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Original Article

The Scalar Unparticle Production from the Collision Process γe^- in Unparicle Physics

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Abstract: The production of scalar unparticle (spin - 0) in the photon - electron (γe^-) collider is calculated in all s-, t-, and u-channels in detail as well as interference between channels together. By searching for missing energy distributions as well as evaluating dependence of differential cross section (DCS) on the scattering angle (θ) and cross section (CS) on the center of mass energy $(\sqrt{s})$, we hope that the unparticles production in high energy collider might be detected in future.

Keywords: Scalar unparticle, photon-electron, DCS, CS.

1. Introduction

The attractive scenario for describing a possible scale-invariant hidden sector with a continuous mass distribution, which is described in terms of "unparticle" was proposed by Georgi [1]. This scale - invariant sector combined with the Standard Model through interactions of the form $\mathcal{O}_{UV}\mathcal{O}_{SM}$, where $\mathcal{O}_{UV}$ is an unparticle operator and $\mathcal{O}_{SM}$ is a Standard Model operator. A concrete example which can support unparticle stuff was suggested by Banks-Zaks [2, 3], with a suitable number of massless fermions, theory attains a non-trivial infrared fixed point and a conformal filed theory can be realzed at a low energy [4].

The Lagrangrian of the uparticle physics is as follows [4]

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$$L = \frac{c_n}{M^{d_{UV}+n-4}} \mathcal{O}_{UV}\mathcal{O}_{SM}, \quad (1)$$

Where M is the energy scale characterizing the new physics, the operator $\mathcal{O}_{UV}$ and operator $\mathcal{O}_{SM}$ have dimension d_{UV} and *n*, respectively and c_n is a dimension-less constant. In the low energy effective theory, the form of the operator is:

$$L = c_n \frac{\Lambda_U^{d_{UV}-d_U}}{M^{d_{UV}+n-4}} \mathcal{O}_U\mathcal{O}_{SM}, \quad (2)$$

Where the unparticle operator $\mathcal{O}_U$ with a dimension d_U.

In this paper, we calculate in details the production of scalar unparticle in the photon – electron (γe^-) collider in all s-, t-, and u-channels. Evaluating the dependence of the DCS on the scattering angle (θ), we have shown the relevant direction to be able to observe unparticles. In addition, the CS are also considered as a function of the center of mass energy $(\sqrt{s})$.

2. The process $\gamma e^- \to U_{spin-0} e^-$ in unparticle physcis

The corresponding Feynman diagrams for the pair production of unparticle and electron in γe^- collider are shown in Fig. 3.1.

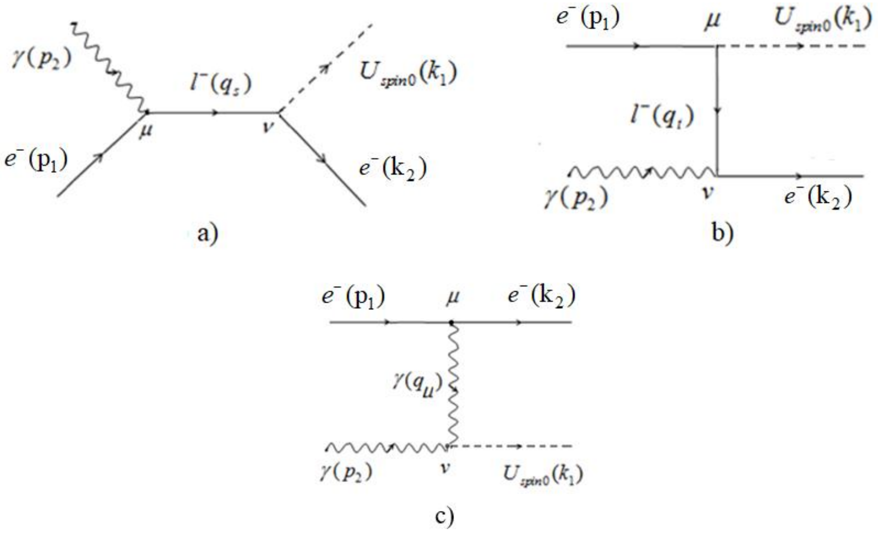

Fig 3.1. The Feynman diagrams for the process $\gamma e^- \to U e^-$

According to the Feynman rules we calculate the amplitude squares of the s-, t- and u- channels as well as the interference between channels together. The resulting expressions are as follows:

$$|M_s|^2 = -8\left(\frac{e\lambda_0}{\Lambda_U^{d_U-1}(q_s^2 - m_l^2)}\right)^2 \{-[2(p_1q_s)(k_2q_s) - q_s^2(p_1k_2)] + 4m_l^2(k_2q_s) + 2m_l^2q_s^2$$

$$+2m_l^4\Lambda_U^{-2}q_s^2 - 2m_l^2(p_1q_s) - \Lambda_U^{-2}q_s^4(p_1k_2) + 2m_l^2\Lambda_U^{-2}(q_sk_2)q_s^2 - 2m_l^2\Lambda_U^{-2}[2(p_1q_s)(k_2q_s)$$
$$-(p_1k_2)q_s^2] + 2m_l^2\Lambda_U^{-2}q_s^4 - 2m_l^2\Lambda_U^{-2}(p_1q_s)q_s^2 - m_l^2(p_1k_2) + 2m_l^4\}, \quad (3)$$

$$|M_t|^2 = -8\left(\frac{e\lambda_0}{\Lambda_U^{d_U-1}(q_t^2 - m_l^2)}\right)^2\{-[2(p_1q_t)(k_2q_t) - (p_1k_2)q_t^2] - 2m_l^2(k_2q_t) - m_l^2(p_1k_2)$$
$$-\Lambda_U^{-2}q_t^4(p_1k_2) - 2m_l^2\Lambda_U^{-2}(q_tk_2)q_t^2 - m_l^2\Lambda_U^{-2}[2(p_1q_t)(k_2q_t) - (p_1k_2)q_t^2]$$
$$+2m_l^2q_t^2 + 4m_l^2(p_1q_t) + 2m_l^4 + 2m_l^2\Lambda_U^{-2}q_t^4 + 4m_l^2\Lambda_U^{-2}(p_1q_t)q_t^2 + 2m_l^4\Lambda_U^{-2}q_t^2\}, \quad (4)$$

$$|M_u|^2 = -4\left(\frac{4e\lambda_0}{\Lambda_U^{d_U}q_u^2}\right)^2\{2[(q_up_2)^2(p_1k_2) - (p_1p_2)(q_uk_2)(q_up_2) - (q_up_2)(p_2k_2)(q_up_1)$$
$$+(p_1p_2)(p_2k_2)q_u^2] + 2[-(k_2p_1) + m_l^2](q_up_2)(q_up_2) + p_2^2q_u^2]\}. \quad (5)$$

The expressions when there are interference of channels as follows:

$$M_s^+M_t = -\frac{8e^2\lambda_1^2}{\Lambda_U^{2(d_U-1)}(q^2 - m_l^2)(q_t^2 - m_l^2)}$$
$$\times\{2(p_1q_t)(k_2q_s) - m_l^2(k_2q_t) - m_l^2(p_1k_2) + 2m_l^2(k_2q_s)$$
$$-\Lambda_U^{-2}q_t^2q_s^2(p_1q_s)(q_sk_2) + 2m_l^2\Lambda_U^{-2}(k_2q_s)q_t^2$$
$$+2m_l^2\Lambda_U^{-2}(p_1q_t)(k_2q_s) - m_l^2\Lambda_U^{-2}q_s^2(k_2q_t) + 2m_l^2(p_1q_t) - m_l^2(q_sq_t) - m_l^2(p_1q_s) + 2m_l^4$$
$$-m_l^2\Lambda_U^{-2}(p_1q_s)q_t^2 + 2m_l^2\Lambda_U^{-2}q_s^2q_t^2 + 2m_l^2\Lambda_U^{-2}(p_1q_t)q_s^2 - m_l^4\Lambda_U^{-2}(q_sq_t)\}, \quad (7)$$

$$M_s^+M_u = -\frac{16e^2\lambda_0^2}{\Lambda_U^{2d_U-1}(q_s^2 - m_l^2)q_u^2}\Lambda_U^{-1}$$
$$\times(q_up_2)\{-2[(p_1k_2)q_s^2] + 4m_l^2(q_sk_2) + 4m_l^2q_s^2 - 2m_l^2(p_1q_s)\}$$
$$-\{q_s^2[(p_1q_u)(k_2p_2) - (p_1k_2)(q_up_2) + (p_1p_2)(k_2q_u)]$$
$$+m_l^2[(q_uq_s)(k_2p_2) - (q_uk_2)(q_sp_2) + (q_up_2)(k_2q_s)]$$
$$+m_l^2(q_up_2)q_s^2 + m_l^2[(p_1q_u)(q_sp_2) - (p_1q_s)(q_up_2) + (p_1p_2)(q_sq_u)]\},$$
(8)

$$M_t^+M_u = -\frac{16e^2\lambda^{02}}{\Lambda_U^{2d_U-1}(q_t^2 - m_l^2)q_u^2}\Lambda_U^{-1}$$
$$\times(q_up_2)\{-2(q_tq_t)(p_1k_2) + 4m_l^2(p_1q_t) - 2m_l^2(q_tk_2) + 4m_l^2(q_tq_t)\}$$
$$-\{q_t^2[(p_1q_u)(k_2p_2) - (p_1k_2)(q_up_2) + (p_1p_2)(k_2q_u)]$$
$$+m_l^2[(p_1q_t)(q_up_2) - (p_1q_u)(q_tp_2) + (p_1p_2)(q_tq_u)]$$
$$+m_l^2[(q_tq_u)(k_2p_2) - (q_tk_2)(q_up_2) + (q_tp_2)(q_uk_2)] + m_l^2[(q_tq_t)(q_up_2)]\}. \quad (9)$$

From these expressions, we evaluated the number of DCS, CS and discussed ability to produce unparticle in the next section.

3. Numerical results and discussions

To estimate the numerical values and examine the DCS and CS, we choose $\lambda_0 = 1$; $\lambda_1 = 1$; $d_U = 1.7$; $\Lambda_U = 1TeV$ [5] and $\sqrt{s} = 3000GeV$.

From the square of matrix elements above, we evaluate the (DCS) as a function of $\cos\theta$ by the expression:

$$\frac{d\sigma}{d\cos\theta} = \frac{1}{64\pi s}\frac{|\vec{k}_1|}{|\vec{p}_1|}|M|^2. \tag{10}$$

the results are shown in figure 3.2.

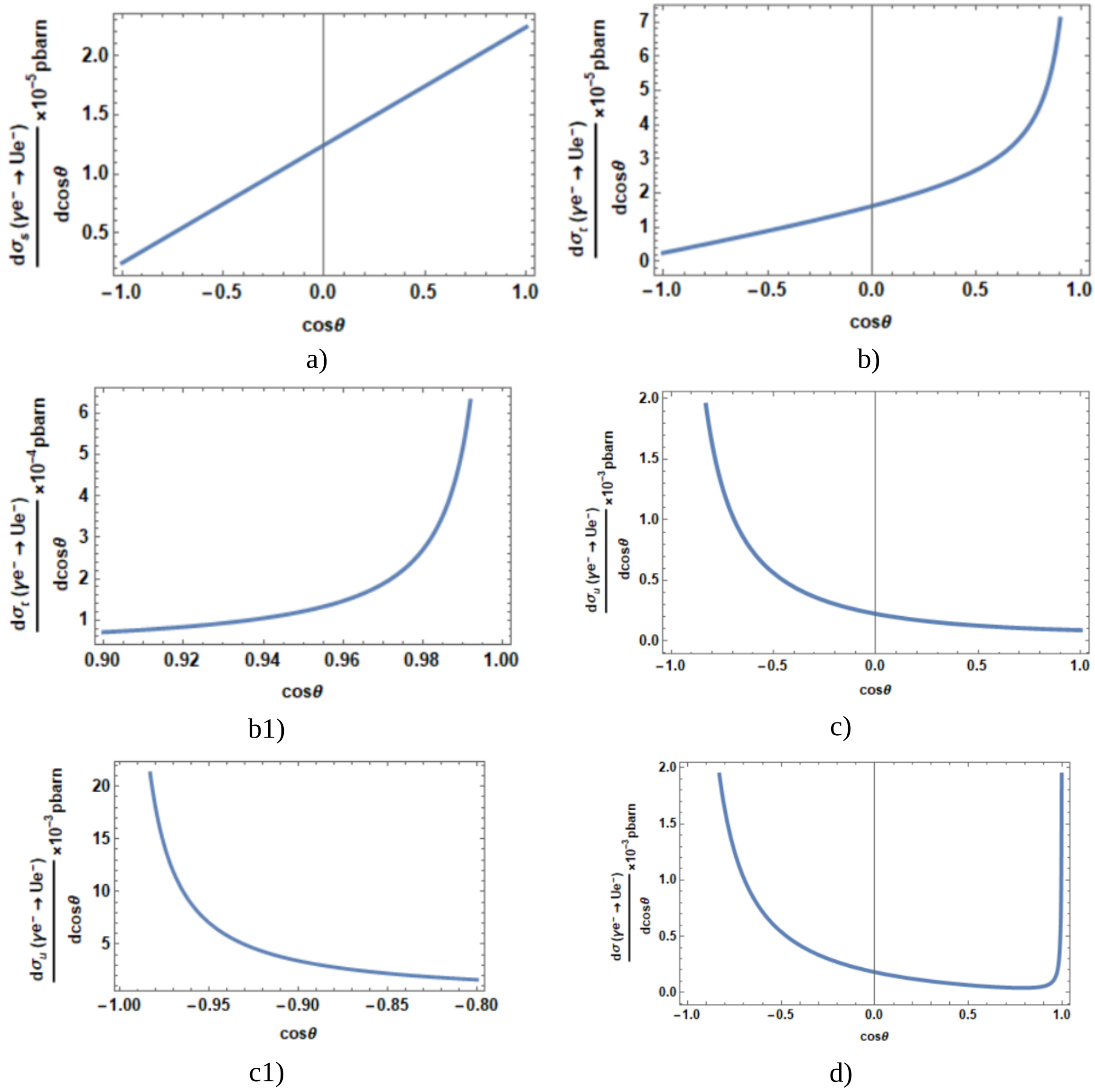

Fig 3.2. The DCS as a function of $\cos\theta$

From the figure 3.2, we see that: for s - and t - channels (fig 3.2 a and fig 3.2 b) the DCS reaches the maximum value ($\approx 2.24\times10^{-5}$ pbarn for s channel and $\approx 6.4\times10^{-4}$ pbarn for t channel see fig3.2b1: the fig 3.2b1 is magnified from figure 3.2b in the range of $\cos\theta$ from 0.9 to 1) if the direction of the particle produces the same direction of the particle at the initial state, while the u-channel (fig 3.2c and fig 3.2c1: the fig 3.2c1 is magnified from figure 3.2c in the range of $\cos\theta$ from -1 to -0.8) is the opposite, the direction of particle generated in reverse with the direction of the particle at the initial state, the DCS has the maximum value: $\approx 24\times10^{-3}$ pbarn (fig 3.2 c1). However, when the phase is associated with all s-, t- and u- channels, the DCS is shown in fig 3.2d, we can see that the DCS has a divergence at $|\cos\theta| = 1$, and the major contribution to the DCS is on u - channel and t – channel.

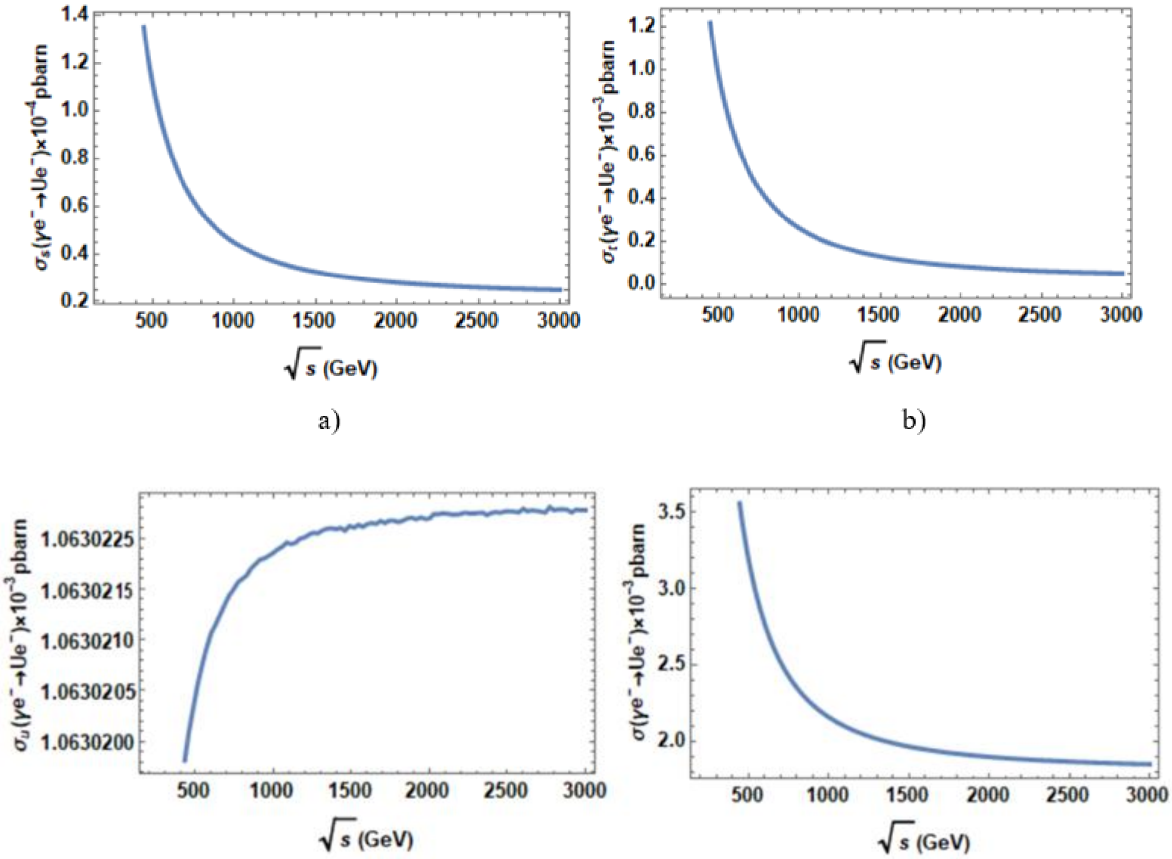

Fig 3.3. The CS as a function of $\sqrt{s}$

In Figure 3.3, we plot the integrated DCS versus the $\sqrt{s}$ with $500GeV \le \sqrt{s} \le 3000GeV$. The CS decrease sharply while $\sqrt{s}$ increases from $500GeV$ to $800GeV$ for the s- and t- channels (fig 3.3 and fig 3.3 b). Similarly, the CS in the case of associating with all s-, t- and u- channels (fig 3.3 d). However, it decrease steadily in the range $\sqrt{s}$ from $800GeV$ to $3000GeV$. Especially, for u–

channel only, the CS increases drammatically while $\sqrt{s}$ increases from $500GeV$ to $1500GeV$, then increases slightly in the range $\sqrt{s}$ from $800GeV$ to $3000GeV$ (fig 3.3 c).

4. Conclusions

The cross sections of the pair production of scalar unparticle γe^- collider depend significantly on the scattering angle and the center of mass energy. We have found the relevant direction to be able to detect unparticles, which the direction of the particle produces the same direction of the particle at the initial state. In addition, the total cross sections increases sharply while $\sqrt{s}$ increases from $500GeV$ to $1500GeV$ for u-channel only. This results may be contribute to experiment in researching unparticles.

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