EWSB from Unparticles

Jong-Phil Lee

Korea Institute for Advanced Study

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Outlook

- Unparticle Brief
- New scalar potential
- EWSB with scalar potential
- Mass spectrum
- Conclusions

Unparticles

Unparticles $\mathcal{U}$: Basic Idea

H. Georgi, PRL98; PLB650

SM Sector

Weakly interacting

Scale Inv. Sector

Particles with definite masses

NO particles With definite nonzero masses

Unparticle!

Effective Theory for $\mathcal{U}$

energy

$\mathcal{BZ}$

Banks-Zaks($\mathcal{BZ}$) Theory

Massless fermionic gauge theory
With an infrared-stable fixed point.

$\mathrm{M}_{\mathcal{U}}$

$$\mathcal{L}_{\mathcal{BZ}} = \frac{\mathcal{O}_{\rm SM}\mathcal{O}_{\mathcal{BZ}}}{M_{\mathcal{U}}^k}$$

Dimensional transmutation

$\Lambda_{\mathcal{U}}$ ← matching

$$\mathcal{L}_{\mathcal{U}} = C_{\mathcal{U}}\frac{\Lambda_{\mathcal{U}}^{d_{\mathcal{BZ}}-d_{\mathcal{U}}}}{M_{\mathcal{U}}^k}\mathcal{O}_{\rm SM}\mathcal{O}_{\mathcal{U}}$$

Scale inv. emerges.

M_{W} ; EWSB
; scale inv. breaking

SM

Phase Space of $\mathcal{U}$

Two-point function

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

Spectral density function

$$\rho_\mathcal{U}(P^2) = A_{d_\mathcal{U}} \theta(P^0)\theta(P^2)(P^2)^{d_\mathcal{U}-2}$$

Fixed by scale inv.

Normalization factor

$$A_{d_\mathcal{U}} = \frac{16\pi^{5/2}}{(2\pi)^{2d_\mathcal{U}}} \frac{\Gamma(d_\mathcal{U}+\frac{1}{2})}{\Gamma(d_\mathcal{U}-1)\Gamma(2d_\mathcal{U})}$$

Unparticles with $d_\mathcal{U}$ looks like a Non-integral number of massless particles.

Propagators of $\mathcal{U}$

Cheung, Keung, Yuan, PRD76
Grinstein, Intriligator, Rothstein, PLB662

Scalar Unparticle Propagator

$$\Delta_F(P^2) = \frac{A_{d_\mathcal{U}}}{2\sin(d_\mathcal{U}\pi)}(-P^2)^{d_\mathcal{U}-2}$$

Vector Unparticle Propagator

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

New Scalar Potential

JPL, arXiv: 0803.0833

Relevant Interaction

$$\mathcal{L}_{\Phi\Phi\mathcal{U}} \sim \lambda_{\Phi\Phi\mathcal{U}}(\Phi^\dagger\Phi)\mathcal{O}_\mathcal{U} \ , \quad [\lambda_{\Phi\Phi\mathcal{U}}] = 2 - d_\mathcal{U} > 0$$

New proposal

$$V(\Phi,\phi) = \lambda_0(\Phi^\dagger\Phi)^2 + \lambda_1(\phi^*\phi)^2 + 2\lambda_2\mu^{2-d_\mathcal{U}}(\Phi^\dagger\Phi)(\phi^*\phi)^{d_\mathcal{U}/2}$$

SM scalar — Hidden scalar — New interaction

ElctroWeak Symmetry Breaking

EWSB with Scalar Potential

Ordinary Higgs mechanism

$$V = \frac{m^2}{2} h^2 + \frac{\lambda}{4} h^4$$

Coleman-Weinberg mechanism

$$V = \frac{\lambda}{4\,!} \varphi_c{}^4 + \frac{\lambda^2 \varphi_c{}^4}{256\pi^2} \left(\ln \frac{\varphi_c{}^2}{M^2} - \frac{25}{6} \right)$$

Gildener-Weinberg mechanism

$$V_0(\Phi) = \tfrac{1}{24} f_{ijkl} \Phi_i \Phi_j \Phi_k \Phi_l .$$

$$\delta V(n\phi) = A\phi^4 + B\phi^4 \ln(\phi^2/\Lambda_W{}^2)$$

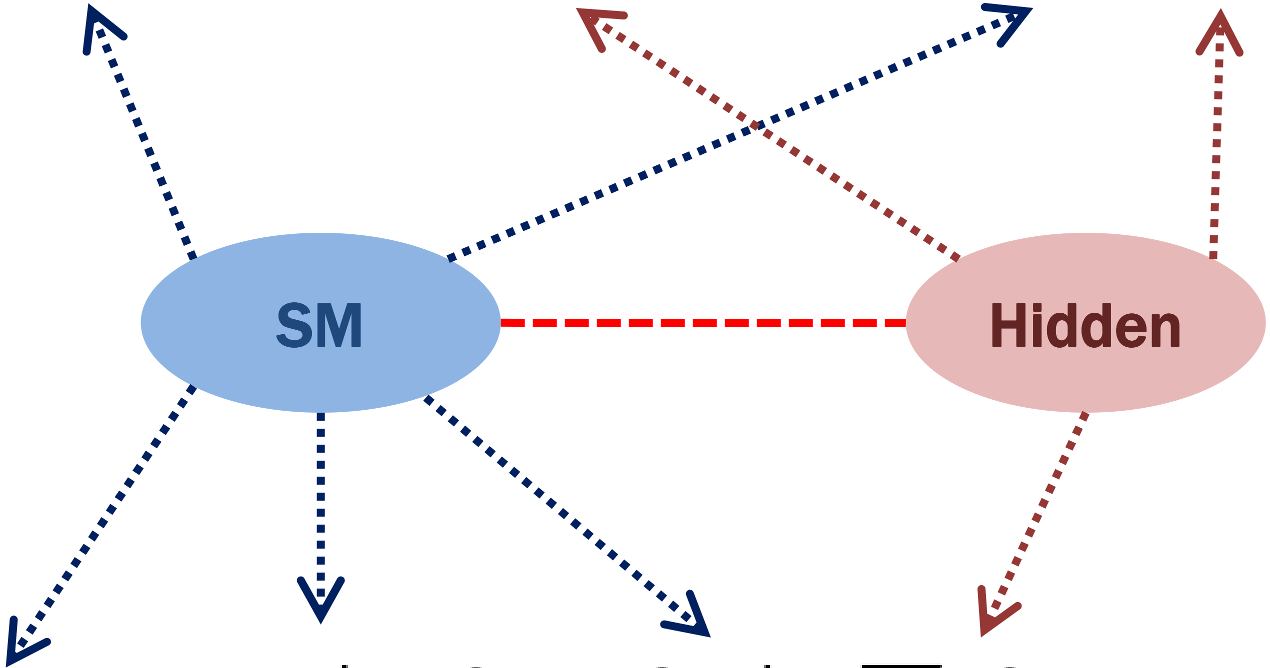
$$A = \frac{1}{64\pi^2 \langle\phi\rangle^4} \{3\,\mathrm{Tr}[\mu^4 \ln(\mu^2/\langle\phi\rangle^2)] + \mathrm{Tr}[M^4 \ln(M^2/\langle\phi\rangle^2)] - 4\,\mathrm{Tr}[m^4 \ln(m^2/\langle\phi\rangle^2)]\}$$

$$B = \frac{1}{64\pi^2 \langle\phi\rangle^4} (3\,\mathrm{Tr}\,\mu^4 + \mathrm{Tr} M^4 - 4\,\mathrm{Tr}\,m^4)$$

EWSB from Hidden Sector

Chang, Ng, Wu, PRD75; Espinosa, Quiros, PRD76

$$V_0(\Phi,\phi_s) = \lambda(\Phi^\dagger\Phi)^2 + \lambda_s(\phi_s^*\phi_s)^2 + 2\kappa(\Phi^\dagger\Phi)(\phi_s^*\phi_s)$$



$$V_0 = m^2 H^\dagger H + \lambda(H^\dagger H)^2 + \zeta^2 H^\dagger H \sum_i S_i^2 .$$

Unparticle-Higgs Interplay

Delgado, Espinosa, Quiros, JHEP0710

SM potential

$$V_0 = m^2|H|^2 + \lambda|H|^4$$

Deconstruction

$$\mathcal{O} \equiv \sum_n F_n \varphi_n$$

$$F_n^2 = \frac{A_{d_U}}{2\pi}\Delta^2 (M_n^2)^{d_U-2}$$

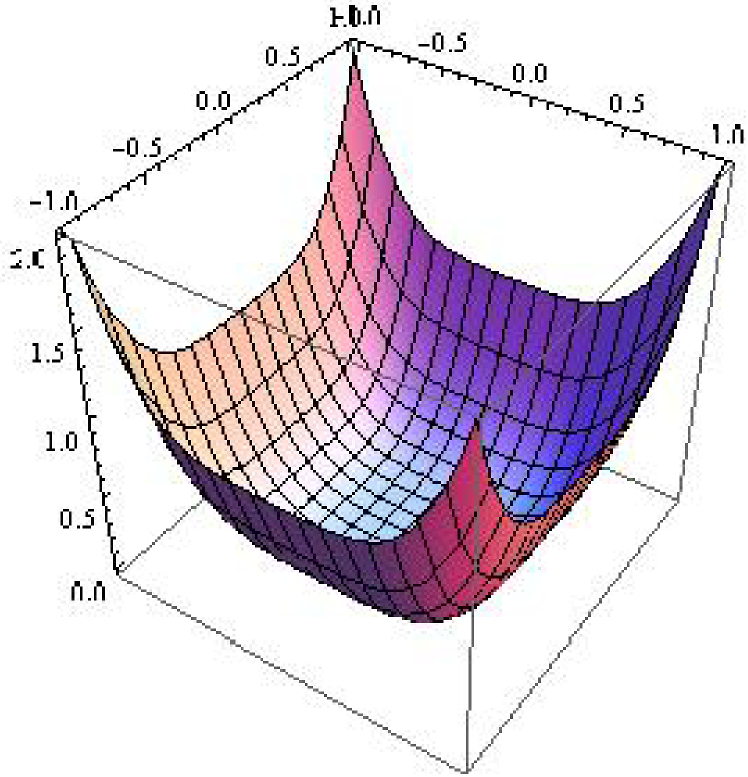
U-sector contribution

$$\delta V = \frac{1}{2}\sum_n M_n^2 \varphi_n^2 + \kappa_U |H|^2 \sum_n F_n \varphi_n$$

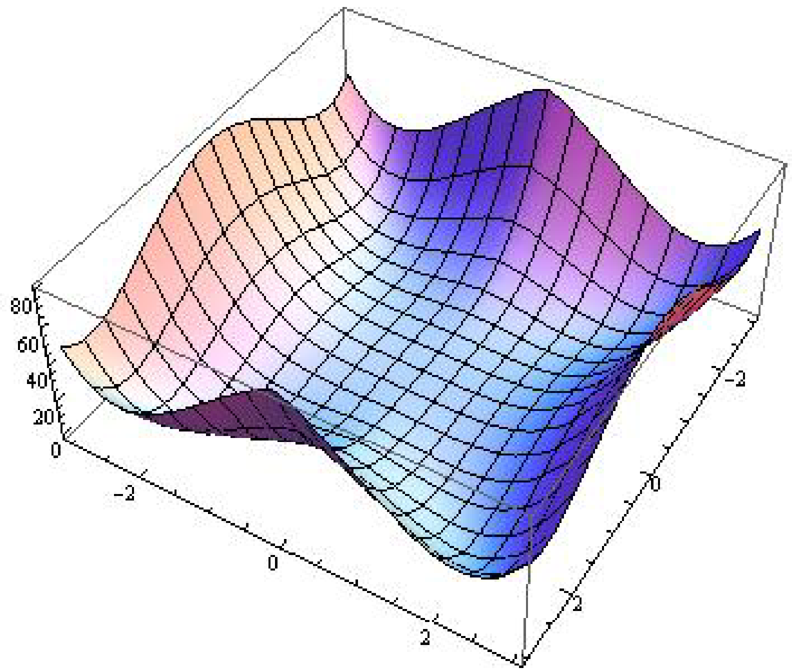
IR regulator

$$\delta V = \zeta |H|^2 \sum_n \varphi_n^2$$

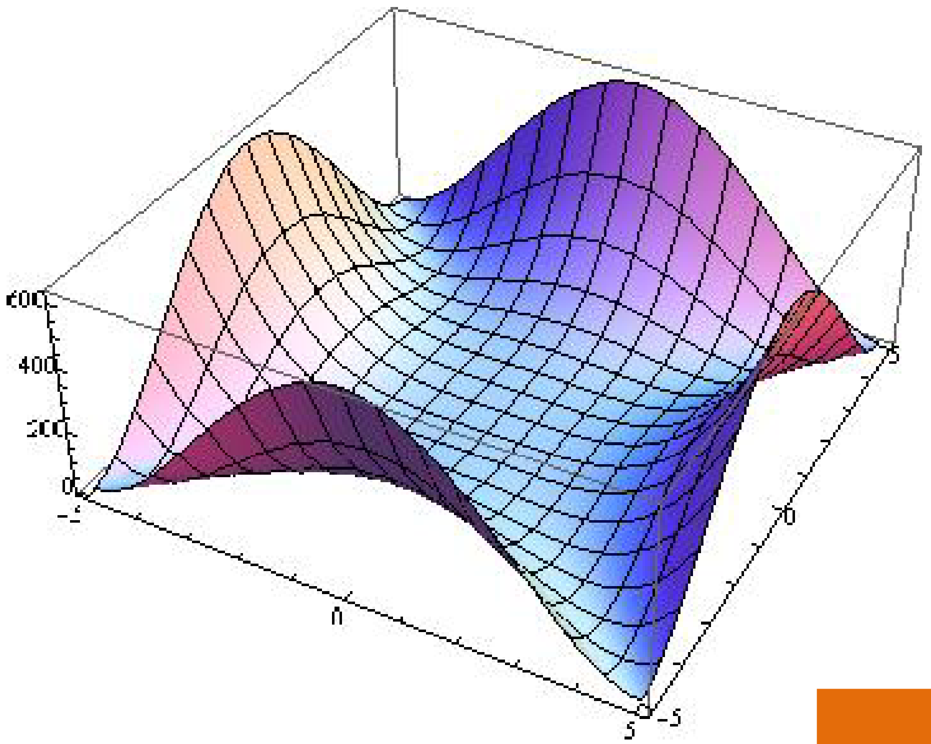
Examples:

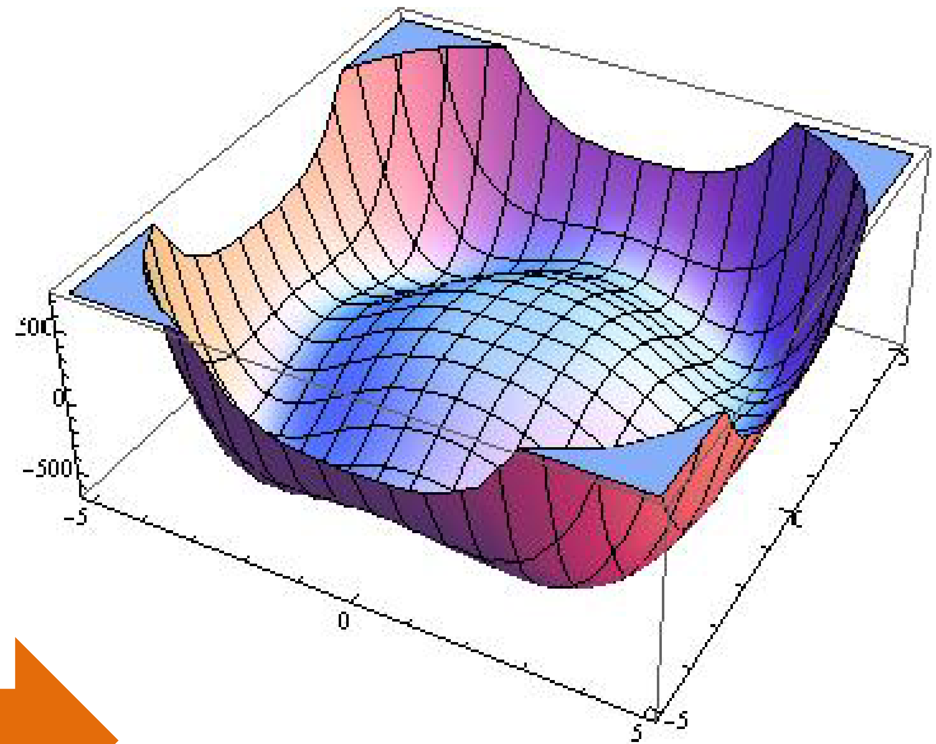


EWSB



Gildener-Weinberg Mechanism

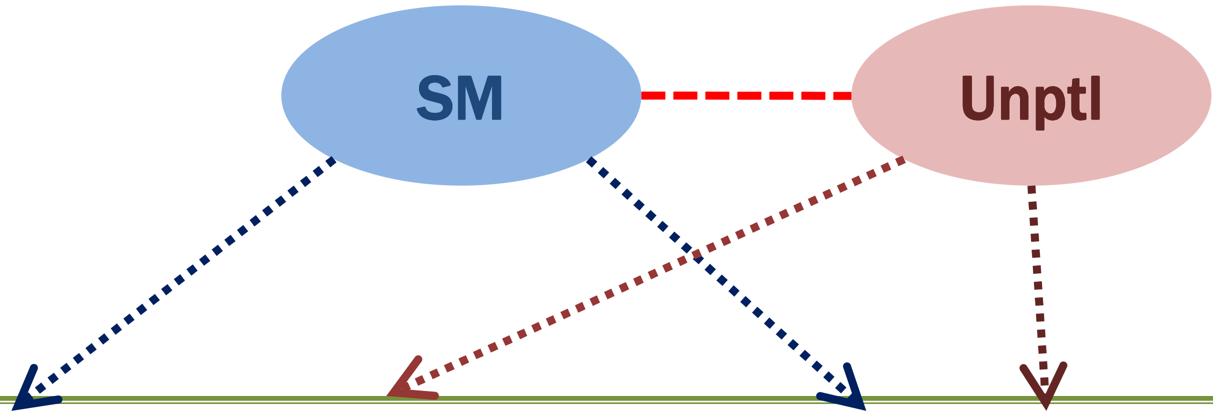




Coleman-Weinberg turned on

Finding Minimum of New Potential

New Potential



$$V(\Phi,\phi) = \lambda_0(\Phi^\dagger\Phi)^2 + \lambda_1(\phi^*\phi)^2 + 2\lambda_2\mu^{2-d_\mathcal{U}}(\Phi^\dagger\Phi)(\phi^*\phi)^{d_\mathcal{U}/2}$$

Stationary Condition

$$(\partial V/\partial N_i)_{\vec{n}} = 0$$

$$\left.\frac{\partial^2 V}{\partial N_i \partial N_j}\right|_{\vec{n}} u_i u_j \geq 0$$

$\Phi_i = (\Phi, \phi) = \rho N_i$

Find the minimum along this ray for unit vector N_i

EWSB with New Potential

Stationary Condition satisfied when

$$\left(\frac{\hat{\rho}^2}{2}\right)^{-\epsilon} \lambda_2 n_1^{d_{\mathcal{U}}} = -\lambda_0 n_0^2 \qquad (d_{\mathcal{U}} = 2 - 2\varepsilon)$$

$$2\lambda_1 n_1^4 = d_{\mathcal{U}} \lambda_0 n_0^4$$

Unit Vectors

$$n_0^2 = \frac{\sqrt{2\lambda_1}}{\sqrt{d_{\mathcal{U}}\lambda_0} + \sqrt{2\lambda_1}} \qquad n_1^2 = \frac{\sqrt{d_{\mathcal{U}}\lambda_0}}{\sqrt{d_{\mathcal{U}}\lambda_0} + \sqrt{2\lambda_1}}$$

VEV of ρ

ρ_0 is fixed:

$$\rho = \rho_0 \equiv \left(- \frac{2^\epsilon \lambda_2 n_1^{d_\mathcal{U}}}{\lambda_0 n_0^2} \right)^{\frac{1}{2\epsilon}} \mu$$

Stability condition for ρ_0

$$\boxed{\lambda_2 = -\sqrt{\lambda_0 \lambda_1} \equiv \bar{\lambda}}$$

$$\Rightarrow \quad \hat{\rho}_0^2 = 2 \left(\frac{d_\mathcal{U}}{2} \right)^{\frac{1}{2-d_\mathcal{U}}} \frac{\sqrt{d_\mathcal{U} \lambda_0} + \sqrt{2\lambda_1}}{\sqrt{d_\mathcal{U} \lambda_0}}$$

$$\to \frac{2}{\sqrt{e}} \frac{\sqrt{\lambda_0} + \sqrt{\lambda_1}}{\sqrt{\lambda_0}}, \quad \text{as} \quad d_\mathcal{U} \to 2$$

Constraints

From the weak boson mass:

$$(n_0\rho_0)^2 = \frac{1}{\sqrt{2}G_F} = (246\ \mathrm{GeV})^2 \equiv v_0^2$$

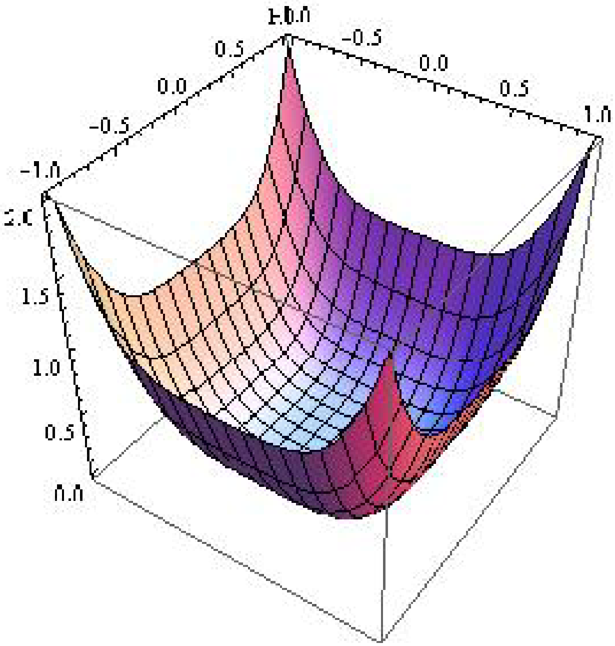
If we choose $\mu = v_0$:

$$\frac{\lambda_1}{\lambda_0} = \frac{1}{4}\left(\frac{2}{d_{\mathcal{U}}}\right)^{\frac{d_{\mathcal{U}}}{2-d_{\mathcal{U}}}}$$

$$\longrightarrow \frac{e}{4} \simeq 0.68 \quad \text{as } d_{\mathcal{U}} \to 2$$

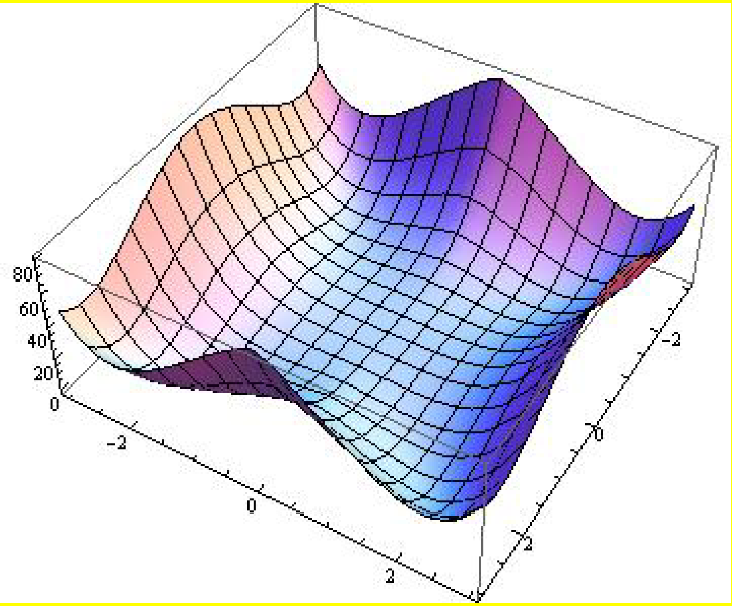
How to break EWS

SM / Scale Inv.



$f(x,y)=x^4+y^4$

SM ⋯ Scale Inv.



$f(x,y)=x^4+y^4-3x^2y^{1.3}$

Mass Spectrum

Fluctuations around the vacuum

Fields redefined

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ n_0\rho_0 + h \end{pmatrix} , \qquad \phi = \frac{1}{\sqrt{2}}(n_1\rho_0 + s)$$

Potential of *h* and *s*

$$\begin{aligned} V(h,s) \;&=\; \frac{\lambda_0}{4}(n_0\rho_0 + h)^4 + \frac{\lambda_1}{4}(n_1\rho_0 + s)^4 \\ &\quad + 2^{-d_{\mathcal{U}}/2}\lambda_2\mu^{2\epsilon}(n_0\rho_0 + h)^2(n_1\rho_0 + s)^{d_{\mathcal{U}}} \end{aligned}$$

Mass Squared Matrix

ψ_i=(*h*,*s*)

$$(M^2)_{i,j} = \left.\frac{\partial^2 V}{\partial\psi_i\partial\psi_j}\right|_0$$

$$= \frac{\rho_0^2 n_0^2}{\sqrt{2\lambda_1}} \begin{pmatrix} 2\lambda_0\sqrt{2\lambda_1} & -(2d_{\mathcal{U}}\lambda_0\lambda_1)^{\frac{3}{4}} \\ -(2d_{\mathcal{U}}\lambda_0\lambda_1)^{\frac{3}{4}} & (4-d_{\mathcal{U}})\lambda_1\sqrt{d_{\mathcal{U}}\lambda_0} \end{pmatrix}$$

Mass Spectrum

$$m_{h,\ell}^2 = \frac{\rho_0^2\sqrt{2\lambda_0\lambda_1}}{\sqrt{d_{\mathcal{U}}\lambda_0}+\sqrt{2\lambda_1}}\left\{\sqrt{\lambda_0}+\left(2-\frac{d_{\mathcal{U}}}{2}\right)\sqrt{\frac{d_{\mathcal{U}}}{2}\lambda_1}\pm\sqrt{D}\right\}$$

$$D = \lambda_0 + \left(2-\frac{d_{\mathcal{U}}}{2}\right)^2\frac{d_{\mathcal{U}}}{2}\lambda_1 + \left(\frac{3d_{\mathcal{U}}}{2}-2\right)\sqrt{2d_{\mathcal{U}}\lambda_0\lambda_1}$$

$$\epsilon = 1 - d_{\mathcal{U}}/2 \ll 1$$

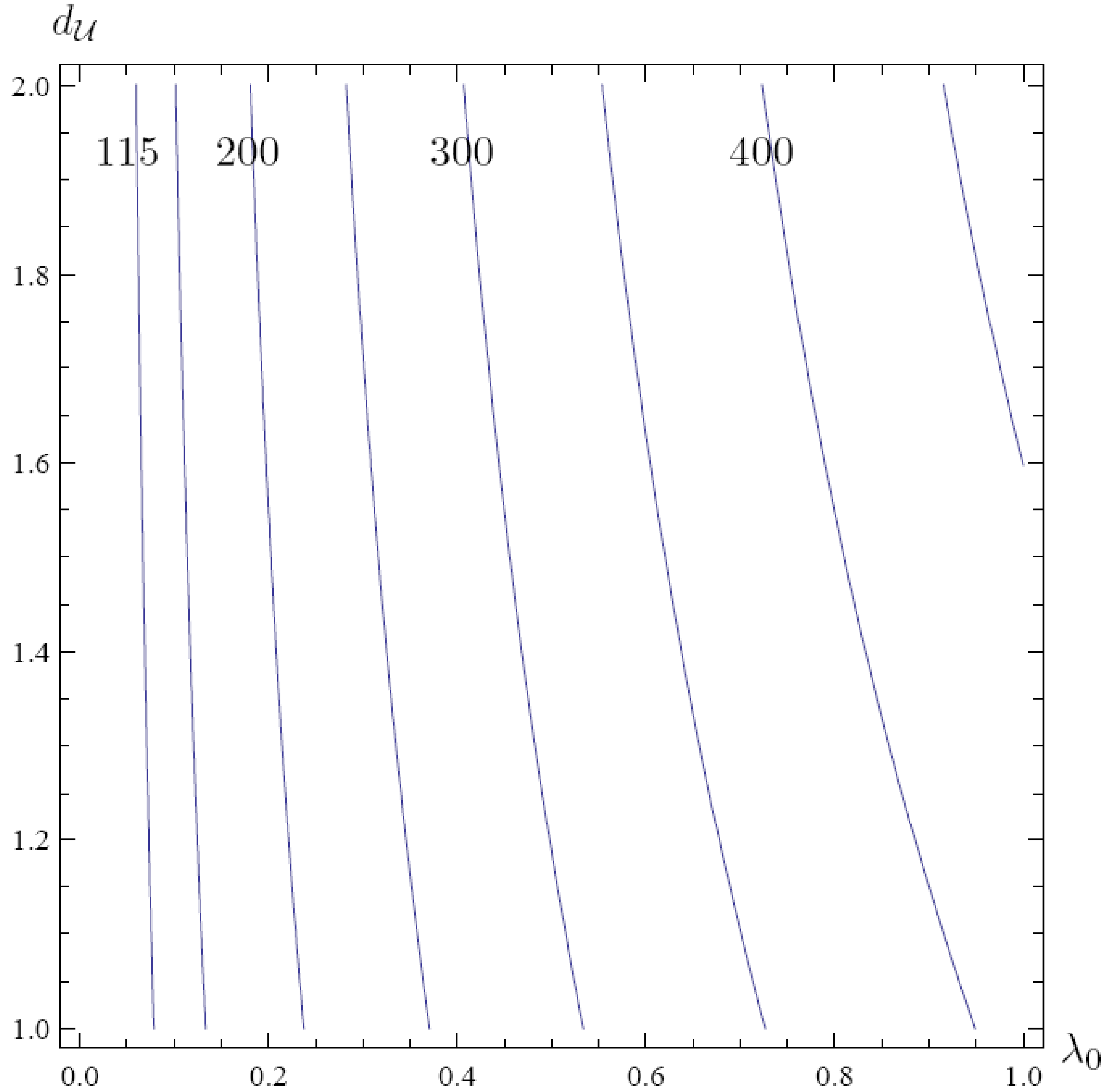
$$\frac{m_h^2}{\rho_0^2} = 2\sqrt{\lambda_0\lambda_1}\left[1+\frac{\epsilon}{2}\left(\frac{\sqrt{\lambda_0}-\sqrt{\lambda_1}}{\sqrt{\lambda_0}+\sqrt{\lambda_1}}\right)^2\right]$$

$$\frac{m_\ell^2}{\rho_0^2} = 2\sqrt{\lambda_0\lambda_1}\left[\frac{2\epsilon\sqrt{\lambda_0\lambda_1}}{(\sqrt{\lambda_0}+\sqrt{\lambda_1})^2}\right].$$

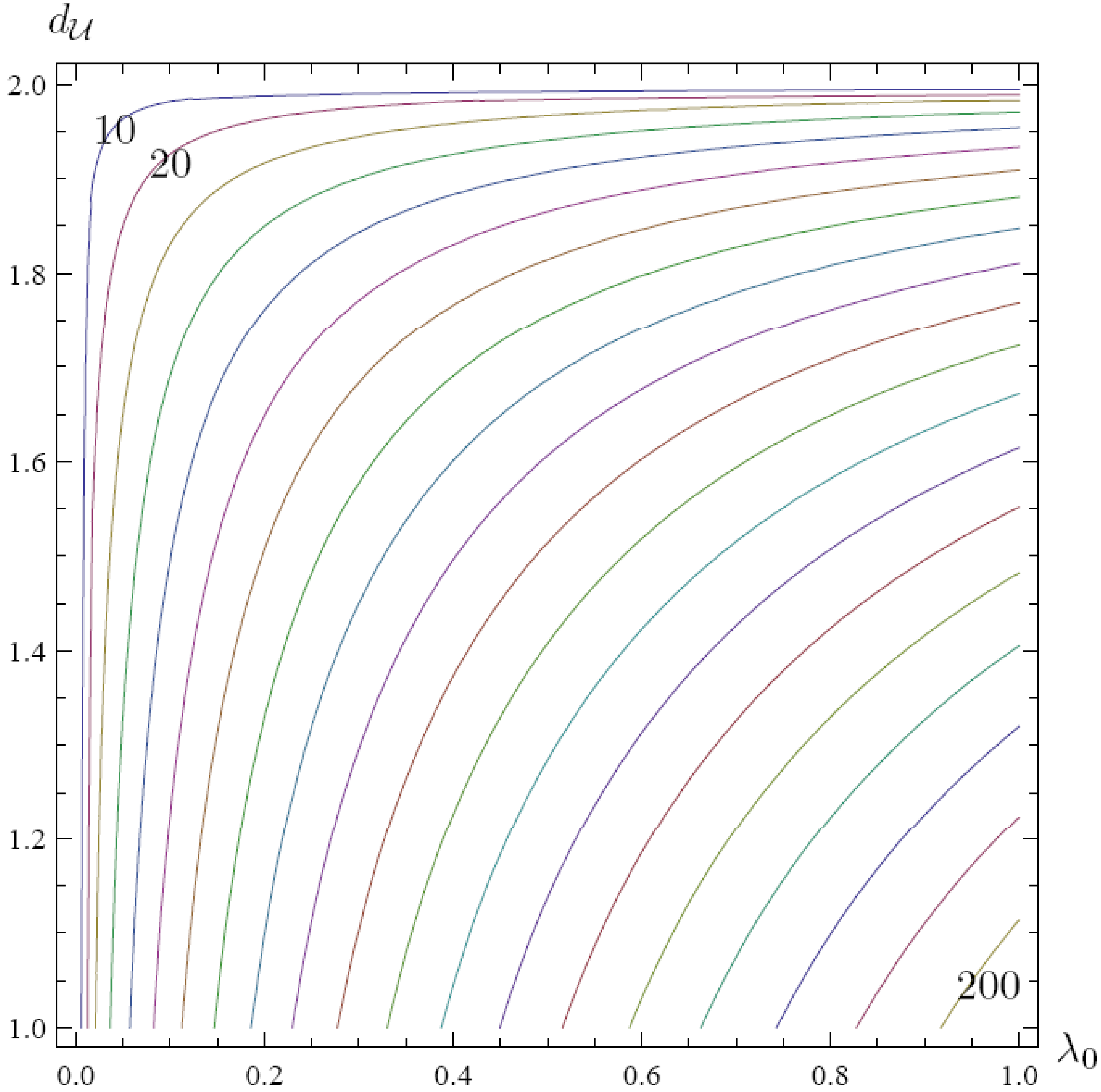
m_h : Higgs boson

m_ℓ : New light scalar

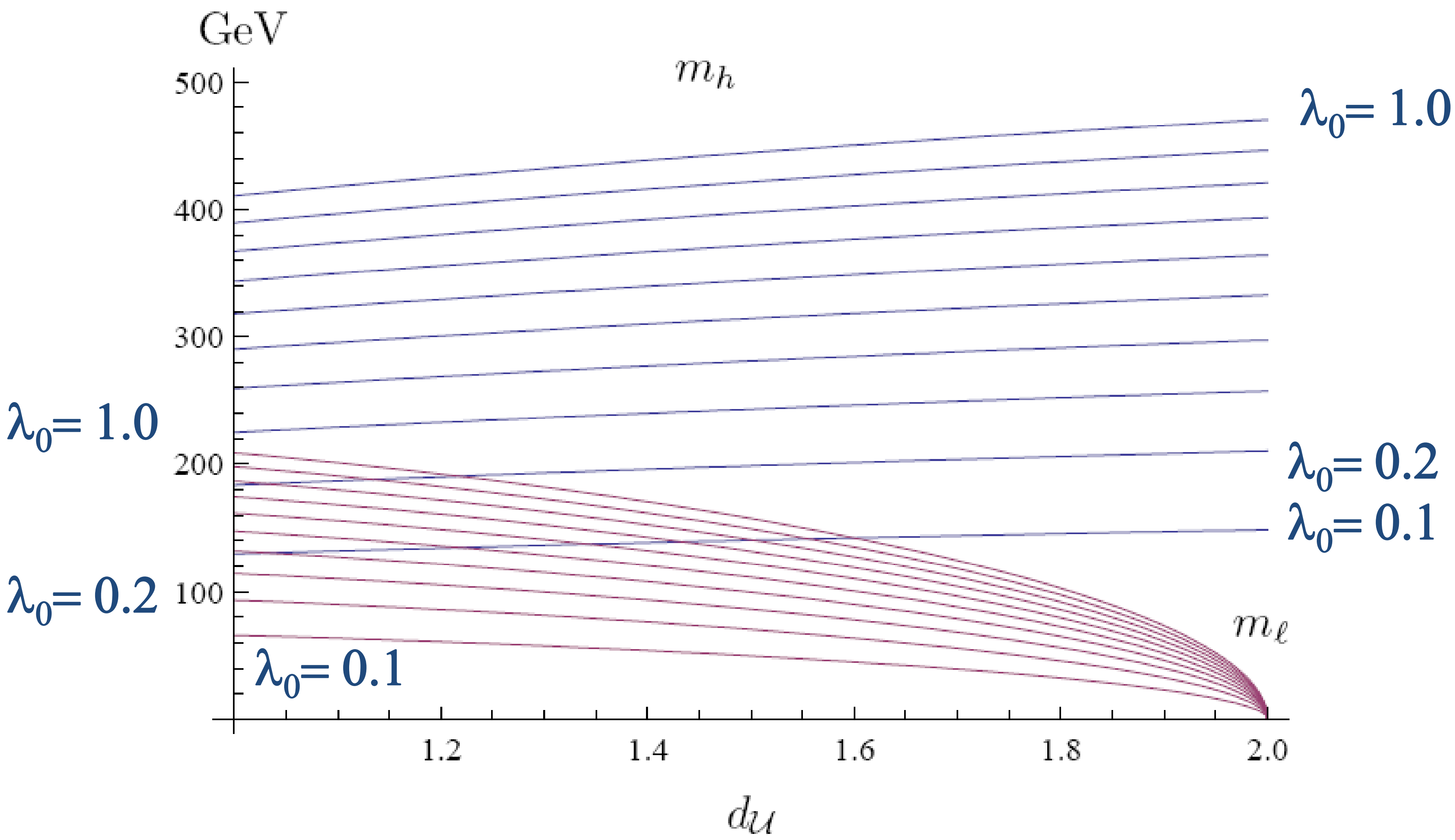
Contours for m_h (GeV)



Contours for m_ℓ (GeV)



$m_{h,\ell}$ vs $d_{\mathcal{U}}$



Conclusions

- Unparticles inspire a new scalar potential.
- EWSB occurs when the unparticle sector begins to interact with the SM sector.
- If the hidden sector were not scale inv., the EWSB occurs via CW mechanism.
- When $d_{\mathcal{U}}$ starts to depart from 2, a new scale is introduced to break EWS.
- After the EWSB, a new light scalar $\lesssim 210\mathrm{GeV}$ appears.

Back Up Slides

Keyboard

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