Title: Stealthy, Composite Stops

Date: Nov 13, 2012 01:00 PM

URL: http://pirsa.org/12110063

Abstract: Light third generation superpartners are one way to avoid bounds on new physics from the early LHC. We will review the theory and phenomenology of light stops and highlight a particular UV model based a partially composite electroweak sector through Seiberg duality.

STEALTHY COMPOSITE STOPS

arXiv: 1201.1293, 1211.soon

Flip Tanedo

Cornell University

In collaboration with C. Csáki, R. Houtz, & J. Terning

Perimeter Institute Particle Physics Seminar, 13 Nov 2012

Physics of the early LHC

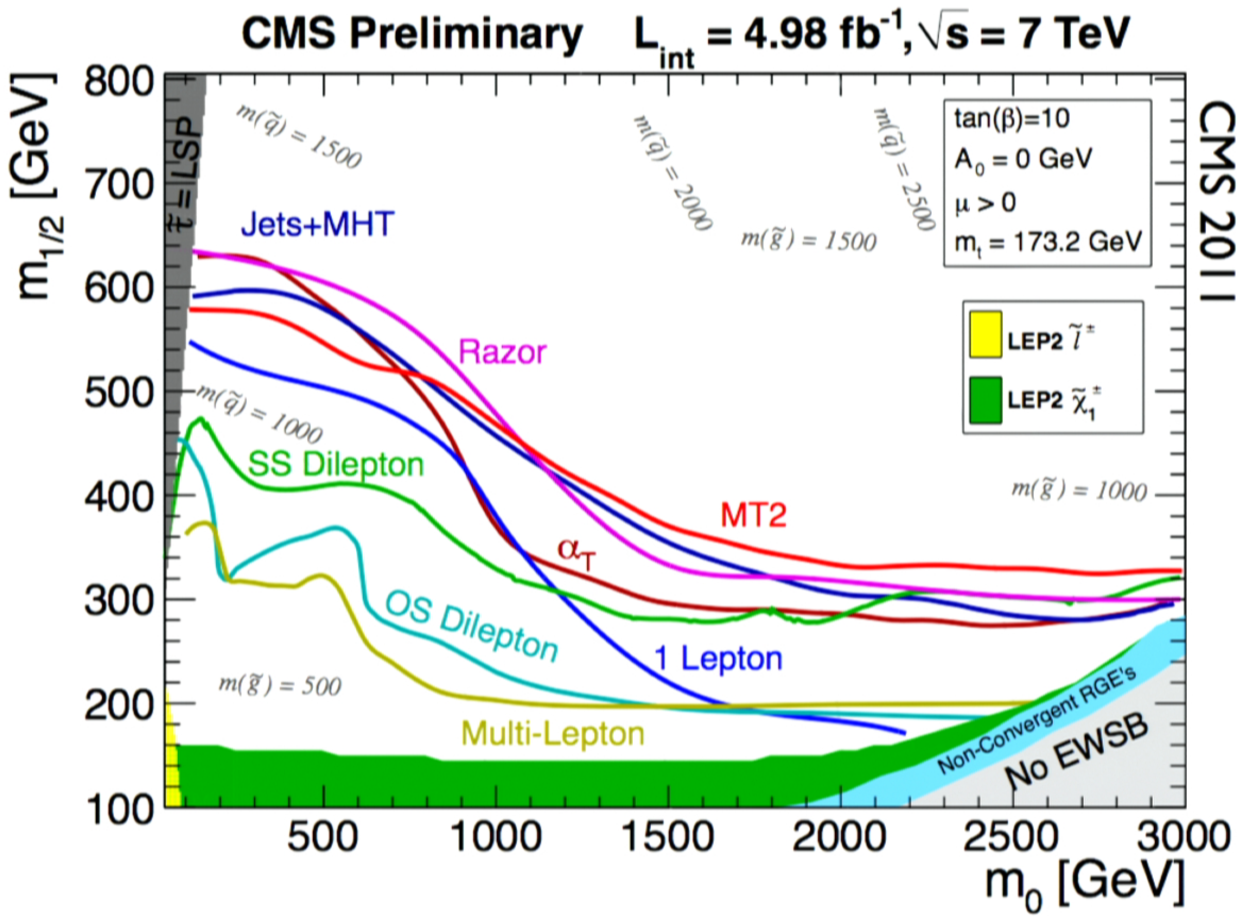
Great for the Standard Model...

... not much for new physics

What ever happened to naturalness ?

supersymmetry ?

LHC vs. SUSY


CMS Preliminary L_{int} = 4.98 fb^{-1}, $\sqrt{s}$ = 7 TeV
$m_{1/2}$ [GeV]
m_0 [GeV]
CMS 2011
tan(β)=10
A_0 = 0 GeV
μ > 0
m_t = 173.2 GeV
LEP2 $\tilde{l}^{\pm}$
LEP2 $\tilde{\chi}_1^{\pm}$
$\tilde{\tau}$ = LSP
Jets+MHT
Razor
MT2
α_T
SS Dilepton
OS Dilepton
1 Lepton
Multi-Lepton
Non-Convergent RGE's
No EWSB
$m(\tilde{q})$ = 1500
$m(\tilde{q})$ = 2000
$m(\tilde{q})$ = 2500
$m(\tilde{q})$ = 1000
$m(\tilde{g})$ = 1500
$m(\tilde{g})$ = 1000
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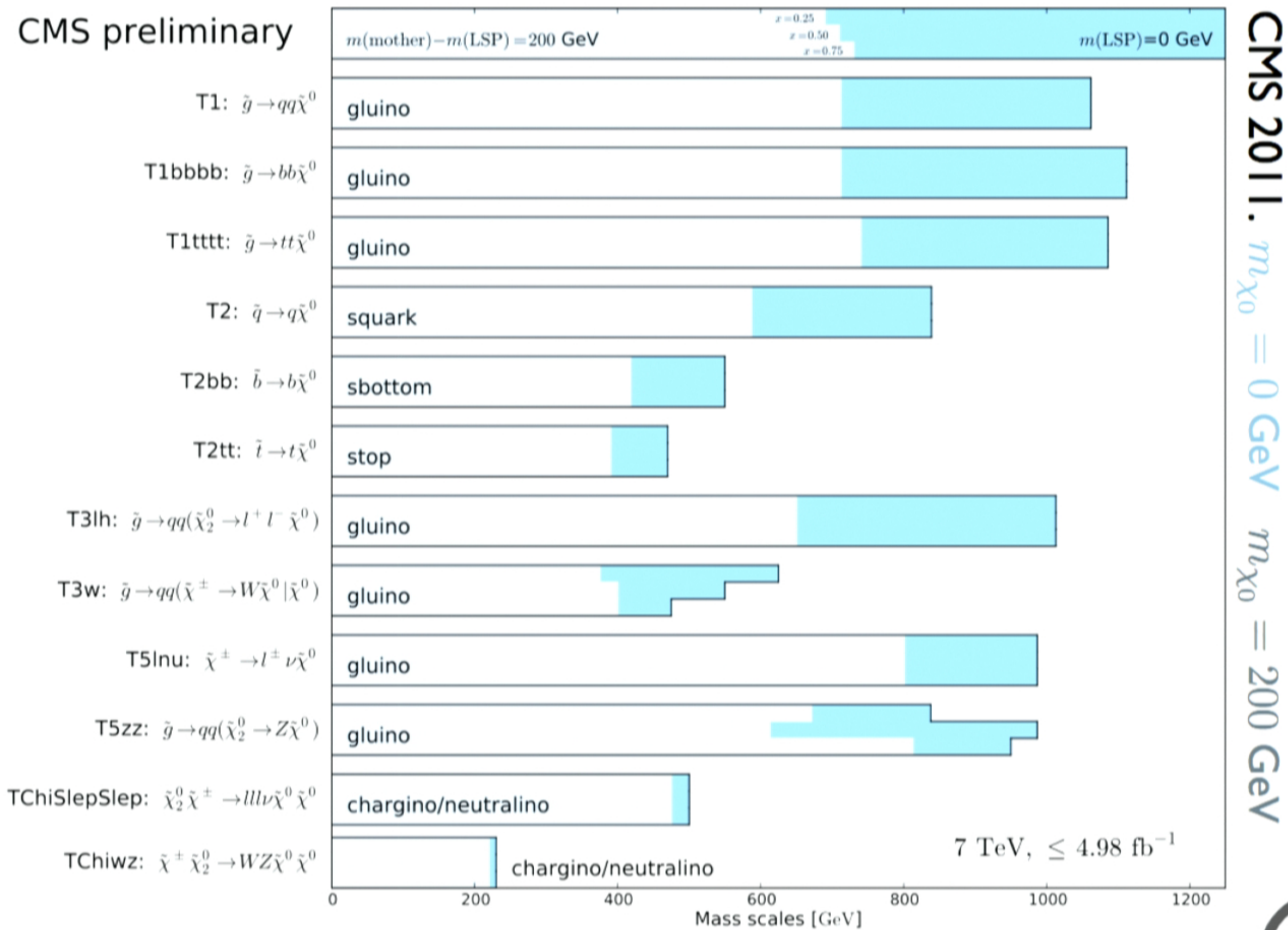
LHC vs. SUSY



Flip Tanedo pt267@cornell.edu Stealthy Composite Stops

LHC vs. SUSY

What it looks like:

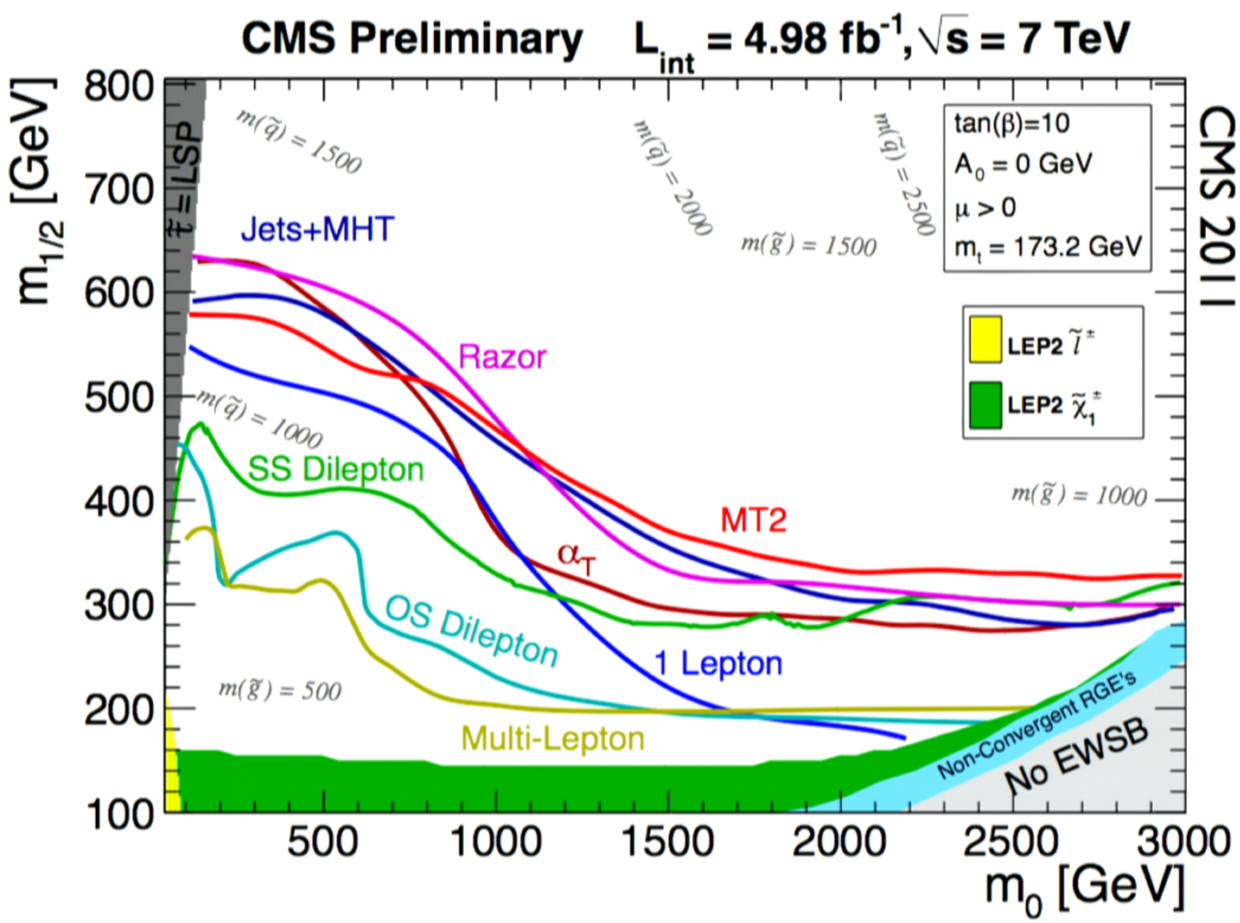
Low-scale supersymmetry is dead. SM is tuned?

What this is really telling us:

There aren't 6 degenerate squarks or an EW-scale color octet that decay to missing energy.

If SUSY exists, then it has an interesting spectrum.

LHC vs. SUSY



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Minimally natural SUSY

The relevant question is:

Can SUSY still solve the Hierarchy problem?
(subject to LHC constraints on spectrum)

Yes. 'Natural SUSY'

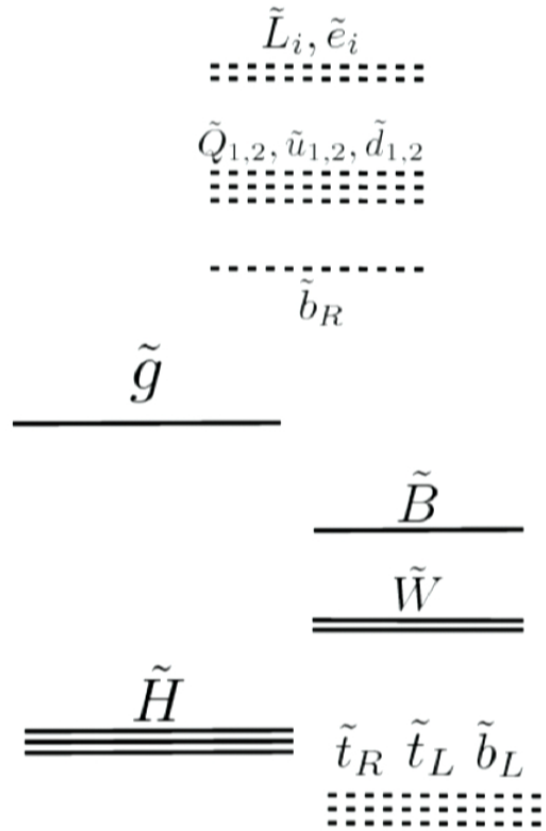
Papucci, Ruderman, Weiler (1110.6926), Brust, Katz, Lawrence, Sundrum (1110.6926), Kats, Meade, Reece, Shih (1110.6444). Dimopoulos, Giudice (hep-ph/9507282), Cohen, Kaplan, Nelson (hep-ph/9607394)

Just keep the superpartners we need for naturalness, allow others to decouple at low energies.

Minimally natural SUSY

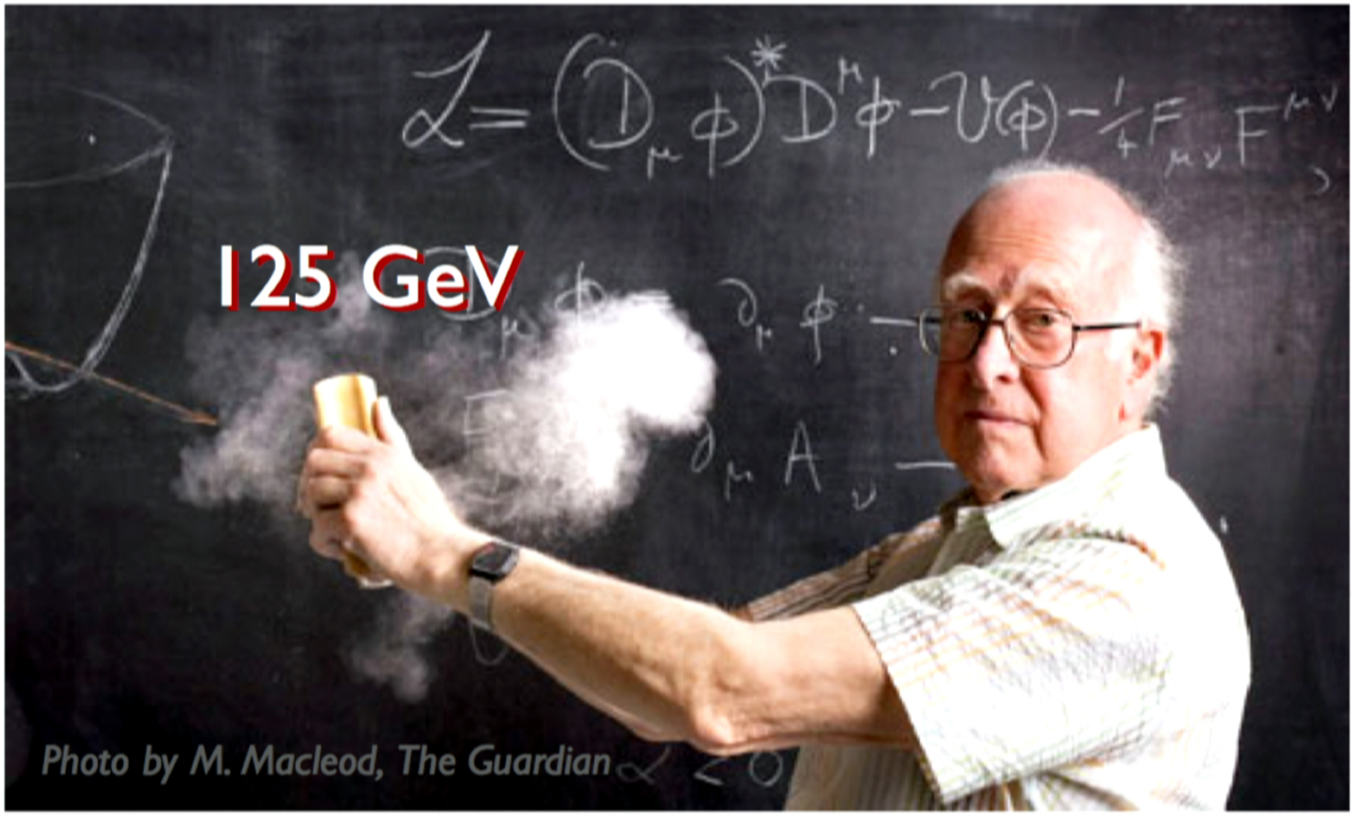
Ingredients:

1. Light stops
2. Light Higgsinos
3. Not-too-heavy gluinos
4. Light-ish EW-inos
5. Decouple the rest



From: Papucci, Ruderman, Weiler
(1110.6926)

A slight complication



Natural SUSY vs. $m_h = 125$ GeV

Tree level contribution from D-term quartic

$$m^2_{h,\text{MSSM}} = m_Z^2 c_{2\beta}^2 + \frac{3m_t^4}{4\pi^2 v^2}\left[\log\left(\frac{M_S^2}{m_t^2}\right) + \text{mix}\right]$$

$$m^2_{h,\text{NMSSM}} = m_Z^2 c_{2\beta}^2 + \lambda^2 v^2 s_{2\beta}^2 + \text{loops}$$

New tree-level quartic contribution from singlet

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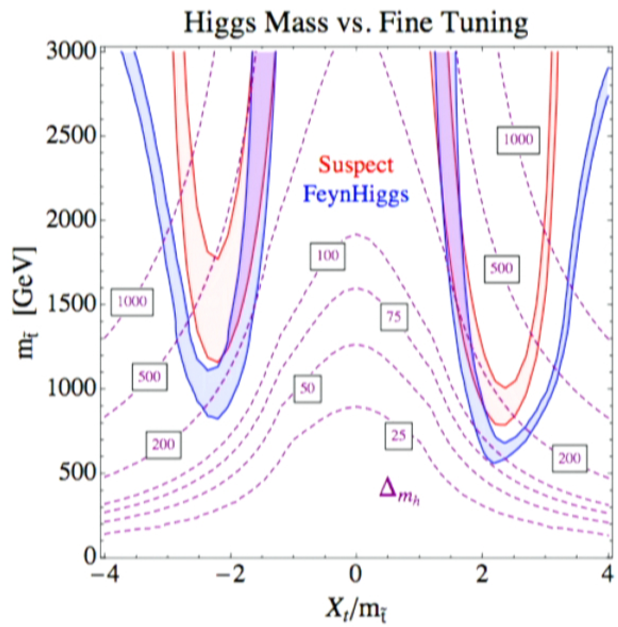
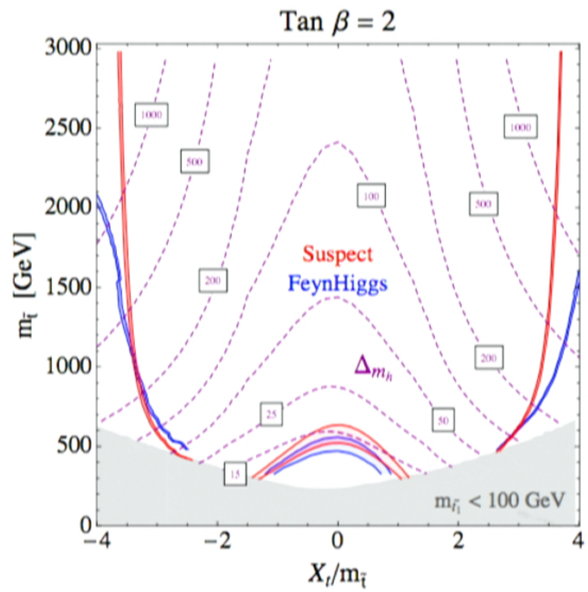
New tree-level quartic contribution from singlet

$m_h = 125$ GeV tuning in the MSSM vs NMSSM





Hall, Pinner Ruderman (1112.2703)

Light stops: direct production

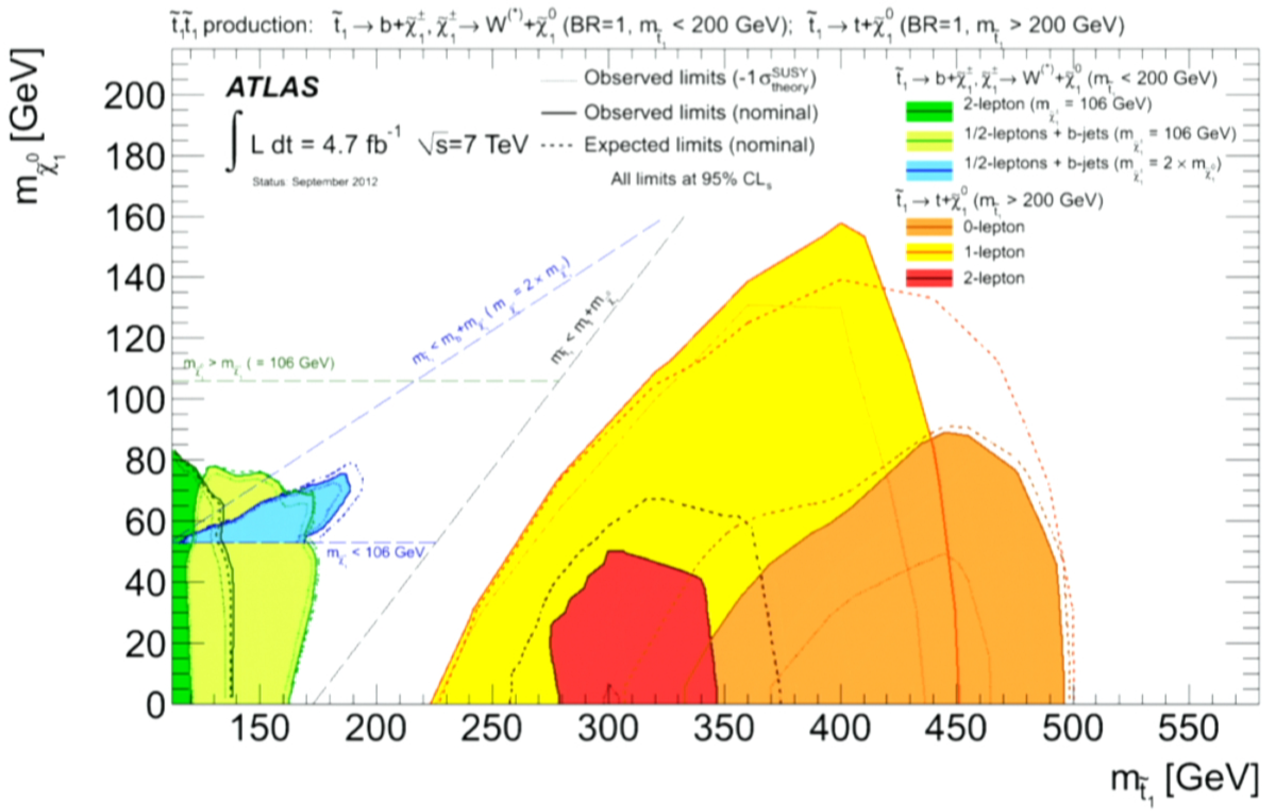
$$\tilde{t} \to bW^+\chi^0 \quad \text{vs.} \quad t \to bW^+$$

- **3 body**, *lightish stop*: Decay via off-shell top
  Can use $m_{\ell b}$ distributions. Chou & Peskin hep-ph/9909536
- **2 body**, *heavyish stop*: Decay via on-shell top
  Can make use of the MET distribution. Fermilab group 1205.5805
- **1 body**, *stealth stop*: $m_{\chi^0} \lll m_{\tilde{t}}$, looks like $t\bar{t}$
  "Blind spot" in current analyses Katz, Meade, Reece, Shih 1110.6444

Other: Displaced decays, stoponium, flavor violation

Light stops

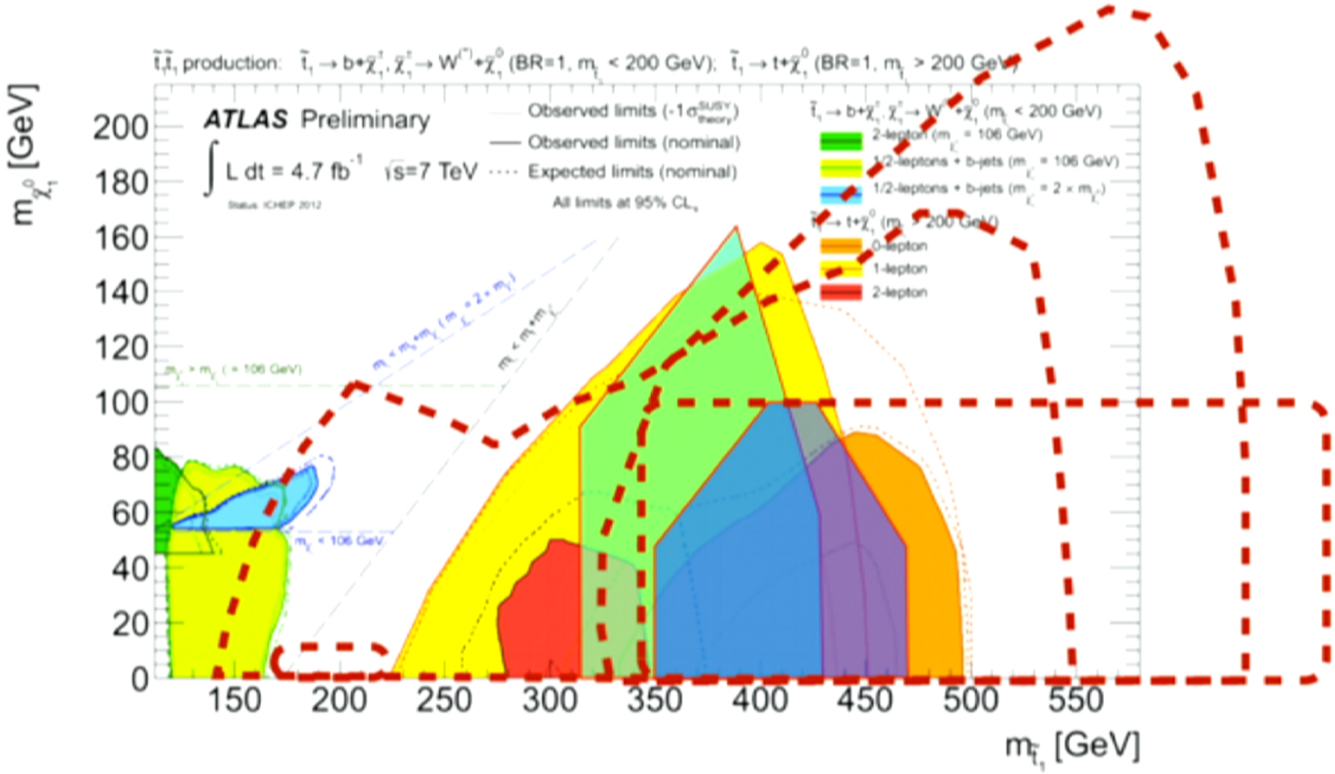
Experimental limits on direct pair production



ATLAS: 1208.4305, 1209.2102, 1208.1447, 1208.2590, 1209.4186

Light stops

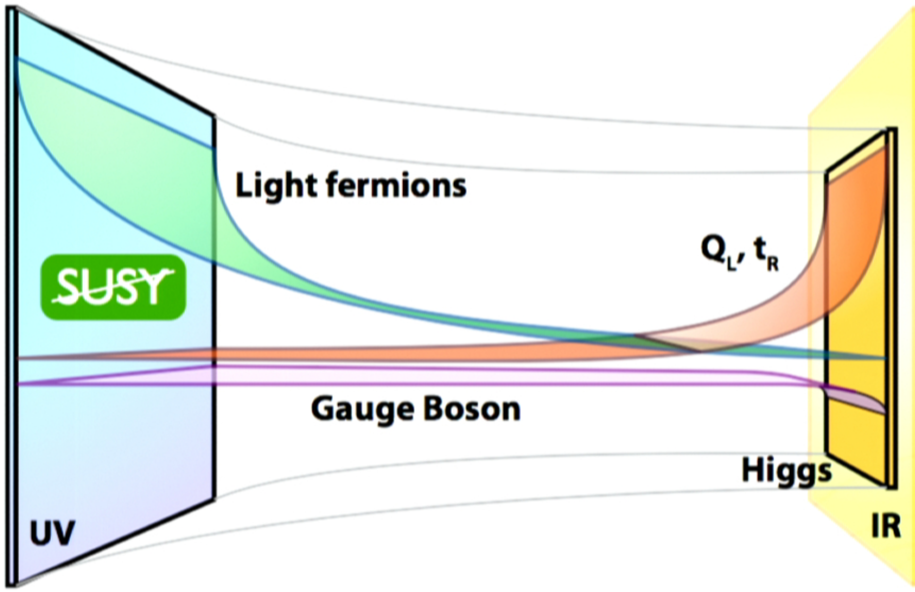
estimated reach with 20/fb @ 8 TeV



Daniele Alves, *Implications of LHC results for TeV-scale physics*, CERN 2012

Warped / Emergent / Accidental SUSY

Supersymmetrize the Randall-Sundrum picture:

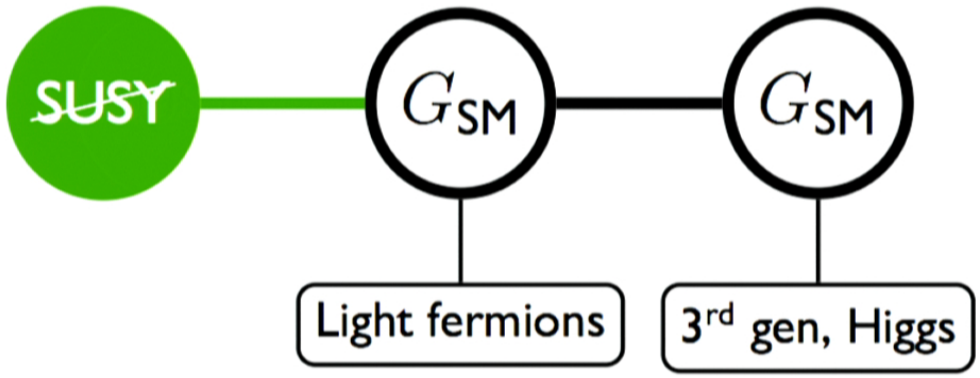


Warped fermion masses → squark spectrum

Gherghetta hep-ph/0302001; Maryland/Hopkins 0909.5430, 1110.6670

Deconstructed SUSY

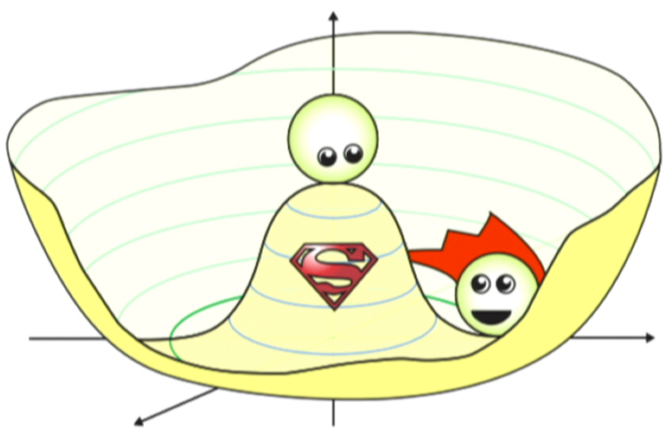
Deconstruct previous picture:



Generic feature: conventional unification difficult.
Craig, Green, Katz 1103.3708; See also Craig, McCullough, Thaler 1203.1622

SUSY Pseudo-Goldstone Higgs

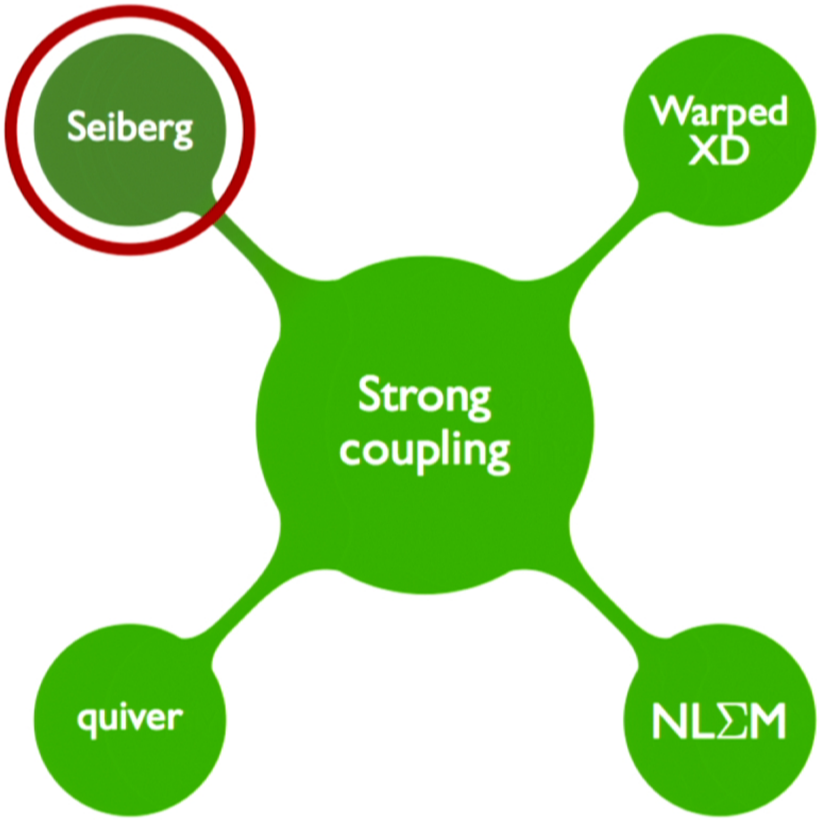
SUSY Minimal Composite Higgs



Derivative couplings of Higgs to strong sector, Yukawas from mixing with elementary states. Higgs potential different from non-SUSY case.

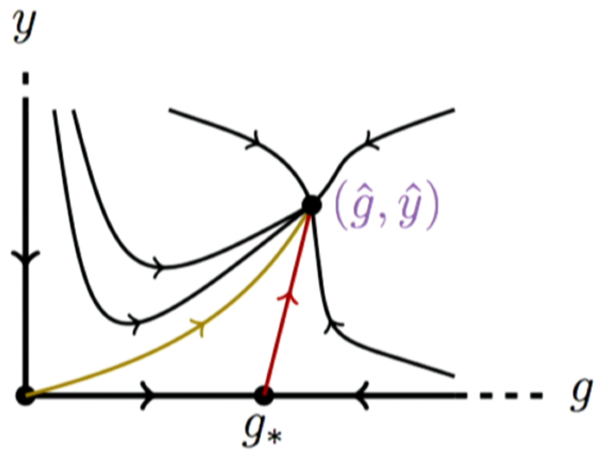
Gripaios, Redi 1004.5114

UV Models: Light Stops $\leftrightarrow$ compositeness



Seiberg Duality

Conformal window: SQCD with F flavors and N colors is dual to a magnetic theory with F flavors and $n = F - N$ colors.



Magnetic theory: dual quarks & mesons with Yukawa interaction

See, e.g., Strassler hep-th/0309149

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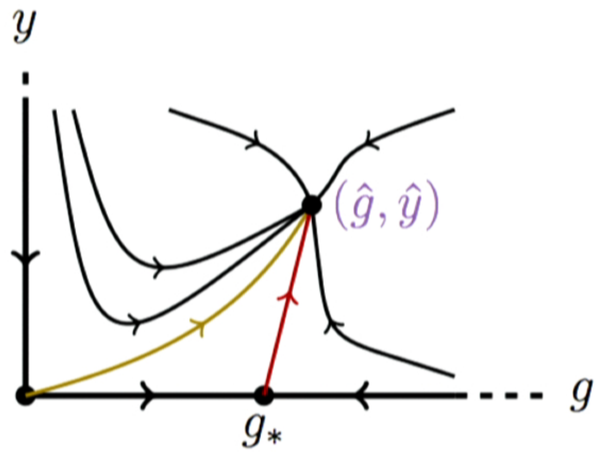

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A composite electroweak sector?

Can the W and Z be composite?
e.g. ρ meson: massive, spin-1 resonance

Abbot & Farhi ('81): model via complementarity
No explanation for electroweak couplings

Seiberg duality ('95): emergent magnetic gauge group
Komargodski ('11): magnetic gauge fields $\Leftrightarrow \rho$

Attempts: Maekawa & Takahashi ('96), Maekawa & Sato ('96), Sannino ('11)

A composite electroweak sector?

	SU(6)	SU$(8)_1$	SU$(8)_2$	$U(1)_V$	$U(1)_R$
$\mathcal{Q}$	$\square$	$\bar{\square}$	1	$1/24$	$1/4$
$\bar{\mathcal{Q}}$	$\bar{\square}$	1	$\bar{\square}$	$-1/24$	$1/4$

	SU$(2)_L$	SU$(8)_1$	SU$(8)_2$	$U(1)_V$	$U(1)_R$
q	$\square$	$\square$	1	$1/8$	$1/4$
$\bar{q}$	$\bar{\square}$	1	$\square$	$-1/8$	$1/4$
M	1	$\bar{\square}$	$\bar{\square}$	0	$3/2$

Magnetic Yukawa coupling: $\bar{q}Mq$. Flavor groups:

$$\text{SU}(8)_1 \supset \text{SU}(3) \times \text{SU}(3) \times \text{SU}(2)_{R,1}$$
$$\text{SU}(8)_2 \supset \text{SU}(3)_G \times \text{SU}(3) \times \text{SU}(2)_{R,2}$$

A composite electroweak sector?

Accommodates SM spectrum + extra pair of Higgses + junk

$$q = \begin{pmatrix} t_n \\ b_n \end{pmatrix}_L, \begin{pmatrix} c_n \\ s_n \end{pmatrix}_L, H_u, H_d'$$

$$\bar{q} = \begin{pmatrix} \nu_{\ell,i} \\ \ell_i \end{pmatrix}_L, \begin{pmatrix} u_n \\ d_n \end{pmatrix}_L, H_d, H_u'$$

SU(3) × SU(3) × SU(2)$_{R,1}$

$$\left(\begin{array}{cc|cc} \multicolumn{2}{c|}{V_n^{ab}} & \bar{\nu}_{\ell,i} & \bar{\ell}_i \\ \hline (*C+X)^1_{mn} & (*C+X)^2_{mn} & \bar{u}_n & \bar{d}_n \\ \hline \bar{b}_n & \bar{s}_n & S & T \\ \bar{t}_n & \bar{c}_n & T^+ & S' \end{array}\right)$$

SU(3)$_G$ × SU(3) × SU(2)$_{R,2}$

A composite electroweak sector?

Features:

- $U(1)_Y \in$ anomaly-free diagonal flavor generators
- Decoupling junk by introducing elementary conjugates $(\bar{V}, \bar{C}, \bar{X})$ automatically cancels anomalies.
- B & L conserved; R-parity accidental

One big problem:

Expect magnetic coupling to be much stronger than EW couplings.

e.g. residual strong coupling between nucleons

Partial Compositeness

Craig, Stolarski, Thaler 1106.2164; Csáki, Shirman, Terning 1106.3074

Work around: mix with elementary states

i.e. pull brane-localized fields into the bulk
... but need additional link fields $\mathcal{H}, \bar{\mathcal{H}}$.

$$\mathsf{SU}(2)_{\mathsf{el}} \times \mathsf{SU}(2)_{\mathsf{mag}} \xrightarrow{\mathcal{H}} \mathsf{SU}(2)_L$$

$$\frac{1}{g^2} = \frac{1}{g^2_{\mathsf{comp}}} + \frac{1}{g^2_{\mathsf{elem}}}$$

Minimize matter content:

only Higgs and 3rd generation composite

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McSSM

Minimal Composite Supersymmetric SM

McSupersymmetry

Minimal Composite Supersymmetric SM

	SU(4)	SU$(6)_1$	SU$(6)_2$	$U(1)_V$	$U(1)_R$
$\mathcal{Q}$	$\square$	$\bar{\square}$	1	1	$1/3$
$\bar{\mathcal{Q}}$	$\bar{\square}$	1	$\bar{\square}$	-1	$1/3$

	SU$(2)_{\text{mag}}$	SU$(6)_1$	SU$(6)_2$	$U(1)_V$	$U(1)_R$
q	$\square$	$\square$	1	2	$2/3$
$\bar{q}$	$\bar{\square}$	1	$\square$	-2	$2/3$
M	1	$\bar{\square}$	$\bar{\square}$	0	$2/3$

$$\text{SU}(6)_1 \supset \text{SU}(3)_c \times \text{SU}(2)_{\text{elem}} \times \text{U}(1)_Y \qquad q = Q_3, \mathcal{H}, H_d$$

$$\text{SU}(6)_2 \supset \text{SU}(3)_X \times \text{SU}(2)_{\text{elem}} \times \text{U}(1)_Y \qquad \bar{q} = X, \bar{\mathcal{H}}, H_u$$

Minimal Composite Supersymmetric SM

$$\text{SU}(6)_1 \supset \text{SU}(3)_c \times \text{SU}(2)_{\text{elem}} \times \text{U}(1)_Y \qquad q = Q_3, \mathcal{H}, H_d$$
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$$W \sim \begin{pmatrix} Q_3 & \mathcal{H} & H_d \end{pmatrix} \begin{pmatrix} V & U & \bar{t} \\ E & G+P & \phi_u \\ R & \phi_d & S \end{pmatrix} \begin{pmatrix} X \\ \bar{\mathcal{H}} \\ H_u \end{pmatrix}$$

- Decouple $V, U, \phi_{u,d}, R \Rightarrow$ cancels $\text{SU}(2)_{\text{elem}}$ & $\text{SU}(3)_c$ anomalies
- X & E: $\text{SU}(2)^2_{\text{mag}} \times \text{U}(1)_Y$ anomaly $\rightarrow \text{SU}(2)^2_{\text{elem}} \times \text{U}(1)_Y$
- ... cancels upon adding remaining SM elementary fermions
- Lose: accidental R-parity

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Minimal Composite Supersymmetric SM

Tune electric theory with mass terms to give P, S tadpoles

$$W \supset yP(\mathcal{H}\bar{\mathcal{H}} - \mathcal{F}^2) + yS(H_uH_d - f^2) + yQ_3H_u\bar{t} + y\mathcal{H}EX$$

$\mathrm{SU}(2)_{\mathrm{elem}} \times \mathrm{SU}(2)_{\mathrm{mag}}$ — 'NMSSM' — Yukawa — Anomaly

- elem×mag→ L gives heavy W', Z' 'KK gauge bosons'
- $\sim$ RS deconstruction, but no anarchic flavor
- **Tuning**: $\mathcal{F} \gg f$, $\tilde{g}$ contribution to m_h^2 ($\sim$10%),

~~SUSY~~ across a duality

Last ingredient for full theory: SUSY breaking terms

Csáki, Randall, Terning 1201.1293

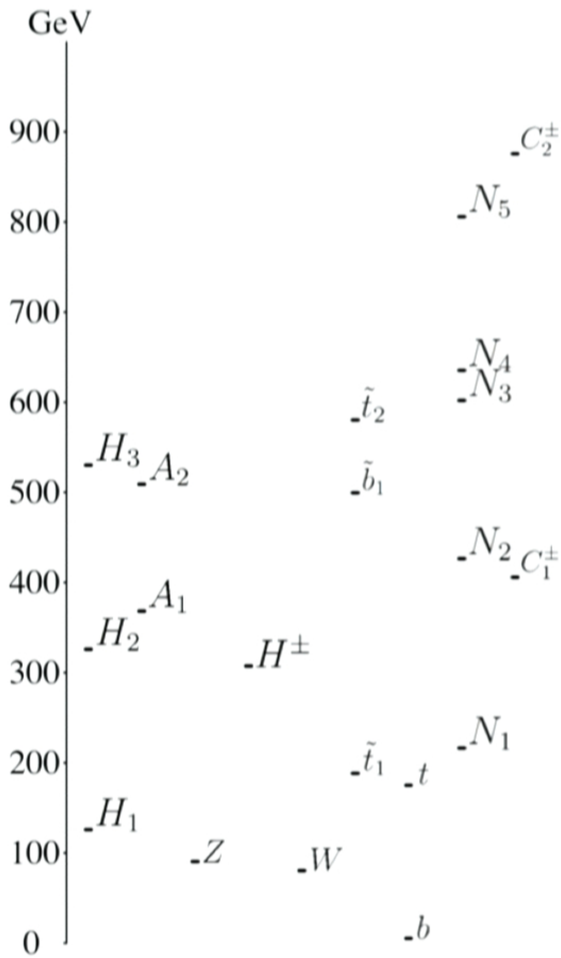
Tool: analytic continuation into superspace

Cheng & Shadmi th/9801146, Arkani-Hamed & Rattazzi th/9804068

Idea: ~~SUSY~~ $\Rightarrow$ soft terms in electric theory

- Parameterize as superspace spurions
- Promote spurions to superfields
- These exhibit a $U(1)_A$ background symmetry
- Can use this to determine LO magnetic soft terms

Sample spectrum: stealth stop

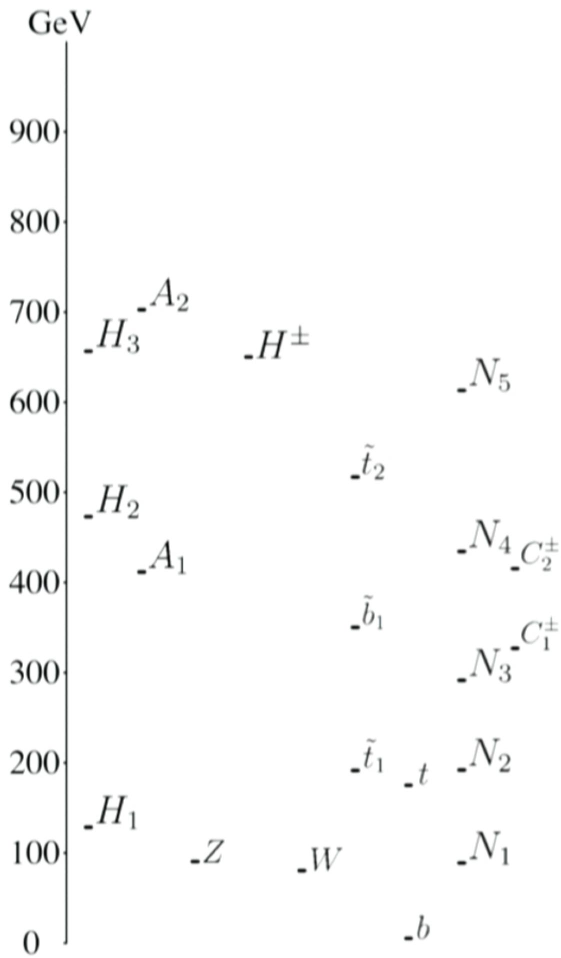


- $\tilde{t} \to t + \tilde{G}$
- $\tilde{G}$ light, low MET
- Possible displaced vertex

$$\Gamma = \frac{m_{\tilde{t}}^5}{16\pi F^2}\left(1 - \frac{m_t^2}{m_{\tilde{t}}^2}\right)^4$$

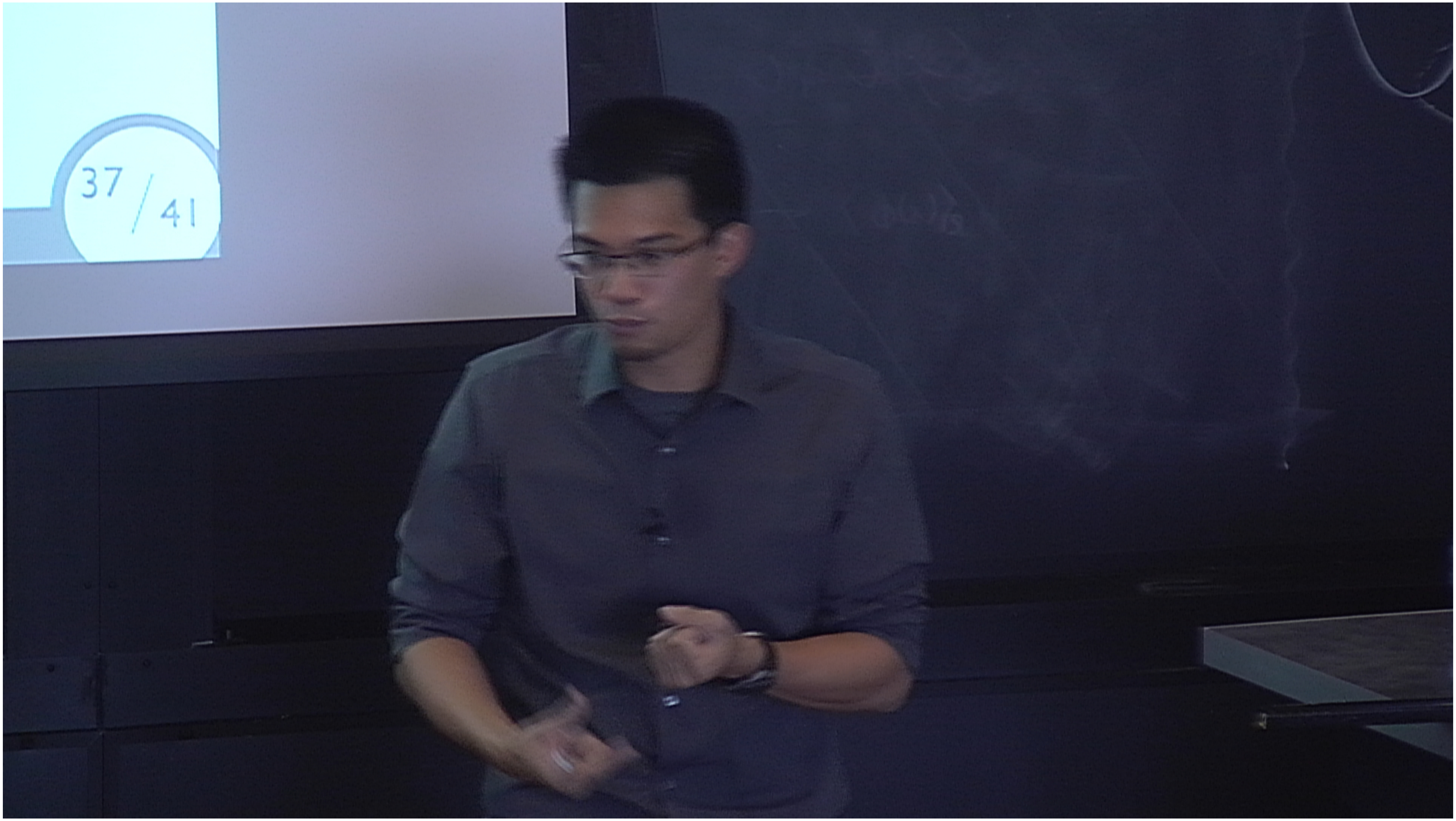
$\tilde{t}_1$	188 GeV	$\to t + \tilde{G}$
$\tilde{b}_1$	499 GeV	$\to \tilde{t}_1 + W$ (97%)
$\tilde{t}_2$	580 GeV	$\to \tilde{t}_1 + Z$ (50%)
N_1	216 GeV	
$\tilde{H}^\pm$	307 GeV	

Sample spectrum: minimal gauge mediation



- $m(N_1) < m(\tilde{t}_1)$: MET
- Heavy $\tilde{g}$, $\tilde{q}_{1,2}$
- Reduced rate for CMSSM-type signal

N_1	88 GeV	$\to \gamma + \tilde{G}$
$\tilde{t}_1$	191 GeV	$\to t^* + N_1$
N_2	192 GeV	
N_3	291 GeV	
C_1	350 GeV	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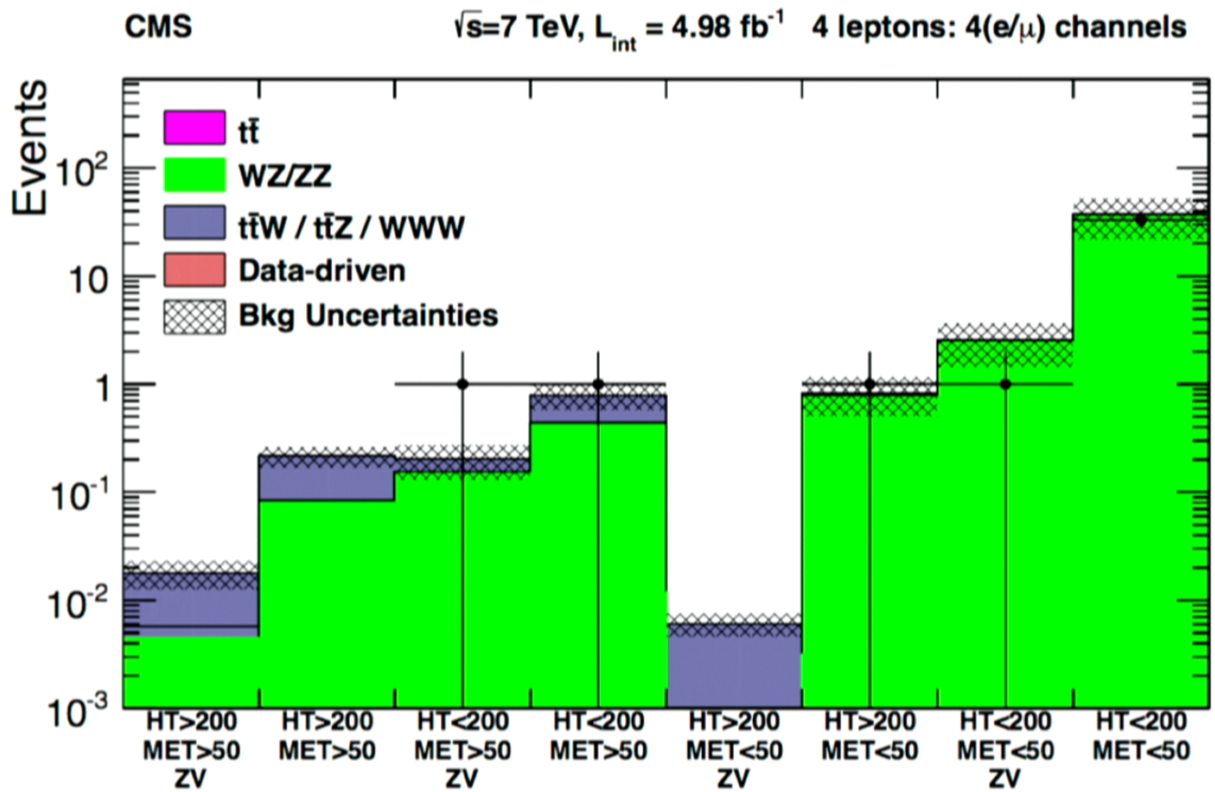
McPhenomenology: multileptons



1204.5341

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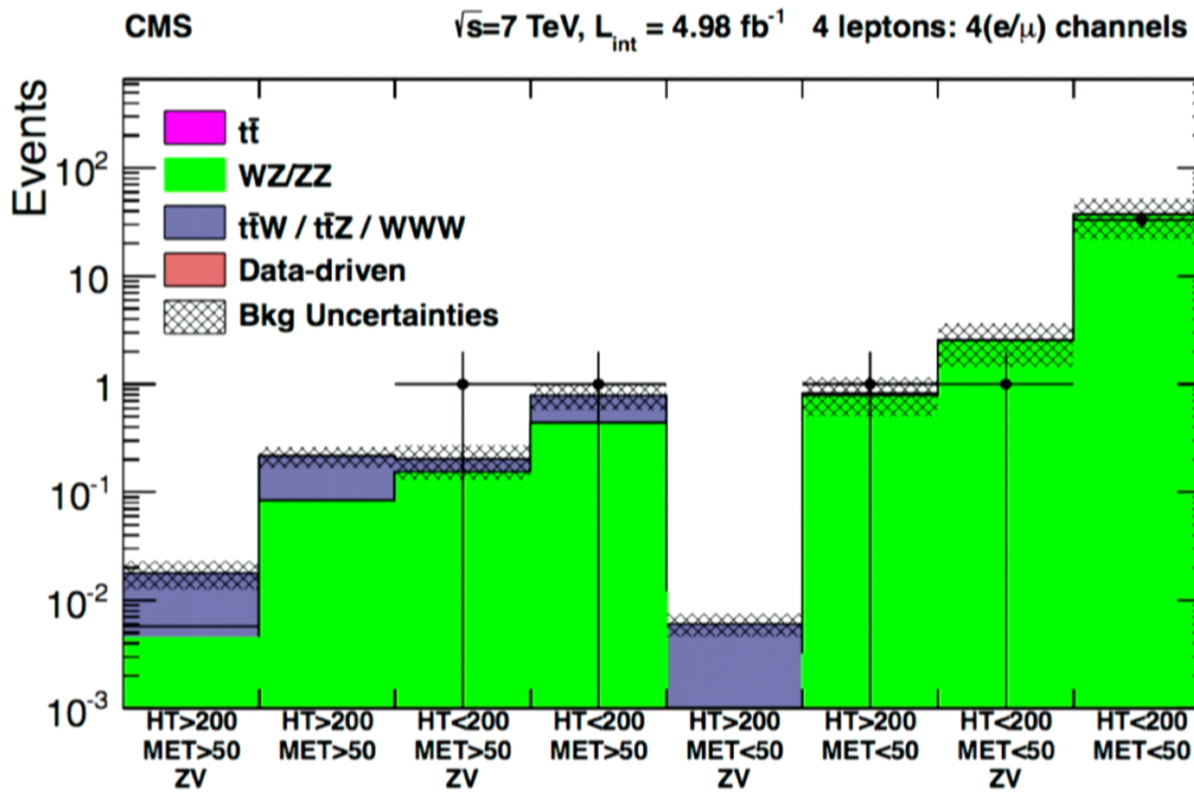

1204.5341

Conclusions and directions

Model building

- McSSM: class of light stops models via Seiberg duality
- To do: leftover tuning in fermion spectrum, tadpoles
- To do: R-parity, flavor, dark matter, unification

Phenomenology

- parameters $\rightarrow$ NMSSMTools $\rightarrow$ MG/Pythia/PGS
- Ongoing: 4ℓ, 3ℓ reach at 14 TeV
- To do: effect of additional states from UV theory

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