Unparticle Phenomenology

Wai-Yee Keung, UIC
In collaboration with Kingman Cheung and T.C. Yuan

H. Georgi, arXiv:0703.260, 1st pheno study
H. Georgi, arXiv:0704.2457, on propagator

Cheung,K,Yuan: arXiv:0704.2588,
on production, propagator, and g-2
C.H. Chen and C.Q. Geng, on CP violation
M. Luo and G. Zhu, on spin-half
G.J. Ding and M.L. Yan, on DIS
Yi Liao, on positronium

Banks and Zaks

T. Banks, A. Zaks / Phase structure of vector-like gauge theories

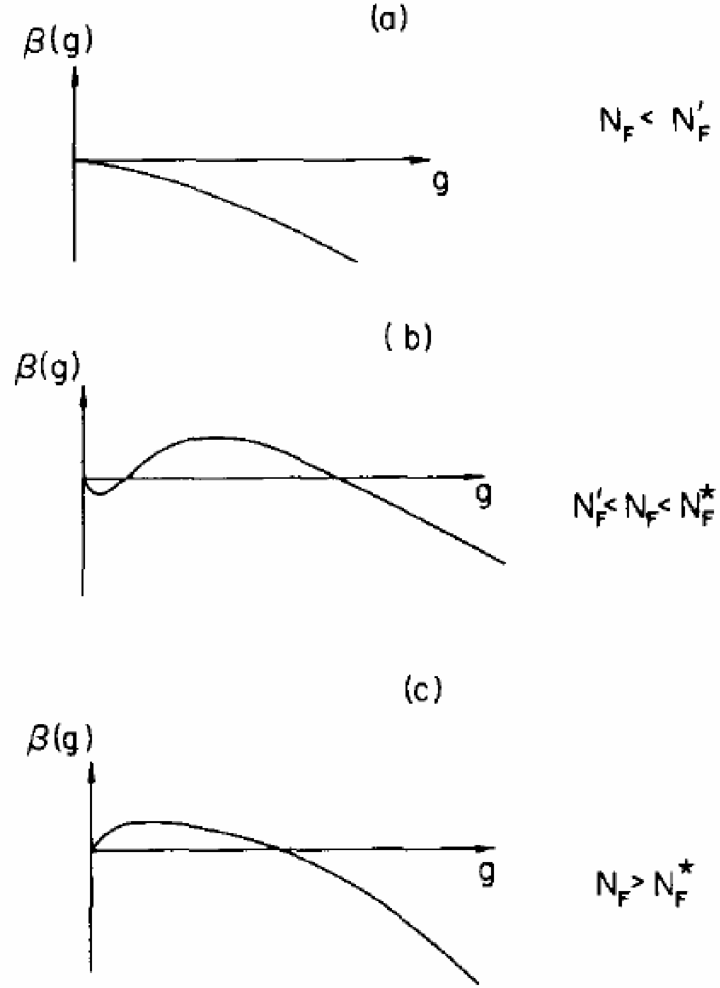


Fig. 1. 2 zero β function.

Phase Space and Spectral density

$$d_n(\text{PS of massless particles}) = A_n s_n^{n-2}\ , \quad A_n = \frac{16\pi^2\sqrt{\pi}}{(2\pi)^{2n}} \frac{\Gamma(n+\frac{1}{2})}{\Gamma(n-1)\Gamma(2n)}\ .$$

$$A_{n\to 1} = 2\pi(n-1)\ , \quad A_2 = \frac{1}{8\pi}\ , \quad A_3 = \frac{1}{256\pi^3}$$

$$A_n s^{n-1} \overset{n\to 1+\epsilon}{\longrightarrow} \frac{2\pi\epsilon}{s^{1-\epsilon}} \to 2\pi\delta(s) \qquad \epsilon \int_{0^+}^{\infty} ds/s^{1-\epsilon} = s^{\epsilon}\big|_{0^+}^{\infty} = 1.$$

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

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

$$\lambda_0 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} G_{\alpha\beta} G^{\alpha\beta} O_{\mathcal{U}} \quad , \quad \lambda_1 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}}\, \bar{f}\gamma_\mu f\, O_{\mathcal{U}}^{\mu} \quad \lambda_2 \frac{1}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} G_{\mu\alpha} G_{\nu}^{\ \alpha} O_{\mathcal{U}}^{\mu\nu}$$

Production

$$\mathcal{O}_{\rm SM}\,\mathcal{O}_{\mathcal{BZ}}/M_{\mathcal{U}}^{k} \qquad (k>0)$$

$$(C_{\mathcal{O}_{\mathcal{U}}}\Lambda^{d_{\mathcal{BZ}}-d_{\mathcal{U}}}/M_{\mathcal{U}}^{k})\,\mathcal{O}_{\rm SM}\,\mathcal{O}_{\mathcal{U}}$$

$$\begin{aligned} gg &\rightarrow g\mathcal{U}\,, \quad q\bar{q}\rightarrow g\mathcal{U}\,, \\ qg &\rightarrow q\mathcal{U}\,, \quad \bar{q}g \rightarrow \bar{q}\mathcal{U}\,. \end{aligned}$$

$$\frac{d^2\hat{\sigma}}{d\hat{t}dP_{\mathcal{U}}^2} = \frac{1}{16\pi\hat{s}^2}|\overline{\mathcal{M}}|^2\,\frac{1}{2\pi}\,A_{d_{\mathcal{U}}}\,\left(\frac{P_{\mathcal{U}}^2}{\Lambda_{\mathcal{U}}^2}\right)^{d_{\mathcal{U}}-2}\,\frac{1}{\Lambda_{\mathcal{U}}^2}$$

$$|\overline{\mathcal{M}}(gg\rightarrow g\mathcal{U})|^2 = \frac{1536\pi\alpha_s}{4\cdot 8\cdot 8}\,\lambda_0^2\,\frac{(P_{\mathcal{U}}^2)^4+\hat{s}^4+\hat{t}^4+\hat{u}^4}{\hat{s}\hat{t}\hat{u}\Lambda_{\mathcal{U}}^2}$$

$$|\overline{\mathcal{M}}(q\bar{q}\rightarrow g\mathcal{U})|^2 = \frac{8}{9}g_s^2\lambda_1^2\,\frac{(\hat{t}-P_{\mathcal{U}}^2)^2+(\hat{u}-P_{\mathcal{U}}^2)^2}{\hat{t}\hat{u}}$$

$$|\overline{\mathcal{M}}(qg\rightarrow q\mathcal{U})|^2 = -\frac{1}{3}g_s^2\lambda_1^2\,\frac{(\hat{t}-P_{\mathcal{U}}^2)^2+(\hat{s}-P_{\mathcal{U}}^2)^2}{\hat{s}\hat{t}}$$

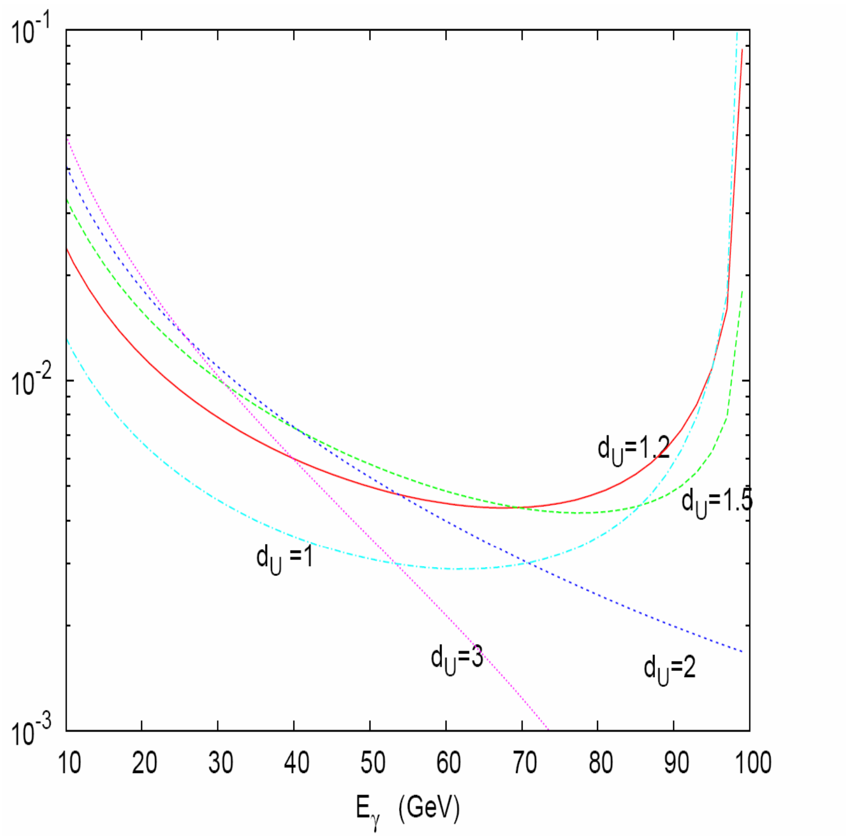
$$e^-(p_1)\,e^+(p_2)\;\rightarrow\gamma(k_1)\,\mathcal{U}(P_{\mathcal{U}})$$

$$|\overline{\mathcal{M}}|^2 = 2e^2Q_e^2\lambda_1^2\,\frac{u^2+t^2+2sP_{\mathcal{U}}^2}{ut}$$

$$d\sigma = \frac{1}{2s}\,|\overline{\mathcal{M}}|^2\,\frac{E_\gamma A_{d_{\mathcal{U}}}}{16\pi^3\Lambda_{\mathcal{U}}^2}\left(\frac{P_{\mathcal{U}}^2}{\Lambda_{\mathcal{U}}^2}\right)^{d_{\mathcal{U}}-2}\,dE_\gamma d\Omega$$

$$P_{\mathcal{U}}^2 = s-2\sqrt{s}\,E_\gamma$$

distributions



: Normalized mono-photon energy spectrum of
$\to \gamma\mathcal{U}$ for $d_{\mathcal{U}} = 1, 1.2, 1.5, 2$ and 3 at $\sqrt{s} = 200$ GeV.
e imposed $|\cos\theta_\gamma| < 0.95$.

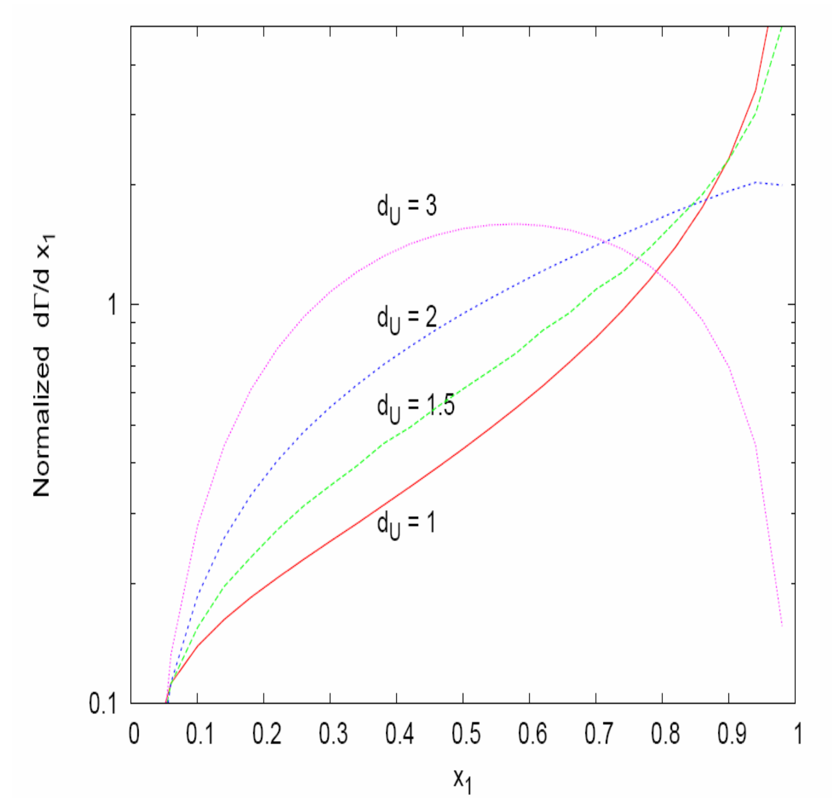


FIG. 1: Normalized decay rate of $Z \to q\bar{q}\mathcal{U}$ versus $x_1 = 2E_f/M_Z$ for different values of $d_{\mathcal{U}} = 1, 1.5, 2$, and 3.

Propagator

(4) Drell-Yan process: Virtual exchange of unparticle corresponding to the vector operator $O^{\mu}_{\mathcal{U}}$ can result in the following 4-fermion interaction

$$\mathcal{M}^{4f} = \lambda_1^2 Z_{d_\mathcal{U}} \frac{1}{\Lambda_\mathcal{U}^2} \left(- \frac{P_\mathcal{U}^2}{\Lambda_\mathcal{U}^2} \right)^{d_\mathcal{U}-2} (\bar{f}_1 \gamma_\mu f_2)(\bar{f}_3 \gamma^\mu f_4) \quad (11)$$

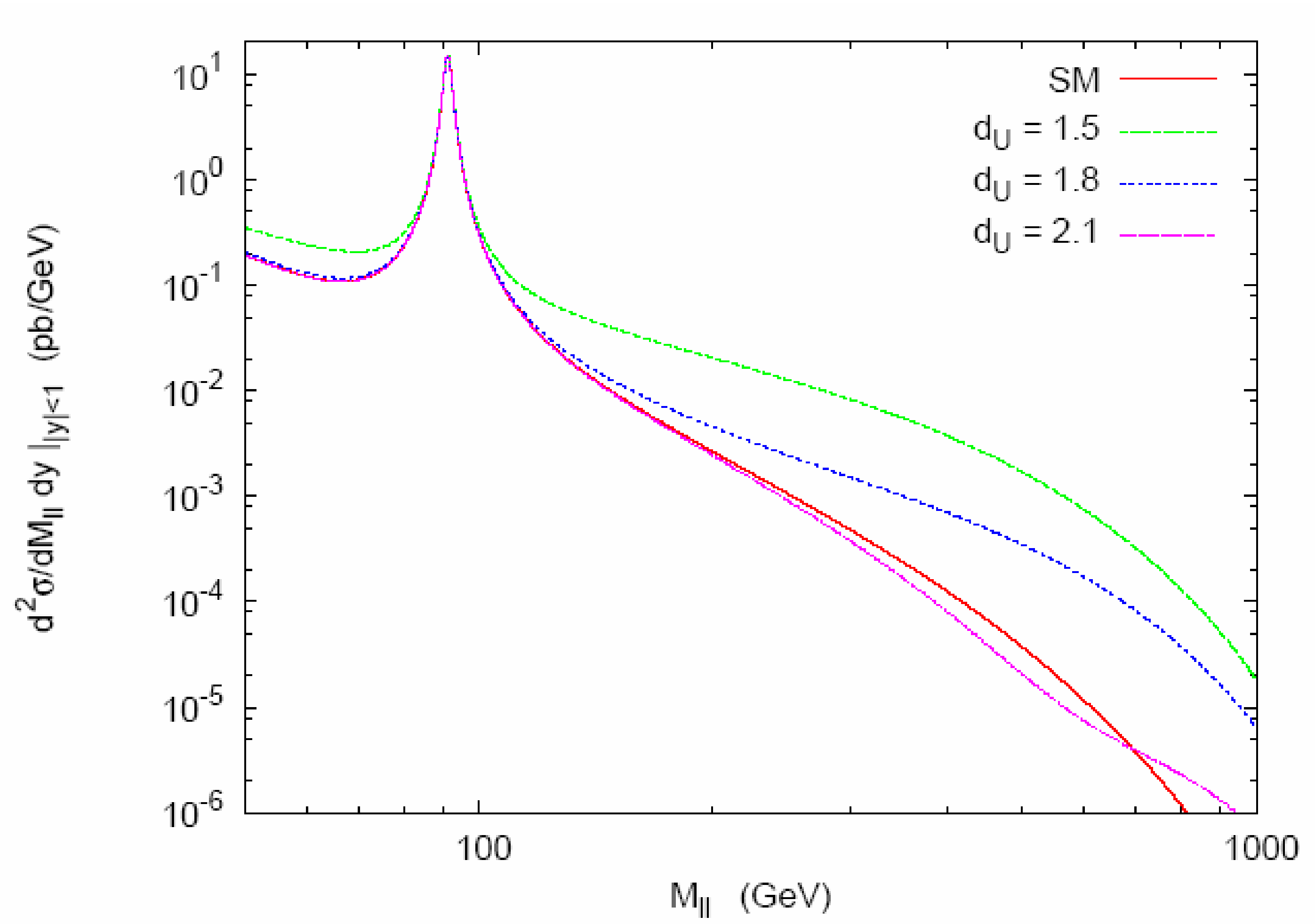
$$(re^{i\theta})^{d_\mathcal{U}-2} = r^{d_\mathcal{U}-2} e^{i\theta(d_\mathcal{U}-2)}$$

for $r > 0$ and $-\pi \leq \theta < \pi$. Using the Källen-Lehmann spectral representation formula, one can derive $Z_{d_\mathcal{U}}$ as

$$Z_{d_\mathcal{U}} = \frac{A_{d_\mathcal{U}}}{2 \sin(d_\mathcal{U} \pi)} \quad \text{for} \quad d_\mathcal{U} < 2 \ . \quad (12)$$

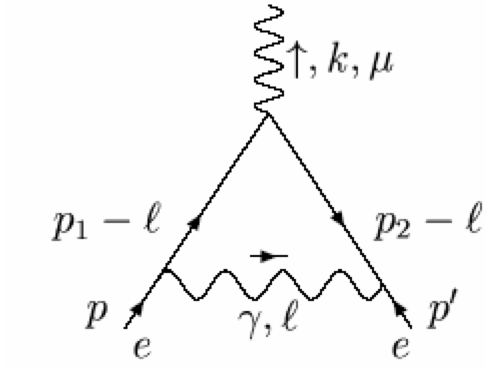
The $(-)$ sign in front of $P_\mathcal{U}^2$ of the unparticle propagator in Eq.(11) gives rise to a phase factor $e^{-i\pi d_\mathcal{U}}$ for time-like momentum $P_\mathcal{U}^2 > 0$, but not for space-like momentum $P_\mathcal{U}^2 < 0$. Note that $P_\mathcal{U}^2$ is taken as the $\hat{s}$ for an s channel

Drell -Yan



SM
d_U = 1.5
d_U = 1.8
d_U = 2.1
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$d^2\sigma/dM_{ll}\,dy\,|_{|y|<1}$ (pb/GeV)
100
1000
M_{ll} (GeV)

g-2



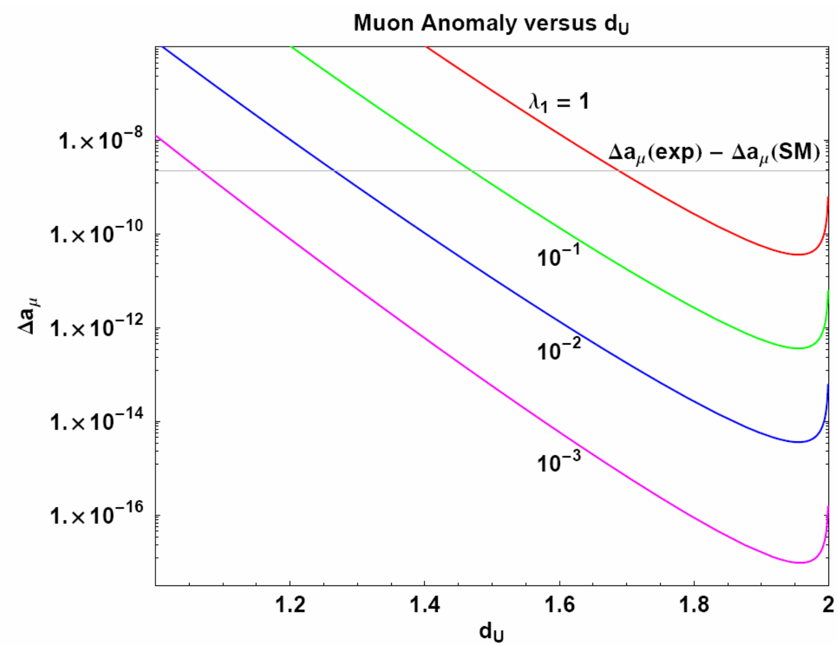
$$i\mathcal{M} = \frac{ie^3}{16\pi^2}\int \frac{q_E^2 dq_E^2 4mi\sigma^{\mu k}}{-[q_E^2 + (1-z)^2 m^2]^3} z(1-z)dzdx$$

$$i\mathcal{M} = e\left(\frac{\alpha}{\pi}\right)\int_0^1 \frac{zdz}{1-z}\int_0^{1-z} dx\frac{\sigma^{\mu k}}{2m} = e\left(\frac{\alpha}{2\pi}\right)\frac{\sigma^{\mu k}}{2m}$$

$$-\frac{i}{16\pi^2}\int \frac{q_E^2 dq_E^2}{(q_E^2+\mu^2)^{2+\beta}} = -\frac{i}{16\pi^2(\mu^2)^\beta}\int_0^\infty \frac{xdx}{(x+1)^{2+\beta}} = -\frac{i}{32\pi^2(\mu^2)^\beta}\left(\frac{2}{\beta(1+\beta)}\right)$$

$$\frac{1}{A_1 A_2 A_3^\beta} = \frac{z^{\beta-1}dxdydz\delta(1-x-y-z)}{(xA_1+yA_2+zA_3)^{2+\beta}}\frac{\Gamma(2+\beta)}{(\beta)}$$

$$a_U = \frac{\lambda_1^2}{4\pi^2}\left(-\frac{A_d}{2\sin(\pi d)}\right)\left(\frac{m^2}{\Lambda}\right)^{d-1}\frac{\Gamma(3-d)\Gamma(2d-1)}{(2+d)}$$



Conclusion

- What is the UNPARTICLE?
- Can it be deconstructed?
- Is it more than a spectator in the EW sector?
- What is its role in cosmology?