A SEARCH FOR NEW PHYSICS IN THE HIGH MASS DILEPTON SPECTRUM AT CDF*

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The high mass dilepton data can be used in searches for a variety of new physics processes. This paper summarises some of the limits obtained in Run I at the Tevatron and the possible Run II reaches. A first glimpse at the initial dilepton data from Collider Detector at Fermilab's (CDF) Run II is shown and the potential capability of the Time-of-Flight detector for cosmic ray rejection is discussed.

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The high mass dilepton[1] data can be used in searches for a variety of new physics processes. Hunting for new physics using the high mass dilepton spectrum has the advantages that there is a low background at high invariant mass and that the dileptons provide a distinctive signature. Dilepton events are identified as those which contain two isolated charged leptons which both have a high transverse momentum and originate from a single interaction point. The main Standard Model contribution to this channel is from the Drell–Yan process. New physics searches are made by looking for deviations from the Standard Model contributions at high invariant mass. Possible physics searches using this channel include new gauge bosons (Z'), extra dimensions, quark–lepton compositeness and Technicolor. The dilepton channel was utilised in Run I at the Tevatron to obtain limits, and it is proposed to be used in Run II. An initial study of the Run II CDF dilepton data has been made.

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[1] Throughout this paper dileptons is used to refer to electrons and muons, not taus.

The Collider Detector at Fermilab (CDF) is one of two general purpose detectors (the other is D0) on the Tevatron Ring at Fermilab, Illinois, USA. The Tevatron and the two detectors have recently been upgraded following Run I (1992–1995). The Tevatron is a proton anti-proton collider, and since the upgrade is operating at a centre of mass energy of 1.96 GeV (compared to 1.8 TeV in Run I). The CDF detector consists of a 1.4 Tesla superconducting solenoid surrounded by projective tower geometry calorimeters and outer muon chambers, enclosing a tracking detector system. The tracking system has silicon vertex detectors at its centre encased by a drift chamber (Central Outer Tracker, COT) [1]. Upgrades to the detector include the replacement of the silicon tracker, central tracking chamber and plug calorimeter, the introduction of a Time-of-Flight (ToF) detector and an extension of the muon detector system. The ToF detector is located just outside the COT and has an expected time resolution of approximately 100 ps. The upgrades are significant for dilepton searches. In particular, in Run II there will be, therefore, an increased electron and muon acceptance due to the new plug calorimeter and the extended muon detector coverage. In addition, the ToF detector will enable better rejection of the cosmic ray background in the dimuon spectrum, and will be, therefore, a powerful tool for Run II.

In Run I, the CDF collaboration examined the dilepton invariant mass spectrum. Using 110 pb^{-1} of data collected, a limit was assertained on the production cross section times branching ratio of a Z' boson decaying into dileptons as a function of Z' mass [2]. For $M_{Z'} > 600\,\mathrm{GeV}/c^2$, the upper limit was 40 fb at the 95 % Confidence Level (C.L.). A lower mass limit of 690 GeV/c^2 was set for the Z' with Standard Model coupling. Performing a simple extrapolation from Run I to 2 fb^{-1}, assuming the efficiency remains constant, if no candidate events in the high mass region are found then the predicted Z' mass reach could be extended to $1000\,\mathrm{GeV}/c^2$ with $\sqrt{s} = 2.0\,\mathrm{TeV}$ [1].

Limits were also set on Extra Dimensional models, in particular, the Arkani-Hamed–Dimopoulos–Dvali model (ADD) [3, 4] and the Randall and Sundrum (RS) model [5]. These models alter both the invariant mass spectrum of the dileptons and their angular distribution, due to the exchange of a spin two virtual graviton. In Run I, the 95 % C.L. for the ADD model effective Planck scale lower limit was determined to be in the range 0.9–1.5 TeV; this is predicted to be extended to 1.3–2.5 TeV in Run IIa and 1.7–3.5 TeV at the LHC, where the range corresponds to the number of extra dimensions $n = 7$–2 [6, 7]. Compactification scale (R^{-1}) limits for the RS model were also set using Run I dilepton data. At the 95 % C.L. the compactification scale was found to be less than 0.9 using Run I data and it is predicted that this can be extended to 1.2 in Run II and up to 6.7 at the LHC [8].

In addition, quark–lepton compositeness was searched for in Run I in both the dimuon and dielectron channels, by looking for an excess of dileptons compared to the Drell–Yan prediction. Run Ib dielectron data set the limits on the compositeness scale to be $\Lambda^- > 3.8\,\mathrm{TeV}$ and $\Lambda^+ > 2.6\,\mathrm{TeV}$, where the $+/-$ corresponds to the constructive/destructive interference with the dominant up-quark contribution to the cross-section. In Run II, it is expected to be able to explore up to limits of approximately 5 TeV with 2 fb^{-1} [9]. Limits were also set on Technicolor, using 120 pb^{-1} Run I D0 dielectron data. No signal was found above the expected background and consequently at the 95 % confidence level they ruled out the possibility of the techni-rho or techni-omega having masses $< 225\,\mathrm{GeV}/c^2$ in the case where both the mass of the techni-rho and the techni-pion are less than the mass of the W boson [10].

In new physics searches, it is essential to be able to determine the dilepton background events. In particular, removal of the cosmic ray background is important in the high mass dimuon samples. CDF Run I methods included back-to-back (in eta and phi) cuts and hadron TDC timing cuts. However, the former method becomes inefficient for the signals for which we are searching; for example dimuons originating from very high mass Z' particles tend to be produced very back-to-back. For this reason, the use of timing cuts is preferred to reject cosmic ray background. In Run II the introduction of the ToF detector will enable timing to be used for cosmic ray rejection and may remove the need for a back-to-back cut.

In an initial study made looking at the some of the first Run II dilepton data, it was found that even using un-calibrated ToF information (the ToF has since been calibrated), the time difference between muons in the upper half of the detector and the lower could discriminate cosmic ray muons from interaction muons. Whereas a cosmic ray muon passes through the detector from the top to the bottom, dimuons from an interaction event originate from near the center of the detector. It was found that ToF time difference for a cosmic muons peaked around -9 ns, whereas for both interaction muons and electrons, the time difference peaked, as expected, around 0 ns, as shown in Fig. 1 on the right and left, respectively. Consequently, in analysing dimuon data, a cut which required the time difference between the upper and lower muon to be greater than $-5\,\mathrm{ns}$ was found to be very effective at rejecting cosmic rays, while keeping interaction dimuons. In future, in addition to the time difference between two muons being used to reject cosmic ray events, timing cuts may be applied to the individual muon legs. Cosmic ray muons are in general out of time with the window of time expected for a muon from a $p\bar{p}$ interaction. This will improve cosmic ray rejection, particularly in the case where only one leg of muon track (upper or lower) is reconstructed. The ToF detector will be, therefore, very useful in cosmic-ray rejection in Run II.

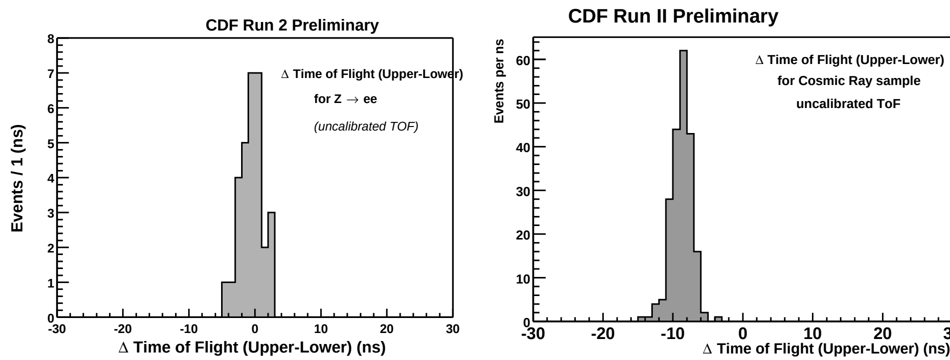

Fig. 1. Time difference of the lepton in the upper and that in the lower half of the ToF detector; for electrons (left) from a $Z \to e^+e^-$ sample and for muons (right) from a cosmic-ray sample.

Using the ToF cut outlined above for the dimuon sample along with standard electron and muon cuts, some of the first Run II data has been studied. Fig. 2 shows the invariant mass distribution for dielectrons (left) with integrated luminosity of 5.5 pb^{-1} and dimuons (right) with 7 pb^{-1}. More Run II data has since been collected and these plots are being continuously updated.

In conclusion, dileptons offer a very interesting channel to search for a variety of new physics processes. CDF has started taking data in Run II and dielectron and dimuon invariant mass plots using this data have been shown.

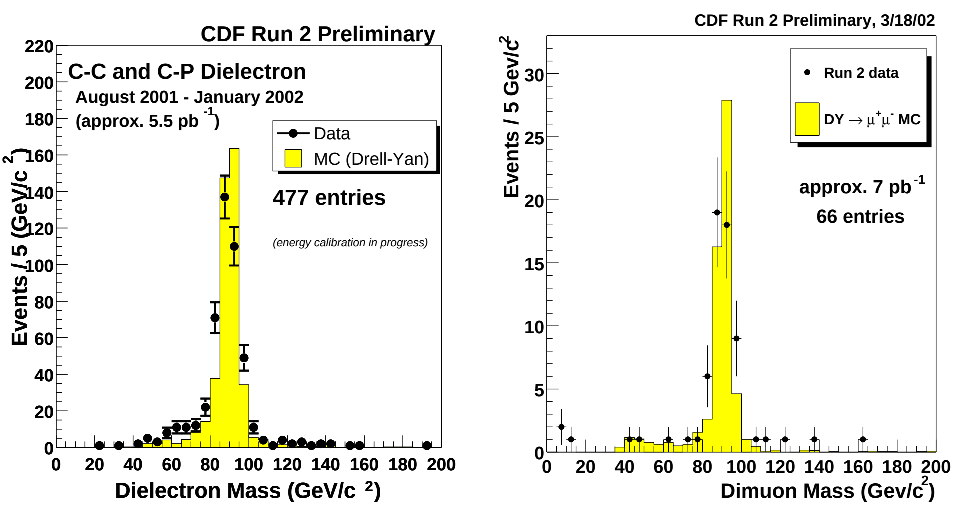

Fig. 2. Invariant mass distribution for dielectrons (left) and dimuons (right).

Improvements made to the Run II detector mean that there is a larger electron and muon acceptance than in Run I and new background rejection techniques are being developed. With more Run II data, we hope to find new physics or to improve present limits set, using the dilepton data.

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