UNPARTICLES AS FIELDS WITH CONTINUOUSLY DISTRIBUTED MASSES

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OUTLINE

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1. Introduction

Recently H.Georgi proposed a model of unparticles. The main speculation :

suppose there is conformal invariant world (gauge theory with fermions with ultraviolet fixed point as an example). For such conformal world all 2-point functions $<O(p)O(-p)>$

behave like $D(p^2) \sim (p^2)^{2\beta+2d-3}$, where β is anomalous dimension of the operator O and d its naive dimension.

As a consequence there is no single particle pole in the spectrum . The spectrum is continuous.

The main support of the possible existence of 4-dimensional conformal models is due to the fact that for some number of matter fields in gauge models one-loop beta function contribution is negative while two-loop correction is positive that leads to speculation about existence of fixed point

For instance for QCD with n_f flavours

$$\beta(\alpha_s) = -\beta_0 \alpha^2_s (2\pi)^{-1} - \beta_1 \alpha^3_s (2\pi)^{-3} + O(\alpha^5_s)$$

$$\beta_0 = 11 - 2n_f/3; \quad \beta_1 = 51 - 19n_f/3$$

For $8 < n_f < 16$ in PT we have fixed point.

Suppose conformal "unparticle world" and our world are connected due to nonrenormalizable interaction

$L_i \quad = \quad c\Lambda^{-n} O(\text{particle}) O(\text{unparticle})$

Due to assumed interactions two types of observable effects are possible:

a. Production of unparticles at colliders :

$qq \rightarrow qU$

$gg \rightarrow gU$

Unparticles being weekly interacting in our world are not detected and behave like neutrino

As a consequence we obtain that unparticles signature are events with missing transverse momentum and hadronic jet(s) like in ADD model which describes our 4 dimensional world plus gravity in (4 +n) dimensional world with compactification of n additional dimensions (tower of massive gravitons).

b. Exchange of unparticles leads to additional propagators

$$D(p^2) \sim (p^2)^{-\Delta}$$

that change the SM predictions for cross sections like DY, γγ production, ...

In other words:

- *Due to assumed interactions of particles and unparticles it is possible to produce unparticles in particle collisions .*
- *As a consequence of continuous spectrum of unparticles and weak interactions with particles unparticles are not*

detected . How to detect unparticles?

1. Missing Transverse Energy

2. Unparticle exchange leads to the modification of particle propagators. So study of processes like dimuon production allows to constrain particle-unparticle interactions

Some unparticle references:

1.H.Georgi, Phys.Rev.Lett. 98 221601(1997).

Plus a lot of "unparticle exercises" , for instance:

2. K.Cheung et al, Collider Phenomenolgy of Unparticle Physics, arXiv:07063155

In this talk I show that the notion of an unparticle can be described as a particular case of a field with continuously distributed mass. I also review the models with continuously distributed masses and describe possible phenomenological implications for Large Hadron Collider(LHC)

This talk is based on my papers:

1. N.V.K., Higgs boson with continuously distributed mass, Phys.Lett. B325(1994)430.
2. N.V.K., Unparticle as a field with continuously distributed mass, Int.J.Mod.Phys. 22 (2007) 5117.
3. N.V.K., LHC signatures for Z` models with continuously distributed mass, Mod.Phys.Lett. 23 (2008) 3233.

Also I have to mention related work

A.A.Slavnov, Theor.Math.Phys. 148(2006)339

2.Fields with continuously distributed mass

Let us start with N free scalar fields $\Phi_k(x_k)$ with masses m_k . For the field

$$\Phi(x_k,m_k,c_k) = \Sigma c_j \Phi_i(x_i,m_j)$$

free propagator has the form

$$D_{int}(k^2) = \Sigma \ |c_j|^2(k^2 - m^2_j + i\varepsilon)^{-1} = \int\rho(t,c_j,m_j)(k^2-t+i\varepsilon)^{-1}dt\ ,$$

$$\rho(t,c_j,m_j) = \Sigma|c_j|^2\delta(t - m^2_j),$$

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In the limit $N \to \infty$,

$$\rho(t,c_j,m_j) \to \rho(t) \text{ and}$$

$$D_{int}(k^2) \to \int\rho(t)(k^2 - t - i\varepsilon)^{-1}dt$$

For instance for

$m^2_k = m^2 + k\Delta N^{-1}$ and $|c_k|^2 = N^{-1}$ in the limit $N \to \infty$

$$\rho(t) = \theta(t-m^2)\theta(m^2+\Delta-t)\Delta^{-1}$$

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For spectral density $\rho(t) \sim t^{\delta-1}$ the propagator

$$D_{int}(k^2) \sim (k^2)^{\delta-1}$$

that corresponds to the case of unparticle propagator and the limiting field $\Phi(x,\rho(t)) = \lim_{N\to\infty}\Phi(x,m_j,c_j)$ describes

unparticle field. It is possible to introduce self interacrion in standard way as

$$L_{int} = -\lambda(\Phi(x,\rho(t))^4$$

For finite $\int\rho(t)dt$ the asymptotics of the effective propagator coincides with free propagator

$D(p) \sim (p^2)\text{-}1$ and the model is renormalizable.

The generalization to the case of vector fields is straightforward. Consider the Lagrangian

$$L = \Sigma[(-1/4)F_{\mu\nu,k}F^{\mu\nu,k} + (1/2)m^2{}_k(A_{\mu,k}-\partial_\mu\Phi_k)^2$$

Gauge invariance:

$$A_{\mu,k} \rightarrow A_{\mu,k} + \partial_\mu\alpha_k \ ,$$

$$\Phi_k \rightarrow \Phi_k + \alpha_k$$

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For the field $B_\mu = \Sigma c_k A_{\mu,k}$ in the limit

$N \to \infty$ we obtain free unparticle vector field

One can introduce gauge invariant interaction with fermion field ψ in standard way

$$L_{int} = e\, \psi \gamma_\mu \psi B_\mu$$

For such model Feynman rules the same as in QED except the change photon propagator $1/k^2 \to D_{int}(k^2)$.

Another approach to the fields with continuously distributed mass related with

the introduction of additional space dimensions.

The main peculiarity is that we postulate Poincare

invariance only in 4-dimensional space-time but not

Poincare invariance in (4+n)-dimensional space-time.

Consider scalar field $\Phi(x_{\mu,}, x_4)$ in five-dimensional

field interacting with the four-dimensional fermion field $\psi(x)$.

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The scalar action has the form

$$S_1 = (1/2)\int[\, \partial_\mu\Phi\partial^\mu\Phi - \Phi f(-\partial_4{}^2)\Phi]d^5x$$

This action is invariant only under 4-dimensional Poincare group and 5-dimensional free propagator is

$$D_0 = (k_\mu k^\mu - f(k^2{}_4))^{-1}$$

The interaction of 5-dimensional scalar field with 4-dimensional fermion field is

$$L_{int} = g\psi(x_\mu)\psi(x_\mu)\Phi(x_\mu,\, x_4 = 0)$$

One can say that fermion field lives on 4-dimensional brane while scalar field lives in 5-dimensional world.

- For such interaction Feynman rules the standard as for 4-dimensional model except the use of effective scalar propagator

$D^{eff}(k^2) = (2\pi)^{-1}\int[k^2-f(k^2_4)+i\varepsilon]^{-1}\,dk_4$

One of possible generalizations to the gauge fields is to consider Yang-Mills in 4-dimensional space-time with standard action and matter fields in 5-dimensional space-time with the replacement of

the mass $m^2 \rightarrow f(-\partial_4{}^2)$. So for such kind of models gauge field $A_\mu{}^a(x)$ lives on four-dimensional brane, while mater field lives in 5-dimensional dimensional space-time and the Poincare invariance holds only in 4-dimensional space-time.

$S_F = \int d^5x[\, \psi(i\gamma^\mu\partial_\mu + gT^aA^a_\mu\gamma^\mu - m(-\partial^2_4))\psi]$

Feynman rules for such model coincide with standard except the use of fermion propagator $i[\gamma^\mu p_\mu - m(p^2_4)]^{-1}$ and additional

integration $(2\pi)^{-1}dp_4$ in fermion loop. For

the case when $m(p^2_4) = 0$ for $|p_4| < \varepsilon\pi$ and

$m(p^2_4) = \infty$ for $|p_4| > \varepsilon\pi$ the single difference

between our model and 4-dimensional case is additional factor ε for each fermion loop due to additional integration over dp_4 in

fermion loop so the model is renormalizable and one loop β-function is

$\beta(g) = -g^3(11N/3 - 2\varepsilon/3)/16\pi^2 + O(g^5)$

Phenomenological implications

There are a lot of possible extensions of

Standard Model with continuously distributed Higgs boson mass. For instance, consider SM in the unitary gauge and make replacement in free Higgs boson propagator

$(p^2 - m^2_H)^{-1} \rightarrow D_{int}(p^2) = \int \rho(t)[p^2 - t + i\varepsilon]^{-1} dt$

For $D_{int}(p^2) = (p^2 - m^2_H + i\Gamma_{int} m_H)^{-1}$ we can interpret Γ_{int} as internal Higgs boson decay width into 5-th dimension.

For large $\Gamma_{int} \gg \Gamma_{tot,H}$ we shall have

additional suppression factor

$\Gamma_{tot,H}(\Gamma_{tot,H} + \Gamma_{int})^{-1}$

for standard signatures like $pp \rightarrow H + \ldots \rightarrow \gamma\gamma + \ldots$

to be used at the LHC that can make the LHC Higgs boson discovery practically impossible.

Phenomenological implications

For $D_{int}(p^2) = \sum|c_n|^2(p^2 - m^2{}_n \; + i\varepsilon)^{-1}$ and for $(m_k - m_{k-1})$ bigger than detector resolution we shall have several peaks

in the reactions

$$pp \rightarrow \gamma\gamma + \ldots$$

$$pp \rightarrow ZZ^* \; + \ldots \rightarrow 4l + \ldots$$

to be used for Higgs boson search at the LHC with factor $|c_n|^2$ suppression for each resonance that for big n makes the Higgs boson discovery at LHC extremely difficult or even impossible

Phenomenological implications

- It should be stressed that the proposed generalization of the SM model is renormalizable if the ultraviolet asymptotics of the Higgs boson propagator $D_{int}(p^2)$ coincides with free propagator

$$D_0(p^2) = (p^2)^{-1}$$

Phenomenological implications

Another possible implications are models of

Z` bosons with continuously distributed mass. Most models predict the existence of new narrow vector boson Z` with

Total decay width $\Gamma_{tot} = O(10^{-2})M_{Z`}$ while in model with continuously distributed Z` boson mass Z` boson could be very broad and

possible consequence is the existence of

broad structure for dimuon mass distribution

in the reaction

$pp \rightarrow \mu^{+}\mu^{-} + \ldots$

Conclusions

1. Unparticles can be interpreted as fields with continuously distributed mass.
2. Fields with continuously distributed mass can be treated as fields in d >4 space-time and from experimental point of view it Is not necessary to require Poincare group in D-dimensional space-time (only 4-dimensional Poincare group follow from experiment)
3. Renormalizable extensions at d > 4 are possible.
4. There are possible testable at the LHC phenomenological consequences like

Higgs boson or Z` boson decaying into additional dimension(s)