LEP
the large electron positron collider

What is LEP ?

The Large Electron Positron Collider, LEP, is the world's largest particle accelerator. Built inside a circular tunnel, it is 27 km in circumference and buried 100 metres underground. At four points around the accelerator, huge detectors called ALEPH, DELPHI, L3, and OPAL study what happens when electrons and their antimatter counterparts, positrons, collide at high energy.

LEP switched on in the summer of 1989. For seven years, its job was to produce and study Z particles, carriers of one of nature's fundamental forces. The Z was first discovered in a Nobel prize-winning CERN experiment in 1983. Z particles are made when electrons and positrons collide with just the required amount of energy, just under 91.2 GeV*.

In 1995, LEP's Z era came to an end, and the machine moved up a gear to 140 GeV, a pilot run for LEP's second phase which will push the energy to over 190 GeV before the end of the decade. Known as LEP2, this second phase of LEP searches for new phenomena and also produces and studies W particles, sister particles of the Z which were also discovered at CERN in 1983.

LEP's Z era was extremely successful. Before LEP, just a few hundred Z particles had been seen at CERN. When LEP moved up to higher energies at the end of 1995, around 20 million had been recorded.

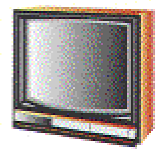
*Mass and Energy

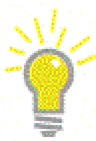
A GeV, or giga electron volt, to give it its full name, is a unit of energy used by particle physicists, it is also used as a unit of mass. Mass (m) is just a form of energy (E), as Einstein told us in his famous equation $E=mc^2$, c is a constant – the speed of light. When high energy particle beams collide, new particles are formed as energy is converted into matter. This is how W and Z particles are produced at LEP.

How do accelerators work ?

Particle accelerators like LEP work by exploiting the way charged particles move in electric and magnetic fields. Electric fields accelerate them. Magnetic fields bend and focus them into beams.

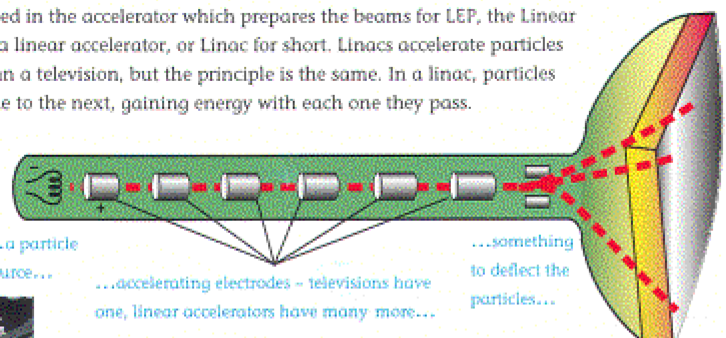
There is a good chance that there is particle accelerator in your home. Televisions are particle accelerators, using the same principles as LEP, but on a much smaller scale.





All particle beams start with a particle source. The simplest particle source is just a hot wire, like the filaments inside light bulbs. This is the kind of source used by televisions. Negatively charged electrons boil off the filament, and accelerate towards and through a positively charged electrode. Electromagnetic fields then sweep the beam across the screen where it causes the points it strikes to glow, and builds up a picture

A similar filament is also used in the accelerator which prepares the beams for LEP, the Linear Injector for LEP, LIL. This is a linear accelerator, or Linac for short. Linacs accelerate particles to much higher energies than a television, but the principle is the same. In a linac, particles accelerate from one electrode to the next, gaining energy with each one they pass.



Particles pass from the Linear Injector for LEP, LIL, into the Electron Positron Accumulator at this junction.

LIL's filament produces LEP's electrons, but positrons, the antimatter partners of electrons, are a little more tricky. To make them, electrons are accelerated through a foil, where they cause pairs of electrons and positrons to be created. The positrons are selected by magnets and stored in the Electron-Positron Accumulator until there are enough of them to form a beam.

All of CERN's beams begin their lives in linacs, but to reach the energies that physicists need would require extremely long accelerators. For this reason, CERN's big machines are circular. Particles beams travel round and round gaining energy with each lap. In LEP, 3368 magnets are needed to bend particle beams and keep them in orbit. Where negatively-charged particles bend to the left, positively-charged ones bend to the right. This allows LEP to accelerate beams of negative electrons and positive positrons in opposite directions using the same magnets.

Particles in LEP travel so fast that they try to skid off the ring, rather like powerful cars on sharp corners. In doing so they lose energy by emitting radiation, and this energy has to be replaced. At LEP2, 272 accelerating cavities keep the energy high. These are made from superconducting metal, and they operate at 269 degrees Celcius below freezing.

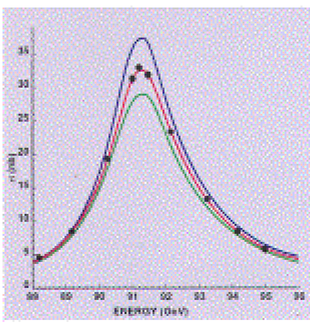
It would take a person about 7 hours to walk around the LEP ring, yet the beams of electrons and positrons do the trip 11 000 times a second travelling close to the speed of light. If just one of LEP's thousands of magnets were slightly out of tune, the beams would be lost. Yet so reliable is the machine that day after day, beams are made to collide head-on with an accuracy of about the thickness of a piece of paper.

Engineers at work on one of LEP2's superconducting accelerating cavities.

What does LEP do ?

LEP was designed to study one of nature's fundamental forces, the weak force which fuels the sun, and is responsible for some forms of natural radioactivity. The weak force is carried between particles of matter by 'messenger-particles' called W^+, W^- and Z.

In its first phase, LEP produced collisions with just the right energy to make Z particles. In its second phase, known as LEP2, the machine runs at nearly twice the Z energy, sufficient to produce W^+ and W^- particles in pairs. W and Z particles live for just a fleeting moment before decaying into other particles, which are detected and measured.

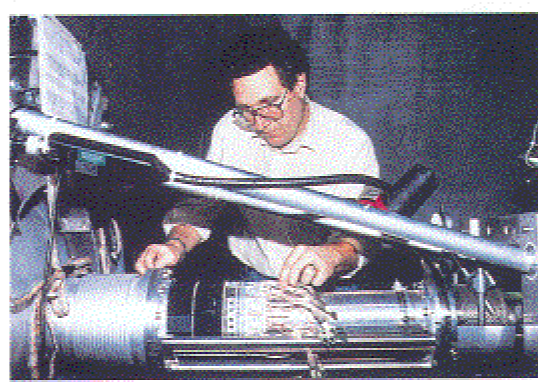


One of the first results to come from LEP is also one of the most profound. LEP has shown that matter comes in three distinct 'families' of particles. All of the things we see around us, ourselves included, are made from particles belonging to the lightest of these families. The other two appear to be just heavier copies of the first. Why there should be three families, instead of just one, is still a mystery.

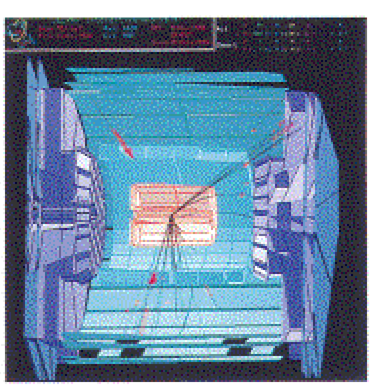
By the end of 1995, the Z's mass had been measured to the extraordinary accuracy of 91.1884 ± 0.0022 GeV, one of the most precise measurements that CERN has ever made. Such precision has put our current theory of how the Universe works, the Standard Model, through its most gruelling test yet.

The points on this graph shows the number of Z particles produced at different energies. The curves are theoretical predictions for two, three, or four families of matter particles. The red curve, corresponding to three families, clearly matches the data best.

We know the Standard Model is just a stepping stone to a more complete theory, and LEP has shown us hints of what may be to come. The Holy Grail of particle physics is a simple theory in which all of nature's apparently different forces are unified into a single force. LEP data suggest that this only happens if a new idea, supersymmetry, or SUSY, is correct.



Despite their enormous size, LEP's particle detectors are extremely delicate instruments.



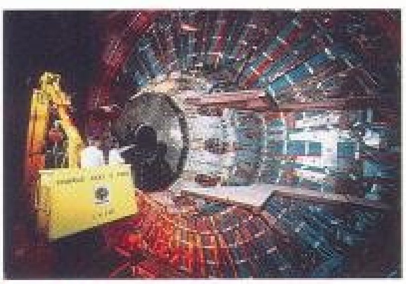
This is what one of LEP's collisions looks like after computer processing.

SUSY introduces a new 'supersymmetric' partner for each ordinary particle, and if SUSY is the right theory, supersymmetric particles might put in an appearance at LEP2.

How do we use LEP ?

ALEPH

LEP's great physics successes would not be possible without exceptional performance from the accelerator itself and the four big detectors which sit around its circumference. Right from the start, LEP's performance has been exemplary both in terms of the intensity of its beams and the precision of their measurement.



DELPHI

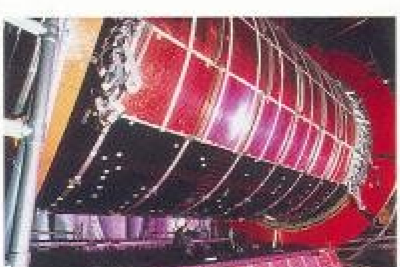
Despite its enormous size, LEP is one of the most sensitive scientific instruments ever built. The beam energy is so precisely measured that it is influenced by the moon's orbit, the level of water in Lake Geneva, and even heavy rainfall. All these phenomena cause slight movement in the rock in which LEP is built, which in turn has a subtle effect on the beam energy.

LEP's beam energy measurement can even tell you when the TGV train leaves Geneva station for Paris. The TGV picks up electricity from overhead wires, and sends it back to the generator along the rails. But some of the returning current escapes, and returns through the earth. The TGV passes within 800 metres of LEP, whose metallic ring provides an attractive route home for returning TGV current, which in turn has a tiny effect on the beam energy.

LEP's particle beams crash into each other producing new particles as matter turns into energy and back again. The four detectors, ALEPH, DELPHI, L3, and OPAL surround the collisions to see what happens.

These detectors are like cylindrical onions. Collisions happen right in the middle, and different layers of detector measure different properties of the emerging particles. Closest to the beam are precision tracking devices which pinpoint particle tracks with thousandth-of-a-millimetre precision. These are surrounded with less exact, but vastly bigger trackers to keep tabs on the particles as they fly away from the collision. Further out are energy measuring devices, calorimeters, in which most particles finish their journey. The final layer of the onion consists again of trackers, this time to identify the only detectable particles which get this far, the weakly interacting muons. A magnet embedded within the detector bends the tracks of charged particles, helping to identify and measure individual ones.

L3



OPAL

All four LEP detectors work on these basic principles, but each is optimized with a different goal in mind. OPAL is based on well understood techniques, to guarantee results right from the start. DELPHI is at the other extreme, packed with innovative technology. ALEPH takes the middle line, whilst L3's design is optimized for muon detection. All four have worked impeccably, and friendly rivalry has spurred the collaborations of physicists who built them on to the dominant place they hold in particle physics today.

Communication & Public Education Group.
CERN, 1211 Geneva 23, Switzerland.
June 1996

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