VNU Journal of Science: Mathematics – Physics, Vol. 35, No. 4 (2019) 93-98

VNU Journal of Science: Mathematics - Physics

Journal homepage: https://js.vnu.edu.vn/MaP

Original Article

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

Nguyen Thi Hau[1,*], Dao Thi Le Thuy[2]

[1]*Hanoi University of Mining and Geology, 18 Pho Vien, Dong Ngac, Hanoi, Vietnam*

[2]*Faculty of Physics, Hanoi National University of Education, 136 Xuan Thuy, Cau Giay, Hanoi, Vietnam*

Received 14 September 2019
Revised 08 November 2019; Accepted 11 November 2019

Abstract: This paper studies the production of Higgs boson and vector U^μ unparticle, which has been proposed as an option for $\mu^+\mu^-$ collision by s, t, u-channels in the Randall-Sundrum model. The cross-section is presented and numerical evaluation is detailed. The study results reveal that the cross-section increases as fast as $1.8 < d_U < 2$. The advantageous directions to collect Higgs boson and U^μ are either the same or opposite 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-

*Corresponding author.
Email address: nguyenthihau@humg.edu.vn

https//doi.org/ 10.25073/2588-1124/vnumap.4375

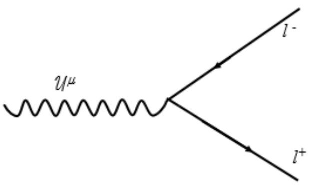
dimensional space-time has two 3-branes placed at two fixed points, the Planck brane (UV brane) at $\phi = 0$ and the TeV brane (IR brane) at $\phi = \pi$.

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

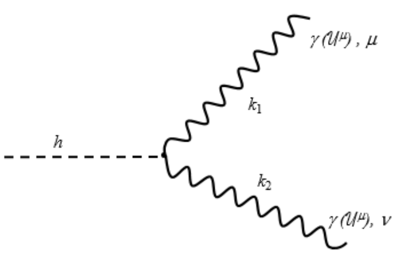
As already mentioned, in this work we only consider the vector unparticle in the unparticle physics and the Randall-Sundrum model. The interaction of vector unparticle with leptons according to the Feynman rules is shown in Fig. 1[11].



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

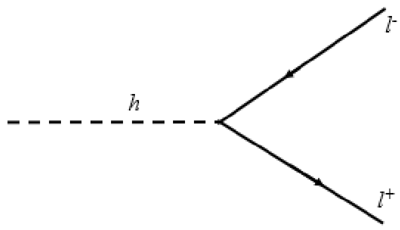
Fig. 1. Feynman rules for the interaction of vector unparticle with leptons.

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:



$$iC_X\left[k_1.k_2\eta^{\mu\nu} - k_1^\nu k_2^\mu\right];\ X = \gamma, U^\mu$$

a)



$$-\frac{ig}{2}\frac{m_\mu}{m_W}(d+\gamma b)$$

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.

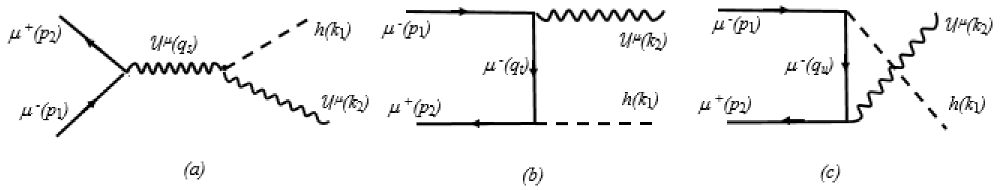


Fig. 3. Feynman diagram for Higgs boson and vector unparticle productions at $\mu^+\mu^-$ collision

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:

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

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

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

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:

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

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

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

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

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

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.

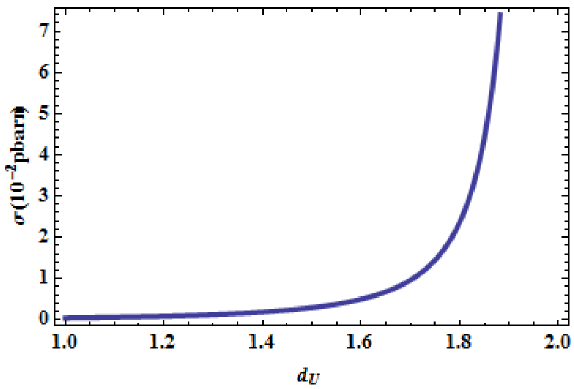


Fig 4. The cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of d_U

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.

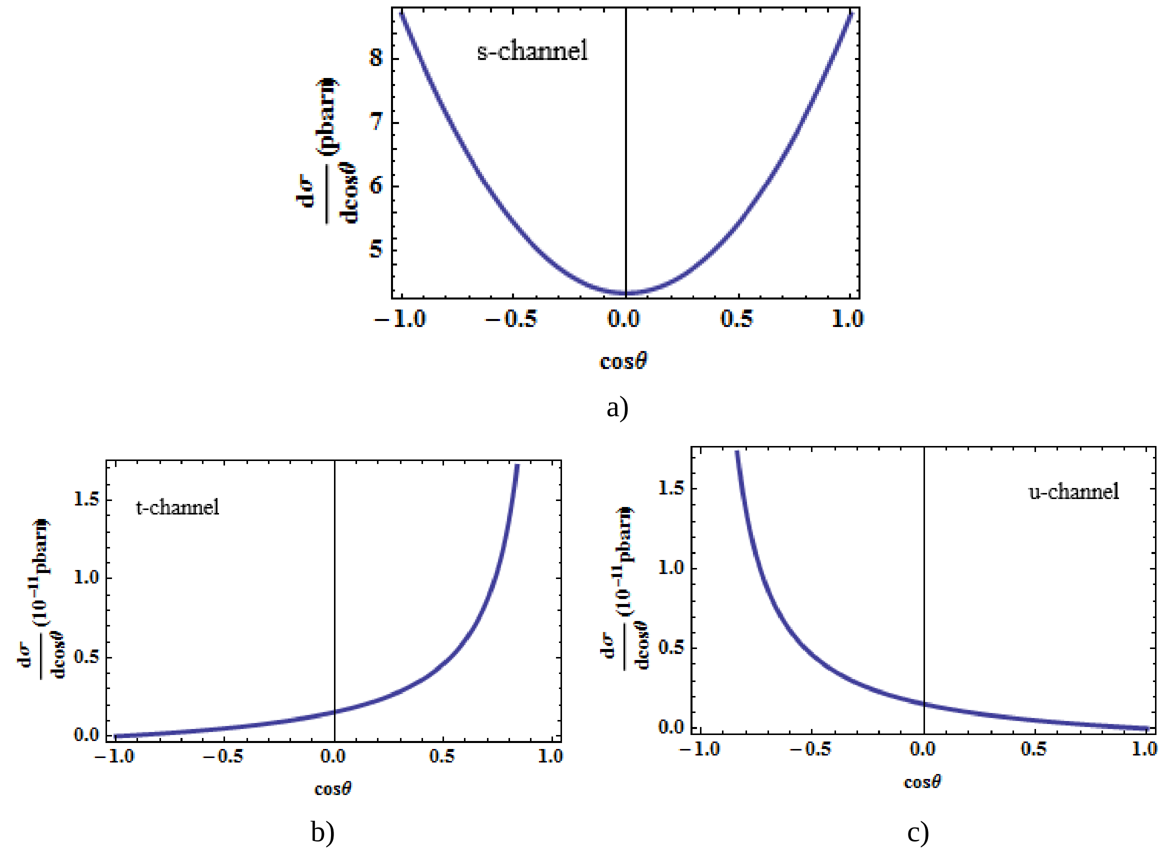


Fig. 5. The differential cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of $\cos\theta$

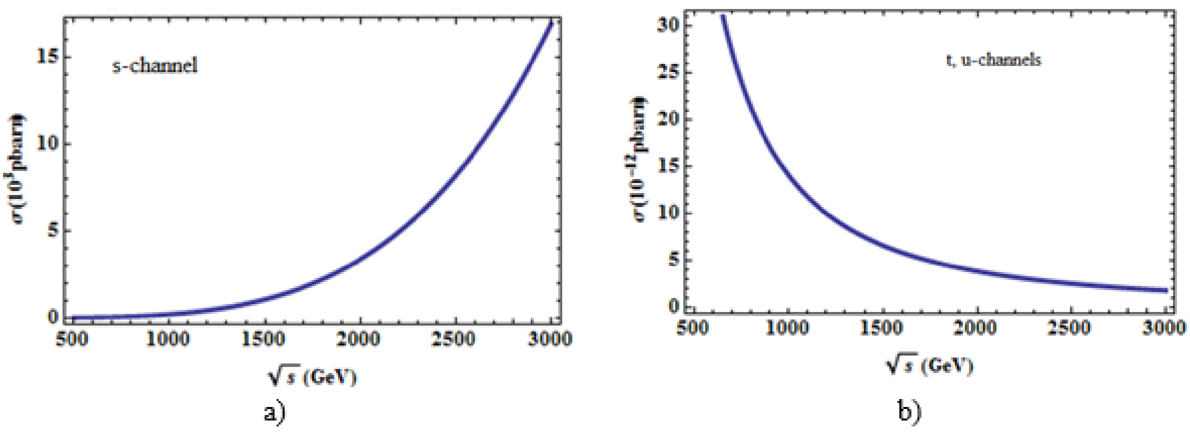


Fig 6. The cross-section of $\mu^+\mu^- \to hU^\mu$ as a function of $\sqrt{s}$

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

The authors would like to thank the sponsors of the Hanoi University of Mining and Geology for the basic science project in 2019, code T19-06.

References

[1] ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B 716 (2012) 1-29. https://doi.org/10.1016/j.physletb.2012.08.020.

[2] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Phys. Lett. B 716 (2012) 30-61. https://doi.org/10.1016/j.physletb.2012.08.021.

[3] Particle Data Group Collaboration, Review of particle physics, Chin. Phys. C 38 (2014) 090001. http://doi.org/ 10.1088/1674-1137/38/9/090001.

[4] L. Randall, R. Sundrum, Large Mass Hierarchy from a Small Extra Dimension, Phys. Rev. Lett. 83 (1999) 3370. https://doi.org/10.1103/PhysRevLett.83.3370.

[5] H. Georgi, Unparticle physics, Phys. Rev. Lett. 98 (2007) 221601. https://doi.org/10.1103/PhysRevLett.98.221601

[6] T. Banks, A. Zaks, On the phase structure of vector-like gauge theories with massless fermion, Nucl. Phys. B196 (1982) 189-204. http://doi.org/10.1016/0550-3213(82)90035-9.

[7] S.L. Chen, X.G. He, Interactions of Unparticles with Standard Model Particles, Phys. Rev. D76 (2007) 091702. https://doi.org/10.1103/PhysRevD.76.091702.

[8] D.T.L. Thuy, N.T. Hau, The process of $e^+e^- \to \mu^+\mu^-$ scattering in unparticle physics, J. Sci. HNUE 7 (2016) 80-87. http://doi.org/10.18173/2354-1059.2016-0035.

[9] N.T. Hau, L.N. Thuc, The process of $e^+e^- \to hU$ in the Randall – Sundrum, J. Mi. Sci. Tec, Special number CBES2 -Humg 2018 (2018) 210-214 (in Vietnamese).

[10] N.T. Hau, D.T.L. Thuy, The process of $e^+e^- \to \mu^+\mu^-$ in the Randall – Sundrum Model, Supersymmetric model and unparticle physics, J. Commu. Phys 1 (2018) 29-40. http://doi.org/10.15625/0868-3166/28/1/9131.

[11] K. Cheung, W.Y. Keung, T.C. Yuan, Collider phenomenology of unparticle physics, Phys. Rev. D76 (2007) 055003. http://doi.org/10.1103/PhysRevD.76.055003.

[12] D. Dominici, B. Grzadkowski, J.F. Gunion, M. Toharia, The scalar Sector of the Randall-Sundrum Model, Nucl. Phys. B671 (2003) 243-292. http://doi.org/10.1016.j.nuclphysb.2003.08.020.

[13] H. Georgi, Another Odd Thing About Unparticle Physics, Phys. Lett. B650 (2007) 275-278. http://doi.org/10.1016/j.physletb.2007.05.037.