DØnote 4404-CONF

Search for mSUGRA SUSY in the Like-Sign Dimuon Channel

The DØ Collaboration
URL: http://www-d0.fnal.gov

(Dated: May 25, 2004)

We describe the search for the associated production of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ particles. In gravity-mediated SUSY models, these particles may decay promptly to produce a trilepton final state which would be observable in a hadron collider environment. By requiring two like-sign leptons, the signal acceptance is increased with respect to requiring three leptons, while maintaining a low background. We use this approach in analyzing dimuon events using 147 ± 10 pb^{-1} from the data set.

Preliminary Results for Winter 2004 Conferences

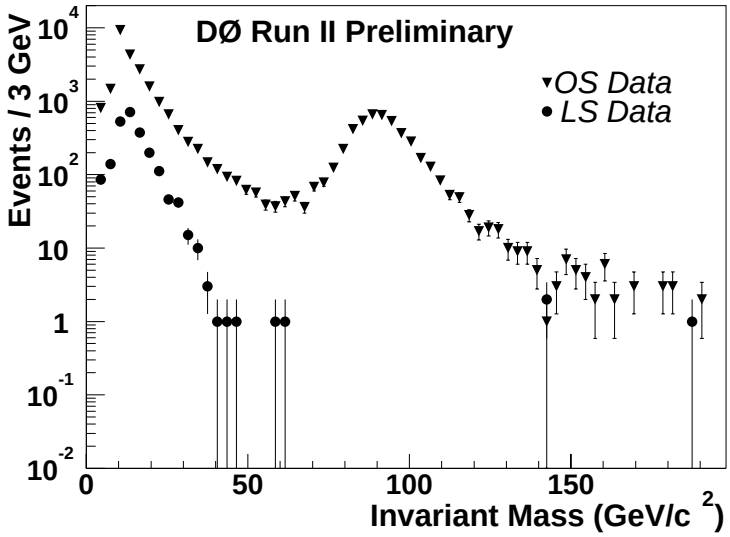

FIG. 1: Comparison between opposite-sign and like-sign invariant mass spectrums.

I. INTRODUCTION

Supersymmetry (SUSY) is a proposed symmetry between fermions and bosons [1]. If this symmetry exists, it is clearly broken as we only see half of the particle spectrum. One model which provides a simple breaking mechanism is called minimal supergravity (mSUGRA) SUSY. We perform a search for supersymmetry within this framework. A clean final state predicted by supersymmetric models is a tri-lepton final state from chargino and neutralino decays.

We search for these events by requiring like-sign (LS) muon pairs. Requiring just two muons increases the signal acceptance. Adding the like-sign requirement reduces the Standard Model background from Drell-Yan dimuon pairs and various resonances in the dimuon spectrum (see Figure 1). It has been suggested that the reach into some parts of mSUGRA parameter space will be greater when searching with the like-sign dilepton final state than the trilepton final state [2].

II. DATA SET

We analyze data from the DØ Run II data set reconstructed with the latest version of the reconstruction code. We examine events triggered by dimuon triggers, with no trigger p_T cut.

The total integrated luminosity of the data sample after removal of questionable quality runs and passing our triggers corresponds to 147 ± 10 pb^{-1}.

Muons are required to be reconstructed in the muon system and matched to central tracks. In addition, they must be isolated from energy in the calorimeter and from nearby tracks in the central tracking system. The hollow cone energy, or energy measured in the calorimeter in the annulus between 0.1 and 0.4 centered around the muon, must be less than 2.5 GeV. The scalar sum of the transverse momenta of all tracks contained within a cone of radius 0.5 around the muon (excluding the track matched to the muon) must be less than 2.5 GeV/c.

III. DØ DETECTOR

The DØ detector is comprised of the following main elements. A magnetic central-tracking system, which consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located within a 2 T superconducting solenoidal magnet [3]. The SMT has $\approx 800,000$ individual strips, with typical pitch of $50 - 80$ μm, and a design optimized for tracking and vertexing capability at $|\eta| < 3$. The system has a six-barrel longitudinal structure, each with a set of four layers arranged axially around the beam pipe, and interspersed with 16 radial disks. The CFT has eight thin coaxial barrels, each supporting two doublets of overlapping scintillating fibers of 0.835 mm diameter, one

doublet being parallel to the collision axis, and the other alternating by $\pm 3^\circ$ relative to the axis. Light signals are transferred via clear light fibers to solid-state photon counters (VLPC) that have ≈ 80 % quantum efficiency.

Central and forward preshower detectors located just outside of the superconducting coil (in front of the calorimetry) are constructed of several layers of extruded triangular scintillator strips that are read out using wavelength-shifting fibers and VLPCs. The next layer of detection involves three liquid-argon/uranium calorimeters: a central section (CC) covering $|\eta| < 1$, and two end calorimeters (EC) extending coverage to $|\eta| < 4.0$, all housed in separate cryostats [4]. In addition to the preshower detectors, scintillators between the CC and EC cryostats provide sampling of developing showers at $1.1 < |\eta| < 1.4$.

A muon system resides beyond the calorimetry, and consists of a layer of tracking detectors and scintillation trigger counters before 1.8 T toroids, followed by two more similar layers after the toroids. Tracking at $|\eta| < 1$ relies on 10 cm wide drift tubes [4], while 1 cm mini-drift tubes are used at $1 < |\eta| < 2$. Coverage for muons is partially compromised in the region of $|\eta| < 1$ and $|\phi| < 0.2$ rad, where the calorimeter is supported mechanically from the ground.

Luminosity is measured using plastic scintillator arrays located in front of the EC cryostats, covering $2.7 < |\eta| < 4.4$. A forward-proton detector, situated in the Tevatron tunnel on either side of the interaction region, consists of a total of 18 Roman pots used for measuring high-momentum charged-particle trajectories close to the incident beam directions.

The trigger and data acquisition systems are designed to accommodate the large luminosity of Run II. Based on preliminary information from tracking, calorimetry, and muon systems, the output of the first level of the trigger is used to limit the rate for accepted events to ≈ 1.5 kHz. At the next trigger stage, with more refined information, the rate is reduced further to ≈ 800 Hz. These first two levels of triggering rely purely on hardware and firmware. The third and final level of the trigger, with access to all the event information, uses software algorithms and a computing farm, and reduces the output rate to ≈ 50 Hz, which is written to tape.

IV. BACKGROUND

Not many Standard Model processes are capable of generating a pair of isolated like-sign muons. The physics background processes that we consider are $t\bar{t}$, $b\bar{b}/c\bar{c}$, W+jets, and di-boson production (WZ and ZZ). These backgrounds are modeled with Monte Carlo samples, with the exception of the $b\bar{b}/c\bar{c}$ background. The PYTHIA [5] event generator and the full DØ simulation and reconstruction software chain were used for the samples with the exception of W+jets, for which the ALPGEN [6] generator was used.

A. Background from $b\bar{b}/c\bar{c}$

We expect the largest source of like-sign dimuon pairs to be $b\bar{b}$ and $c\bar{c}$ production. We estimate this background using data. Our method relies on finding a collection of events which contain muons similar to those that will be present in the sample in which we will look for our signal. We find this collection by looking for like-sign pairs of muons where one muon passes our isolation cuts, and one muon fails our isolation cuts by a small margin. The failing muon will be nearly isolated. That is, if a muon fails the isolation criteria by a small amount, it will resemble an isolated muon more closely than one that failed the criteria by a large amount. A muon is "nearly" isolated if the muon fails at least one of our isolation criteria, its hollow cone energy is less than 7 GeV, and the p_T sum of all tracks within a cone of radius 0.5 (excluding the track matched to the muon) is less than 7 GeV/c.

The number of events in our nearly isolated sample is scaled to the isolated sample to accurately predict the number of events. This scaling is done using an event sample dominated by the $b\bar{b}/c\bar{c}$ background, which is those events where $\Delta\phi(\mu,\mu) > 2.7$. We then make the cut of $\Delta\phi(\mu,\mu) < 2.7$ one of our final cuts on the data to avoid bias due to normalizing to the data.

Once we have this sample, we can test its ability to mimic isolated muons from $b\bar{b}/c\bar{c}$ by looking at the opposite-sign (OS) dimuon invariant mass distribution. The isolated muons from $b\bar{b}/c\bar{c}$ contained in this sample should be similar to those in the like-sign sample. The normalization will be different. We first subtract the Drell-Yan, Z, and Upsilon backgrounds as predicted by the Monte Carlo from the opposite-sign distribution. We should be left with the opposite-sign, isolated muon pairs from $b\bar{b}/c\bar{c}$. We would like to compare our scaled, like-sign, nearly isolated sample to this one since they should be similar. The number of events in each sample will be different. We scale the like-sign, nearly isolated sample by the ratio of the number of entries remaining in the opposite-sign data sample after background subtraction to the number of events in the like-sign, nearly isolated sample. Figure 2 shows the opposite-sign, isolated data, and the various backgrounds, including the $b\bar{b}/c\bar{c}$ background estimate obtained from data as discussed here.

Figure 3 shows the like-sign isolated data (the sample which may contain a signal) compared to the estimation from the scaled nearly isolated sample.

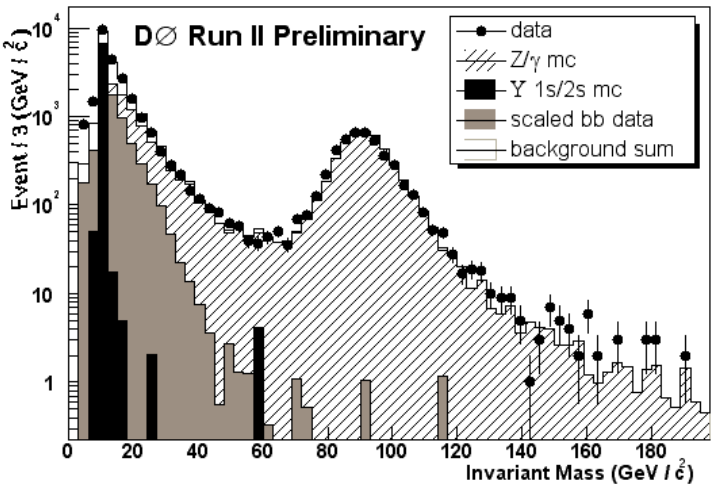

FIG. 2: Data points show the invariant mass distribution of opposite-sign muon pairs.

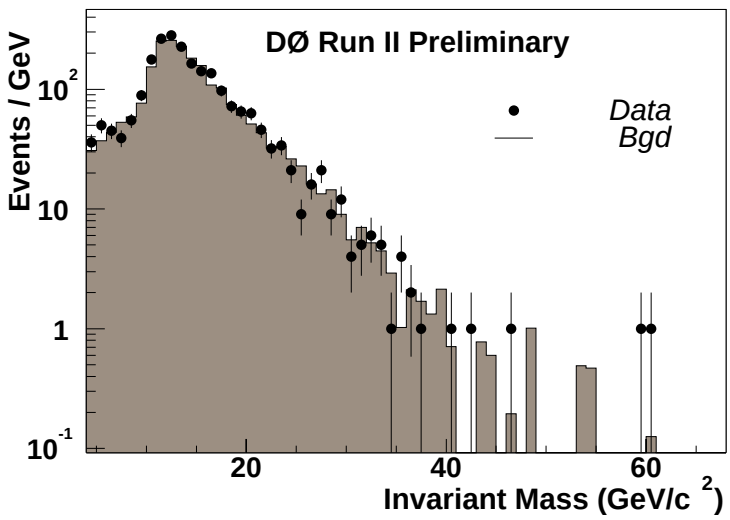

FIG. 3: Data points show the invariant mass distribution of isolated like-sign muon pairs. This is the sample which may contain signal. The shaded histogram is the expected remaining background, from $b\overline{b}/c\overline{c}$, which is estimated using the nearly isolated like-sign data as described in the text.

B. Sign Misidentification Background

Another possible source of like-sign dimuon pairs is mismeasurement. If the p_T of the muon is badly mismeasured, the charge assigned to the muon can be wrong. This can turn an opposite-sign pair into a like-sign pair. Since this analysis depends upon the proper determination of the sign of each muon, an estimate of the sign misidentification rate is necessary. The sign misidentification rate is included in background estimates from Monte Carlo samples.

Monte Carlo and data studies agree that most of the charge misidentification comes from pairs with $\Delta\phi(\mu,\mu) > 2.7$. Thus, the requirement of $\Delta\phi(\mu,\mu) < 2.7$ used to cut the $b\overline{b}$ background will also be effective against this background.

As a check, like-sign pairs with each muon having a p_T greater than 15 GeV/c and with a phi difference greater than 2.8 can be chosen from the Z Monte Carlo and data. We expect these pairs to each contain a muon from a Z decay with its charge mismeasured. Although the statistics are low, there is reasonable agreement with 4 events in data and 3.4 events in Monte Carlo.

Sample	Background	Data
Initial	2189.1 ± 31	2275
$\Delta\phi(\mu,\mu)$	1216.6 ± 23	1279
$p_T > 11$	63.9 ± 4.0	47
MET > 15	20.8 ± 2.1	16
$\Delta\phi(\mathrm{Jet},\mathrm{MET})$	3.74 ± 0.85	4
$\Delta\phi(\mu,\mathrm{MET})$	0.58 ± 0.20	1
LS InvMass	0.16 ± 0.06	1
OS InvMass	0.13 ± 0.06	1

TABLE I: Number of events in data and expected from the sum of all backgrounds after applying each cut.

V. ANALYSIS CUTS

The final analysis cuts are:

- Events must have two track-matched, like-sign muons.
- Both muons must be isolated.
- Both muons must have $p_T > 5$ GeV/c.

This defines our initial data set, part of which is used to predict the background. We then apply the following set of cuts:

- The distance in ϕ between the two muons must be less than 2.7.
- Leading muon $p_T > 11$ GeV/c.
- Missing $E_T > 15$ GeV/c.

If the second muon has a $p_T < 11$ GeV, we look at the separation in ϕ between missing E_T and the muons, and missing E_T and jets. We call $\Delta\phi_{\min}(\mathrm{MET},\mu)$ the separation between the muon closer to the MET, and $\Delta\phi_{\max}(\mathrm{MET},\mu)$ the separation for the muon further away. If there are jets in the event, we look at the $\Delta\phi(\mathrm{Jet},\mathrm{MET})$ between each jet and the MET. We expect these low p_T events to come mostly from $b\bar{b}$ and have muons and jets aligned with MET from the neutrino. We introduce the cuts:

- $\Delta\phi(\mathrm{Jet},\mathrm{MET})) < 2.4$.
- $\Delta\phi_{\min}(\mathrm{MET},\mu) > 0.5$ and $\Delta\phi_{\max}(\mathrm{MET},\mu) < 2.4$.

These two cuts are only applied if the p_T of the second leading muon is less than 11 GeV.
The final two cuts are:

- Invariant mass of opposite-sign muon pairs $M(\mu,\mu) < 70$ GeV/c or $M(\mu,\mu) > 110$ GeV/c. This rejects background events containing Z which come from WZ, ZZ and Z/γ.
- Invariant mass of like-sign muon pairs $M(\mu,\mu) < 80$ GeV/c. This rejects background events containing Z where a charge flip occurred for one of the muons.

The effect of these cuts on our background and data samples is shown in Table I. After all cuts, the remaining backgrounds are from WZ(0.07), $b\bar{b}$(0.04), and ZZ(0.02).

VI. RESULTS

We see one event passing our cuts in the data where we expect 0.13 ± 0.04 from the background. Three event displays of the one event in the data are shown in Figures 4, 5, and 6. The event has two tight muons, MET=33.5 GeV, LS mass=37.8 GeV/c^2, and$\Delta\phi(\mu,\mu)$ =1.5. The muon kinematic values are in Table II.

Our signal monte carlo shows that we expect between 0 and 0.4 events from signal for SUSY points around the LEP limits. Table III shows the parameter values for selected SUSY points, and Table IV shows the expected number of events for each of these points. This channel has been combined with other channels to gain sensitivity to these points. Limits have been set based on this combination.

Muon	E	p_T	px	py	pz	eta	phi	charge
Muon 1	14.1	13.8	12.5	5.8	-2.6	-0.19	0.43	+
Muon 2	62.2	29.1	-10.9	26.9	-55.0	-1.39	1.96	+

TABLE II: Table showing the kinematic values for the two muons in run 177010, event 44096517.

Point	m_0	$m_{1/2}$	tanβ	sign(μ)	A_0	$m_{\chi_2^0}$	$m_{\chi^\pm}$	$m_{\tilde{l}_R}$	$m_{\tilde{\tau}_1}$	$m_{\chi_1^0}$	$\sigma \times BR$ (pb)
SUSY 1	72	165	3	+	0	102	97	102	101	57	0.39
SUSY 2	74	168	3	+	0	104	100	104	103	58	0.35
SUSY 3	76	170	3	+	0	106	101	106	105	59	0.32
SUSY 4	80	175	3	+	0	110	105	110	109	62	0.27
SUSY 5	84	180	3	+	0	114	110	114	113	64	0.21
SUSY 6	88	185	3	+	0	118	114	118	117	67	0.18

TABLE III: Table showing the mSUGRA parameter values for the 6 representative SUSY points, including $\sigma \times BR$ into three leptons.

Acknowledgments

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the Department of Energy and National Science Foundation (USA), Commissariat à L'Energie Atomique and CNRS/Institut National de Physique Nucléaire et de Physique des Particules (France), Ministry for Science and Technology and Ministry for Atomic Energy (Russia), CAPES, CNPq and FAPERJ (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), The Foundation for Fundamental Research on Matter (The Netherlands), PPARC (United Kingdom), Ministry of Education (Czech Republic), Natural Sciences and Engineering Research Council and West-Grid Project (Canada), BMBF (Germany), A.P. Sloan Foundation, Civilian Research and Development Foundation, Research Corporation, Texas Advanced Research Program, and the Alexander von Humboldt Foundation.

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Sample	SUSY 1	SUSY 2	SUSY 3	SUSY 4	SUSY 5	SUSY 6
Events Expected	0.389 ± 0.083	0.360 ± 0.077	0.368 ± 0.077	0.291 ± 0.063	0.159 ± 0.039	0.243 ± 0.051

TABLE IV: Number of events expected from each SUSY point. Errors are in parenthesis.

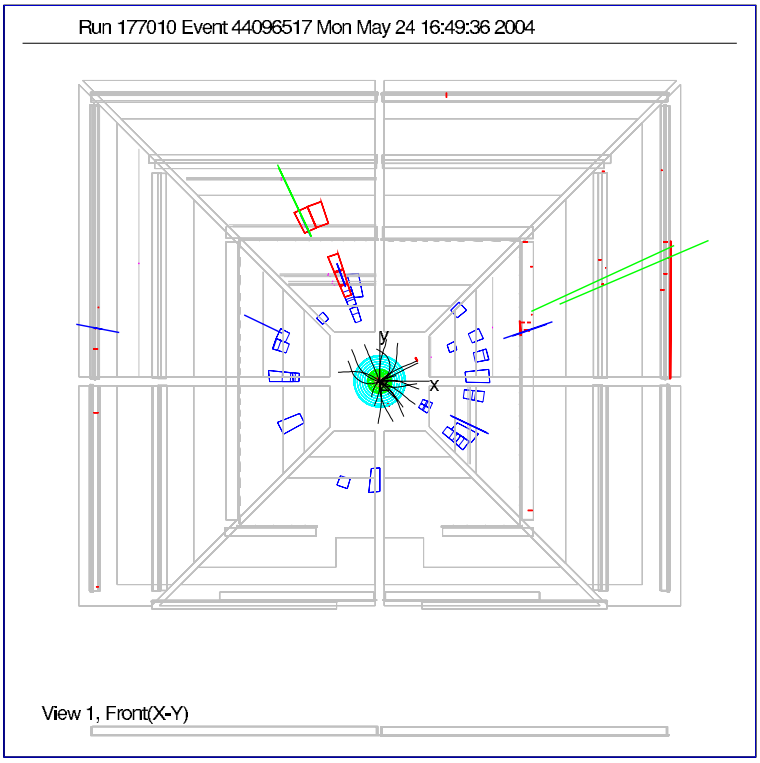

FIG. 4: Event display of event 44096517 from run 177010.

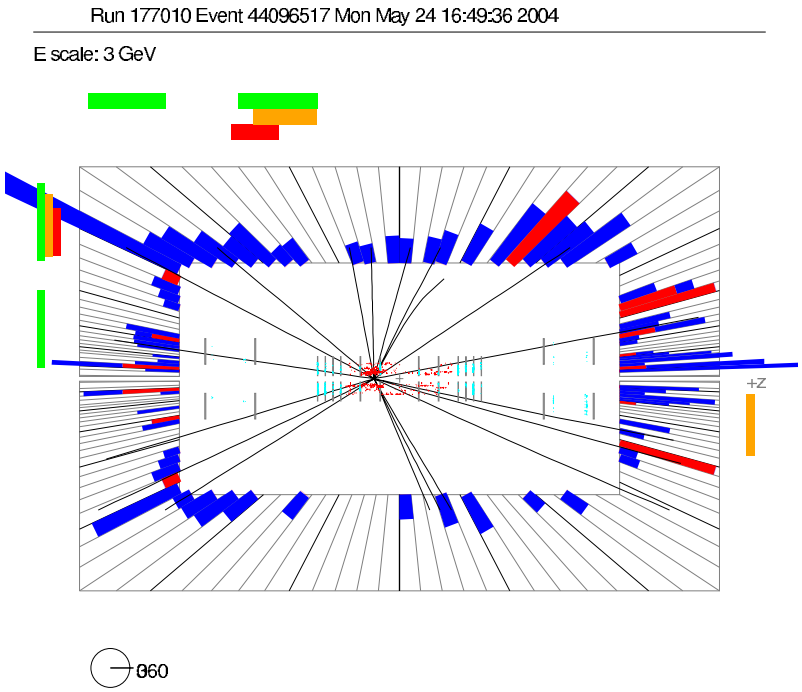

FIG. 5: Event display of event 44096517 from run 177010.

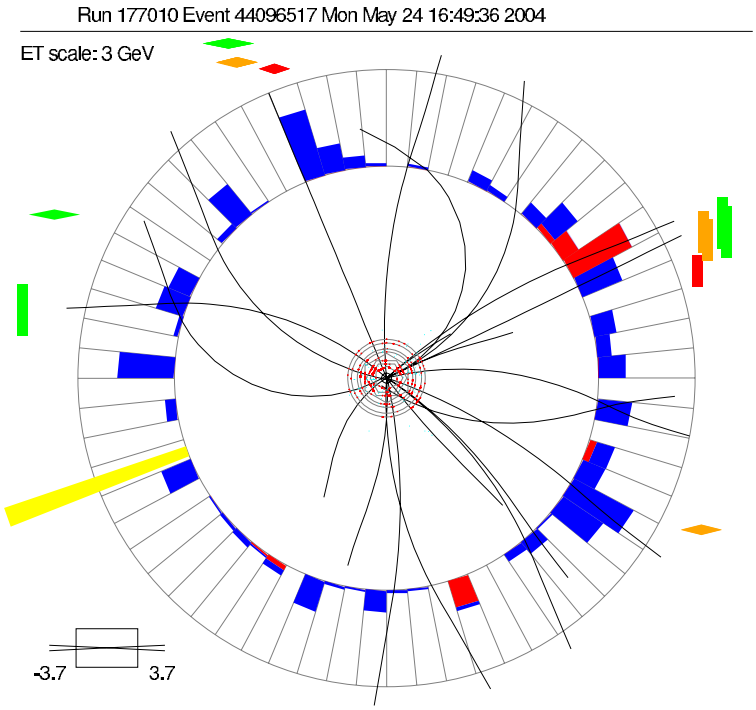

FIG. 6: Event display of event 44096517 from run 177010.