Recreating the Big Bang with the Large Hadron Collider at CERN

Public Lecture – Jammu September 2013

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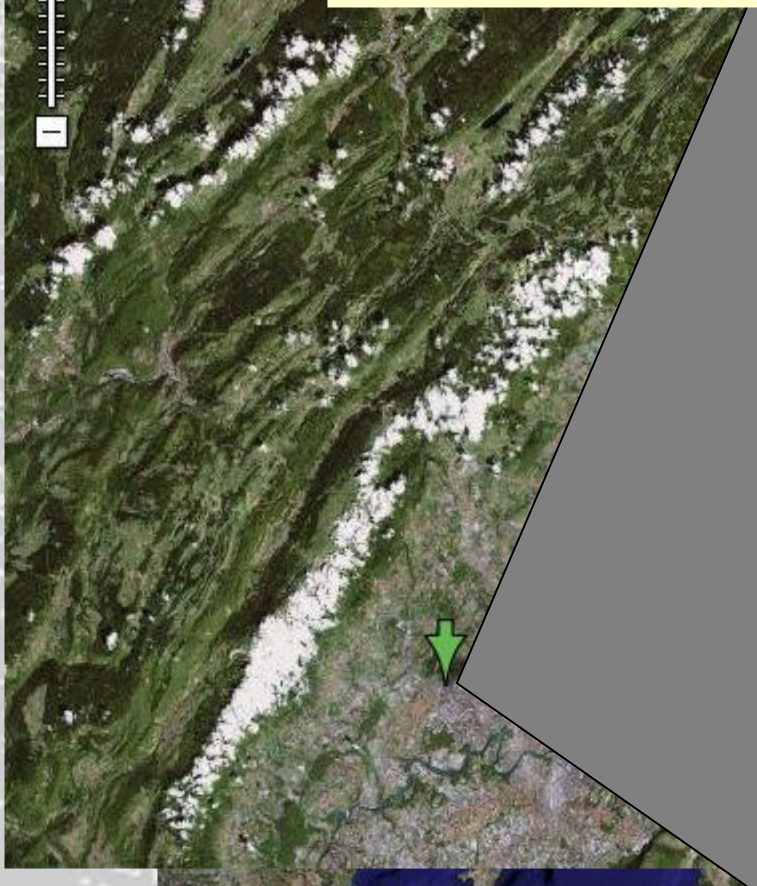
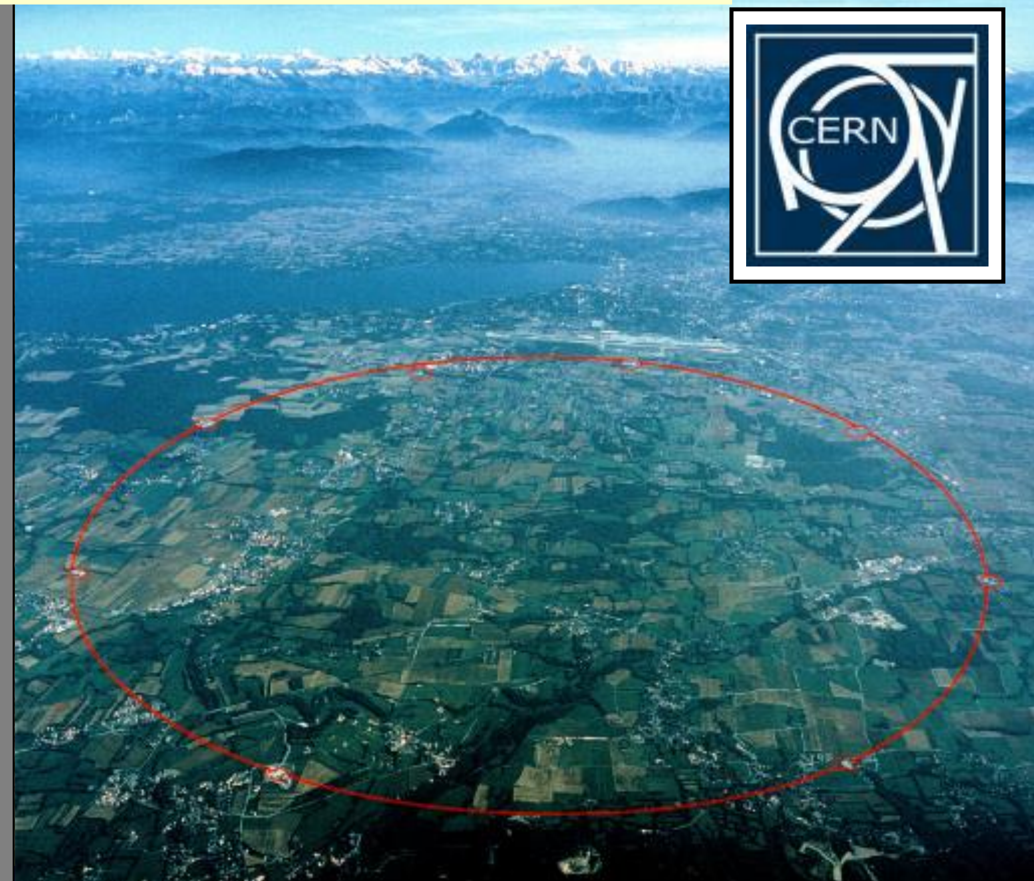
Somewhere in Switzerland…

Situated on the Swiss-French border, near Geneva

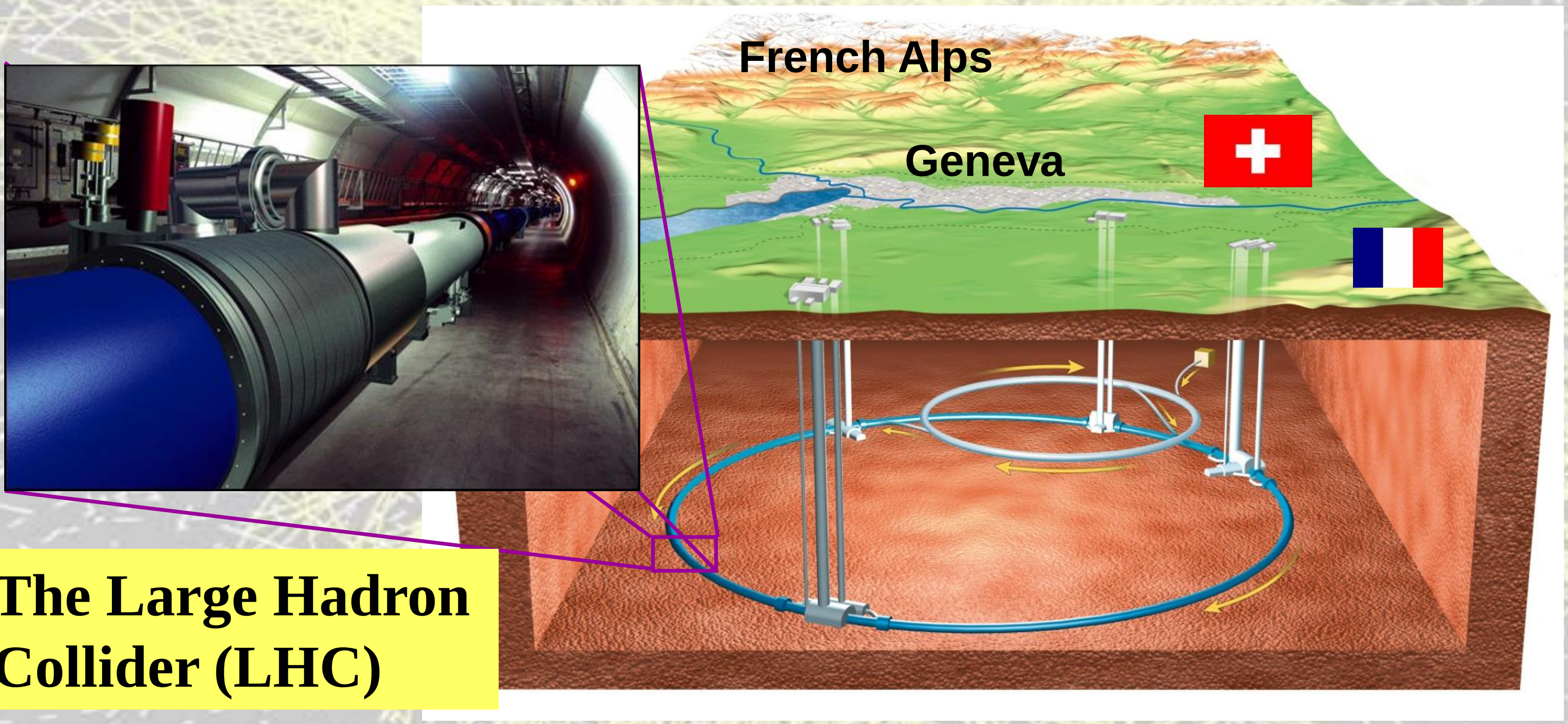
Is the World's largest physics laboratory





CERN

Deep underground, we have built the World's largest machine

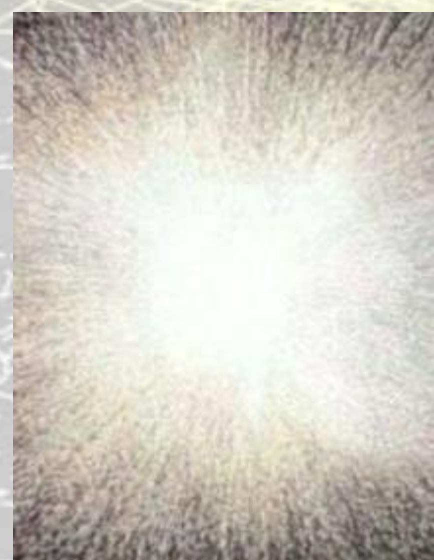


The Large Hadron Collider (LHC)

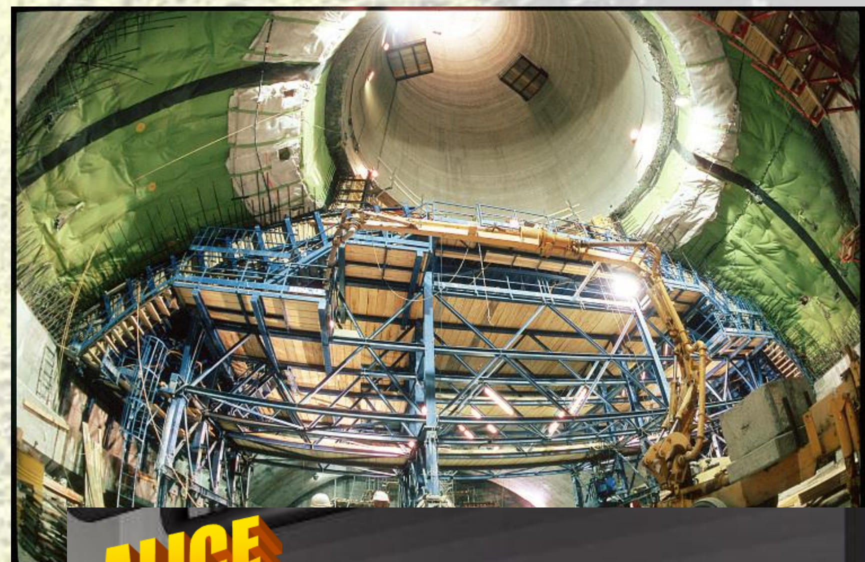
Which will accelerate sub-atomic particles to 0.999999991 the speed of light ….

Large Hadron Collider

…. and collide them together in four cathedral-sized caverns around the 27 km ring.



Creating sub-atomic explosions, and conditions that existed less than a billionth of a second after the Big Bang.



In 4 massive particle detectors

Up to 600 million times per second

The LHC

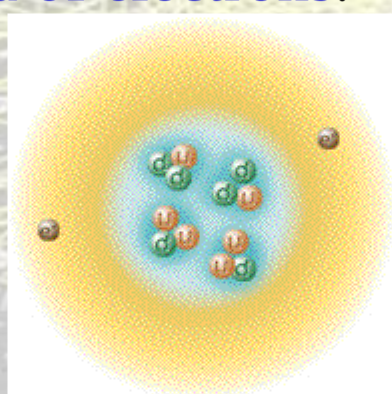
WHY?

Let's start at the beginning…..

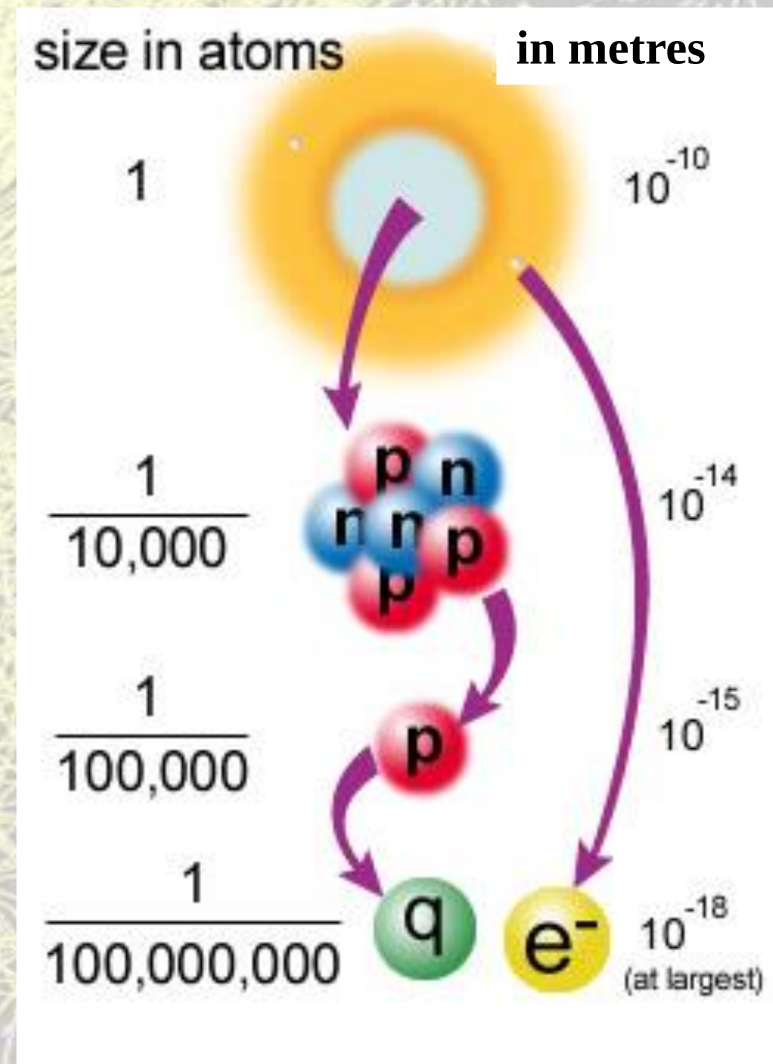
Building Blocks of Matter

We know

- All matter around us is made of atoms.
- Atoms consist of a positive nucleus (containing **99.98%** of the atom's mass) and a cloud of electrons.



- Nuclei consist of protons and neutrons.
- The protons and neutrons are made of three quarks.

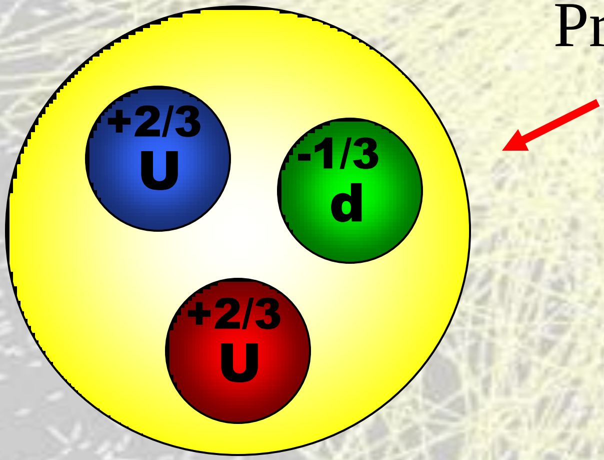


Elementary Particles

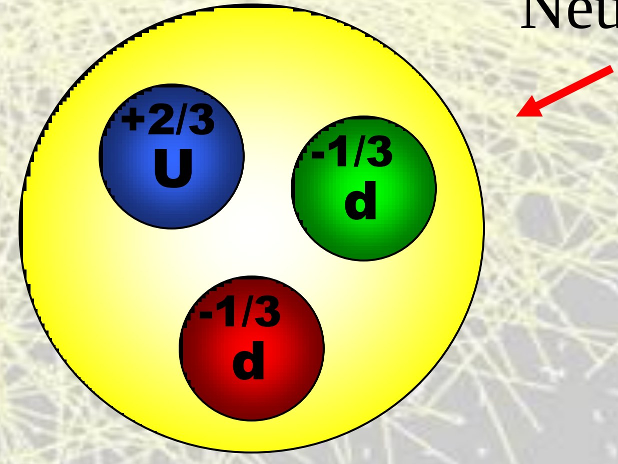
- Protons and neutrons are made from two types of quarks: Up (u) and Down (d).

- u-quarks have electric charge **+2/3** while d-quarks have charge **–1/3** (electron has electric charge **-1** in these units).

Proton



Neutron



Family of Particles

So, there is a family of particles:

Up quark (u) | **Down quark (d)** | **Electron (e^-)** | **Electron neutrino (ν_e)**

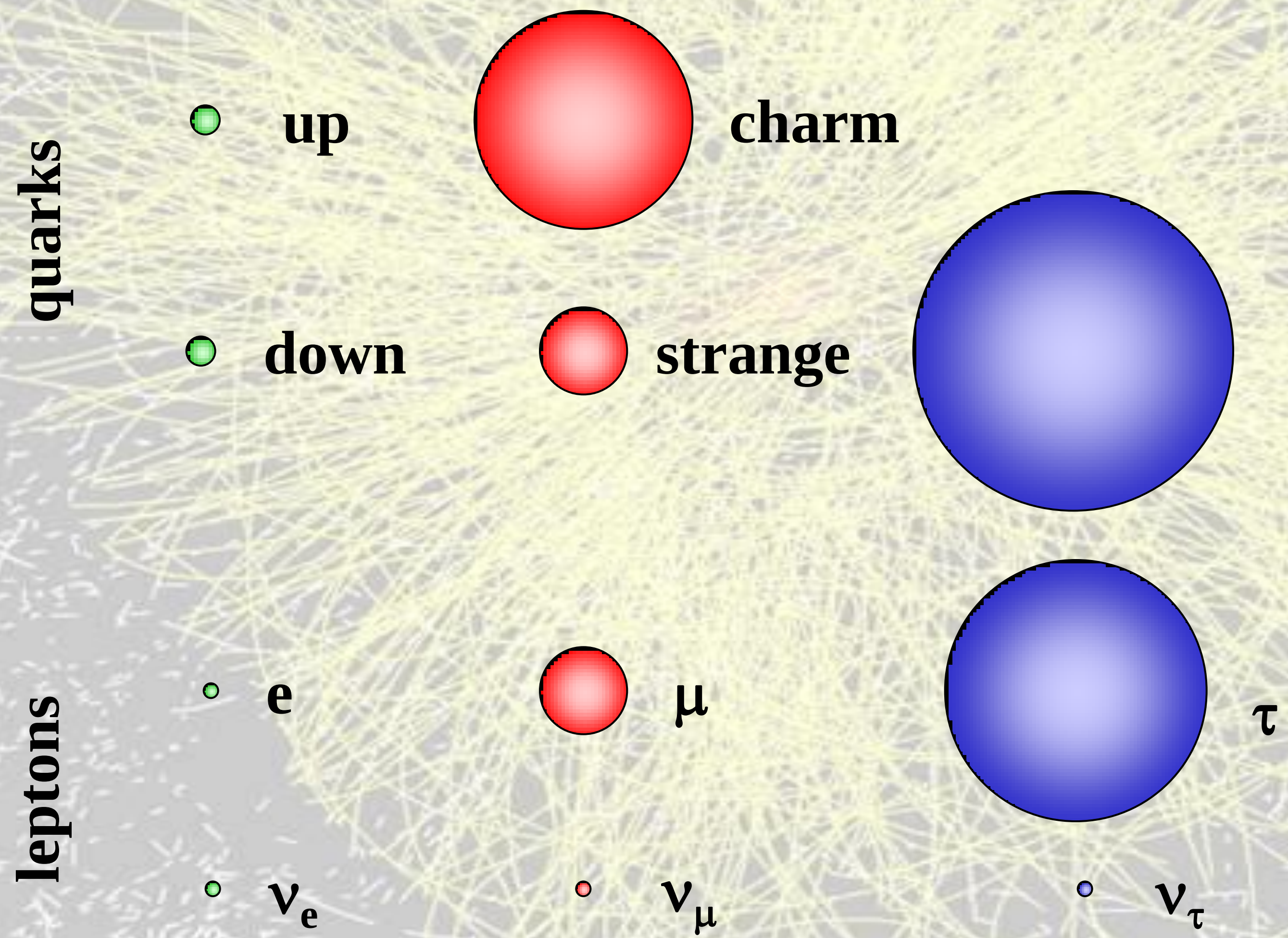
Mass ~ 0.003 ~ 0.006 = 0.0005 < 10^{-8} ?
(relative to the mass of a single proton)

Everything around us (the whole Periodic Tab… …les.

So, that's nice and simple then!

BUT….

Nature supplies us with two extra families that are very much heavier:

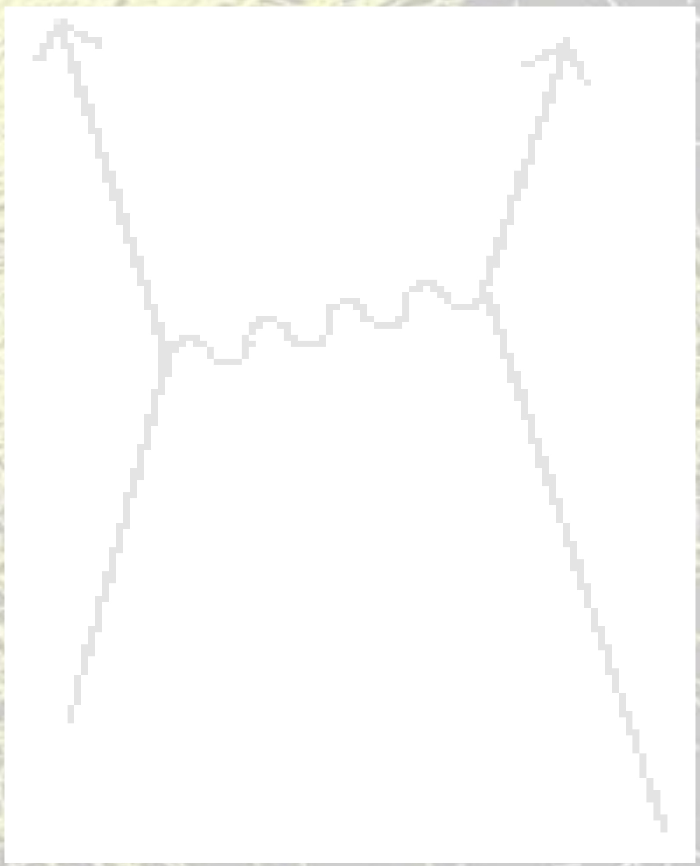


We don't know why!

Virtual Particles

The forces between fundamental particles are mediated by virtual carrier particles.

For example, the electromagnetic interaction between two charged particles (say two electrons) is understood to be due to the exchange of virtual photons.



A virtual particle is one that violates conservation of energy, but only for a short period of time ($\Delta t < \hbar/\Delta E$) – it 'borrows' energy using the Heisenberg uncertainty principle.

The Forces

For Atoms: Gravitational force is:
100,000,000,000,000,000,000,000,000,000,000,000
(a hundred billion trillion trillion)
times weaker than electromagnetic (electric) force

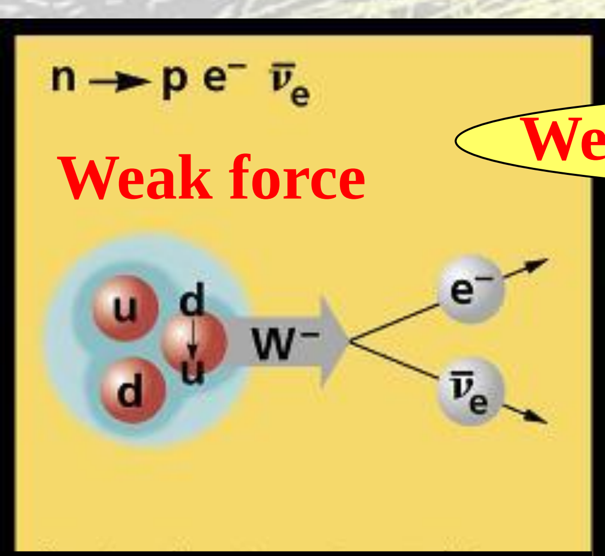
			l. Strength
			10^{-35}
			0.01
			1
Strong	short	gluons (massless)	1000

Gravity – stars, planets etc.

Electromagnetic – atoms, electricity etc.

Weak – beta decay, how stars generate energy

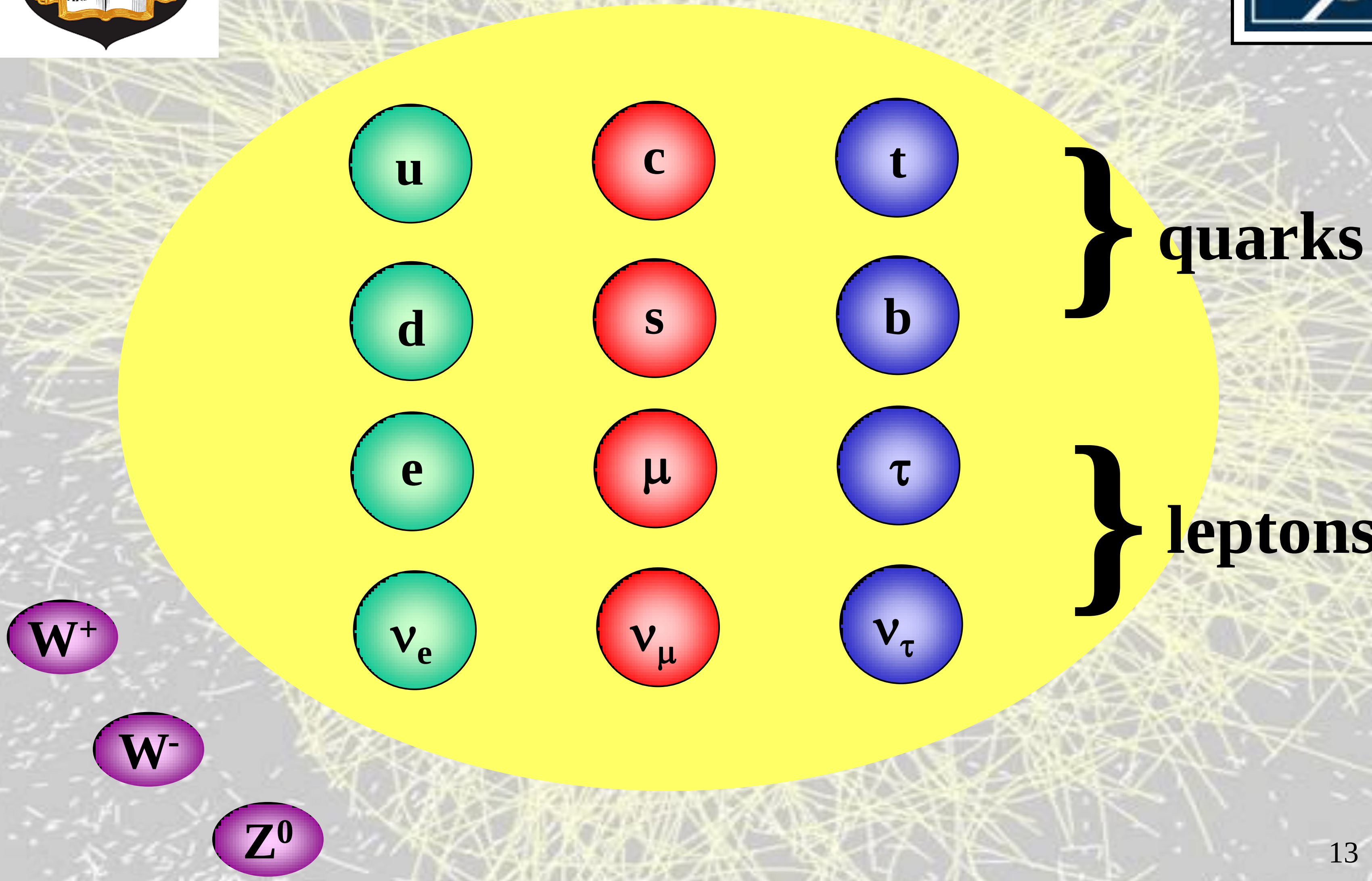
Strong – binds quarks (residual force binds nucleons in nuclei)



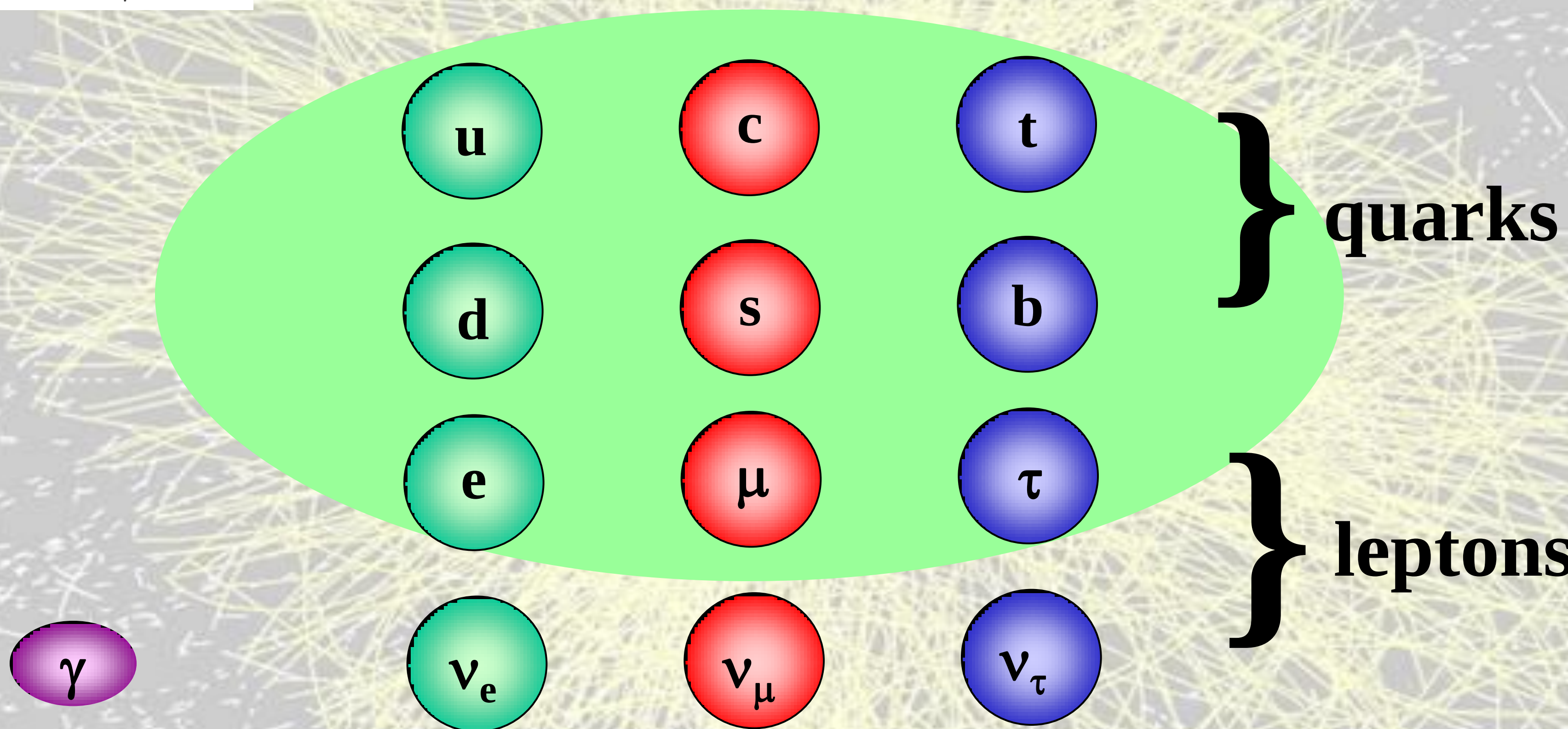
The Standard Model

u	c	t	quarks
d	s	b	quarks
e	μ	τ	leptons
ν_e	ν_μ	ν_τ	leptons

The Weak Force

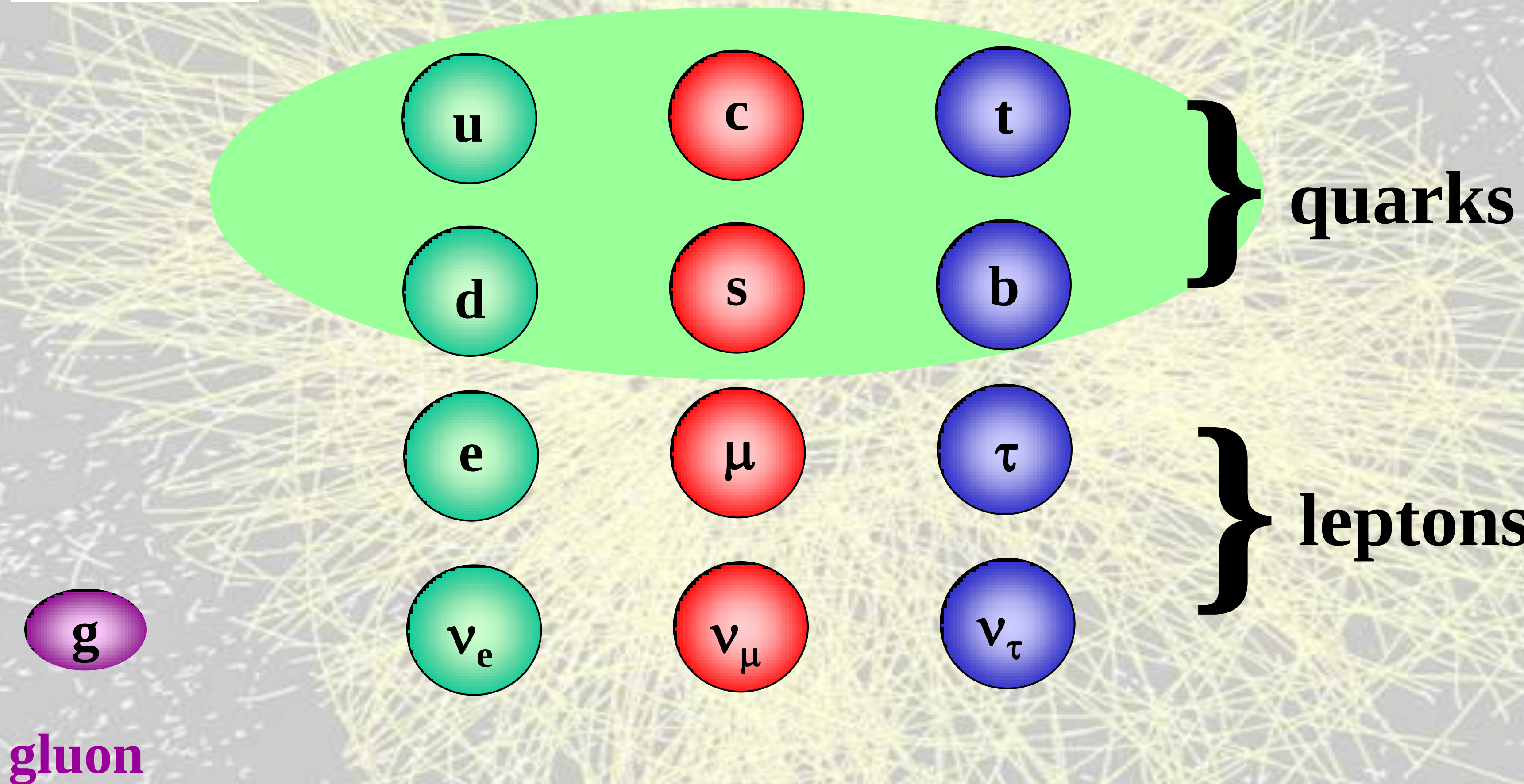


The Electromagnetic Force



Photon

The Strong Force



Gravity too weak to even consider at the atomic scale

Antimatter

- Every fundamental particle has its antiparticle.
  - These have the same mass but opposite charge.

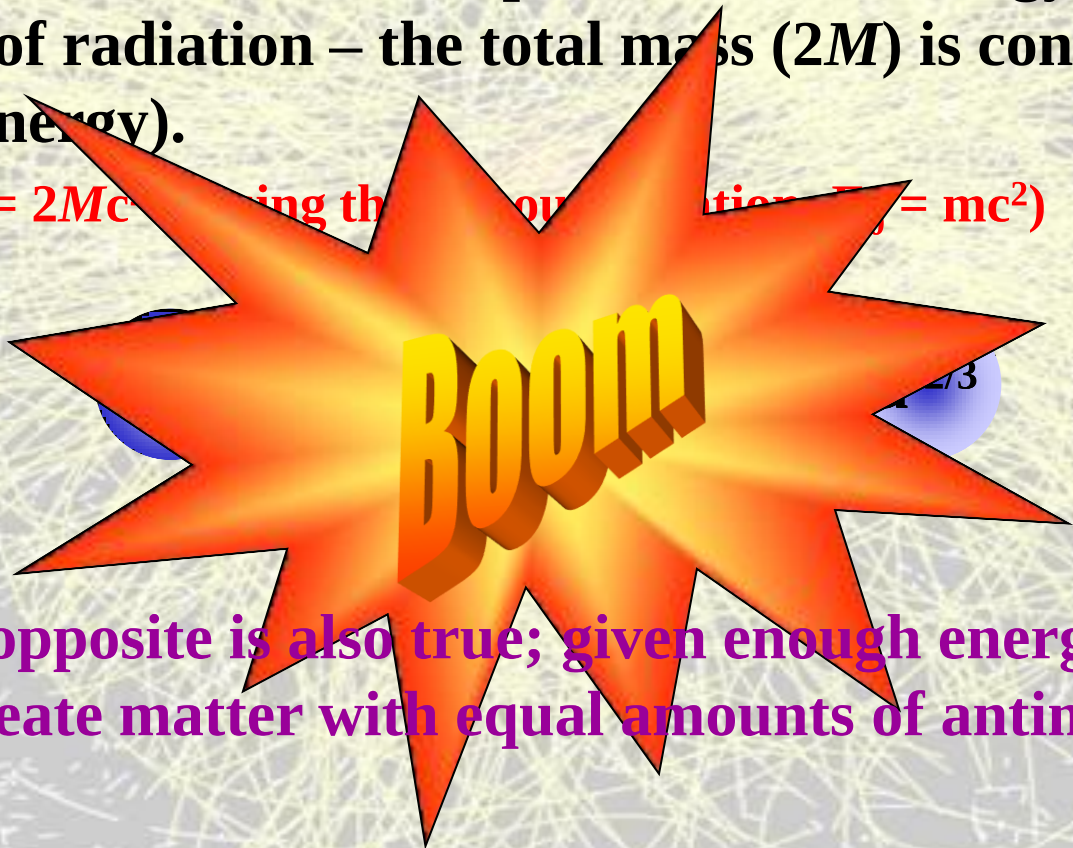
electron e^- e^+ positron

up quark $u^{+2/3}$ $\bar{u}^{-2/3}$ up anti-quark

Etc.

Antimatter

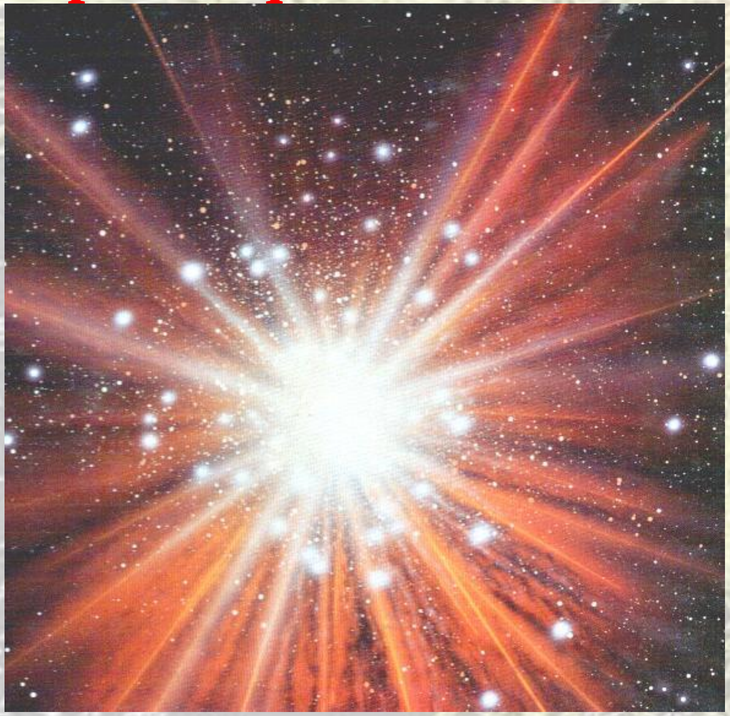
- **If a particle and antiparticle each of mass, *M* collide they annihilate with the production of energy, E in the form of radiation – the total mass (2*M*) is converted into energy).**
  - **E = 2*M*c … ing th … ou … tion E … = mc^2)**



• The opposite is also true; given enough energy, one can create matter with equal amounts of antimatter.

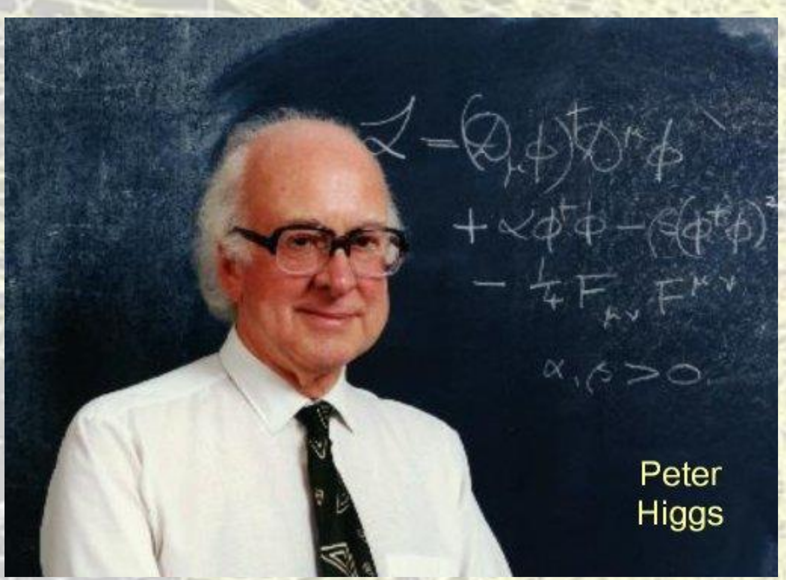
Big Bang

- **So far, our experiments show that equal amounts of matter and anti-matter are produced when energy is converted into matter – for every up quark created, an up anti-quark is also created etc.**



- **So, equal amounts of matter and anti-matter should have been created during the Big Bang.**
- **But we live in a universe made from matter.**
- **Where did all the anti-matter go?**

Other Questions – What is Mass?



In the mid 1960s, British physicist Peter Higgs came up with a theory on why some particles have mass.

He proposed a new heavy particle, now called the Higgs, which generates a Higgs field.

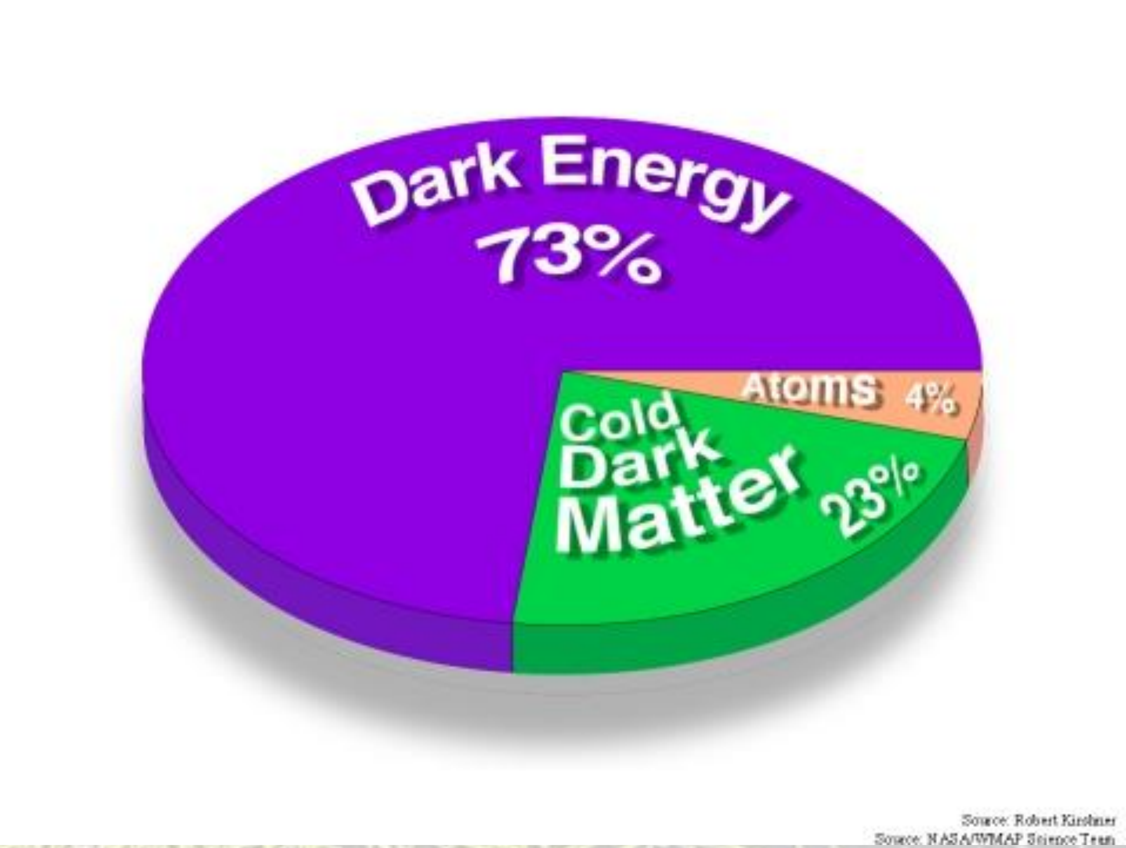
Particles who 'feel' this field gain mass.
Light particle don't feel this field strongly, heavy particles do.

Just one problem with the theory …
Nobody had seen the Higgs particle!

Dark Matter

The visible Universe (made from u, d, e, ν) only accounts for about 4% of its measured mass.

What makes up the rest?



Many More Questions …

How many dimensions?

What is mass?

What about gravity?

4 forces?

12 matter particles?

Where did all the **antimatter** go?

Why no free quarks?

Mini **black holes?**

What about the other 96% of the universe …..

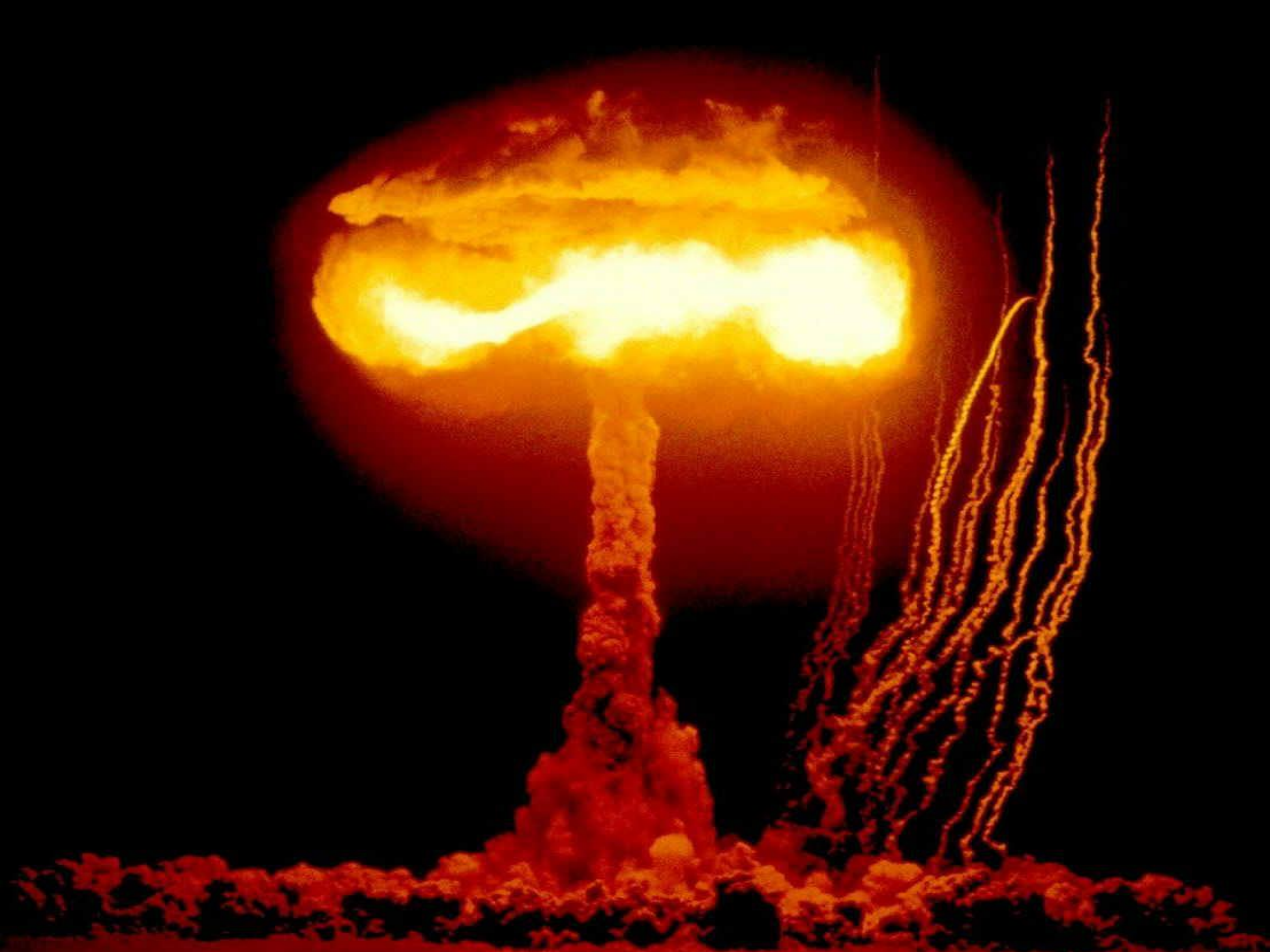
LHC Tunnel

LHC - Facts

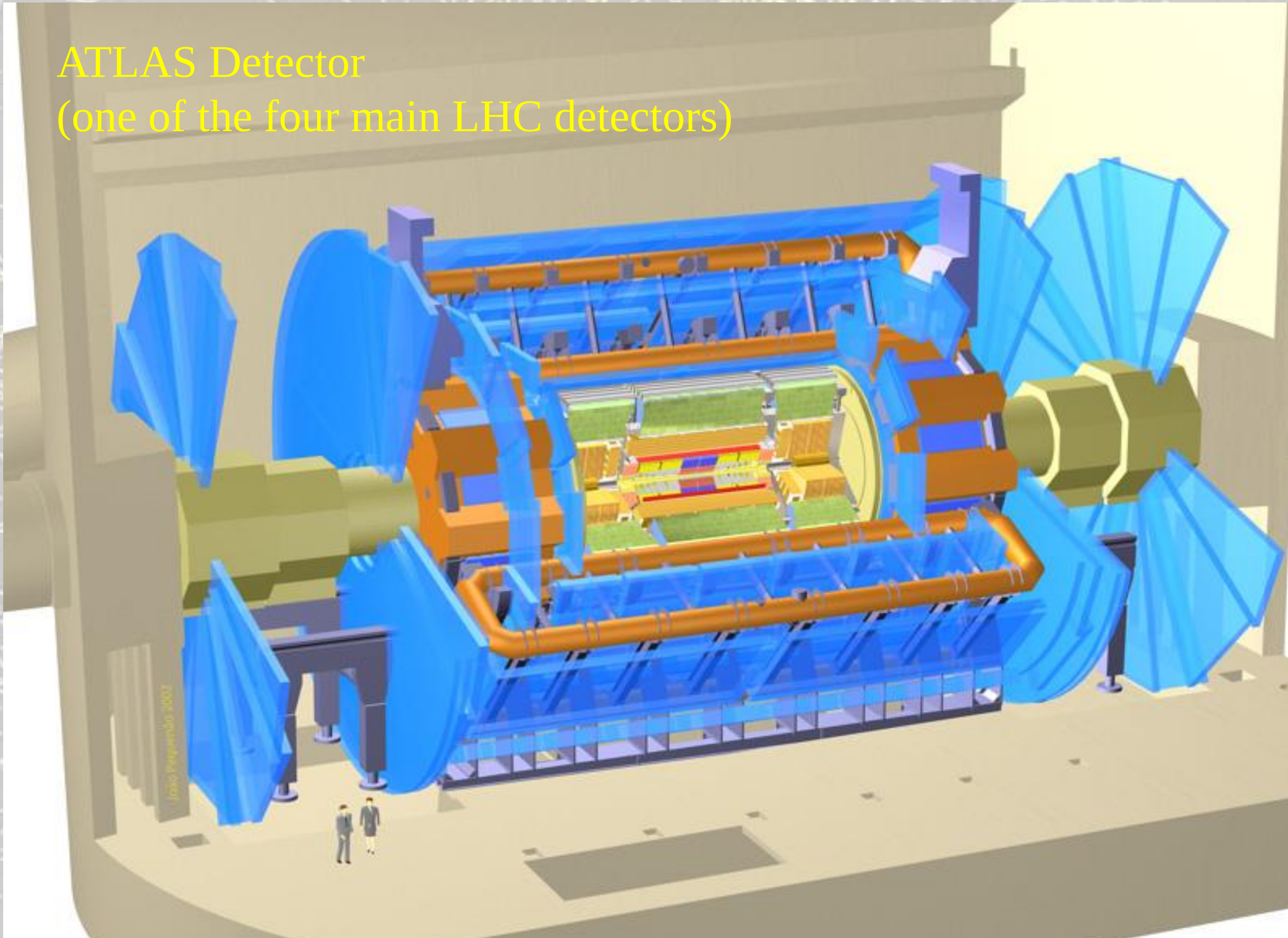
- 27 km circumference
- Each proton goes around the 27km ring over 11,000 times a second.
- 300 trillion protons in the beam
- Energy of proton beam in LHC > 0.3 GJ **(freight train travelling at 100 mph)**
- Energy stored in magnets > 1 GJ
- Super-conducting magnets cooled to ~ 1.9 K (colder than Outer Space).
- Vacuum as low as interplanetary space (10^{-13} atm)

Why so Cold?

- **At LHC energies, we need huge magnetic fields to accelerate and steer the beams of particles – about 10,000 times that of a strong bar magnet.**
- **Not possible with conventional magnets.**
- **Need superconducting magnets.**



ATLAS Detector
(one of the four main LHC detectors)



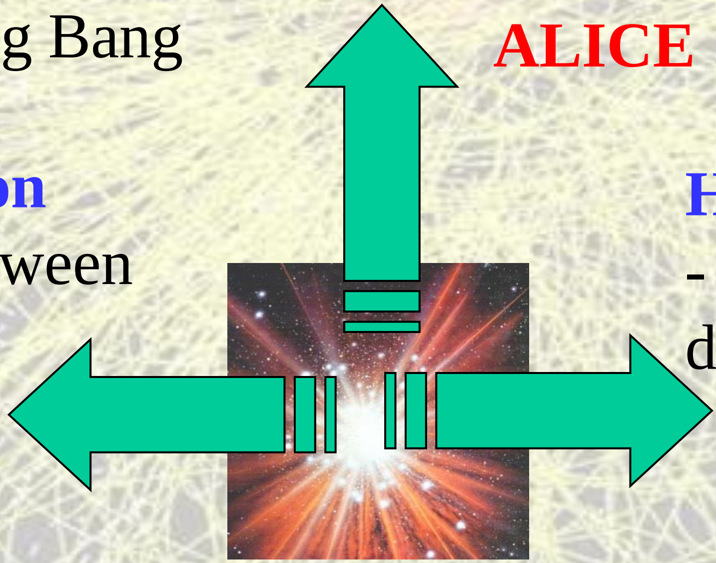
Exploring New Frontiers

- The LHC Project is pushing out the frontiers of physics in **three** directions:

Highest temperatures and densities

Recreate primordial soup (quark-gluon plasma) – a millionth of a second after Big Bang

ALICE



Highest Precision

- Differences between matter and anti-matter

LHCb

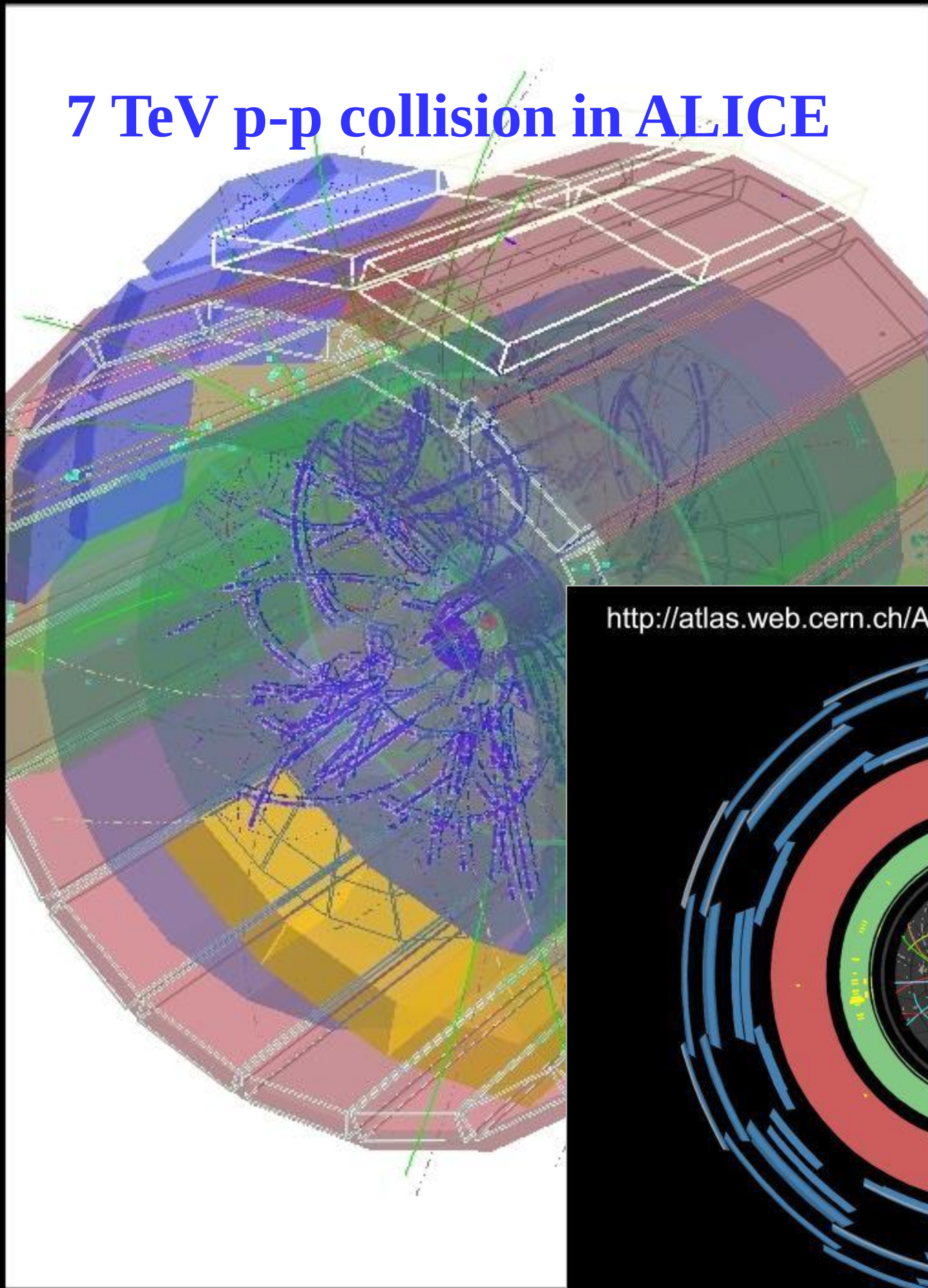
Highest energy collisions

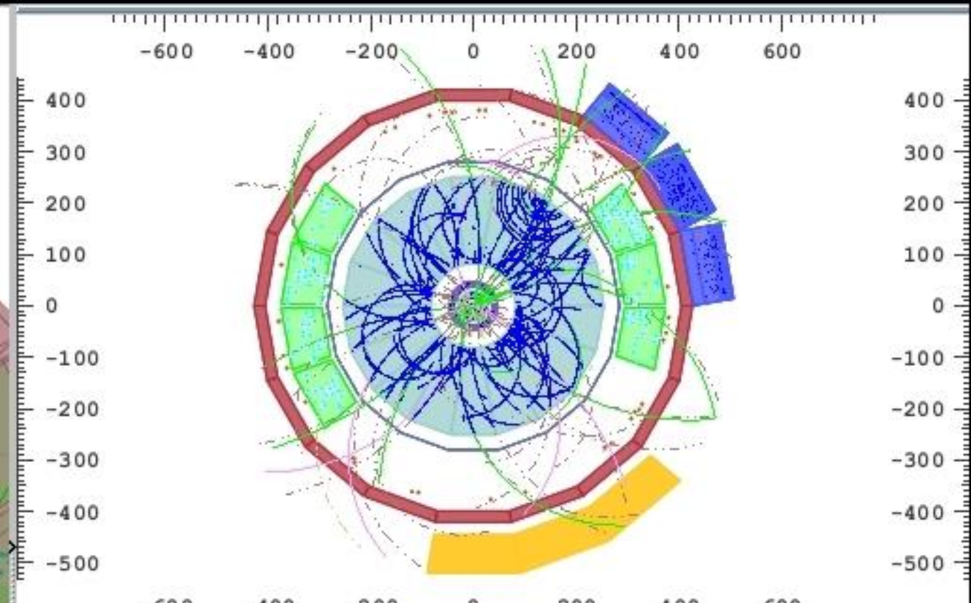
- new particles, eg Higgs, dark matter particles, etc.

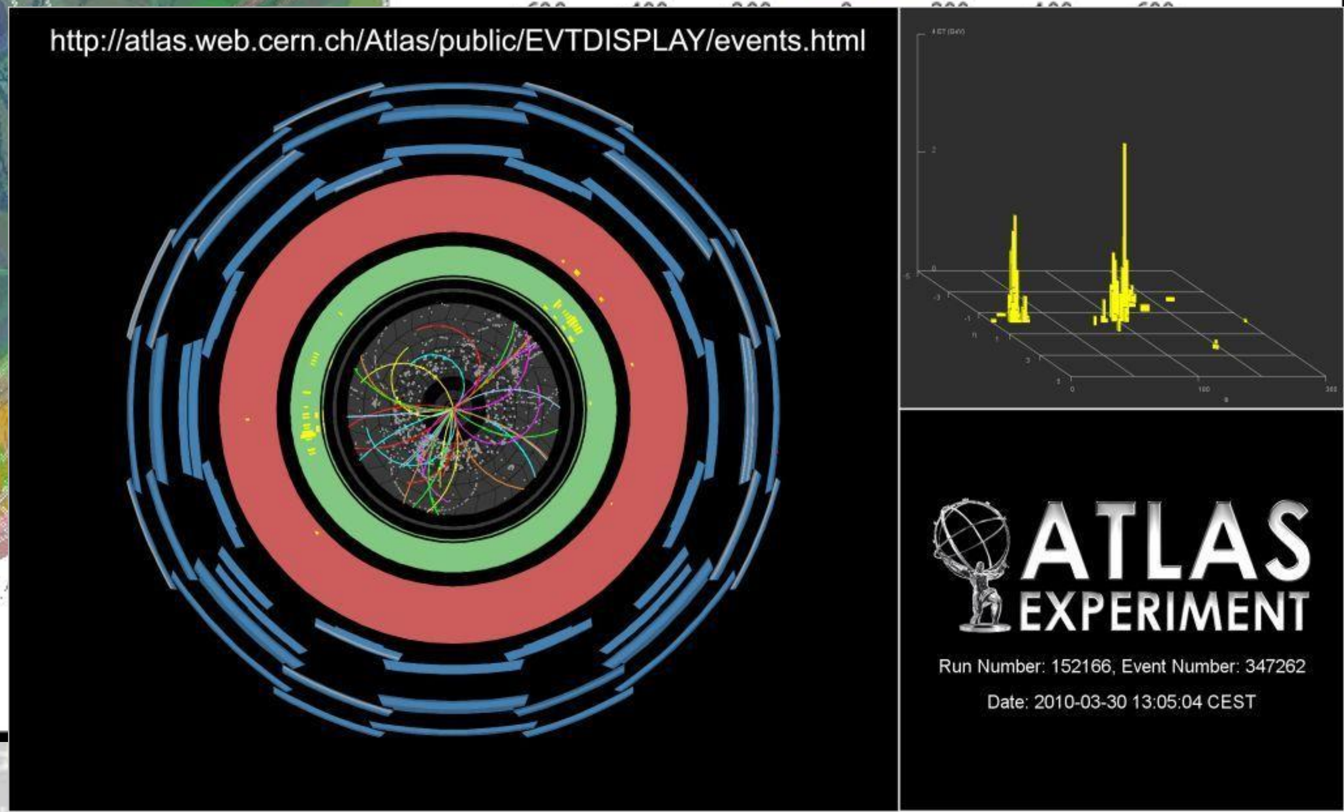
ATLAS and **CMS**

All looking for New physics

7 TeV p-p collision in ALICE

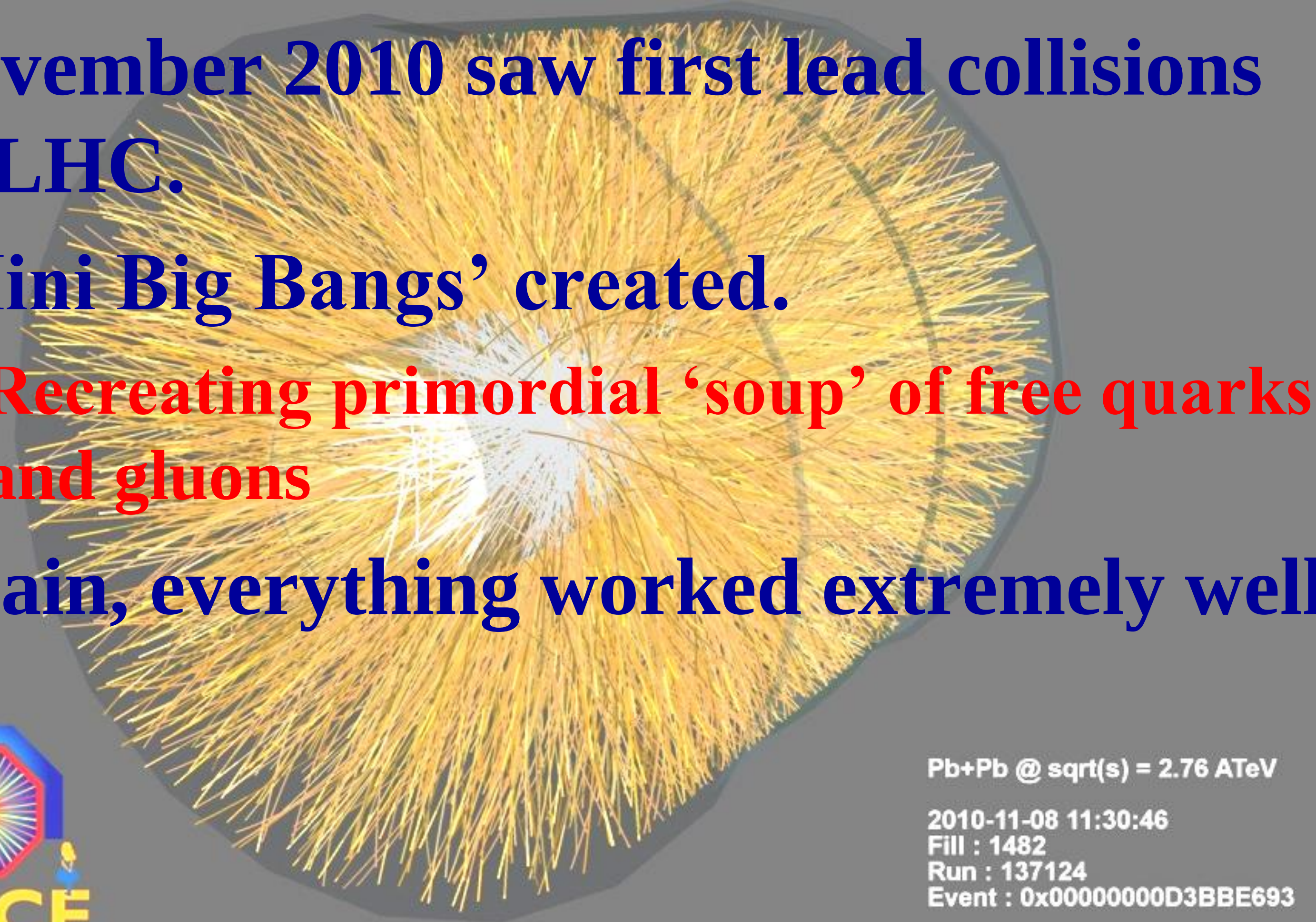






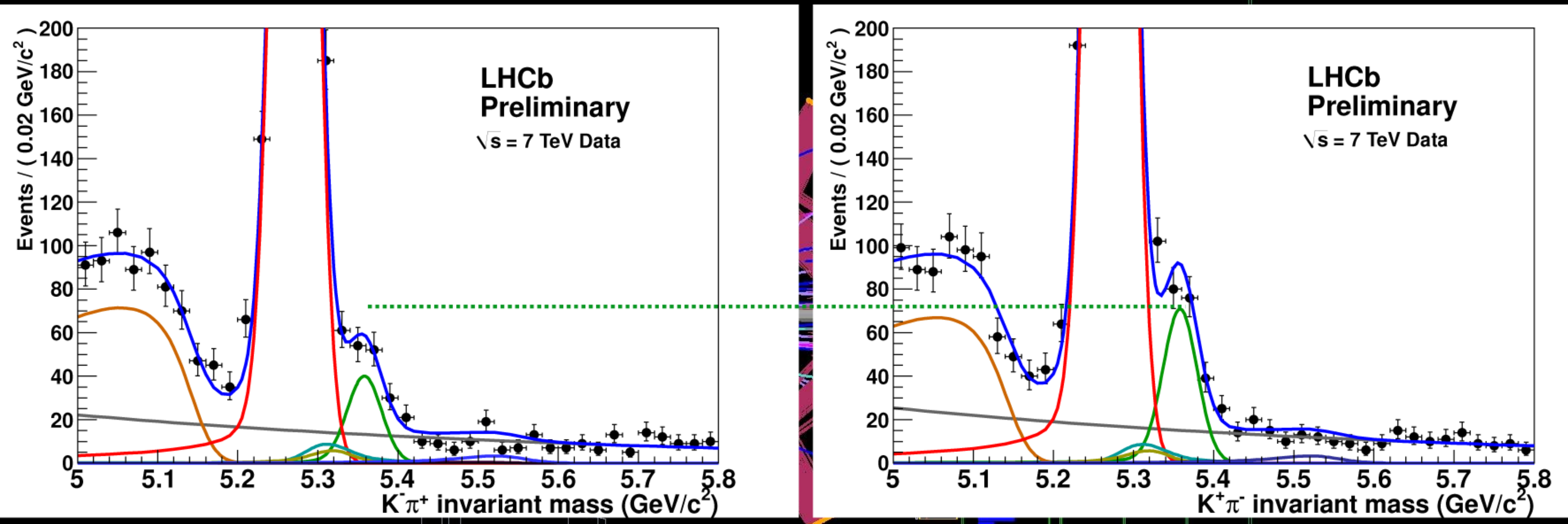
First Lead Collisions

- **November 2010 saw first lead collisions at LHC.**
- **‘Mini Big Bangs’ created.**
  - **Recreating primordial ‘soup’ of free quarks and gluons**
- **Again, everything worked extremely well**



LHCb STATUS

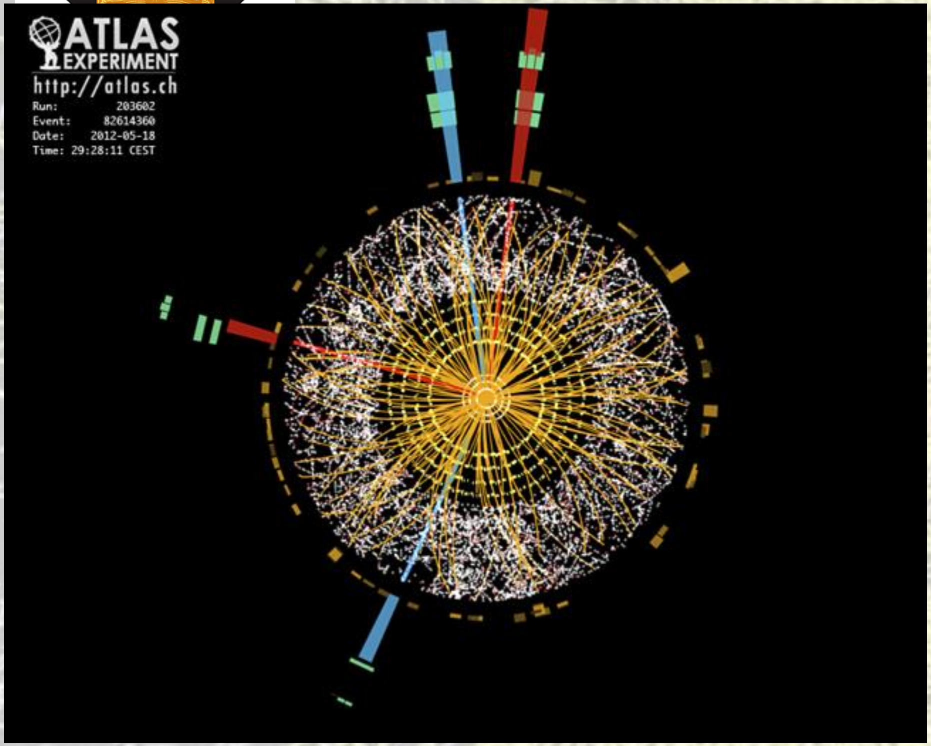
LHCb Event Display

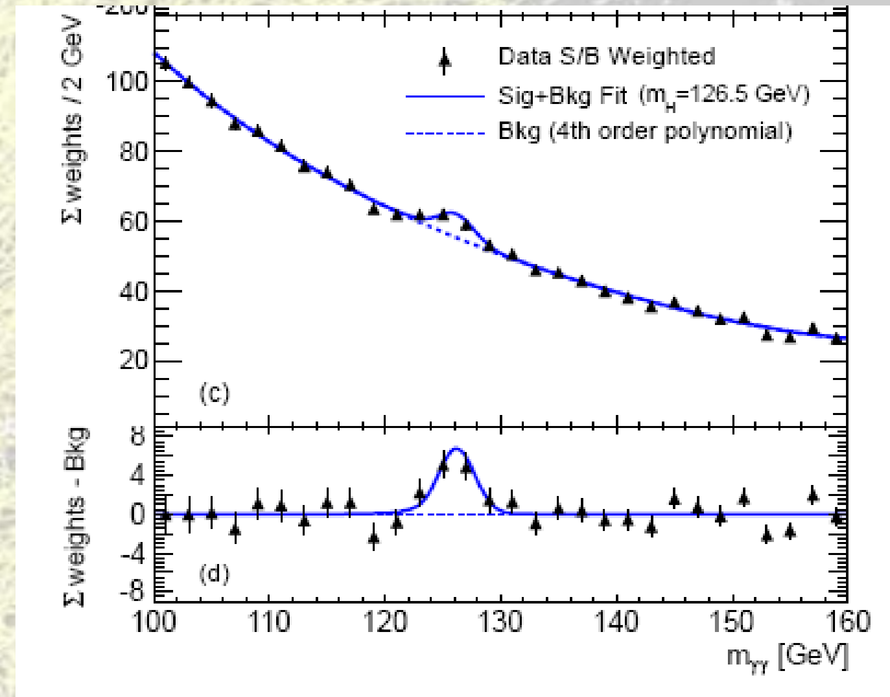


14.6. 2
Run 93

- **LHCb** already making beautiful measurements – some for the first time.
  - Already testing the differences between matter and anti-matter to the highest precisions.

Hunt for the Higgs





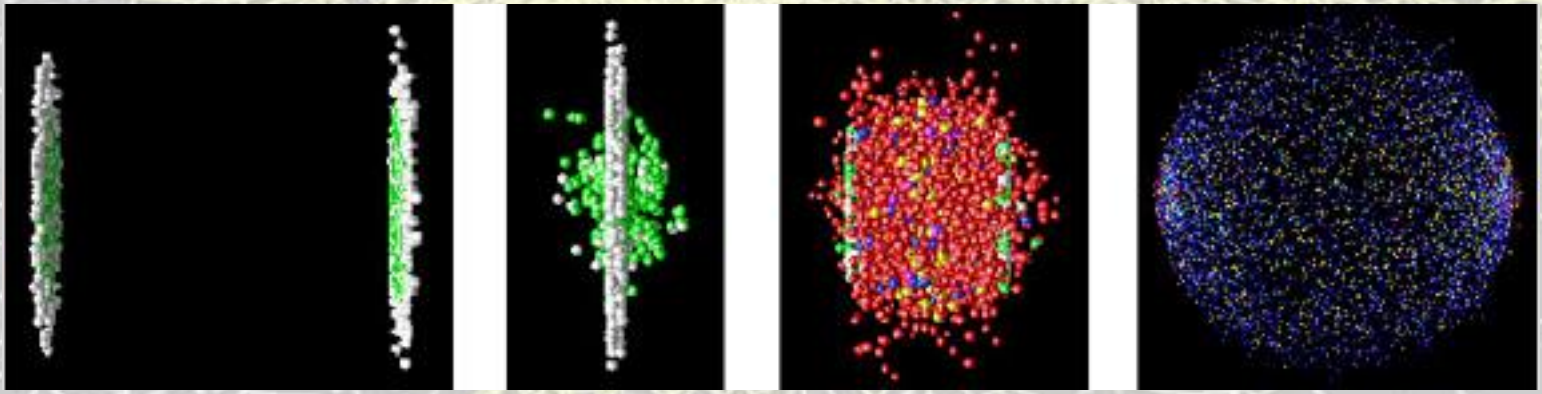
ATLAS & CMS looking for Higgs, dark matter, extra dimensions etc.

Higgs Discovery announced on 4th July 2012

Mass around 125 GeV (133 times proton mass)

ALICE STATUS

- Analysis already shows we have created the **highest temperatures and densities ever produced in an experiment**.
- Results show fireball is over **300,000 times hotter than centre of Sun and 50 times denser than a neutron star** (40 billion tonnes per cm^3).
- Primordial ‘soup’ – the Quark-gluon plasma behaves like **ideal liquid**.



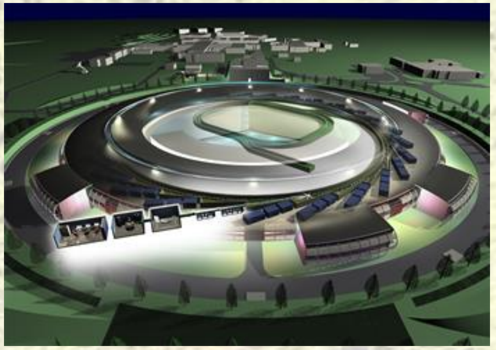
Summary

- Particle physics & nuclear has discovered much about how the Universe works
- Still <u>many</u> outstanding questions
- The World's largest machine (LHC) will add to this knowledge
- Huge challenges ahead
- But LHC will find new & exciting physics
- We will learn more about the very early Universe
- **An exciting journey of discovery lies ahead.**

Thank you for listening

Particle Physics Spin-offs

Medical Imaging

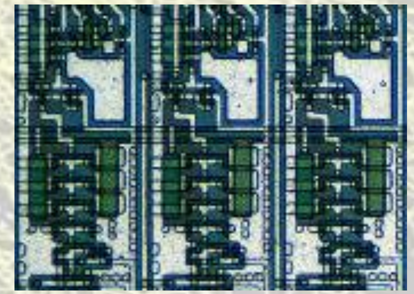


Research

Education

Computing

For every £10 spent on NHS, only 1p is spent on particle physics. No, PET scanners, no MRI scans, no cancer killing particle beams etc. without particle physics



Technology