Searches for Extra Dimensions and Heavy di-lepton Resonances at DØ

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ABSTRACT

Di-lepton final states are among the most distinct and well measured experimental signatures in proton-antiproton collider experiments. In this presentation, the DØ experiment shows its latest results which exploit these channels to search for new extra dimensions and new di-lepton resonances. These results comprise the best limits on such new phenomena in collider experiments to date in the di-electron and di-photon channel (using 200 pb^{-1} of data). Results in the di-muon channel are also presented.

1. Introduction

The Fermilab Tevatron is living up to expectations in Run 2, delivering an increased center-of-mass energy of 1.96 TeV (versus 1.8 TeV in Run 1) and increased particle collision intensities to the 2 collider experiments (DØ and CDF). The DØ experiment is performing well and has begun to publish intermediate Run 2 results surpassing those of Run 1 as we continue to collect statistics and improve measurement systematics. This presentation highlights some of those recent results. See Reference [1] for further details.

2. Searches for Extra Dimensions

Proposals for extra dimensions date back at least to the 1920's. More recently, such theories have experienced a renaissance due to revised theoretical interest and methods but also due in part to an increased relevance to experiments at currently accessible energy scales.

Such theories propose to unite all known forces (including gravity) by confining some or all of the Standard Model (SM) particles, electroweak and strong interactions to a 'brane' (a hypersurface containing the conventional 4 dimensions of space-time) while allowing apparently weaker phenomena such as gravity access to n additional dimensions, making gravity appear weaker in 4D. In these models: $M_{Pl}^2 \propto M_S^{n+2} \times R_c^n$ expresses the dilution of the apparent 4D Planck Scale M_{Pl} by the size R_c of the n dimensions, thus reducing the magnitude of the fundamental Planck Scale M_S.

Known constraints on the number and size of extra dimensions come from from cosmological considerations ($n > 1$ due to known gravitational forces at large distances) and tabletop experiments (extra dimensions must be 'compactified': $R_C < 150\mu m$). High Energy collider experiments are the only known probe for extra dimensions where $n \geq 3$. The DØ experiment shows limits here on two models which predict observable differences in SM cross sections at Tevatron Collider energies.

2.1. Large Extra Dimensions (LED)

In the model proposed by Arkani-Hamed, Dimopoulos, and Dvali [3], SM particles and interactions are confined to the brane while gravity propagates in $4+n$-Dimensional space. A variable η_G is used to parameterize the effect of additional dimensions on the predicted cross section[2] for di-lepton or di-photon production:

$$\frac{d^2\sigma}{dMdcos\theta^*} = f_{SM} + f_{int}\eta_G + f_{KK}\eta_G^2. \tag{1}$$

The strength of the additional terms with LED dependence: f_{int}, the interference of the graviton-induced amplitude and f_{KK}, the pure graviton exchange term have a dependence on η_G, which is parameterized as $\eta_G = F/M_S^4$ where M_S is expected to be closely related to the fundamental Planck Scale. The dimensionless parameter F of order unity reflects the dependence of the cross section on the formalism of the effective Lagrangian for which we explore suggested forms of GRW[5], HLZ[6] and Hewett[7].

In this parameterization, the relevant measurables are M (the invariant mass of the di-boson or di-lepton pair) and $cos\theta^*$ (the cosine of their scattering angle). DØ has used about 200 pb^{-1} of Run 2 data, selecting all di-EM objects (both di-electron and di-photon channels) to enhance sensitivity to LEDs. The data points of Fig. 1 show the measured invariant mass of di-EM candidates meeting fiducial and tight quality requirements (in addition to having $E_t > 25$ GeV). The solid line indicates the expectations from the SM (including the shaded histogram showing misidentified EM objects from the QCD background), while the dashed line shows the expected enhancement of the cross section from a LED signal with $\eta_G = 0.6$.

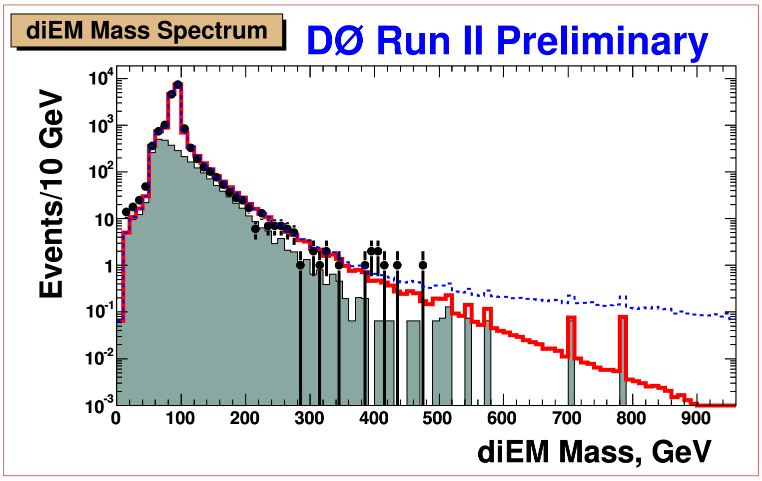

Figure 1: Data points show the invariant mass distribution of di-EM objects (including di-electrons and di-photons) meeting the selection criteria. Solid and dashed lines indicate SM and SM+LED(η_G = 0.6) signals, respectively. The shaded histogram indicates expected misidentified EM objects in QCD background.

The data/theory comparison indicates no evidence for LED. We quantify this comparison by obtaining a best estimate for the parameter η_G from which we extract limits on the fundamental Planck scale. DØ optimizes its limit setting technique by fitting two dimensional distributions of measured M versus $\cos\theta^*$ to the sum of the SM, interference and direct gravity terms. A lower limit of $M_S > 1.36$ TeV is obtained using the GRW[5] formalism, which is further pushed to $M_S > 1.43$ TeV by combining limits from this Run 2 data with the Run 1 sample. Limits using noted formalisms in the di-EM channel along with the limits from a similar analysis in the di-muon channel (currently under revision with increased statistics) are shown in Table 1.

Table 1: Limits (in TeV) on LED in the various formalisms as indicated. Di-EM limits obtained using Run 2 200 pb^{-1} + Run 1 data. Di-MU limits obtained using Run 2 100 pb^{-1} data.

channel	GRW[5]	HLZ[6] with n=						Hewett[7]
		2	3	4	5	6	7	$\lambda = +1$
di-EM	1.43	1.67	1.70	1.43	1.29	1.20	1.14	1.28
di-MU	0.88	1.67	1.70	1.43	1.29	1.20	1.14	0.71

2.2. TeV^{-1} ('longitudinal') Extra Dimensions (TeV^{-1}ED)

A model proposed by Dienes, Dudas, and Gherghetta[4] confines fermions to conventional 4D space-time but proposes to allow SM bosons to propagate in EDs of size $R = 1/M_C$. Kaluza-Klein (KK) states of the gauge bosons (W, Z, γ and g) become possible. In this analysis, we look for a modification of the cross section in the di-electron invariant mass or $\cos\theta^*$ distribution which might result from the virtual exchange of the KK states of the Z and γ. In this case, the effect on the cross section is bilinear in the variable $\eta_C = \frac{\pi^2}{3M_C^2}$, where M_C is the compactification scale of the TeV^{-1} EDs.

The data points of Fig. 2 shows the invariant mass of the di-electron sample using the same data set as in the LED search, but adding a track match requirement for at least one EM object. Unlike the LED enhancement in Fig. 1, this model predicts strong

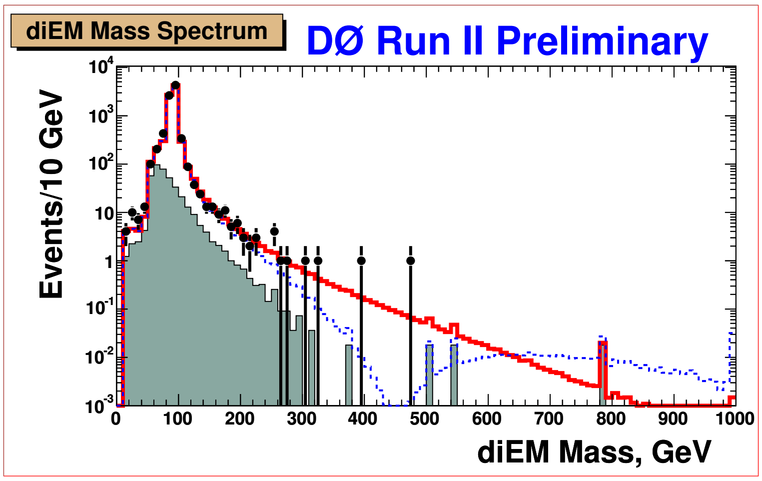

Figure 2: Data points show the invariant mass distribution of di-electron candidates meeting the selection criteria. Solid and dashed lines indicate SM and SM+TeV^{-1}ED($\eta_C = 5$TeV^{-2}) signals, respectively.

negative interference effects which suppresses the cross section at intermediate masses, but strongly enhances them at the highest masses.

Just as in the LED analysis, a best value of the η_C is obtained by comparing the measured two dimensional distribution of measured M versus $\cos\theta^*$ to the SM plus TeV^{-1} ED enhancement in the cross section. We find an upper limit of $\eta_C < 2.63$ TeV^{-2}, yielding a lower limit of $M_C > 1.12$ TeV on the compactification scale at the 95% CL. This result is the first direct limit of this type.

3. Searches for New Heavy Gauge Bosons

Various models propose new neutral gauge bosons[8]. Evidence for a number of those models has been sought using the same dataset as described earlier for the TeV^{-1}ED search for di-electrons and the LED search for di-muons.

In the di-electron channel, a limit of 780 GeV at the 95% CL is set on Z' bosons with SM couplings to fermions. For a variety of E6 GUT inspired models, limits of 575, 640, 650, 680 GeV are set on ϕ, χ, η, and I models, respectively.

In the di-muon channel, a limit of 610 GeV is set (using 100 pb^{-1} of Run 2 data). This di-muon result is currently under revision to utilize increased statistics.

4. Acknowledgements

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