Particle Physics and the Tools of Discovery

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Particle Physics and the Tools of Discovery

- Introduction

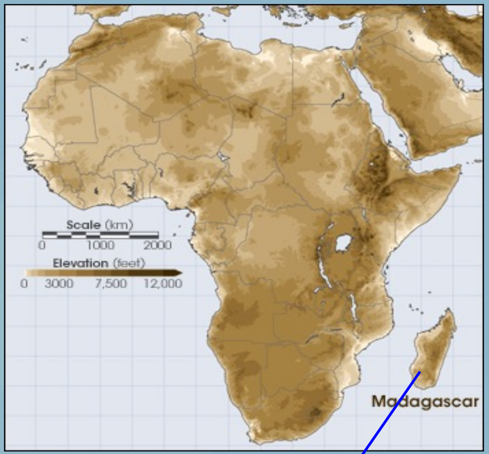
- The Standard Model:
  - The cast of characters
  - The Forces
  - The new periodic table
- Physics/detectors at an *electron(e^-)-anti-electron(e^+)* particle accelerator (at Cornell University)

- The energy frontier: The LHC (a proton-proton collider)

My "Path" in Physics

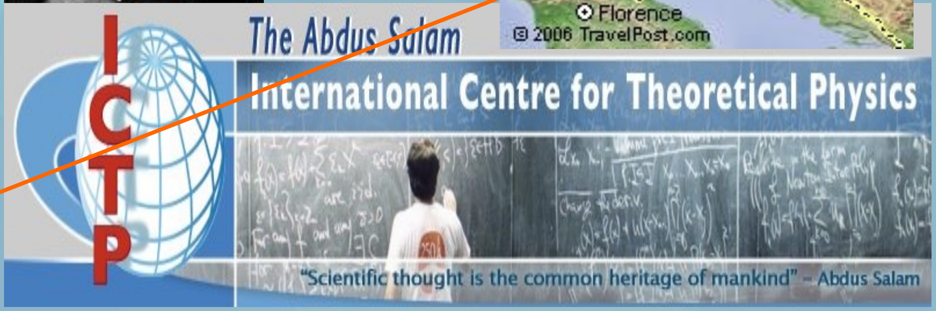
I' m originally from Madagascar

I did my undergraduate studies in Nuclear Physics at the University of Antananarivo, Madagascar



I did a Diploma Programme in Trieste, Italy on High-Energy Physics at the Abdus Salam International Center for Theoretical Physics (ICTP).

The center is in honor of Abdus Salam (1st director) who won a Nobel Prize in 1979.

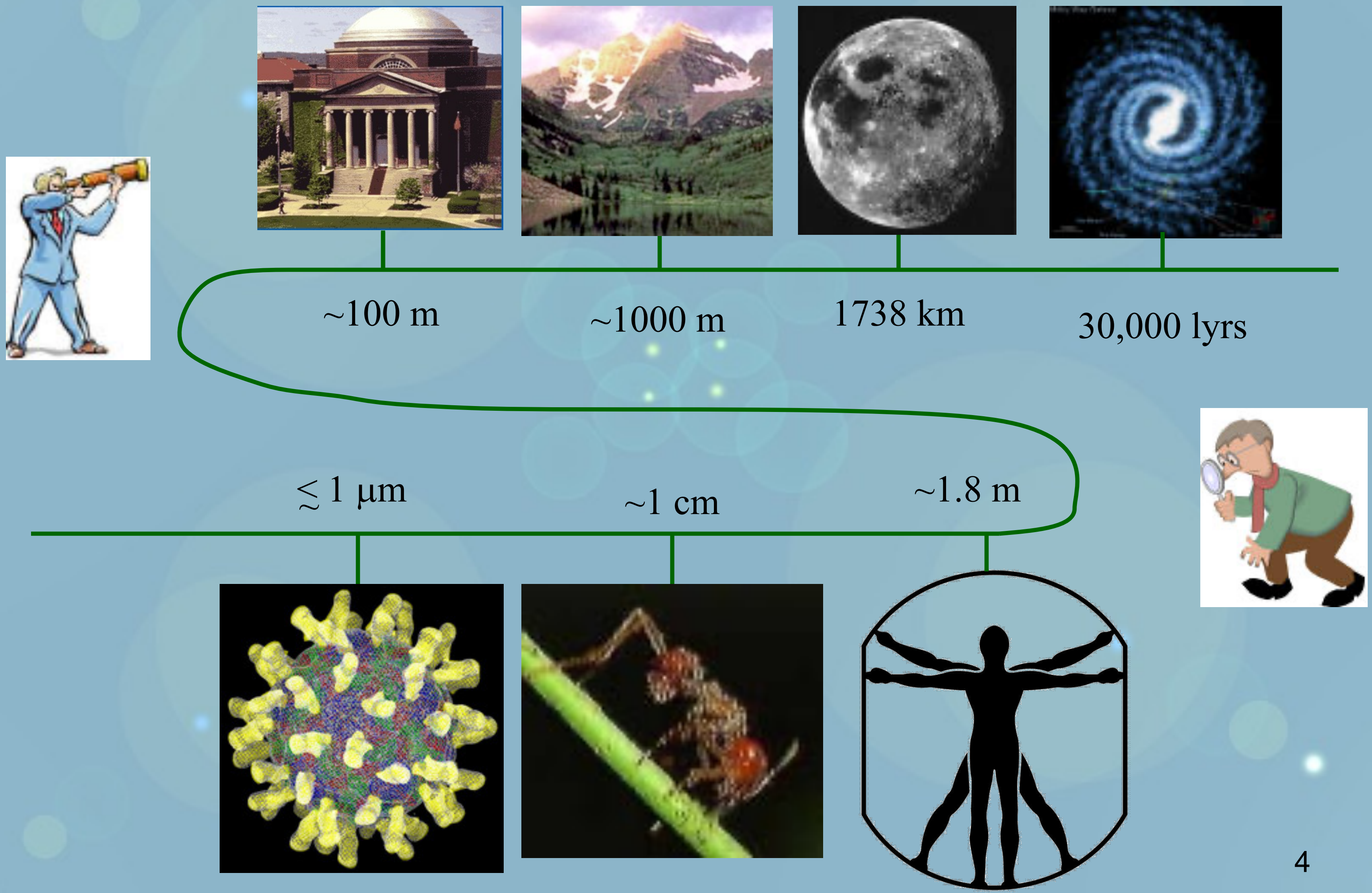


Now, I am a graduate student at the Syracuse University working on experimental High-energy Physics.

http://www.physics.syr.edu

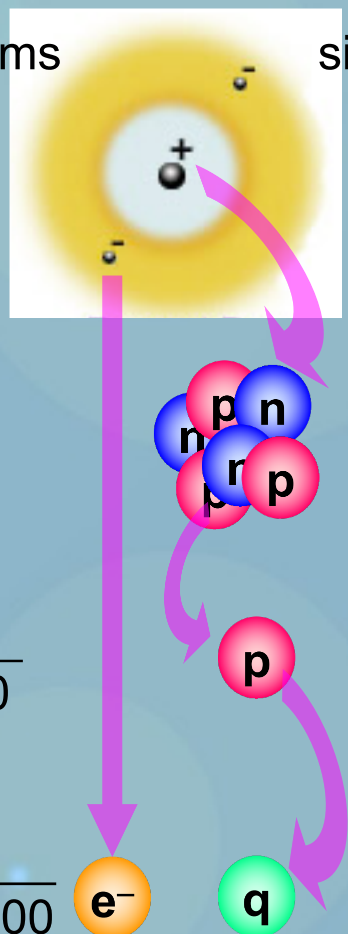
http://hepoutreach.syr.edu

What Do We See in This World ?

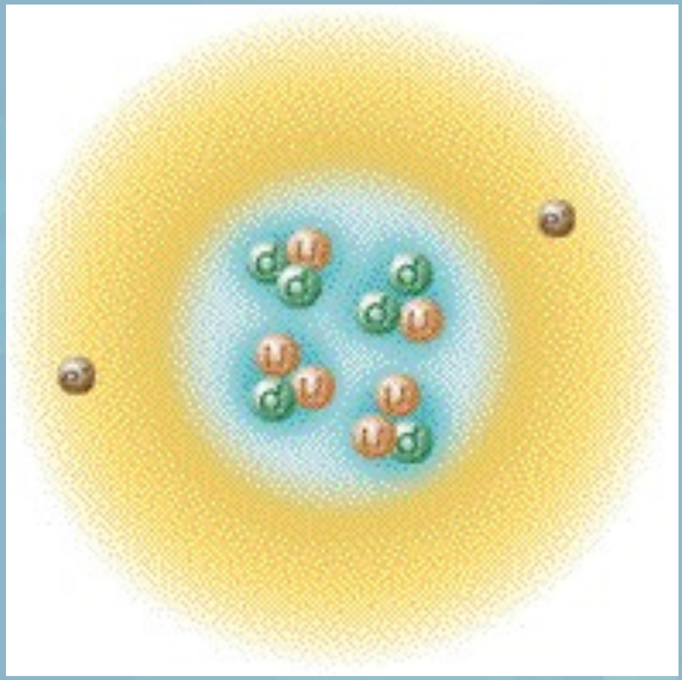


What Are Fundamental Components of This World ?

size in atoms		size in meters
1		10^{-10}
$\frac{1}{10,000}$		10^{-14}
$\frac{1}{100,000}$		10^{-15}
$\frac{1}{100,000,000}$		10^{-18} at largest

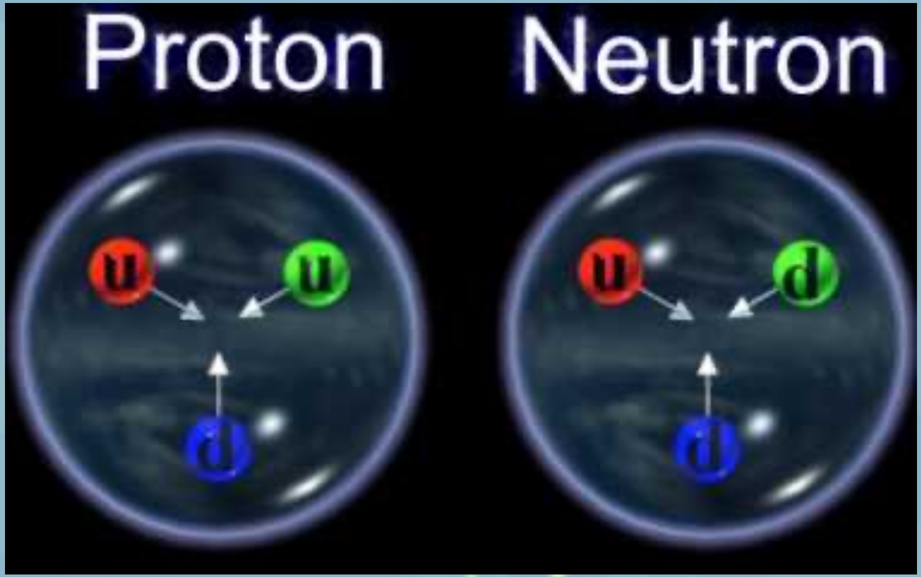


Helium atom



Are quarks and electron fundamental?

Under closer examination of atoms…



- There is overwhelming evidence that protons and neutrons are not "fundamental".

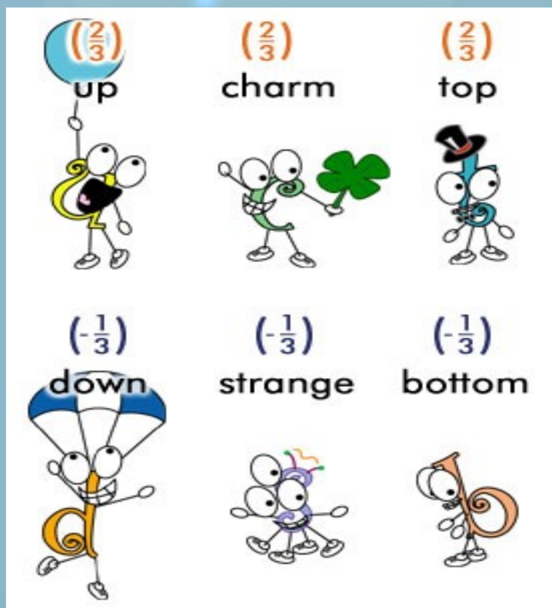
- They are in fact made up of smaller objects, called quarks.

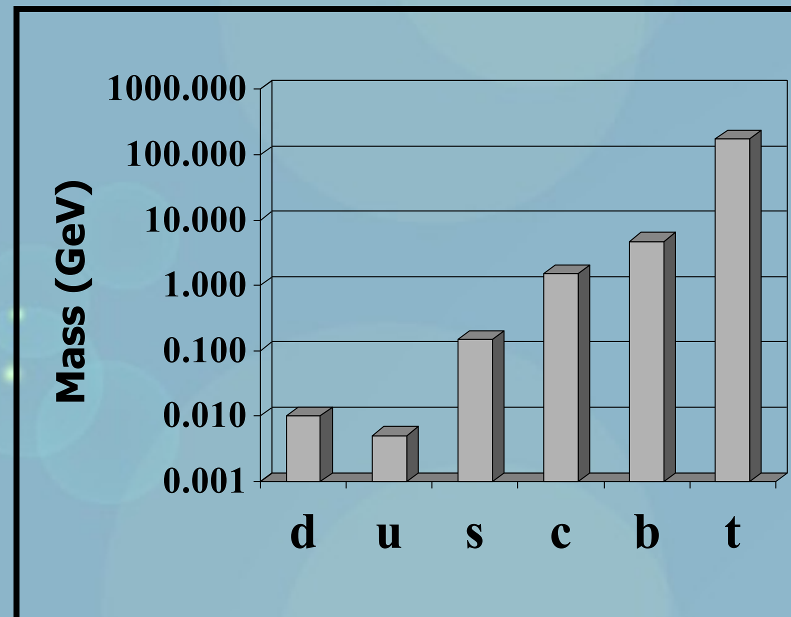
- Like an atom has valence electrons, a proton (or neutron) also contain "valence" quarks of two types: up($Q=+2/3e$) and down ($Q=-1/3e$)

- We know this by smashing particles together at high energy (momentum), and the more energy we have, the deeper we can see.

The Cast of Characters

Many experiments have shown that there is in fact more than just two types of quarks. In fact experiments have shown that:



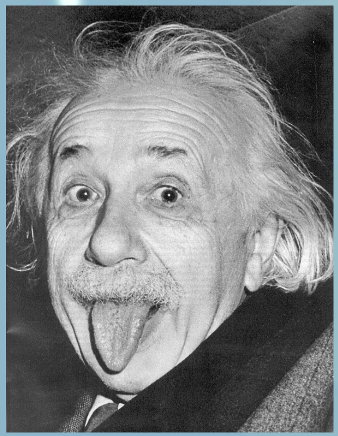


Why do we have3 families of quarks?

Ordinary matter is made of only the lightest quarks (u & d); why?

Only heavier quark decays to light and the light ones do not decay anymore (quasi-stable)

How do we produce the heavier quarks?



$$E = mc^2$$

- The electron and anti-electron (positron) can annihilate into pure energy (*i.e.*, a photon)

- This energy "re-emerges" as a new particle which:
  a) satisfies energy conservation
  b) Carry electric charge

Did you say anti-electron?

Does matter differ from antimatter?

From the origin of the universe, we expect:

$$N_{matter} = N_{antimatter}$$

Then why is our Universe matter-dominated?

What happened to all the antimatter?

We hope to shed some light on this!

- YES, it was already found in 1933.
- Antimatter is just as real as matter.
- Every particle has an antiparticle?

Are there more fundamental particles?

- Quarks form one class of particles.

- How does the electron fit into the big picture?
  - Like quarks, years of experiments have shown that there are 3 "*electron-like*" charged particles: $e^{\pm}$, $\mu^{\pm}$(muon), $\tau^{\pm}$(tau).

e^- μ^- τ^-

- Many experiments have shown that apart from their masses, the "*muon*" and "*tau*" <u>behave identically</u> to the electron. Again 3 families…

- A third type of massless, zero-charge particle, called the neutrino, was hypothesized to exist by Wolfgang Pauli based on the apparent failure of momentum conservation in the decay:

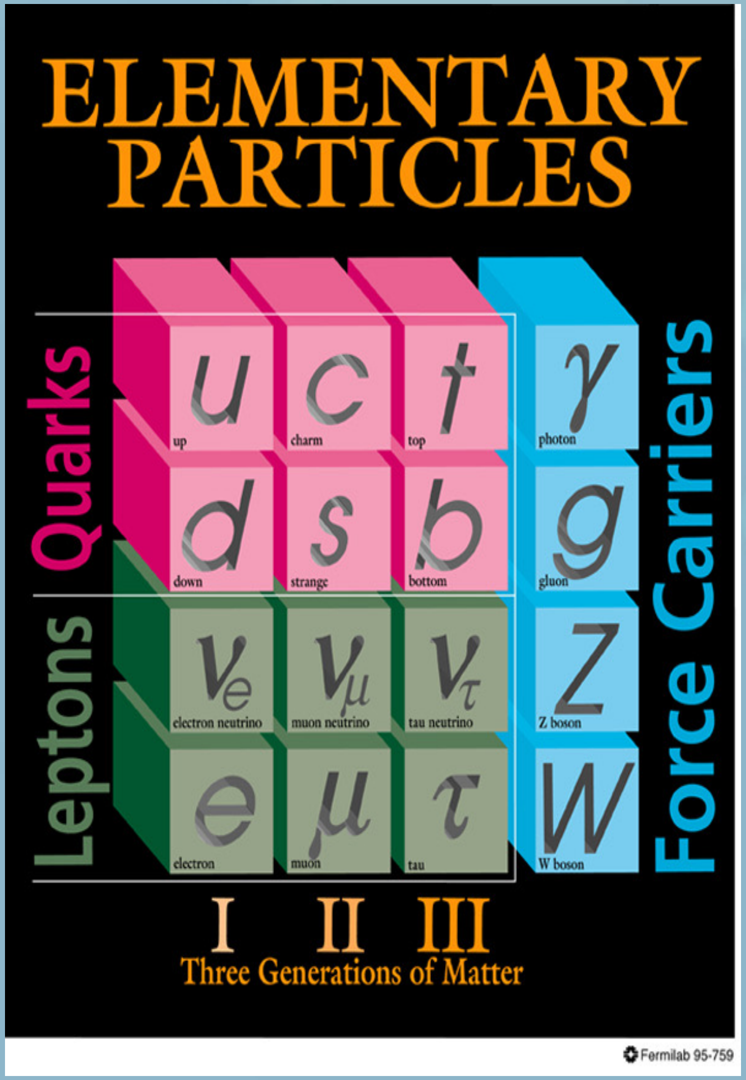
$$n \rightarrow p + e^- \quad (+\nu) \longleftarrow$$ Neutrino was not detected

- In 1956, Reines and Cowan discovered this elusive particle.

ν_e ν_μ ν_τ

- In fact, over the last few decades, we've learned that | there are 3 types of neutrinos.

The Standard Model



- 3 Families of quarks
- 3 Families of leptons

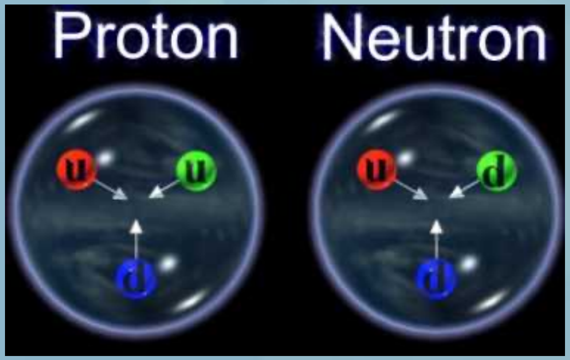
} Matter !

- Fundamental Forces

Force	Relative Strength	Force Carrier	"Charge"
Strong	1	Gluon	Color
EM	~.01	Photon	Electric
Weak	$\sim 10^{-5}$	W, Z	Weak
Gravity	$\sim 10^{-40}$	Graviton ?	Mass

1 Force { (EM, Weak)

Quarks, Baryons & Mesons

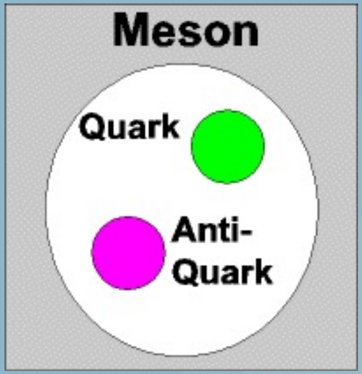


- Quarks combine to form "color neutral" particles:

  1 RED + 1 BLUE + 1 GREEN = COLORLESS

  When combined this way ➔ baryons

Can quarks combine in any other way to form a color neutral object?



Mesons contain 1 quark + 1 antiquark

The quark has "color" and the antiquark has "anticolor"

(hard to show anticolor)

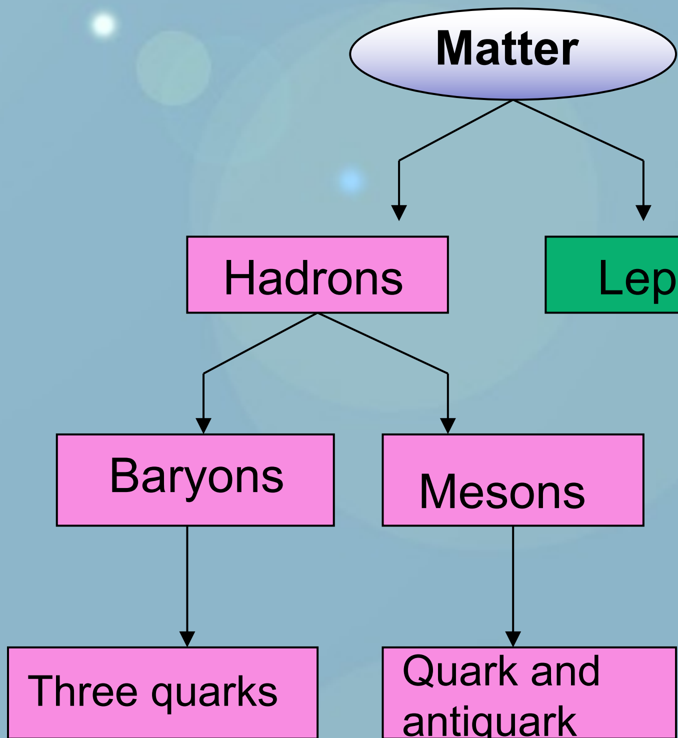
Does this mean that quarks are actually green, red or blue?

No ! It's just a way of expressing that the intrinsic property has 3 values.

Gluons interact with quarks b/c they have color charge.

The new periodic table?

Classification of Matter



Particles of the Standard Model

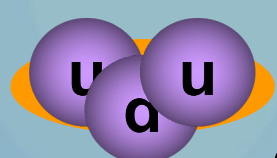
Quarks

Name	**up**	**charm**	**top**
Symbol	u	c	t
Charge	**+2/3 e**	**+2/3 e**	**+2/3 e**
Name	**down**	**strange**	**bottom**
Symbol	d	s	b
Charge	**-1/3 e**	**-1/3 e**	**-1/3 e**

Leptons

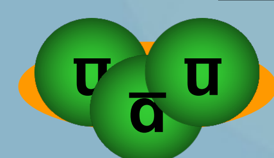
electron	**muon**	**tau**
e	μ	τ
-1e	**-1e**	**-1e**
electron neutrino	**muon neutrino**	**tau neutrino**
V_e	V_{μ}	V_{τ}
0e	**0e**	**0e**

Baryon



proton

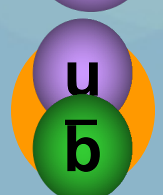
$Q = 2/3+2/3-1/3 = +1e$



anti-proton

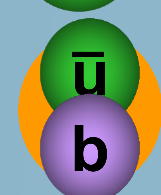
$Q = -2/3-2/3+1/3 = -1e$

Meson



B^+

$Q = +2/3+1/3 = +1e$



B^-

$Q = -2/3-1/3 = -1e$

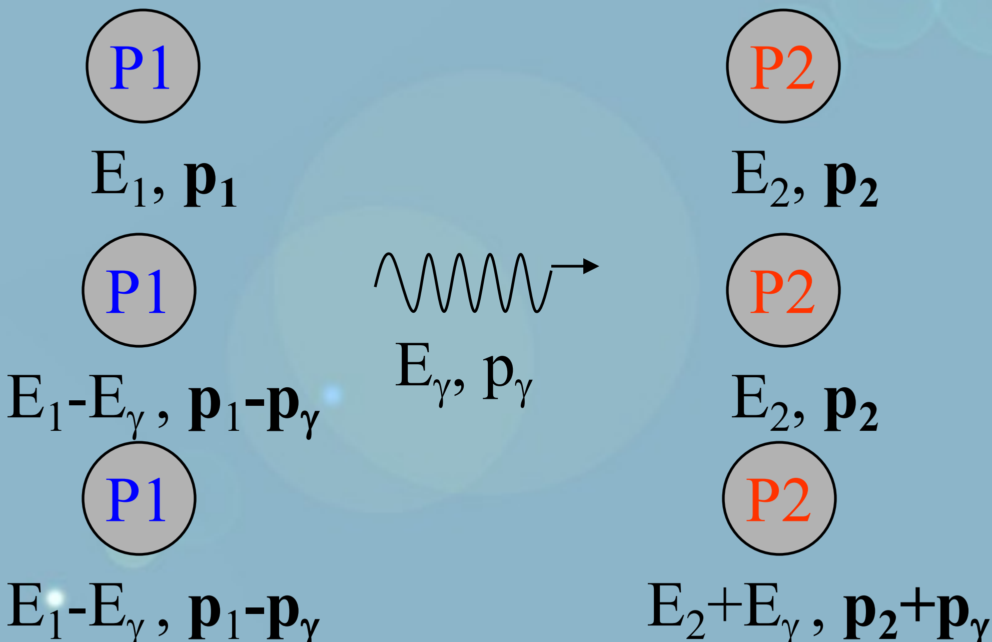
How do particles interact with one another?

The Modern View of Forces

- Forces are the result of an INTERACTION between two objects

- Interaction occurs via the exchange of a "*force carrier*" or "*mediator*". This provides an *EXTREMELY successful description* of subatomic phenomena.

- The basic idea is as follows



- Particles 1 and 2 exchange energy and momentum
- Whallah ! An interaction !!

Annihilation Experiment

Steve

Anti-Steve

Annihilation Experiment

Steve Anti-Steve

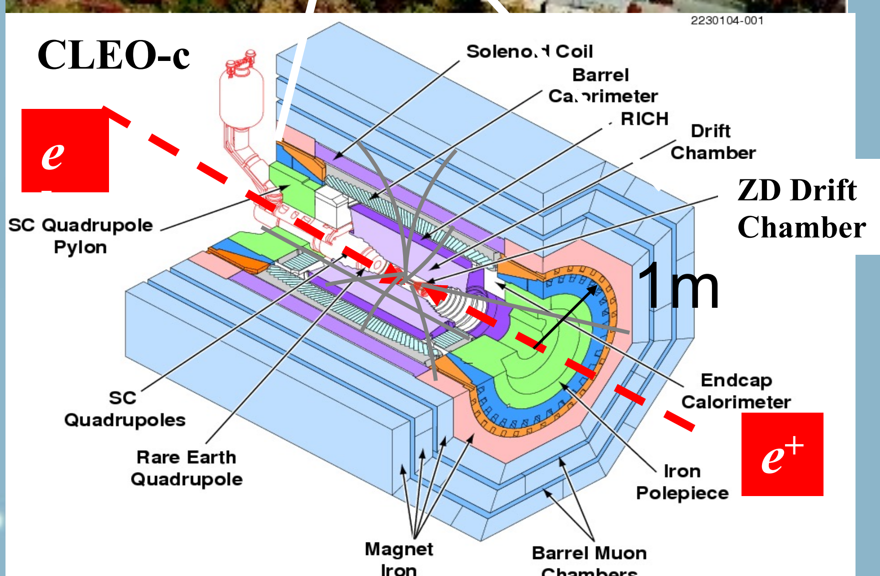
Can we have a look at them?

Accelerators & Detectors

- Accelerator: Aim is to produce beams of particles which are subsequently brought into collision.
  - Three key factors in colliding beam accelerators:
    - What types of particles to accelerate (p, $\bar{p}$, e^+, e^-)
    - Beam energy → Create new particles ($E = mc^2$)
    - Luminosity: To "see" rare events, need a lot of collisions!

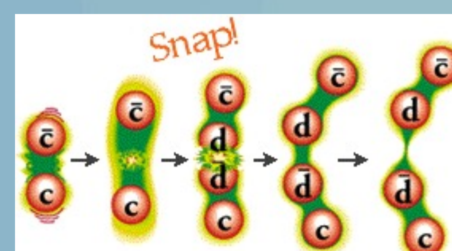
- Detector: Reconstruct as much information as possible about the remnants of the collision (like a detective collecting clues!)
  - Trigger: Can't record all collisions; reject "uninteresting" ones and keep (save on a disk) the interesting ones.
  - Detectors:
    - Reconstruct momentum of all particles and identify them.
      (p, $e^{\pm}$, $\pi^{\pm}$(pions), $K^{\pm}$(kaons), $\mu^{\pm}$, γ)
    - Specialized detectors surround collision region to measure momentum and determine particles' identities.

CLEO-c



- This detector is located at Cornell University, Ithaca NY.
- Collide electrons into positrons.
- Each beam has energy ~ 2 GeV

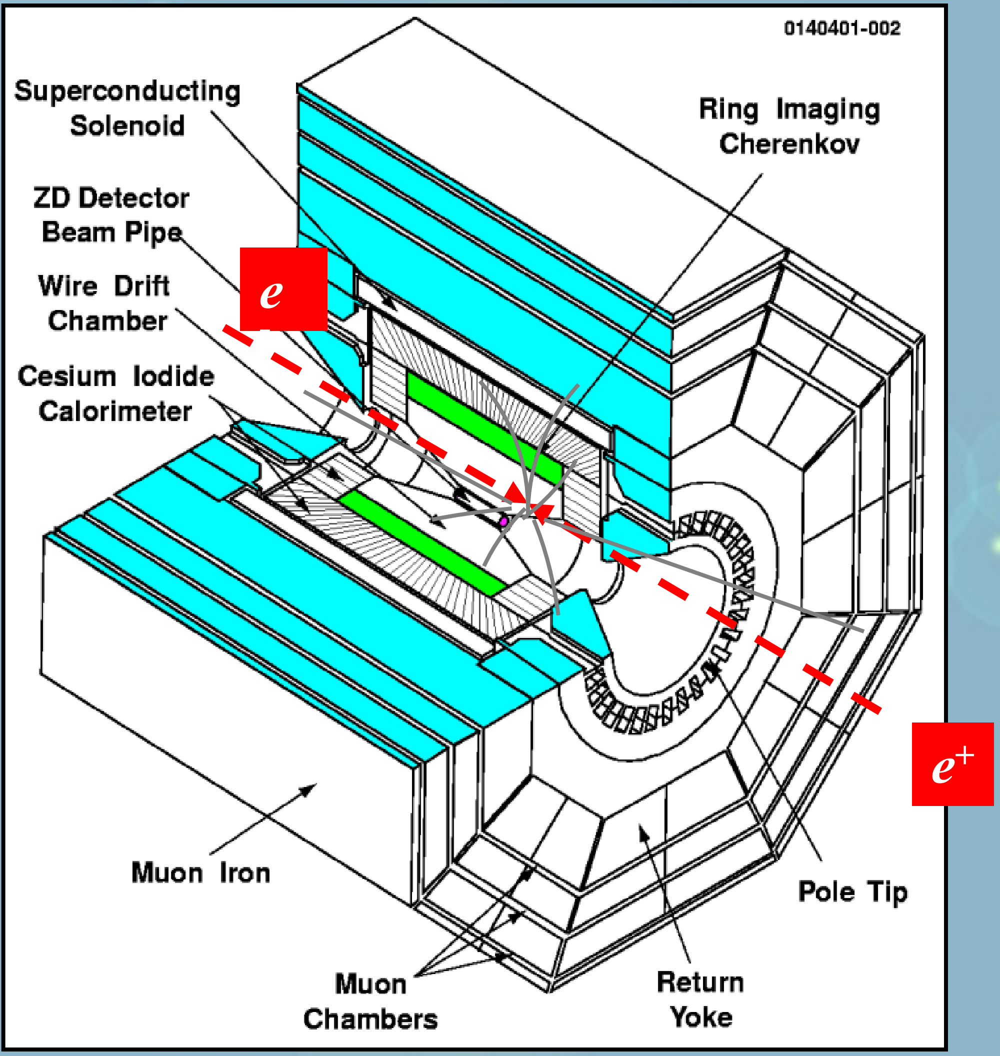
$$e^+e^- \to \gamma^* \to \psi(3770)$$
$$\psi(3770) \to D\bar{D}$$



$$D^0 = c\bar{u}, \overline{D^0} = \bar{c}u$$
$$D^+ = c\bar{d}, D^- = \bar{c}d$$

Copious source of D mesons:

CLEO-c Detector



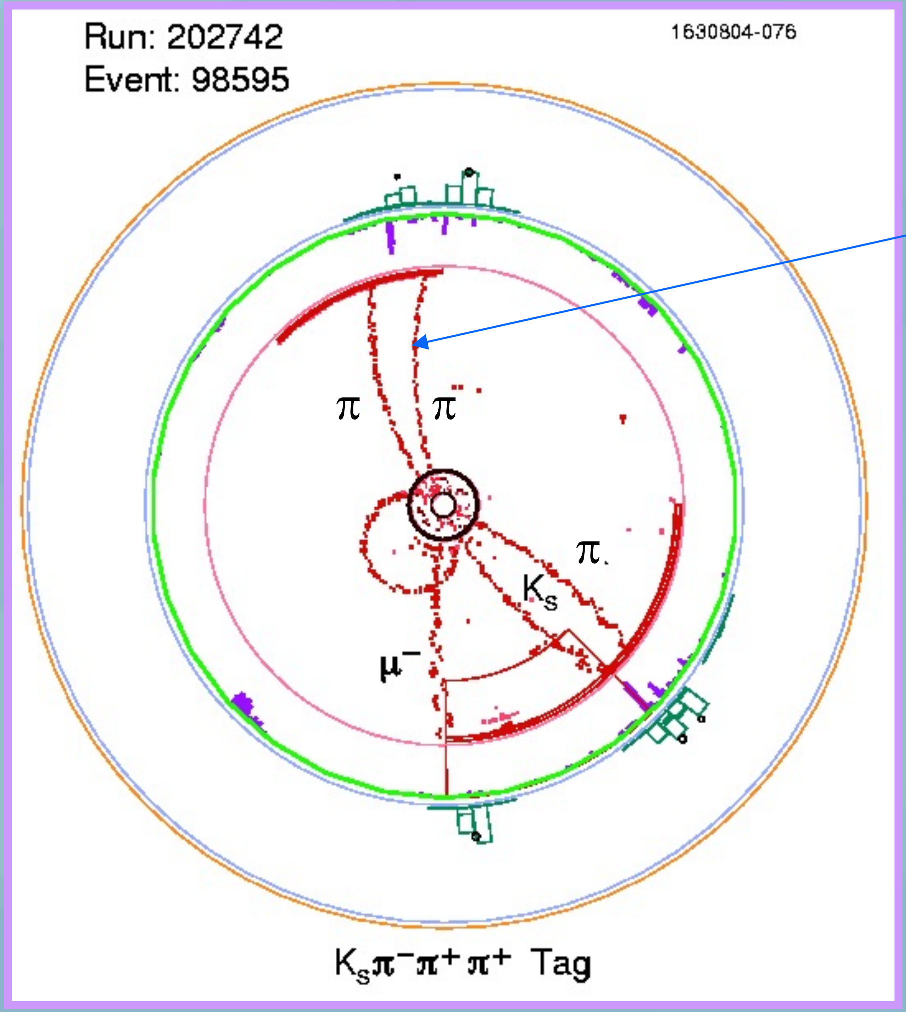
Most of the components are designed and built from Syracuse University, Cornell University and some others …

Why are we interested in D mesons?

Simply, because it tells us about interesting things about nature

Example event (DATA)
$e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$

End view of detector



Charged particles reconstructed in detector

Note that the charged particles are bending, as the entire detector is in a magnetic field (**B** into page)

The energy frontier: LHC

The Large Hadron Collider (LHC) is a particle accelerator which will probe deeper into matter than ever before. Due to switch on in 2007, it will ultimately collide beams of protons at an energy of 14 TeV. It is located in Geneva, Switzerland.

A TeV is a unit of energy used in particle physics. 1 TeV is about the energy of motion of a flying mosquito. What makes the LHC so extraordinary is that it squeezes energy into a space about a million million times smaller than a mosquito.

Because our current understanding of the Universe is incomplete! We have seen that the theory we use, the Standard Model, leaves many unsolved questions. Among them, the reason why elementary particles have mass, and why are their masses different is the most perplexing one. It is remarkable that such a familiar concept is so poorly understood.

The LHC will be a very good 'antimatter-mirror', allowing us to put the Standard Model through one of its most gruelling tests yet.

The LHC is being built in the same tunnel as CERN's Large Electron Positron collider, LEP

Experiments at LHC

There are several experiments, with huge detectors that will study what happens then the LHC's beams collide. They will handle as much information as the entire

European telecommunications network does today!

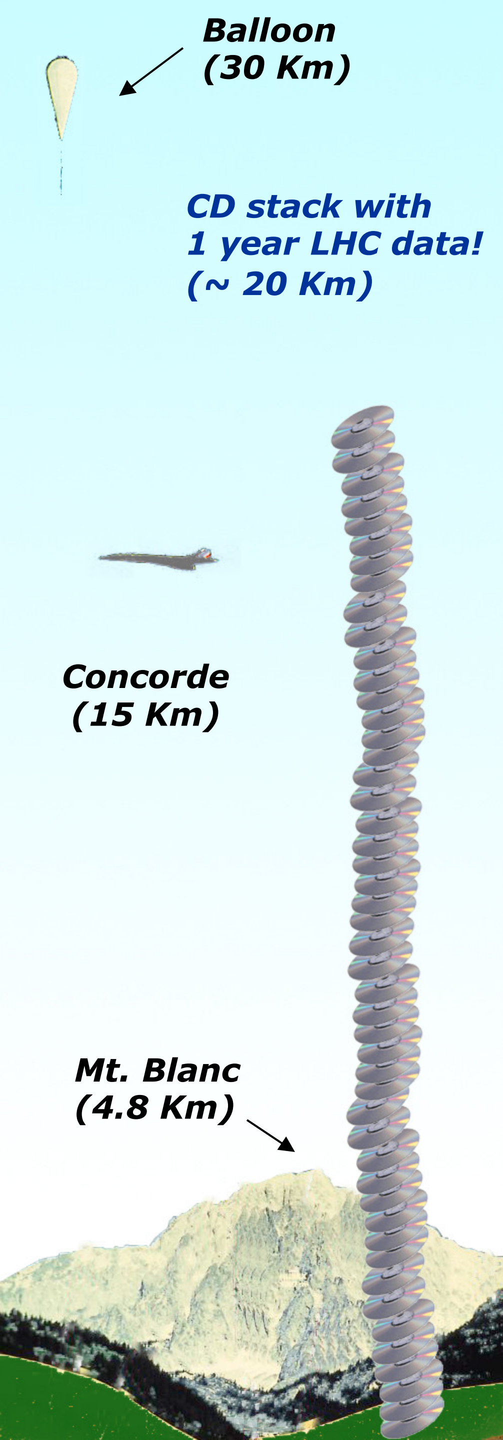
The experiments are:

LHCb (Large Hadron Collider beauty) which is specialized in b-physics experiment. Syracuse Experimental High-Energy Group is part of it.

ATLAS (A Toroidal LHC ApparatuS)

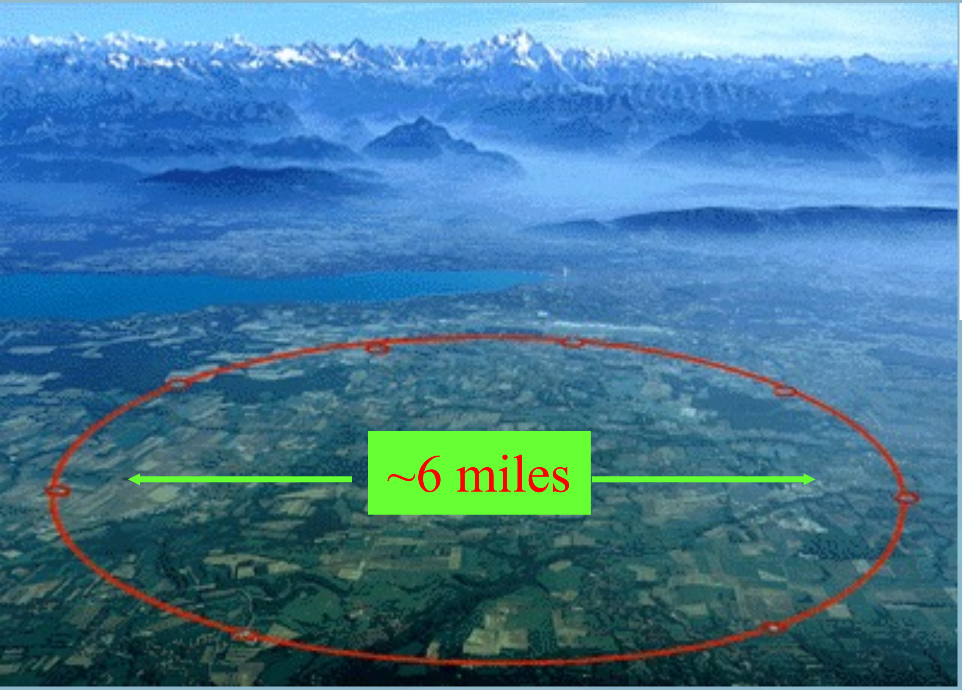
CMS (Compact Muon System)

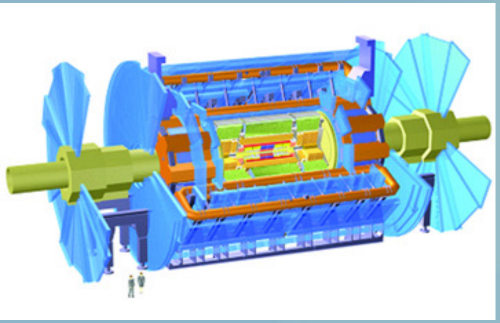
ALICE (A Large Ion Collider Experiment)

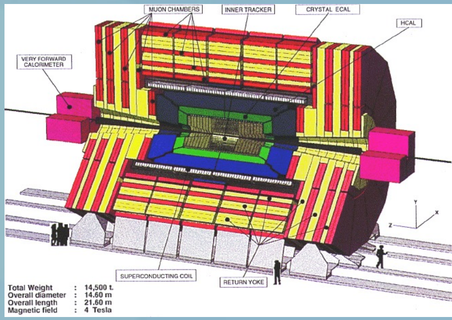


A voyage to CERN-LHC

The Collider of the Future - LHC



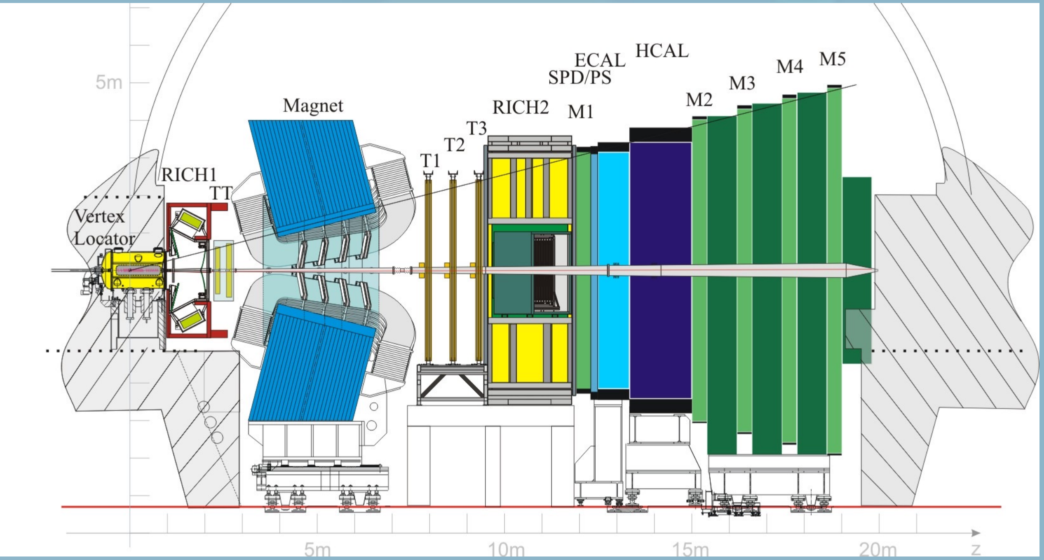


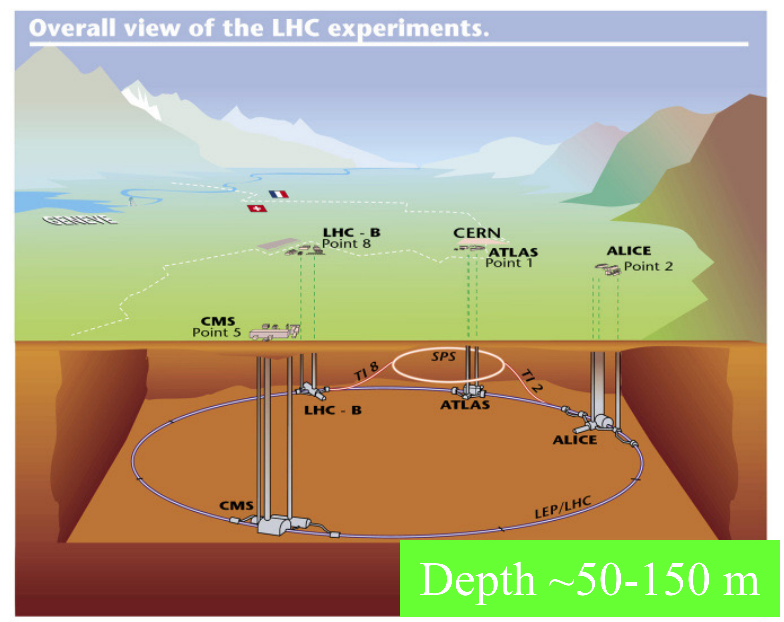


$$E = mc^2$$

KE_p = 7,000,000,000,000 eV

M_p = 1,000,000 eV

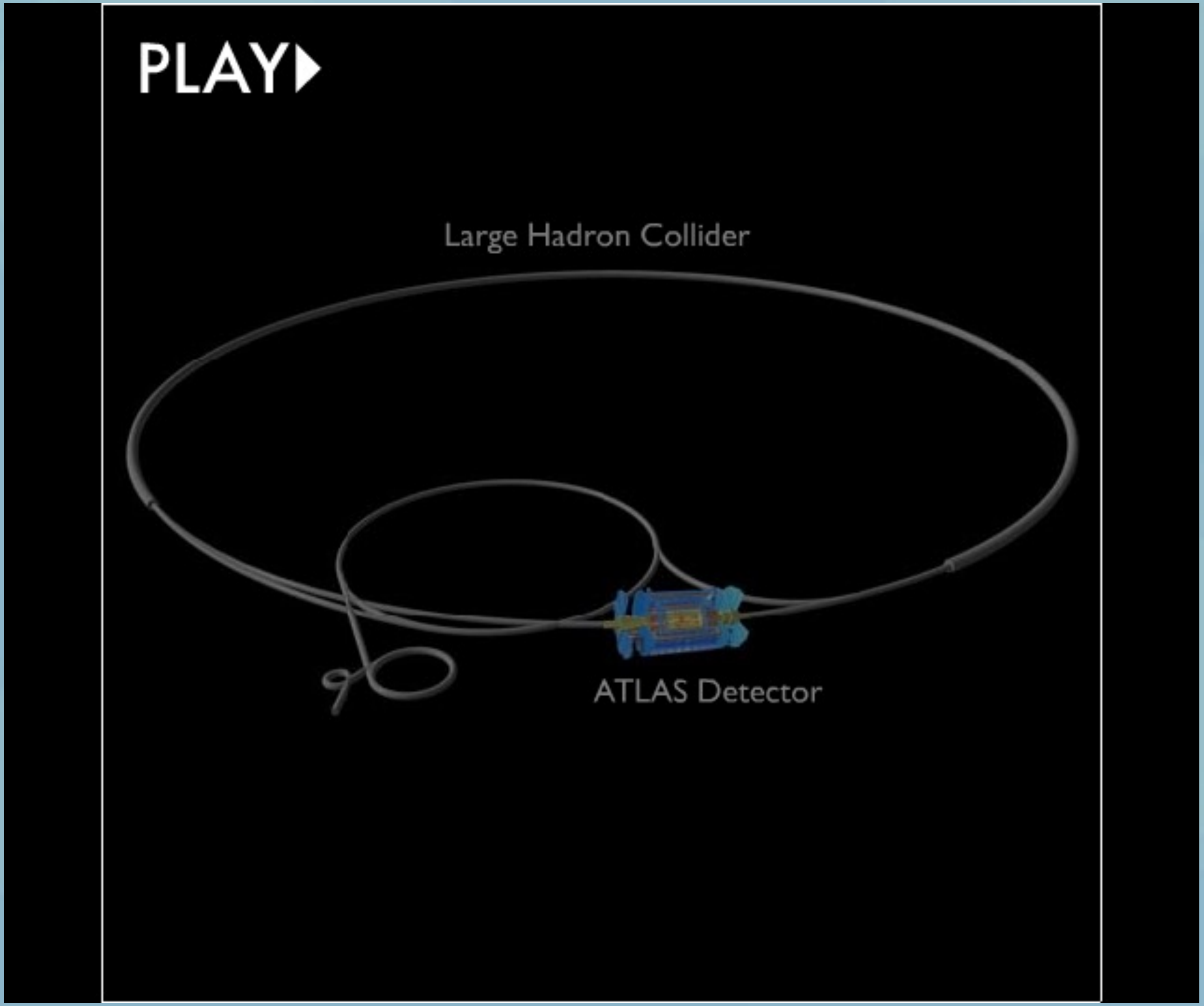




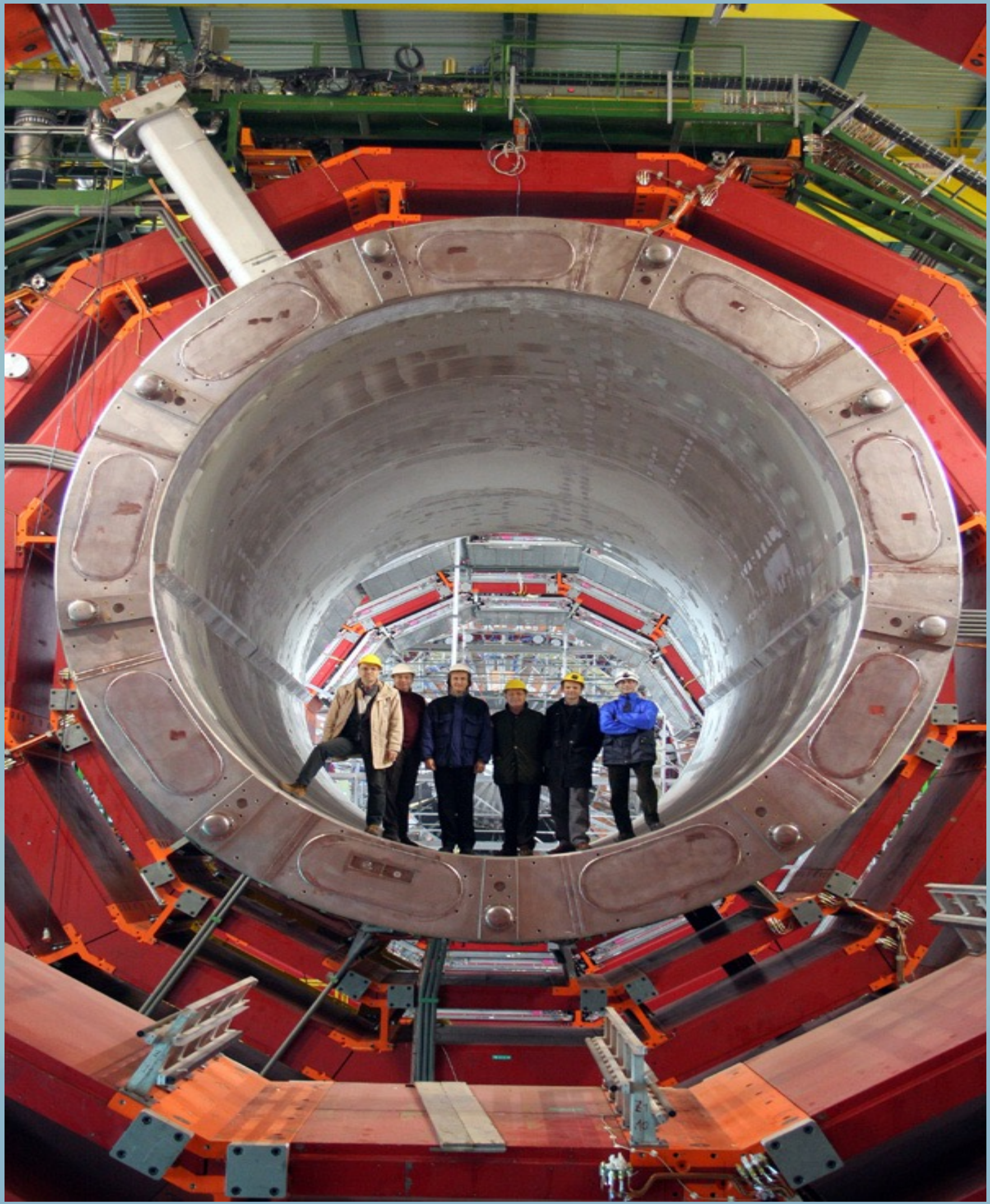
A View of ATLAS

ATLAS, CMS will detect new forms of matter.
The energy of the collision, which is very high, can be transformed into mass

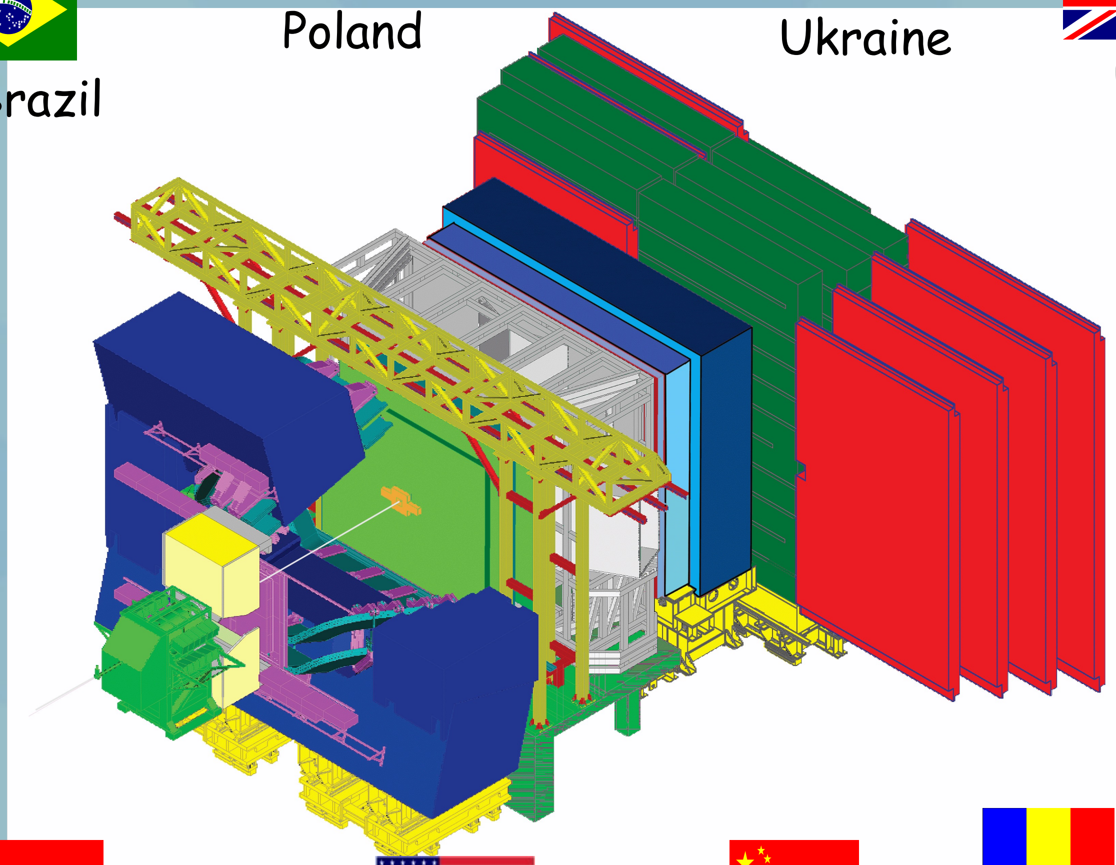
A collision at the LHC (ATLAS)



A view of CMS



The LHCb members



Brazil

Poland

Ukraine

UK

France

Switzerland

Germany

Spain

Italy

Russia

Netherlands

PRC

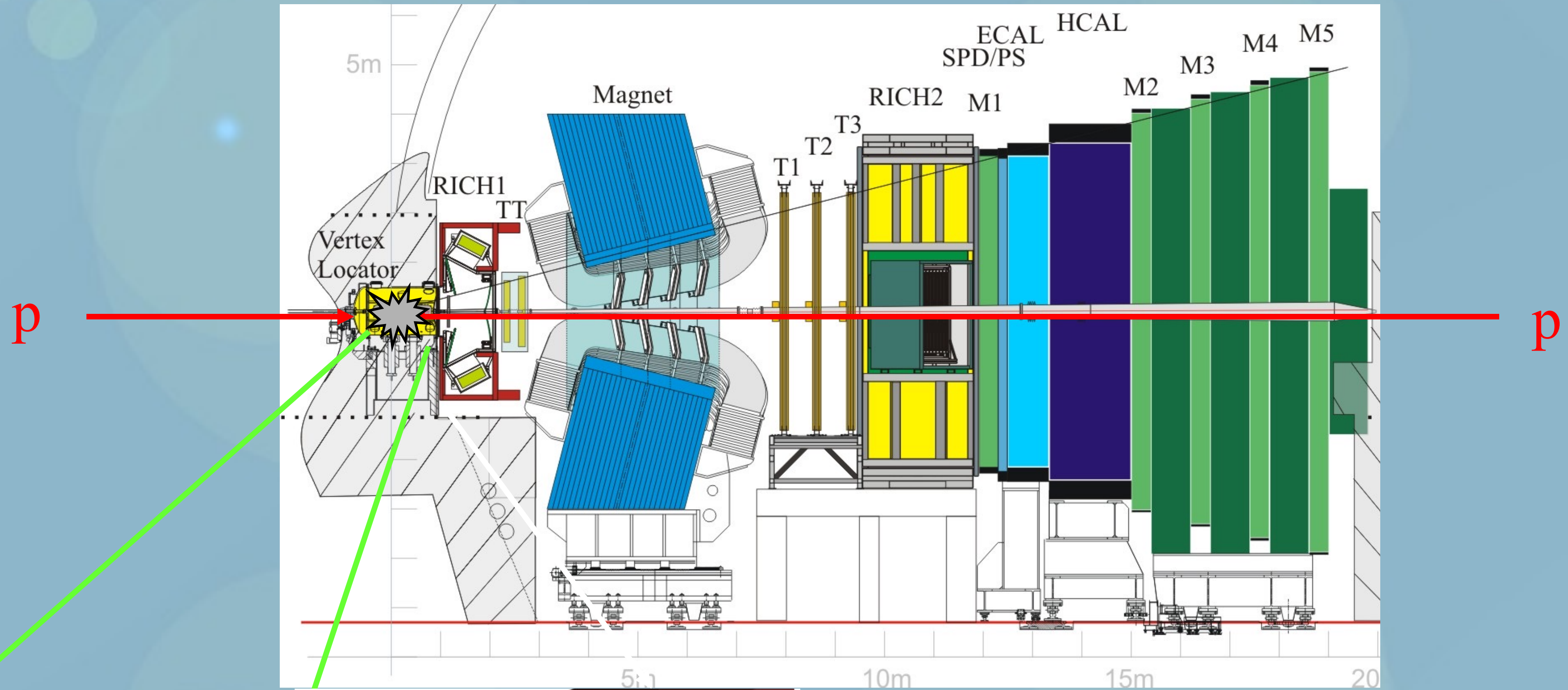
Romania

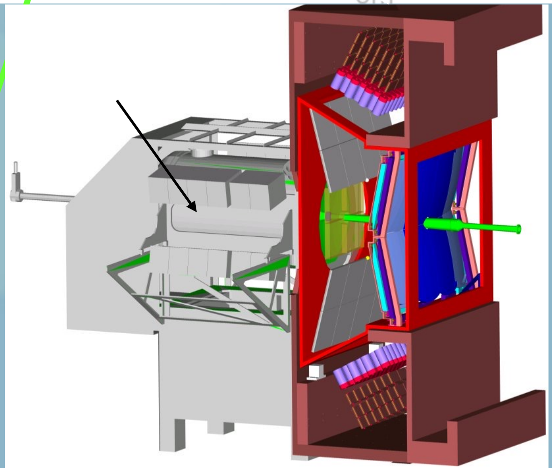
USA- Only 1 Institute involved

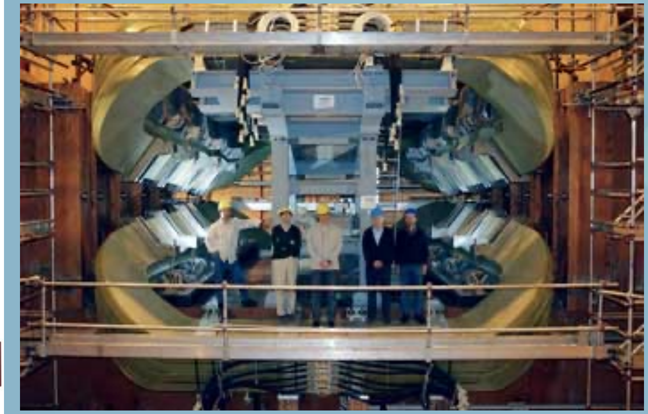
657 people, 47 Institutes and 14 countries

The LHCb Detector

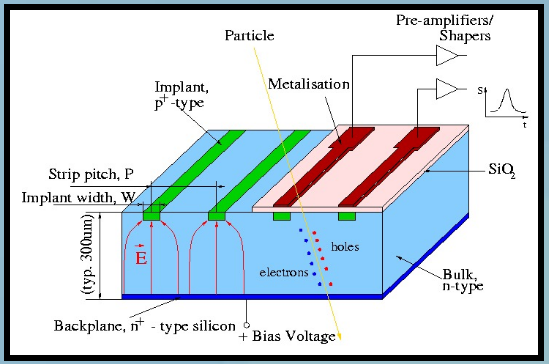
Aim: Discovery/Search for New Physics using B ($b\bar{q}$) mesons

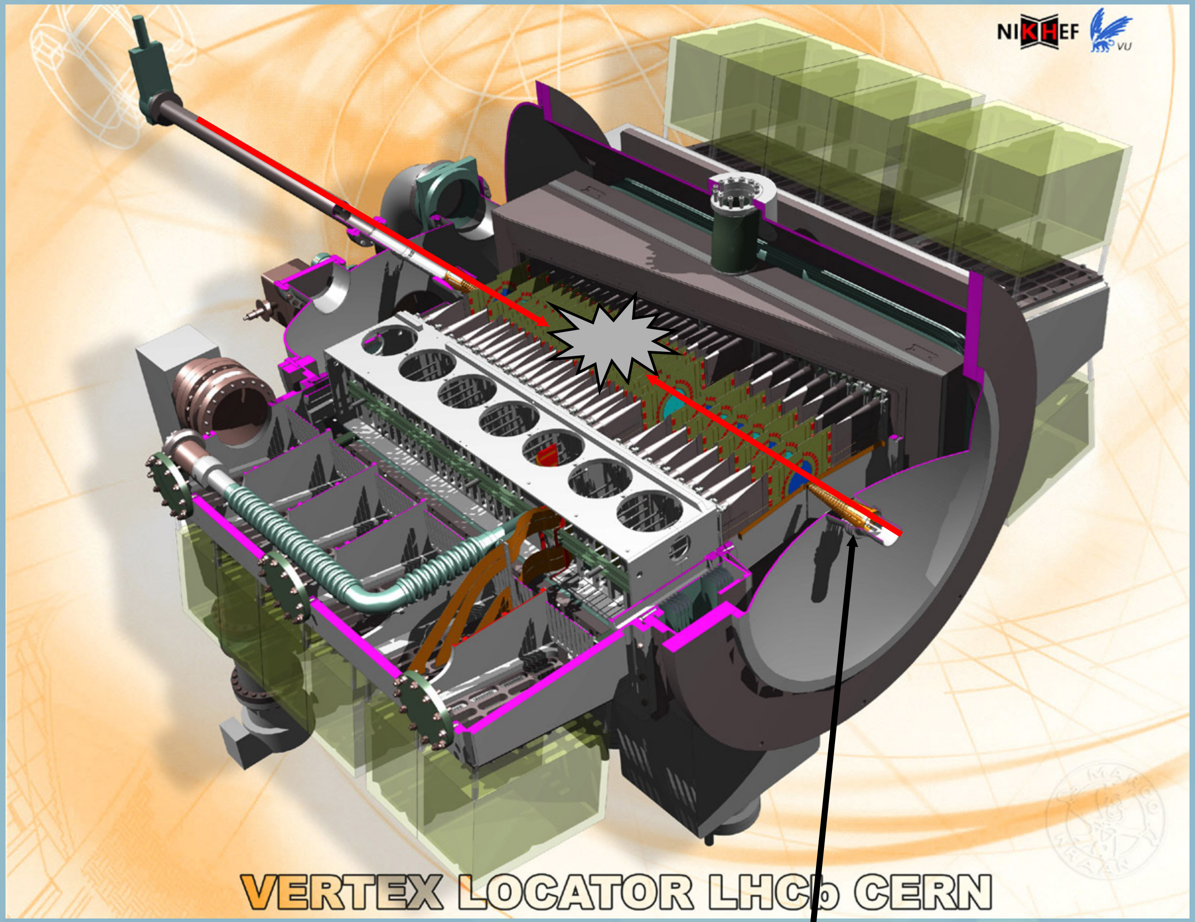


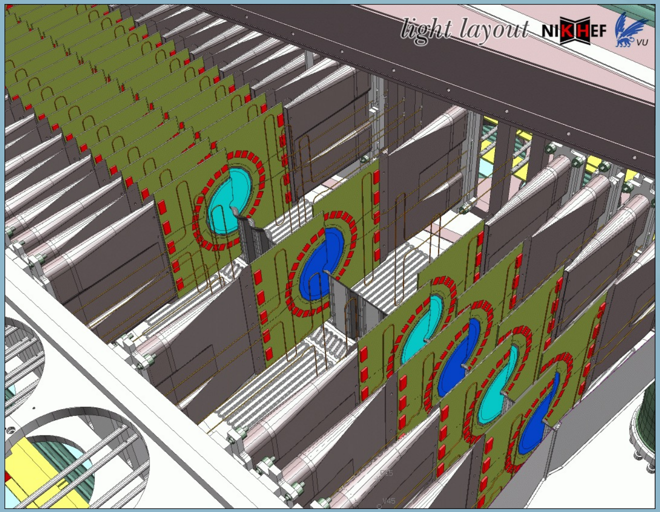




The LHCb Vertex Locator

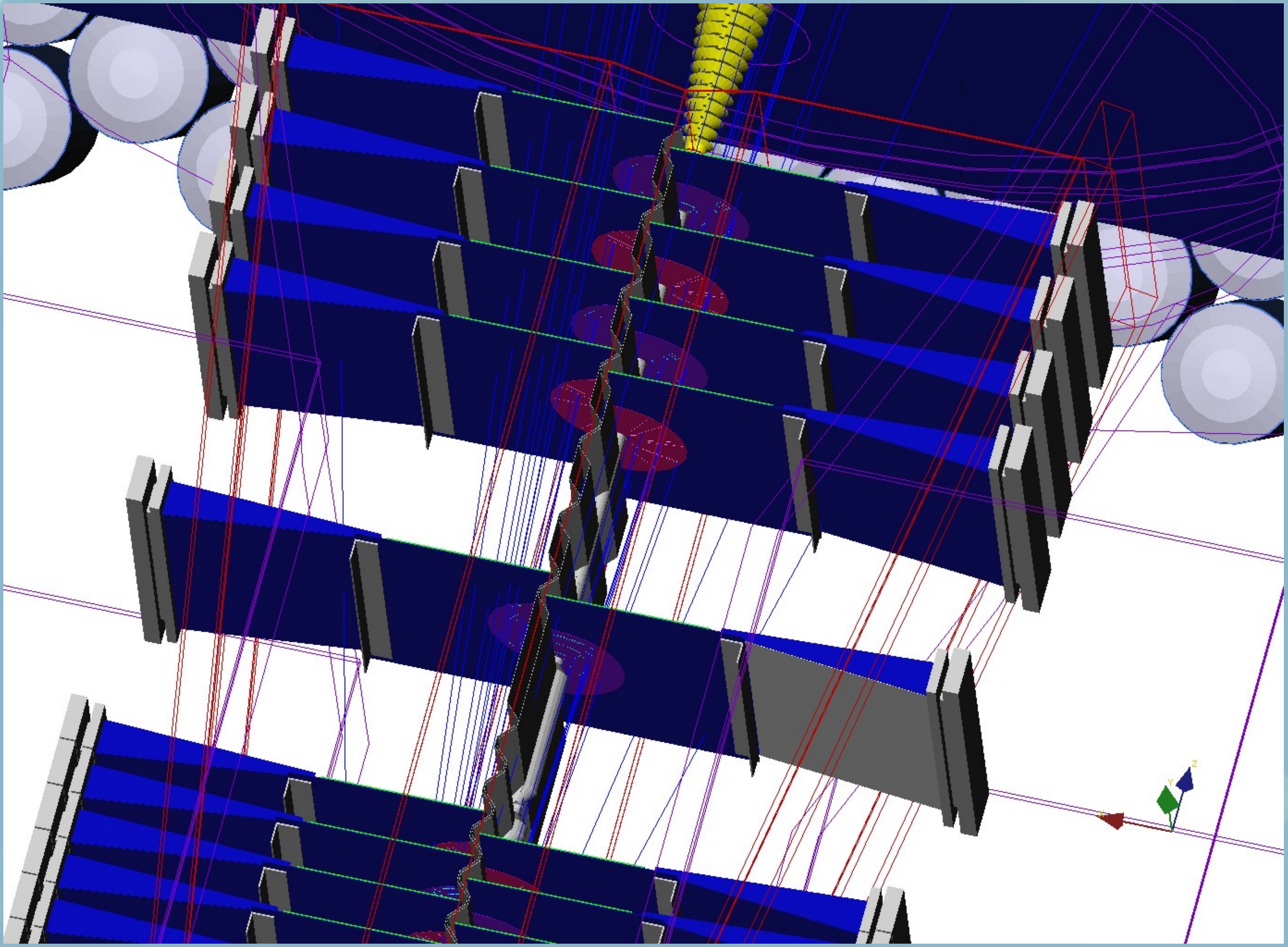






Beam pipe

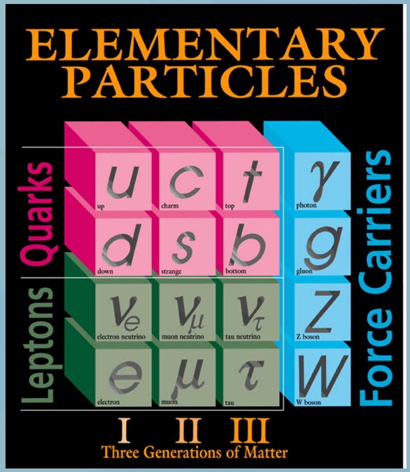
Particles passing through VELO



Summary

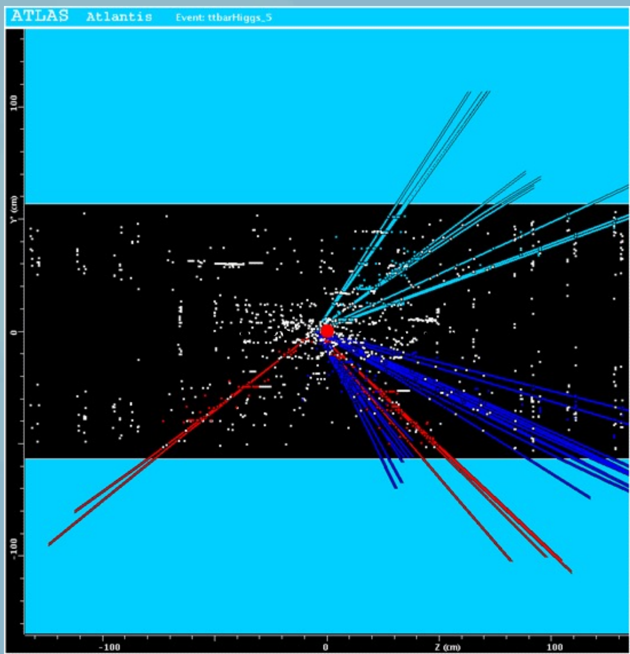
- ❑ Over the last 100 years, we've been probing deeper & deeper into matter.

- ❑ A successful description of data is provided by the Standard Model, but it can't be the end.



- ❑ Many questions remain unanswered though:

  - ❑ Where did all the antimatter go?
  - ❑How do particles acquire their masses ?
  - ❑ Do the forces unify at some high energy scale?
  - ❑ How does gravity fit into this picture?
  - ❑ Why do we have 3 families of particles with the observed mass patterns?



- ❑ We hope that some of these questions will be answered when the LHC turns on in 2007-8..

Stay tuned !

Thank You