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PHYSICS AT CERN - PAST, PRESENT AND FUTURE.

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1 INTRODUCTION

I shall try in these lectures to be as simple and elementary as possible, at least for the first half of each talk. I know that many of you are not particle physicists by training but I hope that you will learn some of the fascination which the subject holds for many of us, and even more important, I hope that you will enjoy the lectures.

Let me first of all describe CERN which you will all enjoy. It is a laboratory which straddles the frontier between Switzerland and France although it is officially located in Switzerland, the country where it all began in 1953, although the organization was only ratified one year later in 1954. It began as a purely European facility with about a dozen countries contributing to its annual budget. The key members were then, as now, Germany, France, United Kingdom and Italy. During the first ten years the laboratory grew healthily and two major proton accelerators were constructed, the Synchrocyclotron (or SC) and the Proton Synchrotron (PS). The SC started life in 1957 with an energy of 600 MeV and worked reliably for many years but it completed its life in December 1990 and was closed down. The 24 GeV PS which started operations in 1959 is still an active part of the CERN accelerator complex and you will see it later in its current rôle.

At the end of 1965, the CERN Council approved the construction of the proton Intersecting Storage Rings (ISR). This was a bold move because up to that time, no storage rings for protons had ever been constructed. The ISR was planned to store protons of the energy of the PS and the first operation took place in 1970. The storage rings worked exceptionally well and allowed the experimentalists to study very high energy collisions in the centre-of-mass for the first time. For example, in order to study collisions at the same energy with a fixed target collision, it would require a proton beam of energy greater than 1200 GeV. The cross-section for proton-proton collisions was clearly demonstrated to rise with the high energy of the collisions.

An important experiment during the 1970’s was carried out by the bubble chamber called Gargamelle. This was the discovery of neutral currents by the study of neutrino and antineutrino interactions in Propane. This experiment was of crucial importance for the future success of the Standard Model and the discoveries of the $W^{\pm}$ and the Z^0.

During the years when the ISR started to operate for physics, the accelerator builders were busy constructing another, even larger, proton synchrotron known as the Super Proton Synchrotron (SPS) which started to operate at 200 GeV in 1976 but increased to 400 GeV by 1978. This was the workhorse of CERN and is still operating very effectively, at energies up to 450 GeV, 20 years later.

The success of the ISR made some physicists dream of using the SPS as a collider for protons and antiprotons. The key element of this idea was to find a way to get enough antiprotons in a sufficiently small phase-space into the SPS circulating in the opposite direction to the protons so that head-on collisions could be observed. The way which was found was to use stochastic cooling of the antiproton beam which was a method of reducing the antiproton beam size so that high-energy collisions could be observed.

The success of this led to the discovery at CERN in 1983 of the Z and W particles and resulted in Nobel prizes in 1984 for Carlo Rubbia, who was the spokesman of an experiment which found the particles, and Simon Van der Meer, who led the engineering effort to produce the antiproton beam. This special operation of the SPS continued until the USA, who followed the CERN example and built a proton-antiproton collider with their large accelerator, succeeded in doubling their energy and thus producing even more antiproton-proton collisions than was possible at CERN.

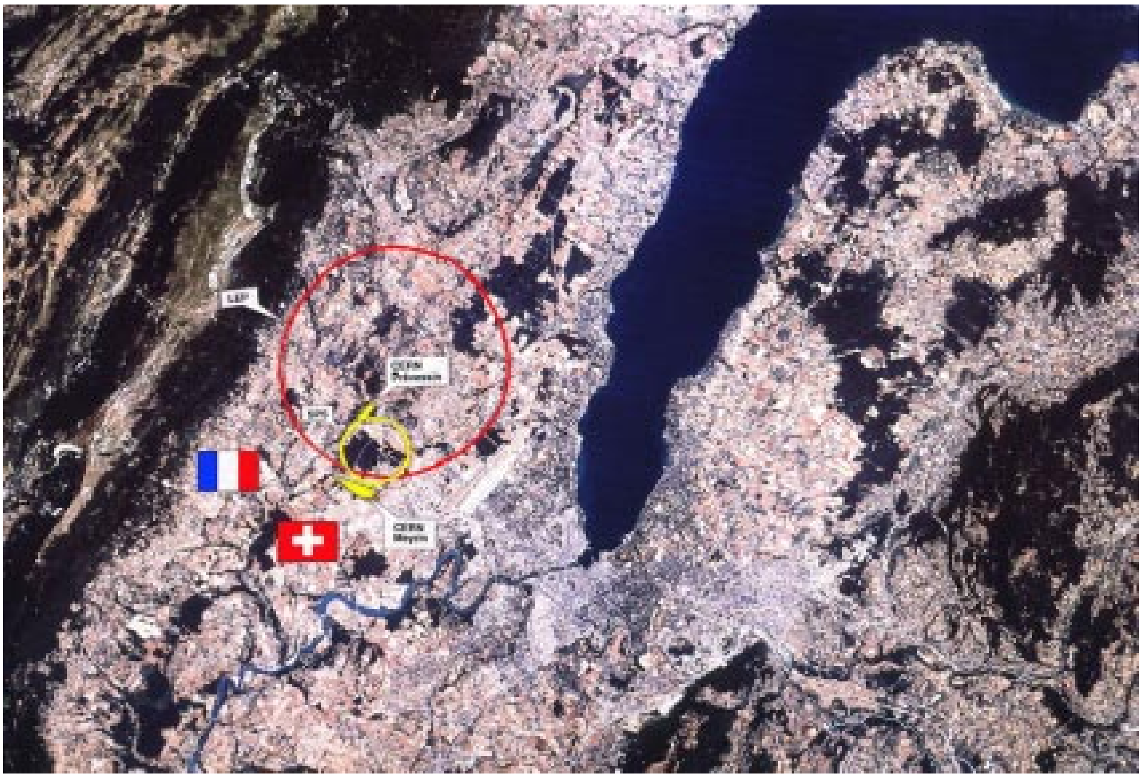


Figure 1: Aerial view of CERN Large Electron-Positron Collider (LEP)

Meanwhile the accelerator builders were once again busy this time to produce not another proton accelerator but a very large electron-positron collider called LEP which is 27 km in circumference as shown in figure 1 . The size was because of the synchrotron radiation emitted by electrons in a magnetic field which means only a weak field can be used to produce the circular orbit. However, the users, who saw the advantages of such a large ring being built at CERN, were very keen on this facility. The LEP collider started to operate in July 1989 and is still the major research tool of CERN and its many users. Its energy was initially limited to 50 GeV on 50 GeV (LEP1) and the research was on the Z peak. Since 1995, the energy has been increased to over 90 GeV per beam (LEP2) and the studies are emphasizing the production of W^+W^- pairs. It is hoped that by the year 1999 it will reach close to 100 GeV per beam and one hopes to see production of the Higgs particle.

This is a brief summary of CERN and its machines up to the present. Its next machine is under construction and is called the Large Hadron Collider.

2 THE LABORATORY

The laboratory which houses CERN has grown enormously during the forty five years since its first staff were hired. Let us look at figure 2 which is an aerial photograph of the CERN site. The first thing which you can see is the Geneva airport. Behind it you see two rings which indicate the location of the SPS (the smaller) and LEP (the larger). You also see a line of white crosses which is the French-Swiss border. On the LEP ring are four small blobs which indicate where are the four large LEP experiments (ALEPH, DELPHI, L3, OPAL).

Figure 2: Aerial Photograph of the CERN site.

Figure 3 shows how the CERN budget (evaluated in 1997 Francs) has evolved during the life of the laboratory. It carries an important message that despite the growing number of accelerators and their ever increasing energy, the annual budget of the laboratory has basically remained constant since 1973 when it was somewhat larger than today. The graph shows personnel costs and basic exploitation (the costs of running the laboratory including the experimental programme) as well as the energy costs and the individual investments for the different accelerator components PS, ISR, SPS, antiproton-proton collisions, LEP1, LEP2 and finally LHC.

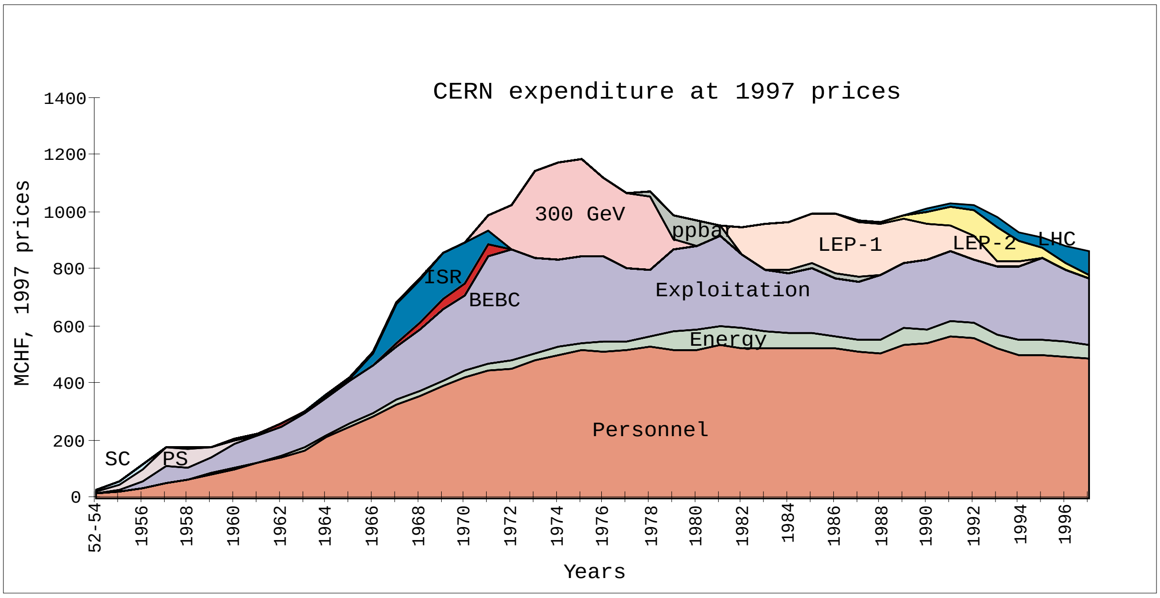


Figure 3: CERN budget (evaluated in 1997 Francs.)

CERN now has 19 member states. The member states, which all are in Europe, share the budgetary costs each year based on their ability to pay which is based on a number called the Net National Income. Although CERN started as a purely European facility it now has a worldwide clientele and there has been a dramatic growth in the number of users over the past twenty years. It now hosts over one half of the world's experimental particle physicists.

The current member states are shown in figure 4. It is worth noting that the most recent countries to join CERN (Poland, Hungary, Czech and Slovak Republics) do not yet contribute their full share to the budget. They will pay the correct sum only from the year 2002.

Figure 4: Current member states

The growth in the user community over the past twenty years is illustrated in figure 5. The total number of users has grown from 1500 to almost 7000 in twenty years. The number of non-member state users is now close to 2000. The member state users have saturated at close to 5000.

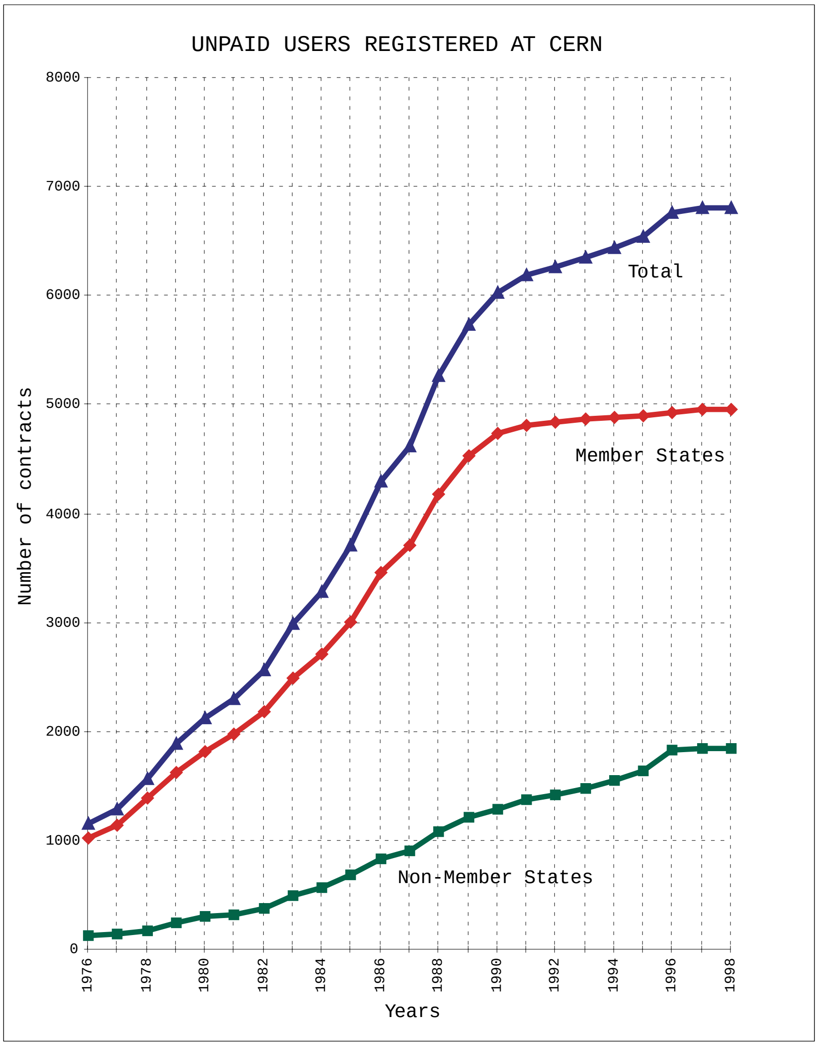


Figure 5: Unpaid users registered at CERN.

Figure 6 shows the distribution of users throughout the world. The greatest number of users come from the member states (≈ 4500). Then the two other large users are the USA and the former Soviet Union, both having around 1000 users. Japan, Canada, China and India all have more than 100 users at CERN. The numbers are slightly different than shown in figure 5 because some users are not yet registered at CERN but are on the LHC technical proposals, whereas some member state users are not registered in the "Grey Book".

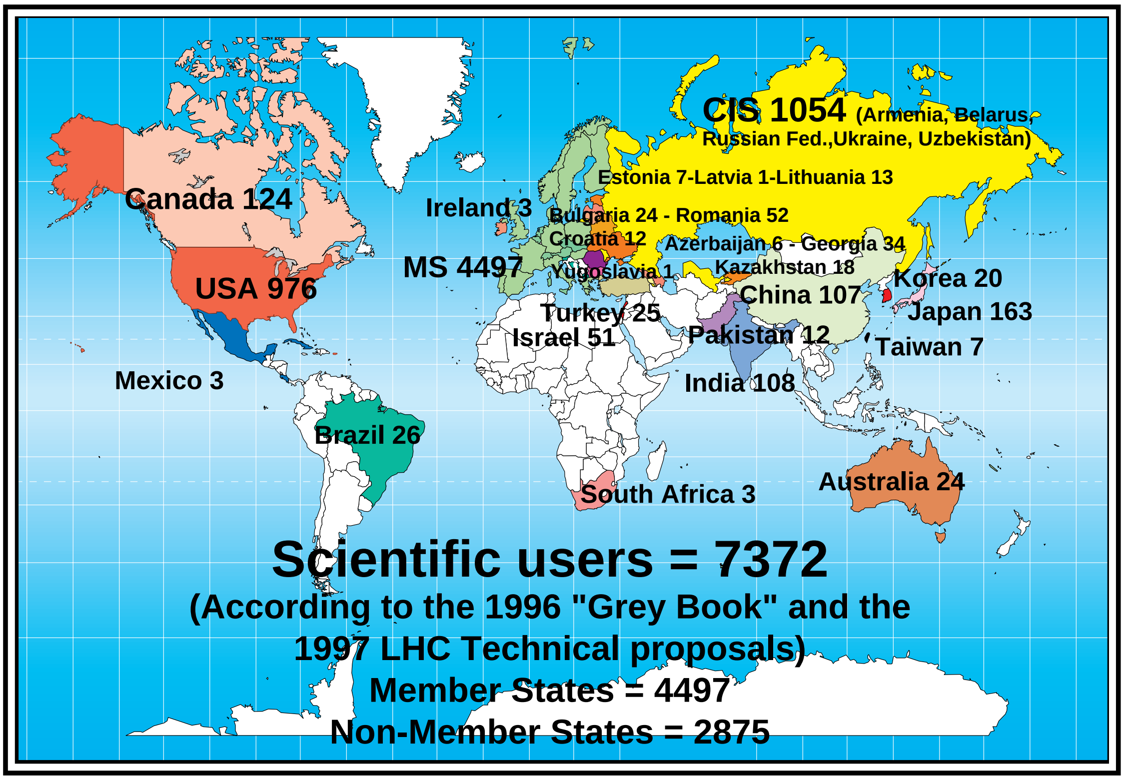


Figure 6: Distribution of CERN users throughout the world.

3 CERN'S ACCELERATORS

Apart from the SC and the ISR, which were closed, CERN still has all the accelerators which have been constructed. Let us first look at the complex of accelerators so that you can appreciate better what is CERN. This is shown in figure 7. The proton beams all start with the 50 MeV linac. This feeds protons into the booster where four beam lines, one on top of the other, are used to feed the maximum possible intensity into the PS at 1 GeV. The PS accelerates the protons to 26 GeV when they are then sent to the SPS. Here they are accelerated to 450 GeV and used for fixed target experiments or they will eventually be injected into the Large Hadron Collider (LHC). The only beam lines which do not exist already are the two beams linking the SPS and the LHC. Thus the major work for the future lies in equipping the LEP tunnel with the high-field magnets for the LHC which we will turn to later.

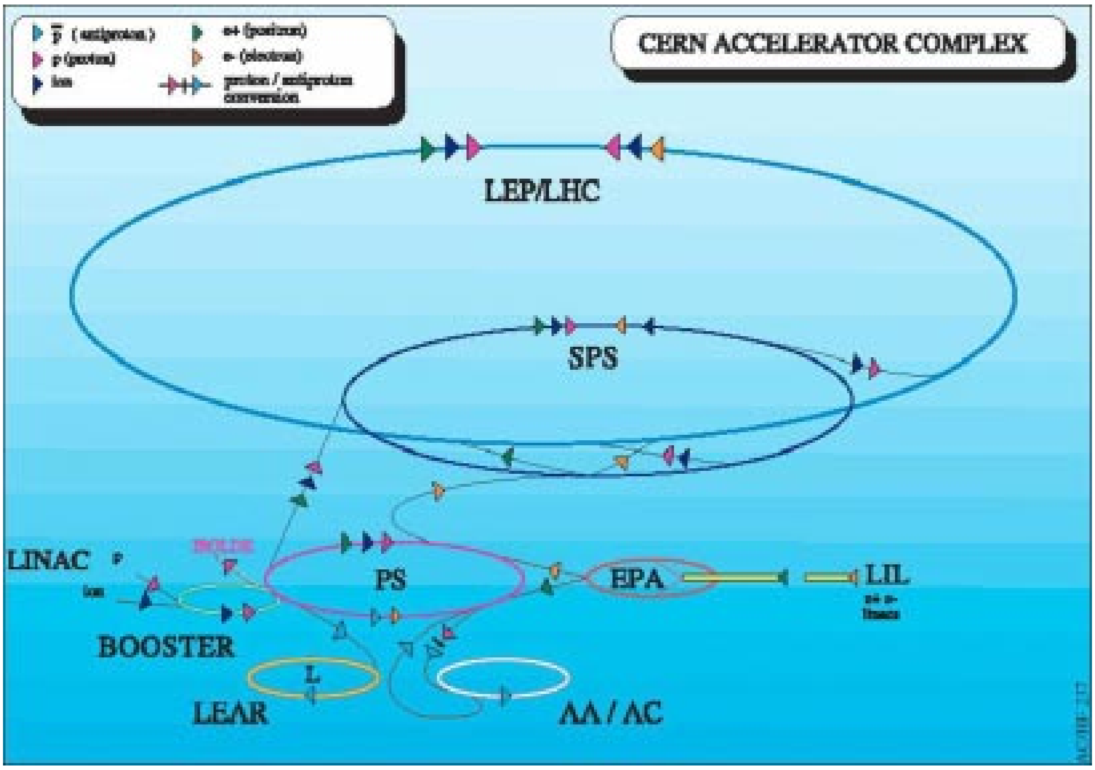


Figure 7: Complex of accelerators.

The electron and positron beams start with the $e^{+}e^{-}$ linacs known as LIL. The electrons are accelerated and then impinged on a target which produces both electrons and positrons. These are both accelerated in the electron-positron accelerator (EPA) to 500 MeV and are then injected into the PS. Here they are accelerated to 3.5 GeV and then pass into the SPS where they are accelerated to 22 GeV before being injected into LEP for their final boost up to close to 100 GeV.

The concept of a collider is an important step in understanding CERN. Figure 8 shows a TV set (an accelerator) and a simplified picture of the LEP collider. The ring contains bending magnets, which make the electrons and positrons follow a circular path, focussing magnets which keep the particles in beams, and accelerating cavities which provide energy to the beams. The electrons and positrons circulate inside a vacuum chamber. The particles are in bunches so that collisions occur at discrete times when the bunches cross each other. Typically there are four bunches of electrons and four bunches of positrons circulating at the velocity of light in opposite directions.

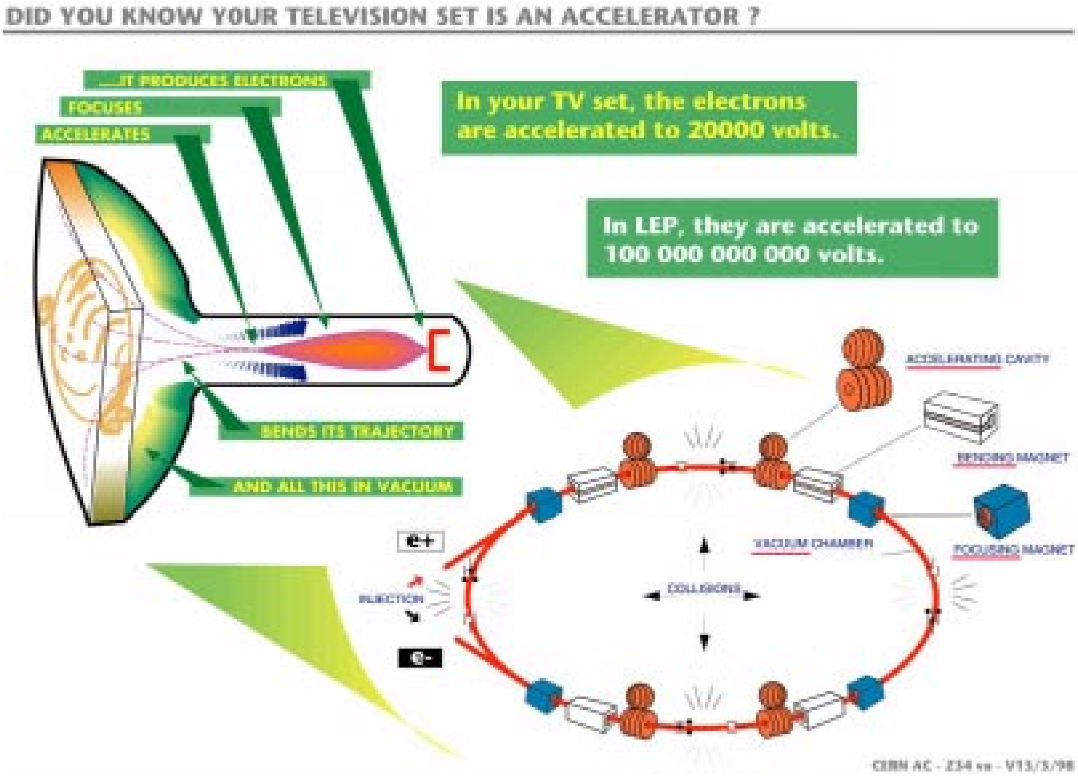


Figure 8: An accelerator and a simplified picture of the LEP collider.

In this simplified picture, there could be four experiments which could observe the electron-positron interactions, as is the case in the real LEP. An example of an accelerating cavity is shown in figure 9 where the electromagnetic wave propels the particles like a surfer on an ocean wave.

The aim of particle physicists is to study the forces of nature which are illustrated in figure 10. One sees here that there are four forces, strong, electro-magnetic, weak and finally gravitation which have a decreasing strength. The weakest, gravitation, will not be further discussed. For the others, we know the field quantum or binding particles which carry the force. These are gluons for the strong nuclear force, photons for the electromagnetic force and bosons (Z^0, W^+, W^-) for the weak nuclear force. These forces are felt in different places from the atomic nucleus (for the strong nuclear force) to the atomic shell (for the electro-magnetic force) to radioactive beta decay (weak nuclear force). A example which illustrates how the exchange of a particle (basketball) can result in a force is shown below. In fact the theory now links the electro-magnetic and weak forces together and describes them with a common theory called the Standard Model.

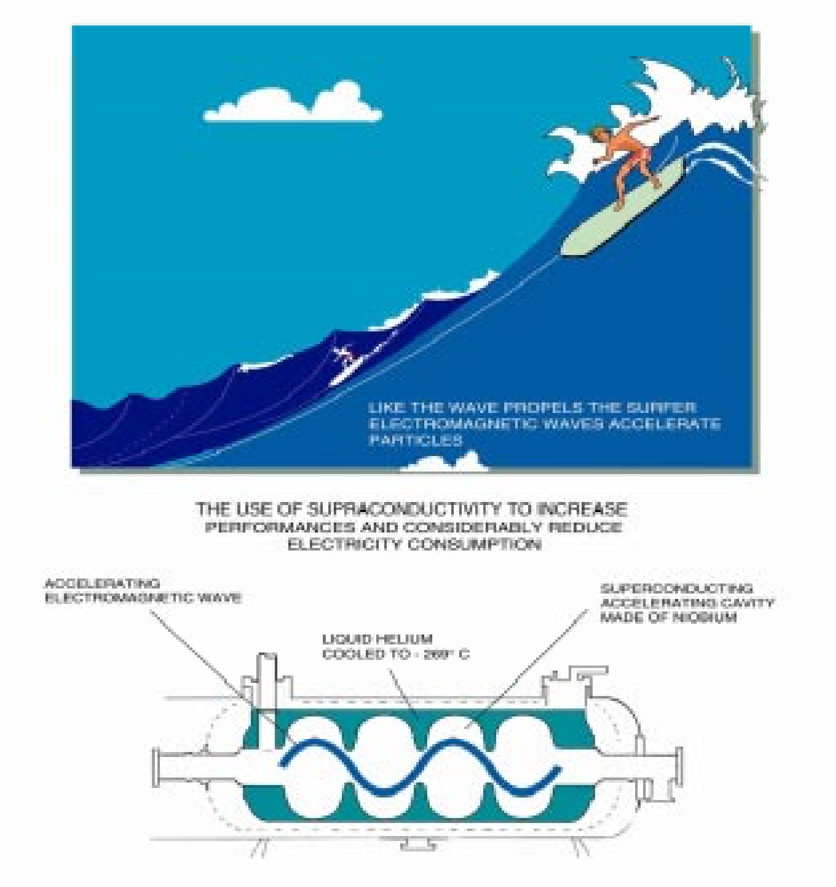
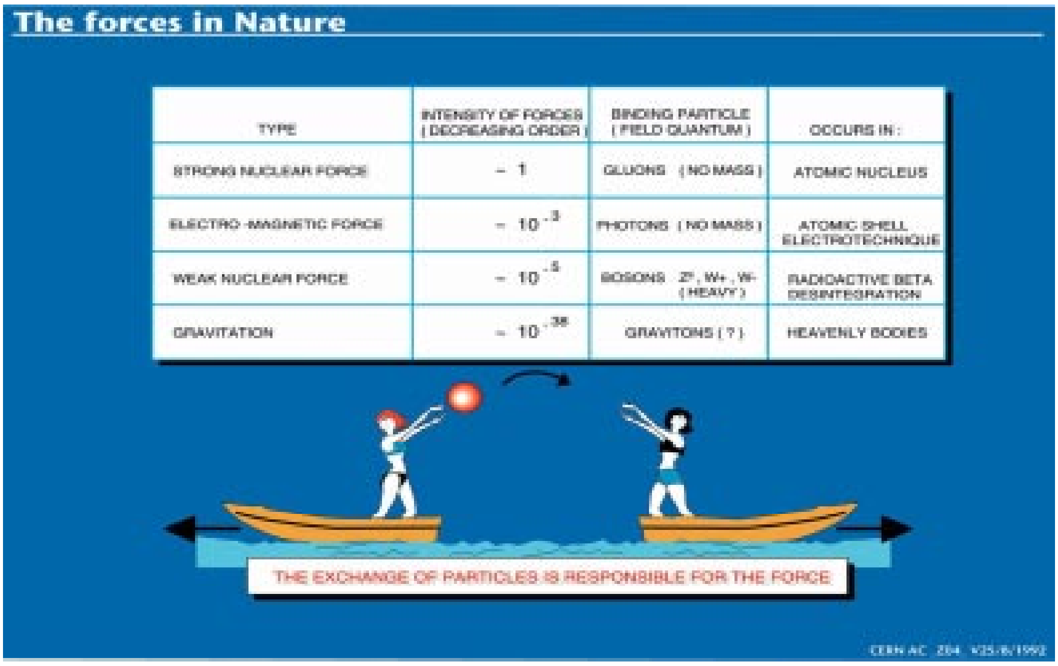


Figure 9: An example of accelerating cavity.



TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO-MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^0, W+, W- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES

Figure 10: The forces in nature.

The experimental work over the past 45 years has led the physicists to describe the world in terms of fundamental elementary particles which are shown in figure 11. There are six quarks and six leptons whose electric charges are shown. There are also an equivalent number of anti-particles with opposite electric charge. Particles which you know, such as the proton, is made up of three quarks, up+up+down, making a charge of unity. A π^+ meson is made up of two quarks, an up+anti-down, also making unit charge.

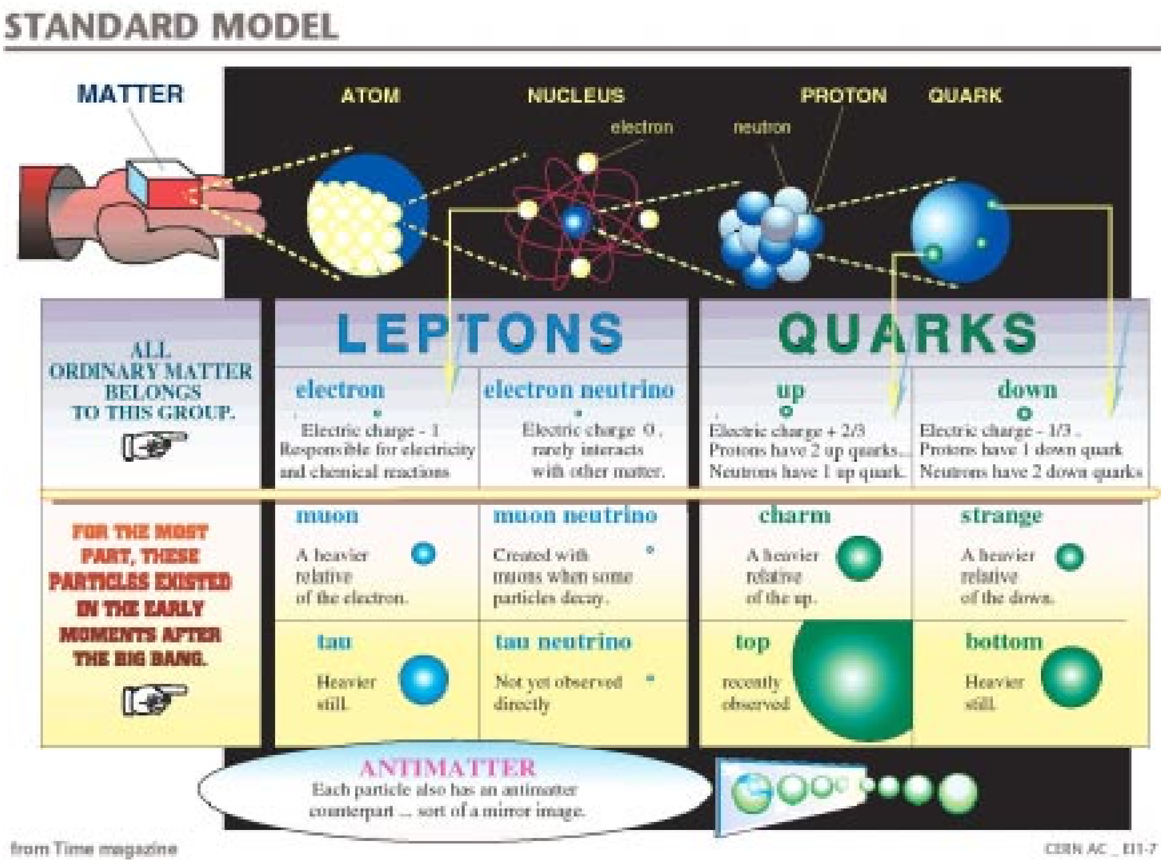


Figure 11: Fundamental elementary particles.

4 EXPERIMENTS

The key to CERN's activities lies in the experiments which can be carried out with its complex of accelerators. CERN supports a diverse programme of physics research including:

- ISOLDE - an on-line Isotope Separator
- Fixed target physics with the 450 GeV SPS (proton and Pb beams)
- LEP Programme of e^+e^- physics.

4.1 LEP Experiments

Let us review the four experiments which are currently in operation at LEP. The physicists which proposed these experiments in the early part of the 1980's were all seeking an excellent detector which would cover most of the solid angle. They also all wanted a good magnetic field in order to measure the momentum of the charged particles and calorimetry to detect electrons and photons as well as hadron calorimetry for the majority of particles produced. Finally they all wished to detect the muons which would inevitably be produced in the annihilation of the electrons and positrons.

All four experiments have succeeded and they have used different techniques for these key detector elements. The layout of LEP is seen in figure 12.

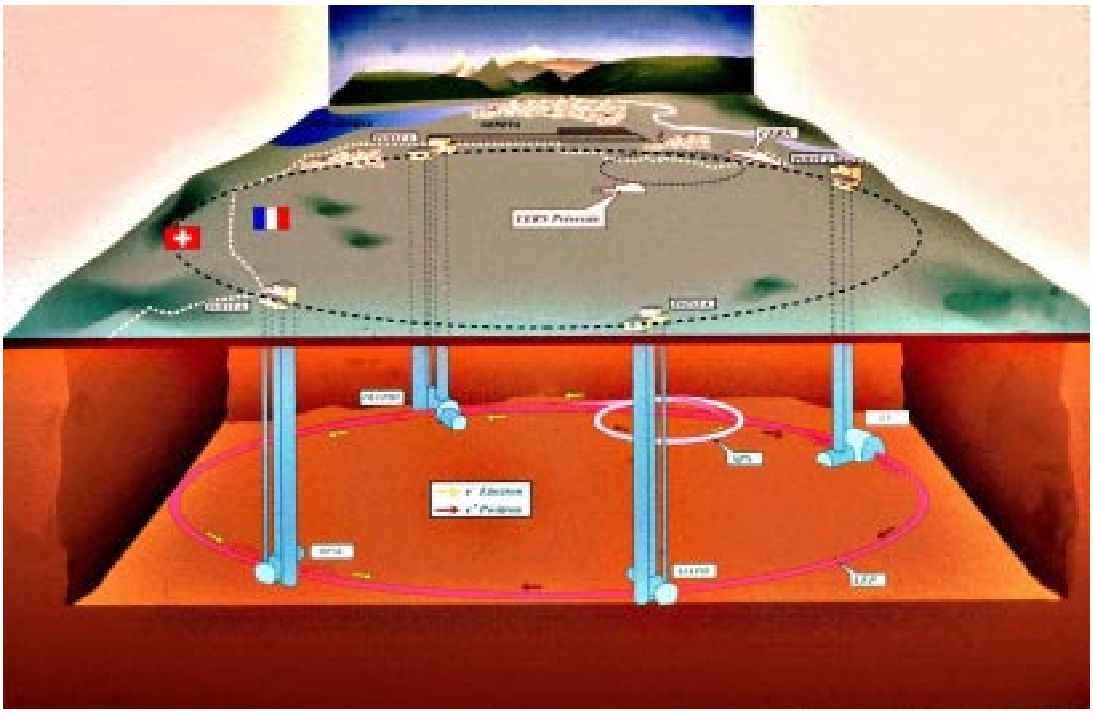


Figure 12: LEP layout.

The fact that all four experiments have operated since the start-up of LEP pays tribute to the ingenuity of the teams of physicists making up these large Collaborations. In fact all four experiments chose a solenoid magnet configuration but two were superconducting (DELPHI and ALEPH) and two used normal magnets (L3 and OPAL).

Figure 13 shows an artist's impression of a LEP detector with a solenoid magnet with the electrons and positrons colliding at its centre and the many secondary particles emerging from the collision. The aim of the experimentalist is to measure and identify all the products of the annihilation. All the experiments now have micro-vertex detectors as their central element but then they differ in their choice of detection techniques.

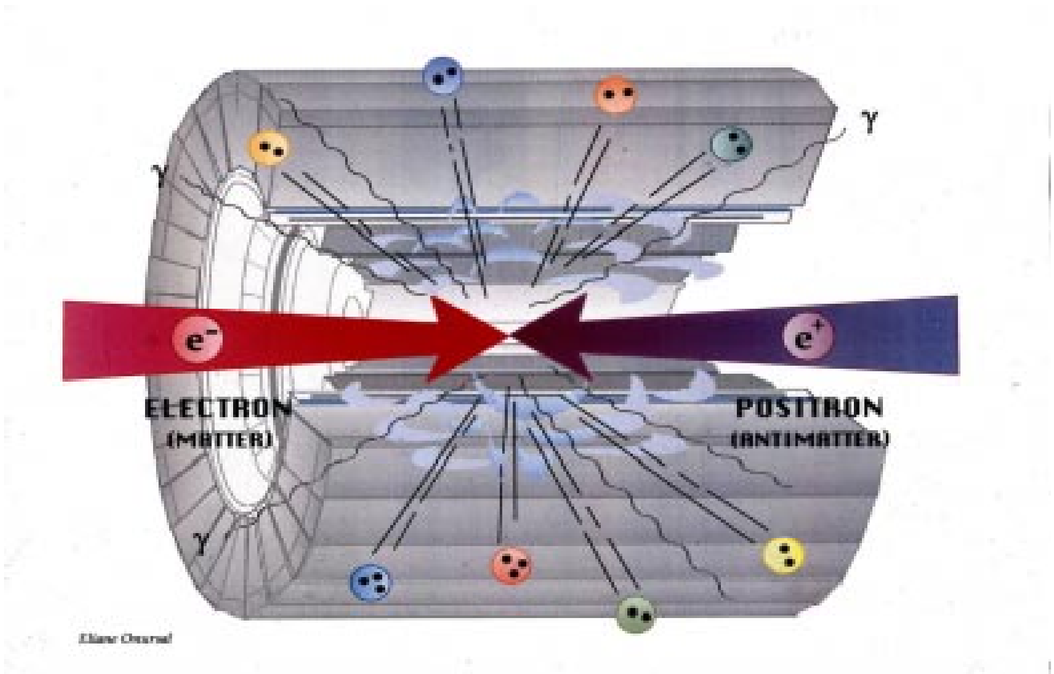


Figure 13: An artist's impression of a LEP detector.

DELPHI has emphasized the identification of the secondaries by means of gas and liquid Cerenkov counters, whereas ALEPH has the largest Time Projection Chamber (TPC) for its charged particle tracking. L3 has emphasized the electromagnetic calorimetry using the unique Bismuth Germanate (BGO) crystals to obtain the best resolution for electromagnetic particles whilst OPAL, perhaps the most conventional of the detectors, was modelled on the DESY detector JADE, and contains a rather conventional electromagnetic calorimeter made of lead glass blocks aligned on the vertex point of the magnet but outside the magnet coil. All the four detectors have well equipped end-caps which extend the barrel region both forward and backward. Finally all four detectors have muon detection chambers outside the barrels which are themselves instrumented to perform hadron calorimetry.

Figure 14 shows a sketch of the DELPHI detector. It has a 1.2 Tesla solenoid magnetic field and the tracking is done by a single layer Time Projection Chamber. Outside the TPC are the Ring Imaging Cerenkov Counters (RICH) which allow DELPHI to decide which particles are pions, kaons or protons in the analysis of the events. The electromagnetic calorimeter, which is inside the coil, is just outside the Cerenkov Counters. The return yoke of the solenoid, outside the coil, is laminated in 5 cm plates and instrumented with proportional chambers to form the hadronic calorimeter. Finally the muon chambers surround the barrel and the end caps and detect the muons which are produced. The end caps are similarly equipped with Cerenkov Counters and electromagnetic and hadronic calorimeters.

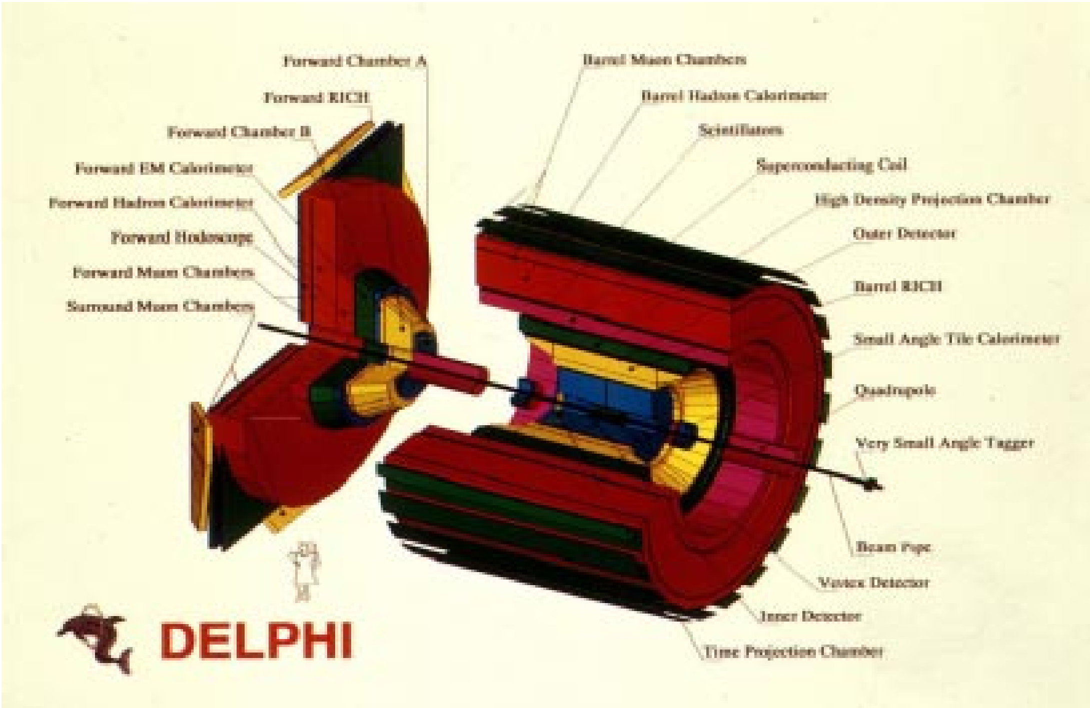


Figure 14: DELPHI detector.

Figure 15 shows a similar sketch of the ALEPH detector where the large TPC can be seen outside of which is the 1.5 Tesla solenoid.

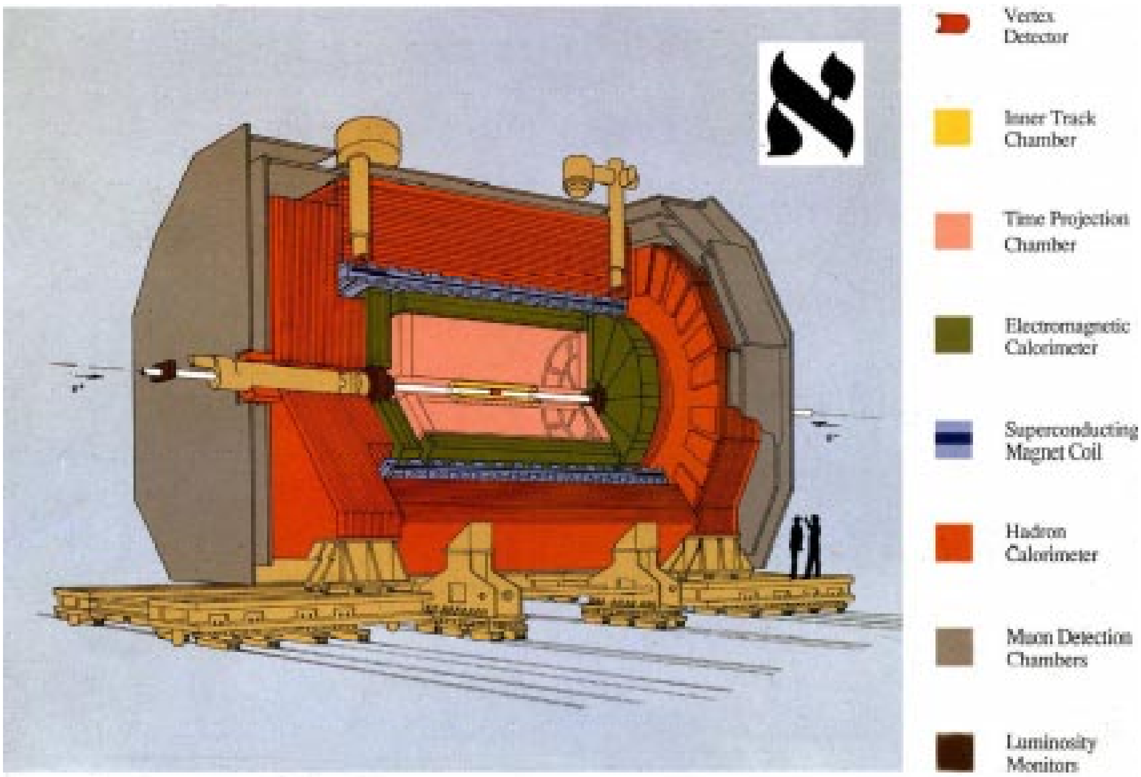


Figure 15: ALEPH detector layout.

Figure 16 is a photograph of the ALEPH detector taken from the end where you can see the instrumentation necessary for the TPC (at the centre) and the hadron calorimeter (outside the coil cryostat). The original spokesman of ALEPH, Nobel Laureate Jack Steinberger, is on the picture. The two other LEP detectors, L3 and OPAL are similarly equipped, but will not be described.

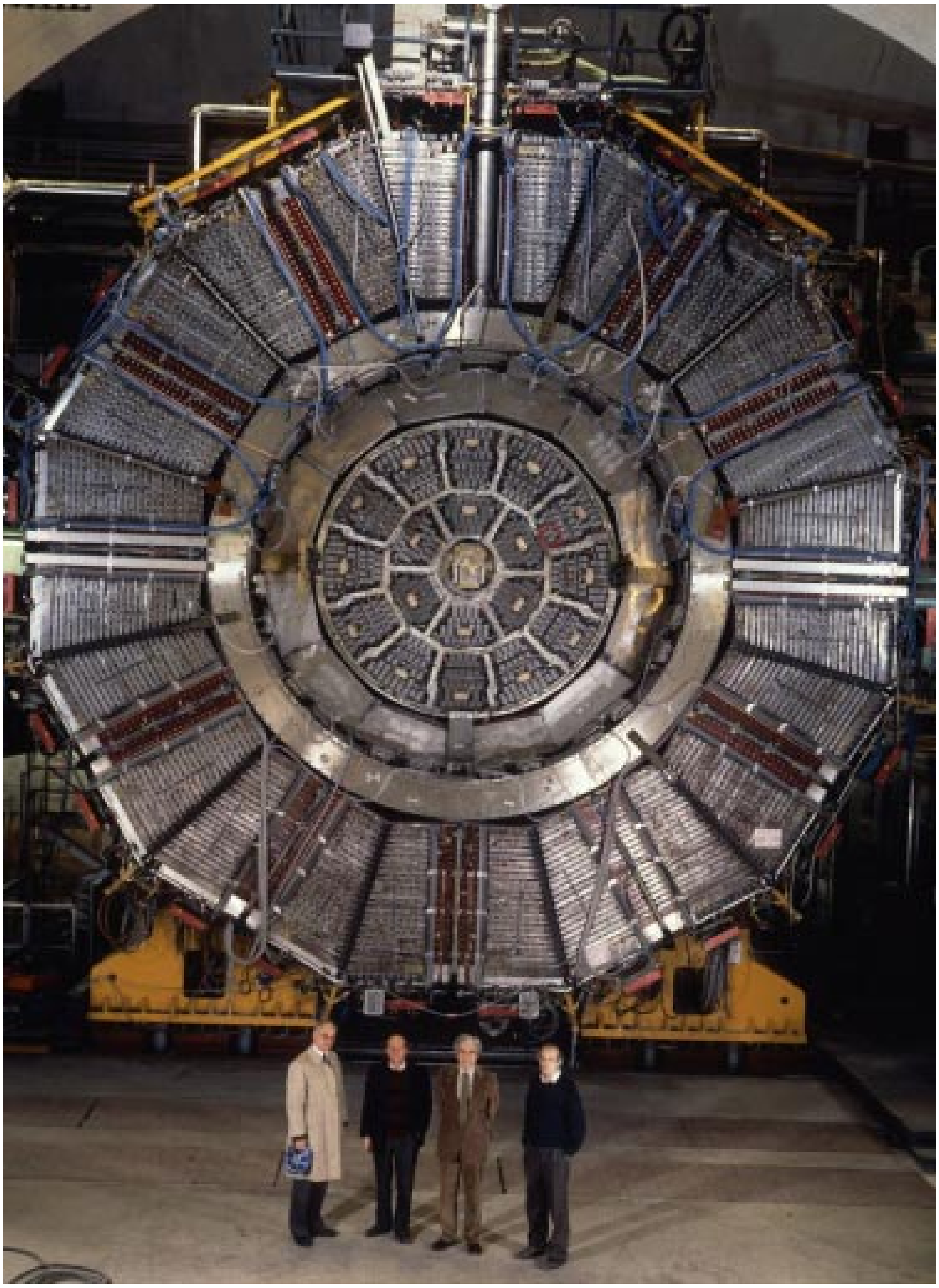


Figure 16: Photograph of the ALEPH detector.

Figure 17 shows the data, from L3, of the cross section as the energy of the electrons and positrons is raised from 88 GeV to 95 GeV. The peak is the production of the Z^0 particle. The three curves represent the theoretical data for a world with two, three and four neutrinos. It is clear that three neutrinos fit the data very well. All the experiments have made similar curves.

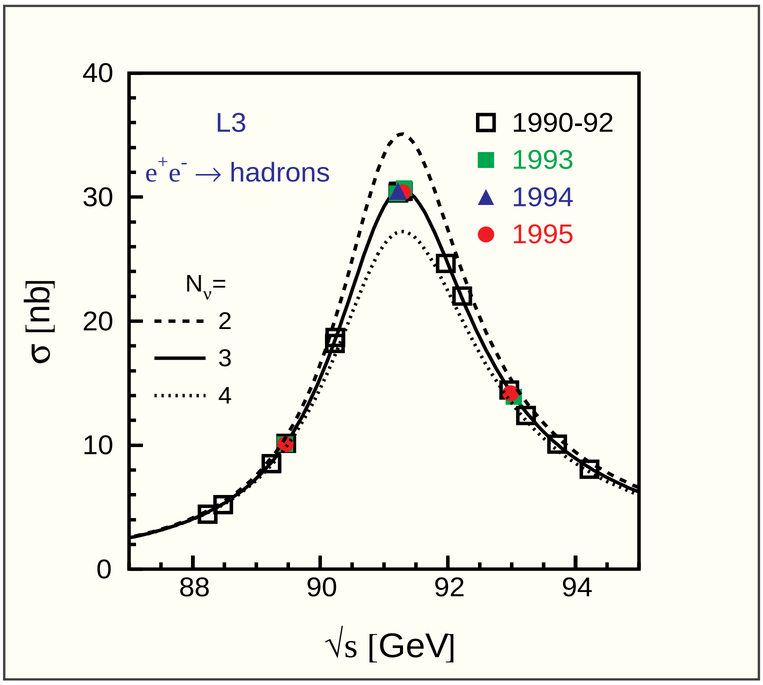


Figure 17: L3 e^+e^- cross section at $\sqrt{s}$ = 88-95 GeV.

Figure 18 shows the data resulting from all four experiments and their average value which is clearly three neutrinos. The data now are much more precise and still support the same result.

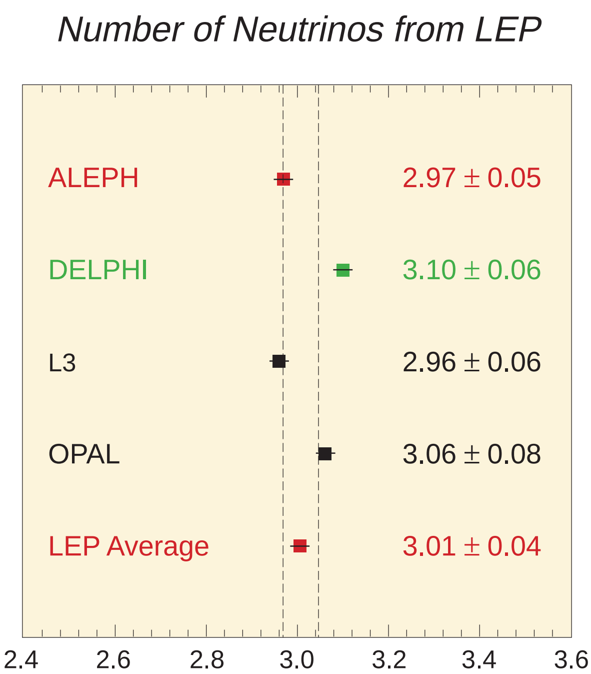


Figure 18: Data from all four experiments and their average value.

I could not resist including figure 19 in this talk. It will not mean much to most of you but I think it illustrates the beauty of the physics at LEP. It was taken five years ago and is a reconstruction of a LEP event in ALEPH. You can see a pair of K's and a pair of μ's. What is interesting is the detail of the event revealed on the right-hand side showing that they are produced from a B_S event. This shows the power of the micro-vertex detectors of LEP which allow the physicist to see the very short lifetimes in real space. All the four LEP detectors are equipped with similar micro-vertex detectors and they have all seen such events.

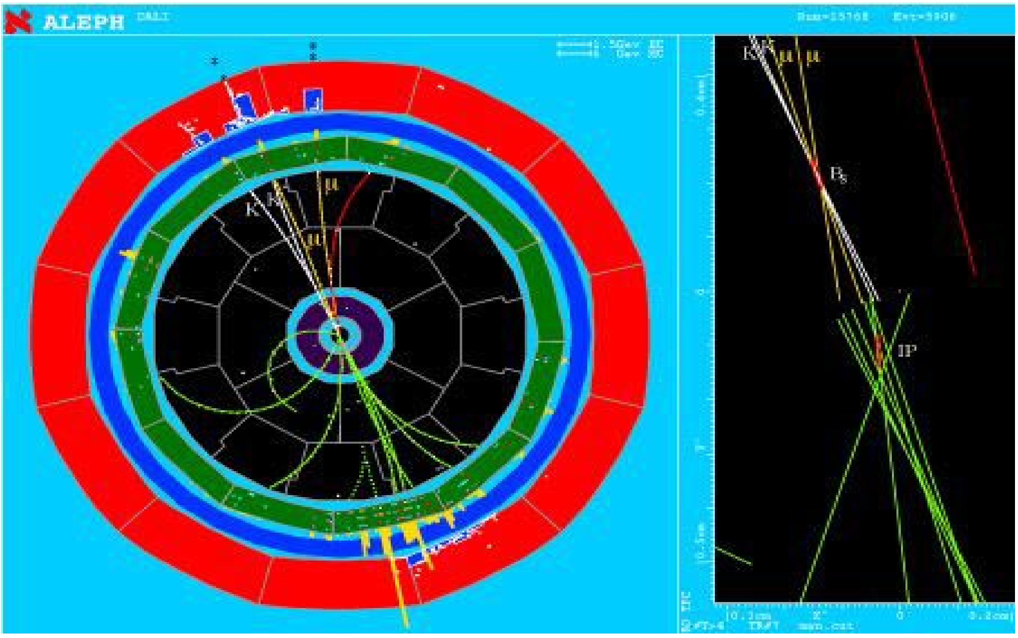


Figure 19: Beauty of the physics at LEP.

I believe that this summary will give you all some feeling for the LEP collider and its experiments which are going on still today. The energy of LEP has been almost doubled and the detectors are studying the production of W pairs and hoping to find the Higgs particle. It is believed that by the year 2000 the experiments will have sufficient high energy data to make a statement on the presence or absence of the Higgs particle below 100 GeV mass. The LEP collider will then close, be dismantled and the installation of the LHC magnets will begin for the next phase which will be described tomorrow.

4.2 The Large Hadron Collider

The future physics at CERN will be carried out with a proton-proton collider known as the Large Hadron Collider or LHC. I shall first of all motivate the reasons for the choice of the LHC for CERN. Then I will describe what is needed to build the LHC, and finally I shall review the experiments being planned for this high energy collider.

The physics questions opened up by the incredible success of the Standard Model which, after nine years of LEP experiments, still gives a highly sophisticated but correct description of the experimental results. This success pushes us to even higher energies of the constituent collisions from the current level of 0.1 TeV (or 100 GeV) to more than 1 TeV. There are strong theoretical arguments to say that at energies above about 1 TeV something fundamental must change in our description of the collisions.

The technology to carry out e^+e^- physics at 1 TeV/beam is not yet available. However, using proton-proton collisions, one can produce constituent collisions (at the quark level) well in excess of 1 TeV/beam. This is the basis of the LHC project (and was also the basis of the SSC project in the USA).

At CERN we can benefit from the investments of the past and use:

- the injector system: linac, booster, PS, SPS
- the LEP tunnel and its infrastructure
- the LEP 200 cryogenics
- the Pb-ion injector to permit Pb-Pb collisions in the LHC.

The basic idea is to utilize the LEP tunnel, which contains a low field magnet because of the synchrotron radiation which is emitted by electrons and positrons which are bent by a magnetic field. If one wants to use protons, which are much heavier than electrons, then one can use a much higher magnetic field and in the same tunnel obtain much more energy. The maximum energy which can be obtained for electrons is 100 GeV per beam when the synchrotron radiation becomes impossibly high. With the use of superconducting coils for the magnets, one can obtain 7 TeV per beam for the protons in the LHC or an increase of 70 times that of the electrons.

In order to get this large increase in energy, one must use the maximum field for the bending magnets and for LHC this field is 8.4 Tesla. The magnet is a dual device with the field going up on one side and down on the other as shown in figure 20. This shows a computed field map for a theoretical magnet with 10 Tesla field. The two coils can be seen which are superconducting. The lines indicate the field and the magnet will bend protons in the same direction whichever way they come into the magnet since the field is reversed in the opposite coil.

One of the novelties of this magnet is not only the superconductor but its temperature which is 1.9 ^{0} K. This can be achieved with superfluid helium as seen in figure 21. This shows the cross-section of the magnet. From the centre of each coil one may see the two beam pipes, the superconducting coils, the non-magnetic collars which hold the coils in place and the iron yoke which guides the field. The heat exchanger pipe at the top contains the superfluid helium which cools all of the material inside the Helium II vessel to 1.9 ^{0} K and it is surrounded by radiative insulation. The vessel is supported on an insulating support post (three in total) and is contained inside a thermal shield at an intermediate temperature (55^0-75^0 K). The whole magnet is finally contained in a vacuum vessel. Figure 22 shows the equivalent diagram for the superconducting quadrupole design which is similar to the dipole.

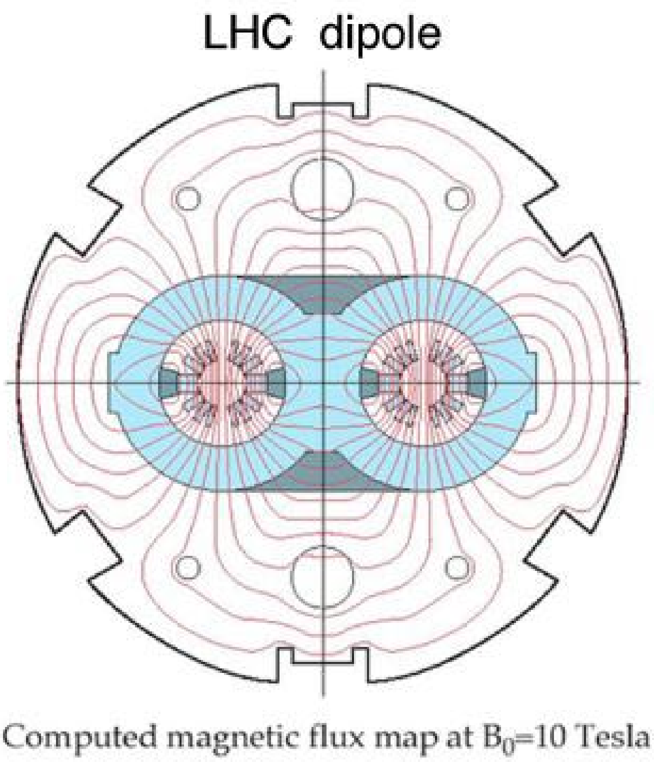


Figure 20: Computed field map for a 10 Tesla field magnet.

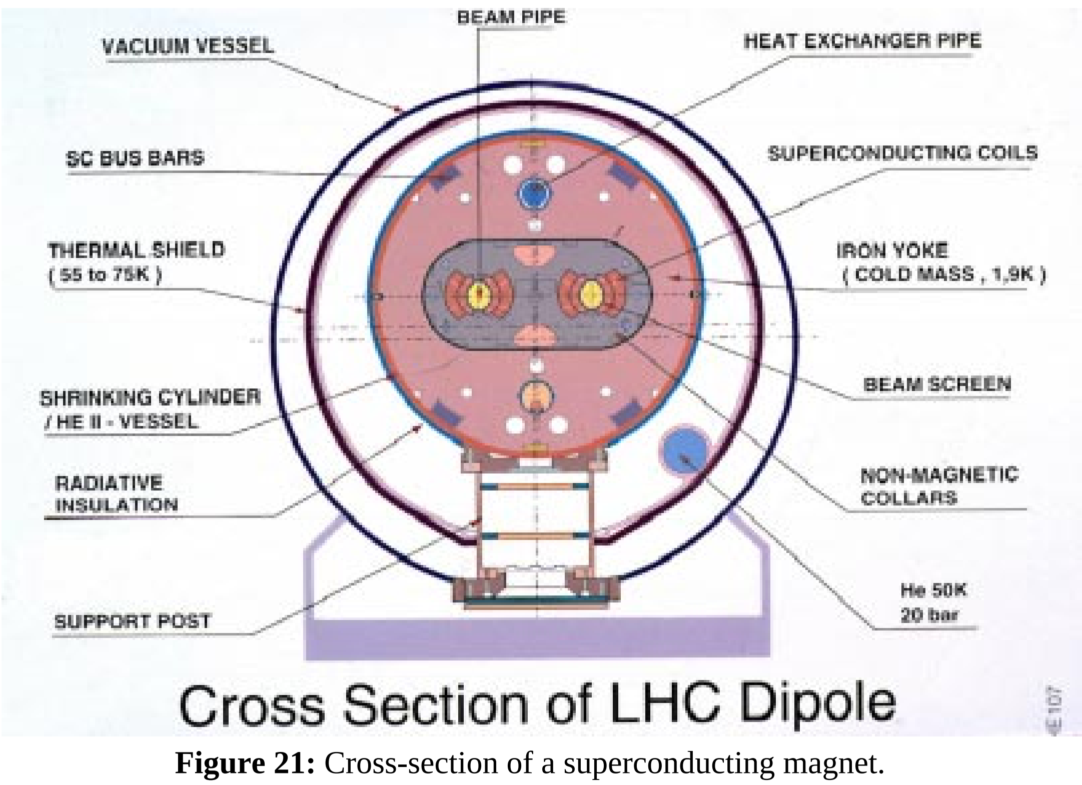


Figure 21: Cross-section of a superconducting magnet.

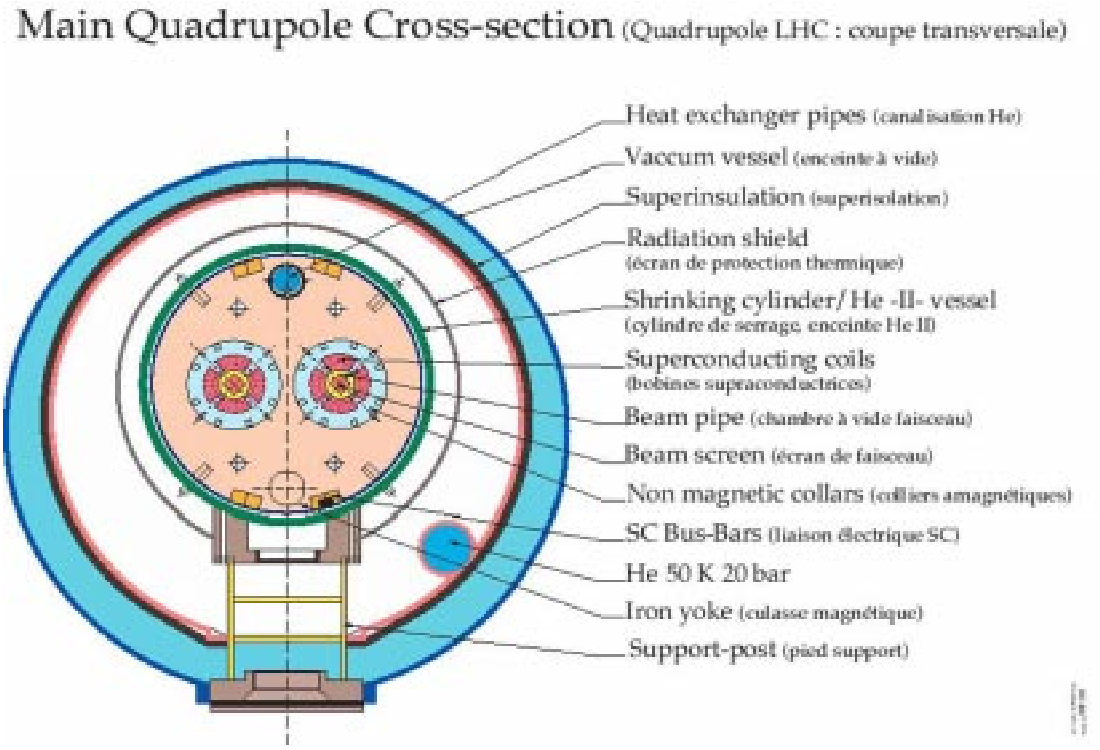


Figure 22: Superconducting Quadrupole design.

Figure 23 shows an artist's impression of how the magnets will appear in the LHC tunnel. The main cryogenics is fed into the magnets only periodically around the ring. Figure 24 shows what is known as the test string of three 10 metre long prototype magnets linked with one prototype quadrupole. This string has been extensively tested and the superconducting coils have been forcibly quenched many times.

Figure 23: How the magnet will appear in the LHC tunnel.

Figure 24: Test string of prototype magnets and quadrupole.

Figure 25 shows a sketch of the final layout of an LHC half-cell. It will contain three 14.3 m long superconducting dipoles in between standard superconducting quadrupoles. This will be repeated some 46x8=368 times making a total of 3x368=1104 dipoles to close the ring. Figure 26 shows the main parameters of the LHC for pp and for Pb-ions. The luminosity for pp is given as 10^{34} cm^{-2} s^{-1} whilst that for Pb-ions is only 10^{27} cm^{-2} s^{-1}. However the energy of the beams is 1148 TeV for Pb-ions compared with 14 TeV for protons.

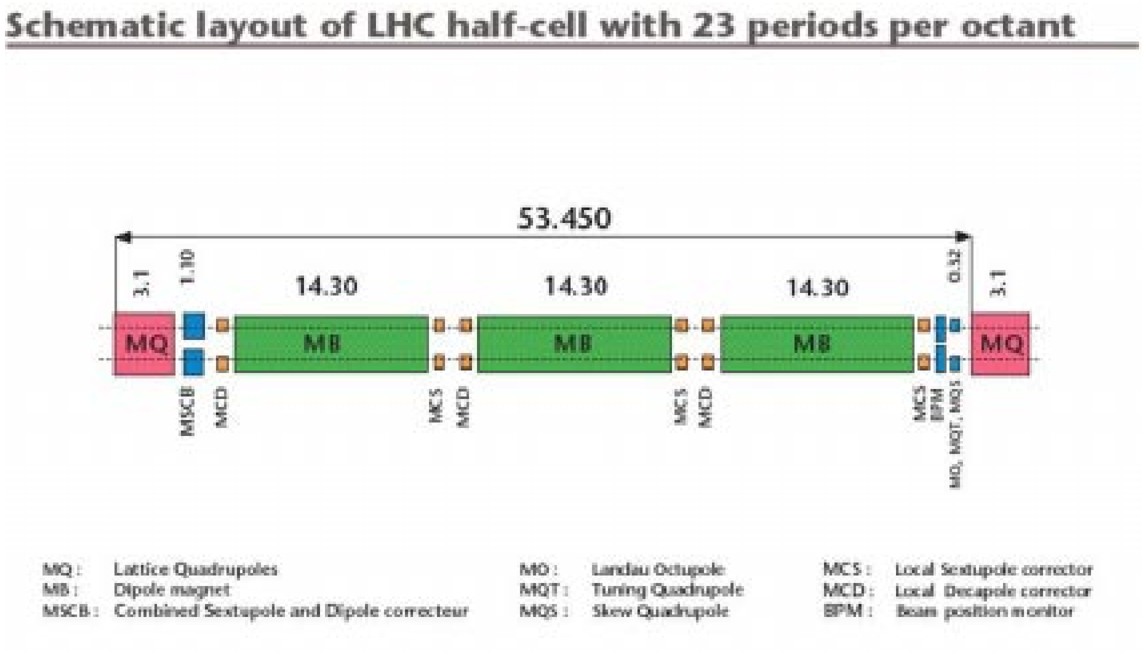


Figure 25: A sketch of the final layout of an LHC half-cell.

LHC Main Parameters (Août 95)

		pp	Pb-Ions
Expected operational cm energy	TeV	14.0	1148
Dipole field (max)	T	8.4 (9.0)	8.4
Luminosity	$cm^{-2}s^{-1}$	10^{34}	$\sim 10^{27}$
Number of bunches		2835	608
Bunch spacing	m | ns	7.5 | 25	37.4 | 124.8
Particles per bunch		10^{11}	9.4×10^{7}
Particles per beam		2.8×10^{14}	4.7×10^{10}
Number of experiments		2	1
β^* at interaction point	m	0.5	0.5
r.m.s. radius at interaction point	μm	16	15
r.m.s. collision length	cm	5.4	5.4
Crossing angle	μrad	200	<100
Synchrotron radiation (2 beams)	kW	7.2	
Luminosity at beam-beam limit	$cm^{-2}s^{-1}$	2.5×10^{34}	

Figure 26: The main parameters of the LHC for pp and for Pb-ions.

Figure 27 shows a sketch of the ring with indications of what is planned for the eight octants. The four experiments currently planned (ATLAS, CMS, ALICE and LHC-B) are all shown in their expected straight sections. The two intersecting lines are the proton beam lines going in opposite directions around the ring. ATLAS and CMS are both experiments concentrating on the proton-proton collisions and both have a low β insertion. This just means that the beams are squeezed down to their minimum size to increase the interaction rate at the points where the protons will cross. The ALICE project is aimed at the collisions between Pb and Pb ions during dedicated runs. The LHC-B project is a study of the B particles which will be produced in large numbers by the proton-proton collisions. The other straight sections are planned for cleaning, RF acceleration and beam dumping as is indicated in the figure. The circumference of the ring is 27 Km.

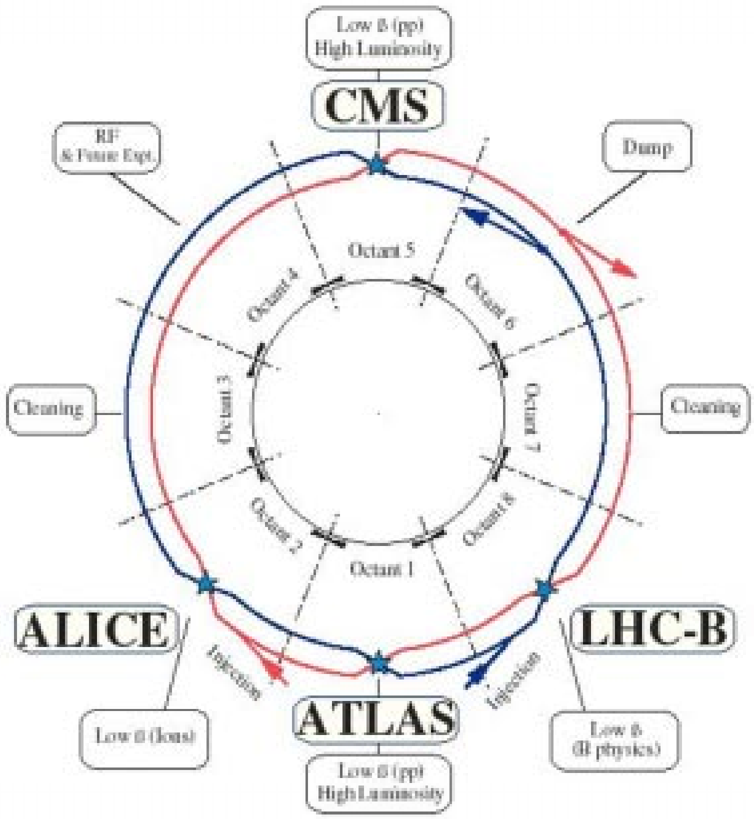


Figure 27: A sketch of the ring with indications of what is planned for the eight octants

4.3 The LHC Experiments

The experiments are quite different in their aims and objectives. Figure 28 shows an artist's impression of the largest detector which is ATLAS. The scale is illustrated by the figures shown standing by the side of ATLAS. Starting from the outside we see the massive muon detectors in two layers surrounding the barrel and end-cap toroids. These will provide a precise measure of the momentum of the muons which emerge from the interaction. Inside the toroids is a system of calorimeters, both electromagnetic and hadronic, and a sophisticated tracking system which is contained inside a small solenoidal coil. This is shown in figure 29 where the barrel is equipped with hadronic tile calorimetry and the two end-caps have liquid argon hadronic calorimetry. The electromagnetic calorimetry is in the form of accordion calorimeters developed for ATLAS. The innermost detector is a very sophisticated tracking system.

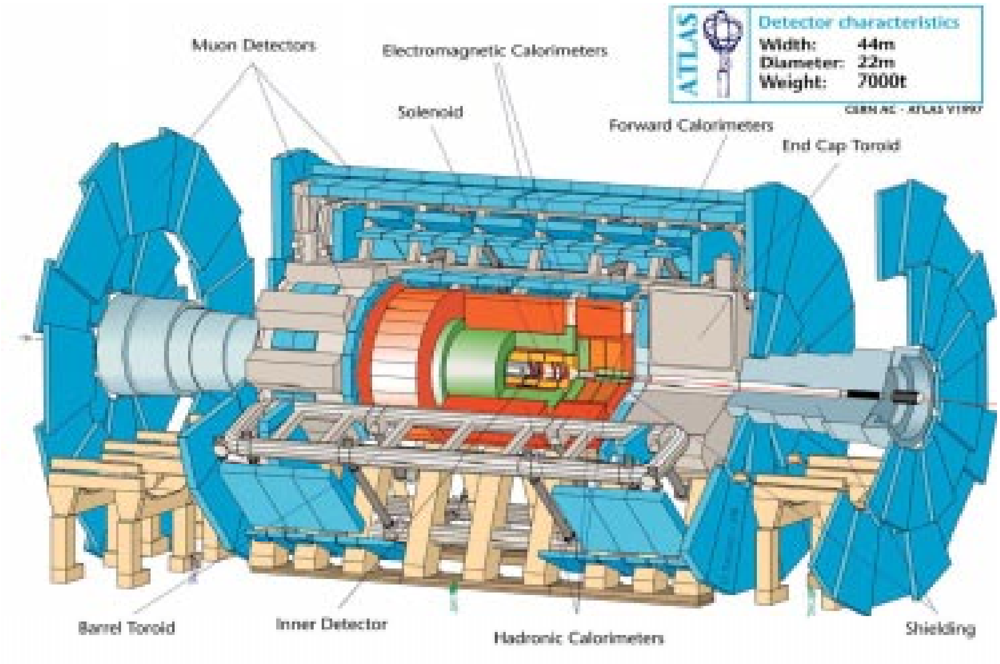


Figure 28: An artist's impression of ATLAS.

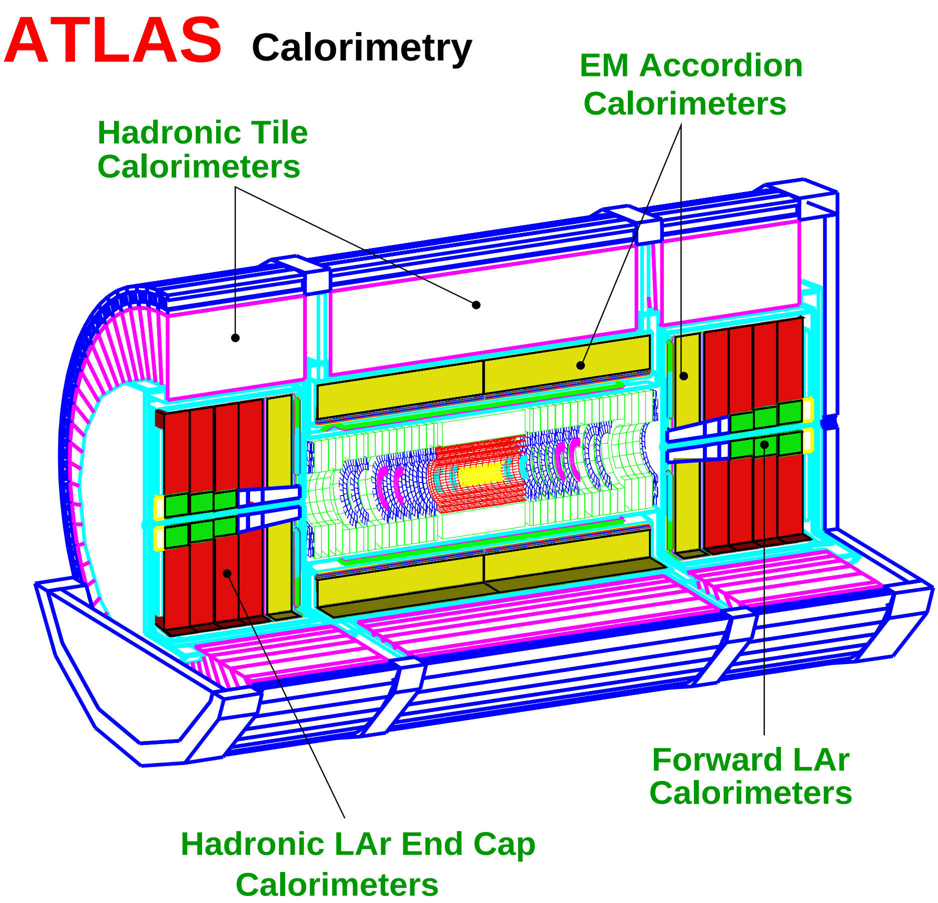


Figure 29: ATLAS Calorimetry.

Figure 30 shows an artist's view of the CMS detector. It is a large detector with four layers of muon chambers sandwiched in between the iron layers of the return yoke of the solenoid. The coil will provide an exceptionally high field of 4 Tesla inside which is the hadronic and electromagnetic calorimetry. The electromagnetic calorimeter is composed of many crystals of $PbWO_4$ or lead tungstanate which is a very high density material. Figure 31 shows the cross-section of the detector where one can see that the coils are more than six metres in diameter and thirteen metres long. The transverse view of the detector is shown in figure 32 where the efforts made by the physicists to make the detector hermetic are evident. Both ATLAS and CMS will make major efforts to understand the new energy regime which will become available with the LHC.

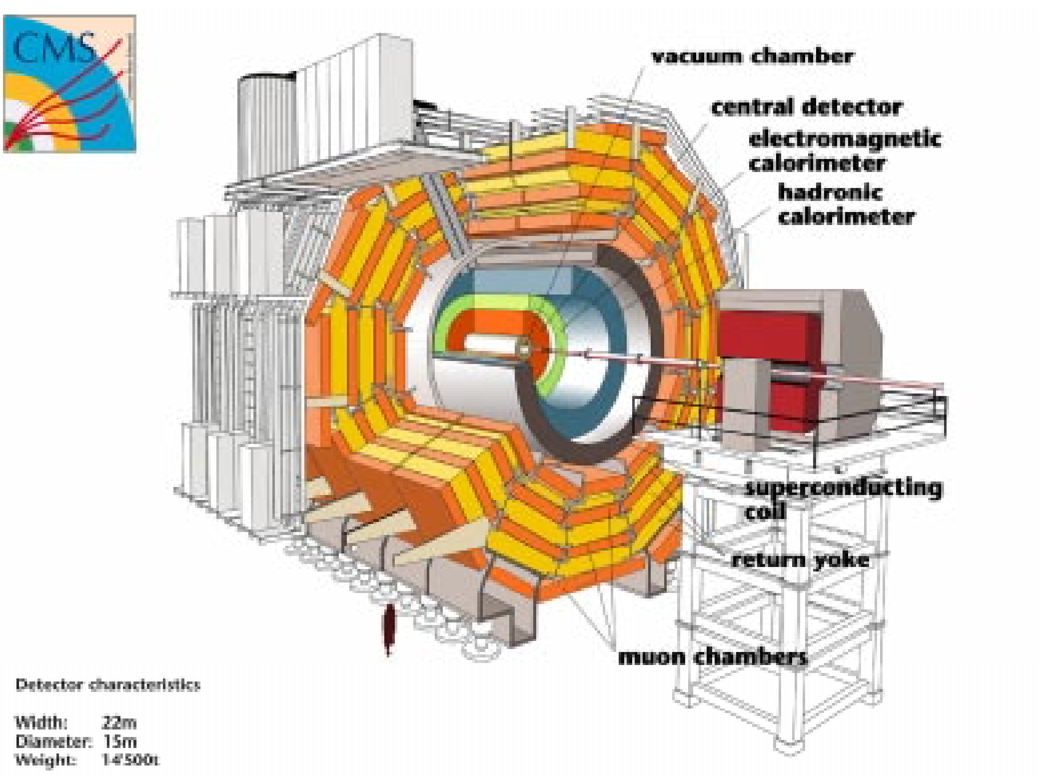


Figure 30: An artist's view of the CMS detector.

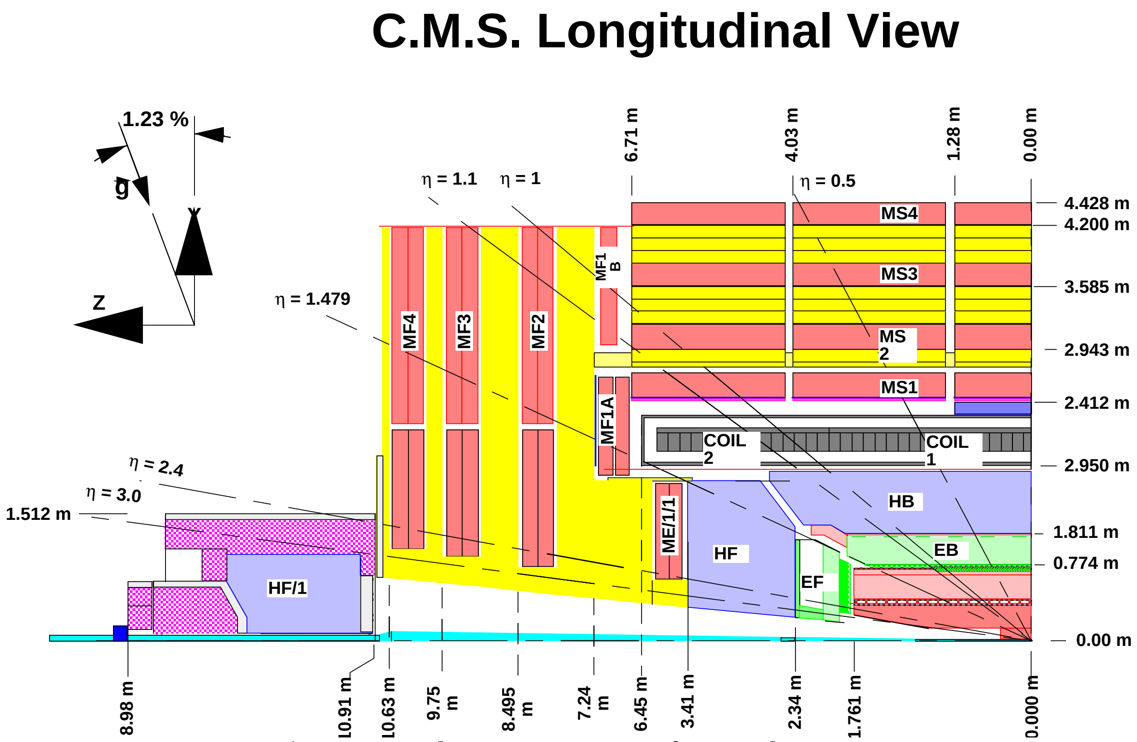


Figure 31: The cross-section of CMS detector.

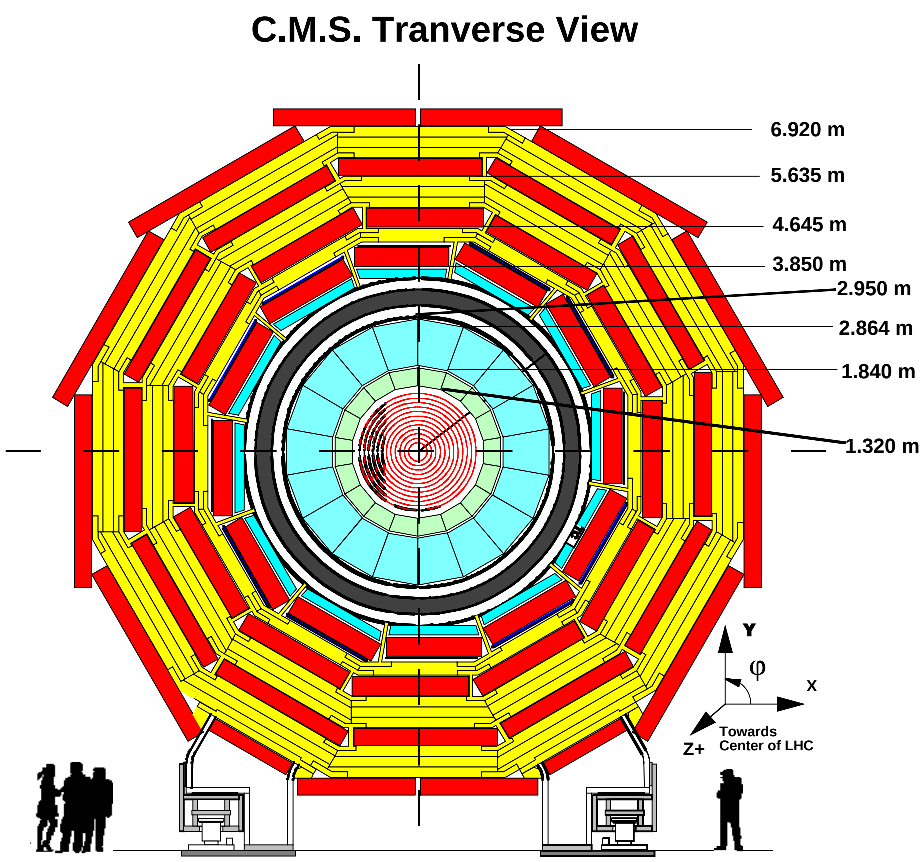
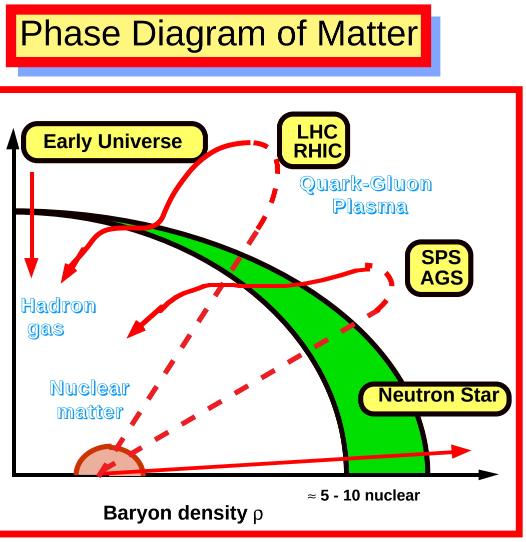


Figure 32: The transverse view of CMS detector.

Let me turn for the final experiment at the LHC to the heavy ion collisions which will be possible with the Pb beams. The experiment to do this research is called ALICE. Let us first look at figure 33 which shows a phase diagram of matter. The y-axis displays the temperature and the x-axis the baryon density which with Pb-Pb collisions can become very high.



● initial conditions in central Pb-Pb

⇨ RHIC and LHC relativ to SPS

	SPS (17)	RHIC (200)	LHC (6000)
Energy density	1	2	7
Volume	1	7	20
QGP lifetime	1	3	20
over relaxation time			

Figure 33: Phase diagram of matter.

The early universe is believed to have been at a very high temperature and to have cooled rapidly to produce the particles which we know today. Experiments carried out on heavy ion collisions at both the SPS and at the AGS, which is at Brookhaven in the USA, have given hints that one may have reached the region of quark gluon plasma (QGP). With the heavy ion colliders, RHIC at Brookhaven and the LHC at CERN, we hope to definitely see the plasma. One hopes that the return from the plasma to the hadronic gas and the nuclear matter will reveal the quark-gluon plasma. The table below figure 33 shows the increase in energy density, volume and quark-gluon plasma lifetime which is expected with the high energy Pb-Pb collisions at RHIC and LHC. The number of secondaries produced will increase from 17 at SPS to 6000 at LHC. The energy density will increase from 1 to 7 and the volume and QGP lifetime from 1 to 20.

Figure 34 shows a simulation of a Pb-Pb event with the 6000 secondaries which are in a jet but spread around in the transverse plane as can be seen. Figure 35 shows an artists impression of the ALICE experiment. The main magnet exists already and forms part of the L3 experiment currently operating at CERN.

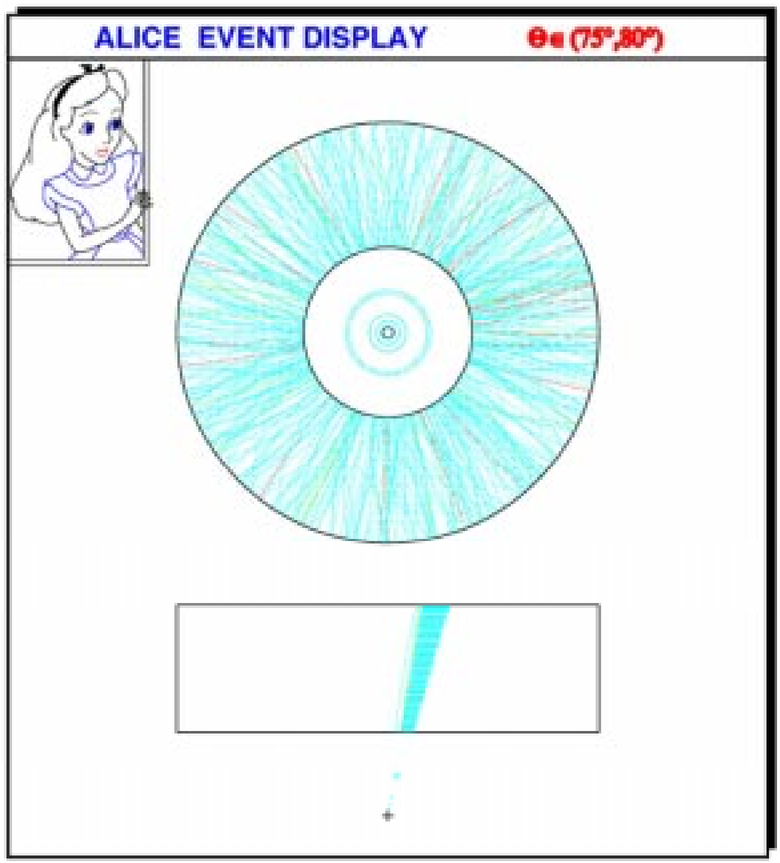


Figure 34: Simulation of a Pb-Pb event

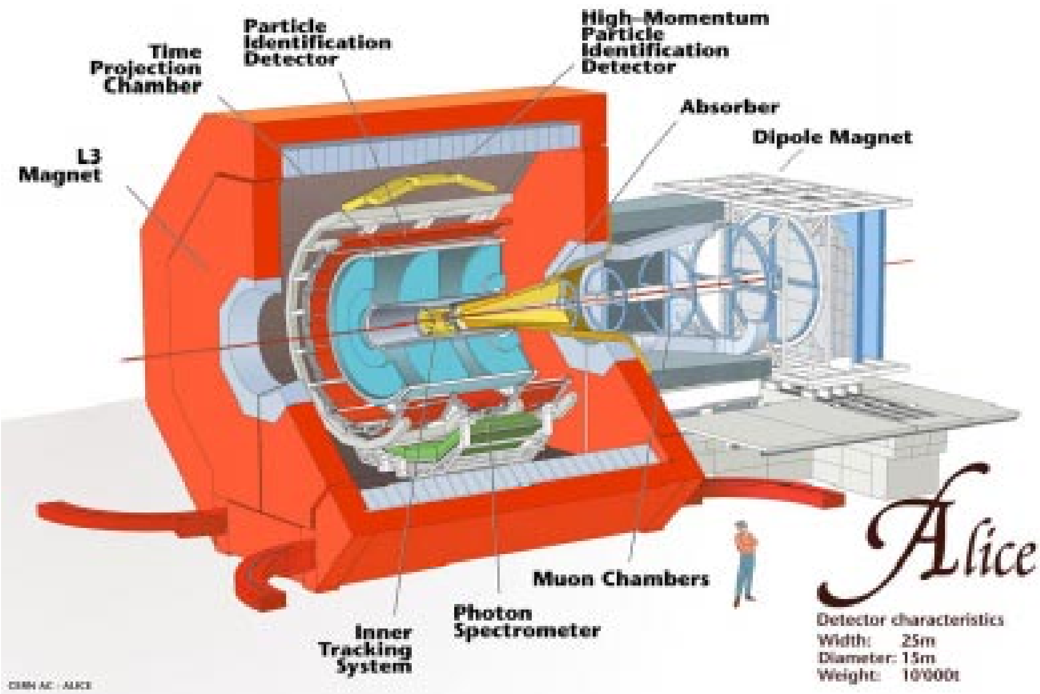


Figure 35: An artist's impression of the ALICE detector.

Inside the magnet is a large Time Projection Chamber (TPC) and an inner tracker as well as smaller solid angle devices to identify the particles and to measure photon production (PHOS). In the forward direction is a dedicated muon arm with a dipole magnet and muon absorber as well as large chambers to measure the track of the muons.

Figure 36 shows a plan view of the ALICE detector as it is planned today.

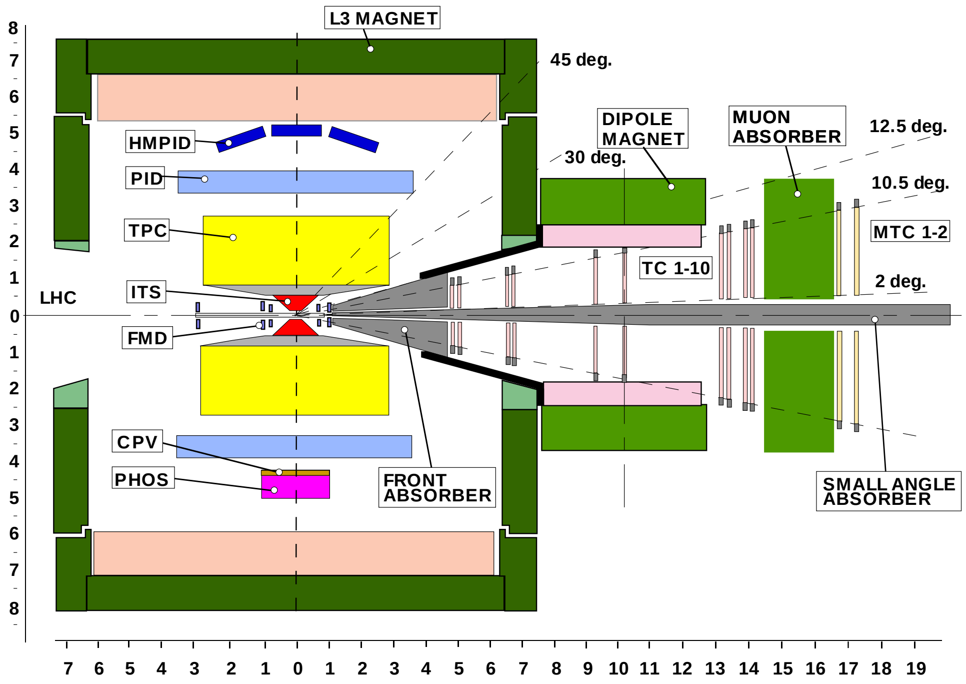


Figure 36: A plan view of the ALICE detector as it is planned today.

It is not at all clear what the ALICE physicists will find in their analysis of the events coming from the Pb-Pb collisio ns. However it is very exciting and will reveal a lot about how heavy ions interact at high energies.

The fourth LHC experiment is likely to be approved soon by the CERN Research Board. It is called LHC-B and it is an experiment which will use the enormous production of B particles at the hadron collider to study the properties of these particles. The experiment is shown in figure 37. It will contain Ring Imaging Cerenkov Counter (RICH) to identify the produced particles, electromagnetic and hadron calorimeters and muon chambers. It will also use a precise vertex detector close to the collision point.

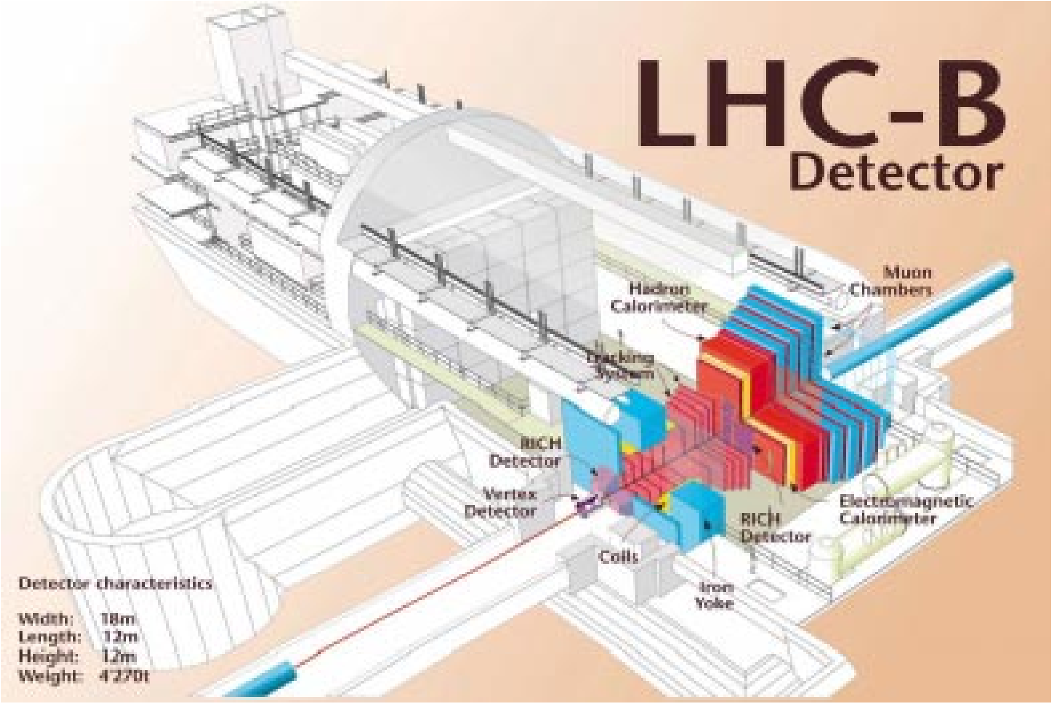


Figure 37: The LHC-B detector.

With four such diverse detectors, we expect exciting results from the operation of LHC which should start in 2005.