RECENT NEW PHENOMENA RESULTS FROM THE D0 EXPERIMENT

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Abstract

Results are described from seven analyses from the New Phenomena group in the D0 experiment, using datasets of 30-50 pb^{-1} of data collected in Run II of the Fermilab Tevatron, at a center-of-mass energy of 1.96 TeV. These analyses are: a search for charginos and neutralinos in the trilepton channel; a search for GMSB SUSY in the 2 γ + missing $\mathrm{E_T}$ channel; a search for SUSY in the jets + missing $\mathrm{E_T}$ channel; a search for new physics in the e-μ channel; a search for leptoquarks in the muon + jets channel; and searches for extra dimensions with dielectrons, diphotons, and dimuons. Also presented are two searches for the Z resonance in τ-τ decays.

1 Introduction

The D0 experiment at the the Fermilab Tevatron is now analyzing first results from a number of searches for phenomena outside the standard model, using data collected from Run II at 1.96 TeV in the center of mass. These results are beginning to rival Run I results in sensitivity, and are clearly demonstrating the physics capabilities for D0 in Run II. As part of this demonstration, we also describe in this article the emerging evidence for Z decaying to τ pairs, which will be a significant Standard Model channel against which to benchmark various New Phenomena searches.

2 Z $\rightarrow \tau$-τ analyses

Taus are often a significant part of the phenomenology of theories beyond the Standard Model. In Higgs searches, SUSY searches via trileptons, and in third generation leptoquark searches, detection of τs is important. However, we need a Standard Model channel to give confidence in our modeling and detection efficiencies. Two searches at D0 are seeing evidence for the decay Z $\rightarrow \tau$-τ, for the first time at the Tevatron.

The first analysis searches for the mode in which one τ has decayed to an electron, and the second τ has decayed hadronically. A collinear approximation is used to calculate the τ-τ invariant mass. First, a preselection is made of a sample containing a good electron with $\mathrm{E_T} > 12$ GeV and a jet which is a τ candidate (a very loose requirement).

The daughter particles from the τ (the jet and electron) are assumed to give the τ direction. The measured missing $\mathrm{E_T}$ is used to project the neutrino momentum along the τ direction. This approximation will have reasonable resolution only because of the application of a cut in $\Delta\phi$, excluding the region $3.0 < \Delta\phi < 3.3$.

Other cuts are applied for background rejection : $M_T(\mathrm{e}\nu) < 60$ GeV and $\mathrm{M(e}\tau) < 60$ GeV. Neural nets are used to further tighten the τ ID of the jet candidate. Different nets are used for $\tau \rightarrow \pi^{\pm}\ \nu$ (type 1)and $\pi^{\pm}\ \pi^{0}\ \nu$ (type 2); three prong decays are not included. The distributions of τ candidates in the data and of τ signal Monte Carlo in the neural net variables are shown in Fig. 1. The cut requires the NN output to be > 0.95.

A like sign sample with the same cuts is used as an estimator of the background. The subtracted distribution of opposite sign events minus like sign events in the τ-τ invariant mass is shown, compared with the signal Monte Carlo, in Fig. 2. The number of events in the distributions is given in Table 1.

The second Z to τ-τ analysis utilizes the channel when one τ decays to a muon, and the other hadronically. For this analysis, the sample contains a central, isolated muon with tight quality cuts and $p_T > 7$ GeV, and a jet flagged as a τ candidate with $\mathrm{E_T} > 15$ Gev. The τ candidate jet must have

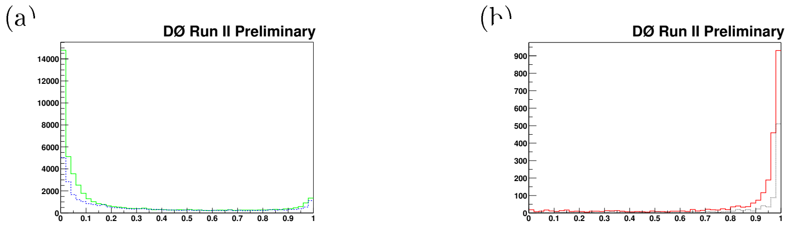

Figure 1: (a) The distribution of the neural net outputs for τ candidates in the data, for the two types of one-prong event (type 1 dotted and type 2 solid). (b) The distribution of the neural net outputs for τ candidates in the signal Monte Carlo, for the same two types.

Table 1: *Number of events from the $\tau\tau$ invariant mass distributions.*

Data	
No. Opposite sign events	49
No. Like sign events	35
Difference	14 ± 9
$\tau\tau$ MC norm. to $50pb^{-1}$	13 ± 4

a single matching isolated central track. The muon and τ are required to be separated in ϕ by at least 2.5 radians.

A quantity called the profile can be used to help distinguish τs from QCD background. The profile is defined as the sum of the two leading E_T towers divided by the total E_T for the τ candidate jet. In order to extract a signal, the 2-dimensional distributions of profile vs isolation are formed for opposite and like sign events in the sample. The subtracted distribution should contain the $Z \to \tau\ \tau$ signal. These distributions are shown in Fig. 3.

3 Chargino-Neutralino search

For the first of the SUSY searches reported here, an analysis is performed within the mSUGRA framework to look for chargino-neutralino pair prodcution with both SUSY particles decaying leptonically. The channel searched for is 2 electrons + a third lepton (identified with an isolated high p_T track) + missing E_T. The luminosity of the sample which was examined was 40 pb^{-1}.

The sample is taken from both single and dielectron triggers. The selection asks that the standard EM ID cuts on each electron be satisfied; that they have $E_T > 15$ GeV and 10 GeV respectively; and that both have a matching

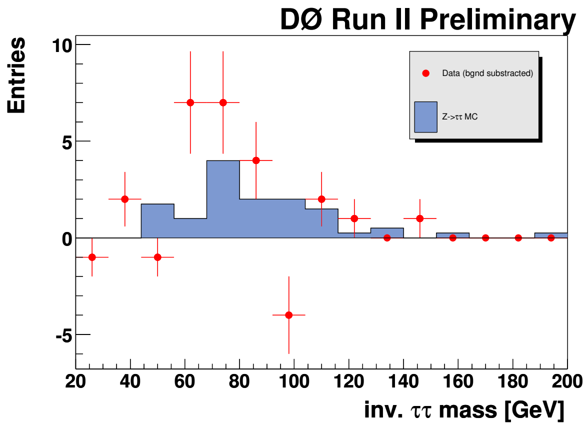

Figure 2: *Distribution vs $\tau\tau$ invariant mass of opposite sign events minus like sign events, from the data (shown as points with errors), compared with the signal Monte Carlo (shown as a filled histogram).*

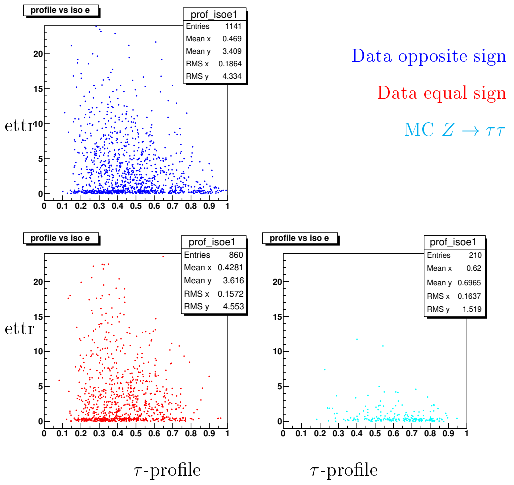

Figure 3: *Distribution of profile vs isolation for opposite sign data, like sign data, and $Z \to \tau\tau$ Monte Carlo.*

Table 2: *Comparison of background with data in chargino-neutralino search.*

	Total Background	Data
ID + kinem + trk	3216 ± 43	3132
$10 < M_{ee} < 70GeV$	660 ± 19	721
$M_T > 15GeV$	96 ± 8	123
3rd trk	3.2 ± 2.3	3
$ME_T > 15GeV$	0.0 ± 1.4	0

central track. Further cuts imposed are 10 GeV $< M_{ee} <$ 70 GeV, and $M_{T(e\nu)}$ $>$ 15 GeV. The requirement of an additional track with $p_T > 5$ GeV, well isolated in both ϕ and η from the other two leptons, and with $\eta < 3$, completes the specification of the trilepton sample. Background estimates are made from two kinds of source: Standard Model processes with real missing $\mathrm{E_T}$, and QCD background with fake missing $\mathrm{E_T}$ from measurement errors. The first type of source is estimated with PYTHIA followed by a full detector simulation, for all contributing processes. The second source is estimated from data using samples with inverted ID cuts. Table 2 shows the number of events in the total background and in the data at each successive stage of the application of cuts. The final entry describes the complete set of cuts, which results in no events in data or in the background estimate. From this analysis, we can not yet exclude the two mSugra points which were simulated for the signal. The cross section $\times$ branching ratio exclusion level was 3.5(2.4) pb^{-1} for the efficienies at the simulated small (large) mSugra mass points.

4 GMSB SUSY Search

The second SUSY search is looking in the 2γ + missing $\mathrm{E_T}$ channel for a characteristic signature of gauge-mediated symmetry breaking models. It uses a luminosity of 40 pb^{-1}.

The triggers used are single or diEM triggers, and have been determined to be $> 97\%$ efficient for 2 photons with $\mathrm{E_T} > 20$ GeV. The first selection requires 2 EM objects in the central η region, with standard EM ID requirements, no matched tracks, and $\mathrm{E_T} > 20$ GeV. The topological and data quality cuts were chosen to minimize QCD background and the non-Gaussian tails for missing $\mathrm{E_T}$. It was required to have no jets in the intercryostat region. Also, the leading jet and the missing $\mathrm{E_T}$ were required to be separated by > 2.5 radians in ϕ. Missing $\mathrm{E_T}$ for this analysis is calculated using cells, but only cells inside jets are used in the coarse outer region of the calorimeters, to avoid some instrumental problems.

Background comes from QCD processes and is estimated by using a sample with inverted EM quality cuts. The comparison of the background estimate and the 2γ data is shown in Table 3. The missing $\mathrm{E_T}$ distributions for data and background estimate are compared in Fig. 4. The data are compared with GMSB SUSY theory, using a model in which the neutralino is the NLSP, and Λ is the scale of SUSY breaking. Using the parameters $N_5 = 1$, $tan\beta = 15$, and the sign of μ positive [1], a limit on Λ of 51 TeV can be established, and this is shown in Fig. 5. This is close to the Run I limits on this parameter.

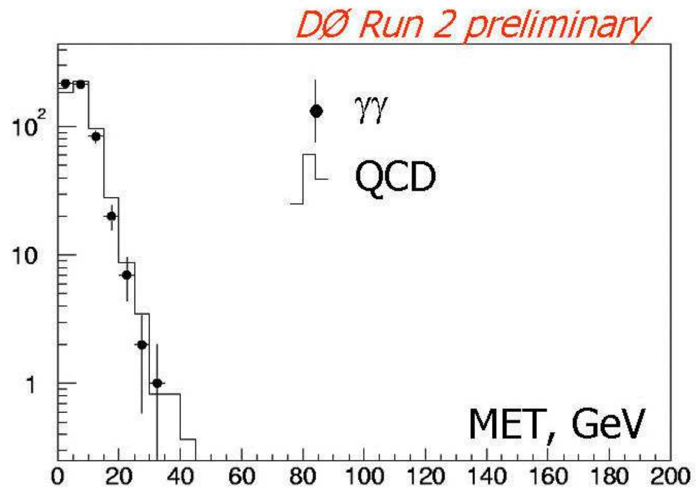

Figure 4: *Distribution of missing E_T for data and background estimate in the 2γ + missing* $\mathrm{E_T}$ *channel.*

5 Jets + missing $\mathrm{E_T}$ Search

The next search uses the jets + missing $\mathrm{E_T}$ channel. The sample encompassed 4 pb^{-1} of luminosity. The trigger required a single high p_T jet above 65 GeV. The analysis required 2 jets found with cone 0.7 algorithm. Missing $\mathrm{E_T}$ was calculated from the calorimeter towers. The standard jet energy scale corrections were applied. The selection cuts included jet quality cuts, cuts to remove electrons, data quality cuts, angular separation cuts between the two leading jets, and between each of the three leading jets and the missing $\mathrm{E_T}$ vector.

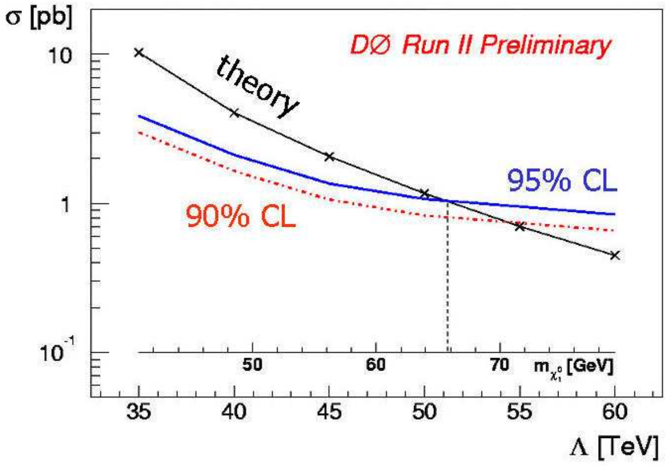

Figure 5: *Limit on* Λ*, the GMSB SUSY breaking scale, established in the* $2\gamma+$ *missing*$\mathrm{E_T}$ *channel.*

Table 3: *Comparison of background with data in jets + ME_T search.*

Missing E_T cut	QCD Fit	Total Background	Data	$95\%CL\epsilon\times\sigma(pb)$
>70 GeV	$17.4\pm7.9\pm2.7$	$18.4\pm7.9\pm2.7$	7	4.18
>80 GeV	$8.5\pm5.0\pm1.7$	$9.5\pm5.0\pm1.7$	6	3.76
>90 GeV	$4.2\pm3.0\pm1.0$	$5.1\pm3.0\pm1.0$	4	3.12
>100 GeV	$2.0\pm1.7\pm0.6$	$2.7\pm1.7\pm0.6$	3	2.69

Also, the leading jet $\mathrm{E_T}$ was required to be >100 GeV to insure full trigger efficiency.

Backgrounds were estimated for the physics background channels, with real missing $\mathrm{E_T}$, using PYTHIA generation and full detector simulation. For the background due to mismeasured missing $\mathrm{E_T}$, a fit to the low missing $\mathrm{E_T}$ region was used to extrapolate into the higher missing $\mathrm{E_T}$ region. Fig. 6 shows the distribution of missing $\mathrm{E_T}$ in the data sample, compared with the fits, using different choices for the fit region. Table 4 gives the results of the analysis, including the limits obtained on cross section times efficiency.

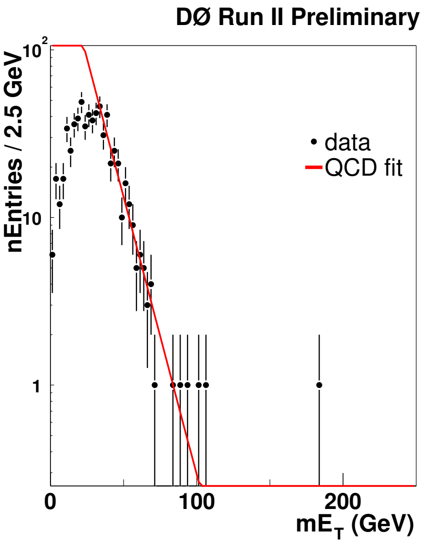

Figure 6: *Distribution of missing E_T for data, compared with the background fits, in the jets + missing* $\mathrm{E_T}$ *channel.*

Table 4: *Comparison of background with data in jets + ME_T search.*

Missing E_T cut	QCD Fit	Total Background	Data	$95\% CL \epsilon \times \sigma(pb)$
$>$ 70 GeV	$17.4 \pm 7.9 \pm 2.7$	$18.4 \pm 7.9 \pm 2.7$	7	4.18
$>$ 80 GeV	$8.5 \pm 5.0 \pm 1.7$	$9.5 \pm 5.0 \pm 1.7$	6	3.76
$>$ 90 GeV	$4.2 \pm 3.0 \pm 1.0$	$5.1 \pm 3.0 \pm 1.0$	4	3.12
$>$ 100 GeV	$2.0 \pm 1.7 \pm 0.6$	$2.7 \pm 1.7 \pm 0.6$	3	2.69

Table 5: *Comparison of background with data in eμ search.*

Missing E_T cut	Data	Total Background
> 0 GeV	13	$9.6 \pm 0.6 \pm 2.6$
> 10 GeV	10	$7.3 \pm 0.5 \pm 2.1$
> 15 GeV	7	$4.6 \pm 0.4 \pm 1.6$
> 20 GeV	6	$3.0 \pm 0.3 \pm 1.3$
> 25 GeV	3	$2.3 \pm 0.3 \pm 1.1$
> 30 GeV	3	$1.9 \pm 0.2 \pm 0.9$
> 35 GeV	2	$1.6 \pm 0.2 \pm 0.8$
> 40 GeV	0	$1.4 \pm 0.2 \pm 0.7$
> 45 GeV	0	$1.1 \pm 0.1 \pm 0.5$

6 Search in the e-μ channel

In this analysis, the e-μ channel was examined, because it has low background and high discovery potential. The goal was to provide a model-independent limit on the cross section for new physics. The analysis used data from 30 pb^{-1} of data.

The trigger for this analysis required 1 electron with $E_T > 20$ GeV and 1 muon inside $\eta = 2$. The offline selection for the muon required that it be identified by the muon system scintillators, matched to a central track, be isolated using both the calorimeter and the track criteria, and pass the cosmic veto criteria. The electron offline selection requirements were: identification by isolated EM cluster, matched with a central track. Both electron and muon were required to have $p_T > 20$ GeV. The misidentification probabilities for electron and muon were measured from the data. The Standard Model contributions to the background were calculated using PYTHIA plus a full detector simulation. The SM processes simulated were WW, ttbar, and Z $\rightarrow \tau\tau$. The comparison of data with total background is shown in Table 5. The cross section limits obtained, as a function of a missing E_T cut, are shown in Fig. 7.

7 Second generation leptoquark search

This search used the channel 2 muons + 2 jets to search for a second generation scalar leptoquark, using 30 pb^{-1} of data.

The trigger required 2 muons at Level 1, 1 muon at Level 2, and no further reqjection at Level 3. A sample was preselected using the requirements: 2 muons, isolated in both the calorimeter and the central tracker, oppositely charged, each with $p_T > 15$ GeV, and with $m_{\mu\mu} > 60$ GeV. This sample was compared with the Drell Yan simulation, and a correction was made based on

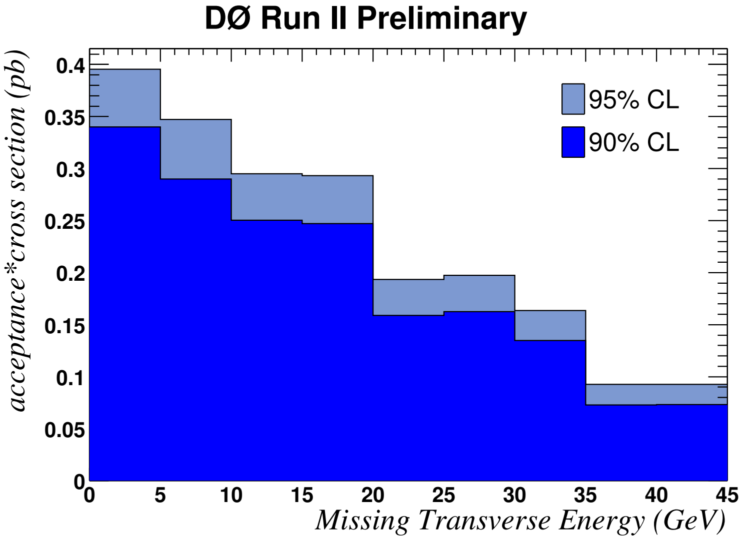

Figure 7: *Cross section limits for the eμ analysis.*

the observed jet multiplicity in the μ-μ mass window [60-110] GeV. Then, the LQ sample was defined to be the preselection + 2 cone 0.5 jets, each with $E_T > 20$ GeV and $\eta < 2.4$, passing standard jet quality cuts, and with the $m_{\mu\mu} >$ 110 GeV. The cross section limit obtained with these cuts is shown in Fig. 8.

8 Large Extra Dimensions search with electrons and photons

In string theories in which the Standard Model processes are restricted to the D3 brane, but in which gravity can propagate in 'extra' dimensions, virtual graviton diagrams can contribute to dilepton and diboson production [2]. D0 has searched for such a signature in the ee + $\gamma\gamma$ channel, using 50 pb^{-1} of data.

The analysis required either a single or diEM trigger to fire. The selection required 2 EM objects, each with $E_T > 25$ GeV and standard EM quality cuts, and a missing $E_T < 25$ GeV. Background was estimated from a fast Monte Carlo for Drell Yan and diphoton production. The misidentification probabilities were estimated from data. The 2-D distributions in the diEM mass and $cos(\theta^*)$ were fitted to obtain three terms: the SM contribution, the direct gravity term, and the interference term. Only the topologies with at least one of the EM objects

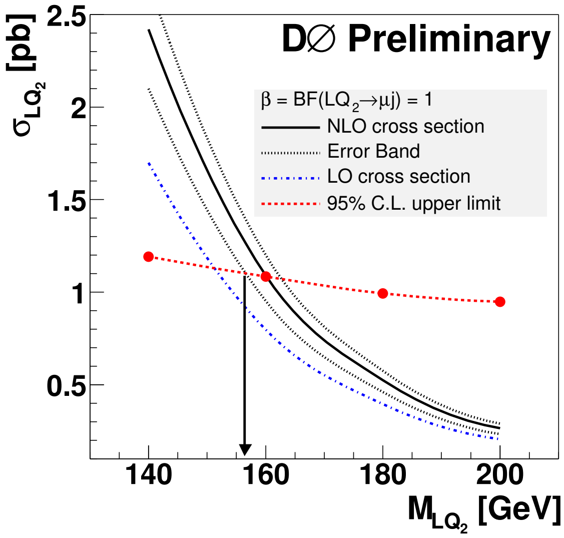

Figure 8: *Cross section limits for the second generation leptoquark analysis.*

in the central calorimeter were used. The results of these fits were translated into lower limits on the Planck scale M_s, given different assumptions about F (a dimensionless parameter which incorporates the dependence of the virtual G_{KK} exchange on the number of extra dimensions). These limits are shown in Table 6.

9 Large Extra Dimensions search with muons

A very similar search for large extra dimensions using the 2μ channel has also been performed. This is the first such search to be reported at the Tevatron. It used 30 pb^{-1} of data.

The trigger used was the same as in the second generation leptoquark search. The offline selection required 2 isolated muons, each with a central track match and $p_T > 15$ GeV. Cosmics were removed. A cut of $m_{\mu\mu} > 40$ GeV was applied. Background was estimated from a fast Monte Carlo for Drell Yan production. The muon misidentification probability was estimated from data. A 2-D fit procedure like the one described in the EM search above was carried out, and the resulting M_s limits are also given in Table 6.

Table 6: *Results of extra dimensions analyses: limits on M_s in TeV.*

	GRW	HLZ n=2	HLZ n=7	Hewett $\lambda = +1$
diEM	1.12	1.16	0.89	1.00
diμ	0.79	0.68	0.63	0.71

10 Conclusion

D0 is continuing to pursue searches for New Phenomena vigorously in Run II of the Tevatron. New search channels are being introduced, and our search reach and capabilities are expanding. As Run II's luminosity accumulates, the discovery potential continues to rise.

References

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2. N. Arkani-Hamed, S. Dimopoulos, G. Dvali, Phys. Lett. **B429**, 263 (1998); I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, G. Dvali, Phys. Lett. **B436**, 257 (1998); N. Arkani-Hamed, S. Dimopoulos, G. Dvali, Phys. Rev. **D59**, 086004 (1999); N. Arkani-Hamed, S. Dimopoulos, J. March-Russell, SLAC-PUB-7949, e-Print Archive: hep-th/9809124.