The Hunt for Supersymmetry

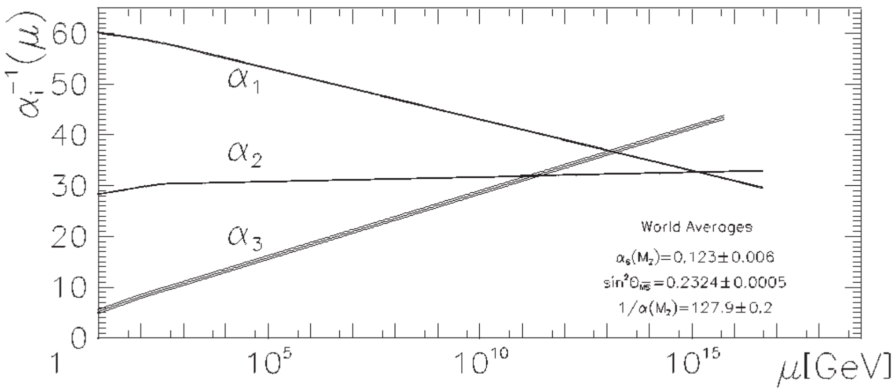
Supersymmetry (SUSY) is one of the most promising and most studied extensions to the so-called Standard Model (SM) of particle physics. It elegantly solves several theoretical problems of the model: How is the mass of the Higgs particle kept finite? Can the forces of Nature be unified a manifestations of one governing principle? SUSY also provides a candidate for the so-called "Dark Matter" that seems to be prevalent in the Universe. Next year, when the physics programme of the Large Hadron Collider starts up we will have the best possibility so far to detect if SUSY is part of Nature.

What is Supersymmetry?

Supersymmetry is a postulated principle that dictates the existence of a "mirror Universe". This should not be understood in the popularized context of parallel worlds. Rather it is the postulate that for every kind of particle in the Standard Model there exists a particle type identical in every aspect but its

Why Extend the Standard Model?

The SM has celebrated remarkable successes in particle physics over the last 30 years. Predictions have been verified to unprecedented precision. However, the model does suffer from inherent problems. The Higgs particle, which is thought to endow all other particles with mass, has a mass itself. This mass may be calculated as a sum of many terms, and it *must* have a value below 1 TeV/c^2. This is very hard to ensure in the SM, as the terms added are all many orders of magnitude larger than the TeV scale. Also, the SM does not seem to have the properties to ensure *unification* of the forces of Nature.



Caption: *The three curves illustrate the strength of the strong and the week nuclear force as well as the electromagnetic force. As can be seen from the figure. They approach the same level of strength but they do not converge in a point.*

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spin. The electron is paired with its so-called *superpartner*, the *selectron* having the same mass and charge but with a spin differing by ½ from the electron. The superpartners of the fermions are named by adding an s to the name (quark *squark*, neutrino *sneutrino* etc.) while the superpartners of the boson get an "*–ino*" appended to their names (gluon *gluino*, Higgs *Higgsino* etc.). These superpartner provide in a natural way counter terms of opposite sign in the calculation of the Higgs mass. They are said to *regularize* the Higgs mass.

A Warped Mirror

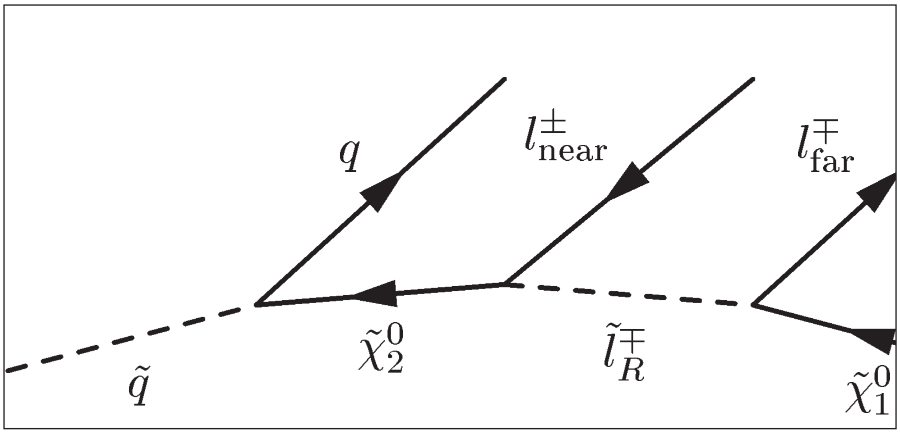
An obvious argument against SUSY is that it cannot be realized as an exact symmetry in Nature. We have never seen an electron with spin 0. It is, however, possible to formulate theories in which SUSY is dynamically broken. Just as a lake may mirror the mountains you are looking at, the wind may warp the image you see.

The Cosmological Connection

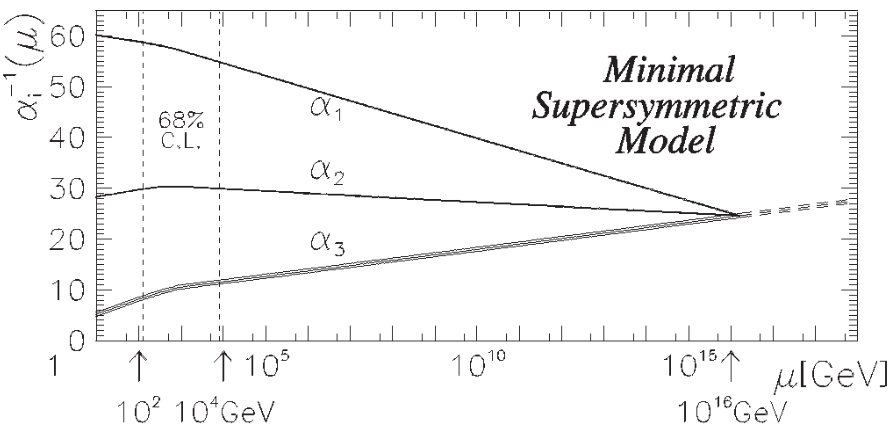
Most SUSY models include a conserved quantum number called R-parity. The effect of this conservation law is that the proton cannot decay. However, it also means that the LSP must be stable. As the LSP must be quite heavy compared to the SM particles a relic density of stable SUSY particles is a good candidate for the observed and unexplained abundance of dark matter in the Universe.

Experimental Signatures

The conjectured stability of the LSP is the cornerstone of most SUSY searches at the Large Hadron Collider (LHC) which is due to commence data-taking in 2009. Two beams of protons will be brought to collisions with energies of several TeV. It is the hope that this energy is high enough to allow for the creation of supersymmetric particles.

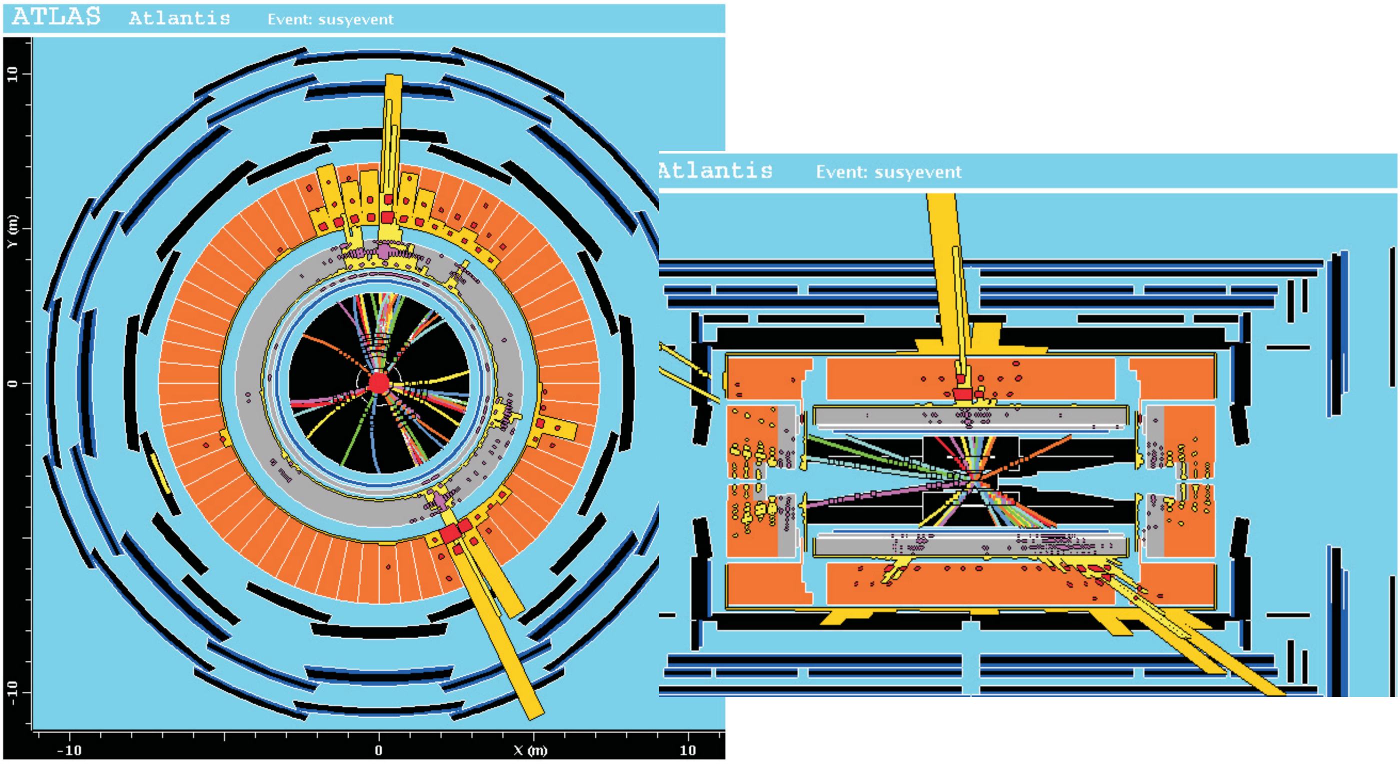


Caption: *A squark decays through a neutralino and a slepton to the LSP which in this model is a weakly interacting neutralino. In the process two leptons and a quark are emitted.*



Caption: *Here, the curves represent the strength of the forces of Nature in a Minimal Super-Gravity theory. The forces are unified in a perfectly supersymmetric scenario at high energies while gravitational interactions at low energies break up the spectrum of (s)particle masses. For such a scenario to have avoided detection the mass of the Lightest Supersymmetric Particle (LSP) must be on the order of hundreds of GeV/c^2.*

The SUSY particles will decay *while conserving R-parity* to the LSP. This particle in most models is a neutralino, a particle weighing hundreds of GeV/c^2 but which *only* interacts through the weak nuclear force. In this respect it is comparable to the neutrino. The neutrino is nearly massless and each second billions of them go through each square centimeter of skin of our bodies without ever interacting. Likewise, the neutralino escapes the detector without being detected. As a consequence of this behaviour the strategy for detecting and identifying SUSY is to look for missing energy in the direction transverse to the beam and to pair this information up with



Caption: *A simulated SUSY event in the ATLAS detector at the LHC (www.atlasexperiment.org). The event contains six jets, two muons of opposite sign penetrating to the outer end-cap of the detector as well as missing transverse energy (energy imbalance) of 283 GeV.*

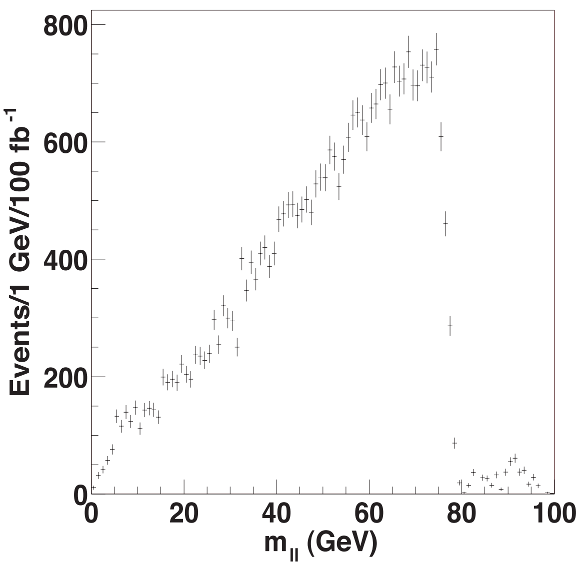
If these events really originate in the imagined decay chain then certain kinematical constraints apply. For instance the invariant mass of the lepton pair is limited from above by the other masses in the particle spectrum. The masses of the two neutralinos on each side of the leptons simply limit the possible phase space for the emissions, just as the mass of the intermediate slepton puts limits on the distribution of energy between the leptons.

the kinematic constraints of these very active events.

The concrete example show-cased by the decay above is from a scenario where two SUSY particles will be produced in the collision (due to conservation of R-parity). One of them is assumed to decay as shown while the other most often decays to three jets and a neutralino. In other words physicist would have to be looking for collisions containing:

- Four jets (a collimated stream of particles arising from the emission of a quark of gluon)
- Two leptons of the same type (eletron/muon) but with opposite charge.
- Missing transverse energy

Many such constraints exists in each SUSY model, and only by measuring a coherent set of masses will we be able to say that whichever new physics we see at the LHC might be supersymmetry.



Caption: *A simulation of collisions using SPS 1a as a model. The plots shows the invariant mass of the lepton pair in the events*

$$\left(m_{ll} = \sqrt{\left(E_{l_1} + E_{l_2}\right)^2 - \left(\vec{p}_{l_1} + \vec{p}_{l_2}\right)^2} \right).$$

The background from SM physics has been subtracted. As can be seen there is a well-defined upper limit.