

Lightest Kaluza–Klein graviton mode in a back-reacted Randall–Sundrum scenario

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Abstract In search of the extra dimensions in the ongoing LHC experiments, the signatures of the Randall–Sundrum (RS) lightest KK graviton have been in the main focus in recent years. The recent data from the dilepton decay channel at the LHC has determined the experimental lower bound on the mass of the RS lightest Kaluza–Klein (KK) graviton for different choices of the underlying parameters of the theory. In this work we explore the effects of the back-reaction of the bulk scalar field, which is employed to stabilise the RS model, in modifying the couplings of the lightest KK graviton with the standard model matter fields located on the visible brane. In such a modified background geometry we show that the coupling of the lightest KK graviton with the SM matter fields gets a significant suppression due to the inclusion of the back-reaction of the bulk stabilising scalar field. This implies that the back-reaction parameter weakens the signals from the RS scenario in collider experiments, which in turn explains the non-visibility of KK graviton in colliders. Thus we show that the modulus stabilisation plays a crucial role in the search of warped extra dimensions in collider experiments.

1 Introduction

Till date, the world of subatomic particles is best described by the standard model (SM) of elementary particles. The validity of the SM has been confirmed with a great accuracy in several experiments up to TeV scale. The recent discovery of the Higgs boson in the large hadron collider (LHC) indeed is a major success story in this endeavour. Such a successful theory, however, continues to encounter a long-standing but unresolved question in the context of the stability of the mass of Higgs boson against a large radiative correction, known as the gauge hierarchy/fine tuning problem.

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The two most popular models, proposed in the context of this problem, are supersymmetry and extra-dimensional models [1–24]. In the absence of any signature of supersymmetry near the TeV scale so far, the significance of the presence of the extra dimension continues to grow. Among these models the warped geometry model proposed by Randall and Sundrum [12, 13] assumed a special significance, because: (a) it resolves the gauge hierarchy problem without introducing any other intermediate scale in the theory, (b) the modulus of the extra dimension can be stabilised by introducing a bulk scalar field [25] without any unnatural fine tuning of the parameter of the model.

It may also be mentioned that a warped solution, though not exactly the same as the RS model, can be found from string theory which as a fundamental theory predicts the inevitable existence of the extra dimensions [26, 27].

Due to these features, the detectors in LHC are designed to explore possible signatures of the warped extra dimensions through various decay channels of RS Kaluza–Klein (KK) graviton. While the CMS detector searches the signal of the extra dimension through the final states of the decay into leptons and hadrons, the ATLAS detector is designed to capture the dileptonic decay of the KK gravitons.

2 Brief description of RS model

The RS model is characterised by the non-factorisable background metric,

$$ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2. \quad (1)$$

The extra-dimensional coordinate is denoted by y and ranges from $-r_0$ to $+r_0$ following a S^1/Z_2 orbifolding. Here, r_0 is the compactification radius of the extra dimension. Two 3-branes are located at the orbifold fixed points $y = (0, r_0)$. The standard model fields are residing on the visible brane and only gravity can propagate in the bulk. The quantity

$k = \sqrt{\frac{-\Lambda}{24M^3}}$ is of the order of the 4-dimensional Planck scale M_{Pl} . Thus k relates the 5D Planck scale M to the 5D cosmological constant Λ .

The visible and Planck brane tensions are $V_{\text{hid}} = -V_{\text{vis}} = 24M^3k^2$. All the dimensionful parameters described above are related to the reduced 4-dimensional Planck scale M_{Pl} by

$$M_{\text{Pl}}^2 = \frac{M^3}{k}(1 - e^{-2kr_0}). \quad (2)$$

For $kr_0 \approx 36$, the exponential factor present in the background metric, which is often called the warp factor, produces a large suppression so that a mass scale of the order of Planck scale is reduced to TeV scale on the visible brane. A scalar mass, say the mass of Higgs, is given by

$$m_H = m_0 e^{-kr_0}. \quad (3)$$

Here, m_H is Higgs mass parameter on the visible brane and m_0 is the natural scale of the theory above which new physics beyond SM is expected to appear [12, 13].

In RS model, the expressions for the mass of first graviton KK mode m_1 and the coupling λ with the SM matter fields on the TeV brane as [28]

$$m_1 = x_1 k e^{-kr_0} \quad (4)$$

where x_1 can be obtained from $J_1(x_n) = 0$ [28], and

$$\lambda = \frac{e^{kr_0}}{M_{\text{Pl}}}. \quad (5)$$

It has been argued in [28] that the value of k/M_{Pl} should be 0.1 or less for the validity of the classical 5-D solution for the metric in RS model. Keeping this constraint in mind, the ATLAS group in LHC estimated the lower bound on the mass of the lightest KK graviton for different values of k/M_{Pl} . The absence of the KK graviton in dileptonic decay channels puts a stringent lower bound on KK graviton masses [29, 30]. According to the most recent experimental data [30] at 8 TeV centre of mass energy and 20 fb^{-1} luminosity, the 95 % confidence level lower limit on the RS lightest KK graviton mass is further restricted to 2.68 TeV for $k/M_{\text{Pl}} = 0.1$.

We write Eq. (4)

$$m_1 = x_1 \frac{k}{M_{\text{Pl}}} M_{\text{Pl}} e^{-kr_0}. \quad (6)$$

From Eq. (6), the mass of the RS lightest KK graviton can be tuned accordingly by increasing the warping parameter e^{-kr_0} from 10^{-16} , so that it goes above the recent experimental lower bound proposed by ATLAS for a fixed parameter k/M_{Pl} , which is related to coupling parameter in the original RS scenario.

However, from Eq. (3), it can be seen that if we increase the warping parameter in order to raise the theoretically calculated graviton mass well above the experimental lower bound,

then one needs to set the fundamental Planck scale of the theory (m_0) a few orders lower than the 4-D Planck scale (M_{Pl}) to obtain a Higgs mass of the order of 125 GeV. Therefore the increment of the warp factor with the rise of this experimental lower bound on the mass of the RS lightest KK graviton implies the inclusion of an intermediate energy scale in between the Planck and TeV scale.

It has been mentioned earlier that the extra-dimensional modulus in the RS model can be stabilised to a value of the order of the inverse Planck length by introducing a massive scalar field in the bulk [25]. In this stabilising mechanism, the effect of the back-reaction of the bulk scalar field on the background geometry is neglected. Later such a warped geometry model was generalised by incorporating the back-reaction of the stabilising scalar field on the background metric [31–35]. We therefore re-examine the mass of the lightest KK graviton and its coupling to the SM matter fields in such a modified warped geometry model endowed with a back-reacted metric due to the stabilising bulk scalar field. In this work we demonstrate that due to the back-reaction of the bulk stabilising scalar field on the background geometry, the effective coupling of the lightest KK graviton with the SM matter fields becomes weaker, which in turn can explain the invisibility of RS lightest KK graviton, even if its lower mass bound is as low as a few hundred GeV, which is much below the value of 2.8 TeV as predicted by ATLAS.

Thus in this scenario we can explain the invisibility of the KK graviton without modifying the value of the warping parameter and m_0 from their respective values in the original RS model.

We organise our work as follows.

In Sect. 3, we describe a five-dimensional warped geometry model which includes the effect of the back-reaction of the bulk stabilising scalar field on the background geometry. Section 4 deals with the KK mass modes of the graviton in this modified RS background. In Sect. 5, we discuss the lightest KK graviton interaction with the SM matter fields localised on the visible brane. Section 6 addresses the phenomenological implications and estimates the lower bound on the lightest graviton mass in the background of this back-reacted warped geometry model. Section 7 ends with some concluding remarks.

3 Back-reaction of the stabilising scalar field on the background geometry

We consider the five-dimensional action [33]

$$S = -M^3 \int d^5x \sqrt{g} R^{(5)} + \int d^5x \sqrt{g} \left(\frac{1}{2} \nabla \phi \nabla \phi - V(\phi) \right) - \int d^4x \sqrt{g_4} \lambda_P(\phi) - \int d^4x \sqrt{g_4} \lambda_T(\phi) \quad (7)$$

where $R^{(5)}$ is the five-dimensional Ricci scalar, ϕ is the bulk scalar field and $V(\phi)$ is the bulk potential term for the scalar field ϕ , g_4 is the induced metric on the brane and λ_P, λ_T are the potential terms on the Planck and TeV branes, respectively, due to the bulk scalar field. The scalar field ϕ in general is a function of both x^μ and y . Here, we consider the background VEV of the field $\phi(x^\mu, y) \equiv \phi(y)$. The 5-dimensional metric ansatz is [33]

$$ds^2 = e^{-2A(y)} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2 \tag{8}$$

which preserves 4-D Lorentz invariance. The function $e^{-A(y)}$ is the modified warp factor.

As shown in [33], the 5-D coupled equations for the metric and the scalar field are

$$4A'^2 - A'' = -\frac{2\kappa^2}{3} V(\phi) - \frac{\kappa^2}{3} \sum_i \lambda_i(\phi) \delta(y - y_i), \tag{9}$$

$$A'^2 = \frac{\kappa^2 \phi'^2}{12} - \frac{\kappa^2}{6} V(\phi)x, \tag{10}$$

$$\phi'' = 4A'\phi' + \frac{\partial V(\phi)}{\partial \phi} + \sum_i \frac{\partial \lambda_i(\phi)}{\partial \phi} \delta(y - y_i), \tag{11}$$

where κ is the five-dimensional Newton constant which is related to the five-dimensional Planck mass M by $\kappa^2 = 1/(2M^3)$. Here a prime and ∂_μ denote the derivatives with respect to y and the 4-D space time coordinate, i.e., x^μ , respectively.

Following the procedure as illustrated in [32,33], integrating Eqs. (9), (11) on a small interval $[(y_i - \epsilon), (y_i + \epsilon)]$, one finds the jump conditions

$$A'|_i = \frac{\kappa^2}{3} \lambda_i(\phi), \tag{12}$$

$$\phi'|_i = \frac{\partial \lambda_i(\phi)}{\partial \phi}. \tag{13}$$

As stated in [32], to find the solutions for the above equations of motion we actually need to reduce Eqs. (9)–(11) to three decoupled first order differential equations such that two of them are separable. The authors of [32] considered a definite form of the potential:

$$V(\phi) = \frac{1}{8} \left(\frac{\partial W(\phi)}{\partial \phi} \right)^2 - \frac{\kappa^2}{6} W(\phi)^2x \tag{14}$$

for some $W(\phi)$.

It is evident that if we implement the two boundary conditions [Eqs. (15) and (16)], it solves the two first order differential equations $\phi' = \frac{1}{2} \frac{\partial W}{\partial \phi}$, $A' = \frac{\kappa^2}{6} W(\phi)$ along with the Einstein and scalar field equations of motions in Eqs. (9)–(11),

$$\frac{1}{2} W(\phi)|_{y_i-\epsilon}^{y_i+\epsilon} = \lambda_i(\phi), \tag{15}$$

$$\frac{1}{2} \frac{\partial W(\phi)}{\partial \phi} \Big|_{y_i-\epsilon}^{y_i+\epsilon} = \frac{\partial \lambda_i}{\partial \phi}(\phi). \tag{16}$$

At this stage we need to make a choice for W to solve for the back-reaction of the bulk scalar field on the metric. It has been shown in [33] that inclusion of the back-reaction of the stabilising field generates a TeV order mass term for the radion, which may have interesting phenomenological consequences.

Considering the form of $W(\phi)$, chosen by the author of [32,33],

$$W(\phi) = \frac{6k}{\kappa^2} - u\phi^2, \tag{17}$$

the brane potential terms become

$$\lambda(\phi)_+ = W(\phi_+) + W'(\phi_+)(\phi - \phi_+) + \gamma_+(\phi - \phi_+)^2, \tag{18}$$

$$\lambda(\phi)_- = W(\phi_-) + W'(\phi_-)(\phi - \phi_-) + \gamma_-(\phi - \phi_-)^2. \tag{19}$$

Here $+/-$ are used to represent the Planck/TeV brane. Choosing a definite form of $W(\phi)$, the solution for the stabilising scalar field (ϕ) and the modified warp factor $A(y)$ can be obtained [32,33]:

$$\phi(y) = \phi_P e^{-uy}, \tag{20}$$

$$A(y) = ky + \frac{\kappa^2 \phi_P^2}{12} e^{-2uy}. \tag{21}$$

Here r_0 is the distance between the two 3-branes which can be stabilised by matching the VEV ϕ_P and ϕ_T of the stabilising scalar field ϕ at 0 (location of the Planck brane) and r_0 (location of the TeV brane). This implies $ur_0 = \ln(\phi_P/\phi_T)$. Therefore,

$$e^{-ur_0} = \frac{\phi_T}{\phi_P}. \tag{22}$$

From Eq. (21), we observe that the warp factor has been modified from that in the five-dimensional Randall–Sundrum model due to the back-reaction of the stabilising scalar field. As expected, in the limit $\kappa^2 \phi_P^2, \kappa^2 \phi_T^2 \ll 1$ we retrieve the original 5-D RS model.

All the dimensionful parameters described in this model are related to the reduced 4-dimensional Planck scale \overline{M}_{Pl} ,

$$M_{Pl}^2 = \frac{M^3}{k} \left[\left\{ 1 - \left(\frac{\phi_P}{\phi_T} \right)^{-\frac{2k}{u}} \right\} - \frac{l^2}{3} \left(1 + \frac{u}{k} \right)^{-1} \left\{ 1 - \left(\frac{\phi_P}{\phi_T} \right)^{-2(1+k/u)} \right\} \right] \tag{23}$$

where $l = \frac{\kappa \phi_P}{\sqrt{2}}$.

It was shown in [33] that the factor e^{-ur_0} appears in the final expression for the radion mass, which may have a significant influence on radion phenomenology.

The questions that arise now are: Does the effect of the back-reaction significantly modify the KK graviton phenomenology also? Can one explain the rise in the value of experimental lower mass bound for the lightest graviton KK mode from the effect of the back-reaction of the stabilising field? We try to address these questions in the following sections.

4 Lightest KK mass mode of graviton in a back-reacted warped geometry

The effective 4-D theory contains a massless as well as a massive KK tower of the gravitons and all these higher excited states are coupled to the standard model fields, located on the TeV brane. Our objective is to determine the mass of the first excited state of the graviton and its coupling with the SM matter fields in a back-reacted RS geometry due to the stabilising bulk scalar field. In this context we wish to explore a possible explanation for the hitherto non-visibility of the RS lightest KK graviton in the collider experiments. The KK mass modes of the graviton and its coupling with the SM matter fields in the background of the original RS model have been evaluated by the authors of [28]. Here we extend this work by incorporating the back-reaction of the bulk stabilising scalar field. The tensor fluctuations $h_{\alpha\beta}$ of the flat metric about its Minkowski value can be expressed through a linear expansion, $\tilde{G}_{\alpha\beta} = e^{-2A(y)}(\eta_{\alpha\beta} + \kappa^* h_{\alpha\beta})$, where κ^* is related to the higher-dimensional Newton constant. In order to find the graviton KK mass modes we expand the 5-dimensional graviton field in terms of the Kaluza–Klein mode expansion,

$$h_{\alpha\beta}(x, y) = \sum_{n=0}^{\infty} h_{\alpha\beta}^{(n)}(x) \frac{\chi^n(y)}{\sqrt{r_0}}, \tag{24}$$

where $h_{\alpha\beta}^{(n)}(x)$ are the KK modes of the graviton on the visible 3-brane and $\chi^n(\phi)$ are the corresponding internal wave functions for the graviton. Imposing the gauge condition, $\partial^\alpha h_{\alpha\beta} = 0$, and compactifying the extra dimension, we obtain the effective 4-D theory for the graviton,

$$S_4 = \int d^4x [\eta^{\mu\nu} \partial_\mu h_{\alpha\beta}^{(n)}(x) \partial_\nu h^{\alpha\beta(n)}(x) - m_n^2 h_{\alpha\beta}^{(n)}(x) h^{\alpha\beta(n)}(x)] \tag{25}$$

provided

$$\partial_y [e^{-4A(y)} \partial_y \chi^n(y)] + m_n^2 e^{-2A(y)} \chi^n(y) = 0 \tag{26}$$

and the orthonormality conditions

$$\frac{1}{r_0} \int_{-r_0}^{+r_0} e^{-2A(y)} \chi^{n_1}(y) \chi^{n_2}(y) dy = \delta_{n_1} \delta_{n_2} \tag{27}$$

are satisfied.

Using $l = \frac{\kappa \phi_P}{\sqrt{2}}$ the warp factor can be expressed as

$$A(y) = ky + \frac{l^2}{6} e^{-2uy}. \tag{28}$$

For $l < \sqrt{6}$, we use a leading order approximation for the series expansion of $e^{\frac{l^2}{6} e^{-2uy}}$.

For $n = 0$, i.e., the zeroth mode of the graviton, the differential equation for χ^0 turns out to be

$$\partial_y [e^{-4A(y)} \partial_y \chi^0(y)] = 0. \tag{29}$$

Solving the above differential equation and applying the continuity condition for the graviton wave function at the two orbifold fixed points we obtain

$$\chi^0 = c_1 = \text{constant}. \tag{30}$$

Normalising the resulting wave function from Eq. (27), we finally get

$$\chi^0 = \sqrt{kr_0} \left[\left(1 - e^{-2kr_0} \right) \left(1 - \frac{l^2}{3} \right) \right]^{-1/2}. \tag{31}$$

In order to find the solution for the higher KK graviton modes we define a set of new variables $\chi^n(y) = e^{2A(y)} \tilde{\chi}^n$ and $z_n = \frac{m_n}{k} e^{A(y)} = \frac{m_n}{k} e^{ky} (1 + \frac{l^2}{6} e^{-2uy})$. At $y = r_0$ the exponential series contains the factor $e^{-ur_0} = \frac{\phi_T}{\phi_P} < 1$, for $u > 0$.

In terms of these new variables we obtain the following differential equation for the graviton higher mode wave function:

$$z_n^2 \frac{d^2 \tilde{\chi}^n}{dz_n^2} + z_n \frac{d \tilde{\chi}^n}{dz_n} + [z_n^2 - 4] \tilde{\chi}^n = 0. \tag{32}$$

Solving the above equation we finally arrive at the solution for χ^n ,

$$\chi^n(y) = \frac{e^{2A(y)}}{N_n} \left[J_2 \left(\frac{m_n}{k} e^{A(y)} \right) + \alpha_n Y_2 \left(\frac{m_n}{k} e^{A(y)} \right) \right], \tag{33}$$

where N_n is the normalisation constant for the wave function χ^n . J_2, Y_2 are the Bessel function and Neumann function of order 2 and α_n is an arbitrary constant. The KK mass modes of the graviton (i.e. m_n) and α_n can be found from the continuity condition of the wave function at the two orbifold fixed points, i.e., at $y = r_0$ and $y = 0$. The continuity condition at $y = 0$ implies $\alpha_n \ll 1$ as $m_n/k \ll 1$. This leads to

$$\chi^n(y) = \frac{e^{2A(y)}}{N_n} J_2 \left(\frac{m_n}{k} e^{A(y)} \right). \tag{34}$$

The continuity condition at $y = r_0$ provides

$$J_1(x_n) = 0 \tag{35}$$

where

$$x_n = \frac{m_n}{k} e^{A(r_0)}. \tag{36}$$

All this finally results in the expression for the KK mass modes of graviton,

$$m_n = x_n k e^{-A(r_0)}. \tag{37}$$

The normalisation constant N_n for the graviton wave function (34), can now be determined by using the orthonormality condition in Eq. (27), as

$$N_n = \frac{1}{\sqrt{kr_0}} e^{A(r_0)} J_2(x_n). \tag{38}$$

5 Coupling of the lightest KK graviton with standard model matter fields on the visible brane

Let us consider the interaction of the first excited Kaluza-Klein mode of the graviton with the standard model matter fields residing on our universe i.e.. on the visible brane, located at $y = r_0$. The solution for tensor fluctuations that appear on our visible brane can be obtained by substituting the solution for $\chi^n(y)$ for $n = 0$ and higher modes (see Eqs. (31) and (34), (38)) in Eq. (24), at $y = r_0$,

$$\begin{aligned} h_{\alpha\beta}(x, y = r_0) &= \sum_{n=0}^{\infty} h_{\alpha\beta}^{(n)}(x) \frac{\chi^n(r_0)}{\sqrt{r_0}} \\ &= \sqrt{k} \left\{ \left(1 - \frac{l^2}{3}\right) (1 - e^{-2kr_0}) \right\}^{-1/2} h_{\alpha\beta}^0(x^\mu) \\ &\quad + \sum_{n=1}^{\infty} \sqrt{k} e^{A(r_0)} h_{\alpha\beta}^n(x^\mu). \end{aligned} \tag{39}$$

The interaction Lagrangian in the effective 4-D theory can be written

$$\mathcal{L}_{\text{int}} = -\frac{1}{M^{3/2}} T^{\alpha\beta}(x) h_{\alpha\beta}(x, y = r_0) \tag{40}$$

where $T^{\alpha\beta}$ is the energy-momentum tensor of the SM matter fields on the visible brane and we use the relation between the 5-D Planck mass (M_5) and the 4-D Planck mass (M_{Pl}) as shown in Eq. (23).

This leads to

$$\begin{aligned} \mathcal{L}_{\text{int}} &= -\frac{1}{M_{\text{Pl}}} T^{\alpha\beta} h_{\alpha\beta}^0(x^\mu) \\ &\quad - \frac{e^{A(r_0)}}{M_{\text{Pl}}} \left[\left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-\frac{2k}{u}} \right\} - \frac{l^2}{3} \left(1 + \frac{u}{k}\right)^{-1} \right. \\ &\quad \left. \times \left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-2(1+k/u)} \right\} \right]^{1/2} \sum_{n=1}^{\infty} T^{\alpha\beta} h_{\alpha\beta}^n(x^\mu). \end{aligned} \tag{41}$$

If we concentrate on the first excited KK mass mode of the graviton and its interaction with SM matter fields on the TeV brane, the mass term can be identified as

$$m_1 = x_1 k e^{-A(r_0)}, \tag{42}$$

while the interaction term of the first excited KK mode of the graviton with the SM matter fields on the TeV brane is

$$\begin{aligned} \Lambda|_{\text{int}} &\cong \frac{e^{A(r_0)}}{M_{\text{Pl}}} \left[\left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-\frac{2k}{u}} \right\} - \frac{l^2}{3} \left(1 + \frac{u}{k}\right)^{-1} \right. \\ &\quad \left. \times \left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-2(1+k/u)} \right\} \right]^{1/2}. \end{aligned} \tag{43}$$

6 Phenomenological implications

In the previous section we have given a description of the KK mass modes of the graviton and the interaction of the first excited KK mode of the graviton with the SM matter fields on the visible brane in the context of the back-reacted RS model. In Eq. (43), we have the term

$$\begin{aligned} &\left[\left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-\frac{2k}{u}} \right\} \right. \\ &\quad \left. \times -\frac{l^2}{3} \left(1 + \frac{u}{k}\right)^{-1} \left\{ 1 - \left(\frac{\phi_P}{\phi_T}\right)^{-2(1+k/u)} \right\} \right]^{1/2} = \beta. \end{aligned} \tag{44}$$

The parameter β gives the modification of the coupling of the KK graviton with the SM matter fields from that evaluated in the original five-dimensional RS model.

In order to address the gauge hierarchy problem we assume that the modified warp factor produces the same warping as in the original RS scenario. Therefore,

$$A(0) - A(r_0) = -37. \tag{45}$$

The above condition produces the following correlation among the parameters $l, k/u$ and $\frac{\phi_P}{\phi_T}$:

$$\frac{k}{u} = \frac{1}{\ln\left(\frac{\phi_P}{\phi_T}\right)} \left[37 + \frac{l^2}{6} \left(1 - \frac{\phi_T^2}{\phi_P^2}\right) \right]. \tag{46}$$

Equation (46) dictates that, for a particular choice of ϕ_P/ϕ_T and l , one fixes the value of the parameter k/u , the value of $l < \sqrt{6}$ and $\phi_P/\phi_T > 1$. We explore the parameter space by varying the back-reaction parameter $l = 1.68, 1.7, 1.71 \dots$, and for each l by varying $\phi_P/\phi_T = 1.5, 2.5, 3.5 \dots$ one can obtain the corresponding values of k/u from Eq. (46). After that we evaluate the parameter β from Eq. (44), which varies over the values $0.17, 0.20, 0.22 \dots$, corresponding to our different choices of the parameters of the model.

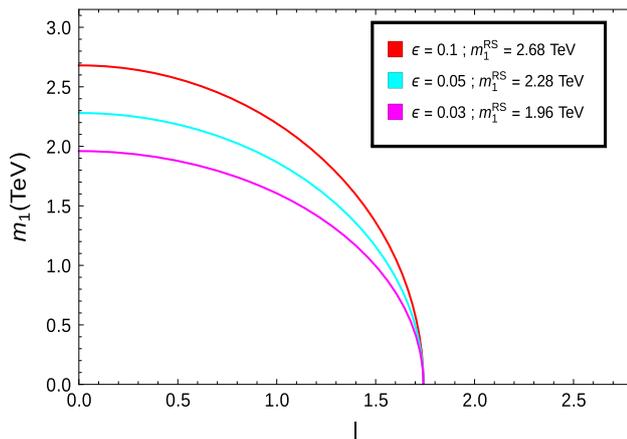


Fig. 1 Dependence of the new mass bound of first KK graviton on the parameter l for different choices of k/M_{Pl}

The values of β clearly point out that there is a significant amount of suppression in the dilepton decay channel of the lightest KK graviton over that evaluated in the original RS scenario. This implies that for an appropriate choice of the parameters, the effect of the back-reaction of the bulk stabilising scalar field on the background geometry of a warped extra-dimensional model can effectively suppress the coupling parameter of the lightest KK graviton with the SM matter fields. This in turn reduces the value of the lower bound on the mass of the lightest KK graviton. For example, the lower bound on the mass of the RS lightest KK graviton, say for $\frac{k}{M_{Pl}} = 0.1$, now can be substantially lower than ~ 2.8 TeV (lower mass bound without back-reaction) for an appropriate choice of the parameter l .

Figure 1 clearly shows the dependence of the lower mass bound of the first KK mode of the graviton with parameter l , for different choices of k/M_{Pl} , which indicates a significant suppression from the lower mass bound proposed by ATLAS for the original RS model.

We fix $\phi_P/\phi_T = 1.5$ and write β in terms of l by replacing k/u from Eq. (46). We then plot the modified lower mass bound of the first excited KK mode of the graviton with l .

In summary, the modulus stabilisation mechanism effectively reduces the lower bound of the mass of the lightest KK graviton by a factor β , which for an appropriate choice of the parameter values can be 5–10 times lower than that in the original RS scenario.

7 Conclusion

We consider a generalised version of RS model where the effect of the back-reaction due to the stabilising bulk scalar field on the background spacetime has been taken into consideration. We aim to study the contribution of this back-reaction

on the mass of the lightest KK graviton and its couplings to the SM matter fields.

Since the modulus stabilisation in the braneworld model is an important requirement to make the prediction of the model more robust, it is worthwhile to look for experimental support for the model in its stabilised version. Our study strongly suggests that due to the inclusion of the back-reaction of the stabilising scalar field, the estimated value of the lower bound of the mass of the lightest KK graviton, by the ongoing collider experiments ($m_1 \sim 2.8$ TeV for $k/M_{Pl} = 0.1$), may get reduced by approximately 5–10 times for a fixed k/M_{Pl} . In summary, the back-reaction of the bulk stabilising scalar field inevitably suppresses the lower bound of the mass of the lightest KK graviton, implying that there is no requirement to fine tune any parameter like the warp factor or m_0 (natural scale of the theory) to justify the estimated lower bound on the mass of RS lightest KK graviton from the ongoing collider experiments.

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