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Search for Extra Dimensions with the CMS Detector

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Abstract

Multidimensional theories at TeV energies, as given in the brane world scenarios with large or compact extra spatial dimensions (ED), are discussed. One interesting feature of recent ED models is the rich low-energy phenomenology that originates from the Kaluza-Klein spectrum of various particles propagating in ED. A series of searches is addressed in the CMS experiment with different signatures.

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1 Introduction

Extra dimension (ED) models have a rich low-energy phenomenology that originates from the Kaluza-Klein (KK) spectrum of various particles propagating in ED. In what follows we consider the ADD [1], RS1 [2], TeV^{-1} [3], and UED [4] models and discuss various experimental signals and the discovery potential of the CMS experiment.

2 ADD Model

The ADD model [1] gives multiple production of KK modes of the graviton that leads to violations from SM predictions in the TeV scale region. The characteristic feature of ADD is the existence of light KK-gravitons which could be directly produced at colliders (real graviton production) in $q\bar{q} \to gG$, $gq \to qG$, $gg \to gG$ processes or observed through virtual KK-graviton exchange.

Real gravitons carry away a fraction of the total energy produced in a hard collision, producing final states with missing energy accompanied by a mono-jet or photons. In the G_{ADD} channels a 5 σ discovery can be made with less than 1 fb^{-1} of data for scenarios with the fundamental Planck mass, M_D in the range of 1-1.5 TeV, and less than 10 fb^{-1} for values of M_D in the range of 2-2.5 TeV, largely independent of the number of extra dimensions [5]. These estimates are conservative taking into account only the events for which the graviton mass is smaller than M_D and should be considered as lower bound.

Virtual gravitons interfere with the SM diagrams, as like lepton pair production or photon pair production, and produce significant modification to these spectra. These signatures are clear, very sensitive to new physics and could signal the existence of extra dimensions. The reachable values of the fundamental Planck mass, M_D, with 5 σ for various number of extra dimensions were estimated in [6]. The uncertainties related to misalignment and trigger systematic effects, PDFs, QCD-scale errors, EW and QCD corrections were taken into account. It shows that even the first LHC run with an integrated luminosity of 1 fb^{-1} allows exploration of the new ADD model scale region between 3.9 and 5.5 TeV uncovered so far by other colliders. An increase of the collected luminosity up to 100 fb^{-1} makes it possible to probe low-scale gravity with M_D in the range 5.7-8.3 TeV.

3 Randall-Sundrum Model

The distinctive feature of Randall-Sundrum (RS1) approach [2] is that the excited massive graviton states (RS1 graviton). These resonance states are strongly coupled to ordinary particles and can significantly contribute to the SM processes above the fundamental scale. Thus, the characteristic experimental signature for these processes is a pair of high-p_T leptons, gammas or jets coming from the same vertex. The Figures 1 shows the LHC discovery potential for Randall-Sundrum graviton in the both dilepton channels (dilectron and dimuon) for the different value of integrated luminosities [7, 8]. These results were obtained with full simulation and reconstruction analyses which took into account systematic uncertainties. The mass region 0.8-2.3 TeV can be explored at LHC with 1 fb^{-1} in the dimuon channel for c = 0.01-0.1. The model parameter c is defined as the ratio k/M_{Pl}, where k is the curvature of the anti-de-Sitter space, M_{Pl} is the 4-D Planck scale. For higher statistics, 10 fb^{-1}, a RS1 graviton can be observed with a 5 σ limit up to the mass values of 1.2-3.1 TeV and 1.35-3.3 TeV in the dimuon and dielectron channel, respectively. The overall 5 σ limit for diphoton channel with a 30 fb^{-1} integrated luminosity is 1.61 TeV for low coupling c = 0.01, and 3.95 TeV for high coupling c= 0.1 [9].

Once a new resonance has been discovered, its properties have to be determined, in order to establish its identity. A characteristic feature of the graviton is its spin-2 nature. Other particles usually considered which give a similar signature are spin-1 Z^0 extra gauge bosons or Kaluza-Klein excitations of a Z boson. Angular disributions of the decay products in the center of mass frame provide a measurement of the spin of the resonance. For an integrated luminosity of L_{int} = 100 fb^{-1}, the spin-1 and spin-2 hypotheses can be discriminated at 2 σ level for graviton decay into a muon pair with mass up to 1.1 TeV for c = 0.01 and 2.5 TeV for c = 0.1 [9].

4 TeV^{-1} Extra Dimension Model

The gravitons are not the only particles possibly sensitive to extra dimensions. For example, gauge bosons could propagate in TeV^{-1}-sized extra dimensions [3]. The phenomenological consequence of this scenario is the appearance of the KK tower of states of gauge boson fields. The LHC will provide sufficiently high energy in the centre of mass to search for the direct production of new heavy resonances. The main discovery channel is the decay of a heavy particle into electrons and muons pairs (Z_{KK} decays), which presents a clear resonance signature over a well controlled Drell-Yan background.

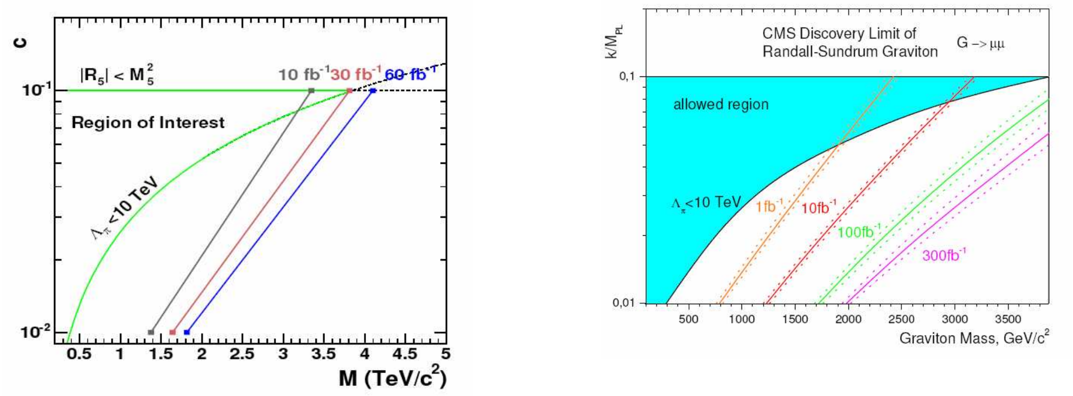

Figure 1: Theoretical and CMS constraints on the RS1 scenario parameter in the $k = M_{Pl}$ and $m_1 = m_G$ plane for dielectrons (left) [7] and dimuons (right) [8].

For Kaluza-Klein excitations of Z decaying into an electron-positron pair, a 5 σ discovery limit is achieved for compactification scales up to M_D = 4.97 TeV for an integrated luminosity of 10 fb^{-1}, M_D = 5.53 TeV for 30 fb^{-1} and M_D = 5.88 TeV for 60 fb^{-1}.

5 Universal Extra Dimensions

The Universal Extra Dimensions model (UED) [4] is a multidimensional field theory in which all the Standard Model (SM) fields, fermions as well as bosons, propagate in the bulk, so that each SM particle has its infinite tower of Kaluza-Klein (KK) partners. In particular, the minimal UED (mUED) assumes that the fields can propagate in a single extra dimension. In this case the 1st KK states must be pair produced. The lightest massive KK particle (LKP) is the KK photon and it is stable. The experimental signatures for KK modes production at hadron colliders are the missing energy carried away by the LKPs in addition to soft leptons radiated in the cascade decay process. In Figure 2, the required integrated luminosity for a 5 σ (reference value and value including systematics) is shown. A discovery of mUED physics with R^{-1} = 300 and 500 GeV will be possible with a luminosity below 1 fb^{-1}, which corresponds roughly to three months LHC running at $L = 10^{33}\ cm^{-2}\ s^{-1}$. The highest significance levels are achieved for the channels with muons because the trigger and reconstruction efficiencies are larger than for electrons, specially for low transverse momentum. For R^{-1} = 300 GeV the lepton spectrum is quite soft and the 4 channel is the most effective. Above R^{-1} 600 GeV the $2e2\mu$ channel becomes the most sensitive because its cross section is two times larger than for the 4μ channel and it is not significantly affected by the trigger inefficiency for low momentum electrons.

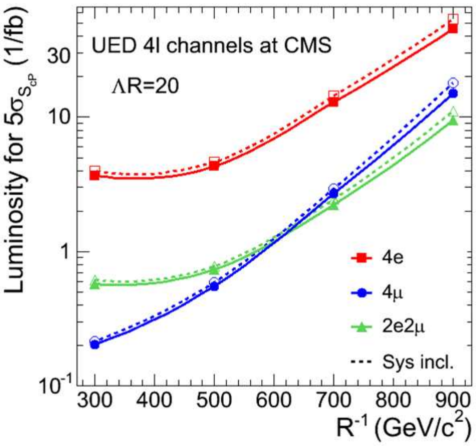

Figure 2: Discovery potential of UED signals in 4l channel. The dotted lines show the influence of experimental uncertainties and the background cross-section uncertainty [10].

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