Unlocking the secrets of the Universe @ Large Hadron Collider

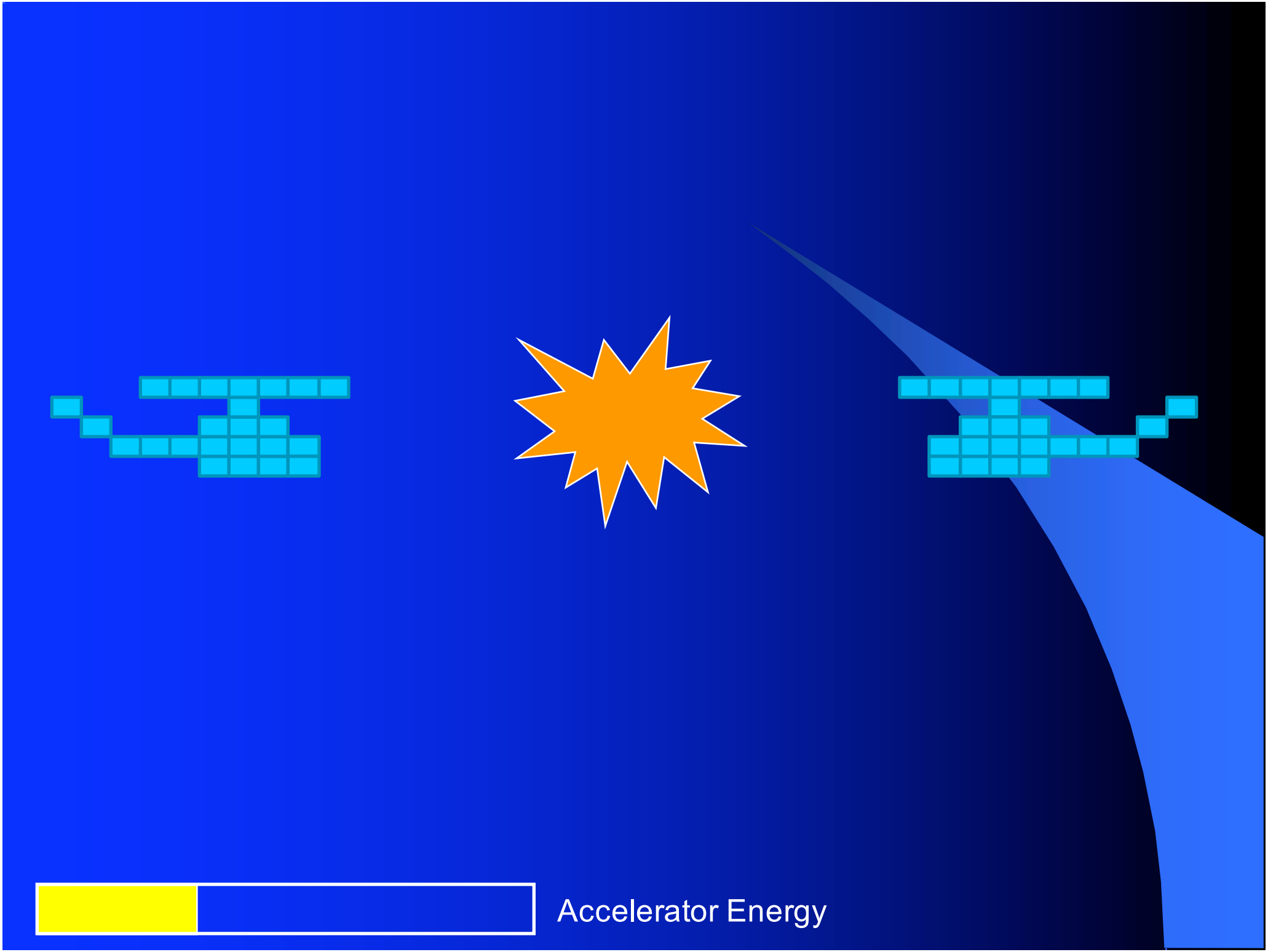
Prof. Tulika Bose
Boston University
April 26th, 2016

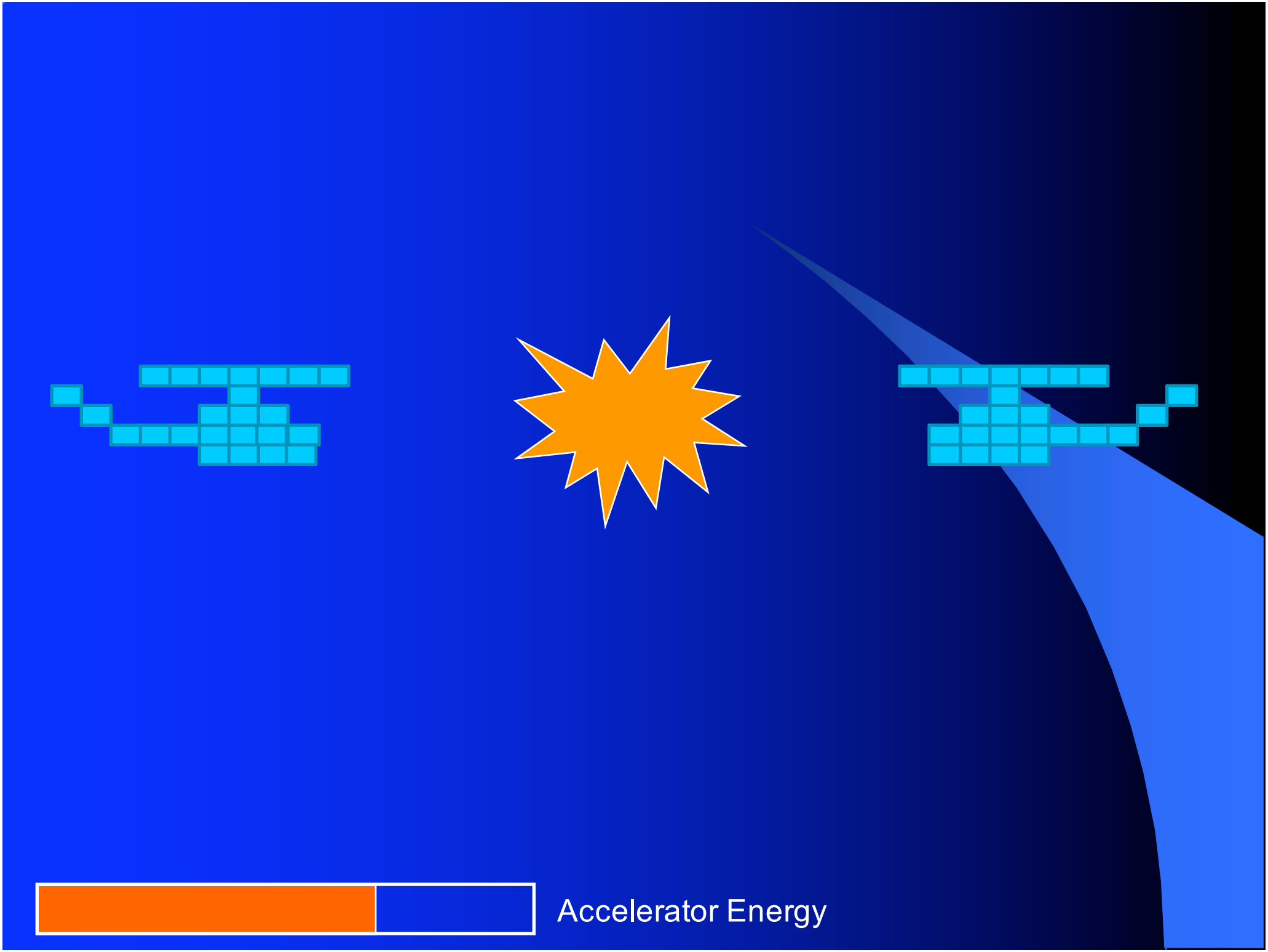
LHC

The Large Hadron Collider.
Large is an understatement!
Hadrons referred to here are protons.
Collide is what it does, as we will see.

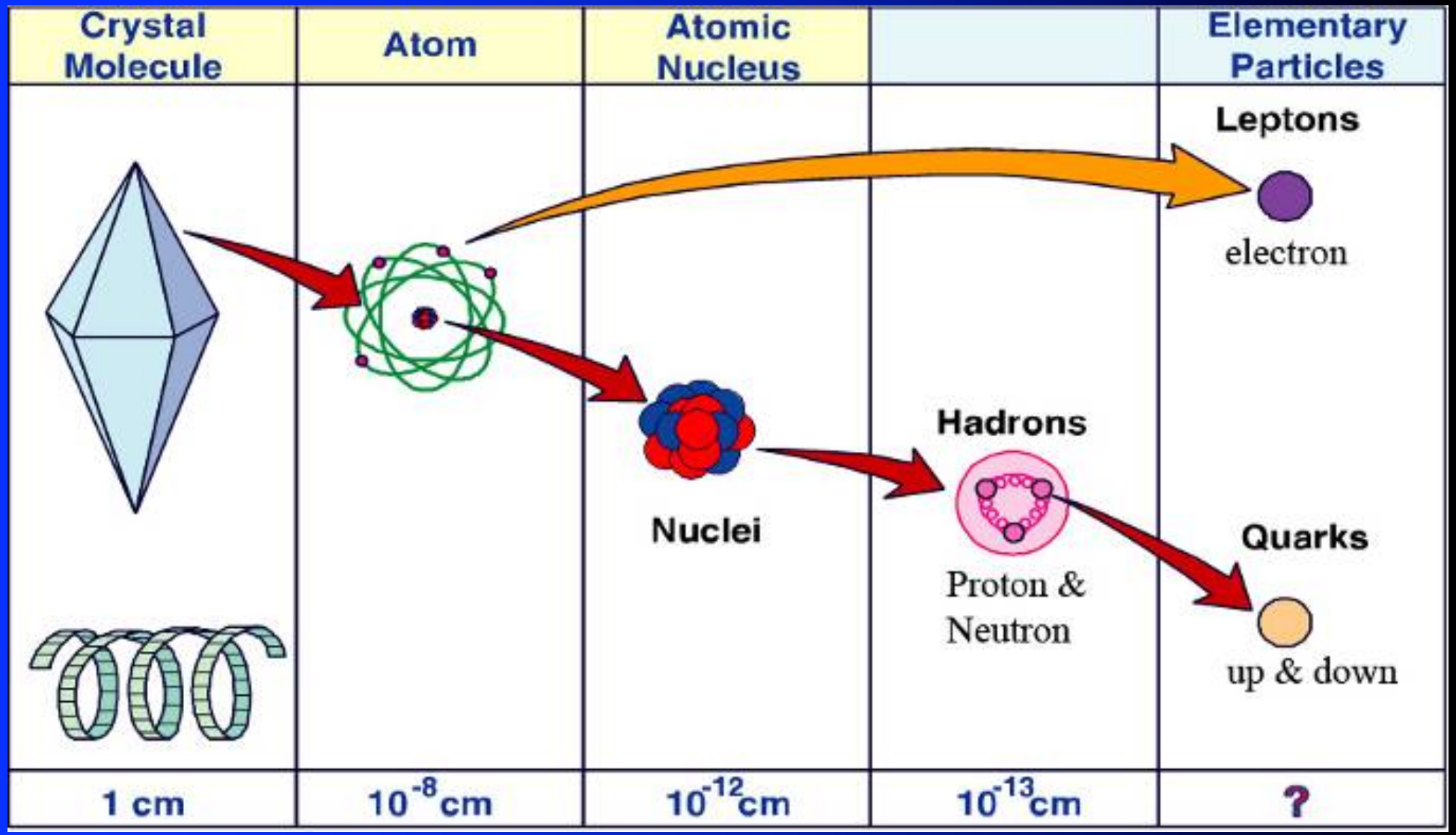
What do we do at the Large Hadron Collider @ CERN?

Smash things together, see what happens!


Accelerator Energy


Accelerator Energy

Our current understanding



Universal Lego Bricks

Quarks

up

down

Lepton

electron

Hadrons

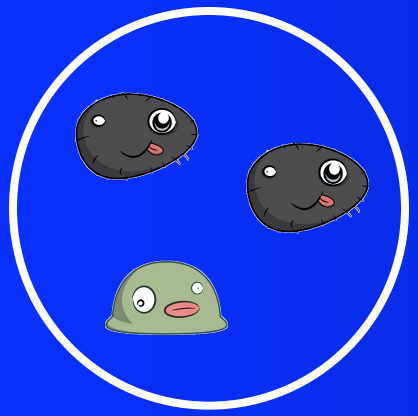
UUD = proton

UDD = neutron

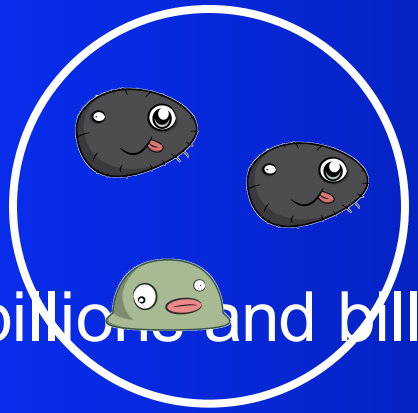
Building an Atom

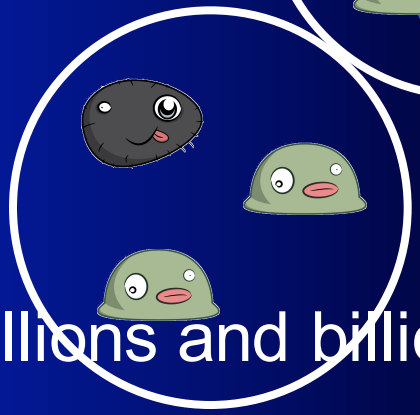
electrons

Helium Atom

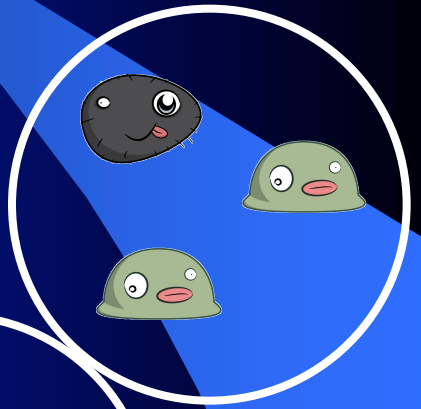


protons



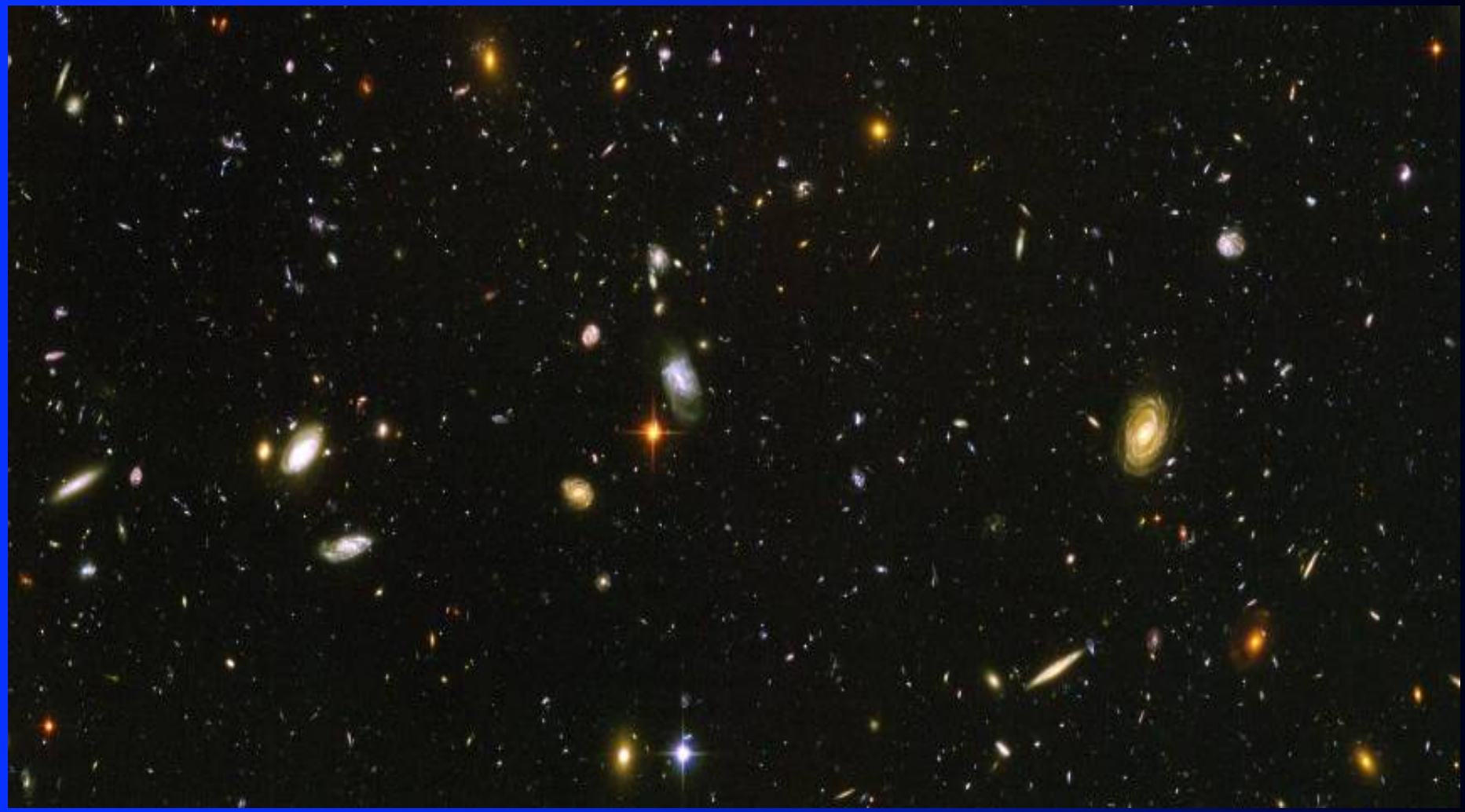


neutrons



Multiply by billions and billions and billions and billions…

Et voila – the Universe!



But that is not the end of the story……..

$E = mc^2$

The collision energy was used
to create something new, that
did exist but does not any more!

Accelerator Energy

13.7 billion years ago, there were other things in the Universe…

Quarks


up


charm


top


down


strange


bottom

Leptons


electron


muon


tau


electron neutrino


muon neutrino

tau neutrino

There is also anti-matter….

For every type of particle

There is an antiparticle

But, as far as we can tell, there is virtually no anti-matter naturally existing in our Universe…..


up


electron


down


electron neutrino


anti-up


positron


anti-down

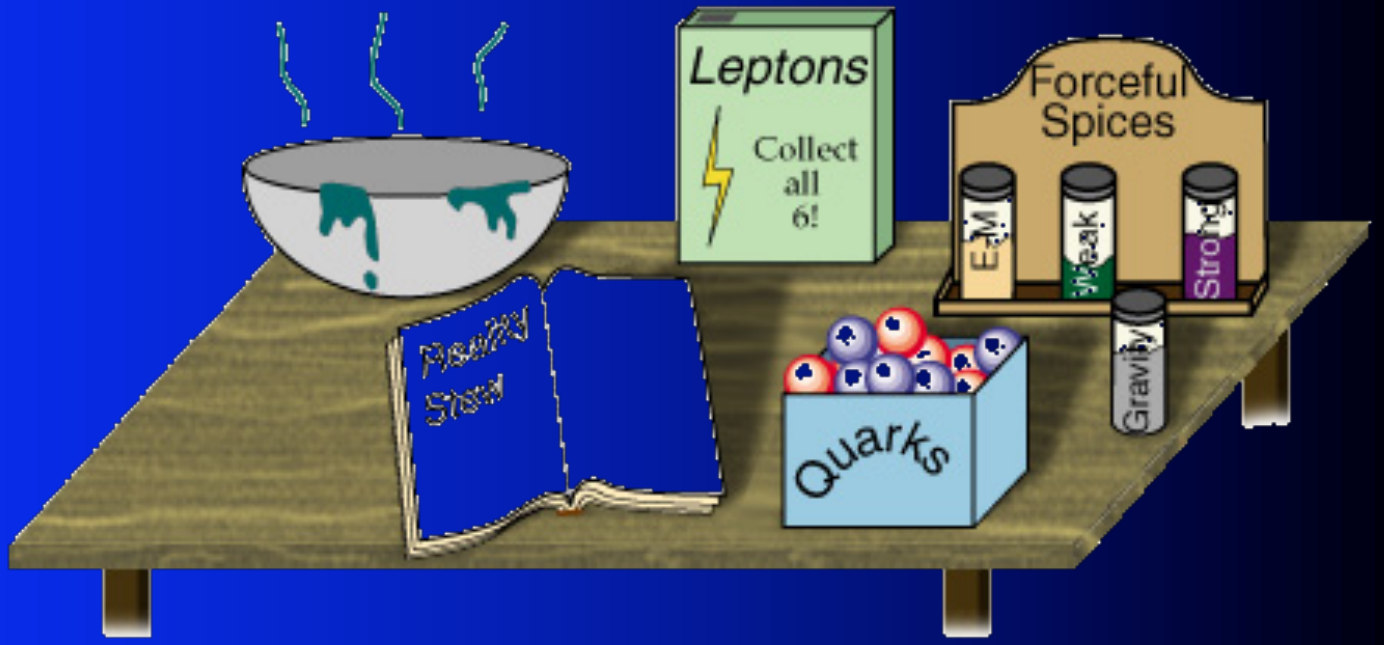

Anti-electron neutrino

Particles and antiparticles have opposite electric charge


It looks like we know everything!
In fact we know very little!

Answers to simple questions

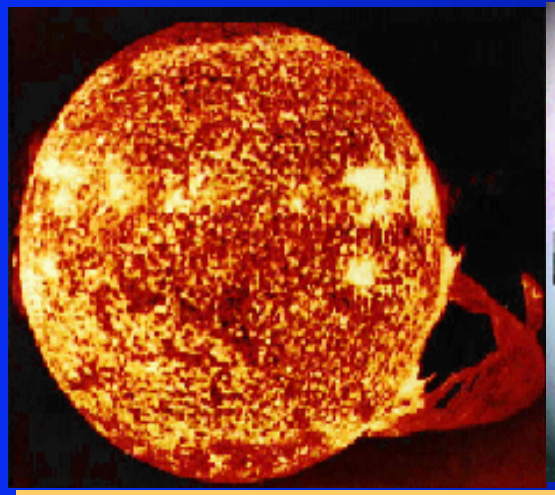
- Since the early 70s, particle physicists have synthesized all their knowledge in a single model: the «Standard Model»
- We know and we understand a lot but we do not know everything …
- Mysteries remain unexplained
- There are things to discover ...



Forces of nature

Weak
- beta-decay
- pp fusion

Mediator:
W+, W-, Z

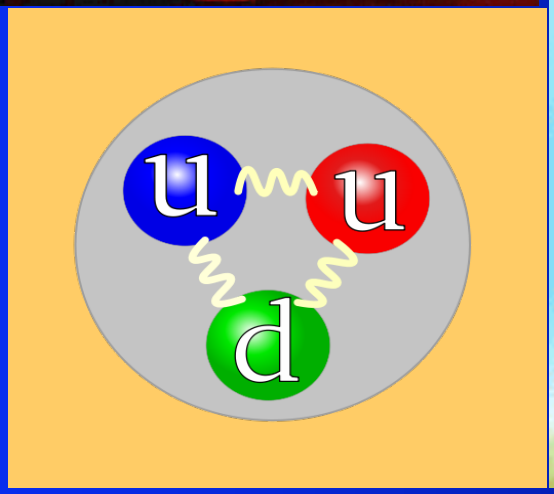


Electromagnetic
- TV, PCs
- Magnets

Mediator: Photon

Strong
- Quark binding

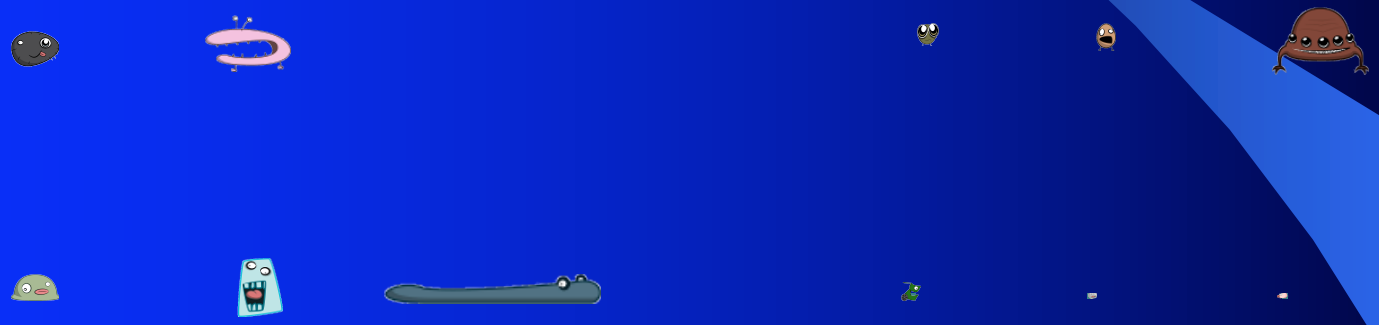
Mediator: Gluon



Gravity
Responsible of Keeping us well-planted on earth
Mediator: Graviton (not yet observed)

Standard Model does not include gravity (yet)

THE MYSTERY OF MASS



quarks leptons

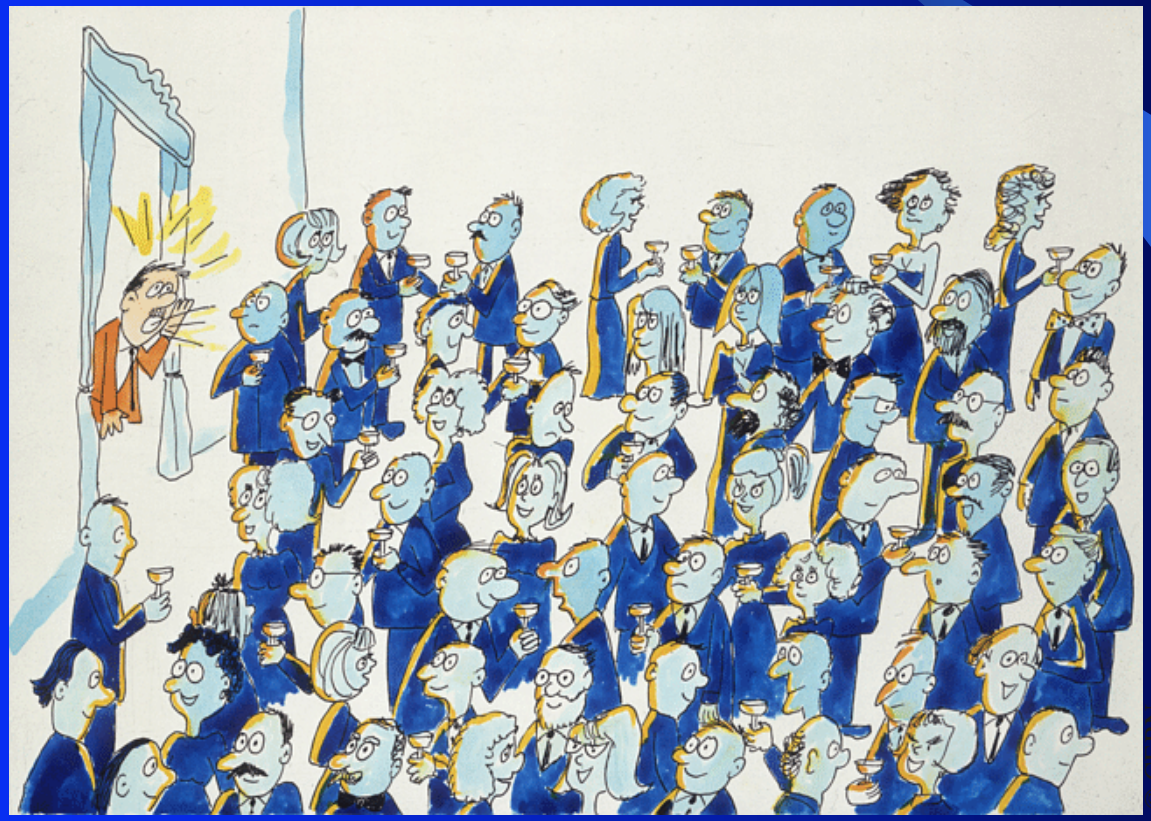
Why do some fundamental particles have mass while others don't?

Nearly 50 years ago six physicists proposed an explanation of how particles get mass…

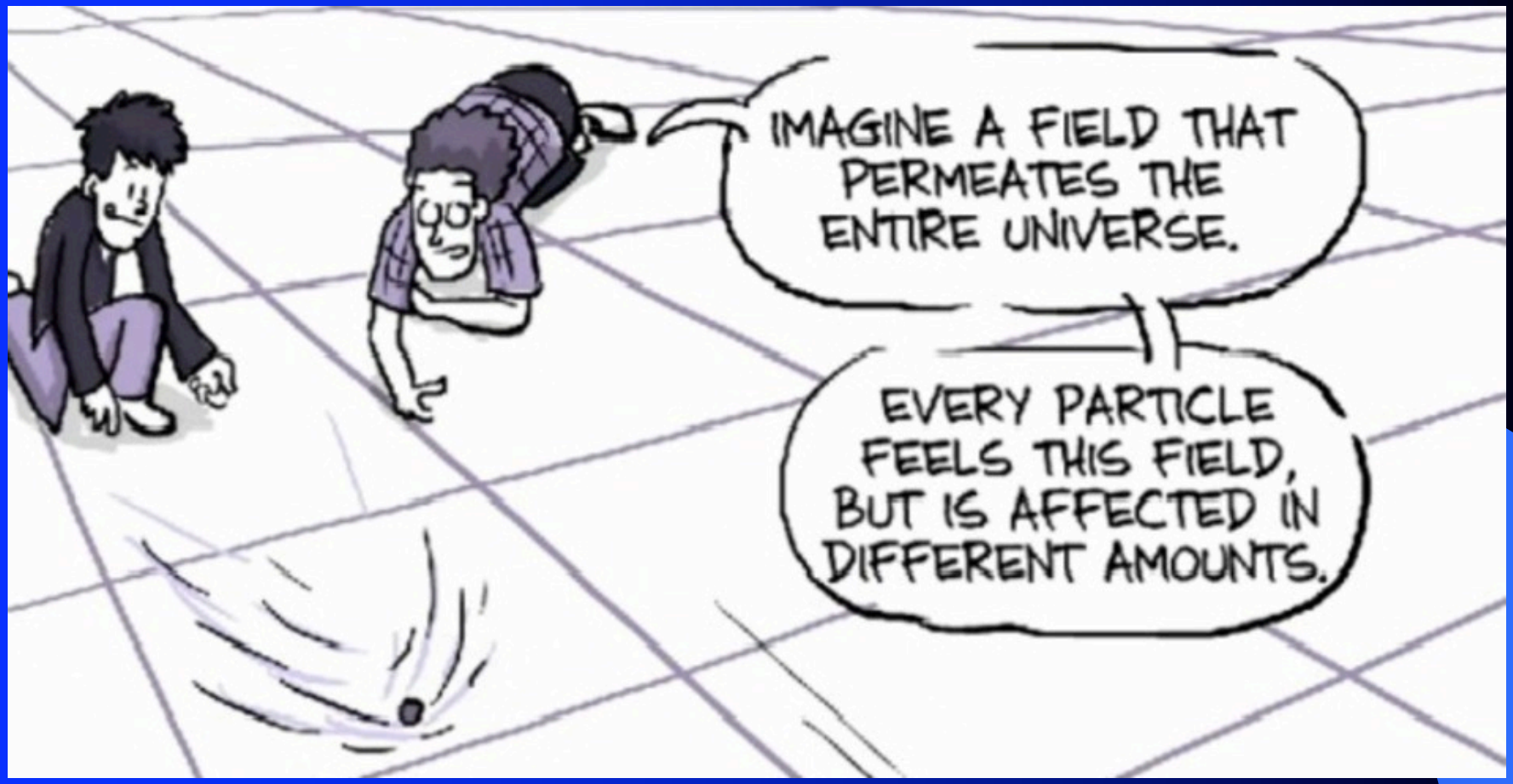
Kibble Guralnik Hagen Englert Brout

Higgs

So how do particles acquire mass ?



THEORY: The Brout-Englert-Higgs Field



The more a particle interacts with this *invisible* field, the more mass it gets.

But if this field is invisible,
how can we PROVE it exists?

The theory predicts that the field has an associated particle:

The Higgs Boson!

We can try to create the Higgs boson in our experiment!

And going back to our analogy…

The interesting things (the dinosaurs!) disappear almost instantly. We "see" the resulting particles – so we have to be like detectives – look at the evidence to see what happened…….

We analyze LHC data and search for the "dinosaurs" **(W^+, W^- , Z and Higgs particles) by searching for the particles they decay into**

Accelerator Energy

How do we do all this in reality?

The Large Hadron Collider…

Run 1:

a) proton beams with 3.5 TeV (trillion electron volts) energy for a total collision energy of 7 TeV (2010-2011)

b) proton beams with 4 TeV energy for a total collision energy of 8 TeV (2012)

Run 2 started in 2015 with proton beams at 6.5 TeV (energy for a total collision energy of 13 TeV

One of the **fastest** racetracks on the planet – the **L**arge **H**adron **C**ollider (LHC)

Several thousand billion protons travelling at 99.9999991% of the speed of light will travel round the 16.8 mile ring over 11000 times a second!

(that's 670,626,025 mph)

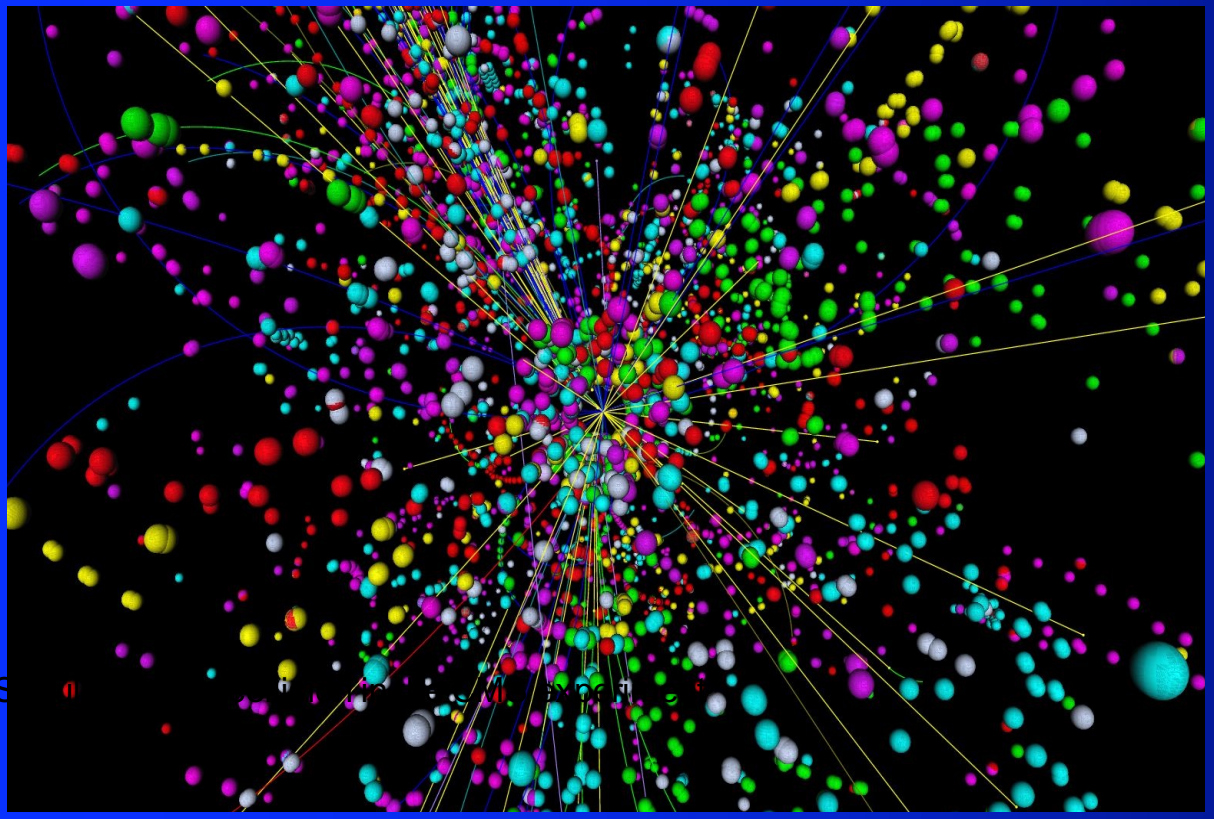
The **emptiest** space in the solar system

To accelerate protons to almost the speed of light, we need a vacuum similar to outer space. The pressure in the beam-pipes of the LHC will be about ten times lower than on the moon.

One of the **coolest** places in the Universe

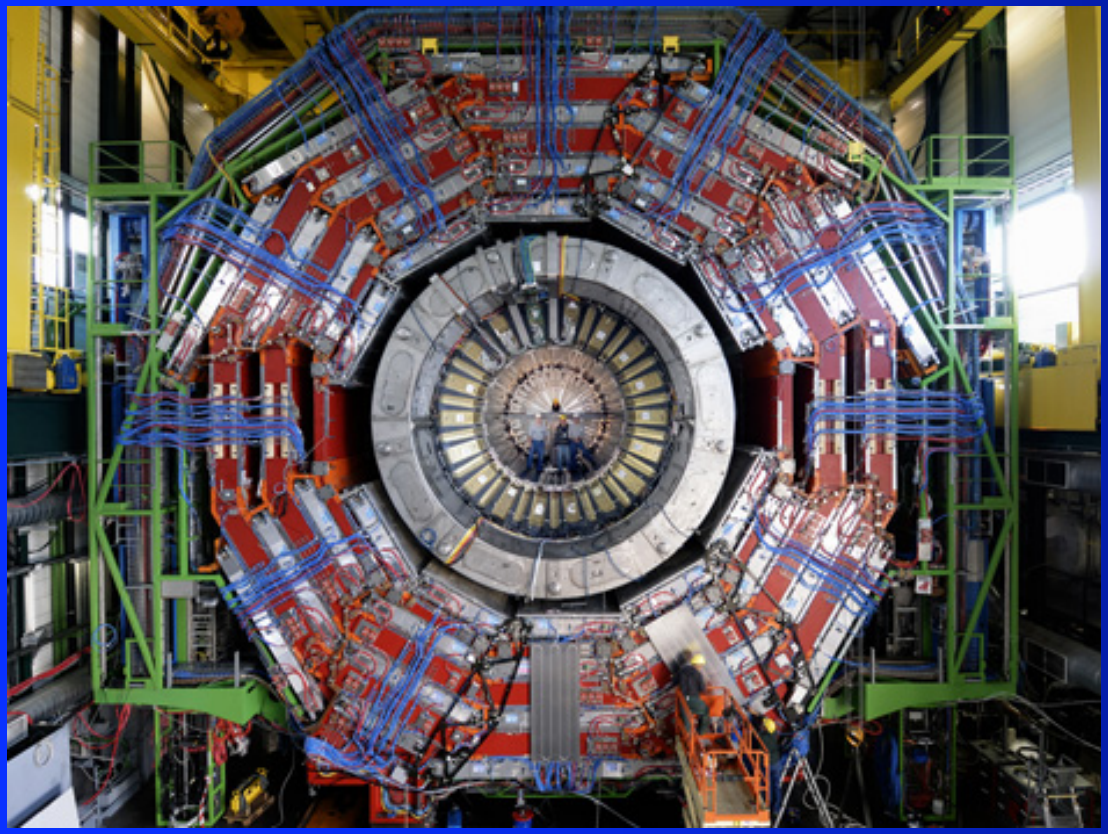
With a temperature of around -271 degrees Celsius, or 1.9 degrees above absolute zero, the LHC is colder than outer space.

One of the **hottest** places in the Galaxy

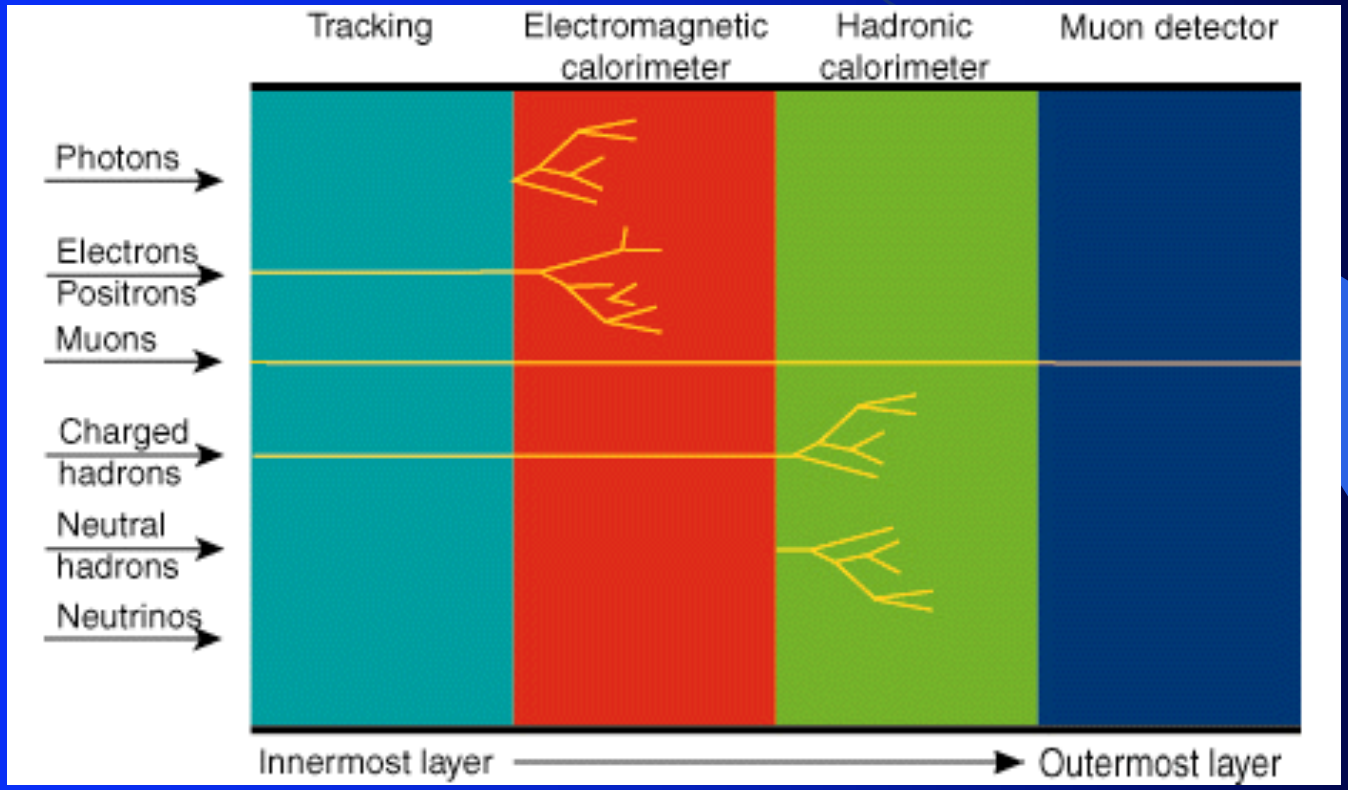


When two beams of protons collide they generate, within a tiny volume and for a tiny fraction of a second, temperatures more than a billion times those in the very heart of the Sun.

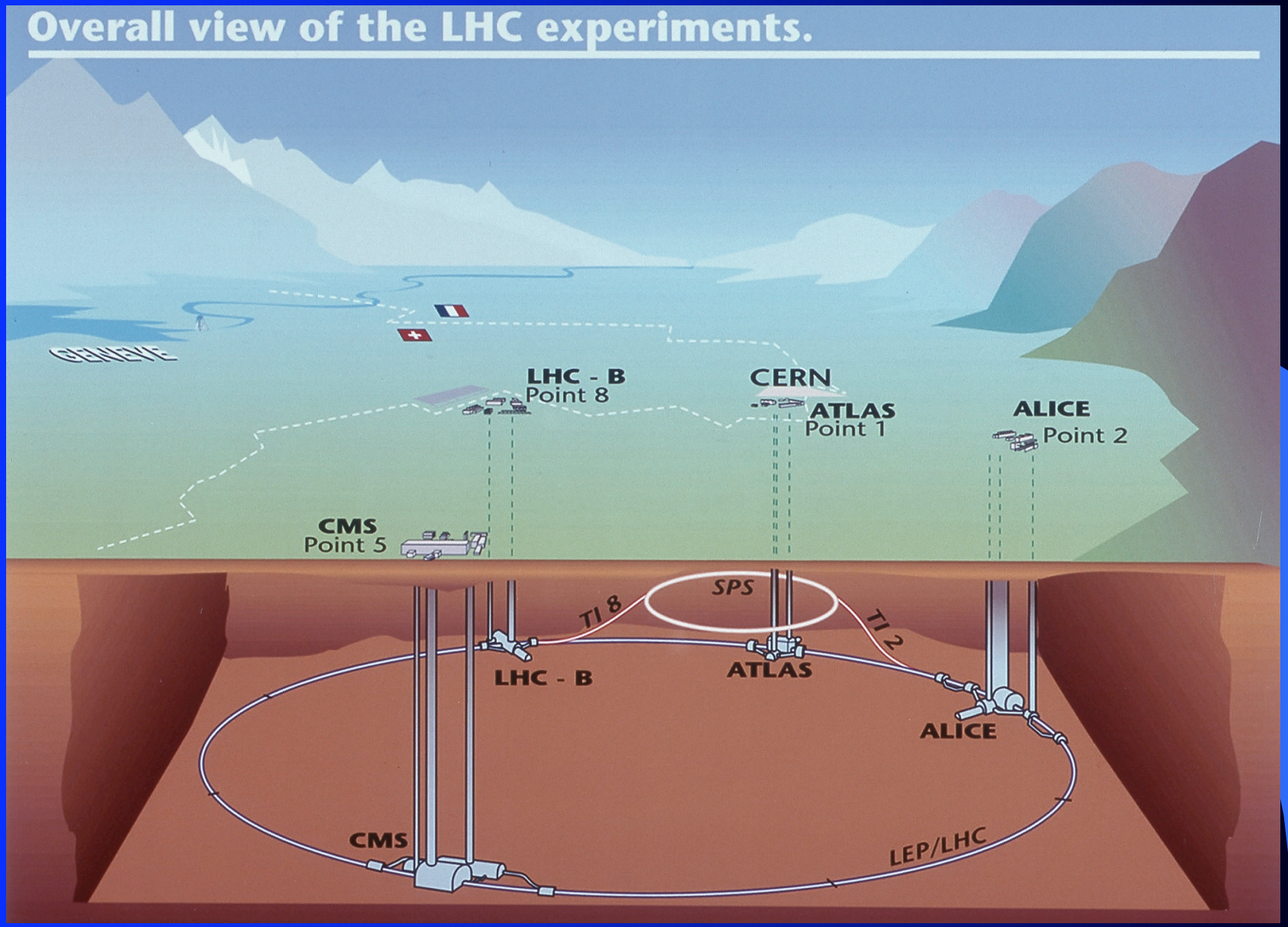
Use the **largest and most complex detectors** ever built



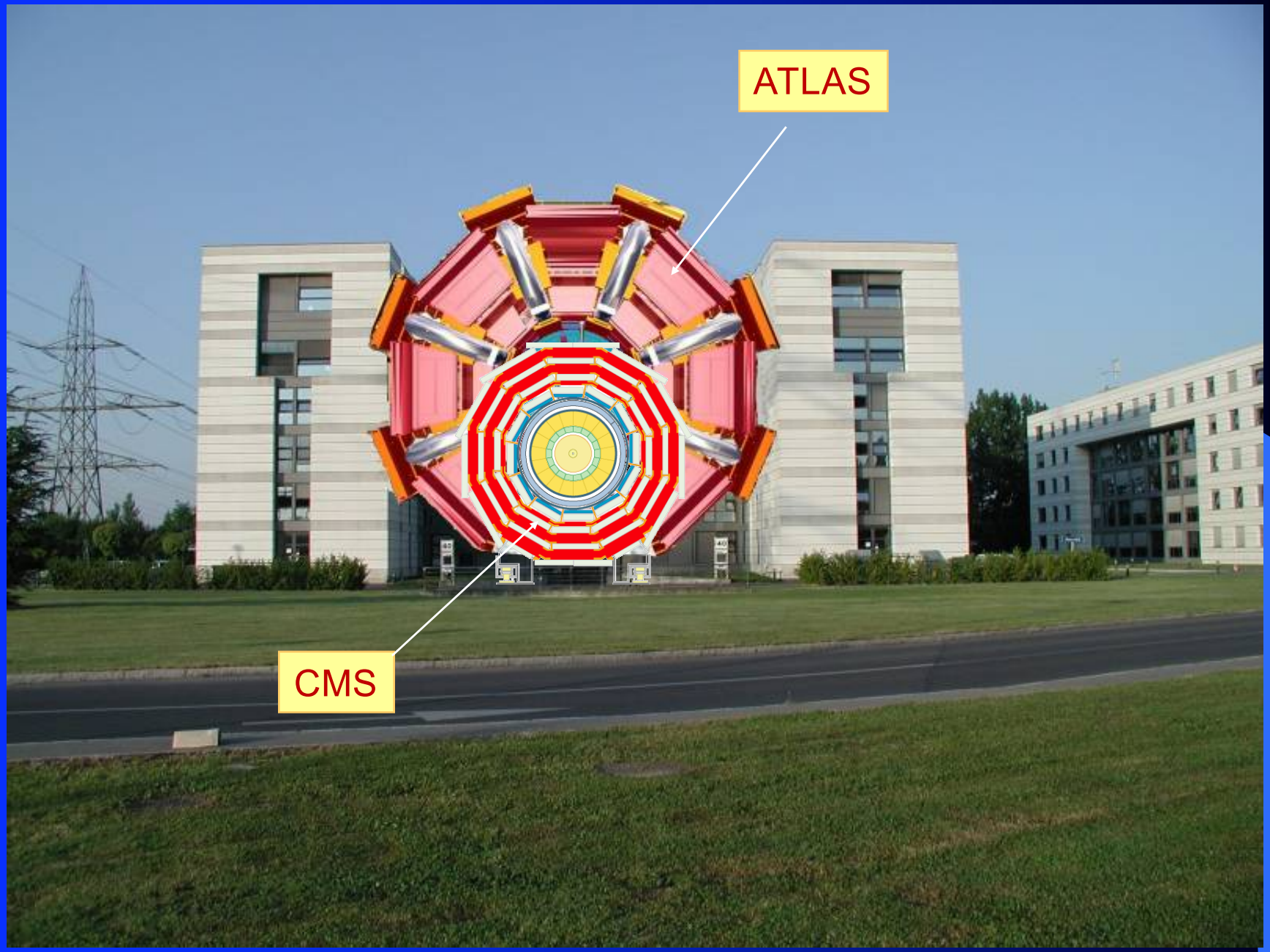
To select and record the signals from the 600 million proton collisions every second, scientists are building huge detectors to measure the tiny particles to an extraordinary precision.


Tracking
Electromagnetic calorimeter
Hadronic calorimeter
Muon detector
Photons
Electrons
Positrons
Muons
Charged hadrons
Neutral hadrons
Neutrinos
Innermost layer
Outermost layer

At the LHC there are 4 main detectors: ATLAS, ALICE, CMS & LHCb

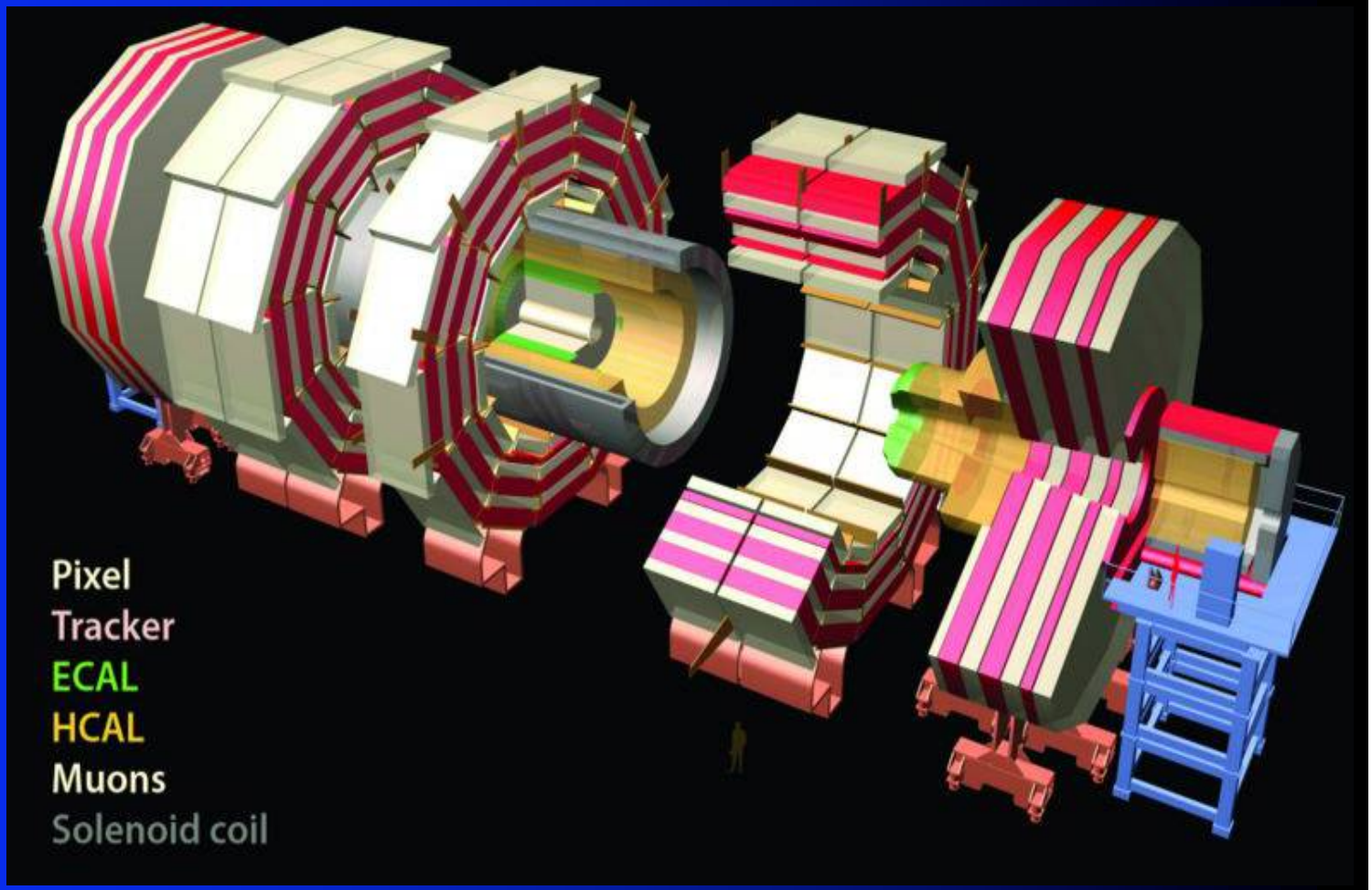


Compact is not small!!

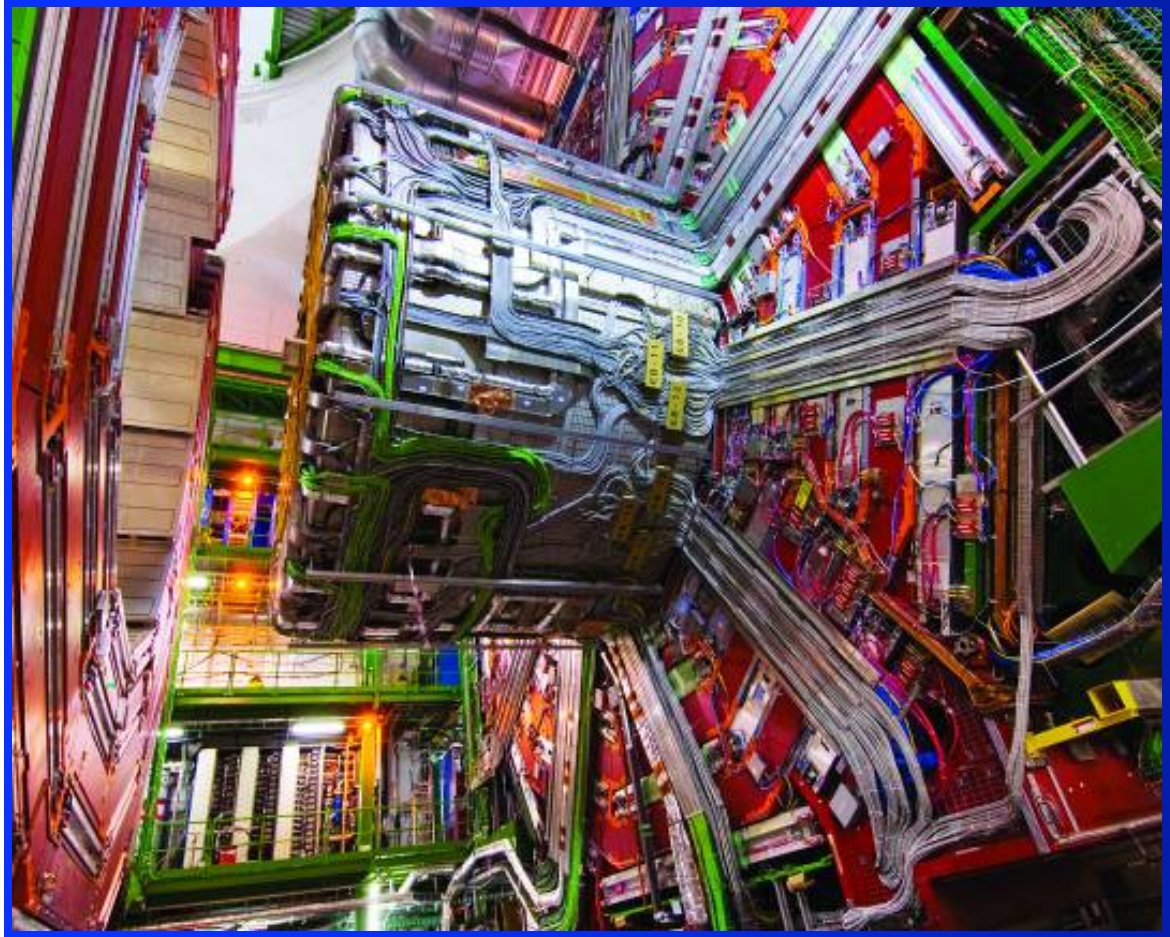


The huge CMS detector

- Took ~2000 scientists and engineers more than 20 years to design and build
- Is about 15 metres wide and 21.5 metres long
- Weighs twice as much as the Eiffel Tower – about 14000t
- Uses the largest, most powerful magnet of its kind ever made

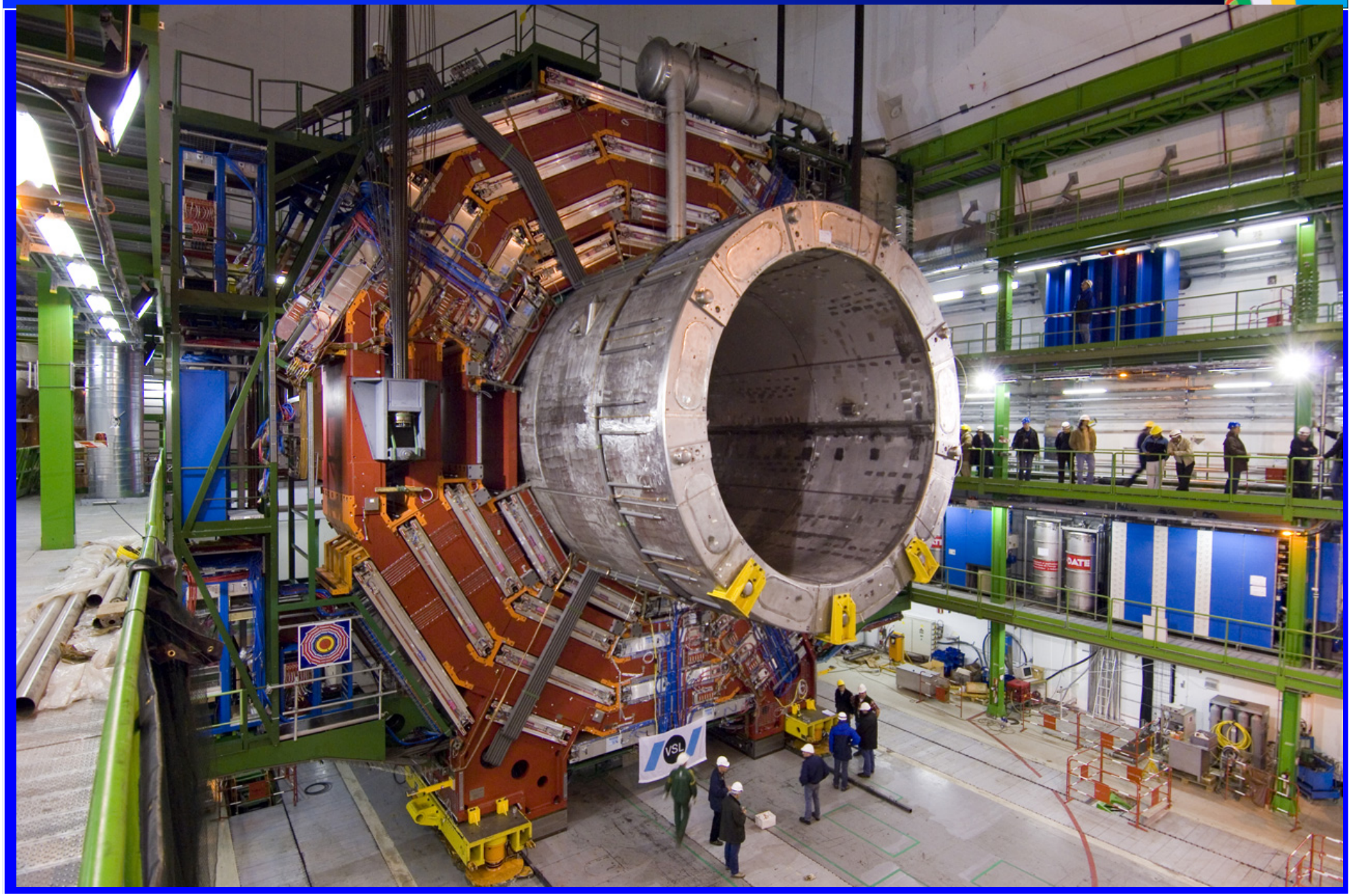


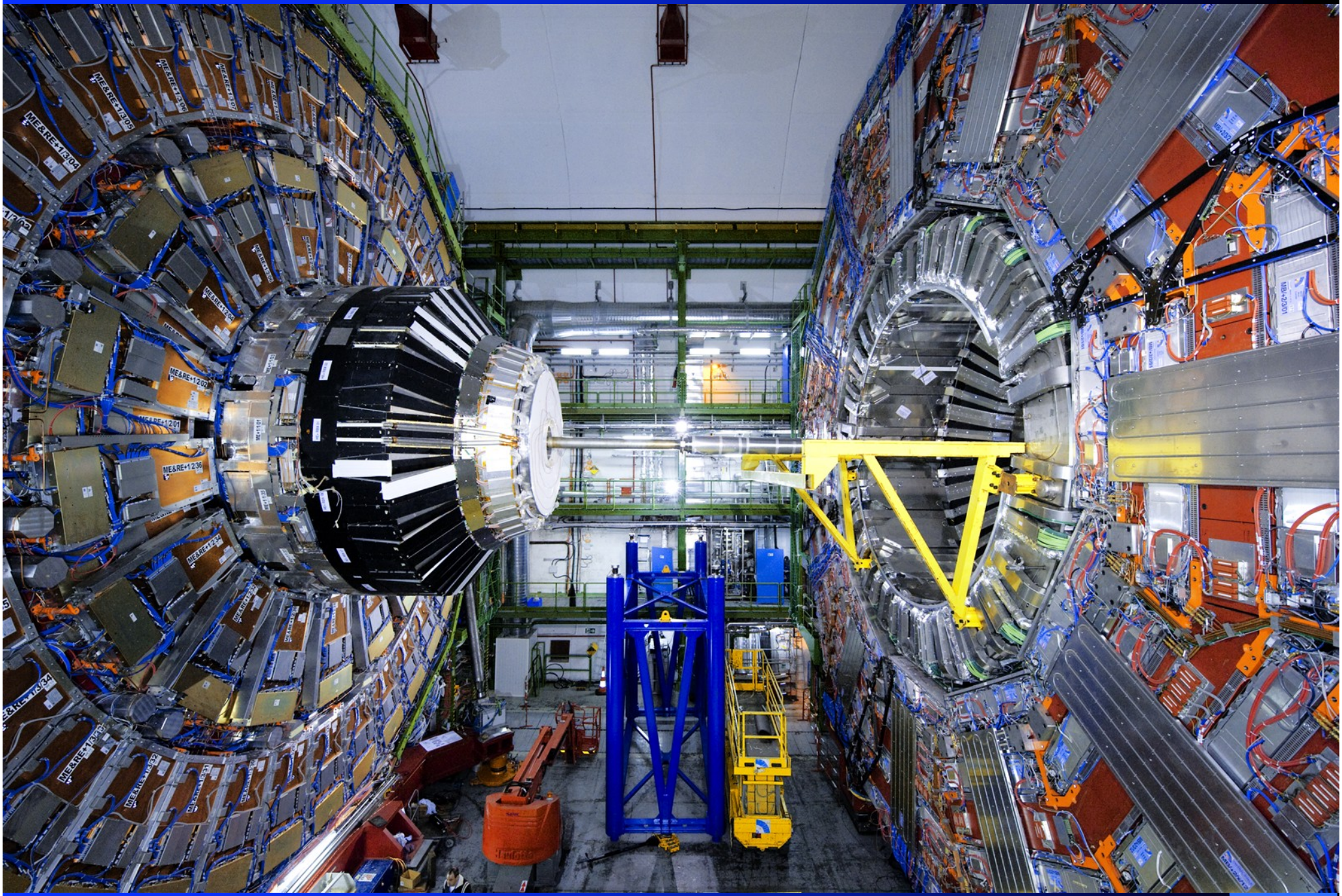
…is built with incredible **precision**…



- Like a 75 million pixel 3D camera taking 40 million photos per second
- Cabling this central section too ~200 people 6 months!

…on the surface and lowered 100m underground!


VSL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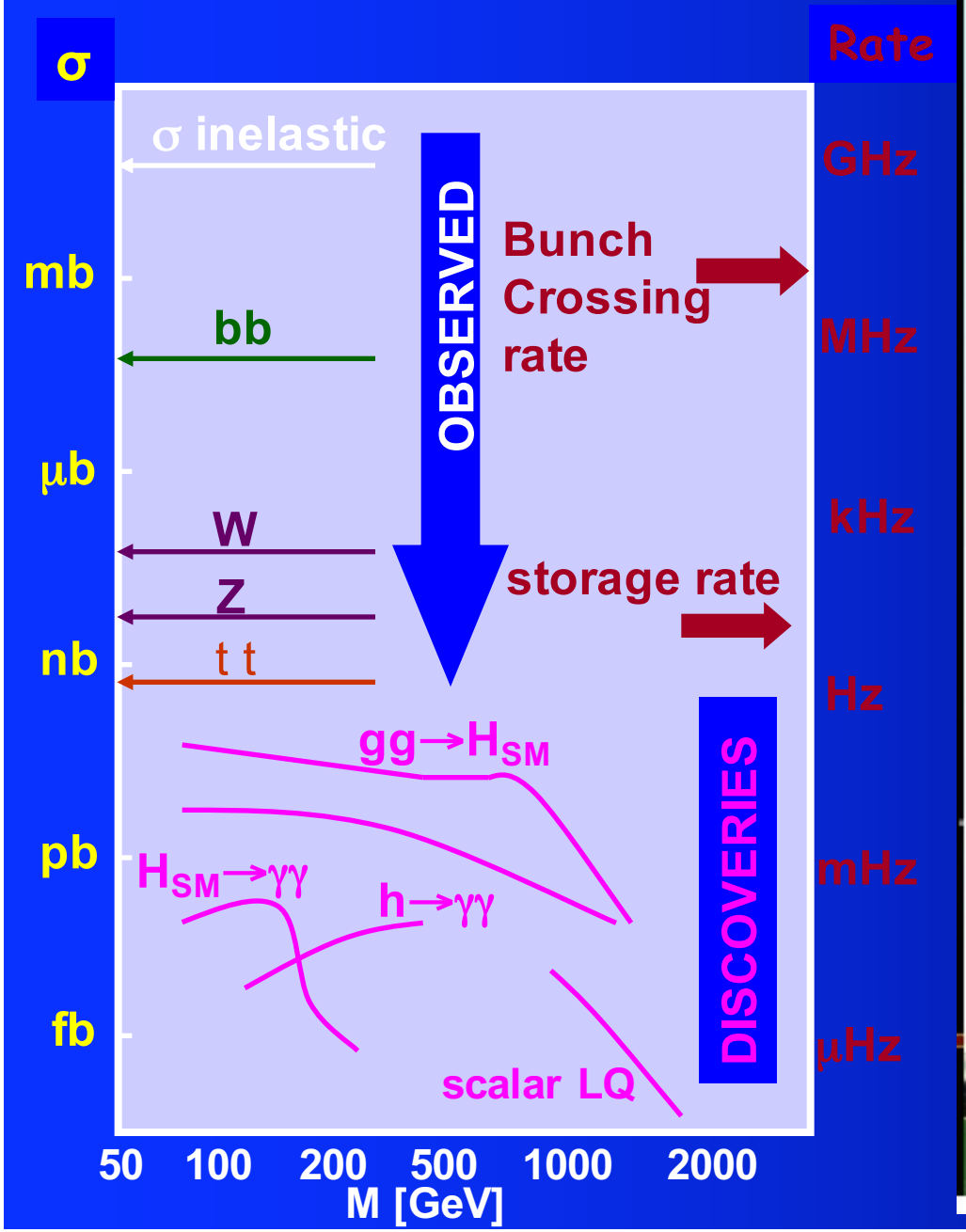
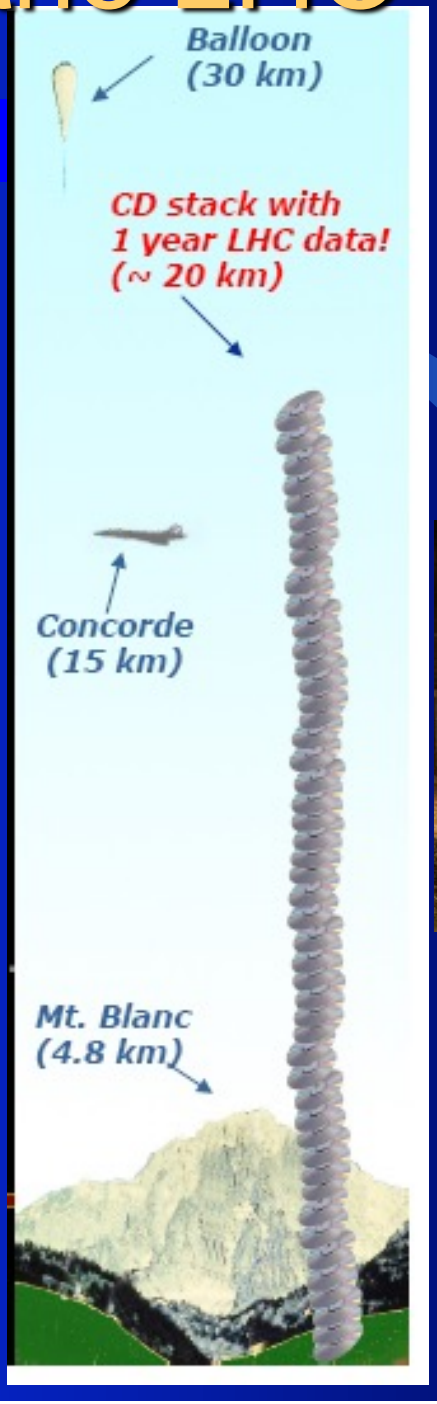
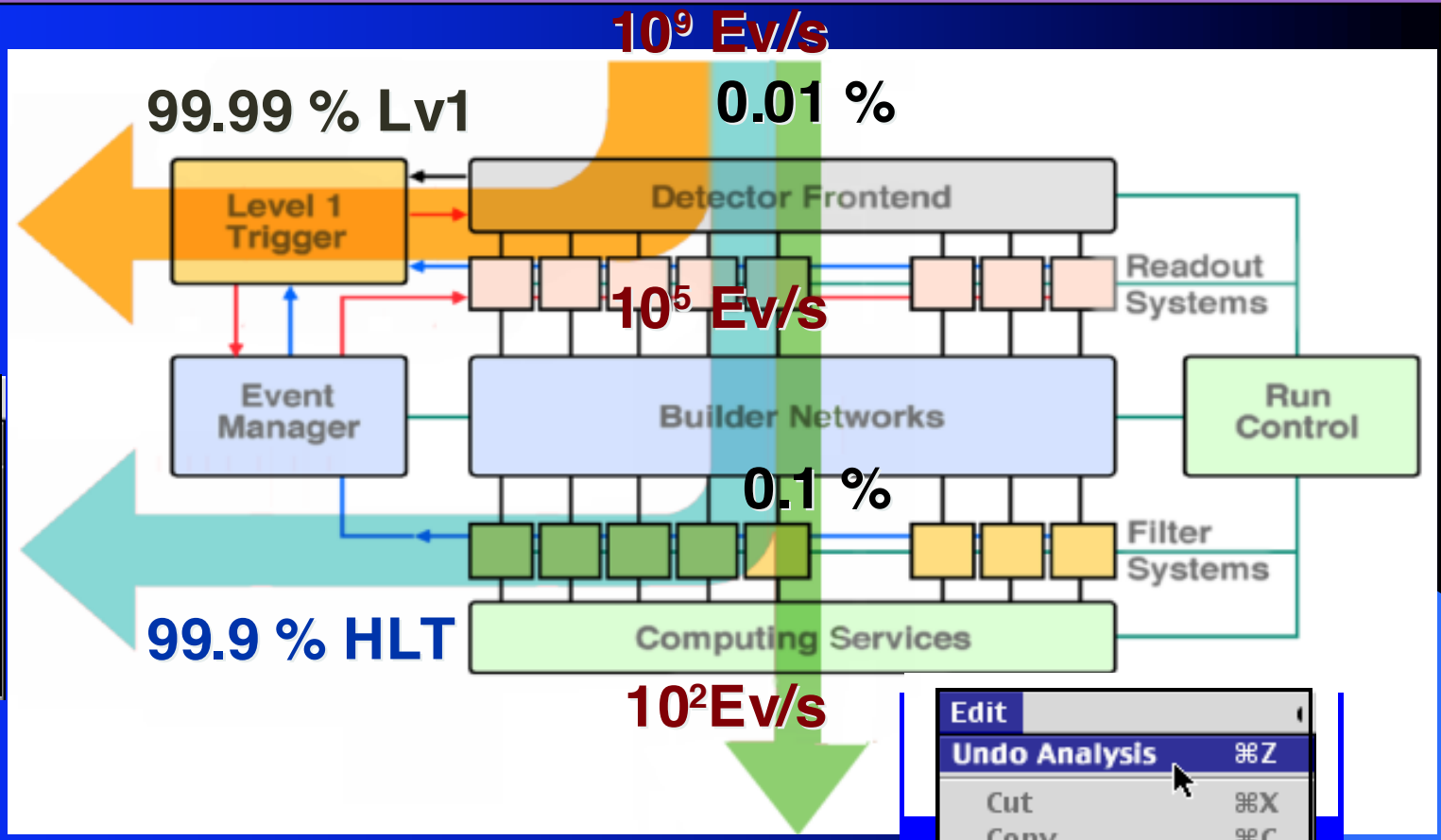
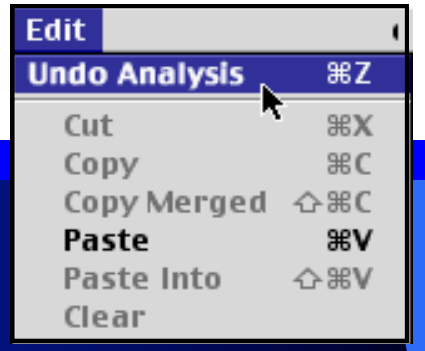
The Challenge at the LHC



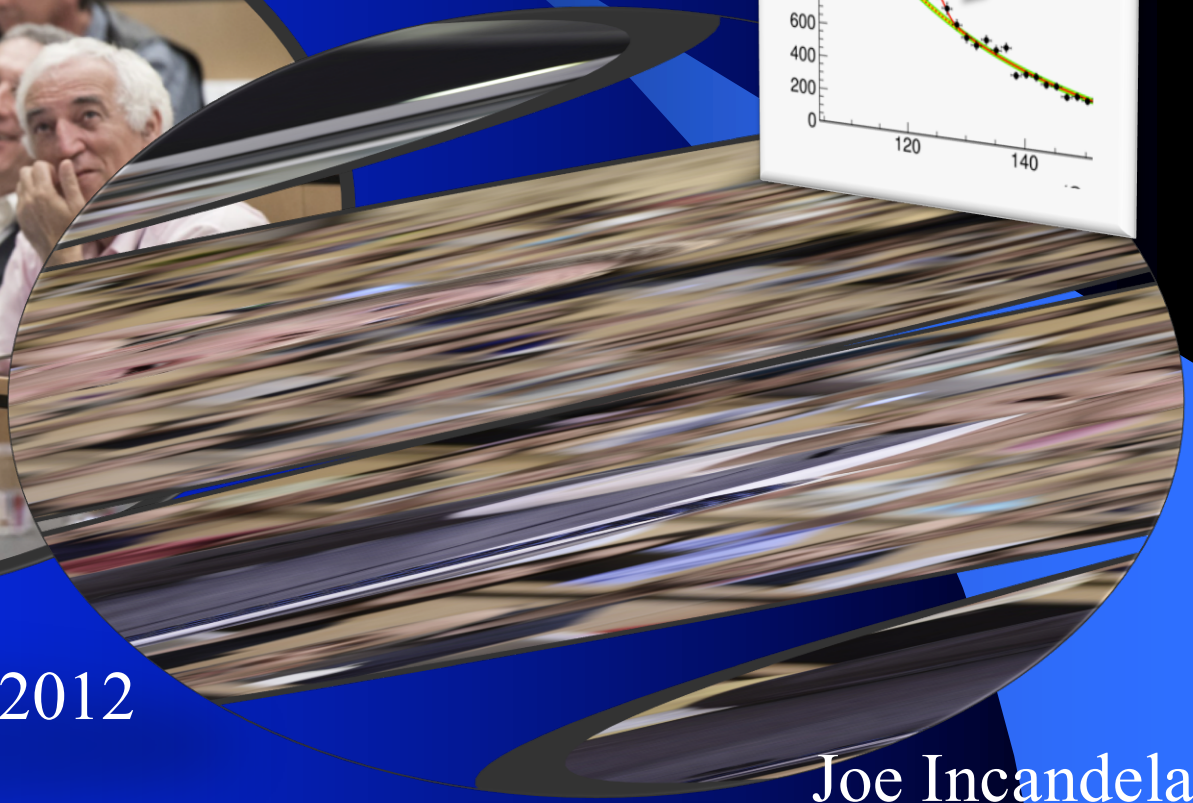


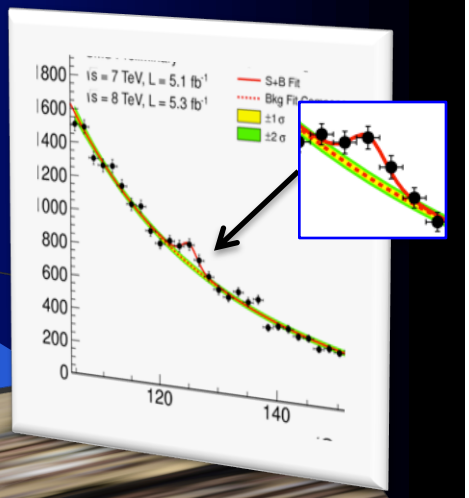




Will your favorite new physics signal be included in the small fraction of selected events?

But despite all these difficulties



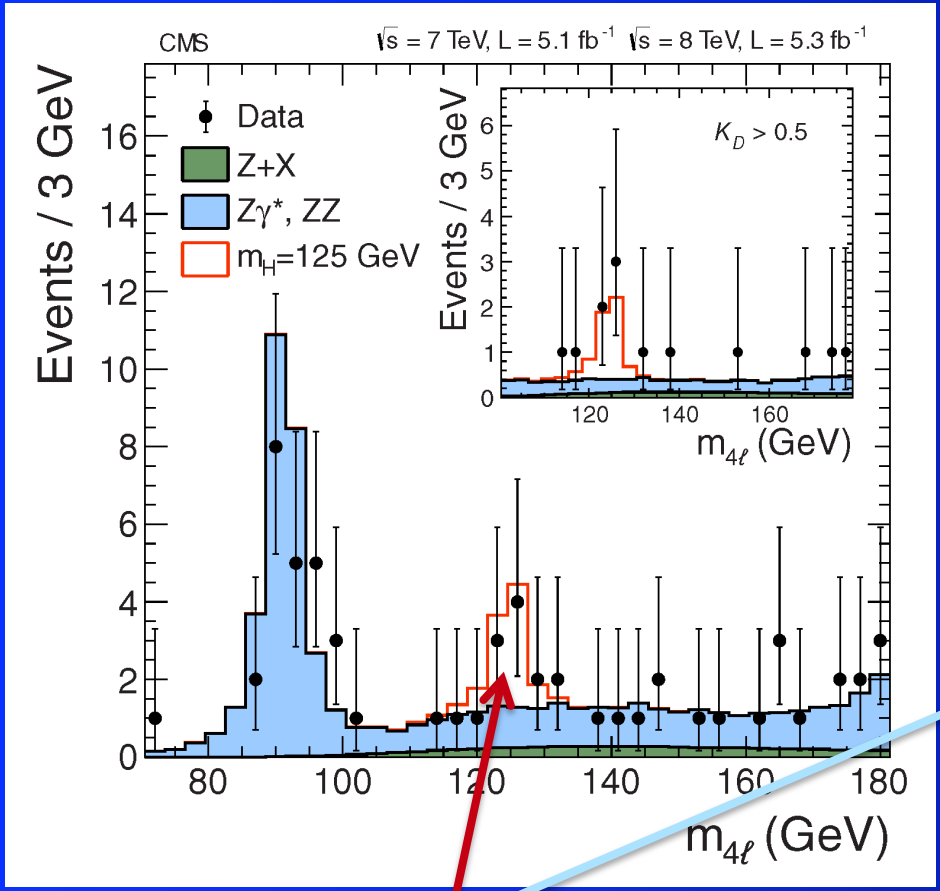


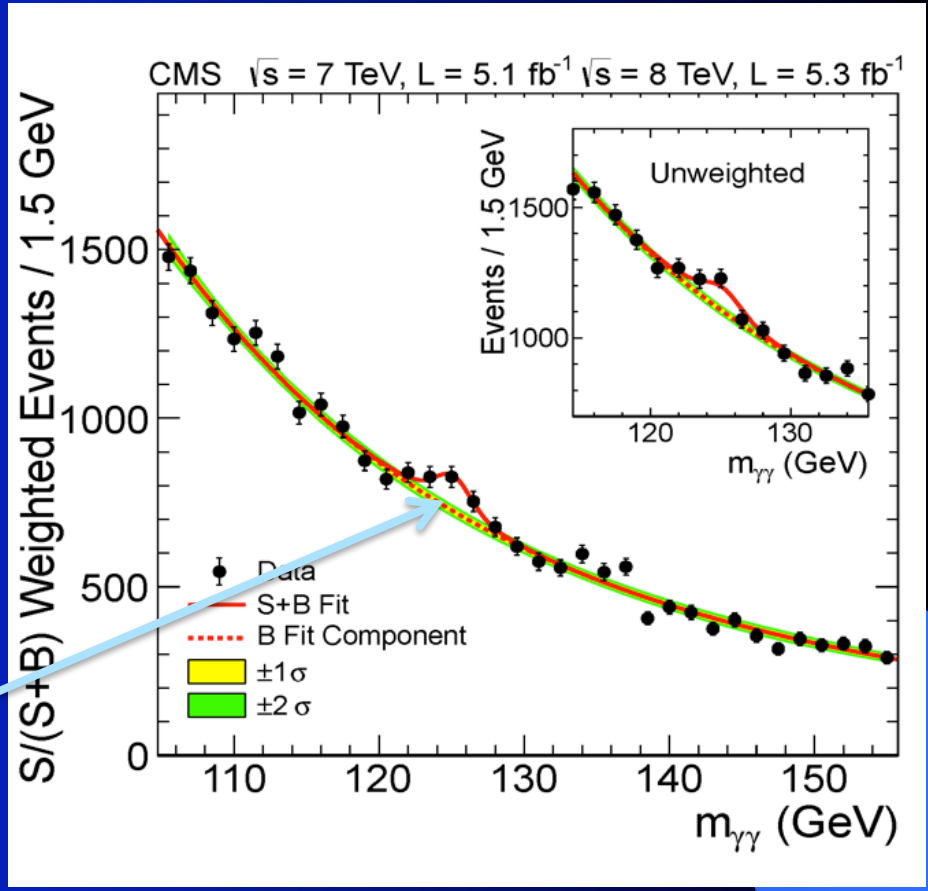
Fabiola Gianotti
ATLAS Spokesperson 2010-2012

We found it!

Joe Incandela
CMS Spokesperson 2012-2013

We Found Some Higgs Bosons!!





These bumps in the data signify a new particle, found in two different ways, at the same mass – about 125 GeV/c2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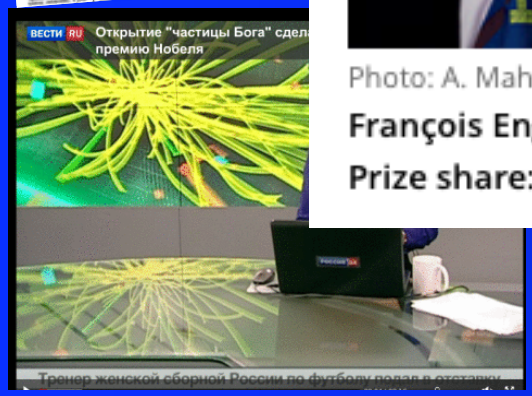
Higgs and the holy grail of physics
By Lawrence M. Krauss, Special to CNN
July 6, 2012 -- Updated 1507 GMT (2307 HKT)


THE AUSTRALIAN
Carbon dealing not over for Labor
After 50 years – and billions of dollars – the God particle is no longer a theory
Asylum calls 'use navy like NRMA'

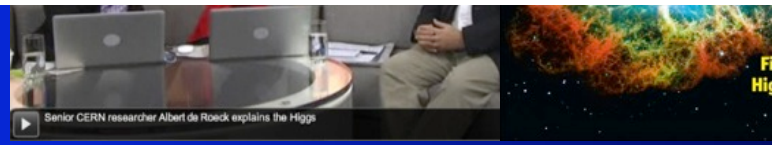

NewScientist


Searching for the 'G


il manifesto
Materiali storico


ВЕСТИ RU
Открытие "частицы Бога" сдела
премию Нобеля
Тренер женской сборной России по футболу попал в аттестаты


The Nobel Prize in Physics 2013
François Englert, Peter Higgs
The Nobel Prize in Physics 2013
Photo: A. Mahmoud
François Englert
Prize share: 1/2
Photo: A. Mahmoud
Peter W. Higgs
Prize share: 1/2


Senior CERN researcher Albert de Roeck explains the Higgs


뉴스
'힉스 입자'에 이름 붙인 건
'무궁화 꽃...' 실제 모델 이휘소 박사


科學人雜誌
facebook
打開盒子那一刻

But we have only just started to understand the Higgs boson…

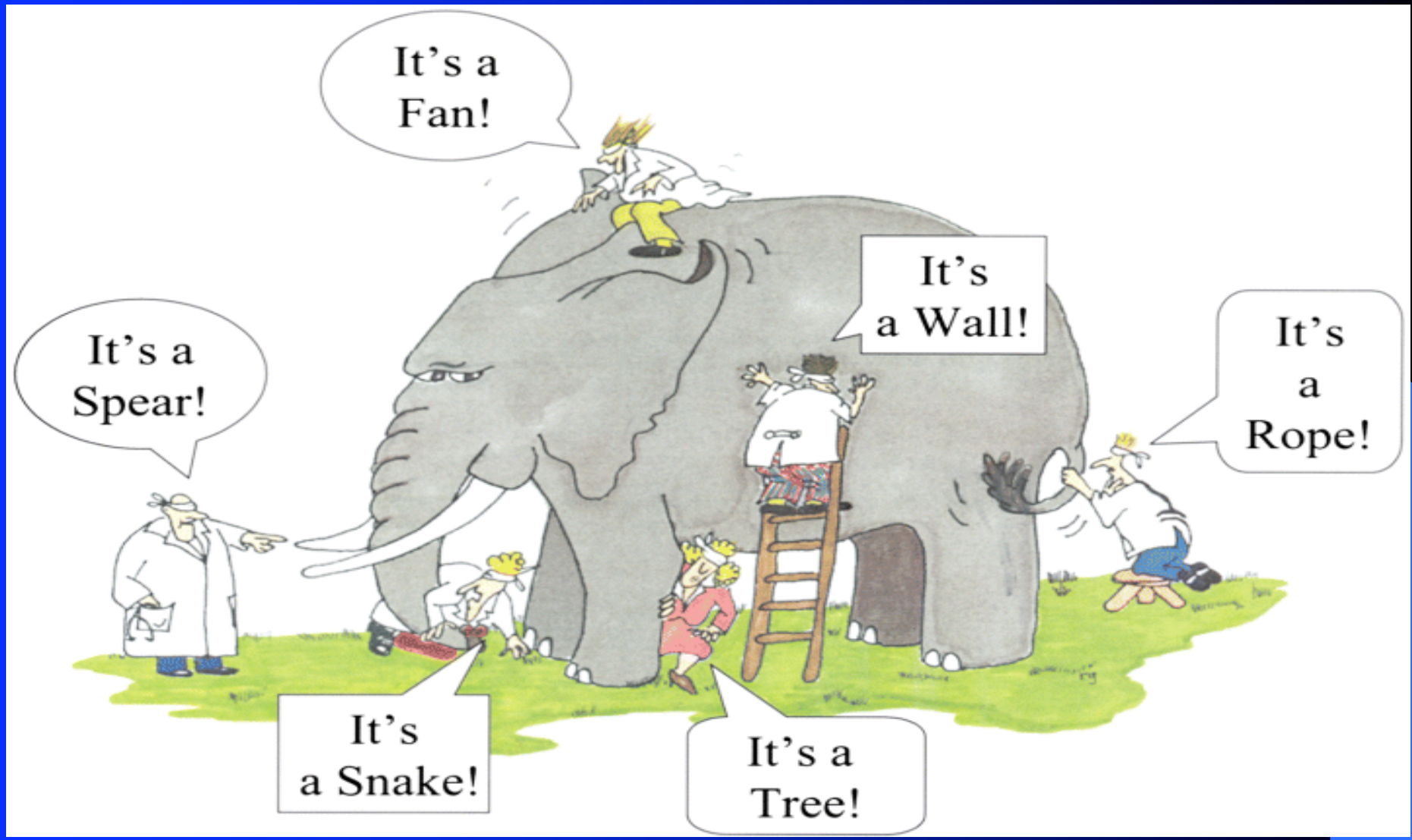
…and we need to look from every angle


It's
a
Rope!


It’s a
Spear!


It's
a Wall!

But we have only just started to understand the Higgs boson…and we need to look from every angle



Is it the Standard Model (SM) Higgs Boson?

- Its mass is in the right window – consistency with SM
- However, its properties are yet to be precisely determined to confirm that it is the SM Higgs Boson

There are other open questions and mysteries…

Matter vs Antimatter

Anti-Tom Hanks

Would look very much like

Tom Hanks

Matter vs Anti-Matter

But were they to meet…

The Mystery of Anti-matter

- 14 billion years ago the Big Bang created equal amounts of matter and antimatter
- We exist because there is no antimatter around
- Where has it all gone?
- Why does Nature prefer matter?

What is really out there? (and in here!)

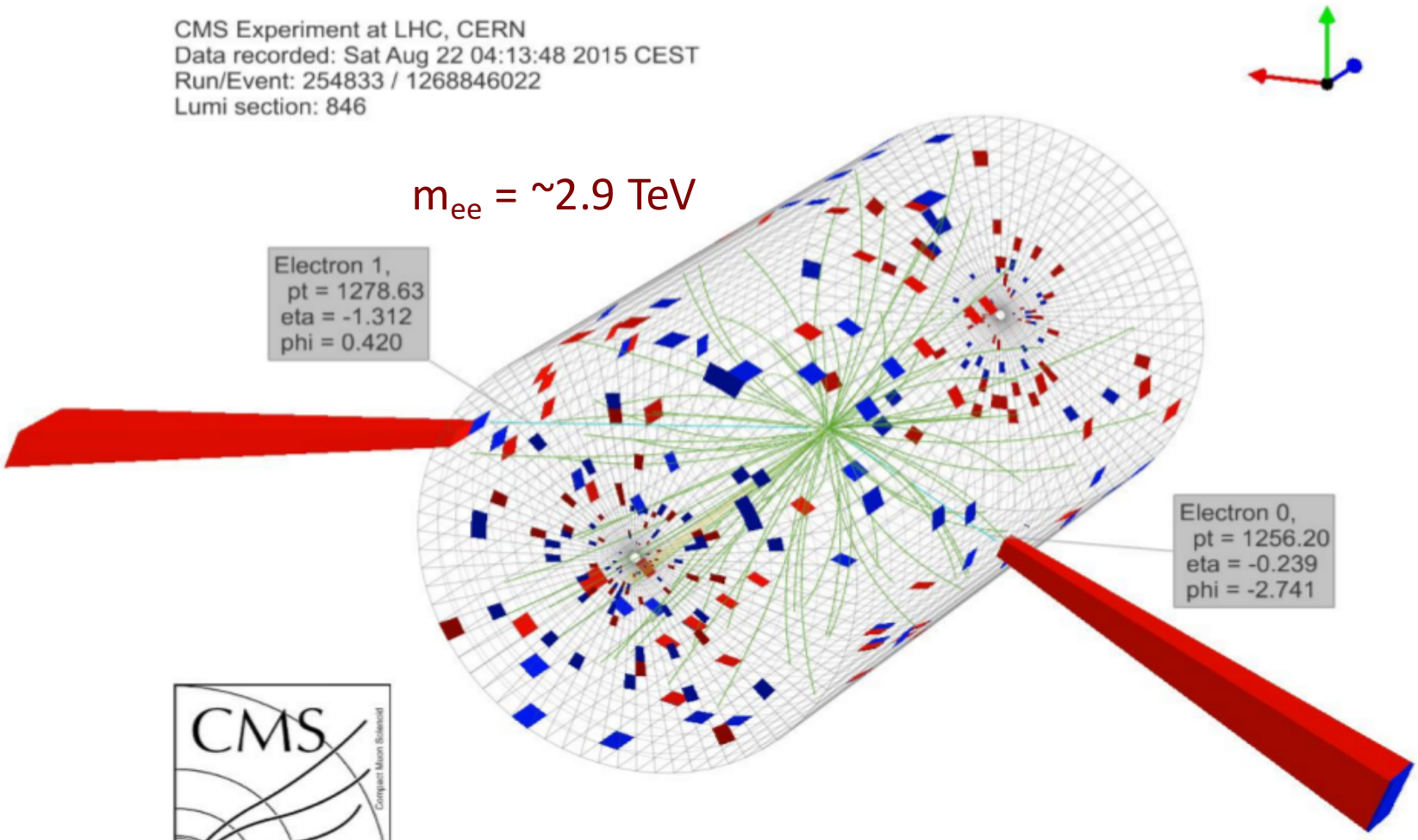
- Astronomy tells us that the matter we know (i.e. protons, neutrons and electrons) accounts for just 5% of the universe
- The rest is dark matter
- And dark energy

Dark Matter

- "Dark" because we can't detect it directly
- Can tell it's there from effects on galaxies
- Could be made of undiscovered particles → SUPERSYMMETRY
- LHC could create these particles and CMS could (indirectly) detect them

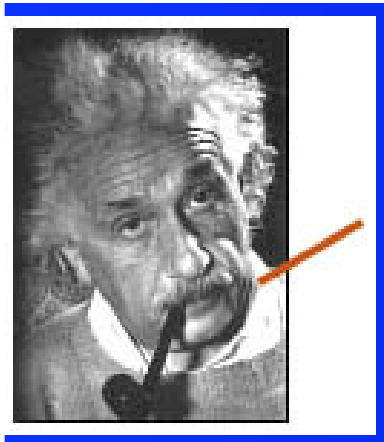
Discoveries awaiting us ?

Z' ???



Discoveries awaiting us ?

Almost certainly the SM needs to be extended with something new in order to thoroughly explain mass, gravity and other phenomena



I wonder what we'll decide to call the new theory that replaces the Standard Model!

The Super-Standard Model?
The New Revised Standard Model?
The Very Standard Model?

Whatever the name, exciting times lie ahead!

The New York Times

New Heavy Particle Discovered

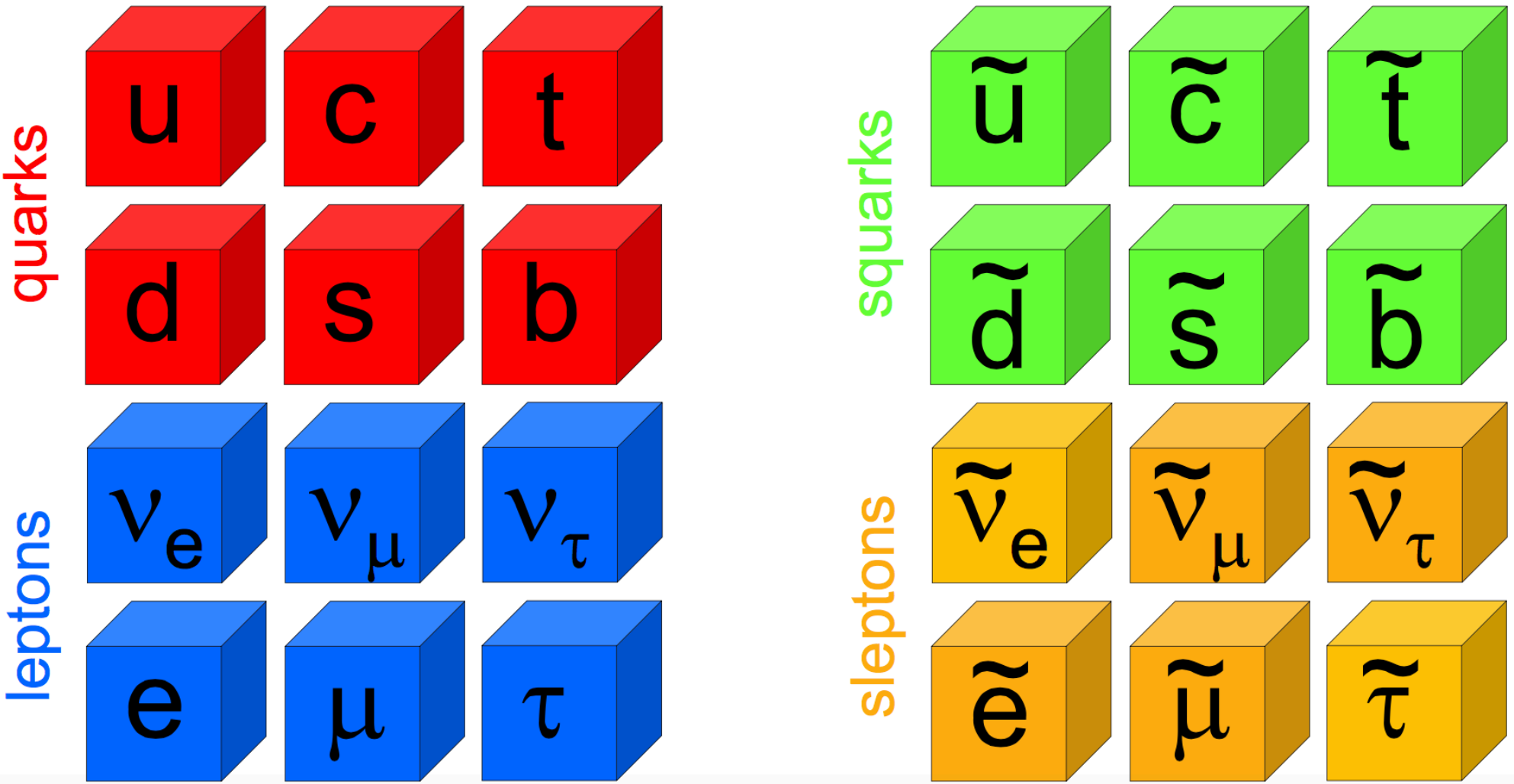
By THE FREE ASSOCIATION PRESS

The scientific community was rocked yesterday when the CMS collaboration announced the discovery of a strange new heavy particle in a press conference at CERN. “This is an historic occasion.”, said the CERN director, congratulating the CMS team that led the effort…

Backup

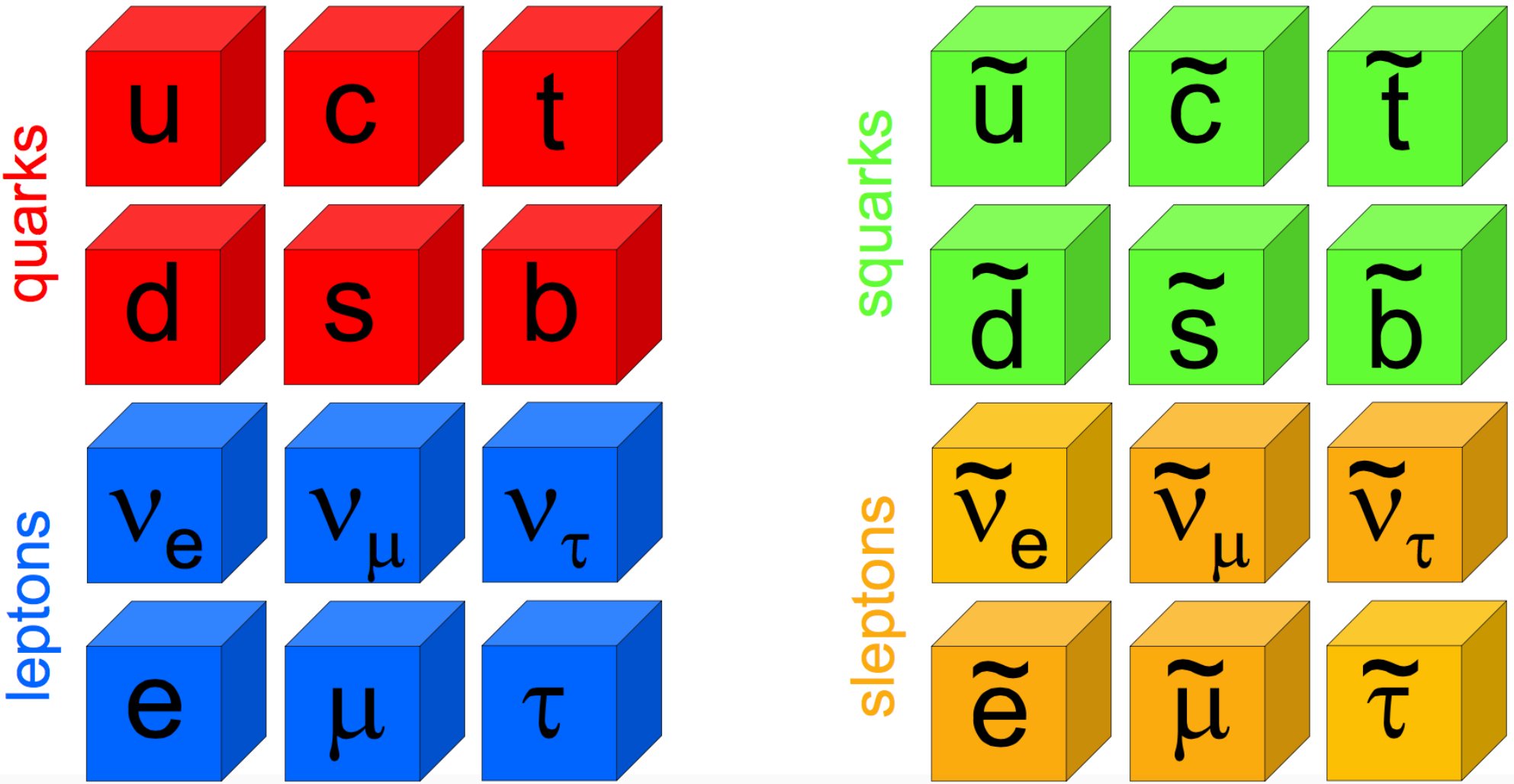
Supersymmetry

SUSY doubles the number of particles.
Each Standard Model particle has a partner



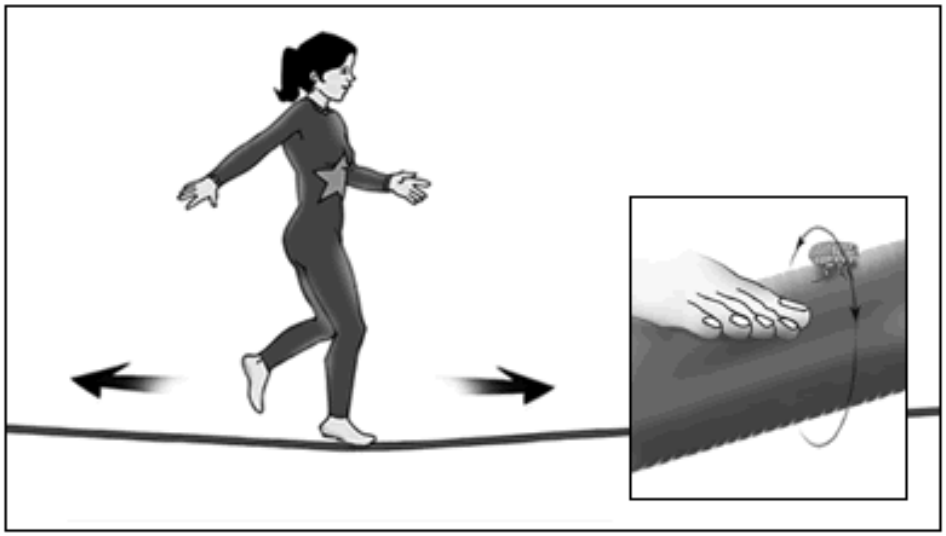
Supersymmetry

The lightest SUSY particle (LSP) is stable and could explain Dark Matter .

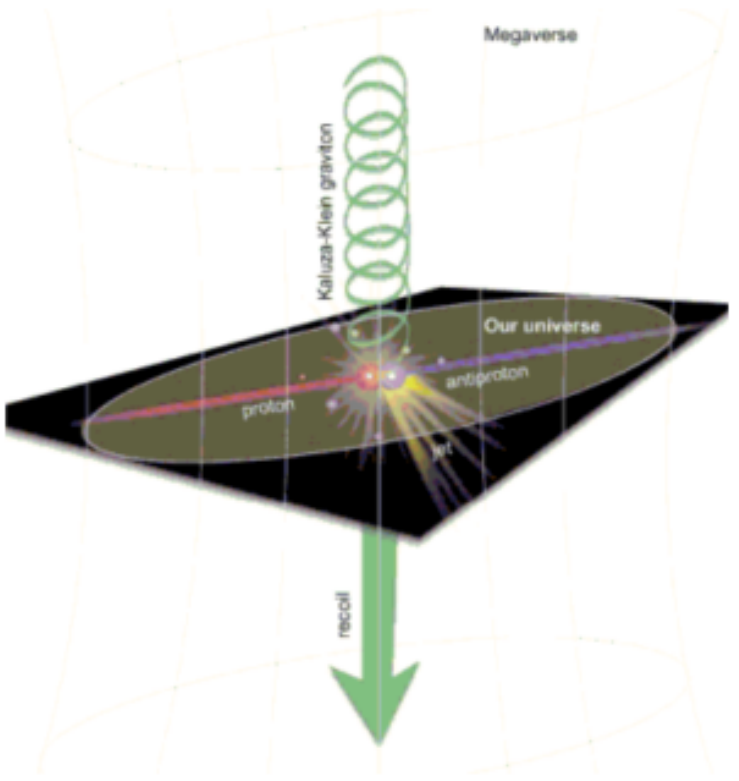


Extra dimensions

- **Extra dimensions ?**
- **Are those dimensions observable? At the LHC we will look for extra dimensions. Perhaps we can push a particle to disappear into the unseen dimensions.**

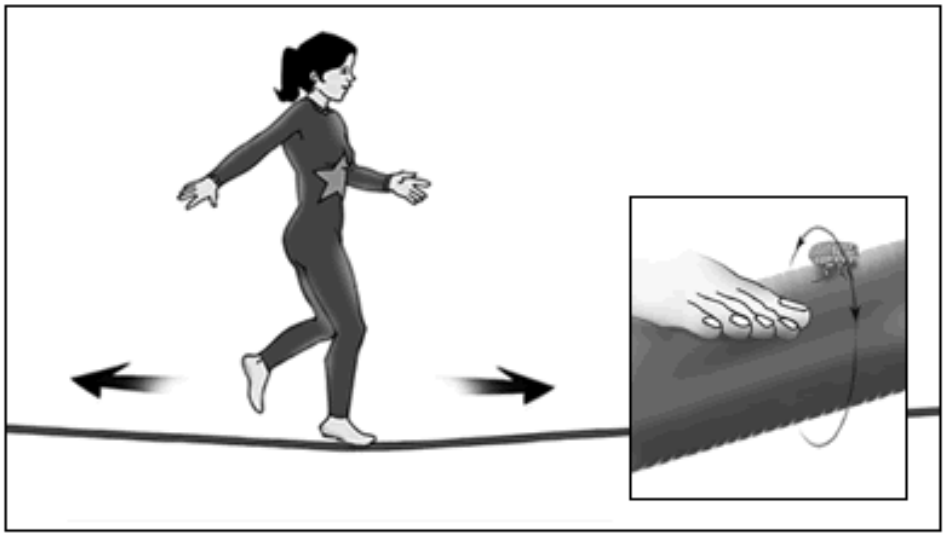


An aerialist on a tight wire can travel in only one dimension, forward and back. A flea on the wire finds a "rolled-up" second dimension.



Extra dimensions & Gravity

- **Gravity is very, very weak – a small magnet can overcome the whole Earth and pick up a nail. Is that because gravity spreads out and dilutes in the additional dimensions?**



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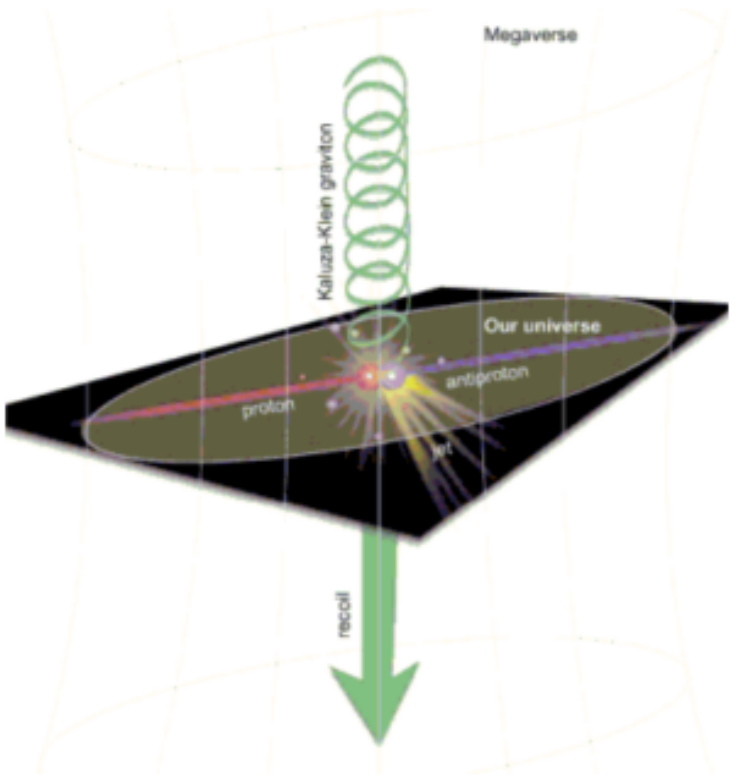
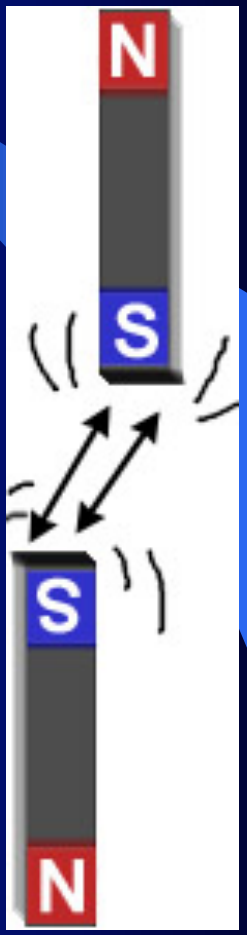


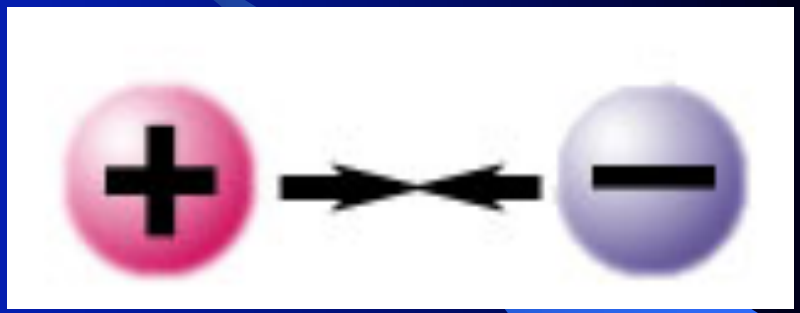
How do particles interact ?

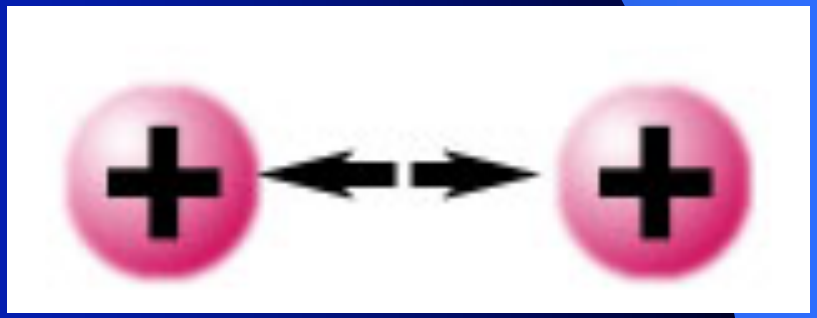
- Objects can interact without touching
- How do magnets “feel” each other to attract or repel?
- A force is something communicated between objects



Electromagnetic Interaction

- Causes opposite charges to attract and like charges to repel
- The carrier is called the **photon (γ)**
- The photon is massless and travels at "the speed of light"



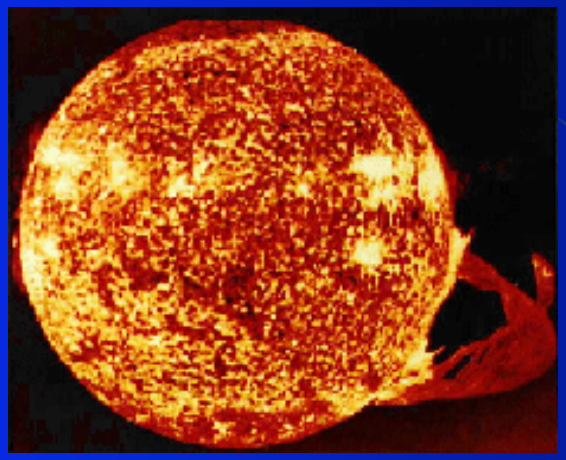


Weak Interaction

- Responsible for the decay of massive quarks and leptons into lighter quarks and leptons
- A (free) neutron decays after 15 min into a proton and an electron
  - Energy appears to be missing – it is carried off by an (anti)neutrino

Long life time (15min is an eternity in particle physics!) ⇒ "weak"

Weak Interaction



Without such weak interactions the Sun would shut down!

The carriers of the weak interaction: **W^+, W^- and Z**

Strong Interaction

What binds a nucleus together ? Or why does a nucleus not blow apart ?

The strong force binds quarks together

Overcomes EM repulsion

Carrier of the strong interaction: **Gluon**