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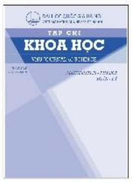

Original Article

Higgs and Vector Unparticle Production via $\mu^+\mu^-$ Collision in the Randall – Sundrum Model

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Abstract: We study the production of Higgs boson and vector U^{μ} unparticle which has been proposed as an option of $\mu^+\mu^-$ collision by s, t, u-channels in the Randall-Sundrum model. The cross-section is presented and numerical evaluation is detailed. Our results reveal that the cross-section increases fastly as $1.8 < d_U < 2$. The advantageous directions to collect Higgs boson and U^{μ} are the same or opposite direction to the initial muon beams by s-channel. The U^{μ} exchange contribution is much larger than muon exchange contribution**.**

Keywords: Randall - Sundrum model, cross-section, Higgs, vector unparticle, muon.

1. Introduction

The discovery of Higgs boson in 2012 at the LHC [1, 2] verify the correctness of the standard model, but it still has many unanswered issues [3]. In order to solve this remaining problems, the extended models are proposed. In this paper, we are interested in two extended models, namely the Randall-Sundrum model and unparticle physics.

The Randall-Sundrum model [4] is one of the extended models that brings many new physical consequences. This model extends 4-dimensional space-time with x_μ coordinates to 5-dimensional space-time with coordinates (x_μ, ϕ). The fifth dimension is a single S^1 / Z_2 orbifold of radius *r*. The 5-

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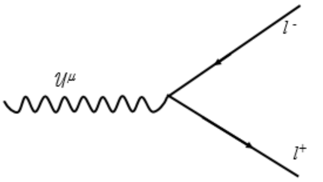
dimensional space-time has two 3-branes placed at two fixed points, the Planck brane (UV brane) at $\phi = 0$ and the TeV brane (IR brane) at $\phi = \pi$.

Unparticle physics proposed by Georgi [5] in 2007, which includes the standard model fields and the Banks-Zaks fields [6]. The two fields interact through the interchange of particles with a large mass scale M_U . In unparticle physics, there are scalar U , vector U^μ and spinor U^s unparticles. Their interactions with standard model particles are presented in Ref. [7].

In the previous paper we have studied the effect of vector unparticle on some of the high energy processes in the Randall-Sundrum model [8-10]. In this article, we discuss the U^μ production in the process $\mu^+\mu^- \to hU^\mu$ in the Randall-Sundrum model. The paper is organized as follows. The Feynman rules for the vector unparticle interactions with leptons and Higgs boson; the Higgs boson interactions with leptons and photons are given in section 2. The calculation results of the cross-section of $\mu^+\mu^-$ collisions are discussed in section 3. Finally, in section 4 we give a brief summary and discussions.

2. Formalism

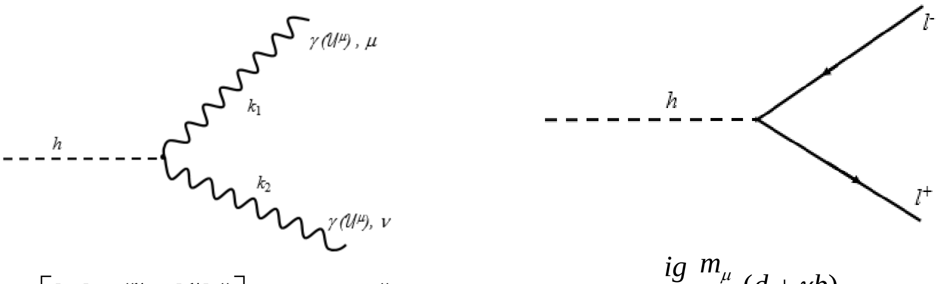
As already mentioned, in this work we only consider the vector unparticle in the unparticle physics and the Randall-Sundrum model. The interaction of vector unparticle with leptons according to the Feynman rules is shown in Fig. 1[11].



$$i\frac{\lambda_1}{\Lambda_U^{d_U-1}}\gamma^\mu(1+\gamma^5)$$

Fig.1. Feynman rules for the interaction of vector unparticle with leptons.

In Ref. [12] shows Feynman rules for the interactions of Higgs boson with photons and leptons in the Randall-Sundrum model (Fig.2). Based on the efficiency theory, we proposed the Feynman rule for the interaction of Higgs boson with vector unparticles in this model (Fig. 2a) following:



$$iC_X\left[k_1.k_2\eta^{\mu\nu}-k_1^\nu k_2^\mu\right];\ X=\gamma,U^\mu \qquad -\frac{ig}{2}\frac{m_\mu}{m_W}(d+\gamma b)$$

a) b)

Fig.2. Feynman rules for the interaction of Higgs boson with photons (vector unparticles) (a) and leptons (b).

where $C_\gamma = -\frac{\alpha}{2\pi\upsilon}\left[g_{fV} \sum_i e_i^2 N_c^i F_i(\tau_i) - (b_2 + b_Y) g_r \right]$[12] and C_U is the coefficient that we included based on the efficiency theory and we evaluated the cross-section according to $C_U = C_\gamma$.

3. The process $\mu^+\mu^- \to hU^\mu$ in the Randall-Sundrum model

In the rest of the paper, we concentrate on the possibility of Higgs boson and vector unparticle production in the $\mu^+\mu^-$ collisions according to s, t, u-channels in the Randall-Sundrum model. The Feynman diagrams of the above processes are shown in Fig. 3.

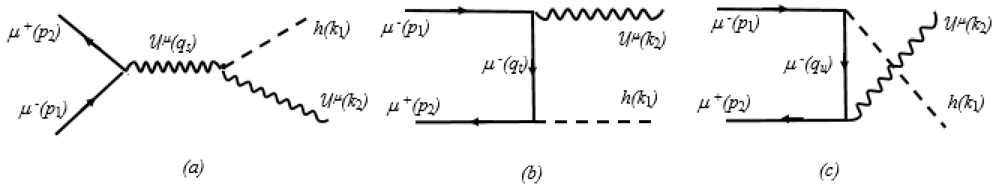


Fig.3. Feynman diagram for Higgs boson and vector unparticle productions at $\mu^+\mu^-$ collision

The matrix elements of the process $\mu^+\mu^- \to hU^\mu$ through by s, t, u-channels in Fig. 3a, b, c, respectively are given by the expression:

$$M_s = -\frac{i\lambda_1 A_{du}}{\Lambda_u^{du-1} 2\sin(du\pi)}(-q_s^2)^{du-2} C_U \bar{v}(p_2)\gamma^\mu(1+\gamma^5)u(p_1)\pi_{\mu\nu}\left(q_s k_2 . g^{\nu\alpha} - q_s^\alpha k_2^\nu\right)\varepsilon_\alpha^*(k_2). \tag{1}$$

$$M_t = \frac{\lambda_1}{\Lambda_u^{d_u-1}} \frac{g m_\mu (d+\gamma b)}{2m_{\mathrm{w}}(q_t^2 - m_\mu^2)} \bar{v}(p_2)(\hat{q}_t + m_\mu)\varepsilon_\mu^*(k_2)\gamma^\mu(1+\gamma^5)u(p_1) \tag{2}$$

$$M_u = \frac{\lambda_1}{\Lambda_u^{d_u-1}} \frac{g m_\mu (d+\gamma b)}{2m_{\mathrm{w}}(q_u^2 - m_\mu^2)} \bar{v}(p_2)\gamma^\mu(1+\gamma^5)\varepsilon_\mu^*(k_2)(\hat{q}_u + m_\mu)u(p_1) \tag{3}$$

where $q_s = p_1 + p_2 = k_1 + k_2;\ q_t = p_1 - k_1 = k_2 - p_2;\ q_u = k_1 - p_2 = p_1 - k_2,\ \pi_{\mu\nu} = \left(-g_{\mu\nu} + \frac{q_{s\mu} q_{s\nu}}{q_s^2}\right)$.

The matrix elements squared for the different channel are given by:

$$\begin{aligned}|M_s|^2 = -2\left(\frac{i\lambda_1 A_{du}}{\Lambda_u^{du-1} 2\sin(du\pi)}(-q_s^2)^{du-2} C_U\right)^2 &\{(q_s k_2)^2[-2(p_1 p_2) + \frac{1}{q_s^2}(-2(p_2 q_s)(p_1 q_s) + (p_1 p_2) q_s^2)] \\ &+ q_s^2[2(p_2 k_2)(p_1 k_2) - (p_1 p_2)k_2^2 + \frac{1}{q_s^4}(2(p_2 q_s)(p_1 q_s)(q_s k_2)^2 - (p_1 p_2) q_s^2 (q_s k_2)^2) \\ &- \frac{1}{q_s^2}(2(p_2 k_2)(p_1 q_s)(q_s k_2) + 2(p_1 k_2)(p_2 q_s)(q_s k_2) - 2(p_1 p_2)(q_s k_2)^2)]\},\end{aligned} \tag{4}$$

$$|M_t|^2 = 4\left(\frac{\lambda_1}{\Lambda_u^{d_u-1}}\frac{gm_\mu(d+\gamma b)}{2m_w(q_t^2-m_\mu^2)}\right)^2 \{2(p_2q_t)(p_1q_t)-(p_2p_1)q_t^2+m_\mu^2(p_2p_1)-2m_\mu^2(p_1q_t)\}, \tag{5}$$

$$|M_u|^2 = 4\left(\frac{\lambda_1}{\Lambda_u^{d_u-1}}\frac{gm_\mu(d+\gamma b)}{2m_w(q_u^2-m_\mu^2)}\right)^2 \{2(p_2q_u)(p_1q_u)-(p_2p_1)q_u^2+m_\mu^2(p_2p_1)+2m_\mu^2(p_2q_u)\}. \tag{6}$$

The differential cross-section for $\mu^+\mu^- \to hU^\mu$ at a center-of-mass energy $\sqrt{s}$ is given by:

$$\frac{d\sigma}{d\cos\theta} = \frac{1}{64\pi s}\frac{|\vec{k}_1|}{|\vec{p}_1|}|M|^2, \tag{7}$$

where $s=(p_1+p_2)^2$, θ is the angle between $\vec{p}_1$ and $\vec{k}_1$.

The cross-section is plotted taking $\lambda_1 = 1$, $\Lambda_U = 1\,TeV$ [11], $C_U = C_\gamma$, $\sqrt{s} = 500\,GeV$ and $1 < d_U < 2$ [13], in Fig. 4.

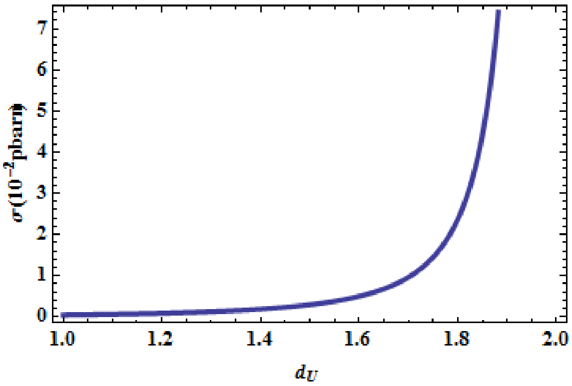
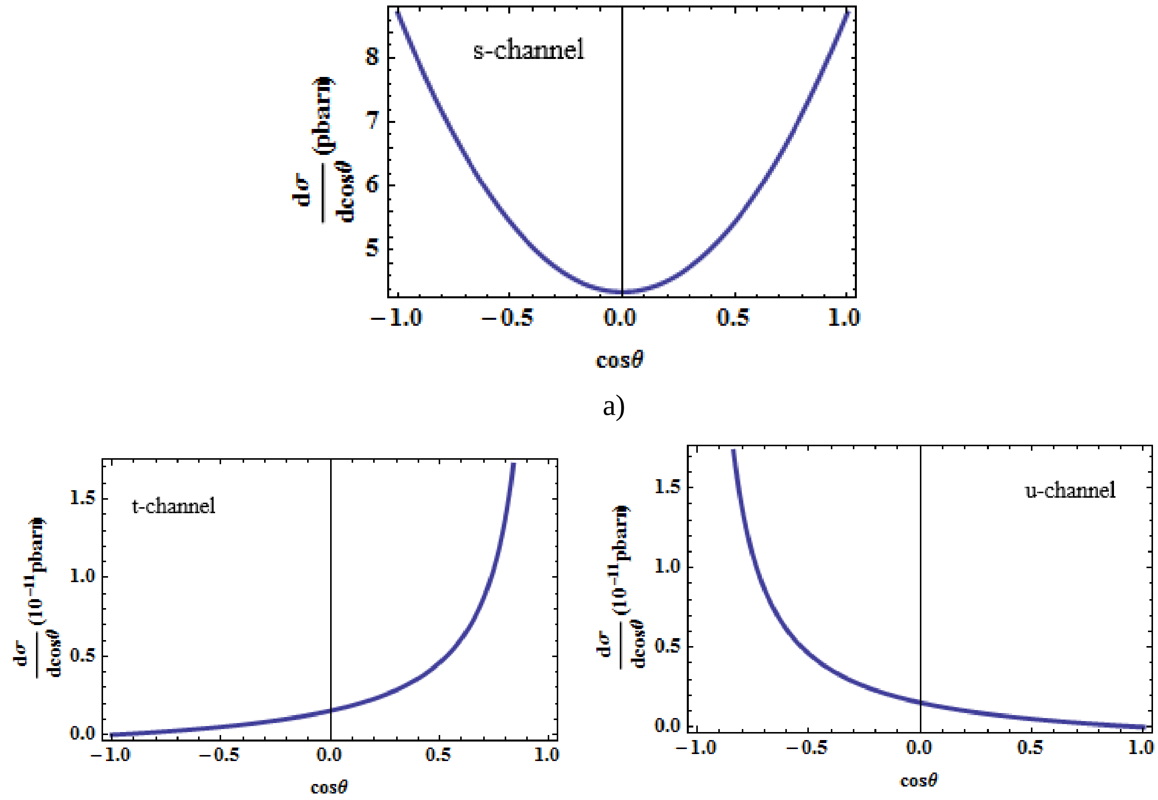


Fig 4. The cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of d_U

Here, the cross-section increases fastly as $1.8 < d_U < 2$. Therefore, we evaluated it at $d_U = 1.9$. In Fig. 5 we charted the differential cross-section of the Higgs and vector unparticle production as a function of $\cos\theta$ at $d_U = 1.9$. The center-of-mass energy is chosen as $\sqrt{s} = 500\,GeV$.

The figure shows that the value of the differential cross-section by s-channel is much larger than t, u-channels. It reaches maximum values when $\cos\theta = \pm 1$. For that reason, the advantageous directions to collect Higgs boson and vector unparticle are the same or opposite direction to the initial μ^+, μ^- beams.

Finally, Figure 6 shows the range of the cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of $\sqrt{s}$ at $d_U = 1.9$. It increases by $\sqrt{s}$ through s-channel and decreases with higher $\sqrt{s}$ through t, u-channels. For the vector unparticle exchange contribution, the higher the center-of-mass energy increases, the bigger the cross-section gets. For the muon exchange contribution, the higher the center-of-mass energy increases, the smaller the cross-section gets. Moreover, the value of the cross-section of s-channel is much larger than t, u-channels.

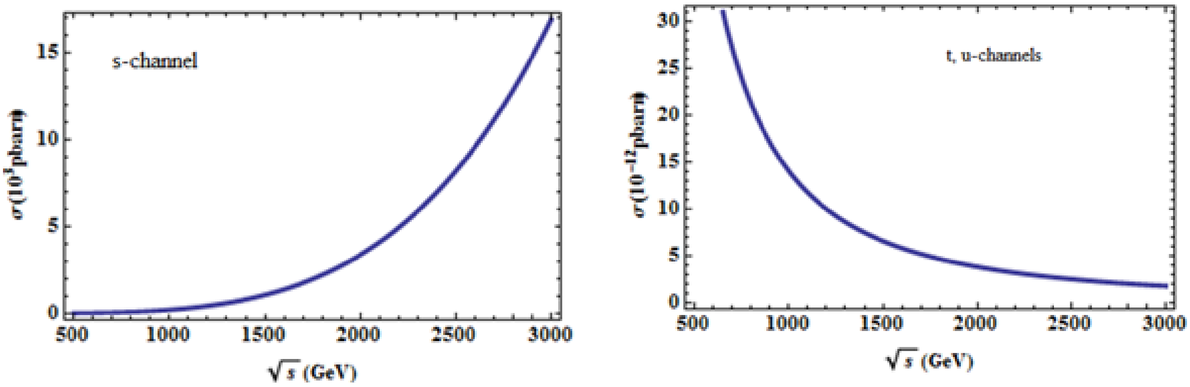


a)

b)

c)

Fig.5. The differential cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of $\cos\theta$



a)

b)

Fig 6. The cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of $\sqrt{s}$

Conclusions

In summary, we have calculated the cross-section of process $\mu^+\mu^- \to hU^\mu$ by s, t, u-channels. The result shows that the cross-section increases fastly as $1.8 < d_U < 2$. According to the s-channel, the advantageous directions to collect Higgs boson and vector unparticle are the same or opposite direction to the initial μ^+, μ^- beams. The vector unparticle exchange contribution is much larger than muon exchange contribution.

Acknowledgments

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