STOP SEARCHES AND NATURAL SUSY



DANIEL STOLARSKI



DAVID E. KAPLAN, KEITH REHERMANN, DS, arXiv:1205.5816

DISCLAIMER

• Distilled the talk to the main points

• Talk may last less than an hour

• I'm happy to talk after about this or other things I'm working on

SUPERSYMMETRY IS GREAT!

- Elegant extension of spacetime symmetries
- Grand unification works better than SM
- Well motivated *R*-parity automatically gives dark matter candidate



• Solves hierarchy problem?

LHC ASSAULT

		ATLAS SUSY Searches* - 95% CL Lower Limits (Status: HCP 2012)			
	MSUGBA/CMSSM : 1 lep + i's + $E_{T,miss}$	L=5.6 fb ⁻¹ 8 TeV [ATLAS-CONF-2012-109]	1.30 Lev $q = q mass$		
	Pheno model : 0 lep + i's + F_{-}	$l = 5.8 \text{ fb}^{-1}$ 8 TeV [ATLAS-CONE-2012-104]	1 18 TeV $\widetilde{\mathbf{Q}}$ Mass $(m\widetilde{\mathbf{Q}}) < 2$ TeV light $\widetilde{\mathbf{Q}}^0$	ATLAS	
nes	Pheno model : 0 lep + i's + $E_{T,miss}$	$L=5.8 \text{ fb}^{-1}$. 8 TeV [ATLAS-CONF-2012-109]	1.38 TeV $\widetilde{\mathbf{Q}}$ Mass $(m\widetilde{\mathbf{Q}}) < 2$ TeV, light $\widetilde{\chi}_{1}^{\prime}$	Preliminary	
arcl	Gluino med. $\tilde{\gamma}^{\pm}$ ($\tilde{a} \rightarrow a \bar{a} \tilde{\gamma}^{\pm}$) : 1 lep + i's + E_{\pm}	L=4.7 fb ⁻¹ , 7 TeV [1208.4688]	900 GeV $\tilde{\mathbf{q}}$ mass $(m(\tilde{\chi}^0) < 200 \text{ GeV}, m(\tilde{\chi}^\pm) = \frac{1}{2}(m)$	$n(\tilde{\chi}^0) + m(\tilde{q}))$	
Seá	$GMSB(\tilde{I} NLSP)$: 2 lep (OS) + i's + E	L=4.7 fb ⁻¹ , 7 TeV [1208.4688]	1.24 TeV $\widetilde{\mathbf{q}}$ mass $(\tan\beta < 15)$		
) Ø	GMSB ($\tilde{\tau}$ NLSP) : 1-2 τ + 0-1 lep + j's + $E_{-}^{T,miss}$	L=4.7 fb ⁻¹ , 7 TeV [1210.1314]	1.20 TeV $\tilde{\mathbf{q}}$ mass (tan β > 20)		
ISİ	$\hat{G}GM$ (bino NLSP) : $\gamma\gamma + E_{\tau}^{T,miss}$	L=4.8 fb ⁻¹ , 7 TeV [1209.0753]	1.07 TeV $\widetilde{\mathbf{q}}$ mass $(m(\widetilde{\chi}^0) > 50 \text{ GeV})$	$\int I dt = (2.1 - 13.0) \text{ fb}^{-1}$	
JCli	GGM (wino NLSP) : γ + lep + $E_{T,miss}^{\gamma,miss}$	L=4.8 fb ⁻¹ , 7 TeV [ATLAS-CONF-2012-144]	619 GeV g mass	$\int Lot = (2.1 - 10.0)$ 10	
-	GGM (higgsino-bino NLSP) : $\gamma + b + E_{T miss}^{\gamma,miss}$	L=4.8 fb ⁻¹ , 7 TeV [1211.1167]	900 GeV \widetilde{g} mass $(m(\widetilde{\chi}^0) > 220 \text{ GeV})$	s = 7.8 TeV	
	GGM (higgsino NLSP) : Z + jets + $E_{T \text{ miss}}^{I,\text{miss}}$	L=5.8 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-152]	690 GeV G Mass (m(H) > 200 GeV)		
	Gravitino LSP : 'monojet' + $E_{T \text{ miss}}$	L=10.5 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-147]	645 GeV $F^{1/2}$ scale $(m(\tilde{G}) > 10^{-4} \text{ eV})$		
<i></i>	$\tilde{q} \rightarrow b \tilde{p} \tilde{\gamma}^{0}$ (virtual \tilde{b}) : 0 lep + 3 b-i's + $E_{T,miss}$	L=12.8 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-145]	1.24 TeV \tilde{g} mass $(m(\tilde{\chi}_{.}^{0}) < 200 \text{ GeV})$		
ne.	$\tilde{q} \rightarrow t \tilde{\chi}^{01}$ (virtual \tilde{t}) : 2 lep (SS) + j's + $E_{T,miss}$	L=5.8 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-105]	850 GeV \widetilde{g} mass $(m(\widetilde{\chi}^0) < 300 \text{ GeV})$		
ien Io r	$\widetilde{q} \rightarrow t \widetilde{\tau} \widetilde{\gamma}^{0}$ (virtual \widetilde{t}) : 3 lep + i's + $E_{\tau \text{miss}}$	L=13.0 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-151]	860 GeV $\tilde{\mathbf{g}}$ mass $(m(\tilde{\chi}^b) < 300 \text{ GeV})$	8 TeV results	
d g uin	$\widetilde{q} \rightarrow t \widetilde{\chi}^{0}$ (virtual \widetilde{t}) : 0 lep + multi-i's + $E_{T,miss}$	L=5.8 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-103]	1.00 TeV $\widetilde{\mathbf{g}}$ mass $(m(\widetilde{\chi}_{4}^{0}) < 300 \text{ GeV})$	7 TeV results	
g	$\widetilde{q} \rightarrow \widetilde{t} \widetilde{\chi}^{0}$ (virtual \widetilde{t}) : 0 lep + 3 b-i's + $E_{\tau \text{ miss}}$	L=12.8 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-145]	1.15 TeV $\widetilde{\mathbf{g}}$ mass $(m(\widetilde{\chi}^0) < 200 \text{ GeV})$		
	$\widetilde{b}\widetilde{b}, \widetilde{b}, \rightarrow \widetilde{b}\widetilde{\chi}^{0}$: 0 lep + 2-b-jets + $E_{T \text{ miss}}$	L=4.7 fb ⁻¹ , 7 TeV [ATLAS-CONF-2012-106]	480 GeV b mass $(m(\tilde{\chi}_{1}^{0}) < 150 \text{ GeV})$		
rks ion	$\widetilde{b}\widetilde{b},\widetilde{b},\rightarrow t\widetilde{\chi}^{\pm}$: 3 lep + j's + $E_{\tau \text{ miss}}$	L=13.0 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-151]	405 GeV b mass $(m(\tilde{\chi}_{1}^{\pm}) = 2 m(\tilde{\chi}_{1}^{0}))$		
ua	$\tilde{t}\tilde{t}$ (very light), $\tilde{t} \rightarrow b\tilde{\chi}^{\pm}$: 2 lep + $E_{T \text{ miss}}$	L=4.7 fb ⁻¹ , 7 TeV [1208.4305] 130 GeV	t mass $(m(\tilde{\chi}_{1}^{0}) < 70 \text{ GeV})$		
sq	$\widetilde{t}\widetilde{t}$ (light), $\widetilde{t} \rightarrow b\widetilde{\chi}^{\pm}$: 1/2 lep + b-jet + $E_{T \text{ miss}}$	L=4.7 fb ⁻¹ , 7 TeV [1209.2102] 123-167 (meV t mass $(m(\tilde{\chi}_1^0) = 55 \text{ GeV})$		
en.	$\widetilde{t}\widetilde{t}$ (medium), $\widetilde{t} \rightarrow t \widetilde{\chi}_{0}^{\circ}$: 2 lep + b-jet + $E_{T,miss}$	L=4.7 fb ⁻¹ , 7 TeV [1209.4186]	298-305 GeV I mass $(m(\tilde{\chi}_1^0) = 0)$		
d g ect	\underbrace{tt}_{t} (heavy), $\underbrace{t} \rightarrow t \widetilde{\chi}_{u}$: 1 lep + b-jet + $E_{T,miss}$	L=4.7 fb ⁻¹ , 7 TeV [1208.2590]	230-440 GeV t mass $(m(\tilde{\chi}_1^0) = 0)$		
3rc dir	\sim tt (heavy), t \rightarrow t $\tilde{\chi}_1$: 0 lep + b-jet + $E_{T,\text{miss}}$	<i>L</i> =4.7 fb ⁻¹ , 7 TeV [1208.1447]	370-465 GeV t mass $(m(\tilde{\chi}_1) = 0)$		
	tt (natural GMSB) $Z(\rightarrow II) + b$ -jet + $E_{T miss}$	L=2.1 fb ⁻¹ , 7 TeV [1204.6736]	310 GeV t mass (115 < $m(\tilde{\chi}_{1}^{0})$ < 230 GeV)		
t	$ L_L, I \rightarrow \widetilde{\chi}_n^\circ : 2 \text{ lep } + E_{T, \text{miss}}$	L=4.7 fb ⁻¹ , 7 TeV [1208.2884] 85-19	5 GeV I mass $(m(\tilde{\chi}_1^0) = 0)$		
N: BC	$\widetilde{\chi}_{1}\widetilde{\chi}_{1},\widetilde{\chi}_{1}\rightarrow h(\widetilde{\nu})\rightarrow h\widetilde{\chi}_{1}$: 2 lep + $E_{T,miss}$	L=4.7 fb ⁻¹ , 7 TeV [1208.2884]	110-340 GeV χ_1^{\perp} MASS $(m(\tilde{\chi}_1^0) < 10 \text{ GeV}, m(\tilde{l}, \tilde{v}) = \frac{1}{2}(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0)))$		
Шij	$\widetilde{\chi}_{1}^{-}\widetilde{\chi}_{2}^{-} \rightarrow [v_{1}]_{1}^{-}(\widetilde{v}v), [\widetilde{v}]_{1}^{-}(\widetilde{v}v) : 3 \text{ lep } + E_{T \text{ miss}}$	L=13.0 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-154]	580 GeV χ_1^- MASS $(m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) = 0, m(l,\tilde{\nu})$ as a	above)	
	$\widetilde{\chi}_{1}\widetilde{\chi}_{2} \rightarrow W^{*}\widetilde{\chi}_{1}Z^{*}\widetilde{\chi}_{1}: 3 \text{ lep } + E_{\tau,\text{miss}}$	L=13.0 fb ⁻¹ , 8 TeV [ATLAS-CONF-2012-154]	140-295 GeV χ_1^- Mass $(m(\chi_1^{\pm}) = m(\chi_2^{\circ}), m(\chi_1^{\circ}) = 0$, sleptons decoupled)		
<i>p</i> ∈ s	Direct χ_1^- pair prod. (AMSB) : long-lived χ_1^-	L=4.7 fb ⁻¹ , 7 TeV [1210.2852]	220 GeV χ_1 mass $(1 < \tau(\chi_1^{\pm}) < 10 \text{ ns})$		
live	Stable \tilde{g} R-hadrons : low β , $\beta\gamma$ (full detector)	L=4.7 fb ⁻¹ , 7 TeV [1211.1597]	985 Gev g mass		
ng- artic	Stable t R-hadrons : low β , $\beta\gamma$ (full detector)	L=4.7 fb ⁻¹ , 7 TeV [1211.1597]	683 GeV T MASS		
Loi Dê	\sim^0 GMSB : stable $\tilde{\tau}$	L=4.7 fb ⁻¹ , 7 TeV [1211.1597]	300 GeV τ MASS (5 < tan β < 20)	~	
	$\chi_1 \rightarrow qq\mu (RPV) : \mu + heavy displaced vertex$	L=4.4 fb ⁻¹ , 7 TeV [1210.7451]	700 GeV q mass $(0.3 \times 10^{\circ} < \lambda_{211}^{\circ} < 1.5 \times 10^{\circ}, 1 \text{ mm} < 1.5 \times 10^{\circ})$	$c\tau < 1 m, g decoupled)$	
	LFV : pp $\rightarrow v_{\tau} + X$, $v_{\tau} \rightarrow e + \mu$ resonance	L=4.6 fb ⁻¹ , 7 TeV [Preliminary]	1.61 TeV V_{τ} (TIASS $(\lambda'_{311}=0.10, \lambda_{132}=0.10, \lambda_{132}=0.10, \lambda_{132}=0.10, \lambda_{133}=0.10, $	0.05)	
	LFV : pp $\rightarrow v_1 + X, v_1 \rightarrow e(\mu) + \tau$ resonance	L=4.6 fb ⁻¹ , 7 TeV [Preliminary]	1.10 TeV V_{τ} IIIass $(\lambda_{311}^2 = 0.10, \lambda_{1(2)33}^2 = 0.05)$		
P	$\sum_{\tau=1}^{1} \sum_{\tau=1}^{1} \sum_{\tau$	L=4.7 fb ⁻¹ , 7 TeV [ATLAS-CONF-2012-140]	1.2 TeV $\mathbf{q} = \mathbf{g} \operatorname{IIIdSS} (c_{\tau_{LSP}} < 1 \text{ mm})$		
Щ	$\chi_1 \chi_{1,2} \chi_1 \rightarrow W \chi_0, \chi_0 \rightarrow e e v_\mu, e \mu v_e$ 4 lep + $E_{T,miss}$	L=13.0 fb ⁻ , 8 TeV [ATLAS-CONF-2012-153]	700 GeV χ_1 IIIdSS $(m(\chi_1) > 300 \text{ GeV}, \lambda_{121} \text{ or } \lambda_{122} > 100 \text{ GeV}$	0)	
	$I_L I_L, I_L \rightarrow I\chi_1, \chi_1 \rightarrow eev_\mu, e\muv_e$: 4 lep + $E_{T,miss}$	L=13.0 fb , 8 lev [AILAS-CONF-2012-153]	430 GeV TITIASS $(m(\chi_1) > 100 \text{ GeV}, m(l_e) = m(l_{\mu}) = m(l_{\mu}), \lambda_{121} \text{ or } \lambda$	₁₂₂ > 0)	
	$g \rightarrow qqq$: 3-jet resonance pair	L=4.0 ID , 7 IEV [1210.4813]			
WIMP interaction (D5, Dirac v): 'monoiet' + F		L=4.0 ID, <i>i</i> lev [1210.4820]	$\frac{100-207 \text{ GeV}}{704 \text{ GeV}} = \frac{300 \text{ GeV}}{100} = \frac{100-207 \text{ GeV}}{100} = 100-207 \text{$	for D9)	
	T,miss	L=10.3 ID , 6 TEV [ATLAS-CONF-2012-147]			
		10''	1	10	

4 D *Only a selection of the available mass limits on new states or phenomena shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty. 10 Mass scale [TeV]

What is the minimal particle content needed for naturalness? Brust, Katz, Lawrence, Sundrum, 1110.6670. Papucci, Ruderman, Weiler, 1110.6926.

Stops



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 $m_{\tilde{t}} \lesssim 400 \text{ GeV}$

*Get left handed sbottom also

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Dirac Gluino

Hall, Randall, 1991. Randall, Ruis, 1992. Fox, Nelson, Weiner, 2002.



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STOP SCENARIO

• Stop is lightest particle required by naturalness

• R-parity and neutralino LSP is well motivated

- Consider minimal spectrum with only right handed stop, light invisible particle, and $m_{\tilde{t}}>m_t+m_{\chi^0}$











FULY LEPTONIC STOPS



FULY LEPTONIC STOPS



ADDITIONAL KINEMATIC VARIABLES

Search can be improved with additional kinematic variables Bai, Cheng, Gallicchio, Gu 1203.4813.

$$M_{T2}^{W} = \min \left\{ m_y \text{ consistent with: } \begin{bmatrix} \vec{p}_1^T + \vec{p}_2^T = \vec{E}_T^{\text{miss}}, \ p_1^2 = 0, \ (p_1 + p_\ell)^2 = p_2^2 = M_W^2, \\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \end{bmatrix} \right\}$$











TOP TAGGING

Use HEPTopTagger to distinguish hadronic top Plehn, Spannowsky, Takeuchi, Zerwas, 1006.2833. See also Thaler et. al. 0806.0023, Kaplan et. al. 0806.0848, Almeida et. al. 0807.0234.



RELEVANT PROCESSES

Process Generator cuts		σ (fb)
	and parameters	$7 { m TeV}$
$\tilde{t}\tilde{t}^*$ (340 GeV)		254
$\tilde{t}\tilde{t}^*$ (440 GeV)	$\tilde{t}\tilde{t}^* \to b\bar{b} + 4j + 2\chi$	48.8
$\tilde{t}\tilde{t}^*$ (540 GeV)		11.8

*LO cross sections

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$\tilde{t}\tilde{t}^*$ (540 GeV)		11.8
$t\bar{t} + jets$	$W_{\to \ell \nu}, \ p_{T_{\nu}} > 80 \text{GeV}$	16.3×10^3
sing. $top + jets$	$p_{T_{\nu}} > 100 \text{ GeV}$	4.65×10^3

*LO cross sections

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sing. $top + jets$	$p_{T_{\nu}} > 100 \text{ GeV}$	4.65×10^3
$V + b\overline{b} + \text{jets}$	$Z \to \nu \bar{\nu}, W \to \ell \nu$	1.08×10^3
V+ jets	$\sum \mathbf{p}_{T_{\nu}} > 80 \text{ GeV}$	66.6×10^3

*LO cross sections

Backgrounds

- QCD
- V + $b\overline{b}$ + jets
- V + jets
- Tops + jets

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- V + $b\overline{b}$ + jets
- V + jets
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<u>Cuts</u>

 Veto on isolated leptons, tau's, and bizarre missing energy events.

Backgrounds

- <u>QCD</u>
- V + $b\overline{b}$ + jets
- V + jets
- Tops + jets

<u>Cuts</u>

- Veto on isolated leptons, tau's, and bizarre missing energy events.
- Missing energy > 175 GeV

Backgrounds

- <u>QCD</u>
- $V + b\bar{b} + jets$
- V+jets
- Tops + jets

<u>Cuts</u>

- Veto on isolated leptons, tau's, and bizarre missing energy events.
- Missing energy > 175 GeV
- One HEPTopTagged fat jet

<u>Backgrounds</u>

- <u>QCD</u>
- $V + b\bar{b} + jets$
- V > jets
- Tops + jets

<u>Cuts</u>

- Veto on isolated leptons, tau's, and bizarre missing energy events.
- Missing energy > 175 GeV
- One HEPTopTagged fat jet
- Opposite fat jet is b-tagged

GOOD SIGNAL TO BACKGROUND



$$\sqrt{s} = 7 \,\mathrm{TeV}$$

 $\mathcal{L} = 5 \,\mathrm{fb}^{-1}$

$$m_{\tilde{t}} = 340 \,\mathrm{GeV}$$

 $m_{\chi} = 0 \,\mathrm{GeV}$

INCREASE NEUTRALINO MASS



$$\sqrt{s} = 7 \,\mathrm{TeV}$$

 $\mathcal{L} = 5 \,\mathrm{fb}^{-1}$

$$m_{\tilde{t}} = 340 \,\mathrm{GeV}$$

 $m_{\chi} = 100 \,\mathrm{GeV}$

KINEMATIC CUTS




 Transverse mass of missing energy with both fat jets > 200 GeV



t

t

 \mathcal{V}

 au_h

j

J

h

b

 Transverse mass of missing energy with both fat jets > 200 GeV

• mT2 > 200 GeV

Lester et. al., hep-ph/9906349, Conlon et. al., hep-ph/0304226.

 Transverse mass of missing energy with both fat jets > 200 GeV



• mT2 > 200 GeV

Lester et. al., hep-ph/9906349, Conlon et. al., hep-ph/0304226.

Plehn, Spannowsky, Takeuchi, Zerwas, 1006.2833

CLEAR SIGNAL DISCRIMINATION



$$\sqrt{s} = 7 \,\mathrm{TeV}$$

 $\mathcal{L} = 5 \,\mathrm{fb}^{-1}$

$$m_{\tilde{t}} = 340 \,\mathrm{GeV}$$

 $m_{\chi} = 0 \,\mathrm{GeV}$

EVEN WITH SMALLER SPLITTING



$$\sqrt{s} = 7 \,\mathrm{TeV}$$

 $\mathcal{L} = 5 \,\mathrm{fb}^{-1}$

$$m_{\tilde{t}} = 340 \,\mathrm{GeV}$$

 $m_{\chi} = 100 \,\mathrm{GeV}$

EVEN WITH SMALLER SPLITTING



$$\sqrt{s} = 7 \,\mathrm{TeV}$$

 $\mathcal{L} = 5 \,\mathrm{fb}^{-1}$

$$m_{\tilde{t}} = 340 \,\mathrm{GeV}$$

 $m_{\chi} = 100 \,\mathrm{GeV}$

7 TeV RESULTS



ATLAS RESULT

Cute

Control Sample



ATLAS RESULT



8 TeV RUNNING

ALICE: 8.27 pb⁻¹ ATLAS: 21.6 fb⁻¹ CMS: 21.42 fb⁻¹ LHCb: 2.04 fb⁻¹



*As of Monday

RELEVANT PROCESSES

Process	Generator cuts	σ (fb)
	and parameters	$7 { m TeV}$
$\tilde{t}\tilde{t}^*$ (340 GeV)		254
$\tilde{t}\tilde{t}^*$ (440 GeV)	$\tilde{t}\tilde{t}^* \to b\bar{b} + 4j + 2\chi$	48.8
$\tilde{t}\tilde{t}^*$ (540 GeV)		11.8
$t\bar{t} + jets$	$W_{\to \ell \nu}, \ p_{T_{\nu}} > 80 \text{GeV}$	16.3×10^{3}
sing. $top + jets$	$p_{T_{\nu}} > 100 \text{ GeV}$	4.65×10^3
$V + b\overline{b} + \text{jets}$	$Z \to \nu \bar{\nu}, W \to \ell \nu$	1.08×10^3
V+ jets	$\sum \mathbf{p}_{T_{\nu}} > 80 \text{ GeV}$	66.6×10^{3}

*LO cross sections

RELEVANT PROCESSES

Process	Generator cuts	σ (fb)	σ (fb)
	and parameters	$7 { m TeV}$	$8 { m TeV}$
$\tilde{t}\tilde{t}^*$ (340 GeV)		254	1.04×10^{3}
$\tilde{t}\tilde{t}^*$ (440 GeV)	$\tilde{t}\tilde{t}^* \to b\bar{b} + 4j + 2\chi$	48.8	205
$\tilde{t}\tilde{t}^*$ (540 GeV)		11.8	51.1
$t\bar{t} + jets$	$W_{\to \ell \nu}, \ p_{T_{\nu}} > 80 \text{GeV}$	16.3×10^{3}	26.7×10^3
sing. $top + jets$	$p_{T_{\nu}} > 100 \text{ GeV}$	4.65×10^3	8.27×10^3
$V + b\overline{b} + \text{jets}$	$Z \to \nu \bar{\nu}, W \to \ell \nu$	1.08×10^3	1.53×10^3
V+ jets	$\sum \mathbf{p}_{T_{\nu}} > 80 \text{ GeV}$	66.6×10^{3}	96.3×10^{3}

*LO cross sections

2012 PROSPECTS



$$\sqrt{s} = 8 \,\mathrm{TeV}$$

 $\mathcal{L} = 20 \,\mathrm{fb}^{-1}$

 $m_{\tilde{t}} = 440 \,\mathrm{GeV}$ $m_{\chi} = 100 \,\mathrm{GeV}$

8 TeV RESULTS



SYSTEMATICS

- Systematics such as BG x-section uncertainties not taken into account
- Can do more sophisticated shape analysis of distributions
- Can do data driven measurements of backgrounds



MULTI-JET BG

• Cutting hard on MET eliminates QCD bg. Is that necessary?

• Experimentalists can potentially make data driven measurement. Can we reduce MET cut?

• Allows us to push into lighter stop region





$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t} ilde{t}$	ř* ′			$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\mathrm{fb}^{-1}}$
$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	700						400
ℓ veto, $n_{\rm fat} \ge 1$	378	186	92.3	47.8	14.0	4.40	$6.9 \cdot 10^4$	$3.8 \cdot 10^{7}$	$1.9 \cdot 10^{5}$	$5.0 \cdot 10^{4}$	$5 \cdot 10^{-6}$	0.1
$\not p_T > 100 \text{ GeV}$	264	149	78.6	42.1	12.9	4.15	$7.1 \cdot 10^{3}$	$3.8 \cdot 10^5$	$1.3 \cdot 10^4$	$3.2 \cdot 10^{3}$	$ 4 \cdot 10^{-4} $	0.7
$n_{\mathrm{tag}} \geq 1$	48.8	32.6	19.9	12.0	4.29	1.54	959	$2.7 \cdot 10^{3}$	106	57.3	$9 \cdot 10^{-3}$	1.7
$n_{\text{tag}} = 1$, <i>b</i> -tag inside	13.0	8.57	5.34	3.14	1.15	0.42	322	26.4	1.05	0.57	0.024	1.4
additional b -tag	4.41	2.81	1.75	1.04	0.39	0.15	116	0.26	0.01	_	0.024	0.82
$m_T^{(b)} > 200 \text{ GeV}$	0.92	0.90	0.73	0.50	0.24	0.10	1.20	_	_	—	0.73	2.6



$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}t$	~ _*			$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\mathrm{fb}^{-1}}$
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$n_{\rm tag} \ge 1$	48.8	32.6	19.9	12.0	4.29	1.54	959	$2.7 \cdot 10^3$	106	57.3	$9 \cdot 10^{-3}$	1.7
$n_{\text{tag}} = 1, b$ -tag inside	13.0	8.57	5.34	3.14	1.15	0.42	322	26.4	1.05	0.57	0.024	1.4
additional b -tag	4.41	2.81	1.75	1.04	0.39	0.15	116	0.26	0.01	—	0.024	0.82
$m_T^{(b)} > 200 \text{ GeV}$	0.92	0.90	0.73	0.50	0.24	0.10	1.20	_	_	_	0.73	2.6



$\sqrt{s} = 8 \text{ TeV}$			$\tilde{t}\tilde{t}$	ř*			t	$t\overline{t}$	$t\overline{t}Z$	W+	jets	S/B	$S/\sqrt{B}_{10{\rm fb}^{-1}}$
$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	700							400
cross section [fb]	760	337	160	80.5	23.0	7.19	$2.3 \cdot 10$	5 2	21.5	$1.6 \cdot$	10^{6}		
$n_\ell = 1$	241	108	52.3	26.5	7.58	2.39	$6.9 \cdot 10$	4 6	5.24	$2.8 \cdot$	10^{5}		
$n_{\rm fat} \ge 1$	145	76.5	40.6	22.1	6.83	2.24	$2.4 \cdot 10$	4 3	3.21	$3.7 \cdot$	10^{4}		
$\not p_T > 100 \text{ GeV}$	104	61.5	34.8	19.5	6.28	2.11	563	$1 \ 2$	2.20	8	3547		
$n_{\rm tag} = 1$	13.1	9.02	5.80	3.60	1.33	0.50	78	9 ().33		80.5	0.01	1.0
$m_T > 150 \text{ GeV}$	4.63	4.27	3.25	2.19	0.94	0.38	3.2	8 ().10		0.99	1.0	6.5
<i>b</i> -tag inside top	1.47	1.38	1.06	0.70	0.31	0.13	0.6	3 ().03		_	2.1	5.4
$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}$	\tilde{t}^*			$t\overline{t}$		t	$t\bar{t}Z$		/B	$S/\sqrt{B}_{10 {\rm fb}^{-1}}$
$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	0 700							400
$n_{\ell} = 2$	31.0	14.3	7.07	3.58	1.04	0.33	7651		1	n.a.			
$\not \! p_T > 100 {\rm GeV}$	19.0	9.99	5.40	2.94	0.91	0.30	1313		(0.35			
$\overline{m_{T2}^{\ell\ell} > 100 \text{ GeV}}$	6.05	4.30	2.70	1.65	0.56	6 0.20	0.65 ([0.7]	79) (0.09	5.8	(4.9)	15.8(14.5)
$m_{T2}^{\ell\ell} > 150 \text{ GeV}$	0.81	1.21	1.06	0.81	0.34	0.14	0.00	[0.0])3) (0.02	n	.a.	n.a.

	$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}t$	/				$t\overline{t}$	$t\bar{t}Z$	W+	jets	S/B	$S/\sqrt{B}_{10 {\rm fb}}$	-1
	$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	700							400	
	cross section [fb]	760	337	160	80.5	23.0	7.19	$2.3 \cdot$	10^{5}	21.5	$1.6 \cdot$	10^{6}			
($n_\ell = 1$	241	108	52.3	26.5	7.58	2.39	$6.9 \cdot$	10^{4}	6.24	$2.8 \cdot$	10^{5}			
	$n_{\rm fat} \ge 1$	145	76.5	40.6	22.1	6.83	2.24	$2.4 \cdot$	10^{4}	3.21	$3.7 \cdot$	10^{4}			
	$\not p_T > 100 \text{ GeV}$	104	61.5	34.8	19.5	6.28	2.11	5	631	2.20	8	547			
	$n_{\rm tag} = 1$	13.1	9.02	5.80	3.60	1.33	0.50		789	0.33		80.5	0.01	1.0	
	$m_T > 150 \text{ GeV}$	4.63	4.27	3.25	2.19	0.94	0.38		8.28	0.10	(0.99	1.0	6.5	
	<i>b</i> -tag inside top	1.47	1.38	1.06	0.70	0.31	0.13	C	0.63	0.03		_	2.1	5.4	
	$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}$	$ ilde{t}^*$			$t\overline{t}$		ī	$t\bar{t}Z$	$ S_{\lambda}$	B	$S/\sqrt{B}_{10 \text{fb}}$	-1
	$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	700							400	
	$n_\ell = 2$	31.0	14.3	7.07	3.58	1.04	0.33	765	1]	n.a.				
	$\not \! p_T > 100 {\rm GeV}$	19.0	9.99	5.40	2.94	0.91	0.30	131	3		0.35				
	$m_{T2}^{\ell\ell} > 100 \text{ GeV}$	6.05	4.30	2.70	1.65	0.56	0.20	0.65	5(0)	.79) (0.09	5.8	(4.9)	15.8 (14.5	5)
	$m_{T2}^{\ell\ell} > 150 \text{ GeV}$	0.81	1.21	1.06	0.81	0.34	0.14	0.00) (0	.03)	0.02	n	.a.	n.a.	

<u> </u>	1		~	~								
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$\not p_T > 100 \text{ GeV}$	104	61.5	34.8	19.5	6.28	2.11	563	1 2.20	8	8547		
$n_{\rm tag} = 1$	13.1	9.02	5.80	3.60	1.33	0.50	78	9 0.33		80.5	0.01	1.0
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F I '	0 0 0			0.000	0 0		0.0 -	0.00		0.00		
$m_{T_{T}}^{\ell\ell}$	$_{2} > 100$	GeV	6.05	4.30	2.70	1.65	0.56	0.20	$0.65 \ (0.79)$	0.09	5.8(4.9)	15.8 (14)
$m_{T_{T}}^{\ell\ell}$	$_{2} > 150$	GeV	0.81	1.21	1.06	0.81	0.34	0.14	$0.00 \ (0.03)$	0.02	n.a.	n.a.

Similar analysis by a different group Plehn, Spannowsky, Takeuchi 1205.2696.

$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}$	\tilde{t}^*			$t\overline{t}$	$t\bar{t}Z$	W+jets	S/B	$S/\sqrt{B}_{10{\rm fb}^{-1}}$
$m_{ ilde{t}}[{ m GeV}]$	350	400	450	500	600	700					400
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<i>b</i> -tag inside top	1.47	1.38	1.06	0.70	0.31	0.13	0.63	0.03	_	2.1	5.4
$\sqrt{s} = 8 \text{ TeV}$			$ ilde{t}$	\tilde{t}^*			$t\bar{t}$	1	$t\bar{t}Z \parallel S$	B	$S/\sqrt{B}_{10\mathrm{fb}^{-1}}$
$m_{\tilde{t}}[\text{GeV}]$	350	400	450	500	600	700)				400
$n_\ell = 2$	31.0	14.3	7.07	3.58	3 1.04	0.33	8 7651]	n.a.		

$\vec{p}_T > 100 \text{GeV}$	19.0	9.99	5.40	2.94	0.91	0.30	1313		0.35		
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$m_{T2}^{\ell\ell} > 150 \text{ GeV}$	0.81	1.21	1.06	0.81	0.34	0.14	0.00	(0.03)	0.02	n.a.	n.a.

See also:

Cao, Han, Wu, Yan, Zhang, 1206.3865. Dutta, Teruki, Kamon, Kolev, Sinha, Wang, 1207.1873.

33 DANIEL STOLARSKI November 21, 2012 Galileo Galilei Institute

Other paths to naturalness?

• Make stops lighter

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- Squeezed spectrum/ degeneracy

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Theory estimate Kats et. al, 1110.6444 $m_{\tilde{t}}\gtrsim 175\,{
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 $m_{\tilde{t}} \gtrsim 180 \, {
m GeV} \, {
m cDF} \, {
m 1203.4171}$ ATLAS ICHEP searches Various LHC searches ongoing

ATLAS RESULTS

 $m_{\widetilde{\chi}^0_1}$ [GeV]



CMS RESULTS



STEALTH STOPS

Stop mass near top mass recently studied Han, Katz, Krohn, Reece, 1205.5808

Difficult because $\sigma_{top} \sim 6\sigma_{stop}$

Spin correlations

Rapidity gap


STEALTH STOPS

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STEALTH STOPS

Stop mass near top mass recently studied Han, Katz, Krohn, Reece, 1205.5808



See also:

Alves, Buckley, Fox, Lykken, Yu, 1205.5805

with combination

WHAT ABOUT SBOTTOM?

- Naturalness requires left handed sbottom
- $\tilde{b} \to b \, \chi^0$ has more missing energy than corresponding stop
- 2012 data can probe up to ~ 800 GeV sbottom
- Natural SUSY sbottoms out Lee, Sanz, Trott, 1204.0802



SBOTTOM BOUNDS



GLUNO BOUNDS



CONCLUSIONS

- Stops are lightest indication of naturalness
- All hadronic final states are good way to search for missing energy
- Top tagging combined with other simple cuts can bring out stop signal with data already taken
- Many other stop scenarios, a lot of work has been done
- Searches for stops and gluinos are well underway
- Modern techniques helped disfavor natural vanilla stops

#