Searches for New Physics with Leptons at the Tevatron

J. Hays on behalf of the CDF and DØ Collaborations
Imperial College London, Department of Physics, Prince Consort Road,
London, SW7 2BW, United Kingdom.

Searches for new physics in multi-lepton final states in data collected by the CDF and D0 experiments at the Fermilab Tevatron are presented. These include preliminary and published results making use of between 1fb^{-1} and 4fb^{-1} of integrated luminosity from proton-antiproton collisions at a centre-of-mass energy of 1.96 TeV. Included are searches for charginos, neutralinos, stop-quarks and diboson resonances.

1 Introduction

The very high production rate from proton-antiproton collisions of final states containing jets of hadrons at large transverse momentum, p_T, poses particular challenges to searches for new physics. Events with one or more isolated leptons occur with much lower rates typical of electroweak production processes and provide very clean signatures which can be used to identify interesting candidates for new interactions and particles. A collection of searches performed by the CDF and D0 Collaborations are presented below which rely on signatures with one or more charged leptons in the final state.

2 Lepton Identification

Descriptions of the CDF and D0 detectors can be found in [1,2]. Electrons are identified by their characteristic energy deposits in the calorimeters. Clusters of energy in the calorimeters are required to be isolated and match a reconstructed charged track, suppressing photon backgrounds. Muons are identified by matching charged tracks in the central tracking detectors with hits in the muon detectors. Muon candidates are also required to be isolated in both the central tracking detectors and in the calorimetry.

3 Neutralino and Chargino searches: trileptons

In the minimal supersymmetric standard model (MSSM) [3] neutralinos and charginos can be relatively light. Direct electroweak production and subsequent decays into leptons plus the lightest-supersymmetric-particle (LSP) leads to a striking three charged lepton signature with missing tranverse momentum, $\not\!\!E_T$, carried away by neutrinos and the LSP. This is the golden signature for supersymmetry at the Tevatron but the cross sections are relatively low, ~1pb, and in certain regions of phase space the mass differences between the supersymmetric (SUSY) particles can be small and lead to very soft lepton momenta.

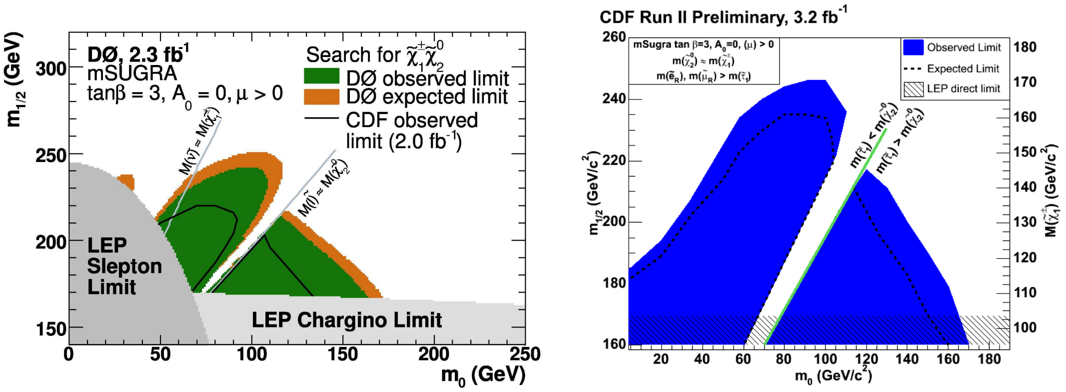

Figure 1: Limits on neutralino and chargino production in the $m_{1/2}$–m_o plane at 95% C.L. for 2.3 (3.2) fb^{-1} of integrated luminosity at D0 (CDF).

The search for neutralino and chargino production at D0 [4] is carried out in four different final states with three charged leptons ($eel, \mu\mu l, \mu\tau l, \mu\tau\tau$) and missing transverse energy, $\not\!\!E_T$, where l and τ denote a lepton candidate formed of an isolated charged track without further lepton identification requirements and the hadronic decays of a τ lepton, respectively. Hadronic τ lepton decays are identified using NN classifiers. Three-prong τ lepton decays are not considered in this analysis since backgrounds from jets mean little additional sensitivity is achieved by their inclusion. A similar search is peformed by CDF [5] with three charged lepton final states categorised by lepton quality (tight, loose, track-only) rather than flavour and no explicit τ lepton identification. Standard model (SM) backgrounds (Drell-Yan, diboson, Υ, $t\bar{t}$ production, and W+jet/γ) are estimated using Monte Carlo simulations with instrumental fake-rates of tracks and leptons estimated using data driven methods. Events are selected via a range of single- and dilepton triggers (CDF+D0) as well as triggers requiring only one positively identifed lepton but with an additional high p_T charged track (D0). Drell-Yan and Z boson production backgrounds are reduced by cuts on the dilepton invariant mass and opening angle. Cuts on the scalar sum of the p_T of all high p_T jets , H_T, supresses contributions from $t\bar{t}$ production. After the requirement of the third object, electroweak boson and diboson production dominate the backgrounds. These are further supressed by requirements on kinematic properties of the event. Optimisation of the analysis is carried out with respect to minimal supergravity (mSUGRA) [3] as a reference model, assuming the neutralino is the LSP and for chargino, neutralino, and slepton masses in the range 100–200 GeV. Five independent parameters are used to describe the mSUGRA scenarios: the unified scalar and gaugino masses m_0 and $m_{1/2}$, the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta$, the unified trilinear coupling A_0, and the sign of the Higgs mass parameter μ. No evidence for a signal of new physics is observed by either experiment and limits are set in the $m_{1/2}$–m_0 plane for $\tan\beta = 3$, A_0=0, $\mu > 0$ as shown in Figure 1.

4 Supersymmetric top searches: dileptons

4.1 Light chargino

In R-parity conserving SUSY models the LSP is typically the neutralino and stop particles can be pair produced via the strong interaction. If the stop is lighter than the top quark and the chargino is lighter than the stop then the decay channel: $\tilde{t} \to b\tilde{\chi}_1^{\pm}$ dominates. The leptonic decay of the chargino then results in a final state with two high p_T charged leptons, two b-quark jets and significant $\not\!\!E_T$. This signature mimics that of the dilepton final state in $t\bar{t}$ production. CDF perform a search for events with this signature in 2.7 fb^{-1} of integrated luminosity [6]. Events are

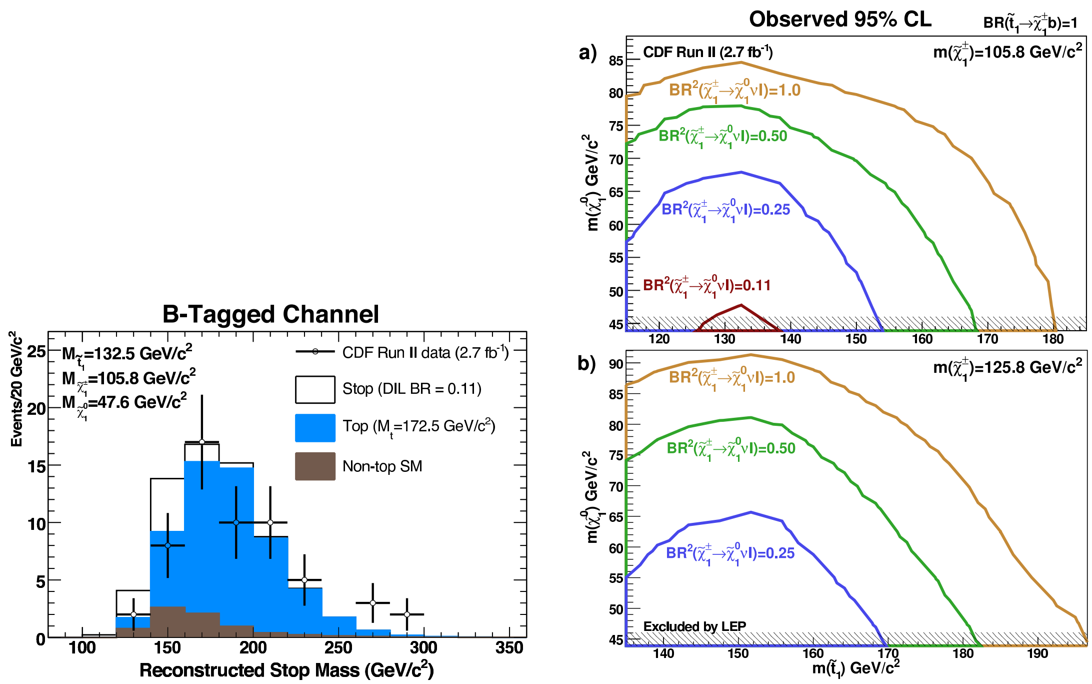

Figure 2: Reconstructed stop mass in the b-tagged channel (left).The stop signal contribution shown corresponds to a point in the SUSY parameer space excluded at 95%C.L. Exclusion regions at 95% C.L. (right) in the $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t}_1}$ plane for different values of $\mathcal{B}(\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm} \nu)$ and $m_{\tilde{\chi}_1^{\pm}}$.

selected containing two high p_T leptons (electron or muon) and two high p_T jets. b-quark jets are identified by the presence of a displaced secondary vertex within the jet coming from the decay of a long-lived B-hadron. Events are categorised according to whether or not the jets are tagged as coming from a b-quark. The dominant background is $t\bar{t}$ production with other sources being Z/γ^*+jets, diboson and W+jets production. W+jets production is estimated from data with the other contributions modeled using Monte Carlo simulations. Normalisation is taken from the worlds average measurement for $t\bar{t}$, from theory for diboson production and from data for Z/γ^*+jets and W+jets. The search sensitivity is enhanced through a kinematic reconstruction of each event under the stop production and decay hypothesis. The reconstructed stop mass for the b-tagged channel is shown in the left panel of Fig.2, where good agreement is seen between the SM processes and the data. No evidence for stop production is seen and limits are set in the $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t}_1}$ plane for different values of $\mathcal{B}(\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm} \nu)$ and $m_{\tilde{\chi}_1^{\pm}}$ and shown graphically in the right hand panel of Fig.2.

4.2 Heavy chargino

In the case where the decays: $\tilde{t} \rightarrow b\tilde{\chi}^+$ and $\tilde{t} \rightarrow t\tilde{\chi}^0$ are forbidden kinematically then the most probable decays modes proceed either via: the two-body process $\tilde{t} \rightarrow c\tilde{\chi}^0$, the three body process $\tilde{t} \rightarrow \tilde{\nu}^0 l^+$, and the four body decay $\tilde{t} \rightarrow b\tilde{\chi}^0 f\bar{f}$. D0 search for three body decay of pair produced stop quarks assuming: a 100% branching fraction in the three body mode; R-parity conservation; and the sneutrino as the LSP or having an invisible decay, with the final state signature of: $b\bar{b}e^{\pm}\mu^{\mp}\tilde{\nu}\bar{\tilde{\nu}}$ in 3.1fb^{-1} of integrated luminosity [7]. Events are selected with an opposite sign isolated electron and muon for which the SM backgrounds are small. Dominant backgrounds come from $Z \rightarrow \tau\tau$, multijet, diboson and $t\bar{t}$ production. Multijet backgrounds are estimated from data with all others being modeled from Monte Carlo simulations. Cuts on the $\not{E}_T$ and the angular difference between the leptons and the direction of the $\not{E}_T$ reduce

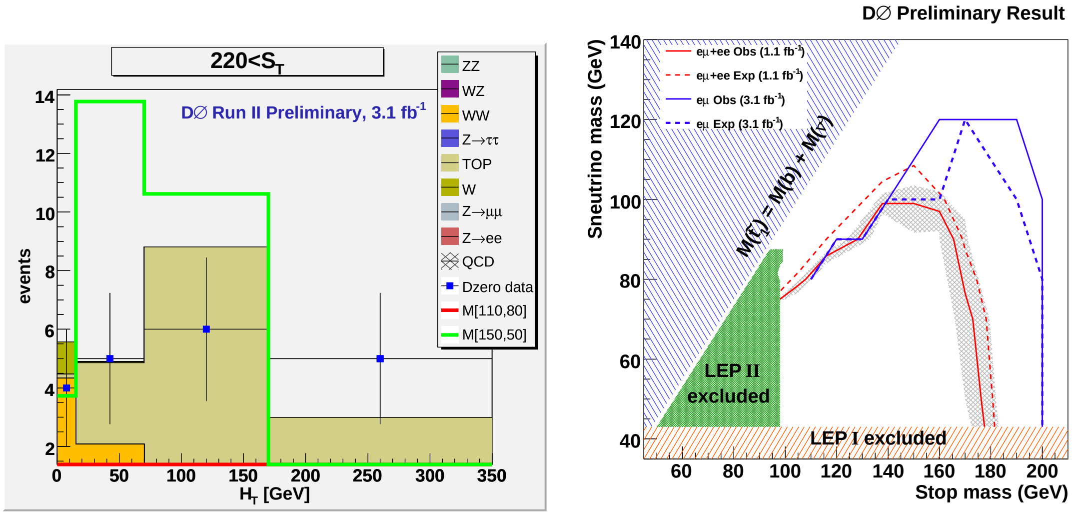

Figure 3: (left) H_T bins for $S_T > 220$ GeV. Data are shown as points and the background predictions as histograms. The green line shows the prediction for the hard signal benchmarkl ($m_{\tilde{t}_1} - 150$ GeV, $m_{\tilde{\nu}} = 50$ GeV. Limits in the $m_{\tilde{\nu}}$–$m_{\tilde{t}}$ plane are shown on the right, the blue lines are from this analysis.

contributions from multijets and $Z \to \tau\tau$ backgrounds. The remaining events are collected into 12 bins in the H_T–S_T plane, where S_T is defined as the scalar sum of the $\not{E}_T$, the electron p_T and the muon p_T to isolate the WW and $t\bar{t}$ events into a few bins whilst maximising the signal to background ratio in the remaining bins. The left plot of Fig.3 shows the predictions and data for all the bins in H_T in the highest S_T bin - good agreement is seen between data and the SM expectation. Limits are set in the $m_{\tilde{\nu}}$–$m_{\tilde{t}}$ plane, assuming the central value of the theoretical prediction of the stop production cross section. These limits are shown in Fig.3.

5 Diboson resonances: single and multileptons

There are models of beyond the standard model physics which predict the existance of resonant states which decay into pairs of on-shell bosons such as Z', W', or the Randall-Sundrum graviton, G^*. CDF conduct a search for these particles decays into WW or WZ and one W decays into an electron and a neutrino and the other boson decays into jets [8]. Events are selected by requiring a central isolated high p_T electron candidate, large $\not{E}_T$, two or three jets and large H_T. The WW or WZ hypothesis is first combines the electron with the $\not{E}_T$ to form one of the Ws. Two jets are then combined to form the second boson - in the case of three jet events the pairing of two jets is chosen that is closest to the W or the Z mass. The dominant background arises from W+jets production with other contributions from multijets, $t\bar{t}$, WW, Z+jets, single top, WZ, $W\gamma$, $\gamma\gamma$, and ZZ. Multijet backgrounds are estimated from data with all other backgrounds being modeled using Monte Carlo simulations. Cuts on the transverse energies of the final state objects are optimised depending on the hypothesised resonance (W', Z', G^*) and its mass. No statistically signifcant excess above SM expectation is observed and limits are set on the production cross sections at 95% C.L. The left panel of Fig. 4 shows these limits intepreted as limit on Z' production in the $M_{Z'}$–ξ plane, where ξ is the ratio of the new gauge coupling strength to that in the SM.

D0 search in 4.1fb^{-1} of integrated luminosity for a charged W' resonance decaying into a WZ pair in the three lepton (electron or muon) + $\not{E}_T$ final state [9]. Events are selected by first requiring either two electrons or two muons with a combined invariant mass close to the mass of the Z boson. Then the highest p_T remaining lepton is assumed to have come from

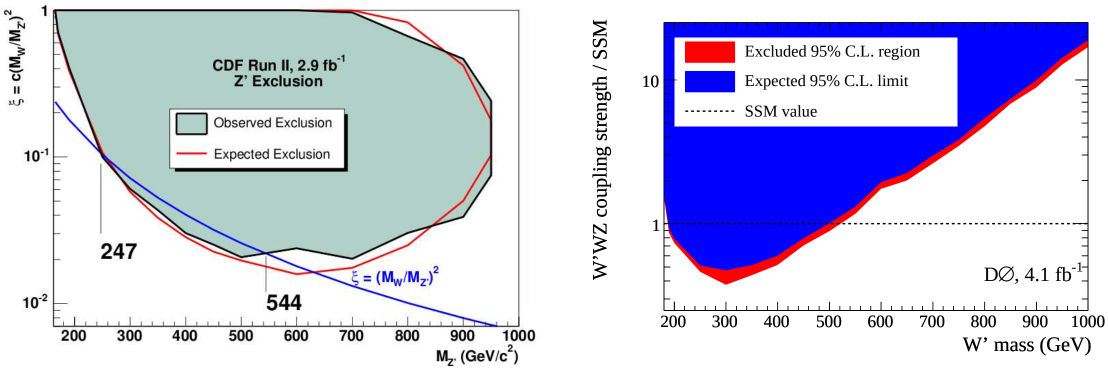

Figure 4: Z' (left) exclusion regions as function of mass and ξ. The blue line indicates $\xi = (M_W/M_V)^2$, commonly used for mass exclusion regions.

the decay of the W boson. The largest backgrounds come from SM production of WZ and ZZ where one of the leptons is not reconstructed in the detector and are modeled using Monte Carlo simulations. Two further important sources of instrumental background arise from Z+jets and $Z+\gamma$ production where either jets or a photon are misidentifed as a lepton. These contributions are estimated using data driven methods. In the absence of a significant signal limits are set using the WZ transverse mass distribution as the observable. The 95% confidence limits of the $W'WZ$ coupling strength (normalised to that in the sequential standard model) as a function of W' mass are shown in the right panel of Fig.4.

6 Conclusions

A small selection of searches for new physics in multilepton final states has been presented. This represents a tiny part of the full new phenomena and exotic physics programmes of the CDF and D0 experiments. While, as yet no evidence for new physics has been observed, only a fraction of the expected final data-set has been analyzed and sensitivity is increasing. Discovery could be around the corner.

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