The Search For New Physics at the LHC

Early SUSY searches at ATLAS in leptonic final states

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1 Abstract

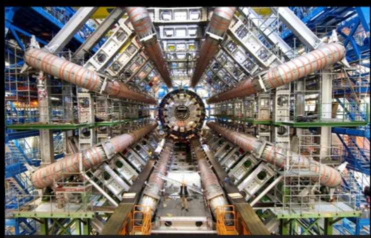
The Large Hadron Collider (LHC) at CERN is the biggest scientific experiment in history, involving scientists from all over the world. ATLAS is the largest of the four main detectors located around the LHC tunnel. It is a multi-purpose detector dedicated to the search for new physics. In the quest to understand more about the universe in which we live, ATLAS hopes to provide answers to the origin of mass, extra dimensions and dark matter. Supersymmetry (SUSY) is one of the theories which will be investigated at the LHC. My project involves using Monte Carlo data to establish the early discovery potential of SUSY.

2 The LHC, ATLAS and Supersymmetry

At the LHC proton beams will be accelerated around the 27km circumference tunnel, colliding with centre of mass energies (E_{cm}) which have never been reached before by a particle accelerator, placing the LHC at the high energy frontier.

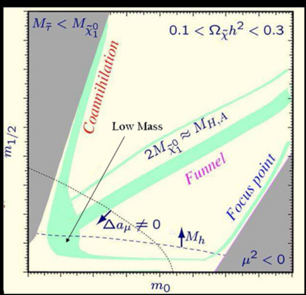
$$E_{cm}^{max} = 14TeV$$

ATLAS will lead the search for physics beyond the Standard Model (SM). This summer (2009), I have been investigating the possibility of early SUSY discovery at ATLAS.



The ATLAS (A Toroidal LHC ApparatuS) detector at CERN (European Centre for Nuclear Research).
Credit: http://atlas.ch/photos/full-detector-photos.html

The Standard Model does not provide a satisfactory explanation of particles and their interactions at very high energies (GUT scale ~10^{18}GeV). Supersymmetry appears to unify the fundamental forces at these energies. If SUSY is realized at the LHC, we should see a spectrum of massive sparticles (SUSY particles). The lightest of these, the LSP (Lightest SUSY Particle) is massive and weakly interacting, making an excellent dark matter candidate.



The mSUGRA m_0 vrs $m_{1/2}$ parameter space. Constraints from cosmological measurements can be placed on parameter space, giving rise to narrow bands which direct SUSY scenarios. SU4 lies in the low mass region. [1]

Three benchmark SUSY scenarios have which could result in the production of three leptons have been considered by ATLAS.

SU2 – Focus Point Region

SU3 – Bulk Region

SU4 – Low Mass Region

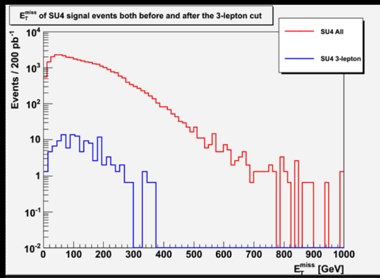
	SU2	SU3	SU4
σ_{total} (pb)	7.18	27.7	402
$\sigma_{3lepton}$ (pb)	0.07	0.3	2.49

From the table of cross sections (left) it can be seen that SU4 (in the low mass region) boasts the largest cross section, even for trilepton events, making it a perfect candidate for early detection by ATLAS.

3 Signal and Background Properties

Typical SUSY signature:

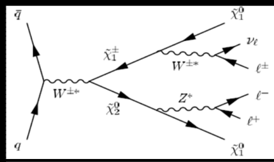
- multiple hadronic jets
- multiple leptons
- large amount of missing energy (E_T^{miss})



E_T^{miss} of all signal events (red solid line) and trilepton signal events only. Notice that 3-lepton SUSY events have less E_T^{miss} than generic SUSY events, although still a substantial amount more than their SM background processes (see plot below).

Why study leptonic final states?

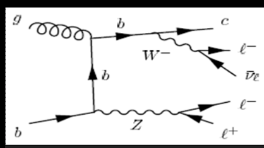
- hadronic jets are messy!
- leptons are easier to distinguish from hadronic "noise" (i.e. background)
- presence of leptons implies a weak process is taking place



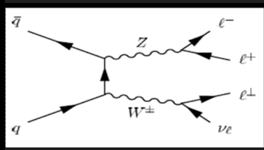
A Feynman diagram of a trilepton SUSY event resulting from direct chargino-neutralino pair production.[1]

A selection can be set such that only events with a minimum of 3 leptons in the final state are kept as possible SU4 candidates.

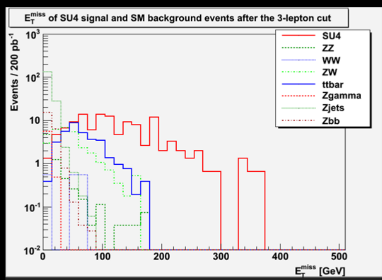
Standard Model Backgrounds – of course we will not see a clean SUSY signal on its own. When we make the 3-lepton selection there will be some Standard Model events which pass the cut too: ttbar, ZZ, ZW, WW, Z + jets & Zbb are the backgrounds considered in this analysis.



A Feynman diagram of 3-lepton production by the SM process Zbb.[1]



A Feynman diagram of 3-lepton production by the SM process ZW.[1]



E_T^{miss} of all trilepton events from SU4 signal and SM background processes. Notice that the typical SUSY signature of large amounts of E_T^{miss} can be seen in this plot. The SU4 line extends to higher energies than any of the SM backgrounds. This large amount of missing energy is due to massive escaping LSPs which are stable, but have the detector signature of a neutrino.

4 Signal Significance

In Poisson statistics the number of events fluctuates about a mean value, λ, with a standard deviation of $\sqrt{\lambda}$. When analysing data from the LHC we will want to find an excess in the number of events in our distribution, but how can we be sure that this is not due to Poisson noise?

- Use $\frac{S}{\sqrt{B}}$, where S = Number of signal events, and B = Number of background events.

This tells us how many standard deviations our excess is from the mean value.

3σ = EVIDENCE
5σ = DISCOVERY

So we want $\frac{S}{\sqrt{B}}$ to be a large as possible to claim discovery.

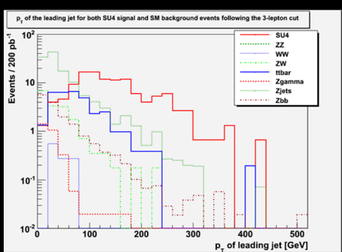
Limitations! The above definition for signal significance is only valid when S << B.

During this analysis, in addition to the 3-lepton selection, other parameters had cuts imposed to further reduce the background and improve signal significance.

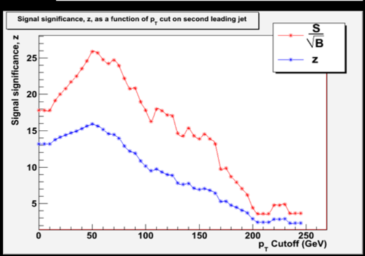
Result: S >> B

A different, more appropriate definition of signal significance was therefore implemented, denoted by Z.

$$z = \sqrt{2\left((S+B)\ln\left(1+\frac{S}{B}\right) - S\right)}$$



p_T of the leading hadronic jet of SU4 signal and SM background events. Imposing a cut on this parameter further reduces the SM background on our SU4 signal.



The plot on the left shows both definitions of signal significance. Z gives a smoother distribution as it is less susceptible to statistical fluctuations. This plot was made with events containing at least 3-leptons and with the p_T of the leading jet > 80GeV. It shows the signal significance as a function of a cut on the second leading jet.

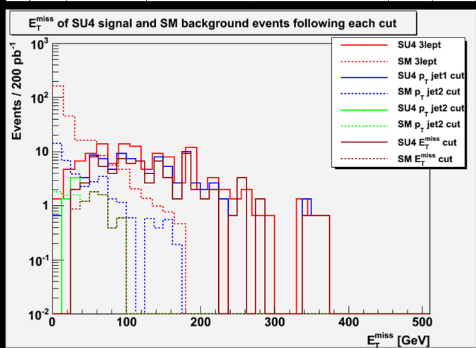
5 Results

Four selection criteria were set in total (see table).

	Cutoff (GeV)	# Signal Events	# Background Events	$S/\sqrt{B}$	z
3-Lepton	-	118.71	263.99	7.31	6.84
p_T Jet 1	80	99.58	41.18	15.5	12.1
p_T Jet 2	60	79.8	10.37	24.8	15.2
E_T^{miss}	30	77.16	6.31	30.7	16.6

By setting these criteria the signal significance of SU4 is greatly improved, and we are able to get rid of most of the SM background.

All values of z shown in the table are above the result of 5 necessary in order to claim discovery. This suggests that if SUSY manifests itself in nature according to the SU4 benchmark scenario, it has excellent early discovery potential at the LHC in the 3-lepton channel.



E_T^{miss} of both signal (solid line) and background (dashed line) events following the 3-lepton, p_T and E_T^{miss} cuts. Notice that the background decreases far more substantially than the signal after each cut.

References and collaborators

[1] Potter, C., 2009. *The search for evidence of super symmetry in trilepton final states at the LHC*. Ph. D. Royal Holloway: University of London.
[2] Potter, C. De Santo, A. & Dragic, J., 2008. *Trilepton SUSY signatures at ATLAS*. ATL-PHYS-COM-2008-060. Royal Holloway: University of London.

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All uncredited figures were generated by the author.

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