CDF note 8419

Search for Massive Resonances Decaying to Z^0Z^0 in the Final State $eeee$.

The CDF Collaboration
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We report the results of a search for a massive object decaying to a pair of Z^0 bosons, which both decay to electrons. The cross section times branching fraction for Randall-Sundrum [1],[2] Gravitons which decay to Z^0 bosons are small, which leads to an expectation of order one $G \rightarrow Z^0Z^0 \rightarrow eeee$ event produced in 2 fb^{-1} of data. In order to be maximally sensitive to any signal we might record, we have developed a very efficient electron selection, which is twice as efficient as CDF standard tight selection for Standard Model $Z^0 \rightarrow e^+e^-$ events and a factor of four times more efficient for $G \rightarrow Z^0Z^0 \rightarrow eeee$ events. Using a novel data-based background estimation technique, we estimate the background in our signal region to be 0.02 ± 0.02 events in 1.1 fb^{-1} of data. After finding zero events in our signal region, we set limits on graviton production assuming Randall-Sundrum couplings.

Preliminary Results for Summer 2006 Conferences

TABLE I: Central Electron Identification Criteria

Selection Criteria	Trigger (CEM)	Minimal (CEM)
E_T(GeV)	≥ 20	≥ 5
$\lvert$Track $z_0\rvert$ (cm)	< 60	< 60
Had/EM	$< 0.055 + (0.00045 \times E)$	$< 0.055 + (0.00045 \times E)$
Isolation	< 0.2	< 0.2
LshrTrk	< 0.4	
Track p_T (GeV/c)	≥ 10	

TABLE II: Plug Electron Identification Criteria

Selection Criteria	Minimal (PEM)
E_T(GeV)	≥ 5
Had/EM	< 0.05
Isolation	< 0.2
$\lvert\eta_{\mathrm{det}}\rvert$	< 2.5

I. INTRODUCTION

In this note we present a search for production of massive ($m > 500$GeV) resonances decaying to Z^0Z^0 in the final state $eeee$ in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. The Standard Model predicts 0.008 Z^0Z^0 events with $m_{eeee} > 500$ GeV in 1.1fb^{-1}. Any events observed with $m_{eeee} > 500$ GeV would be interesting and could be a hint of physics beyond the Standard Model.

The CDF detector is described in detail in [3]. A summary of the data sample used and our event selection criteria is in Section II. We have developed a method to estimate backgrounds using data which we describe in Section III. In Section V we report the results of unhiding the signal region in data and we interpret our results in the context of the Randall-Sundrum Graviton model.

II. DATA SAMPLE & EVENT SELECTION

This analysis is based on an integrated luminosity of 1.1fb^{-1} collected with the CDFII detector between March 2002 and February 2006. The data are collected with inclusive lepton triggers that require a central electron and associated track with E_T >18 GeV, $p_T > 9$ GeV and $\mathrm{E_{Had}/E_{EM}} < 0.125$, or E_T¿70GeV and $p_T > 15$ GeV with no $\mathrm{E_{Had}/E_{EM}}$ requirement.

From this inclusive lepton dataset we select events offline with a reconstructed isolated central electron with E_T greater than 20 GeV which satisfies offline trigger criteria (Trigger), and three additonal Minimal Calorimeter (Isolated Track) electron candidates with $\mathrm{E_T} > 5(10)$ GeV. Isolated Track electron candidates are further required to be separated by at least 0.2 in ΔR_{EM}, the distance in the $|\eta| - \phi$ plane between the track candidate and the closest calorimeter electron candidate. We additionally require electron candidates satisfy the requirements summarized in Tables I, II, and III.

Standard electron selection was designed to reconstruct clean samples of W bosons, and therefore trades efficiency for purity. These selection criteria are inappropriate when trying to fully-reconstruct four lepton final states. We have relaxed many requirements, and added track electron candidates to recover efficiency. The relaxed selection admits more background, which we reject later by imposing kinematic requirements on the invariant masses of the two Z^0 candidates. A comparison of the di-electron invariant mass using standard W-like electron selection and our relaxed selection is shown in Figure 1 for the first 367 pb^{-1}.

The dataset selected above is dominated by production of Z^0 bosons with multiple jets that are misidentified as electrons. We characterize events by the invariant mass of the four-electron system, and a χ^2 variable formed from the two Z^0 candidates' invariant masses:

$$\chi^2 = \left(\frac{m_1 - m_{\mathrm{PDG}}}{\sigma_1}\right)^2 + \left(\frac{m_2 - m_{\mathrm{PDG}}}{\sigma_2}\right)^2. \quad (1)$$

TABLE III: Track Electron Identification Criteria

Selection Criteria	Track Electrons
Track Type	DefTracks
p_T(GeV)	≥ 10
COT Axial Segments	≥ 3
COT Stereo Segments	≥ 2
$\lvert$Track $z_0\rvert$ (cm)	< 60
Track Isolation	< 0.9
$\lvert d_0\rvert(cm)$	< 0.2 (< 0.02 if silicon present)
ΔR_{EM}	> 0.2

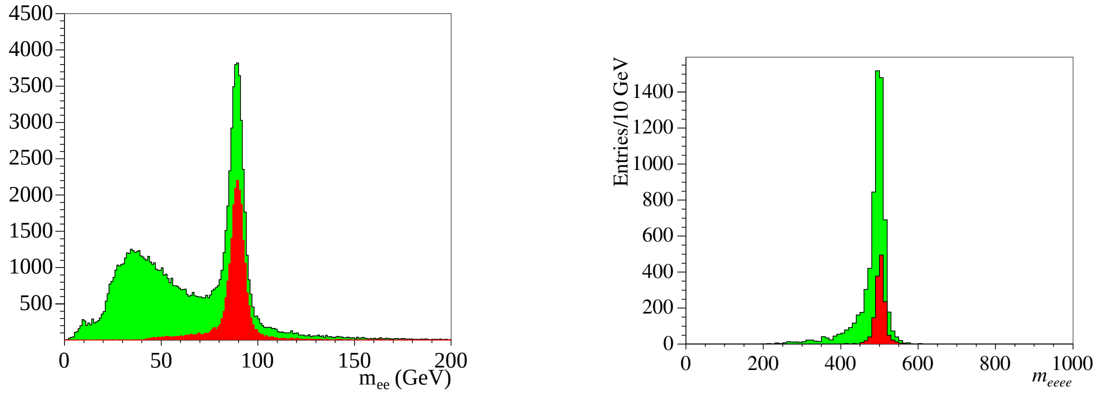

FIG. 1: Comparison for standard W-like electron selection (red) and relaxed selection(green) for the m_{ee} distribution in the first 367 pb^{-1} of data (left), and the m_{eeee} distribution in signal Monte Carlo (right).

We *a priori* define our signal region to be $m_{eeee} > 500$ GeV and $\chi^2 < 50$ using signal Monte Carlo. A data-driven technique for estimating the background in the signal region is used.

III. BACKGROUND ESTIMATION

We expect the background from events with at least one object faking an electron in the signal region $m_{eeee} > 500$ GeV to be dominated by Z+jets, W+jets, and QCD. We have looked at Monte Carlo samples for each of these background sources and have found rough consistency with data in the low-mass region, but are limited by the statistics of these samples in the high-mass region. The distribution of m_{eeee} after selecting events with $\chi^2 < 50$ for data with normalized background Monte Carlo is shown in Figure 2, along with the χ^2 versus m_{eeee} distribution. Instead of relying on Monte Carlo, we have developed a method using data to estimate the background.

In order to estimate the shape of the background in m_{eeee} without relying on Monte Carlo, we have selected a sample in data which is kinematically similar to the signal and used it to estimate backgrounds in the signal region. We select a sample of electron-like candidates by identifying energy deposits in our electromagnetic calorimeter which have associated large energy deposits in the hadronic calorimeter and are thus inconsistent with originating from a true electron (hadronic fake). Specifically, we require hadronic fakes to satisfy $\mathrm{E_{Had}/E_{EM}} > 0.055 + 0.00045 \times E$. We then form four mutually-exclusive control samples by selecting events with n electrons and $(4 - n)$ hadronic fakes, with $n \in [1, 4]$.

The distribution of χ^2 versus m_{eeee} is fit simultaneously to all categories above 185 GeV ($\sim 2 \times m_{Z^0}$) to a single Probability Density Function(PDF) which emperically describes the shape, and is motivated by the expectation that the m_{eeee} distribution in background should be governed by phase-space considerations and thus described by a power law,

$$f(\chi^2, m_{eeee}) \;=\; m_{eeee}^{\gamma} \times e^{\chi^2/\tau}, \tag{2}$$

where γ is the parameter which describes the power-law behavior, and τ describes the shape of the χ^2 distribution.

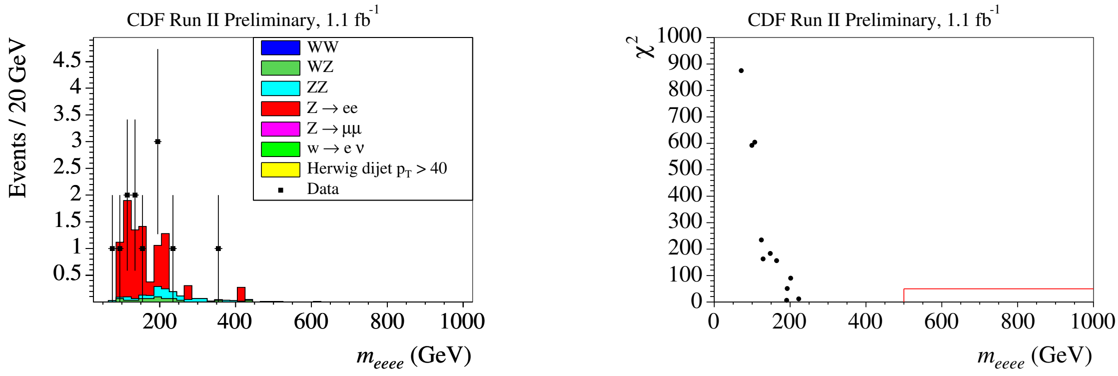

FIG. 2: At left, Distribution m_{eeee} for data (black points) and Monte Carlo (colored histograms). The distribution of χ^2 versus m_{eeee} is shown at right. The search region is outlined in red.

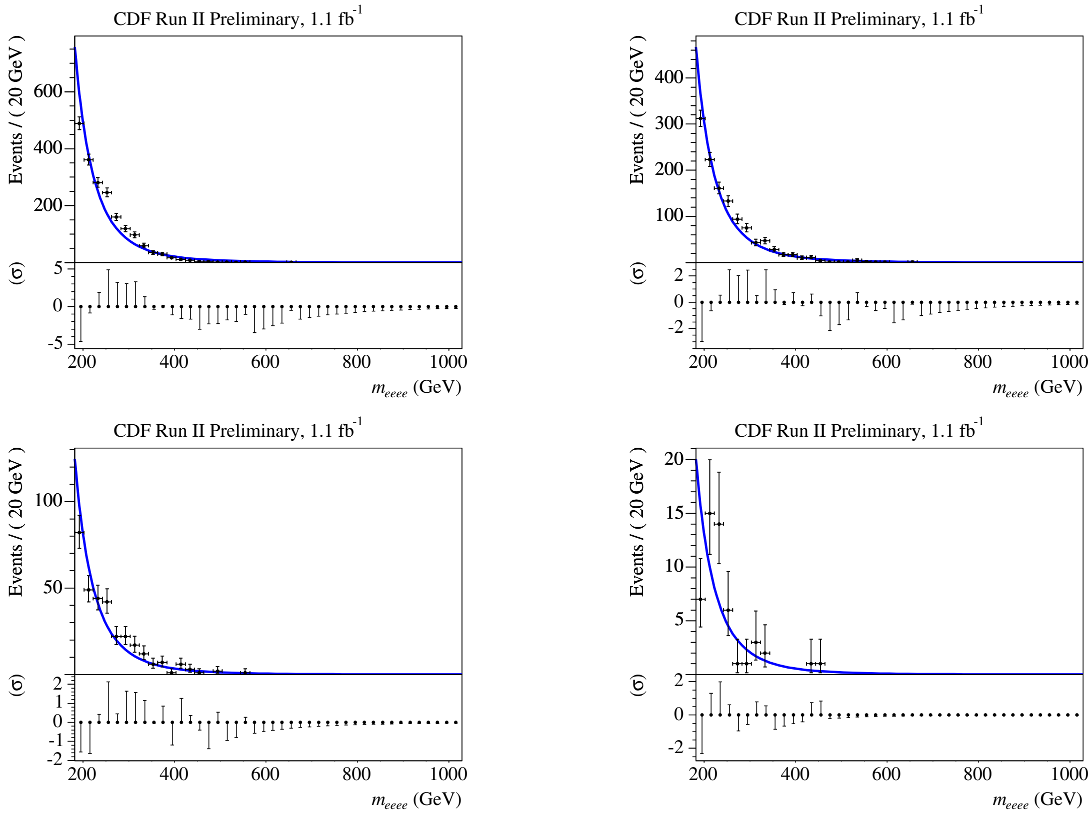

FIG. 3: Distribution m_{eeee} for fits to control samples having 4, 3, 2, and 1 electron replaced with a hadronic fake.

We integrate the signal PDF above 500 GeV and for $\chi^2 < 50$ to obtain an estimate of the expected background in this region. The result of this fit is shown in Figure 3.

IV. ACCEPTANCE AND EFFICIENCY

The geometric and kinematic acceptance of the basic event selection is measured using the HERWIG Monte Carlo program [4] to generate samples of Randall-Sundrum Gravitons for masses between 500GeV and 1 TeV. The total acceptance and efficiency varies from 60% to 40%, and is shown as a function of the invariant mass of the generated

TABLE IV: Nominal Background Fit Result.

Floating Parameter	FinalValue	$\pm$	Error
γ	-4.630	$\pm$	0.064
n_0	4.0	$\pm$	2.0
n_1	51.0	$\pm$	7.1
n_2	317	$\pm$	18
n_3	1188	$\pm$	35
n_4	1927	$\pm$	44
τ	-0.003127	$\pm$	0.000072

Graviton in Figure 4.

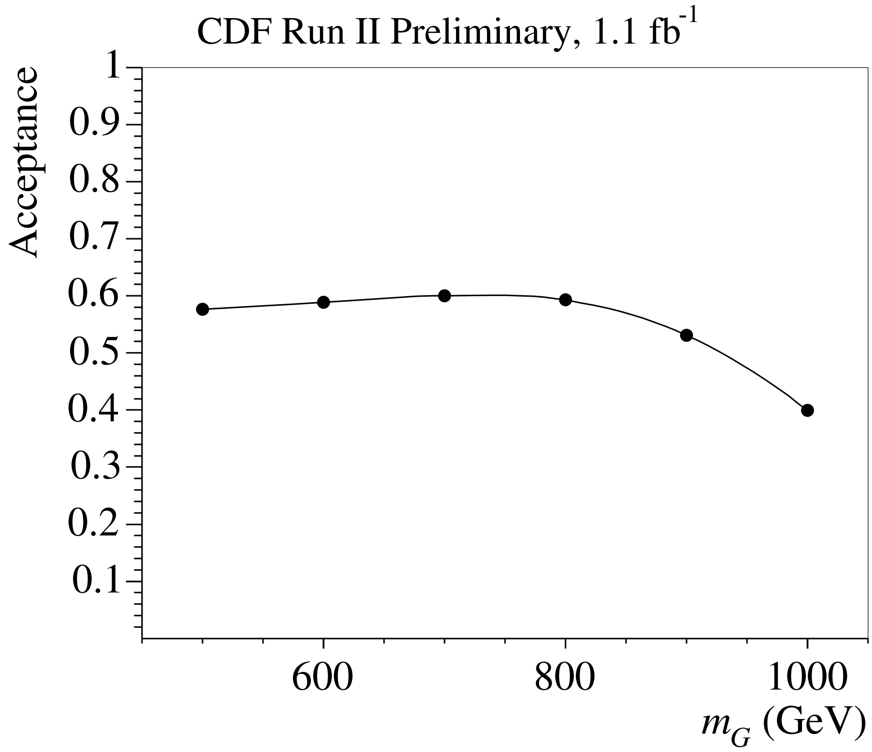

FIG. 4: Acceptance for the RS Graviton model with $k/m_P = 0.1$ versus Graviton mass

V. RESULTS

After unhiding the signal region, we observe zeero events with $m_{eeee} > 500$. The lowest χ^2 event is shown in Figure 6. The invaraint masses of the two Z^0 candidates in the lowest-chisquared ordering are 91 and 92 GeV, consistent with $Z^0 Z^0$ production. We compute cross section times branching fraction limits assuming zero backgrounds, and using the background prediction from Section III as an estimate of the uncertainty of the background estimation.

A. Limit

Using the Acceptance and efficiency from Section IV, and conservatively estimating our background to be 0 ± 0.02, we find mass-dependent limits shown in Figure 5. We include systematic uncertainties when setting the limit using

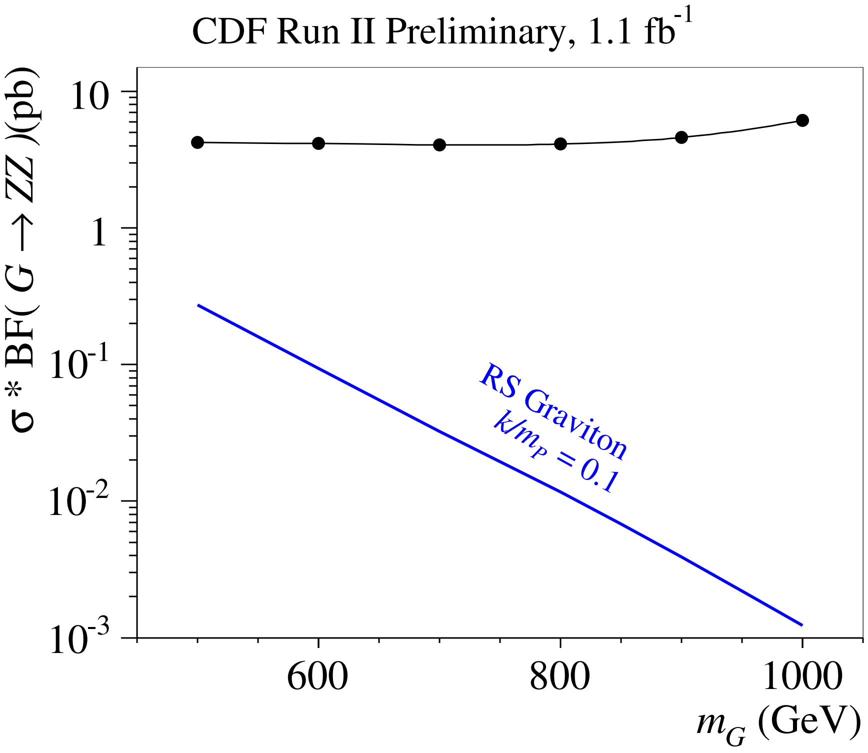

FIG. 5: Limits on $\sigma \times \text{BF}(G \to Z^0 Z^0)$.

CDF standard reccomended techniques. The sources of uncertainty are uncertainty on luminosity (5.9%), PDF uncertainties (0.4%), signal Monte Carlo Statistics (1.3%), ISR/FSR(1.0%), and the electron identification Monte Carlo to data matching correction (1.0% per electron). The total systematic uncertainty from all sources is 7.3%.

Acknowledgments

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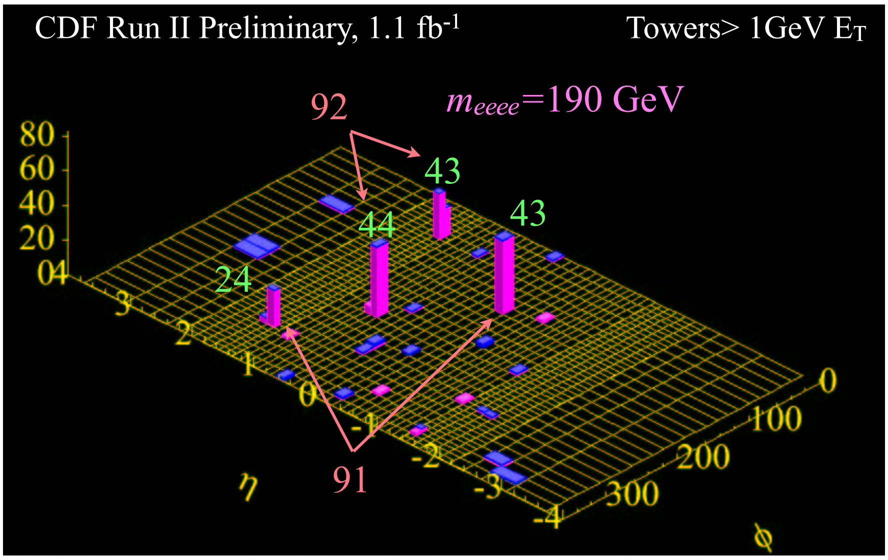

FIG. 6: Event display of lowest χ^2 event