Constraint on Universal Extra Dimensions from scalar boson searches

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Abstract

We show the bounds on five- and six-dimensional Universal Extra Dimension models from the result of the Higgs boson searches at the Large Hadron Collider and electroweak precision measurement. The latest data released by the ATLAS and the CMS gives the lower bounds on Kaluza-Klein scale which are from 650 GeV to 1350 GeV depending on models from Higgs to diboson/diphoton decay signal. The Higgs production cross section can be enhanced by factor 1.5 in crude estimation, diphoton decay signal is suppressed about 10%. Electroweak precision measurement also gives the lower bounds as from 700 GeV to 1500 GeV. This is a proceedings of the conference "Rencontres de Moriond EW 2013".

1 Introduction

The ATLAS and CMS experiments reported their recent results on signal strengths of the Higgs like boson for its decay into diphoton ($\gamma\gamma$) and diboson (ZZ and WW) [1,2,3,4,5,6]. The signal strengths of $H \to \gamma\gamma$, ZZ and WW turn out to be $1.65 \pm 0.24^{+0.25}_{-0.18}$, $1.7^{+0.5}_{-0.4}$ and 1.01 ± 0.31 at the ATLAS experiment, while 0.78 ± 0.27 (MVA based), $0.91^{+0.30}_{-0.24}$ and 0.71 ± 0.37 (cut based) at the CMS experiment. These results are consistent with the SM but there still is a room for a new physics effect in these processes. In this work, we put bounds on universal extra dimension (UED) models.

The UED is a candidate of new physics, in which all the SM particles propagate in extra compactified spacial dimensions. The five-dimensional minimal UED (mUED) model without tree-level brane-localized term as a minimal extension of the SM, which is constructed on S^1/Z_2 [7], has been well studied. Six-dimensional UED models with various two-dimensional compactified spaces are also considered. We investigate the 6D UED models based on two torus, T^2/Z_2 [7], T^2/Z_4 [8,9], $T^2/(Z_2 \times Z_2')$ [10], on two sphere S^2/Z_2 [11] and S^2 with Stueckelbarg field, and on the non-orientable manifolds, namely the real projective plane RP^2 [12] and the projective sphere (PS) [13], by putting bounds on the Kaluza-Klein (KK) scale from the results

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model	mUED	T^2/Z_2	$T^2/(Z_2 \times Z_2')$	T^2/Z_4	S^2	S^2/Z_2	RP^2	PS
$\tilde{\Lambda}_{\max}$	5.0	2.5	2.9	3.4	2.3	3.2	2.0	1.9

Table 1: Upper bounds on cutoff scale $\Lambda_{\max} = \tilde{\Lambda}_{\max} M_{\mathrm{KK}}$ with $M_{\mathrm{KK}} = 1\,\mathrm{TeV}$.

of the Higgs signal search and the electroweak precision measurements. For details of these models, see for example Refs. [14,15].

For bounds on the UED models from the electroweak precision measurements, we use the S and T parameters. The recent constraints on the S and T parameters are given in Ref. [16]. For the bounds from the Higgs signal search, we use the recent results obtained in Ref. [1,2,3,4,5,6] for each decay process. In order to calculate these quantities in the UED models, we need to know an ultraviolet (UV) cutoff scale in a view point of four-dimensional effective theory. To search for the highest possible UV cutoff scale, we have evaluated the vacuum stability bound on the Higgs potential by solving renormalization group equation (RGE).

2 RGE and vacuum stability bound in UED

Let us review how to compute RGE in a theory with compactified extra dimension(s). We adopt the bottom-up approach in Refs. [17,18], where we take into account a contribution of a massive particle to the beta functions when the increasing scale μ passes its mass. In the case of the UED, after KK decomposition, the corresponding 4D effective theory contains not only the SM fields, but also their KK partners. Following this prescription, we get the beta function of coupling constant c as

$$\beta_c = \beta_c^{(\mathrm{SM})} + \sum_{s:\,\text{massive states}} \theta(\mu - M_s)\left(N_s \beta_{s,c}^{(\mathrm{NP})}\right), \tag{1}$$

where $\beta_c^{(\mathrm{SM})}$ and $\beta_{s,c}^{(\mathrm{NP})}$ are the contributions from the SM particles and from the new massive ones with mass M_s, respectively, and N_s is the number of degenerated states in the KK state s. The vacuum stability bound can be evaluated by solving RGE as the point where the running Higgs self-coupling $\lambda(\mu)$ turns out to be zero. Table 1 shows the vacuum stability bound $\Lambda_{\max}$ for each model in the case of the KK scale $M_{\mathrm{KK}} = 1\,\mathrm{TeV}$. Note that the values of $\Lambda_{\max}$ are almost universal within the case of $M_{\mathrm{KK}} \sim$ a few TeV. The details are found in [19]. In the following analyses, we employ the numbers in Table 1 as the UV cutoff scale in four-dimensional effective theory.

3 Higgs signals at the Large Hadron Collider

The Higgs signal at the LHC can be divided into two parts, production and decay processes. Higgs production at the LHC mainly comes from gluon fusion through the top loop. On the other hand, Higgs to diphoton and digluon decays are also induced as loop processes that are mainly constructed by top and W boson loops. KK tower in the UED models affects such loop processes. We compute a signal strength for the gluon fusion production channel in the UED models:

$$\mu_{gg\to H\to X} = \frac{\sigma^{\mathrm{UED}}_{gg\to H\to X}}{\sigma^{\mathrm{SM}}_{gg\to H\to X}} \simeq \frac{\Gamma^{\mathrm{UED}}_{H\to gg}\Gamma^{\mathrm{UED}}_{H\to X}/\Gamma^{\mathrm{UED}}_{H}}{\Gamma^{\mathrm{SM}}_{H\to gg}\Gamma^{\mathrm{SM}}_{H\to X}/\Gamma^{\mathrm{SM}}_{H}}, \tag{2}$$

where $X = \gamma\gamma, ZZ, WW$, etc, $\Gamma_H^{\mathrm{UED/SM}}$ is total decay width of the Higgs in UED/SM case. For each model we analyzed, $\Gamma^{\mathrm{UED}}_{H\to gg}$ is enhanced by KK top loops comparing with the SM. For the final states $X = ZZ/WW$, we can approximate as $\Gamma^{\mathrm{UED}}_{H\to ZZ/WW} \sim \Gamma^{\mathrm{SM}}_{H\to ZZ/WW}$ because Higgs decays into ZZ/WW boson pair at the tree level, and hence KK loop contributions are negligible. For the final state $X = \gamma\gamma$, the sum of KK towers supress $\Gamma^{\mathrm{UED}}_{H\to\gamma\gamma}$. The reason of the suppression is as follows. Each KK fermion mode is vectorlike, and hence has twice the degrees of freedom compared to its zero mode. Therefore their negative contributions to decay rate become larger than the positive ones coming from the KK W loops [14,20]. If we

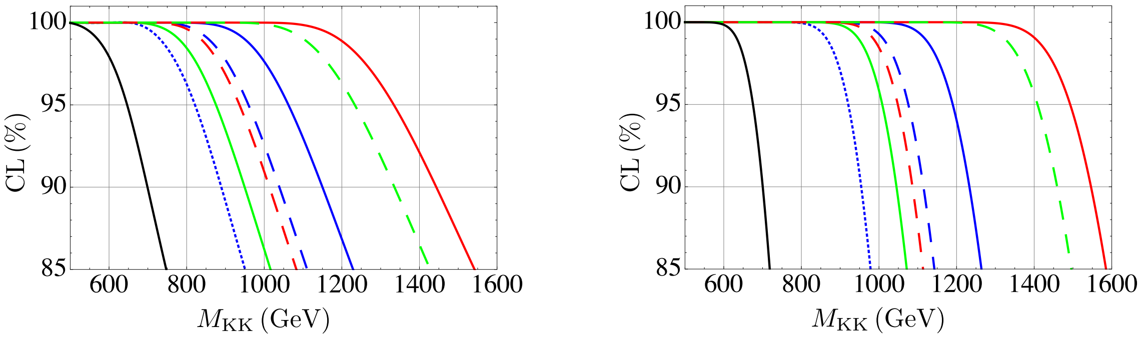

Figure 1: An exclusion CL of all UED models as a function of the KK scale M_{KK} by use of all the ATLAS and CMS results of $H \to \gamma\gamma, WW, ZZ$ (left), and recent S, T result (right), where the blue line, dashed line, and dotted line show the results in $T^2/Z_2, T^2/Z_2 \times Z_2'$, and T^2/Z_4 models; the red line and dashed line show that in S^2 and S^2/Z_2 models; the green line and dashed line show that in RP^2 and PS models; and the black line indicate that in mUED model.

consider the KK scale as 1 TeV, the signal strength of $H \to \gamma\gamma$ is enhanced by a factor 1.5 from that of the SM, while the diphoton decay rate is suppressed by 10%. Thus, $\mu_{gg\to H\to\gamma\gamma}$ becomes about 1.35 times larger than that in the SM. The details of the enhancement and suppression are given in Ref. [14,20,19].

As shown above, the UED models give different production cross section in the gluon fusion (GF). On the other hand, the other productions: the vector boson fusion (VBF), the Higgs-strahlung (VH), and the associated production with a $t\bar{t}$ pair (ttH) are the same as in the SM. The ATLAS and CMS have reported on the proportions of these production channels for each event category of $H \to \gamma\gamma, ZZ$ and WW [1,2,3,4,5,6]. We take these contributions into account. The details are given in [19]. The left of Figure 1 shows the bounds on the KK scale from all the ATLAS and CMS results of $H \to \gamma\gamma, WW, ZZ$ channels.

4 Electroweak precision test

A measurement related to electroweak sector can be used to obtain indirect bounds on phenomenological models. The S and T parameters are very useful quantities for such a purpose. These parameters are represented by two point functions of the gauge bosons. Several measurable quantities are represented as functions of the S and T parameters, and from the global fit to the experimental results, the values of S, T are estimated as [16]

$$S|_{U=0}^{\mathrm{exp}} = 0.05 \pm 0.09, \quad T|_{U=0}^{\mathrm{exp}} = 0.08 \pm 0.07, \tag{3}$$

with 126 GeV reference Higgs mass and its correlation being +0.91, assuming that the U parameter is zero. In an operator-analysis point of view, the U parameter is represented as a coefficient of a higher dimensional operator involving the Higgs doublet than those for S and T in the UED models, and hence we ignore the effect in our analysis. The KK top and KK Higgs contributions to S and T in the mUED are already estimated in [21,22]. Our analysis newly take into acount the effect of KK gauge bosons. The detailed forms of S, T in UED models are found in Ref. [19]. The right of Figure 1 shows the bounds on the KK scales from the fit to the results in Eq. (3).

5 Summary

We have estimated the two types of bounds on the KK scales in 5D and 6D UED models from the Higgs boson searches at the LHC and from the electroweak precision data via the S and T parameters. Due to the contributions of the KK loops including KK top and KK gauge bosons, the Higgs decay ratio and production cross section are modified. The KK excited states of the massive SM particles (top quark, Higgs boson and gauge boson) alter the S and T parameters. Comparing the bounds from the Higgs signal search with those from the electroweak measurements, we find that the latter bounds are slightly severer than the former ones in the UED models for now. However, in future the Higgs signal search at the LHC will put more strong constraints on the KK scales in the UED models.

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