CDF note 7833

Search for the associated production of Charginos and Neutralinos in the $\mu\mu + \mu/e$ final state

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Supersymmetry, if realized in Nature, predicts the existence of new particles, such as chargino and neutralino. If kinematically accessible, these particles would be produced at the Fermi National Accelerator Laboratory in proton-antiproton collisions at the center−of−mass energy $\sqrt{s} = 1.96$ GeV. Within the mSUGRA scenario of the MSSM they decay into leptons and LSPs (stable neutralinos), giving rise to a peculiar signature with three isolated leptons and substantial energy imbalance in the detector. We searched a total of $\int \mathcal{L}dt = 346\ \mathrm{pb}^{-1}$ of data collected by the CDF experiment during Tevatron Run II and performed a blind analysis of $\mu\mu + \mu/e$ final states. We find 0 events, compatible with the expectation from the Standard Model backgrounds.

I. INTRODUCTION

SUSY is a proposed symmetry of Nature extending the Standard Model (SM) with the solution to the naturalness problem. For each SM particle characterized by spin s, it introduces a partner with the same quantum numbers but the spin ($s^{'} = s$ - $\frac{1}{2}$). Because fermions and bosons induce opposite sign radiative corrections to the Higgs mass, the correction that is quadratically divergent in the SM, is indeed cancelled in the Supersymmetric extension of the SM (SSM). Since no sparticles have been observed yet, it is assumed that SUSY is a broken symmetry with an as yet unknown breaking mechanism. One proposed model is Supergravity (SUGRA) which postulates the existence of a "hidden sector" at high energy where the dynamical breaking occurs and that the superfields populating the hidden sector couple to the electroweak sector only by gravitational interaction. In the minimal Supergravity assumption, the supersymmetric particles universally couple to the hidden sector and all scalars and all gauginos assume a common value of the mass, namely m_0 and $m_{\frac{1}{2}}$, at the GUT scale [1].

This note describes a search for SUSY in events with associated production of chargino and neutralino (Fig.1), which are a combination of the electroweak gauginos and of the higgsinos. Within the Minimal Supersymmetric Standard Model (MSSM) framework, if baryon and lepton numbers are conserved, charginos and neutralinos can either decay into the lighter charginos and neutralinos accompained by gauge or Higgs bosons, or into fermion-sfermion pairs. A subsequent leptonic decay provides a clean signature with three leptons and a significant imbalance of energy in the detector, registered as missing transverse energy in the Tevatron detectors. The results shown in the current note refer to $\mu\mu + \mu/e$ final states characterized by significant missing transverse energy. They have been interpreted within the mSUGRA scenario for low value tanβ in order to investigate the region of the parameter space with the highest reach.

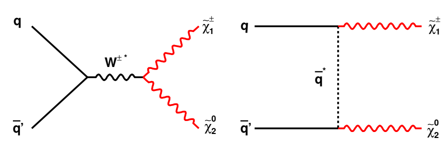

FIG. 1: Associated production of chargino and neutralino.

II. DATA SAMPLE AND MONTE CARLO SAMPLES

This analysis is based on an integrated luminosity of 346±21 pb^{-1} collected with the CDFII detector [2] between March 2002 and August 2004. The data are collected with an inclusive muon trigger that requires a muon with P$_T >$ 18 GeV/c. Signal Monte Carlo samples have been generated for several points in the mSUGRA parameter space. In this note we report the results for the parameter set $m_0 = 100$ GeV/c^2, $m_{\frac{1}{2}} = 180$ GeV/c^2, $A_0 = 0$ GeV/c^2, sign$\mu = 1$ and $tan\beta = 5$, since it provides the highest yield beyond the LEPII limit. The Monte Carlo samples are generated by PYTHIA 6.216 with mSUGRA and parton distribution function CTEQ5L, whereas the cross sections are calculated with NLO PROSPINO 6L.

III. EVENT SELECTION

From the inclusive muon dataset we select events with three isolated leptons well separated in $\eta-\phi$ space but coming from the same vertex [3]. The two highest P$_T$ leptons in the event are required to be central muons matched to a track with P$_T$ greater than 20/8 GeV/c. The lowest P$_T$ lepton may be either a muon or a central electron with P$_T/E_T$ greater than 5 GeV/c [4] . In case of the third lepton being a muon, the analysis is not affected by muon reconstruction inefficiency since the standard CDF muon identification, which proceeds by matching extrapolated tracks found in the central tracker to track segments reconstructed in the muon chamber, is loosened [5] . A prominent non-collisional background, cosmics, is efficiently rejected by using geometrical and timing constraints. Instrumental background is reduced by rejecting events where the missing transverse energy is aligned to either muons or to a identified jet, since the missing transverse energy typically points into the direction of the mismeasured lepton or jet. The optimization of the analysis cuts is performed by maximizing the reach defined as $S_{SUSY}/\sqrt{B_{tot}}$ while mantaining the data blind. As the analysis cuts are fixed, the confidence in understanding the SM background is obtained by comparing the data and the expectation from the SM backgrounds in control regions where the signal from SUSY is expected to be small.

A. Backgrounds

All SM contributions are evaluated using NLO Monte Carlo samples filtered with two muon and an additional lepton (electron or muon) at generator level [6] , but the contribution from fake leptons is instead estimated from data. The fake rate is measured as a function of the P_T/E_T of fakeable objects in jet data as the ratio of fake leptons to fakeable objects. This probability varies in the range $[10^{-4}; 10^{-1}]$ depending on the lepton type, highest for muons without reconstructed segments in the muon chambers. The estimation procedure has been validated by using Monte Carlo samples. The fake rate is subsequently applied to a dimuon data sample, where dimuon events with an additional fake lepton are combined into a sample of fake trilepton events and weighted according to the fake rate of the selected fake lepton.

B. Acceptance

The total acceptance is obtained from the geometrical and kinematical acceptance measured in the Monte Carlo samples and from the efficiency of identifying leptons measured in Drell Yan Monte Carlo and scaled to the value measured in the data using the unbiased leg in J/Ψ and Z decays. This efficiency scaling is dependent on both the lepton type and the P_T range. The probability that the event in the Monte Carlo sample fires a given muon trigger is taken into account as an additional scale factor applied to the simulated event. The total signal acceptance at this point is 1.4%.

C. Analysis selection

Number of events	SUSY (a)	Total Background
Trilepton Selection	0.48±0.02	2.85±0.27

TABLE I: Number of predicted SUSY and SM events for an integrated luminosity of 346pb^{-1} (statistical uncertainty only)

As shown in Tab.I, the SUSY signal before any analysis cut is small, thus calling for highly efficient selection cuts. The dataset selected at this stage is dominated by Drell Yan production where the prompt muons are accompained by a third lepton, which is either a fake lepton or originates from photon radiations. The latter is suppressed by dedicated conversion removal cuts. Events are therefore rejected if opposite sign muons have an invariant mass consistent with low mass resonances or a Z^0 ($15 < M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2). $t\bar{t}$ events involving jets can be removed from the dataset by placing a cut on the jet multiplicity where the jet accounted for must have a trasverse energy larger than 20 GeV/c^2: $n_{jet20} < 2$. The residual background has an irreducible component due to diboson production and still a substantial component from Drell Yan events. The latter tipically has small transverse missing energy which distinguishes it from the SUSY signal so that $Z/\gamma* \rightarrow \mu\mu$ events are further suppressed by setting a cut of minimal missing transverse enery of 15 GeV/c^2. The results of the sequential cuts are shown in Tab.II while the distributions of the invariant mass, of the jet multiplicity and of the missing transverse energy are shown in Fig.2 to Fig.4.

Kinematic cut	SUSY (a)	Total Background
Invariant mass cut	0.42±0.02	1.06±0.18
Jet cut	0.42±0.02	1.04±0.18
Missing E_T cut	0.37±0.02	0.09±0.03

TABLE II: Number of predicted SUSY and SM events for an integrated luminosity of 346pb^{-1} at each stage of the analysis selection (statistical uncertainty only)

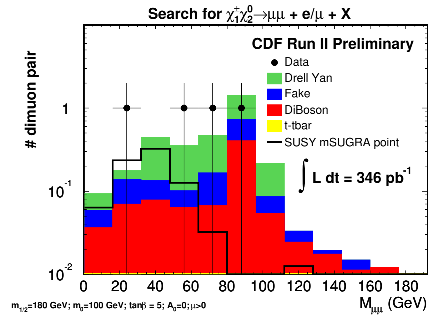

FIG. 2: Distribution of the invariant mass of opposite sign muons in trilepton before any analysis cut is applied.

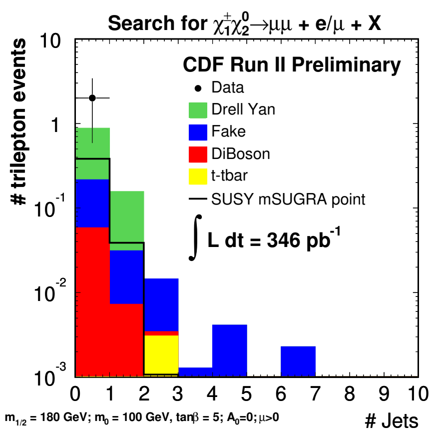

FIG. 3: Jet multiplicity in trilepton events where the invariant mass cut is applied.

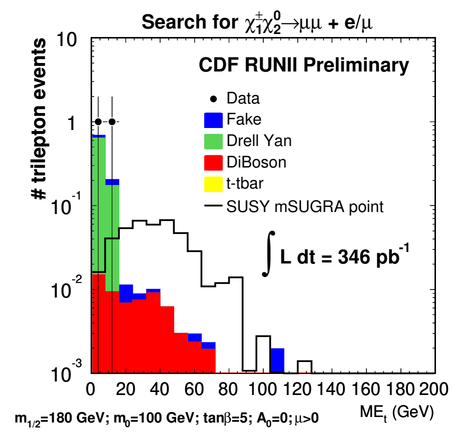

FIG. 4: Distribution of the missing transverse energy in trilepton events where both the invariant mass and the jet cuts are applied.

D. Control regions

The details of the contributions from the different background sources in all control regions are given in Tab.III and Tab.IV. The naming used for the control region can be found below.

- A: $15 < M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2, $\mathrm{n}_{jet20} < 2$, MET > 15 GeV/c^2.
- B: $15 < M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2, $\mathrm{n}_{jet20} < 2$, MET < 10 GeV/c^2.
- C: $76 < M_{\mu\mu} < 106$ GeV/c^2, $\mathrm{n}_{jet20} < 2$, MET < 10 GeV/c^2.
- D: $76 < M_{\mu\mu} < 106$ GeV/c^2, $\mathrm{n}_{jet20} < 2$, MET > 15 GeV/c^2.
- E: $15 < M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2, $\mathrm{n}_{jet20} > 1$, MET > 15 GeV/c^2.
- F: $76 < M_{\mu\mu} < 106$ GeV/c^2, $\mathrm{n}_{jet20} > 1$, MET > 15 GeV/c^2.
- G: $15 < M_{\mu\mu} < 76$ or $M_{\mu\mu} > 106$ GeV/c^2, $\mathrm{n}_{jet20} > 1$, MET < 10 GeV/c^2.
- H: $76 < M_{\mu\mu} < 106$ GeV/c^2, $\mathrm{n}_{jet20} > 1$, MET < 10 GeV/c^2

It can be seen that the expectations from the SM backgrounds agree with the observation.

CR	Diboson	HF	Fake	Drell Yan	Total Background	DATA
A	2.3 ± 0.13	0.24 ± 0.02	2 ± 1	23 ± 3	23 ± 8	33
B	0.21 ± 0.03	0.009 ± 0.004	3 ± 1.5	519 ± 13	522 ± 13	538
C	0.28 ± 0.03	0.002 ± 0.002	23 ± 11.5	2823 ± 30	2845 ± 30	2814
D	1.07 ± 0.06	0.05 ± 0.01	14 ± 7	41 ± 4	57 ± 4	60
E	0.04 ± 0.02	0.68 ± 0.04	0.03 ± 0.015	0.52 ± 0.37	1.3 ± 0.4	2
F	0.02 ± 0.01	0.18 ± 0.02	0.1 ± 0.05	1.5 ± 0.7	1.8 ± 0.7	2
G	$5 \times 10^{-4} \pm 5 \times 10^{-4}$	0.028 ± 0.008	0.03 ± 0.015	4 ± 1	4.0 ± 1.1	7
H	0.003 ± 0.001	0.004 ± 0.003	0.15 ± 0.075	22 ± 3	22 ± 3	20

TABLE III: Dimuon control regions (statistical uncertainty only)

CR	SUSY	Diboson	HF	Fake	Drell Yan	Total Background	DATA
A	0.37 ± 0.03	0.043 ± 0.003	0.0 ± 0.004	0.01 ± 0.005	0.035 ± 0.035	0.09 ± 0.03	BLIND
B	0.023 ± 0.006	0.020 ± 0.003	0.0 ± 0.004	0.16 ± 0.008	0.66 ± 0.17	0.84 ± 0.17	2
C	0.0 ± 0.003	0.079 ± 0.006	0.0 ± 0.004	0.22 ± 0.11	0.66 ± 0.17	0.96 ± 0.17	0
D	0.011 ± 0.04	0.29 ± 0.01	0.0 ± 0.004	0.14 ± 0.7	0.0 ± 0.7	0.43 ± 0.7	0
E	0.001 ± 0.001	0.0 ± 0.001	0.003 ± 0.002	0.002 ± 0.001	0.0 ± 0.7	0.005 ± 0.7	0
F	0.0 ± 0.003	0.004 ± 0.001	0.0 ± 0.004	0.007 ± 0.0035	0.0 ± 0.7	0.001 ± 0.7	0
G	0.0 ± 0.003	0.0 ± 0.001	0.0 ± 0.004	0.01 ± 0.005	0.0 ± 0.7	0.001 ± 0.7	0
H	0.012 ± 0.004	0.001 ± 0.001	0.0 ± 0.004	0.02 ± 0.01	0.0 ± 0.7	0.02 ± 0.7	1

TABLE IV: Trilepton control regions (statistical uncertainty only)

E. Systematic uncertainties

Sources of systematic uncertainties in the present analysis derive from luminosity uncertainty, muon P_T resolution, lepton and jet identification, fake rate calculation, along with the theoretical calculation of the cross sections, PDFs (Parton Distribution Function) and ISR (Initial State Radiation) effects. The impact of the P_T resolution is determined by comparing the results obtained from two Monte Carlo samples with different tracking resolution, while the uncertainty from the identification of leptons and jet is derived by varying the central value of the lepton scale factors and the jet correction factor used to weight the Monte Carlo event. The uncertainty due to the fake rate is determined from the variation of the fake rate depending on the sample used for its measurement. The uncertainties from the theoretical calculation of cross section, PDF and ISR are instead measured by comparing different choices for PDFs and varying the ISR and theoretical cross section. The systematic uncertainties are summarized in Tab.V.

Source	SUSY (%)	SM Background (%)
Luminosity	6	6
P_T resolution	—	7
Fake rate	—	5.5
Muon Identification scale factor	3.7	2.4
Muon Isolation scake factor	4	3.4
Jet Energy scale	0.3	1.3
Theoretical cross section	7	6.5
ISR	1.9	4.1
PDF	2	2

TABLE V: Main systematic uncertainties.

IV. RESULTS

After all analysis cuts are applied and the remaining data is unblinded 0 events are found. The result is compatible with the expectation from the Standard Model backgrounds $0.09 \pm 0.03(stat) \pm 0.01(sys)$.

V. CONCLUSIONS

A search for the associated production of chargino and neutralino with a subsequent decay into three leptons is performed as a blind analysis using the final state $\mu\mu + \mu/e$ in 346pb^{-1} of CDFII data. After all analysis cuts are applied 0 events are observed which means that we do not see any evidence of chargino and neutralino production of the kinematically allowed masses.

Acknowledgments

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[3] The isolation is defined as the energy in a cone of 0.4 rad centered around the lepton divided by the transverse momentum (transverse energy in case of an electron) of the lepton itself

[4] "CMUP" muon chambes covers the region $\mid \eta \mid < 0.6$ and "CMX" muon chamber covers the region $0.6 < \mid \eta \mid < 1.0$. The central electromagnetic calorimeter covers the region $\mid \eta \mid < 1.0$.

[5] In order to ensure good quality, the transverse momentum of the associated track is required to be greater than 10 GeV/c and the number of hits in the Central Outer Track to be greater than 30.

[6] In case of Drell Yan production the generator level filter requires two muons and one γ