MP1. The strongest argument for new particles at the TeV scale is that they are needed to provide a "natural" explanation of electroweak symmetry breaking. But many of these proposed particles are strongly excluded by LHC and flavor constraints. Have we excluded "naturalness"? Is there a goal, in terms of an accelerator energy, for example, to exclude "naturalness"?

“Naturalness” is part 2 of a 2-part question.

Here is part 1:

It is a profound phenomenon in nature that the gauge symmetry SU(2)xU(1) is spontaneously broken.

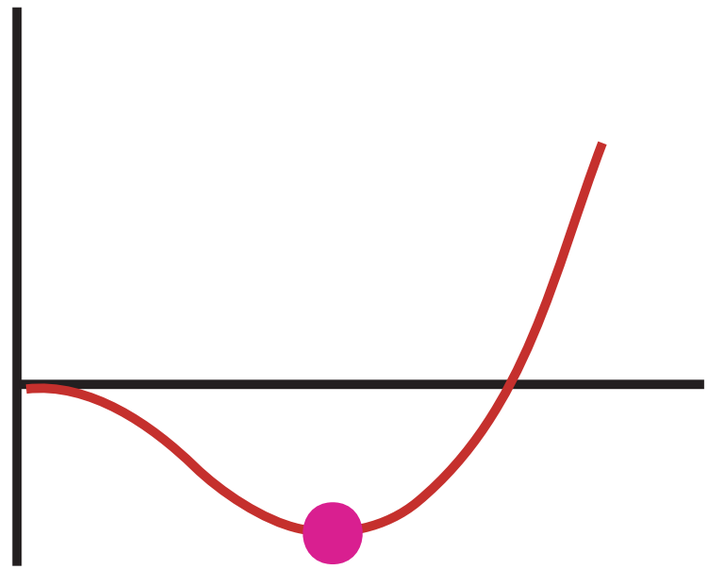
Why does this happen ?

Here is the answer given in the Standard Model:

$$V(\Phi) = \mu^2|\Phi|^2 + \lambda|\Phi|^4$$

Assume that $\mu^2 < 0$.

Then this potential has the form

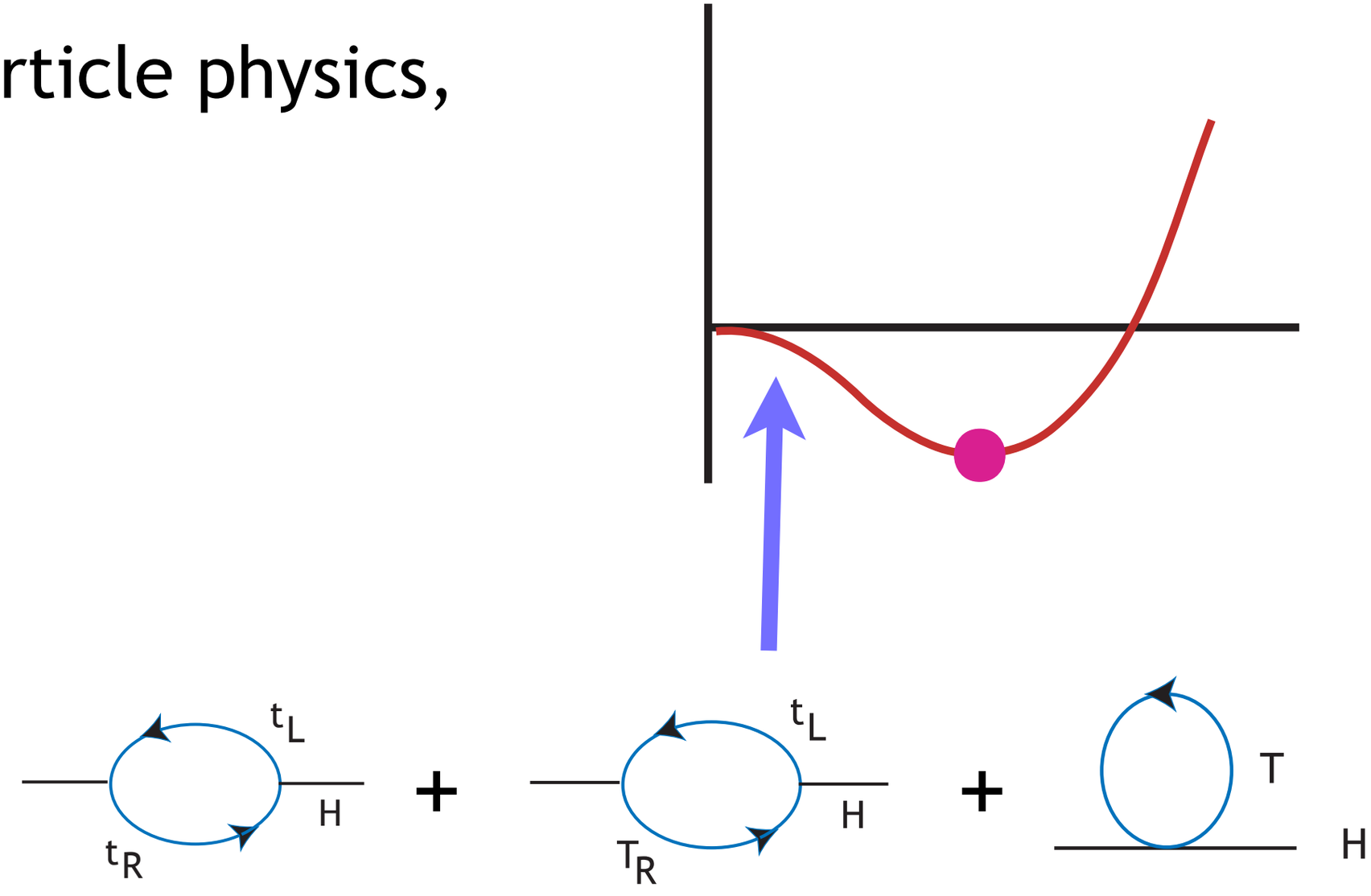


The issue here is not a naturalness problem, it is a "no physics explanation" problem.

What does an explanation look like ?

In condensed matter physics: Cooper pairing, Hund's rule, Peierls instability, ...

In particle physics,



New particles are needed.

Naively, they are at 100 GeV.

(Hmm, they are not there ....)

“Naturalness” arguments come in at this stage.
They estimate how heavy these particles can be.

SUSY is a special case. There is a potentially large positive contribution to the Higgs mass term that must be cancelled.

$$m_Z^2 = 2\,\frac{M_{Hd}^2 - \tan^2\beta M_{Hu}^2}{\tan^2\beta - 1} - 2\mu^2$$

No large cancellations:

$$\mu \lesssim 200\ \mathrm{GeV}$$ Higgsino mass

$$m(\widetilde{t}) \lesssim 1\ \mathrm{TeV}$$ stop mass

$$m(\widetilde{g}) \lesssim 3\ \mathrm{TeV}$$ gluino mass

Optimistically, we will get there at HL-LHC.

There are other concrete models of the negative Higgs mass term. Models with extra dimensions, Goldstone bosons, etc. have formulae like

$$\mu^2 \sim -\alpha_t m_T^2$$

and so suggest

$$m_T \sim 1 - 3 \text{ TeV}$$

We are not there yet at LHC. Optimistically, we will reach this at HL-LHC.

If there is no discovery, we may need a pp collider at still higher energy to kill “Naturalness”.

But, the goal is not to kill “Naturalness”.

The goal is to find the explanation for a phenomenon that needs one.

The HL-LHC has very respectable reach. We will find it.