Search for bottom squark pair production with the ATLAS detector in proton-proton collisions at $\sqrt{s}$ = 13TeV

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ATLAS EXPERIMENT

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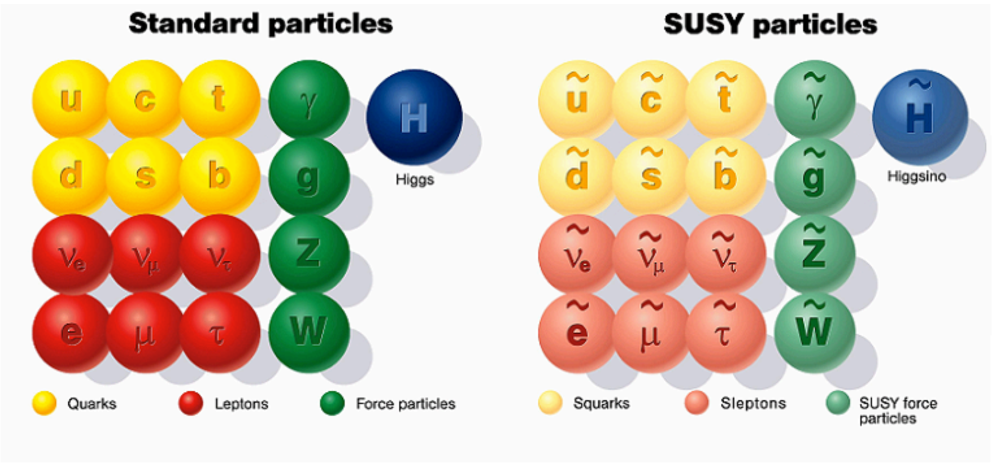
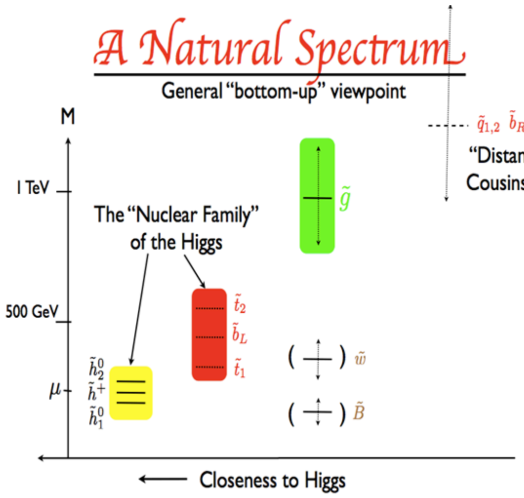
Supersymmetry Overview

Third Generation SUSY

- Supersymmetry (SUSY) is one of the theories of beyond the standard model (SM) physics which provides solutions to unanswered questions, such as the hierarchy problem and offers a candidate for dark matter.



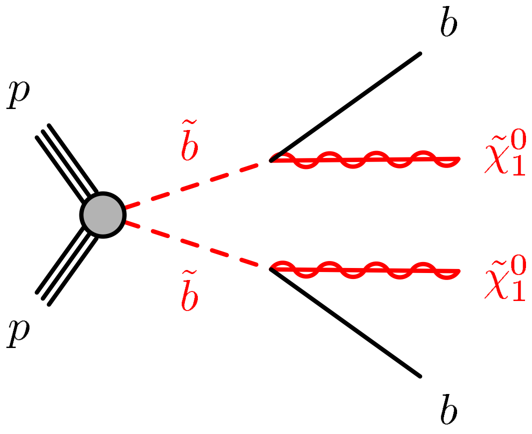


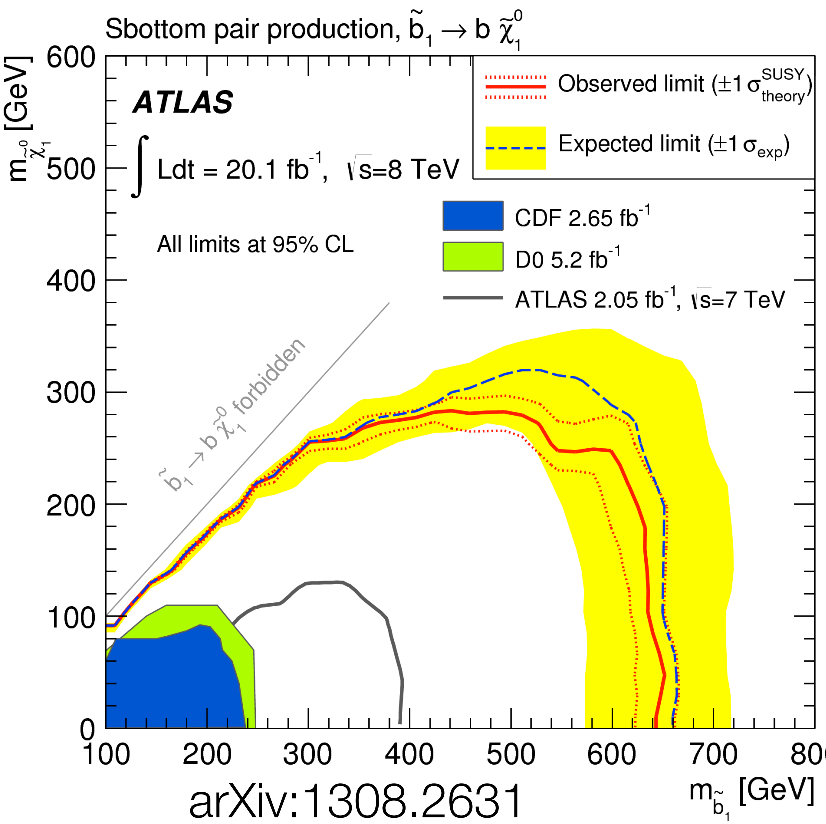
- Introduces a super-partner for each of the standard model particles, with spin differing by ½
- Naturalness considerations suggest that the third generation sparticles (top/bottom squark) should have masses < 1 TeV.
- Focus on searches for direct top/bottom squark production.
  - Additionally focused on R-parity conserving models, with the lightest SUSY particle (LSP) is stable and a dark matter candidate, in the scenarios considered, this is the neutralino $\tilde{\chi}_1^0$.

Search for Sbottom Pair Production

ATLAS Run 1 Analysis & Motivation for an early Run 2 result.

- A search was performed by ATLAS investigating bottom squark pair production during Run 1 of the LHC.
  - $\tilde{b} \rightarrow b + \tilde{\chi}_1^0$
  - No significant excesses found, and exclusion limits were placed in the sbottom neutralino phase space





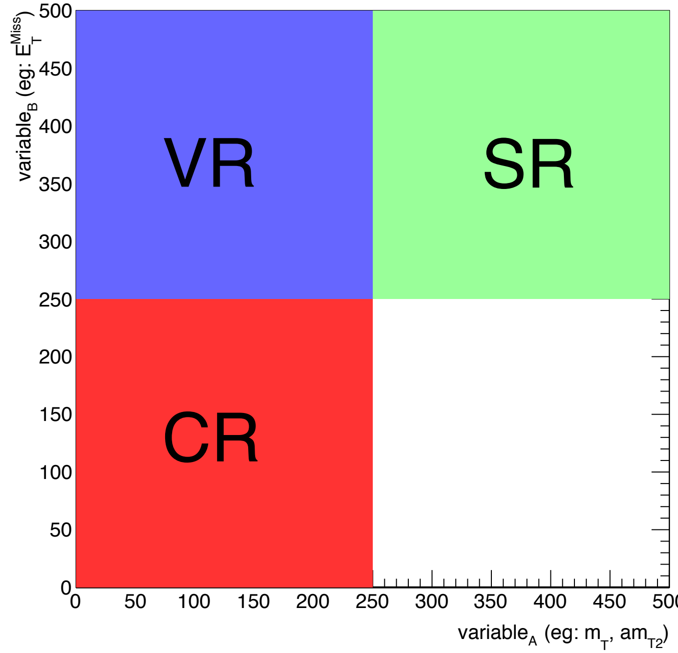
arXiv:1308.2631

- Limits were also placed in the stop neutralino mass plane (as the analysis is sensitive to compressed scenarios)
- The increase in E_{CMS} to 13 TeV for Run 2, increases the production cross section for bottom squark pair production
  - $\sigma_{sbottom}$(800 GeV) increases by a factor of ~10 (2.9 to 28 fb^{-1})
  - In comparison, σ_{Z+Jets}, the main SM background from the Run 1 analysis, only increases by a factor ~2

Search for Sbottom Pair Production

General Search Strategy

- Define Signal Regions (SRs) targeting a specific model & SUSY mass parameter set
  - Optimise by attempting to maximise the discovery or exclusion significance for a model
- Define multiple Control Regions (CRs) to constrain the main SM background processes in the SR
  - Kinematically close to the SRs, however designed such that they are orthogonal to the SR
  - Designed to contain events with only the specific background process considered (where possible)
  - Number of events in CRs are used to rescale the SM predictions for the process of interest from MC simulation and extrapolated to the SRs as normalization parameters (μ)
- The validity of the extrapolation is checked in Validation Regions (VRs)
  - Kinematically close to the SR, however orthogonal to both the SR and the CR
- After validation the observed yields in the SRs are compared to the prediction
  - If no significant excesses are seen, limits are placed on the signal models under consideration



Search for Sbottom Pair Production

Bulk Region Signal Topology (SRA-like)

- Scenarios with large $\Delta m(\tilde{b},\tilde{\chi}_1^0)$ (the "bulk region") are expected to contain: 0 leptons, 2 high p_T b-tagged jets, and missing transverse momentum (E_T^{miss}) from the $\tilde{\chi}_1^0$.
- Three overlapping SRs (SRA) are defined for the "bulk region", defined with increasingly tighter selections on the m_{CT} variable (contransverse mass), which is used to reduce $t\bar{t}$, and is the main discriminating variable.
  - For the decays of two of identical heavy massive particles into two visible (v1, v2) and two invisible particles.

$$m_{\mathrm{CT}}^2(v1,\ v2) = [E_{\mathrm{T}}(v1) + E_{\mathrm{T}}(v2)]^2 - [\mathbf{p}_{\mathrm{T}}(v1) - \mathbf{p}_{\mathrm{T}}(v2)]^2$$

  - For $t\bar{t}$ the kinematic end point is at m_{CT} = 135 GeV
- CRs are defined for the main backgrounds: Z-Jets, W-Jets, single top, $t\bar{t}$

SRA250	SRA350	SRA450
No baseline electron or muon		
Leading (in p_{T}) two jets b-tagged		
$p_{\mathrm{T}} > 130$ GeV for the leading jet		
$m_{bb} > 200$ GeV		
$E_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV		
Veto on 4^{th} jet with $p_{\mathrm{T}} > 50$ GeV		
$m_{\mathrm{CT}} > 250$ GeV	$m_{\mathrm{CT}} > 350$ GeV	$m_{\mathrm{CT}} > 450$ GeV

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Search for Sbottom Pair Production

Diagonal Region Signal Topology (SRB)

- Scenarios with small $\Delta m(\tilde{b}, \tilde{\chi}_1^0)$ (the "diagonal region") lead to softer sbottom decay products resulting in a different topology to the bulk region.
- Initial State Radiation (ISR) is exploited to select sbottom pairs which recoil against a high p_T ISR jet.
- SR is defined with one high p_T non b-tagged jet, large E_T^{miss} a sub-leading b-tagged jet, and an additional b-tagged jet.
- CRs are defined for the two main backgrounds in this region $t\bar{t}$, Z-Jets

Variable	SR selection
Lepton selection	No baseline electron or muon
Leading-p_T jet	not b-tagged, $p_T > 300$ GeV
SubLeading-p_T jet	b-tagged
$\Delta\phi(1^{st}$ jet, $E_T^{miss})$	> 2.5
JetVeto	$p_T(4^{th}$ jet$) < 50$ GeV
E_T^{miss}	> 400 GeV

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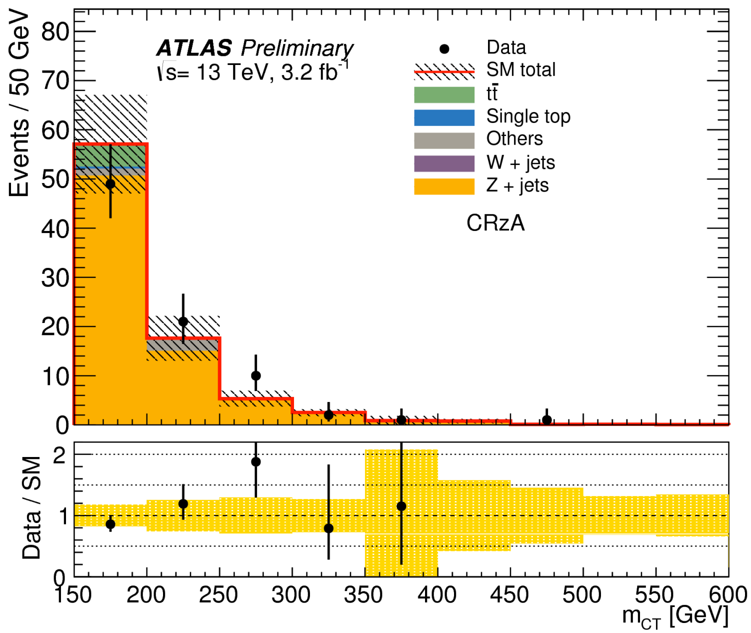
Search for Sbottom Pair Production

CRA Regions

- W-Jets (1 Lepton (e/μ) & 1 b-tagged jet region)
- Z-Jets (2 Lepton same flavour (SF) opposite sign (OS) region in the Z-mass window, 2 b-tagged jets)
- Single top (1 Lepton (e/μ) region, 2 b-tagged jets with m_{bb} > 200 GeV)
- $t\bar{t}$ (1 Lepton (e/μ) region, 2 b-tagged jets with m_{bb} < 200 GeV)

Variable	CRzA	CRttA	CRstA	CRwA
Number of lep.	2 SFOS	1	1	1
Lead. lep. p_T [GeV]	> 26	> 26	> 26	> 26
2nd lep. p_T [GeV]	> 20	-	-	-
$m_{\ell\ell}$ [GeV]	[76 – 106]	-	-	-
m_T [GeV]	-	-	-	> 30
Lead. jet $p_T(j_1)$ [GeV]	-	> 130	-	> 130
4th jet $p_T(j_4)$	vetoed if > 50 GeV			
b-tagged jets	j_1 and j_2	j_1 and j_2	j_1 and j_2	j_1
E_T^{miss} [GeV]	< 100	> 100	> 100	> 100
$E_T^{miss,cor}$ [GeV]	> 100	-	-	-
m_{bb} [GeV]	-	< 200	> 200	$(m_{bj}) > 200$
m_{CT} [GeV]	> 150	> 150	> 150	> 150
$m_{b\ell}^{min}$ [GeV]	-	-	> 170	-
$\Delta\phi(j_1, E_T^{miss})$	-	-	-	-

m_{CT} in the CRZA region



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Validation of the fit is performed in two VRs:
VRm_{CT}A: Data = 42, Bkg fit = 52.71 ± 8.36
VRm_{bb}A: Data = 69, Bkg fit = 88.55 ± 14.50

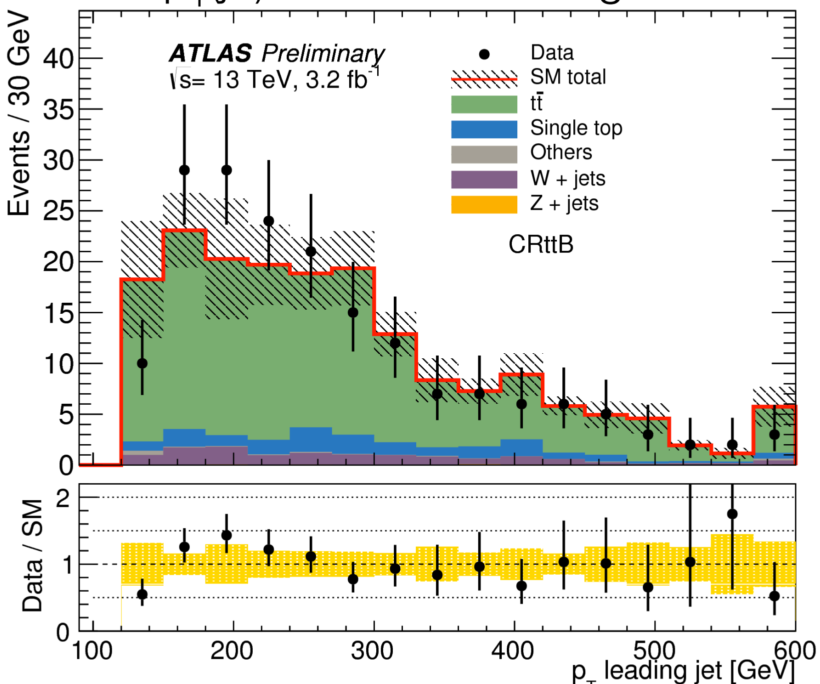
Search for Sbottom Pair Production

CRB Regions

- Z-Jets (2 Lepton same flavour (SF) opposite sign (OS) region in the Z-mass window, 2 b-tagged jets)
- $t\bar{t}$ (1 Lepton (e/μ) region)

Variable	CRzB	CRttB
Number of lep.	2 SFOS	1
Lead. lep. p_{T} [GeV]	> 26	> 26
2nd lep. p_{T} [GeV]	> 20	-
$m_{\ell\ell}$ [GeV]	[76 – 106]	-
m_{T} [GeV]	-	-
Lead. jet $p_{\mathrm{T}}(j_1)$ [GeV]	50	130
4th jet $p_{\mathrm{T}}(j_4)$		
b-tagged jets	j_2 and (j_3 or j_4)	j_2 and (j_3 or j_4)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	< 70	> 200
$E_{\mathrm{T}}^{\mathrm{miss,cor}}$ [GeV]	> 100	-
m_{bb} [GeV]	-	-
m_{CT} [GeV]	-	-
$m_{b\ell}^{\mathrm{min}}$ [GeV]	-	-
$\Delta\phi(j_1,\ E_{\mathrm{T}}^{\mathrm{miss}})$	> 2.0	> 2.5

p_T(j1) in the CRTB region



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Validation of the fit is performed in a single VR:
VRB: Data = 71, Bkg fit = 67.77 ± 8.95

Search for Sbottom Pair Production

Fit Results

- The observed and expected yields in the CRs are used to in a combined profile likelihood fit, to determine the expected number of events in each of the SRs.
- The main experimental uncertainties are related to the b-tagging procedure and the jet energy scale
- The main theory uncertainties are from the residual modelling uncertainty on the Z+Heavy Flavour background.

Signal region channels	SRA250	SRA350	SRA450	SRB
Observed events	22	6	1	5
Fitted bkg events	40 ± 8	9.5 ± 2.6	2.2 ± 0.6	13.1 ± 3.2
Fitted $t\bar{t}$ events	0.9 ± 0.4	0.37 ± 0.16	0.06 ± 0.03	5.9 ± 2.4
Fitted single top events	2.1 ± 1.3	0.54 ± 0.37	0.15 ± 0.10	1.2 ± 0.8
Fitted W+jets events	6.3 ± 2.4	1.3 ± 0.6	0.41 ± 0.23	1.2 ± 0.6
Fitted Z+jets events	30 ± 7	7.1 ± 2.4	1.5 ± 0.5	3.3 ± 1.4
(Alt. method Z+jets events)	(33 ± 7)	(7.2 ± 1.9)	(2.7 ± 0.9)	
Fitted "Other" events	0.7 ± 0.6	0.1 ± 0.1	0.02 ± 0.02	1.4 ± 0.4

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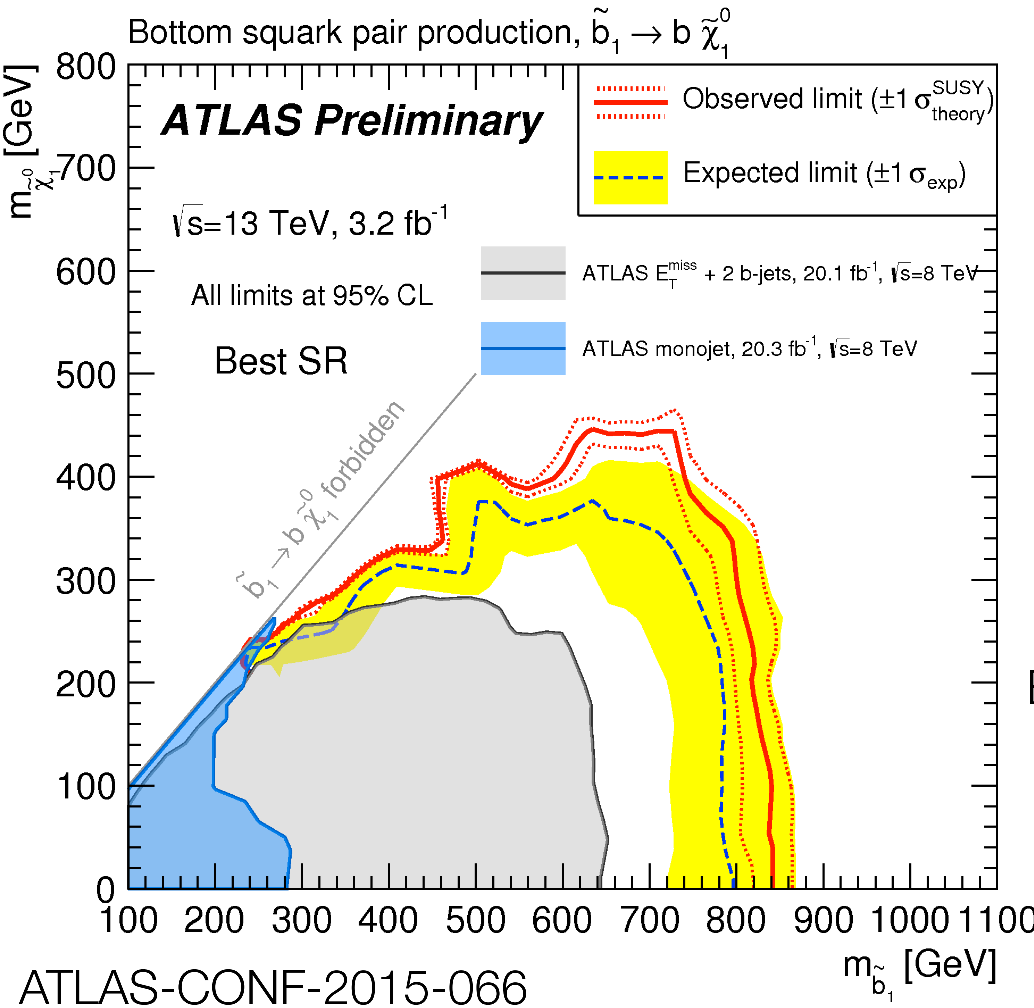
- No significant excesses in any of the SRs

(Alt. method for Z+Jets covered in Calum MacDonald's talk)

Search for Sbottom Pair Production

Exclusion Limits

- Exclusion limits are placed (95% CL) on the masses of the bottom squark and the neutralino.



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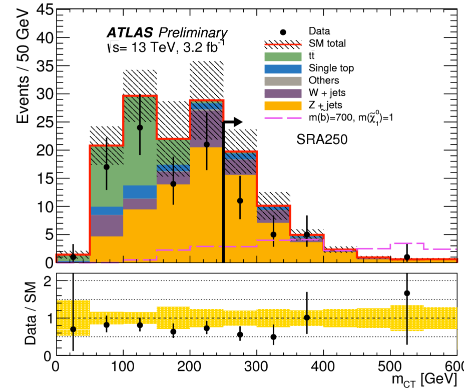
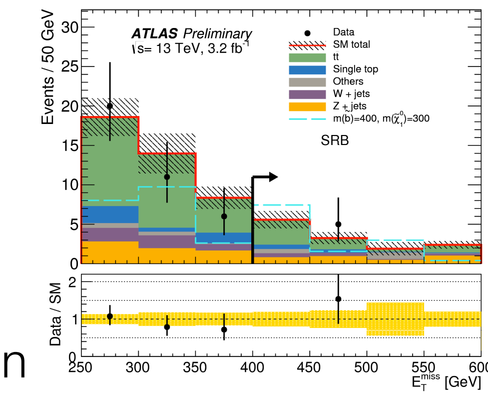


m_{CT} in SRA-Regions



E_T^{miss} in SRB region

- For a light neutralino, this extends the previous ATLAS exclusion limits on the bottom squark to 840 GeV.

Search for Sbottom Pair Production

Conclusions

- A search for direct bottom squark pair production using 3.2fb-1 collected by ATLAS during LHC Run 2 pp collisions at $\sqrt{s}$ = 13TeV was presented.
- No excess above the SM background prediction is found
  - Exclusion limits at 95% CL are placed on the mass of the bottom squark and neutralino.
  - Bottom squark masses are excluded up to 840 GeV for light neutralinos, increasing the exclusion from the corresponding Run 1 ATLAS search by 150 GeV.
- With the additional data to be provided by the LHC during 2016, the search will become more sensitive to larger bottom squark masses, increasing the possible discovery/exclusion potential.

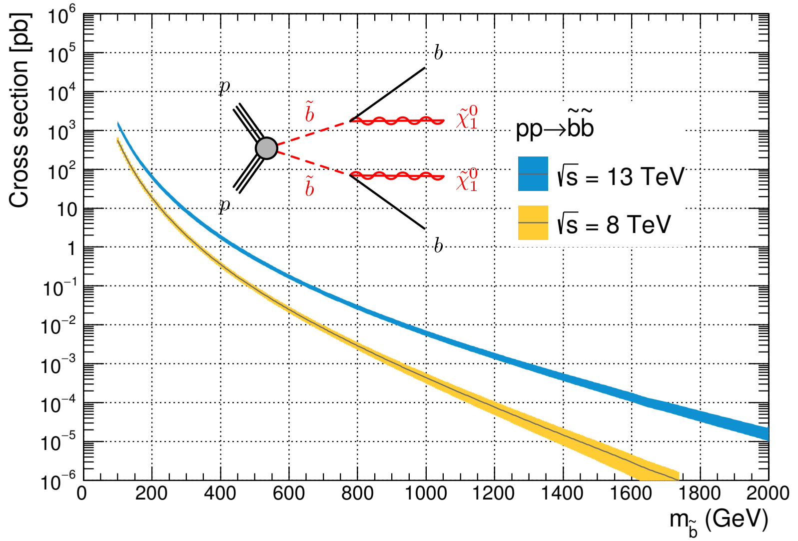
Appendix

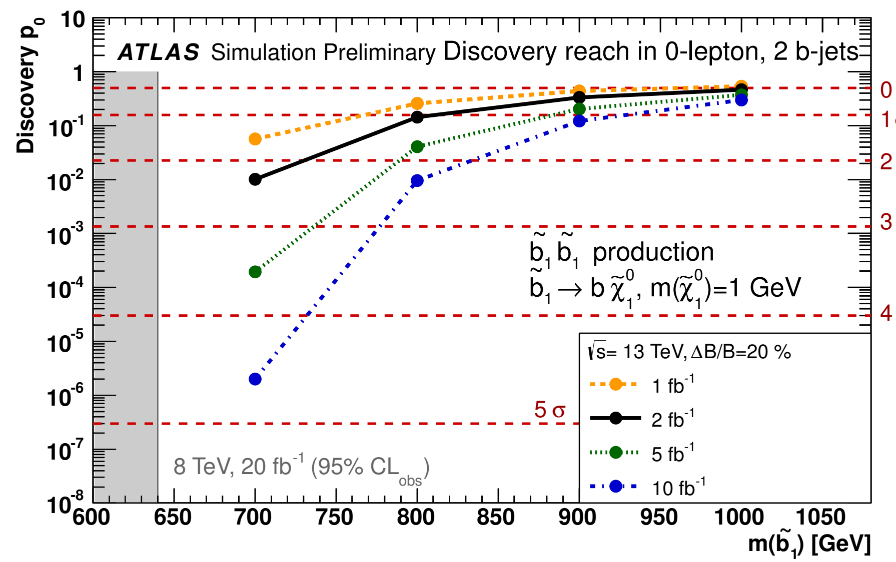
References

- [1] ATLAS Collaboration, *Search for direct third-generation squark pair production in final states with missing transverse momentum and two b-jets in $\sqrt{s}$ = 8 TeV pp collisions with the ATLAS detector*, JHEP 1310 (2013) 189, arXiv:1308.2631.
- [2] ATLAS Collaboration, *Search for Bottom Squark Pair Production with the ATLAS Detector in proton-proton Collisions at $\sqrt{s}$ = 13 TeV*, ATLAS-CONF-2015-066, https://cds.cern.ch/record/2114833

Appendix

Motivation for a search using early Run 2 Data





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- The analysis strategy closely follows the Run 1 analysis, with a few changes for Run 2.
- Preliminary sensitivity investigations: https://cds.cern.ch/record/2002608/

Appendix

Full SR Selections

Variable	SRA	SRB
Event cleaning	Common to all SR	
Lepton veto	No e/μ with $p_{\mathrm{T}} > 10$ GeV after overlap removal	
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 250 GeV	> 400 GeV
Leading jet $p_{\mathrm{T}}(j_1)$	> 130 GeV	> 300 GeV
2nd jet $p_{\mathrm{T}}(j_2)$	> 50 GeV	> 50 GeV
Fourth jet $p_{\mathrm{T}}(j_4)$	vetoed if > 50 GeV	
$\Delta\phi^{j}_{\mathrm{min}}$	> 0.4	> 0.4
$\Delta\phi(j_1,)$	-	> 2.5
b-tagging	j_1 and j_2	j_2 and (j_3 or j_4)
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.25	> 0.25
m_{CT}	$> 250, 350, 450$ GeV	-
m_{bb}	> 200 GeV	-

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Full CR Selections

Variable	CRzA	CRttA	CRstA	CRwA	CRzB	CRttB
Number of lep.	2 SFOS	1	1	1	2 SFOS	1
Lead. lep. p_{T} [GeV]	> 26	> 26	> 26	> 26	> 26	> 26
2nd lep. p_{T} [GeV]	> 20	-	-	-	> 20	-
$m_{\ell\ell}$ [GeV]	$[76 - 106]$	-	-	-	$[76 - 106]$	-
m_{T} [GeV]	-	-	-	> 30	-	-
Lead. jet $p_{\mathrm{T}}(j_1)$ [GeV]	-	> 130	-	> 130	50	130
4th jet $p_{\mathrm{T}}(j_4)$	vetoed if > 50 GeV					
b-tagged jets	j_1 and j_2	j_1 and j_2	j_1 and j_2	j_1	j_2 and (j_3 or j_4)	j_2 and (j_3 or j_4)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	< 100	> 100	> 100	> 100	< 70	> 200
$E_{\mathrm{T}}^{\mathrm{miss,cor}}$ [GeV]	> 100	-	-	-	> 100	-
m_{bb} [GeV]	-	< 200	> 200	$(m_{bj}) > 200$	-	-
m_{CT} [GeV]	> 150	> 150	> 150	> 150	-	-
$m_{b\ell}^{\mathrm{min}}$ [GeV]	-	-	> 170	-	-	-
$\Delta\phi(j_1,\ E_{\mathrm{T}}^{\mathrm{miss}})$	-	-	-	-	> 2.0	> 2.5

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Model Independent Limits

Signal channel	$\langle \epsilon A \sigma \rangle^{95}_{\text{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}
SRA250	2.74	8.8	$15.8^{+6.3}_{-4.4}$
SRA350	1.90	6.1	$8.1^{+3.7}_{-2.3}$
SRA450	1.16	3.7	$4.4^{+2.6}_{-1.0}$
SRB	1.57	5.0	$8.5^{+3.9}_{-2.4}$

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