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Search for GMSB SUSY in Diphoton Events with Large Missing Et

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We report a search for GMSB SUSY in approximately 185 pb^{-1} of Run II data in diphoton final state. No excess of events was found and a lower limit on the lightest neutralino (chargino) mass of about 105 (180) GeV was set.

Preliminary Results for Winter 2004 Conferences

I. PHYSICS MOTIVATION

Models with Gauge Mediated SUSY breaking drew a lot of attention after CDF found the famous $ee\gamma\gamma\not{E}_T$ event [1]. The phenomenology of these models is strikingly different from gravity mediated SUSY, which is in part why interest in them outlived the GMSB SUSY interpretation of that CDF event.

Current exclusions interpreted as lower limit on neutralino mass are 65, 75 and 100 GeV from CDF [1], DØ [2] and combined LEP [3].

The model line that we are interested in is GMSB with neutralino NLSP. The line has one dimensionful parameter, Λ which determines the scale of SUSY breaking. The minimal GMSB parameters then are messenger mass scale $M = 2 \cdot \Lambda$, number of messengers $N_5 = 1$, ratio of Higgs vev's $tan\beta = 5$ and the sign of Higgsino mass term $\mu > 0$.

The lifetime of the neutralino is not fixed by the model, but we assume it is short enough so that it decays well inside the calorimeter. It mostly decays into a photon and a gravitino, but decays into a Z and gravitino are also possible. For non-negligible lifetimes, pointing of EM clusters using preshowers become important. One can look for detached photons in photon plus jets final state and for Z's detached from the primary vertex. Estimates suggest that cluster pointing does not significantly increase discovery potential in a diphoton final state, though it is certainly essential for neutralino lifetime measurement if it's discovered.

II. ANALYSIS OVERVIEW

All SM sources of events with two photons and large missing transverse energy (MET) can be divided into ones where MET is due to mis-measurement:

- QCD with direct photons or jets misidentifies as photons (dominant);
- Drell-Yan with both electrons mis-identified as photons;

and with true MET:

- $W\gamma \longrightarrow e\nu\gamma$ (dominant)
- $Wj \longrightarrow e\nu$ "γ"
- $Z \longrightarrow \tau\tau \longrightarrow ee\ + X$
- $t\bar{t}$, WW, WZ, etc.

For the QCD background the idea is that missing E_T resolution should be very similar for events with photons and with jets faking photons, since a jet that fakes a photon fragments into one or a few π^0's. Therefore one can obtain a conservative estimate of QCD background by extracting a shape of missing E_T distribution from a sample in which at least one EM cluster fails ID cuts (it is important, however, to keep isolation and EM fraction cuts close to the certified EM ID), as this sample should have much smaller fraction of events coming from non-QCD processes. We estimate total QCD background by assuming that all diphoton events with small MET are coming from QCD and use the measured shape to predict QCD background at high values of MET.

Drell-Yan can be suppressed by matching track veto. Since DY events do not have any true missing E_T they look exactly like QCD, so their contribution is subtracted automatically when QCD subtraction is done.

All SM backgrounds with true missing E_T involve electrons and not photons, so they are reduced by the matching track veto. The yield of these backgrounds can be measured using an electron-photon sample. After QCD subtraction (done in exactly the same way as for $\gamma\gamma$ sample) the observed number of electron-photon events is multiplied by ratio of probabilities for electron to be identified as an electron and as a photon to obtain the contribution to the diphoton sample. These probabilities are measured using the data.

III. OBJECT IDENTIFICATION

A. EM ID

We used standard DZero EM ID definitions. EM clusters were required to be in the central calorimeter and have isolation less than 0.15 and EM fraction of more than 0.90 and have the seven-variable H-matrix χ^2 less than 15.

Identification efficiency was determined from Z events to be 0.927 ± 0.002. The total di-em efficiency is then

$$\epsilon_{diEM} = 0.859 \pm 0.004 \quad (1)$$

The electron energy after geometry and scale corrections was required to be greater than 20 GeV. These corrections are small and are verified using Monte Carlo and measured Z mass.

EM cluster was considered an electron if there was a track with spatial only χ^2 match probability to the EM cluster greater than 10^{-3}, and a photon otherwise. The efficiency of such track matching is

$$\epsilon_{trk} = 0.942 \pm 0.003 \quad (2)$$

We also used track isolation. The scalar sum of p_T of all tracks with z_{DCA} within 2 cm of the primary vertex in a hollow cone ($0.05 < R < 0.4$) around photon candidate was required to be less than 2 GeV.

To check if the track isolation is described by the MC we determined its efficiency using $Z \longrightarrow ee$ signal in data and in MC, and found them consistent within errors.

A photon can be misidentified as electron if it converts close to the interaction point and an electron from conversion is reconstructed, or if a random track overlaps with it. The latter effect is very small (about 0.003). The former was taken from the MC simulation. To correct for possible underestimation of the detector material in the MC we apply additional inefficiency for a photon pair reconstruction of 0.97 ± 0.02.

B. Jets and Missing E_T

While jets are not explicitly required in this analysis they are important for correct MET calculation. Jets are reconstructed in a 0.5 cone and their energy is corrected for jet energy scale if they passed standard DZero quality cuts. Missing Et was calculated using cells above 0. Only coarse hadronic (CH) cells belonging to cone 0.5 jets were used in the calculation.

We also rejected events which had correlated calorimeter noise flag set, or had sum of Et of all "bad" jets greater than 30 GeV. This removes about 3% of events. We checked that the rejection fraction does not depend on the sample (i.e. $Z \longrightarrow e^+e^-$ v.s. QCD). We assigned it efficiency of 0.97 ± 0.02.

IV. DATA ANALYSIS

A. Triggers

We use EM_MX_SH, 2EM_HI and 2EM_HI_SH triggers for trigger lists versions 11 and below, and Ex_SHT20, Ex_2SH8, Ex_2L15_SH15 where x is 1, 2 or 3 for version 12. Trigger studies in data and MC simulations show that trigger efficiency for events with two photons above 20 GeV is 0.97 ± 0.01.

Data sample includes all the data except a few (about 60) runs with anomaly high fraction of events with missing E_T, and runs in range 157K - 162K which suffer from calorimeter timing problem. The total luminosity is estimated to be 185 ± 10 pb^{-1}.

B. Diphoton Events

We select events with two EM clusters passing ID cuts described in section III A with $E_T > 20$ GeV within $|\eta_{det}| < 1.1$. There are also two topological cuts that were devised using a QCD background sample (described in a section below) to minimize MET resolution and non-gaussian tails from catastrophic mis-measuremenst and wrong primary vertex selection.

- the azimuthal opening angle between direction of missing E_T and the leading jet should be less than 2.5 radians. SUSY signal has a uniform opening angle distribution, while the background is highly peaked at π due to jet mismeasurement
- the azimuthal opening angle between direction of missing E_T and both photons should be at least 0.5 radians.

These selections yield 1308 events. The MET distribution for these events is shown in figure 1. Table I shows event counts for different MET regions.

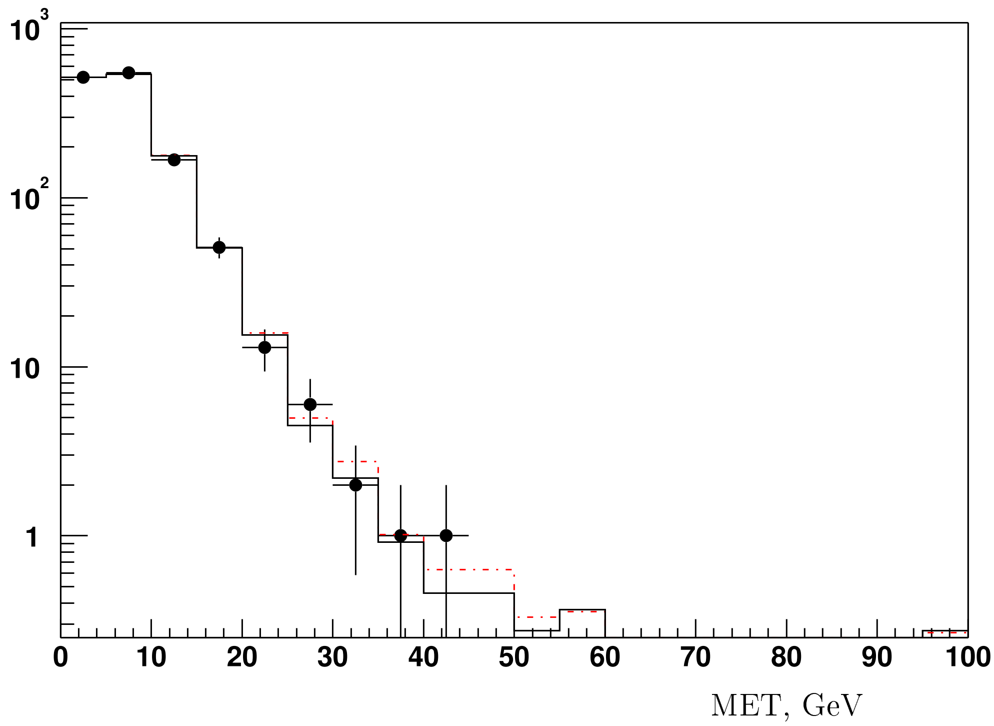

FIG. 1: MET distribution in the di-photon sample after all cuts (points). Solid black istogram is QCD background, dashed red histogram is the total estimated backgound.

C. QCD Background

The sample of QCD events which is expected to have similar MET resolution was selected from the same starting dataset, using the same kinematic and cuts as for di-photon sample. The photon candidates were required to have seven variable H-matrix χ^2 greater than 20 and eight variable H-matrix less then 200 (last cut is needed to synchronize with the algorithm of removal of good EM objects from jets in d0correct), isolation less than 0.15, and EM fraction above 0.9.

The resulting QCD sample is comprised of 14324 events (see figure 1). We use the number of events with MET$<$ 15 GeV in the QCD and diphoton sample to predict QCD background rates for high MET. The estimates are shown in table I.

D. Electron Background

Though high E_T cuts and selection of central photons should suppress the largest source of the electron background $W(e\nu)$ γ, we tried to determine it's contribution from data.

Electron plus photon sample was selected from the same starting sample using the same cuts as for di-photons, except that exactly one of the EM clusters was required to have a matched track and satisfy electron track isolation.

There are 608 events, most of them coming from the QCD background. The latter was determined using same method as for di-photons (see table I). To estimate electron background to the $\gamma\gamma$ sample we multiplied the number of observed $e\gamma$ events by $(1-\epsilon_{trk})/\epsilon_{trk}$, where ϵ_{trk} is the track matching efficiency.

The sum of the electron and the QCD backgrounds is shown in figure 1 in dashed red histogram.

V. SUSY SIMULATION

To estimate the acceptance of the event kinematics cuts we used MC for several model points. The single largest contribution to the cross-section for all of the points is second neutralino-first chargino and first chargino pair pro-

TABLE I: The event counts in the $\gamma\gamma$, $e\gamma$ and QCD samples, and determination of the total background to di-photon sample.

	Total events	$MET < 15$ GeV	> 20 GeV	> 25 GeV	> 30 GeV	> 35 GeV	> 40 GeV	> 45 GeV	> 50 GeV	> 55 GeV
$\gamma\gamma$	1308	1234	23	10	4	2	1	0	0	0
$e\gamma$	608	543	44	30	20	10	8	5	2	1
QCD	14324	13492	275	106	57	33	23	18	13	10
QCD BG to $\gamma\gamma$			25.2 ± 1.7	9.7 ± 1.0	5.2 ± 0.7	3.0 ± 0.5	2.1 ± 0.4	1.7 ± 0.4	1.2 ± 0.3	0.9 ± 0.3
QCD BG to $e\gamma$			11.1 ± 0.8	4.3 ± 0.5	2.3 ± 0.3	1.3 ± 0.2	0.9 ± 0.2	0.7 ± 0.2	0.5 ± 0.2	0.4 ± 0.1
$e\gamma$ total			32.3 ± 6.7	25.7 ± 5.5	17.7 ± 4.5	8.7 ± 3.2	7.1 ± 2.8	4.3 ± 2.2	1.5 ± 1.5	0.6 ± 1.0
$e\gamma$ BG to $\gamma\gamma$			1.7 ± 0.3	1.3 ± 0.3	0.9 ± 0.2	0.4 ± 0.2	0.4 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
Total BG to $\gamma\gamma$			26.8 ± 1.7	11.0 ± 1.0	6.1 ± 0.7	3.5 ± 0.6	2.5 ± 0.5	1.9 ± 0.4	1.3 ± 0.3	0.9 ± 0.3

TABLE II: Points on the Snowmass slopes and their cross-section and efficiencies. The efficiency does not include reconstruction efficiency of 0.80 ± 0.04.

Λ, TeV	$tan\beta$	$m_{\chi_1^0}$, GeV	$m_{\chi_1^+}$, GeV	σ_{TOT}^{LO} , pb	k-factor	Acceptance for given MET cut, %					
						25	30	35	40	45	50
55	5	69.4	122.0	0.860	1.24	16.2	14.5	13.3	11.7	9.80	8.45
60	5	77.0	136.2	0.532	1.23	17.2	15.9	14.6	13.2	11.2	10.1
65	5	84.5	153.1	0.339	1.22	19.3	18.1	16.8	15.6	13.6	12.4
70	5	92.0	165.0	0.225	1.21	21.8	21.0	20.0	18.5	17.0	15.5
75	5	99.5	179.2	0.151	1.20	22.8	21.7	20.6	19.7	18.3	17.3
80	5	106.8	193.1	0.103	1.19	22.0	21.3	20.5	19.5	18.3	17.2
85	5	114.2	207.2	0.071	1.18	21.2	20.0	19.4	18.1	17.1	16.7

duction. The MC events were processed through the full detector simulation, reconstructed and processed with the same analysis program as real data.

The missing E_T distribution for some of the points is shown in figure 2.

The SUSY cross-sections and efficiency to pass the kinematic cuts are presented in the table II. The total cross-section in the table is a leading order Pythia cross-section. The k-factor should be applied to get an NLO cross-section. The values of the k factor in the table were taken from [4]. Note that the efficiencies of the EM ID (1) and noise veto are not included in the table.

VI. LIMIT CALCULATION

We determined the optimal value of the MET cut using predicted background and MC signal, optimizing for significance. The optimal cut is 40 GeV.

The limits were set using web-based realization of prescription of [5] (uses Bayesian approach) and are shown in table III and in figure 3. The limit is $\Lambda > 78.8TeV$, or in terms of gaugino masses, $m_{\chi_1^0} > 105GeV$ and $m_{\chi_1^+} > 180GeV$ (see figure 3).

The error on total efficiency comes from event reconstruction efficiency (5%), luminosity error (6.5%) and MC acceptance (6%). We tested how strong the resulting limits depend on acceptance error, by increasing the MC acceptance error to 20%. The limits on cross-section become about 11% worse, shifting a limit on neutralino mass by about 1.5 GeV.

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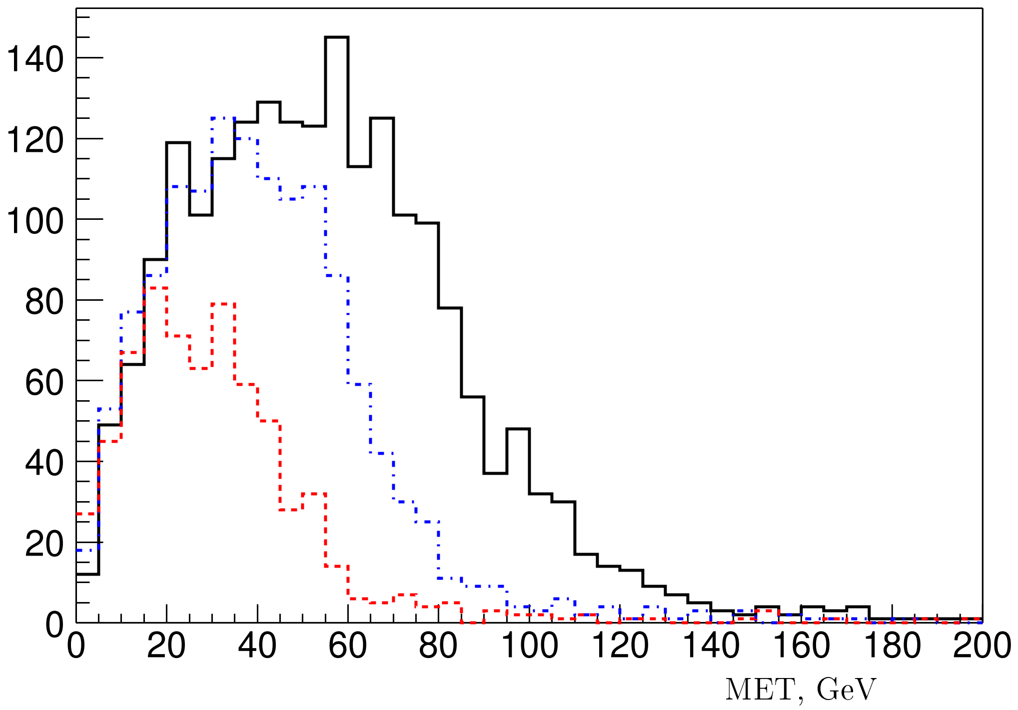

FIG. 2: MET distributions for SUSY events ($tan\beta$ = 15, Λ = 35, 45 and 60 TeV) passing kinematic cuts. Normalization is arbitrary.

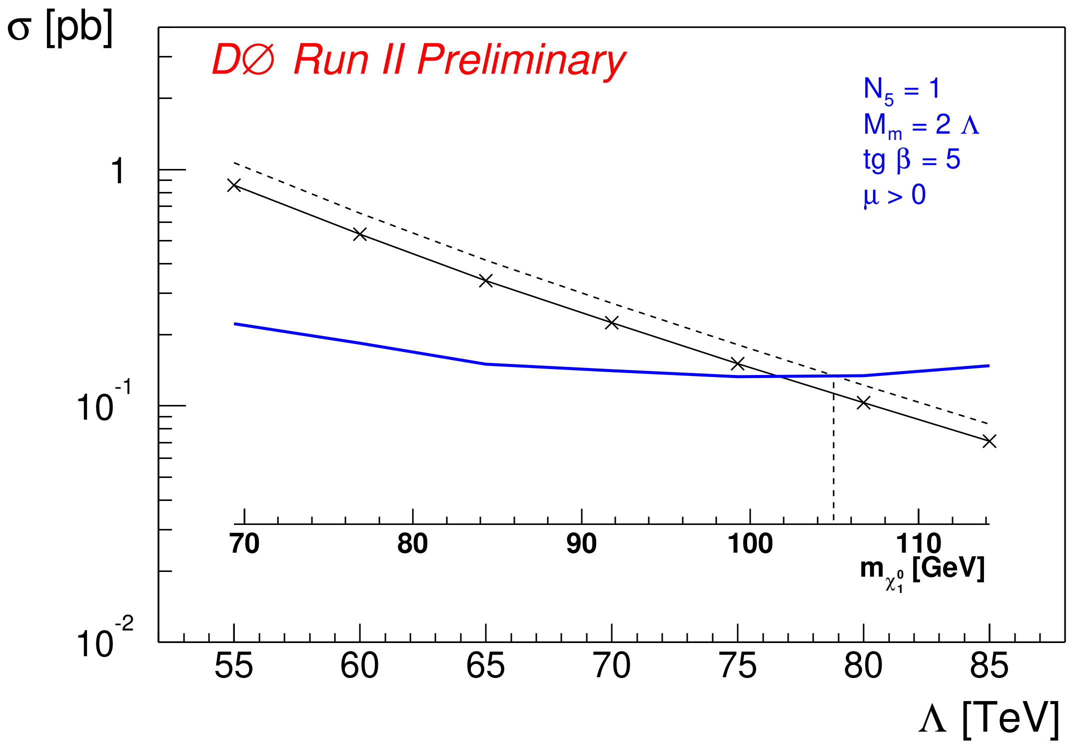

FIG. 3: GMSB cross-section v.s.Λ in LO (black line), multiplied by k-factor (dashed line) and 95 percent CL limits.

TABLE III: The cross-section limits for the SUSY points.

Λ, TeV	95% CL limit on cross-section $tan\beta = 5$
55	0.223
60	0.184
65	0.150
70	0.141
75	0.133
80	0.134
85	0.148

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