Simplified Models with MET at $\sim 1$ fb$^{-1}$

Natalia Toro
Perimeter Institute for Theoretical Physics

based in part on work with
Michele Papucci, Josh Ruderman, Andi Weiler

thanks also to M. D’Alfonso, P. Schuster for discussions
Very broad program of searches

- Jets+MET with ≥0, 1, 2 b-tag and various discriminating variables: $\alpha_T$, $m_{T2}$, $H_T$, /$H_T$
- Jets+MET+1 lepton with ≥0, 1 b-tag
- Di-leptons (OS, SS, Z) and multi-leptons
- $\gamma\gamma$, $\gamma+\text{lepton}$
- Stable R-hadron or charged LSP
- RPV multi-jet (36 pb$^{-1}$)
- Lepton jets, hidden valleys (36 pb$^{-1}$)

I can’t possibly comment on all...

1 fb$^{-1}$ squark, gluino limits from 500 to 1000 GeV depending on details of production and decay → a big range

Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}^0)$

For limits on $m(\tilde{g})$, $m(\tilde{q}) \gg m(\tilde{g})$ (and vice versa), $\sigma_{\text{prod}} = \sigma_{\text{NLO-QCD}}$,

$m(\tilde{\chi}^0), m(\tilde{\chi}^0) = \frac{m(\tilde{g}) + m(\tilde{q})}{2}$

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c$^2$ (dark blue) to $m(\tilde{g})$-200 GeV/c$^2$ (light blue).
What are we learning?

– Naturalness expectations in conflict with data, *in some scenarios*

  e.g.:

  squark decoupling: only gluino, LSP masses matter

  If gluino and squark decay to light-flavor quarks, and LSP lighter than ~200 GeV:
  
  • heavier of gluino or squark $\geq 1.1$ TeV
  
  • lighter of gluino or squark $\geq 800$ GeV
  
  • If only squark or gluino is light, lose associated cross-section $\Rightarrow$ lighter mass still allowed

*ATLAS-CONF-2011-086*
A Simple Case: $\tilde{g}$, $\tilde{q}$, LSP

(no cascades)

- On the other hand, this plot leaves out some crucial information

squark decoupling: only gluino, LSP masses matter

Important limitation – should be highlighted & studied!
Similar limit shape from CMS $\alpha_T$

see https://indico.fnal.gov/materialDisplay.py?contribId=396&sessionId=11&materialId=slides&confId=3563, as well as https://indico.fnal.gov/materialDisplay.py?contribId=494&sessionId=12&materialId=slides&confId=3563 for additional searches
Some $\gamma$ simplified models from CMS

800 GeV limits comparable to jets+MET limits on ‘direct decay to light bino’

GGM Phenomenology

- If $R$-parity is conserved, all events have two NLSP’s

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<thead>
<tr>
<th>channel</th>
<th>bino</th>
<th>wino</th>
<th>$Z$-higgsino</th>
<th>bino-higgsino mix</th>
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Covered in this talk (only prompt NLSP decays)
CMS/ATLAS search exists
Scenario-dependence
– heavier LSP // cascade decays –

Limits from 1-lepton search (see Renaud Bruneliere’s talk)

Light \( (x \approx \frac{1}{4}) \) charginos ⇒ weakest limit (soft leptons?):

\[ m_{\text{gluino}} > 550 \text{ GeV, or } m_{\text{LSP}} > 175 \text{ GeV} \] (contrast 800 GeV and 275 for direct decay)
Scenario-dependence
– heavier LSP // cascade decays –

Limits from 1-lepton search (see Renaud Bruneliere’s talk)

Same parameter space probed by hadronic search – here limited by lower MET at low x (nearby $\chi^0$ and $\chi^\pm$), and softer jets for intermediate x.

… in many cases, inaccessible “low” MET need not be buried below trigger thresholds, but buried below systematics. There is hope to probe this parameter range, but it isn’t easy.
Scenario-dependence
– light 3rd-generation squarks –

As an example, the impact of a non-negligible BR in $t\tilde{\chi}_1^0$ is studied for a specific MSSM point with gluino mass of 500 GeV and stop mass of 290 GeV. In case of $b\tilde{X}_1^\pm$ decay mode only, the efficiency for gluino-pair production is found to be 3.2%, while in the case of $t\tilde{\chi}_1^0$ decays the efficiency is about 4%. For stop pair production, the increase in efficiency with respect to the $b\tilde{X}_1^\pm$ decay mode is found to be about 40% if both stops decay as $t\tilde{\chi}_1^0$. Since this decay mode is not considered in the interpretation of the results, conservative exclusion limits are set.

For inclusive $t\bar{t}$- SUSY signals, where only gluino-pair production (at least in this kinematic regime, the difference $bW^* + \text{MET}$ vs. $t + \text{MET}$ has only minor impact
...but LSP mass evidently significant)
Prejudice?

• Models where each of these topologies is “typical” have been discussed over the last 20+ years
  – proponents advertise each as “generic”, while opponents call it “contrived” (a new HSBC ad for GVA?)

  We are learning step by step about what nature isn’t. Figure of merit for what topologies to spend time on is
  (1) is it reasonable?
  (2) is it non-trivial (new signature or phase space)?
  i.e. excludable but non-excluded regions

A large collection of simplified models can form basis for wide-ranging model exclusion studies …

but with data doubling frequently, this is far less vital than trying to expand the range of signatures explored

• Focus on areas where limits are weak
Scenarios with Light Stops

— motivation —

• Stop regulates 1-loop ⇒ should be light
  − Separating from 1st, 2nd generations motivated by flavor
    Dimopoulos & Giudice 1995; Cohen, Kaplan, Nelson 1996; …
  − Realized in single-sector models w/ composite 1st, 2nd gen
    Arkani-Hamed, Luty, Terning 1997; Luty, Terning 1998; …

• The Price
  − Need to hide or lift higgs mass (more new physics e.g. nMSSM…)
  − Very heavy squarks or flavor symmetry to suppress FCNC
    concerns are surmountable (in multiple ways)
    e.g. Barbieri’s talk

• LHC is only starting to directly test this scenario – the limits
  are weak
This search was “lucky” – is the expected power of other searches greater?

In general, I hope different searches can share some high-overlap “benchmark topologies” (e.g. gluino pair \( \rightarrow 4t + \text{MET} \) also shows up in jets+btag+MET, jets+0, 1, 2 lepton+MET)

It’s useful to know where strongest limits come from

Probably not:

– 2\( t \)-like decay \( \Rightarrow \) more/softer jets, less MET, moderate \( M_{\text{eff}} \)

\( \Rightarrow \) harder to find in jets+MET

– For this signal, only top is irreducible

– Btag and \( m_T \) reduce background, allows looser \( M_{\text{eff}} \) and MET cuts

4jets+MET

(see I. Vivarelli EPS and ATLAS-CONF-2011-130 for full tables)
Scenarios with Light Stops
— what next? —

• $m_t$ isn’t small – impact on kinematics needs to be explored (not a simple sector)
  − Combined effects of on-shell squarks and changing LSP mass
  − LSP with chargino partner (Wino or Higgsino) vs. Bino

• Optimization on sbottom/stop direct production
  (and even quantifying existing searches’ sensitivity)

• Moving towards combining channels for gluino $\rightarrow$ stop searches?
**Direct Stop/Sbottom Constraints?**

*estimated* direct stop/sbottom limits from ATLAS 2-4 jet searches at 1 fb$^{-1}$

(both stops and the left-handed sbottom are all taken to be light)

Dedicated search could likely improve reach

But already many searches and measurements likely constrain light stop/sbottom.
Are Natural-Looking Models OK?

- A look at one parameter space, with various processes and searches

- Preliminary study of one scenario:
  - $\mu=200$ GeV
  - $M_1=100$ GeV
  - $(M_2 \gg M_3$ GeV)
  - $\sim q_{3L}$ and $\sim t_R$ light; other squarks $\geq 1.5$ TeV
  - several but not all 1 fb$^{-1}$ searches accounted for

  ATLAS jets+MET, bjets+MET, b+l+MET shown

  CMS jets+MET similar
Making Contact with Nature

- Both ATLAS and CMS have presented broad and aggressive arrays of new-physics searches with MET.
- Simplified model interpretations have accentuated when these searches are applicable, and what signature/model regions require further study.
- While reaching up in mass, reach out as well!
  - Direct stop/sbottom and even weakino production
  - Squeezed spectra
  - Stop-rich gluino decays
    
    Low energy supersymmetry is still a possibility (with some heavier partners) – the scenarios that remain unconstrained are important ones to wrestle with!

- (low-MET possibilities, which I’ve omitted, also deserve some thought)