Non-SUSY scenarios with MET signatures

Ben Gripaios

CERN TH

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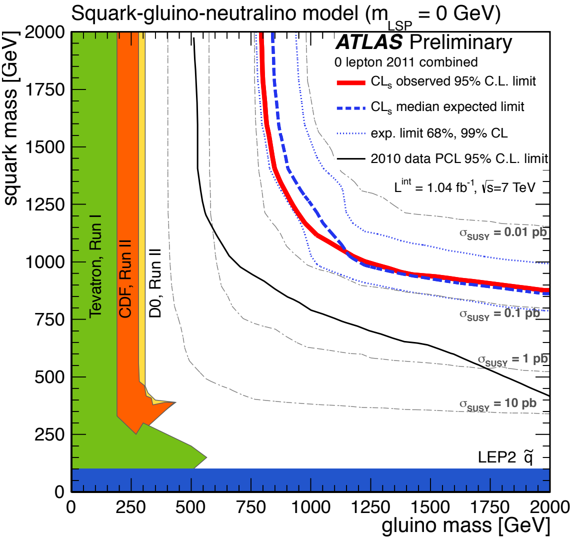
Outline

- SUSY, but not as we know it
- everything else
- a proposal: counting DM particles

SUSY, but not as we know it

SUSY, but not as we know it

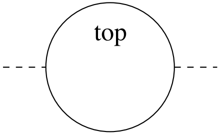
Isn't SUSY dead already?



SUSY, but not as we know it

There are now strong bounds on

- gluino mass
- common squark mass



SUSY, but not as we know it

Naturalness at the LHC $\implies$

- stop quarks
- a higgsino

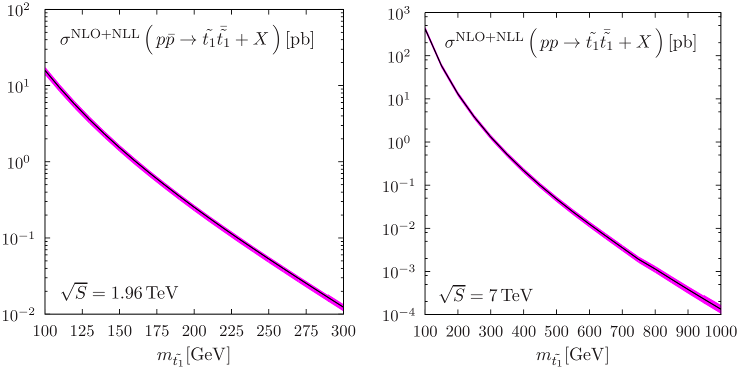
$$m_Z^2 \sim -m_{H^u}^2 - |\mu|^2$$

So could see only

- $2(\tilde{t} \to t\tilde{\chi}^0) \implies t\bar{t} + \not{E}_T$
- $2(\tilde{t} \to b\tilde{\chi}^\pm) \implies b\bar{b} + \not{E}_T$

SUSY, but not as we know it

Stop bounds are (and always will be) weak



Beenakker et al., 1006.4771

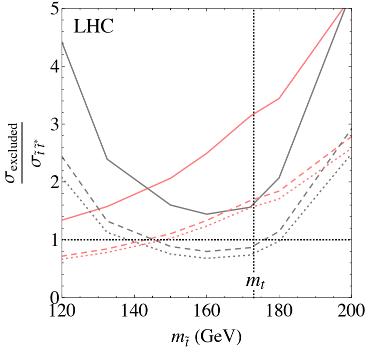
Small x-section at $m_{\tilde{t}} - m_{\tilde{\chi}} \gg m_t$

SUSY, but not as we know it

Stop bounds are (and always will be) weak
CDF, $2.7/fb$: $m_{\tilde{t}} > 150 GeV$

CDF, 0912.1308

Kats & Shih, 1106.0030



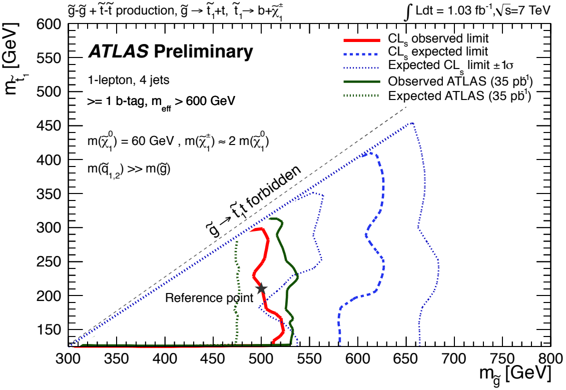
ATLAS, $3/fb$: $m_{\tilde{t}} > 180 GeV$

Kats & Shih, 1106.0030

SUSY, but not as we know it

Gluino: $\delta m_{\tilde{t}}^2 \sim \frac{8\alpha_s}{3\pi} M_3^2 \log \frac{\Lambda}{m_{\tilde{t}}}$

- Either M_3 or Λ not large
- $2(\tilde{g} \to \tilde{t}t)$



ATLAS-CONF-2011-130

SUSY, but not as we know it

Are there models for this?

- More minimal SUSY

Cohen, Kaplan, & Nelson, 9607394

- Flavourful SUSY

Dimopoulos & Giudice, 1995

Barbieri & al., 1004.2256, 1105.2296

Craig, Green, & Katz, 1103.3708

- Partial SUSY

Gherghetta and Pomarol, 0302001

Sundrum, 0909.5430

BMG & Redi, 1004.5114

Gherghetta & al., 1104.3171

SUSY, but not as we know it

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

- $W \supset \frac{QQQL}{\Lambda}$

Yanagida & Sakai, 1982

Weinberg, 1982

- Consequences for colliders and DM

The LHC will not kill SUSY . . .

… but it is unlikely to be the SUSY we* know and love.

* Well, some of us.

Everything else

Everything else

Focus on the DM motivation
Not so hard to build a model with a DM candidate

- Need a neutral, colourless particle
- Need it to be long-lived
- Need the right relic density

Everything else

Not so hard to build a model with a DM candidate

- Need a neutral, colourless particle. Fiat
- Need it to be long-lived. Fiat
- Need the right relic density. Fiat

Everything else

A symmetry, exact or accidental, makes the LSP long-lived or stable

- DM/SM charged/uncharged
- Exact $\implies$ stable
- Accidental $\implies$ long-lived

Everything else

Two particles are long-lived, but shouldn't be

- DM
- The proton

There may be an interesting interplay.

Everything else, e.g. I

In SUSY

- *R*-parity stabilizes DM
- *R*-parity makes the proton long-lived

Everything else, e.g. II

In the SM plus a singlet

- a Z_2 stabilizes DM
- unnaturalness ($\implies B$) makes the proton long-lived

McDonald, 1994

Everything else, e.g. III

In a composite Higgs model

- approximate B makes the proton long-lived
- $3B - n_c + \overline{n}_c \mod 3$ (a $Z_3 \subset U(1)_B \times SU(3)_c$) stabilizes DM

Agashe & Servant, 0403143

- Z_2 vs. Z_3

Walker, 0907.3142

Agashe & al., 1003.0899

Agashe & al., 1012.4460

Everything else, e.g. IV

Non-Abelian symmetry, S_3

- Fields $\in \mathbf{1}', \mathbf{2}$
- Multiple stable components

Adulpravitchai, Batell & Pradler, 1103.3053

Conjecture: most models could be extended to have a DM candidate ...

... so what should we look for at the LHC & beyond?

Guess a TeV-scale Lagrangian

- Post-dict relic density
- Tricky at LHC: Strong *vs*. weak interactions.

Baltz & al., 0602187

Guess a TeV-scale Simplified Model

Arkani-Hamed & al., 0703088

Alves & al., 1105.2838

Guess a sub-TeV, effective Lagrangian

- Relate direct/indirect detection to collider searches
- There are a lot of operators

Goodman & al., 1005.1286

Bai, Fox & Harnik, 1005.3797

Goodman & al., 1008.1783

Davoudiasl & al., 1106.4320

How about counting invisible particles in collider events?

Giudice, BMG, & Mahbubani, 1108.1800

Why count DM?

- Multiple production $\implies$ evidence for a symmetry
- Counting $\implies$ nature of the symmetry
- *e.g.* Count mod 2
- Odd $\implies \not{Z}_2$
- Odd $\implies$ non-Abelian or $DM \neq \overline{DM}$

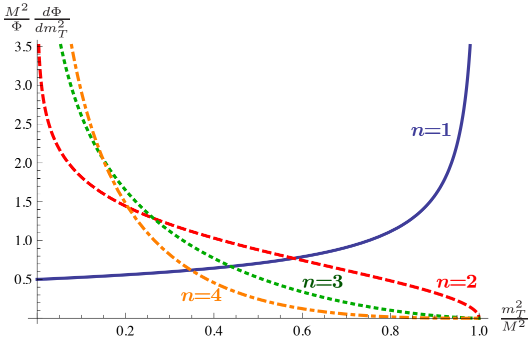
How to count DM?

- # invisibles, n, sets dimension of phase space
- observables are projections thereof
- strong dependence on n

Toy example

$M \to P + nX$, massless X

- m_T is maximised $\implies$ invisibles parallel and transverse
- $\frac{d\Phi}{dm_T^2} \propto (1 - \frac{m_T^2}{M^2})^{n-\frac{3}{2}}$



How to count DM?

- Strong dependence on n
- Other dependencies should be small or known
- Can tolerate errors up to $O(0.5)$

Other dependencies

- pdfs
- decay widths
- detector effects
- topology
- masses
- spins

e. g. Mass dependence

$M \to P + nX$, massive X

- m_T is maximised $\implies$ invisibles transverse and relatively at rest
- $\frac{d\Phi}{dm_T^2} \propto (1 - \frac{m_T^2}{M^2})^{\frac{3n}{2}-2}$
- Allow mass to float as a nuisance parameter

e. g. Spin dependence

e.g. $n{=}2$

- *e.g.* $h \to WW \to 2l2\nu, m_h = 2m_W$
- $\implies$ measure $n{<}2$

- *e.g.* $\mathscr{L} \supset A\Psi P_L \psi + B\Psi P_R \psi$
- $A \to \psi\Psi \to \psi\overline{\psi}B$
- $\implies$ measure $n{>}2$

or other spin effects

Wang & Yavin, 0802.2726

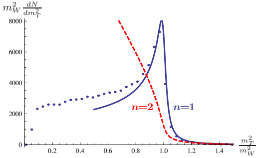
Rare pathologies more a blessing than a curse.

Strategy

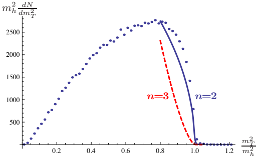
- Generate phase space with n invisibles
- Float invisible mass and topology
- Convolve width/detector effects
- Fit endpoint behaviour of appropriate observables (invariant masses, m_T, m_{T2})

SM examples

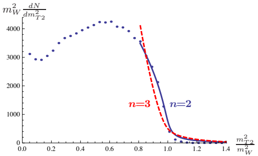
$W \to l\nu, h \to 2l2\nu, 2t \to 2b2l2\nu$



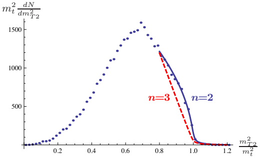
(a) m_T^2 distribution for W production and leptonic decay at the Tevatron.



(b) m_T^2 distribution for $h \to W^+W^-$ and leptonic W decay at the LHC, with $m_h = 180$ GeV.



(c) m_{T2}^2 distribution for $h \to W^+W^-$ and leptonic W decay at the LHC, with $m_h = 180$ GeV.



(d) m_{T2}^2 distribution for $t\bar{t}$ production and leptonic decay at the LHC.

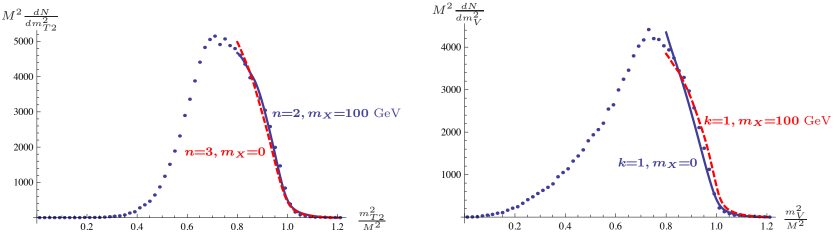
- No showering or detector effects
- Best fit correct in all cases

BSM example

- $2(\tilde{u}_L \to u_L\tilde{\chi}_2^0 \to u_L\ell_R^+\tilde{\ell}_R^- \to u_L\ell_R^+\ell_R^-\tilde{\chi}_1^0)$
- Spin effects present

Barr, 0405052

- Float mass, not topology



(a) m_T^2 distribution for SUSY cascade process at the LHC.

(b) m_V^2 distribution for one leg of same SUSY cascade process at the LHC. Similar results are obtained for the other leg.

Summary

- Reports of the death of SUSY are greatly exaggerated
- The alternatives are countless
- Count invisible particles instead?