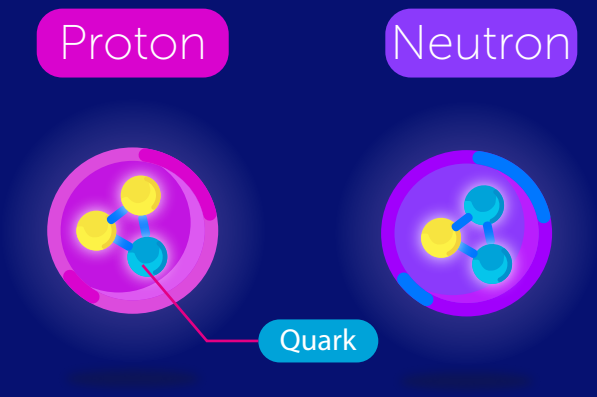
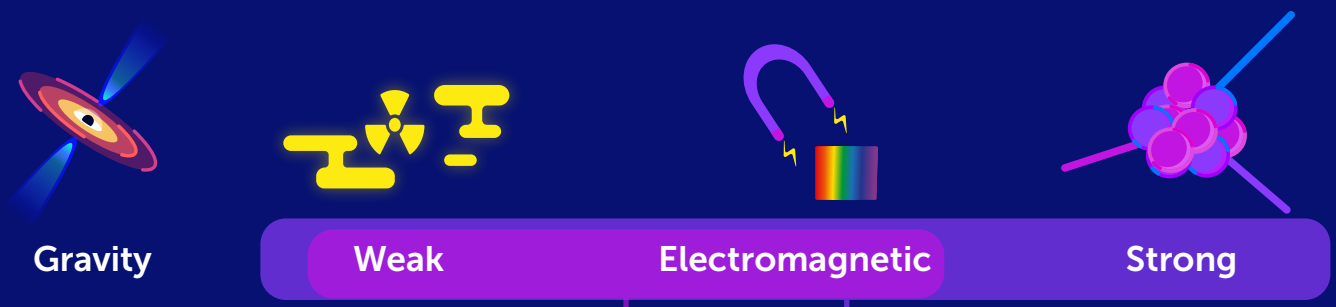
What's Inside the nucleon?

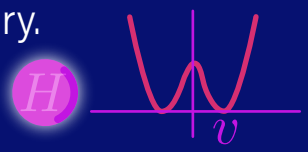


Protons and neutrons are not elementary particles.
Rather, they are bound states of particles called : "quarks"
Quarks are matter particles, in addition to *leptons* they form the fermionic sector of the Standard Model.

Fundamental interactions



Gravity is unlike the rest of interactions, it has no complete quantum description so far and not considered a quantum gauge theory.

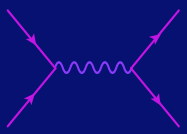


Electroweak

~10^3 GeV

The Standard Model is based on the unification of the weak and EM interactions.
The breaking of this unification is mediated via the Higgs boson

There are 4 fundamental interactions known in nature.
These interactions are based on Gauge Theory, a theory relating internal symmetries to interactions.



In gauge theory, interactions are mediated via Propagated particles known as gauge bosons.

Grand Unified Theory

~10^{16} GeV

The electroweak interaction *could* be unified with the strong interaction in a Grand Unified Theory.

Inclusion of gravity might be done via exotic theories like String Theory, yet to beyond particle colliders.

The Standard Model

Fermions

Quarks

up-type: Q=+2/3

flavour: up | charm | top

mass: ~2.2 MeV | **1.3 GeV** | 173.0 GeV

down-type: Q=-1/3

down ~4.7MeV | **strange** 95 MeV | **beauty** 4.7 GeV

leptons

neutrinos: Q=0

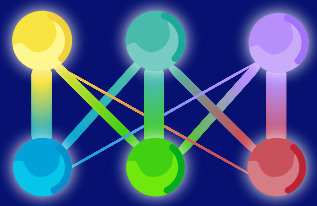
electron | muon unknown | tau

charged: Q=-1

electron 0.5 MeV | muon 105.6 MeV | tau 1.8 GeV

All quarks and charged leptons, except the **1st generation** are unstable and decay evantually into the 1st generation

Flavour mixing and CKM



Quark flavours mix due to the CKM matrix emerging from Yukawa coupling with the Higgs

Quarks within the same generation mix strongly

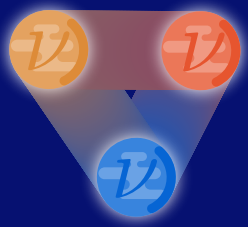
Scalars

Higgs
125.1 GeV

The Higgs is the central piece of the SM, it has a non-vanishing vacuum, creating a mass to every particle that couples to it

The Higgs vacuum is responsible for the breaking of electroweak symmetry into the EM one

Neutrino oscillation



Neutrinos change their flavour, indicating they have a mass

There is no explanation in the SM for the neutrino oscillations

Gauge bosons

The W and Z acquire their mass by interacting with the Higgs vacuum. They are the mediators of the weak interaction

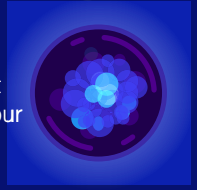
Higgs vacuum
246 GeV

Z^0
91.2 GeV

$W^{\pm}$
80.4 GeV

The W only couples to left-handed fermions

Interacting with the Z and the photon does not change the flavour



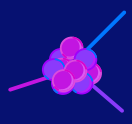
photon
massless

Photons are the mediators of the EM interaction. They the massless bit left after EW symmetry breaking

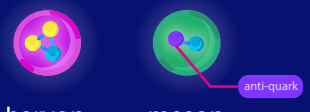
There are 8 gluons, interacting with coloured particles. i.e. quarks

gluon
massless

Gluons are responsible for the strong interaction, binding the quarks inside the nucleon



The strong interaction form 2 types of bound states of quarks called Hadrons



baryon | meson

The residual interaction that binds nucleons together, mediated by mesons called pions