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SUGRA–GUT Motivated SUSY Search in the Dielectron Channel at DØ

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The DØ Collaboration[1]

(July 1996)

In this paper we present a search for events consistent with the production and decay of supersymmetric particles in the Supergravity-GUT framework in the D0 detector at Fermilab. We examine the 1994-95 Run 1B data for events containing two or more electrons, two or more jets, and a substantial missing transverse energy. This is complementary to the search in the canonical jets and missing transverse energy channel. We observe 2 events in 92.9 pb^{-1} of the Run 1B data consistent with the estimated total background contribution of 3.0±1.3 events from the Standard Model. The non-observation of excess events has been interpreted as an excluded region on the two-dimensional $m_0 - m_{1/2}$ plane.

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I. INTRODUCTION

Supersymmetry (SUSY) is a space-time symmetry relating fermions and bosons (1–5). Supersymmetric extensions of the Standard Model require a bosonic (fermionic) 'superpartner' for every standard model fermion (boson) with the same internal quantum numbers but with the spin differing by 1/2.

The simplest possibility is the Minimal Supersymmetric Standard model (MSSM) which is a direct supersymmetrization of the Standard Model (SM) in which a minimal number of new particles are introduced without contradicting the observed phenomenology. In this model, with the additional constraint of baryon and lepton number conservation, it is possible to define a multiplicatively conserved quantum number called R-parity which is $+1$ for the SM particles and -1 for their superpartners. A direct consequence of this is the fact that the lightest supersymmetric particle (LSP) is stable. Thus the LSP, which is weakly interacting and the end product of every supersymmetric particle decay chain, evades detection resulting in an overall energy-momentum imbalance in the detector.

The MSSM requires more than 20 new parameters for its description which makes the experimental analyses very difficult. In the present analysis, we work within the SUGRA-GUT framework (6–8) which has only five free parameters which can be taken to be: a common SUSY-breaking scalar mass (m_0) for all scalars, a common mass for all gauginos

($m_{1/2}$), a common value for all trilinear couplings (A_0), the ratio of the vacuum expectation values of the two Higgs fields ($\tan(\beta)$) and the sign of μ where μ is the Higgsino mass mixing parameter. The masses and couplings at the weak scale are obtained from the above unification scale parameters by solving the renormalization group equations. Experimentally, it allows us to combine searches in different channels in a unified and consistent way.

II. EXPERIMENTAL SEARCH

In the early searches for squarks and gluons, probing the low mass region, one assumed a one step decay of squarks and gluinos into quark jets and LSPs. In these searches, one looked for energetic jets (due to final state quarks) and $\not\!\!E_T$ (due to the undetected stable and neutral LSPs) as the canonical SUSY signature.

However, as the mass limits for the SUSY particles, specially for squarks and gluinos were pushed higher, it became evident that the sparticles must be considerably heavy and new decay channels through chargino and neutralino intermediate states become kinematically accessible. Although recent searches by both DØ and CDF have taken such cascade decays into account, they are confined to the jets and $\not\!\!E_T$ channel and thus sensitive only to the hadronic decays of charginos and neutralinos to the LSP (9–11).

In addition to their hadronic decays, the charginos and higher mass neutralinos can also decay leptonically. In fact, in certain regions of the SUSY parameter space, there can be substantial enhancement of their leptonic decay branching fractions. The final states in such decays contain leptons in addition to jets and $\not\!\!E_T$. Leptonic SUSY searches, using isolated leptons, jets and $\not\!\!E_T$ therefore complement the canonical SUSY searches which look only for the jets and $\not\!\!E_T$. The collection of 92.9 pb^{-1} of data in the DØ detector during the 1994-95 run and the availability of elaborate SUSY event generators have made the SUSY search in the leptonic channels more viable.

The DØ detector has three major subsystem: central tracking detectors, a nearly hermatic liquid argon calorimeter, and a muon spectrometer. This detector with its excellent calorimeter resolution and the eta coverage for electrons and jets is well suited for a search of SUSY particles in the dielectron channel. In this search, we look for events with at least two isolated, high E_T electrons, two jets, and missing E_T. The major SM background processes which can mimic the signal are the leptonic decays of $t\bar{t}$, WW and Z. Heavy flavour production, mainly $b\bar{b}$ and $c\bar{c}$ gives rise to non-isolated soft leptons and can be easily rejected with great efficiency by the electron E_T and isolation cuts. The major instrumental background arises out of the mis-identification of a jet as an electron.

Events for this analysis are selected by requiring at least two electrons with $E_T > 15$ GeV within an $|\eta| < 2.5$ satisfying electron identification cuts, two jets with $E_T > 20$ GeV and $|\eta| < 2.5$ satisfying jet quality cuts and $\not\!\!E_T > 25$ GeV. In addition, events in which the invariant mass of the two electrons lies between 79 and 103 GeV are removed as possible Z events unless the $\not\!\!E_T$ in such events is above 40 GeV. Only 2 events survive all the above cuts. In Table 1 we show the effects of the cuts on data.

Table 1

Cut	No. of events
Passed Trigger requirement	117191
Electron Quality Cuts	369
Electron Et/Eta Cuts	318
Z-mass Cut	104
Missing Et Cut	46
Jet Cuts	2
Expected Background	3.0±1.3

To estimate contributions from various physics background sources, we have used Monte Carlo events which are then processed through DØ detector simulation and event reconstruction packages. However these events are used only to estimate the effects of trigger and various offline cuts, i.e. to estimate only the trigger and kinematic efficiencies. For the top quark and Z boson production, experimentally measured cross sections have been used to estimate the number of background events. Cross section for WW production is taken from theoretical calculation. In order to estimate the fake background, we used the complete 1994-95 Run 1B W+jets data sample. We first select all the events with at least one electron and three jets with at least two having $E_T > 20$ GeV that also pass the $\not{E}_T$ cut and the trigger requirement. The probability of a jet mimicking an electron is then folded in to estimate the number of fake events in our final data sample. In Table 2, we give the breakdown of the various background contributions including the statistical and systematic errors. The main sources of systematic uncertainties are calorimeter energy scale, the error on the luminosity and the uncertainties in the measured cross sections.

Table 2

Background Process	Expected Contribution in 92.9 pb^{-1}
$t\bar{t} \to$ ee (180 GeV)	$1.202 \pm 0.051 \pm 0.427$
$WW \to$ ee	$0.038 \pm 0.007 \pm 0.002$
$Z \to \tau\tau \to$ ee	$0.248 \pm 0.029 \pm 0.074$
$Z \to$ ee	$0.982 \pm 0.667 \pm 1.034$
QCD $\to$ ee (from $b\bar{b}, c\bar{c}$)	0.079
fakes	0.436 ± 0.026
Total	$2.985 \pm 0.670 \pm 1.121$

The total number of expected background events is 3.0±0.7±1.1, which is consistent with the observed number of candidate events in the data. Thus, we find no excess of events above the SM predictions.

In order to interpret this null result as an exclusion region in the SUGRA parameter space, events are generated (ISAJET 7.13) at various points in the 2-dimensional $m_0 - m_{1/2}$ plane. The three SUGRA parameters A_0, $\tan(\beta)$, $\mathrm{sgn}(\mu)$ are fixed at 0, 2 and negative respectively and the top mass is assumed to be 180 GeV. The events are then generated for various values of (m_0,$m_{1/2}$). This effectively reduces the number of free parameters to just two and the result can then be presented as an exclusion region in the m_0-$m_{1/2}$ plane. To choose the sensitive regions for m_0 and $m_{1/2}$, a first pass was made over various different values on this 2-dimensional plane at the generator level. Events are then generated using a subset of these points and processed through the DØ detector simulation and reconstruction packages. To be sensitive to the effect of the changing branching ratio to dielectron final states, a fine granularity is needed. Accordingly, events have been generated at more than 100 points on this two dimensional plane. Since we are interested in the dielectron final states coming from all of the allowed SUSY processes incorporated in the generator, the total cross section is generated by allowing all possible processes. The dielectron events are then streamed out by using very loose generator level cuts. The signal efficiency times branching ratio at each of these points is then estimated using the number of signal events that pass all our selection cuts. In Table 3, we give the signal efficiency times branching ratio for some points in the m_0-$m_{1/2}$ plane.

TABLE 3

m_0	$m_{1/2}$	$\epsilon\times$B.R.(%)	m_0	$m_{1/2}$	$\epsilon\times$B.R.(%)
0	85	$0.08\pm0.01^{+0.00}_{-0.00}$	20	85	$0.13\pm0.02^{+0.00}_{-0.00}$
40	70	$0.09\pm0.01^{+0.00}_{-0.00}$	60	55	$0.10\pm0.01^{+0.00}_{-0.00}$
80	90	$0.55\pm0.05^{+0.01}_{-0.01}$	120	85	$1.23\pm0.08^{+0.00}_{-0.02}$
150	90	$1.16\pm0.08^{+0.01}_{-0.00}$	180	70	$1.49\pm0.09^{+0.01}_{-0.01}$
220	90	$0.91\pm0.06^{+0.01}_{-0.01}$	250	60	$0.33\pm0.03^{+0.00}_{-0.00}$
300	60	$0.22\pm0.03^{+0.00}_{-0.00}$	350	55	$0.18\pm0.02^{+0.00}_{-0.00}$
370	70	$0.15\pm0.02^{+0.00}_{-0.01}$	400	40	$0.02\pm0.01^{+0.00}_{-0.00}$

Using the efficiencies, the total luminosity and the expected background contributions, the cross section limits are calculated at the 95% confidence level. The exclusion region in the $m_0 - m_{1/2}$ plane is shown in Fig. 1. Here, (a) is the region that is excluded by theory and (b) is the region which is allowed theoretically but with a sneutrino rather than the lightest neutralino as the LSP. The dip in the contour around m_0 = 70 - 80 is the region where the sneutrinos become lighter than $\tilde{Z}_2$ and are also lighter than selectrons. As a result, in this region, $\tilde{Z}_2$ dominantly decays into $\tilde{Z}_1$ and neutrinos thus reducing the branching ratio to dielectron final states substantially. At still lower values of m_0, the selectrons become lighter than $\tilde{Z}_2$ as well, and the channels for $\tilde{Z}_2$ decay to leptons and $\tilde{Z}_1$ open up again.

III. CONCLUSIONS AND FUTURE PLANS

In the present analysis, we observe no excess of events above what is predicted by the Standard Model. Using this information and the Monte Carlo study of the signal at various points on the $m_0 - m_{1/2}$ plane, we have interpreted this result as an excluded region on the same at the 95 % C.L. At present work is in progress to determine the effects of changing the other parameters, notably $\tan(\beta)$, on our results.

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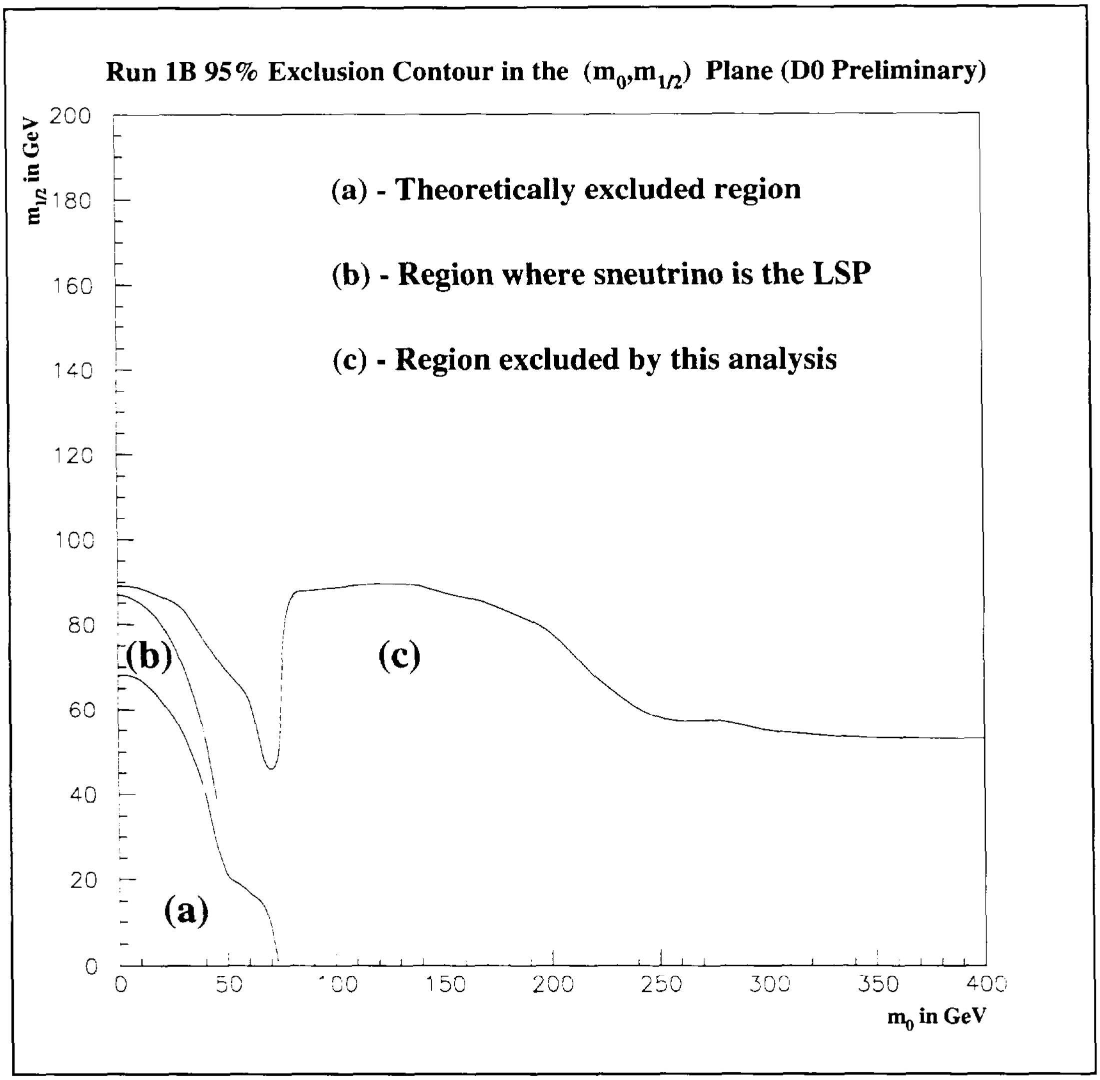

FIG. 1. 95% exclusion contour in the m_0-$m_{1/2}$ plane from the present analysis with $\tan(\beta)= 2$, $A_0 = 0$ and $\mathrm{sign}(\mu) = -1$