SUSY beyond the lampost

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Allanach & BMG, to appear

Outline

SUSY, but not as we know it

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Closing the loopholes

SUSY can stabilize the electroweak hierarchy all the way up to the Planck scale ...

... but the LHC has ruled out the minimal models which do this.

 \implies Hubris.

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SUSY @ LHC



SUSY @ LHC

There are now strong bounds on

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- gluino mass
- common squark mass



Even before LHC, LEP et al. put strong constraints on less-minimal models, e.g. MSSM, NMSSM ...

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Constraints

- ▶ direct searches, ≥ 100 GeV
- nucleon decay, $\gtrsim 10^{16}~{
 m GeV}$
- flavour physics, $\gtrsim 10^{6}$ GeV
- electroweak precision tests, $\gtrsim 10^3$ GeV

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Why no superpartners @ LEP?



 m^2/μ^2

So what, if anything, should we look for now?

Less ambitious: little hierarchy problem. (1-10 TeV)

Brust & al., 1110.6670

Even then, constraints are hard to evade.

Can we exclude a natural solution to the little hierarchy problem?

We only need a few light d. o. f. to solve the hierarchy up to 10 TeV

Dimopoulos & Georgi 1981, Sakai 1981

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A few d. o. f. may not be so hard to hide ...



What must be within reach of the LHC?

• A \tilde{Q}_R^3 and \tilde{U}_R^3 ?







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Loophole *I*. Stable stops.





CMS PAS EXO-11-022



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Higgsino masses $\tilde{H}_{u,d}$?

 $\blacktriangleright W \supset \int d^2 \theta \mu H_u H_d \Longrightarrow m_Z^2 \sim -m_{H^u}^2 - |\mu|^2$

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(Also anomaly cancellation).

Loophole *II*.

$$> 2(\tilde{t} \to t\tilde{\chi}^0) \Longrightarrow t\bar{t} + \not\!\!\! E_T$$

$$\blacktriangleright 2(\tilde{t} \rightarrow b\tilde{\chi}^{\pm}) \implies b\overline{b} + \not\!\!\! E_T$$

Kats & Shih, 1106.0030

Sakurai & Takayama., 1106.3794

Loophole *II*



Loophole // bounds are (and always will be) weak

Beenakker et al., 1006.4771

Small x-section at $m_{\tilde{t}} - m_{\tilde{\chi}} \gg m_t$

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Loophole //



CDF, 2.7/*fb*: *m_t* > 150*GeV*

CDF, 0912.1308

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(Loop)loophole //. Non-standard Higgsino mass.

•
$$W \supset \int d^2 \theta \mu H_u H_d \implies m_Z^2 \sim -m_{H^u}^2 - |\mu|^2$$

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• or
$$W \supset \int d^4 \theta \frac{X^{\dagger} X}{M^3} D_{\alpha} H_u D^{\alpha} H_d$$

or extended Higgs sector ...

A Gluino?



 $\delta m_{\tilde{t}}^2 \sim rac{8lpha_s}{3\pi} M_3^2 \log rac{\Lambda}{m_{\tilde{t}}}$ Fighther M_3 or Λ not large $M_3 \lesssim 2m_{\tilde{t}}$

Essig & al., 1110.6443

Kats & al., 1110.6444

Brust & al., 1110.6670

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Papucci & al., 1110.6926

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Loophole III.

2(*ỹ* → *t̃t*)
2(*t̃* → *tχ̃*⁰) ⇒ *tt̄* + ∉_T
2(*t̃* → *bχ̃*[±]) ⇒ *bb̄* + ∉_T

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Loophole III



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Are there models for this?

More minimal SUSY

Flavourful SUSY

Cohen, Kaplan, & Nelson, 9607394

Dimopoulos & Giudice, 1995

Barbieri & al., 1004.2256, 1105.2296

Craig, Green, & Katz, 1103.3708

Gherghetta and Pomarol, 0302001

Sundrum, 0909.5430

BMG & Redi, 1004.5114

Gherghetta & al., 1104.3171

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Csaki, Randall & Terning, 1201.1293

Partial SUSY

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One more loophole ...

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Is *R*-parity sufficient to prevent proton decay?

• $W \supset \frac{QQQL}{\Lambda}$

Yanagida & Sakai, 1982

Weinberg, 1982

Brust & al., 1110.6670



More loopholes ...

Loophole *I*[']. (Collider) stable stop.

Loophole *I*". RPV stop decay.

- QLD or UDD
- $2\tilde{t} \rightarrow 4q$ or 2q2b or 2q2l or 2b2l
- a.k.a leptoquark/diquark

BMG, 0910.1789

BMG & al., 1010.3962

Giudice, BMG, & Sundrum, 1105.3161

Also single production of 'diquark'

Giudice, BMG, & Sundrum, 1105.3161

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Loophole III'. What if we add the gluino?

- Boost production x-section
- ▶ $2\tilde{g} \rightarrow 2\tilde{t}2t$
- Followed by RPV stop decays.
- The \tilde{g} is Majorana: SS lepton signature. And MET.

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What if the $\tilde{b} \subset \tilde{Q}_3$ were lightest?

- ▶ 2 $ilde{g}$ ightarrow 2 $ilde{b}$ 2b
- With *UDD*, $\tilde{b} \rightarrow tq$
- SS top \implies SS leptons again
- With *QLD*, get SS leptons (possibly τ)

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Prospects for same sign taus ...?

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Existing limits

- Final state: SS lepton plus b-jets plus some MET.
- ATLAS SS μ search, 1.6/fb

ATLAS-CONF-2011-126



BMG & Allanach, to appear

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Summary

- The LHC will not kill SUSY ...
- ... but it will come pretty close
- Must work to close the loopholes

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RPV and same-sign tops