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Research Article

On Decays of Z' into Unparticle Stuff

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We study the decay of a Z'-boson into U-unparticle and a photon. The extended Landau-Yang theorem is used. The clear photon signal would make the decay $Z' \to \gamma U$ as an additional contribution mode for study of unparticle physics.

1. Introduction

In 1982, Banks and Zaks [1] investigated gauge theories containing noninteger number of Dirac fermions where the two-loop β-function disappears. There is no chance to interpret theory at the nontrivial infrared (IR) fixed point where it possesses the scale-invariant nature in terms of particles with definite masses. The main idea is based on the following statement: at very high energies the theory contains both fields of the standard model (SM) and fields yielding the sector with the IR point. Both of these sectors interact with each other by means of exchange with the particles (fields) having a large mass M. The hidden conformal sector may flow to IR fixed point at some scale $\Lambda < M$, where the interaction between fields has the form $\sim\Lambda^{d_{\rm BZ}-d} O_{\rm SM} O_U M^{-a}$, where $a > 0$, $d_{\rm BZ}$ and d mean the scale dimensions of the Banks-Zaks (BZ) sector operator and the operator O_U of the U-unparticle, respectively; $O_{\rm SM}$ is the operator of the SM fields.

The unparticles (or the scale-invariant stuff) with continuous mass distribution, introduced by Georgi in 2007 [2, 3], obey the conformal (or scale) invariance. There is an extensive literature (see, e.g., the incomplete set of papers [4–13] and the references therein) concerning the phenomenology of unparticles.

The most interesting scale is $\Lambda \sim O(\text{TeV})$, at which the dynamics of unparticles could be seen at CERN LHC through the different processes including the decays with the production of U-unparticles.

It has been emphasized [2, 3] that the renormalizable interactions between the SM fields and the fields of yet hidden conformal sector could be realized by means of exploring the hidden energy at high-energy collisions and/or associated with the registration of noninteger number of invisible particles. In this case, the conformal sector described in terms of "unparticles" does not possess those quantum numbers which are known in the SM.

Unparticle production at hadron colliders will be a signal that the scale where conformal invariance becomes important for particle physics is as low as a few TeV. At this scale, the unparticle stuff sector is strongly coupled. This requires that, somehow, a series of new reactions that involve unparticle stuff in an essential way turn on between the Tevatron and LHC energies. It will be important to understand this transition as precisely as possible. This can be done through the study of $p\overline{p}, pp \rightarrow \gamma + U$ and the identification of the effects from, for example, Z-, Z'-resonances [14] in $p\overline{p}, pp \rightarrow fermion + antifermion$.

The experimental channels of multigauge boson production ensure the unique possibility to investigate the anomalous triple effects of interaction between the bosons. We point out the study of nonabelian gauge structure of the SM, and, in addition, the search for new types of interaction which, as expected, can be evident at the energies above the electroweak scale. The triple couplings of neutral gauge bosons, for example, $ZZ'\gamma$, ZZZ', and so forth, can be studied in pair production at the hadron (lepton) colliders: $pp, p\overline{p}(e^+e^-) \rightarrow Z' \rightarrow Z\gamma, ZZ, \ldots$

In this paper, we study the production of unparticle U in decays of Z' with a single photon emission. There is a hidden sector where the main couplings to matter fields are through the gauge fields. Before using the concrete model, we have to make the following retreat. First of all, we go to the extension of the Landau-Yang theorem [15, 16] for the decay of a vector particle into two vector states. Within this theorem, the decay of particle with spin-1 into two photons is forbidden (because both outgoing particles are massless). The direct interaction between Z'-boson and a vector massive particle, for example, Z or U-vector unparticle, accompanied by a photon, does not exist. To the lowest order of the coupling constant g, the contribution given by g^3 in the decay $Z' \rightarrow \gamma U$ is provided mainly by heavy quarks in the loop. What is the origin of this claim? First, it is worth to remember the known calculation of the anomaly triangle diagram $ZZ\gamma$ [17], where the anomaly contribution result contains two parts, one of which has no dependence of the mass m_f of (intermediate) charged fermions in the loop while the second part is proportional to m_f^2. An anomaly term disappears in the case if all the fermions from the same generation are taking into account or the masses of the fermions of each of generation are equal to each other. The reason which explains the above-mentioned note is the equality to zero of the sum $\Sigma_f N_c^f g_V^f g_A^f Q_f$, where $g_V^f(g_A^f)$ is the vector (axial-vector) coupling constant of massive gauge bosons to fermions, Q_f is the fermion charge, $N_c^f = 3(1)$ for quarks (leptons). The anomaly contribution for the decay $Z' \rightarrow \gamma U$ does not disappear due to heavy quarks, and the amplitude of this decay is induced by the anomaly effect. The contribution from light quarks with the mass m_q is suppressed as $m_q^2/m_{Z'}^2 \sim 10^{-8}$–$10^{-6}$, where $m_{Z'}$ is the mass of Z'-boson. Despite the decay $Z' \rightarrow \gamma U$ being the rare process, there is a special attention to the sensitivity of this decay to top-quark and even to quarks of fourth generation.

Since the photon has the only vector nature of interaction with the SM fields, the possible types of interaction $Z' - U - \gamma$ would be either $V - A - V$ or $A - V - V$, where $V(A)$ means the vector (axial-vector) interaction.

2. Setup

Let us consider the following interaction Lagrangian density:

$$-L = g_{Z'} \sum_q \overline{q}\left(v'_q \gamma^\mu - a'_q \gamma^\mu \gamma_5\right) q Z'_\mu + \frac{1}{\Lambda^{d-1}} \sum_q \overline{q}\left(c_v \gamma^\mu - a_v \gamma^\mu \gamma_5\right) q O_{\mu_U}, \tag{2.1}$$

where $g_{Z'} = (\sqrt{5b/3} s_W g_Z)$ is the gauge constant of $U'(1)$ group (the coupling constant of Z' with a quark q) with the group factor $\sqrt{5/3}$, $b \sim O(1)$, $g_Z = g/c_W$; $s_W(c_W) = \sin\theta_W(\cos\theta_W)$, θ_W is the angle of weak interactions (often called Weinberg angle); v'_q and a'_q are generalized vector and the axial-vector $U'(1)$-charges, respectively. These latter charges are dependent on both (joint) gauge group and the Higgs representation which is responsible for the breaking of initial gauge group to the SM one; c_v and a_v are unknown vector and axial-vector couplings. Actually, the second term in (2.1) is identical to the first one up to the factor Λ^{1-d}.

In conformal theory the unparticle does not have a fixed invariant mass, but instead has a continuous mass spectrum. In the paper we assume that O_{μ_U} is a nonprimary operator derived by $O_{\mu_U}(x) = \partial_\mu S(x)$ through the light pseudo-Goldstone field $S(x)$ which is the consequence of an approximate continuous symmetry. The scalar field $S(x)$ is a "grandfather" potential which serves as an approximate conformal compensator with continuous mass. The scale dimension of the gauge invariant nonprimary vector operator is $d \geq 2$ as opposed to $d \geq 3$ for primary gauge-invariant vector operators. In conformal theory, a primary operator defines the highest weight of representation of the conformal symmetry and this operator obeys the unitarity condition $d \geq j_1 + j_2 + 2 - \delta_{j_1 j_2,0}$, where j_1 and j_2 are the operator Lorentz spins (primary means not a derivative of another operator). For the review of the constraints of gauge invariant primary operators in conformal theory and the violations of the unitarity, see [18] and the references therein. Furthermore, we consider $d \geq 1$ which does not contradict the unitarity condition because the operator $O_{\mu_U}(x) = \partial_\mu S(x)$ is not gauge invariant. Because the conformal sector is strongly coupled, the mode $S(x)$ may be one of new states accessible at high energies. The operator O_{μ_U} has both the vector and the axial-vector couplings to quarks in the loop.

We consider the model containing the Z_χ-boson on the scale $O(1\,\text{TeV})$ in the frame of the symmetry based on the E_6 effective gauge group [19, 20]. The coupling constant of $U(1)_x$ has the form $g_\chi = \sqrt{5/3} e/c_W$.

The amplitude of the decay $Z' \to \gamma U$, where the coupling $Z' U \gamma$ is supposed to be extended by the intermediate quark loop, has the following form:

$$Am(z_u, z_q) = \frac{e^2}{c_W}\sqrt{\frac{5}{3}} \frac{3}{\Lambda^{d-1}} \sum_q e_q \left(c_v a'_q + a_v v'_q\right) I(z_u, z_q), \tag{2.2}$$

with $z_u = P_U^2/m_{Z'}^2$, $z_q = m_q^2/m_{Z'}^2$ for the momentum P_U of U-unparticle and the quarks q (in the loop) with the mass m_q. We deal with the following expression for $I(z_u, z_q)$:

$$I = \frac{1}{1-z_u}\left\{\frac{1}{2} + \frac{z_q}{1-z_u}\left[F(z_q) - F\left(\frac{z_q}{z_u}\right)\right] - \frac{1}{2(1-z_u)}\left[G(z_q) - G\left(\frac{z_q}{z_u}\right)\right]\right\}, \tag{2.3}$$

adopted for the decay $Z' \to \gamma U$ taking into account the results obtained in [20, 21]. For heavy quarks, $m_q > 0.5 m_{Z'}$, the functions $F(x)$ and $G(x)$ in (2.3) are

$$F(x) = -2\left(\sin^{-1}\sqrt{\frac{1}{4x}}\right)^2, \qquad G(x) = 2\sqrt{4x-1}\,\sin^{-1}\left(\sqrt{\frac{1}{4x}}\right), \tag{2.4}$$

while for light quarks ($m_q < 0.5m_{Z'}$), one has to use the following formulas:

$$F(x) = \frac{1}{2}\left(\ln\frac{y^+}{y^-}\right)^2 + i\pi\ln\frac{y^+}{y^-} - \frac{\pi^2}{2}, \qquad G(x) = \sqrt{1-4x}\left(\ln\frac{y^+}{y^-} + i\pi\right), \tag{2.5}$$

where $y^{\pm} = 1 \pm \sqrt{1-4x}$. The variable z_u is related to the photon energy E_γ as $z_u = 1-2E_\gamma/m_{Z'}$. In the frame of the Z_χ-model, we choose $v'_{\rm up} = 0$, $a'_{\rm up} = \sqrt{6}s_W/3$, $v'_{\rm down} = 2\sqrt{6}s_W/3$, $a'_{\rm down} = -\sqrt{6}s_W/3$ for *up* and *down* quarks. Actually, the account of the only light quarks leads to the zeroth result for the amplitude (2.2). In the heavy quark sector, the contribution $\sim a_v v'_q$ is nonzero for the only b-quarks and down quarks of fourth generation. We emphasize that the nonvanishing result for the amplitude $Z' \to \gamma U$ is the reflection of the anomaly contribution due to the presence of heavy quarks.

3. Decay Rate

In the decay $Z' \to \gamma U$, the unparticle cannot be identified with the definite invariant mass. U-stuff possesses by continuous mass spectrum, and can not be in the rest frame (there is the similarity to the massless particles). Since the unparticles are stable (and do not decay), the experimental signal of their identification could be looking through the hidden (missing) energy and/or the measurement of the momentum distributions when the U-unparticle is produced in $Z' \to \gamma U$ decay.

The differential distribution of the decay width—$\Gamma(Z' \to \gamma U)$ over the variable z_u looks like (see also [14]):

$$\frac{d\Gamma}{dz_u} = \frac{1}{2m_{Z'}}\sum_q |M_q|^2 \frac{A_d}{16\,\pi^2}\left(m_{Z'}^2\right)^{d-1} z_u^{d-2}(1-z_u), \tag{3.1}$$

where

$$\sum_q |M_q|^2 = \frac{1}{6\pi^4} z_u(1-z_u)^2(1+z_u)\left|Am(z_u, z_q)\right|^2 m_{Z'}^2, \tag{3.2}$$

and [2, 3]

$$A_d = \frac{16\pi^{5/2}}{(2\pi)^{2d}}\,\frac{\Gamma(d+1/2)}{\Gamma(d-1)\Gamma(2d)}. \tag{3.3}$$

One of the requirements applied to the amplitude in (3.2) is that it disappears in case of “massless” unparticle (Landau-Yang theorem), and when $z_u = 1$.

Some bound regimes in (3.1) may be both useful and instructive for further investigation. For this, we consider the quark-loop couplings in the amplitude (2.2) as the sum of the contributions given by light quarks q and heavy ones Q (Q may be referred to the quarks of fourth generation as well):

$$\sum_q e_q\left(c_v a'_q + a_v v'_q\right) I(z_u, z_q) + \sum_Q e_Q\left(c_v a'_Q + a_v v'_Q\right) I(z_u, z_Q). \tag{3.4}$$

For the SM quarks with $z_q < 1/4$ and $(z_q/z_u) > 1/4$ one gets the one-loop function $I(z_u, z_q)$

$$I(z_u, z_q) \simeq \frac{1}{2(1-z_u)}\left(\frac{1}{3} - i\pi\right)(1+z_u), \tag{3.5}$$

and the distribution $d\Gamma/dz_u$ has the form

$$\frac{d\Gamma}{dz_u} \simeq \frac{5A_d}{6}\left(\frac{1}{9}+\pi^2\right)\left(\frac{s_W}{c_W}\right)^2\left(\frac{\alpha}{2\pi^2}\right)^2\left(\frac{m_{Z'}^2}{\Lambda^2}\right)^{d-1} z_u^{d-1}\left(1-z_u^2\right)(1+2z_u). \tag{3.6}$$

On the other hand, if the quarks inside the loop become heavy enough, $z_Q > 1/4$, we estimate the following function $I(z_u, z_Q)$

$$I(z_u, z_Q) \simeq \frac{1}{12 z_Q (1-z_u)}\left[\frac{1}{2}(1+z_u)\left(\frac{1}{8z_Q} - 1\right) + 1\right], \tag{3.7}$$

which is very small in the limit $z_Q \gg 1$.

The photon energy $E_\gamma = m_{Z'}(1-z_u)/2$ in the limit $z_u \to 0$ gets its finite value. The limit $z_u \to 1$ is trivial and we do not consider this.

Within the fact of the combination $c_v a'_q + a_v v'_q$ in (2.2) the decay amplitude of $Z' \to \gamma U$ does not disappear when the summation on all the quarks degree of freedom is performed.

Constraints on the unparticle parameter Λ can be obtained through, for example, limits on measurable collider phenomenology. In particular, it has been noted [22] that this bound never dips below 1 TeV. In Figure 1, the monophoton energy distribution $E_\gamma^{-1} d\Gamma/dz_u$ is presented for a range of photon energy E_γ = 0–500 GeV and various choices of d. For simplicity, we use the E_χ-model assuming the flavor blind universality $c_v = a_v = 1$ for all three generation quarks; Λ and $m_{Z'}$ are set to be 1 TeV each.

The sensitivity of the scale dimension d to the energy distribution is evident. As d moves away from unity, the energy spectrum begins to flatten out gradually, excepting $d = 1.2$ distribution which is above $d = 1.1$. Such a behaviour is given by the factor (3.3).

The U-unparticle could behave as a very broad vector boson since its mass could be distributed over a large energy spectrum. The production cross-section into each energy bin could be much smaller than in the case where an SM vector boson has that particular mass. This may be the reason why we have not yet seen the U-unparticle trace in the experiment.

In the appropriate approximation when the relation between the total decay width $\Gamma_{Z'}$ of Z'-boson and $m_{Z'}$ is small, the contribution to the cross-section of the process $pp \to Z' \to \gamma U$ can be separated into Z' production cross-section $\sigma(pp \to Z')$ and the branching ratio of the decay $Z' \to \gamma U$, $B(Z' \to \gamma U) = \Gamma(Z' \to \gamma U)/\Gamma_{Z'}$: $\sigma(pp \to Z' \to \gamma U) = \sigma(pp \to Z') \cdot B(Z' \to \gamma U)$. The Z'-boson can be directly produced at a hadron collider via

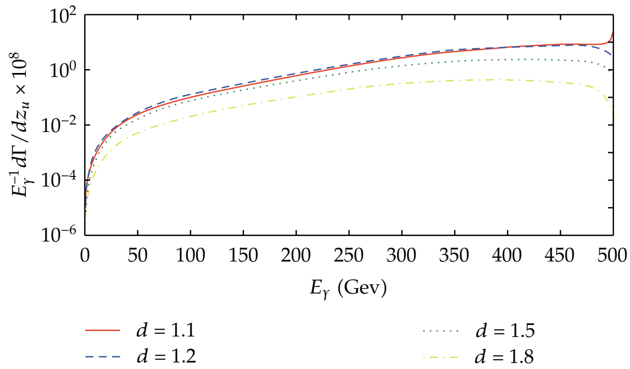

Figure 1: Energy distribution $E_\gamma^{-1} d\Gamma/dz_u \times 10^8$ for $E_\gamma = 0$–500 GeV, depending on $d = 1.1, 1.2, 1.5, 1.8$; $c_v = a_v = 1$, $\Lambda = 1$ TeV, $m_{Z'} = 1$ TeV.

the quark-antiquark annihilation subprocess $\overline{q}q \to Z'$, for which the cross-section in the case of infinitely narrow Z' is given by

$$\sigma(\overline{q}q \longrightarrow Z') = k_{\text{QCD}} \frac{4\pi^2}{3} \frac{\Gamma(Z' \longrightarrow \overline{q}q)}{m_{Z'}} \delta\left(\hat{s} - m_{Z'}^2\right), \tag{3.8}$$

where $k_{QCD} \simeq 1.3$ represents the enhancement from higher-order QCD processes. Conservation of the energy-momentum implies that the invariant mass of Z' is equal to the parton center-of-mass energy $\sqrt{\hat{s}}$, with $\hat{s} = x_1 x_2 s$; x_1 and x_2 are the fractions of the momenta carried by partons in the process $\overline{q}q \to Z'$. The decay width $\Gamma(Z' \to \overline{q}q)$ is

$$\Gamma(Z' \longrightarrow \overline{q}q) = \frac{G_F m_Z^2}{6\pi\sqrt{2}} N_c m_{Z'} \sqrt{1 - 4z_q} \left[\left(v'_q\right)^2 (1 + 2z_q) + \left(a'_q\right)^2 (1 - 4z_q)\right], \tag{3.9}$$

where G_F is the Fermi coupling constant. In the narrow width approximation, the cross-section (3.8) reduces to ($z_q \ll 1$)

$$\sigma(\overline{q}q \longrightarrow Z') \simeq k_{\text{QCD}} \frac{2a}{3} \frac{G_F}{\sqrt{2}} \left(\frac{m_Z}{m_{Z'}}\right)^2 \frac{\left[\left(v'_q\right)^2 + \left(a'_q\right)^2\right]}{\left(\hat{s}/m_{Z'}^2 - 1\right)^2 + a^2}, \tag{3.10}$$

where $a = \Gamma_{Z'}/m_{Z'}$.

For the SM quarks, $z_q \le 1/4$, the branching ratio $B(Z' \to \gamma U)$ is

$$B = \frac{5A_d}{3a} \left(\frac{1}{9} + \pi^2\right) \left(\frac{s_W}{c_W}\right)^2 \left(\frac{\alpha}{2\pi^2}\right)^2 \left(\frac{m_{Z'}^2}{\Lambda^2}\right)^{d-1} \left[\frac{1}{d(d+2)} + \frac{2}{(d+1)(d+3)}\right]. \tag{3.11}$$

In Figure 2, the branching ratio $B(Z' \to \gamma U)$ is presented with the assumption $c_v = a_v = 1$ for all three generation quarks; Λ is set to be 1 TeV, the range of d is chosen as $= 1.1, 1.2, 1.5, 1.8$ for $m_{Z'} = 0.5$–3.0 TeV. The width $\Gamma_{Z'}$ is chosen in the framework of the sequential SM (Z'_{SSM}),

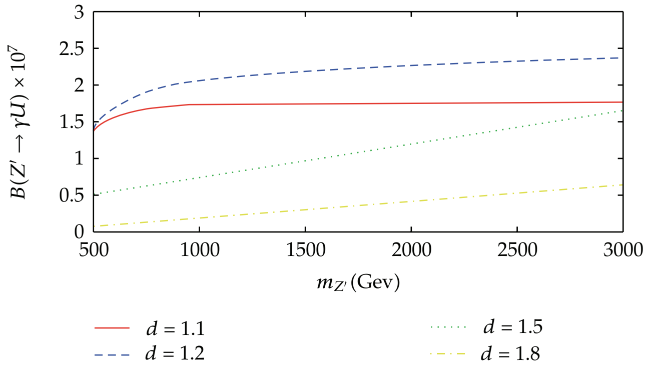

Figure 2: Branching ratio $B(Z' \to \gamma U) \times 10^7$ for $c_v = a_v = 1$, $\Lambda = 1$ TeV depending on $d = 1.1, 1.2, 1.5, 1.8$ and $m_{Z'} = 0.5$–3.0 TeV with $\Gamma_{Z'}$ given by the Z'_{SSM}-model ($a = 0.03$).

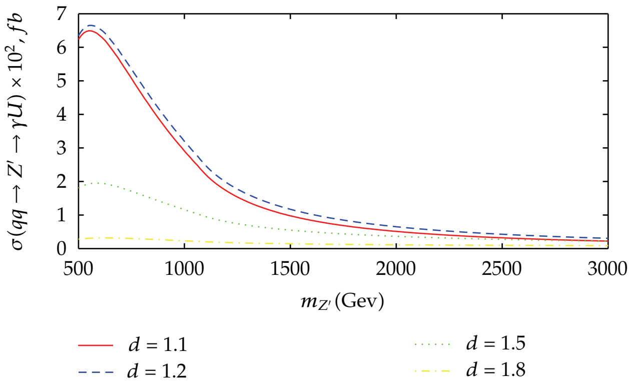

Figure 3: Cross-section $\sigma(\bar{q}q \to Z' \to \gamma U) \times 10^2, fb$ with the assumption of up quarks annihilation, where $d = 1.1, 1.2, 1.5, 1.8, m_{Z'} = 0.5$–$3.0$ TeV, $a = 0.03$.

where the ratio $\Gamma_{Z'}/m_{Z'}$ has the maximal value $a = 0.03$ among the grand unification theories-(GUT-) inspired Z' models [23].

We find the smooth increasing of $B(Z' \to \gamma U)$ with $m_{Z'}$ and its decreasing with the dimension d excepting $d = 1.2$ branching ratio.

In Figure 3, we plot the cross-section $\sigma(\bar{q}q \to Z' \to \gamma U)$ in the case of up-quarks annihilation, where $x_1 \sim x_2 \sim \sqrt{x_{\text{min}}}$, $x_{\text{min}} = m_{Z'}^2/s$; the range of d is chosen as $= 1.1, 1.2, 1.5, 1.8$ for $m_{Z'} = 0.5$–3.0 TeV; $a = 0.03$.

For 100 fb^{-1} luminosity at the LHC, the detection of the process $Z' \to \gamma U$ can be achieved with about 10 signal events for $m_{Z'} \sim O(1\,\text{TeV})$ at $d = 1.1$.

4. Constraints

The hidden sector can be strongly constrained by existing experimental data. One of the important and practical implications for unparticle phenomenon is the analysis of the operator form

$$\frac{\Lambda^{d_{\text{BZ}}-d}}{M^{d_{\text{BZ}}-2}} |\text{H}|^2 O_U, \tag{4.1}$$

containing the SM Higgs field H. Within the Higgs vacuum expectation value (v) requirement, the theory becomes nonconformal below the scale

$$\tilde{\Lambda} = \left(\frac{\Lambda^{d_{\rm BZ}-d}}{M^{d_{\rm BZ}-2}} v^2 \right)^{1/(4-d)} < \Lambda, \tag{4.2}$$

where U-unparticle sector becomes a standard sector. For practical consistency we require $\tilde{\Lambda} < \sqrt{s}$. It implies that unparticle physics phenomena can be seen at high-energy experiment with the energies

$$s > \left(\frac{\Lambda^{d_{\rm BZ}-d}}{M^{d_{\rm BZ}-2}} v^2 \right)^{2/(4-d)}, \tag{4.3}$$

even when $d \to d_{\rm BZ}$. Note, that any observable involving operators $O_{\rm SM}$ and O_U in (4.1) will be given by the operator

$$\hat{o} = \left(\frac{\Lambda^{d_{\rm BZ}-d}}{M^{d_{\rm BZ}+n-4}} \right)^2 s^{d+n-4}, \tag{4.4}$$

where n is the dimension of the SM operator. Then, the observation of the unparticle sector is bounded by the minimal energy

$$s > \hat{o}^{1/n} M^2 \left(\frac{v}{M} \right)^{4/n}. \tag{4.5}$$

In (4.5) we don't have dependence on both d- and $d_{\rm BZ}$-dimensiions. The main model parameter is the mass M of heavy messenger. If the experimental deviation from the SM is detected at the level of the order $\hat{o} \sim 1\%$ at $n = 4$, the lower bound on $\sqrt{s}$ would be from 0.9 TeV to 2.8 TeV for $M's$ running from 10 TeV to 100 TeV, respectively. Thus, both the Tevatron and the LHC are the ideal colliders where the unparticle physics can be tested well.

5. Conclusion

We studied the decay of the extra neutral gauge boson Z' into a vector U-unparticle and a photon. Both vector and axial-vector couplings to quarks play a significant role. The energy distribution for $pp \to Z' \to \gamma U$ can discriminate d. The branching ratio $B(Z' \to \gamma U)$ is at best of the order of 10^{-7} for the scale dimension $d = 1.1$. For larger d, the branching ratio is at least smaller by one order of the magnitude. Unless the LHC can collect a very large sample of Z'-bosons, detection of U through the decay $Z' \to \gamma U$ would be challenging compared to the decay $Z \to \gamma U$, where the branching ratio $B(Z \to \gamma U) \sim 10^{-8}$ [14].

For 100 fb^{-1} integrated luminosity, the detection of $Z' \to \gamma U$ can be with about 10 signal events at $d = 1.1$ for a 1.0 TeV Z', while for larger values of d there is the decreasing of the events number.

For the case when Z'-boson has continuously distributed mass [24], the branching ratio has an additional suppression factor due to nonzero internal decay width $\Gamma_{Z'}^{\text{int}}$ in formulas:

$$\int_0^{\infty} \frac{\rho(t)dt}{p^2 - t - i\epsilon} \simeq \frac{1}{p^2 - m_{Z'}^2 + i m_{Z'} \Gamma_{Z'}^{\text{int}}}, \qquad \rho(t) = \frac{1}{\pi} \frac{\Gamma_{Z'}^{\text{int}} m_{Z'}}{\left(t - m_{Z'}^2\right)^2 + \Gamma_{Z'}^{2\,\text{int}} m_{Z'}^2}. \tag{5.1}$$

The experimental estimation of $B(Z' \to \gamma U)$ could provide the quantity $\Gamma_{Z'}^{\text{int}}$, and since the γ-quantum energy has a continuous spectrum, by measuring the photon energy spectrum in the Z'-decay, one can discriminate the presence of the U-unparticle or not.

We have shown numerical results for Z'-bosons associated with the Z_χ-model. The calculations are easily applicable to other extended gauge models, for example, little Higgs scenario models, left-right symmetry model, and sequential SM.

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