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Searches in Dilepton and Diphoton Final States at the Tevatron

Christopher Hays*
University of Oxford
E-mail: christopher.paul.hays@cern.ch

Neutral resonances decaying to dileptons or diphotons are common in models of physics beyond the standard model. The Tevatron experiments have analyzed up to 5.4 fb^{-1} of dilepton and diphoton data, and found no significant evidence of such neutral resonances. The CDF and D0 experiments set the world's highest mass limits on new spin-0 sneutrinos, spin-1 gauge bosons, and spin-2 gravitons.

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*Speaker.

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1. Introduction

A promising candidate for the next particle discovery is a resonance decaying to pairs of leptons or photons. Experimentally, such a resonance would appear as a clear narrow peak in the mass spectrum, since detector resolutions are optimal for leptons and photons and such a resonance would typically have a narrow intrinsic width. Currently the Tevatron has the best sensitivity to new resonances decaying to leptons and photons, with limits approaching the kinematic limit for resonances with the largest predicted couplings. While improving sensitivity near this limit simply requires accumulating more integrated luminosity because of negligible backgrounds, improving sensitivity to weakly coupled resonances benefits from improved experimental techniques to separate the resonance from the background. Recently, CDF has observed a 2.5σ excess at a mass of about 240 GeV/c^2 in the dielectron spectrum [1], motivating further investigation in this mass region with additional data and decay channels.

From a theoretical standpoint, resonances decaying to leptons or photons are highly motivated. They are ubiquitous in models of new physics, and can appear as spin-0, 1, or 2 bosons. Examples of spin-0 resonances are Higgs bosons [2] or sneutrinos in supersymmetric models [3]. Sneutrinos would be produced as resonances at the Tevatron if there are R-parity violating $qq\tilde{\nu}$ and $ll\tilde{\nu}$ couplings. Such couplings are allowed by proton decay limits, and conserve baryon number. This conservation provides greater suppression of proton decay than the conservation of R-parity alone.

Spin-1 resonances are predicted in models with extended gauge groups that break down to the standard model (SM) plus a new U(1) group near the electroweak mass scale [4]. In superstring-inspired grand unified theories, the extended gauge group is E8$\times$E8 and the coupling of the new neutral gauge boson (Z') is determined by a single parameter. Other models with an additional U(1) group are the Stückelberg model where the Z' boson acquires mass without a Higgs mechanism, and a model where the Z' boson has flavor-dependent charge.

Models of warped extra dimensions predict a tower of spin-2 graviton resonances with masses and couplings determined by the ratio of the curvature of the extra dimension (k) to the Planck mass (M_{Pl}) [5]. Such models were originally proposed by Randall and Sundrum and explain the hierarchy of mass scales between the electroweak and gravitational forces through a metric with an exponential factor as a function of position in the extra dimension.

The CDF and D0 collaborations at the Tevatron are actively searching for new resonances decaying to dileptons and diphotons, recently updating a number of decay modes and interpreting the results in terms of new models. In addition, the collaborations are applying new techniques to improve the senstivity of the searches beyond the simple addition of newly collected data.

2. CDF Dilepton and Diphoton Searches

CDF has published resonance searches in the dimuon [6] and dielectron [1] channels, with the dimuon search giving the best published sensitivity to sneutrino and Z' boson production at high mass. The dimuon search uses a novel method of fitting the inverse dimuon mass ($1/m$) distribution [6, 7], for which the detector has approximately constant resolution. Thus, a resonance would have about the same width at any point in the $1/m$ spectrum. The search also fits for a Z' contribution over the full $1/m$ distribution for mass above 100 GeV/c^2, increasing sensitivity relative to a search

$\tilde{\nu}$	$\tilde{\nu}$	Z'	Z'	RS graviton	graviton
$(\lambda'_{i11})^2 \cdot BR$	mass limit[a]	model	mass limit[b]	k/M_{Pl}	mass limit[c]
0.0001	397	Z'_I	817	0.01	472
0.0002	441	Z'_{sec}	858	0.015	560
0.0005	541	Z'_N	900	0.025	706
0.001	662	Z'_ψ	917	0.035	790
0.002	731	Z'_χ	930	0.05	850
0.005	810	Z'_η	938	0.07	899
0.01	866	Z'_{SM}	1071	0.1	976

Table 1: 95% C.L. lower mass limits in GeV/c^2 from CDF searches for a resonance decaying to dimuons in [a]2.3 fb^{-1} [6] and [b]4.6 fb^{-1} of data, and for a resonance decaying to diphotons in [c]5.4 fb^{-1} of data. Limits are set on representative models for resonances with spin 0 (sneutrinos), spin 1 (Z' bosons), and spin 2 (gravitons). The Z'_{SM} boson has the same couplings to fermions as the Z boson.

that uses mass windows. Table 1 shows the mass limits on sneutrinos, Z' bosons, and gravitons, derived from the CDF dimuon searches in 2.3 and 4.6 fb^{-1} of data, and from the CDF diphoton search in 5.4 fb^{-1} of data.

CDF has also searched in dielectron data using 2.5 fb^{-1} of data [1]. The search finds an excess in the data at a mass near 240 GeV/c^2 with a 2.5σ significance as determined from pseudoexperiments searching the entire mass spectrum. A new result from CDF in 4.6 fb^{-1} of dimuon data improves on the 2.3 fb^{-1} search in $1/m$ by calculating a per-event likelihood as a function of mass, based on the Z' boson matrix element. The result gains 20% in sensitivity beyond the increase in luminosity, by probing angular distributions and accounting for expected muon resolutions for each event. The search directly fits for both the mass and yield of the most significant excess in a simultaneous measurement. The best-fit point in the mass-yield plane has a mass of 199 GeV/c^2 and a 16% probability of arising from a background fluctuation. The world's highest mass limits are set on Z' bosons in various superstring inspired models and in a model with flavor-violating couplings.

A spin-2 graviton has a larger branching ratio to spin-1 photons than to spin-1/2 fermions, so searches for resonances decaying to diphotons are generally the most sensitive to graviton production. CDF has performed such a search with 5.4 fb^{-1} of data, observing a small excess at a mass of 200 GeV/c^2 (Fig. 1) that is consistent with a background fluctuation. Lower mass limits on gravitons are set as a function of k/M_{Pl} (Fig. 1); representative limits are given in Table 1.

3. DØ Dilepton and Diphoton Searches

While CDF does not confirm its dielectron excess in the dimuon data, it is still possible that a Z' boson with non-universal flavor couplings could be the source of the excess. To test this possibility, DØ has searched for a Z' boson in its dielectron data [8], finding no excess near a dielectron mass of 240 GeV/c^2. DØ sets limits on the mass of a Z' boson in the suite of superstring-inspired models shown in Table 1 (e.g., $M_{Z'_I} > 795$ GeV/c^2), and in the Stückelberg model (e.g., $M_{Z'} > 417$ GeV/c^2

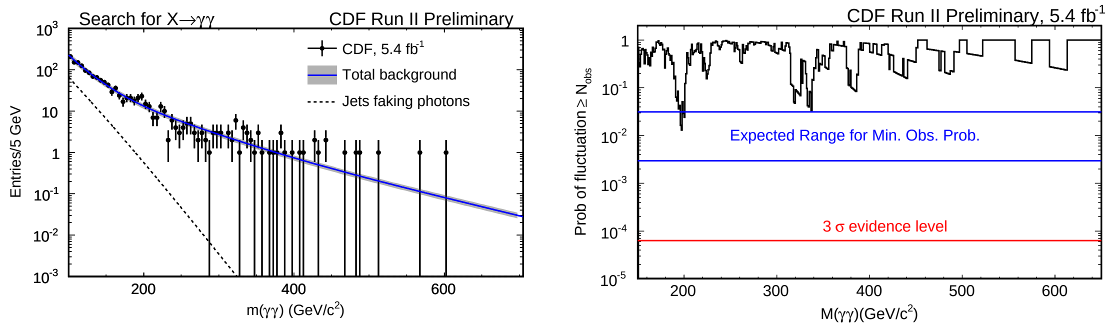

Figure 1: Left: The CDF diphoton mass spectrum in 5.4 fb^{-1} of data, compared to SM background (solid line). Right: The probability for a background to fluctuate up to or above the observed number of events in the CDF data, as a function of diphoton mass.

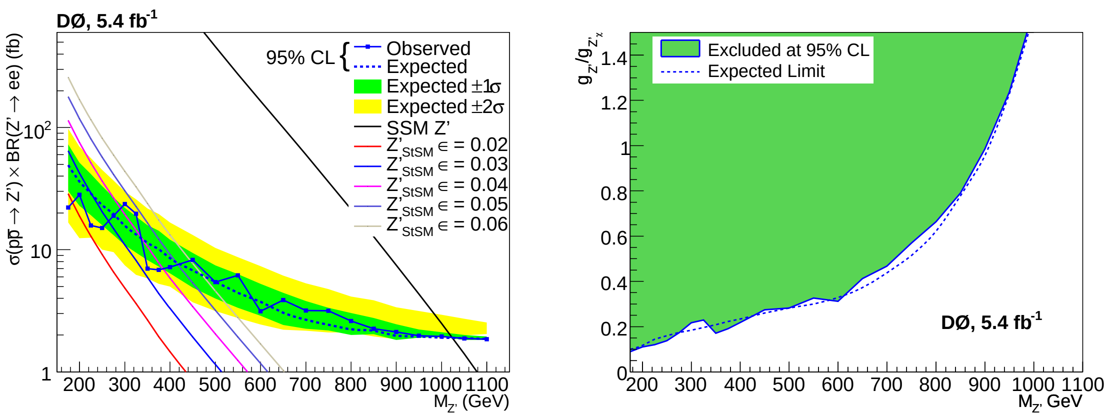

Figure 2: Left: Limits on the production cross section of a Z' boson in the Stückelberg model, compared to theoretical predictions for several values of the parameter defining its mixing with the SM photon (ε). Right: Limits in the plane of Z'_χ boson mass and the ratio of the gauge coupling to that predicted by the model with an additional $U(1)_\chi$.

for mixing parameter $\varepsilon = 0.05$). To cover a broader class of models, DØ has set limits in the mass-coupling ratio plane (Fig. 2), where the coupling ratio is defined in the Z'_χ model as $g'_Z/g_{Z'_\chi}$.

DØ also combines searches in 5.4 fb^{-1} of dielectron and diphoton data to maximize its sensitivity to resonant graviton production [9]. The diphoton data has an excess over the SM background near a mass of 450 GeV/c^2 (Fig. 3), with a significance of 2.3σ for the background to fluctuate to at least as large an excess anywhere in the mass distribution. There is no corresponding excess in the dielectron data however, and the CDF diphoton search shows only a small excess in this mass region. After combining its searches, DØ sets the world's highest mass limits on resonant graviton production (Fig. 3).

4. Summary

The Tevatron experiments continue to search for resonances decaying to dileptons and dipho-

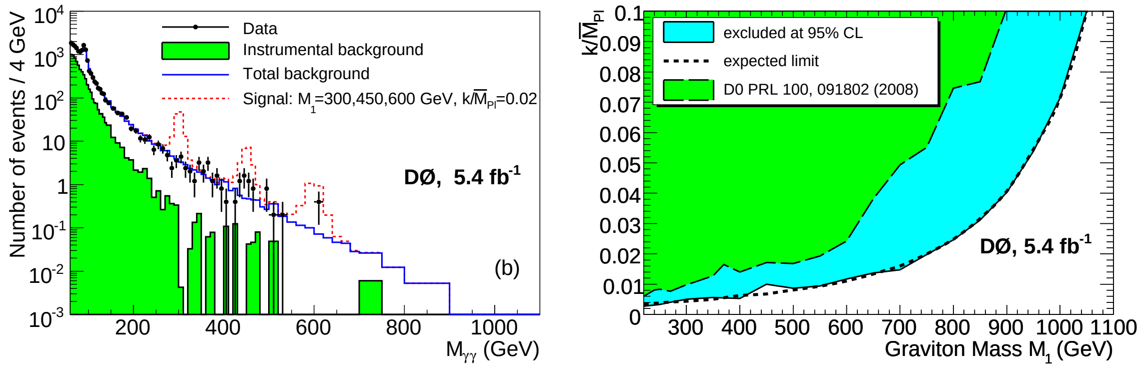

Figure 3: Left: The DØ diphoton mass spectrum in 5.4 fb^{-1} of data, compared to SM background (blue solid line) and to hypothetical graviton resonances (dashed red line). Right: Expected (dashed) and observed (solid) limits on the graviton mass as a function of k/M_{Pl} from the combined DØ dielectron and diphoton searches.

tons. Continued data taking improves sensitivity near the kinematic limit where background is low, and improved analysis techniques are increasing the power to separate a signal from background at lower mass values. The sensitivity of the searches are thus extending both to higher masses, above 1 TeV/c^2 in some cases, and to weaker couplings. While no evidence for a new neutral resonance has been observed, various peaks in the distributions will be vigorously pursued with the larger available data sets, now totaling more than 9 fb^{-1} per experiment.

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