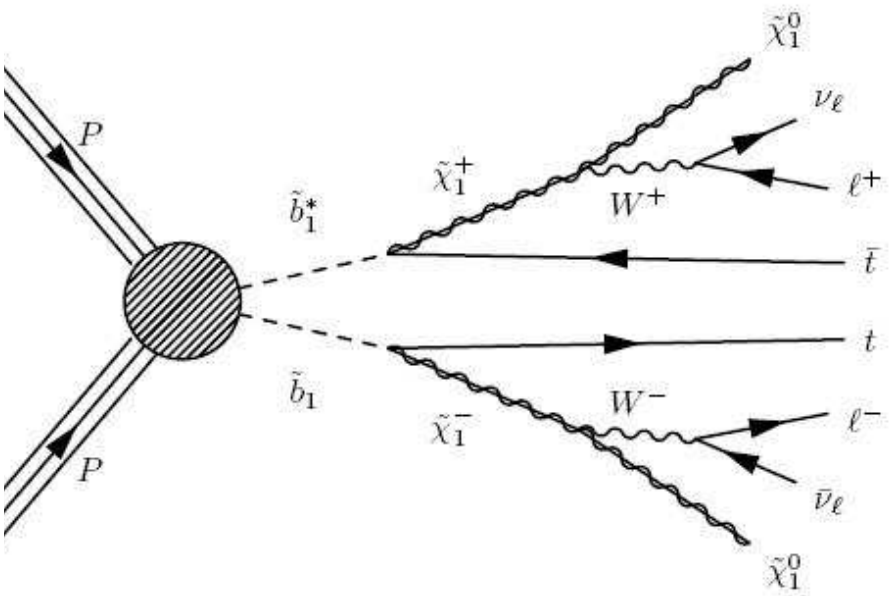
Sbottom Pair Production

- ***Sbottom might be lightest squark or only somewhat heavier than stop***
  - $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
  - $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm}$
- ***Final states rich in b quarks***
  - large $\Delta m(\tilde{b}, \tilde{\chi}_1^0)$: 2 b-jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
  - small $\Delta m(\tilde{b}, \tilde{\chi}_1^0)$: focus on events with hard ISR jet





0-lepton ≥ 2 b-jet Final State

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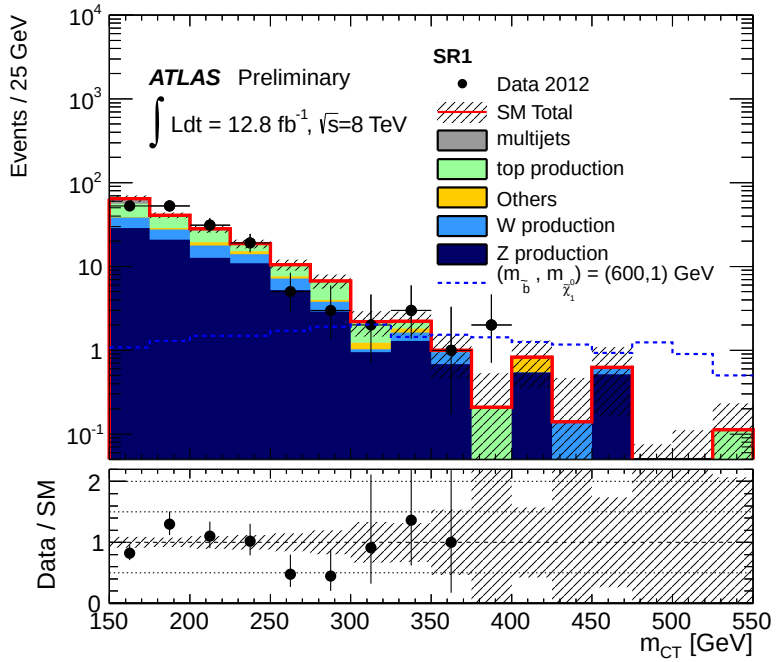

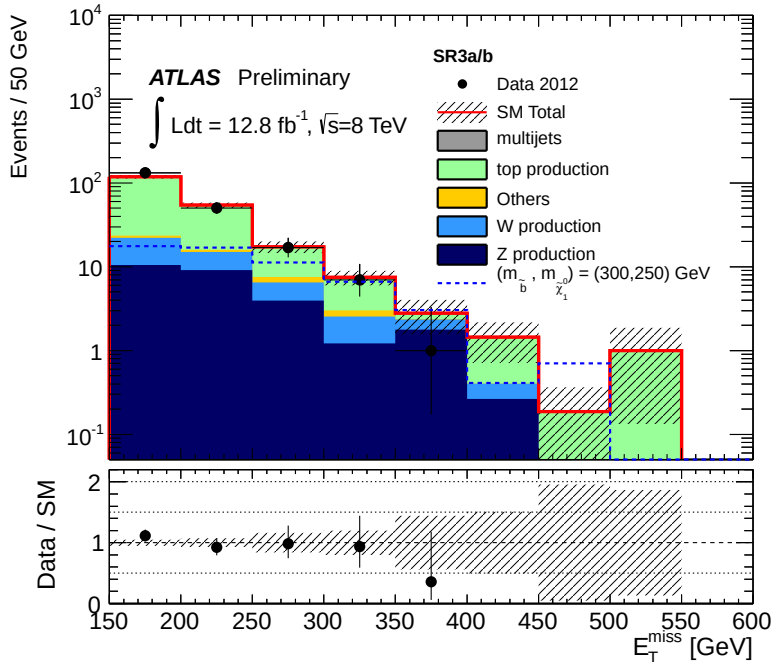

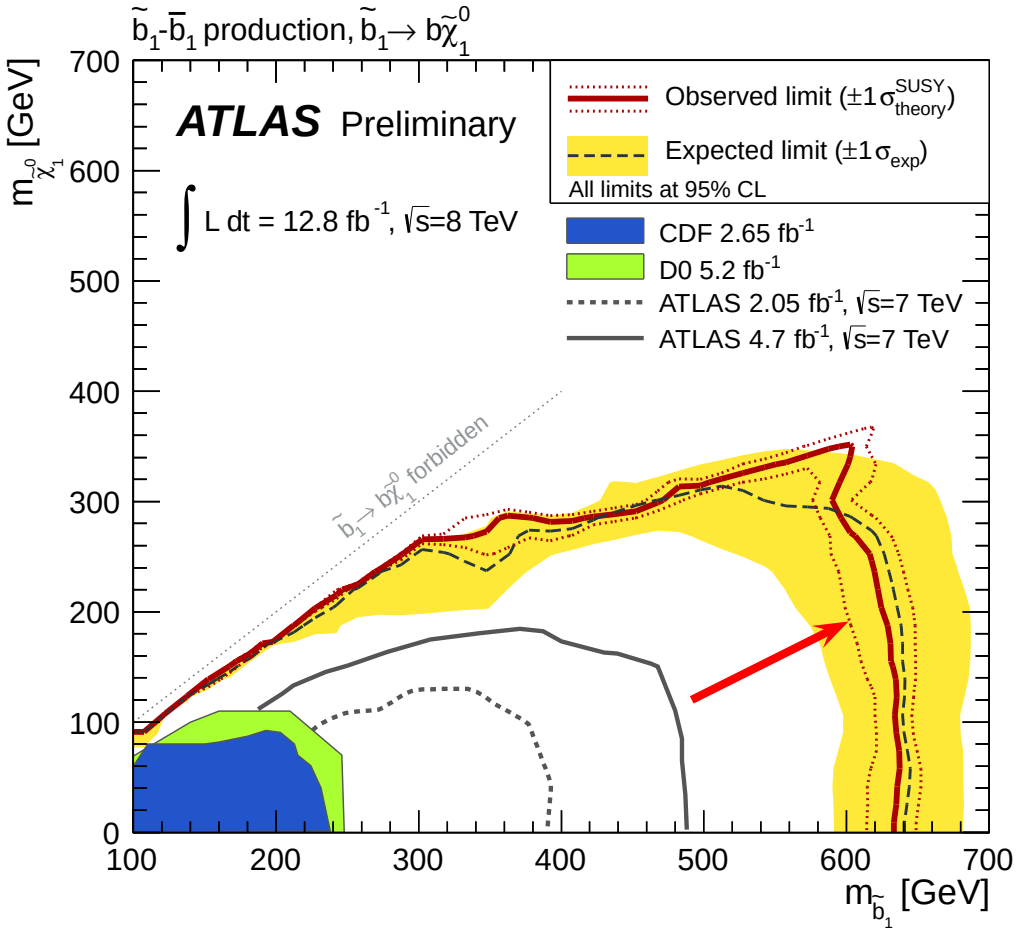

Channel	SR1, m_{CT} selection				SR2	SR3	
	150 GeV	200 GeV	250 GeV	300 GeV		SR3a	SR3b
Observed	172	66	16	8	104	207	21
SM Total	176 ± 25	71 ± 11	25 ± 4	7.4 ± 1.7	95 ± 11	203 ± 35	27 ± 5
Top production	45 ± 13	17 ± 6	7 ± 3	1.6 ± 0.6	15 ± 4	146 ± 40	15 ± 5
Z production	85 ± 15	36 ± 6	12 ± 2	4.0 ± 0.9	60 ± 9	27 ± 9	7 ± 2
W production	28 ± 23	12 ± 10	4 ± 3	1 ± 1	15 ± 5	22 ± 7	4 ± 1
Others	6 ± 3	4 ± 2	1.4 ± 0.8	0.7 ± 0.4	4 ± 2	4 ± 2	1.5 ± 0.9
Multijet production	12 ± 12	2 ± 2	0.2 ± 0.2	0.01 ± 0.01	0.6 ± 0.6	4 ± 4	—

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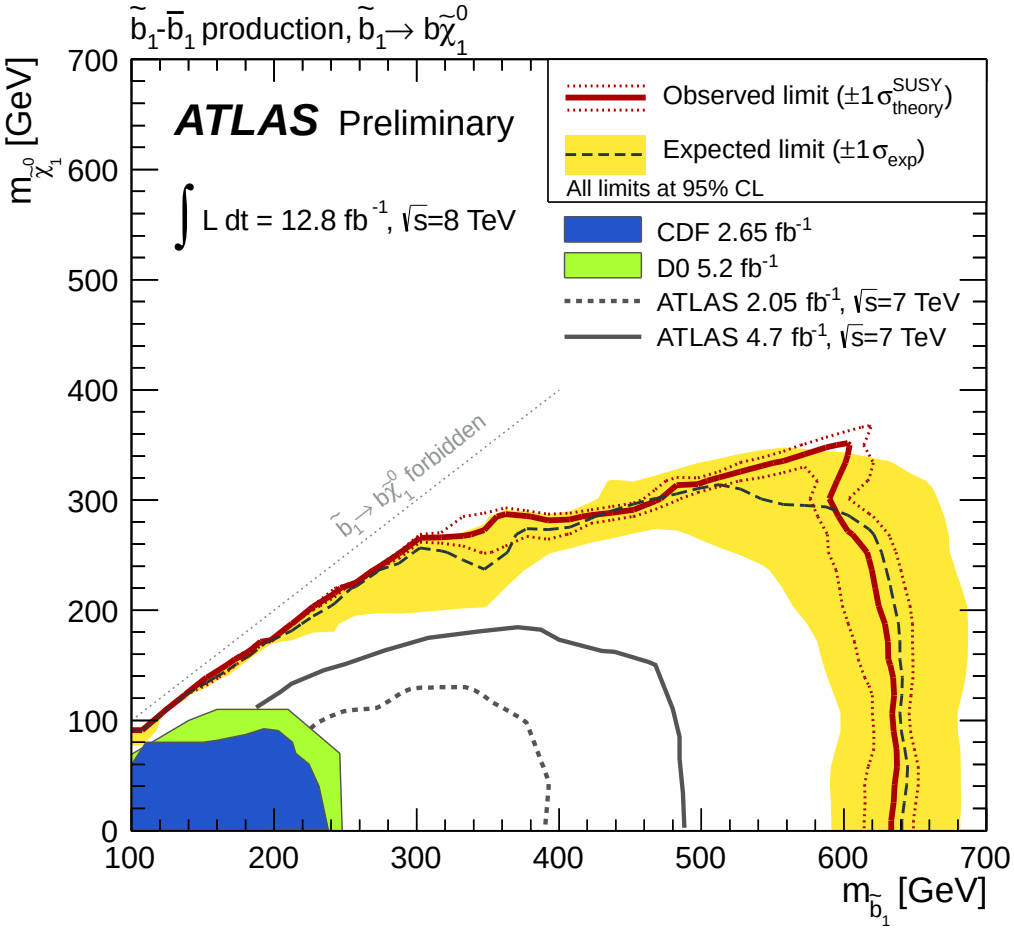
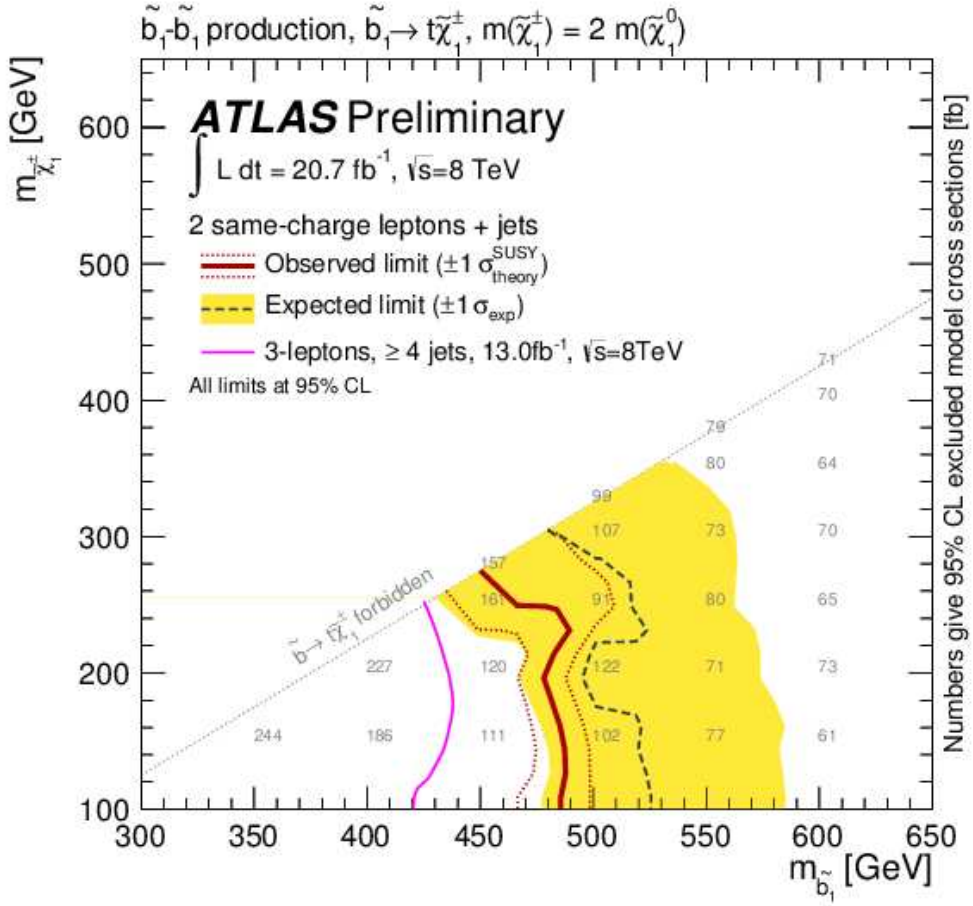
Sbottom Limits





Gluino-Mediated Production

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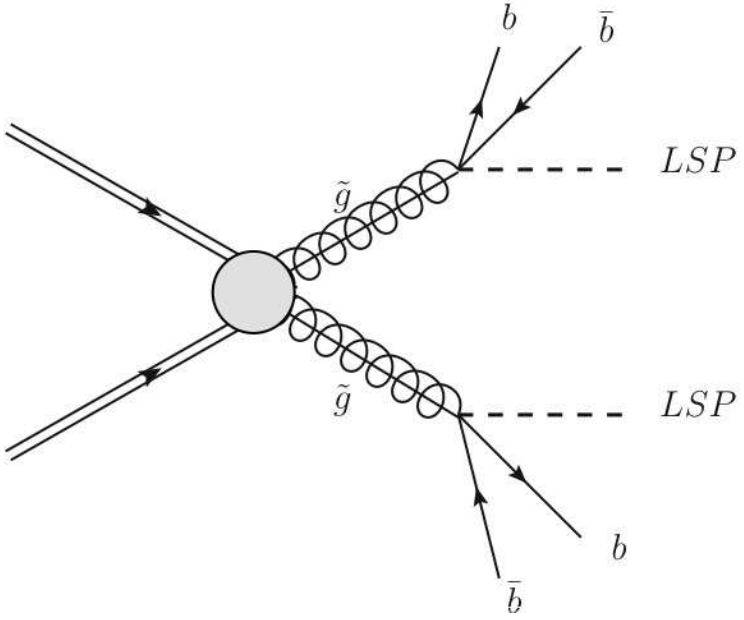
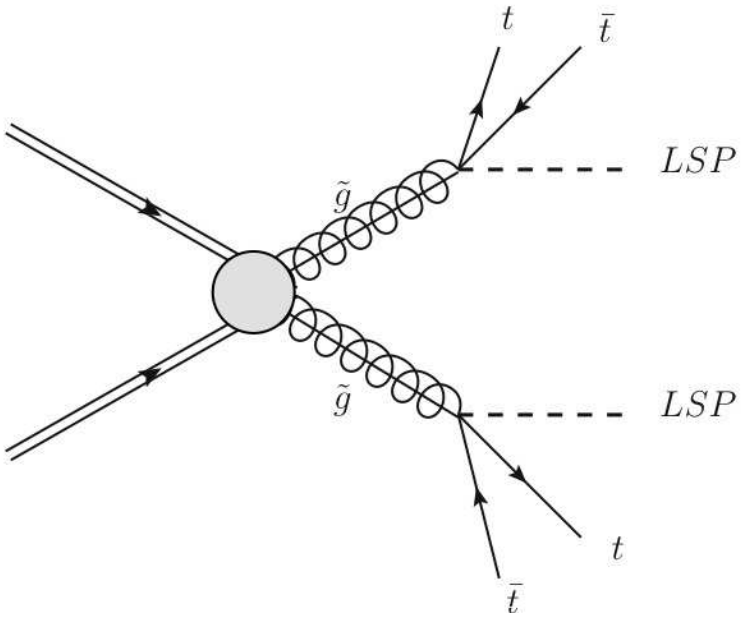
- ***If gluinos are light, they can be produced in pairs and decay to on- or off-shell sbottoms and stops***





- ***Final state contains up to 4 b-jets, up to 12 jets, and up to 4 leptons (possibly same sign)***

0-lepton ≥ 3 b-jet Final State

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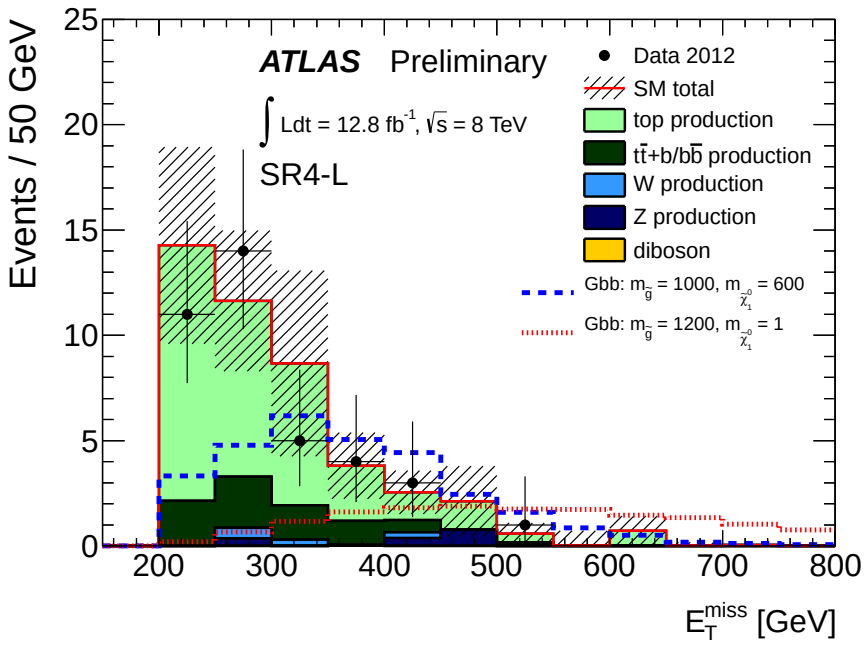

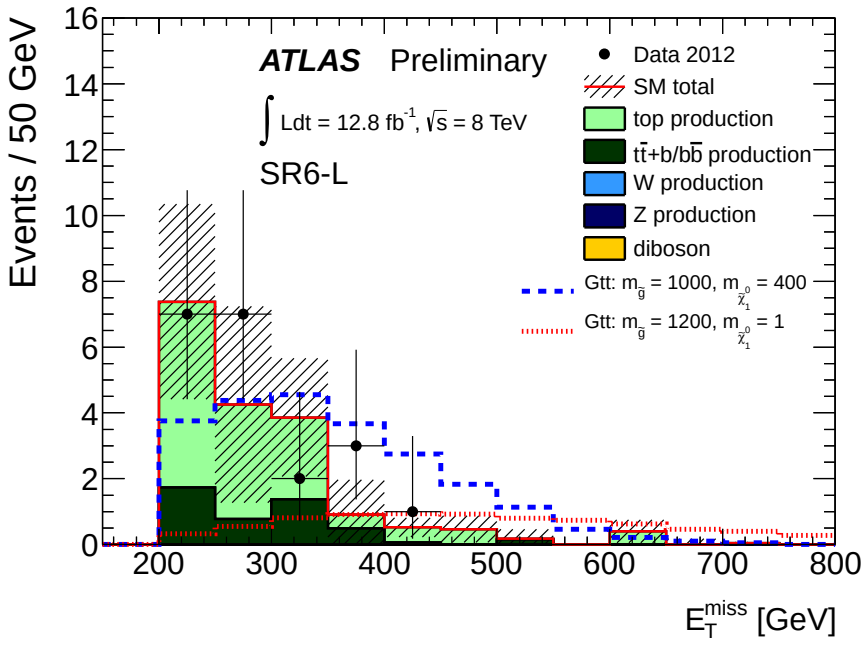

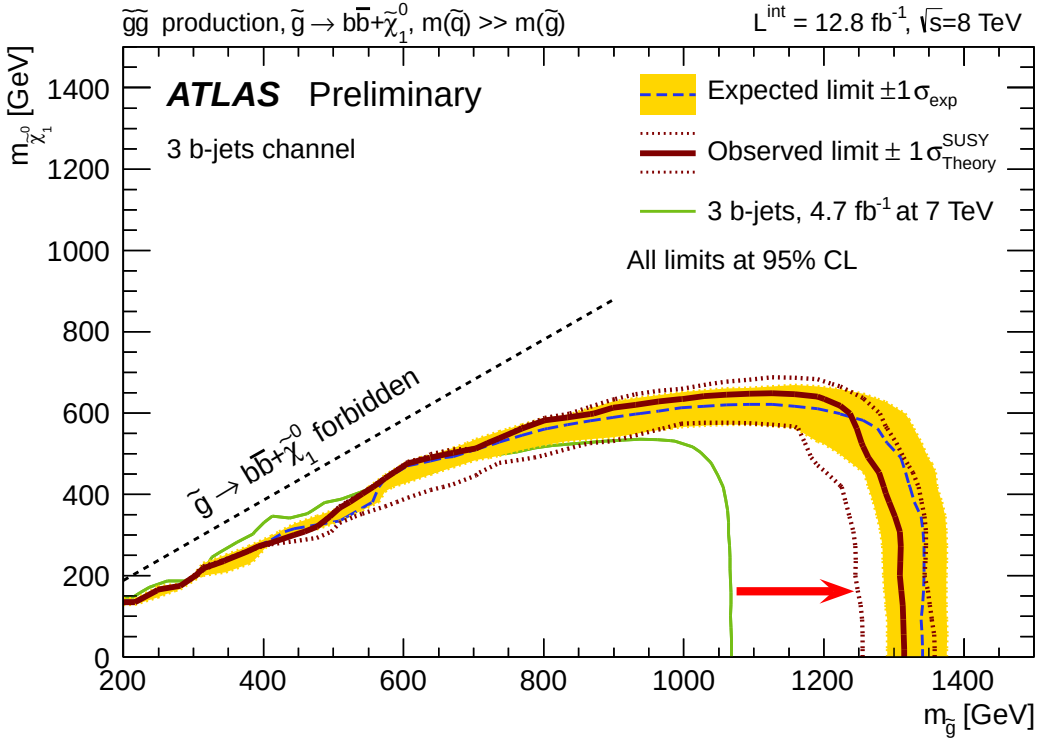

Common criteria: lepton veto, $p_T^{j1} > 90$ GeV, $E_T^{miss} > 200$ GeV, ≥ 3 b-jets, $E_T^{miss}/m_{eff}^{4j} > 0.2$, $\Delta\phi_{min}^{4j} > 0.4$

SR	N_j ($p_T > 50$ GeV)	p_T b-jets	m_{eff}
SR4-L/M/T	≥ 4 jets	> 50 GeV	$m_{eff}^{4j} > 900/1100/1300$ GeV
SR6-L/M/T	≥ 6 jets	> 30 GeV	$m_{eff}^{incl} > 1100/1300/1500$ GeV

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0-lepton ≥ 3 b-jet Final State

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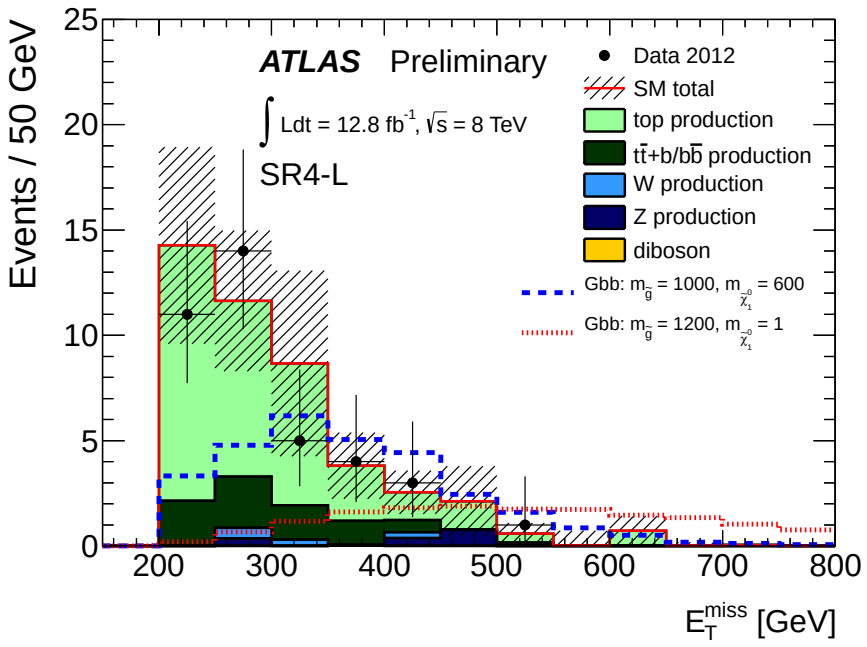

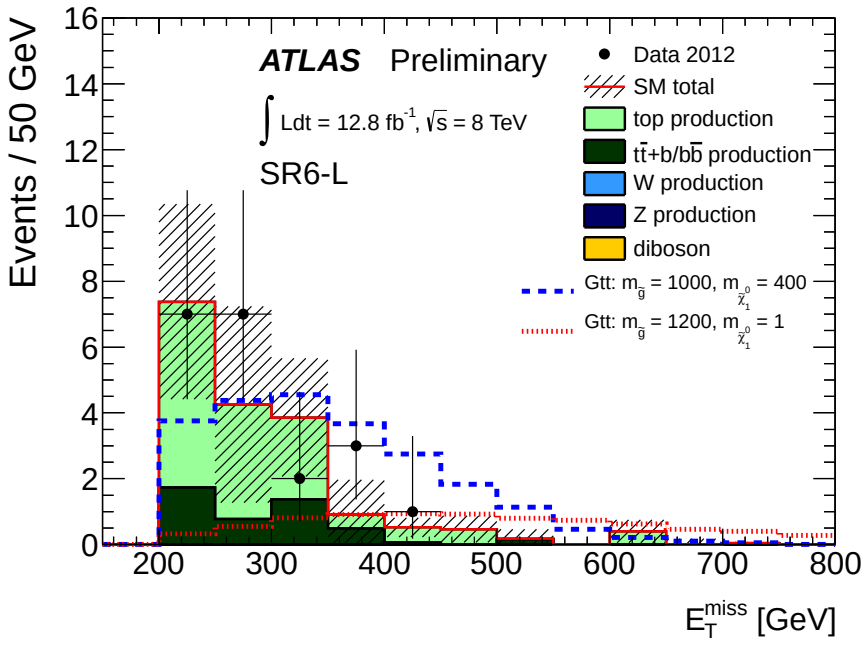

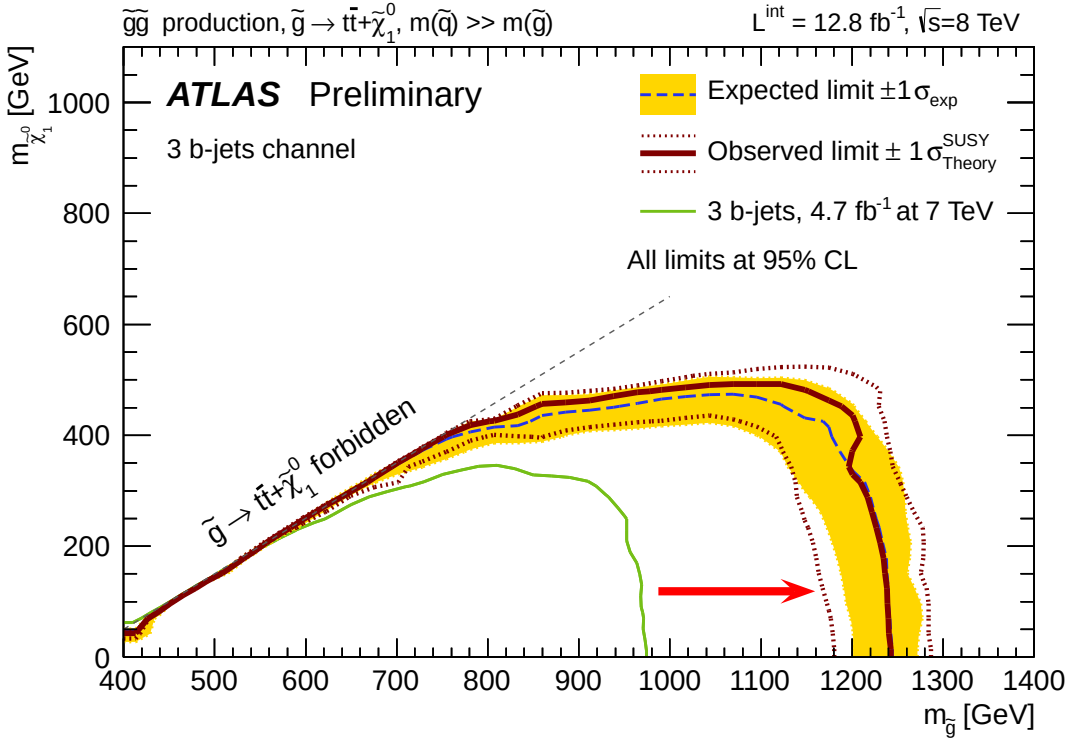

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SR	N_j ($p_T > 50$ GeV)	p_T b-jets	m_{eff}
SR4-L/M/T	≥ 4 jets	> 50 GeV	$m_{eff}^{4j} > 900/1100/1300$ GeV
SR6-L/M/T	≥ 6 jets	> 30 GeV	$m_{eff}^{incl} > 1100/1300/1500$ GeV

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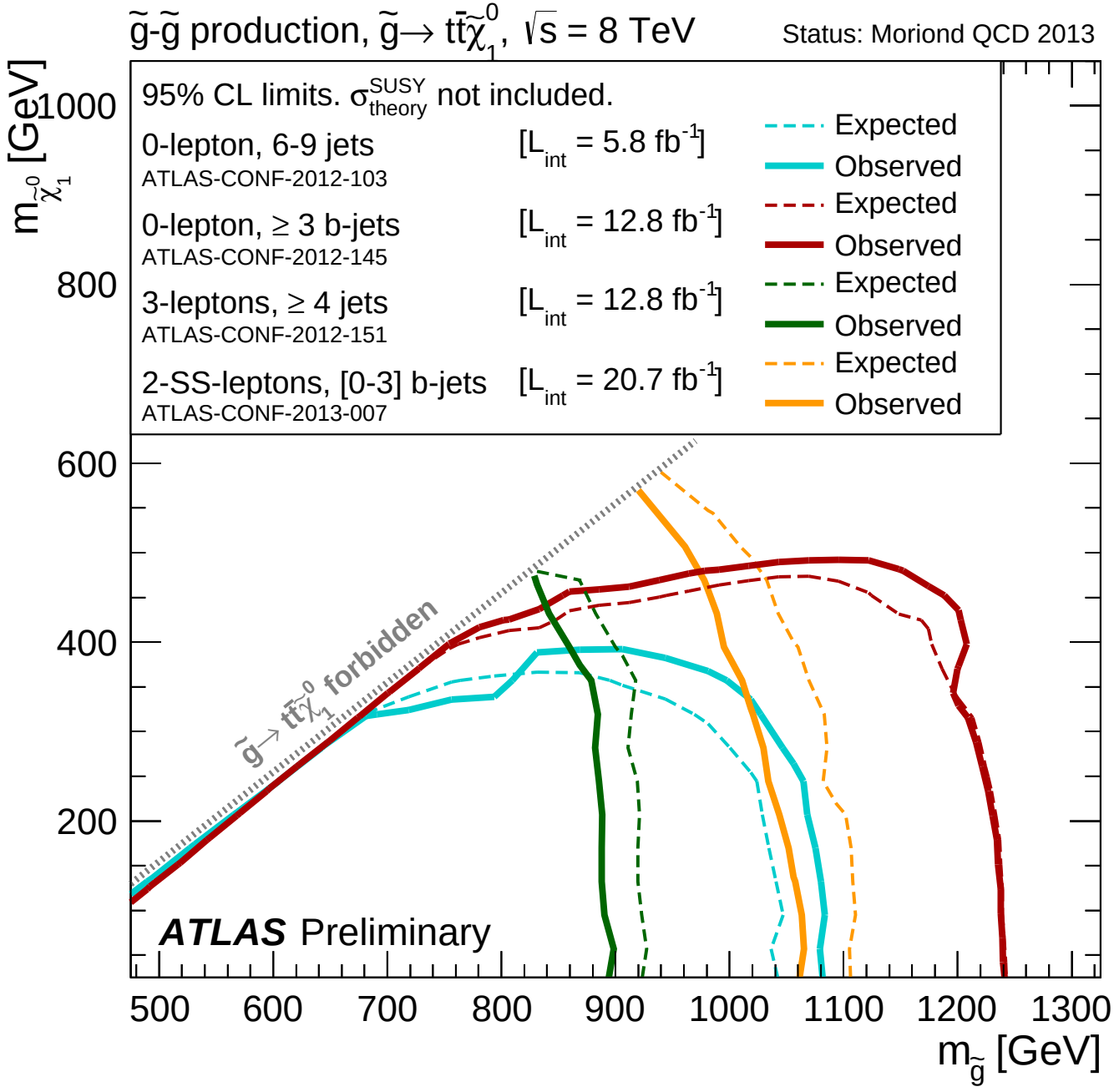
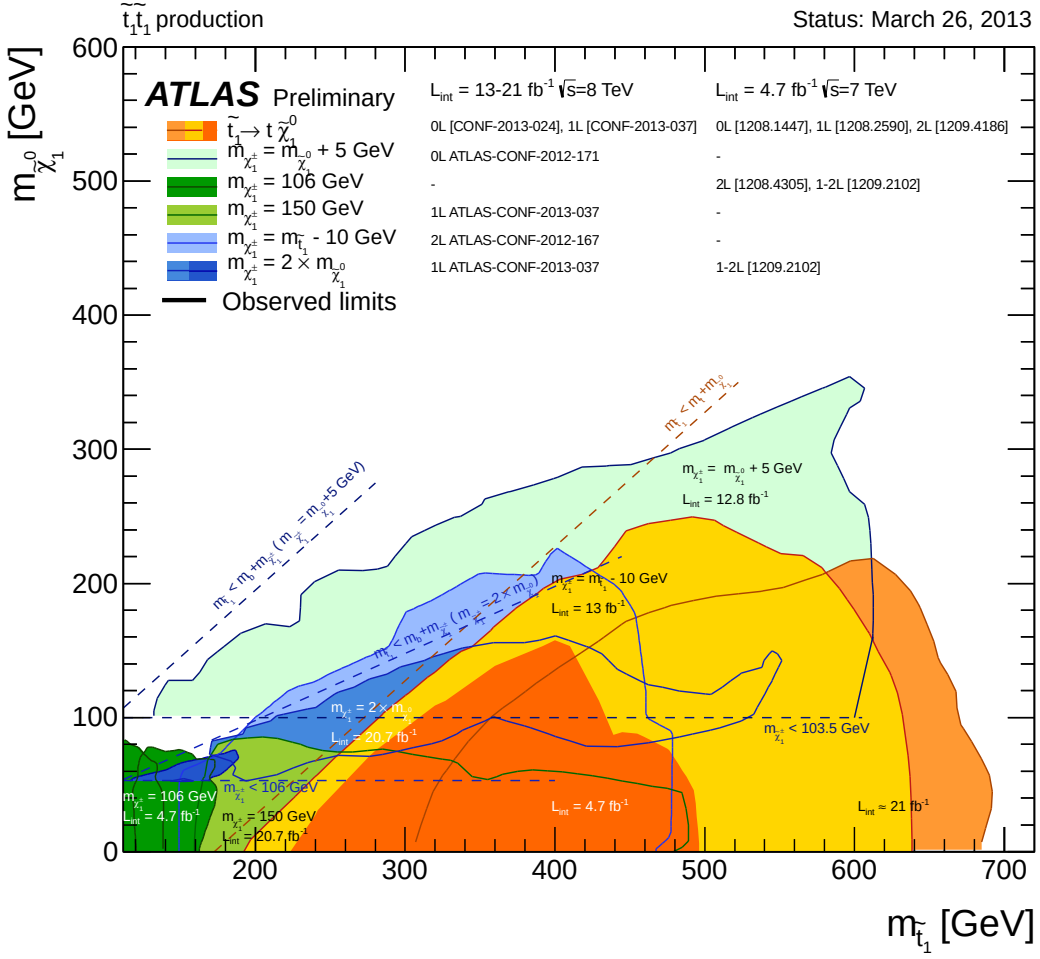
Gluino-Mediated Summary



Summary

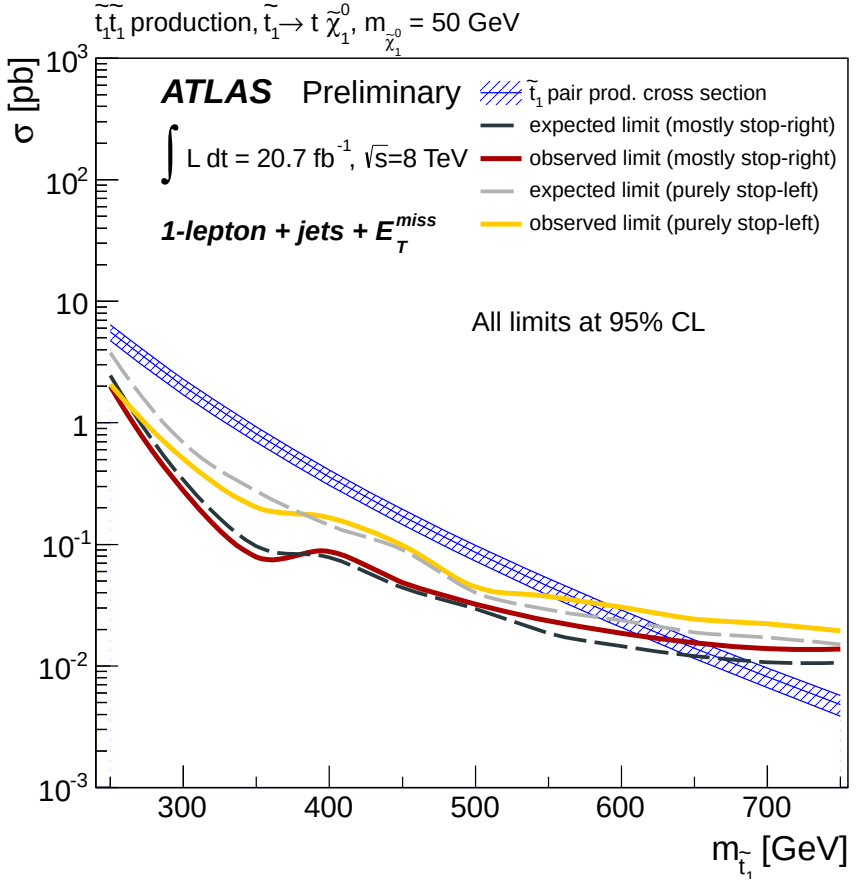
- ***LHC Run 1 has been an exciting period for third-generation SUSY searches***
- ***Unfortunately, we haven't discovered SUSY***
  - increases pressure on naturalness and fine tuning
- ***The search continues. . .***
  - still investigating additional decay channels
  - looking forward to higher $\sqrt{s}$ in 2015
- ***. . .stay tuned!***

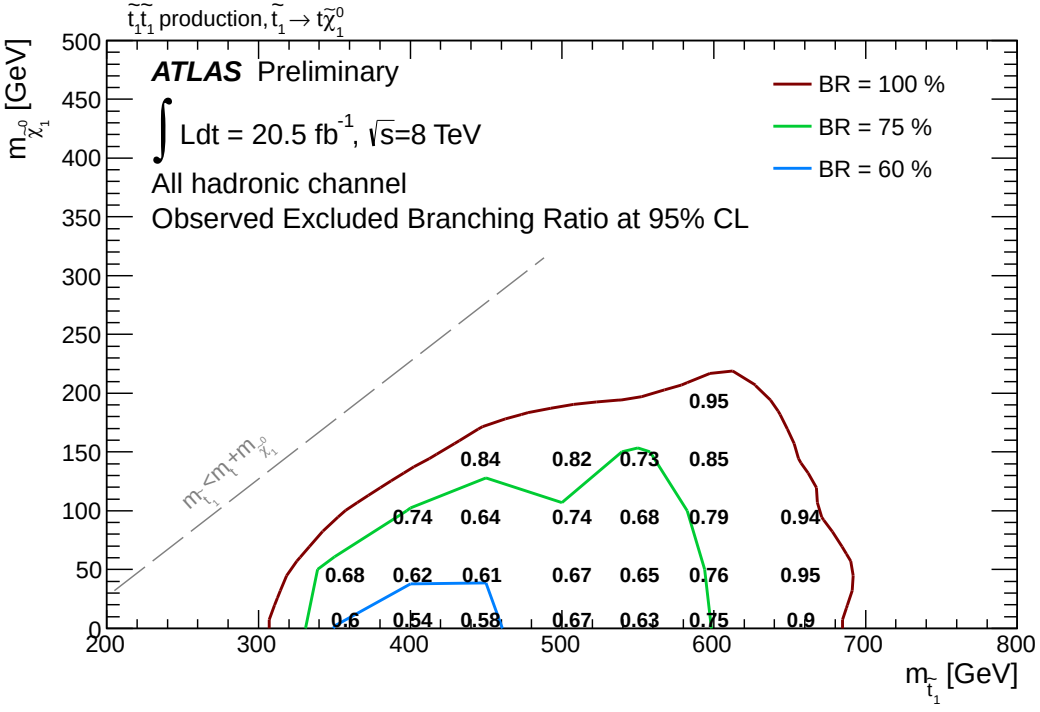


Backup

$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ Model Dependence

- ***Stop chirality: if the top quark is left handed***
  - 1-lepton slightly penalized by lepton ⇒ decreased acceptance
  - 0-lepton almost insensitive





- ***What if BR not 100%?***
  - assuming other decay mode invisible (good approximation for 0-lepton analysis)