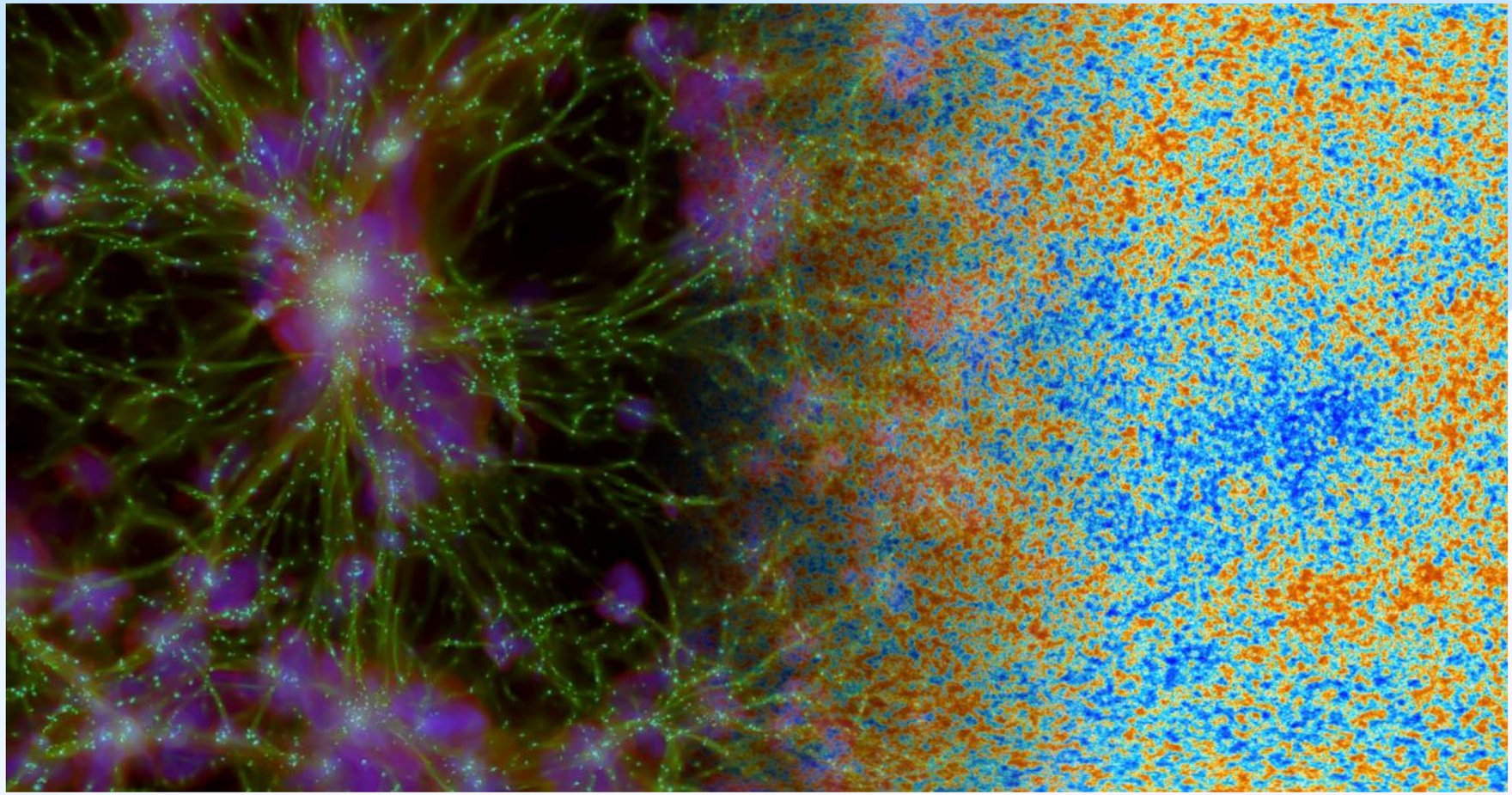
PHYS252 Quantum Physics and Applications

Module 5: Particle Physics

Dr. Shikha Bangar

Module 5

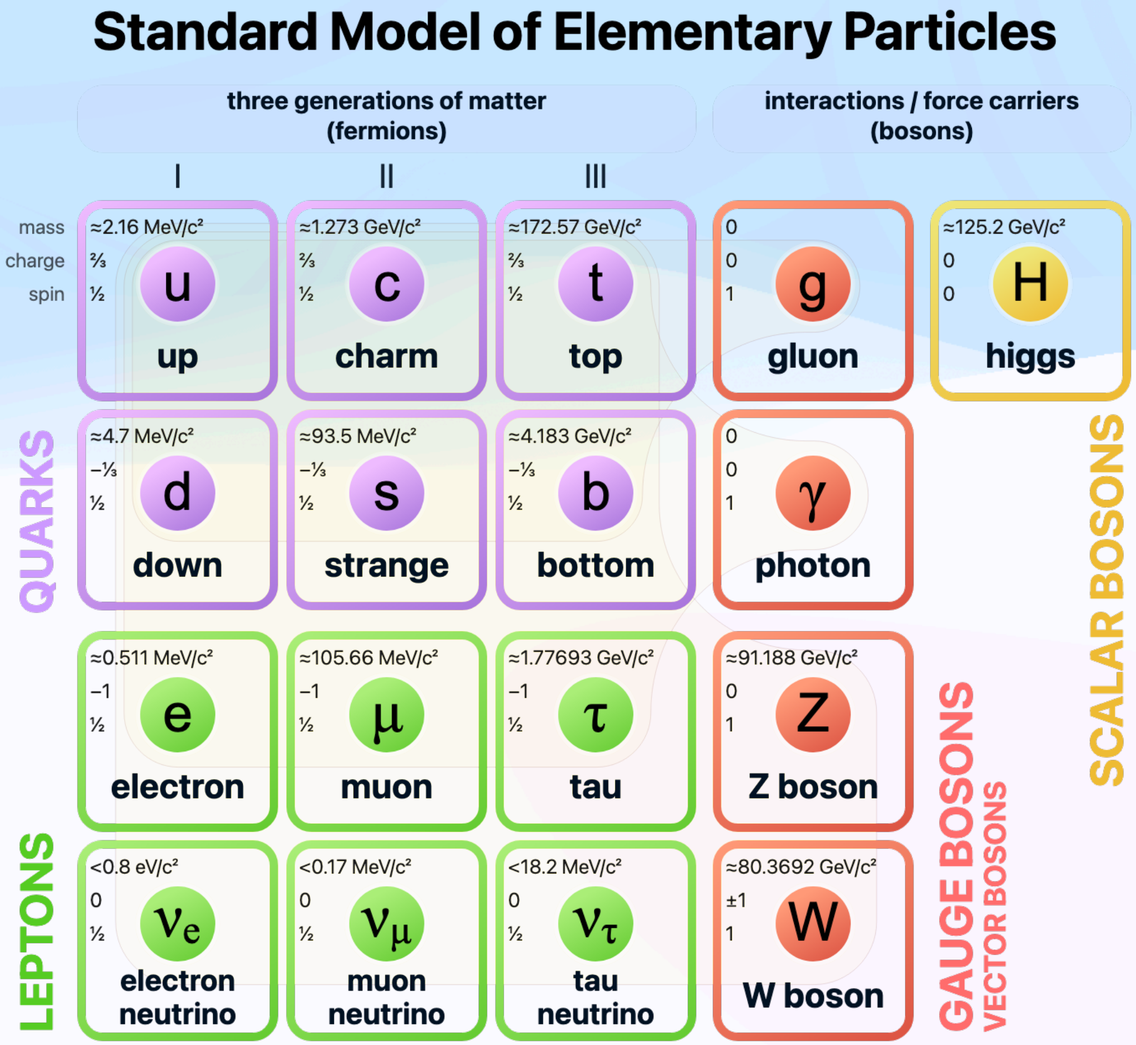
- Particle Physics
- Cosmology



Chapter 14: Elementary Particles and Standard Model

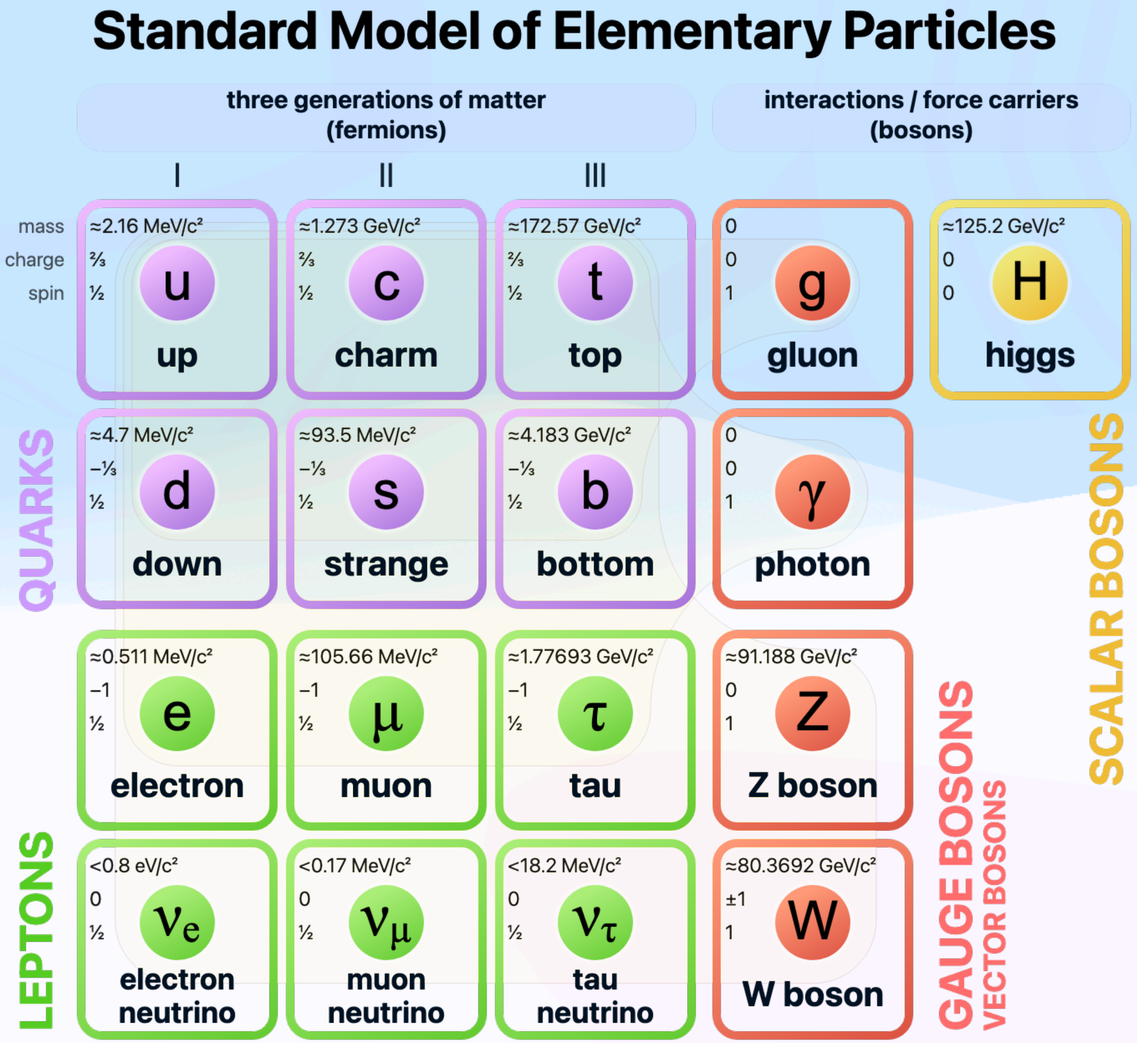
- The four interactions of nature
- Elementary particles
- Conservation laws
- Quark model of hadrons

Instead of following this order of topics, I will give you an overview of everything, and then we will review this.



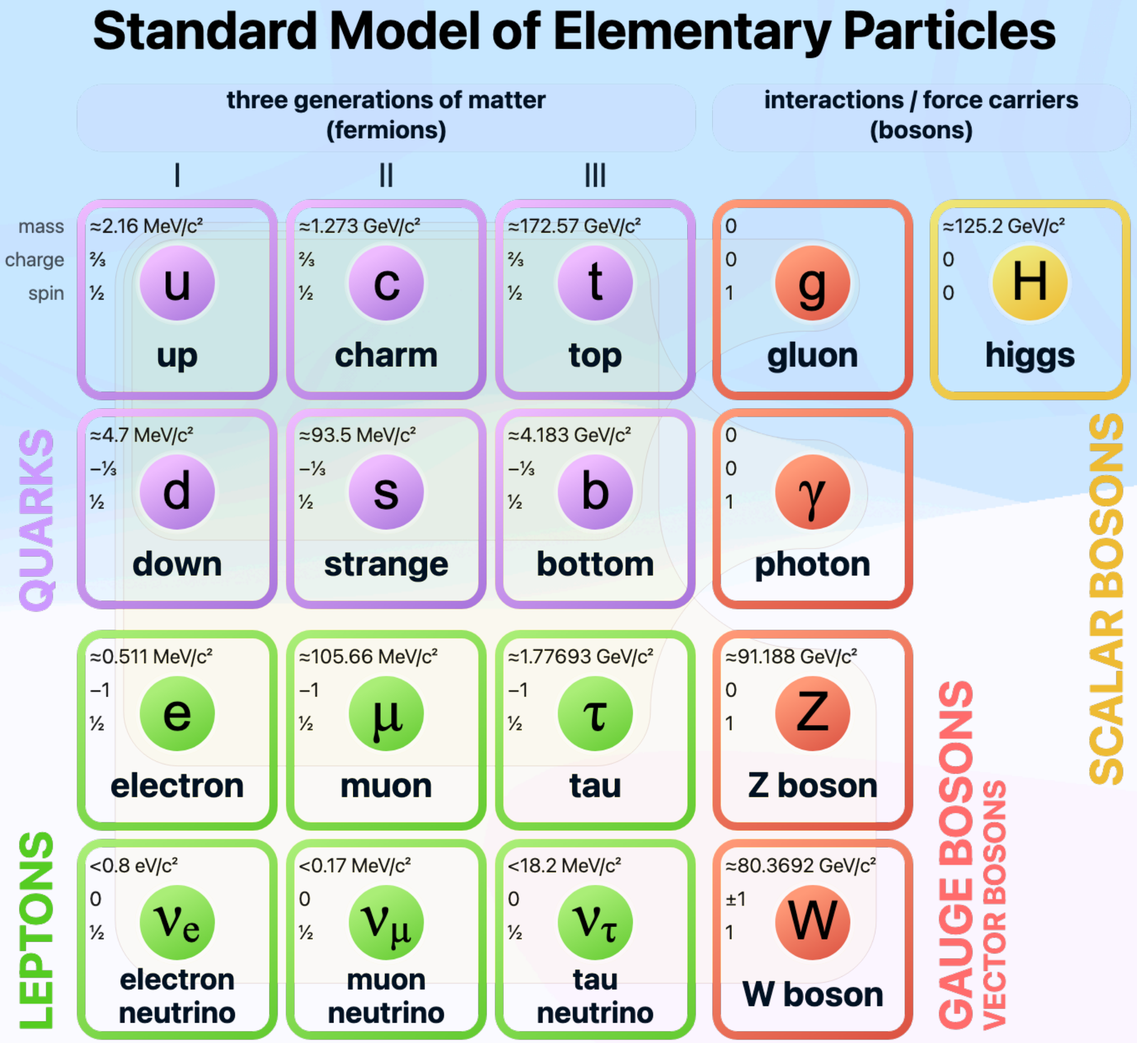
Standard Model

- A model to understand everything:
  - What is the universe made of?
    - Elementary particles
  - How do they interact?
    - via 4 fundamental interactions of nature

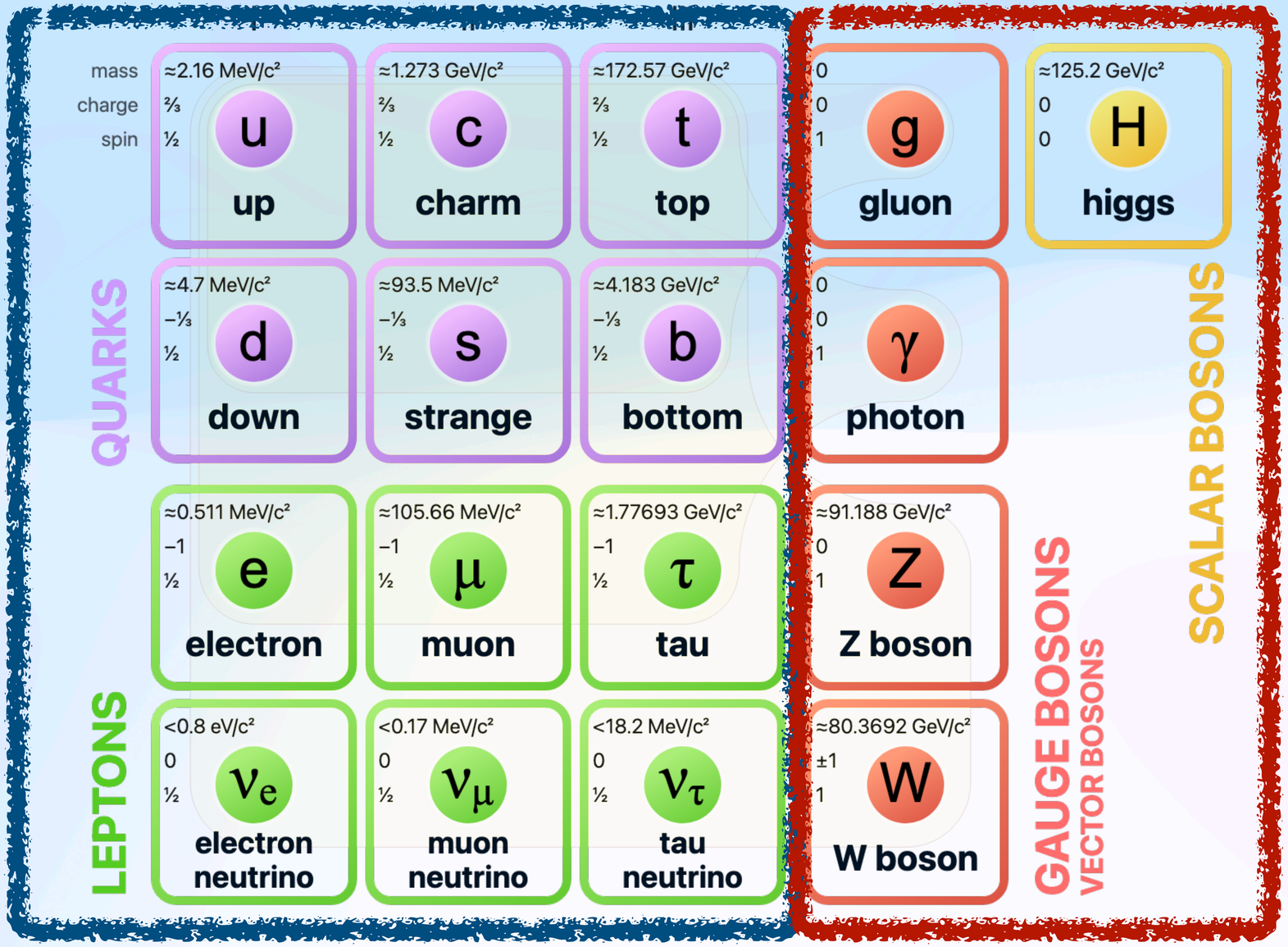


Standard Model

- It is written in a language known as Quantum Field Theory
- The matter is made up fields
- But understand this, we will use the language of particles



Standard Model



Standard Model

FERMIONS

They form the matter particles

BOSONS

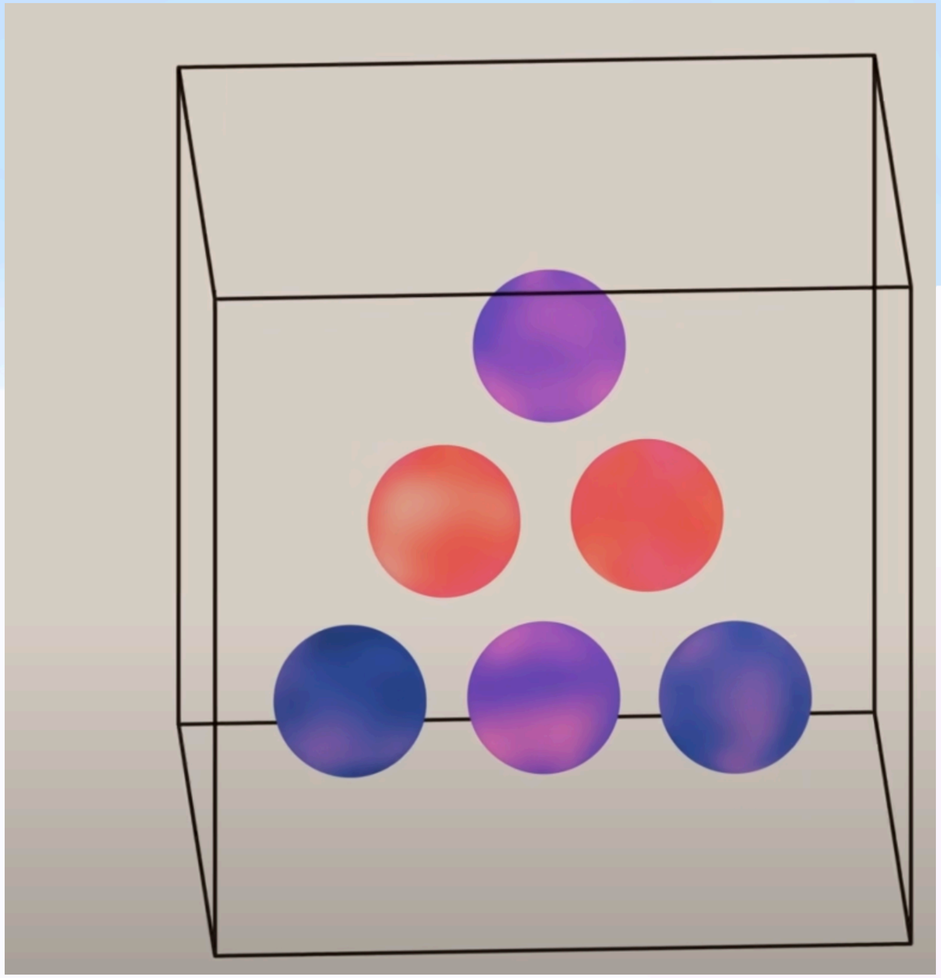
They form the force interaction particles

Standard Model

FERMIONS

They form the matter particles

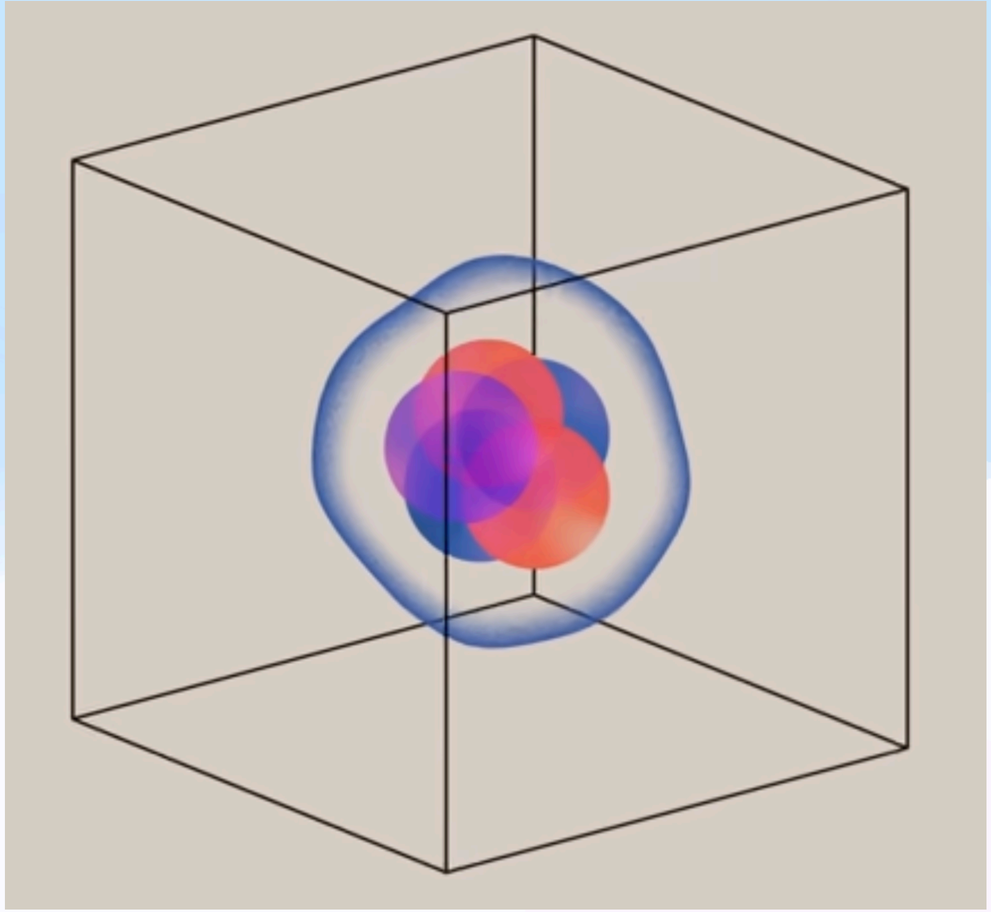
PAULI EXCLUSION PRINCIPLE



Standard Model

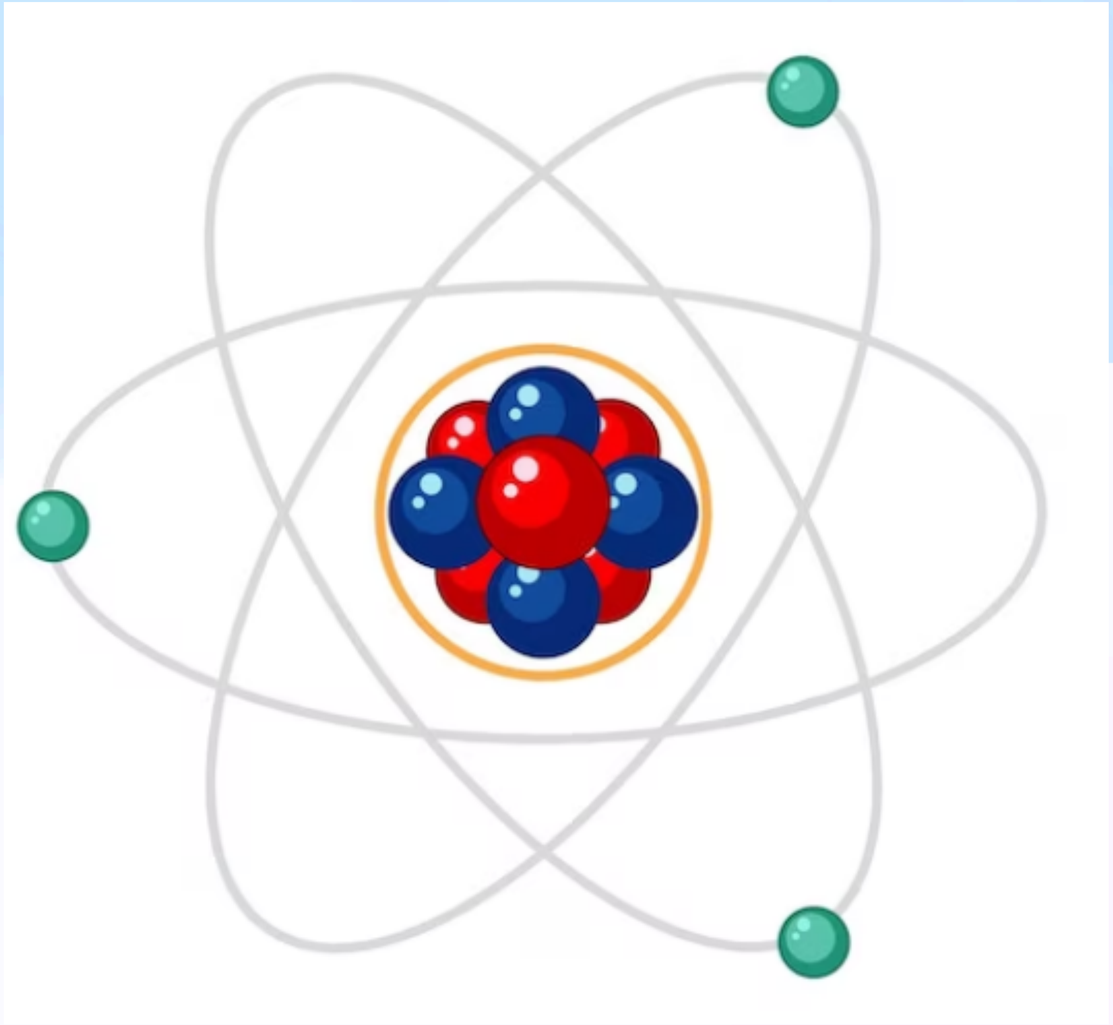
BOSONS

They form the force interaction particles



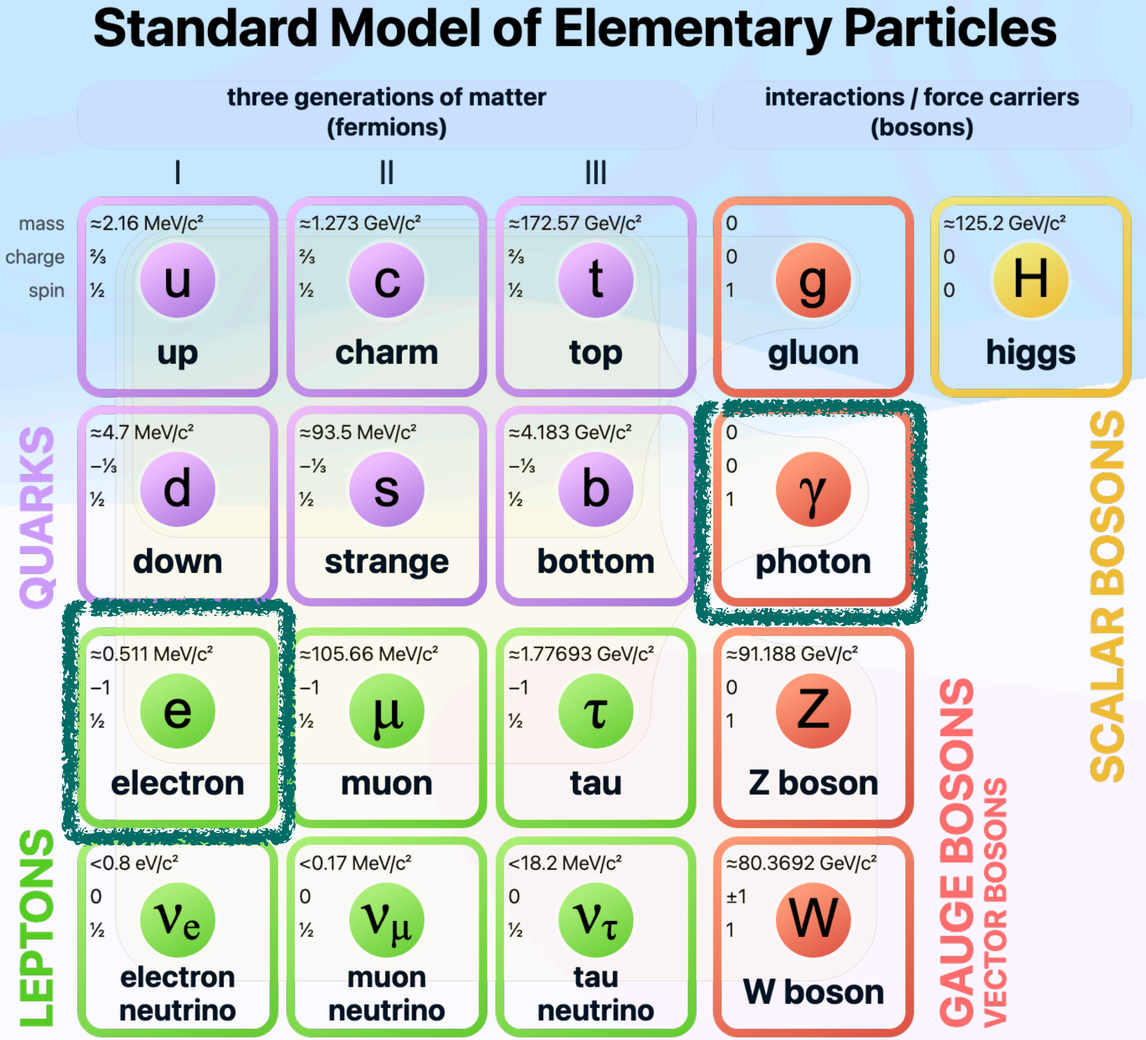
Fundamental building blocks

- Atoms are building blocks of matter
- They look something like this:
  - Electrons
  - Protons
  - Neutrons



Fundamental building blocks

- An electron is a fundamental particle.
- It interacts via electromagnetic force
- It can emit and absorb a photon which is the particle for EM force



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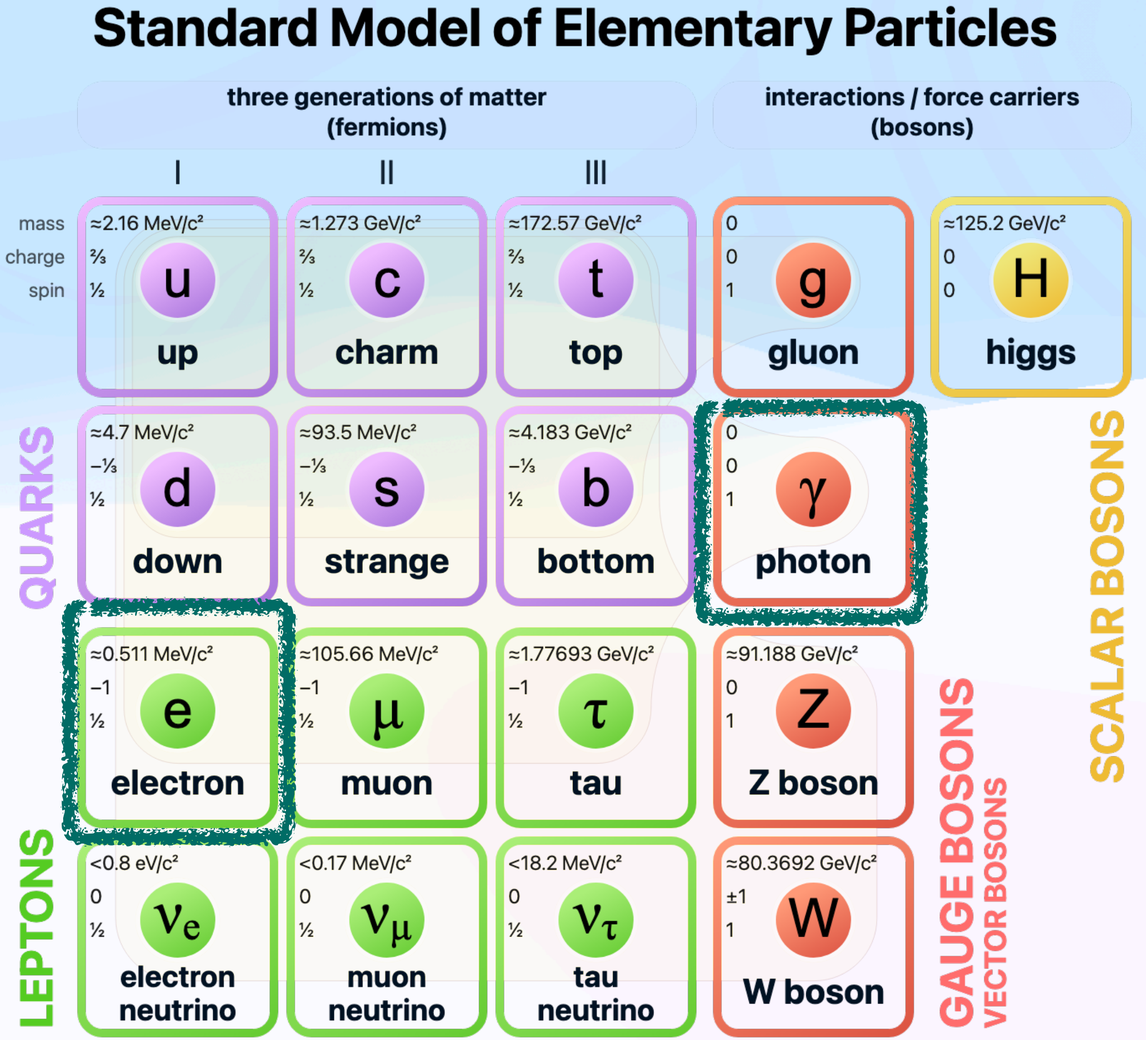
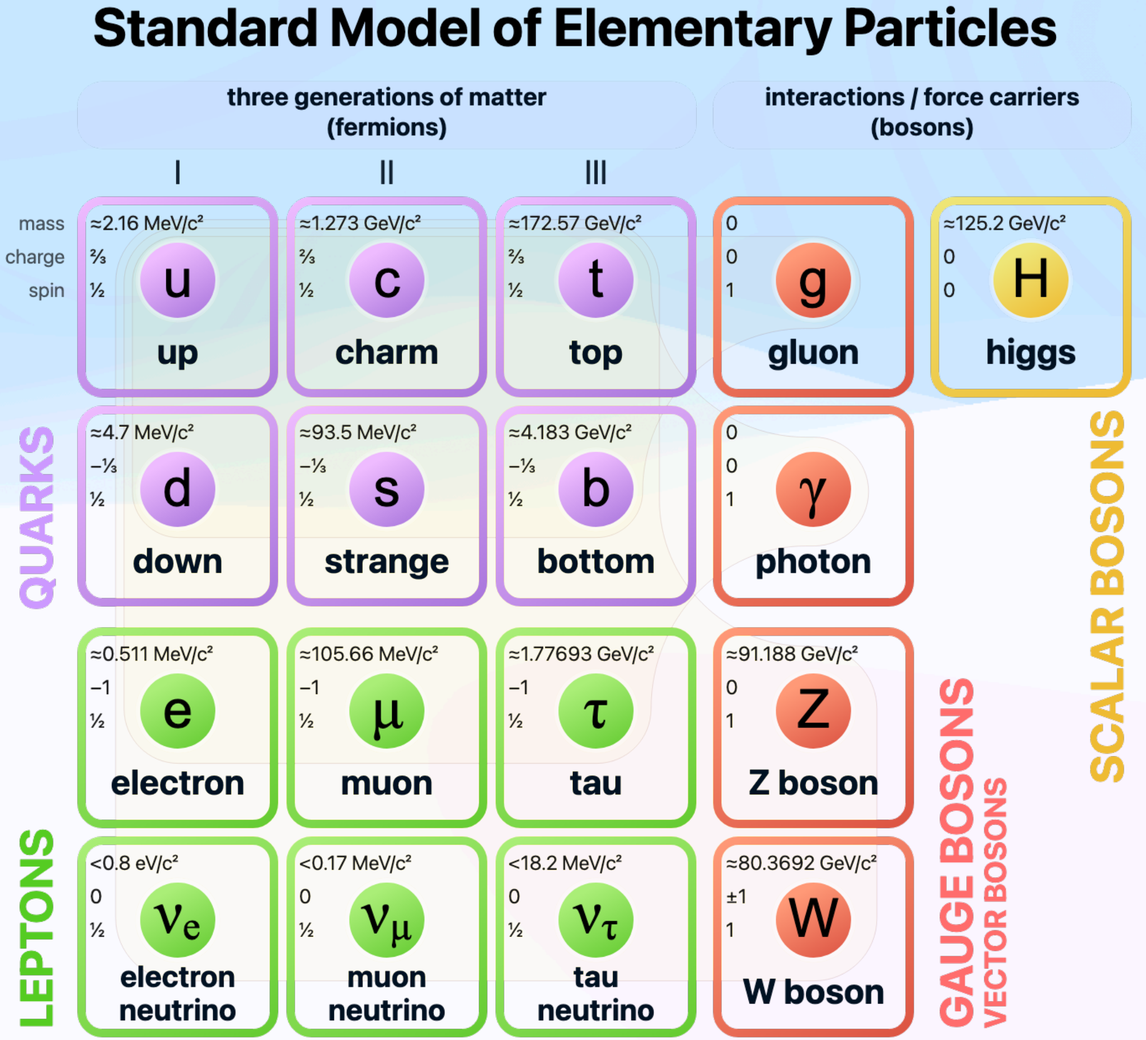
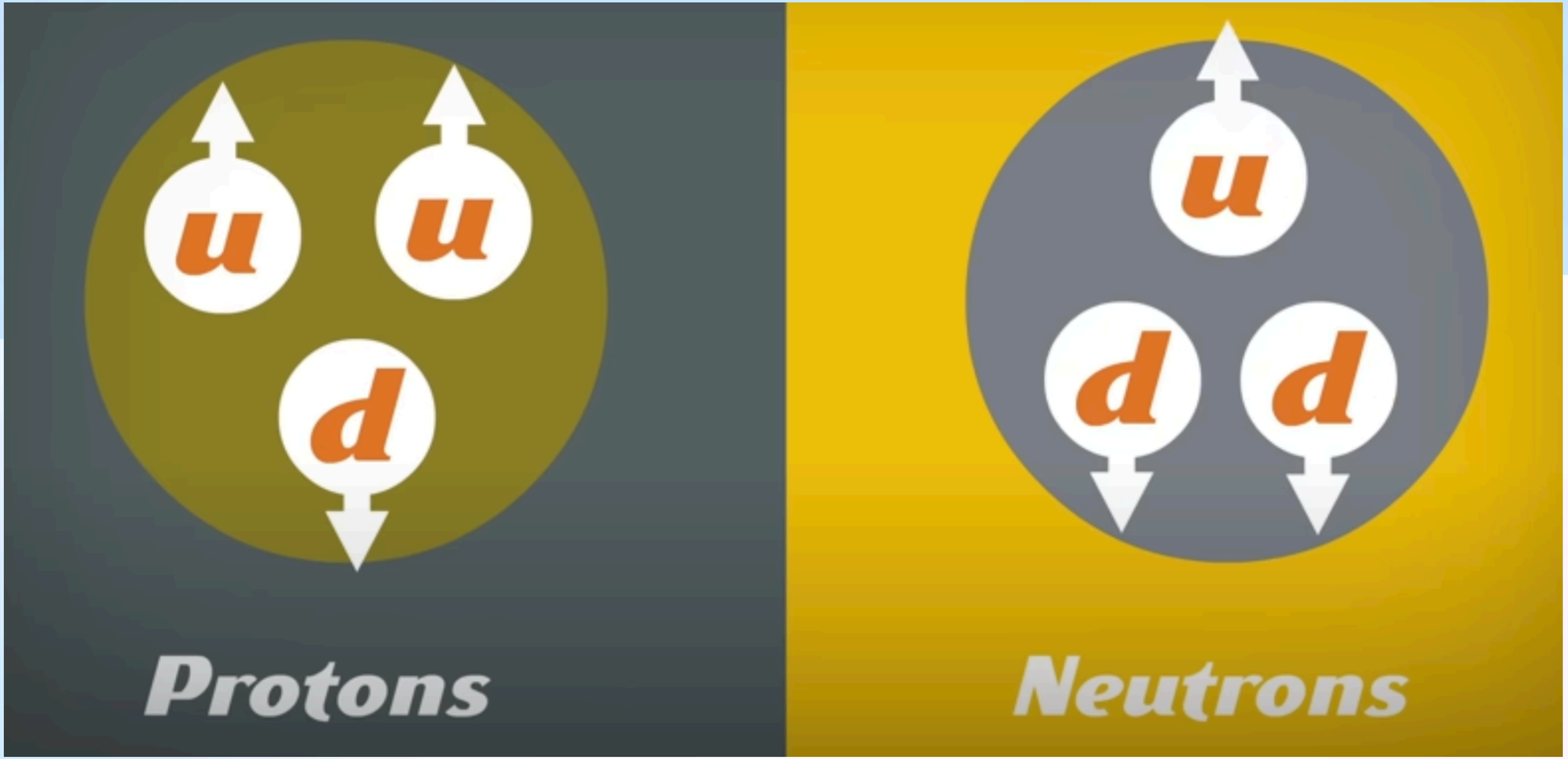


Fundamental building blocks

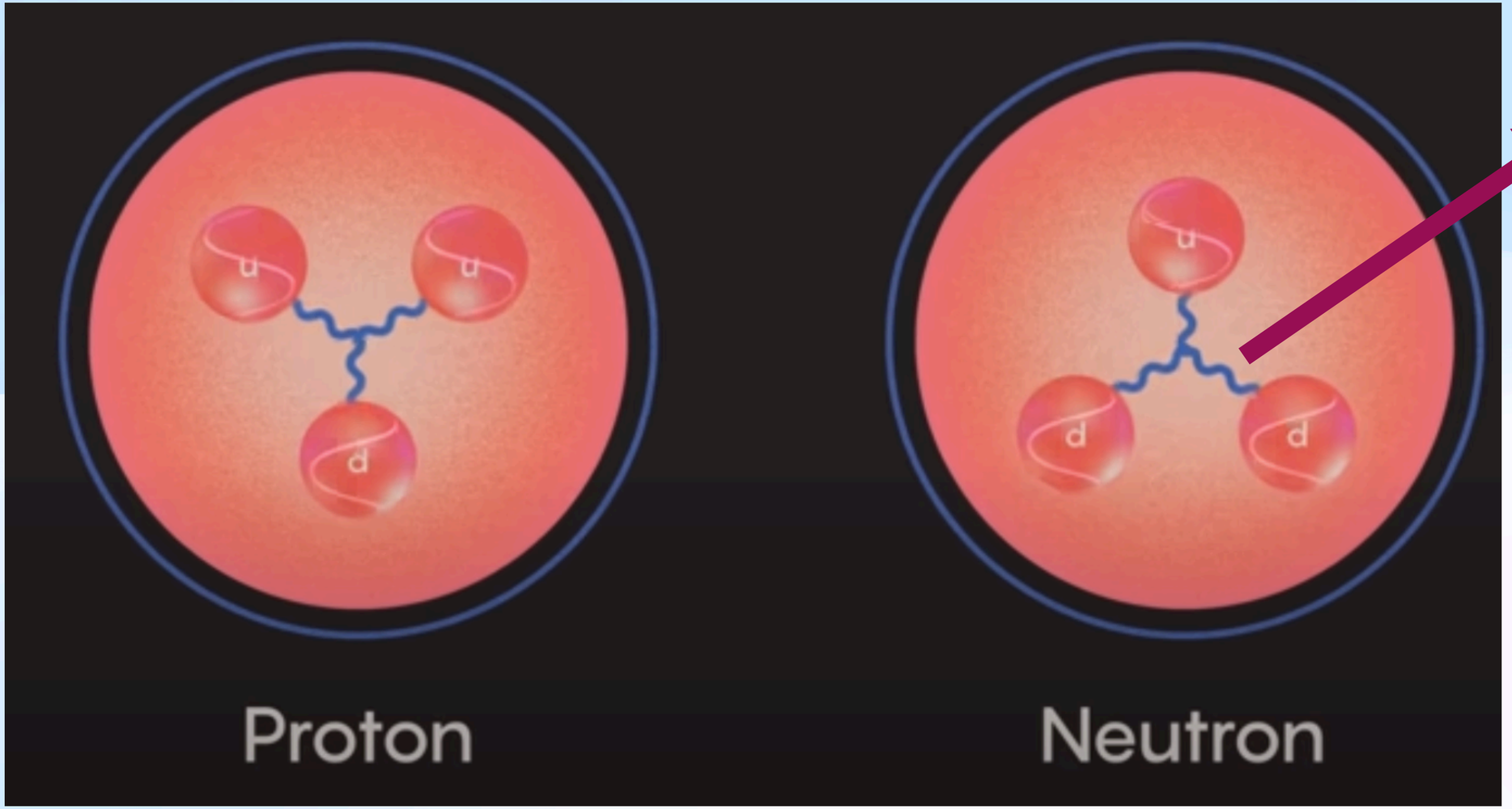
- The nucleus of the atom is made-up of proton and neutrons
- Historically, they were thought to be fundamental particles
- But that is not true



Fundamental building blocks



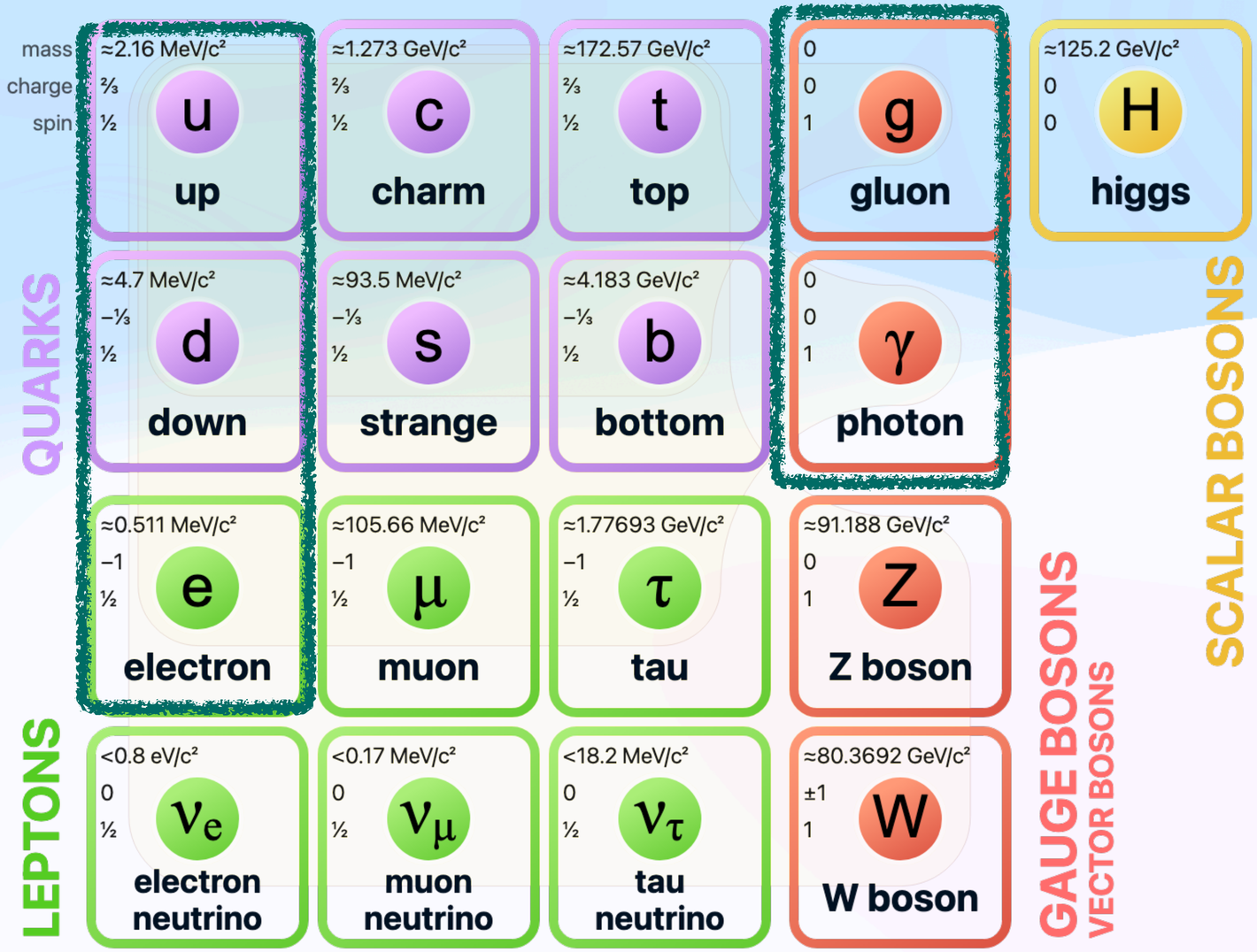
Fundamental building blocks



Gluon - particle for Strong force

Fundamental building blocks

- All the matter which you can see around you is made-up of just 3 fundamental particles
- They are just arranged in different ways to make the matter



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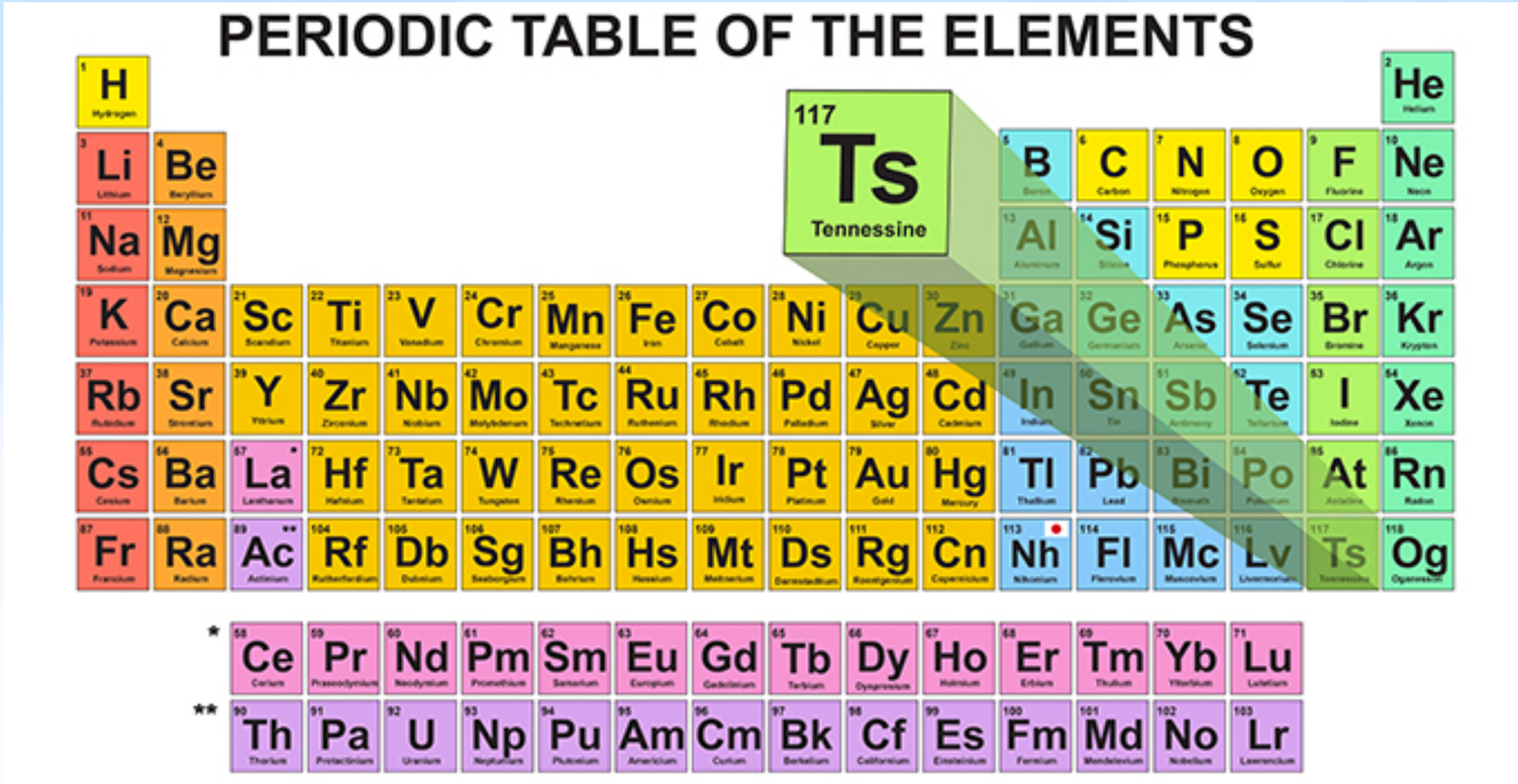


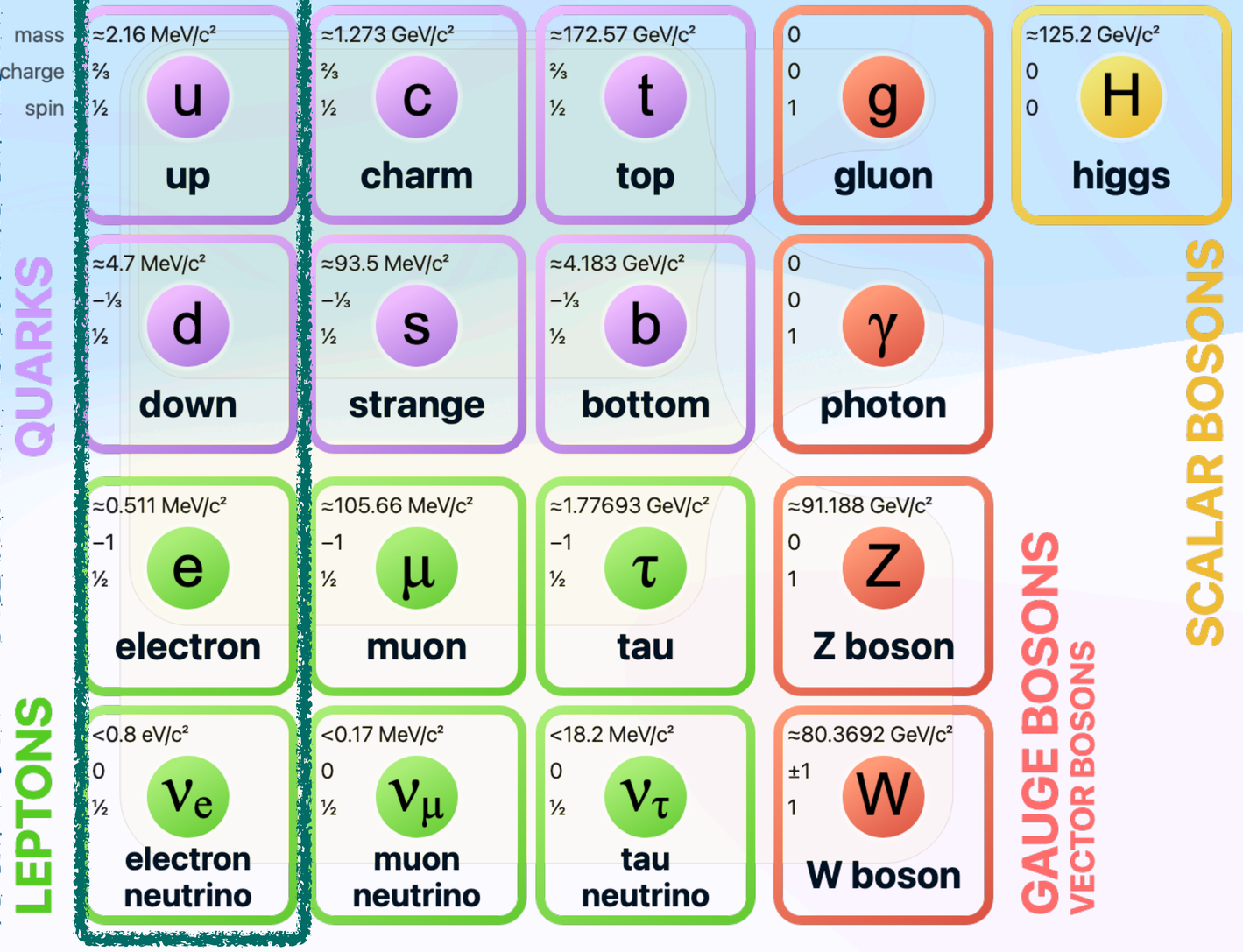
Fundamental building blocks

- The fourth matter particle is neutrino
- They are almost non-interacting particles and, hence, very hard to detect
- But they are huge in numbers
- And constantly following through us

Fundamental building blocks

These three make-up all the matter

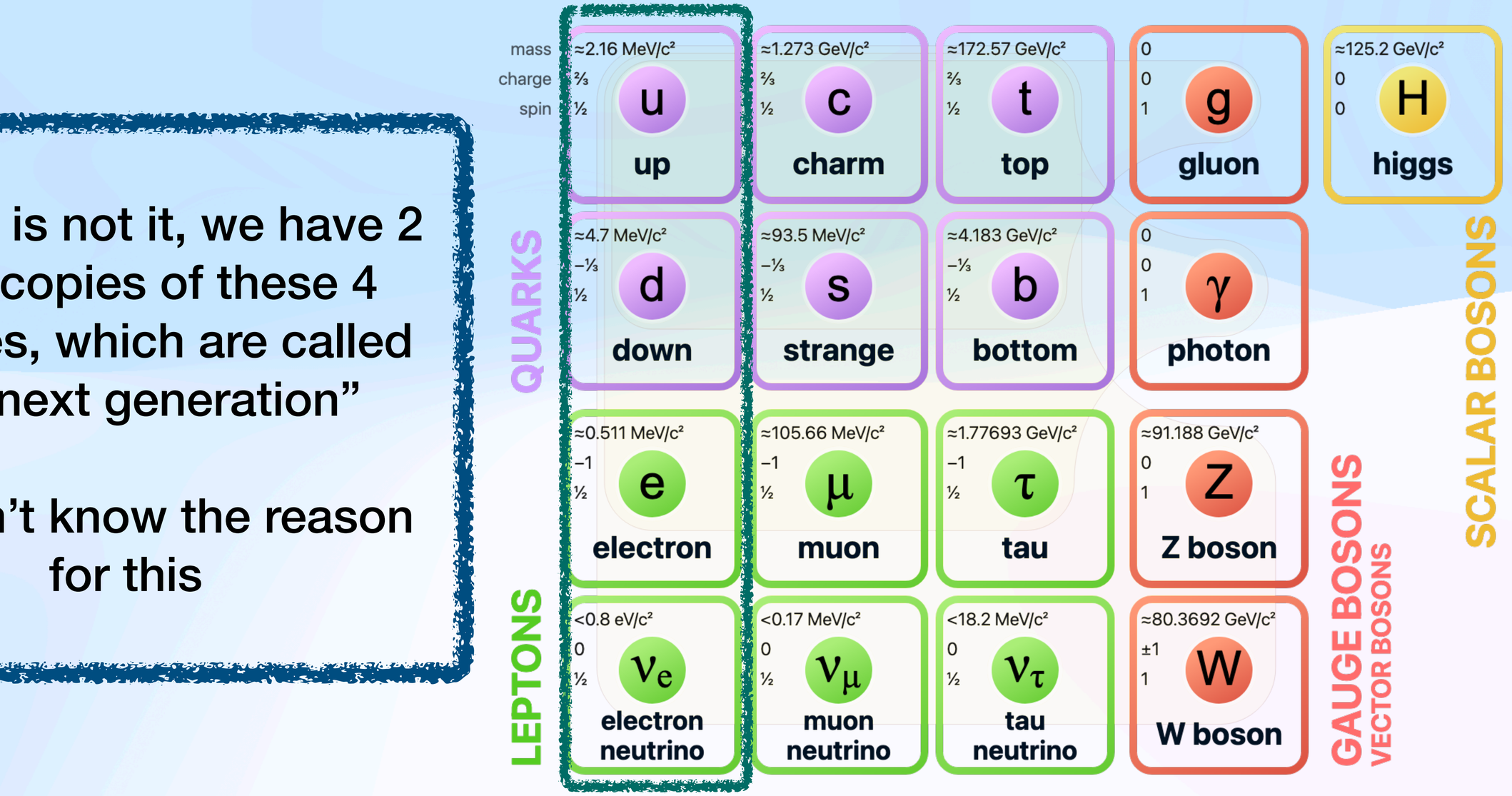
A peculiar cosmic ghost which follows through us



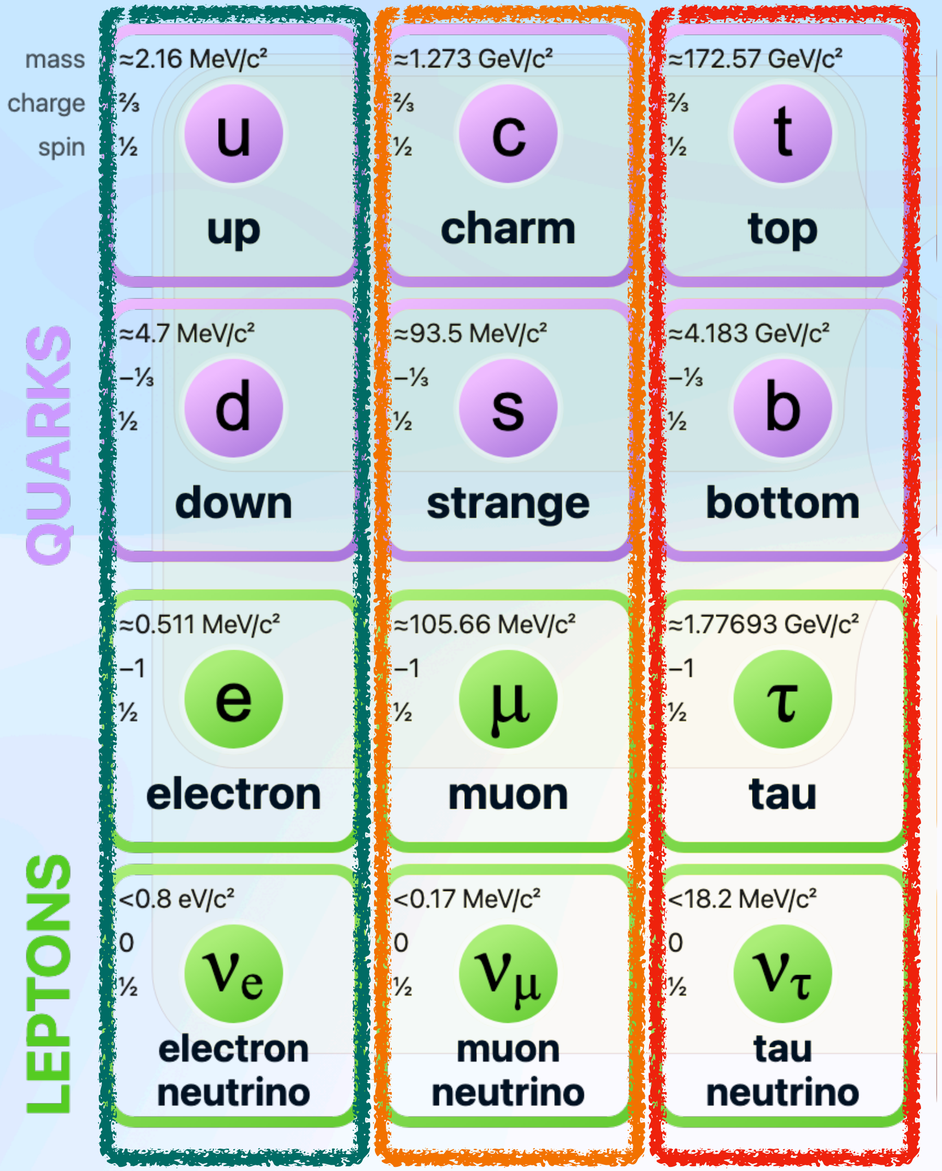
Fundamental building blocks

But this is not it, we have 2 more copies of these 4 particles, which are called the “next generation”

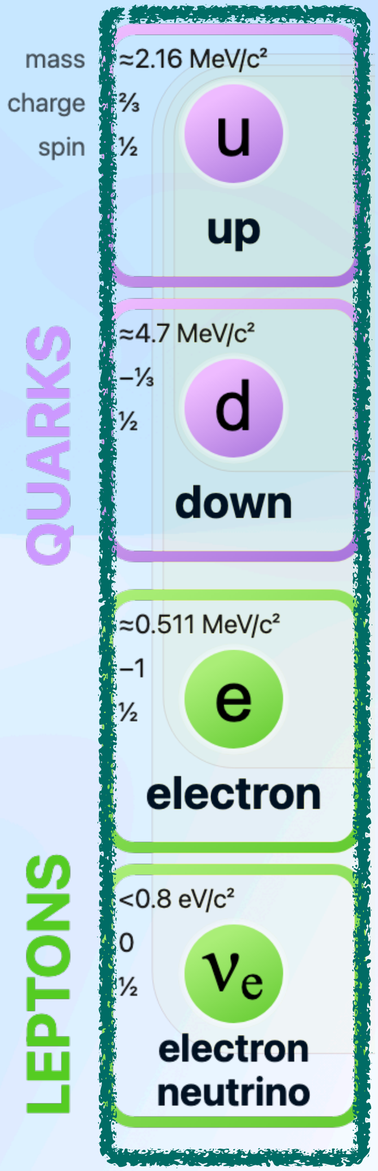
We don’t know the reason for this

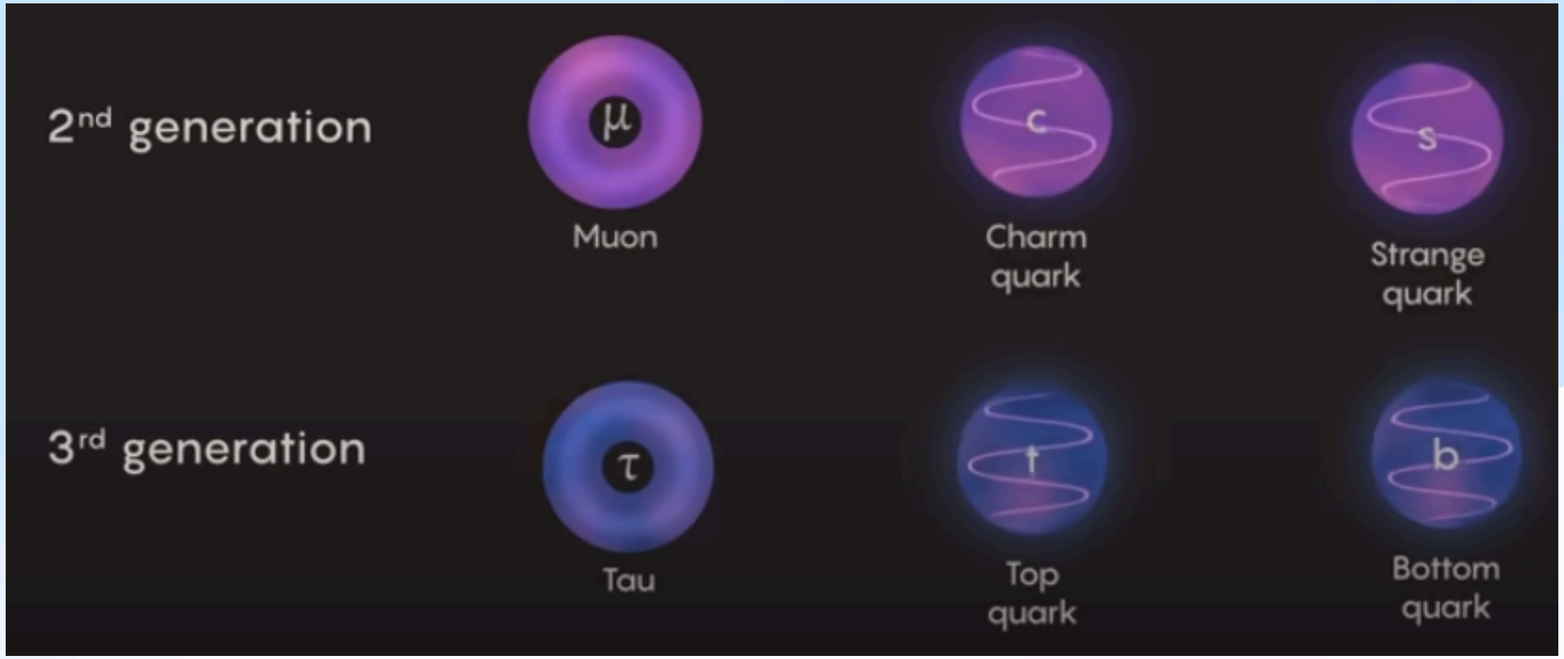


Fundamental building blocks



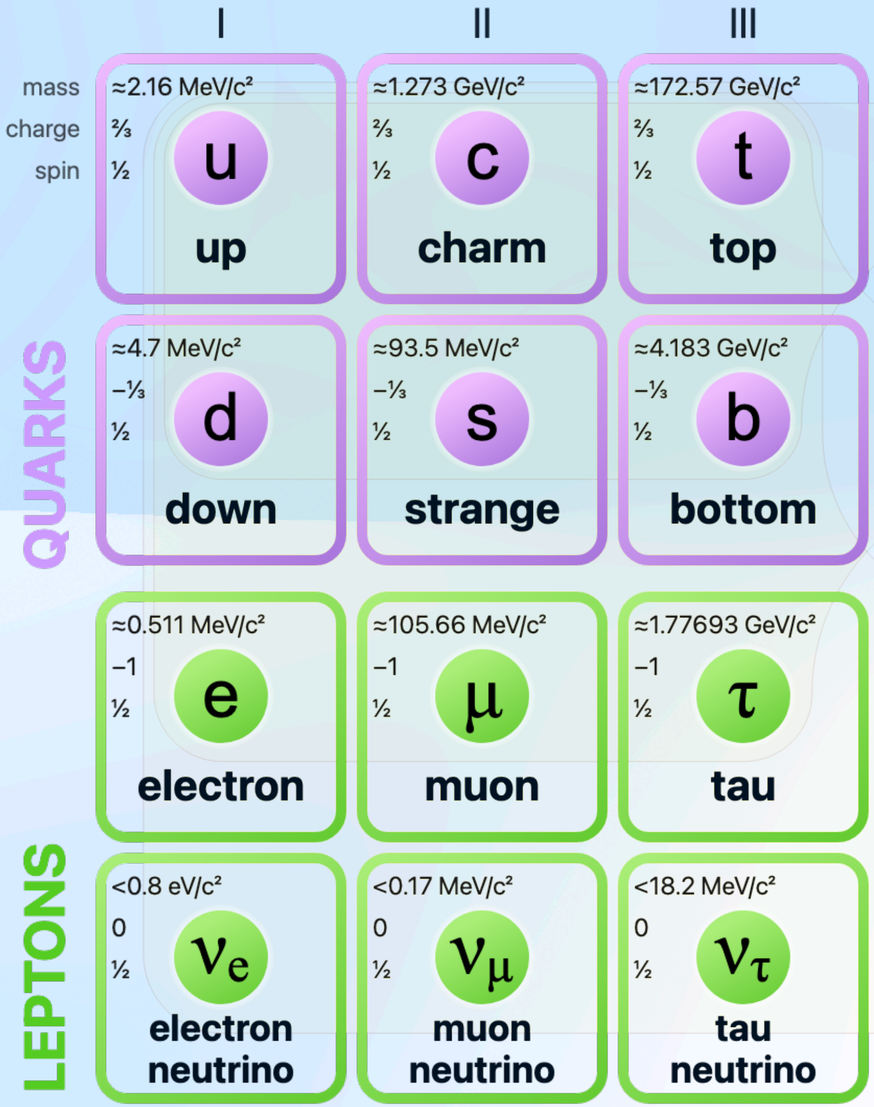
Fundamental building blocks





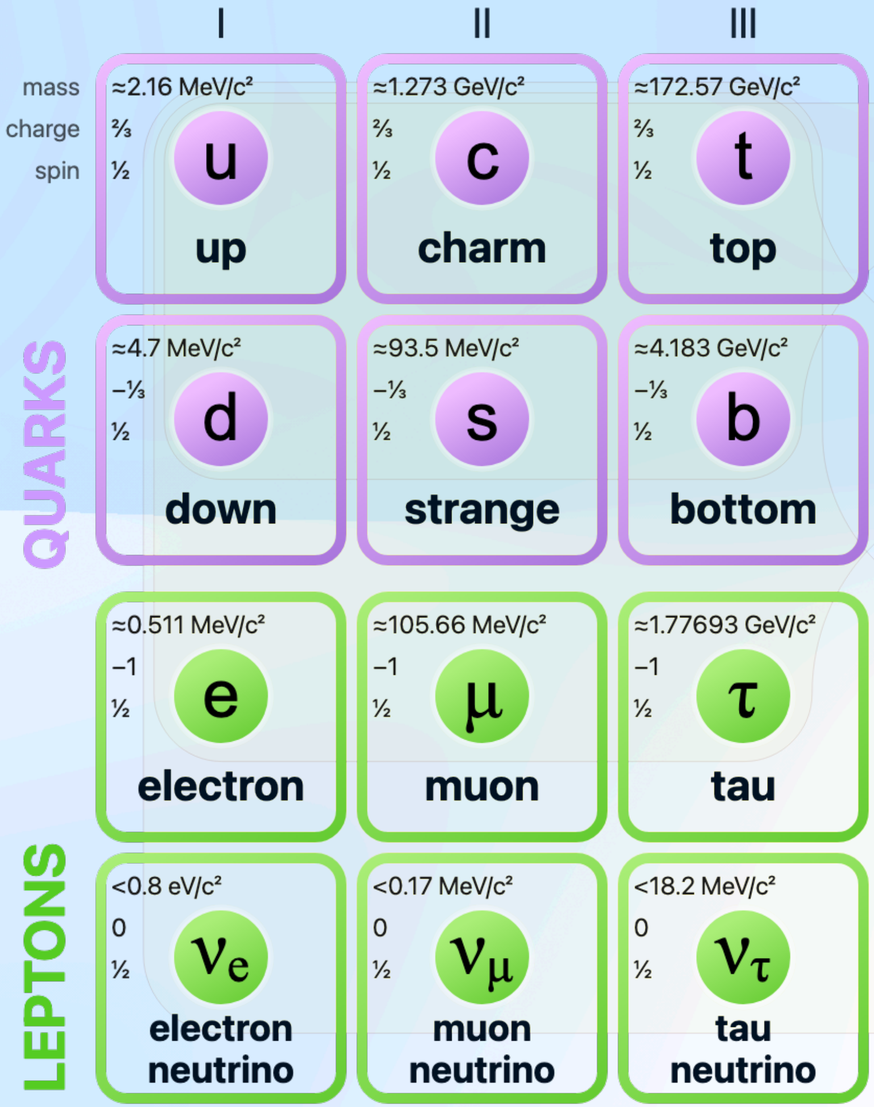
We can create these particles, but they are unstable. They decay into the 1st generations particles very quickly

Fundamental building blocks



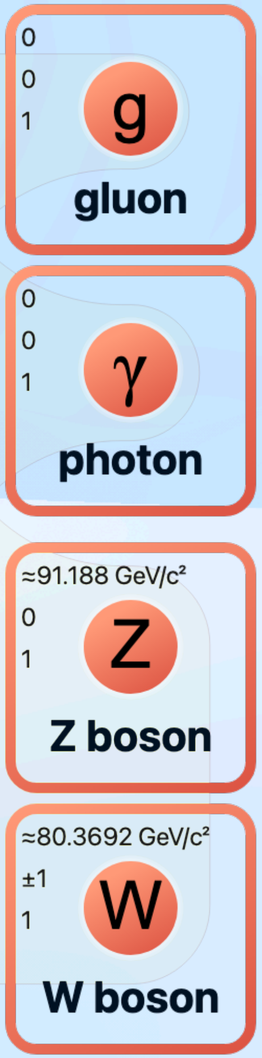
- Here are all the fundamental particles that make matter
- We understand a few things about them but there are still many mysteries
- Why 3 generations?

Fundamental building blocks



- What about the forces?

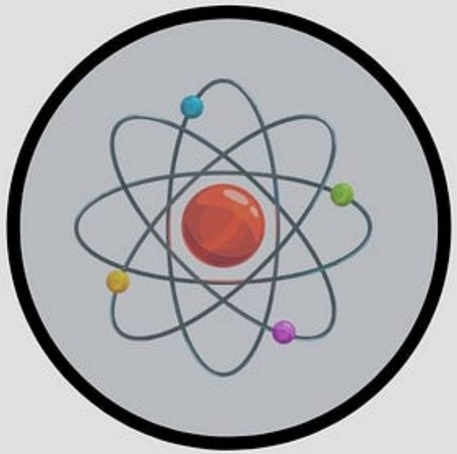
Fundamental building blocks



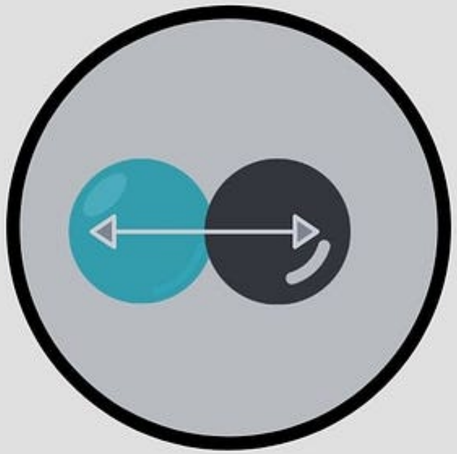
- What about the forces?
- There are 4 fundamental forces in nature and we have 3 of them here in the Standard Model
- All 3 forces have an associated particle through which the matter particles interact.
- All force particles are bosons in nature

Four Basic Forces

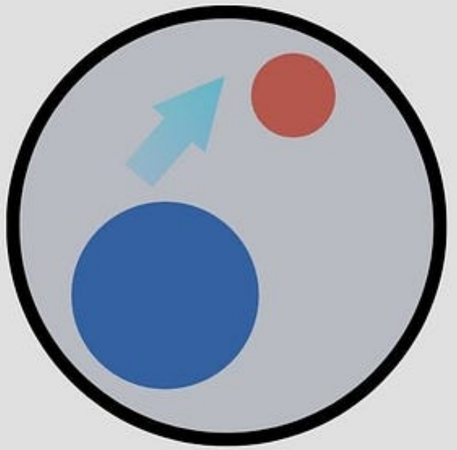
Gravitation



Elecctro-magnetism



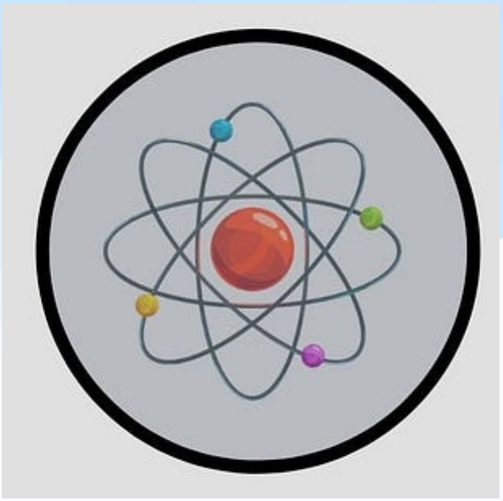
Strong Force



Weak Force

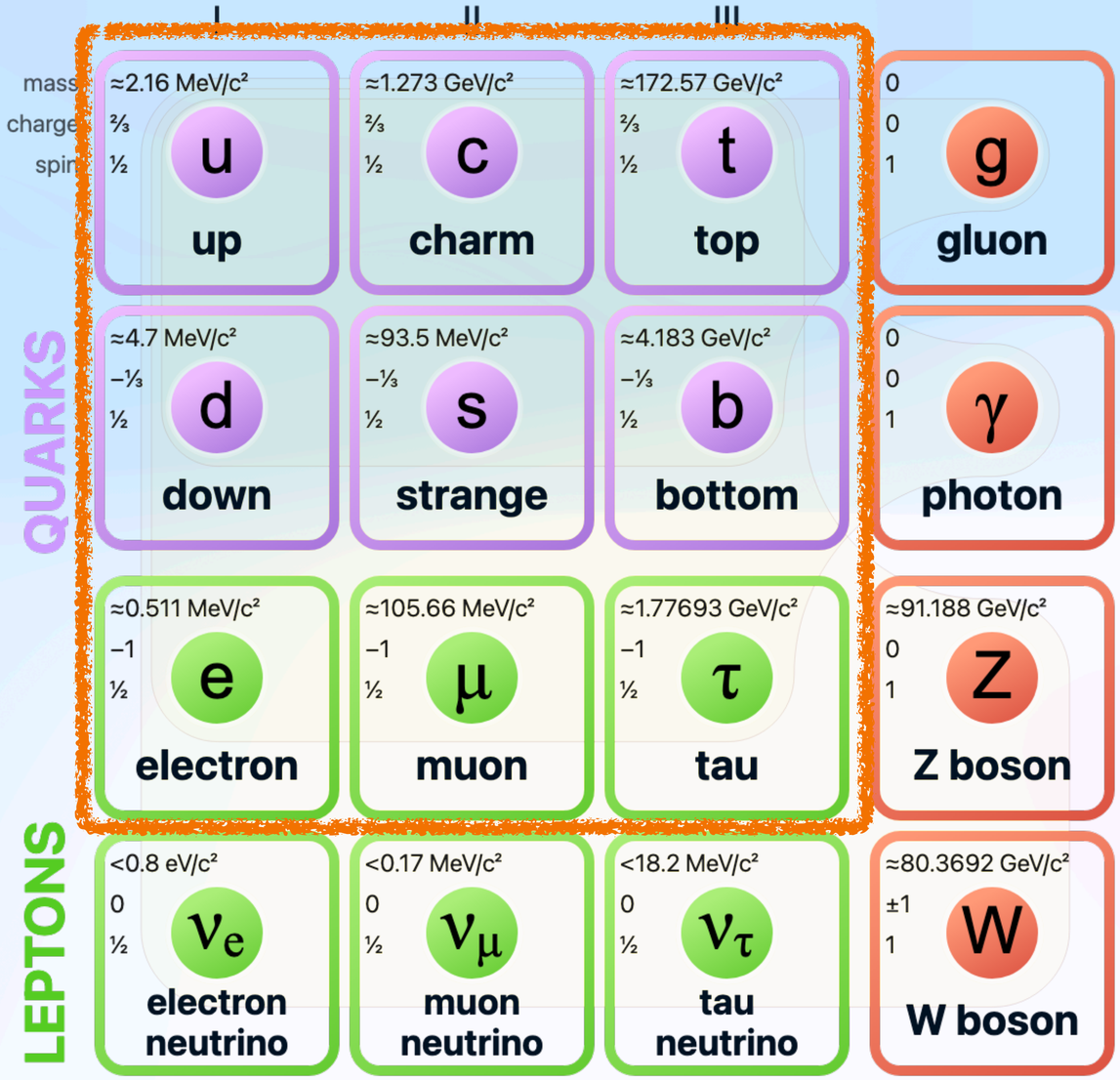
Electromagnetic(EM) Interaction

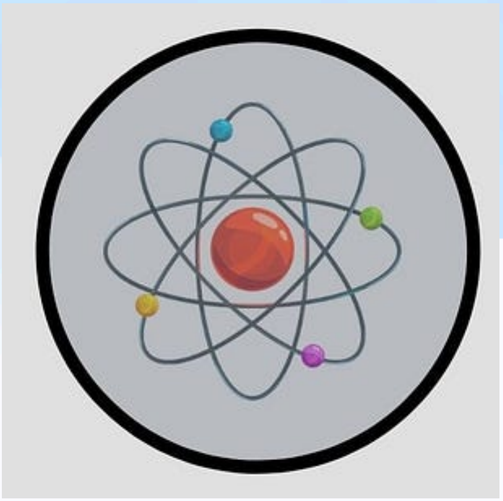
- Responsible for the structure and the interactions of the fundamental particles
- Within the atom, EM forces dominate
- Many common macroscopic forces (such as friction, air resistance, drag, and tension) are due to EM forces at the atomic level
- Between two protons in the nucleus, EM is about 10^{-2} of strong force with an infinite range
- According to QED, the mediator of the electromagnetic force is the photon.



Electromagnetic(EM) Interaction

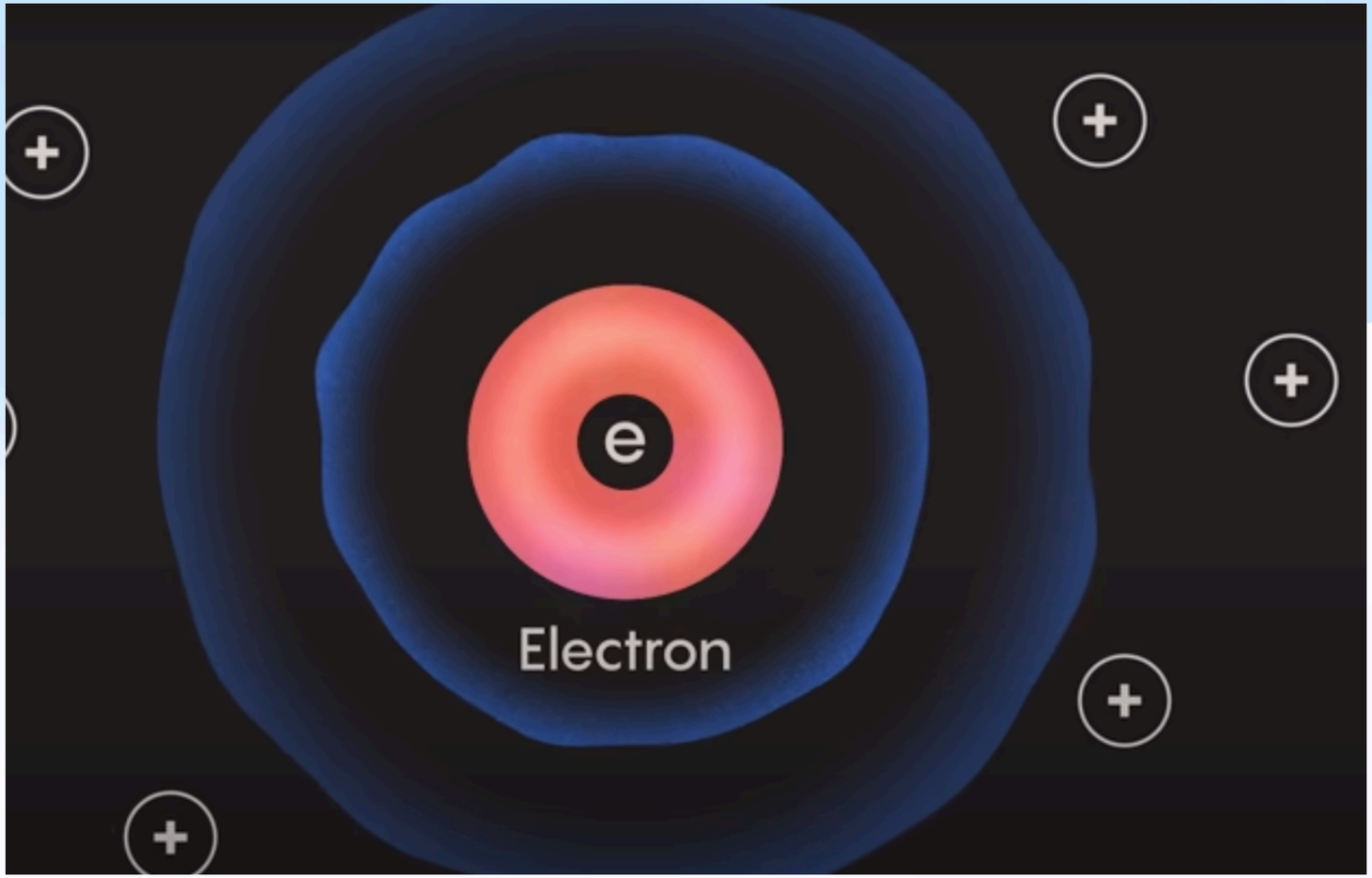
- EM force is felt by all the matter particles except the neutrinos (as they are neutral)





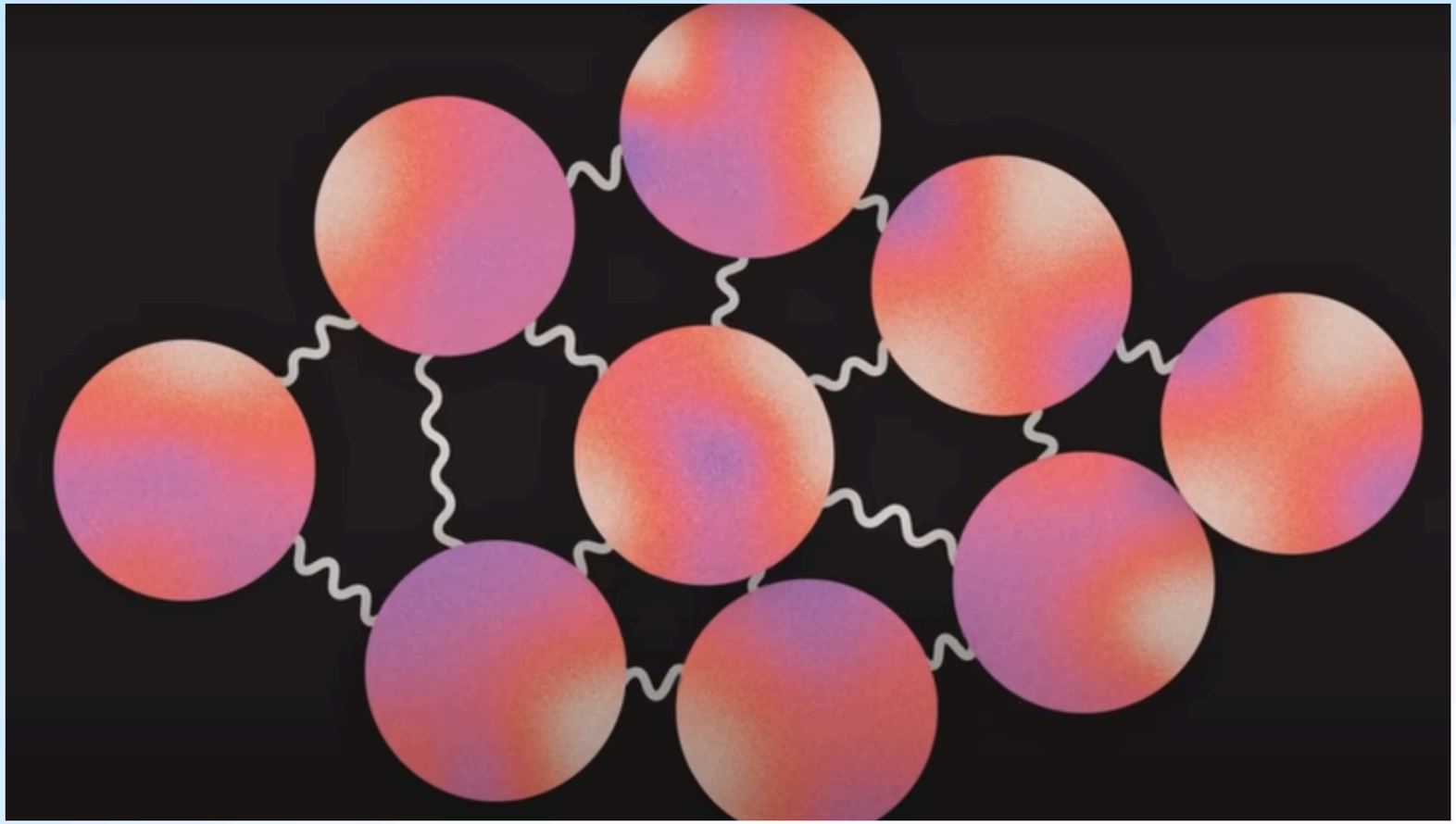
Electromagnetic(EM) Interaction

- EM force is applied **radially**



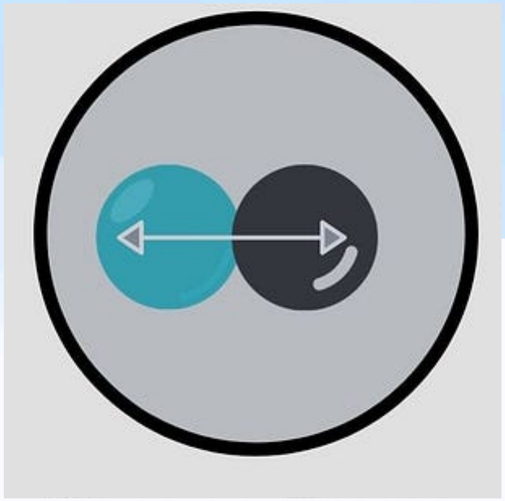
Strong Interaction

- Responsible for binding the nucleus together



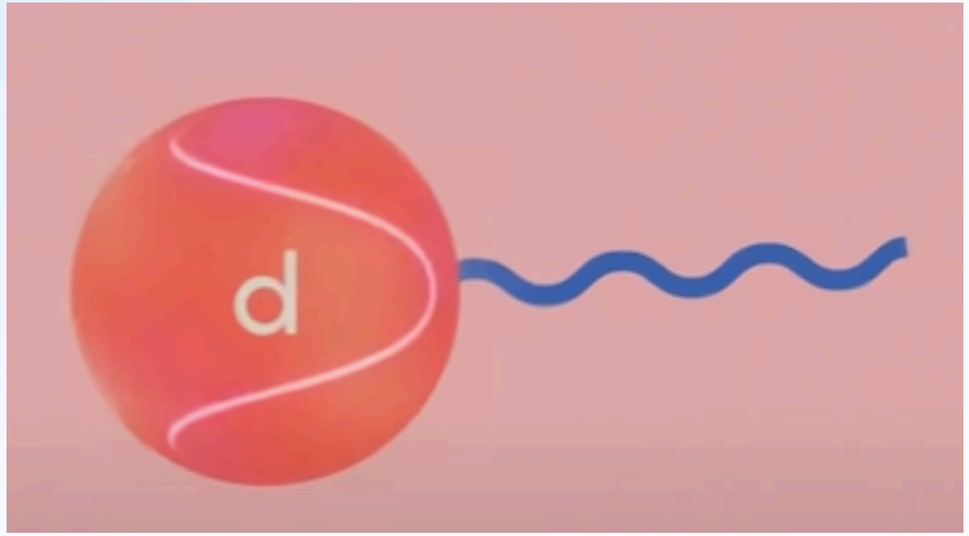
Strong Interaction

- Responsible for binding the nucleus together
- It is the dominant one in the reactions and decays of most of the fundamental particles
- The strong force is 10^7 times stronger for two protons touching.
- The mediator of the strong force is the gluon.
- Within the framework of the Standard Model, the strong force is due to color charge, analogous to the electromagnetic force being due to electric charge.

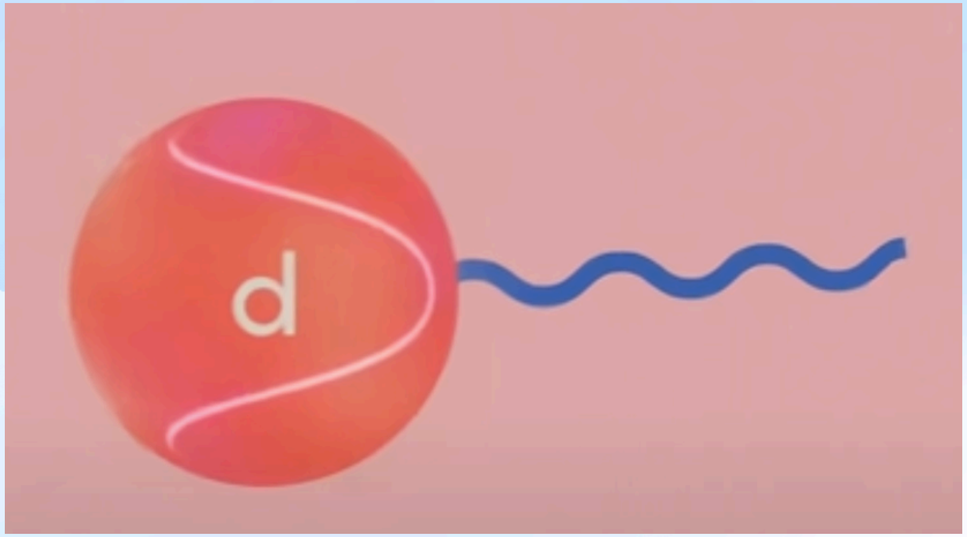


Strong Interaction

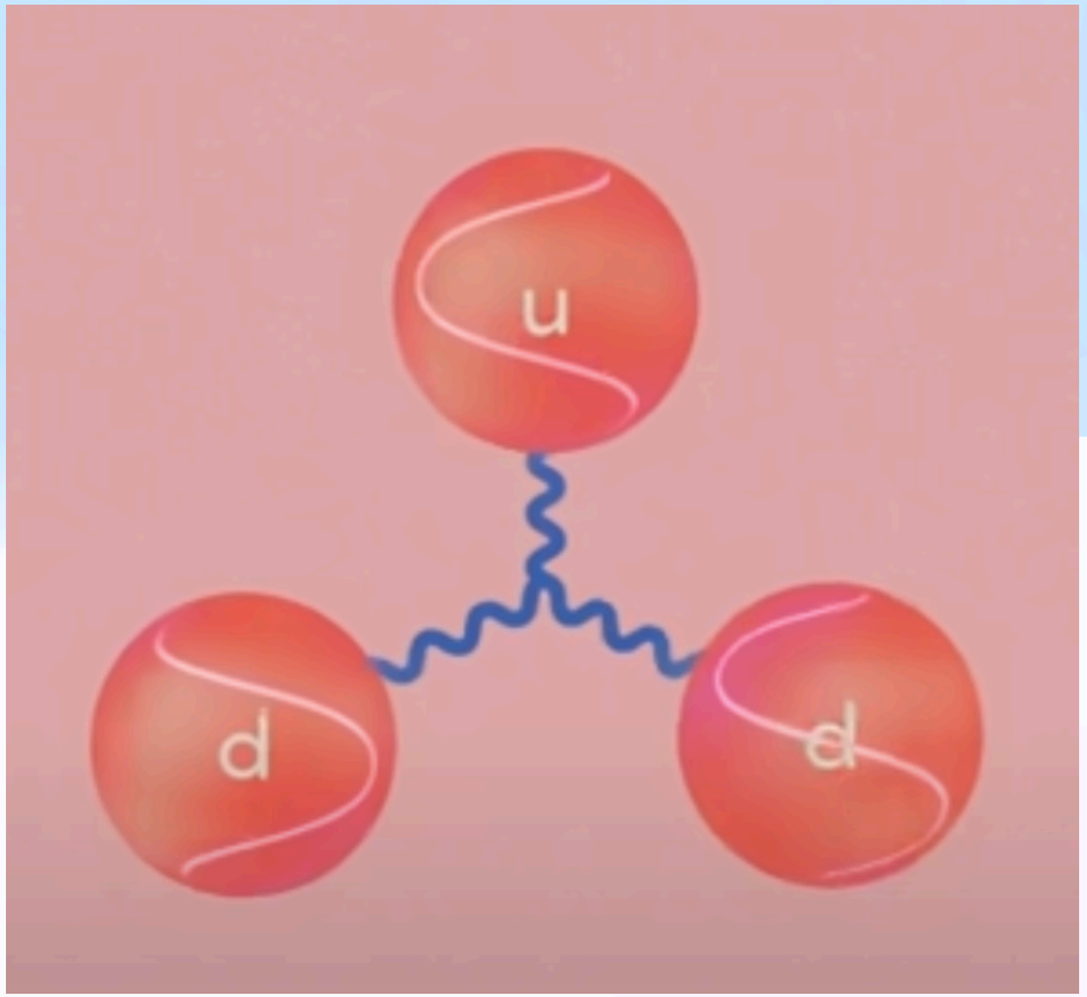
- Gluons - glues the quarks together to make protons and neutrons
- But gluons and strong force are very different than EM force
- It does not spread out radially
- There is thin string-like object which only ends when it meets the other quark



Strong Interaction



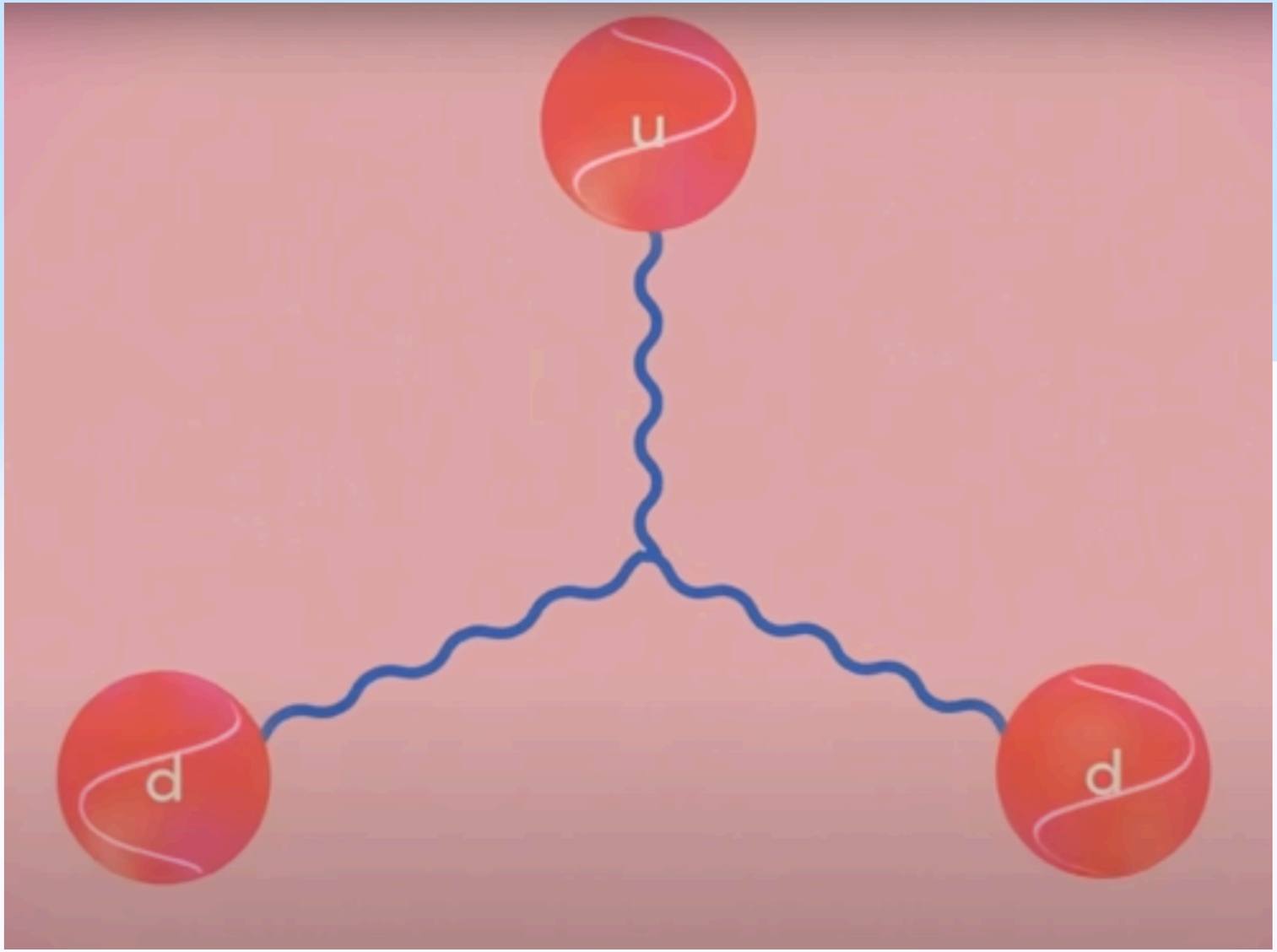
This makes strong force - strong



Strong Interaction

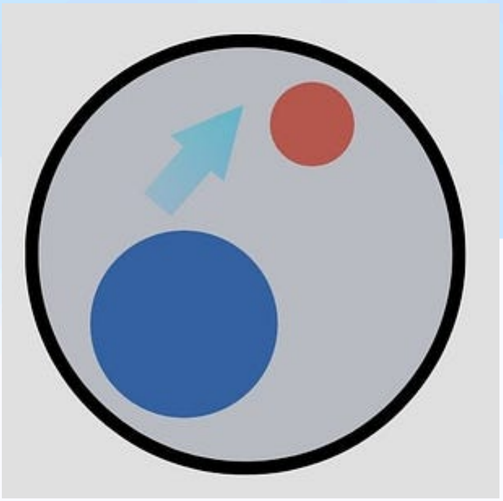
This makes strong force - strong.

It would require much energy to break these connections

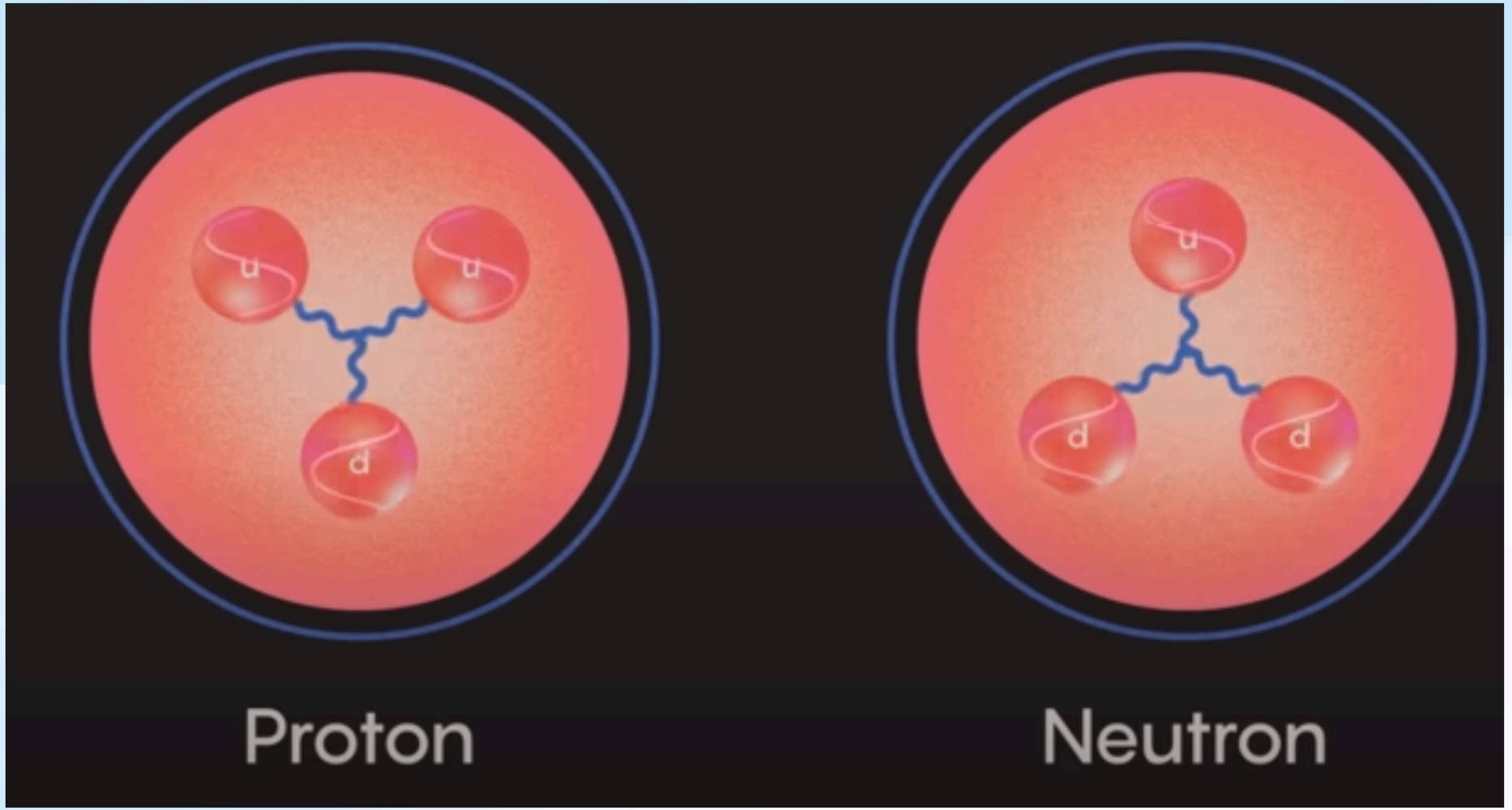


Weak Interaction

- Responsible for nuclear beta decay and other processes.
- It does not play a major role in binding the nucleus together.
- The strong force is 10^7 times stronger for two protons touching.
- Three particles carry the weak force:
  - the charged weak force by the W+ and W- and
  - the neutral weak force by the Z^0
  - All three have spin 1 and thus are bosons

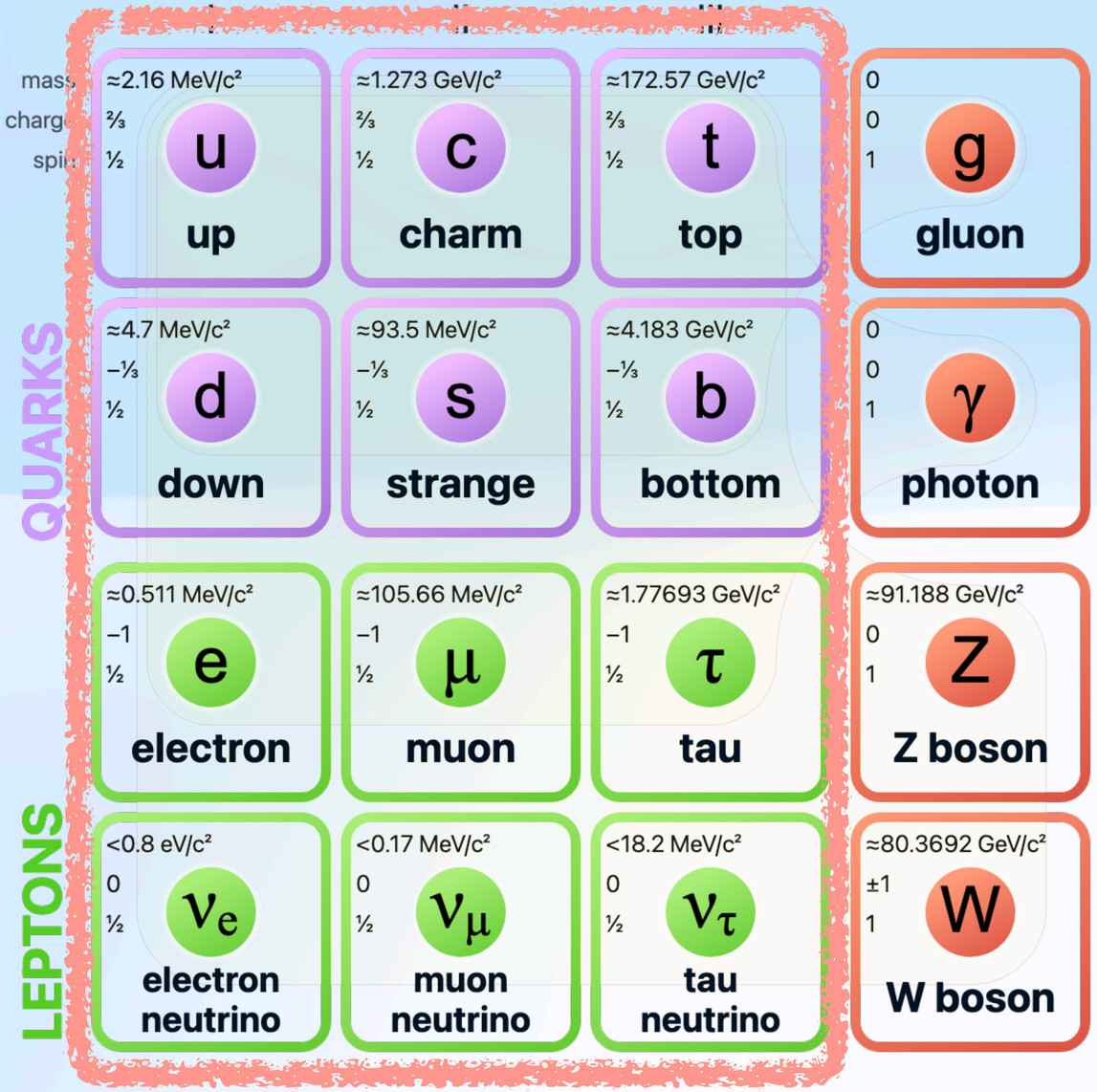


Weak Interaction



Responsible for conversions from proton to neutron and vice-versa

Weak Interaction



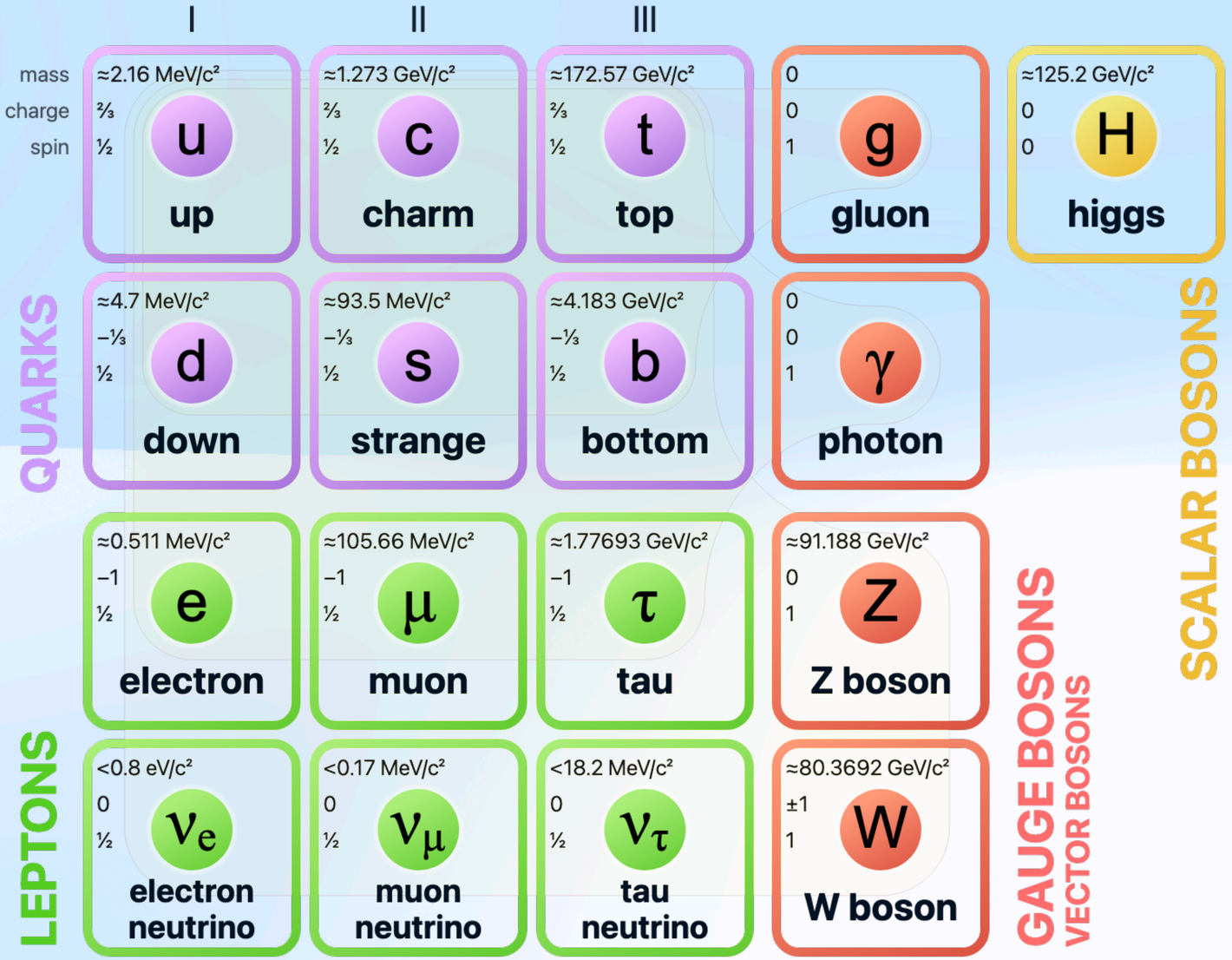
Responsible for conversions from proton to neutron and vice-versa

All matter particles can interact via weak interaction

Gravitation

- Gravity is essential for macroscopic objects (from the solar system to the humans)
- It is not important for the elementary particles. Two protons just touching experience a force that is 10^{38} times stronger than gravity.
- The mediating particle for this force is the graviton, which is expected to be uncharged, massless, and has spin 2.
- This particle has not yet been observed, nor does the experimental capability to do so yet exist.

Gravitation

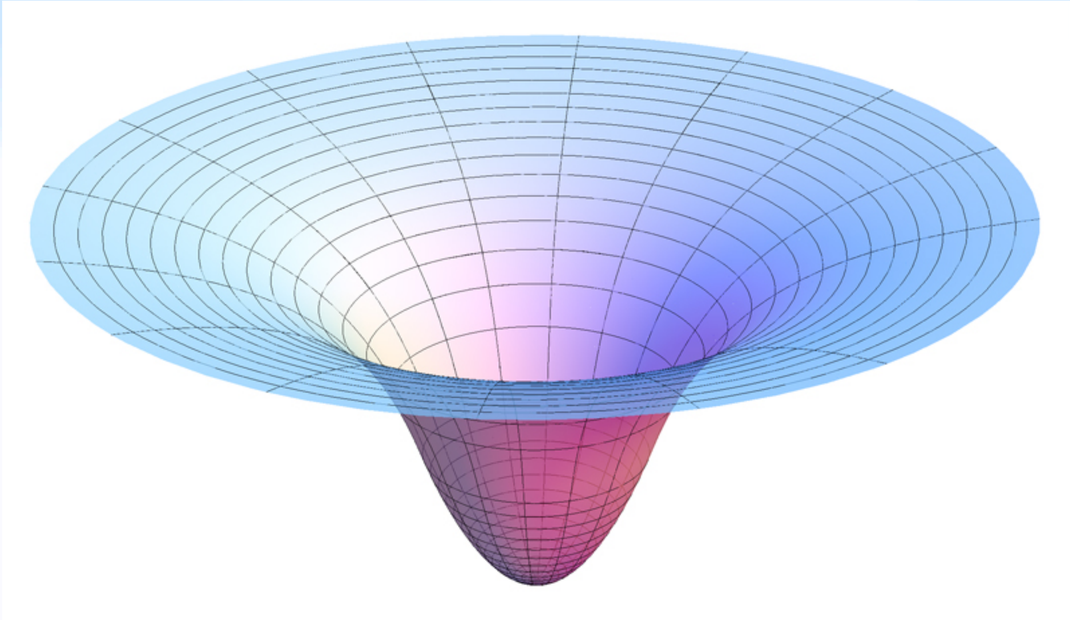


Where is gravity in this?

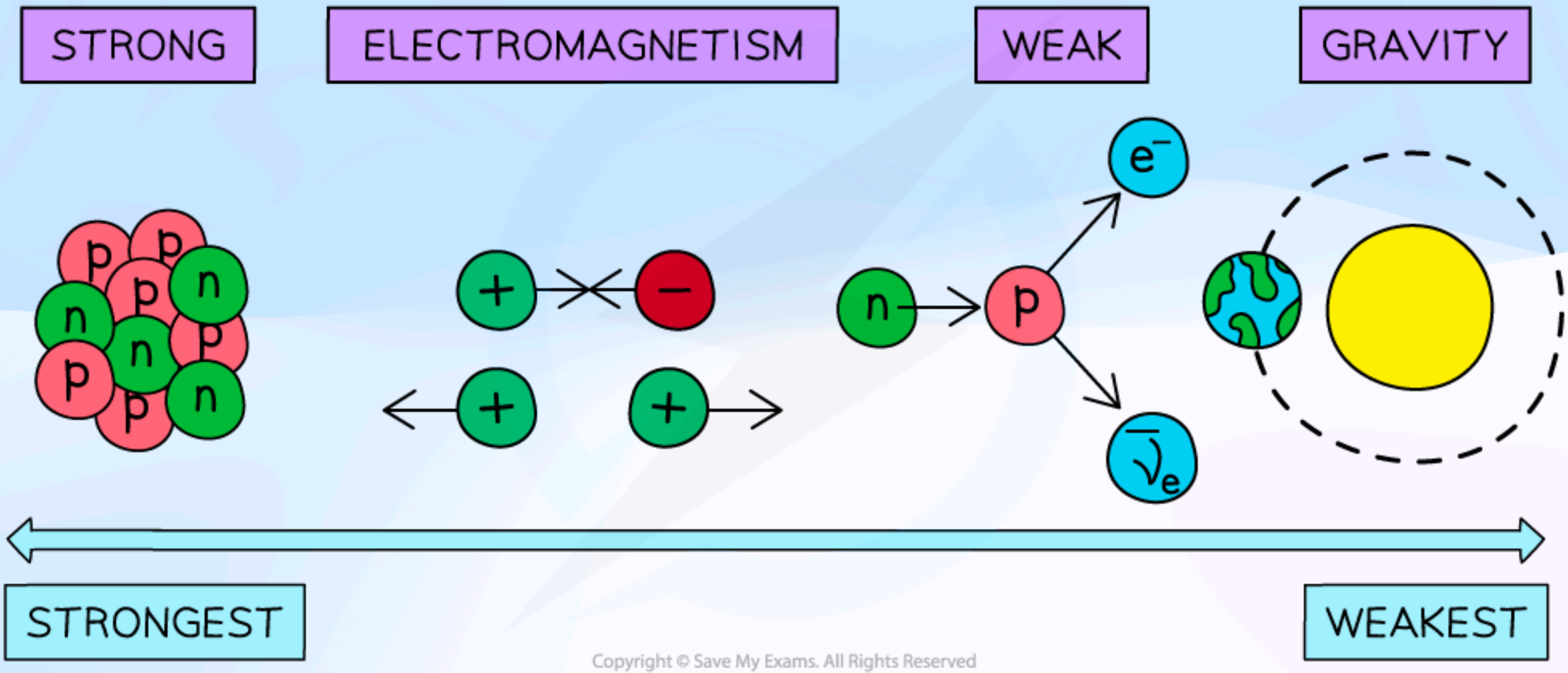
Why is it missing from the Standard Model?

Gravitation

- The Standard Model is written in the language of quantum field theory.
- We can easily view gravity as a field, but we don’t understand how to study it on the quantum level



Four Interactions

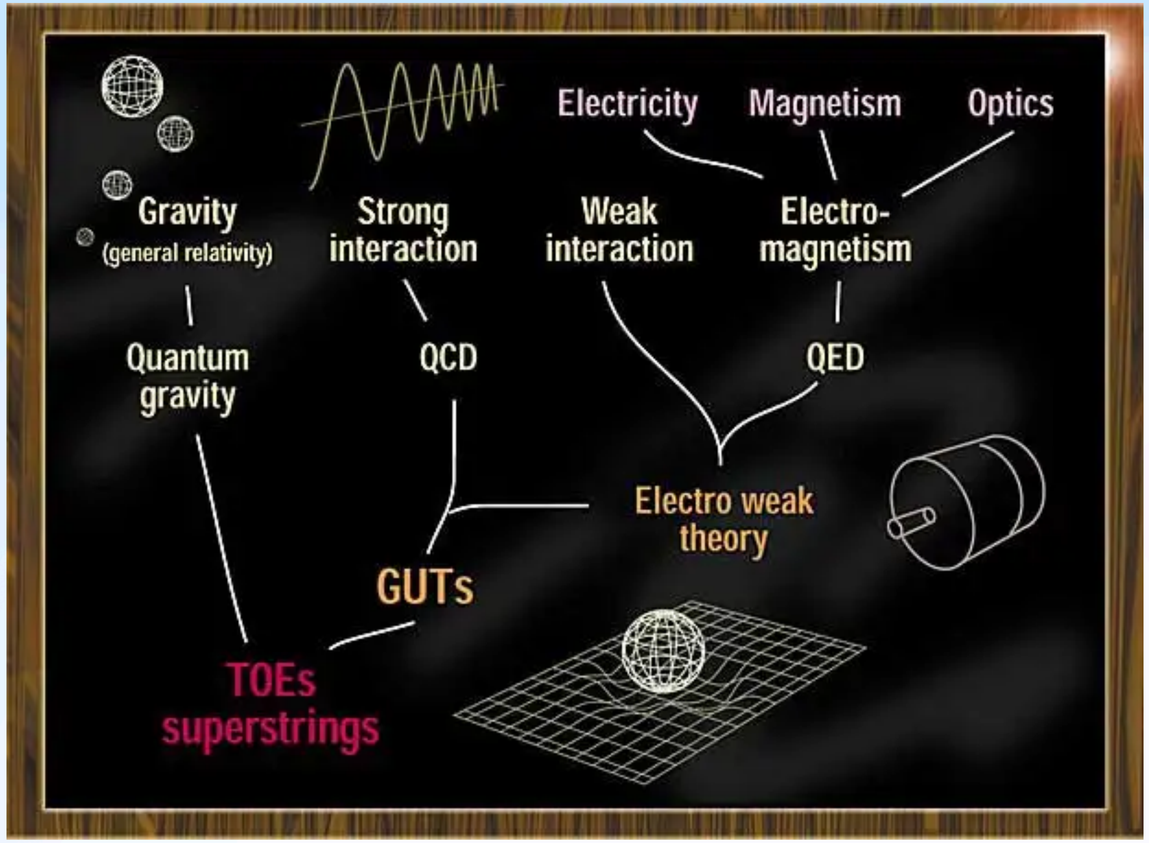


Four Interactions

- The fundamental forces may not be truly “fundamental” but may actually be different aspects of the same force.
- Electric + magnetic forces = electromagnetic force
- In the 1970s unified the electromagnetic force with the weak nuclear force into an **electroweak force**.

Four Interactions

- Any scientific theory that attempts to unify the electroweak force and strong nuclear force is called a **grand unified theory**, and any theory that attempts to unify all four forces is called a **theory of everything**.



Four Interactions

Type	Range	Relative Strength	Characteristic Time	Typical Particles
Strong	1 fm	1	$< 10^{-22}$s	π, K, n, p
Electromagnetic	∞	10^{-2}	$10^{-14} - 10^{-20}$s	e, μ, π, K, n, p
Weak	10^{-3}fm	10^{-7}	$10^{-8} - 10^{-13}$s	All
Gravitational	∞	10^{-38}	Years	All

- Characteristic time: If we bring two particles close enough together, it takes much longer for the weak force to cause a decay or a reaction than the strong force.

Four Interactions

Force	Field Particle	Symbol	Charge (e)	Spin $(\hbar)$	Rest Energy (GeV)
Strong	Gluon	g	0	1	0
EM	Photon	γ	0	1	0
Weak	Weak Boson	$W^+, W^-,$ Z^0	± 1 0	1	80.4 91.2
Gravitational	Graviton	Not yet observed	0	2	0