Lessons from future colliders

Francesco Riva
(Geneva University)

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There is little I can add to the great work that has been presented these days...

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... I will say less, less precisely, and with less generality

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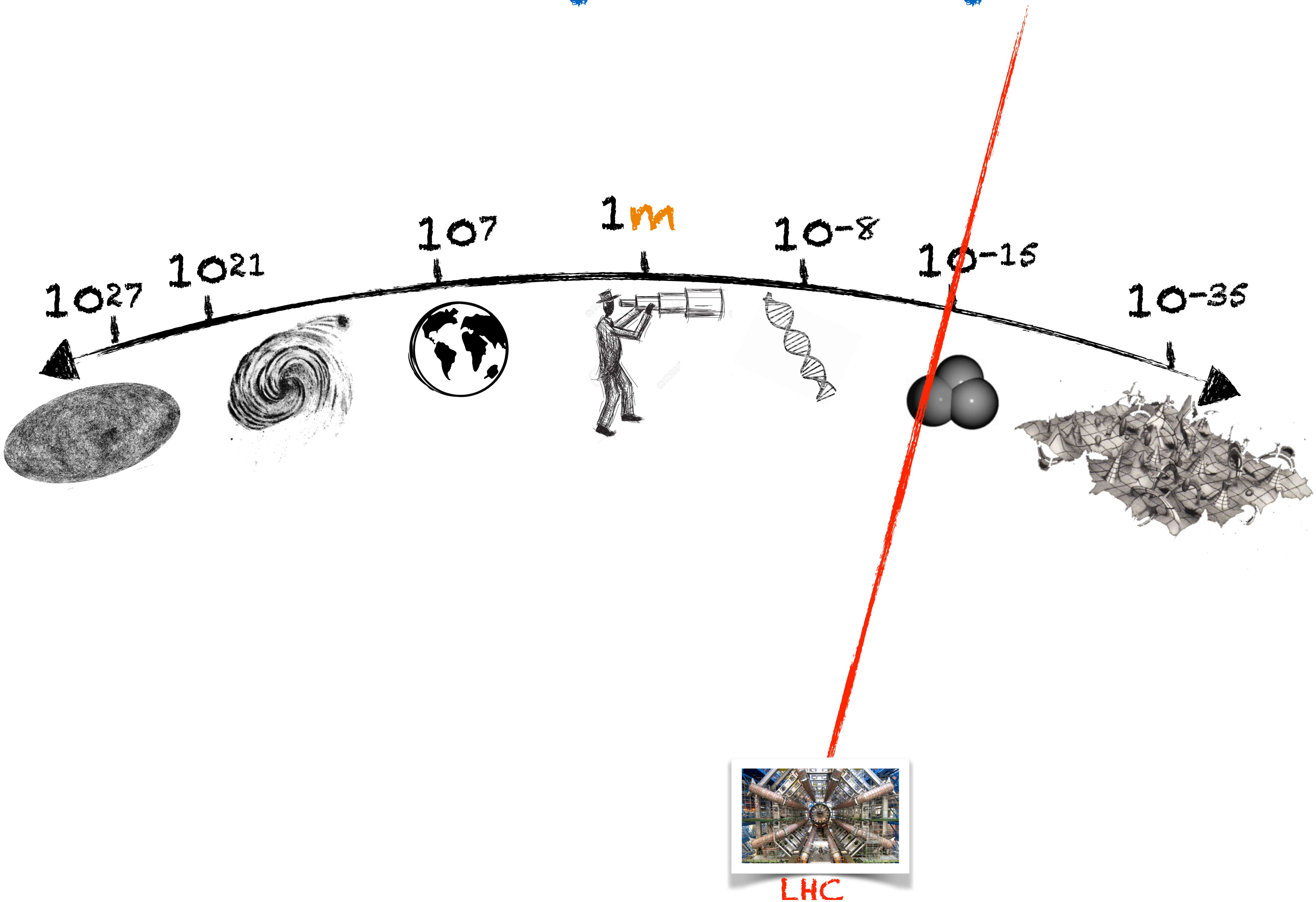
- I'm ~~not~~ a model builder $\rightarrow$ talk ~~not~~ about fancy ideas or ideologies

High-Energy Particle Physics



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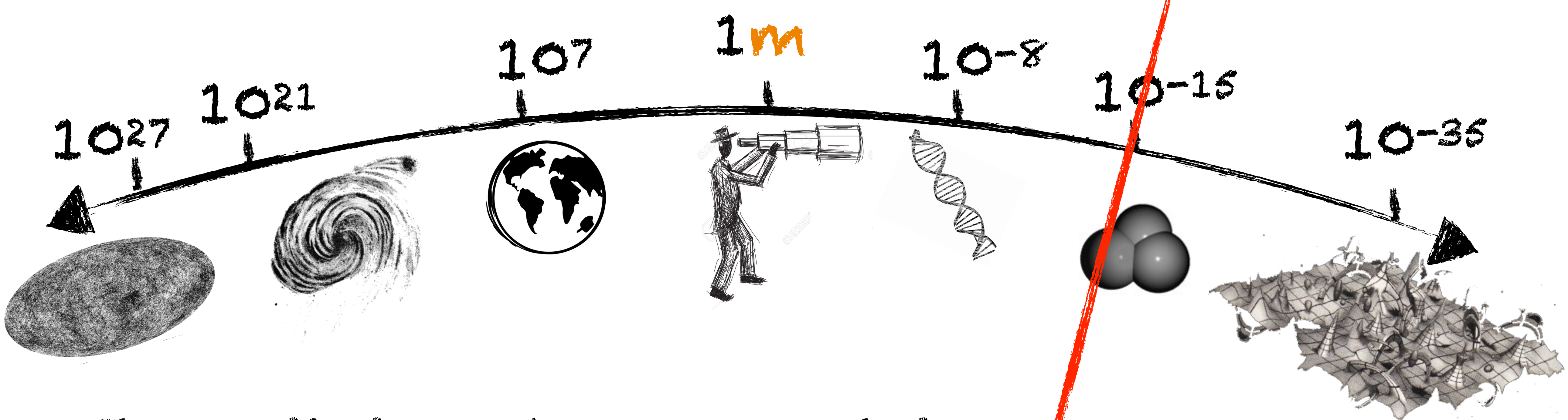
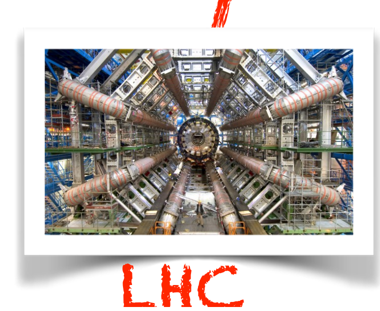


Things that are large enough to
be accessed in experiments...



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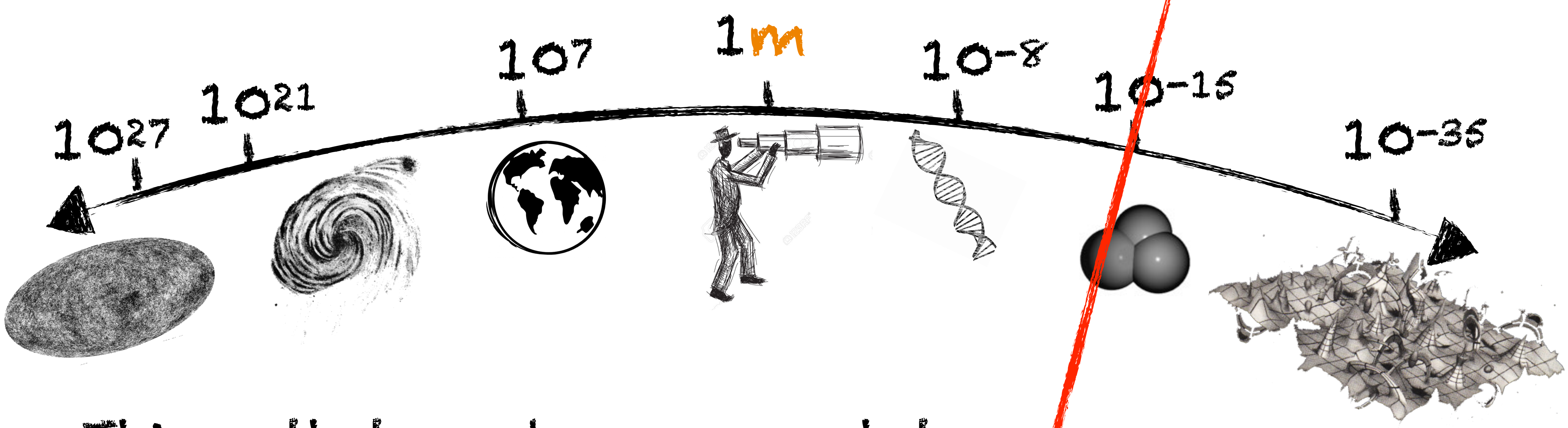

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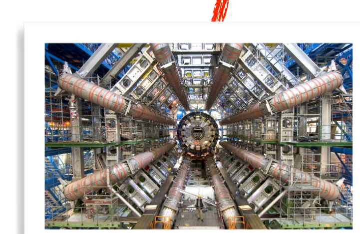
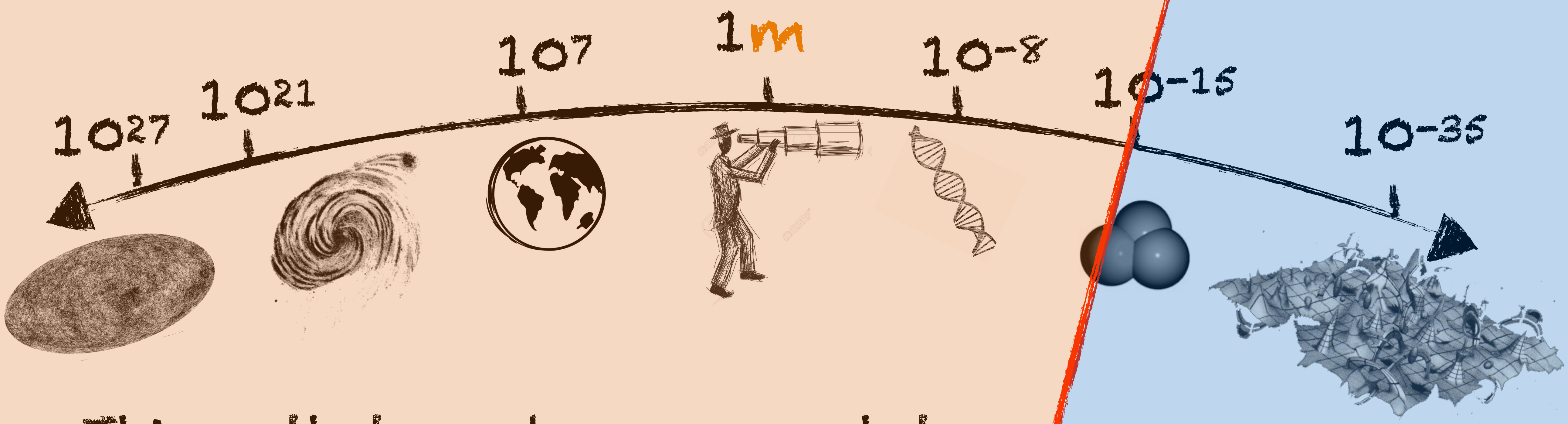


IR

High-Energy Particle Physics

UV



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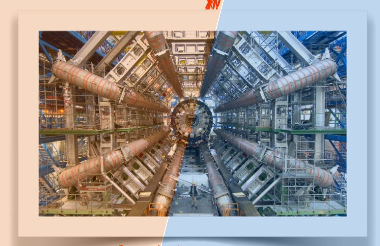

LHC

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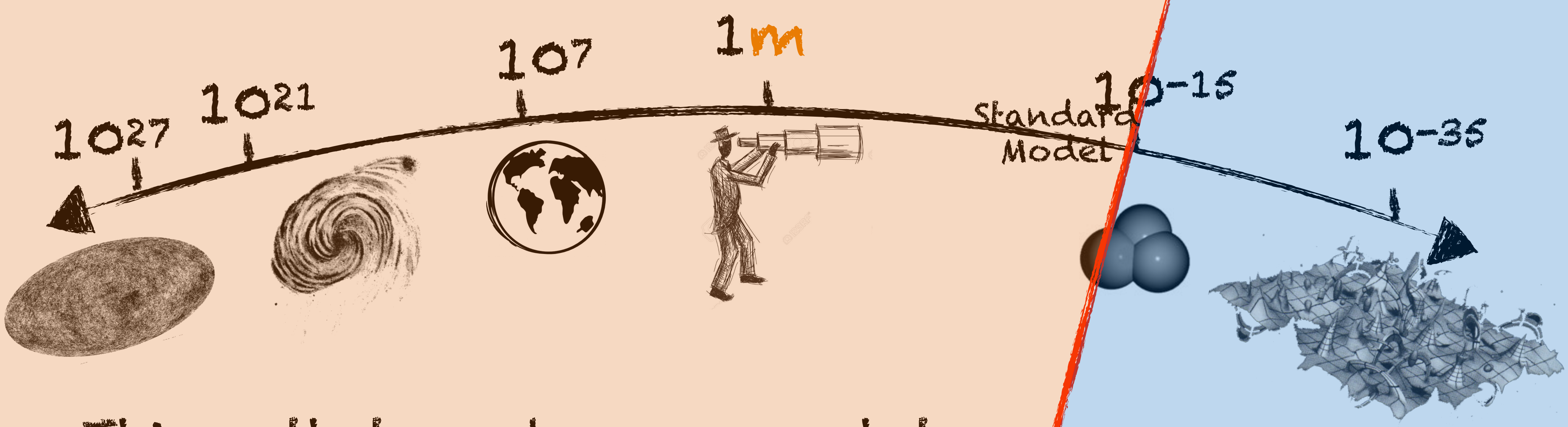

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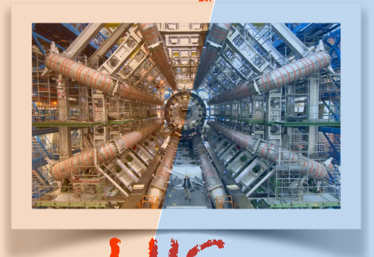

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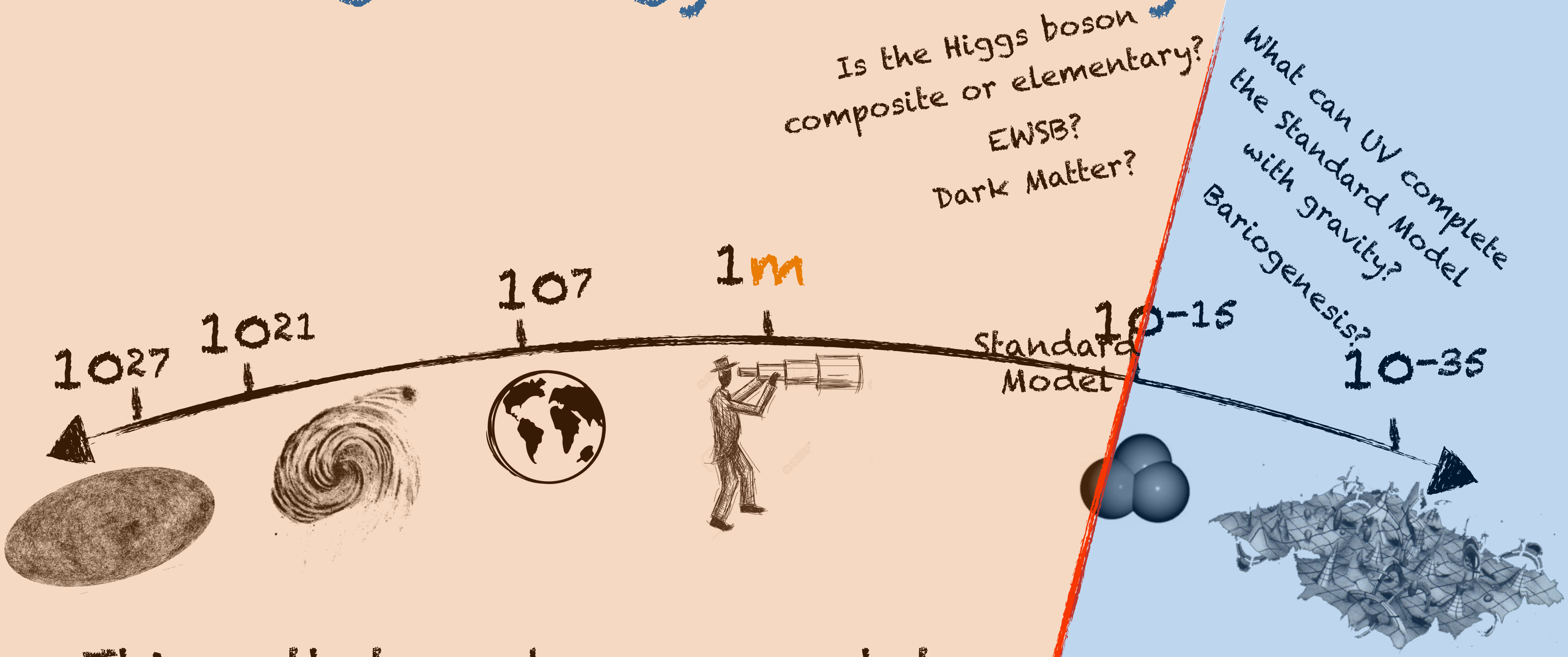

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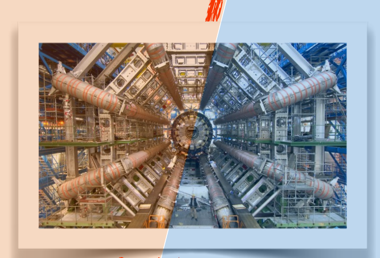
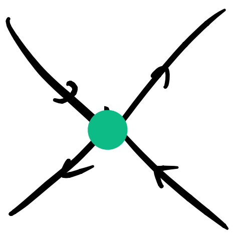


LHC

No Lose Theorems

HEP: a history of guaranteed discoveries



$$\frac{1}{v^2}(\bar{\psi}\gamma_\mu\psi)^2$$

$$\psi\psi \to \psi\psi$$

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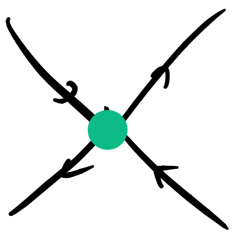

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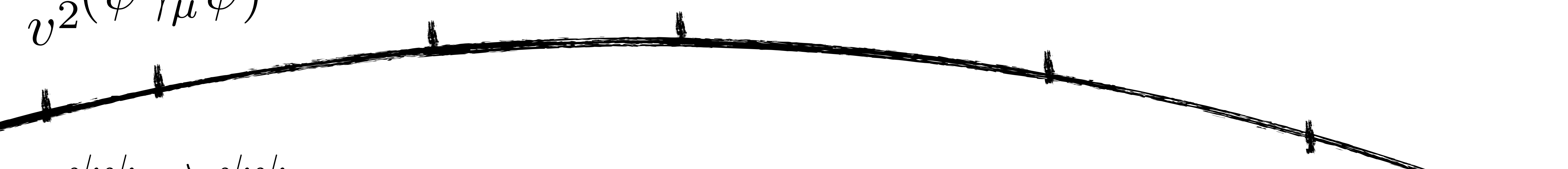

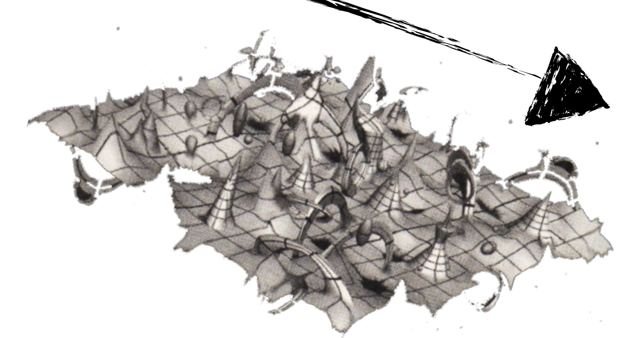

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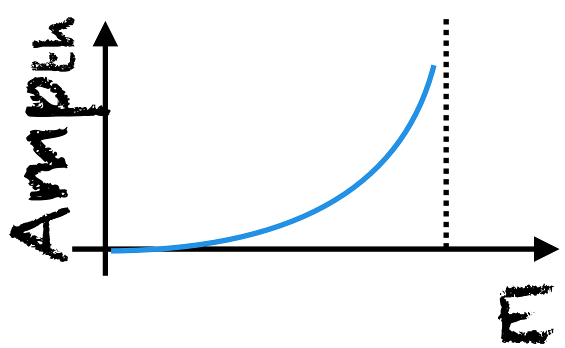

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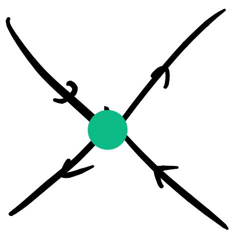

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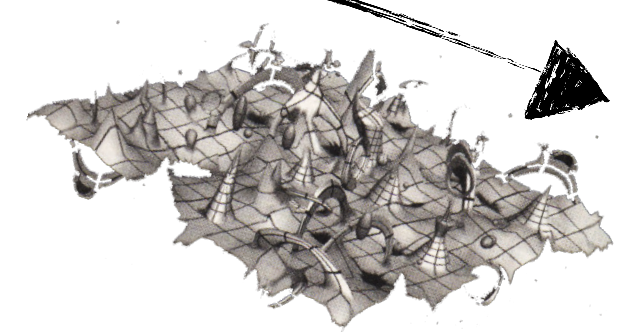

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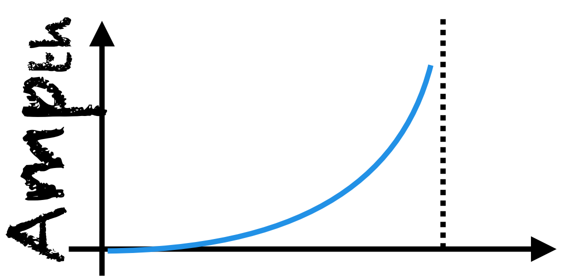

need W-boson

$m_W \lesssim 3TeV$

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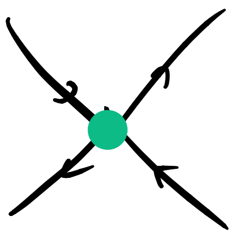

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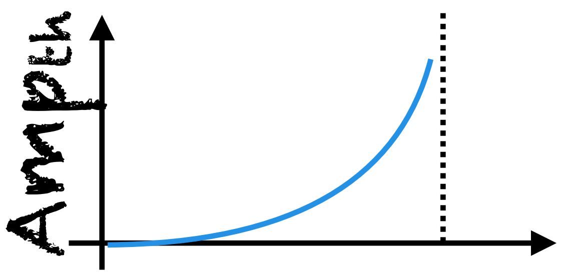

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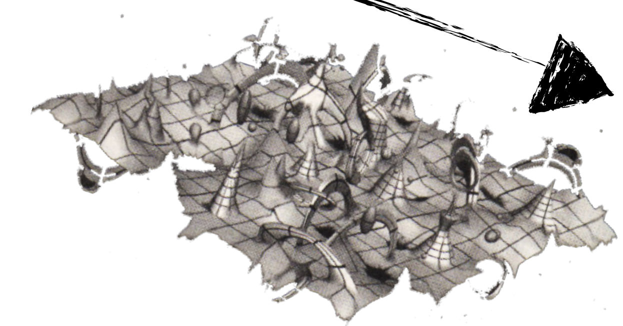

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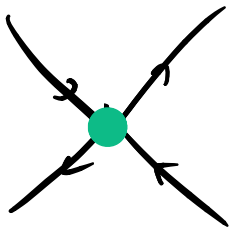

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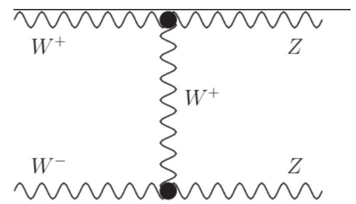

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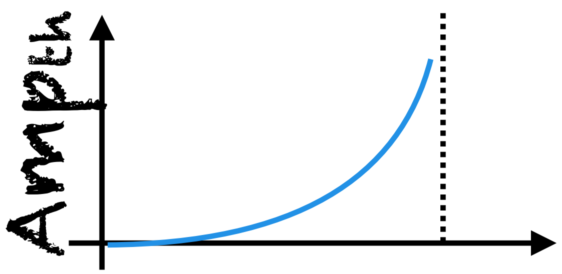

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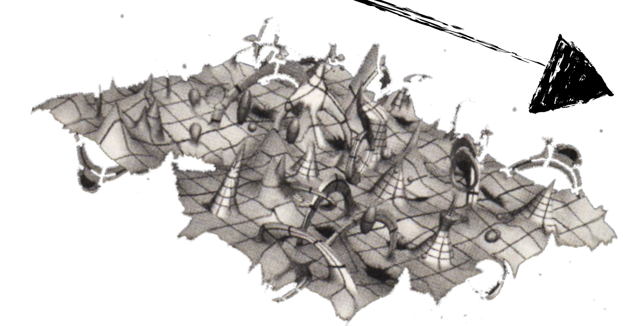

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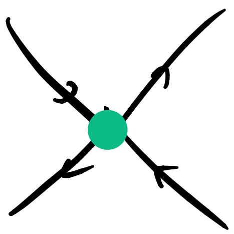

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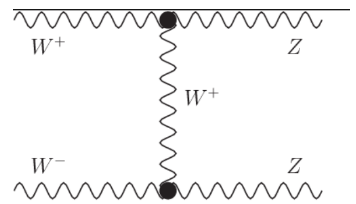

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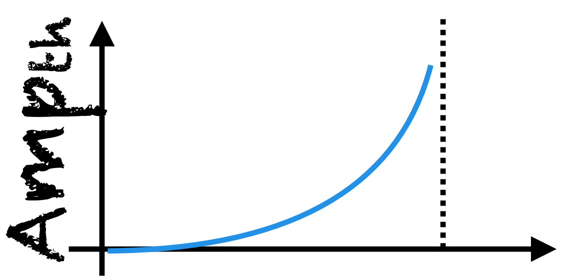
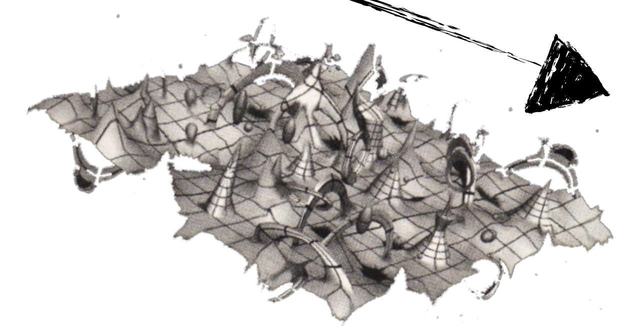
$WW \to WW$





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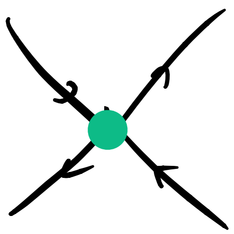

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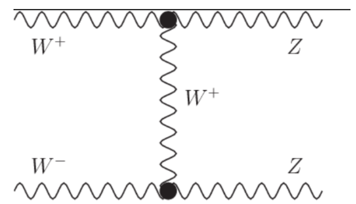

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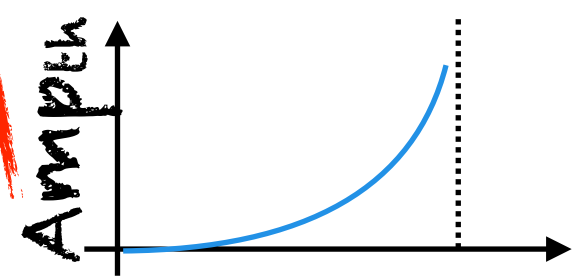

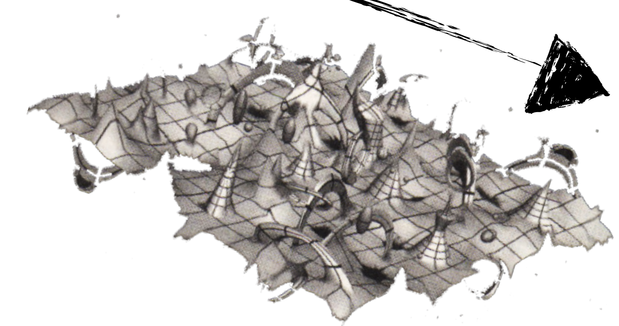

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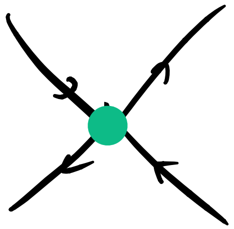

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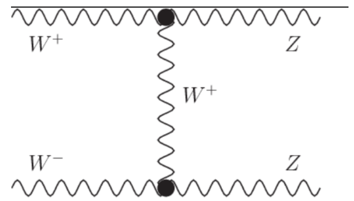

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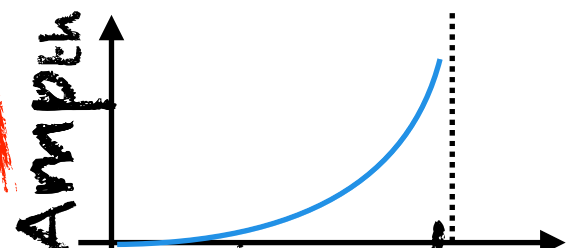

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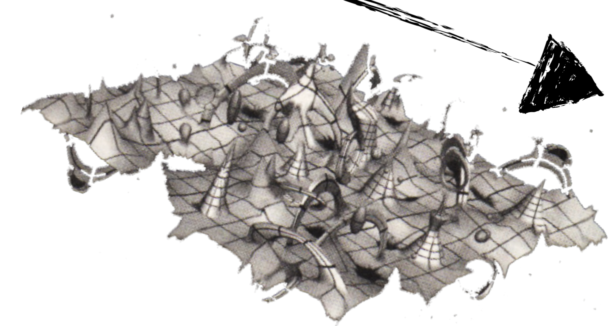

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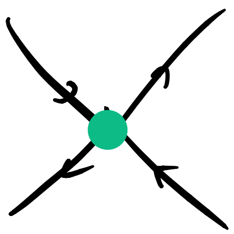

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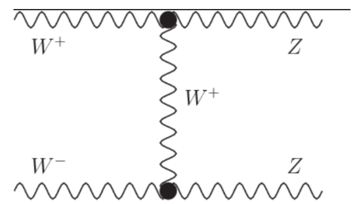

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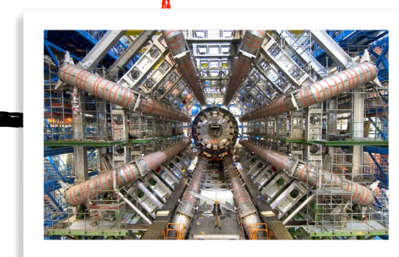

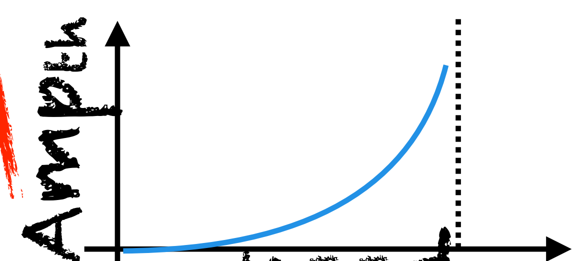

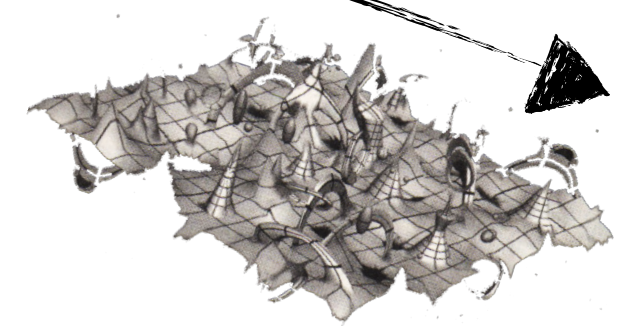

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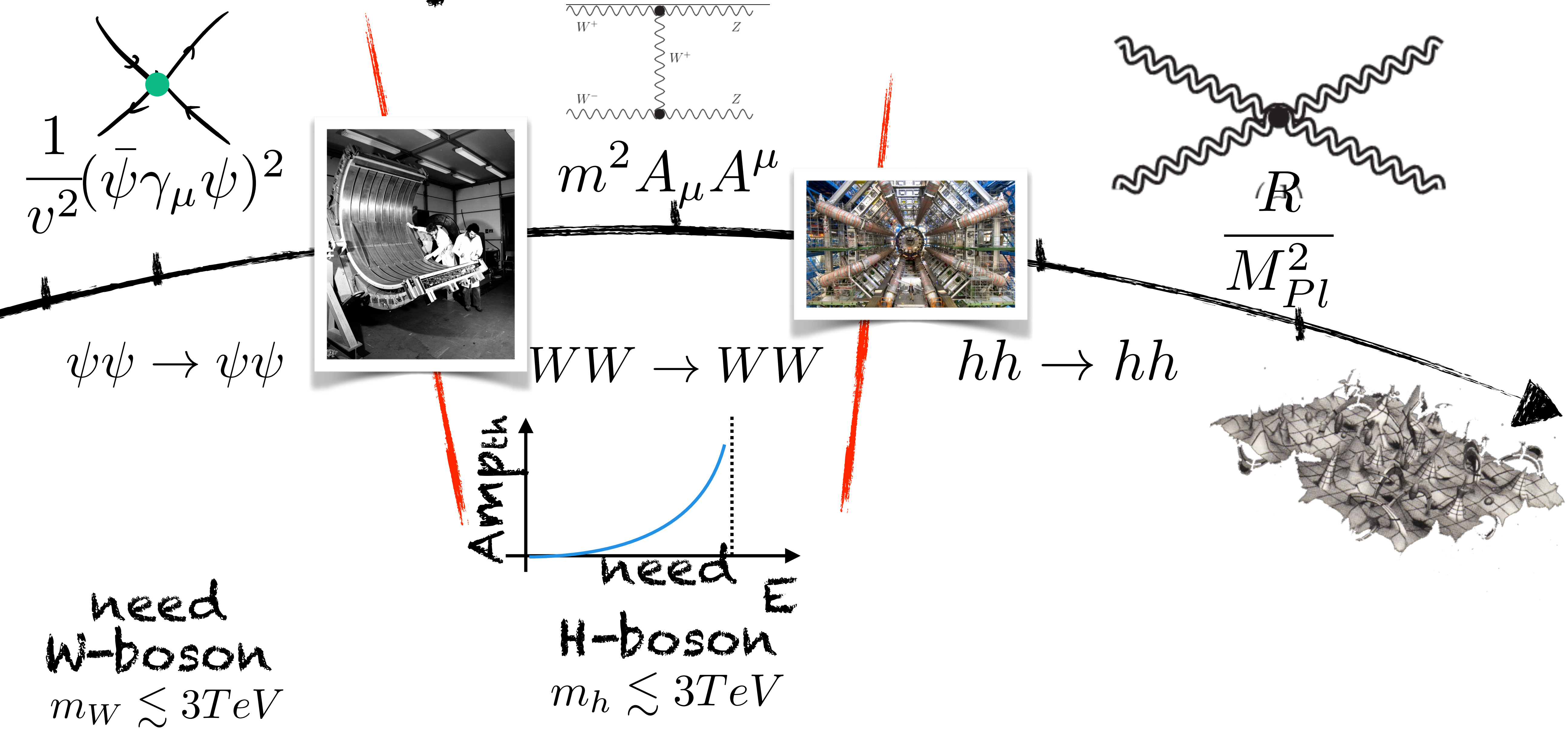

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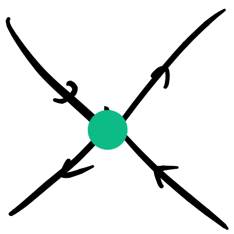

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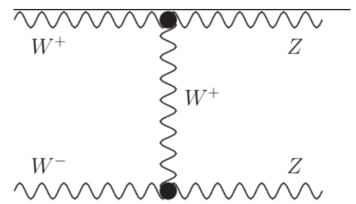

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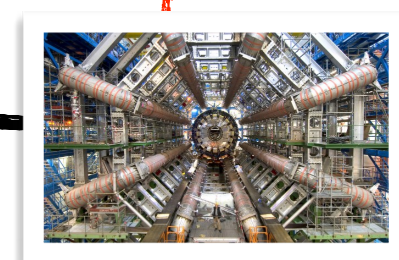
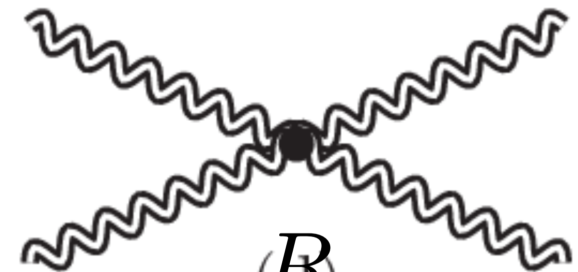


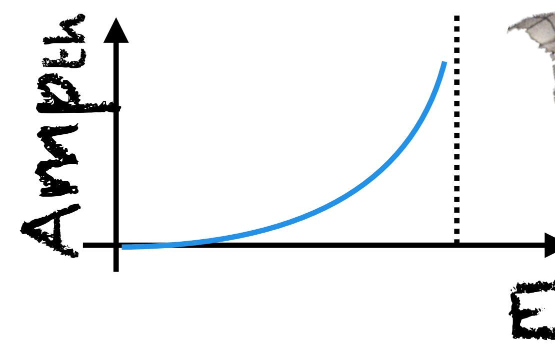


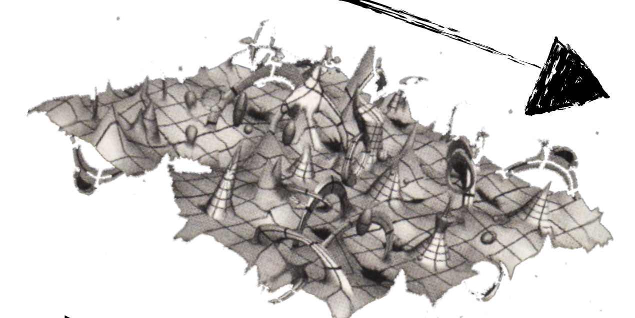
$$\frac{R}{M_{Pl}^2}$$

$\psi\psi \to \psi\psi$

$WW \to WW$

$hh \to hh$





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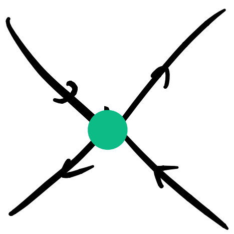

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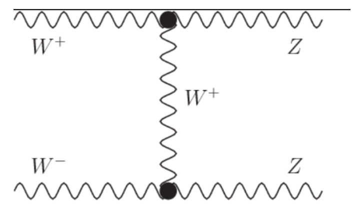

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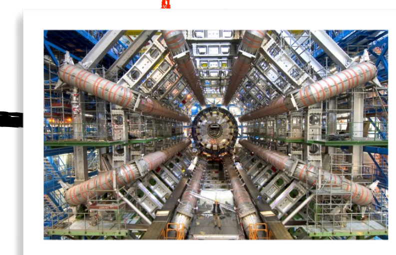

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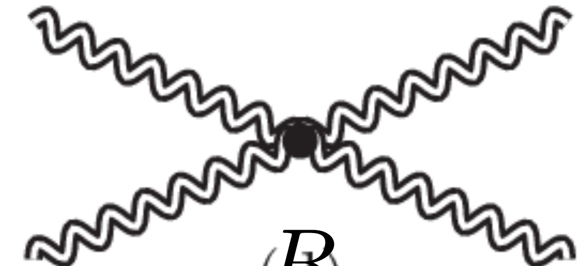

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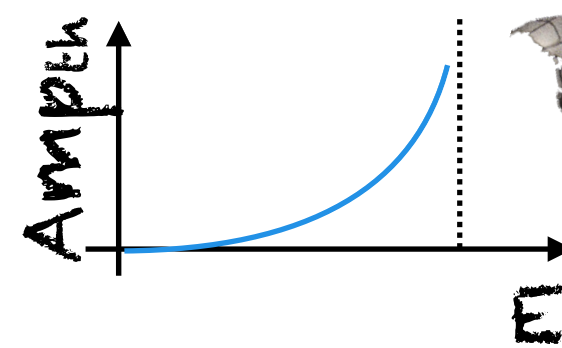
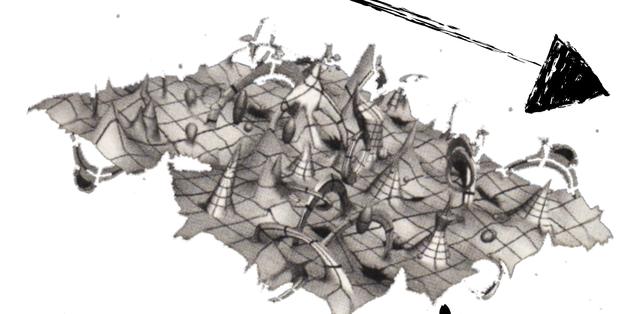




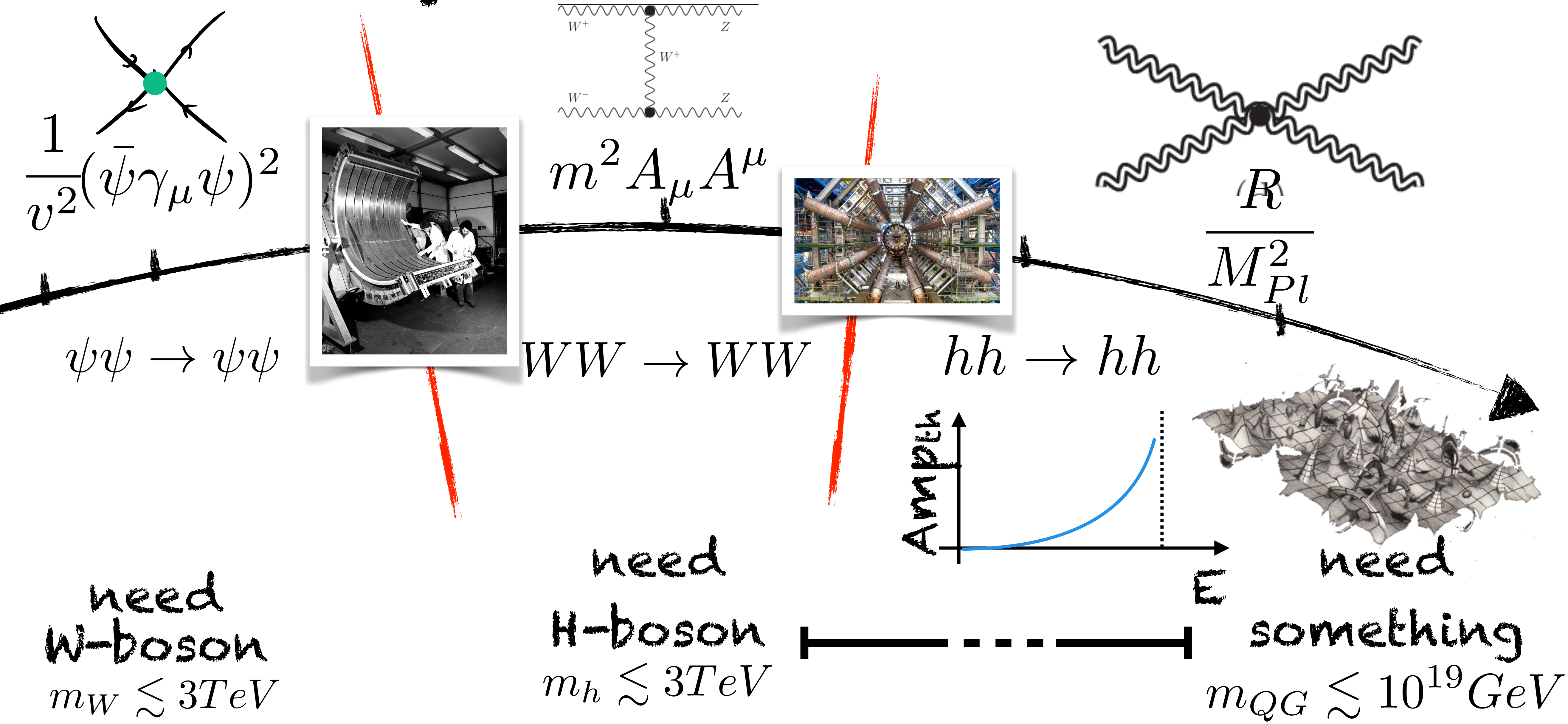
need W-boson
$m_W \lesssim 3TeV$

need H-boson
$m_h \lesssim 3TeV$

need something
$m_{QG} \lesssim 10^{19}GeV$

No Lose Theorems

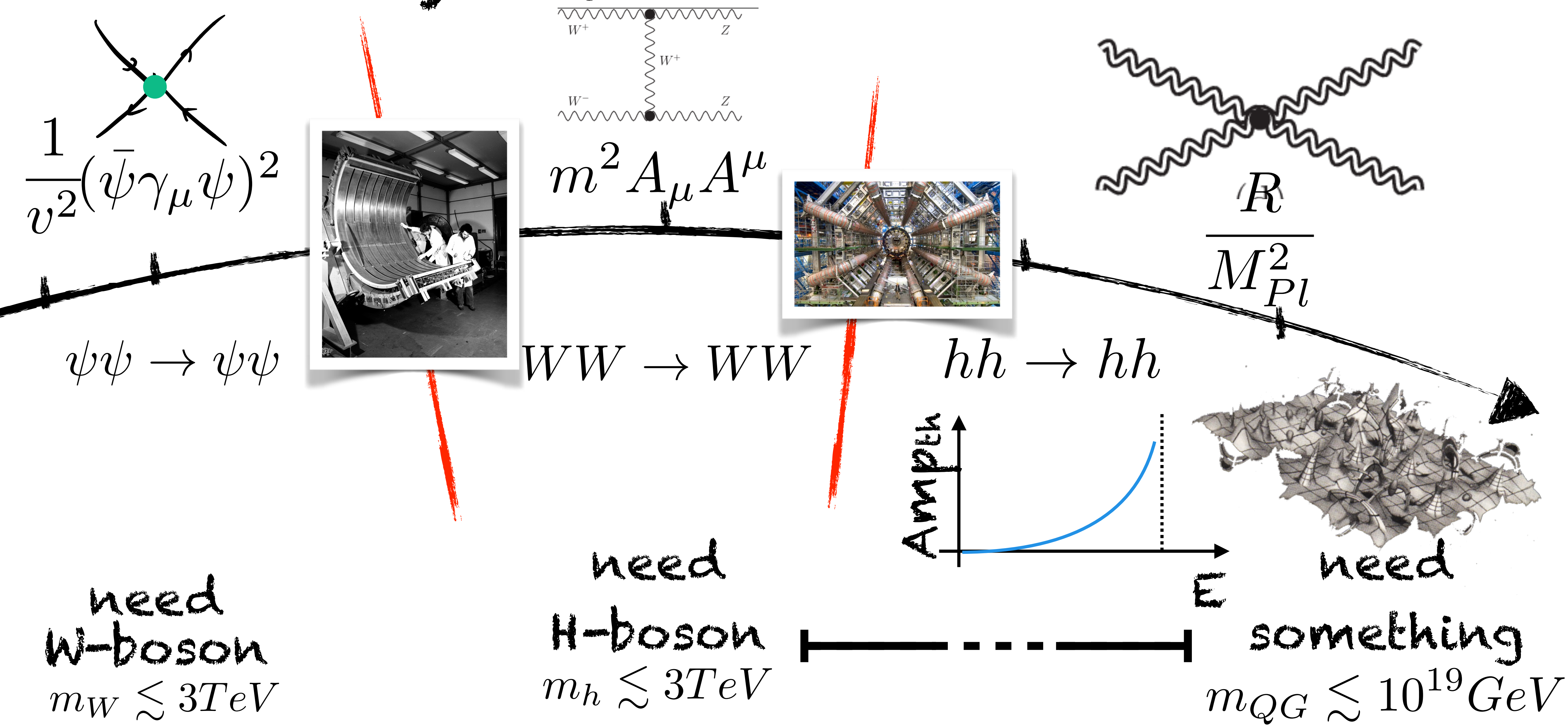
HEP: a history of guaranteed discoveries



- Exceptional story, but science is not about no lose theorems

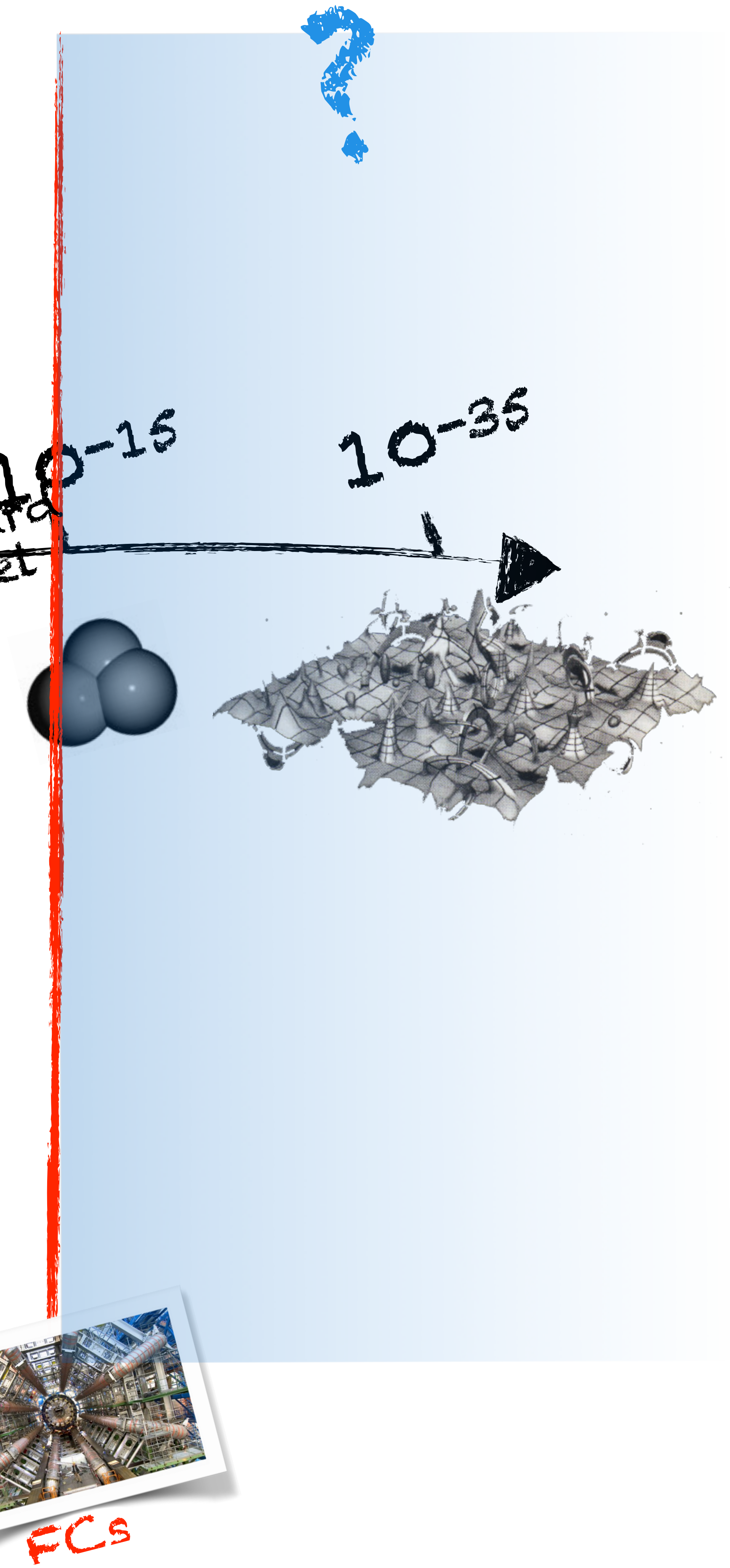
No Lose Theorems

HEP: a history of guaranteed discoveries



- Exceptional story, but science is not about no lose theorems
- What will we learn from this exploration?
- If you have to focus on one question, what will it be?

High-Energy Particle Physics Mindset



- Think of the unexplored as REALLY unknown

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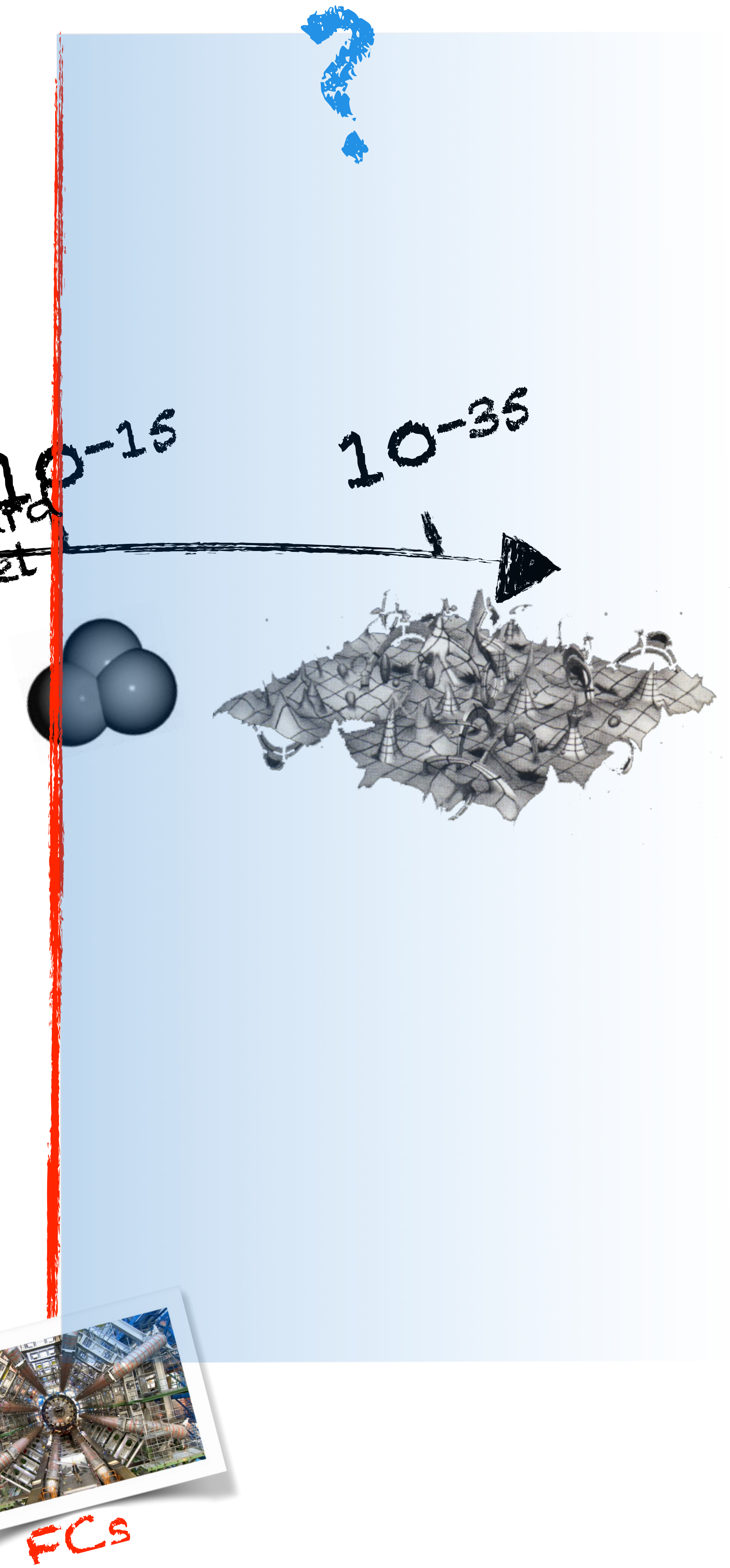

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- No notion of "confirming the SM": there is no SM+Gravity theory!

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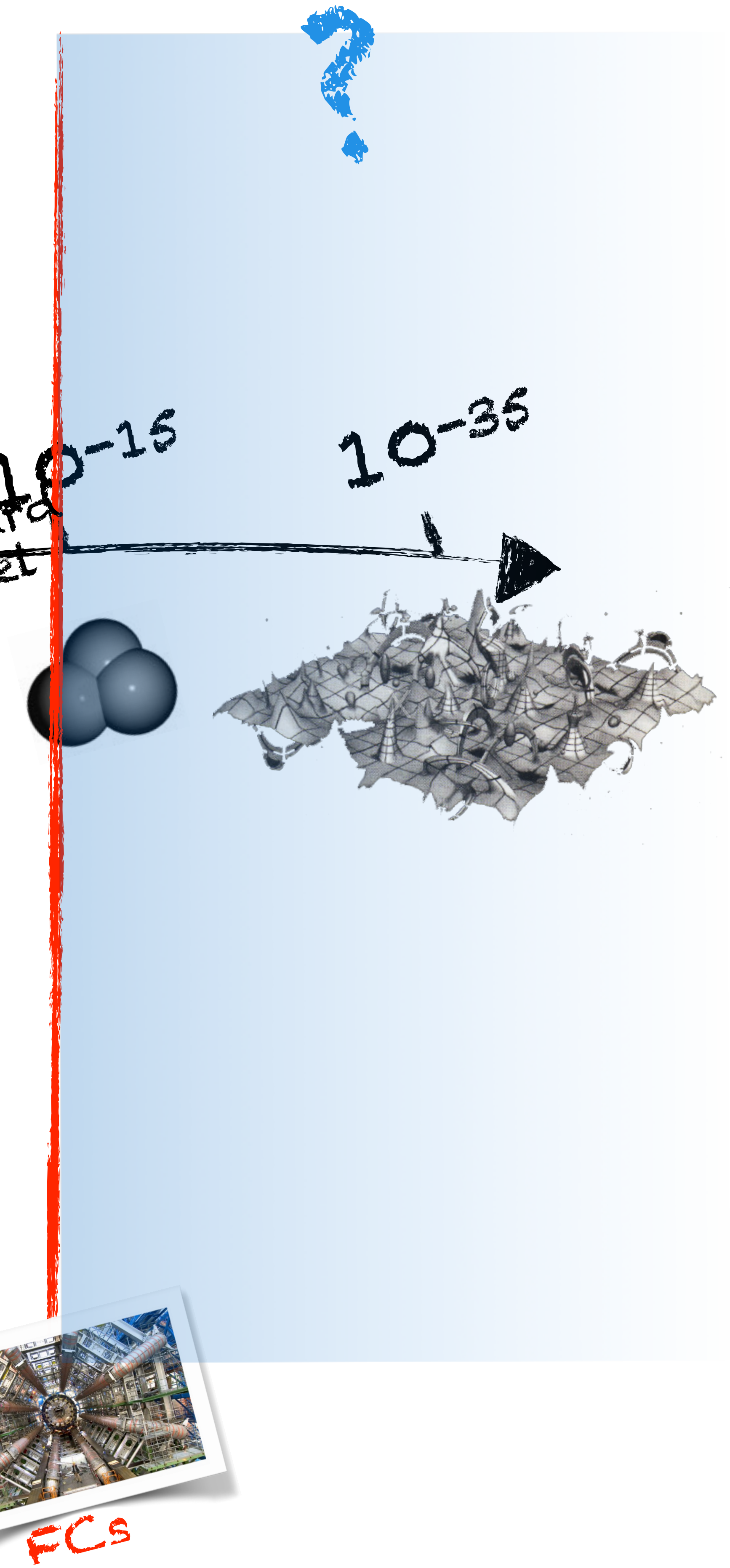


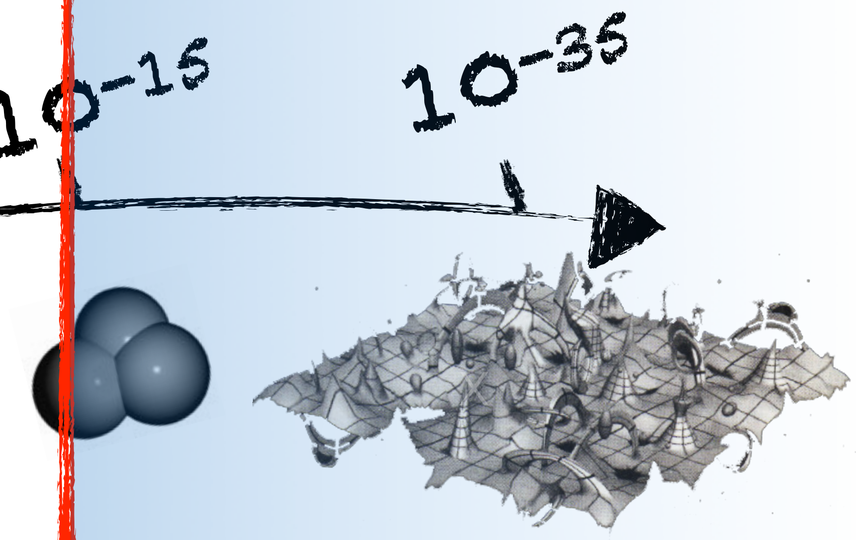
- Think of the unexplored as REALLY unknown
- No notion of "confirming the SM": there is no SM+Gravity theory!
- The SM really is an EFT with many possible features: every new measurement teaches us something new about these

microscopic laws of nature

$$\mathcal{L} = \sum_i c_i \frac{O_i^{(n)}}{\Lambda_i^{n-4}}$$

High-Energy Particle Physics

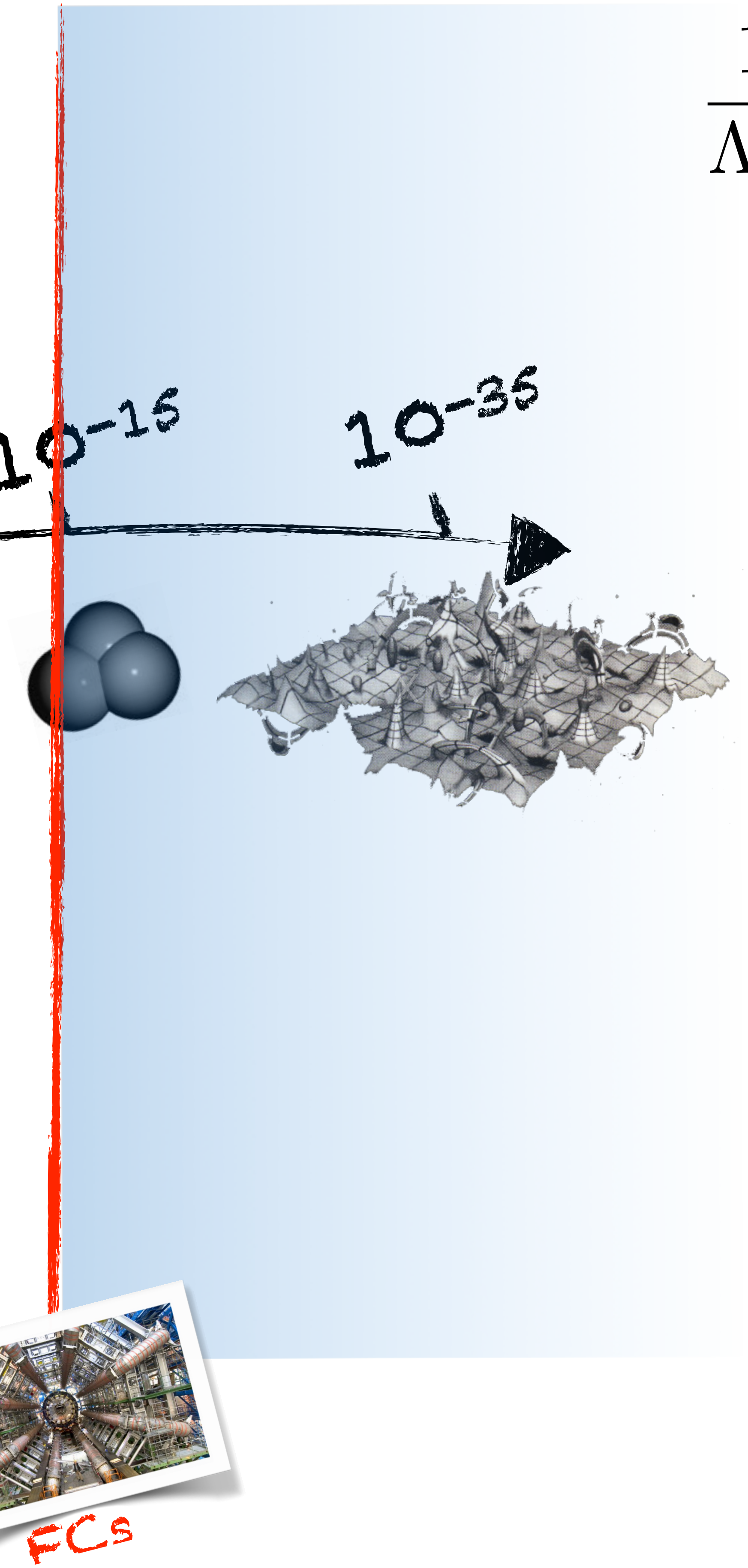
$$\frac{1}{\Lambda^2_{\not{B}}}\left[(d_p^{\alpha})^T C u_r^{\beta}\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$$



High-Energy Particle Physics

$$\frac{1}{\Lambda^2_{\not{B}}}[(d^\alpha_p)^T C u^\beta_r]\,[(q^{\gamma j}_s)^T C l^k_t]$$

Proton Lifetime $t_p > 10^{34} y$



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$\Lambda_{\not B} > 10^{16}\,\mathrm{GeV}$

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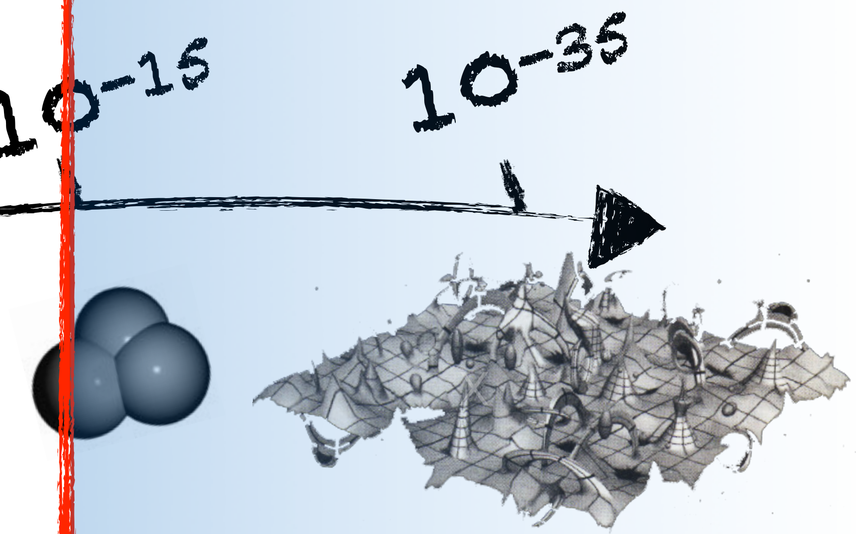

FCs

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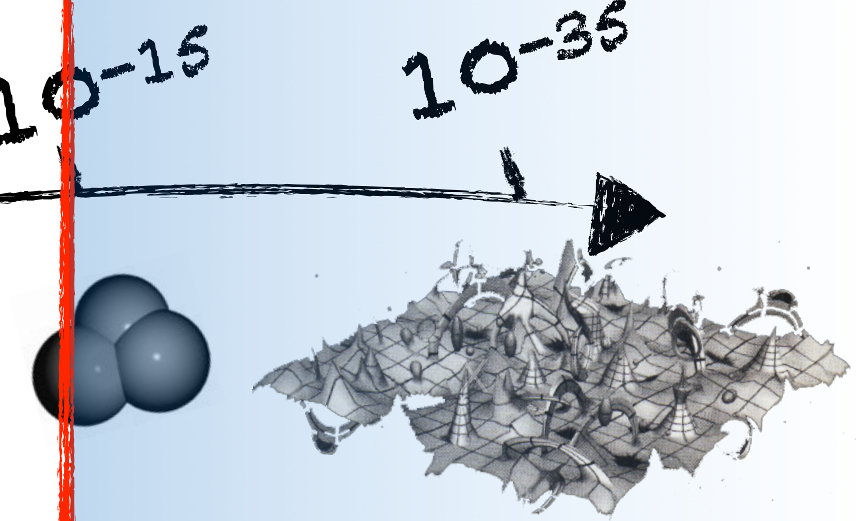

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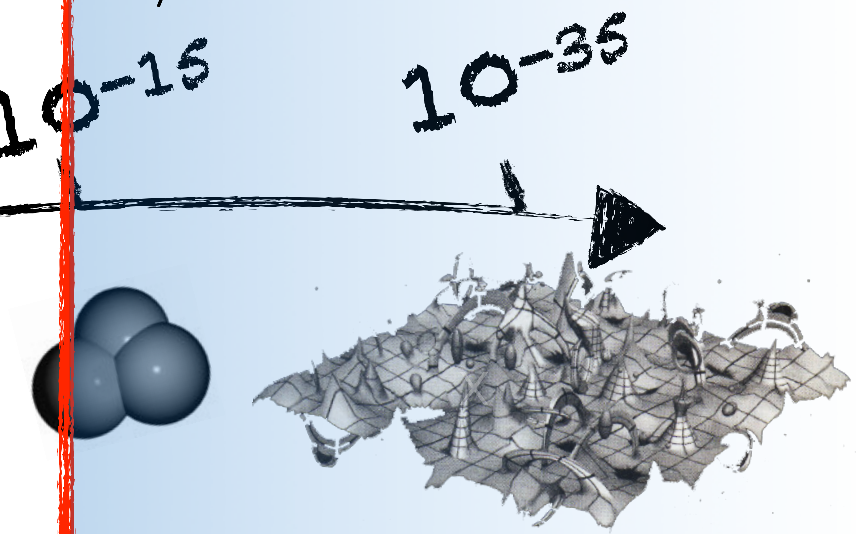

- Laws of nature governed by (emerging) symmetries

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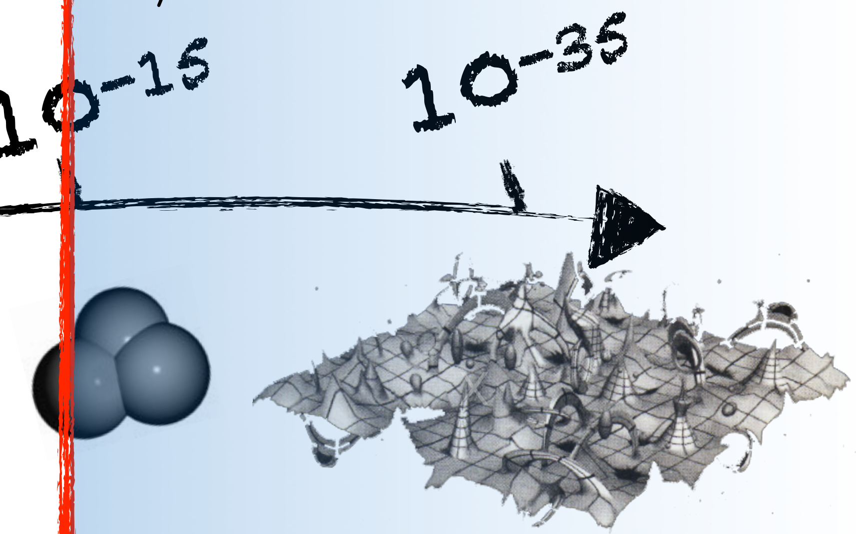

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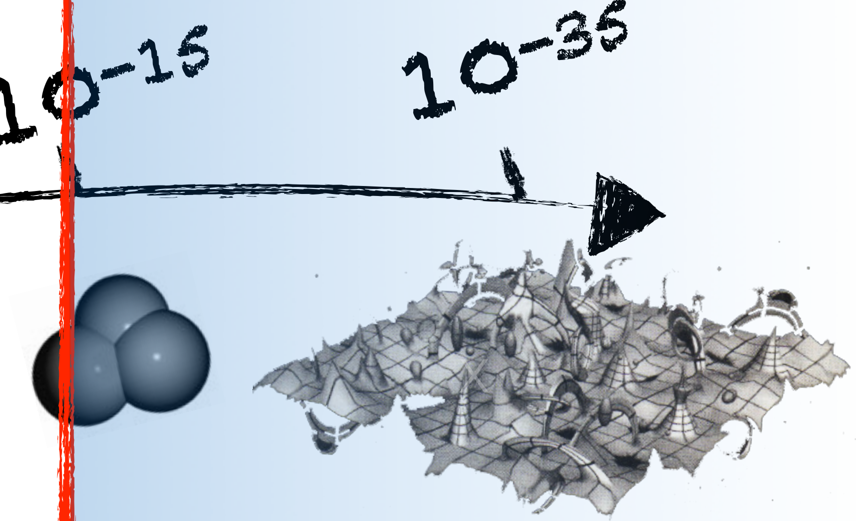

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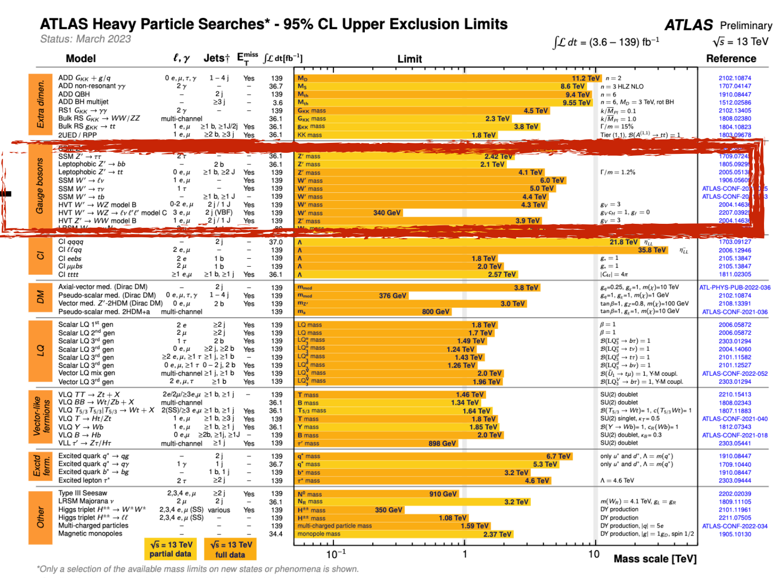

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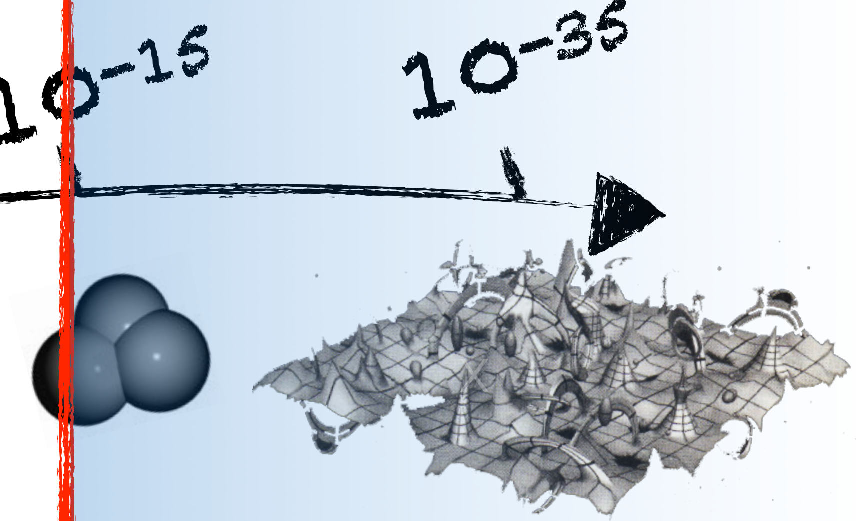

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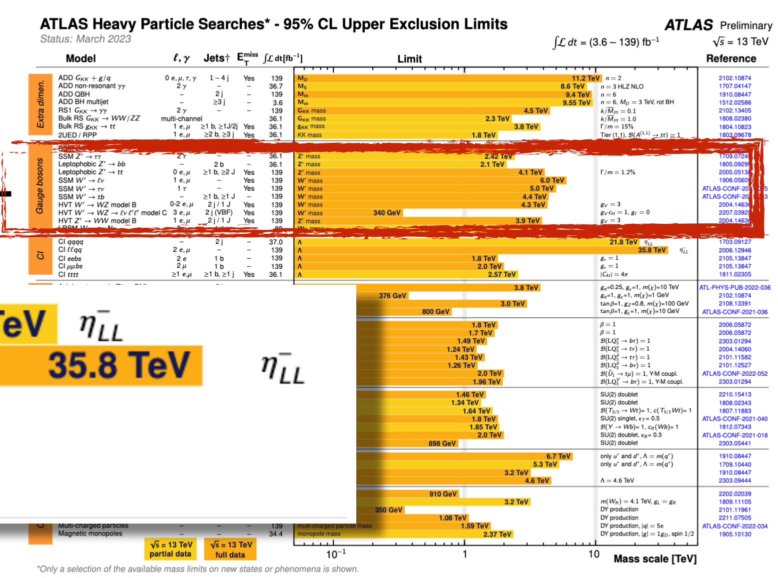

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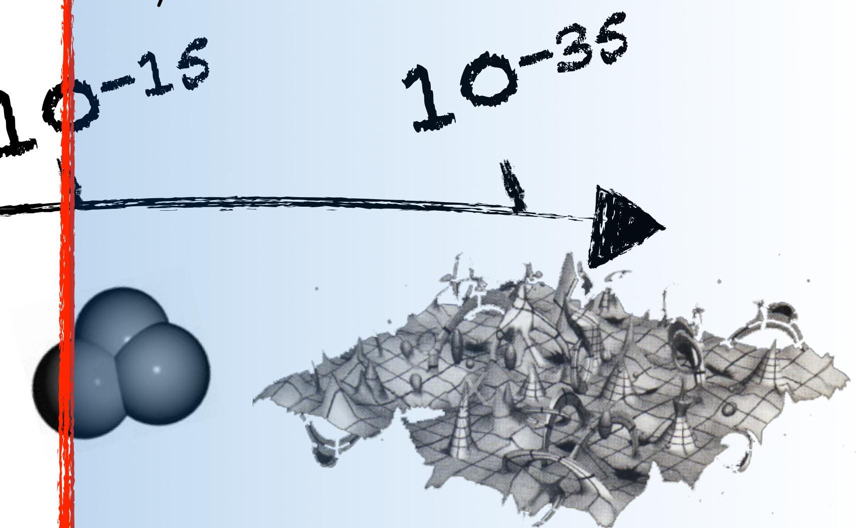

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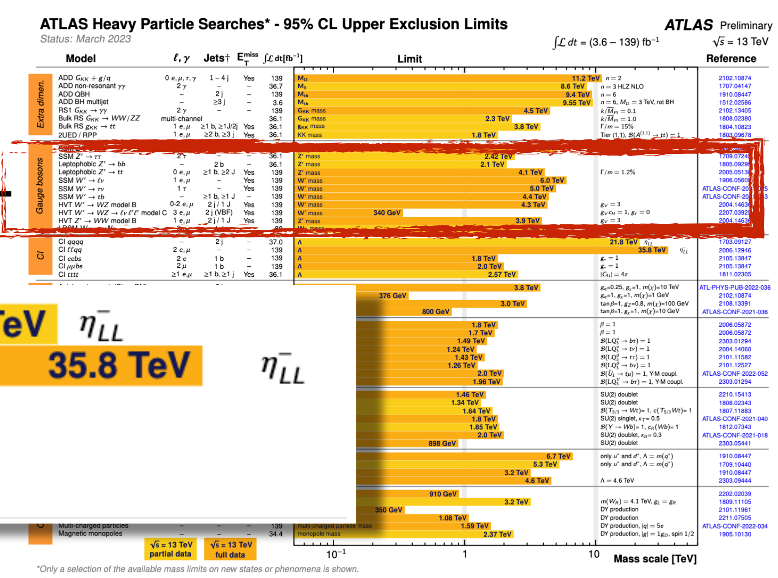

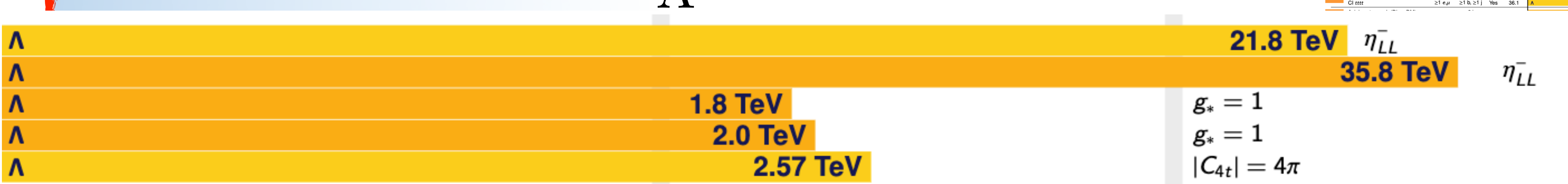

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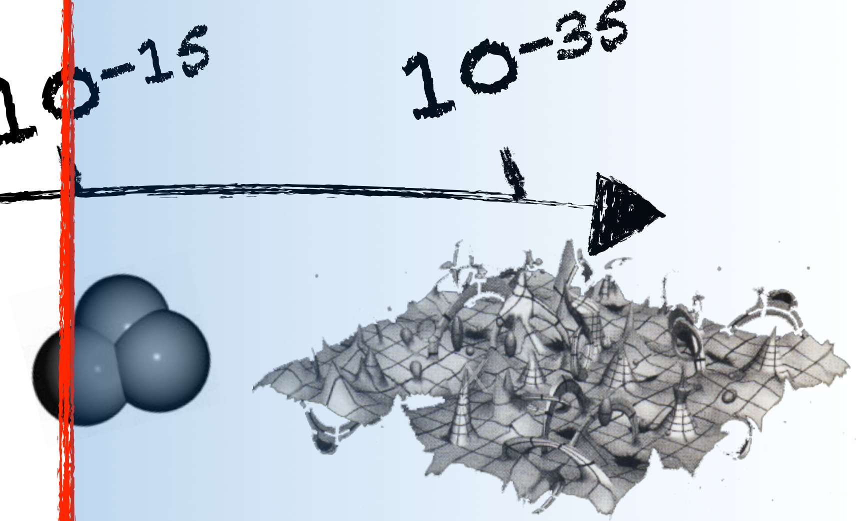

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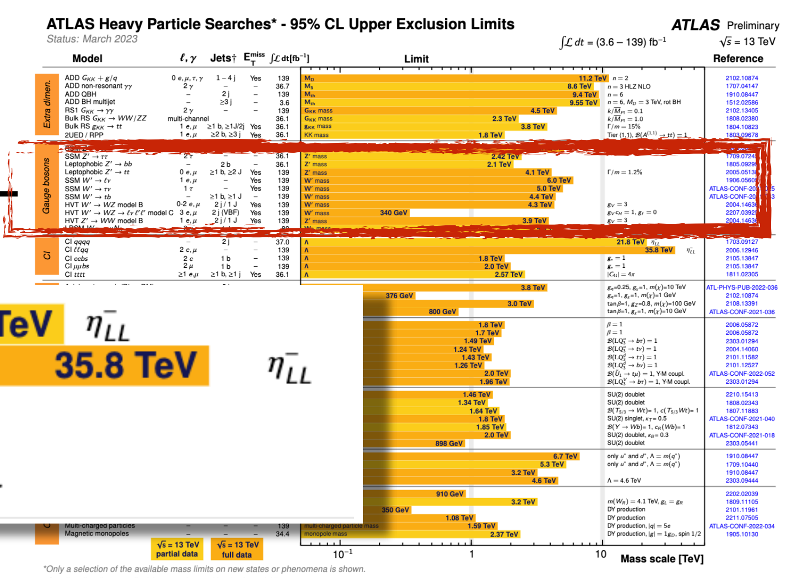

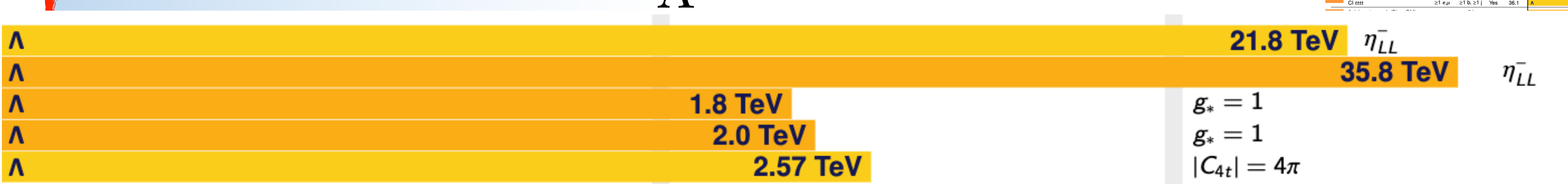

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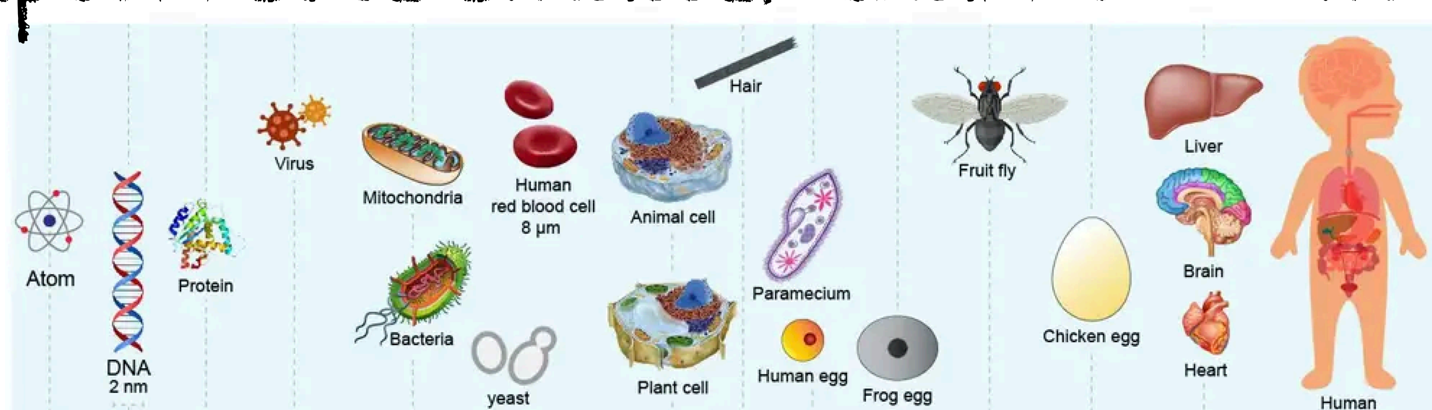

FCs

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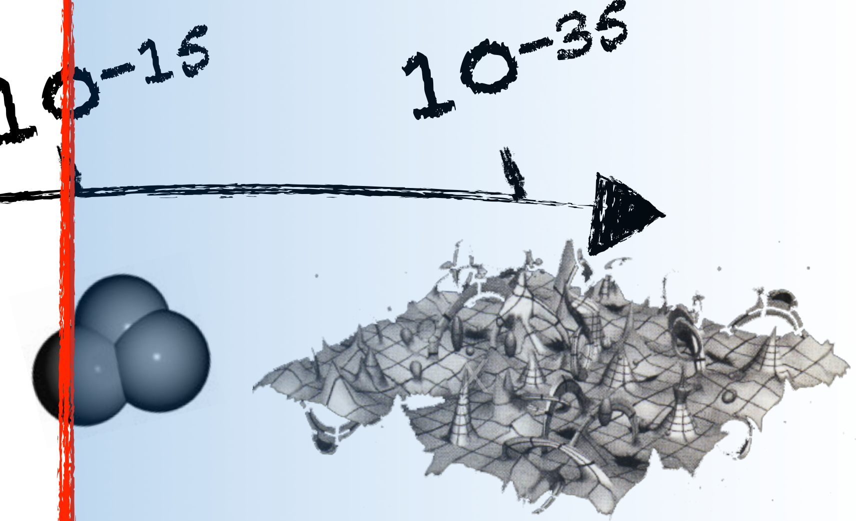

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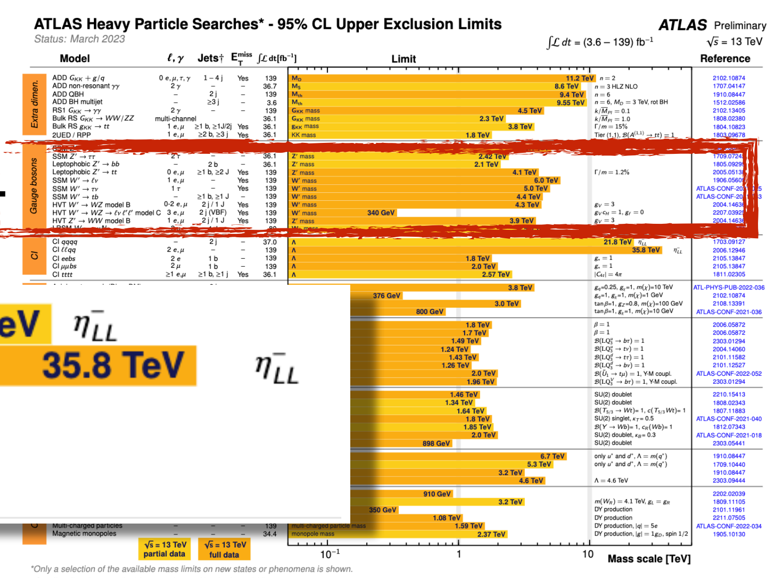

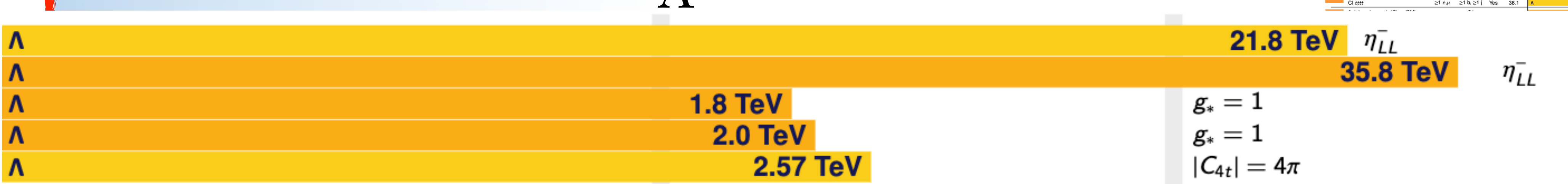

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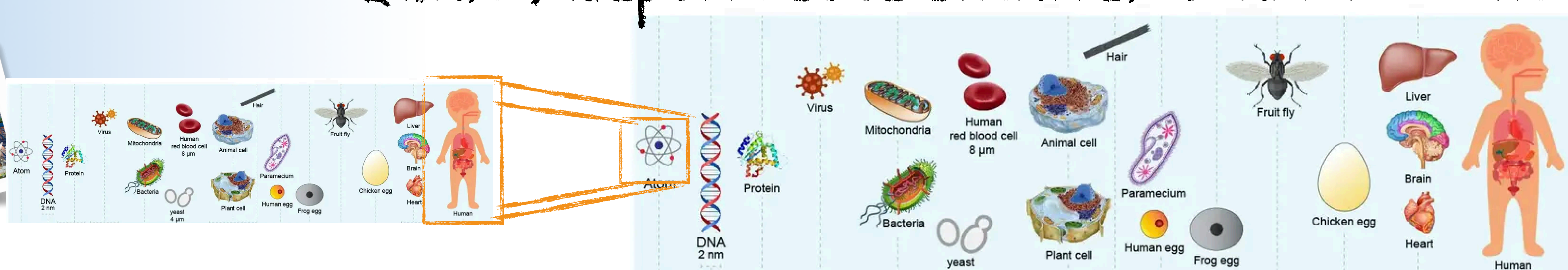

One question for future colliders:

What is the size of the Higgs boson?

The size of spin-0 particles in HEP

$$L_{compton} \sim \frac{1}{m}$$

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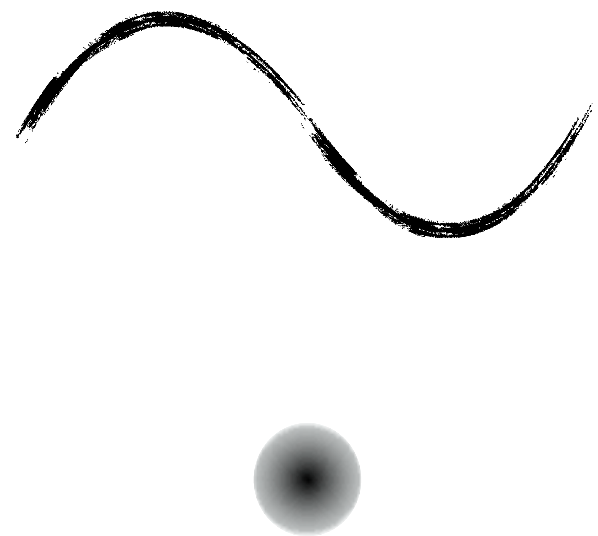

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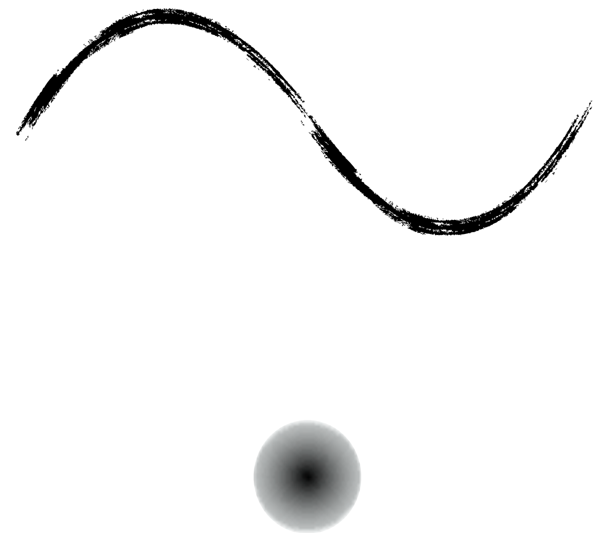

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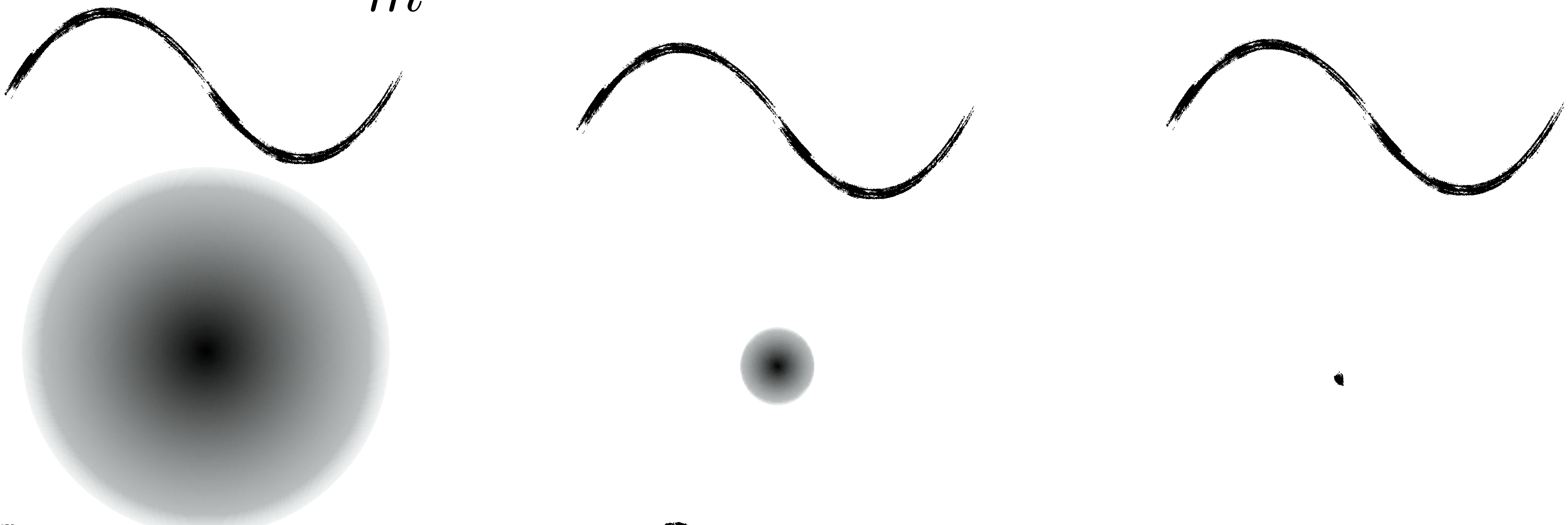

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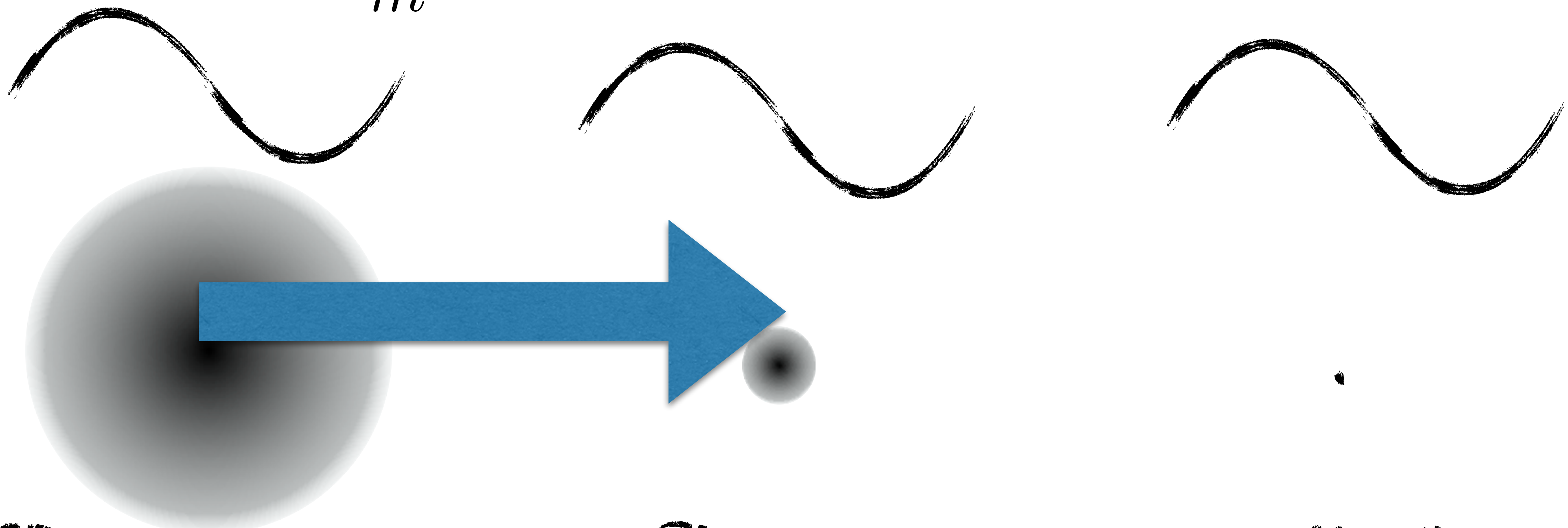

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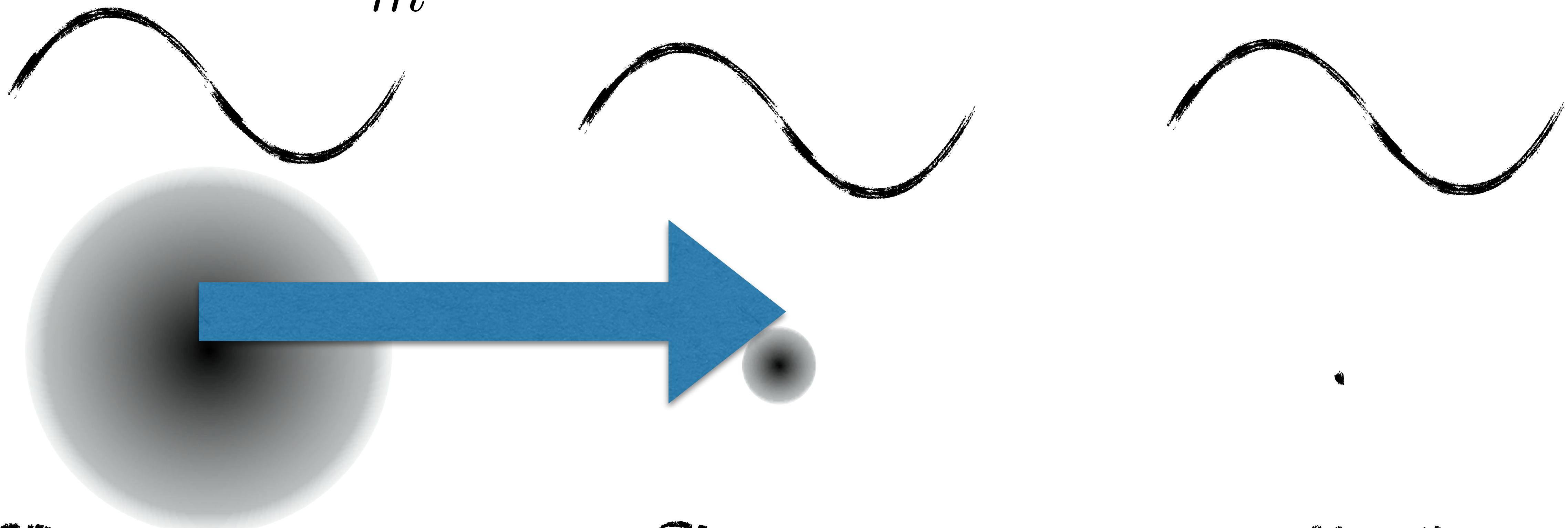

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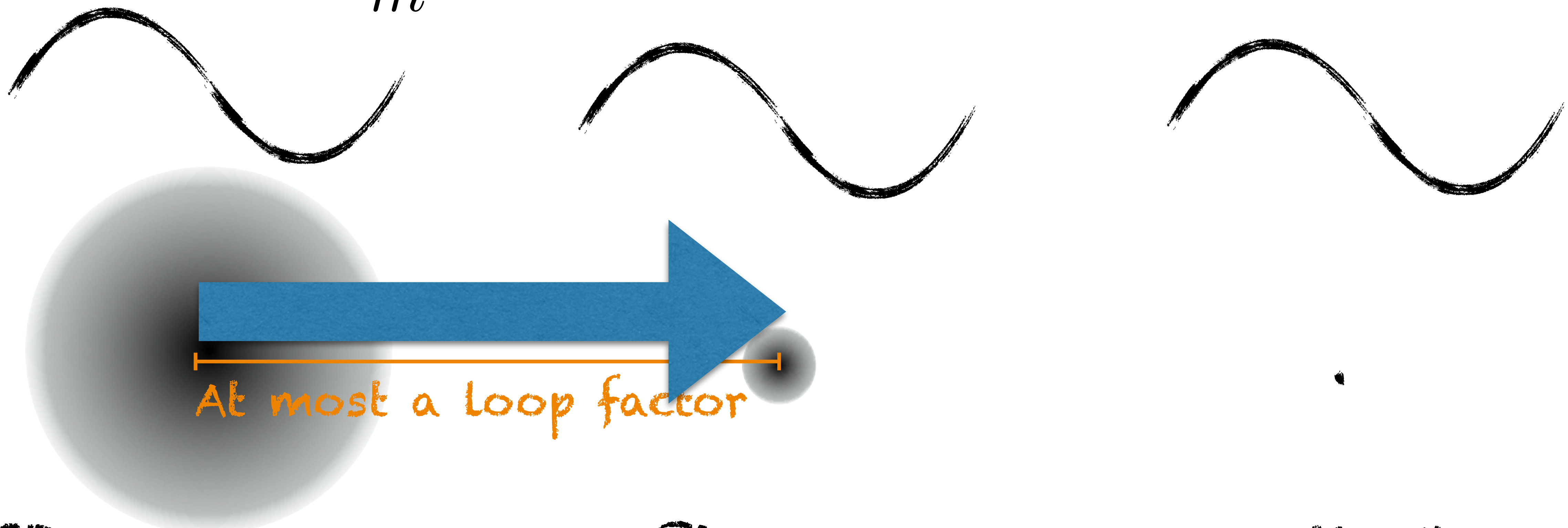

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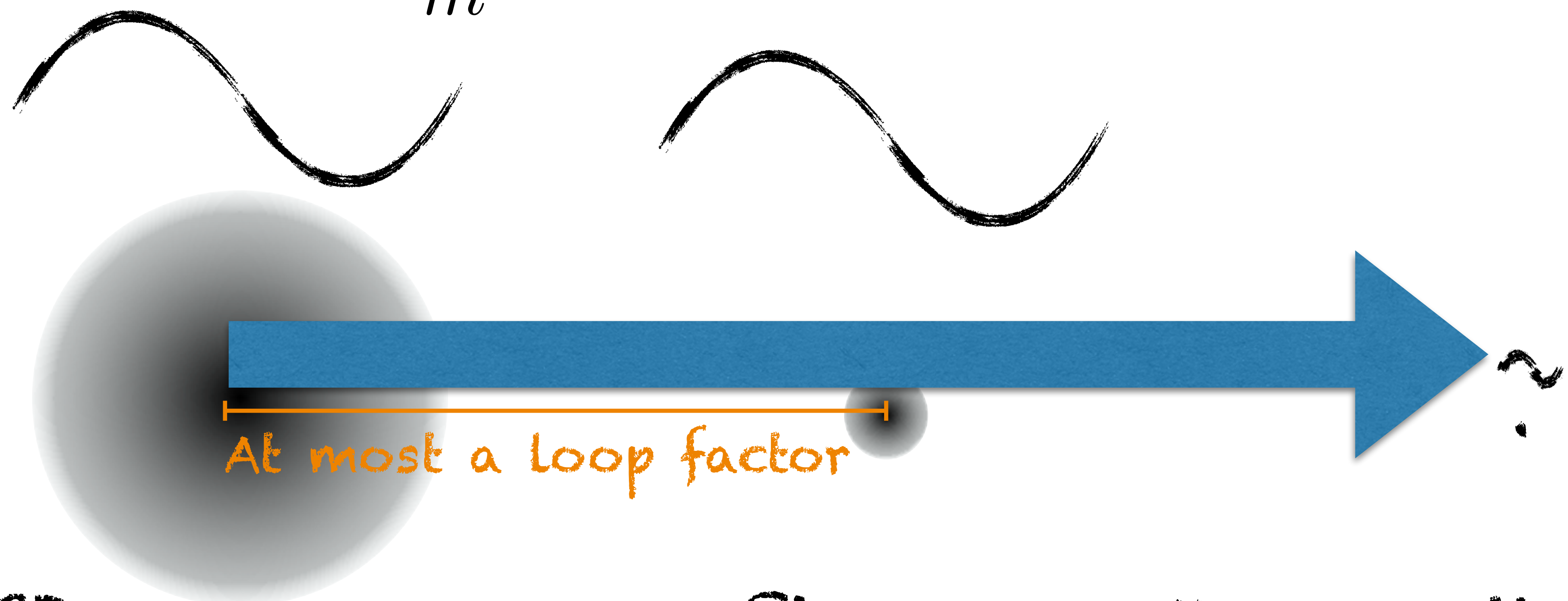

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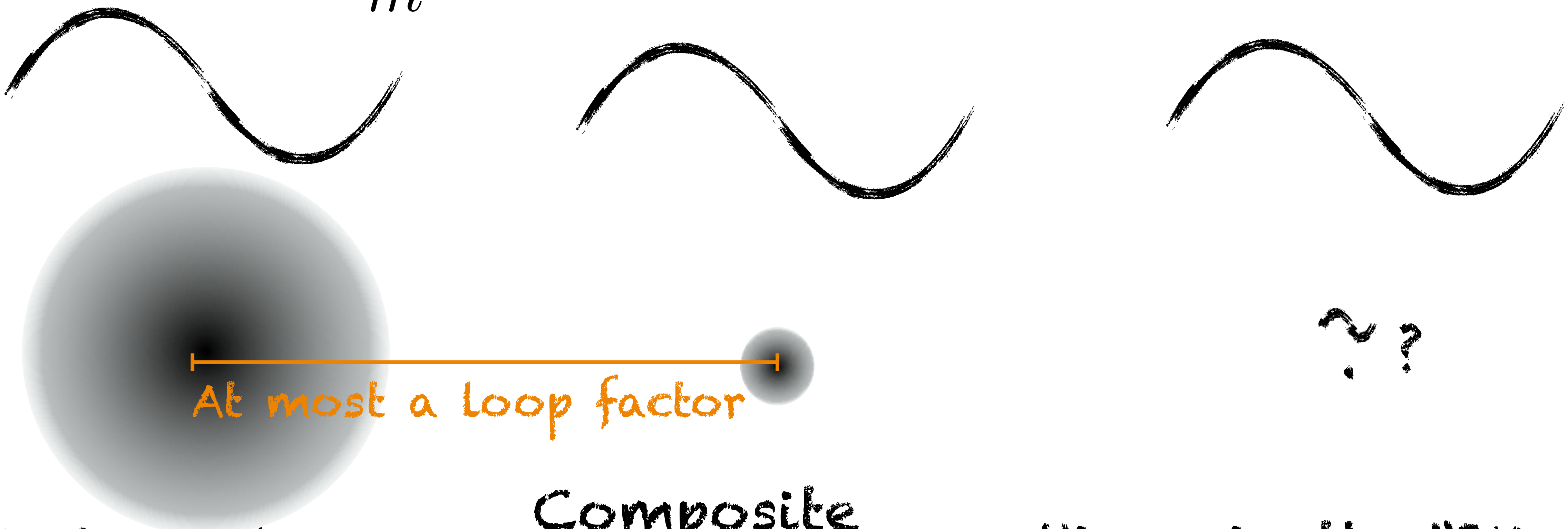

Technicolor

$$L \sim \frac{1}{m} \sim \frac{1}{125 GeV}$$

Composite PGB Higgs

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At most a loop factor

$\sim$?

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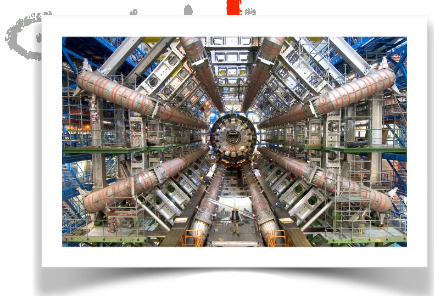

LHC

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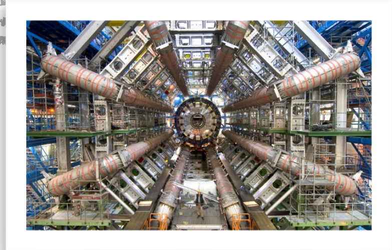

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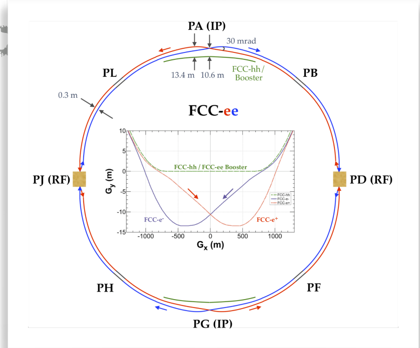

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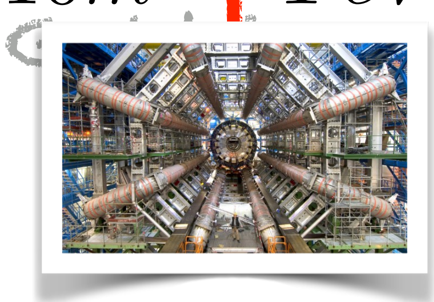

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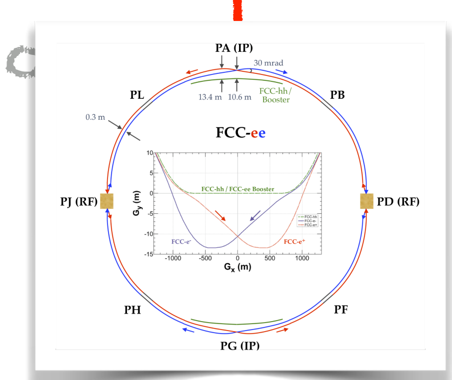

FCs

Future colliders will tell us how much the Higgs resembles one of the spin-0 particles that we already know, by measuring its size

The Hierarchy Problem

EFT decouples: $\dfrac{O_i^{(n)}}{\Lambda_i^{n-4}}$ Details of UV not important

- Small observables ⇔ larger scales

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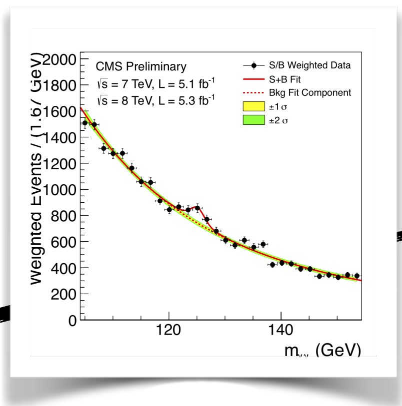

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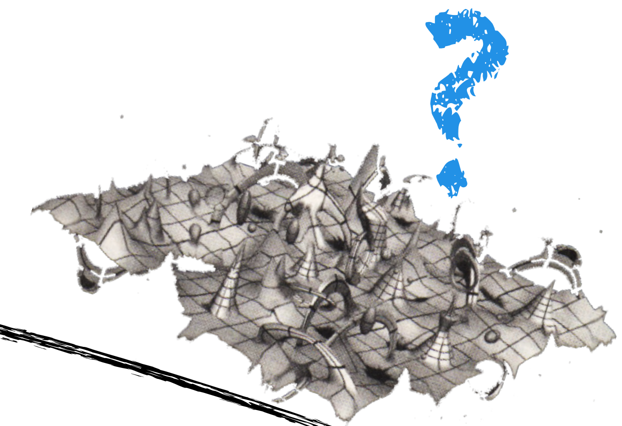

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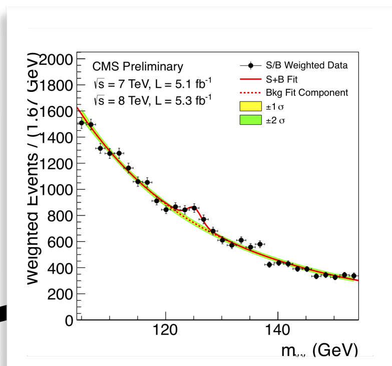

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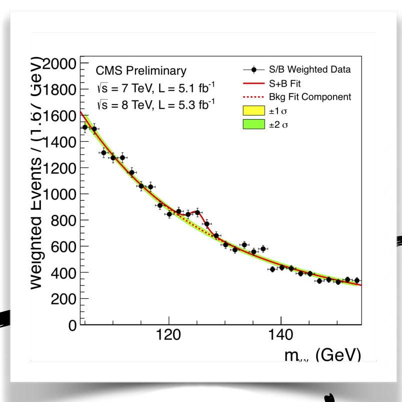

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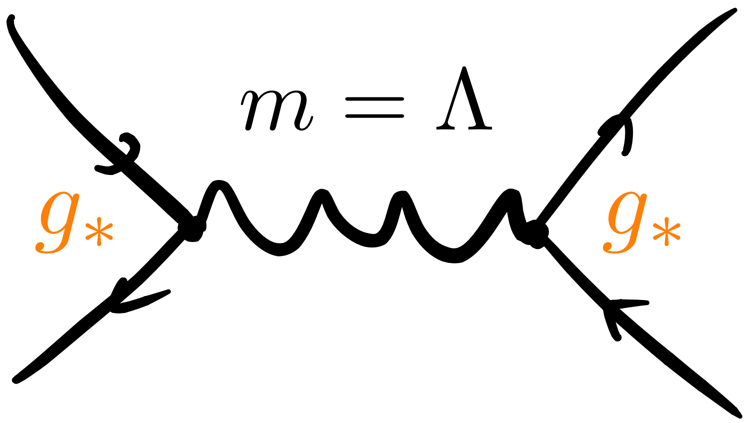
Theories with finite size Higgs screen us from our QG ignorance, and are computable and testable at FCC

Is this a good question for e+e- machines?

Lepton colliders designer for precision physics, EFTs...



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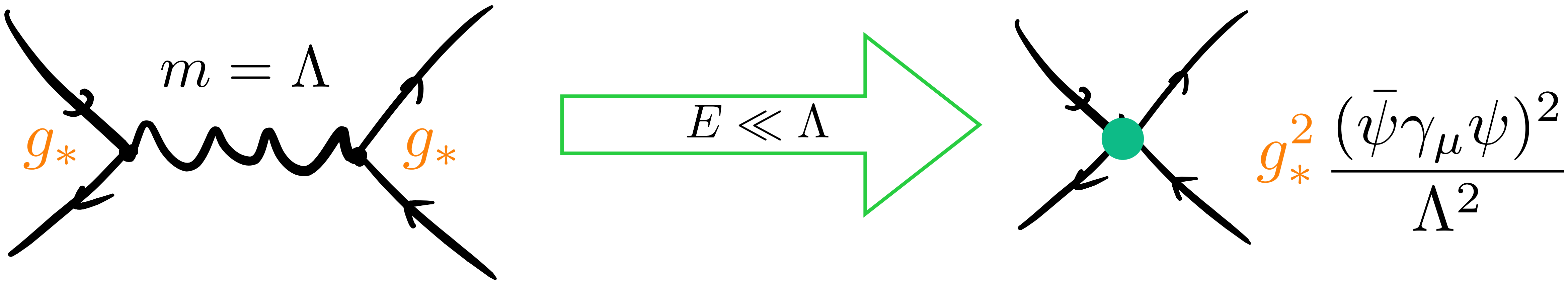

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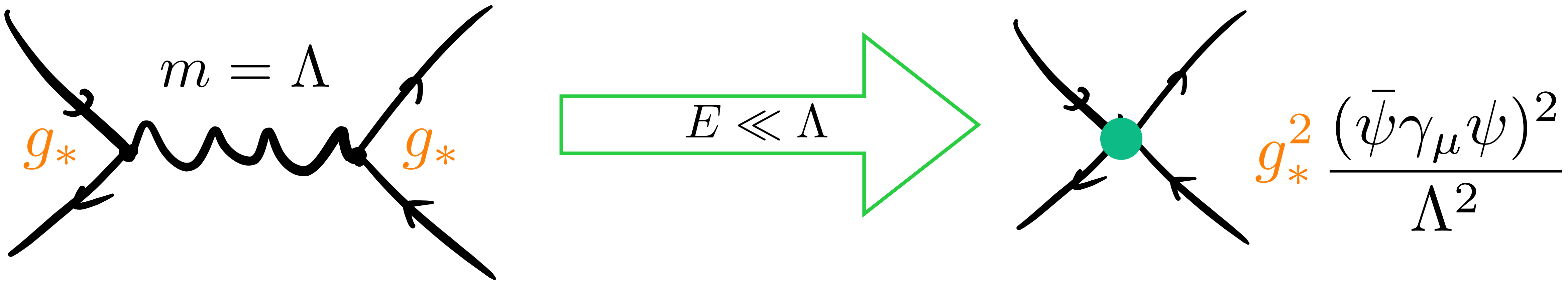

UV theories that are strongly coupled,

$$g_* \gtrsim 1$$

create composites and have particles with substructure, like pions or protons.

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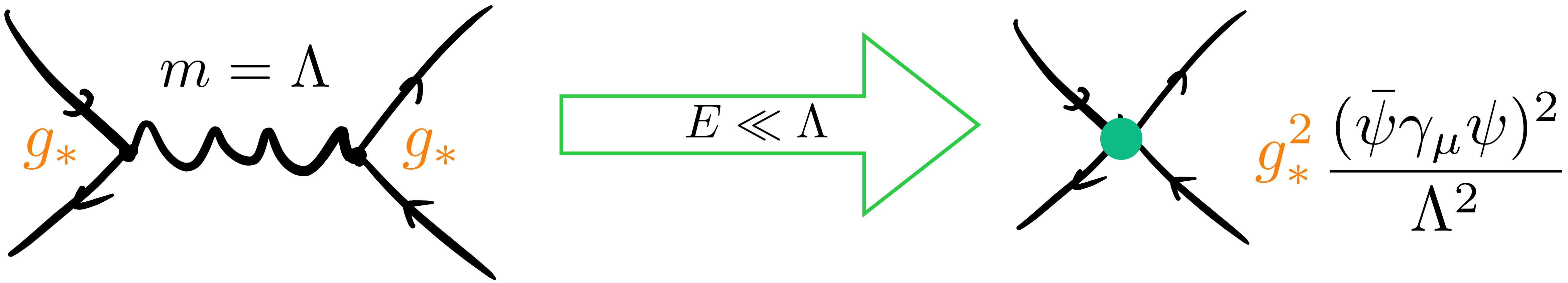

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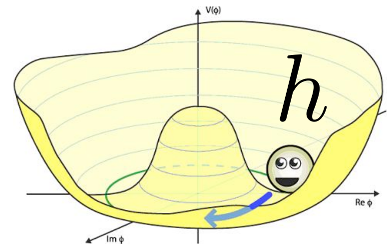
create composites and have particles with substructure, like pions or protons.

But are also the ones that have the largest effects at lower energies

A Higgs smaller than its size?

To be composite and lighter than its size, it must be a (Pseudo) Goldstone Boson:



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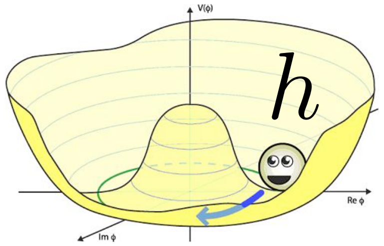

SM | **BSM**

$$h \longrightarrow \sin\frac{h}{f} = \frac{h}{f} - \frac{h^3}{3!f^3} + \cdots$$

$$\bar{\psi}\psi h \qquad\qquad \bar{\psi}\psi h + c\,\bar{\psi}\psi h^3$$

$$y$$

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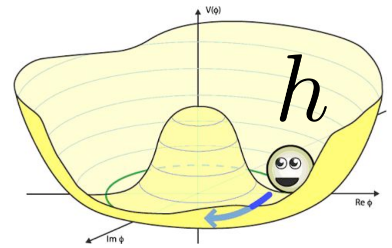

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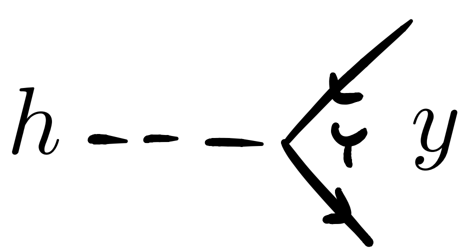
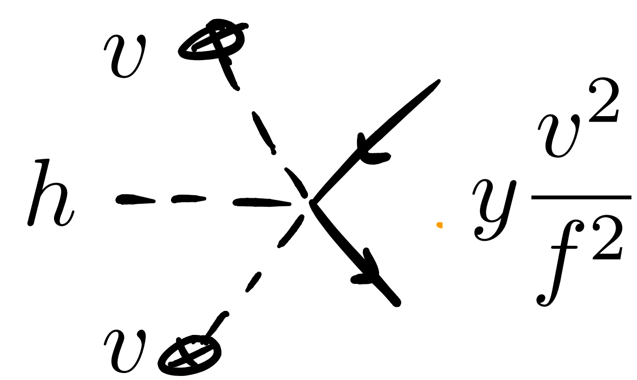


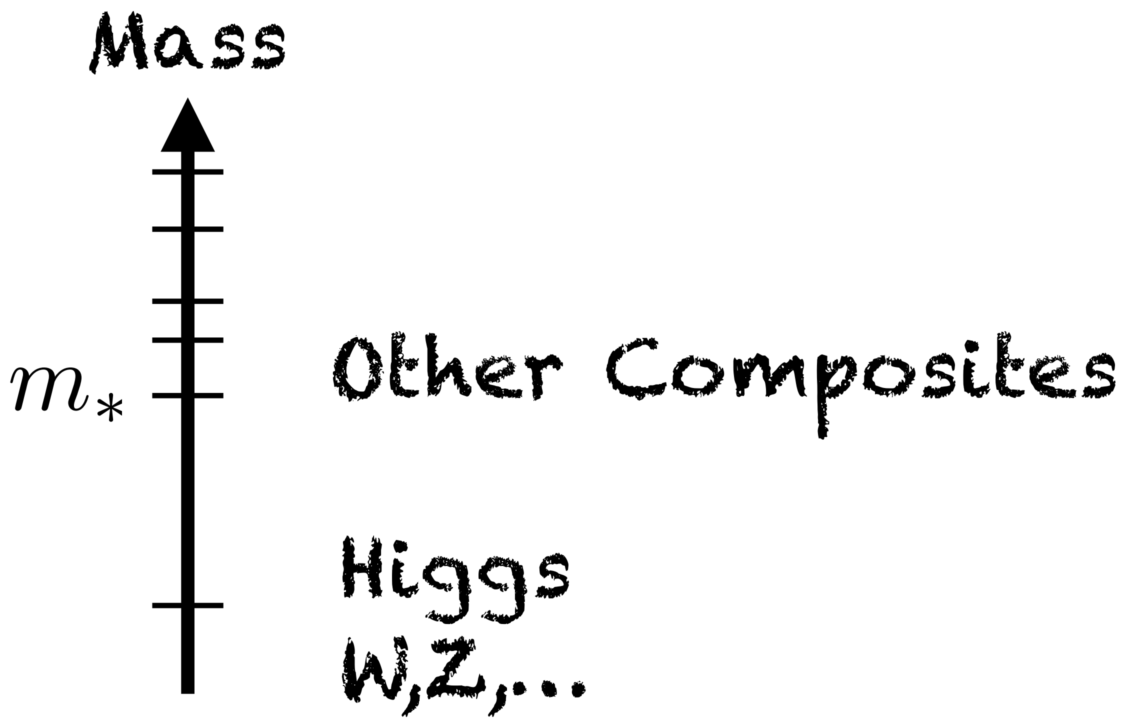


tree-level **Higgs Couplings** are modified

Strongly Interacting Light Higgs

The same constituents that make up the Higgs can make up other composites with

$$m_* \sim \frac{1}{L_H}$$



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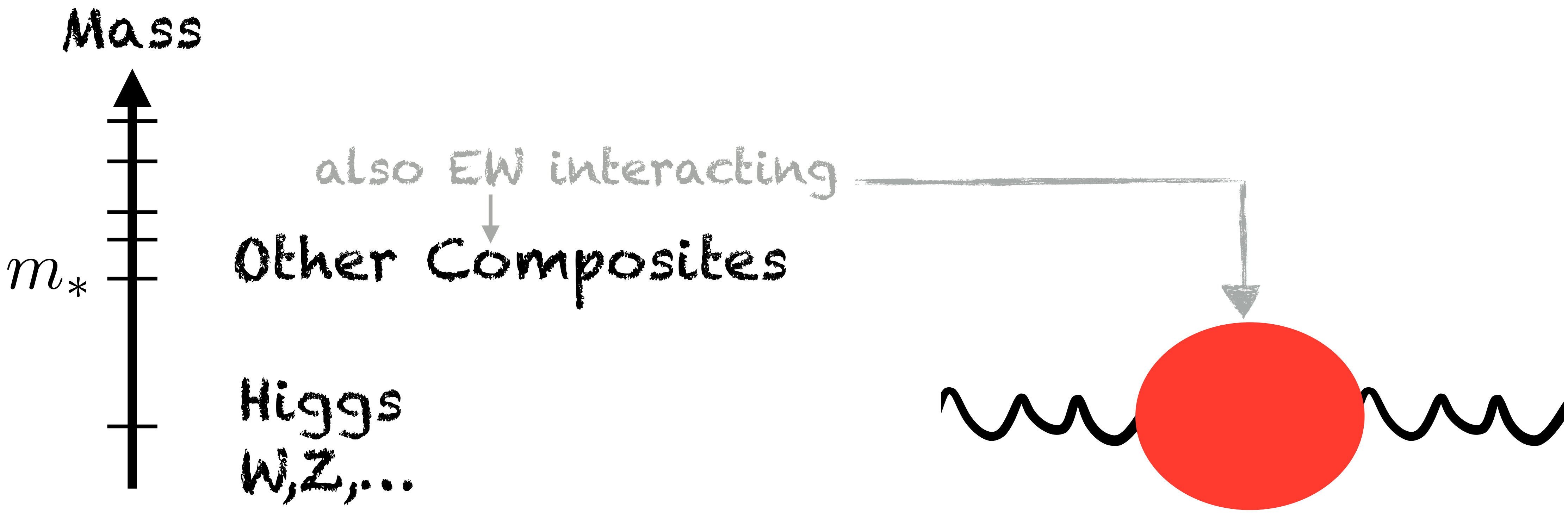

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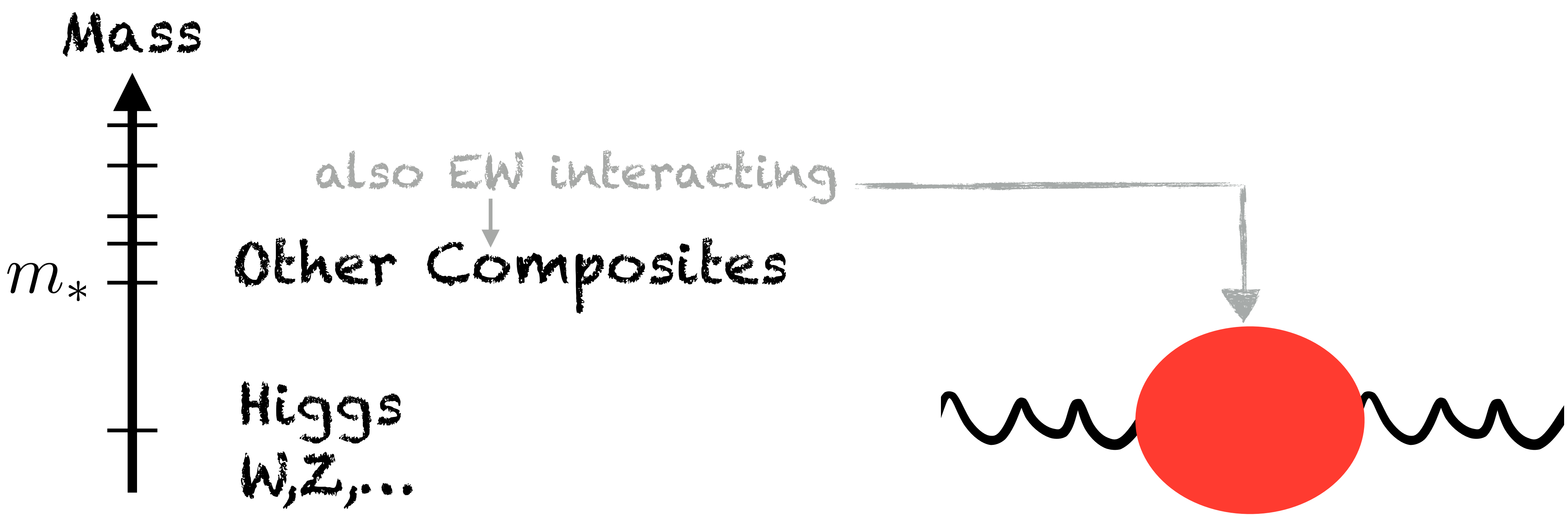

$$\frac{1}{m_*^2} g'(H^\dagger \overleftrightarrow{D}_\mu H)(\partial_\nu B^{\mu\nu}) \qquad \frac{1}{m_*^2} g(H^\dagger \sigma^i \overleftrightarrow{D}_\mu H)(D_\nu W^{\mu\nu})^i$$

modify Z-boson propagation (S-Parameter)

A Higgs smaller than its size?

Giudice,Grojean,Pomarol,Rattazzi'08;

Higgs size reflected into EFT effects:

$$\mathcal{O}_r = \frac{|H|^2}{f^2}\partial_\mu H^\dagger \partial^\mu H \qquad \mathcal{O}_{y_\psi} = Y_\psi \frac{|H|^2}{f^2}\psi_L H \psi_R \qquad \mathcal{O}_6 = \frac{|H|^6}{f^2}$$

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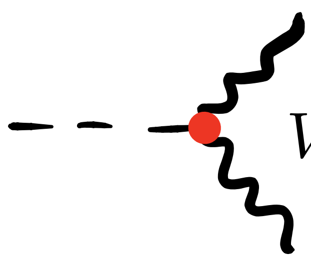

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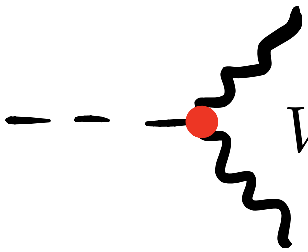

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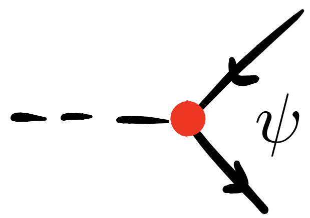

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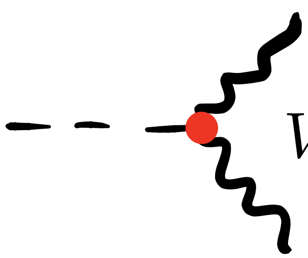

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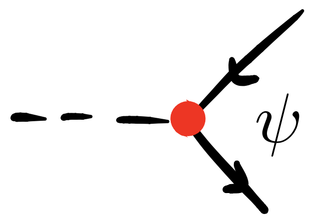

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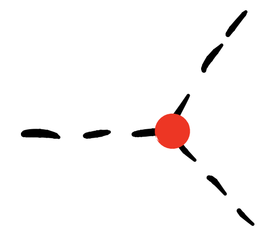

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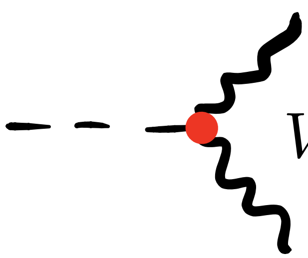

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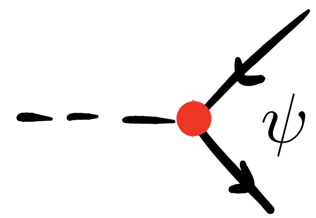

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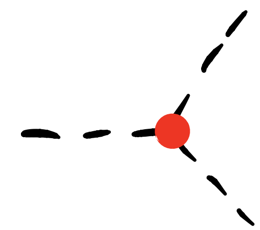

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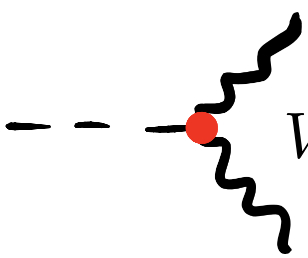

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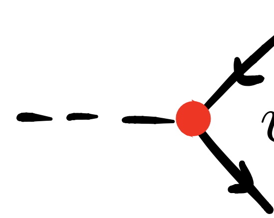

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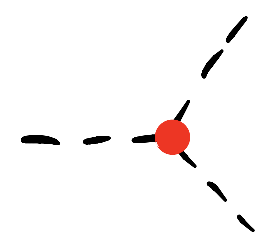

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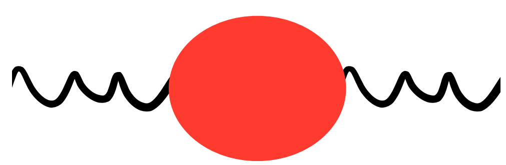

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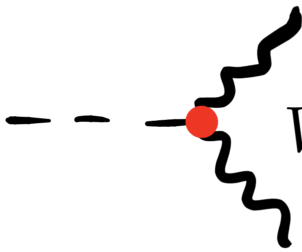
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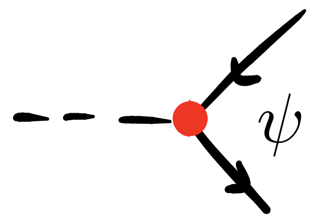
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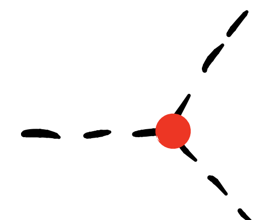

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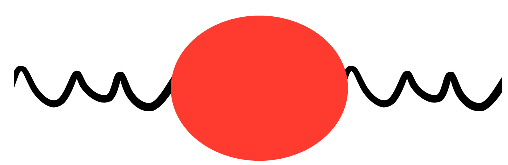

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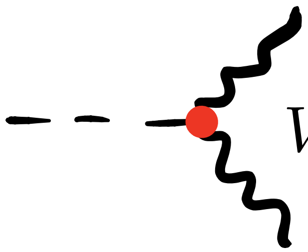

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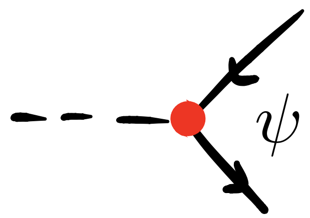

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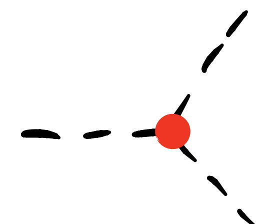

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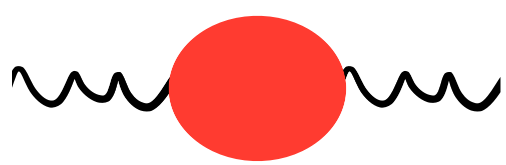

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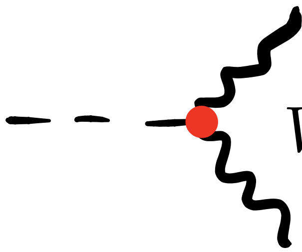

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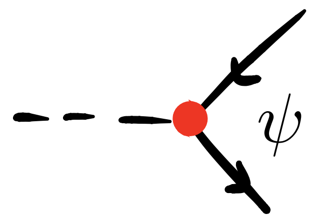

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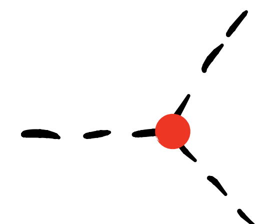

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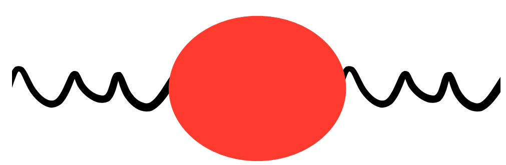

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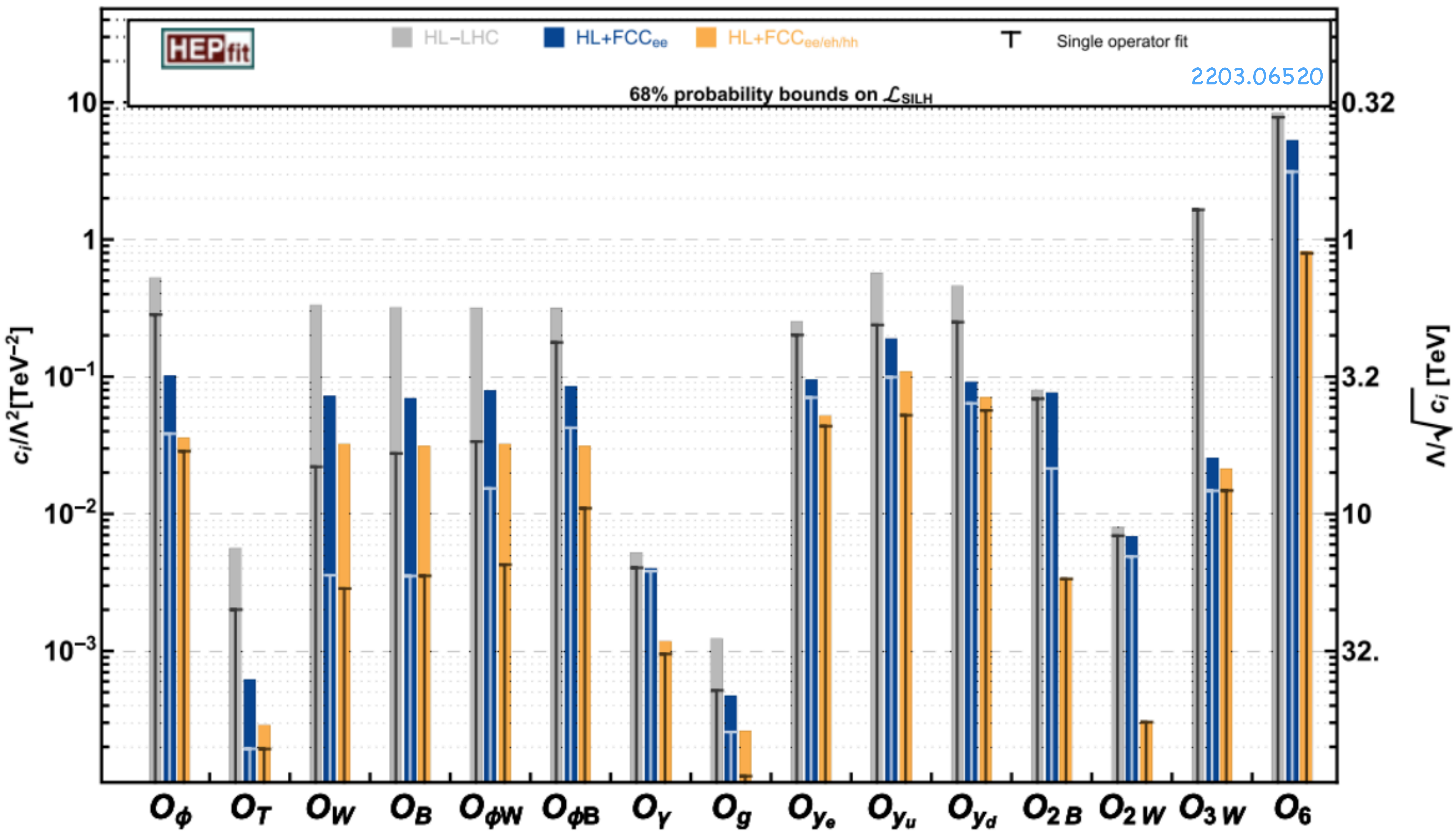
Pions would have v=f → v/f measures how SM-like the Higgs size is

Physics Questions vs Global Fits



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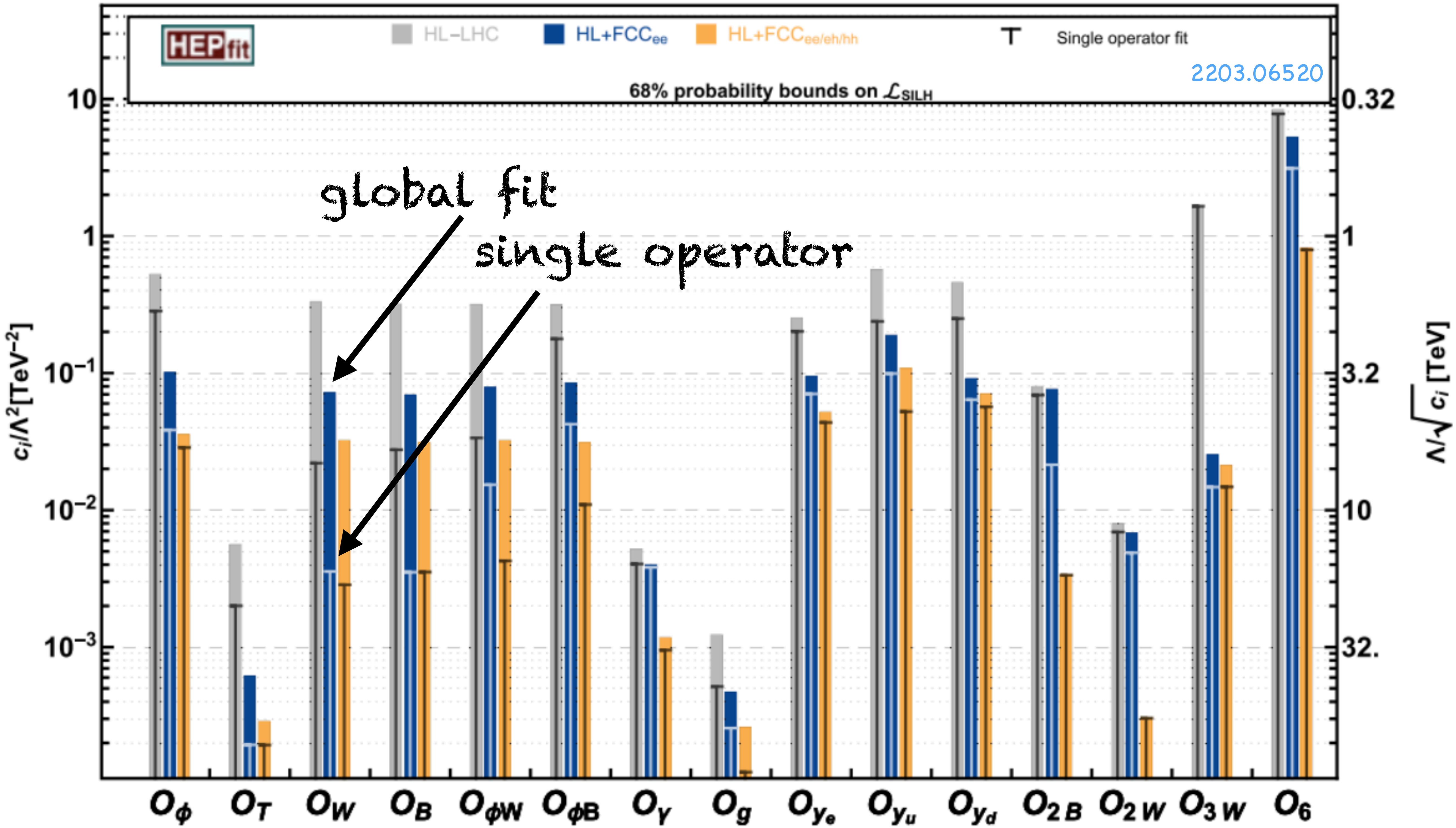

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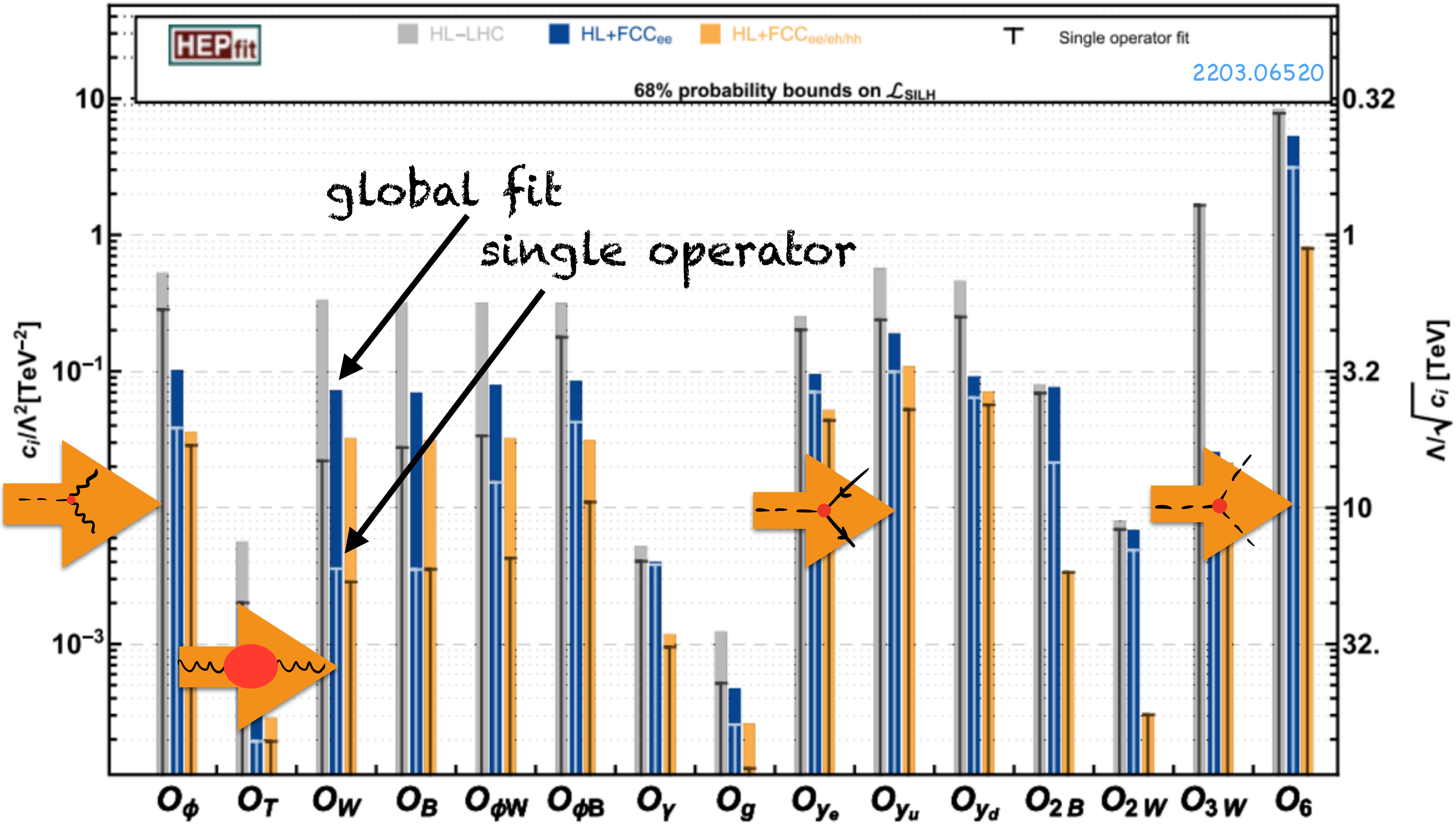

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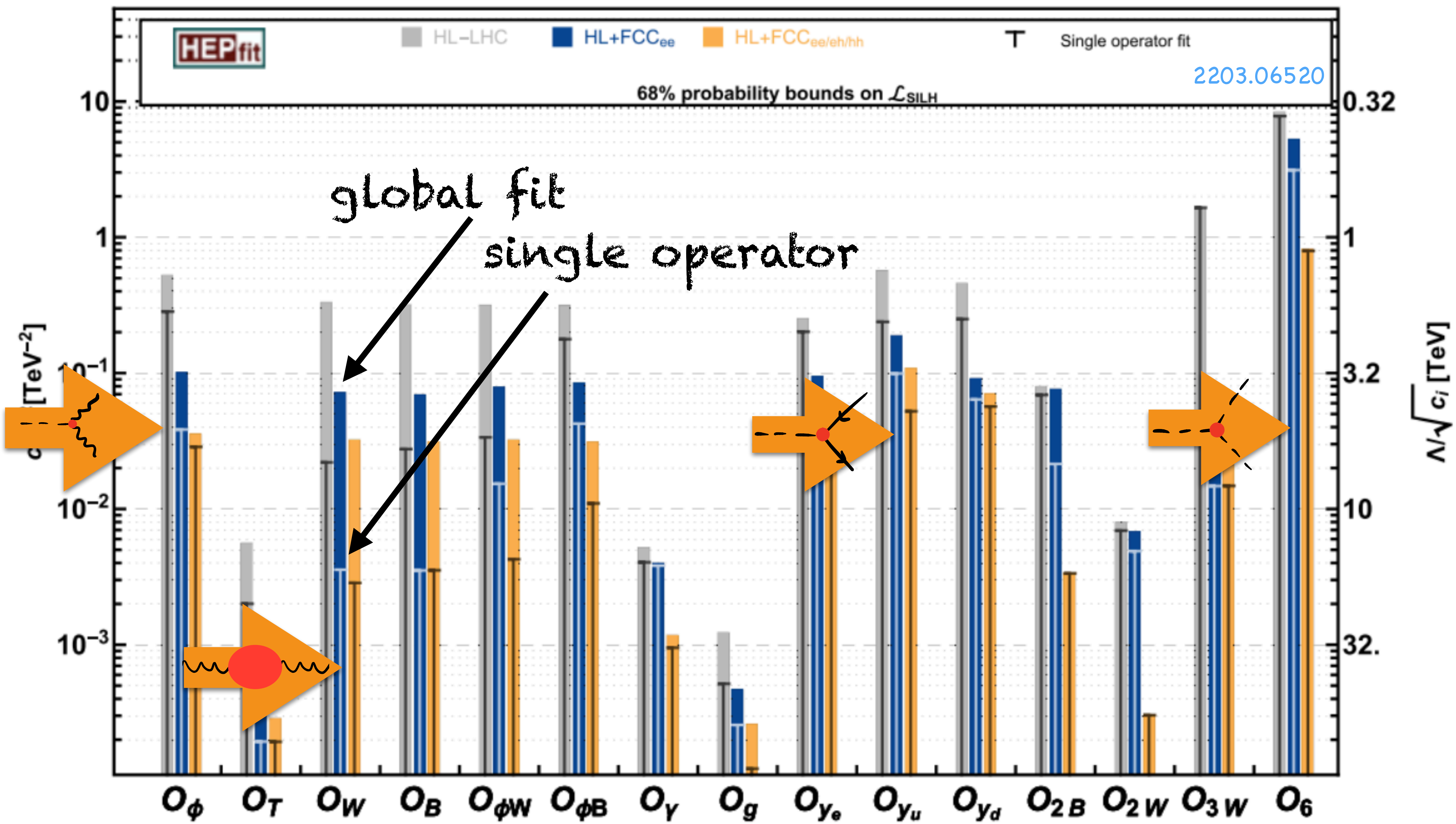

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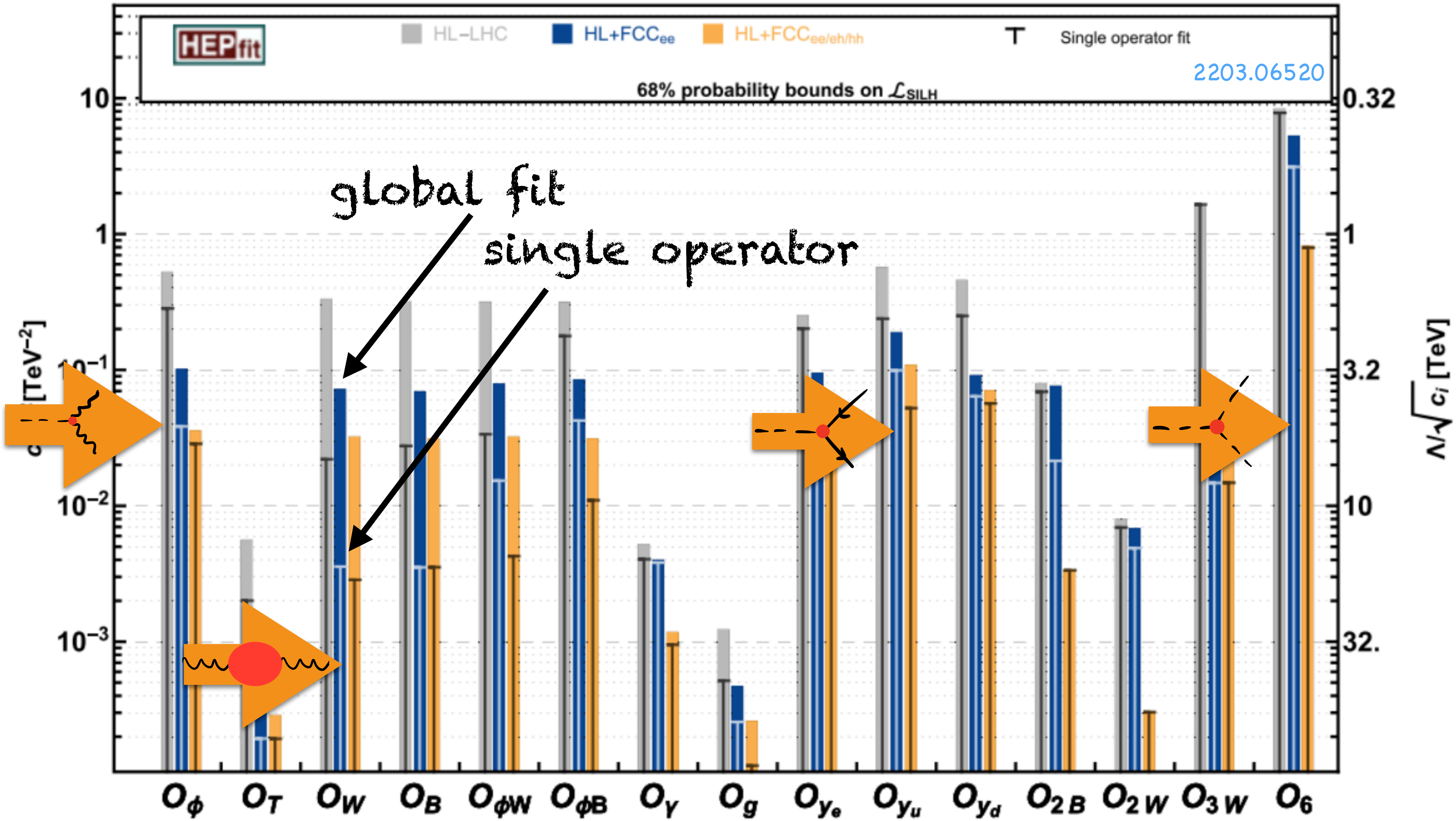
Higgs couplings: (hZZ) $\frac{v^2}{f^2} \lesssim 10^{-3}$



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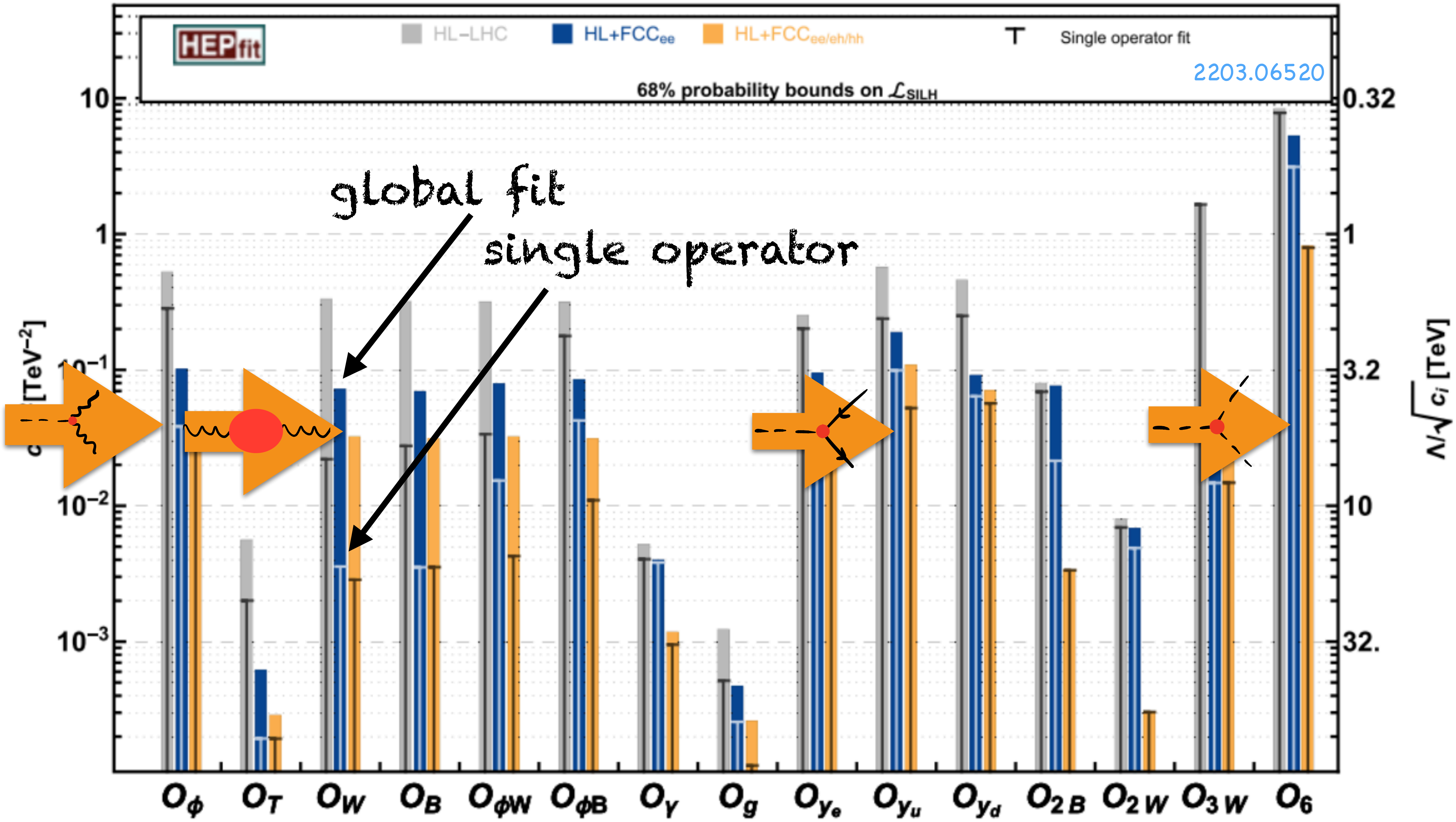

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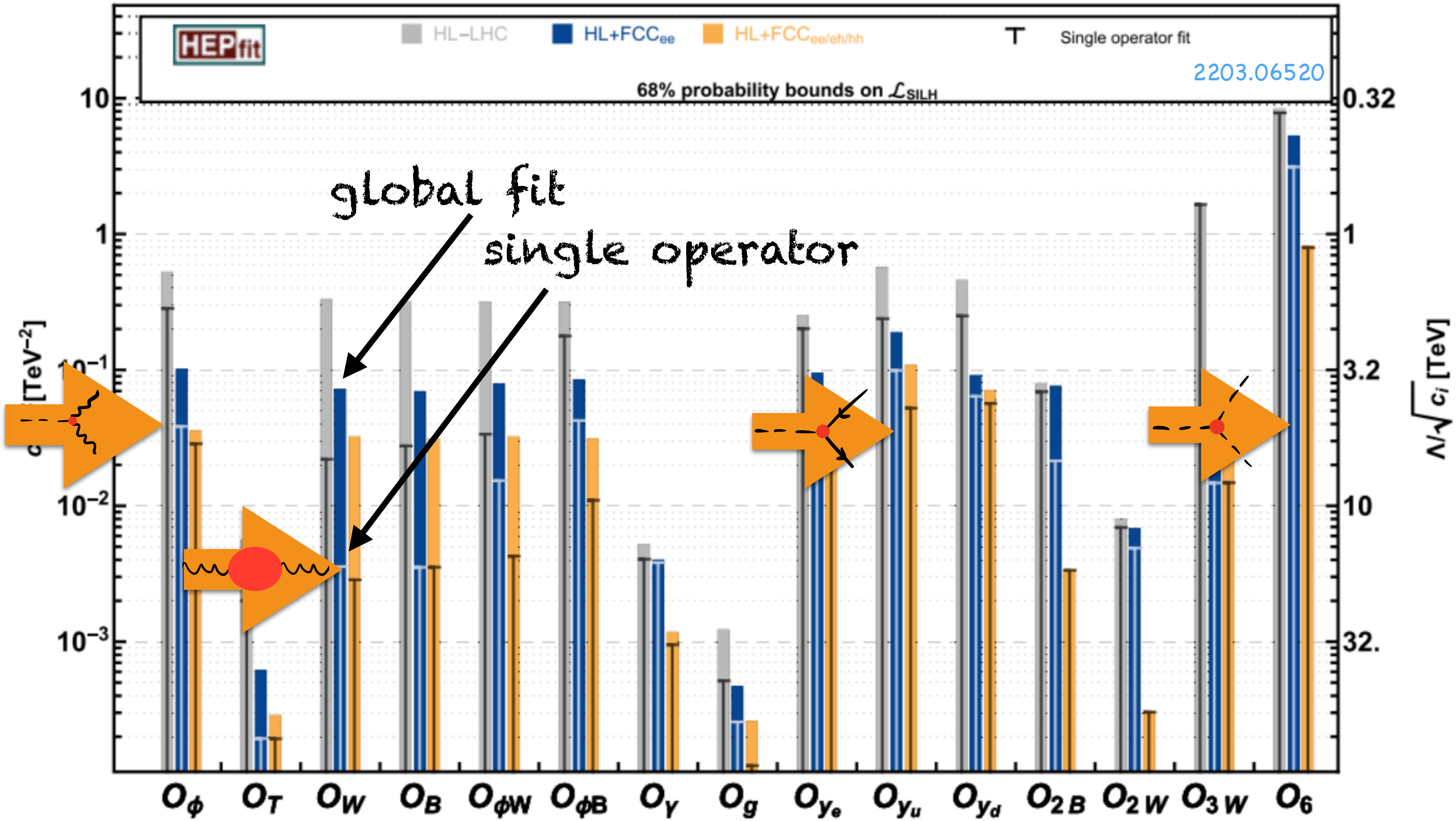

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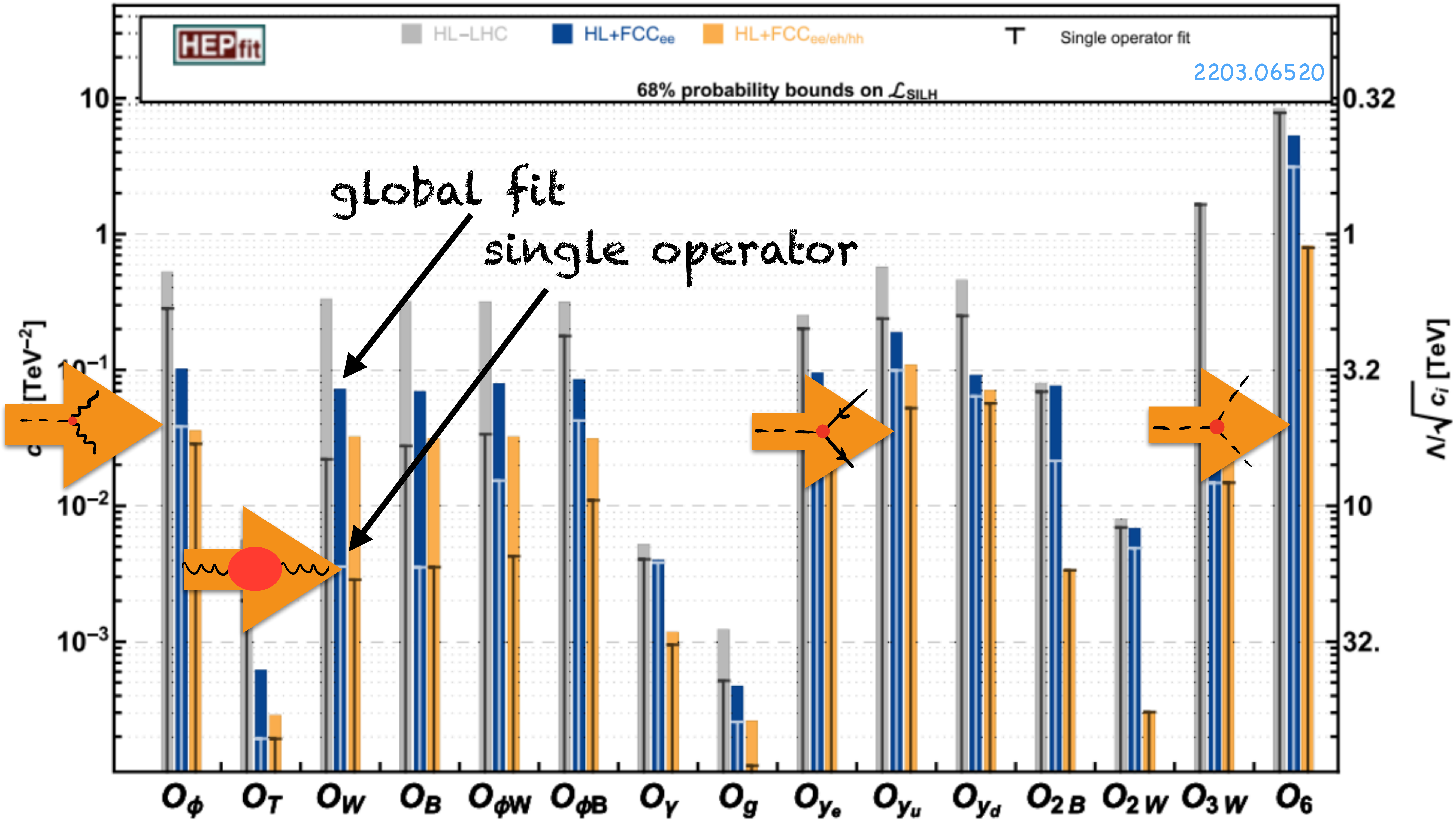
EW physics: $\frac{v^2}{f^2} \lesssim 10^{-3} \left(\frac{g_*}{5}\right)^2$



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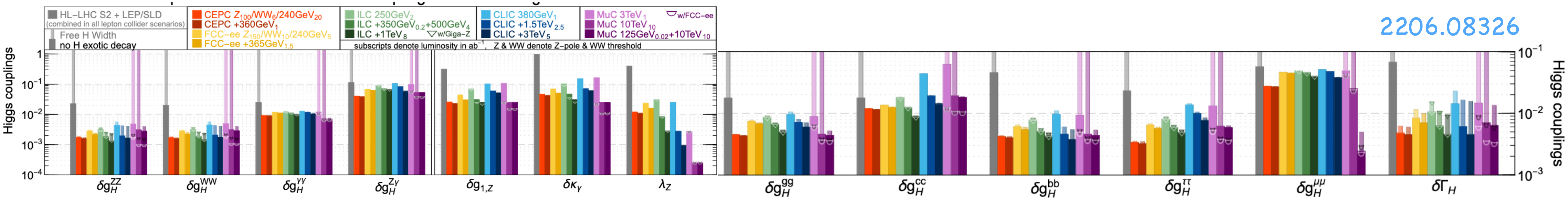

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Global fits are important for generic quantitative statements about different machines...

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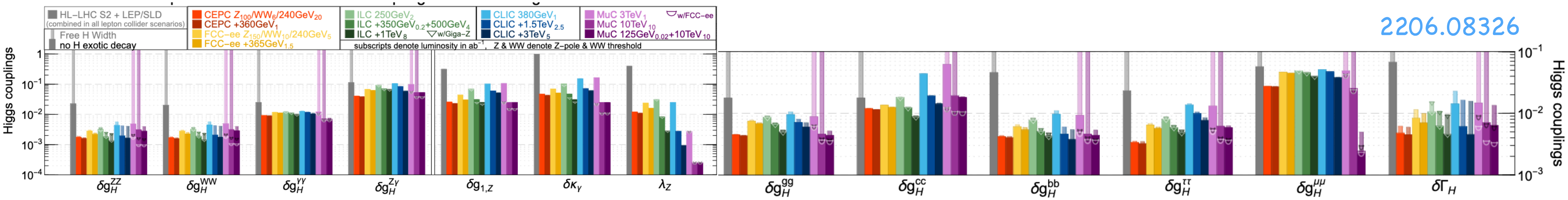

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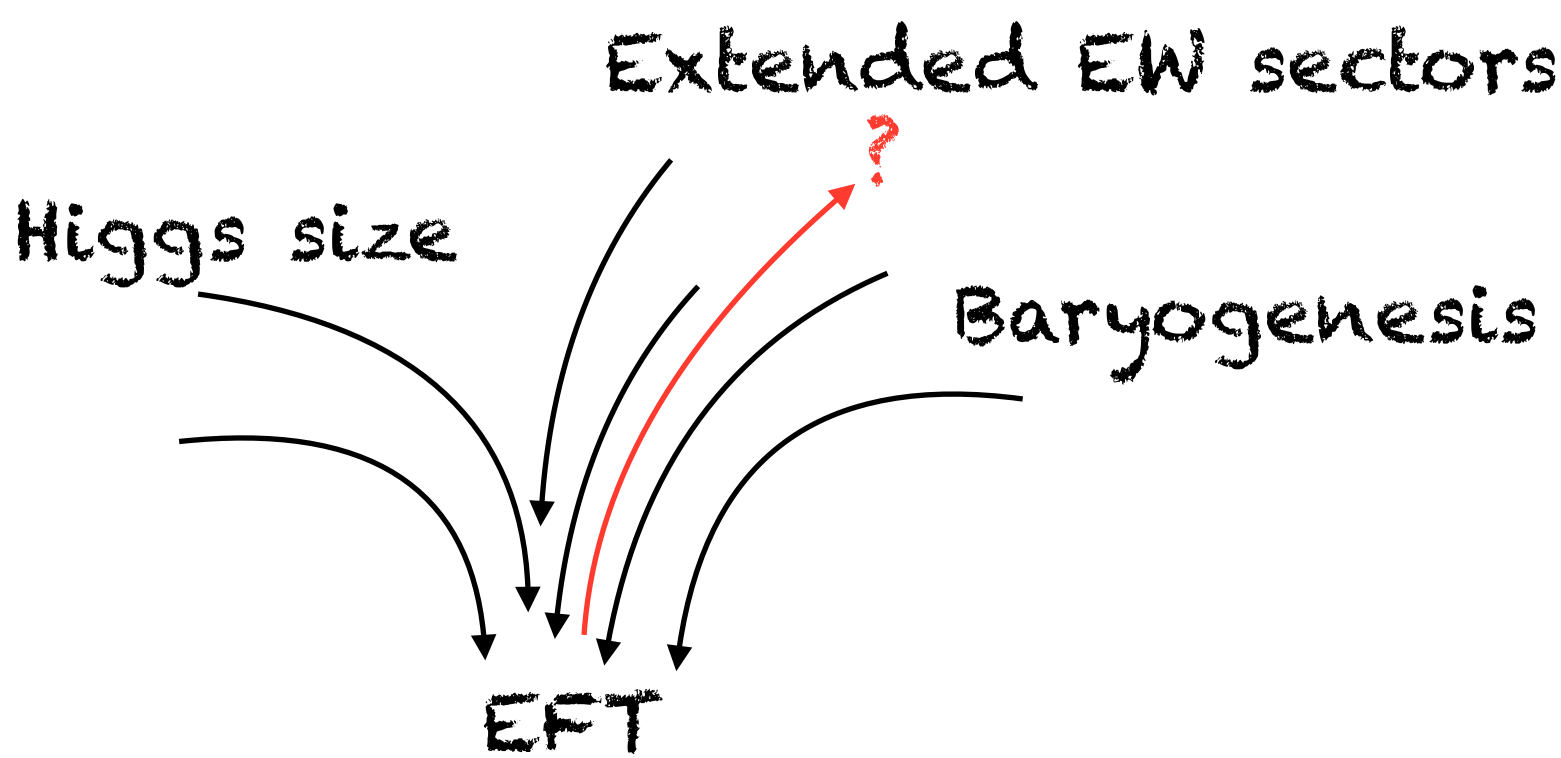
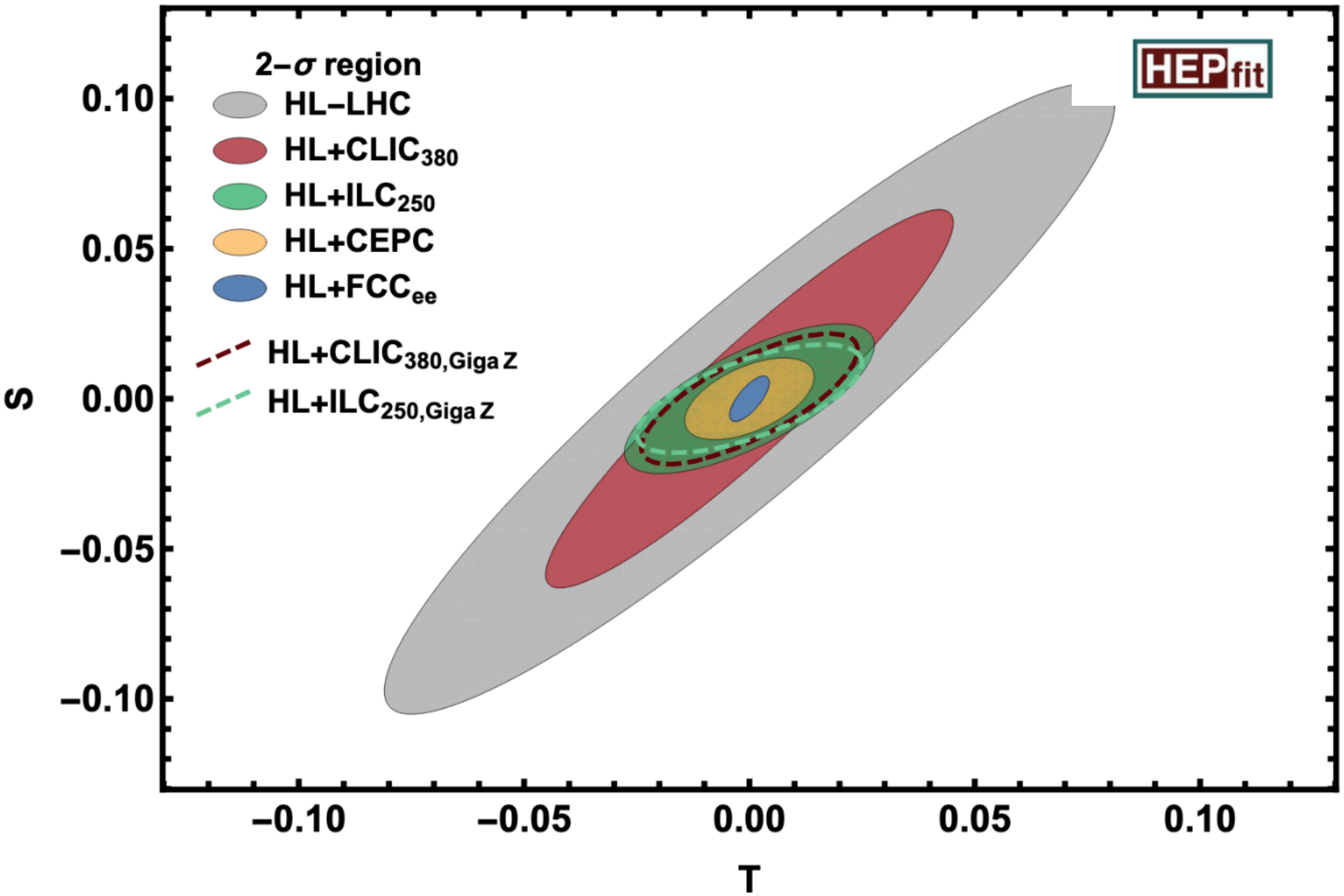
... but have the danger of hiding important hypotheses under too much information



The Z-Boson run and the Higgs

S (and T) parameters:

- best universal tests for EW related physics
- if it couples to the Higgs it will likely enter in S,T



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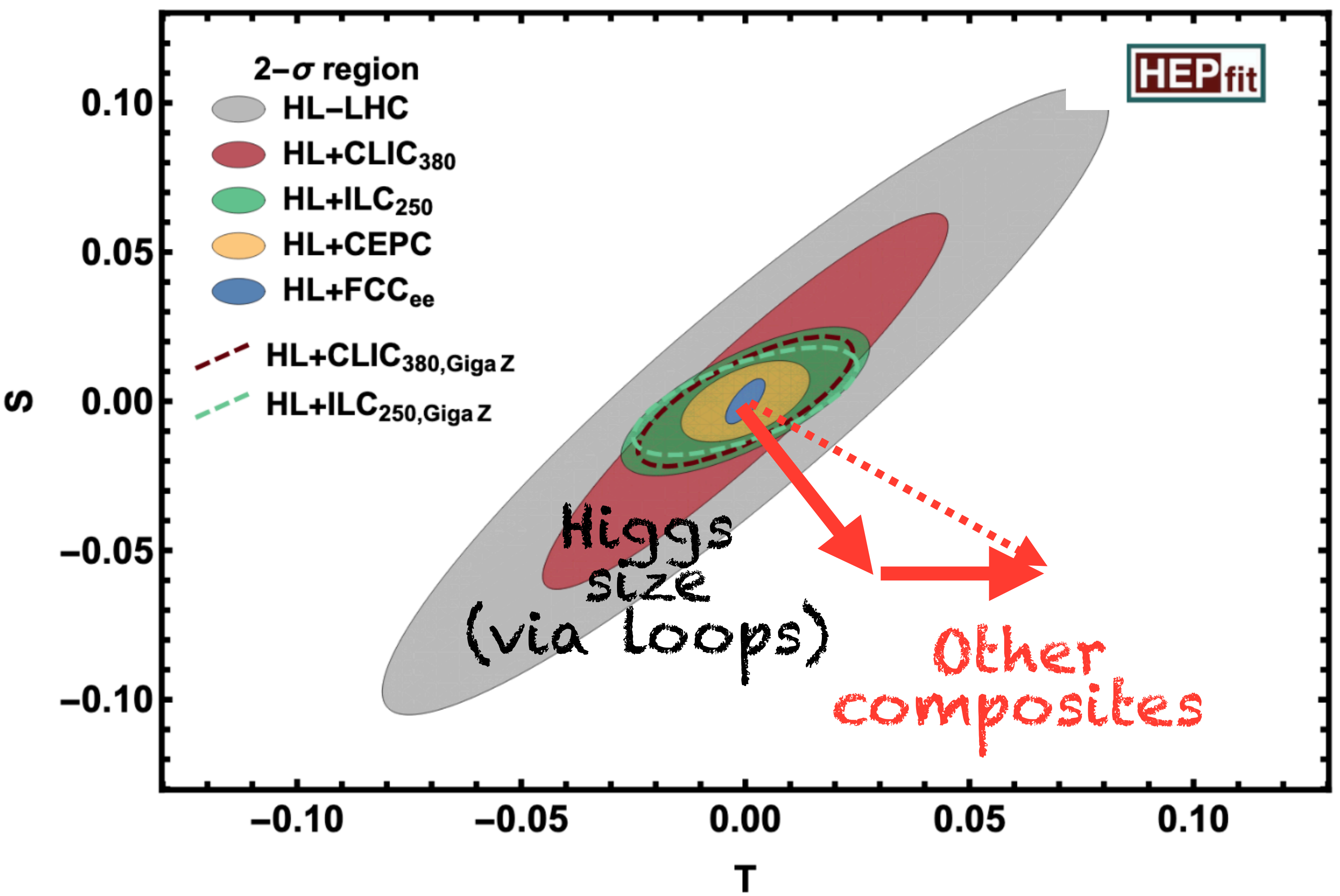

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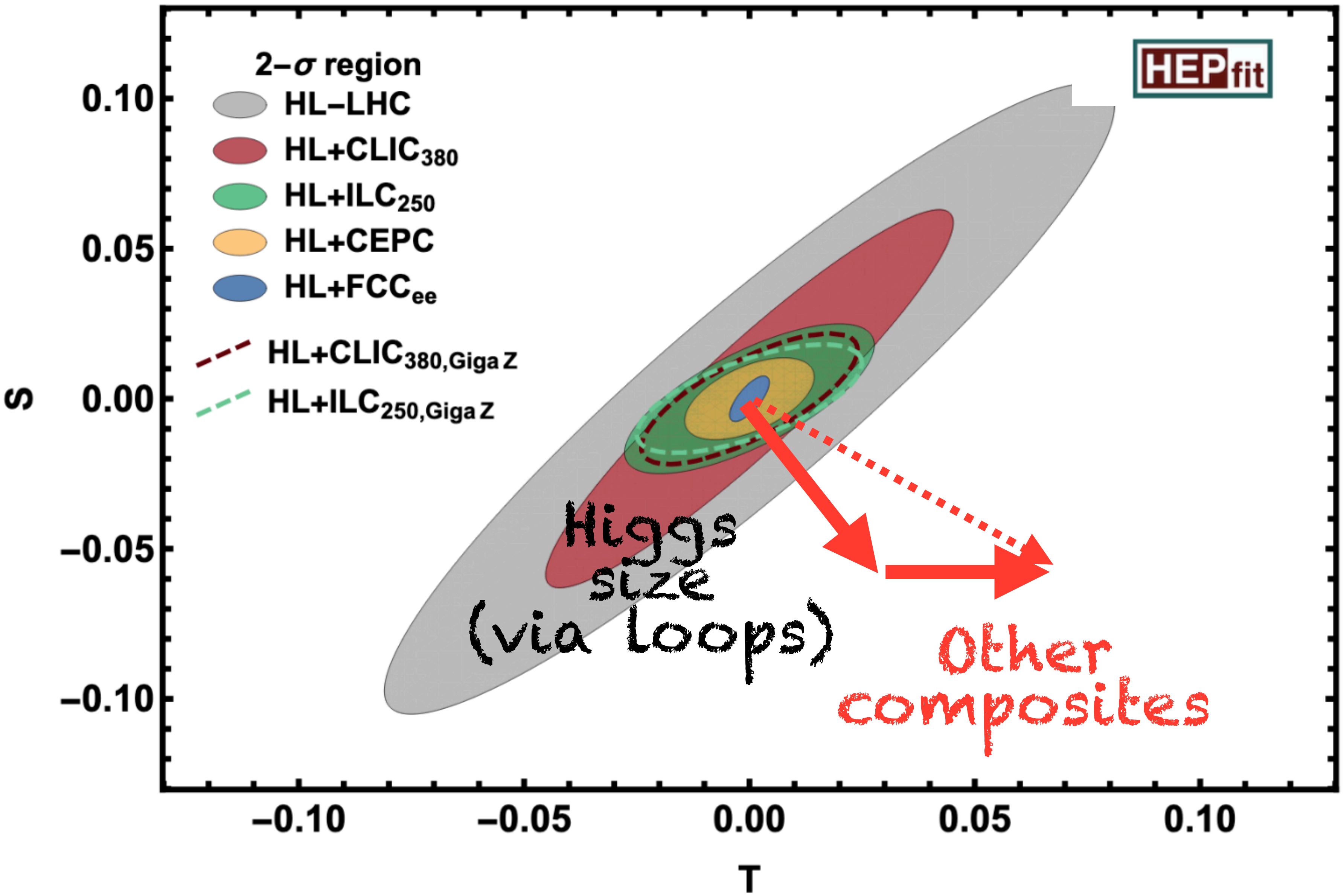

- A Z-pole run is crucial!

summary

Future colliders can discover many exciting new physics

(new particles, Dark Matter, matter asymmetry...)

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Z-Pole run will teach us much about the Higgs, as well

Social Experiment

PollEv.com /francescoriva506

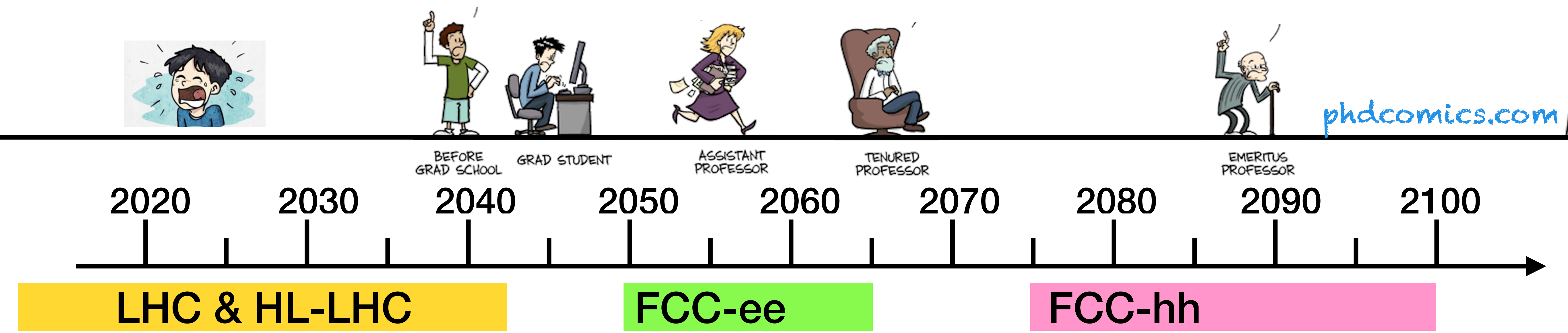
How much are you excited by the physics of FCs?

I'm willing to invest 25 years of my life fully on one of these projects (or would like my children to)

I'm willing to invest 25 years of my life partially (e.g in parallel with other experiments)

I want a job in HEP, no matter the specific context

Outreach - TUTTI QUANTUM



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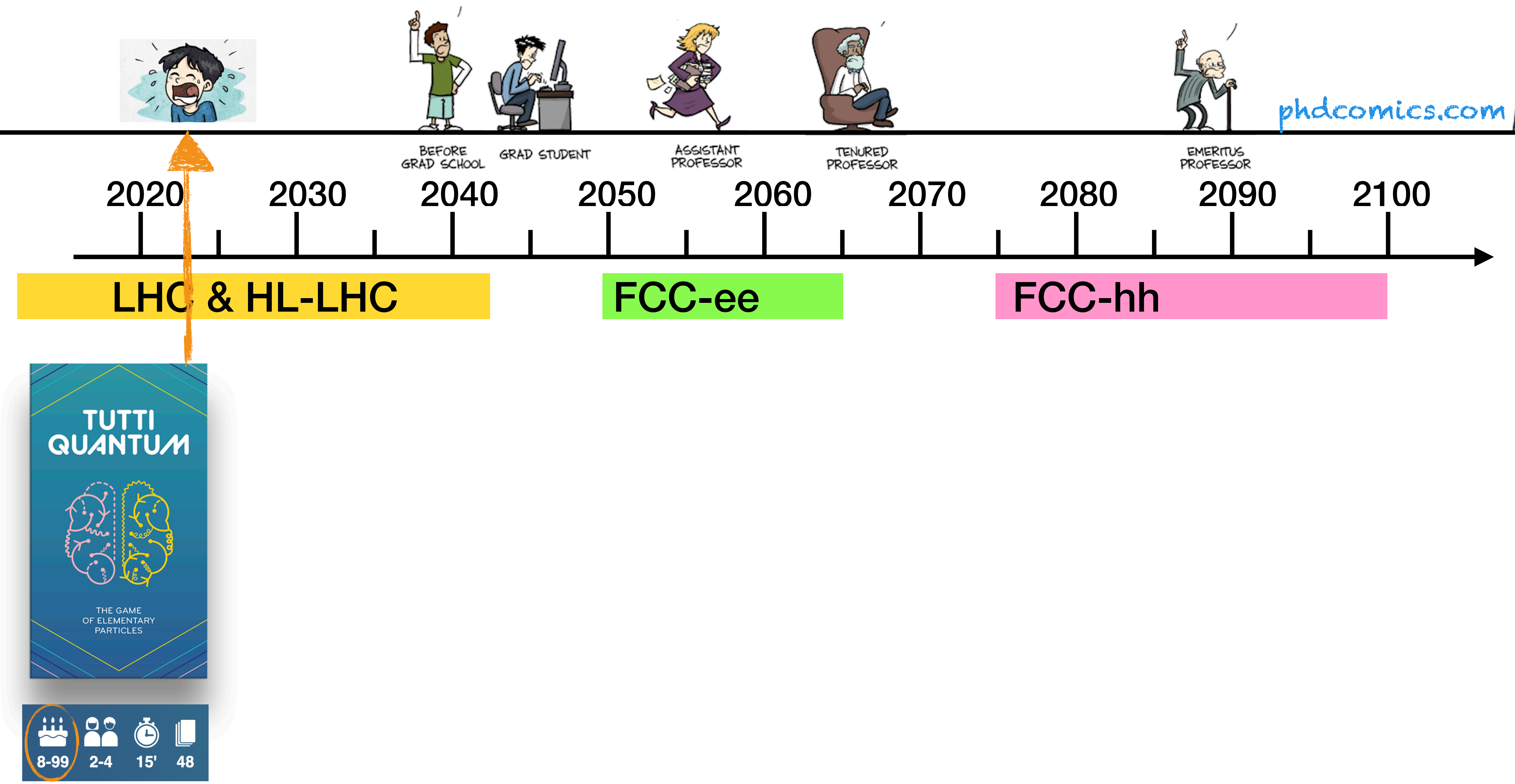

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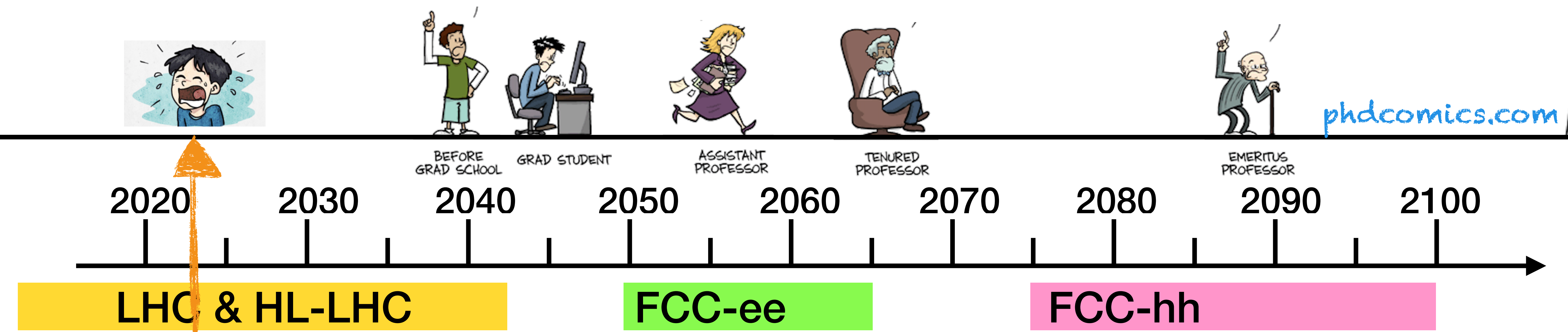

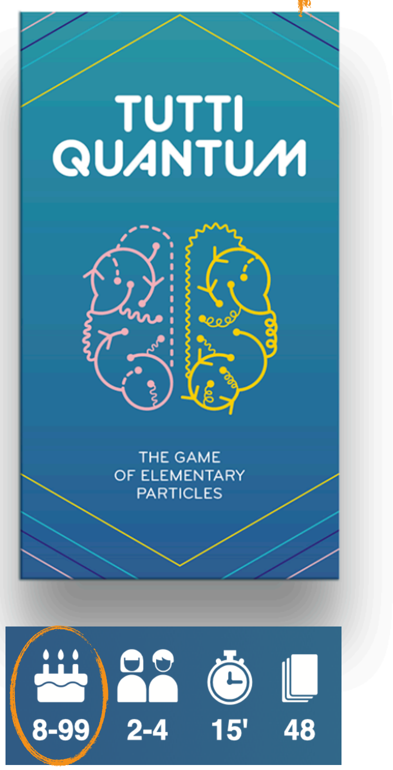

Particles are simple (simpler than e.g. cells)

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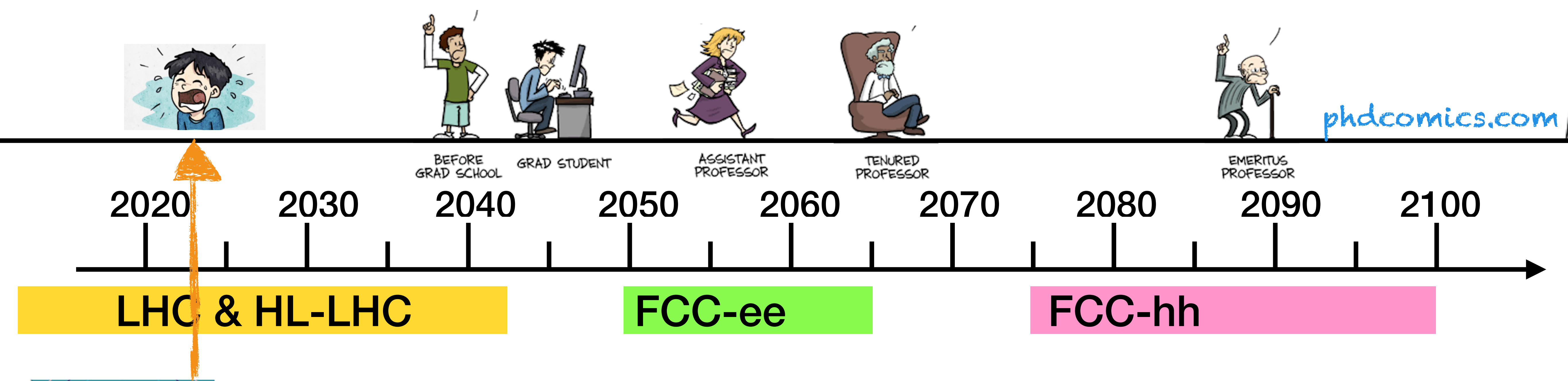

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→ Learn laws of nature as rules of a card game

(even before you realize you are learning physics)