SUSY phenomenology and inclusive searches

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2014-07-01

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Section 1

Why SUSY?

Why SUSY?

The SM fits the experimental data very well. However, few problems remain, e.g.:

- dark matter
- the hierarchy problem
- unification of forces at the GUT scale

SUSY was created to remedy these problems.

Dark matter

Astrophysicists observe that the gravitational lensing effect and rotational speed of a galaxy suggest far more mass than expected by the visible mass of the galaxy. This suggests new, unobserved particles.

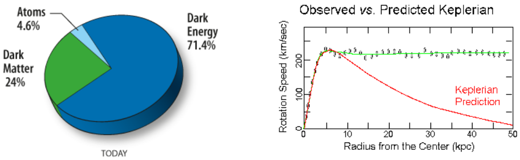

Figure: *left - from: http://wmap.gsfc.nasa.gov/universe/uni_matter.html, right - from: http://www.astronomy.ohio-state.edu/ thompson/1144/Lecture40.html*

Hierarchy problem

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The SM so far has no explanation.

Unification of forces at the GUT scale

Theoreticians have always tried to unify all forces. The SM as it is makes this impossible, however.

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Unification possible in SUSY models:

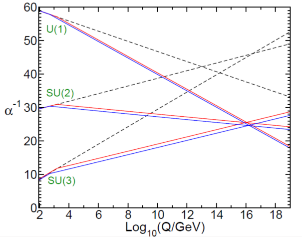

Figure: *The evolution of the inverse coupling constants of the interactions with energy for the SM (dashed lines) and SUSY (solid lines) [1]*

Section 2

What is SUSY?

What is SUSY?

A new symmetry between fermions and bosons is enforced.
This results in a new set of particles:

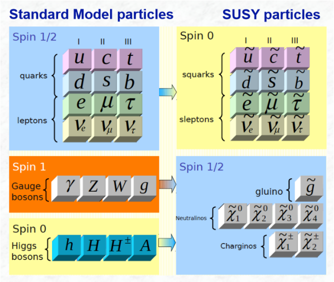

Figure: *Particles according to SUSY [2]*

R-parity

Due to new interactions, lepton and baryon numbers can be violated. To remedy this problem, in many, not all SUSY models a new symmetry is introduced, called R-parity:

$$R = (-1)^{3(B-L)+2S} = \begin{cases} +1 & \text{SM particle} \\ -1 & \text{SUSY particle} \end{cases}$$

Due to R-parity SUSY particles can only be produced in pairs and the lightest SUSY particle cannot decay any further.

SUSY symmetry breaking

unbroken SUSY $\Rightarrow$ SUSY particles have same mass as SM counterpart

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This gives limits on the masses of the SUSY particles.

Minimal SUSY Standard Model (MSSM)

The new SUSY gauge bosons mix to create mass eigenstates (SUSY is broken):

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- **Charginos** $\tilde{\chi}^{\pm}_{1,2}$: mixture of charged fields $\tilde{W}^{\pm}$, $\tilde{H}_2^{+}$, $\tilde{H}_1^{-}$
- **Neutralinos** $\tilde{\chi}^{0}_{1,2,3,4}$: mixture of neutral fields $\tilde{B}$, $\tilde{W}^3$, $\tilde{H}^0_{1,2}$

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Charginos $\tilde{\chi}^{\pm}_{1,2}$: mixture of charged fields $\tilde{W}^{\pm}$, $\tilde{H}^{+}_{2}$, $\tilde{H}^{-}_{1}$

Neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$: mixture of neutral fields $\tilde{B}$, $\tilde{W}^{3}$, $\tilde{H}^{0}_{1,2}$

The lightest Neutralino (usually called LSP- lightest supersymmetric particle) is a prime candidate for dark matter.

Minimal Supergravity (mSUGRA)

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This particle can be interpreted as gravitino. Gravity, however is not fully implemented.

The neutralino can remains LSP, else the gravitino is chosen.

Free parameters of the MSSM

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- *pMSSM:* fixing mass hierarchies of the SUSY particles to gain sensitivity to certain decay chains and topologies (22 free parameters)
- *cMSSM:* Assumption of unification of masses at the GUT scale leads to 5 remaining parameters.

free parameters of the MSSM (cont.)

pMSSM	cMSSM
• sfermion masses	• unification of scalar masses m_0
• gaugino masses	• unification of gaugino masses $m_{1/2}$
• proportionality factors of the trilinear couplings A_f	• unification of the trilinear couplings A_0
• squared Higgs boson masses	• the sign of the higgsino mass factor μ
• $\tan\beta$	• $\tan\beta$

with $\tan\beta = \tan\frac{v_1}{v_2}$, v_1, v_2 vacuum expectation values of the Higgs field.

Section 3

SUSY event topology

SUSY event topology

The different types of SUSY events are very diverse, reaching from pair production to multistage decay cascades.

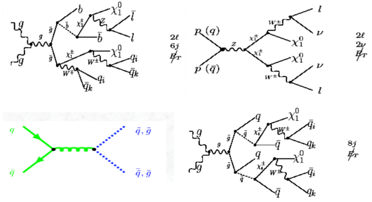

Figure: *some examples of SUSY events [3]*

Events typically have large amounts of missing E_T, multiple jets and 0-2 leptons.

Section 4

Searches for SUSY with the LHC

2-6 jets + 0 leptons search by ATLAS

Search for squarks and gluinos with the ATLAS detector in final states with jets and missing transverse momentum and 20.3 fb^{-1} of $\sqrt{s}$ = 8 TeV proton-proton collision data

definition of signal regions

Requirement	Channel									
	A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
	L	M	M	T	M	T	–	L	M	T
E_T^{miss}[GeV] >	160									
$p_T(j_1)$ [GeV] >	130									
$p_T(j_2)$ [GeV] >	60									
$p_T(j_3)$ [GeV] >	–		60		60		60	60		
$p_T(j_4)$ [GeV] >	–		–		60		60	60		
$p_T(j_5)$ [GeV] >	–		–		–		60	60		
$p_T(j_6)$ [GeV] >	–		–		–		–	60		
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ >	0.4 ($i = \{1, 2, (3$ if $p_T(j_3) > 40$ GeV$)\}$)				0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T > 40$ GeV jets)					
$E_T^{miss}/m_{eff}(Nj)$ >	0.2	–[a]	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
m_{eff}(incl.) [GeV] >	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

(a) For SR A-medium the cut on $E_T^{miss}/m_{eff}(Nj)$ is replaced by a requirement $E_T^{miss}/\sqrt{H_T} > 15$ GeV$^{1/2}$.

Figure: *definition of signal regions in [4]*

m_{eff} = scalar sum of p_T of the N highest p_T jets (or all for incl.) and E_T^{miss}

definition of signal regions (cont.)

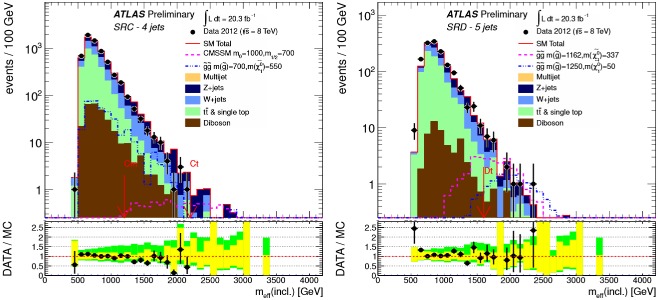

Figure: *m_{eff} (incl.) distribution for SR C and D in [4], the red arrow denotes the cut*

major backgrounds

Four different backgrounds were identified as important for the analysis:

- Z ($\rightarrow \nu\nu$)+jets (modelled by γ+jets samples)
- multi-jet QCD backgrounds
- W($\rightarrow \ell\nu$)+jets
- $t\bar{t}$ and single-t (modelled by $t\bar{t} \rightarrow bbqq'\ell\nu$)

results

Signal Region	A-loose	A-medium	B-medium	B-tight	C-medium	C-tight
			MC expected events			
Diboson	428.6	15.0	4.3	0.0	25.5	0.0
Z/γ^*+jets	2044.4	83.1	20.6	2.3	119.4	2.6
W+jets	2109.0	58.8	16.4	2.1	88.7	1.0
$t\bar{t}$(+EW) + single top	785.9	8.2	2.0	0.3	45.9	0.3
			Fitted background events			
Diboson	430 ± 190	15 ± 7	4.3 ± 2.0	–	26 ± 11	–
Z/γ^*+jets	1870 ± 320	57 ± 11	16 ± 5	0.2 ± 0.5	80 ± 29	$0.0^{+0.6}_{-0.0}$
W+jets	1540 ± 260	42 ± 11	10 ± 4	1.6 ± 1.2	55 ± 18	0.7 ± 0.9
$t\bar{t}$(+EW) + single top	870 ± 180	7.8 ± 2.8	2.2 ± 2.0	0.6 ± 0.7	50 ± 11	0.9 ± 0.9
Multi-jets	33 ± 33	–	0.1 ± 0.1	–	–	–
Total bkg	4700 ± 500	122 ± 18	33 ± 7	2.4 ± 1.4	210 ± 40	1.6 ± 1.4
Observed	5333	135	29	4	228	0
$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	66.07	2.52	0.73	0.33	4.00	0.12
$S^{95}_{\rm obs}$	1341.2	51.3	14.9	6.7	81.2	2.4
$S^{95}_{\rm exp}$	$1135.0^{+332.7}_{-291.5}$	$42.7^{+15.5}_{-11.4}$	$17.0^{+6.6}_{-4.6}$	$5.8^{+2.9}_{-1.8}$	$72.9^{+23.6}_{-18.0}$	$3.3^{+2.1}_{-1.2}$
p_0 (Z_n)	0.45 (0.1)	0.27 (0.6)	0.50 (0.0)	0.34 (0.4)	0.34 (0.4)	0.50 (0.0)

Figure: *results of the analysis in [4]*

results (cont.)

Signal Region	D	E-loose	E-medium	E-tight
MC expected events				
Diboson	2.0	5.5	1.7	0.0
Z/γ^*+jets	8.5	19.6	6.3	1.9
W+jets	4.8	23.1	5.2	0.8
$t\bar{t}$(+EW) + single top	5.0	67.3	16.8	1.5
Fitted background events				
Diboson	2.0 ± 2.0	5.5 ± 2.1	1.7 ± 0.8	–
Z/γ^*+jets	3.8 ± 2.5	12 ± 7	2.9 ± 2.6	0.4 ± 0.6
W+jets	3.3 ± 2.5	18 ± 7	4.9 ± 2.7	0.7 ± 0.5
$t\bar{t}$(+EW) + single top	5.8 ± 2.1	76 ± 19	20 ± 6	1.7 ± 1.4
Multi-jets	–	1.0 ± 1.0	–	–
Total bkg	15 ± 5	113 ± 21	30 ± 8	2.9 ± 1.8
Observed	18	166	41	5
$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	0.77	4.55	1.41	0.41
$S^{95}_{\rm obs}$	15.5	92.4	28.6	8.3
$S^{95}_{\rm exp}$	$13.6^{+5.1}_{-3.5}$	$57.3^{+20.0}_{-14.4}$	$21.4^{+7.6}_{-5.8}$	$6.5^{+3.0}_{-1.9}$
p_0 (Z_n)	0.32 (0.5)	0.03 (1.9)	0.14 (1.1)	0.22 (0.8)

Figure: *results of the analysis in [4]*

exclusion limits

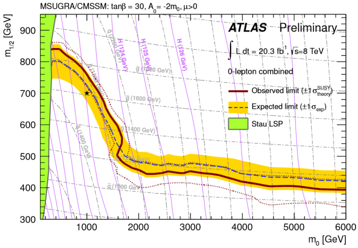

Figure: *exclusion limits for the CMSSM of the analysis in [4]*

This gives limits to $m_{\tilde{q}} \gtrsim 2000$ GeV and $m_{\tilde{g}} \gtrsim 1200$ GeV

exclusion limits (cont.)

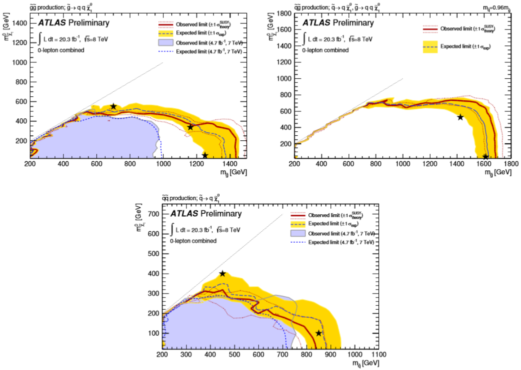

Figure: *exclusion limits for three decay chain models of the analysis in [4]*

2-6 jets + 1-2 leptons search by ATLAS

Search for squarks and gluinos in events with isolated leptons, jets and missing transverse momentum at $\sqrt{s} = 8$ TeV with the ATLAS detector

isolated lepton

A lepton is only accepted, should it be either closer than $\Delta R = 0.2$ or further away than $\Delta R = 0.4$ from a jet.

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In the case that $\Delta R \leq 0.2$, the jet is discarded and the lepton kept. The lepton is then called isolated.

decay chains (examples)

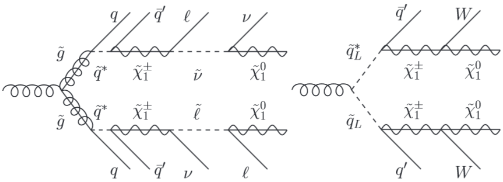


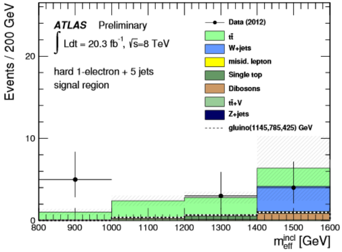
Figure: *example for decays analysed in [5]*

definition of signal regions

	inclusive (binned) hard single-lepton		
	3-jet	**5-jet**	**6-jet**
N_ℓ	1 (electron or muon)		
p_T^ℓ(GeV)	> 25		
$p_T^{\text{add. } \ell}$ (GeV)	< 10		
N_{jet}	≥ 3	≥ 5	≥ 6
p_T^{jet}(GeV)	$> 80, 80, 30$	$> 80, 50, 40, 40, 40$	$> 80, 50, 40, 40, 40, 40$
$p_T^{\text{add. jets}}$(GeV)	$- (< 40)$	$- (< 40)$	$-$
E_T^{miss} (GeV)	>500 (300)	>300	>350 (250)
m_T (GeV)	> 150	> 200 (150)	> 150
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{excl}}$	> 0.3	$-$	$-$
$m_{\text{eff}}^{\text{incl}}$ (GeV)	> 1400 (800)		> 600

Figure: *example for definitions of signal regions in [5]*

definition of signal regions (cont.)



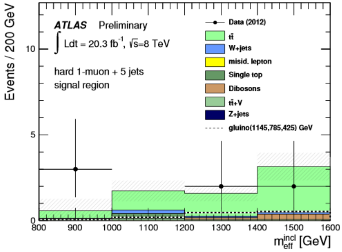


Figure: *m_{eff} (incl.) distribution for SR hard 5 jets in [5]*

Major backgrounds are:

- $t\bar{t}$ (CR)
- W+jets (CR)
- lepton misidentification (e.g. in $Z \to \nu\nu$+jets)
- single-top, dibosons $t\bar{t} + W$ and $t\bar{t} + Z$ from theory

results

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$
soft single-lepton one *b*-jet channels					
low-mass	0.43 (0.42)	8.8 (8.6)	$6.9^{+3.0}_{-2.0}$ $(6.9^{+3.4}_{-2.1})$	0.76 (0.71)	0.26 (0.27)
high-mass	0.39 (0.38)	7.9 (7.7)	$6.3^{+1.9}_{-1.1}$ $(5.9^{+3.0}_{-1.9})$	0.79 (0.75)	0.21 (0.22)
soft single-lepton two *b*-jet channels					
low-mass	0.66 (0.62)	13.4 (12.7)	$13.2^{+5.9}_{-4.1}$ $(13.1^{+5.6}_{-3.8})$	0.52 (0.46)	0.50 (0.50)
high-mass	0.26 (0.24)	5.3 (4.9)	$5.3^{+2.4}_{-1.4}$ $(5.5^{+2.8}_{-1.8})$	0.50 (0.40)	0.50 (0.50)
soft single-lepton channels					
3-jet	0.40 (0.39)	8.1 (8.1)	$7.3^{+2.7}_{-1.8}$ $(6.8^{+3.3}_{-2.1})$	0.67 (0.66)	0.36 (0.31)
5-jet	0.35 (0.33)	7.1 (6.8)	$10.0^{+3.6}_{-3.0}$ $(9.8^{+4.2}_{-2.9})$	0.15 (0.15)	0.50 (0.50)
soft dimuon channel	0.57 (0.54)	11.5 (11.1)	$5.9^{+2.1}_{-1.0}$ $(6.5^{+3.1}_{-1.9})$	0.98 (0.92)	0.01 (0.02)
binned hard single-lepton channels					
3-jet (electron)	0.97 (0.98)	19.8 (19.9)	$20.2^{+8.3}_{-4.8}$ $(20.7^{+7.9}_{-5.6})$	0.47 (0.45)	0.50 (0.50)
3-jet (muon)	0.57 (0.52)	11.6 (10.6)	$15.6^{+5.8}_{-3.8}$ $(15.8^{+6.5}_{-4.4})$	0.13 (0.12)	0.50 (0.50)
5-jet (electron)	0.63 (0.60)	12.7 (12.1)	$12.6^{+3.2}_{-2.7}$ $(12.2^{+4.5}_{-3.2})$	0.50 (0.49)	0.50 (0.50)
5-jet (muon)	0.38 (0.36)	7.7 (7.2)	$7.6^{+2.8}_{-2.4}$ $(7.3^{+3.4}_{-2.2})$	0.53 (0.49)	0.50 (0.50)
6-jet (electron)	0.33 (0.34)	6.6 (6.8)	$7.8^{+3.1}_{-2.4}$ $(7.7^{+3.6}_{-2.4})$	0.32 (0.37)	0.50 (0.50)
6-jet (muon)	0.35 (0.35)	7.1 (7.1)	$7.1^{+3.4}_{-1.4}$ $(7.4^{+3.5}_{-2.3})$	0.50 (0.46)	0.50 (0.50)
inclusive hard single-lepton channels					
3-jet (electron)	0.30 (0.28)	6.0 (5.7)	$5.7^{+2.2}_{-1.5}$ $(5.6^{+2.9}_{-1.8})$	0.56 (0.51)	0.48 (0.48)
3-jet (muon)	0.38 (0.37)	7.7 (7.5)	$5.1^{+2.0}_{-1.5}$ $(5.1^{+2.7}_{-1.7})$	0.89 (0.82)	0.13 (0.13)
5-jet (electron)	0.30 (0.29)	6.0 (5.9)	$5.4^{+2.3}_{-1.5}$ $(5.5^{+2.9}_{-1.7})$	0.60 (0.56)	0.43 (0.43)
5-jet (muon)	0.22 (0.21)	4.6 (4.2)	$4.7^{+1.9}_{-1.2}$ $(4.7^{+2.5}_{-1.6})$	0.44 (0.41)	0.50 (0.50)
6-jet (electron)	0.23 (0.22)	4.6 (4.4)	$4.4^{+1.9}_{-0.8}$ $(4.4^{+2.5}_{-1.5})$	0.56 (0.49)	0.50 (0.50)
6-jet (muon)	0.15 (0.12)	3.0 (2.5)	$4.1^{+1.3}_{-1.1}$ $(3.8^{+2.3}_{-1.3})$	0.13 (0.16)	0.50 (0.50)

Figure: *results of the analysis in [5]*

exclusion limits

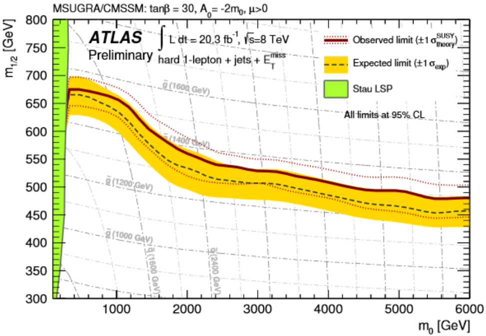


Figure: *exclusion limits for the CMSSM of the analysis in [5]*

exclusion limits (cont.)

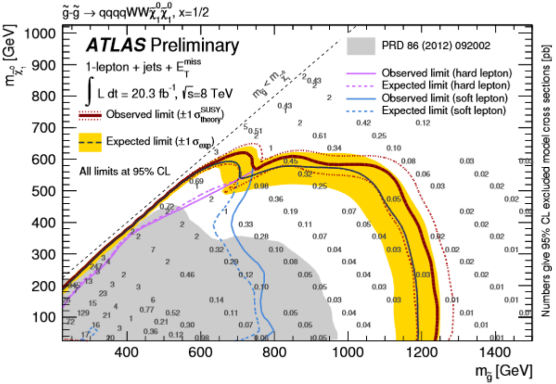


Figure: *exclusion limits for one of the decay chains of the analysis in [5]*

Search using the variable α_T and b-quark multiplicity by CMS

Search for supersymmetry in hadronic final states with missing transverse energy using the variables α_T and b-quark multiplicity in pp collisions at $\sqrt{s} = 8$ TeV

variable definitions

following variables not familiar to everyone are used in this analysis:

$$\alpha_T = \frac{E_T^{j_2}}{M_T}$$

$$M_T = \sqrt{(E_T^{j_1} + E_T^{j_2})^2 - (p_x^{j_1} + p_x^{j_2})^2 - (p_y^{j_1} + p_y^{j_2})^2}$$

$$H_T = \sum_{i=1}^{n_{\text{jet}}} E_T^{j_i}$$

$$\not{H}_T = \left| \sum_{i=1}^{n_{\text{jet}}} p_T^{j_i} \right|$$

generalization of α_T

α_T can be generalized to more than 2 jets. All jets are summed up in such a way, that their H_T are as close together as possible (difference: ΔH_T):

$$\alpha_T = \frac{H_t - \Delta H_T}{2\sqrt{H_t^2 - \not{H}_T^2}}$$

definition of signal decays

Model	Production/decay mode	Reference model m_{parent} [GeV]	Reference model m_{LSP} [GeV]
D1	$pp \to \tilde{q}\tilde{q}^* \to q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_1^0$	600	250
D2	$pp \to \tilde{b}\tilde{b}^* \to b\tilde{\chi}_1^0 \bar{b}\tilde{\chi}_1^0$	500	150
D3	$pp \to \tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0 \bar{t}\tilde{\chi}_1^0$	400	0
G1	$pp \to \tilde{g}\tilde{g} \to q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$	700	300
G2	$pp \to \tilde{g}\tilde{g} \to b\bar{b}\tilde{\chi}_1^0 b\bar{b}\tilde{\chi}_1^0$	900	500
G3	$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$	850	250

Figure: *definition of signal decays in [6]*

definition of signal regions

Analysis bin H_T [GeV]	Trigger thresholds H_T [GeV]	α_T	Trigger efficiency [%] $2 \leq n_{jet} \leq 3$	$n_{jet} \geq 4$
275–325	250	0.55	$89.1^{+0.4}_{-0.4}$	$83.7^{+0.6}_{-0.6}$
325–375	300	0.53	$98.7^{+0.2}_{-0.3}$	$98.2^{+0.4}_{-0.5}$
375–475	350	0.52	$99.0^{+0.4}_{-0.5}$	$99.7^{+0.2}_{-0.6}$
≥475	400	0.51	$100.0^{+0.0}_{-0.6}$	$100.0^{+0.0}_{-0.8}$

Figure: *definition of signal regions in [6]*

major backgrounds

Major backgrounds are:

- Z+jets and W+jets for $n_b = 0$
- $t\bar{t}$ and single-top for $n_b \geq 1$
- QCD multijet is surpressed by cuts

results

	n_{jet}	n_{b}	H_T bin [GeV] 275–325	325–375	375–475	475–575	575–675	675–775	775–875	875–∞
SM	2–3	0	6235^{+100}_{-67}	2900^{+60}_{-54}	1955^{+34}_{-39}	558^{+14}_{-15}	186^{+11}_{-10}	$51.3^{+3.4}_{-3.8}$	$21.2^{+2.3}_{-2.2}$	$16.1^{+1.7}_{-1.7}$
Data	2–3	0	6232	2904	1965	552	177	58	16	25
SM	2–3	1	1162^{+37}_{-29}	481^{+18}_{-19}	341^{+15}_{-16}	$86.7^{+4.2}_{-5.6}$	$24.8^{+2.8}_{-2.7}$	$7.2^{+1.1}_{-1.0}$	$3.3^{+0.7}_{-0.7}$	$2.1^{+0.5}_{-0.5}$
Data	2–3	1	1164	473	329	95	23	8	4	1
SM	2–3	2	224^{+15}_{-14}	$98.2^{+8.4}_{-6.4}$	$59.0^{+5.2}_{-6.0}$	$12.8^{+1.6}_{-1.6}$	$3.0^{+0.9}_{-0.7}$	$0.5^{+0.2}_{-0.2}$	$0.1^{+0.1}_{-0.1}$	$0.1^{+0.1}_{-0.1}$
Data	2–3	2	222	107	58	12	5	1	0	0
SM	≥4	0	1010^{+34}_{-24}	447^{+19}_{-16}	390^{+19}_{-15}	250^{+12}_{-11}	111^{+9}_{-7}	$53.3^{+4.3}_{-4.3}$	$18.5^{+2.4}_{-2.4}$	$19.4^{+2.5}_{-2.7}$
Data	≥4	0	1009	452	375	274	113	56	16	27
SM	≥4	1	521^{+25}_{-17}	232^{+15}_{-12}	188^{+12}_{-11}	106^{+6}_{-6}	$42.1^{+4.1}_{-4.4}$	$17.9^{+2.2}_{-2.0}$	$9.8^{+1.5}_{-1.4}$	$6.8^{+1.2}_{-1.1}$
Data	≥4	1	515	236	204	92	51	13	13	6
SM	≥4	2	208^{+17}_{-9}	103^{+9}_{-7}	$85.9^{+7.2}_{-6.9}$	$51.7^{+4.6}_{-4.7}$	$19.9^{+3.4}_{-3.0}$	$6.8^{+1.2}_{-1.3}$	$1.7^{+0.7}_{-0.4}$	$1.3^{+0.4}_{-0.3}$
Data	≥4	2	204	107	84	59	24	5	1	2
SM	≥4	3	$25.3^{+5.0}_{-4.2}$	$11.7^{+1.7}_{-1.8}$	$6.7^{+1.4}_{-1.2}$	$3.9^{+0.8}_{-0.8}$	$2.3^{+0.6}_{-0.6}$	$1.2^{+0.3}_{-0.4}$	$0.3^{+0.2}_{-0.1}$	$0.1^{+0.1}_{-0.1}$
Data	≥4	3	25	13	4	2	2	3	0	0
SM	≥4	≥4	$0.9^{+0.4}_{-0.7}$	$0.3^{+0.2}_{-0.2}$	$0.6^{+0.3}_{-0.3}$	–	–	–	–	–
Data	≥4	≥4	1	0	2	–	–	–	–	–

Figure: *Confrontation of SM and data in [6]*

exclusion limits

to interpret the result, each model was given a channel:

Model	n_{jet}	n_{b}
D1	2–3	0
D2	2–3	1, 2
D3	$\geq$4	1, 2
G1	$\geq$4	0
G2	$\geq$4	2, 3, $\geq$4
G3	$\geq$4	2, 3, $\geq$4

Figure: *Channels used for exclusion by model [6]*

exclusion limits (cont.)

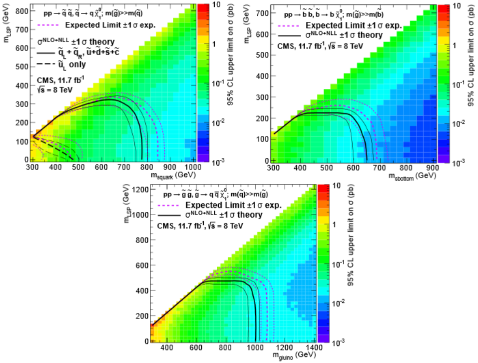


Figure: *exclusion limits for three of the decay chains of the analysis in [6]*

exclusion limits (cont.)

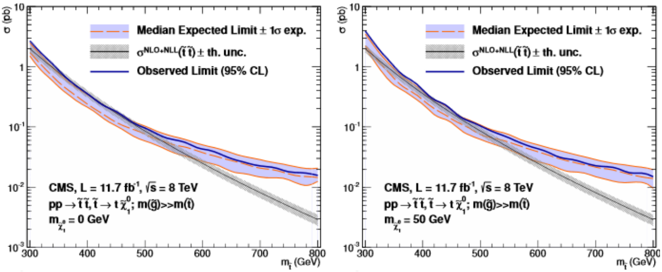


Figure: *exclusion limits for the production cross section of stop pairs given in [6]*

- Fehling-Kaschek, M.: Search for Scalar Bottom and Top Quarks with the ATLAS Detector at the LHC, dissertation, Uni Freiburg, 2013
- Jakobs, K.: Searches for Physics Beyond the Standard Model at the LHC, talk, Les Houches, 2011
- Jakobs, K.: Search for Supersymmetry at the LHC, talk, Les Houches, 2011
- ATLAS Collaboration: ATLAS-CONF-2013-047, note, 2013
- ATLAS Collaboration: ATLAS-CONF-2013-062, note, 2013
- CMS Collaboration: CMS-SUS-12-028, paper, 2013
- Ellis, J: BEYOND THE STANDARD MODEL FOR HILLWALKERS, lecture, 1998

Section 5

Backup

cut study (ATLAS-1)

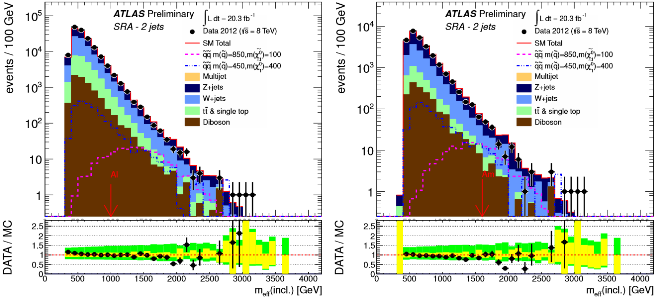


Figure: *a study of m_{eff} (incl.) in [4]*

cut study (ATLAS-1)

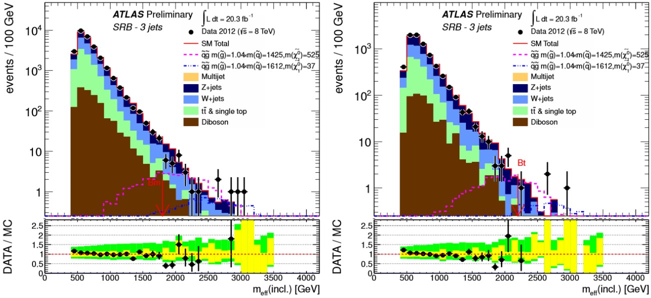


Figure: *a study of m_{eff} (incl.) in [4]*

cut study (ATLAS-1)

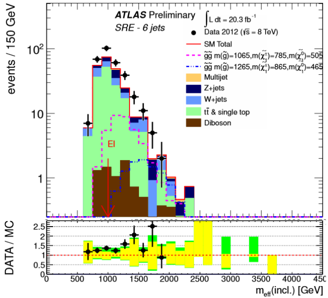


Figure: *a study of m_{eff} (incl.) in [4]*

cut study (ATLAS-1)

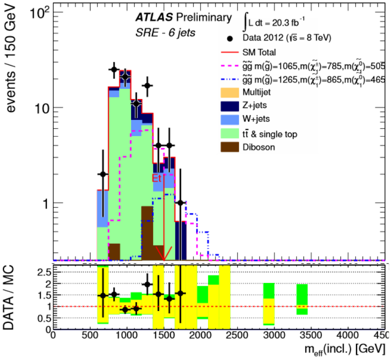


Figure: *a study of m_{eff} (incl.) in [4]*

cut study in control region (ATLAS-1)

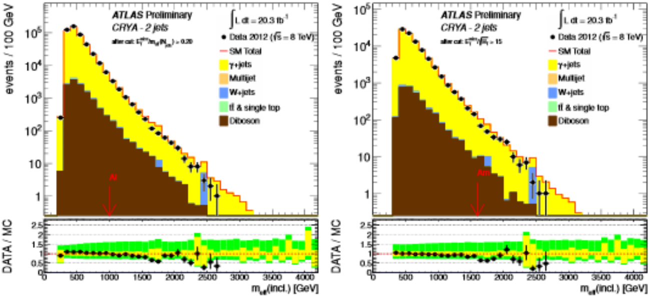


Figure: *a study of m_{eff} (incl.) in [4]*

cut study in control region (ATLAS-1)

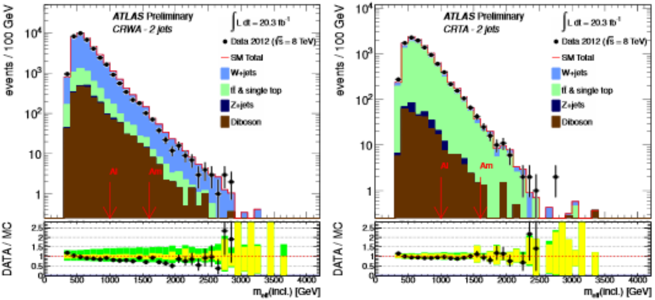


Figure: *a study of m_{eff} (incl.) in [4]*

exclusion plots (ATLAS-1)

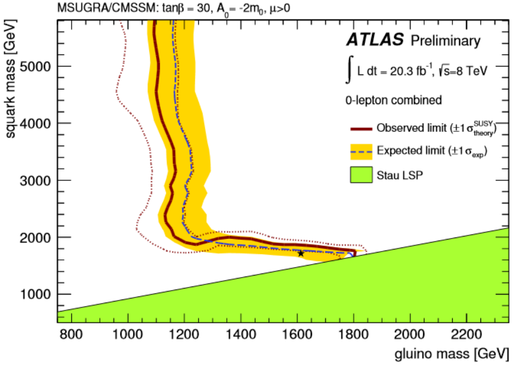


Figure: *exclusion plot taken from the analysis in [4]*

exclusion plots (ATLAS-1)

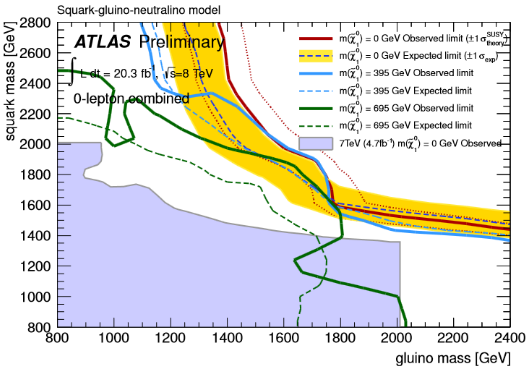


Figure: *exclusion plot taken from the analysis in [4]*

exclusion plots (ATLAS-1)

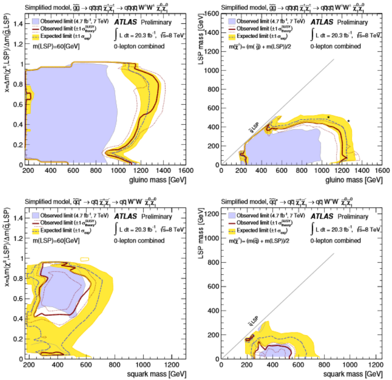


Figure: *exclusion plots taken from the analysis in [4]*

exclusion plots (ATLAS-1)

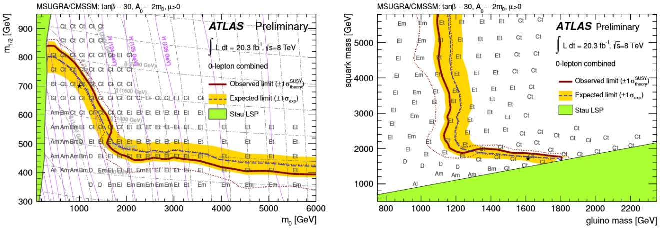


Figure: *alternate form of an exclusion plot shown before [4]*

definition of signal regions (ATLAS-2)

	soft single-lepton one b-jet		soft single-lepton two b-jets	
	low-mass	high-mass	low-mass	high-mass
N_ℓ	1 (electron or muon)			
p_T^ℓ(GeV)	[10,25] (electron) , [6,25] (muon)			
$p_T^{\text{add. } \ell}$ (GeV)	<7 (electron), <6 (muon)			
N_{jet}	≥ 3		≥ 2	
p_T^{jets}(GeV)	$>180,40,40$	$>180,25,25$	$>60,60$	
$p_T^{\text{add. jets}}$(GeV)	–		<50	
$N_{b\text{-tag}}$	≥ 1, but not the leading jet		2	
E_T^{miss} (GeV)	>250	>300	>200	>300
m_T (GeV)	>100		–	
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$	>0.35		–	
$\Delta R_{\text{min}}(\text{jet}, \ell)$	>1.0		–	
$\Delta\phi_{\text{min}}$	–		>0.4	
m_{CT} (GeV)	–		>150	>200
$H_{T,2}$ (GeV)	–		<50	–

Figure: *example for definitions of signal regions in [5]*

definition of signal regions (ATLAS-2)

	soft single-lepton		soft dimuon
	3-jet	**5-jet**	**2-jet**
N_ℓ	1 (electron or muon)		2 (muons)
p_T^ℓ(GeV)	[10,25] (electron) , [6,25] (muon)		[6,25]
$p_T{}^{\text{add. }\ell}$ (GeV)	<7 (electron), <6 (muon)		
$m_{\mu\mu}$ (GeV)	–	–	>15 and $\lvert m_{\mu\mu} - m_Z \rvert > 10$
N_{jet}	[3,4]	≥ 5	≥ 2
$p_T{}^{\text{leading jet}}$(GeV)	> 180		>70
$p_T{}^{\text{subleading jets}}$(GeV)	> 25		
$N_{b\text{-tag}}$	–	–	0
E_T^{miss} (GeV)	>400	>300	>170
m_T (GeV)	> 100		> 80
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$	> 0.3		–
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0	–	> 1.0

Figure: *example for definitions of signal regions in [5]*

definition of control regions (ATLAS-2)

	soft single-lepton one b-jet			
	low-mass	high-mass	low-mass	high-mass
	$t\bar{t}$		W + jets	
N_ℓ	1 (electron or muon)			
p_T^ℓ(GeV)	>25			
$p_T{}^{\text{add. } \ell}$ (GeV)	< 7 (electron), < 6 (muon)			
N_{jet}	≥ 3			
$p_T{}^{\text{jets}}$(GeV)	> 180,40,40	> 180,25,25	> 180,40,40	> 180,25,25
$N_{b-\text{tag}}$	$\geq$ 1, but not the leading jet		0	
E_T^{miss} (GeV)	>150		>250	>300
m_T (GeV)	> 100		[40,80]	
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0			

Figure: *example for definitions of control regions for W+jets and $t\bar{t}$ in [5]*

definition of control regions (ATLAS-2)

	soft single-lepton two b-jet			
	low-mass	**high-mass**	**low-mass**	**high-mass**
	$t\bar{t}$		$W+\text{jets}$	
N_ℓ	1 (electron or muon)			
p_T^ℓ(GeV)	>25			
$p_T{}^{\text{add. }\ell}$ (GeV)	< 7 (electron), < 6 (muon)			
N_{jet}	≥ 2			
$p_T{}^{\text{jets}}$(GeV)	> 60			
$p_T{}^{\text{add. jets}}$(GeV)	< 50			
$N_{b-\text{tag}}$	2		0	
E_T^{miss} (GeV)	>150		>200	>300
$\Delta\phi_{\text{min}}$	> 0.4			
m_{CT} (GeV)	> 150	> 200	>150	>200
$H_{T,2}$ (GeV)	<50	–	<50	–

Figure: *example for definitions of control regions for W+jets and $t\bar{t}$ in [5]*

definition of control regions (ATLAS-2)

	soft single-lepton		soft dimuon
	3-jet	**5-jet**	**2-jet**
	W+jets / $t\bar{t}$		$t\bar{t}$
N_ℓ	1 (electron or muon)		2 (muons)
p_T^ℓ(GeV)	[10,25] (electron) , [6,25] (muon)		>25,6
$p_T{}^{\text{add. }\ell}$ (GeV)	< 7 (electron), < 6 (muon)		
$m_{\mu\mu}$ (GeV)	–	–	>15 and $\lvert m_{\mu\mu} - m_Z\rvert > 10$
N_{jet}	[3,4]	≥ 5	≥ 2
$p_T{}^{\text{leading jet}}$(GeV)	> 180		>70
$p_T{}^{\text{subleading jets}}$(GeV)	> 25		
$N_{b\text{-tag}}$	$0 / \geq 1$		≥ 1
E_T^{miss} (GeV)	[180,250]		> 170
m_T (GeV)	[40,80]		< 80
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0	–	> 1.0

Figure: *example for definitions of control regions for W+jets and $t\bar{t}$ in [5]*

definition of control regions (ATLAS-2)

	hard single-lepton		
	3-jet	**5-jet**	**6-jet**
	W+jets / $t\bar{t}$		
N_ℓ	1 (electron or muon)		
p_T^ℓ(GeV)	> 25		
$p_T{}^{\text{add. }\ell}$ (GeV)	< 10		
N_{jet}	≥ 3	≥ 5	≥ 6
$p_T{}^{\text{jet}}$(GeV)	$> 80, 80, 30$	$> 80, 50, 30, 30, 30$	$> 80, 50, 30, 30, 30, 30$
$p_T{}^{\text{add. jets}}$(GeV)	< 30	< 30	–
$N_{b\text{-tag}}$	$0 / \geq 1$		
E_T^{miss} (GeV)	[150,300]		[150,250] / [100,200]
m_T (GeV)	[80,150]	[60,150]	[40,150] / [40,80]
$m_{\text{eff}}^{\text{incl}}$ (GeV)	> 800		> 600

Figure: *example for definitions of control regions for W+jets and $t\bar{t}$ in [5]*

background cut study (ATLAS-2)

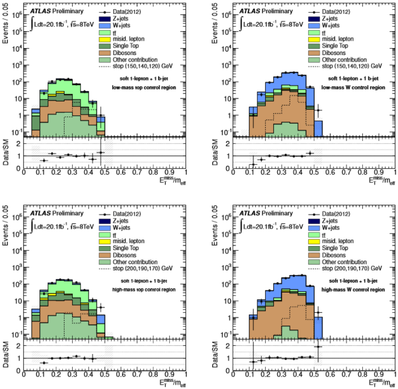


Figure: *background study for the analysis in [5]*

background cut study (ATLAS-2)

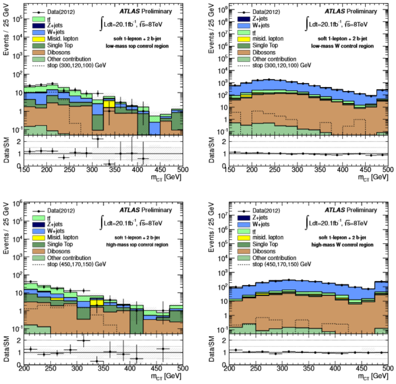


Figure: *background study for the analysis in [5]*

background cut study (ATLAS-2)

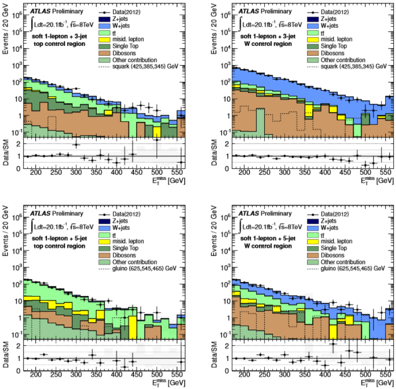


Figure: *background study for the analysis in [5]*

background cut study (ATLAS-2)

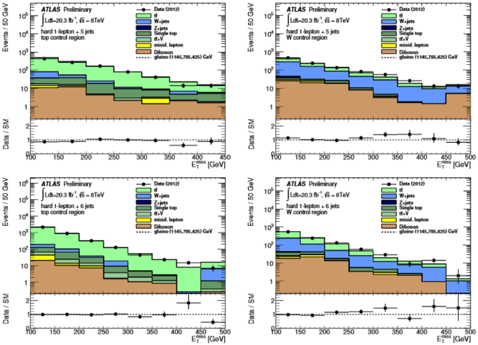


Figure: *background study for the analysis in [5]*

definition of validation regions (ATLAS-2)

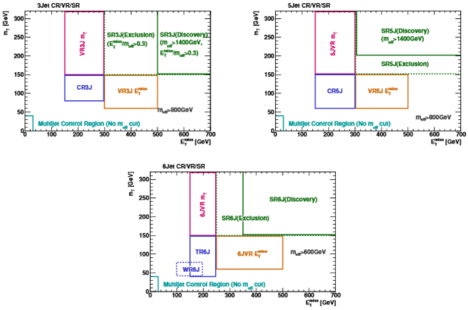


Figure: *illustration of regions in for the hard lepton analysis in [5]*

definition of validation regions (ATLAS-2)

	hard single-lepton					
	3-jet		5-jet		6-jet	
	E_T^{miss} region	**m_T region**	**E_T^{miss} region**	**m_T region**	**E_T^{miss} region**	**m_T region**
p_T^{jet}(GeV)	$> 80, 80, 30$		$> 80, 50, 40, 40, 40$		$> 80, 50, 40, 40, 40, 40$	
$p_T^{add. jets}$(GeV)	< 40		< 40		–	
N_{b-tag}	–					
E_T^{miss} (GeV)	[300,500]	[150,300]	[300,500]	[150,300]	[250,500]	[150,250]
m_T (GeV)	[60,150]	[150,320]	[60,150]	[150,320]	[60,150]	[120,320]

Figure: *definition of validation regions in [5]*

definition of validation regions (ATLAS-2)

	binned hard single-lepton					
	3-jet		5-jet		6-jet	
	electron	muon	electron	muon	electron	muon
Observed events	45	28	12	7	7	7
Fitted background events	46.4 ± 8.0	38.1 ± 5.8	12.2 ± 5.2	7.1 ± 1.6	9.7 ± 2.0	7.4 ± 1.7
Fitted $t\bar{t}$ events	23.8 ± 6.4	20.0 ± 5.0	7.4 ± 3.3	5.6 ± 1.5	8.0 ± 1.9	5.6 ± 1.5
Fitted W+jets events	15.4 ± 5.5	10.7 ± 4.0	3.1 ± 2.2	0.4 ± 0.4	$0.1^{+0.2}_{-0.1}$	0.3 ± 0.3
Fitted diboson events	4.4 ± 2.3	3.3 ± 1.7	0.9 ± 0.6	0.4 ± 0.2	0.5 ± 0.3	0.06 ± 0.03
Fitted misidentified lepton events	$0.4^{+0.5}_{-0.4}$	$0.8^{+0.9}_{-0.8}$	$0.01^{+0.08}_{-0.01}$	$0.0^{+0.03}_{-0.0}$	$0.07^{+0.09}_{-0.07}$	$0.8^{+0.9}_{-0.8}$
Fitted other background events	2.3 ± 0.8	3.3 ± 1.1	0.7 ± 0.3	0.6 ± 0.2	1.0 ± 0.3	0.6 ± 0.1
MC expected SM events	54.8 ± 10.3	43.0 ± 7.1	14.1 ± 6.3	7.0 ± 1.6	10.1 ± 1.9	7.9 ± 1.7
MC expected $t\bar{t}$ events	23.3 ± 3.7	19.7 ± 2.6	7.1 ± 3.0	5.3 ± 1.2	8.4 ± 1.7	6.0 ± 1.3
MC expected W+jets events	24.4 ± 7.3	16.1 ± 5.1	5.3 ± 3.4	0.6 ± 0.5	0.2 ± 0.2	0.5 ± 0.5
MC expected diboson events	4.5 ± 2.3	3.4 ± 1.7	0.9 ± 0.6	0.4 ± 0.2	0.6 ± 0.3	0.07 ± 0.03
data-driven misidentified lepton events	$0.4^{+0.5}_{-0.4}$	$0.8^{+0.9}_{-0.8}$	$0.01^{+0.08}_{-0.01}$	$0.0^{+0.03}_{-0.0}$	$0.07^{+0.09}_{-0.07}$	$0.8^{+0.9}_{-0.8}$
MC expected other background events	2.1 ± 0.8	3.1 ± 1.2	0.8 ± 0.3	0.7 ± 0.2	1.0 ± 0.3	0.6 ± 0.2

Figure: *definition of validation regions in [5]*

cut study (ATLAS-2)

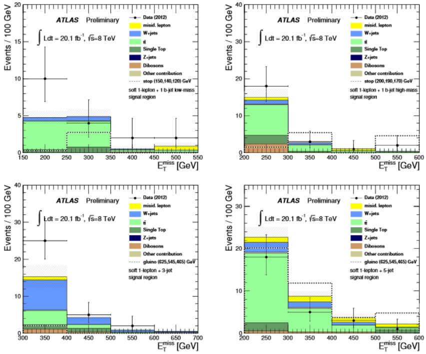


Figure: *a study of E_T^{miss} in [5]*

cut study (ATLAS-2)

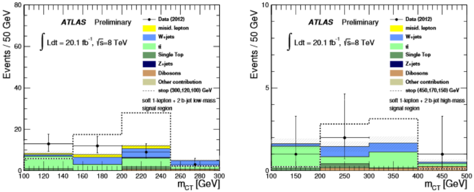


Figure: *a study of m_{CT} in [5]*

cut study (ATLAS-2)

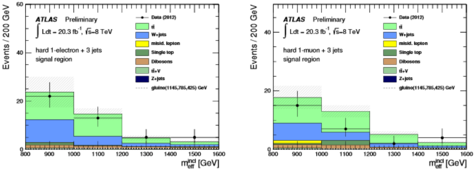


Figure: *a study of m_{eff} (incl.) in [5]*