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Search for Randall-Sundrum Gravitons in CMS

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Abstract

The sensitivity of the CMS experiment to the production of massive Kaluza-Klein excitations of gravitons is investigated in the framework of the Randall-Sundrum model. Full simulation and reconstruction of the CMS detector are used to investigate the production of graviton excitations in proton-proton collisions followed by their decay into electron-positron pairs. With a value of the Randall-Sundrum model coupling parameter $c = 0.01$ for which the graviton excitations have weak couplings to Standard Model particles, and an integrated luminosity of 100 fb^{-1} , resonances can be discovered at the 5σ level for masses reaching $1775 \text{ GeV}/c^2$. Heavier resonances are accessible for larger values of the c parameter, with a discovery mass reach up to $3800 \text{ GeV}/c^2$ for $c = 0.1$ and an integrated luminosity of 100 fb^{-1} .

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1 Introduction

Recently, phenomenological models with extra spatial dimensions have flourished in particle physics [1]. The attractiveness of these models comes from the decrease of the gravity mass scale from the Planck mass ($M_{\text{Pl}} \sim 10^{19}$ GeV) to the TeV range, allowing new physics to be discovered at colliders.

One of them, the Randall and Sundrum (RS) model [2], proposes a five dimensional Anti-de-Sitter (AdS_5) space-time in which the extra dimension Φ is compactified on a S_1/Z_2 orbifold, with fixed points holding two 3-branes: the Planck brane at $\Phi = 0$ where the gravity is localized and the Standard Model (SM) brane at $\Phi = \pi$ where the SM particles are living. The gravity scale Λ_π on the Planck brane is given by

$$\Lambda_\pi = M_{\text{Pl}} e^{-kr_c\pi} \quad (1)$$

where k is the AdS_5 curvature ($\sim M_{\text{Pl}}$), r_c is the compactification radius and the exponential term is called the warp factor. The scale Λ_π can be of the order of 1 TeV if $kr_c \simeq 11$ to 12 which can be achieved with the stabilization of the radion ([3] for experimental aspects).

In the RS model, massive Kaluza-Klein (KK) excitations of gravitons appear due to the compactification of the extra dimension, with mass

$$m_n = kx_n e^{-kr_c\pi} \quad (2)$$

(of order TeV/c^2) and width given by

$$\Gamma_n = \rho m_n x_n^2 c^2, \quad (3)$$

where x_n is the n^{th} root of the Bessel function J_1 , $c = k/M_{\text{Pl}}$ is the coupling constant and ρ is a constant depending on the number of open decay channels.

These gravitons can be detected in collider experiments. Their couplings to SM fermions and bosons are expected to be universal and the decay branching fractions for masses of the order of 1 TeV/c^2 depend essentially on the multiplicity of the possible quantum states (spin, colours, flavours).

Two parameters control the properties of the RS model: the mass of the first KK graviton excitation $M_G = m_1$, and the coupling constant $c = k/M_{\text{Pl}}$. Two theoretical constraints exist on these two parameters. The first one, $|R_5| < M_5^2$, is a limit on the curvature originally formulated in [2] as $k < M_5$, where $M_5 \sim M_{\text{Pl}}$ is the fundamental five-dimensional Planck scale. The second constraint, $\Lambda_\pi < 10$ TeV, ensures that no new hierarchy appears between the electroweak mass scale M_{EW} and Λ_π [4].

The LHC will provide sufficiently high energy in the centre of mass to allow searches on extra dimensions in the framework of the RS model. The main discovery channel comes from the decay of the first KK excitation into an e^+e^- pair. This signal presents a clear resonance signature over a well controlled Drell-Yan background, although the branching ratio for this channel is only 2 %.

2 Signal and background generation

At parton level, single gravitons can be resonantly produced at LHC via $q\bar{q} \rightarrow G$ or $gg \rightarrow G$. Each production mode gives different angular distributions which also depend on the nature of final state particles. In the case of the electron decay mode, the expected signal is formed by an e^+e^- pair, with both electrons balancing at very high p_t , and giving rise to a clear invariant mass peak. The standard model background in this channel consists mostly of the Drell-Yan process: $q\bar{q} \rightarrow \gamma/Z \rightarrow e^+e^-$.

The generation of proton-proton collisions at 14 TeV centre-of-mass energy is done with a version of PYTHIA 6.215 [5] modified to take into account a s^4 evolution of the squared amplitude of the RS process as suggested by [6]. The CTEQ5L proton parton distribution set [7] has been chosen and PHOTOS 2.03 [8] has been used for the inner Bremsstrahlung production. The events were generated in the pseudorapidity region $|\eta| < 2.5$.

A K factor of 1.3 is used for the background to take into account the higher order terms in the Drell-Yan cross section. This value comes from the CDF analysis [9] and is compatible with the K factor estimated by CMS in a fast simulation study [10]. No K factor is used for the signal.

3 Simulation and reconstruction

A detailed description of the CMS detector can be found elsewhere [11]. The corresponding simulation package CMSIM version 131 [12] has been used to describe the detector geometry and materials. This package also handles

the particle propagation and their interactions with the detector. Special care has been taken for the Bremsstrahlung in the tracker material and for the synchrotron radiation. The latter was found to have a negligible effect on the reconstructed electron energy in comparison to Bremsstrahlung.

The reconstruction was done with the CMS reconstruction package ORCA version 7.2.2 [13] without including pile-up effects. This package handles all reconstruction tasks as well as the simulation of the detector response, the Level-1 and High Level Triggers.

The two electrons requested for this analysis are reconstructed in the electromagnetic calorimeter ECAL as Super-Clusters using the Island algorithm [14] within the barrel and endcap fiducial regions ($|\eta| < 1.4442$ or $1.566 < |\eta| < 2.5$).

In order to avoid a deterioration of the signal for very energetic electrons, which might saturate the multi-gain-pre-amplifiers of the electromagnetic calorimeter electronics, a simple algorithm has been developed. Saturation is expected at 1.7 TeV in the barrel with a measured crystal light yield of 4.5 photo-electrons/MeV. The study is done here with the crystal light yield of 6 p.e./MeV which provides the most pessimistic limit for saturation, i.e. 1.25 TeV.

The saturation correction was applied based on the energy correlation (Fig. 1) between the most energetic crystal ($energy = E_1$) and the less energetic corner formed of five crystals ($energy = Red_5 = E_9 - E_4$, where E_9 and E_4 are the energies in the most energetic 3×3 and 2×2 crystal towers).

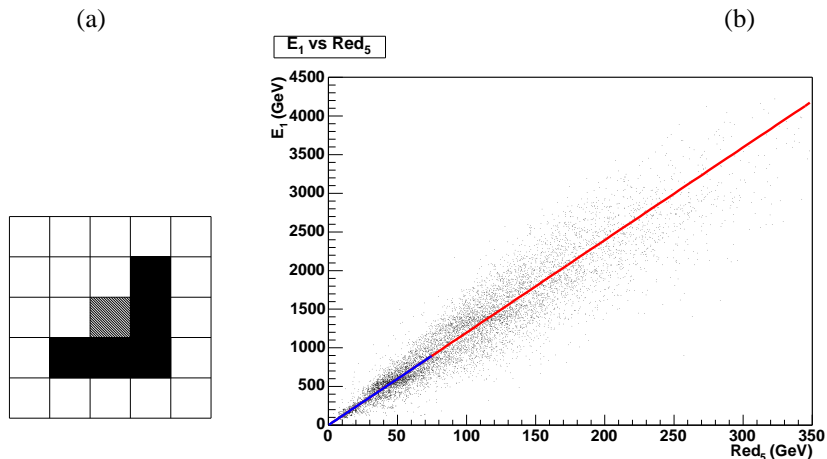


Figure 1: (a) Definition in a 5×5 crystal tower of E_1 as the energy of the central (hatched) crystal and of $Red_5 = E_9 - E_4$ as the energy of the less energetic corner of five crystals in black. (b) Correlation between E_1 and Red_5 . The blue and red lines correspond respectively to the range used for the fit and its extrapolation.

A linear behaviour is observed between Red_5 and E_1 over the full energy range. In order to establish a correction factor for data where saturation applies, a fit restricted to low energy data (in the absence of saturation) is performed.

The deterioration of the mass reconstruction in case of electronics saturation at 1.25 TeV is observed in Fig. 2a for a graviton of $4 \text{ TeV}/c^2$ and $c = 0.1$. In comparison, the improvement by using the algorithm correction is shown in Fig. 2b.

4 Selection cuts and Results

To be selected, the events must satisfy the high level trigger 2.5 requirement [11]. The selection cuts are based on the reconstruction of two very energetic and isolated electrons in the final state. The two Super-Clusters with the highest p_t are selected, each with a p_t greater than $100 \text{ GeV}/c$. They must be isolated in the electromagnetic calorimeter in order to reduce the background coming from jets: the sum of the transverse energies deposited in clusters within a cone of aperture $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$ centred around and excluding the Super-Cluster should be below $0.02E_{SC}^T$, where E_{SC}^T is the transverse energy of the Super-Cluster. The background from isolated charged pions is eliminated with a cut on the hadronic-over-electromagnetic energy fraction: $H/E < 0.1$, where $H(E)$ is measured in the hadron (electromagnetic) calorimeter. To identify electrons and reject neutral pions and

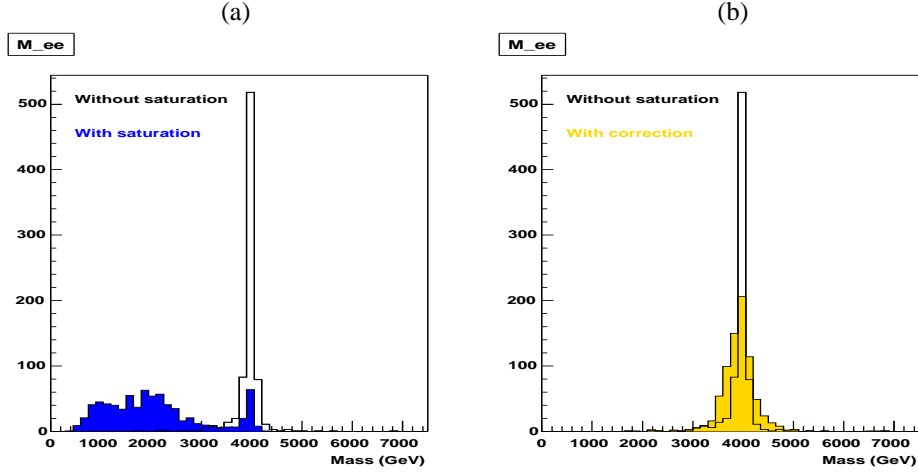


Figure 2: The white histogram represents the reconstructed graviton mass if no saturation occurs (signal of 4 TeV with a coupling $c = 0.1$). The shaded histograms represent the reconstructed mass with the effect of the saturation at 1.25 TeV before (a) and after (b) correction.

photons, each Super-Cluster has to be associated to a charged particle track reconstructed with at least two hits.

The graviton invariant mass is reconstructed from the energy and angles of the two Super-Clusters, the measurement in η being improved with the knowledge of the z vertex position. The peak is fitted with a Gaussian and a mass window is defined $\pm 3\sigma$ around the peak to compute the number of signal events N_S and background events N_B . For the low coupling study ($c = 0.01$), only events below the saturation limit ($E_1 < 1250$ GeV) are taken into account; if all the events are considered, the significance limit is not significantly affected. Figure 3 presents the signal, with three mass hypotheses : 1500, 1750 and 2000 GeV/ c^2 and $c = 0.01$, over background for an integrated luminosity of 100 fb^{-1} . Figure 4 presents the signal over background for a larger coupling value $c = 0.1$ and a heavier graviton mass $M_G = 3500 \text{ GeV}/c^2$, after saturation correction.

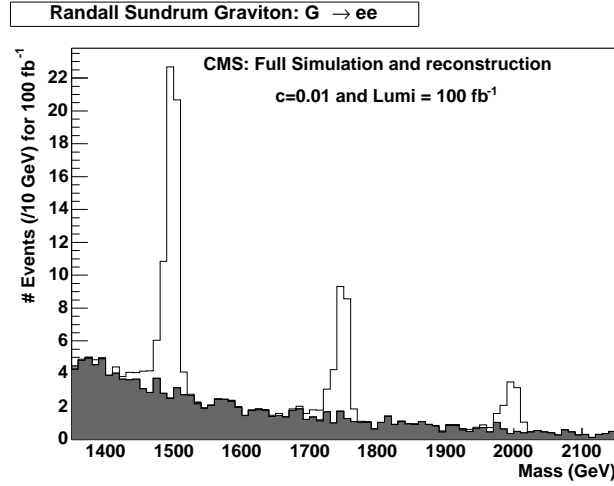


Figure 3: Expected e^+e^- mass distributions for Kaluza-Klein gravitons in the Randall-Sundrum model with mass $M_G = 1500, 1750$ and $2000 \text{ GeV}/c^2$ and coupling value $c = 0.01$ are plotted over the background for an integrated LHC luminosity of 100 fb^{-1} .

The best estimate of the significance is evaluated with the formula [15]:

$$S = 2(\sqrt{N_S + N_B} - \sqrt{N_B}). \quad (4)$$

With an integrated luminosity of 100 fb^{-1} , a 5σ discovery can be extracted up to $1775 \text{ GeV}/c^2$ for $c = 0.01$ and to $3800 \text{ GeV}/c^2$ for $c = 0.1$, covering completely the region of interest defined by theoretical constraints

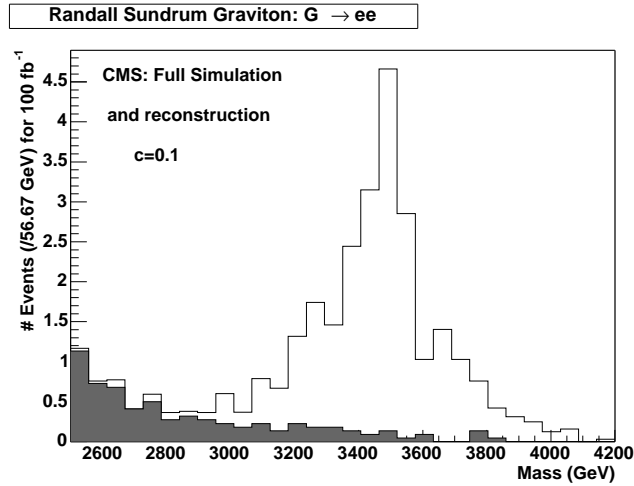


Figure 4: Expected e^+e^- m_{as} distribution for Kaluza-Klein graviton in the Randall-Sundrum model with mass $M_G = 3500 \text{ GeV}/c^2$ and coupling value $c = 0.1$ is plotted over background for an integrated luminosity of 100 fb^{-1} , after saturation correction.

(Section 1) in the plane showing the “coupling parameter c vs graviton mass M_G ” displayed in Fig. 5. Limits for lower luminosities have also been estimated.

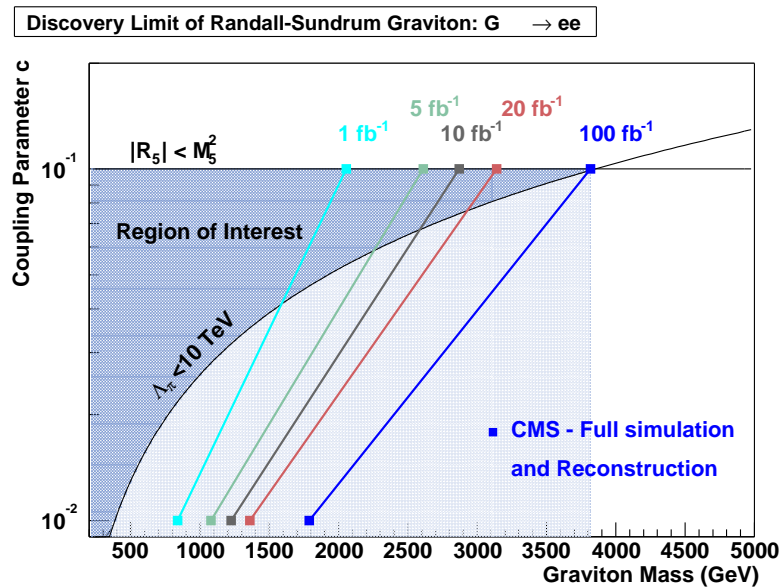


Figure 5: Discovery prospects in the (graviton mass M_G , coupling parameter c) plane in the Randall-Sundrum model. The lines correspond to the 5σ discovery reach for various integrated luminosities at the LHC. The shaded area corresponds to the “region of interest” of the model.

5 Conclusions

The results of the full simulation and reconstruction analysis on Randall-Sundrum graviton excitations have been presented. For a weak coupling ($c = 0.01$), a 5σ discovery is possible up to a mass of $1775 \text{ GeV}/c^2$ with an integrated luminosity of 100 fb^{-1} . Concerning the heavy resonances, a preliminary study of the saturation in the ECAL electronics gives encouraging results on the mass reconstruction: a 5σ discovery limit for 100 fb^{-1} and $c = 0.1$ is found at $3800 \text{ GeV}/c^2$. With 100 fb^{-1} , the whole region of interest defined by the theoretical constraints will be accessible with the CMS detector. With an integrated luminosity of 1 fb^{-1} , a large part of this

region will be covered at the beginning of the LHC running. In order to identify the spin-2 nature of the graviton, some work is needed on the angular distribution analysis. The study of other decay channels will also provide some help in verifying the universal coupling of the graviton and rejecting other interpretations (for example the $\gamma\gamma$ decay channel is allowed for the RS graviton but not for the new Z' boson.).

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