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

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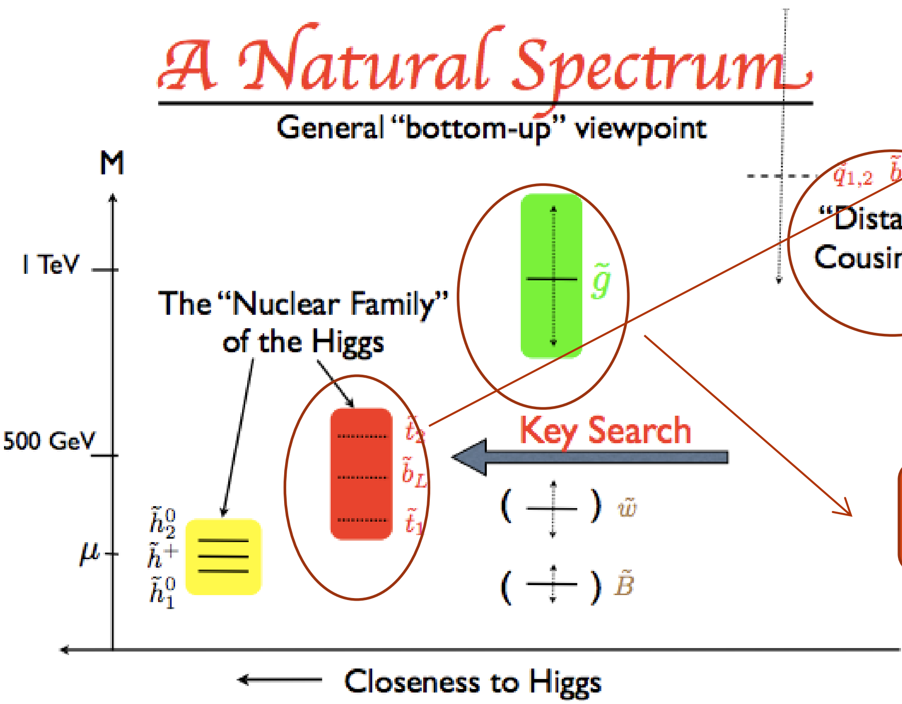
OUTLINE

1. 3rd generation searches and their motivations
2. Production and decay modes
3. Gluino-mediated production of 3rd generation squarks
    - 2 same-sign leptons, jets, MET
    - 0/1lepton, 3bjets, MET
    - 0 lepton, [7-10] jets
    - 0 lepton, [2-6] jets, MET
4. Summary and conclusion

3rd generation searches and their motivations

SUSY→ is one of the most theoretically promising candidates to solve some of the open questions of the SM

One of the assets of SUSY is its ability to solve the *hierarchy* problem of the SM.



L. Hall (LBL Workshop, 21-Oct11)

The Higgs boson mass is regularized by the scalar top mass and it is still possible to have a natural SUSY with a sufficiently light stop and sbottom .

In the context of natural SUSY not much constrains are on the first two generations squarks.

The gluino should not be too heavy.

Dedicated search program for: "3rd generation SUSY": direct production (see D.Guest talk) or gluino-mediated production of sbottom/stop pairs.

Production and decay modes

The focus of this talk is the ATLAS searches for gluino-mediated production of SUSY partners of top and bottom quarks (stop, sbottom).

→ Simplified models based on MSSM extension of SM are exploited

→ If R-parity is conserved → SUSY particles are produced in pairs and LSP is stable

If not → LSP is not stable (e.g : $\tilde{\chi}_1^0$→qqq) OR is missing

see J. Benitez talk

→ For all models $\tilde{g}\tilde{g}$ production is assumed

→Decays of gluinos via on-shell or off-shell stops and sbottoms

$\boldsymbol{\tilde{g} \to t\tilde{t}, b\tilde{b}}$ **with** $\boldsymbol{\tilde{t} \to t\,\tilde{\chi}_1^0, \tilde{t} \to c\,\tilde{\chi}_1^0, \tilde{t} \to b\tilde{\chi}_1^{\pm}, \tilde{b} \to b\,\tilde{\chi}_1^0}$

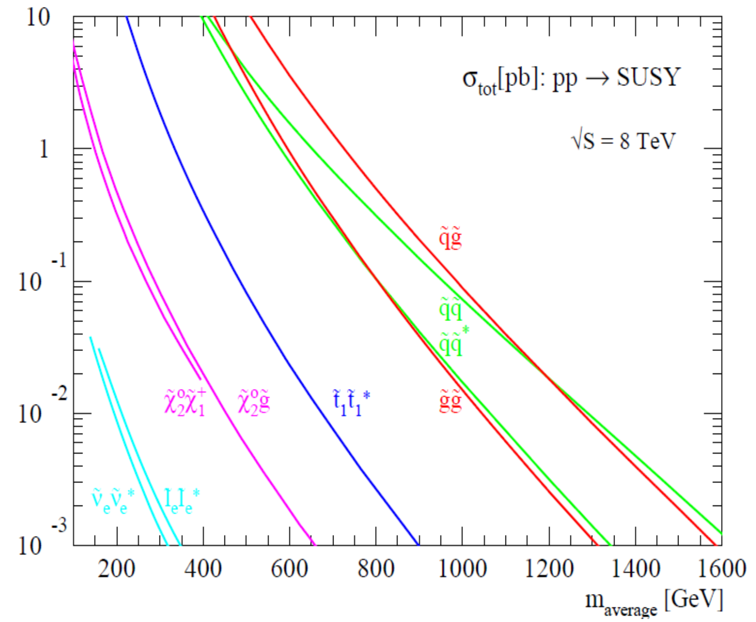
→ Each scenario a 100% BR is assumed

→ Final state: Large missing transverse momentum due to LSP

Multiple jets / b-jets

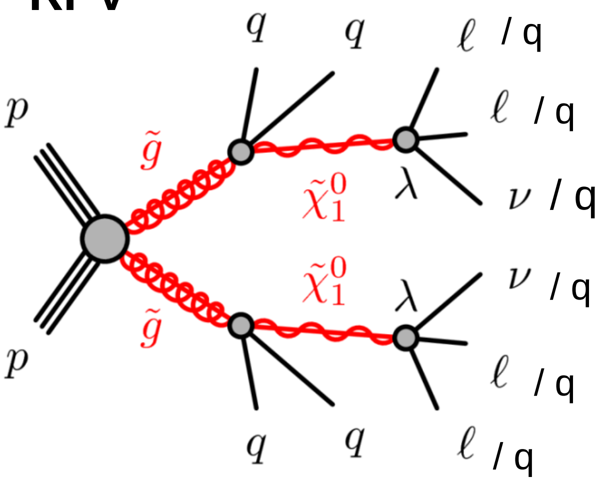
Multiple leptons, possible same-sign pairs

→ Wide range of signatures allows for several analyses covering the same topic

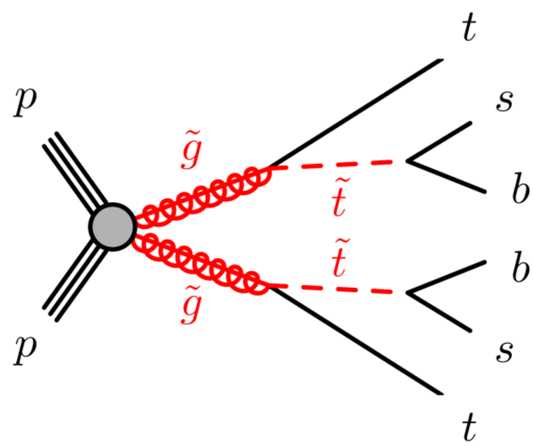


Production and decay modes

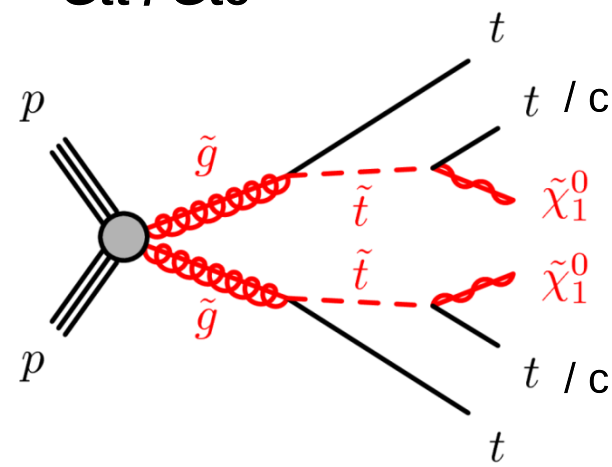
RPV



RPV



Gtt / Gtc



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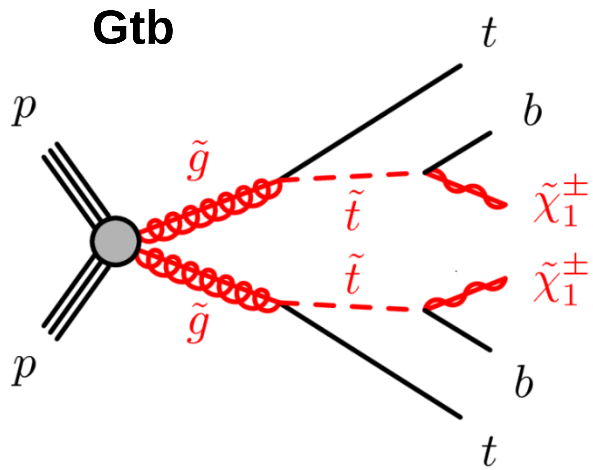

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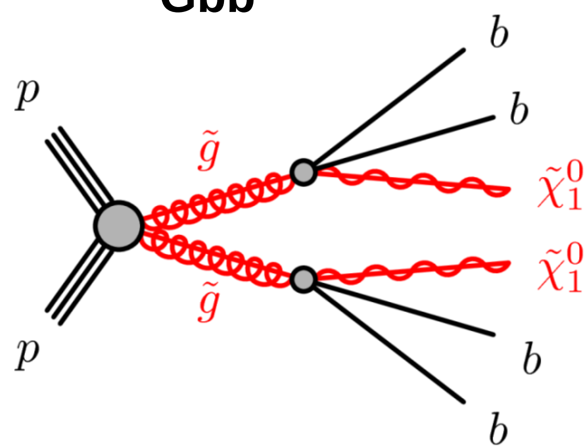
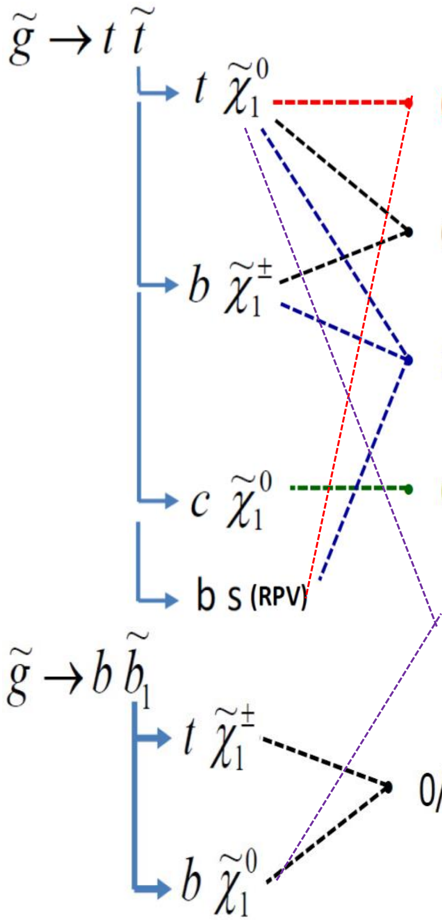


3rd generation gluino-mediates squark searches



Final state	Dataset	Reference
0 lepton + [7-10] jets	@8TeV, $\mathcal{L} = 20.3 fb^{-1}$	arXiv:1308.1841[hep-ex]
0/1 lepton + 3 b-jets + ETmiss	@8TeV, $\mathcal{L} = 20.1 fb^{-1}$	ATLAS-CONF-2013-061
2 same-charge leptons + [0-3] b-jets	@8TeV, $\mathcal{L} = 20.7 fb^{-1}$	ATLAS-CONF-2013-007
0 lepton + [2-6] jets + ETmiss	@8TeV, $\mathcal{L} = 20.3 fb^{-1}$	ATLAS-CONF-2013-047
3 lepton+jets+ETmiss	@8TeV, $\mathcal{L} = 13 fb^{-1}$	ATLAS-CONF-2012-151
0/1 lepton + 3 b-jets + ETmiss	@8TeV, $\mathcal{L} = 20.1 fb^{-1}$	ATLAS-CONF-2013-061

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

ATLAS-CONF-2013-007

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

ATLAS-CONF-2013-007

Target:

→ **2 SS** lepton pairs (ee, eμ, $\mu\mu$), jets, b-jets and MET

→ **Same-sign** lepton pairs: gluino mediated top squarks production leads to 4 top quarks in the final state

→ Searches in events with two same-sign leptons are characterized by very low background

Strategy:

Preselection:

Baseline: Select at least 2 same-sign isolated leptons (e,μ) with p_T > 20 GeV

Triggers: combination of E_T^{miss} or 1 lepton or 2 leptons

(b-jet with p_T >20 GeV, jets with p_T > 40 GeV and $\eta < |2.8|$)

Signal Region-3 signal regions built to provide sensitivity to various scenarios.

Kinematical variables:

$$m_{eff} = E_T^{miss} + \sum_{i=1,2} lep_i p_T + \sum_j jet_j\, p_T;\ m_T = \sqrt{2 p_T^l\, E_T^{miss}\ (1 - \cos[\Delta\phi(l, E_T^{miss})])}\ ;\quad E_T^{miss}$$

Signal regions

Baseline kinematic selection: at least 3jets, E_T^{miss} >150GeV, m_T>100GeV

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

SR0b -sensitive to gluino / squark pair production and no b-jets in the final state (gluino decays via 1st and 2nd generation involving W / Z in the decay chain)

SR1b -b-jet in the final state

SR3b -built to increase the sensitivity to scenarios characterized by the presence of 4 b-jets

Important for gluino-mediated stop

Backgrounds

Due to rareness of same-sign events in SM processes low background expectation:

Irreducible → ZZ+jets, WZ+jets, WW → contributes mainly in SR0b
→ $t\bar{t}$+Z/W production → dominates in SR1b and SR3b

estimated with MC

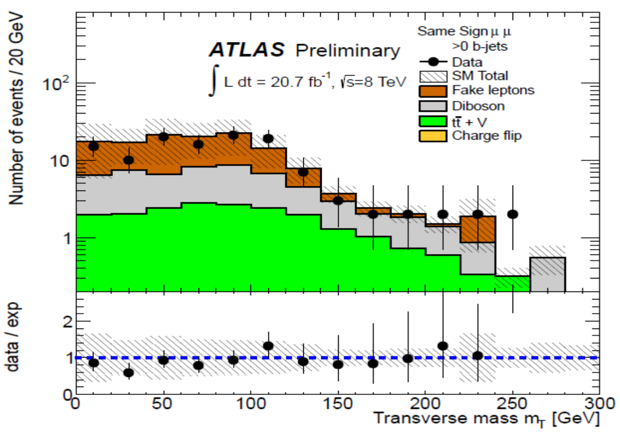
Charge mis-measurement → events of OS -1 lepton charge is mis-identified
$e^{\pm} \rightarrow e^{\pm}\gamma \rightarrow e^{\pm}\, e^{\pm}\, e^{\mp}$
→ mainly from $t\bar{t}$, in dileptonic decays involving electrons

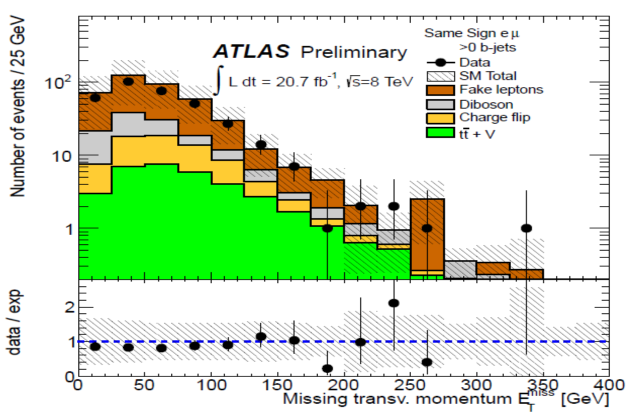
data-driven: measure ratio of SS/OS pairs with Z invariant mass

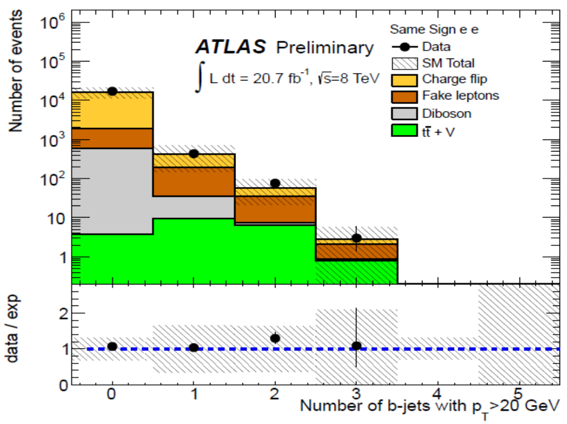
Fakes → at least one of the selected leptons is misidentified
→ mainly from semi/dileptonic with fake from *b* decay ($t \rightarrow Wb$)

data-driven: estimated by a matrix method

Backgrounds checked in validation regions for all same-sign channels (ee, eμ, μμ) separately

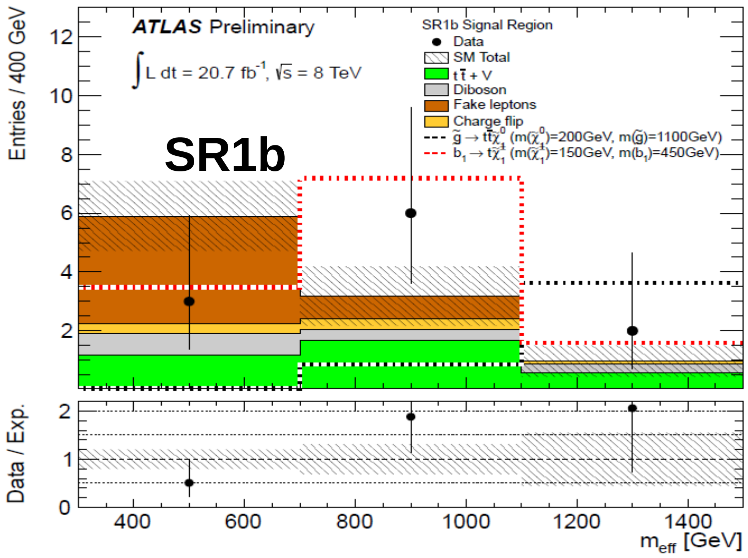






Good agreement within uncertainties between data and background estimation

Results

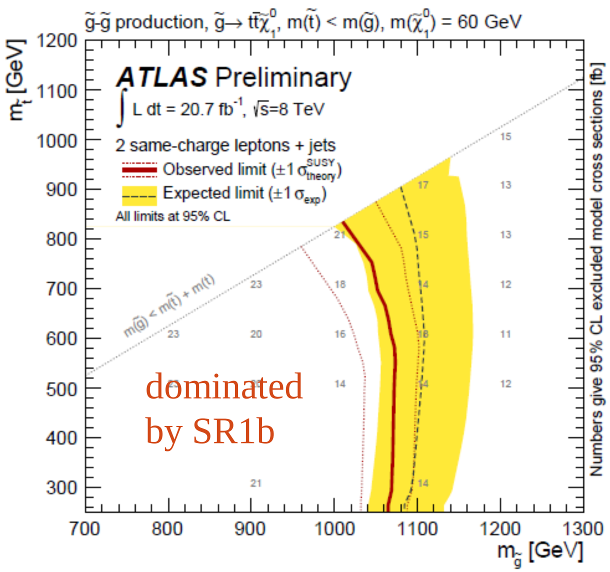


→ perform simultaneous fit across SR using binned m_{eff}
→ fakes contribute at low m_{eff}
→ no significant excess observed
→ SR1b: the largest background contribution and uncertainty is expected from $t\bar{t}$+V events.

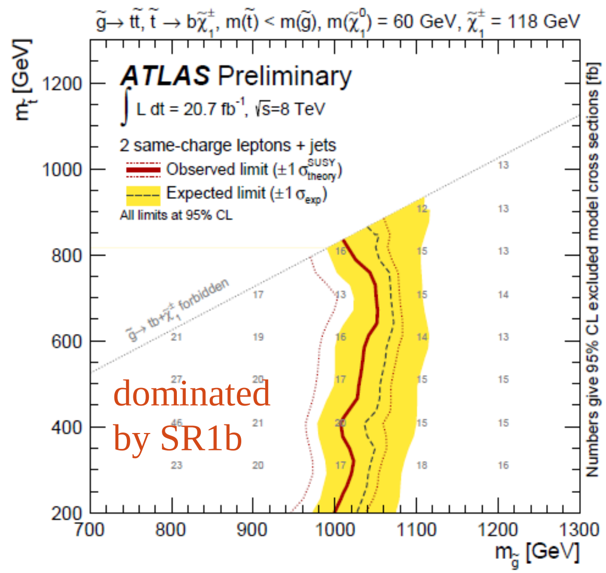
B) Exclusion case	SR0b	SR1b	SR3b
Observed events	5	11	1
Expected background events	7.5 ± 3.2	10.1 ± 3.9	1.8 ± 1.3
Expected $t\bar{t}+V$ events	0.5 ± 0.4	3.4 ± 1.5	0.6 ± 0.4
Expected diboson events	3.4 ± 1.1	1.4 ± 0.7	< 0.1
Expected fake lepton events	3.4 ± 2.9	4.4 ± 3.1	1.0 ± 1.1
Expected charge mis-measurement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

Background errors include statistical and systematic uncertainties

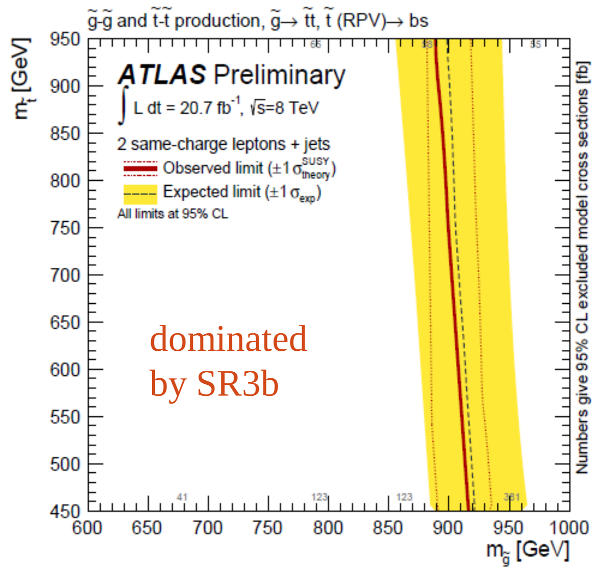
Interpretation



Gluino-stop on-shell



Gluino-stop on-shell



Gluino-stop

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

$\tilde{g} \to t\tilde{t}$, $\tilde{t} \to b\tilde{\chi}^\pm_1$

$\tilde{g} \to t\tilde{t}$, $\tilde{t} \to bs$ (RPV)

Excluding $m_{\tilde{g}} < \sim 1$ TeV, largely independently of the stop mass

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

ATLAS-CONF-2013-061

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

ATLAS-CONF-2013-061

Strategy

Preselection:

Triggers: fully efficient E_T^{miss}
Leading jet with p_T > 90 GeV
E_T^{miss} > 150 GeV
At least 4 jets with p_T > 30 GeV ; At least 3 b-tagged jets with p_T > 30 GeV

Split sample in two:
At least 1 tight isolated lepton (e,μ) with p_T > 20 GeV
Lepton veto

Subdivide the two samples in optimized signal regions, using these variables:
m_{eff}^{incl} → the scalar sum of E_T^{miss} and the p_T of all selected jets and leptons (if any)
m_{eff}^{4j} → the scalar sum of E_T^{miss} and the p_T of the four leading jets
$\Delta\phi_{min}^{4j}$ → the minimum azimuthal angle between E_T^{miss} and any of the four leading jets
Transverse mass → $m_T = \sqrt{2p_T^l E_T^{miss} (1 - \cos[\Delta\phi(l, E_T^{miss})])}$

Signal regions

To enhance the sensitivity to the various models

0 lepton channel:

$\tilde{g} \rightarrow \tilde{b}b$

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

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

0-ℓ region	N jets	p_T jets [GeV]	E_T^{miss} [GeV]	m_{eff} [GeV]	$E_T^{miss}/\sqrt{H_T^{4j}}$ [GeV$^{\frac{1}{2}}$]
SR-0l-4j-A	≥ 4	> 30	> 200	$m_{eff}^{4j} > 1000$	> 16
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 lepton channel:

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

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

1-ℓ region	N jets	E_T^{miss} [GeV]	m_T [GeV]	m_{eff}^{incl} [GeV]	$E_T^{miss}/\sqrt{H_T^{incl}}$ [GeV$^{\frac{1}{2}}$]
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

Backgrounds

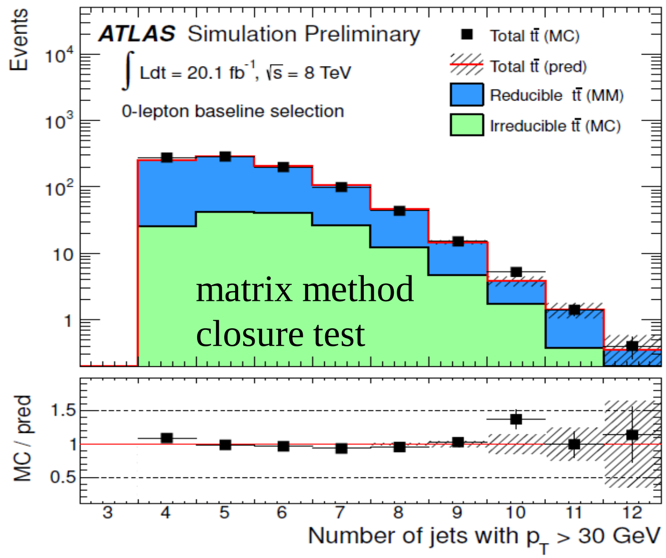
Reducible→ production of $t\bar{t}$ events in association with non b- jets which represents the dominant background
→single t, W+jets, Z+jets, dibosons

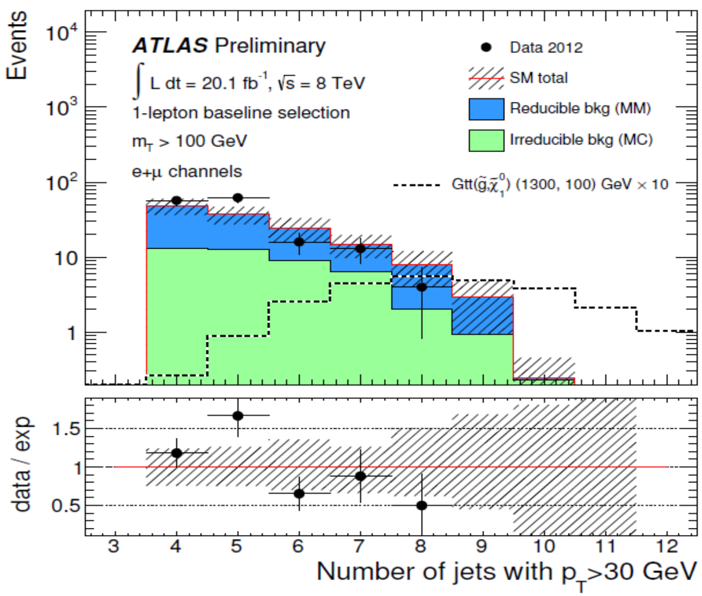
→ data-driven: estimated by a matrix method based on number of b-jets in the event
→ generalization of lepton MM[$2^n \times 2^n$]
→ 2^n-combinations of real and fake b-jets

Irreducticible→ $t\bar{t} + b/b\bar{b}, t\bar{t}$ + V/h with V/h→ $b\bar{b}$

estimated with MC

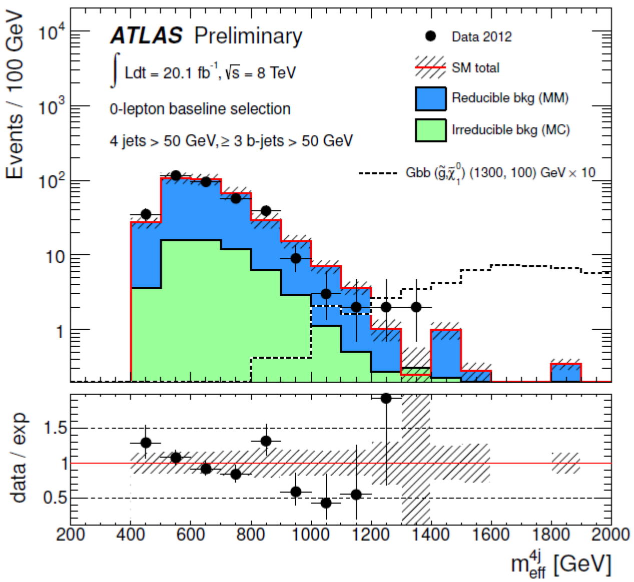
Main uncertainty from fake b-jets estimate

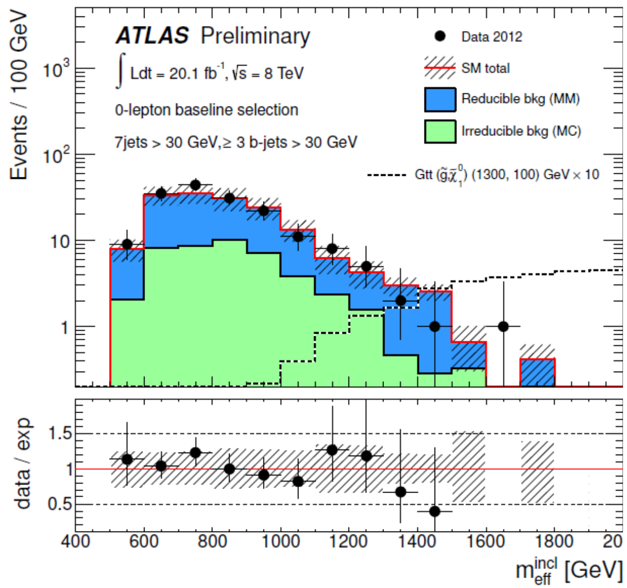


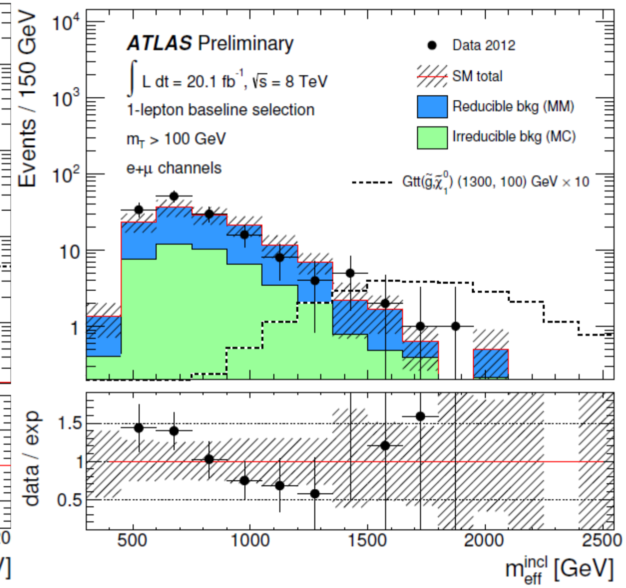


Good agreement between data and background estimation

Results







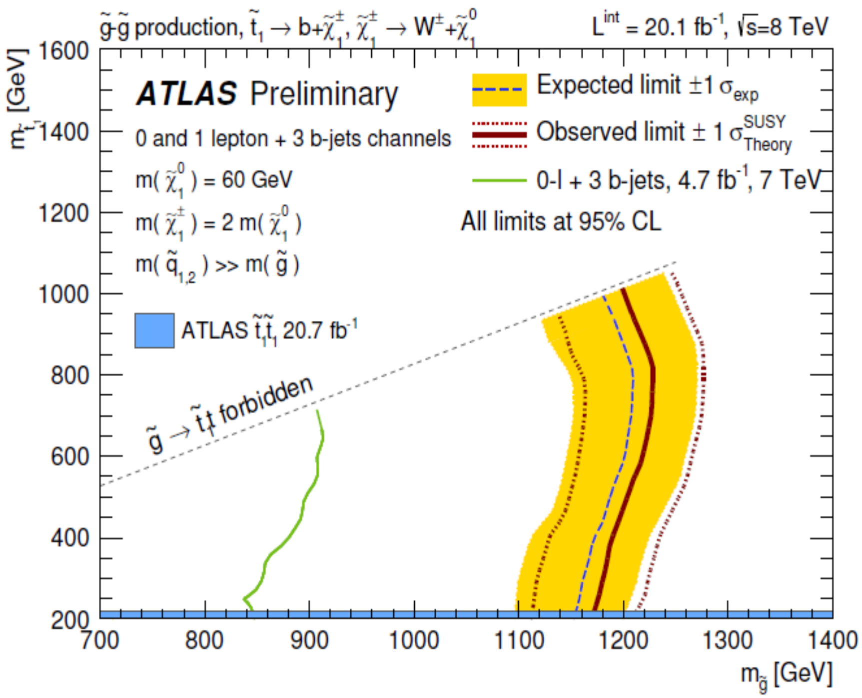
Background estimates in the signal regions

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

→ good agreement between background estimation and observed data.
→ simultaneous fit to 0L and 1L channels for model-dependent exclusion tests.

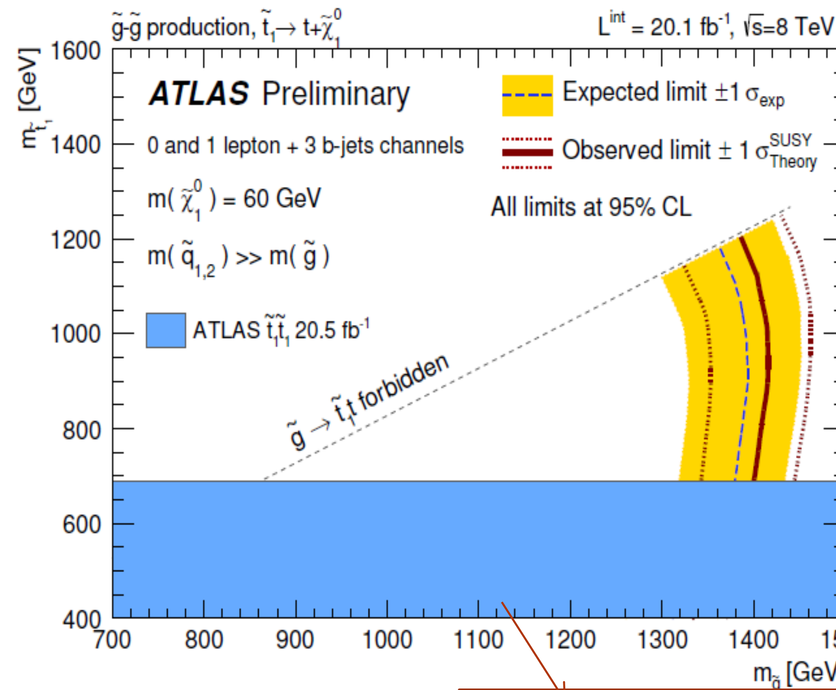
Interpretation

Gluino-stop I



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

Gluino-stop II



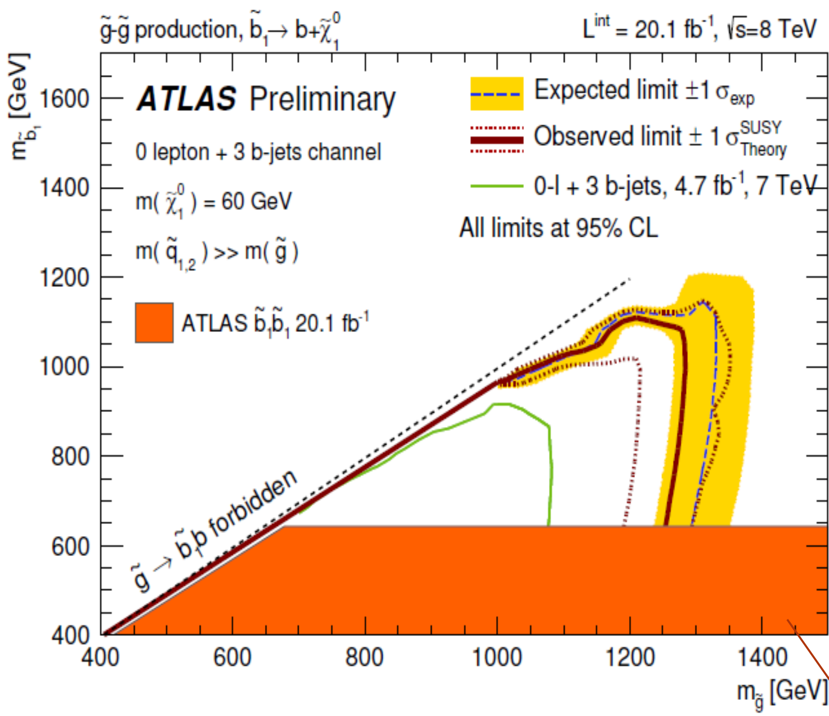
direct stop searches
See Daniel Guest

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

Excluding up to $m_{\tilde{g}} <\sim 1.4$ TeV, largely independently of the stop mass.

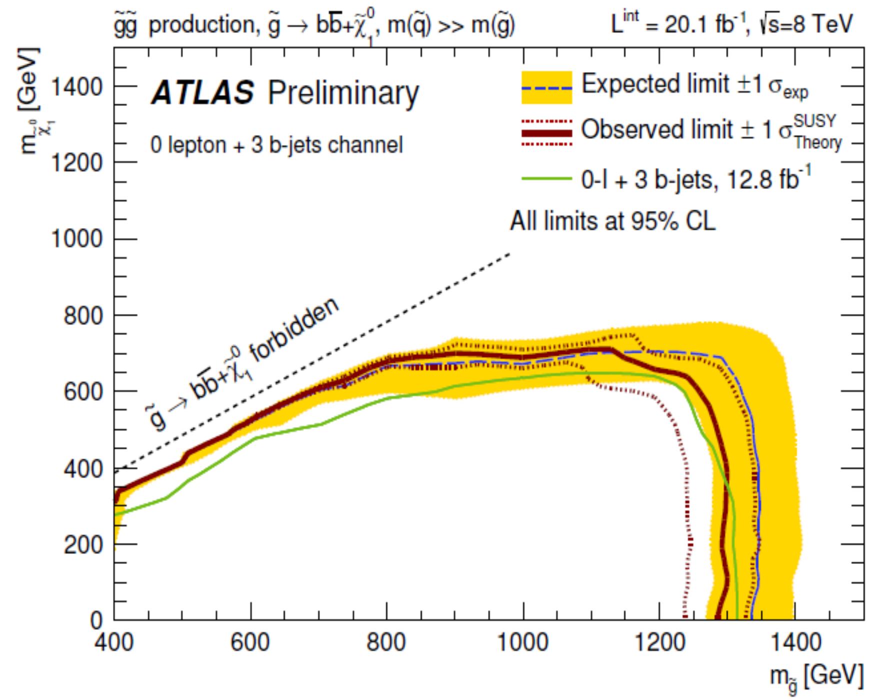
Interpretation

Gluino-Sbottom



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

Gbb



$m_{\tilde{g}}$< 1.2 TeV excluded for $m_{\tilde{b}}$~ 1TeV

direct sbottom searches
See Daniel Guest

Excluding $m_{\tilde{g}}$ < 1.2 TeV for $m_{\tilde{\chi}_1^0}$ < ~ 600 GeV.

0 lepton + [7-10] jets

arXiv:1308.1841 [hep-ex]

0 lepton + [7-10] jets

arXiv:1308.1841 [hep-ex],

See Ljiljana Morvaj talk

Strategy

The usage multi-jet triggers without E_T^{miss} requirements allows to have low cuts on E_T^{miss}

Preselection

Veto events with high p_T electrons or muons in order to suppress W +jets or $t\bar{t}$ background

Large jet multiplicity: from >= 7 to >= 10

Three sets of signal regions:

→ 8, 9 or at least 10 jets with p_T > 50 GeV and zero, one or at least two b-tagged jets

→ 7 or at least 8 jets with p_T > 80 GeV and zero, one or at least two b-tagged jets

Signal regions with "fat-jets":

→ At least 8, 9 or 10 jets with p_T > 50 GeV and M_J^{Σ} > 340 or 420 GeV

All signal regions also impose $E_T^{miss}/\sqrt{H_T} > 4\sqrt{GeV}$ ($H_T = \Sigma\, p_T^{jet}$ using p_T > 40 GeV and $\eta < |2.8|$)

Backgrounds

→ multijets: fully hadronic decays of $t\bar{t}$ and hadronic decay of W and Z bosons + jets

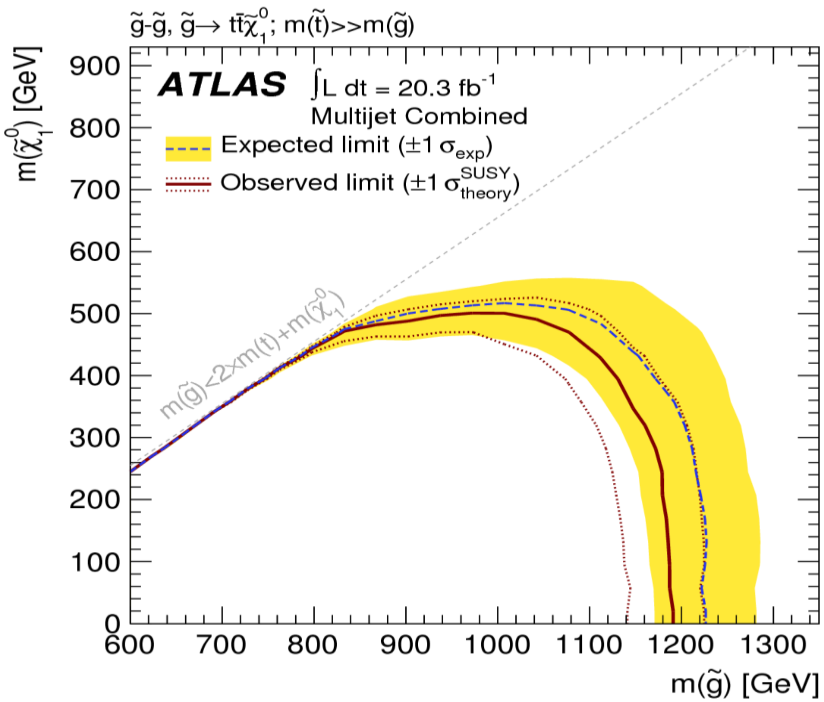
→ semi and fully leptonic decays of $t\bar{t}$

→ leptonically decaying W or Z + jets

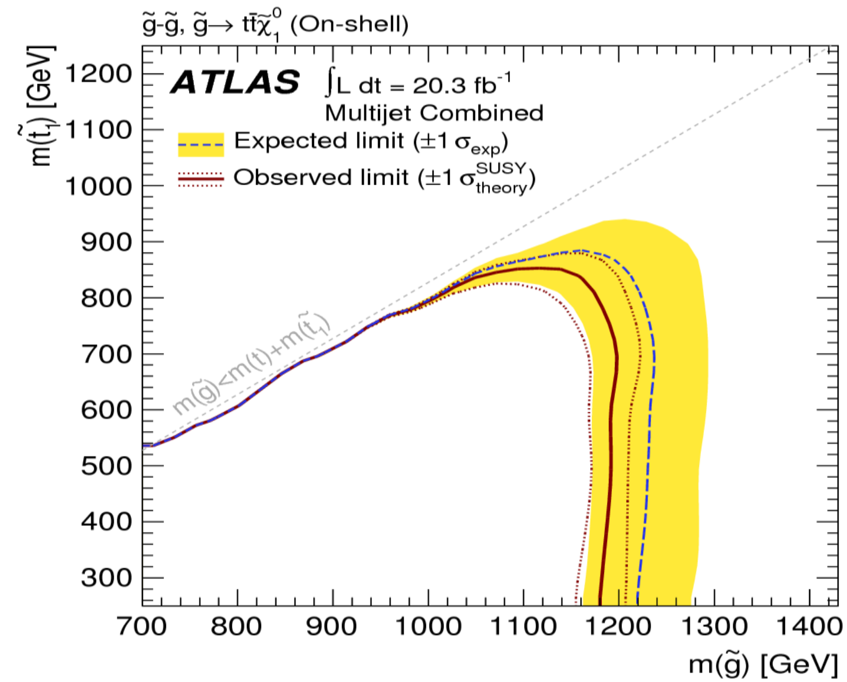
Signal regions with 50 GeV jets are the most sensitive to gluino-mediated stop from flavor stream.

Interpretation

Gluino-stop (off-shell) $\tilde{g} \rightarrow t\tilde{t}^{*}$, $\tilde{t} \rightarrow t\tilde{\chi}_1^0$



Gluino-stop (on-shell) $\tilde{g} \rightarrow t\tilde{t}$, $\tilde{t} \rightarrow t\tilde{\chi}_1^0$



$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ with unit probability via an off-shell $\tilde{t}$
→ $m(\tilde{g}) \leq 1.1$ TeV excluded for $m(\tilde{\chi}_1^0) \leq 350$ GeV

With fixed $m(\tilde{\chi}_1^0) = 60$ GeV
→ $m(\tilde{g}) \leq 1.1$ TeV excluded for $m(\tilde{t}) \leq 750$ GeV

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

ATLAS-CONF-2013-047

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

ATLAS-CONF-2013-047

See Ljiljana Morvaj talk

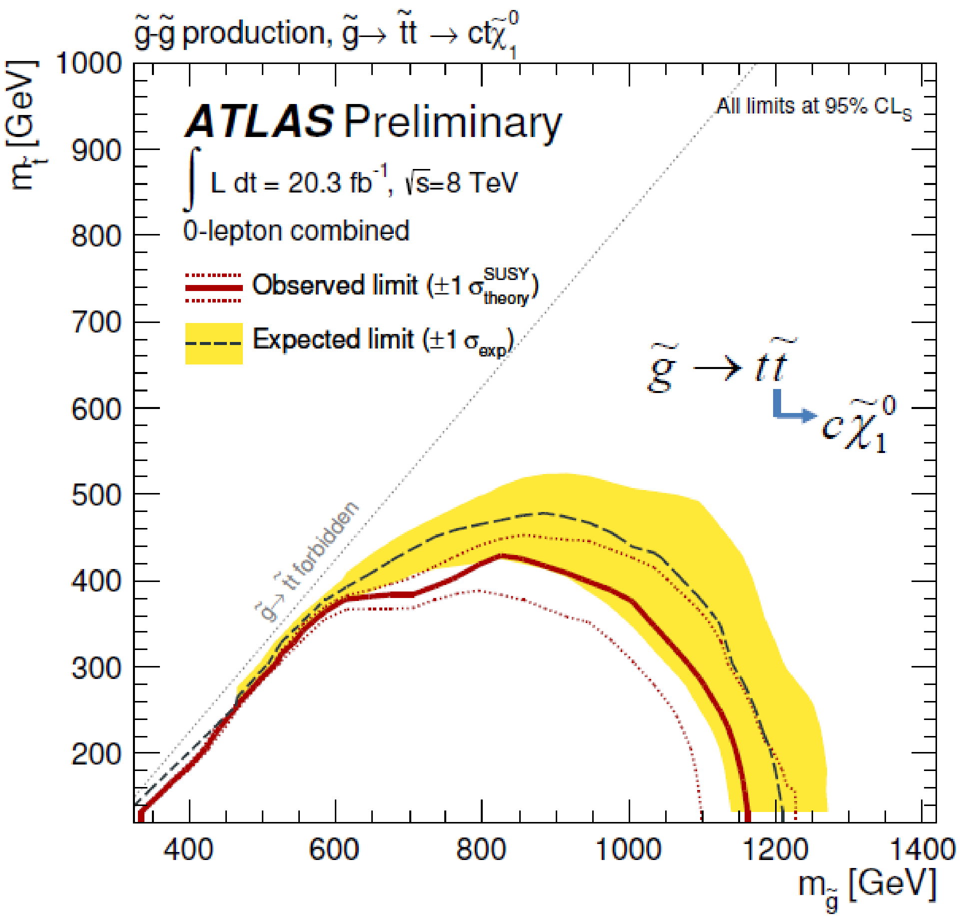
→ Five types of signal regions
→ SRE(6jets) best for gluino-mediated stop→charm

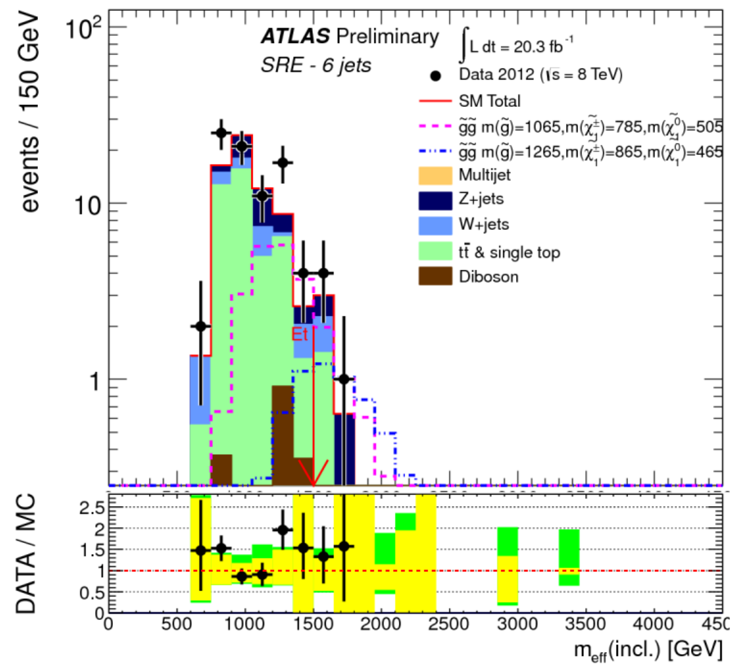
Requirement	Channel										
	A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
	L	M	M	T	M	T	–	L	M	T
E_T^{miss} [GeV] >	160									
$p_T(j_1)$ [GeV] >	130									
$p_T(j_2)$ [GeV] >	60									
$p_T(j_3)$ [GeV] >	–		60		60		60	60		
$p_T(j_4)$ [GeV] >	–		–		60		60	60		
$p_T(j_5)$ [GeV] >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

(a) For SR A-medium the cut on $E_T^{miss}/m_{eff}(Nj)$ is replaced by a requirement $E_T^{miss}/\sqrt{H_T} > 15\ \text{GeV}^{1/2}$.

Interpretation

ATLAS-CONF-2013-047



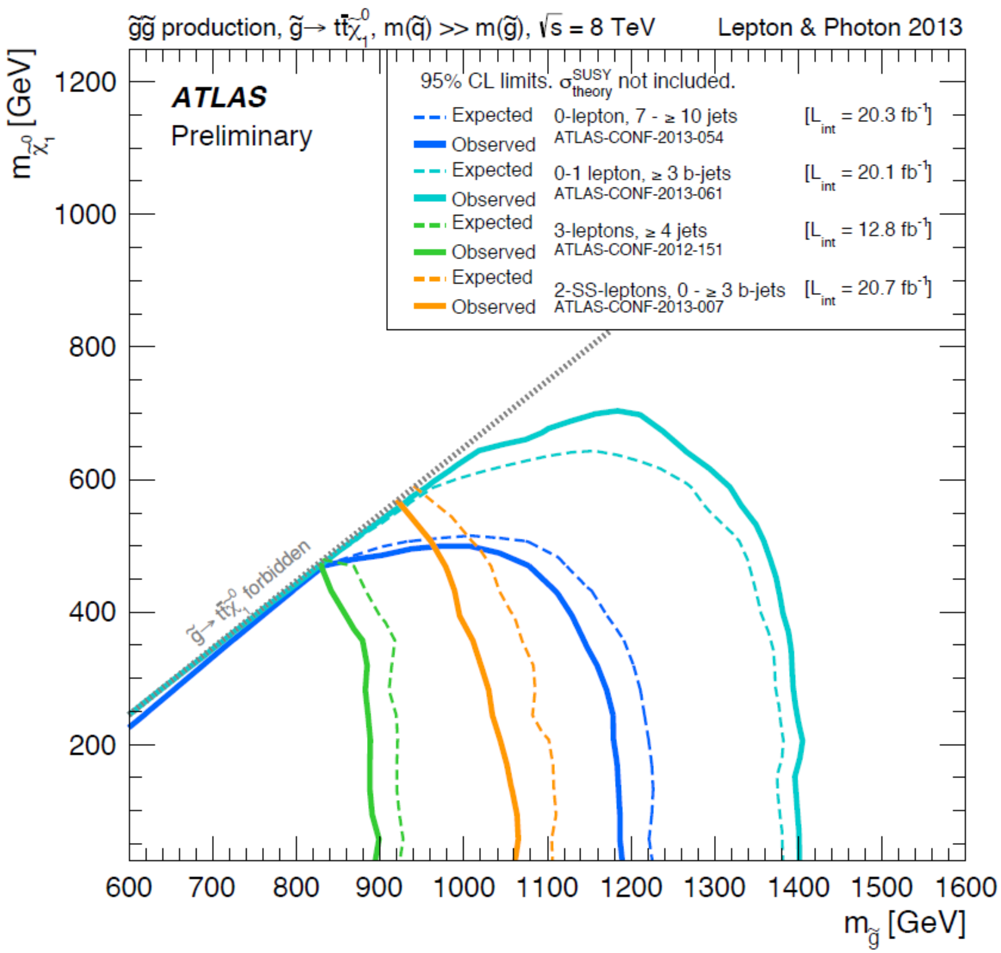


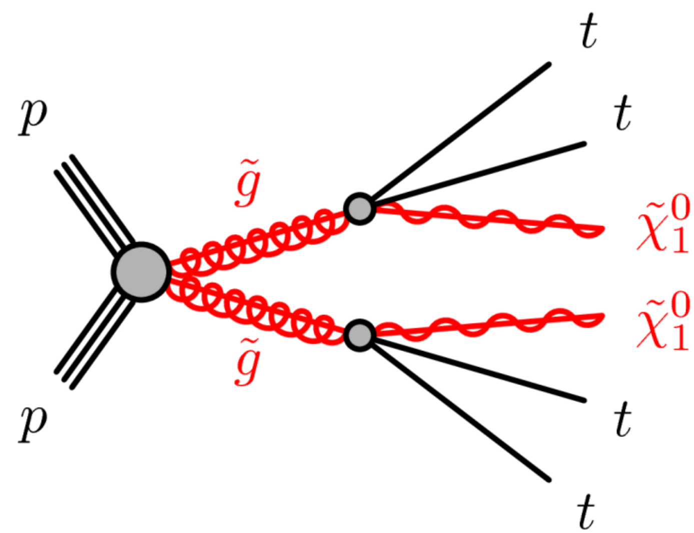
Exclusion limits for pair produced gluinos

$\tilde{t} \rightarrow c\tilde{\chi}_1^0$ and $\Delta M\ (\tilde{t}, \tilde{\chi}_1^0) = 20$ GeV

Exlclude m($\tilde{g}$) up to 1 TeV for m($\tilde{t}$) up to 420 GeV

Results of various SUSY searches for gluino-mediated stop → top χ_1^0 model





Sensitivity dominated by
0/1 lepton + 3 b-jets + E_T^{miss}
ATLAS-CONF-2012-151
Excluding $m_{\tilde{g}}$<~ 1.4 TeV
for $m_{\tilde{\chi}_1^0}$ < ~350 GeV.

Conclusions

Gluino-mediated production of 3rd generation squarks strongly motivated by SUSY Naturalness.

Stringent limits from several analyses :

- 2 same-sign leptons, jets, MET
- 0/1lepton, 3bjets, MET
- 0 lepton, [7-10] jets
- 0 lepton, [2-6] jets, MET

Limits set are largely independent from *stop* and *sbottom* masses

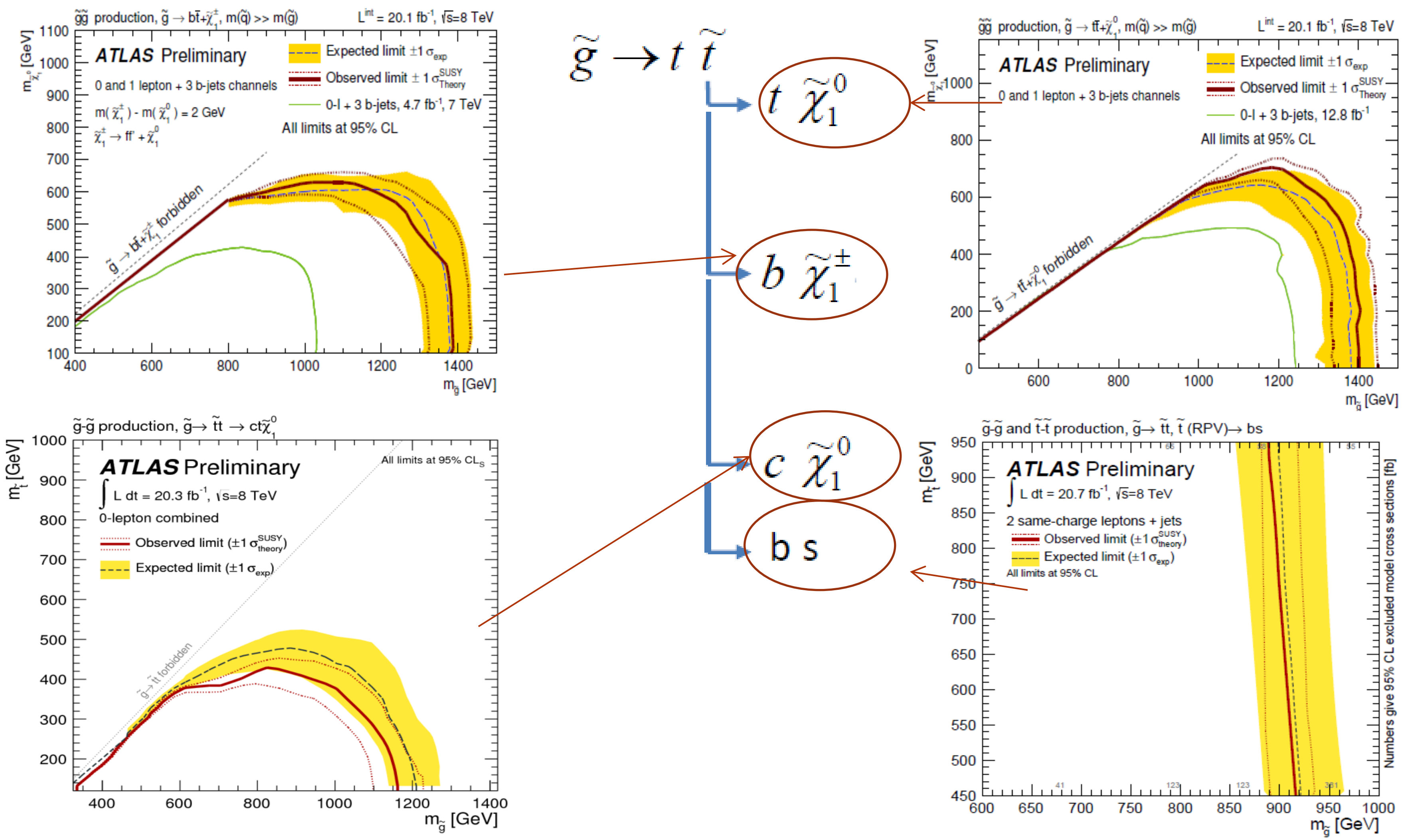
No significant excess above SM expectations has been seen.

Looking forward to ~14 TeV data!

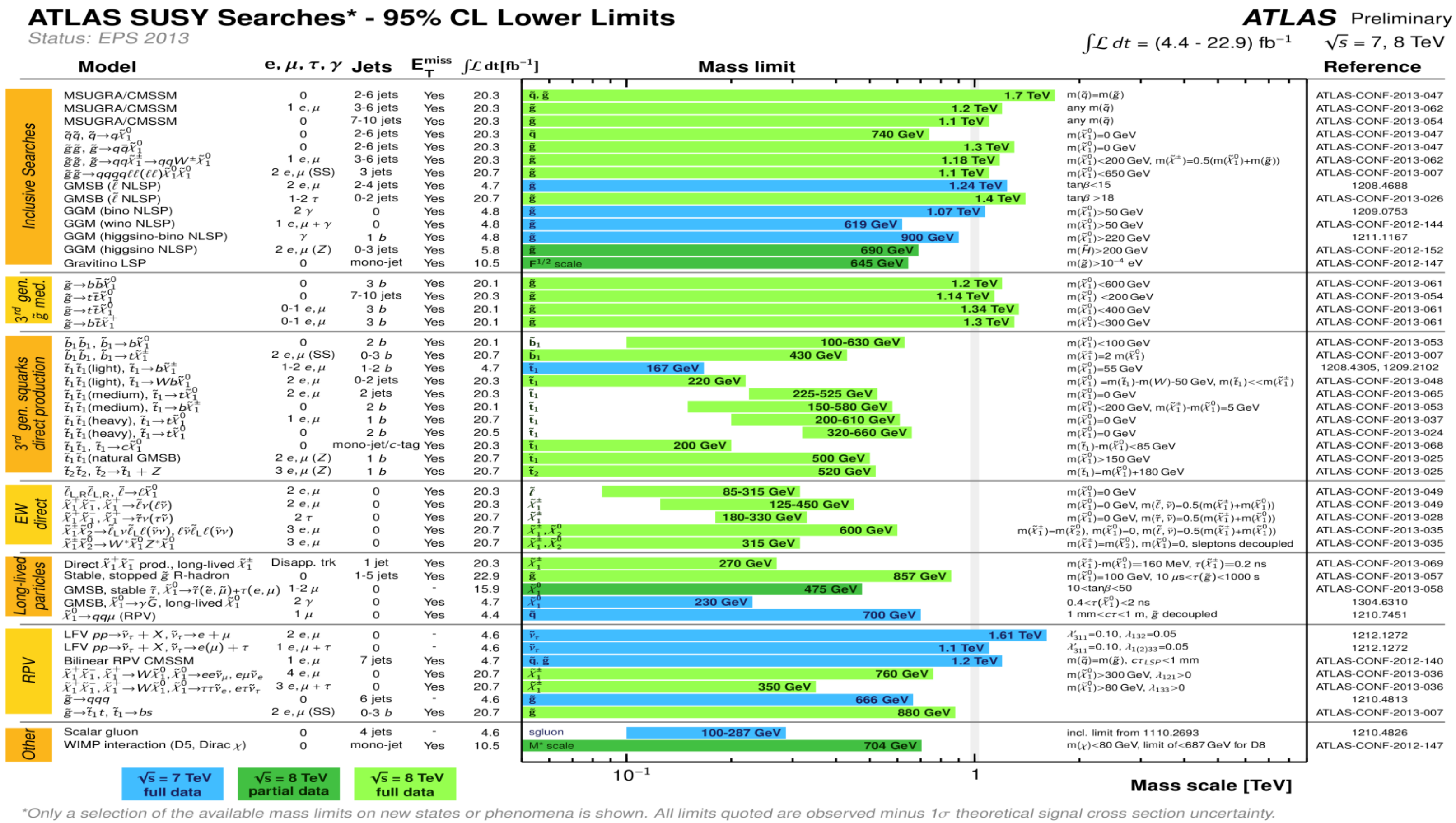
All results can be found on this webpage, summarising all public ATLAS SUSY results.

Backup

Limits on all gluino-mediated stop decays



Mapping SUSY



3 lepton + jets + E_T^{miss}

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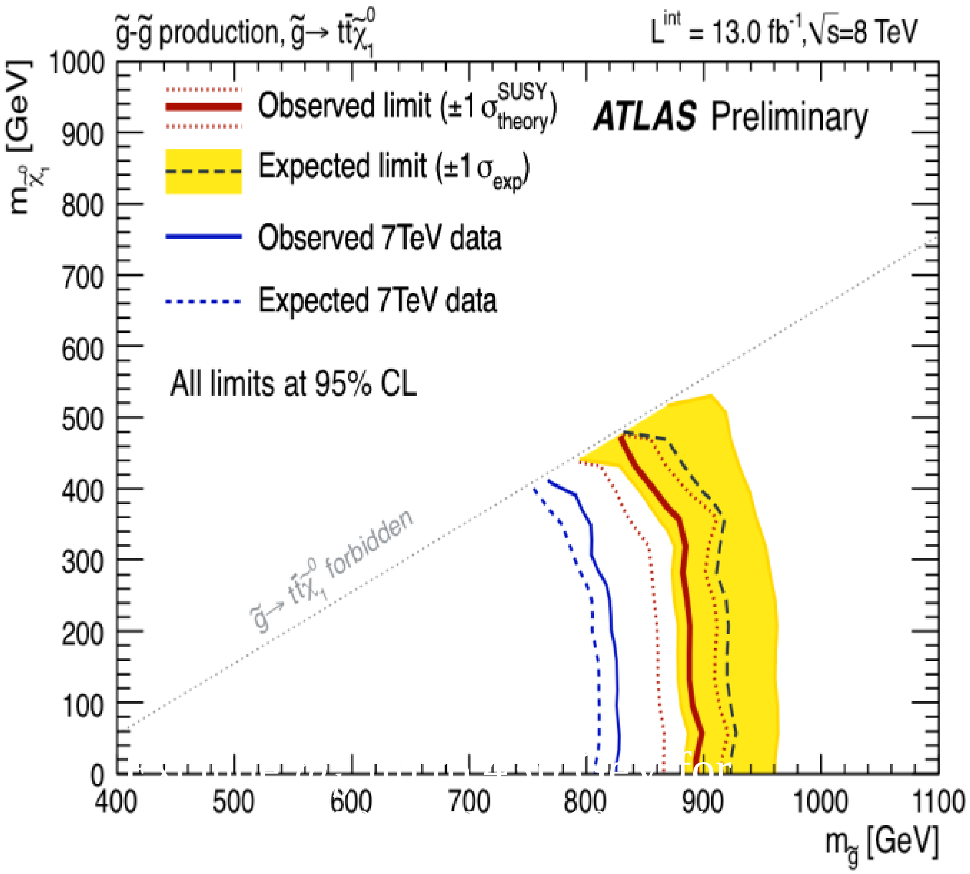
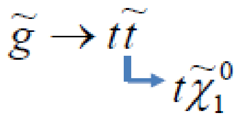




$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$

Exclude $\tilde{\chi}_1^0$ below 440 GeV for $m_{\tilde{g}} = 800$ GeV

Matrix Method

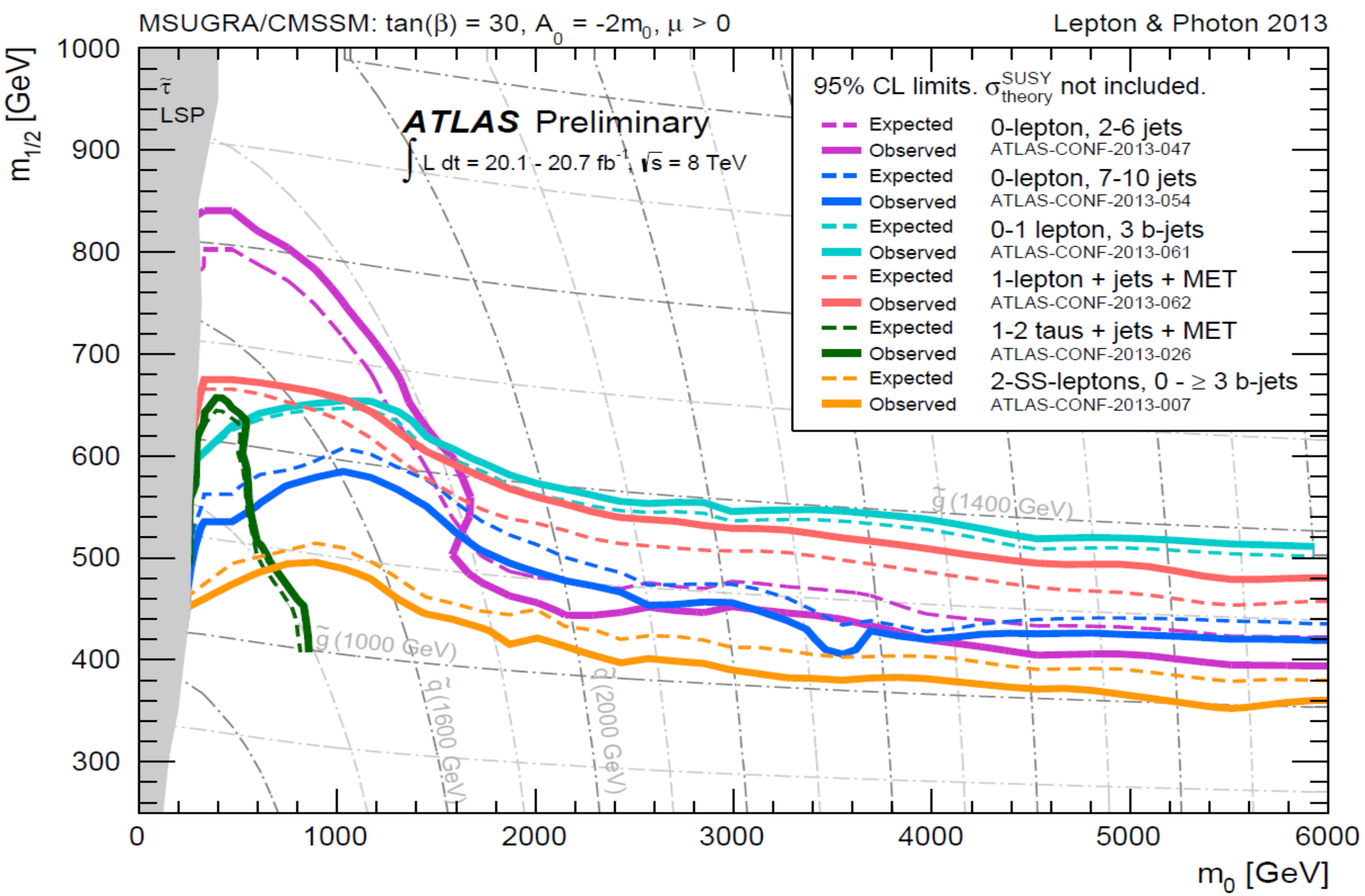
- Matrix method of estimation of multijet backgrounds faking leptons:
    - Construct four high-statistics control regions with respectively tight (T) and loose (L) lepton definitions: TT,TL,LT,LL
    - The event yields in these regions is correlated to the number of events from real and fake leptons through this matrix:

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

ς_i: misidenfication rate, ε_i: real lepton efficiency

    - By inverting the matrix, one obtains the fake rate estimate from the yields in the control regions
- This method can be generalized to estimate light multijet backgrounds faking b-flavoured jets

MSUGRA/CMSSM model



Gluino-mediated stop dominates at large m_0, showing sensitivity of 1 lepton + jets + E_T^{miss}