Kraków Applied Physics and Computer Science

Summer School'21

1st of July 2021

Introduction to High Energy Physics

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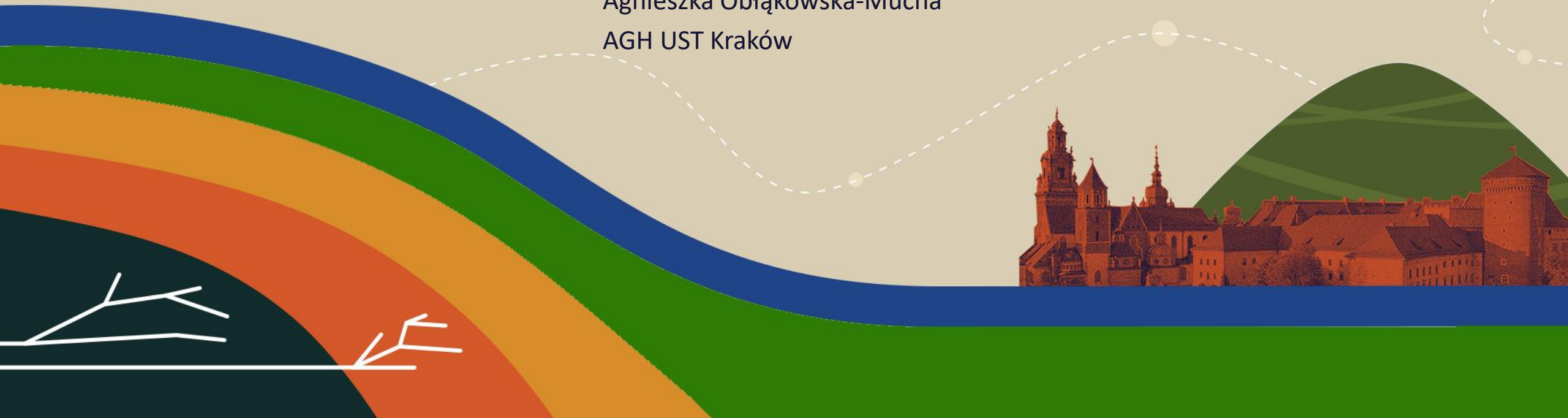
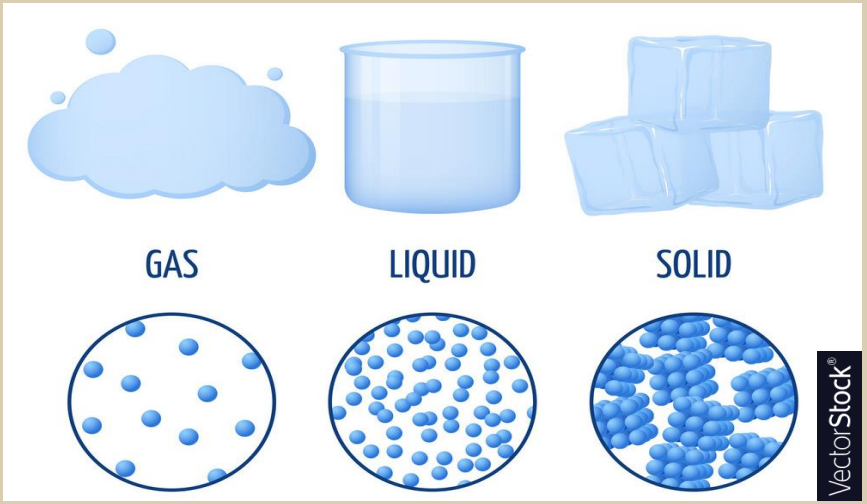


High Energy Physics deals with particles

Where can we search for particlcels?

Matter

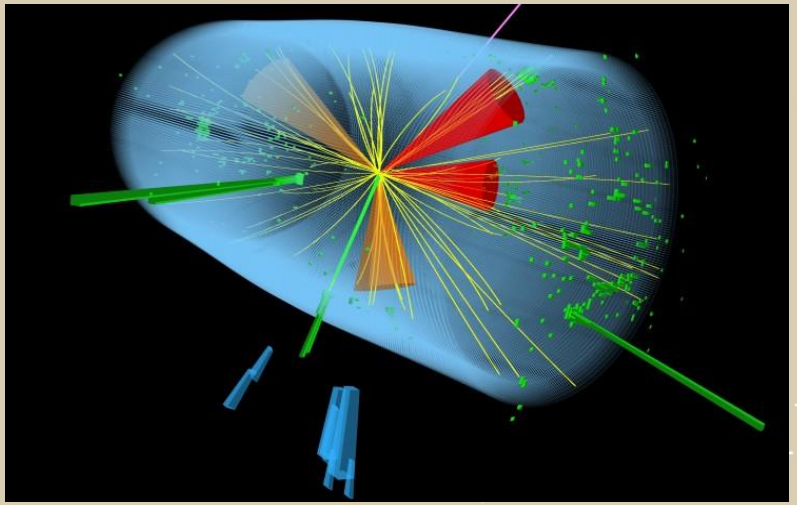


Smog, beer, mobile

Cosmos

Cosmic radiation

Physics experiment

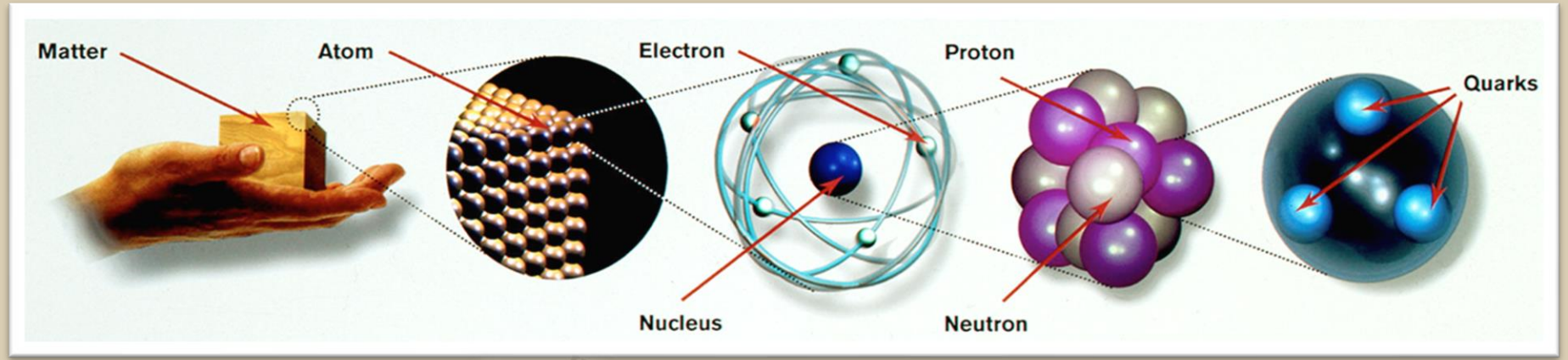


Large Hadron Collider

The same constitutions are present in all these situations

Matter

- Our matter consist of atoms which contains electron and nucleus, nucleus has structure build of quarks and gluons
- How can you believe in this? Because you can see it?



?

No, you know this because you can make an experiment to prove it

Matter = atoms + interactions

Particles are either:

FUNDAMENTAL

(they have no internal structure)

or

COMPOSITE

(they are composed of some combination of the fundamental particles)

Matter

Atoms, nuclei, protons, and neutrons are **COMPOSITE**

Electron, neutrino and quarks are **FUNDAMENTAL**

Atom = nucleons + electrons

Particles are either:

FUNDAMENTAL

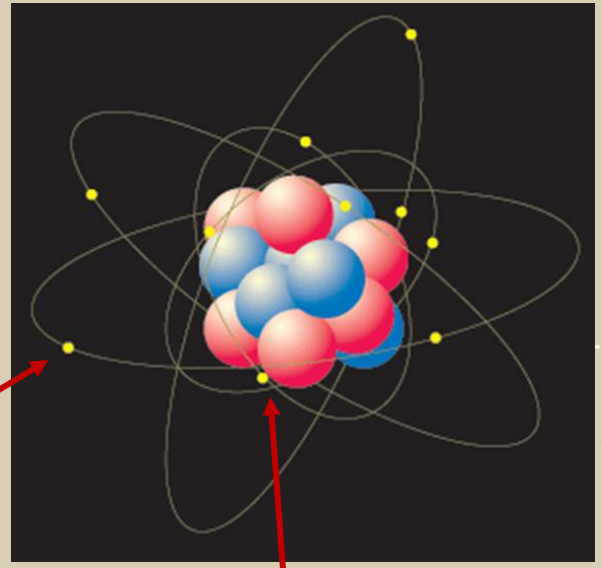
(they have no internal strucure)

or

COMPOSITE

(they are composed of some combination of the fundamental particles)

Atom



Atoms, nuclei, protons, and neutrons are **COMPOSITE**

Electron, neutrino and quarks are **FUNDAMENTAL**

Nucleon = proton or neutron

Particles are either:

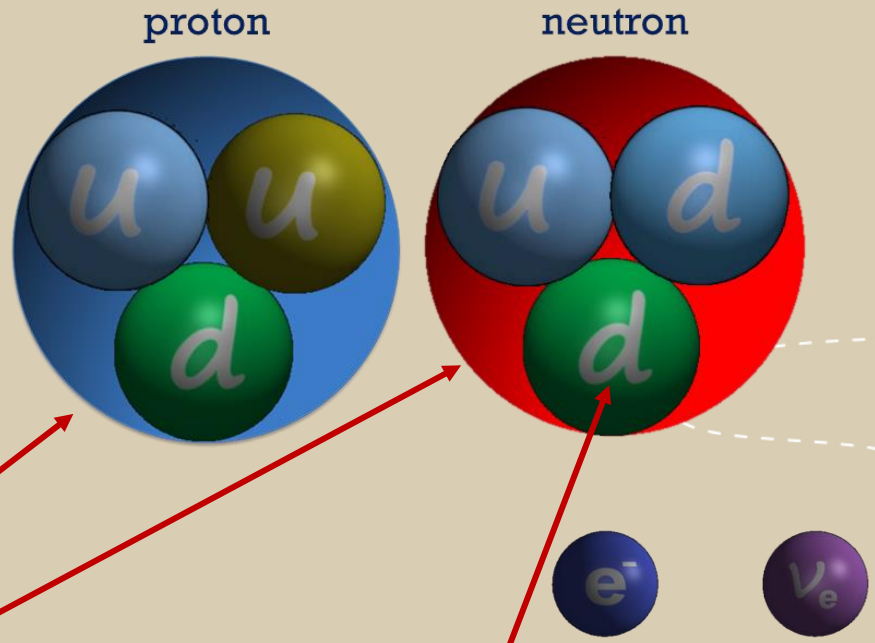
FUNDAMENTAL

(they have no internal structure)

or

COMPOSITE

(they are composed of some combination of the fundamental particles)



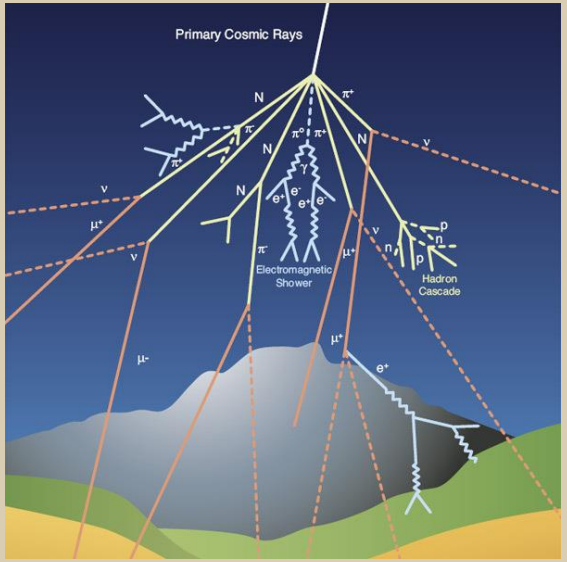
Protons and neutrons are **COMPOSITE**

Electron, neutrino and quarks are **FUNDAMENTAL**

Cosmic radiation = protons + muons + strange particles

Wait long enough and you can see it in cosmic rays…

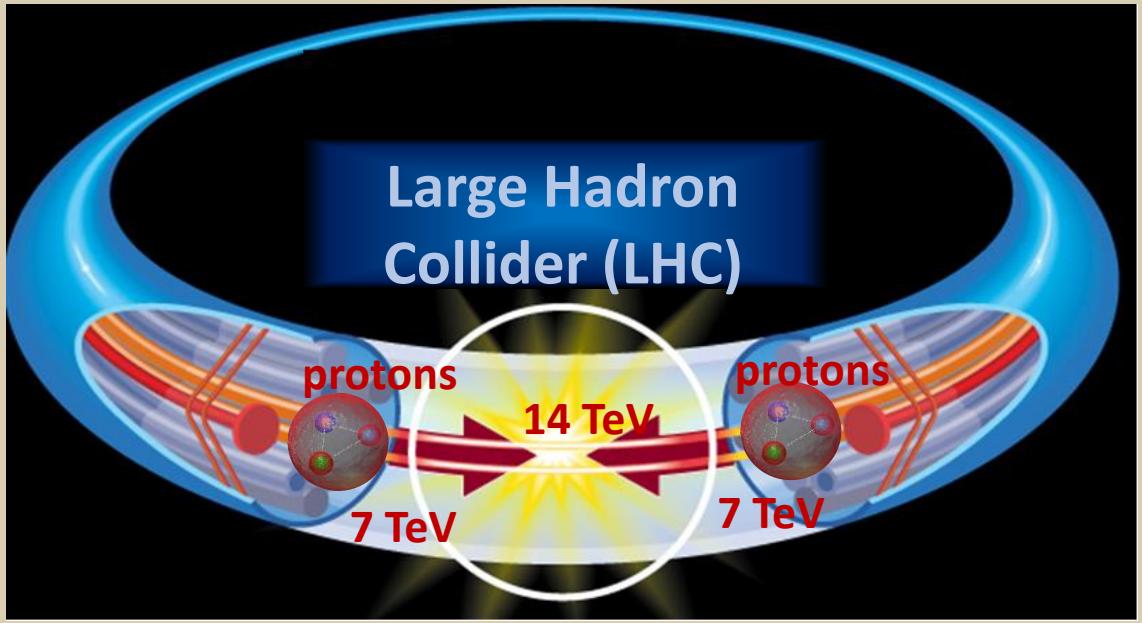
… and even find some **strange** particles

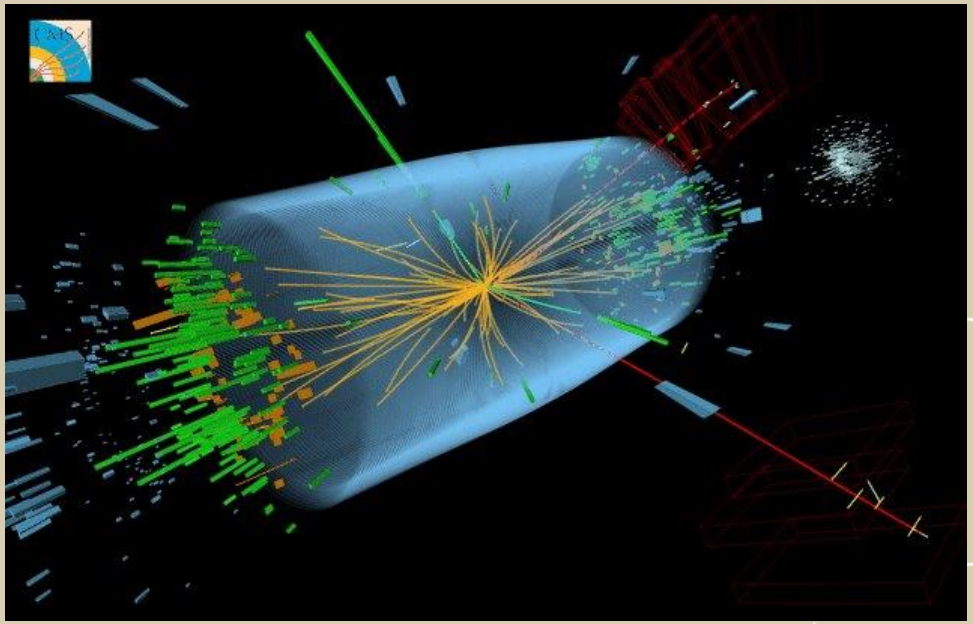


They are produced when protons enter the Earth's atmosphere and collide with gases

Physics experiments = accelerator + detectors

Instead of waiting for a cosmic event we can make such collisons in laboratory, like CERN.





The maximum achievable energy is limited by the technical capabilities only (and time & money).

Particles = leptons + quarks + bosons

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, …

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0–0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009–0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04–0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

Bosons

- γ photon
- Z Z boson
- W W boson
- g gluon
- H Higgs* boson

- The reason for breaking the energy limit is because more interesting particles are heavier and heavier.
- Energy = mass?
- Well, almost:

$E = mc^2$

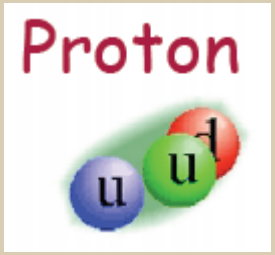
Albert Einstein 1905

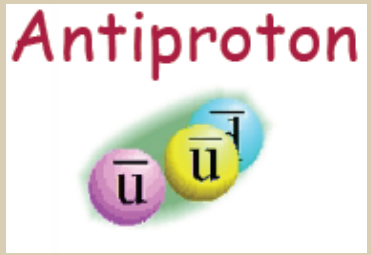
$$E_e = (9.1 \times 10^{-31}\, kg) \times \left(3 \times 10^8 \frac{m}{s}\right)^2 = 8.2 \times 10^{-14}\, J$$

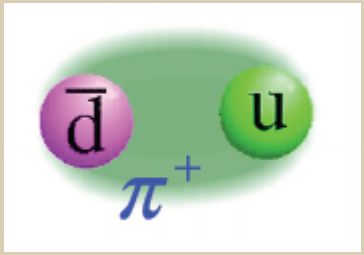
$$\approx 510\,000\, eV = \mathbf{510\ keV}$$

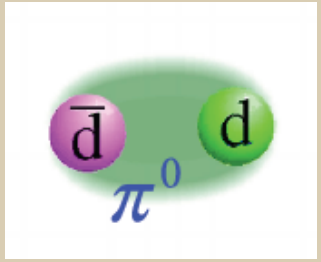
Problem: quarks cannot exist as free particles

Quarks are always confined in composite particles called hadrons.





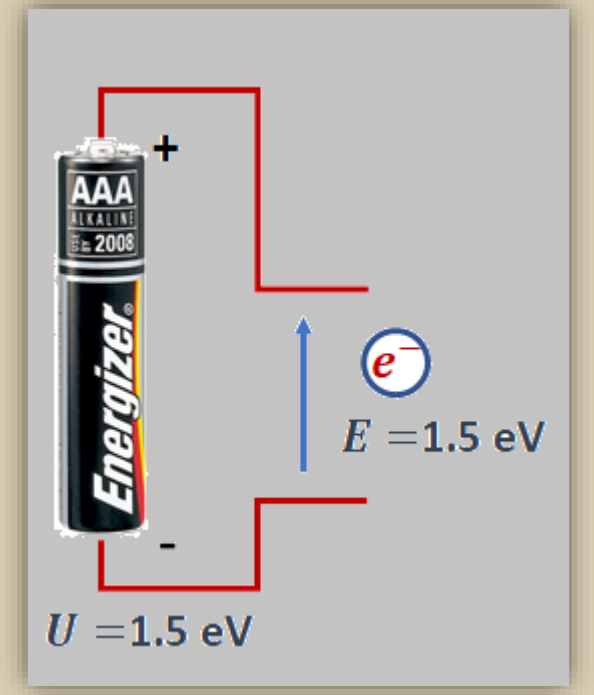




- The only stable particle is proton, heavier particles decay to lighter states.
- In an experiment, we can catch only stable particles (proton, electron, muon) or particles which lifetime is long enough to interact with active material of detectors (pions, kaons, and a few more).
- Other particles can be reconstructed from the final decay products.

Accelerator (Large Hadron Collider)

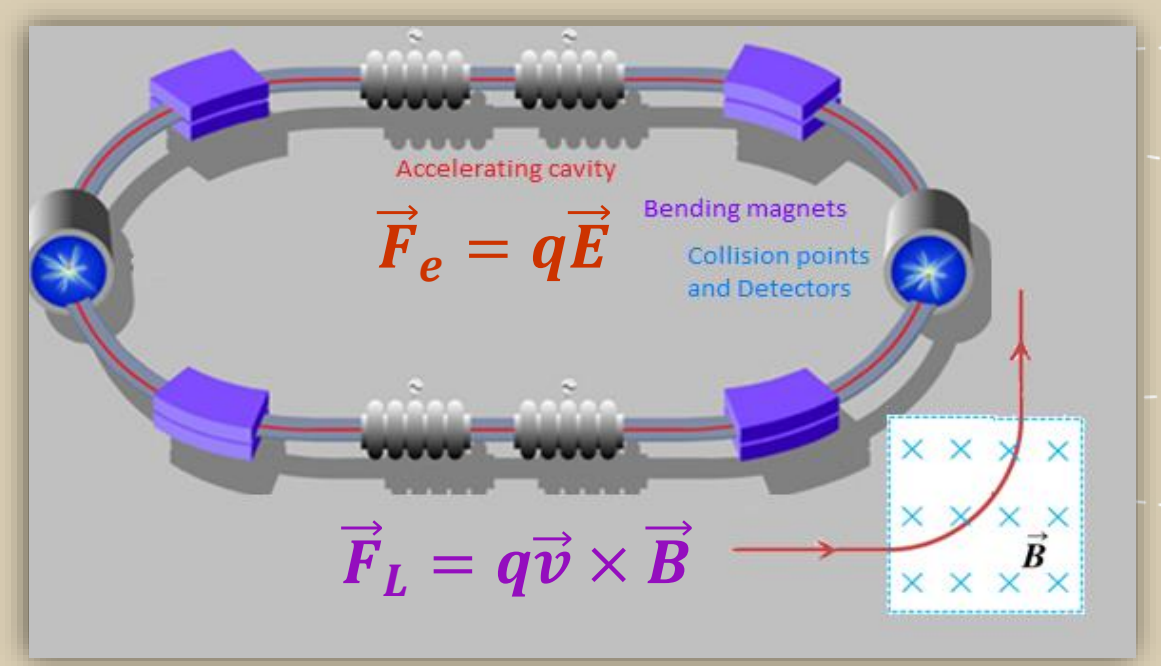
Charged particle (protons, elektrons, ions) can be accelerated in electric field.



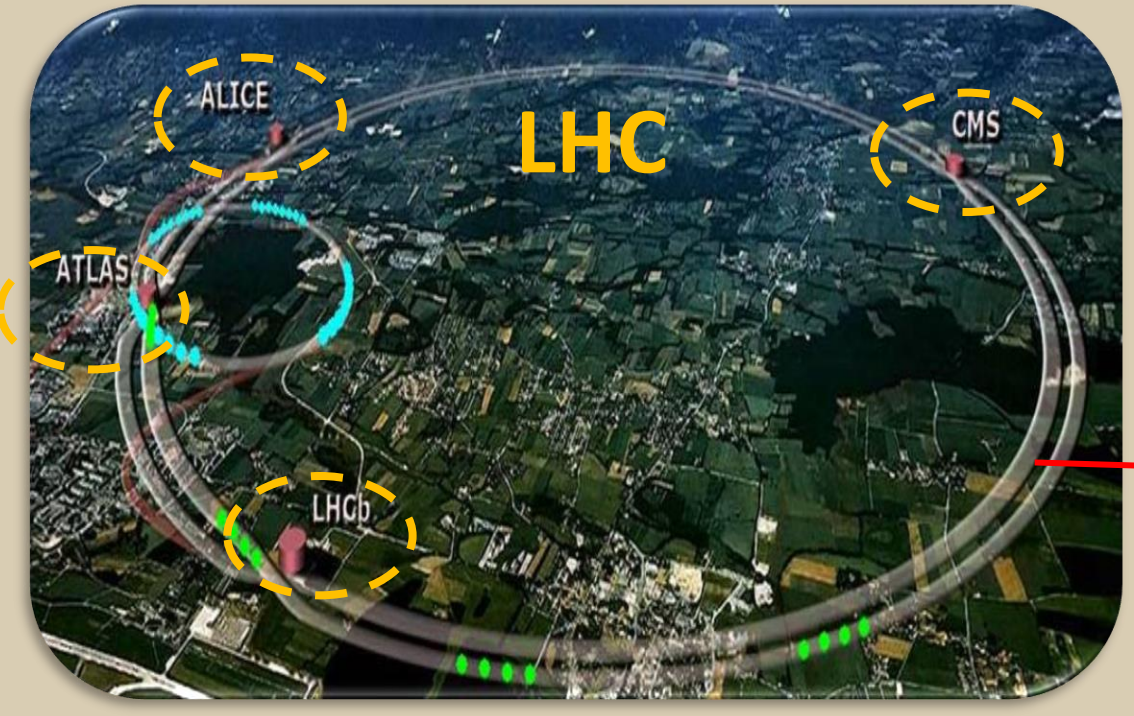
$$\vec{F}_e = m\vec{a}$$

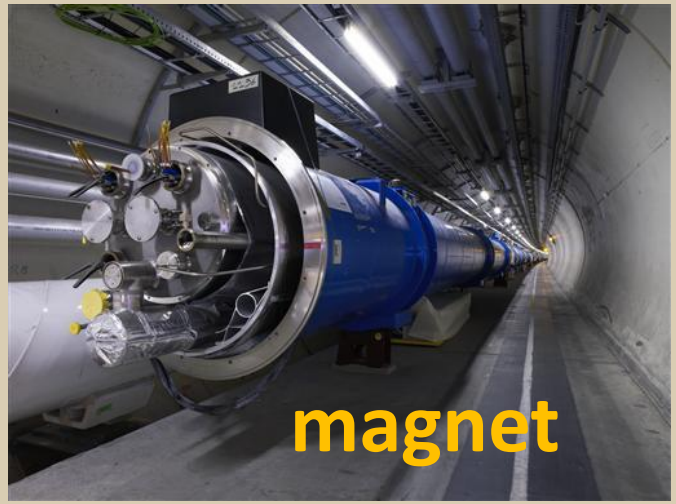
But we need more batteries to build LHC, therefore it is more economical to re-use the same accelerating devices many (10^8) times.

But to make protons move in stable orbit, one needs huge magnetic field.



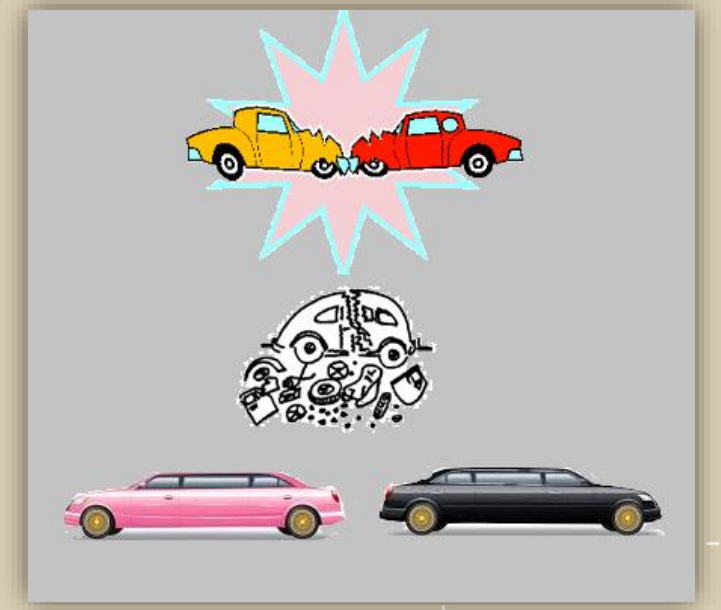
CERN = people + accelerator + detectors



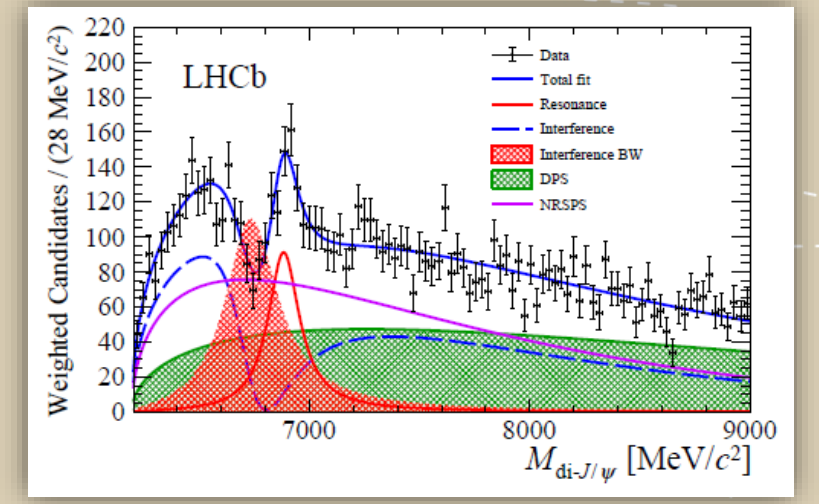


Collisions – a few facts and figures

- The energy of a collision (centre-of-mass-energy $\sqrt{s}$) is transferred to the production of new particles.
- Theory predicts what might happen during a collision at given energy and with what probability.
- We call it a cross-section for a production of a state (like beauty quark or Higgs boson) at centre-of-mass-energy σ(√s).
- A lot of distributions, parameters have to be determined from experiment and compared with theory to win a Nobel prize.

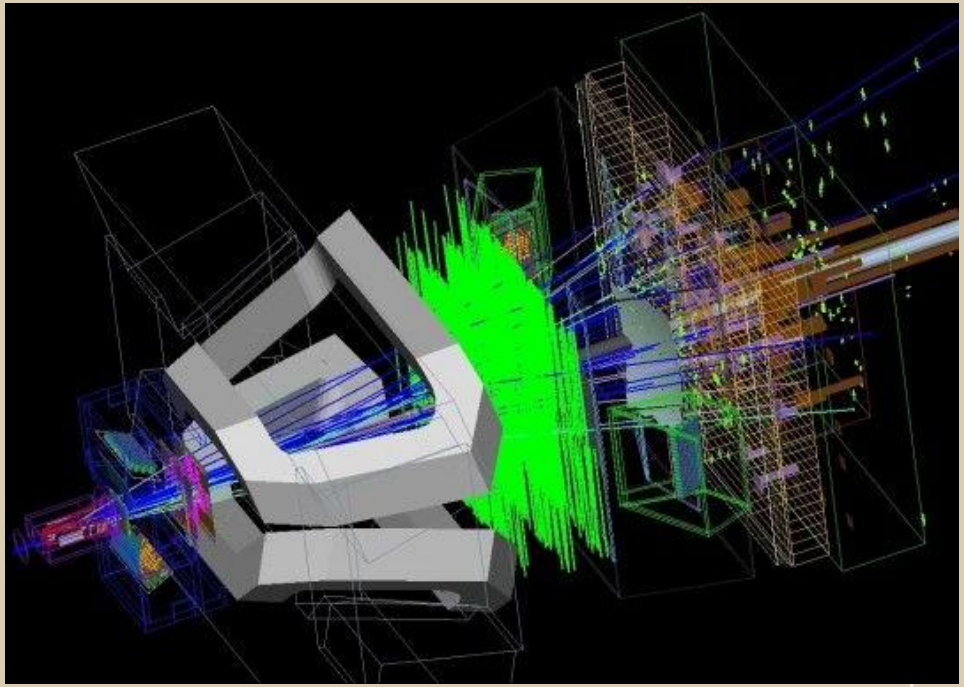


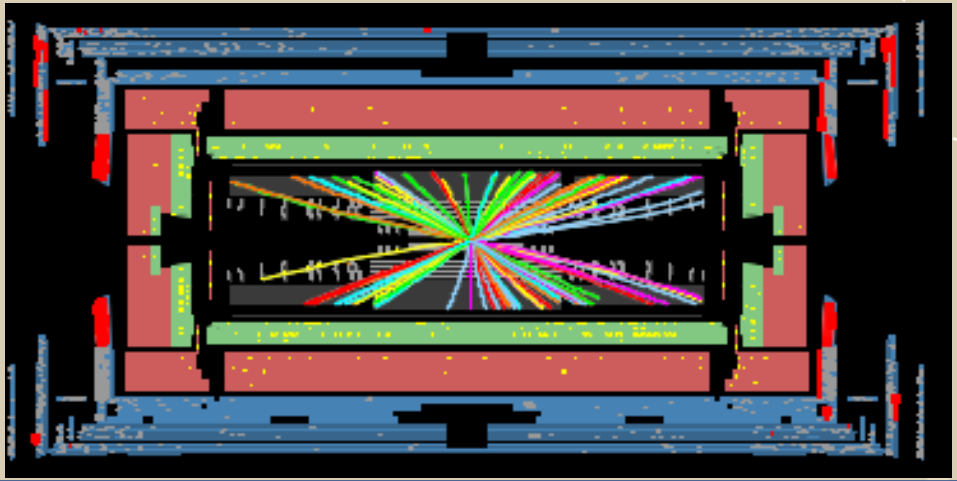
- In most often situations physics makes tricks and is hidden beneath the prevalent uninteresting events (background).
- And then comes the Computer Science and Machine Learning.



Where are quarks?

- Stable or long-lived particles interact with the material of detectors.
- As a result an electric signal or flash of light is produced and sent to the readout electronic.
- Signals from many stations, layers, sensors must be connected to form a track (track reconstruction).
- If the reconstruction is correct then we can attribute this track to a given type of particle.
- Particle has mass, charge, spin, time of decay, angular distribution – this information helps to establish what type of quarks or leptons were produced and what kind of interaction occurred among them.





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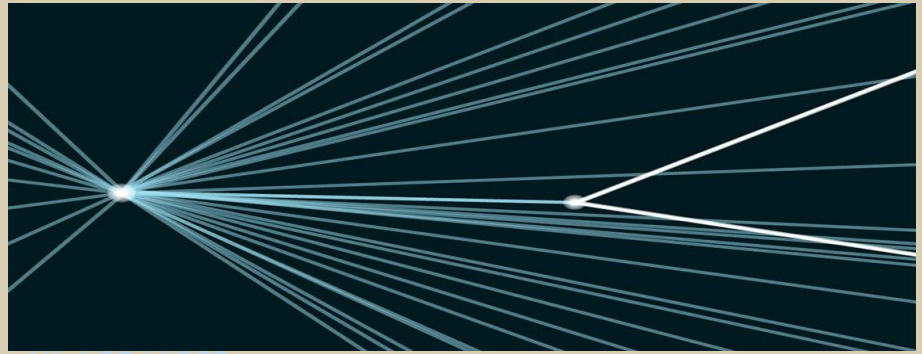

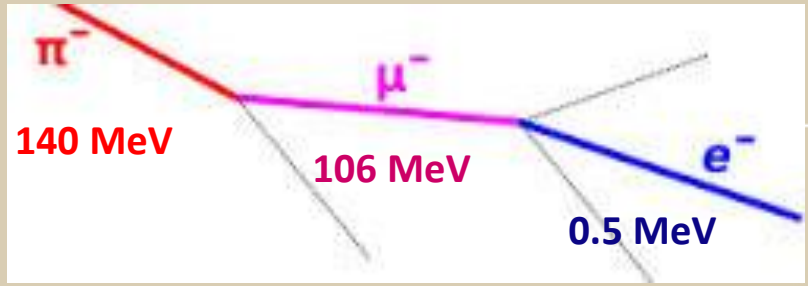

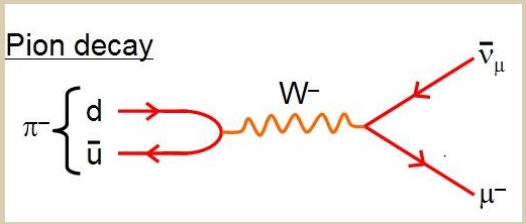

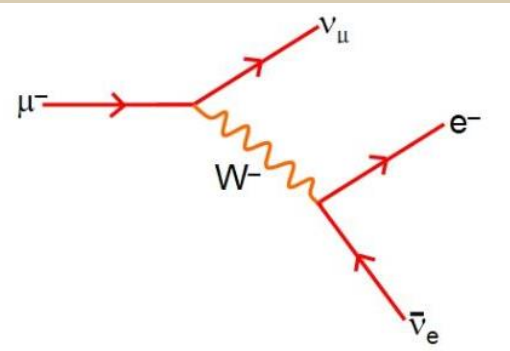

We need you….

High Energy Experiment requires huge human resources for many purposes and tasks:

- Theory of physics for an idea of an experiment.
- Bank loan.
- Design of accelerators and detectors.
- Production and assembly of the devices.
- Electronics for signal formation and processing.
- Computer scientists on each stage of design, reconstruction and analysis.
- Physicists for data interpretation.
- Guides for visitors.
- Journalists for a nice story.

Thank you!

We will have plenty of time for a discussion but I suggest that we listen to the next lectures today and tomorrow