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Update of the Unified Trilepton Search with 3.2 fb^{-1} of Data

The CDF Collaboration [1]

Abstract

We update a unified chargino-neutralino trilepton search using 3.2 fb^{-1} of data gathered with the CDF II detector at the Tevatron. This search defines exclusive trilepton channels of generalized lepton types to increase sensitivity. We expect the trilepton categories to produce 1.47 ± 0.21 background events and observe one event. In categories with a track object we predict 9.38 ± 1.44 background events and observe 6 events. We observe no signs of SUSY and set upper limits on the cross section of certain mSugra models.

1 Introduction

In the search for new phenomena, one well-motivated extension to the Standard Model (SM) is supersymmetry (SUSY). The SUSY particles (sparticles) contribute to the Higgs mass squared with opposite sign relative to the contributions of SM particles, and thus protect the weak mass scale, M_W, from divergences. SUSY is a broken symmetry since the sparticles obviously do not have the same mass as their SM partners, but the breaking must be 'soft' to allow the divergence canceling to remain effective. If R_p parity is conserved[2], the lightest SUSY particle (LSP) is absolutely stable and provides a viable candidate for cosmological dark matter [1]. We use as a reference the mSUGRA model of SUSY breaking. This model has the virtue of containing only five free parameters to specify. However, our search is signature-based; we do not modify our selection to follow the details of mSUGRA.

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[2]$R_p = (-1)^{3B+L+2S}$, where B is baryon number, L is lepton number, and S is spin.

One very promising mode for SUSY discovery at hadron colliders is that of chargino-neutralino associated production with decay into three leptons. Charginos decay into a single lepton through a slepton

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{l}^{(*)} \, \nu_l \rightarrow \tilde{\chi}_1^0 \, l^{\pm} \, \nu_l$$

and neutralinos similarly decay into two detectable leptons

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}^{\pm(*)} \, l^{\mp} \rightarrow \tilde{\chi}_1^0 \, l^{\pm} \, l^{\mp}.$$

The decays can also proceed via W and Z bosons. The detector signature is thus three SM leptons with associated missing energy from the undetected neutrinos and lightest neutralinos, $\tilde{\chi}_1^0$ (LSP), in the event. Due to its electroweak production, this is one of the few 'jet-free' SUSY signatures.

2 Analysis Overview

We follow the same analysis strategy and implementation used in the previous CDF II search [2]. From the outset, we define lepton categories and event level trilepton channels. Each lepton and category is exclusive and selected based on expected purity. This channel independence allows easy statistical combination of the final results.

The general procedure is as follows. For each event, we select muons, electrons and tracks of some quality. Each of these objects, except the tracks (T), have tight (t) and loose (l) categories. We then define event level exclusive trilepton channels composed of combinations of these objects and arrange them sequentially by expected signal sensitivity. There are several virtues of this approach. The largest advantage is that we perform several lepton flavor, channel-specific searches simultaneously, without the need to account for overlapping results.

We define two selection stages to test our background estimations against data. The first stage is the dilepton selection, which consists of the first two objects of the trilepton selection. The second stage is the final trilepton selection, with some event cuts applied. Once we are satisfied with the agreement in the control regions, we apply SUSY specific cuts and look at signal region data to compare against background.

3 Detector and Dataset

This analysis is preformed with the CDF II detector at the Tevatron with $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The CDF II detector is a mostly cylindrical particle detector composed of cylindrical sub-detectors. From the beam axis outwards there is a silicon strip vertex detector, and a gas filled drift chamber. The tracking system is surrounded by a solenoid providing a 1.4 T magnetic field, followed by electromagnetic and hadronic calorimeters. The outermost detectors are wire chambers used to detect muons that escape the inner detectors.

For this analysis we will use two categories of event triggers. The first are the high P_t inclusive lepton triggers, which consist of single muon or electron objects with thresholds of $P_t > 18$ GeV/c. The second category is the SUSY dilepton trigger. This trigger requires two low P_t leptons, generally with a threshold of 8 and 4 GeV/c respectively. These data are combined and in the analysis overlapping trigger effects and trigger efficiencies are accounted for. These data were collected up until 1 Jul, 2008, totaling 3.23 fb^{-1} for the unprescaled triggers.

4 Object Selection, Event Categories and Event Cuts

As previously mentioned there are both tight and loose lepton categories as well as a track object. All of these objects are central to the detector, meaning that generally $|\eta| < 1.0$ and they are isolated from nearby objects. Tight muons are objects that originate from the event vertex, leave a good quality track in the tracking chamber, deposit a minimum amount of ionizing energy in the calorimeter system and are detected in the outer muon systems. Loose muons are similar, but they are 'stubless' meaning that the requirement of the muon system detection is relaxed. This compensates for gaps in the muon detector coverage. Tight electrons are again required to originate at the event vertex, and leave a good track, but they are expected to deposit a majority of their energy in the electromagnetic calorimeter. Loose electrons have slightly fewer requirements on the matching between objects in the sub-detectors. We also include one type of track object in the analysis as a possible third object. This greatly increases our sensitivity by allowing detection of leptons that failed selection cuts, as well as single pronged hadronic tau decays. The track object is a single, isolated track in the tracking chamber that originates from the event vertex. It differs from loose muons in that, it can have an arbitrary amount of energy deposition.

After the object selection, we categorize the trilepton events. The event categories can be thought of in terms of two types - those without a track, the trilepton events; and those with a track, the dilepton+track events. For the trilepton type events we look for three tight leptons. If the event does not qualify, we look for two tight and one loose lepton. If the event still does not qualify, we look for one tight and two loose leptons. Events that do not make it into the trilepton selection are tested for two tight leptons and a track and finally one tight, one loose and one track object. The complete list is shown in Table 1 along with the E_t (electrons) or P_t (muons) requirements on these objects.

Channel	Selection	E_t or P_t
ttt	3 Tight leptons or 2 tight leptons and 1 loose electron	15, 5, 5
ttC	2 Tight leptons + 1 loose muon	15, 5, 10 (loose muon)
tll	1 Tight leptons + 2 loose leptons	20, 8, 5
tt$T$	2 Tight leptons + 1 isolated track	15, 5, 5
tl$T$	1 Tight leptons + 1 loose lepton + 1 isolated track	20, 8 (10 loose muon), 5

Table 1: Trilepton selection. An event with two tight leptons and one loose electron is still categorized as ttt.

At this stage we apply additional event level cleaning cuts. We require that every analysis level object (leptons, tracks and jets) be separated from each other by $\Delta R > 0.4$. Events with a mismeasured jet can have false $\not\!\!E_T$. We remove events with $\not\!\!E_T$ and any jet separated by less than $\Delta\phi < 0.35$. We also make invariant mass cuts at this stage. We form invariant masses from each combination of the three leptons. The highest opposite signed object pair invariant mass is required to be above $20\mathrm{GeV}/c^2$ and the second highest oppositely-charged object pair is required to be above $13\mathrm{GeV}/c^2$. This cut helps eliminate heavy flavor backgrounds.

Additional backgrounds due to mismeasurement are removed by cutting events that have $\not\!\!E_T$ and leptons aligned, requiring $\Delta\phi > 0.17$ for each of the leading two leptons. A summary of these cuts is listed in Table 2.

To further clean up events, we require the third lepton in trilepton events to be isolated. We also require that there not be more than three leptons or

Cut	Description
$\Delta R > 0.4$	Cut between all leptons, tracks and jets.
$\Delta\phi > 0.35$	Between $\not\!\!E_T$ and jets.
$\Delta\phi > 0.17$	Between $\not\!\!E_T$ and leptons.
$\mathrm{M}_{OS1,2} > 20, 13$ GeV/c^2	Highest and second highest OS invariant mass.

Table 2: Trilepton level cuts.

tracks in the event above 10 GeV and that the three objects' charges sum to ± 1.

5 Background Determination

The standard model background estimation for the analysis differs slightly between the lepton+track channels and the trilepton channels. Generally, Monte Carlo is used to estimate the backgrounds, and trigger efficiency and scale factors are applied as an event weight to the Monte Carlo. Isolated track, fake lepton and gamma conversion rates are determined from data.

5.1 Trilepton Backgrounds

Backgrounds are treated differently based on the underlying process. Those that give three real leptons (WZ , ZZ, $t\bar{t}$) are estimated with Monte Carlo by taking them through the analysis and applying the appropriate event weight.

The remaining background processes have two real leptons (Z, WW) and require a third object from elsewhere in the event. This can happen, for example, with FSR photon conversion where a photon radiated off a charged particle hits matter in the detector and converts to an $e\bar{e}$ pair. For these processes, we estimate this 2 lepton plus conversion rate from Monte Carlo.

The final contribution to the trilepton background is from objects in the underlying event faking a third lepton in an event that has two genuine leptons. This fake contribution is estimated in the trilepton channels by selecting two well identified leptons and a third fakeable object from data events. Fake rates have been measured for jets faking electrons and for tracks faking muons of both tight and loose quality. These jets and tracks are the fakeable objects selected. The event is then carried through the analysis as if it were real, and the fakeable object were a genuine lepton. This event is then weighted by the appropriate fake rate for the fakeable object it contains. Backgrounds from events with two fake objects are considered to be negligible.

5.2 Dilepton + Track Backgrounds

For these channels, backgrounds are handled slightly differently. Background processes that give three real leptons (WZ , ZZ, $t\bar{t}$) are still estimated from Monte Carlo and taken through the analysis as previously described.

As for fakes in dilepton + Track channels, we account for fake leptons, and separately estimate the rate of isolated tracks in dilepton backgrounds.

For fake leptons, we use a method similar to the trilepton method. Fake lepton backgrounds in dilepton + track events have one real lepton, one isolated track and a fake lepton that comes from the underlying event. This contribution includes W + jet events from which the lepton comes from the W, the track comes from the jet, and there is a third fake lepton from the underlying event. This background also accounts for Drell-Yan processes where one of the two DY leptons fails a cut and is reconstructed as a track, and the third fake lepton comes from the underlying event. This fake contribution is calculated from data by selecting lepton + track events containing a fakeable object. As was done with trilepton fakes, we carry the event through the analysis, and apply the object's fake rate to the event.

The remaining background in the dilepton + track channels is that of dilepton events with an isolated track from the underlying event. We measure the rate of isolated tracks from data, and apply this rate to dilepton Monte Carlo. This procedure gives very good agreement in our dilepton + track control regions.

6 Control Regions

We inspect both our dilepton selection and our trilepton selection for agreement against predictions. The control region parameter space is $\not{E}_T$ vs. Invariant mass, and for easy reference is coded according to Figure 1.

We select the first two leptons in the event and check agreement against backgrounds. See Figure 2 for a complete listing of all the dilepton control

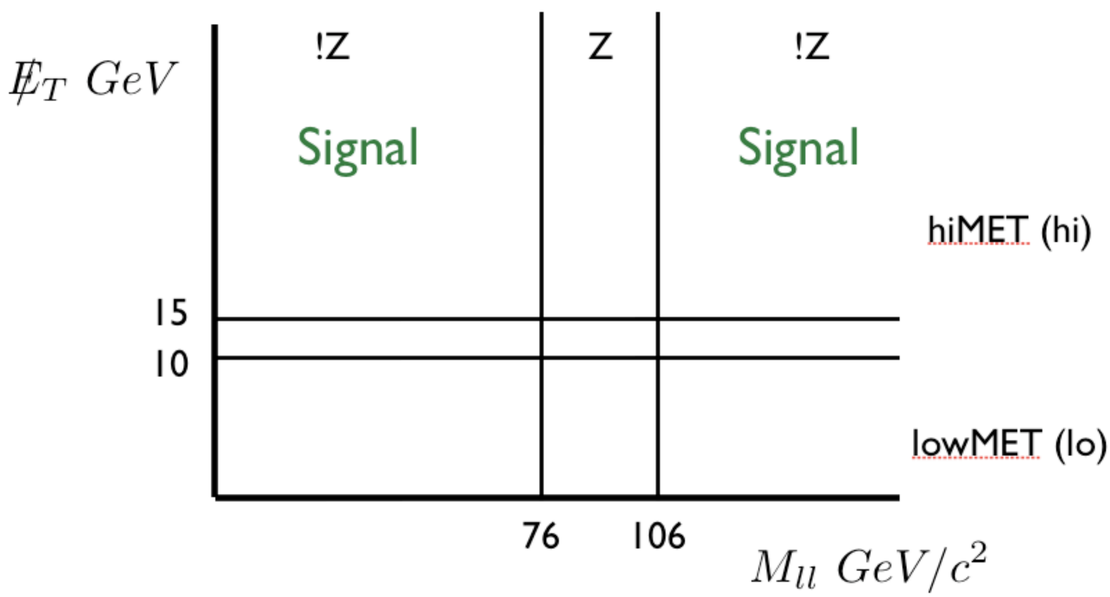

Figure 1: Control regions and codes used to refer to the control regions.

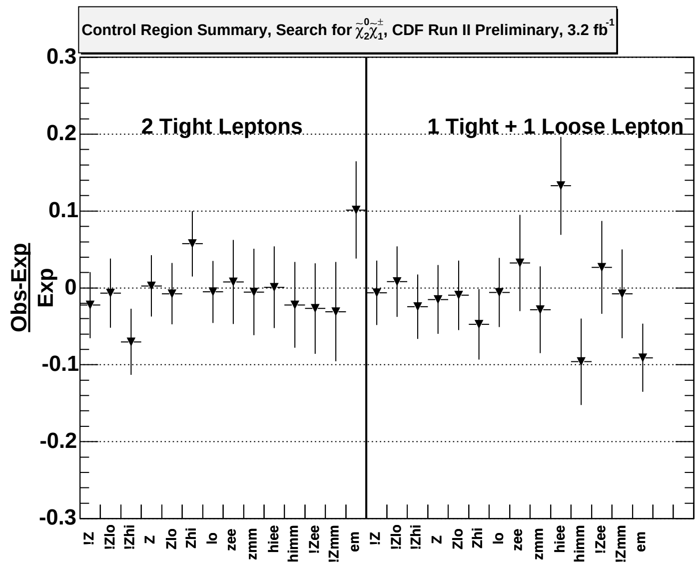

Figure 2: Summary of dilepton control regions. (Observed - Expected) / Expected number of events for each control region.

regions. Dilepton plots are displayed and described in Figure 3.

After we are satisfied with the dilepton control region agreement, the trilepton selection is applied to an event. We account for fakes, as described above and check trilepton plots and tables to ensure good agreement between background and predictions. The total trilepton background and prediction comparison is shown in Figure 4. The control regions are labeled similarly to the dilepton plots where, for example, !Zlo is the region outside of the Z window with low $\not\!\!E_T$ and so on.

We can again look at distributions comparing data and predictions in control regions. Trilepton control region plots are shown in Figure 5.

7 Final Event Selection

After we are satisfied with the agreement between data and Monte Carlo in the trilepton control regions, we make final event selections to optimize for the SUSY signal. These cuts are motivated by the signal topology as well as past analysis that used similar SUSY signal points as a reference.

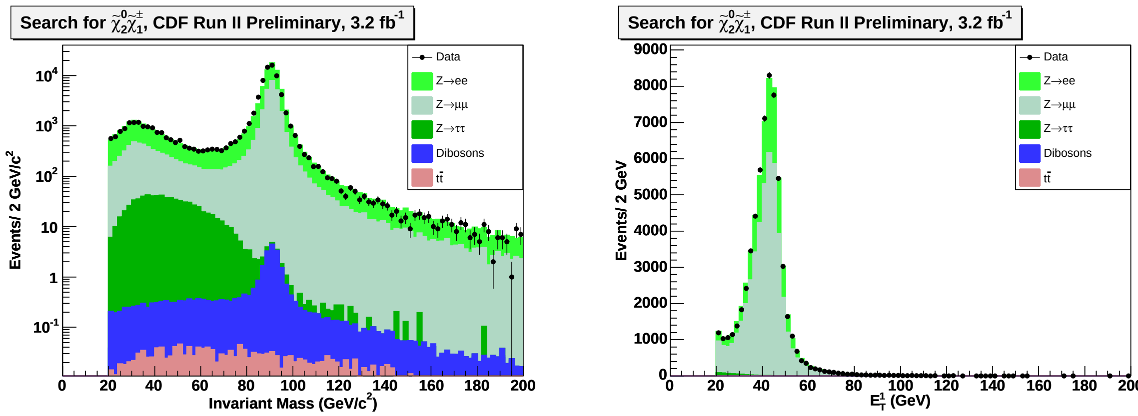

Figure 3: Invariant mass of the first two tight leptons in events with low $\not\!\!E_T$ (left). E_t of the leading lepton in the tight-loose selection in events with low $\not\!\!E_T$.

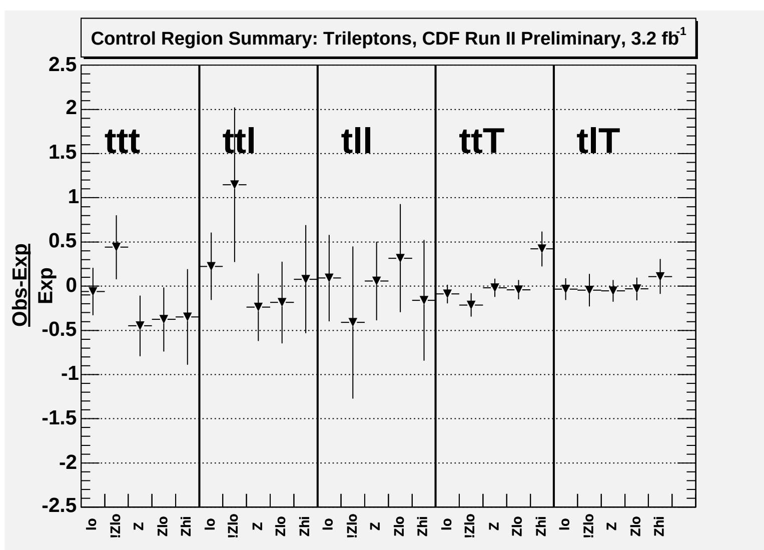

Figure 4: Trilepton Control Region Summary. (Observed - Expected)/Expected number of events.

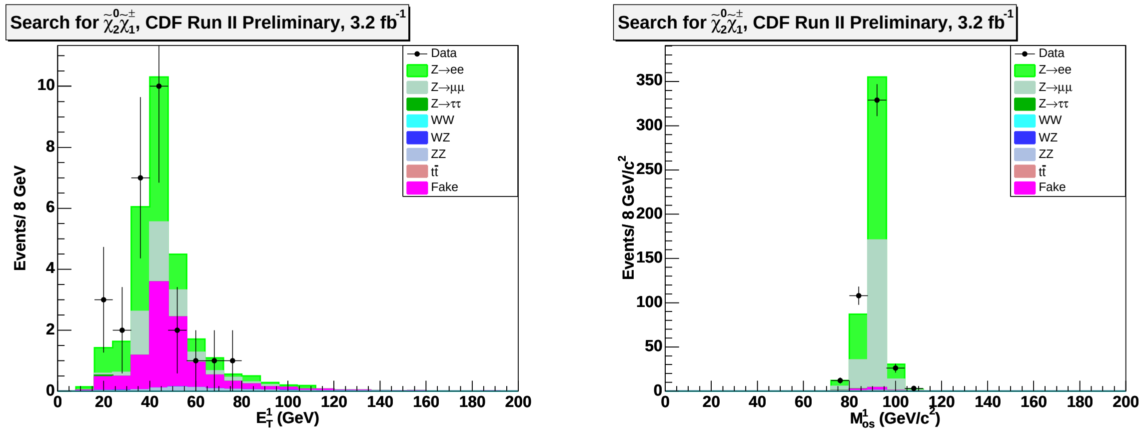

Figure 5: Trilepton Channels. Invariant mass of the first two tight leptons in events with low $\not\!\!E_T$ in the ttt channel (left). Invariant mass of the first two leading leptons in the ttT selection in events with low $\not\!\!E_T$ (right).

We cut in ϕ the highest invariant mass object pair with opposite charge by requiring $\Delta\phi < 2.9(2.8)$ for trilepton (dilepton+track) channels. This helps reduce Drell-Yan backgrounds. Any oppositely charged object pair that falls into the Z window also disqualifies the event.

The overall $\not\!\!E_T$ cut on events is 20 GeV, because trilepton events are expected to have larger values of $\not\!\!E_T$.

The remaining cuts reduce the $t\bar{t}$ background. We require the $\Sigma E_t(\text{jets}) \leq$ 80 GeV and $N(\text{jets}) < 2$.

A summary of these cuts is listed in Table 3.

Requirement	Description
$\Delta\phi_{OS} < 2.9(2.8)$ rad	Reduce back-to-back DY in trilepton (dilepton+track) channels.
$M_{ll} \leq 76$ GeV or $M_{ll} \geq 106$ GeV	Remove Z window for OS pairs.
$\Sigma E_t(\text{jets}) \leq 80$ GeV	Reduce $t\bar{t}$, QCD.
$N(\text{jets}) < 2$	Reduce $t\bar{t}$, QCD.

Table 3: Final event selection cuts.

8 Systematic Uncertainties

Systematic uncertainties are evaluated similarly to previous analysis [2]. The values used in that analysis are listed in Table 4. Systematics include lepton/trigger identification, jet energy scale, cross section, ISR/FSR radiation, conversions, isolated track rate measurements (ITR) and fake rate uncertainties.

Channel/Source	ID (%)	Trig (%)	JES (%)	X-sec (%)	PDF (%)	ISR/FSR (%)	Conv (%)	ITR(nom) (%)	ITR(alt) (%)	Fake (%)
3tight	2.3	0.3	1.5	5.0	1.4	2.3	2.2	-	-	12.2
2tight,1loose	2.5	0.3	1.7	5.9	1.6	2.5	2.1	-	-	8
1tight,2loose	2.2	0.3	3.5	5.0	1.3	2.2	1.8	-	-	10.7
2tight,1Track	1.8	0.2	3.9	2.3	1.5	1.8	-	5.8	6.0	11.6
1tight,1loose,1Track	1.8	0.2	5.2	2.4	1.5	1.8	-	8.6	10.5	9.0
Signal	4	0.5	0.5	10	2	4	-	-	-	-

Table 4: Systematics used in previous iteration of the analysis. The rows show the effect on the individual channels and the last row shows the effect on the signal point.

9 Results and Limits

For a reference point we use $\mathrm{M}_0 = 60, \mathrm{M}_{1/2} = 190, \tan\beta = 3, \mathrm{A}_0 = 0$; the results of background and expected signal are shown in Table 5 and Table 6. After looking at the signal region in the data, we see a total of seven signal events on an expected background of 10.84 ± 1.34 events. A list of some of the details of the observed events are listed in Table 9.

To extract a 1-D 95% confidence level limit, we set $M_0 = 60$ and vary $M_{1/2}$ which has the direct effect of varying the chargino mass. For each point we scan, we get the expected limit based on the acceptance of our analysis to the signal at that point. If we plot this against the theoretical $\sigma \times BR$ of the signal mSugra point as a function of chargino mass, we expect to exclude regions where our analysis's $\sigma \times BR$ is less than the theoretical value. Our expected limit is about 156 GeV/c^2 Figure 6, while we observe a limit of 164 GeV/c^2.

CDF II Preliminary, 3.2 fb^{-1}											
	$Z \rightarrow ee$	$Z \rightarrow \mu\mu$	$Z \rightarrow \tau\tau$	WW	WZ	ZZ	$t\bar{t}$	Fakes	Total Background	Signal Point	Observed
ttt	0.19	0.00	0.00	0.02	0.38	0.08	0.02	0.16	0.83 ± 0.18	3.64 ± 0.53	1
ttC	0.00	0.06	0.00	0.00	0.21	0.07	0.00	0.04	0.39 ± 0.08	2.62 ± 0.39	0
tll	0.00	0.00	0.08	0.00	0.10	0.03	0.01	0.03	0.25 ± 0.08	1.12 ± 0.19	0
Trilepton	0.19	0.06	0.08	0.02	0.69	0.18	0.03	0.23	1.47 ± 0.21	7.38 ± 0.68	1
ttT	1.33	0.27	1.10	0.53	0.24	0.11	0.29	1.98	5.85 ± 1.25	7.15 ± 0.96	4
tlT	0.83	0.60	0.52	0.40	0.07	0.07	0.14	0.91	3.53 ± 0.72	4.06 ± 0.57	2
Dilepton + Track	2.16	0.87	1.62	0.93	0.31	0.18	0.43	2.89	9.38 ± 1.44	11.21 ± 1.12	6

mSugra Signal point: $M_0 = 60, M_{1/2} = 190, \tan\beta = 3, A_0 = 0$

Table 5: Expected backgrounds and signal, errors are statistical and full systematic.

CDF II Preliminary, 3.2 fb^{-1}			
Channel	Total Background ± (stat) ± (sys)	Signal Point ± (stat) ± (sys)	Observed
ttt	0.83 ± 0.14 ± 0.11	3.64 ± 0.22 ± 0.49	1
ttC	0.39 ± 0.07 ± 0.04	2.62 ± 0.18 ± 0.35	0
tll	0.25 ± 0.08 ± 0.03	1.12 ± 0.12 ± 0.15	0
ttT	5.85 ± 0.57 ± 1.11	7.15 ± 0.31± 0.91	4
tlT	3.53 ± 0.52 ± 0.5	4.06 ± 0.23 ± 0.53	2

mSugra Signal point: $M_0 = 60, M_{1/2} = 190, \tan\beta = 3, A_0 = 0$

Table 6: Expected background and signal, errors are statistical and full systematic.

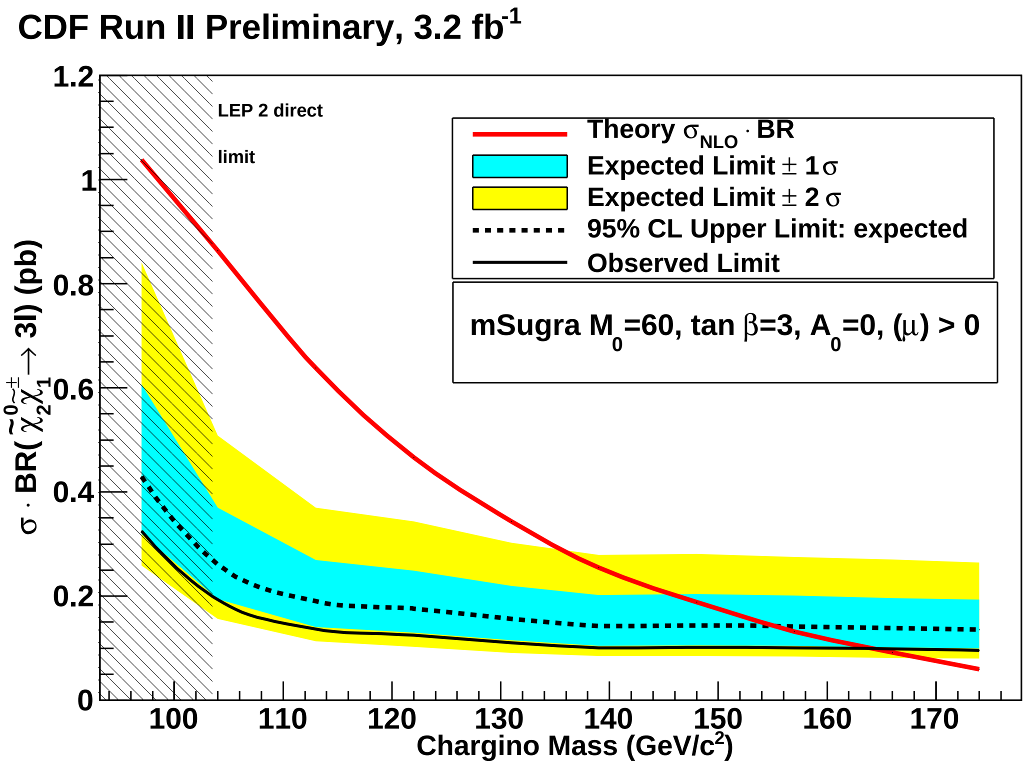

Figure 6: Expected and observed limit for the mSugra model $M_0 = 60, tan\beta = 3, A_0 = 0, (\mu) > 0$. In red is the theoretical $\sigma \times BR$ and in black is our expected limit with one and two σ errors. We expect to set a limit of about 156 GeV/c^2, and observe a limit of 164 GeV/c^2.

To explore a broader parameter space it is useful to scan both M_0 and $M_{1/2}$ simultaneously. We use Prospino2 [3] to calculate NLO cross section of the process as a function of M_0 and $M_{1/2}$. We then use ISAJET to calculate branching ratio to three leptons in this same range. This gives us a plot of $\sigma \times BR$. We generate signal Monte Carlo to test the expected and observed sensitivity at many points in M_0 and $M_{1/2}$ space.

We calculate (Expected - Theory $\sigma\times$ BR) /(Theory $\sigma\times$ BR) for both the expected and observed limits. The final exclusion contains both of these contours which can be seen in Figure 7.

CDF II Preliminary, 3.2 fb^{-1}								
Channel	Type	E_T^1 (GeV)	E_T^2 (GeV)	E_T^3 (GeV)	M_{OS}^1 (GeV/c^2)	M_{OS}^2 (GeV/c^2)	MET (GeV)	Jet$^1 E_T$ (GeV)
3 Tight	$e^-e^+e^-$	24	17	6	29	16	37	59
2 Tight, 1 Track	$e^-\mu^+T^+$	22	17	6	38	13	20	-
	$\mu^+\mu^-T^-$	34	6	9	33	28	20	21
	$\mu^-\mu^+T^-$	45	21	8	29	26	39	41
1 Tight, 1 Loose	$\mu^+\mu^-T^+$	23	12	7	39	18	29	34
	$\mu^+\mu^-T^-$	59	70	44	124	58	37	-

Table 7: Details of observed signal events.

Our observed 1-D limit excludes chargino masses of less than 164 GeV/c^2, an improvement over the expectation due to the deficit of data events in the lepton + track channels.

References

[1] A Supersymmetry Primer, Stephen P. Martin.

[2] Search for Supersymmetry in p[overline p] Collisions at sqrt(s) = 1.96 TeV Using the Trilepton Signature for Chargino-Neutralino Production, CDF Collaboration, Phys. Rev. Lett. 101, 251801 (2008), DOI:10.1103/PhysRevLett.101.251801

[3] W. Beenakker, R. Hopker, and M. Spira, hep-ph/9611232; http://pheno.physics.wisc.edu/ plehn/prospino/prospino.html.

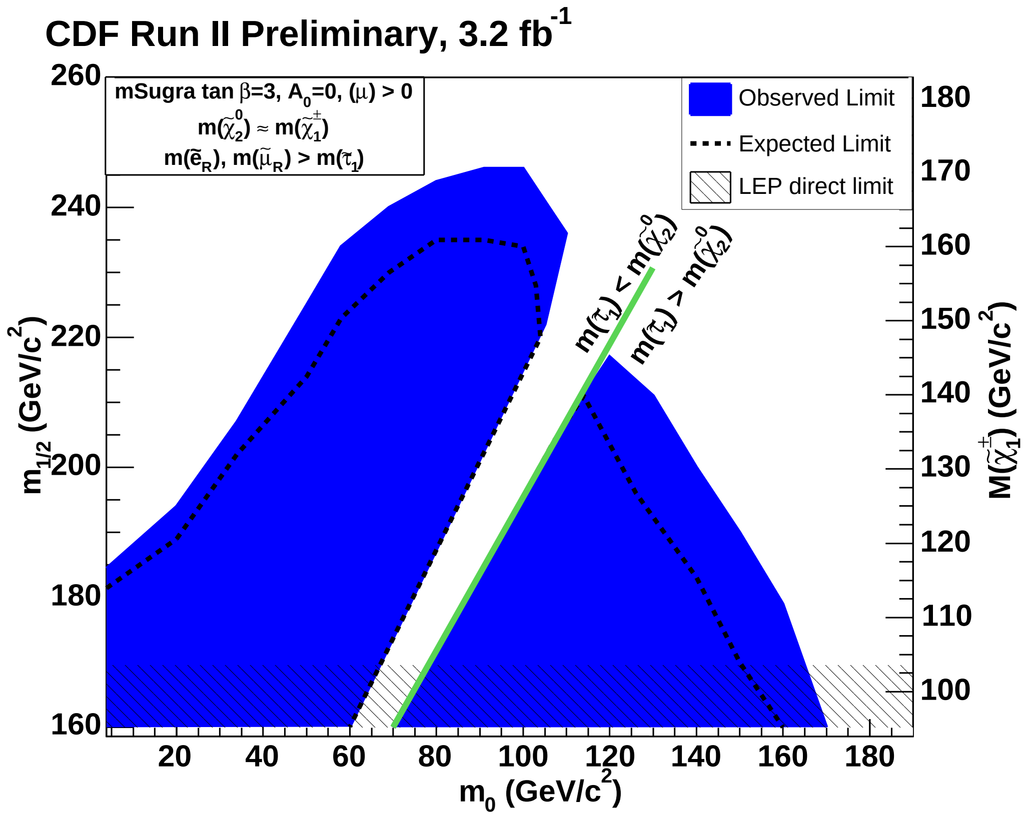

Figure 7: Expected and observed limit contours for the mSugra model $tan\beta = 3, A_0 = 0, (\mu) > 0$ in M_0 vs $M_{1/2}$ space.