Searches for *R*-Parity Violating Supersymmetry with Baryon Number Violation

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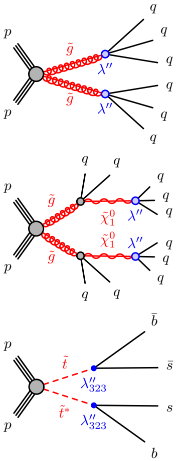
Introduction

- Generic MSSM violates leptons and baryon number
  - $W_{\Delta L=1} = \frac{1}{2}\lambda^{ijk} L_i L_j \bar{e}_k + \lambda'^{ijk} L_i Q_j \bar{d}_k + \mu'^i L_i H_\mathrm{u}$
  - $W_{\Delta B=1} = \frac{1}{2}\lambda''^{ijk} \bar{u}_i \bar{d}_j \bar{d}_k$
- Forbid these by imposing R-Parity conservation
  - $R = (-1)^{3(B-L)+2s}$
- Sufficient to forbid either baryon or lepton number violation
- This talk presents searches for baryon number violating processes
  - Multi-jet search: Phys. Rev. D 91, 112016 (2015)
  - All hadronic stop search: ATLAS-CONF-2015-026
- See Emma Torró's talk for lepton number violating processes



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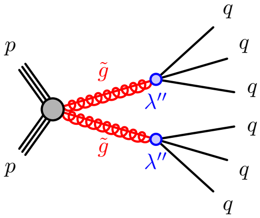
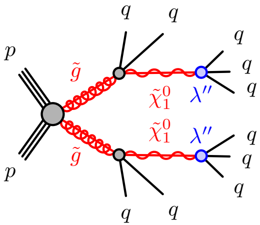
Multi-jet search

- Two complimentary search strategies

Jet counting Exploits differences in the jet multiplicity

Total jet mass Exploits difference in shape of the jet mass distribution



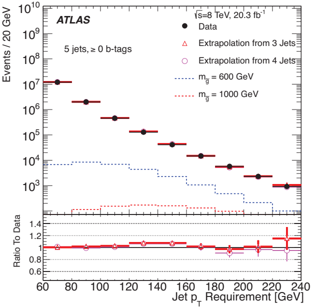


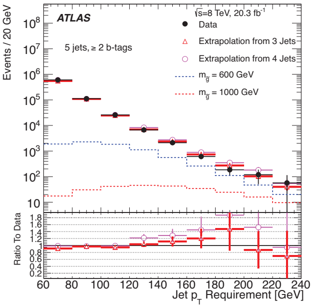
Object definitions

- Standard jets
  - anti-k_{T} $R = 0.4$
  - $p_{\mathrm{T}} > 60\ \mathrm{GeV}$ in all regions
- Large-R jets
  - anti-k_{T} $R = 1.0$
  - Trim subjets if $p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{jet} < 0.05$
  - Mass constructed from trimmed jets
  - Used in total jet mass analysis
- b-tagging: 70% efficient when applied

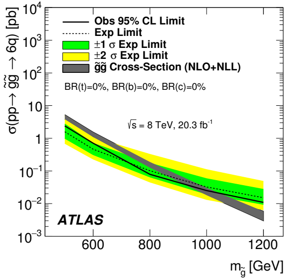
Jet counting

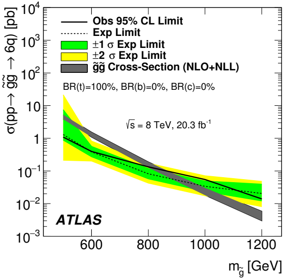
- Looking for excess of events with ≥ 6, ≥ 7 high p_{T} jets
- Define 48 signal regions: optimal region selected for each model
  - $n_{\mathrm{jet}} \geq 6, 7$
  - $p_{\mathrm{T}} > 80 - 220\ \mathrm{GeV}$ in steps of $20\ \mathrm{GeV}$
  - $n_{b-\mathrm{tagged}} \geq 0, 1, 2$
- SM multijet background extrapolated from control regions
  - $m_{\mathrm{jet}} = n_{\mathrm{jet}} - 2$ (depends on signal region)
  - $N_{\mathrm{SR}} = \left(N_{\mathrm{CR}}^{\mathrm{data}} - N_{\mathrm{CR,\ other\ BG}}^{\mathrm{MC}}\right)\left(\frac{N_{\mathrm{SR}}^{\mathrm{MC}}}{N_{\mathrm{CR}}^{\mathrm{MC}}}\right) + N_{\mathrm{SR,\ other\ BG}}^{\mathrm{MC}}$

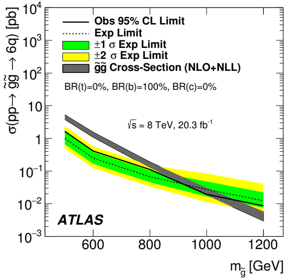


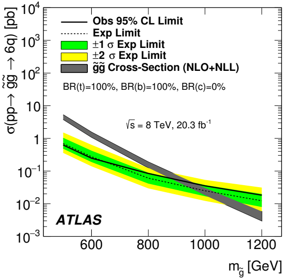


Jet counting results: 6-quark model





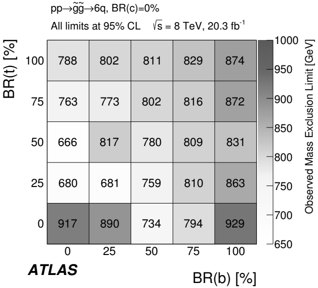




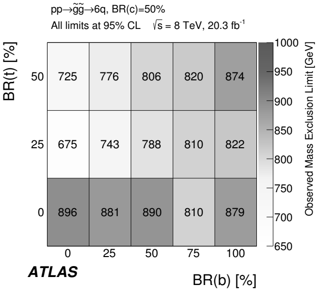
Jet counting results: 6-quark model

- Observed mass exclusion limits

BR(c)=0 %



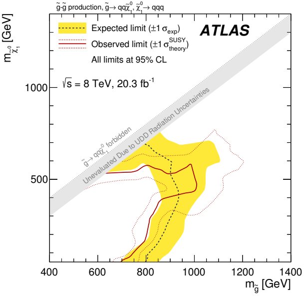
BR(c)=50 %



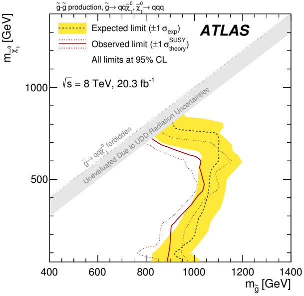
Jet counting results: 10-quark model

- Expected and observed mass exclusion limits

Without *b*-tagging



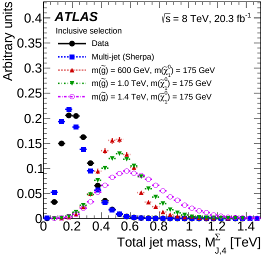
With *b*-tagging

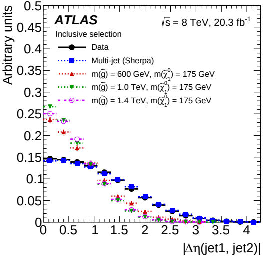


Total jet mass

- Total jet mass = scalar sum of masses of four leading large-R jets
  - $M_{\mathrm{J}}^{\Sigma} = \sum m_{\mathrm{jet}}$
- Also use $|\Delta\eta|$ between leading two large-R jets to provide additional discrimination

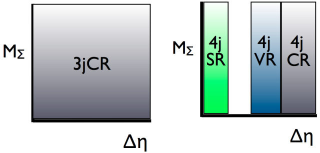
Region Name	n_{jet}	$\lvert\Delta\eta\rvert$	p_{T}^{3} [GeV]	p_{T}^{4} [GeV]	M_{J}^{Σ} [GeV]
3jCR	$n_{\mathrm{jet}} = 3$	–		–	–
4jCR	$n_{\mathrm{jet}} \geq 4$	> 1.40	> 100 > 250	> 100	– –
4jVR	$n_{\mathrm{jet}} \geq 4$	1.0–1.40	> 100 > 250	> 100	– –
SR1 SR100 SR250	$n_{\mathrm{jet}} \geq 4$	< 0.7	> 250 > 100 > 250	> 100	> 625 > 350 (binned) > 350 (binned)

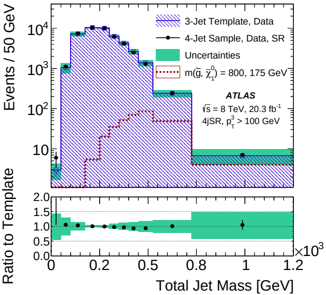




Background estimate

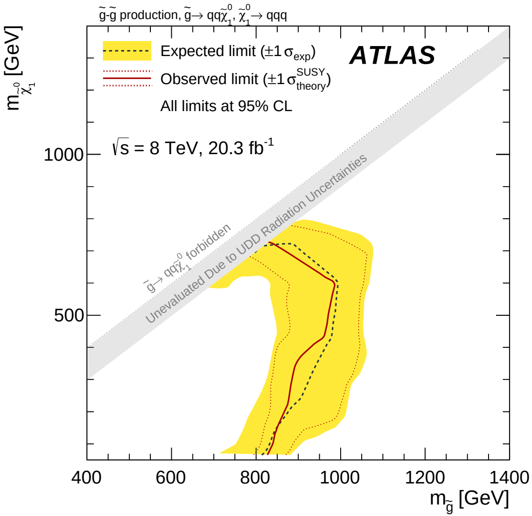
- Extract jet mass templates from 3-jet control region
    - Probability density function for mass of a given jet
    - Function of jet p_T and η
- Use mass templates to construct data driven estimate
    - Apply jet mass template to each jet in event
    - Combine resulting masses to predict total jet mass for event





Total jet mass results: 10-quark model

- Expected and observed mass exclusion limits



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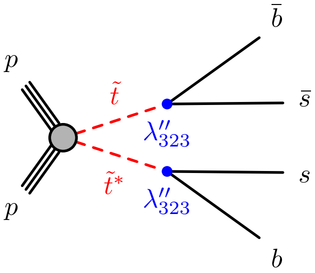
All hadronic stop search

- Targets direct production of light stops
  - $m_{\tilde{t}} = 100 - 400\ \ \mathrm{GeV}$
  - Region previously missed because of trigger requirement
- Search for resonant decay of stops
  - Each stop decays to two SM quarks
  - Fully hadronic final state



Strategy

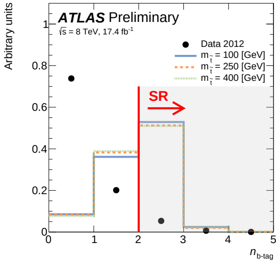
- Difficult to target light stops at the LHC
  - Multijet trigger applies heavy prescale
  - Hard to distinguish 4-jet final state from QCD multijet background
- Using boosted jets, it is possible to work around these challenges
  - Cross sections are high for light stops. Able to cut hard on stop p_{T}
  - Recluster jets into two large-R jets with substructure
- Require b-tagged jets
  - This restricts the search to 3rd generation couplings only

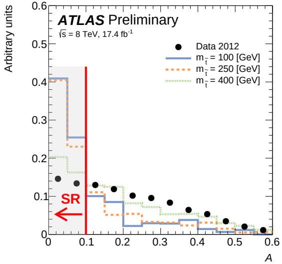
Selection

- Jets
  - anti-k_{T} $R = 0.4$
  - $p_{\mathrm{T}} > 20$ GeV
- "Large-R" jets
  - Recluster groomed jets using anti-k_{T} $R = 1.5$
  - $p_{\mathrm{T}} > 200$ GeV
  - $m > 20$ GeV
  - Require at least two large-R jets
- Trigger
  - Leading $R = 0.4$ jet with $p_{\mathrm{T}} > 175$ GeV
  - $H_{\mathrm{T}} = \sum p_{\mathrm{T}} > 650$ GeV
- b-tagging
  - Applied on $R = 0.4$ jets
  - 70% efficient working point

Signal region

- Number of b-tagged jets ≥ 2
- Mass asymmetry between leading and sub-leading large-R jets
  - Expect stops to have equal mass
  - No preference for QCD jets
  - $\mathcal{A} = \left|\frac{m_1 - m_2}{m_1 + m_2}\right| < 0.1$
- Angle between the stop pair and the beam axis in center-of-mass frame
  - Distinguishes between centrally produced massive particles (stops) and high-mass forward-scattering event from QCD
  - $|\cos\theta^*| < 0.3$
- Subjet p_{T} ratio
  - Applied to leading two large-R jets
  - $\frac{\min[p_{\mathrm{T}}(a), p_{\mathrm{T}}(b)]}{\max[p_{\mathrm{T}}(a), p_{\mathrm{T}}(b)]} > 0.3$





Signal region

- Number of b-tagged jets ≥ 2
- Mass asymmetry between leading and sub-leading large-R jets
  - Expect stops to have equal mass
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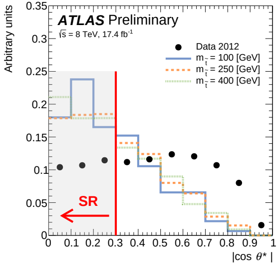
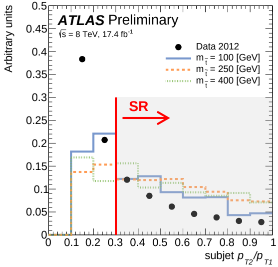
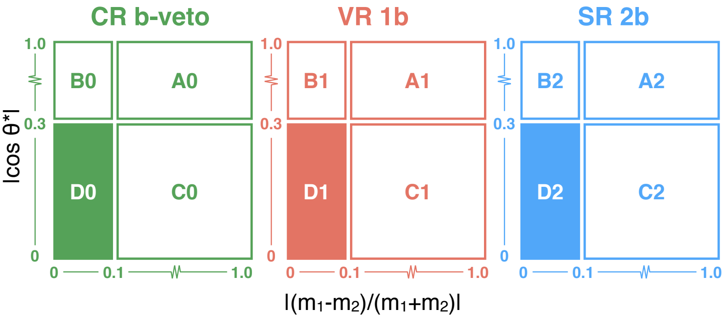




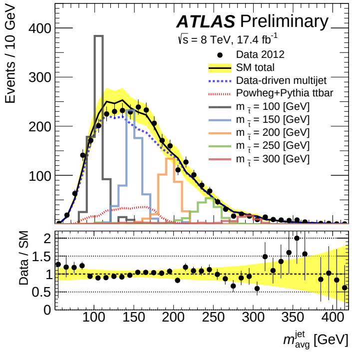
Background estimation

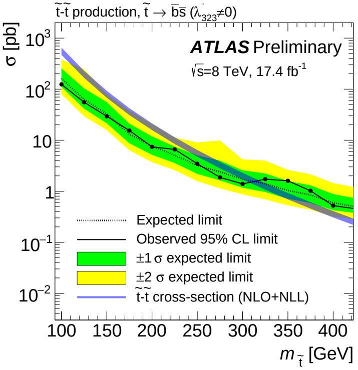


- SM multijet background estimated from sideband regions
  - Assumes the $m_{\mathrm{avg}}^{\mathrm{jet}}$ distribution does not depend on the *b*-jet multiplicity
- $t\bar{t}$ estimate taken from Monte Carlo simulation

Results

- Search performed in regions of the average mass of the leading two large-R jets: $m_{\text{avg}}^{\text{jet}} = \left(m_1^{\text{jet}} + m_2^{\text{jet}} \right) /2$
- No observed excess
- Stops with mass between $100 \leq m_{\tilde{t}} \leq 310\ \text{GeV}$ were excluded





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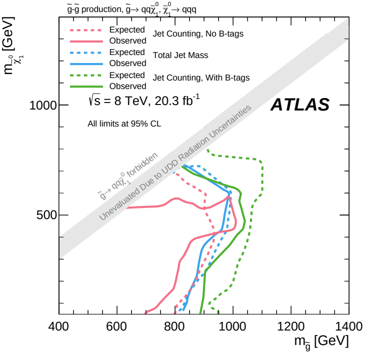
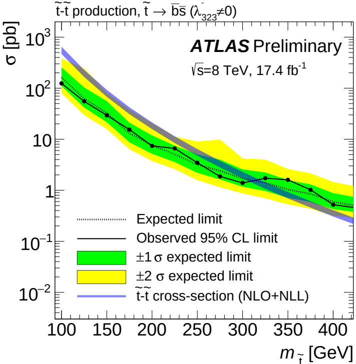
Summary

- Presented ATLAS searches for RPV SUSY with baryon number violation
- Lower mass limits on gluino production
  - $m_{\tilde{g}} > 917$ GeV when gluino decays to six light quarks
  - $m_{\tilde{g}} > 1$ TeV when gluino has cascade decay to ten quarks
- Limits on stop decaying to all hadronic final state
  - Exclude stops with mass $100 \leq m_{\tilde{t}} \leq 310$ GeV



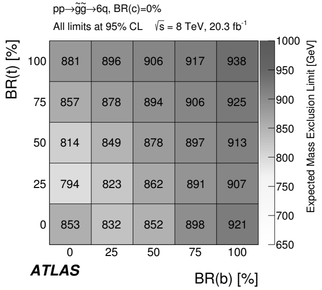


Backup

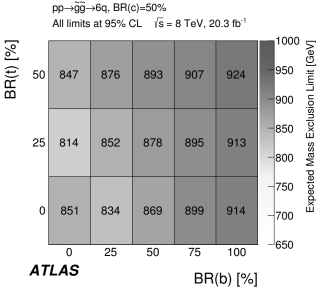
Jet counting results: 6-quark model

- Expected mass exclusion limits

BR(c)=0 %



BR(c)=50 %



Jet counting event yields: 6 quark model

Sample $m_{\tilde{g}}$ [GeV]	Jet p_T req. [GeV]	# of jets	# of b-tags	Signal (Acceptance)	Back-ground	Data
(BR(t), BR(b), BR(c))=(0%, 0%, 0%)						
500	120	7	0	600±230 (0.7%)	370±60	444
600	120	7	0	410±100 (1.5%)	370±60	444
800	180	7	0	13±4 (0.4%)	6.1±2.2	4
1000	180	7	0	6.8±2.3 (1.4%)	6.1±2.2	4
1200	180	7	0	2.7±0.5 (3.0%)	6.1±2.2	4
(BR(t), BR(b), BR(c))=(0%, 100%, 0%)						
500	80	7	2	1900±400 (2.1%)	1670±190	1560
600	120	7	1	300±60 (1.1%)	138±26	178
800	120	7	1	131±25 (4.1%)	138±26	178
1000	180	7	1	4.4±1.0 (0.9%)	2.3±1.0	1
1200	180	7	1	1.86±0.31 (2.1%)	2.3±1.0	1
(BR(t), BR(b), BR(c))=(100%, 0%, 0%)						
500	80	7	1	4600±800 (5.0%)	5900±700	5800
600	100	7	1	940±190 (3.5%)	940±140	936
800	120	7	1	108±18 (3.4%)	138±26	178
1000	120	7	1	42±6 (8.5%)	138±26	178
1200	180	7	1	1.3±0.4 (1.5%)	2.3±1.0	1
(BR(t), BR(b), BR(c))=(100%, 100%, 0%)						
500	80	7	2	3600±600 (3.9%)	1670±190	1560
600	80	7	2	2300±400 (8.6%)	1670±190	1560
800	120	7	2	94±15 (3.0%)	38±17	56
1000	120	7	2	37±6 (7.5%)	38±17	56
1200	140	7	2	5.5±1.0 (6.2%)	10±5	18

Jet counting results event yields: 10 quark model

Sample ($m_{\tilde{g}}, m_{\tilde{\chi}_1^0}$)	Jet p_T req. [GeV]	# jets	# b-tagged jets	Signal (Acceptance)	Background	Data
(400 GeV, 50 GeV)	80	7	2	1900±400 (0.5%)	1670±190	1558
(400 GeV, 300 GeV)	80	7	2	2500±600 (0.7%)	1670±290	1558
(600 GeV, 50 GeV)	120	7	1	180±40 (0.7%)	138±26	178
(600 GeV, 300 GeV)	80	7	2	2200±350 (8.3%)	1670±200	1558
(800 GeV, 50 GeV)	120	7	1	95±16 (3.0%)	138±26	178
(800 GeV, 300 GeV)	120	7	1	172±28 (5.4%)	138±26	178
(800 GeV, 600 GeV)	120	7	1	150±23 (4.7%)	138±26	178
(1000 GeV, 50 GeV)	220	6	1	7.0±1.3 (1.4%)	3.8±3.0	5
(1000 GeV, 300 GeV)	120	7	1	67±8 (14%)	138±26	178
(1000 GeV, 600 GeV)	120	7	1	101±13 (20%)	138±26	178
(1000 GeV, 900 GeV)	120	7	1	33±4 (6.7%)	138±26	178
(1200 GeV, 50 GeV)	220	6	1	3.8±0.7 (4.3%)	3.8±3.0	5
(1200 GeV, 300 GeV)	180	7	1	2.01±0.32 (2.3%)	2.3±1.0	1
(1200 GeV, 600 GeV)	140	7	1	18.9±2.3 (21%)	41±12	45
(1200 GeV, 900 GeV)	140	7	1	12.6±1.5 (14%)	41±12	45

Total jet mass results event yields

SR1

Summary yield table for SR1

$M_{\mathbf{J}}^{\Sigma}$ **Bin**	**Expected SM**	**Obs.**	$m_{\tilde{g}} = 600$ GeV $m_{\tilde{\chi}_1^0} = 50$ GeV	$m_{\tilde{g}} = 1$ TeV $m_{\tilde{\chi}_1^0} = 600$ GeV	$m_{\tilde{g}} = 1.4$ TeV $m_{\tilde{\chi}_1^0} = 900$ GeV
> 625 GeV	$160 \pm 9.7\ ^{+40}_{-34}$	176	$70 \pm 4.2 \pm 25 \pm 30$ (0.26%)	$55 \pm 0.51 \pm 8.6 \pm 14$ (11%)	$6.3 \pm 0.07 \pm 0.46 \pm 2.5$ (35%)

SR100

Summary yield table for SR100

$M_{\mathbf{J}}^{\Sigma}$ **Bin**	**Expected SM**	**Obs.**	$m_{\tilde{g}} = 600$ GeV $m_{\tilde{\chi}_1^0} = 50$ GeV	$m_{\tilde{g}} = 1$ TeV $m_{\tilde{\chi}_1^0} = 600$ GeV	$m_{\tilde{g}} = 1.4$ TeV $m_{\tilde{\chi}_1^0} = 900$ GeV
350 - 400 GeV	$4300 \pm 78\ ^{+510}_{-500}$	5034	$200 \pm 7.2 \pm 22 \pm 35$	$5.8 \pm 0.17 \pm 1.3 \pm 1.5$	$0.19 \pm 0.01 \pm 0.04 \pm 0.07$
400 - 450 GeV	$2600 \pm 49\ ^{+380}_{-380}$	2474	$200. \pm 7.1 \pm 9.5 \pm 35$	$9.7 \pm 0.21 \pm 2.2 \pm 2.5$	$0.31 \pm 0.02 \pm 0.07 \pm 0.12$
450 - 525 GeV	$2100 \pm 42\ ^{+360}_{-360}$	1844	$280. \pm 8.4 \pm 13 \pm 49$	$26 \pm 0.35 \pm 4.3 \pm 6.7$	$0.88 \pm 0.03 \pm 0.14 \pm .34$
525 - 725 GeV	$960 \pm 25\ ^{+200}_{-200}$	1070	$280. \pm 8.4 \pm 57 \pm 49$	$77 \pm 0.60 \pm 3.2$	$3.6 \pm 0.05 \pm 0.36 \pm 1.4$
> 725 GeV	$71 \pm 7.0\ ^{+32}_{-27}$	79	$35. \pm 2.9 \pm 18 \pm 6.0$	$35 \pm 0.40 \pm 9.9 \pm 9.0$	$4.8 \pm 0.06 \pm 0.61 \pm 1.9$

SR250

Summary yield table for SR250

$M_{\mathbf{J}}^{\Sigma}$ **Bin**	**Expected SM**	**Obs.**	$m_{\tilde{g}} = 600$ GeV $m_{\tilde{\chi}_1^0} = 50$ GeV	$m_{\tilde{g}} = 1$ TeV $m_{\tilde{\chi}_1^0} = 600$ GeV	$m_{\tilde{g}} = 1.4$ TeV $m_{\tilde{\chi}_1^0} = 900$ GeV
350 - 400 GeV	$1400 \pm 35\ ^{+120}_{-134}$	1543	$83 \pm 4.6 \pm 15 \pm 14$	$3.3 \pm 0.12 \pm 0.78 \pm 0.85$	$0.17 \pm 0.01 \pm 0.03 \pm 0.07$
400 - 450 GeV	$920 \pm 33\ ^{+140}_{-140}$	980	$92 \pm 4.8 \pm 11 \pm 16$	$5.6 \pm 0.16 \pm 1.5 \pm 1.5$	$0.27 \pm 0.01 \pm 0.07 \pm 0.11$
450 - 525 GeV	$780 \pm 33\ ^{+94}_{-94}$	823	$140 \pm 5.8 \pm 15 \pm 23$	$17 \pm 0.28 \pm 3.3 \pm 4.4$	$0.79 \pm 0.02 \pm 0.13 \pm 0.31$
525 - 725 GeV	$490 \pm 24\ ^{+67}_{-67}$	495	$160 \pm 6.2 \pm 30. \pm 27$	$56 \pm 0.51 \pm 4.1 \pm 15$	$3.3 \pm 0.05 \pm 0.34 \pm 1.3$
> 725 GeV	$37 \pm 5.5\ ^{+16}_{-12}$	42	$22 \pm 2.3 \pm 9.1 \pm 3.9$	$27 \pm 0.36 \pm 7.4 \pm 7.0$	$4.4 \pm 0.06 \pm 0.56 \pm 1.7$

All hadronic stop search event yields

$m_{\tilde{t}}$ [GeV]	Window [GeV]	$N_B^{\text{data-driven est.}}$	$N_B^{t\bar{t}\text{ est.}}$	$N_B^{\text{tot. est.}}$	N_{data}	N_S
100	[95, 115]	405 ± 50	37 ± 29	442 ± 58	391	540 ± 130
125	[115, 135]	440 ± 46	64 ± 36	504 ± 59	484	510 ± 130
150	[135, 165]	604 ± 59	98 ± 50	702 ± 77	680	490 ± 140
175	[165, 190]	416 ± 46	62 ± 34	478 ± 58	503	379 ± 82
200	[185, 210]	351 ± 47	15 ± 11	366 ± 48	363	285 ± 61
225	[210, 235]	236 ± 38	2.5 ± 2.5	238 ± 38	270	170 ± 30
250	[235, 265]	162 ± 30	1.1 ± 1.1	163 ± 30	169	124 ± 28
275	[260, 295]	94 ± 21	0.78 ± 0.78	95 ± 21	79	70 ± 19
300	[280, 315]	63 ± 17	0.75 ± 0.70	64 ± 17	54	46 ± 10
325	[305, 350]	39 ± 13	0.59 ± 0.40	39 ± 13	47	28.7 ± 6.9
350	[325, 370]	23.9 ± 9.6	0.16 ± 0.096	24.0 ± 9.6	38	19.3 ± 4.2
375	[345, 395]	16.2 ± 8.0	0.076 ± 0.072	16.3 ± 8.0	21	12.6 ± 3.0
400	[375, 420]	8.8 ± 5.6	0.071 ± 0.071	8.9 ± 5.6	6	7.8 ± 1.8