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Gaugino Search using the Z^0+$W^{+/-}$+ME_T channel

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We report on a search for gaugino pairs using events with Z^0 (to e^+e^-), two or more jets and large missing E_T . This is a final state not previously studied. With ~3/fb integrated luminosity, the number of Z^0 (to e^+e^-) events is more than 100,000 and there are events with large missing E_T, which could indicate the presence of SUSY particles through a pair of gauginos, neutralino (χ^0_2) and chargino ($\chi^{+/-}_1$), production. This search assumes the mass of χ^0_2 ($\chi^{+/-}_1$) to be larger than the lightest neutralino (χ^0_1) by at least the Z^0 ($W^{+/-}$) mass such that χ^0_2 ($\chi^{+/-}_1$) can decay to real Z^0 ($W^{+/-}$) and χ^0_1. The missing E_T is from χ^0_1. Since the mass of $\chi^{+/-}_1$ is expected to be similar to χ^0_2 in most SUSY models, $\chi^0_2 \to \chi^0_1$+ real Z^0 automatically satisfies $\chi^{+/-}_1 \to \chi^0_1$+ real $W^{+/-}$ where two jet decay modes of $W^{+/-}$are used in this analysis. Using this channel, we set the limit on the pair gaugino production cross section at 95% confidence level as a function of χ^0_2 mass.

1. Introduction

We present a new SUSY particle search using events with Z^0 and large missing E_T. This search is aimed at the specific SUSY parameter space where the mass difference between χ^0_2 and χ^0_1 is greater than the Z^0 mass. For example, $p\bar{p}$-> $\chi^0_2 \chi^0_1$ –> $Z^0 \chi^0_1 \chi^0_1$ could be a process resulting in events with Z^0 and large ME_T. (R-Parity conservation is assumed in this analysis, i.e., χ^0_1 is stable.) With little jet activity, this could be a clean discovery channel. However, it turns out that the production cross section of this process is extremely low under the usual SUGRA parameters.

Another interaction with Z^0 and large ME_T final state but with much larger cross section is $p\bar{p}$-> $\chi^0_2 \chi^{+/-}_1$ –> $Z^0 \chi^0_1 W^{+/-} \chi^0_1$ (Figure 1). This channel is the focus of this analysis. Because the $\chi^{+/-}_1$ mass is expected to be similar to the χ^0_2 mass, $\chi^{+/-}_1$ decays to a real $W^{+/-}$ and χ^0_1. The decay modes of W to two jets are used to further enhance the signal to background ratio.

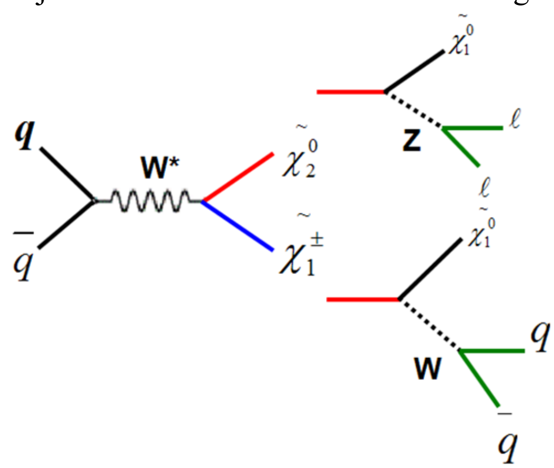

Figure1. Feynman diagram for $p\bar{p}$ -> $\chi^0_2 \chi^{+/-}_1$ –> ($Z^0 \chi^0_1$) ($W^{+/-}\chi^0_1$)

The aim of this analysis is not very different from the tri-lepton final state analysis [1]. One difference is that the tri-lepton analysis also includes virtual Z^0 and $W^{+/-}$, and thus can cover a lower χ^0_2 mass region. Another is that the parameter space in the tri-lepton analysis allows gauginos to decay through sleptons resulting in almost 100% triletpon final state branching ratio. However the present analysis should be more sensitive where the two analyses overlap (decay via real Z^0 and $W^{+/-}$) because the $W^{+/-}$ to two jets decay rate is much larger than in the leptonic mode.

2. Data and Event Selection

This analysis is based on an integrated luminosity of 2.68/fb collected with the CDFII detector between March 2002 and February 2008 [2]. The data are collected with an inclusive electron trigger that requires a central electron with E_T > 18 GeV. The trigger efficiency for electrons with E_T > 20 GeV is close to 100%. The cuts used in this analysis are as follows: E_T cut for electrons and jets is 20 GeV. Electrons only within $|\eta|<2$ and jets only within $|\eta|<2.75$ are used. For ME_T, three cuts, 40, 50 and 60 GeV are tested. The Z^0 mass window is defined as between 85 and 97 GeV and the $W^{+/-}$ mass window is defined as between 60 and 95 GeV. The $W^{+/-}$ mass window is much larger than the Z^0 mass window because Z^0 is reconstructed with electrons while $W^{+/-}$ is reconstructed with jets.
Events with a good vertex between -60 cm and 60 cm are selected if there are two electrons passing tight electron selection criteria, two or more jets and ME_T greater than 40GeV.

3. Analysis

From the events, three distributions are plotted and compared with the expected background. Figure 2 shows the two electron invariant mass distribution (M_{ee}) after requiring events to pass the W mass cut and ME_T > 40 GeV. Figure 3 shows the ME_T distribution of events passing Z^0 and $W^{+/-}$ mass cuts. Figure 4 shows the two jet invariant mass (M_{jj}) of events passing the Z^0 mass and ME_t >40 GeV cuts. An event is said to pass the Z^0 mass cut if the two electron invariant mass is within the Z^0 mass window and to pass the $W^{+/-}$ mass cut if there is at least one two-jet invariant mass within the $W^{+/-}$ mass window. When there are more than two jets in an event, the invariant combination closest to the $W^{+/-}$ mass is plotted to reduce the combinatorial effect. The data points are shown with + symbols and the colored histograms are the background stack-ups. For the background contributions, 8 standard model processes are taken into account. Of these, 7 are evaluated by using Monte Carlo data [4,5]. The background from QCD jet events is estimated using 20 GeV jet triggered data and the fake rate (a jet faking an electron) as a function of E_T [3]. The fake rate is also used to estimate the contribution from W+jet events [4]. In these figures, the QCD background is not shown because it is less than 1% (Table1). The hatched areas on the background histograms indicate the total errors which are the quadratic sum of statistical and systematic error. The signal (signal x10) points are from the PYTHIA [5] event generator using mSUGRA parameters as described later.

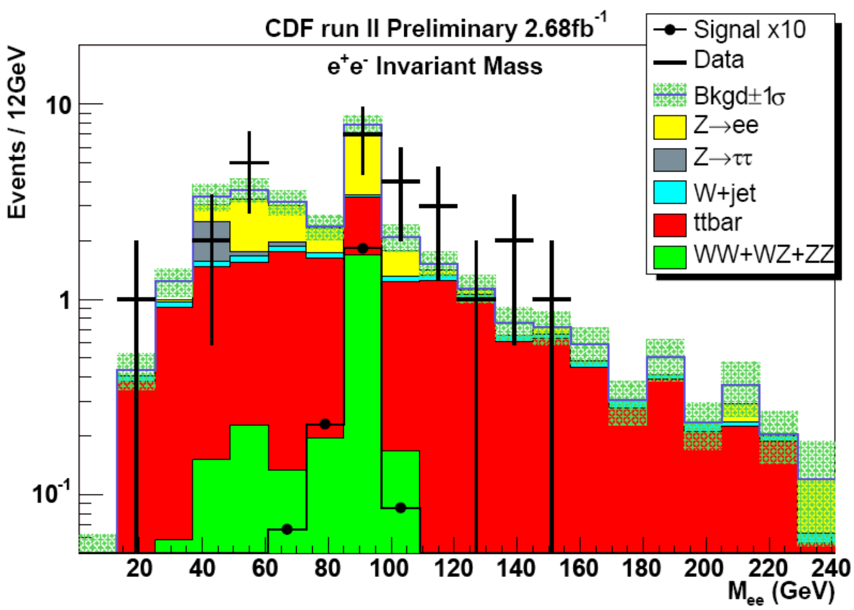

Figure 2. M_{ee} distribution after ME_T >40 GeV and $W^{+/-}$ mass cuts. The hatched area on the background histogram indicates the total error, statistical and systematic errors. W+jet data is from Alpgen and the other data are generated with PYTHIA,

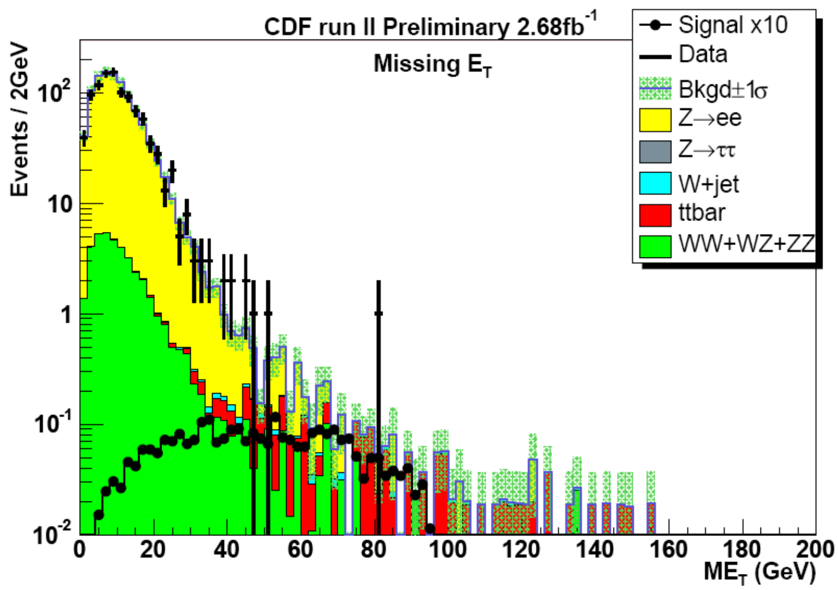

Figure 3. ME_T distribution after Z^0 and $W^{+/-}$ mass cuts.

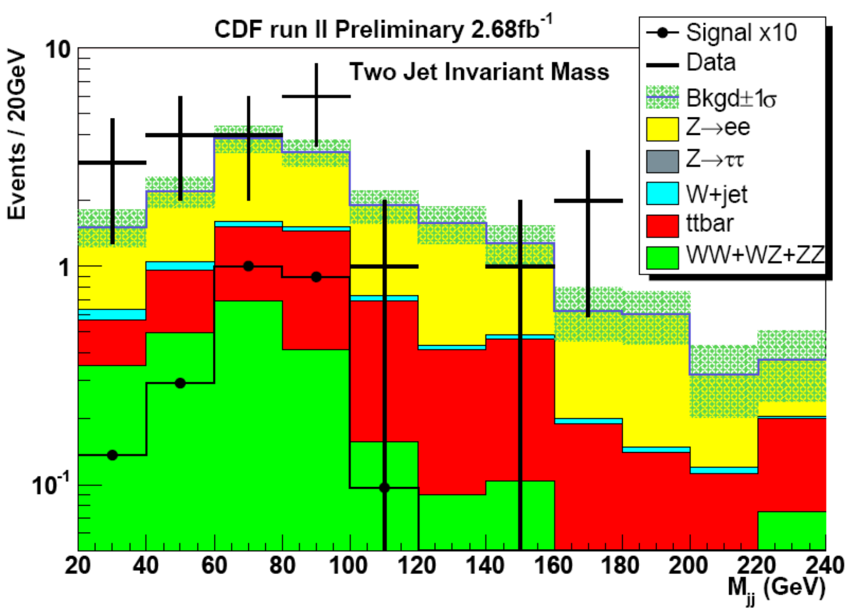

Figure 4. M_{jj} distribution after Z^0 and ME_T >40 GeVcuts.

Because of unique requirements (Z^0 and $W^{+/-}$ mass cuts and large ME_T), the SM background estimation is either straightforward or small. The QCD contribution is small because of the two fake electrons and ME_T requirements. The contribution from di-boson events (WZ and ZZ) is also small because both bosons decay without neutrinos (low ME_T). This is a relatively simple and clean channel for a discovery.

Although not utilized in this analysis, the ttbar background can be reduced further by making a tighter Z^0 mass cut since the e^+e^- invariant mass distribution from ttbar events is broad (Figure 2). Another way to reduce the ttbar background is to utilize the b tagging. With about 50% single b tagging efficiency, ~75% of ttbar events can be removed without reducing the signal appreciably. Both could be useful as the ttbar cross section is expected to rise much faster than the signal as the center of mass energy increases (LHC).

The events passing all three cuts (Z^0, $W^{+/-}$ and ME_T) are counted and compared with the background estimation. With the ME_T > 40 GeV cut, there are seven real data events, while the background prediction is 6.41+/- 0.69 (stat. error)+/-0.64 (sys. error). The data continue to match the background estimation with higher ME_T cuts. For a 50 GeV ME_T cut, the data value is 2 and the estimated background is 3.76+/-0.48 +/-0.33 and for a 60 GeV ME_T cut, the data value is 1 and the expected background is 2.02+/-0.30 +/-0.13. Table 1 shows a detailed comparison. With these numbers, we can conclude that there is no evidence of gaugino pair production and proceed to calculate the cross section limits.

	ME_T>40 GeV	**ME_T>50 GeV**	**ME_T>60 GeV**
Data	**7**	**2**	**1**
Backg. Total	**6.41+/-0.69(stat)+/-0.64(sys)**	**3.76+/-0.48+/-0.33**	**2.02+/-0.30+/-0.13**
Z+Jet	3.73+/-0.64+/-0.63	1.82+/-0.45+/-0.27	0.63+/-0.26+/-0.07
ttbar	1.48+/-0.16+/-0.14	1.23+/-0.15+/-0.12	0.97+/-0.13+/-0.09
WZ	0.60+/-0.12+/-0.06	0.41+/-0.10+/-0.04	0.23+/-0.07+/-0.02
ZZ	0.42+/-0.06+/-0.04	0.21+/-0.04+/-0.02	0.13+/-0.03+/-0.01
WW	0	0	0
Z->ττ	0	0	0
W+Jet	0.1+/-0.003+/-0.041	0.07+/-0.003+/0.029	0.05+/-0.002+/0.021
QCD	0.03+/-0.002+/0.018	0.02+/-0.002+/0.012	0.01+/-0.001+/0.006

Table 1. The number of events with Z^0 mass, $W^{+/-}$ mass and ME_T >40 GeV, 50 and 60 GeV cuts (from left to right column).

Table 2 has a breakdown of statistical and systematic errors for the corresponding background channels and three ME_T values. Only one value is shown for the Fake rate row because the differences among different ME_T cuts are small. The cross section errors are from the theoretical uncertainties and JES (Jet Energy Scale) takes into account the uncertainly in the energy calibration between MC simulation data and real data. This is calculated by changing the energy calibration curve by +/-1 sigma.

		Total Backg. error	Z+Jet	ttbar	WZ	ZZ	WW	Z->ττ	W+Jet	QCD
Statistical MEt >40 GeV		**10.6%**	17.2	10.9	19.9	14.9	0	0	3.2	6
Statistical (MEt >50)		**12.6%**	24.6	11.93	24.2	20.7	0	0	3.7	8.
Statistical (MEt>60)		**15.0%**	41.8	13.2	32.1	26.7	0	0	4.7	11.
X-section MEt >40 MEt >50 MEt >60		 **6.3%** **5.5%** **4.8%**	10.	7.4	7.4	7.2	6.5	1.6	20.	0
JES MEt >40 MEt >50 MEt >60		 **8%** **6%** **2%**	 14 12 7	 1 1 1	 2 4 1	 2 4 1	 0 0 0	 0 0 0	 14. 16. 16.	 0 0 0
Fake rate		**1.0%**	0	0	0	0	0	0	30.	60
Luminosity MEt >40 MEt >50 MEt >60		 **2.5%** **3.1%** **4.1%**	0	6	6	6	6	6	6	0

Table 2. Statistical and systematic errors for the background processes. The luminosity uncertainty for Z+Jet data is set to zero because it is normalized to the real data. The Z+Jet cross section error is from normalization uncertainty of multiple jet events. The QCD luminosity uncertainty is set to zero because real data is used. These errors are used for the limit calculation.

4. Signal detection efficiency and 95% CL cross section calculation

Without evident excess in data over background, we set the 95% CL limit on the gaugino pair production cross section as a function of χ^0_2 mass for $\mu < 0$ and $\mu > 0$ separately. To calculate the limit, the signal efficiency (**ε**) is obtained with the PYTHIA event generator and CDFSIM, the CDF detector simulator. The five mSUGRA parameters have to satisfy the mass condition $M(\chi^0_2) > M(\chi^0_1) + M(Z^0)$. We have tried several sets and settled with the following set of parameters shown in Table 3. Because the χ^0_2 mass is mainly sensitive to $M_{1/2}$, the signal detection efficiency is calculated as a function of $M_{1/2}$ for $\mu < 0$ and $\mu > 0$ while all other parameters are fixed at default values (Table 3). The efficiency varies from ~3% ($M(\chi^0_2)$ ~190 GeV) to ~5.5% (~220 GeV) and to ~6.5% (~250 GeV) with the ME_T >40 GeV cut. For the 50 GeV cut (60 GeV) the efficiency is ~1 (2) % lower than for the 40 GeV cut.

The PYTHIA total cross section for this process is 30 fb and the branching ratio of χ^0_2 (or $\chi^{+/-}_1$) to $Z^0\chi^0_1$(or $W^{+/-}\chi^0_1$) is 100% for the default parameters. It is worthwhile to point out that for the range of $M_{1/2}$ values considered here, the mass of χ^0_2 and $\chi^{\pm}_1$ is directly proportional to $\sim 0.8 M_{1/2}$ and the mass difference between χ^0_2 and $\chi^{\pm}_1$ is less than 0.5 GeV for a given $M_{1/2}$ and μ. Also, the χ^0_2 mass for $\mu<0$ is about 6 GeV less than in the $\mu>0$ case for a fixed $M_{1/2}$.

M_0 =1000 GeV
$M_{1/2}$ =275 GeV
tanβ =10.0
A=0.0
Sign (μ) < 0

Table3. The default mSUGRA parameters. For these parameters, the χ^0_2 mass is 221 GeV.

The signal M_{ee}, ME_T and M_{jj} distributions generated with the default parameters are plotted in Figures 2, 3 and 4. Because of small cross section, the signal is multiplied by a factor of 10.

The systematic uncertainties due to JES, PDF, ISR, FSR and luminosity are included in the efficiency error. The PDF (Parton Distribution Function), ISR (Initial State Radiation) and FSR (Final State Radiation) uncertainties are listed in Table 4 after all cuts. PDF uncertainty takes care of the difference among various parton distribution functions and ISR and FSR uncertainties take care of uncertainty in the bremsstrahlung process. JES uncertainty exhibits $M_{1/2}$ and ME_T dependence, while PDF, ISR and FSR uncertainties show weak dependence on the two variables.

	Systematic uncertainty on Signal
JES	As a function of ME_T and $M_{1/2}$
PDF	2.3%
ISR	3.5%
FSR	2.5%
Luminosity	6%

Table 4. Signal systematic uncertainties due to JES, PDF, ISR and FSR. JES systematic uncertainty varies from ~ 15% at $M_{1/2}$ = 230 GeV to ~ 8% at 270 GeV and changes little for higher $M_{1/2}$.

Inputs to the limit calculation are the integrated luminosity, the signal efficiency (**ε**), the estimated background (**b**), the number of observed events (**n**), and their respective errors. In this Bayesian approach [6], **ε** and **b** are assigned priors. The expected 95% CL cross sections are calculated for three ME_T values, 40, 50 and 60 GeV, as a function of χ^0_2 mass. For a given χ^0_2 mass, the ME_T value giving the best expected limit is chosen and the limit is plotted in Figure 5 ($\mu < 0$) and Figure 6 ($\mu > 0$). The limits calculated from data (called data limit) are also plotted in the same figures.

The expected and data limits are compared with the gaugino pair production cross section. In order to take into account the NLO contribution, the cross section calculation package PROSPINO [7] is utilized with SOFTSUSY. The PROSPINO cross section is about 10-20% higher than PYTHIA results at the same χ^0_2 mass. Since PROSPINO does not produce a decay table, the PYTHIA branching ratios for $\chi^0_2 \to Z^0 \chi^0_1$ and $\chi^{+/-}_1 \to W^{+/-}\chi^0_1$ are used for the given χ^0_2 mass. Because of low production cross section of the gaugino pairs, no parameter region is excluded. The sharp decrease in the cross section around 230 GeV is because of an onset of the $\chi^0_2 \to h^0\chi^0_1$ mode. Its branching ratio compared to $\chi^0_2 \to Z^0\chi^0_1$ depends on the sign of μ.

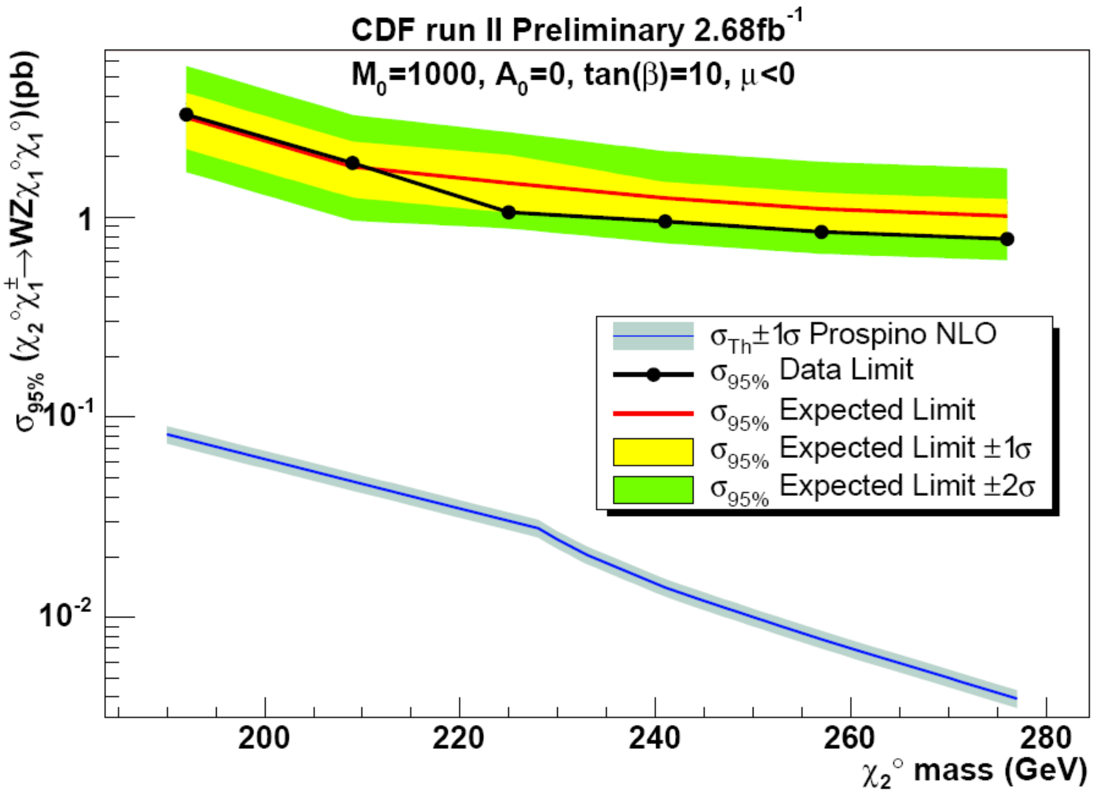

Figure 5. Cross section x branching ratio limits at 95% CL for gaugino pair production with $\mu < 0$. Red line is expected limit. Yellow band is ±1 sigma of expected limit. Green band is ±2 sigma of expected limit. Black line with dots is the data limit. Blue line is theoretical cross section from NLO Prospino. The branching ratio is from Pythia.

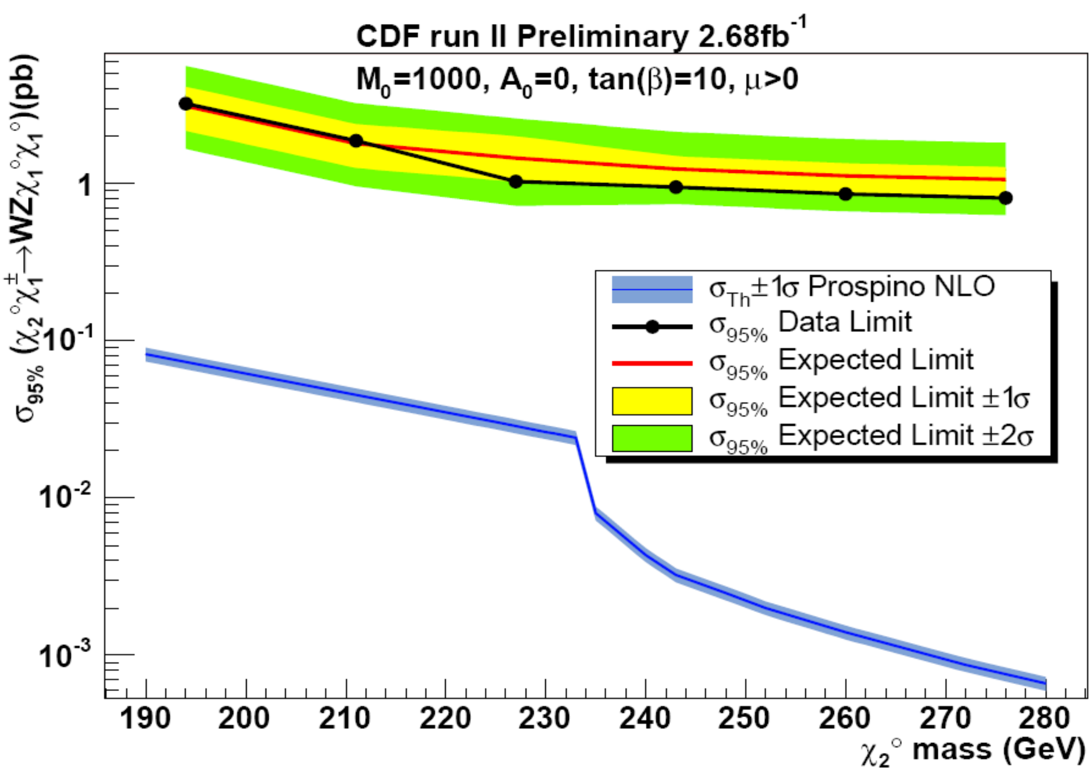

Figure 6. The same as Figure 5 but with $\mu > 0$.

5. Summary

Using events with Z^0 ($\to e^+e^-$), two or more jets and large ME_T, we have searched for a signature of gaugino pair production ($p\bar{p} \to \chi^0_2 \chi^{+/-}_1 \to Z^0 \chi^0_1 W^{+/-}\chi^0_1$) with 2.68/fb of data. Because of unique requirements (Z^0 and $W^{+/-}$ mass cuts and large ME_T), the SM background estimation is either straightforward or small. This is a relatively simple and clean channel for a discovery.

The number of events passing our default cuts is 7 while the background prediction is 6.41+/- 0.69 (stat. error)+/-0.64 (sys. error). With the 50 GeV MEt cut, the data is 2 and the background is 3.76+/-0.48+/-0.33 and with the 60 GeV cut, the data is 1 and the background is 2.02+/-0.30+/-0.13. Without any evidence of excess, the 95% CL limits on the pair gaugino production cross section have been calculated as a function of χ^0_2 mass.

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[1] T. Aaltonen et al., The CDF Collaboration, Phys. Rev. Lett. 101, 251801 (2008)
V. M. Abazov, et al (D0 Collaboration), Phys. Rev. Lett. 95, 151805 (2005)
[2] F. Abe, et al., Nucl. Instrum. Methods Phys. Res. A 271, 387 (1988); D. Amidei, et al., Nucl. Instum. Methods Phys. Res. A 350, 73 (1994); F. Abe, et al., Phys. Rev. D 52, 4784 (1995); P. Azzi, et al., Nucl. Instrum. Methods Phys. Res. A 360, 137 (1995); The CDFII Detector Technical Design Report, Fermilab-Pub-96/390-E
[3] T. Aaltonen, *et al* (CDF collaboration), Phys. Rev. Lett. 102, 031801 (2009)
[4] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau, A. Polosa, ALPGEN, a generator for hard multiparton processes in hadronic collisions, JHEP 0307, 001 (2003).
[5] T. Sjostrand et al., High-Energy-Physics Event Generation with PYTHIA 6.1, Comput. Phys. Commun. 135, 238 (2001).
[6] J. Heinrich, CDF public note 7587. http://www-cdf.fnal.gov/publications/cdf7587_genlimit.pdf
[7] W. Beenakker, R. H¨opker, M. Spira and P.M. Zerwas, Nucl. Phys. B492: 51-103 (1997).