Higgs-Unparticle Interplay

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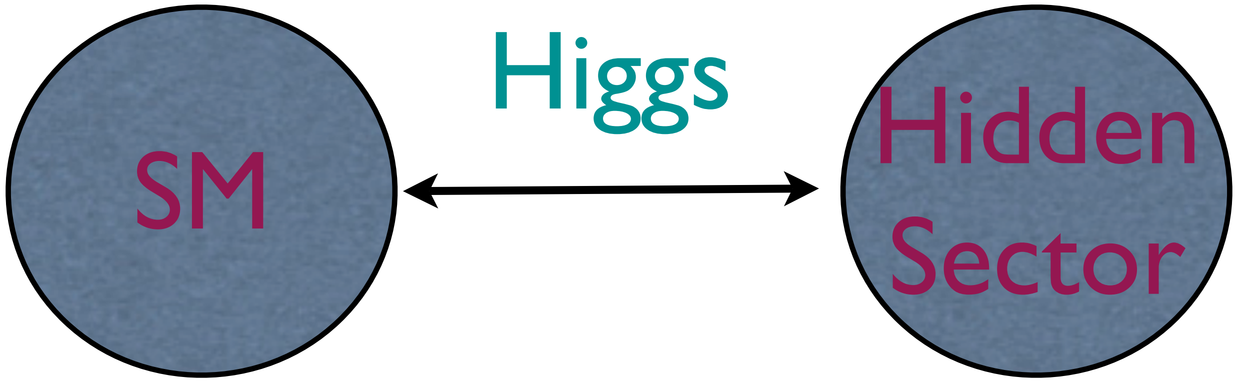
LEPP theory seminar-10/22/08

- 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 constrains
- 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 O:
    - Multisinglets
    - Hidden-valleys
    - Unparticles
    - .....

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  - Multisinglets
  - Hidden-valleys ← whole new particle sectors
  - 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 at follows:

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

$$\frac{1}{M^k} O_{SM} O_{hid} \quad O_{hid} \equiv q\bar{q}, \lambda\lambda, \ldots$$

$k = d_{sm} + d$

  - 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:

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

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To match 1-particle propagator

- Having a phase leads to new interference patterns when dealing interactions of the type: $tu\mathcal{O}_U$ $\overline{\Psi}\Psi\gamma_\mu\mathcal{O}_U^\mu$

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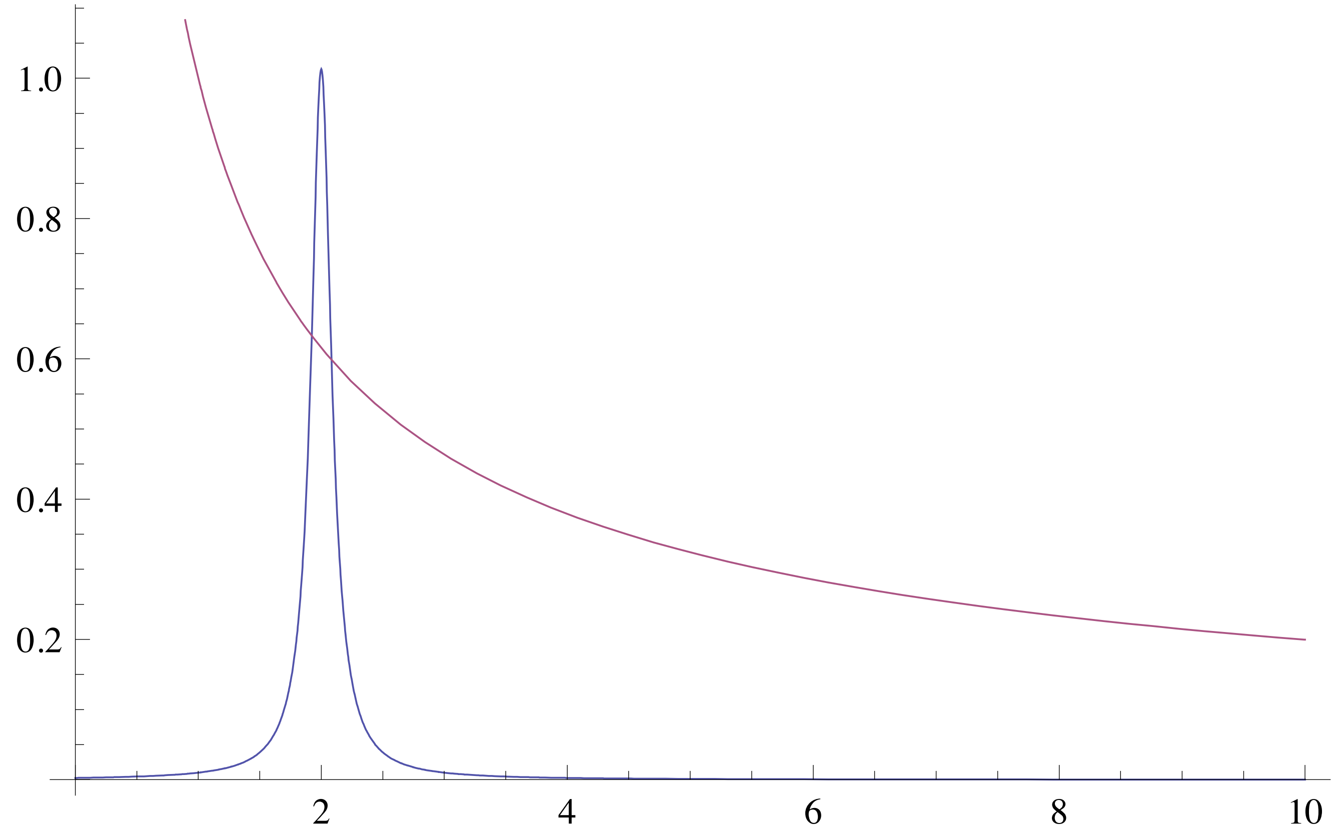

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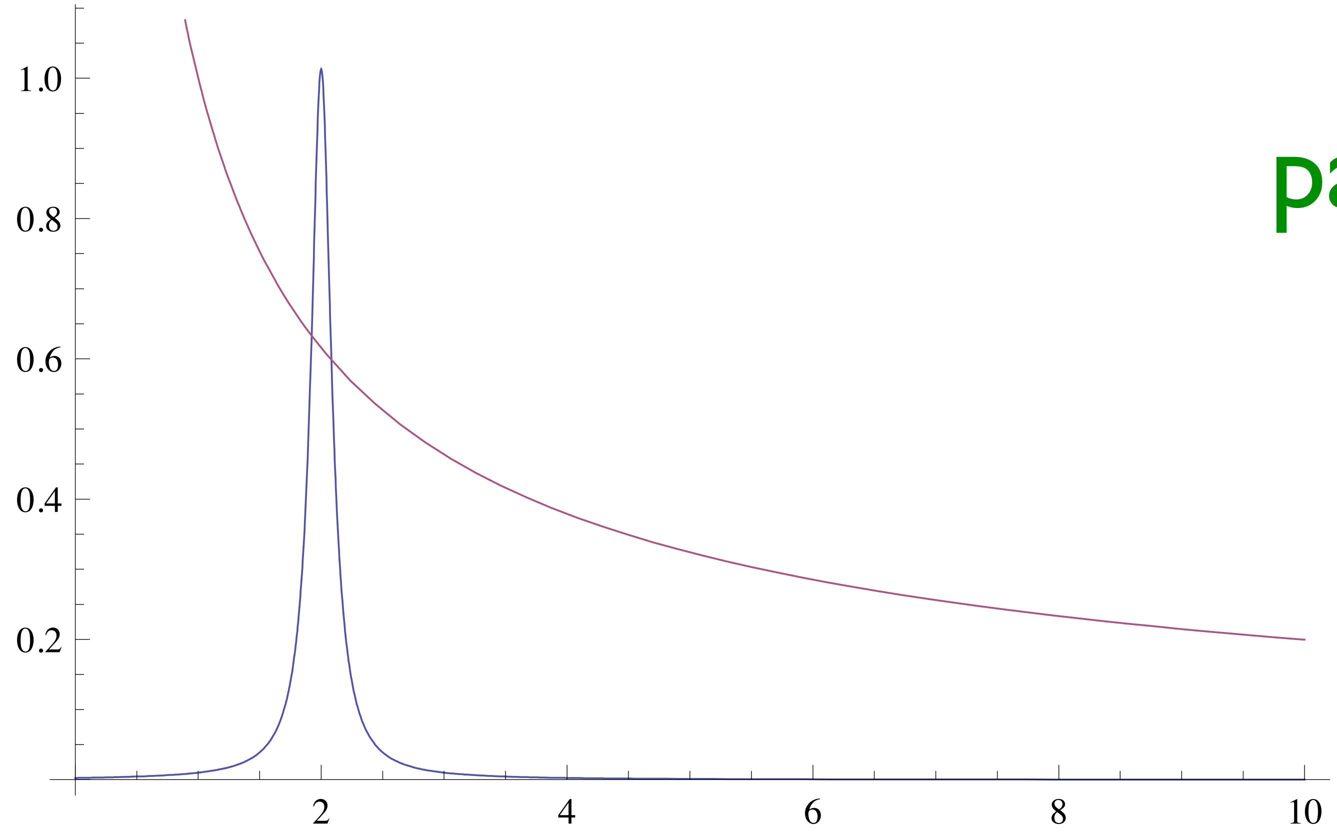

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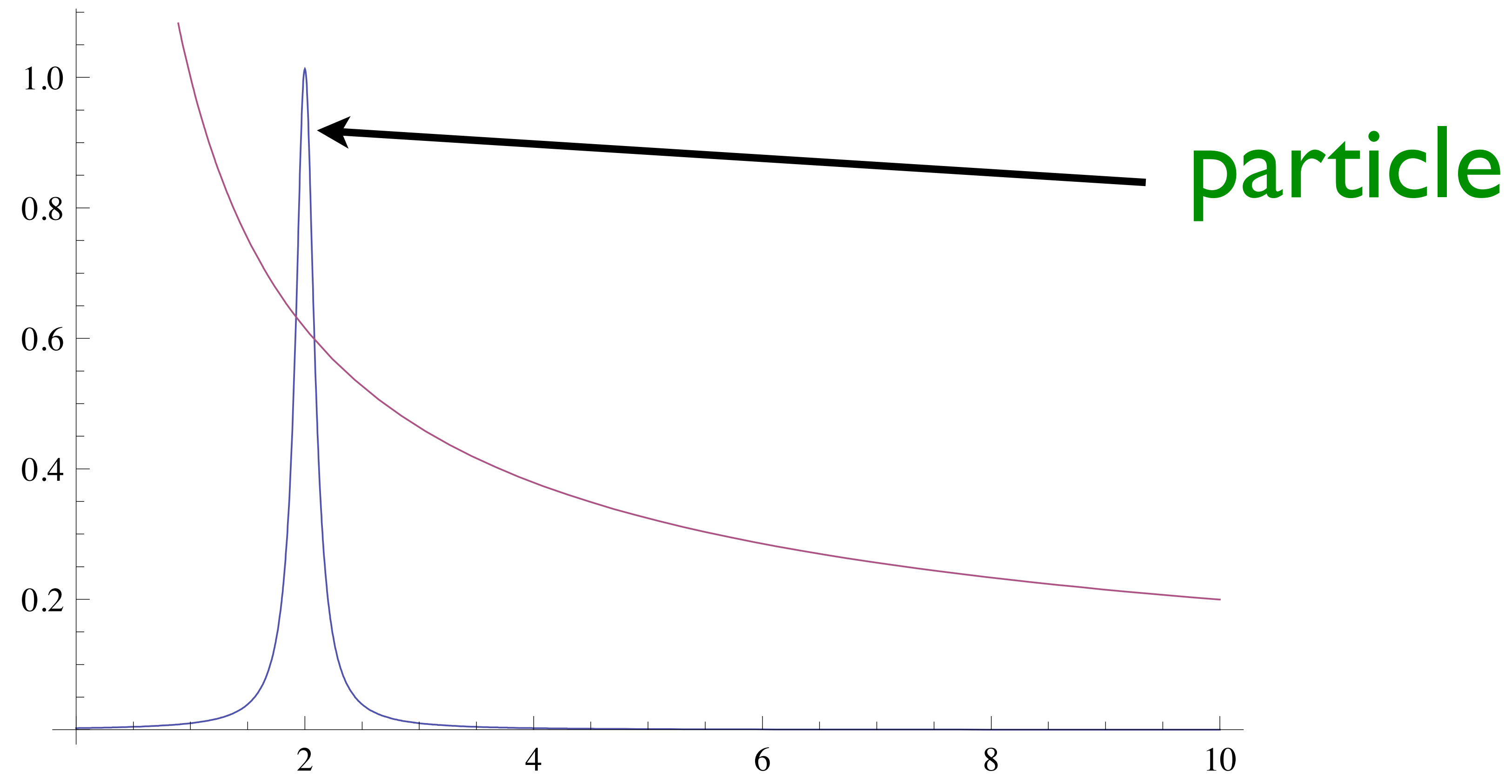

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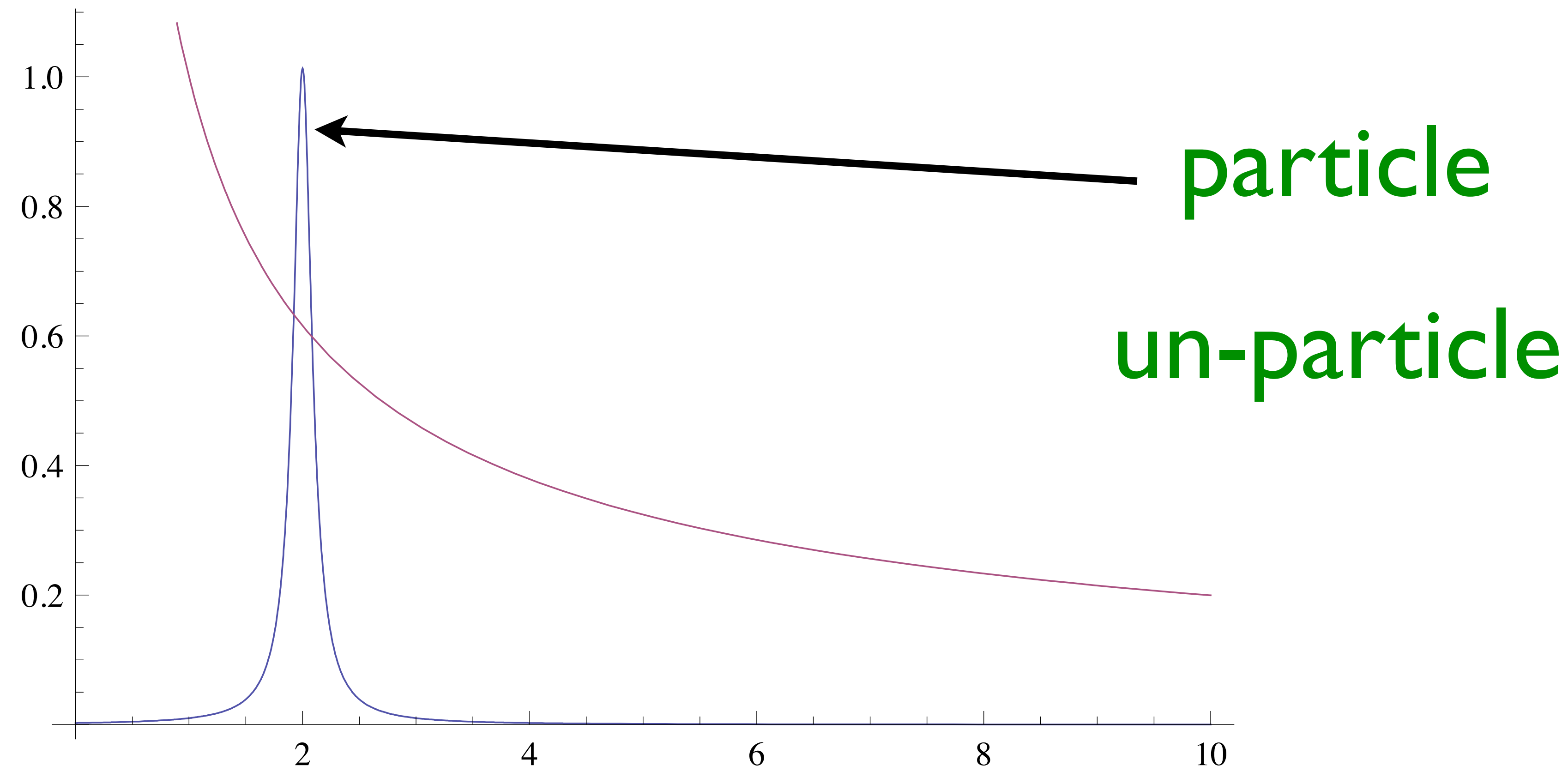

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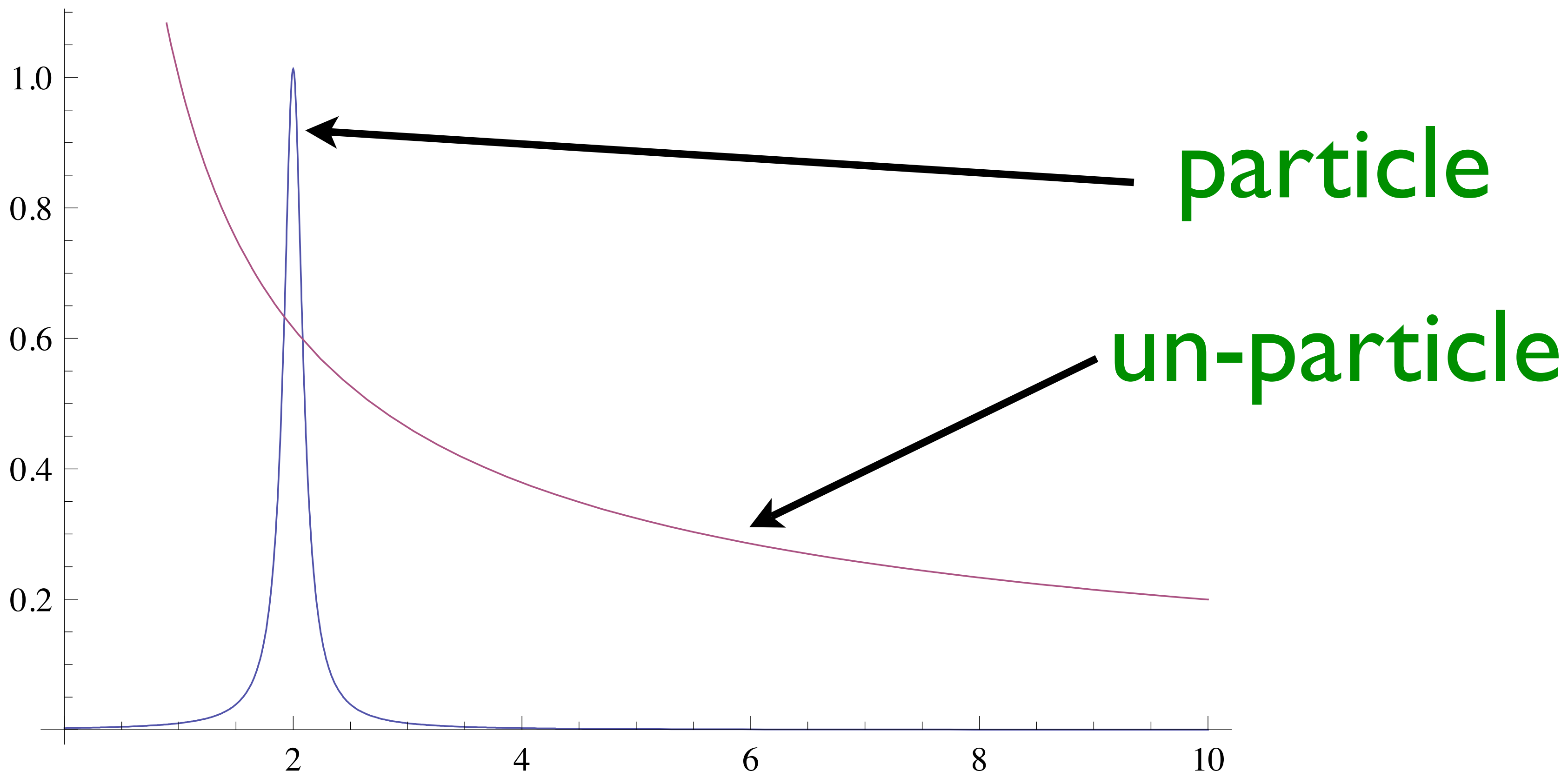

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Higgs-unparticle interaction

- I will focus in the case where Ou 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 Ou has the following correlator:

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- 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 EWSB 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:

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

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

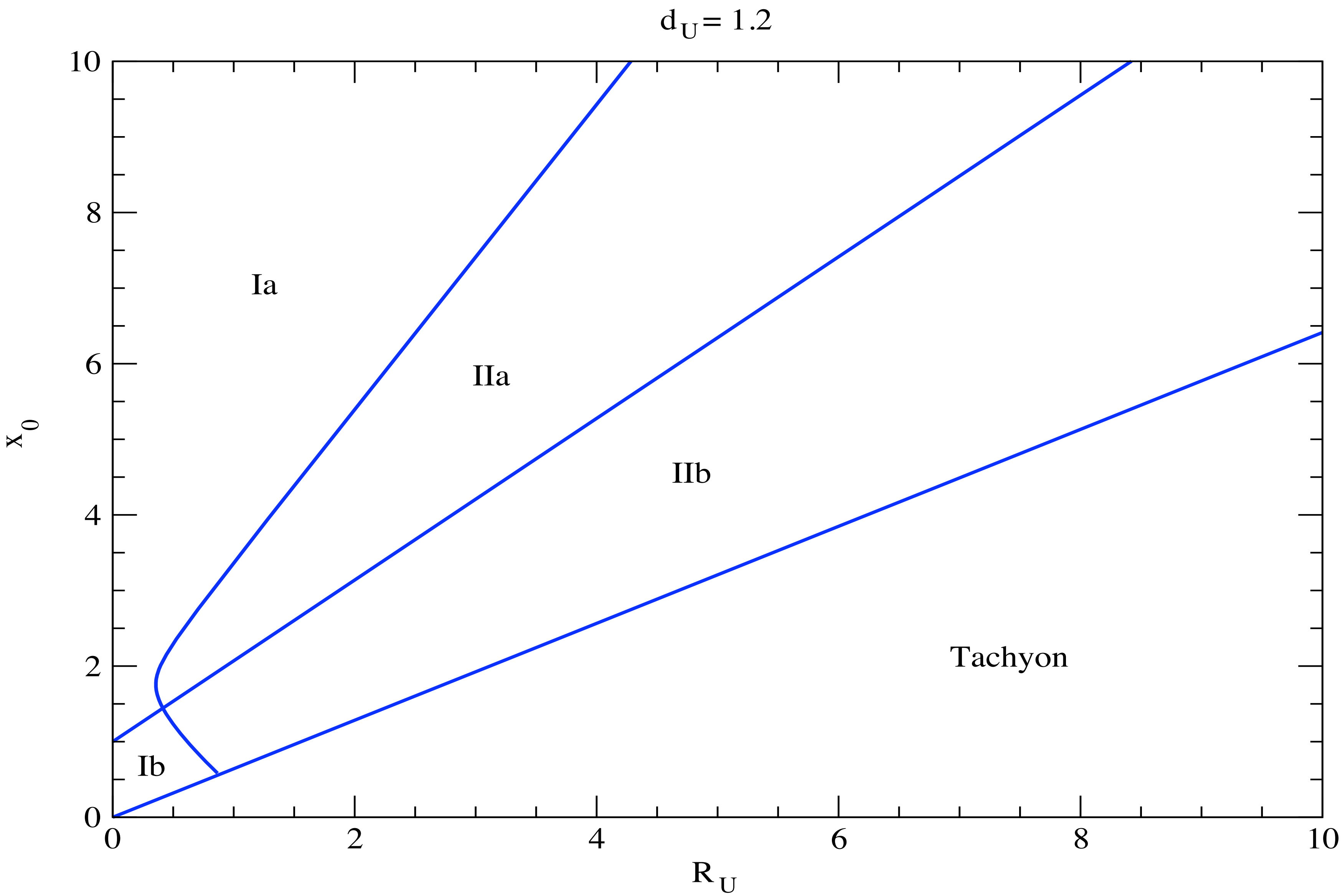
$$M_{nm}^2 = (M_n^2 + m_g^2)\delta_{nm}$$

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

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

Parameter space

The Higgs can be embedded in the continuum!!!



$$R_U \equiv \frac{A_{d_U} v^2 \kappa_U^2}{2\pi m_g^{6-2d_U}}$$

$$x_0 \equiv \frac{m_{h0}^2}{m_g^2}$$

Ia. Single (complex) pole>mg **Ib.** Single (real) pole<mg

IIa. Two (complex) poles>mg **IIb.** One (complex)>mg
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- 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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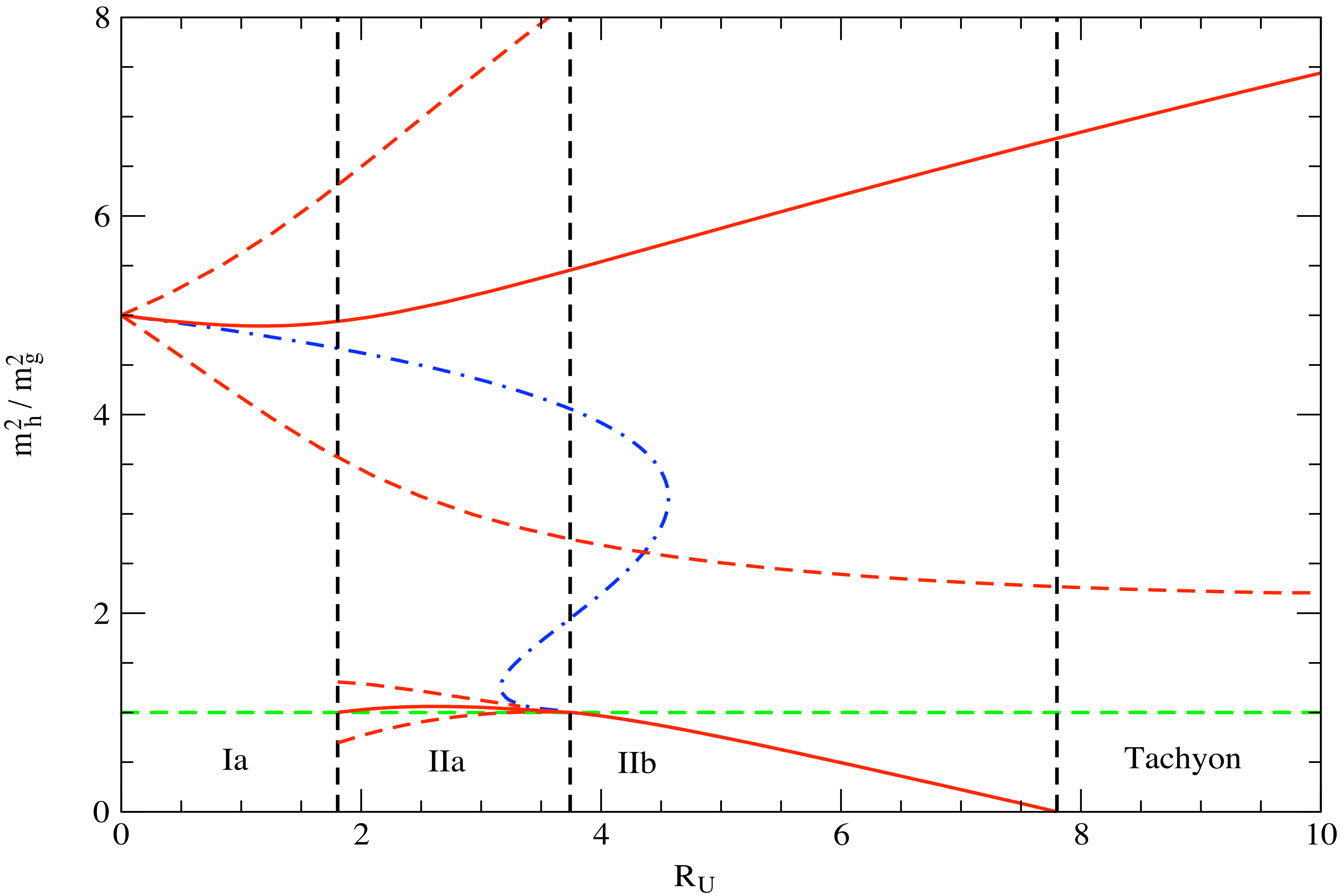

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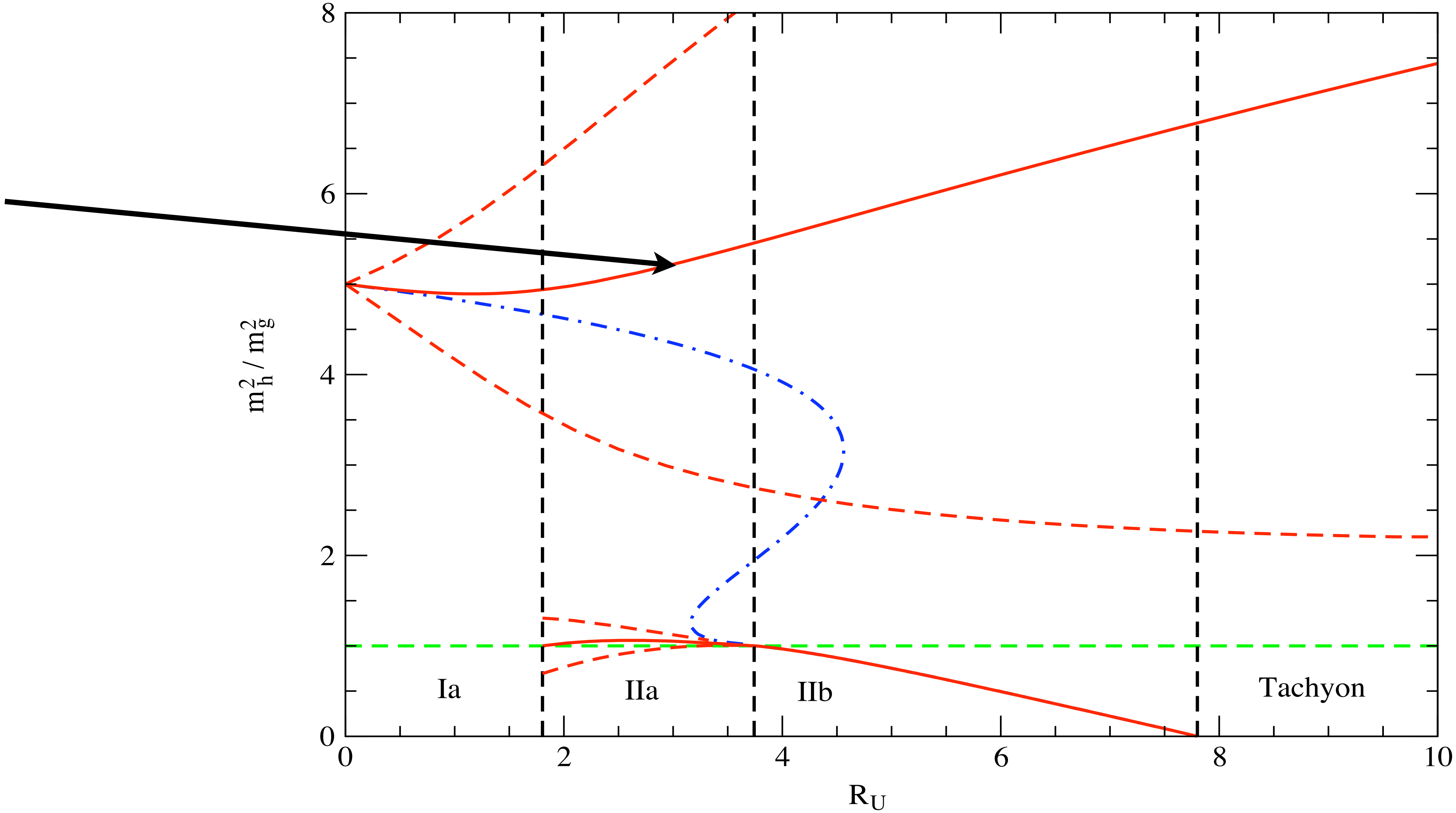

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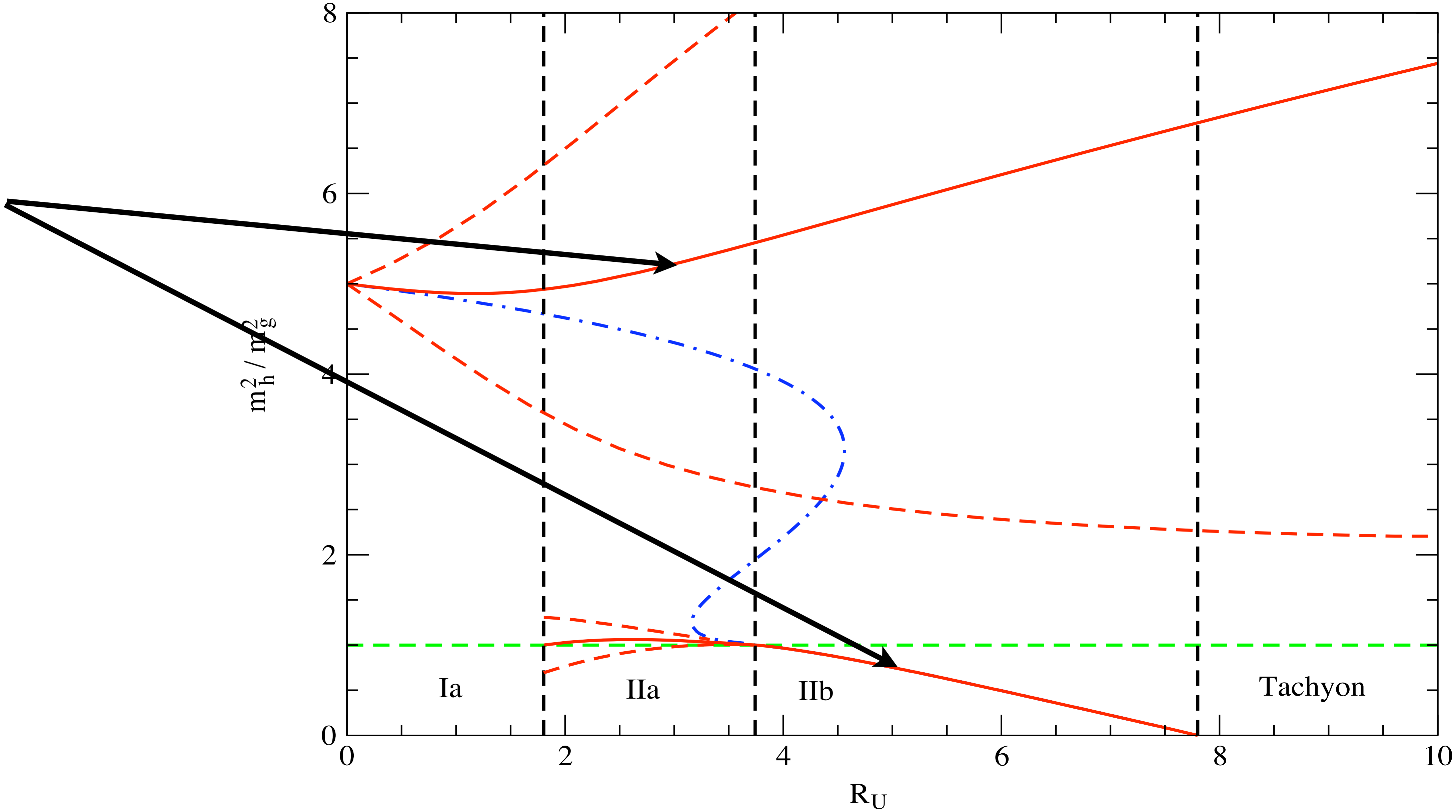

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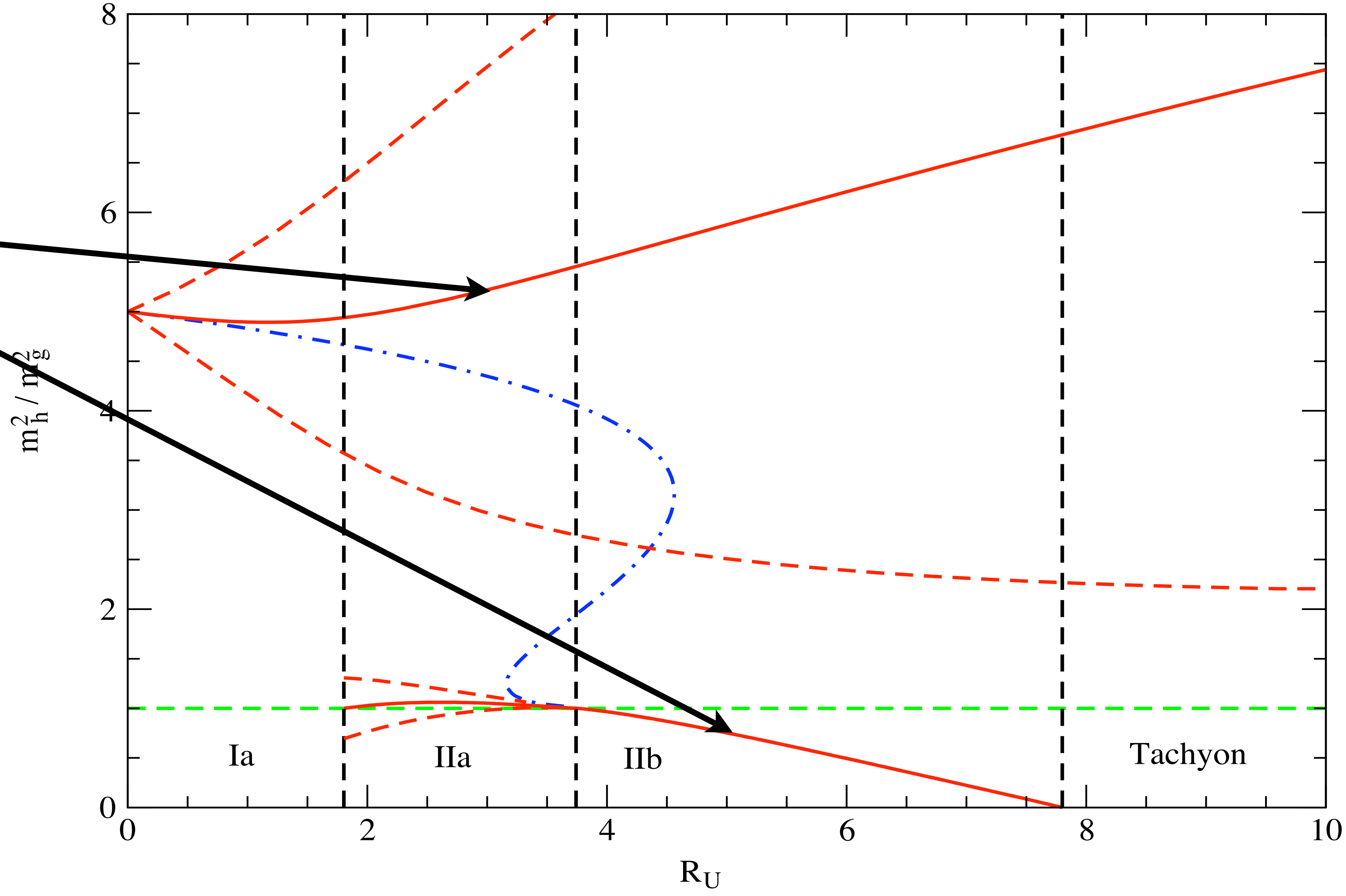

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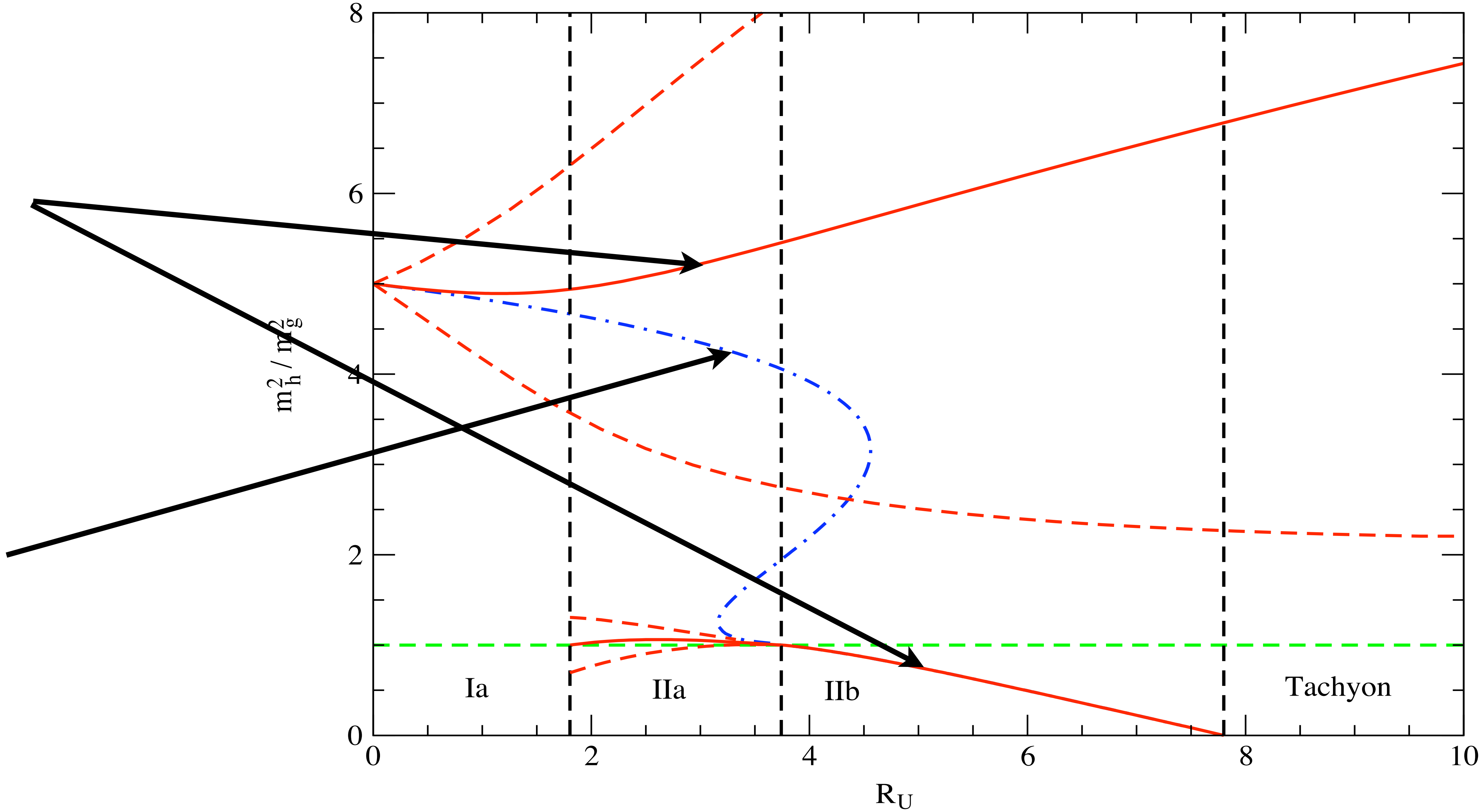

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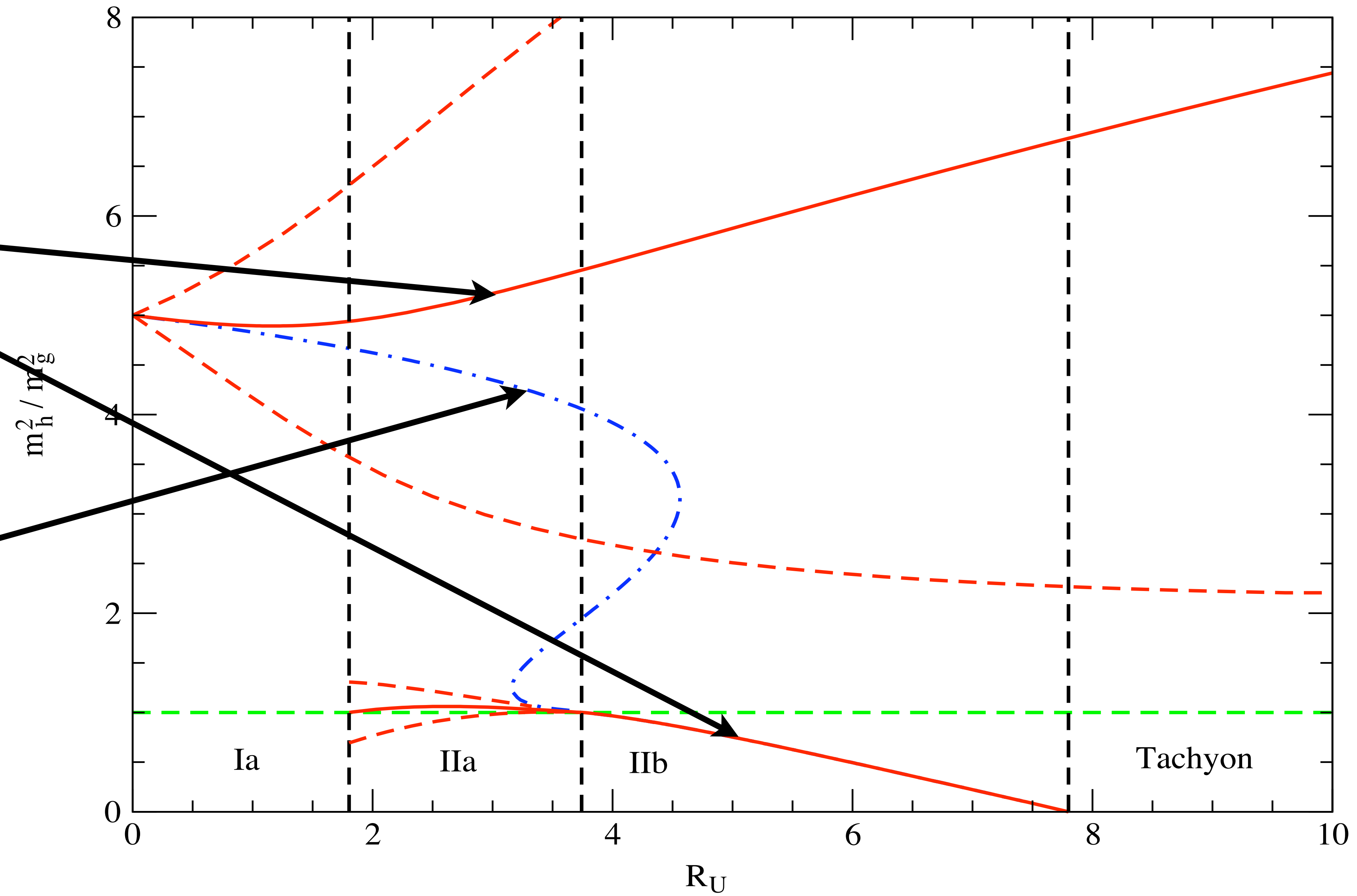

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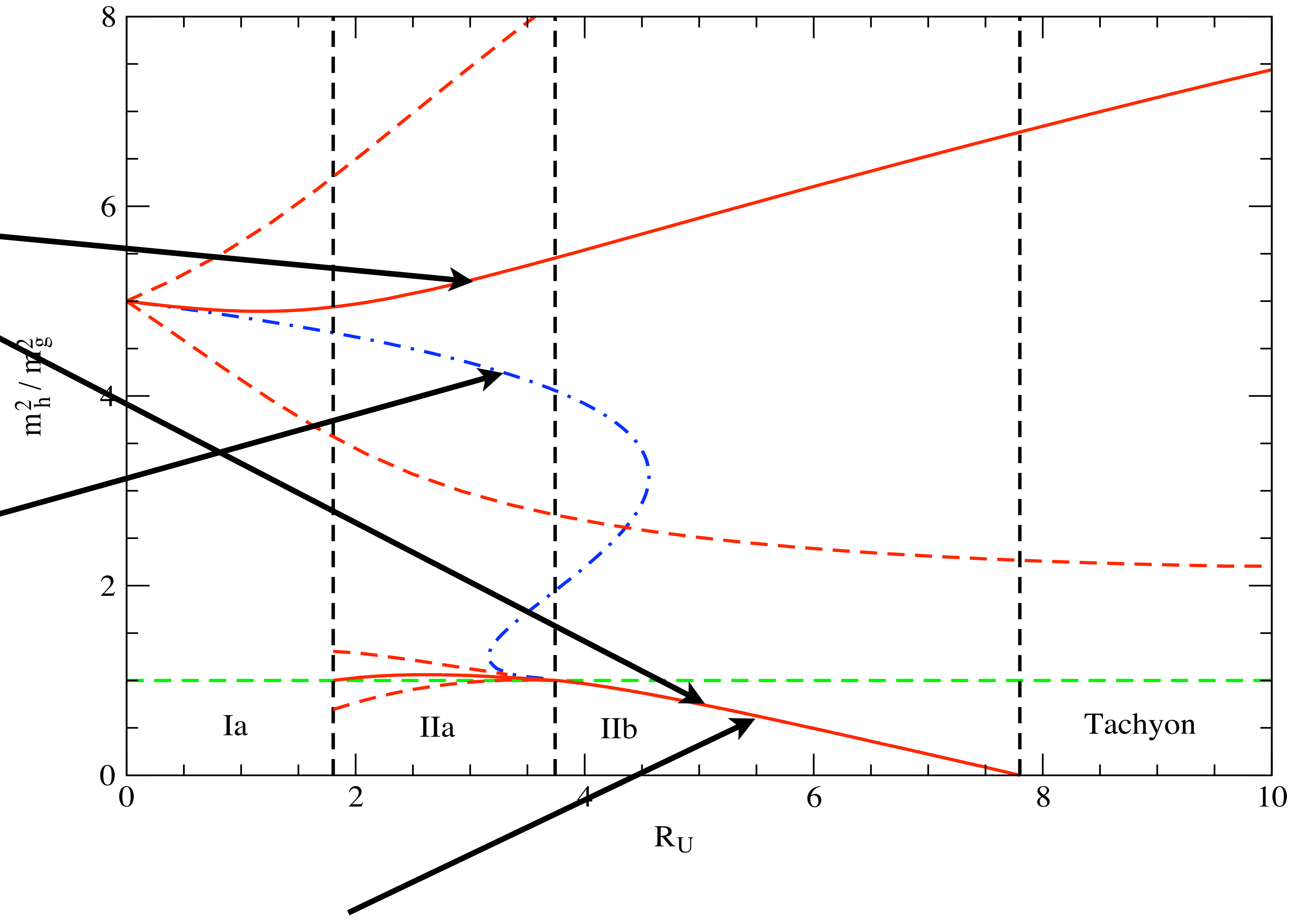

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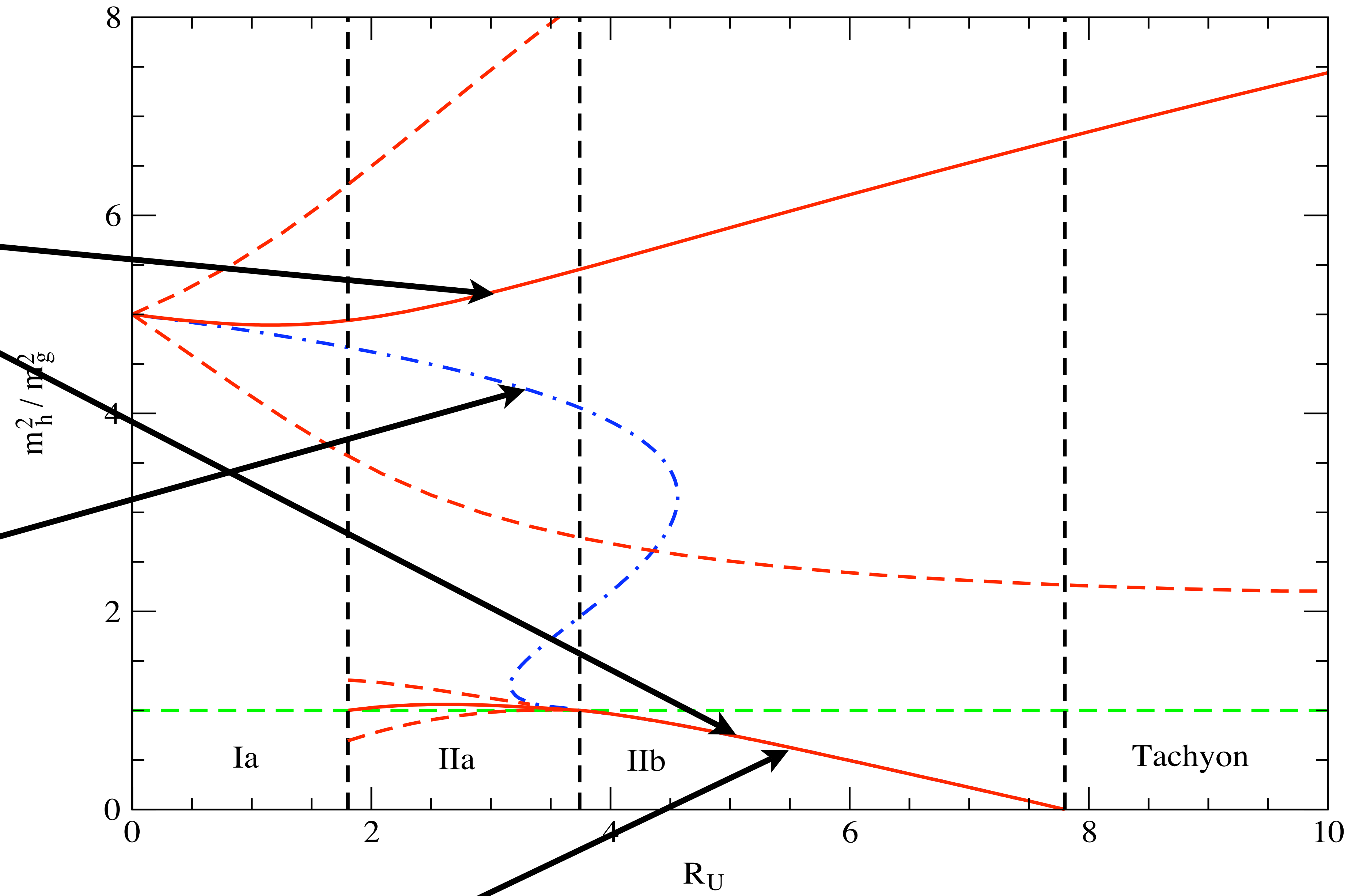

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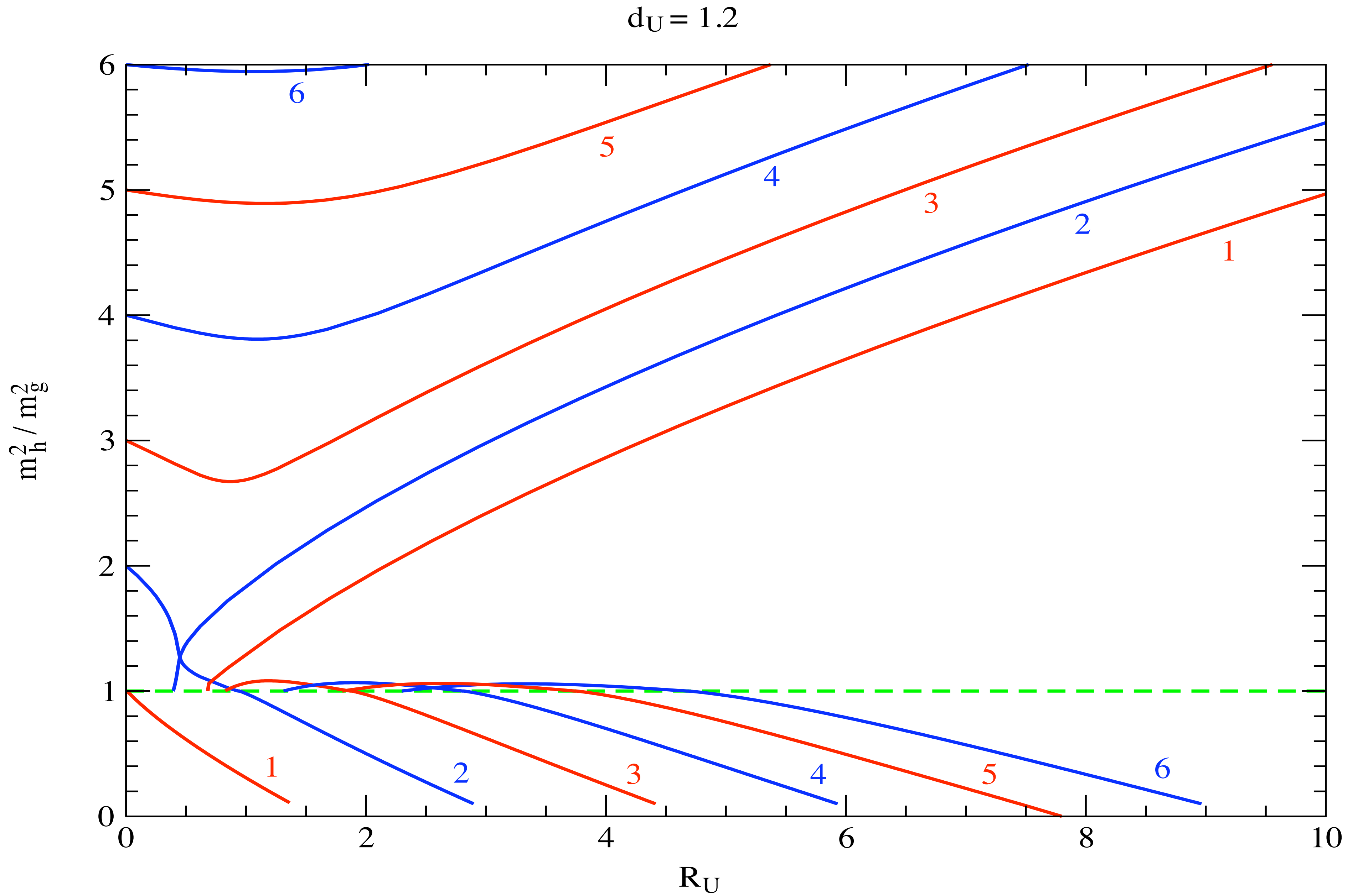
A resonance is spit from the continuum (phantom)



- 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

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

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

  - isolated poles: $\dfrac{1}{x+i\epsilon} \to \mathrm{P}.V.\dfrac{1}{x} - i\pi\delta(x)$

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

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

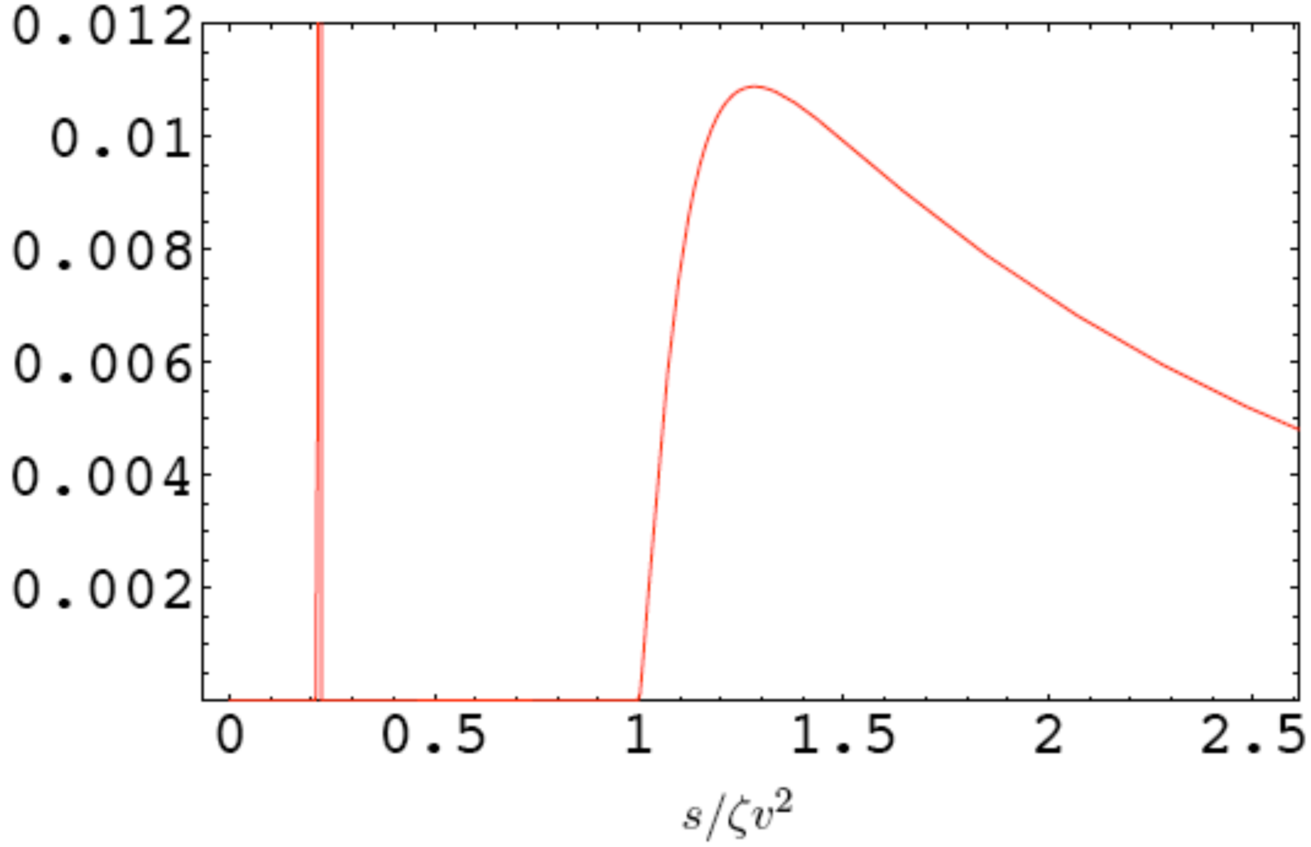
$$\rho_{hh}(s) = \frac{1}{K^2(m_h^2)}\delta(s - m_h^2) + \theta(s - m_g^2)\frac{T_U(s)}{\mathcal{D}^2(s) + \pi^2 T_U^2(s)}$$

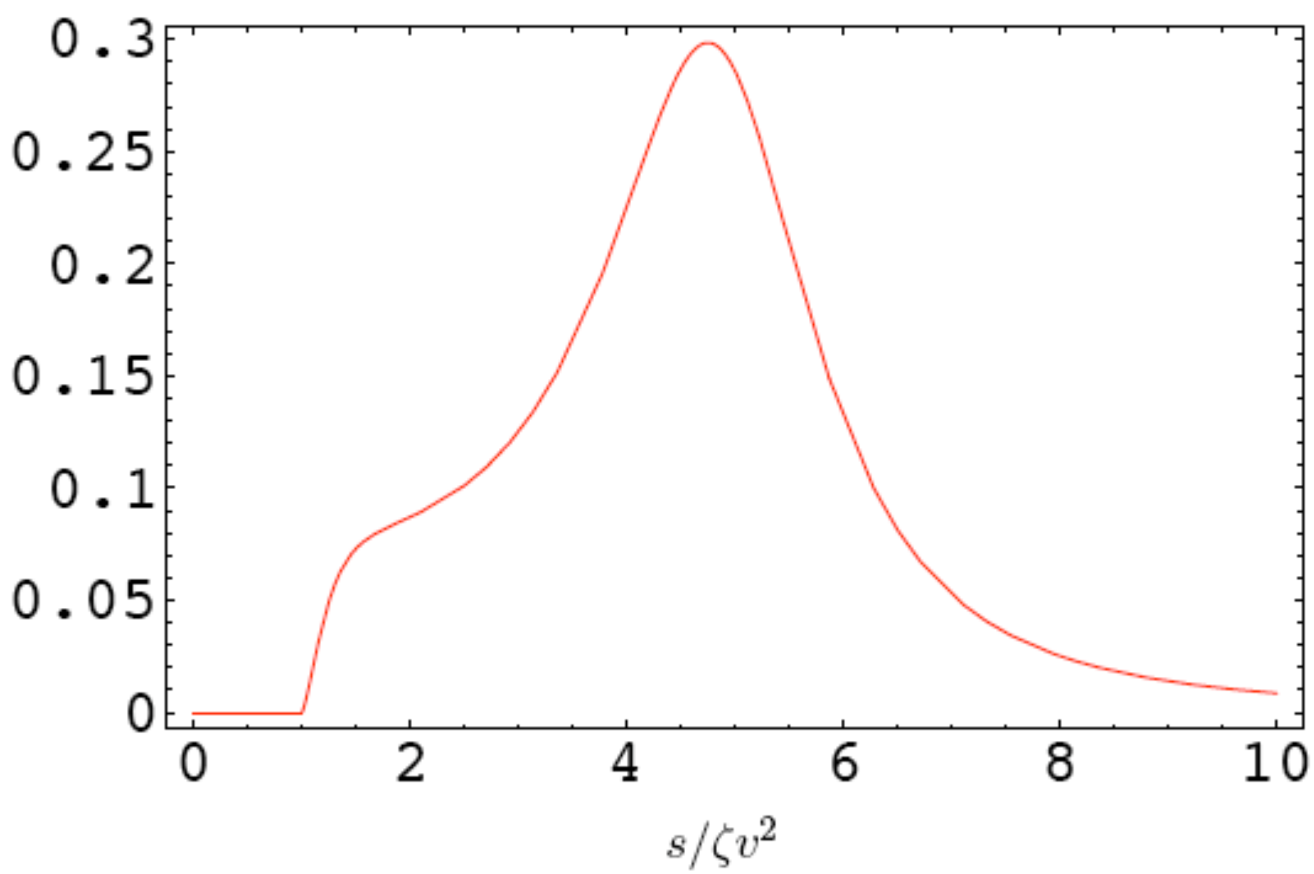
$$\rho_{hh}(s) = \theta(s - m_g^2)\frac{T_U(s)}{\mathcal{D}^2(s) + \pi^2 T_U^2(s)}$$

- 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)

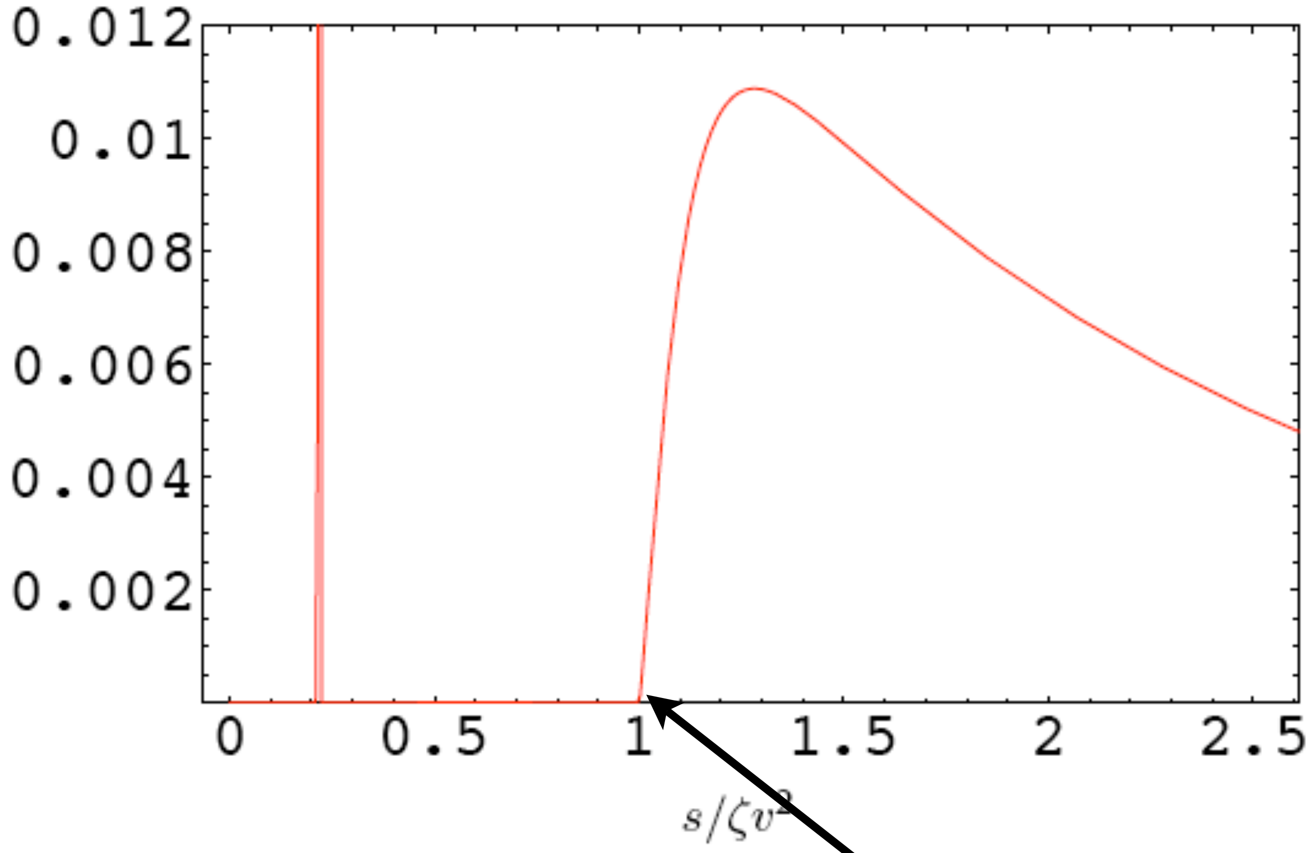
$$\int_0^\infty \rho_{hh}(s)ds = 1$$

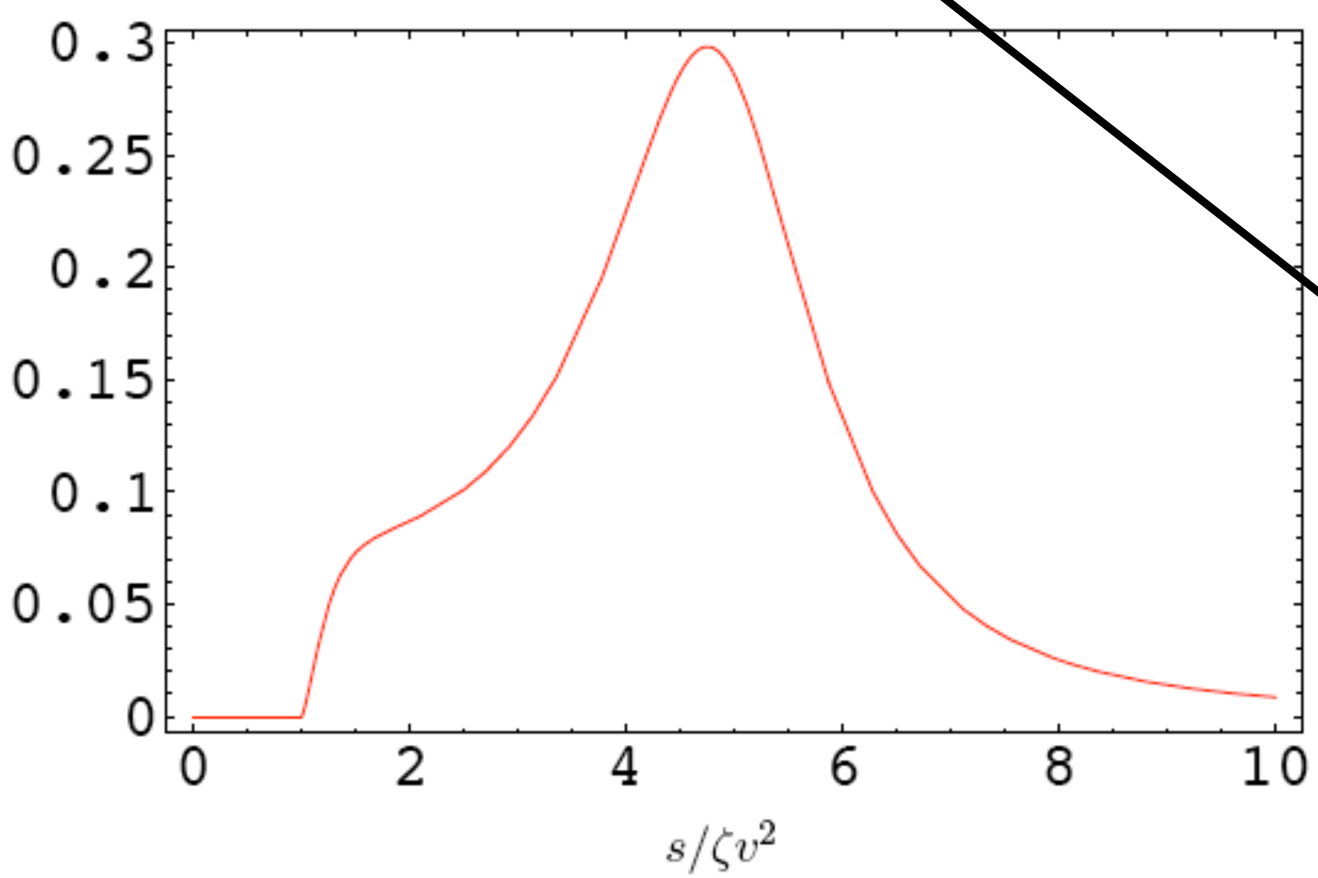
$$\rho_{hh}(s) \equiv \langle h|s\rangle\langle s|h\rangle = |\langle H|h\rangle|^2\delta(s - m_h^2) + \theta(s - m_g^2)|\langle U, M|h\rangle|^2$$





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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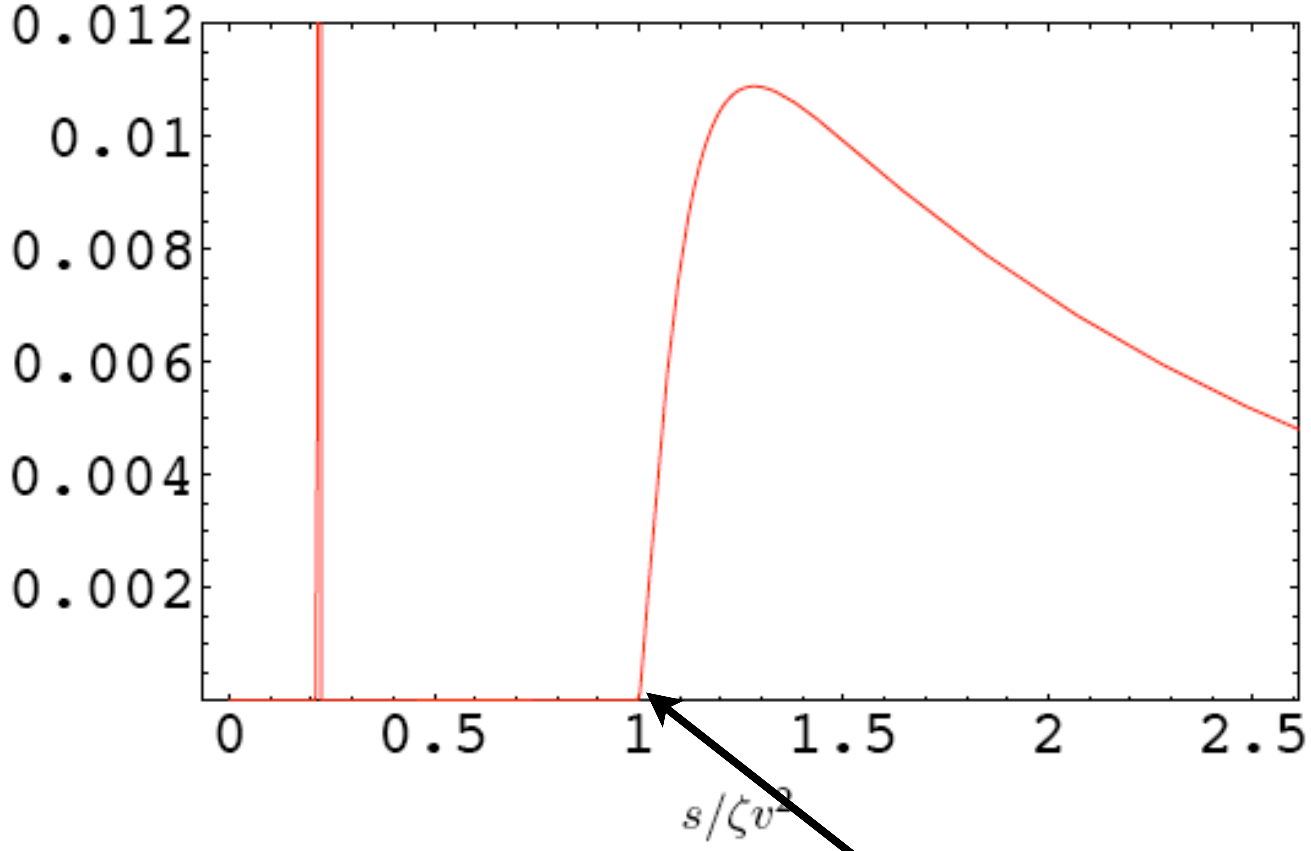

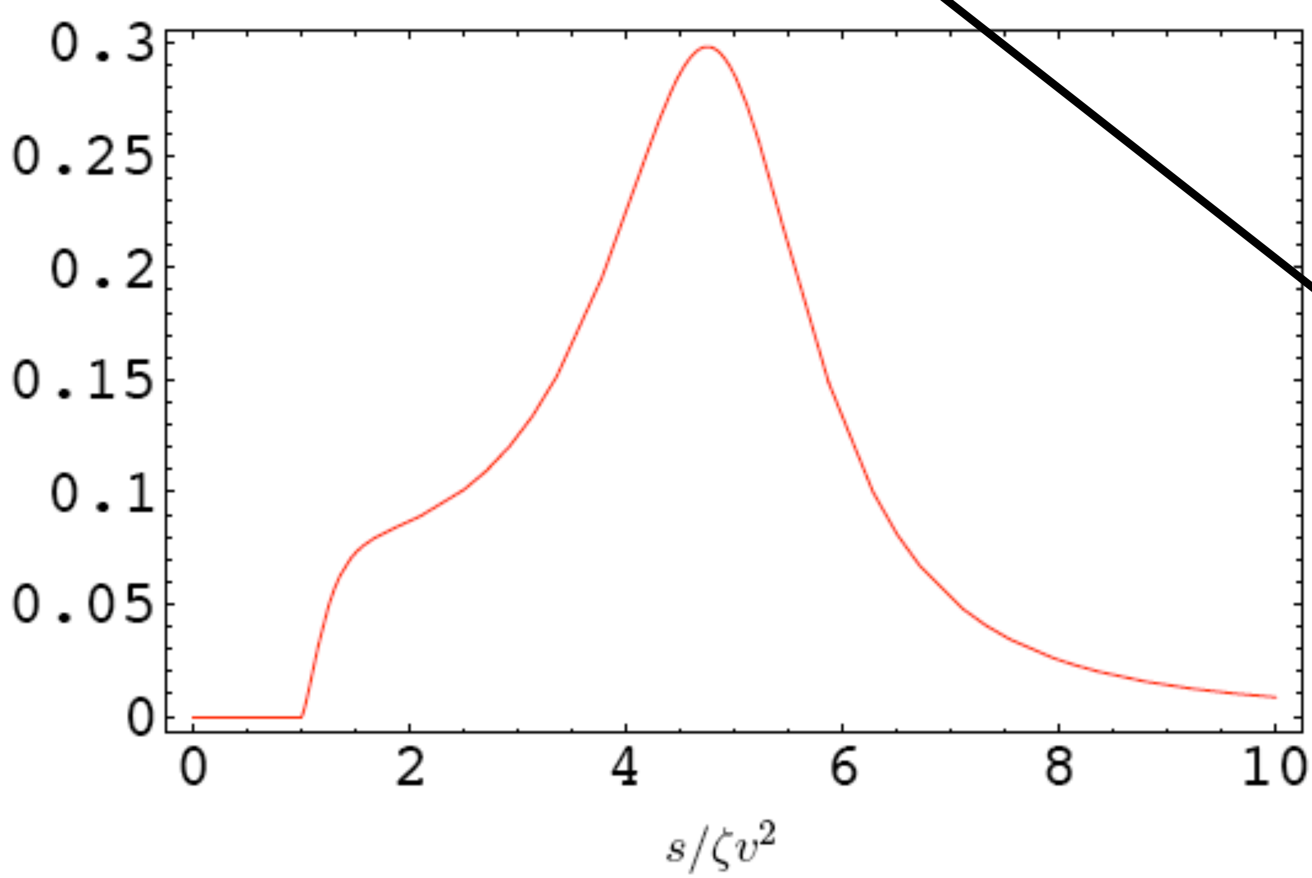

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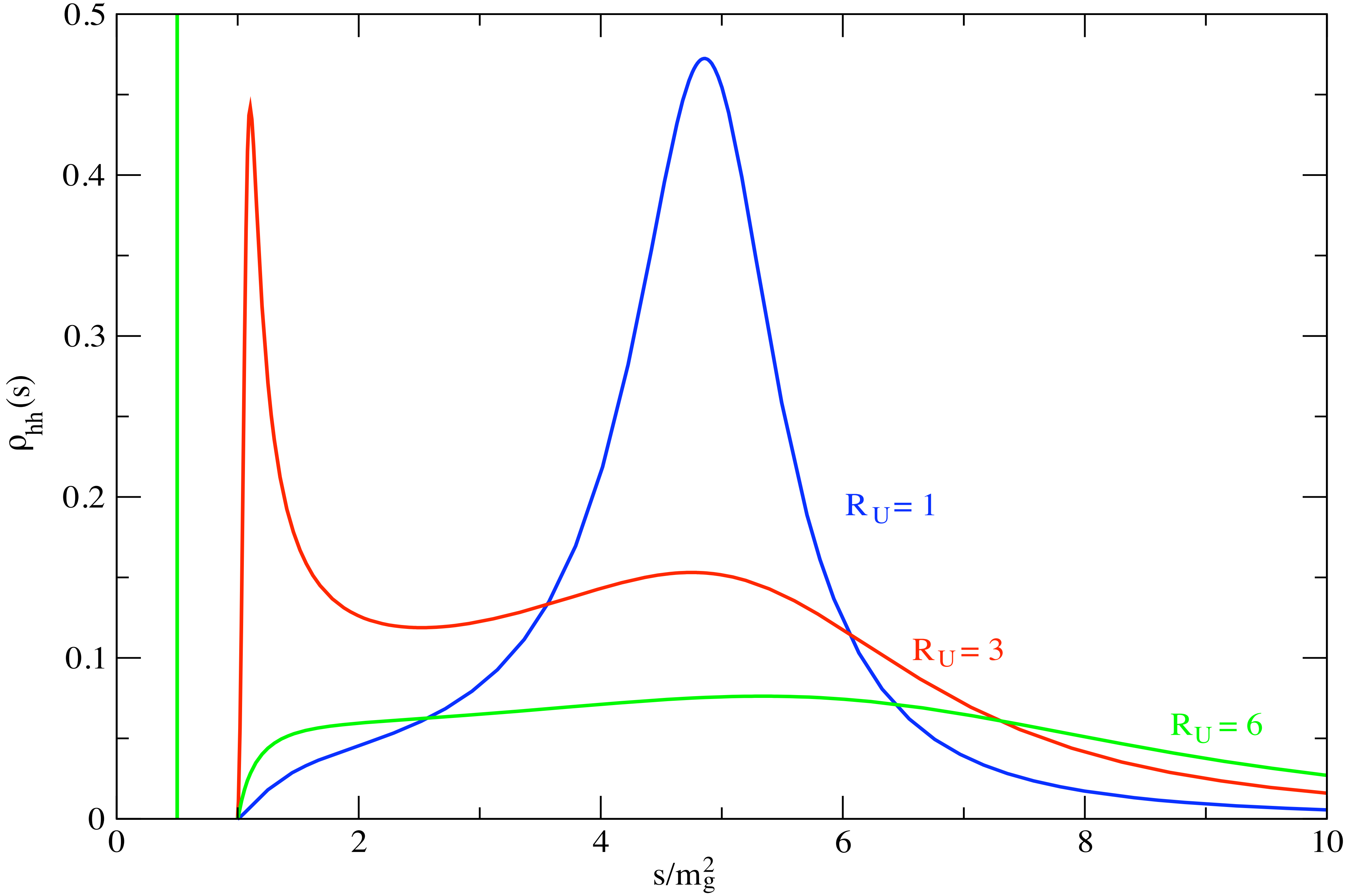
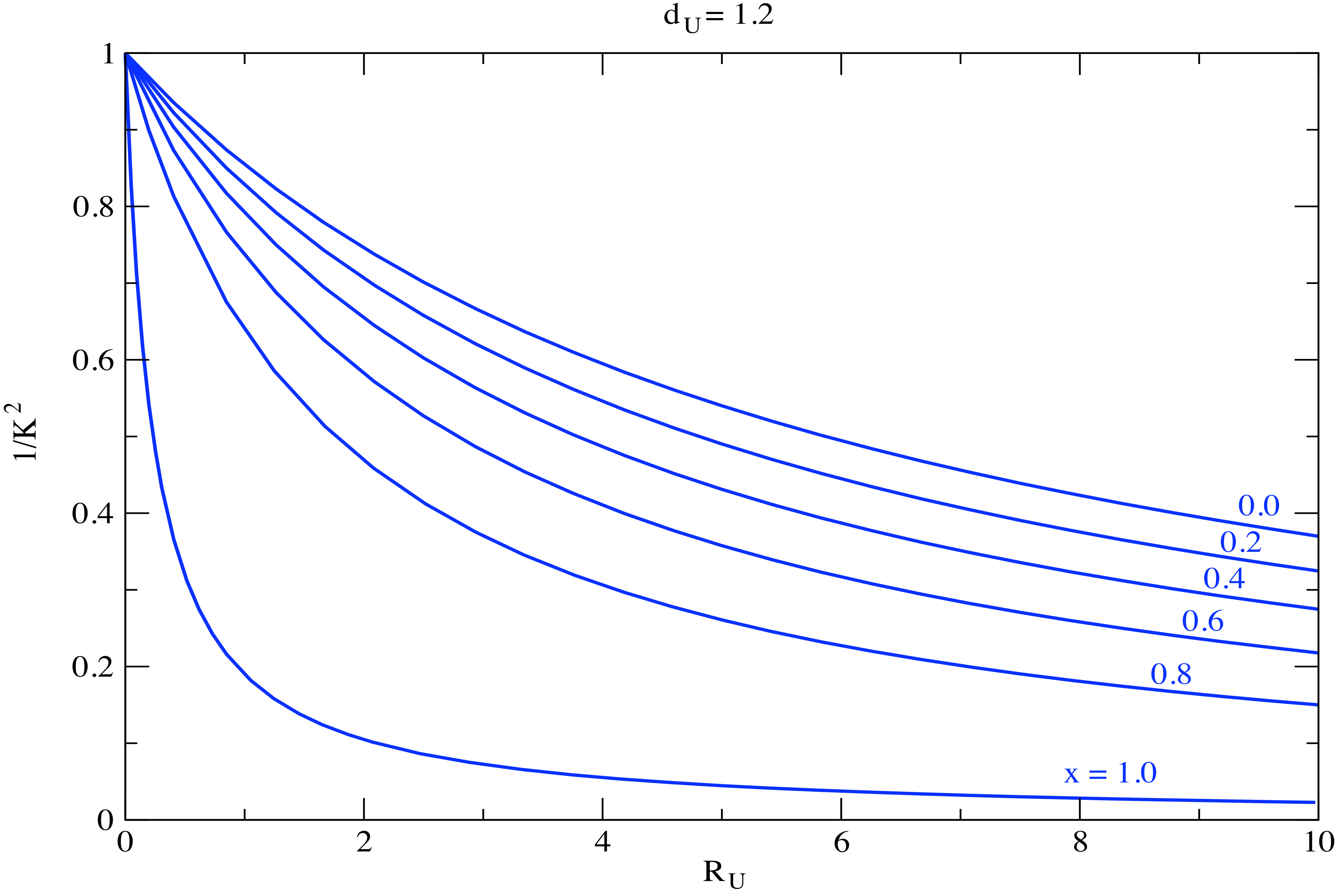
Note the mass gap



- 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 resumed 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 poles gets an imaginary part proportional to the polarization
- Therefore unparticles can decay!!!

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- A mass gap is generated for the unparticles, the higgs can appear as an isolated pole, be merged into the continuum or phantom (diluted) higgs can be obtained
- Unparticles can decay as resonances