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THE PROCESS $e^+e^- \to \phi U$ VIA VECTOR UNPARTICLE EXCHANGE IN THE RANDALL - SUNDRUM MODEL

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Abstract. In this work, the effects of vector unparticle on the process $e^+e^- \to \phi U$ in the Randall - Sundrum model is studied. Specifically, we calculate the cross-section for the process $e^+e^- \to \phi U$ by s-channel and evaluated the cross-section as a function of the center of mass energy $\sqrt{s}$, cosine of scattering angle θ, scaling dimention d_U and the square of unknown coefficient $|C_U|^2$ of the unparticle operator O_U. Our results reveal that the cross-section changes strongly when $1.9 < d_U < 2.0$ and its value is in the high energy domain much larger than the low energy domain. The cross-section increases when $|C_\gamma|^2 < |C_U|^2 < |C_Z|^2$. The differential cross section has a maximum value at $\cos\theta = \pm 1$ and a minimum value at $\cos\theta = 0$.
Keywords: Unparticle physics, Randall - Sundrum model, cross-section.

1. Introduction

Randall and Sundrum (RS) model [1] is one of the extended models of the standard model. The RS proposed a 5-dimensional space-time model with a nonfactorizable metric to solve the hierarchy problem. A new scalar particle is predicted in the RS model called radion with a mass of GeV. The process of finding radion in experimental data will be important evidence to prove the correctness of the RS model.

In this article we consider new physics proposed by Georgi [2], which is described in term of Unparticle physics (UP). The UP theory is a high-energy theory, which contains both the fields of the standard model and the Banks-Zaks fields [3]. After the idea of unparticle was proposed, its effects have been explored in many areas spanning

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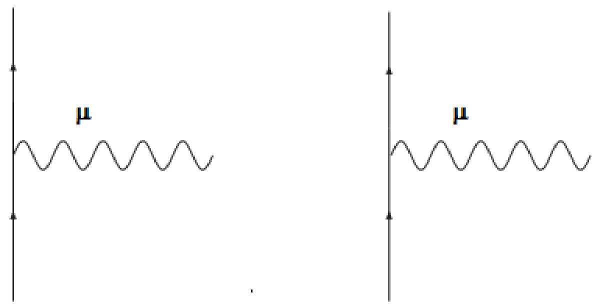
collider physics [4-15]. We are interested in some of the following researches: effects of unparticle in the Moller scattering [16], the effects of unparticles in photon-photon scattering [17-19], effects of the scalar unparticle at high energy colliders (electron-positron, photon-photon, and gluon-gluon) in the RS model [20].

Recently, we have investigated the effects of unparticle on the process $e^+e^- \to \mu^+\mu^-$ in the UP [21], the process $e^+e^- \to hU$ [22] and the process $e^+e^- \to \mu^+\mu^-$ [23] in the RS model. In this work, we want to continue to study the effects of vector unparticle on the process $e^+e^- \to \phi U$ in the RS model.

2. Content

2.1. The Feynman rules for the interaction of vector unparticle with fermions and radion

In the unparticle physics, the Feynman rules for the interactions of vector unparticle with fermions are shown in Figure 1.



$$i\frac{\lambda_1}{\Lambda_U^{d_U-1}}\gamma^\mu \qquad\qquad i\frac{\lambda_1}{\Lambda_U^{d_U-1}}\gamma^\mu\gamma^5$$

Figure 1. Feynman rules for the interaction of fermions with the vector unparticle

Figure 2 describes the interaction of photons and Z bosons with radion in the RS model.

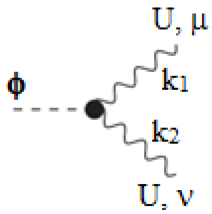
$$iC_\gamma\left[k_1.k_2\eta^{\mu\nu} - k_1^\nu k_2^\mu\right] \qquad\qquad iC_Z\eta^{\mu\nu}$$

a) b)

Figure 2. Feynman rules for the interaction of photons (a) and Z bosons (b) with radion ϕ

where $C_\gamma = -\dfrac{\alpha}{2\pi\upsilon}\left[g_{fV}\sum_i e_i^2 N_c^i F_i(\tau_i) - (b_2 + b_Y) g_r \right]$ and $C_Z = \dfrac{g m_z}{c_w}(c + \gamma a)$ [24].

Based on the effective Lagrangian of describing of radion and vector unparticle interaction, the Feynman rules for the vector unparticle-vector unparticle-radion couplings in the RS model is given by



$$iC_U\left[k_1.k_2\eta^{\mu\nu} - k_1^\nu k_2^\mu\right]$$

Figure 3. Feynman rules for the vector unparticle couplings of the scalar ϕ

2.2. The process $e^+e^- \to \phi U$

In this section, we studied the radion and vector unparticle production in the e^+e^- collision according to s-channel in the RS model. The Feynman diagram for the process $e^+e^- \to \phi U$ is shown in Figure 4.

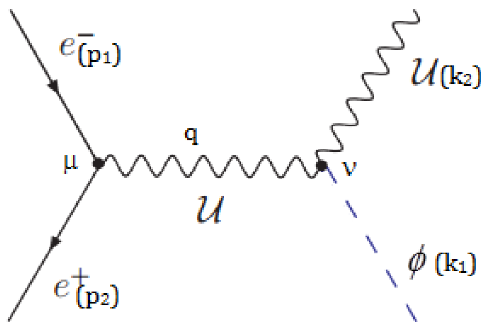


Figure 4. Feynman diagram for the process $e^+e^- \to \phi U$ in the RS model

The matrix element of the process $e^+e^- \to \phi U$ is given by the expression

$$M = -\frac{i\lambda_1 A_{du}}{\Lambda_u^{du-1} 2\sin(du\pi)}(-q^2)^{du-2} C_U \bar{v}(p_2)\gamma^\mu(1+\gamma^5)u(p_1)\pi_{\mu\nu}\left(qk_2.g^{\nu\alpha} - q^\alpha k_2^\nu\right)\varepsilon_\alpha^*(k_2). \qquad (1)$$

From (1), we obtained the square of matrix element of the process $e^+e^- \to \phi U$ as following:

$$\begin{aligned}\sum_{spin}|M|^2 = -2\left(\frac{i\lambda_1 A_{du}}{\Lambda_u^{du-1} 2\sin(du\pi)}(-q^2)^{du-2} C_U\right)^2 (p_2^\mu p_1^{\mu'} + p_2^{\mu'} p_1^\mu - p_1 p_2 g^{\mu\mu'})\pi_{\mu\nu}\pi_{\mu'\nu'} \\ \times\left(\left(qk_2\right)^2 g^{\nu\nu'} - \left(qk_2\right)q^\nu k_2^{\nu'} - \left(qk_2\right)q^{\nu'} k_2^\nu + q^2 k_2^\nu k_2^{\nu'}\right),\end{aligned} \qquad (2)$$

where $q = p_1 + p_2 = k_1 + k_2$, $\pi_{\mu\nu} = \left(-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}\right)$, $\pi_{\mu'\nu'} = \left(-g_{\mu'\nu'} + \frac{q_{\mu'} q_{\nu'}}{q^2}\right)$.

Then, the differential cross section (DCS) of the process $e^+e^- \to \phi U$ can be written as

$$\frac{d\sigma}{d\cos\theta} = \frac{1}{64\pi s}\frac{|\vec{k}_1|}{|\vec{p}_1|}|M|^2, \tag{3}$$

where $\sqrt{s}$ is the center of mass energy, θ is the angle between $\vec{p}_1$ and $\vec{k}_1$.

We choose the following inputs for numerical analysis: $\Lambda_U = 1\,TeV$, $|C_\gamma|^2 = |3.96398\times10^{-7}|^2$, $|C_Z|^2 = |3.34426|^2$, $\lambda_1 = 1$, $\sqrt{s} = 3\,TeV$, $m_\phi = 10\,GeV$. In Figure 5, we charted the total cross-section according to of d_U and $|C_U|^2$ in the range $1 < d_U < 2$ and $|C_\gamma|^2 < |C_U|^2 < |C_Z|^2$. According to Figure 5, we can see that the total cross-section increases quickly as $1.9 < d_U < 2.0$ and its value is in the high energy domain much larger than the low energy domain.

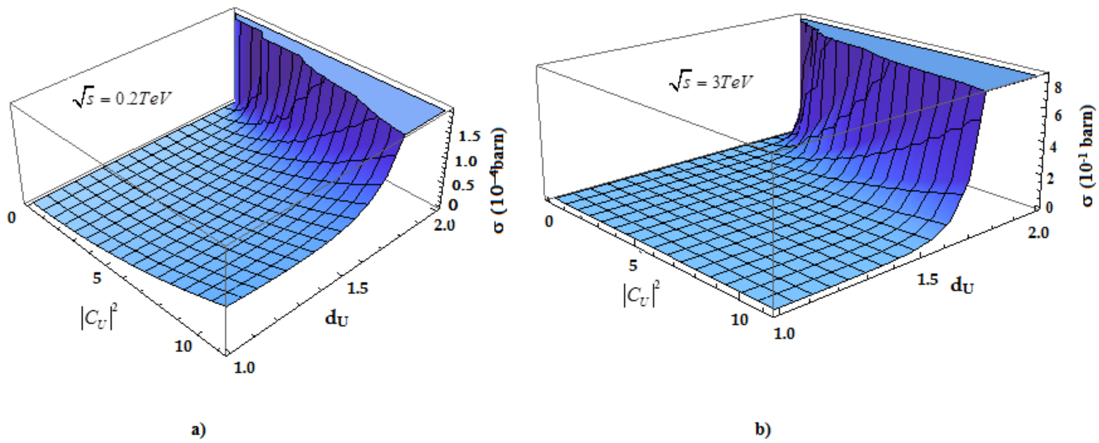


Figure 5. The total cross-section of $e^+e^- \to \phi U$ as a function of d_U and $|C_U|^2$

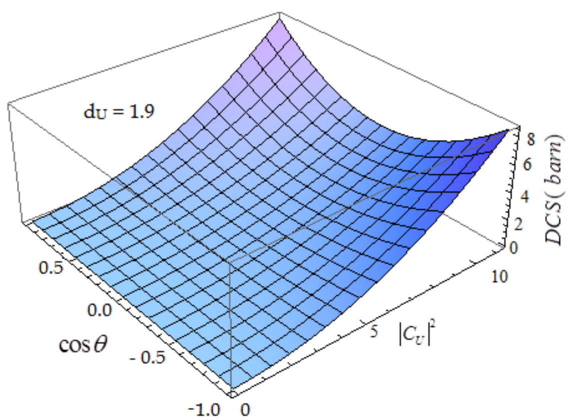


Figure 6. The DCS of $e^+e^- \to \phi U$ as a function of $\cos\theta$ and $|C_U|^2$

The next, we charted the DCS according to $\cos\theta$ and $|C_U|^2$ at $d_U = 1.9$ and $\sqrt{s} = 3\ TeV$ (Compact Linear Collider - CLIC) in Figure 6. We can see that the DCS reaches to a maximum value at $\cos\theta = \pm 1$ and a minimum value at $\cos\theta = 0$ and the DCS increases when $|C_\gamma|^2 < |C_U|^2 < |C_Z|^2$.

Finally, we charted the total cross-section according to $\sqrt{s}$ and $|C_U|^2$ at $d_U = 1.9$ in Figure 7. Figure 7 indicates that the total cross-section increases with higher $\sqrt{s}$. Moreover, the total cross-section increases quickly when $8 < |C_U|^2 < 10$ and $2\ TeV < \sqrt{s} < 3\ TeV$.

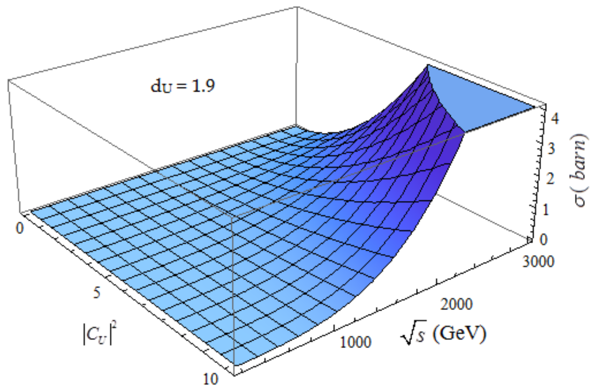


Figure 7. The total cross-section of $e^+e^- \to \phi U$ as a function of $\sqrt{s}$ and $|C_U|^2$

3. Conclusions

We calculate the cross-section of the process $e^+e^- \to \phi U$ by s-channel and evaluate the cross-section as a function of d_U, $\cos\theta$, $\sqrt{s}$ and $|C_U|^2$. We find that the cross-section dependent of the center of mass energy $\sqrt{s}$, the scale dimension d_U of the unparticle operator and coefficient function C_U. In addition, our results reveal that the cross-section in the high energy domain has great value, therefore the ability to lose energy (or unparticle production) is very large.

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