The Compact Muon Solenoid Experiment
Conference Report

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11 August 2009 (v2, 24 August 2009)

Search for Minimum Universal Extra Dimensions with Four Leptons Final State at CMS

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Abstract

In models where extra dimensions are accessible to all particles, a new set of particles is predicted with a mass spectrum that can mimic a SUSY scenario: all Standard Model particles will have so called Kaluza-Klein partners. Recent studies of the CMS collaboration are presented on the sensitivity to searches for the minimum universal extra dimensions with a compactification scale up to 900 GeV^{-1} , using the 4 leptons final state. These studies are based on detailed detector simulation, including all Standard Model backgrounds.

Presented at *SUSY09: 17th International Conference On Supersymmetry And The Unification Of Fundamental Interactions*

1 Introduction

The universal extra dimensions [1] (UED) theory is a model in which all SM particles uniformly propagate in extra dimensions of size $R^{-1} \sim \text{TeV}$. It predicts for all SM particles there exist corresponding Kaluza Klein (KK) states in extra dimensions. They have the same quantum numbers and spins as their SM partners. The masses of KK states follow approximately

$$m_n^2 \sim m_0^2 + n^2/R^2 + \text{boundary terms}, \quad (1)$$

where n is the KK excitation level, R is the radius of extra dimensions, and m_0 is the SM partner mass. All KK states conserve a KK parity symmetry, which makes the lightest KK state stable. This lightest KK particle (LKP) becomes naturally a dark matter candidate. The UED also holds that the first KK mode is always pair-produced and looks quite like SUSY. The Minimum Universal Extra Dimensions (MUED) theory is defined in 4+1 dimensions, with only 3 free parameters R , Λ (cut off scale in MUED) and m_{higgs} (SM higgs mass). From the EW precision measurements[1][6], the R^{-1} should be $> \sim 300 \text{ GeV}$, and the dark matter constraints give an upper limit for $R^{-1} < \sim 1050 \text{ GeV}$ [1]. The KK masses are degenerated at tree level, and the mass splitting is introduced from the radiative corrections and normally within 100 GeV range. Thus the resulting leptons in the MUED decay chain are normally soft.

Figure 1: The decay cascades of the level 1 KK modes in the MUED model, depicting the dominant (solid) and rare (dotted) transitions and the resulting decay products. The upper case letter is for left-handed particles, and lower case letter is for right-handed particles. The subscript 1 indicates a level 1 KK particle. Letters without subscript are SM particles.

Fig. 1 shows the mass spectrum for the MUED from Ref. [2]. We see the dominant decay chains are through KK W (W_1) or KK Z (Z_1). If we only consider the decays from the Z_1 , this results in two SM leptons, thus becomes much easier to identify experimentally. At the LHC, proton and proton collide through the $g_1 g_1$, $g_1 q_1$, and $q_1 \bar{q}_1$ processes, and the g_1 decays to $l^+ l^- + 2 \text{ jets} + \text{MET}$, while the q_1 decays to $l^+ l^- + 2 \text{ jets} + \text{MET}$. Therefore, the final state will be two pairs of Oppose Sign Same Flavour (OSSF) leptons, i.e., $e^+ e^- e^+ e^-$ or $e^+ e^- \mu^+ \mu^-$ or $\mu^+ \mu^- \mu^+ \mu^- + \text{MET} + \text{Jets}$.

2 Full Simulation Study at CMS[3]

The MUED signals are generated by the CompHEP[4] and the KK particles are decayed by the UEDDECAY[5], enabling only $4\mu, 4e$ and $2e2\mu$ decay channels. We fix higgs mass to 120 GeV and ΛR to 20, then we vary the R^{-1} value with 300, 500, 700, and 900 GeV. This covers most of theoretically allowed parameter space. Table 1 lists the cross sections for signal and main backgrounds we identified. We see the background is either comparable or much bigger than the signal cross sections, depending on the R^{-1} scale. Therefore, background rejection is our main focus in this analysis.

We use single lepton (e/μ) or di-lepton triggers. For offline selection, we require electrons to have $p_T > 7 \text{ GeV}$, $|\eta| < 2.5$, $0.9 < E/P < 1.5$, and $E_{\text{Hcal}}/E_{\text{Ecal}} < 0.1$, and muons to have $p_T > 5 \text{ GeV}$ and $|\eta| < 2.4$. This way, we get very pure lepton samples. We also require at least 4 isolated leptons and 2 pairs of OSSF. By isolation, we mean the sum p_T of charged tracks within a $R=0.3$ cone around μ/e is less than 3 GeV. We further use b tag veto to reject events which have one or more tagged b -jets. Fig. 2 shows the missing E_T distributions after above offline selections. We see all the backgrounds are restricted to the $\text{MET} < 200 \text{ GeV}$ region, so $\text{MET} > 60 \text{ GeV}$ is also applied to reject Zbb & ZZ backgrounds.

Signal/Background	cross section pb
ued- 300	2
ued- 500	0.23
ued- 700	0.05
ued- 900	0.01
$ZZ \rightarrow 4$ leptons	0.1
$t\bar{t} + n$ jets and $b\bar{b}b\bar{b} \rightarrow 4$ leptons	1.2
$Z\bar{b}b \rightarrow 4$ leptons	0.7

Table 1: Cross sections for the MUED signal and SM backgrounds.

Figure 2: MET distribution after initial offline selections.

To further reject the ZZ background, we use the fact that the MUED leptons are often very soft due to the small mass splitting between Z_1 and l_1 . The cut used is the momentum of the 1st, 2nd, 3rd, and 4th hardest lepton in the event to be less than 70, 60, 40, 30 GeV respectively. Finally, we remove the combinatorial uncertainty for $4e$ and 4μ channels by subtracting the same sign lepton pairs, as shown in Fig. 3. Here, we also reject those events in which there's one or more OSSF lepton pair with invariant mass < 5 or > 80 GeV to further reject Z and $t\bar{t}$ background. The end-point transition shown in Fig. 3 is a clear indication of decay products from heavy particles.

Figure 3: Di-lepton invariant mass (combinatorial uncertainty subtracted) for $R^{-1} = 900$ GeV MUED signal and SM background, Left: $\mu^+\mu^-\mu^+\mu^-$ channel, Right: $e^+e^-\mu^+\mu^-$ channel.

Fig. 4 gives the luminosity needed to achieve a 5σ discovery for the 3 channels we considered. Here the significance is calculated using the S_{CP} defined in the CMS physics technical design report[7]. The experimental systematical uncertainties are due to limited detector understanding for early phase of LHC running. One sees the 4μ channel has the best discovering power in the low R^{-1} region, and the $2e2\mu$ channel becomes better in the high R^{-1} region, mainly due to the larger cross section.

Figure 4: The luminosity needed to achieve a 5σ discovery of the MUED in the 4 leptons channels, respective to the compactification scale.

3 Conclusions

The MUED four leptons final state was studied[8] and the backgrounds are strongly suppressed by current selection. The MUED can be discovered at the CMS with $\sim 30 \text{ fb}^{-1}$ data for the allowed theoretical parameter space ($300 < R^{-1} < 1050 \text{ GeV}$). For the $R^{-1} < 600 \text{ GeV}$ signals, $\mu^+\mu^-\mu^+\mu^-$ and $e^+e^-\mu^+\mu^-$ channels can have a 5σ discovery with less than 1 fb^{-1} data. Further improvement aimed at the 10 TeV 200 pb^{-1} data is ongoing.

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