Why the Higgs is important

Gavin Salam

Rudolf Peierls Centre for Theoretical Physics

& All Souls College, University of Oxford

Science and Technology Facilities Council

European Research Council
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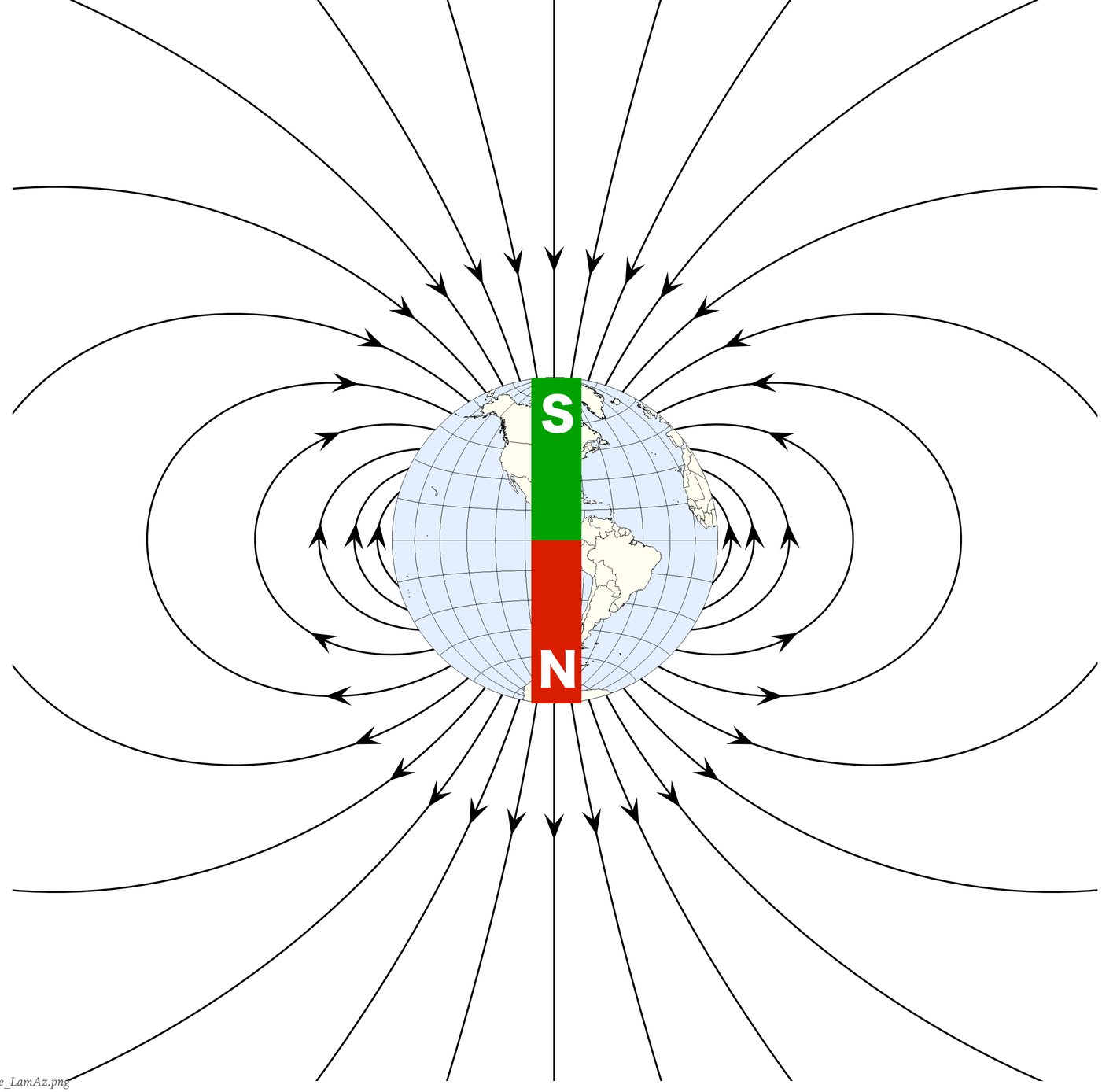

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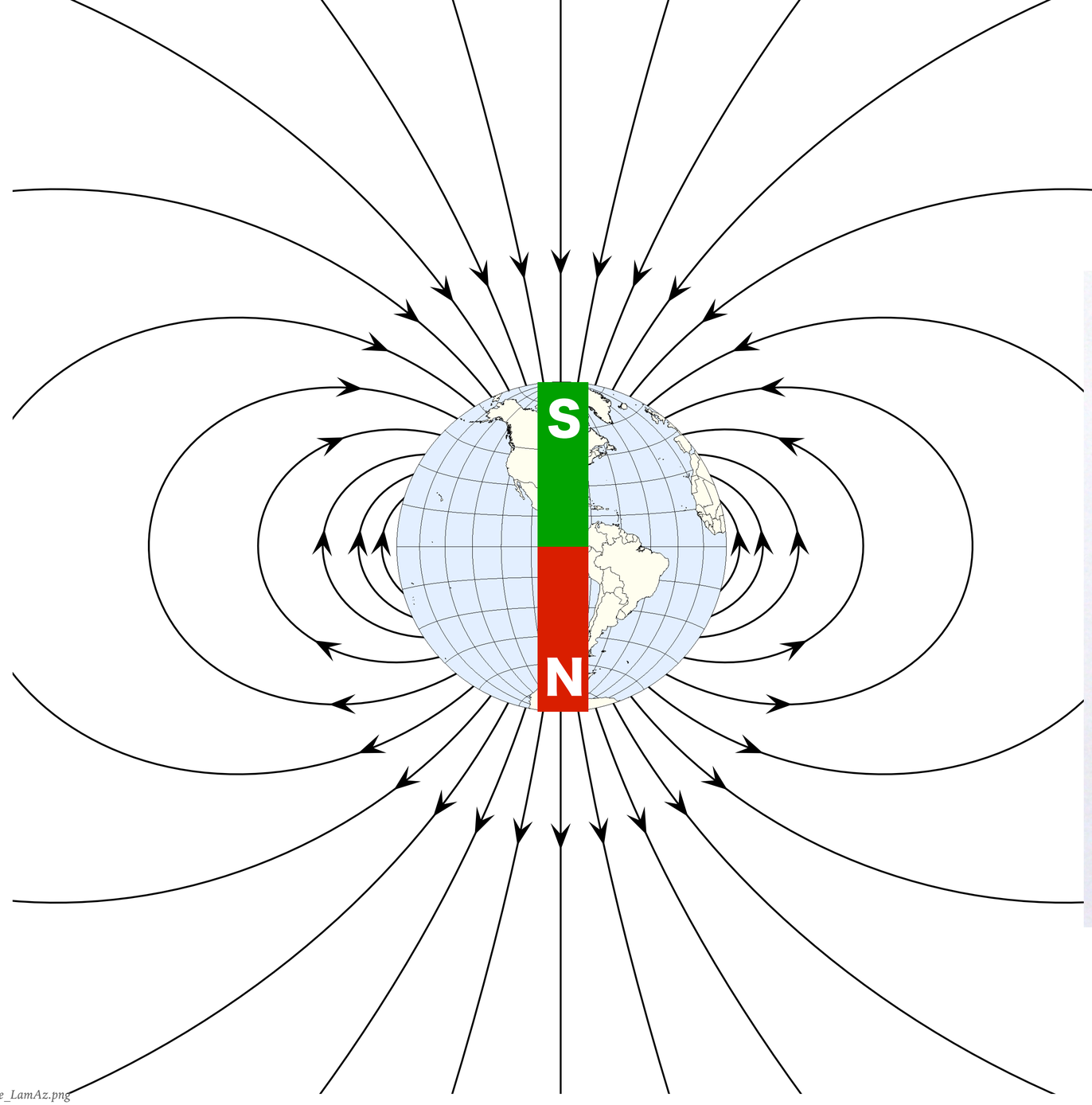

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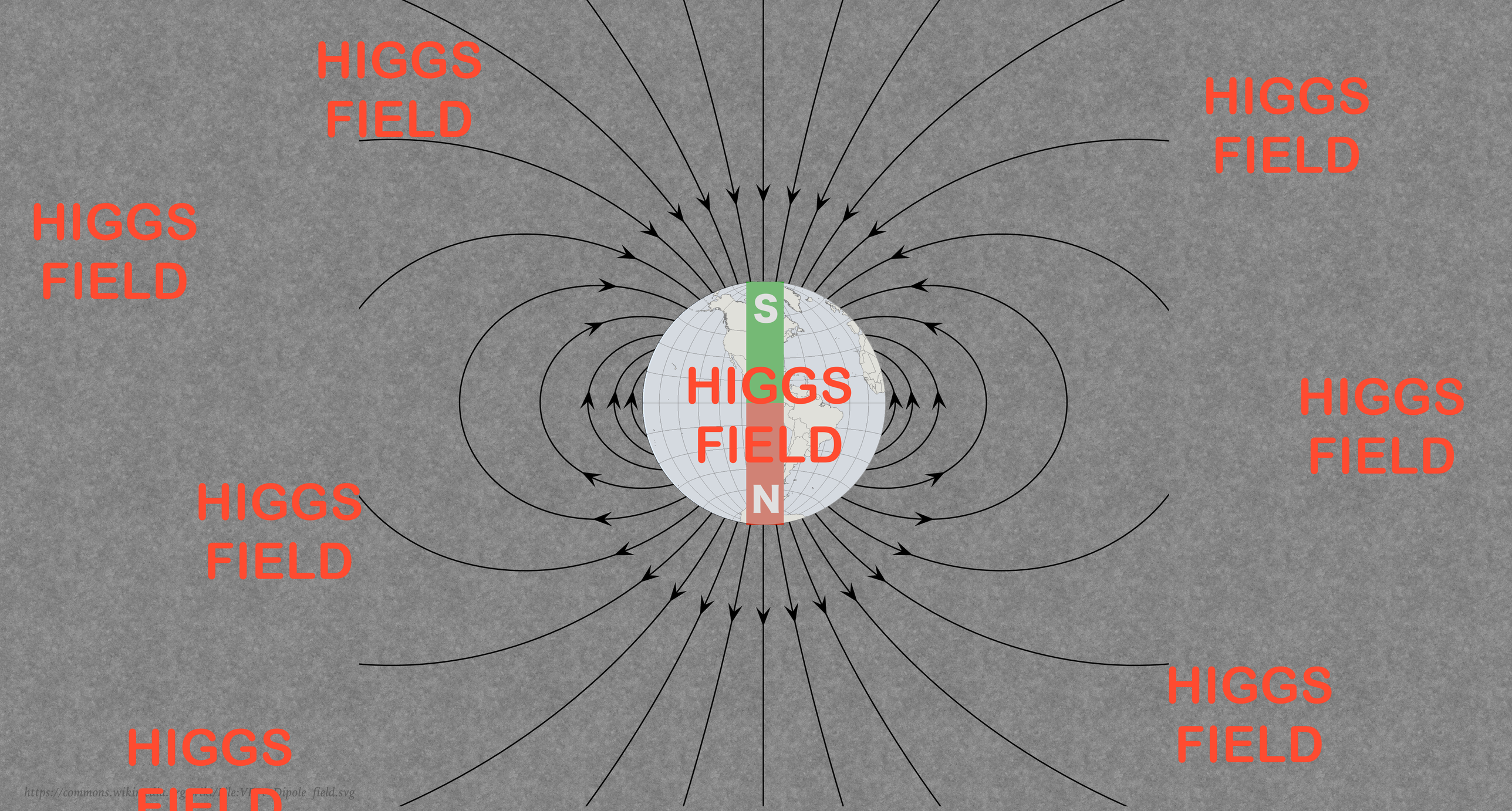

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HIGGS FIELD

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HIGGS

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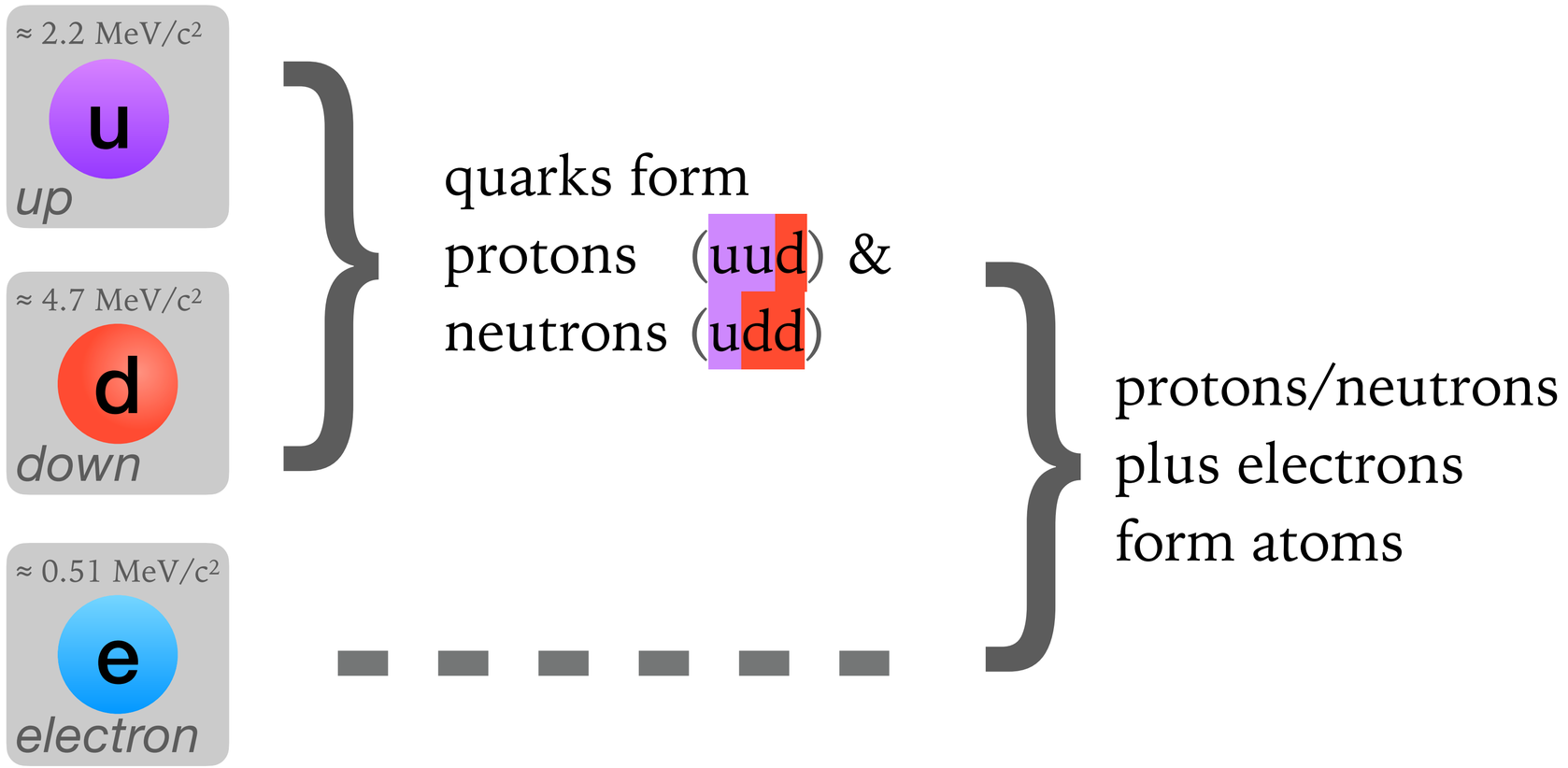
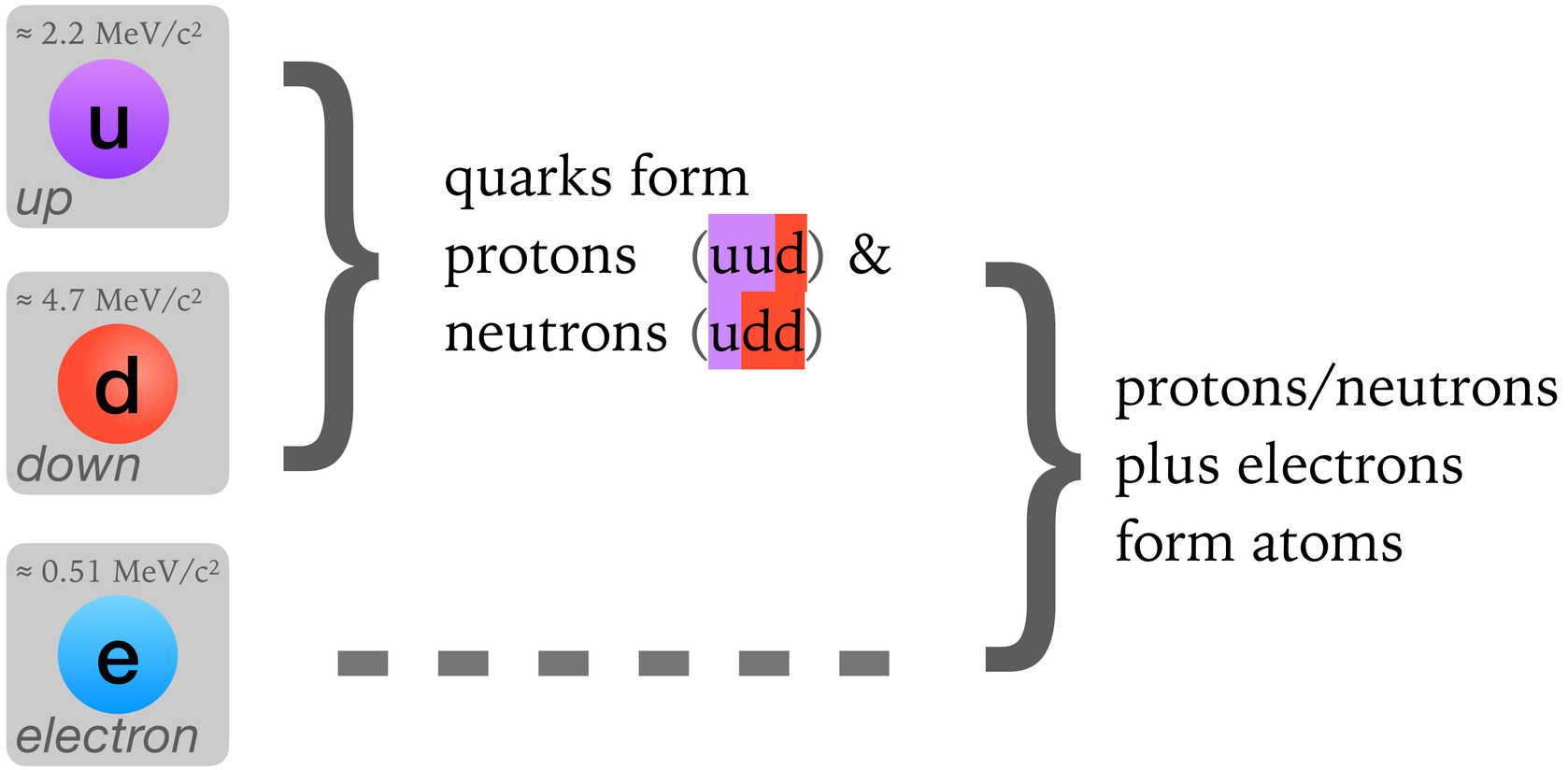
Large Hadron Collider @ CERN

first generation
elementary
fermions



masses

first generation elementary fermions

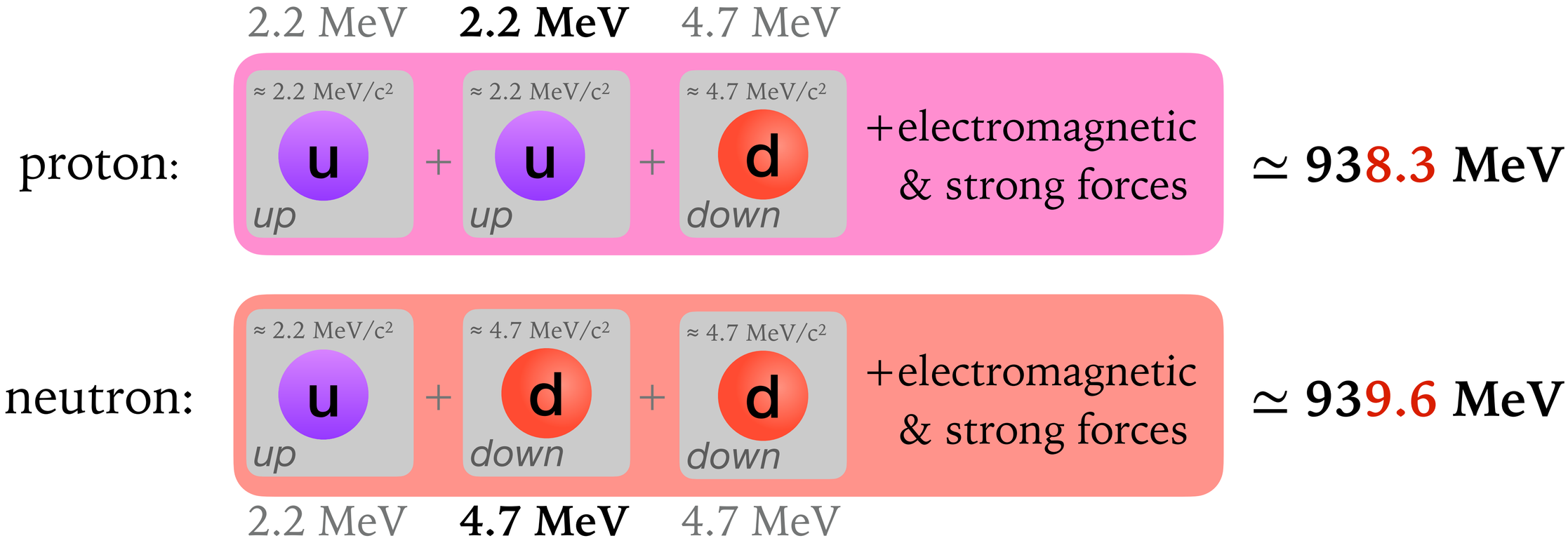


≃ 2.2 MeV

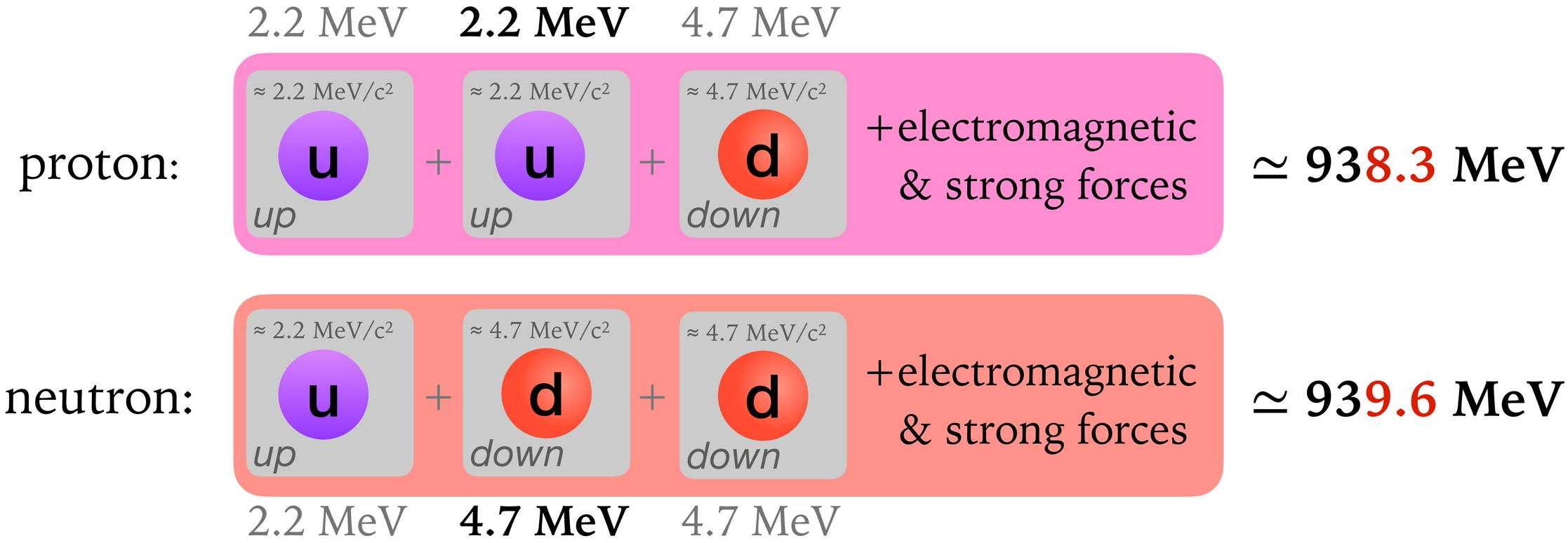
≃ 4.7 MeV

≃ 0.51 MeV

Standard *Model* "hypothesis" says these different masses are a consequence of different interactions with the non-zero Higgs field all around us



Protons are **lighter** than neutrons→ protons are stable.
Giving us the hydrogen atom, & chemistry and biology as we know it



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Supposedly because up quarks interact more weakly with the Higgs field than down quarks

masses make proton stable

1st gen. fermions	2nd gen. fermions	3rd gen. fermions	massive force carriers
≈ 2.2 MeV/c² **u** *up*	≈ 1.3 GeV/c² **c** *charm*	≈ 173 GeV/c² **t** *top*	
≈ 4.7 MeV/c² **d** *down*	≈ 93 MeV/c² **s** *strange*	≈ 4.2 GeV/c² **b** *bottom*	≈ 91.2 GeV/c² **Z** *Z-boson*
≈ 0.51 MeV/c² **e** *electron*	≈ 106 MeV/c² **μ** *muon*	≈ 1.78 GeV/c² **τ** *tau*	≈ 80.4 GeV/c² **W** *W-boson*

masses make proton stable

mass sets size of atoms

1st gen. fermions	2nd gen. fermions	3rd gen. fermions	massive force carriers
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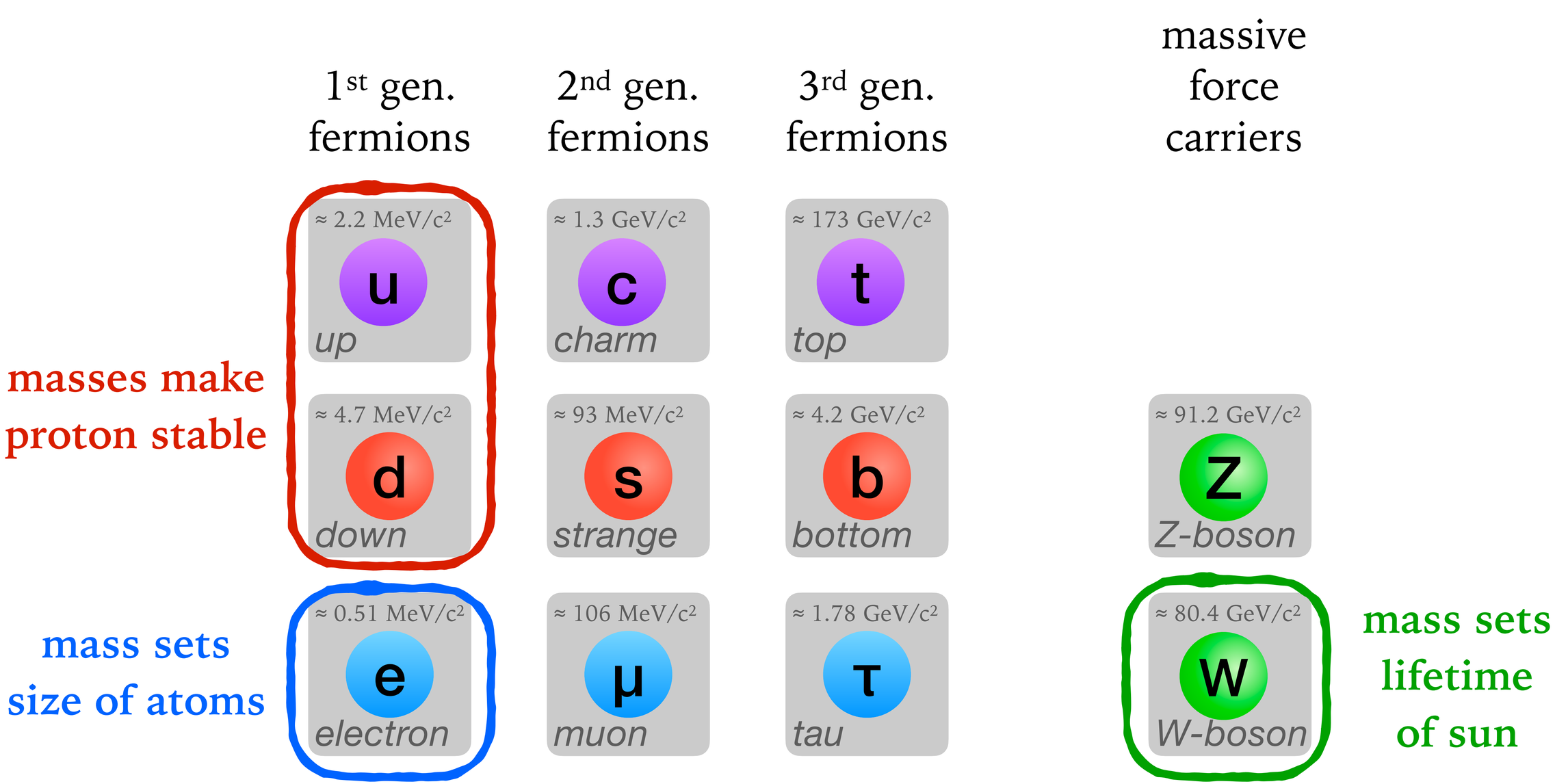
1st gen. fermions
2nd gen. fermions
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massive force carriers
masses make proton stable
mass sets size of atoms
mass sets lifetime of sun
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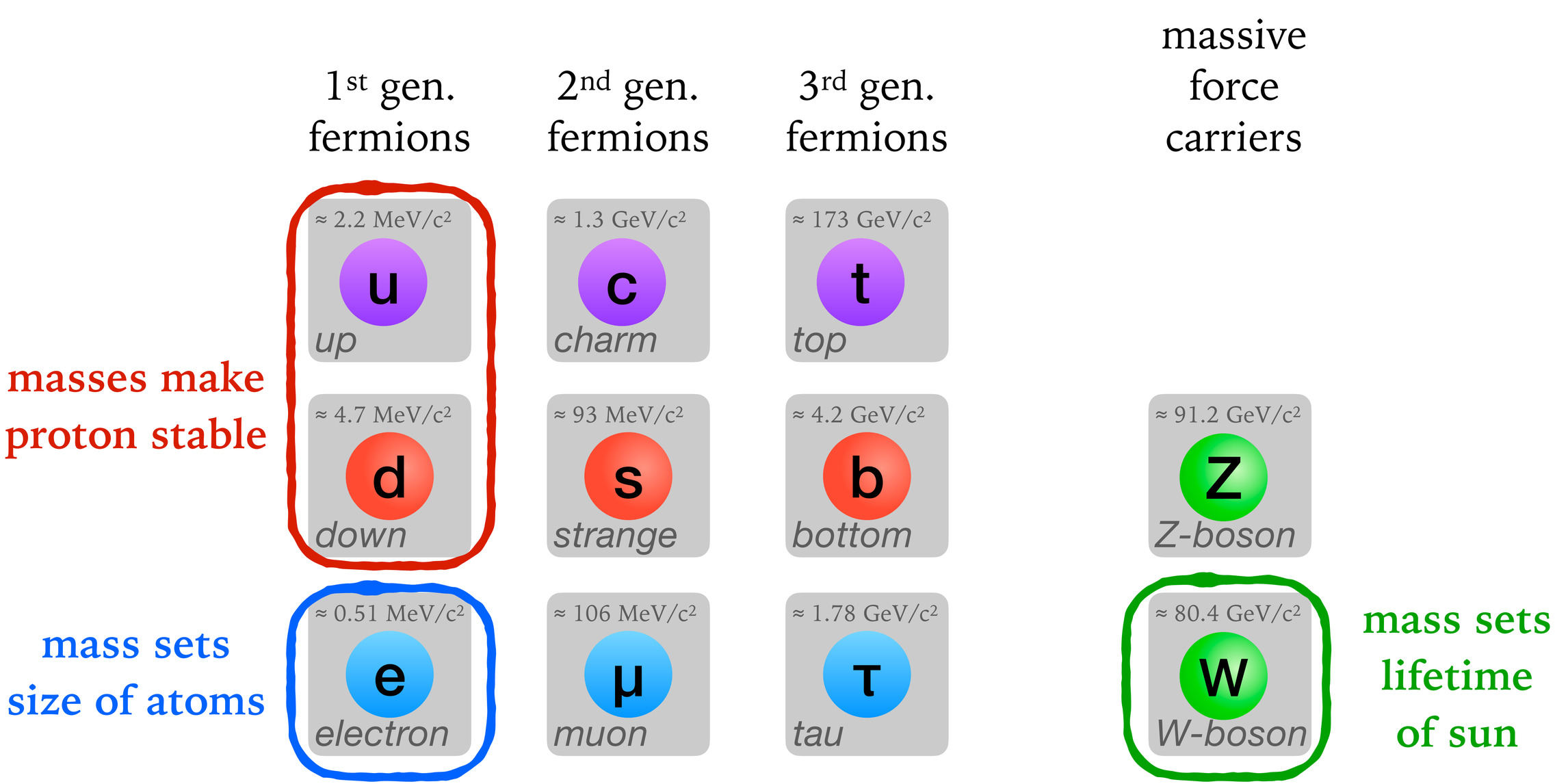
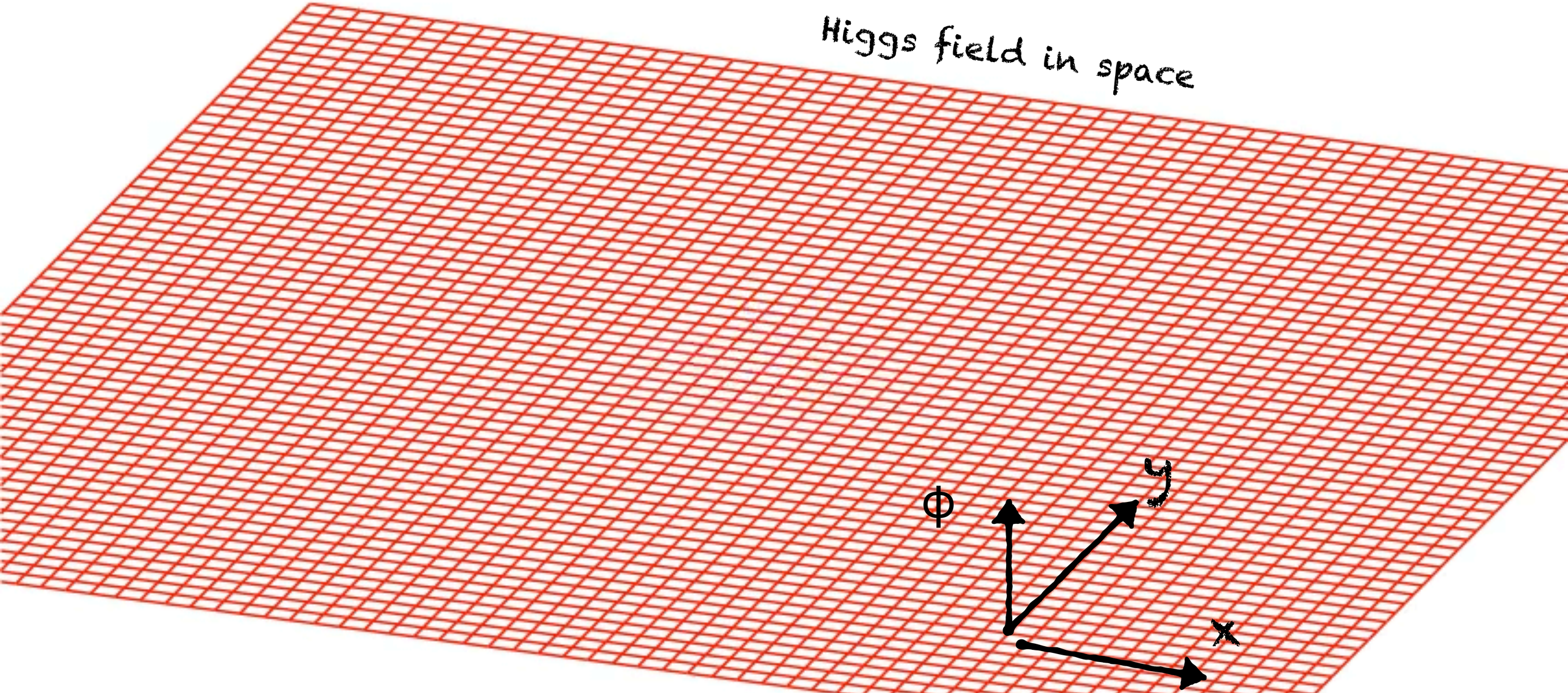
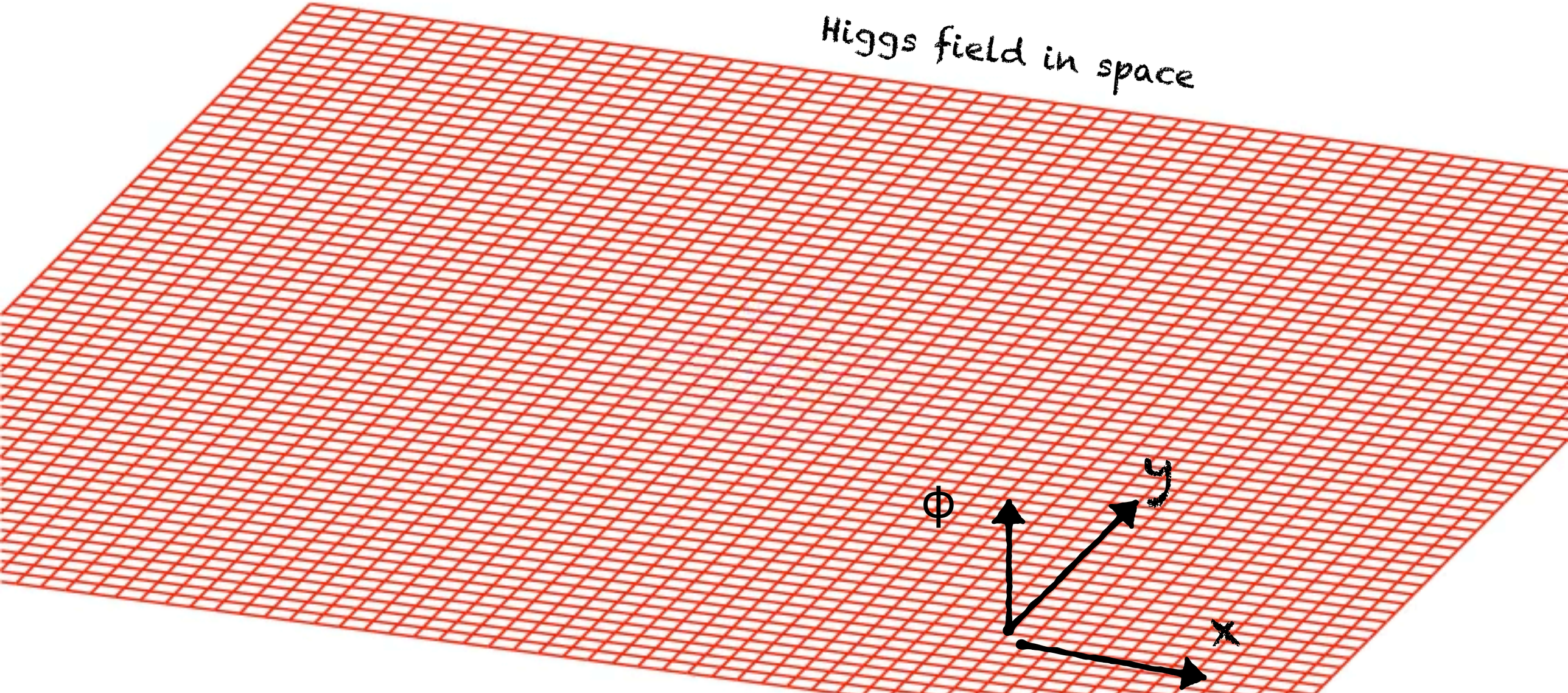


Is the Higgs mechanism actually responsible for these particle masses?

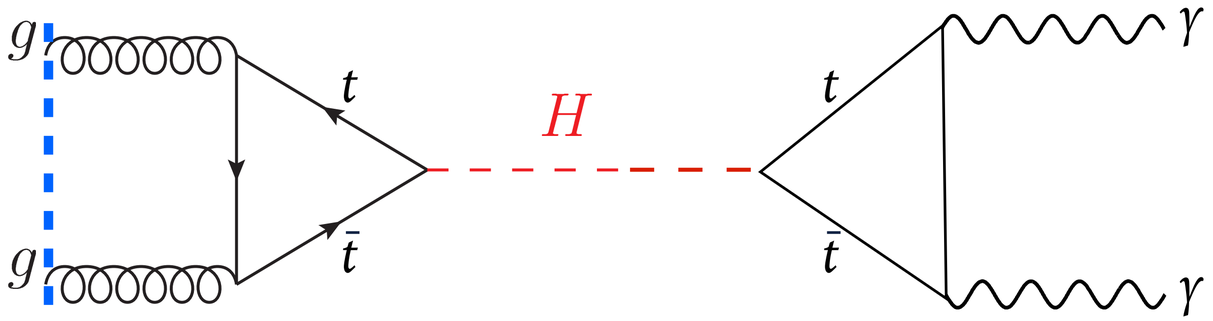
A Higgs boson is a localised fluctuation of the Higgs field



A Higgs boson is a localised fluctuation of the Higgs field



https://cern.ch/gsalam/higgs



luon

gluo

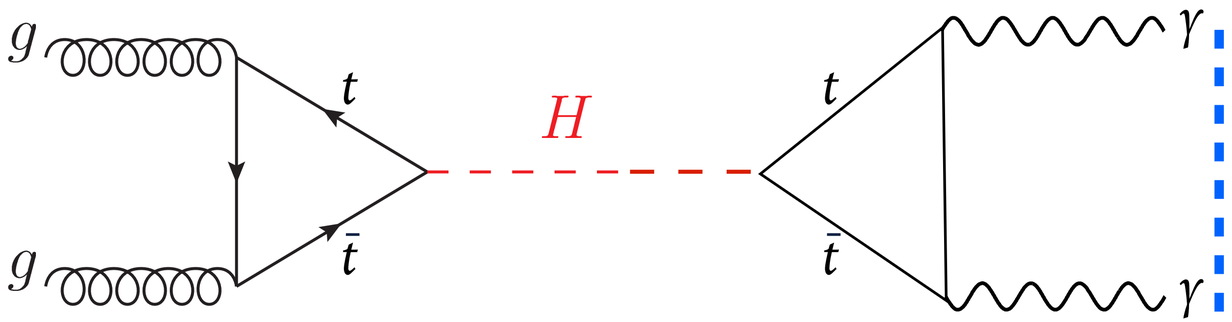
Φ

y

x

Higgs field in space

https://cern.ch/gsalam/higgs



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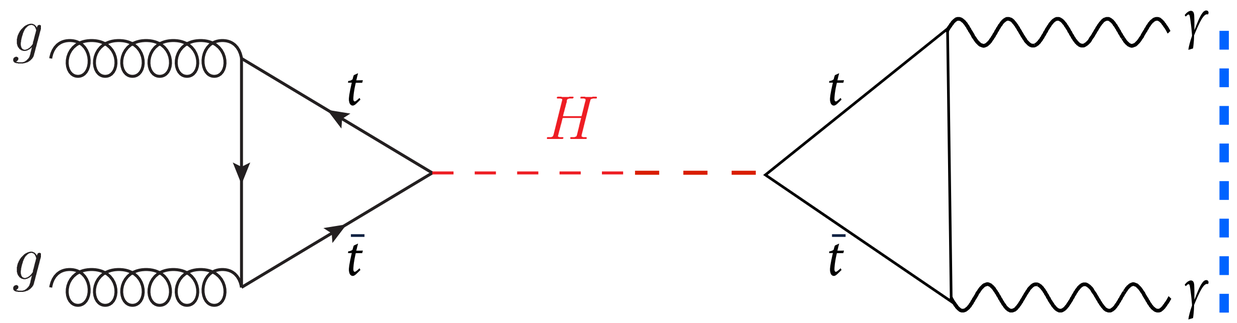


How strongly a top-quark interacts with the Higgs field determines how often this reaction happens.

That makes it possible to test whether that interaction strength is as needed to generate the top-quark mass

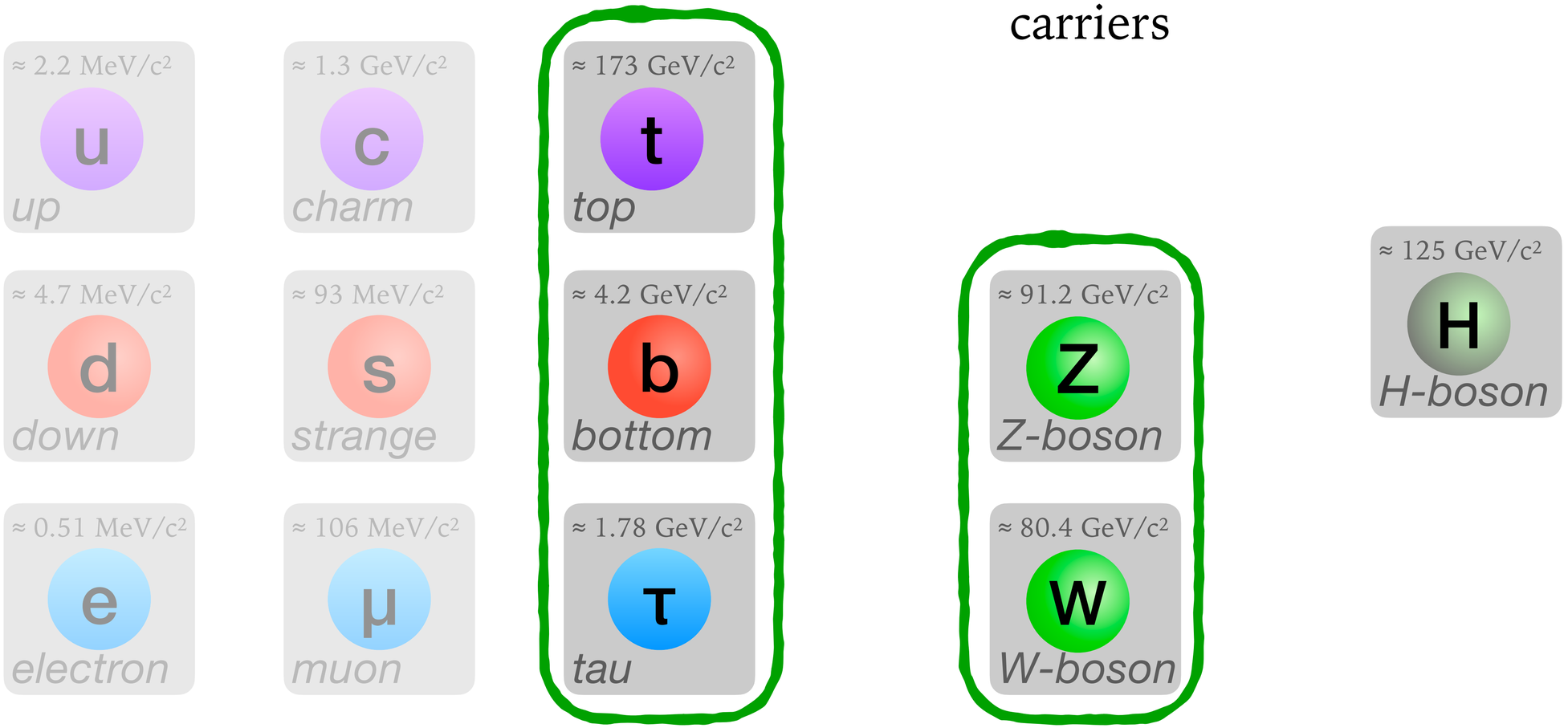
luon

gluo

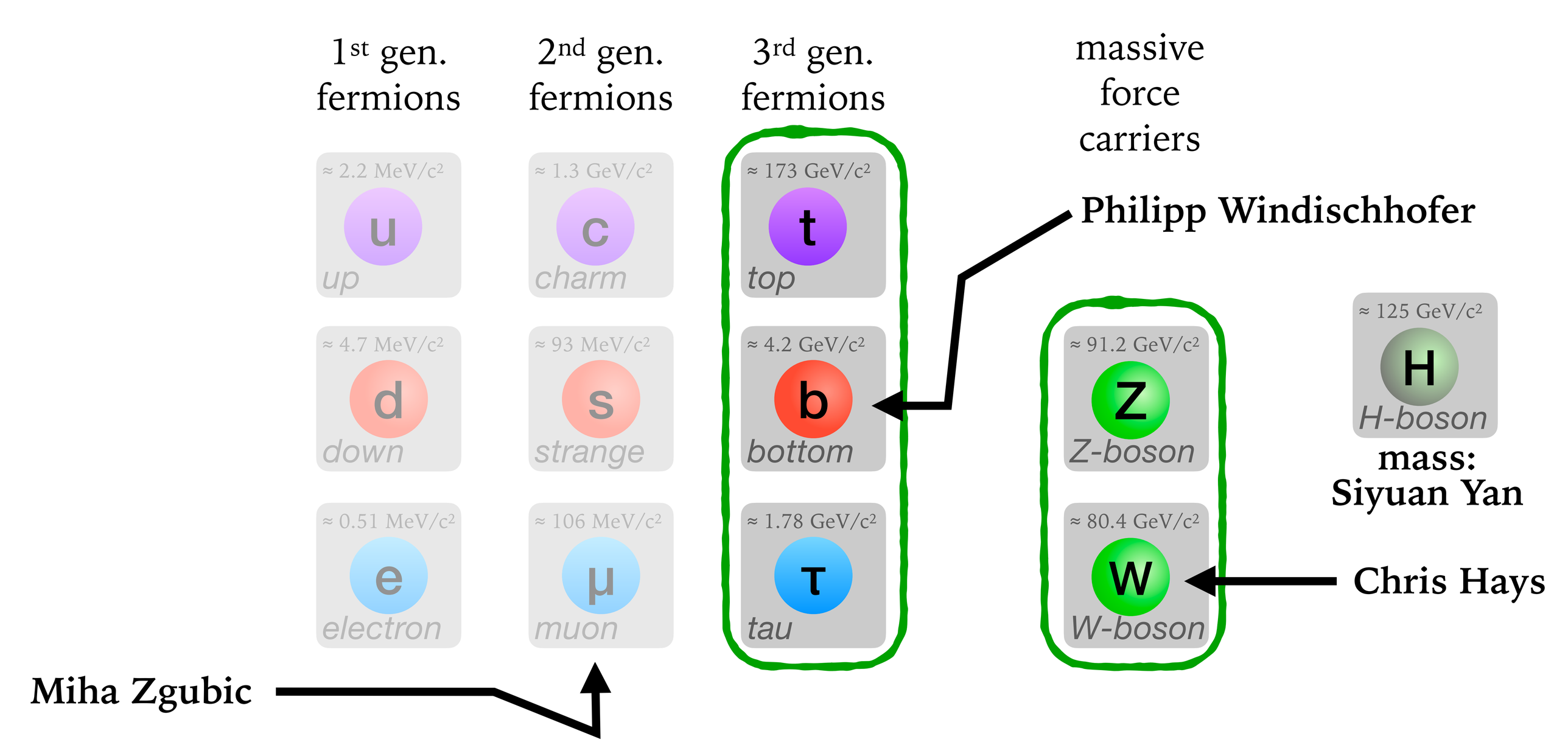
Φ

x

Higgs field in space



particles for which data shows that interaction with the Higgs field is responsible for their mass



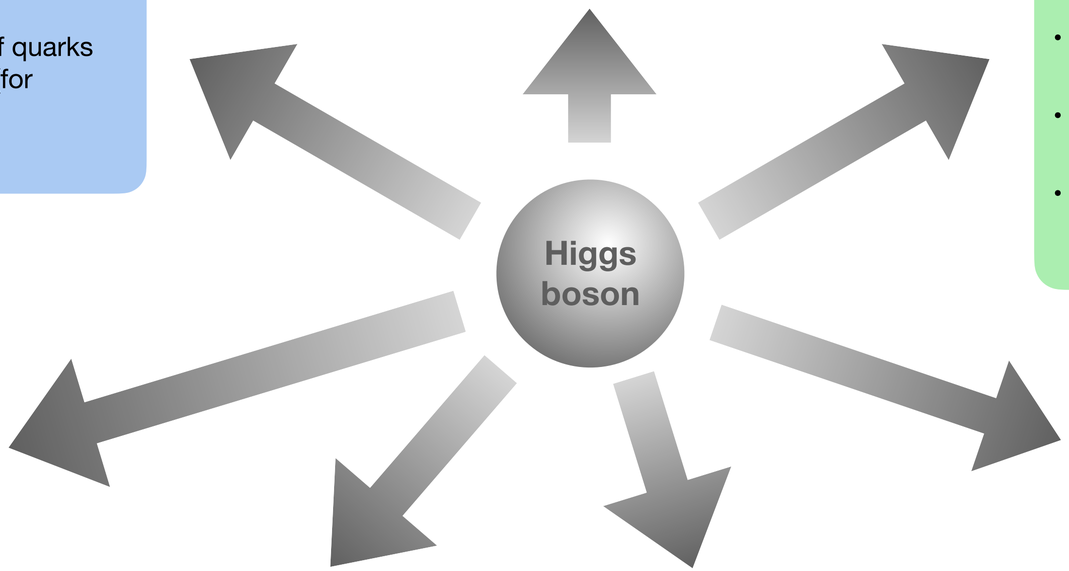
particles for which data shows that interaction with the Higgs field is responsible for their mass

What is the origin of the vast range of quark and lepton masses in the Standard Model?

- Are there modified interactions to the Higgs boson and known particles?
- Does the Higgs decay into pairs of quarks and leptons with distinct flavours (for example, $H \to \mu^+\tau^-$)?

What is the origin of the early-universe inflation?

- Is the Higgs connected to the mechanism that drives inflation?
- Are there any imprints in cosmological observations?



Why is the electroweak interaction so much stronger than gravity?

- Are there new particles close to the mass of the Higgs boson?
- Is the Higgs boson elementary or made of other particles?
- Are there anomalies in the interactions of the Higgs with the W and Z?

What is dark matter?

- Can the Higgs provide a portal to dark matter or a dark sector?
- Is the Higgs lifetime consistent with the Standard Model?
- Are there new decay modes of the Higgs?

Why is there more matter than antimatter in the universe?

- Are there charge-parity violating Higgs decays?
- Are there anomalies in the Higgs self-coupling that would imply a strong first-order early-universe electroweak phase transition?
- Are there multiple Higgs sectors?

Why is the Higgs field non-zero?

- Supposedly because the Higgs potential makes that the lowest energy state
- Can we verify the SM prediction for the Higgs potential?

The Higgs boson as the mediator of a fifth force

- unlike other electroweak and strong forces, strength of interaction is not quantised
- i.e. does not come in multiples of some elementary charge