ATOMS

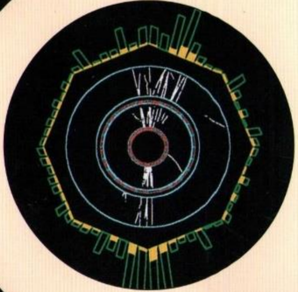
Probing PARTICLES

Probing Particles

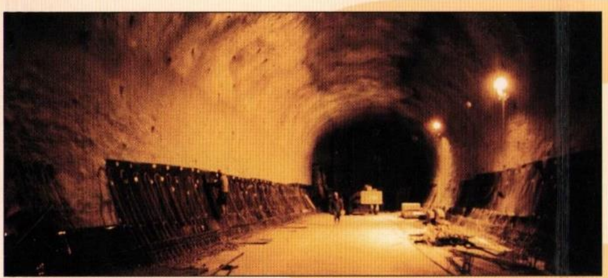
Experiments at particle accelerators, where beams of sub-atomic particles collide at very high energies, reveal details of particles and conditions that prevailed just after the Big Bang over 15 billion years ago.

Most experiments involve large international collaborations and are performed at overseas laboratories such as CERN in Geneva and DESY in Hamburg. These collaborations typically involve more than 300 people and the work at CERN is supported by 19 European countries.

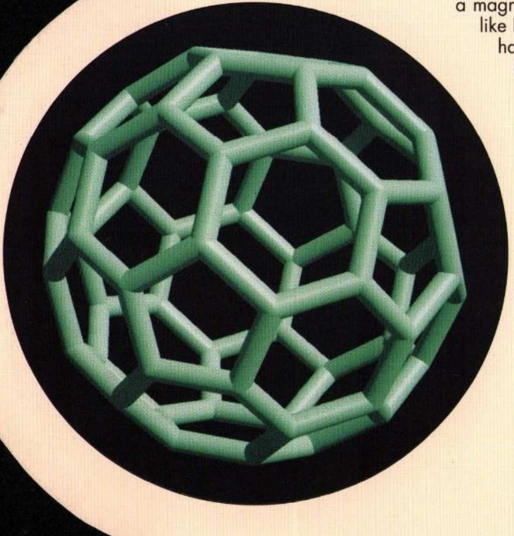
Accelerators



The accelerator is the basic tool of particle physics. It allows us to create the particle collisions that we want to study in our own laboratories. The high energy collisions between particles that physicists are interested in do occur naturally but the events are unpredictable and the number that can be observed (in cosmic rays) is low.



Accelerators work by accelerating charged particles using electric fields. A linear accelerator accelerates particles in a straight line: the biggest linear machine, in Stanford, California, is three kilometres long. Circular machines are more common. As well as accelerating the particles using an electric field, circular accelerators bend their paths using a magnetic field. In a machine like LEP at CERN, where they have opposite charges, the beams being accelerated travel in opposite directions until they are forced to collide. The drawback is that the faster a particle travels, the harder it is to keep it moving in a circle but, in the largest circles (LEP is the largest in the world with a circumference of 27 km) less energy is wasted when accelerating particles to high speeds.

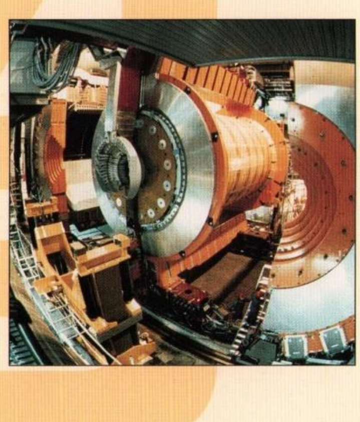


Detectors

Detectors are used to examine tracks made by the new particles that are produced when accelerated particles collide. In the early days photographic film, spark chambers and bubble chambers were used. Since the late 1960s electronic detectors have taken over. There are two basic kinds – tracking detectors which reveal the trajectories of individual charged particles, and calorimeters which measure energies. A modern electronic detector is built like an onion, with layers of trackers and calorimeters to give as much information as possible about the particles produced in each collision.

Antimatter

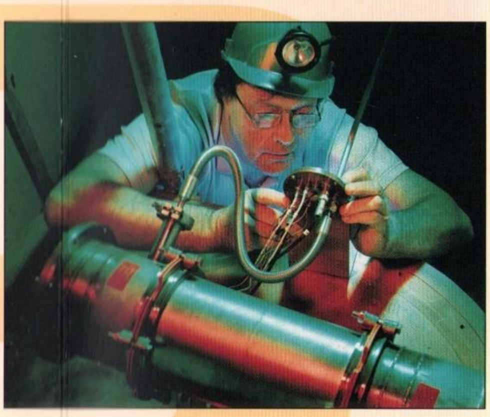
Particles of antimatter are very much like ordinary matter, but carry the opposite charge. An anti-electron (a positively charged electron) is just another way of describing a positron. Crashing matter and antimatter together is now a daily occurrence in machines like LEP. The fact that the universe seems to be full of matter and not antimatter is one of the most baffling problems in modern physics. At the time of the Big Bang, matter and antimatter are thought to have been produced in equal quantities. What seems to have happened is that, at a somewhat later time, collisions between the

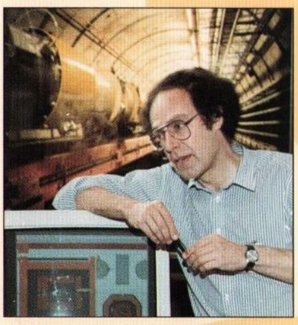


two types have destroyed all the antimatter but left a little of the matter behind, from which our universe is made. The reason seems to be a tiny asymmetry in the way particles of matter and antimatter decay, thereby creating an excess of matter.

Big Bang science

It is thought that the universe began around 15 billion years ago in the Big Bang and that it has been cooling down and expanding ever since. For physicists, the most interesting time was within the very first moment (within 10^{-34} seconds) where conditions were so extreme that the laws of physics as we know them today did not apply. After about 0.01 seconds,the universe was cold enough for quarks to stick together,forming protons and neutrons. These formed the first helium nuclei after 100 seconds,



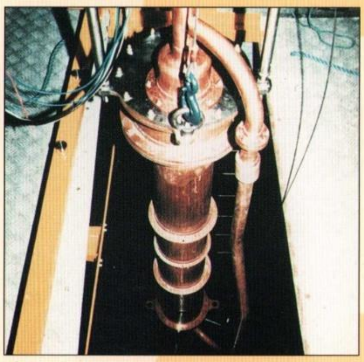


but the first atoms didn't appear for 100 000 years. After a few billion years stars began to form, using hydrogen and helium to build the heavier elements that make up the familiar world around us -elements heavier than helium owe their origin to stars.

The Big Bang theory correctly predicts that about 75% of all visible matter is hydrogen and about 25% helium. (All other matter accounts for less than 1%). Another great success of the theory is the presence of background microwave radiation in our universe, a relic of the Big Bang.

Dark Matter

We know from observing the rotation of galaxies that about 90% of the matter they contain is invisible to us. The matter we can't see is called 'missing' or 'dark' matter. The amount of dark matter contained in the universe is crucial to its fate. If it is greater than a certain amount, the universe will eventually collapse. Below this, and it will keep on expanding for ever.



There are many ideas about what dark matter might be, ranging from exotic new particles to black holes. One idea says that the neutrino, an abundant fundamental particle which is thought to have zero mass, actually has a tiny mass. However, neutrinos generally move about the universe quickly and are not stuck together in clumps, as they would need to be to explain the rotation of the galaxies. The most recent explanations of dark matter therefore use a combination of 'hot' matter, like neutrinos, and 'cold' matter like possible "supersymmetry" particles. The true answer has yet to be found.

Heavy Light

LEP

The Large Electron Positron collider, LEP, is the world's largest scientific instrument, designed to study some of the smallest things known to man. In a tunnel longer than that of the London Underground Circle Line, LEP collides electrons and their antimatter counterparts, positrons, at nearly the speed of light. RAL scientists play leading roles in three of the four huge experiments formed to observe these collisions.

When electrons and positrons collide with enough energy they sometimes disappear, creating a Z0 particle in their place. some people have called Z0 particles

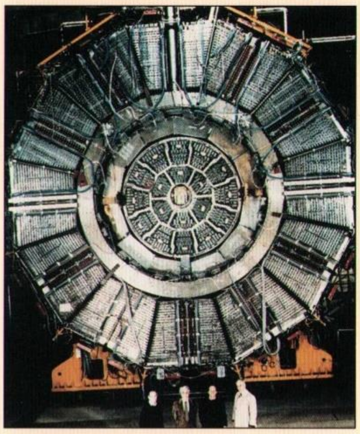
and their charged companions W+ and W- 'heavy' light, as they play the same role in carrying the weak nuclear force as light particles (photons) do in carrying the electromagnetic force. The weak nuclear force underlies the processes which fuel the Sun.

Inside the Proton

HERA

HERA is another circular accelerator, like LEP but smaller. Instead of colliding electrons and positrons, HERA uses the electron as a probe to look inside the much larger proton. The two detectors used in HERA are similar to those at LEP, and RAL scientists are involved with both.

It has been known since the late 1960s that protons and neutrons are not fundamental particles but are made from smaller entities: 'the quarks'. At the simplest level a proton or a neutron is made up of three quarks but experiments reveal a much more complicated picture. The strong nuclear force which glues the three quarks together also gives rise to a swarming sea of other quarks flickering in and out of existence. This is what HERA's electrons study.



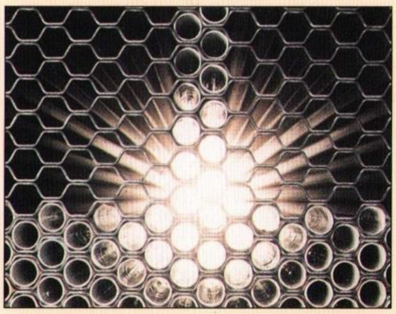
Proton Decay and Dark Matter

Underground experiments

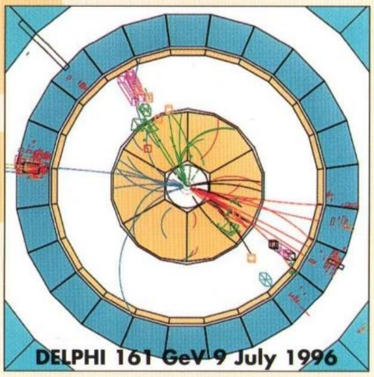
Not all of the big questions in particle physics need huge accelerators. Some of the most intriguing problems that have been exposed by modern physics need very quiet places for their study. Proton decay is one of these.

RAL physicists have built a significant part of the 1000 tonne SOUDAN II detector housed in a mine in Minnesota. Protons are expected to live for billions and billions of years, but there are billions and billions of protons in 1000 tonnes of material, so if they do decay, even if it is only a few per year, SOUDAN II should detect the events.

The search for 'dark' matter also needs to take place far from the 'background noise' of cosmic rays



at the Earth's surface. RAL has installed a detector 1km underground in a mine near Whitby in Yorkshire to look for a possible explanation of this mystery.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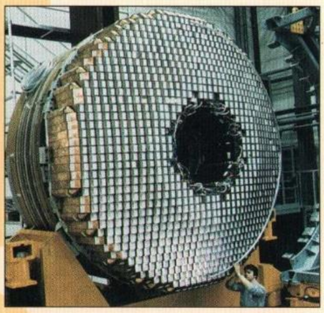
The Higgs Bosons

Future experiments

One of the key features of modern thinking in particle physics is that at high enough temperatures (like those at the time of the Big Bang) the disparate fundamental forces we know today are all manifestations of a single force.

In today's cold universe, the electromagnetic force and the weak nuclear force differ because the carriers of the weak force, W and Z particles, have mass. This restricts the force to short range, unlike electromagnetic force and the weak nuclear force differ because the carriers of the weak force, W and Z particles, have mass. This restricts the force to short range, unlike electromagnetism whose range is infinite because photons have no mass.



Heavy W and Z particles have been incorporated tidily into the modern theory by Professor Peter Higgs, whose ideas demand the existence of new particles. The hunt for these particles will be one of the main thrusts of particle physics research in years to come. RAL is involved with the design of experiments to find them.

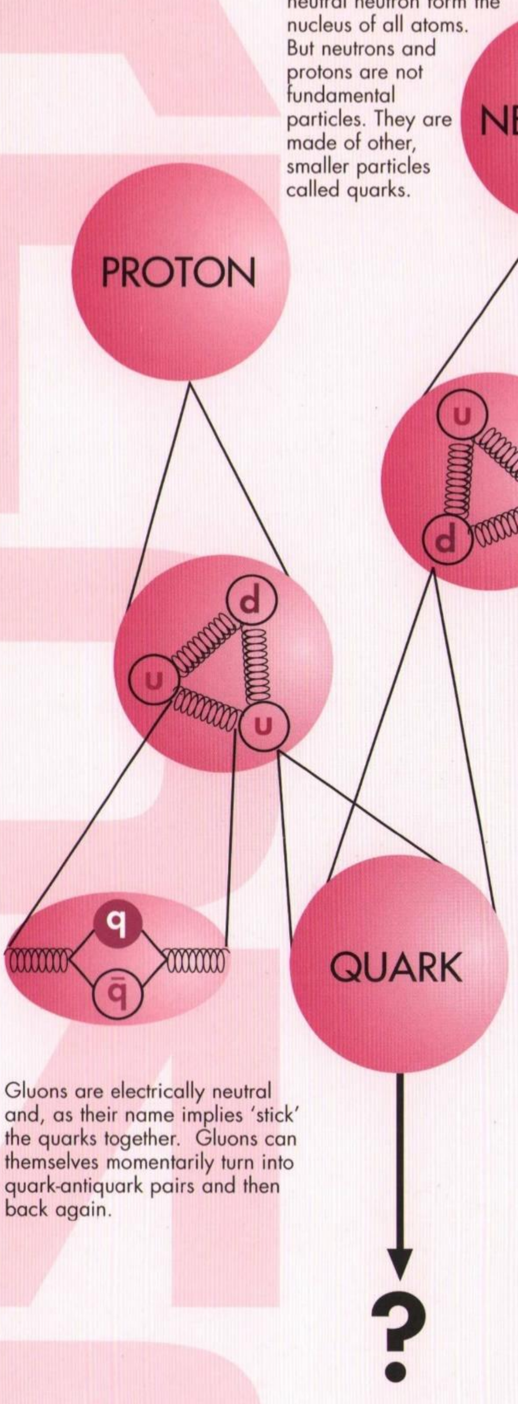
Particle Physics

Particle physics is the study of the basic elements of matter and the forces acting among them. It aims to determine the fundamental laws that control the make-up of matter and the physical universe.

RAL makes major contributions to all parts of the UK particle physics programme, building equipment, performing experiments and analysing results.

Inside the Nucleus

The positively-charged proton and neutral neutron form the nucleus of all atoms. But neutrons and protons are not fundamental particles. They are made of other, smaller particles called quarks.



'Up' quarks have a $+^2/_3$ electric charge and 'Down' quarks have a $-^1/_3$ electric charge. The proton has two 'up' quarks and one 'down' giving a charge of $+^2/_3+^2/_3-^1/_3=1$ and the neutron has two 'down' giving a charge of $-^1/_3-^1/_3+^2/_3=0$.

Gluons are electrically neutral and, as their name implies 'stick' the quarks together. Gluons can themselves momentarily turn into quark-antiquark pairs and then back again.

Quarks and their make-up remain a mystery. In spite of many searches, no quarks have yet been observed in isolation although experiment clearly shows them to exist inside protons and neutrons.

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