On Vector Unparticle Physics from B to K (γ) + missing energy (work in progress)

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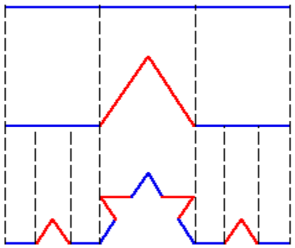
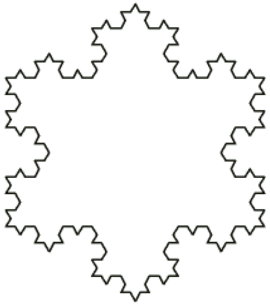
Outline

- Brief Introduction
- Vector Unparticle (Grinstein et.al)
- b to s transition and Vector Unparticle effective interactions
- B decay into K + missing energy
- B decay into γ + missing energy
- Invisible Z decay
- conclusion

Brief Introduction

Unparticles have fractional scaling dimension
Fractional dim. appears in physics in the context of Dim. Reg.
It is common in math, Fractals





Brief Introduction

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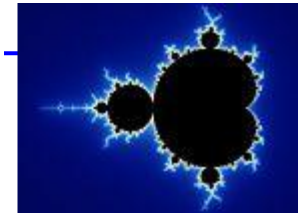
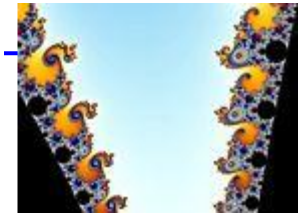


Start

Step 1

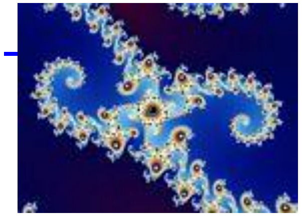


Step 2

Step 3

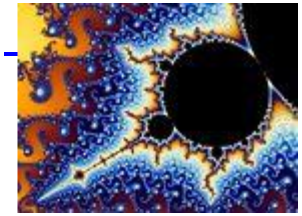
Step 4

Step 5

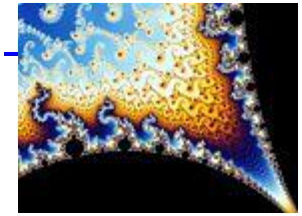


Step 6

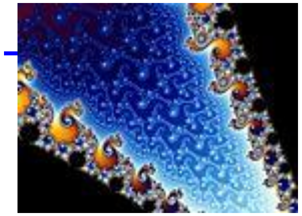
Step 7



Step 8



Step 9

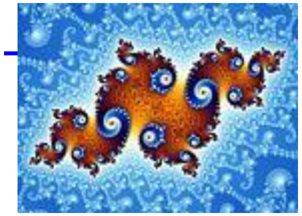


Step 10

Step 11

Step 12

Step 13



Step 14

Vector Unparticles

There are unitarity constraints on gauge invariant primary CFT operator of scaling dimension, d

$$d \geq j_1 + j_2 + 2 - \delta_{j_1 j_2, 0}$$

where j's are Lorentz spins

G. Mack, "All Unitary Ray Representations Of The Conformal Group SU(2,2) With Positive Energy," Commun. Math. Phys. **55**, 1 (1977).

For gauge invariant primary vector operator $\mathcal{U}^\mu$ we have $d \geq 3$ with $d = 3$ IFF $\partial_\mu \mathcal{U}^\mu = 0$

B. Grinstein, K. Intriligator and I. Z. Rothstein, arXiv:0801.1140 [hep-ph].

H. Osborn and A. C. Petkou Annals Phys. **231**, 311 (1994) [arXiv:hep-th/9307010].

Vector Unparticles

The 2-point function for $\mathcal{U}^\mu$ is determined by

$$\langle \mathcal{O}_\mu(x)^\dagger \mathcal{O}_\nu(0)\rangle = C\frac{1}{(2\pi)^2}\frac{I_{\mu\nu}(x)}{(x^2)^d} \quad where \quad I_{\mu\nu} \equiv g_{\mu\nu} - 2\frac{x_\mu x_\nu}{x^2}$$

and going to momentum space then

$$\frac{1}{(2\pi)^2}\frac{I_{\mu\nu}(x)}{(x^2)^d} = \frac{(d-1)\Gamma(2-d)}{4^{d-1}\Gamma(d+1)}\int \frac{d^4k}{(2\pi)^4} e^{ik\cdot x}(k^2)^{d-2}\left[g_{\mu\nu} - \frac{2(d-2)}{d-1}\frac{k_\mu k_\nu}{k^2}\right]$$

Hence,

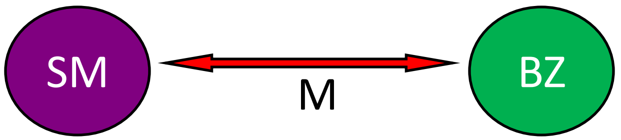
$$\int d^4x e^{-ik\cdot x}\langle 0|T(O_\mu(x)O_\nu(0))|0\rangle = -iC(-k^2-i\epsilon)^{d-3}\left[k^2 g_{\mu\nu} - \frac{2(d-2)}{d-1}k_\mu k_\nu\right]$$

$$\sum \eta^\mu \eta^\nu = -g^{\mu\nu} + a\frac{q^\mu q^\nu}{q^2} \qquad a = \frac{2(d-2)}{d-1}$$

FCNC Effective Interactions

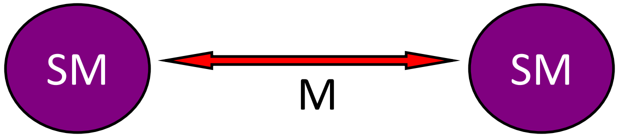
Integrating out M between Unparticles and SM

$$\mathcal{L} = \frac{g}{M^2} \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-3}} \ \bar{s}\gamma_\mu (C_V + C_A \gamma_5) b \, \mathcal{U}^\mu + h.c.$$



Integrating out M between SM operators

$$\mathcal{L} = \frac{C_V^2}{M^2} \ (\bar{s}\gamma_\mu b)^2 + h.c.$$



Bounds from effective contact interactions for $\Delta B = 2$ transitions

$$\mathcal{L}_{\Delta B=2} = \frac{C_{bd}^2}{M^2} (\bar{d_L} \gamma_\mu b_L)^2 + \frac{C_{bs}^2}{M^2} (\bar{s_L} \gamma_\mu b_L)^2$$

These terms contribute to B mass difference

$$\frac{\Delta m_B}{m_B} = \frac{2|M_{12}^B|}{m_B} \sim \frac{C^2}{3} \frac{f_B^2}{M^2}$$

FCNC Effective Interactions

Experimentally

$$\frac{\Delta m_B}{m_B} \sim 6.3 \times 10^{-14} \quad and \quad \frac{\Delta m_{B_s}}{m_{B_s}} \sim 6.3 \times 10^{-12}$$

Hence

$$C_{bd}^2 \leq 6 \times 10^{-6} (\frac{M}{1\ TeV})^2 \quad and \quad C_{bs}^2 \leq 2 \times 10^{-4} (\frac{M}{1\ TeV})^2$$

In the numerical analysis we will be using

$$(\frac{C}{M})^2 \leq 10^{-11} GeV^{-2}$$

But Scale Invariance is Broken

$$\frac{\Lambda^{3-d}}{M}|H|^2\mathcal{U}$$

Shirman et. al, Phys. Rev. D76 (2007) 075004
Shirman et. al, Phys. Rev. D76 (2007) 115002

$$\mathcal{U}^2\left(H^\dagger H\right)$$

T. Kikuchi et al arXiv:0711.1506 [hep-ph]

$$\frac{\Lambda^{6-d^*}}{M^4}|H|^2\mathcal{U}^\mu\mathcal{U}_\mu$$

V. Barger et al Phys.Lett.B661: 276-286,2008

$$|\langle 0|O_{\mathcal{U}}|P\rangle|^2\rho(P^2) = A_{d_{\mathcal{U}}}\theta(P^0)\theta(P^2-\mu^2)(P^2-\mu^2)^{d_{\mathcal{U}}-2}$$

We will take $\mu = 0.5\ GeV$

B to K + Missing energy

SM

$$B \longrightarrow K + \nu\bar{\nu}$$

Effective Interaction

$$H_{eff} = C \ (\bar{s}b)_{V-A}(\bar{\nu}\nu)_{V-A}$$

$$C = \frac{2G_F}{\sqrt{2}}\frac{\alpha}{2\pi}V_{tb}V_{ts}^{*}\frac{X(x_t)}{sin^2\theta_w}$$

Inami Lim fn.

$$X(x_t) = \frac{x_t}{8}\left[\frac{x_t+1}{x_t-1} + Ln(x_t)\frac{3x_t-6}{(x_t-1)^2}\right]$$

$$x_t = \frac{m_t^2}{m_W^2}$$

Theoretical estimate

$$\mathcal{BR}(B \rightarrow K\nu\bar{\nu}) \sim 10^{-6}$$

Experimental Bound

$$\mathcal{BR}(B \rightarrow K\nu\bar{\nu}) < 1.4 \times 10^{-5}$$

B to K + Missing energy

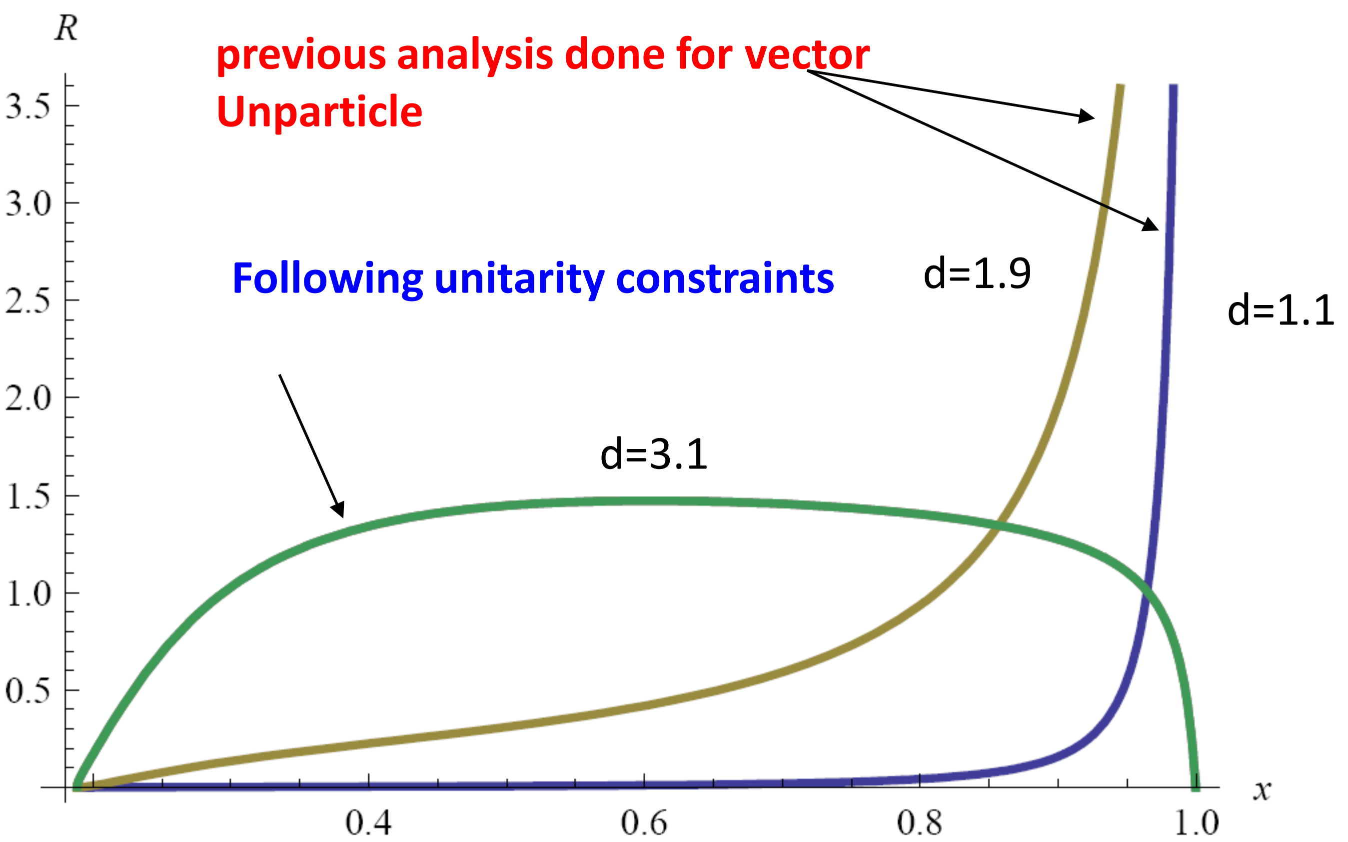
$$B \to K + \mathcal{U}$$

$$\frac{d\Gamma}{dE_X} = \frac{A_{d_\mathcal{U}}}{8\pi^2 m_B} \, \frac{\sqrt{E_X^2 - m_X^2}\; \theta(m_B^2 - 2m_B E_X + m_X^2 - \mu^2)}{(m_B^2 - 2m_B E_X + m_X^2 - \mu^2)^{2-d_\mathcal{U}}} \; |\overline{\mathcal{M}}|^2$$

$$\begin{aligned} |\overline{\mathcal{M}}|^2 \;\; &= \;\; (\frac{g}{M})^2 (\frac{C_V}{M})^2 \frac{1}{\Lambda^{2d-6}} \; (|f_+|^2 \left[a \frac{(m_B^2 - m_K^2)^2}{m_B^2 + m_K^2 - 2m_B E_K} - (m_B^2 + m_K^2 + 2m_B E_K) \right] \\ &+ (a-1)|f_-|^2 (m_B^2 + m_K^2 - 2m_B E_K) \\ &+ 2(a-1) f_+ f_- (m_B^2 - m_K^2)) \end{aligned}$$

B to K + Missing energy

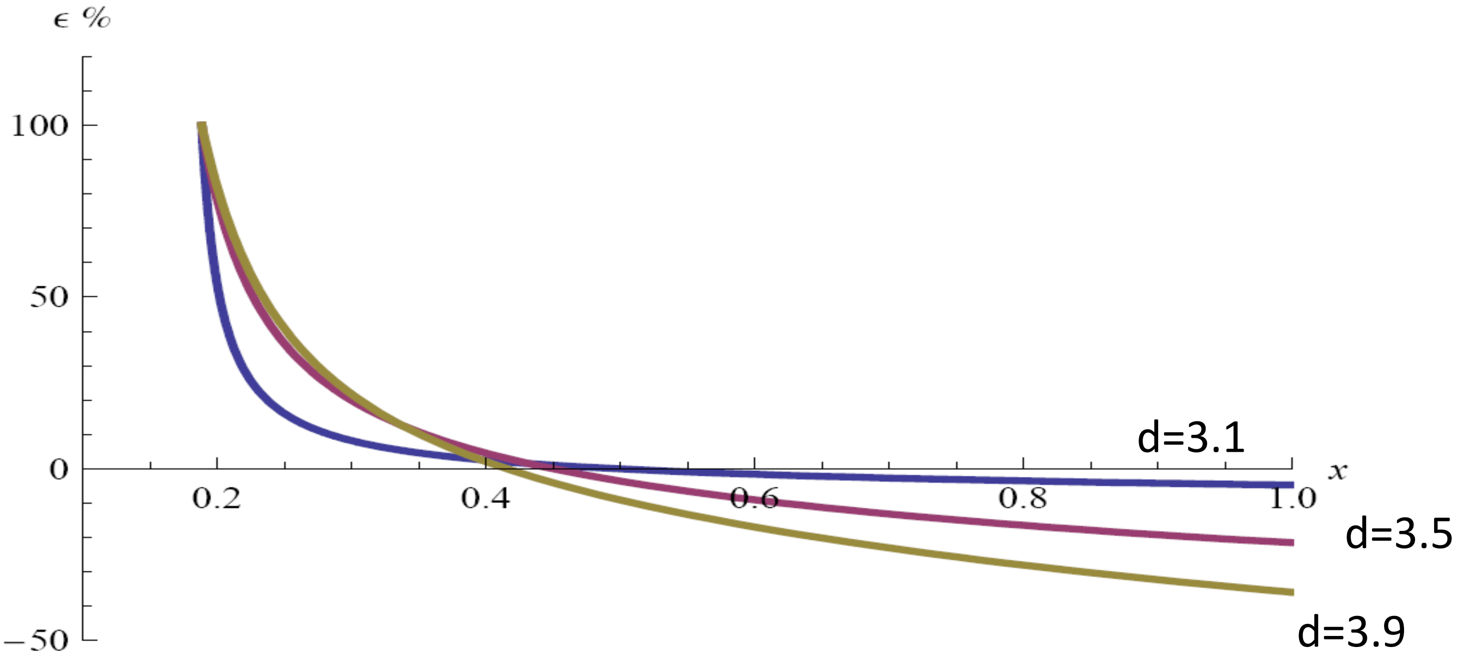
Plotting the spectrum $R = \frac{1}{\Gamma}\frac{d\Gamma}{dx}$ where $x = \frac{2E_K}{m_B}$



B to K + Missing energy

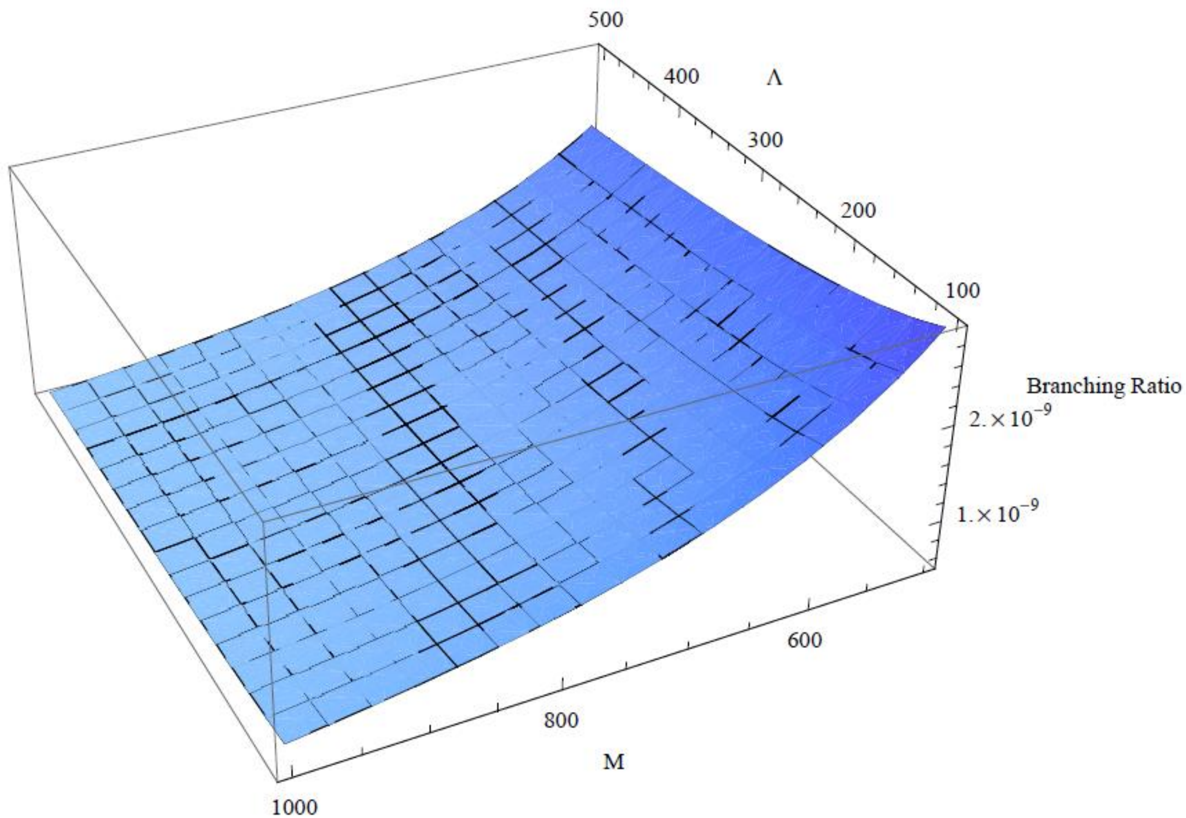
The difference between using the correct treatment of vector Unparticle and the old one can be parameterized by

$$\epsilon(x,d) \equiv \frac{R(x,d,a) - R(x,d,a=1)}{R(x,d,a)} 100\%$$



B to K + Vector Unparticle

Dependence of the branching ratio on M and Λ in GeV



B to γ + Missing energy

SM

$$B \longrightarrow \gamma + \nu\bar{\nu}$$

Effective Interaction

$$H_{eff} = C \; (\bar{s}b)_{V-A}(\bar{\nu}\nu)_{V-A}$$

$$C = \frac{G_F}{\sqrt{2}} \; \frac{\alpha}{2\pi sin^2\theta_W} V_{tb}V^*_{tq} \; \frac{x}{8}\left(\frac{x+2}{x-1} + \frac{3x-6}{(x-1)^2} \; Ln(x)\right)$$

Theoretical estimate

$$\mathcal{BR}(B_d \to \gamma\nu\bar{\nu}) \sim \times 10^{-9}$$

$$\mathcal{BR}(B_s \to \gamma\nu\bar{\nu}) \sim \times 10^{-8}$$

Experimental Bound

$$\mathcal{BR}(B_d \to \gamma\nu\bar{\nu}) < 4.7 \times 10^{-5}$$

B to γ + Missing energy

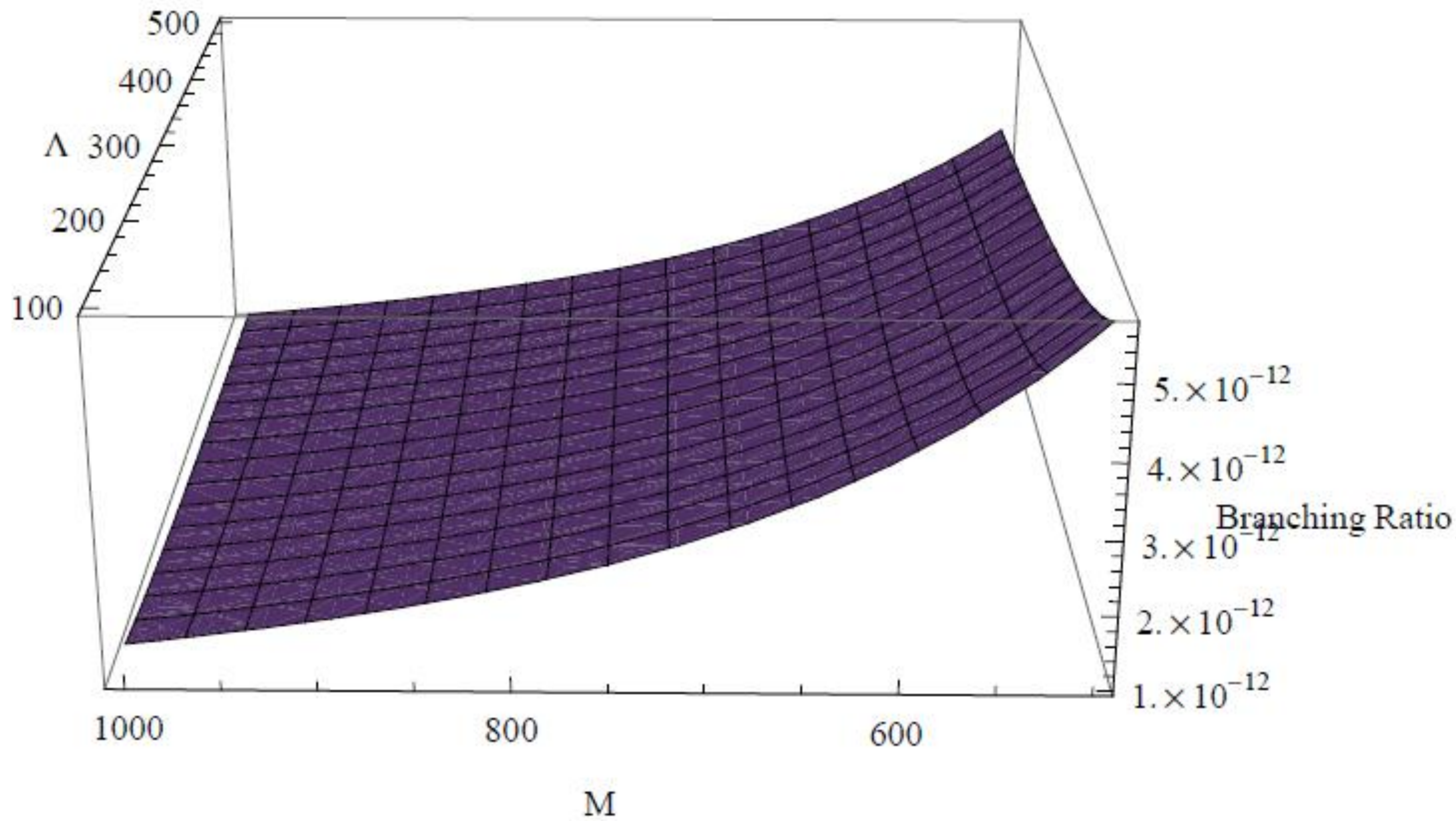
$$B \to \gamma + \mathcal{U}$$

$$|\overline{\mathcal{M}}|^2 = 2(k \cdot q)^2 (\frac{g}{M})^2 (\frac{C_V}{M})^2 \frac{1}{\Lambda^{2d-6}} \frac{4\pi\alpha}{m_B^2} \left(F_V^2(q^2) + F_A^2(q^2)\right)$$

$$\frac{d\Gamma}{dE_\gamma} = \frac{A_{d_\mathcal{U}}}{8\pi^2 m_B} \frac{E_\gamma \ \theta(m_B^2 - 2m_B E_\gamma - \mu^2)}{(m_B^2 - 2m_B E_\gamma - \mu^2)^{2-d_\mathcal{U}}} \ |\overline{\mathcal{M}}|^2$$

B to γ + vector Unparticle

Dependence of the branching ratio on M and Λ in GeV



Invisible Decay of Z boson

Effective interaction

$$\mathcal{L} = \frac{\Lambda^{3-d}}{M^2} H^\dagger D_\mu H \mathcal{U}^\mu \sim \frac{\Lambda^{3-d}}{M^2} \frac{v}{2} M_Z Z_\mu \mathcal{U}^\mu$$

The decay rate of Z into vector Unparticle is

$$\Gamma(Z \to \mathcal{U}) = \frac{v^2 A_d}{8 M_Z} \left(\frac{M_Z}{\Lambda}\right)^{2d-6} \left(\frac{M_Z}{M}\right)^4$$

Bounds on M from effective contact interactions

$$\mathcal{L} = \frac{c}{M} |H^\dagger D_\mu H|^2$$

$$M > 4.6\ TeV\ \ for\ c = -1 \qquad and \qquad M > 5.6\ TeV\ \ for\ c = 1$$

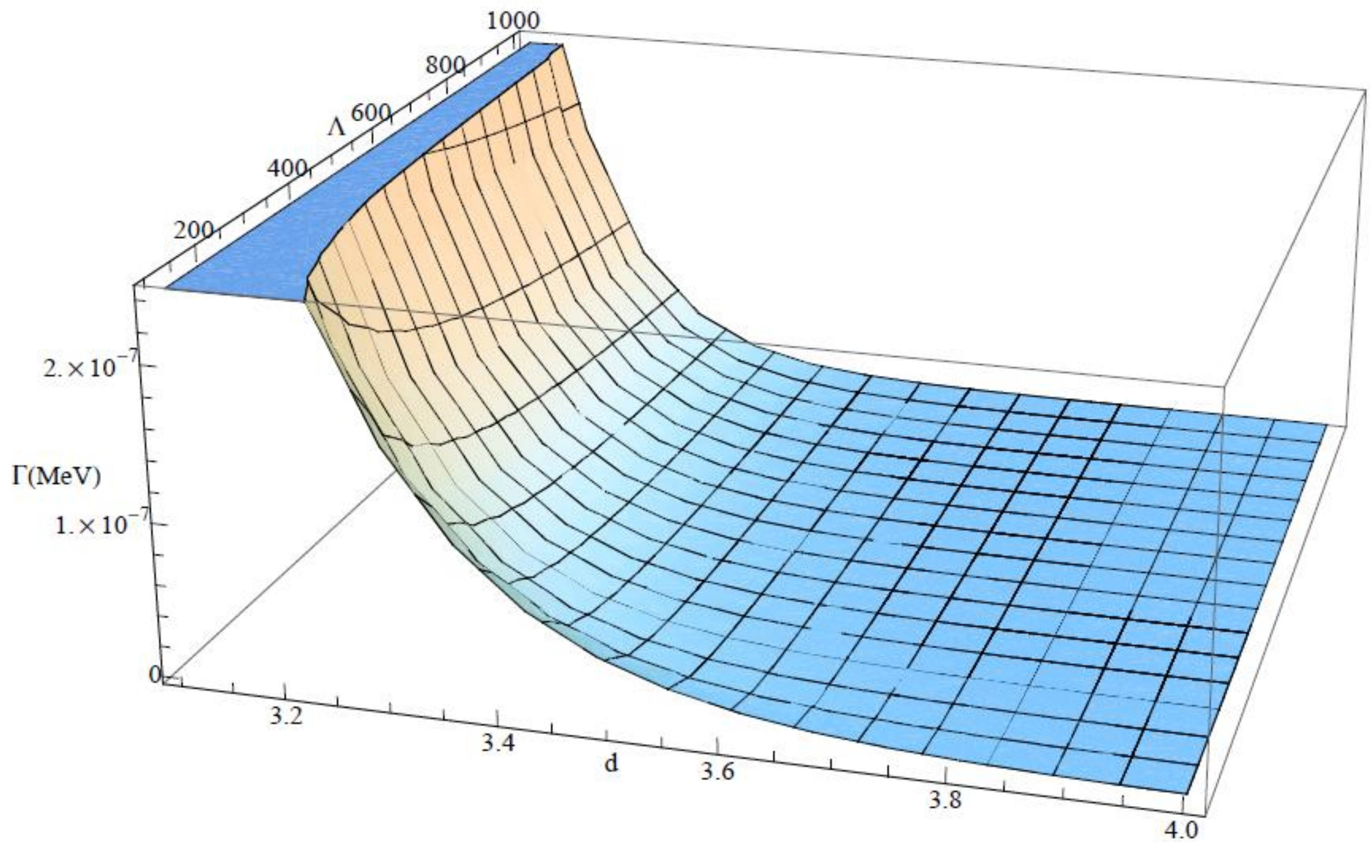
Invisible Decay of Z boson

New physics contribution to invisible Z decay is severely constrained

$$\Gamma^{SM}(Z \to invisible) = 501.65 \pm 0.11\ MeV$$

$$\Gamma^{Exp.}(Z \to invisible) = 499.0 \pm 1.5\ MeV$$

Invisible Decay of Z boson into Vector Unparticle



Conclusion

- We have studied missing energy signals in the b to s FCNC transition in B to K + missing energy and B to gamma + missing energy.
- These channels cannot be used to constrain vector Unparticle because the branching ratios are very small for reasonable values of parameter space
- High energy probes as in Z decay are also very suppressed
- Unparticles as sub classes of hidden valleys, HEIDI, Infraparticle, self interaction, gauged unparticles
- More studies are needed for models that are scale invariant but not conformal invariant