Unparticle Physics

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Scale Invariance

- No scale invariance in SM
- An unseen sector of theory with scale invariance could exist.
- Particles with no mass lead to *unparticle physcis.*
- Unparticles look like particles with non-integer scale dimensions.

The High Energy Theory

- In high energies

$$\frac{1}{M_U^k} O_{sm} O_{BZ} \tag{1}$$

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- Eq.(1) does not effect the IR scale invariance since it decouples at high energies.
- M_U might be large enough to prevent strong coupling.

Vacuum Matrix Element

- Start with the vacuum

$$\langle 0|O_{\mathcal{U}}(x)O^{\dagger}_{\mathcal{U}}(0)|0\rangle = \int e^{-ipx}\, |\langle 0|O_{\mathcal{U}}(0)|P\rangle\,|^2\,\rho\left(P^2\right)\frac{d^4P}{(2\pi)^4}$$

- We demand that the matrix element scale with $2d_{\mathcal{U}}$

$$|\langle 0|O_{\mathcal{U}}(0)|P\rangle\,|^2\,\rho\left(P^2\right) = A_{d_{\mathcal{U}}}\Theta(P^0)\Theta(P^2)(P^2)^{d_{\mathcal{U}}-2}$$

Vacuum Matrix Element

- This looks very familiar to the phase space of n massless particles

$$(2\pi)^4\delta^4(P-\sum_{j=1}^{n} p_j)\prod_{j=1}^{n}\delta\left(p_j^2\right)\theta\left(p_j^0\right)\frac{d^4p_j}{(2\pi)^3} = A_n\theta\left(P^0\right)\theta\left(P^2\right)\left(P^2\right)^{n-2}$$

- Taking the limit $n \to 1$ from above, this reduces to our 1-unparticle phase space.
- Unparticles with scale dimension $d_{\mathcal{U}}$ looks like a non-integral number $d_{\mathcal{U}}$ of particles.

$t \to u + \mathcal{U}$

- For the decay $t \to u + \mathcal{U}$ with the coupling

$$i \frac{\lambda}{\Lambda^{d_\mathcal{U}}} \bar{u} \gamma_\mu (1 - \gamma_5) t \partial^\mu O_\mathcal{U} + \mathrm{h.c.}$$

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- Final state densities are

$$d\Phi_u \left(p_u\right) = 2\pi\theta \left(p_u^0\right) \delta \left(p_u^2\right)$$
$$d\Phi_\mathcal{U} \left(p_\mathcal{U}\right) = A_{d_\mathcal{U}} \theta \left(p_\mathcal{U}^0\right) \theta \left(p_\mathcal{U}^2\right) \left(p_\mathcal{U}^2\right)^{d_\mathcal{U} - 2}$$

- With the differential decay rate

$$\frac{1}{\Gamma} \frac{d\Gamma}{dE_u} = 4 d_\mathcal{U} \left(d_\mathcal{U}^2 - 1\right) \left(1 - 2E_u/m_t\right)^{d_\mathcal{U} - 2} E_u^2/m_t^2$$

$t \to u + \mathcal{U}$

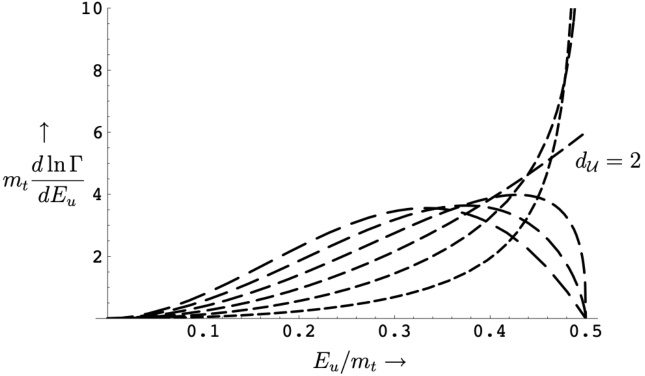

Figure: Decay rates for values of $d_{\mathcal{U}} = j/3$ for $j = 4$ to 9.

Summary

- A sector with scale invariance might exist in the low energy
- These unparticles resemble particles with non-integer scaling dimensions.
- Some phenomenology have been proposed along with cosmological consequences.

References I

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[2] Tatsuru Kikuchi and Nobuchika Okada. “Unparticle dark matter”. In: *Physics Letters B* 665.4 (July 2008), pp. 186–189. ISSN: 0370-2693. DOI: 10.1016/j.physletb.2008.06.021. URL: http://dx.doi.org/10.1016/j.physletb.2008.06.021.