SUSY searches at the Tevatron

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Abstract. The Tevatron collider has provided the CDF and D0 collaborations with large datasets as input to a rich program of physics beyond the standard model The results presented here are from recent searches for SUSY particles using up to 6 fb^{-1} of data.

1 Introduction

Supersymmetry (SUSY) [1] is one of the most favored theories beyond the standard model (SM). Each SM particle is associated to a sparticle whose spin differs by one half unit. This boson-fermion symmetry is obviously broken by some unknown mechanism. Even in the minimal supersymmetric extension of the SM (MSSM [2]) there are a large number of free parameters. To reduce this number one can introduce new assumptions on the symmetry breaking mechanism and build models based on minimal supergravity (as mSUGRA [3]) or on a Gauge Mediated Symmetry Breaking scenario (GMSB [4]), a top-down approach. Another possibility is to make phenomelogical assumptions to reduce the number of particles accessible to the experiment while keeping some of the properties of the above models (bottom-up approach).

As the sparticles are heavy, to produce them one has to make collisions at the highest center of mass energy. The Tevatron was the best place for discovery until the start of LHC. In the near term, Tevatron experiments and their large datasets remain competitive in areas like production of third generation squarks and of non-coloured sparticles.

I will report on recent results from the CDF and D0 collaborations, assuming R-parity [5] is conserved, i.e the sparticles are produced in pairs, and the lightest of them (LSP) is stable, neutral, weakly interacting, and detected as missing transverse energy, $\not{E}_T$.

2 Scalar bottom and top quarks

In the MSSM, the mass splitting between the mass eigenstates of the two scalar partners of a SM fermion depends on the mass of the fermion. As such, the lightest scalar partners of the third generation may be light enough to be produced copiously at the Tevatron. In a data sample of 5.2 fb^{-1}, D0 has searched for a scalar bottom quark assuming it decays exclusively into a bottom quark and the lightest neutralino (LSP), resulting in events with two b-jets and large $\not{E}_T$. This topology is identical to that for $p\bar{p} \to ZH \to \nu\bar{\nu} + b\bar{b}$ production, and the two analyses are based on the same trigger and event selection criteria [6]. The SM background processes which contribute

in this topology are the production of W/Z bosons in association with b-jets and top quark production. No excess of events is observed above the expected SM processes which allows D0 to increase the excluded domain in the $(m_{\tilde{b}}, m_{\tilde{\chi}_1^0})$ mass plane excluding a 247 GeV scalar bottom for a massless scalar neutralino and a 110 GeV neutralino for $160 < m_{\tilde{b}} < 200$ GeV [7].

Scalar top quarks have been also searched for in various decay channels. The most recent analysis is from D0 with a 5.4 fb^{-1} data sample. The scalar top quark is assumed to decay exclusively in the three body decay mode $\tilde{t} \to bl\tilde{\nu}$ with equal fraction to each lepton type, l; the scalar neutrino, $\tilde{\nu}$, is either the LSP or decays invisibly to a ν and the LSP. The event selection requires exactly one isolated electron and one isolated muon of opposite charge, with transverse momenta, $p_T > 15$ and 10 GeV respectively. The SM backgrounds are from the Drell-Yan process ($\gamma/Z* \to \tau\tau$), or from diboson and top quark pair production. Several combinations of estimators are built to discriminate signal from the different backgrounds depending on the mass difference, $\Delta m = m_{\tilde{t}} - m_{\tilde{\nu}}$. Scalar top masses below 210 GeV are excluded for a scalar neutrino mass below 110 GeV and $\Delta m > 30$ GeV [8] (Fig. 1).

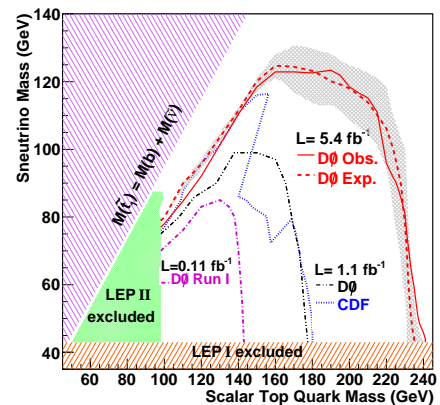**Fig. 1.** D0 observed and expected 95% C.L. exclusion contour in the sneutrino and scalar top mass plot, and comparison with previous results.

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3 Diphotons and large $\not{E}_T$

Events with two high transverse momentum photons and large $\not{E}_T$ are relatively rare in SM processes. This topology is then very attractive for testing the GMSB model where the LSP is the gravitino, a very light and weakly interacting particle. In the case where the next-to-lightest SUSY particle (NLSP) is the neutralino, $\tilde{\chi}_1^0$, it will decay to a photon and a gravitino. At the Tevatron, a large cross section is expected from chargino-neutralino pair production which will cascade decay to two NLSP's and other leptons or jets, followed by the NLSP decays to a pair of photons and gravitinos. D0 has analysed 6.3 fb^{-1} of data [9] requiring events with two photon candidates with $p_T > 25$ GeV. Events with real photons from SM processes and multijet events where jets are faking one or more photons appear mostly at low $\not{E}_T$, as shown in Fig. 2. Signal is expected at large $\not{E}_T$ where no excess of events is observed. D0 obtained a quantitative result when considering the Snow Mass Slope scenario, SPS8 [10]; an effective SUSY breaking scale below 124 TeV is excluded at 95%C.L., as well as gaugino masses $m_{\tilde{\chi}_1^0} < 175$ GeV and $m_{\tilde{\chi}_1^\pm} < 330$ GeV.
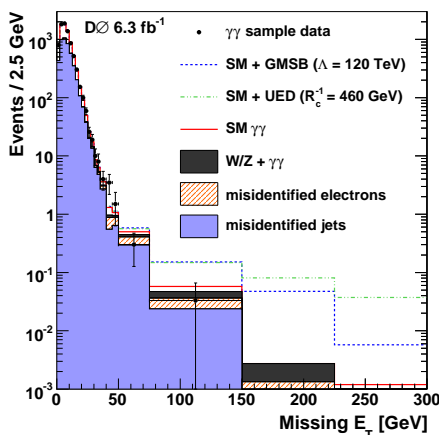

Fig. 2. D0 observed $\not{E}_T$ distribution in the diphoton event sample; expected distribution from SM backgrounds with and without contribution of GMSB events.

4 SUSY simplified models

Same charge dilepton events are a signature which has very low SM backgrounds, essentially from WZ and ZZ diboson production. CDF has developped a general model independent strategy using simplified models as described in ref. [11].

4.1 Same charge dileptons with jets

The analysis requires two isolated leptons of the same charge with $p_T > 20$ GeV and at least two jets with $p_T > 15$ GeV. The two leptons are either ee, $\mu\mu$ or $e\mu$. This topology is a SUSY signature; it results from the decays of squark and gluino pairs. The simplified model restricts the decay chain to proceed only through W or Z bosons. Sleptons are much heavier such that they have not influence on
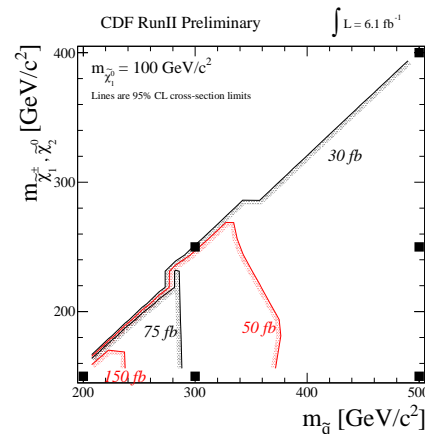

Fig. 3. CDF limits on squark pair production for a neutralino mass of 100 GeV.

the event selection. The model is further simplified by considering only the first generation of squarks and assuming that squarks decay equally to $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ which are degenerate in mass. Finally the only parameters of the model are the masses : $m_{\tilde{q}}$,$m_{\tilde{g}}$, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^0}$ and $m_{\tilde{\chi}_1^0}$, the mass of the LSP. The acceptance is largely affected by the mass difference between the $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ and the LSP. In a 6.1 fb^{-1} data sample, CDF has not observed any significant deviations over the background expectations [12]. Cross section limits on squark and gluino pair production are provided as a function of the sparticle masses. In Fig. 3, the limits are obtained for gluinos heavier squarks and a 100 GeV LSP.

4.2 Same charge dileptons including a tau

In this analysis [13], CDF requires that one of the lepton is a τ decaying hadronically, the other one being either an e or a μ. Two classes of models are considered : a simplified gravity model reproducing some of the properties of mSUGRA and a simplified model motivated by gauge mediated SUSY breaking. In both classes, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are degenerate in mass and decay to sleptons. The slepton decays to their SM partners and the LSP, either the $\tilde{\chi}_1^0$ or the gravitino. In these decay chains, 2 cases were considered either all lepton flavors are equally probable or modes involving τ are favored. The multijet background from QCD jets faking a τ has been reduced by requiring a minimum value for H_T defined as the scalar sum of the τ p_T, lepton p_T and $\not{E}_T$ in the event. Cross section limits are presented for each model in the ($m_{\tilde{\chi}_1^\pm}$,$m_{\tilde{l}}$) mass plane. As an example, Fig. 4 shows the excluded domain in the simplified gravity model for a 45 GeV LSP and a $\tilde{\chi}_1^\pm$ decaying exclusively to $\tilde{\tau}X$.

5 Trileptons

At the Tevatron, the trilepton final state is known as the "SUSY golden mode" because of the small background level. It is obtained by the production of a $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ pair, which subsequently decay via W and Z bosons (if sleptons are heavy) or via sleptons. The first case suffers from the small leptonic branching ratios of the W/Z decays. In the
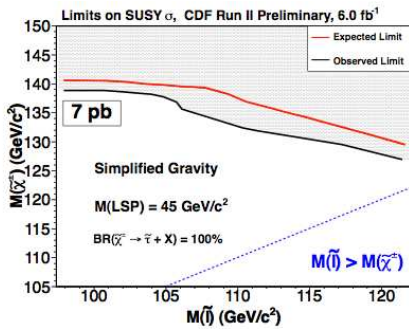
Fig. 4. CDF limits in a simplified gravity model where the LSP mass is 45 GeV.

second one, tau production may be enhanced if the lightest $\tilde{\tau}$ is much lighter than the other sleptons. In a 5.8 fb^{-1} data sample, CDF analysed events with two electrons or two muons requiring either the third lepton to be an identified lepton (e, μ or τ decaying hadronically) or an isolated track [14]. In addition to a larger luminosity, this analysis benefits from an extension of the lepton acceptance to the forward region, and from a decrease of the minimum p_T of the non-leading leptons down to 5 GeV. A large effort was devoted to study the background yields in a lot of SM dominated control regions. Overall, no excess of events has been observed over the expectation leading to a limit on the cross section times branching ratio into three leptons of 0.1 pb. Interpreted within the mSUGRA model, this limit excludes a $\tilde{\chi}_1^\pm$ mass below 168 GeV for a particular set of values for the other parameters (Fig. 5).
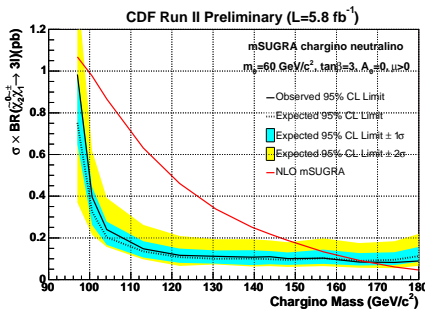

Fig. 5. CDF 95% CL upper limit on the chargino-neutralino production cross section with subsequent trileptonic decay as a function of the chargino mass.

6 Leptonic jets

Hidden Valley (HV) scenarios [15] introduce a hidden sector which is weakly coupled to SM particles. They become popular as they provide a convincing explanation of observed astrophysical anomalies and discrepancies in dark matter searches. New low mass particles are introduced in the hidden sector, and the dark photon, which is the force carrier, would have a mass around 1 GeV or less and would decay into a fermion or pion pair. The case of decays to a lepton pair (electron or muon) is particularly attractive. SUSY is often included in HV models, and one could have

a situation where the lightest neutralino will decay to a dark photon and $\tilde{X}$, the lightest SUSY particle of the hidden sector, which will escape detection, leading to large $\not{E}_T$. As the dark photon is light, it will be highly boosted in the neutralino decay, and the two leptons will be close to each other. Experimentally, one has to change the isolation criteria usually applied to identify leptons. The presence of a track of opposite charge close to the lepton candidate will identify the so-called leptonic jet (*l*-jet). Using 5.8 fb^{-1} of data, D0 [16] has searched for pair production of *l*-jets in three configurations : *ee*, $\mu\mu$ and $e\mu$. No evidence of *l*-jets is observed in the distributions of the electron and muon pair masses. Limits on the production cross section, around 100 fb for a 1 GeV dark photon, are obtained (Fig. 6). They are substantially weaker when the dark photon branching ratio to hadrons is larger, particularly near the ρ and ϕ resonances.
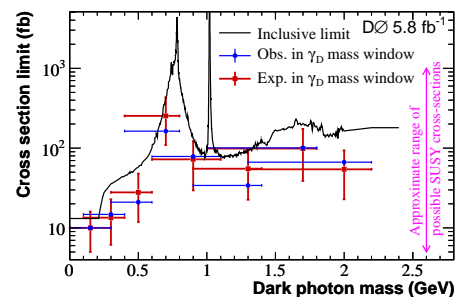

Fig. 6. Limit on the observed cross section for the three channels (*ee*, $\mu\mu$, $e\mu$) combined as a function of the dark photon mass.

7 Charged massive long lived particles (CMLLP)

Some recent extensions of SM predict the existence of CMLLPs. Indeed, they may help resolve difficulties of the model of the big bang nucleosynthesis at explaining the lithium abundance. Within SUSY, charginos could be long lived if they are almost degenerate in mass with the LSP. Experimentally, a long live time means that a CMLLP will decay outside the sensitive volume of the detector, a large mass means a low speed and high ionisation loss. CMLLPs would ressemble slow moving heavy muons. In D0 [17], their low speed is measured by the time of flight recorded by the muon scintillation counters; their energy loss compared to minimum ionising muons is measured by the silicon detectors. The analysis requires at least one well identified muon of high p_T. Muons from meson decays are rejected by imposing isolation criteria in the tracking system and in the calorimeter. Then, the remaining background originates from mismeasured real muons. A background model has been built from data, essentially the production of W bosons decaying leptonically into a muon and a neutrino. Requiring the W transverse mass to be below 200 GeV and a high speed for the muon selects a signal free region. The absence of any excess of events in 5.2 fb^{-1} of data allows one to derive cross section limits of about 0.01 pb for the production of a pair of CMLLPs with

masses between 200 and 300 GeV. Comparing this limit to chargino pair production gives mass limits on charginos according to their nature, being mostly a gaugino (Fig. 7) or mostly a higgsino. The results of the analysis include also the limits for a light scalar top, after taking into account the complications of hadronization and charge exchange of this strong interacting particle between the production vertex and the muon system.
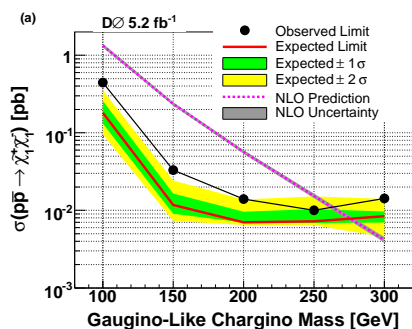

Fig. 7. D0 95% C.L. cross-section limit as a function of the mass of a gaugino-like chargino.

8 Summary

Despite the start of LHC, SUSY searches at the Tevatron are still active. With their large datasets, CDF and D0 have proved that there are domains where they have competitive results. Further details on physics results from the CDF and D0 collaborations can be obtained respectively from :

http://www-cdf.fnal.gov/physics/physics.html
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

Acknowledgments

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