INTRODUCING PARTICLE PHYSICS

PPARC

Royal Holloway
University of London

Particle physics is the study of the smallest particles of matter in the universe (called quarks and leptons) and of the forces between them. It is carried out using huge machines that accelerate particles to close to the speed of light before smashing them together. By studying the debris from large numbers of such collisions physicists can learn about the particles and forces.

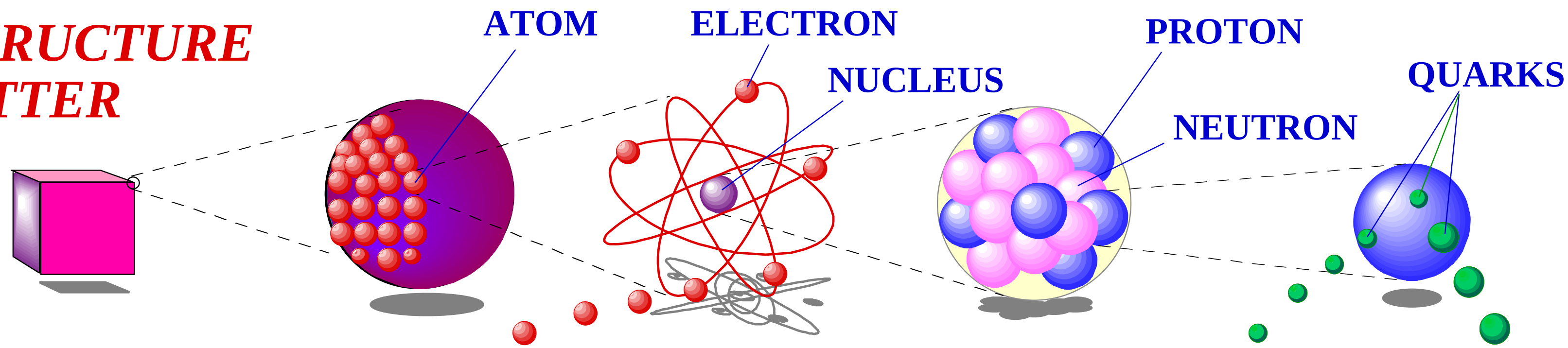
These same forces govern the behaviour of everything in the universe from the earliest times in the Big Bang. Thus there are strong links between particle physics and cosmology, currently two of the most fundamental and exciting areas of research in physics.

Particle physics in Great Britain is funded by the Particle Physics and Astronomy Research Council. There are research groups in this field at fifteen universities and at the Rutherford Appleton Laboratory in Oxfordshire.

Accelerators are built and operated at laboratories such as CERN, near Geneva, which is used by physicists from many countries. The first accelerator at CERN began operating in 1956; the Large Hadron Collider, currently under development, is planned to operate from 2004.

This series of 6 sheets summarising some of the key points of particle physics has been produced by the Particle Physics Group at Royal Holloway, University of London with financial support from PPARC. They may be freely copied or additional copies can be obtained from the Physics Secretary, Royal Holloway, University of London, Egham, Surrey TW20 0EX. Tel. 01784 443448.
Copies are also available from the World Wide Web via http://www.ph.rhbnc.ac.uk/
To request a talk at your school contact Dr Mike Green at the above address, e-mail M.Green@rhbnc.ac.uk Tel. 01784 443454.
Further information about PPARC can be obtained from Public Relations Office, PPARC, Polaris House, North Star Avenue, Swindon SN2 1SZ. Tel. 01793 442098.
Further information about CERN can be obtained from Communication and Public Education Group, CERN, 1211 Geneva 23, Switzerland.
Tel. 00 41 22 7674101 (Web address http://www.cern.ch/)

THE STRUCTURE OF MATTER



Constituents of ordinary matter.

These particles existed in the early moments after the Big Bang. Now they are found only in cosmic rays and particle accelerators.

LEPTONS

These particles exist on their own

1st FAMILY	**ELECTRON** (e^-) Charge = -1 Responsible for electricity and chemical reactions. Mass = 0.51 MeV/c^2	**ELECTRON NEUTRINO** (ν_e) Charge = 0 Rarely interacts with other matter. Mass possibly zero.
2nd FAMILY	**MUON** (μ^-) A heavier relative of the electron. Discovered 1937. Mass = 0.106 GeV/c^2	**MUON NEUTRINO** (ν_μ) A relative of ν_e. Discovered 1962. Mass possibly zero.
3rd FAMILY	**TAU** (τ^-) A heavier relative of the electron and muon. Discovered 1975. Mass = 1.78 GeV/c^2	**TAU NEUTRINO** (ν_τ) Not yet discovered. Mass possibly zero.

QUARKS

These particles only exist bound together

UP (u) Charge = +2/3. Mass ~ 5 MeV/c^2	**DOWN** (d) Charge = -1/3. Mass ~ 10 MeV/c^2
Protons are made up of two up quarks and one down quark. Neutrons are made up of one up quark and two down quarks.	
CHARM (c) A heavier relative of the up quark. Discovered 1973. Mass ~ 1.3 GeV/c^2	**STRANGE** (s) A heavier relative of the down quark. Discovered 1947. Mass ~ 0.2 GeV/c^2
TOP (t) The heaviest quark. Discovered 1994. Mass ~ 180 GeV/c^2	**BOTTOM** (b) A heavier relative of the down and strange quark. Discovered 1977. Mass ~ 4.3 GeV/c^2

ALL OF THE ABOVE PARTICLES HAVE AN ANTIPARTICLE COUNTERPART.

A particle and its antiparticle can annihilate to produce the bosons that carry forces eg $e^+e^- \rightarrow \gamma + \gamma$.	A particle - antiparticle pair can be produced from a force-carrying boson eg $Z \rightarrow b\bar{b}$, $\gamma \rightarrow e^+e^-$.

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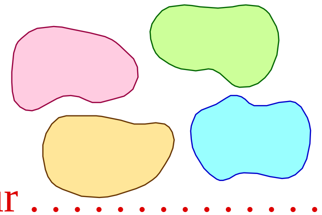
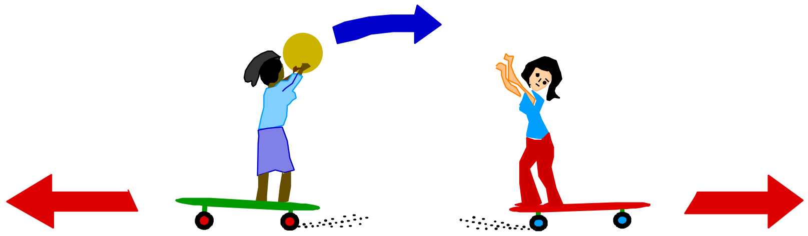
THE FORCES

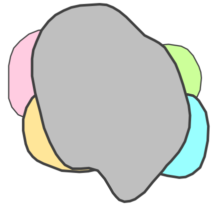


Four . . . .



THE FORCES OF NATURE ARISE FROM THE EXCHANGE OF OBJECTS CALLED BOSONS BETWEEN PARTICLES.

A particle continually emits and reabsorbs bosons. If one particle absorbs bosons emitted by another particle there is a force between the two.



. . . . or one ?

GRAVITY
The weakest force, but responsible for the force between astronomical objects. The graviton has not been observed. Felt by all particles with mass.

STRONG
Felt by quarks only, this force also holds nuclei together. There are eight different types of gluon carrying different combinations of colour.

FORCE	BOSON	SOURCE	RELATIVE STRENGTH*	RANGE
Gravity	graviton	mass	10^{-39}	infinite
Weak	W^+, W^-, Z	weak charge	10^{-5}	10^{-18} m
Electromagnetism	photon	charge	10^{-2}	infinite
Strong	gluons	colour	1	10^{-15} m

* in the nucleus

WEAK
Responsible for radioactive β decay. The force carriers ($W^\pm$, Z bosons) have mass and were discovered at CERN in 1983-4. Felt by all particles.

These two forces are different manifestations of the electroweak force. The mathematical theory of this force predicts the existence of the Higgs boson, responsible for the mass of all objects, but not yet discovered.

ELECTROMAGNETISM
Holds atoms together and plays a major role in everyday life. The force carrier is the familiar photon. Electricity and magnetism are simply different manifestations of this force. Felt by all particles except neutrinos, which are uncharged.

Can all four forces be combined in a Grand Unified Theory ?

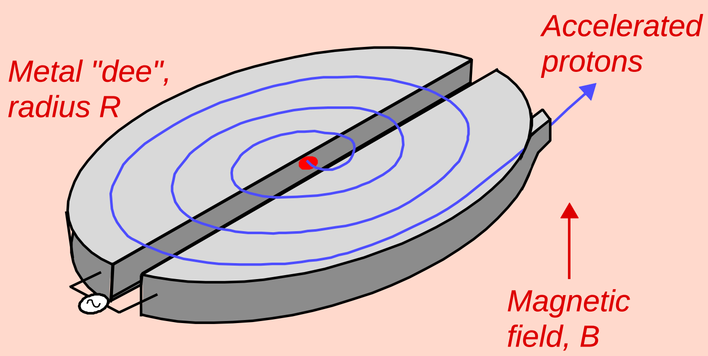
No.3

PARTICLE ACCELERATORS

Some of the largest machines ever built accelerate the smallest particles to a speed very close to the speed of light.

The equation $E = hf = \frac{hc}{\lambda}$ shows that high energy particles have a short wavelength and can therefore probe each other more deeply when they collide.

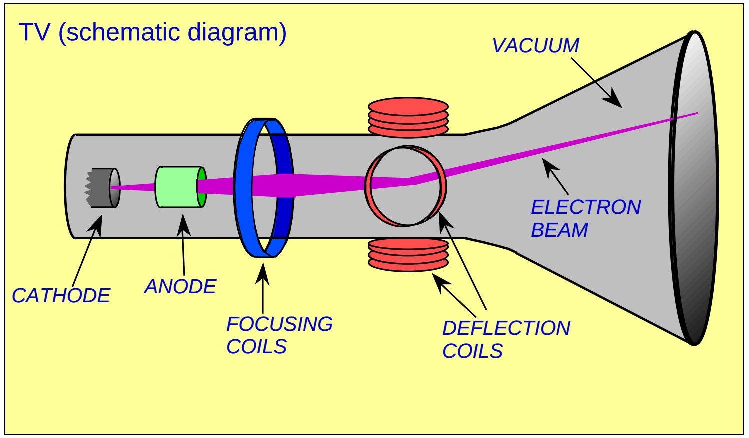
The first circular accelerator was the cyclotron.

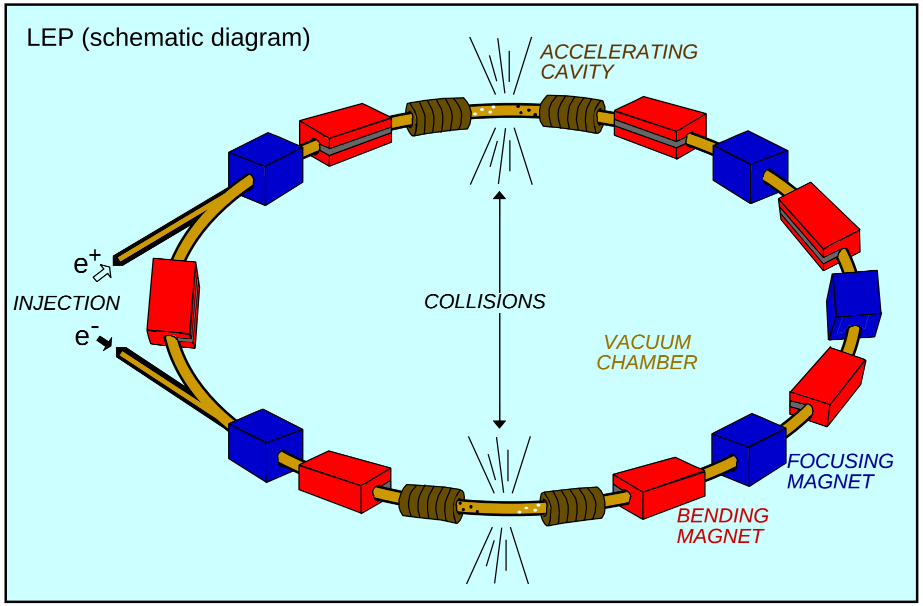


Equating forces $\frac{mv^2}{r} = Bev$ and the time for half a turn, $t = \frac{\pi r}{v}$; hence $t = \frac{\pi m}{eB}$.

This is independent of radius, so with the correct choice of frequency for the ac voltage protons will be accelerated every time they cross the gap. The final kinetic energy $= \frac{(BeR)^2}{2m}$ and is about 10MeV for R = 0.3m.

A television set is a particle accelerator in which electrons reach an energy of about 20keV.





The same features seen in the television set are found in the LEP accelerator at CERN but on a larger scale (27km in circumference, over 4000 magnets). LEP accelerates electrons and positrons to 50GeV before they collide.

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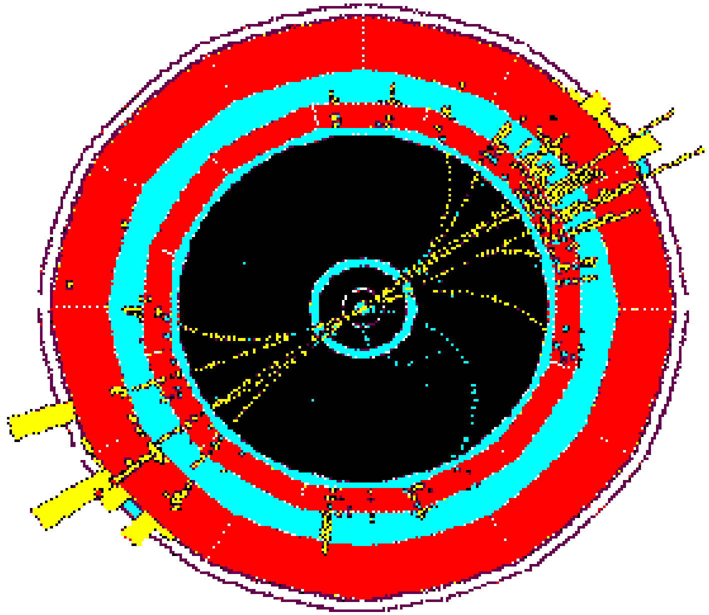
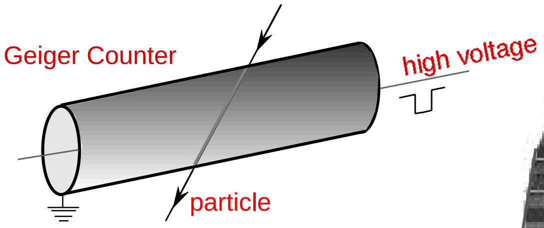
PARTICLE DETECTORS

Particle detection can be based on several effects such as ionization, Cerenkov radiation, electron-hole pair production in semiconductors.

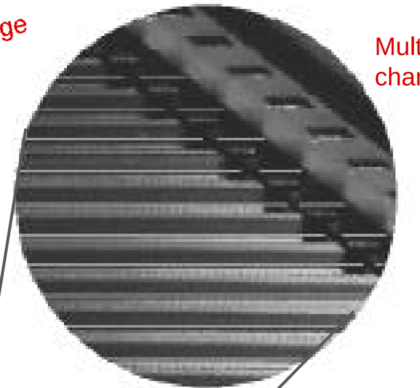


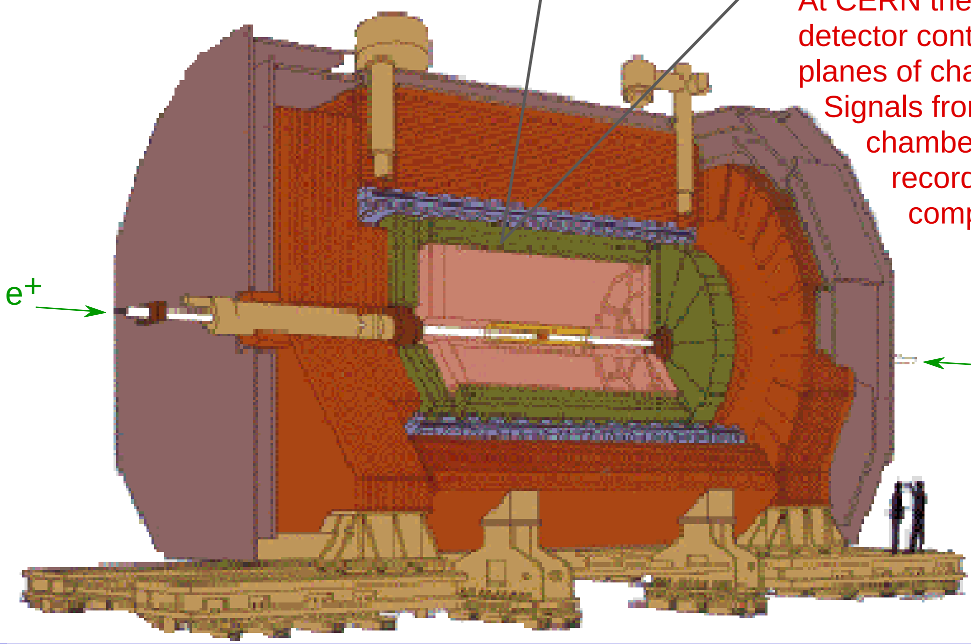
The picture above is a reconstruction of a collision in ALEPH. The e^+ and e^- annihilated and a quark and antiquark were created, each evolving into a jet of several other particles. Particles of opposite charge are bent in opposite directions in the magnetic field. The different particles interact in different ways in the outer layers of the detector allowing them to be identified.

A charged particle passing through a Geiger counter causes ionization. The ionization electrons drift to the wire creating further ionization, so producing a large signal.



Many particle detectors are based on the Geiger counter. An example is the multi-wire chamber with many counters side-by-side.





At CERN the ALEPH detector contains many planes of chambers. Signals from these chambers are recorded on a computer.

No.5

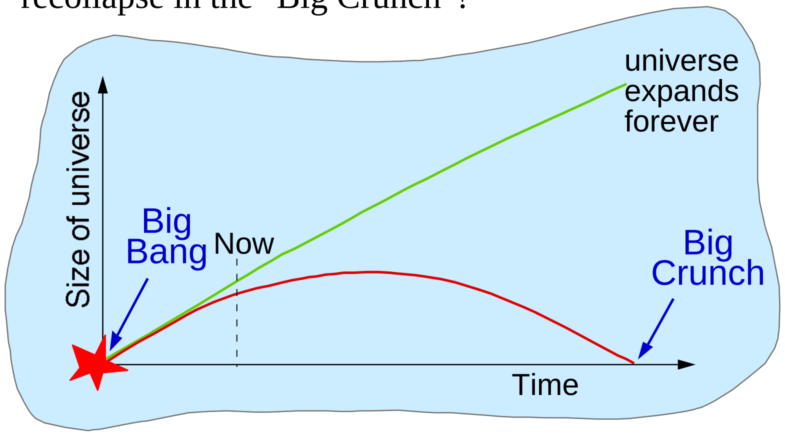
PARTICLE PHYSICS AND THE BIG BANG

Much evidence suggests that the universe started in a "Big Bang" about 15 billion years ago.

Equal numbers of particles (quarks and leptons) and their antiparticles were created; most annihilated to produce γ-rays, but a subtle, unknown effect left a small excess of particles.

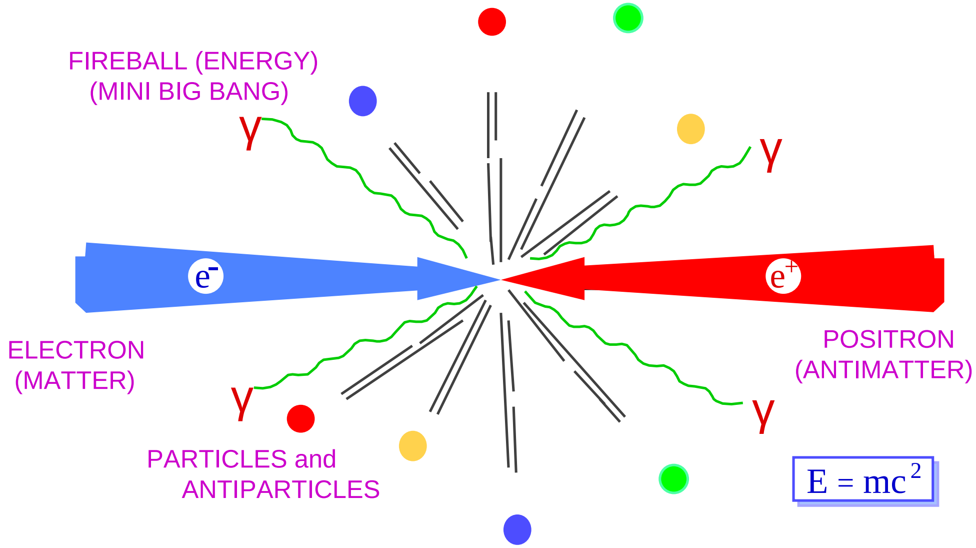
Since then the universe has expanded and cooled and very complicated structures (such as you) have formed from those quarks and leptons.

Currently we don't know if the universe will expand forever or if the force of gravity will cause it to recollapse in the "Big Crunch"?



The answer depends on the amount of matter in the Universe; the directly observed matter in galaxies is not enough to cause a recollapse. However we do know that at least some extra matter, called dark matter, exists that has not yet been directly observed.

Conditions similar to those 10^{9} s after the Big Bang are created in collisions at LEP and equal numbers of particles and antiparticles are formed.



There are still many vital questions to be answered if we are to understand fully our Universe and its origins. In fact plenty for the next generation of particle physicists and cosmologists.

Why is there only matter and no antimatter ?
What is the dark matter made of ?
Could it be that neutrinos have mass ?
What is mass anyway ?
Do Higgs particles exist ?