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High-Mass Dielectron Resonance Search in $p\bar{p}$ Collisions at $\sqrt{s}$ =1.96 TeV

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Based on 0.9 fb^{-1} of $p\bar{p}$ collision data collected with the CDF II detector at the Fermilab Tevatron at $\sqrt{s}$ =1.96 TeV, we report on a search for high-mass narrow resonance in the dielectron channel. The most significant region of excess of data over background occurs for a dielectron mass window of ≈240 GeV/c^2, and is 2.8 to 3.7 standard deviations from the Standard Model prediction. The probability of observing a background fluctuation with significance $(S/\sigma_B) \geq 3.7$ anywhere in the mass range 150-500 GeV/c^2 is about 1.7%.

I. INTRODUCTION

The lepton-antilepton pair, in particular e^+e^- and $\mu^+\mu^-$, signature has been a leading discovery channel for new particles, such as J/ψ and Υ mesons, and Z boson. Even though leptonic decay rates are generally lower than hadronic decay rates, these channels are preferred for particle searches since leptonic channels have relatively low backgrounds compared to hadronic channels. Further, leptons are relatively easy to identify and their energies and momenta can be measured more precisely than hadrons. Many extensions of the Standard Model and other models beyond the Standard Model predict the existence of particles decaying to lepton-antilepton pairs such as the heavy gauge boson (Z') [1] or graviton arising from large extra dimensions [2].

In a recent publication, the CDF collaboration has set limits on several models by analyzing the dielectron invariant mass and angular distributions of dielectron events with 0.45 fb^{-1} of integrated luminosity [3]. The lower mass limits for new particles vary from 650 to 910 GeV/c^2, depending on the model. This note describes an updated search based on 0.9 fb^{-1} of luminosity, with focus on an excess of events in the dielectron invariant mass spectrum near 240 GeV/c^2.

II. DATA SAMPLE & EVENT SELECTION

This analysis is based on an integrated luminosity of 0.9 fb^{-1} collected with the CDF II detector between March 2002 and September 2005. The CDF detector is described in detail in [4]. Three triggers are used to select the data for this analysis. The first trigger requires two EM clusters with E_T >18 GeV in the calorimeter, the second one requires a central EM cluster with E_T >70 GeV and the last one requires one central EM cluster with E_T >18 GeV and loose electron (throughout this note the charge conjugate state is implied) selection. For the latter two triggers, a well-measured track pointing to an energy deposition in the calorimeter is required. With these three triggers, the efficiency for events passing offline selections is ≈100%. For this analysis, we require an event to have one electron in the central region and the other electron in either the central or forward ("plug") region. The transverse energy of electrons is required to be greater than 25 GeV and the pseudo-rapidity of electrons is required to be within ±2. The central region electrons are required to have a well-measured track pointing at an energy deposition in the calorimeter. For electrons in the plug region, the track association uses a calorimeter-seeded silicon tracking algorithm [5].

III. BACKGROUNDS

There are three categories of background contributing to the dielectron final state. One is Drell-Yan production, which is the dominant source of background and is irreducible. Another is the QCD jet production in dijets and W+jets ("QCD"), where the jets are misidentified as electrons. Other than Drell-Yan and QCD production, there are contributions from $W\gamma$, $Z/\gamma^* \to \tau\tau$, $t\bar{t}$ and diboson ($WW/WZ/ZZ/\gamma\gamma$) production, which are referred to as "Other Standard Model" backgrounds. The Drell-Yan MC generated with PYTHIA [6] is used to to estimate the Drell-Yan contribution. The Drell-Yan MC is normalized to the data in an invariant mass window from 76 to 106 GeV/c^2 for central-central dielectron events and from 81 to 101 GeV/c^2 for central-plug region events. The mass windows are different because the QCD background in the central-plug region events is higher than in the central-central region. We assign 3.6% systematic uncertainty in the Drell-Yan prediction due to the invariant mass dependency of the k-factor [7].

The QCD background estimation is data driven and is obtained using the probability for a jet to be misidentified as an electron ("fake rate"), which is measured using jet triggered data samples. The fake rate obtained from jet data is applied to each jet in events with one good electron candidate and one or more jets. Both W and Z boson events are removed from the sample before applying the fake rate for dijet background contribution. To estimate W+jet background, Z boson events are removed and W boson events are retained before applying the fake rate. The dominant systematic uncertainty on the QCD background is due to the fake rate uncertainties, which are 20% in the central region and 25% in the plug region. Other Standard Model contributions are estimated with MC samples, which are normalized using the theoretical cross sections. The dominant systematic uncertainty of other Standard Model background is due to luminosity [8], and it 6%. Table I summarizes the expected background contributions other than Drell-Yan production. Figure 1 shows the total background estimation including Drell-Yan, along with the observed data for the combined central-central and the central-plug dielectron samples.

Source	central-central (CC)	central-plug (CP)	CC+CP
Other Standard Model	60.3±5.4	49.7±4.6	110.0±10.0
QCD	10.0±2.0	20.4±6.1	30.4±8.1

TABLE I: The expected backgrounds in the mass range greater than 50 GeV/c^2. The uncertainties include systematical and statistical uncertainties.

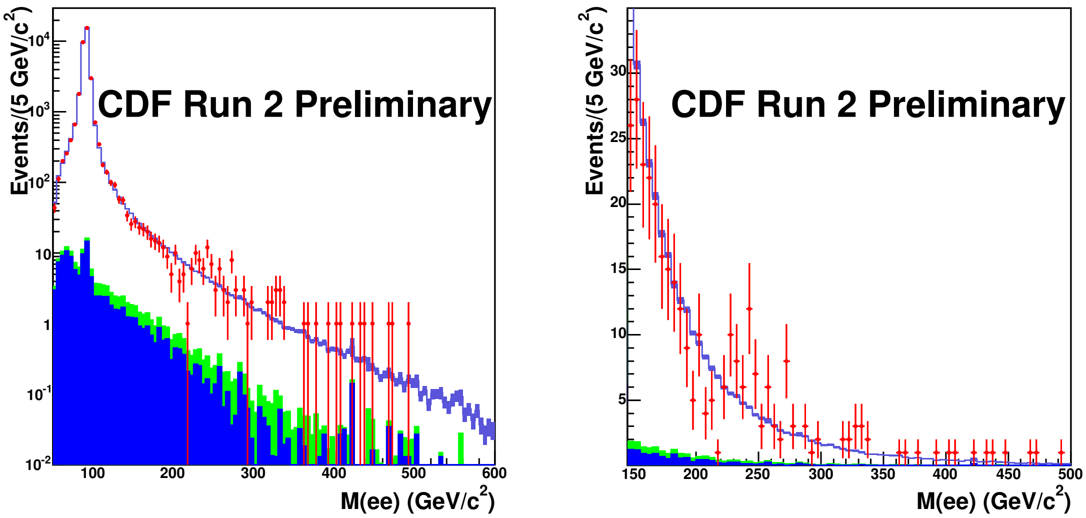

FIG. 1: Invariant mass distribution of dielectron data compared to the expected backgrounds. Red dots with error bars are data. The blue shaded region is "Other Standard Model" background, the green region is "QCD" background, and the white region is $Z/\gamma^* \rightarrow e^+e^-$ background. The left plot shows the entire mass region and the right plot shows the high-mass search region.

IV. SIGNAL SIGNIFICANCE

We calculate $S/\sqrt{B}$ by counting the number of observed events and estimated backgrounds for several mass windows in the region of the most significant excess of data over background, and show the results in Table II. The mass windows are chosen to be compatible with the detector resolution which are obtained using narrow width spin-1 particle and CDF full simulation. To estimate the probability of observing an excess equal or greater to the maximum observed excess, we use a $\Delta\chi^2$ method. The $\Delta\chi^2$ is defined as $\Delta\chi^2 = \chi^2_{bkg} - \chi^2_{sig+bkg}$, where χ^2_{bkg} is the χ^2 with the null hypothesis, which is described by background only, and $\chi^2_{sig+bkg}$ is the χ^2 with the test hypothesis, which is described by a gaussian signal in addition to background. We find a maximum $\Delta\chi^2$ of 17.3 at a dielectron mass of 240 GeV/c^2 when scanning the mass spectrum between 150 GeV/c^2 and 500 GeV/c^2 in steps of 5 GeV/c^2 (Fig. 2). To quantify the probability associated with the maximum $\Delta\chi^2$ observed in data, we repeat the procedure with 50,000 pseudo-experiments with no signal included. The probability of observing an equal or greater excess anywhere in the 150-500 GeV/c^2 mass range is found to be 1.7%.

V. SYSTEMATIC UNCERTAINTIES

The dominant source of systematic uncertainty in this analysis are the Drell-Yan prediction, fake rate and luminosity. Other systematic sources are the uncertainty on the electron identification efficiency (2.0% for central and 2.2% for plug electrons), the energy scale (1.5% for both central and plug electrons) and the energy resolution (1.1% for central and 0.5% for plug electrons). The uncertainty related to the choice of the parton distribution functions set (CTEQ6M) [9] is evaluated using the Hessian method [10] and found to be 1.9% for central-central and 0.6% for central-plug dielectron events.

Mass Range (GeV/c^2)	N_S	N_B	$S/\sqrt{B}$	S/σ_B
[220, 260]	58	37.1±2.6	3.4	3.2
[225, 260]	52	31.1±2.2	3.7	3.5
[230, 260]	42	25.5±1.8	3.3	3.1
[235, 260]	34	20.2±1.4	3.1	2.9
[225, 250]	43	24.0±1.7	3.9	3.7
[230, 255]	36	22.1±1.6	3.0	2.8

TABLE II: $S/\sqrt{B}$ for different mass windows. N_S is observed data and N_B is expected background. The σ_B is defined by $\sqrt{N_B + \sigma_{sys}^2}$, where σ_{sys} is total systematic uncertainty.

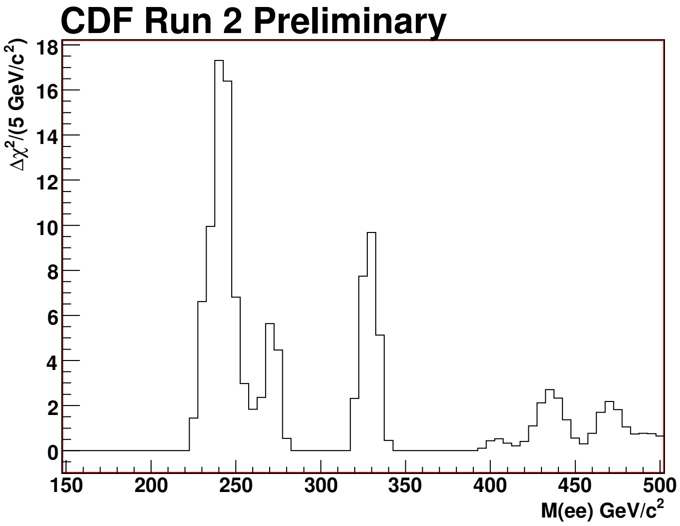

FIG. 2: The $\Delta\chi^2$ distribution based on 0.9 fb^{-1} of integrated luminosity.

VI. SUMMARY

We have searched 0.9 fb^{-1} of CDF Run 2 data for a narrow dielectron resonance. The discrepancy between data and the expected background in the region of maximum excess of data over background is 2.8 to 3.7 standard deviations, depending on the mass window. This excess has a 1.7% probability that it is caused by the background fluctuation, given that the search probes the mass range 150-500 GeV/c^2.

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