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Viewpoint

The Large Hadron Collider enters the race for supersymmetry

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Results from the first search for supersymmetry at the LHC have arrived.

Subject Areas: **Particles and Fields**

A Viewpoint on:
Search for Supersymmetry Using Final States with One Lepton, Jets, and Missing Transverse Momentum with the ATLAS Detector in s=7 TeV pp Collisions
G. Aad et al. (ATLAS Collaboration)
Phys. Rev. Lett. **106**, 131802 (2011) – Published March 28, 2011

A top priority for the entire field of particle physics is the search for particles predicted by supersymmetry—a theory that aspires to explain much of the physics that cannot be understood within the standard model. Now, after decades of planning and work by thousands of scientists around the world, a report appearing in *Physical Review Letters* from the ATLAS collaboration [1] and a similar paper from the CMS collaboration [2] are presenting the results of the first supersymmetry searches at the 7 tera-electron-volt (TeV) Large Hadron Collider (LHC) at CERN. While these early searches did not turn up the long-sought-after particles, there is good reason to believe that supersymmetry is there to be discovered at the LHC (Fig. 1).

The standard model (SM) of particle physics has been incredibly successful, but few physicists believe it is the final story. The model doesn't explain why particles have mass, the presence of dark matter and dark energy in the universe, or the excess of matter over antimatter. Nor does the standard model incorporate a quantum theory of gravity. Among the many theories that go beyond the standard model, there are few that are sufficiently compelling that they warrant a comprehensive and systematic set of searches to see if they are realized in nature. Supersymmetry (SUSY) is one such theory [3]. Essentially, SUSY is a theory that predicts an as-yet-unobserved symmetry between fermions and bosons. For example, each of the quarks and leptons have bosonic counterparts, often called squarks and sleptons, and these and other "sparticles" can be searched for in the high-energy collisions at the LHC.

FIG. 1: The Large Hadron Collider (LHC) is in a prime position to search for supersymmetry. (Credit: Alan Stonebraker)

At the cost of predicting a whole set of new particles, SUSY provides a fix for a number of the standard model's problems. For example, the standard model predicts a divergent value for corrections to the Higgs boson's mass, but SUSY offers a way around this problem, provided the sparticles aren't too heavy [4]. Another exciting possibility is that SUSY provides a way to unify the different forces coupling constants at very high energy. There is no *a priori* requirement that this must happen, but the potential unification of the electroweak and strong forces has an elegance that is tantalizing [5]. Many versions of SUSY have an extra conservation law that would prohibit the decay of the lightest SUSY particle. Not only would this particle become a dark matter candidate, but in this context SUSY can be used to provide both a full calculation of early universe physics and the dark matter relic density, a central problem in modern cosmology [6]. Finally, SUSY allows a possible connection to quantum gravity through superstring theory.

While a search for all possible versions of SUSY is probably not possible, the LHC and its giant detectors were designed to be very sensitive to the most

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compelling models. Experimental constraints and hints from theory help narrow down the parameter space in which to hunt for the new particles. Dark matter models of cosmology favor a weakly interacting neutral particle in the 100 GeV/c^2 mass range. The nonobservation of sparticles from Fermilab and LEP—accelerators operating at the previous high-energy frontiers—suggest that the masses of most of the heavier superpartner particles would have to exceed hundreds of GeV[3]. Furthermore, the sparticles are not likely to be too much higher than a few TeV if SUSY is to offer a means to correct the Higgs boson's mass. Taken together, it is not unreasonable to think we may well have entered a golden window of opportunity as the masses of the sparticles may well be within reach of the LHC.

In 2010, the LHC started producing high-energy proton-proton collisions and the CMS and ATLAS detectors started to collect data. It was not a flood of data to be sure (Fermilab experiments have studied more than 250 times more collisions), but the higher energy collisions at the LHC (more than 3.5 times as high) more than make up for it, as it should be much easier to produce the desired sparticles. A long-awaited new era in particle physics has officially begun.

The experimental challenges to test even a single version of SUSY are vast, and the literature is replete with reasonable choices. Given a semi-infinite number of potential final states to study and finite resources (and a time-critical race to get results out), experimentalists have chosen to start by focusing on one of the most straight-forward and well-studied versions of SUSY that meets all the criteria above. This version, which is the minimal model of SUSY that also includes potential grand unification with gravity, is known as Minimal Supergravity, or mSUGRA for short [7]. From a purely practical standpoint, it has the big advantage of being well described by only a few parameters.

If mSUGRA is realized in nature, and the masses are low enough, the enormous energy of the LHC should be able to produce supersymmetric versions of the quarks and gluons (known as squarks and gluinos) in large quantities. These sparticles should then decay away quickly, and depending on how they do so, their decay products can be identified by the detectors. For example, quarks and gluons (which produce jets of hadrons, simply referred to as jets) can be identified, and the same is true for the vector bosons like W's and Z's, which decay to the known leptons (electrons, muons, or taus), or quarks (more jets). In addition to these familiar particles, every sparticle will eventually decay into the lightest supersymmetric particle which, by a conservation law, will be stable and, if it is dark matter, be neutral and weakly interacting. It should thus leave the detector withough interacting with anything. This smoking gun signature is known as "missing" energy. Since there are many ways the SUSY particles can decay, there are many combinations of final-state particles produced; the collaborations are looking for all of these combinations. For example, CMS reported on its search for events with missing energy with lots of jets [2], while ATLAS reported on its search for one lepton, missing energy, and lots of jets [1]. There are lots of other "golden" search modes, including multiple leptons, jets, and missing energy, and results on all of them are on the way.

Unfortunately, the data so far are consistent with a world described by the standard model alone. While it's always more exciting to make a discovery, an explorer must report on their search sensitivity in order to make their expedition most useful to their community. As is typical for searches for SUSY, both collaborations set 95% confidence level limits as a way of conveying the sensitivity of their search. By way of comparison, the most sensitive limits from the Fermilab Tevatron—in comparable models, but at a single point in parameter space—were obtained at collision energies of only about 2 TeV of energy but from 100 times more data and excluded squarks with a mass less than about 400 GeV/c^2[3]. In other words, while one can't say for sure that a squark or gluino doesn't exist with a mass of 400 GeV, what we can say is that if it did exist within such a model, then in 95% of experiments it should have been observed in the experiments. Since it wasn't, we exclude it at this level. In the ATLAS result, squarks were excluded up 700 GeV/c^2 in certain models [1]. CMS reported a comparable sensitivity in similar, but not identical models [2].

For this type of SUSY search, the torch has been fully passed from Fermilab to the LHC. While there is no guarantee that SUSY will be discovered at the LHC, most physicists think the bulk of the favored energy space is within its final reach. With many results on the 2010 data in the pipeline, more data coming this year, and a doubling of the collision energy and maybe 1000 times more in the not-too-distant future, it is not unreasonable to think that the LHC will allow the experimental teams working there to either discover SUSY if it has a mass of 2 TeV/c^2 or less or say "maybe it isn't right." History teaches us that great discoveries come from great new tools; let's hope that history is on our side one way or the other.

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