

Higgs-Unparticle Interplay

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- Motivation: What are the unparticles?
- Higgs-unparticle interaction: curing the IR divergence
- Pole structure & spectral analysis
- Decays?
- (Un)Conclusions

Work done in collaboration with: J.R. Espinosa, J.M. No and M. Quirós:

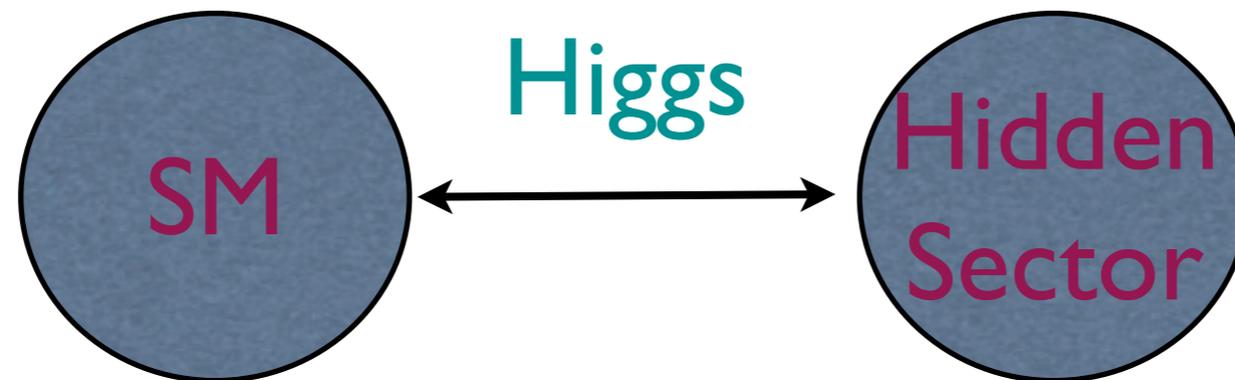
JHEP 0710:094,2007

JHEP 0804:028,2008

arXiv 0804:4574 [hep-ph]

Motivation

- The Higgs boson can act as a **portal** to a hidden-sector of the SM (Schabinger, Wells; Patt, Wilczek)



- Higgs physics is **yet** to be explored therefore there are very few constraints
- The Higgs forms the smallest dimension singlet operator: $|H|^2$

- We can then write the following operator:

$$\kappa |H|^2 \mathcal{O}$$

- Then we have different scenarios depending on the nature of \mathcal{O} :

- Multisinglets

- Hidden-valleys

- Unparticles

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- Unparticles ← what the heck is this?

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- But what is a conformal sector? what implications will it have?
- In general, a **conformal theory**, is one where there is exact scale invariance (apart from more technical aspects...)
- The first consequence is that on a conformal theory **there are no masses!!!**

- Coupling the SM directly to this conformal sector goes as follows:

- First we can imagine the following “normal” coupling between the SM and a hidden sector of dimension d

$$\frac{1}{M^k} O_{SM} O_{hid} \quad O_{hid} \equiv q\bar{q}, \lambda\lambda, \dots \quad k=d_{sm}+d$$

- Then we will suppose that the new sector, through RGE evolution, will reach an **IR conformal fixed point**

$$\frac{\Lambda^{d-d_U}}{M^k} O_{SM} \mathcal{O}_U$$

There is a change on dimensions!!

- Through this flow, the dynamics of the hidden sector are such that the operator acquires a **big anomalous dimension**
- The theory is describe not in terms of particles but in terms of operators **like the one coupling to the SM**
- Because there is conformal symmetry in the theory **some correlation functions are exactly known:**

$$\langle \mathcal{O}_U(x) \mathcal{O}_U(y) \rangle \sim \frac{1}{|x - y|^{2d_U}}$$

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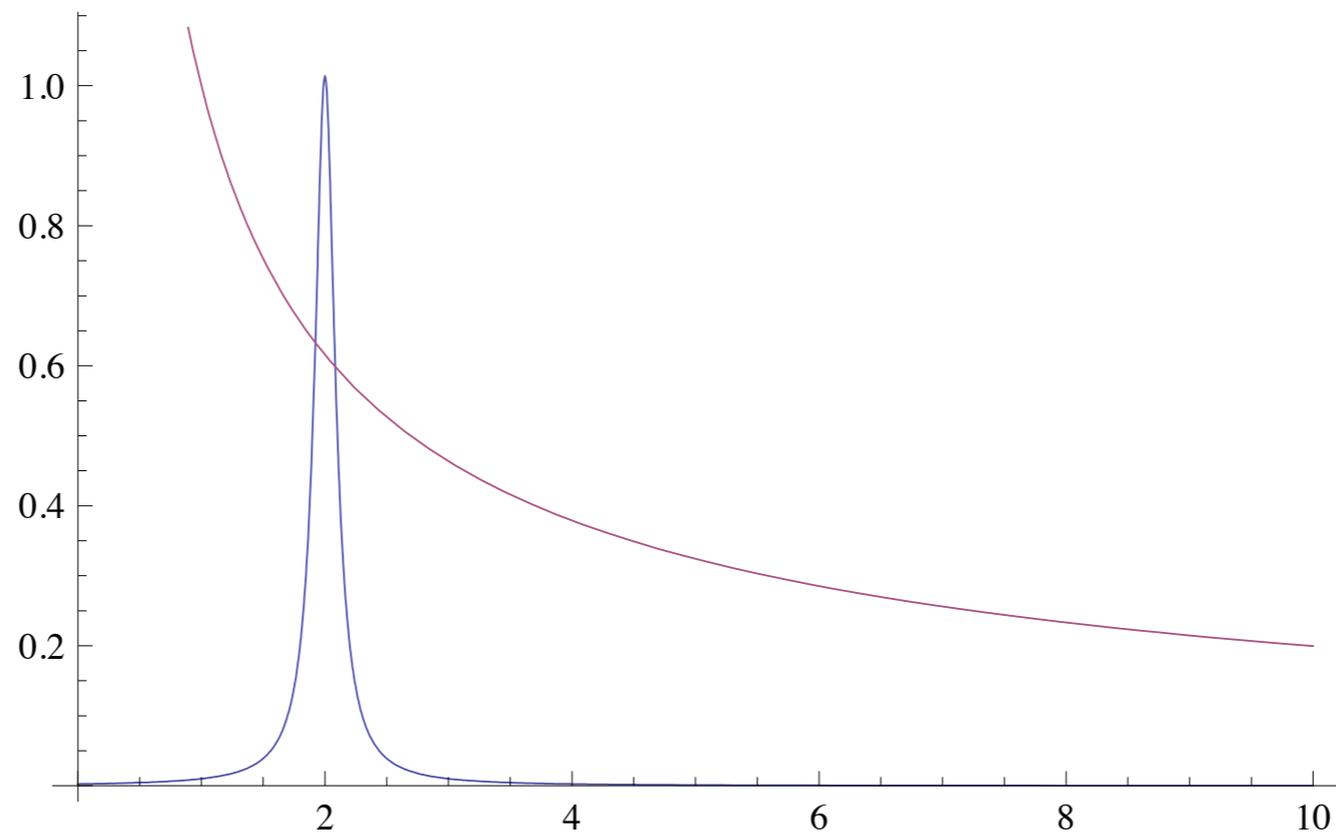
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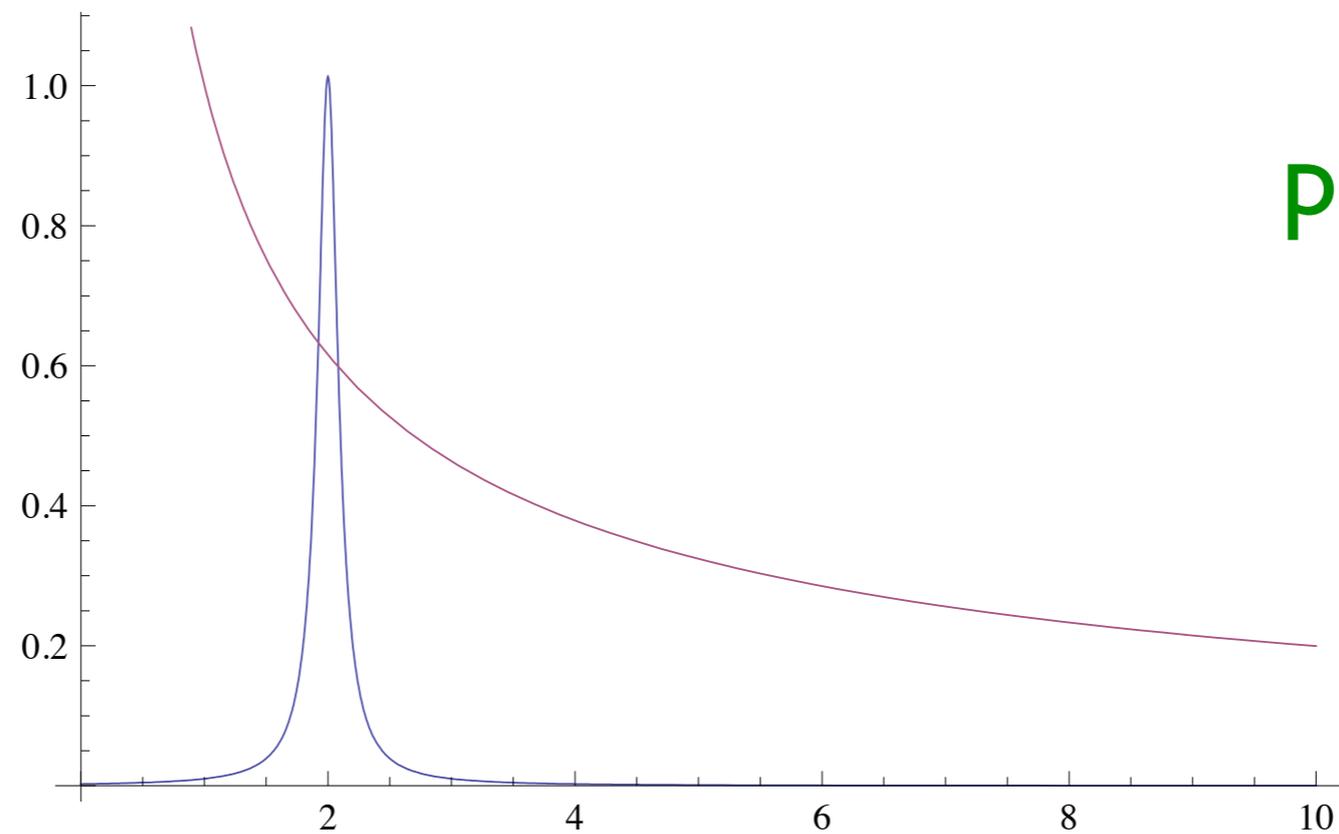
To match 1-particle propagator

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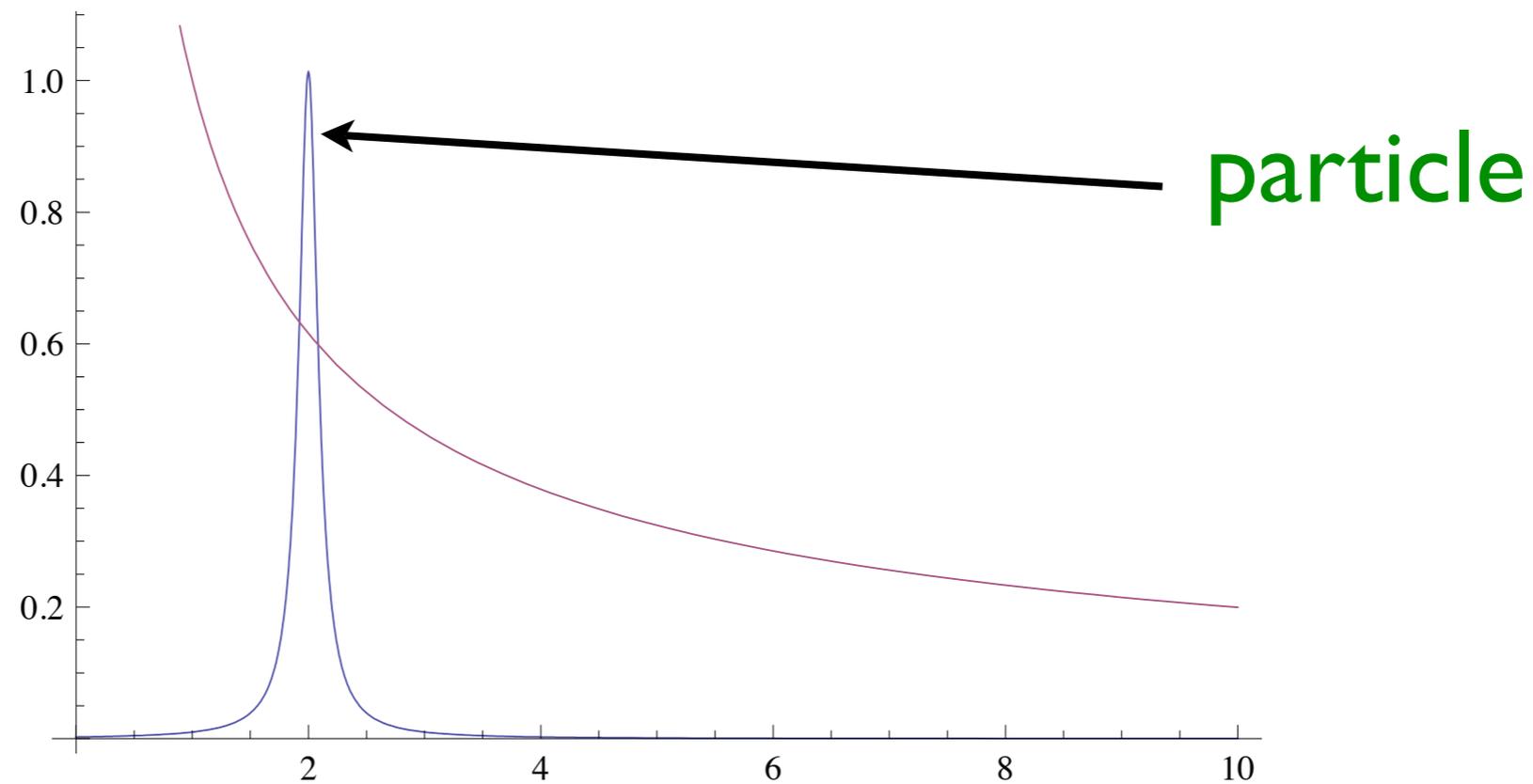


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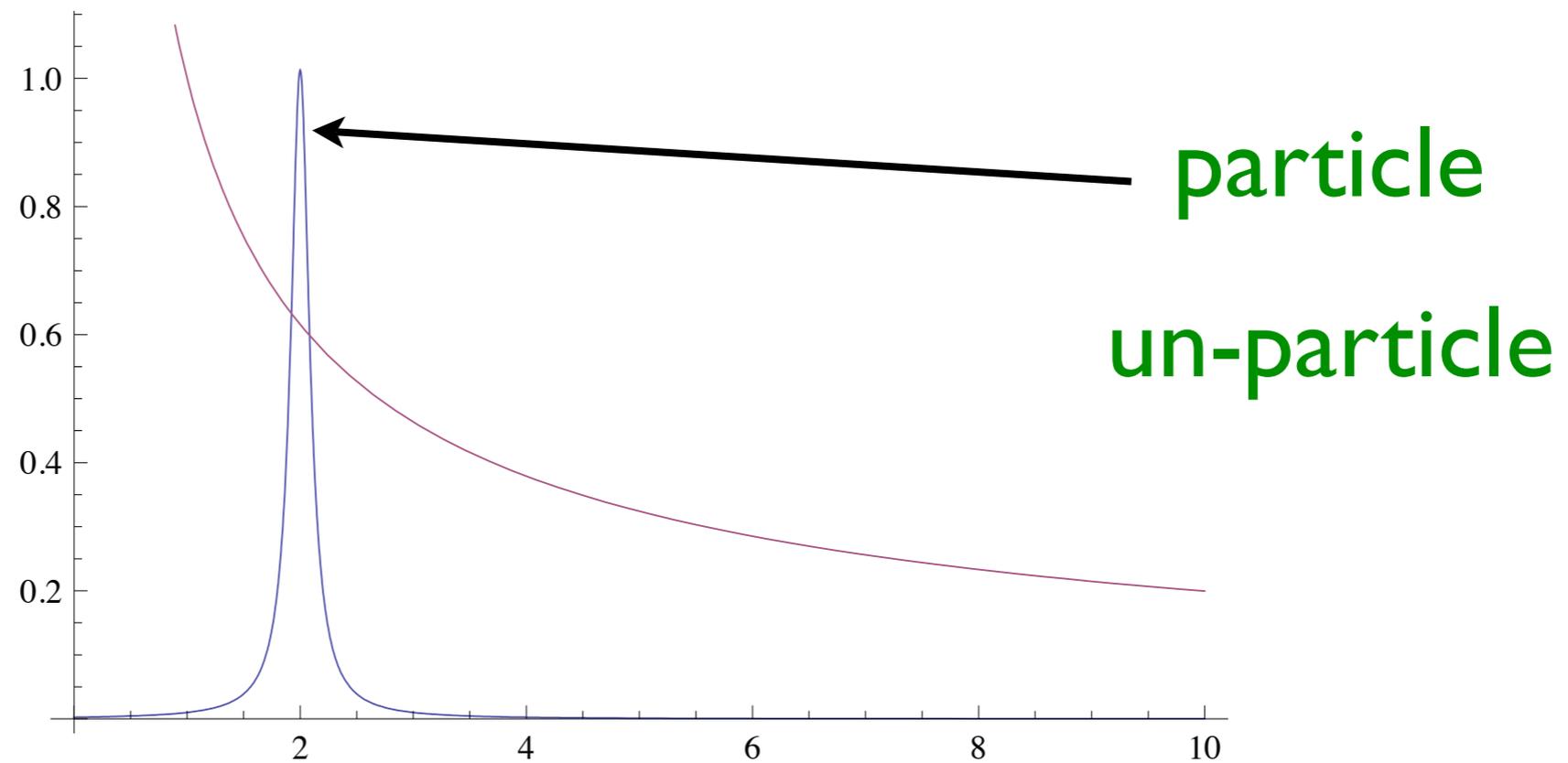


particle

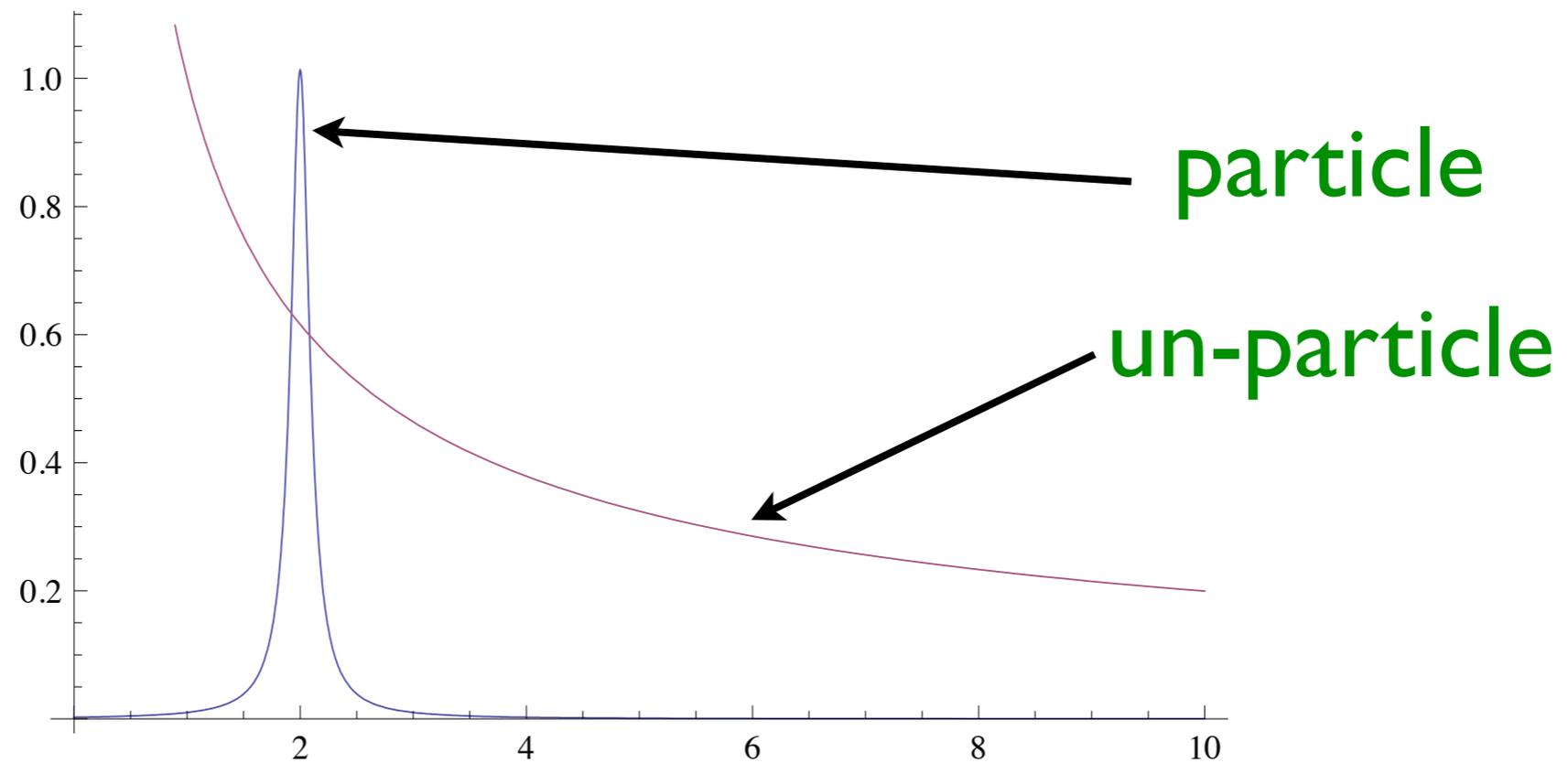
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Higgs-unparticle interaction

- I will focus in the case where \mathcal{O}_U is a scalar unparticle operator with $1 < d < 2$ and with the following scalar potential:

$$V_0 = m^2 |H|^2 + \lambda |H|^4 + \kappa_U |H|^2 \mathcal{O}_U$$

- As shown in the previous slides, the \mathcal{O}_U has the following correlator:

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$$\langle \mathcal{O} \mathcal{O} \rangle \xrightarrow{\Delta \rightarrow 0} \langle \mathcal{O}_U \mathcal{O}_U \rangle$$

- The potential now reads:

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

- Imposing that **EWSB is broken** gives the following **vev's** for the deconstructed fields:

$$v_n \equiv \langle \varphi_n \rangle = -\frac{\kappa_U v^2}{2M_n^2} F_n$$

- And in the continuous limit gives an **IR divergence**:

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

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

- One way of solving this **IR** problem is to include the following new term in the potential:

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

- Which in turn generates the following **finite** vev for the unparticle operator (note the mass gap)

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

- It is interesting to point out that **EWWSB** exists even when the origin is a minimum $m^2 > 0$

$$\lambda = -\frac{m^2}{v^2} + \frac{d_U}{8\pi} A_{d_U} \zeta^{d_U-2} \Gamma(d_U-1) \Gamma(2-d_U) \kappa_U^2 v^{2d_U-4}$$

Pole structure & Spectral analysis

- Once the true vacuum is found the spectrum is obtained diagonalizing the infinite matrix that mixes h and φ_n :

$$M_{hh}^2 = 2\lambda v^2 \equiv m_{h0}^2$$

$$M_{hn}^2 = \kappa_U v F_n \frac{M_n^2}{M_n^2 + m_g^2} \quad m_g^2 \equiv \zeta v^2$$

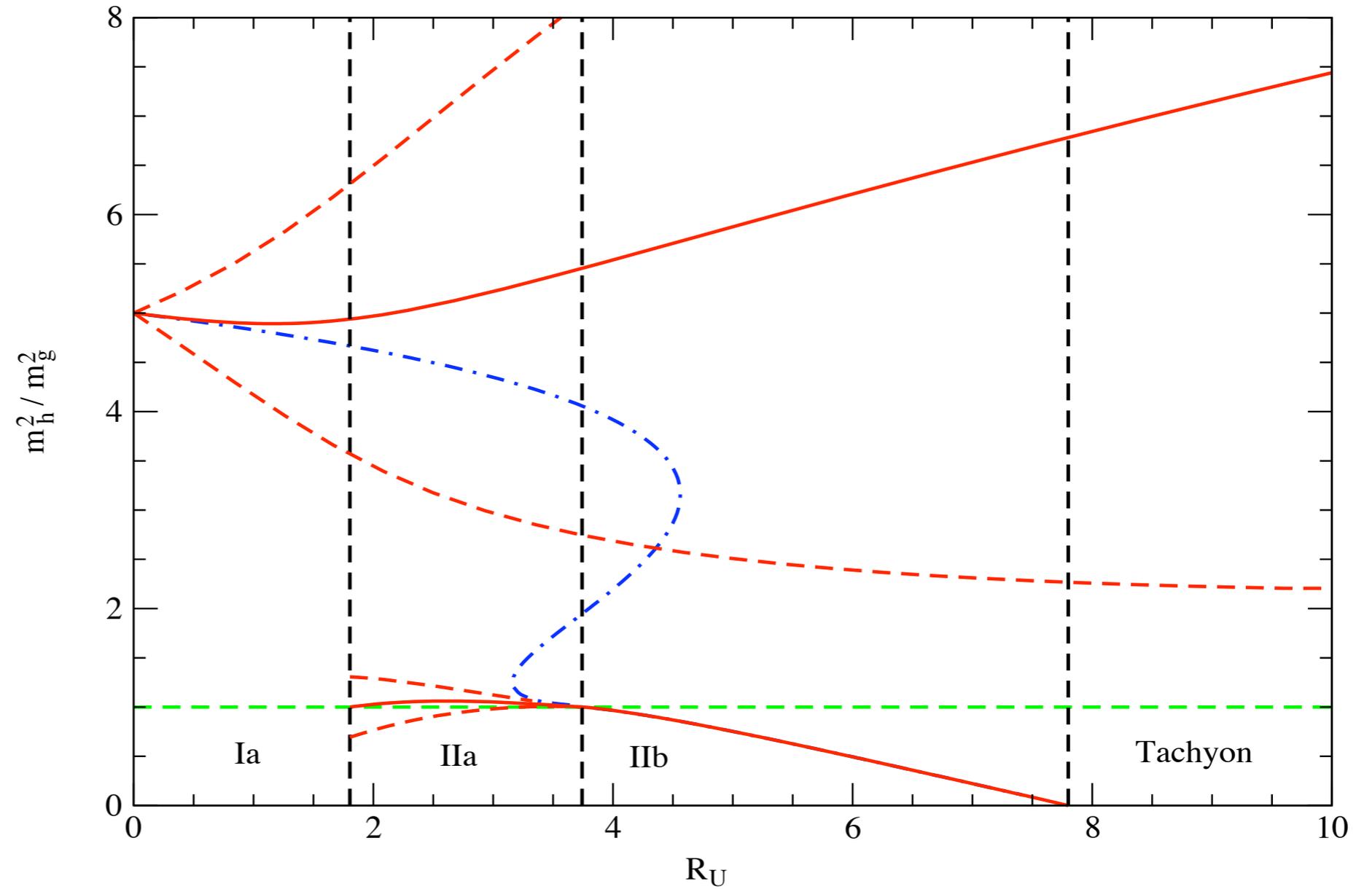
$$M_{nm}^2 = (M_n^2 + m_g^2) \delta_{nm}$$

- The inverse of the **hh** entry corresponds to the propagator of the higgs in the interaction basis:

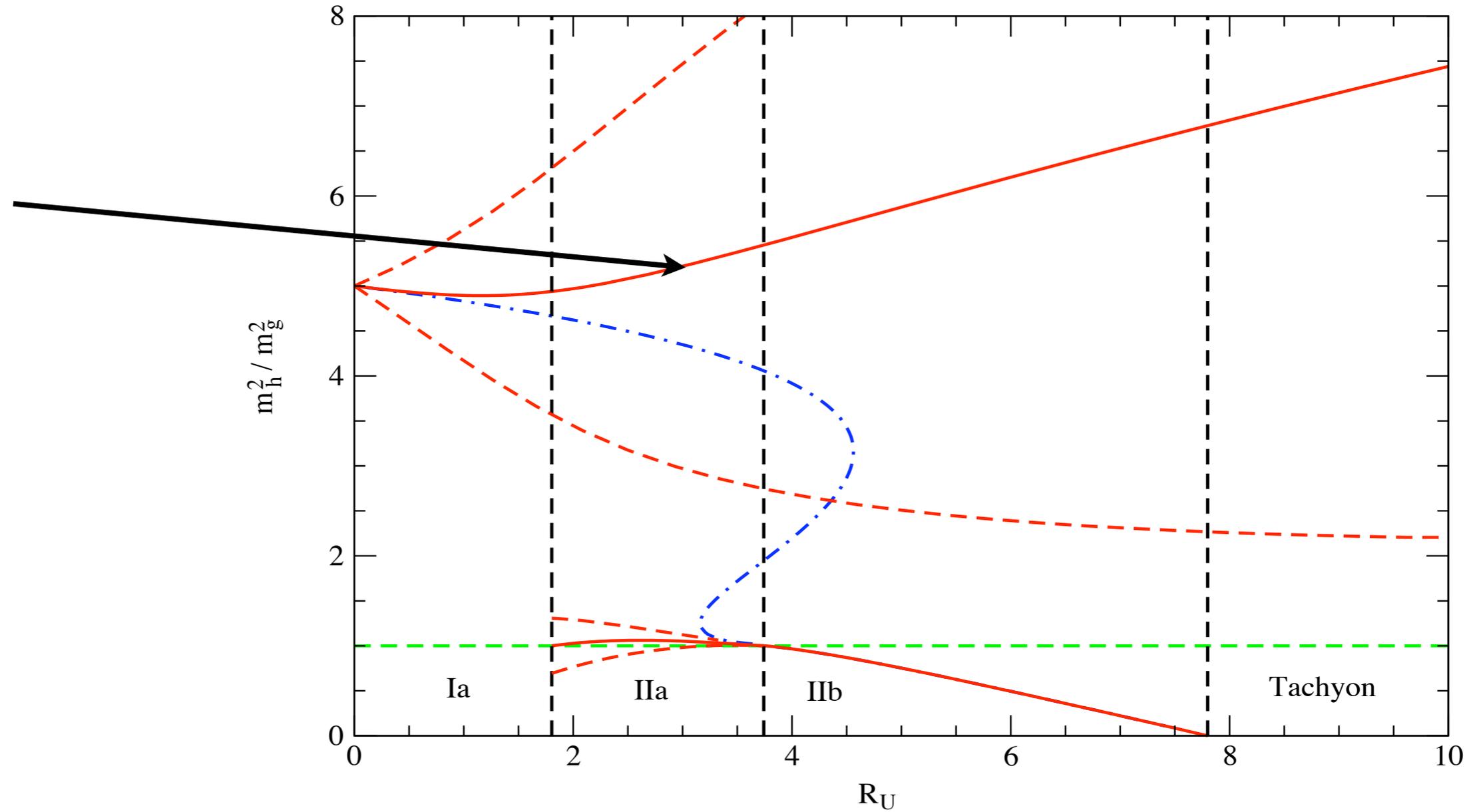
$$iP_{hh}(p^2)^{-1} = p^2 - m_{h0}^2 + \frac{v^2 \kappa_U^2 A_{d_U}}{2\pi p^4} \Gamma(d_U - 1) \Gamma(2 - d_U) \\ \times \left[(m_g^2 - p^2)^{d_U} + d_U p^2 (m_g^2)^{d_U - 1} - (m_g^2)^{d_U} \right]$$

- Let's examine a particular case with $x_0=5$ and the (complex) solutions of the pole equation for $d_u=1.2$
 $m_g=1$

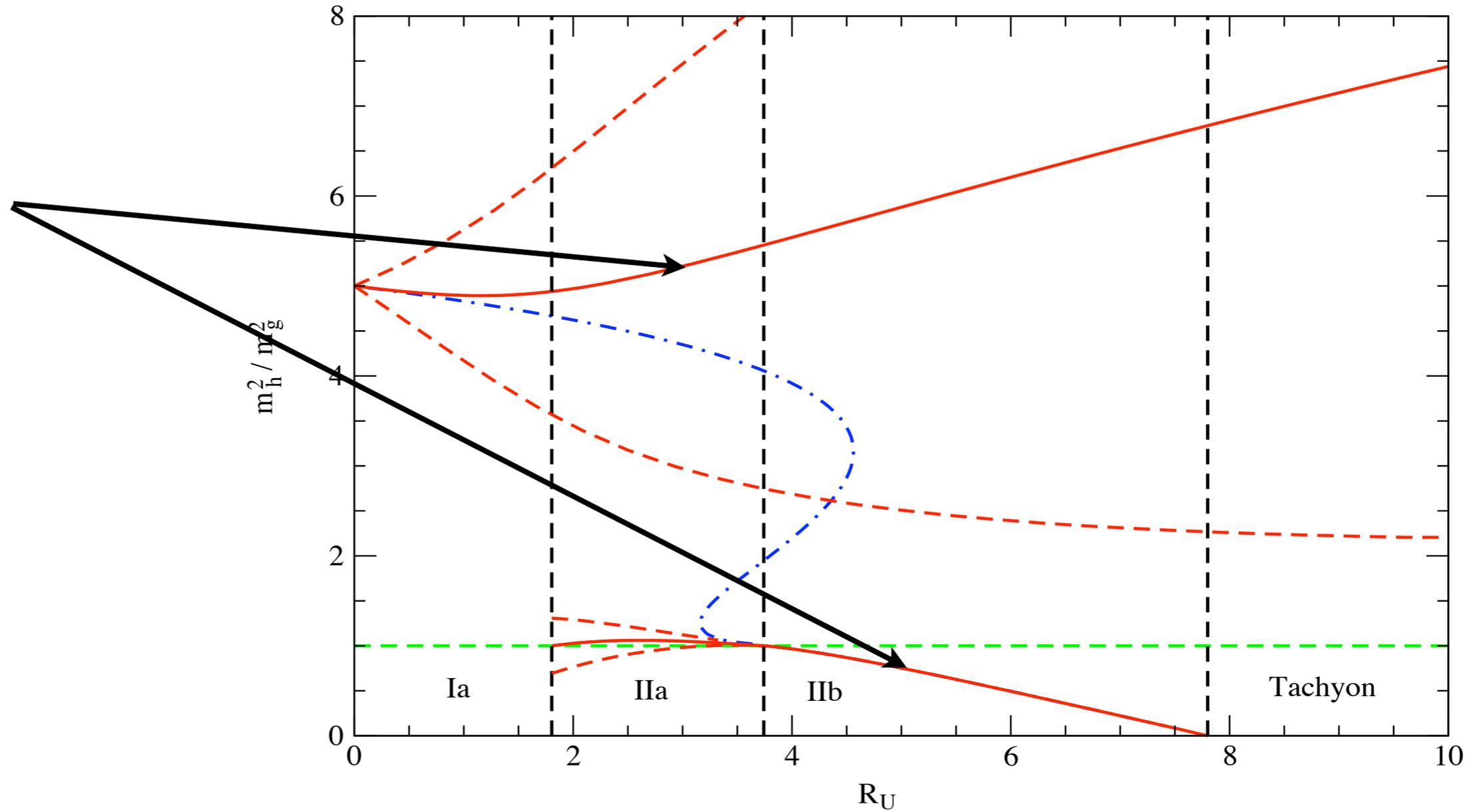
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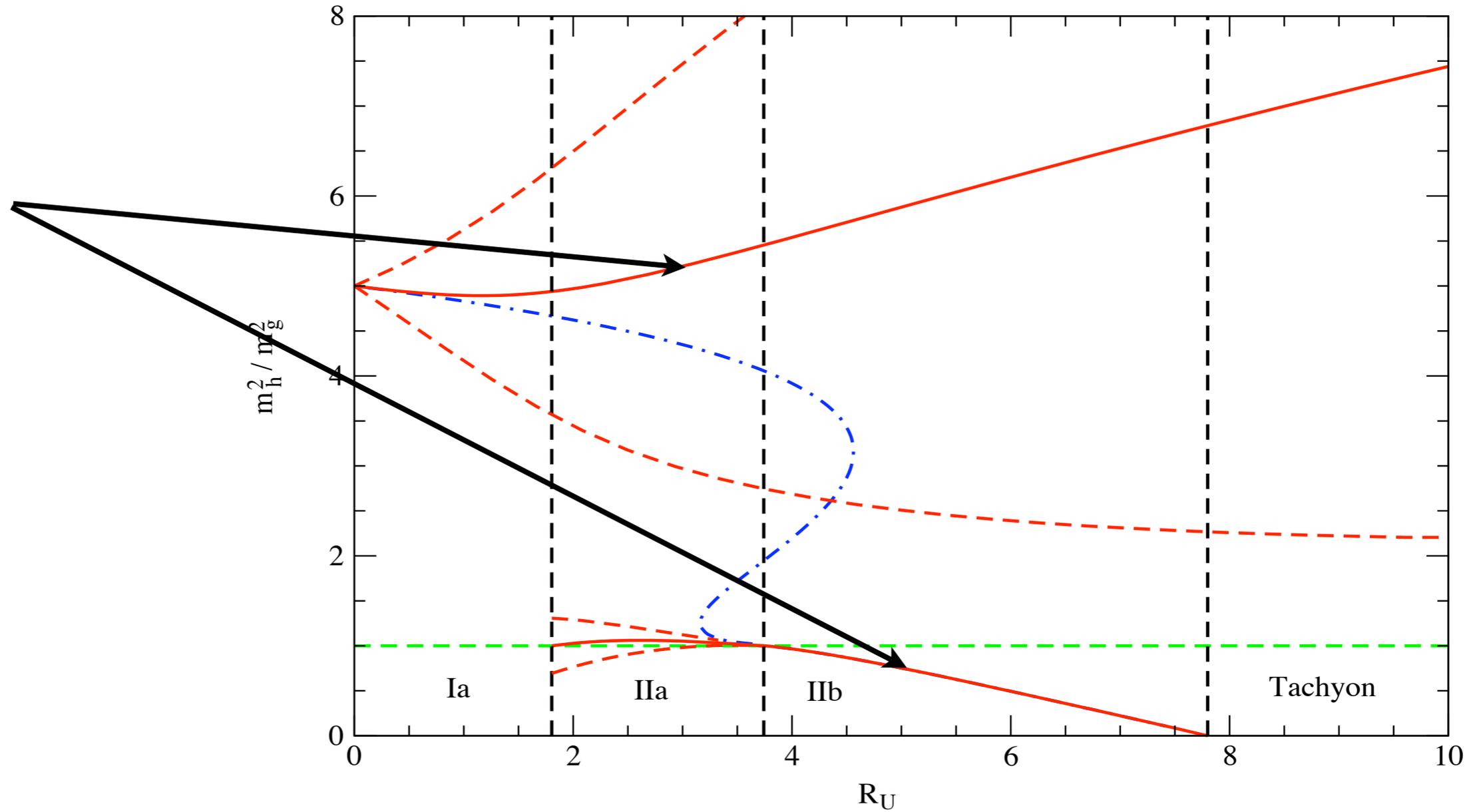


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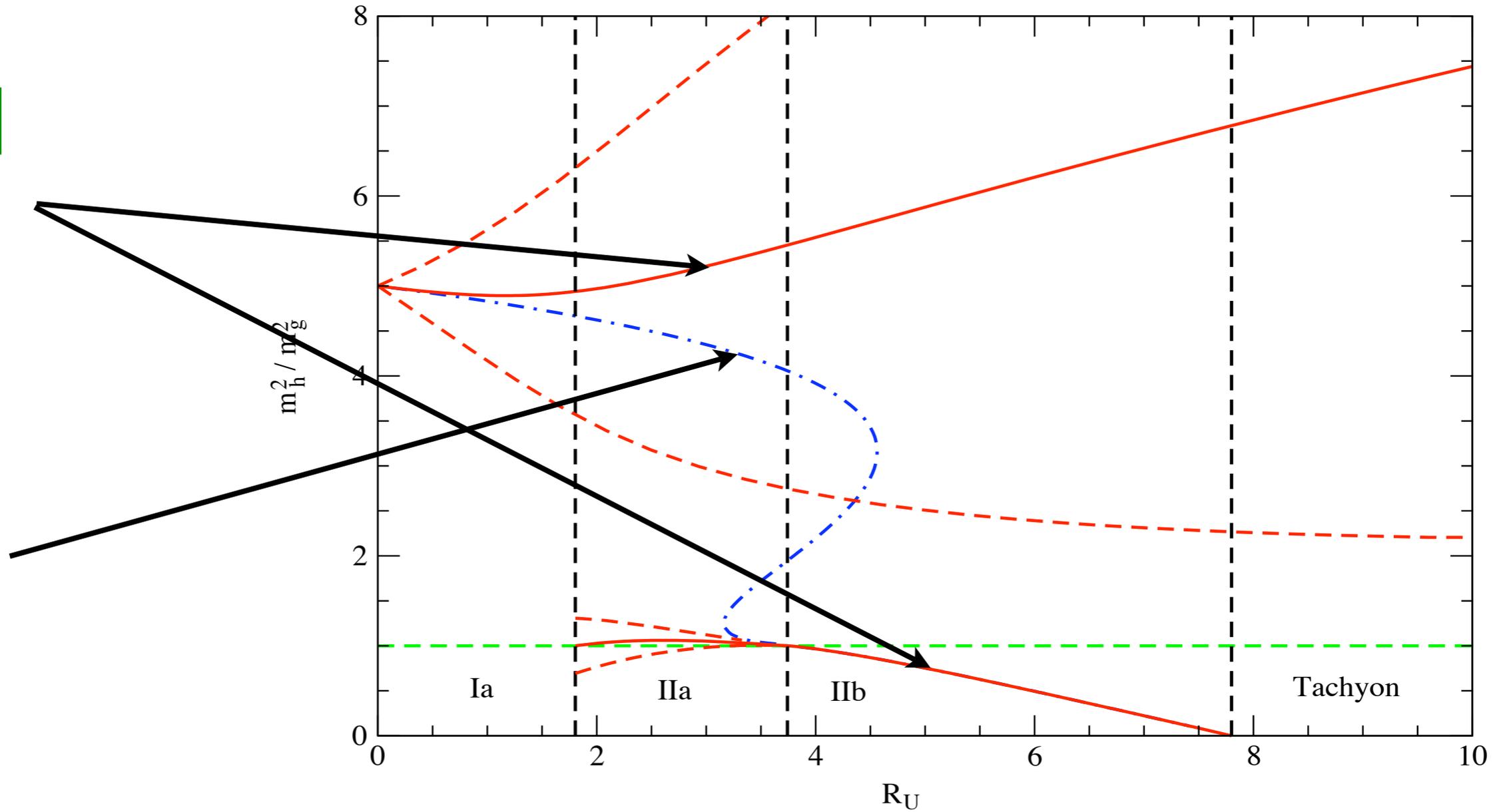
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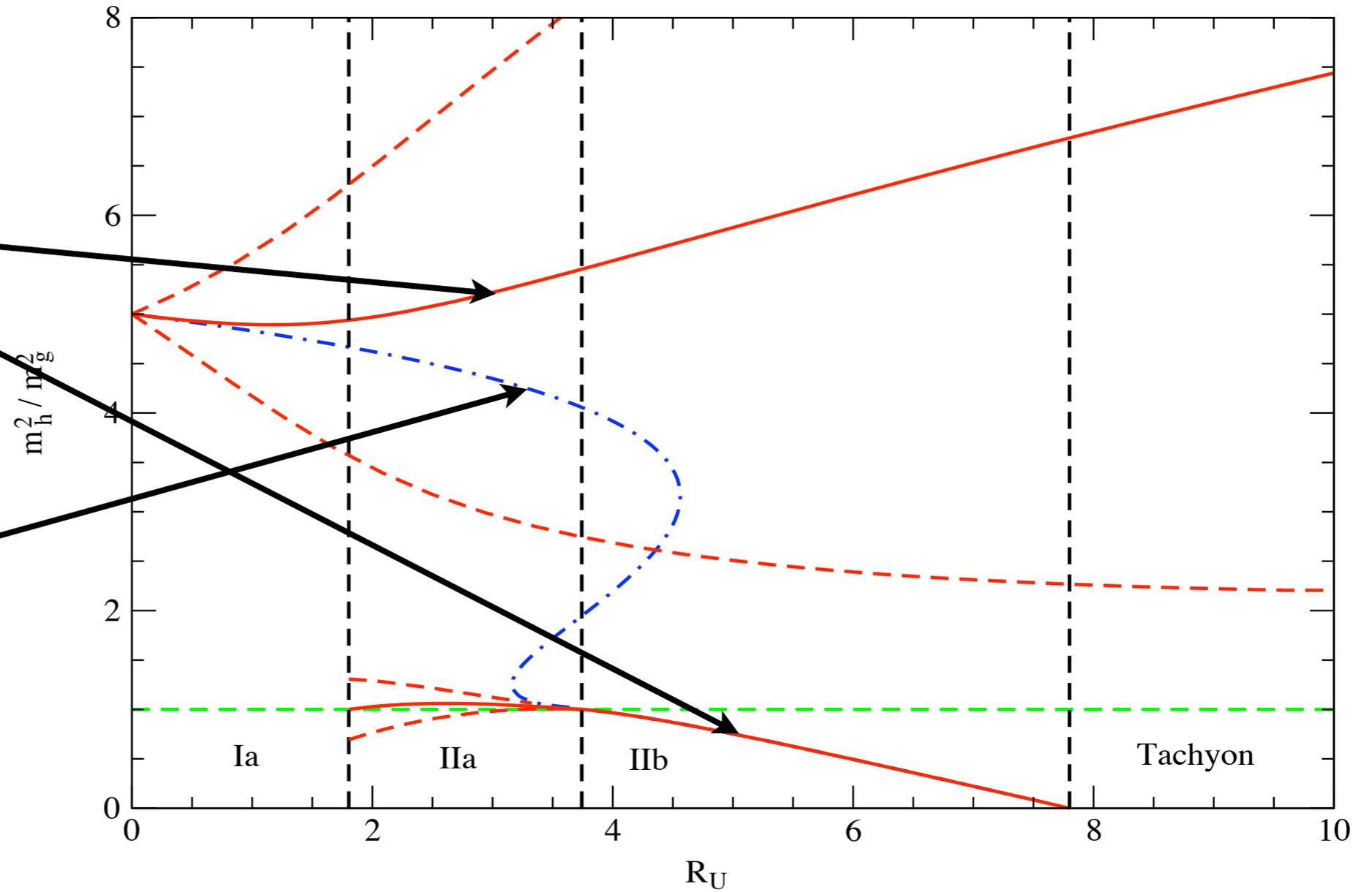
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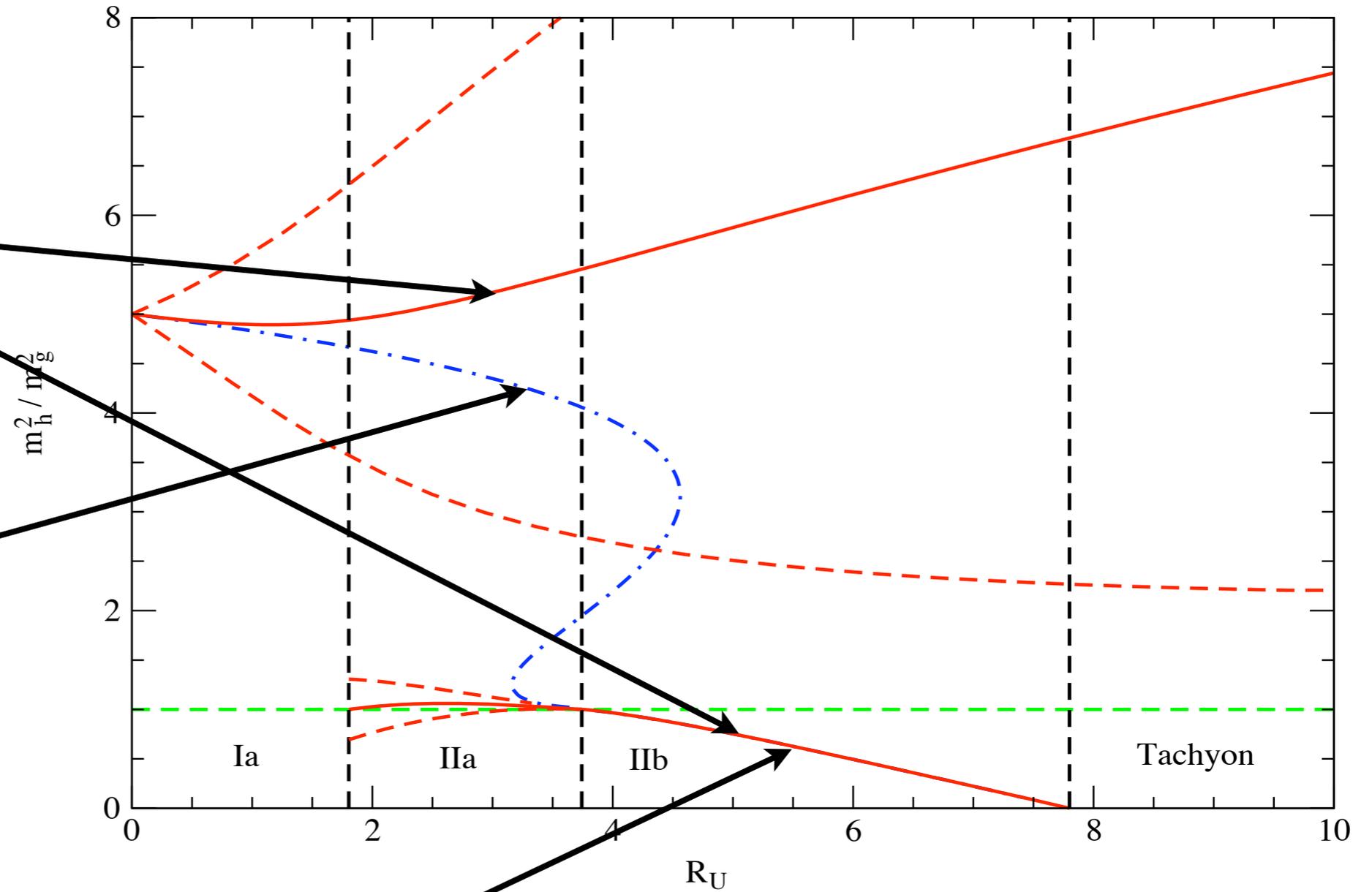
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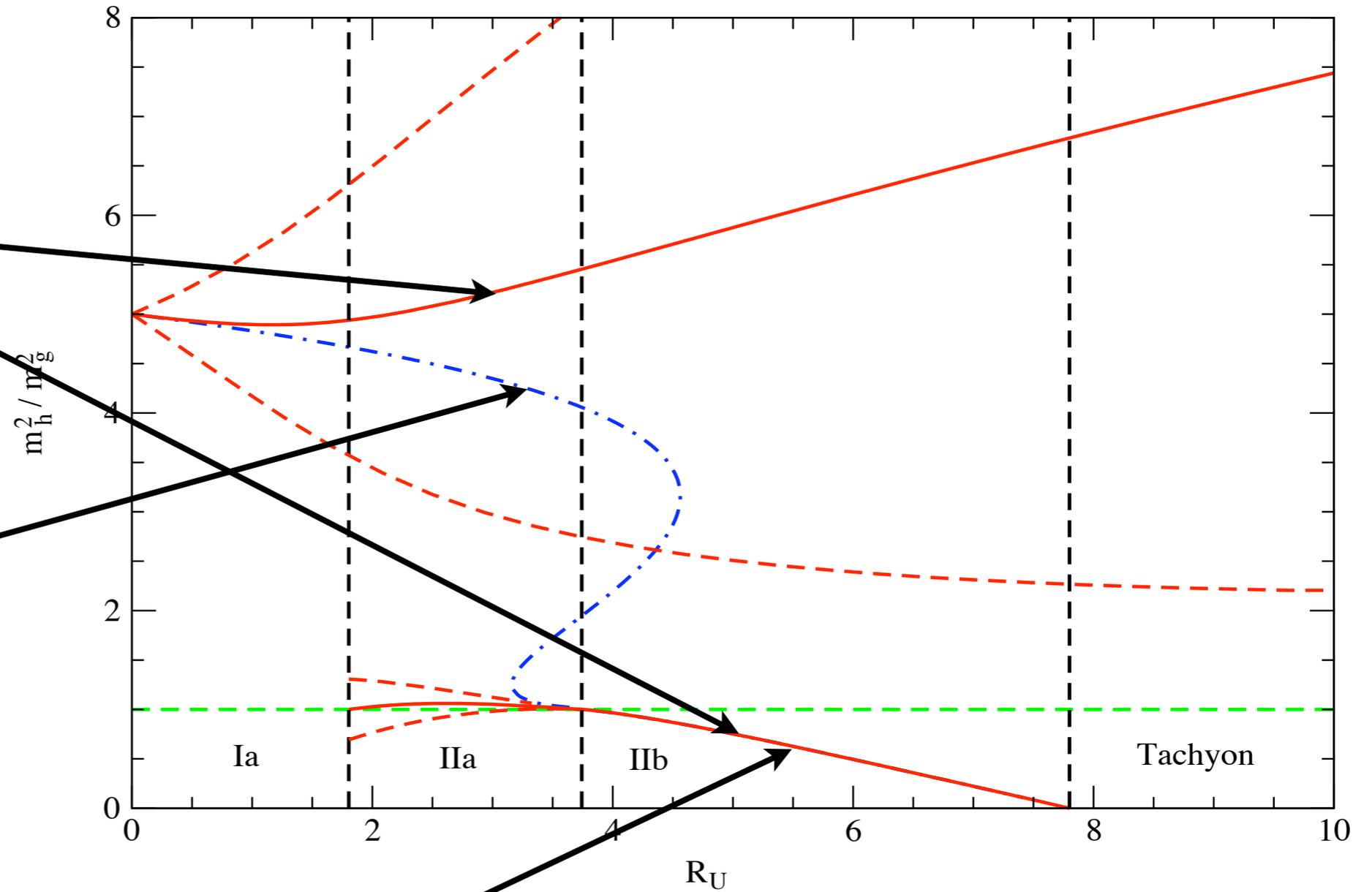
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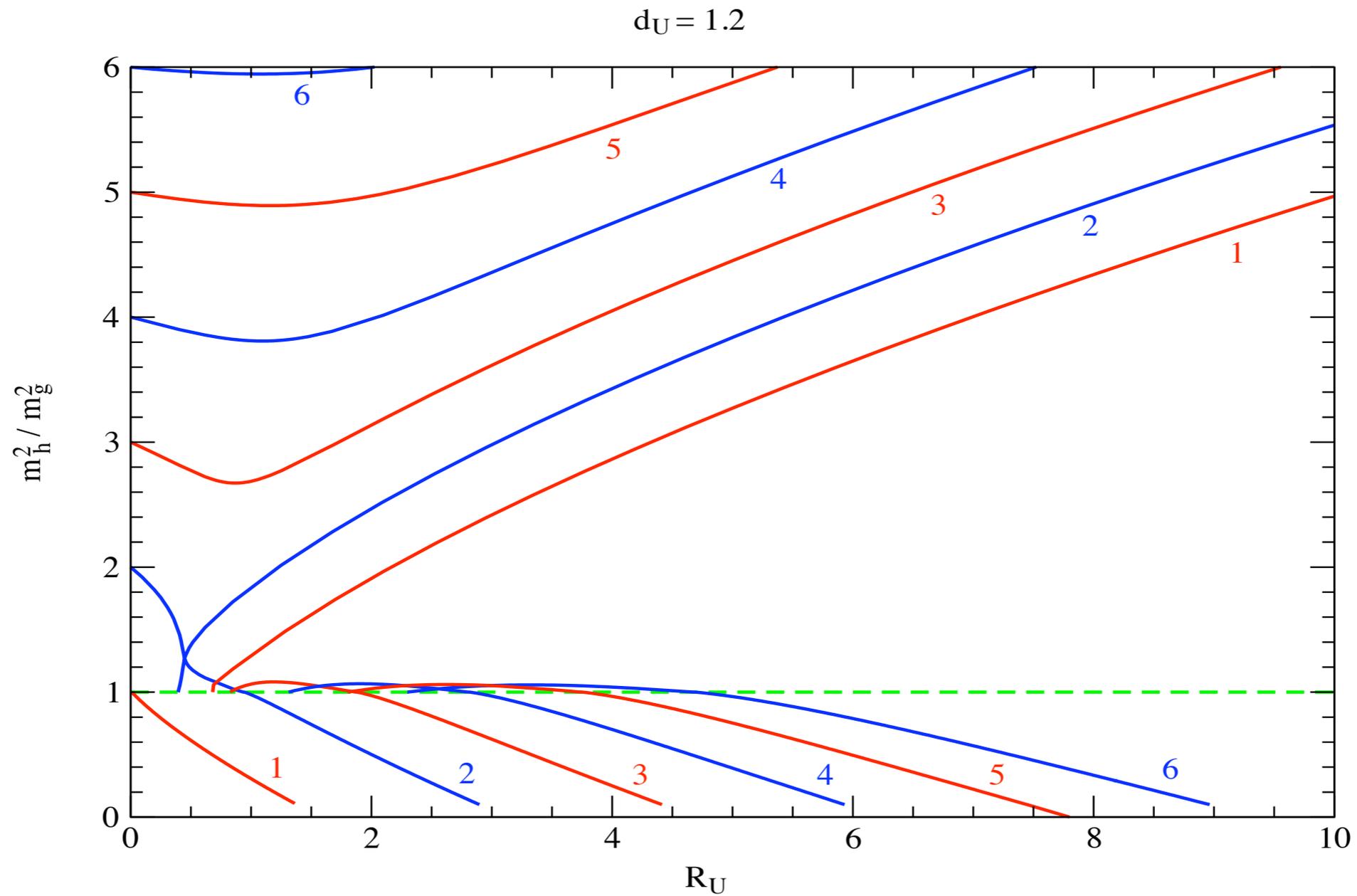
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A resonance is **spit** from the continuum (phantom)



- The effect occurs for every $x_0 > 1$ for $x_0 < 1$ there is always an isolated pole

Spectral analysis

- We can try to capture better the structure of our propagator calculating the **spectral function**

$$\rho_{hh}(s) = -\frac{1}{\pi} \text{Im}[-iP_{hh}(s + i\epsilon)]$$

- There are two pieces of the **imaginary** part of the propagator

- **isolated poles:** $\frac{1}{x + i\epsilon} \rightarrow \text{P.V.} \frac{1}{x} - i\pi\delta(x)$

- $(m_g^2 - p^2)^{d_U} = (p^2 - m_g^2)^{d_U} (\cos(d_U\pi) + i \sin(d_U\pi)) \quad p > m_g$

- There are two forms for the **spectral function** depending on whether there is an isolated pole:

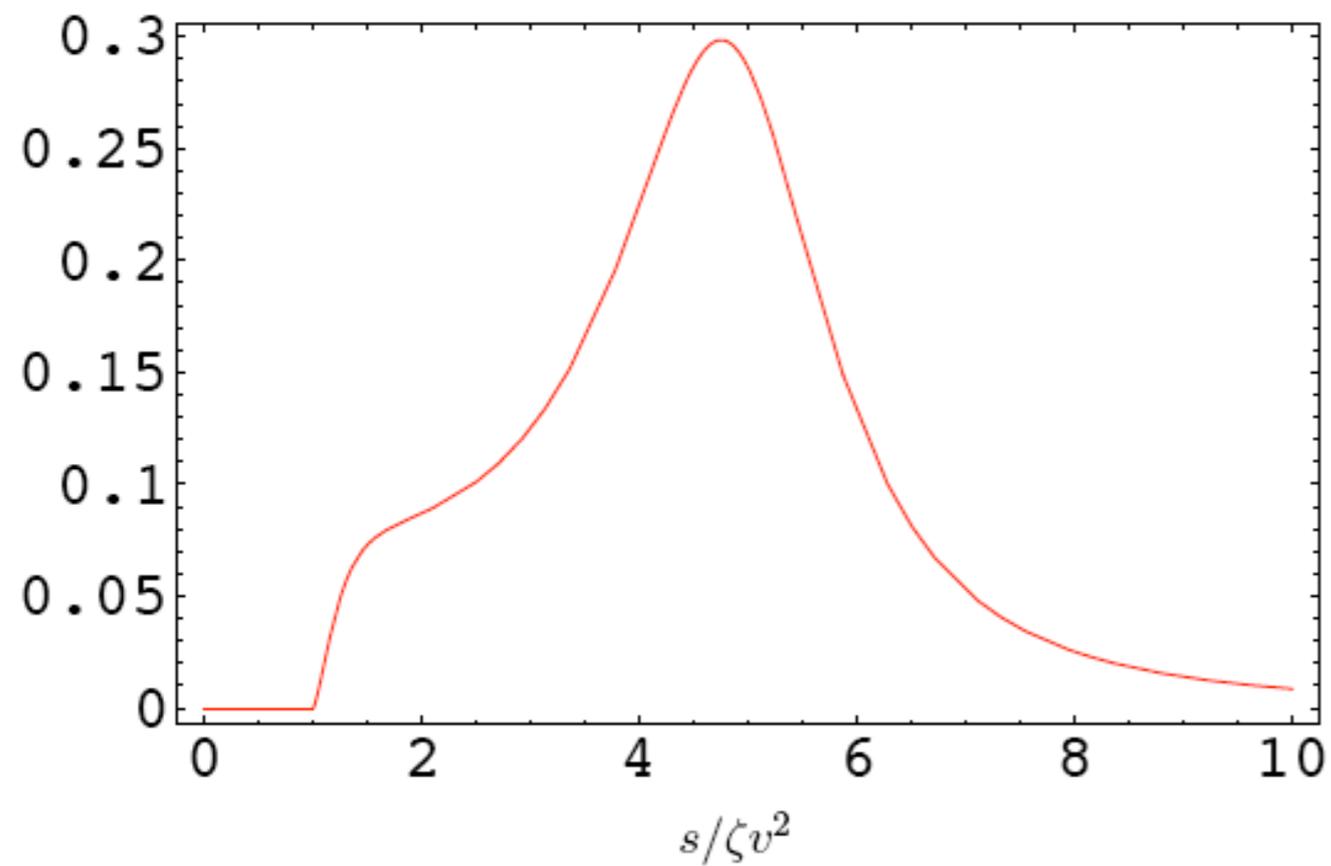
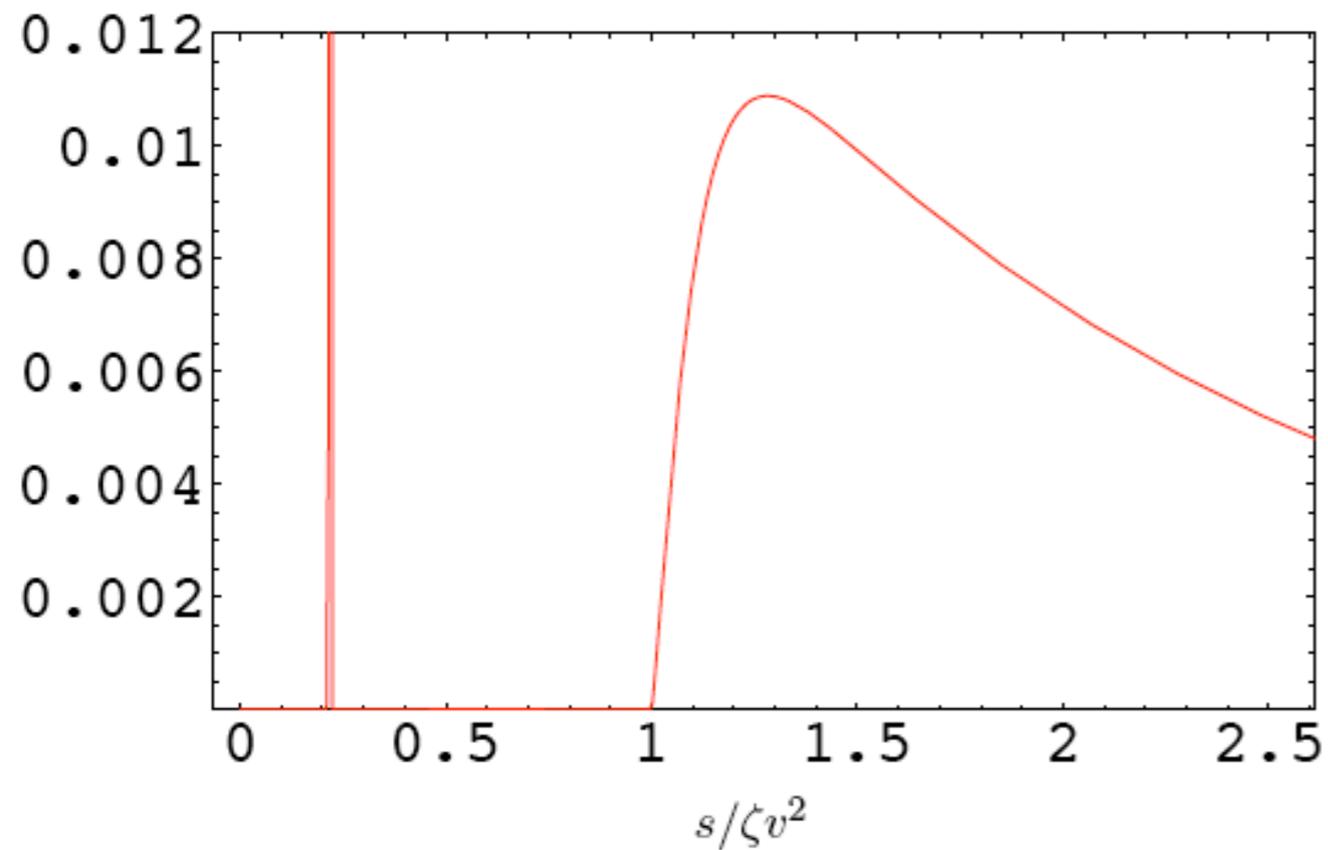
$$\rho_{hh}(s) = \frac{1}{K^2(m_h^2)} \delta(s - m_h^2) + \theta(s - m_g^2) \frac{T_U(s)}{\mathcal{D}^2(s) + \pi^2 T_U^2(s)}$$

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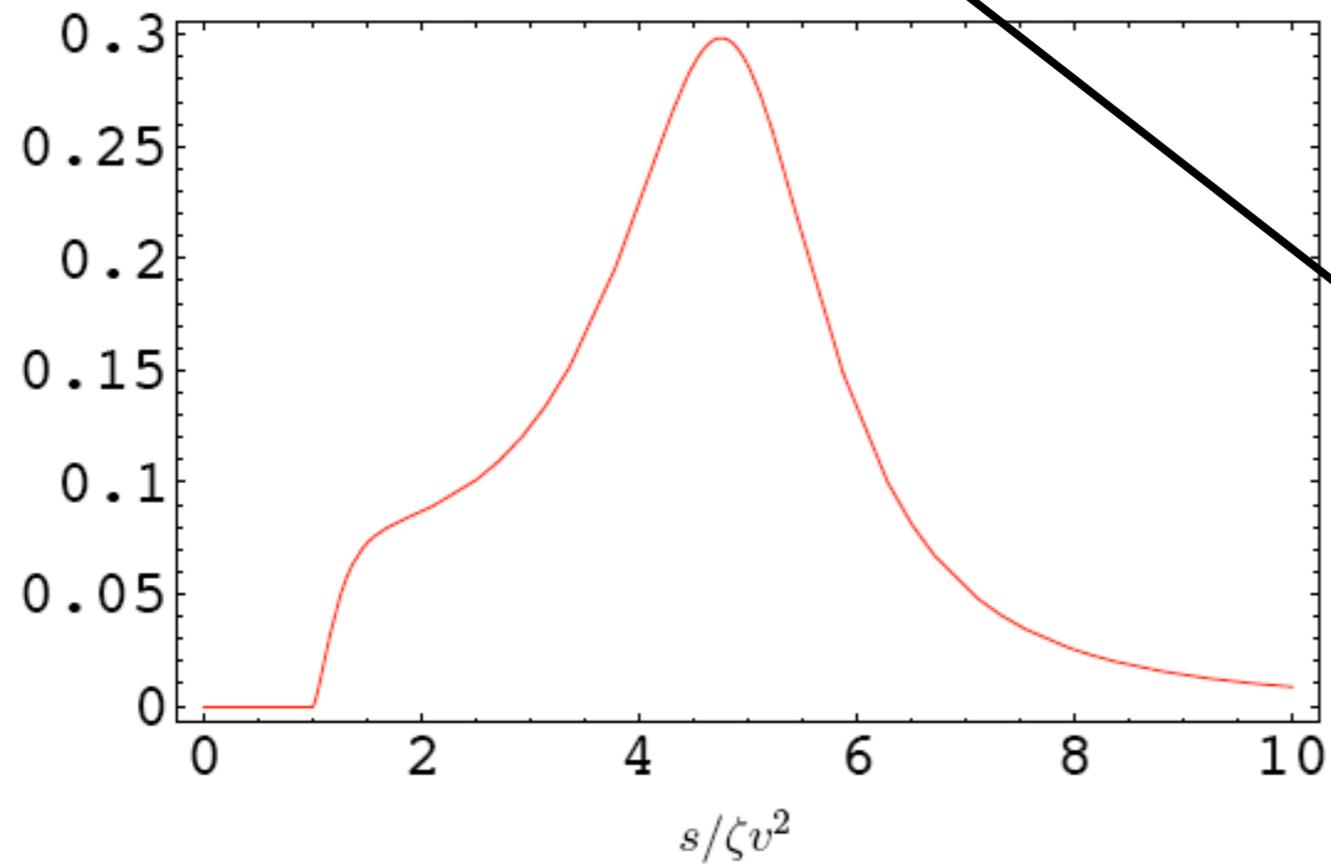
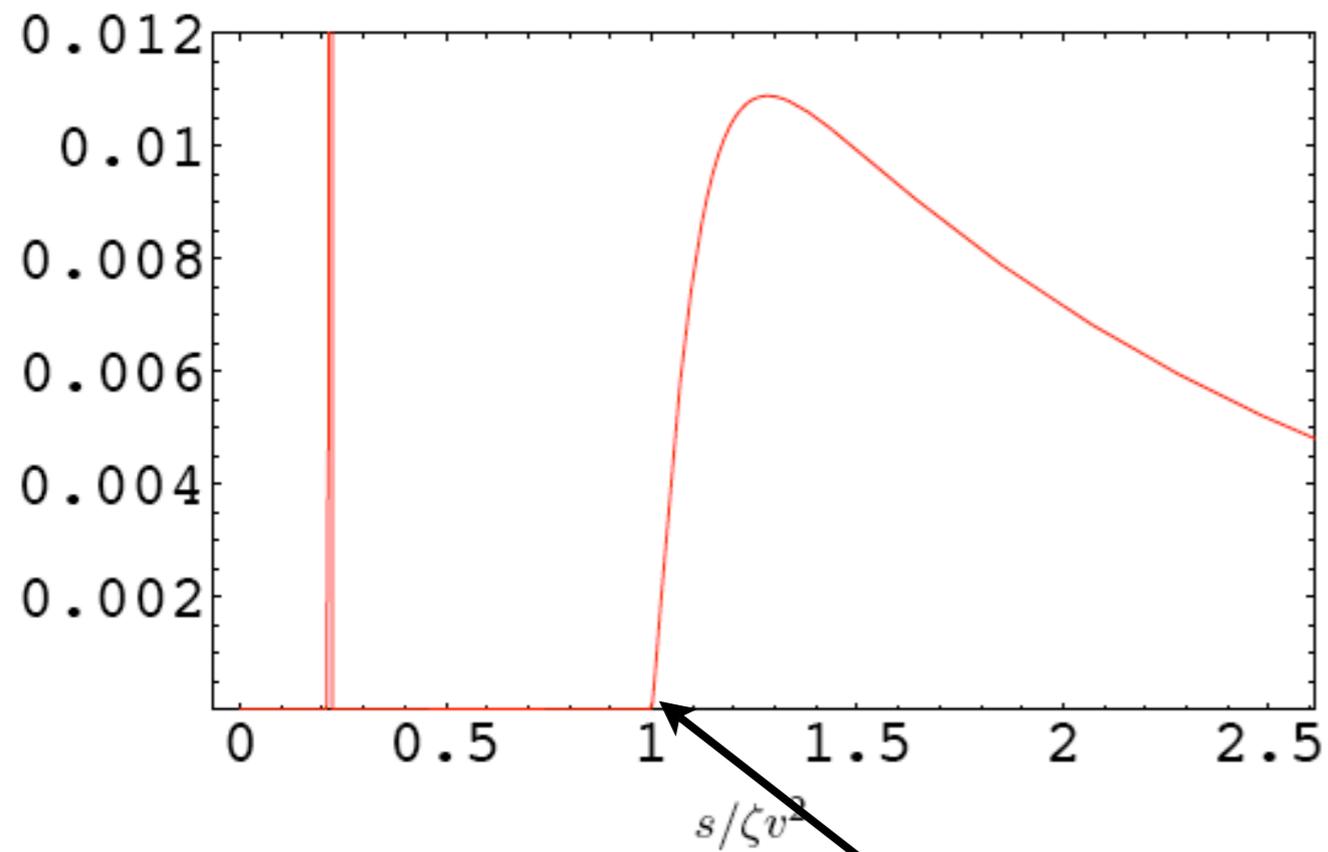
- The **spectral function** is normalized to 1 and can be interpreted as the projection of **mass eigenstates (H,U)** into the **higgs interaction state (h)**

$$\int_0^\infty \rho_{hh}(s) ds = 1$$

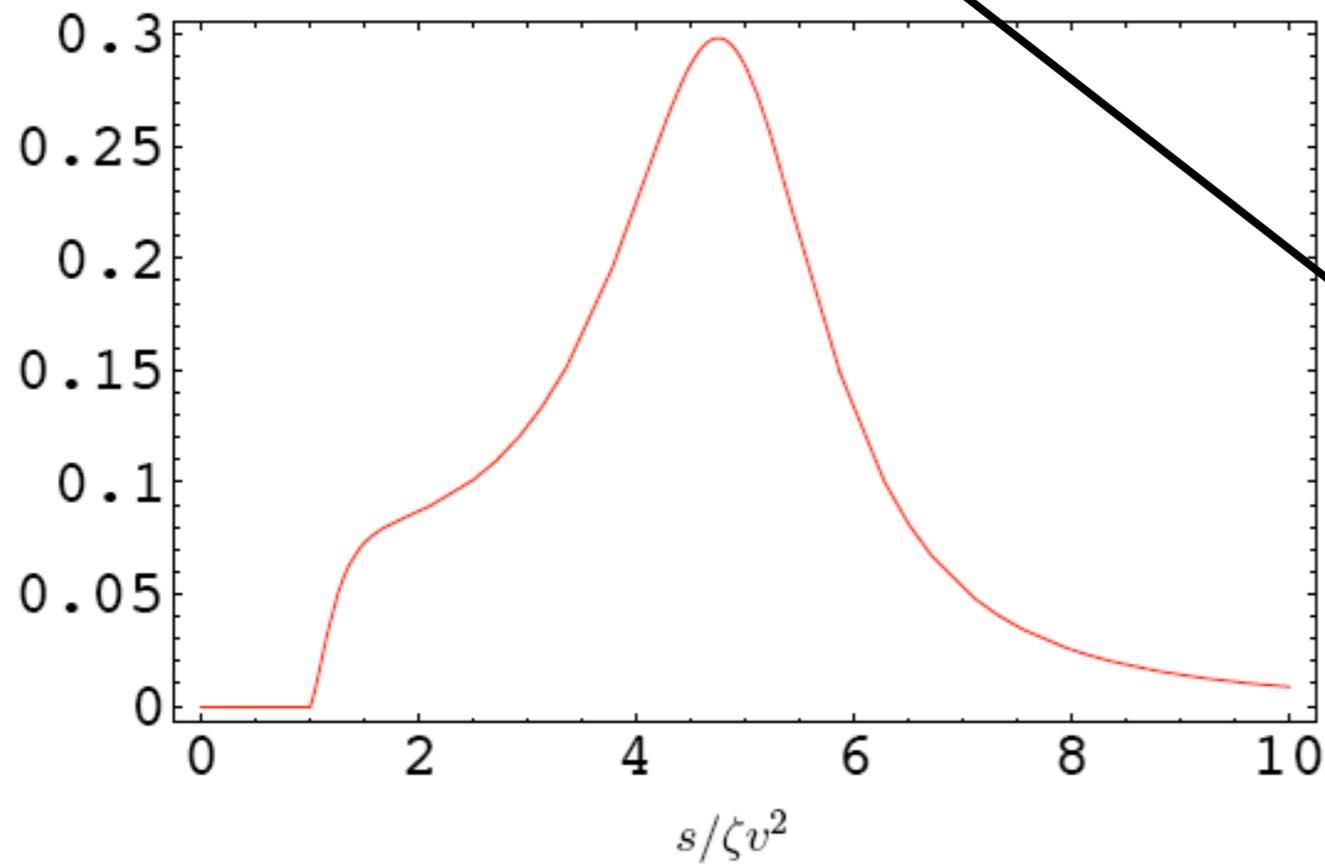
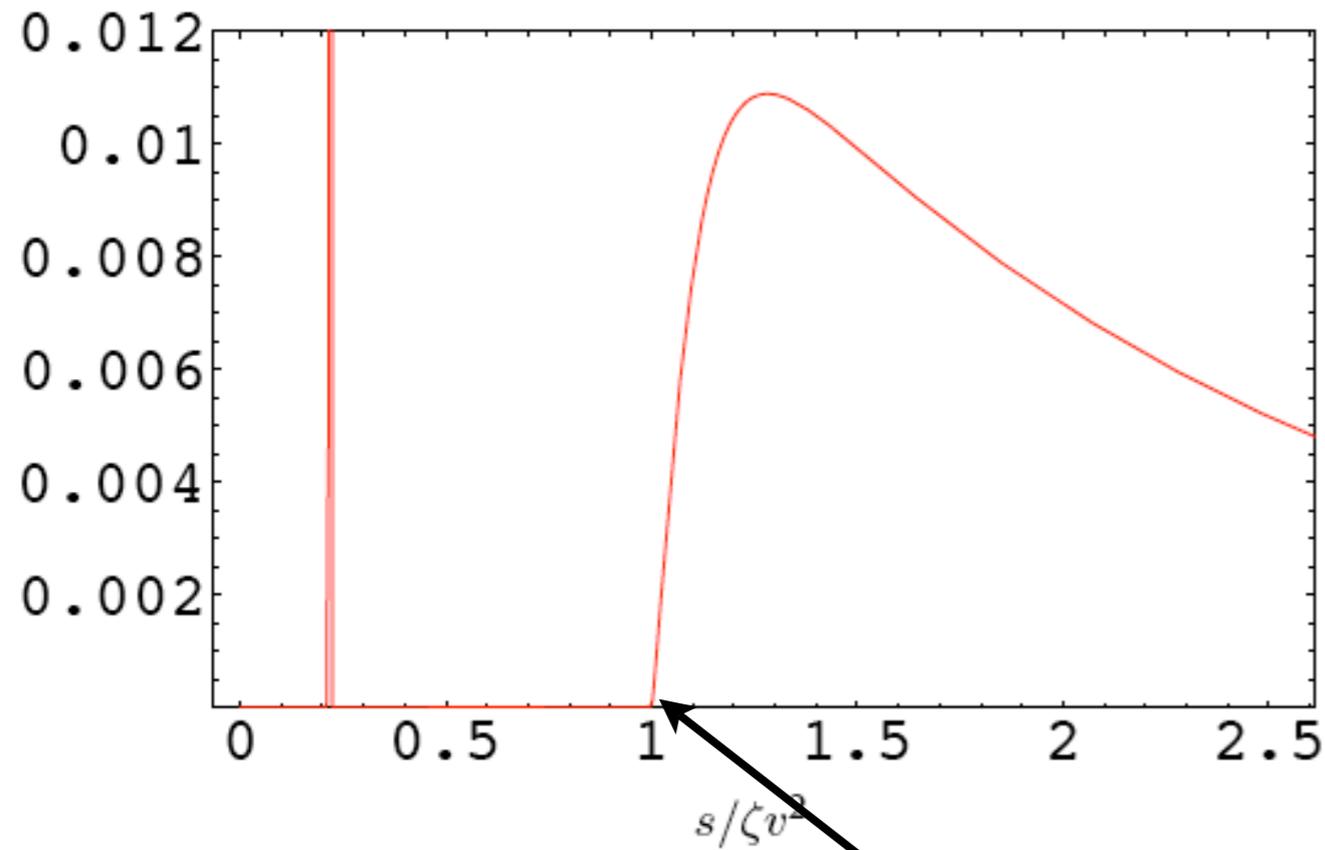
$$\rho_{hh}(s) \equiv \langle h|s\rangle\langle s|h\rangle = |\langle H|h\rangle|^2 \delta(s - m_h^2) + \theta(s - m_g^2) |\langle U, M|h\rangle|^2$$



These are two examples of spectral functions for $d_u = 1.2$ one with an isolate pole the second with the higgs embedded in the continuum it is a broad resonance

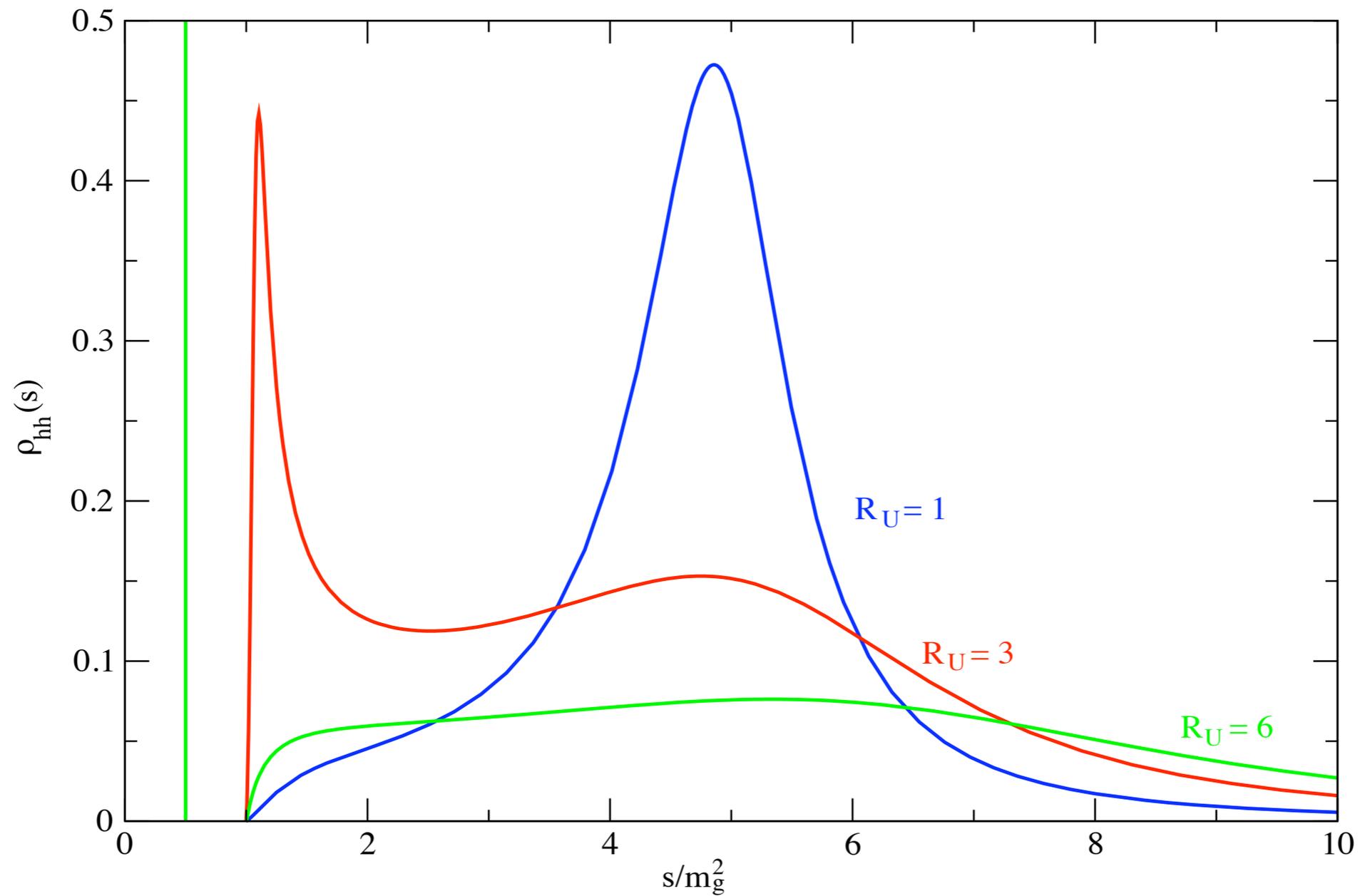


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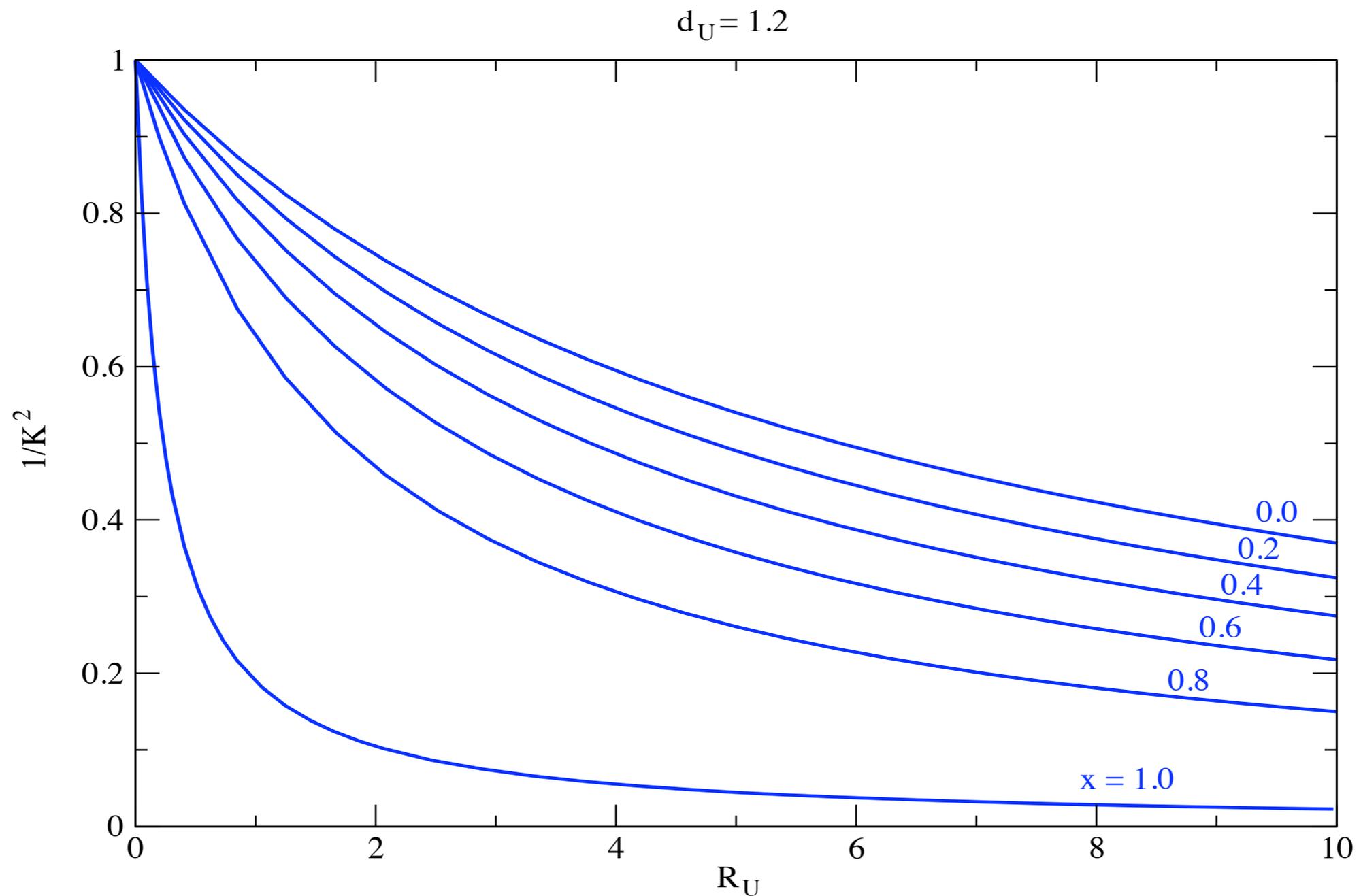


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Note the mass gap



- Evolution of the pole for large R_U and appearance of the phantom higgs



- Projection onto the higgs interaction state of the isolated pole for different masses $x = m_h^2/m_g^2$ it can be very diluted!!!

Decays? (preliminary)

- In the example I have been discussing until now where the higgs mixes with an **unparticle** operator there are decays but can be explained by the normal decays of the **higgs**
- I would like to study the case where the **unparticles** do not mixed **but can decay**
- Let's start with the following (toy)-lagrangian:

$$\mathcal{L} = \frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m_0^2 \phi^2 - \frac{1}{2} \kappa_u \phi^2 \mathcal{O}_U$$

- In order to avoid any problems with a tadpole for the unparticle operator, the following correlator will be supposed:

$$-iP^{(0)}(s) = \frac{1}{D^{(0)}} = \frac{A_d}{2 \sin(\pi d)} \frac{1}{(-s + m_g^2 - i\epsilon)^{2-d}}$$

- On the other hand I will suppose that the field φ will have $m > 0$

- There is a **one loop** contribution to the 2-point function of the unparticles that can be resummed in the following way:

$$-iP^{(1)} = \frac{1}{D^{(0)} + \Sigma}$$

$$\Sigma \simeq \frac{\kappa_u^2}{32\pi^2} \log \frac{\Lambda_U}{m^2} + i \frac{\kappa_u^2}{32\pi} \sqrt{1 - \frac{4m^2}{s}} \theta(s - 4m^2)$$

- The consequences of that polarization are as follows:
 - A new isolated pole appears with a mass less than m_g
 - If $m_g > m$ this pole gets an imaginary part proportional to the polarization
- Therefore unparticles can decay!!!

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