Searches for direct pair production of third generation squarks with the ATLAS detector

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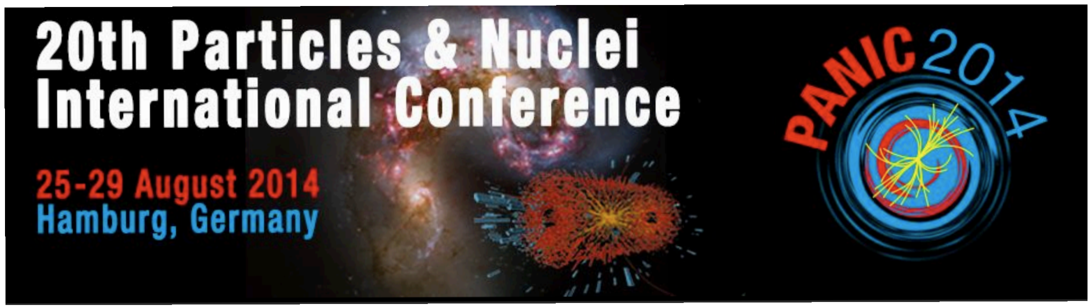
on behalf of the ATLAS collaboration



Outline

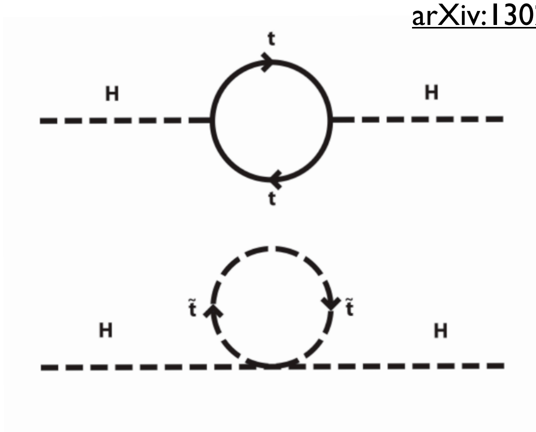
- introduction
- searches for direct production of top squark pairs
- searches for direct production of bottom squark pairs

all results shown and more are available at the ATLAS SUSY summary page

3^{rd} generation searches

- Supersymmetry provides an extension of the Standard Model which can solve the hierarchy problem and provide a Dark Matter candidate.
- Theoretical argument of naturalness favour the third generation squark (stop and sbottom) to be light (<1TeV) strongly motivating these searches at LHC.
- For ATLAS searches of gluinos and first generation squarks see talk from Bertrand Martin.
- Summary of ATLAS searches for direct production of stop/sbottom using full 8TeV dataset are summarized here.

arXiv:1302.6587



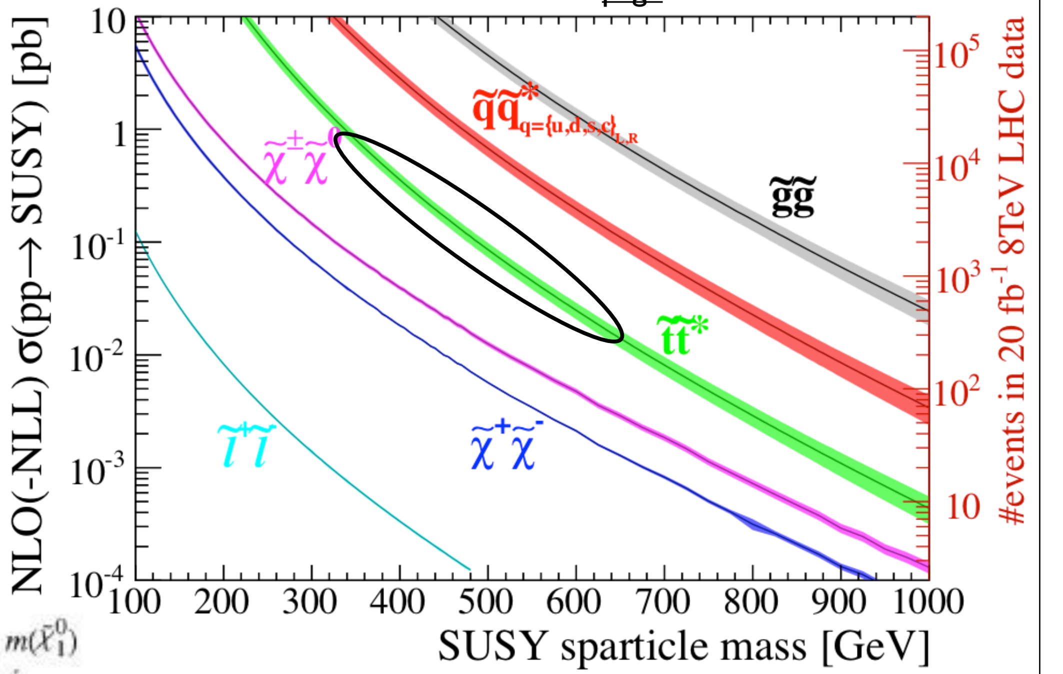
$$m_h^2 \approx m_{h\,0}^2 + \frac{\lambda_f^2}{8\pi^2} N_c^f \left(m_{\tilde{f}}^2 - m_f^2\right) \ln\left(\Lambda^2/m_{\tilde{f}}^2\right)$$

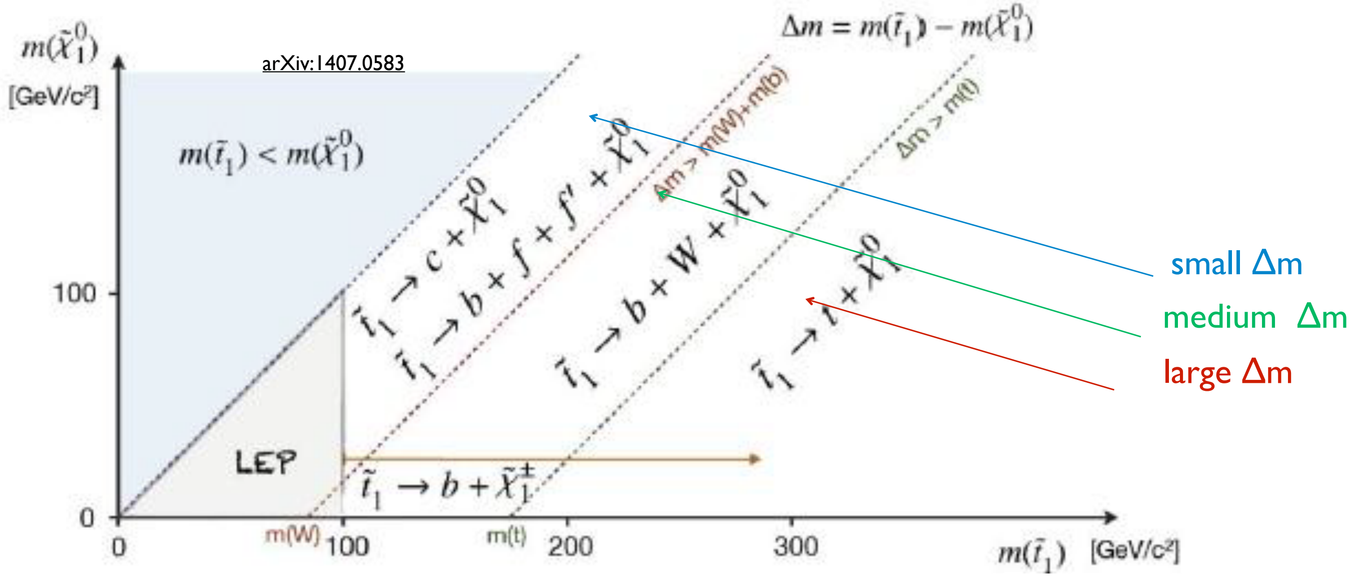
$$m_{\tilde{f}} \lesssim 800 \text{ GeV} \frac{1.0}{\lambda_f} \left[\frac{3}{N_c^f}\right]^{\frac{1}{2}} \left[\frac{70}{\ln(\Lambda^2/m_{\tilde{f}}^2)}\right]^{\frac{1}{2}} \left[\frac{\mathcal{N}_{\max}^0}{100}\right]^{\frac{1}{2}}$$

3rd generation squarks production and decay

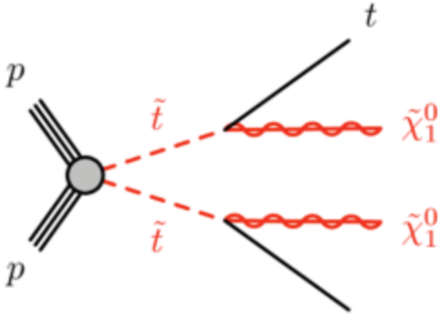
- direct stop/sbottom production cross section at the NLO+NLL order
- stop decay depends on the mass/L-R mixing parameters and masses/mixing parameters of charginos and neutralinos
- results are mostly interpreted with simplified models where the rest of SUSY spectrum is decoupled and 100% BR is mostly assumed. Few exceptions: pMSSM, GMSB model.

LHC SUSY WG page

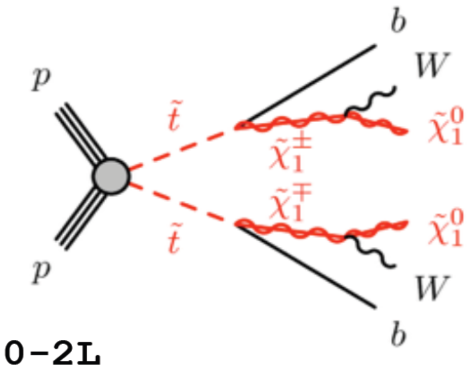




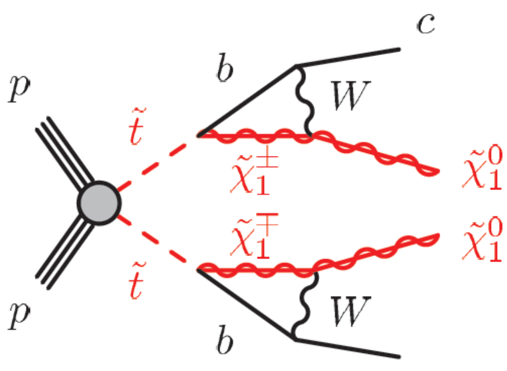
Direct production of top squark pairs



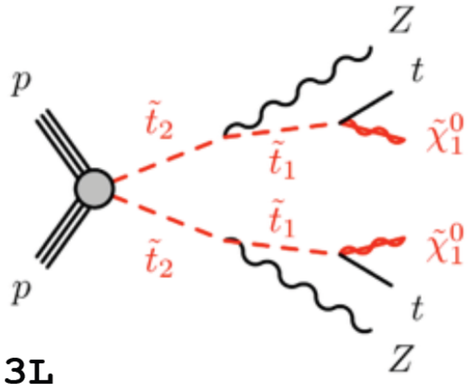
0-2L



0-2L



0L



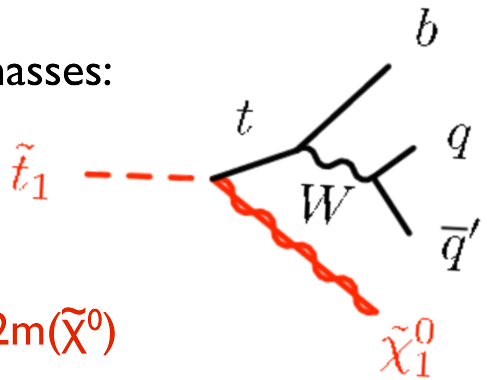
2-3L

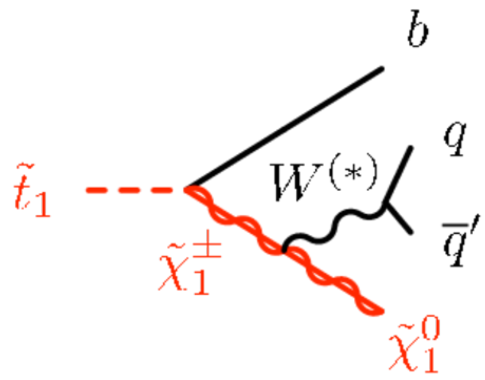
0-lepton,6(2b-)jets+ $\not{E}_T$

Accepted by JHEP
arXiv:1406.1122

specific signature of third generation

- targeting high and medium stop masses:
  - $\tilde{t}_1 \rightarrow t\tilde{\chi}^0$
  - $\tilde{t}_1 \rightarrow b\tilde{\chi}^+ \rightarrow bW^{(*)}\tilde{\chi}^0$ $\quad m(\tilde{\chi}^+)=2m(\tilde{\chi}^0)$



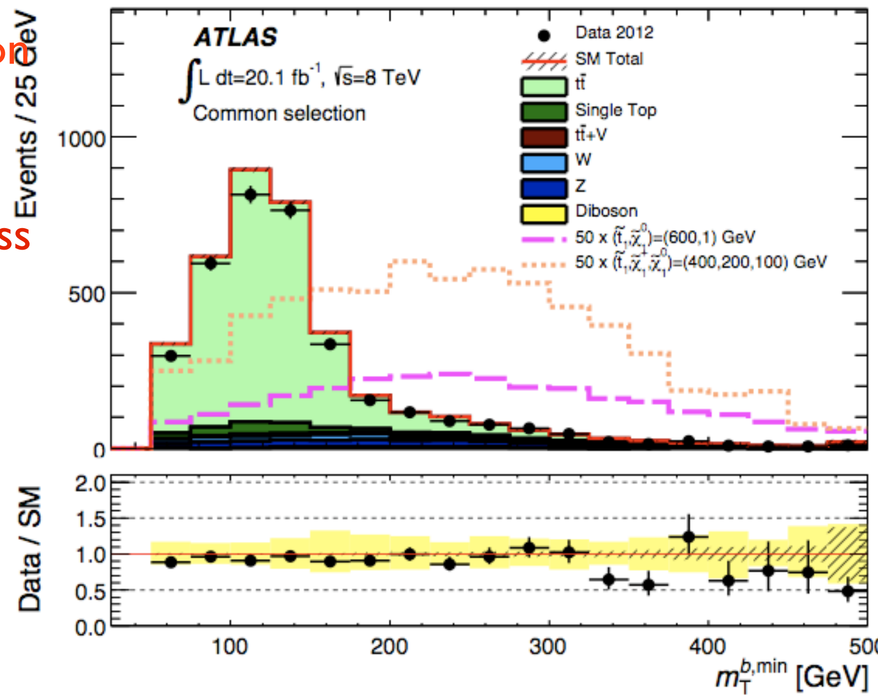


Selections

many optimized signal regions with a common selection of 2 b-jets, lepton veto, missing ET >150 GeV

- (4) resolved topology: ≥6 jets, hadronic top mass
  MET > 150/250/300/350 GeV
- (2)partially resolved (4/5 jets) heavy stop:
  ≥2-reclustered jets (ΔR=1.2), $m_{jet}^{\Delta R=08}$
  MET > 325/400 GeV
- (2) =5 jets targeting $b\chi^+$ mode at lower Δm
  MET > 160/215 GeV

$$m_T^{b,\min} = \sqrt{2\, p_T^b E_T^{\rm miss}\left[1-\cos\Delta\phi\left(\mathbf{p}_T^b, \mathbf{p}_T^{\rm miss}\right)\right]} > 175 \text{ GeV}$$



0-lepton,6(2b-)jets+ $\not{E}_T$

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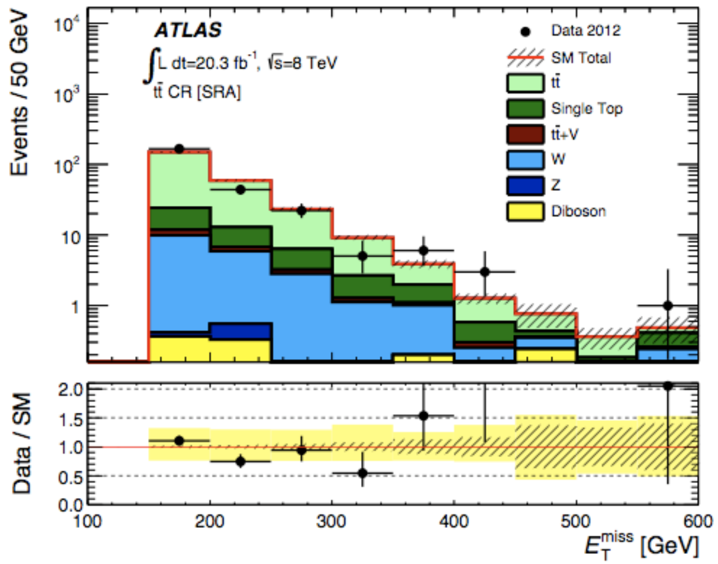


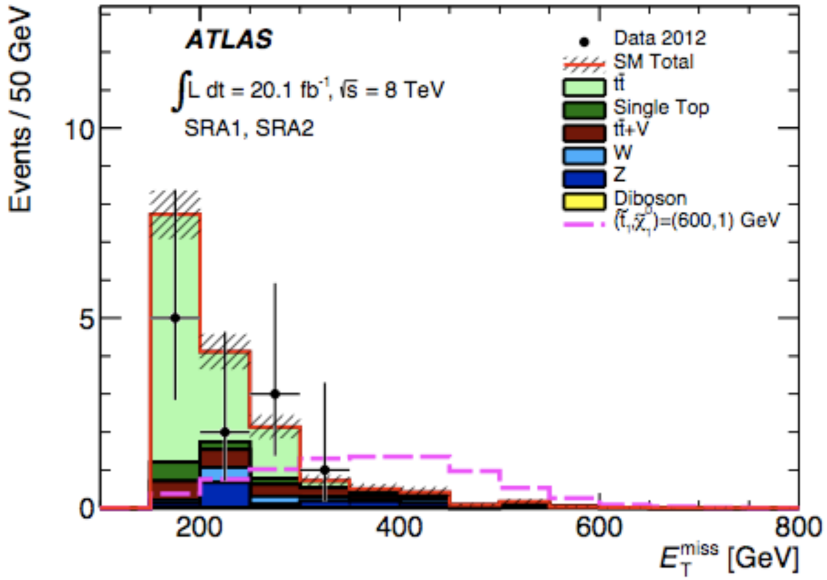
Background control

- semi-leptonic ttbar with a misidentified lepton , Z(νν)+jets ,W+jets: estimated with background enriched samples (CRs)
- ttbar+W/Z, single top, VV: estimated with MC

Results

	SRA1	SRA2	SRA3	SRA4	SRB	SRC1	SRC2	SRC3
Observed events	11	4	5	4	2	59	30	15
Total SM	15.8 ± 1.9	4.1 ± 0.8	4.1 ± 0.9	2.4 ± 0.7	2.4 ± 0.7	68 ± 7	34 ± 5	20.3 ± 3.0

- no significant excess over the expected background.



0-lepton,6(2b-)jets+ $\not{E}_T$

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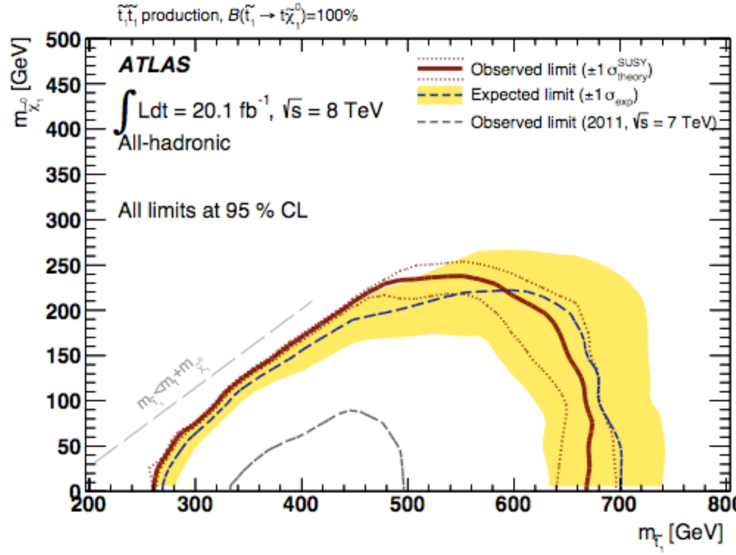
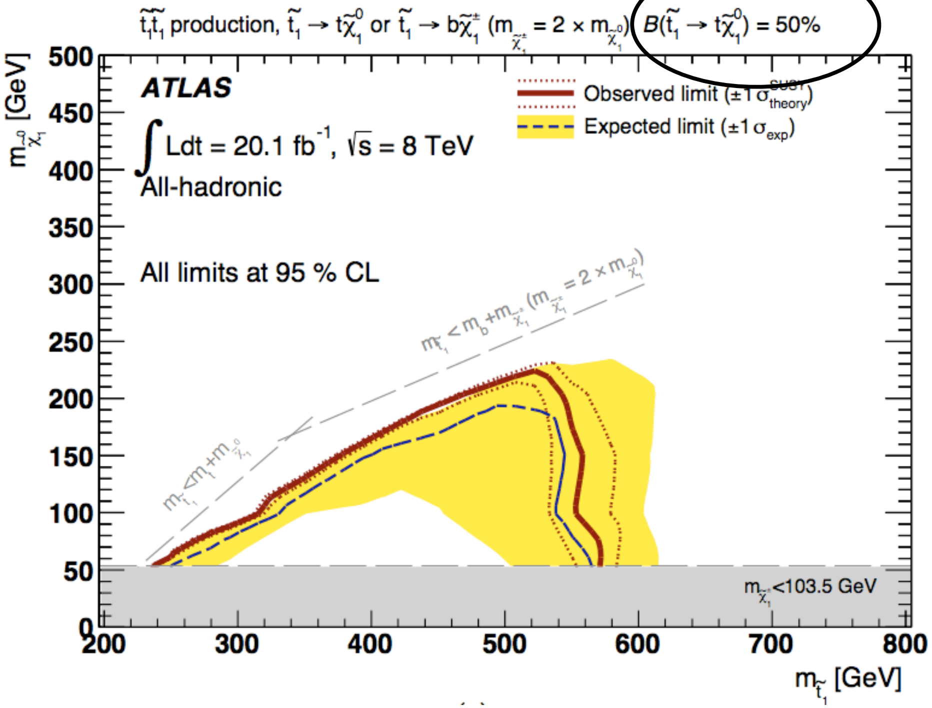
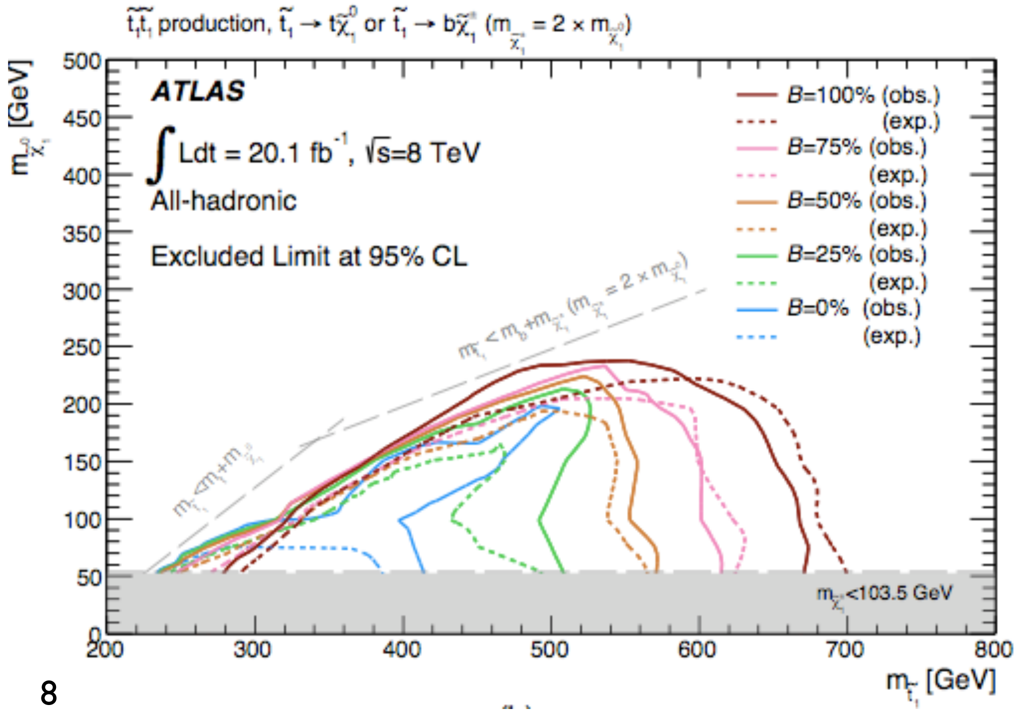
- interpretation with 100% BR to $\tilde{t}_1 \rightarrow t\tilde{\chi}^0$
- interpretation with mixed decays : $\tilde{t}_1 \rightarrow t\tilde{\chi}^0$ and $\tilde{t}_1 \rightarrow b\tilde{\chi}^+$



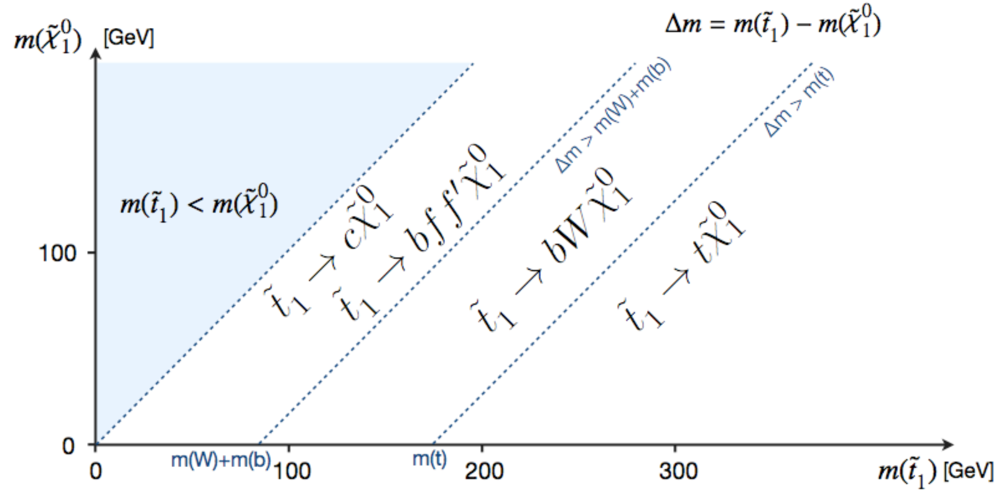




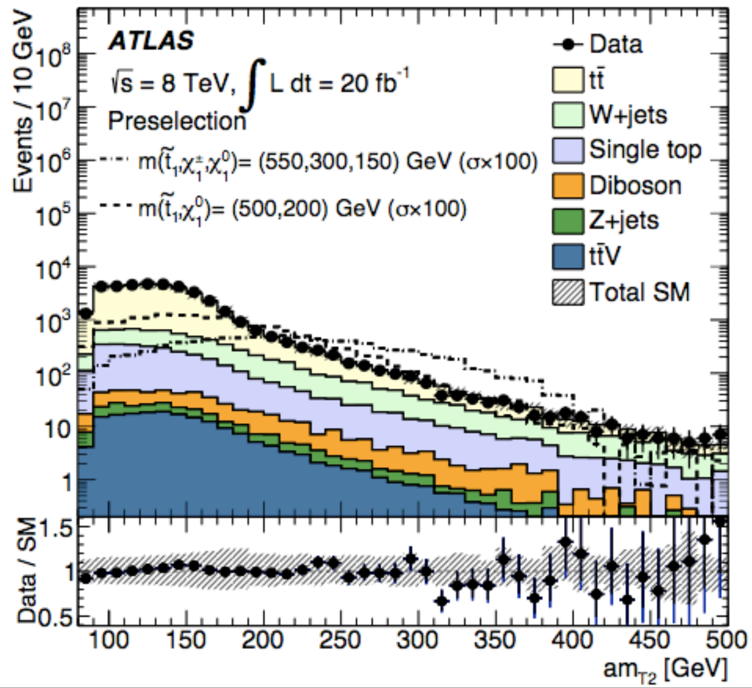
1-lepton,4-jets (1b-jet) and $\not{E}_T$

arXiv:1407.0583

- sensitive to many different signal scenarios depending on the masses of $\tilde{t}_1$, $\tilde{\chi}^+$, $\tilde{\chi}^0$
- use either hard or soft lepton (MET trigger) that allow to reach low $\Delta m(\tilde{t}_1, \tilde{\chi}^0)$
- b-tagged jet used for selection and to build kinematic variables
- Large (ΔR=1) jets are used for heavy stop.



$$am^2_{T2}(\chi) = \min_{\not{q}_T^{(1)} + \not{q}_T^{(2)} = \not{p}_T} \left[\max \left\{ m_T^2(\mathbf{p}_T(\nu_1), \not{q}_T^{(1)}; \chi), m_T^2(\mathbf{p}_T(\nu_2), \not{q}_T^{(2)}; \chi) \right\} \right]$$



Selection

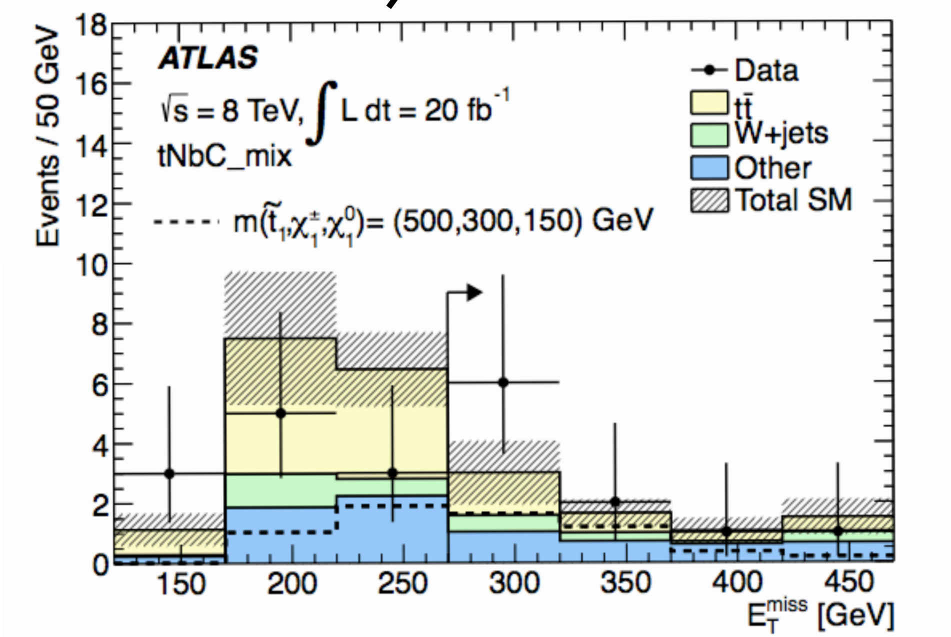
- common: 1 isolated lepton,4 jets,1b-jet, large MET and m_T.
- 15 SR using many different kinematic variables, probing each decay mode.

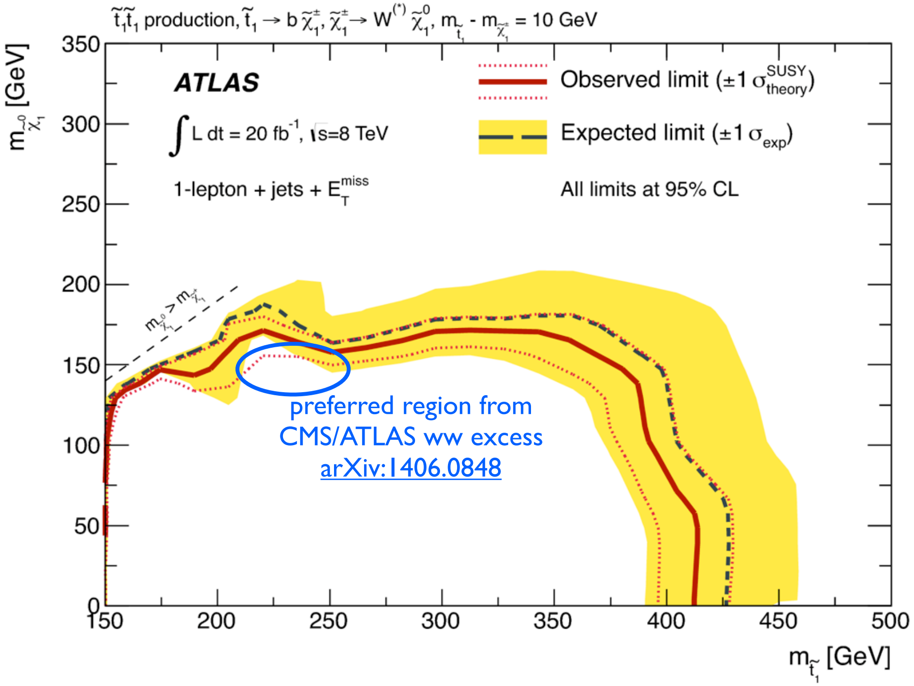
1-lepton,4-jets (1b-jet) and $\not{E}_T$

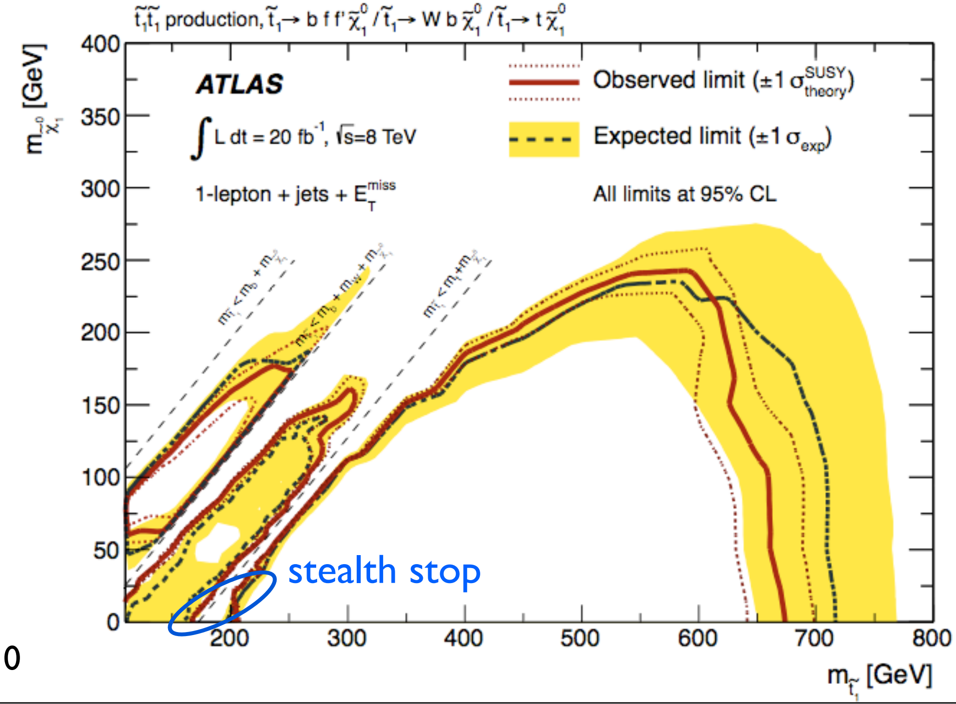
arXiv:1407.0583

background control

- ttbar and W+jet with W decay to lepton are the main backgrounds. these are estimated with dedicated control regions.
- single top, VV, Z+jet from simulation.
- no excess observed. cut and count and shape fit techniques (on MET, mT, lepton pT) used to estimate the exclusion limits.







2 leptons, b-jets and $\not{E}_T$

Published on
[JHEP 06 (2014) 124]
arXiv:1403.4853

$$m_{T2}(\vec{p}_T^{\,\alpha}, \vec{p}_T^{\,\beta}, \vec{p}_T^{\,miss}) = min_{\vec{q}_T^{\,1}+\vec{q}_T^{\,2}=\vec{p}_T^{\,miss}} \{max(m_T^2(\vec{p}_T^{\,\alpha}, \vec{q}_T^{\,1}), m_T^2(\vec{p}_T^{\,\beta}, \vec{q}_T^{\,2}))\}$$

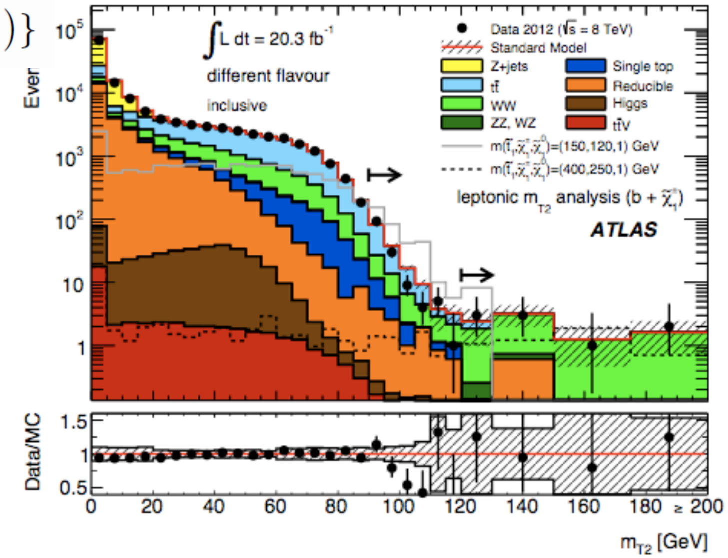
- large $\Delta m(\tilde{t}_1, \tilde{\chi}^0)$: $\tilde{t} \rightarrow t\, \tilde{\chi}_1^0$ using MVA with:

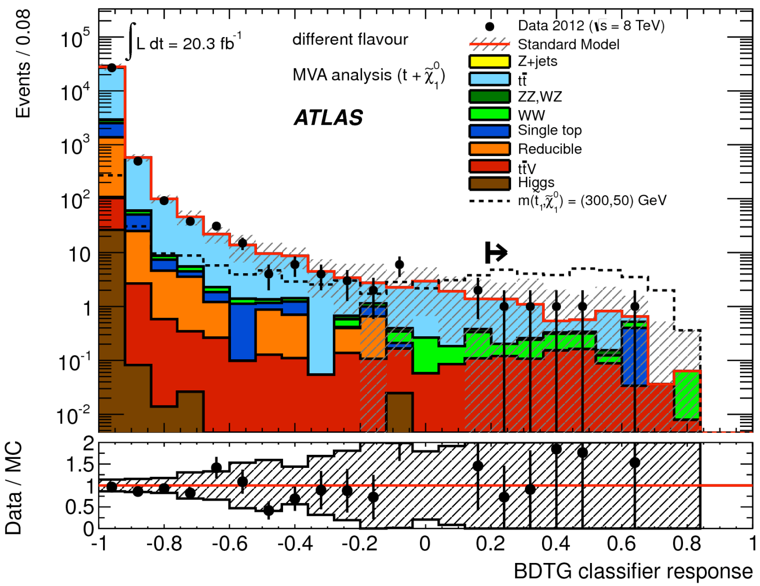
  $E_T^{miss}, m_{ll}, m_{T2}, \Delta\varphi_{ll}, \Delta\vartheta_{ll}, \Delta\varphi_{1j}, \Delta\varphi_{1 E_T^{miss}}$

- medium $\Delta m(\tilde{t}_1, \tilde{\chi}^0)$: $\tilde{t} \rightarrow b\tilde{\chi}^+ \rightarrow bW^{(*)}\, \tilde{\chi}^0$
  real W: leptonic MT2; virtual W: hadronic MT2

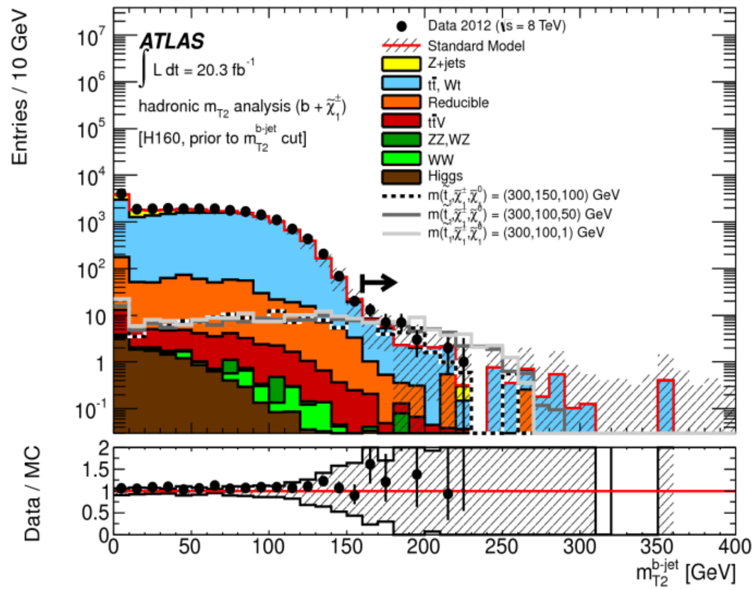
- background yield: ttbar, WW, Wt estimated with dedicated control regions

Leptonic m_{T2}





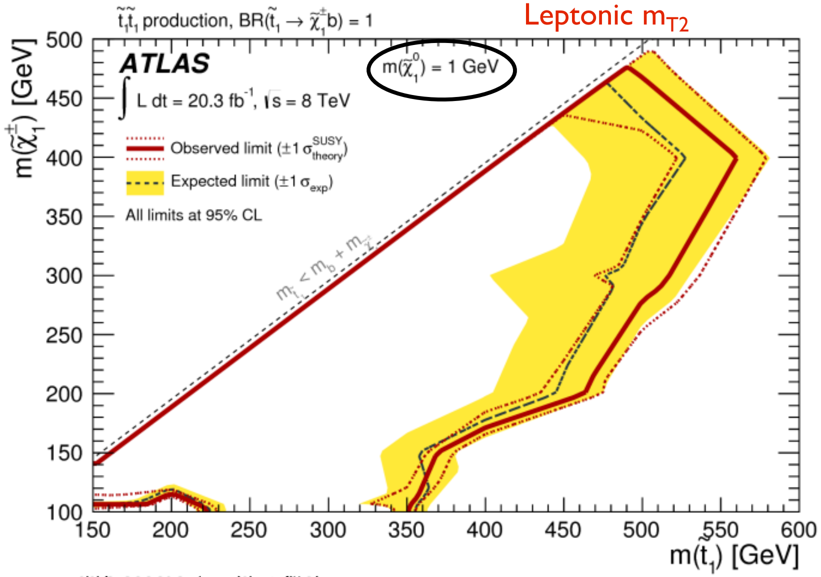
Hadronic m_{T2}

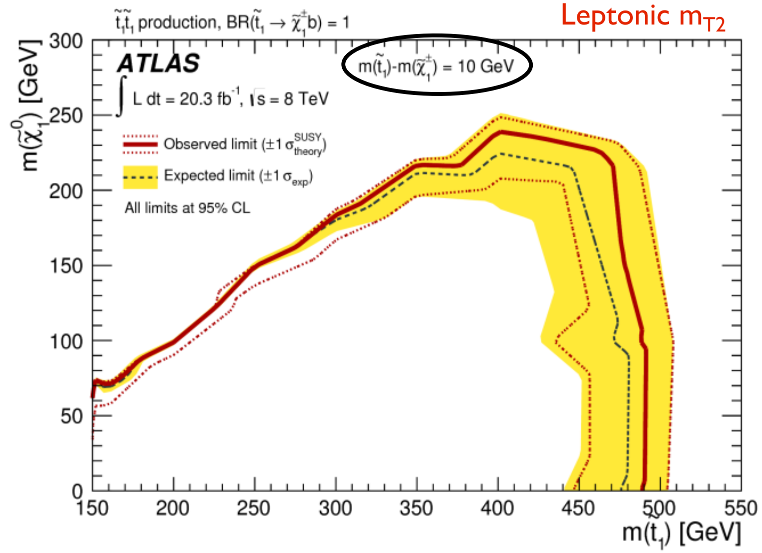


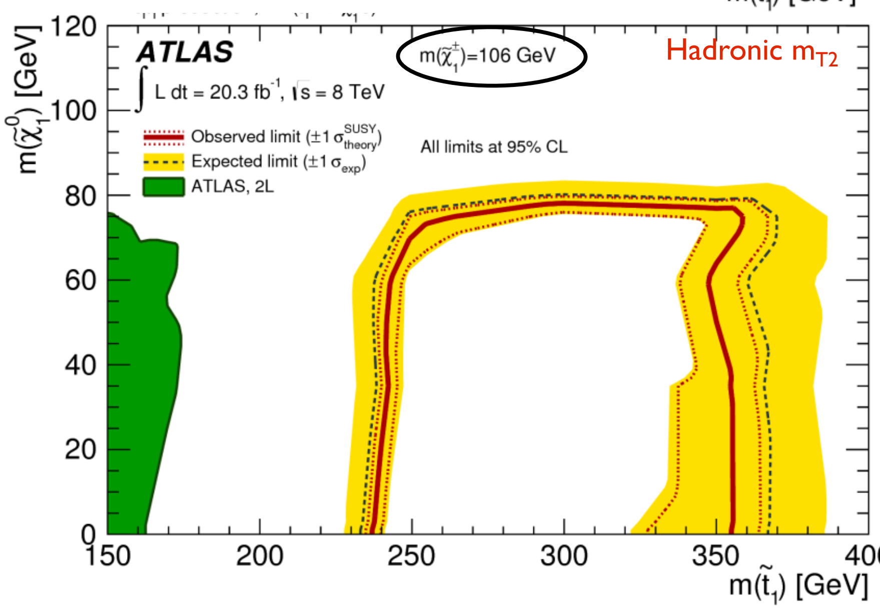
2 leptons, b-jets and $\not{E}_T$

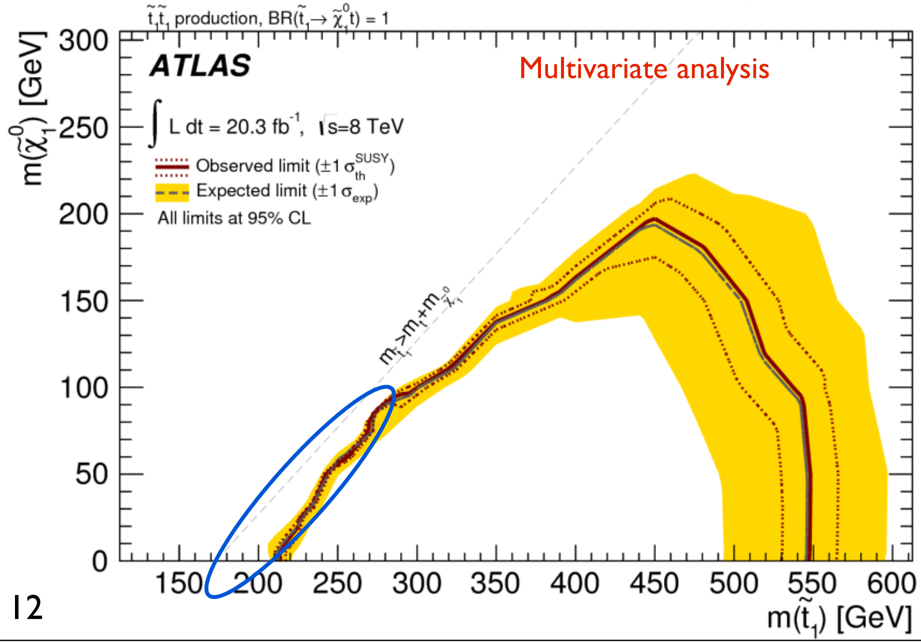
Published on
JHEP 06 (2014) 124
arXiv:1403.4853

- no significant excess over expected background ⇒ exclusion limits in many different scenarios.







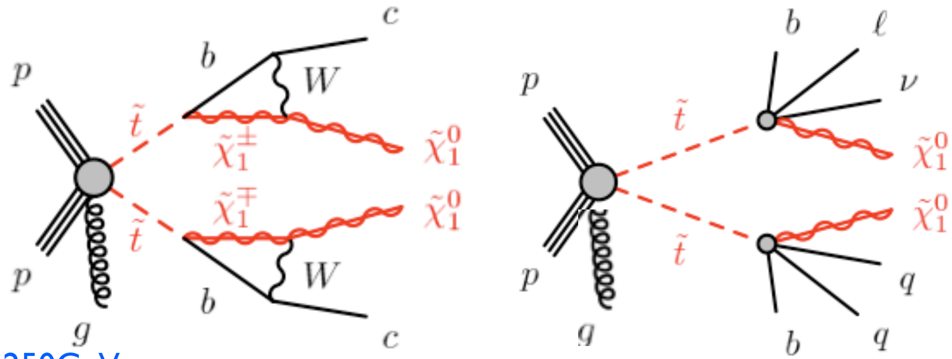


c-jet/mono-jet and $\not{E}_T$

arXiv:1407.0608

compressed spectra: $m_b \leq \Delta m(\tilde{t}_1, \tilde{\chi}^0) \leq m_W + m_b$

ISF/FSR



- $\tilde{t} \rightarrow c\tilde{\chi}_1^0$
- $\tilde{t} \rightarrow b\, ff'\tilde{\chi}_1^0$ $\Rightarrow$soft leptons and jets

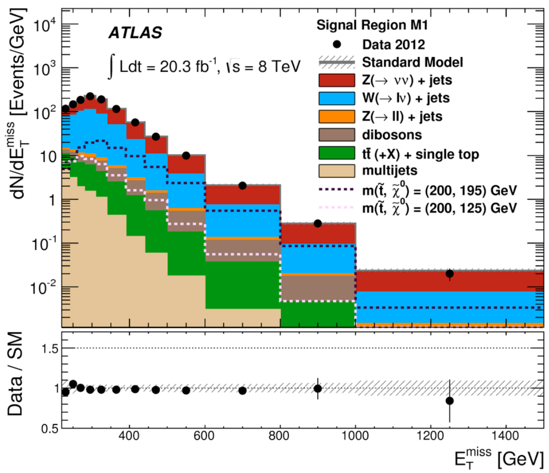
for $\Delta m > 20$ GeV

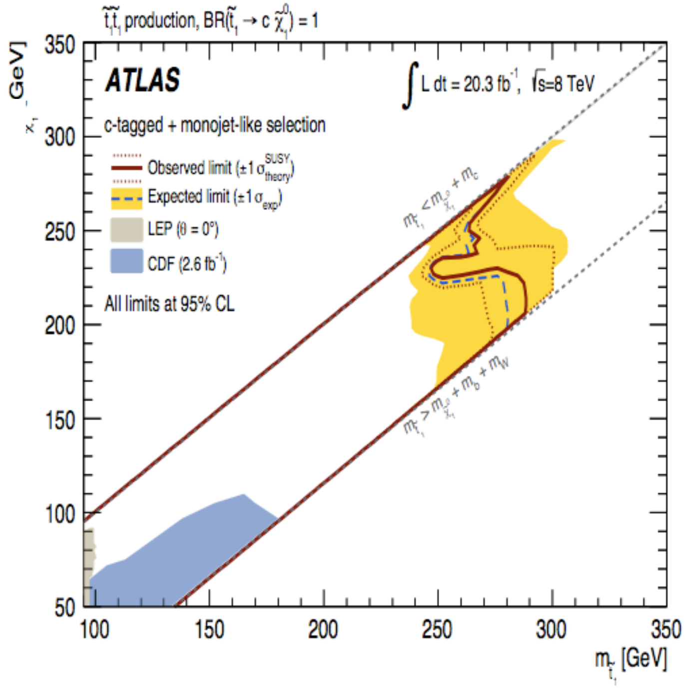
charm tagging: max 4 jets with $p_T \geq 30$GeV; $p_T(j_1) \geq 290$ GeV, MET$\geq$250GeV.

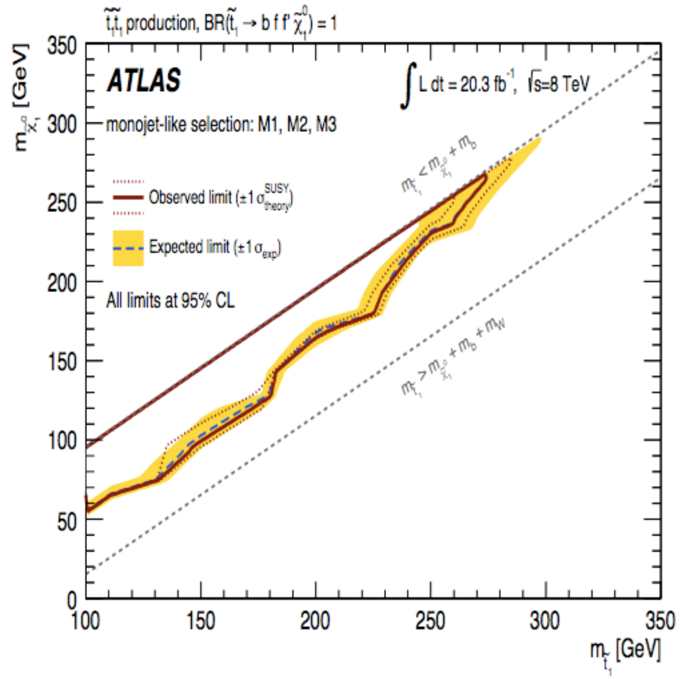
for $\Delta m < 20$ GeV

monojet selection: max 3 jets with $p_T \geq 30$GeV; $p_T(j_1) \geq 280$ GeV, MET$\geq$220GeV.

$\Delta\varphi$(jet, **MET**) > 0.4







Z+b-jets and $\not{E}_T$

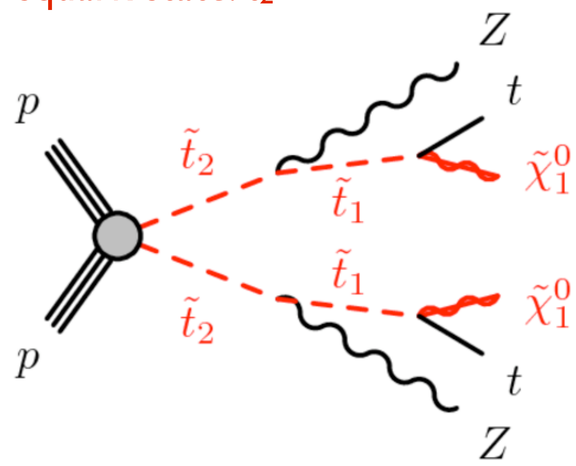
Eur. Phys. J. C (2014) 74:2883

arXiv:1403.5222

- $\tilde{t}_2 \rightarrow Z\,\tilde{t}_1 \rightarrow Zt\tilde{\chi}_1^0$

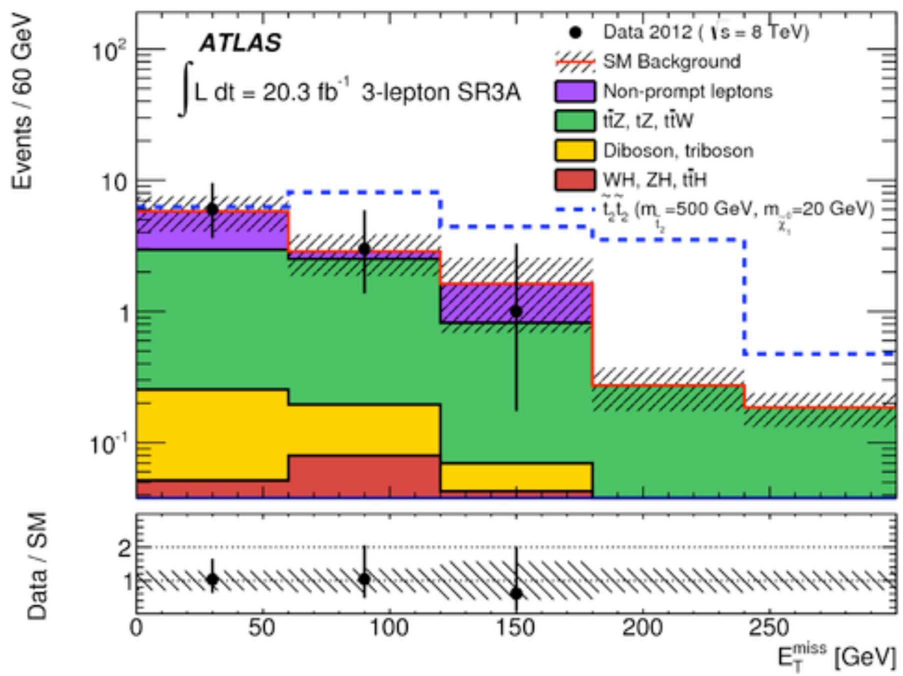
heavier top squark state: t_2

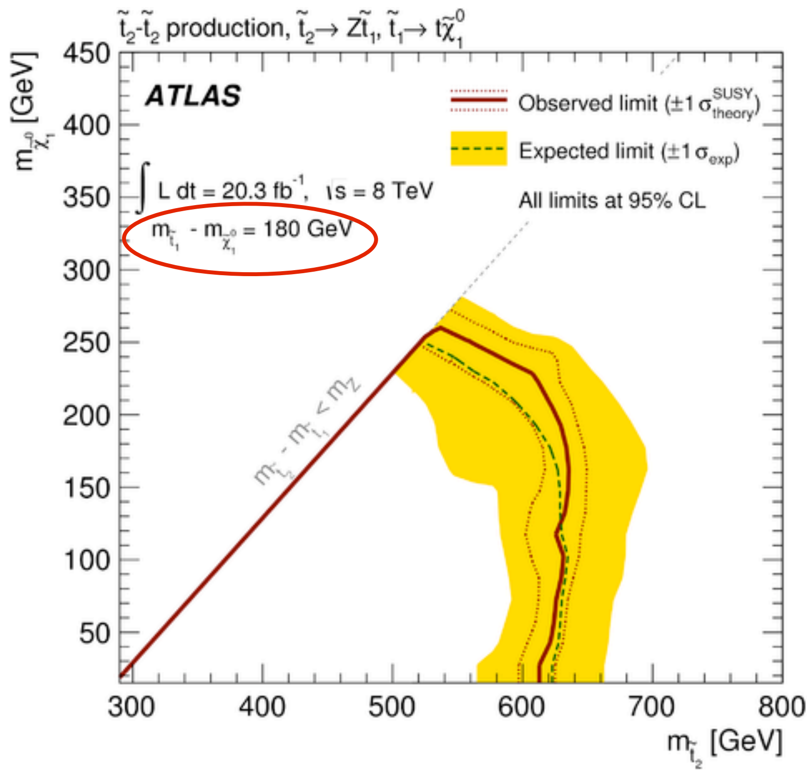
$\tilde{t}_2$ decay provide indirect sensitivity to stealth stop:
$\Delta m(\tilde{t}_1, \tilde{\chi}^0) \approx m_t$



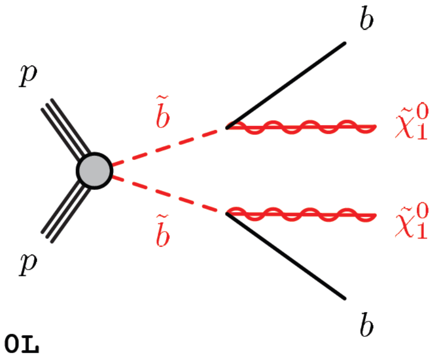
- Selection: $\geq$2 leptons (1Z), $\geq$3jet (1bjet), large MET

- main SM backgrounds: fake leptons, ttbarV,tZ,VV

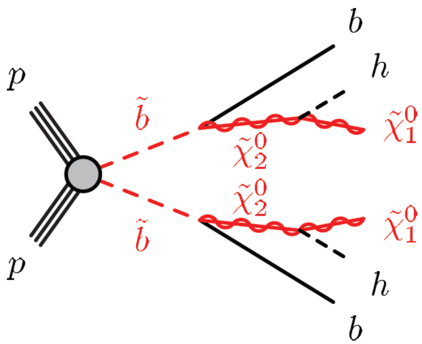




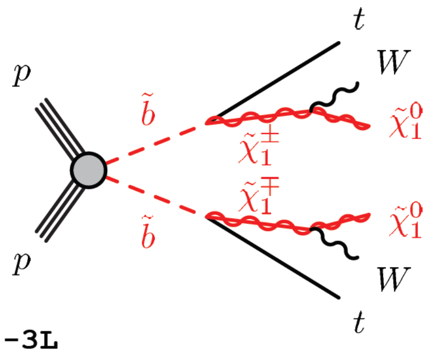
Direct production of bottom squark pairs



0L



0L



2-3L

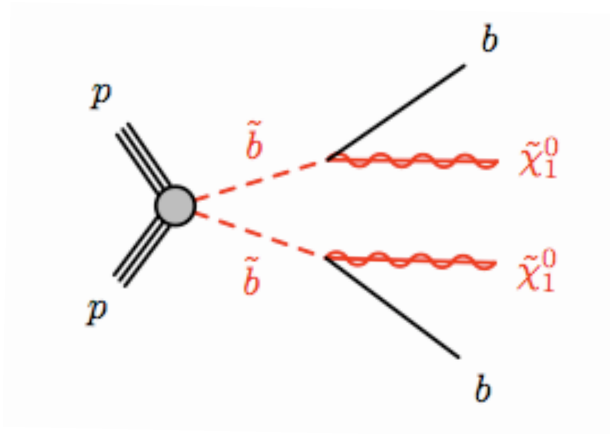
0 leptons 2b-jets and $\not{E}_T$

JHEP 10 (2013) 189

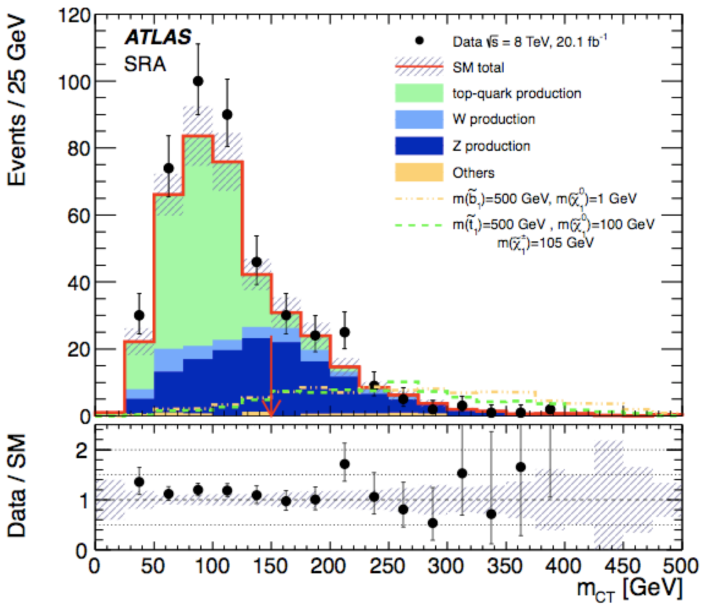
arXiv:1308.2631

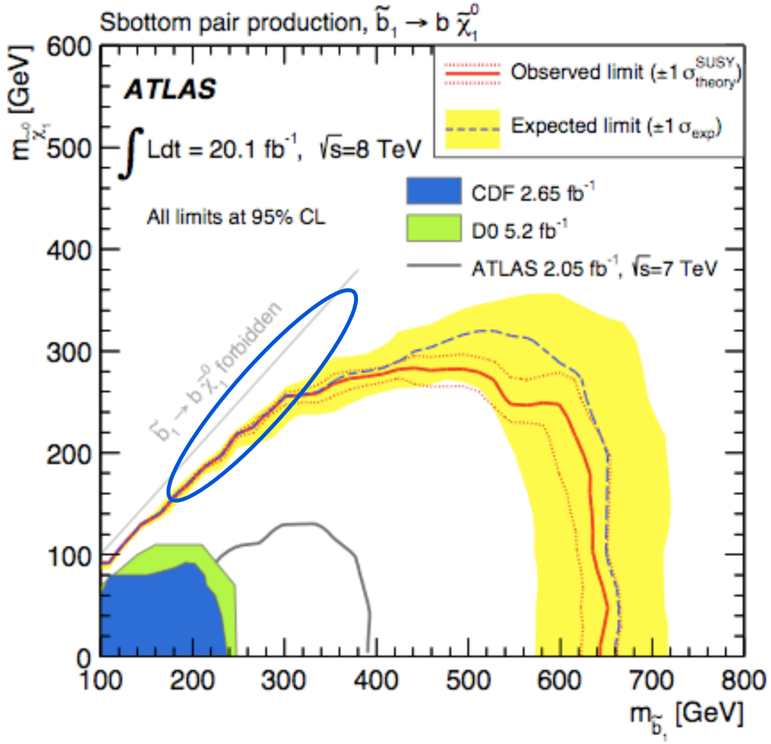
Fully hadronic final state search targeting:

- $\tilde{b} \rightarrow b\ \tilde{\chi}^0$
- Two signal regions optimized for large and small $\Delta m(\tilde{b},\tilde{\chi}^0)$.
- main SM backgrounds, ttbar and Z/W+HF jets are estimated using dedicated data samples.



$$m_{\mathrm{CT}}^2(v_1, v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\boldsymbol{p}_{\mathrm{T}}(v_1) - \boldsymbol{p}_{\mathrm{T}}(v_2)]^2$$





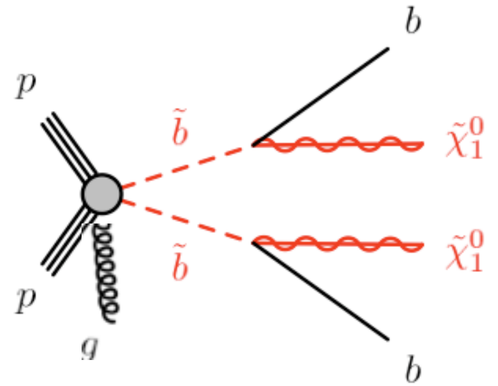
mono-jets and $\not{E}_T$

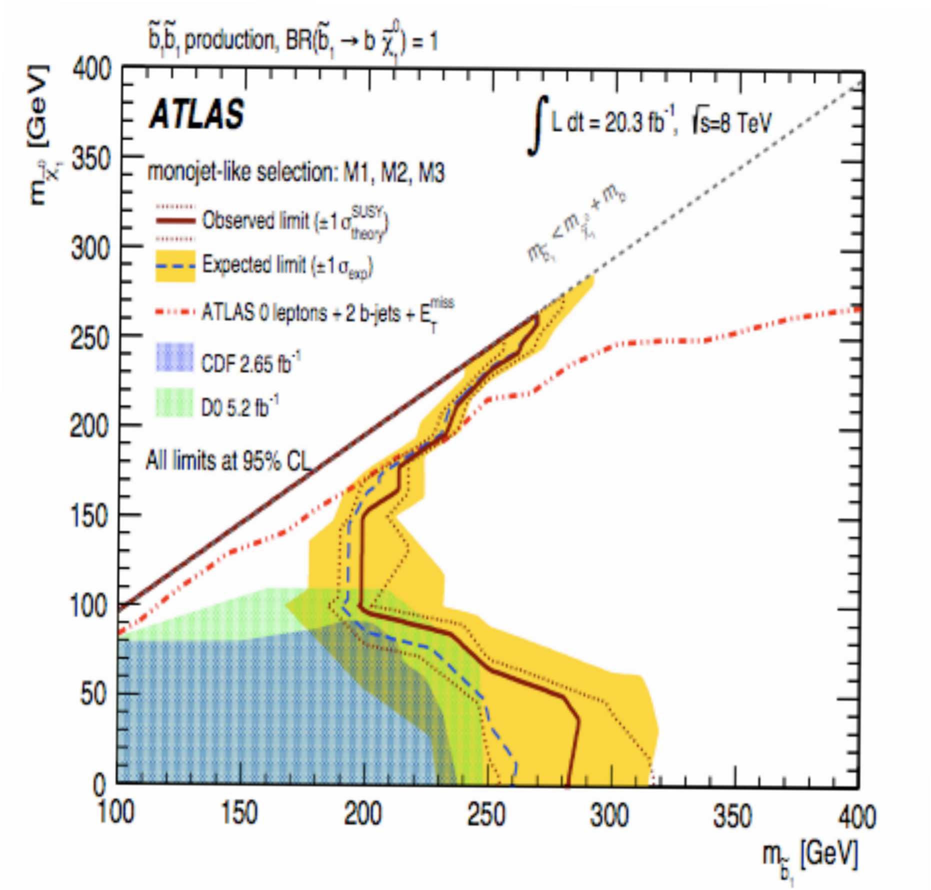
arXiv:1407.0608

compressed spectra: $m_b \leq \Delta m(\tilde{b}_1, \tilde{\chi}^0) \leq m_W + m_b$

- $\tilde{b}_1 \to b\tilde{\chi}_1^0$

- help improve the limit of 0L in the region where b_1 and χ^0 are almost degenerate





monojet selection:

max 3 jets with $p_T \geq 30$GeV;

M1: $p_T(j_1) \geq 280$ GeV, MET$\geq$220GeV.

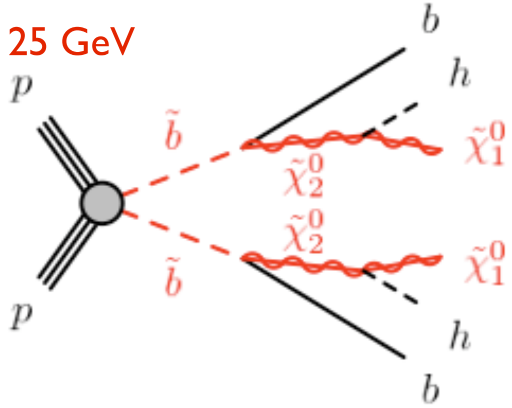
3b-jets, 0-1lepton + $\not{E}_T$

arXiv:1407.0600

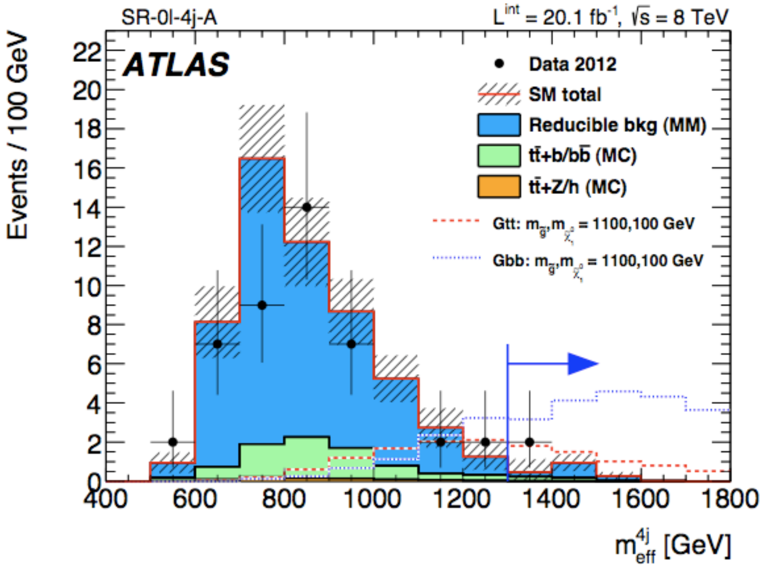
More details in the ATLAS talk of Bertrand Martin

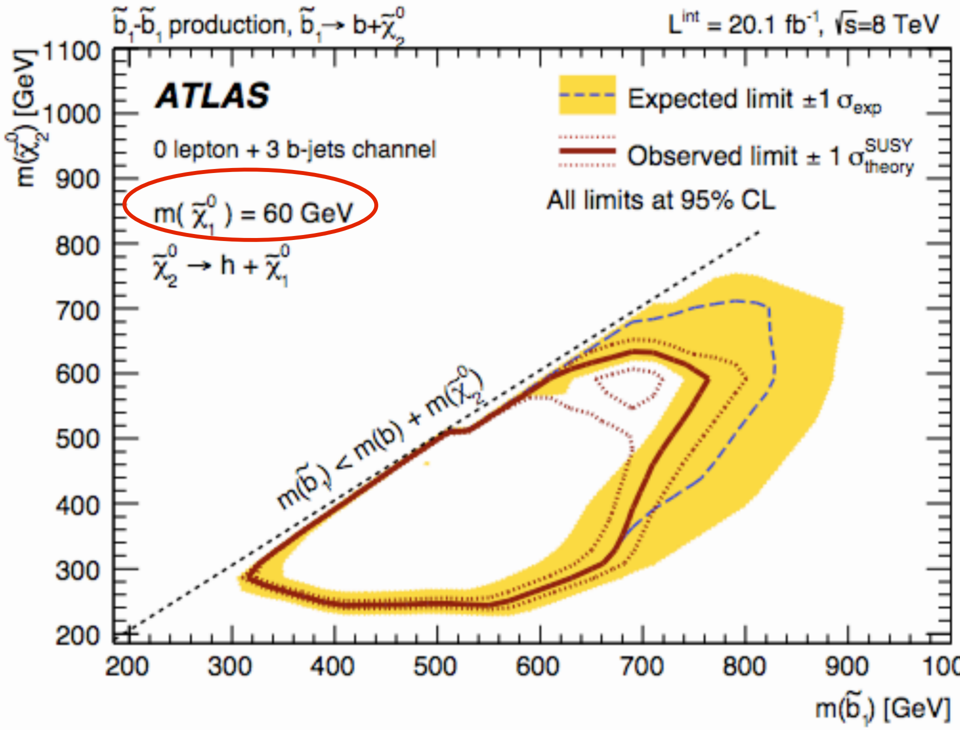
search targeting both direct and gluino mediated production, the model considered here:

lightest higgs, m_h=125 GeV



- $\tilde{b} \to b\, \tilde{\chi}_2^0 \to bh\, \tilde{\chi}_1^0$ (h→bbbar)
  $\tilde{\chi}_2^0$: heavier neutralino state
- ≥ 4 jets, (≥3b-jets), lepton veto , large missing momentum.
- main SM backgrounds: ttbar+b/bbbar is estimated with MC, fake b-jets estimated with data driven techniques.



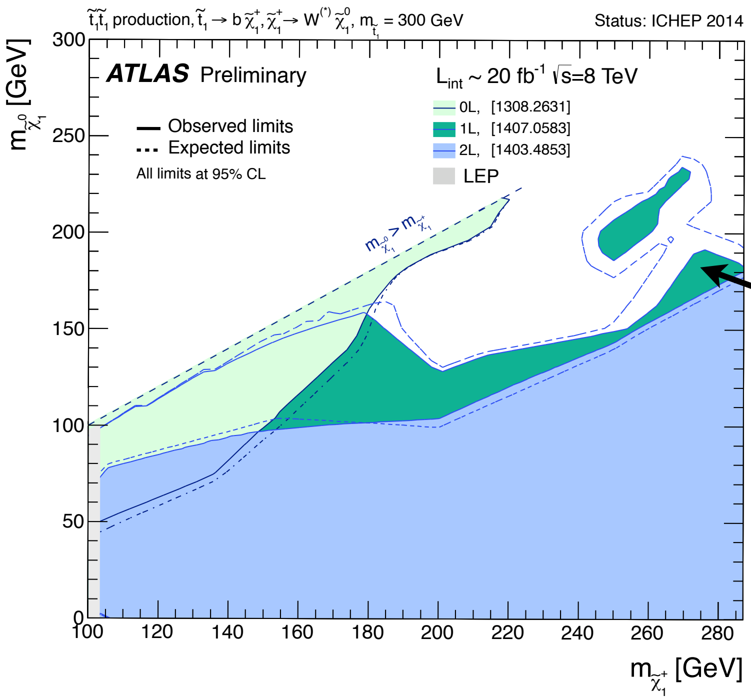


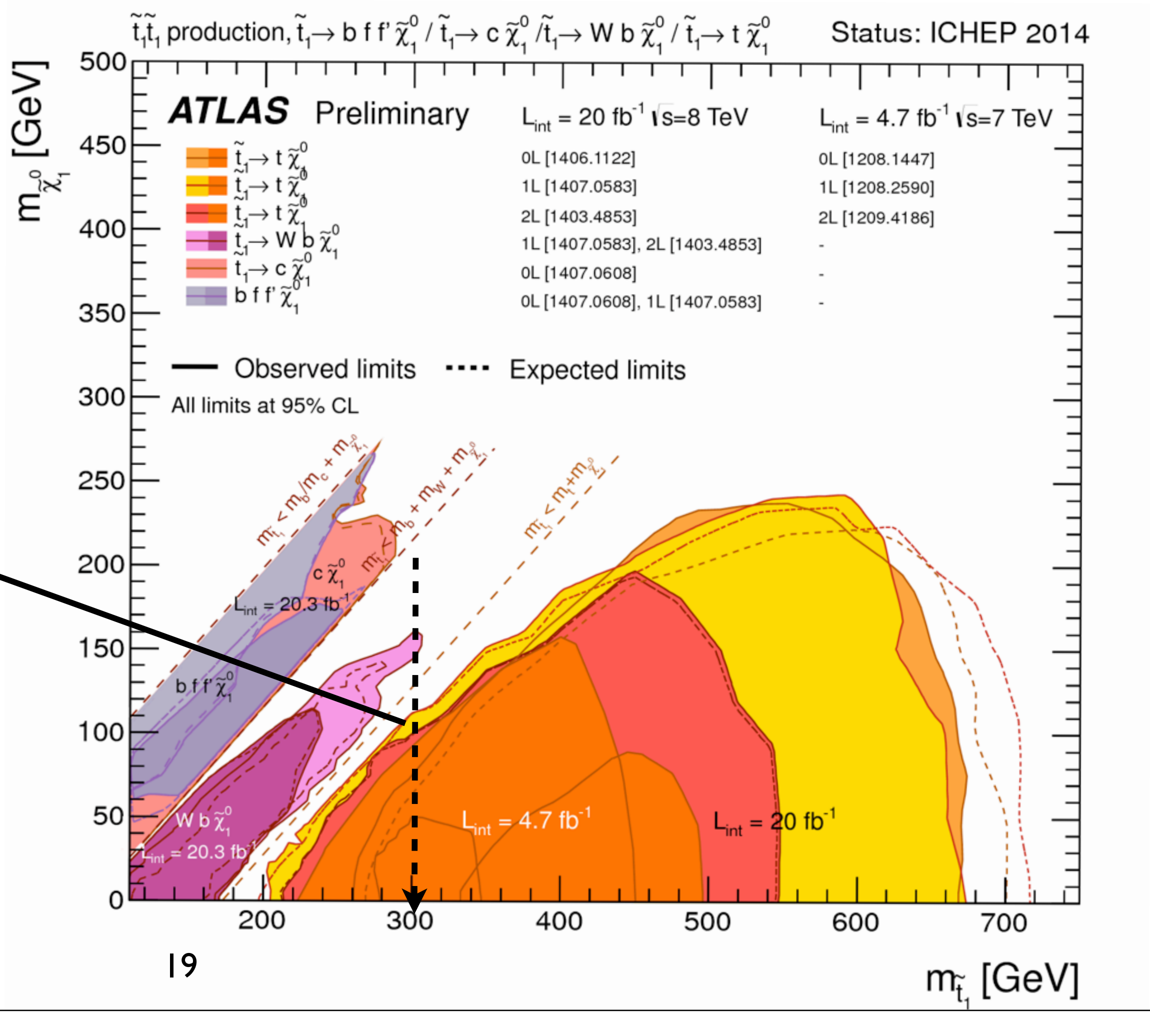
summary

- ATLAS has a comprehensive set of searches for third generation squarks. Few have been shown in this talk. No significan excess from SM expectation has been observed.

- searches extend limits from previous experiments, but still many gaps remain...

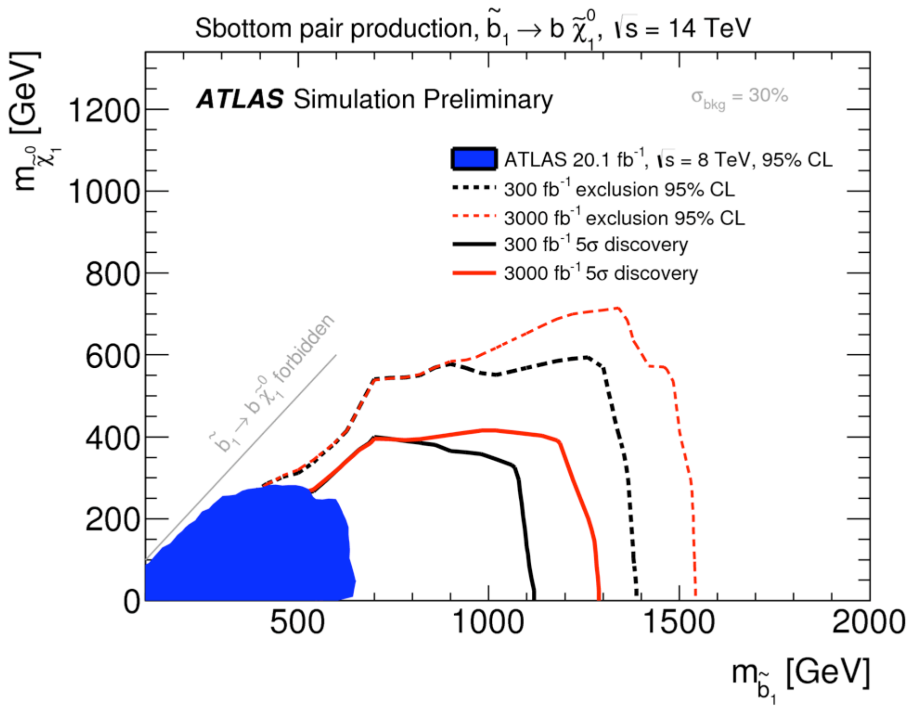
- the gap m(t)-m(χ_1^0)≈m(top) reinterpretation of ttbar cross-section arXiv:1406.5375 and spin correlation analysis (to be released soon)

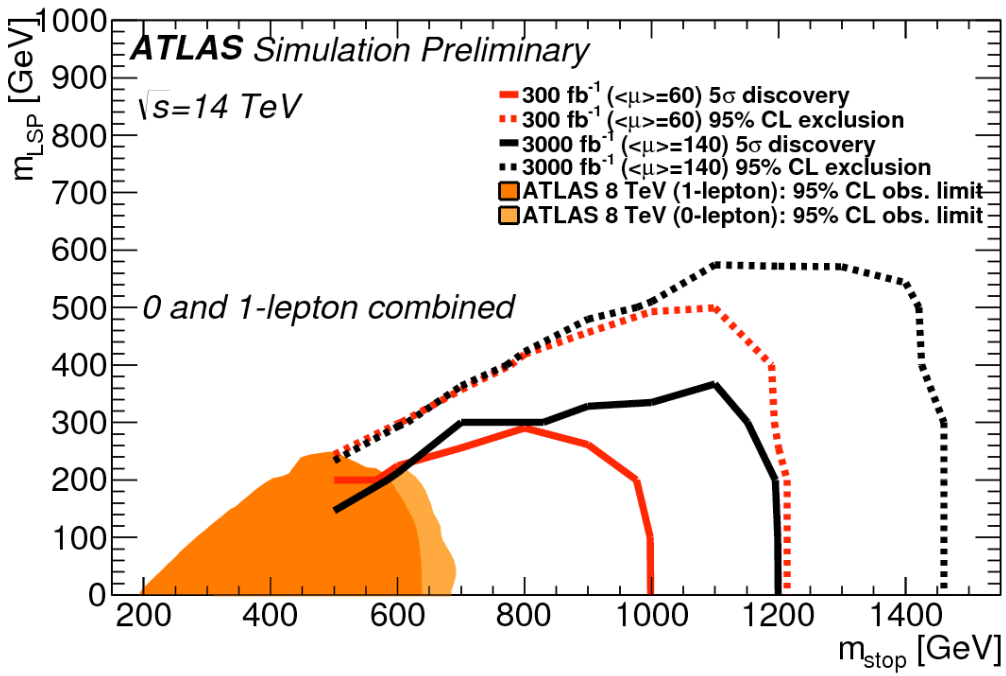




Looking forward

- to run-2. expected ATLAS reach at 14 TeV with increased luminosity:
- ATL-PHYS-PUB-2014-010- and ATL-PHYS-PUB-2013-011
- stay tunned...



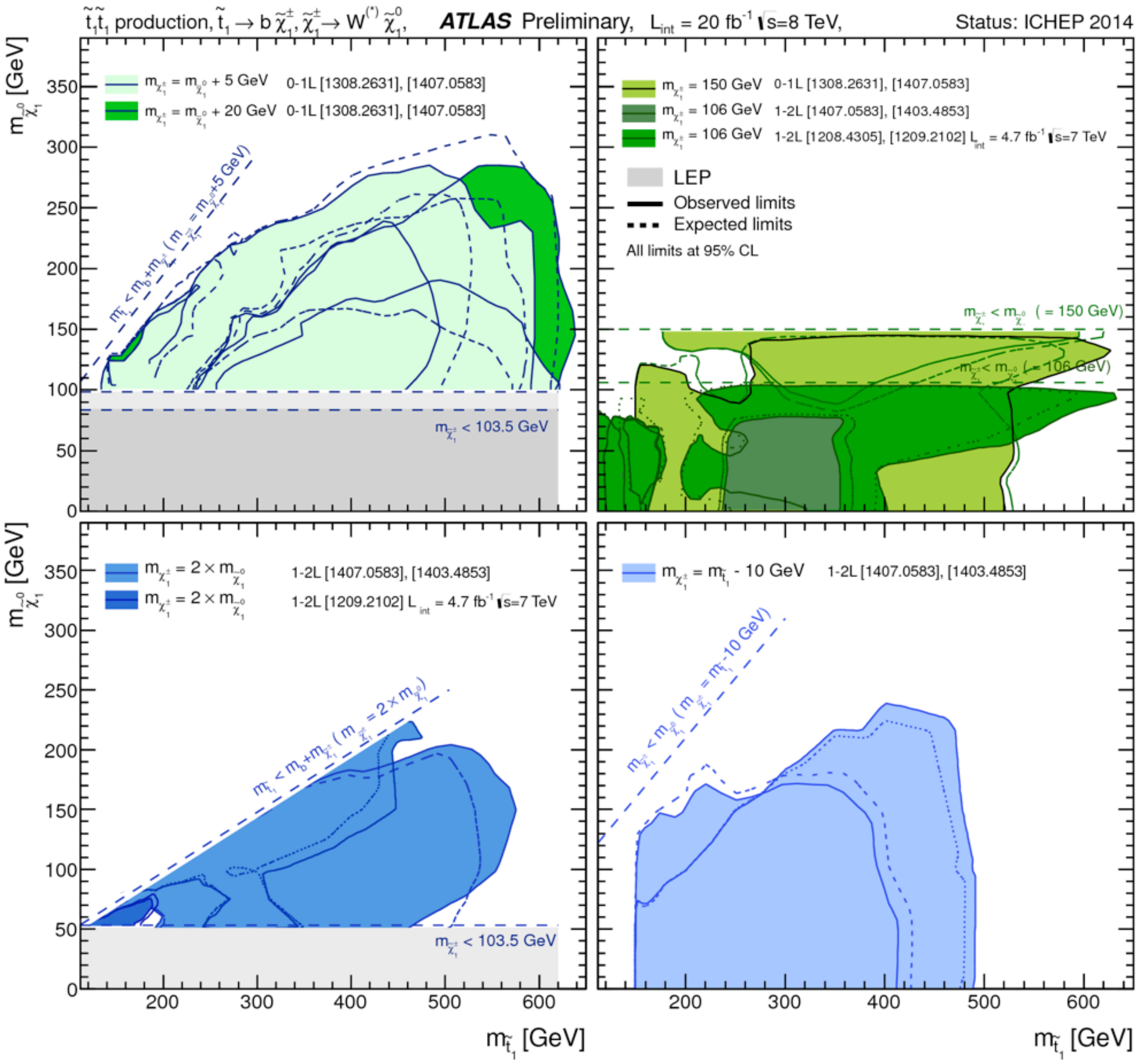


Backup slides

one other summary plot

- No significant excess from SM expectations. Searches extend considerably the previous limits from LEP and Tevatron

- excluded $\tilde{t}_1$-$\tilde{\chi}_1^0$ massin the b $\tilde{\chi}_1^+$ mode ass plane for different assumptions on $\tilde{\chi}_1^+$ mass



fully hadronic final states

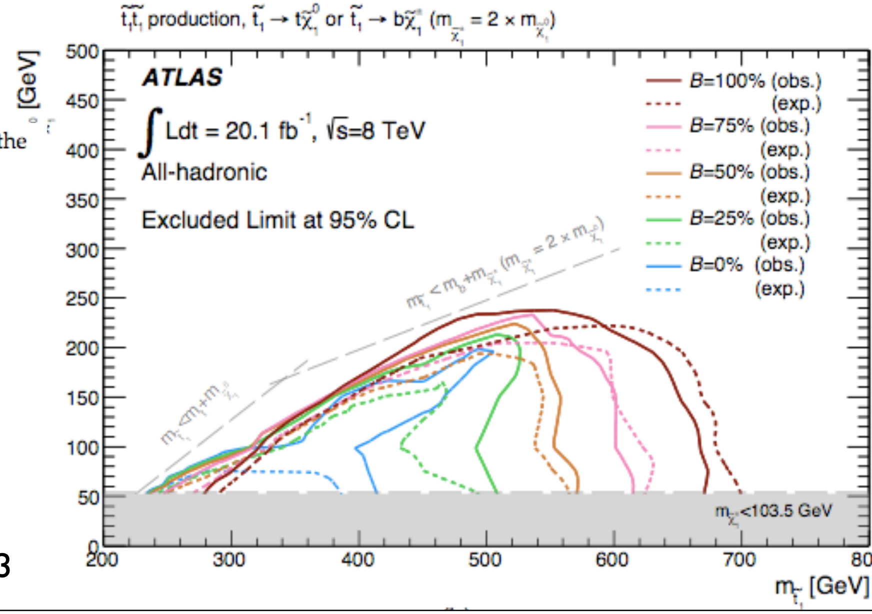
arXiv:1406.1122

Table 11. Event yields in each signal region (SRA, SRB, and SRC) are compared to the background estimate from the profile likelihood fit. Statistical, detector, and theoretical systematic uncertainties are included; the total systematic uncertainty in the background estimate includes all correlations. For each signal region, the 95% CL upper limits on the expected (observed) visible cross sections σ_{vis} (exp) (σ_{vis} (obs)) and the expected (observed) event yields N^{95}_{exp} (N^{95}_{obs}) are summarized.

	SRA1	SRA2	SRA3	SRA4	SRB	SRC1	SRC2	SRC3
Observed events	11	4	5	4	2	59	30	15
Total SM	15.8 ± 1.9	4.1 ± 0.8	4.1 ± 0.9	2.4 ± 0.7	2.4 ± 0.7	68 ± 7	34 ± 5	20.3 ± 3.0
$t\bar{t}$	10.6 ± 1.9	1.8 ± 0.5	1.1 ± 0.6	0.49 ± 0.34	$0.10^{+0.14}_{-0.10}$	32 ± 4	12.9 ± 2.0	6.7 ± 1.2
$t\bar{t} + W/Z$	1.8 ± 0.6	0.85 ± 0.29	0.82 ± 0.29	0.50 ± 0.17	0.47 ± 0.17	3.2 ± 0.8	1.9 ± 0.5	1.3 ± 0.4
Z + jets	1.4 ± 0.5	0.63 ± 0.22	1.2 ± 0.4	0.68 ± 0.27	1.23 ± 0.31	15.7 ± 3.5	9.0 ± 1.9	6.1 ± 1.3
W + jets	1.0 ± 0.5	0.46 ± 0.21	0.21 ± 0.19	$0.06^{+0.10}_{-0.06}$	0.49 ± 0.33	8 ± 4	4.8 ± 2.2	2.8 ± 1.2
Single top	1.0 ± 0.4	0.30 ± 0.17	0.44 ± 0.14	0.31 ± 0.16	0.08 ± 0.06	7.2 ± 2.9	4.5 ± 1.8	2.9 ± 1.4
Diboson	< 0.4	< 0.13	0.32 ± 0.17	0.32 ± 0.18	0.02 ± 0.01	1.1 ± 0.8	$0.6^{+0.7}_{-0.6}$	$0.6^{+0.7}_{-0.6}$
Multijets	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.24 ± 0.24	0.06 ± 0.06	0.01 ± 0.01
σ_{vis} (obs) [fb]	0.33	0.29	0.33	0.32	0.21	0.78	0.62	0.40
σ_{vis} (exp) [fb]	$0.48^{+0.21}_{-0.14}$	$0.29^{+0.13}_{-0.09}$	$0.29^{+0.14}_{-0.09}$	$0.25^{+0.13}_{-0.07}$	$0.24^{+0.13}_{-0.06}$	$1.03^{+0.42}_{-0.29}$	$0.73^{+0.31}_{-0.21}$	$0.55^{+0.24}_{-0.15}$
N^{95}_{obs}	6.6	5.7	6.7	6.5	4.2	15.7	12.4	8.0
N^{95}_{exp}	$9.7^{+4.3}_{-3.0}$	$5.8^{+2.6}_{-1.8}$	$5.9^{+2.8}_{-1.9}$	$5.0^{+2.6}_{-1.4}$	$4.7^{+2.6}_{-1.2}$	$20.7^{+8.4}_{-5.8}$	$14.7^{+6.2}_{-4.2}$	$11.0^{+4.9}_{-3.1}$

Table 8. Normalization of the $t\bar{t}$, W + jets, and Z + jets SM background as obtained from the background fits for SRA, SRB and SRC.

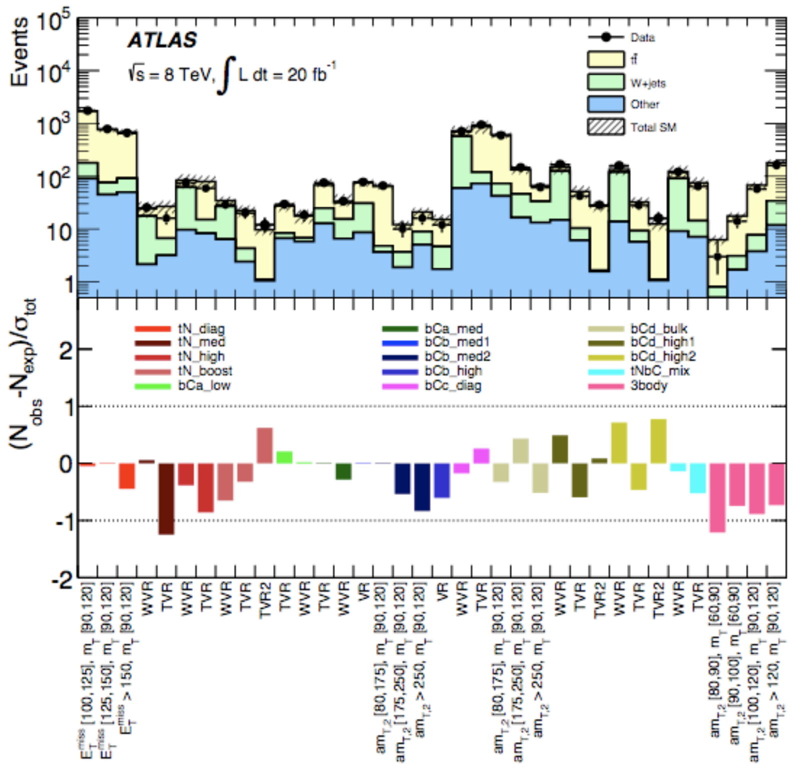
Background Source	SRA	SRB	SRC
$t\bar{t}$	1.24 ± 0.13	$1.00^{+0.10}_{-0.05}$	1.07 ± 0.11
W + jets	–	1.0 ± 0.4	–
Z + jets	$0.94^{+0.16}_{-0.15}$	1.07 ± 0.07	1.07 ± 0.07



1-lepton,4-jets (1b-jet) and $\not{E}_T$

arXiv:1407.0583

Results



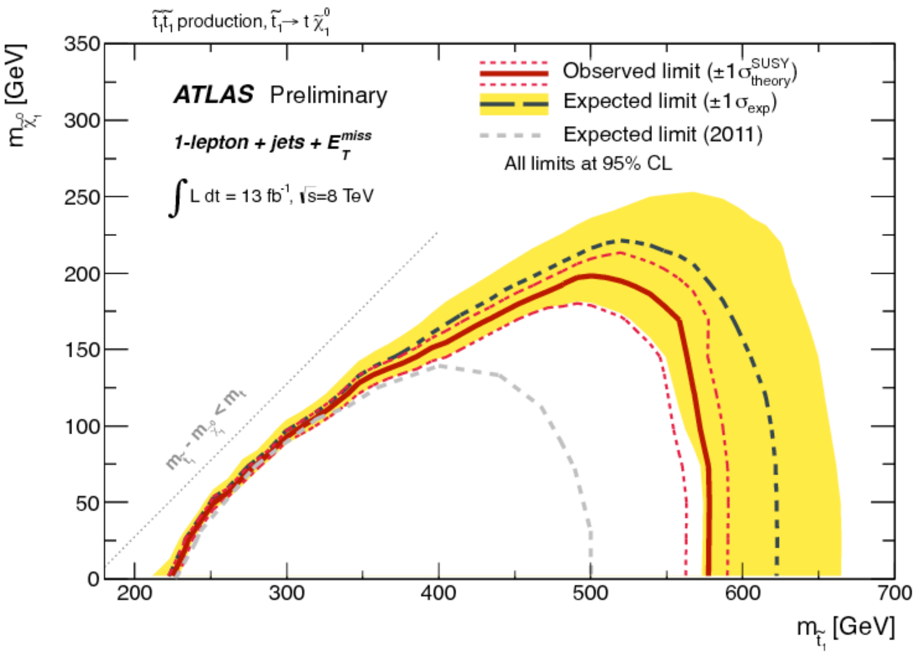
Region	Obs.	Exp. bkg.	p_0	$N_{\mathrm{non-SM}}$ Obs.	Exp.	σ_{vis} [fb] Obs.	Exp.
tN_med	12	13.0 ± 2.2	≥ 0.5	8.5	9.2	0.4	0.5
tN_high	5	5.0 ± 1.0	≥ 0.5	6.0	6.0	0.3	0.3
tN_boost	5	3.3 ± 0.7	0.17	7.0	5.3	0.3	0.3
bCa_low	11	6.5 ± 1.4	0.08	12.2	7.8	0.61	0.92
bCa_med	20	17 ± 4	0.33	14.4	12.3	0.72	0.68
bCb_med1	41	32 ± 5	0.12	23.5	16.0	1.17	0.88
bCb_high	7	9.8 ± 1.6	≥ 0.5	6.5	7.9	0.32	0.22
bCc_diag	493	470 ± 50	0.27	110.6	95.1	5.4	4.7
bCd_high1	16	11.0 ± 1.5	0.09	13.2	8.5	0.7	0.4
bCd_high2	5	4.4 ± 0.8	0.36	6.3	5.7	0.3	0.3
tNbC_mix	10	7.2 ± 1.0	0.13	9.7	7.0	0.5	0.3
tN_diag							
$125 < E_T^{miss} < 150$ GeV, $120 < m_T < 140$ GeV	117	136 ± 22	≥ 0.5	42.1	55.7	2.1	2.7
$125 < E_T^{miss} < 150$ GeV, $m_T > 140$ GeV	163	152 ± 20	0.35	55.4	47.8	2.7	2.4
$E_T^{miss} > 150$ GeV, $120 < m_T < 140$ GeV	101	98 ± 13	0.43	36.1	33.9	1.8	1.7
$E_T^{miss} > 150$ GeV, $m_T > 140$ GeV	217	236 ± 29	≥ 0.5	58.7	71.4	2.9	3.5
bCb_med2							
$175 < am_{T2} < 250$ GeV, $90 < m_T < 120$ GeV	10	12.1 ± 2.0	≥ 0.5	7.3	8.8	0.4	0.4
$175 < am_{T2} < 250$ GeV, $m_T > 120$ GeV	10	7.4 ± 1.4	0.10	9.7	7.3	0.5	0.4
$am_{T2} > 250$ GeV, $90 < m_T < 120$ GeV	16	21 ± 4	≥ 0.5	9.3	12.3	0.5	0.6
$am_{T2} > 250$ GeV, $m_T > 120$ GeV	9	9.1 ± 1.6	≥ 0.5	7.7	7.8	0.4	0.4
bCd_bulk							
$175 < am_{T2} < 250$ GeV, $90 < m_T < 120$ GeV	144	133 ± 22	0.29	36.1	33.9	1.8	1.7
$175 < am_{T2} < 250$ GeV, $m_T > 120$ GeV	78	73 ± 8	0.34	58.7	71.4	2.9	3.5
$am_{T2} > 250$ GeV, $90 < m_T < 120$ GeV	61	66 ± 6	≥ 0.5	17.5	20.9	0.9	1.0
$am_{T2} > 250$ GeV, $m_T > 120$ GeV	29	26.5 ± 2.6	0.34	14.8	12.6	0.7	0.6
3body							
$80 < am_{T2} < 90$ GeV, $90 < m_T < 120$ GeV	12	16.9 ± 2.8	≥ 0.5	7.3	9.9	0.4	0.5
$80 < am_{T2} < 90$ GeV, $m_T > 120$ GeV	8	8.4 ± 2.2	≥ 0.5	7.9	7.8	0.4	0.4
$90 < am_{T2} < 100$ GeV, $90 < m_T < 120$ GeV	29	35 ± 4	≥ 0.5	11.7	14.7	0.6	0.7
$90 < am_{T2} < 100$ GeV, $m_T > 120$ GeV	22	29 ± 5	≥ 0.5	55.4	47.8	2.7	2.4

1-lepton,4-jets (1b-jet) and $\not{E}_T$

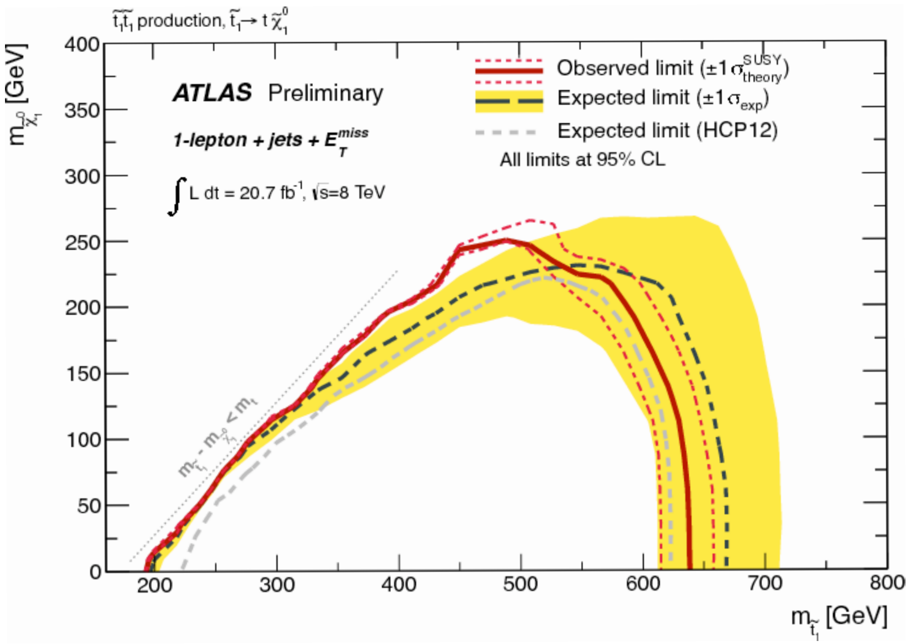
arXiv:1407.0583

use of shape fit techniques (on MET, mT, lepton pT variables) to estimate the exclusion limits

⇒ push the sensitivity toward the very challenging diagonal.



ATLAS-CONF-2012-166

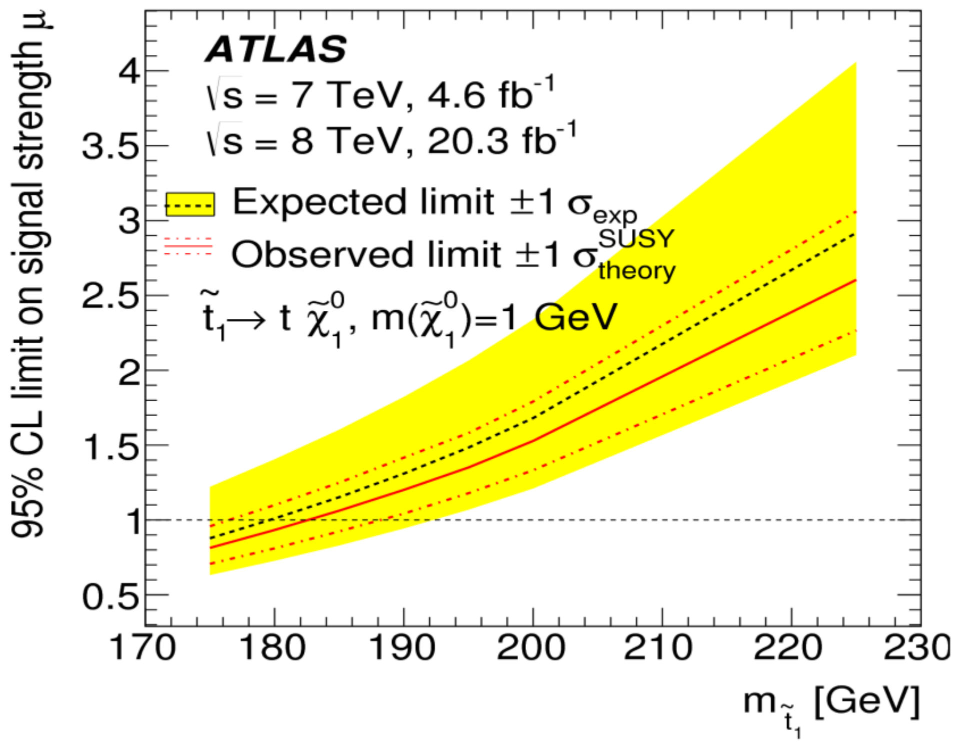


ATLAS-CONF-2013-037

ttbar cross section measurements reinterpretation

arXiv:1406.5375

- By comparing precise measurements of ttbar cross section at $\sqrt{s}$ = 7 and 8 TeV with QCD predictions, limits are placed on the pair-production of stop squarks with masses close to m_t decaying to mostly right-handed top quarks and a light neutralino

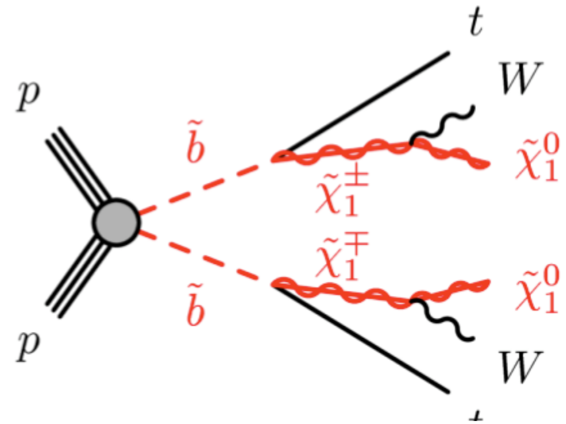


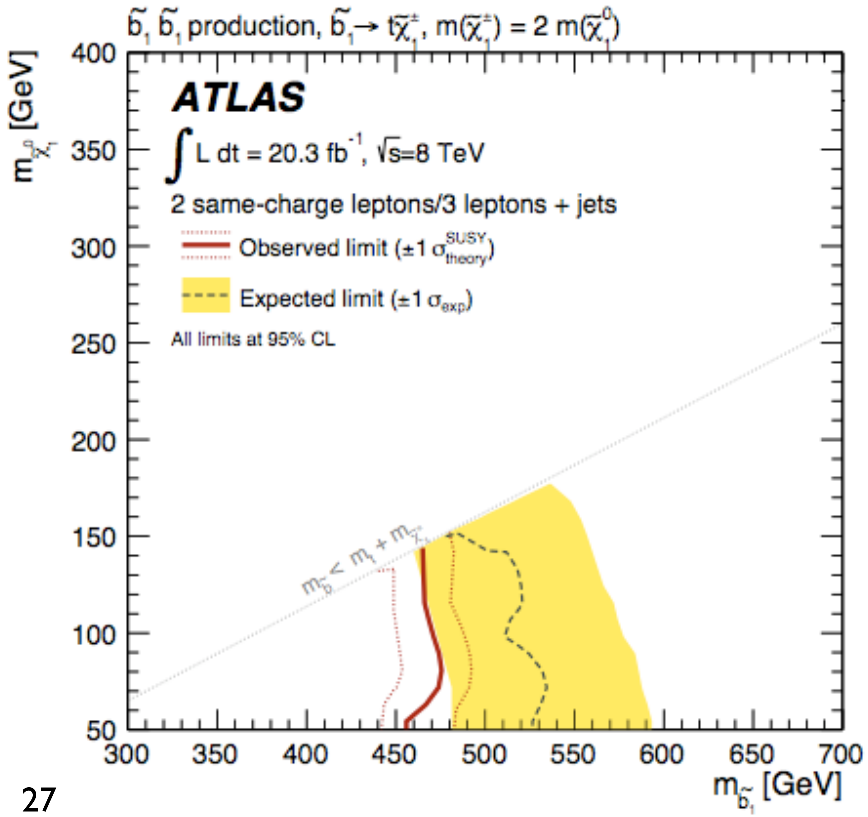
2SS, 3-leptons +jets and $E\!\!\!/_T$

JHEP 06 (2014) 035
arXiv:1404.2500

targeting many SUSY model, direct and gluino mediated production

- $\tilde{b} \rightarrow t\, \tilde{\chi}_1^+ \rightarrow tW^{(*)}\, \tilde{\chi}_1^0$ with $m(\tilde{\chi}_1^+)=2m(\tilde{\chi}_1^0)$
- $\geq$ 3 jets, ($\geq$1b-jets), 2 SS or 3L, large missing momentum.
- main SM backgrounds:ttbar+V,VV estimated with MC and fake leptons, charge flips with data driven techniques.

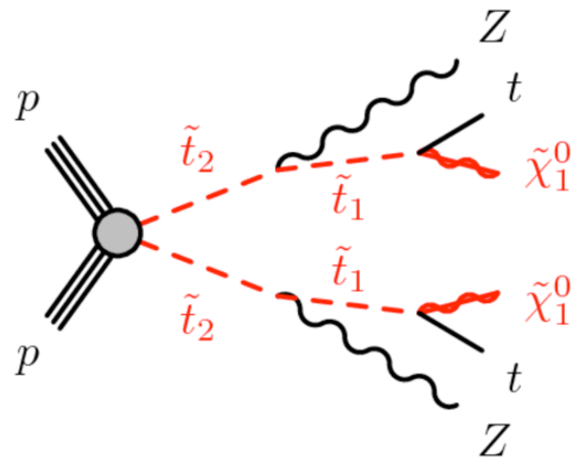




Z+b-jets and $\not\!E_T$

Eur. Phys. J. C (2014) 74:2883
arXiv:1403.5222

heavier top squark state: t_2



- $\tilde{t}_2 \rightarrow Z\,\tilde{t}_1 \rightarrow Zt\tilde{\chi}_1^0$

$\tilde{t}_2$ decay provide indirect sensitivity to stealth stop: $\Delta m(\tilde{t}_1, \tilde{\chi}^0) \approx m_t$ and $\tilde{t}_2$ is not too heavy