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Search for lepton cascades in like-sign dilepton events with jets at CDF with 6.1 fb^{-1} using simplified models

The CDF Collaboration
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We present a search for cascade decays of new particles leading to leptons and invisible particles, typical of supersymmetric decays or universal extra dimensions. We analyze events with two leptons of the same electric charge using data with an integrated luminosity of 6.1 fb^{-1}. The observed data are consistent with standard model predictions, and we set cross-section upper limits on production of squarks and gluinos (or UED equivalent), as a function of the new particle masses. These limits may be applied to any SUSY or UED theory which includes these production and decay modes.

I. INTRODUCTION

Events with like-sign dileptons have a very small Standard Model backgrounds and are a common signature in models with a complete set of particle partners, such as SUSY [1] or Universal Extra Dimensions [2], both of which address the heirarchy problem [3].

We present a search for cascade decays of new particles leading to production of jets, a pair of vector bosons (WW, WZ or ZZ) and invisible particles. We analyze events with two like-signed leptons using a simplified model [4] which allows for general model-independent limits.

This note is a companion to an inclusive analysis of the like-sign dilepton signature [7].

II. DATASET, SELECTION AND BACKGROUNDS

A description of the dataset, selection and background model is provided in the companion note [7]. This study uses the subset of the inclusive sample with at least two jets.

A. Event Yield

Table I shows the observed and predicted event yields.

TABLE I: Predicted and observed event yields of same-sign dilepton events with at least two jets in data with 6.1 fb^{-1} fb of luminosity.

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}				
Process	Total $\ell\ell$	$\mu\mu$	ee	$e\mu$
$t\bar{t}$	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
$Z \to \ell\ell$	5.9 ± 1.7	0.0 ± 0.0	4.8 ± 1.6	1.1 ± 0.8
WW, WZ, ZZ	7.2 ± 0.5	1.5 ± 0.2	2.0 ± 0.2	3.7 ± 0.4
$W(\to \ell\nu)\gamma$	0.9 ± 0.7	0.0 ± 0.0	0.5 ± 0.5	0.4 ± 0.4
Fakes	13.8 ± 7.2	3.2 ± 2.4	4.6 ± 2.2	6.0 ± 3.1
Total	28.0 ± 7.5	4.7 ± 2.4	11.9 ± 2.8	11.3 ± 3.3
Data	27	2	16	9

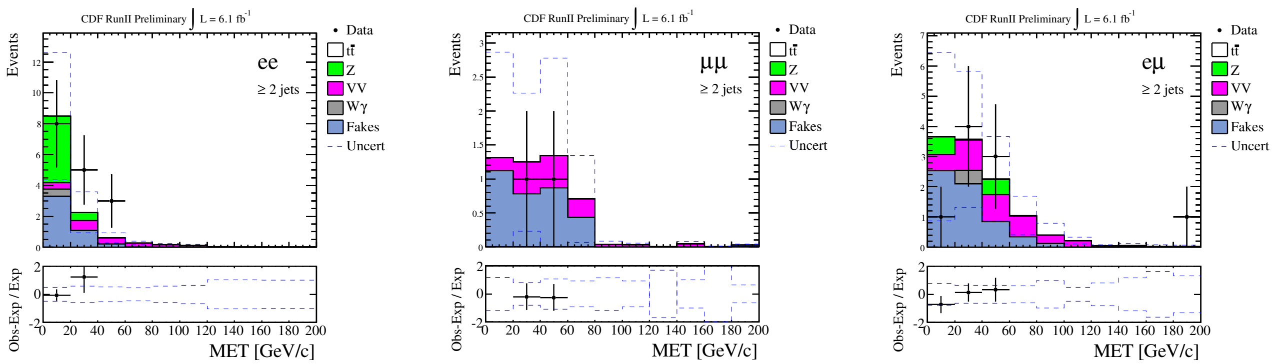

FIG. 1: Distribution of missing transverse energy in observed same-sign dilepton events with at least two jets and expected backgrounds.

B. Event Kinematics

Figures 1- 2 show the observed missing energy and H_T distributions in events with two same-sign leptons and at least two jets.

III. SIMPLIFIED MODEL

Many current models of supersymmetry contain a large number of parameters, making them impractical hypotheses. As a result, specific models which impose constraints on the parameters (eg mSUGRA) have become the standard

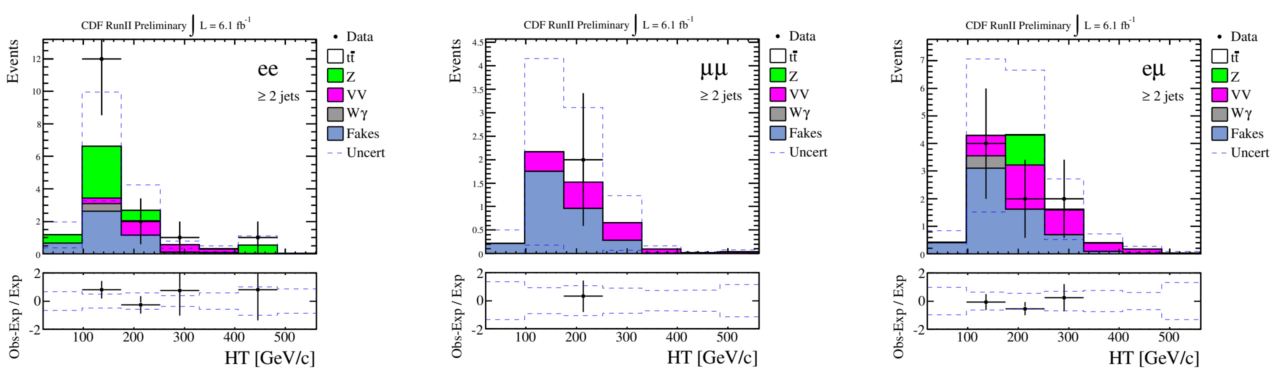

FIG. 2: Distribution of H_T in observed same-sign dilepton events with at least two jets and expected backgrounds.

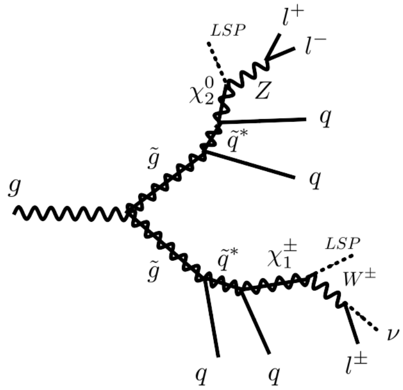

FIG. 3: Feynman diagrams of gluino pair production with subsequent decays leading to same-sign dileptons. Diagram is similar for squark pair production, see Figure 4.

hypothesis for experimental tests.

Rather than imposing assumptions and constraints on the parameters, we build a practical SUSY model by choosing specific production and decay modes, and including in the model the minimal necessary particle content: only the particles which appear in the modes being tested. The parameters of this simplified model [4] are simply the masses of the sparticles. We express our results for each mode as limits on the cross-section times branching ratio as a function of the sparticle masses, so that we do not need to make any assumptions about the coupling at each vertex.

This dramatically reduces the dimensionality of the model, while avoiding placing strong constraints on the mass relationships.

Limits on the simplified model can be trivially applied to any theory which contains these modes, including other theories which postulate a complete set of mirror particles, such as UED.

A. Model Details

We design our simplified model based on these requirements:

- For final states with leptons, the model must contain chargino $\tilde{\chi}^\pm$ and neutralino $\tilde{\chi}^0$, which decay to W and Z bosons. We do not consider slepton modes.
- R-parity conservation was adopted, which requires the presence of LSP's.
- Pair production of colored states such as gluinos and squarks are considered for their large cross-sections.

For simplification, only the first generation of squarks and sleptons were taken into account for a simplification. The simplified model was constructed in MadGraph [5] to generate the initial sparticle-pair production for the Monte Carlo simulation. BRIDGE [6] handled the following decay chains of the sparticles, restricting to the diagrams of interest.

If $m_{\tilde{\chi}} \ll m_{\tilde{l}}$, then the chargino and neutralino decay primarily to the LSP and W or Z, and the kinematics of the process, and therefore the selection efficiency is independent of the slepton mass. This note focuses on these modes. Assuming that the chargino and neutralino are largely degenerate, this results in four mass parameters for the model: $m_{\rm LSP}, m_{\tilde{\chi}}, m_{\tilde{g}}, m_{\tilde{q}}$.

In this note, we consider two three-dimensional subspaces: squark pair production when $m_{\tilde{g}} > m_{\tilde{q}}$ and gluino pair production when $m_{\tilde{g}} < m_{\tilde{q}}$, see Figure 3. In both cases, we allow for WW, WZ, or ZZ final states, see Figure 4. The complete list of production and decay modes is:

$$\tilde{q}\tilde{q} \to \tilde{\chi}_1^\pm \tilde{\chi}^\pm qq \to W^\pm W^\pm \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (1)$$
$$\tilde{q}\tilde{q} \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 qq \to W^\pm Z \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (2)$$
$$\tilde{q}\tilde{q} \to \tilde{\chi}_2^0 \tilde{\chi}_2^0 qq \to ZZ \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (3)$$
$$\tilde{g}\tilde{g} \to \tilde{\chi}_1^\pm \tilde{\chi}^\pm qqqq \to W^\pm W^\pm \tilde{\chi}_1^0 \tilde{\chi}_1^0 qqqq \quad (4)$$
$$\tilde{g}\tilde{g} \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 qqqq \to W^\pm Z \tilde{\chi}_1^0 \tilde{\chi}_1^0 qqqq \quad (5)$$
$$\tilde{g}\tilde{g} \to \tilde{\chi}_2^0 \tilde{\chi}_2^0 qqqq \to ZZ \tilde{\chi}_1^0 \tilde{\chi}_1^0 qqqq \quad (6)$$

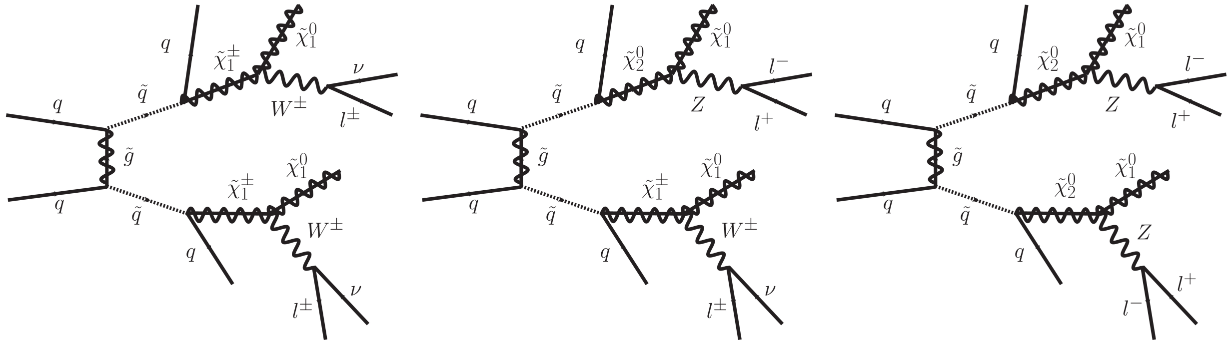

FIG. 4: Feynman diagrams of squark pair production with subsequent decays leading to same-sign dilepton (left), trilepton (center), and four-lepton (right) final states. Diagrams are similar for gluino pair production, see Figure 3.

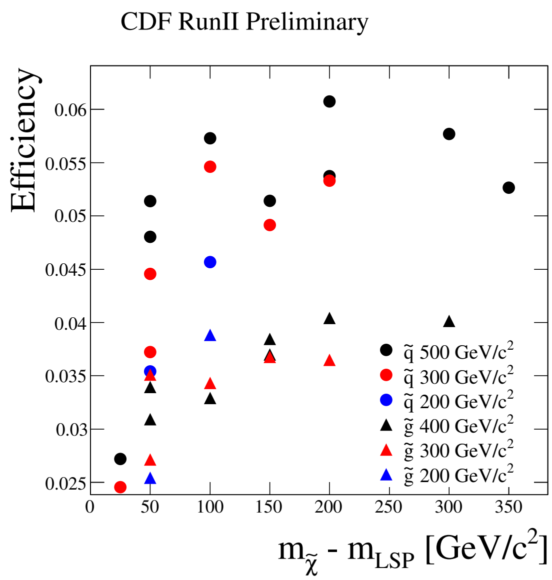

FIG. 5: Selection efficiency for squark and gluino events, shown as a function of the mass difference between $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ and the LSP $\tilde{\chi}_1^0$.

We assume $\mathrm{BR}(\tilde{q} \to q\tilde{\chi_1}^{\pm}) = \mathrm{BR}(\tilde{q} \to q\tilde{\chi}_2^0) = 0.5$ which gives a 1:2:1 mixture of the $WW : WZ : ZZ$ modes.

The selection efficiency for each of these modes is largely determined by the mass difference between the $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ and the LSP $\tilde{\chi}_1^0$, see Figure 5, with a secondary dependence on the number of jets in the event, due to the lepton isolation requirement.

B. Results

Figure 6 shows the observed data and background prediction for the analysis variable, H_T in same-sign dilepton events with at least two jets.

We perform a binned maximum likelihood fit of the data to the signal and backgrounds at each point in sparticle mass space for both topologies. We built frequentist confidence intervals using the unified ordering scheme [9].

Figure 7 shows the observed limits for squark pair production, and the results are listed in Table II. Figure 8 shows the observed limits for gluino pair production, and the results are listed in Table III.

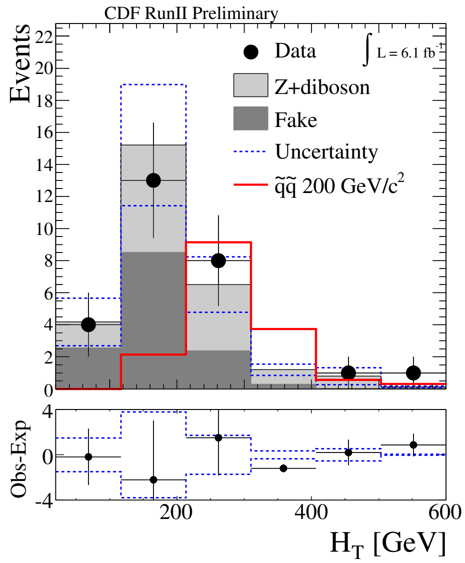

FIG. 6: Distribution of H_T in observed same-sign dilepton events with at least two jets and expected backgrounds, with expected 200 GeV squark pair signal overlaid.

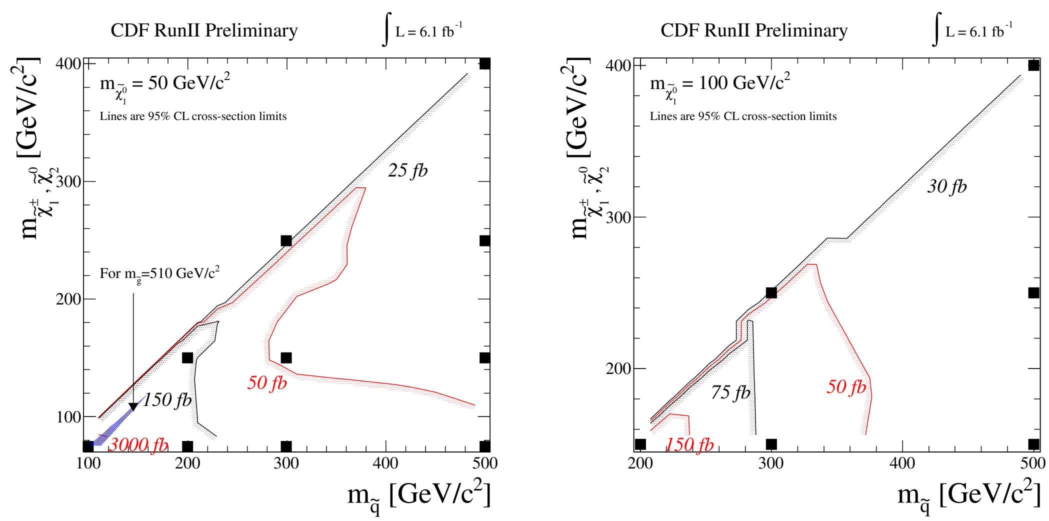

FIG. 7: Limits on squark pair production for LSP mass of 50 GeV (left) and 100 GeV (right).

IV. CONCLUSIONS

We present a search for cascade decays of new particles leading to leptons and invisible particles, typical of supersymmetric decays or universal extra dimensions. We analyze events with two leptons of the same electric charge using data with an integrated luminosity of 6.1 fb^{-1}. The observed data are consistent with standard model predictions, and we set cross-section upper limits on production of squarks and gluinos (or UED equivalent), as a function of the new particle masses. These limits may be applied to any SUSY or UED theory which includes these production and decay modes.

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Particle masses [GeV]			Cross-sections and Limits [fb]		
$m_{\tilde{q}}$	$m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	σ_{obs}^{95}	σ_{exp}^{95}	σ^{NLO}
100	75	50	3603.1	3261.5	4819.5
200	150	100	205.4	180.3	65
200	150	50	74.1	60.7	65
200	75	50	182.1	140.1	65
300	150	100	57.8	45.8	2.0
300	150	50	41.6	34.1	2.0
300	250	100	53.0	46.6	2.0
300	250	200	80.1	96.6	2.0
300	250	50	58.8	43.7	2.0
300	75	50	90.4	94.5	2.0
500	150	100	35.6	147.0	3e-3
500	150	50	30.0	279.4	3e-3
500	250	100	37.8	132.4	3e-3
500	250	200	95.6	69.7	3e-3
500	250	50	29.7	192.9	3e-3
500	400	100	34.9	45.4	3e-3
500	400	200	62.7	46.6	3e-3
500	400	50	39.2	62.0	3e-3
500	75	50	65.0	532.3	3e-3

TABLE II: Expected and observed 95% CL upper limits on the squark pair production cross-section times branching ratios, compared to NLO theory calculation [8].

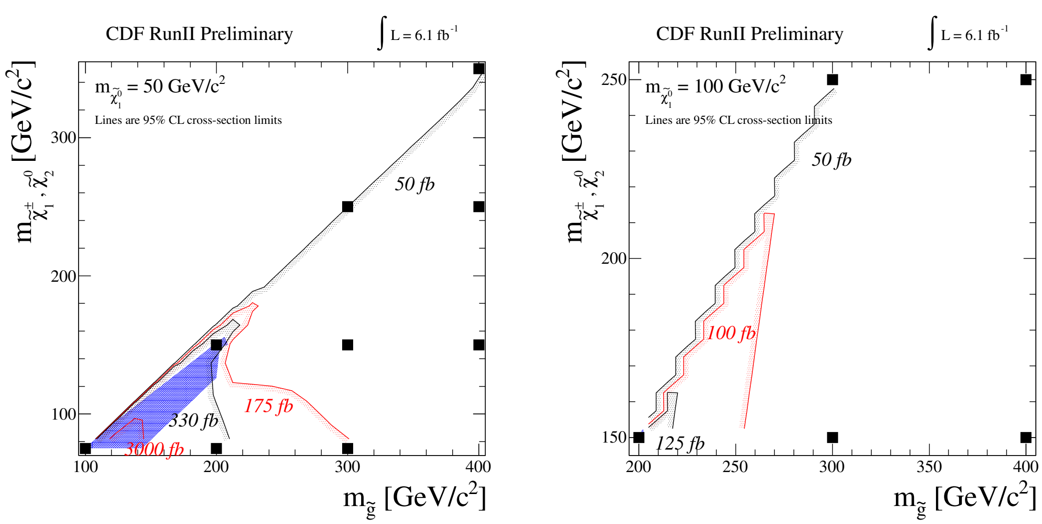

FIG. 8: Limits on gluino pair production for LSP mass of 50 GeV (left) and 100 GeV (right).

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CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}					
Particle masses [GeV]			Cross-sections and Limits [fb]		
$m_{\tilde{g}}$	$m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	σ_{obs}^{95}	σ_{exp}^{95}	σ^{NLO}
100	75	50	5174.9	5934.5	23206.5
200	150	100	136.3	160.7	167.3
200	150	50	87.2	71.8	167.3
200	75	50	339.2	288.2	167.23
300	150	100	68.9	52.9	9.8
300	150	50	57.9	49.2	9.8
300	250	100	86.3	66.8	9.8
300	250	200	543.2	424.5	9.8
300	250	50	81.3	57.8	9.8
300	75	50	184.8	136.0	9.8
400	150	100	56.4	77.7	1.2
400	150	50	56.9	157.5	1.2
400	250	100	89.8	66.9	1.2
400	250	200	77.0	58.6	1.2
400	250	50	88.7	59.6	1.2
400	350	200	75.3	57.9	1.2
400	350	50	58.4	57.8	1.2

TABLE III: Expected and observed 95% CL upper limits on the gluino pair production cross-section times branching ratios, compared to NLO theory calculation [8].

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