SUSY Searches at Tevatron

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Search for Supersymmetry is a predominant experimental preoccupation because Supersymmetry gives theoretically appealing solutions to several significant issues in particle physics as well as in cosmology. CDF and D0 experiments at the Tevatron collider at Fermilab are carrying out multipronged strategies to discern Supersymmetry on the background of Standard Model processes. Here, I give an elementary introduction to Supersymmetry and then follow it by outlining recent search results from the Tevatron.

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1. Supersymmetry

Supersymmetry gives bosonic superpartners to fermions and vice versa, thus postulating the existence of sleptons, squarks, gauginos and higgsinos. No matter the appeal of supersymmetry, this doubling of particle spectrum seems to be too large a price to pay. However, we have exercised this exact doubling logic once before with wonderful consequences when we assigned "antimatter" partners to known particles. For example, we take the electron to be a point particle and know experimentally that its radius is less than 10^{-18} to 10^{-20} m. First-year physics tells us that assembling the charge of the electron in a sphere of radious 10^{-18} m costs $\sim 10,000$ MeV, which is far more than the mass of the electron. We solved this "hierarchy problem" long time ago by doubling the particle spectrum when we invoked an oppositely charged partner, positron, to the electron. The positrons from the electron-positron vacuum pairs dramatically reduce the energy budget for the charge assembly.

In the present reincarnation of the hierarchy problem, fermion loops push up the Higgs mass to very high values, but sfermion loops bring it back to the electroweak scale where it is needed for symmetry breaking. Supersymmetry is also credited with gauge unification, giving new sources of CP violating phases for baryogenesis, and with anticipating the heaviness of the top quark. A broad class of supersymmetric theories preserve the supersymmetric nature of the superpartners ("R Parity"), thus leading to stable Lightest Supersymmetric Particles (LSP's). By interacting only weakly, the LSP not only provides an attractive dark matter candidate, but also an experimentally crucial missing-E_T (MET) signature by escaping detection and creating a (transverse) momentum imbalance. However, R-parity is not sacrosanct, as dark matter could come from somewhere else and lepton number conservation may be sufficient to protect the proton lifetime. In that case, R-parity violating (RPV) multi-jet resonant signatures gain ascendancy over the classic missing-E_T driven searches.

We know to a great precision that particles and antiparticles weigh exactly the same. However, electron's superpartner, selectron, must be far more massive than the electron. Thus, supersymmetry is a broken symmetry. Experimental searches are guided by the nature of supersymmetry breaking and the mass and mixing hierarchy it creates. At the Tevatron, squarks tend to be too massive and thus have relatively small production cross sections. Gauginos, however, tend to be lighter and their direct electroweak production is competitive. At the LHC, with its energy edge, strong production also comes into the picture, making almost all search signatures "jetty".

2. Trileptons

Isolated electrons and muons suffer from relatively little standard model backgrounds. Therefore, the "trilepton" signature consisting of three electrons or muons with a good dose of missing transverse energy is a classic low-background SUSY signature. The extended trilepton signature allows for the replacement of an electron or a muon by a track that is isolated from electromagnetic energy and/or from other tracks. This isolated track serves as a proxy for the single-prong hadronic decay of the tau lepton, generally allowing for a higher $\tan(\beta)$ reach. The standard model backgrounds to this signaure are from Drell-Yan dilepton production accompanied by a "fake" lepton, irreducible background from (WZ) diboson production, top-pair production etc. For the isolated

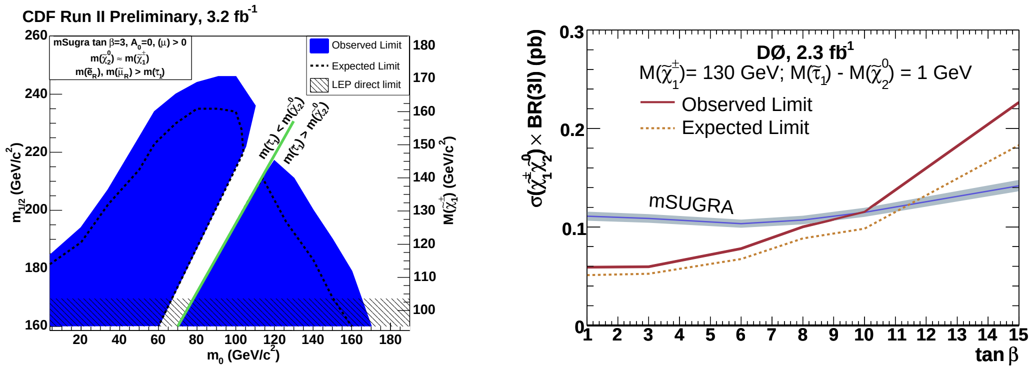

Figure 1: Left: CDF's 3.2fb^{-1} mSUGRA trilepton exclusion. D0's exclusion is similar. Right: D0's trilepton exclusion as a function of tan(β) for a specific SUSY mass spectrum.

track analysis, W(+jets) also constitutes a background. Figure 1 shows the CDF [1] and D0 [2] trilepton results from ~3fb^{-1} data analysis each. The exclusion gap seen in the figure represents a region in the mSUGRA parameter space where the third, i.e. the lowest p$_T$ lepton is produced at rest. As such, this gap region would benefit by a like-sign lepton search. As the figure shows, mSUGRA is the *lingua franca* for both CDF and D0 trilepton results and thus they are of little value in interpreting other SUSY theories such as the slepton co-NLSP model which are on a significantly stronger theoretical footing than mSUGRA. Therefore, a model-independent method of expressing experimental result is desirable. Since the number of parameters in a model can be unwieldy, model-independence in stating experimental results can be achieved [3] by factoring out the branching ratio dependence from the dependence of experimental acceptance on the SUSY mass spectrum in the model. Reference [3] gives an explicit recipe for model-independence using this factorization followed by a parametrization in terms of generic mass parameters. The experimental results, thus reexpressed more generally, can be reconstituted in the context of other relevant models as well as to address the mSUGRA parameter space not articulated by the original experimental results.

3. Squark and Gluino Searches

Whereas the trilepton signature at the Tevatron results mostly from direct electroweak production, squarks and gluinos can be strongly produced, yielding an "n-Jet and Missing E$_T$" signature which typically also has a requirement on a the sum of jet p$_T$'s (H$_T$). Both CDF [4] and D0 [5] limit the generic squark and gluino masses to be above ~300 GeV/c^2 and ~380 GeV/c^2, respectively. Figure 2 shows the exclusion from null results obtained by both CDF and D0 experiments.

3.1 Stop and Sbottom

The stop quark can be quite light when large L-R mixing leading to level repulsion akin to the see-saw mechanism. In that case, the stop can decay to a b-quark, a lepton and the sneutrino which serves as the LSP, giving a stop-antistop pair signature of an oppositely-charged lepton pair, jets and missing E$_T$. With 3.1 fb^{-1} e-μ search, D0 limits the stop mass to be above ~200 GeV/c^2. CDF employs e-e,e-μ, and $\mu-\mu$ channels with 1 fb^{-1} data to get a lower limit of ~180 GeV/c^2.

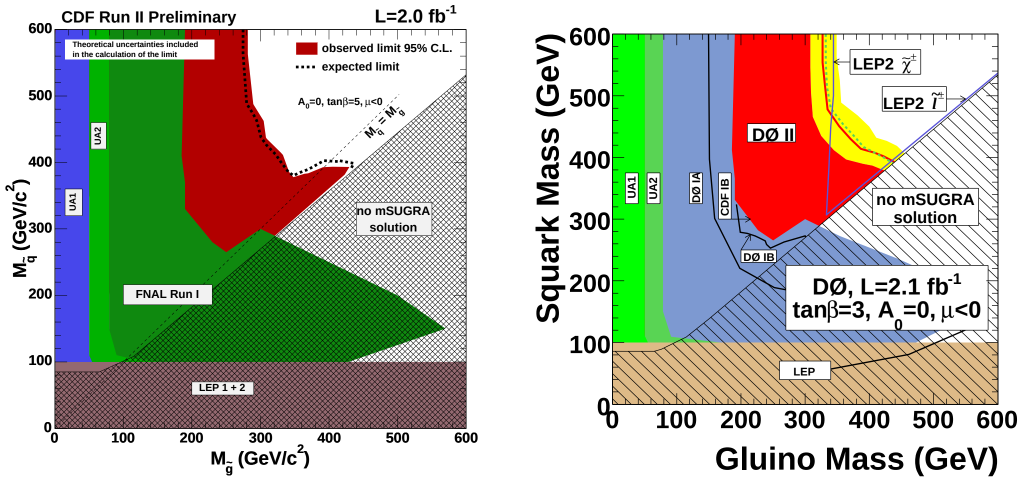

Figure 2: Exclusion contours due to the null findings of generic n-jet+MET squark-gluino searches from CDF (left) and D0 (right).

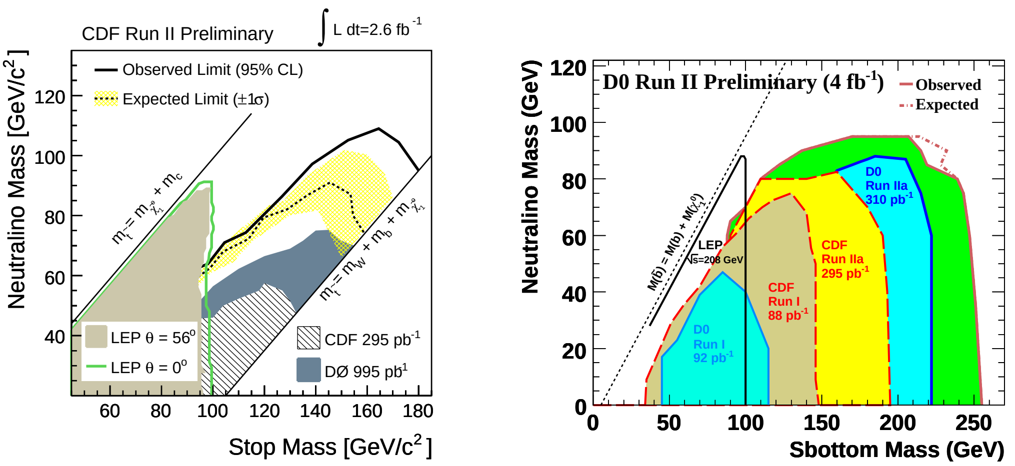

Figure 3: Exclusion results from CDF's stop search with charm-tagging (left) and from D0's sbottom search (right).

When the Renormalization Group Equation running in SUSY induces stop-charm mixing, one can also look for the stop quark by tagging the c-quark resulting from a stop decay (along with a neutralino LSP). Since c-tagging is experimentally challenging, this is a high-background open search for two jets, missing-E_T and at least one c-tagged jet. CDF, with 2.6 fb^{-1} data, expects 132 events and observes 115 events in this channel, with a possible stop signal as large as 90 events when the stop and LSP masses are 125 GeV/c^2 and 70 GeV/c^2, respectively. Mass limits on such a stop go as high as $\sim$180 GeV/c^2, as shown in Figure 3.

The figure also shows a limit from D0 on the sbottom mass. For high values of tanβ, the sbottom squark could be the lightest colored particle (*cf* level repulsion, above.) In that case, it would decay to a b-quark and the LSP neutralino, hence the sbottom pair production leading to two b-jets and missing-E_T. The search strategy for sbottom is to require b-tagged jet(s) with missing-

E_T and a substantial jet E_T sum. Figure 3 shows D0 limits with 4 fb^{-1} data. CDF also has limits (not shown) with 2.65 fb^{-1} data.

4. R-parity Violating Sneutrinos

Although R-parity conservation has the nice feature of giving a dark matter candidate (the LSP), Nature may not have chosen to kill two birds with one stone. In the absence of R-parity, single sparticle production is possible. In addition, the sparticle decay need not result in a missing-E_T signature. R-parity violating (RPV) sneutrino production results in a striking signature of high mass eμ resonances and for a change, missing-E_T and jets serve as vetoes in event selection for this search. The background results from Standard Model processes such as Drell Yan production, especially of $\tau^+\tau^-$ pairs. Diboson production can also lead to backgrounds. CDF [6] has done a search for this mode with 1 fb^{-1} data, but D0 has surpassed it with a 4.1 fb^{-1} preliminary result that constrains the appropriate couplings in this model as a function of the sneutrino mass.

5. Photons and GMSB, Dark Photons and Hidden Valley

There is a rich trove of possible SUSY signatures with photons. In particular, the Gauge Mediated SUSY Breaking (GMSB) class of models offers regions of parameter space that are rich in photon signatures. GMSB comes closest to a complete theory of SUSY, where the SUSY-breaking takes place at the 10-100 TeV scale. The squarks and gluinos are typically heavy (i.e. have small production cross sections) and the gravitino LSP is very light. The *Next* Lightest Supersymmetric Particle (NLSP) to the gravitino can be a neutralino or a slepton. When neutralino is the NLSP, its exclusive decay to the gravitino LSP yields a photon. The typical signature, given the associated (pair) production of sparticles, is then two energetic photons and a substantial missing E_T. Although photonic SUSY searches are typically associated with GMSB, GMSB models are amenable to leptonic signatures over larges swaths of their parameter space.

CDF [7] conducts its 2.6 fb^{-1} diphoton GMSB search in a 3-dimensional space carved by three variables: i)The azimuthal angle between the two photons, ii)A construct called “missing E_T significance” which discriminates against the likelihood of the missing E_T in the event having come from Standard Model background (fluctuations) and iii)The scalar sum of the E_T’s of the two photons and the missing-E_T. The electroweak backgrounds $Z\gamma\gamma \to \nu\nu\gamma\gamma$ and $W\gamma \to \nu\gamma\gamma_{fake}$ contribute about 63% of the backgrounds and the rest comes from QCD. No events are observed despite a Standard Model background expectation of 1.23 events. The lack of candidates results in an exclusion in the neutralino mass and lifetime plane as shown in figure 4.

D0 [8] has carried out a very interesting analysis with its 4.1 fb^{-1} photon sample by searching for closely spaced lepton pairs. The physics motivation behind this analysis is the so-called Supersymmetric Hidden Valley model in which the collider energy serves to make connection between the Standard Model and a “hidden valley” which is a stable, but higher energy sector. This scenario is motivated by anomalous astrophysical results from experiments such as DAMA/LIBRA, PAMELA, etc. The net import of significance to an experimentalist is the prediction of a $\sim$1 GeV gauge boson from this new sector (“dark photon”) that mixes with the photon with some unknown coupling, resulting in an occasional decay into a closely spaced lepton (e or μ) pair that can be

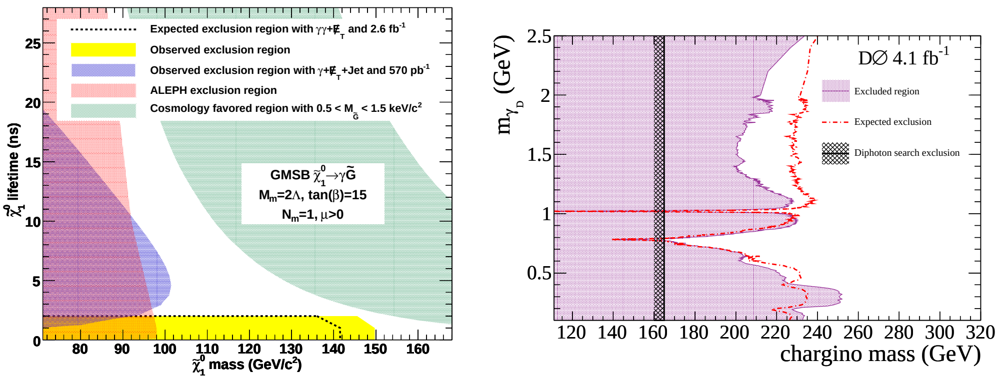

Figure 4: Exclusions from the CDF diphoton search (left) and the D0 dark photon search (right).

detected. The model is otherwise similar in phenomenology to GMSB, hence the lepton pair is also accompanied by a (high energy) photon. The "darkino" produced with the dark photon results in missing-E_T. The main background in this search for two closely spaced leptons accompanied by a photon and missing-E_T search comes from multijets and W+γ/jets processes. As shown in figure 4, in the absence of a significant signal find, strong costraints in the dark photon mass and chargino mass plane are set.

6. Conclusion

Both CDF and D0 have covered substantial SUSY parameter space analyzing upto $\sim 4\text{fb}^{-1}$ data. Although the results are consistent with Standard Model expectations, both experiments continue to collect and analyze substantially higher quantities of data from a smoothly performing Tevatron and new physics could very well materialize from the expected 10-12fb^{-1} data that each experiment hopes to analyze.

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