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Model Independent Search for New Physics in Leptonic Final States at DØ

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Abstract. One of the greatest uncertainties in physics today is what theory lies beyond the Standard Model. This analysis scans 1 fb^{-1} of data from DØ for new physics without requiring the assumption of a specific model.

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INTRODUCTION

The Standard Model (SM) of particle physics is has been remarkably successful, However, there are problems with the theory at energies above the electroweak scale, which require fine tuning of the parameters of the standard model to withing $M_W/M_{Planck} = 10^{-16}$. While several models of new physics have been proposed to remove this fine tuning, it is not clear which if any is correct. The minimal supersymmetric model (MSSM), for example, has over a hundred adjustable parameters [1], and the new physics signatures the model can vary significantly depending on the values of these parameters. Traditionally searches for new physics have been done by optimizing an analysis to look for the signature of a specific theory or set of theories. However, it is not practical to do a dedicated search for new physics for every possible theory.

The Model Independent Search (MIS), therefore, uses an alternative approach to searching for new physics. In MIS, we do not optimize for a specific signature. Instead, we compare data to the SM prediction in as many final states as possible, and look for overall deviations. While not as sensitive to new physics in a specific final state as a dedicated search, MIS can look for deviations across multiple final states.

The MIS search strategy trades sensitivity for breadth of search. We do not do detailed systematics or different object selections for each final state. This allows us to look across a broad variety of final states without dedicating the time to optimizing a specific channel. If a channel does show a statistically significant discrepancy, it would be possible to do a full systematic study to determine if new physics is indicated.

DØ DETECTOR

“The DØ detector [2, 3, 4] 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 ($|\eta| = 2$). The CFT has eight concentric cylindrical layers of overlapped scintillating fibers providing axial and stereo ($\pm 3^{\circ}$) measurements. 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 for to five hadronic sections, and transverse to the particle direction with typically $\Delta\eta = \Delta\phi = 0.1$, where ϕ is the azimuthal angle. The calorimeters are supplemented with central and forward scintillating strip preshower detectors (CPS and FPS) located in front of the CC and EC. Muons are measured just outside the calorimeters, and twice more outside the 1.8T iron toroidal magnets, over the range $|\eta| < 2$. Scintillators surrounding the exiting beams allow determination of the luminosity. A three level trigger system selects events for data logging at about 100 Hz." [5]

DATA AND MC SAMPLES

The data for this analysis were collected between 2002 to 2006, referred to here as Run IIa. The total integrated luminosity of this sample is 1.07 fb^{-1}.

To model the standard model background from Drell-Yan, W, and $t\bar{t}$, we use ALPGEN Monte Carlo matched to PYTHIA for partonic showering and hadronization. We use the MLM matching scheme to avoid double counting in areas of phase space where PYTHIA and ALPGEN may overlap. PYTHIA is used exclusively for the production of our diboson (WW, WZ, ZZ) events. The DØ detector is simulated using GEANT. In order to model the QCD contribution to single lepton final states and electron plus tau or muon plus tau final states, we use events where one of the leptons has had some of its quality criteria reversed, making it more likely that these objects were produced by jets. In the other final states, our fitting procedure, described below, has indicated that the QCD contribution is small enough that it may be ignored.

We have found that our MC does not always correctly reproduce the data distributions due to detector mismodeling or uncertainties within the MC production. We apply weights to our MC events to correct for detector efficiencies, Z and W transverse momentum (p_T) distributions, and heavy to light flavor jet production ratios.

STRATEGY

In the first stage of the analysis we fit the contributions from all SM background sources in 7 inclusive final states to data. These states are e + jets, μ + jets, ee, $\mu\mu$, $\mu\tau$, eτ, and eμ. Additional objects are kept in each event if they pass object specific p_T and η cuts. To avoid contamination from new physics, we exclude the any event with an object in the high p_T tail from the fit. The object p_T, η, ϕ, and the event $\not{E}_T$ and $\Delta(\phi_{obj} - \phi_{\not{E}_T})$ are used in the fit, with more complicated quantities, such as invariant mass, transverse mass, or Z p_T are left out of the fit to provide a cross check. The shapes of the distributions in the SM processes are not allowed to change, only their relative contributions.

In the second stage of the analysis, called Vista, the inclusive final states are divided into exclusive final states, e.g., dimuon inclusive to $\mu^+\mu^- + 1$ jet, $\mu^+\mu^- +$ 2 jets $+\not{E}_T$, $\mu^+\mu^+$, etc. For each inclusive final state, a number of kinematic plots are made, such as of the object p_T, η, mass, etc. We then look at the discrepancy between data and MC, both in the total number of events and in the shapes of the kinematic plots. The shape agreement is assessed using a Kolomogorov-Smirnov test, while the significance of the number difference is based off the data's statistical error. Only final states with at least one data event are considered. We convert the Poisson probabilities and K-S statistics into Gaussian sigmas using $\int_\sigma^\infty \frac{1}{\sqrt{2\pi}} e^{\frac{x^2}{2}} dx = p$. The more final states we examine, the more likely it is for a statistical fluctuation to lead to an excess. To account for this, we multiply the probability of agreement with the SM by the number of final states.

After checking for discrepant final states in Vista, the events are passed to the final stage of the analysis, Sleuth. In Sleuth, the exclusive channels are combined by charge conjugation, light lepton universality (eX and μX are combined), and assuming jets always come in pairs (the 1 jet and 2 jet final states are combined, as are the 3 and 4 jet final states). Sleuth takes advantage of the fact that new physics at high mass is likely to produce high p_T decay daughters by comparing $\sum p_T + \not{E}_T$ for all objects in the event. For each data point in the sum p_T distribution, the high p_T tail of the event is checked, the largest possible discrepancy in the high p_T tail is reported.

A similar strategy has been employed on data from DØ Run I [6, 7, 8], H1 at HERA [9] and CDF Run II [10, 11].

In order to test if we could discover new physics, we removed the $t\bar{t}$ MC from our sample and ran the full analysis. Without top, there were significant discrepancies in the $b\bar{b}\,l+$ 2 jets + $\not{E}_T$, $b\bar{b}\,l + \not{E}_T$, and $b\bar{b}\,e^\pm\mu^\mp + \not{E}_T$ final states in Sleuth (Fig. 1). The probability that this would be due to a statistical fluctuation is $< 1.6\times10^{-7}$, showing that Sleuth is able to "rediscover" $t\bar{t}$. These discrepancies are fixed by including $t\bar{t}$ (Fig. 1).

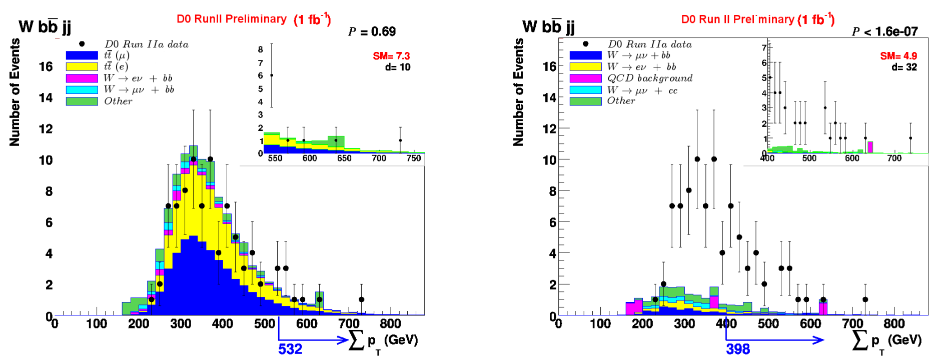

FIGURE 1. Sleuth plots with and without $t\bar{t}$ Monte Carlo for $b\bar{b}\,\ell$ + 2 jets + $\not{E}_T$. The $\mathscr{P}$ value at the top right corner is the probability before final state trials factor.

RESULTS

Running over the full 1.07 fb^{-1} Run IIa dataset, Vista finds 180 exclusive final states with 9335 kinematic shape histograms. The number of events found is compared to the number expected from the SM in each final state using the statistic $p = 1-(1-p_{fs})^{180}$, where p_{fs} is the probability that the SM expectation would fluctuate to the observed number of events. This p is converted to a Gaussian sigma and the distribution is shown in figure 2. There are 4 final states that are discrepant here. Two of them, $\mu + \gamma + 1$ jet + $\not\!\!E_T$ and $\mu^+\mu^- + \gamma$ are related to our difficulties modeling the jet$\rightarrow \gamma$ fake rate. The μ + 2 jet + $\not\!\!E_T$ difference is believed to be due to trigger modeling issues and the $\mu^+\mu^- + \not\!\!E_T$ excess is thought to be from mismodeling high p_T muons in the MC.

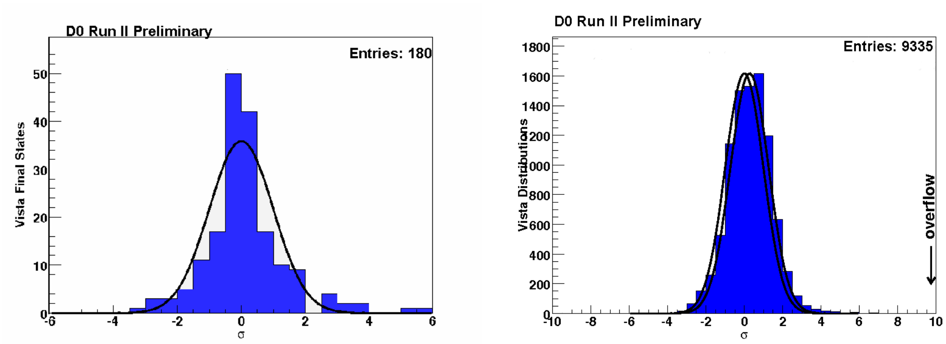

FIGURE 2. Vista final state number (left) and histogram (right) σ distribution for 100% sample before accounting for the trials factors. The curve on the left distribution represents a Gaussian centered at zero. Negative values of σ indicate a deficit in MC; positive ones indicate an excess. Both curves on right plot are Gaussian. The curve that is shifted to lower values is centered at zero while the second curve is centered at the mean. The negative values of σ indicate better than average K-S values, and positive values indicate worse than average agreement, so our average agreement is slighty less than 50%.

The probability of one of the 9335 1-D histograms being significantly divergent is given by $p = 1-(1-p_{shp})^{9335}$, where p_{shp} is the K-S probability associated with the plot. We convert this probability into a Gaussian sigma and plot the distribution in figure 2. After applying the trials factor, 23 plots have a 3σ discrepancy. These issues appear to be due to the oversimplifications in our modeling, as mentioned above.

All Vista final states are input to Sleuth and the 180 exclusive final states become 44 final states after applying the rebinnings described above. The 4 Vista final states with numerical excesses are found again in Sleuth, as expected. There is one additional final state that shows an agreement of less than 0.001 after trials factor, $e^{\pm} + \mu^{\mp} + \not\!\!E_T$. As with the $\mu^+\mu^- + \not\!\!E_T$ final state, we believe that this is due to muon p_T resolution issues.

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