ATLAS – HIDDEN SUSY
ATLAS SUSY Searches - 95% CL Lower Limits (Status: BSM-LHC 2011)

- **MSUGRA/CMSSM**: 0-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $q = \tilde{q}$ mass
  - $\tilde{q} = \tilde{g}$ mass

- **MSUGRA/CMSSM**: 1-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $q = \tilde{q}$ mass

- **MSUGRA/CMSSM**: multijets + $E_{T,miss}$
  - $L=1.34 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{q} = \tilde{g}$ mass (for $m(\tilde{g}) = 2m(\tilde{q})$)

- **Simpl. mod. (light $\tilde{\chi}_1^0$)**: 0-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{q} = \tilde{g}$ mass

- **Simpl. mod. (light $\tilde{\chi}_1^0$)**: 0-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{q} = \tilde{g}$ mass

- **Simpl. mod. (light $\tilde{\chi}_1^0$)**: 0-lep + b-jets + j's + $E_{T,miss}$
  - $L=0.83 \, fb^{-1}$ (2011) [ATLAS-CONF-2011-099]
  - $\tilde{q} = \tilde{g}$ mass (for $m(\tilde{g}) < 600 \, GeV$)

- **Simpl. mod. ($\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$)**: 1-lep + b-jets + j's + $E_{T,miss}$
  - $L=1.03 \, fb^{-1}$ (2011) [ATLAS-CONF-2011-130]
  - $\tilde{g}$ mass (for $m(\tilde{\chi}_1^0) < 80 \, GeV$)

- **Pheno-MSSM (light $\tilde{\chi}_1^0$)**: 2-lep SS + $E_{T,miss}$
  - $L=35 \, pb^{-1}$ (2010) [arXiv:1103.6214]
  - $\tilde{q} = \tilde{g}$ mass

- **Pheno-MSSM (light $\tilde{\chi}_1^0$)**: 2-lep OS_{SF} + $E_{T,miss}$
  - $L=35 \, pb^{-1}$ (2010) [arXiv:1103.6268]
  - $\tilde{q} = \tilde{g}$ mass

- **Simpl. mod. ($\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$)**: 1-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{\chi}_1^0$ mass (for $m(\tilde{g}) < 600 \, GeV$, $(m(\tilde{\chi}_1^0) - m(\tilde{\chi}_1^0)) / (m(\tilde{g}) - m(\tilde{\chi}_1^0)) > 1/2$)

- **GMSB (GGM) + Simpl. model**: $\gamma\gamma$ + $E_{T,miss}$
  - $L=1.01 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{g}$ mass (for $m(\text{bino}) > 50 \, GeV$)

- **GMSB**: stable $\tilde{\tau}$
  - $L=37 \, pb^{-1}$ (2010) [arXiv:1106.4465]
  - $\tilde{\tau}$ mass

- **Stable massive particles**: R-hadrons
  - $\tilde{g}$ mass

- **Stable massive particles**: R-hadrons
  - $\tilde{b}$ mass

- **Stable massive particles**: R-hadrons
  - $\tilde{t}$ mass

- **Hypercolour scalar gluons**: 4 jets, $m_{ij} \approx m_{\tilde{q}}$
  - $\tilde{g}$ mass

- **RPV ($\lambda_{311} \approx 0.10$, $\lambda_{312} \approx 0.05$)**: high-mass $e\mu$
  - $L=1.07 \, fb^{-1}$ (2011) [arXiv:1109.3089]
  - $\tilde{\nu}_\tau$ mass

- **Bilinear RPV (c\tau_{LSP} < 15 \, mm)**: 1-lep + j's + $E_{T,miss}$
  - $L=1.04 \, fb^{-1}$ (2011) [Preliminary]
  - $\tilde{q} = \tilde{g}$ mass

*Only a selection of the available results leading to mass limits shown

- $\int Ldt = (0.034 - 1.34) \, fb^{-1}$
- $\sqrt{s} = 7 \, TeV$

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G. Watts (UW/Seattle)
we’ve seen nothing
where is it?

hiding at a higher scale ➔ wait for $\sqrt{s}$ increase (2014/2015)

normal, but low $\sigma$ ➔ wait for more data (HCP, winter for $5 fb^{-1}$)

already there ➔ better search strategies

concentrate on “hidden” searches for this talk

better catalogs of models
better triggers
better offline searches
SUSY with out prejudice

large range of models examined

gaps!

or...

simplified models

for hidden senarios
SUSY
Normal, Hidden, Soft, Squished, Compressed, Hidden Valley

Trigger

Offline Analysis

Discovery!
triggering is grim...

... and getting grimmer

bunch spacing, protons in bunch, beam tunes and focus

your favorite trigger squeezed here

rate limit driven by $$disk, cpu, etc.$$

unprescaled @ end of 2011

em: $1e@22, 2e@12, 1e@12+2e@6, 1\gamma@80, 2\gamma@20, 1e@20+{E_T^{miss}} > 40$
muon: $1\mu@18, 1\mu@40sl, 1\mu@15+1\mu@10, 1\mu@15+{E_T^{miss}} > 30$
tau: $1\tau@125, 1\tau@29+1\tau@20, 1\tau@29+{E_T^{miss}} > 35$
jets: $1j@250, 3j@100, 4j@45, 5j@30, 1j@75+{E_T^{miss}} > 55, 1j@100+H_T > 400, 4j@40+H_T > 350$
combo: $1\mu@18+1j@10, 1e@5+1\mu@6, 1\tau@20+1e@15, 1\tau@20+1\mu@15$
long lived particle triggers

b-tagging triggers

- good for a decay a few millimeters from primary vertex
- commissioned
- not used in any analysis currently

Long Lived Neutral Particle Triggers

- neutral particle decays mid-detector
- appearance trigger
- run for full 2011 dataset ($5 fb^{-1}$)
3 triggers

**trackless jet trigger**
- jet $E_T > 35$ GeV
- no tracks with $p_T > 1$ GeV near jet
- muon spectrometer activity
- low efficiency

**log($E_{had}/E_{EM}$)**
- jet $E_T > 35$ GeV
- no tracks with $p_T > 1$ GeV near jet
- $\log(E_{had}/E_{EM}) > 1.0$
- very good efficiency

**muon spectrometer cluster trigger**
- three RoI clusters all close by
- no jets
- no tracks
- really very good efficiency

- decays in inner detector
- decays beyond the EM calorimeter
- decays beyond the hadronic calorimeter
offline analysis

standard SUSY analyses

jets $p_T > 50$ GeV
electrons $p_T > 10 - 20$ GeV
muons $p_T > 10 - 20$ GeV
$E_T^{miss} > 50$ GeV

non-standard SUSY searches

highly ionizing particles
displaced vertices
kinked tracks
stopped particles
stable massive particles

color charge, subluminal → time-of-flight, ionization

use calorimeter for electrically neutral R-hadrons

pixels: $dE/dx$

tile calorimeter: time of flight ($0.3 < \beta < 1.0$)

trigger on calorimeter $E_T^{\text{miss}} > 40$ GeV

mass from ionization or from time of flight
stable massive particles
stable massive particles

mass estimates must be compatible
stable massive particles

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**R-hadron exclusion**

$\sqrt{s} = 7$ TeV  $\int L \, dt = 34$ pb$^{-1}$

- **ATLAS**
Stable, charged ($\mu$-based)

electrically charged by the time they leave the calorimeter

charged, long lived particles

colored, but interact in calorimeter leading to a spray of charged particles in the muon spectrometer

GMSB SUSY

trigger is the muon drift tube

reconstruction method 1:

fit inner detector track to imperfect muon spectrometer segments
take into account $\beta$ which alters drift time
sub-par muon spectrometer segments also used

reconstruction method 2:

muon spectromter based only
segment reconstruction starts from trigger information
efficiency is not great for low $\beta$.  

$L=37 \, pb^{-1}$
Stable, charged ($\mu$-based)
displaced vertices

displaced vertex

trigger

vertex reconstruction
standard
use tracks that have no pixel hits
reject vertices near material

SUSY++

L=33 pb$^{-1}$

efficiency

g. watts (uw/seattle)
displaced vertices
displaced vertices

95% CL limit
stopped particles

- Long-lived particles produced with low $\beta$ can stop in detector material and decay much later.
- Most likely to stop in densest part of ATLAS $\Rightarrow$ calorimeters.
- Look for events with large energy deposits in calorimeter in "empty" bunches.

backgrounds: calorimeter noise, cosmics, beam-halo
stopped particles

depends on detector uptime

G. Watts (UW/Seattle)
hidden valley SUSY

LSP is in the HV sector
result are long lived
decays in the detector
analysis technique is a
riff on the long lived
triggers
b-tagging

big improvements coming
conclusions

- lots of information from the ATLAS detector can be used in new ways to help with some corners of SUSY parameter space
  - if we can figure out how to control backgrounds!
- new results at HCP with $2 - 3 fb^{-1}$ and $5 fb^{-1}$ for winter conferences
- improving algorithms all the time
- other results out there
  - e.g. squashed SUSY reinterpretation
2 leptons, $E_T^{miss}$

leptons: $=2 \, e, \mu$ (both ss/os)

jets: Bin in # of jets (up to 8)

$\rho_T > 55,80$ GeV

$\frac{E_T^{miss}}{\sqrt{H_T}} > 3.5$ GeV

luminosity: $1.34 \, fb^{-1}$

r parity conserving
Large # Jets, $E_T^{miss}$

leptons: $e, \mu$ with $p_T^e > 20$ GeV, $p_T^\mu > 10$ GeV
jets: 0-4, $p_T > 40 - 100$ GeV
$E_T^{miss}$ used as the limit setting variable
luminosity: $1 fb^{-1}$
r parity conserving
1 lepton, jets, $E_T^{miss}$

leptons: $=1 e, \mu$

$p_T^e > 20$ GeV, $p_T^\mu > 10$ GeV

jets: 3, $p_T > 60$ GeV, $E_T^{miss} > 125$

3, $p_T > 80$ GeV, $E_T^{miss} > 240$

4, $p_T > 60(1), 25(3)$ GeV, $E_T^{miss} > 140$

4, $p_T > 60(1), 40(3)$ GeV, $E_T^{miss} > 200$

luminosity: 1.04 fb$^{-1}$

r parity conserving

simplified models
jets, $E_T^{\text{miss}}$

leptons: $e, \mu$ with $p_T^{e,\mu} > 20$ GeV
jets: leading $p_T > 130$, 2-4 $p_T > 40$, or 4 $p_T > 80$
$E_T^{\text{miss}} > 130$ GeV
luminosity: 1.04 $fb^{-1}$
r parity conserving

Figure 2: Combined exclusion limits for simplified SUSY models with $m(\tilde{g}) = 0$ (left) and MSUGRA/CMSSM models with $\tan \beta = 10$, $A_0 = 0$ and $\mu > 0$ (right). The combined limits are obtained by using the signal region which generates the best expected limit at each point in the parameter plane. The dashed-blue line corresponds to the median expected 95% C.L. limit and the red line corresponds to the observed limit at 95% C.L. The dotted blue lines correspond to the $\pm 1\sigma$ variation in the expected limits. Also shown for comparison purposes in the figures are limits from the Tevatron [35, 36, 37, 38] and LEP [39, 40], although it should be noted that some of these limits were generated with different models or parameter choices (see legends). The previous published ATLAS limits from this analysis [5] are also shown. The MSUGRA/CMSSM reference point used in Figure 1 is indicated by the star in the right-hand figure.
2 lepton (high mass)

leptons: $\pm e, \pm \mu$

$p_T^{e,\mu} > 25$ GeV

luminosity: $1.07 \text{ fb}^{-1}$

r parity violating
1 lepton, b-jets, $E_T^{miss}$

leptons: $e, \mu$

$p_T^e > 20$ GeV, $p_T^\mu > 10$ GeV

jets: 4, $p_T > 50$ GeV ($\geq 1$ b-tag)

$E_T^{miss} > 80$ GeV

$m_T(l, E_T^{miss}) > 100$ GeV

luminosity: $1.03 fb^{-1}$

$\text{r parity conserving}$
0 leptons, b-jets, $E_T^{\text{miss}}$

leptons: $e, \mu$

\[ p_T^e > 20 \text{ GeV}, \quad p_T^\mu > 10 \text{ GeV} \]

jets: $\geq 3$, $p_T > 130, 50, 50 \text{ GeV}$ ($\geq 1$ b-tag w/ $p_T > 50 \text{ GeV}$)

Split signal regions by # of b-jets, $m_{\text{eff}}$

$E_T^{\text{miss}} > 130 \text{ GeV}$

$m_T(l, E_T^{\text{miss}}) > 100 \text{ GeV}$

luminosity: 0.83 $fb^{-1}$

r parity conserving