

HIDDEN SECTOR EFFECTS ON ELECTROWEAK BREAKING

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Abstract

The Higgs boson offers a unique window to hidden sectors via relevant (or marginal) operators. Such interactions can provide new patterns for electroweak breaking (including radiative breaking by dimensional transmutation consistent with LEP bounds) and trigger a strong enough first order phase transition

Outline

- Motivation
- Particle Hidden Sector
 - Electroweak breaking
 - Electroweak phase transition
- Unparticle Hidden Sector
 - Deconstructing unparticles
 - Electroweak breaking
 - Pole Higgs mass and width
- Conclusions

Work with: J.R. Espinosa and A. Delgado

Motivation

- The Standard Model (SM) can not be considered as a fundamental theory, since it fails to provide an answer to many open questions: the hierarchy, cosmological constant and flavor problems, the origin of baryons, the Dark Matter and Dark Energy of the Universe, . . .
- Rather it must be considered as an effective theory with a physical cutoff Λ that most likely shall be probed at LHC

- Many SM extensions, e.g. string theory, contain hidden sectors with a matter content transforming non-trivially under a hidden sector gauge group but singlet under the SM gauge group
- The SM Higgs field H plays a very special role with respect to such hidden sectors since it can provide a window (a portal) into it through the renormalizable interaction $|H|^2 \dots$
- We will assume that the hidden sector is “singlet” under the SM gauge group

Particle Hidden Sector

- We will consider interactions between the hidden sector fields S_i and the SM Higgs H as $|H|^2 S_i^2$ ^a

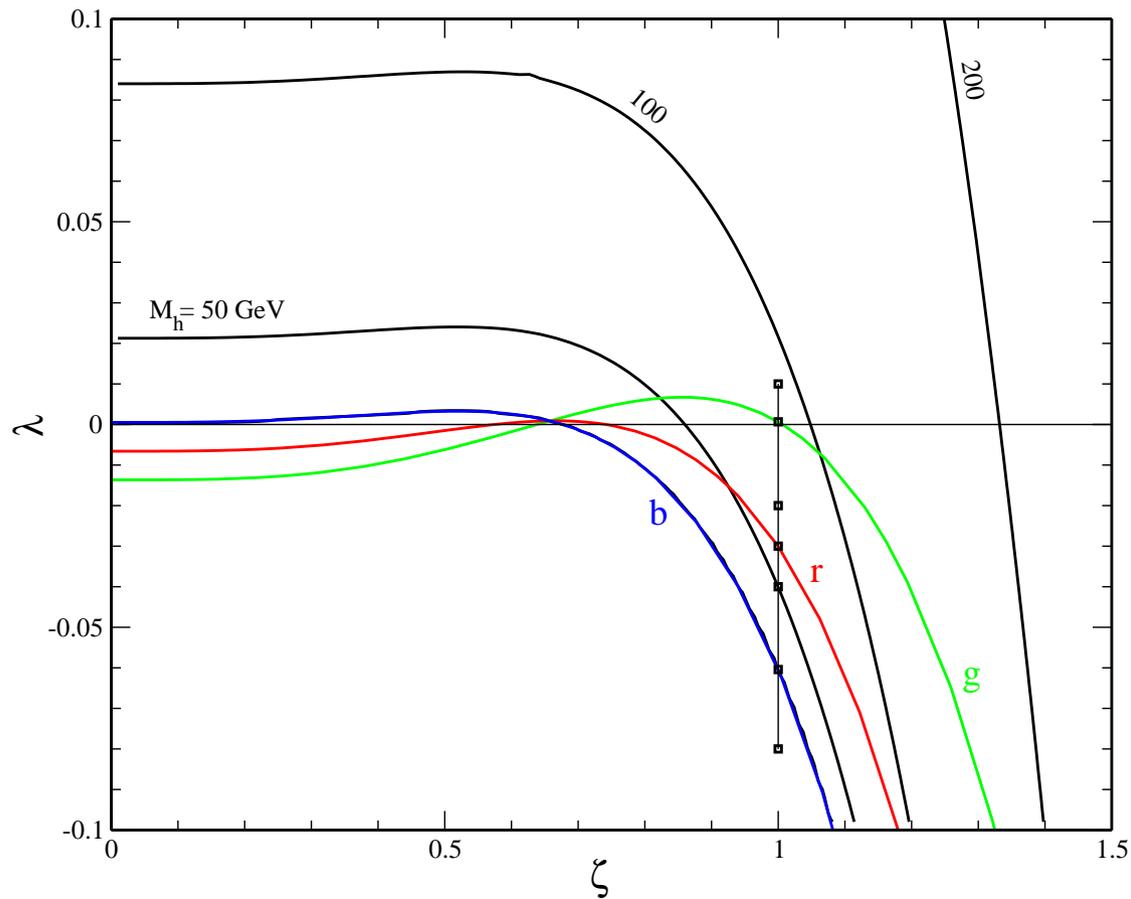
- The SM Lagrangian is extended minimally to

$$\mathcal{L} = \mathcal{L}_{SM} - \zeta^2 |H|^2 S_i^2$$

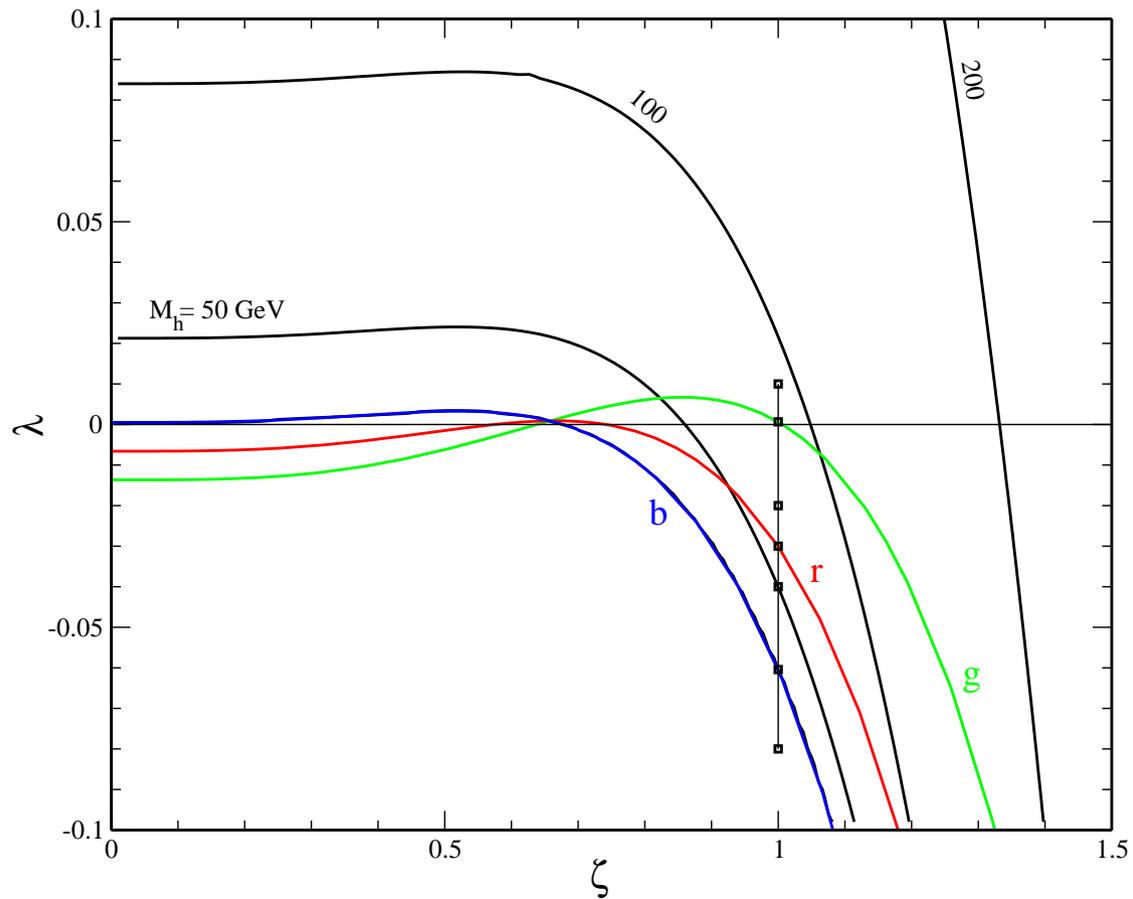
- Such a simple term can dramatically change **at one-loop** the patterns of electroweak breaking and the strength of the electroweak phase transition

^aJ.R. Espinosa and M.Q., PRD 76 (2007) 076004

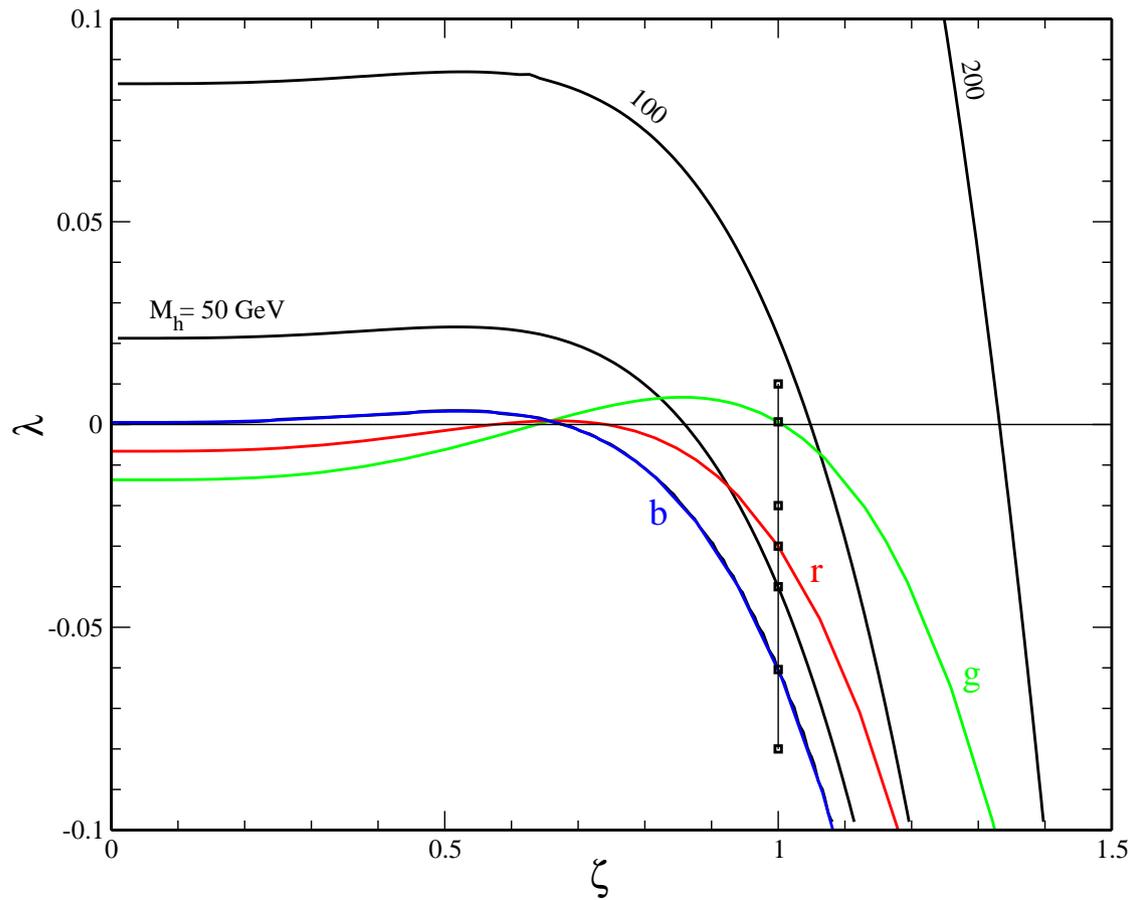
Electroweak breaking



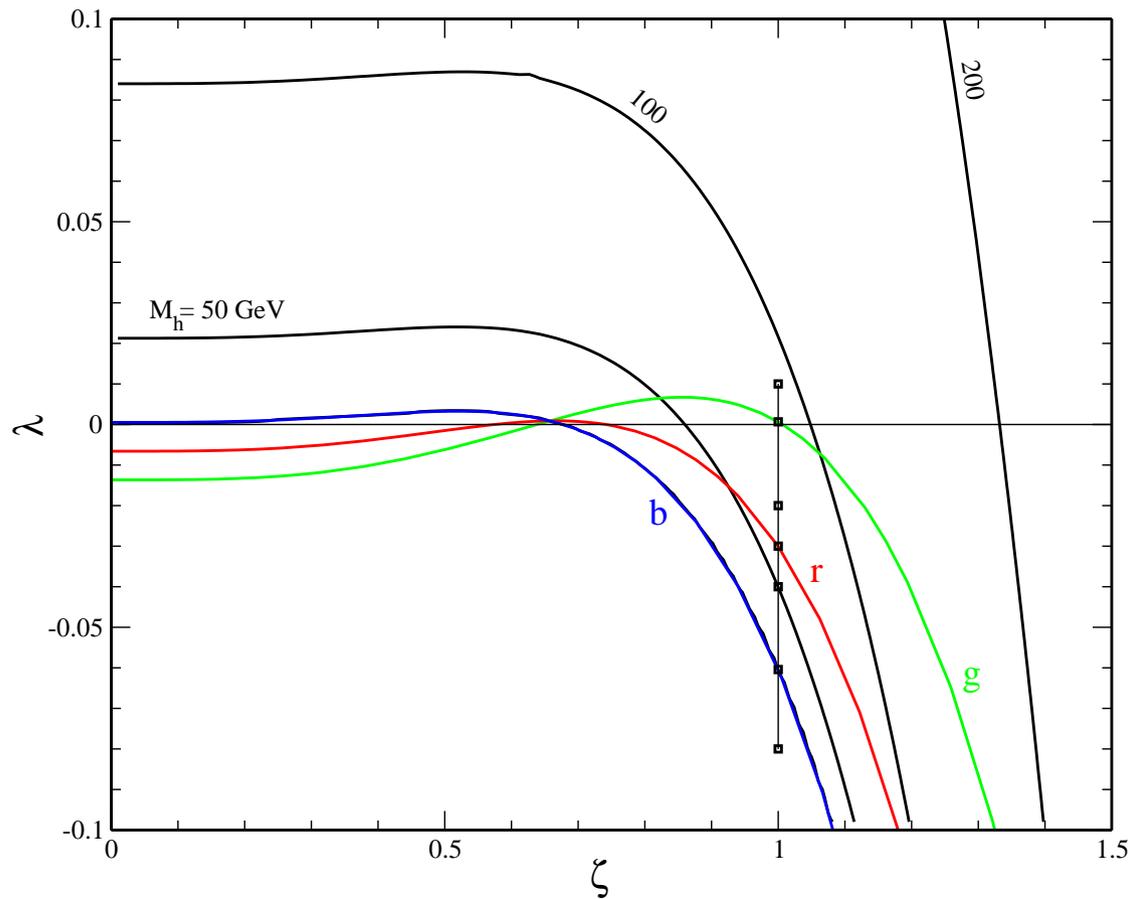
The region below the **blue** line is forbidden: there
 $M_h^2 < 0$.



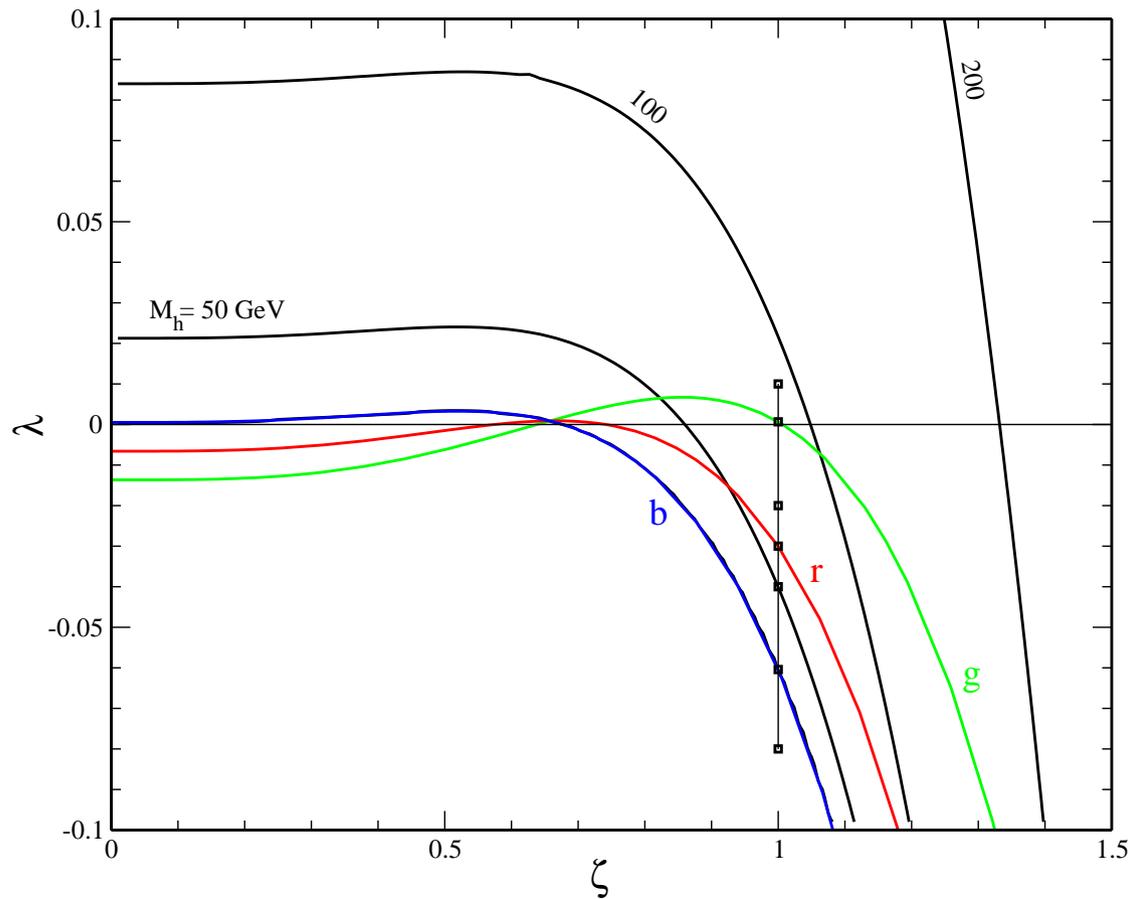
In the region between the **blue** and the **red** line ($m^2 > 0$) there is a false electroweak minimum



On the **red** line the minima at the origin and at v are degenerate



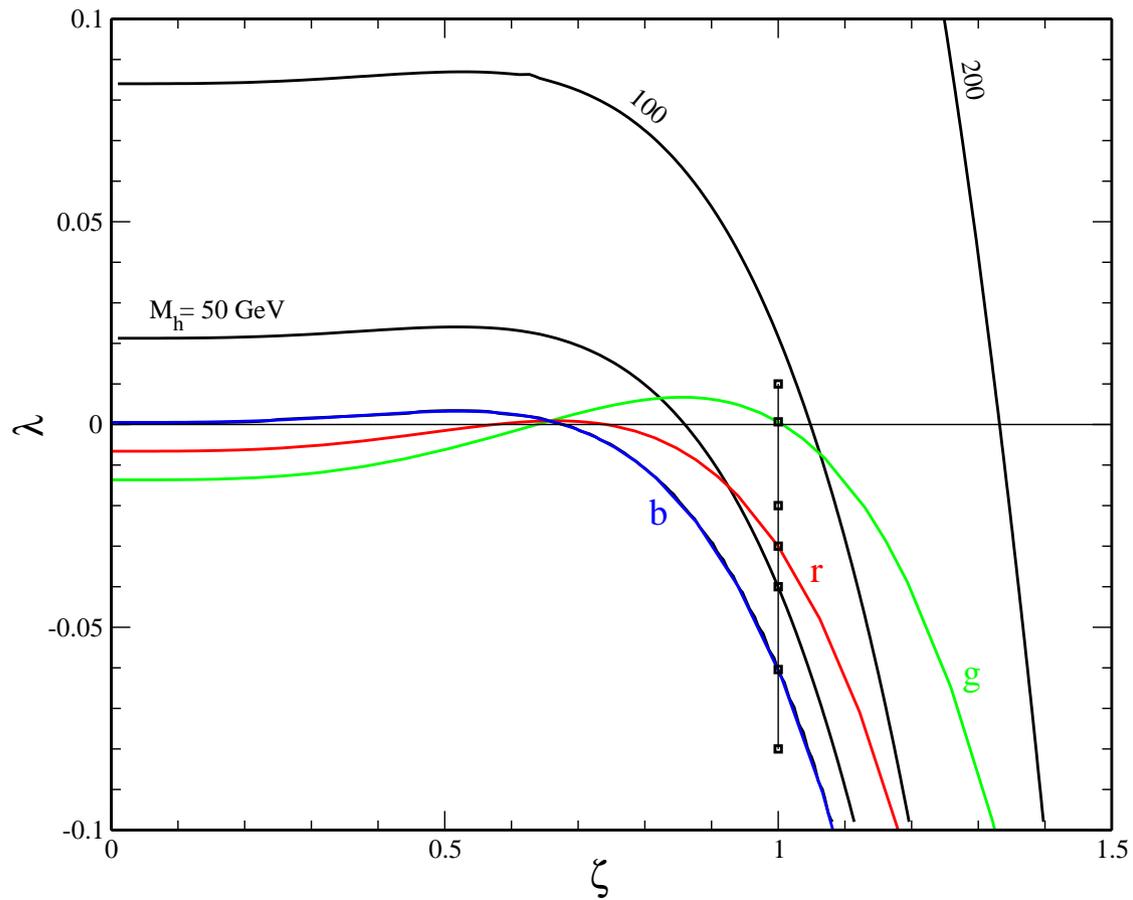
Between the **red** and **green** line [defined by $V''(0) = 0$] the electroweak minimum is stable



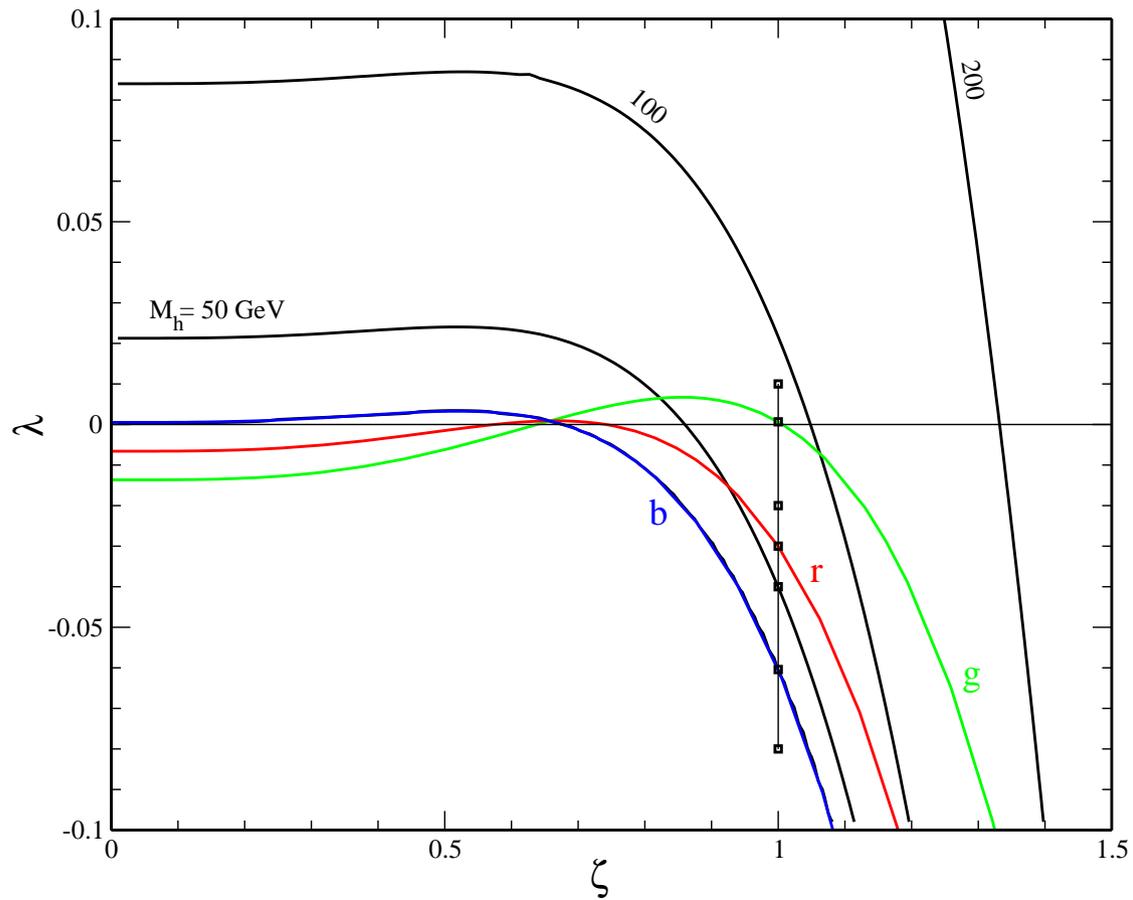
and there is a barrier separating the false minimum at the origin from the electroweak minimum

This region is very interesting for two reasons

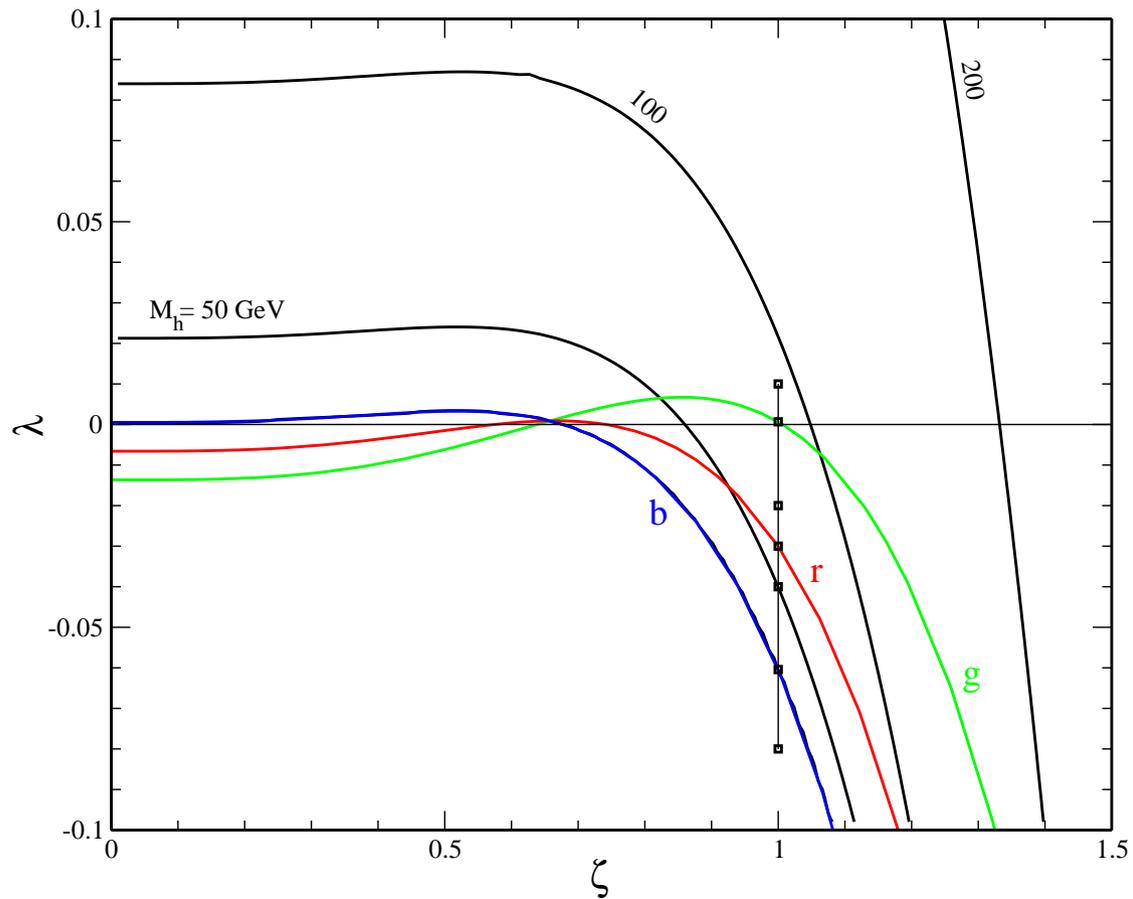
- The barrier between both minima (at zero temperature) will produce an overcooling of the Higgs field at the origin at finite temperature, strengthening the first order phase transition (see below)
- Electroweak symmetry breaking is not associated with the presence of a tachyonic mass at the origin, as in the SM. Instead it is triggered by radiative corrections via the mechanism of dimensional transmutation



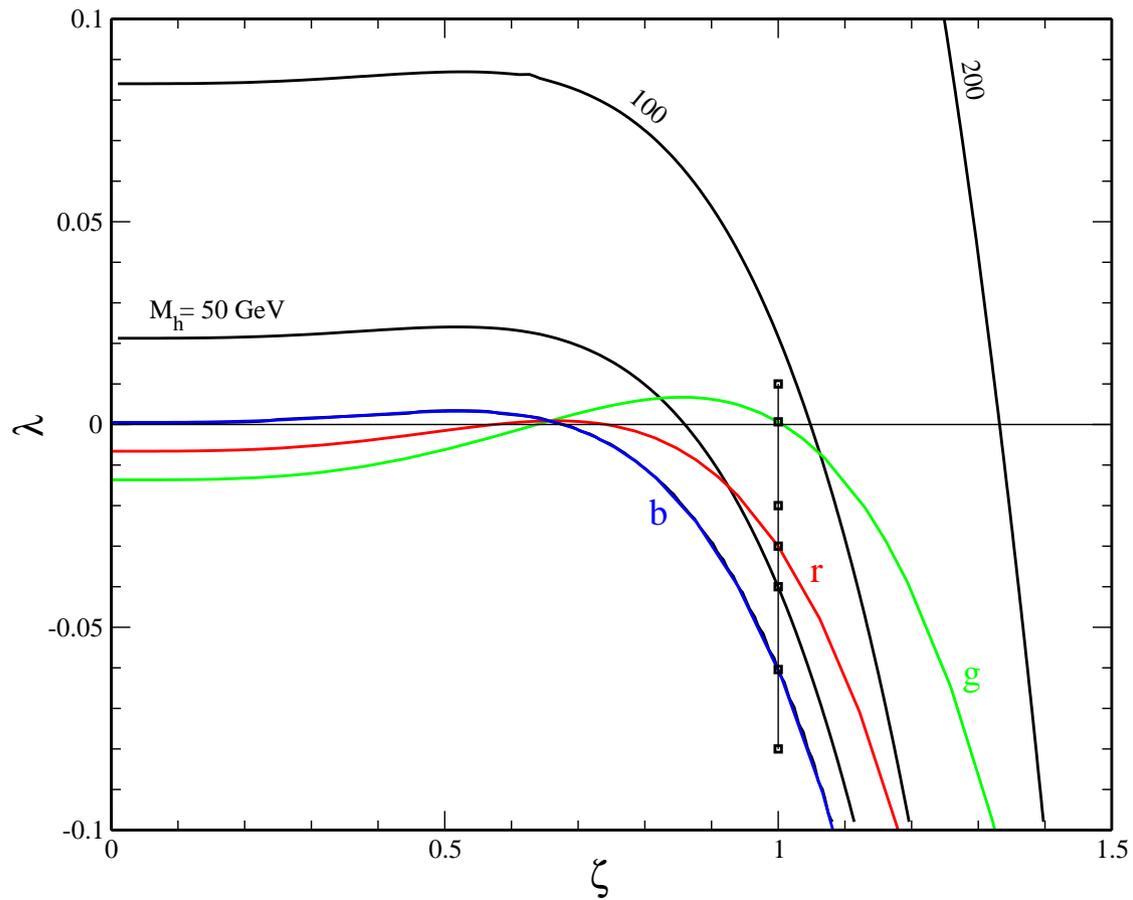
Green line corresponds to the conformal case
 where $m^2 = 0$



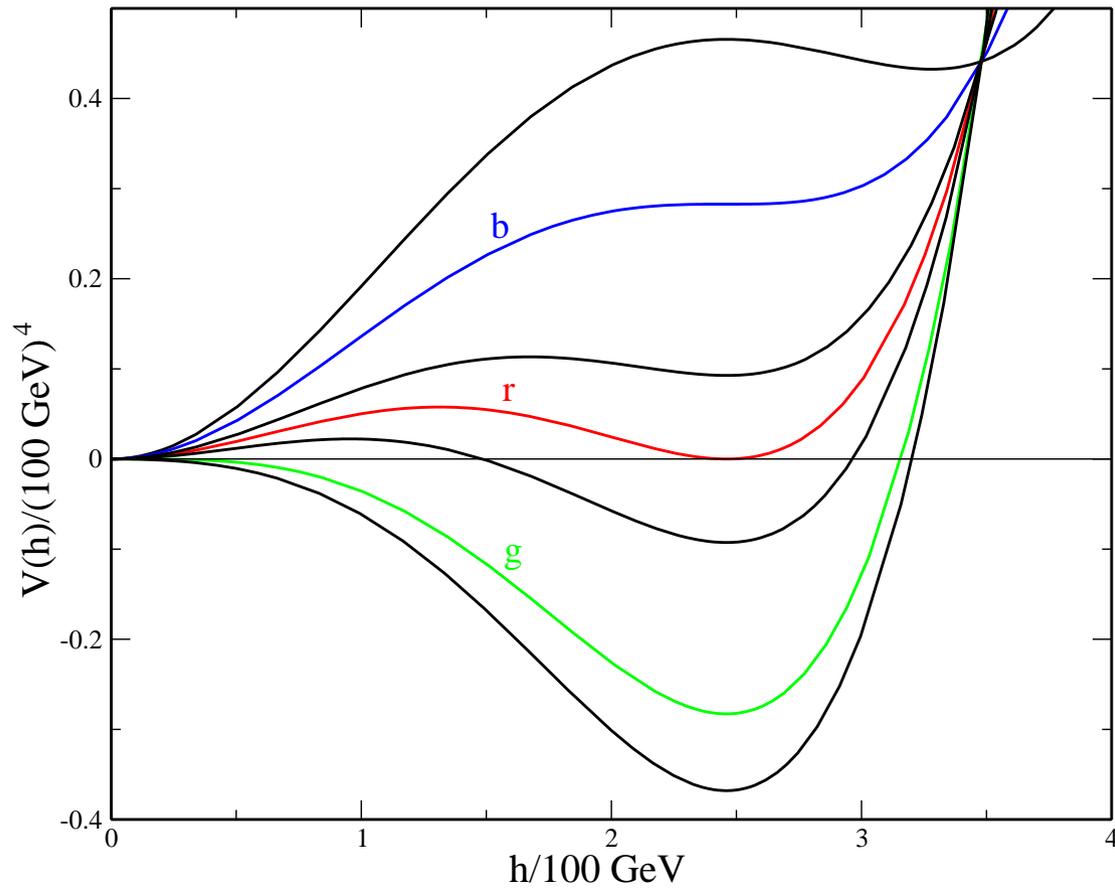
and electroweak breaking proceeds by
dimensional transmutation



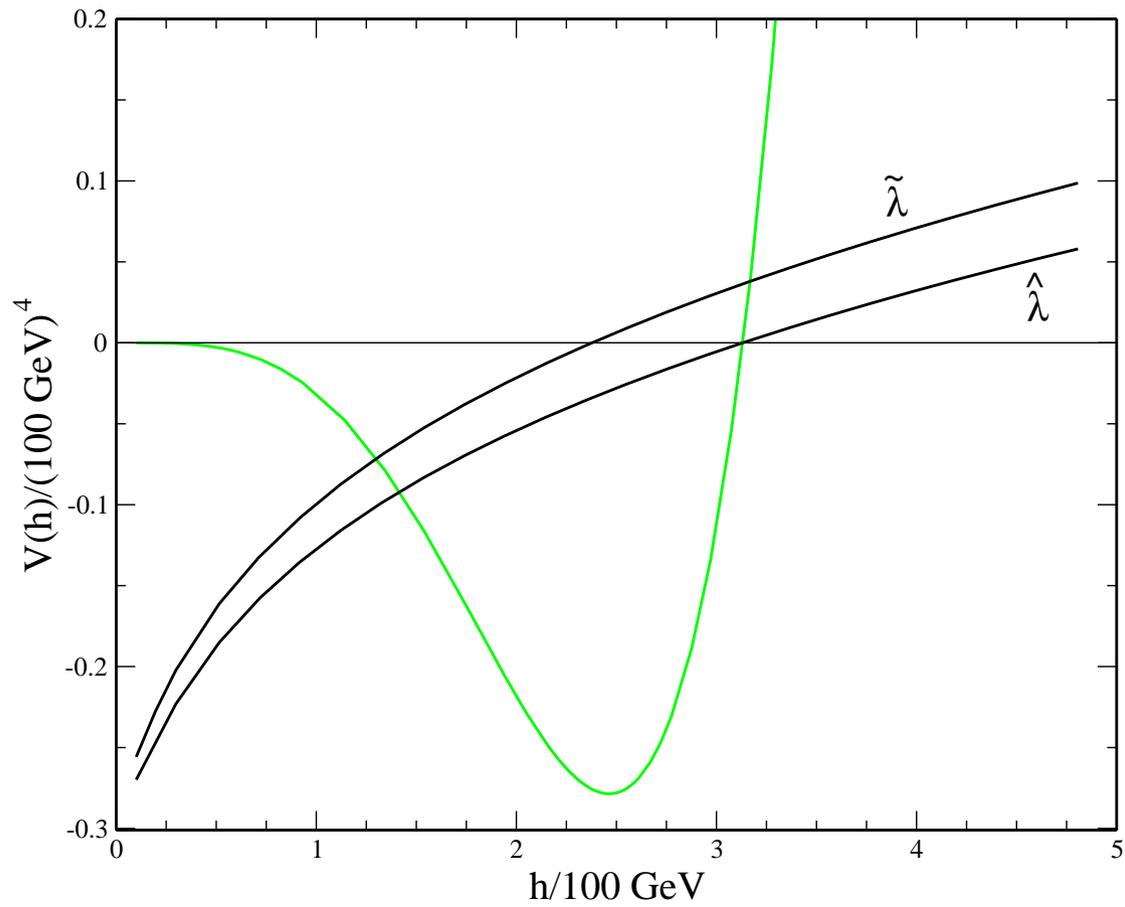
In the region above the **green** line the origin is a maximum as in the SM, with $m^2 < 0$



The potential for the spots in the above figure



The different effective potentials



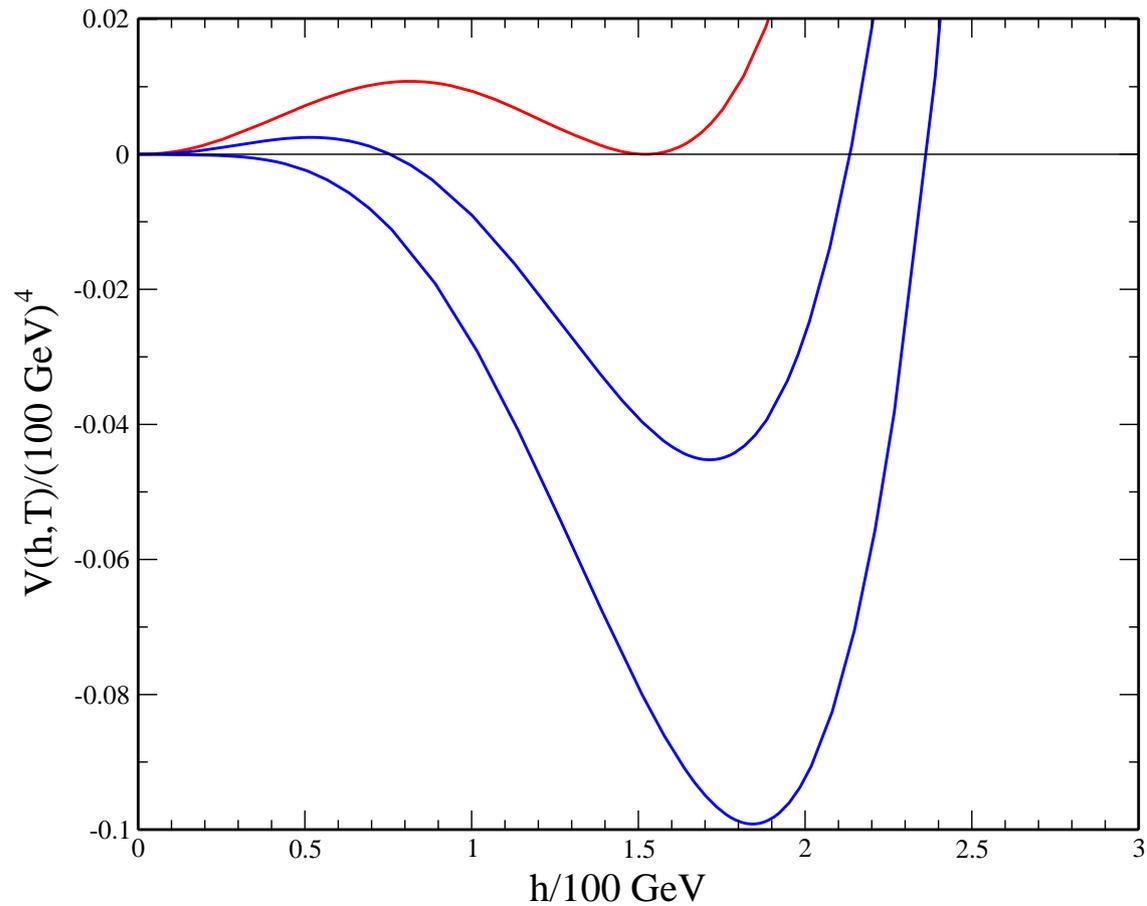
The conformal case with λ running

Electroweak phase transition

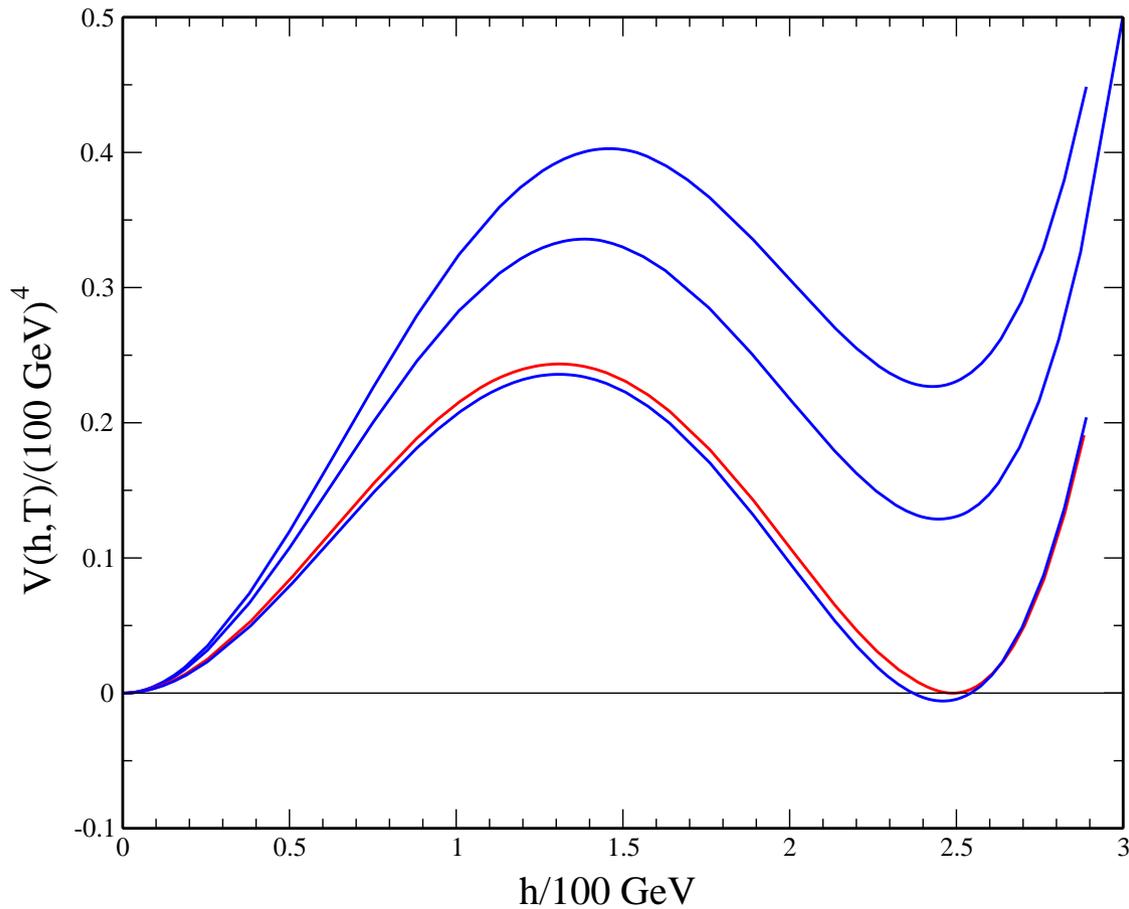
In the presence of hidden sector fields S_i coupled to the SM Higgs the electroweak phase transition is strengthened by:

- The thermal contribution from S_i , if ζ is large enough. "This fact was already known"
- The fact that, in part of the (ζ, λ) -plane, there is a barrier separating the origin (energetically favored at high temperature) and the electroweak minimum at zero temperature. "This effect is new"

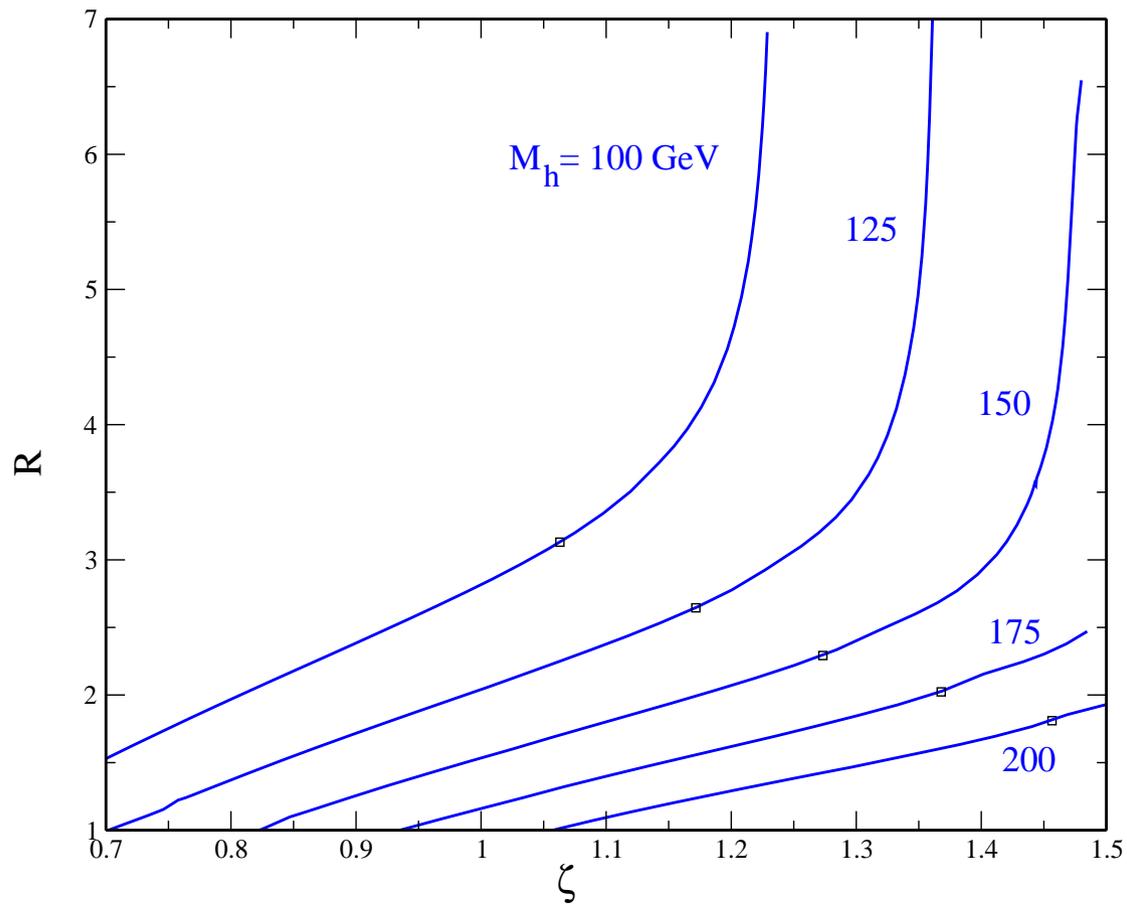
We have studied the effective potential at finite temperature



Case $N = 12$, $M_h = 125$ GeV $\zeta = 0.8$ and $T =$
 110.85, 108 and 105 GeV



Case $N = 12$, $M_h = 125$ GeV $\zeta = 1.365$ and $T =$
 50, 40 and 30 GeV



Plot of $\langle h \rangle / T_c$

Unparticle Hidden Sector

- H. Georgi has proposed ^a to look seriously at the possibility that a conformal sector with a non-trivial fixed point might be realized in nature and couple to our standard world
- The ultraviolet (UV) coupling of an operator of dimension d_{UV} in the unparticle sector to the SM \mathcal{O}_{SM} (dimension d_{SM}) as

$$\mathcal{L} = -\frac{1}{\mathcal{M}_U^{d_{UV}+d_{SM}-4}} \mathcal{O}_{SM} \mathcal{O}_{UV} ,$$

^aH. Georgi, arXiv:hep-ph/0703260; 0704.2457; Joint Theory-Experiment Seminar, Fermilab, November 2, 2007

- It flows in the infrared (IR) to

$$\mathcal{L} \equiv -\kappa_U \mathcal{O}_{SM} \mathcal{O}_U$$

where $1 < d_U < 2$ is the scaling dimension of the unparticle operator \mathcal{O}_U and κ_U has mass dimension $4 - d_{SM} - d_U$ and propagator

$$P_U(p^2) = \frac{A_{d_U}}{2 \sin(\pi d_U)} \frac{i}{(-p^2 - i\epsilon)^{2-d_U}}$$

$$A_{d_U} \equiv \frac{16\pi^{5/2}}{(2\pi)^{2d_U}} \frac{\Gamma(d_U + 1/2)}{\Gamma(d_U - 1)\Gamma(2d_U)} .$$

Deconstructing unparticles

- One can use a “deconstructed” version of unparticles ^a
- One considers an infinite tower of scalars φ_n , ($n = 1, \dots, \infty$), with masses squared $M_n^2 = \Delta^2 n$
- $\Delta \rightarrow 0$ in the conformal limit
- The deconstructed form of the operator \mathcal{O}_U is

$$\mathcal{O} \equiv \sum_n F_n \varphi_n, \quad F_n^2 = \frac{A_{d_U}}{2\pi} \Delta^2 (M_n^2)^{d_U-2}$$

- $\langle \mathcal{O}_U \mathcal{O}_U \rangle = \lim_{\Delta \rightarrow 0} \langle \mathcal{O} \mathcal{O} \rangle$

^aM.A. Stephanov, arXiv:0705.3049

- In particular one can use the Higgs portal and take $\mathcal{O}_{SM} = |H|^2$ ^a with $d_{SM} = 2$
- A non-zero VEV, $\langle |H|^2 \rangle = v^2/2$, would trigger then conformal breaking

$$\langle \varphi_n \rangle \equiv \Delta u_n \rightarrow \Delta u(M^2)$$

$$u(M^2) = -\frac{\kappa_U v^2 F(M^2)}{2M^2}$$

$$F^2(M^2) = \frac{A_{d_U}}{2\pi} (M^2)^{d_U-2}$$

^aP. Fox, A. Rajaraman and Y. Shirman, arXiv:0705.3092

- In turn it provides in the continuum limit a VEV

$$\langle \mathcal{O}_U \rangle = -\frac{\kappa_U v^2}{2} \int_0^\infty \frac{F^2(M^2)}{M^2} dM^2$$

- We immediately see that $\langle \mathcal{O}_U \rangle$ has an IR divergence ^a
- One can easily get an IR regulator by including the **conformal** coupling

$$\delta V = \zeta |H|^2 \sum_n \varphi_n^2 \rightarrow \zeta |H|^2 \int_0^\infty u(M^2) dM^2$$

- It leads (in the continuum limit) to

$$u(M^2) \equiv -\frac{\kappa_U v^2}{2} \frac{F(M^2)}{M^2 + m_{gap}^2}, \quad m_{gap}^2 = \zeta v^2$$

$$\langle \mathcal{O}_U \rangle = -\frac{\kappa_U v^2}{2} \int_0^\infty \frac{F^2(M^2)}{M^2 + m_{gap}^2} dM^2$$

- In the absence of κ_U the unparticle propagator

$$P_U(p^2) = \frac{A_{d_U}}{2 \sin(\pi d_U)} \frac{i}{(-p^2 + m_{gap}^2 - i\epsilon)^{2-d_U}}$$

- With κ_U Higgs and unparticle would mix

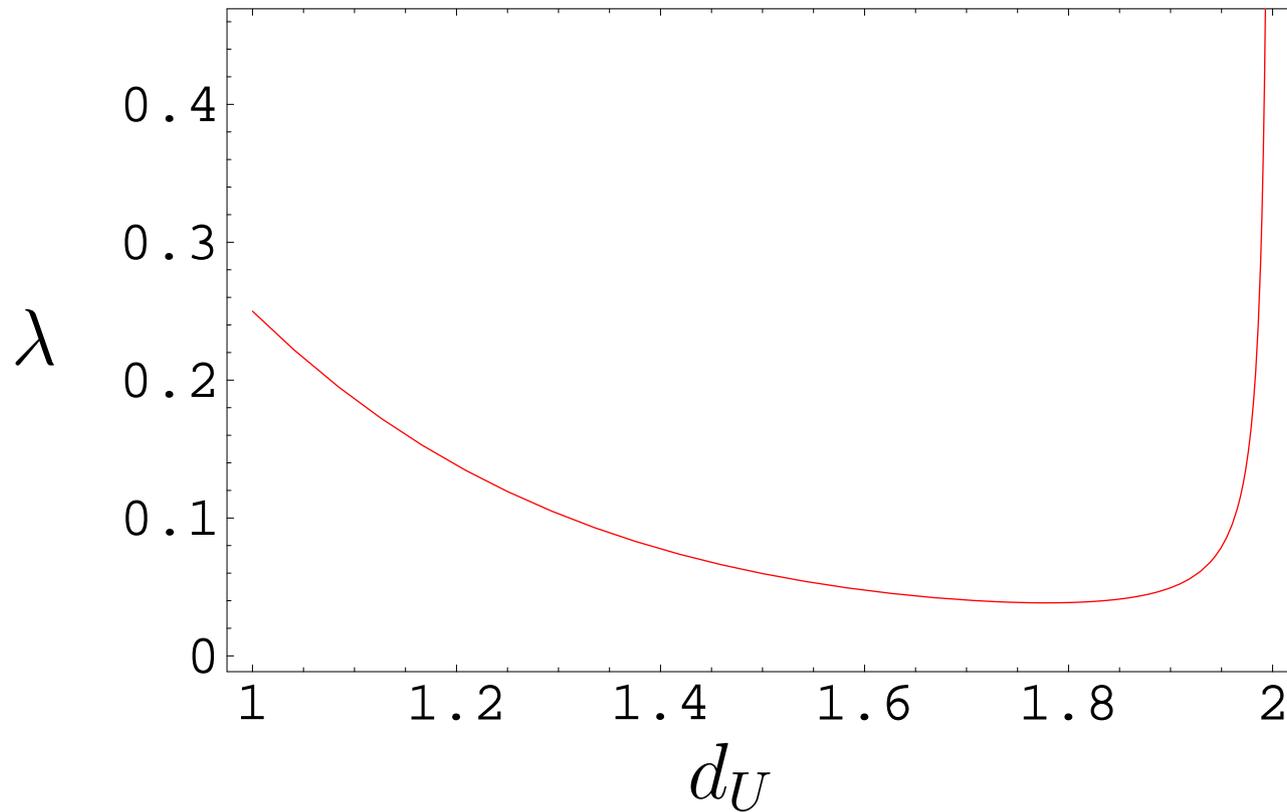
Electroweak breaking

- In the presence of $\langle \mathcal{O}_U \rangle$ the minimization condition for the Higgs VEV changes
- Because $\langle \mathcal{O}_U \rangle < 0$ electroweak breaking can proceed even for $m^2 \geq 0$
- It becomes

$$m^2 + \lambda v^2 - \lambda_U (\mu_U^2)^{2-d_U} v^{2(d_U-1)} = 0$$

$$\lambda_U \equiv \frac{d_U}{4} \zeta^{d_U-2} \Gamma(d_U - 1) \Gamma(2 - d_U)$$

$$(\mu_U^2)^{2-d_U} \equiv \kappa_U^2 \frac{A_{d_U}}{2\pi}$$



Minimization condition for the case $m = 0$, $\zeta = 1$,
 $\kappa_U = v^{2-d_U}$

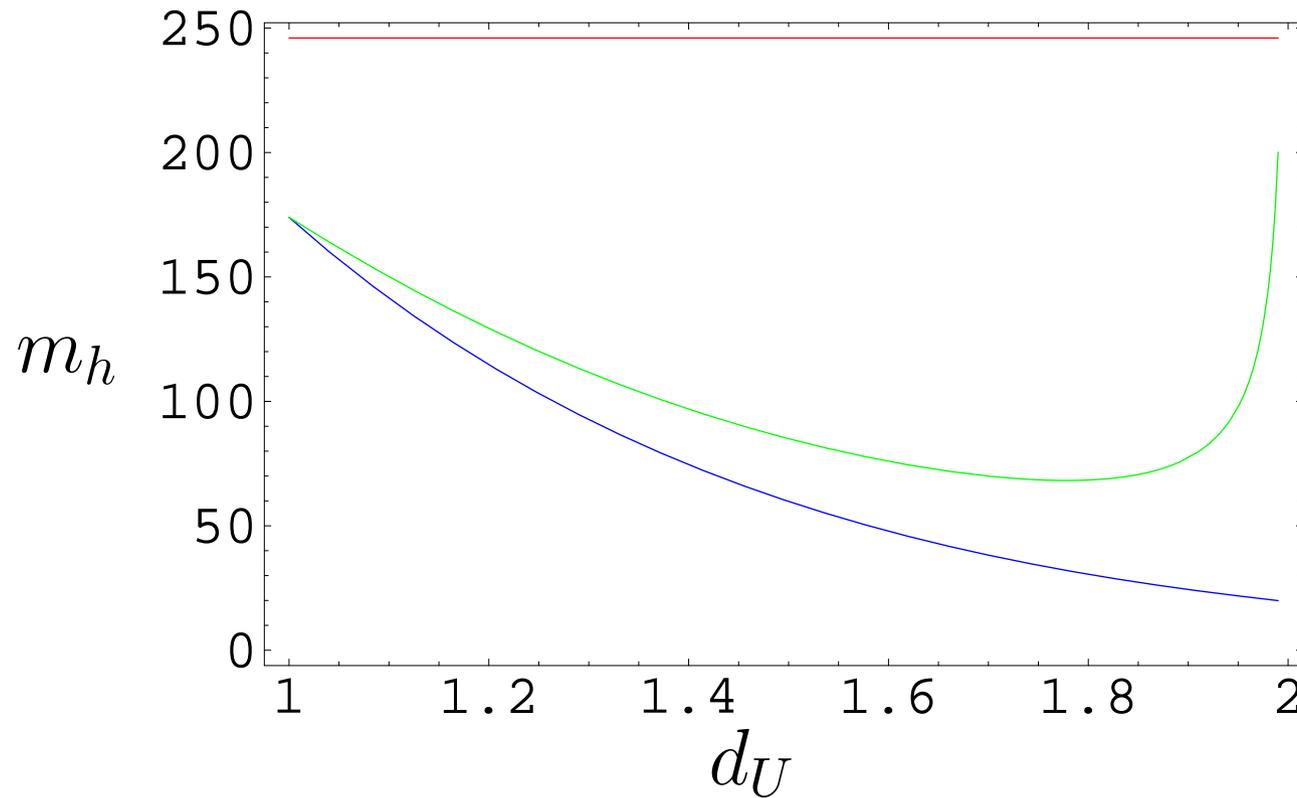
Pole Higgs mass and width

- In the presence of κ_U the neutral component of the Higgs, h^0 , mixes with the φ_n fields in an infinite scalar mass matrix. Taking its continuum limit one obtains the corresponding propagator for the coupled Higgs-unparticle system

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

- $P(m_h^2)^{-1} \equiv 0$

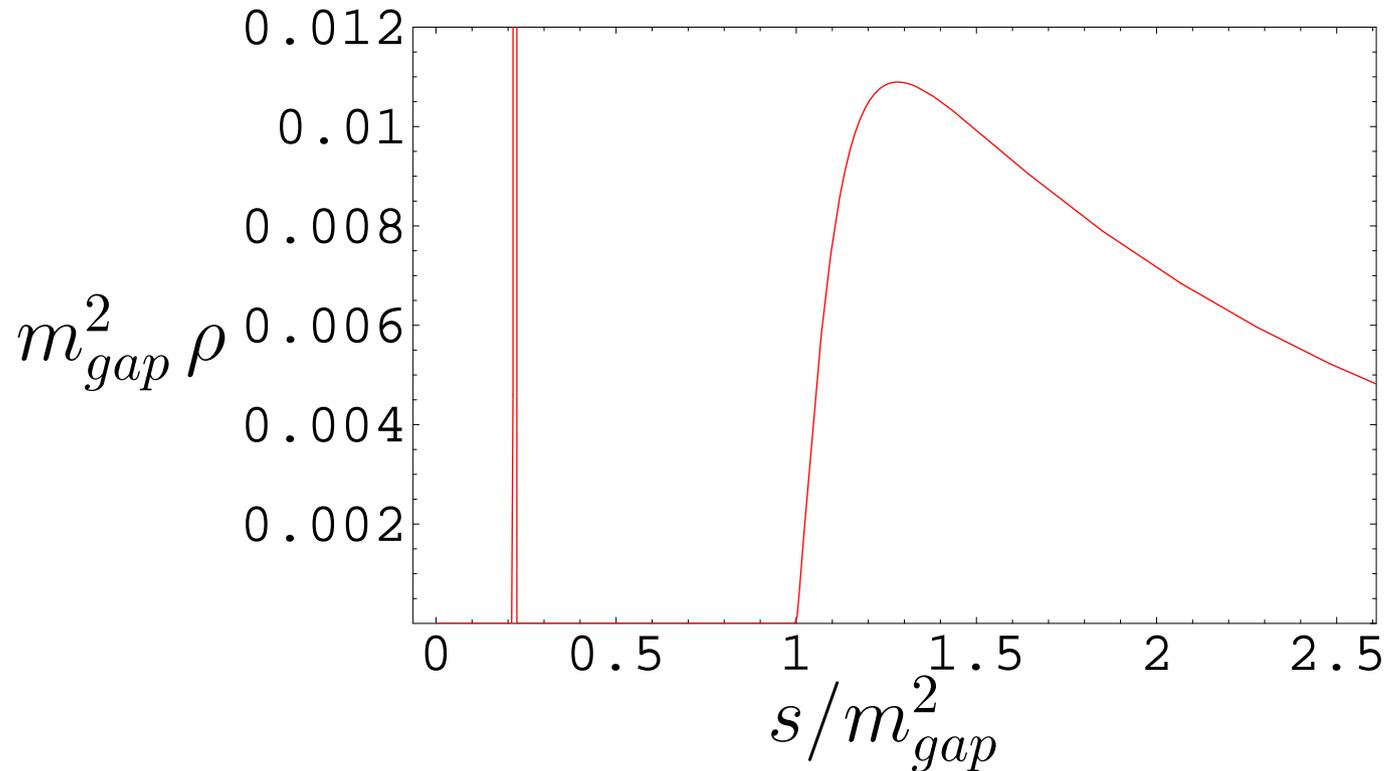
1. Case $m_h^2 < m_{gap}^2$



Pole mass and **unresummed** Higgs mass for $\zeta = 1$.

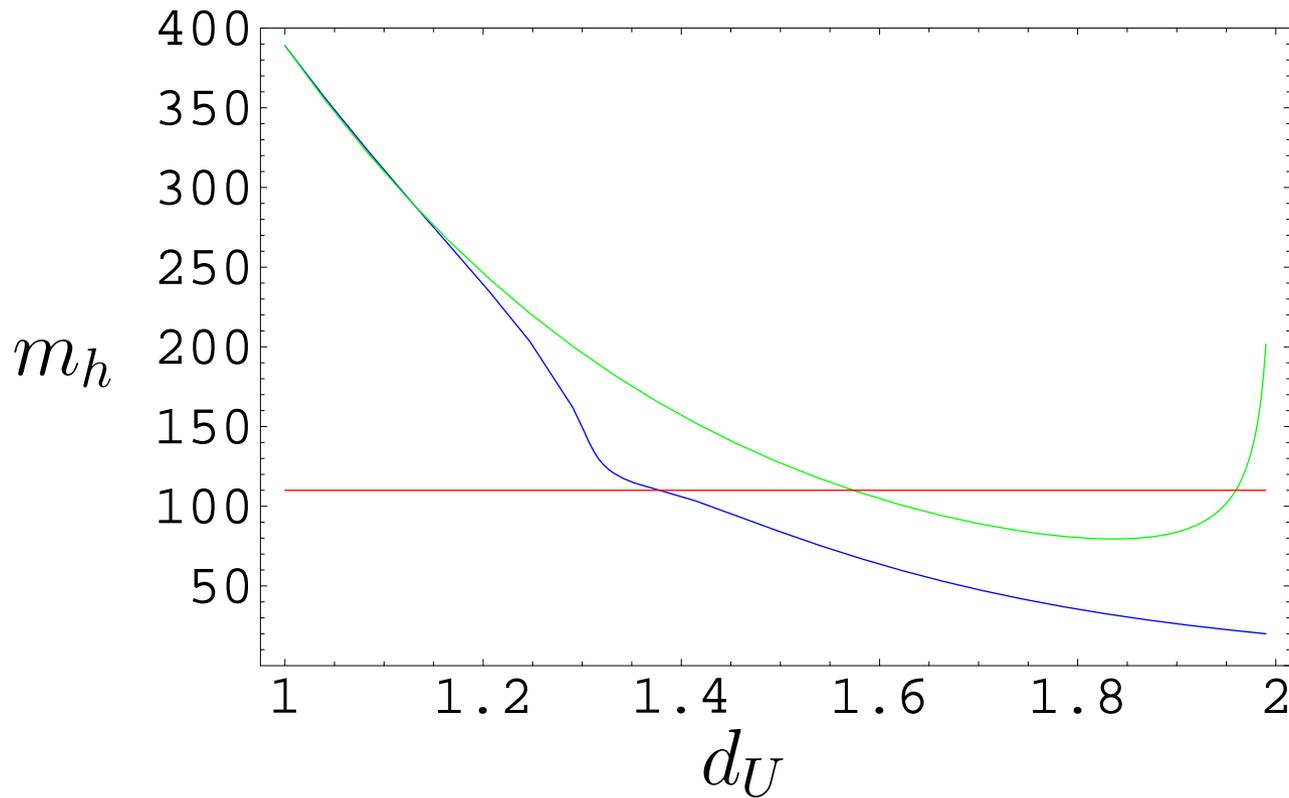
Straight line is m_{gap}

$$m_h^2 < m_{gap}^2$$



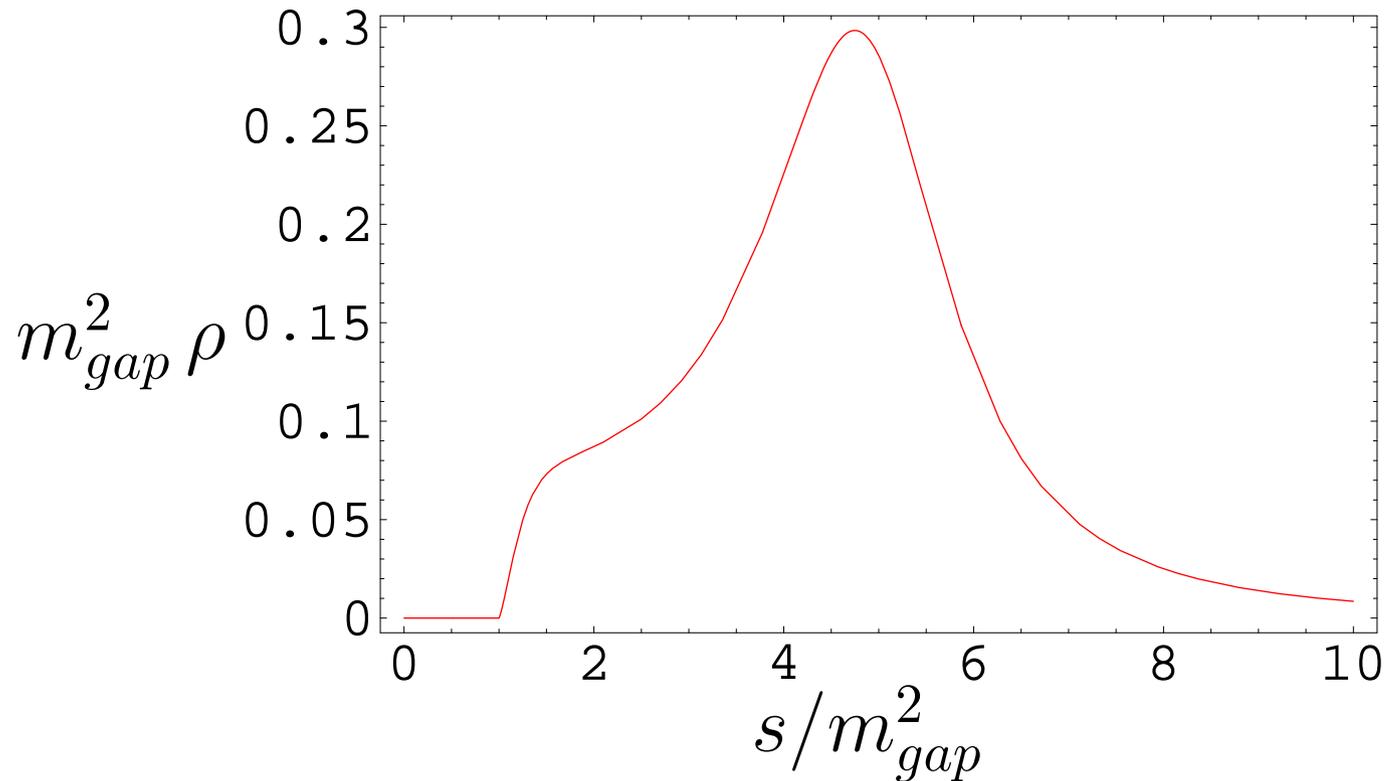
Spectral function for the Higgs (pole) and unparticles (continuous distribution) for $d_U = 1.2$

2. Case $m_h^2 > m_{gap}^2$



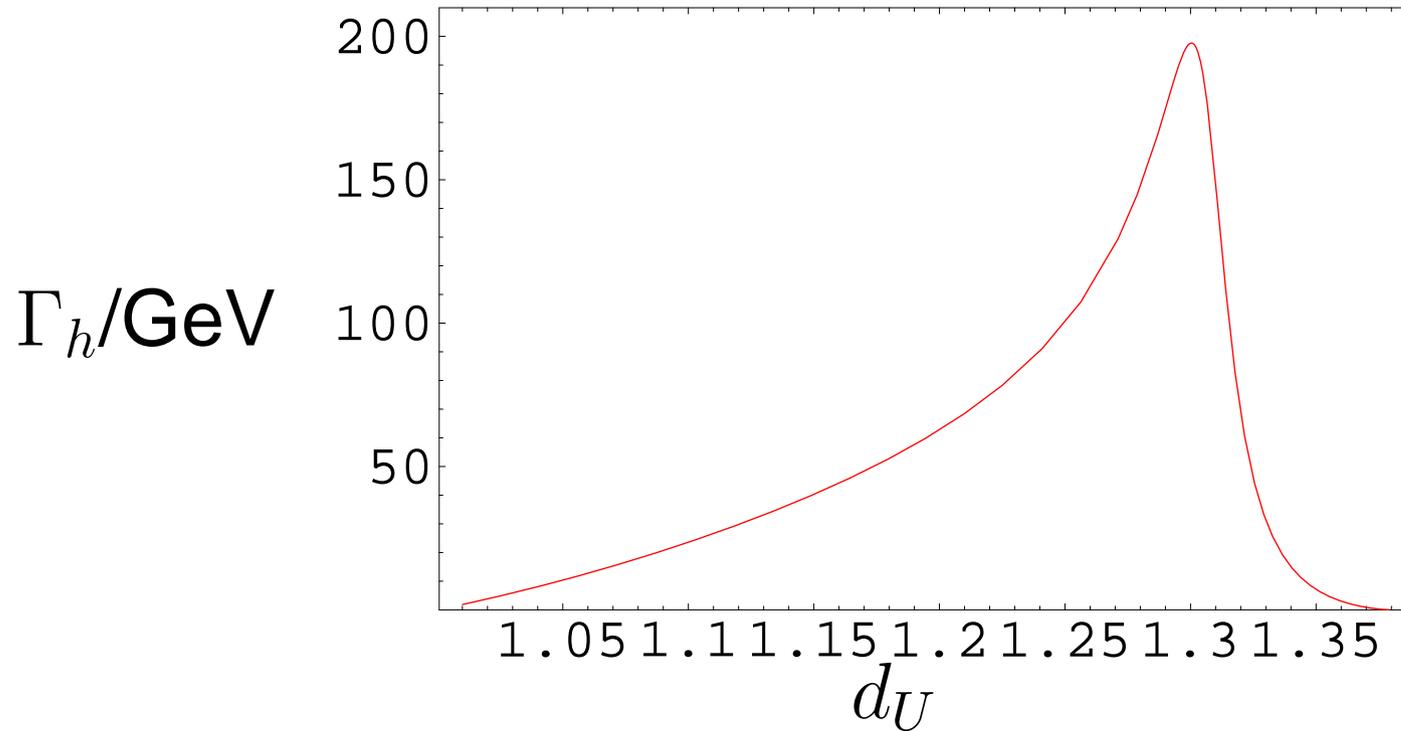
Pole mass and **unresummed** Higgs mass for $\zeta = 0.2$. **Straight line is m_{gap}**

$$m_h^2 > m_{gap}^2$$



Spectral function for the Higgs-unparticle system
(continuous distribution) for $d_U = 1.2$

$$m_h^2 > m_{gap}^2$$



Width of the Higgs boson from unparticle merging
for $\zeta = 0.2$

Conclusion

Plethora of new phenomena that can appear at LHC

- The Higgs has an “intrinsic” width from unparticle mixing (no invisible width): **it can be a broad resonance**
- The Higgs mixes with unparticles and its coupling to the Z boson changes
- The continuum of unparticles can decay into the HH -channel
- Electroweak phase transition modified
- . . .