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Search for SUSY at the Tevatron

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We review the latest results on searches for supersymmetry at CDF and DØ Run II in a data sample with integrated luminosity up to 4.1 fb^{-1}.

1 Introduction

The Standard Model [1] of particle physics (SM) describes data from collider experiments very well [2] with no unambiguous hints of physics beyond the SM, so called "New Physics" (NP). The only missing component in the SM is the Higgs boson, which is, unlike other SM particles, directly sensitive to an ultraviolet momentum cutoff, Λ_{UV}, which leads to enormous quantum corrections $\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{\rm UV}^2 + \ldots$. There are a few other flaws in the SM, such as massive neutrinos, and astrophysical data, which provides a strong motivation for massive stable particles, missing in the SM. In supersymmetry (SUSY) models [3], each of the SM particles has a partner differing by a half-unit of spin, which resolves the Δm_H^2 issue. If R-parity is conserved, SUSY particles are produced in pairs and their decay leads to SM particles and to the lightest SUSY particle, which is stable, and therefore is a "Dark Matter" candidate. In these proceedings we present the latest CDF and *DØ* results on the searches for SUSY in a data sample with integrated luminosity up to 4.1 fb^{-1}.

2 Understanding the Data

To better understand data, we use both Monte Carlo (MC) and data-driven (DD) approaches. A DD approach to backgrounds is preferred due to difficulties in MC simulation associated with modeling the QCD contribution. We also can not trust the MC simulation alone to predict instrumental effects and backgrounds involving the tails of distributions.

The most common objects in the analyses presented in these proceedings are leptons and $\not\!\!E_{\rm T}$. To estimate a contribution from jets misidentified as leptons, we (a) invert lepton identification criteria to create background-dominated samples [4]; (b) use track isolation for leptons (jets misidentified as leptons tend to be non-isolated) [5]; or (c) look for a misidentification rate in jet triggered QCD samples. To study misidentified $\not\!\!E_{\rm T}$, the SM processes predicted with MC or DD methods can be tested in background-dominated control regions, for instance one can require a jet or a lepton to be aligned with $\not\!\!E_{\rm T}$.

3 Stop

In the decay scenarios $\tilde{t} \to b\tilde{\chi}_1^{\pm} \to b\tilde{\chi}_1^0\ell\nu$ (on-shell charginos, $m_{\tilde{t}_1} < m_t$) and $\tilde{t} \to \ell b\tilde{\nu}$ (off-shell charginos, $m_{\widetilde{\chi}_1^{\pm}} > m_{\tilde{t}}$) the scalar top decay products are similar to those from the decay of top quarks, i.e. two isolated leptons, missing transverse energy, and jets ($\ell\ell\not\!\!E_{\rm T} + jets$). Therefore, in this case stop events would enter the top quark data sample and mimic the top event signatures, thus affecting top properties measurements, for instance, the top mass. The dominating background for the stop searches is SM $t\bar{t}$ production.

For the $\tilde{t} \to b\tilde{\chi}_1^{\pm} \to b\tilde{\chi}_1^0 \ell\nu$ search we also require at least one b-tagged jet, and reconstruct the stop mass in ee, $\mu\mu$ and $e\mu$ channels, looking for deviations from the expected SM top mass distribution. We find 57 events in 2.7 fb^{-1} of data versus 56 $\pm$ 7.3 expected from the SM [6]. Figure 1 shows the reconstructed top mass and the observed 95% CL in the neutralino vs stop mass plane for a chargino mass of 125.8 GeV, for various dilepton ($\ell\ell$) branching ratios. It is assumed that electrons, muons, and taus all occur with the same frequency in the final state.

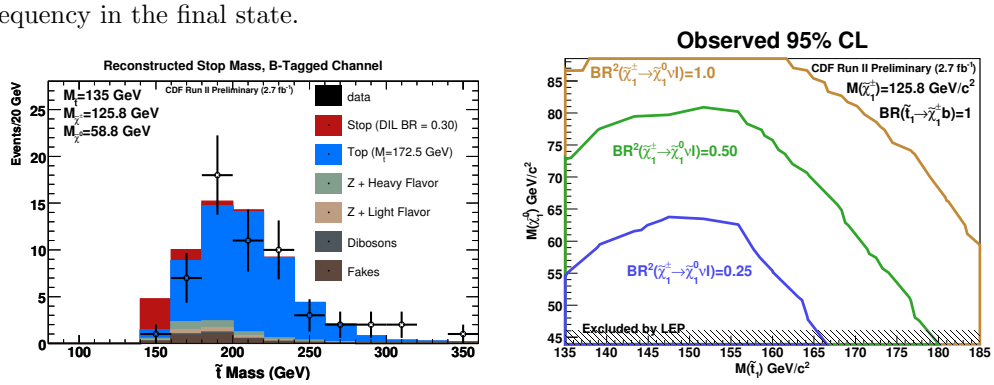

Figure 1: On the left: The reconstructed stop mass M_{stop} distribution. On the right: observed 95% CL limits.

The $\tilde{t} \to \ell b\tilde{\nu}$ search is performed in the $\ell\ell$ final states (ee and $e\mu$ at $D\emptyset$ [7] and ee, $\mu\mu$ and $e\mu$ at CDF [8]) using 1 fb^{-1}. Figure 2 shows the $\not\!\!E_{\rm T}$ in $\ell\ell$ events for the CDF search, and the 95% limits in the stop versus sneutrino mass plane, measured by CDF and $D\emptyset$.

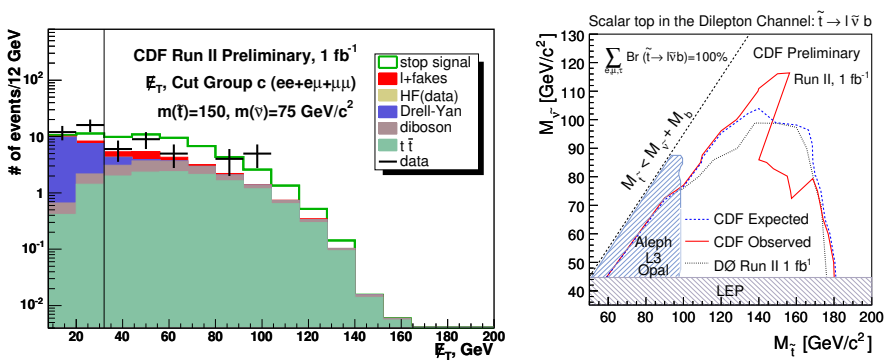

Figure 2: On the left: The $\not\!\!E_{\rm T}$ distribution in ee, $\mu\mu$ and $e\mu$ channels. On the right: observed limits at 95% CL in the stop versus sneutrino mass plane.

4 Sbottom

We perform a search for sbottom production from gluino decay, $\tilde{g} \to \tilde{b}\bar{b}$, where decays $\tilde{b} \to b\tilde{\chi}_1^0$. Since this process is expected to have a $\not\!\!E_{\rm T}$+4 b-jets final state, an inclusive signature for the search is at least 2 jets and $\not\!\!E_{\rm T}$. Furthermore, two categories were made by requiring only one of the jets (one exclusive tag) or at least two jets to be tagged (two inclusive tags).

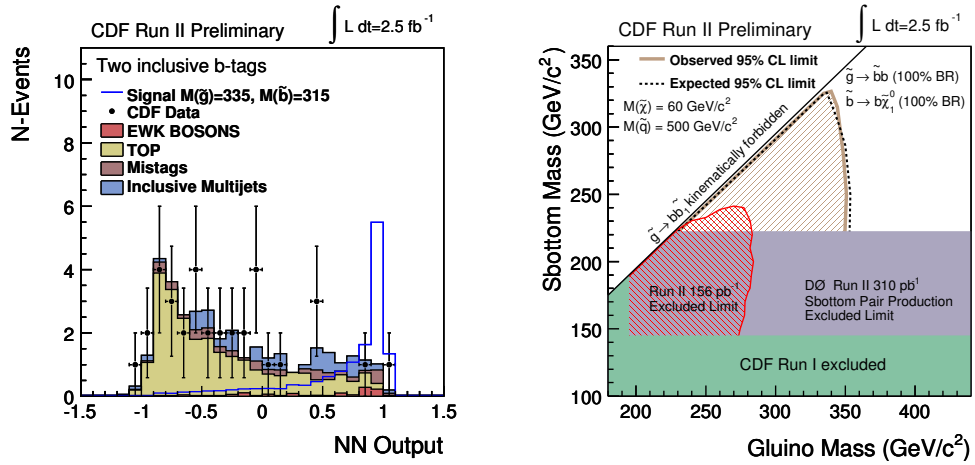

Figure 3: On the left: NN output for the two-tag sample (we found 0.8 an optimal selection cut in the small $\Delta m_{\tilde{g}\tilde{b}}$ region). On the right: the exclusion limits; the $D\emptyset$ limits are for direct sbottom production, therefore they are flat versus gluino mass.

The SM processes predicted with MC or DD methods were tested in background-dominated control regions, "multijet QCD" (a 2nd jet aligned with $\not\!\!E_{\rm T}$), "lepton" (lepton aligned with MET), "pre-optimization". We used two 2 neural networks (NN) for small and large $\Delta m_{\tilde{g}\tilde{b}}$ to optimize the sensitivity keeping a reasonable amount of $\tilde{b}$ signal. The two-tag sample (Fig. 3) is more sensitive to the signal, so it is used to extract an exclusion limit for the cross-section. The single-tag category is used as an additional control region.

Fig. 3 shows the NN output for the two-tag sample, optimized for small $\Delta m_{\tilde{g}\tilde{b}}$ and the exclusion limits from CDF (2.5 fb^{-1}) [9] and $D\emptyset$ experiments (310 pb^{-1}, direct sbottom production) [10].

5 R-Parity Violation

The analysis is performed under the hypothesis that the tau sneutrino is the lightest SUSY particle (LSP), that is we assume that SUSY is correct but has nothing to do with the "Dark Matter candidate" issue. We perform a search for R-Parity violating $\tilde{\nu}_\tau$ production and subsequent decay to dileptons. The analysis has been done in $e\mu$ channel with 4.1 fb^{-1} at $D\emptyset$ [11], and in $e\mu$, $\mu\tau$ and $e\tau$ channels with 1.0 fb^{-1} at CDF [12]. Backgrounds are dominated by EWK and W+jets with misidentified leptons. Fig. 4 shows the $M_{e\mu}$ for the $D\emptyset$ search, and the 95% $m_{\tilde{\nu}_\tau}$ $D\emptyset$ exclusion limits.

6 Chargino / Neutralino (Direct Production of Gauginos)

In $p\bar{p}$ collisions, charginos $\tilde{\chi}_1^\pm$ and neutralinos $\tilde{\chi}_2^0$ can be produced in pairs via an off-shell W or the exchange of squarks. CDF [13] and $D\emptyset$ [14] performed a search for $p\bar{p} \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0$ in final states with $\not\!\!E_{\rm T}$, produced by undetected $\tilde{\chi}_1^0$, and three charged leptons.

Data agree well with the SM predictions. For instance, for all channels in the CDF search 7 trilepton events are observed versus 6.4 ± 1.1 expected, where 1.4 events are expected from

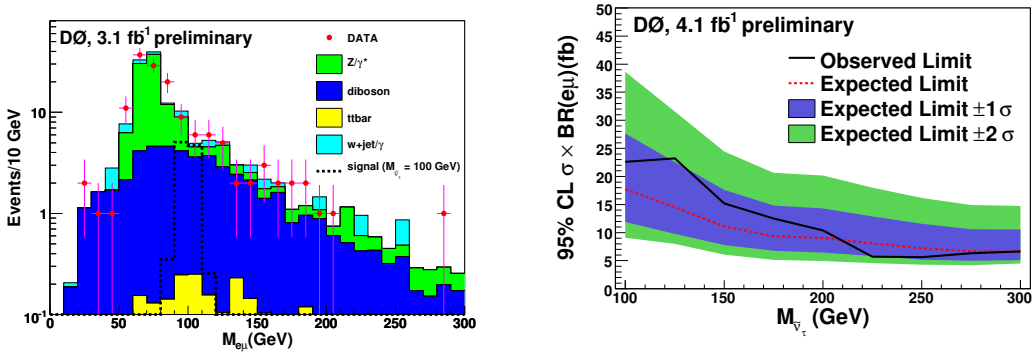

Figure 4: On the left: invariant $e\mu$ mass $M_{e\mu}$, $D\emptyset$ finds 143 $e\mu$ events in 4.1 fb^{-1} vs 144.9 $\pm$ 8.3 expected. On the right: the $m_{\tilde{\nu}_\tau}$ exclusion limits for the R-Parity violating $\tilde{\nu}_\tau$ search.

misidentified leptons, 3 from Drell-Yan, 1.6 from dibosons and 0.5 from $t\bar{t}$. Figure 5 (left) shows the region excluded for mSUGRA parameter space $tan\beta = 3$, $A_0 = 0$ and $\mu > 0$.

7 Squark/Gluino

If squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) are sufficiently light, they would be abundantly produced in $p\bar{p}$ collisions, and decay $\tilde{q} \rightarrow q\tilde{\chi}_1^0$, $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$, leading to final states containing jets and $\not\!\!E_{\rm T}$. Depending on the relative masses of squarks and gluinos, different event topologies are expected, such as 2 jets + $\not\!\!E_{\rm T}$ ($m_{\tilde{q}} < m_{\tilde{g}}$, $\tilde{q}\tilde{q}$ dominates), 3 jets + $\not\!\!E_{\rm T}$ ($m_{\tilde{q}} \sim m_{\tilde{g}}$, $\tilde{q}\tilde{g}$ dominates), 4 jets + $\not\!\!E_{\rm T}$ ($m_{\tilde{q}} > m_{\tilde{g}}$, $\tilde{g}\tilde{g}$ dominates). $D\emptyset$ optimized its search for the three different channels - low m_0 (2 jets + $\not\!\!E_{\rm T}$), $m_{\tilde{q}} \approx m_{\tilde{g}}$ (3 jets + $\not\!\!E_{\rm T}$) high m_0 (4 jets + $\not\!\!E_{\rm T}$).

Main backgrounds for the search are QCD (multijets), $Z \rightarrow \nu\bar{\nu}$+jets, $W \rightarrow \ell\nu$+jets and $t\bar{t}$. To remove events where the energy of a jet is mismeasured, leading to "fake" $\not\!\!E_{\rm T}$, $\Delta\phi(\not\!\!E_{\rm T}, jet)$ was used. A veto on lepton candidates (e.g. isolated tracks and jets with a large fraction of energy measured in electromagnetic calorimeters) has been applied to

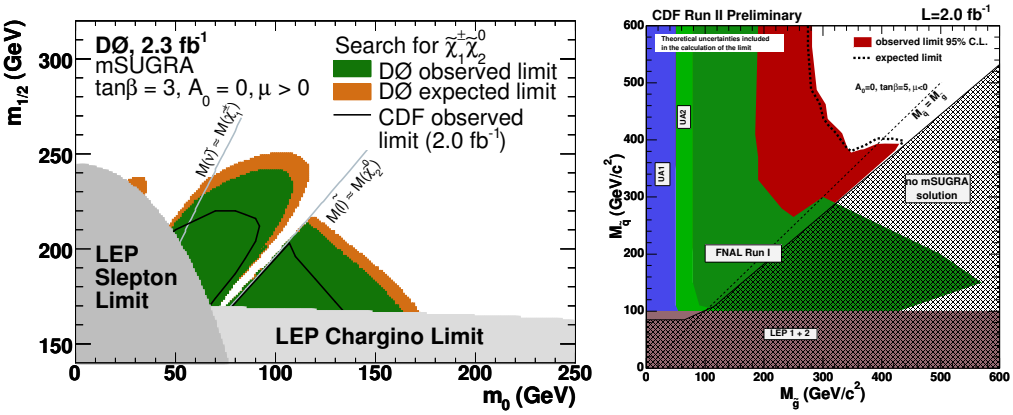

Figure 5: On the left (chargino/neutralino search): exclusion regions in $m_0 - m_{1/2}$ space ($tan\beta = 3$, $A_0 = 0$ and $\mu > 0$). On the right (squark/gluino search): CDF Run II exclusion limits at the 95% C.L. in the $M_{\tilde{q}} - M_{\tilde{g}}$ region ($tan\beta = 5, A_0 = 0, \mu < 0$).

reject backgrounds containing leptons. The results are consistent with SM expectations for all three analyses for both CDF (2 fb^{-1}) [15] and $D\emptyset$ (2.1 fb^{-1}) [16] searches. In the framework of mSUGRA we set limits for $m_{\tilde{q}}$ and $m_{\tilde{g}}$. For instance, $D\emptyset$ set limits $m_{\tilde{q}} > 379\ GeV$ and $m_{\tilde{g}} > 308\ GeV$ ($tan\beta = 3, A_0 = 0, \mu < 0$); for $m_{\tilde{g}} \approx m_{\tilde{q}}$ scenario CDF sets limits $m_{\tilde{g}} > 392\ GeV$ ($tan\beta = 5, A_0 = 0, \mu < 0$). Figure 5 (right) shows exclusion limits in the $M_{\tilde{q}} - M_{\tilde{g}}$ region, assuming mSUGRA parameters $tan\beta = 5, A_0 = 0, \mu < 0$.

8 Charged Massive Stable Particles

We perform a search for the production of charged massive particles (CHAMPs). CHAMPs are predicted by several NP models, and have a signature of "slow moving muons" in a detector. Both CDF and $D\emptyset$ use data-driven techniques, described below.

To isolate slowly-moving, high-$\mathrm{P_T}$ particles CDF uses the time-of-flight and tracking detectors [17]. The $\mathrm{W}^{\pm} \to e^{\pm}\nu$ and $\mathrm{Z}^0 \to e^+e^-$ samples are used to study systematic effects. CDF finds 1 with a measured $\mu\mu$ mass above 100 GeV with an expected background of ≈1.5 events. Within the context of a stable scalar stop squark, CDF sets a lower limit on the mass of 250 GeV. The same result implies a cross section limit of 10 fb for a weakly-interacting charged stable particle produced with $\mathrm{p_T} > 40\ GeV$, $|\eta| < 1.0$, a velocity $0.4 < \beta < 0.9$.

$D\emptyset$ uses timing in the muon scintillator layers to calculate the average speed $\bar{v}$, and reconstructs the mass of a CHAMP candidate [18]. $D\emptyset$ uses unphysical values of a speed significance $(1 - \bar{v})/\sigma_v < 0$ and events within a Z boson mass window as control samples, to study systematic effects and to model background shapes. $D\emptyset$ sees no evidence of a signal and sets lower mass limits of 206 GeV (171 GeV) for pair-produced charged gauginos (higgsinos).

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