Chap 14

Particle Physics

- Early Discoveries
- Classification of Particles
- The Fundamental Interactions

What is inside the nucleus?

What are the basic building blocks of matter?

What are the forces that hold matter together?

What we have learned so far:

- Before 1930, the known elementary particles were the photon, the electron, and the proton.
- 1928, Dirac's theory combines quantum mechanics with relativity. It opened the possibility of antiparticles.
- 1932, Chadwick proved the existence of the neutron.

Also,

- 1932 Anderson found positron in cosmic rays
- 1937 Street and Stevenson found **muon** in cosmic rays.
- 1947 Powell and Occhialini found Yukawa's meson **pion** in cosmic rays.

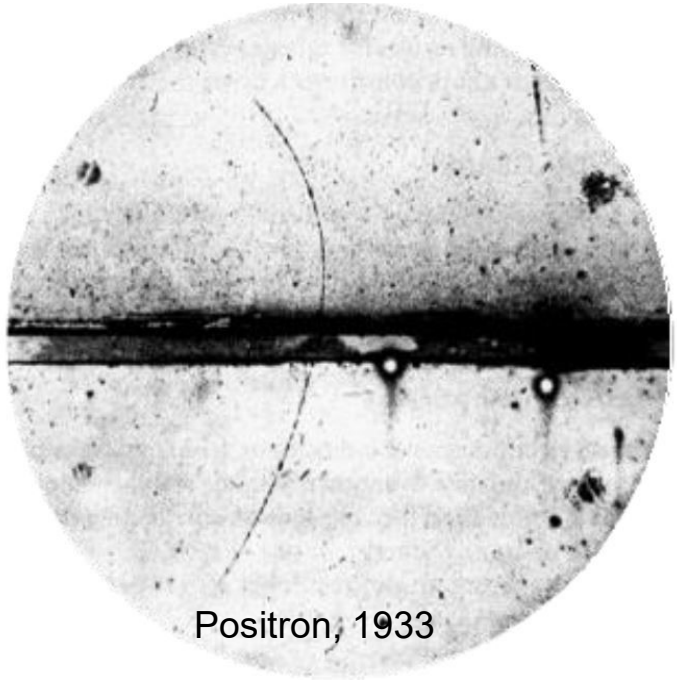
渺子

Three Types of Detectors of Charged Particles

I. Ionization chamber, Geiger counter, Scintillation counter, Cerenkov counter, etc.

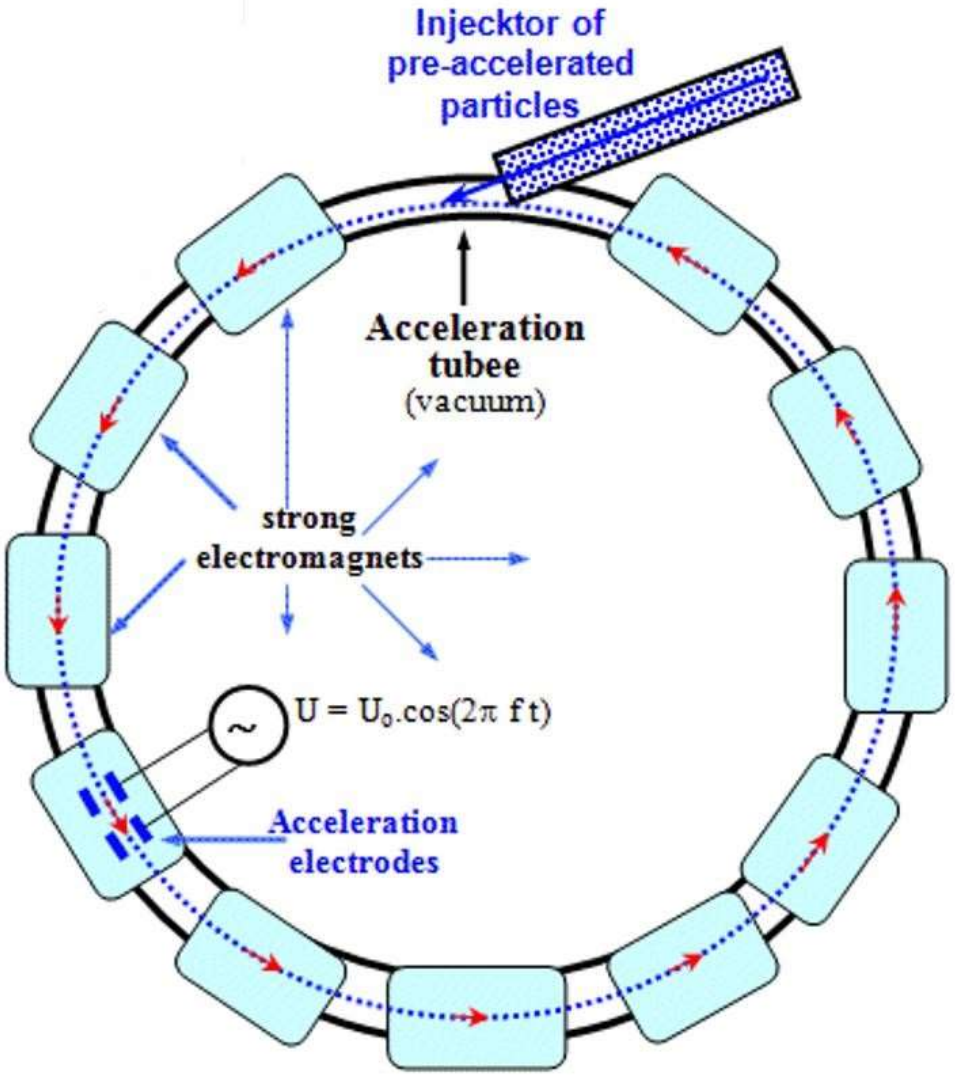
II. 雲霧室 Cloud chamber, Diffusion chamber, Bubble chamber.

III. Photographic Emulsion.



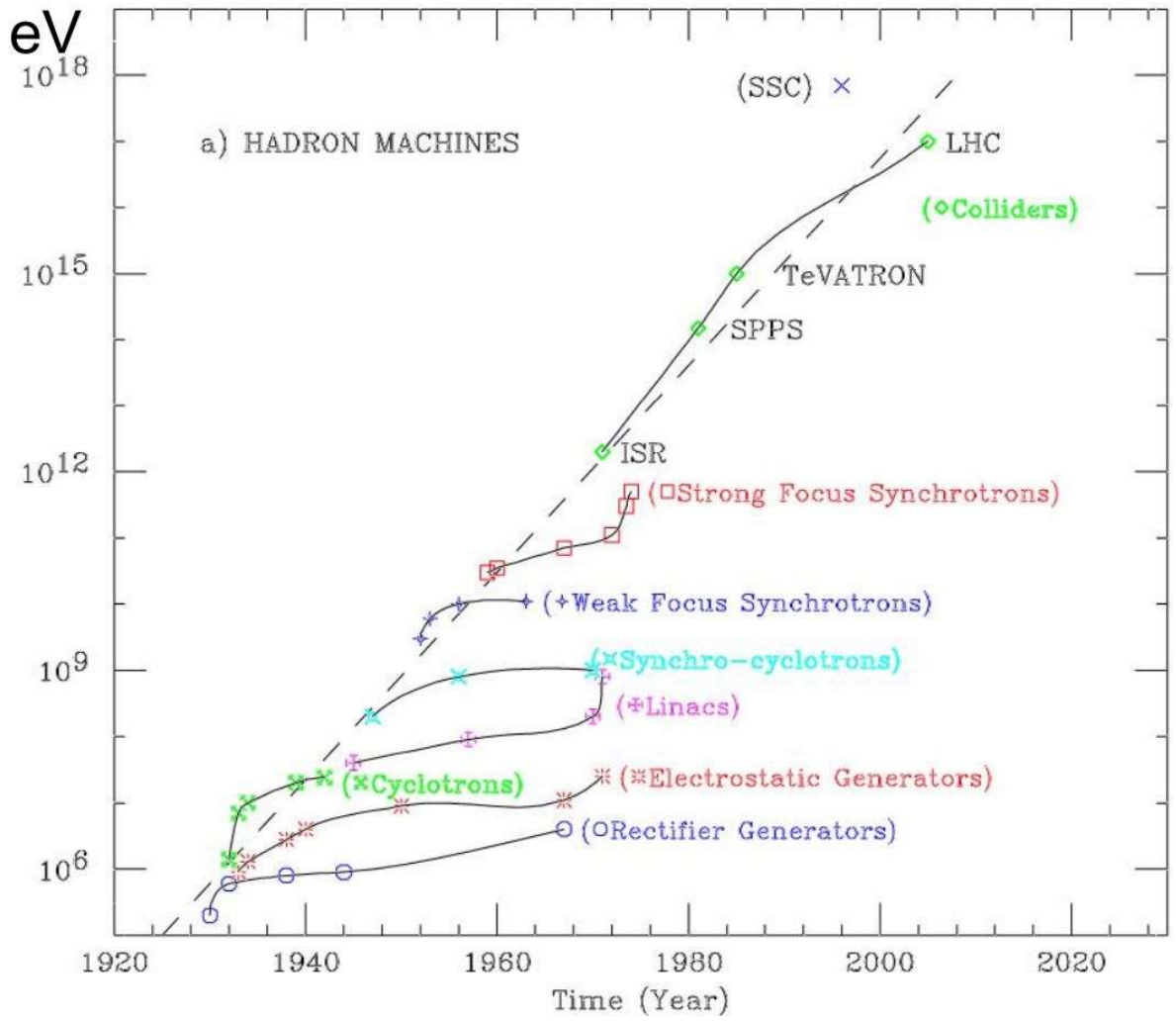
Positron, 1933

Synchrotron accelerator 同步加速器
(electron 1945, proton 1952)



https://astronuclphysics.info/JadRadFyzika5.htm

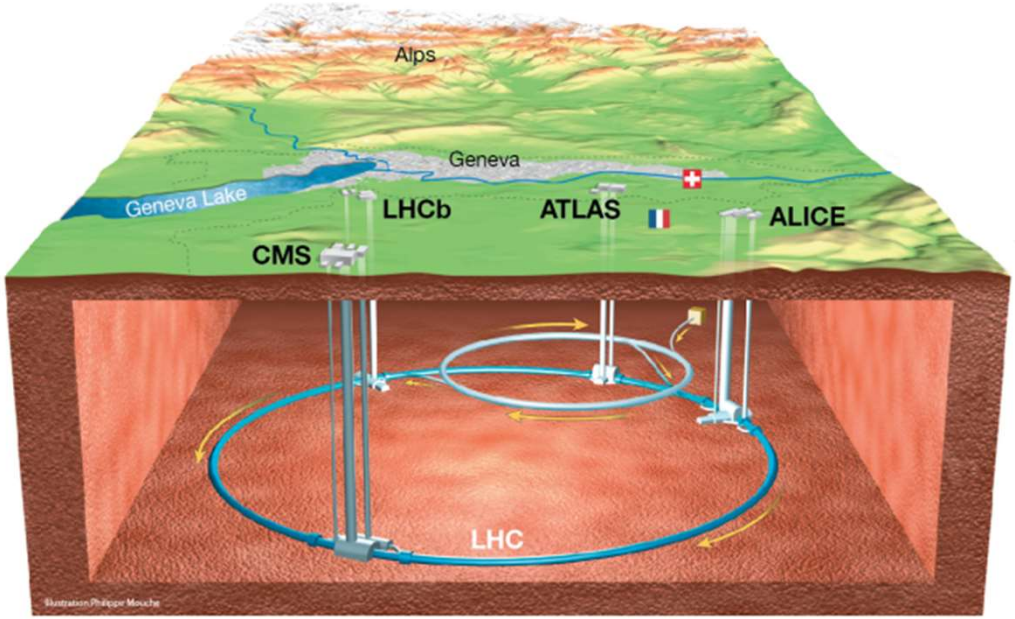
Development of particle accelerator



Note: highest energy cosmic ray being detected have a few 10^{20} eV!

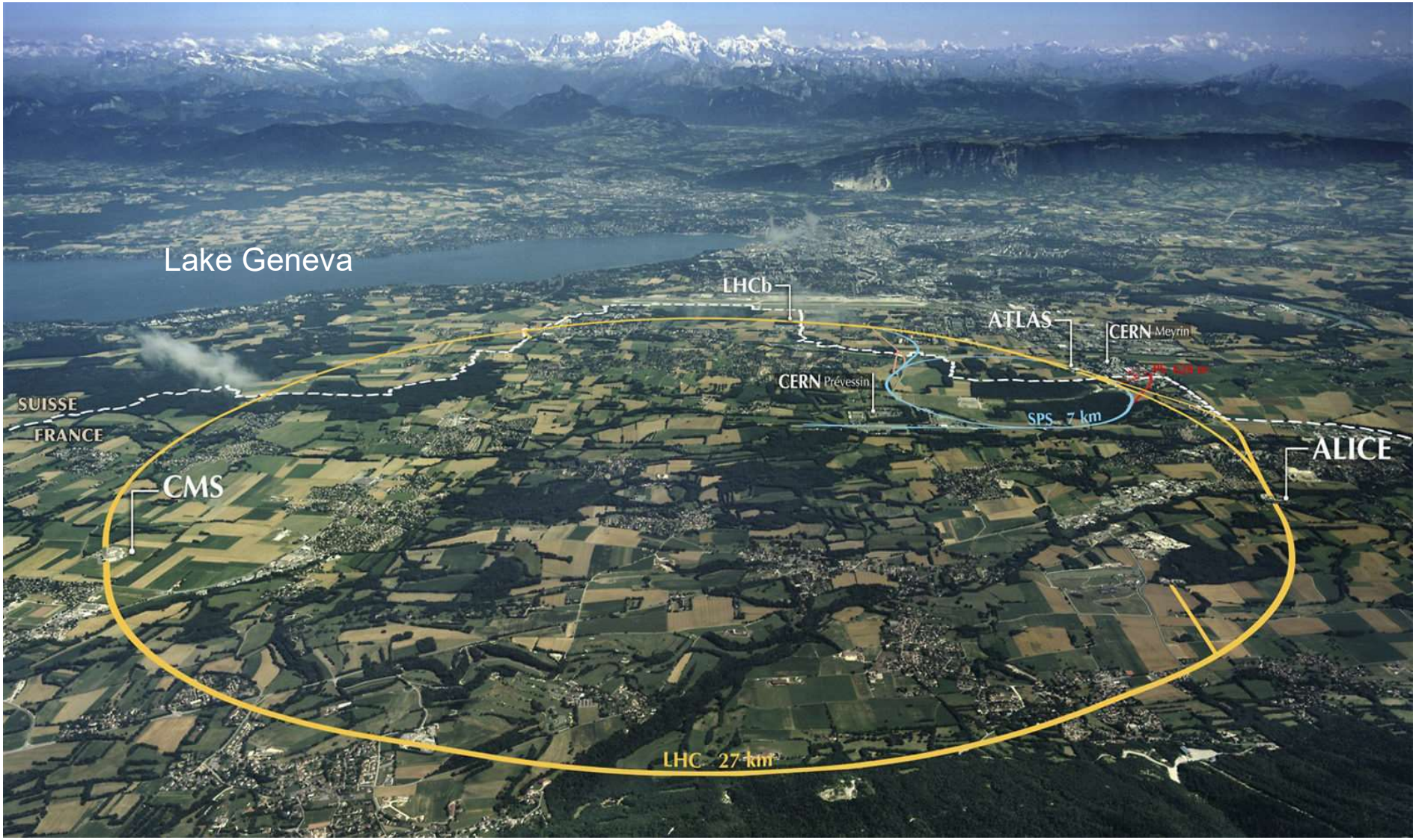
CERN LHC (2008-) proton-proton or lead nuclei collisions

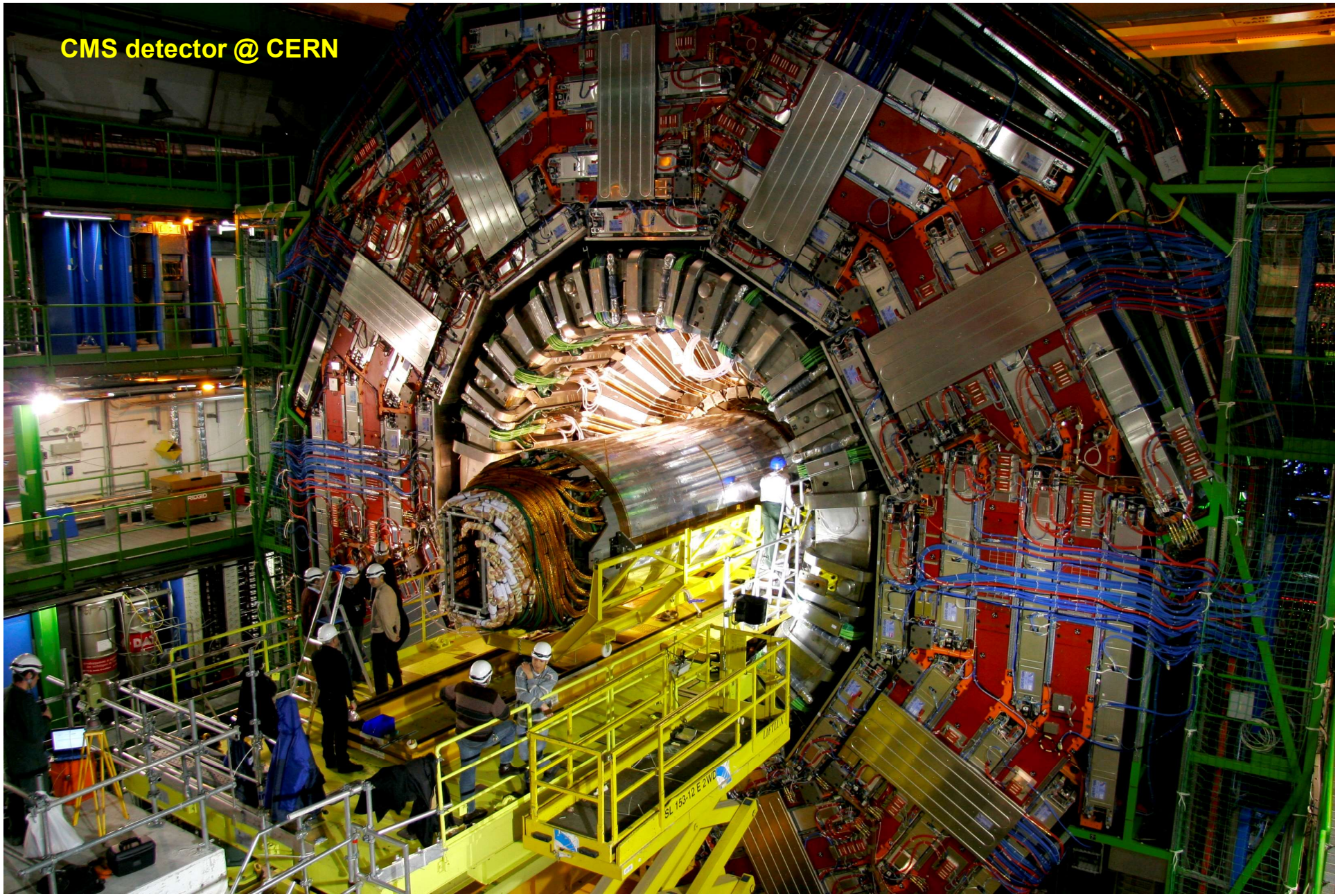
大強子對撞機



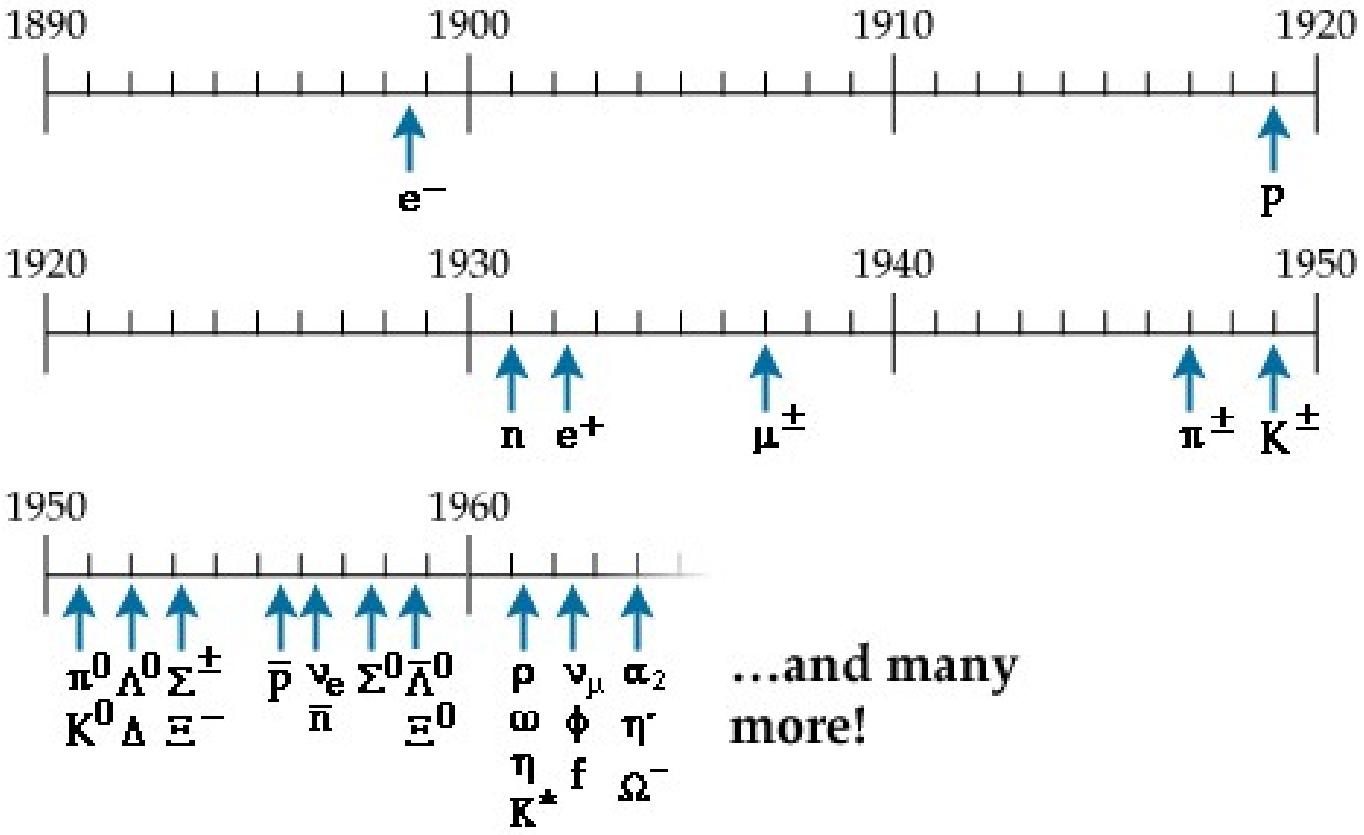
- Circumference: 26.6 km; 100 m below ground
- 6.8 TeV per proton beam (13.6 TeV collision energy)

How CERN's Large Hadron Collider works
Introducing the CMS Experiment at CERN
A timelapse visit of CERN, LHC and the ATLAS Experiment


Lake Geneva
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km


CMS detector @ CERN

After the invention of particle accelerators, several hundreds new particles are produced.



"If I could remember the names of all these particles, I would have been a botanist." -- Fermi

The table of elementary fermions (→ matter)

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

	Flavor	Mass GeV/c^2	Electric charge
1st generation	ν_e electron neutrino	$<1\times10^{-8}$	0
	e electron	0.000511	−1
2nd generation	ν_μ muon neutrino	<0.0002	0
	μ muon	0.106	−1
3rd generation	ν_τ tau neutrino	<0.02	0
	τ tau	1.7771	−1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

All visible matter in the universe is made from the first generation; 2nd- and 3rd-generation particles are unstable and decay into first-generation particles.

Interaction between matters (in addition to gravitation and EM force)

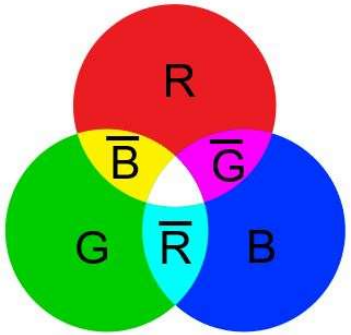
First, strong interaction (or strong force)

膠子

- The quanta of strong (color) force is called **gluons**. We can say that gluons transmit strong (color) force, just like photons transmit EM force.

- Each gluon consists of a color and an anti-color, and 3x3=9 combinations: (red anti-red, red anti-blue, red anti-green, blue anti-red, blue anti-blue, blue anti-green, green anti-red, green anti-blue, green anti-green).

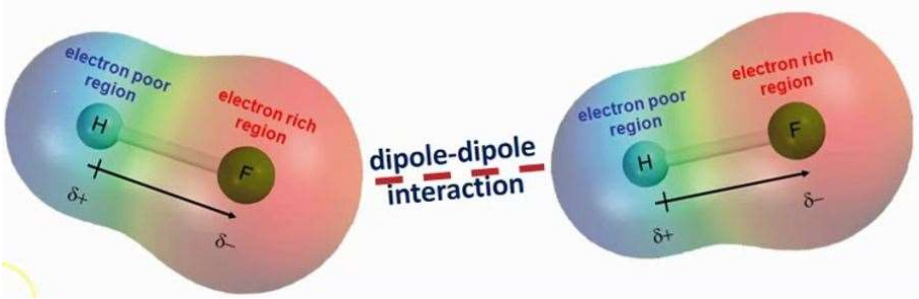
- But there is one constraint: red + blue + green = colorless



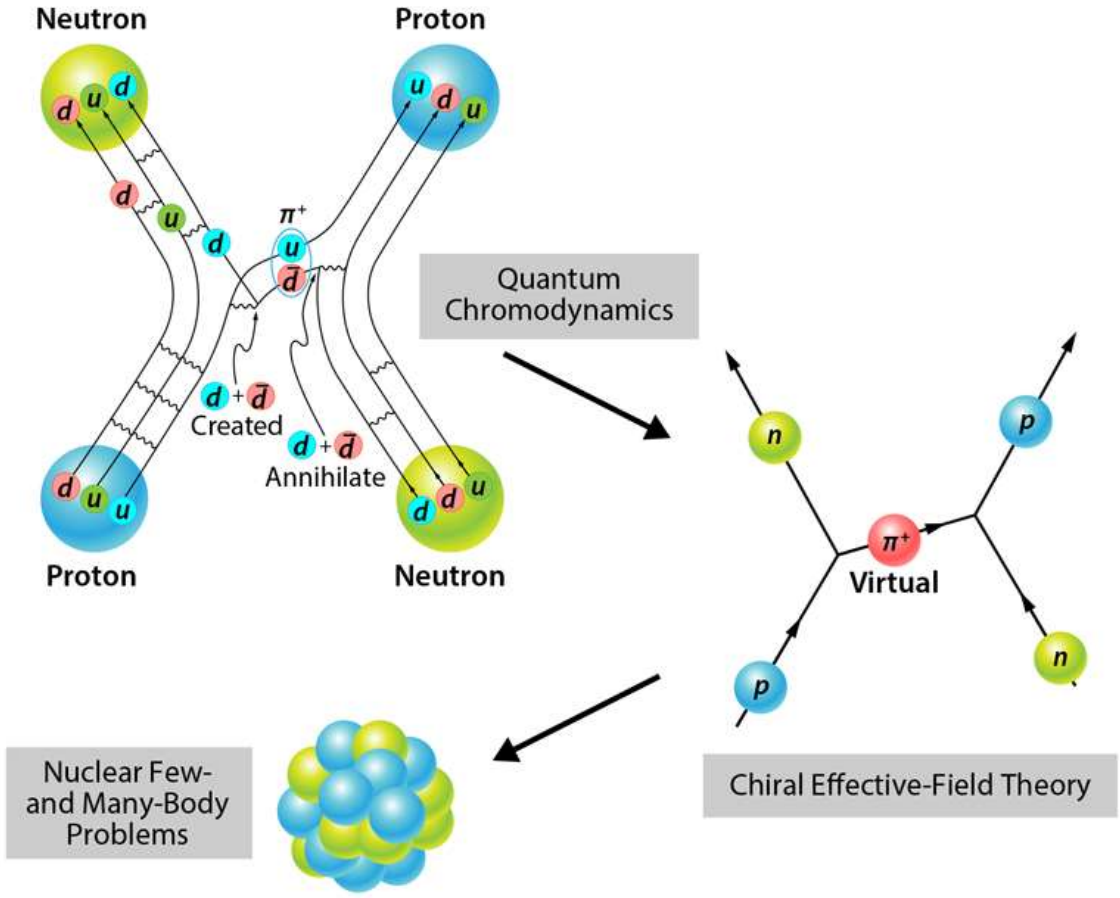
Comparison

- For EM interaction, there are 2 kinds of electric charge (positive, negative), and 1 type of force quanta (photon).
- For strong interaction, there are 3 kinds of color charge (blue, green, red), and 8 types of force quanta (gluons).

- Van der Waals force as residual EM interaction



- Nuclear force as residual strong interaction



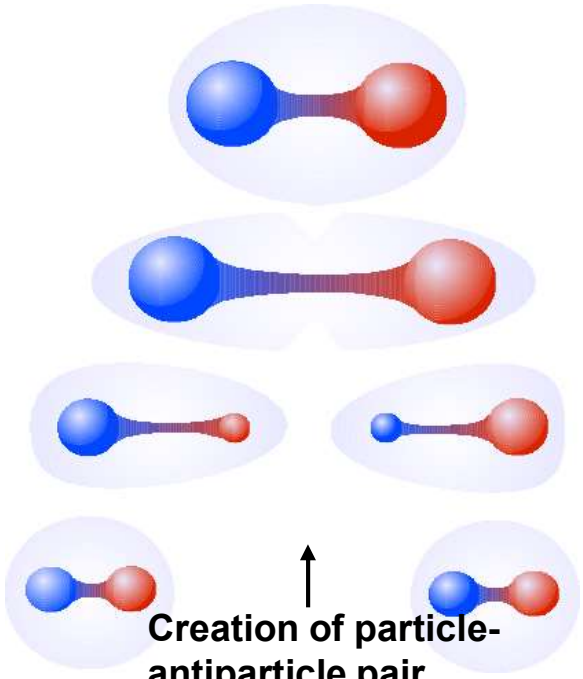
Q: Are we able to kick one quark out of a nucleon?

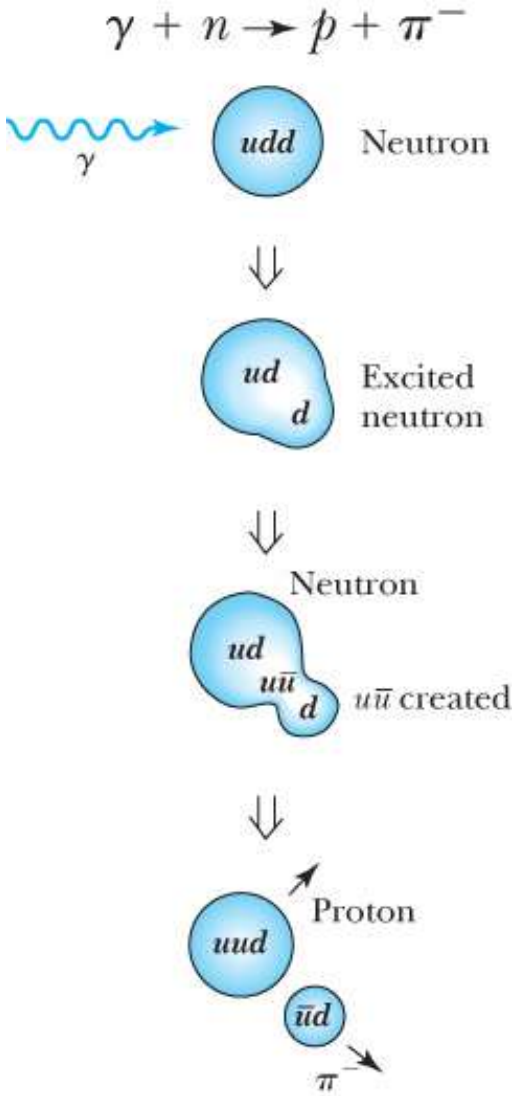
A: No, according to **Quantum chromodynamics** (**QCD**): 量子色動力學

The interaction strength between two quarks increases with their distance!

This is called **Quark confinement.**

夸克局限

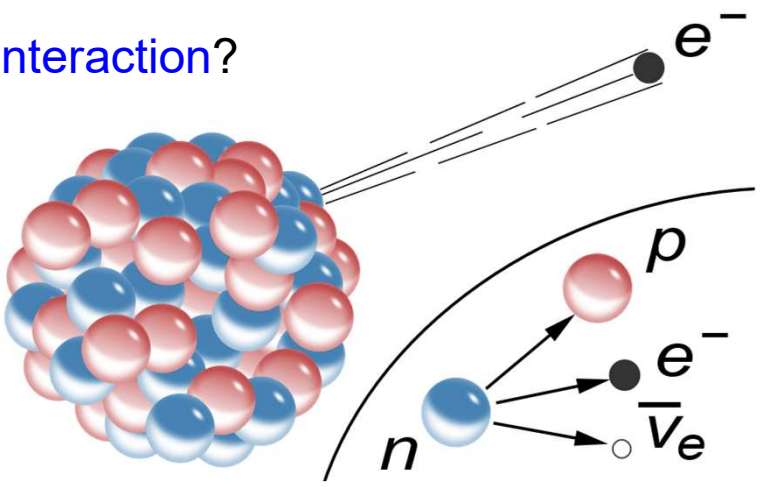




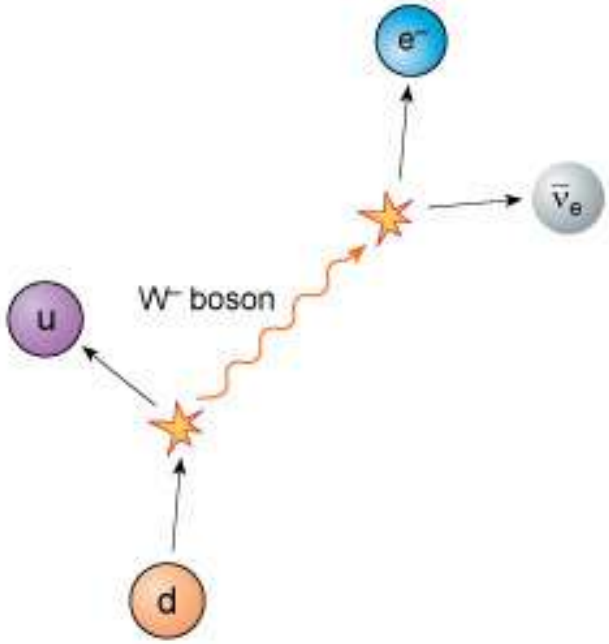
Second, weak interaction

What's the quanta of weak interaction?

- Beta decay

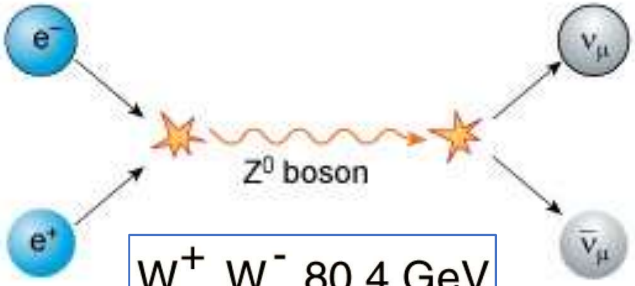


- Updated view of the Beta decay



The weak interaction is transmitted by 3 types of boson: $W^{\pm}, Z^{0}$

Salam, Weinberg (1964, 1967)



W^+ W^-	80.4 GeV
Z^0	91.2 GeV

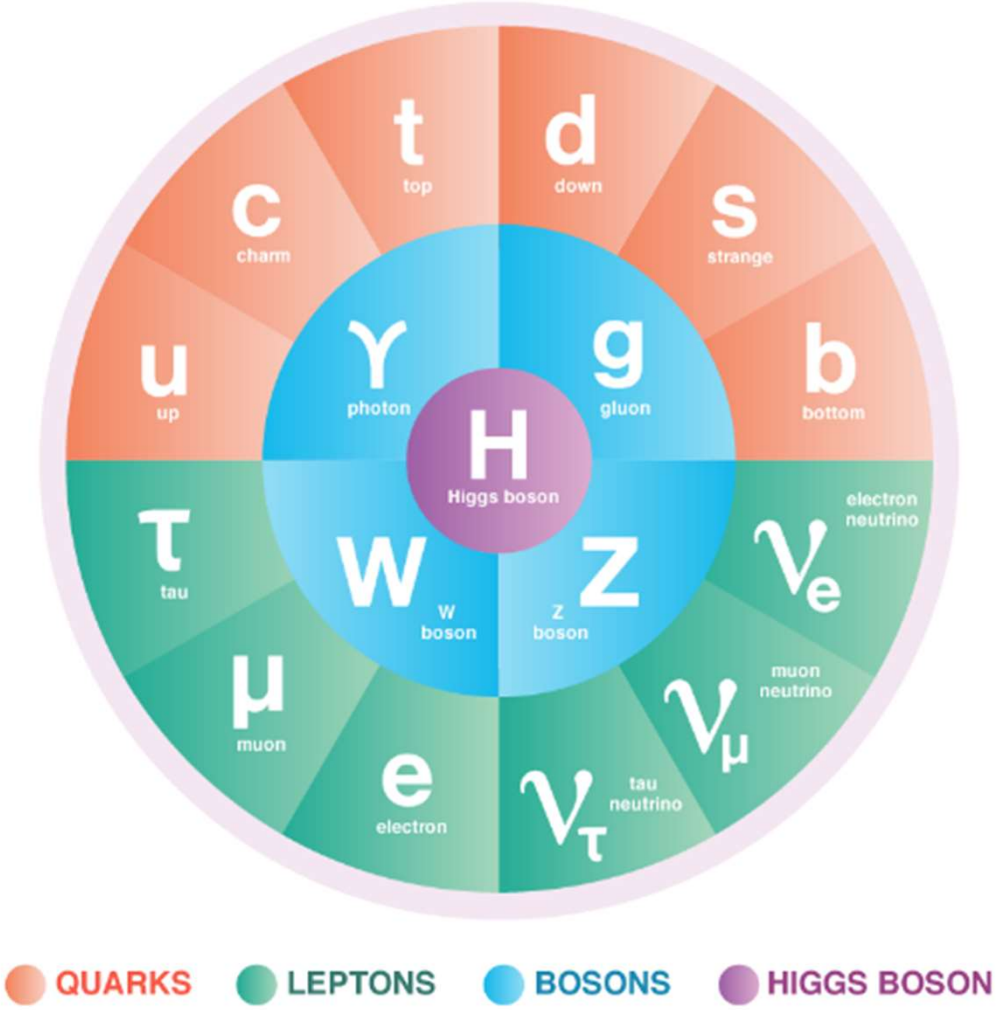
~ 100 times the mass of a proton

Summary: There are 4 fundamental Interactions

massless, and travel at the speed of light.

Interaction	**Relative Strength**	**Range**	**Mediating Particle**
Gravitation	10^{-43}	∞	**Graviton** [hypothetical]
Electromagnetic	10^{-2}	∞	Photons
Weak	10^{-6}	10^{-18} m	$W^{\pm}$, Z bosons
Strong	1	10^{-15} m	Gluons

Summary: Building blocks of the universe



Constituents of matter