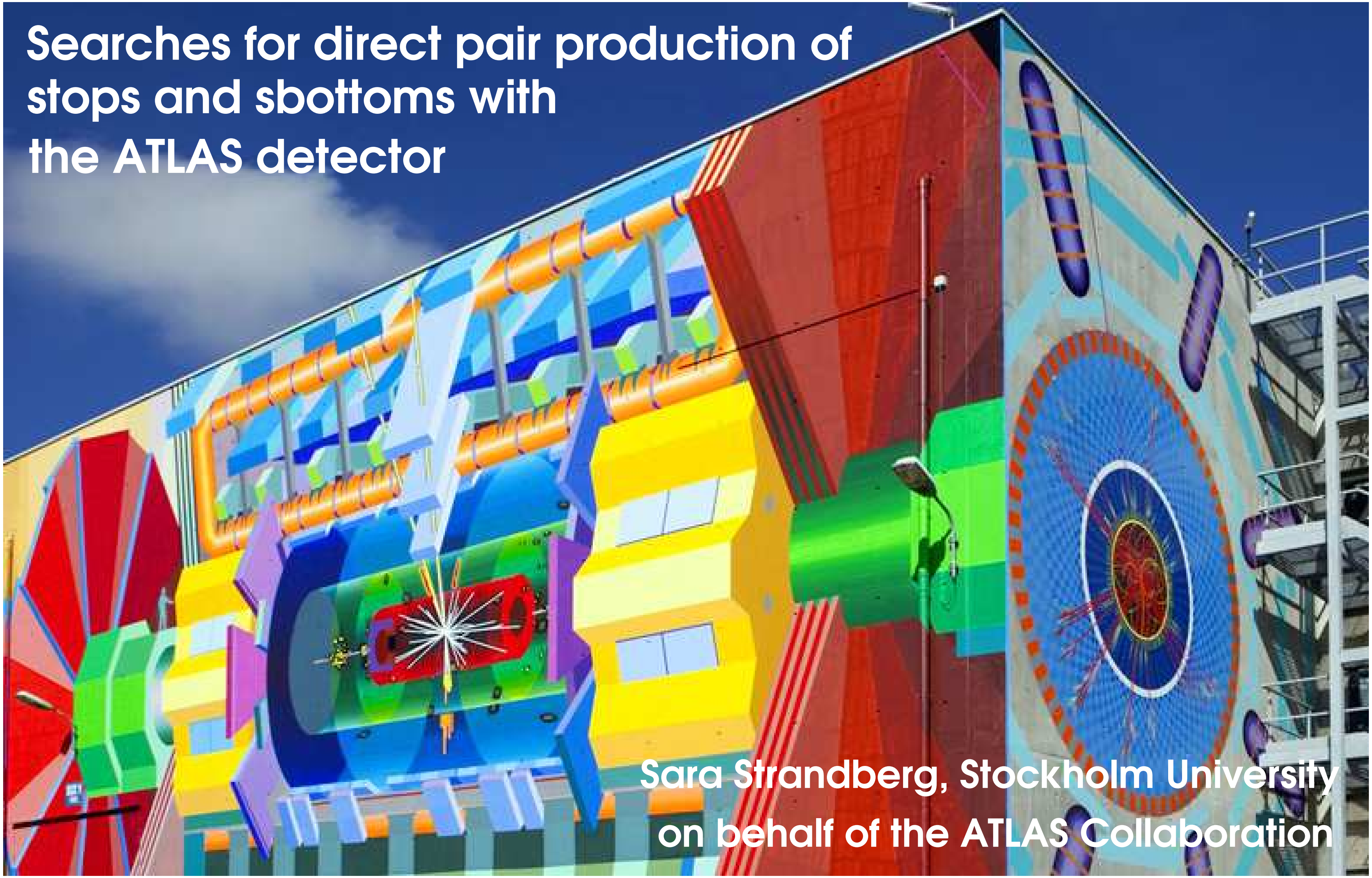
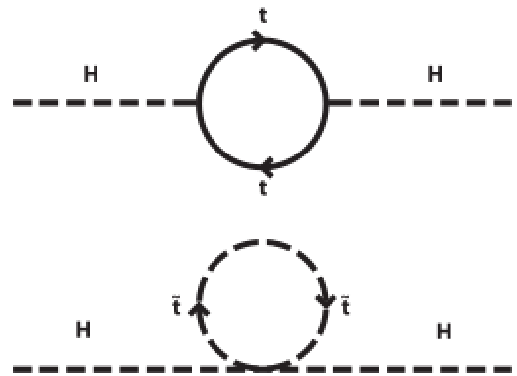
Searches for direct pair production of stops and sbottoms with the ATLAS detector



Sara Strandberg, Stockholm University
on behalf of the ATLAS Collaboration

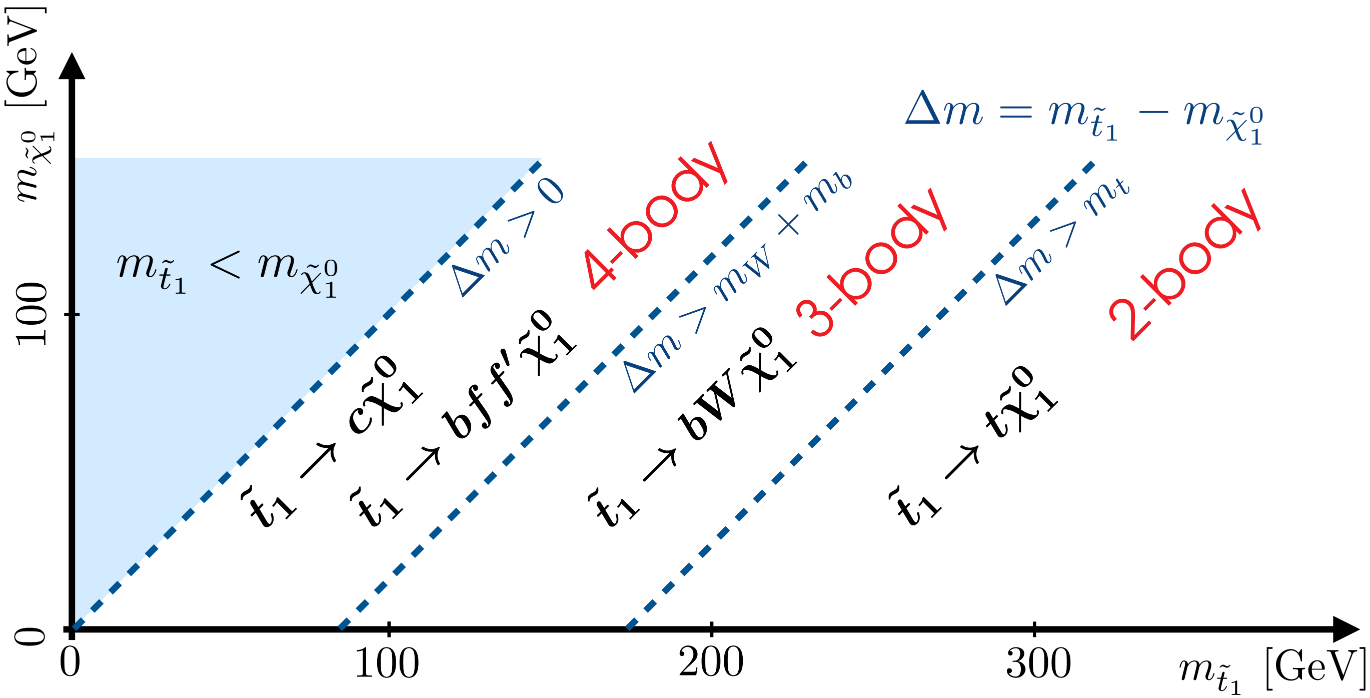
- Light stop ($\mathcal{O}(1)$ TeV) required for SUSY to solve Higgs fine-tuning problem. Also, large top Yukawa can give large stop mixing.

Short name	Webpage	Paper
stop0L	SUSY-2016-15	arXiv:1709.04183
stop1L	SUSY-2016-16	arXiv:1711.11520
stop2L	SUSY-2016-17	arXiv:1708.03247
stop3L/sbottom2L	SUSY-2016-14	JHEP 09 (2017) 084
sbottom0L/1L	SUSY-2016-28	arXiv:1708.09266



- This talk covers results from conventional simplified models:
  - only $\tilde{t}_1$ (or $\tilde{b}_1$) and $\tilde{\chi}_1^0$ within LHC reach,
    (also cover decays to $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ for stop3L/sbottom2L, sbottom1L);
  - $\tilde{t}_1$ mainly composed of $\tilde{t}_R$;
  - $\tilde{\chi}_1^0$ mainly composed of $\tilde{B}^0$.
- Results based on pMSSM-inspired simplified models will be covered in the following talk, by Ian Snyder.

- The decay of $\tilde{t}_1$ depends on the SUSY mass spectrum.



- If only $\tilde{\chi}_1^0$ is lighter than $\tilde{t}_1$:

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

$\tilde{t}_1 \to bW\tilde{\chi}_1^0$

$\tilde{t}_1 \to bff'\tilde{\chi}_1^0$

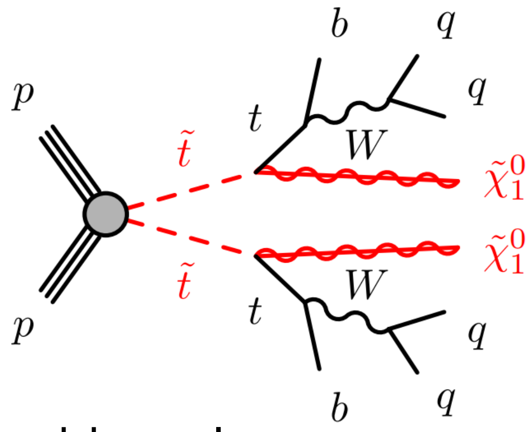
$(\tilde{t}_1 \to c\tilde{\chi}_1^0)$

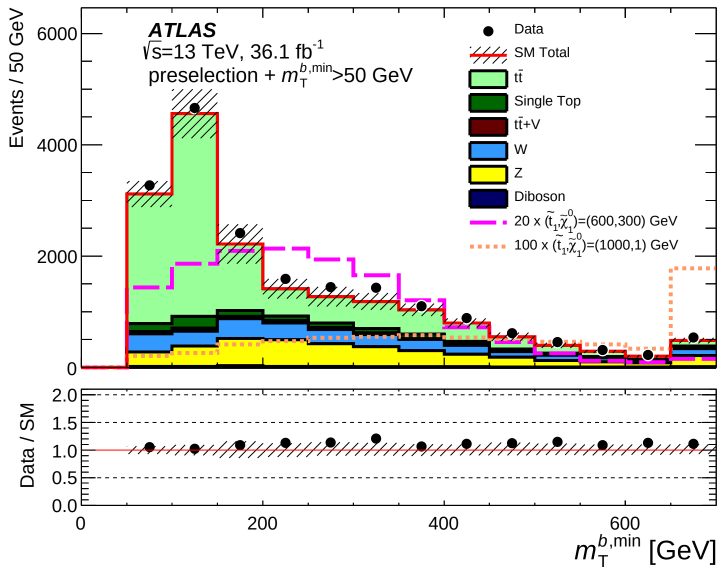
- If also $\tilde{\chi}_1^\pm$ or $\tilde{\chi}_2^0$ is lighter than $\tilde{t}_1$:

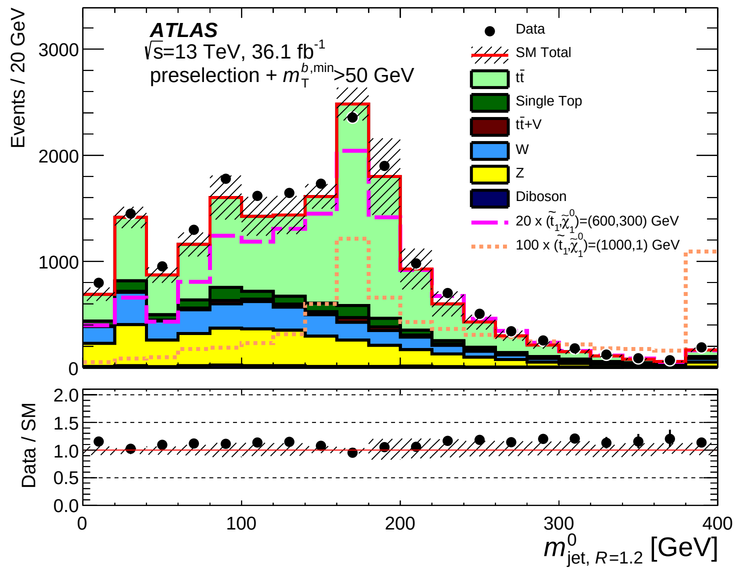
$\tilde{t}_1 \to b\tilde{\chi}_1^\pm$

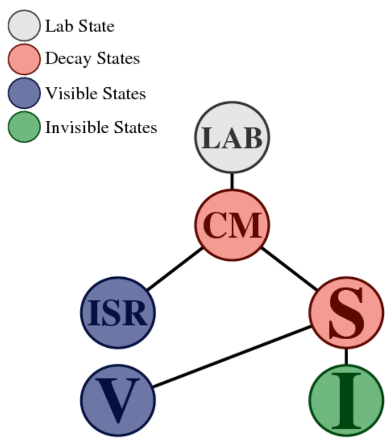
$\tilde{t}_1 \to t\tilde{\chi}_2^0$

- Lepton veto.
- At least four jets (two b-tagged)
- Reject QCD with $\min\{\Delta\phi(\mathrm{jet}_{1-3}, E_{\mathrm{T}}^{\mathrm{miss}})\} > 0.4$.
- Reject $t\bar{t}$ with cut on $\min\{m_{\mathrm{T}}(\mathrm{jet}_{1-4}, E_{\mathrm{T}}^{\mathrm{miss}})\}$.
- Top reconstruction using large-radius jets in boosted topology.
- Jigsaw analysis with ISR selection in diagonal region ($m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx m_{\mathrm{top}}$).

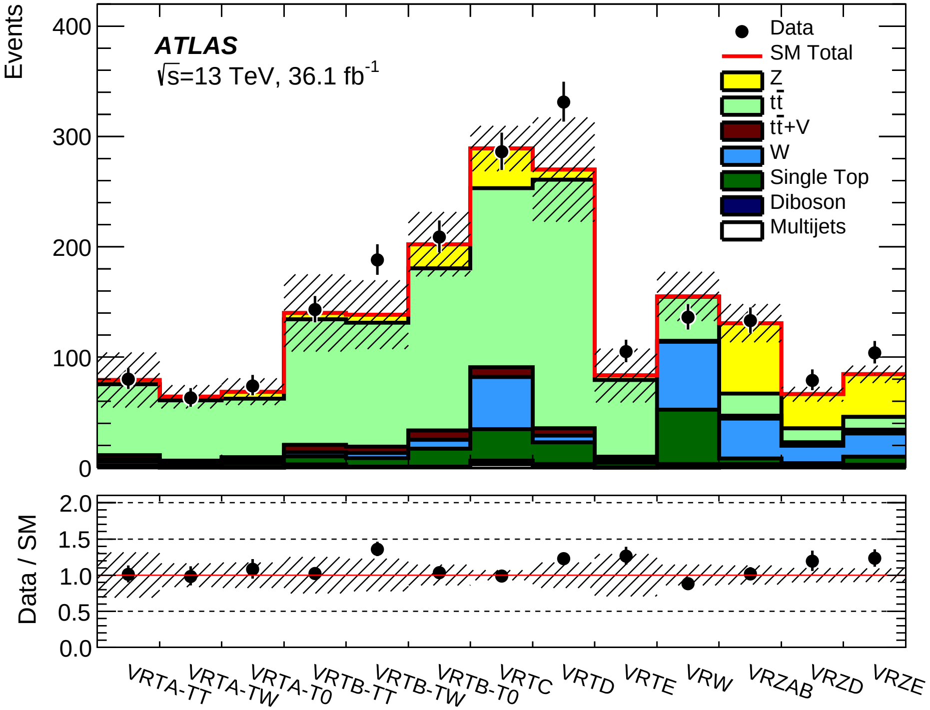


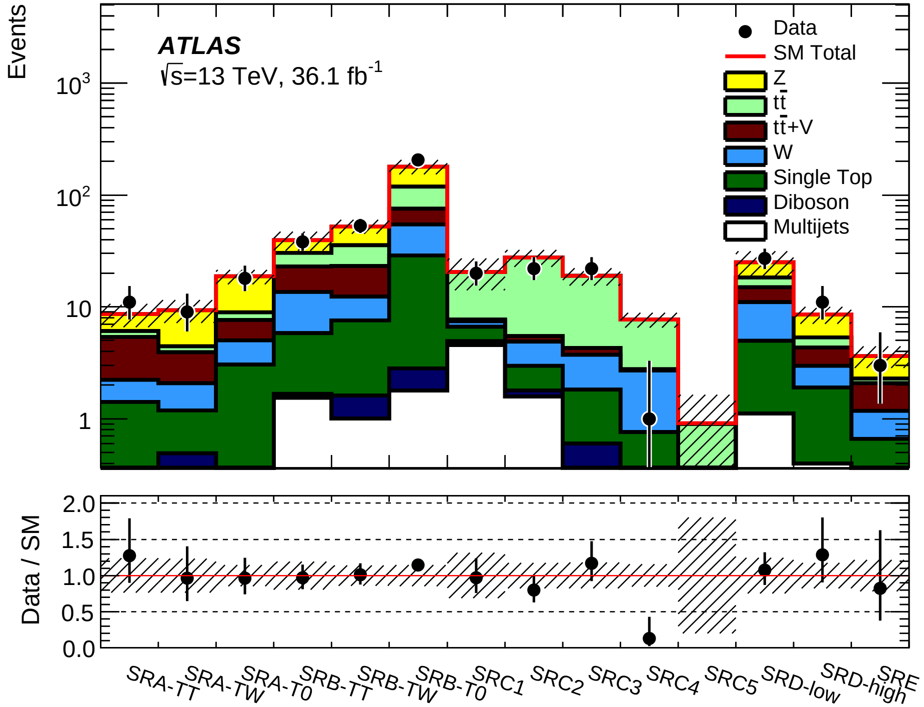






- The dominant backgrounds are normalized in dedicated control regions (CRs), and validated in intermediate validation regions (VRs) before extrapolated to the signal regions (SRs).

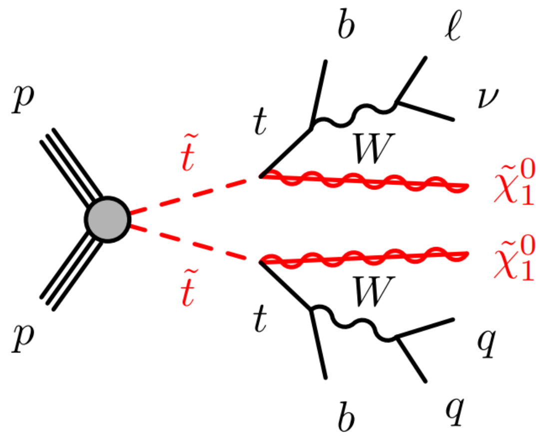


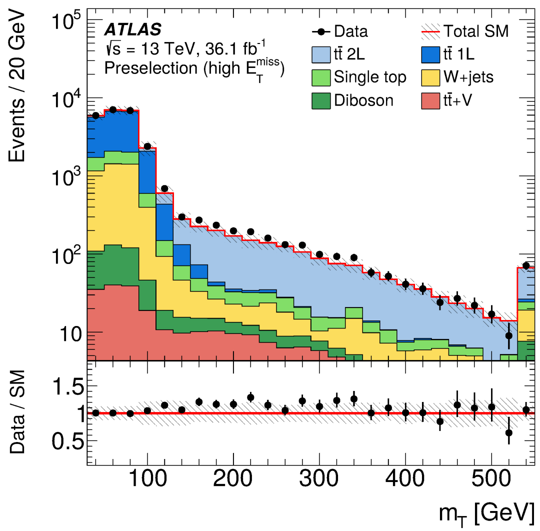


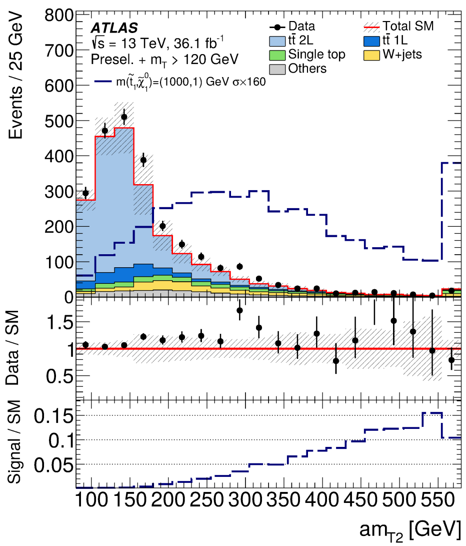
- The VRs show good background modeling.
- The data in all SRs are compatible with the SM expectations.

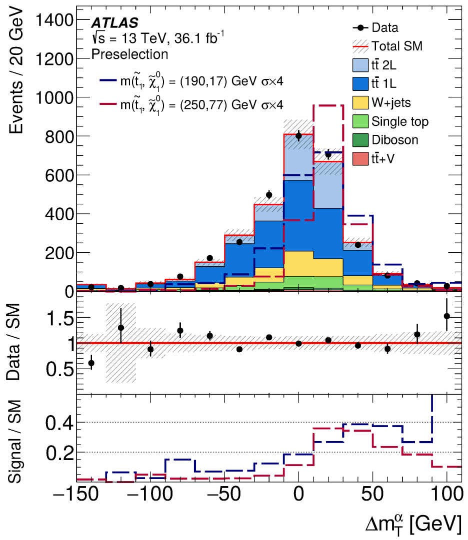
Large $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$ (2-body)

- Exactly one isolated lepton.
- At least four jets (one b-tagged).
- Use m_{T} to suppress $1\ell\ t\bar{t}$ background.
- Asymmetric stransverse mass (am_{T2}) to suppress $2\ell\ t\bar{t}$.
- Use BDT to get sensitivity in diagonal region ($m_{\tilde{t}_1} \approx m_{\mathrm{top}} + m_{\tilde{\chi}_1^0}$).







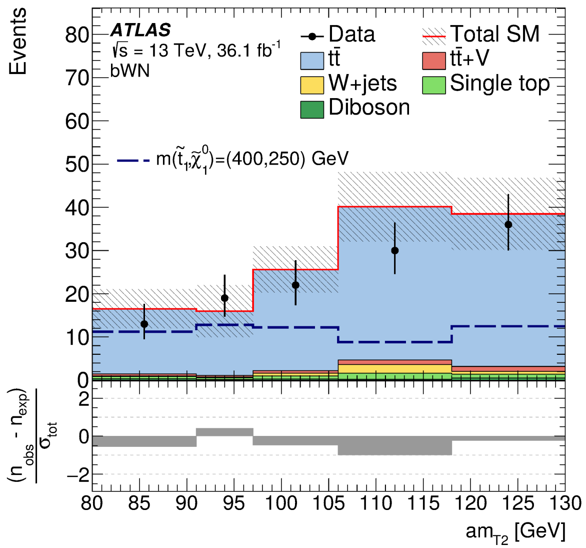


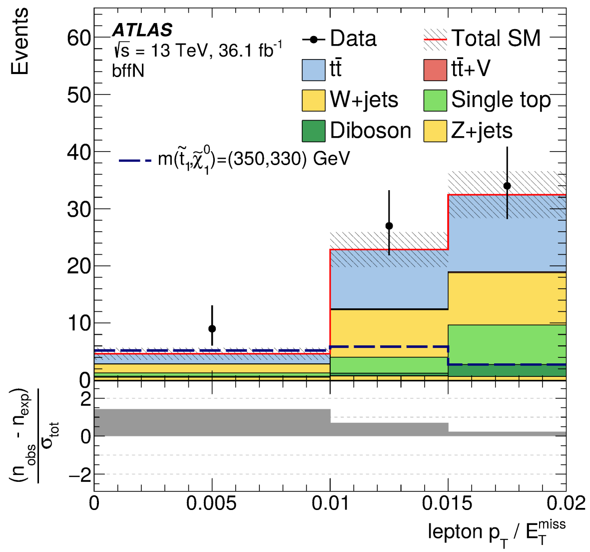
Medium $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$ (3-body)

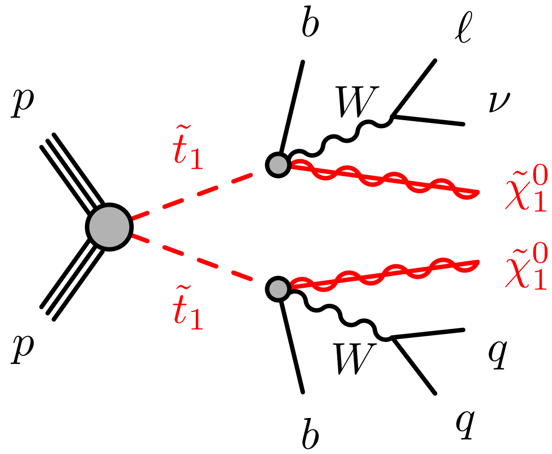
- Shape-fit in am_{T2}.

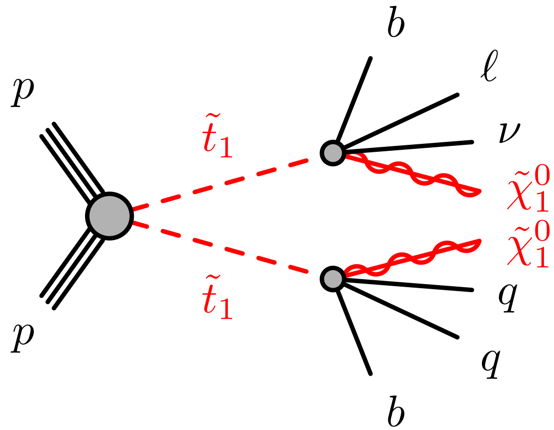
Small $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$ (4-body)

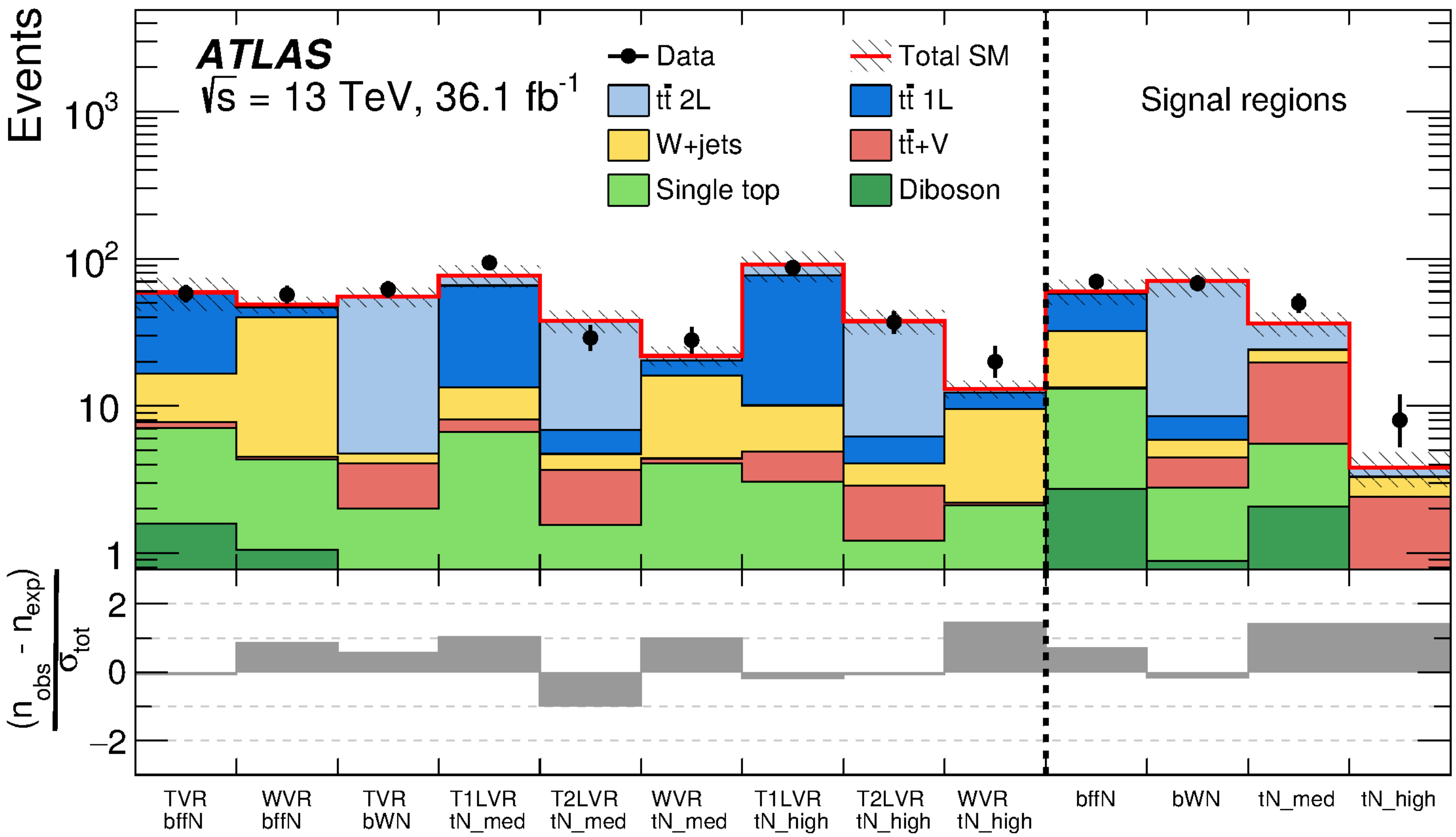
- Soft-lepton selection with shape-fit in $p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$.





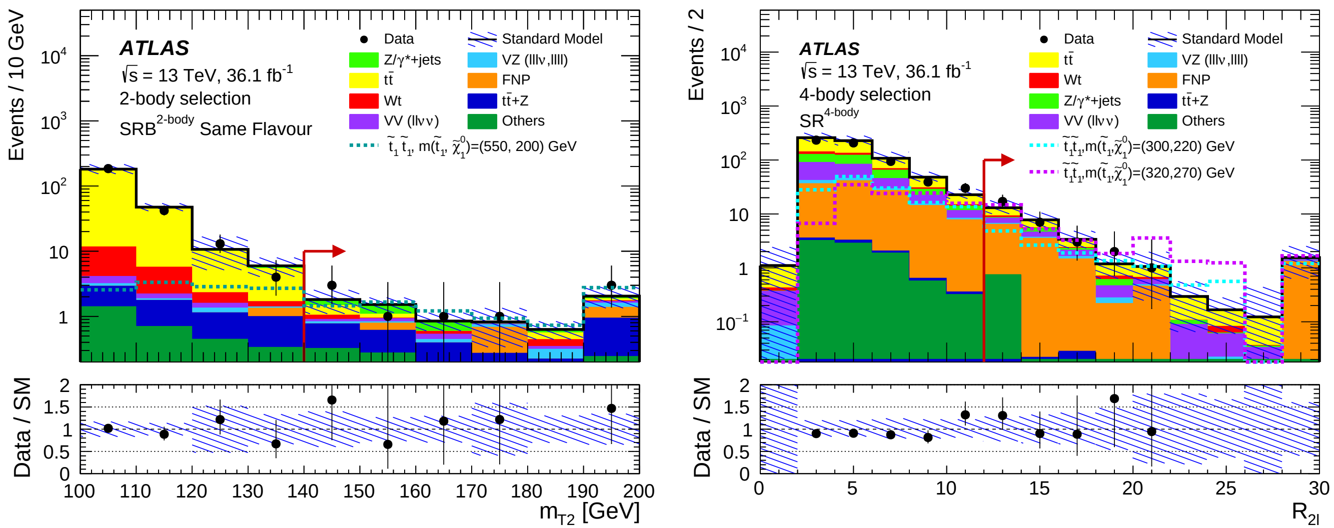




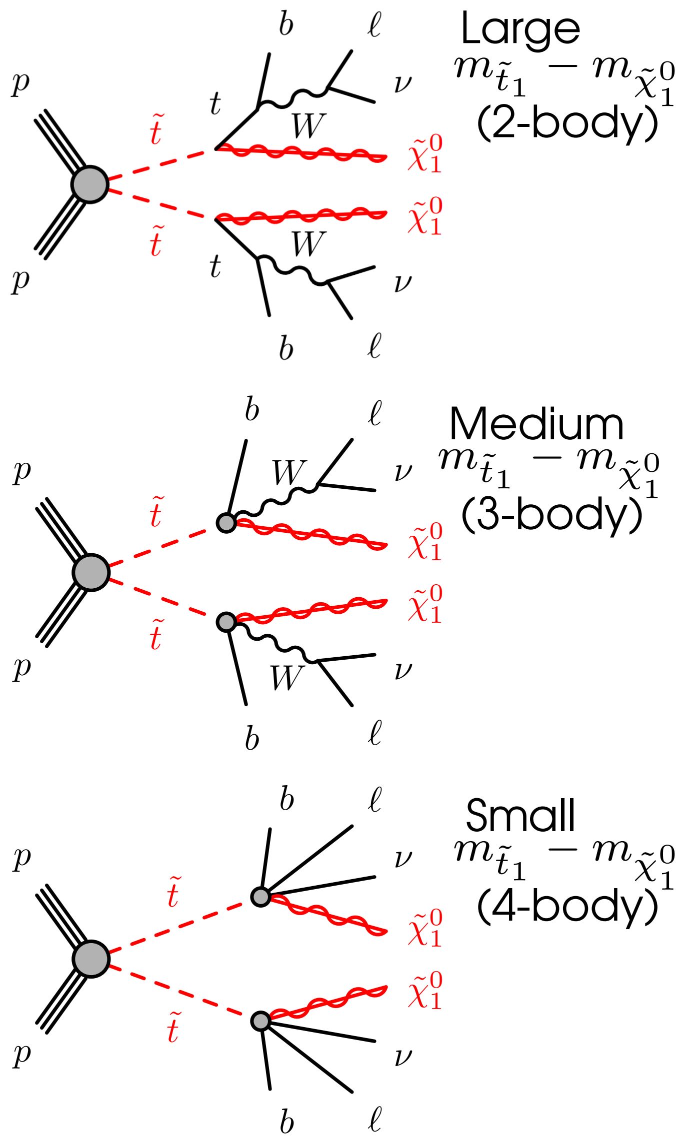


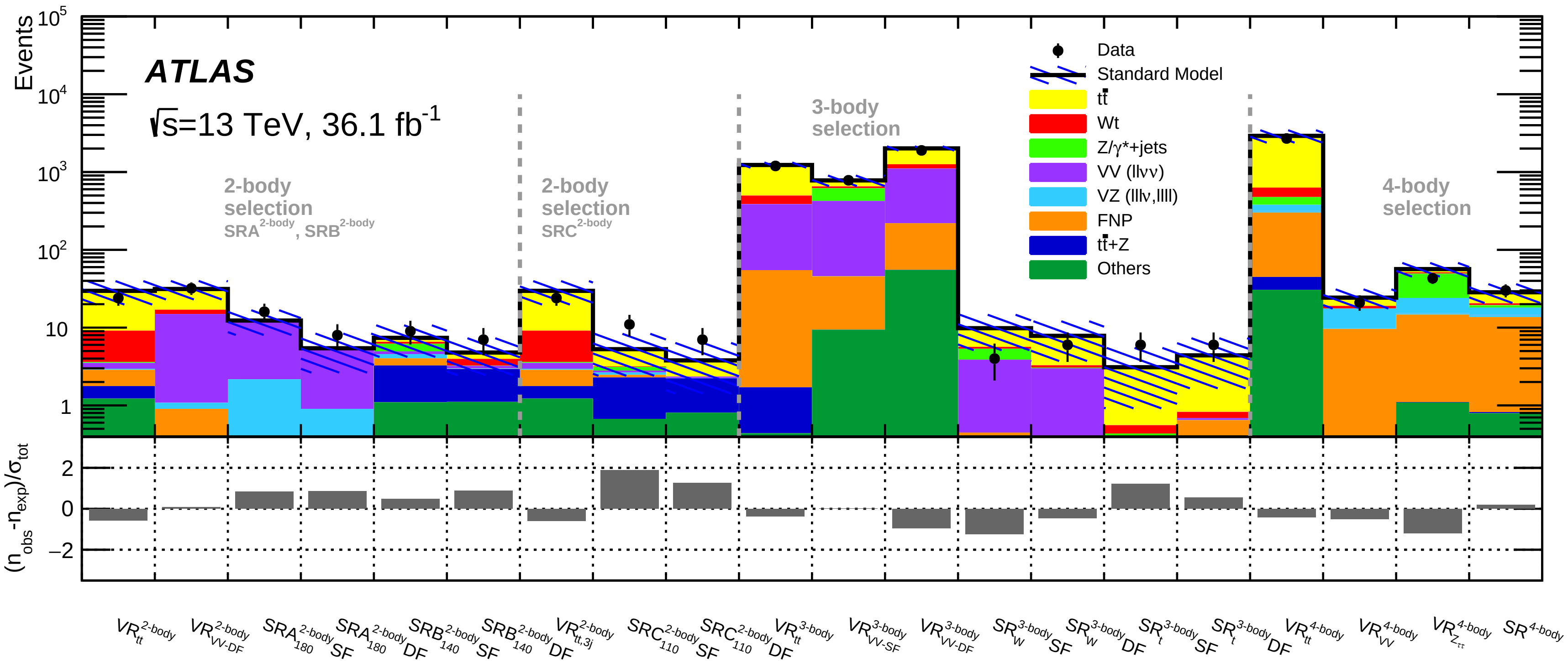
- Good agreement with SM expectations in both VRs and SRs.

- Exactly two isolated leptons, opposite charge.
- Invariant mass $m_{\ell\ell}$ not in Z window (SF).
- Use kinematic end-point of lepton-based stransverse mass (2-body).
- Jigsaw variables (3-body).
- Ratios of p_{T}'s and $E_{\mathrm{T}}^{\mathrm{miss}}$ (4-body).



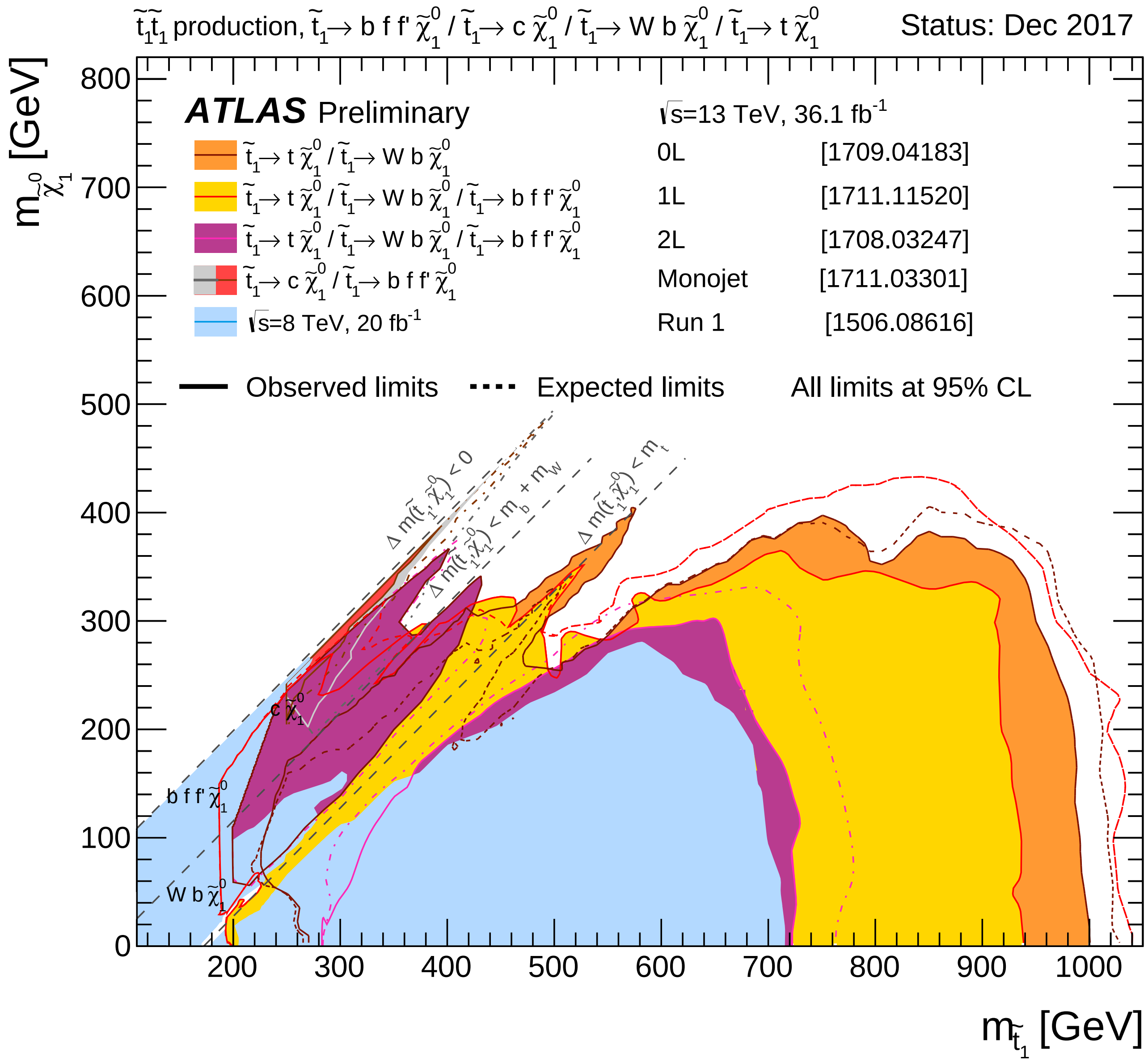
$$R_{2\ell} = E_{\mathrm{T}}^{\mathrm{miss}} / (p_{\mathrm{T}}(\ell_1) + p_{\mathrm{T}}(\ell_2))$$





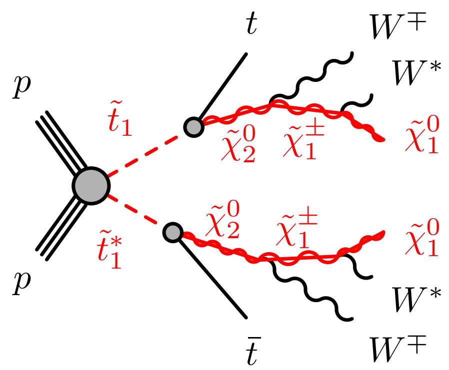
- Good agreement with SM expectations in both VRs and SRs.

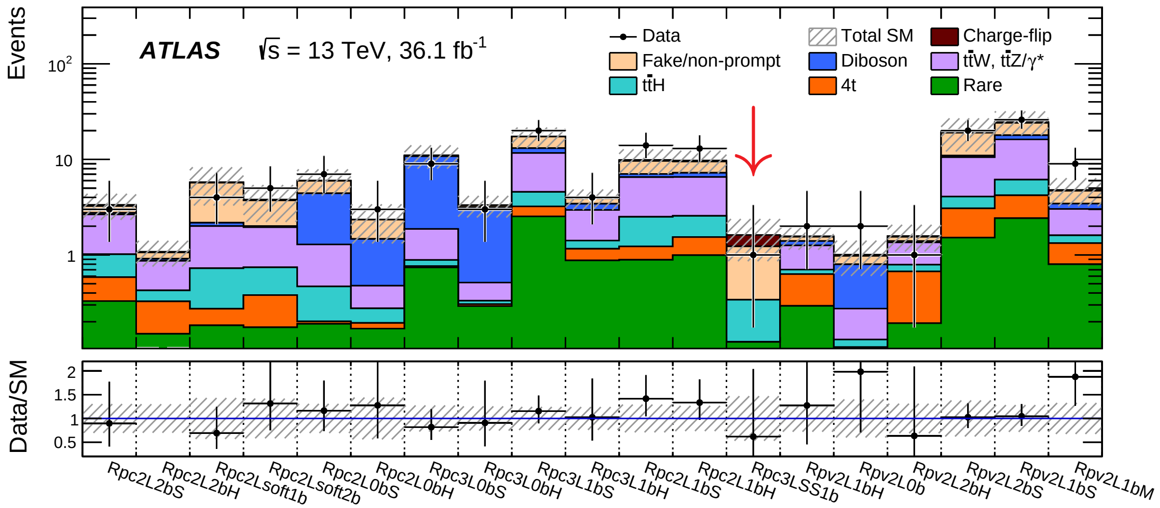
stop0L/1L/2L

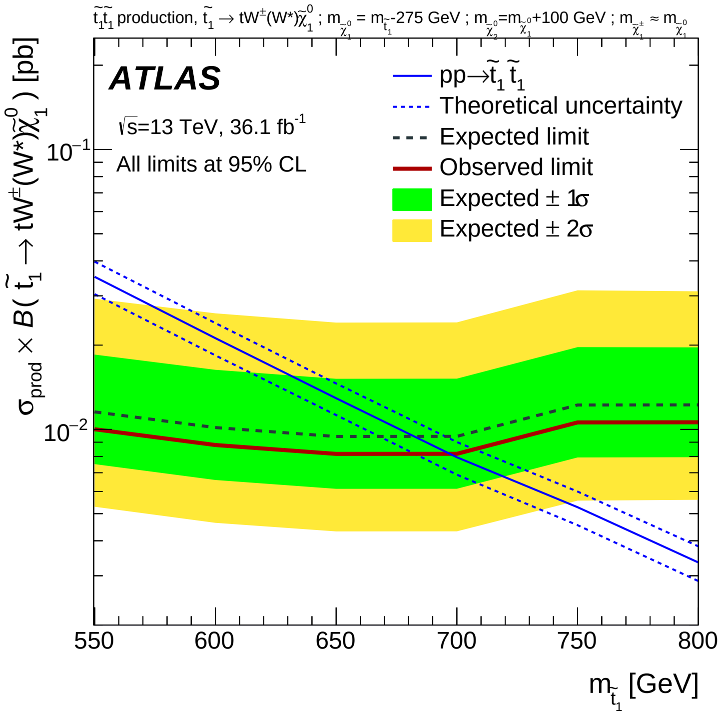


- Exclude stops below 1 TeV for a massless neutralino.
- Much improved sensitivity to the diagonal, 3-body and 4-body regions.

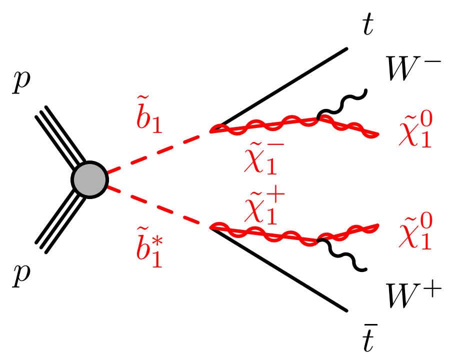
- Three leptons with same charge.
- Invariant mass m_{ee} not in Z window.



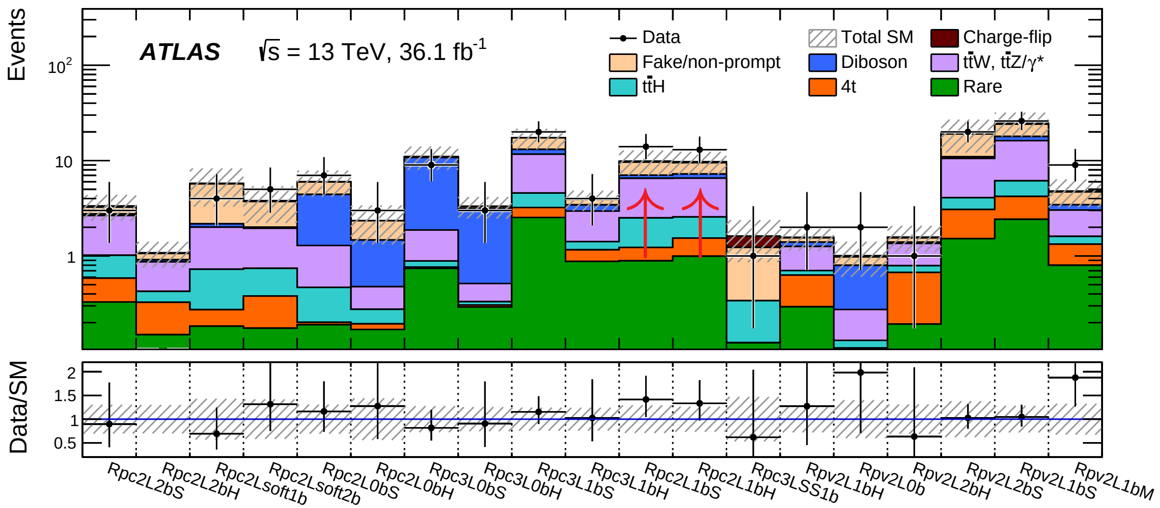


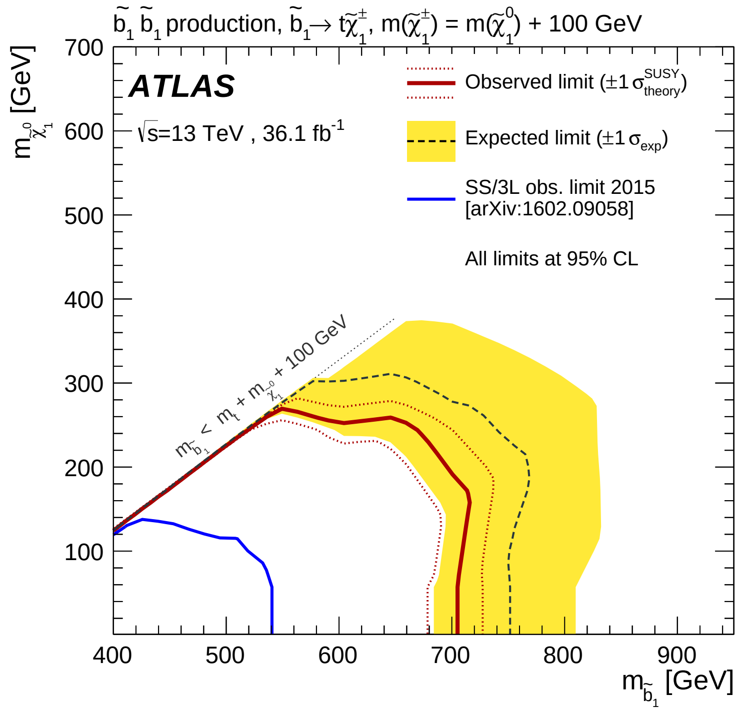


- Good agreement with SM expectations in both VRs and SRs.
- Exclude stops below 700 GeV.



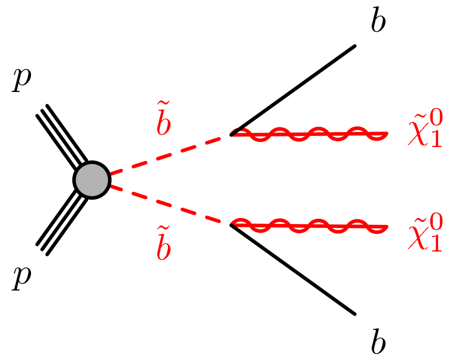
- Two leptons with same charge.

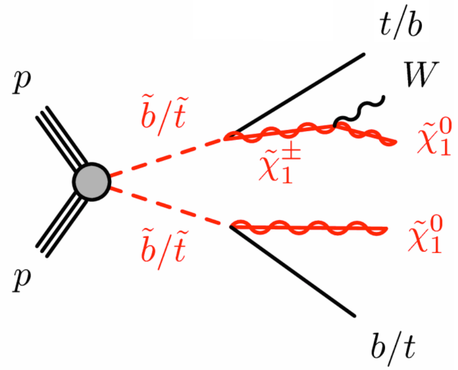


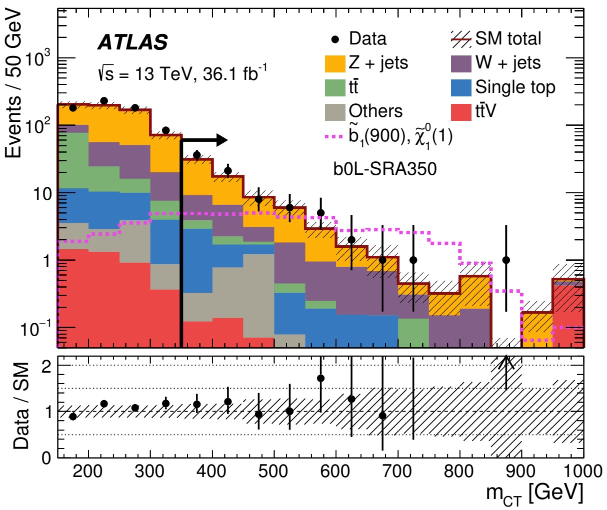


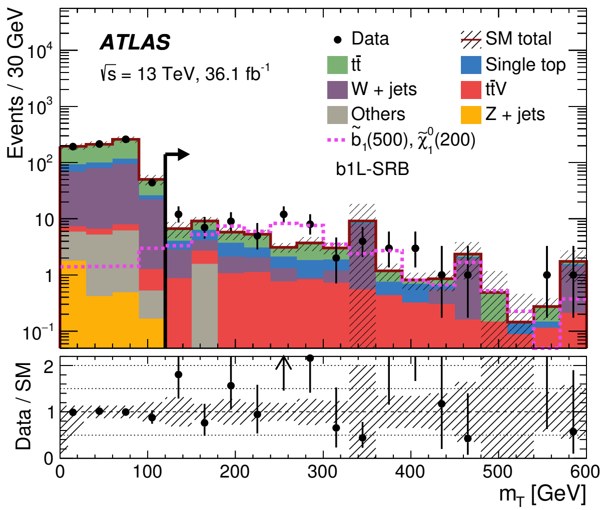
- Good agreement with SM expectations in both VRs and SRs.
- Exclude sbottoms below 700 GeV.

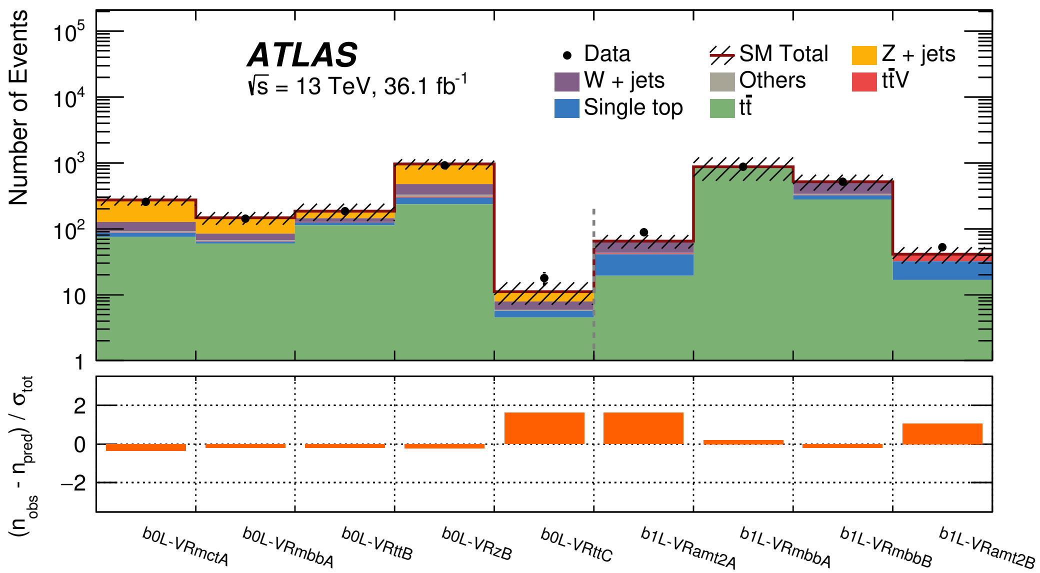
- Either 0 or 1 lepton.
- At least two b-tagged jets.
- Reject QCD with $\min_{i=0\ldots4}\{\Delta\phi(\mathrm{jet_i}, E_{\mathrm{T}}^{\mathrm{miss}})\}$.
- Large cotransverse mass (0L) $m_{\mathrm{CT}}^2(b_1, b_2) = [E_{\mathrm{T}}(b_1)+E_{\mathrm{T}}(b_2)]^2-[\mathbf{p}_{\mathrm{T}}(b_1)-\mathbf{p}_{\mathrm{T}}(b_2)]$.
- Large m_{T} and am_{T2} (1L).

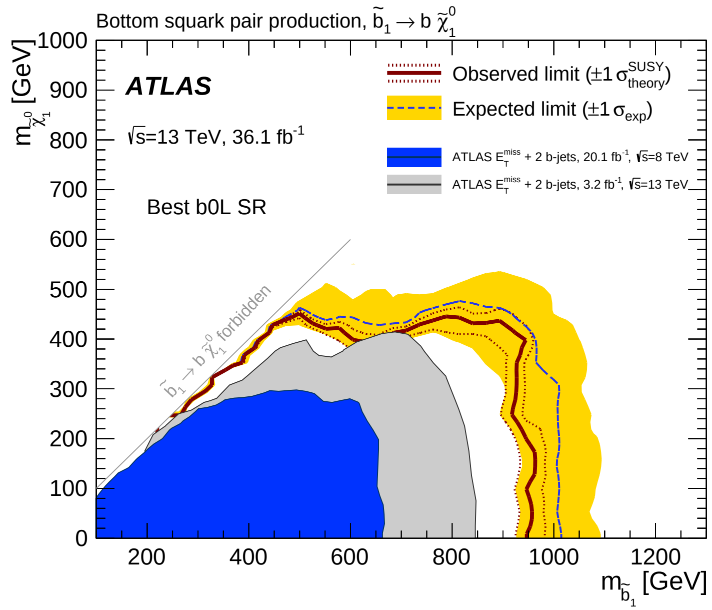


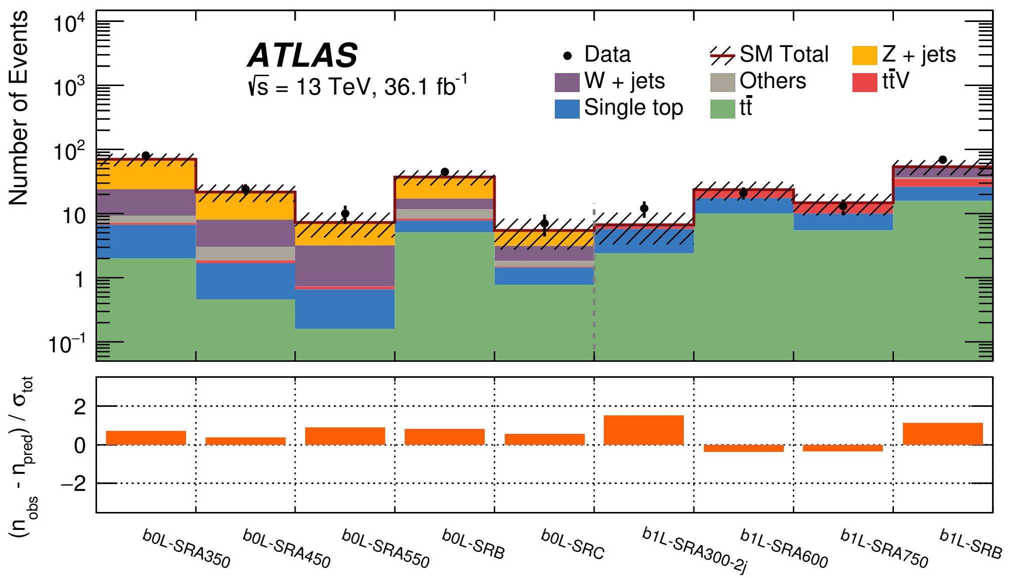


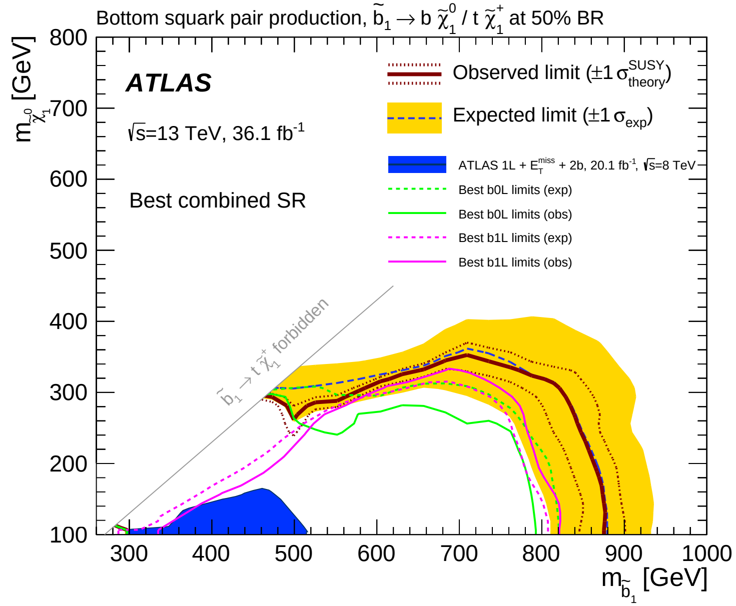





ATLAS
√s = 13 TeV, 36.1 fb-1
Data
SM Total
Z + jets
W + jets
Others
ttV
Single top
tt
Number of Events
(n_obs - n_pred) / σ_tot
b0L-VRmctA
b0L-VRmbbA
b0L-VRttB
b0L-VRzB
b0L-VRttC
b1L-VRamt2A
b1L-VRmbbA
b1L-VRmbbB
b1L-VRamt2B


Bottom squark pair production, b̃1 → b χ̃0 1
ATLAS
√s=13 TeV, 36.1 fb-1
Best b0L SR
Observed limit (±1 σ SUSY theory)
Expected limit (±1 σ exp)
ATLAS E miss T + 2 b-jets, 20.1 fb-1, √s=8 TeV
ATLAS E miss T + 2 b-jets, 3.2 fb-1, √s=13 TeV
b̃1 → b χ̃0 1 forbidden
m χ̃0 1 [GeV]
m b̃1 [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Data
SM Total
Z + jets
W + jets
Others
ttV
Single top
tt
Number of Events
(n_obs - n_pred) / σ_tot
b0L-SRA350
b0L-SRA450
b0L-SRA550
b0L-SRB
b0L-SRC
b1L-SRA300-2j
b1L-SRA600
b1L-SRA750
b1L-SRB

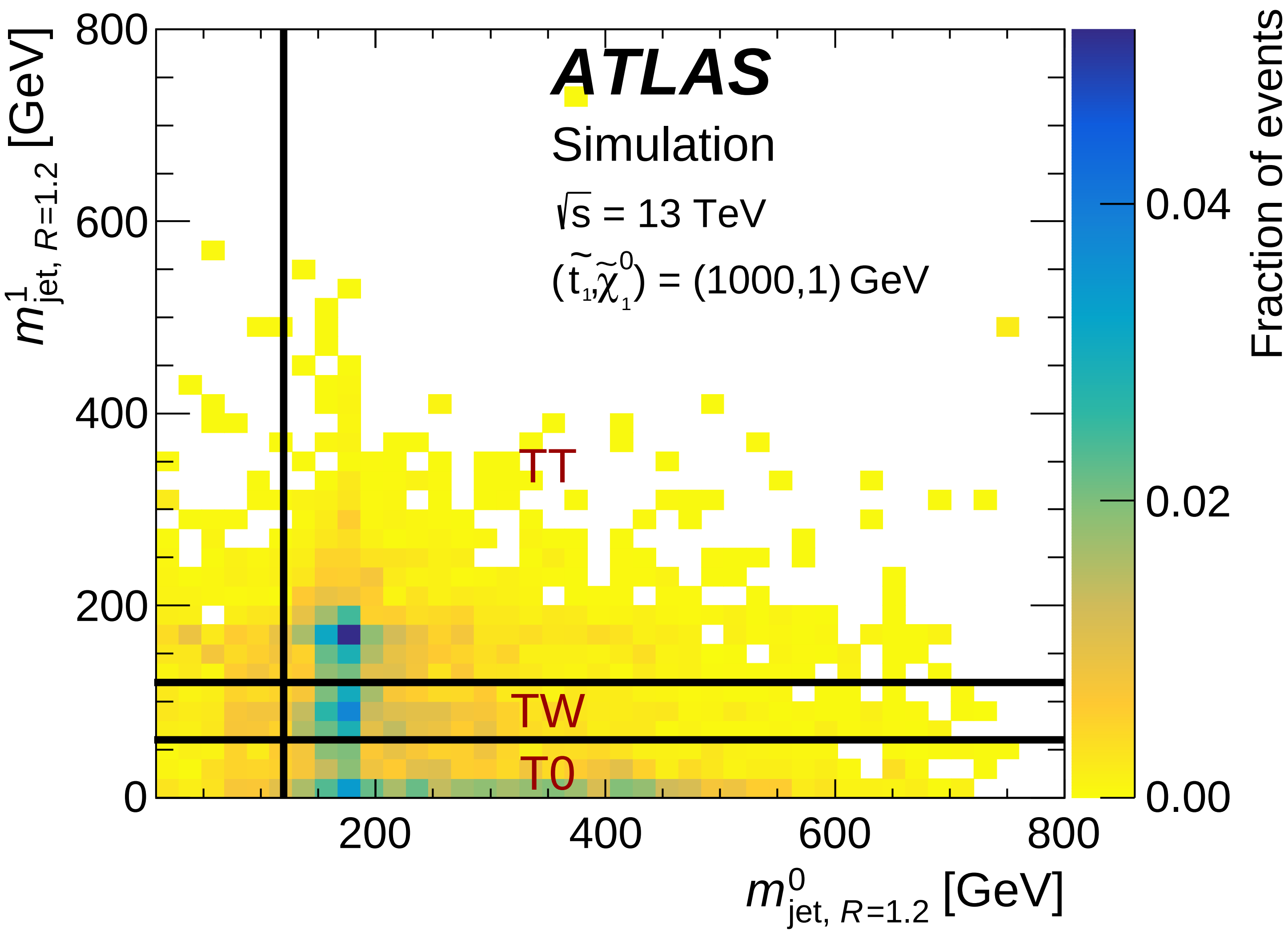

Bottom squark pair production, b̃1 → b χ̃0 1 / t χ̃± 1 at 50% BR
ATLAS
√s=13 TeV, 36.1 fb-1
Best combined SR
Observed limit (±1 σ SUSY theory)
Expected limit (±1 σ exp)
ATLAS 1L + E miss T + 2b, 20.1 fb-1, √s=8 TeV
Best b0L limits (exp)
Best b0L limits (obs)
Best b1L limits (exp)
Best b1L limits (obs)
b̃1 → t χ̃± 1 forbidden
m χ̃0 1 [GeV]
m b̃1 [GeV]

Summary and outlook

- Many results from ATLAS in searches for direct production of stops and sbottoms based on the full 2015+2016 dataset (36 fb^{-1}).
- No significant excess above the Standard Model expectation found. $\rightarrow$ limits are set on the stop and sbottom masses.
- Limits are significantly improved with respect to previous results.
- The search for SUSY continues. Stay tuned for results on the full Run 2 dataset.

3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$	950 GeV
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$	275-700 GeV
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV; 200-720 GeV
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$	90-198 GeV; 0.195-1.0 TeV
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet	Yes	36.1	$\tilde{t}_1$	90-430 GeV
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-600 GeV
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e,μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$	290-790 GeV
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2 \rightarrow \tilde{t}_1 + h$	1-2 e,μ	4 b	Yes	36.1	$\tilde{t}_2$	320-880 GeV

Backup

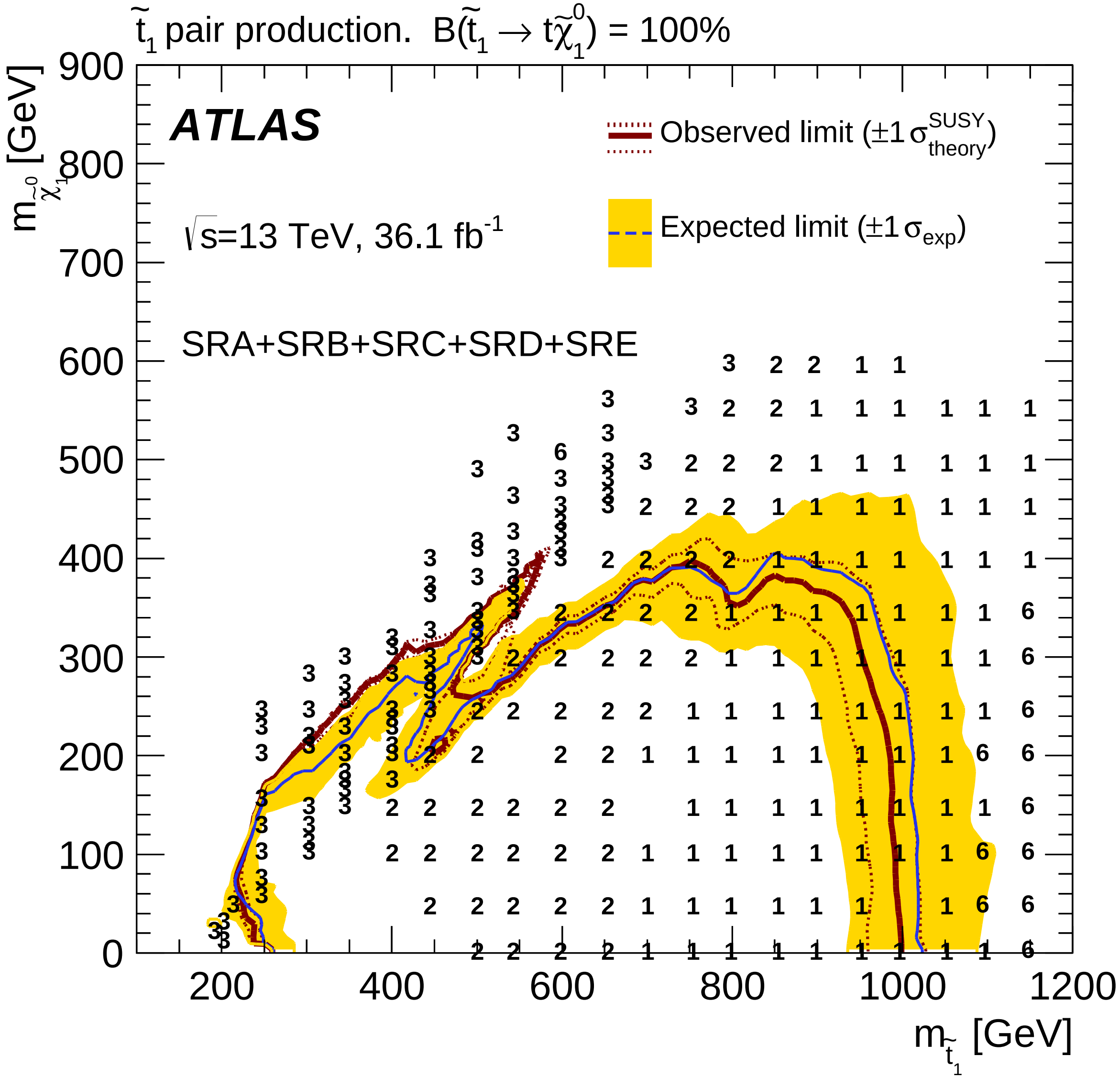

ATLAS
Simulation
$\sqrt{s}$ = 13 TeV
$(\tilde{t}_1, \tilde{\chi}_1^0)$ = (1000,1) GeV
TT
TW
T0
$m^1_{\mathrm{jet},\,R=1.2}$ [GeV]
$m^0_{\mathrm{jet},\,R=1.2}$ [GeV]
Fraction of events
0
200
400
600
800
0.00
0.02
0.04

Large $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$ (SRA $m_{\tilde{t}_1} = 1000$ GeV, $m_{\tilde{\chi}_1^0} = 1$ GeV;
SRB $m_{\tilde{t}_1} = 600$ GeV, $m_{\tilde{\chi}_1^0} = 300$ GeV)

Signal Region		**TT**	**TW**	**T0**
	$m^0_{\mathrm{jet},R=1.2}$	> 120 GeV		
	$m^1_{\mathrm{jet},R=1.2}$	> 120 GeV	$[60, 120]$ GeV	< 60 GeV
	$m_{\mathrm{T}}^{b,\mathrm{min}}$	> 200 GeV		
	$N_{b-\mathrm{jet}}$	≥ 2		
	τ-veto	yes		
	$\left\|\Delta\phi\left(\mathrm{jet}^{0,1,2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\right)\right\|$	> 0.4		
A	$m^0_{\mathrm{jet},R=0.8}$	> 60 GeV		
	$\Delta R\,(b,b)$	> 1	-	
	$m_{\mathrm{T2}}^{\chi^2}$	> 400 GeV	> 400 GeV	> 500 GeV
	$E_{\mathrm{T}}^{\mathrm{miss}}$	> 400 GeV	> 500 GeV	> 550 GeV
B	$m_{\mathrm{T}}^{b,\mathrm{max}}$	> 200 GeV		
	$\Delta R\,(b,b)$	> 1.2		

$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx m_t$

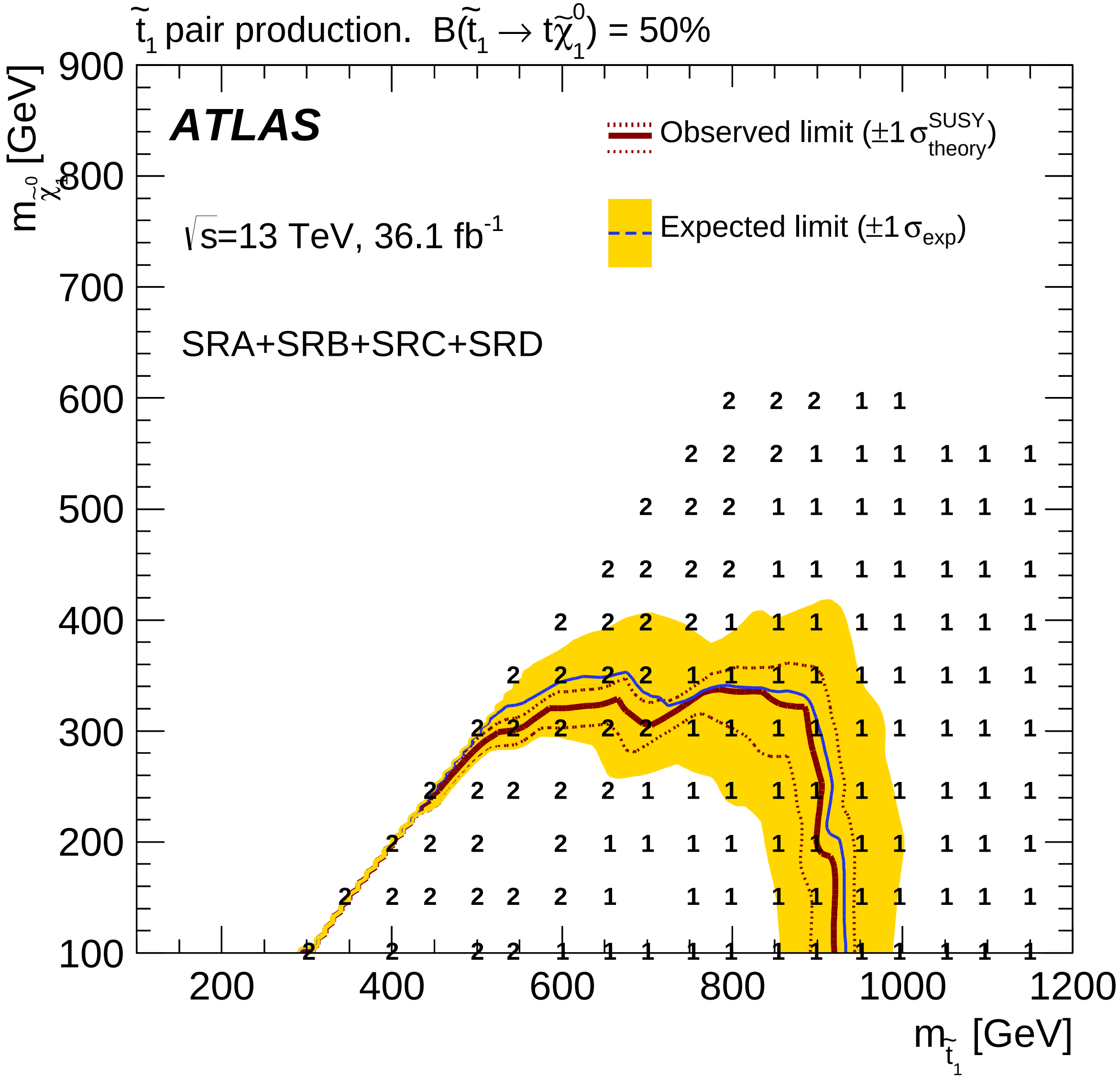
Variable	SRC1	SRC2	SRC3	SRC4	SRC5
$N_{b-\mathrm{jet}}$	≥ 1				
$N_{b-\mathrm{jet}}^{\mathrm{S}}$	≥ 1				
$N_{\mathrm{jet}}^{\mathrm{S}}$	≥ 5				
$p_{\mathrm{T},b}^{0,\mathrm{S}}$	> 40 GeV				
m_{S}	> 300 GeV				
$\Delta\phi(\mathrm{ISR}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	> 3.0				
$p_{\mathrm{T}}^{\mathrm{ISR}}$	> 400 GeV				
$p_{\mathrm{T}}^{4,\mathrm{S}}$	> 50 GeV				
R_{ISR}	0.30–0.40	0.40–0.50	0.50–0.60	0.60–0.70	0.70–0.80



1=SRA

2=SRB

3=SRC



1=SRA

2=SRB

3=SRC

stop1L preselection

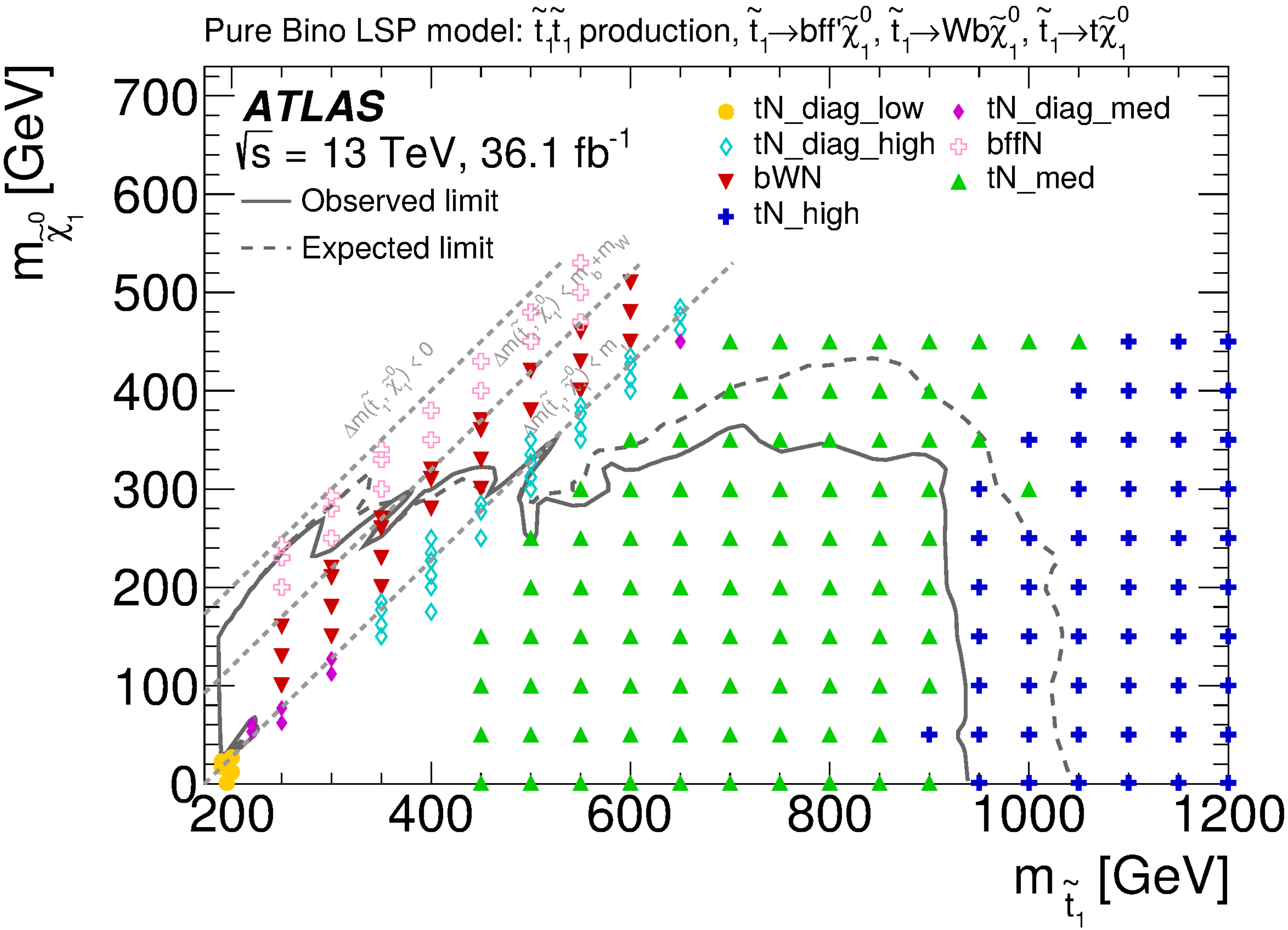
Selection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	soft-lepton
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ triggers only	$E_{\mathrm{T}}^{\mathrm{miss}}$ and lepton triggers	$E_{\mathrm{T}}^{\mathrm{miss}}$ triggers only
Data quality	jet cleaning, primary vertex		
Second-lepton veto	no additional baseline leptons		
Number of leptons, tightness	= 1 'loose' lepton	= 1 'tight' lepton	= 1 'tight' lepton
Lepton p_{T} [GeV]	> 25	> 27	> 4 for μ
			> 5 for e
Number of (jets, b-tags)	$(\geq 2, \geq 0)$	$(\geq 4, \geq 1)$	$(\geq 2, \geq 1)$
Jet p_{T} [GeV]	$> (25,\ 25)$	$> (50,\ 25,\ 25,\ 25)$	$> (25,\ 25)$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 230	> 100	> 230
m_{T} [GeV]	> 30	> 90	–

Signal region	tN_med	tN_high
Preselection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$ preselection	
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet p_{T} [GeV]	$> (60, 50, 40, 40)$	$> (100, 80, 50, 30)$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 250	> 550
$E_{\mathrm{T},\perp}^{\mathrm{miss}}$ [GeV]	> 230	–
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 27
m_{T} [GeV]	> 160	
am_{T2} [GeV]	> 175	
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	> 150	> 130
$\Delta R(b,\ell)$	< 2.0	
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4	
m_{T2}^{τ} based τ-veto [GeV]	> 80	
Exclusion technique	shape-fit in $E_{\mathrm{T}}^{\mathrm{miss}}$	cut-and-count
Bin boundaries	$[250, 350, 450, 600, \mathrm{inf}]$	

Variable	tN_diag_low	tN_diag_med	tN_diag_high
Preselection	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	high-$E_{\mathrm{T}}^{\mathrm{miss}}$
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 5, \geq 1)$
Jet p_{T} [GeV]	$> (120,\ 25,\ 25,\ 25)$	$> (100,\ 50,\ 25,\ 25)$	$> (25,\ 25,\ 25,\ 25,\ 25)$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	> 120	> 230
m_{T} [GeV]	> 90	> 120	> 120
R_{ISR}	–	–	¿ 0.4
$p_{\mathrm{T}}(t\bar{t})$ [GeV]	> 400	–	–
$\lvert\Delta\phi(\ell, t\bar{t})\rvert$	> 1.0	–	–
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4	> 0.4	–
m_{T2}^{τ} based τ-veto [GeV]	–	> 80	–
BDT score	BDT_low > 0.55	BDT_med > 0.75	BDT_high> 0.8
Exclusion technique	cut-and-count	shape-fit in BDT score	shape-fit in BDT score
Bin boundaries	–	$[0.4, 0.5, 0.6, 0.7, 0.8, 1.0]$	$[0.6, 0.7, 0.8, 1.0]$

Signal region	bWN	bffN
Preselection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$	soft-lepton
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 2, \geq 1)$
Jet p_{T} [GeV]	$> (50,\ 25,\ 25,\ 25)$	$> (400,\ 25)$
b-tagged jet p_{T} [GeV]	> 25	> 25
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300	> 300
m_{T} [GeV]	> 130	< 160
am_{T2} [GeV]	< 110	–
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	–	top veto
$p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$	–	< 0.02
$\Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	< 2.5	–
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, b\text{-jet}_i))$	–	< 1.5
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4	
m_{T2}^{τ} based τ-veto [GeV]	> 80	–
Exclusion technique	shape-fit in am_{T2}	shape-fit in $p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$
Bin boundaries	$[0, 91, 97, 106, 118, 130]$	$[0, 0.01, 0.015, 0.02]$

stop1L SR mapping



stop2L 2-body SRs

Table 2: *Two-body selection* signal region definitions.

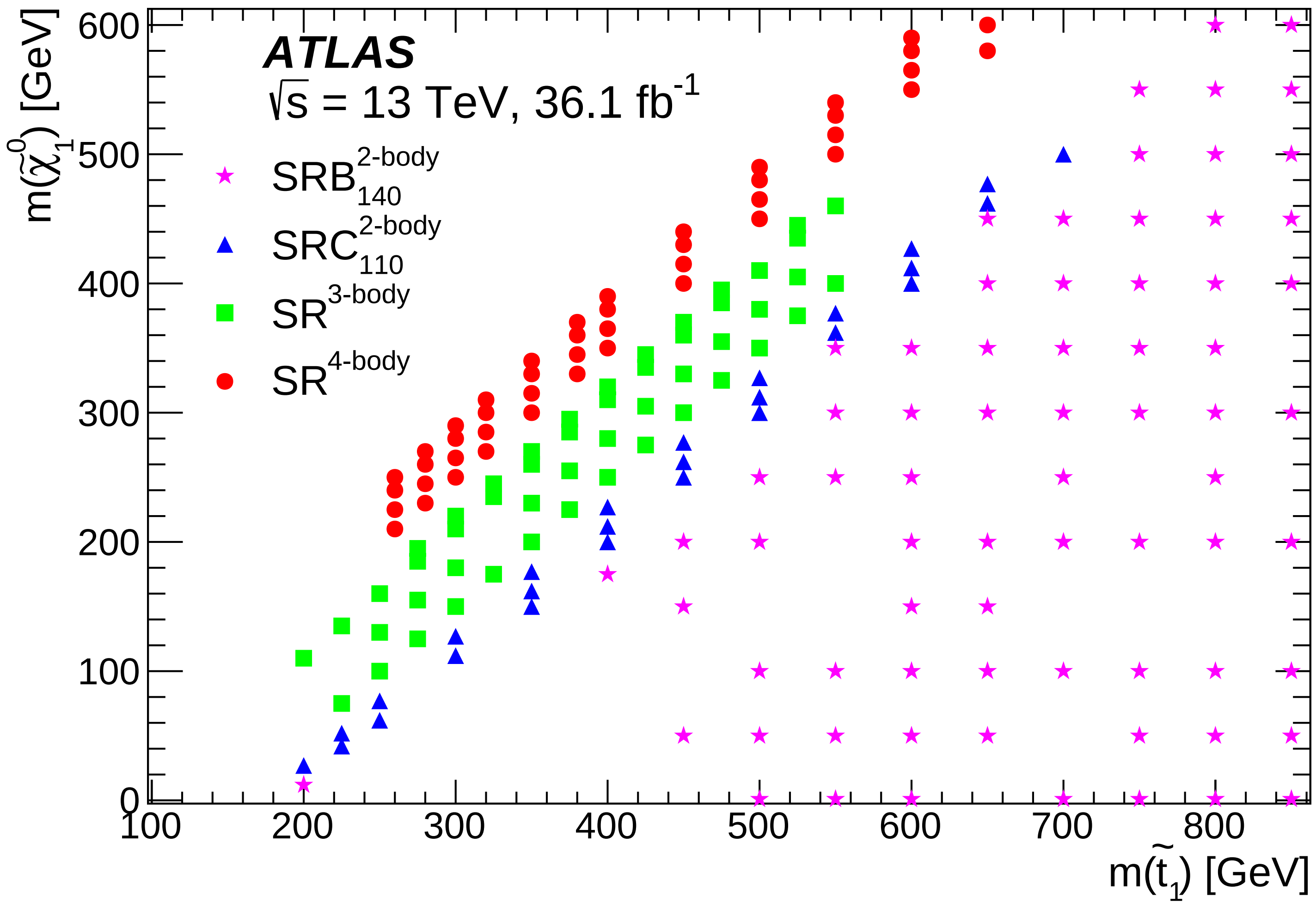
	$\mathrm{SRA}^{\text{2-body}}_{180}$		$\mathrm{SRB}^{\text{2-body}}_{140}$		$\mathrm{SRC}^{\text{2-body}}_{110}$	
Lepton flavour	SF	DF	SF	DF	SF	DF
$p_{\mathrm{T}}(\ell_1), p_{\mathrm{T}}(\ell_2)$ [GeV]	$> 25, > 20$		$> 25, > 20$		$> 25, > 20$	
$m_{\ell\ell}$ [GeV]	> 111.2	> 20	[20, 71.2] or > 111.2	> 20	[20, 71.2] or > 111.2	> 20
$R_{2\ell 2j}$	> 0.3	–	–		–	
$R_{2\ell}$	–		–		> 1.2	
Δx	< 0.07		–		–	
$\Delta\phi_{\mathrm{boost}}$	–		< 1.5		–	
n_{jets}	–		≥ 2		≥ 3	
$n_{b\text{-jets}}$	$= 0$		≥ 1		≥ 1	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	–		–		> 200	
$m_{\mathrm{T2}}^{\ell\ell}$ [GeV]	> 180		> 140		> 110	

Table 3: *Three-body selection* signal region definitions.

	$\mathrm{SR}_W^{\text{3-body}}$		$\mathrm{SR}_t^{\text{3-body}}$	
Lepton flavour	SF	DF	SF	DF
$p_\mathrm{T}(\ell_1), p_\mathrm{T}(\ell_2)$ [GeV]	$> 25, > 20$		$> 25, > 20$	
$m_{\ell\ell}$ [GeV]	[20, 71.2] or > 111.2	> 20	[20, 71.2] or > 111.2	> 20
$n_{b\text{-jets}}$	$= 0$		≥ 1	
M_Δ^R [GeV]	> 95		> 110	
R_{p_T}	> 0.7		> 0.7	
$1/\gamma_{\mathrm{R}+1}$	> 0.7		> 0.7	
$\Delta\phi_\beta^\mathrm{R}$	$> 0.9\lvert\cos\theta_b\rvert + 1.6$		$> 0.9\lvert\cos\theta_b\rvert + 1.6$	

Table 4: *Four-body selection* signal region definition.

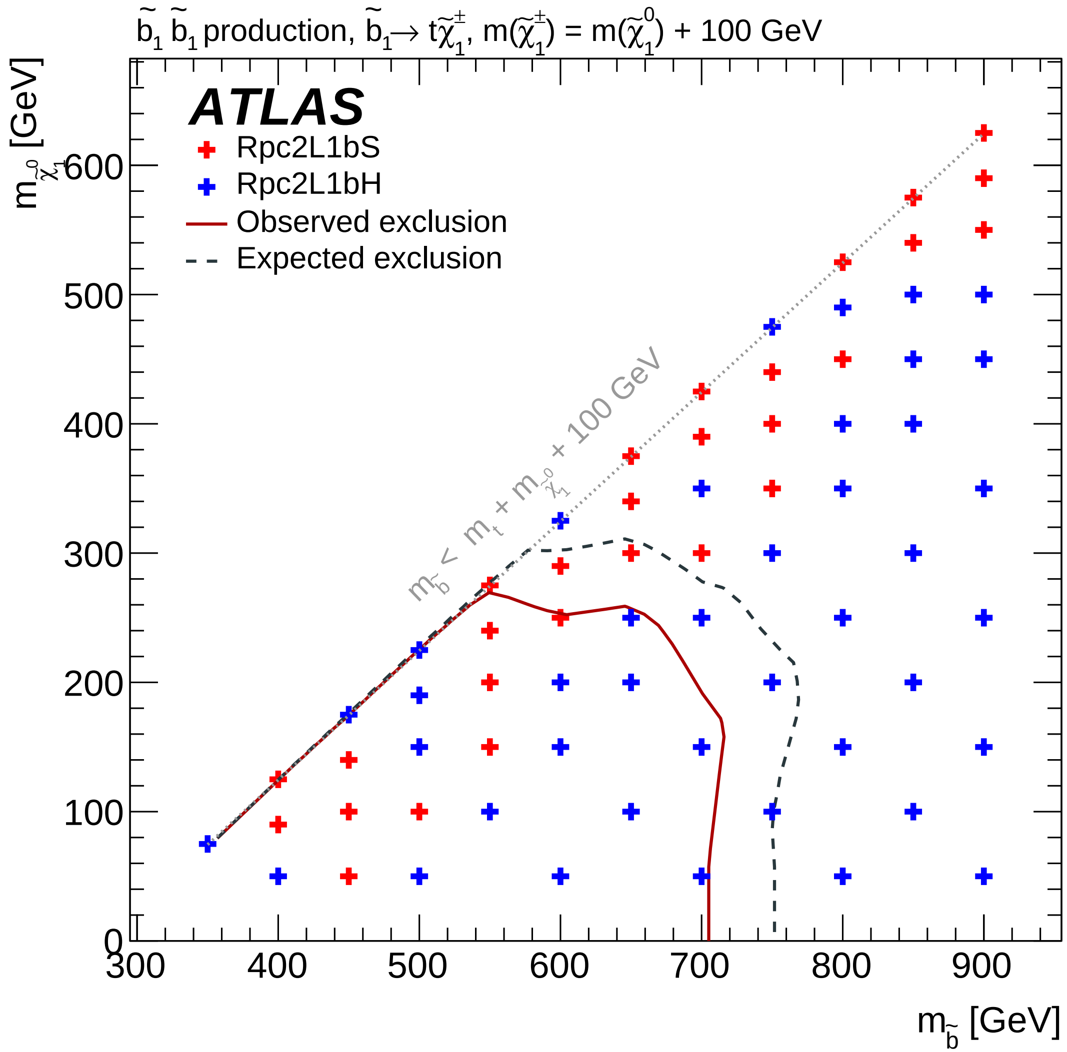
	SR^{4-body}
Lepton flavour	SF and DF
E_T^{miss} [GeV]	> 200
$p_T(\ell_1)$ [GeV]	[7, 80]
$p_T(\ell_2)$ [GeV]	[7, 35]
$m_{\ell\ell}$ [GeV]	> 10
n_{jets}	≥ 2
$p_T(j_1)$ [GeV]	> 150
$p_T(j_2)$ [GeV]	> 25
$p_T(j_3)/E_T^{miss}$	< 0.14
$R_{2\ell 4j}$	> 0.35
$R_{2\ell}$	> 12
$n_{b\text{-jets}}$	veto on j_1 and j_2


ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SRB$^{2\text{-body}}_{140}$
SRC$^{2\text{-body}}_{110}$
SR$^{3\text{-body}}$
SR$^{4\text{-body}}$
$m(\tilde{\chi}^0_1)$ [GeV]
$m(\tilde{t}_1)$ [GeV]
0
100
200
300
400
500
600
700
800

stop3L/sbottom2L SRs

Signal region	$N_{\text{leptons}}^{\text{signal}}$	$N_{b\text{-jets}}$	N_{jets}	$p_{\text{T}}^{\text{jet}}$ [GeV]	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]	$E_{\text{T}}^{\text{miss}}/m_{\text{eff}}$	Other	Targeted Signal
Rpc2L2bS	≥ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	–	Fig. 1(a)
Rpc2L2bH	≥ 2SS	≥ 2	≥ 6	> 25	–	> 1800	> 0.15	–	Fig. 1(a), NUHM2
Rpc2Lsoft1b	≥ 2SS	≥ 1	≥ 6	> 25	> 100	–	> 0.3	$20,10 < p_{\text{T}}^{\ell_1}, p_{\text{T}}^{\ell_2} < 100$ GeV	Fig. 1(b)
Rpc2Lsoft2b	≥ 2SS	≥ 2	≥ 6	> 25	> 200	> 600	> 0.25	$20,10 < p_{\text{T}}^{\ell_1}, p_{\text{T}}^{\ell_2} < 100$ GeV	Fig. 1(b)
Rpc2L0bS	≥ 2SS	$= 0$	≥ 6	> 25	> 150	–	> 0.25	–	Fig. 1(c)
Rpc2L0bH	≥ 2SS	$= 0$	≥ 6	> 40	> 250	> 900	–	–	Fig. 1(c)
Rpc3L0bS	≥ 3	$= 0$	≥ 4	> 40	> 200	> 600	–	–	Fig. 1(d)
Rpc3L0bH	≥ 3	$= 0$	≥ 4	> 40	> 200	> 1600	–	–	Fig. 1(d)
Rpc3L1bS	≥ 3	≥ 1	≥ 4	> 40	> 200	> 600	–	–	Other
Rpc3L1bH	≥ 3	≥ 1	≥ 4	> 40	> 200	> 1600	–	–	Other
Rpc2L1bS	≥ 2SS	≥ 1	≥ 6	> 25	> 150	> 600	> 0.25	–	Fig. 1(e) sbottom
Rpc2L1bH	≥ 2SS	≥ 1	≥ 6	> 25	> 250	–	> 0.2	–	Fig. 1(e)
Rpc3LSS1b	$\geq \ell^{\pm}\ell^{\pm}\ell^{\pm}$	≥ 1	–	–	–	–	–	veto $81 < m_{e^{\pm}e^{\pm}} < 101$ GeV	Fig. 1(f) stop
Rpv2L1bH	≥ 2SS	≥ 1	≥ 6	> 50	–	> 2200	–	–	Figs. 1(g), 1(h)
Rpv2L0b	$= 2$SS	$= 0$	≥ 6	> 40	–	> 1800	–	veto $81 < m_{e^{\pm}e^{\pm}} < 101$ GeV	Fig. 1(i)
Rpv2L2bH	≥ 2SS	≥ 2	≥ 6	> 40	–	> 2000	–	veto $81 < m_{e^{\pm}e^{\pm}} < 101$ GeV	Fig. 1(j)
Rpv2L2bS	$\geq \ell^{-}\ell^{-}$	≥ 2	≥ 3	> 50	–	> 1200	–	–	Fig. 1(k)
Rpv2L1bS	$\geq \ell^{-}\ell^{-}$	≥ 1	≥ 4	> 50	–	> 1200	–	–	Fig. 1(l)
Rpv2L1bM	$\geq \ell^{-}\ell^{-}$	≥ 1	≥ 4	> 50	–	> 1800	–	–	Fig. 1(l)

- Fake-non-prompt and charge-flip backgrounds estimated with data.
- $t\bar{t}V$ backgrouds estimated with MC but checked in VRs.



$\tilde{b}_1 \tilde{b}_1$ production, $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm}$, $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_1^{0}) + 100$ GeV
ATLAS
Rpc2L1bS
Rpc2L1bH
Observed exclusion
Expected exclusion
$m_{\tilde{b}} < m_t + m_{\tilde{\chi}_1^0} + 100$ GeV
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{b}}$ [GeV]
0
100
200
300
400
500
600
300
400
500
600
700
800
900

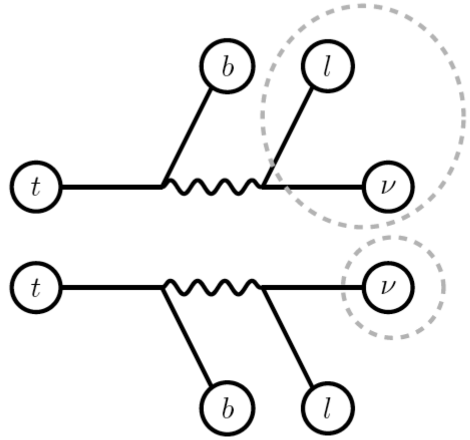
	b0L-SRAx	b0L-SRB	b0L-SRC
Lepton veto		No e/μ with p_{T} >10 GeV after overlap removal	
N_{jets} ($p_{\mathrm{T}} > 35$ GeV)	2–4	2–4	-
N_{jets} ($p_{\mathrm{T}} > 20$ GeV)	-	-	2–5
$p_{\mathrm{T}}(j_1)$ [GeV]	> 130	> 50	> 500
$p_{\mathrm{T}}(j_2)$ [GeV]	> 50	> 50	> 20
$p_{\mathrm{T}}(j_4)$ [GeV]	< 50	-	-
H_{T4} [GeV]	-	-	< 70
b-jets	j_1 and j_2	any 2	j_2 and (j_3 or j_4 or j_5)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 250	> 250	> 500
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.25	-	-
$\min[\Delta\phi(\mathrm{jet}_{1-4}, E_{\mathrm{T}}^{\mathrm{miss}})]$	> 0.4	> 0.4	-
$\min[\Delta\phi(\mathrm{jet}_{1-2}, E_{\mathrm{T}}^{\mathrm{miss}})]$	-	-	> 0.2
$\Delta\phi(b_1, E_{\mathrm{T}}^{\mathrm{miss}})$	-	< 2.0	-
$\Delta\phi(b_2, E_{\mathrm{T}}^{\mathrm{miss}})$	-	< 2.5	-
$\Delta\phi(j_1, E_{\mathrm{T}}^{\mathrm{miss}})$	-	-	> 2.5
m_{jj} [GeV]	> 200	-	> 200
m_{CT} [GeV]	>350, 450, 550	-	-
$m_{\mathrm{T}}^{\mathrm{min}}(\mathrm{jet}_{1-4}, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	-	> 250	-
m_{eff} [GeV]	-	-	> 1300
$\mathcal{A}$	-	-	> 0.8

sbottom1L SRs

	b1L-SRAx	b1L-SRA300-2j	b1L-SRB
Number of leptons (e, μ)	1	1	1
N_{jets} $(p_{\text{T}} > 35\ GeV)$	≥ 2	$= 2$	≥ 2
b-jets	any 2	j_1 and j_2	any 2
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 200	> 200	> 200
$E_{\text{T}}^{\text{miss}}/\sqrt{H_{\text{T}}}$ [GeV$^{1/2}$]	> 8	> 8	> 8
$m_{b\ell}^{\text{min}}$ [GeV]	< 170	< 170	< 170
$\Delta\phi_{\text{min}}^{j}$	> 0.4	–	> 0.4
$\min[\Delta\phi(\text{jet}_{1-2}, E_{\text{T}}^{\text{miss}})]$	–	> 0.4	–
am_{T2} [GeV]	> 250	> 250	> 200
m_{T} [GeV]	> 140	> 140	> 120
m_{bb} [GeV]	> 200	> 200	< 200
m_{eff} [GeV]	$> 600, 750$	> 300	> 300
$m_{\text{T}}^{\text{min}}(b\text{-jet}_{1-2}, E_{\text{T}}^{\text{miss}})$ [GeV]	–	–	> 200
$\Delta\phi(b_1, E_{\text{T}}^{\text{miss}})$	–	–	> 2.0

Stransverse Mass, m_{T2}

- Branches a and b, partly unreconstrcuted.
- Sum of measured 4-vec momenta: $p_i = (E_i, \vec{p}_{\mathrm{Ti}}, p_{zi})$; $i \in \{a, b\}$.
- Sum of unmeasured 4-vec momenta: $q_i = (F_i, \vec{q}_{\mathrm{Ti}}, q_{zi})$.



- m_{T} in branch i: $m^2_{\mathrm{Ti}} = \left(\sqrt{p^2_{\mathrm{Ti}} + m^2_{p_i}} + \sqrt{q^2_{\mathrm{Ti}} + m^2_{q_i}}\right)^2 - (\vec{p}_{\mathrm{Ti}} + \vec{q}_{\mathrm{Ti}})^2$
- $m_{\mathrm{T2}} \equiv \min_{\vec{q}_{\mathrm{Ta}} + \vec{q}_{\mathrm{Tb}} = \vec{p}^{\mathrm{miss}}_{\mathrm{T}}} \{\max(m_{\mathrm{Ta}}, m_{\mathrm{Tb}})\}$,
- Minimisation over allocation of $\vec{p}^{\mathrm{miss}}_{\mathrm{T}}$ between $\vec{q}_{\mathrm{Ta}}$ and $\vec{q}_{\mathrm{Tb}}$ of the maximum of the corresponding m_{Ta} or m_{Tb}, with assumption of m_{q_a} and m_{q_b} in computation of m_{Ta} and m_{Tb}.
- Minimum parent mass consistent with the observed kinematic distributions under the inputs m_{q_a} and m_{q_b}.

Asymmetric m_{T2}, am_{T2}

- Measured particles: For branch a, this is one of the b-jets and for branch b this is the second b-jet and the charged lepton. The b-jets are identified based on the highest b-tagging weights. Since there are two ways of assigning the b-tagged jets to branches a and b, both m_{T2} values are computed and the minimum kept for the final discriminant.

- Unmeasured particles: For branch a, this is a W boson that decays leptonically, with the charged lepton unidentified as such. The unmeasured particle for branch b is the neutrino associated with the measured charged lepton.

- Input masses: $m_{q_a} = m_W = 80$ GeV and $m_{q_b} = m_\nu = 0$ GeV.

- $m_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}{}^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\vec{\ell}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right)}$
- $\Delta m_{\mathrm{T}}{}^{\alpha} = m_{\mathrm{T}} - m_{\mathrm{T}}{}^{\alpha}$, where $m_{\mathrm{T}}{}^{\alpha}$ uses the lepton and ν^{α}, and the p_{T} of the reconstructed $t\bar{t}$ system under the SM hypothesis, $p_{\mathrm{T}}(t\bar{t})$.
- $\alpha \equiv \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{t}_1}} \sim \frac{p_{\mathrm{T}}(\tilde{\chi}_1^0 \tilde{\chi}_1^0)}{p_{\mathrm{T}}(\tilde{t}_1 \tilde{t}_1)}$
- Mass ratio $\alpha = 0.135$ is used throughout the stop1L paper, as is calculated from $m_{\tilde{t}_1} = 200$ GeV and $m_{\tilde{\chi}_1^0} = 27$ GeV.
- χ^2 minimization to define hadronic top mass candidate, $t_{\mathrm{had}}^{\mathrm{ISR}}$.
- For signal hypothesis, collinearity of each $\tilde{t}_1$ with both of its decay products is assumed. Can calculate transverse-momentum vector of neutrino from leptonic W-boson decay by subtracting momenta of the LSPs from $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$, when assuming a specific mass ratio α:
$\vec{p_{\mathrm{T}}}(\nu^{\alpha}) = (1 - \alpha)\vec{p}_{\mathrm{T}}^{\mathrm{miss}} - \alpha \vec{p_{\mathrm{T}}}(t_{\mathrm{had}}^{\mathrm{ISR}} + b_{\mathrm{lep}} + \ell)$

Motivation for 3rd generation SUSY

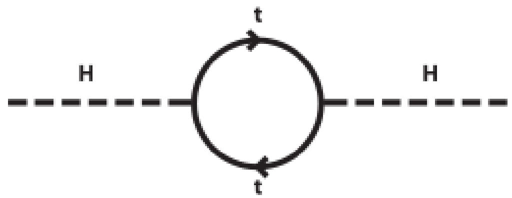
- In the SM, Higgs mass is destabilized by large quantum corrections.
- Severe fine-tuning is required to obtain the measured mass of 125 GeV.

$\rightarrow$ Naturalness or Higgs fine-tuning problem.

$$m_H^2 \approx (125\ \text{GeV})^2 = m_H^2(\text{tree}) - \frac{\lambda_t^2}{8\pi^2}(\Lambda^2 + \int_0^1 dx 2\Delta \ln \frac{\Lambda^2+\Delta}{\Delta}) + \ldots$$

- If SM is valid up th the Planck scale, then $\Lambda \sim M_{\text{plank}} \sim 10^{19}$ GeV.
- In SUSY, the correction from the top quark is cancelled by an (almost) equal but opposite contribution from its SUSY partner, the stop.

$$m_H^2 \approx (125\ \text{GeV})^2 = m_H^2(\text{tree}) - \frac{\lambda_t^2}{8\pi^2}(\Lambda^2 + \int_0^1 dx 2\Delta \ln \frac{\Lambda^2+\Delta}{\Delta})$$
$$+ \frac{\lambda_{\tilde{t}}}{16\pi^2}(2\Lambda^2 - m_{\tilde{t}_1}^2 \ln \frac{\Lambda^2+m_{\tilde{t}_1}^2}{m_{\tilde{t}_1}^2} - m_{\tilde{t}_2}^2 \ln \frac{\Lambda^2+m_{\tilde{t}_2}^2}{m_{\tilde{t}_2}^2}) + \ldots$$



- Stop must be light for cancellation to happen.
- Above $\mathcal{O}(1)$ TeV corrections start to get large.