UNPARTICLES

A VIEW FROM THE HIGGS WINDOW

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★ Introduction to Unparticles

★ Exploring the Unparticle World through the Higgs boson

Work with A. Delgado (NotreDame), J.M. No (IFT) & M. Quirós (IFAE)

[hep-ph/0707.4309] [hep-ph/0802.2680]

HIDDEN SECTOR OF UNPARTICLES

Georgi-03

Assume a scale invariant sector of the theory

⇨ Very different from our observable sector

★ SM contains explicit mass term $V \supset -m^2|H|^2$

Scale inv. sector ⇨ Massless fields*

★ Quantum corrections can generate a scale (QCD)

Scale inv. sector ⇨ $\beta(g)=0$ required & $g \neq 0$ ($g=0$ is trivial)

Ex:

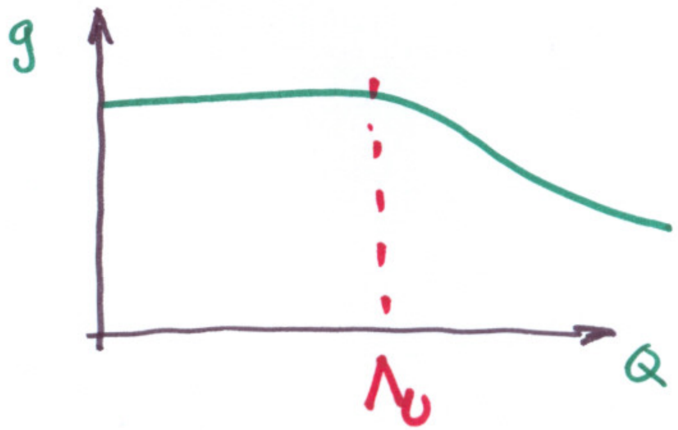
Banks-Zaks

$SU(N_c)$

N_f flavors

tailored

to give →



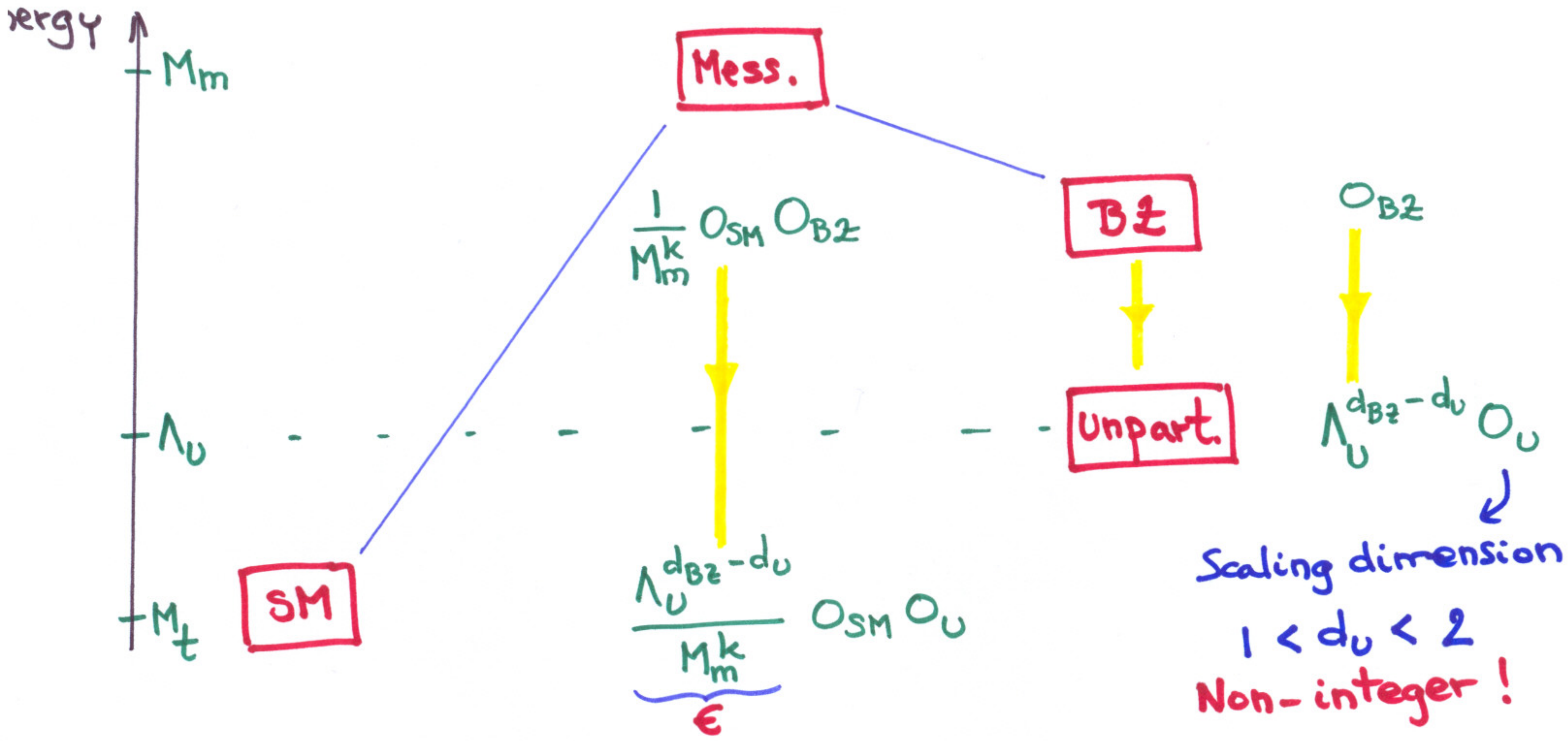
Non-trivial IR fixed point

⇩

Dimensional

"anti-transmutation"

COUPLE SM TO SCALE INV. SECTOR

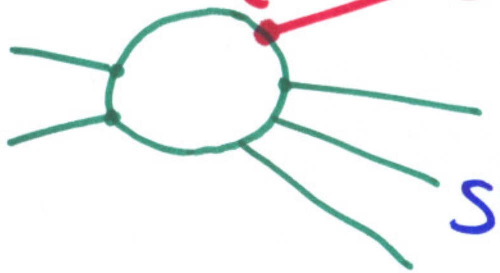


* d_U: O_U cannot be interpreted in terms of particles

* As ϵ small ⇒ Unparticle effects not seen (so far...)

UNPARTICLE PRODUCTION

$\epsilon\, O_{SM} O_U \Rightarrow$



At lowest order in ϵ

⇓

Missing energy & momentum

Probability $\rightarrow \epsilon^2 |\langle SM_{out}| O_{SM} | SM_{in}\rangle|^2 |\langle U | O_U | 0\rangle|^2$

Phase space for unparticles ⇒ determined by scale invariance :

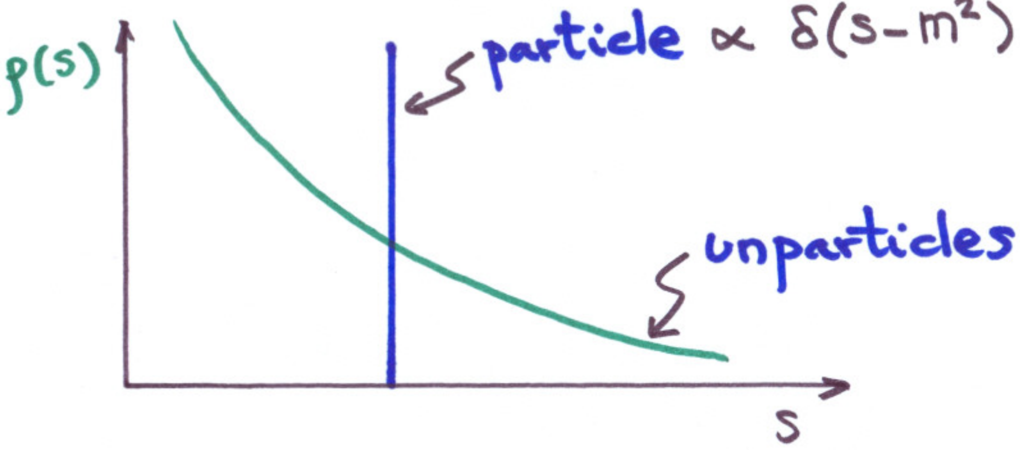
$$\langle 0| O_U(x) O_U^\dagger(0) |0\rangle = \int e^{-ipx} \underbrace{|\langle U,p | O_U(0) | 0\rangle|^2 \rho(p^2)}_{A_{d_U}\, \theta(p^0)\, \theta(p^2)\, (p^2)^{d_U-2}} \frac{d^4p}{(2\pi)^4} \sim x^{-2d_U}$$

Compare phase space for n massless particles $dLIPS_n = A_n\, s^{n-2}$

Unparticles ~ non-integer number of massless particles !

UNPARTICLE SPECTRAL FUNCTION

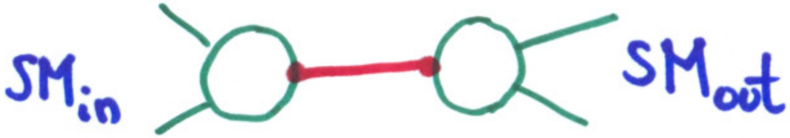
rom $P(p^2) \sim (p^2)^{d_U - 2}$ ⇒ $\rho(s) \sim s^{d_U - 2}$



O_U does not create particles out of the vacuum but a non-localized wave over the full range of p^2 ⇒ **Unparticles**

⇒ Lots of phenomenological implications explored.

E.g.



Interference $\sim \epsilon^2 \Delta_U(p^2)$

↑ strange phase inside

DECONSTRUCTING UNPARTICLES

Stephanov-05

Unparticles as infinite tower of massive scalars φ_n $(n=1,\dots\infty)$ with

$$M_n^2 = \Delta^2 n$$

in the limit of zero mass splitting $M_{n+1}^2 - M_n^2 = \Delta^2 \to 0$

⇨ **Scale invariant continuous mass spectrum !**

$$S = \int d^4x \sum_{n=1}^{\infty} \left[\frac{1}{2}(\partial_\mu \varphi_n)^2 + \frac{1}{2} M_n^2 \varphi_n^2\right] \quad \xrightarrow{\Delta \to 0} \quad S = \int d^4x \int_0^\infty dM^2 \left[\frac{1}{2}(\partial_\mu u)^2 + \frac{1}{2} M^2 u^2\right]$$

$\Delta^2 \to dM^2$

$\varphi_n \to \Delta\, u(M^2)$

$\varphi_n(x) \to \lambda \varphi_n(x\lambda)$

$u(M^2, x) \longrightarrow u(M^2/\lambda^2, x\lambda)$

Deconstructed O_U :

$$O \equiv \sum_n F_n \varphi_n \longrightarrow O_U \quad \text{for} \quad F_n^2 = \frac{A_{d_U}}{2\pi} \Delta^2 (M_n^2)^{d_U - 2}$$

⇨ Not clear phys. interp. (relation to RS ?) but very useful tool

HIGGS AS PORTAL TO UNPARTICLE WORLD

$$\kappa_U O_{SM} O_U \rightarrow \kappa_U |H|^2 O_U$$ **Relevant operator!**

⇨ After EWSB this is the main source of conformal breaking

Difficulty: $\langle H \rangle = \frac{v}{2}$ induces a tadpole for O_U triggering the VEV

$$\langle O_U \rangle = -\frac{\kappa_U v^2}{2} \int_0^\infty \frac{F^2(M^2)}{M^2} dM^2 \propto \int_0^\infty (M^2)^{d_U-3} dM^2$$

$d_U < 2$ ⇨ **IR Divergence**

DEQ-07

- Tadpole $\sim \sum_n F_n \varphi_n \sim M_n^{d_U-2} \varphi_n \xrightarrow[M_n^2 \to 0]{} \infty$
- Restoring mass $\sim M_n^2 \varphi_n^2 \rightarrow 0$

CURES FOR IR PROBLEM

(A) Add coupling $\zeta |H|^2 \sum_n \varphi_n^2$ ⇒ ζv^2 as **IR cutoff**

Delgado, E, Quirós

(B) Add coupling $\frac{1}{4}\lambda_U \left(\sum_n \varphi_n\right)^2$ work in progress

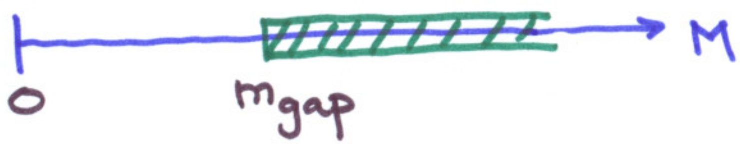
Delgado, E, Quirós, No

(A) ⇒

$$\langle O_U \rangle = -\frac{\kappa_U v^2}{2}\int_0^\infty \frac{F^2(M^2)}{M^2+\zeta v^2}\, dM^2 \propto \int_0^\infty \frac{(M^2)^{d_U-2}}{M^2+\zeta v^2}\, dM^2$$

IR finite ✓

$\zeta v^2 = m_{gap}^2$ for unparticle continuum



⇒ **Changes dramatically pheno and constraints**

EFFECTS ON EWSB

Deconstructed potential

$$V = m^2|H|^2 + \lambda|H|^4 + \frac{1}{2}\sum_n M_n^2 \varphi_n^2 + \kappa_U |H|^2 \sum_n F_n \varphi_n + \zeta |H|^2 \sum_n \varphi_n^2$$

Min Conditions ⇨

$$m^2 + \lambda v^2 + \kappa_U \sum_n F_n v_n + \zeta \sum_n v_n^2 = 0$$

and $v_n = -\dfrac{\kappa_U v^2}{2(M_n^2 + \zeta v^2)} F_n$

Continuum limit ⇨ $m^2 + \lambda v^2 - \lambda_U (\mu_U^2)^{2-d_U} v^{2(d_U-1)} = 0$ $\left[(\mu_U^2)^{2-d_U} \equiv \kappa_U^2 \frac{A_{d_U}}{2\pi} \right]$

Correction looks like coming from $\delta V \propto h^{2d_U}$ between h^2 & h^4 !

⇨ It's posible to have a minimum for $m^2 \geq 0$

HIGGS-UNPARTICLES INTERPLAY

(Infinite) Mass Matrix after EWSB ⇒

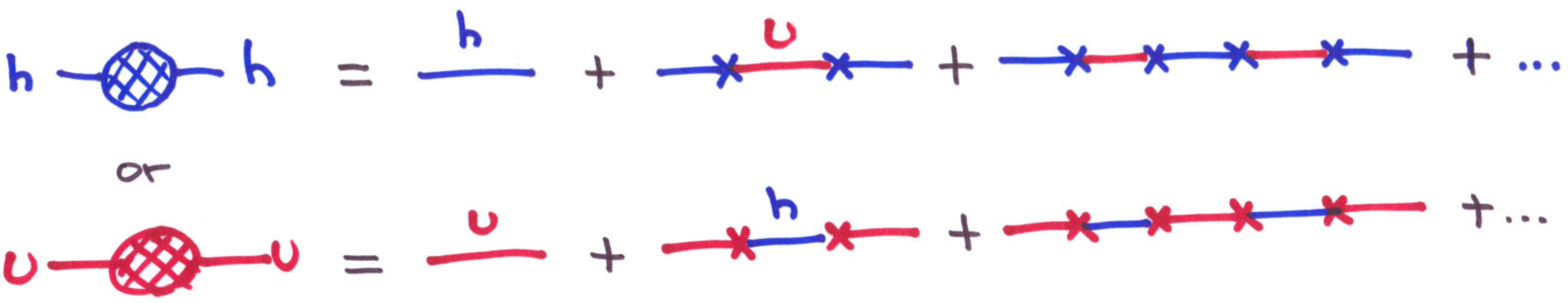
$$\begin{bmatrix} m_{h0}^2 & A_1 & \cdots & A_n & \cdots \\ A_1 & M_1^2+\zeta v^2 & & & \\ \vdots & & \ddots & & \\ A_n & & & M_n^2+\zeta v^2 & \\ \vdots & & & & \ddots \end{bmatrix}$$

1. Mass gap in diagonal entries $m_g^2 = \zeta v^2$
2. Mixing Higgs-Unparticles

$$A_n = v\left(\kappa_U F_n + 2\zeta v_n\right)$$

3. Pole structure? Examine $p^2\mathbb{I} - M^2$

MIXED PROPAGATOR



$$\Rightarrow \quad iP(p^2)^{-1} = p^2 - m_{h0}^2 + \omega^2(\mu_U^2)^{2-d_U}\int_0^\infty \frac{(M^2)^{d_U-2}}{(M^2+m_{gap}^2-p^2)}\left(\frac{M^2}{M^2+m_{gap}^2}\right)^2 dM^2$$

For the pole structure $\Rightarrow$ Spectral Function

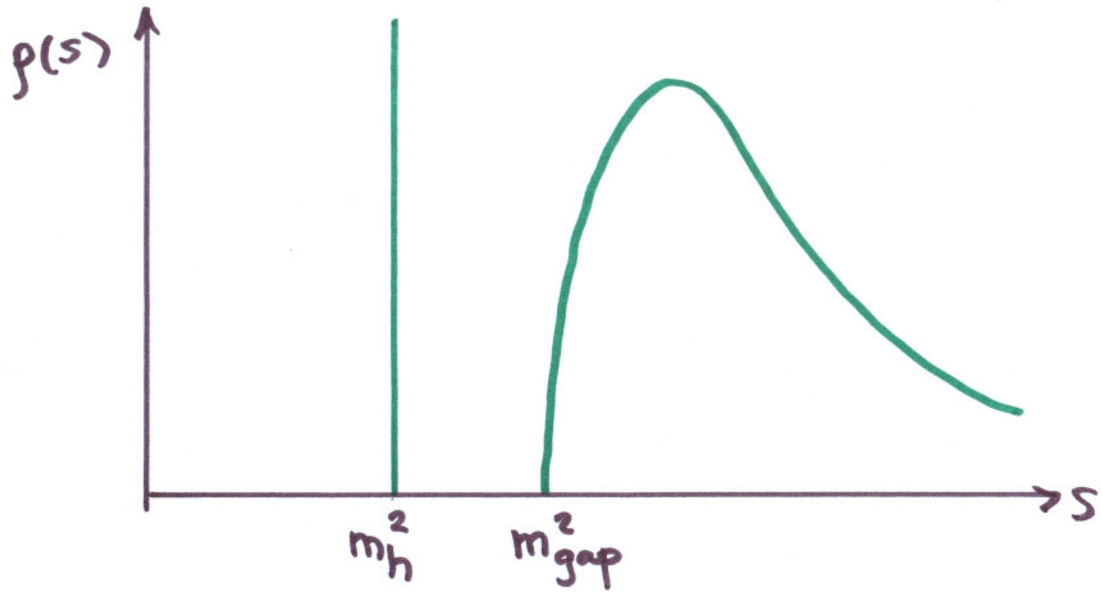
Two Cases:

- $m_h < m_{gap}$

- $m_h > m_{gap}$

SPECTRAL FUNCTION ($m_h < m_{gap}$)

m_h^2 shifted down from SM value $m_{h0}^2 = 2\lambda v^2$ (eigenvalue repulsion)



$$\rho(s) = \frac{1}{K^2}\delta(s-m_h^2) + \Theta(s-m_{gap}^2)\frac{Q_U^2(s)}{[iP(s)^{-1}]^2 + \pi^2 Q_U^4(s)}$$

ZZ COUPLING

$$\rho_{hh}(s) \equiv \langle h|s\rangle\langle s|h\rangle = |\langle h|H\rangle|^2 \delta(s-m_h^2) + \Theta(s-m_g^2)\,|\langle h|U,s\rangle|^2$$

Int. Eigenstates $\begin{cases} |h\rangle \\ |u,s\rangle \end{cases}$ → Mass Eig. $\begin{cases} |H\rangle \\ |U,s\rangle \end{cases}$

★ HZZ coupling ⇨ diluted by unparticle contamination of isolated pole

Pure Higgs composition ⇨ $R_h \equiv \langle h|H\rangle = \frac{1}{K}$

★ UZZ coupling ⇨ induced by Higgs contamination

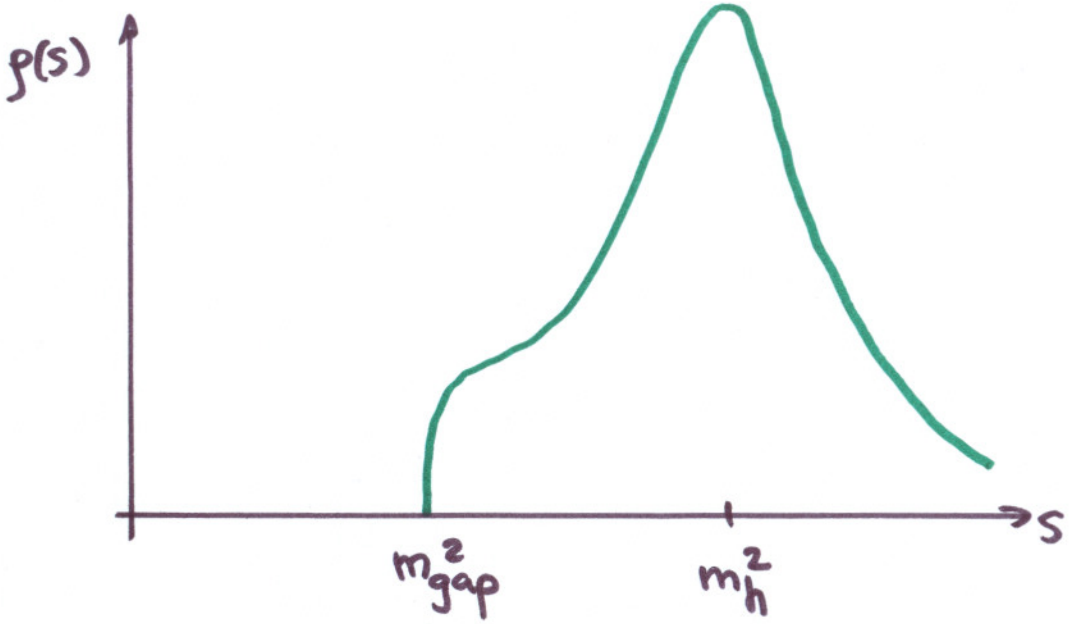
Higgs diffused in unparticle continuum

⇨ $R_U(M^2) = \Theta(M^2 - m_g^2)\,|\langle h|U,M^2\rangle|^2$

Sum Rule ⇨ $$R_h^2 + \int_{m_g^2}^{\infty} R_U^2(M^2)\,dM^2 = 1$$

SPECTRAL FUNCTION ($m_h > m_{gap}$)

Higgs pole is subsumed in unparticle continuum



$$\rho(s) = \Theta(s - m_{gap}^2) \frac{Q_U^2(s)}{[iP(s)^{-1}]^2 + \pi^2 Q_U^4(s)}$$

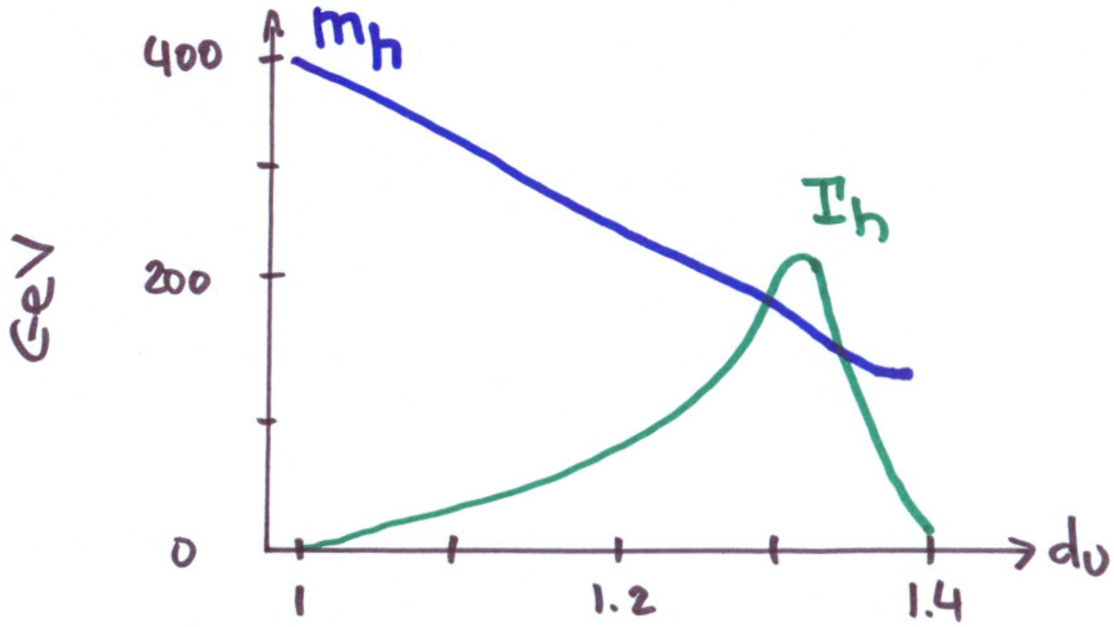
HIGGS WIDTH ($m_h > m_{gap}$)

Near Higgs pole $\Rightarrow$ $iP(s)^{-1} \simeq (s - m_h^2)\tilde{K}$

$\Downarrow$

$$\Gamma_h = \frac{\pi Q_U^2(m_h^2)}{m_h \tilde{K}^2}$$

Γ_h can be quite large



UN-CONCLUSIONS

Unparticles extremely speculative, no good motivation?

But keep in mind for LHC; interesting Higgs effects ...

⇨ $|H|^2 O_U$ can destabilize the theory but can be cured

⇨ EWSB Effects as h^{2d_U} !

Unconventional possibilities allowed ($m^2 \geq 0$)

EWSB ⇨ Induces a mass gap

Dramatic impact in phenomenology and constraints

Higgs - Unparticles : Drastic changes in Higgs mass, couplings, width

Unparticles get "Higgs contaminated" : UZZ