Fermi National Accelerator Laboratory

FERMILAB-Conf-95/095-E

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May 1995

Presented at the *Rencontres des Moriond XXX Electroweak Interactions and Unified Theories*,
Meribel, France, March 11-18, 1995

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

DØ SEARCH FOR NEW PHENOMENA

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ABSTRACT

Presented here are the results from three searches for non-standard model particles using approximately 13 pb^{-1} of data taken with the DØ detector at Fermilab's Tevatron, a $p\bar{p}$ collider operating at center-of-mass energy $\sqrt{s}$=1.8 TeV. A heavy right-handed W, predicted by left-right symmetric theories, is excluded at 95% confidence level with mass between 200 GeV/c^2 and 540 GeV/c^2, for a right-handed neutrino mass less than 100 GeV/c^2, regardless of the decay-properties of the neutrino, and assuming the W_R's couplings and C-K-M matrix are the same as the standard model W. Stricter limits are given on the right-handed neutrino mass for W_R masses near the upper limit, and for specific assumptions on the right-handed neutrino decay modes. A 95% confidence-level limit on the cross-section $p\bar{p} \rightarrow \tilde{W}_1\tilde{Z}_2 \rightarrow$ 3 leptons, where $\tilde{W}_1$ is the lightest supersymmetric partner of the charged vector bosons and charged higgs and $\tilde{Z}_2$ is the second lightest supersymmetric partner of the Z, γ, and neutral higgs, ranging from 3 pb for $M_{\tilde{W}_1}$=45 GeV/c^2 to 1 pb for $M_{\tilde{W}_1}$=100 GeV/c^2 is presented, assuming mass relations between the supersymmetric particles predicted by a popular supergravity inspired model.[1] Third, a 95% confidence-level limit on the mass of the supersymmetric partner of the gluon of 144 GeV/c^2, if the supersymmetric partner of the quarks are very heavy, or 212 GeV/c^2, if they have equal masses, is presented within the framework of the same popular model.

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1. Introduction

Most theories of physics beyond the standard model predict the existence of new heavy particles. The Tevatron is a $p\bar{p}$ collider operating at a center-of-mass energy $\sqrt{s}$=1.8 TeV, and is currently the world's highest energy accelerator. The DØ detector[2] has a hermetic, compensating sampling calorimeter with fine longitudinal and transverse segmentation in pseudorapidity and azimuth. Muons within $|\eta| < 3.3$ are reconstructed using proportional drift tubes before and after magnetized iron toroids located outside the calorimeter. DØ is optimized for measuring the high transverse-momentum (P_T) electrons, muons, jets and missing transverse energy ($\not{E}_T$) that are often the signatures of new massive particles.

2. Heavy Vector Bosons

Heavy right-handed W's (W_R) and associated right-handed neutrinos (N_R) are predicted in models which restore left-right symmetry at high energy.[3] In models where N_R is a heavy majorana neutrino, the so-called see-saw mechanism naturally predicts that the left-handed neutrinos will be very light. While there are interesting limits on the masses of these particles from precision low energy experiments,[4] these limits are in general model dependent.

A W_R can be produced in $p\bar{p}$ collisions, for example through $u\,\bar{d}$ annihilation, followed by subsequent decay to the N_R and an electron. If the W mass eigenstates are the same as the helicity eigenstates, we assume N_R will decay to an electron and a W_R. If there is significant mixing, and the 80 GeV W is thus a mixture of the standard model W_L and this new W_R, then we assume the N_R can decay to an electron and the 80 GeV W. If the W then decays to a quark-anti-quark doublet, and if the N_R is heavy enough, a virtually background-free signal will be two electrons, two jets, and no $\not{E}_T$. We have searched 13.5$\pm$1.8 pb^{-1} of data for events satisfying this signature (electron and jet E_T >25 GeV), and where the mass of the electron pair is inconsistent with the Z mass, and have found 1 event with an expected background of 0.5 events. The dominant backgrounds are Drell-Yan production of lepton pairs with associated jets and top-pair production. The acceptance reaches 50% with uncertainty typically $\pm$12% for W_R masses around 600 GeV and N_R masses around 400 GeV. The acceptance depends on the mixing between the W_L and W_R, and is higher for the no-mixing case, because the 80 GeV W can decay to any of the quark or lepton doublets while the W_R can only decay to the quark doublets (the heavy neutrino can not decay via a W_R to itself and a lepton, but the W(80) can decay via a W_L to the light left-handed neutrino and a lepton). The efficiency depends on the $|\eta|$'s of the electrons. If both have $|\eta|<1$, the efficiency is 61.7$\pm$2.4%, if both have $|\eta|>1$, the efficiency is 30.5±3.1%, if it is mixed, the efficiency is 44.2±2.6%. Figure 2 shows correlated 95% confidence level non-background-subtracted limits on the mass of the W_R and its associated N_R. A W_R is excluded at 95% confidence level with mass between 200 GeV/c^2 and 460 GeV/c^2, for N_R mass less than approximately M_{W_R}-50 GeV/c^2 and greater than approximately 50 GeV/c^2, assuming the W_R's couplings and C-K-M matrix are the same as the standard model W and no mixing between the W_R and W_L. The excluded area is reduced for significant mixing. In these plots, β_R is $(\frac{g_R}{g_L}\frac{V^R_{ud}}{V^L_{ud}})^2$ and is a measure the relative coupling strength of the W_R and the W_L to quarks and electrons.

If the right-handed neutrino is light, the decay products of the W may coalesce into 1 jet, and the signal will be 1 electron recoiling against one jet. This signature has many backgrounds, from W's, Z's, and from di-jets where one jet fakes a lepton. We collect an inclusive high E_T electron sample ($E_T > 50$ GeV), and search for a jacobian peak in the electron E_T spectrum. We require tight electron ID requirements, which have an efficiency of approximately 50%, and $|\eta_e| < 1$. This search is also sensitive to any other particle which produces very high E_T electrons in the final state. We expect that most of the events which pass this cut will be from the tail of the 80 GeV W, and thus to contain large $\not{E}_T$, and that the transverse mass of the electron and the $\not{E}_T$ shows a jacobian peak at 80 GeV. Figure 1 (a) shows the good agreement for transverse mass with the prediction from the 80 GeV W Monte Carlo and the prediction of the Z and QCD backgrounds. Figure 1 (b) shows the electron E_T spectrum, along with the predictions from the background Monte Carlo. The plot does not show any evidence of a jacobian peak from a new particle. Figure 2 shows 95% confidence level limits in the M_{W_R}-M_{N_R} plane based on this search. A W_R is excluded at 95% confidence level with mass between 200 GeV/c^2 and 540 GeV/c^2, for a right-handed neutrino mass less than 100 GeV/c^2, assuming the W_R's couplings and C-K-M matrix are the same as the standard model W. More details can be found in reference.[5]

3. Supersymmetry Searches

Supersymmetry (SUSY) is a spacetime symmetry which relates bosons to fermions and introduces a supersymmetric partner (sparticle) for each Standard Model particle. Most SUSY models have a conserved quantity called R-parity, which is +1 for standard model particles and -1 for their supersymmetric partners. Thus, supersymmetric particles are produced in pairs, and the lightest supersymmetric particle (LSP) is stable. In most models, cosmological and experimental constraints require the LSP to be weakly-interacting and neutrally charged, and thus it will not interact in the detector. SUSY provides a natural solution to the fine-tuning

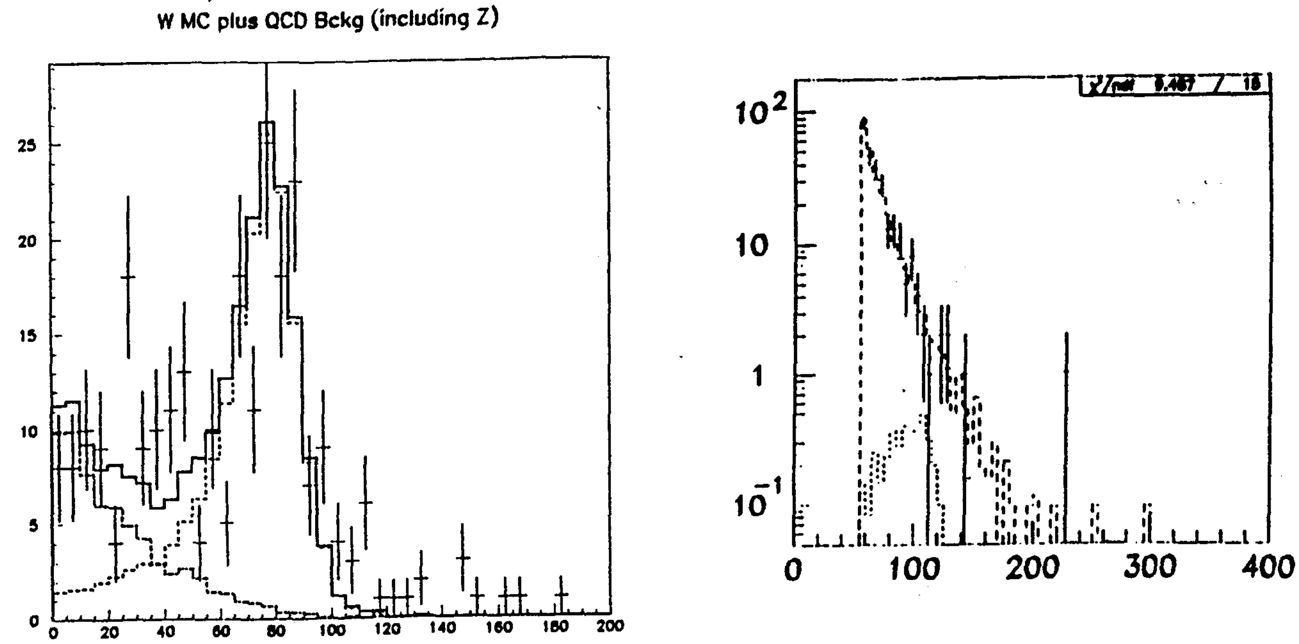

Fig. 1. (a)Transverse mass distribution of events in a sample of inclusive electrons with $E_T > 50$ GeV, along with predictions from an 80 GeV W Monte Carlo and predictions for the Z and QCD backgrounds (b)E_T spectrum for the same sample, along with background predictions and the prediction for a 300 GeV W_R with an associated 150 GeV N_R

problem of the Standard Model, yields a candidate for dark matter, and can allow the unification of the U(1), SU(2), and SU(3) couplings of the standard model at high energy.

3.1. Charginos/Neutralinos

The lightest Chargino ($\tilde{W}_1$) and second-lightest neutralino ($\tilde{Z}_2$), the supersymmetric partners of the vector bosons and Higgs, can be produced in $p\bar{p}$ collisions $p\bar{p} \rightarrow \tilde{W}_1\tilde{Z}_2 + X$. The $\tilde{W}_1$ can decay to a lepton, a neutrino (ν), and the lightest neutralino ($\tilde{Z}_1$, which is the LSP). The $\tilde{Z}_2$ can decay to two leptons and the LSP. A virtually background-free signature for $p\bar{p} \rightarrow \tilde{W}_1\tilde{Z}_2 + X$ is thus 3 leptons plus $\not{E}_T$ plus low jet activity. The DØ new phenomena group has searched for such events in the eee, e$\mu\mu$, eeμ, and $\mu\mu\mu$ channels. Because the leptons are from tertiary decays of rather low mass objects (the limits from LEP are around 45 GeV), their E_T's are low. The E_T thresholds depend on the channel, and are determined by the need to keep the hardware event trigger rate under control. Typical cuts require 1 lepton with E_T above 15 GeV, and 2 more with E_T above 5 GeV. Standard model sources of low E_T leptons are electrons from photon conversion, bottom production, muons from π decay, Drell-Yan production of charged lepton pairs, J/Ψ production, and cosmic rays. Topological cuts remove these backgrounds. No events pass the cuts in approximately 12 pb^{-1} of data in the eee, e$\mu\mu$, eeμ channels and 9 pb^{-1} in the $\mu\mu\mu$ channel, consistent with background expectation of 0.8 events.

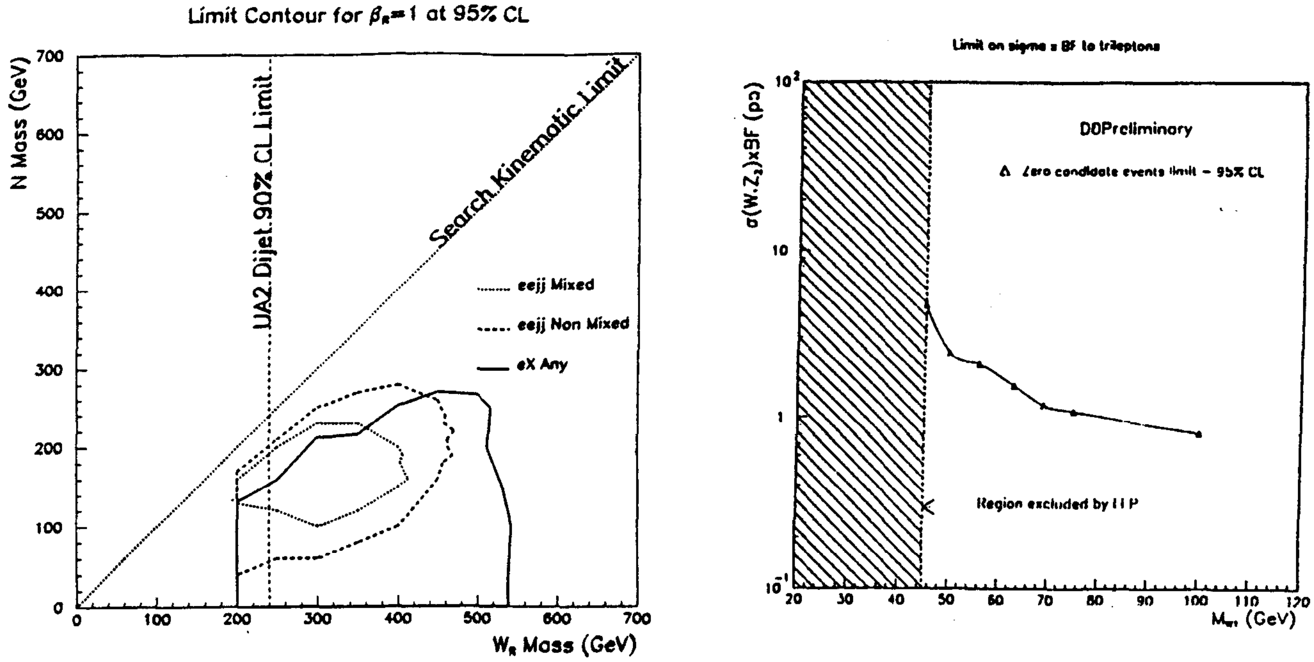

Fig. 2. (a)95% confidence level mass limits on the mass of a heavy right-handed W and associated heavy right-handed neutrino, assuming the W's couplings and C-K-M matrix are the same as the standard model W (b)95% confidence level limit on $\sigma \cdot BR(\ p\bar{p} \ \rightarrow \tilde{W}_1 \tilde{Z}_2 \rightarrow 3$ leptons + X),

The background is dominated by Drell-Yan with associated jet production, where the jet fakes a lepton. Figure 2 shows the limit for the cross-section times branching ratio $p\bar{p} \ \rightarrow \tilde{W}_1 \tilde{Z}_2 \rightarrow 3$ leptons + X from the run 1a data. The prediction for this cross-section is very model dependent. For a popular model,[1] the acceptance ranges from 2% for M_{W_1}=45 GeV to 16 % for M_{W_1}=100 GeV in the eee channel. The dominant source of inefficiency is the lepton P_T cuts, The cross-section ranges from about 1 *pb* for $M_{\tilde{W}_1}$=45 GeV to 0.1 *pb* for $M_{\tilde{W}_1}$=100 GeV.

3.2. Squarks and Gluinos

Squarks ($\tilde{q}$) and gluinos ($\tilde{g}$), the supersymmetric partners of quarks and gluons, can also be produced in $p\bar{p}$ collisions. ($p\bar{p} \ \rightarrow \tilde{q}\tilde{q}$, $p\bar{p} \ \rightarrow \tilde{q}\tilde{g}$, and $p\bar{p} \ \rightarrow \tilde{g}\tilde{g}$). The $\tilde{q}$, $\tilde{g}$ decay to jets and LSP's, and thus would result in an excess above standard model predictions of events with 3 or more jets and missing transverse energy ($\not\!\!E_T$). The DØ collaboration has searched for events with 3 or more jets with $E_T > 25$ GeV and with $\not\!\!E_T > 80$ GeV. DØ's hermetic hadron calorimetry gives very good rejection against backgrounds from multi-jet production, where one of the jet's is lost or mis-measured. Topological cuts remove the small remaining background from this source. This search also requires that there be one and only one primary vertex. This cut eliminates backgrounds from multi-jet production which have apparent $\not\!\!E_T$ because the wrong vertex was when calculating the E_T's of the calorimeter towers. This cut eliminates approximately 50% of the run 1a data. After these cuts, the remaining backgrounds to this

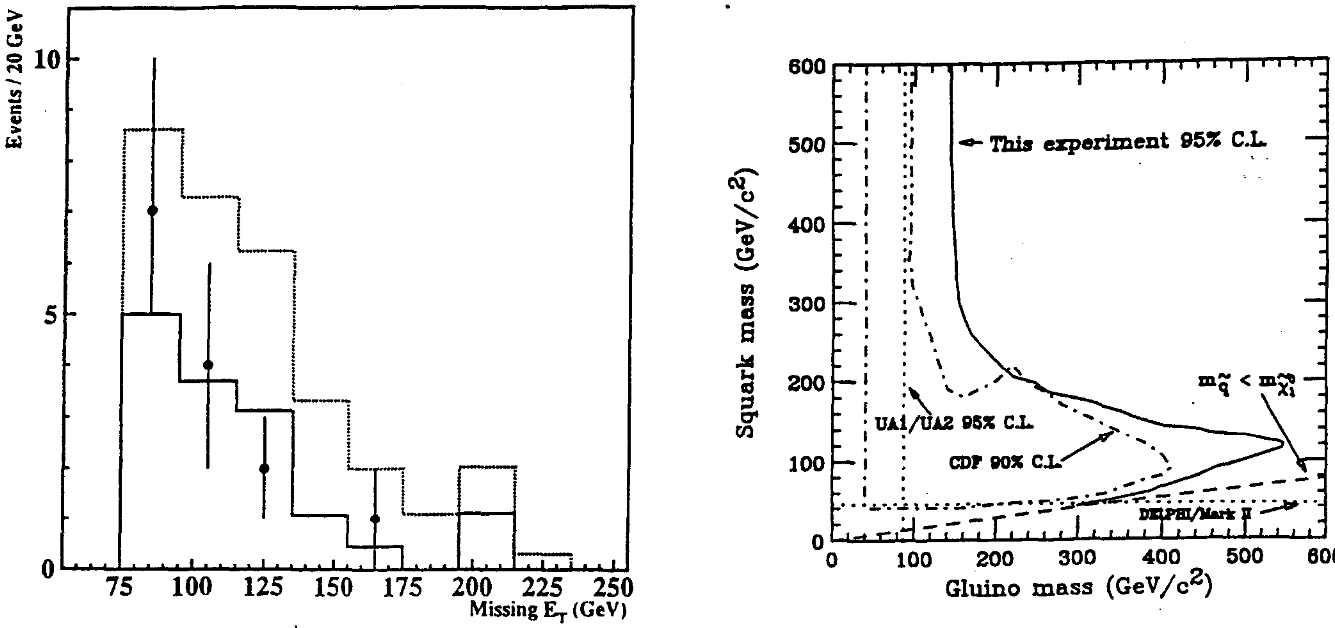

Fig. 3. (a) $\not\!\!E_T$ distribution for events passing squark and gluino search cuts. The points are data, the solid is the background Monte Carlo, and the dots are background Monte Carlo plus 200 GeV $\tilde{q}$ and 200 GeV $\tilde{g}$. (b) 95% confidence level mass limits using acceptances and cross sections from a popular SUGRA-GUT SUSY model, along with results from previous experiments

signature come from events with real $\not\!\!E_T$, such as semi-leptonic W decay or $Z \rightarrow \nu\bar{\nu}$.

Fig. 3 (a) shows the $\not\!\!E_T$ distribution of events from the final sample, along with the prediction from standard model backgrounds (mostly W's and Z's of various sorts), and the prediction for the standard model plus 200 GeV $\tilde{q}$'s and 200 GeV $\tilde{g}$'s. The data agrees well with the standard model prediction. Figure 3 (b) shows the 95% confidence level limits on the masses of the $\tilde{q}$ and $\tilde{g}$, using cross-sections and efficiencies calculated using a popular SUSY model.[1] More details can be found in reference.[7]

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