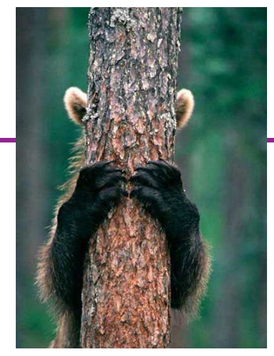
Where could SUSY be hiding?
– Searching for di-slepton production in ATLAS

UNIVERSITY OF CAMBRIDGE

Sarah Williams
Supervised by Dr. Christopher Lester
High Energy Physics Group, Cavendish Laboratory



Introduction to SUSY

- Supersymmetry is an extension to the Standard Model that relates fermions and bosons.
- Because no SUSY particles have yet been observed it must be a broken symmetry, and thus predicts heavier superpartners for all of the Standard Model particles.
- The MSSM ("Minimal Supersymmetric Standard Model") has minimal particle content- the superpartners are divided into squarks , gluinos, neutralinos , charginos and sleptons.
- In R-parity conserving SUSY, the lightest neutralino is the lightest supersymmetric particle (LSP)- and is stable.
- The supersymmetric partners have the same weak and strong couplings as their Standard Model counterparts.
- Consequently, being a hadron collider, the production of squarks and gluinos is favoured at the LHC as they are produced by the strong interaction.
- Typical signatures include large missing energy, and high $\mathbf{p_T}$ jets and leptons.

Motivation for searching for slepton production

- The SUSY searches in ATLAS have been very successful this year at excluding large areas of SUSY parameter space.
- As an example in mSUGRA models with $\mathbf{\tan(\beta) = 10, A_0 = 0}$ and $\mu > 0$ the 0-lepton search excluded squarks and gluinos of equal mass below **950GeV** with just $\mathbf{165fb^{-1}}$ of data. (See ATLAS-CONF-2011-086)
- These searches are very powerful at detecting (reasonably) light squarks and gluinos, but are not very sensitive to models with heavy squarks and gluinos $\rightarrow$ For these models, direct production of the lighter gauginos and sleptons can be important
- The low masses can (partly) counteract the small cross sections for direct production:

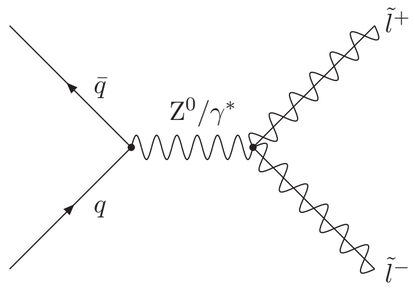


Figure: Feynman diagram for di-slepton production at the LHC

- In mSUGRA the slepton/squark mass relation means if there is slepton production there should also be significant squark production- mass gap between squarks and sleptons does not compensate for the low Electroweak cross section- so to observe sleptons we should also have observed squarks and gluinos...
- But...assuming that SUSY is hiding somewhere....there are theories where slepton production could be a discovery channel.

Where to look?

- Such a search would be sensitive to any new particles with weak couplings carrying lepton number, which then decay to a lepton and an invisible particle.
- For a framework use the pMSSM ("Phenomenological MSSM")- this applies several phenomenological constraints to the unconstrained MSSM which has 105 free parameters.The pMSSM then requires only 19 input parameters which include the sfermion masses.
- Look for models with mass hierarchy $\mathbf{m_{\tilde{\chi}}, m_{\tilde{q}} > m_{\tilde{l}} > m_{\tilde{\chi}_1^0}}$ which provides a competitive search for SUSY if $\mathbf{m_{\tilde{g}}, m_{\tilde{q}} >> m_{\tilde{l}}}$.
- Mass spectrum for such a model shown below:

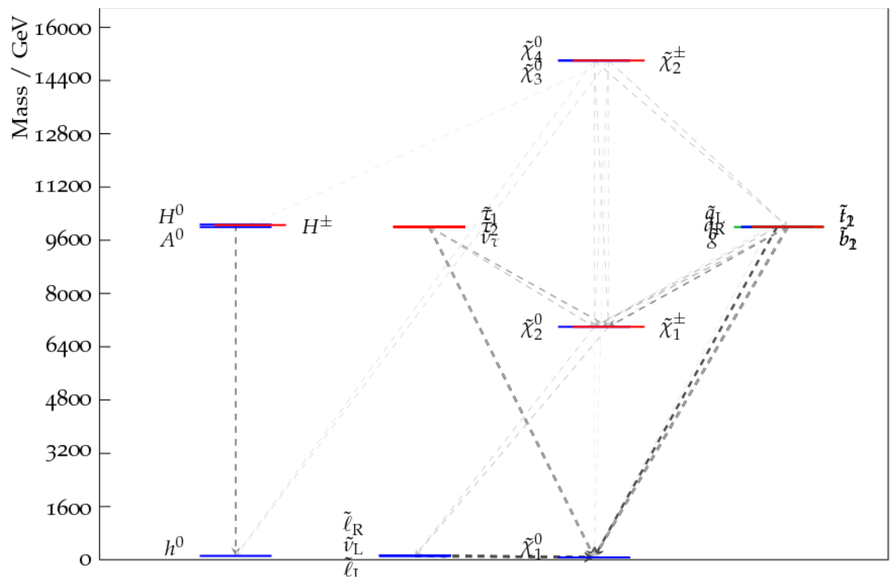


Figure: SUSY mass spectrum for a pMSSM model where di-slepton production could give a signal

The Di-Slepton Signature

- Feynman diagram for di-slepton production shown below:

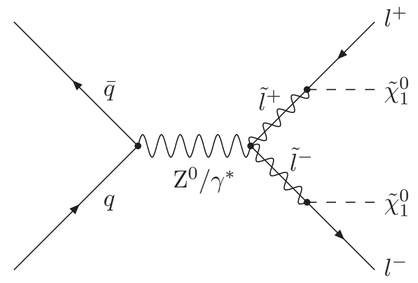


Figure: Feynman diagram showing the production of a slepton pair, where each of the sleptons decays to a lepton and an invisible neutralino (the lsp)

- Characteristics of such an event are two high $\mathbf{p_T}$ isolated, opposite signed, same flavour leptons, no jets except for ISR and pileup, and missing transverse energy ($\mathbf{E_T^{miss}}$)
- Major backgrounds come from di-leptonic $\mathbf{t\bar{t}}$, diboson and $\mathbf{Z \rightarrow \tau\tau \rightarrow ee/\mu\mu}$ events, as well as other backgrounds with fake leptons and/or missing energy (single top, QCD...)

Opposite Sign Di-lepton SUSY searches in ATLAS

- SUSY searches in events in ATLAS with 2 oppositely signed leptons and missing energy are sensitive to events involving cascade decays:

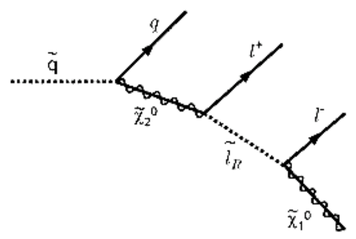
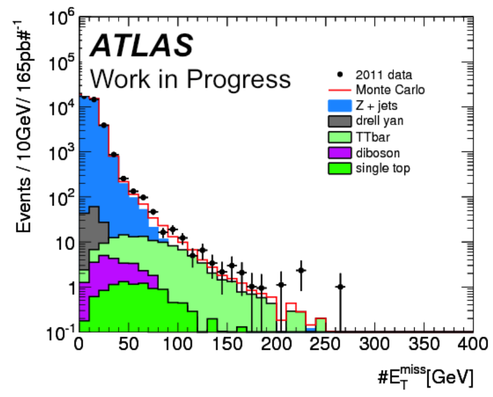
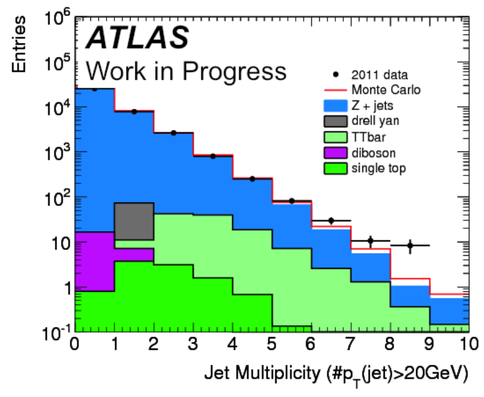


Figure: Feynman diagram showing the cascade decay of a squark where two oppositely signed same flavour leptons are produced.

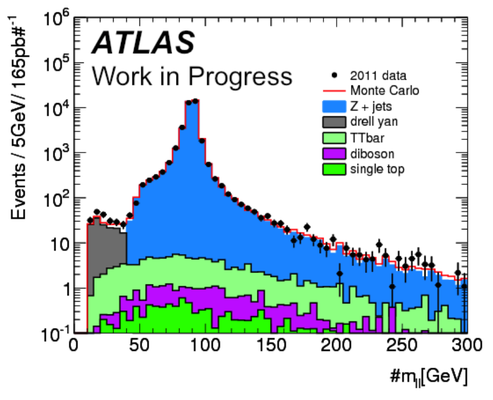
- Plots below show kinematic distributions after event selection, object selection and event cleaning, and with a requirement of exactly two leptons, for $\mathbf{165pb^{-1}}$ data.



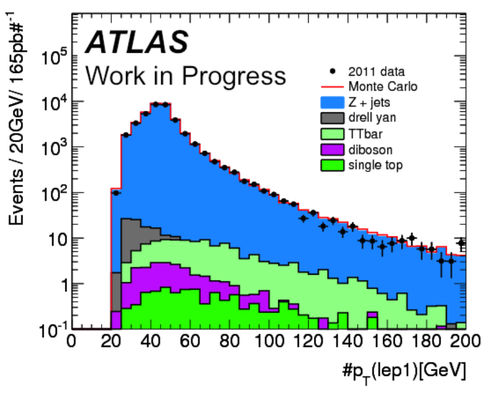
(a) Missing transverse energy $\mathbf{E_T^{miss}}$



(b) Jet multiplicity $\mathbf{N_{jet}(p_T > 20GeV)}$



(c) Invariant mass of the di-lepton pair $\mathbf{m_{ll}}$



(d) Transverse momentum ($\mathbf{p_T}$) of the leading lepton

Figure: Data vs MC distributions for 2-lepton events in the ATLAS detector for $\mathbf{165pb^{-1}}$ of data

Chasing down a signal...

- Need to define an approach for searching for di-slepton production in 2 lepton events... current ideas involve:

1. Central Jet Veto- this would reduce $\mathbf{t\bar{t}}$ background.
2. Potentially use the "Stransverse mass" variable $\mathbf{m_{T2}}$ [C.G. Lester and D. J. Summers, 1999], defined as:
   $\mathbf{m_{T2} = \min_{\vec{p}_T + \vec{q}_T = \vec{p}_T} \max\left(m_T[a_T^\alpha, \tilde{p}_T^\alpha(\tilde{\chi})], m_T[b_T^\alpha, \tilde{q}_T^\alpha(\tilde{\chi})]\right)}$ where here **a** and **b** refer to the transverse momenta of the leptons and **p** and **q** to the hypothetical momenta of the neutralinos. It can be shown to be bounded above by the mass of the pair-produced parents.
3. Investigating possible angular variables.

- Hopefully there will be more to come in the future....

sarahw@hep.phy.cam.ac.uk