Searches for gluino-mediated production of third generation squarks with the ATLAS detector

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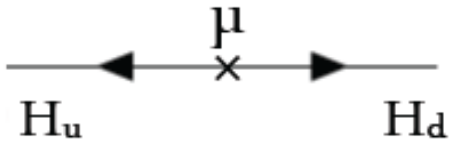
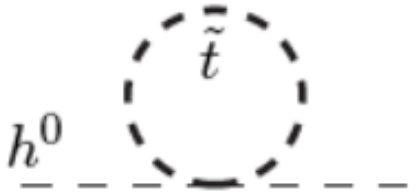
on behalf of the ATLAS Collaboration
EPS-HEP – July 2013

Natural SUSY (I)

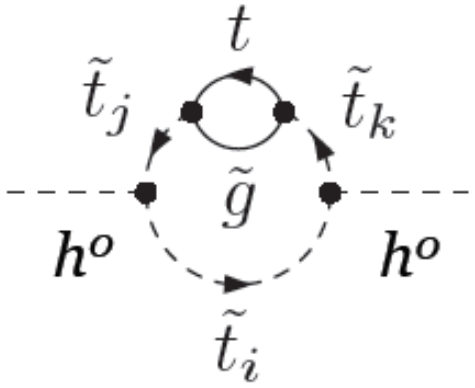
Tree-level: Higgsino < ~350 GeV



One loop: stop < ~1 TeV

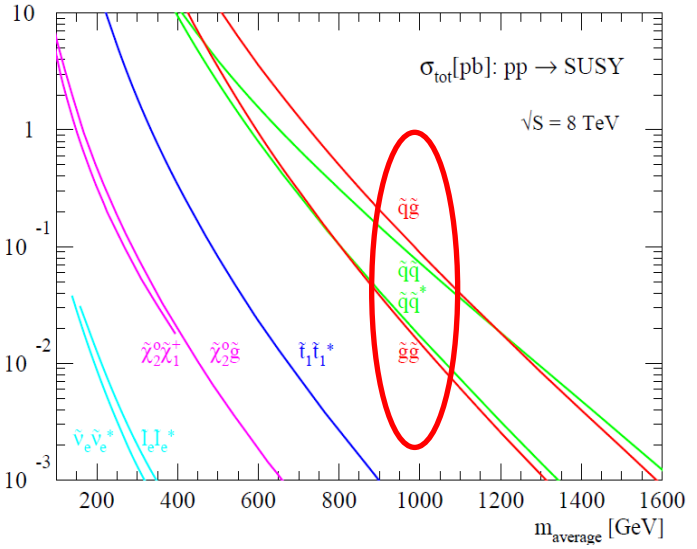


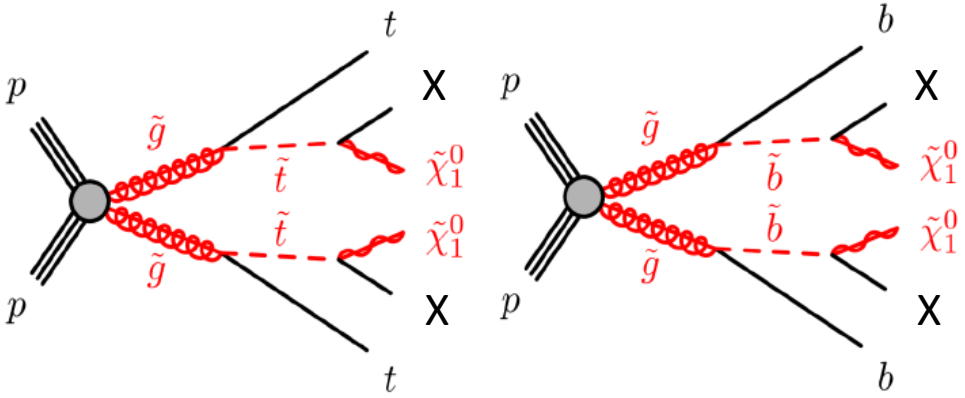
Two loops: gluino < ~2 TeV



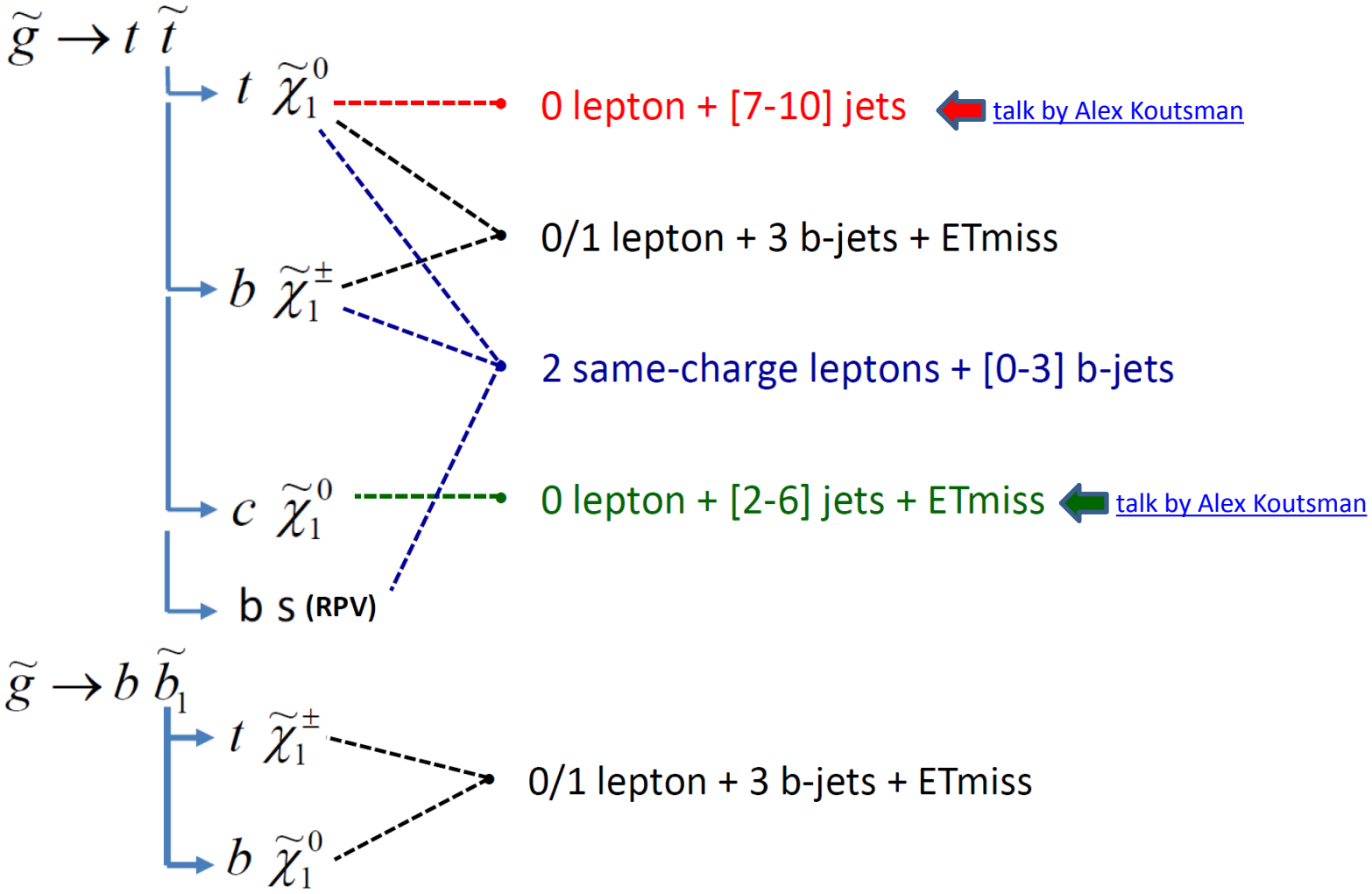
Natural SUSY (II)

- Light gluinos have a large cross section at the LHC
- BF(gluino→stop/sbottom)≈100% if 3rd generation squarks are lightest
- Looking for each possible stop/sbottom → X decay with several dedicated searches





ATLAS searches for gluino → stop/sbottom



Light sbottom$_L$ implied by light stop$_L$ from SU(2)$_L$ symmetry of the Standard Model.

ATLAS-CONF-2013-007

2 same-charge leptons + [0-3] b-jets

- Signal regions:

triggers: combination of MET or 1lepton or 2leptons.
lepton p_T > 20 GeV, jet p_T > 40 GeV, b-jet p_T > 20 GeV.

Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV,
		m_T> 100 GeV, m_{eff}>400 GeV	binned shape fit in m_{eff} for m_{eff} >300 GeV
SR1b	≥1	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV,
		m_T>100 GeV, m_{eff}>700 GeV	binned shape fit in m_{eff} for m_{eff}>300 GeV
SR3b	≥3	$N_{jets} \geq 4$	$N_{jets} \geq 5$,
		-	E_T^{miss}< 150 GeV or m_T< 100 GeV

SR1b and SR3b are important for gluino-mediated stop.
Note: SR3b has no cut on ETmiss.

$$m_{eff} = E_T^{miss} + \sum_{i=1,2} lep_i\, p_T + \sum_j jet_j\, p_T$$

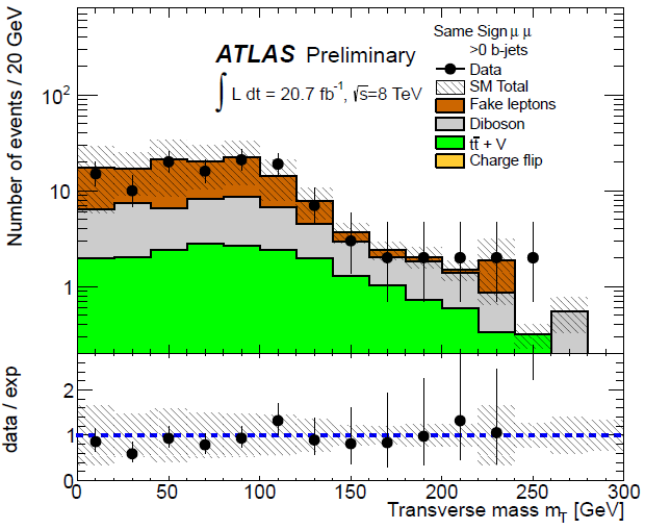
ATLAS-CONF-2013-007

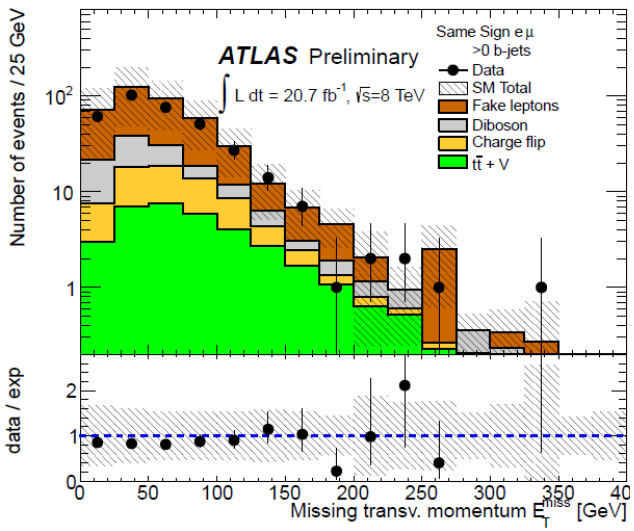
2 same-charge leptons + [0-3] b-jets

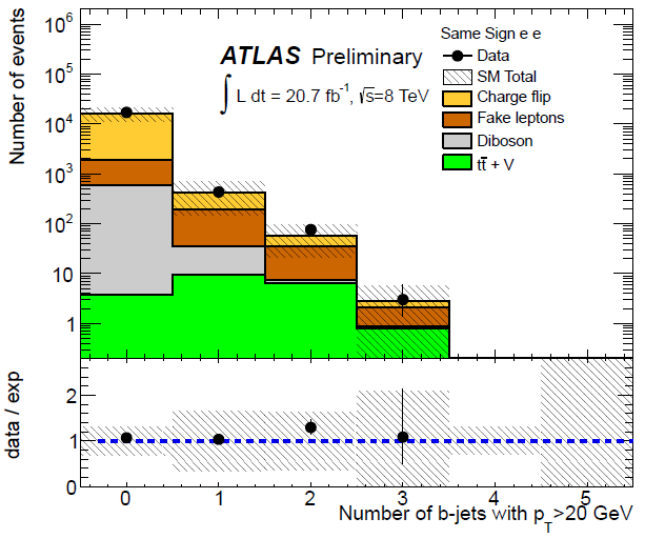
- Main backgrounds:
  - ttbar+W/Z and dibosons [MC]
  - misidentified lepton [data-driven]
    - loose-to-tight matrix method
      - define tight [nominal] and loose lepton identification criteria
      - measure loose-to-tight efficiency in data
      - count number of loose and tight leptons in each signal region
      - estimate misidentified lepton contribution with matrix formula
  - charge mis-measurement [data-driven]
    - measure ratio of SS/OS pairs with Z invariant mass

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} \varepsilon_1\varepsilon_2 & \varepsilon_1\zeta_2 & \zeta_1\varepsilon_2 & \zeta_1\zeta_2 \\ \varepsilon_1(1-\varepsilon_2) & \varepsilon_1(1-\zeta_2) & \zeta_1(1-\varepsilon_2) & \zeta_1(1-\zeta_2) \\ (1-\varepsilon_1)\varepsilon_2 & (1-\varepsilon_1)\zeta_2 & (1-\zeta_1)\varepsilon_2 & (1-\zeta_1)\zeta_2 \\ (1-\varepsilon_1)(1-\varepsilon_2) & (1-\varepsilon_1)(1-\zeta_2) & (1-\zeta_1)(1-\varepsilon_2) & (1-\zeta_1)(1-\zeta_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

ε_i: misidenfication rate, ζ_i: real lepton efficiency





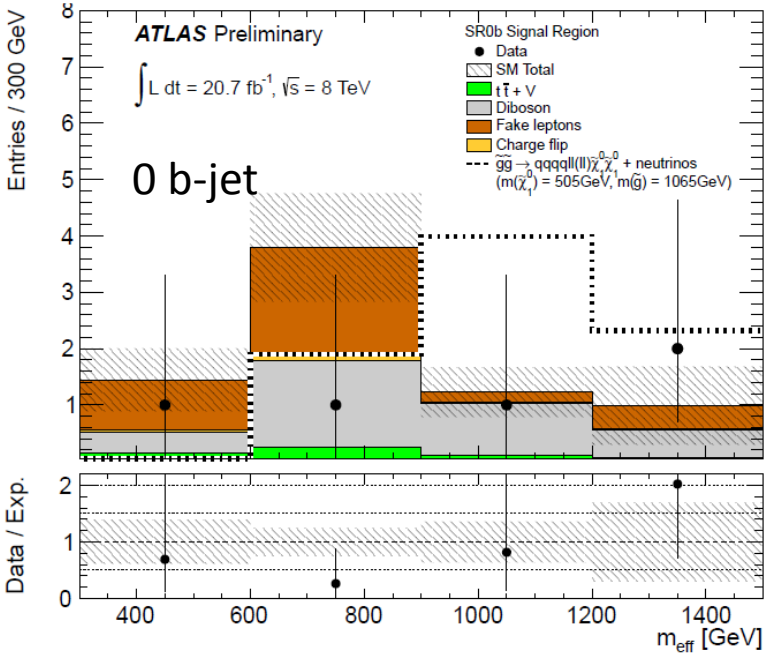


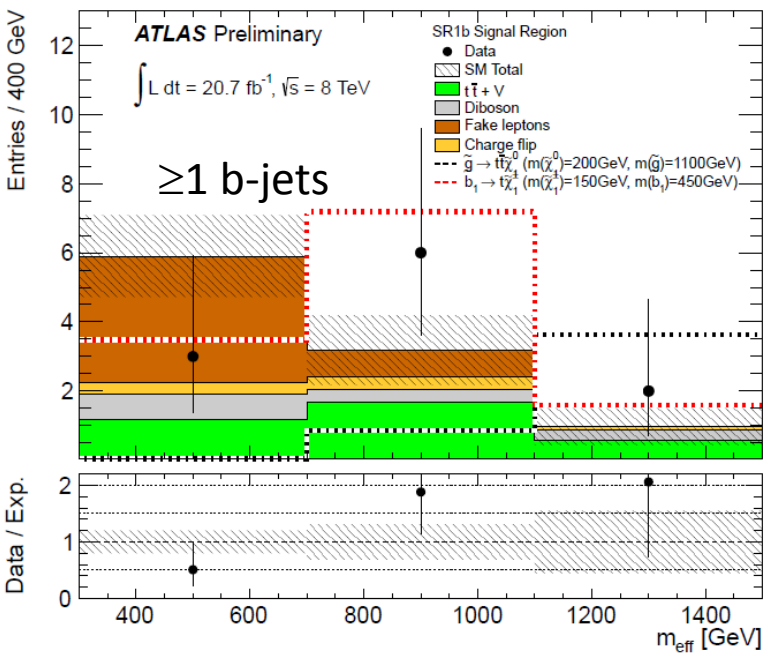
2 same-charge leptons + [0-3] b-jets

- Results:

Simultaneous fit to SR0b, SR1b and SR3b, binned in m_{eff}, for model-dependent exclusion tests.

B) Exclusion case	SR0b	SR1b	SR3b
Observed events	5	11	1
Expected background events	7.5 ± 3.2	10.1 ± 3.9	1.8 ± 1.3
Expected $t\bar{t}$ + V events	0.5 ± 0.4	3.4 ± 1.5	0.6 ± 0.4
Expected diboson events	3.4 ± 1.1	1.4 ± 0.7	< 0.1
Expected fake lepton events	3.4 ± 2.9	4.4 ± 3.1	1.0 ± 1.1
Expected charge mis-measurement events	0.2 ± 0.1	0.8 ± 0.3	0.1 ± 0.1

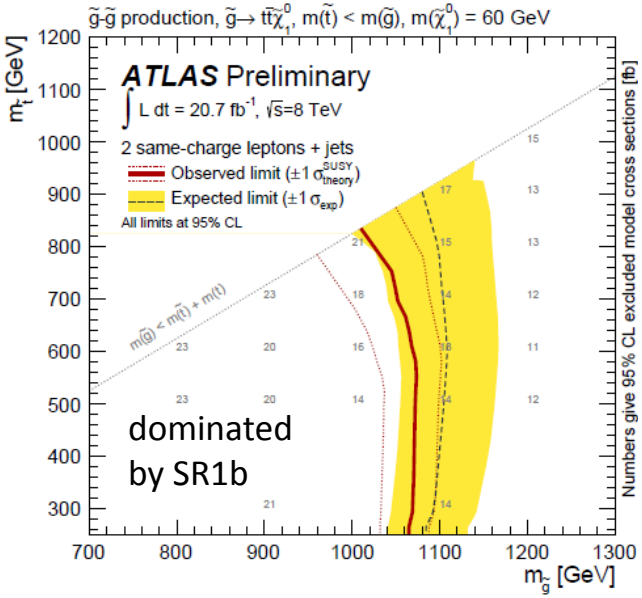




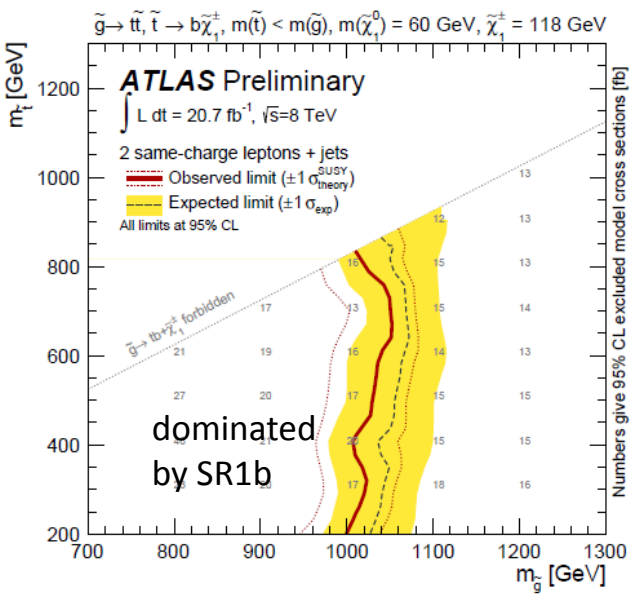
ATLAS-CONF-2013-007

2 same-charge leptons + [0-3] b-jets

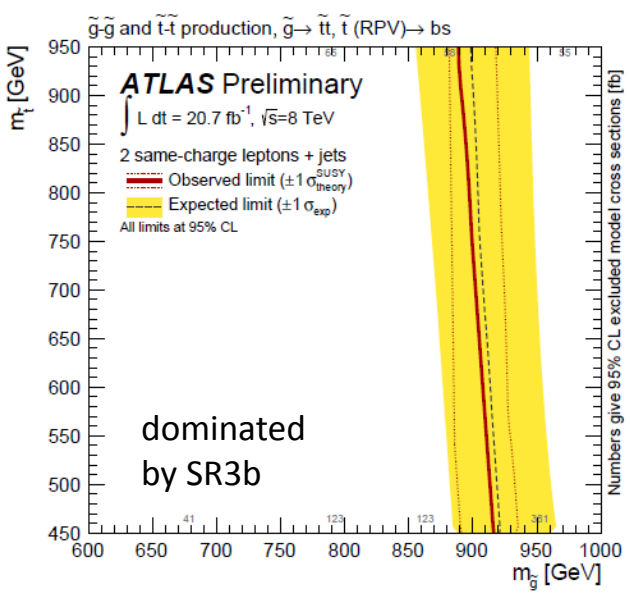
- Interpretations:



$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$



$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^{\pm}$



$\tilde{g} \rightarrow t\bar{t}$ → bs

Excluding m_{gluino} < ~1 TeV, largely independently of the stop mass.

ATLAS-CONF-2013-061

0/1 lepton + 3 b-jets + ETmiss

- Signal regions:

baseline selection: baseline lepton veto, $p_T^{j_1} > 90$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV, ≥ 4 jets with $p_T > 30$ GeV, $\Delta\phi_{\mathrm{min}}^{4j} > 0.5$, $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{4\mathrm{j}} > 0.2$, ≥ 3 b-jets with $p_T > 30$ GeV

	0-ℓ region	N jets	p_T jets [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	m_{eff} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}^{4\mathrm{j}}}$ [GeV$^{\frac{1}{2}}$]
$\tilde{g} \to b\tilde{b}$	SR-0l-4j-A	≥ 4	> 30	> 200	$m_{\mathrm{eff}}^{4\mathrm{j}} > 1000$	> 16
	SR-0l-4j-B	≥ 4	> 50	> 350	$m_{\mathrm{eff}}^{4\mathrm{j}} > 1100$	-
	SR-0l-4j-C	≥ 4	> 50	> 250	$m_{\mathrm{eff}}^{4\mathrm{j}} > 1300$	-
$\tilde{g} \to t\tilde{t}$	SR-0l-7j-A	≥ 7	> 30	> 200	$m_{\mathrm{eff}}^{\mathrm{incl}} > 1000$	-
	SR-0l-7j-B	≥ 7	> 30	> 350	$m_{\mathrm{eff}}^{\mathrm{incl}} > 1000$	-
	SR-0l-7j-C	≥ 7	> 30	> 250	$m_{\mathrm{eff}}^{\mathrm{incl}} > 1500$	-

new channel

baseline selection: $\geqslant 1$ signal lepton (e,μ), $p_T^{j_1} > 90$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV, ≥ 4 jets with $p_T > 30$ GeV, ≥ 3 b-jets with $p_T > 30$ GeV

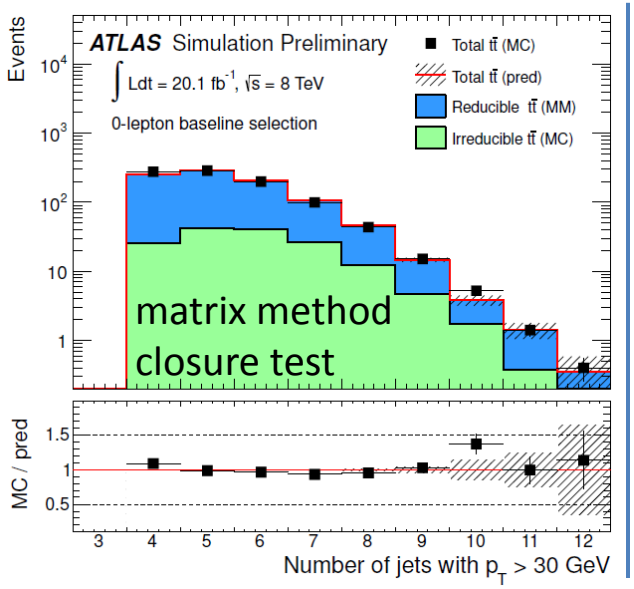
	1-ℓ region	N jets	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	m_{T} [GeV]	$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}^{\mathrm{incl}}}$ [GeV$^{\frac{1}{2}}$]
$\tilde{g} \to t\tilde{t}$	SR-1l-6j-A	≥ 6	> 175	> 140	> 700	> 5
	SR-1l-6j-B	≥ 6	> 225	> 140	> 800	> 5
	SR-1l-6j-C	≥ 6	> 275	> 160	> 900	> 5

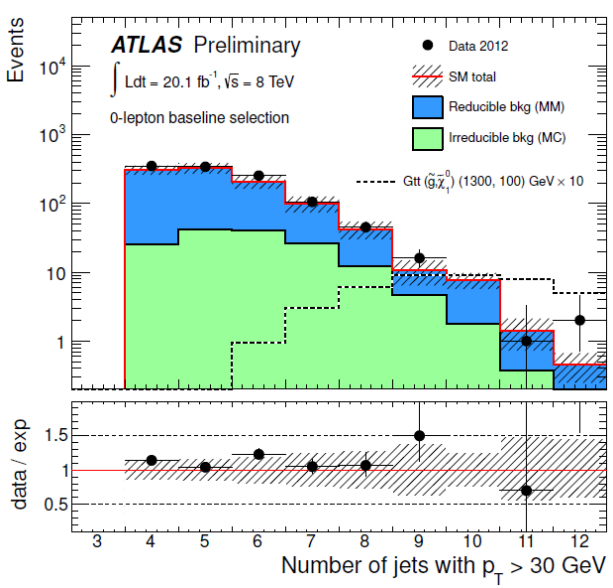
All regions based on MET trigger and baseline lepton $p_T > 20$ GeV.

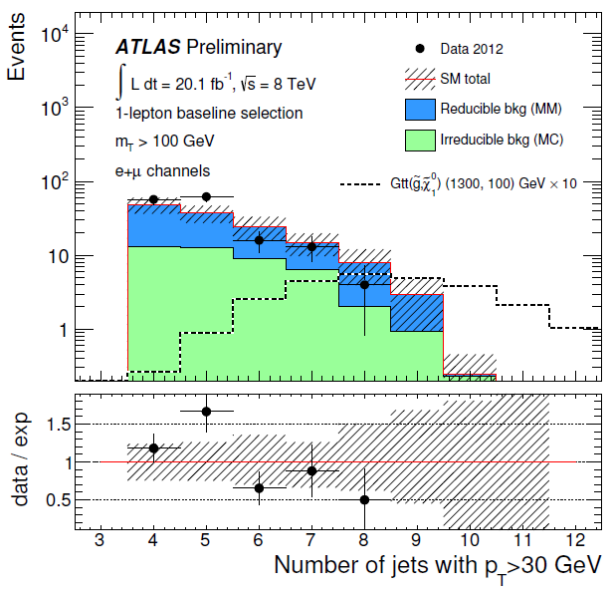
ATLAS-CONF-2013-061

0/1 lepton + 3 b-jets + ETmiss

- Main backgrounds:
  - reducible: misidentified b-jet [data-driven]
    - loose-to-tight Matrix Method
      - 4 components: real b, misidentified light jet, c-jet, τ
      - generalization of lepton matrix method [size: $2^{N(jets)} \times 2^{N(jets)}$] see page 6
  - irreducible: ttbar + bb [MC]
    - main uncertainty: theoretical cross section







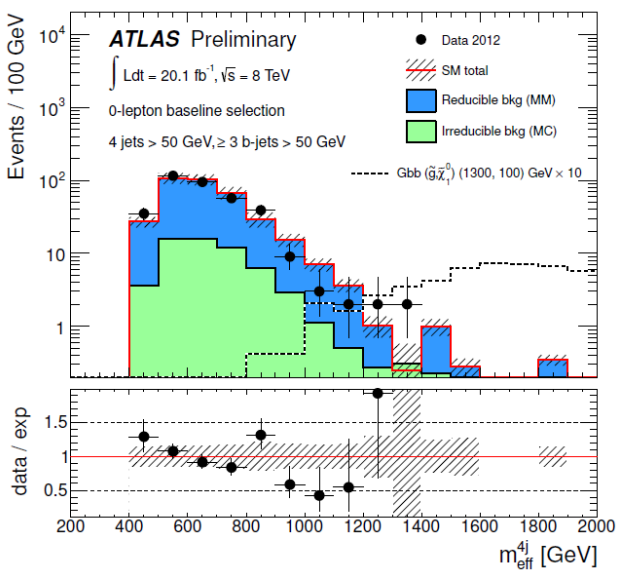
ATLAS-CONF-2013-061

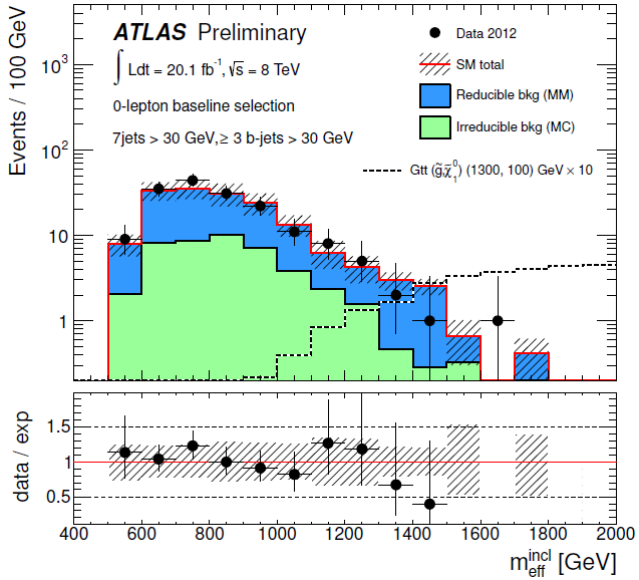
0/1 lepton + 3 b-jets + ETmiss

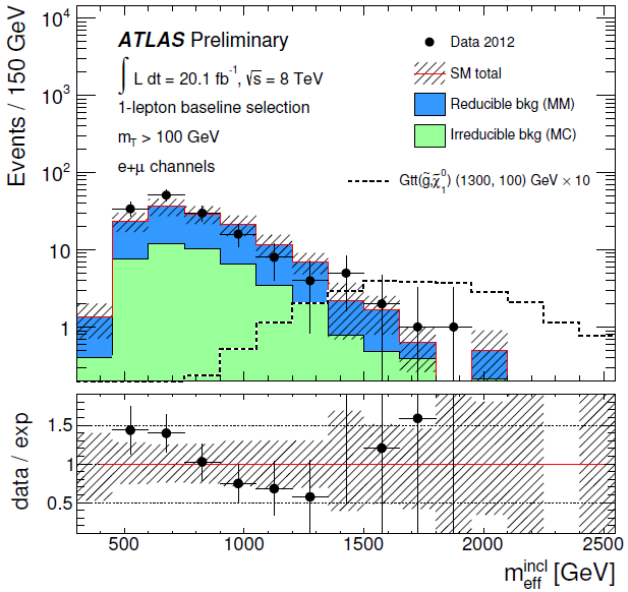
- Results:

Simultaneous fit to 0L and 1L channels for model-dependent exclusion tests.

region	reducible bkg	irreducible bkg	total bkg (MC)	data
SR-0l-4j-A	2.2 ± 1.1	0.8 ± 0.7	3.0 ± 1.3 (5.1)	2
SR-0l-4j-B	0.8 ± 0.9	0.5 ± 0.5	1.3 ± 1.0 (3.9)	3
SR-0l-4j-C	1.2 ± 0.8	0.6 ± 0.6	1.8 ± 1.0 (2.5)	2
SR-0l-7j-A	15.5 ± 3.4	7.0 ± 6.0	22.5 ± 6.9 (28.8)	22
SR-0l-7j-B	2.3 ± 2.3	1.3 ± 1.1	3.6 ± 2.5 (6.2)	3
SR-0l-7j-C	$0 \pm 0.5^{+0.5}_{-0}$	0.8 ± 0.7	$0.8 \pm ^{+0.9}_{-0.8}$ (3.1)	1
SR-1l-6j-A	$10.7\ ^{+7.5}_{-6.8}$	4.8 ± 3.7	15.5 ± 8.4 (13.8)	7
SR-1l-6j-B	5.7 ± 5.5	1.7 ± 1.4	7.4 ± 5.7 (6.3)	0
SR-1l-6j-C	$2.4\ ^{+2.7}_{-2.4}$	$0.6\ ^{+0.6}_{-0.5}$	3.0 ± 2.8 (2.6)	0





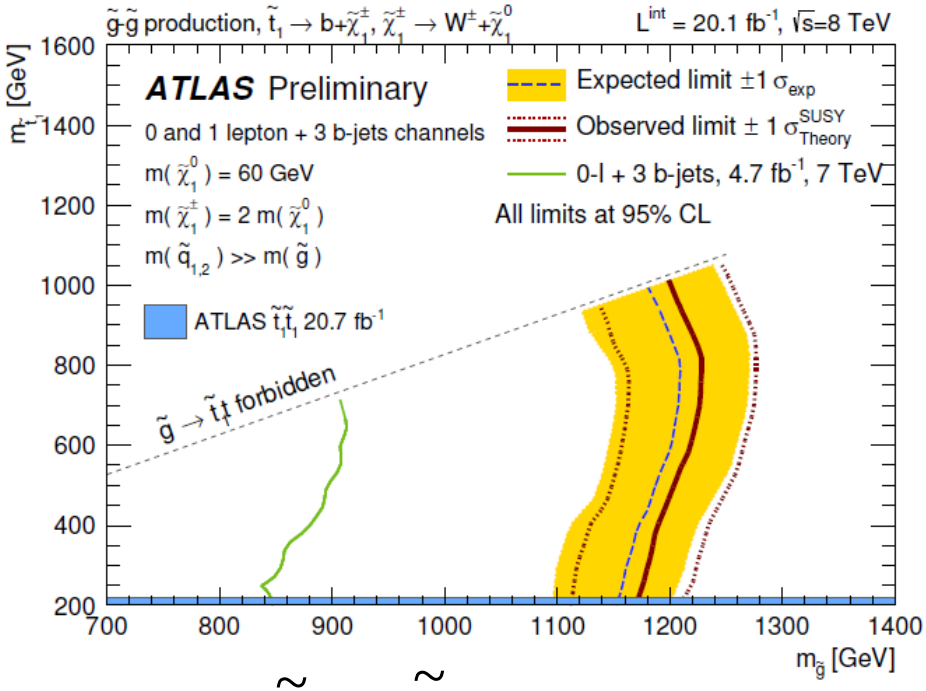


ATLAS-CONF-2013-061

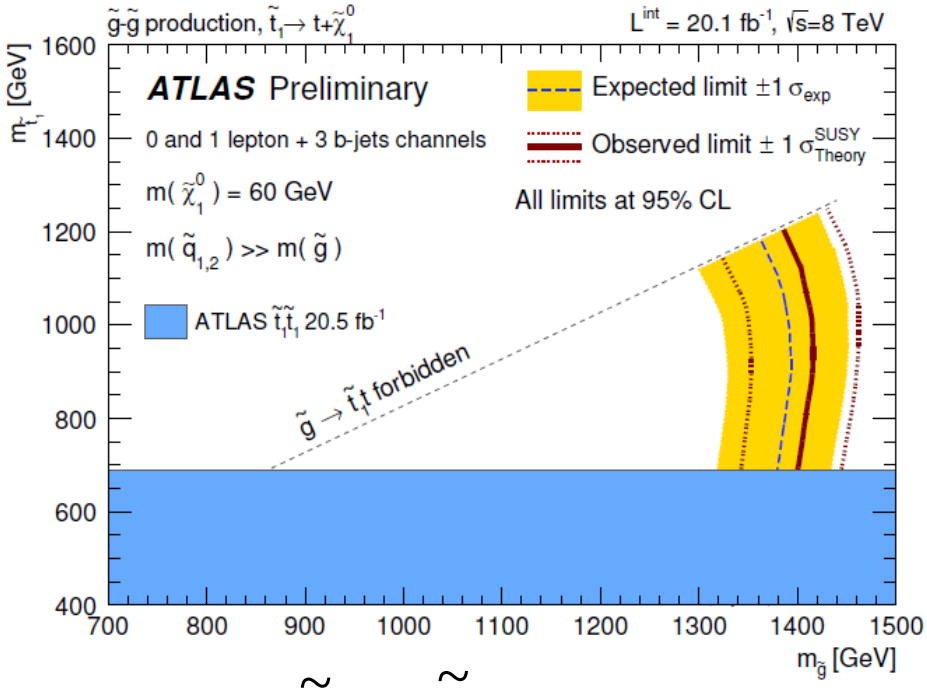
0/1 lepton + 3 b-jets + ETmiss

- Interpretations:

= direct stop searches.
See talk by Tommaso Lari.



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



$\tilde{g} \rightarrow t\tilde{t}$, $\tilde{t} \rightarrow t\tilde{\chi}_1^{0}$

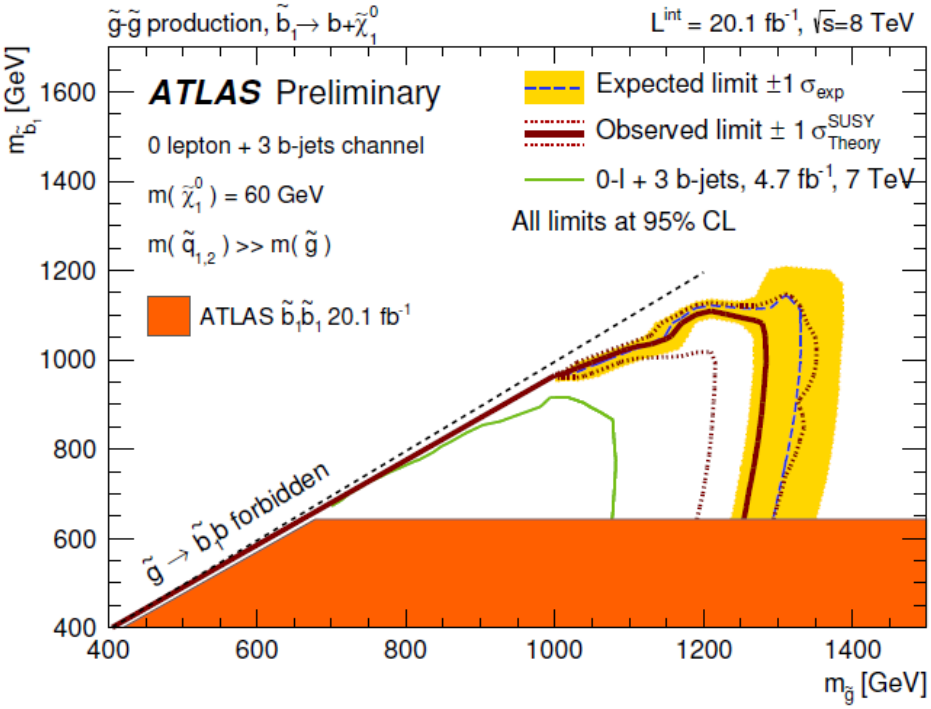
Excluding up to m_{gluino} < ~1.4 TeV, largely independently of the stop mass.

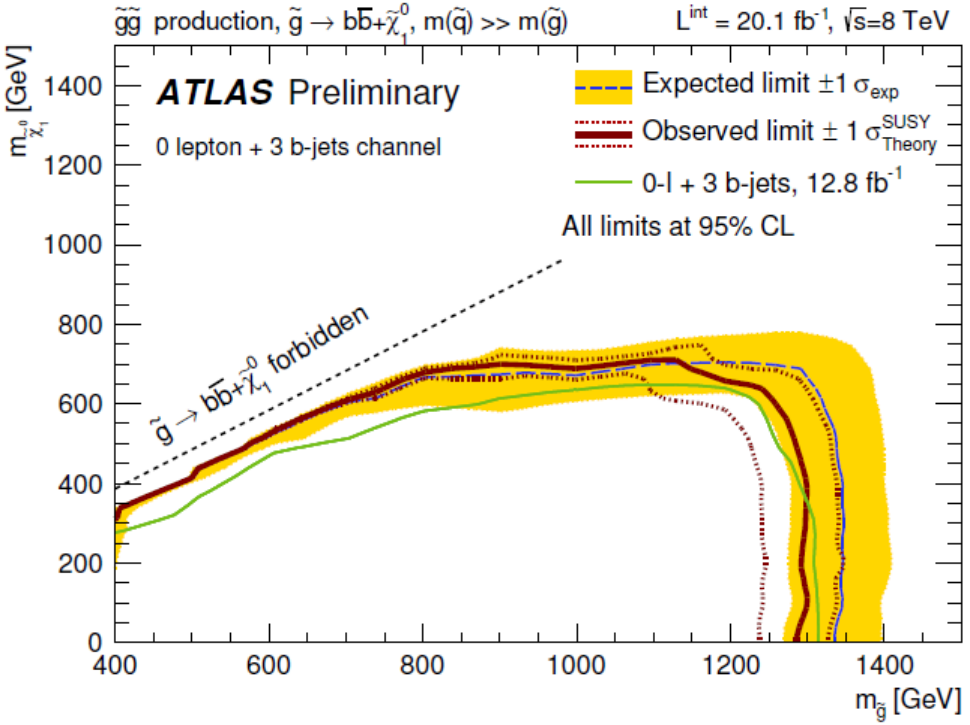
ATLAS-CONF-2013-061

0/1 lepton + 3 b-jets + ETmiss

- Interpretations: $\tilde{g} \rightarrow b\tilde{b}$, $\tilde{b} \rightarrow b\tilde{\chi}_1^0$

= direct sbottom searches.
See talk by Tommaso Lari.





Excluding m_{gluino} < ~1.3 TeV for $m_{\chi^0_1}$ < ~600 GeV,
similarly for on-shell sbottom ($m_{sbottom} < m_{gluino}$) and off-shell sbottom* ($m_{sbottom} > m_{gluino}$).

ATLAS-CONF-2013-047

0 lepton + [2-6] jets + ETmiss

- Five types of signal regions
  - SRE (6 jets) best for gluino-mediated stop→charm

See backup and talk by Alex Koutsman.

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
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160									
$p_{\mathrm{T}}(j_1)$ [GeV] >	130									
$p_{\mathrm{T}}(j_2)$ [GeV] >	60									
$p_{\mathrm{T}}(j_3)$ [GeV] >	–		60		60		60	60		
$p_{\mathrm{T}}(j_4)$ [GeV] >	–		–		60		60	60		
$p_{\mathrm{T}}(j_5)$ [GeV] >	–		–		–		60	60		
$p_{\mathrm{T}}(j_6)$ [GeV] >	–		–		–		–	60		
$\Delta\phi(\mathrm{jet}_i, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4 ($i = \{1, 2, (3 \text{ if } p_{\mathrm{T}}(j_3) > 40 \text{ GeV})\}$)				0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_{\mathrm{T}} > 40$ GeV jets)					
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(N\,j)$ >	0.2	–[a]	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
m_{eff}(incl.) [GeV] >	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

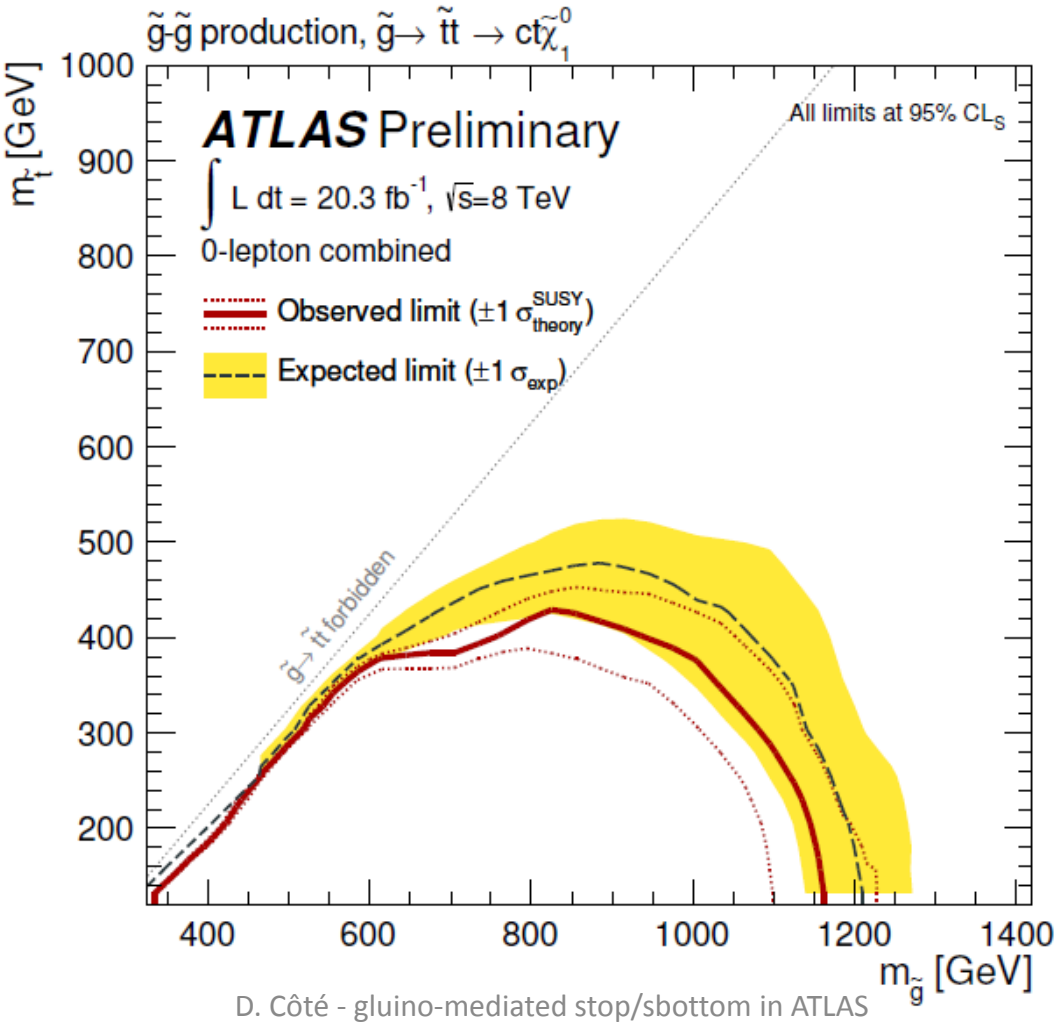
(a) For SR A-medium the cut on $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(N\,j)$ is replaced by a requirement $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 15\ \mathrm{GeV}^{1/2}$.

ATLAS-CONF-2013-047

0 lepton + [2-6] jets + ETmiss

- Interpretation:

See backup and talk by Alex Koutsman.



new interpretation

$$\tilde{g} \to t\tilde{t} \to c\tilde{\chi}_1^0$$

ATLAS-CONF-2013-054

0 lepton + [7-10] jets

- Signal regions:

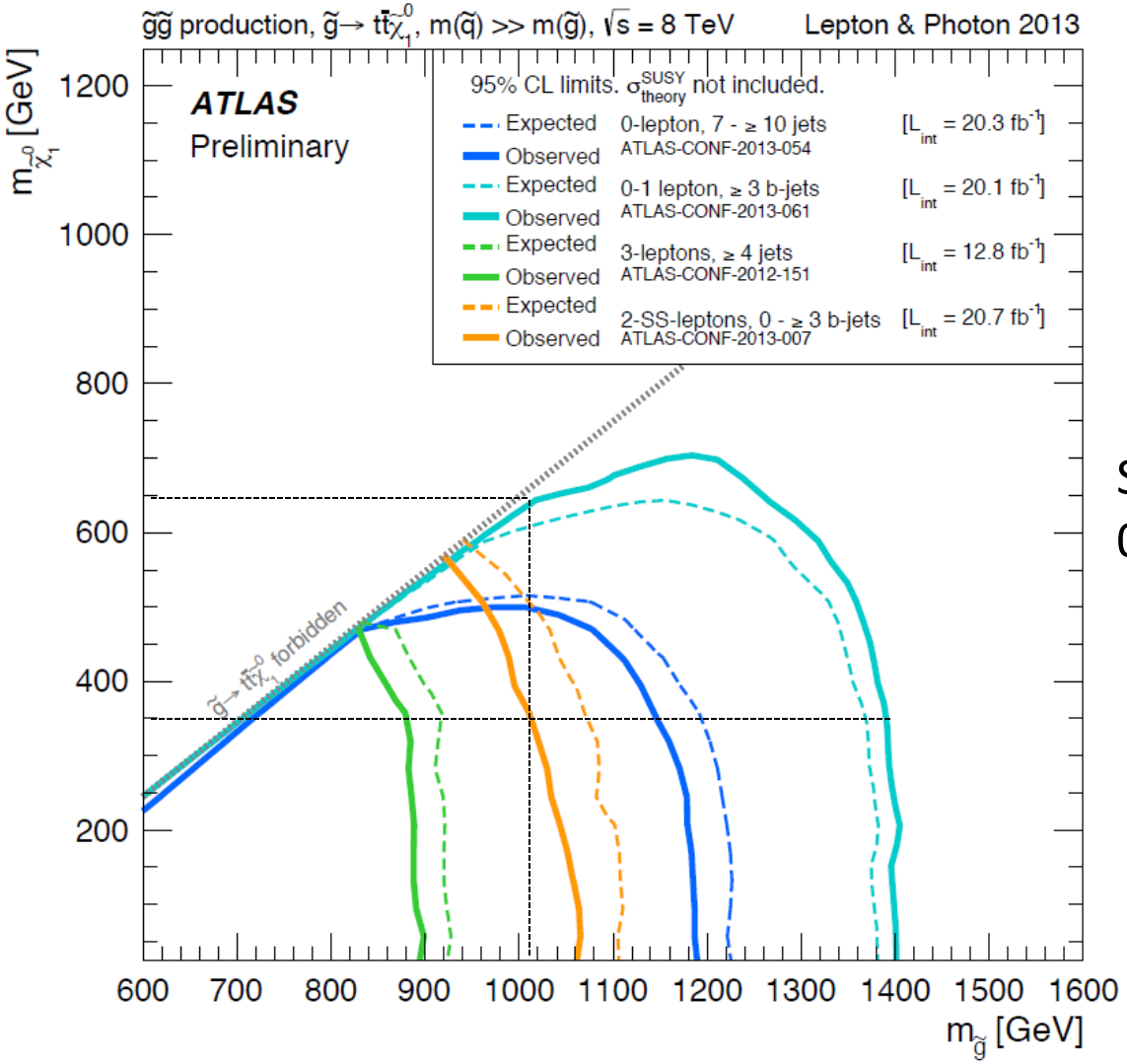
See backup and talk by Alex Koutsman.

	Multi-jet + flavour stream												Multi-jet + M_J^{Σ} stream		
Identifier	8j50			9j50			≥ 10j50	7j80			≥ 8j80			≥ 8j50	≥ 9j50	≥ 10j50
Jet $\|\eta\|$	< 2.0							< 2.0						< 2.8		
Jet p_T	> 50 GeV							> 80 GeV						> 50 GeV		
Jet count	= 8			= 9			≥ 10	= 7			≥ 8			≥ 8	≥ 9	≥ 10
b-jets ($p_T > 40$ GeV, $\|\eta\| < 2.5$)	0	1	≥ 2	0	1	≥ 2	—	0	1	≥ 2	0	1	≥ 2	—		
M_J^{Σ} [GeV]	—							—						> 340 and > 420 for each case		
$E_T^{miss}/\sqrt{H_T}$	> 4 GeV$^{1/2}$							> 4 GeV$^{1/2}$						> 4 GeV$^{1/2}$		

Signal regions with 50 GeV jets are the most sensitive to gluino-mediated stop.

new technique: "fat jets"

Summary of gluino-mediated stop→top χ^0_1

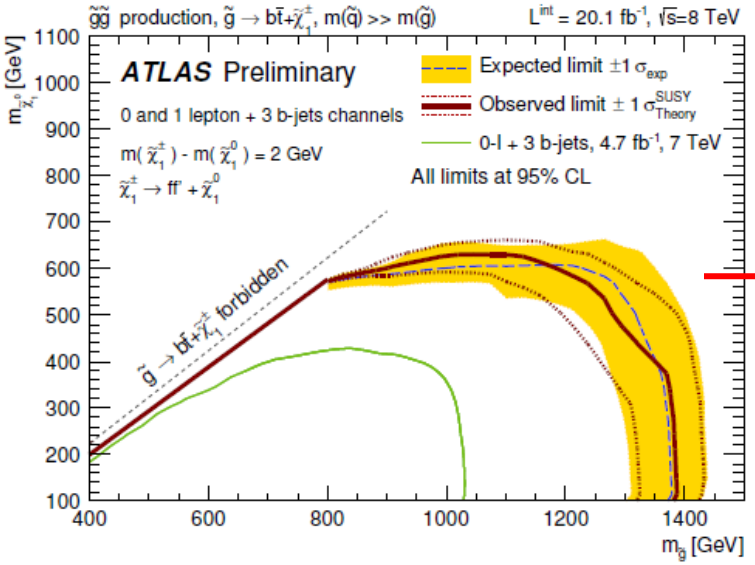


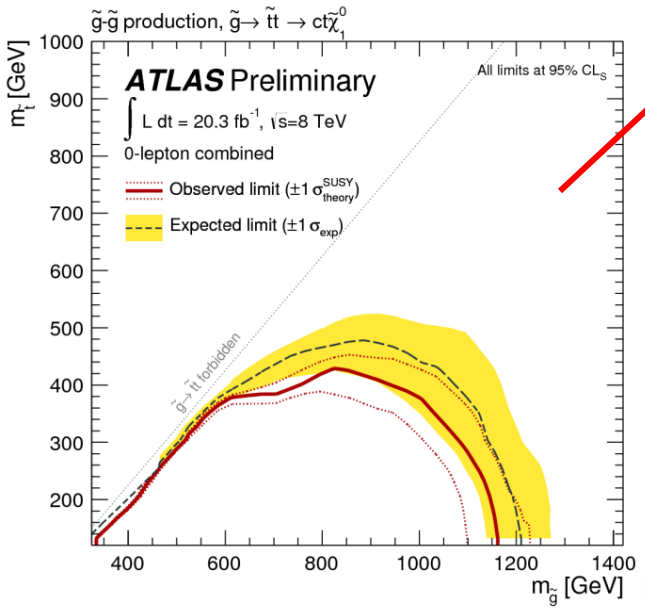
$$\tilde{g} \rightarrow t\tilde{t}^{*} \hookrightarrow t\tilde{\chi}_1^0$$

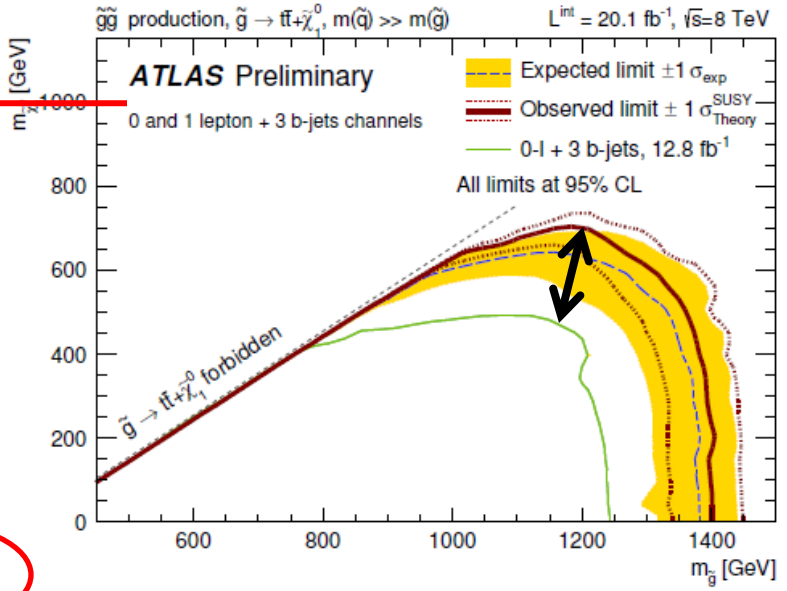
Sensitivity dominated by
0/1 lepton + 3 b-jets + ETmiss

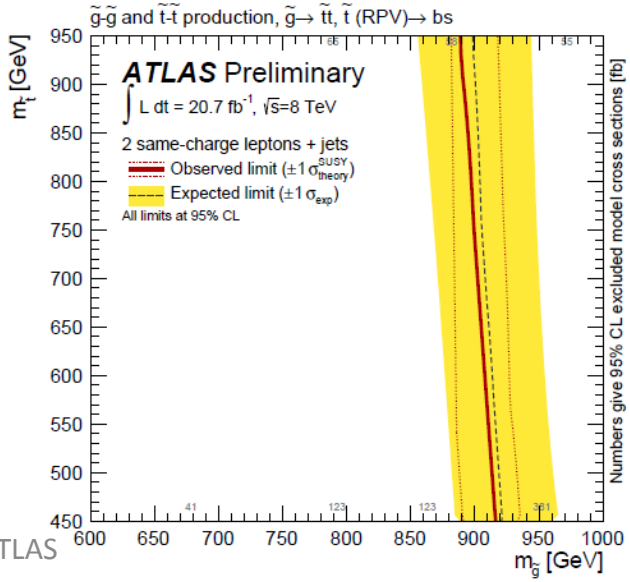
Excluding $m_{gluino} < \sim 1.4$ TeV for $m_{\chi^0_1} < \sim 350$ GeV.

Limits on all gluino-mediated stop decays









$\tilde{g} \rightarrow t\,\tilde{t}$

$t\,\tilde{\chi}_1^0$

$b\,\tilde{\chi}_1^{\pm}$

$c\,\tilde{\chi}_1^0$

b s (RPV)

Conclusion

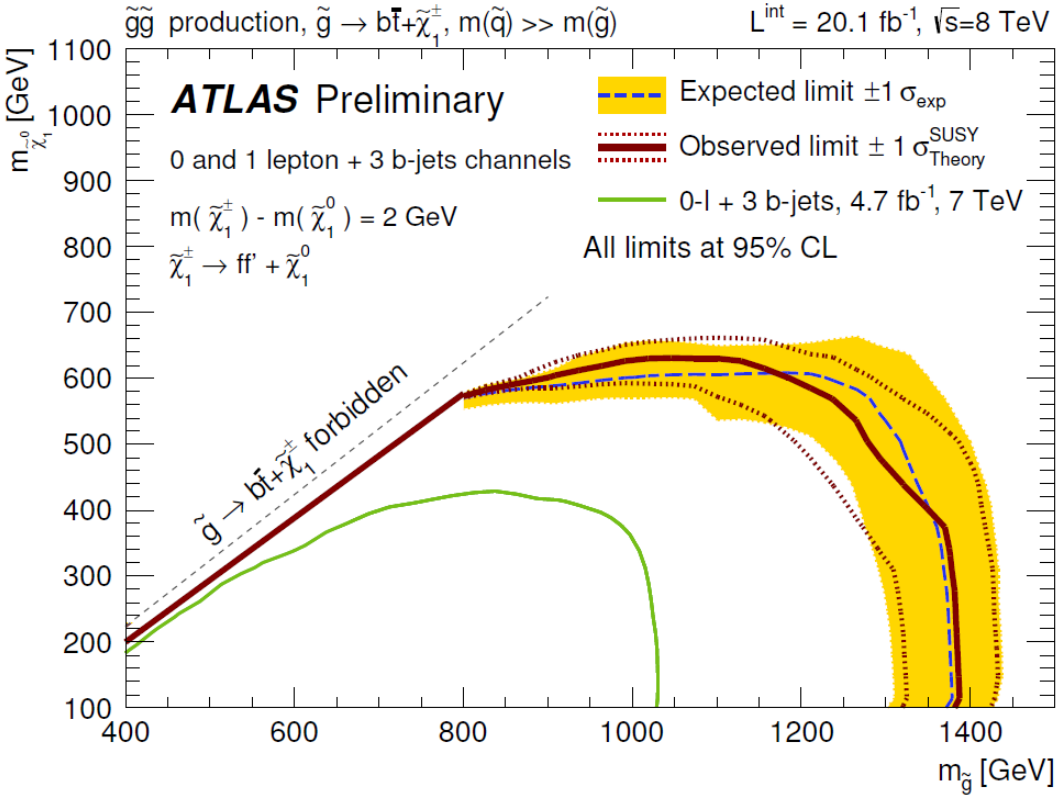
- Gluino-mediated production of 3rd generation squarks strongly motivated by SUSY Naturalness
- Stringent limits from several analyses
  - 0/1Lep + 3 b-jets + ETmiss
  - 2Lep same-charge + jets (+ ETmiss)
  - 0Lep + 2-6 jets + ETmiss
  - 0Lep + 7-10 jets
  - largely independent from stop/sbottom mass and decay
- Looking forward to ~14 TeV data!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

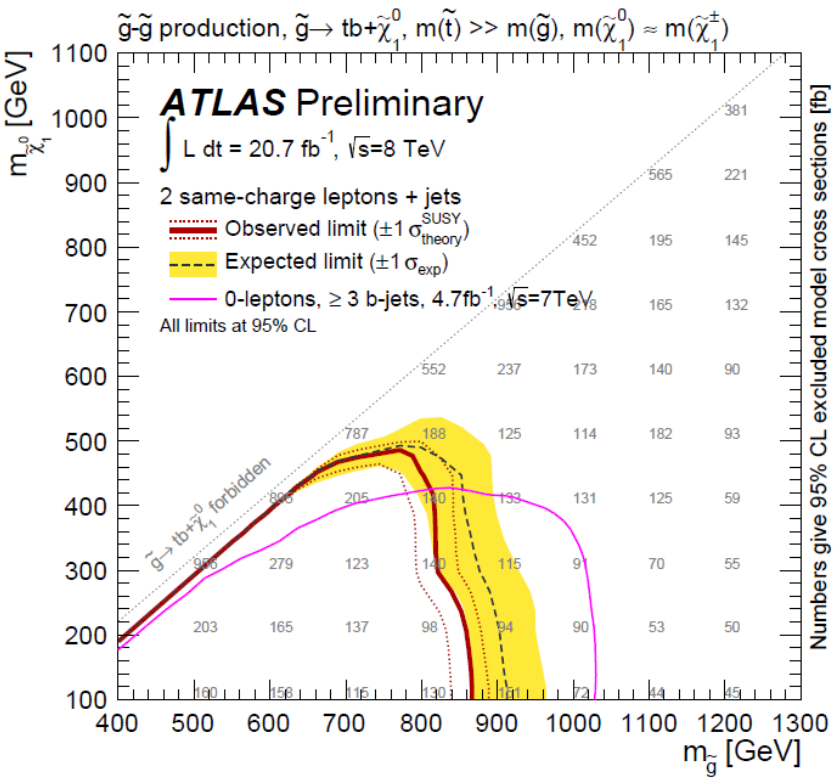
Backup material

Limits on gluino → sbottom → $t\chi^{\pm}_1$

ATLAS-CONF-2013-061



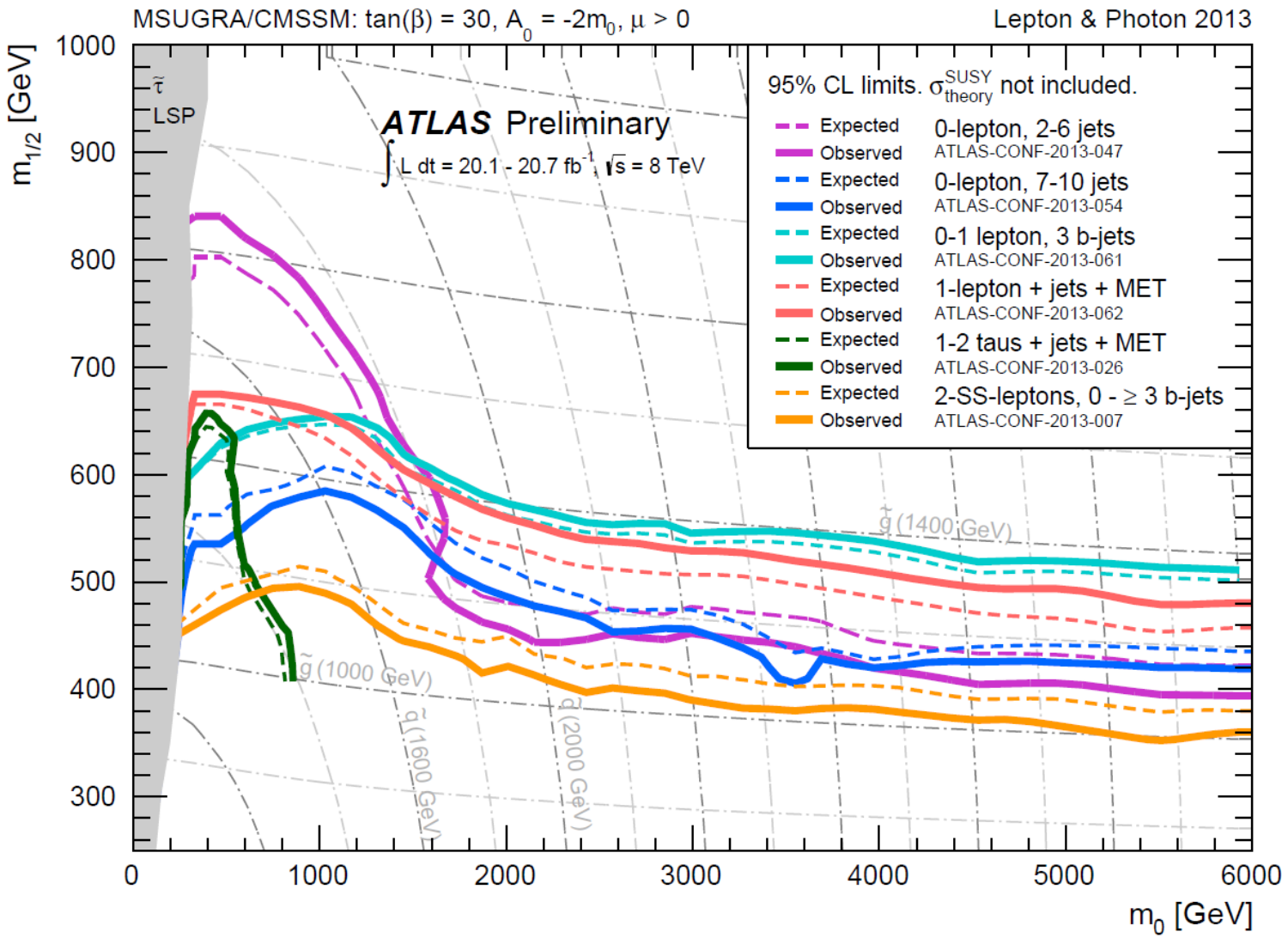
ATLAS-CONF-2013-007



$$\tilde{g} \to b\,\tilde{b}_1^* \to \begin{cases} t\,\tilde{\chi}_1^{\pm} \\ b\,\tilde{\chi}_1^{\pm} \end{cases} \Big\} \tilde{\chi}_1^{\pm} \to W^{\pm *}\tilde{\chi}_1^0 \quad \text{with compressed } \Delta m\left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0\right) = 2\ GeV$$

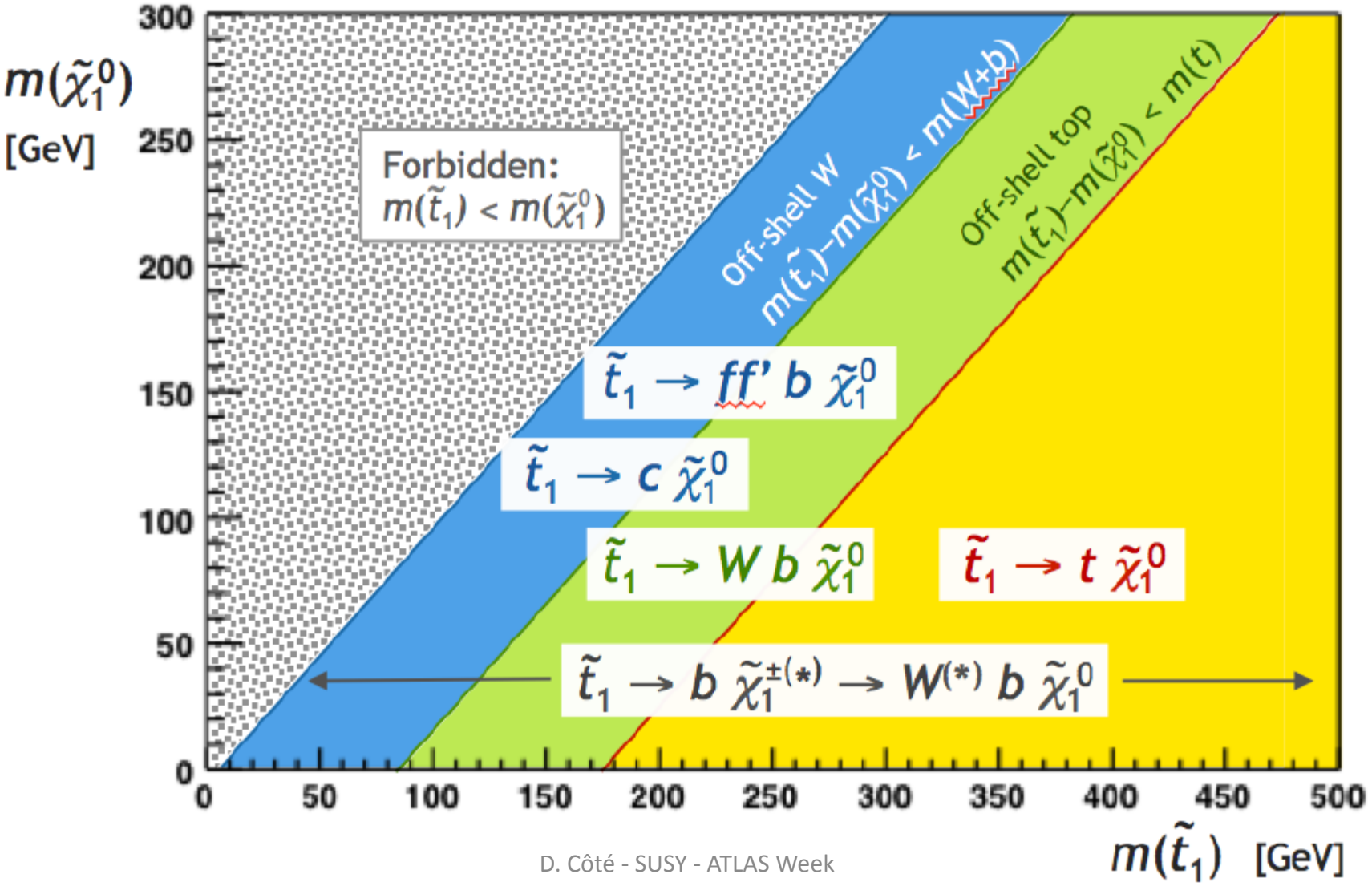
$$\tilde{g} \to t\,\tilde{t}_1^*$$

Higgs-aware mSUGRA



Gluino-mediated stop dominates at large m_0, showing sensitivity of 1-lepton + jets + ETmiss.

decay modes of the stop to χ^0_1



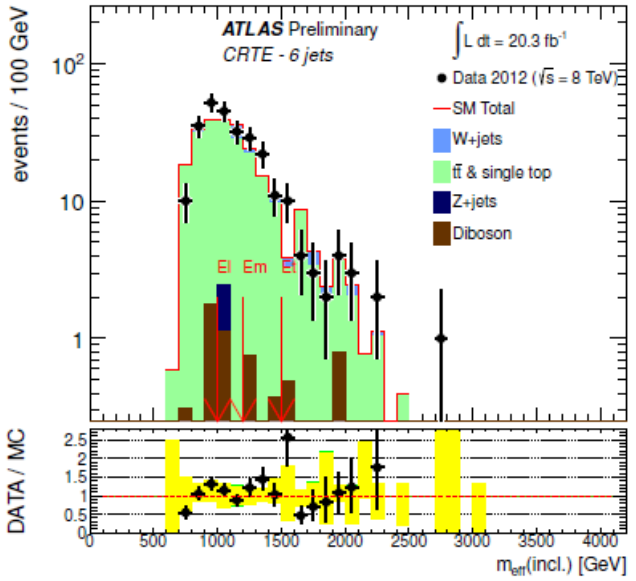
ATLAS-CONF-2013-047

0 lepton + [2-6] jets + ETmiss

See talk by Alex Koutsman.

- Main backgrounds:
  - ttbar, W+jets & Z→νν [MC + control regions]
    - fitted independently in each signal region

CR	SR background	CR process	CR selection
CRY	$Z(\rightarrow \nu\nu)$+jets	γ+jets	Isolated photon
CRQ	multi-jets	multi-jets	Reversed $\Delta\phi(\text{jet}, \mathbf{E}_{\text{T}}^{\text{miss}})_{\text{min}}$ and $E_{\text{T}}^{\text{miss}}/m_{\text{eff}}(Nj)$ requirements[a]
CRW	$W(\rightarrow \ell\nu)$+jets	$W(\rightarrow \ell\nu)$+jets	30 GeV $< m_T(\ell, E_{\text{T}}^{\text{miss}}) <$ 100 GeV, b-veto
CRT	$t\bar{t}$ and single-t	$t\bar{t} \rightarrow bbqq'\ell\nu$	30 GeV $< m_T(\ell, E_{\text{T}}^{\text{miss}}) <$ 100 GeV, b-tag



ATLAS-CONF-2013-047

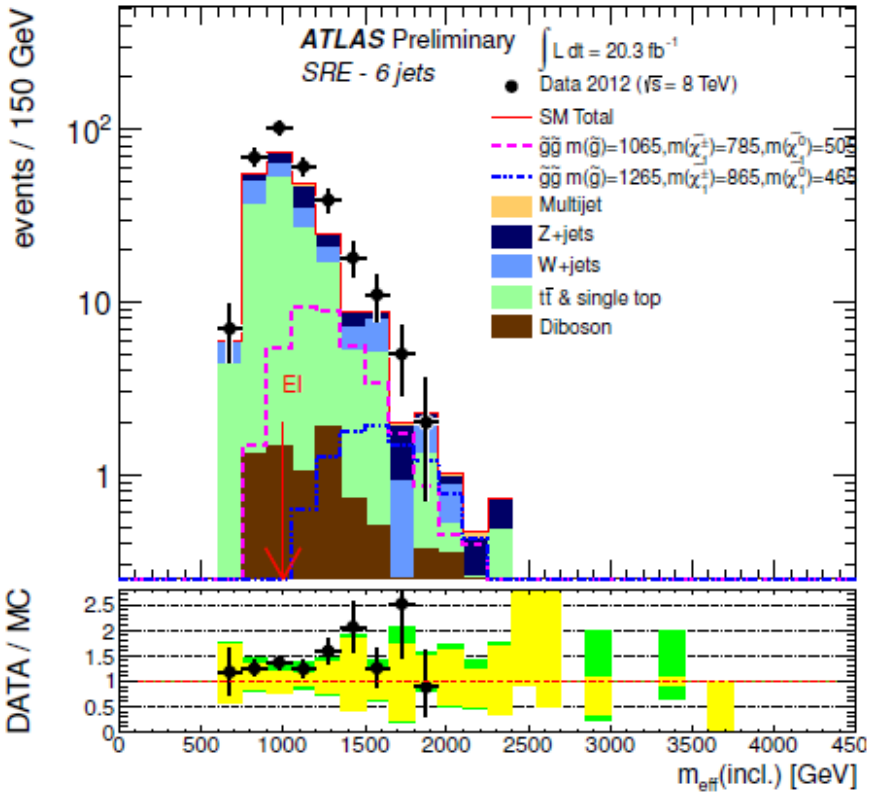
0 lepton + [2-6] jets + ETmiss

- Results:

See talk by Alex Koutsman.

Signal Region	E-loose	E-medium	E-tight
Diboson	5.5 ± 2.1	1.7 ± 0.8	–
Z/γ^*+jets	12 ± 7	2.9 ± 2.6	0.4 ± 0.6
W+jets	18 ± 7	4.9 ± 2.7	0.7 ± 0.5
$t\bar{t}$(+EW) + single top	76 ± 19	20 ± 6	1.7 ± 1.4
Multi-jets	1.0 ± 1.0	–	–
Total bkg	113 ± 21	30 ± 8	2.9 ± 1.8
Observed	166	41	5

1.9 sigma



ATLAS-CONF-2013-047

0 lepton + [2-6] jets + ETmiss

- Breakdown of uncertainties:

See talk by Alex Koutsman.

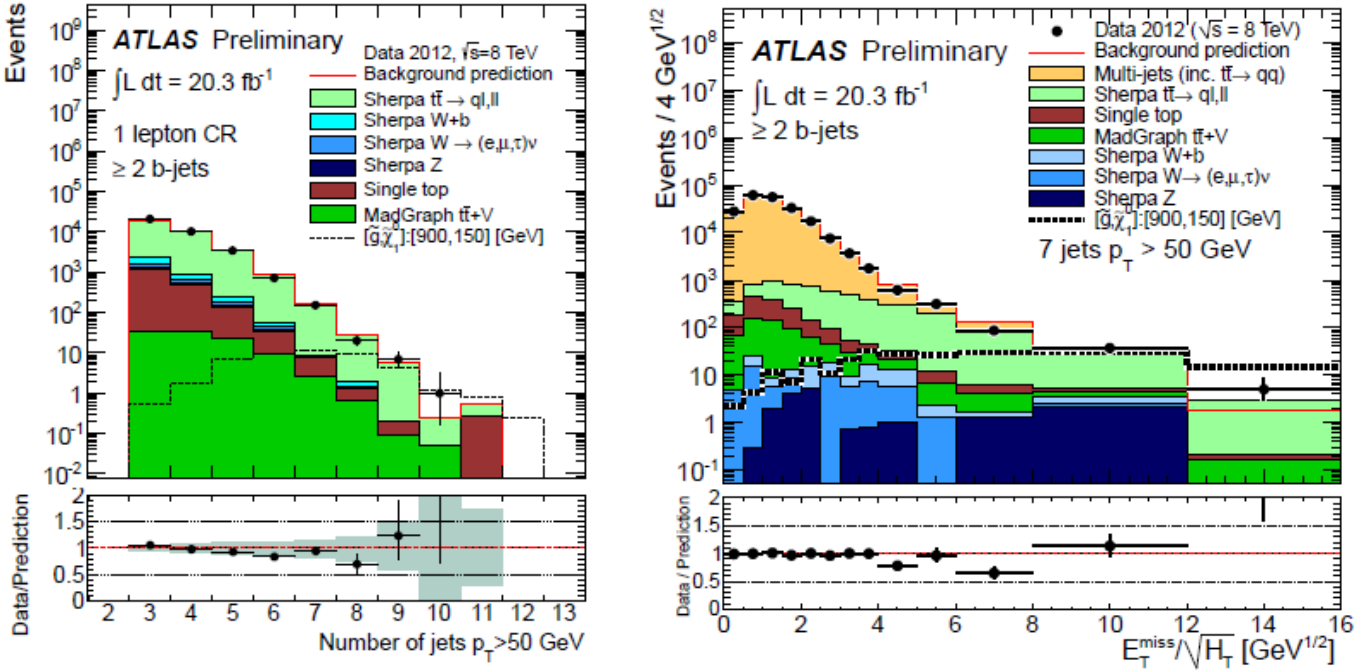
Signal Region	D	E-loose	E-medium	E-tight
Total bkg	15	113	30	2.9
Total bkg unc.	±5	±21	±8	±1.8
$\Delta\mu_{\text{Multi-jets}}$	±0.1 [1%]	±0.1 [0%]	–	–
$\Delta\mu_{\text{Top}}$	±0.8 [5%]	±10 [9%]	±3.1 [10%]	±0.3 [11%]
$\Delta\mu_{\text{W+jets}}$	±0.6 [4%]	±5 [4%]	±1.4 [5%]	±0.2 [8%]
$\Delta\mu_{\text{Z+jets}}$	±1.3 [9%]	±2.2 [2%]	±0.8 [3%]	±0.4 [14%]
MC statistics	±2.0 [13%]	±8 [7%]	±4 [13%]	±0.7 [24%]
Jet/MET	±0.7 [5%]	±2.4 [2%]	±4 [13%]	±1.4 [48%]
Theory Z+jets	±2.0 [13%]	±6 [5%]	±2.2 [7%]	±0.3 [10%]
Theory W+jets	±2.3 [15%]	±4 [4%]	±2.0 [7%]	±0.4 [14%]
Theory Top	±1.4 [9%]	±15 [13%]	±4 [13%]	±0.5 [17%]
Theory Diboson	±1.9 [13%]	±2.1 [2%]	±0.8 [3%]	–
Theory scales unc.	±0.1 [1%]	±0.04 [0%]	±0.02 [0%]	±0.03 [1%]
Other	±0.3 [2%]	±1.3 [1%]	±1.0 [3%]	±0.2 [7%]

ATLAS-CONF-2013-054

0 lepton + [7-10] jets

See talk by Alex Koutsman.

- Main backgrounds:
  - multijets [data-driven: ETmiss significance shape]
  - semileptonic ttbar [MC + control regions]



ATLAS-CONF-2013-054

0 lepton + [7-10] jets

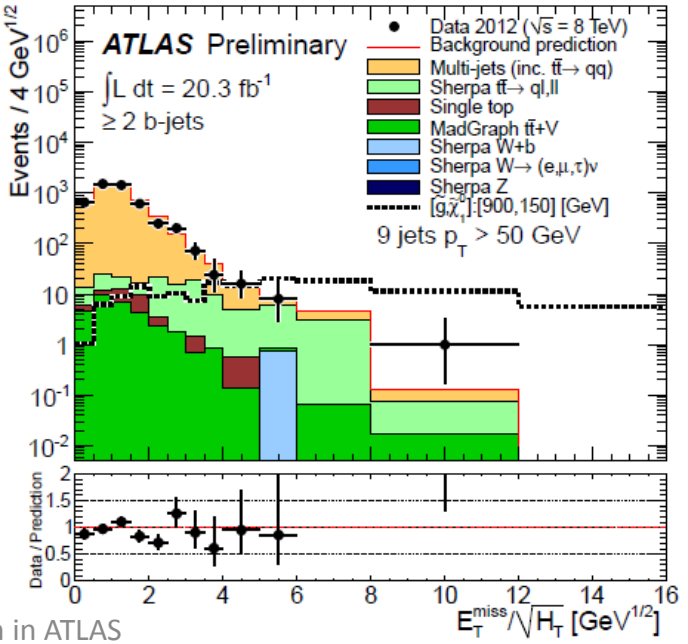
- Results:

See talk by Alex Koutsman.

Signal region	8j50			9j50			10j50
b-jets	0	1	≥ 2	0	1	≥ 2	—
Observed events	40	44	44	5	8	7	3
Total events after fit	35 ± 4	40 ± 10	50 ± 10	3.3 ± 0.7	6.1 ± 1.7	8.0 ± 2.7	1.37 ± 0.35
Fitted $t\bar{t}$	2.7 ± 0.9	11.8 ± 3.0	23.0 ± 5.0	0.36 ± 0.18	1.5 ± 0.5	3.2 ± 1.1	$0.06^{+0.09}_{-0.06}$
Fitted W+jets	$2.0^{+2.6}_{-2.0}$	$0.62^{+0.81}_{-0.62}$	$0.20^{+0.28}_{-0.20}$	-	$0.24^{+0.65}_{-0.24}$	-	-
Fitted others	$2.9^{+1.8}_{-1.8}$	$1.7^{+1.5}_{-1.2}$	$2.8^{+2.3}_{-2.0}$	0.03 ± 0.03	0.38 ± 0.25	$0.40^{+0.60}_{-0.24}$	0.08 ± 0.08

Signal regions with 50 GeV jets are the most sensitive to gluino-mediated stop.

Simultaneous fit to the 7 signal region bins for model-dependent exclusion tests.

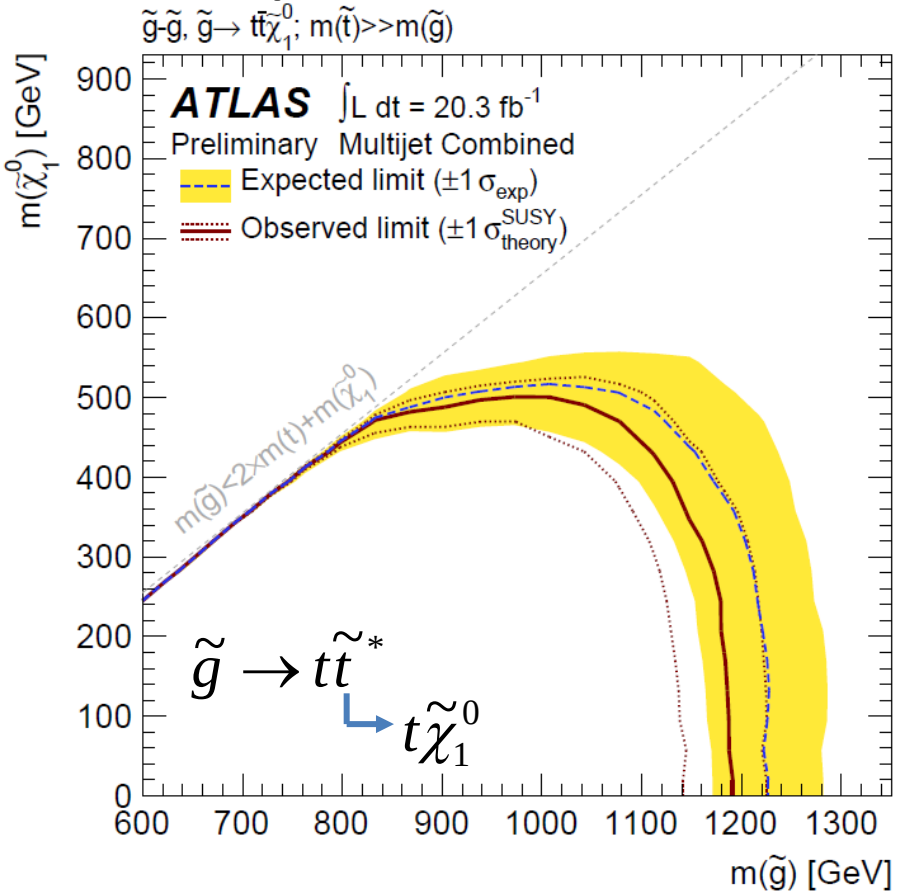


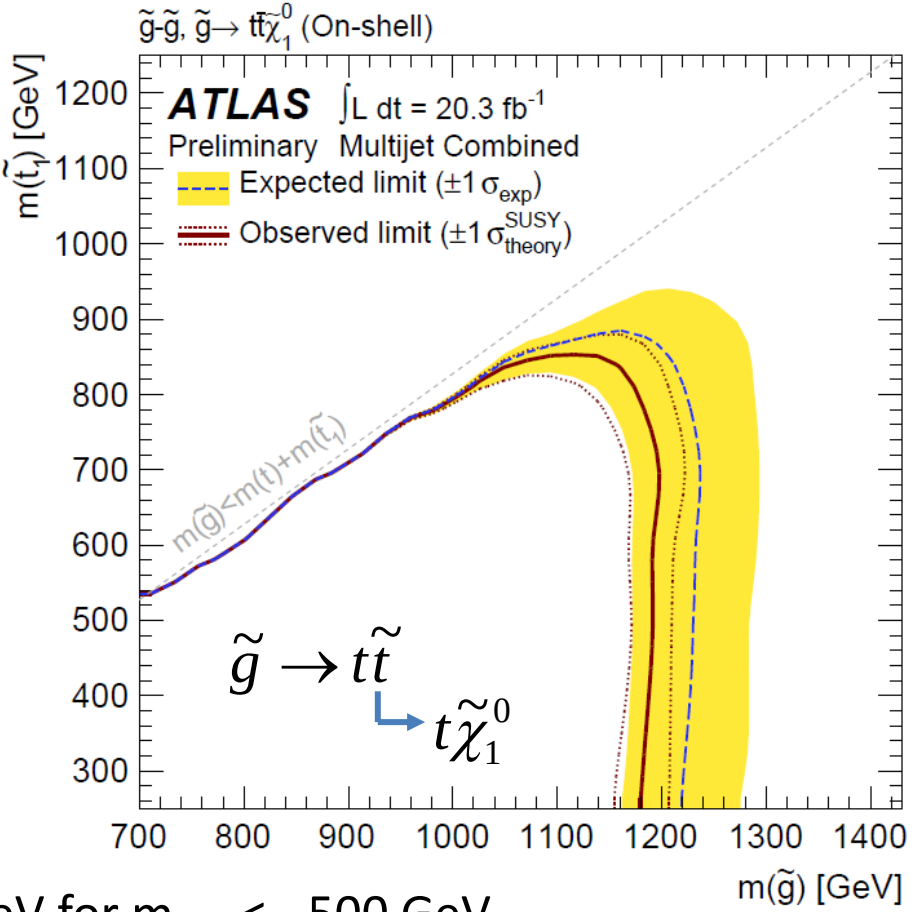
ATLAS-CONF-2013-054

0 lepton + [7-10] jets

- Interpretations:

See backup and talk by Alex Koutsman.





Excluding m_{gluino} < ~1.2 TeV for $m_{\chi^0_1}$ < ~500 GeV,
similarly for on-shell stop ($m_{stop} < m_{gluino}$) and off-shell stop* ($m_{stop} > m_{gluino}$).