Stuff: What is it?...
An Introduction to Particle Physics and the LHC

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UNIVERSITY OF BIRMINGHAM

Physics Work Experience Week
28 June 2012

Late 19th Century: Atoms as nature's basic building blocks

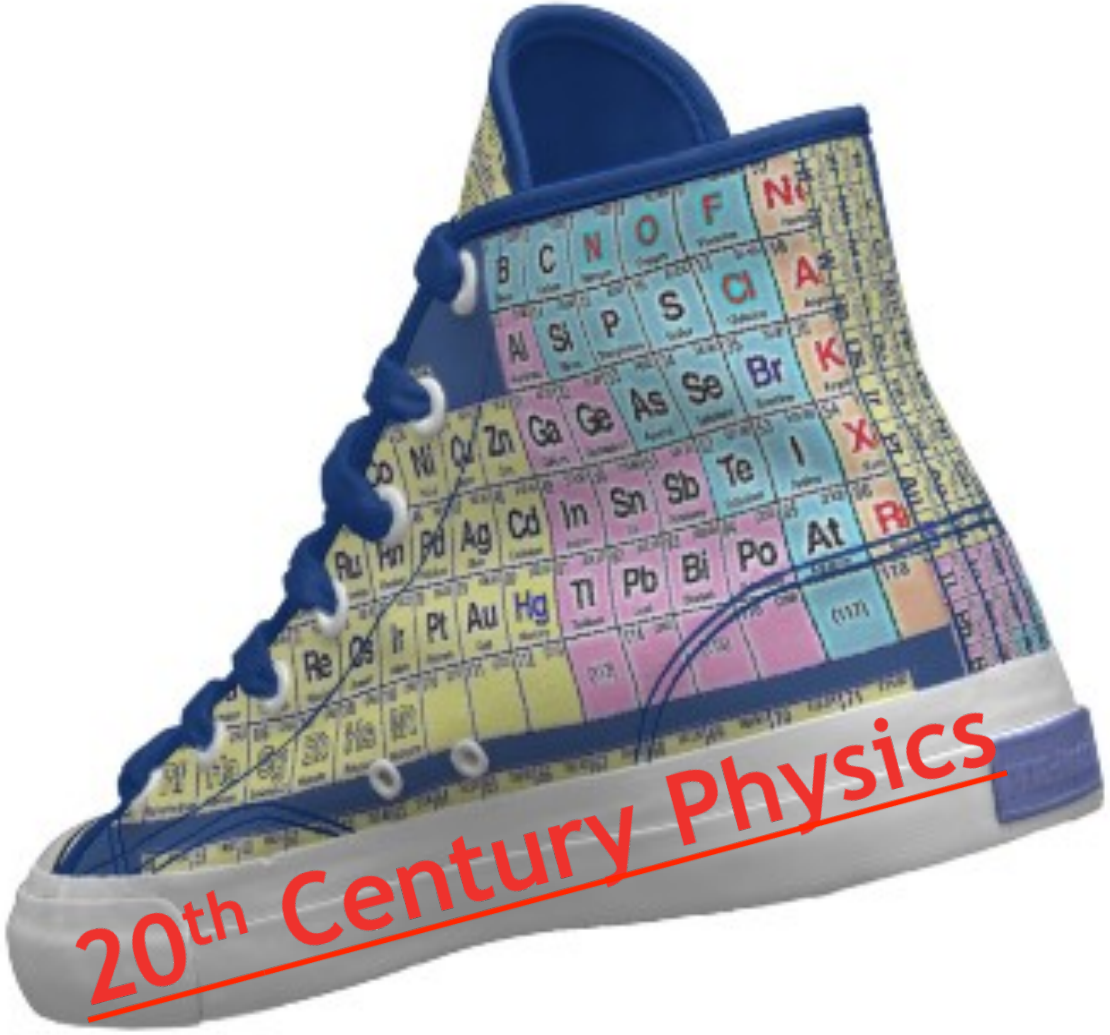
1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112 Cn Copernicium (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

"There is nothing new to be discovered in physics now,
All that remains is more and more precise measurement."

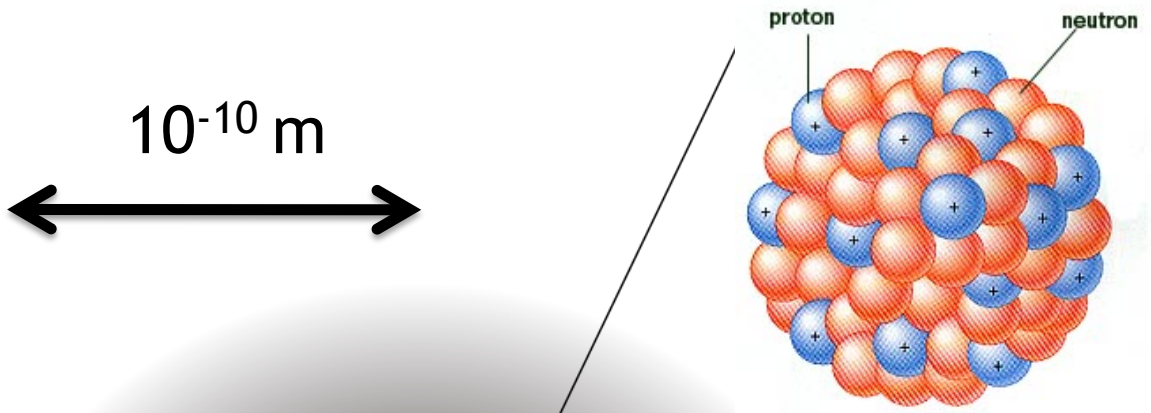
Lord Kelvin, 1900

Late 19th Century: Atoms as nature's basic building blocks



A much deeper (and simpler) structure has been revealed in collisions of very high energy particles at accelerators

A Modern Picture of the Atom



10^{-10} m

10^{-14} … 10^{-15} m

Nucleus

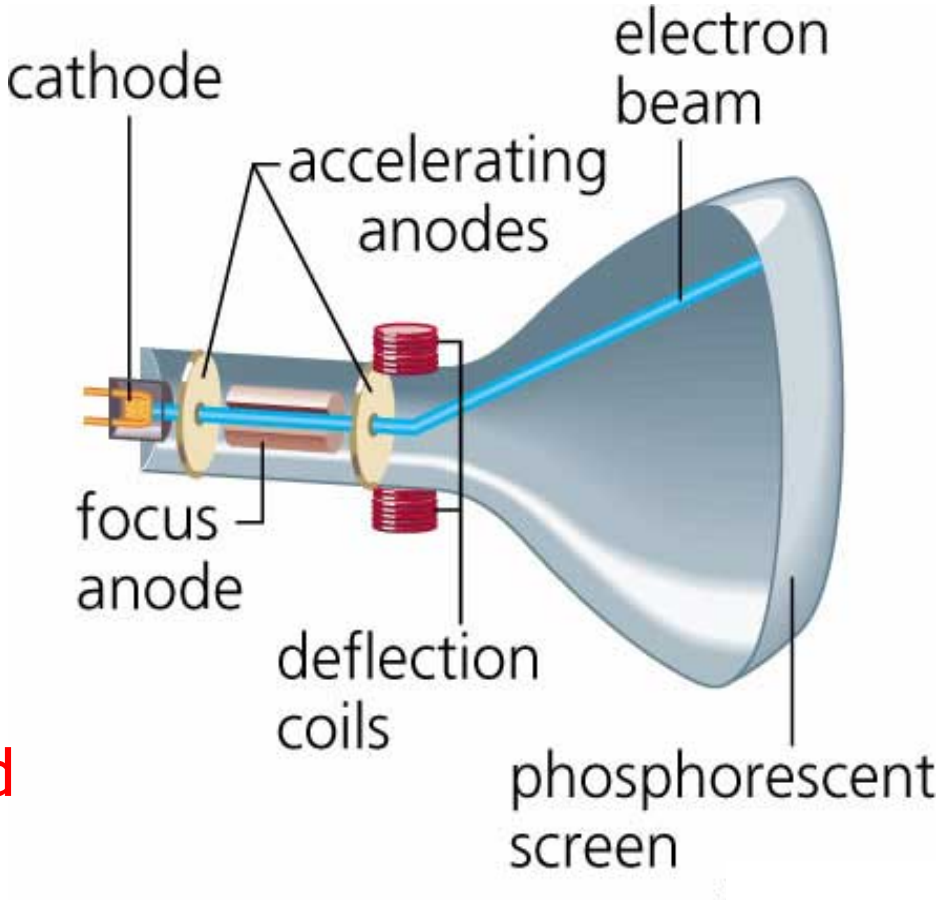
… a marble in a football stadium …

Cloud of orbiting electrons

To probe even deeper inside the protons and neutrons, we hit them with very high energy particles …

A simple particle accelerator: The Telly!

- Accelerate electrons through a potential difference (battery)
- Bend them using magnets
- Image on light-emitting screen



Particle physics accelerators are giant cathode ray tubes!

A USEFUL UNIT

A particle of charge q accelerated through a voltage V acquires a kinetic energy KE=qV.

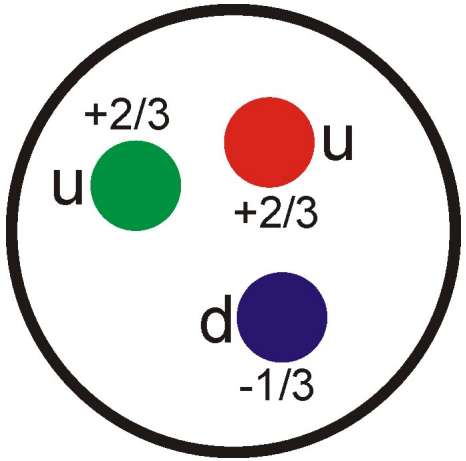
1 volt gives an electron an energy of 1 electron-volt (eV)

- A cathode ray tube TV accelerates electrons to ~ 20,000 eV
- A Large Hadron Collider accelerates protons to 7 trillion eV

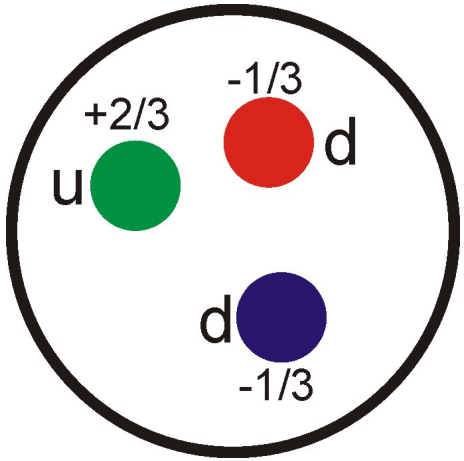
The Modern Picture of Protons and Neutrons

In 1969, an experiment using a 2-mile long 20 billion eV electron accelerator showed that protons have structure → "quarks"

- Protons and neutrons made from Up (u) and Down (d) quarks.
- u-quarks have +2/3 of electron charge, d-quarks have -1/3

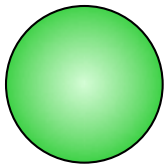
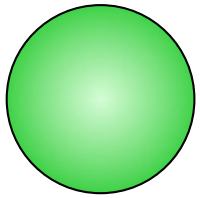


Proton



Neutron

… A Nice Happy Family of Particles

Up quark (u)	Down quark (d)	Electron (e^-)	Electron neutrino (ν_e)
			
Mass ~ 0.003	~ 0.006	= 0.0005	~ 10^{-8} ?

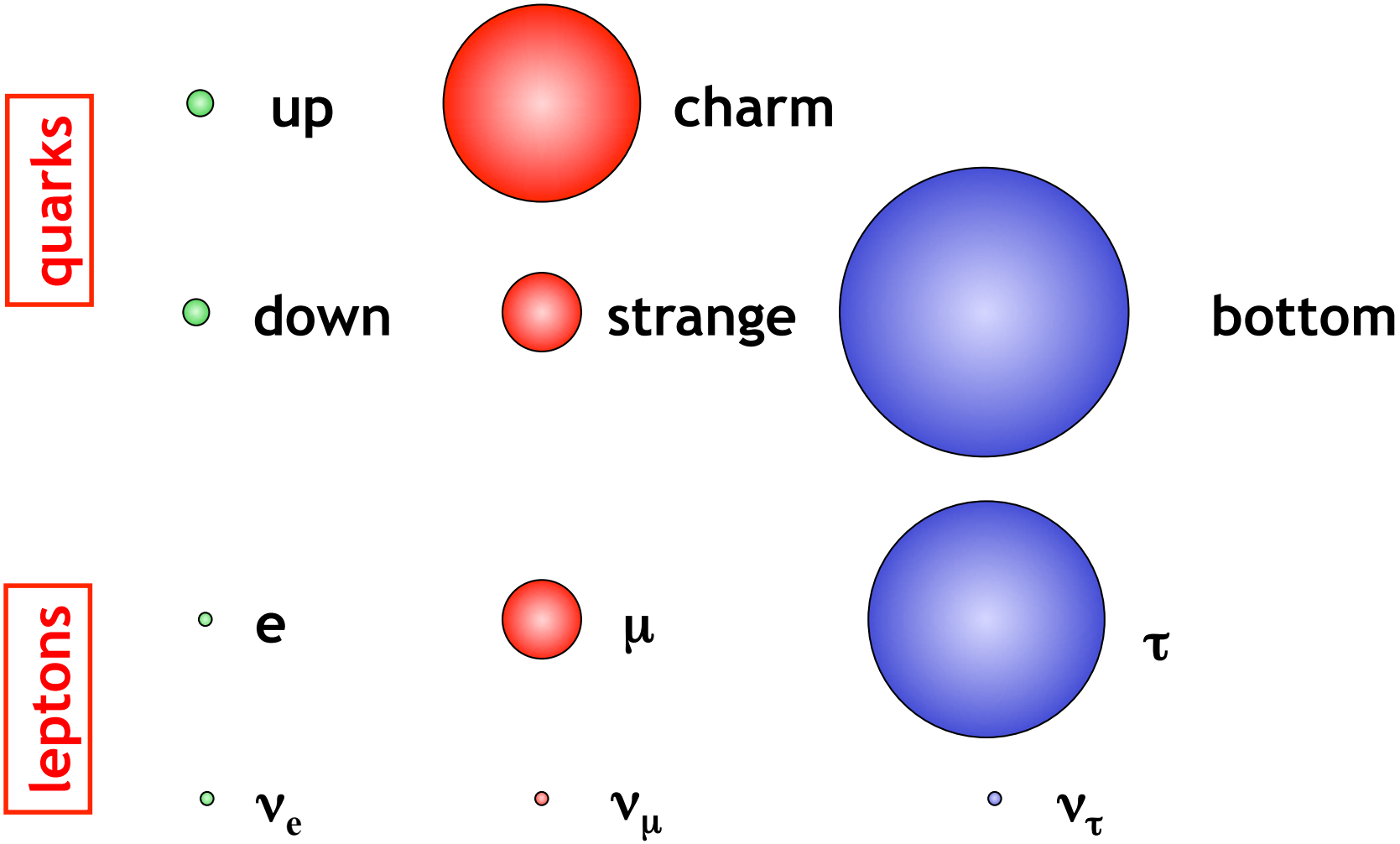
(relative to the mass of a single proton)

Everything around us (the whole Periodic Table) is made of up quarks, down quarks and electrons.

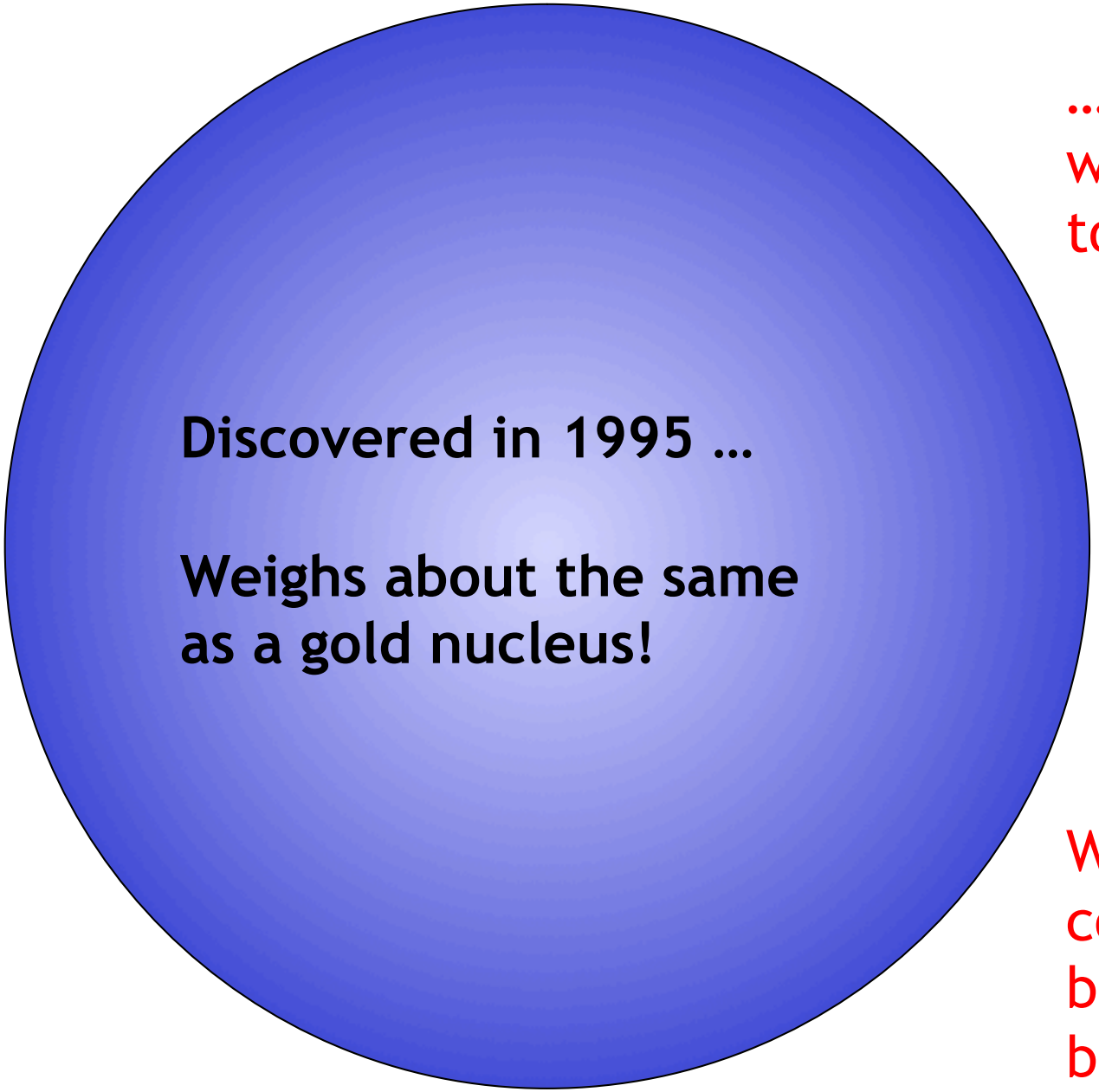
… but for some reason, there is more …

Nature supplies us with a copy of the family … but heavier …

… and another copy of the family … but even heavier …



The Top Quark



… and that is where it seems to stop

Why the heavy copies of the basic building blocks?

What about Antimatter?

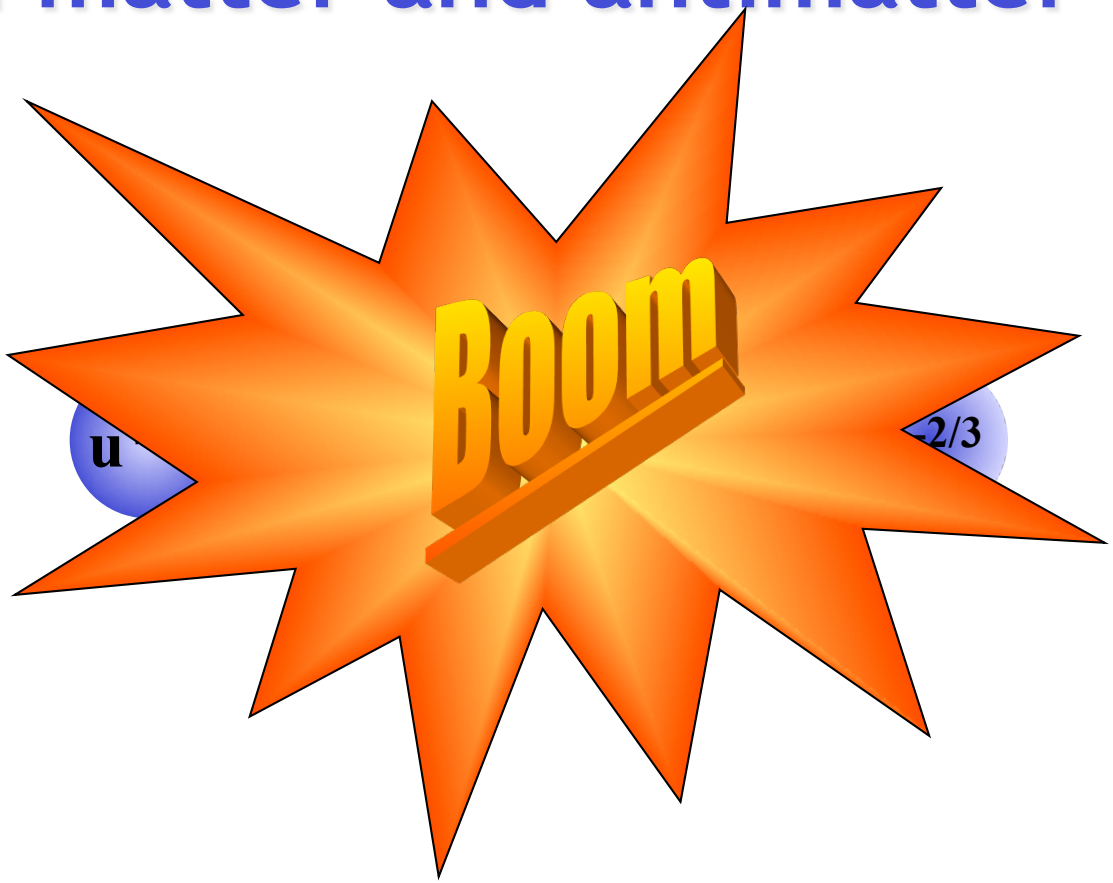
1928: Paul Dirac discovered the theory of the electron …
but it also predicted anti-electrons (`positrons')

Every fundamental particle has an antiparticle, with the same mass, but opposite charge.

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

etc etc …

When matter and antimatter meet …



• If a particle and an antiparticle, each of mass m, collide, they annihilate, producing energy $\underline{E = 2mc^2}$

• That energy can be used to produce new (perhaps undiscovered?) particles …

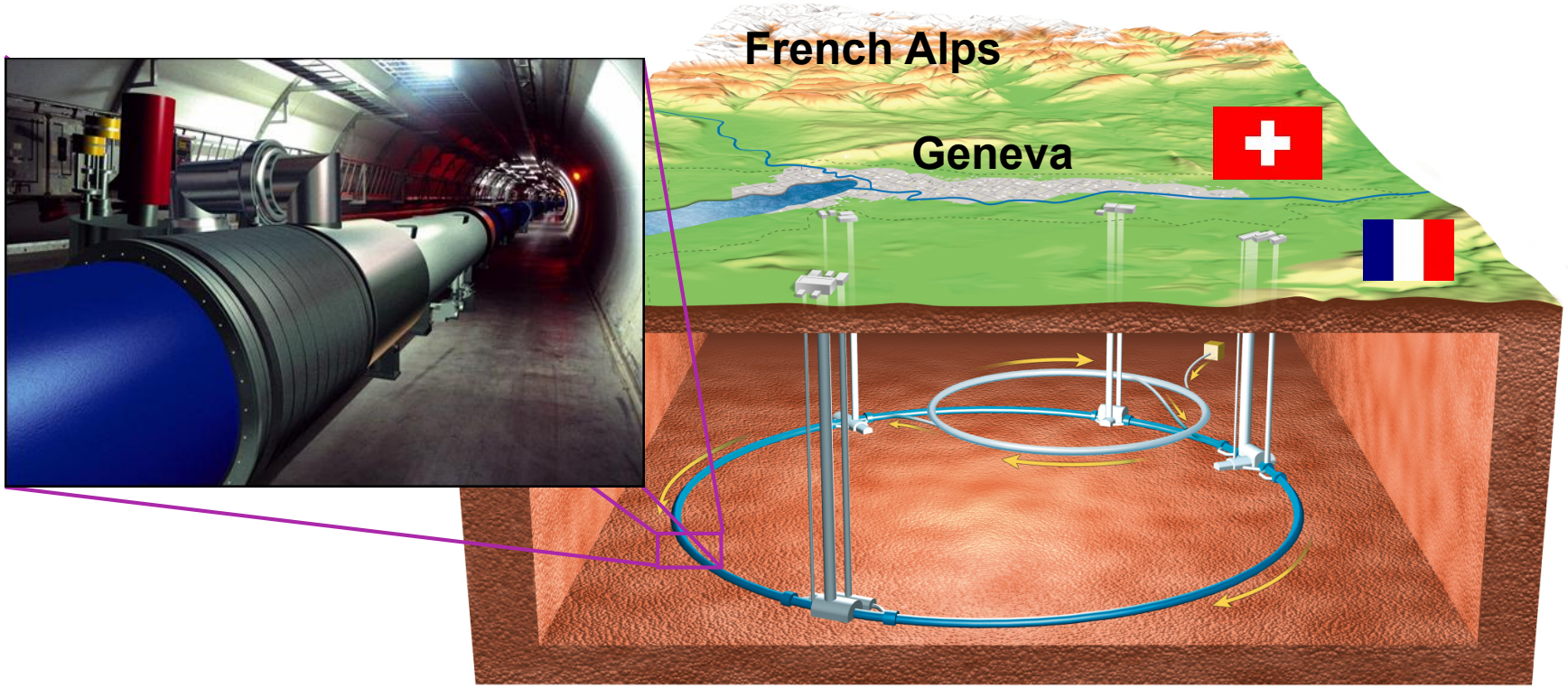
→ The present day …
on the Swiss French Border …

… near Lake Geneva, between the Alps and the Jura

… is the world's largest Physics Laboratory

CERN

… what CERN is currently doing …

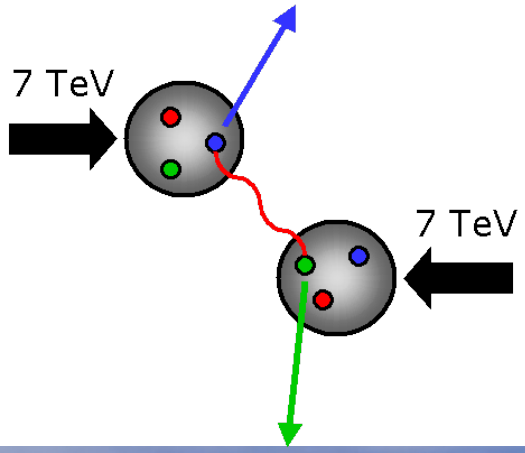


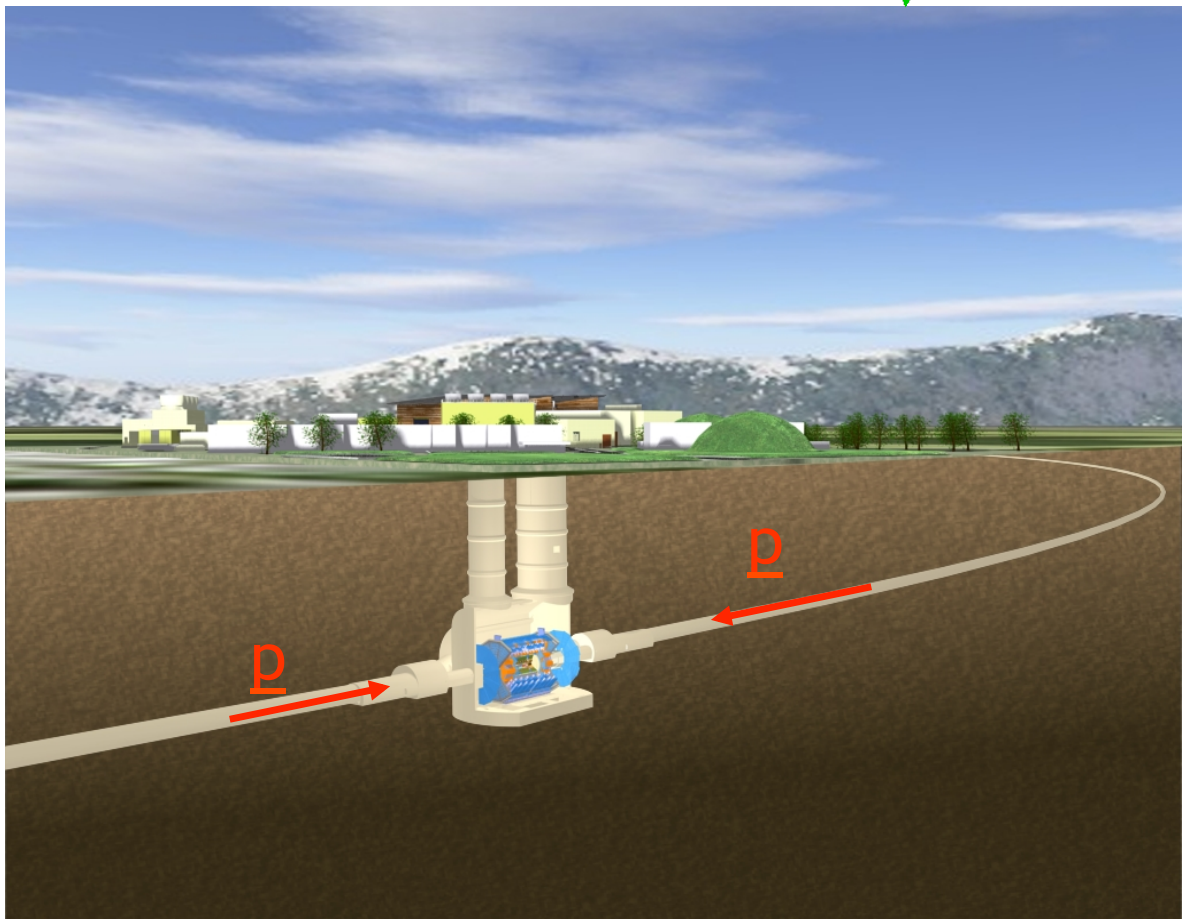
The Large Hadron Collider (LHC)

100m underground … in a 27km long tunnel…
… accelerates protons to 0.99999996 of the speed of light.

The LHC Beams

Colliding protons with 7 TeV each (7×10^{12} = 7 trillion electron-volts)





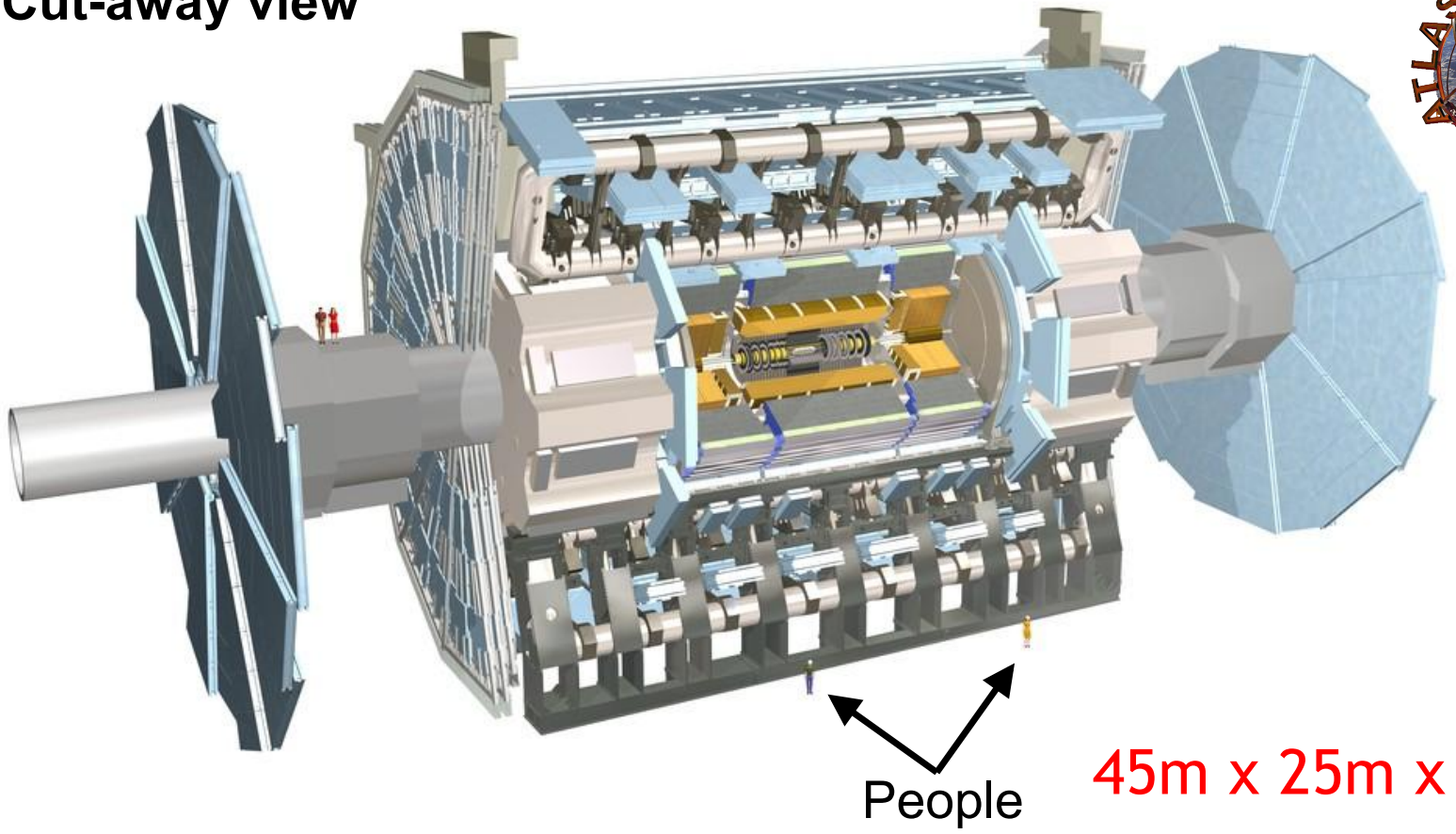
- Each proton goes round ring 11,000 times per Second.
- 10^{11} protons per bunch, with 40 million bunch crossings per second
- Total stored energy of 300 MJ … equivalent to a family car at 1000 mph

The LHC has been running successfully in 2010, 2011 and 2012 ☺

Detecting the Results of the Collisions

The protons or ions collide in four cathedral sized caverns, creating conditions and particles which have not existed since a fraction of a second after the big bang.

Cut-away view

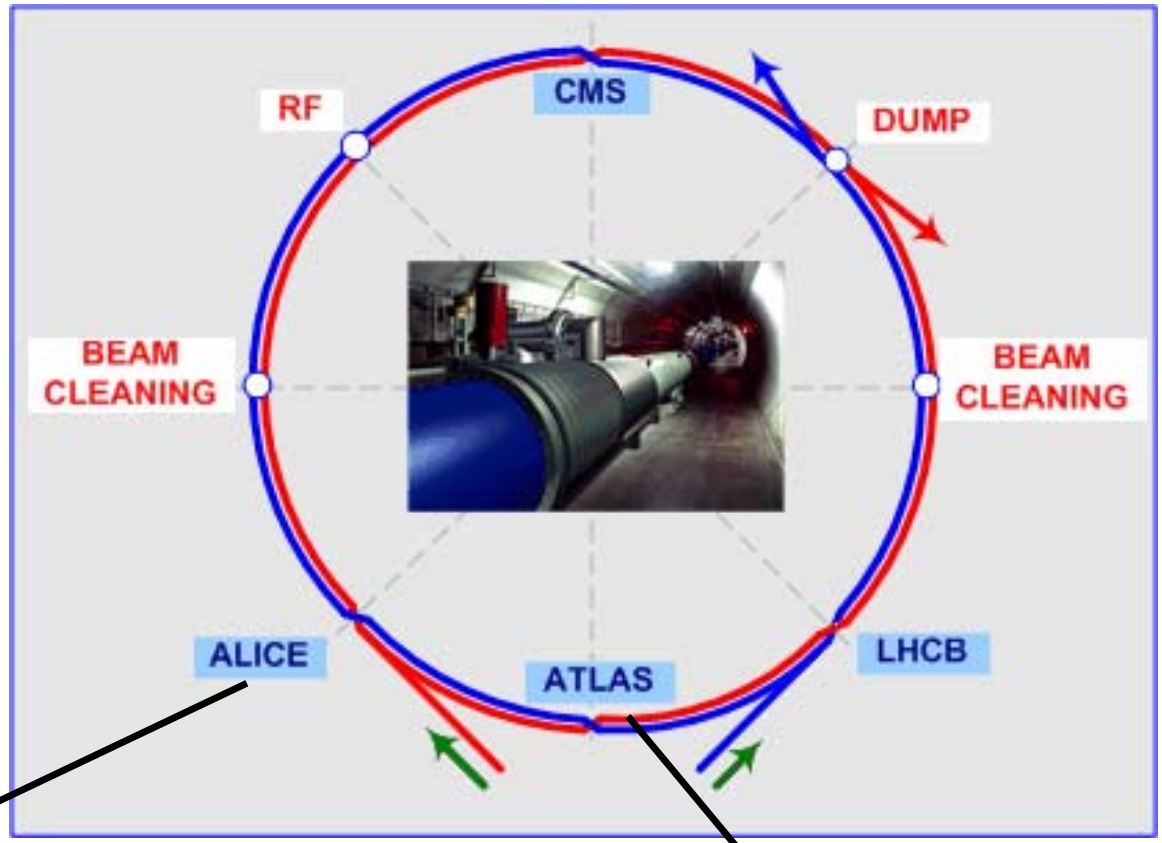


45m x 25m x 25m

The scientific collaborations are as big as the detectors …
e.g. ATLAS involves ~3000 physicists from 174 institutes
in 38 different countries

Birmingham & the LHC

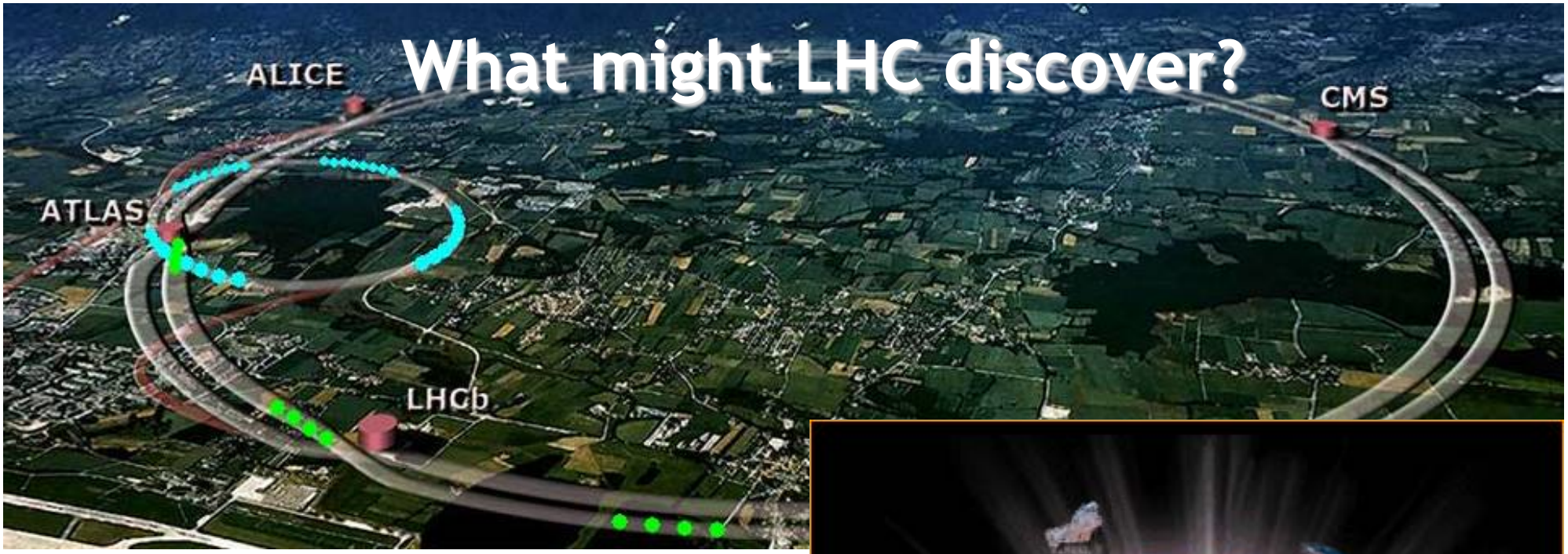
Birmingham has large groups, playing important roles in three of the four LHC experiments, ALICE, ALTAS & LHCb

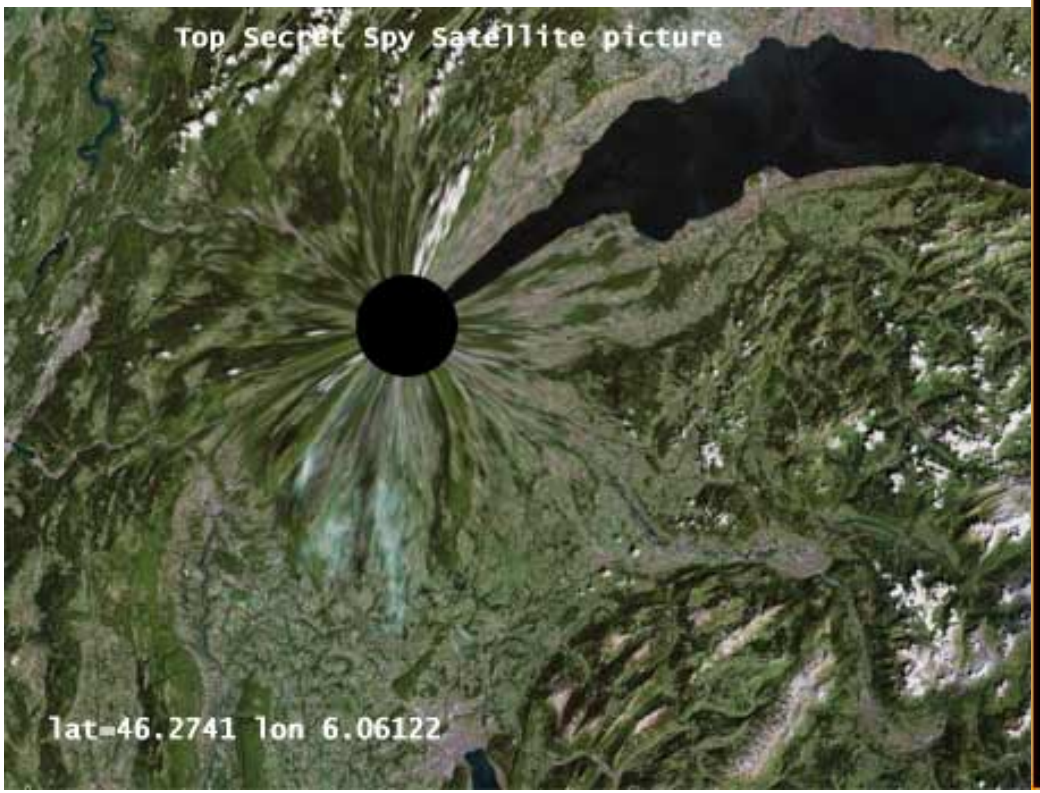


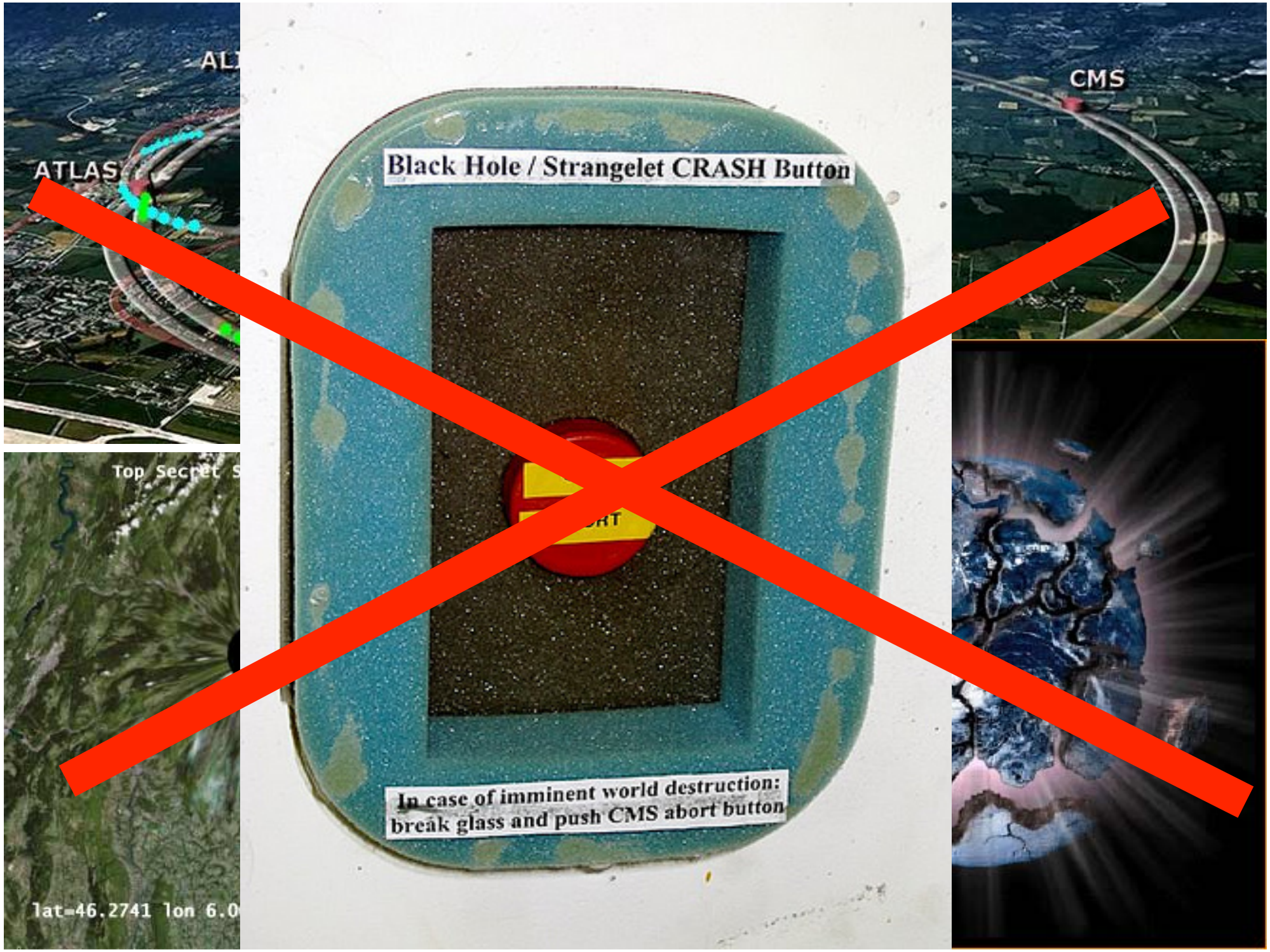
David Evans, UK ALICE Spokesman

Dave Charlton, ATLAS Deputy Spokesman (and next Spokesman)

What might LHC discover?

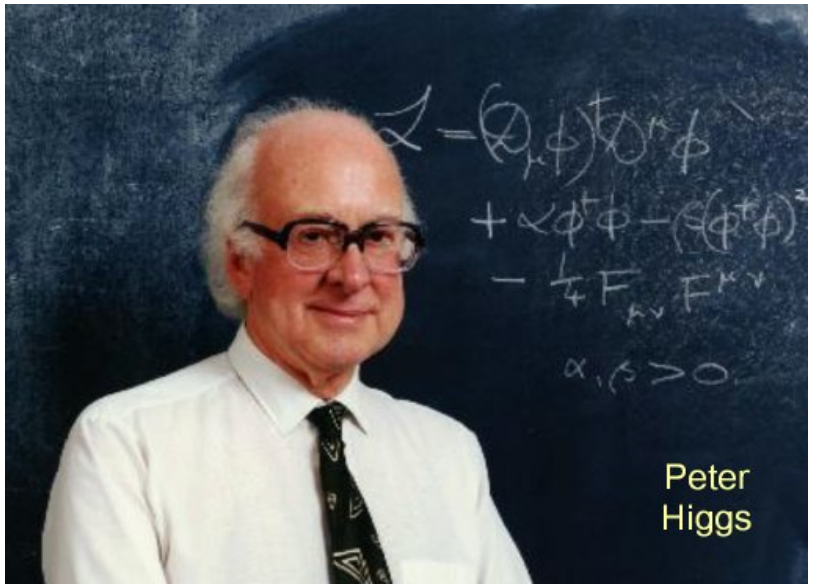





ATLAS
CMS
Top Secret
lat=46.2741 lon 6.0
Black Hole / Strangelet CRASH Button
In case of imminent world destruction:
break glass and push CMS abort button

What might the LHC Discover?…

Biggest open problem is how particles acquire mass & why some are heavier than others

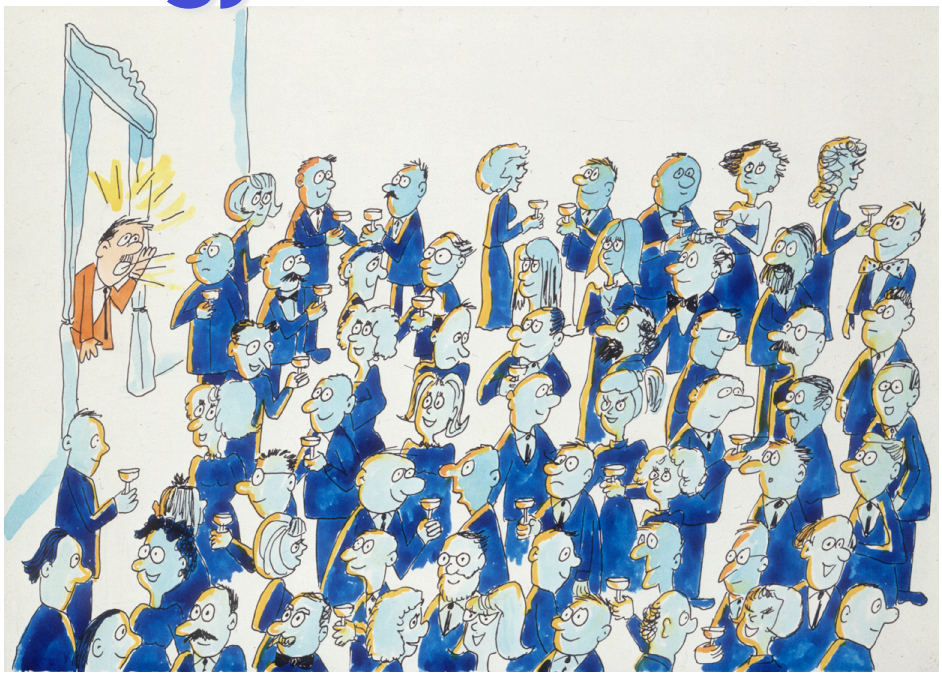


In the mid 1960s, British physicist Peter Higgs came up with a theory

A new heavy particle, the Higgs Boson `grabs hold of' particles to slow them down

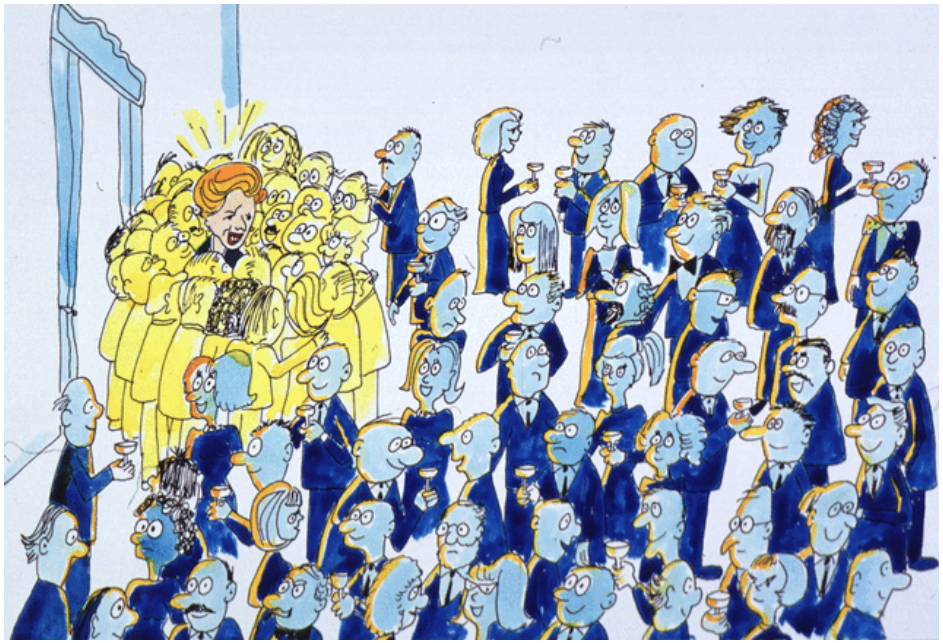
Particles which 'feel' this Higgs boson field gain mass…
… Light particles don't feel it strongly, heavy particles do.

A Higgs Analogy



What happens when a Mr Nobody and a Mrs Thatcher try to walk quickly through a room full of Conservative party workers?...

... so all we need to do is go and find it ...



How a Higgs boson event might look in ATLAS

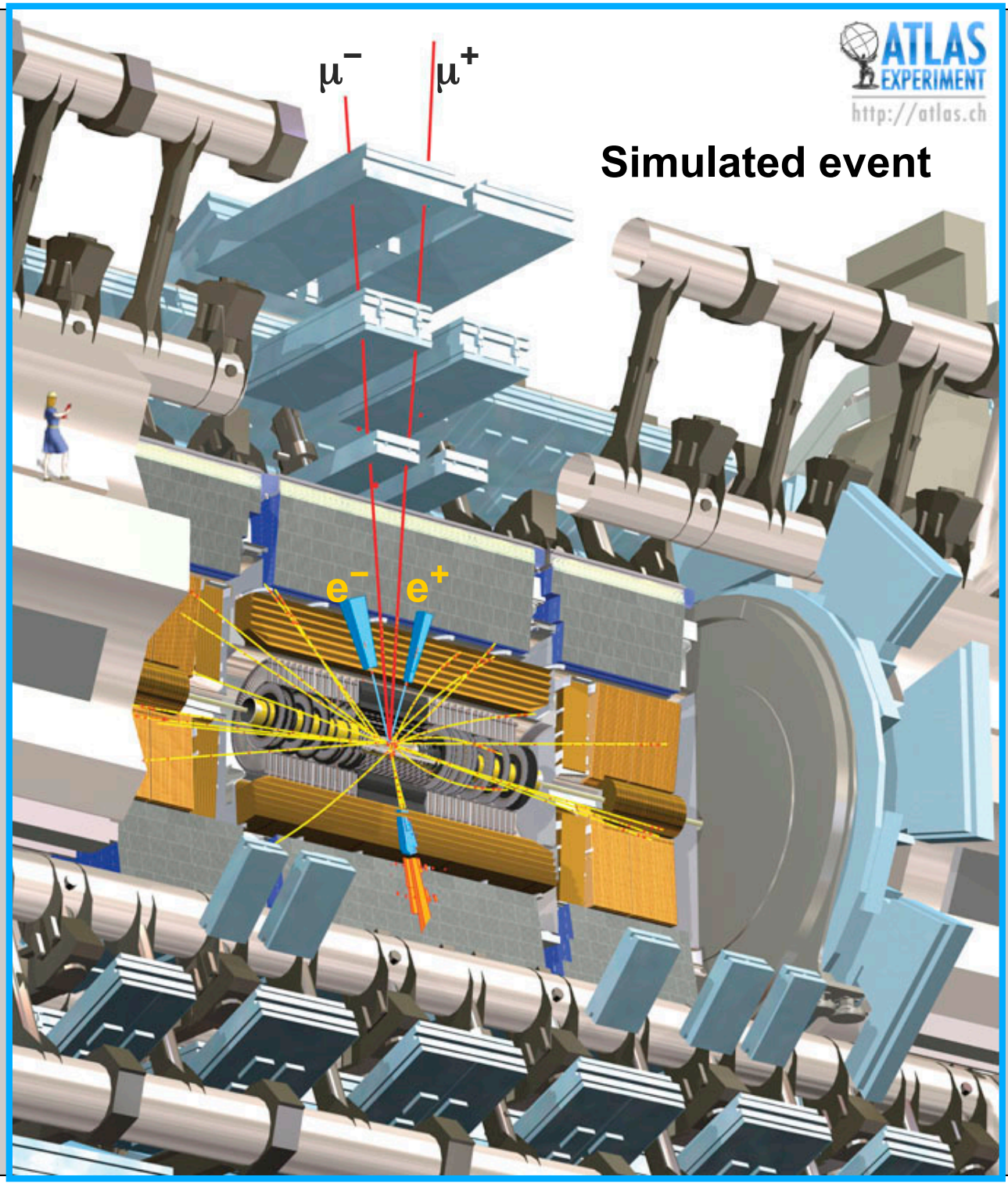
In this event, a cluster of particles was produced going downward,

and a Higgs was produced going upward but decayed almost instantly.

$$H \rightarrow e^- + e^+ + \mu^- + \mu^+$$

1 billion events per second

1 Higgs produced every 10 seconds!



What can we say about the Higgs Boson?

~~It's like looking for a needle in a haystack~~

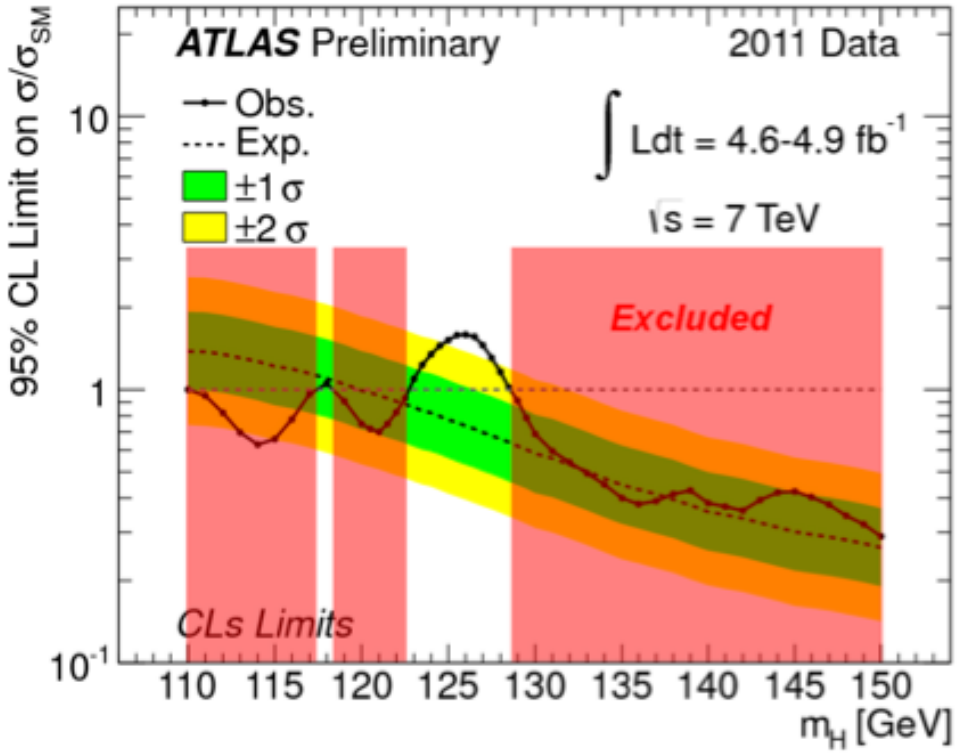
~~It's like looking for a needle in 10000 haystacks~~

It's like looking for a piece of hay in 10000 haystacks

We're running out of hay …

2011 data wiped out huge region of possible Higgs masses.

Small window remaining:
123 < Higgs mass < 129 GeV



Something interesting
at about 126 GeV

… but need more data to be sure …

The Very Latest News

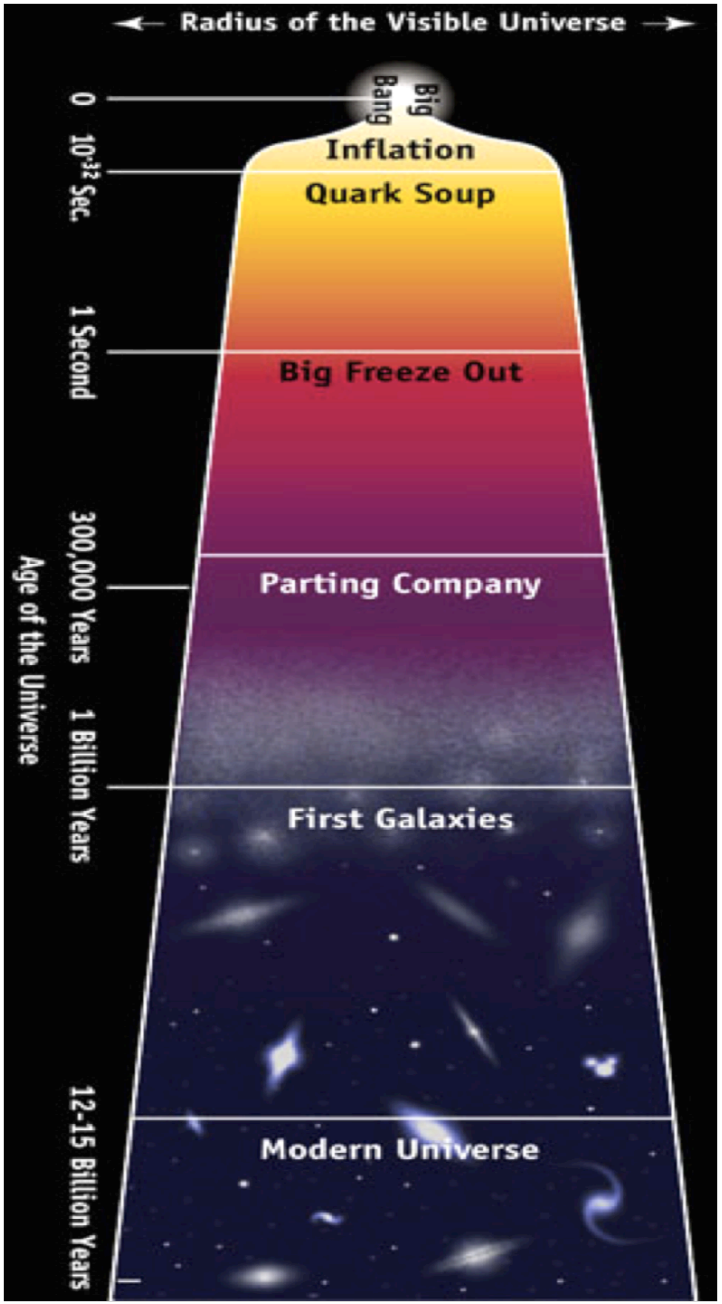
- First half of 2012 data taking recently completed
- More collisions than 2011 already!
- Intense data analysis taking place, results very soon …

Geneva, 22 June 2012. CERN[1] will hold a scientific seminar at 9:00CEST on 4 July to deliver the latest update in the search for the Higgs boson. At this seminar, coming on the eve of this year's major particle physics conference, ICHEP, in Melbourne, the ATLAS and CMS experiments will deliver the preliminary results of their 2012 data analysis.

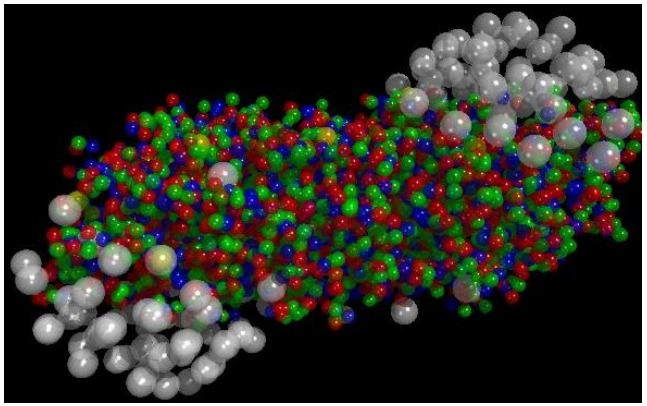
CERN Press Release

… we will have the answer by end of 2012 one way or another!

ALICE and the Quark Gluon Plasma



ALICE experiment aims to study collisions between pairs of lead nuclei!



… this should recreate a state of matter in which hadrons 'dissolve' to produce a soup of unbound quarks and gluons (a 'Quark-Gluon Plasma')

… recreating conditions that last existed around 10^{-6} seconds after the big bang

… when the temperature of the universe was ~10^{13} ^{o}C!

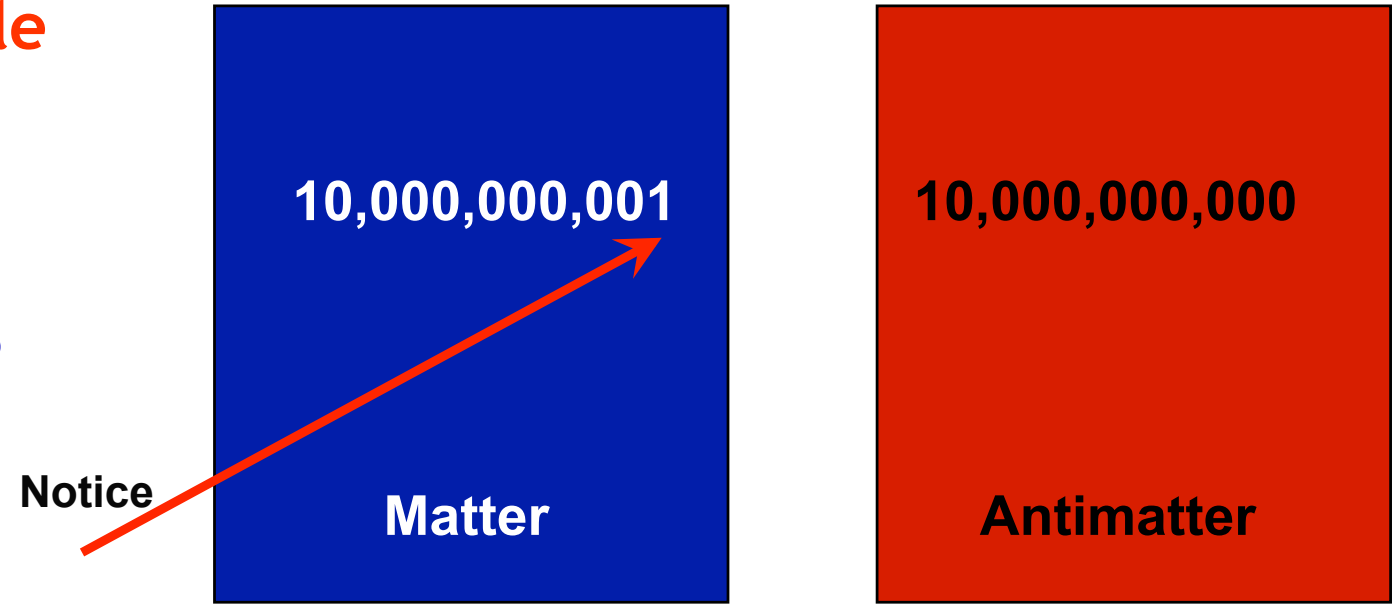
LHCb & the Matter/Antimatter Puzzle.

… if the big bang gave us equal amounts of matter and antimatter, where did all the antimatter go?…

The LHCb experiment is studying tiny differences between the lifetimes of beauty quarks and beauty antiquarks

… so a possible answer …

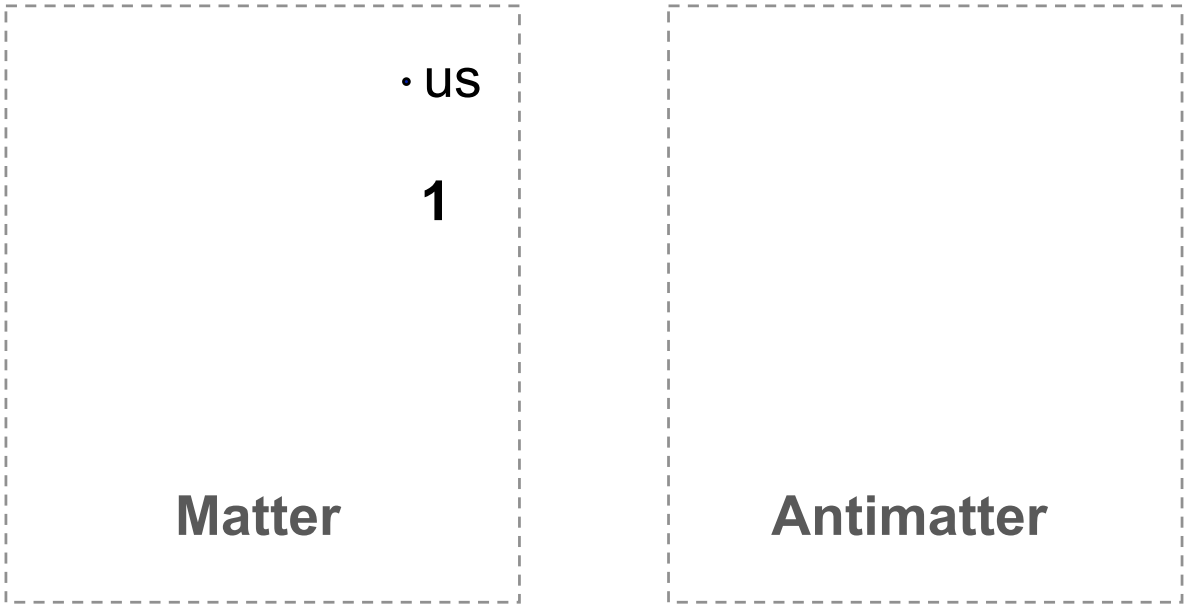
sometime just after the big bang …



Where is all the Antimatter?

… a great annihilation then took place …

… leaving only a “tiny” part of the matter … us!



The Future?

- Will we see a deeper structure to the quarks?

- Will we understand why there are three families of quarks?

- Will we see the Higgs boson?

- Will we see Supersymmetry, Extra Dimensions, or something completely unexpected!

… it's early days. Currently → half design beam energy
→ 1/300 of planned collisions

- We should have an answer to the Higgs boson question soon

… many other possibilities, but will require even more data

- The LHC will run for 15-20 years … **WATCH THIS SPACE!**