PROCEEDINGS OF SCIENCE

Radion in Randall-Sundrum model at the LHC and photon collider

Yoshiko Ohno
Ochanomizu University
E-mail: ohno@hep.phys.ocha.ac.jp

A warped extra dimension model proposed by Randall and Sundrum (RS) is one of the attractive candidates to solve the gauge hierarchy problem in the Standard Model. In a simplest version of the RS model, there are only two extra particles beyond the Standard Model - a spin-2 graviton (and its Kaluza-Klein excitations) and a radion which is a spin-0 and electrically neutral particle. In this paper, we discuss a possibility of discovering the radion at a photon collider, which has been considered as an option of e^+e^- liner collider (ILC), focusing on characteristic features of radion interactions with photon or gluon, in addition to constraints on mass and coupling of the radion from the SM Higgs boson search at the LHC.

KMI International Symposium 2013 on "Quest for the Origin of Particles and the Universe"
11-13 December, 2013
Nagoya University, Japan

PoS(KMI2013)041

1. Introduction

A warped extra dimension model (so called Randall-Sundrum (RS) model) has been accepted as an attractive solution of the gauge hierarchy problem [1]. This is a model in five-dimensional space time with a warped extra spatial dimension y which is compactified on the orbifold S^1/Z_2. There are two 3-branes located at $y = 0$ and πr_c, and they are called the Planck and the TeV branes, respectively. With this set up, the spacetime metric in the RS model is given by

$$ds^2 = e^{-2k\pi r_c}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2, \tag{1.1}$$

where $\eta_{\mu\nu}$ is the Minkowski metric and k denotes the AdS_5 curvature. Then, the SM Higgs boson mass on the TeV brane could be the weak scale naturally, i.e., $M_{\rm pl}e^{-k\pi r_c} \sim O(100\text{GeV})$, when $kr_c \sim 12$, where $M_{\rm pl}$ is the four dimensional Planck scale.

In the original RS model, only graviton propagates into the bulk[1]. Then there are only two types of extra paritlces beyond the SM - a spin-2 graviton (and its Kaluza-Klein (KK) excitations) and a radion which is a spin-0 and electrically neutral particle. The latter corresponds to fluctuations of a distance between two branes. When the distance between two branes is not fixed, the radion is massless. However the gauge hierarchy problem requires the distance to be a certain value, $kr_c \sim 12$. The stabilization mechanism of the distance between two branes in the RS model has been proposed by Goldberger and Wise (GW) [2], and as a result of the GW mechanism, the radion acquires the mass in the electroweak scale and it could be a lighter than the 1st KK graviton [2, 3].

In this presentation, we study production and decay of the radion in a photon collider, which has been considered as an option of e^+e^- linear collider (ILC). We have shown that the SM Higgs boson search experiments at the LHC give stringent constraints on the radion parameters except for the low-mass region of the radion [4]. Then we will show that a photon collider has an excellent potential to search for the radion in low-mass region.

2. Interactions

A radion field ϕ couples to the trace part of the energy-momentum (EM) tensor of the SM:

$$\mathscr{L}_{\rm int} = \frac{\phi}{\Lambda_\phi} T^\mu_\mu \tag{2.1}$$

where the scale parameter Λ_ϕ is expected to be $O(\text{TeV})$ [5, 6]. The trace of EM tensor consists of the SM part $T^{\mu\ \rm SM}_\mu$ and terms from the trace anomaly $T^{\mu\ \rm anom}_\mu$. The latter is given by

$$T^{\mu\ \rm anom}_\mu = \sum_{a=1,3} \frac{\beta_a(g_a)}{2g_a} F^a_{\mu\nu} F^{a\mu\nu} \tag{2.2}$$

where $\beta_a(g_a)$ denotes the beta function of QED ($a = 1$) and QCD ($a = 3$), respectively. Note that the interactions of radion with $T^{\mu\ \rm SM}_\mu$ are completely same with the those of the SM Higgs boson replacing Λ_ϕ by the vacuum expectation value v $(= 246\ \text{GeV})$. The exception is interactions with $T^{\mu\ \rm anom}_\mu$, which could sizably enhance couplings of the radion with photon pair and/or gluon pair.

[1]There are variants of the original model which allows (some of) the SM fields also propagate into the bulk.

It is straightforward to calculate production and decay of radion. The decay branching ratio of the radion is shown in ref. [4]. In general, radion and the SM Higgs boson can mix after the electroweak symmetry breaking because of scalar-curvature term from 4-dimensional effective action, this is called radion-Higgs mixing [6, 7]. However, we do not consider the mixing because a discovered scalar particle at the LHC is consistent with the SM [8, 9].

3. Production and decay of radion at LHC and photon collider

As we mentioned earlier, since the radion interactions are similar to the SM Higgs boson, the mass and scale parameter of radion, m_ϕ and Λ_ϕ, are constrained from the SM Higgs boson search experiments at the LHC [4]. Since both ATLAS and CMS reported that there is no signal of any scalar particles except for the mass ~ 125 GeV, it could be read as bounds on the radion parameters. We found that the $pp \to h \to ZZ$ process gives the most severe bound on (m_ϕ, Λ_ϕ). For example, $\Lambda_\phi < 8$ TeV is disfavored for $m_\phi \sim 260$ GeV. It is worth mentioning that the LHC experiments are less sensitive to search for the radion in low-mass (~ 100 GeV) region where the decay mode into $\gamma\gamma$ has been measured well rather than WW and ZZ modes. This is because that, due to the trace anomaly, not only the radion interactions with photons but also with gluons are enhanced simultaneously and the decay into gg dominates over the $\gamma\gamma$ mode.

In the photon collider, the radion is produced in a s-channel annihilation of two photons and is dominantly decay into gluon pair when $m_\phi \sim O(100 \text{ GeV})$. We show the production cross section of radion in the photon collider which is convoluted with energy distribution of photon beams in Fig. 1 as functions of m_ϕ for $\Lambda_\phi = 1$ TeV and 3 TeV. Each line corresponds to the collision energy of electron beams $\sqrt{s} = 250$ GeV, 500 GeV and 1 TeV, respectively.

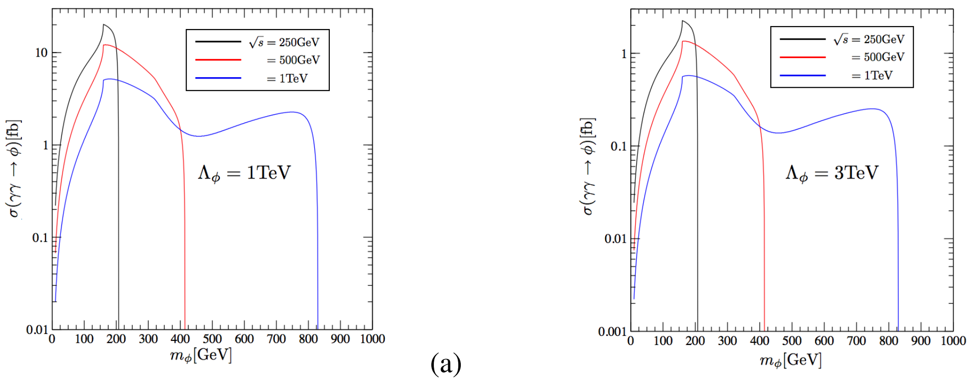

Figure 1: The production cross sections of radion at a photon collider which is convoluted with energy distribution of photon beams for center-of-mass of electrons $\sqrt{s} = 250$ GeV (black), 500 GeV (red) and 1 TeV (blue). These figures (a) and (b) indicate this value for $\Lambda_\phi = 1, 3$ TeV, respectively.

Next we examin a possibility of discovering the radion at the photon collider assuming the effective integrated luminosity $\int \mathscr{L}_{\text{eff}}\, dt$. We compare the signal process $\gamma\gamma \to \phi \to VV$, $(V = g, \gamma, W, Z)$ and the background process $\gamma\gamma \to h \to VV$, and estimate a significance which is defined by a ratio of the signal events S and a square root of background events $\sqrt{B}$. The regions on (m_ϕ, Λ_ϕ) plane where the significance $S/\sqrt{B} > 5$ are shown in Fig. 2. There are sizable parameter

PoS(KMI2013)041

regions where the radion is expected to be discovered. For example, when $m_\phi \sim 150$ GeV, the radion can be found up to $\Lambda_\phi \sim 3$ TeV for $\sqrt{s} = 250$, 500 GeV and 1 TeV. The excluded region of the radion in low-mass region from the LHC experiments in $\gamma\gamma$ mode is also shown in the figure. We can see that the photon collider is much sensitive than the LHC for $m_\phi \lesssim 150$ GeV.

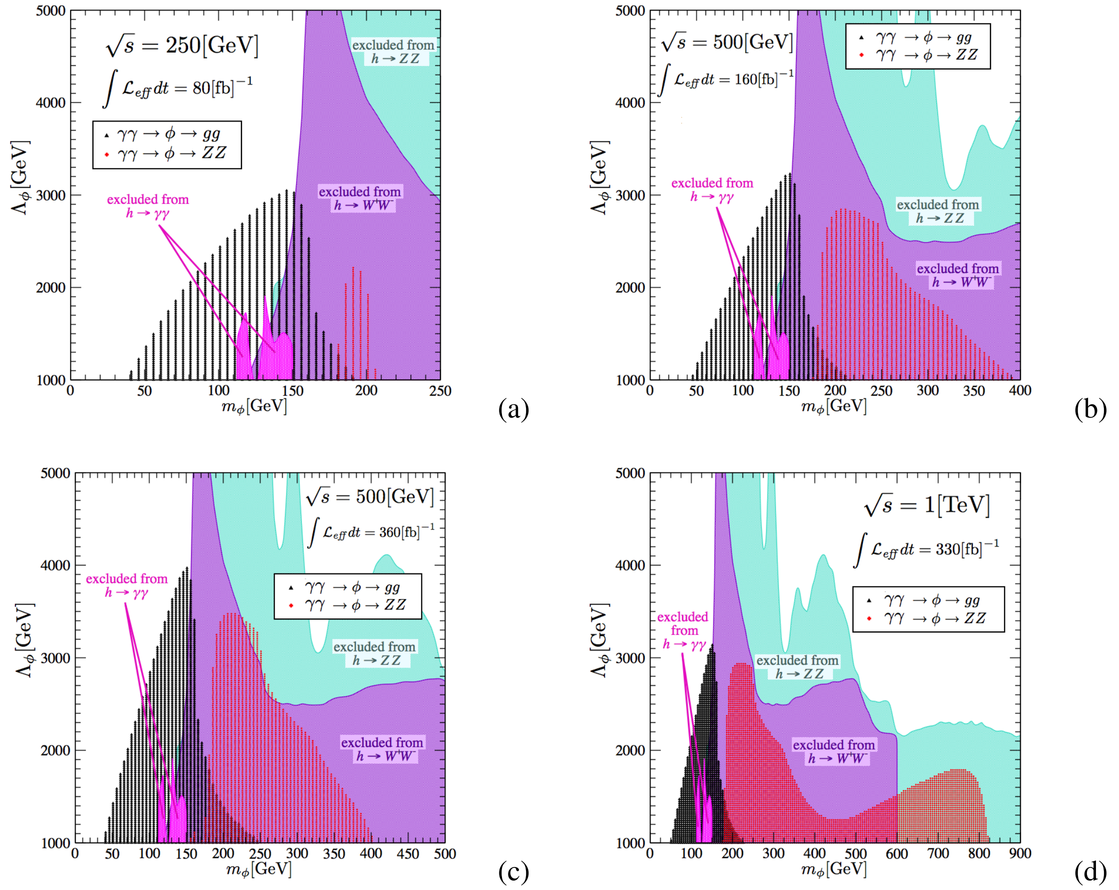

Figure 2: Allowed parameter regions on $(m_\phi,\ \Lambda_\phi)$ plane at the photon collider for various center-of-mass of electrons $\sqrt{s} = (a)$ 250 GeV, (b) 500 GeV, (c) 500 GeV (with high luminosity) and (d) 1 TeV which include bounds from the recent result at the LHC [4]. Black and red regions denote parameter regions where signal significance is $S/\sqrt{B} > 5$ for $\gamma\gamma \to \phi \to gg$ and $\gamma\gamma \to \phi \to ZZ$ processes, respectively. Region in turquoise, purple and magenta show that the 95% CL excluded region from $pp \to h \to ZZ$, $pp \to h \to W^+W^-$ and $pp \to h \to \gamma\gamma$ processes at the LHC. We assume the effective luminosity $\int \mathscr{L}_{eff}\, dt$ is 1/3 of that in ILC [10], following the TESLA technical design report [11].

4. Summary

We studied production and decay of the radion in the Randall-Sundrum model at the LHC and the photon collider as an option of e^+e^- linear collider (e.g. the ILC). As a result of our numerical analysis, we found the significance $S/\sqrt{B} > 5$ could be expected at the photon collider in sizable parameter region. For example, when $m_\phi \sim 150$ GeV, the radion can be found up to $\Lambda_\phi \sim 3$ TeV for $\sqrt{s} = 250$, 500 GeV and 1 TeV.

Acknowledgements

The author thanks G. -C. Cho and D. Nomura for collaborations which this presentation is based upon.

References

[1] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) [hep-ph/9905221].

[2] W. D. Goldberger and M. B. Wise, Phys. Rev. Lett. **83**, 4922 (1999) [hep-ph/9907447].

[3] G. D. Kribs, hep-ph/0605325.

[4] G. -C. Cho, D. Nomura and Y. Ohno, Mod. Phys. Lett. A **28**, 1350148 (2013) [arXiv:1305.4431 [hep-ph]].

[5] C. Csaki, M. Graesser, L. Randall and J. Terning, Phys. Rev. D **62**, 045015 (2000) [hep-ph/9911406].

[6] C. Csaki, M. L. Graesser and G. D. Kribs, Phys. Rev. D **63**, 065002 (2001) [hep-th/0008151].

[7] G. F. Giudice, R. Rattazzi and J. D. Wells, Nucl. Phys. B **595**, 250 (2001) [hep-ph/0002178].

[8] G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **716**, 1 (2012) [arXiv:1207.7214 [hep-ex]].

[9] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Lett. B **716**, 30 (2012) [arXiv:1207.7235 [hep-ex]].

[10] T. Behnke, J. E. Brau, B. Foster, J. Fuster, M. Harrison, J. M. Paterson, M. Peskin and M. Stanitzki *et al.*, arXiv:1306.6327 [physics.acc-ph].

[11] B. Badelek *et al.* [ECFA/DESY Photon Collider Working Group Collaboration], Int. J. Mod. Phys. A **19**, 5097 (2004) [hep-ex/0108012].