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Search for trilepton SUSY signal at CDF

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Abstract. The chargino-neutralino production with subsequent leptonic decays is one of the most promising supersymmetry (SUSY) signatures at the Tevatron proton-antiproton collider. We present the most recent results on the search for the three-lepton and missing-transverse-energy SUSY signature using 3.2 fb^{-1} of data collected with the CDF II detector. The results are interpreted within the minimal supergravity (mSUGRA) scenario.

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INTRODUCTION

Theories with supersymmetry (SUSY) are arguably the most compelling of those that attempt to resolve the outstanding particle-physics questions [1]. Starting from the simple hypothesis of the existence of an identical fermion for every known boson and vice-versa, we can resolve remaining asymmetry problems (fermion/boson, particle/antiparticle), allow for the exact unification of interactions, and solve the fine-tuning problem. If R-parity is conserved, an axiom that is often invoked to avoid proton decay, then the lightest supersymmetric particle (LSP) will be stable, providing an excellent candidate for cold dark matter. Moreover, SUSY offers a radiative electroweak-symmetry breaking capability.

Superpartners of the known standard-model (SM) particles, differing only in spin, have not been observed and have been ruled out. As a result, SUSY should be a broken symmetry. Our working assumption is a minimal supersymmetric standard model (MSSM) with soft SUSY breaking. If the transfer of SUSY-breaking to the visible sector happens through gravity, the SUSY scenario is SUGRA and the LSP is the lightest neutralino. If the transfer takes place through gauge fields, the SUSY scenario is the GMSB and the LSP is the gravitino. In mSUGRA, the only free parameters of the theory are the common scalar mass m_0, the common gaugino mass $m_{1/2}$, the ratio of Higgs vacuum expectation values $\tan\beta$, the trilinear sfermion-sfermion-Higgs coupling A_0 and the the sign of the higgsino scale parameter μ. In this paper we interpret our result in the mSUGRA scenario, although the search is performed in a scenario-independent manner.

CHARGINO-NEUTRALINO PRODUCTION AND DECAY

The fermionic partners of the SM gauge bosons and the Higgs, the gauginos and the higgsinos, mix to give two observable charginos and four observable neutralinos. Assuming R-parity conservation, the charginos and neutralinos have to be produced in pairs. Due

to the nature of the gaugino and higgsino mixing under the assumption of gaugino mass unification, the highest cross section at the Tevatron is that of the associated production of the lightest chargino and the next-to-lightest neutralino. The production takes place mainly through an off-shell W boson, since the t-channel production with a squark propagator is unfavored due the high squark mass limits.

The charginos and neutralinos decay either through sleptons, which always decay to leptons, or through off-shell gauge bosons, which decay to leptons only a fraction of the time. In any case, the leptonic decays of the chargino-neutralino pair will result in three leptons and missing transverse energy ($\not\!\!E_T$) from the undetected neutrinos and lightest neutralino (LSP). We investigate the leptonic decays because the SM trilepton backgrounds are very low. Given that the chargino-neutralino production cross sections of the order of 0.1-1 pb (depending on the SUSY parameter space) have not been excluded yet, and given the current mass limits for squarks and gluinos (> 300 GeV/c^2), the trilepton signature is the "golden" channel for the discovery of supersymmetry at the Tevatron [2].

In order to estimate the SUSY signal for a particular mSUGRA point, we determine the mSUGRA mass spectrum and decay branching ratios using ISASUGRA [3] and we simulate the events using Monte Carlo (PYTHIA generator [4] and CDF detector simulation). We normalize the events using production cross sections determined with PROSPINO [5].

STANDARD-MODEL TRILEPTON BACKGROUNDS

The main sources of dileptons at the Tevatron are the Drell-Yan (DY) process and the semileptonic heavy-flavor quark (b, c) decays, the latter being significant at low dilepton invariant masses ($M_{\ell\ell} < 35$ GeV) [6]. The main sources of trileptons are the diboson leptonic decays and the above dilepton production with the addition of a photon (that converts) or a fake lepton, i.e., a jet that fakes an electron or a track that fakes a muon. The source of fakes is hadrons (mainly kaons and pions) that decay-in-flight or punch-through; we thus associate the fakes to light-flavor quarks. The $\not\!\!E_T$ comes from neutrinos or from limited energy resolution or from event mis-reconstruction. At higher $M_{\ell\ell}$ and $\not\!\!E_T$, trileptonic $t\bar{t}$ signal is also considered.

The electroweak backgrounds (diboson, DY+γ) as well as $t\bar{t}$ are estimated using Monte Carlo simulation. In this analysis we eliminate the heavy-flavor QCD by applying appropriate dilepton-mass, lepton-p_T and $\not\!\!E_T$ cuts. The light-flavor QCD (fakes) is estimated from CDF data, by selecting two leptons and applying a fake-rate on additional jets or tracks present in the event. These fake-rates are measured as a function of the fakeable jet E_T or track p_T using jet-rich CDF data.

ANALYSIS STRATEGY AND EVENT SELECTION

The most critical part of any new-physics search is the accurate estimation of the SM backgrounds. For this purpose we define dilepton and trilepton control regions – kinematically orthogonal to our signal region – where we confirm good understanding

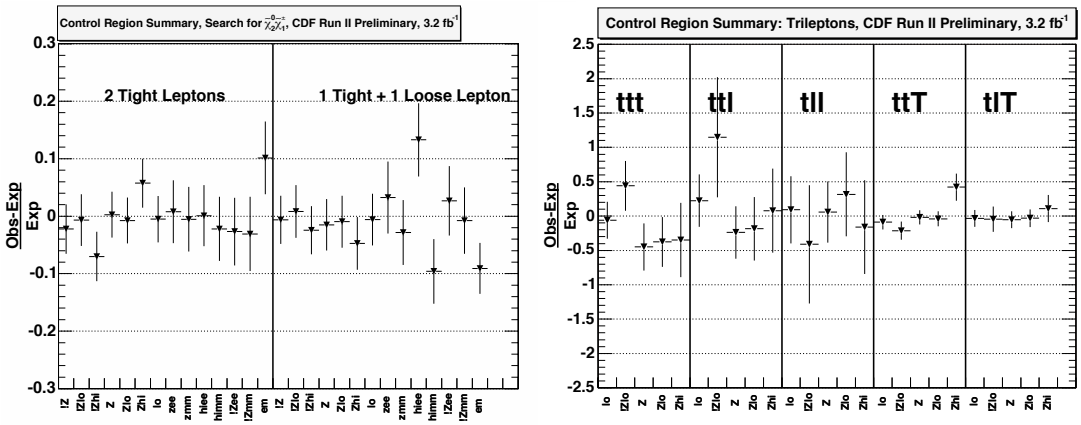

FIGURE 1. Comparison between observation and expectation in the dilepton (left) and trilepton (right) control regions, for tight (t) and loose (l) leptons and tracks (T).

of the backgrounds. We look at the signal region only after confirming that the CDF data and SM expectation agree in the control regions in both event yields and kinematic distributions, thus performing a statistically unbiased analysis.

We analyze 3.2 fb^{-1} of CDF data, collected up to the summer of 2008. We utilize the low-p_T (> 4 GeV/c) dielectron/dimuon and the high-p_T (> 18 GeV/c) single electron and single muon triggers. Our leptonic objects are high-quality isolated central electrons and muons, whereas the third leptonic object can be an isolated central track. The leptons are isolated if the extra energy in a cone of $\Delta R = 0.4$ around them is less than 10% of their energy. To maximize sensitivity, we investigate tight and loose lepton channels separately. This analysis [7] is the update of a previous CDF search [8].

The signal region is defined as trileptons with $M_{\ell\ell} > 20$ GeV/c^2 (for reduction of photonic DY and heavy-flavor QCD), $M_{\ell\ell} < 76$ GeV/c^2 or $M_{\ell\ell} > 106$ GeV/c^2 (for reduction of Z boson resonances), $\not\!\!E_T > 20$ GeV (for DY/QCD reduction and increase of signal sensitivity), and low jet activity (for $t\bar{t}$ and QCD reduction). The p_T of the leading lepton is > 15 or > 20 GeV/c (depending on the channel) whereas the two subleading leptons can be as low as 5 GeV/c. After this selection, the remaining trilepton SM backgrounds in the signal region are diboson (61%), DY+γ (22%) and QCD (15%).

The control regions are defined in the $M_{\ell\ell}$ vs. $\not\!\!E_T$ phase space, for both dilepton and trileptons (for the latter case, at least one of the signal kinematic cuts has to be inverted). The Z-boson dilepton control regions validate the DY background, the trigger and lepton-identification efficiencies, and our knowledge of the luminosity. The low-mass low-$\not\!\!E_T$ control regions validate the QCD backgrounds. The high jet multiplicity regions validate the $t\bar{t}$ background.

RESULTS AND CURRENT WORK

Figure 1 shows the comparison between background expectation and CDF dilepton and trilepton data in our control regions. After observing excellent agreement in the control regions, we look at the signal region. There, we expect 1.5 ± 0.2 SM trilepton

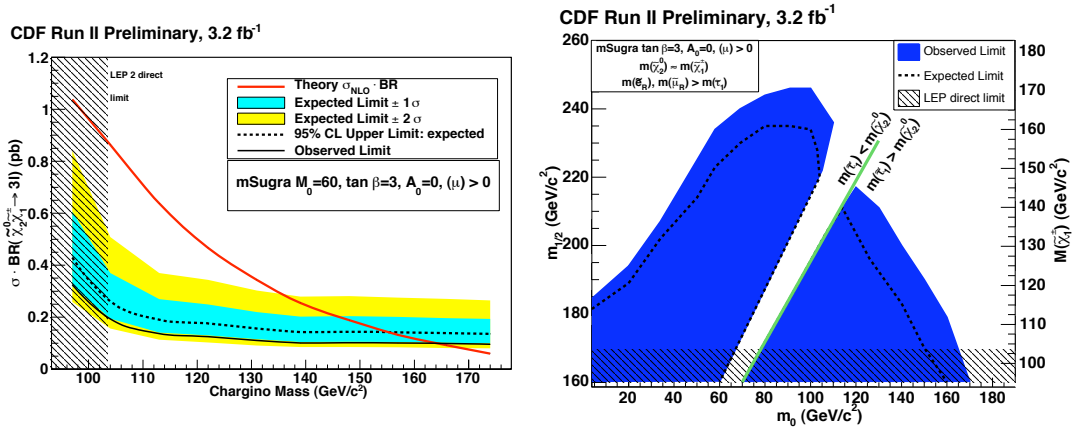

FIGURE 2. One-dimensional chargino-neutralino cross-section vs. chargino-mass limit (left) and two-dimensional $m_{1/2}$ vs. m_0 limit (right) in the mSUGRA scenario.

and 9.4 ± 1.4 SM dilepton+track events and we observe 1 and 6 events respectively. Our results are consistent with SM predictions, so we proceed to setting limits in the mSUGRA scenario.

First, we set $m_0 = 60$ GeV/c^2, $\tan\beta = 3$ and $\mu > 0$ and vary $m_{1/2}$ to investigate a range of chargino masses from 98 to 174 GeV/c^2. The expected and observed excluded limits in cross section times branching ratio vs. chargino mass can be seen in Figure 2. Limits are calculated with a frequentist method [9]. The chargino-mass 95% confidence level limit is 164 GeV/c^2 (155 GeV/c^2 expected) for a cross section of ~ 0.1 pb. By varying both m_0 and $m_{1/2}$ we can set limits on these mSUGRA parameters, as seen in Figure 2.

We are currently in the process of improving these results by including very low-p_T leptons (> 5 GeV/c for all objects) and low-$M_{\ell\ell}$ (< 20 GeV/c^2) – continuing the work in [6]) – by including forward ($|\eta| > 1$) leptons and also by including hadronically decaying tau leptons. These improvements not only increase the event yield by threefold, but also allow us to investigate new regions in parameter and kinematic phase space. For example, the predominant decays of charginos and neutralinos through staus (especially for high $\tan\beta$ values) will result in lower-p_T leptons from the leptonic decays of the final-state tau leptons, and in hadronically decaying taus. Cascade decays of SUSY particles will also result in low-p_T leptons and low dilepton masses. This search will maximize our discovery potential and sensitivity to SUSY parameter space.

REFERENCES

1. H. Baer and X. Tata, "Weak Scale Supersymmetry", Cambridge University Press (2006).
2. H. Baer *et al.* Phys. Rev. D **61**, 095007 (2000).
3. H. Baer, F. Paige, S. Protopopescu, and X. Tata (2000), arXiv:hep-ph/0001086.
4. T. Sjöstrand, S. Mrenna, and P. Skands, J. High Energy Phys.05 (2006) 026, arXiv:hep-ph/0603175.
5. W. Beenakker *et al.*, Phys. Rev. Lett. **83**, 3780 (1999).
6. T. Aaltonen *et al.* (CDF collaboration), Phys. Rev. D **79** 052004 (2009).
7. CDF public note 9817 (2009).
8. T. Aaltonen *et al.* (CDF collaboration), Phys. Rev. Lett. **101** 251801 (2008).
9. T. Junk, Nucl. Instrum. Methods A **434**, 435 (1999).