Searches for Beyond the Standard Model Physics at D0

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INTRODUCTION

The standard model (SM) of particle physics has been remarkably successful at predicting the outcomes of particle physics experiments, but there are reasons to expect new physics at the electroweak scale [1]. Over the last several years, there have been a number of searches for beyond the standard model (BSM) physics at D0. Here, we limit our focus to three: searches for diphoton events with large missing transverse energy \( (\not{E}_T) \) [2], searches for leptonic jets and \( \not{E}_T \) [3], and searches for single vector-like quarks [4].

D0 DETECTOR

The D0 detector [5, 6] contains tracking, calorimeter and muon subdetector systems. Silicon microstrip tracking detectors (SMT) near the interaction point cover pseudorapidity \(|\eta|<3\) to provide tracking and vertexing information. The central fiber tracker (CFT) surrounds the SMT, providing coverage to about \(|\eta|=2\) with eight concentric cylindrical layers of overlapped scintillating fibers. A 2T solenoid surrounds these tracking detectors. Three uranium-liquid argon calorimeters measure particle energies. The central calorimeter (CC) covers \(|\eta|<1\), and two end calorimeters (EC) extend coverage to about \(|\eta|=4\). The calorimeter is highly segmented along the particle direction, with four electromagnetic (EM) and four to five hadronic sections. Scintillating strip preshower detectors, CPS and FPS, are located in front of the CC and EC respectively. Muons are measured just outside the calorimeters, and twice more outside the 1.8T iron toroidal magnets, over the range \(|\eta|<2\).

DIPHOTON EVENTS WITH LARGE \( \not{E}_T \)

It is rare for events with two photons (\(\gamma\)) and large \(\not{E}_T\) to occur in the SM, but it is more likely in some proposed BSM models. We have conducted a search for an excess of these events over SM expectation at D0 with 6.3 fb\(^{-1}\) of integrated luminosity, and have
placed limits on two models that predict an excess in this final state. In Gauge Mediated Supersymmetry (SUSY) Breaking (GMSB) models with R-parity conservation [7] and the lightest neutralino as the next-to-lightest SUSY particle (NLSP), we expect the neutralinos to be pair produced and decay to a photon and gravitino, which escapes the detector unseen. In some Universal Extra-Dimensional models [8], the Lightest Kaluza-Klein Particle (LKP) is pair-produced and decays to a photon and a graviton, which escapes the detector unseen.

Candidate events must have two reconstructed photons in the CC. These photons consist of a narrow cone of energy in the calorimeter with transverse energy $E_T > 25$ GeV and at least 95% of the cone energy in the EM calorimeter. This photon must pass a calorimeter isolation cut and a hollow-cone isolation cut in the tracker. The photon must also pass a cut on a neural net derived from CC, CPS, and track information that separates photons from hadronic jets. To differentiate $\gamma$ and electrons ($e$), we reject objects where hits in the tracking system are consistent with a track pointing to the calorimeter object.

The missing transverse energy, $E_T$, is calculated for each event from the calorimeter cells, with the energy corrections for jets, muons ($\mu$), $e$ and $\gamma$ included. We require the $E_T$ be separated in the azimuthal angle $\phi$ from the $\gamma$ and highest $p_T$ jet.

The backgrounds for $\gamma\gamma$ events are from SM $\gamma\gamma$ production with fake missing energy from energy mismeasurement, $\gamma +$ jet events where the jet is misidentified as a photon, $W\gamma \rightarrow e\nu\gamma$ events where the $e$ track is missed, and $Z\gamma \rightarrow \nu\nu\gamma\gamma$ and $W\gamma \rightarrow \ell\nu\gamma\gamma$, where the lepton $\ell$ is missed. The $E_T$ spectrum from misidentified jets is estimated by reversing some of the photon quality requirements on one of the two photons. The $E_T$ spectrum from SM $\gamma\gamma$ is estimated using $Z \rightarrow ee$ data. The $W\gamma$ background $E_T$ distribution is estimated with $e\gamma$ events from data, while the latter two backgrounds are estimated using MADGRAPH [9].

The $E_T$ distribution for the $\gamma\gamma$ events is shown on the left in Fig. 1. As no significant excess is seen, we proceed to set limits. For the GMSB SPS8 [10] signal modeled using SUSYHIT [11] and PROSPINO [12], we find that the SUSY breaking scale $\Lambda < 124$ TeV and $m_{\chi^0_1} < 175$ GeV at a 95% C.L. The limit on the compactification radius $R_c$ of the UED model with KK decays via gravity with signal estimated using PYTHIA [13] is $R_c^{-1} < 477$ GeV at 95% C.L.

**LEPTONIC JETS AND LARGE $E_T$**

Hidden-valley models [14] provide a possible explanation for recently observed astrophysical phenomenon [15] by introducing new low-mass particles. In this scenario, the force carrier for the hidden sector is the dark photon, $\gamma_D$, is assumed to have a mass at or less than 2 GeV, and decay mostly to lepton pairs. If SUSY exists, R parity is conserved and the lightest SUSY particle (LSP) is a partner of the hidden sector, then the lightest SM SUSY partner is pair produced and can decay to a $\gamma_D$ and the LSP, which would escape the detector as $E_T$. We have conducted a search of the D0 dataset in 5.8 fb$^{-1}$ for these decays.

If the dark photon has a mass $< 2m_\pi$, it will decay entirely to charged leptons. Because the $\gamma_D$ has a small mass and significant boost, we look for leptonic jets. An electron jet
is defined in a similar manner to the photons above, but we require $E_T > 15$ GeV and a track matched to the EM cluster with an oppositely charged track nearby. In a muon jet, the track requirements are the same, but with a match to hits in the muon system. If there is matched to both, the object is considered a muon jet. As the leptonic jets are expected to be highly collimated, a hollow-cone track isolation and calorimeter isolation cuts are used to reject hadronic jets. We require a $E_T > 30$ GeV.

The main background for the leptonic jets are SM hadronic jets, which is estimated from data by reversing the hollow-cone track isolation on one of the hadronic jets. The background is normalized to data in events with $E_T < 15$ GeV. We use MADGRAPH [9] to simulate the signal.

With no observed excess in data, we set limits on $\gamma_D$ production in the Hidden Valley model vs. $\gamma_D$ mass, shown on the right in Fig. 1.

VECTORS LIKE QUARKS

Vector-like quarks, $Q$, are particles similar to SM quarks, except that the left-handed and right-handed components transform the same way under $SU(3) \times SU(2) \times U(1)$ [16]. We have searched for singly-produced vector-like quarks that couple to first generation SM quarks in events with $W + 2$ jets and $Z + 2$ jets in 5.4 fb$^{-1}$ of integrated luminosity. In these events, one jet is produced as recoil during $Q$ production, the vector boson and second jet are produced by the $Q$ decay, and we look for the decays of $W \rightarrow \ell \nu$ and $Z \rightarrow \ell \ell$, where $\ell = e, \mu$.

The electron criteria here are similar to electron definition above, except that electrons are reconstructed in both the EC and CC. The muons are reconstructed by looking for an isolated track pointing to hits in the muon system. We reconstruct jets in the calorimeter using an iterative midpoint cone algorithm [17] with a cone radius of $\Delta R = 0.5$.

The main backgrounds for this search are SM $Z +$ jets, $W +$ jets, and $t\bar{t}$ production, modeled by ALPGEN [18], and SM diboson production, modeled using PYTHIA [13]. Multijet backgrounds are modeled from data by reversing isolation cuts on the lepton.
Our signal is modeled by MADGRAPH \[9\] with \( Q \) widths modeled by BRIDGE \[19\].

We require all events to have \( \ell p_T > 50 \text{ GeV} \), the highest jet \( p_T > 100 \text{ GeV} \). For the single lepton plus \( \not{E}_T + 2 \) jet final state, \( \not{E}_T > 40(50) \text{ GeV} \) for the \( \mu (e) \) final states and \( M_T(\ell, \not{E}_T) < 150 \text{ GeV} \). We also take advantage of the event kinematics by requiring that the charge of the lepton times the \( \eta \) of the second jet be less than one. In the dilepton events, we require that the dilepton mass be consistent with a \( Z \) peak, the \( Z p_T > 100 \text{ GeV} \). We also require \( \Delta \phi < 2.0 \) between \( \ell, \not{E}_T \) in the single lepton final state and between the \( \ell, \ell \) in the dilepton final state.

With no significant excess observed, we proceed to set limits. For a coupling strength of 1 between the SM \( u \) quark and up-like \( Q \) and of \( \sqrt{2} \) between the \( u \) quark and the down-like \( Q \), we exclude \( Q \) masses < 693 GeV for \( Q \to W + \text{jet} \) exclusively and \( Q \) masses < 551 GeV for \( Q \to Z + \text{jet} \) exclusively at 95\% C.L.

**CONCLUSION**

We have discussed three recent searches at D0. There are many more, including limits on heavy neutral gauge boson in the \( ee \) channel \[20\], a search for scalar top quarks \[21\], a search for quirks \[22\], and limits on a new resonance decaying to \( WW \) or \( WZ \) \[23\].

**REFERENCES**