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AN ANALYISIS OF THE CONSTRAINTS ON UNPARTICLES USING CERN-LEP DATA FOR $e^{+}e^{-} \rightarrow \mu^{-}\mu^{+}$ SCATTERING

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Abstract

In this work, using the CERN LEP data for the cross section measurments of $e^{-}e^{+} \rightarrow \mu^{-}\mu^{+}$ process at the center of mass energies 189-207GeV observability limits of the unparticles are calculated. In the calculations of the energy dependent Standard Model cross sections the semi-analitic computer program ZFITTER which includes radiative corrections has been used. For various values of the scaling dimension d of the unparticles the limits on the unparticle couplings have been extracted using chi-square analyisis at the 95% confidence level.

Key Words: CERN-LEP Accelerator, Electron-Positron Scattering, Unparticles.

1. Introduction

Unparticle Physics, put forward by Georgi, is one of the research topics that has attracted great attention lately [1]. In his article which is the subject of this research, Georgi has considered the existence of a *scale invariant sector* that is probable to be found in very high energy in nature. As the result of the analyses, he revealed that if there really is a sector that does not change under a scaling symmetry in very high energy in nature and when the calculation of possible observable effects of this sector in present high energy particle accelerator is asked for, quantum areas that describe this sector will not behave as ordinary particles. When two-point function that describes scale constant sector was put to scale alternation, he showed that the corresponding particle flow can express fractional amount of particles and in order to express and emphasize this extra-ordinary strange situation he named them *unparticles.*

We can make a short description about phenomenological calculations of unparticles by taking Georgi's theory into consideration in this way. Areas of scale constant sectors are expressed with Banks-Zaks (BZ),[2] and shown with O_{BZ} in high-energy area. On the other hand, known Standart Model(SM) particles are shown with O_{SM} . Interaction of BZ areas with SM areas in high energy with the exchange of particles in M_k energy scale is shown with interaction Lagrangian below.

$$\frac{1}{M^{k}} O_{BZ} O_{SM} \tag{1}$$

Here d_{BZ} is the mass dimension of O_{BZ} processors that represents BZ areas, and d_{SM} is the mass dimension of O_{SM} processors that represents SM areas. In this case, $k = d_{BZ} + d_{SM} - 4$. Coupling constants of renormalizing O_{BZ} processors necessitate a dimensional transmutation in energy levels under the energy levels as in Λ. So, under this energy level BZ processors correspond to O_U processors one-to-one and the Equation (1) is redefined for the unparticle processors as in below.

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$$\frac{C_U \Lambda^{d_{BZ}-d}}{M^k} O_U O_{SM} \tag{2}$$

Here d represents scaling dimensionof unparticles and C_U is an ordinary coefficient constant. In two of Georgi's articles in 2007 [1] and afterwards, in the article of Cheung vd.[3,4] basic calculation principles about the affective interactions of SM areas with unparticles and Feynman rules were told. An important literature was formed based on Georgi's theory by examination of observability boundaries and many other characteristics of unparticles in today's high energy. To get information about calculations of observability boundaries of unparticles, [3,4,5,6,7,8] articles and the references in these articles can be looked over.

The topic of this study is the calculation of scattering process of $e^-e^+ \to \mu^-\mu^+$ by taking the contributions of unparticles and calculating the coupling constants of unparticles by using Chi-square distibution and the test data obtained from CERN-LEP Accelerator under Lorentz symmetry and with the help of ZFITTER computer programme that can calculate reflectional contributions.

2. $e^-e^+ \to \mu^-\mu^+$ Scattering

Interaction lagrangian for the contribution of the scalar featured unparticles to the $e^-e^+ \to \mu^-\mu^+$ process is expressed below.

$$\frac{\lambda}{\Lambda^{d-1}} \bar{f} f O_U + h.e. \tag{3}$$

Here, $\lambda = \dfrac{C_U \Lambda^{d_{BZ}}}{M^{d_{BZ}-1}}$

Affective interactions constant of unparticles, *f*, SM fermions, *h.e.* hermitian conjugate. According to this, scattering amplitude that the exchange contribution of unparticles expression is as in below.

$$M^s = [f_d][\overline{v_{e^+}}(p_2) u_{e^-}(p_1)][\overline{u_{\mu^+}}(p_3) v_{\mu^+}(p_4)][-s]^{d-2} \tag{4}$$

$$M^t = [f_d][\overline{u_{\mu^-}}(p_3) u_{e^-}(p_1)][\overline{v_{e^+}}(p_2) v_{\mu^+}(p_4)][-t]^{d-2} \tag{5}$$

Here, *s* and *t show* Mandelstam parameters and the expressions below are used.

$$f_d = \frac{\lambda^2}{\Lambda^{2d-2}} \frac{A_d}{2\sin(d\pi)} \tag{6}$$

$$A_d = \frac{16\pi^{5/2}}{(2\pi)^{2d}} \frac{\Gamma(d+1/2)}{\Gamma(d-1)\Gamma(2d)} \tag{7}$$

Exchange of photon that corresponds to tree diagrams in SM and Z bosons takes place in s-channel. Differential scattering effect sector that includes helicity amplitudes different from zero represents SM and unparticles by taking their contributions into consideration together and the change of scattering effect section according to scattering angle.

$$\frac{d\sigma}{d\cos\theta}=\frac{1}{128\pi s}\left\{\begin{array}{l}\left|M_{SM}(RLRL)\right|^2+\left|M_{SM}(RLLR)\right|^2+\left|M_{SM}(LRRL)\right|^2+\left|M_{SM}(LRRL)\right|^2\\ +\left|M^s{}_U(RRRR)\right|^2+\left|M^s{}_U(RRLL)\right|^2+\left|M^s{}_U(LLRR)\right|^2+\left|M^s{}_U(LLLL)\right|^2\\ +\left|M^t{}_U(RRLL)\right|^2+\left|M^t{}_U(RLLR)\right|^2+\left|M^s{}_U(LLRR)\right|^2+\left|M^s{}_U(LRRL)\right|^2\\ +2\,\mathrm{Re}[M^t{}_U{}^*(RRLL)M^s{}_U(RRLL)]+2\,\mathrm{Re}[M^t{}_U{}^*(LLRR)M^s{}_U(LLRR)]\end{array}\right\} \tag{8}$$

Here, square of helisity amplitude different from zero is as in below.

$$\left|M_{SM}(RLRL)\right|^2=4u^2\left|-\frac{e^2}{s}-\frac{C_R{}^2}{s-M_Z{}^2+iM_Z\Gamma_Z}\right|^2 \tag{9}$$

$$\left|M_{SM}(LRLR)\right|^2=4u^2\left|-\frac{e^2}{s}-\frac{C_L{}^2}{s-M_Z{}^2+iM_Z\Gamma_Z}\right|^2 \tag{10}$$

$$\left|M_{SM}(RLLR)\right|^2=\left|M_{SM}(LRRL)\right|^2=4t^2\left|-\frac{e^2}{s}-\frac{C_LC_R}{s-M_Z{}^2+iM_Z\Gamma_Z}\right|^2 \tag{11}$$

$$\left|M^s{}_U(RLRL)\right|^2=\left|M^s{}_U(LRLR)\right|^2=\left|M^s{}_U(RRLL)\right|^2=\left|M^s{}_U(LLRR)\right|^2=f_d{}^2[-s]^{2d-2} \tag{12}$$

$$\left|M^t{}_U(RRRR)\right|^2=\left|M^t{}_U(RRLL)\right|^2=\left|M^t{}_U(LLRR)\right|^2=\left|M^t{}_U(LLLL)\right|^2=f_d{}^2[-t]^{2d-2} \tag{13}$$

$$2\,\mathrm{Re}[M^t{}_U{}^*(RRLL)M^s{}_U(RRLL)]=2\,\mathrm{Re}[M^t{}_U{}^*(LLRR)M^s{}_U(LLRR)]=-\frac{1}{2}f_d{}^2[st]^{d-1} \tag{14}$$

Here, the collision energy of fermions masses were taken into consideration and were neglected since it is too small, and the order in amplitudes are $M(e^-,e^+,\mu^-,\mu^+)$ when R and L show right and left helisity polarisations. Coupling constant of weak interaction and Mandelstam parameters are as in below.

$$C_R\ \frac{2e\sin\theta_W}{\cos\theta_W},\qquad C_L\ \frac{e[2\sin^2\theta_W-1]}{\sin\theta_W\cos\theta_W},\qquad \cos\theta_W=\frac{M_W}{M_Z} \tag{15}$$

$$t=-\frac{s}{2}(1-\cos\theta),\qquad u=-\frac{s}{2}(1+\cos\theta) \tag{16}$$

Here, M_Z, M_W represents Z and W masses of bosons respectively and θ_W represents Weinberg angle.

Figure 1 was drawn in order to express the effect of unparticle scalar to $e^-e^+\to\mu^-\mu^+$ process. Energy level scale of unparticles was assumed as $\Lambda=1000\ GeV$ and coupling constant was assumed as $\lambda=0.5$ in this figure, direct line shows pure SM effect section and dashed line shows exrinsic effect section.

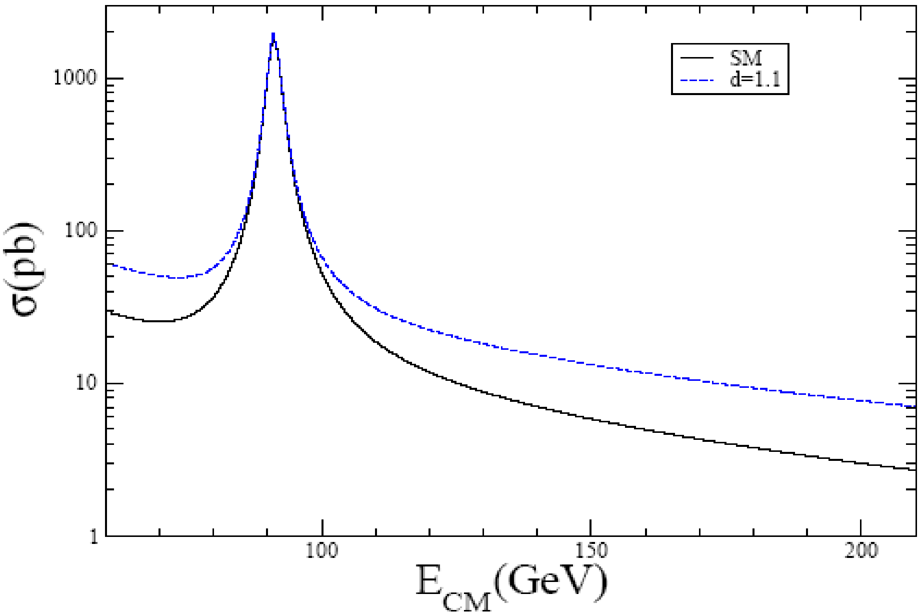

Figure 1. Energy dependency of total effect section that expresses only SM contribution and the one that expresses the contributions of not only SM but also scalar unparticles. $\Lambda = 1000 GeV$ and $\lambda = 0.5$

3. Observability Boundaries of Unparticles According to CERN-LEP Data

Considerations of reflectional contributions for each calculation in high-energy physics is quite important from the point of comparison of theoretical predictions with test data. The expression below is used commonly since it is quite useful in calculating the processes of reflectional contributions where X is a particle that belongs to new physics beyond SM as in $e^- e^+ \to X \to f\,f$.

$$O_{YF}{}' = O_{YF} \times \frac{O_{SM}{}'}{O_{SM}} \tag{17}$$

Here, OYF '(OSM)' represents the observable reflectional contribution expression that belongs to new physics (SM) and O_{YF} (O_{SM}) represents the expression of new physics (SM) without the observable reflectional contribution. In this study, effect section values obtained from ZFITTER were used in calculations of SM effect section including reflectional contributions ([13] can be looked over for more information about ZFITTER). The expressions below used for the calculations of realistic boundaries over the coupling constant of λ Standart Chi-square analyses.

Here, i represents different energy values and TEST lower label represents experimental effect section obtained from CERN_LEP Accelerator. These experimental effect sections obtained by OPAL detector in 189-207GeV mass central energy in CERN_LEP and theoretical SM predictions were obtained according to Equation (16) by using ZFITTER programme and shown in Table 1. In the table, cut values according to mass central energy that were used in OPAL detector are $s'/s > 0.01$ and $s'/s > 0.7225$.

Table 1. Values of effect section according to the energy for $e^-e^+ \rightarrow \mu^-\mu^+$ process.

$s(GeV)$	σ (pb) $s'/s > 0.01$	$\sigma_{SM}\,(pb)$ $s'/s > 0.01$	σ (pb) $s'/s > 0.7225$	$\sigma_{SM}\,(pb)$ $s'/s > 0.7225$
189	$7.85 \pm 0.25 \pm 0.09$	7.75	$3.14 \pm 0.15 \pm 0.03$	3.21
192	$7.40 \pm 0.61 \pm 0.09$	7.47	$2.86 \pm 0.34 \pm 0.03$	3.10
196	$7.08 \pm 0.37 \pm 0.08$	7.13	$2.93 \pm 0.22 \pm 0.03$	2.96
200	$6.67 \pm 0.36 \pm 0.08$	6.80	$2.77 \pm 0.22 \pm 0.03$	2.83
202	$5.63 \pm 0.48 \pm 0.07$	6.64	$2.36 \pm 0.28 \pm 0.03$	2.77
205	$6.53 \pm 0.35 \pm 0.08$	6.41	$2.88 \pm 0.21 \pm 0.03$	2.67
207	$6.81 \pm 0.28 \pm 0.08$	6.29	$2.77 \pm 0.16 \pm 0.03$	2.63

An analysis was done according to single sided Chi-square analyses in 95% reliability level for $\chi^2 \geq 2.7$ value, $\sigma(pb)$ is experimental that was measured by OPAL detector in CERN_LEP, $\sigma_{SM}\,(pb)$ is SM effect section which was calculated by ZFITTER. For the different values of scale parameter of unparticle d, observability boundaries of coupling constant λ were calculated as $\Lambda = 1000 GeV$ and the results of these calculations are shown in Table 2.

Table 2. Limits of coupling constants of unparticles according to Chi-square analyses in 95% reliability level.

$\sqrt{s}(GeV)$	λ_{top} (d=1.1)	λ_{top} (d=1.3)	λ_{top} (d=1.5)	λ_{top} (d=1.7)	λ_{top} (d=1.9)
189	0.31	0.65	1.30	2.38	3.20
192	0.36	0.76	1.53	2.79	3.75
196	0.34	0.71	1.43	2.59	3.46
200	0.33	0.69	1.38	2.50	3.33
202	0.31	0.65	1.28	2.32	3.08
205	0.36	0.75	1.49	2.67	3.55
207	0.33	0.69	1.37	2.46	3.25
Combination	0.25	0.52	1.03	1.88	2.51

4. Result and Discussion

In this study, contributions of scalar unparticles to $e^-e^+ \rightarrow \mu^-\mu^+$ process were examined. Limits of coupling constants of unparticles according to standart Chi-square analyses in 95% reliability level were calculated for observability boundaries according to CERN-LEP data. The boundaries that were founded are bigger than the boundaries that were obtained from different processes such as [7,10,11] but they are in accordance with [5] in which similar processes were taken into consideration.

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