Communications in Physics, Vol. 22, No. 2 (2012), pp. 97-101

RADION PRODUCTION IN THE HIGH ENERGY γe^- COLLIDERS

TRAN DINH THAM
Pham Van Dong University, 986 Quang Trung, Quang Ngai
NGUYEN HUY THAO
Institute of Physics, VAST
DANG VAN SOA, DAO LE THUY, AND BUI THI HA GIANG
Department of Physics, Hanoi University of Education

Abstract. *We analyze the potential of Compact Linear Colliders (CLIC) based on the γe^- collisions to search for the radion in the Randall - Sundrum (RS) model, where compactification radius of the extra dimension is stabilized by the radion, which is a scalar field lighter than the graviton Kaluza-Klein states. The production of radion in the high energy γe^- colliders are calculated in detail. Numerical evaluation shows that if the radion mass is not too heavy then the reaction can give observable cross section in future colliders.*

I. INTRODUCTION

There has been a lot of attention devoted to models of physics above the weak scale utilizing extradimensions in solving the hierarchy problem. Recently the scenario proposed by Randall and Sundrum (RS) [1] can solve the hierarchy problem by localizing all the SM particles on the IR brane. This model predicts a Kaluza-Klein tower of gravitons and graviscalar, called radion, which stabilize the size of the extra dimension without fine tuning of parameters and is the lowest gravitational excitation in this scenario. The mass of the light radion is expected to be of order of GeV, which implies that the radion detection in experiments will be the first important signature of the RS model. Several authors have discussed the search of radion in inclusive processes at Tevaron and LHC [2, 3]. In our earlier work[4], we have calculated the production cross-sections of radion in the external electromagnetic fields. In this paper we will present the production of radion in the high energy γe^- colliders.

II. A REVIEW OF RS MODEL

The RS model is based on a 5D spacetime with non-factorizable geometry [1]. The single extradimension is compactified on a S^1/Z_2 orbifold of which two fixed points accommodate two three-branes (4D hyper-surfaces), the Planck brane at $y = 0$ and TeV brane at $y = 1/2$. The ordinary 4D Poincare invariance is shown to be maintained by the following classical solution to the Einstein equation:

$$ds^2 = e^{-2\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu - b_0^2 dy^2, \qquad \sigma(y) = m_0 b_0 |y|, \tag{1}$$

where x^μ ($\mu = 0, 1, 2, 3$) denote the coordinates on the 4D hyper-surfaces of constant y with metric $\eta_{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$. The m_0 and b_0 are the fundamental mass parameter and compactification radius, respectively.

Gravitational fluctuations about the RS metric,

$$\eta_{\mu\nu} \to g_{\mu\nu} = \eta_{\mu\nu} + \epsilon h_{\mu\nu}(x, y), \qquad b_0 \to b_0 + b(x), \tag{2}$$

yield two kinds of new phenomenological ingredients on the TeV brane: the KK graviton modes $h^{(n)}_{\mu\nu}(x)$ and the canonically normalized radion field $\phi_0(x)$, respectively defined as

$$h_{\mu\nu}(x, y) = \sum_{n=0}^{\infty} h^{(n)}_{\mu\nu}(x) \frac{\chi^{(n)}(y)}{\sqrt{b_0}}, \qquad \phi_0(x) = \sqrt{6} M_{\mathrm{Pl}} \Omega_b(x), \tag{3}$$

where $\Omega_b(x) \equiv e^{-m_0[b_0+b(x)]/2}$. The 5D Planck mass M_5 ($\epsilon^2 = 16\pi G_5 = 1/M_5^3$) is related to its 4D one ($M_{\mathrm{Pl}} \equiv 1/\sqrt{8\pi G_{\mathrm{N}}}$) by

$$\frac{M_{\mathrm{Pl}}^2}{2} = \frac{1 - \Omega_0^2}{\epsilon^2 m_0}. \tag{4}$$

Here $\Omega_0 \equiv e^{-m_0 b_0/2}$ is known as the warp factor. Because our TeV brane is arranged to be at $y = 1/2$, a canonically normalized scalar field has the mass multiplied by the warp factor, i.e, $m_{\mathrm{phys}} = \Omega_0 m_0$. Since the moderate value of $m_0 b_0/2 \simeq 35$ can generate TeV scale physical mass, the gauge hierarchy problem is explained.

The 4D effective Lagrangian is then

$$\mathcal{L} = -\frac{\phi_0}{\Lambda_\phi} T^\mu_\mu - \frac{1}{\hat{\Lambda}_W} T^{\mu\nu}(x) \sum_{n=1}^{\infty} h^{(n)}_{\mu\nu}(x), \tag{5}$$

where $\Lambda_\phi \equiv \sqrt{6} M_{\mathrm{Pl}} \Omega_0$ is the VEV of the radion field, and $\hat{\Lambda}_W \equiv \sqrt{2} M_{\mathrm{Pl}} \Omega_0$. The $T^{\mu\nu}$ is the energy-momentum tensor of the TeV brane localized SM fields. The T^μ_μ is the trace of the energy-momentum tensor, which is given at the tree level as [5, 6]

$$T^\mu_\mu = \sum_f m_f \bar{f} f - 2m_W^2 W^+_\mu W^{-\mu} - m_Z^2 Z_\mu Z^\mu + (2m_{h_0}^2 h_0^2 - \partial_\mu h_0 \partial^\mu h_0) + \cdots \tag{6}$$

The gravity-scalar mixing arises at the TeV-brane by [7]

$$S_\xi = -\xi \int d^4x \sqrt{-g_{\mathrm{vis}}} R(g_{\mathrm{vis}}) \hat{H}^\dagger \hat{H}, \tag{7}$$

where $R(g_{\mathrm{vis}})$ is the Ricci scalar for the induced metric on the visible brane or TeV brane, $g^{\mu\nu}_{\mathrm{vis}} = \Omega_b^2(x)(\eta^{\mu\nu} + \epsilon h^{\mu\nu})$. $\hat{H}$ is the Higgs field before re-scaling, i.e., $H_0 = \Omega_0 \hat{H}$. The parameter ξ denotes the size of the mixing term.

III. RADION COUPLING TO PHOTONS

For the massless gauge bosons such as photon and gluon, there are no large couplings to the radion because there are no brane-localized mass terms. However, the potentially large contributions to these couplings may come from the loop effects of the gauge bosons, the higgs field and the top quark as well as the localized trace anomalies. We lay out the necessary radion-photon coupling

$$\mathcal{L}_{\gamma\gamma\phi} = \frac{1}{2} c_{\phi\gamma\gamma}\phi F_{\mu\nu}F^{\mu\nu}, \tag{8}$$

with

$$c_{\phi\gamma\gamma} = -\frac{\alpha}{4\pi\Lambda_\phi}\left\{a(b_2+b_Y) - a_{12}[F_1(\tau_W) + 4/3F_{1/2}(\tau_t)]\right\}, \tag{9}$$

where $b_2 = 19/6, b_Y = -41/6$ are the $\mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$ β-function coefficients in the SM, and $a_{12} = a + c/\gamma$, $\tau_t = 4m_t^2/q^2$ and $\tau_W = 4m_W^2/q^2$.

The form factors $F_{1/2}(\tau_t)$ and $F_1(\tau_W)$ are given by

$$\begin{aligned} F_{1/2}(\tau) &= -2\tau[1+(1-\tau)f(\tau)], \\ F_1(\tau) &= 2+3\tau+3\tau(2-\tau)f(\tau), \end{aligned} \tag{10}$$

with

$$f(\tau) = \begin{cases} \arcsin^2(1/\sqrt{\tau}), & \tau \geq 1, \\ -\frac{1}{4}\left[\ln\left(\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}\right) - i\pi\right]^2 & \tau < 1. \end{cases} \tag{11}$$

The important property of $F_{1/2}(\tau)$ is that, for $\tau > 1$, it very quickly saturates to $-4/3$, and to 0 for $\tau < 1$. $F_1(\tau)$ saturates quickly to 7 for $\tau > 1$, and to 0 for $\tau < 1$ [8].

IV. RADION PRODUCTION IN γe^- COLLISIONS

In this paper we are interested in the production of radions in the high energy γe^- colliders,

$$\gamma(p_1,\lambda) + e^-(p_2,\lambda') \to\ e^-(k_1,\tau) + \phi(k_2). \tag{12}$$

Here p_i, k_i stand for the momentum and λ,λ', τ are the helicity of the particle, respectively. There are three Feynman diagrams contributing to reaction (12), representing the *s, u, t* - channel exchange depicted in Fig. 1.

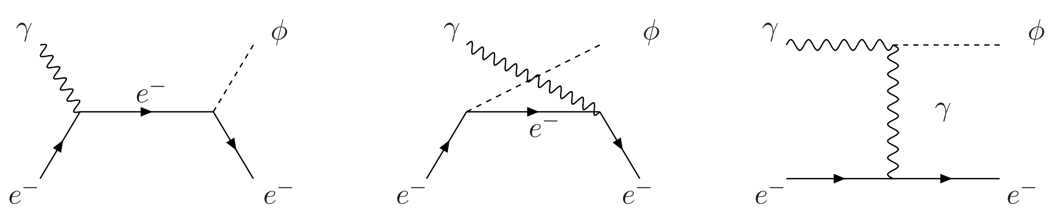

Fig. 1. Feynman diagrams for $e^-\gamma \to \phi\ e^-$

The amplitude for this process can be written as

$$M_i = \epsilon_\mu(p_2)\overline{u}(k_1)A_i^\mu u(p_1), (i = s,u,t) \tag{13}$$

where $\epsilon_\mu(p_2)$ are the polarization vector of the γ photon.

In the high energy limit $s >> m_e^2$, assuming a vanishing mass of electron, the A_i^μ for the three diagrams are given by

$$A_s^\mu = \frac{-iem_e}{\Lambda_\phi q_s^2} \not{q}_s \gamma^\mu, \tag{14}$$

$$A_u^\mu = \frac{-iem_e}{\Lambda_\phi q_u^2} \gamma^\mu \not{q}_u, \tag{15}$$

$$A_t^\mu = \frac{4ec_{\phi\gamma\gamma}}{q_t^2}[(p_2.q_t)\gamma^\mu - \not{p}_2 q_t^\mu]. \tag{16}$$

Here, $q_s = p_1+p_2 = k_1+k_2$, $q_u = p_1-k_1 = k_2-p_2$, $q_t = p_1-k_2 = k_1-p_2$, and $s = (p_1+p_2)^2$ is the square of the collision energy. We work in the center-of-mass frame and denote the scattering angle by θ. We have evaluated the θ dependence of the differential cross-section $d\sigma/\cos\theta$ and also the radion mass dependence of the total cross-section σ

i) We show in Fig. 2 the behaviour of $d\sigma/\cos\theta$ for the collision energy $\sqrt{s} = 1$ TeV, the radion mass is taken to be $m_\phi = 10$ GeV for definiteness. From the figure we see that $d\sigma/\cos\theta$ is peaked in the backward direction (this is due to the e^- pole term in the u - channel) but it is flat in the forward direction.

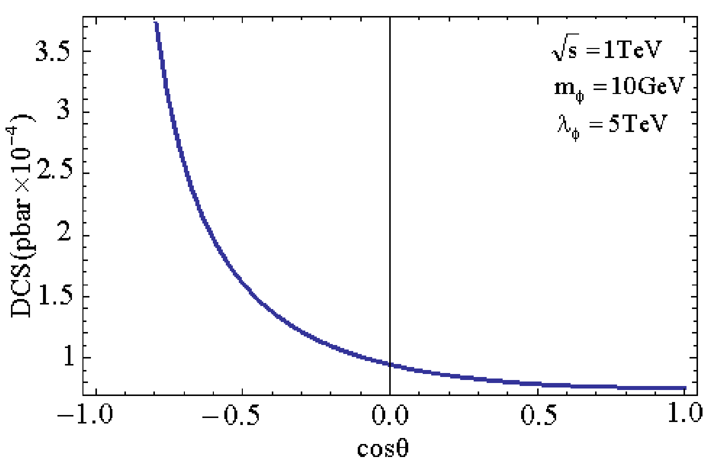

Fig. 2. Different cross-section of the process $\gamma e^- \to \phi e^-$ as a function of $\cos\theta$. The collision energy is taken to be $\sqrt{s} = 1$ TeV.

ii) The radion mass dependence of the cross-section σ at three energies, $\sqrt{s} = 1$ TeV, $\sqrt{s} = 2$ TeV and 3 TeV (CLIC) is shown in Fig. 3, respectively. From the figure we can see that there is no difference between three lines at $m_\phi = 10$ GeV. At CLIC we get $\sigma_{max} = 1.1372 \times 10^{-3}$ pb for $m_\phi = 10$ GeV, which is smaller than production cross section of the bilepton and Z' in the 3-3-1 models [9, 10], but it is large enough to measure the radion production. With the high integrated luminosity $L = 9 \times 10^4 fb^{-1}$, the number of events is approximately $N = 102348$, as expected.

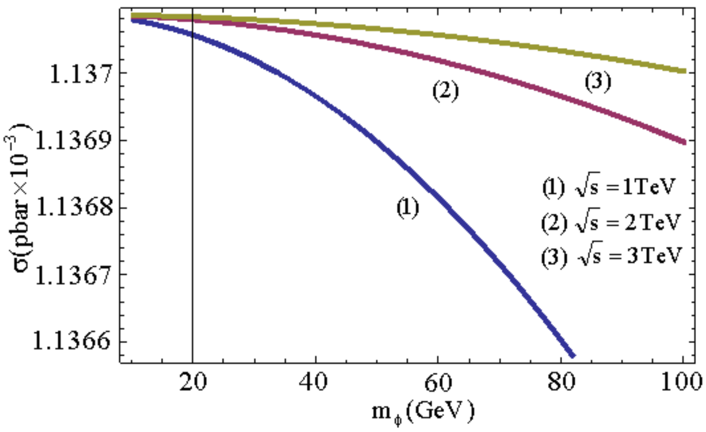

Fig. 3. Cross-section of the process $\gamma e^- \to \phi e^-$ as a function of the radion mass m_ϕ.

V. CONCLUSION

In our work, we have evaluated the radion production in γe^- collisions. The result shows that cross - sections for the radion production at high energies are smaller than those of the bilepton and Z' in the 3-3-1 models, but it is large enough to measure the radion production. If the radion mass is not too heavy then the reaction can give observable cross section in future colliders.

REFERENCES

[1] L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83** (1999) 3370.
[2] Hooman Davoudiasl, Thomas McElmurry, and Amarjit Soni, *Phys. Rev.* **D82** (2010) 115028.
[3] V. P. Goncalves and W. K. Sauter, *Phys.Rev.* **D82** (2010) 056009.
[4] P. V. Dong, D. V. Soa, H. N. Long and N. H. Thao, *Comm.in Physics: Special Issue*, **19** (2010) 13.
[5] S. Bae, P. Ko, H. S. Lee, and J. Lee, *Phys. Lett.* **B487**, (2000) 299.
[6] C. Csaki, M. L. Graesser and G. D. Kribs, *Phys. Rev.* **D63** (2001) 065002.
[7] G. F. Giudice, R. Rattazzi and J. D. Wells, *Nucl. Phys.* **B595** (2001) 250.
[8] C. Csaki, J. Hubisz and S. J. Lee, *Phys. Rev.* **D76** (2007) 125015.
[9] D. V. Soa, Takeo Inami and H. N. Long, *Eur. Phys. J. C* **34** (2004) 285.
[10] D. V. Soa, H. N. Long, D. T. Binh and D. P. Khoi, *J. Exp. Theor.Phys.* **98** (2004) 661.

Received 23 September 2011.