

3rd Generation SUSY Searches at ATLAS

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SEPNet SUSY Conference, Kent
12/01/2016

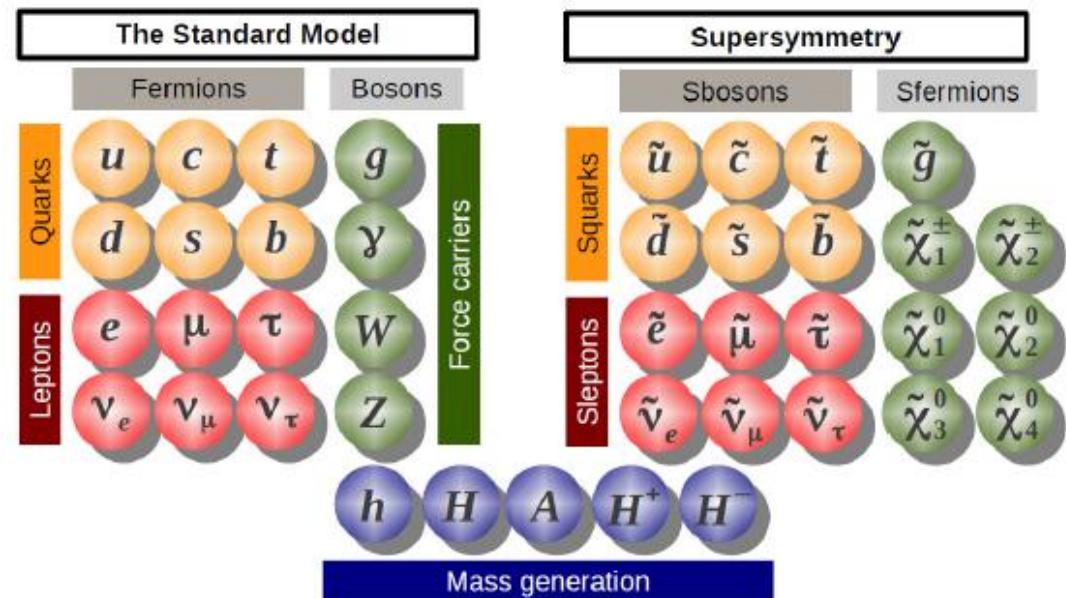


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- Supersymmetry – what, why, how
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- Prospects for Run 2
 - Stop searches at $\sqrt{s} = 13 \text{ TeV}$
 - Possible reinterpretations
 - Recent sbottom search result

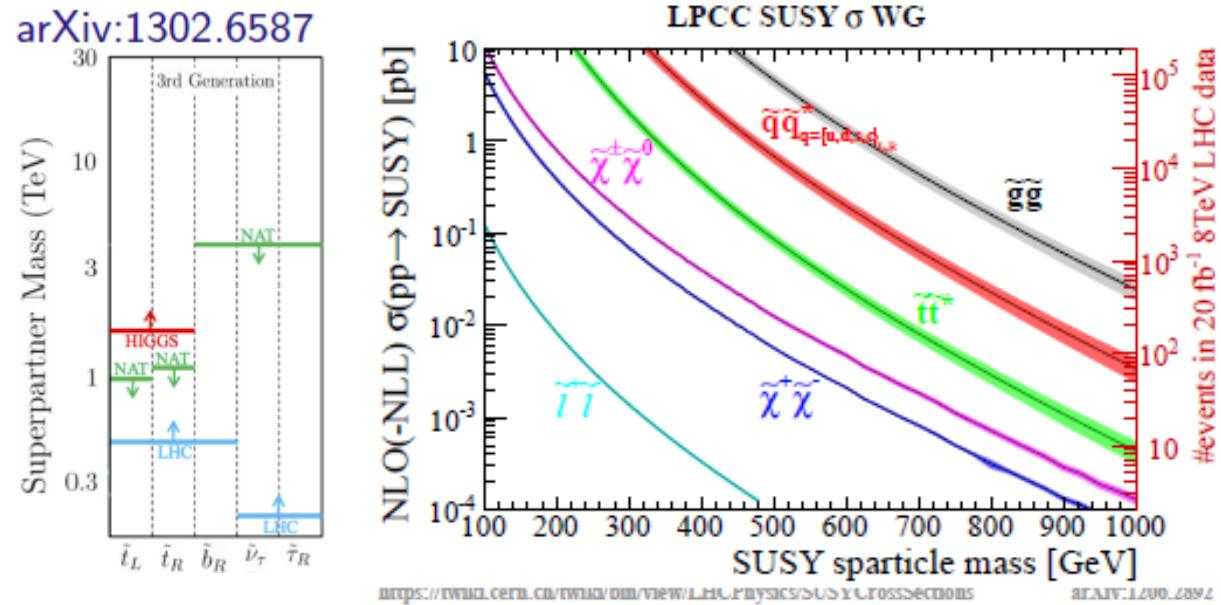
Supersymmetry - What is it?

- Extension of Standard Model
 - Superpartner for every SM particle
 - Spin differs by $\frac{1}{2}$
- Offers a solution to hierarchy problem, + lightest sparticle is a dark matter candidate
 - Neutralino!
- To avoid “unnatural” fine-tuning in Higgs mass corrections, some sparticles must be light
 - i.e. $< 1 \text{ TeV}$



3rd Generation Squarks

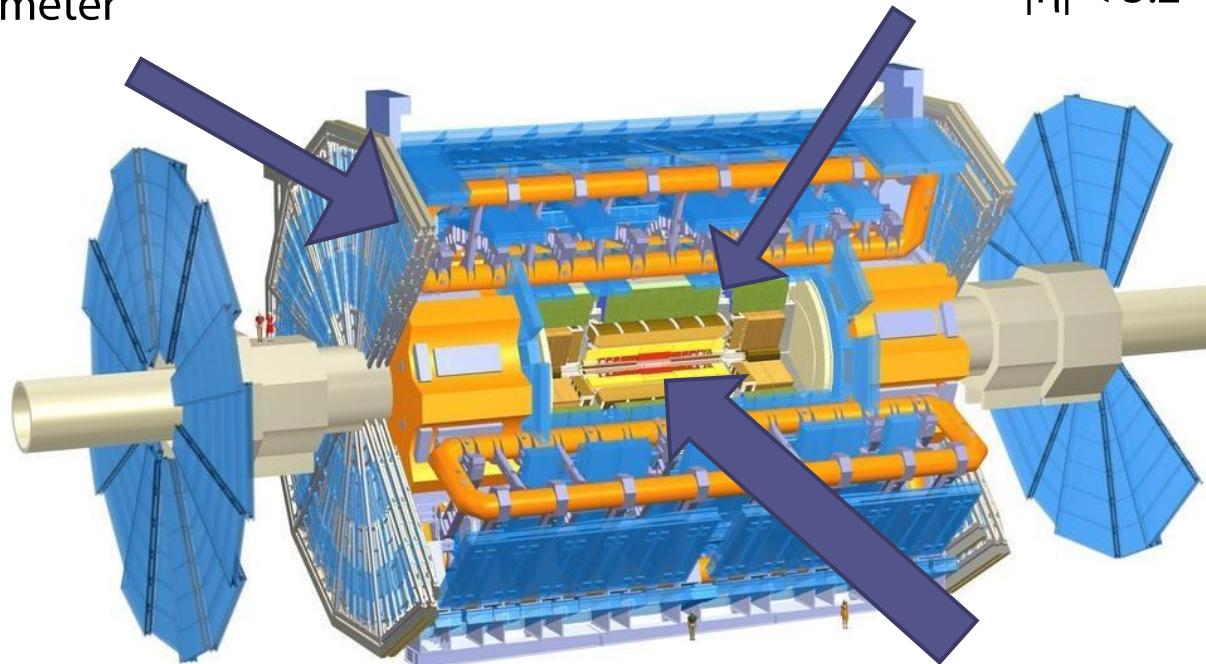
- Large Yukawa coupling and $\tilde{q}_R - \tilde{q}_L$ mixing mean 3rd generation squarks are expected to be lighter than other squarks
- TeV-scale stop/sbottom masses favoured by naturalness arguments
- → Within reach of the LHC!



The ATLAS Experiment

Muon spectrometer

- $|\eta| < 2.7$



4T toroidal magnetic field for muon spectrometer

2T solenoid magnet for inner detector

Liquid argon calorimeter

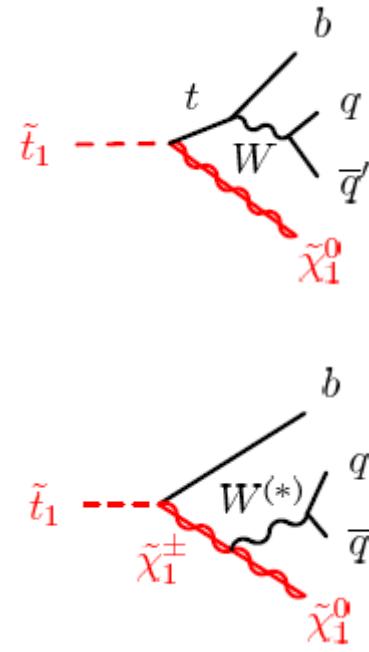
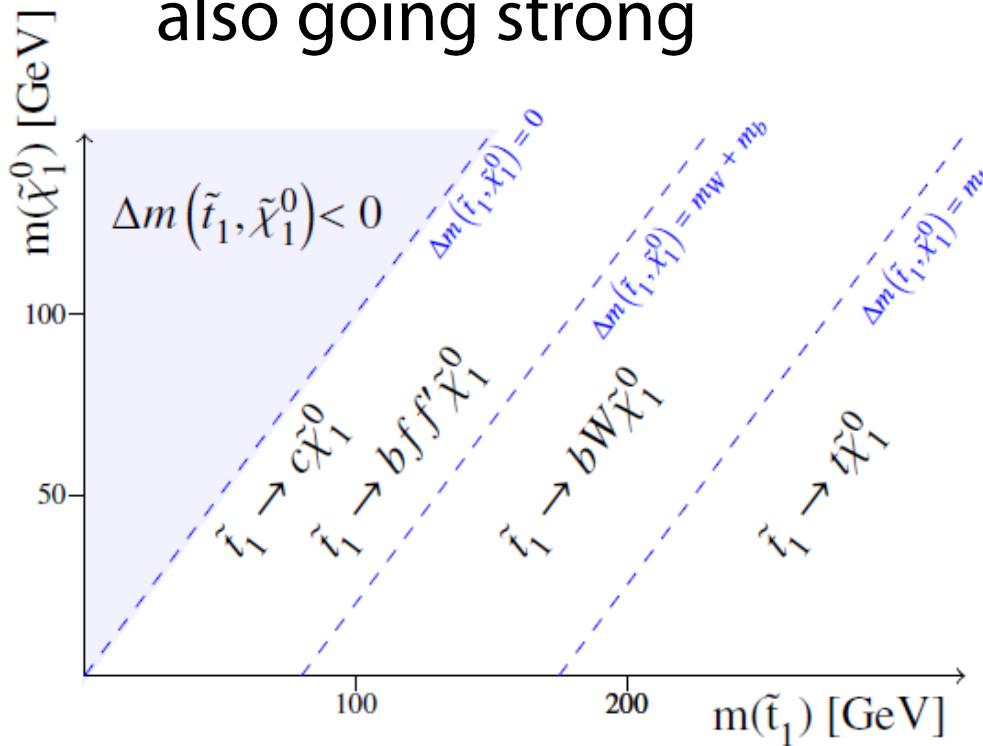
- $|\eta| < 3.2$

Inner detector

- Pixel detector
- Semiconductor tracker
- $|\eta| < 2.5$

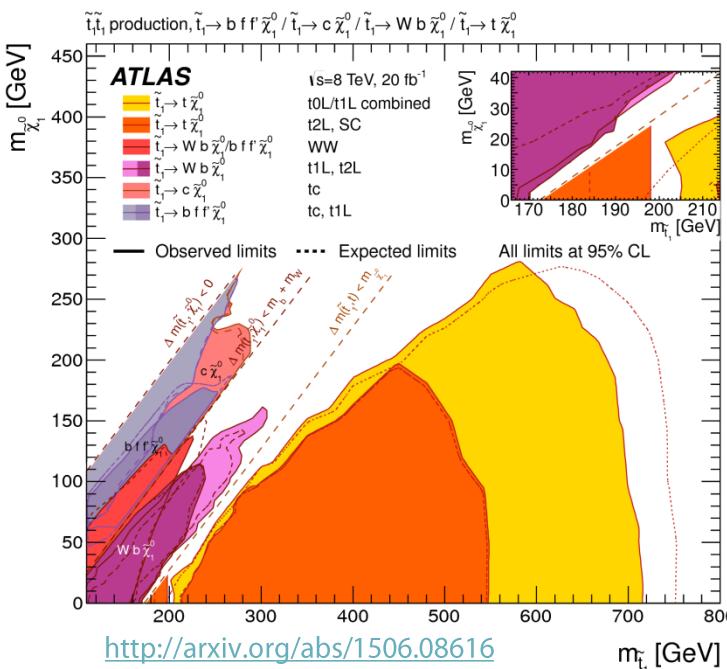
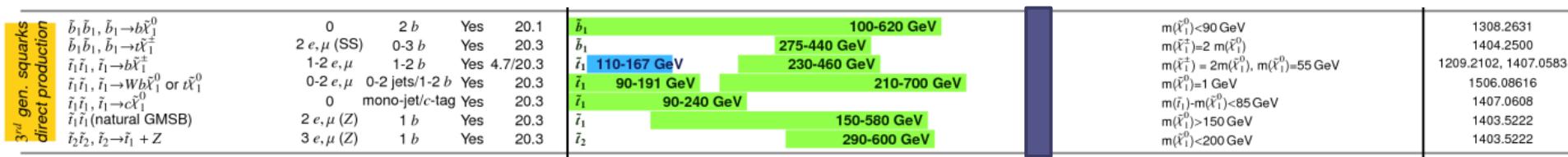
3rd Generation Searches at ATLAS

- Many analyses targeting many decay modes
- This talk focuses on hadronic stop searches
- Leptonic/semi-leptonic stop and sbottom searches also going strong



Run 1 results

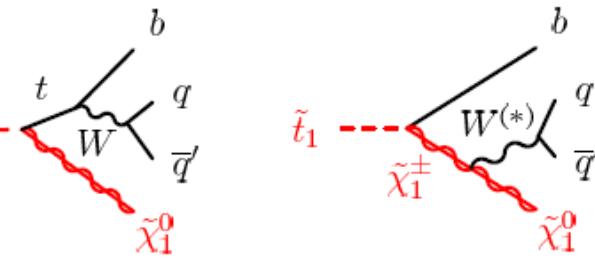
- Limits from 20.3 fb^{-1} $\sqrt{s} = 8 \text{ TeV}$ data
 - 95% CL lower limits



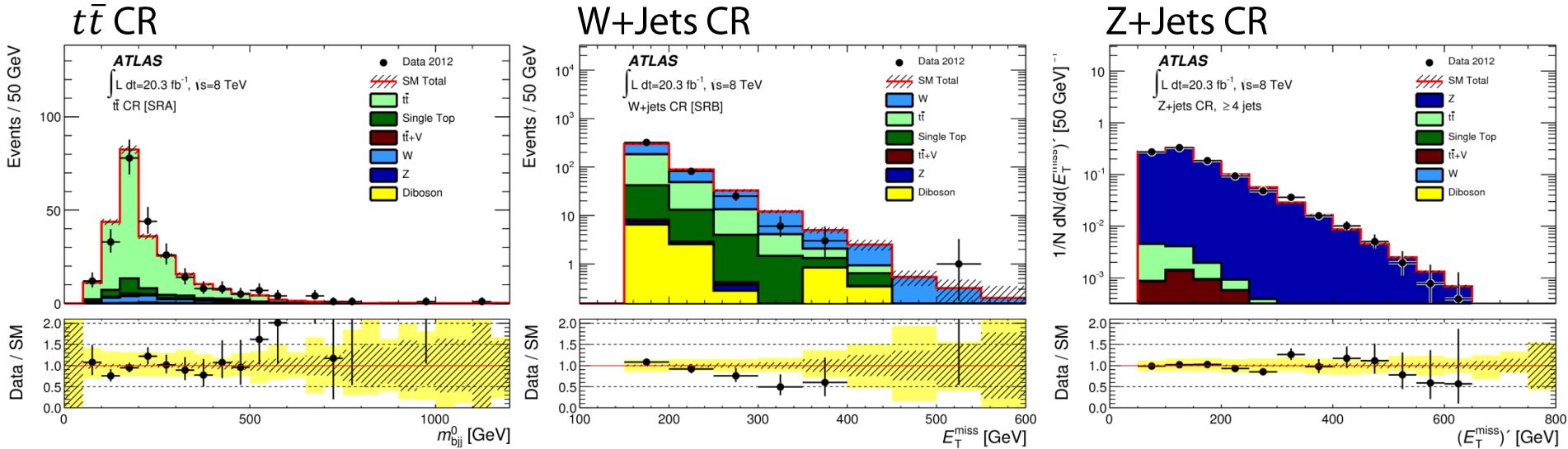
- $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$ decays provides strongest limit on stop mass
 - $m_{\tilde{t}} < 700 \text{ GeV}$ excluded
- But – still plenty of room for ‘natural’ stop to be found!

Hadronic Stop Search in Run 1

- $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, or $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$
 - Always pair-produced
- Main backgrounds:
 - $t\bar{t}$, single top, $V + \text{jets}$, $t\bar{t}V + \text{jets}$
- Signal regions (SR) defined to contain signal-like events, low bkg
- Use control regions (CR) to estimate background
 - Extrapolate from CR into related SR



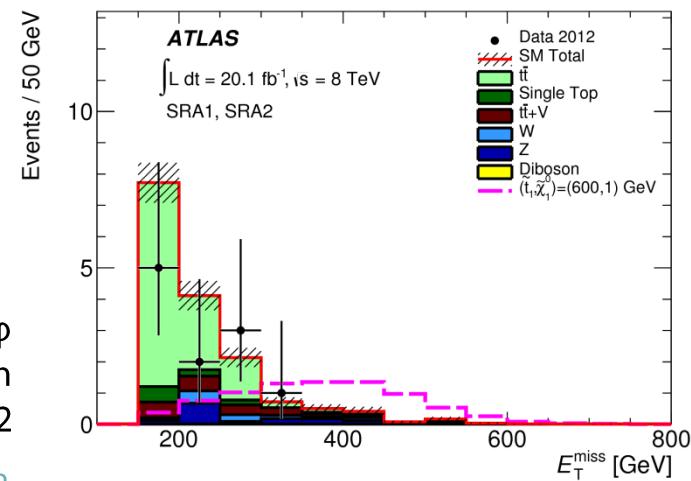
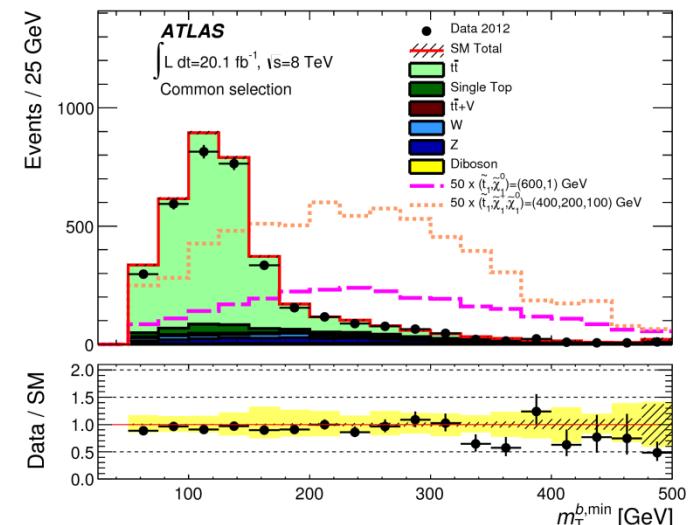
<http://arxiv.org/abs/1406.1122>



Hadronic Stop Search in Run 1

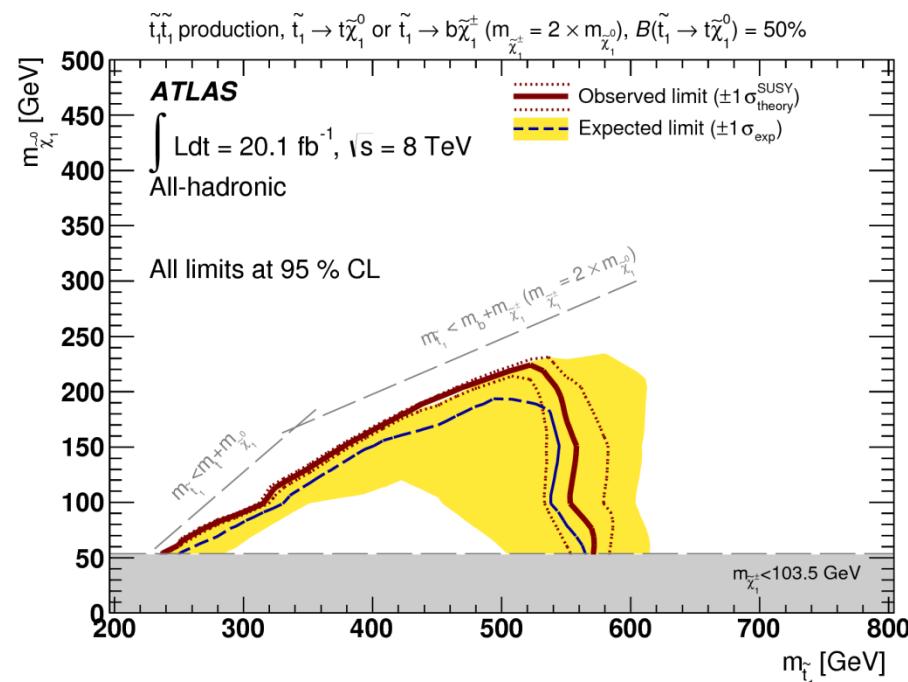
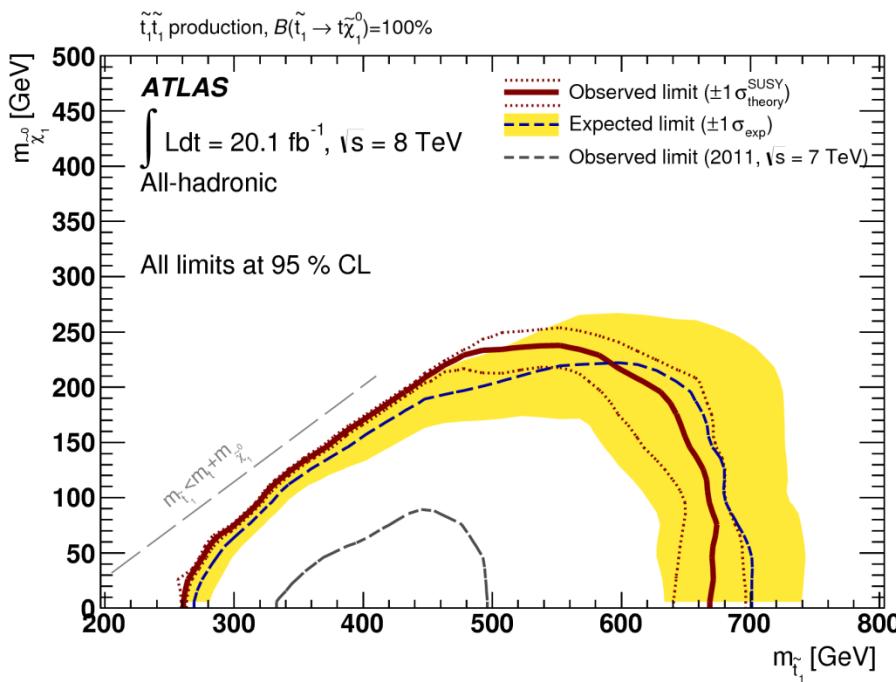
- ‘Cut and count’ analysis
 - Blind data in signal regions
 - Estimate SM background in SRs
 - Unblind data
 - Does data agree with SM?
- Number of observed events goes directly into significance
- Each SR has individual significance
 - Can combine orthogonal SRs to maximise significance

Top right: $m_T^{b,\min}$: transverse mass of bjet closest in ϕ to p_T^{miss} , common selection
 Bottom right: E_T^{miss} in SRA1,SRA2



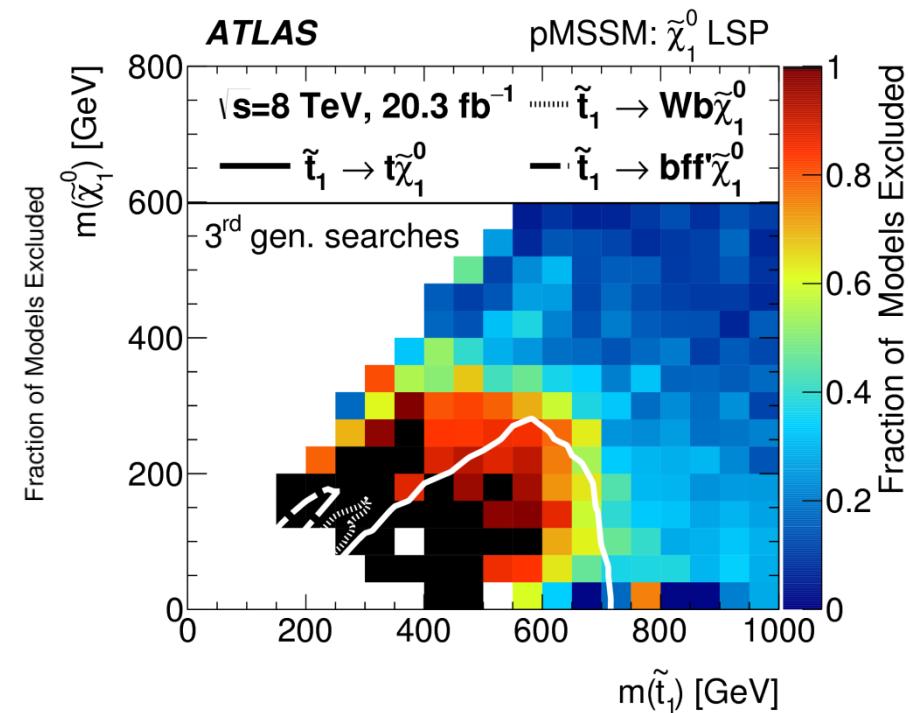
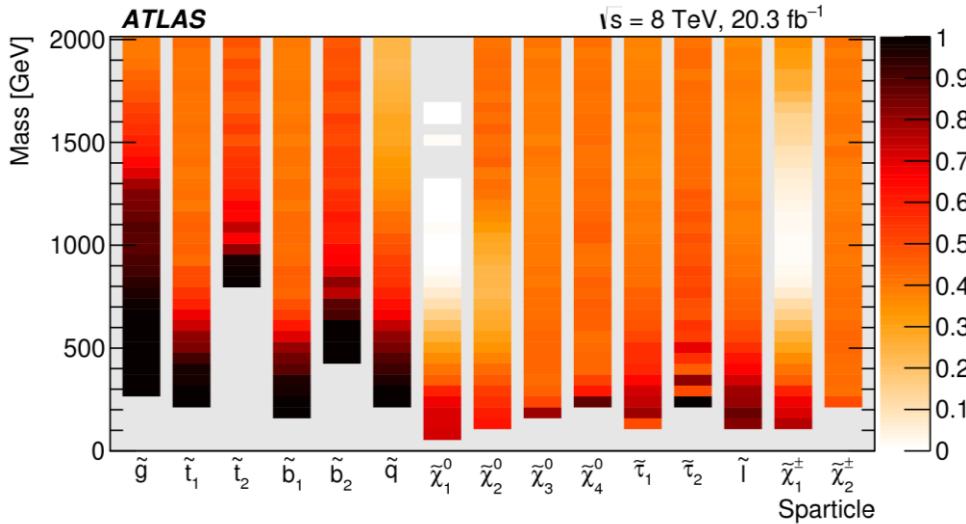
Hadronic Stop Search in Run 1

- No excess observed – set limits!
- Below: limit plots for the two hadronic decay modes
 - Red line: 8 TeV area of exclusion



pMSSM Reinterpretation

- Many, many models - $\sim 310,000$ over all free parameters
- ATLAS 3rd generation searches show good coverage in general
- Below left: fraction of pMSSM models excluded for each sparticle
- Below right: exclusion plot for \tilde{t}_1
 - White line = 95% CL limit

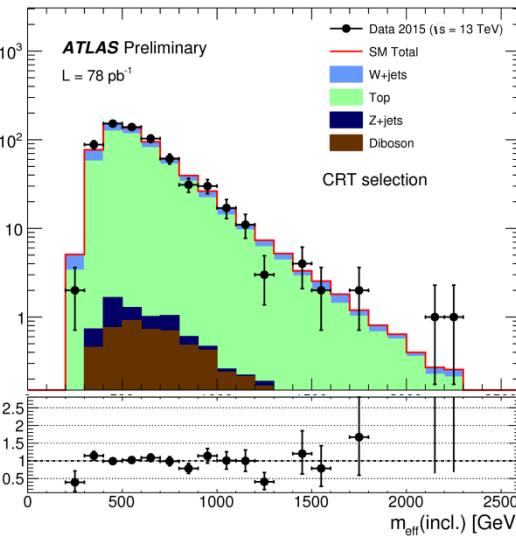
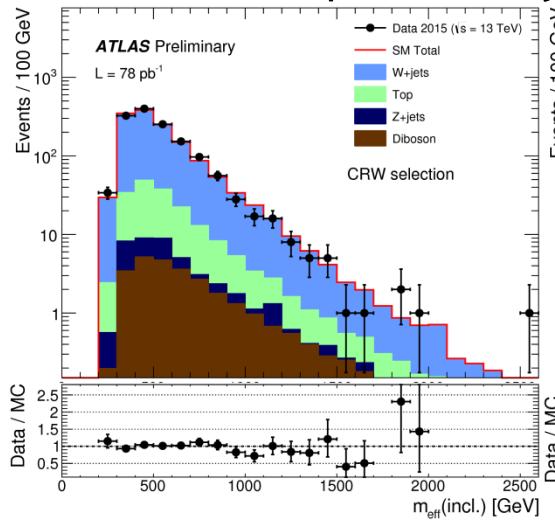


Looking to Run 2

- Higher energy, more luminosity → more room for discovery!
- ATLAS already recorded 3.87 fb^{-1} data
- First SUSY physics results on their way!

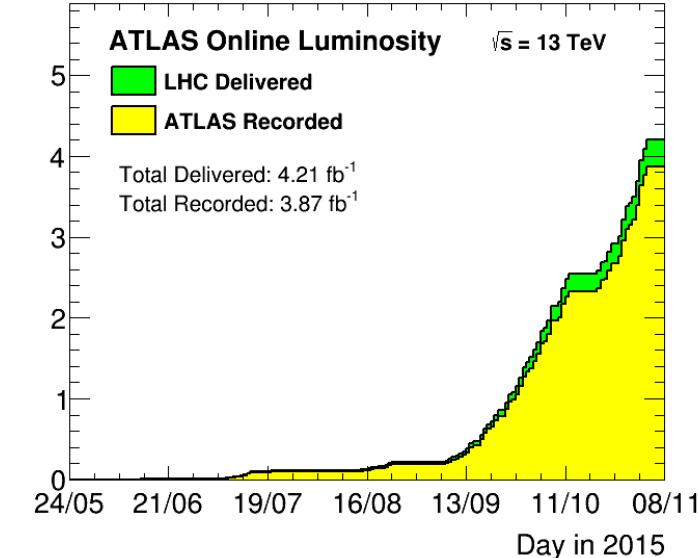
<https://cds.cern.ch/record/2037905/>

Inclusive zero-lepton + 2-6 jets + MET

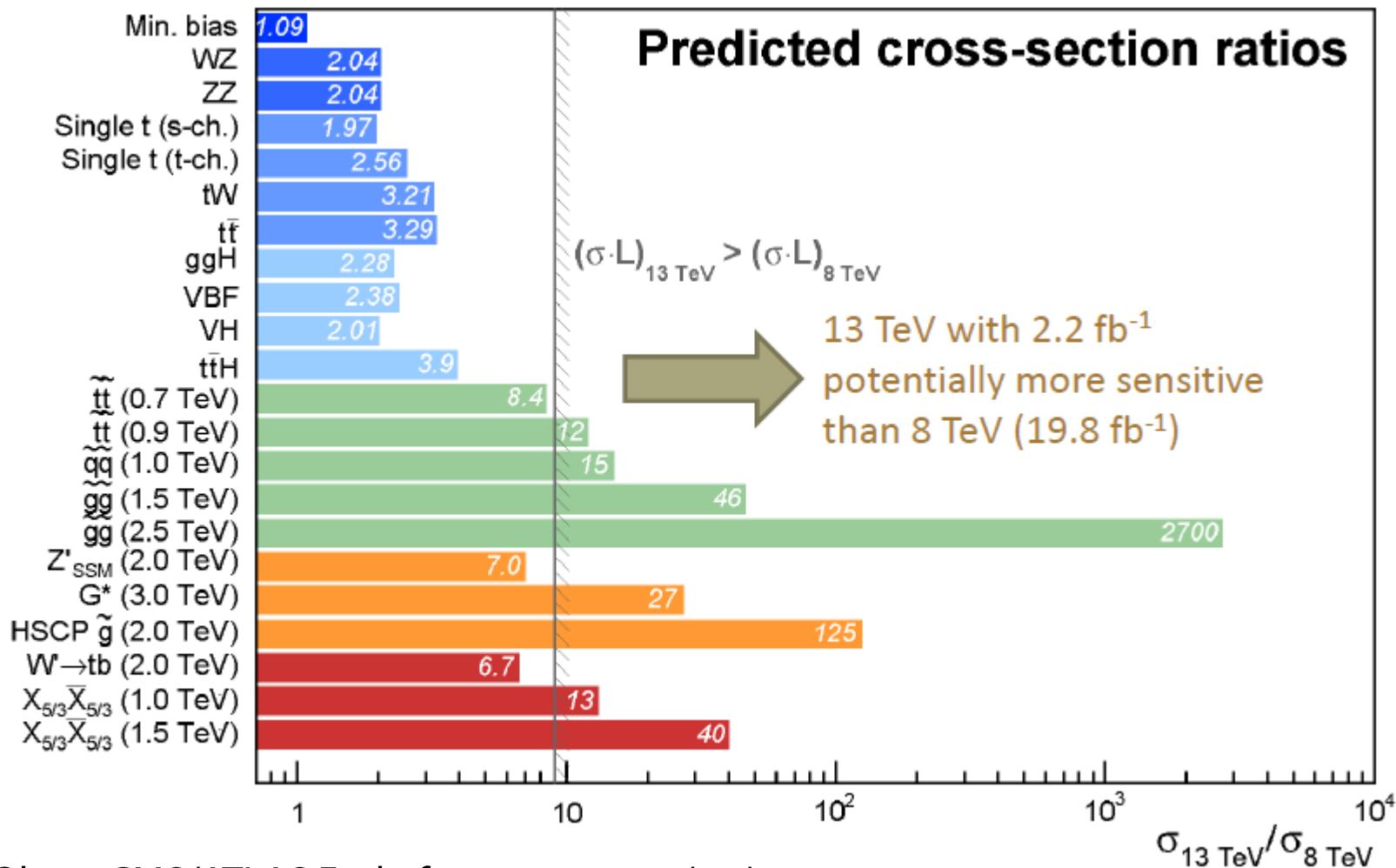


W control region

Top control region

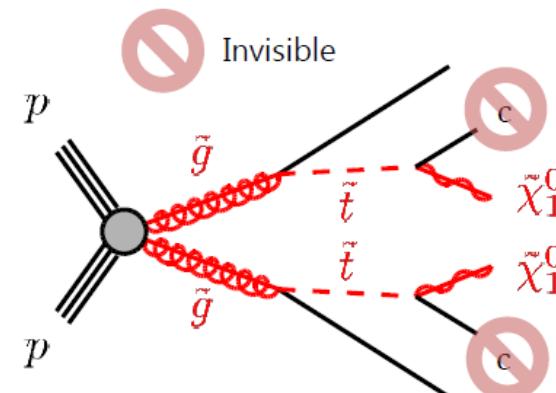
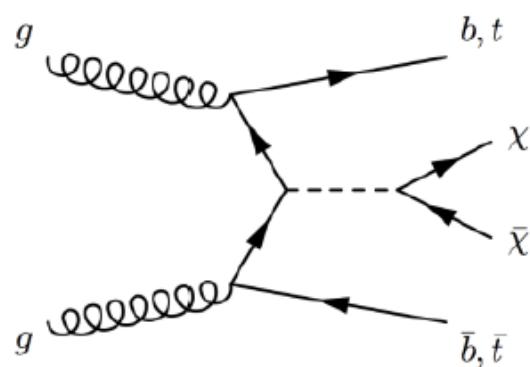


Stop Discovery Potential



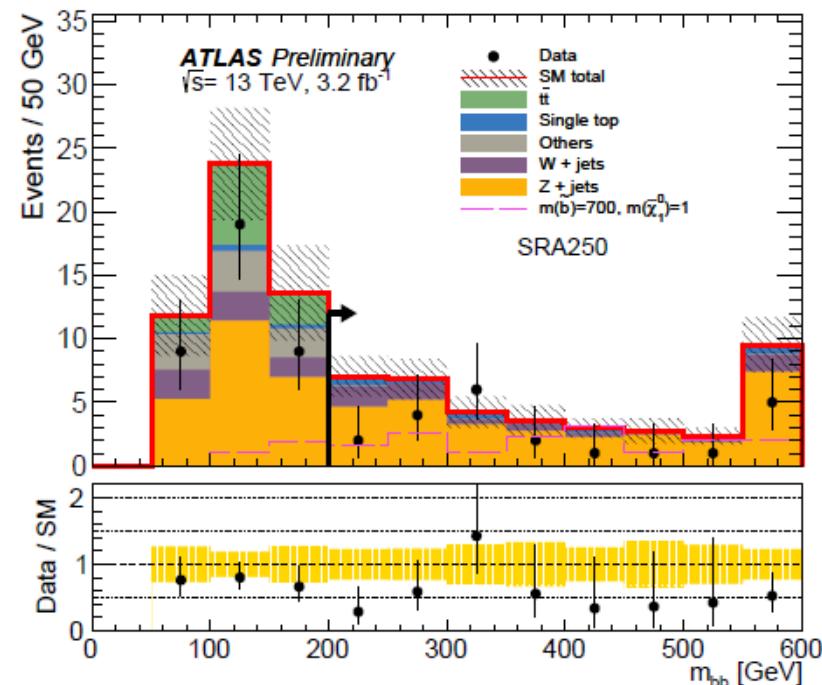
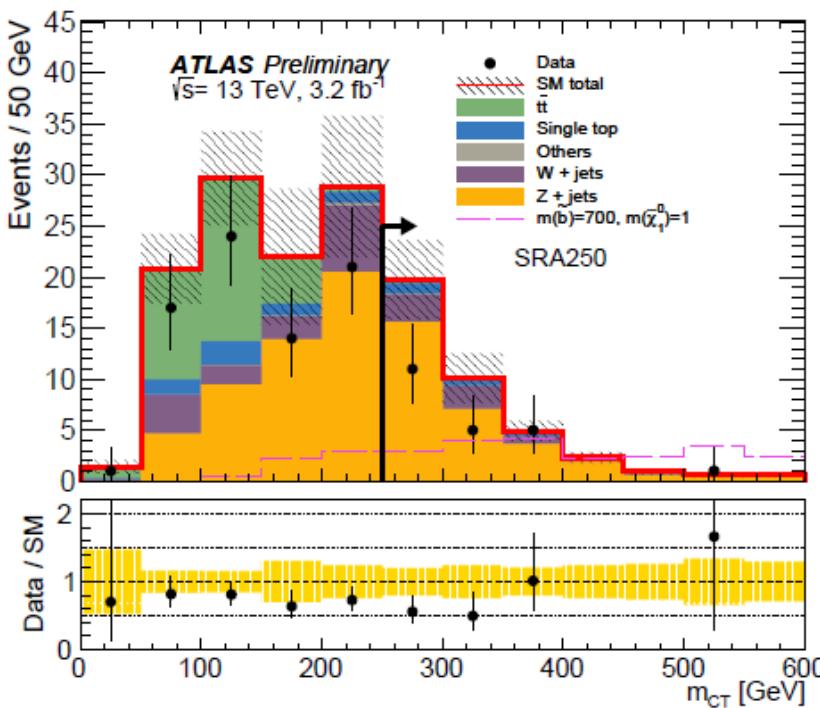
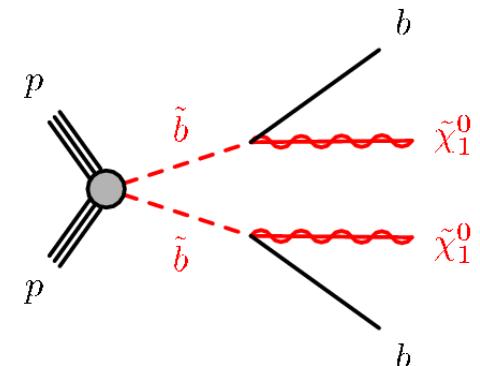
Hadronic Stop Search

- Big R&D effort to improve every aspect of the analysis
 - Top reconstruction, lepton veto, $\gamma + \text{jets}$ studies...
- Can improve on Run 1 limits with just 5fb^{-1} of data!
- Start with simplified model, but alternate model interpretations are also being studied
 - DM+ $t\bar{t}$ search, Gtc decays, pMSSM



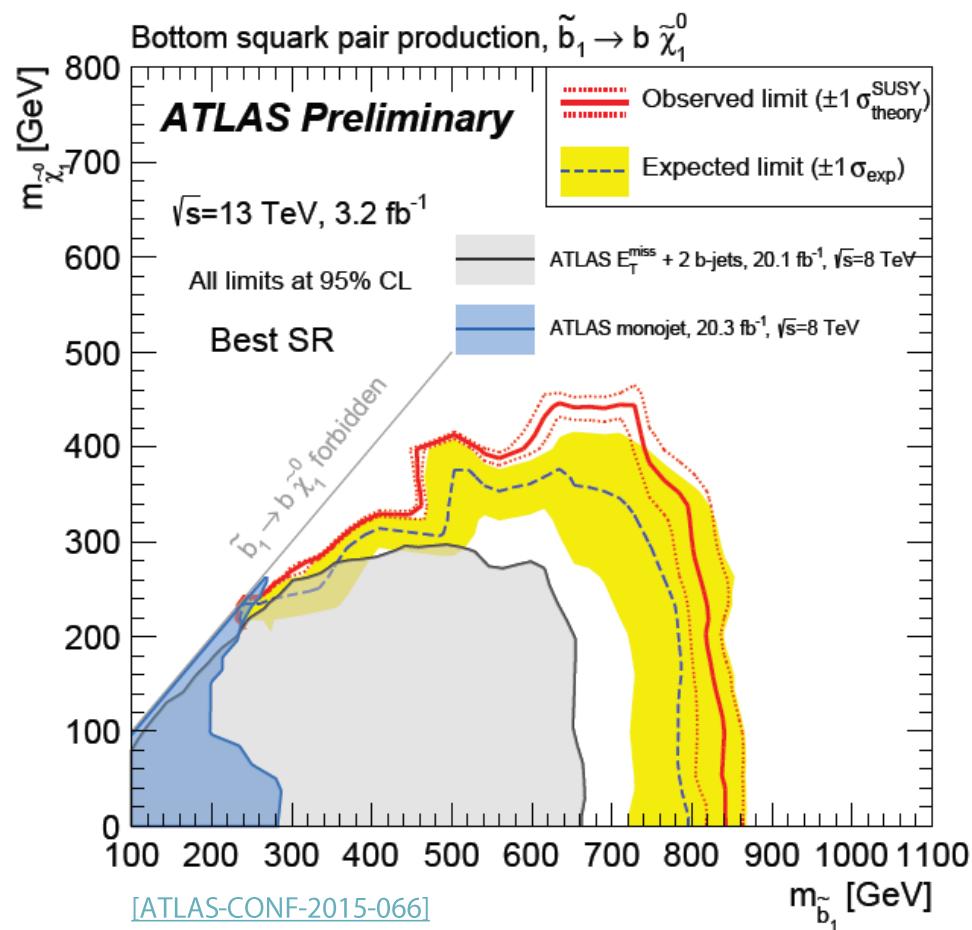
Sbottom Search

- Very recent result! [\[ATLAS-CONF-2015-066\]](#)
- Uses first 3.2fb^{-1} data taken at $\sqrt{s} = 13\text{ TeV}$
- Below: data in nominal signal region
 - m_{CT} contransverse mass, $m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$



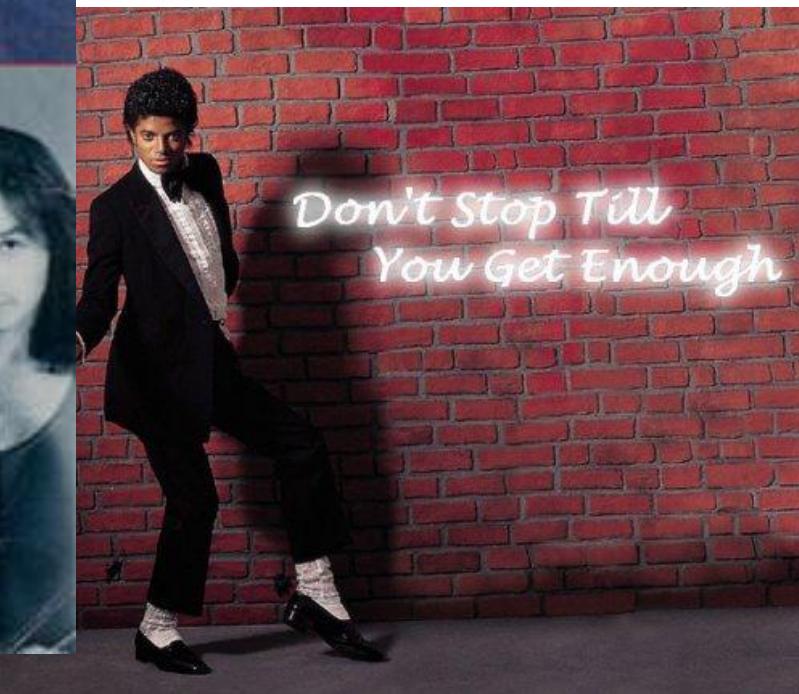
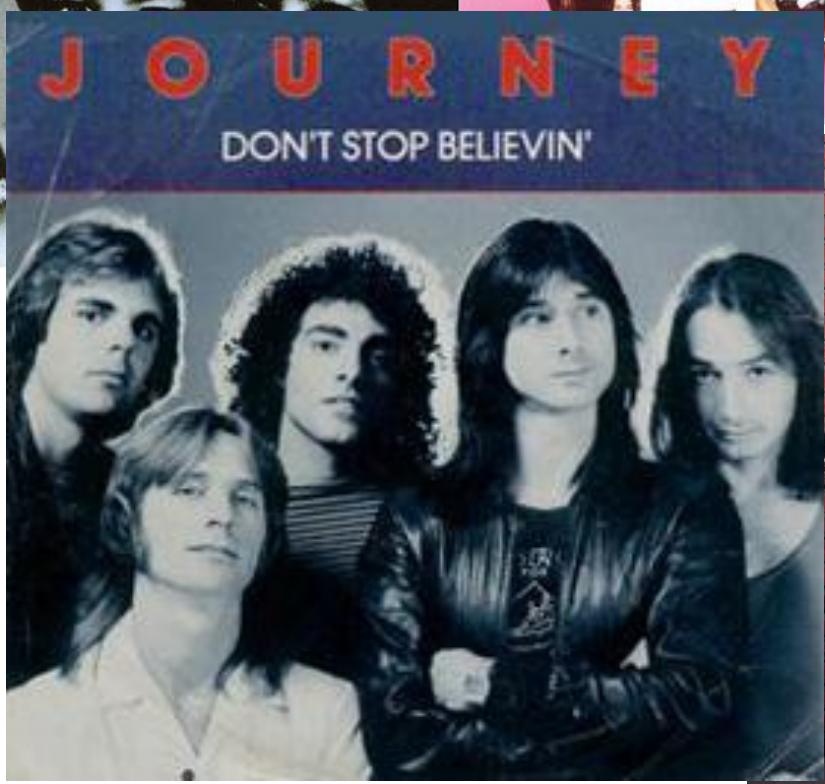
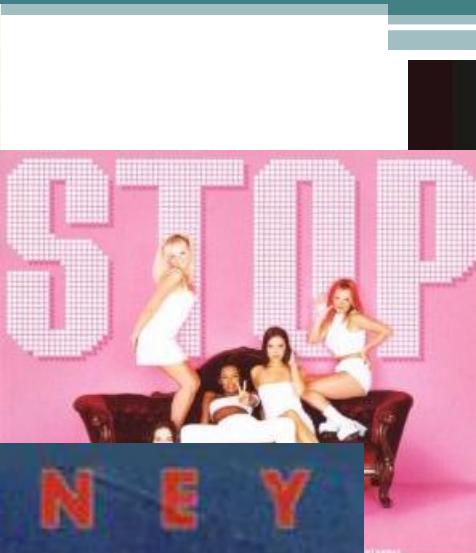
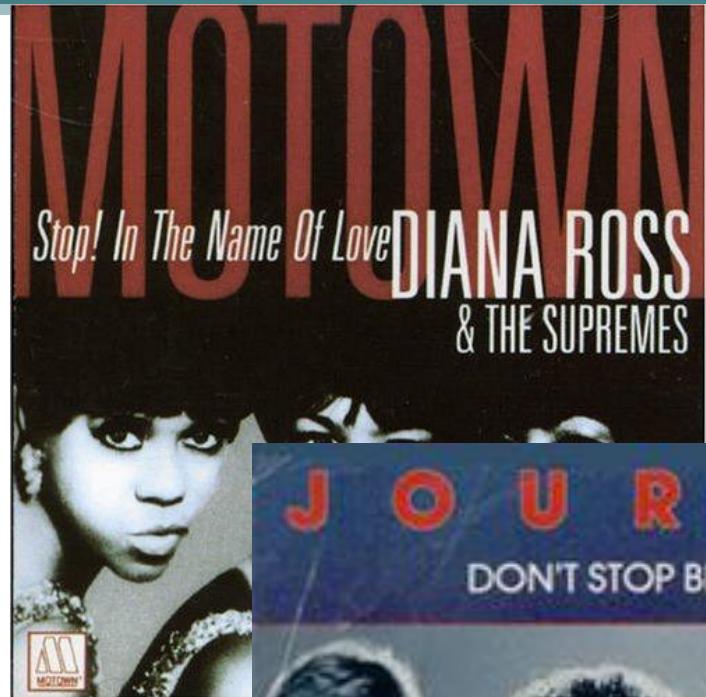
Sbottom Search

- No excess observed – set limits!
- Blue + grey regions:
 - Run 1 limits
- Sbottom masses excluded:
 - 800 GeV for $m_{\tilde{\chi}} < 360$ GeV
 - 840 GeV for $m_{\tilde{\chi}} < 100$ GeV



Conclusions

- Supersymmetry is a good candidate for BSM physics
- ATLAS has a rich program of SUSY searches
- In Run 1, 3rd generation squark searches placed limits up to 700 GeV on stop mass
- Run 2 has great discovery potential!
 - Hadronic stop search is still developing
 - Sbottom search with 3.2 fb^{-1} already completed
 - $m_{\tilde{b}} < 800 \text{ (840) GeV}$ excluded!



Backup



Stop 0L signal region definitions

Common selection

Trigger	E_T^{miss}
N_{lep}	0
b -tagged jets	≥ 2
E_T^{miss}	$> 150 \text{ GeV}$
$ \Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) $	$> \pi/5$
$ \Delta\phi(\mathbf{p}_T^{\text{miss}}, \mathbf{p}_T^{\text{miss,track}}) $	$< \pi/3$
$m_T^{b, \text{min}}$	$> 175 \text{ GeV}$

SR A (fully resolved $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$)

	SRA1	SRA2	SRA3	SRA4
anti- k_t $R = 0.4$ jets	$\geq 6, p_T > 80, 80, 35, 35, 35, 35 \text{ GeV}$			
$m_{b jj}^0$	$< 225 \text{ GeV}$	$[50, 250] \text{ GeV}$		
$m_{b jj}^1$	$< 250 \text{ GeV}$	$[50, 400] \text{ GeV}$		
$\min[m_T(\text{jet}^i, \mathbf{p}_T^{\text{miss}})]$	—		$> 50 \text{ GeV}$	
τ veto		yes		
E_T^{miss}	$> 150 \text{ GeV}$	$> 250 \text{ GeV}$	$> 300 \text{ GeV}$	$> 350 \text{ GeV}$

SR B (partially resolved $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$)

	SRB1	SRB2
anti- k_t $R = 0.4$ jets	4 or 5, $p_T > 80, 80, 35, 35, (35) \text{ GeV}$	5, $p_T > 100, 100, 35, 35, 35 \text{ GeV}$
\mathcal{A}_{m_t}	< 0.5	> 0.5
$p_{T, \text{jet}, R=1.2}^0$	—	$> 350 \text{ GeV}$
$m_{\text{jet}, R=1.2}^0$	$> 80 \text{ GeV}$	$[140, 500] \text{ GeV}$
$m_{\text{jet}, R=1.2}^1$	$[60, 200] \text{ GeV}$	—
$m_{\text{jet}, R=0.8}^0$	$> 50 \text{ GeV}$	$[70, 300] \text{ GeV}$
m_T^{min}	$> 175 \text{ GeV}$	$> 125 \text{ GeV}$
$m_T(\text{jet}^3, \mathbf{p}_T^{\text{miss}})$	$> 280 \text{ GeV}$ for 4-jet case	—
$E_T^{\text{miss}}/\sqrt{H_T}$	—	$> 17\sqrt{ } \text{ GeV}$
E_T^{miss}	$> 325 \text{ GeV}$	$> 400 \text{ GeV}$

SR C ($\tilde{t}_1 \rightarrow b\chi_1^\pm \rightarrow bW\tilde{\chi}_1^0$)

	SRC1	SRC2	SRC3
anti- k_t $R = 0.4$ jets	$5, p_T > 80, 80, 35, 35, 35 \text{ GeV}$		
$ \Delta\phi(b, b) $		$> 0.2\pi$	
$m_T^{b, \text{min}}$	$> 185 \text{ GeV}$	$> 200 \text{ GeV}$	$> 200 \text{ GeV}$
$m_T^{b, \text{max}}$	$> 205 \text{ GeV}$	$> 290 \text{ GeV}$	$> 325 \text{ GeV}$
τ veto		yes	
E_T^{miss}	$> 160 \text{ GeV}$	$> 160 \text{ GeV}$	$> 215 \text{ GeV}$

Stop 0L control region definitions

CRs for only SRA are shown; only requirements different from common selection are shown.

	$t\bar{t}$ CR	$Z + \text{jets}$ CR	Multijet CR
Trigger	electron (muon)	electron (muon)	same
N_{lep}	1	2	same
p_T^ℓ	$> 35(35)$ GeV	$> 25(25)$ GeV	–
$p_T^{\ell_2}$	same	$> 10(10)$ GeV	same
$m_{\ell\ell}$	–	[86, 96] GeV	–
$E_T^{\text{miss,track}}$	–	–	same
$ \Delta\phi(\mathbf{p}_T^{\text{miss}}, \mathbf{p}_T^{\text{miss,track}}) $	–	–	–
$ \Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) $	$> \pi/10$	–	< 0.1
$m_T^{b, \text{min}}$	> 125 GeV	–	–
$m_T(\ell, \mathbf{p}_T^{\text{miss}})$	[40, 120] GeV	–	–
$\min[m_T(\text{jet}^i, \mathbf{p}_T^{\text{miss}})]$	–	–	–
$m_{bjj}^0 \text{ or } m_{bjj}^1$	< 600 GeV	–	–
E_T^{miss}	> 150 GeV	< 50 GeV	> 150 GeV
$(E_T^{\text{miss}})'$	–	> 70 GeV	–

Stop 0L Event Yields

Background estimates taken from profile likelihood fit; statistical, detector and theoretical systematic uncertainties included

	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
$Z + \text{jets}$	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
$W + \text{jets}$	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
$\sigma_{\text{vis}} (\text{obs}) [\text{fb}]$	0.33	0.29	0.33	0.32	0.21	0.78	0.62	0.40
$\sigma_{\text{vis}} (\text{exp}) [\text{fb}]$	$0.48^{+0.21}_{-0.14}$	$0.29^{+0.13}_{-0.09}$	$0.29^{+0.14}_{-0.09}$	$0.25^{+0.13}_{-0.07}$	$0.24^{+0.13}_{-0.06}$	$1.03^{+0.42}_{-0.29}$	$0.73^{+0.31}_{-0.21}$	$0.55^{+0.24}_{-0.15}$
N_{obs}^{95}	6.6	5.7	6.7	6.5	4.2	15.7	12.4	8.0
N_{exp}^{95}	$9.7^{+4.3}_{-3.0}$	$5.8^{+2.6}_{-1.8}$	$5.9^{+2.8}_{-1.9}$	$5.0^{+2.6}_{-1.4}$	$4.7^{+2.6}_{-1.2}$	$20.7^{+8.4}_{-5.8}$	$14.7^{+6.2}_{-4.2}$	$11.0^{+4.9}_{-3.1}$

Expected and observed 95% CL upper limits on cross sections and event yields shown for each SR

Useful references

- Stop 0L Run 1 paper:
 - <http://arxiv.org/abs/1406.1122>
- Sbottom Run 1 paper:
 - <http://arxiv.org/abs/1308.2631>
- 3rd generation SUSY search summary paper:
 - <http://arxiv.org/abs/1506.08616>
- pMSSM reinterpretation paper:
 - <http://arxiv.org/abs/1508.06608>
- First look at Run 2 data (squark/gluino inclusive search):
 - <https://cds.cern.ch/record/2037905/>