Search for strongly produced superpartners in final states with same-sign leptons and jets

LHC France workshop, 5th April 2013

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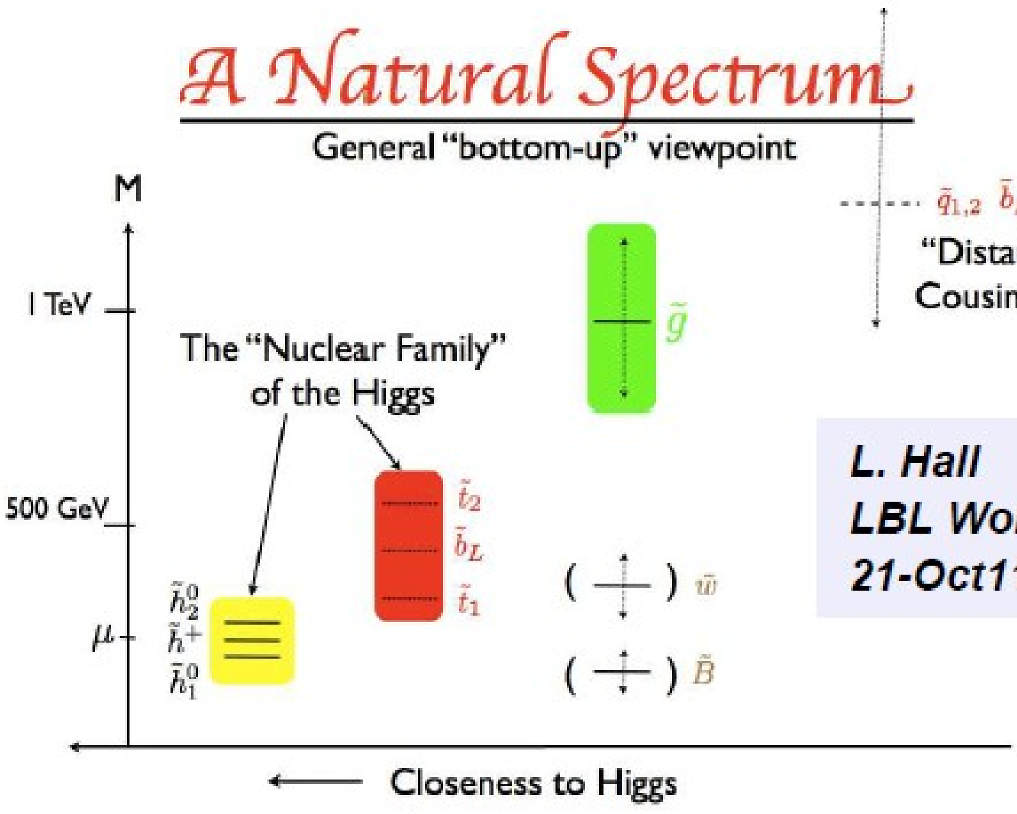
CPPM

ATLAS EXPERIMENT

Motivations

- **Natural SUSY**: protects Higgs mass divergence by loop cancellations with superpartners



L. Hall
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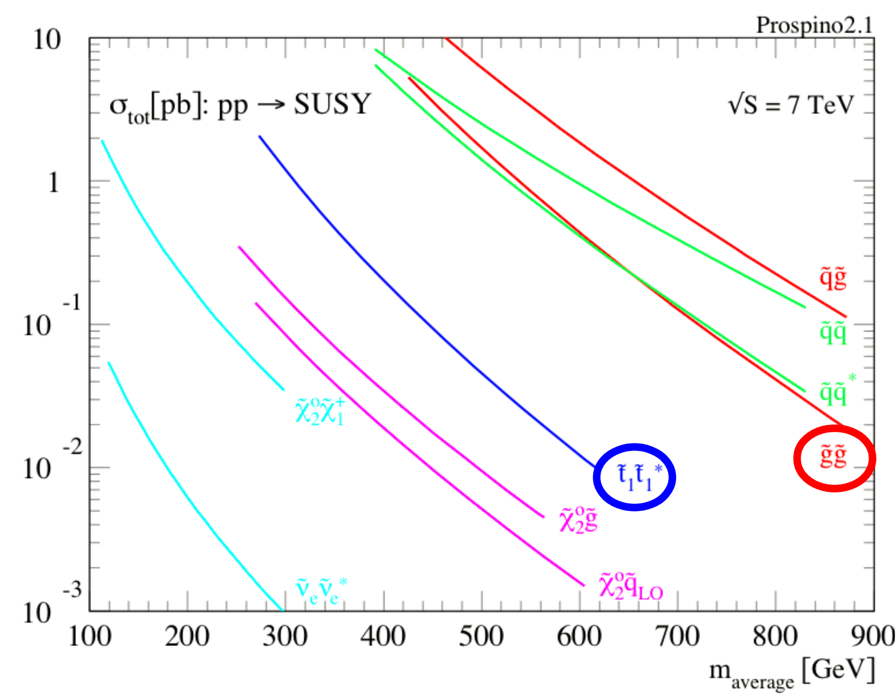

- Great interest in searches for 3rd generation squarks

Overview

- **Search** for strongly produced superpartners in final states with same-sign leptons

  → useful complement to 0-lepton searches, thanks to low SM background

- **Preliminary ATLAS results** with whole 2012 dataset, $L = 20.7\ fb^{-1}$, $\sqrt{s} = 8$ TeV

  ATLAS-CONF-2013-007

  - SUSY signatures
  - Definition of signal regions
  - Background estimation

- **Large improvement** of earlier results (07/2012) with 5.8 fb^{-1}, $\sqrt{s} = 7$ TeV

  ATLAS-CONF-2012-105

- **Also highlights** from latest CMS results with 10.5 fb^{-1}, $\sqrt{s} = 8$ TeV

  arXiv:1212.6194

Signatures with strong production

- Same-sign leptons in MSSM: Majorana nature of gluino, multi-lepton final states

gluino-mediated stop/sbottom

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

$\tilde{g} \to t\,\tilde{t}_1$, $\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm}$ / $t\,\tilde{\chi}_1^{0}$ / b s

- $t\,\tilde{\chi}_1^{\pm}$: Gluino-stop ($b\tilde{\chi}_1^{\pm}$) degenerate ($m_{\tilde{\chi}_1^{\pm}}, m_{\tilde{\chi}_1^{0}}$)
- $b\,\tilde{\chi}_1^{\pm}$: Gluino-stop ($b\tilde{\chi}_1^{\pm}$) on-shell
- with $\tilde{\chi}_1^{\pm} \to W^{\pm(*)}\tilde{\chi}_1^{0}$

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

- $t\,\tilde{\chi}_1^{0}$: Gluino-stop ($t\tilde{\chi}_1^{0}$) off-shell ($m_{\tilde{g}} < m_{\tilde{t}} + m_t$)
- $t\,\tilde{\chi}_1^{0}$: Gluino-stop ($t\tilde{\chi}_1^{0}$) on-shell ($m_{\tilde{g}} > m_{\tilde{t}} + m_t$)
- b s: Gluino-stop (bs) RPV
  → Allanach,Gripaios arXiv:1202.6616

Gluino-squark

$\tilde{g} \to q\,\tilde{q}$

- $\tilde{q} \to q'\,\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to W^{\pm(*)}\tilde{\chi}_1^{0}$: Gluino-squark (via W)
- $\tilde{q} \to q'\,\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to \tilde{\ell}\nu, \ell\tilde{\nu}$; $\tilde{q} \to q\,\tilde{\chi}_2^{0}$, $\tilde{\chi}_2^{0} \to \tilde{\ell}\ell, \tilde{\nu}\nu$: Gluino-squark (via slepton)

$$\tilde{g}\,\tilde{g} \to qqqq\,ll\,(ll, \nu\nu)\,\tilde{\chi}_1^0\tilde{\chi}_1^0$$

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direct sbottom

$\tilde{b}_1 \to t\,\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to W^{\pm(*)}\tilde{\chi}_1^{0}$

- direct sbottom ($t\tilde{\chi}_1^{\pm}$) fixed $m_{\tilde{\chi}_1^0}$
- direct sbottom ($t\tilde{\chi}_1^{\pm}$) varied $m_{\tilde{\chi}_1^0}$

$$\tilde{b}_1\tilde{b}_1^* \to bbWWWW\,\tilde{\chi}_1^0\tilde{\chi}_1^0$$

direct squark

$\tilde{q} \to q'\,\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to \tilde{\ell}\nu, \ell\tilde{\nu}$

$\tilde{q} \to q\,\tilde{\chi}_2^{0}$, $\tilde{\chi}_2^{0} \to \tilde{\ell}\ell, \tilde{\nu}\nu$

- direct squark (via slepton)

Many others :
- direct stop
- compressed gauginos

...

A powerful signature to look for new physics !

Signal region definitions

- **Optimized** signal regions to be sensitive to various SUSY scenarios

  using #(b-) jets, E_T^{miss}, m_T (leading lepton), $m_{eff} = E_T^{miss} + \sum |p_T|$ (jets+leptons)

- **Base requirement** : two leptons (e,μ, p_T>20 GeV) with identical charge

  \+ mll >12 GeV to reject bottom/charmed hadrons leptonic decays

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	≥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	≥3	$N_{jets} \geq 4$ -	$N_{jets} \geq 5$, E_T^{miss}< 150 GeV or m_T< 100 GeV

Main signal region: wide coverage

- Models with 4 b-quarks
- Almost no SM background
- No cut on $\not{E}_T$, m_{eff}, m_T

Changes wrt 5.8 fb^{-1} results :

- Split regions in #b-jets
- Add m_{eff}, m_T + softer cuts

Irreducible background

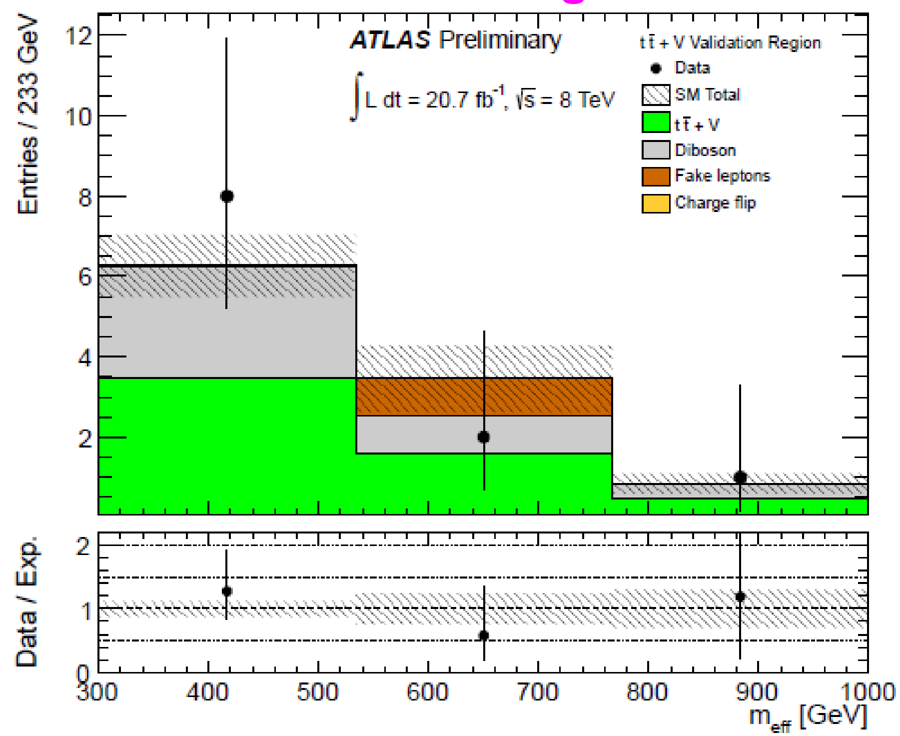
- **A few processes** in SM contribute to the production of same-sign leptons final states

Main bkg in SR0b → diboson

Main bkg in SR1,3b → ttbar + boson

		σ
diboson:	**WZ**	12 pb
	ZZ	4.7 pb
	$W^{\pm}W^{\pm}$	40 fb
	WWW*,WZW*,ZZZ*	0.4 pb
ttbar + boson:		
	tt+W	0.23 pb
	tt+Z	0.21 pb
	tt+WW	1 fb
Associate Higgs production:		
	tt+H,WH,ZH	0.3 BR × 1.2 pb

Validation region tt+V



- **Estimated** by Monte-Carlo prediction
- **Low cross-sections** processes : can't use normalization regions, rely on theory

Main systematics

- Cross-section : up to 30% for tt+V
- Shape (comparing MC generators)
- Jet energy scale, b-tag mistag rate

→ Not well-known processes
tt+W never observed alone

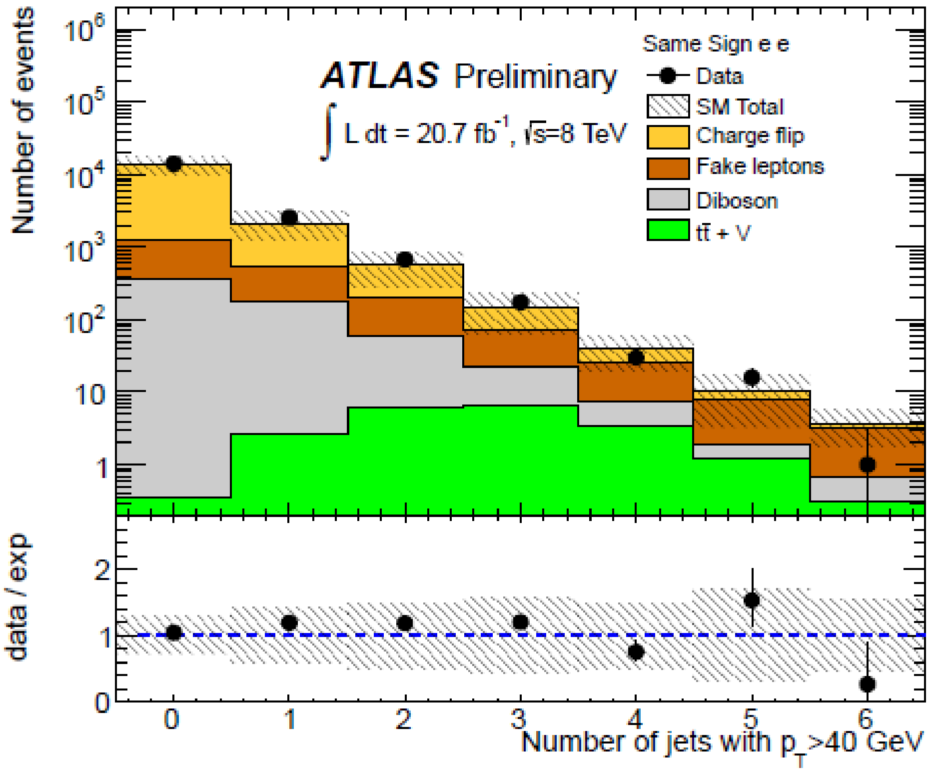
Detector background : electron charge flip

- **Reconstructed electron charge** flipped with respect to original electron
  - Mostly brehmstrahlung photons that convert in e^+e^- pair in material
  - Converted electron track picked by reco algorithm instead of original
  - **Negligible for muons !**
- **Contribution to SR** mainly from dileptonic ttbar
- **Charge flip (CF) rate** measured in data
  - Use abundant Z→ee decays
  - Check yield of $e^\pm e^\pm$ over e^+e^-
  - Large variation over η, less p_T
- **Bkg in SR:** weight opposite-sign pair events in data by charge-flip rate
  → fully data-driven

Systematics

- Closure test on rate measurement
  → 10 to 40%

Validation region CF, ee pairs



Detector background : fake leptons

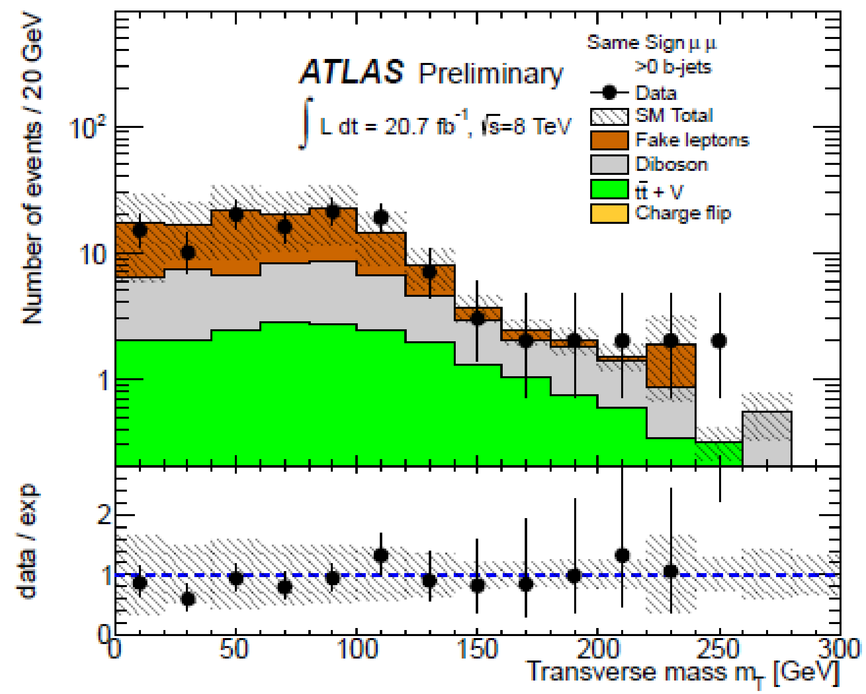
- **Several sources** of lepton fakes:
  - Light hadrons faking electrons
  - In-flight decays of kaons to muons
  - Non-isolated leptons in bottom/charmed hadrons decays

- **Dominant source** in SR1b: semi-leptonic ttbar with non-prompt lepton from b hadron

- **Estimated** by data-driven ***matrix method***

- Classify events in 4 categories, from loosely identified leptons passing or not tight isolation cuts
- Probability to pass tight cut lower for fake leptons
- Express #pass/#fail as a function of #real/#fake → build system of 4 equations
- Invert system to get the number of fake leptons

Validation region fakes, μμ pairs



- Requires prior knowledge of efficiencies → measured in samples enriched in real/fakes
- Large systematic (≥50%) from fake rate: nature of fakes, extrapolation to SR...

Wrap-up : background estimation

Standard Model SS

- Mainly tt+V, diboson in SR0b
- MC estimate
- Major source of bkg

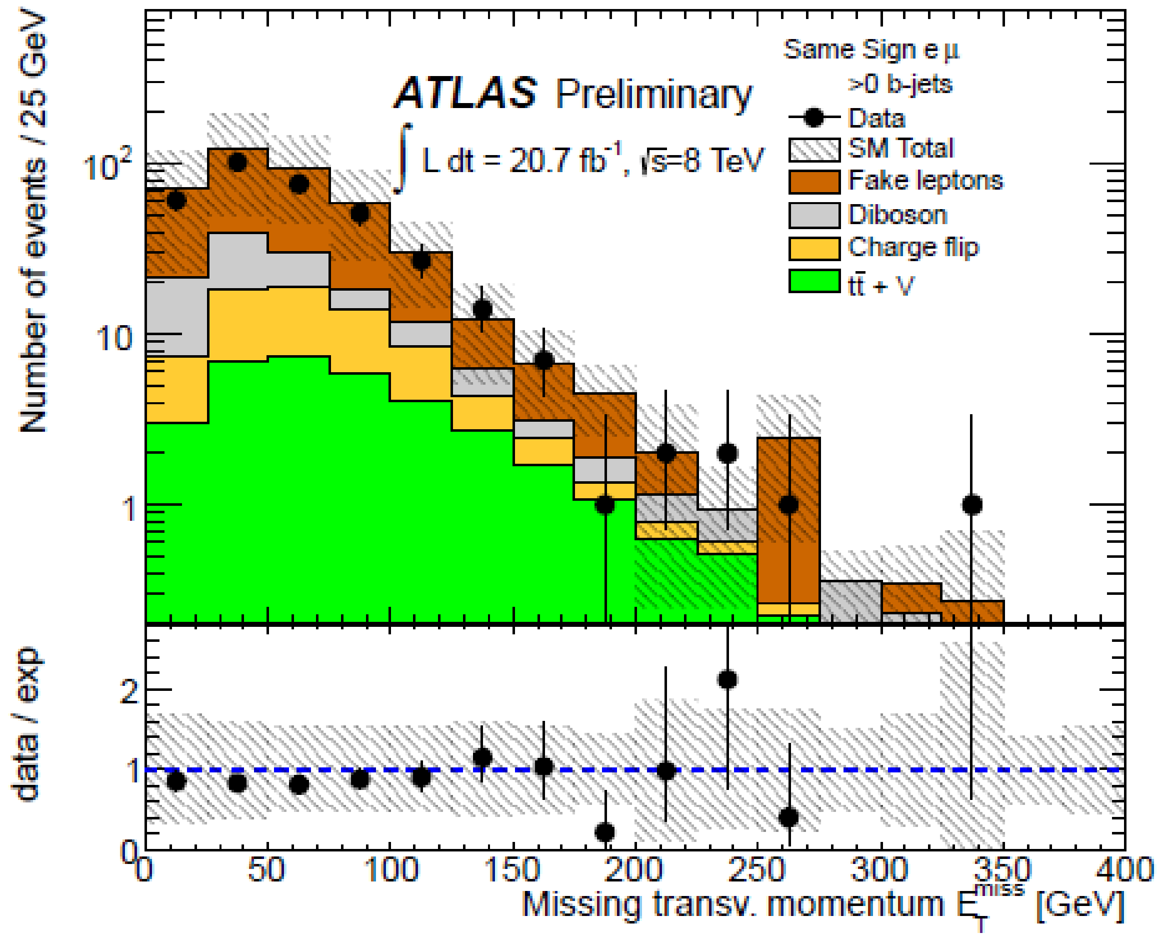
Electron charge flip

- Data-driven estimate in ee,eμ
- OS data, weighted
- Generally minor component

Fake leptons

- Data-driven estimate
- Matrix method: lept. isolation
- Contributes up to 50% in SR

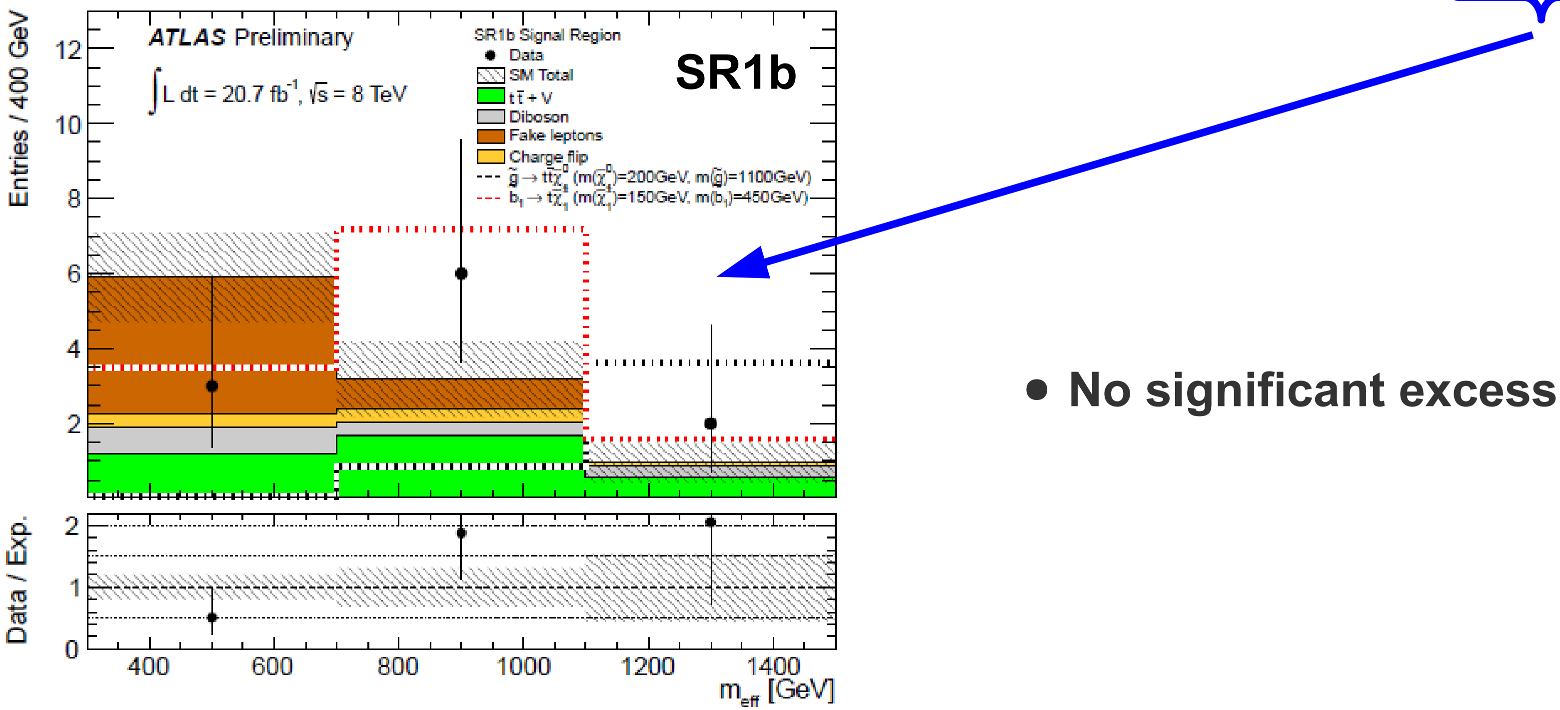
Validation region, eμ pairs



Background estimation validated by checking numerous distributions → satisfying agreement

Observed data in signal regions

A) Discovery case	SR0b	SR1b	SR3b
Observed events	5	8	4
Expected background events	7.5 ± 3.3	3.7 ± 1.6	3.1 ± 1.6
Expected $t\bar{t} + V$ events	0.5 ± 0.4	2.2 ± 1.0	1.7 ± 0.8
Expected diboson events	3.4 ± 1.0	0.7 ± 0.4	0.1 ± 0.1
Expected fake lepton events	3.4 ± 3.1	$0.3^{+1.1}_{-0.3}$	$0.9^{+1.4}_{-0.9}$
Expected charge mis-measurement events	0.1 ± 0.1	0.5 ± 0.2	0.4 ± 0.1
p_0	0.50	0.11	0.36



- **No significant excess** observed in data

Interpretation of the results

- **Model-independent limits** on visible cross-section, and observed amount signal

  → 95% confidence intervals in CLs formalism

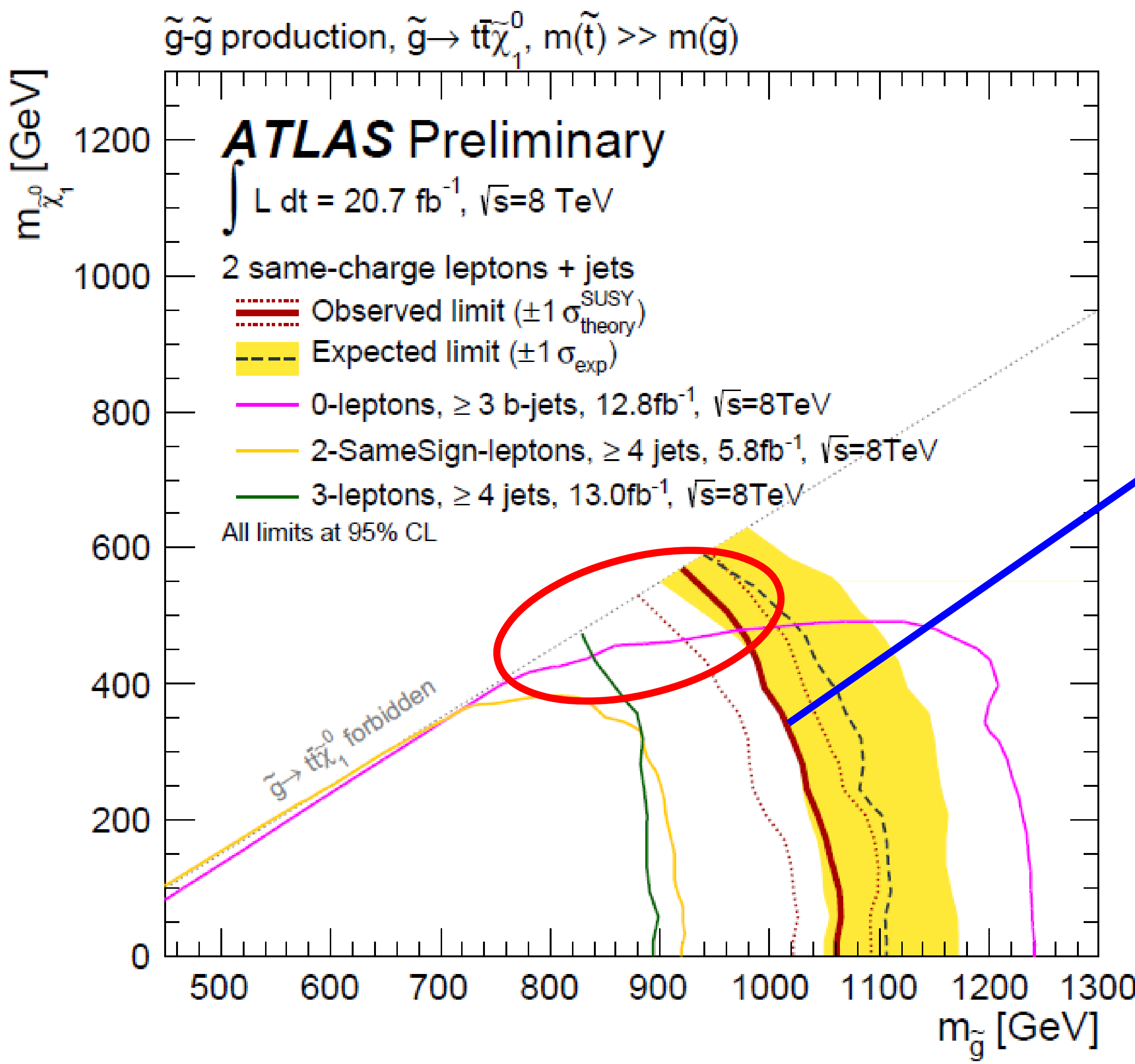
  - Limit on number of events in SR originating from any BSM process
  - Any model predicting more can be excluded, we would have seen it !

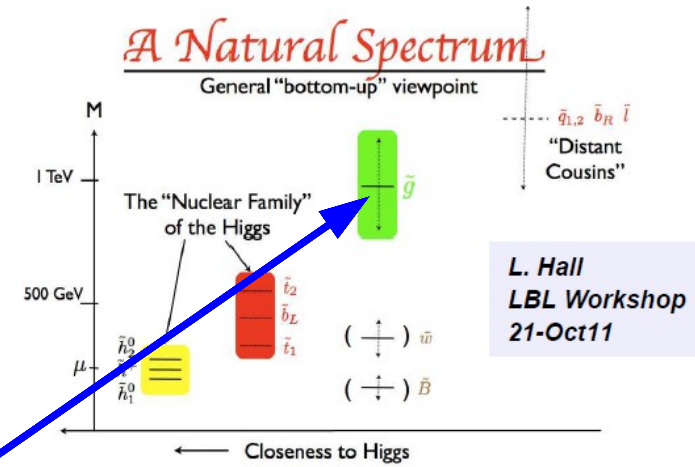
Signal regions	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}
SR0b	0.33	6.7	$7.9^{+2.6}_{-2.0}$
SR1b	0.53	11.0	$6.8^{+2.6}_{-1.5}$
SR3b	0.34	7.0	$5.9^{+2.4}_{-1.3}$

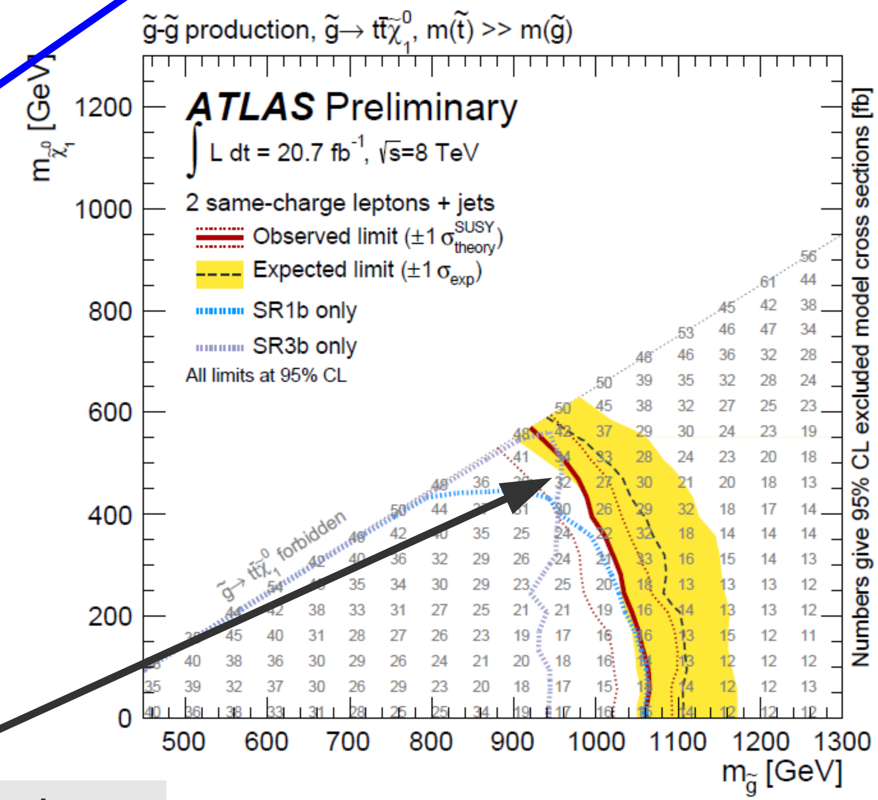
- **Exclusion limits** also set on the signal models listed at the beginning
  → simplified models = only 2-3 sparticles coupling, BR 100%, not complete theories

- **Relax m_{eff} cut** and replace by a **signal+bkg combined fit** in the 3 SRs
  - Large shape variability over models/phase space
  - Similar to optimizing m_{eff} cut for each point
  - Significant gain seen with respect to fixed cut

Exclusion limits: offshell gluino-stop





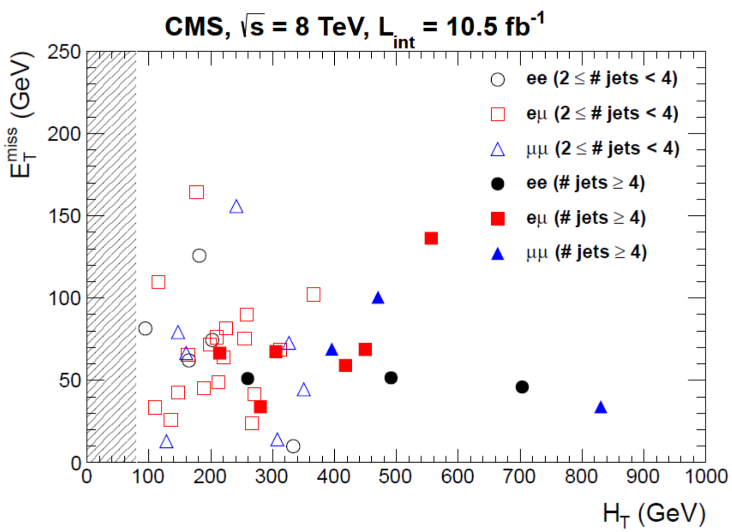


Completing SR1b by SR3b to cover full plane

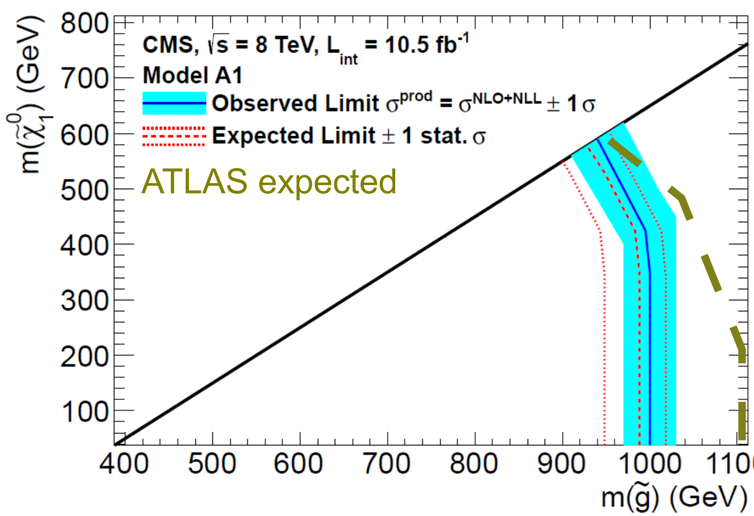
What about CMS ?

- **'Sister-ship' analysis** with ≥2 b-tagged jets, results currently available with 10.5 fb^{-1}

	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4	≥ 4	≥ 4	≥ 3	≥ 4
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	>0 GeV	>30 GeV	>30 GeV	>120 GeV	>50 GeV	>50 GeV	>120 GeV	>50 GeV	>0 GeV
H_T	>80 GeV	>80 GeV	>80 GeV	>200 GeV	>200 GeV	>320 GeV	>320 GeV	>200 GeV	>320 GeV
Fake BG	25 ± 13	19 ± 10	9.6 ± 5.0	0.99 ± 0.69	4.5 ± 2.9	2.9 ± 1.7	0.7 ± 0.5	0.71 ± 0.47	4.4 ± 2.6
Charge-flip BG	3.4 ± 0.7	2.7 ± 0.5	1.4 ± 0.3	0.04 ± 0.01	0.21 ± 0.05	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.21 ± 0.05
Rare SM BG	11.8 ± 5.9	10.5 ± 5.3	6.7 ± 3.4	1.2 ± 0.7	3.4 ± 1.8	2.7 ± 1.5	1.0 ± 0.6	0.44 ± 0.39	3.5 ± 1.9
Total BG	40 ± 14	32 ± 11	17.7 ± 6.1	2.2 ± 1.0	8.1 ± 3.4	5.7 ± 2.4	1.7 ± 0.7	1.2 ± 0.6	8.1 ± 3.3
Event yield	43	38	14	1	10	7	1	1	9
N_{UL} (13% unc.)	27.2	26.0	9.9	3.6	10.8	8.6	3.6	3.7	9.6
N_{UL} (20% unc.)	28.2	27.2	10.2	3.6	11.2	8.9	3.7	3.8	9.9
N_{UL} (30% unc.)	30.4	29.6	10.7	3.8	12.0	9.6	3.9	4.0	10.5

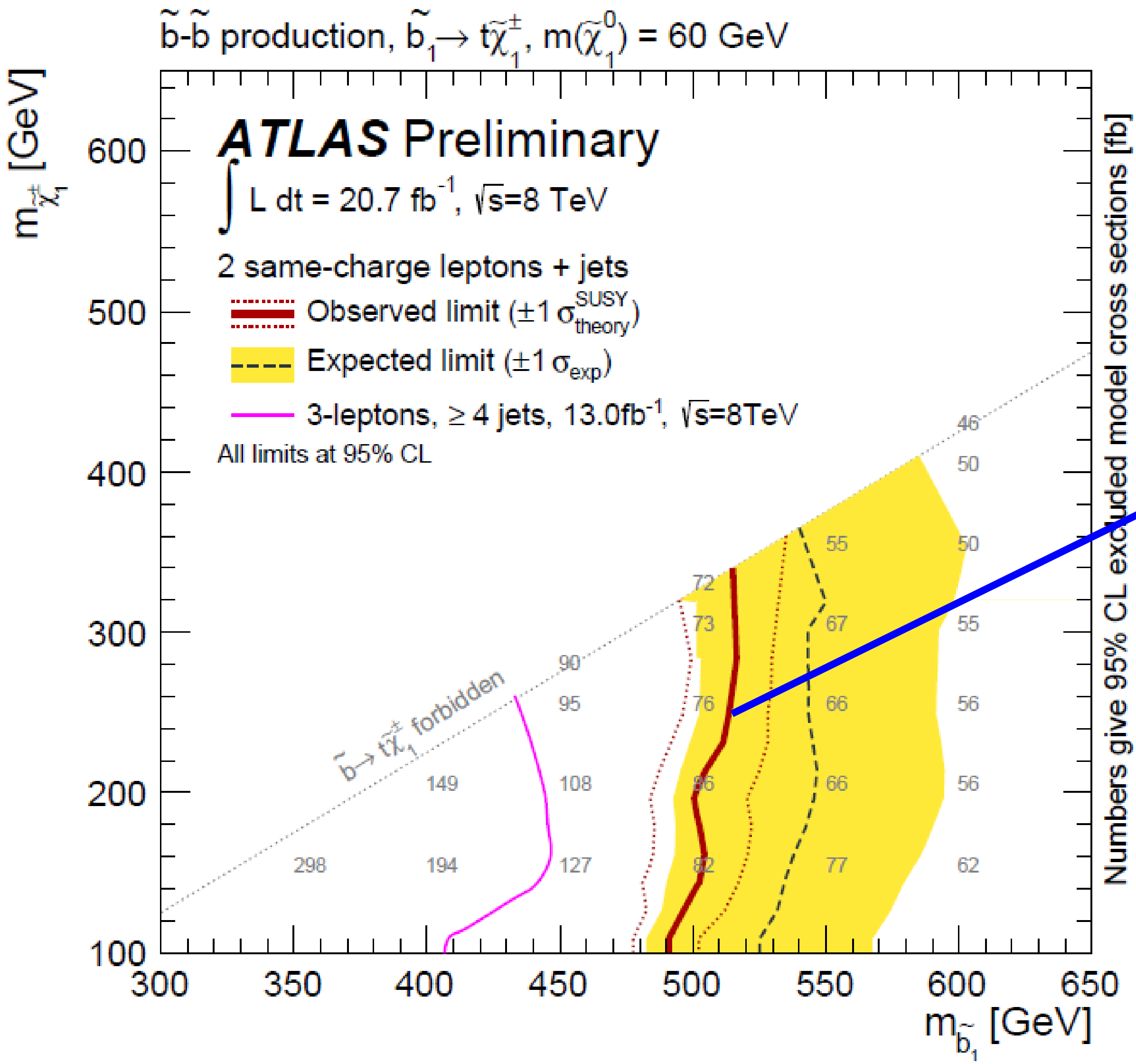


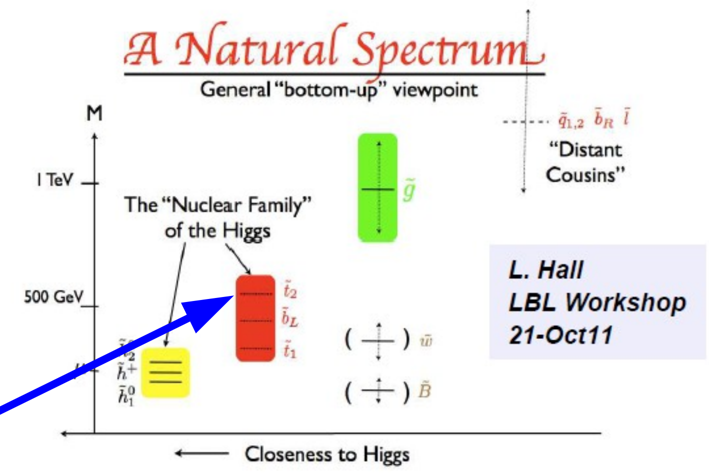
- SRs 'loosely motivated' by BSM scenarios
- Softer cuts, except jets
- Bkg estimation similar
- Comparable bkg level in 'tight' signal regions

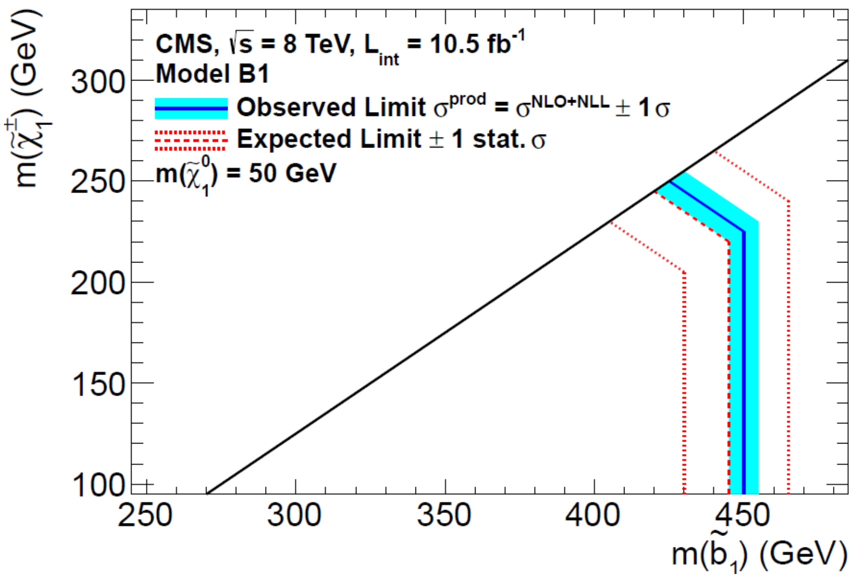


- Limits provided for gluino-stop and direct sbottom
- Simple cut-count, SR choice = best expected

Exclusion limits: direct sbottom



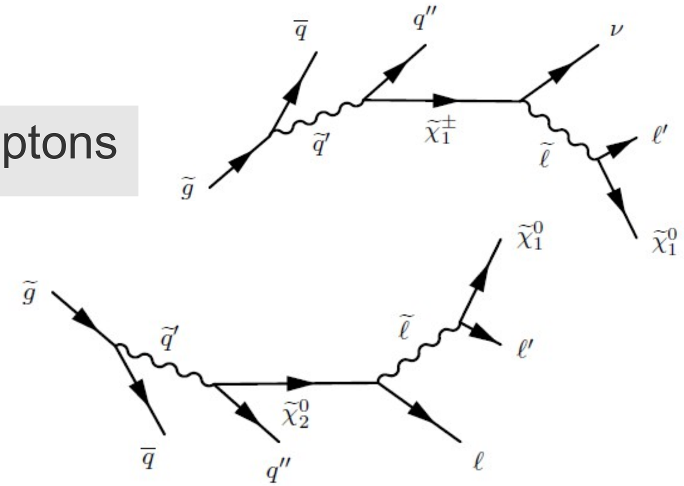


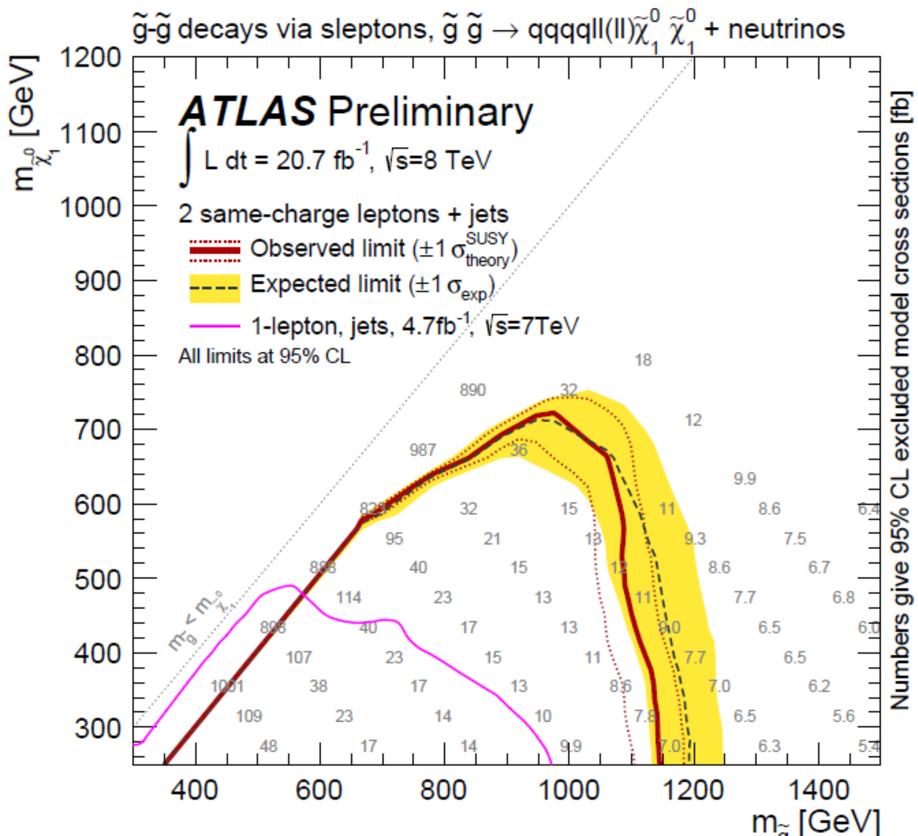


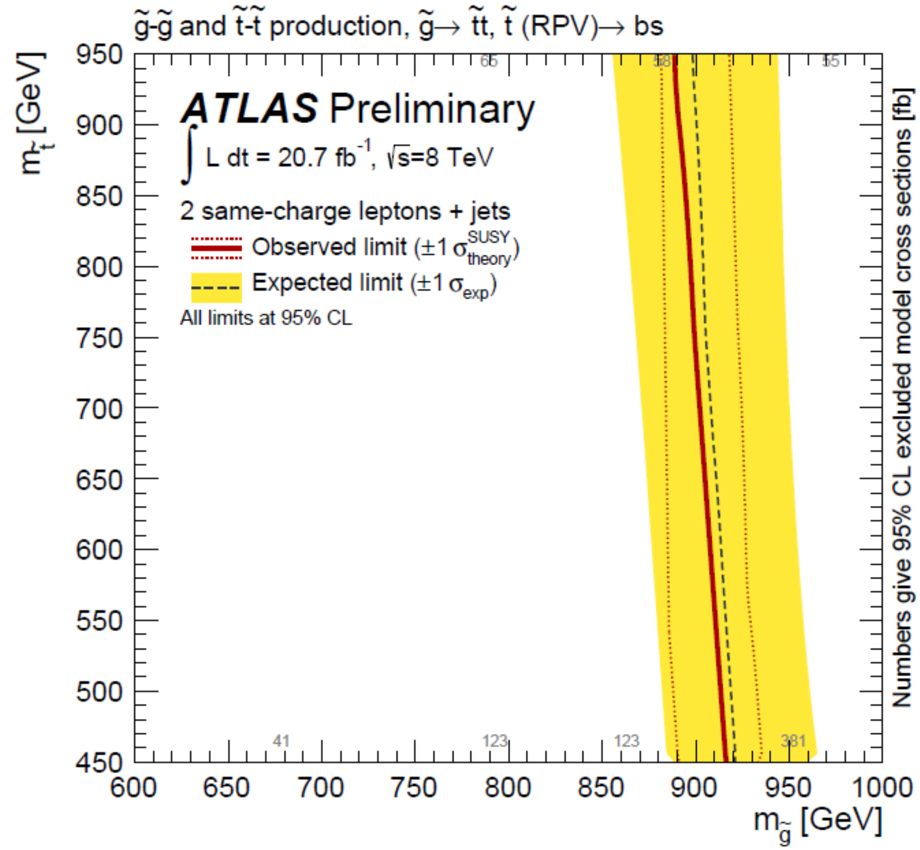
- Improving substantially current limits

Exclusion limits: when no b-jet / no $\not{E}_T$

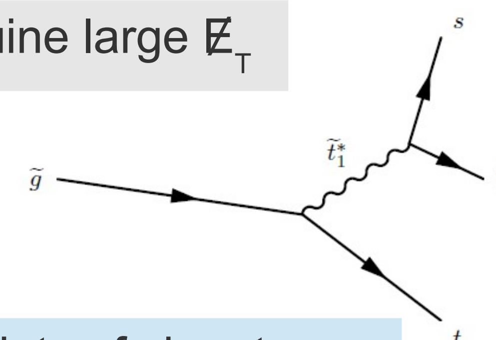
- sleptons





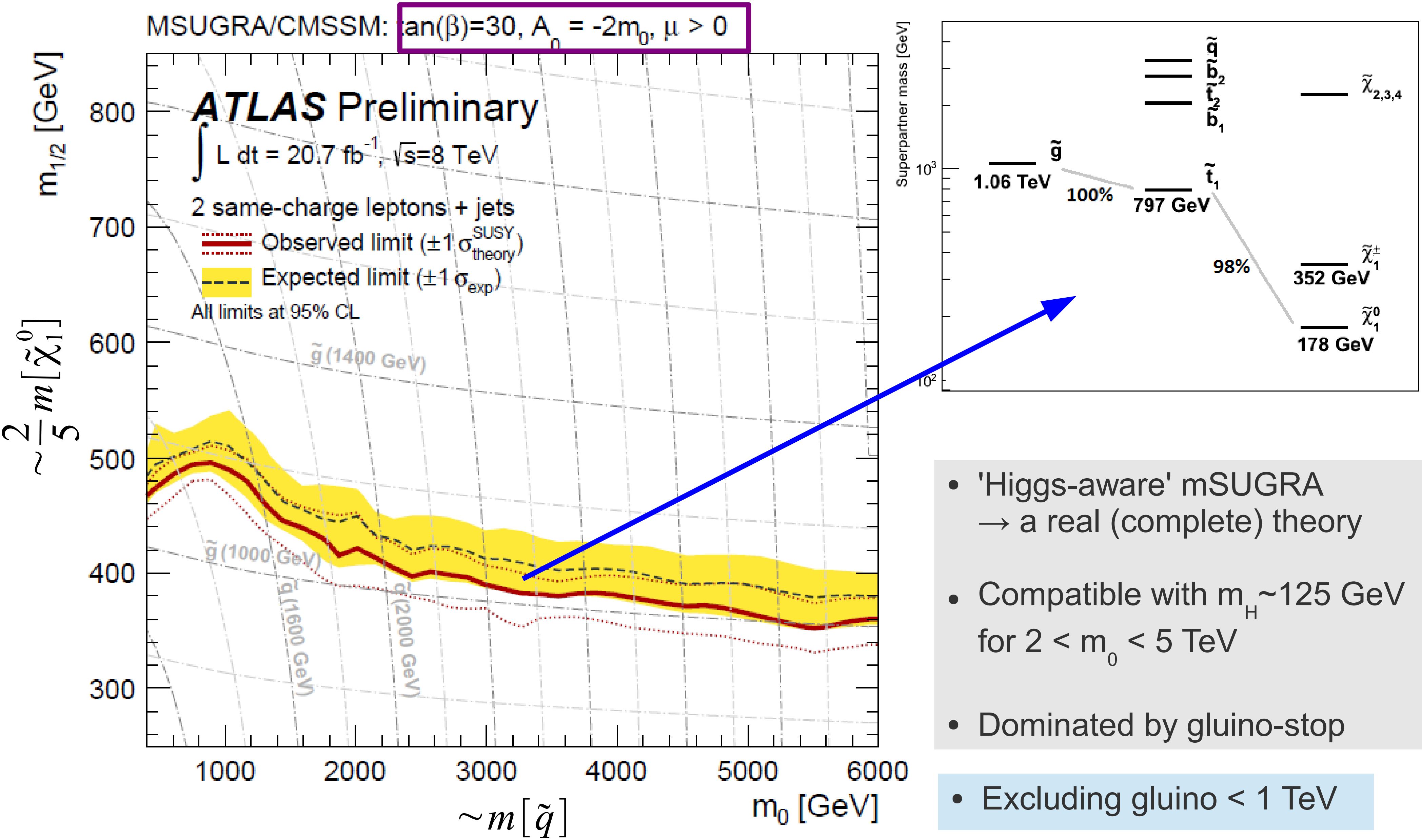


- RPV, no genuine large $\not{E}_T$



- Sensitive to large variety of signatures

Exclusion limits: mSUGRA/cMSSM



- 'Higgs-aware' mSUGRA → a real (complete) theory
- Compatible with m_H~125 GeV for $2 < m_0 < 5$ TeV
- Dominated by gluino-stop

- Excluding gluino < 1 TeV

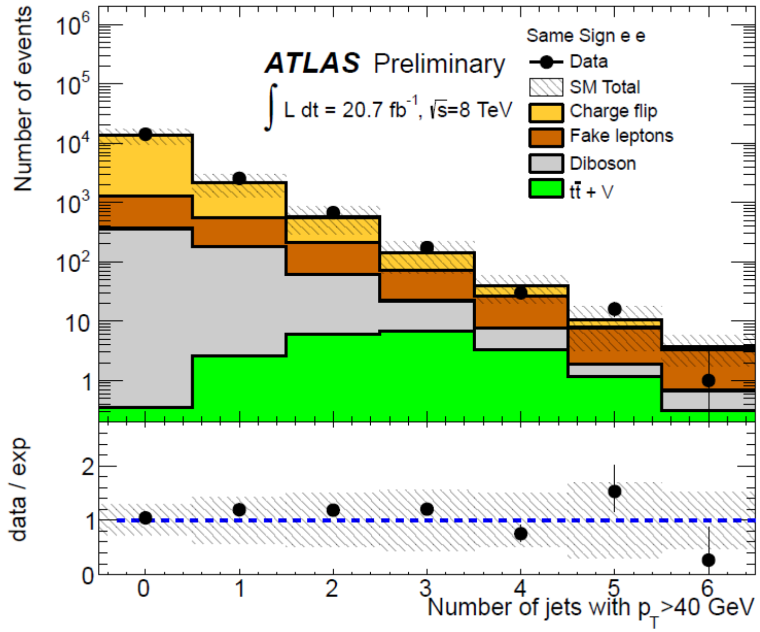
Conclusion

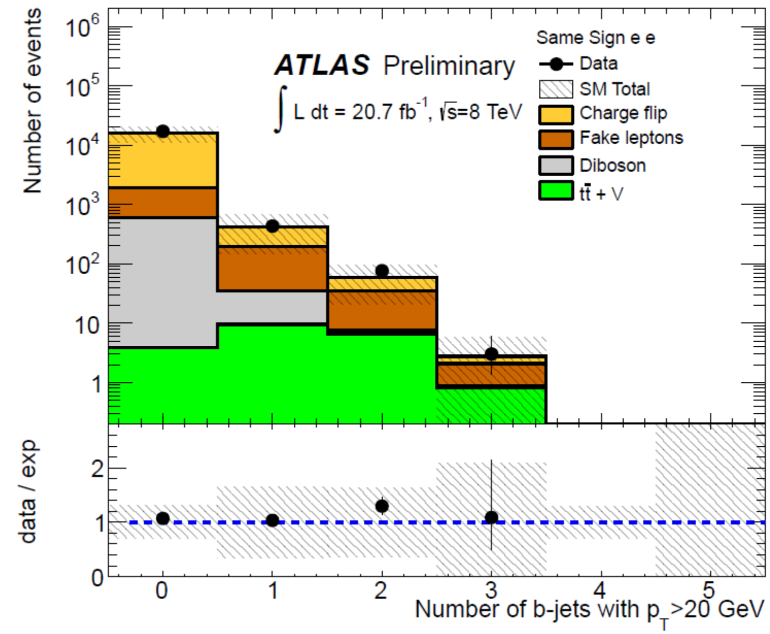
- **Search** for SUSY in final states with same-sign leptons, L = 20.7 fb^{-1}
  → interesting signature with low SM background, great sensitivity to new physics...
- **No evidence** of BSM processes, shall they come from SUSY or anything else
- **Exclusion limits** set on various natural SUSY scenarios
  - Sensitivity to gluino masses up to 1 TeV, sbottom up to 500 GeV
- **Prospects** for ATLAS :
  - Access even more compressed scenarios with soft leptons
  - Combine results with searches in 3 lepton final states
  - Improve current background estimates

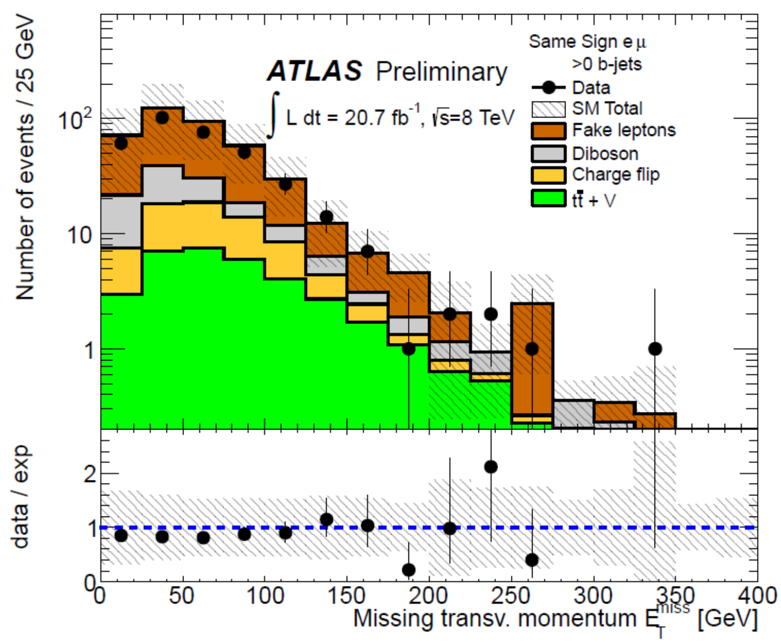
Have also a look at related poster by O.Ducu

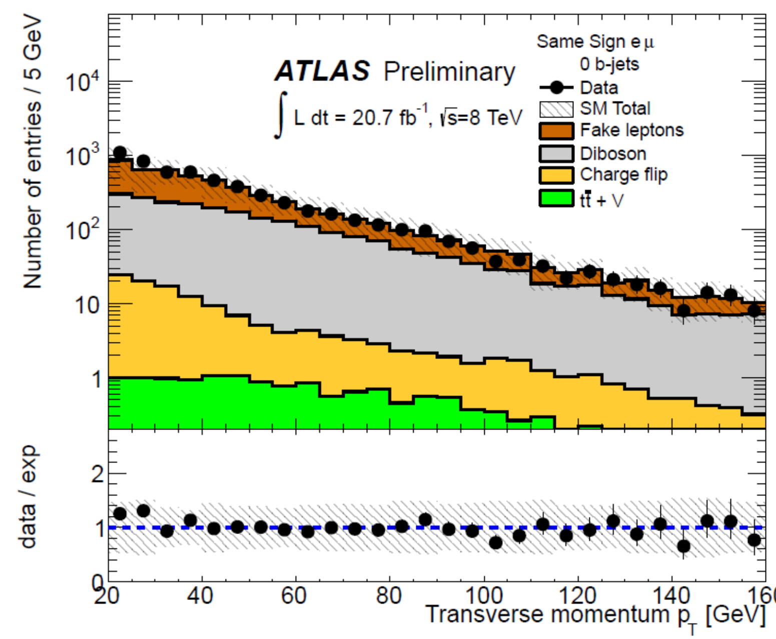
Backup

Kinematic distributions

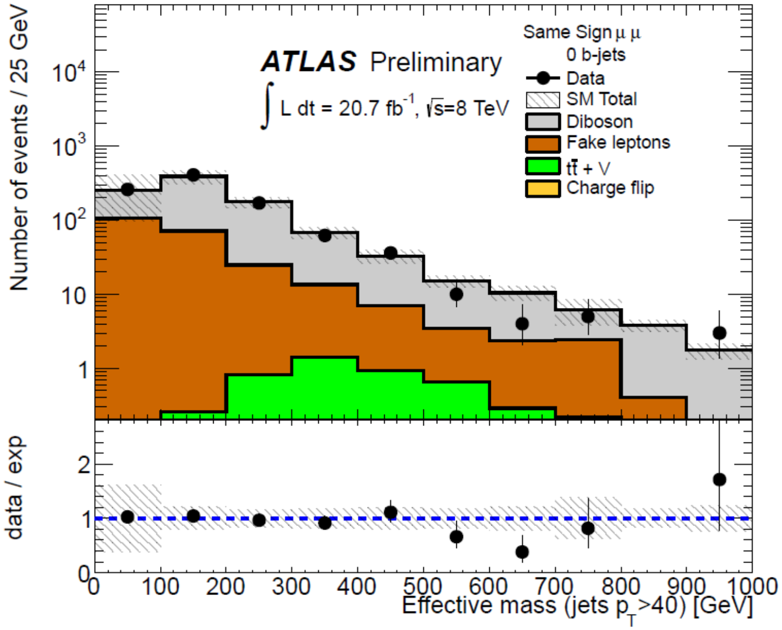


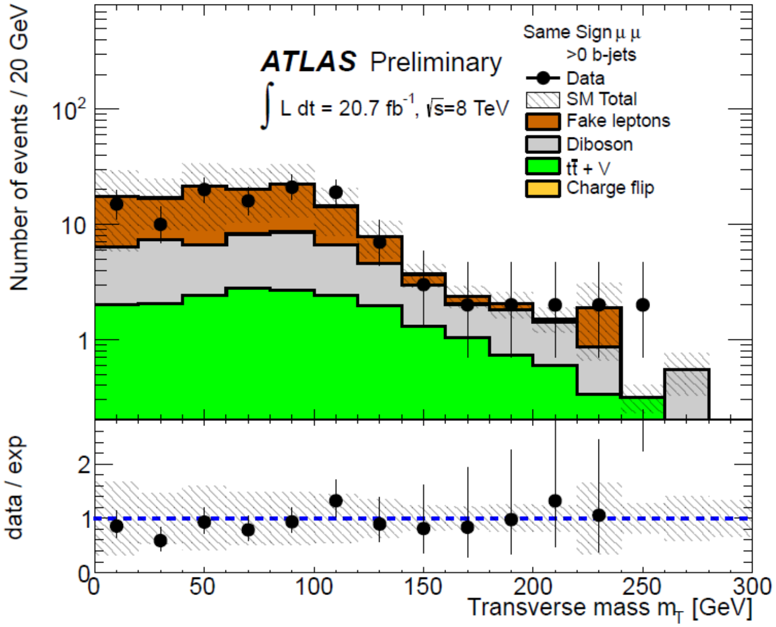






Kinematic distributions





Distributions in signal regions

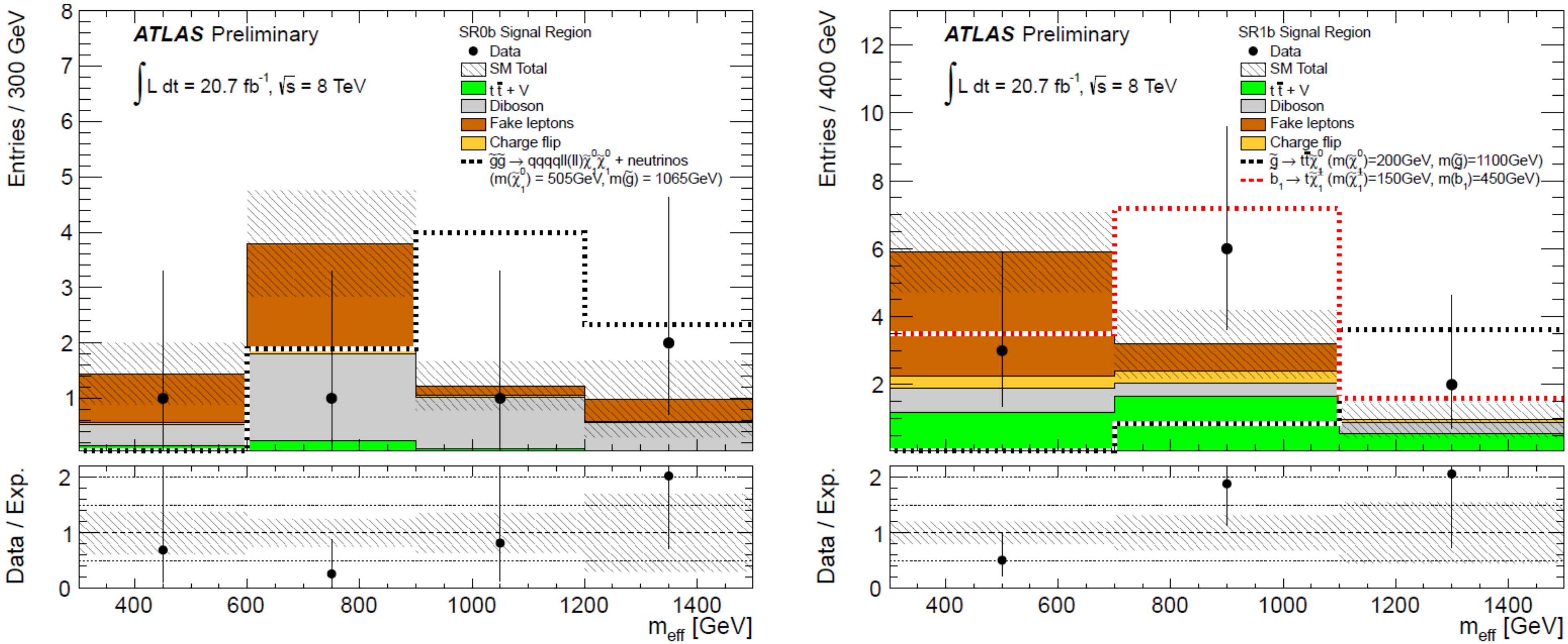
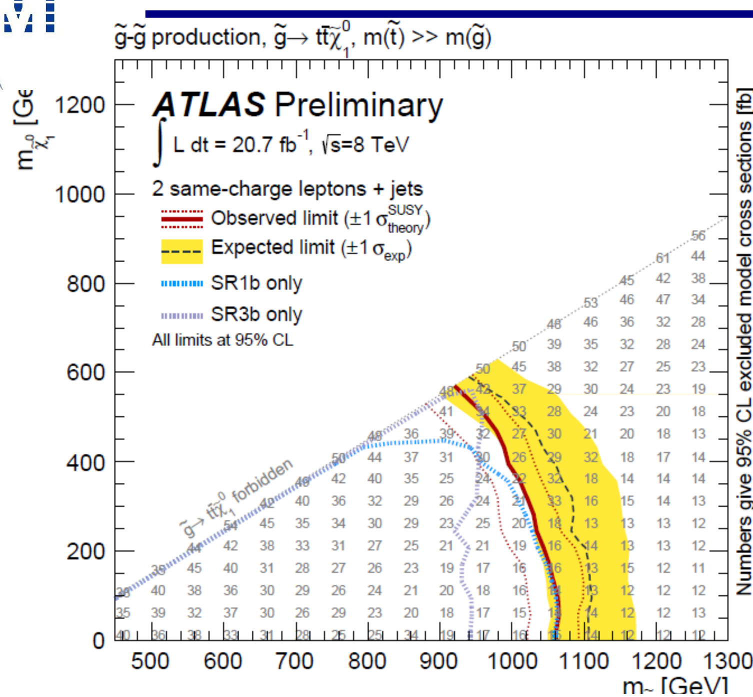
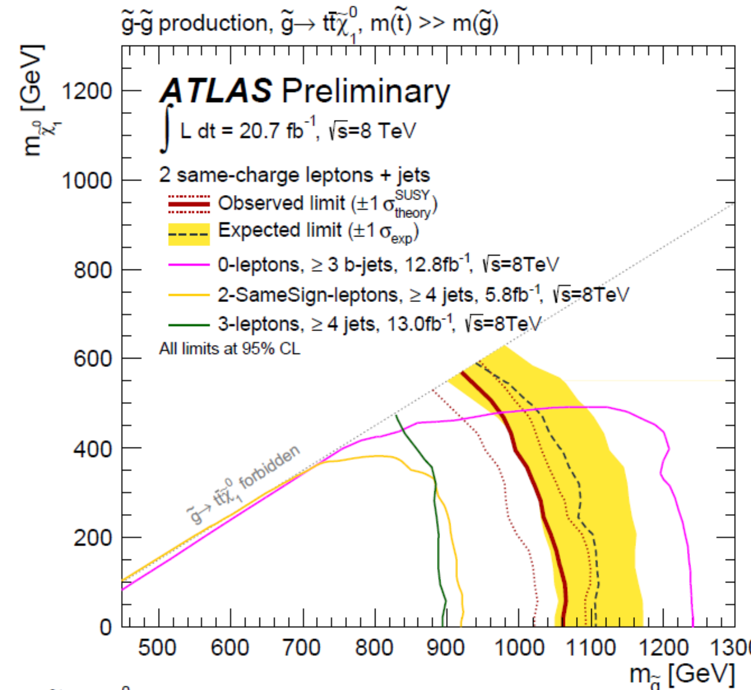
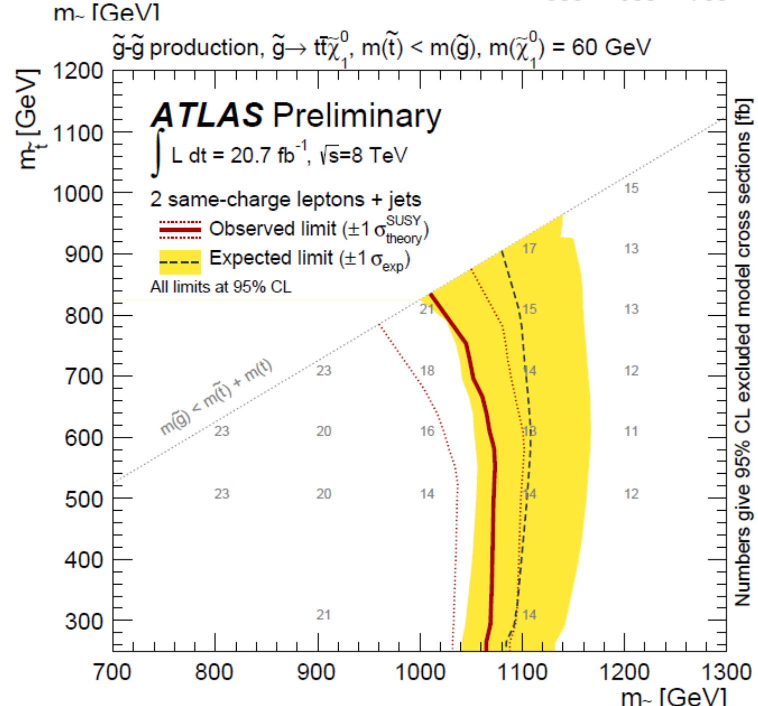


Figure 6: Effective mass distributions in the signal regions SR0b (left) and SR1b (right) using the exclusion case event sample. The last bin includes overflows.

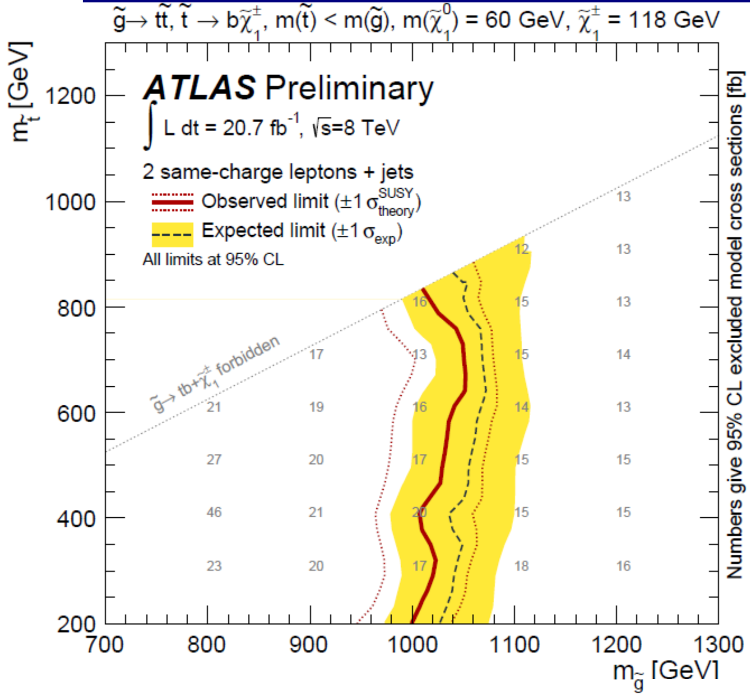
Exclusion limits : gluino stop ($t\chi^0$)

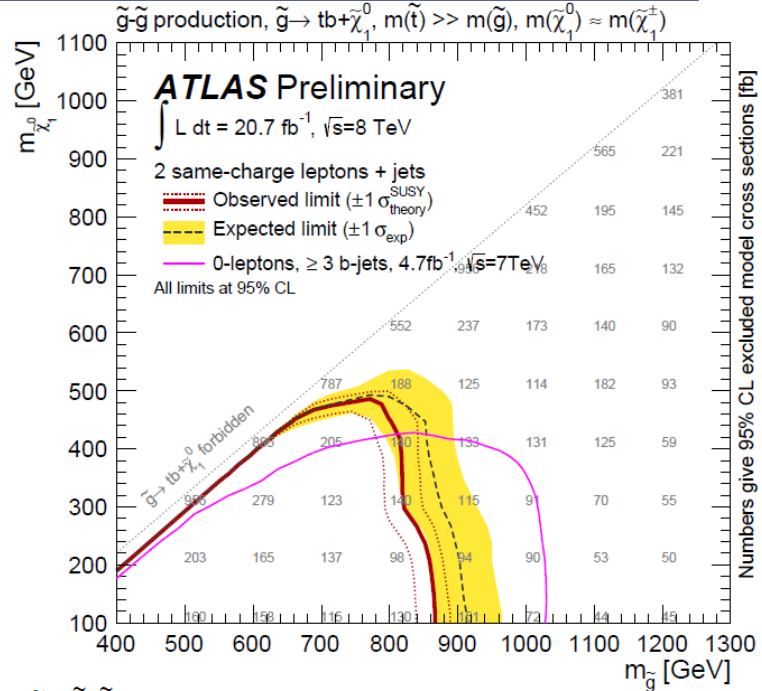


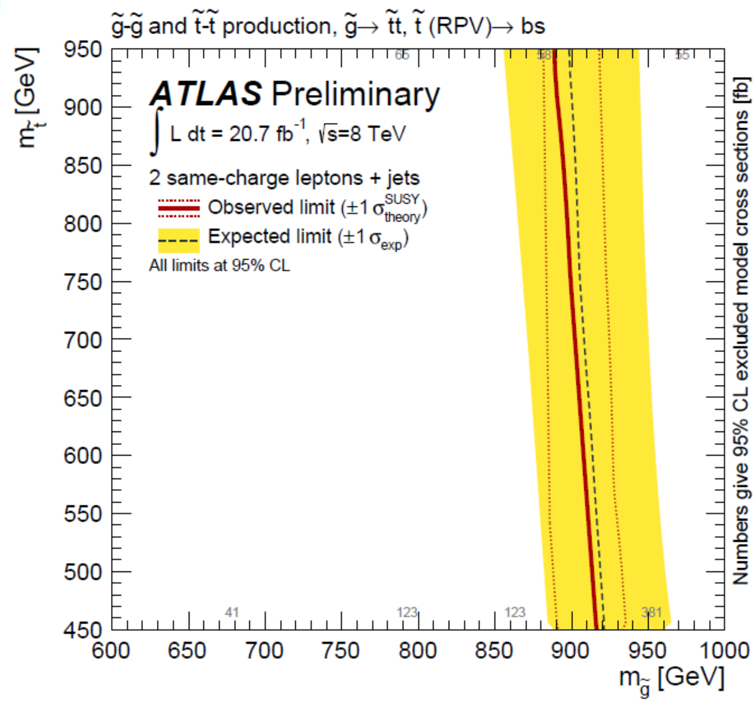




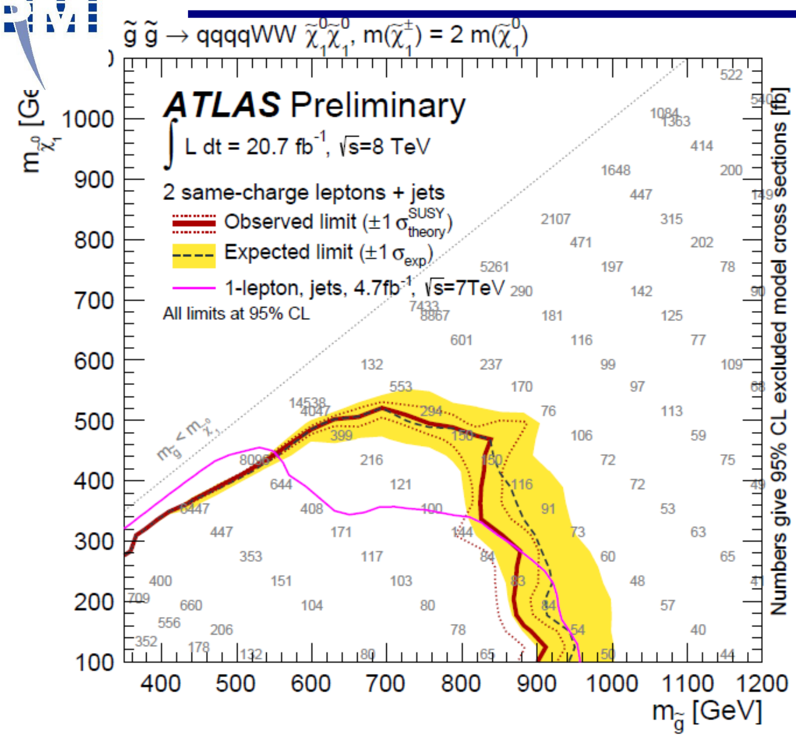
Exclusion limits : gluino stop ($b\chi^{\pm}$) / RPV

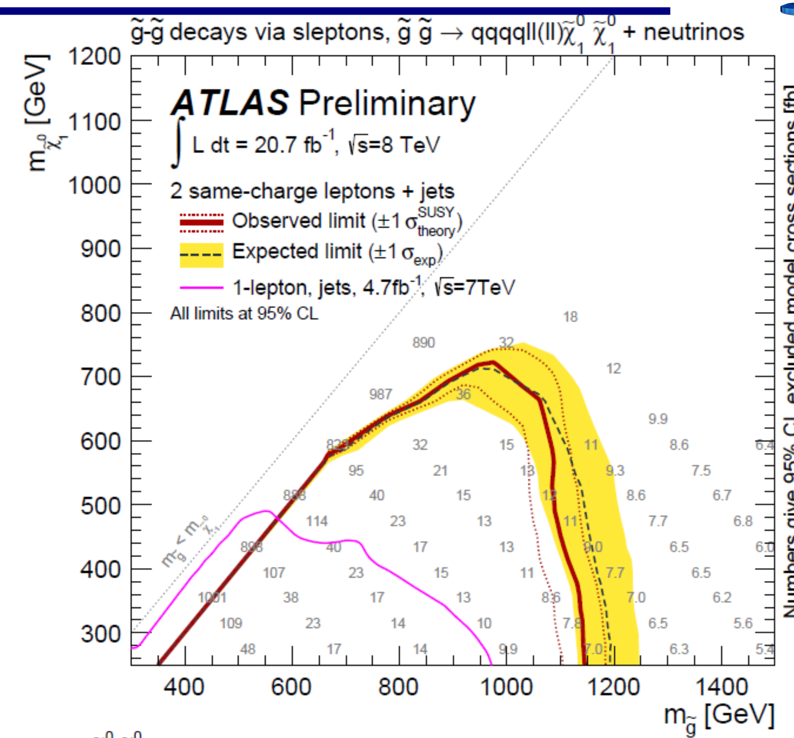


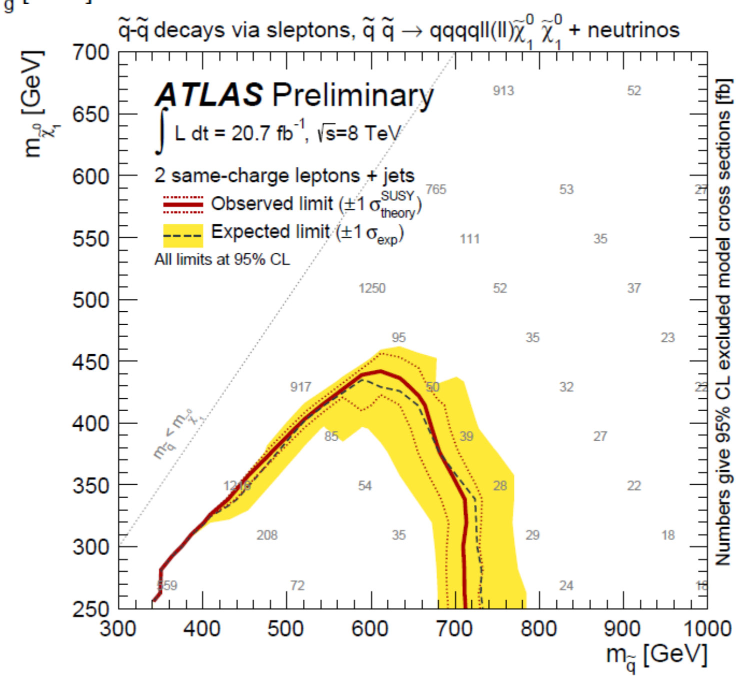




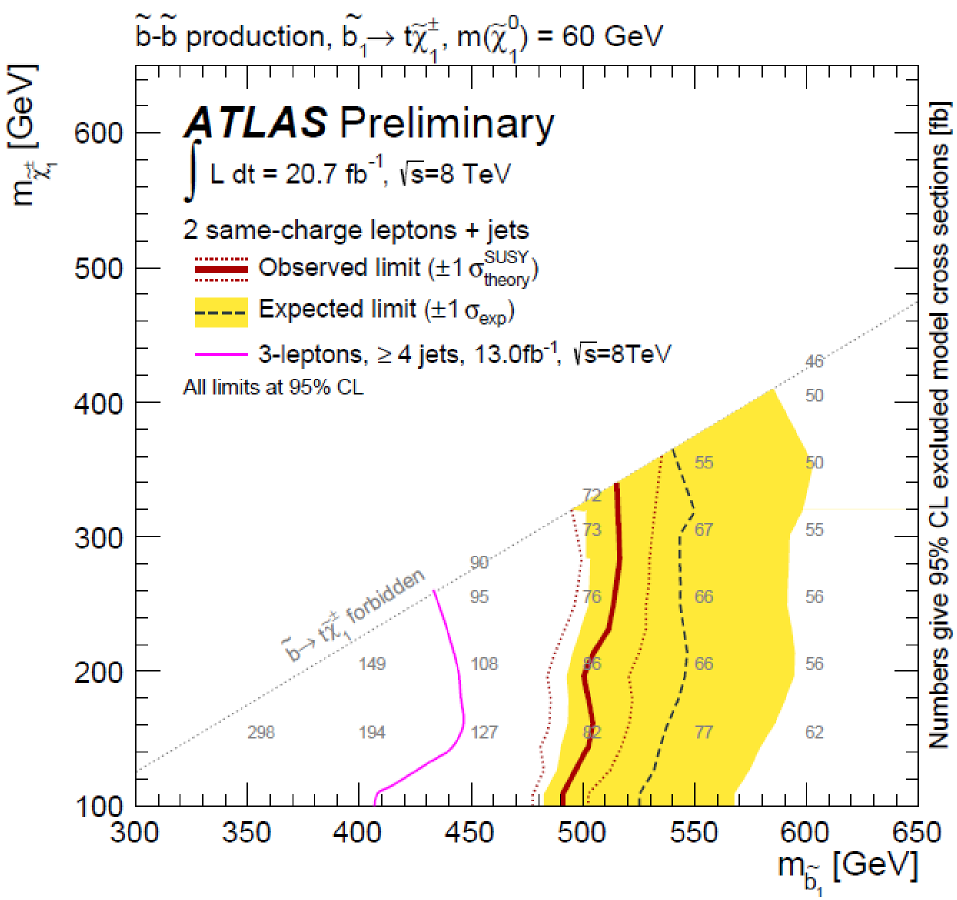
Exclusion limits: gluino-squark/direct squark

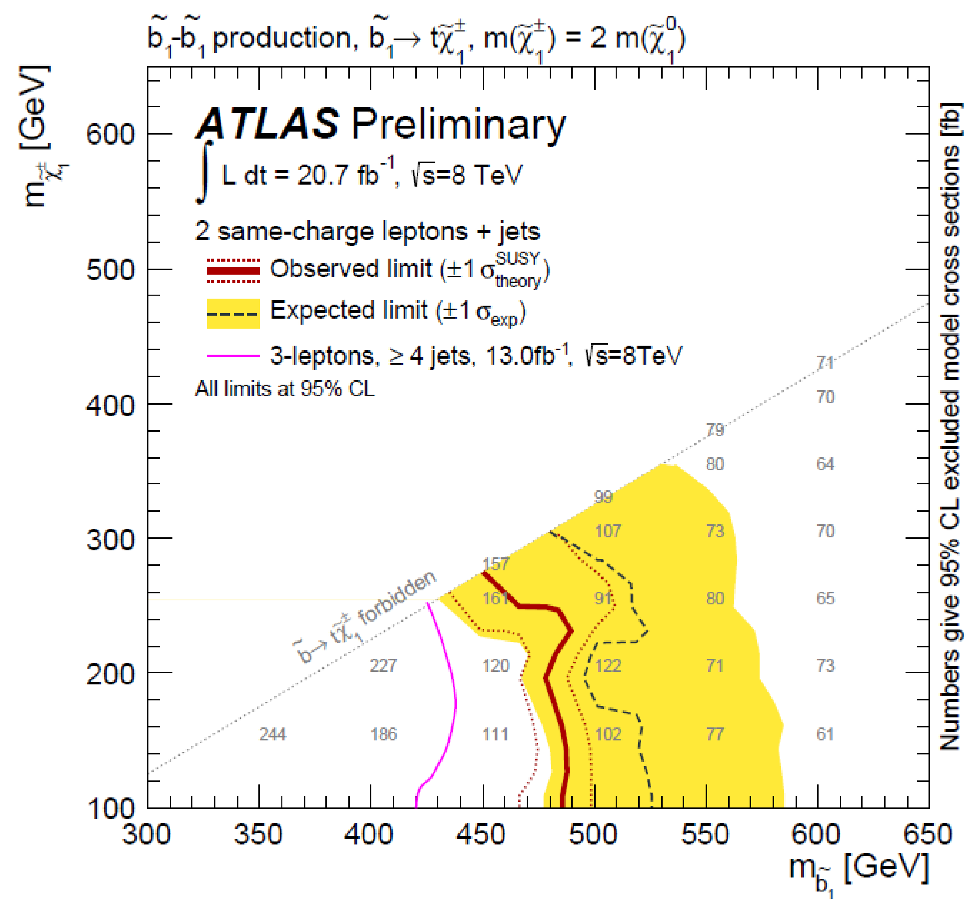




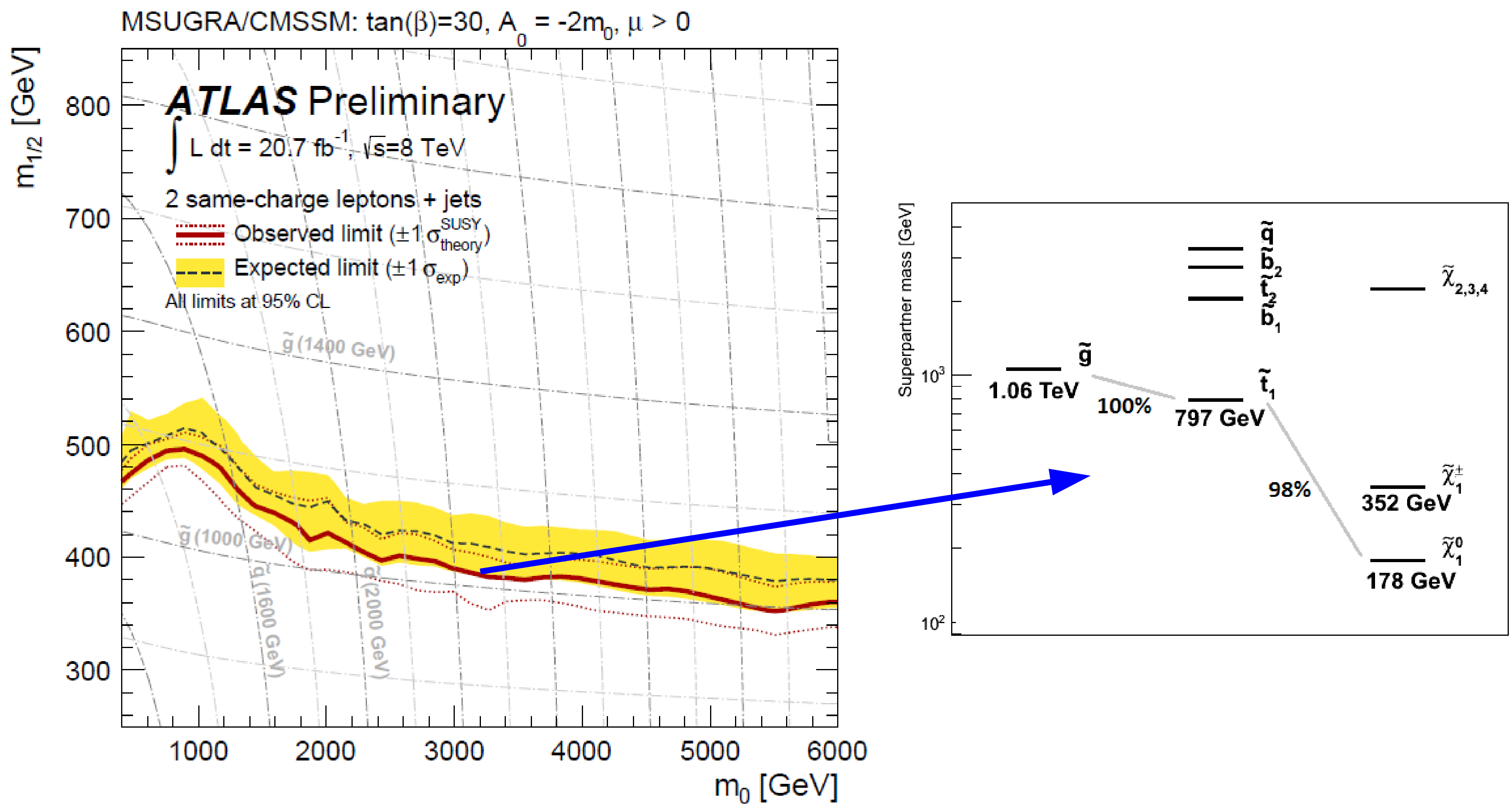


Exclusion limits : direct sbottom

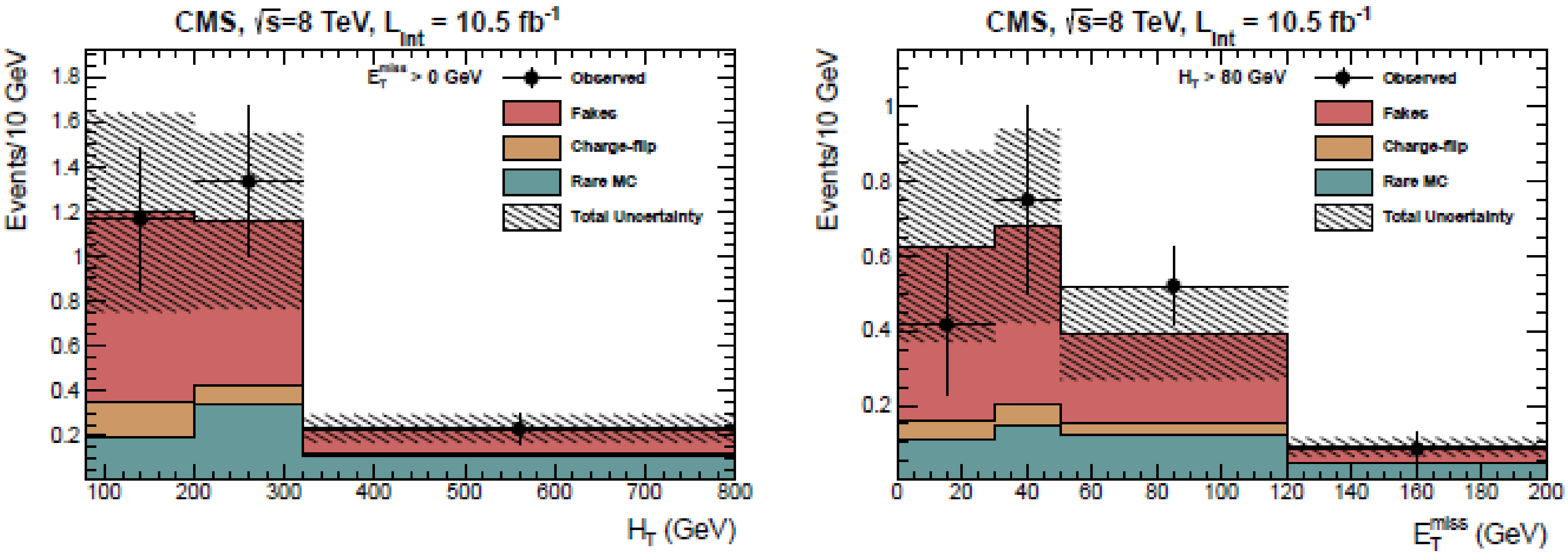




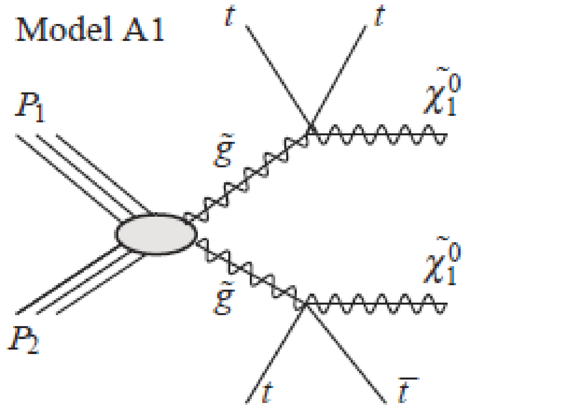
Exclusion limits : mSUGRA

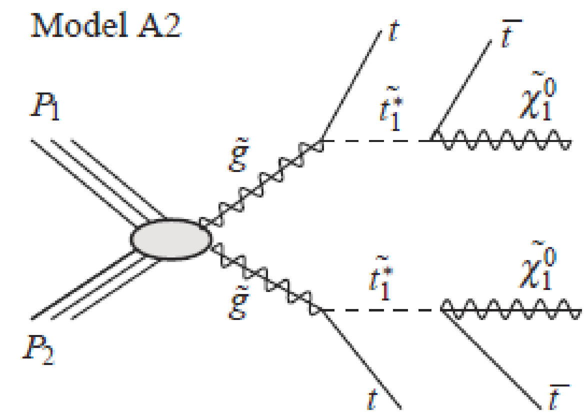


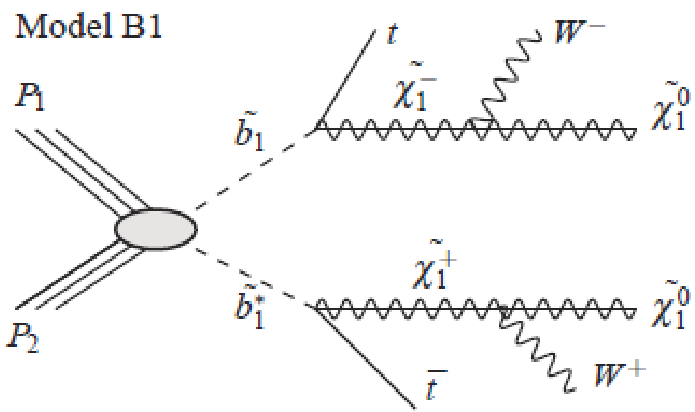
- Compatible with a Higgs mass of 125 GeV, at least for 2 TeV < m_0 < 5 TeV

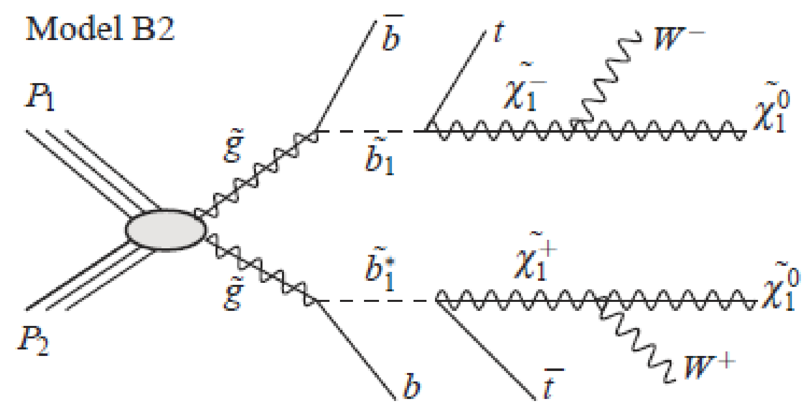


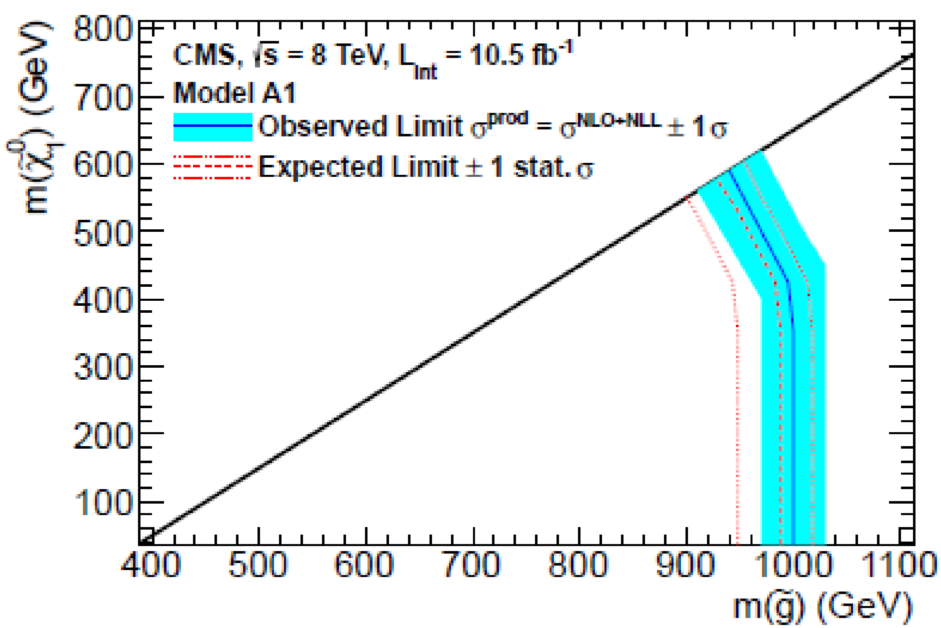
CMS : MET and HT distributions in SR0 (most inclusive)

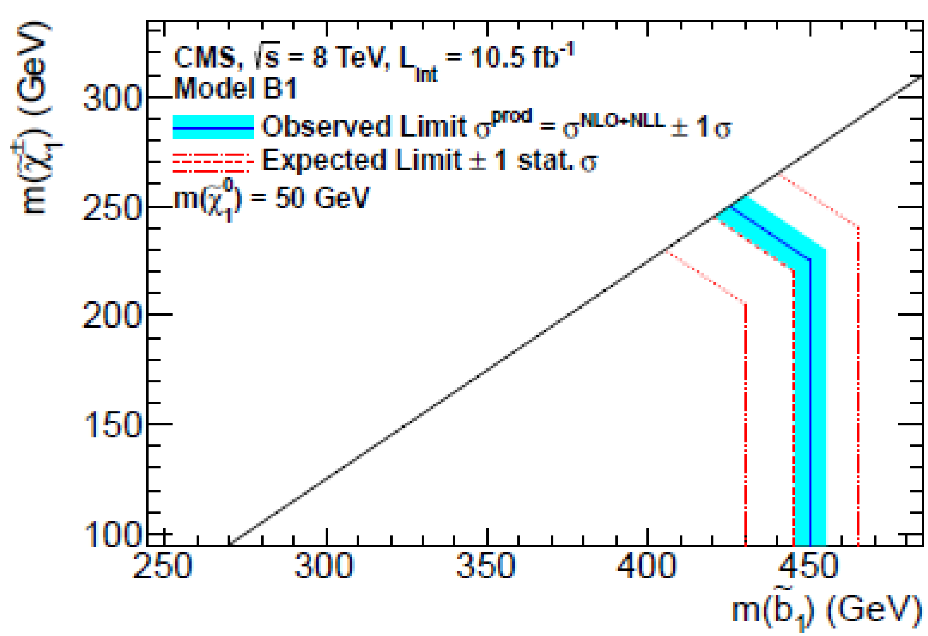

Model A1
P1
P2
g̃
t
t̄
$\tilde{\chi}_1^0$

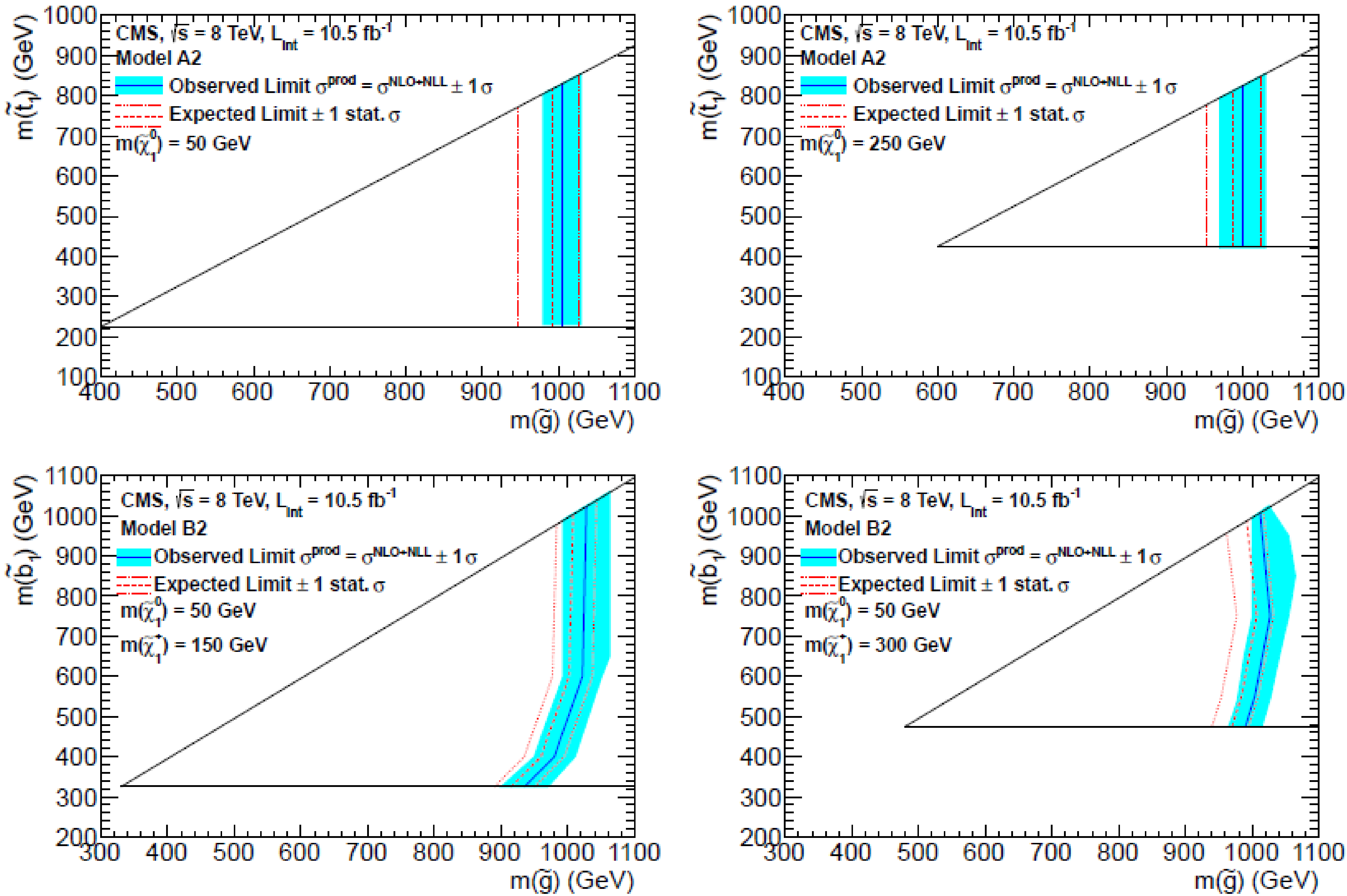

Model A2
P1
P2
g̃
$\tilde{t}_1^*$
t
t̄
$\tilde{\chi}_1^0$


Model B1
P1
P2
$\tilde{b}_1$
$\tilde{b}_1^*$
t
t̄
$\tilde{\chi}_1^-$
$\tilde{\chi}_1^+$
W^-
W^+
$\tilde{\chi}_1^0$


Model B2
P1
P2
g̃
b̄
b
$\tilde{b}_1$
$\tilde{b}_1^*$
t
t̄
$\tilde{\chi}_1^-$
$\tilde{\chi}_1^+$
W^-
W^+
$\tilde{\chi}_1^0$


CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model A1
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m($\tilde{\chi}_1^0$) (GeV)
m(g̃) (GeV)
800
700
600
500
400
300
200
100
400
500
600
700
800
900
1000
1100


CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model B1
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m($\tilde{\chi}_1^0$) = 50 GeV
m($\tilde{\chi}_1^\pm$) (GeV)
m($\tilde{b}_1$) (GeV)
300
250
200
150
100
250
300
350
400
450



CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model A2
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m(χ̃_1^0) = 50 GeV
m(t̃_1) (GeV)
m(g̃) (GeV)
CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model A2
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m(χ̃_1^0) = 250 GeV
m(t̃_1) (GeV)
m(g̃) (GeV)
CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model B2
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m(χ̃_1^0) = 50 GeV
m(χ̃_1^+) = 150 GeV
m(b̃_1) (GeV)
m(g̃) (GeV)
CMS, √s = 8 TeV, L_int = 10.5 fb^-1
Model B2
Observed Limit σ^prod = σ^NLO+NLL ± 1σ
Expected Limit ± 1 stat. σ
m(χ̃_1^0) = 50 GeV
m(χ̃_1^+) = 300 GeV
m(b̃_1) (GeV)
m(g̃) (GeV)