Introduction to Higgs physics

Search for Higgs pair production with the CMS collaboration

Didier-Estève Éva

Institut de Physique des 2 Infinis
Université Claude Bernard - Lyon1

Under the supervision of Maxime Gouzevitch

April 24, 2026

Introduction

Understanding the mechanics of the Higgs boson:
Lets derive together the SM equation:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\overline{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + h.c + |D_\mu\phi^2| - V(\phi) \quad (1)$$

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Higgs physics: if the Higgs boson was a minecraft block, which one would it be?

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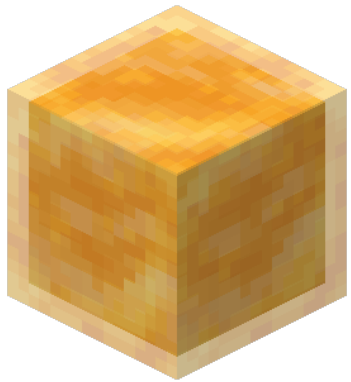
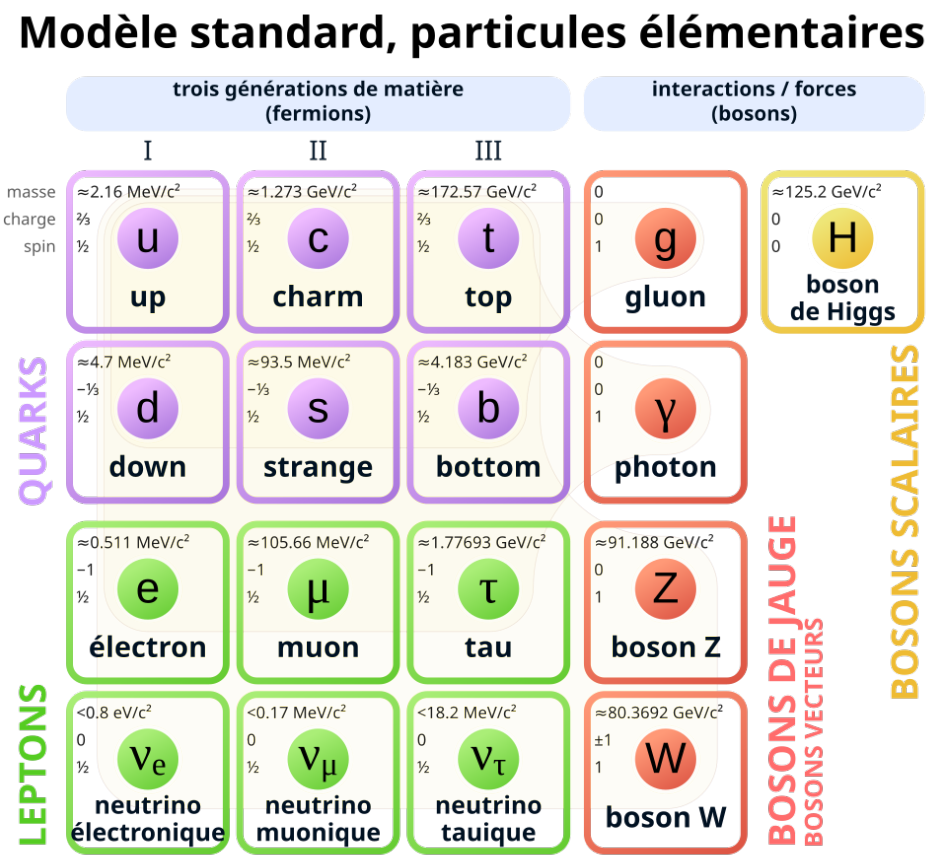


Introduction: the zoology of particles



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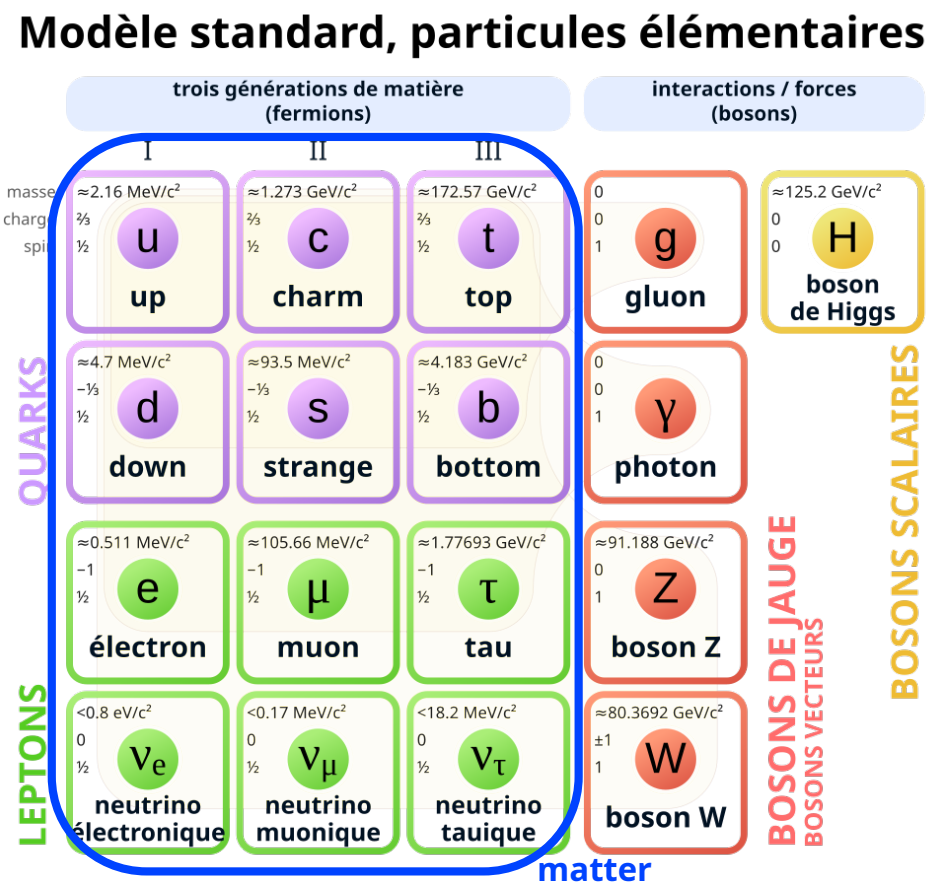

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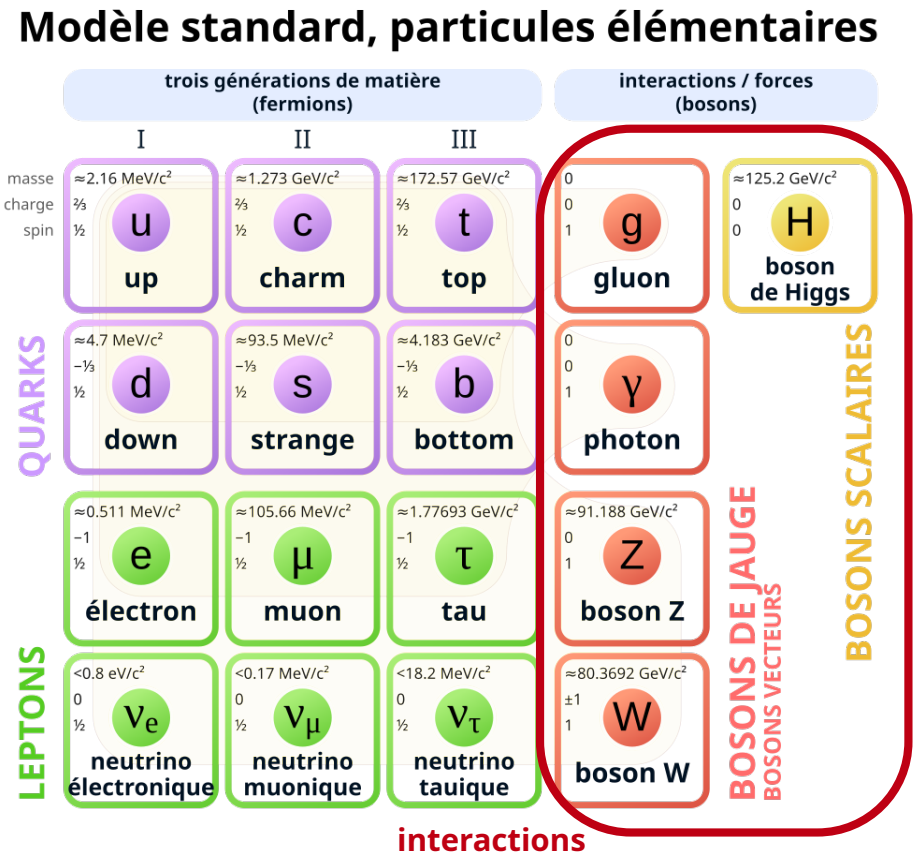

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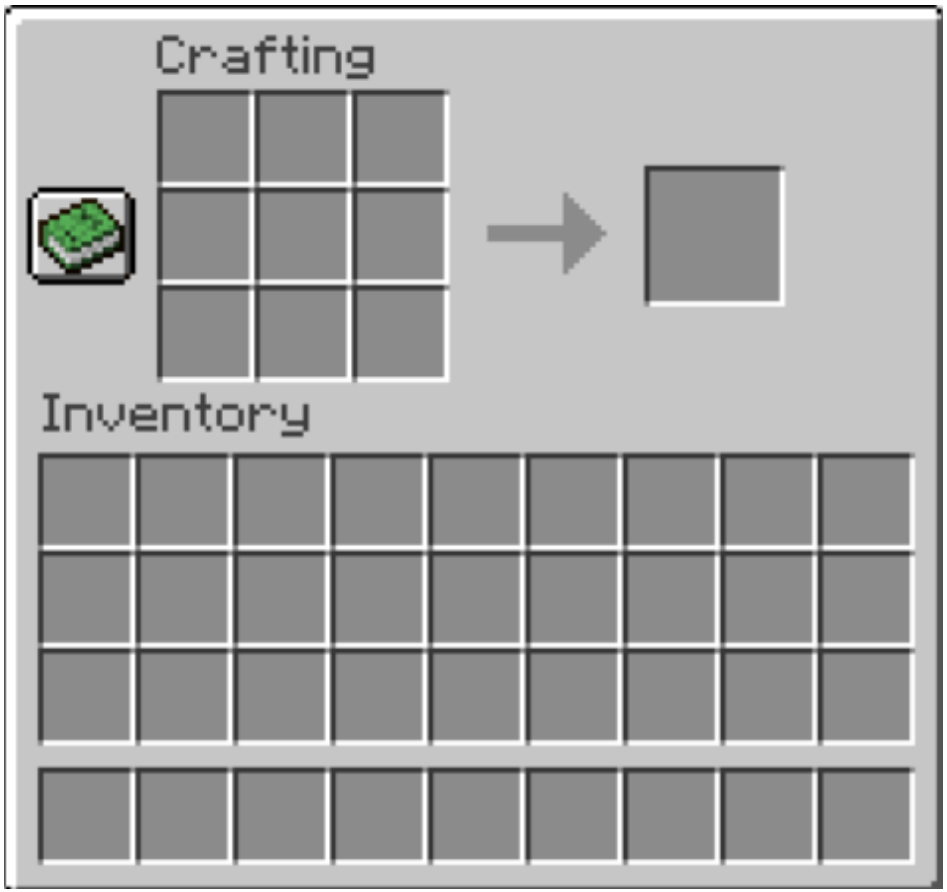
Modèle standard, particules élémentaires



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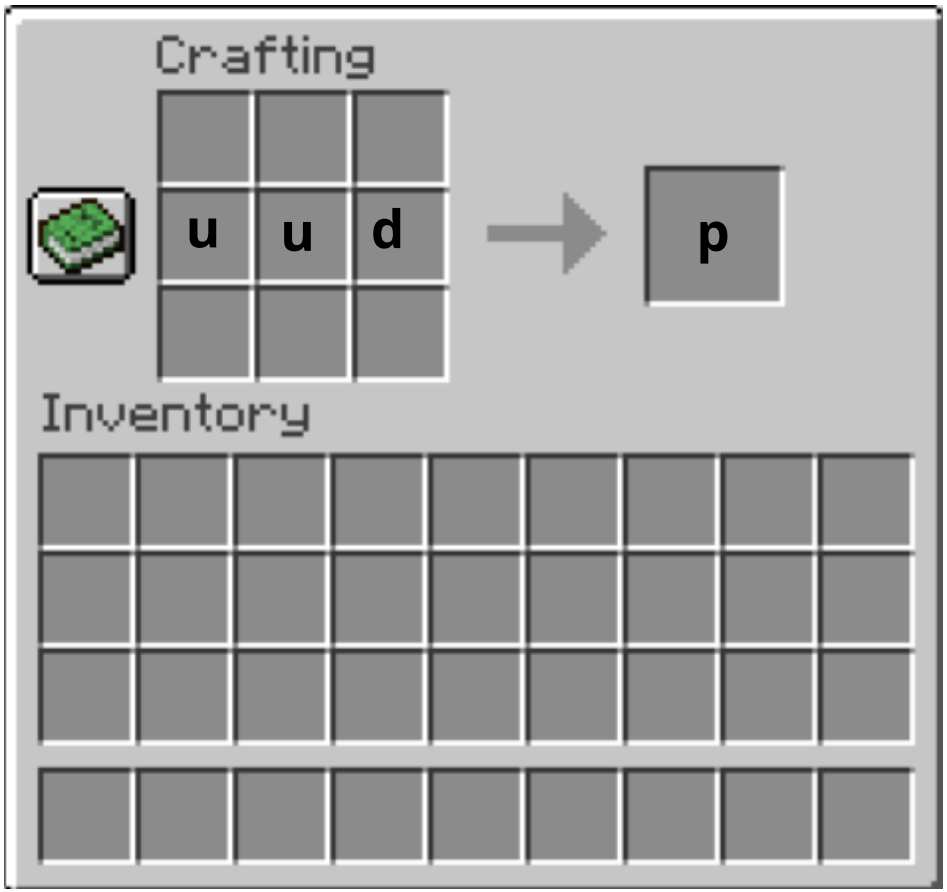

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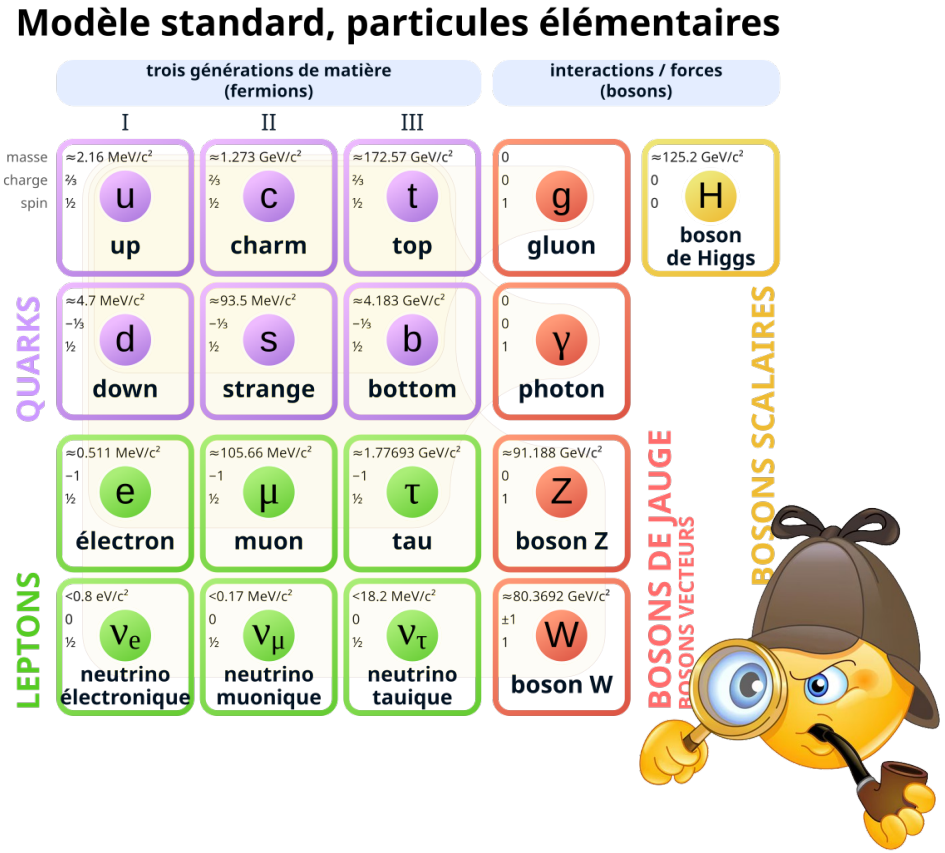

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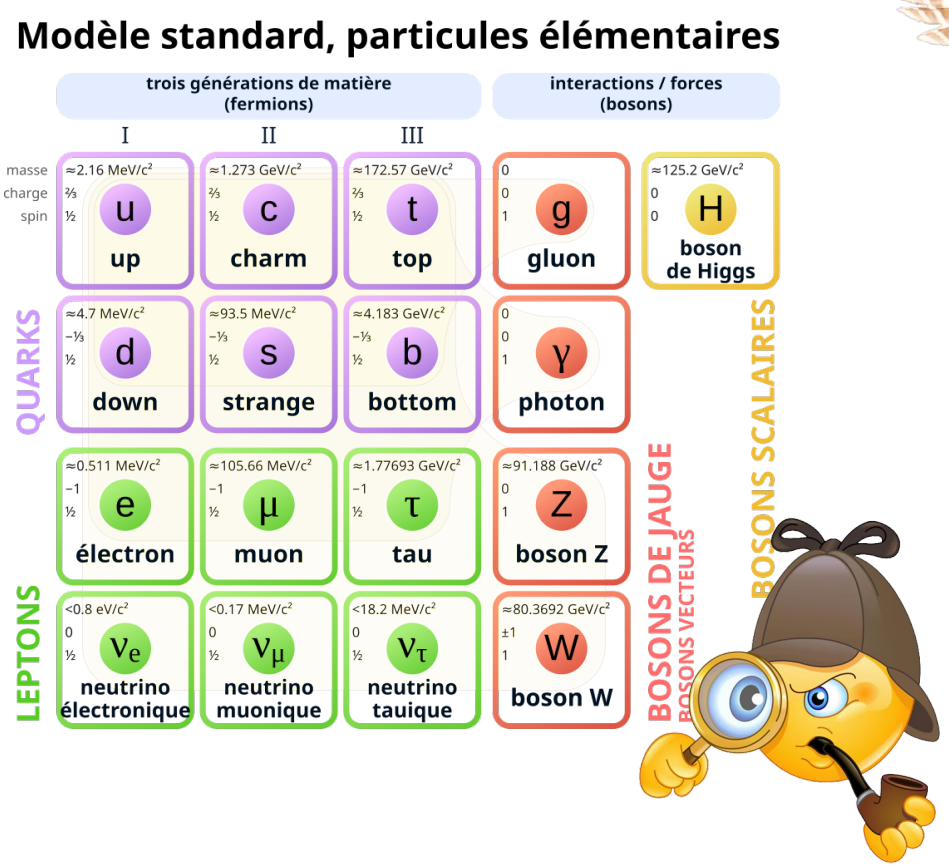

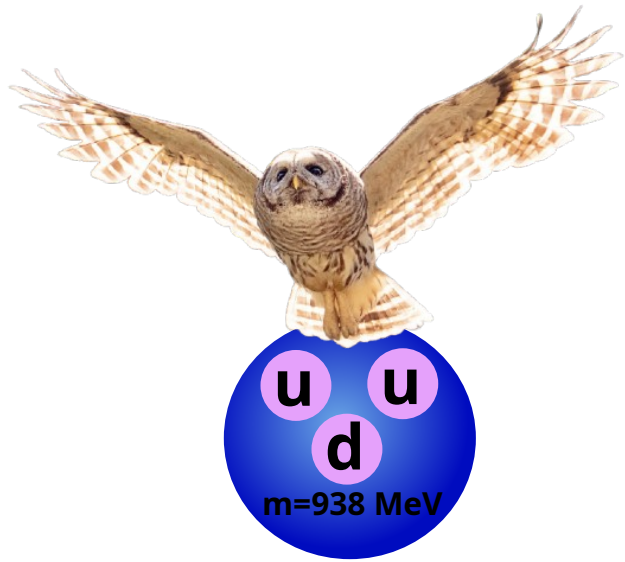

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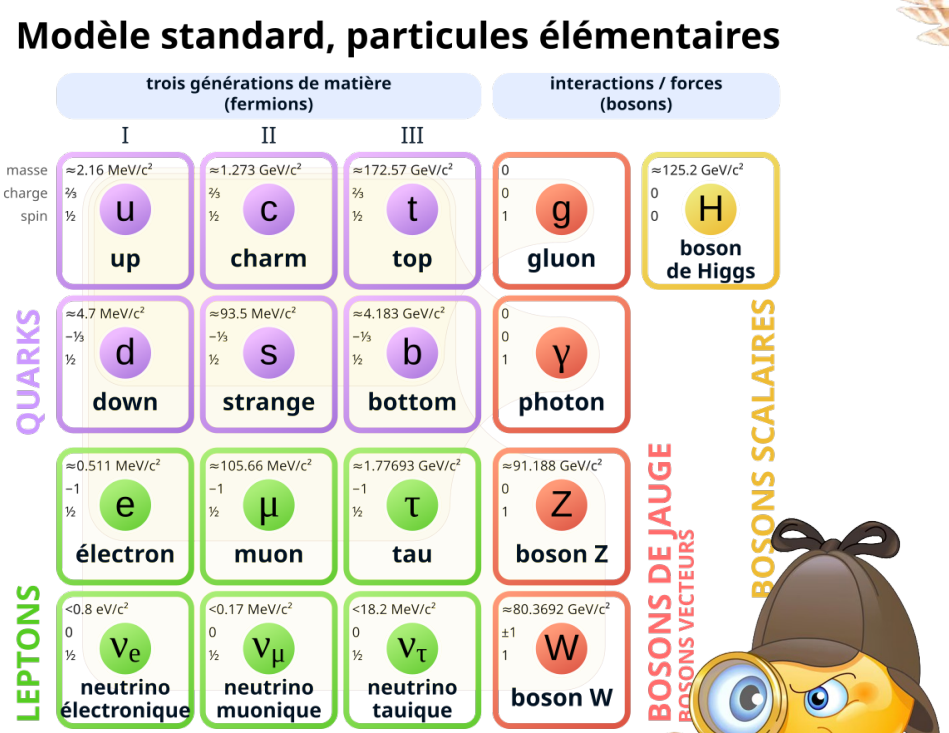

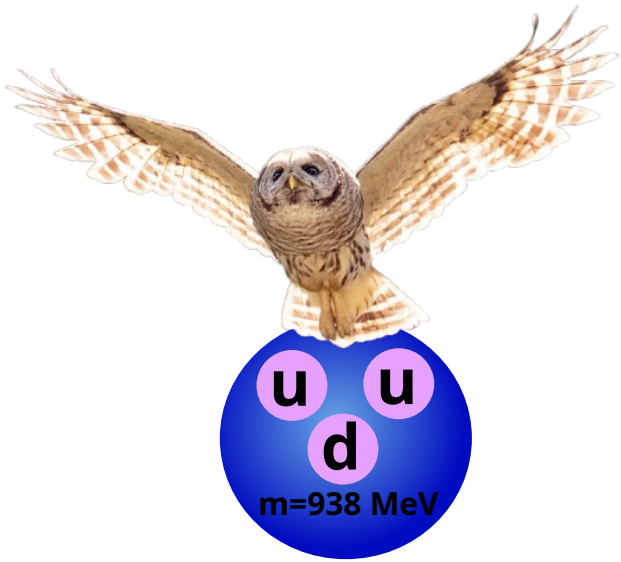

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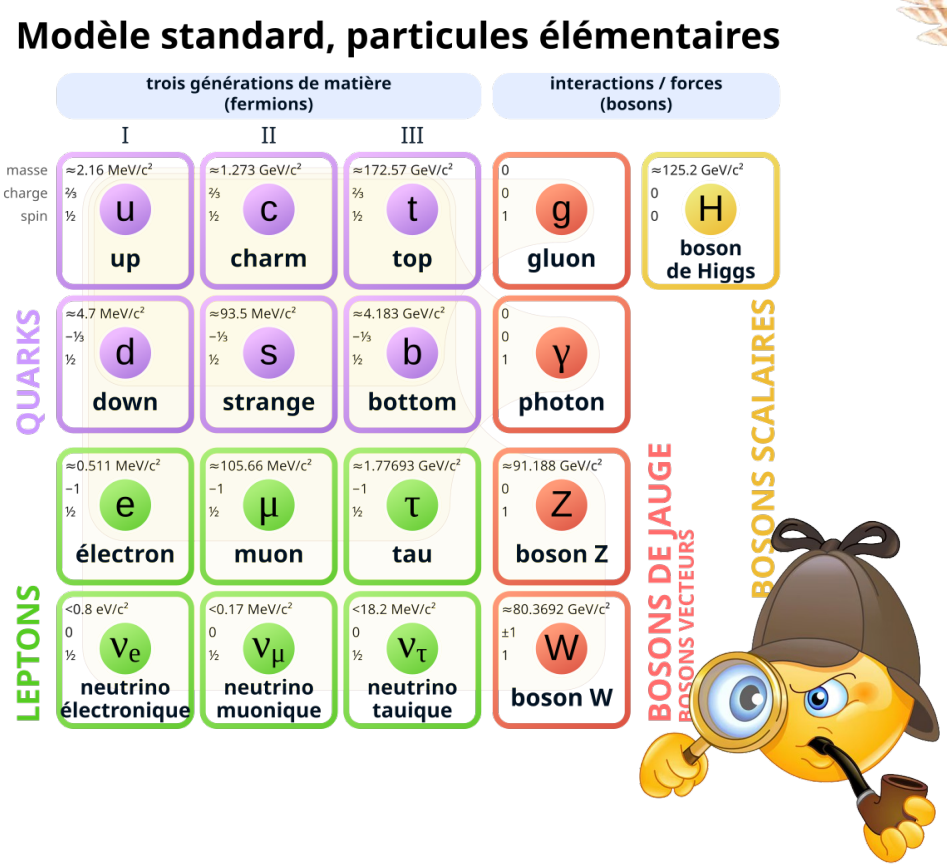
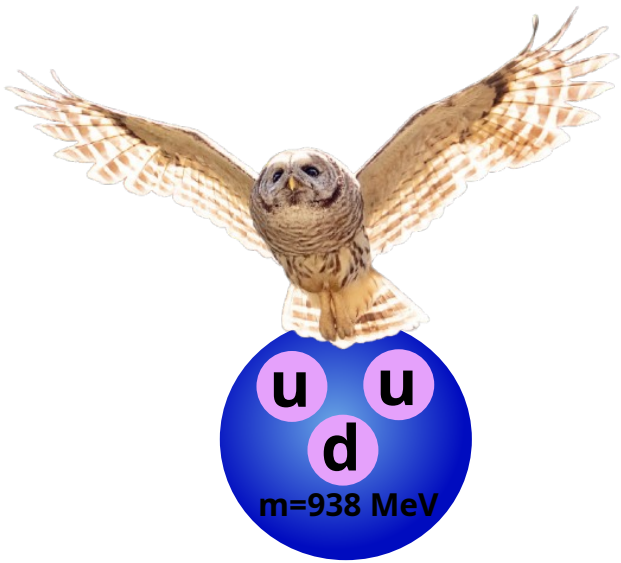




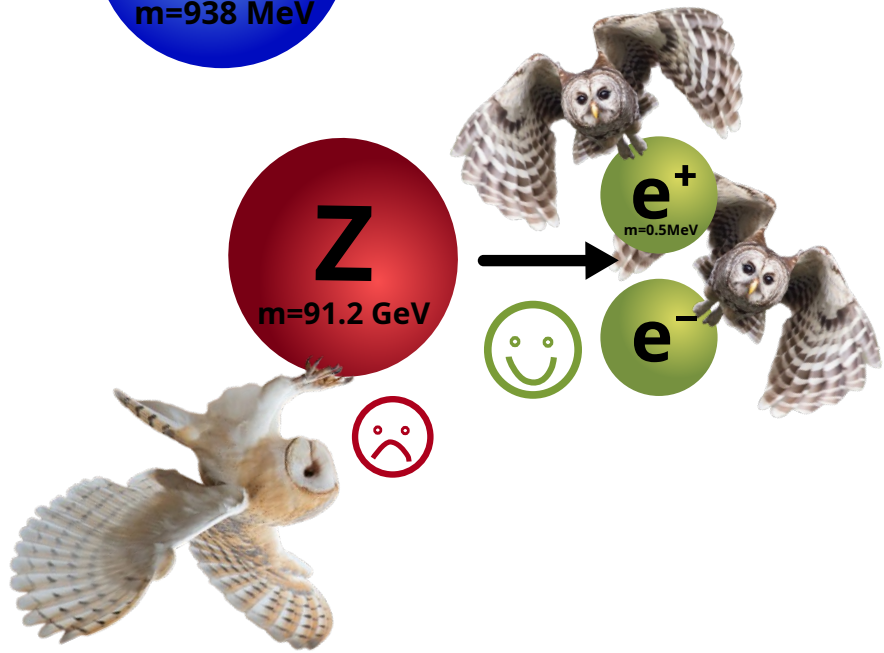


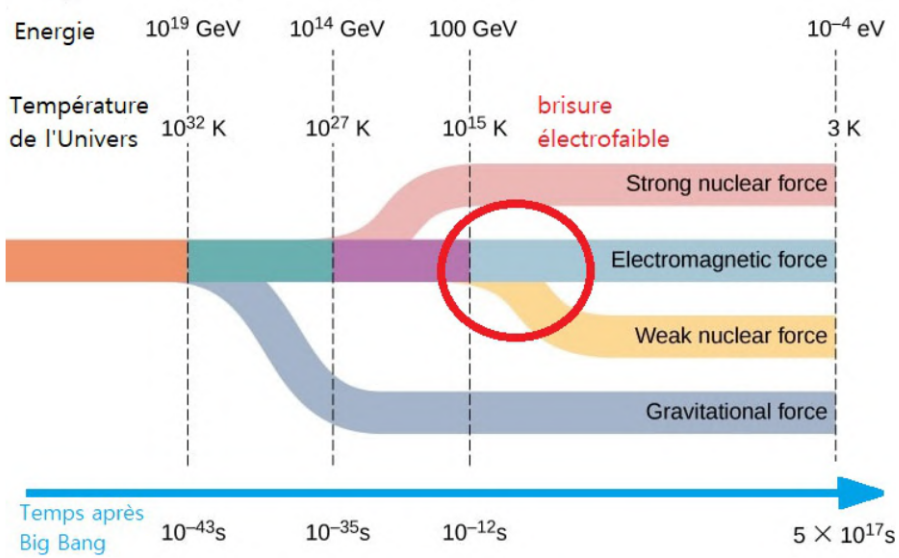
Photo credits: Sandra Rothenberg, mzphoto11

The Higgs mechanism

What gives particles their mass?

The Brout-Englert-Higgs mechanism (BEH), during the Early Universe

(Technically the Englert–Brout–Higgs–Guralnik–Hagen–Kibble mechanism, but i am NOT saying that); 1964



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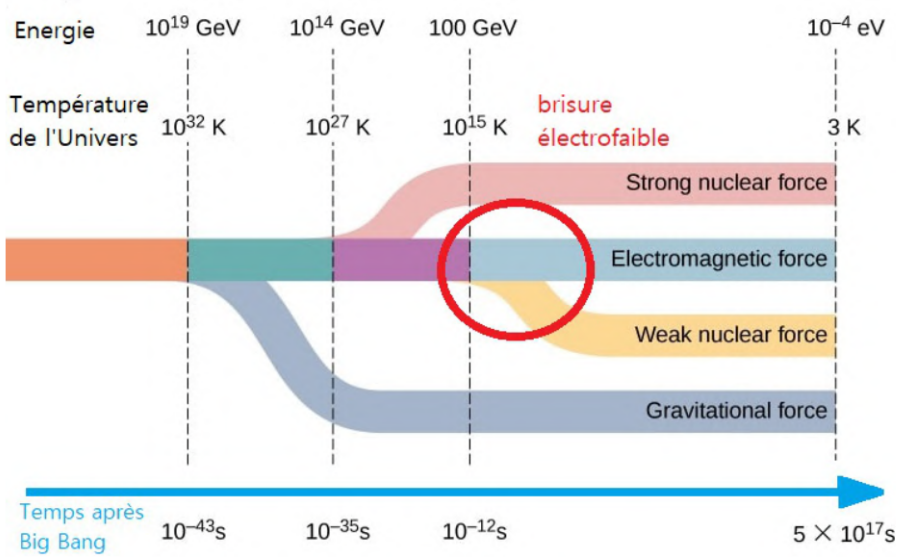

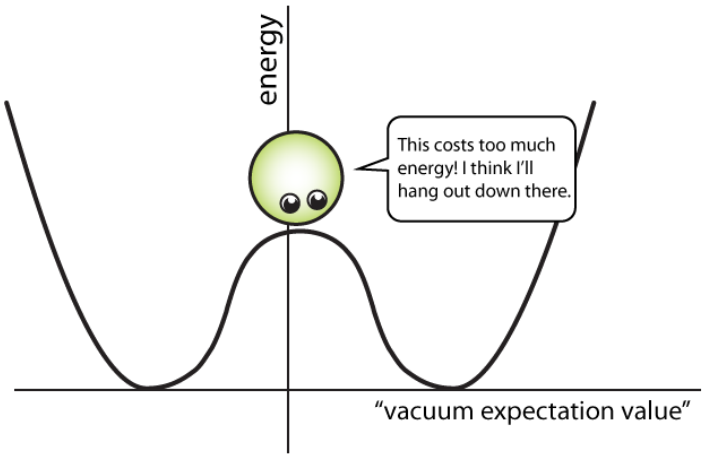

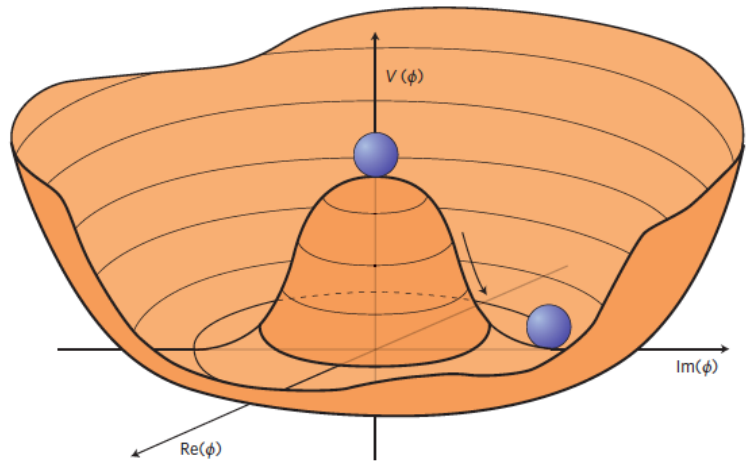

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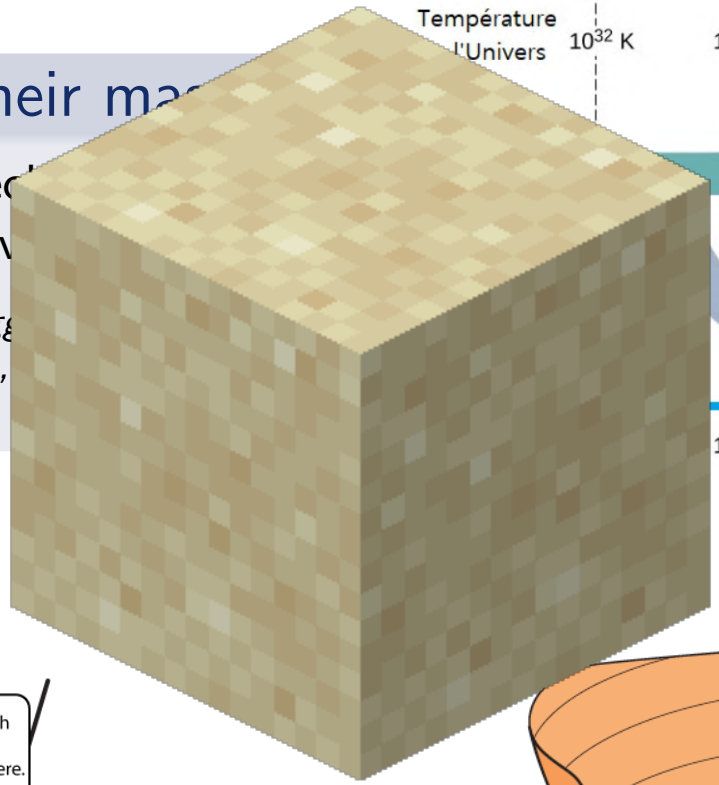

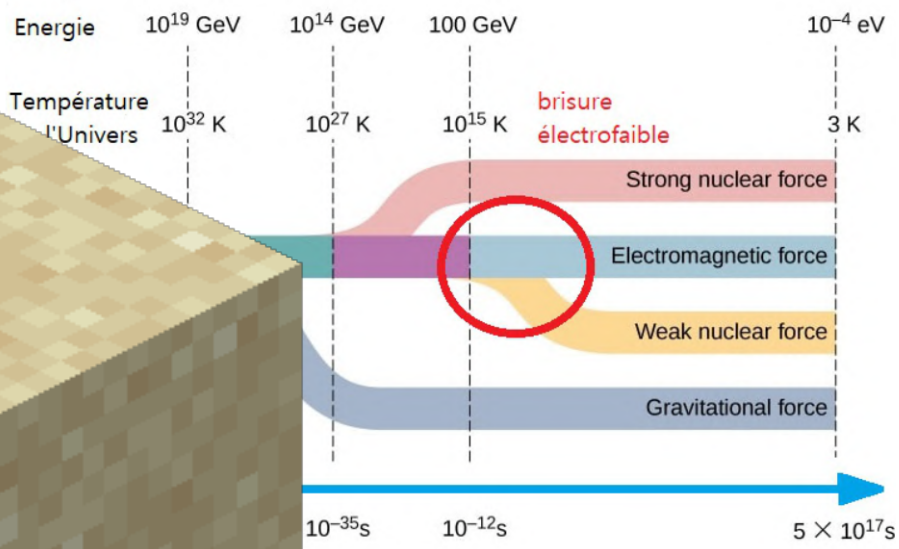

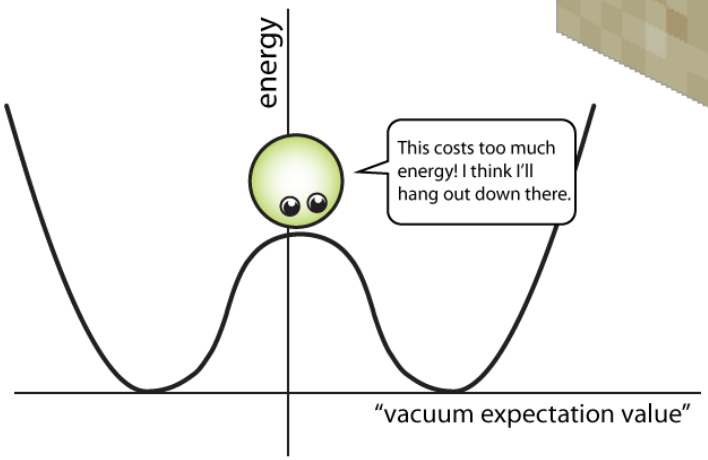

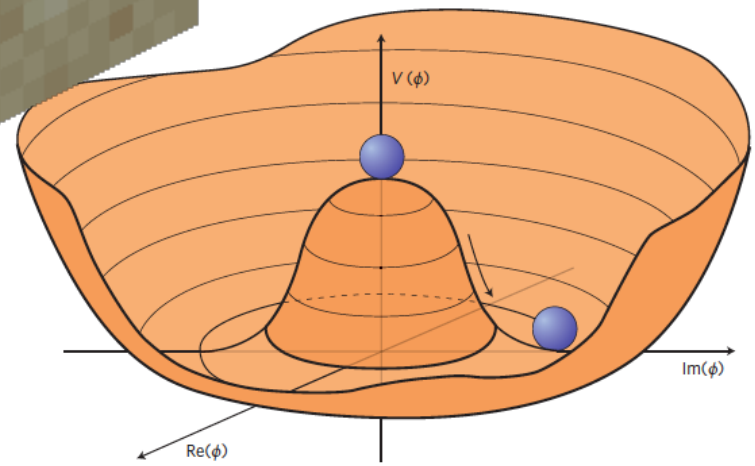

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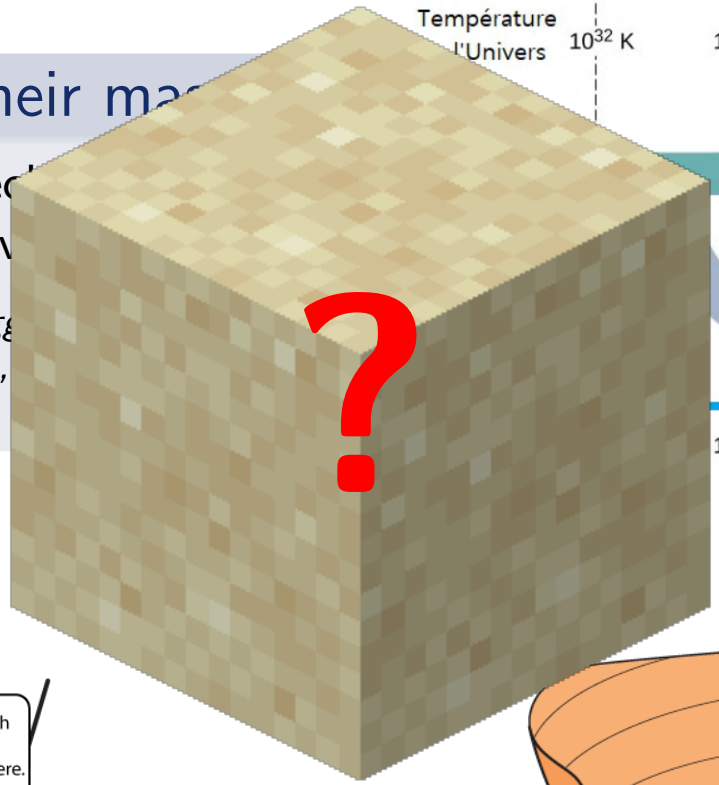

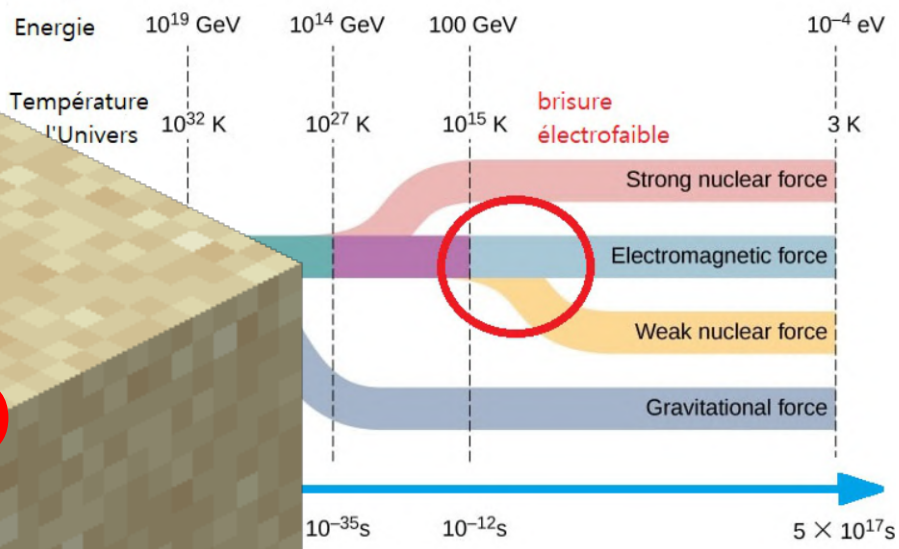

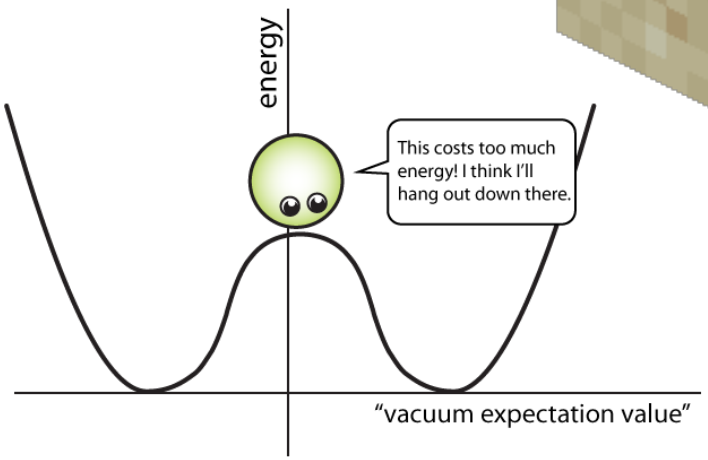

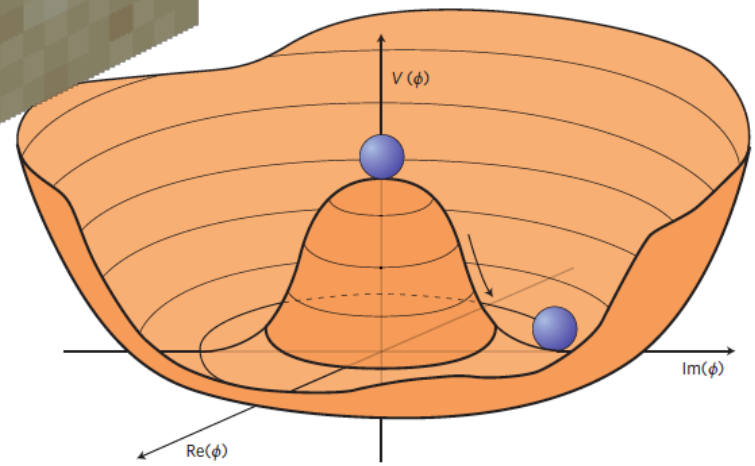

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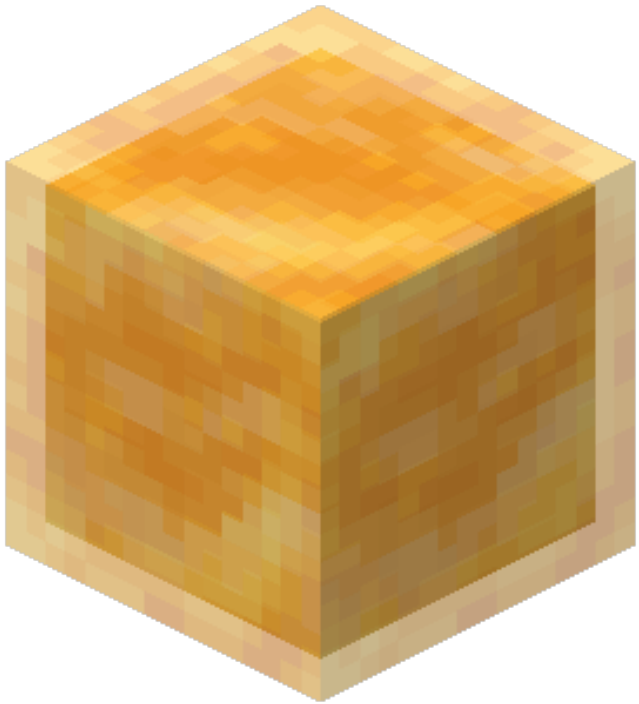

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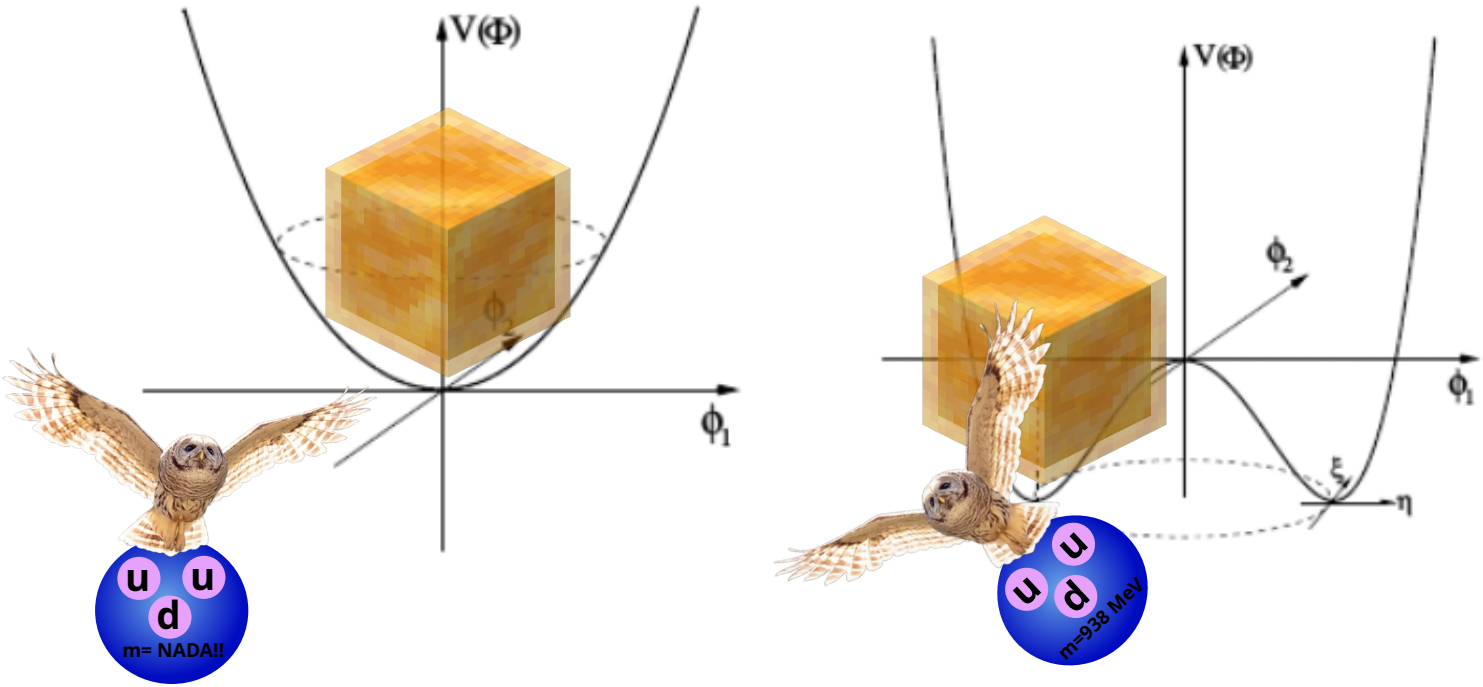
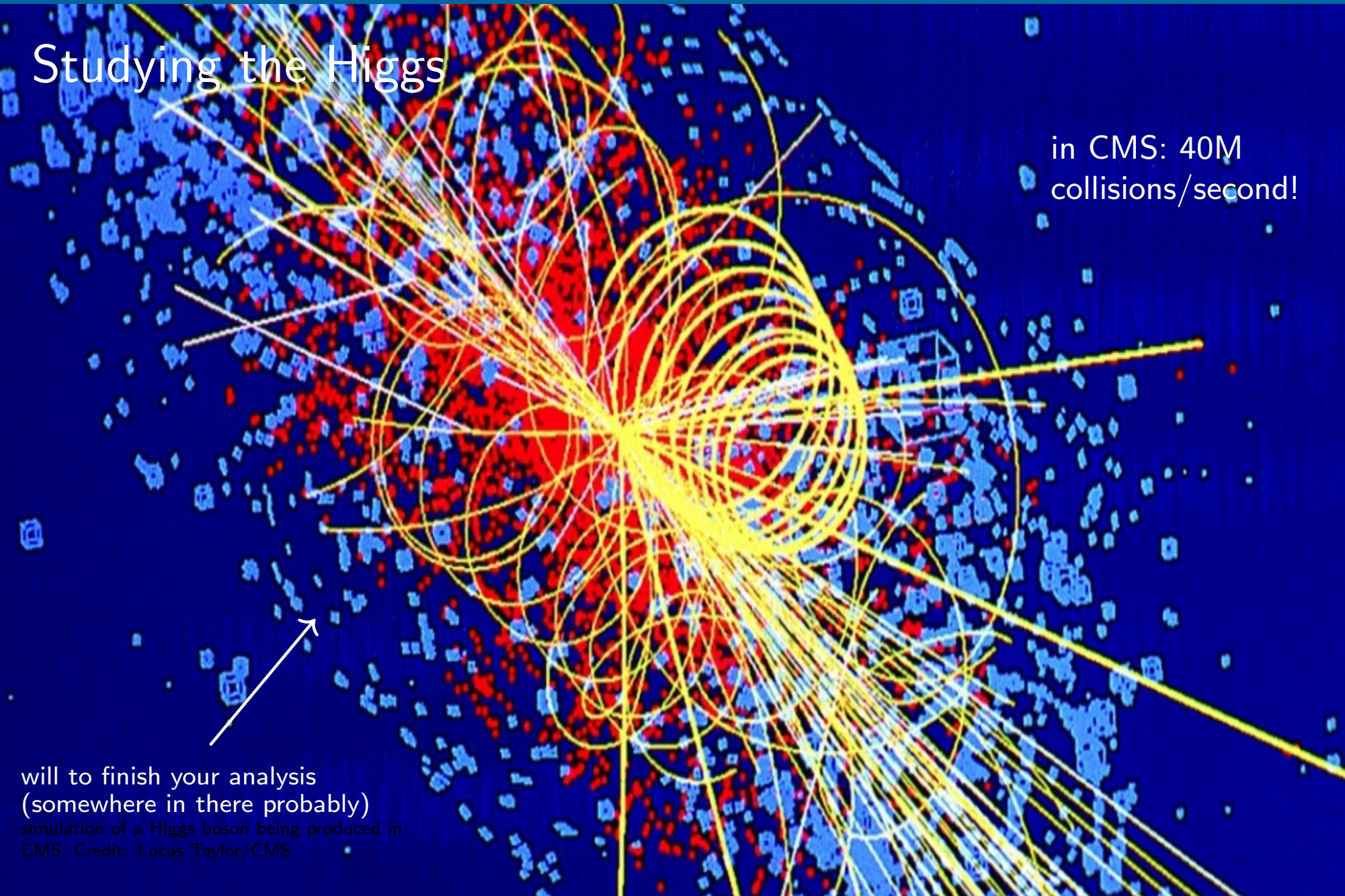


Mass = interaction with the Higgs boson!
The **more** it interacts = the heavier it is.

Discovery of the Higgs at CERN

$m_H(theoretical) \approx 125\text{GeV}$.
$(m_{e^-} \approx 0.5\ \text{MeV})$
$\Rightarrow$ LHC=27km diameter: 8T magnets, $\approx$ 13 TeV of energy!

Studying the Higgs



simulation of a Higgs boson being produced in CMS. Credit: Lucas Taylor/CMS

A missing piece: λ

Measuring the Higgs boson

✓ Measuring its mass
✓ Measuring its interaction with other particles
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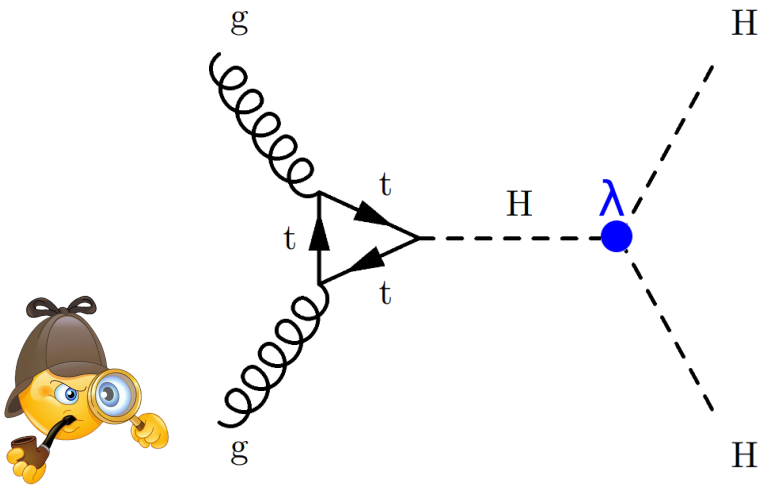

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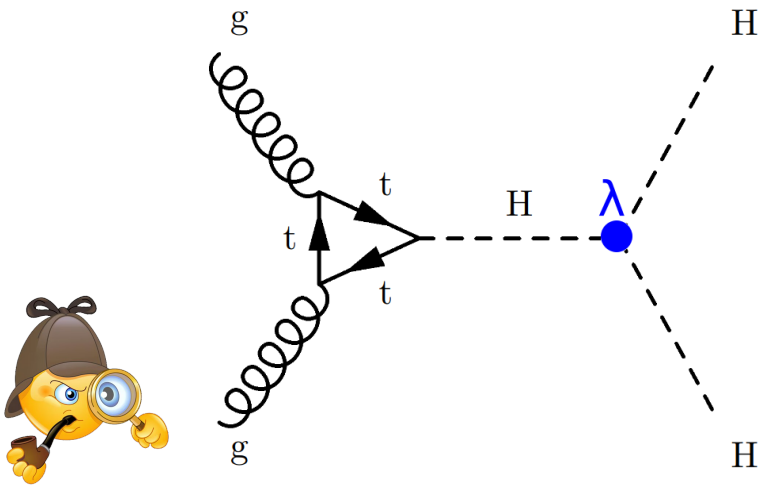

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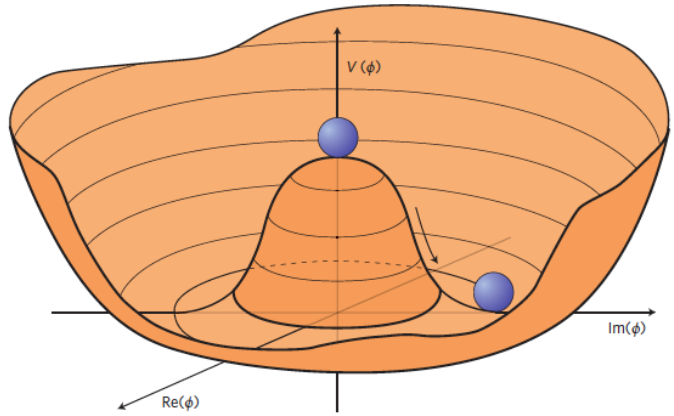

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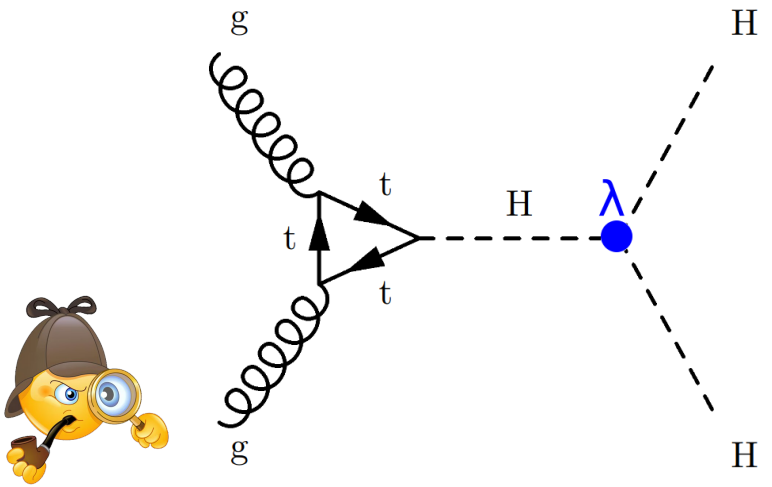

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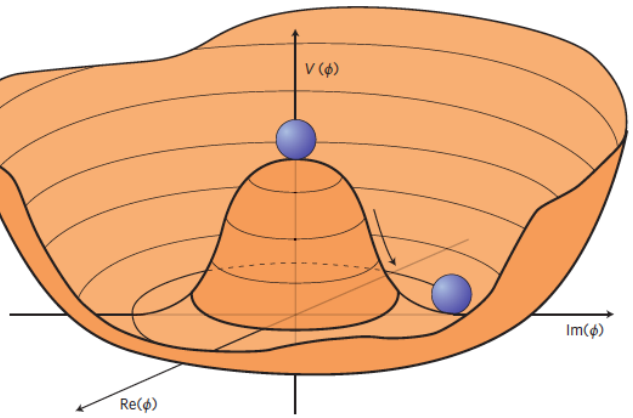

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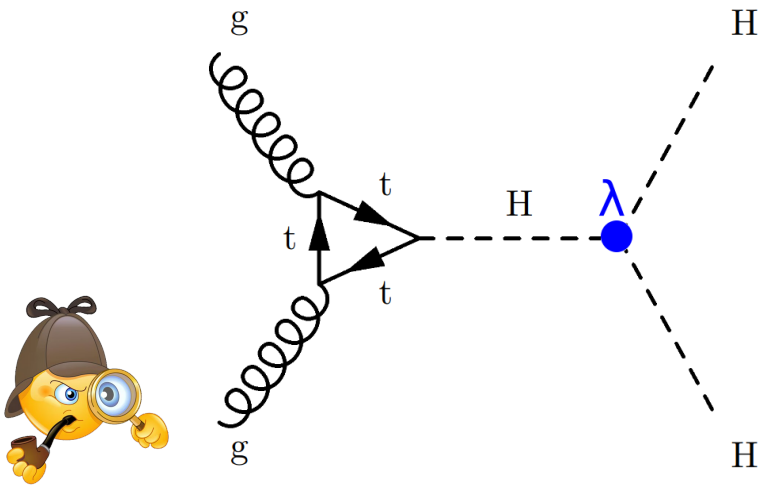

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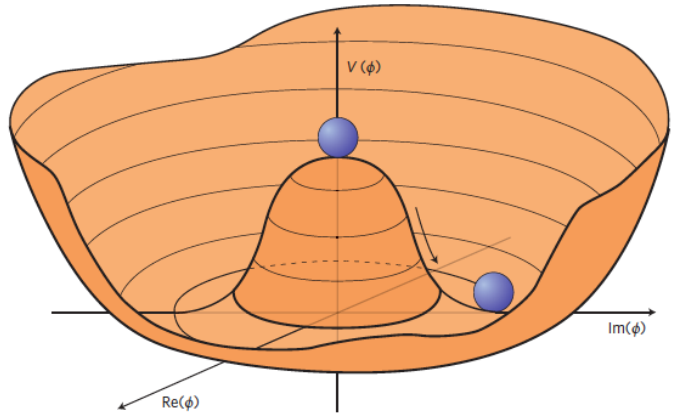

$\Rightarrow$ λ parametrizes **shape** of higgs potential.

Theoretical value: $\lambda_{th} = \approx 0.13$.
If $\lambda_{th} \neq \lambda$: **missing piece in our understanding of the Universe.**

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End goal:

Learn to measure Higgs self-interaction λ.

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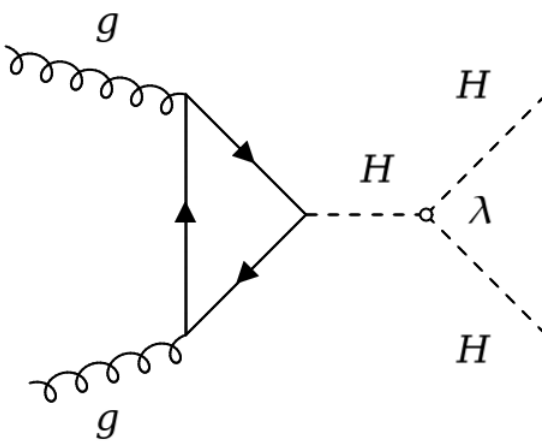

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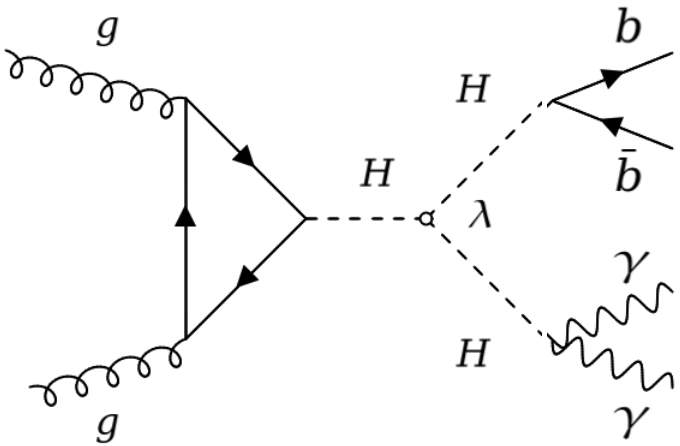

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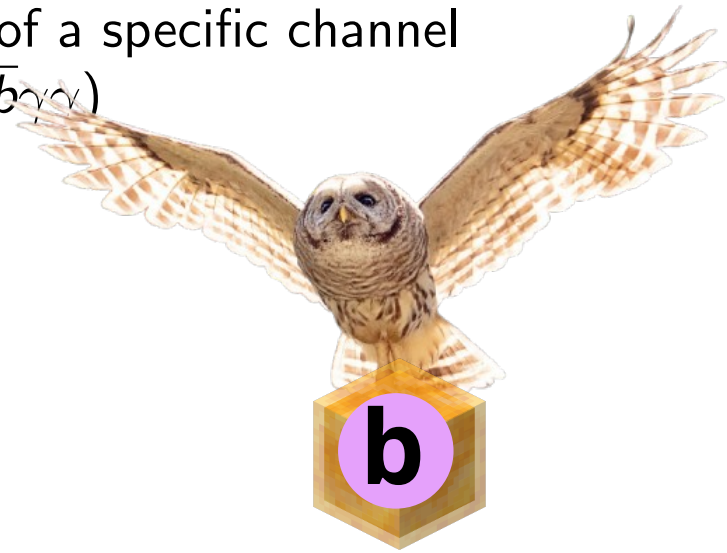
⇒Choice of a specific channel ($HH \to b\bar{b}\gamma\gamma$)



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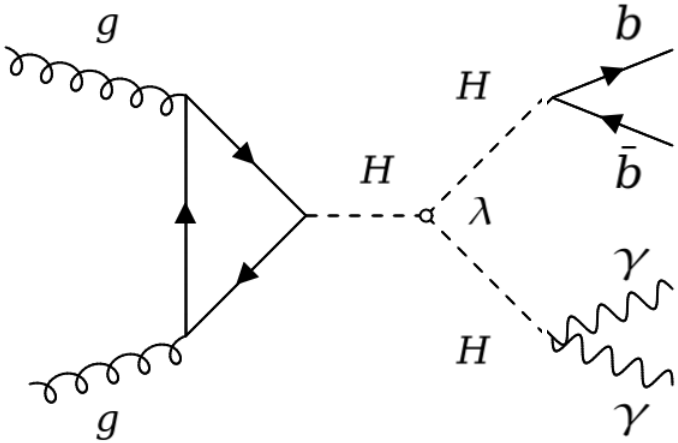

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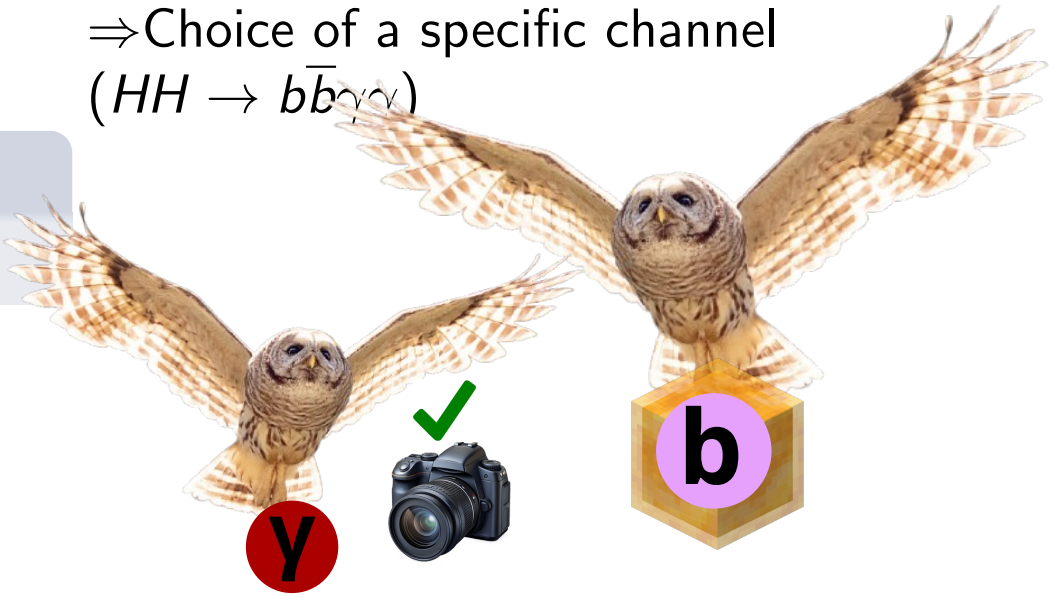

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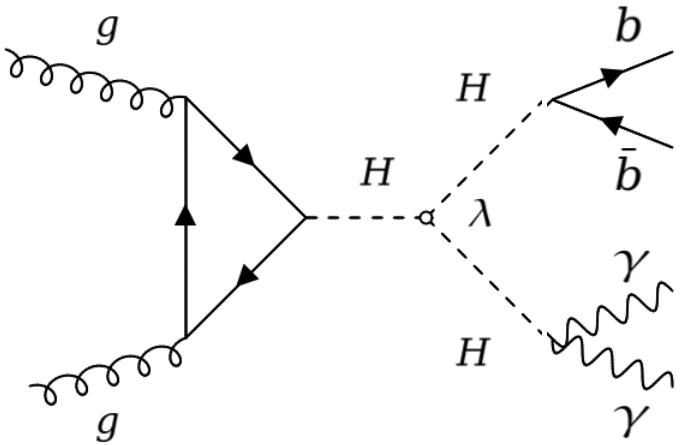

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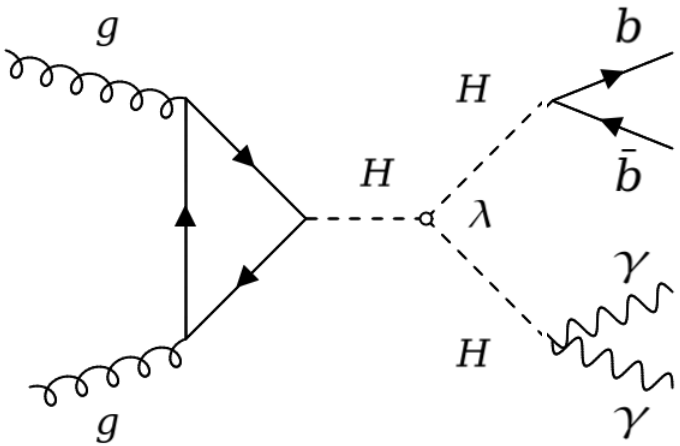

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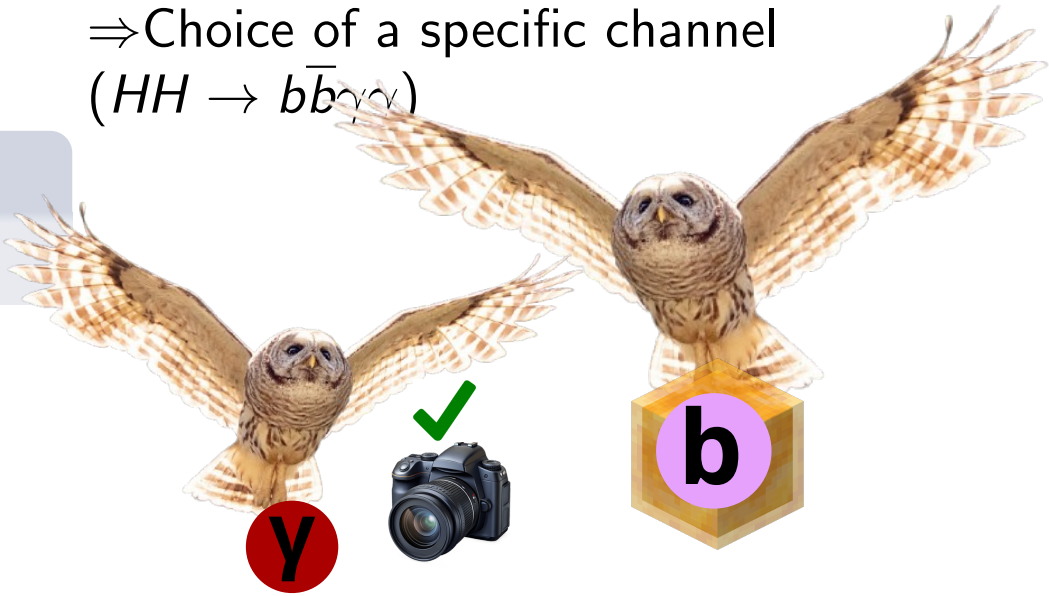
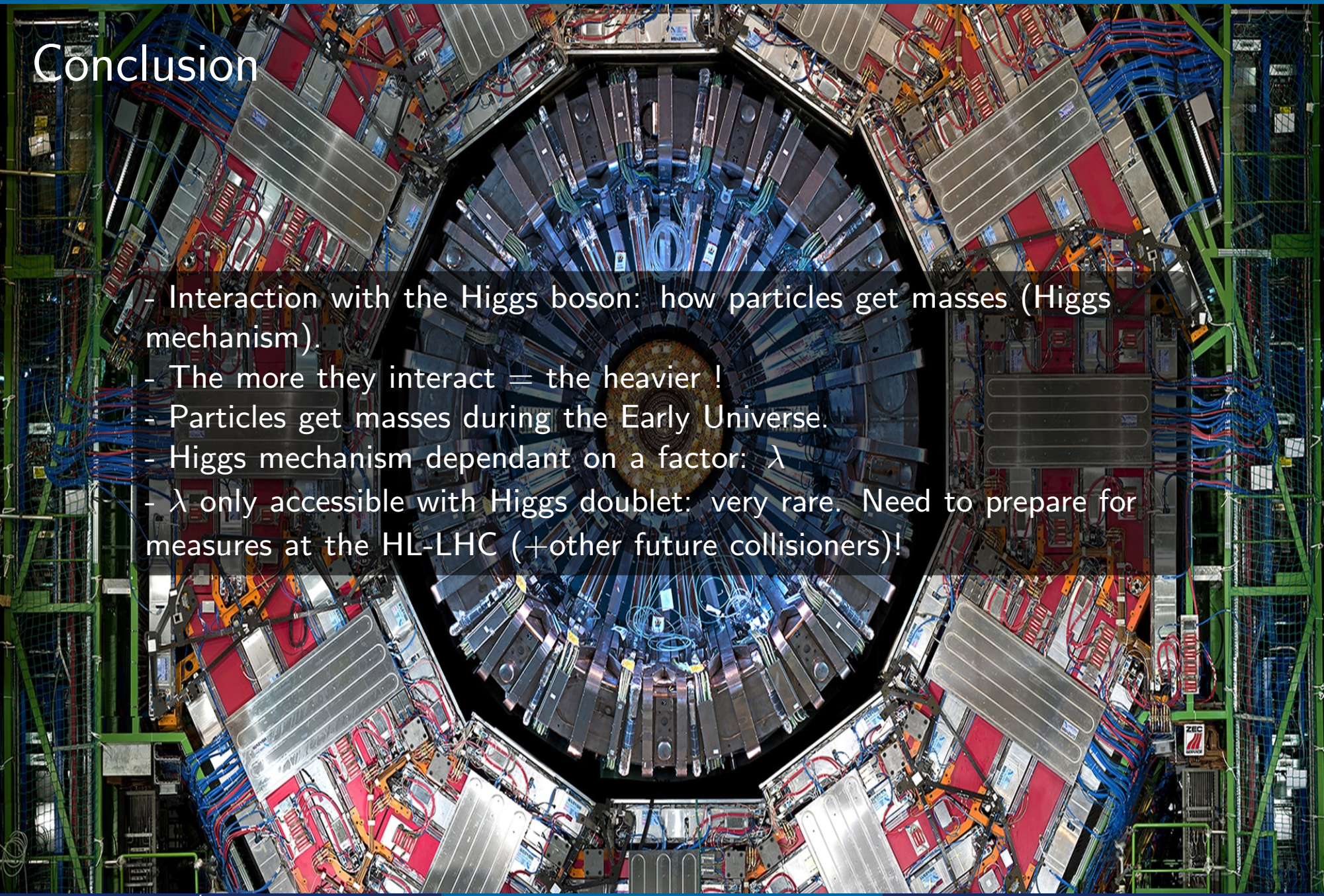


⇒ Data analysis: train Deep Neural Network (DNN) on LHC data to separate background from signal.
⇒ Data simulation: generate LHC-like events, with a Higgs boson pair. Use it to see if we can extract signal.

Conclusion



- Interaction with the Higgs boson: how particles get masses (Higgs mechanism).
- The more they interact = the heavier !
- Particles get masses during the Early Universe.
- Higgs mechanism dependant on a factor: λ
- λ only accessible with Higgs doublet: very rare. Need to prepare for measures at the HL-LHC (+other future collisioners)!

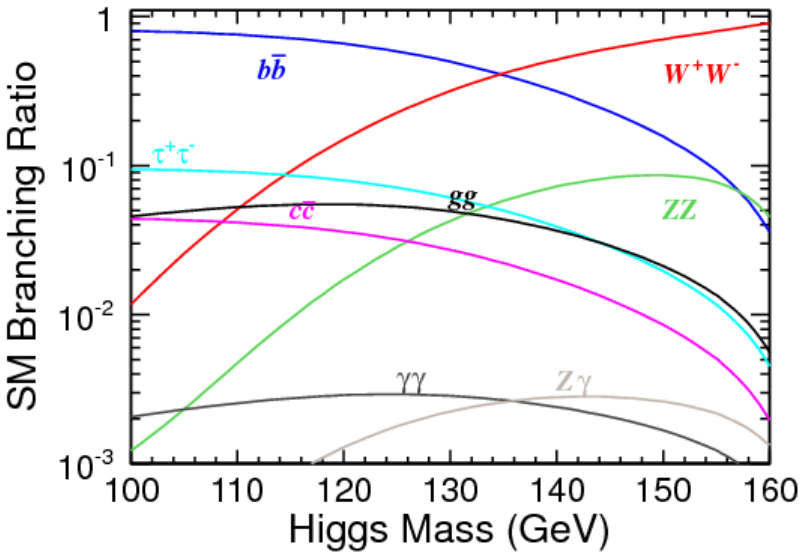
Questions

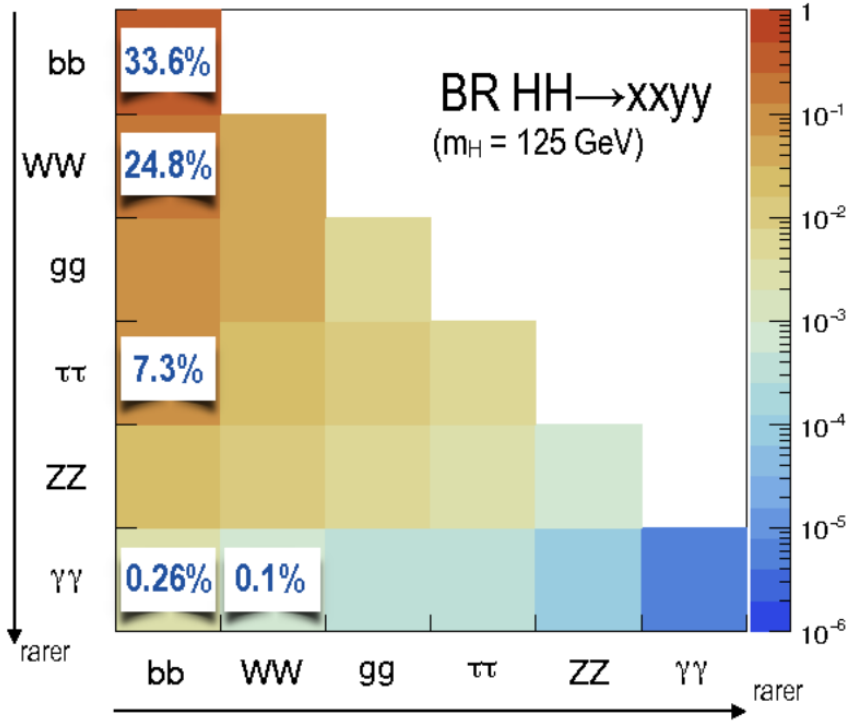
Some suggestions:

- How can they be sure in 2012 that it was the Higgs that they observed?
- Why $HH \to b\bar{b}\gamma\gamma$ specifically? And not just $b\bar{b}$, $\gamma\gamma$, or another particle in the standard model?
- Why do we need an energy of 13TeV (CERN collision energy) to discover a particle whose mass is only 125GeV?
- Why is the Higgs / a Higgs pair so rare of an event?
- What is your favourite minecraft block / owl?
- Have you ever been diagnosed with any sort of mental illness?
- **Others questions more than welcome!**

Annex

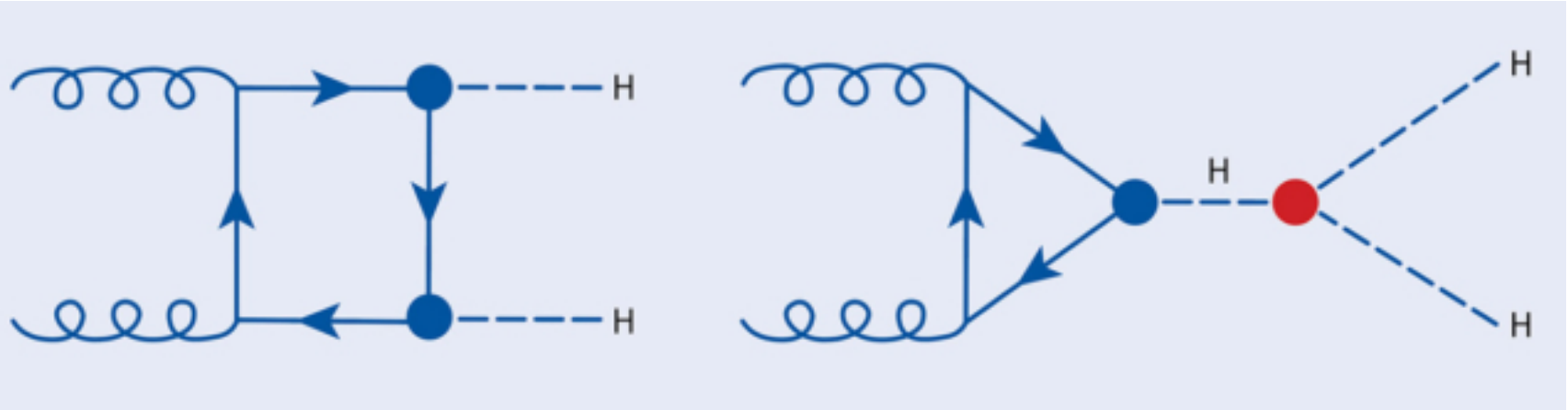
Higgs branching ratios





Annex

Interfering diagrams for di-Higgs production at the LHC:



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